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MedCORDEX-Baltic Earth-COST Workshop

Regional Climate System Modelling for the European Sea Regions

Universitat de les Illes Baleares, Palma de Mallorca, Spain
14 - 16 March 2018

Programme, Abstracts, Participants

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Table of Contents

A MedCORDEX-Baltic Earth-COST Workshop

Regional Climate System Modelling for the European Sea Regions

Universitat de les Illes Balears, Palma de Mallorca, Spain, 14- 16 March 2018

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Scope

The aim of this workshop is to share recent progress in the understanding of regional climate variability with special focus on coupled effects between sea, atmosphere, land and anthroposphere. In this workshop, we will focus on European seas and their catchment areas like the Mediterranean Sea, Black Sea, North Sea, Baltic Sea and Arctic Ocean - highly sensitive areas where global models fail to give reliable information about changing climate because key processes are not properly resolved.

Coupled atmosphere–sea ice–ocean models have been developed further in the recent past by using a hierarchy of sub-models for the Earth system. In these Earth system models, regional climate models are combined with sub-models for surface waves, land surface and vegetation, hydrology, land and marine biogeochemistry, the marine carbon cycle as well as marine biology and food webs. These model systems aim to investigate the impact of climate change on the entire terrestrial and marine environment.

Contributions related to any aspect of the description and modelling of regional climate are welcome. Some of the topics addressed in the workshop will be the description of present and future regional climates, the development and evaluation of regional climate system models and the assessment of extreme and high impact events.

Sessions

Session 1: Development and evaluation of regional climate system models and reanalyses

New regional reanalyses and coupled atmosphere - ice - ocean - land surface/vegetation - biogeochemical/carbon - food web models; comparisons of hindcast simulations to observations; the problem of initialization of regional climate system models and the application of ocean synthesis for this purpose; model improvement, new data sets for model evaluation and bias correction methods.

Session 2: Studies on the added value of air-sea coupling and/or high resolution

Contributions on land-atmosphere, ocean-atmosphere and land-ocean (rivers, wetting and drying) interactions; discussions on benefits (or lack of them) of the use of improved regional climate system models.

Session 3: Regional process studies and extreme and high impact events

Studies of all kind of regional processes including extreme and high impact events; the focus of the session will be on the basic scientific understanding of those processes and on assessing impacts on key areas with different adaptation potential.

Session 4: Climate change impact studies and uncertainty assessments of projections using coupled model simulations

Dynamical downscaling of Earth System Models, multi-model ensemble studies and multi-stressor approaches; studies comparing different emission scenarios and scenarios of other drivers of the Earth system like environmental stressors and studies analyzing the effects of mitigation measures.

MedCORDEX-Baltic Earth-COST Workshop

Regional Climate System Modelling for the European Sea Regions

14 - 16 March 2018
Palma de Mallorca, Spain

Programme
as of 22 February 2018

Day 1: Wednesday, 14 March	
8:30	Registration
9:00 - 9:10	Welcome and Opening **Introduction to the Workshop** Gabriel Jorda and Markus Meier
9:10 - 9:25	**Baltic Earth and Integrated Earth System Modeling for the Baltic Sea Region** Meier H.E.M.
9:25-9:40	**The MedCORDEX -2 Initiative** Gabriel Jorda

Topic 1: Development and evaluation of regional climate system models and reanalyses	
9:40-10.10	**SOLICITED: A 15-year history of coupled regional climate modelling for the Mediterranean: success stories and current challenges** Somot S
10:10 - 10:30	**A regional coupled Earth system model to study climate variations in the regions of the Baltic Sea** Brunnabend S-E, Frauen C, Placke N, Börgel F, Meier HEM
10:30 - 10:50	**A North Sea-Baltic Sea regional models: coupling of ocean and atmosphere through a dynamic wave interface** Staneva J, Schrum C, Behrens A, Grayek S, Wiese A, Ho-Hagemann H, Rockel B, Geyer B, Breivik Ø, Bidlot J, Fegnollio-Marc L
10:50 - 11:10	**The Regional Earth System Model of IPSL (RegIPSL), a contribution to MEDCORDEX** Polcher J, Pennel R, Arsouze T, Bastin S, Fita L, Béranger K, Stéfanon M, Drobinski P
11:10-11:30	*Coffee Break*
11:30 - 11:50	**The Regional Climate System CNRM-RCSM6: description and first results of a 1980-2013 hindcast simulation** Sevault F, Somot S, Adloff F, Waldmann R, Alias A
11:50 - 12:10	**Modeling the Mediterranean circulation: skills and flaws of present day models** Soto-Navarro J, Jordà G
12:10 - 12:30	**Assessment of biogeochemical models in the NW Mediterranean** Ramirez-Romero E, Jordà G, Calalan I, Segura-Noguera M, Amores A
Topic 2: Studies on the added value of air-sea coupling and/or high resolution	
12:30-13:00	**SOLICITED: Coupled Regional Climate Modelling Systems: Pros and Cons** Ahrens B, Pothapakula PK, Leps N, Akhtar N, Primo Ramos C
13:00-14.30	Lunch Break

14:30-14.50	**Coordinated Experiments of coupled Atmosphere-Ocean Regional Climate Models for North Sea and Baltic Sea regions** Ho-Hagemann H and the Coordinated Experiments team (HZG, AWI, DWD, IOW, SMHI
14.50-15:10	**Role of atmospheric forcing resolution in the long-term seasonal variability of the Tyrrhenian Sea circulation from a set of ocean hindcast simulations (1997 - 2008)** de la Vara A, Galan del Sastre P, Arsouze T, Gallardo C, Angel Gaertner M
15:10-15:30	**A global integration technique for a better description of the Mediterranean water cycle using satellite data** Pellet V, Filipe Aires, Simon Munier, Gabriel Jordà, Wouter Dorigo, Jan Polcher, Fuxing Wang, Luca Brocca, Stefania Camici, Christian Massari
15:30-16:30	**Poster Presentation**
16:30-16:50	Coffee Break
16:50-17:10	**Role of air-sea coupling in the simulation of moisture sources over the Mediterranean Basin** Batibeniz F, Ashfaq M, Turuncoglu UU, Onol B
17:10-17:30	**Role of the ocean thermal structure in the modulation of heavy precipitations over the Ligurian Sea** Meroni A, Renault L, Parodi A, Pasquero C
17:30-17:50	**Cascading ocean basins: numerical simulations of the circulation and inter-basin exchange in the Azov-Black-Marmara-Mediterranean Seas system** Stanev E
17:50-18:10	**The comparison of observational data with the results from ROMS model in the Porsanger fjord, Norway.** Aniskiewicz P
18:10	**END DAY 1**

Day 2: Thursday, 15 March	
9:00-9:20	**Modeling study of the Svalbard fjord - Hornsund** Jakacki J, Przyborska A
9:20-9:40	**Mesoscale eddy properties in the Mediterranean sea from high-resolution models.** Amores A, Jordà G
9:40-10:00	**First evaluation of a high resolution model of the Central Mediterranean Sea** Harzallah A, Mehra A, Thiaw W
10:00-11:10	**ROUND TABLE**
11:10-11:30	Coffee Break
Topic 3: Regional process studies and extreme and high impact events	
11:30-12:00	**SOLICITED: Effects of ocean-atmosphere coupling in regional climate models on the simulation of medicanes: present climate representation and future projections** Gaertner MA, Gonzalez-Aleman JJ, Gutierrez J, De la Vara A
12:00-12:20	**Climatology, precipitation types and atmospheric conditions of extreme precipitation events in western Turkey** Baltaci H
12:20-12:40	**Long-term variability of extreme storm surges in the German Bight** Lang A, Mikolajewicz U
12:40-13:00	**Sensitivity of Mediterranean Sea function to uncertainties in the surface freshwater forcing** Jordà G, Martinez-Asensio A, Amores A, Sevault F, Somot S
13:00-13:20	**Is there a need for coupled chemistry/climate simulations for modelling Mediterranean heat waves? The role of atmospheric aerosols** Jiménez-Guerrero P, Palacios-Peña L, Jerez S, Gómez-Navarro J, López-Romero J, Lorente-Plazas R, Montávez J

13:20-14:50	Lunch Break
14:50-15:20	<u>SOLICITED:</u> **The future regime of Atlantic nutrient supply to the Northwest European Shelf** Mathis M, Elizalde A, Mikolajewicz U
15:20-15:40	**Exploring future scenarios for the NW Mediterranean Sea for the horizon 2030. Consequences for marine productivity and resources exploitation** Macias D, Piroddi C, Garcia-Gorriz E, Stips A
15:40-16:00	**Drought assessment and projection under climate change in northern Tunisia** Mathlouthi, M, Fehthi L
16:00-16:20	**The climate change signal for temperature and salinity in the Western Mediterranean Sea in a regionally coupled ocean-atmosphere model** Cabos W, Sein D, Parras I, Izquierdo A
16:20-16:40	Coffee Break
16:40-17:00	**The individual role of temperature and salinity change for different trophic levels in global climate scenarios downscaled for the Baltic Sea and North Sea** Gröger M, Andersson H, Dieterich C, Meier HEM, Wåhlström I, MacKenzie B
17:00-17:20	**Projected Changes in Baltic Sea Upwelling in Climate Change Scenarios** Dieterich C, Gröger M, Schimanke S, Meier HEM
17:20-17:40	**Future droughts in Southern Ukraine – reasons and possible consequences for water resources and agriculturek** Khokhlov V, Yermolenko N, Zamphirova M
17:40-18:00	Wrap-Up of the plenary sessions
18:00	**END OF PLENARY SESSIONS**

Day 3: Friday, 16 March	
Outbreak sessions MedCORDEX/Baltic Earth	
9:00 - 10:30	**Breakout meetings 1**
10:30 - 11:00	Coffee Break
11:00 - 12:00	**Breakout meetings 2**
12:00 - 13:00	**Overall workshop discussion and wrap-up**
13:00	**Lunch and End of the meeting**

Poster presentations

Topic 1: Development and evaluation of regional climate system models
Integration of Engineering Data of ocean floor in Environmental and Ecosystem Modeling with Geophysics Precursors Invading Impact of Global Warming on Deep Sea Creatures Hadi N, Glaser S, Ziran Z
Closing the water balance in a regional coupled system model over the North and the Baltic Sea Hagemann S, Ho-Hagemann H
Comparison of satellite and in situ soil moisture measurements for modelling Mačiulytė V
Preliminary results of the RegCM-ES model with an active biogeochemical component (BFM) over the Med-CORDEX domain Reale M, Giorgi F, Solidoro C, Di Biagio V, Mariotti L, Farneti R

Topic 2: Studies on the added value of air-sea coupling and/or high resolution
The high-resolution simulations of WRF model in two high-latitude fjords: Porsanger and Hornsund. Aniskiewicz P, Stramska M
Activities with COSMO-CLM and NEMO for the North and Baltic seas at DWD Brauch J, Dröse M, Stegert C, Van Pham T, Früh B
Adaptation of the MIKE 3d model for the fjord Hornsund Przyborska A, Jakacki J

Topic 3: Regional process studies and extreme and high impact events
Comparison of regional and global oceanic reanalyses in the Mediterranean Sea Beuvier J, Drévillon M, Lellouche J-M, Garric G, Drillet Y
The Impact of Water Constituents on Radiative Heat Transfer in the Open Ocean and Shelf Seas Cahill B, Fischer J, Graewe U, Burchard H, Wilkin J, Warner J, Ganju N
Haline convection due to sea ice brine rejection in the Northern Baltic Sea Gieße C, Meier HEM
Global warming, new energy balance, new atmospheric circulation and extreme meteorological phenomena in Western Mediterranean Karrouk M-S
Regional model of forming catastrophic spring runoff in condition climate change on the plain rivers Black sea basin in Ukraine Ovcharuk V, Gopchenko E
Assessing the climate Impacts of the Atlantic Multidecadal Variability on the Mediterranean basin Sanchez-Gomez E, Qasmi S, Cassou C, Boe J

Abstracts in first author alphabetical order

Coupled Regional Climate Modelling Systems: Pros and Cons

Bodo Ahrens, Praveen K. Pothapakula, Nora Leps, Naveed Akhtar, Cristina Primo Ramos

Institute for Atmospheric and Environmental Science, Goethe Univ. Frankfurt, Germany (Bodo.Ahrens@iau.uni-frankfurt)

1. Goal

Recently regional climate models were coupled to regional ocean models and applied in process studies and already in a few climate projections (see, e.g., the examples presented in this book of abstracts). This presentation discusses our first experience with a coupled regional system over and near European Sea regions, and also in Central Europe.

2. Modelling System

The coupled modelling system consists of the regional climate model COSMO-CLM version 5clm9 and two implementations of the ocean model NEMO version 3.6 (Fig. 1). The applied coupler is OASIS-MCT2. For the atmosphere, several grid-spacings have been applied successfully (from 0.44° to 0.11°). Even higher resolutions are ongoing for the medcordex domain (see www.medcordex.org).

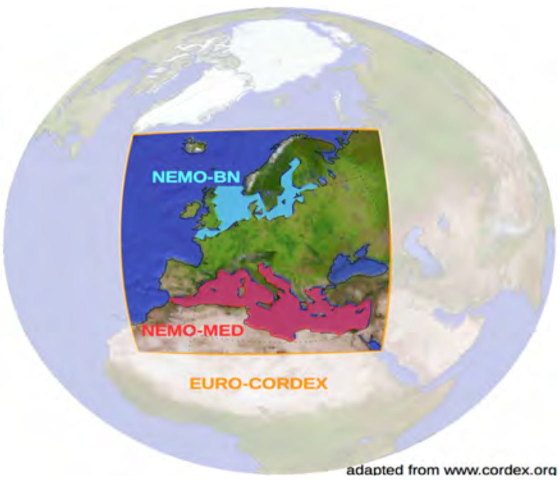

Figure 1. Atmospheric modelling domain and the domains of the two coupled ocean models. Sea surface temperature for the uncoupled ocean/dark blue area is prescribed by the driving global climate model.

3. Application Examples

The coupled modelling system COSMO-CLM/NEMO performed well in comparison with other systems over the Mediterranean Sea (e.g. Ruti et al., 2016) in mean quantities (like mean evaporation, radiation fluxes). The coupled system performed better than the uncoupled, atmosphere-only regional climate system COSMO-CLM (Akhtar et al., 2017).

The coupled modelling system also performed better than the uncoupled one for examples of extreme events. For example, medicane tracks and intensities were on average better simulated (Akhtar et al., 2014). Also, Mistral and Tramontane events seem to be better represented in the coupled system (priv. comm. A. Obermann-Hellhund). Another extreme phenomenon better represented in the coupled system were convective snowbands over the Baltic Sea (Pham et al., 2016).

Investigation of mean temperature or precipitation in Central Europe, i.e. far away from coastal areas, showed no or at least no significant impact. Even in centennial simulations driven by NOAA/NCEP 20CR the impact of coupling on mean quantities is of minor importance (Ramos et al., in preparation).

Investigation of Central European extremes is ongoing. Heavy precipitation events in Central Europe linked to so-called Vb cyclonic tracks are sensitive to coupling. Akhtar et al. (in preparation) shows simulation with coupling of the Northern seas, the Mediterranean Sea, both and none. The results indicate that coupling might add value, but also adds internal variability to the regional modelling system and thus adds inconsistency to the driving model data set. This obscures the potential positive signal of coupling.

4. Conclusions

The coupled system shows added value over/near the marginal European seas. For climate projections near coastlines of for islands the regional coupled system should be applied after further increasing maturity (e.g. performing multi-centennial control simulation for system's stability confirmation).

The added value inland, like in Central Europe, is at present obscured by uncertainties of the modelling systems (e.g. through the nesting strategy). Given the added amount of necessary resources, if the coupled modelling system shall be used instead of the atmosphere-only regional climate model, it might not be worth the effort yet if the area of interest is a few hundred kilometers from the coastline inland. But, further investigations are ongoing. For sure, regional coupled systems can be used as relatively cheap testbed for global earth system model's developments.

References

Akhtar, N., J. Brauch, A. Dobler, K. Berenger, *B. Ahrens* (2014). Medicanes in an ocean-atmosphere coupled regional climate model. Nat. Hazards Earth Syst. Sci., 14, 2189–2201. doi:10.5194/nhess-14-2189-2014

Akhtar, N., J. Brauch, *B. Ahrens* (2017). Climate Modeling over the Mediterranean Sea: Impact of Resolution and Ocean Coupling. Climate Dynamics. DOI 10.1007/s00382-017-3570-8

Ruti et al. (2016) MED-CORDEX initiative for Mediterranean Climate studies. Bull. of the American Meteorological Society, 1187-1208. doi: http://dx.doi.org/10.1175/BAMS-D-14-00176.1

Pham, v. T., J. Brauch, B. Früh, *B. Ahrens* (2016). Simulation of snowbands in the Baltic Sea area with the coupled atmosphere-ocean-ice model COSMO-CLM/NEMO. Met.Z., 26(1), 71-82. doi:10.1127/metz/2016/0775

Mesoscale eddy properties in the Mediterranean sea from high resolution models.

Angel Amores[1] and Gabriel Jordà[1]

[1] Mediterranean Institute of Advanced Studies (IMEDEA), UIB-CSIC, Mallorca, Spain (angel.amores@uib.es)

1. Introduction

Eddies are oceanic vortexes that are located all around in the global ocean [Chelton et al., 2011]. Those eddies have the ability to trap water inside their cores or to stir the surrounding water while moving, having as a result a net transport of volume, heat, salt and other properties. The effects of the movement of the eddies are not only limited to the physical aspect but also affect the ecosystems. It has been shown that eddies are able to transport entire ecosystems inside their cores, trapping larvae and dragging the predators with them. Due to their importance it is necessary to study the eddy properties. Taking advantage that most of eddies have a surface signal in sea water height, their properties have been studied applying automatic eddy detection and tracking algorithms to the sea level anomaly (SLA) fields derived from satellite altimetry measurements [Chelton et al., 2011; Faghmous et al., 2015].

However, a recent study [Amores and Jordà, 2018] has shown that the eddy field and characteristics extracted from satellite SLA fields could differ considerably from the real ones. For example, applying the satellite measuring process and the optimal interpolation algorithm to a high resolution numerical model for the Mediterranean sea showed that this process tends to merge several small eddies into a larger one and strongly modifies the eddy amplitude and radius. More precisely, only a 9% of the detected eddies in the fields computed mimicking the satellite measurement process and applying an OI algorithm corresponded to a single real eddy. Moreover, the eddy radius for eddies smaller than 60 km was overestimated and the amplitude of eddies larger than 2.5 cm underestimated. Only around 2% of the real eddies corresponded to a single eddy in the satellite-like SLA fields derived from the model with the correct radius and amplitude.

Due to that the eddy properties computed from altimetric observations are not reliable the use of numerical simulations to characterize the eddy field becomes a need. Here we analyze the eddy field statistics from an ensemble of high resolution models to determine the role of different factors, such as the spatial resolution or the data assimilation, in defining the eddy characteristics for the Mediterranean sea.

2. Data and Methods

Nine different high resolution numerical simulation were used (mostly from MedCORDEX). These simulations included different spatial resolution, spanning from 1/12 of a degree to 1/32º, different number of vertical layers, different vertical coordinates (z or sigma), and with and without data assimilation.

The eddy detection and tracking algorithm used was the one developed by Faghmous et al. (2015). The algorithm allows to only retain the eddies with the desired properties, so only eddies that lived longer than 7 days were kept, regardless of their amplitude and radius.

3. Results

The eddy properties (radius, amplitude, number of them, life, rotational velocity, translational distance, ...) for each numerical simulation were computed and compared.

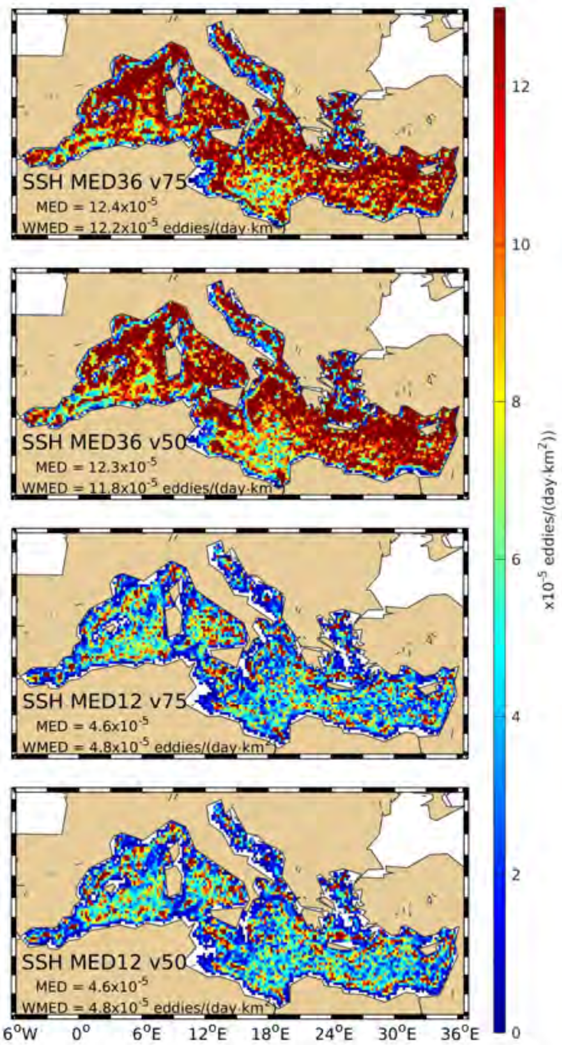

Figure 1. Maps of density of eddies in 4 different NEMO numerical simulations changing the spatial resolution (1/12 or 1/36 of a

As an example, Figure 1 shows the density of eddies computed for a 4 different runs of the NEMO model combining two different spatial resolution (1/12º or

1/36º) and two different number of vertical levels (50 or 75). It can be seen that the numerical simulations with higher spatial resolution (MED36v50 and MED36v75) had a larger number of eddies than the simulations with coarser spatial resolution (MED12v50 and MED12v75) regardless the number of vertical levels. The higher spatial resolution allowed the numerical model to generate eddies with smaller radius, increasing the absolute number of them. It was translated in a reduction of the median eddy radius from 27 km in the 1/12º simulations to 15 km in the 1/36º, with no radius change when modifying the number of vertical layers.

However, different spatial resolution or different number of vertical layer did not affect to the spatial map of eddy amplitude (Figure 2). It can be seen that the four different numerical simulation show eddies with larger amplitudes along the African coast, coinciding with the stronger current systems such as the Algerian current. The median value of amplitude was slightly smaller in the simulations with higher spatial resolution (0.6 cm; 0.9 cm in the 1/12º resolution) as a result of the inclusion of eddies with smaller radius.

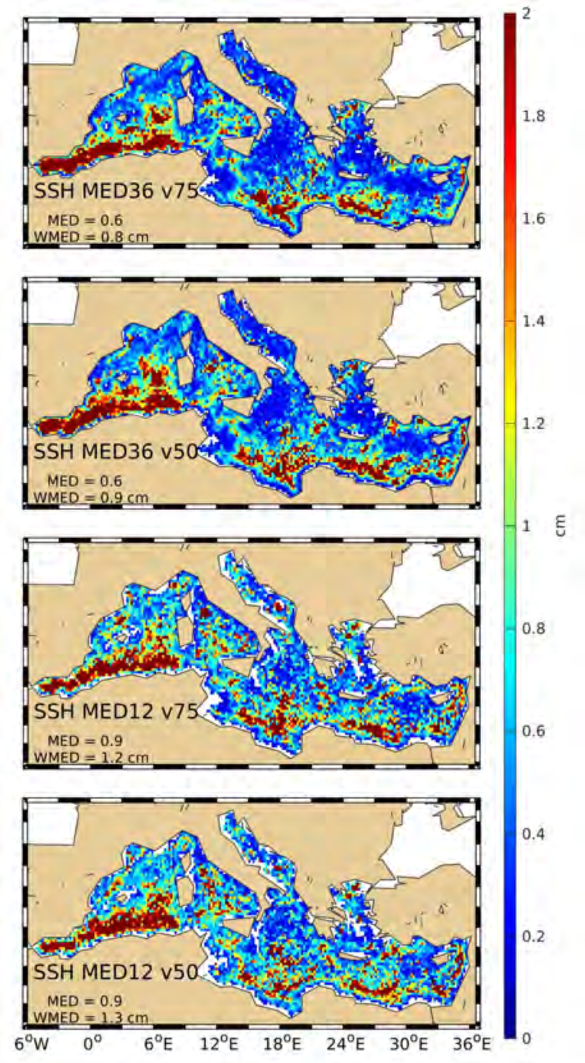

Figure 2. Maps of eddy amplitude in 4 different NEMO numerical simulations changing the spatial resolution (1/12 or 1/36 of a

4. Discussion and Conclusions

This work compares, for the first time, the eddy properties in the Mediterranean sea derived from nine different numerical simulations that combine different spatial resolutions, different number of vertical level, with and without data assimilation, and different vertical coordinates. This ensemble provides a complementary view to the Mediterranean field characterization that has traditionally been done using altimetry, which is not reliable. The regions of eddy generation are consistent among models although the size of the eddies depends on the model resolution (but not only). Data assimilation also modifies the eddy field properties as far as introduces more eddies seen by altimetry, although the resulting eddy field is not realistic yet.

References

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Faghmous, J. H., I. Frenger, Y. Yao, R. Warmka, A. Lindell, and V. Kumar (2015), A daily global mesoscale ocean eddy dataset from satellite altimetry, *Sci. Data*, **2**, doi:10.1038/sdata.2015.28

The comparison of observational data with the results from ROMS model in the Porsanger fjord, Norway.

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1. Introduction

The climate on the Earth is continually changing. Warmer and cooler periods in the past have been documented by Scientists. However during the last 100 years the average temperature on the Earth has still rising. The rate of annual warming for global land areas over the 1901-2000 period was estimated by 0.007°C per year. In the Arctic zone it was even higher (0.0079°C per year) (Jones, Moberg, 2003). Therefore the studies of long-term climate shift should be focused on climate sensitive regions in the Arctic, where glacier and sea ice retreat have been observed. It was documented that sea surface temperature (SST) was increased in the Barents Sea by 0.03°C per year in the last 32-years. In the area near the Norwegian coast of the Barents Sea the SST increased at even higher rate of 0.04-0.05°C per year (Jakowczyk and Stramska, 2014). For comparison, the globally averaged SST trend has been estimated as 0.018°C - 0.017°C per year (Good et al., 2007).

The fjord Porsanger (fig. 1) is located in high-latitude area, in the northern part of Norway (25.0 - 26.5°E, 70.0 - 71.0°N). Its length and width is equal to 100 km and 20 km, respectively. Its depth is defined as 310 m (Sunnset, 2008). Based on the bathymetry it may be divided into three zones: inner (0-30 km), middle (30-70 km) and outer (70-100 km). The inner part of the fjord has limited connectivity with the Barents Sea due to its separation from the remainder of the fjord by the 60 m deep sill. Because the environment in the inner part differs significantly from the other zones and holds a unique ecosystem (e. g. Myksvoll et al., 2012), it is important to develop modeling system in this fjord, to understand mechanisms responsible for these local changes.

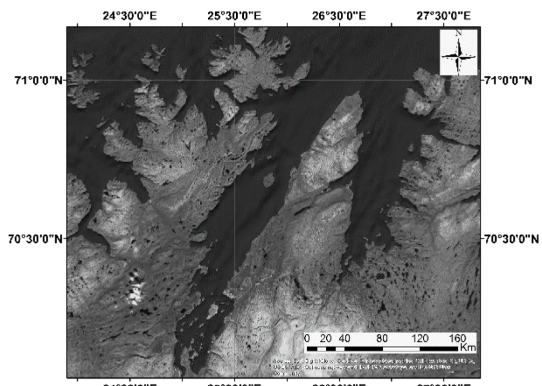

Figure 1. Research area (based on: www.arcgis.com)

2. Methodology

In this research, the Regional Ocean Modeling System (ROMS) was used to simulate the circulation of the fjord water. ROMS has been used successfully in similar studies (e. g. Budgell, 2005; ; Di Lorenzo, 2003; Dinniman et al., 2003; Marchesiello et al., 2003; Peliz et al., 2003). For detailed description of the model see www.myroms.org. ROMS is a free-surface, terrain-following, primitive equation model with potential temperature, salinity and an equation of state. The hydrostatic assumption and Boussinesq approximation are used in the formulation of the dynamic equations. Model uses horizontal orthogonal-curvilinear coordinates and vertical sigma coordinates (Hedström, 1994). ROMS solves the Reynolds-averaged Navier-Stokes equations using Boussinesq and hydrostatic assumption. The main equations in Cartesian coordinates of the momentum balance in the x-direction (1) and y-direction (2) are shown below:

$$\frac{\partial u}{\partial t} + \vec{u}\cdot\nabla u - fv = -\frac{\partial \phi}{\partial x} - \frac{\partial}{\partial z}\left(\overline{u'w'} - \nu\frac{\partial u}{\partial z}\right) + F_u + D_u \quad (1)$$

$$\frac{\partial v}{\partial t} + \vec{u}\cdot\nabla v - fu = -\frac{\partial \phi}{\partial x} - \frac{\partial}{\partial z}\left(\overline{v'w'} - \nu\frac{\partial v}{\partial z}\right) + F_v + D_v \quad (2)$$

The equation of state is given by formula (3):

$$\rho = \rho(T, S, P) \quad (3)$$

(Hedström, 1994). To check the differences of using different resolution grid of the fjord in the model we compared results with grid resolution equal to 800 m (fig. 2) and 160 m (fig. 3). These data were compared with observational data collected in year 2014 (NORDFLUX project).

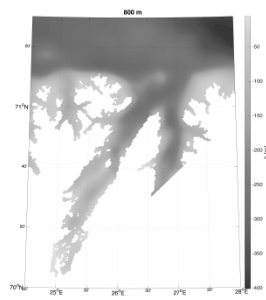

Figure 2. The grid of the Porsanger fjord (Δx=800 m).

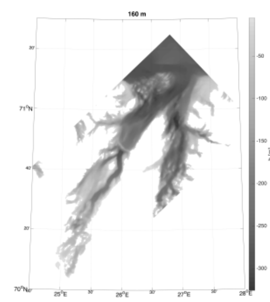

Figure 3. The grid of the Porsanger fjord (Δx=160 m).

Temperature at 140 m depth and subsurface currents were measured by the Nortek Continental 190 kHz ADCP (www.nortek.no), located at mooring point (70.87°N, 26.182°E). ADCP provided currents data in 5 m vertical bins from the 140 m depth up to the surface. The instrument position was equal to 140 m depth, while the bottom depth in this point was higher (239 m). Temperature and salinity data at 20 m depth were provided from Seacat NY deployed from a buoy, mounted in the mooring point.

All observational data were compared with modeled results in 15 days (9th June – 23rd June 2014). To verify if there is any spatial shift, temperature at 140 m depth was compared with modeled data from: 130 m, 135 m, 140 m, 145 m, 150 m. Temperature and salinity at 20 m depth were verified with modeled data from: 10 m, 15 m, 20 m, 25 m and 30 m. Subsurface currents were compared in vertical profiles using corresponding depths in the model.

In addition, all parameters were verified with modeled data from nine surrounded points in the model. For better presentation of the comparison, the correlation coefficient (r), statistical error (St. E) and systematic error (Sy. E) were calculated.

3. Conclusions

The currents data from ADCP should not be analyzed near the surface because of high uncertainty of measurements. It was visible in very low correlation coefficient in three first layers (0 m, 5 m, and 10 m). The highest correlation was observed for north velocity component in all points at all depths. The main reason may be that the ROMS model is adapted to well predict the south-northern water exchange between the fjord and surrounded ocean.

Thanks to comparing with the nine surrounding locations of mooring point we could see if there are any horizontal and vertical differences in the model. The analysis of subsurface currents showed the best current correlation in three points located in similar latitude. In these locations there was observed the lowest statistical and systematic error.

Low values of correlation coefficient of salinity are caused by large fresh-water discharge from the land to the Porsanger fjord. The large temporary river-water inflow may change local salinity immediately. In addition, for simulations with 800 m resolution of horizontal grid, the local salinity changes can be difficult to predict.

4. Acknowledgment

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The high-resolution simulations of WRF model in two high-latitude fjords: Porsanger and Hornsund.

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1. Introduction

In this research we were focused on weather modeling in two Arctic fjords: Porsanger, which is located in the northern part of Norway, in the coastal waters of the Barents Sea, and Hornsund, located in the western part of the Svalbard archipelago. The atmospheric downscaling was based on The Weather Research and Forecasting Model (WRF, www.wrf-model.org) with polar stereographic projection.

