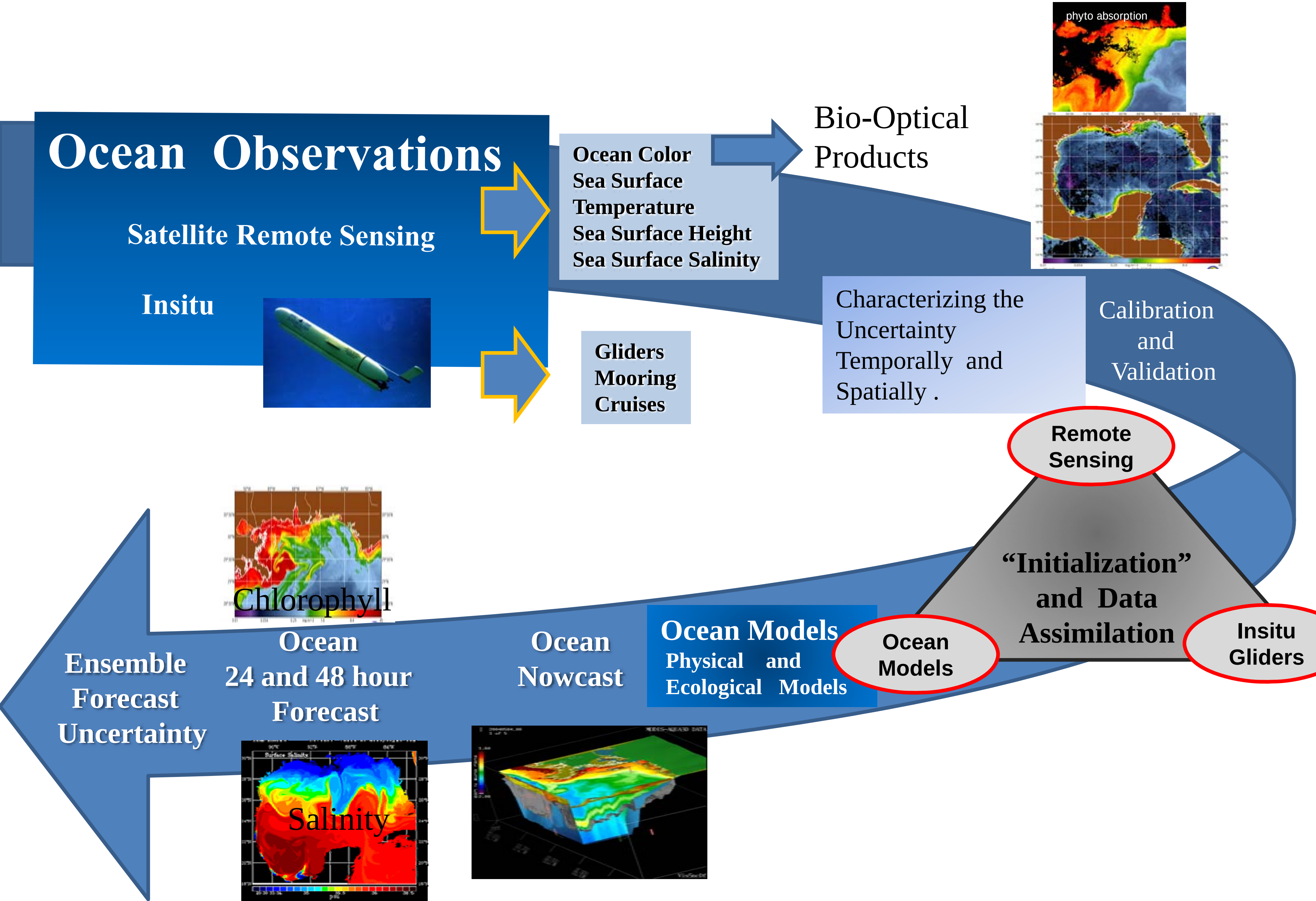
"Towards Optics-Based Measurements in Ocean Observatories"

"Ocean Observatories Contributions to Ocean Models and Data Assimilation For Ecosystems"

Ocean Optics 2012
Glasgow Scotland
Robert Arnone - Oct 2012

Charactering the Marine Ecosystem



Characterizing the Ocean Optical Environment

	Limitations	Advantage
• **Remote Sensors – Ocean color Sensors** – MODIS, SeaWIFS, Hyperion, HICO, NPP/JPSS – UAV- – Ocean optics, Biological – Laser penetration - New opportunity	• Surface only • Clouds • Inter satellite Consistency	Wide Coverage Global coverage
• **Insitu Sensors –** (Gliders, Mooring floats, Ships) – Fluorescence, (chlorophyll), backscattering, – Nutrients,	•Point Measurement •Data access • Weather	Most Accurate Multiple Samples
• **Ocean models** – Physical Models – Statistical 3d satellite optics – Biological, Sediment, Ecological	•Not constrained •Validation • Assimilation methods	Wide Coverage Nowcast /Forecast

Data quality of insitu and satellite products

Requires characterizing the spatial and temporal "uncertainty"

- **Model assimilation requires data which includes the ocean "variability"**
  - **similarly to validate satellites products.**

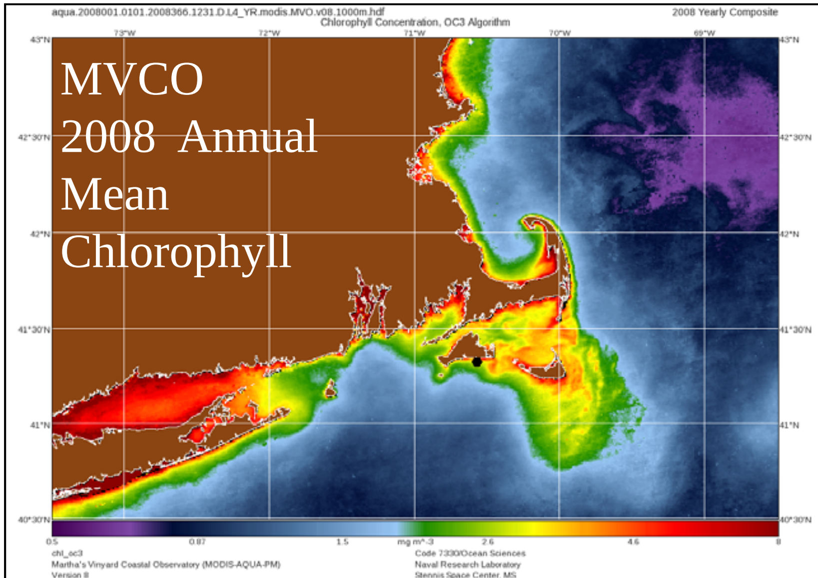
- **Representativeness Error - the environment**
- **Measurement (Sensor) Error**
- **Model physics and model biology error**

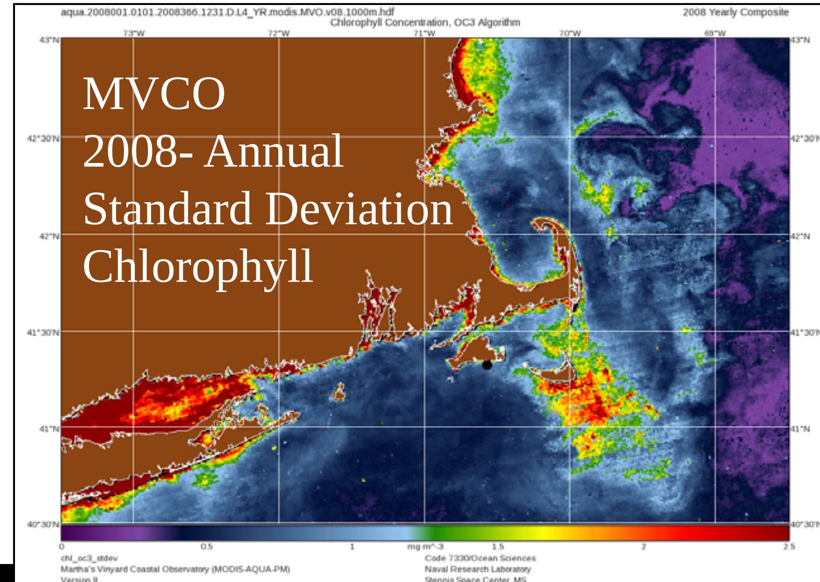
→ **Data Assimilation Tools**

- **Use the spatial mean and spatial variability to identify uncertainty.**
- **How can we define the uncertainty of an observation?**
- **Uncertainty based the spatial mean and variance for different ocean regions and seasons?**

Examples of Satellite Bio-Optical – but can expend to insitu observations!

Example of Spatial and Temporal uncertainty



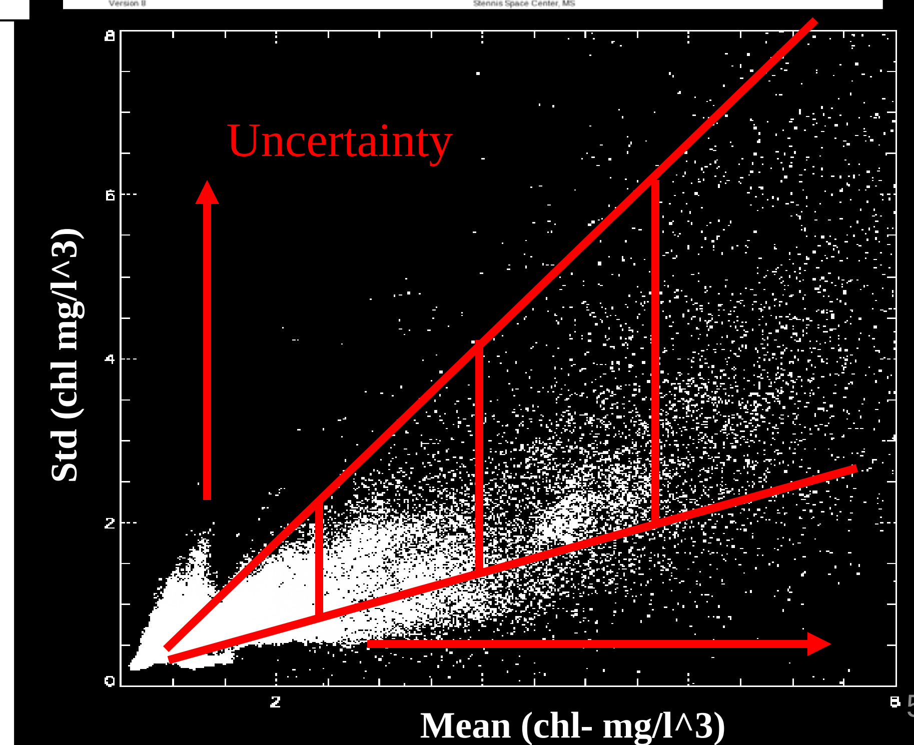


There is a relationship of the
Mean to variance at 1km
For the entire region

i.e. as increase the magnitude the
“uncertainty’ increases.

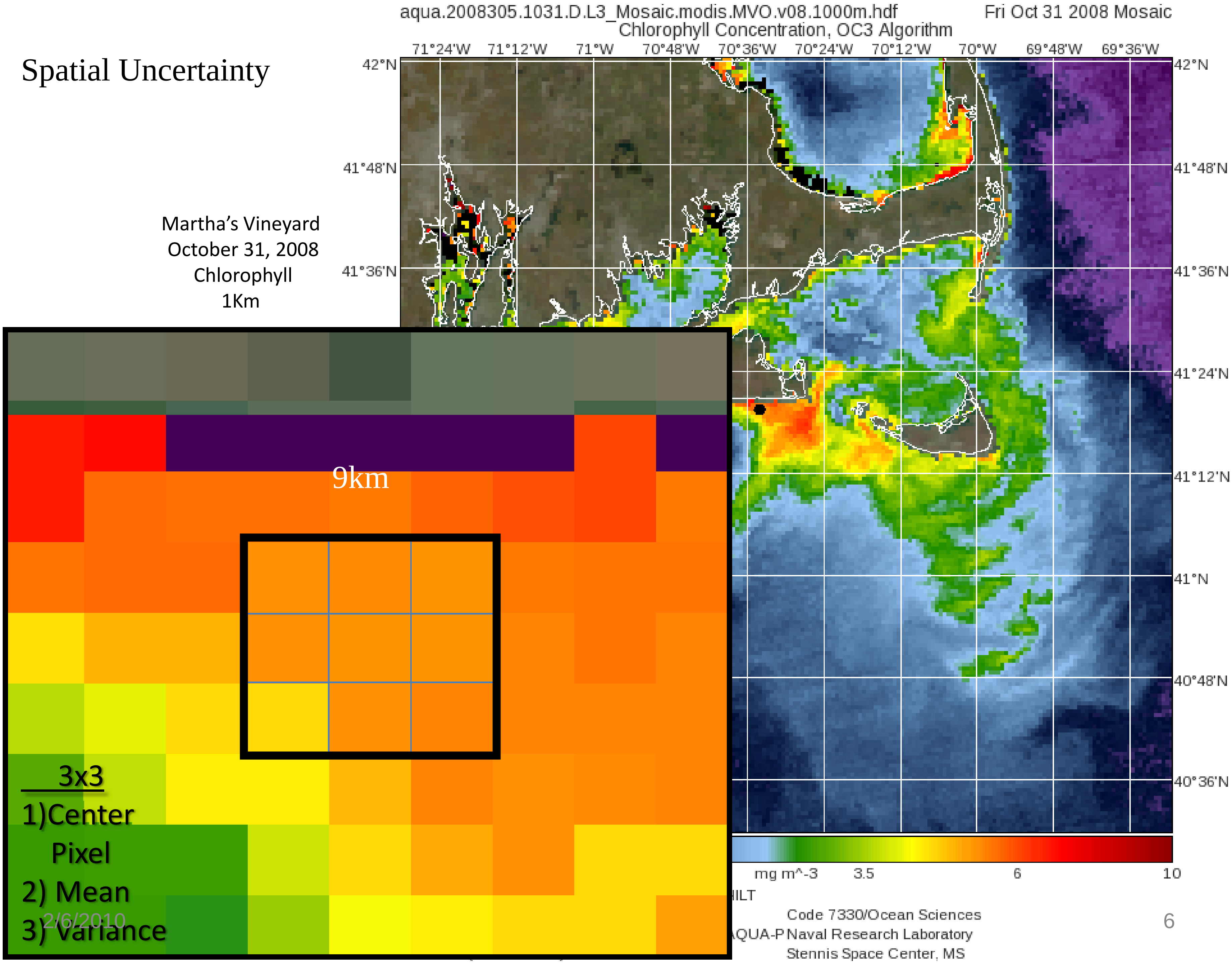
“Temporal Uncertainty.”

This is at 1km, what occurs at
different spatial resolutions?



