Impact of water constituents on radiative heat transfer in the open ocean and shelf seas

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Hudson River Plume

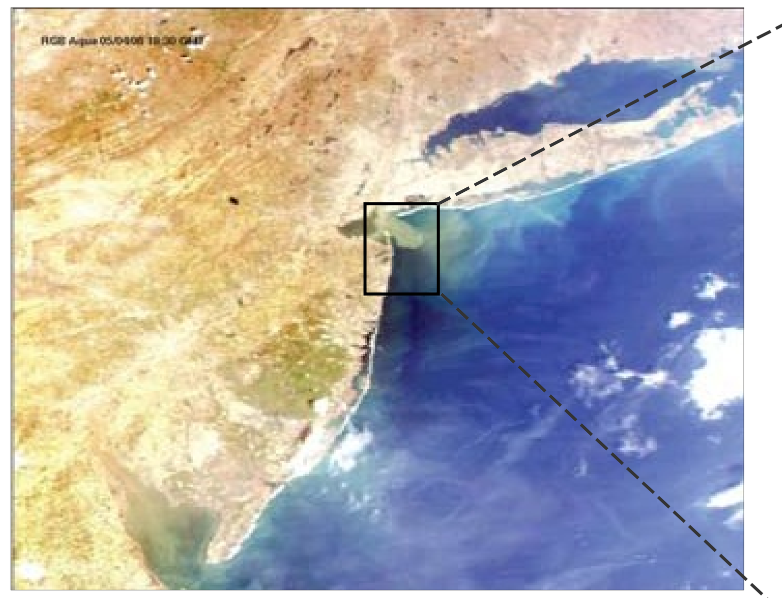

Figure 1. Visible satellite imagery (MODIS) of the New York / New Jersey Bight, 6th April 2005 showing distinct regions of highly turbid water of differing optical properties associated with the Hudson River plume.

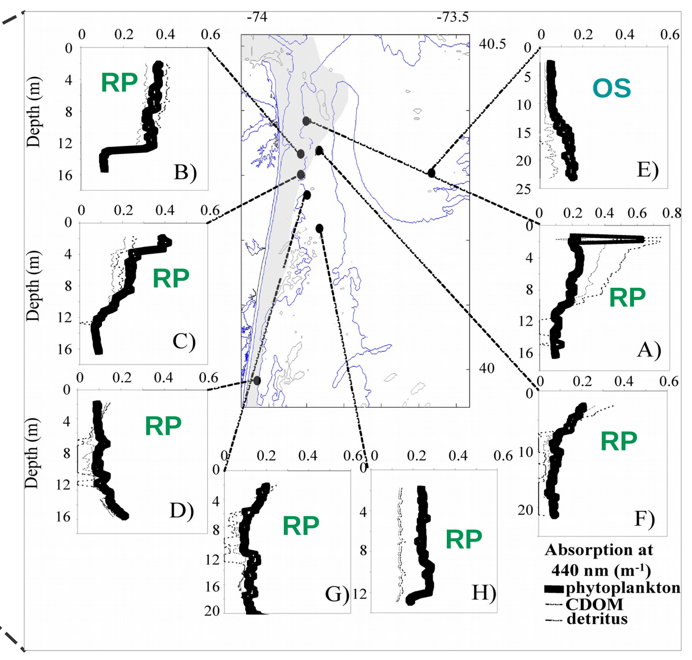

Figure 2. April 2005 absorption profiles derived from Wetlabs AC-9 absorption-attenuation data using an optical signature inversion model (Schofield et al., 2004).

High freshwater discharge event from Hudson River into NY/NJ Sea Bight, April 2005: relative contributions of phytoplankton, detritus and CDOM to total light absorption indicate two distinct water masses:

Total Absorption > 0.2 m^{-1} => River Plume (RP)

Total Absorption < 0.1 m^{-1} => Open Shelf (OS)

Modelling Different Water Types

Different parameterizations of downward irradiance (I(z)) lead to different results in upper ocean water mass structures.