2. Methodology

We have compared the results of different settings in the model. We have tested what is the impact of the spatial resolution of the model on derived meteorological quantities. First simulations were done using parent domain (dx_1=20 km) with nested subdomains (dx_2=4 km), dx_3=0.8 km, dx_4=0.16 km) for both fjords. Note that child domains had 5 times higher resolution than parent domains. In this part, we used planetary boundary layer (PBL) scheme with simple turbulence and mixing. PBL is used to distribute surface fluxes through the boundary layer and to use vertical diffusion. This assumption begin to break down if $dx \ll 1$ km. Because for the future work we need very high-resolution meteorological data for the fjords, we decided to run model once again using large eddy simulation approach with parent (dx_1=320m) and one nested domain (dx_2=160 m). In this part 3d diffusion scheme was used and planetary boundary layer settings were turned off. We also changed other parameters in the model to adapt initial values to the fjords.

To validate the results we used meteorological data from the Norwegian Meteorological Institute. We estimated coefficients of determination (r^2), statistical errors (St. E) and systematic errors (Sy. E) between measured and modelled air temperature and wind speed at each station.

Thanks to this research, in the future we will be able to create high resolution spatially variable meteorological fields that will serve as forcing for numerical models of the fjords. We will investigate the role of different meteorological conditions like wind or precipitation on hydrographic processes in fjords.

3. Acknowledgments

The project has been financed from the funds of the Leading National Research Centre (KNOW) received by the Centre for Polar Studies for the period 2014-2018.

Climatology, precipitation types and atmospheric conditions of extreme precipitation events in western Turkey

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1. Abstract

This paper investigates the climatology, precipitation types and background physical mechanisms of extreme precipitations events (EPEs) over western Turkey during the period 2006-2015. The EPEs are described as the precipitation values above the 90^{th} percentile obtained from the hourly precipitation dataset having high spatial resolution. Precipitation types associated with EPEs are identified by using radar outputs and Lamb Weather Type (LWT) approach. It is found that EPEs occurred more frequently in the Marmara and Aegean regions during autumn and winter months. In Marmara, mainly 21%, 17% and 15% of total autumn EPEs are observed as convective (E circulation types (CTs)), cyclonic (C), and sea-effect (NE) extreme precipitations (EPs), in order. While convective EPEs are generally more active in the southern portions having rugged topography, cyclonic and sea effect EPs are more effective in the southwest and northeastern parts of Marmara. Among these three precipitation types, convective CTs produce more intense daily precipitation in the Marmara region with daily average value of 66.1 mm. Based on the hourly observations, convective types of EP which developed by the interaction between high pressure center over Balkan Peninsula and low pressure center over eastern Mediterranean, show two peak values during afternoon and evening times of the day and are linked to diurnal heating. In terms of Aegean region, cyclonic originated EPs, which include 65% of the total winter EPEs, are more common in the whole territory and reach to its peak value during the first hours of the day.

2. Introduction

Owing to the spatial complexity, rugged topography, and land-sea interactions of the Mediterranean Basin, many devastating flash floods occurred in the various part of the region in the last decade. Therefore, researchers have analyzed the atmospheric conditions that cause these extraordinary events by focusing on the selected flood days Only a few researchers analyzed the climatological and general synoptic behaviors of the EPEs for this large territory (Ricard et al., 2011; Reale and Lionello, 2013).

Turkey is located at the east Mediterranean and EPEs there, in general, cause sudden flash floods resulting with deaths and economic losses in infrastructure and agriculture (Fig. 1). As a result of the EPEs in the last decade, numerous flash floods and landslides occurred in some particular regions of Turkey. During September 2009, Ayamama creek in Istanbul (NW of Turkey, most populated city in Europe) was overflowed as the consequence of the dense daily precipitation episodes, which produced more than 250 mm rainfall over 3-day, and 32 people died together with millions of dollars of economic losses (Kömüşçü and Çelik, 2013). During 9 October 2011, 238 mm rainfall total was measured during an 6 hour time-period at the province of Antalya (south of Turkey) and damaged the infrastructure of the tourism center of the country (Demirtaş, 2016). During August 2015, torrential rainfalls ended up with a devestating landslide in Hopa district (NE Turkey, sloppy domain of the country) and 11 people died during this natural hazard (Baltaci, 2017). Turkey and its sub-basins are mainly influenced by these EPEs in all seasons in the variety of the atmospheric conditions such as baroclinic waves and cyclones, mesoscale convective systems, land-sea interactions and orographic forcing. Therefore, the goal of this study is to document the spatio-temporal and environmental characteristics of the EPEs, and investigate the synoptic-scale patterns associated with EPEs by using radar products (Fig. 2) and Lamb Weather Type approach.

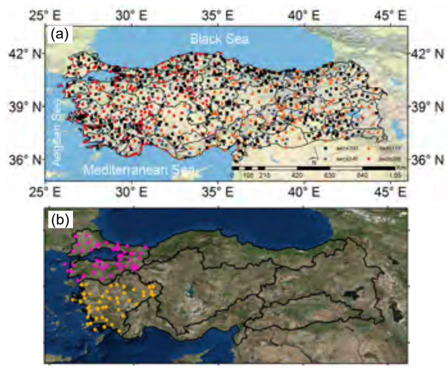

Figure 1. **(a)** The distribution of totally 953 automatic weather observing systems (AWOS) over Turkey depending on the four projects (AWOS 206, 151, 246 and 350) and **(b)** the locations of the 51 (pink points) and 47 (light brown points) AWOS stations, at Marmara and Aegean regions,. Hourly precipitation data of these 97 stations were provided by the Turkish State Meteorological Service (TSMS) for the period of 2006-2015.

Figure 2. The distribution of 14 radar network over Turkey. Precipitation products of six radars (Istanbul, Bursa, Balikesir, Izmir, Mugla, and Afyon), which were taken from TSMS were evaluated manually to describe the characteristics of the precipitation types.

3. First Results

For the first time, different daily precipitation threshold limits of 97 stations (Fig. 1b) were constructed from a 10-year dataset (Fig. 3a). According to the results, highest daily precipitation rates exceeding 100 mm are observed on the southern Aegean region where it can be classified as 'rich' in terms of extreme amounts of precipitation. This suggests that if the daily precipitation amount of a station located in the south Aegean exceed this limit, that day is recorded as an EPE for that station. Daily precipitation threshold ranging from 60 to 100 mm is shown to be mainly located on the coastal regions of the west Turkey. When one move towards interior continental areas, daily EP threshold decrease from 60 to 20 mm level. The lowest limits are observed in the semi-arid continental areas of the Aegean and Marmara region as having threshold value lower than 40 mm, as illustrated with blue color in Fig. 3a and can be classified as 'poor' in terms of extreme amounts of precipitation.

The annual contribution of EPs for each station (cumulative totals of EPs for each station divided by 10) is shown in Fig. 3b. We observe that the largest normalized annual amounts of EPEs is located mainly on the southwest of Aegean, middle-south and northeast of the Marmara region with values larger than 60 mm. It is interesting to see that the interior continental areas of the Aegean and Marmara region that was characterized as poor in terms of extreme amounts of precipitation (Fig. 3a), now exhibit a better picture in their normalized value as generally having a better value between 40-60 mm. The reason of this can be the convective precipitation, generating intensified rain that can accumulate higher amounts of precipitation during a single rainstorm. On the other hand, western regions of Marmara that exhibited considerably larger threshold value with precipitation totals larger than 60 mm (Fig. 3a), show a worse image with the normalized values as having precipitation values between 40 to 60 mm.

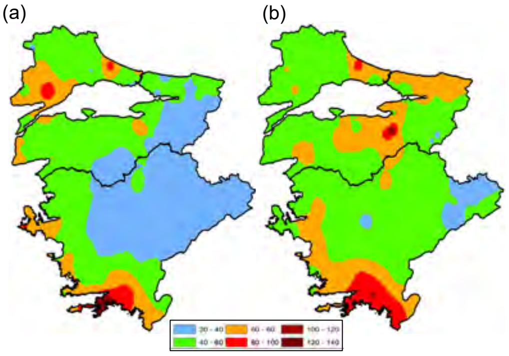

Figure 3. a) Maps show the threshold values (in mm) of the stations during 2006-2015 when precipitation exceeded the 90th percentile generating an EPE. **(b)** the contribution of total EPs of a station to its annual mean precipitation (mm).

Seasonal distribution of the EPE frequencies can provide important information to understand the physical mechanisms forcing these extreme events. For this reason, we analyzed total counts of EPEs for four seasons and the results are depicted in Fig. 4. It can be stated from Fig. 4 that winter (DJF) and autumn (SON) are more significant than the other seasons (Figs. 4a, d). During winter, two cores over Aegean result in more than 6 extreme precipitation days (Fig. 4a). Spring is mainly characterized as having EPEs between 2 to 4 days on the eastern portions of the Aegean region (Fig. 4b). During summer, highest count of the EPEs with 3 days is shown to be located over the Black Sea effected areas of the Marmara region (Fig. 4c). Seasonally, second highest frequency of EPEs can be found in the autumn. In this season, an area extending from northeast to south of Marmara receive a frequency considerably higher than 6 days (Fig. 4d). From this point of view, a detailed analysis of the atmospheric systems generating EPEs and effecting Aegean region mainly during winter and Marmara region during autumn becomes important.

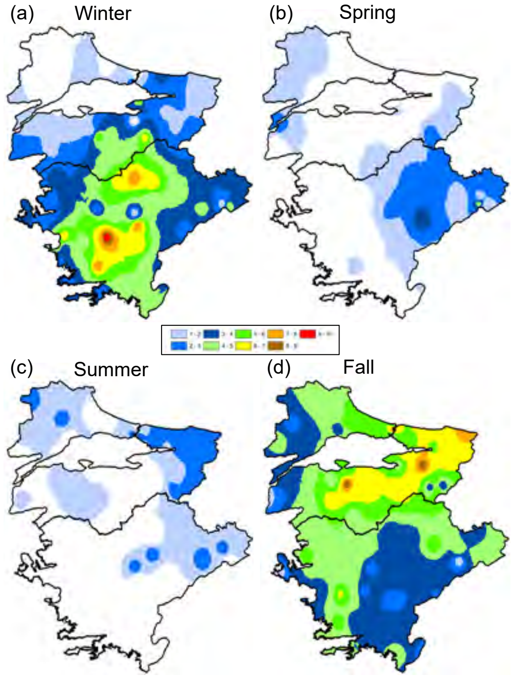

Figure 4. Seasonal distribution of the counts of the days for the stations when precipitation exceeded their 90th percentile during an EPE case for **(a)** winter, **(b)** spring, **(c)** summer, and **(d)** autumn seasons.

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Role of air-sea coupling in the simulation of moisture sources over the Mediterranean Basin

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1. Abstract

We investigate precipitation dynamics over the Mediterranean region using Reanalysis data and a coupled Regional Earth System Model (RegESM). The RegESM model is run in coupled (RegCM4 coupled with ROMS) and uncoupled mode (atmosphere –land only) for 1979-2012 period using Era-Interim Reanalysis. The recently developed modeling system RegESM incorporates atmosphere, ocean, river routing and wave components and thereby is better capable to improve the understanding of coupled climate system processes. We compare two model configurations to investigate the role of air sea interaction in the simulation of key processes that govern precipitation variability over the study area. Seasonal analyses have been performed for 34-simulation year and observations. Additionally, we use a Lagrangian based moisture back trajectory analyses to understand the role of various oceanic and terrestrial evaporative sources that contribute to the seasonal precipitation distribution. In this approach, we divide the whole region in 7 sub-regions and daily precipitation over each grid point within the Mediterranean basin is backtracked to one of the seven source regions. Our results indicate that uncoupled model simulation generally exhibits a cold temperature bias over the Mediterranean land region, as well as underestimation of moisture contribution from Mediterranean Sea and local recycling, both of which are major contributors to the precipitation over the study area. These biases in temperature and moisture contribution are improved in the coupled model simulation, which are in part driven by enhanced evaporation over the Mediterranean in the coupled model. Overall, our results highlight the importance of atmosphere-ocean coupling in accurate representation of physical processes that influence precipitation distribution at intra-seasonal timescale over the Mediterranean region.

2. Introduction

Mediterranean climate is known for relatively dry summers and mild, moist winters. The movement of high-pressure cells namely the Azores High, South Atlantic High, North Pacific High, South Pacific High, and Indian Ocean High influences the seasonal characteristics of the regions within Mediterranean climate. In winter, the high-pressure cells move equator-ward, allowing the intrusion of storms associated with polar jet stream and consequently heavy precipitation events during the season. In summer, the high-pressure cells move pole-ward, which is reflected by the dry air and rare precipitation events over the Mediterranean regions. Overall, the Mediterranean climate has mild and wet winters and warm and dry summers. Within the Mediterranean climate regions, the Mediterranean basin is the land regions encompassing the Mediterranean Sea, including European and Middle Eastern countries. The Mediterranean basin is considered as one of the hotspots for climate change because of strong precipitation seasonality and high population density. Moreover, due to a combination of the regions with very complex topography (i.e. Alps, Anatolian Peninsula), different land-use characteristics (rocky shores, impenetrable scrub, semi-arid steppes, coastal wetlands) and the large water bodies (Mediterranean and the Black Sea), the Mediterranean Basin exhibits strong spatial heterogeneity in precipitation and temperature distribution and is one of the ideal places to study regional climate change, atmosphere–land, and atmosphere–ocean interactions (Turuncoglu U.U. et al. 2016).

Earlier studies have shown that Mediterranean basin contributes significant amount of moisture to the whole Northern Hemisphere, particularly to the land regions immediately surrounding it. Mediterranean is at the crossroad of airstreams where air enters mainly from the northwest and continues in two separate streams, one going southwest over North Africa into the trade wind zone and the other one to the northeast through Central Asia, which suggests that a lot of moisture is perhaps sourced through the regions from Atlantic and areas west of it. Future increases in greenhouse gas forcing will likely increase land, ocean and atmosphere temperatures, leading to higher moisture content in the air and stronger evaporation rates over the land and ocean. Such changes will have a profound impact on the moisture transport to and from the Mediterranean basin, which will likely impact regional precipitation distribution by intensifying hydrological cycle. Therefore, it is important to establish a clear understanding about the moisture sources over the Mediterranean basin, their variation under enhanced greenhouse gas forcing, and subsequent influence on the mean and extreme precipitation distributions.

Given that the investigation of future climate response over topographically complex Mediterranean basin requires understanding of both synoptic and regional to local scale processes, this study aims to apply advanced analyses techniques and regional coupled modeling system to develop a renewed understanding of physical processes that govern weather and climate over the Mediterranean basin. Overall objective of this study is to establish an improved understanding of dynamic and thermodynamic drivers of both large-scale mesoscale patterns and fine-scale coastal processes in the Mediterranean basin that are associated with its hydro climate in the historic climate.

3. Method and Experimental Design

The RegESM model is run in coupled (RegCM4 coupled with ROMS) and uncoupled mode (atmosphere –land only) for 1979-2012 period using Era-Interim Reanalysis. The RegESM modeling system is able to couple four different model components (atmosphere-land, ocean, wave and river routing) to support many modeling applications that require detailed representation of the interactions among different earth system processes. The state-of-art driver that is responsible for the orchestration of the overall modeling system resides in the middle and acts as a translator among model components. In the design of the coupled modeling system, the coupling interfaces and driver are mainly developed at Istanbul Technical University (ITU) (Turuncoglu and Sannino, 2016). In the current study, only atmosphere and ocean components are activated. The details of coupled model validation over the Mediterranean Basin can be found in Turuncoglu and Sannino (2016).

4. Moisture Source Analysis

The key in determining the moisture sources and sinks through Langrangian moisture source analyses is the identification of the major regions that contribute to the precipitation over study domain. Therefore, the whole Mediterranean Basin is divided in 7 parts (Figure 1). We note that the simulation domain is not large enough to account for all the moisture sources for precipitation over the Mediterranean. It only accounts for up to 62% of the moisture sources during the summer season, 52% during the winter season, 56% during the spring and autumn seasons (Figure 3). We note that Mediterranean Sea plays a significant direct role in the moisture contribution towards seasonal precipitation over the land. It should be noted that Mediterranean Sea also provides indirect contribution to the moisture sourcing by local recycling over the land. Once the moisture transported from the ocean is precipitated over the land, it goes into the soils, which later evaporates back to the atmosphere through local recycling and contributes to the atmospheric moisture available for precipitation over oceanic and terrestrial regions. Therefore, we focus the comparison on only Mediterranean Sea (Region #1) and Mediterranean land (local recycling – Region #4) regions as a major moisture sources (are not shown here).

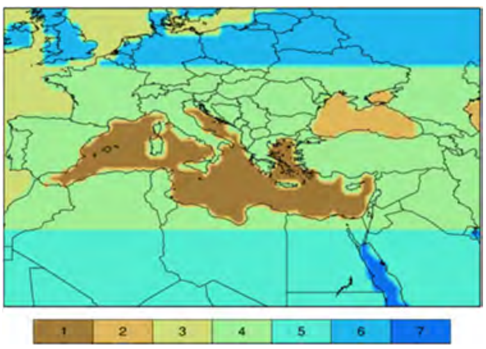

Figure 1. Defined regions for the Lagrangian moisture source analysis.

In Figure 2, first row shows results based on the analyses of Era-Interim Reanalysis data, second row shows the differences of uncoupled model from Era-Interim and third row shows the differences of the uncoupled model (RegCM) from the coupled model (RegESM). Figure 2 shows sum of the precipitation contribution from each region to the core region (Mediterranean land) in four seasons. Grids that exhibit same color in second and third column represent the improvements in the errors exhibited by the uncoupled model due to the addition of air-sea interaction in the coupled configuration. RegCM4 and RegESM generally capture the magnitude and spatial distribution of the precipitation contribution from each of the regions to the Mediterranean basin in each season. As mentioned before, simulation domain is not large enough to include all important precipitation source regions for the core region. Therefore, simulations are only able to capture up to ~ 2.2 mm/day of total seasonal precipitation. Nonetheless, coupling improves the overall representation of precipitation especially over Turkey and the coastlines around the Mediterranean Sea.

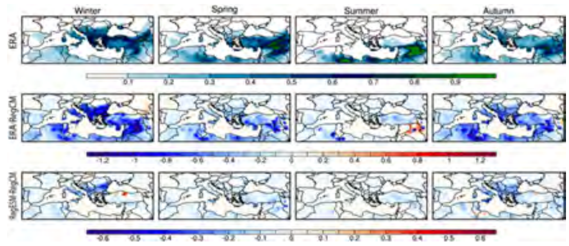

Figure 2. Seasonal precipitation sum of all regions over the Mediterranean Basin. First row shows Era-Interim, second row shows Era-Interim-RegCM4 and third row shows RegESM-RegCM.

Figure 3 is same as in Figure 2 but for recycling ratio. RegCM4 generally captures the magnitude and spatial distribution of the contribution from each of the regions to Mediterranean basin. However, we note that RegCM4 moisture recycling over major parts of Europe is substantially stronger in spring and autumn compared to that in Reanalysis. Additionally, uncoupled model (RegCM) exhibits a dipolar bias in the total recycling ratio (sum from all regions) with higher (lower) than ERA-interim recycling ratio in the west (east). This dipolar bias is mainly driven by the similar pattern of bias over Region #1 (local Mediterranean land-is not shown here). Grids that exhibit same color in second and third column shows that coupled model has some improvements in the errors exhibited by the uncoupled model over most of the core region. Stronger recycling ratio in coupled model drives stronger contribution to precipitation from Mediterranean Sea and local Mediterranean land. Both of these biases seem to improve in the coupled model simulation.

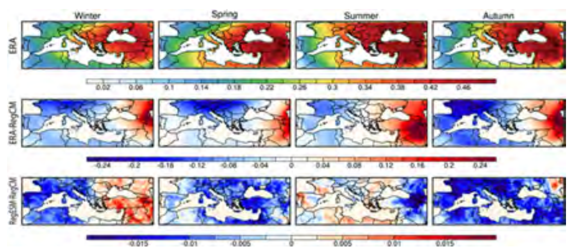

Figure 3. Seasonal recycling ratio sum of all regions over the Mediterranean Basin. First row shows Era-Interim, second row

shows Era-Interim-RegCM4 and third row shows RegESM-RegCM.

Overall, interactive ocean in the regional climate model improves the representation of physical processes particularly those related with evaporation and moisture transport over the Mediterranean basin.

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Comparison of regional and global oceanic reanalyses in the Mediterranean Sea

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1. Introduction

One of the objectives of the COST action "Evaluation of Ocean Syntheses" is to foster global and regional ocean reanalyses intercomparisons, with a focus on the evaluation of specific regional processes and variability, in particular in ocean and climate variability "choke points" such as the Mediterranean Sea.

Reanalyses are used to have a realistic description of the ocean state over the recent decades and help, in our case, to understand the long-term budgets of the Mediterranean basin in terms of variability and trends.

We present here a first assess on how a regional reanalysis with a dedicated configuration is able to reproduce the recent evolution of the Mediterranean Sea, and how global reanalyses behave with respect to the regional product.

2. Description of the set of reanalyses used

The regional reanalysis used here is MEDRYS1V2, described in Hamon et al. (2016) and Beuvier et al. (2016). It is based on the NEMO-MED12 regional configuration at 1/12° horizontal resolution, with 75 vertical z-levels. Exchanges with the Atlantic Ocean are performed through a buffer zone with a closed western boundary and a retroaction towards T, S and SSH fields from the global oceanic reanalysis ORA-S4, Balmaseda et al. (2012). The atmospheric forcings come from the ALDERA dataset, described in Hamon et al. (2016), a regional downscaling of the ERA-Interim atmospheric reanalysis. MEDRYS is forced with a flux formulation, at a resolution of 12km and 3h; there is an SST retroaction in the heat flux term and no SSS damping. It covers the period from October 1992 to June 2013, starting from the state of a twin free run (without data assimilation).

Global reanalyses are base on NEMO configurations too, at 1/4° horizontal resolution with 75 z-levels for GLORYS2V4 (configuration described in Ferry et al. (2012)), and at 1/12° horizontal resolution with 50 z-levels for GLORYS12V1 (same configuration as the high-resolution one described in Lellouche et al. (2013)). Both global reanalyses are forced by the ERA-Interim atmospheric reanalysis, with bulk formulations, at a resolution of 80km and 3h. They cover the period from 1992 to 2016.

These 3 configurations, MEDRYS1V2, GLORYS2V4 and GLORYS12V1, shared the same data assimilation system SAM (see Figure 1). It uses a reduced order Kalman filter with a 3D multivariate modal decomposition of the forecast error. A 3D-Var scheme corrects biases in temperature and salinity for the slowly evolving large-scale. Temperature and salinity vertical profiles from the CORA database, altimeter data from AVISO and satellite SST are jointly assimilated (multi-observations assimilation) but are subsampled to avoid an over-constraining of the data assimilation system.

MEDRYS1V2 has some specific assimilation settings dedicated to the Mediterranean area, such as a 5-day assimilation cycle, whereas global reanalyses used here have a 7-day assimilation cycle. We will not assess in this study the potential impact in MEDRYS of a shorter assimilation cycle (leading thus to more frequent analyses).

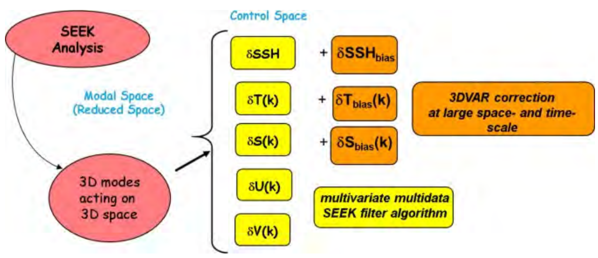

Figure 1. Schematic overview of SAM, Assimilation System of Mercator, Lellouche et al. (2013).

3. Main results

Global reanalyses have too high water transports through the Strait of Gibraltar (see Figure 2, averages over the 1993-2012 common period), leading to a negative net salt transport for the Mediterranean Sea in long-term average (opposite to what is observed), and also to an important decrease of the salinity in surface and in the sub-surface layer (0-150m, not shown). The intermediate layer is slightly too warm and too salty both in the regional and global reanalyses, but the low-resolution global reanalysis GLORYS2V4 shows an unrealistic variability of the intermediate salinity in the late 1990's - early 2000's. For the deep layer (below 600m) GLORYS2V4 again displays a similar unrealistic interannual variability, both in temperature and salinity, before year 2005, date of the substantial deployment of the Argo network in the Mediterranean. This latter point is improved in the new high-resolution global reanalysis, whose deep layer is closer to what is simulated in MEDRYS1V2.

Averaged surface circulation (not shown here) and variability (see EKE maps in Figure 3) in the 3 reanalyses are compared. Due to its lower resolution, GLORYS2V4 reproduces only the very large scale currents, but no mean mesoscale features. The latters are well captured in both 1/12° reanalyses, GLORYS12V1 and MEDRYS1V2. Looking at the EKE (Figure 3), a same comment can be made for GLORYS2V4, but larger differences between GLORYS12V1 and MEDRYS1V2 are highlighted, especially in the Algerian current and in the area of the Ierapetra eddy.

Transports through the Strait of Gibraltar 1993-2012 (observed values)	Reanalysis	IN	OUT	NET
Water (Sv) IN : +0,75/+0,85 OUT : -0,70/-0,80 NET : ~+0,05	GLORYS2V4	+1,49	-1,46	+0,030
	GLORYS12V1	+1,12	-1,11	+0,004
	MEDRYS1V2	+0,81	-0,78	+0,049
T (°C) and net heat (normalised in W/m²) NET : +4/+7	GLORYS2V4	17,1	13,2	+9,6
	GLORYS12V1	16,4	13,2	+6,5
	MEDRYS1V2	17,1	13,3	+6,5
S (psu) and net salt (normalised in 10^{-3} psu/an) NET : +1,5/+2,5	GLORYS2V4	36,32	38,36	-17
	GLORYS12V1	36,41	38,43	-18
	MEDRYS1V2	36,53	38,44	+1.8

Figure 2. Water transports, averaged temperature and salinity of the incoming and exiting waters, and net heat and salt budgets through the Strait of Gibraltar (1993-2012 averages). **Reference** values are indicated in **green** on the left column and come from Soto-Navarro et al. (2010, 2015) for the water and net heat transports, and deduced from the EN4 reconstruction, Good et al. (2013), for the net salt transport. For the reanalyses values, **red**/**green** colors indicate values respectively **outside**/**within** the observed ranges.

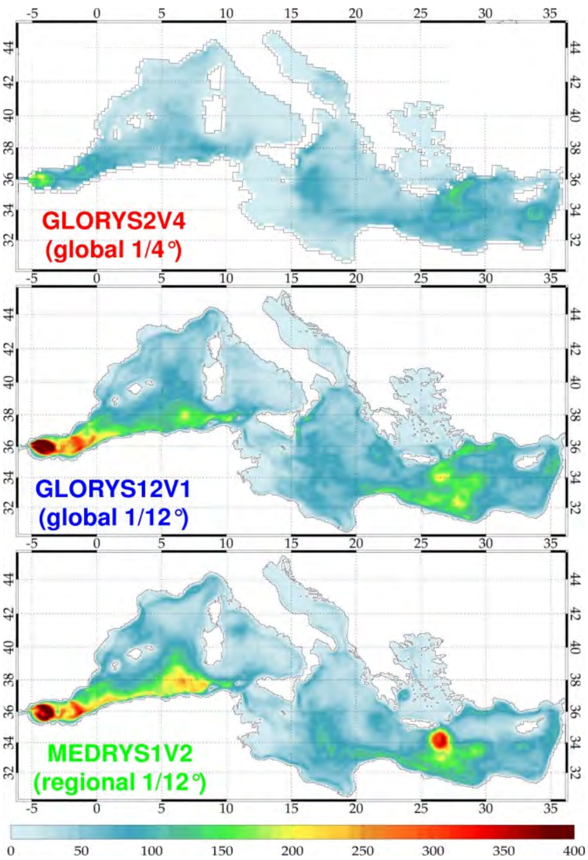

Figure 3. 40m-depth Eddy Kinetic Energy (EKE, in $cm^2.s^{-2}$) in average over 1993-2012.

For the deep convection, a focus is made on winter 2013 in the Gulf of Lions, to benefit from the oceanic Special Observation Period of the HyMeX program, Estournel et al. (2016). We compare, for a specific day (19th February 2013) the extension of the mixed patch in this area deduced from a satellite observation of Chl-a concentration, with the simulated extensions deduced from the sea surface density field in the reanalyses (not shown here). As expected, GLORYS2V4 shows less small scales meanders around the mixed patch. GLORYS12V1 has a quite correct extension around the center of the Gulf of Lions, but do not reproduce the extension towards the Ligurian sub-basin, correctly simulated in MEDRYS1V2. This difference in the 1/12° reanalyses is attributed to the low (resp. high)-resolution atmospheric forcings used in GLORYS12V1 (resp. MEDRYS1V2).

4. Conclusions and perspectives

This study shows that a regional reanalysis with a dedicated configuration can be used as a reference to validate global reanalyses and to highlight places and processes where improvements are needed in such global configurations. Moreover, it can help to modify specific settings towards values dedicated to the Mediterranean Sea, such as the lateral friction boundary condition in the Strait of Gibraltar (which is expecting to lead to better values of in and out water transports, and thus to smaller salinity biases in the Mediterranean Sea), or the need of dedicated and balanced atmospheric forcings, at higher resolution when possible.

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Activities with COSMO-CLM and NEMO for the North and Baltic seas at DWD

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1. Background

The region east of the Baltic Sea has been identified as a hot-spot of climate change by Giorgi, 2006, on the base of temperature and precipitation variability. For this purpose, the atmosphere model COSMO-CLM has been coupled to the ocean model NEMO, including the sea ice model LIM3, via the OASIS3-MCT coupler (Pham et al., 2014). The coupler interpolates heat, fresh water, momentum fluxes, sea level pressure and the fraction of sea ice at the interface in space and time. The setup of NEMO for the North and Baltic seas was designed at the Swedish Meteorological and Hydrological Institute (SMHI).

Regional climate predictions and projections are very important to provide future climate information for stakeholders and politicians. At DWD, the regional ocean-atmosphere model (ROAM) for the North and Baltic Seas is one tool to provide this information.

2. ROAM at DWD

ROAM is used in different projects at DWD. In the first phase of the national project MiKlip, it was shown, that there is an added value of using a regional climate model for decadal predictions. In the ongoing second phase of MiKlip, the added value will be further investigated by analysing and improving the initial- and lateral boundary conditions for ROAM and by introducing a river runoff scheme to close the hydrological cycle in close cooperation with Goethe University Frankfurt. The aim of these studies is to improve the understanding of the high resolution interactions between ocean, atmosphere and land surface, and to represent more regional feedback mechanisms while using the coupled regional modelling system. The single-model atmosphere-only CCLM ensemble for regional decadal predictions is augmented with the simulations of ROAM as an additional physics perturbation member.

In another national project "NOCO" funded by BMVI (Federal Ministry for Transport and Digital Infrastructure), the technical performance of the coupled system was investigated. Two simulations with different coupling time step for ten years show no significant differences when compared to observations.

DWD is also involved in a new pilot project on climate, waterways and shipping "ProWaS" initiated by BMVI. The main purpose is the development of tools and provision of operational pilot services for assessment of climate change and adaption measures. The involved federal agencies will derive products for water ways and shipping in the regions Rhine, Elbe and German Bight.

The results from the decadal forecast simulations with ROAM will be shown as well as the investigations of the coupling time step.

3. Outlook

Together with the Federal Maritime and Hydrographic Agency (BSH), DWD plans to improve the ocean component of the coupled system and reference data sets will be provided to the project partners with the coupled climate model for the recent past and future in the frame of ProWaS.

The tasks of the DWD are the following:

- Installation of a local ESGF node at DWD for data exchange with the project partners
- Provision of meteorological observations and climate projections for the ProWaS relevant areas
- Simulation with coupled model system (ERA Interim reanalysis, climate projection)
- Adaption of ICON for climate projections for Europe (ICON-LAM in climate mode) and conceptual considerations about a fitting regional ocean model

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A regional coupled Earth system model to study climate variations in the regions of the Baltic Sea

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1. Introduction

The Baltic Sea is a semi-enclosed sea in Northern Europe with a complex marine ecosystem. Since reliable long term observations are limited, climate models are needed to understand how a changing climate has impacted the marine ecosystem in the past or to predict the consequences of future climate change. Especially, local air-sea interactions play an important role for future projections (Schrum, 2017). However, these are not resolved in the coarse resolution global climate models and neglected in stand-alone regional atmosphere or ocean models.

Therefore, a new regional earth system model is under development to study the Baltic Sea and its ecosystem under past and future climate conditions. In this study, we present the concept for the IOW Regional Climate System Model (IOW-RCSM) covering the Baltic Sea and a first evaluation of the model prototype, which is compared to observations and reanalyses datasets.