Spatial Uncertainty

Martha's Vineyard
October 31, 2008
Chlorophyll
1Km



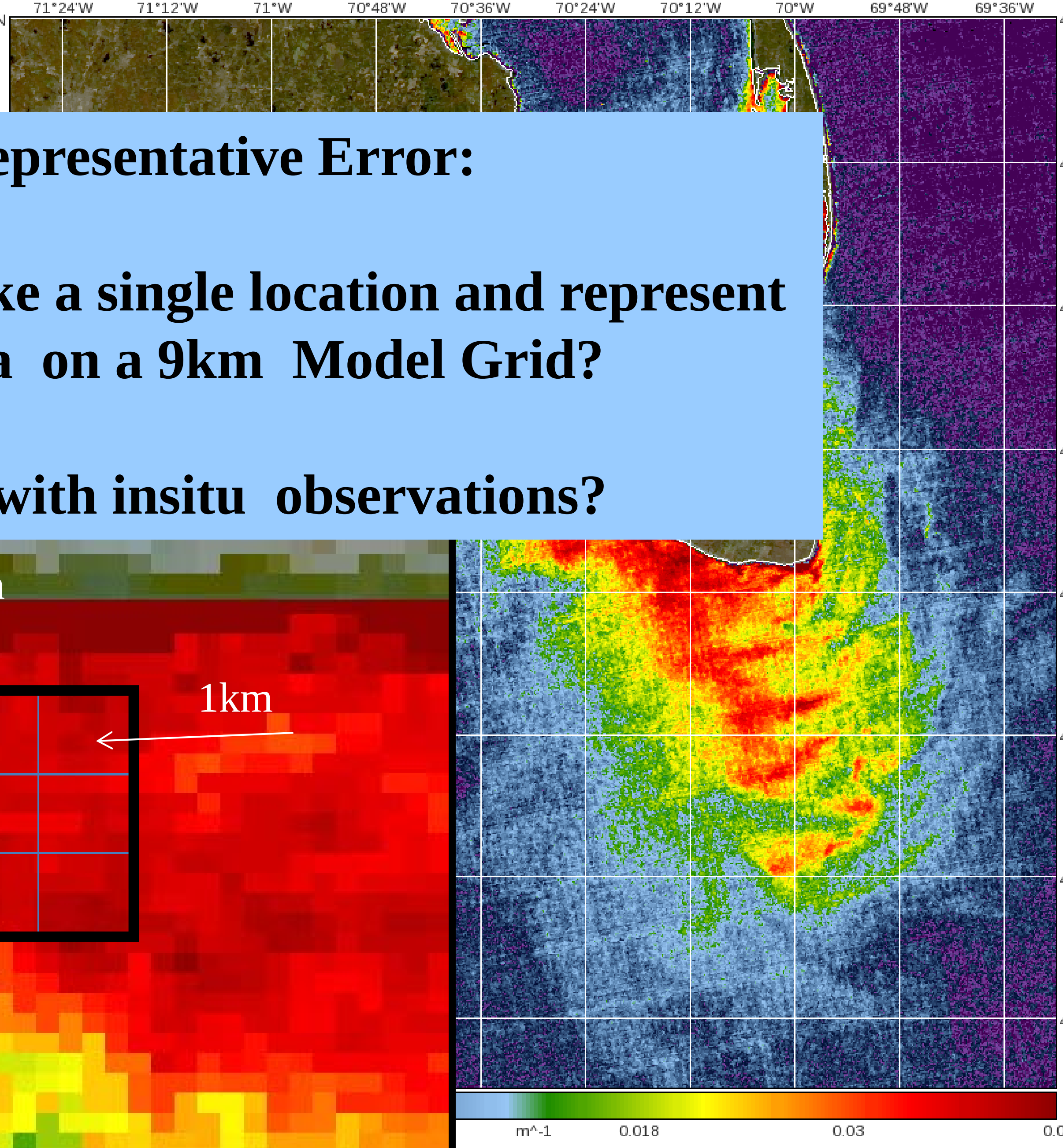
3x3
1) Center Pixel
2) Mean
3) Variance

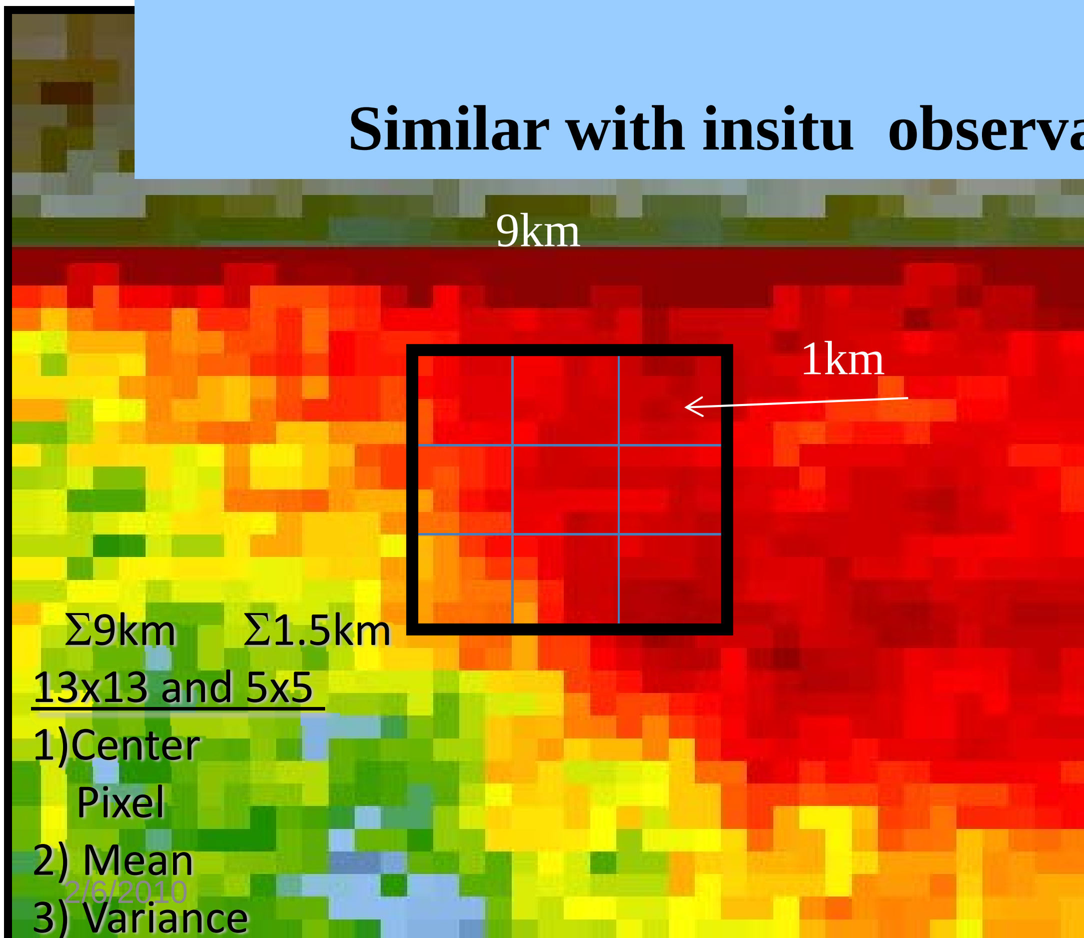
Spatial – Uncertainty

Representative Error:

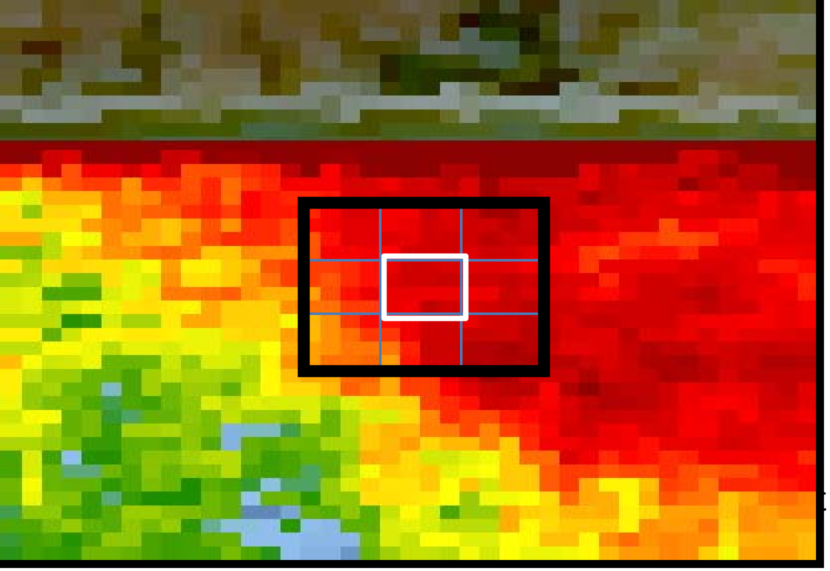
How do you take a single location and represent the data on a 9km Model Grid?

Similar with insitu observations?



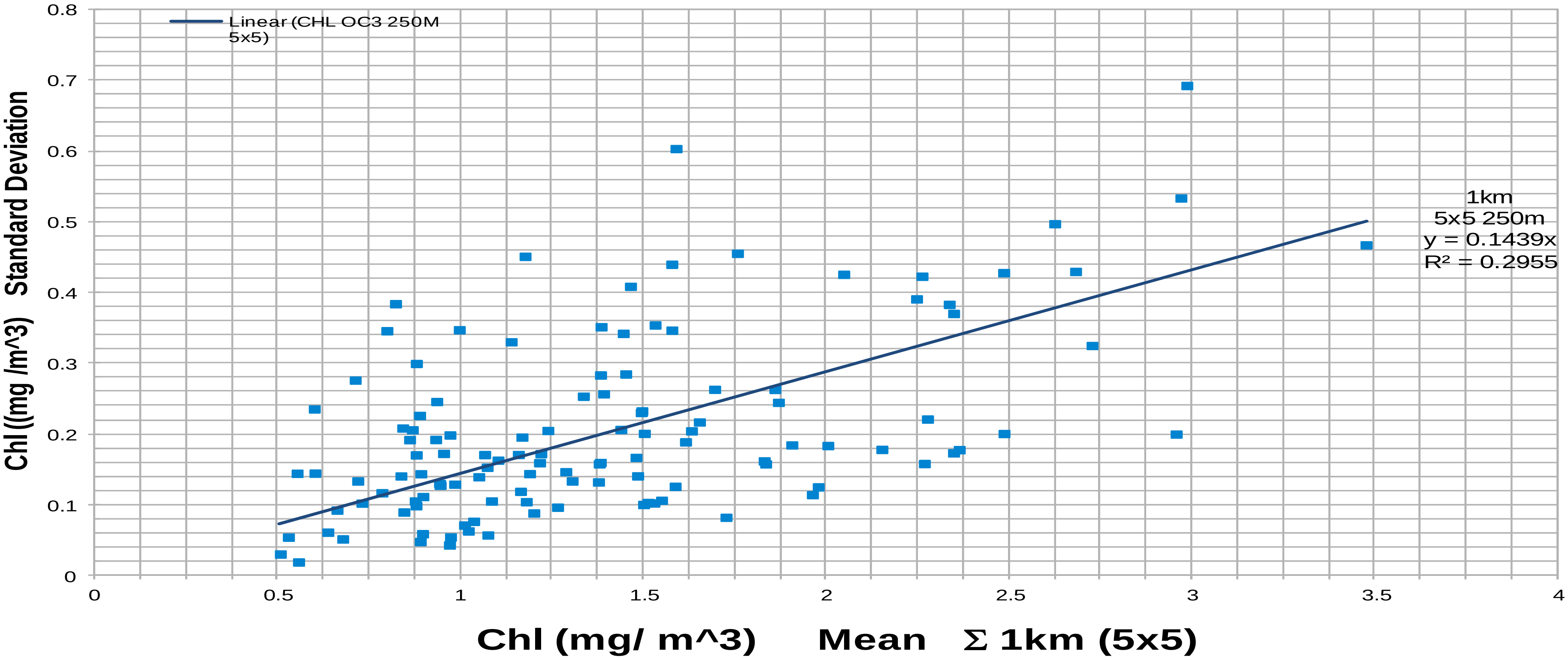


Martha's Vineyard – 2008



How does the variance change within 1km?
Can we define the uncertainty of the 1km?

Σ 1km (mean 5x5) vs the standard deviation (250)



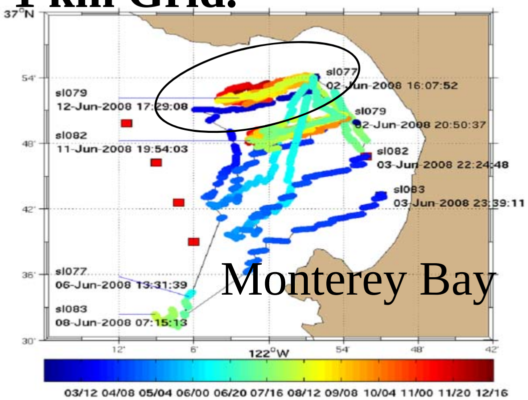
Representative errors associated with Glider profiles

- Along track vertical sections have internal tides / waves
- in addition to the spatial and temporal uncertainty .

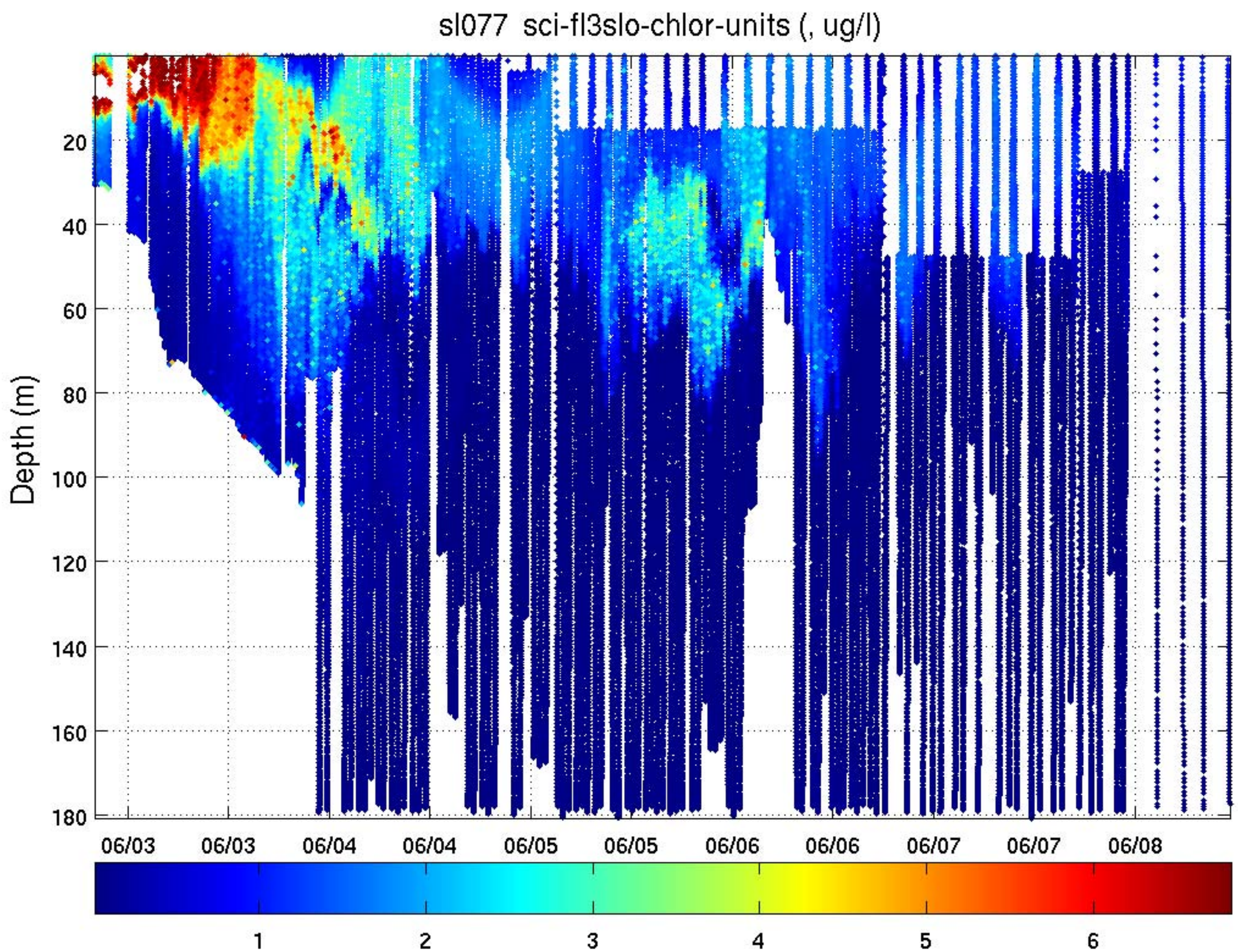
Physical and Bio-optical Coupling

Variability of the Mixed Layer Depth and stratification

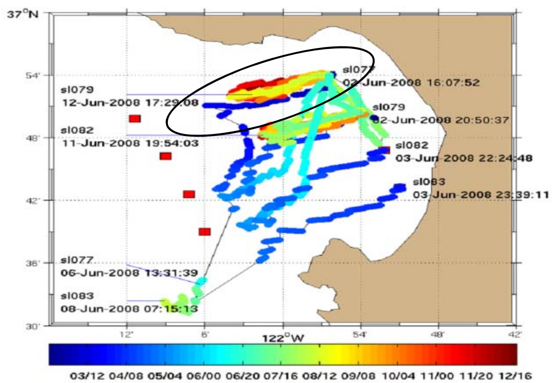
Impact on the Biological response.
Represent into the 1 km Grid.