How does this impact …

… surface radiant heating, stratification and circulation

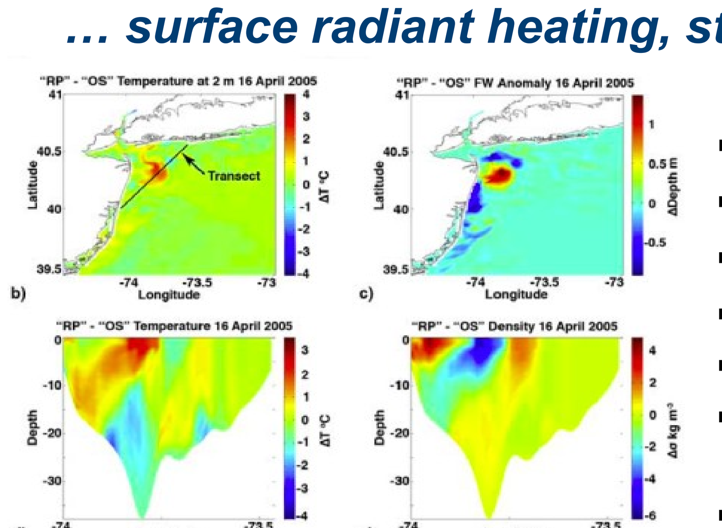

Figure 3: RP – OS ΔT, ΔFreshwater and ΔDensity

River Plume – Open Shelf:

- Warmer surface temp: ΔT ~ +2°C
- Deeper, warmer surface mixed layer
- Colder bottom water: ΔT ~ -2°C
- Sharper temperature gradient
- Greater velocity shear
- Narrow, southward buoyancy driven current along NJ coast
- Anti-cyclonic freshwater bulge at head of Hudson River Canyon

… light attenuation and biogeochemistry

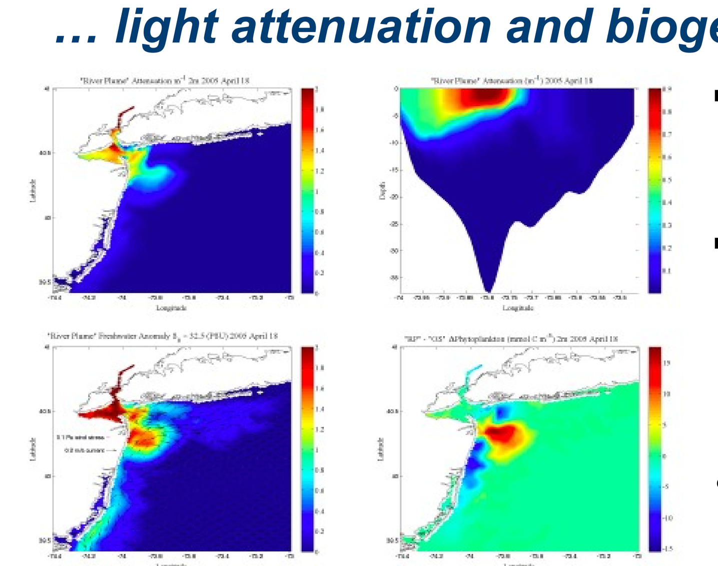

Figure 4: RP attenuation, RP freshwater anomaly and RP-OS phytoplankton biomass

- Causality between light attenuation, transport of river plume properties and biogeochemical transformations.
- Light attenuation impacts growth of phytoplankton which subsequently modifies evolution of attenuation field and feedback into overall heat budget.
- Phytoplankton biomass tracks fresh water anomaly.

(Cahill et al., 2008)

Motivation

How important is the temporal and spatial variability in the underwater light field to modelling biogeochemical and physical processes in coastal and shelf seas?