2. Regional Climate System Model

The IOW-RCSM will consist of ocean, atmosphere, sea-ice, hydrology, and biogeochemical components (Figure 1)

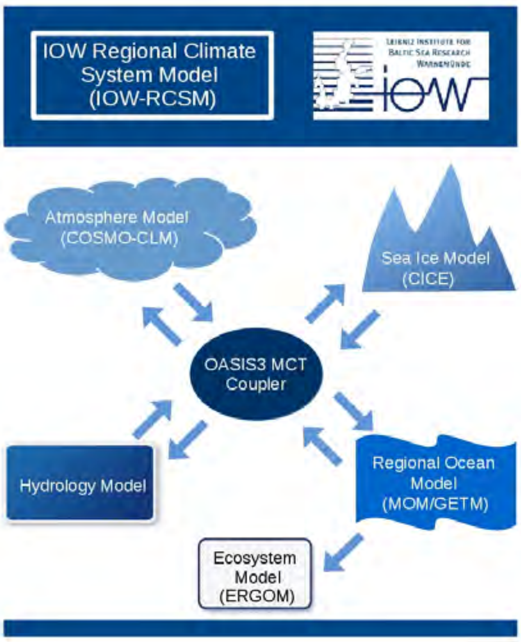

Figure 1. IOW Regional Climate System Model for the Baltic Sea (IOW-RCSM).

As a first step the atmospheric model COSMO-CLM (Rockel et al., 2008; EURO-CORDEX domain) with a horizontal grid resolution of 25 km is coupled over the Baltic Sea to the ocean model MOM-5 (Griffies, 2015) with a horizontal grid resolution of 8nm (about 14.8 km). The MOM-5 model already contains a thermodynamic/dynamic sea ice model (Winton, 2000), which is used in the first prototype. It will later be replaced by the more complex model CICE (Hunke et al., 2013). Further, it also includes a coupling to the biogeochemical model ERGOM (Neumann (2009); Neumann et al. (2017)). The ERGOM model reasonably simulates the biogeochemical processes in the Baltic Sea, including the phosphorus and nitrogen cycle, three phytoplankton groups and a dynamically developing zooplankton variable. In addition, the oxygen development is coupled to the biogeochemical processes (Neumann et al., 2017).

Within the first prototype of the coupled model system no hydrology model is included. The runoff from land is based on data from the HELCOM assessments (www.helcom.fi), while at the open ocean boundary in the Kattegat the same boundary conditions (sea surface height from a statistical model; climatological temperature and salinity datasets) as in Neumann et al., (2017) are applied. The ERA-Interim reanalysis data (Dee et al., 2011) are used as boundary conditions for the atmospheric model. Outside the Baltic Sea, sea surface temperature (SST) data from the Ocean Reanalysis System 4 (ORAS4, Balmaseda et al., 2012) are prescribed.

3. Coupling of Atmosphere and Ocean

The atmosphere and ocean model components are coupled with the fully parallelized OASIS3-MCT (Valcke et al., 2015). The coupler provides the coupling routines between the atmosphere and ocean components and handles the interpolation of the exchanged data between the different model grids. Each component is included as separate executable that are executed within a single MPI context. The atmospheric component already provides an interface to the coupler (Will et al., 2017). The interface in the ocean component to the coupler has been implemented. The exchange of information is performed at a frequency of 3 hours. During the two-way coupling process, variables sent from the ocean to the atmospheric component are SST and the sea-ice area fraction. The atmospheric component computes sea level pressure, heat and freshwater fluxes and sends them to the ocean component. Initialization is provided by stand-alone simulations of atmosphere and ocean that are forced with ERA-Interim reanalysis datasets.

4. Model Evaluation

The coupled model simulates individual years during the ERA-Interim period 1979-present to analyze its general performance and stability. Especially the realistic simulation of the air-sea fluxes will be assessed by comparing them to observations. Then the coupled model will be run for the ERA-Interim period and compared with corresponding uncoupled simulations (Figure 2), to investigate the added value of the model coupling.

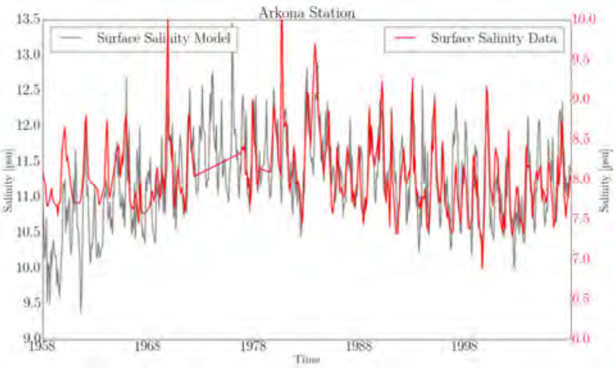

Figure 2. Surface salinity simulated with MOM-5, forced with coastDat2 atmospheric data (Geyer, 2014), and compared with observations at the Arkona Station (Boergel, 2016).

5. Future Work

Once the model system is set up and validated, it can be used to study different science questions. Long-term paleo simulations will be performed to study for example the variability of Major Baltic Inflows and its relation to the large-scale atmospheric circulation or the conditions of the Baltic Sea during the medieval warm period. Future scenario simulations will be used to study the impact of global climate change on the Baltic Sea ecosystem. We will also contribute to the coordinated experiments in the Baltic Earth framework.

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The model development, simulations and validation were performed with resources provided by the North-German Supercomputing Alliance (HLRN).

The climate change signal for temperature and salinity in the Western Mediterranean Sea in a regionally coupled ocean-atmosphere model

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1. Introduction

The Mediterranean Sea and adjacent land is expected to be one of the most prominent and vulnerable climate change "hot spots" in the coming century. In this context, climate change lies at the heart of sustainable development in the Mediterranean. As such, the region is an optimal test bed for new approaches to science-society partnerships sustained by the provision of adequate climate information and applicable to a broad range of vulnerable sectors. The region is located in a transitional area between tropical and mid-latitudes and presents a complex orography and coastlines where intense local air-sea and land-sea interactions take place. These intense local air-sea interactions together with the inflow of Atlantic water drive the Mediterranean thermohaline circulation. Global climate models have too coarse a resolution to correctly describe these air–sea fluxes of energy and mass that play a key role in the process of deep water formation in the Mediterranean Sea, and stand-alone atmospheric models can be inadequate to simulate the correct fluxes.

For these reasons, the Mediterranean Sea is a region where atmosphere-ocean regional climate models (AORCM) are critical for the study of the processes in the atmosphere and ocean. It is useful not only in order to improve our knowledge about its mechanisms but also because it provide one of the few regions in the word ocean where it is possible to study the processes involved in deep water formation.

2. Methods

In this work we present simulations with the regionally coupled model ROM in order to assess the role of ocean feedbacks in the simulation of the present climate and on the downscaled climate change signal. To this end, two sets of coupled and uncoupled atmospheric simulations driven by ERA-Interim and a climate change simulation by MPI-ESM under the RCP8.5 scenario have been carried out.

ROM includes a global ocean with regionally high horizontal resolution (MPIOM), which is coupled to an atmospheric regional model (REMO) and global terrestrial hydrology model (HD). The coupling is only effective within a selected domain, where the ocean and the atmosphere are interacting. Outside this domain, the ocean model is uncoupled, driven by prescribed atmospheric forcing, thus running in a so-called stand-alone mode.

3. Results

The experiments in which our model is driven by ERA-Interim show a good performance in simulating the present climate. The biases of the main climate variables are in the range of those shown by other state of art regional models.

Our analysis of the simulations driven by the MPI-ESM climate change simulation shows that under the RCP8.5 scenario by the end of the century the Mediterranean waters the Mediterranean Sea will be warmer and saltier across most of the basin. The temperature in the upper ocean layer during the 2069-2099 period in comparison with the 1950-1980 control period is proyected to have a mean increase of 2,82 °C while the mean salinity increases by 0,03 psu. The warming, that initially takes place in the surface layer propagates gradually to the deeper ocean, causing changes in the Mediterranean overturning circulation

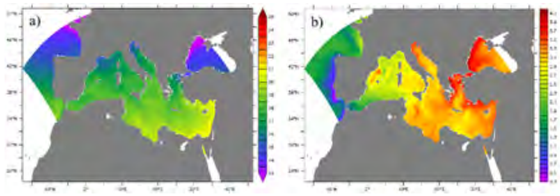

Figure 1. a)Mean SST in the Mediterranean (°C) for the 1950-1980 period; b) SST change (°C) for the 2069-2099 period with respect to 1950-1980.

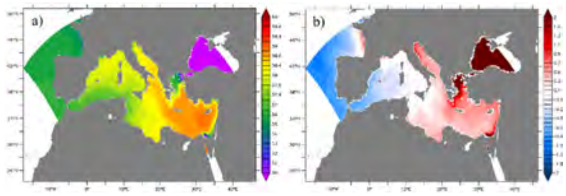

Figure 2. a)Mean SSS in the Mediterranean (psu) for the 1950-1980 period; b) SSS change (psu) for the 2069-2099 period with respect to 1950-1980.

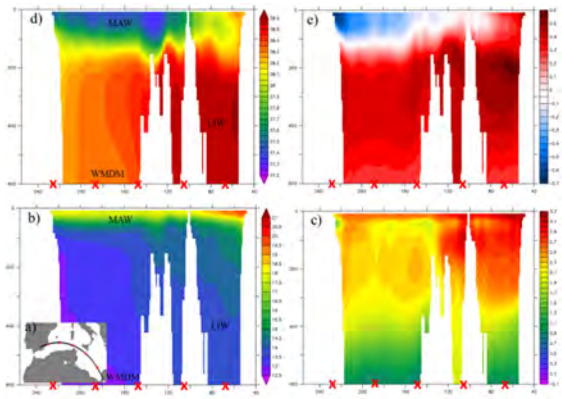

Figure 3. a) Vertical transect in the western basin. In the vertical axis we represent the depth (m) while in the horizontal we represent the nodes along the transect; b) mean temperature for 1950-1980 (°C); c) temperature change (2069-2099 minus 1950-1980); d) mean salinity (psu) normal for 1950-1980; (c) temperature change (psu) entre 2069-2099 y 1950-1980

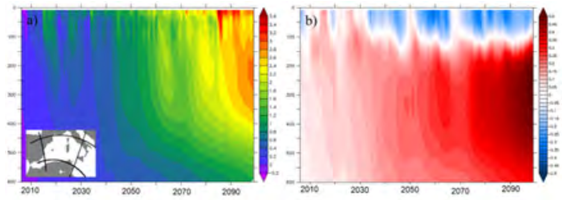

Figure 4. Evolución temporal a lo largo de la columna de agua (600) m en la cuenca occidental; a) temperatura (ºC); b) salinidad (psu).

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The Impact of Water Constituents on Radiative Heat Transfer in the Open Ocean and Shelf Seas

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1. Introduction

Radiant energy fluxes impact biological production in the ocean and are modulated as a result of biological production. This has fundamental consequences for upper ocean physics, surface nutrient supply, net primary and export production and the exchange of soluble gases across the air-sea interface into the marine atmospheric boundary layer. The contribution of optically active water constituents to heating rates in the upper ocean is intrinsically linked to net primary and export production, through the direct effect of temperature on metabolic rates of marine plankton. This plays an important role in controlling the flow of carbon and energy through pelagic systems (Wohlers et al., 2009; Taucher and Oschlies, 2011), in particular, the partitioning between particulate and dissolved organic carbon, the transfer of primary produced organic matter to higher trophic levels, the efficiency of the biological carbon pump and the exchange of CO_2 across the air-sea interface.

Heterogeneity of water constituents in shelf seas and coastal waters is increased by the presence of inorganic suspended particulate matter and coloured dissolved organic matter (CDOM). Sources of CDOM and changes to its composition through non-conservative processes are tightly coupled to the underwater light field. These will vary with environmental conditions and phytoplankton community structure. Moreover, heterogeneity in phytoplankton pigments and other water constituents will have implications for sub-mesoscale vertical mixing and advective fluxes, and thus water temperature, density and the supply of nutrients to the surface. Understanding what the consequences are for energy fluxes in the upper ocean and across the air-sea interface, and the accumulative effect on the upper ocean heat budget in shelf seas and coastal waters is of particular importance for our capacity to adequately model regional ocean climate.

2. Approach

We are using a coupled ocean-atmosphere circulation model (Figure 1) incorporating a bio-optical module with multiple phytoplankton groups in tandem with an atmosphere-ocean radiative transfer model to explore the contribution of optically active water constituents (including phytoplankton, CDOM and inorganic suspended sediments) to energy fluxes in the upper ocean and across the air-sea interface. Specifically, we are investigating:

- How heterogeneity in optically active water constituents in shelf seas affects the characteristics of sub-mesoscale vertical turbulent mixing and advective fluxes, through feedbacks with upper ocean heating rates and water density?
- What are the consequences for the supply of surface nutrients and the transport and transformation of phytoplankton biomass?
- What is the seasonal modulation of the flux of thermal energy across the ocean atmosphere interface as a result of heating rates induced by optically active water constituents?
- To what extent is variability in CDOM attenuation reflected by environmental conditions and phytoplankton community structure?

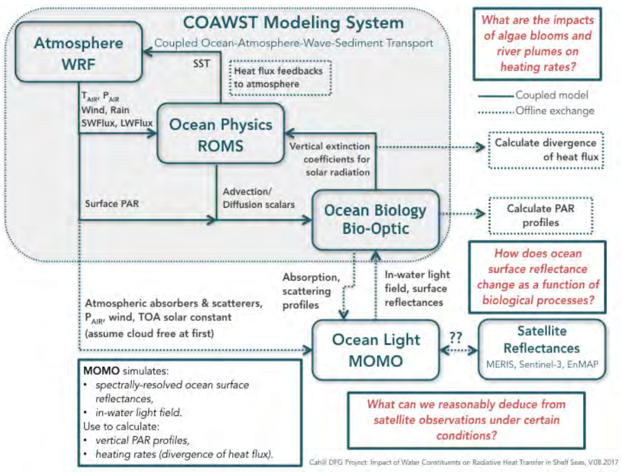

Figure 1. Overview of modelling system(s), interaction between components and data streams.

The coupled ocean-atmosphere-bio-optical circulation model is being applied to selected shelf sea regions characterized by different freshwater and nutrient regimes, and complex bio-optical and hydrodynamic processes (Figure 2). The bio-optical module, which explicitly follows the spectrally-resolved vertical light stream, accounts for optically active water constituents' contribution to the divergence of the heat flux within the full hydrodynamic solution. This means that heating rates due to the highly variable concentrations of optically active water constituents can be estimated and their impact on ocean biophysical processes evaluated.

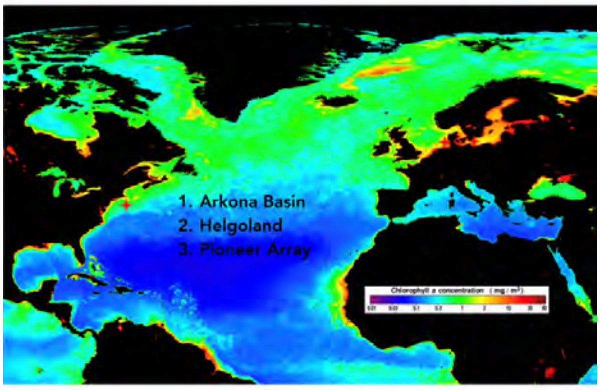

Figure 2. Ocean colour image of annual average chlorophyll concentration in 2007 (source: NASA GFSC) indicating location of three sites: (a) coastal waters of the western Baltic Sea, (b) the central German Bight and (c) Central Mooring of the Pioneer Array in Northwest Atlantic.

We will evaluate these modelled heating rates against more rigourous co-located heating rate calculations performed using the atmosphere-ocean radiative transfer model, MOMO. The coupled 3D model solution will thus be optimized for regional applications. This will lead to improved net surface solar radiation forcing fields, an accurate underwater vertical description of the light field and a resolution of the radiative flux divergence between physics and biology in the ocean. In so doing, we expect to make a major contribution toward overcoming some of the obstacles inherent in studying optically complex shelf and coastal waters. The outcome will be a rigorous assessment of the impact of optically active water constituents on upper ocean heat budgets and will establish a framework for regional two-way coupled ocean-atmosphere investigations with important consequences for weather forecasting and climate change.

3. Acknowledgements

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Role of atmospheric forcing resolution in the long-term seasonal variability of the Tyrrhenian Sea circulation from a set of ocean hindcast simulations (1997 - 2008)

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1. Objective

The Tyrrhenian Sea circulation is driven by the interplay of local climate and transport at its main straits and features a distinct seasonal variability. In this work we investigate the role of the horizontal resolution of atmospheric forcing (50 km or 25 km) in the long-term seasonal variability of the Tyrrhenian Sea circulation. To this end, we adopt an ocean general circulation model and a new collection of atmospheric forcing.

The main objectives of this work are (i) to study the capability of this forcing to simulate the main features of the Mediterranean Sea dynamics, (ii) to assess the ability of state-of-the-art hindcast simulations to reproduce the seasonal variability of the Tyrrhenian circulation, (iii) to examine the Tyrrhenian intermediate-depth circulation and update formerly proposed circulation patterns and (iv) to investigate the mechanisms responsible for changes in circulation when the atmospheric forcing resolution is increased.

2. Model setup

In this analysis we use NEMO-MED12, a Mediterranean configuration of the Nucleus for European Modelling of the Ocean (NEMO) v3.2 (Madec et al., 2008). Atmospheric variables derive from two previous simulations conducted with the atmosphere regional climate model PROMES (Domínguez et al., 2013) nested in ERA-Interim. PROMES fields are here used for the first time to force ocean simulations. PROMES fields have a horizontal resolution of 50 km and 25 km and are available with a frequency of 3 h or 6 h, depending on the variable. This work is a first step towards the development of a coupled PROMES-NEMO-MED12 configuration.

3. Results and conclusions

As to the Mediterranean Sea, the calculated air-sea fluxes reproduce relatively well the seasonal cycle derived from observational datasets. The presented model setup captures the seasonal cycle of the water transport at the Strait of Gibraltar, as well as the interannual variability of the hydrographic properties of the different Mediterranean water masses.

Regarding the Tyrrhenian surface circulation, our results show that, in winter and spring, a cyclonic stream that borders the sub-basin arises. This stream does not develop in summer and fall. The surface patterns we find and their seasonal variability are in line with altimeter data and results presented in previous works (Artale et al., 1994; Iacono et al., 2013). Intermediate circulation patterns encountered for winter-spring and summer-fall, respectively, show a good agreement with schemes from Krivosheya and Ovchinnikov (1973).

Whereas the basin-scale seasonal variability of the Tyrrhenian circulation does not respond to the prescription of 50 km or 25 km resolution forcing, mesoscale circulation improves when 25 km atmospheric forcing is used. The improvements observed involve changes in the position, geometry and velocity of the mesoscale structures. Only the most intense surface eddies are found at intermediate depths. Overall, the use of 25 km forcing intensifies surface mesoscale structures and thus, with this forcing, more meanders and eddies are reproduced at 400 m depth.

The improved mesoscale circulation when 25 km forcing is prescribed does not seem to be caused by changes in the transport across Sardinia, Corsica and Sicily straits, but may be related to changes in the regional distribution of the atmospheric fields. Wind intensification across the Bonifacio Strait and changes in the heat flux seem to be behind the improvements observed with higher resolution forcing.

Acknowledgements

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Projected Changes in Baltic Sea Upwelling in Climate Change Scenarios

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1. Introduction

Climate change scenarios with global circulation models (GCMs) do not represent regional processes adequately enough to permit an analysis of regional effects of possible changes in the Baltic Sea region. Dynamical downscaling with regional climate models (RCMs) allow for a consistent projection of climate change in the Baltic Sea region and for a closer look at regional phenomena like coastal upwelling. Upwelling in the Baltic Sea has been identified to play a potential role for the algae bloom forecast, fisheries, weather prediction and tourism (Lehmann and Myrberg, 2008).

Sea surface temperature in the Baltic Sea is expected to increase between 1 and 4 degrees depending on the Representative Concentration Pathways (RCPs) and on the season. An analysis of Lehmann et al. (2012) has shown that the upwelling frequency in the upwelling regions along the southeastern Swedish coast has increased by up to 30% within the period 1990 to 2009. We aim to verify whether upwelling will occur more frequently under projected changes of the regional climate during this century.

2. Methods

To this end we ran an ensemble of scenarios with the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO (Wang et al., 2013). The ensemble consists of three different RCP scenarios from five different GCMs. This yields a number of different trajectories for the possible evolution of the climate in the Baltic Sea region. The GCMs that are applied on the open boundaries of the atmosphere and the ice-ocean model together with the RCPs are listed in Table 1.

Experiment	RCP8.5	RCP4.5	RCP2.6
MPI-ESM-LR	1961 - 2099	1961 - 2099	1961 - 2099
EC-EARTH	1961 - 2099	1961 - 2099	1961 - 2099
GFDL-ESM2M	1961 - 2099	1961 - 2099	1961 - 2099
HadGEM2-ES	1961 - 2099	1961 - 2099	1961 - 2099
IPSL-CM5A-MR	1961 - 2099	1961 - 2099	

Table 1. Ensemble of RCP scenario experiments conducted with RCA4-NEMO.

RCA4-NEMO consists of the RCA4 atmosphere model in a model domain covering the Northeast Atlantic and Europe and the NEMO-Nordic setup for the North Sea and Baltic Sea (Dieterich et al., 2013). RCA4-NEMO is a fully coupled atmosphere-ice-ocean model, where the different components are coupled every 3 hours using the Oasis3 coupler. The coupler does exchange the surface temperatures of open water and sea ice together with the ice fraction and ice albedo to the atmosphere model. From the atmosphere the ice-ocean model receives the momentum fluxes and pressure at the surface, the shortwave and non-solar heat fluxes and the freshwater fluxes due to the evaporation - precipitation. For the experiments discussed here the river discharge was prescribed using results from an E-HYPE simulation driven by a downscaled ERA-interim reanalysis (Donnelly et al., 2016). To approximate the expected increase in river discharge in the Bothnian Sea and the Bothnian Bay an artificial trend of 10% per century has been added for the years 2008 - 2099 to the climatological seasonal cycle derived from the E-HYPE simulation.

3. Results

The modeled changes in sea surface temperature are not uniformly distributed in the Baltic Sea. The summer SST in the middle and at the end of the century changes most pronounced in those areas that have been identified as typical upwelling areas by Bychkova et al. (1988).

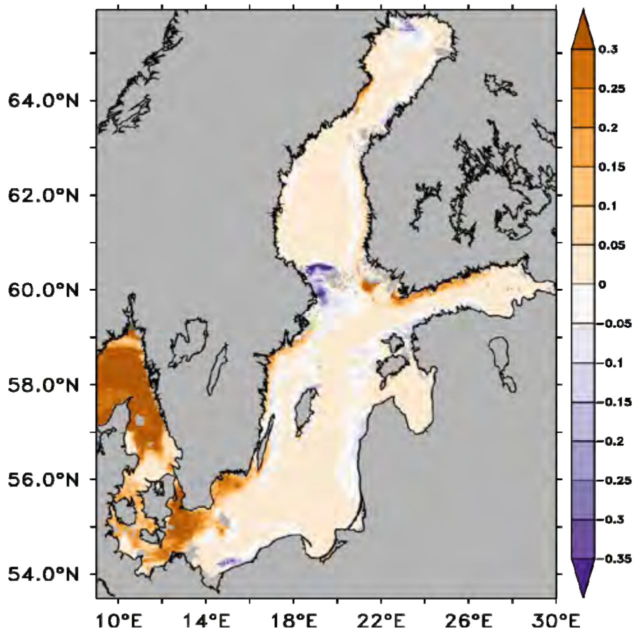

Figure 1. Changes in upwelling frequency [1] between the far future (2070 to 2099) and the recent past (1970 to 1999) for the RCP8.5 ensemble median. Values of 0.2 and above are significant and represent a change of 20%.

There is a tendency for the upwelling areas along the Swedish south and east coasts and the Finish south coast to produce more intense or more frequent upwelling (Figure 1). In the middle of the century the SST has increased by 1 degree on average. In the upwelling areas that are favored by strong westerlies the SST has actually decreased compared to the reference period. On the eastern side of the Baltic Sea and on the Estonian coast of the Gulf of Finland SST increased more rapidly than on average and those upwelling areas seem to have been weakened. The same principal picture emerges towards the end of the century although the SST signals of the upwelling areas are masked somewhat on the backdrop of the overall increase in SST of 2 degrees.

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Effects of ocean-atmosphere coupling in regional climate models on the simulation of medicanes: present climate representation and future projections

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1. Introduction

Medicanes are a particular type of intense cyclones over the Mediterranean Sea that present tropical characteristics, usually over a short period. The small size of medicanes and the importance of air-sea interaction in their formation and intensification represents a challenge for their simulation by regional climate models (RCMs).

Air-sea interaction frequently produces a negative intensity feedback for tropical cyclones, which depends on the oceanic mixed layer depth. This negative feedback is inhibited in case of deep oceanic mixed layers. Here we examine if the negative intensity feedback prevails or not in RCM simulations of medicanes.

2. Data and methods

Multi-model ensembles of ocean-atmosphere coupled RCM simulations are available from MedCORDEX and other sources. Pairs of coupled/uncoupled runs with the same atmospheric RCM are used to detect differences due to coupling. The cyclone detection and tracking method from Picornell et al. (2001), adapted for mesocyclones, is applied together with the cyclone phase space method of Hart (2003) for identifying tropical characteristics.

RCM simulations nested in reanalysis are used for assessing the ability of the models to reproduce present climate characteristics of medicanes. The observational database of Miglietta (2013) is used as a reference for this evaluation.

For some of these RCMs, we also analyze long period simulations (1951-2100) nested in global climate models (GCMs). Pairs of coupled/uncoupled runs allow us here to assess the effect of coupling on future projections of medicanes.

3. Results and discussion

For simulations nested in reanalysis, the use of air-sea coupled RCMs has a limited impact on the simulated frequency and intensity of medicanes, but it causes an interesting seasonal shift from autumn to winter (Gaertner et al., 2016). This could point towards an influence of oceanic mixed layer depths, which are higher in winter in the Mediterranean Sea. It is important to note in this respect that medicanes typically do not occur in July or August, when the mixed layer is very shallow.

An analysis of two contradictory simulated medicane cases suggests that the negative intensity feedback may depend on the mesoscale distribution of the oceanic mixed layer depth and the associated fine structure of SST. The presence of mesoscale structures in the surface circulation of the coupled runs affects the differences in SST between the uncoupled and coupled runs, as the SST fields in the uncoupled run are much smoother.

First results in future projections point towards an important effect of coupling, which at least in some cases seems not to be a simple consequence of the negative intensity feedback. These results increase the interest of applying air-sea coupled RCMs for climate change analysis of this type of cyclones.

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Haline convection due to sea ice brine rejection in the Northern Baltic Sea

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1. Abstract

The aim of this study is to investigate the role of haline convection due to sea ice brine rejection in the water mass formation and circulation of the Baltic Sea. The main research questions are to what extent and under which conditions brine release in the Northern Baltic Sea (Gulf of Bothnia and Gulf of Finland) leads to deep water formation, and whether there is an inflow of this water into the Baltic proper.

For this purpose, a sensitivity study using the General Estuarine Transport Model (GETM, Burchard and Bolding, 2002) is conducted. The brine release is simulated via an "artificial salt source", i.e. negative freshwater fluxes are prescribed as a surface boundary condition. Experiments with varying strength, spatial and temporal patterns of the fluxes are performed. In particular, three experiments with fluxes being representative for (a) an average winter in the present climate state, (b) a severe winter in the present climate state and (c) an average winter during the Little Ice Age are evaluated and compared to a control simulation without a salt source. The deep water formation and flow of the water masses is tracked by use of passive tracers.

In a second step, it is planned to implement a subgrid-scale brine rejection parametrization as in Nguyen et al. (2008) into the GETM model and to re-run the experiments. It is expected to yield much more realistic results due to a reduction of excessive grid-scale vertical mixing.

2. Introduction

The process of brine release associated with the formation of sea ice is a major source of deep water formation in the polar regions and an important driver of the global thermohaline circulation. When sea water freezes, salt accumulates into so-called brine droplets, which are gradually rejected back into the ocean. The increase of near-surface water salinity leads to buoyancy fluxes destabilizing the water column and resulting in (possibly deep) haline convection. The major part of sea ice formation and with that brine rejection occurs in openings of the sea ice which can be either induced by ice motion (leads) or by persistent winds or upwelling of warm water (polynyas).

While in the Arctic and Antarctic ocean the process has been studied extensively, not much attention has been drawn to haline convection in temperate seas as the Baltic Sea. The latter freezes regularly each winter with largely varying ice extents ranging from 50.000 – 420.000 km^2 (Seinä and Palosuo, 1996) and typical ice thicknesses of 65-80 cm in the Bothnian Bay (Alenius et al., 2003).

In 1993, Marmefelt and Omstedt presented a study concluding from rough estimations based on measured salinity profiles and typical ice thicknesses that deep haline convection is not likely to occur frequently in the entire water mass of the Gulf of Bothnia. As localized effects like the formation of salt plumes in leads are neglected in these estimations, it seems worthwhile to re-investigate this process for the Baltic Sea using a sophisticated, high-resolution circulation model.

3. Method

The simulations presented in this study are conducted with the General Estuarine Transport Model (GETM) with a Baltic Sea setup of 1 nm resolution. The GETM model uses vertically adaptive coordinates, which is favorable for the addressed problem because numerical mixing is substantially reduced as shown by Gräwe et al. (2015).

The GETM model is coupled to a simple, thermodynamic sea ice model which does not include fluxes between the water and sea ice. Instead, the brine release is simulated by prescribing negative freshwater fluxes as a surface boundary condition, which effectively leads to an increase of sea surface salinity. The strengths, temporal and spatial patterns of the input fluxes are chosen based on output data of simulations from Neumann et al. (2017) conducted with the Modular Ocean Model (MOM version 5.1, Griffies et al., 2004) using a 3-nm-resolution Baltic Sea setup. The MOM model includes a dynamic-thermodynamic ice model yielding realistic ice data for the Baltic Sea.

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The individual role of temperature and salinity change for different trophic levels in global climate scenarios downscaled for the Baltic Sea and North Sea

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1. Introduction

The estuarine characteristics of the Baltic Sea promotes a wide range of water masses with specific physical and biogeochemical signatures. Oceanographic conditions range from nearly open ocean characteristics in the southwest to brackish waters in the northern parts of the Baltic Sea. Accordingly, the diversity of many different water bodies compared to other marginal seas like e.g. the North Sea support a high biodiversity under the present climate. Modified global atmospheric moisture and heat transports are expected to have substantial impact on water mass properties in the Baltic Sea (e.g. Meier et al, 2012) in the course of ongoing climate change. Expected water mass warming and freshening affects lower trophic species at the base of the food chain along contrasting ways:

A stronger thermocline and halocline is which is likely to occur during the 21st century tends to weaken nutrient transport into the euphotic layer while higher temperatures stimulates phytoplankton growths and facilitates the decomposition of particular organic matter (POC) with positive effect on nutrient concentration.

2. Methodical approach

We here use a hierarchy of high resolution 3D models to investigate concomitant changes on of temperature and salinity and to distinguish their effect on vertical mixing. Mainly two challenging problems are associated with this:

1) A realistic thermal air sea coupling is necessary to model mixed layer dynamics (Gröger et al., 2015) and to circumvent a to strong constrain of the regional model to the driving global model (Mathis et al., 2017).

2) The global pattern of regional precipitation changes exhibits a large disagreement in state of the art global climate scenarios in the framework of CMIP5especiall over the land surface (e.g. Greve et al., 2014; Roderick et al., 2014) giving rise to a high uncertainty on the regional scale.

We address the above mentioned problems by 1) applying a high resolution interactively coupled ocean-atmosphere model to keep mixed laer dynamics as realistic as possible thereby maintaining the added value of regionalization (Mathis et al.,2017) and 2) we use the to our knowledge by far largest ensemble of interactively coupled downscaled CMIP3 and CMIP5 scenarios to address the uncertainty inherent in global projections of future precipitation changes.

In a second approach an offline 3D regional ocean and biogeochemistry model is applied to estimate the impact of projected changes in temperature, salinity and oxygen on habitat size of higher trophic species in the Baltic Sea.

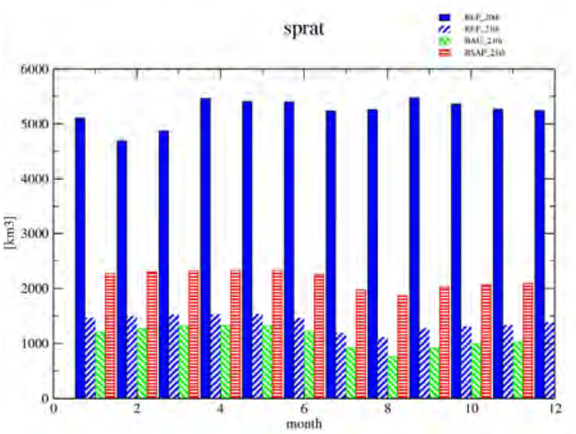

Figure 1: Water mass volume support spawning success under different climate and eutrophication scenarios.