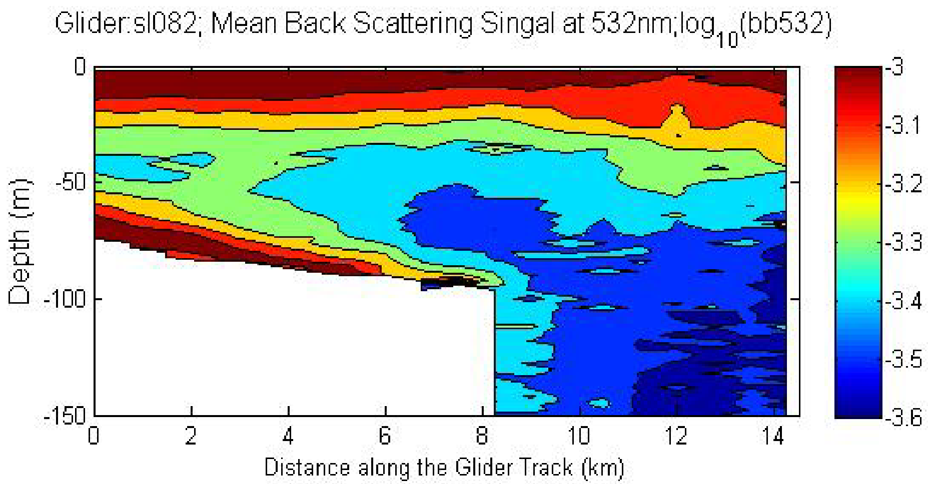


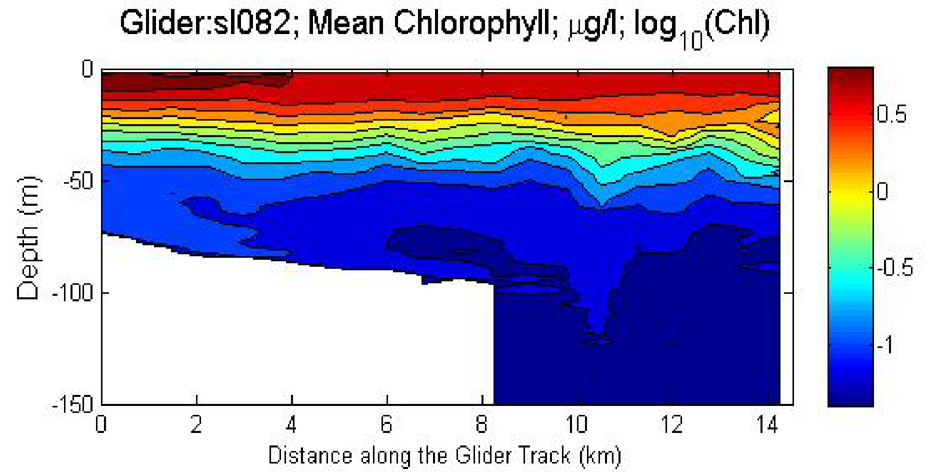
HemanthaWijesekera,

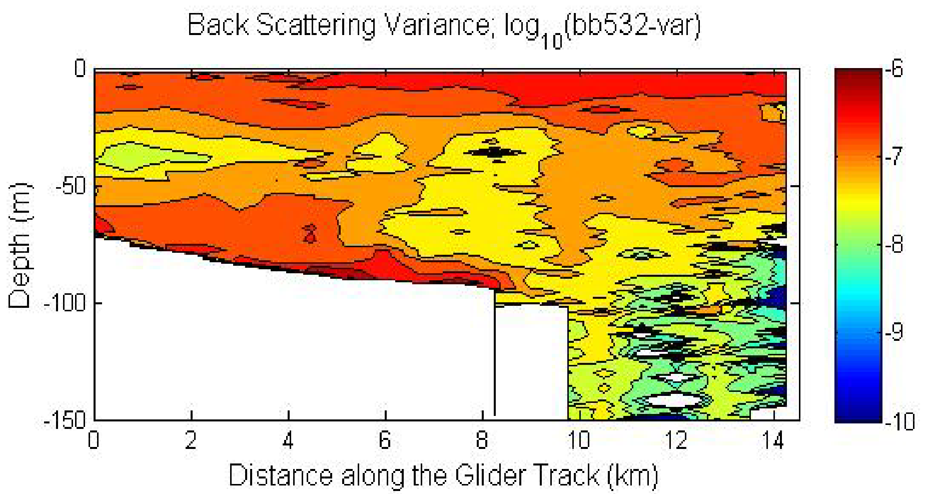


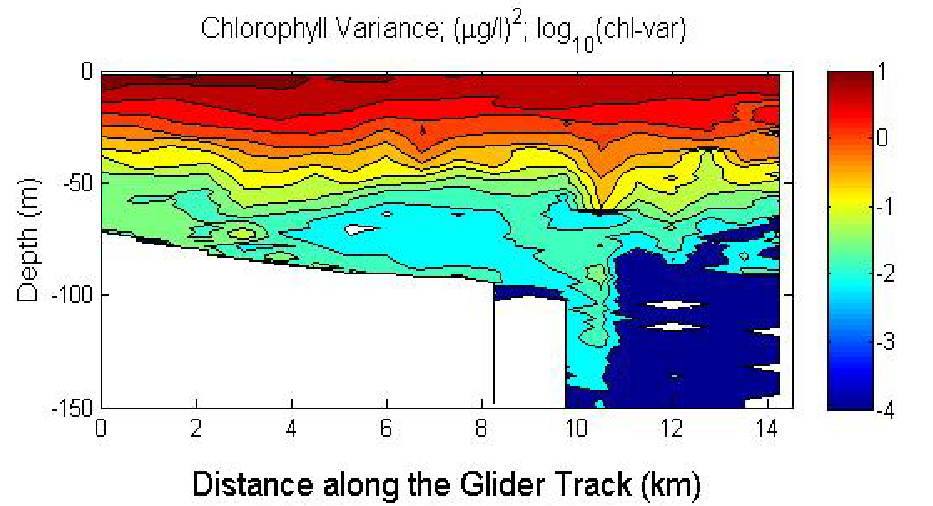
Cruise-mean Glider (sl082) Data: Averaged of 14 Glider sections
Sensor – Differences can be large ! Impacts data QC.











HemanthaWijesekera,

Ocean Models :

ROMS – Regional Ocean Model
NCOM - Navy Coupled Ocean Model
HYCOM - Hybrid Coordinate Ocean Model
Delth 3d

Physical Models :

- **Advanced ocean circulation models**

  Data assimilation --

  Sea Surface Temperatures
  Sea Surface height → Altimeter → Synthetic BT profiles
  Glider, TS profiles

  - **NCODA - Navy Coupled Ocean data Assimilation**
  - **Adjoints – Optimal interpolation**
  - **Tangent Linear**

Biological and Bio-optical Models

- ***Imbedded into Circulation Models***
- ***Data assimilation not as mature and more complex***
- ***Results from the model complexity and data uncertainty ..***
- ***Importance of the Correct Initialization field !!***
- ***Importance of Boundary Conditions - bathymetry, runoff, offshore waters***
- ***Heat Flux – Short wave radiance and***
- ***Importance of the Physics*** **Get the physics correct!!**

  Bio-optical models results respond to subtle physical changes !!

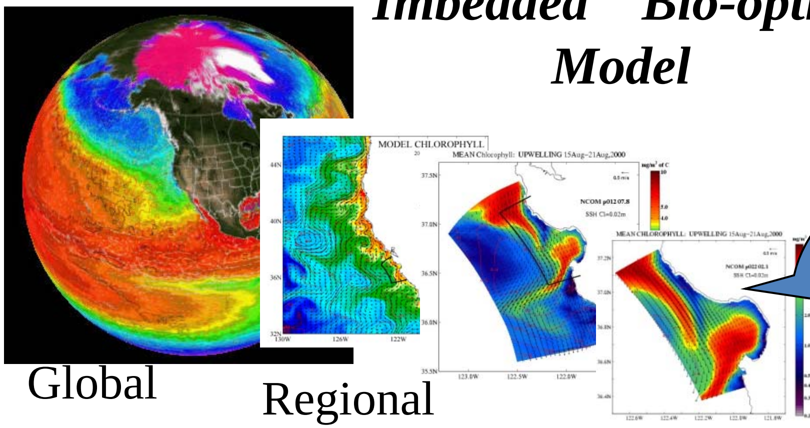
1. Biological model (NPZ) → and infer the optics (i.e. hydrolight) → (COSINE)
2. Inherent Optical Properties model → based on radiance and particle
3. Statistical optimization approach (optical- physical processes) → (Example)

Physical Model

Nested models

Boundary Conditions

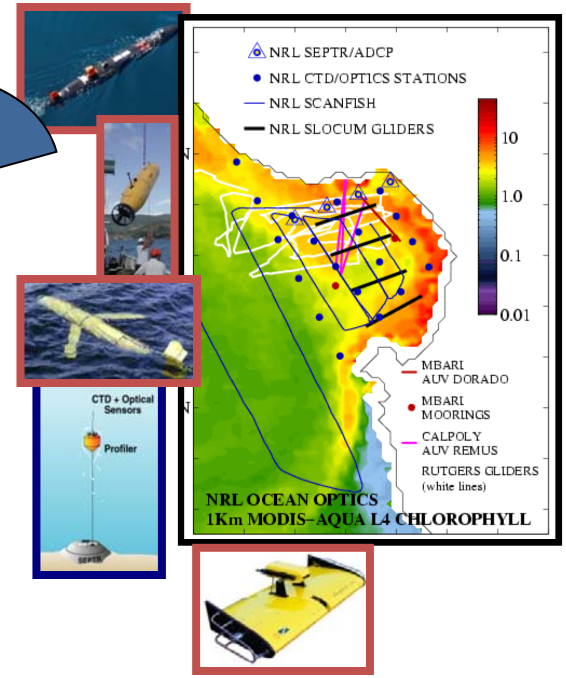
Imbedded Bio-optical Model



Global Regional Coastal models

Bio-optical, physical , data assimilative, nested models

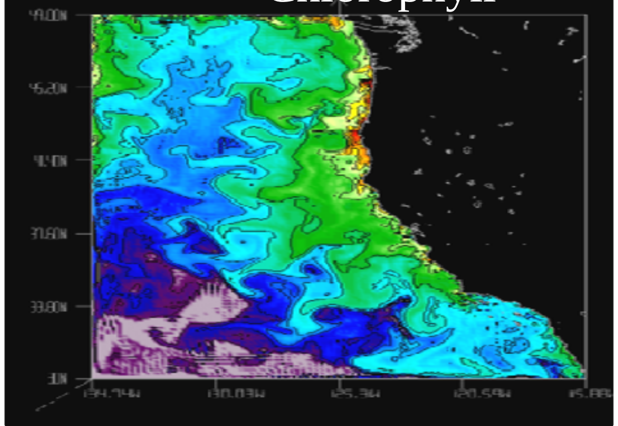
…merged with in-situ and remotely sensed observations



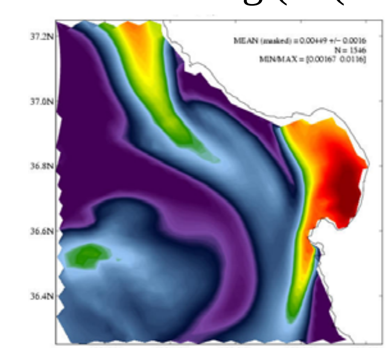
California Current System

…into predictions of coupled bio-optical physical properties

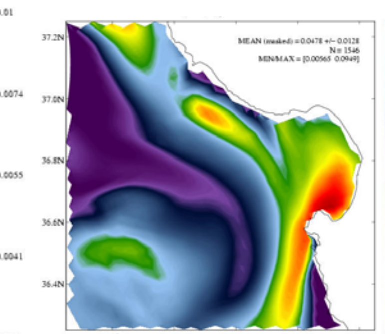
Chlorophyll



Backscattering (bb(488))

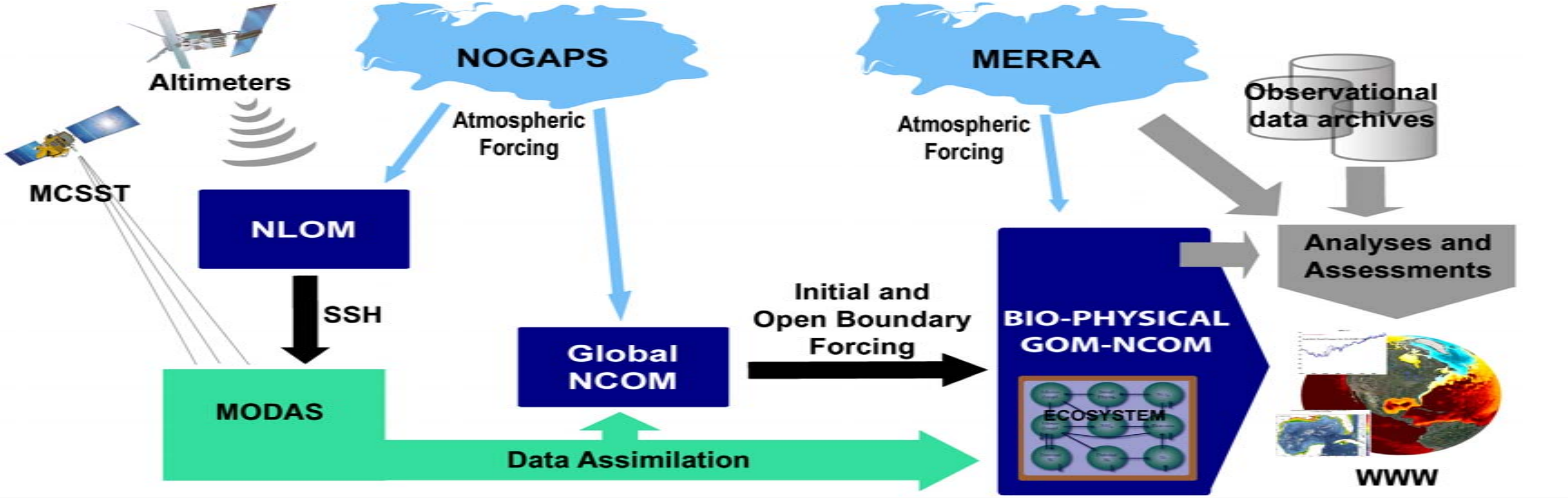


Absorption (a(440))