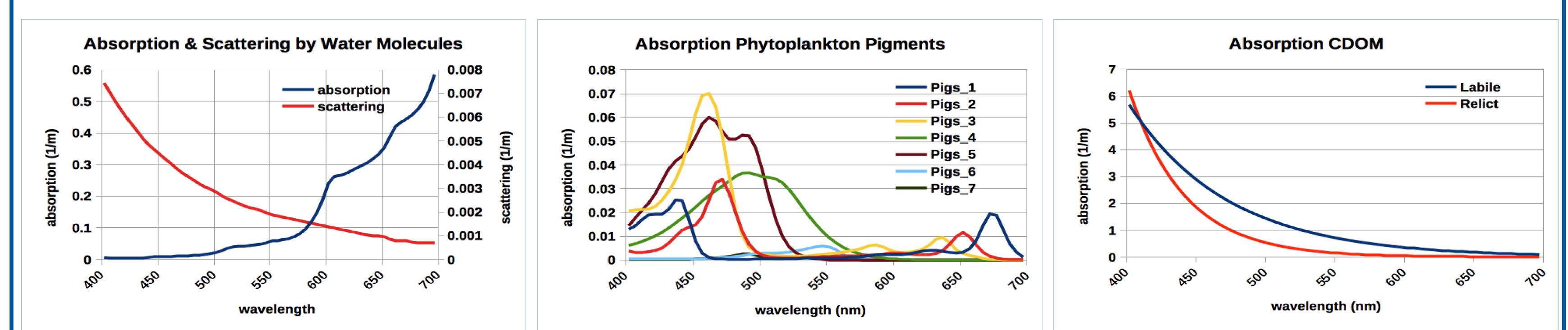

Figure 5: Absorption and scattering of water molecules, various phytoplankton pigments and CDOM

Attenuation of underwater light especially complex in shelf and coastal waters due to absorption and scattering of optically active constituents: water molecules, phytoplankton, detritus, CDOM, suspended sediments

Research Questions

- **What is the contribution of optically active water constituents, OACs (phytoplankton, CDOM, inorganic suspended sediments, detritus) to energy fluxes in upper ocean and across air-sea interface?**
- **How does heterogeneity in water constituents impact characteristics of sub-mesoscale vertical turbulent mixing and advective fluxes?**
- **How is variability in CDOM attenuation reflected by environmental conditions and phytoplankton community structure?**

1D / 3D Experiments in Different Water Types

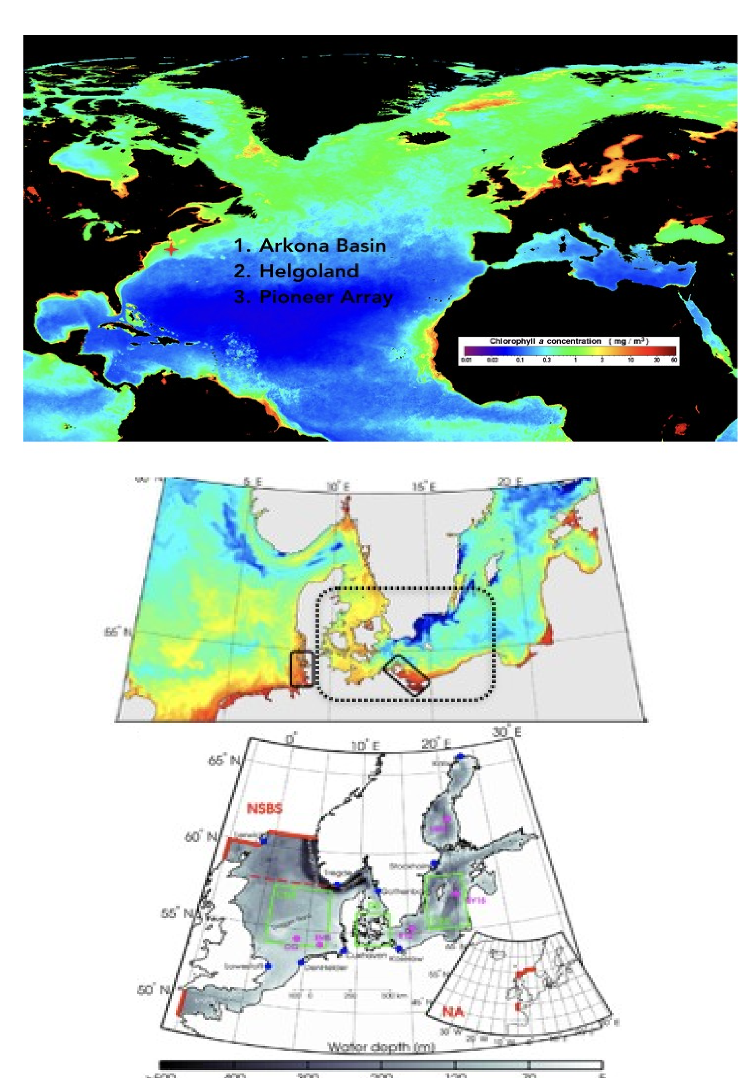

Figure 6: Location of 1D experiment sites (top) and 3D Western Baltic Sea Assessment (bottom)