We here follow an approach by (MacKenzie et al., in prep.) that relies on the estimated success for reproduction. We here focus on a number of different benthic-spawning species and pelagic species and analyze future habitat sizes. We here consider likewise different scenarios for likely future eutrophication scenarios and its impact on oxygen (Figure 1).

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Integration of Engineering Data of ocean floor in Environmental and Ecosystem Modeling with Geophysics Precursors Invading Impact of Global Warming on Deep Sea Creatures.

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1. Introduction I

Paper comprising research works as listed below:

To go in depth of how Climate Change is messing with deep sea creatures and ecological cycle by developing a critical path analysis and ecosystem modeling to ensure the food security

Considering the statistics: France's "4 per 1000 - soils for food security and the climate" is based on the fact that an annual increase of soil carbon at a rate of just 4% would be enough to stop the present increase in atmospheric carbon. This national effort by France will focus on ecological agricultural practices to sequester carbon to restore stability to our climate", its important pay attention to the living condition of deep sea creatures to ensure the sustainable ecological balance.

Promote Carbon Footprint of Sea Creature Site: Proposed Time Lapse Seismic - Ecosystem Modeling and IECM (Integrated Environmental Control Model) to Estimate and Monitor the CO2 Saturation during Carbon Sequestration Aspects combining Reservoir Saturation Tool (RST) engaging Engineering Data (such as Relative Permeability and Fractional) emphasizing the maximum possible Carbon Sequestration in Sea floor to promote carbon footprint.

Research Paper Highlighted Works:

i. Integrating the knowledge about site's engineering data (wettability, relative permeability, pressure etc.) with geophysical technique to obtain a more accurate and reliable results in estimating CO2 saturation in Sea Soil. CONUS-SOIL can be helpful tool as to develop Environmental Modeling and Ecosystem Management.

ii. An overview of some techniques in estimating the saturation including RST, being more focused on Time Lapse Seismic Modeling and IECM (Integrated Environmental Control Model) to provide the estimation and situation of saturation over the whole storage area in Deep Sea floor.

iii. Fluid sampling in the storage reservoir can give information about the changes in the fluids compositions and pH which can be used to infer geochemical changes in the soil-water rocks of sea floor. TOUGH2 Software can be helpful to get the proper feature of the condition.

iv. Core-flood experimental studies can provide useful data average maximum and average expected CO2 saturation which can be used to constrain and validate the saturation estimation in Ocean Soil ecosystem of Deep Ocean.

2. Introduction II

Deep Sea Creature Site Temperature Monitoring and Observation: 4D Geophysical Monitoring and Modeling of Ocean Soil Hydrogeological Precursors to Regulate Ecosystem Responses to the Global Climate Change

Research Paper Highlighted Works:

i. The study which can be used to justify the proposal is – Ocean Soil hydrological properties can modify ecosystem responses to changes in precipitation patterns, warming, and elevated atmospheric [CO2] by altering partitioning of rainwater among runoff, evaporation, and transpiration.

ii. Water partitioning patterns along a ocean soil texture gradient alter soil water content, and then regulate ecosystem responses to changes in global change factors.

iii. To get this study done- TECO (Terrestrial ECOsystem (TECO) Model) precursor model is to be considered. Which is a process-based ecosystem model and designed to examine critical processes in regulating interactive responses of plants and ecosystems to elevated CO2, warming, altered precipitation.

iv. The calibrated model can be used to simulate responses of ocean soil moisture, evaporation, transpiration, runoff, net primary production (NPP), ecosystem respiration (Rh), and net ecosystem production (NEP) to changes in precipitation amounts and intensity, increased temperature, and elevated atmospheric [CO2] along a ocean soil texture gradient (sand, sandy loam, loam, silt loam, and clay loam). Ocean Soil available water capacity (AWC), which is the difference between field capacity and wilting point, can be addressed as the index to represent ocean soil hydrological properties due to the climate change.

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Closing the water balance in a regional coupled system model over the North and the Baltic Sea

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1. Background

In many regional ocean models river flows are obtained from climatological data, which are often monthly data, thus, high peaks due to heavy precipitation are not taken into account. This is often even the case in a coupled setup where the regional ocean model is coupled to a regional atmosphere model. Recently, a few regional atmosphere-ocean coupled system models have been introduced where the river runoff is calculated interactively by a hydrology model or routing model. In line with these developments, this is also done at the Helmholtz-Zentrum Geesthacht.

2. Coupled System Model

In this study, we consider a subset of the regional coupled system model GCOAST, which comprises the regional atmospheric model COSMO-CLM vs. 5.0 (Rockel et al. 2008) and the ocean model NEMO vs. 3.6 (Madec et al. 2016) that are communicating with each other via the coupler OASIS3-MCT vs. 2.0 (Valcke et al. 2013). COSMO-CLM uses the EURO-CORDEX domain with 0.22° resolution and NEMO covers the Baltic Sea, North Sea and parts of the North Atlantic with 3.5 km.

Using this GCOAST-subset, we have integrated the hydrological discharge (HD) model (Hagemann and Dümenil 1998; Hagemann and Dümenil Gates 2001) into GCOAST for the calculation of river runoff, such as it is shown in Figure 1. The HD model has already been used for many years in the global Earth System Model (ESM) MPI-ESM (Giorgetta et al. 2013) and its predecessor ECHAM5/MPIOM (Roeckner et al. 2003; Jungclaus et al. 2006), but was also recently implemented into the regional ESMs ROM (Sein et al. 2015) and RegCM-ES (Sitz et al. 2017) as well as the regional climate model REMO-MPIOM (Elizalde 2011). The HD model is designed to run on a fixed global regular grid of 0.5° horizontal resolution, and it uses a pre-computed river channel network to simulate the horizontal transport of water within model watersheds. To do so, different flow processes are considered, such as overland flow, base flow, and river flow.

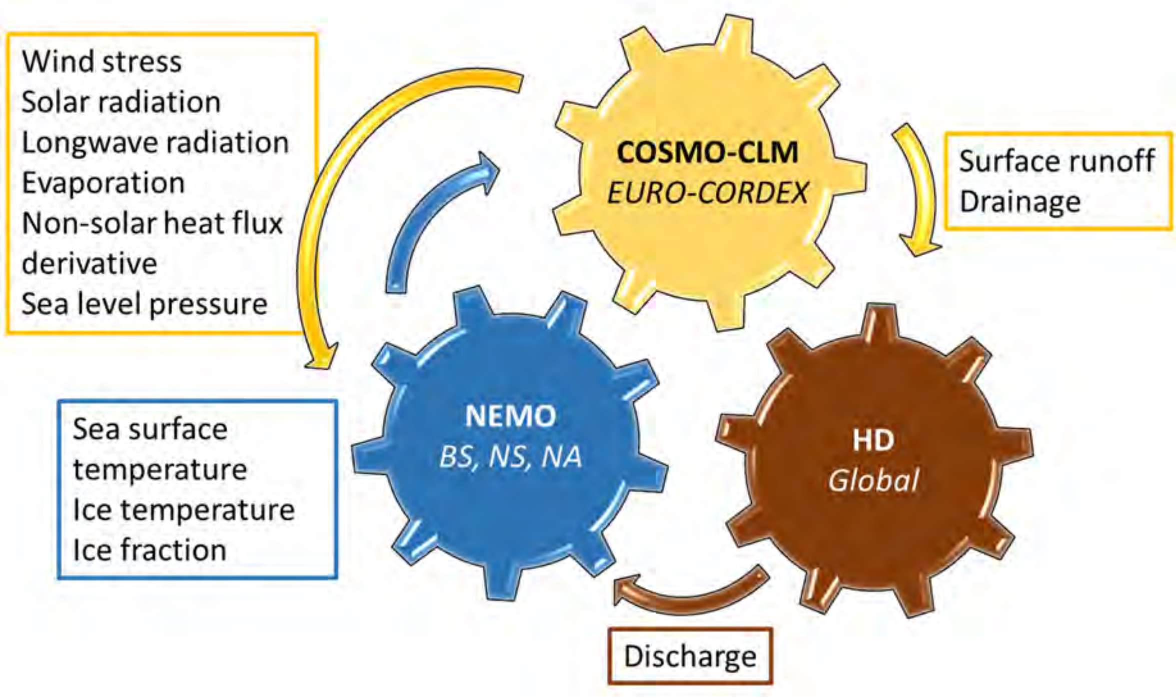

Figure 1. Atmosphere-ocean-river coupled model, a subset of the GCOAST regional earth system model. The atmospheric model COSMO-CLM covers the EURO-CORDEX domain (orange). The ocean model NEMO covers Baltic Sea, North Sea and Northern Atlantic (blue). The hydrological model HD has a global domain (brown).

3. Setting up the coupled system

In our presentation, we will show various problems encountered with setting up the coupled system and how we solved them. We will especially address water conservation that is an important issue while passing the runoff amounts from an atmospheric model through a river runoff scheme to an ocean model, because usually, the atmosphere, ocean and river runoff models use different spatial resolutions.

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First evaluation of a high resolution model of the Central Mediterranean Sea

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1. Introduction

The Central Mediterranean is a key area connecting the western and eastern basins of the Mediterranean Sea through the Strait of Sicily. The Atlantic current crosses this Strait mainly along the north-eastern Tunisia coasts. It reaches the Tunisia eastern and southern coasts occasionally, depending mostly on the atmospheric conditions (Poulain and Zambianchi, 2007). During some particular events in the summer season the Atlantic vein penetrates in the Gulf of Gabès, whereas during other episodes in winter it is directed eastward, towards the eastern basin. Some variability also occurs in the northern branches of the Atlantic vein, close to Sicily. The Gulf of Gabès constitutes a singular area in the Mediterranean Sea. It is a large and shallow water body where the interactions with the atmosphere are very strong. The air-sea coupling hence plays a crucial role in this zone. On the other hand the water renewal from the Atlantic is still under debate (Drira et al., 2014). The present work aims at the setting up of a high resolution numerical model for the Central Mediterranean Sea with special focus on the Tunisia coasts. The model will be used to study the small scale processes within this region; it will also serve as a tool providing highly accurate high resolution maps of temperature, salinity and currents that can be used in a wide range of applications. They can be used for example for the determination of the regions where marine dynamics can be harnessed for energy generation or for off-shore aquaculture studies.

2. Model and observations used

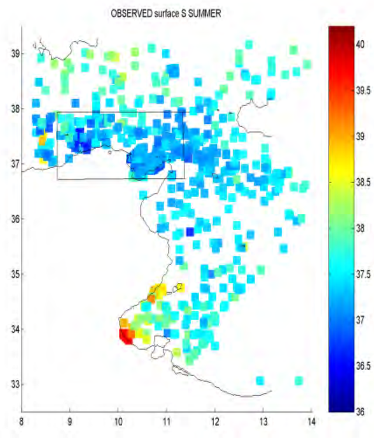
The model set up for the Central Mediterranean Sea is called INSTMCOTRHD and is based on the Princeton Ocean Model (POM, Mellor and Yamada, 1982). It is a high resolution version of a previous coarser resolution one (Alioua and Harzallah, 2008). The bathymetry is based on the Global Multi-Resolution Topography (GMRT, Ryan et al, 2009). An initial resolution of 791 m was used. The model is eddy-resolving with 2 km horizontal resolution (~1/52°). The lateral conditions use daily global operational Real-Time Ocean Forecast System (RTOFS, Mehra and Rivin, 2010) which are based on the 1/12° global HYbrid Coordinates Ocean Model (HYCOM, Chassignet et al., 2009). The atmospheric forcing conditions are based on ERA-Interim with nearly 80 Km resolution (Dee et al., 2011). Data are updated 6-hourly and surface water and heat fluxes are estimated interactively during the simulation. The model is started with the initial conditions of January, 1st 2014 and run for the entire year.

The model validation is performed using available temperature and salinity estimates. These are based on published (e.g., Medatlas, 2002) and unpublished (e.g., reports of cruises in the Tunisia coasts) data sets.

3. Simulated salinity

As mentioned before, the simulation has been performed for the year 2014. The resulting temperature and salinity fields are compared to the RTOFS ones and to the available observations. Figure 1 shows the horizontal distribution of the summer surface salinity from the model and from the observations. Data for depths down to 10 m are retained for observations due to the scarcity of the estimates in the coastal zones. The model realistically reproduces the distribution of low salinity values of the Atlantic waters with a close resemblance with that of RTOFS (not shown). The mesoscale eddies north of the Algeria-Tunisia border coasts are also reproduced. The penetration of the Atlantic vein in the Gulf of Gabès is also clear both in the model and observations. The model also shows the high salinity values in the shallowest zones of the Gulf of Gabès. Such high values are also present in the observations but not in RTOFS. This is attributed to the minimum bathymetry depth, being 5 m in the RTOFS HYCOM model while it is only 1m in INSTMCOTRHD. Similarly high sea surface temperature values are found in the Gulf of Gabès in the INSTMCOTRHD model. It is important to note that such high values extend over large areas and thus probably highly impacts the whole south-eastern Tunisia marine area.

a)



b)

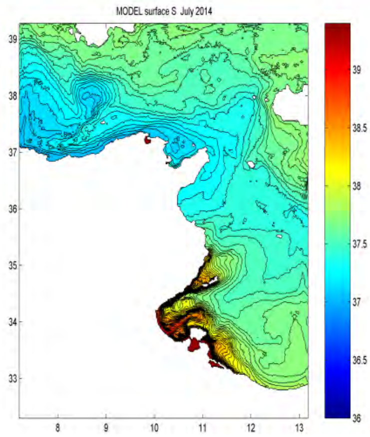


Figure 1. (a) Sea surface salinity from a collection of observations made during the summer season (June, July and August). (b) Sea salinity simulated by the INSTMCOTRHD model for the month of July. Depths less than 10 m are retained for observations and surface values are shown for the simulation. Units are PSU.

4. Simulated Temperature

The seasonal cycle of the surface temperature simulated by the INSTMCOTRHD model, from RTOFS and based on the observations are shown in figure 2. The temperature is averaged over the area North of Tunisia (shown in Figure 1a). A strong agreement is found between the three time evolutions indicating that the seasonal behaviour in this key area is realistic in the two models. A similar agreement was also found in other test areas and for the salinity.

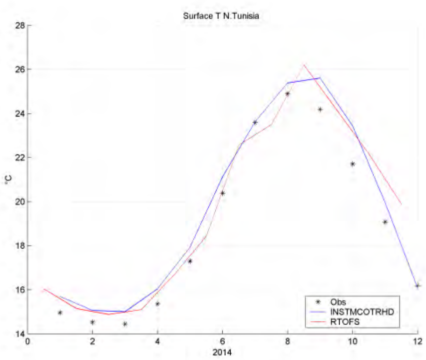


Figure 2. Sea Surface temperature averaged over the area in the northern Tunisia coasts (8.6 to 11.4°E ; 36.85 to 37.95°N). The series show the model simulations from RTOFS (red), INSTMCOTRHD (blue) and observations (stars). Values are monthly averages. Units are °C.

5. Conclusion and future work

Preliminary validation of the high resolution model set up in the Central Mediterranean has shown a realistic behaviour concerning the spatial distributions and seasonal evolution of surface temperature and salinity. Additional validation tests are being performed. A new set of simulations is currently performed using the Mediterranean Sea physical reanalysis (MEDREA, Simoncelli et al., 2014) and the Mediterranean Forecasting System (MFS, Pinardi and Coppini, 2010) as lateral boundary conditions. These new simulations will be compared to that using the RTOFS data. The entire set of simulations will constitute a high resolution data base for the Central Mediterranean Sea that will be used in dynamical processes and product-application studies.

Acknowledgment

This work is part of the Med-CORDEX initiative (www.medcordex.eu) supported by the HyMeX programme (www.hymex.org). It is partly supported by the United States Agency for International Development (USAID) in collaboration with NOAA, under grant PEER-195.

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Coordinated Experiments of coupled Atmosphere-Ocean Regional Climate Models for North Sea and Baltic Sea regions

Ha T.M. Ho-Hagemann[1] and the Coordinated Experiments team (HZG, AWI, DWD, IOW, SMHI)

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1. Motivation

Air-sea coupling is important to bridge two important components of the climate system, the atmosphere and ocean. Future climate projections of the coastal zone might be fundamentally flawed if important regional and local air-sea feedbacks, which are not resolved in global climate models, are neglected in stand-alone ocean or atmospheric models (Schrum 2017). Air-sea interactions and feedback taken into account in coupled atmosphere-ocean regional climate models (AORCMs) lead to a significant improvement of simulated surface ocean conditions compared to stand-alone ocean models (Schrum et al. 2003; Gröger et al. 2015).

Several studies indicated that air-sea coupling not only has an effect over the ocean, where the atmosphere and ocean communicate with each other, but also has a remote influence inland (Somot et al. 2008; Pham et al. 2014; Ho-Hagemann et al. 2015, 2017). For example Ho-Hagemann et al. (2015) showed that the heavy rainfall over Central Europe during phase 2 of the Oder flood event in July 1997 was captured well in the coupled model while it was missed in the stand-alone atmospheric model (see Ho-Hagemann et al. 2015, Fig.2). Excessively small large-scale moisture convergence from the oceans to the continental area led to the large dry bias of the atmosphere-only run over Central Europe during this extreme event. The large-scale moisture convergence was improved in the air-sea coupled system model, and the dry bias was strongly reduced.

However, the effect of coupling on precipitation inland was found small in some other studies (Wang et al. 2015; Gröger et al. 2015). There are several potential reasons for the varying conclusions on the coupling effect: The used coupled models differ not only in their model physics and dynamics but also in their configurations, i.e. domain, resolution. In case the same coupled models were used, the components were coupled at different coupling frequencies and using different coupling methods. Computing systems used to run the coupled models at individual institutions are often not the same. Methods to evaluate the air-sea coupling effect are not unified.

In order to obtain robust results, setting up coordinated experiments for AORCMs is indispensable and this comprises also unified evaluation methods and shared observation data. This motivated us to initiate the Coordinated Experiments activity under the Baltic Earth Program.

2. Members

On 7 and 8 February 2017, about 34 scientists met at the Baltic Earth Workshop on Coupled atmosphere-ocean modeling for the Baltic Sea and North Sea in Warnemünde, Germany, to discuss scientific results from state-of-the-art coupled atmosphere – ice – ocean – waves - land surface models for the North Sea and Baltic Sea regions and collaboration in the future. One of two common activities open for all interested scientists agreed by workshop participants is an implementation of coordinated experiments with several coupled model systems for a common 30+ year period and their evaluation with various observational data sets. Colleagues from 5 Institutions HZG, AWI, DWD, IOW, and SMHI already agreed to join this activity. The activity will be led by HZG. Fig.1 shows the member institutions and their used models.

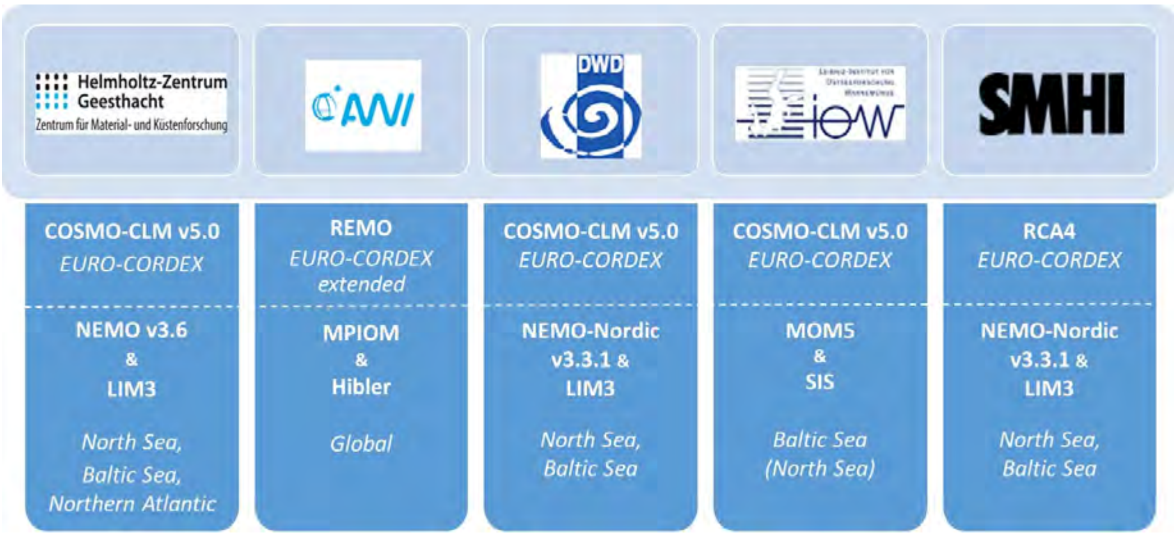

Figure 1. Institutions joining the activity and their used coupled models. In each blue box: Atmospheric models and their domains are listed on top, ocean and sea ice models as well as their domains are given below.

3. Aims

We aim to conduct long term (ca. 30 years) climate simulations from different coupled models using the same domain EURO-CORDEX and resolution of about 25 km for the atmospheric models and about 3.5 km for the ocean models which cover the Baltic Sea, North Sea. Note that the ocean model of HZG also covers a part of North Atlantic Ocean. The simulations shall cover the period from 1979 to 2015, and they shall be commonly validated in an inter-comparison using various observational data sets. We will focus on the potential effect of coupling between atmosphere and ocean on mid-latitude cyclone intensity and cyclone tracks affecting inter-alia coastal rainfall, coastal winds, and heavy rainfall events in summer over land and related cooling (like in the case of hurricanes and medicanes). The impact of coupling between atmosphere, sea ice and ocean on snowbands and upwelling events is also an interesting topic. Beside the atmospheric and ocean components, some coupled models also include a wave model or/and a hydrological discharge model which allow us to investigate the impact of coupling between wind, waves and currents on sea level extremes (with impact on coastal defense) or the closure of the hydrological cycle in regional climate models. More robust conclusions about the effect of air-sea coupling on climate simulations are expected.

A benefit from coordinated experiments is that sensitivity tests on the effect of specific coupling characteristics may be performed, for example, coupling frequency (e.g. 1hr, 3hr or longer), coupling method, or coupling domain. This allows a better understanding of their influence on climate simulations as other factors such as domain or resolution of component models remain unchanged in these tests. Based on these sensitivity tests the most optimal configuration for each coupled model will be determined for climate projections in the future.

It is planned that the results from these experiments will be published in joint publications.

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Modeling study of the Svalbard fjord - Hornsund

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1. Introduction

Hornsund is small, south west fjord of the Svalbard archipelago. This fjord is under the influence of two main currents – the coastal Sørkapp current carrying fresher and colder water masses from the Barents Sea and the West Spitsbergen Current, which is the branch of the Norwegian Atlantic Current and carries warm and salty waters from the North Atlantic. The hydrological conditions of the basin depend on the processes of water exchange between the fjord and the shelf. The main local forcing, which is tidal motion, brings shelf waters into the central fjord basin and then the transformed masses are carried into the easternmost part of the fjord, Brepolen. On the other hand, the hydrological conditions inside the fjord as: melting processes, freshwater inflow, glacier calving and atmospheric conditions are important

2. Modelling approach

For the purpose of this study a three-dimensional hydrodynamic model has been implemented and validated (Jakacki et al. 2017). The model is based on MIKE by DHI product and covers the Hornsund fjord with the shelf area, which is the fjord foreground. It is the sigma coordinate model (in our case 35 vertical levels) with variable horizontal resolution (mesh grid). The smallest cell has less than one hundred meters and the largest cells about 5 km.

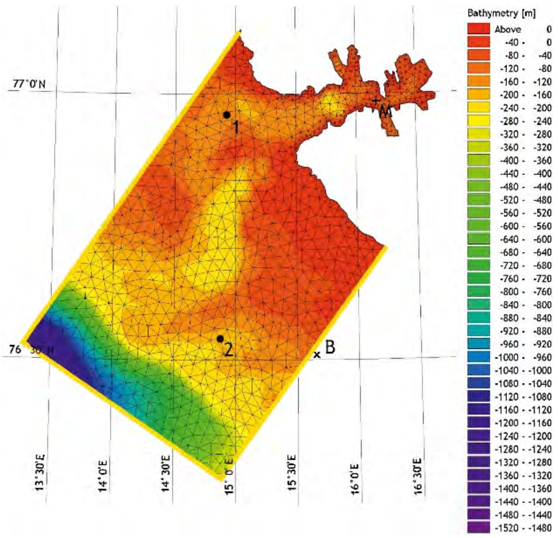

Figure 1. Model domain, bathymetry and mesh grid

The spatial discretization in solutions of equations is performed by the finite element method. This model solves Reynolds averaged Navier Stokes equations for an incompressible medium with the Boussinesq assumption and shallow water approximation. The regional scale of the model implicated implementation of external data at the lateral boundary region. In our case Flather's boundary condition let us to force the model with combined information - at the same time tidal ordinate and barotropic component of velocity that reflects the West Spitsbergen Current were implemented. Also, salinity and temperature were prescribed at the boundary area. The upper boundary conditions were also implemented. The data for the boundary were taken from Global Tide Model (all tidal components), and 800 m ROMS simulation of the Svalbard area made by the Norwegian Institute of Marine Research (barotropic velocities, temperature and salinity) and European Centre for Medium Weather Forecast (ECMWF).

3. The results

In Hornsund fjord are two typical circulation regimes. The Fig. 2 represent the average circulation for the whole domain (temporal and depth mean) for January and July of 2008, which is equivalent to the winter and summer states.

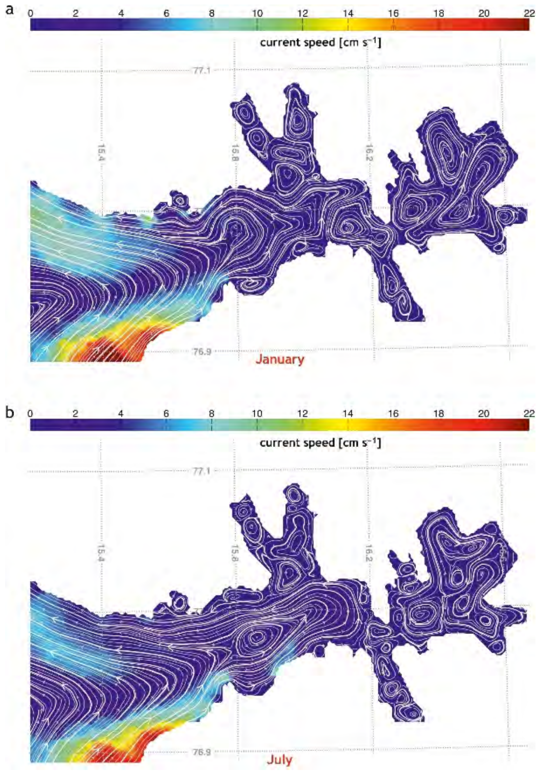

Figure 2. Streamlines (white lines) and current speed (colour-coded) over domain and time averaged in Hornsund for January and July 2008.

In summer, waters of shelf origin penetrate much farther into the fjord's main basin and reach the entrance of the inner basin called Brepollen. In winter, fresh water sources are limited to meltwater from marine terminating glaciers, thus the residual circulation pattern is similar but the volume exchange between the fjord and the shelf is much smaller than in summer (MIKE DHI does not have any assimilation data module or parameterization of ocean-glacier interaction such as surface melting or submerged plume discharge, so the representation of underwater glaciers is not possible). A cyclonic circulation is observed in the central area of the fjord mostly during the periods when fresh water inputs are the smallest. In summer, this cyclonic flow is disrupted by an intense circulation driven by fresh water from terrestrial and glacial sources. The circulation in Brepollen, the easternmost part of the fjord, is also characterized by seasonal variability, with the main winter circulation pattern significantly different from that in July. Small-scale eddies in Brepollen, Samarinvagen and Burgerbukta are also more abundant in July. Increased fresh water discharge in summer results in stronger stratification in the fjord; as a consequence, submesoscale eddies are generated owing to the internal Rossby deformation radius. In fjord is clearly forming the hydrological front whose position strongly depends by the season, affected by the bathymetry and internal tides.

As it was mentioned before, we can say (following Cottier et al., 2010) that in the annual cycle, the arctic fjords are transformed from the Arctic winter regime into the Atlantic regime in summer. It is also clean visible at the TS diagrams presented in fig. 3.

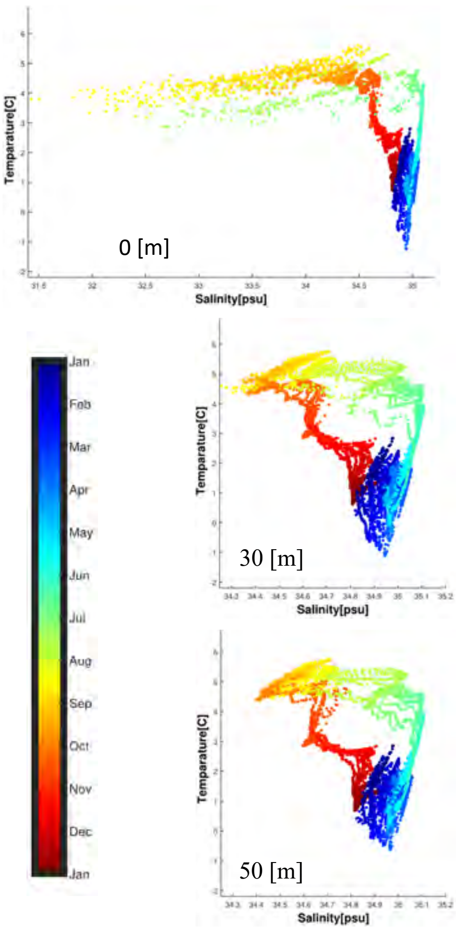

Figure 3. TS diagrams for main fjord locations and three different depths (note: different range of salinity axis in the top image)

The biggest changes in water properties are observed in the surface layer for points located in the main fjord and these variability (especially salinity in the range 31-35.2 for points from the main fjord) for three points in the water column is presented in figure 3. This is mainly related to the atmospheric conditions and the fresh water inflow. The influence of these factors disappears with depth. The TS diagrams show that the change of conditions from winter to summer takes place in the end of April and in the beginning of May (when melting processes (of fast ice and snow) starts). The winters starts in the middle of October as it is visible on TS diagrams. During the conference, other locations and its variability are going to be presented too.

In the Hornsund fjord the fronts, natural boundaries between waters of different properties, are clearly seen. The fronts may be visible on the surface as a demarcation lines, color changes, foam accumulation or choppy waters (Fedorov, 1986). In the Hornsund the front is represented by strong gradients of temperature and salinity.

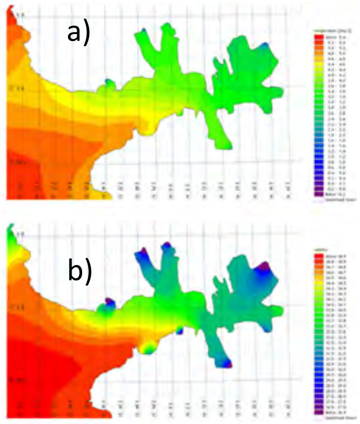

Figure 4. Hydrological front represented as strong temperature (a) and salinity (b) gradients.

The hydrological front is clearly marked in the form of a water division zone with various properties and the front face is visible in the form of a line of maximum gradients. Fresh water from the catchment area flows out at northern part of the main fjord and oceanic water enters the fjord through the southern part of the mouth. The shape and density gradient of the front depends mostly on the fresh water content in the surface layers of the fjord. Important influence on the front have also atmospheric conditions as well as physical conditions in the shelf area. The hydrological front has strong influence on local dynamics, for example on seasonal variability of internal tides.
Other results will be presented during conference.

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Is there a need for coupled chemistry/climate simulations for modelling Mediterranean heat waves? The role of atmospheric aerosols

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1. Introduction

Atmospheric aerosol particles are widely known to have an impact on global and regional radiative budget due to their optical, microphysical and chemical properties and are considered to be the most uncertain forcing agent according to the Fifth Report of the Intergovernmental Panel on Climate Change (IPCC AR5). They influence climate by aerosol-radiation and aerosol-cloud interactions (ARI and ACI, respectively). But they also play an important role in the particular occurrence of extreme events. For instance, forcing due to ARI may have an important effect in European and Mediterranean heatwaves. Effects due to ACI are subtler, yet equally important, since they influence the conversion from cloud droplets into rain drops, and thus affect the vertical profile of latent heat release.

