A High-Resolution 3D Hypoxia Model for the Louisiana Shelf

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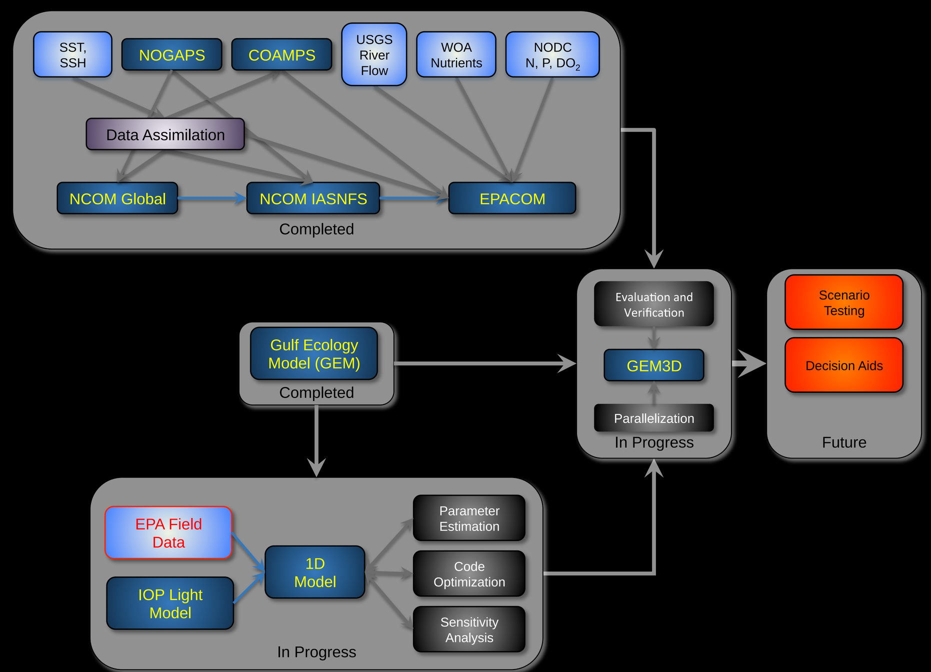
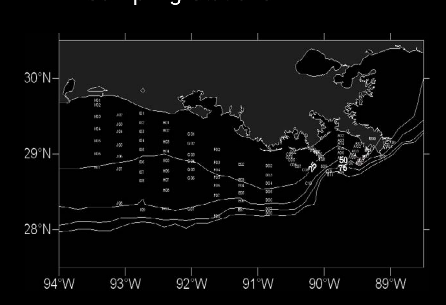
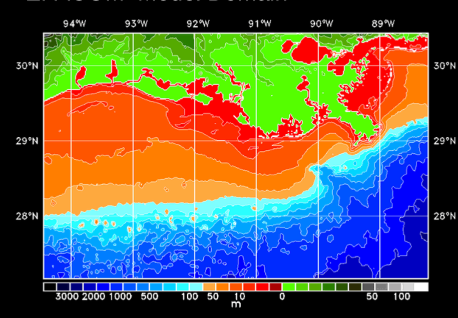
NRL - EPA Hypoxia Model System



