

# **Predicting Upwelling Radiance on the West Florida Shelf**

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## **LONG-TERM GOALS**

The prediction of inherent optical properties [IOPs] and water-leaving radiance [ $L_w$ ] in coastal waters over a 5 to 10 day time horizon will require a numerical simulation that accurately forecasts the physical, ecological, and optical environment. Critical to the ecological and optical forecast is the ability to directly compare the water-leaving radiance field to those being collected by aircraft and satellite platforms. Our goal is to develop the ecological and optical models and computer codes to initialize, validate, and predict the IOPs and  $L_w$  over an operational time horizon.

## **OBJECTIVES**

- 1) Couple EcoSim 2.0 to a robust radiative transfer model to yield water-leaving radiance for a given IOP distribution
- 2) Initialize and validate spectral water-leaving radiance with remote sensing data.
- 3) Couple EcoSim 2.0 to the WFS version of the Princeton Ocean Model [POM]

## **APPROACH**

The pace of development of prognostic ecological/optical data and modeling systems has greatly accelerated in recent years such that we can now reasonably discuss the likelihood of predicting red tides, and concomitant impacts on water clarity on the West Florida Shelf [WFS]. Accurate prediction of water clarity and color suggests a fundamental knowledge of marine ecological systems, and the validation of such data and modeling systems would provide characterization of the littoral environment over operational time horizons. Water clarity and color are directly dependent on the IOPs of the water column and the modeling component of these prognostic systems requires a fundamental set of equations that describe the interactions between the production and destruction of the IOPs. As the IOPs of absorption, scattering, and the scattering phase function can be described by a summation of the individual components, the cycle of color can be described by equations representing the individual active color constituents, i.e., phytoplankton, organic detritus, Colored Dissolved Organic Matter [CDOM], sediments, bathymetry, and bottom classification. The description of the cycling of each component allows for feedback effects between the in-water light field and the production and destruction of color.

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| 14. ABSTRACT<br><b>The prediction of inherent optical properties [IOPs] and water-leaving radiance [Lw] in coastal waters over a 5 to 10 day time horizon will require a numerical simulation that accurately forecasts the physical, ecological, and optical environment. Critical to the ecological and optical forecast is the ability to directly compare the water-leaving radiance field to those being collected by aircraft and satellite platforms. Our goal is to develop the ecological and optical models and computer codes to initialize, validate, and predict the IOPs and Lw over an operational time horizon.</b>                                                                                                                                                                                                                    |                                   |                                    |                                                           |                                                     |                                 |
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The marine optical environment may change at the same time scale of weather change, so any operational prognostic optical system would need to be embedded into a larger system of data collection and numerical modeling. Such a system would use moorings, ships, Autonomous Underwater Vehicles [AUVs], satellites, and physical/ecological/optical numerical models to provide integrated data streams to a wide community of users. The systems would need to be able to assimilate data as it became available, and provide forecasts over a wide range of time and space scales. The West Florida Shelf [WFS] is an ideal location to help develop these nowcast/forecast systems, in part due to a large number of other research programs focused on the WFS, including other ONR funded technology programs, NOAA/EPA ECOlogy of Harmful Algal Blooms [ECOHAB] program, and the State of Florida Coastal Ocean Monitoring and Prediction System [COMPS] program. The ECOHAB and COMPS programs are focused on time scales ranging from months to years and spatial scales ranging from kilometers to 1000s of kilometers. Therefore, this site provides a natural location to develop broad scale time and space models of the inherent optical properties.

The WFS is unique in other ways that make it ideal for the development of forecasting systems. In particular, the variance in color and clarity of the near-shore waters is extreme, ranging from oligotrophic Case 1-type waters to highly attenuating Case 2 waters (Bissett et al., 1997; Carder and Steward, 1985; Carder et al., 1989). The low-nutrient and low-colored waters of the WFS are derived from the oligotrophic waters of the central Gulf of Mexico and the waters of the Caribbean Sea via the Loop Current. These waters have typical open ocean color signals. In the deeper waters off the shelf, the variations in surface color are driven by seasonal nutrients and CDOM introductions via deep mixing, as well as eddy fluxes, much like the classic understanding of Case 1 ocean color. As one moves across the shelf break onto the outer shelf, complications to the classic blue ocean signal arise from both Loop Current intrusions that bring higher nutrient waters (and CDOM) into the euphotic zone and river CDOM fluxes from the Mississippi, Mobile, and Apalachicola Rivers. In the inner shelf, the color signal becomes even more complicated as the introduction of waters from Suwannee, Hillsborough, Peace, and Caloosahatchee Rivers mix with the above water masses, as well as with those waters created locally from high energy mixing (waves, long-shore currents, etc.) and heat flux imbalances.