2. Methodology

In this sense, the Spanish projects REPAIR and ACEX try to assess the impacts of present (1991-2010) and future (2031-2050) aerosols on air pollution, climate change and extreme events. This contribution takes REPAIR and ACEX data and presents the results devoted to the representation of present-climate most important heatwaves over the Mediterranean and southern Europe (e.g. 2003, 2005 or 2015, affecting respectively southwestern-central Europe, western Mediterranean and central-southern Europe) and how the inclusions of aerosols in a fully coupled regional chemistry-climate model improves the representation of these events. The model used is WRF-Chem, using EDGAR emissions from HTAP. Simulations cover the Euro-CORDEX compliant domain, including (or not) ARI and ACI interactions. Modelling outputs have been evaluated against the E-OBS v15.0 gridded data (for temperature) and SeaWiFS satellite (for aerosol representation). A number of extreme indices (recommended by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices, ETCCDI) have been used, including consecutive summer days (CSU), maximum heat wave duration per year (HWd), monthly maximum value of daily maximum temperature (TXx), number of tropical nights (TR), etc.

3. Results and conclusion

The results indicate that all the aforementioned index greatly improve when including atmospheric aerosols in the regional climate model simulations. For instance, the relative bias in CSU for the 2003 European heatwave reduces by 20% when including aerosol interactions (Fig. 1). It is not only the indices improving, but the most noticeable improvements are found for the variability of the daily maximum and minimum temperatures during the heatwaves, whose bias reduces by over 50% when including atmospheric aerosols in the simulations. The causes of this improvement are not straightforward and depend on the meteorological situation: reinforcing the ridge responsible for dry and warm air advection over western Europe, modifying the winds and altering the relative humidity, or other modifications in the radiative budget (Nabat et al., 2015; Baró et al., 2017).

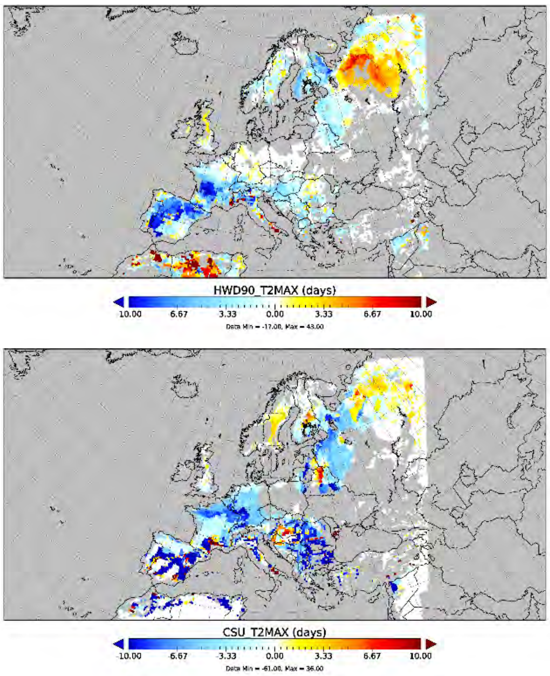

Figure 1. (Top) Improvement of the error (days) of the index heat wave duration (HWd) and (bottom) consecutive summer days (CSU) for the 2003 heatwave when comparing the simulations not including and including aerosols. A blue color represents an improvement of the error in the simulations including aerosols (lower error) with respect the same simulation not including ARI and ACI.

4. Ackowledgments

The authors acknowledge Project REPAIR-CGL2014-59677-R and ACEX-CGL 2017-87921-R of the Spanish Ministry of the Economy and Competitiveness and the FEDER European program for support to conduct this research.

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Sensitivity of Mediterranean Sea function to uncertainties in the surface freshwater forcing

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1. Introduction

The surface freshwater fluxes in the Mediterranean suffer from large uncertainties (i.e. Jordà et al., 2017). Very few observations are available on sea to constrain precipitation and evaporation products and interproduct comparisons suggest a large spread in both the mean values and also the variability at daily and monthly scales. Up to which extent those uncertainties affect the modelling of the Mediterranean Sea has not been quantified yet. In this work we will present a set of sensitivity experiments designed with the aim to address this question. In particular we perturb a state-of-the-art ocean climate model with anomalies in the surface freshwater fluxes that mimic the actual uncertainties existing in the freshwater estimates.

2. Data and methods

The NEMOMED12 model configuration has been used in this work. This is an implementation of the NEMO model at 1/12º of spatial resolution and forced by the ARPERA atmospheric fields at the sea surface and ORAS4 global reanalyses at the Atlantic open boundary. For more details see Hamon et al. (2016).

Six model simulations have been run for the period 1980-1989. In five of them the surface freshwater flux fields used to force the REFERENCE run have been perturbed. Namely, we have applied a spatial and temporal constant positive bias of +0.6 mm/day to characterize the discrepancies exisiting in the mean freshwater value (exp bias+). We have also added the same perturbation with a seasonal modulation (exp bias+seas) and a negative bias of -0.6 mm/day (exp bias-). Finally, in order to simulate the uncertainties in the freshwater variability we have run a

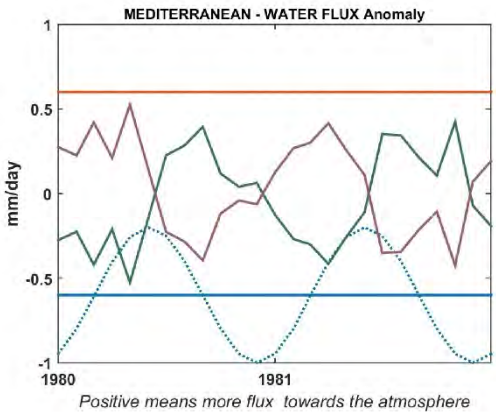

Figure 1. Zoom of the monthly freshwater anomalies applied in the different experiments.

simulation increasing (exp var+) and decreasing (exp var-) the temporal variability by multiplying the 3-h freshwater fields by 1.25 and 0.75 respectively. After the multiplication it has been ensured that the resulting fields are not biased with respect to the reference run. An example of the perturbations applied to the freshwater reference fields are shown in Figure 1

3. Results

The perturbation of the surface freshwater fluxes has an o impact on the salt content of the basin, as expected. However, it is interesting to notice that the salinity anomalies are differently distributed depending on the sign of the bias. For positive anomalies (e.g. more precipitation in the basin), the salinity decreases in the upper and intermediate layers. After few years the salinity seems to have reached an equilibrium in the upper layer while after 10 years the salinity still drifts in the intermediate layers. Conversely, for a negative bias the salinity increases relatively fast in the upper and intermediate layers and estabilizes after 5 years. However, after that is in the bottom layer where the salinity starts to increase without reaching the equilibrium after 10 years. Also, it is worth mentioning that changing the variability without modifying the mean value has little impact on the salinity (see Figure 2). Experiments also show an impact on the heat content distribution, although relatively weak.

Other impacts have been observed in the experiments. The increase in the freshwater leads to an increased stratification which difficult the convection events. Thus, convection is reduced (~20-30%) which also implies a reduction of the overturning circulation in the Mediterranean. In turn, this is also reflected in a decrease in the transports through the Straits of Gibraltar and Sicily. The situation with a negative bias is roughly the inverse (less stratification in the upper layers, more convection and enhanced overturning circulation).

Finally, the horizontal circulation is also affected by the perturbation of the surface freshwater. The current intensity (represented by the Kinetic Energy, KE) is increased with a positive bias and decreased with a negative bias. The reason is that the increase of freshwater leads to stronger vertical and also horizontal density gradients, which favors the intensity of the geostrophic currents and the development of baroclinic instabilities.

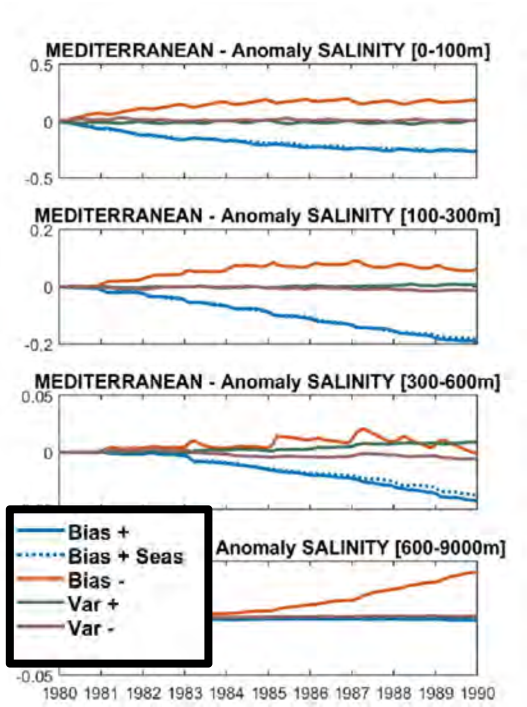

Figure 2. Time series of basin averaged salinity anomalies at different layers for the 5 sensitivity experiments.

4. Conclusions

The perturbation the surface freshwater fluxes (i.e. due to errors in the forcing fields or to a shift in the climate regimes) have an impact on the Mediterranean functioning. In particular the vertical and horizontal stratification is strongly modified which has implications for the convective events, the overturning circulation and the heat and salt redistribution in the basin. Also, horizontal mean currents and mesoscale variabilty are modified by those perturbations.

Global warming, new energy balance, new atmospheric circulation and extreme meteorological phenomena in Western Mediterranean

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Cumulating ocean-atmospheric thermal energy caused by global warming has resulted in the reversal of the energy balance towards the poles. This situation is characterized by a new ocean-continental thermal distribution: over the ocean, the balance is more in excess than in the mainland, if not the opposite when the balance is negative inland.

Thanks to satellite observation and daily monitoring of meteorological conditions for more than ten years, we have observed that the positive balance has shifted more towards the poles, mainly in the northern hemisphere. Subtropical anticyclones are strengthened and have extended to high latitudes, especially over the Atlantic oceans. This situation creates global peaks strengthened in winter periods, and imposes on cosmic cold the deep advection toward the south under the form of planetary valleys "Polar Vortex".

This situation imposes on the jet stream a pronounced ripple and installs a meridional atmospheric circulation in winter, which brings the warm tropical air masses to reach the Arctic Circle, and cold polar air masses to reach North Africa and Western Mediterranean.

This situation creates unusual atmospheric events, characterized by hydrothermal "extreme" conditions: excessive heat at high latitudes, accompanied by heavy rains and floods, as well as cold at low latitudes and the appearance of snow in the south Western Mediterranean (Andalucía and Cecilia) !

The populations are profoundly influenced by the new phenomena. The socioeconomic infrastructures can no longer assume their basic functions and man when unprotected is weak and hence the advanced vulnerability of all the countries especially those belonging to poor and developing regions.

This is why climate sciences must deal nowadays with short term prediction of phenomena: weekly, monthly, or seasonly a bit more advanced than meteorology (72 hours) but less advanced than climate models (50-100 years) to allow the policy makers enough time to intervene efficiently in order to protect the populations from extreme meteorological phenomena and to benefit from the opportunities of the new meteorological conditions

These are the characteristics of "New Meteorological Events" resulting from the "New Atmospheric Circulation", caused by the "New planetary Climate" consequence of "Global Warming".

It is the new global challenge.

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Future droughts in Southern Ukraine – reasons and possible consequences for water resources and agriculture

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1. Introduction

The frequency and severity of droughts in Ukraine has considerably increased since 1980s. This feature is especially pronounced in the southern regions of Ukraine, which are the areas with intensive agriculture but mainly have not irrigation systems. Preliminary analysis has showed (Khokhlov and Yermolenko, 2014) that the Southern Ukraine is the region with considerably increasing number of droughts. As the temperature will most probably rise in further it is reasonable to consider what peculiarities of future droughts in Ukraine we can expect.

2. Methodology

We used the standardized precipitation evapotranspiration index (SPEI) to investigate spatiotemporal droughts variability caused by the climate change. The SPEI is the multi-scalar drought index and allows determining the onset, duration and severity of drought conditions on different time scales. It is common practice to assess the meteorological droughts on the time scale 1–2 months, agricultural ones – 3–12 months, and hydrological ones – 13–24 months. The monthly SPEIs were calculated using the data on the temperature and precipitation. The two periods – nearest-past 1981–2010 and nearest-future 2011–2040 – were used to reveal a climate change impact. The index for the first period was calculated using the 0.5 degree grid reanalysis data. The future conditions were estimated using the outcomes from the CORDEX Project – the 14 runs of 5 regional climate models (RCM). For the latter period, the SPEIs were calculated for each RCM and then were averaged to obtain a single ensemble-mean value.

The mean value and standard deviation of the SPEI are 0 and 1, respectively. This index is the standardized value and can be compared with similar values in other sites and for other time periods. The table shows the drought category for the valued of the SPEI:

SPEI values	Drought category
0 to −0.99	mild drought
−1.0 to −1.49	moderate drought
−1.5 to −1.99	severe drought
≤ −2.0	extreme drought

3. Future Temperature and Precipitation

In Figure 1, the box plots visualize min/max, 25/75-percentile, median and mean (dots) by the 14 runs of RCMs. It shows rising temperature (about 0.8 °C per 30 years) and precipitation (about 40 mm per 30 years) during the 2021-2050 in the Southern Ukraine. Let's note that precipitation will usually decrease in Ukraine and southern region is rather exception to the rule. In this Figure, we can see (i) changeable increase of temperature and sharp decrease of precipitation during the 2023-26; (ii) sharp increase of temperature following decrease of precipitation during the 2028-31; and (iii) sharp decrease of temperature against the steady precipitation background during the 2037-40.

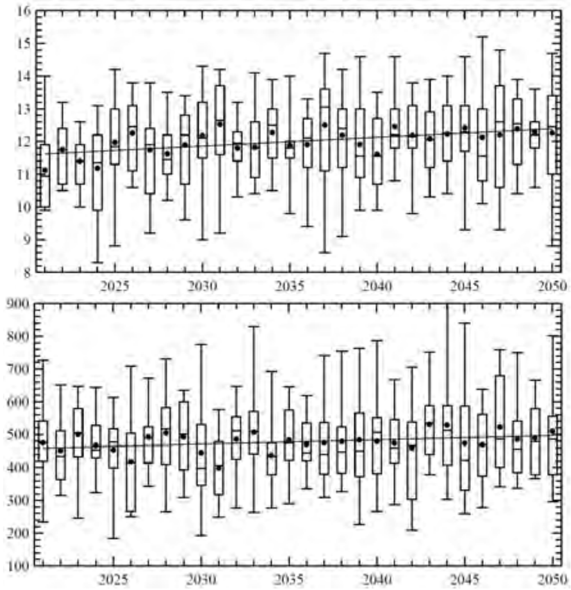

Figure 1. Annual mean temperature (°C; upper panel) and total precipitation (mm; lower panel) in Odessa estimated using the outcomes from the CORDEX Project

4. Future Droughts in Southern Ukraine

The analysis of nearest-future SPEI time series showed (Fig. 2) that the trend to drier conditions will be expected for whole Ukraine, and this trend will be remarkable for its southern part. It is noteworthy that the model ensemble reveals the drought in 2014–16, especially pronounced in Southern and Eastern Ukraine, i.e. the current drought; this result is rather surprising. The next long and severe droughts can be registered about 2025 and after 2030. Moreover, we can expect in all likelihood that the period 2031-2040 will be driest, and duration of drought in Southern Ukraine will be a few year.

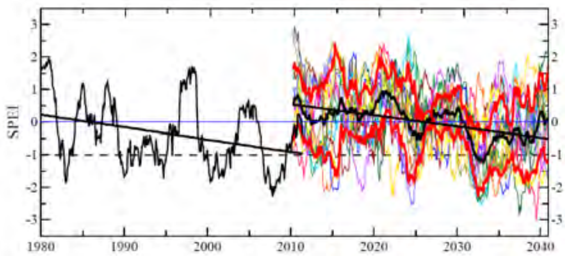

Figure 2. SPEI24 in Odessa estimated using reanalysis data and outcomes from the CORDEX Project

Considering Figs. 1 and 2, the drought of 2025 will develop by reason of decreasing precipitation, the prolonged drought starting from 2035 will arise from joint impact of high temperature and low precipitation. Also, the latter drought will terminate due to decreasing temperature.

5. Consequences for Water Resources

We also considered a connection between time series of SPEI24, i.e. the SPEI on the 24-month time scale, and annual runoff on a few hydrological sites in the drainage basin of Southern Buh – the river is sourcing in Western Ukraine and flowing into the Black Sea. As a result we can note that the SPEI24 can explain high and low water discharge on the annual time scale (Fig. 3).

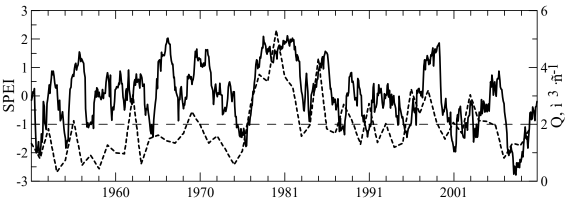

Figure 3. SPEI24 vs. annual mean water discharge (dotted line) in Katerynka gauge site (the Southern Buh River) from 1951 to 2010.

In the past, the strong positive trend exists up to the end of 1970th in the water flows for all sites, and the strong trend with opposite sign was registered from the end of 1970th up to the now. Also, the temporal features of water flow changes are in close agreement with the SPEI24 during the first 30-year period – all years with high water flows were registered during the wet years, i.e. the absence of atmospheric droughts. For example, the droughts were not registered during five years resulting in the maximal water flow in the 1980. During the second 30-year period, the minimal annual water flows and the atmospheric droughts coincided not always. This fact can be explained by intensive water-management activities at the Southern Buh catchment during the last years.

6. Conclusion

Our results show that a vulnerability of different community in Southern Ukraine to the droughts in the nearest future will be rather high (Pietrapertosa et al., 2018). This hazard will impact both the water-management and agricultural sector (Yermolenko and Khokhlov, 2014). The future droughts together with the undeveloped irrigation system will result in negative effect on the cereals, the main crop in Ukraine.

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Long-term variability of extreme storm surges in the German Bight

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1. Introduction

Inundation due to storm floods bears a high damage potential for low-lying coastal environments such as the German Bight. A deeper understanding of the variability of strength and occurrence of extreme storm floods is therefore of uttermost importance for coastal planning and risk assessment.

Observations of storm surges from tide gauges in the German Bight show a marked variability on multiple timescales. While the mechanisms for shorter term variability at specific locations have been studied in detail (e.g. Gerber et al. 2016), the variability on decadal and longer scales and their associated large scale climatic drivers has received little attention. Studies analyzing mean sea level records, however, have suggested remote Atlantic drivers to be responsible for variability on (multi)decadal time-scales (e.g. Dangendorf et al. 2014). This raises the question whether a similar link exists between multi-decadal climate variability in the North Atlantic and variations in the statistics of extreme sea level.

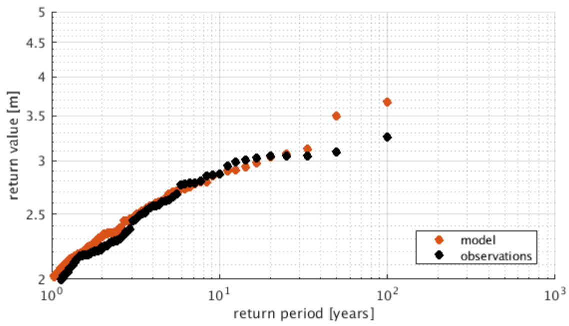

Figure 1. Return value plot of modeled (red) and observed (red) hourly sea level at Husum. Both refer to sea level above mean high water. For comparative reasons only the last 100 model years are shown here.

2. Model setup & experiment

As observational records are not sufficiently long to derive a statistical relation between the aforementioned, we use here the regionally coupled atmosphere-ocean model REMO-MPIOM (Mikolajewicz et al. 2005, Sein et al. 2015). Aside from conventional coupled Global Climate Models this model configuration includes tides and has a high enough resolution to realistically represent shelf sea processes and storm surges, while it still maintains a global ocean domain and thus allows for the continuous propagation of climate signals into the region of interest. This model setup is employed to downscale climate variations of the Last Millennium Simulation of MPI-ESM-P, providing hourly sea surface height fields of AD 1000-2000.

3. Preliminary results

First analysis of the resulting 1000 years of model data shows that the statistical behavior of storm surge occurrence and strength is well captured: Modeled return values are similar to the (detrended) observations from the Husum tide gauge record (Fig. 1; corrected observations from Wahl et al. 2011 for the period 1900-2000). Yet, for return periods larger than 30 years, the curves diverge. A kink at around 30-50 year return periods in the modeled return values suggests that an additional process is acting on these timescales. The causes for this are currently under investigation.

Spectral analysis reveals that extreme storm surges (defined as the highest 2000 storm surges over the entire millennium) in the German Bight exhibit variability on timescales from years to centuries (Fig. 2, bottom). Yet, the respective modes of variability are different to those of mean sea level (Fig. 2, top), suggesting distinct large-scale forcing mechanisms: Climate conditions associated with high winter mean sea level comprise a SLP pattern resembling the positive phase of the NAO at multi-decadal timescales (Fig. 3, top) and North Sea sea surface temperature variations on longer timescales up to centuries. Climate conditions favoring extreme storm surge activity (defined as the 10-year sum of excess sea level over the long-term 6-month return period) are less pronounced, with the SLP centers of action shifter further East and a more North-westerly flow. A direct link to the NAO is less evident, as a high variability over the Eastern North Atlantic masks clearer signals (Fig. 3, bottom). A high spatial correlation between different locations along the German Bight suggests that this pattern is robust for the entire region.

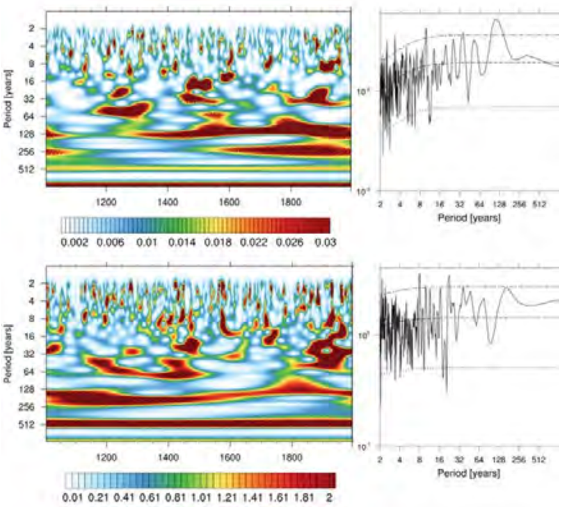

Figure 2. Wavelet spectra of winter mean sea level (top) and extreme storm surge index (bottom) at Husum. 5 and 95 percent confidence bounds are indicated by the dashed lines.

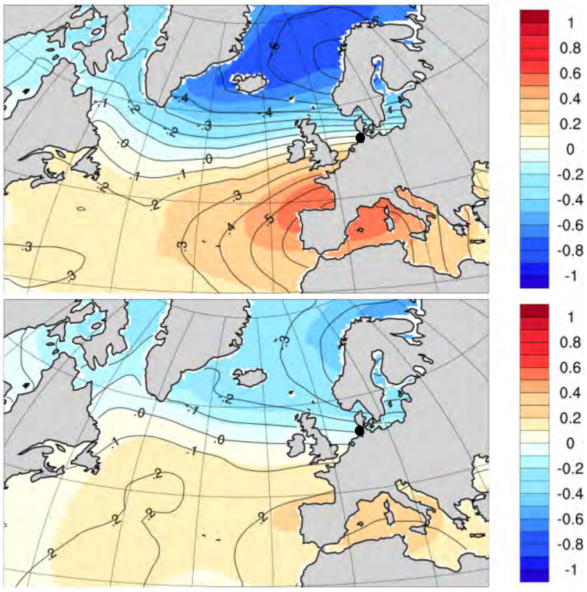

Figure 3. Pointwise regression (filled contours) and correlation (black contour lines) of sea level pressure [hPa] against winter mean sea level (top) and extreme storm surge index (bottom) at the specified location.

4. Conclusion

The model reasonably reproduces observed storm surge statistics, while due to its 1000-year long and controlled model simulation it allows for a statistically more significant analysis with respect to large-scale climate modes. Thus, it has a great potential to contribute to a better understanding of variability and large-scale forcing mechanisms of severe storm surges. At the same time, the differing modes of variability and associated large scale circulation patterns between mean and extreme high sea level suggest that conclusions drawn from studies addressing the former cannot necessarily be applied to changes in storm surge behavior.

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Exploring future scenarios for the NW Mediterranean Sea for the horizon 2030. Consequences for marine productivity and resources exploitation

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1. Abstract

The Northwestern Mediterranean Sea is one of the productivity 'hotspots' of the basin (D'Ortenzio & Ribera d'Alcalà, 2009) and a region where intense fishing activities take place (Palomera et al., 2007; Druon et al., 2015).

Deep water convection and mesoscale activity are two of the main reasons for its marine productivity (Somot et al., 2006; Severine et al., 2014), which are both physical processes depending on external forcings (such as atmospheric conditions).

We use the Marine Modelling Framework (MMF) (Stips et al., 2015) developed at the Joint Research Centre (JRC), European Commission, to explore how hydrodynamic conditions will change for the horizon 2030 in the context of climate change. We do this by using two different global circulation models (MPI & EcEarth) under two different emission scenarios (rcp4.5 & rcp8.5) to force the ocean model after a dynamical downscale by a regional climate model (COSMO-CLM).

The strength, spatial distribution and seasonality of deep water convection and horizontal mesoscale features are simulated to change in the future scenarios with consequences on the phenology, intensity and spatial distribution of marine primary and secondary production.

In the present-day conditions, phytoplankton blooms are spatially and temporally linked to the occurrence of the deep water convection in winter (Fig. 1). In the future scenarios, however, this link is weaker and other hydrodynamic processes like the meandering North Current become more important for pelagic biological production (Fig. 1).

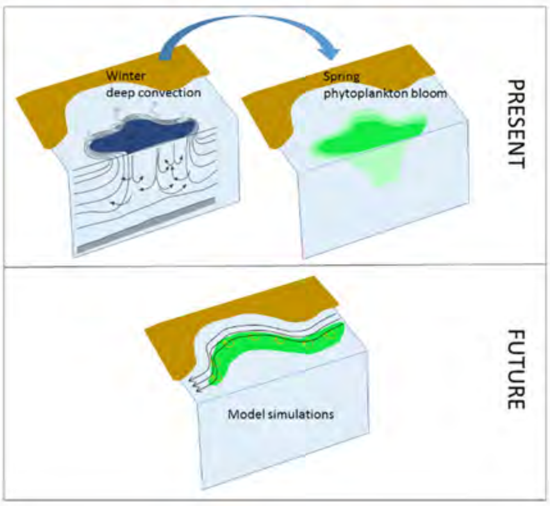

Figure 1. Upper panel represents the present-day link between deep water convection and phytoplankton blooms in the NW Mediterranean. Lower panel represents the future conditions simulated by the MMF where plankton production is mostly linked to horizontal currents and mesoscale structures.

Finally we feed these environmental conditions into an ecosystem model (Piroddi et al., 2017) designed to embrace the main functional groups of the food web in the region and analyze how the ecosystem structure will be affected in the future. Changes in species' biomass, relative importance in the food web and shifts in trophic relationships are simulated for the future scenarios.

The MMF represents, thus, an end-to-end conceptualization of the marine environment and it is a useful tool to help managers and stakeholder better prepare and adapt to future circumstances due to changes in climatic conditions.

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Comparison of satellite and *in situ* soil moisture measurements for modelling

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1. Introduction

Soil moisture is one of important parameters to determine climate humidity regime, the efficiency of the water use and the assessment of the soil's needs (Žemės ūkio.., 2013). There are lots of methods to measure soil moisture, but gravimetric (weighing) is the only one direct *in situ* method, which estimates real water amount in the soil. This method is quite simple and based on laboratory and soil sample to be taken from the same point for the second time (Wagner et al., 2011). Other methods estimate soil moisture indirectly.

In situ point measurements have better accuracy, but poor spatial representation, so remote sensing methods could help to improve resolution (Brocca et al., 2017).

30 year ago in Lithuania soil moisture (mm in soil layers) was measured using gravimetric method on 10, 20, 50 and 100 cm layers every ten days. Then measurements were discontinued and in 1999-2008 there were no soil moisture estimations at all. In 2009, agrometeorological stations were re-established, with automatic Watermark sensors, and now we get information about the amount energy, which plants need to absorb water from soil (in cbar) (Valiukas, 2015).

Soil moisture is necessary in modelling. Now in Lithuania there are no usable soil moisture measurements (models do not assimilate moisture in cbar), so satellite information could be one of main modelling inputs.

The goal of this research is to estimate satellite information errors compared with gravimetric soil moisture in Lithuania covering the period from 1982 to 1998.

2. Data and methods

Analysed area is the eastern Baltic Sea region (53–60°N and 20–30°E.) (Figure 1). Analysed time – 1982-1998 years' warm seasons (April - October).

Remote sensing soil moisture data were used from *ESA Soil Moisture CCI Project* soil moisture product created from merged active and passive products (water amount m^3/m^3) with 25 km spatial and daily temporal resolution).

Figure 1. Analysed area.

Remote sensing data are compared with *in situ* measurements at 7 points in Lithuania, one time per ten days. In analysed time, there are about 600 remote sensing and 300 *in situ* measurements in every cell.

For all 7 *in situ* points were selected satellite data cells based not only on distance, but also on correlation between soil moisture, relief and representation of the territory. *In situ* soil moisture was converted from mm in layers to m^3/m^3 (same as remote sensing data).

3. Results

It was found that average error of remote sensing data is about 0.2 m^3/m^3 and satellite moisture mostly is overestimated (Figure 2). This error depends on which *in situ* moisture depth data is used for comparison. The smaller errors were found comparing remote sensing with 0-10 cm depth data (average error about 0.1 m^3/m^3). Error size depends on the analysed point.

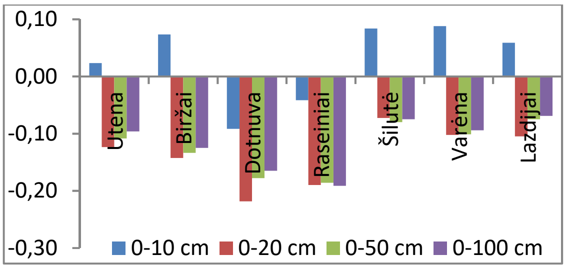

Figure 2. Average error (in m^3/m^3) between remote sensing and *in situ* data in 1982-1998.

The correlation encounters the problem that these observations are often not matched with each other, resulting that there are about 50 overlapping data in both satellite and *in situ* observations. It was found that remote sensing and *in situ* data correlate about 0.4-0.6. Šilutė station shows a weaker relation (Table 1).

Table 1. Correlation between *in situ* and remote sensing soil moisture data.

	Utena	Biržai	Dotnuva	Raseiniai	Šilutė	Varėna	Lazdijai
0-10 cm	0.43	0.57	0.51	0.46	0.28	0.40	0.45
0-20 cm	0.39	0.61	0.57	0.41	0.27	0.46	0.43
0-50 cm	0.38	0.56	0.59	0,30	0.17	0.48	0.38
0-100 cm	0.41	0.49	0.57	0.43	-0.06	0.14	0.26

In situ correlation with satellite observations in all territory makes it possible to assess the territorial representativeness of *in situ* observations. It was found that in Biržai *in situ* soil moisture is strongly correlated (r=0.5-0.7) to remotely measured soil moisture in the Middle Lithuania and Žiemgalė lowlands (Figure 3 a). The change of soil moisture in Varėna (Figure 3 c) reflects the moisture regime of the southwestern part of Lithuania - the Sūduva heights and in Lazdijai (Figure 3 b) - the south-western part of the Central Lithuania. Analyzing the data in Šilutė, it is observed that relations with the southwestern part of Lithuania and several cells in the seaside of Latvia and Estonia (Figure 3 d) are stronger.

In other stations, there were no clearer relationships noticed.

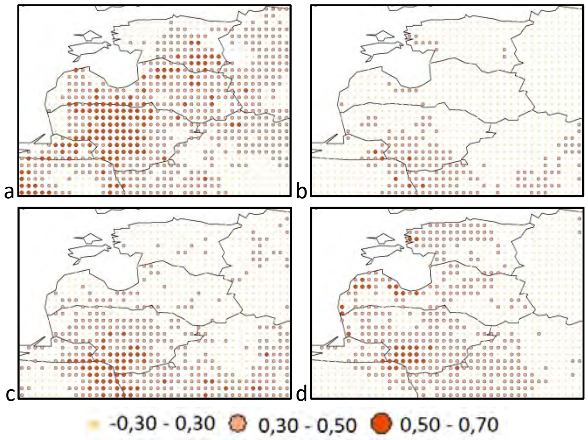

Figure 3. Soil moisture correlation between *in situ* (integrated 0-10 cm) and remote sensing soil moisture data in Biržai (a), Lazdijai (b), Varėna (c) and Šilutė (d).