EPA Sampling Stations



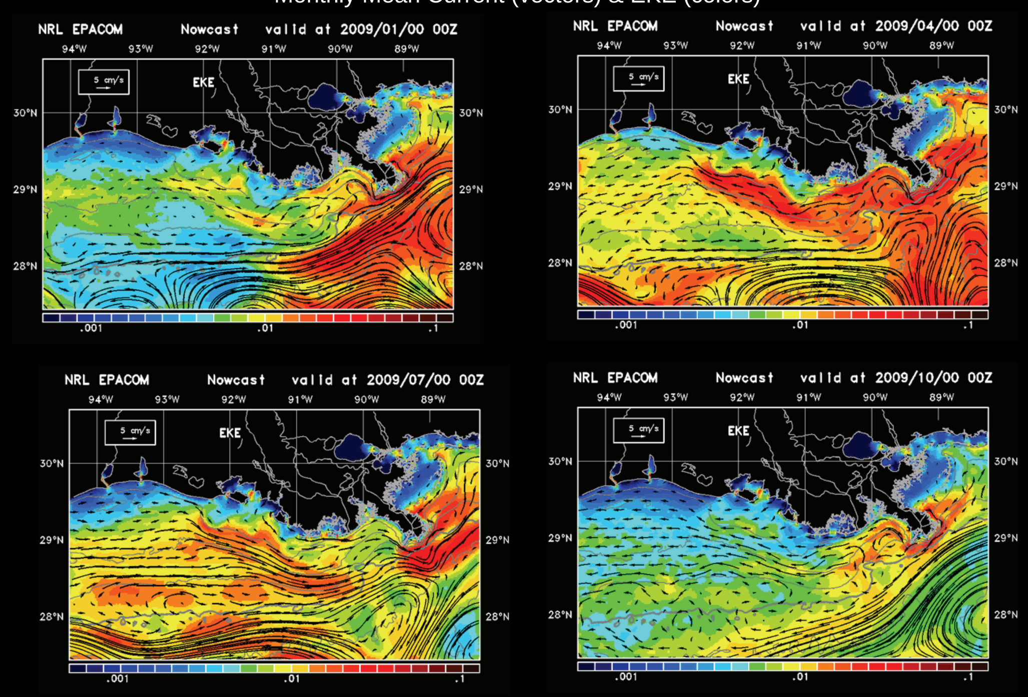
EPACOM Model Domain



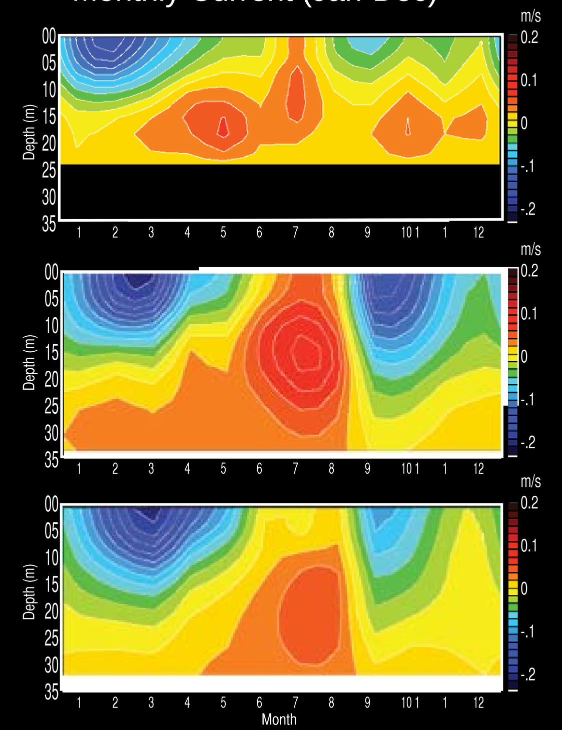
EPACOM – A fine resolution (~2km) fully 3D circulation model

EPACOM Simulation - Flow Pattern

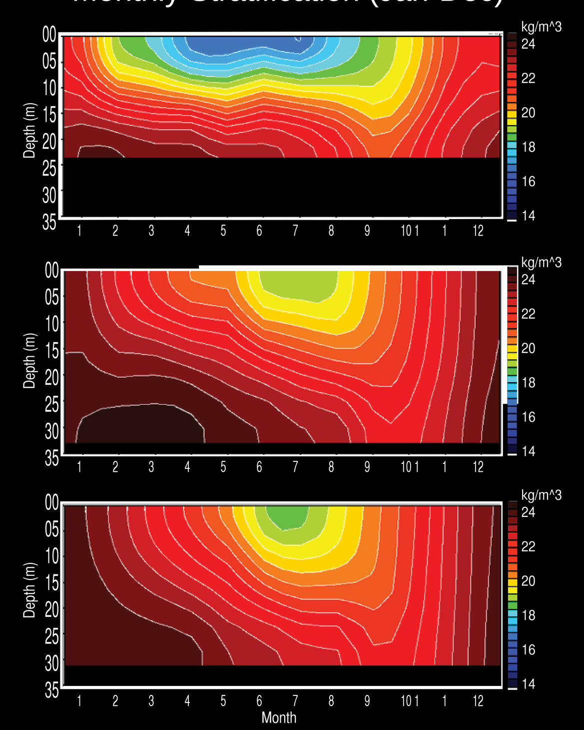
Monthly Mean Current (vectors) & EKE (colors)



Monthly Current (Jan-Dec)