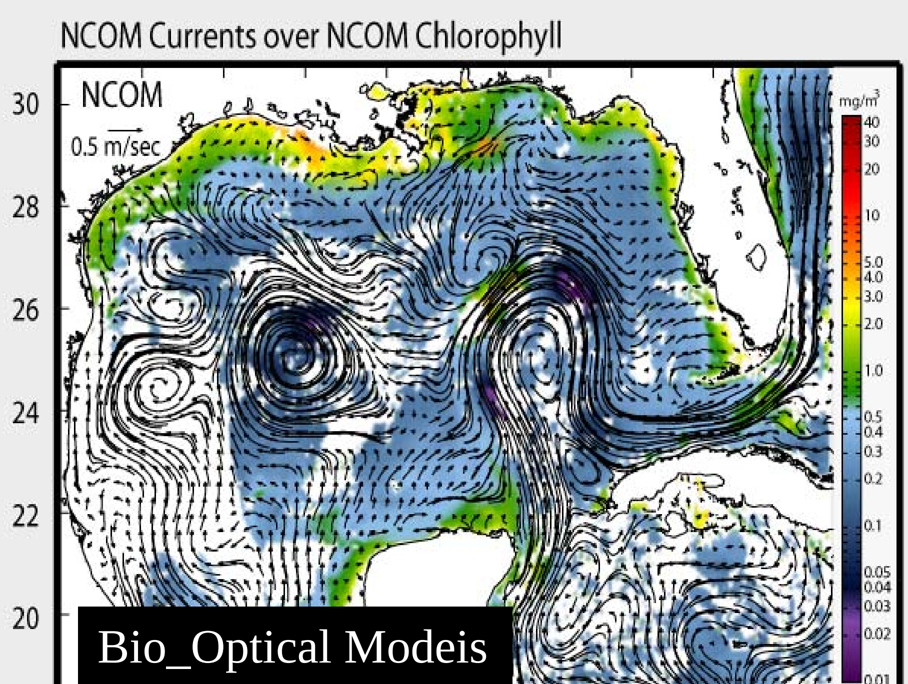


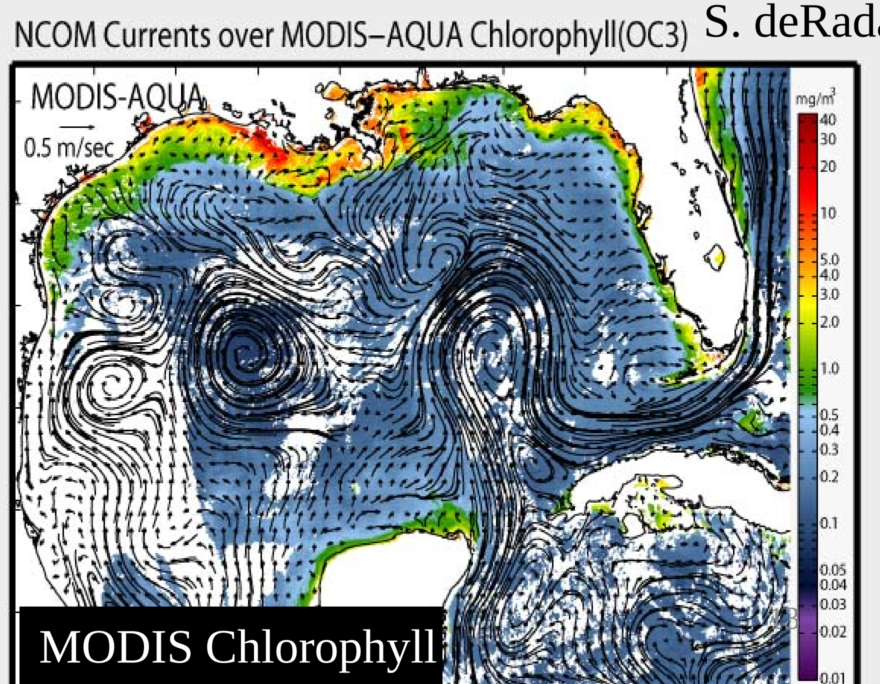
Igor Shulman et al

Gulf of Mexico Ocean BIO-OPTICAL Model



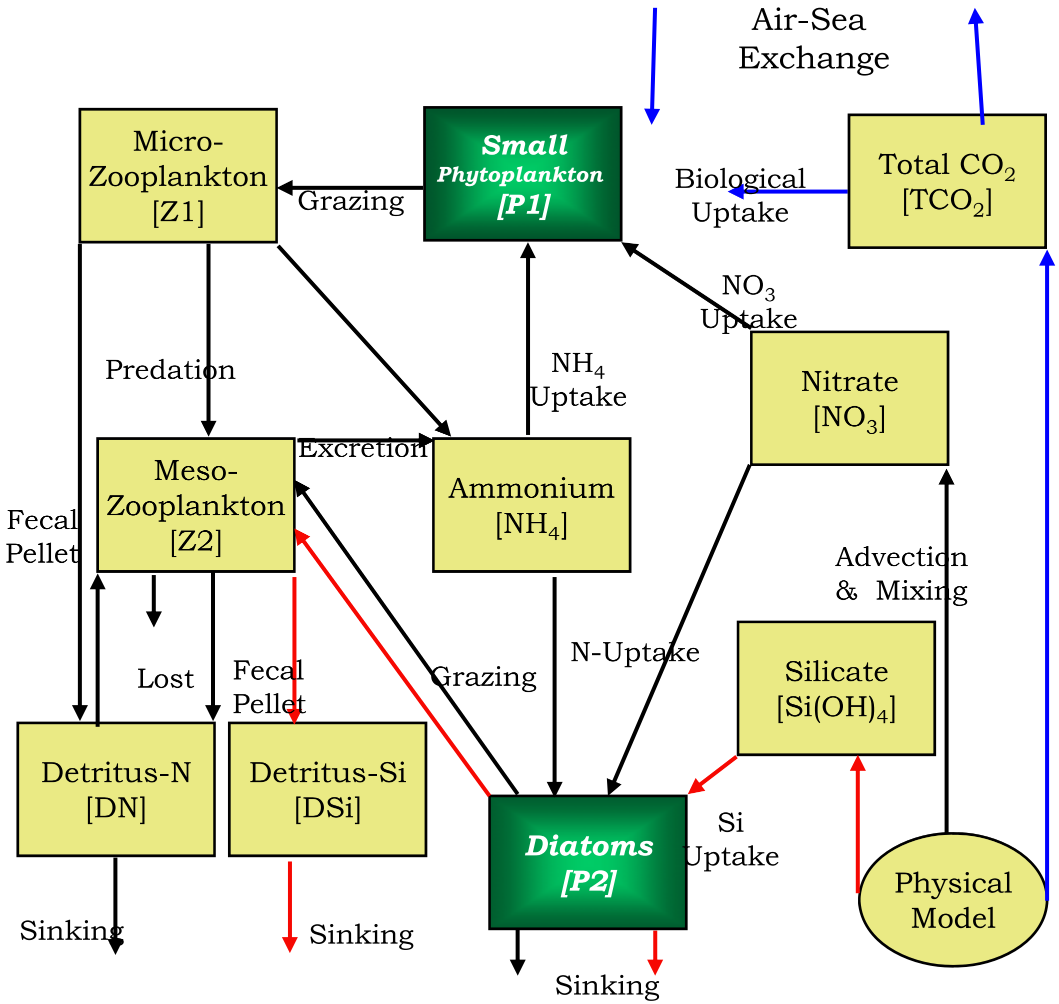
S. deRada





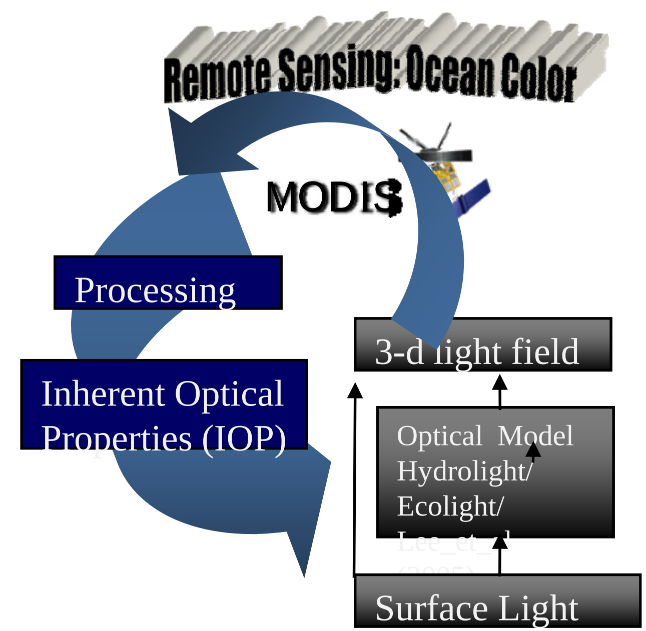
Bio-optical Model into Physical Model (CoSINE) Carbon, Silicate and Nitrogen Ecosystem

Physical-Biogeochemical Model: Fei Chai



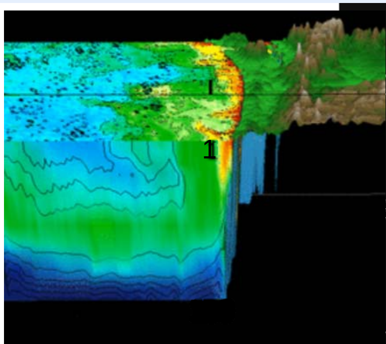
Constraining Ecosystem Models with Inherent Optical Properties

Satellite Derived Light Field

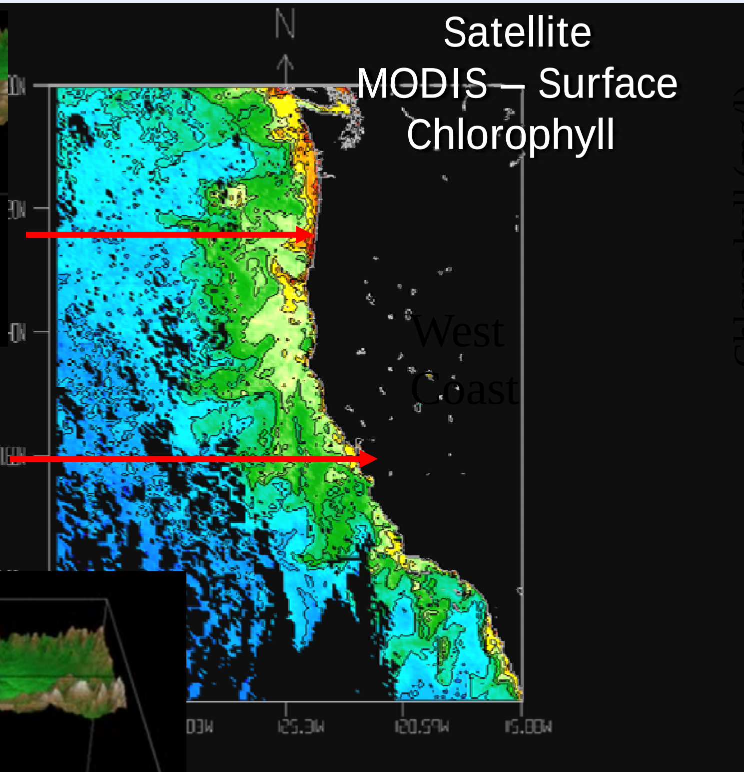


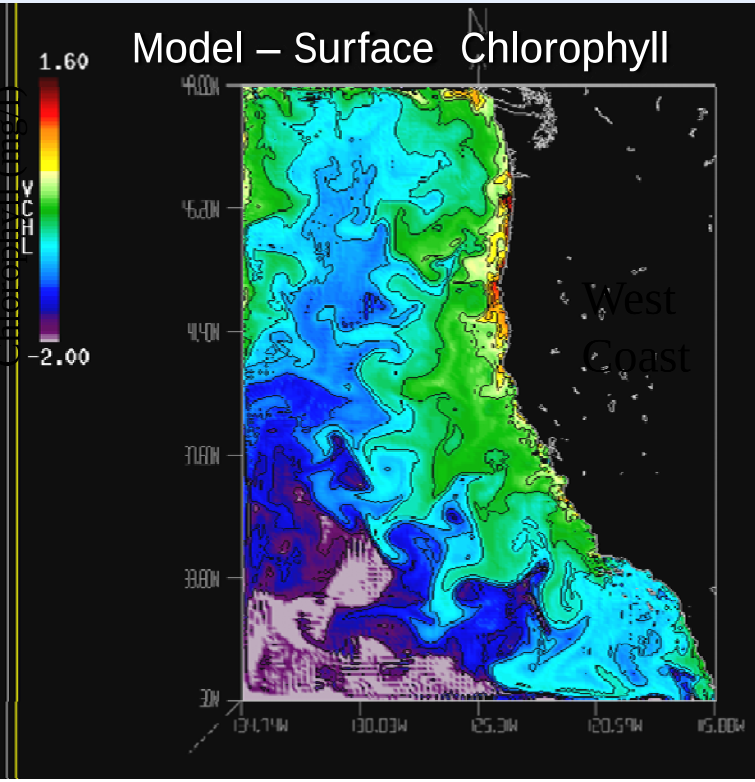
I. Shulman , S. deRada B. Penta

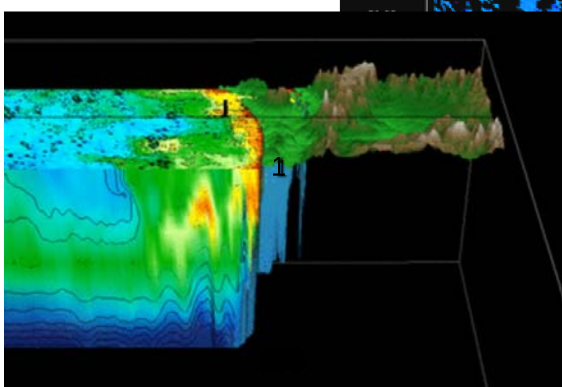
Biological Modeling and Optical properties
West Coast - (CoSINE)



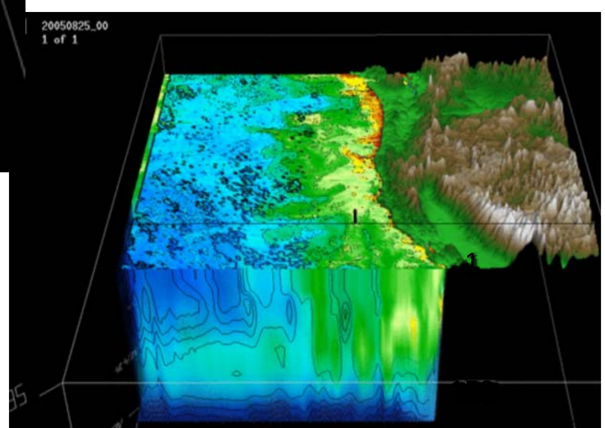
Cross Sections of the Biological Layers







Modeling the 3d-phytoplankton !



Shulman et al .
Paper on Multi-variant Coupling of Surface measurements with Water column

Assimilating sea surface absorption, backscatter, temperature, and velocities on water column properties.