Soil moisture data are standardized by using the median and standard deviation of every month in 1978-2016. This generates standardized values which show every single mean deviation. It was found that average deviation throughout all analyzed area less than -1.5 were in 1996.08, 1992.06, 1996.09, 2001.06, 1999.09, 2000.05, 2002.08, which shows strong negative anomalies. In these months, the analysed territory shows a negative precipitation anomaly. Extremely large anomalies of precipitation were in 1996 and 1992 (-76 % and -69 %) (Mačiulytė, 2017).

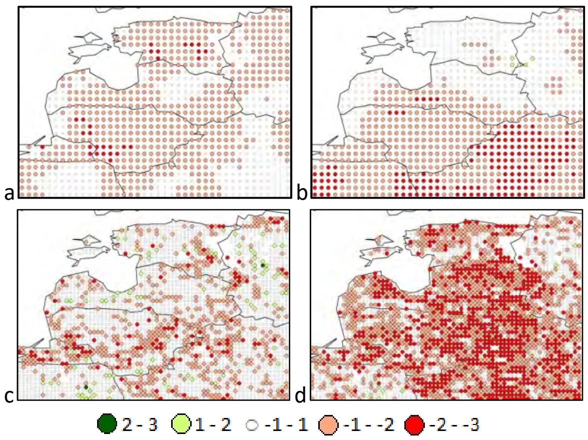

Figure 4. Standardized soil moisture in 1992 June (a), July (b) and standardized NDVI in 1992. July (c), August (d).

Satellite soil moisture data can also be used to assess the effects of drought. The standardized soil moisture needs from the satellite data are related to the vegetation deviations. Figure 4 show the standardized values of soil moisture and NDVI (Normalised Difference Vegetation Index) in 1992, when there was one of the strongest droughts in Lithuania (Valiukas, 2015). The negative NDVI deviations have connection with negative soil moisture anomalies in June and July.

4. Conclusions

This research is one of the first satellite studies on soil moisture in Lithuania. It was found that satellite observations of soil moisture are correlated to those *in situ*. Therefore, satellite observations could be used not only for environmental analysis, but also for modelling the effects of droughts, as currently no monitoring of water content in soil is carried out in Lithuania. In the future, it is planned to further develop the assessment of the use of satellite observations for the needs of Lithuania and to model the soil moisture and vegetation conditions.

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The future regime of Atlantic nutrient supply to the Northwest European Shelf

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1. Introduction

Global earth system models consistently project future decreases in winter mixed layer depth (MLD) and surface nutrient concentrations in the subpolar North Atlantic as a response to anthropogenic global warming (e.g. Steinacher et al., 2010; Bopp et al., 2013). Accordingly, it is expected that Atlantic nutrient import to the Northwest European Shelf (NWES) decreases and net primary production on the shelf weakens.

Dynamical downscalings to study potential impacts on the NWES ecosystem are usually based on uncoupled ocean simulations with limited domain sizes (e.g. Holt et al., 2012; Gröger et al., 2013). Changes in several key parameters affecting primary production, however, sensitively depend on coupled ocean-atmosphere interaction in the NWES and eastern North Atlantic (Mathis et al., 2017; Schrum, 2017).

To study the evolution of NWES primary production we downscaled global MPI-ESM climate projections of emission scenarios RCP4.5 and RCP8.5 with a high-resolution regionally coupled ocean-atmosphere climate system model. Since the ocean component of this model system is global with higher resolutions in the North Atlantic and NWES, it allows for a consistent simulation of climatic signals propagating from the Atlantic to the shelf and thus is particularly advantageous for investigating climate change signals driven by changes in the regional North Atlantic circulation.

2. Results

In accord with previous studies (e.g. Holt et al., 2012; Gröger et al., 2013; Mathis et al., 2017) Atlantic nutrient import to the NWES decreases in our simulations by up to 30% and net primary production weakens (Fig. 1). As a case study we focus our analysis on the northern North Sea, as being the largest connected shelf area predominantly influenced by Atlantic inflow. Projected biogeochemical changes are therefore mainly governed by physical processes responding to increasing atmospheric greenhouse gas concentrations rather than by prescribed riverine nutrient loads associated with additional uncertainty and a risk for eutrophication

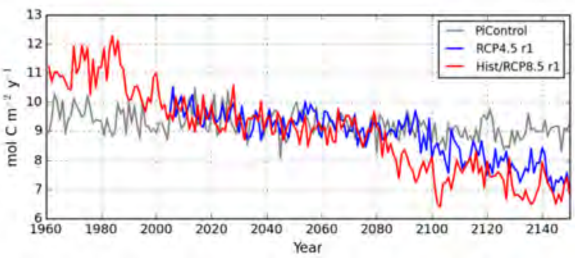

Figure 1. Northern North Sea primary production for scenario RCP4.5 (blue), RCP8.5 (red) and preindustrial control (gray). (Wakelin et al., 2015; Mathis et al., 2017).

A new result of our simulations, though, is that beyond the year 2100 the variability of northern North Sea primary production enhances for scenario RCP8.5. In particular, an enhanced variability of winter nutrient concentrations is found along the shelf break on interannual and multidecadal scales (Fig. 2 and 3). Similar variations are found in northern North Sea nutrient concentrations and primary production.

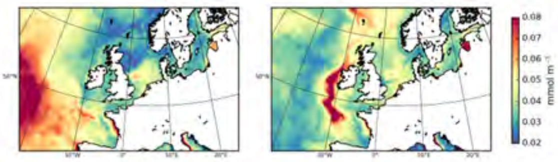

Figure 2. Standard deviation of winter surface phosphate concentrations for the near-future period 2011-2060 (left) and far-future period 2101-2150 (right) of scenario RCP8.5.

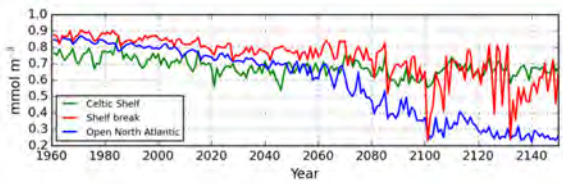

Figure 3. RCP8.5 time series of March surface phosphate concentrations at 50.5°N for the open North Atlantic (20-15°W; blue), the shelf break (12-10°W; red) and the Celtic Shelf (8-6°W; green).

Another new result is, that while nutrient concentrations in the North Atlantic drop substantially, relatively high concentrations are maintained on the shelf due to exchange with the deeper ocean, forming an ocean-shelf nutrient front (Fig. 3 and 4).

The strong interannual variability can be attributed to interaction between the atmospheric forcing and the shallow Atlantic MLD, causing variations in vertical mixing at the shelf break (Fig. 4 and 5).

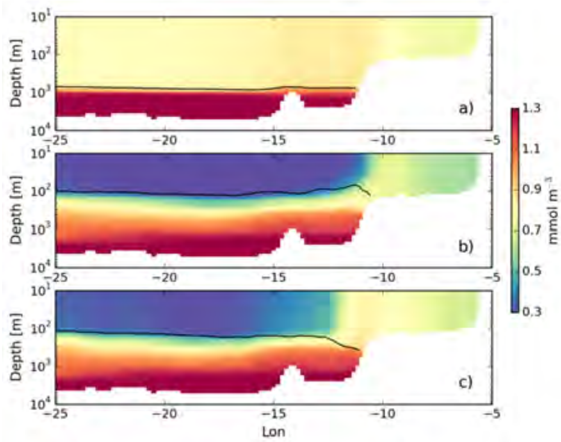

Figure 4. March phosphate concentrations at 50.5°N for the historical period 1961-2010 (a) as well as negative (b) and positive (c) composites of pronounced anomalies at the Celtic Shelf break during the far-future period 2101-2150. Black line: MLD.

Furthermore, the shoaling Atlantic winter MLD dissociates intermediate depths from surface water characteristics (Fig. 5). Deeper levels become undisturbed by winter convection earlier in the century than shallow levels. After about the 2090s, mean MLDs no longer exceed 200 m, leading to higher sub-pycnocline nutrient concentrations. Remaining multidecadal variations, regulated by the strength and extension of the Subpolar Gyre, are transferred to the shelf by exchange with the deeper ocean.

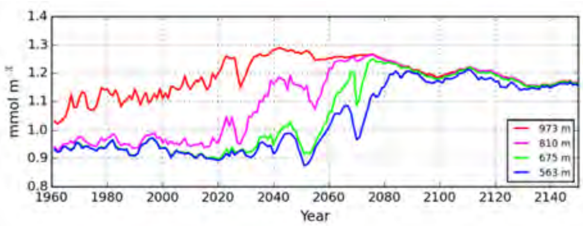

Figure 5. RCP8.5 time series of March phosphate concentrations at intermediate depths south of the high-variability region at the Celtic Shelf break (Fig. 2). Given depths refer to model layers 18-21.

The future development of a cross-shelf break nutrient front depends on the projected shoaling of the MLD, on-shelf nutrient transport, sediment resuspension on the shelf limiting deposition of organic matter, and tidal currents exceeding critical bed shear stress. Thus, in the parent RCP8.5 simulation by MPI-ESM a nutrient front with enhanced variability at the continental margin does not develop. Typical for global circulation models, MPI-ESM underestimates MLDs, ignors tidal waves and sediment resuspension, and simulates substantially weaker slope currents and cross-shelf break exchange (e.g. Sallee et al., 2013; Huang et al., 2014).

3. Conclusions

Future changes in NWES primary production during the 21st century are mainly driven by decreasing Atlantic nutrient import due to a substantial shoaling of winter MLDs. Shallow coastal areas, however, are subject to high uncertainty. By the end of the century, Atlantic MLD shoaling passes a critical value and invokes a regime shift in the dynamics of Atlantic nutrient supply.

For scenario RCP8.5, the far-future regime is characterized by enhanced multidecadal variability due to variations in Atlantic sub-mixed layer nutrient concentrations advected to the shelf by exchange with the deeper ocean. Interannual variability is enhanced because of NAO-induced variations of vertical mixing at the shelf break. None of these phenomena, i.e. sub-pycnocline multidecadal variations, ocean-shelf exchange and vertical mixing at the shelf break, emerges initially in the future but under deep present-day Atlantic winter convection their ability to shape shelf conditions is negligibly small.

The projected high variability of NWES primary production bears the potential to destabilize the ecosystem, hindering its adaptation to the future climate. Since the main driving mechanism is Atlantic MLD shoaling, a similar tendency is indicated for other biologically rich shelf seas with marked cross-shelf break transports and deep present-day MLDs off the shelf, such as the Faroe Shelf, Iceland Shelf and East Greenland Shelf.

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Drought assessment and projection under climate change in northern Tunisia

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Abstract: This contribution focuses on an analysis by event of dry event, according to a predetermined threshold, from series of observations of the daily rainfall. The approach has been illustrated on a case study of the Ghézala dam localized to the North of Tunisia where the average rainfall is 680 mm. The dry events are constituted of a series of dry days framed by the rainfall event. Rainfall events are defined themselves in the form an uninterrupted series of rainfall days understanding at least a day having received a precipitation superior to a threshold of 3.6 mm. The rainfall events are defined by depth and duration, which are found to be correlated. An analysis of the depth per event conditioned on the event duration has been undertaken. The negative binomial distribution appears the best overall fit for the depth per event. The duration of the rainfall event follows a geometric distribution while that the dry event follows the negative binomial distribution. The length of the climatically cycle fits to the Incomplete Gamma. Synthetic sequences of rainfall events and dry events with correspondent lengths of rainy season were generated. This analysis allows the calibration of precipitations model with few data for realistic dam management, water demand estimation and the study of climate change effects.

Key words: event-based analysis, dry spell, generation of synthetic events, climate change.

1. DATA

The data used in this analysis are the daily precipitation records of rain gauges located in the basin of Ichkeul Northern Tunisia. The rainy season starting at September and lasting until the beginning of May. The mean of annual rainfall is 680 mm. Except in occasional wet years, most precipitation is confined to the winter months in this basin. The dry season lasts from May to August. Daily values of precipitation are quite variable.

2. METHODOLOGY

A rainfall *event* is an uninterrupted sequence of wets periods. The definition of event is associated with a rainfall threshold value which defines *wet*. As this limit 3.6 mm d^{-1} has been selected. This amount of water corresponds to the expected daily evapotranspiration rate, marking the lowest physical limit for considering rainfall that may produce utilizable surface water resources. In this approach, the process of rainfall occurrences is specified by the probability laws of the length of the wet periods (storm duration), and the length of the dry periods (time between storms or inter-event time). The rainfall event *m* in a given rainy season *n* will be characterized by its duration $D_{n,m}$, the temporal position within the rainy season, the dry event or inter-event time $Z_{n,m}$ and by the cumulative rainfall amounts of $H_{n,m}$ of $D_{n,m}$, rainy days in mm:

$$H_{n,m} = \sum_{i=1}^{Dn,m} h_i \qquad (1)$$

Where h_i is positive and represent the daily precipitation totals in mm. Note that for at least one h_i >3.6 mm.

3. RESULTS

Approximately 33% of the events last at most one day. The persistence of uninterrupted sequences of rainy days sometimes lasting nearly two weeks (the maximum observed duration is 13 days). However, the frequency of such long-duration events decreases rapidly with increasing duration. An arithmetic mean of 2.79 days and a standard deviation of 1.87 were obtained. The geometric pdf appears most adequate for the fitting (Fig. 1).

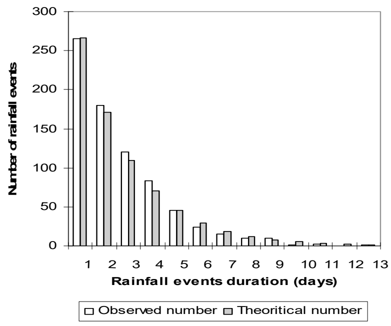

Fig. 1. Distribution of rainfall event duration

The regression analysis display that the dry event can be assumed to be independent from the rainfall event and the rainfall depth per event. Thus the distribution of the dry event (interevent time), which can only assume integer values, follows an unconditional probability distribution function. The negative binomial pdf has been found as best fitted to describe the distribution of the dry event (Fig. 4). As Fig. 4 reveals, the shortest interruption (one day) is the most frequent one. Almost a fifth of the observed dry events are only one day long. Dry periods up to 30 or even more days may be recorded (a 56 days maximum is recorded). The arithmetic mean and the standard deviation for the dry event are respectively 7.3 days and 7.9; for the longest dry event there are 30.2 days and 3.6.

The time series of the beginning of the first rainfall event in the year was analysed. The best fitting of this random variable is a law of the leaks (Fig. 2). It was concluded that on average the first rainfall event occurs in the mid-September whereas the probability of surpassing this value is 0.52 for a biennial return period. In the extreme case, the hydrological year starts about the first decade of October.

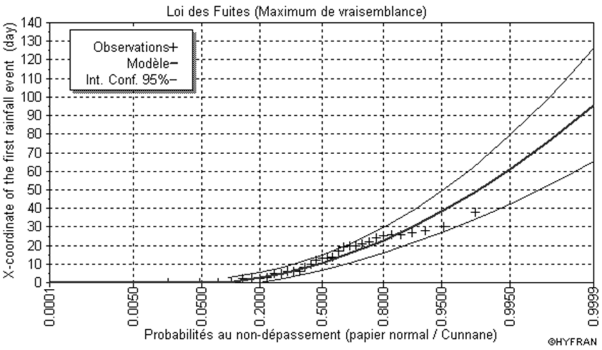

Fig. 2. Fitting leaks law for the chronological position of the first rainfall event in rainy season

4. CONCLUSIONS

The case study, by using rainfall records of the Ichkeul Lake, confirms the concept of the independence of rainfall and dry event duration. The dry spell phenomenon in this region seems to be particularly well described by fitting a pdf to the length of the interevent time. The negative binomial pdf provides an excellent fit for the prolonged dry periods between subsequent rainfall events. Conceptually, in a true Poisson process, the time "without event" should follow the exponential pdf or, in a discrete case, the geometric pdf (Fogel and Duckstein, 1982). It is relevant to note that this "flaw" could be eliminated by defining the interevent time as the dry event. Consequently, the present role of the interevent time would be taken over by the rainfall events duration. The theoretical requirements of the fitted geometric pdf are satisfied.

Event-based analysis has been used to generate synthetic rainfall event time series. By coupling this with a rainfall-runoff model, one obtains synthetic streamflow series to be used for reservoir simulation studies and design flood estimations. As another application, the study of the effects of a climatologically change.

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Integrated Earth System Modeling for the Baltic Sea Region

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1. Introduction

The Baltic Sea is a semi-enclosed coastal sea with a large catchment area located in northern Europe in the transition zone between maritime and continental climates. The north of the Baltic Sea region is characterized by extensive forests, low population density, mostly rocky coasts and subarctic winter climate. On the other hand, the south is characterized by agricultural land, high population density, mostly sandy coasts and moderate winter climate. About 90 million people in 14 countries are living in the catchment area of the Baltic creating a considerable impact on the marine environment. For instance, reinforced riverborne nutrient loads from agriculture and sewage treatment plants since the 1940/50s caused today the world largest anthropogenic induced dead sea bottoms without higher forms of life. In addition to environmental pressures, the Baltic Sea is affected by global warming more than other coastal seas perhaps because of its hydrodynamic features and location surrounded by land. During 1982-2006, the Baltic Sea warmed the most among all known large marine ecosystems worldwide. Hence, Earth system science focuses on multiple drivers of regional changes. A mixture of interwoven factors, such as eutrophication, pollution, fisheries, hydrographic engineering, agricultural and forestry practices and land cover change, is responsible for the current environmental situation and of potential importance as drivers of future changes.

Within Baltic Earth, an Earth System science program for the Baltic Sea region (www.baltic.earth), both observations and models play a crucial role. For instance, environmental and climate monitoring has a long tradition in the Baltic Sea. Since 1869 Denmark and Sweden performed monitoring cruises, and in 1898 Denmark, Finland, Germany, Russia and Sweden signed an agreement on simultaneous investigations on a regular basis at a few selected deep stations. Further, within Baltic Earth and its predecessor program BALTEX coupled models for the atmosphere, land and sea including terrestrial and marine ecosystems were developed with the aim to contribute to the understanding of regional energy, water, and matter fluxes and their effects on the regional climate.

2. Methods

In this presentation, I will give an overview of recent modeling activities within Baltic Earth using regional Earth system models and I will present multi-model ensemble simulations for the Baltic Sea region for the period 1850–2100. For the past period 1850–2006, atmospheric, hydrological and nutrient forcings were reconstructed, based on historical measurements. For the future period 1961-2100, scenario simulations were driven by regionalized global general circulation model (GCM) data using several regional climate system models (RCSMs) and forced by various future greenhouse gas emission and air- and riverborne nutrient load scenarios (ranging from a pessimistic 'business-as-usual' to the most optimistic case). To estimate uncertainties caused by biases of RCSMs and GCMs, natural variability and unknown forcing scenarios, different models for the various parts of the Earth system were applied. These simulations constitute the largest ever analyzed multi-model ensemble for the Baltic Sea region allowing, inter alia, the statistical evaluation of the ensemble spread. We found that water temperatures at the end of this century may be higher and salinities and oxygen concentrations may be lower than ever measured since 1850. There is also a tendency of increased deoxygenation and eutrophication in the future, depending on the nutrient load scenario. Despite considerable shortcomings of state-of-the-art models, this study suggests that the future Baltic Sea ecosystem may unprecedentedly change compared to the past 150 years.

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Role of the ocean thermal structure in the modulation of heavy precipitations over the Ligurian Sea

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1. Introduction

Along the coasts of the Mediterranean sea, the vicinity of relatively high orography to the sea and, thus, the consequent strong gradients in the air properties (pressure, temperature, moisture) are thought to be a key factor in the generation of the so-called heavy-rain-producing mesoscale convective systems (MCSs). This kind of systems, which are typically embedded in larger synoptic structures, by bringing large volumes of rain in few hours and over areas of the order of 100 km^2 (Ducrocq et al., 2014), can trigger consistent hydrological responses, that can cause economical damages and even casualties (Nuissier et al., 2008; Llasat et al., 2013).

Surface wind convergence has been identified as a common trigger of such MCSs (Nuissier et al., 2008; Fiori et al., 2017) and is known to be controlled, in terms of its horizontal structure, by the sea surface temperature (SST; Small et al., 2008). In particular, Small et al. (2008) review the two main physical mechanisms that explain the control exerted by the SST on the marine atmospheric boundary layer: the downward momentum mixing (DMM) mechanism (Wallace et al., 1989) and the pressure adjustment (PA) one (Lindzen and Nigam, 1987).

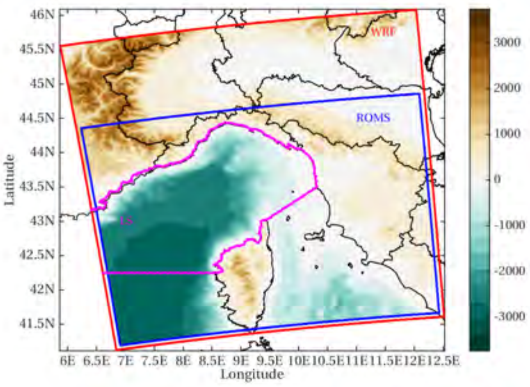

Figure 1. The domain of interest is the Ligurian Sea, in northern Italy.

2. Role of the SST structure

These two mechanisms, DMM and PA, are studied by means of numerical simulations run with a non-hydrostatic fully compressible primitive equation model (Weather and Research Forecasting model) in a realistic midlatitudes setup, leading to the 9 October 2014 Genoa heavy rainfall event.

Starting from a simulation with high resolution submesoscale eddy-permitting SST field, the surface temperature boundary conditions are changed to enhance, reduce or smooth the SST gradients. It is found that the marine atmospheric boundary layer responds to the submesoscale SST forcing structures over time scales of the order of hours. In particular, through the downward momentum mixing mechanism, the presence of SST horizontal gradients impacts the spatial structure of the surface wind convergence, which can displace the convective heavy rain bands that develop over the sea.

Figure 2 proves that, in the setup considered, the DMM mechanism is more important than the PA one, by showing that the spatial correlation between surface wind convergence and downwind SST gradient is stronger than the spatial correlation between surface convergence and the SST laplacian in all the simulations. The former correlation is indicative of the action of the DMM mechanism and the latter of the PA one. Each symbol corresponds to a simulation and the larger the value of μ, the smoother the SST forcing field.

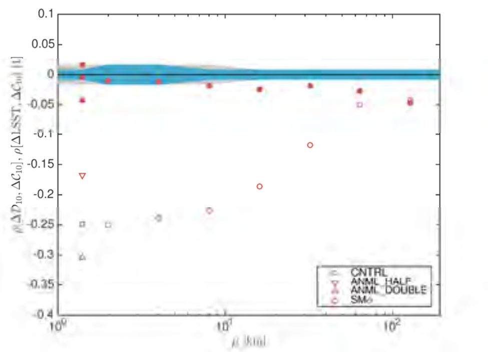

Figure 2. The spatial correlation coefficients between surface convergence and downwind SST gradient (empty symbols) are larger in absolute value than the correlation coefficients between surface convergence and the SST laplacian (full symbols). The 95% significance levels are shaded and the variables of interest are appropriately time-averaged.

3. Role of the vertical thermal stratification

Further analysis are carried out to quantify the effect of ocean coupling in the case study considered and to infer the importance of the upper ocean thermal vertical structure (mixed layer depth and stratification) in the control of the precipitation during a heavy-rain-producing MCS.

A hydrostatic Boussinesq equation model for the ocean (Regional Ocean Modeling System) is coupled to the atmospheric model both with realistic initial and boundary conditions and with simpler, semi-idealized vertical temperature profile forcing. An exponential decaying profile, with an upper uniform temperature layer, representing the mixed layer, is chosen. This enables to control both the mixed layer depth and the underlying vertical stratification.

It is found that the action of the winds associated with the synoptic system, in which the heavy precipitation event is embedded, can entrain deep and cold water in the oceanic mixed layer, generating surface cooling. This, in the case study considered, is not important because the mixed layer is deep enough to insulate the marine atmospheric boundary layer from any feedback effects coming from the fully three-dimensional dynamical ocean. Moreover, in the case of shallow mixed layer and strongly stratified water column, this decrease in sea surface temperature can significantly reduce the air column instability and, thus, the total amount of precipitation produced. Figure 3 highlights this finding by showing the total precipitation cumulated over the day of the MCS as a function of the daily mean SST of the Ligurian Sea on the day before, for different simulations. The lowest value of precipitation is obtained for the case with the shallowest initial mixed layer and the strongest stratification (simulation L5_M5_sea).

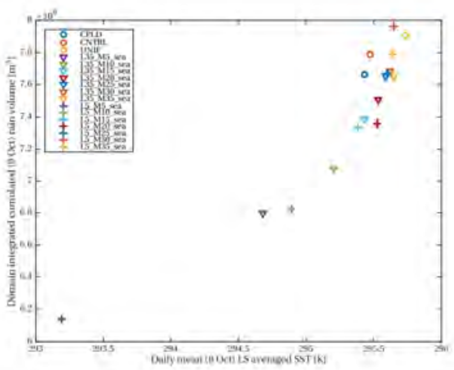

Figure 3. Total precipitation volume cumulated over 24 h as a function of the daily mean SST temperature of the Ligurian Sea. Different symbols correspond to different simulations and the initial mixed layer depth in meters is indicated in the legend with the letter M, while the initial e-folding length of the decaying temperature profile is denoted with L. The lowest precipitation value is obtained with the shallowest mixed layer and the strongest stratification (simulation L5_M5_sea).

4. Conclusions

Concerning the role of the SST, it is found that the downward mixing of momentum induced by the decreased air column stability while crossing a front from cold to warm is the mechanism that produces a remarkable spatial correlation between the SST and the wind magnitude, with the large scale circulation removed. The competing mechanism, controlled by the air pressure adjustment above the SST local minima and maxima, is found to be of negligible importance for the submesoscale eddy-containing SST fields. Only for very smooth SST fields, with variations of temperature happening over O(100 km) length scales, the two mechanisms have comparable importance, which, however, appears to be small.

Concerning the coupling with the ocean, it is found to be important only in the cases with shallow mixed layer and strong stratification, typical of the end of the summer. In such cases, the winds associated to the synoptic system in which the MCS is embedded are able to entrain cold water in the oceanic mixed layer, resulting in lower SST and reduced precipitation. The relation between SST and precipitation is already known (Pastor et al., 2001; Lebeaupin et al., 2006) and involves changes in the air column stability and the moisture and heat fluxes. Future developments include both extension to other case studies and the analysis of the mechanisms mentioned above over climatic time scales.

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Regional model of forming catastrophic spring runoff in condition climate change on the plain rivers Black sea basin in Ukraine

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1. Introduction

The study is devoted to solving an important scientific problem - concerning the development, implementation and verification of a unified calculation method for determining the characteristics of the spring flood runoff of ungauged rivers in the territory of plain Ukraine, taking into account current and future climate change. Spring floods is the most voluminous and potentially dangerous phase of the water regime of the plain rivers of Ukraine. In some years, spring floods can be catastrophic, the probability of occurrence of such phenomena is estimated at the level of 1-2 times per 100 years. In the development of techniques for determining the maximum water discharges of ungauged rivers the base probability, as a rule, is taken at 1%, and the estimated values are the maximum modules or the discharges of spring flood with the probability of exceeding P = 1%.

2. Methodology and data

An analytical review of the normative framework in the field of calculations of maximum runoff showed that despite the vast experience gained by scientists in this issue, the problem is still far from its solution due to the multifactority of the investigated phenomenon and regional features of the forming of maximum runoff on the rivers.

The author proposed a new modified version of the operator model [1] for determining the maximum runoff of spring flood, which allows to take into account the possible impact of climate change on the estimated values of the maximum modules 1% probability of exceeding (Fig.1).

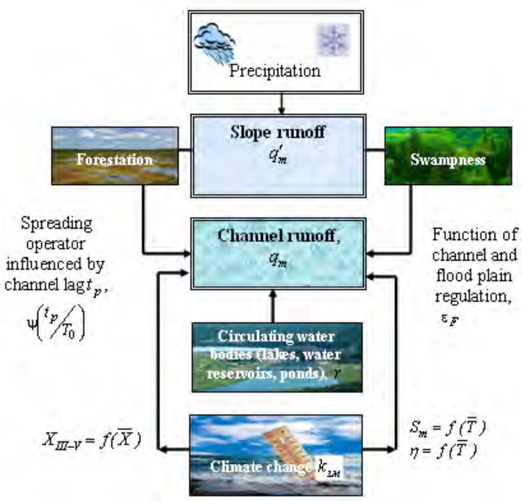

Figure 1. Block diagram of maximum runoff formation.

Climate change is taken into account by introducing a separate coefficient, based on a comparison of the main parameters of the method obtained on the basis of current data (maximum snow supply at the beginning of the spring flood, precipitation during the spring flood and runoff coefficients), and similar values obtained from climatic modeling data.

To substantiate the main parameters of the proposed method, data from 340 hydrological stations and 229 meteorological stations on plain rivers Black sea basin in Ukraine were used.

3. Results

During the spatial-temporal generalizations of the maximum runoff characteristics, was analyzed the cyclicity of the fluctuations of the maximum runoff of spring flood and done the synchronization zoning of the plain territory of Ukraine on the of spring runoff using factor, cluster and hydro-genetic analysis; was carried out estimate homogeneity of the initial information, statistical processing of the initial time-series of maximum snow supplies, maximum discharges and layers of the spring runoff. For the determination of precipitation in the spring period, proposed the regional calculation formula, the maximum snow supplies and the coefficients of their variation are generalized in the form of a map. The runoff coefficients is determine through the coefficients of runoff formation, which are generalized in the form of a map and taking into account the coefficients of the influence of the size of the catchments on the losses of the runoff in the spring flood period.

The characteristics of the slope influx, which are an important component of the calculation scheme, are represented by the maximum slope modulus, which in turn is determined by the coefficient of unevenness of the sloping influx, the duration of the flow into the channel network and the total water supplies to the catchments. All listed parameters are valided for the studied territory, in particular, to determine the influence of intra-zonal factors on the duration of the sloping influx, they was zoning within the limits of physical geographic zones and separate river basins was carried out.

The transformation of the maximum slope modulus is represented by functions that take into account the channel time, flood-plain regulation and the impact of flowing lakes and reservoirs. For the determination of the transformation function and the coefficients of flood-plain regulation, the equations of exponential form are derived, with separate parameters in physical geographic zones and for small catchments (with an area up to 100 km2).

For the plain rivers of Ukraine the author's modified version of the calculating method for determining the characteristics of spring flood in climate change conditions has implement. The implementation of the proposed calculation option using different models and scenarios has shown that the results differ significantly, but in practically all cases up to 2050 It is forecasted a significant decrease in the runoff of spring flood (from 10-20% in the north of the investigated area and 40-50% in the south).

As an example, Figure 2 show the results of modeling the change in the maximum runoff of spring floods in two scenarios of RCP 4.5 and RCP 8.5 according to the model RACMO2.

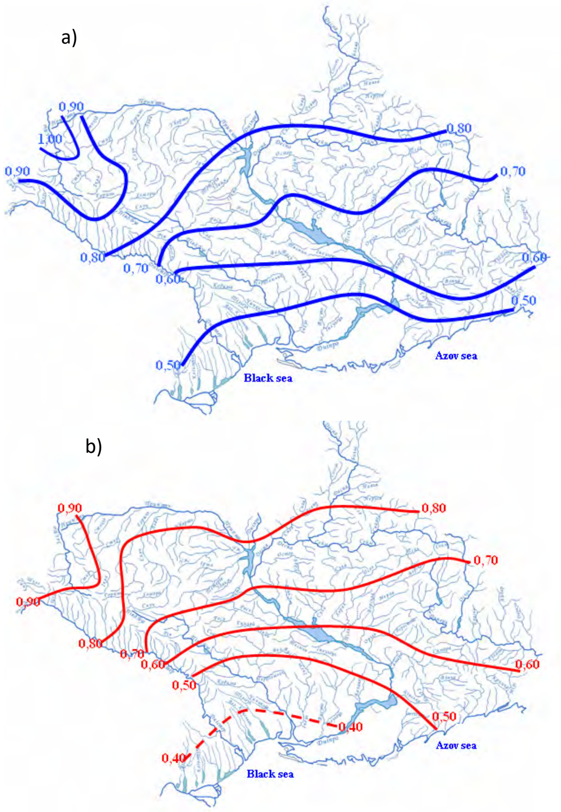

Figure 2. Distribution of the coefficients of influence of climate change on the maximum runoff of spring flood on the plain territory of Ukraine (model RACMO2, scenario RCP4.5 (a) and RCP8.5 (b) for the period up to 2050, relative to 2010.