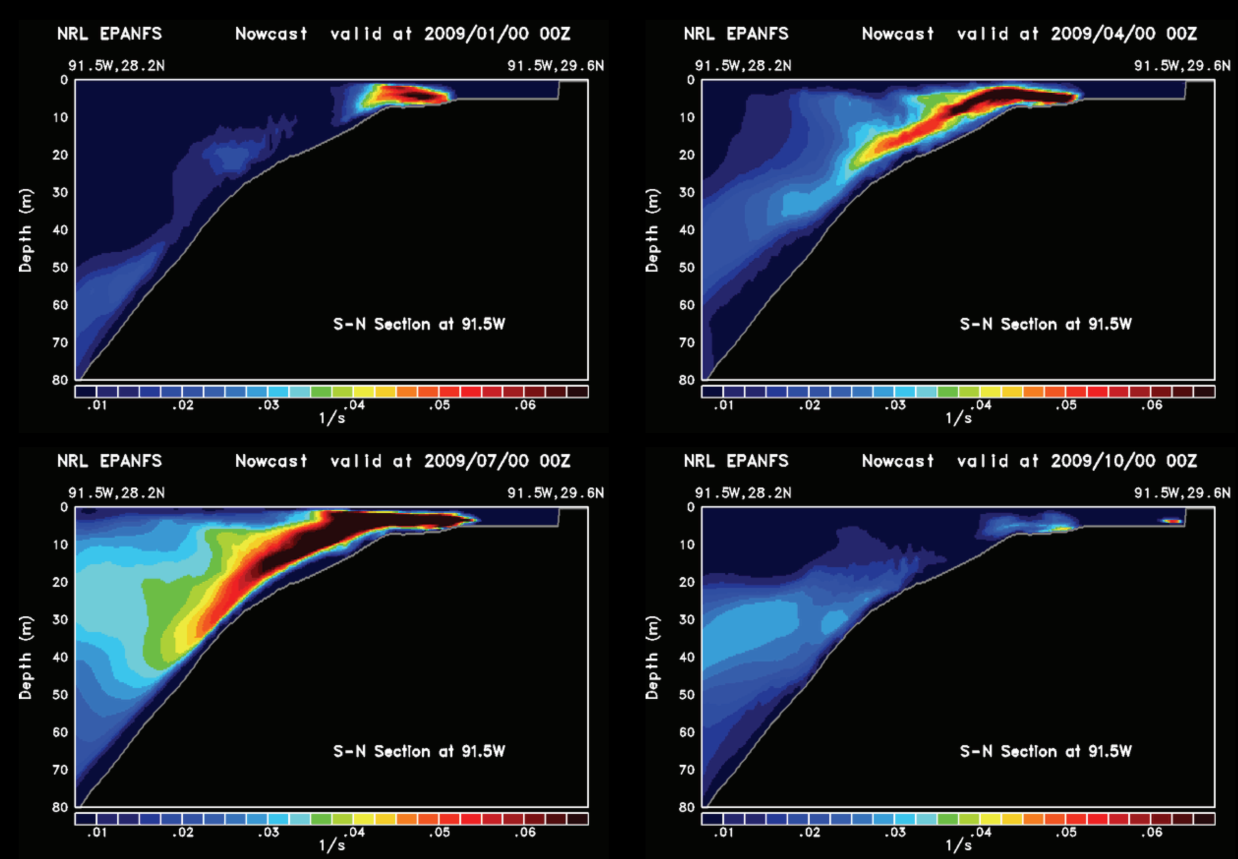


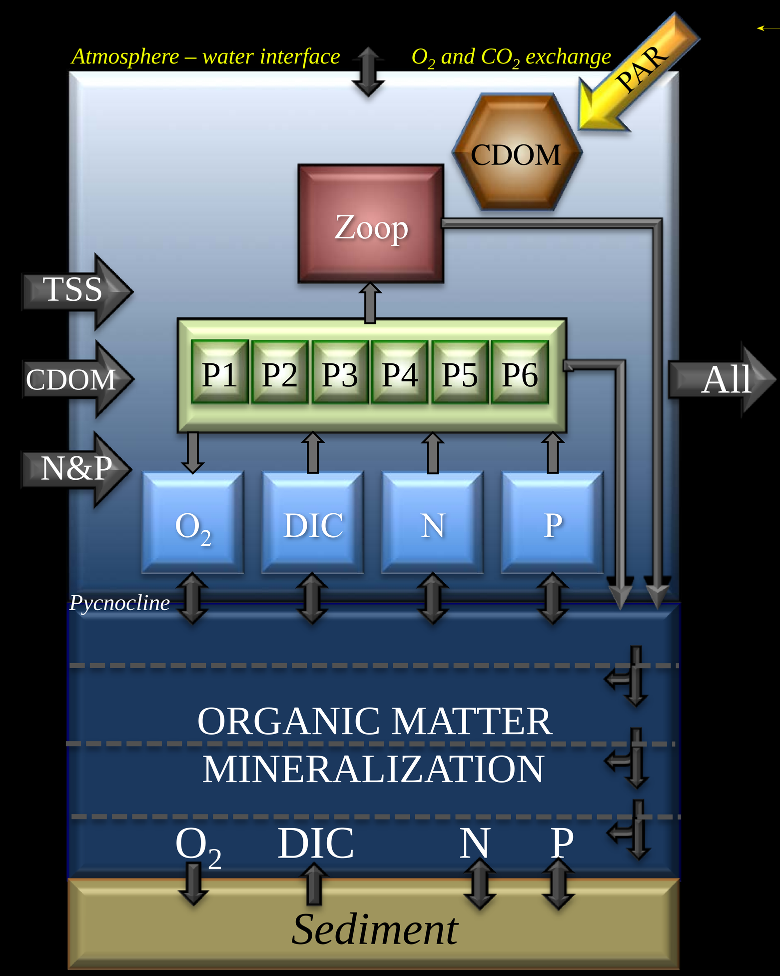
Monthly Stratification (Jan-Dec)



EPACOM Simulation - Stratification

Seasonal Stratification On the Louisiana Shelf