I. Shulman et al

Issues with Assimilation of bio-optical data with Models

1- Inconsistency of values

satellite values and insitu don't agree.

inter-satellite inconsistency (log scales) temperature ok

2. Quality control over insitu data

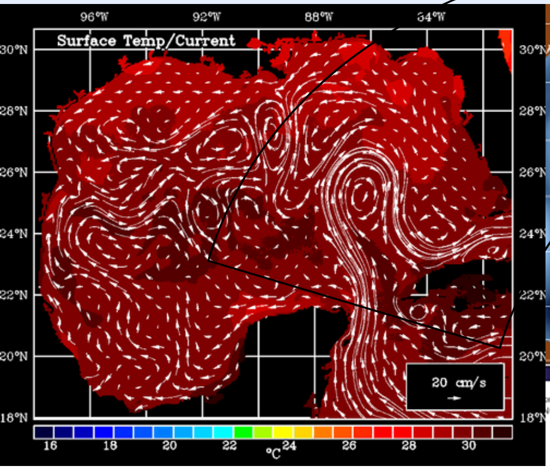
- values checks with climatology / seasons
- determine the data uncertainty

3. Complexity of the model required

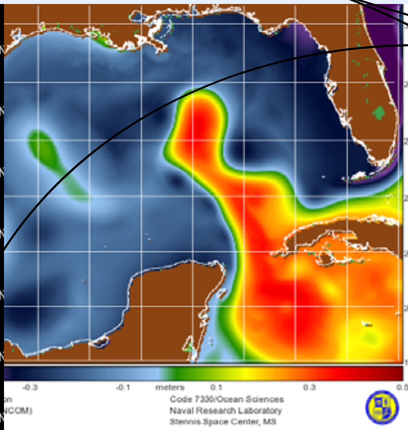
- number of state variables needed
- additional types of data make assimilation more complex

4. Determine if errors are from bio-optical or physics models

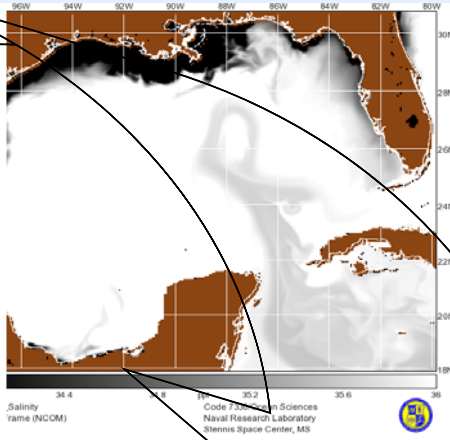
Fusing Optical Products and Physical Models



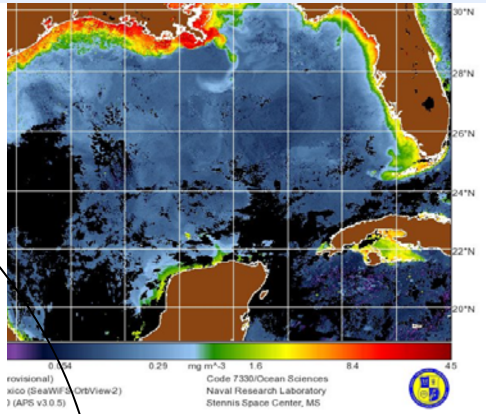
Currents – NCOM
"Intra Americas Seas"



SSH– NCOM



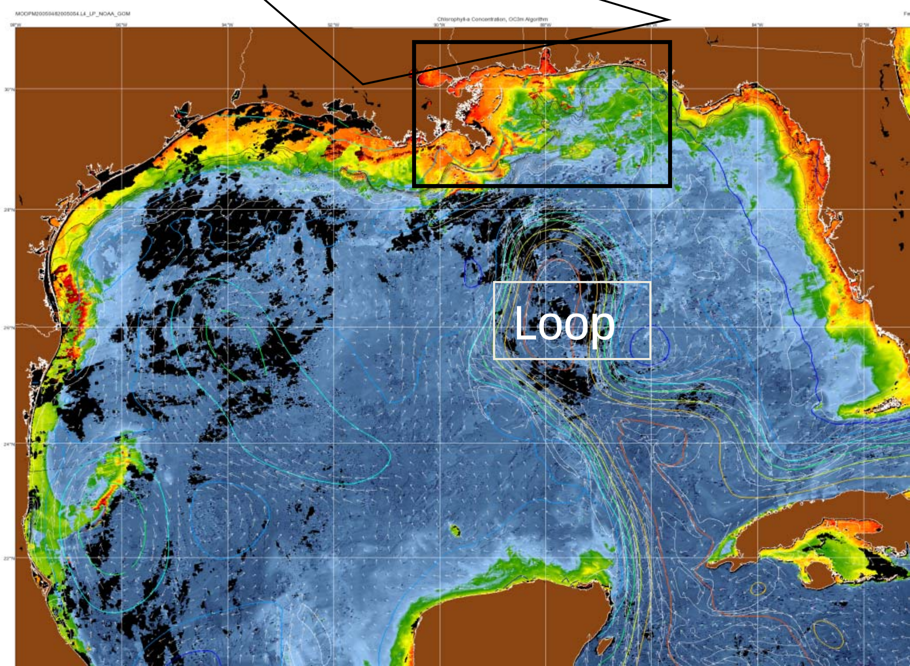
Salinity



SeaWIFS, MODIS Chlorophyll
Absorption, Scattering, Photic Depth etc

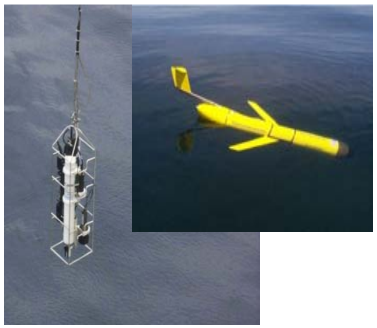
- **-Naval Coastal Ocean Model (NCOM)**
- **-41 Vertical layers,**
- **-Wind Forcing (CAMPS)**
- **-Assimilation of Altimetry and SST (MODIS)**
- **- River inputs →Climatology**

Daily Real Time Imagery – Cloud removed
Latest Pixel Composite



-Optimization Approach -
Combining Physical and Bio -Optical Structures

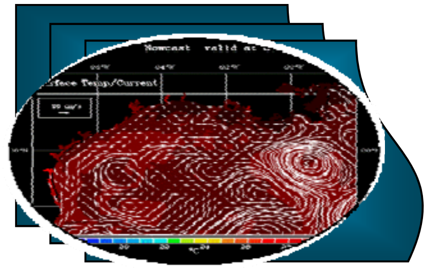
Subsurface Profiler
" Gliders , Buoys,



- **Most limited**

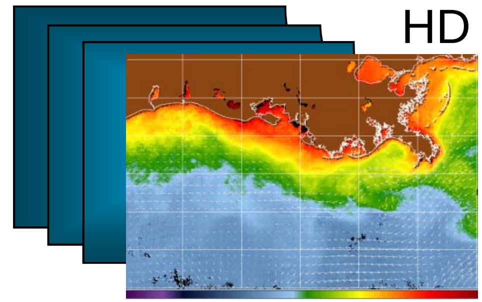
1. **Data costly**
2. **What parameters**
3. **Where Sample**

3D Physical Models



Forecast Physical ocean
Nested –
Coupled Atm-Ocean

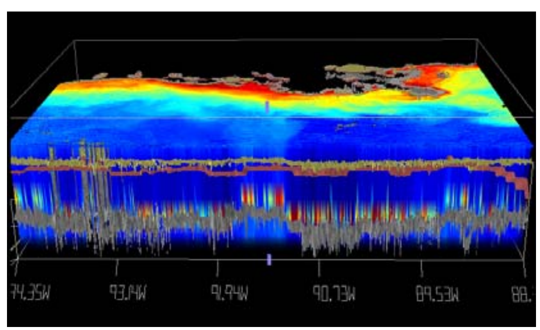
Satellite Bio-Optics and SST ,
HD RADAR



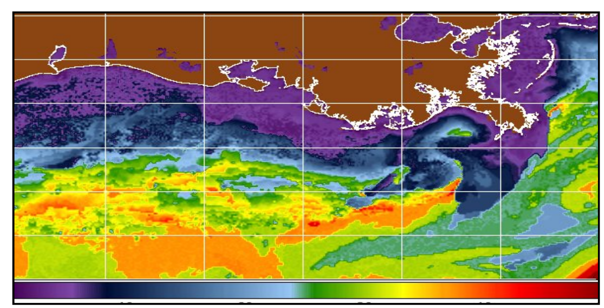
Extends Spatial coverage

Ensemble spread of the Physical Ecological Forecast

Ensembles Enables Adaptive Sampling

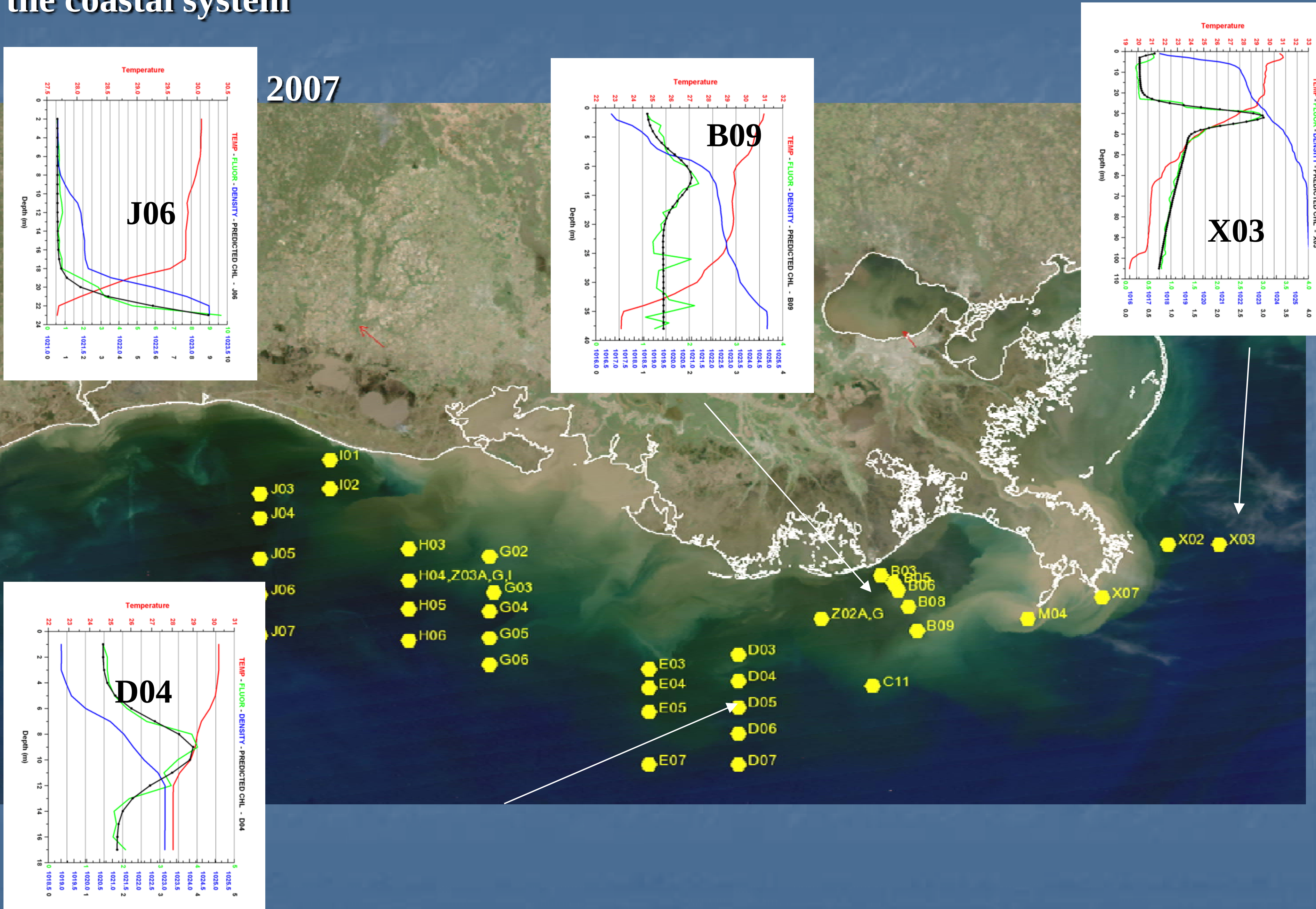


3d Ocean environment



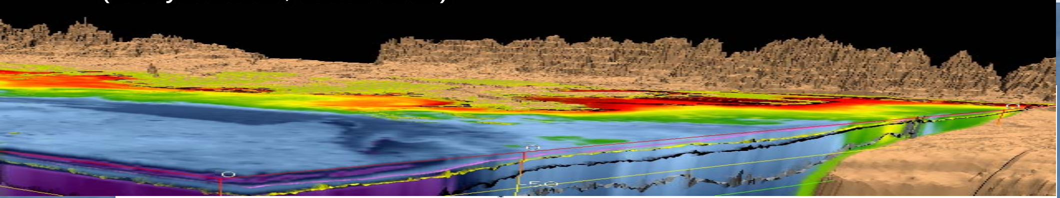
3d - Product Uncertainty

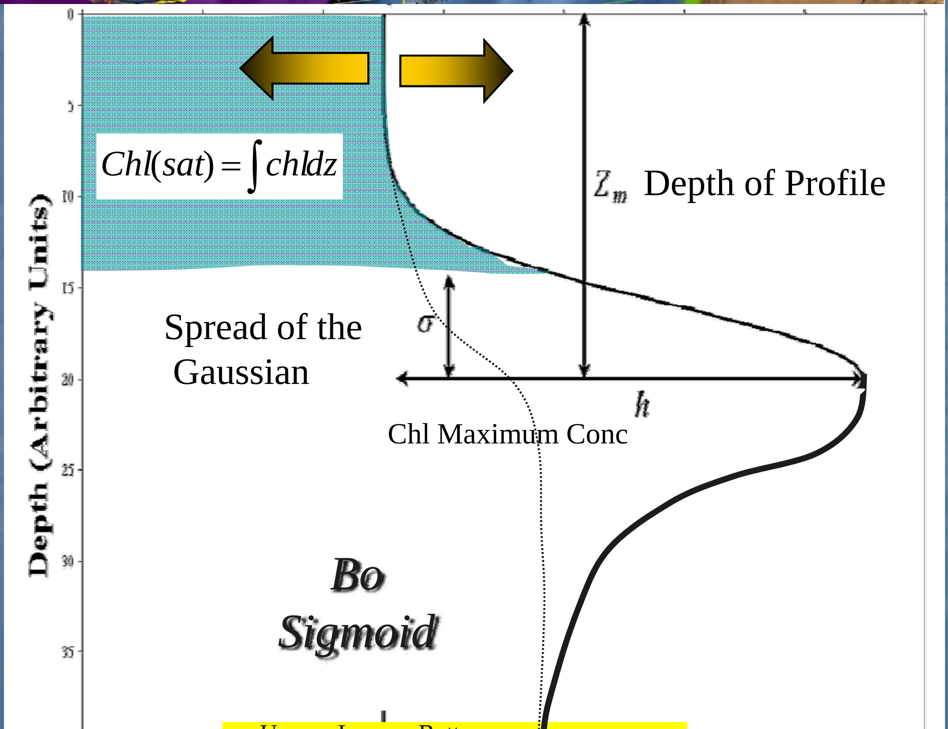
In situ Station Data Describing the coastal system



Parameterize the Vertical Bio-optical profile extending the surface Bio-optical and physical characteristics

Profile Shape
Characterized by a Gaussian
(Sathydrantha , Lewis et al.)