4. Conclusions

Verification of the modified methodic taking into account climate change has shown the possibility of its application for the assessment of changes in water content during the spring flood on the flat rivers of Ukraine, both in the framework of the basic scheme and in the form of separate calculations using climate data as an option for implementing the design scheme under climate change conditions..

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A global integration technique for a better description of the Mediterranean water cycle using satellite data.

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1. Abstract

The Mediterranean region has been identified as one of the main climate change hotspots by the IPCC: its sensitivity to global change is high and its evolution remains uncertain. The region experiences many interactions and feedbacks at the oceanic, atmospheric, and hydrological levels, while facing high anthropogenic activities. Analysing the Water Cycle (WC) over the Mediterranean region and the causes of its inter-annual variability are of major importance to environmental and socio-economic aspects. The satellite monitoring of the Mediterranean WC represents one of the key challenges for the climate community. The WACMOS-MED project of ESA (http://wacmosmed.estellus.fr/) goal is thus to obtain a better understanding and quantification of the hydrological cycle and related processes in the Mediterranean region, by using satellite Earth Observations (EO).

One of the goals of WACMOS-MED is to build a model-independent database that can help evaluating the Regional Climate Models (RCMs) for this particular region. An increasing number of satellite missions can be used to monitor the Mediterranean region. However, using EO to study the WC is still a challenge, at the regional as well as at the global scales. Indeed, EO data suffer from numerous systematic and/or random errors and they are often not coherent with each other (in the sense that they do not close the water budget). Several integration techniques are currently being investigated to optimize the use of EO data to study the WC (Pan et al. 2012; Aires et al. 2014) at the basin (Shefield et al. 2009; Munier et al. 2016) or at the global (Rodel et al. 2015; Munier et al. 2018) scales. Our method does not only focus on the terrestrial hydrological processes; the full WC is examined by including its atmospheric and oceanic components too. The analysis is conducted at the monthly scale, and at the basin (i.e. entire drainage area of the Mediterranean and Black seas) or sub-basin (i.e. drainage area of a particular coastal region) scales. The best way to use the multiplicity of datasets is investigated given the criteria of minimizing the water cycle budget residual. The integration approach allows to obtain a long-term dataset describing the full water cycle over the Mediterranean region, using as observations as possible. The closure of the WC is largely improved: the RMS of the WC budget residuals goes down to 3.55 mm/month over land and 5.27 mm/month in the atmosphere (i.e. an improvement of respectively 78% and 80% compared to the best direct satellite datasets). Evaluation is performed using in situ data for precipitation and evapotranspiration: in addition to better close the WC budget, optimized datasets are also closer to in situ measurements. These spatial, multi-EO based databases describing the terrestrial, oceanic and atmospheric water cycles over the Mediterranean can be used as an independent reference for RCM evaluation/calibration. They are now proposed to the scientific community.

The integration dataset has also been used in four case studies : (1) the sensitivity of the Mediterranean Sea to anomalies in the surface freshwater forcing has been evaluated, (2) in situ river discharges have been assimilated in ORCHIDEE land surface model to better constrain the surface runoff and deep drainage, (3) Climate analysis was has been performed to relate the precipitation in the Mediterranean region to North Atlantic Oscillations, and (4) the impact of improved precipitation datasets in the estimation of river discharges has been evaluated.

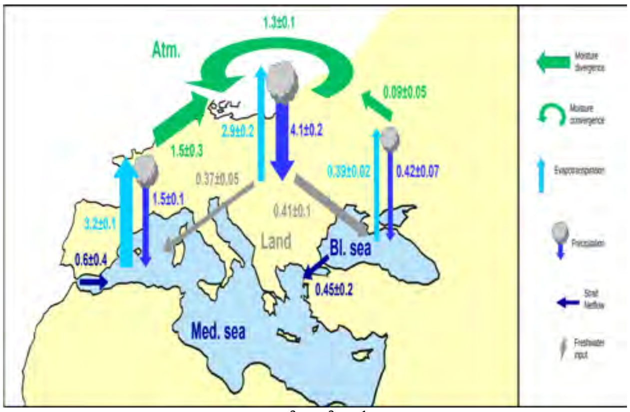

Figure 1. Mean annual fluxes (10^3 km^3 yr^{-1}) of the Mediterranean water cycle and associated uncertainties, during the 2004-2009 period.

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The Regional Earth System Model of IPSL (RegIPSL), a contribution to MEDCORDEX

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1. Introduction

A regional Earth system model is developed at IPSL and is applied to the study of the Mediterranean region climate (past and future). It is an evolution of the MORCE platform (Drobinski et al., 2012). The model couples an ocean model (NEMO), a land surface model (ORCHIDEE) and an atmospheric model (WRF) using the OASIS3-mct coupler. The entire system is embedded in the IPSL modelling infrastructure and thus takes advantage of simulation and data management used for the global IPSL Earth system model. It is our ambition to couple this system also to the CHIMERE atmospheric chemistry model in order to explore the role of aerosols and chemical composition for the climate of this region.

2. RegIPSL configuration

The configuration presented in this work contributes to the MEDCORDEX initiative. The domain covers therefore the domain prescribed by MEDCORDEX (Fig. 1).

The atmospheric model WRF (WRF 3.7.1 Skamarock et al. 2008) is used at a horizontal resolution of 20km on a Lambert conformal projection, and with 45 vertical levels with a high resolution in the planetary boundary layer (PBL). The large scale circulation is nudged to the re-analysis or climate model above the PBL.

The land surface model ORCHIDEE (Krinner et al. 2005, Ngo-Duc et al. 2006) is used on the same grid as WRF and includes a high resolution routing scheme which transports the excess water to the ocean. The outflow at 200 estuaries are sent directly to the ocean while the diffuse flow from the continents is interpolated together with the other fluxes coming from the atmosphere. In ORCHIDEE the Interactive phenology is not activated for the MEDCORDEX simulations.

The ocean model NEMO (NEMO v3.6 stable Madec et al. 2016) in the regional configuration NEMO- MED12 is used to represent only the Mediterranean Sea (Black Sea is not included) at an horizontal resolution of 1/12° and on 75 z-levels.

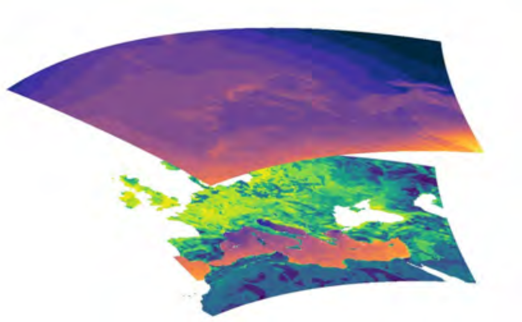

Figure 1. Schematic of the MEDCORDEX domain showing the region simulated by the atmospheric model, the land surface model and the ocean model.

3. Coupling

Around 40 variables are exchanged by the OASIS3-mct coupler (Valcke, 2006) between the models (Fig. 2) and are interpolated if needed from the atmospheric grid or land surface grid to the ocean grid (and vice-versa). The exchange between the continental surfaces and the atmosphere occurs at every time step (60 seconds), while the exchange of the ocean with the two other components only takes place every hour.

Each of the components sends their diagnostic variables to XIOS (Meurdesoif et al. 2017) so that the user can define, independently of all components, which statistical treatment is needed before the variables are written to the discs.

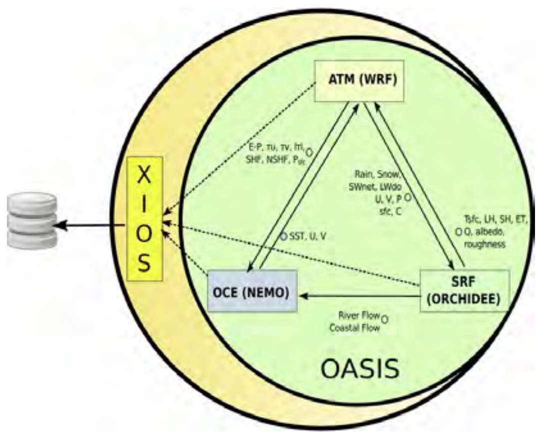

Figure 2. RegIPSL platform flow chart.

4. Simulations

A first hindcast involving only the atmospheric and land-surface components has been performed using ERA-I forcing for the period 1979-2017. The detailed evaluation of this simulation will be presented.

The atmospheric conditions of this first hindcast is then used to run only the ocean and land surface components. This system, limited to the coupling of the riverine freshwater flux is used to evaluate the ocean spin-up and stability. It provides essential guidance for the fully coupled system.

Once those hindcasts are completed and analysed, a set of historical and scenario (RCP 8.5) simulations will be performed using the IPSL-CM5 simulations done for CMIP5 (Dufresne et al. 2013). This will allow to downscale these climate change predictions and explore the regional coupling which are not fully represented by the global system.

5. Conclusion

MEDCORDEX is the prototype application for RegIPSL. It is a well observed region where the model can be validated and the contribution of the higher resolution to the quality of the regional climate change prediction evaluated. Throughout the MEDCORDEX exercise the RegIPSL system will evolve because of the development of the IPSL components and our progressing improvement of the understanding of the coupling processes. Foreseen major evolutions of the system are the adding of atmospheric chemistry with CHIMERE and a new limited area atmospheric model. The new atmospheric model of IPSL (DYNAMICO) will also be configurable in limited area and non-hydrostatic, thus providing IPSL with an Earth system model applicable from global to regional high resolution studies.

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Adaptation of the MIKE 3d model for the fjord Hornsund

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1. Introduction

Hornsund is small, south west fjord of the Svalbard archipelago. This fjord is under the influence of two main currents – the coastal Sørkapp Current carrying fresher and colder water masses from the Barents Sea and the West Spitsbergen Current, which is the branch of the Norwegian Atlantic Current and carries warm and salty waters from the North Atlantic. The hydrological conditions of the basin depend on the processes of water exchange between the fjord and the shelf . The main local forcing, which is tidal motion, brings shelf waters into the central fjord basin and then the transformed masses are carried into the easternmost part of the fjord, Brepolen. On the other hand, the hydrological conditions inside the fjord as: melting processes, freshwater inflow, glacier calving and atmospheric conditions are important

2. Modelling approach

For the purpose of studying circulation and water exchange in this area a three-dimensional hydrodynamic model has been implemented and validated (Jakacki, 2017). The model is based on MIKE by DHI product and covers the Hornsund fjord with the shelf area, which is the fjord foreground. It is sigma a coordinate model (in our case 35 vertical levels) with variable horizontal resolution (mesh grid). The smallest cell has a horizontal dimension less than one hundred meters and the largest cells about 5 km.

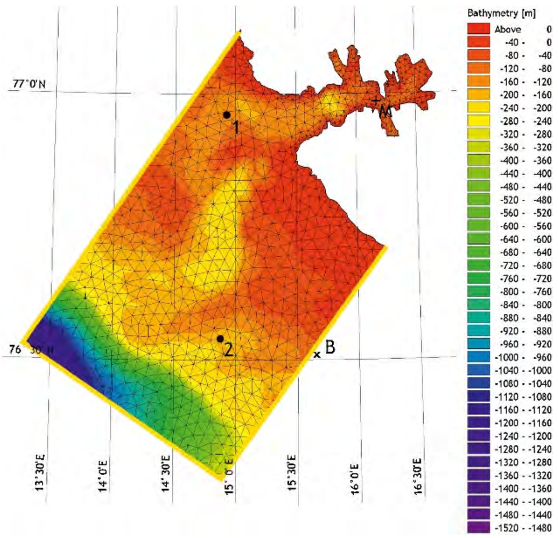

Figure 1. Model domain, bathymetry and mesh grid

The spatial discretization in solutions of equations is performed by the finite element method. This model solves Reynolds averaged Navier Stokes equations for anincompressible medium with the Boussinesq assumption and shallow water approximation. The regional scale of the model implicated implementation of external data at the lateral boundary region. In our case Flather's boundary condition let us to force the model with combined information. At the same time tidal ordinate and barotropic component of velocity that reflects the West Spitsbergen Current are implemented. Also salinity and temperature were nested at the boundary area. The upper boundary conditions was also introduced. The data for the boundary were taken from Global Tide Model (all tidal components), an 800 m ROMS simulation of the Svalbard area made by the Norwegian Institute of Marine Research (bartoropic velocities, temperature and salinity), European Centre for Medium Weather Forecast (ECMWF).

3. Model results

The fjord's dynamics strongly depend on the season. The annual variability could be represented by the fjord's heat and salt content. Furthermore, the fjord is known to be under the strong influence of shelf waters consisting of WSC and SC, and it is impossible to separate them because these two currents mix at the fjord's mouth (Gluchowska et al., 2016; Walczowski, 2013).

Analysis of the salt and heat content in the whole fjord shows the clearly visible seasonal variability in the heat and salt content of the entire fjord and Brepollen (Fig. 2). Moreover, any increase in the salt content during any part of the year, except during periods of decreasing catchment area activity, which begins in mid-July, means that it is mostly under the influence of WSC.

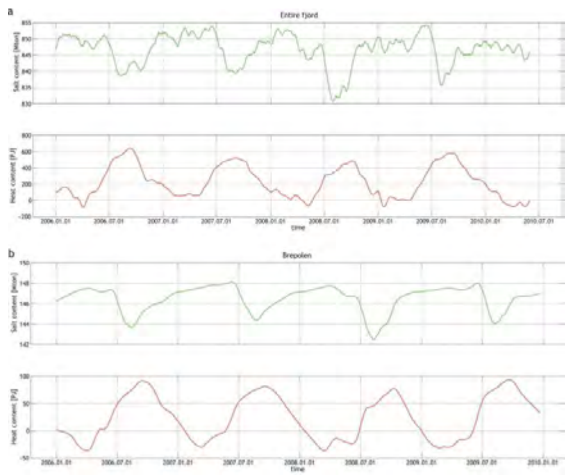

Figure 2. Heat and salt content for the entire fjord (a) and Brepollen (b) for the period 01.01.2006–31.12.2009

The anomaly was integrated because this process removes all small oscillations. The salt anomaly integrated over time for the entire fjord provides no evidence that only WSC or only SC (Fig. 3) exert an influence there.

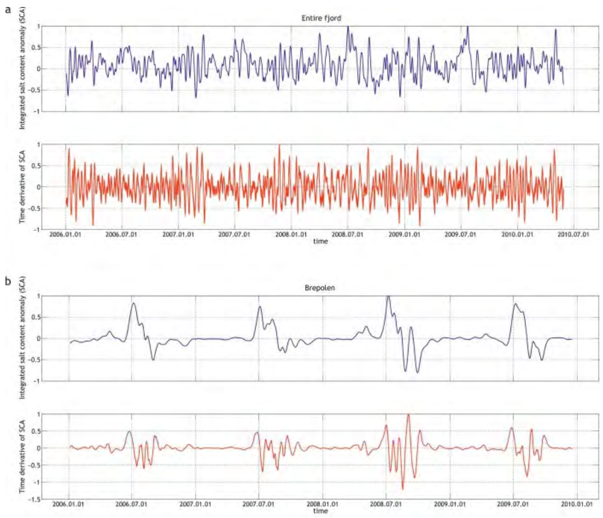

Figure 3. The SCA (over time) and its derivative for the entire fjord (a) and the Brepollen area (b) for the period 01.01.2006–31.12.2009.

However, Fig. 4 shows that the method detects inflows of more saline or fresher water into the fjord or Brepollen, but it is still difficult to say whether Hornsund is under the influence of only one of them.

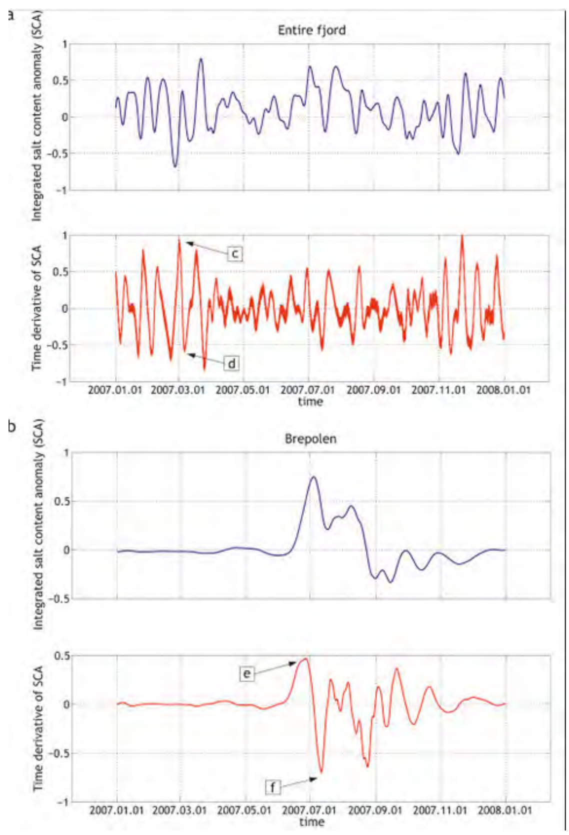

Figure 4. The SCA (over time) and its derivative for the entire fjord (a) and the Brepollen area (b) for the period 01.01.2006–31.12.2009.

In the Hornsund fiord the Fronts, natural boundaries between waters of different properties, are clearly seen. The fronts may be visible on the surface as a demarcation lines, color changes, foam accumulation or choppy waters. (Fedorov, 1986), but here in use temperature, salinity and density.

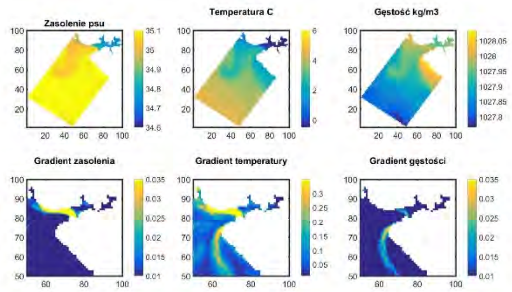

Figure 5. Salinity, temperature, density and the corresponding gradients 06-05-2005

This front is represented by strong temperature and salinity gradients (Fig. 4). the hydrological front is clearly marked in the form of a water division zone with various properties and the front face is visible in the form of a line of maximum gradients. Fresh water from the catchment area leaves the northern area of the main fjord and oceanic water enters the fjord through the southern part of the mouth. The shape and gradient of the front depends mostly on the fresh water content in the surface layers of the fjord and the situation on the shelf.

More model results will be presented during conference.

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Assessment of biogeochemical models in the NW Mediterranean

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1. Introduction

This work aims to assess the skills of different physical-biological coupled models, using several sources of *in situ* biogeochemical (BGC) data, focusing on the Balearic Sea (NW Mediterranean) (Figure 1). This subbasin is relevant from the point of view of the economic activities such as marine resources and tourism. Furthermore, this is an interesting and dynamic region for oceanographers that also includes different ecoregions with divergent planktonic seasonal cycle and drivers of the primary production (Lavigne et al. 2013).

2. Material and Methods

The re-analysis of coupled BGC models included here covered different domains and features, being all of them Plankton Functional Types models: (i) IBI-W Mediterranean (NEMO-PISCES), which assimilates only physical data (ii) Mediterranean region (NEMO-BFM), which assimilates only physical data. (iii) Finally, an extra model was included covering the IBI-Mediterranean domain (POLCOMS-ERSEM), which does not include any data assimilation.

Observational *in situ* data used here include public databases as IBAMAR, MEDAR-MEDATLAS, CMEMS *in situ* products monitoring station (OOCS) and high spatial resolution glider data from SOCIB (www.socib.es). Other observation platforms were included such as satellite data from CMEMS including SST, chlorophyll and geostrophic currents from SLA. Basic variables were included for describing biogeochemical processes, such as: density and derived estimates (stratification, MLD), chlorophyll and dissolved macronutrients.

Two kind of analysis were performed aiming to compare observational data with model outputs: (i) surface climatologies vs satellite observations; (ii) seasonal climatological profiles of the variables for the different seasons and 4 areas including different ecoregions with different BGC patterns already described (Figure 1): Balearic Channels (IC and MC, dominated by stratification), Ebro delta (ED,shallow and productive area) and Catalan shelf (CS, intense winter mixing).

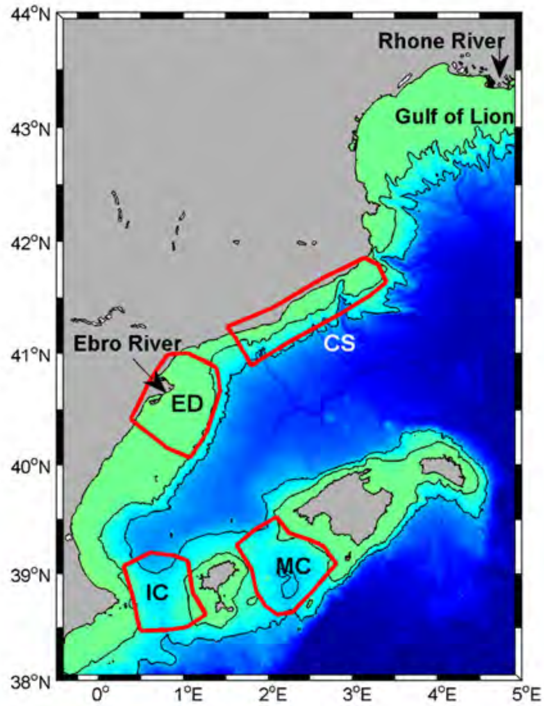

Figure 1. Balearic Sea in the NW Mediterranean. Chosen areas for this analysis: IC-Ibiza Channel, MC-Mallorca Channel, ED-Ebro Delta, CS-Catalan Shelf.

3. Results and Discussion

The hydrological cycle including the mixing/stratification cycle was well captured by the models, including the spatial variability in this region. The basic hydrodynamic patterns of this region as the North Current and its seasonal modulation was also reasonably reproduced. However, there were some biases that modify the advection of BGC properties.

The BGC reanalyses partially followed the main spatial and temporal patterns of each ecoregion, including the late winter/spring bloom and the deep chlorophyll maximum features during stratified periods. However, absolute nutrient and chlorophyll values were largely over or underestimated for NEMO-PISCES and NEMO-BFM respectively (Figure 2). Riverine nutrient inputs partially followed in situ patterns, with some deviations. We discuss potential implications of our work concerning both, future model development and recommendations for end users, including those envisaging model in projections based on RCP scenarios.

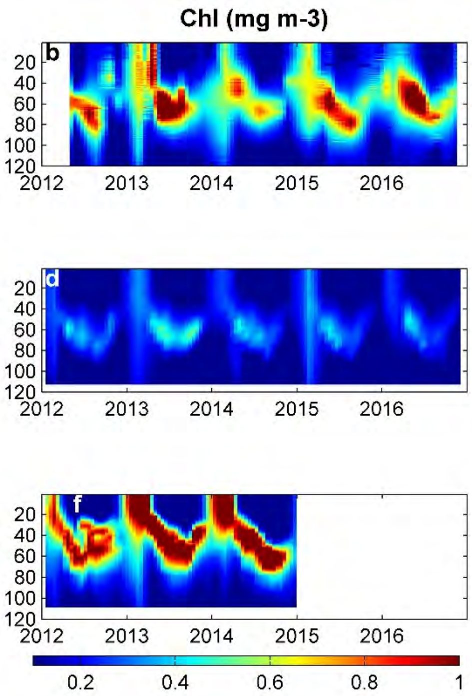

Figure2 . Time volution of Chla (mg/m3) at the Ibiza Channel at different depths from Glider data (top), NEMO-BFM (middle) and NEMO-PISCES (bottom)

Acknowledgements

This work has been conducted in the frame of the H2020 CERES project (ref: 678193)

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Preliminary results of the RegCM-ES model with an active biogeochemical component (BFM) over the Med-CORDEX domain

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1. Introduction

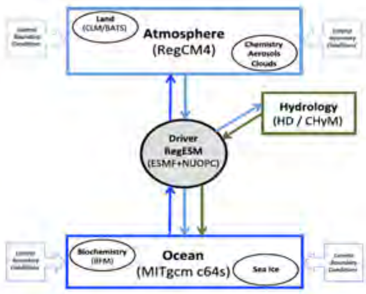
The Mediterranean region has been identified as an hot spot for climate change (Giorgi,2006) with its marine ecosystems already strongly affected by the impacts of human activities in the area , potential targets of the predicted increase (decrease) in the sea temperature (pH), as a consequence of global warming. It comes out the need to quantify these impacts through the inclusion of a marine biogeochemical model in the regional earth system models implemented over the area.

Here we illustrate some preliminary results , with particular emphasis on the biogeochemistry, of the RegCM-ES (Earth System Regional Climate Model, fig.1a) model, developed and used at ICTP (Sitz et al.,2017), recently coupled with an active biogeochemical component (BFM, Biogeochemical Flux Model; Vichi et al.,2015) in the Mediterranean region.

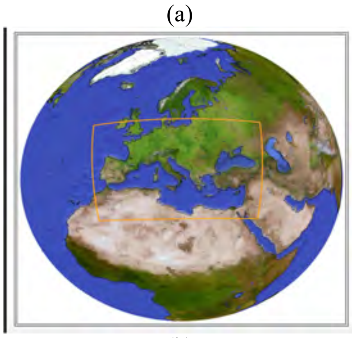
2. Data and methods

RegCM-ES (fig.1a) includes an atmospheric component (RegCM.4.6.1,Giorgi et al.,2012) with a spatial resolution of 30 km coupled with a land model (CLM4.5),an ocean component (MITgcm,Marshall et al.,1997) with a resolution of 1/12 degree recently coupled with BFM (Cossarini et al.,2017), and a component to simulate river discharge (HD,Hagemann et al.,2001).

RegCM-ES/BFM has been implemented and tested over the Med-CORDEX domain (fig.1b; Giorgi et al.,2009). The period of this preliminary analysis is 1998-2002.



(a)



(b)

Figure 1. RegCM-ES (a,Sitz et al., 2017), Med-Cordex domain (b, http://cordex.org/domains/region-12-mediterranean/)

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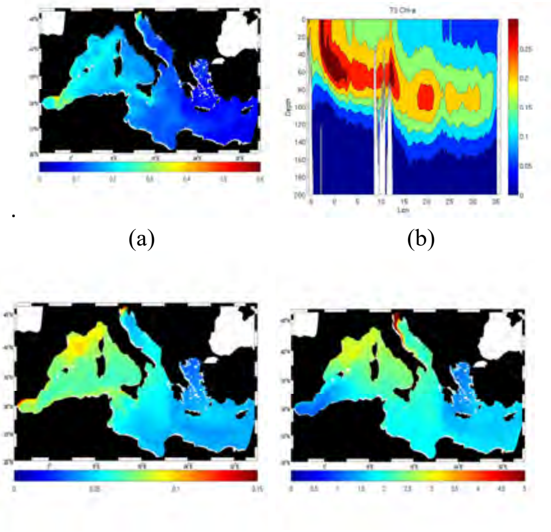
3. Results



(a) (b)

(c) (d)

Figure 2. Mean Surface Chl-a (mg/m^3,a), Mean Transect of Chl-a (mg/m^3,b), along the Mediterranean Sea , Mean Surface Phosphate (mmol/m^3,c) and Mean Surface Nitrate (mmol/m^3,d) in the period 1998-2002

Preliminary comparisons with climatological data and available reanalysis show that the new coupled model is able to reproduce the spatial pattern (fig.2 a,d) and the seasonal variability of phytoplankton and zooplankton as well as of nutrients as phosphate and nitrate in the domain of study and, in particular , in areas where vertical mixing is substantial , e.g. in the gulf of Lions and in the southern Adriatic. Systematic differences in nutrients concentration in the surface layers are observed in areas where vertical mixing is significant , e.g. the Gulf of Lions. Biogeochemistry dynamics confirms the importance of physical forcings in influencing the dynamics of marine ecosystems

Further experiments are planned with particular focus on the past climate variability in the area and future climate scenarios.

Acknowledgments

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Assessing the climate Impacts of the Atlantic Multidecadal Variability on the Mediterranean basin

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1. The Atlantic Multidecadal Variability and climate impacts

During the last decades, the evolution North Atlantic sea surface temperature (SST) has been affected by both, low frequency intrinsic climate variability and external forcing, both anthropogenic and natural. The low frequency internal climate variability, also known as Atlantic Multidecadal Variability (AMV), has received particular attention in the last years, since this low-varying fluctuation in the ocean could lead to climate predictable signals. The SST pattern associated with the AMV exhibits homogeneous basin-wide SST anomalies of the same sign Knight et al. 2006, leading to the warm AMV (AMV+, positive SST anomalies) and cold AMV (AMV-, negative SST anomalies) phases. Observational studies have shown that the AMV could impact not only the North and Tropical Atlantic oceans, but also the adjacent continents (Sutton and Hodson, 2010; Kushnir et al. 2010). It has been argued that the existence of a causal link between the warm phase of the AMV+ and warmer conditions over central Europe, drier conditions over the Mediterranean basin, and wetter conditions over northern Europe during boreal summer. A number of studies have also suggested that the AMV could impact the mid- latitude winter atmospheric circulation. Based on an observational study, Mariotti and Dell'Aquila (2012) show the existence of decadal climate variability in the Mediterranean basin in the period 1850-2009, moreover agreat part of this decadal variability can be explained by the AMV. All these studies highlight the importance of better understanding and predicting the AMV and its climate impacts to address the near term future changes in the Mediterranean-European climate. However, the shortness of the historical observational record compared to the AMV period makes it difficult to rigorously isolate the drivers and the impacts of the AMV. In this context, numerical coupled climate models offer a valuable alternative to investigate the AMV climate impacts and associated mechanisms. In this study we investigate the AMV impacts over the Mediterranean basin by using a set of idealized coupled experiments.

2. Coupled experiments

In order to isolate and maximize the AMV signal, we perform idealized experiments in which the patterns of North Atlantic SST anomalies corresponding to the AMV phases are restored in the coupled model. Following a similar protocol as in Ruprich et al. 2017, the CNRM-CM5 coupled model (Voldoire et al. 2012) is used to carried out two ensembles of 40 members each, with SST restored to both, the warm and cold phases of the AMV. The difference of these two ensembles gives an estimate of the climate response to the AMV forcing. This experimental protocol has been adopted in CMIP6 (Coupled Model Intercomparison phase 6) for the Decadal Climate Prediction Panel component C.

3. Preliminary Results and ongoing work

In this study we focus on the AMV impacts and associated mechanism over the Mediterranean basin for two particular seasons, winter and summer. Preliminary analysis shows that the response of surface temperature (2m) to the AMV SST anomalies is quite consistent with previous studies, with a prominent warming and cooling over the Mediterranean area for the AMV+ and AMV- respectively. The temperature impact over the Mediterranean area is more prominent in the western part of the basin. The AMV impact on precipitation during summer displays a general drying over the Mediterranean countries. Much less clear is the response of the atmospheric dynamics to AMV anomalies. An assessment of how AMV affect the temperature extremes in summer and cyclogenetic activity in late summer-autumn will be also investigated. Finally, the mechanisms explaining the AMV impacts over the Mediterranean basin are addressed by isolating the role of the atmospheric dynamics from the thermodynamically driven processes.

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The Regional Climate System CNRM-RCSM6: description and first results of a 1980-2013 hindcast simulation

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1. Introduction

Regional Climate System Models (RCSM) belong to the same family as the global earth system models (ESM) used in the CMIP experiments, but generally have a higher resolution. They allow to reproduce medium scale atmospheric and oceanic phenomena on periods going from present time hindcast to scenarios for the 21st century.

The previous CNRM-RCSM4 model for the Mediterranean region (Sevault et al. (2014)) and CNRM-RCSM5 (Nabat et al. (2015a)) were using a 50 km resolution in the atmosphere and an around 10 km resolution in the ocean (1⁄8°*1⁄8° cos(lat) grid). In the new CNRM-RCSM6 version presented here both resolutions are refined (12 km and 91 levels in the atmosphere, 6-8 km and 75 levels in the ocean), still allowing climatic scale simulations, with the most recent versions of atmosphere and ocean models available at the CNRM, which are used for CMIP experiments. The atmosphere model (ALADIN-Climate v6, with new atmospheric physics), the multi-surface model (SURFEX v8, new physics,), the river routine model (CTRIP, with deep drainage and flood plains, but still a 50 km resolution), the inland model (FLAKE) are described in Voldoire et al. (2017). The ocean model is NEMOMED12 v3.6 (Beuvier et al. (2012), Hamon et al (2016) for the v3.2). OASIS3-MCT (Valcke et al. (2015)) is used at the coupler, at a 1h-frequency. With the use of new lateral boundary conditions, we show that the model can better reproduce the late tendencies in sea surface height (SSH) and sea surface temperature (SST) than with the previous version. Thanks to the 1h-coupling frequency, the model can simulate the diurnal cycle of SST and the comparison to buoys will be possible.