(Brunt-Vaisala / Buoyancy Frequency)

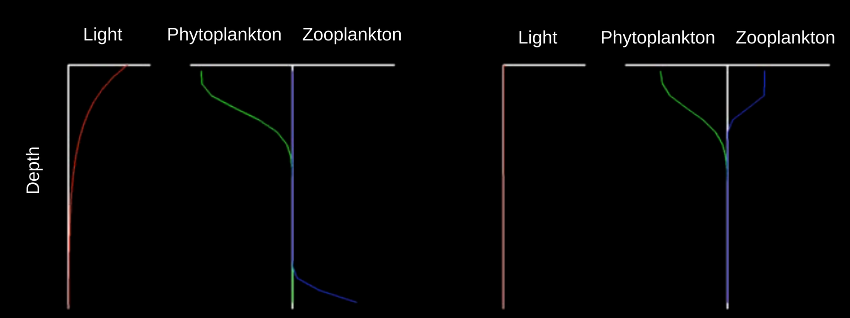




EPA-GEM3D Simulation of Plankton Dynamics

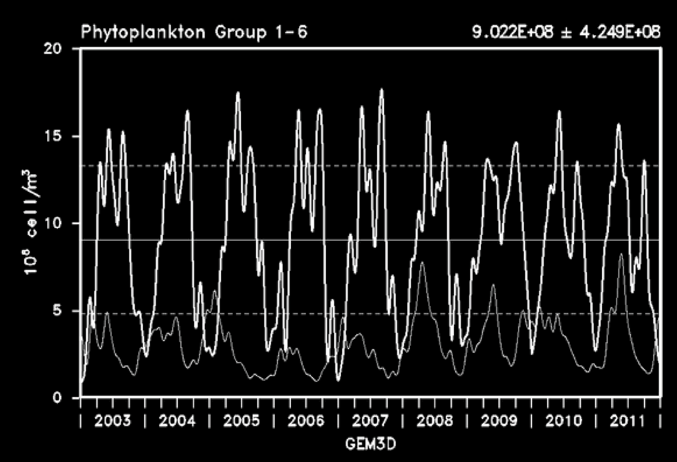
Vertical Variation due to Migration, Growth, Death and 3D Advection