Upper Lower Bottom

$$Chl(z) = B_0 + \frac{h}{\sigma\sqrt{2\pi}} e[-\frac{(z-z_m)^2}{2\sigma^2}]$$

Decay Rates

Profile Shape Constraints

Surface Satellite Optics

First attenuation coefficient (satellite depth) “1/ k”

Bottom – 1% Light level

- using the IOP based from Lee et al, 2003

Middle-

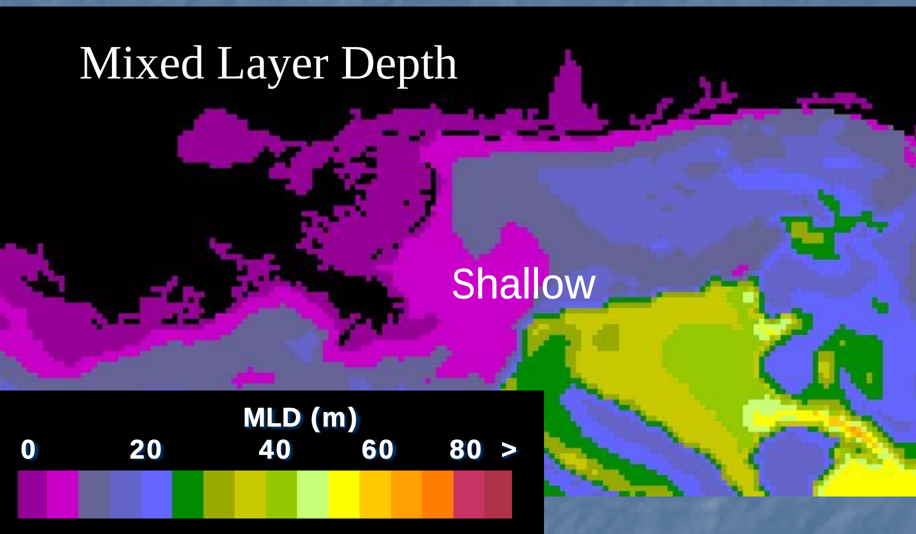
- using Gaussian shape with Physical vertical properties

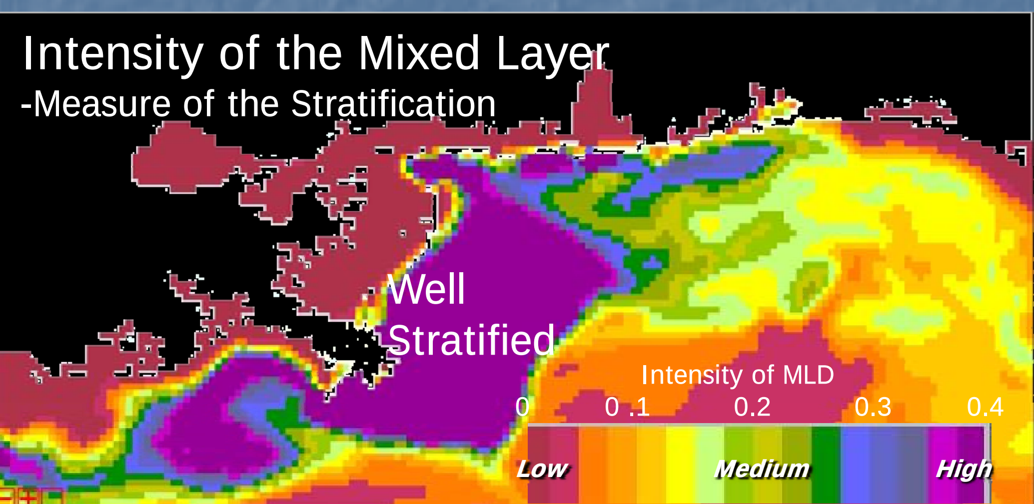
Arnone, Ladner, Casey

Physical Links to the Profile Shape - Middle Levels

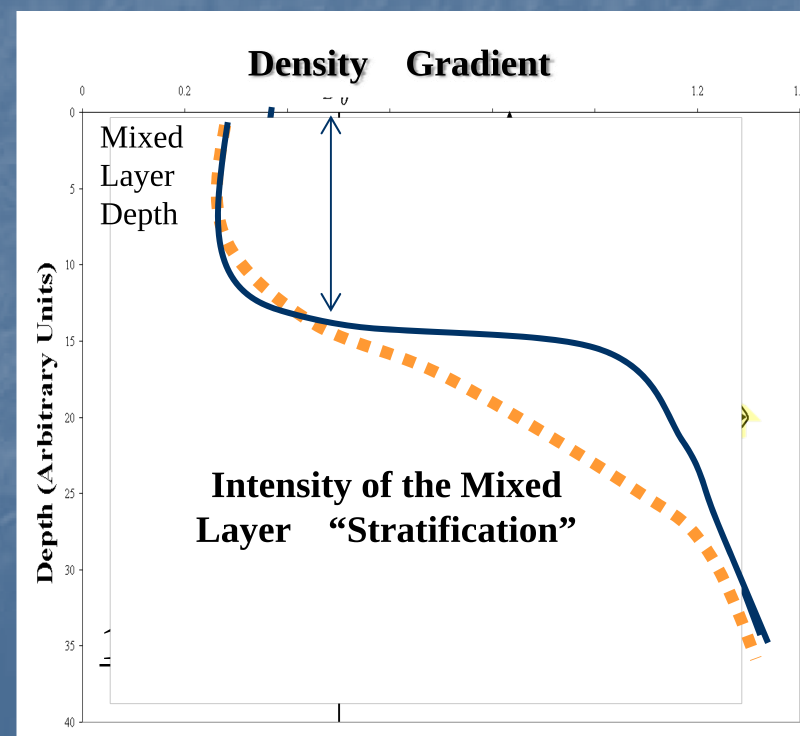
Applied the Insitu parameterization to NCOM MODEL

Link with Physical Model Properties





-Stratification used to Constrain the Optical Layer width and intensity



Ko, Arnone, Ladner, Casey

Optimizing Physical to Optical coefficients To define the Profile Shape

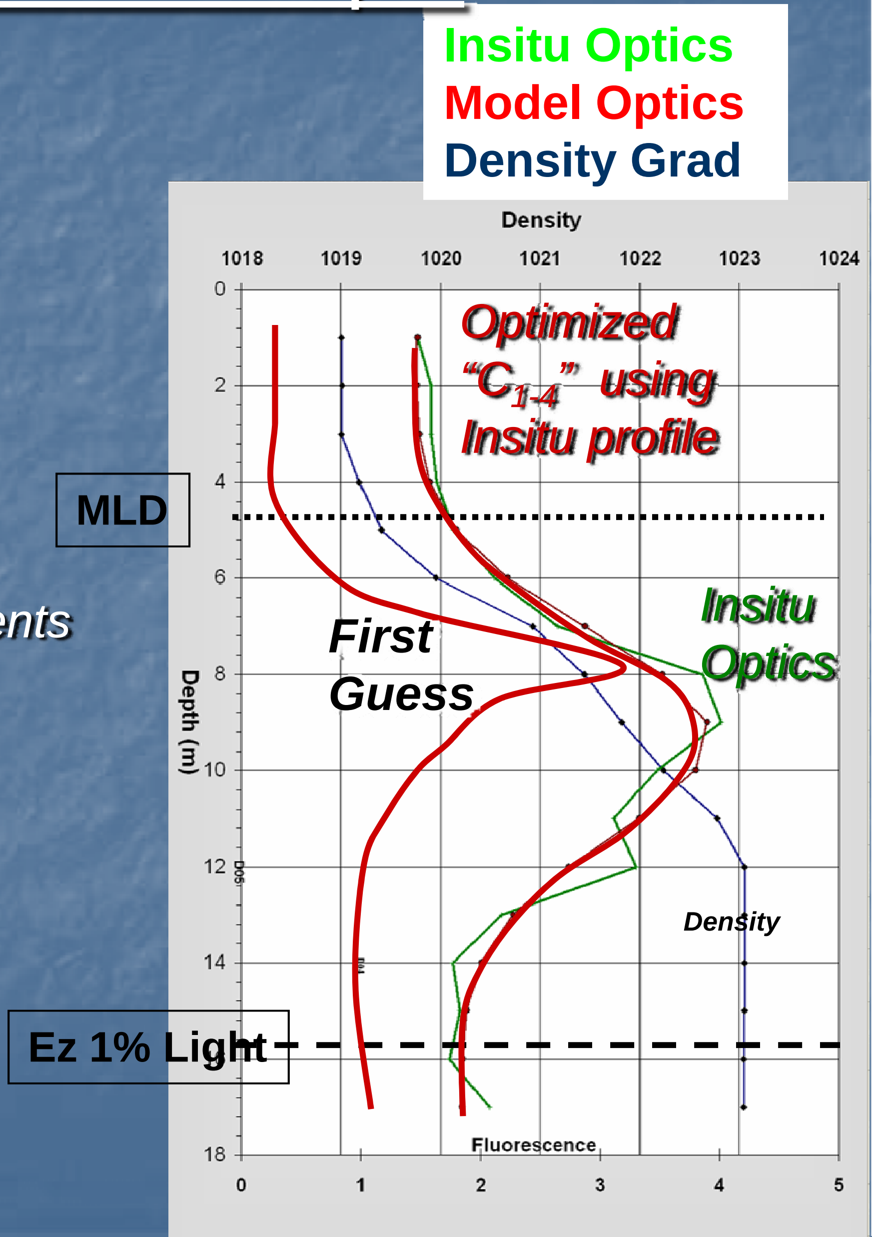
- Coupling the insitu data (Gliders – Profiles) with equations.
- Optimize the coefficients to minimize the Root Mean Square (RMS) of the insitu profiles with the equations.

Optimization

Input

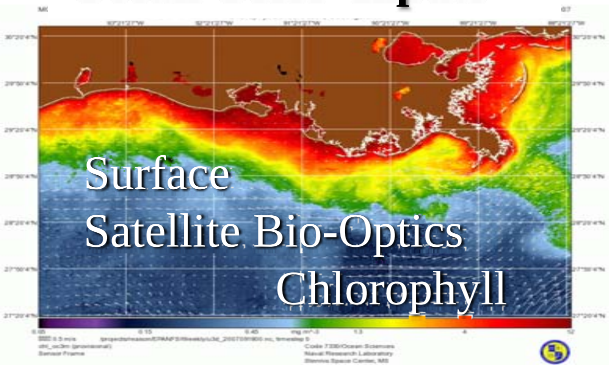
ChlSat	1.64	zMax coeff	2.01715604	C1
Kd	0.17095475	chlMax coef	36.5276019	C2
Bathy	24.3	sigma coeff	2.57302103	C3
MLD	20	sigma coeff	0.5	
iMLD	0.80626978	Bottom Scal	2	C5
Kd_final	0.17095475	Bottom Coe	1	C6
Ez_final	23.2810006	B0 ratio	1.37754608	C4
Zmax_final	20.6451816			
ChlMax_final	19.7512405			
Sigma	2.05112719			
SUMSQ	87.5666264			
COUNT	22			
RMS	1.99506922			

Coefficients



Applying the Optical – Physical Coefficients

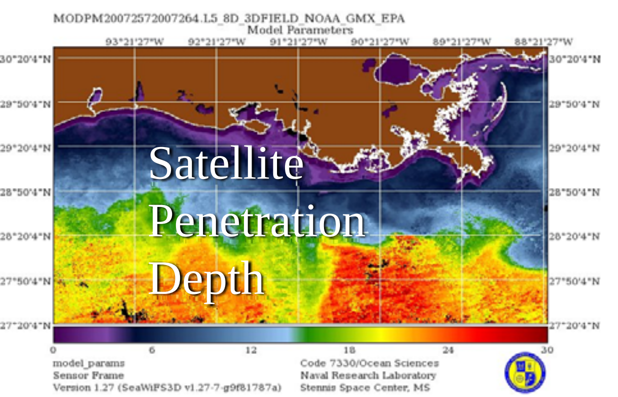
Ocean Color Inputs

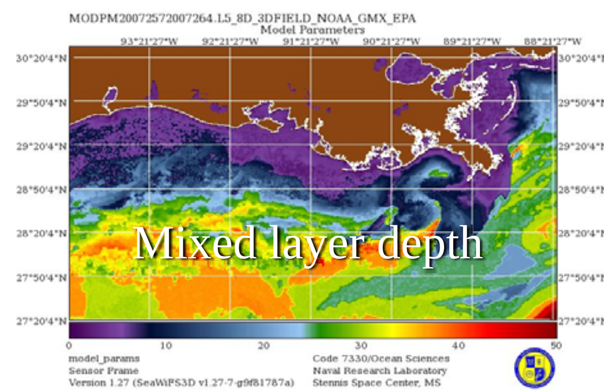


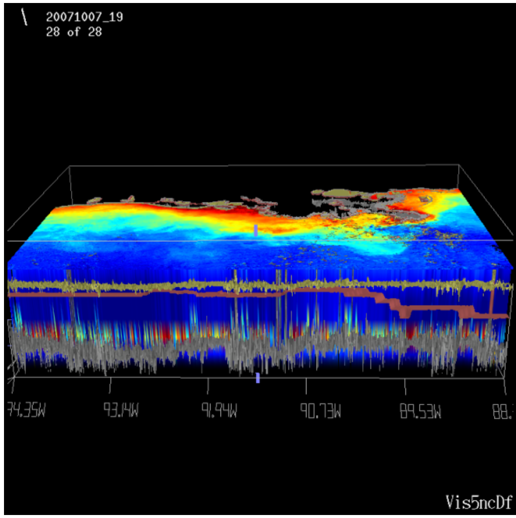
Physical Model Inputs

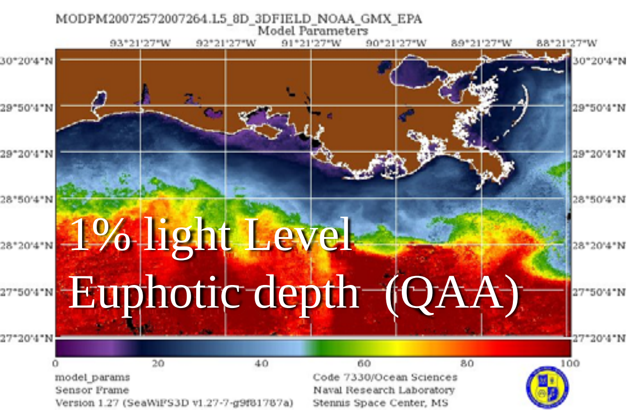
Extending the Surface satellite Bio- optics

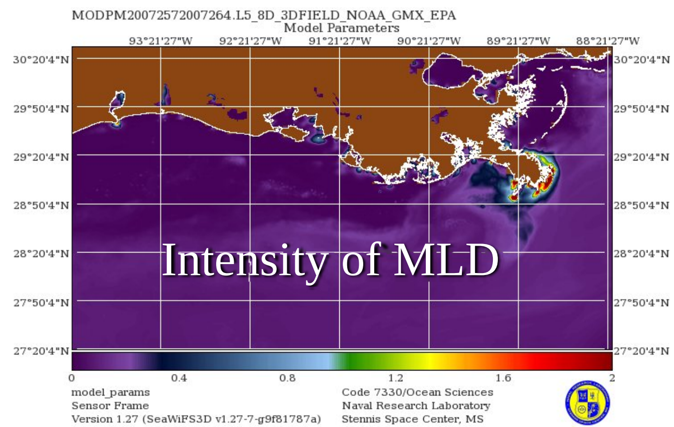
3d Optical Volume





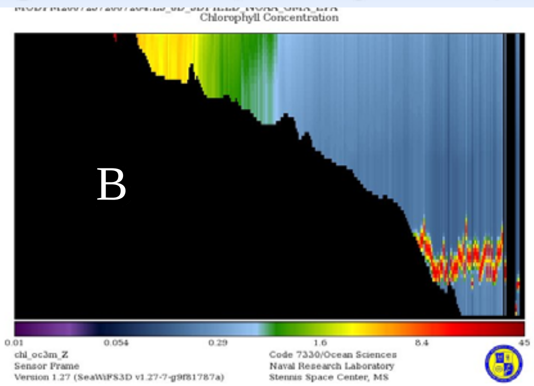


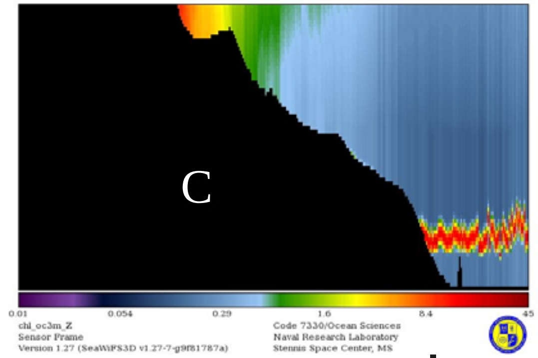


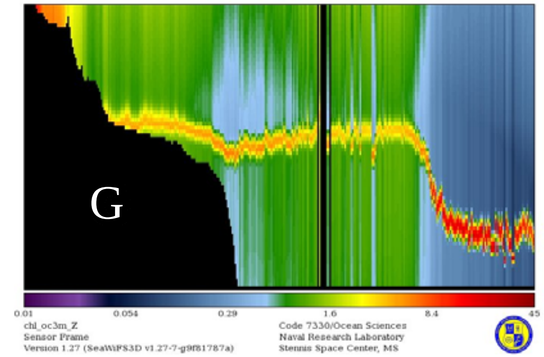


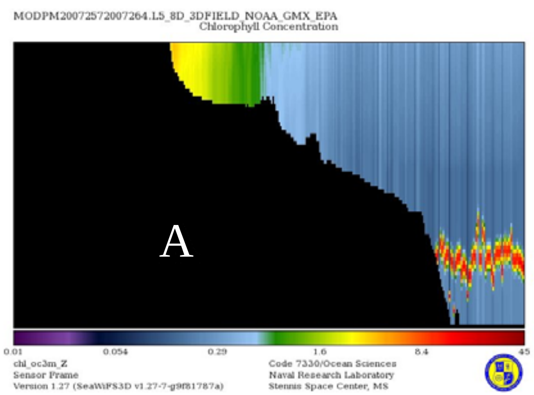
Cross Sectional Bio- Optical Structure

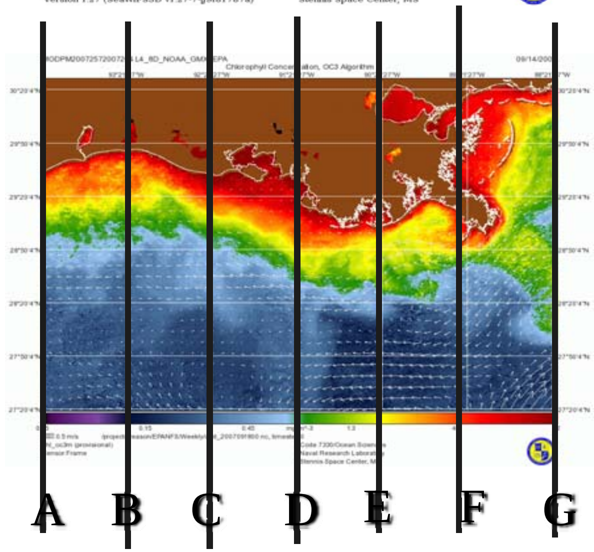
Sept 14 – 21 (weekly mean)