The ecological/optical conditions on the WFS are as complicated as any coastal region, yielding situations where the chlorophyll a biomass may range from 0.01 to  $>20 \mu\text{g liter}^{-1}$  at the same location during different time periods. When oligotrophic waters dominant the shelf, bottom features are clearly evident in high-resolution hyperspectral data to a depth of 30 meters. At other times, river and estuary waters dominate, and the bottom is undistinguishable in waters  $<2$  meters deep. In between these two conditions, the color signal is mainly a function of the ecological interactions between phytoplankton growth and loss and CDOM creation and destruction. Within the inner shelf the color signal is further modified by the bottom classification and sediment re-suspension. Our goal on the WFS is to derive and validate a set of fundamental ecological/optical/physical equations that addresses, and eventually predicts, the complexity of the IOPs and the resultant water-leaving radiance. This site is an ideal location for the regional time and space scales being studied.

## **WORK COMPLETED**

In conjunction with another ONR funded effort (N00014-01-1-0201) we have created a rapid, computationally efficient version of Hydrolight 4.1 that is optimized for ingesting the IOP output of

EcoSim 2.0. EcoSim 2.0 uses a single scattering approximation for description of the downwelling light field that is reasonable downwelling irradiance,  $E_d$ , but does not contain a solution for the upwelling irradiance or radiance field. Such calculations require a more robust solution of the radiative transfer equation, RTE. The Hydrolight radiative transfer numerical model (Mobley, 1994) gives an exact solution of the in-water radiative transfer equation given the water inherent optical properties (IOPs, namely the absorption and scattering properties of the water body), the incident sky radiance, and the bottom depth and reflectance (bottom BRDF). In addition, the use of this model as the basis for predicting upwelling radiance facilitates our comparisons with other experimental groups' predictions of upwelling radiance from in situ data.

The quadrature discretization technique as described by (Mobley, 1994) is maintained at 20 theta (polar) quads and 24 phi (azimuthal) quads, yielding a 10 degree angular resolution in the polar and a 15 degree resolution in the azimuth. However, we are only interested in the solution for the upwelling radiance field. The full quadrature discretization is unnecessary for a solution solely through the polar cap. Once across the air-sea interface the need to solve for the quadrature discretization is reduced and the gain in computational efficiency comes from only solving the invariant imbedding solution to the RTE for the first mode of the Fourier polynomial analysis (see N00014-01-1-0201 for a more complete description). Additional efficiencies were gained by pre-solving the BRDF across the domain of the model, and using a look-up-table approach for bottom reflectance.