Daytime Night-time

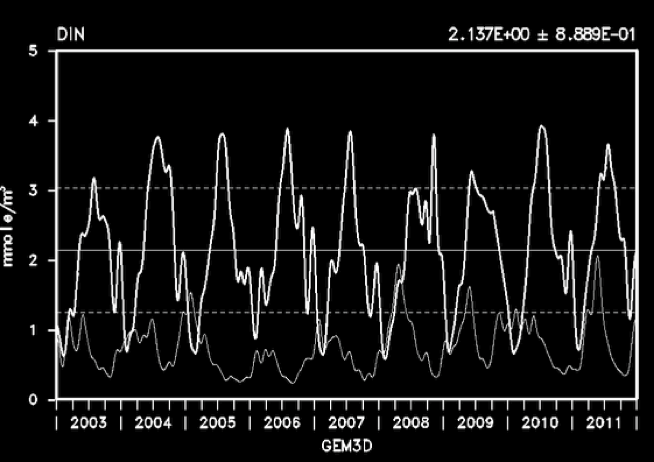


EPA-GEM3D Simulation

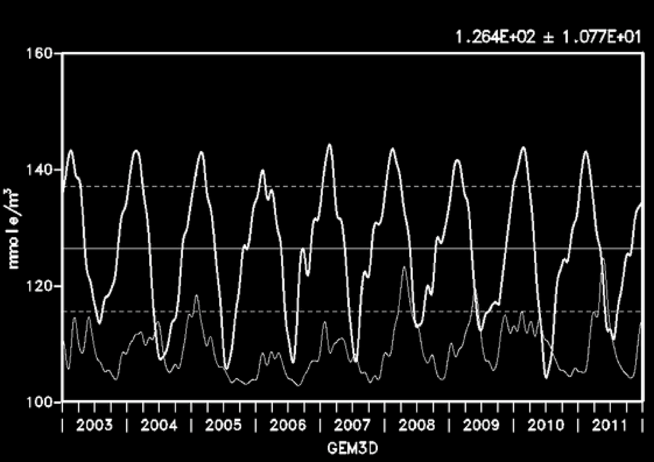
Phytoplankton



Dissolved Inorganic Nitrogen

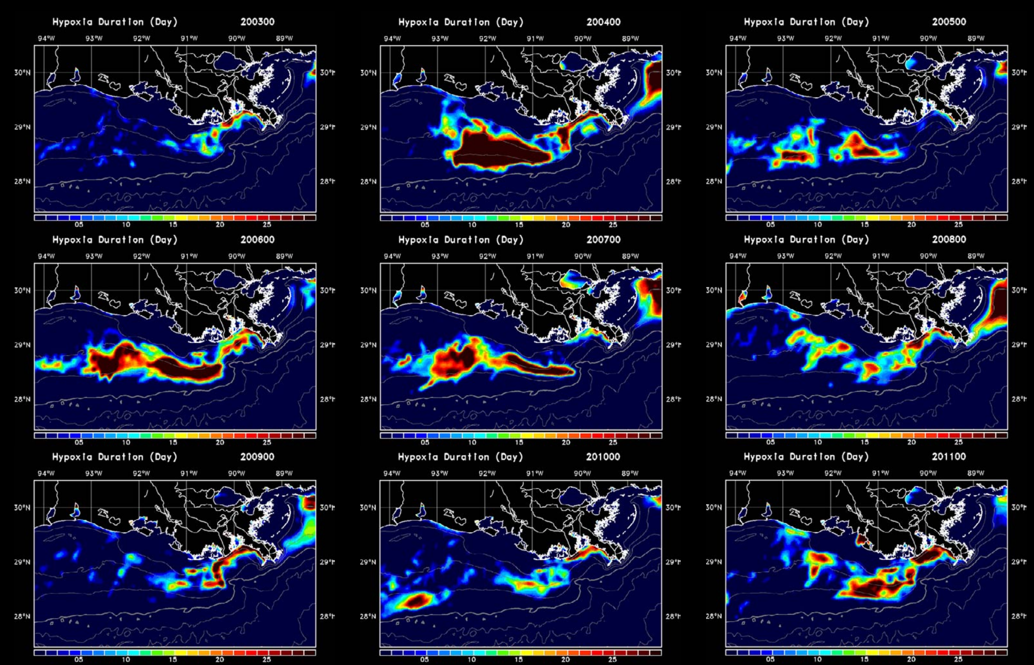


Dissolved Oxygen



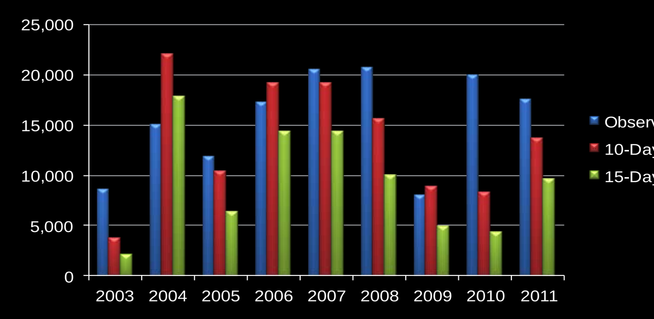
EPA-GEM3D Simulation - Area of Bottom Water Hypoxia