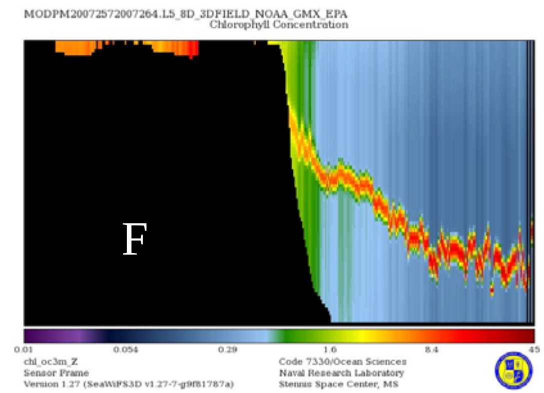


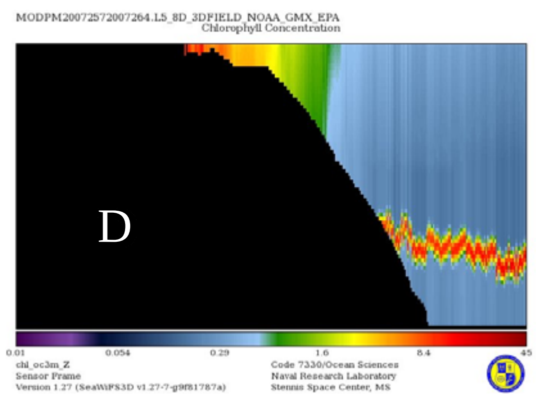


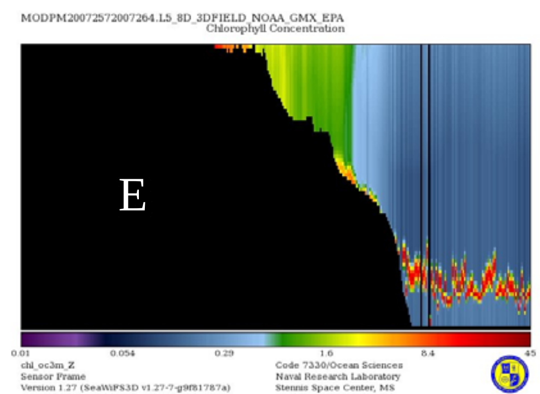




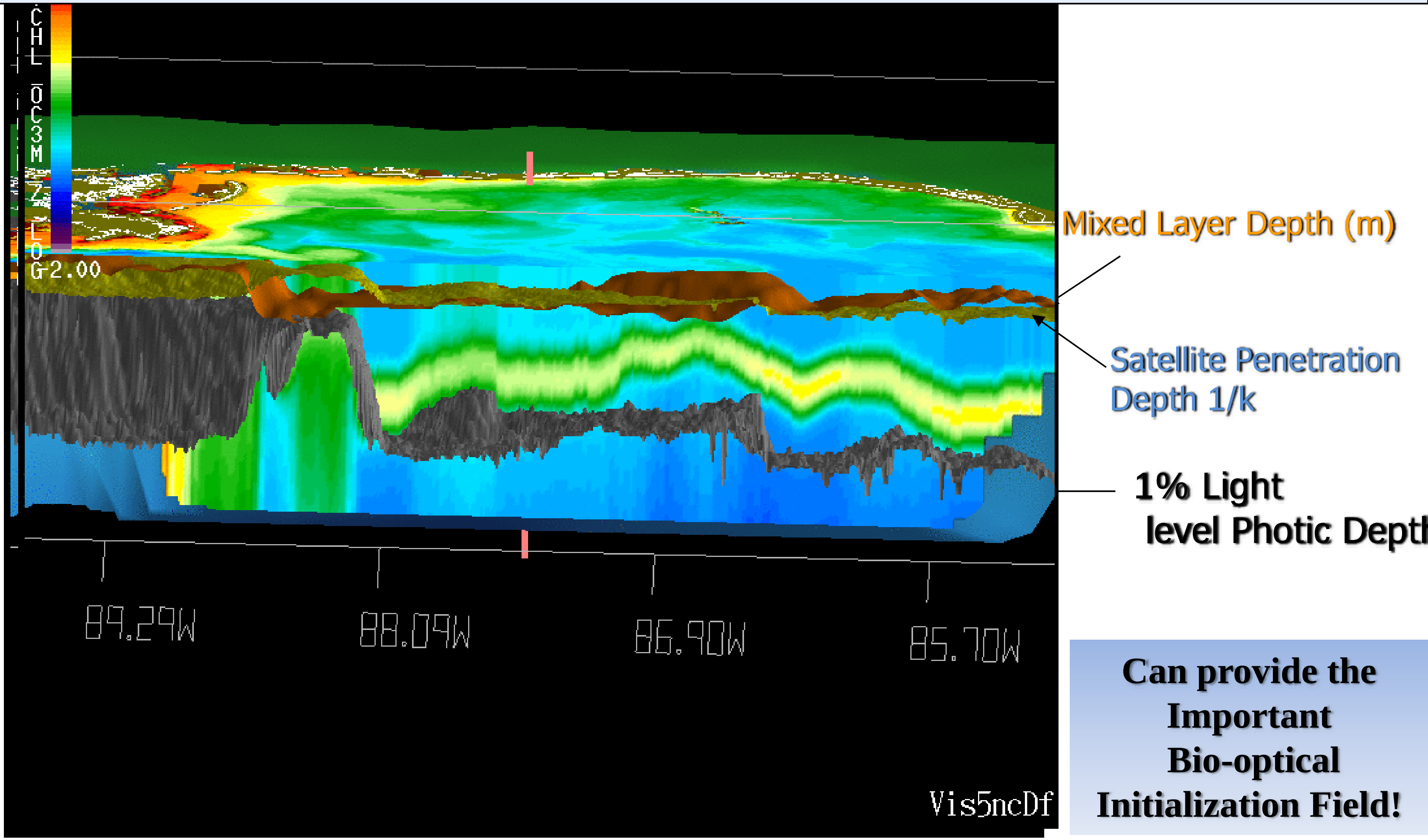








Below the Surface Layers
Interaction of the Physical and Bio-optical layers



Can provide the Important Bio-optical Initialization Field!

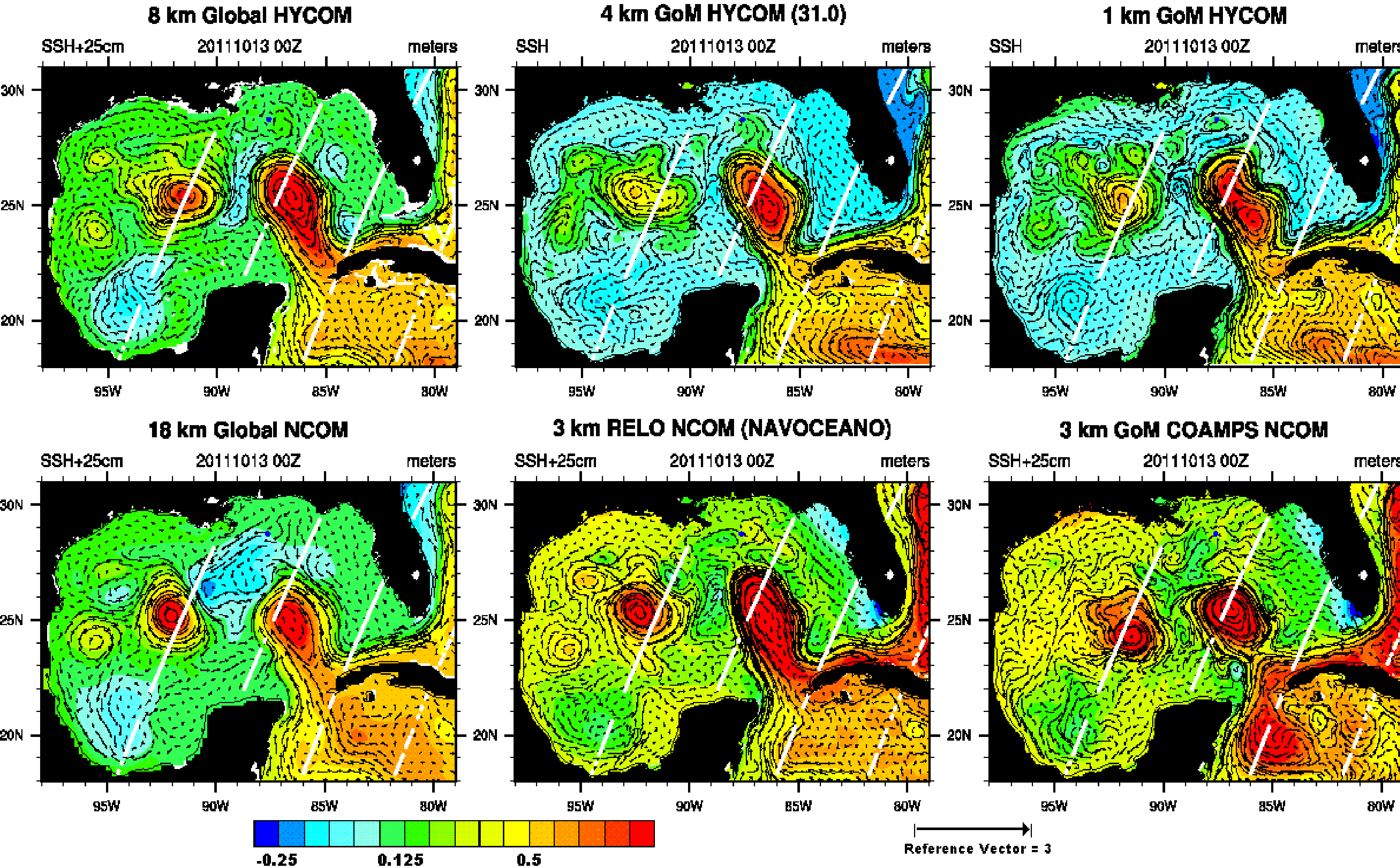
Advantages:

Assume the surface satellite is correct and the physics models correct!
Requires insitu profile data to optimize the vertical profile.
- the more data the better the product .

Approach is initialized daily with new satellite and insitu data!!
New initialization field .

Uncertainty and Ensembles
Physical processes
Physical to Optical relationships?

ENSEMBLES (w/ COAMPS) Physical Processes



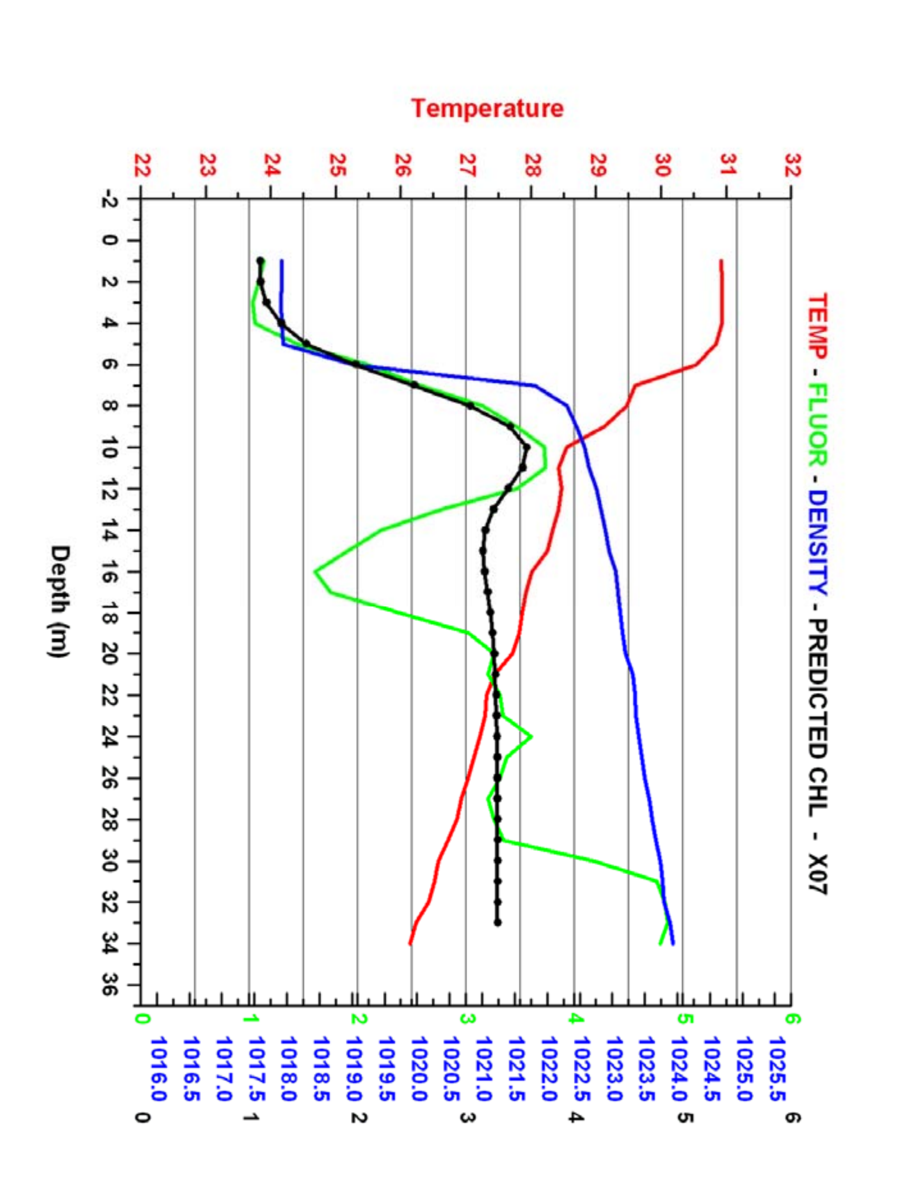
Comparison of six different NRL ocean models for the Gulf of Mexico (SSH shown)

Uncertainty of the Physics

Hogan, Derada

Performance and Defining the Uncertainty

Station profiles Used in Optimization



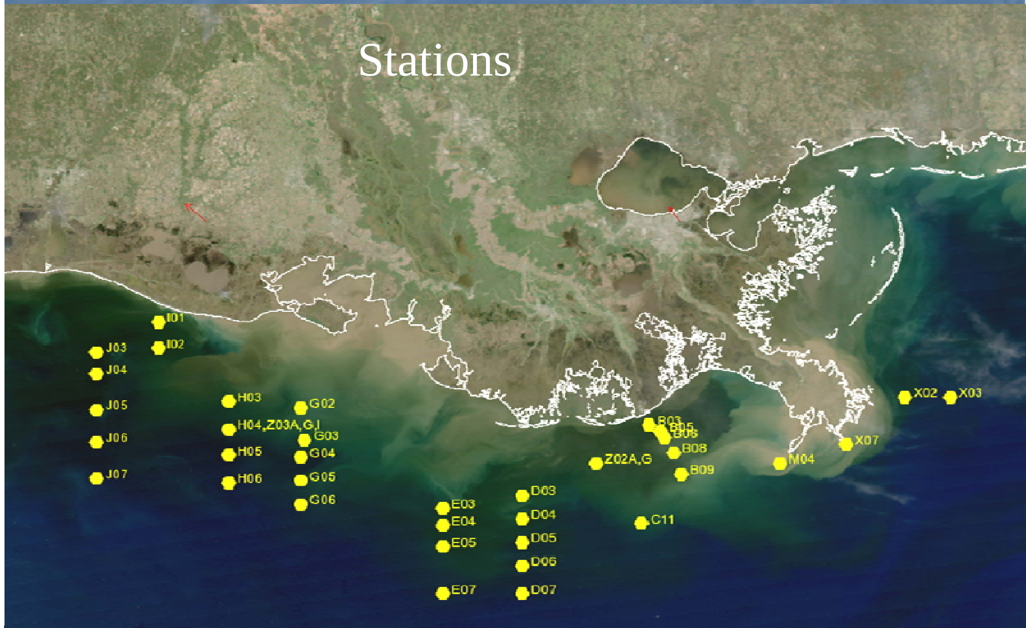
Optimization results

Green – Insitu bio-optics

Black – optimized Profile

How good can we define individual profile optimization?