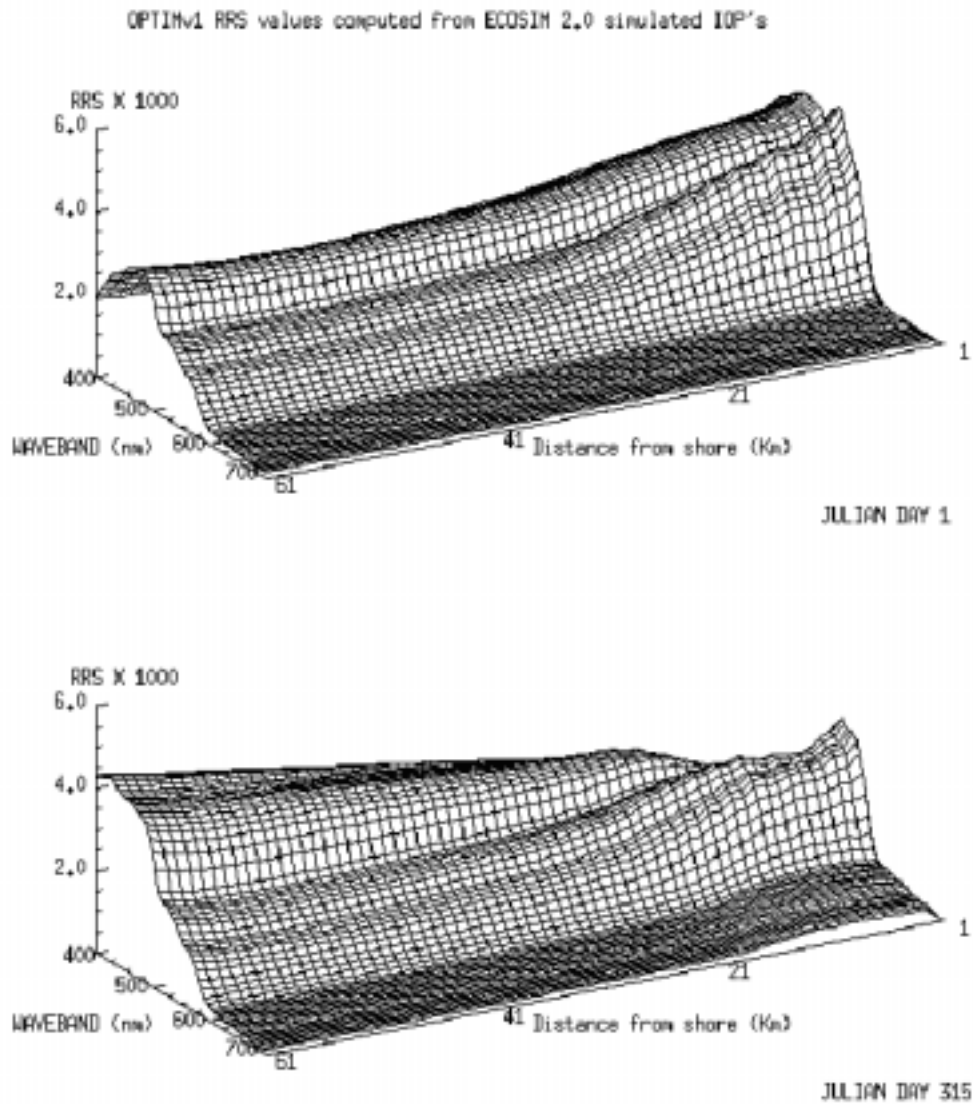
## RESULTS

Simulated IOPs outputs were generated from a 2-dimensional solution of EcoSim 2.0 on the WFS (see N00014-98-1-0844) for the year 1998. These IOPs were output every 3 days and yield over 7000 one-dimensional depth-dependent profiles of absorption and scattering. The OPTIMv1 solution was solved for at local 10:30 am each simulated day, using RATRAN to derive the input solar irradiance field. These runs are at a spectral resolution of 60 wavebands between 400 and 700 nm ( $\Delta\lambda=5$  nm), yielding over 420,000 simulated  $R_{rs}$  values. Figure 1 shows the spectral  $R_{rs}$  plots as a function of wavelength and transect position across the shelf for day-of-year 1 and 315. On day 1 there is very little absorption and scattering from optical constituents in the water, and the rise in spectral  $R_{rs}$  results mainly from bottom reflectance. However on day 315 there is a large population of phytoplankton in the surface waters resulting from an estuarine outflow following Hurricane Mitch. This population was dominated by dinoflagellates, some of which were the toxic *Karenia brevis*.