Each Season from 2003 to 2008



EPA-GEM3D Simulation - Area of Bottom Water Hypoxia

Each Season from 2003 to 2011

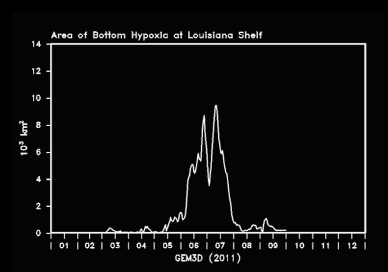


Year	Square Kilometers	Square Miles
1998	12,480	4,811
1999	20,000	7,710
2000	4,400	1,696
2001	20,720	7,988
2002	22,000	8,481
2003	8,560	3,300
2004	15,040	5,798
2005	11,840	4,564
2006	17,280	6,662
2007	20,500	7,903
2008	20,720	7,988
2009	8,000	3,084
2010	20,000	7,722

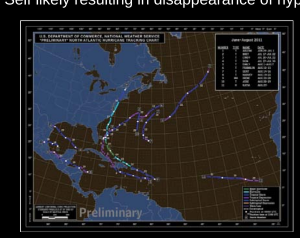
- Comparison of observations to the model predicted area of bottom water hypoxia that is persistent over 10 days or over 15 days for the season.
- This observed area of bottom water hypoxia is an estimation based on ship surveys. The estimation for 2011 is 17,548 km² (LUMCON).
- For 2010, the hypoxic zone is in a part located on the Texas shelf - an area out of our model domain.

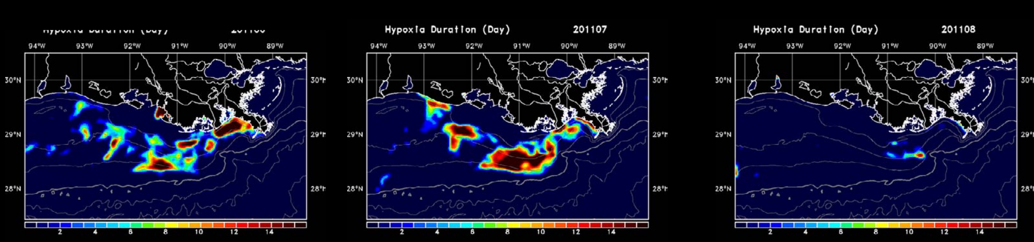
EPA-GEM3D Simulation - Area of Bottom Water Hypoxia

Prediction for 2011



- At end of July, Tropic Storm Don passed through the LaTex Self likely resulting in disappearance of hypoxia





LUMCON found that hypoxia covered an estimated 6,765 sq. mi (17,548 km²) of the Gulf this year (2011)

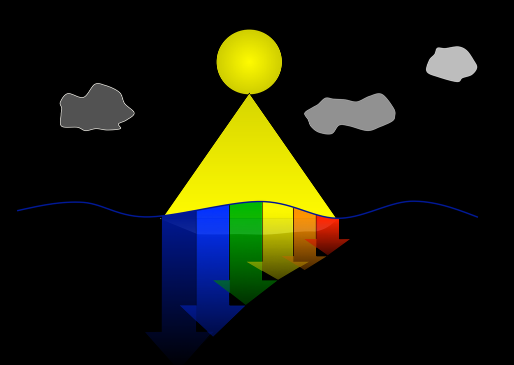
"Standard" Light Model

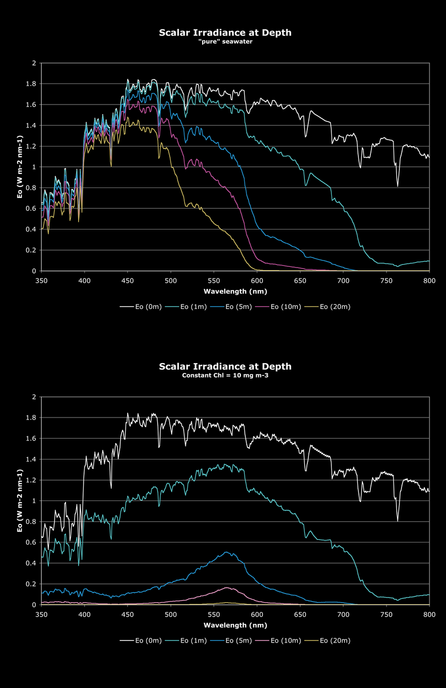
$$\mathrm{PAR}(z) = \mathrm{PAR}(0^-)e^{-k(z)} \quad \boxed{\text{non-spectral}}$$

where:

$$k(z) = k_w \cdot z + k_p \int_0^z \mathrm{chl}(z)\,dz$$

K_w and k_p are constants





IOP Light Model (Lee *et al*., 2005; Penta *et al*., 2008)