Site specific comparative 1D simulations of 1D COAWST/Bio-Optic, with and without feedback of biological and sediment heating rates, and MOMO

- Calculate PAR and heating rates
- Evaluate regional implications MOMO vs. Bio-Optic underwater flight field characteristics and heating rates
  - → *Importance of including **upward** irradiance in heat flux calculations?*
- Analyse impact on marine atmospheric boundary layer heat fluxes
- Optimise Bio-Optic heat flux algorithms

3D Western Baltic Sea Assessment

- Relationship between ocean state, variability in CDOM attenuation, mixing processes and phytoplankton community structure.

Coupled Ocean-Atmosphere Model

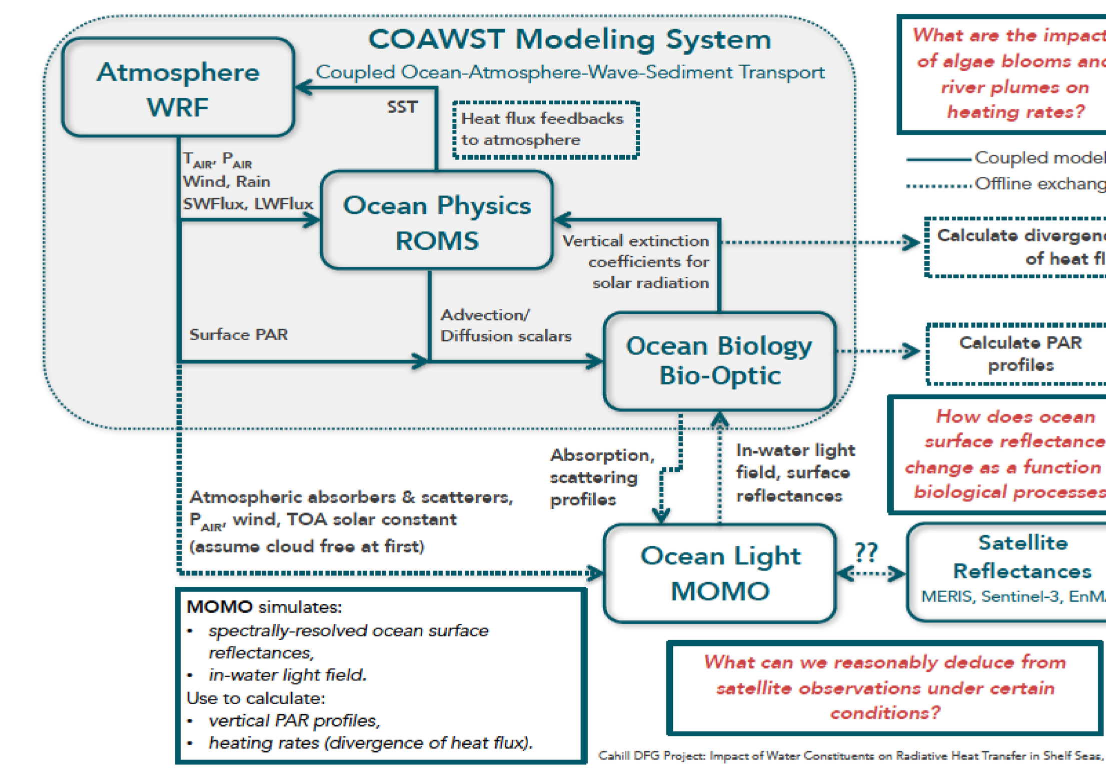

Figure 7: Overview of modelling system(s), interaction between components and data streams

Bio-Optic (Ocean Biology & IOPs)