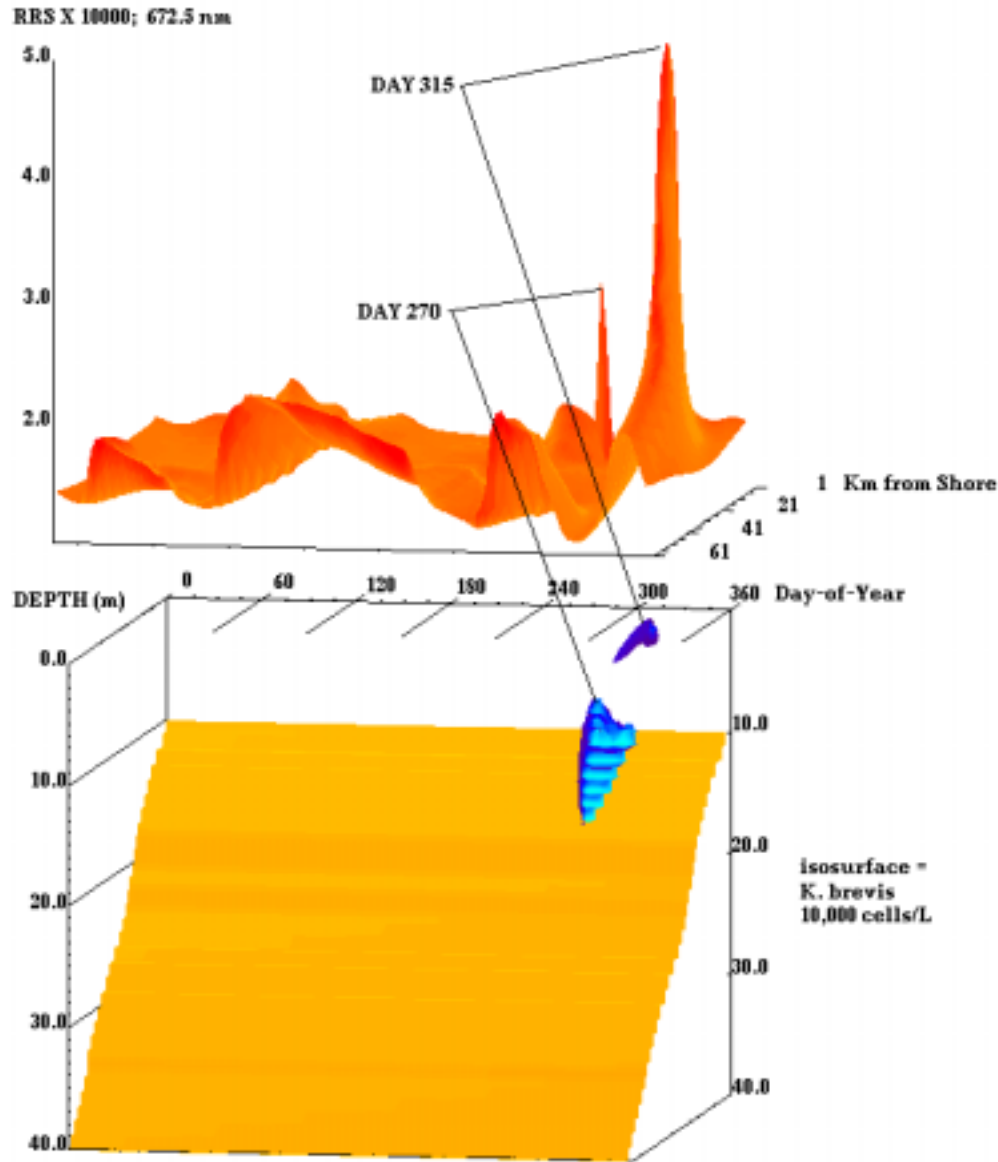
The population effects on the upwelling radiance field at 672.5 nm can be seen in Figure 2. In addition, the figure also shows an earlier subsurface population of *K. brevis*. For a similar concentration in cells, the surface population has a much greater impact on the  $R_{rs}$  than the subsurface population on day 270. These plots demonstrate the impact of depth-dependent optical constituents on the water leaving radiance signal, and the need to resolve depth-dependence for nowcast/forecast solutions.

## IMPACT/APPLICATIONS

Forecasting IOPs over operational time horizons of 5 to 10 days will require the ability to directly compare predictions of water-leaving radiance to the data most likely to be used for initialization and validation of the predictions, i.e., aircraft and satellite hyperspectral remote sensing data. This effort will yield a simulation ready to begin direct data assimilation of the water column optical properties to predict absorption and scattering over short-term time horizons.



**Figure 1. Predicted Remote Sensing Reflectance ( $R_{rs}$ ) as a function of wavelength and distance offshore from EcoSim 2.0 simulation of the WFS in 1998. Upper panel is from the day-of-year 1. Lower panel is from day- of- year 315. There is a large surface bloom of phytoplankton on day 315 near the shore resulting from estuarine outflows following Hurricane Mitch in 1998.**



**Figure 2. Simulated depth-dependent populations of *K. brevis* during 1998 (lower panel) and their impacts on *Rrs* at 672.5 nm (upper panel). The surface population has a much greater impact on *Rrs* on day 315 than the subsurface population on day 270.**

## RELATED PROJECTS

This is an ambitious effort and will be accomplished with the collaboration of Dr. J. J. Walsh at the University of South Florida [USF]. Our responsibilities focus on the first two objectives, while Dr. Walsh is focused on the development of the transport code to be coupled with the hydrographic forecasting (in collaboration with Dr. R. Weisberg, USF). We are collaborating with Dr. C. Mobley of Sequoia Scientific, Inc for the coupling of EcoSim with Hydrolight, and Drs. R. Arnone, NRL, and K. Carder, USF, for satellite data analysis, and Drs. C. Davis and J. Bowles, NRL, for hyperspectral aircraft data collection and analysis.

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