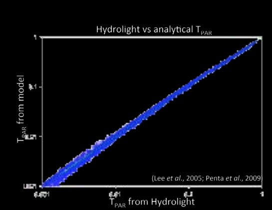
(a) $$\mathrm{PAR}(z) = \mathrm{PAR}(0^-)e^{-k_{par}(z)z}$$

(b) $$k_{PAR}(z) = k_1\left(a \,\&\, b_b 490\right) + \frac{k_2(a \,\&\, b_b 490)}{(1+z)^{0.5}} \quad \boxed{\text{pseudo-spectral}}$$

(c) $$k_1 = \left(\chi_0 + \chi_1 (a_{490})^{0.5} + \chi_2 b_{b_{490}}\right)\left(1 + \alpha_0 \sin(\theta_a)\right)$$
$$k_2 = \left(\zeta_0 + \zeta_1 (a_{490}) + \zeta_2 b_{b_{490}}\right)\left(\alpha_1 + \alpha_2 \cos(\theta_a)\right)$$

(d) $$a_{490}(z) = \left[a^*_{490} \frac{\sum_0^z chl(z)}{z}\right] + a_{w_{490}} + a_{CDM_{490}} + a_{?_{490}}$$

(e) $$b_{b_{490}}(z) = 0.015\left\{0.3\left[\left(\frac{\sum_0^z chl(z)}{z}\right)^{0.62} \frac{550}{490}\right]\right\} + b_{b_{w490}} + b_{b_{NAP490}} + b_{b_{CDM490}} + b_{b_{?490}}$$



Parameter	Value
χ_0	-0.057
χ_1	0.482
χ_2	4.221
ζ_0	0.183
ζ_1	0.702
ζ_2	-2.567
α_0	0.090
α_1	1.465
α_2	-0.667

Derived from Hydrolight™ modeling

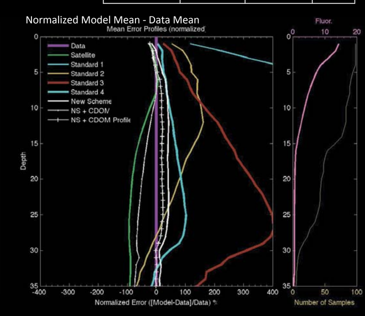
PAR ≡ integrated downwelling solar radiation 350-700nm
a_{w490} = 0.015 (Pope and Fry, 1997)
a^*_{490} = 0.0375 (chlorophyll specific absorption coefficient at 490nm; Prieur and Sathyendranath, 1981)
{also can (should) be computed from local data}
b_{b490} (backscattering at 490nm) is computed from this phytoplankton absorption (Gordon and Morel, 1983)
θ_a ≡ solar zenith angle
$\theta_a = \pi/2$ for overcast sky
? ≡ any absorbing or backscattering component prescribed by the research questions (or data)

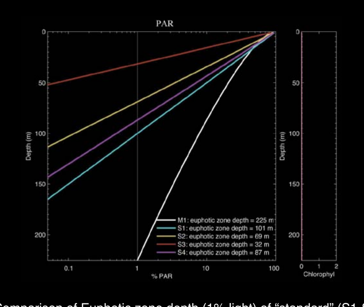
Total Absorption (a), total backscattering (b_b) and/or individual components (a_{cdm}, b_{bcdm}, a_{det}, b_{bdet}, etc.) can be modeled, from literature, or data (*in situ* and/or remote sensing)

Results of Validation

	k_w	k_p	
Standard 1	0.067	0.0095	Newberger, et al., 2003
Standard 2	0.146	0.024	Olivieri and Chavez, 2000
Standard 3	0.046	0.048	Chai et al., 2002
Standard 4	0.053	0.064	Fujii et al., 2007