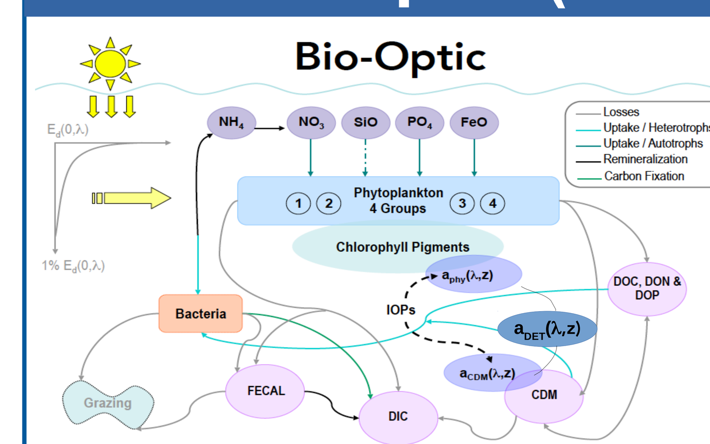

Figure 8: Bio-Optic schematic (adaptation of EcoSim (Bissett et al., 1999))

Calculates in-water (400 – 700nm; 5nm):

- Absorption, scattering, backscatter coefficients, **a, b, b_b**
- Average cosine zenith angle, μ_0
- Downwelling irradiance attenuation coefficient, K_d
- Scalar and downward irradiance fields, E_0 and E_d

Rate of radiant energy converted into heat (horizontally homogeneous water body) ~ divergence of net radiative flux:

$$\frac{dT}{dt} = -\frac{d(E_d - E_u)}{dZ}\frac{1}{\rho C_p} \Longrightarrow \frac{d(E_d - E_u)}{dZ} = -aE_0 = K_d E_d$$

OACs contribution to divergence of heat flux accounted for in full hydrodynamic solution ➡ water constituent heating rates

MOMO (Ocean Light)

MOMO simulates light field in stratified atmosphere-ocean system for VIS and NIR spectral ranges

Given:

- Absorption, scattering coefficients and phase function, **a, b, P**

MOMO calculates:

- Downwelling irradiance attenuation coefficient, K_d
- Downward, **upward** and scalar irradiance fields, E_d, E_u and E_0
- Surface **reflectances** ➡ direct evaluation of MOMO output with satellite reflectances, MERIS 10 year archive

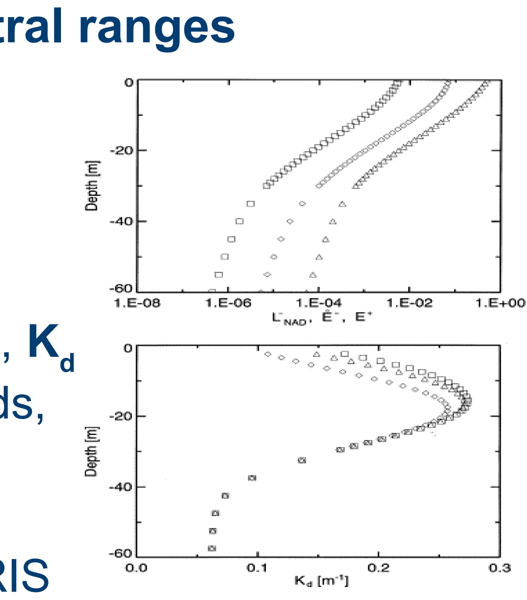

Figure 9: MOMO predictions of in-water light field (see Fell and Fischer, 2001)

References: Bissett et al., 1999. Carbon cycling in the upper waters of the Sargasso Sea: II. Numerical simulation of apparent and inherent optical properties, *Deep Sea Res.*, Part I, 46, 271–317

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Fell, F. and J. Fischer, 2001. Numerical simulation of the light field in the atmosphere-ocean system using the matrix-operator method. *Journal of Quantitative Spectroscopy & Radiative Transfer*, 69, 351-388

Schofield et al., 2004. Inversion of spectral absorption in the optically complex coastal waters of the Mid-Atlantic Bight, *Journal Geophysical Research*, 109, C12S04, doi:10.1029/2003JC002071

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