When writing this abstract, the simulation of the ERA-Interim period is not completed, we will only be able to present partial results.

2. Experimental setup

A special attention has been given to lateral boundary conditions:

- ERA-Interim reanalysis (Berrisford et al. (2009)) for the spectral nudging in the atmosphere, and for the SST outside the Mediterranean region;
- a new climatology for the aerosols (Nabat et al. (2013);
- ORAS4 ocean reanalysis (Balmaseda et al. (2013)) for the Atlantic part of the model, monthly fields in temperature and salinity;
- a new SSH climatology is used for relaxation in the Atlantic part, composed by the ORAS4 monthly fields, with a corrected seasonal cycle which follows the one of CCI-ECV (Adloff et al. (2017));
- monthly climatology of the surface Chlorophyll concentration (2003-2011 ESA-CCI, T. Arsouze personal communication)

The ocean restart is a combination of the 1960-1980 ORAS4 average for the Atlantic part of the domain, and the pre-EMT Medatlas condition in the Mediterranean Sea. A 7-year ocean spin-up is done with a 3D relaxation to this ocean state.

Finally the Black Sea (fully coupled) and the Nile (climatology) are treated in the same way as in Sevault et al. (2014).

3. First results

The mean SSH (Fig. 1) shows a good representation by the coupled systems compared to the MEDRYS reanalysis (Hamon et al. (2016)) and the observations. Fig2 and 3 show that the interannual average and the seasonal cycle of the Mediterranean SSH are better reproduced with CNRM-RCSM6, thanks to the new Atlantic SSH climatology prescribed.

Figure 4 shows the mean Mediterranean SST of the two RCSM compared to different observation sets. The CNRM-RCSM6 SST is highly correlated to the Marullo data, but overestimated, and more work particularly on the atmospheric fluxes is to be done. The tendency of SST is equal to 0.02°/year in CNRM-RCSM4, 0.03°/year in CNRM-RCSM6, and 0.04°/year in Marullo for example. It is thus better represented in CNRM-RCSM6.

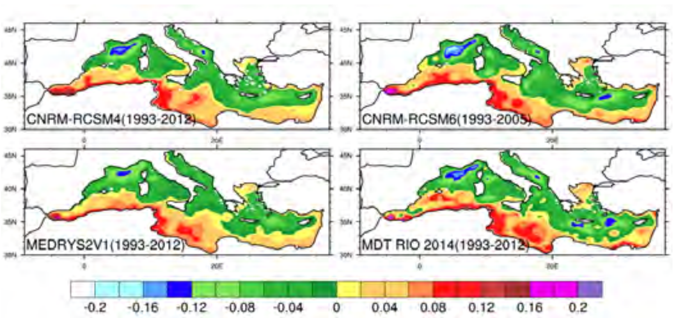

Fig. 1: mean SSH on the indicated period for each dataset.

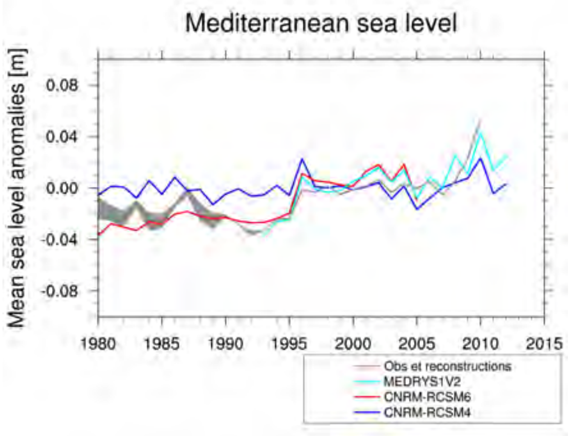

Fig. 2: Interannual time series of sea level average on the Mediterranean Sea, values are centered on the 1993-2008 period (1993-2005 for CNRM-RCSM6)

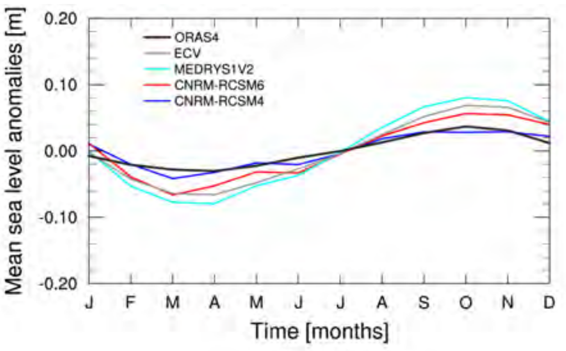

Fig. 3: Mean seasonal cycle of Mediterranean sea level for the 1993-2008 period (1993-2005 for CNRM-RCSM6)

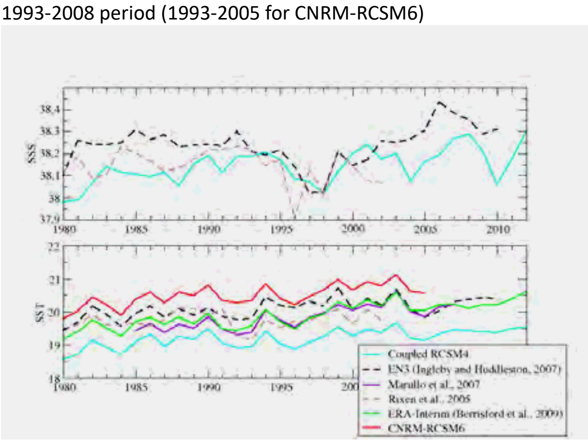

Fig. 4: Mean annual SST on the Mediterranean, compared to some observations

4. Conclusion and perspective

We showed a few results of this new hindcast with CNRM-RCSM6, showing some improvements in some ways compared to the previous version, but many diagnostics are still to be done (thermohaline circulation, diurnal cycle of SST, analysis of the air-sea fluxes).

After the validation of the hindcast simulation, scenario simulations are planned. Future evolutions of the system are also possible, among other the use of AGRIF grid-refinement in the ocean, the introduction of the TACTIC interactive aerosols scheme in the atmosphere (Nabat et al. (2015b)), and the use of a 12 km grid for the CTRIP model.

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A 15-year history of coupled regional climate modelling for the Mediterranean: success stories and current challenges

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1. Introduction

The Mediterranean climate and the Mediterranean Sea are strongly coupled by fine-scale and high-frequency physical phenomena such as regional winds, meso-scale cyclones and medicanes, strong air-sea fluxes, sea breeze, aerosol-radiation interactions or coastal upwelling. This naturally led the climate and ocean modelling community to develop high-resolution and fully-coupled climate models to study this specific area. The history of the coupled regional climate models dedicated to the Mediterranean study is now a 15-year long story. I propose here to give a synthetic view of this history focusing on success stories and coming challenges.

2. History of coupled regional climate modelling for the Mediterranean

Coupled regional climate models are relatively recent within the history of climate modelling. They appeared first as Atmosphere-Ocean Regional Climate Models (AORCM) at the beginning of the year 2000s for the Baltic Sea (Döscher et al. 2002) and the Arctic Sea (Rinke et al. 2003). This trend was followed by the Mediterranean Sea community with the implementation of the first coupled Atmosphere-Ocean Regional Climate Models in the 2000s at CNRM (Sevault et al. 2002, Somot et al. 2008, 2009) and ENEA (Artale et al. 2010). In their infancy, Mediterranean AORCMs included land-surface models but climatological rivers, were daily coupled at the air-sea interface and had a typical spatial resolution of 50km for the atmosphere and 10km for the ocean.

Following the complexity path, the river coupling and a parameterization for the Black Sea water inflow were introduced to close the Mediterranean Sea water budget (Carillo et al. 2012, Sevault et al. 2014, see also Figure 1). From this stage, former AORCM were called either Regional Climate System Model (RCSM) to take into account the coupling of many components of the regional climate system (e.g. atmosphere-land-river- ocean). The following step was to add the marine biogeochemistry (Sein et al. 2015), the natural and anthropogenic aerosols (Nabat et al. 2015) and the lakes, aquifers and flood plains (Voldoire et al. 2017).

3. Success stories

Since 15 years, the history of the development and of the scientific use of the coupled RCMs is full of success stories. First of all, the interest is clearly growing for this new generation of climate modelling tools. Indeed, starting from pioneer efforts at CNRM and ENEA, the European project CIRCE allowed to establish a first coordinated multi-model exercice with 5 AORCMs (Gualdi et al. 2013) followed by the on-going Med-CORDEX initiative (Ruti et al. 2016) in which 12 different plateforms are developed, run and intercompared.

Finding the right methodologies and reference datasets to evaluate AORCM or RCSM was probably one of the first challenging task as it requires to assess at high spatio-temporal resolution the new components and the interfaces between them. This took time but nowadays, river discharges, sea level, SST diurnal cycle, intense air-sea fluxes, land-atmosphere interactions, regional winds, heavy precipitation events, surface radiation, aerosol load, strait transports or ocean heat and salt contents can be evaluated (e.g. Sevault et al. 2014, Nabat et al. 2015, Adloff et al. 2017).

The main benefit of coupled RCMs is the expected improvement of the interface representation and in particular of the heat, water and momentum fluxes. The new degrees of freedom at the interfaces naturally allow to study the climate variability of regional phenomena strongly dependent of those exchanges. As most of the Mediterranean coupled RCMs are reaching a mature state, the coupled phenomena studies are becoming more and more relevant. For example, recent publications using coupled RCMs within the Med-CORDEX framework explored the past climate variability of medicanes (Gaertner et al. 2016), cyclones (Sanna et al. 2013, Flaounas et al. 2016), intense air-sea fluxes and related deep water formation (L'Hévéder et al. 2013, Somot et al. 2016), heavy precipitation events (Berthou et al. 2015), Mediterranean Sea heat and water budgets (Sevault et al. 2014, Lebeaupin-Brossier et al. 2015, Harzallah et al. 2016), the regional winds (Herrmann et al. 2011), the aerosol-climate coupling (Nabat et al. 2015), the sea breezes (Drobinski et al. 2017) and the SST trend (Nabat et al. 2014).

Last but not least, coupled RCMs allow, for the first time, to assess the future evolution of the Mediterranean Sea under climate change by (1) using a natural representation of the air-sea and land-sea interfaces and (2) keeping all the GCM low-resolution climate change information at the boundaries of the regional climate system. Studies (sometimes multi-model studies) of the future evolution of the SST (Somot et al. 2008, Gualdi et al. 2013), the Mediterranean Sea heat and water budgets (Dubois et al. 2012) and the sea level (Tsimplis et al. 2008, Carillo et al. 2012) have been already carried out (see also the overviews by Planton et al. 2012 and Ruti et al. 2016).

4. Coming challenges

Despite the above success stories, the community is still facing big challenges. Coupled RCMs are still under-used within the regional climate modelling community which clearly prefers Atmosphere-only RCMs. This is probably due to three main weaknesses: (1) the complexity to set- up, maintain and improve such a complex modelling tools, (2) the small number of multi-model studies using coupled RCMs future projections probably due to the still limited number of available simulations and (3) the lack of clear proofs of the added-value of coupled tools to represent climate over land. Indeed, most of the studies trying to identify this added-value faced the SST bias issue in coupled models that can often hide it. In future climate change projections, Somot et al. (2008) showed that an AORCM can significantly modify the SST climate change signal of its driving GCM with implications for the climate change signal over land. However this key result remain to be confirmed in multi-model studies.

Concerning the future development of the RCSM, key challenges should be addressed: (1) to add the human component through the anthropogenic aerosols, the water reservoirs (dams), the land and water use (irrigation) or the cities to finally obtain Regional Earth System Models (RESM) (2) to sustain the improvement of the model quality and the large diversity of the current coupled RCMs ensemble , (3) to make model outputs and expertise easily accessible outside the modelling community using standardized file formats and user- friendly databases. This would allow to develop robust studies of the impacts of climate change on marine ecosystems and maritime activities which are key factors towards climate-aware adaptation measures.

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Modeling the Mediterranean circulation: skills and flaws of present day models

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1. Introduction

The modeling of Mediterranean circulation is of paramount importance to understand the functioning and variability of the Mediterranean system. The advection and mixing of physical and biogeochemical properties is determined by the circulation patterns and their variability. Unfortunately the observations of water circulation are limited in space and/or time, so numerical modeling is required to complement them. At present, lots of efforts are being devoted to the implementation of circulation models at basin and sub-basin scale, with spatial resolution ranging from 1 to 10 km and covering from few years to multi-decadal periods. However, a complete assessment of the skills and flaws of those models has not been done yet. In this work we will show a comparison of different types of simulations (basin climate models, sub-basin high resolution models and reanalysis) with observations from different platforms (moored current meters, altimetry and HF radar). The goal is to assess up to which extent the present day models are able to reproduce the main circulation patterns, their variability and the mesoscale and submesoscale fields.

2. Data and methodology

2.1 Mooring current meters

The map of figure 1a shows the spatial distribution of the 155 stations comprising the data set used in this study. Each one provides zonal and meridional velocity measures at one or more specific depths. Depending on the site, these measures have been acquired by a point-wise current meter or and ADCP (Acoustic Doppler Current Profiler). The temporal coverage and the time steps of the velocity records vary a lot among stations; a summary can be found in figure 1b. In addition to those performed by the institutions of origin, we have carried out an exhaustive quality control of the data in order to ensure the robustness of our results.

2.2 HF radar data

As a complement to the moorings, surface currents from three high frequency radar (HFR) systems have been included in the model validation. Two of them are operated by Puertos del Estado (the Spanish ports authority), located at the Strait of Gibraltar and the Ebro river delta (Catalan coast), and the third one is operated by SOCIB (Balearic Islands Coastal Observing and Forecasting System), at the Ibiza channel (fig. 1a).

2.3 Satellite data

Two different satellite products have been used in this study: Along track absolute dynamic topography (ADT) data from AVISO (Archiving Validation and Interpretation of Satellite Oceanographic) were used to get the tracks of the satellites running at a given time and to extract the SSH data from the numerical models.

The second set of satellite data used is the geostrophic velocity derived from the gridded SSH AVISO product for the Mediterranean Sea, from 1993 to 2016. In this case the altimetry data have been treated as another simulation in the comparative analysis.

2.4 Models and simulations

A set of nine simulations based on three different climatic ocean circulation models have been analyzed in this study: seven based on NEMO - OPA (Nucleus for European Modeling of the Ocean-Ocean Parallelise) model, one on ROMS (Regional Ocean Modeling System) model and one on SYMPHONIE. Covering different periods between 1987 and 2017, the simulations main differences are the resolution (horizontal and vertical), the boundary and atmospheric forcing and the assimilation (or not) of observational data.

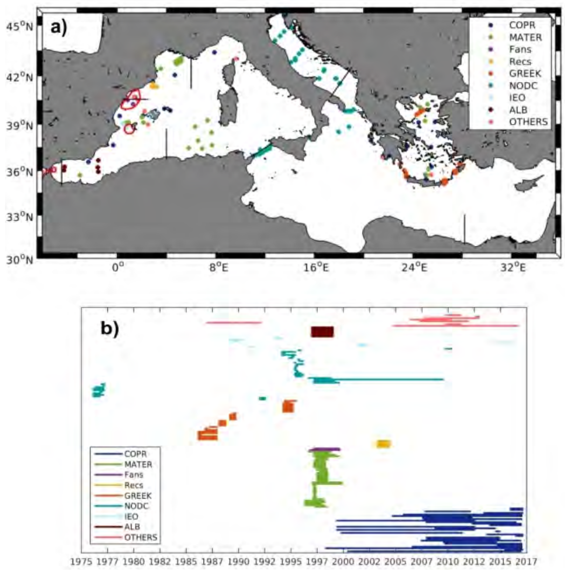

Figure 1. a) Dots: positions of the moorings (colors indicate different sources of the data); Red contours: boundaries of HFR domains; Black lines: sections of the models analyzed. b) Period sampled by each mooring.

2.5 Data analysis

The analysis of the models performance have been carried out in two steps: first we validated the models outputs comparing them with the observations, then we intercopared the models to point out their differences.

The comparison between simulations and observations was performed using three main diagnostics: the correlation between modeled and observed velocities projected onto their respective principal direction; the ratio between the eddy kinetic energy (EKE) of model and observations; the veering angle between observed and modeled velocity vectors, calculated as the counter clockwise angle between the modeled and measured velocity vectors.

The comparison between HFR and models velocities was carried out by means of the complex correlation, veering angle, mean kinetic energy (MKE) and EKE ratios between modeled and measured data.

The performance of each model in the representation of the Mediterranean circulation have been assessed through the average surface circulation, the surface EKE and the SSH variability. In addition, eight vertical sections have been analyzed to get a picture of the discrepancies in the 3D velocity fields. These sections are representative of the main slope currents of the basin, the exchanges at the Gibraltar and Sicily Straits and the Alboran and Adriatic gyres (see fig 1a). The evaluation has been completed estimating the zonal overturning stream function (ZOF).

3. Summary of the main results

3.1. Model validation

The comparison between models and observations evidences the deficiencies of these resolving the variability of the Mediterranean currents. All the simulations show low daily correlation and a misrepresentation of the current variability, mostly underestimating it, at most of the moorings locations. Figure 2 attempt to illustrate the general performance of each simulation depicting the median of the correlation against the median of the EKE ratio. The median correlations range between 0.07 (SYM) and 0.26 (MDY) and the EKE ratios between 0.85 (ROMS) and 0.13, which gives an idea of the general poor results. In COPR the median correlation is 0.2, and the median eddy kinetic energy ratio 0.33. The rest of the z – coordinates simulations are around these values. For NM12 and MDY the correlation is slightly better, but both highly underestimate the current variability (EKE ratio ~ 0.2). On the contrary, the ENSTA simulations show median correlation lower but close to COPR (~0.15), with an EKE ratio slightly higher, better in ENS36s (0.36) than in ENS12s (0.31). ROMS and SYM show the better results for the variability (0.85 and 0.69 median EKE ratio respectively), but their median correlation is still very low (0.17 and 0.01). For the observationally based AVS the results are not better. The median correlation is very low (0.07), and the mean EKE ratio of 0.56. Note that in this case only the surface layer is considered.

The outcome of the HFR – model comparison is similar to the obtained with the moorings: low correlations and underestimation of the current daily variability. Results are slightly better for the radar at the Ibiza channel and the Catalan coast, but are on the same range. Unfortunately, there are no surface current meters data at the Strait of Gibraltar area, but the result would be likely of the same order than for the HFR considering the natures of the surface current in the region.

3.2 Model Intercomparison

The surface circulation analysis shows that the simulations with higher resolution have stronger currents. In the Western Mediterranean the main elements of the basin circulation are present in all the models (Northern Current, Algerian Current and Alboran Gyres), although with disparity of intensity. In the Eastern basin the differences among models are more evident. The surface EKE is also larger in the simulations with higher resolution, meaning stronger mesoscale activity. This is confirmed when comparing with the SSH variability from the satellite observations, although in this case the simulations which assimilate altimetry data show also good agreement, even if their resolution is lower.

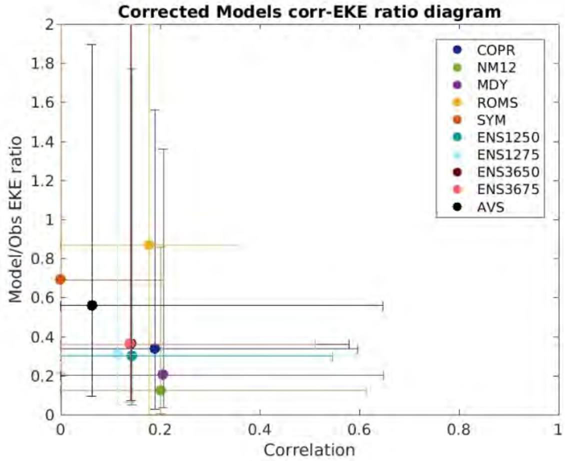

Figure 2. Summary of the models – moorings comparison: median correlation against the median EKE ratio for each simulation. Data is corrected to take into account the different number of mooring coinciding in time with each simulation.

The 3D current field analysis shows that the representation of the slope currents also differs among simulations. Although present in all the models, strong discrepancies are found in the extension, depth, intensity and even the position of the principal currents. On the other hand, the transports at the Straits of Gibraltar and Sicily are in good agreement with the observations for most of the simulations.

4. Conclusions

An ensemble of state of the art ocean climate models for the Mediterranean Sea has been analyzed paying special attention to the circulation. In general the models are not able to properly reproduce the current variability and, in some cases, neither the main patterns. They also underestimate the currents intensity and mesoscale activity. The main factor explaining the discrepancies among models seems to be the spatial resolution. The simulations with higher resolution show more intense currents and higher EKE. The assimilation of altimetry data seems to slightly improve the results of the models in the surface layer, although the improvement is modest.

Cascading ocean basins: numerical simulations of the circulation and inter-basin exchange in the Azov-Black-Marmara-Mediterranean Seas system

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1. The model

In this paper, we use the unstructured grid model SCHISM to simulate the thermo-hydrodynamics in a chain of baroclinic, interconnected basins starting from the Azov Sea and ending at the Aegean Sea (Fig. 1). SCHISM is a derivative product of the original semi-implicit Eulerian-Lagrangian finite-element (SELFE) model (Zhang and Baptista 2008), with many improvements described in Zhang et al. (2016b) and freely distributed under an open source Apache v2 license (http://www.schism.wiki; last accessed January 2017). The model solves Reynolds averaged Navier-Stokes equations along with transport of heat and salt. The model uses a hybrid finite-element and finite volume approach. Its efficiency and robustness is mostly attributed to the implicit treatment of all terms that place stringent stability constraints (e.g., CFL) and the use of Eulerian-Lagrangian method for the momentum advection.

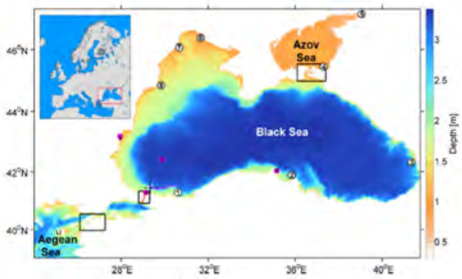

Figure 1. Model area and bathymetry in log scale (2 means 10^2 m). The position of the Black Sea is shown as an inset in the upper left.

2. Model performance

The model shows a good skill in simulating the horizontal circulation and vertical profiles of temperature, salinity, and currents. The magnitude and phases of the seasonal changes of circulation are consistent with earlier observations. Among the mesoscale and sub-basinscale circulation features that are realistically simulated are the anticyclonic coastal eddies, the Sebastopol and Batumi eddies, the Marmara Sea outflow around the southern coast of the Limnos Island, and the pathway of the cold water originating from the shelf.

3. Novel results

The superiority of the simulations compared to earlier numerical studies is demonstrated with the example of model capabilities to resolve the strait dynamics, gravity currents originating from the straits, high-salinity bottom layer on the shallow shelf, as well as the multiple intrusions from the Bosporus Strait down to 700 m depth. The warm temperature intrusions from the strait produce the warm water mass in the intermediate layers of the Black Sea. One novel result is that the seasonal intensification of circulation affects the inter-basin exchange, thus allowing us to formulate the concept of circulation-controlled inter-basin exchange. To the best of our knowledge, the present numerical simulations, for the first time, suggest that the sea level in the interior part of the Black Sea can be lower than the sea level in the Marmara Sea and even in some parts of the Aegean Sea. The comparison with observations shows that the timings and magnitude of exchange flows are also realistically simulated, along with the blocking events. The short-term variability of the strait transports is largely controlled by the anomalies of wind (Fig. 2).

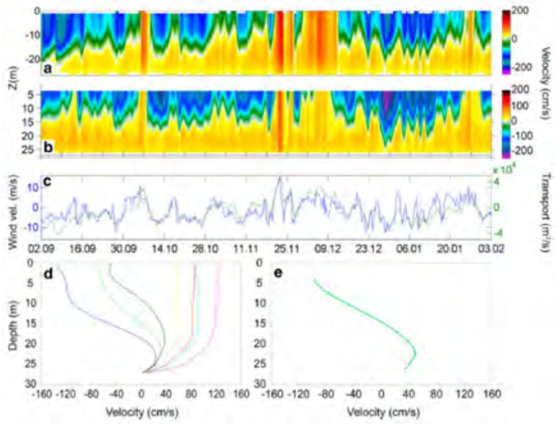

Figure 2. Along-strait components of currents (positive toward the Black Sea) in the southern Bosporus during September 2008–March 2009. a Numerical simulations. b Replotted from Jarosz et al. (2011). c The along-channel wind velocity (positive is along the channel directed to the Black Sea, that is roughly to the north) and the net transport (positive to the Black Sea). Velocity profiles are shown from the simulations (d) and observations (e, replotted from Jarosz et al. 2011).
The green lines in d and e show time-averaged profiles for the period in a–b.

The simulations demonstrate the crucial role of the narrow and shallow strait of Bosporus in separating the two pairs of basins: Aegean-Marmara Seas from one side and Azov-Black Seas from the other side. The straits of Kerch and Dardanelles provide sufficient interbasin connectivity that prevents large phase lags of the sea levels in the neighboring basins.

The two-layer flows in the three straits considered here show different dependencies upon the net transport, and the spatial variability of this dependence is also quite pronounced. We show that the blocking of the surface flow can occur at different net transports, thus casting doubt on a previous approach of using simple relationships to prescribe (steady) outflow and inflow. Specific attention is paid to the role of synoptic atmospheric forcing for the basin-wide circulation and redistribution of mass in the Black Sea. An important controlling process is the propagation of coastal waves.

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A North Sea-Baltic Sea regional models: coupling of ocean and atmosphere through a dynamic wave interface

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1. Motivation

The coupling of models is a commonly used approach when addressing the complex interactions between different components of earth system. In climate and forecasting research and activities, advanced models are needed and there is an urge towards the use of coupled modelling. This study presents the developments and implementation of a high-resolution, coupled model system for the North Sea and the Baltic Sea, as a part of the Geestacht COAstal model SysTem GCOAST (Fig.1). We focus on the nonlinear feedback between strong tidal currents and wind-waves, which can no longer be ignored, in particular in the coastal zone where its role seems to be dominant. Sensitivity experiments are performed to estimate the individual and collective role of different coupling components. The performance of the coupled modelling system is illustrated for the cases of several extreme storm events.

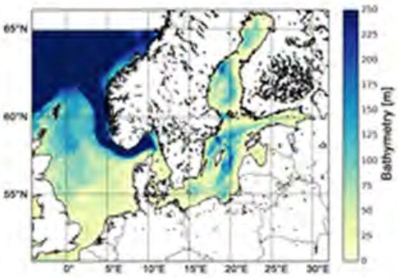

Figure 1. Model area

2. Wave effects in the ocean model

Ocean waves influence the circulation through number of processes: turbulence due to breaking and non-breaking waves, momentum transfer from breaking waves to currents in deep and shallow water, wave interaction with planetary and local vorticity, Langmuir turbulence. The NEMO ocean model (Madec 2008) has been modified to take into account the following wave effects as described by Staneva et al. (2017) and Alari et al. (2016): (1) The Stokes-Coriolis forcing; (2) Sea state dependent momentum flux; and (3) Sea state dependent energy flux. A schematic overview of these processes is shown on Fig. 2. The wave model WAM is a third-generation wave model, which solves the action balance equation without any a priori restriction on the evolution of spectrum. The last release of the third generation wave model WAM Cycle 4.5.4 is an update of the WAM Cycle 4 (Staneva et al., 2015).

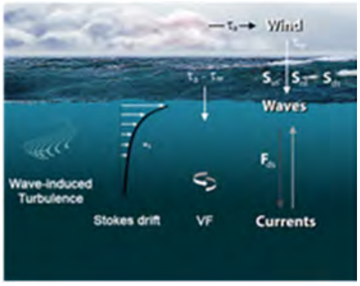

Figure 2. Wave induced processes into NEMO.

We found improved skill in the predicted sea level and circulation during storm conditions when using a wave-forced circulation model system (Staneva et al., 2017). In the periods of storm events, the ocean stress was significantly enhanced by the wind-wave interaction leading to an increase in the estimated storm surge (compared to the ocean-only integration) to values closer to the observed water level. The numerical experiment with the coupled wave-circulation model (Staneva et al., 2016) yielded an increase of 48 cm in and surge level in the south-eastern shallow North Sea and along the North-Frisian Wadden Sea coast for the Xaver event (Fig. 3)

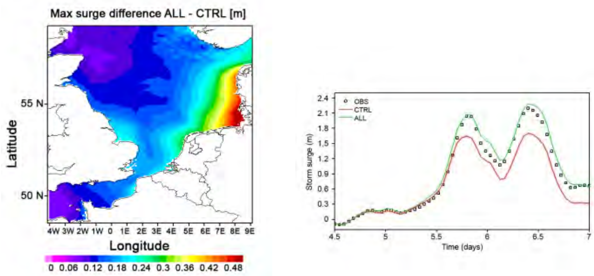

Figure 3: Left: Maximum surge difference in (m) during the storm Xaver between (a) coupled and NEMO model only; right: Observed (black squares) against computed storm surges for the circulation model only (red line) and the coupled wave-circulation model (green line) during storm Xaver at station Helgoland. The X-axis corresponds to the time in days from 01. December 2013

3. Impact of coupling between the atmosphere and wave models

The proposed wave-atmosphere coupling parameterizations account for the feedback between of the upper ocean on the atmosphere by accounting for the effects the sea surface roughness. We aim at a quantification of the effects of coupling of wave and atmospheric models, also during extreme storm events (Wahle et al., 2017). The atmospheric model used in this study is the non-hydrostatic regional climate model COSMO-CLM (CCLM) version 4.8 (Rockel et al., 2008). We compare simulations between coupled and stand-alone models that we validate with newly available space-based observational data. In the one-way coupled setup, the wind wave model only receives wind data from the atmospheric model. In the two-way coupled setup, the wind wave model sends the computed sea-surface roughness back to the atmospheric model. Our novel contribution here is that we simultaneously run (via a coupler) a regional North Sea coupled wave-atmosphere model together with a nested-grid high resolution (ca.1 km) in the German Bight wave model (one atmospheric model and two wind wave models). Using this configuration allows us to study the individual and combined effects of (1) model coupling one-way (1wc) versius 2-way (2wc) and (2) grid resolution, especially under severe storm conditions, which is a challenging aspect for wave modelling at the German Bight (GB) because it is a very shallow and dynamically complex coastal area. Figure 4 illustrates the time variability of the significant wave height (top) and the wind speed (bottom) at the Helgoland stations from observations (black line) and the different model runs during the storm Xaver. The storm characteristics are matched well (Fig.4). Throughout this period, the highest values of significant wave heights are simulated by the WAM-NS-1wc experiment.

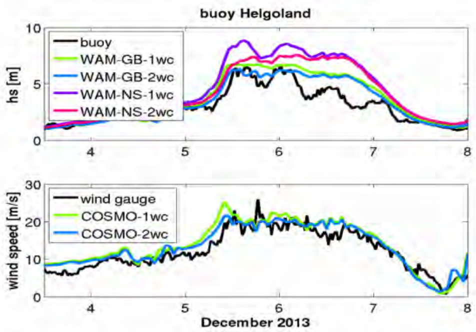

Figure 4: Significant wave height (m, top) and wind speed (m/s, bottom) during the storm 'Xaver' at the buoys Helgoland.

bouy	FINO-1(30m)		Elbe (25m)		Helgoland (30m)	
mean Hs	1.95		1.42		1.63	
	1-way	2-way	1-way	2-way	1-way	2-way
bias Hs	-0.14	-0.03	-0.07	-0.01	-0.13	-0.03

Table 1: German Bight wave model comparisons against wave-buoy data. Hs states for significant wave height (m)

The lowest values, and closest to the observations, are from the WAM-GB-2wc simulations. The wave heights predicted by the WAM-GB-2wc are in best agreement with the observations (Table 1). The influence of spatial resolution on the simulated characteristics can be clearly seen in the time series at the deep water buoy at Helgoland. The importance of the two-way coupling is clearly demonstrated by comparing the WAM-GB-2wc (the blue line) and WAM-GB-1wc (the red line) in Fig. 4. The simulated significant wave height WAM-GB-2wc is reduced, especially during the Xaver peak, and is closer to the measurements.

4. Outlook

The model comparisons with data from new satellite altimeter and in-situ observations showed that the use of the coupled models reduces the errors, especially under severe storm events. For example, the inclusion of wave coupling leads to decreases strong winds through wave dependent surface roughness or changes sea surface temperature, the mixing and ocean circulation; leading to better agreement with in-situ and satellite measurements, especially in the coastal areas. The wave-induced forcing in the circulation model leads to surge simulations closer to observations during extremes. All this justifies the further developments and implementation of the wave model component in coupled model systems for both operational (Kourafalou et al., 2015) and climate research and development activities.

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