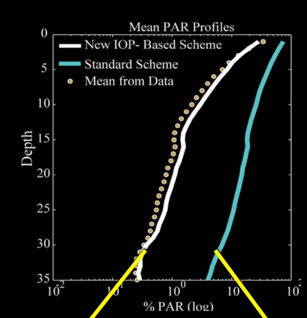
	RMSE (%)	Correlation Coefficient
Standard 1	1521	0.8945
Standard 2	99	0.9859
Standard 3	261	0.9888
Standard 4	63	0.9969
Satellite	69	0.9896
New Scheme 1	32	0.9907
New Scheme 2	47	0.9938
New Scheme 3	16	0.9949



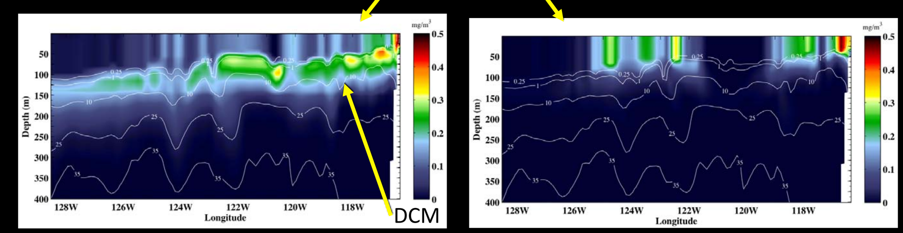


Comparison of Euphotic zone depth (1% light) of "standard" (S1-S4) and IOP light model (1) for an idealized water column with no chlorophyll

Mean of 98 PAR profiles (dots) from *in situ* measurements in Monterey Bay, CA. vs simulated profiles from the "standard" light attenuation scheme and the new IOP-based scheme.

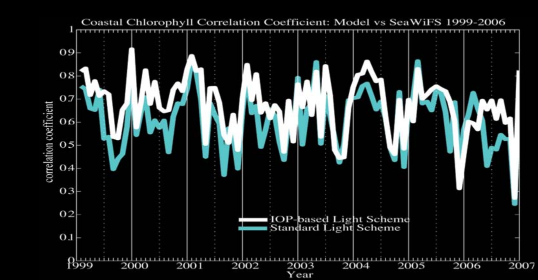


In the upper water column the "standard" scheme overestimates PAR. In contrast, at greater depths (> the data profiles shown) the "standard scheme underestimates PAR.



Total chlorophyll comparison between NCOM-CCS (California Current System) model with the new IOP based underwater light scheme (left) and the "standard" scheme (right). The new scheme is able to simulate the deep chlorophyll maximum (DCM) which occurs at the nutricline (contour lines represent nitrate concentration [NO_3]).

Impact of the new scheme within NCOM-CCS at the sea surface:
Correlation between NCOM-CCS; with the IOP-based light scheme (black) and the "standard" scheme (red); and SeaWiFS Chlorophyll within 100 km of the U.S. West coast (1999-2007).



Application to EPA Gulf of Mexico Data Set

Interpolate all variables to 0.5 m depth bins

Extrapolate to surface

Convert EstTSS to NAP i.e. remove contribution from phytoplankton
- Convert mg chl l^{-1} to mass
  - mg to g
  - chl to C (100)
  - gC to moles C (12 g $mole^{-1}$)
  - Redfield ratios to get moles N, Si, P, O, and H
    - C:Si:N:P = 106:15:16:1 (Brzezinski, 1985)
    - C:O = 1
    - 2H per O
  - Convert C, N, Si, P, O, and H back to grams (12, 14, 28, 31, 16, 1)
  - Sum elements
  - Convert to mg and subtract from EstTSS to get NAP

CDOM a function of salinity
- Spectral slopes from D'Sa and DiMarco (2009) (Mar, May, Jun, Aug) interpolate to other months
- Use pvcnoDepth (measured) to partition surface and bottom layers
- Convert from absorption at 412nm (D'Sa) to 488nm for light model

For all optical components calculate averages from surface to each binDepth
- assume all chlorophyll is from diatoms

Calculate optical (absorption and backscatter at 488nm) profiles

Apply light model of Penta et al. (2008)
- Calculate PAR attenuation as a percent of the incident surface PAR

Model comparison with CPAR from data set ("Z" stations)

Green Dots are the Data
Dotted lines on small plots (upper right portion of frame) are the averages (from surface to each depth)
Upper-left PAR plot – x-axis is log10 of %PAR
Lower-left PAR plot – x-axis is linear
Also calculated:
- PAR attenuated without CDOM or NAP contribution (dotted blue line)
- PAR attenuation due to water alone (gray line)
- PAR assuming cloud cover (use 45º sun angle; thin blue line)