Difference in the coefficients ?



Uncertainty of optimized Coefficient

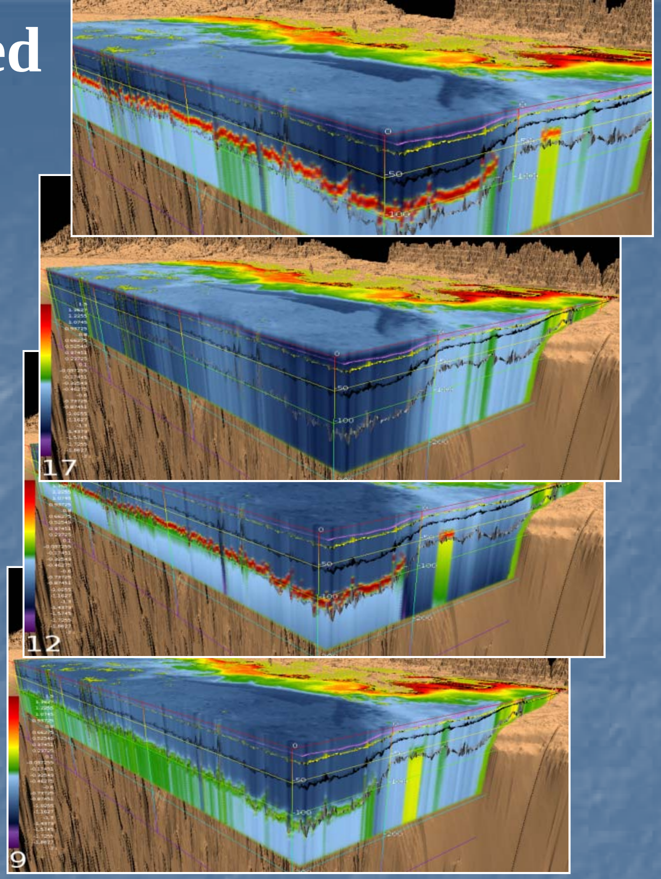
Individual Profiles

C1, C2 , C3, C4

17 sets Physical / bio-optical coefficients

Physical – Bio-optical response

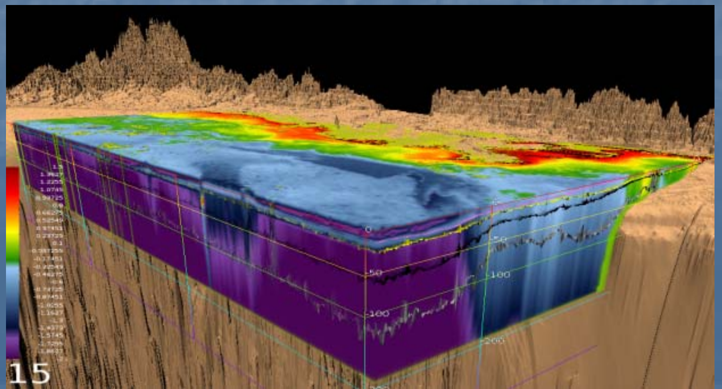
3d Bio-optical VOLUMES Ensembles



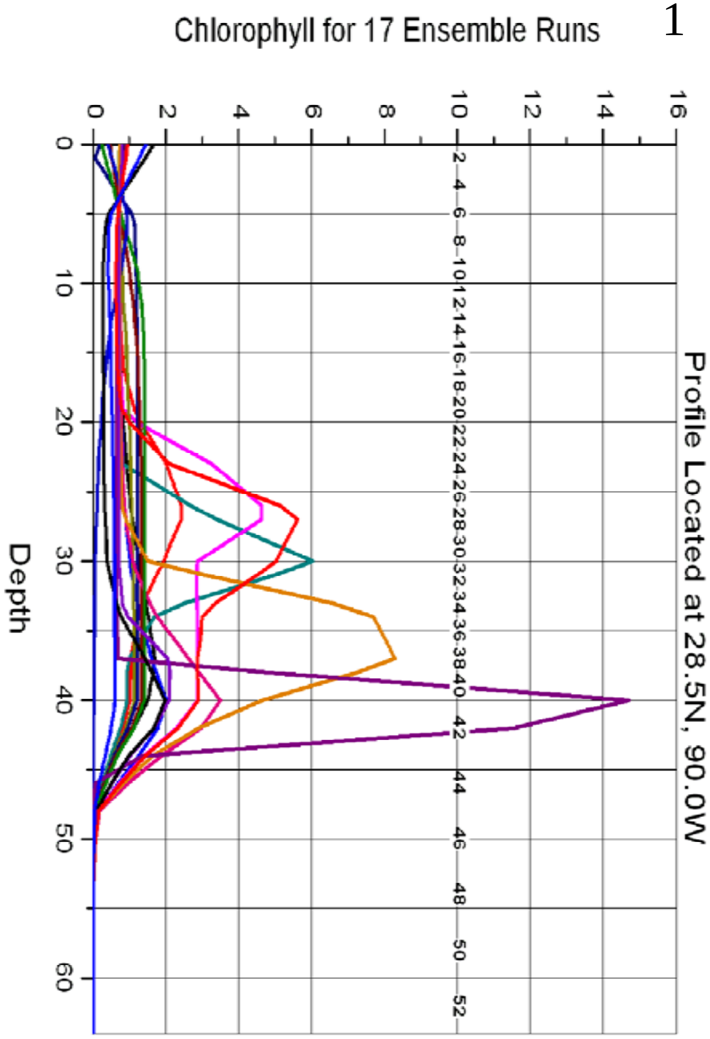
Ensemble Mean and Variance

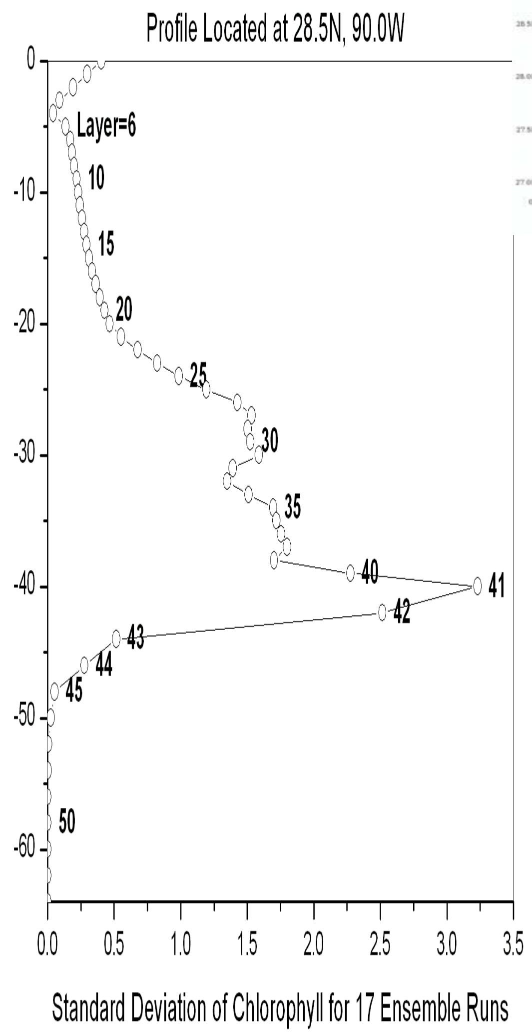
Optimized "all" profiles to determine the Coefficients $C^{s}_{(1\text{-}4)}$

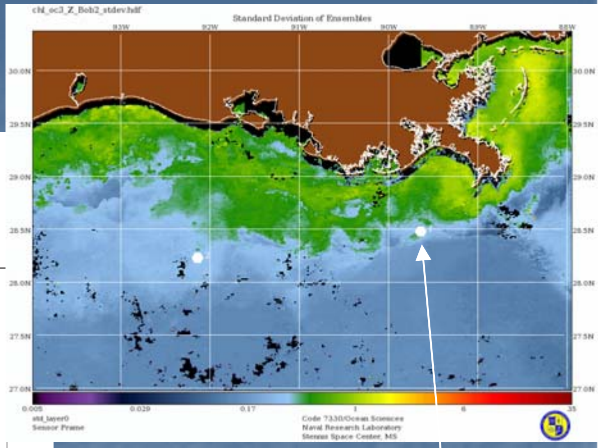
3d Bio-optical VOLUMES

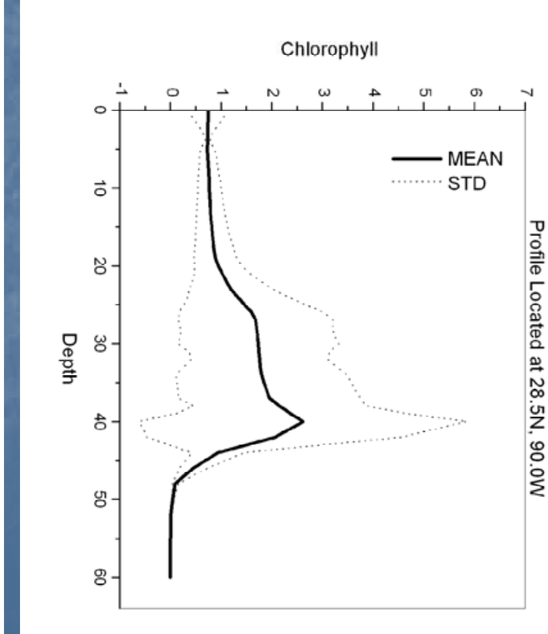


Variability of the Ensemble profiles and the Uncertainty.





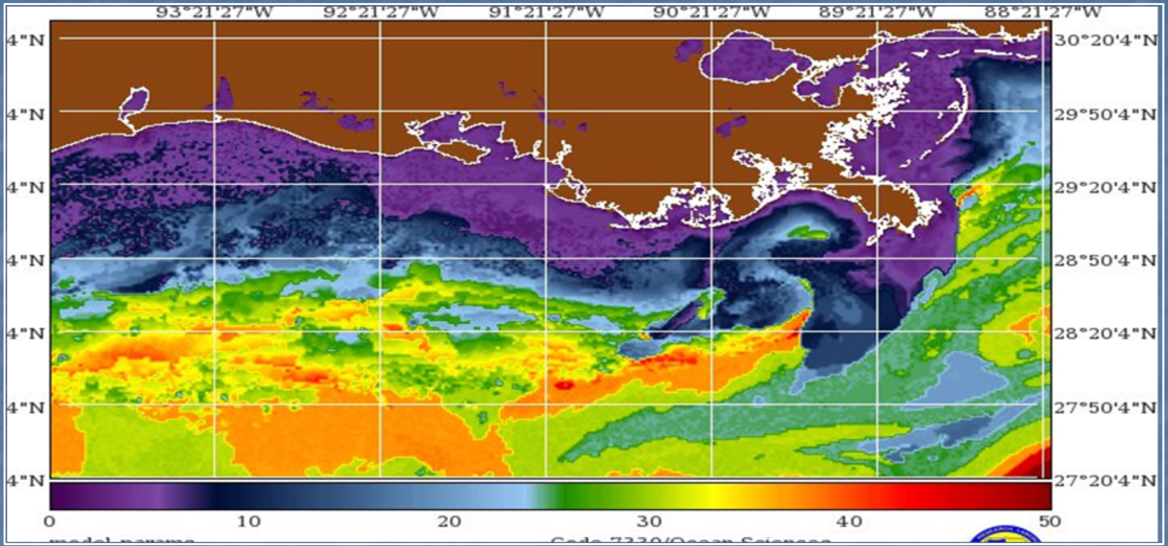


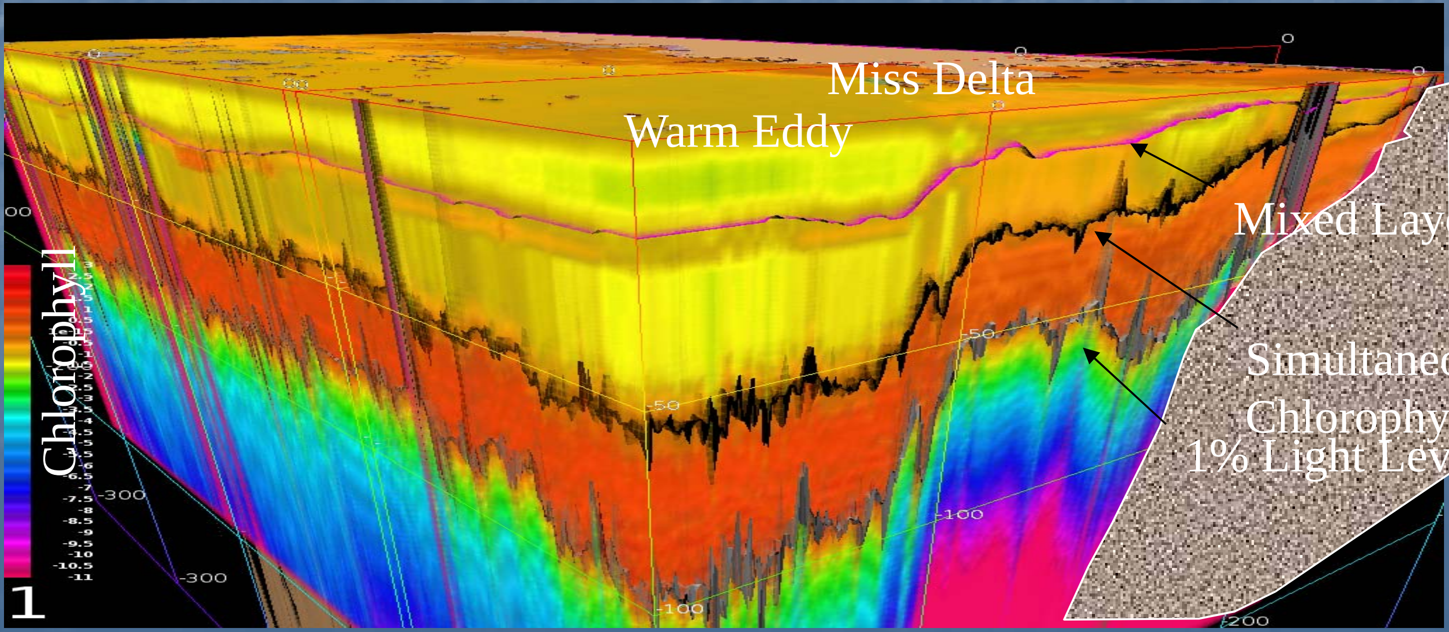


Volume of the “Standard Deviation” of the Chlorophyll Profile from the 17 Ensembles.

Uncertainity

3d - Product Uncertainty





Ensemble spread of the Physical Ecological Forecast

"Ocean Observatory contributions to Ocean Models and Data Assimilation For Ecosystems"

Summary:

Ecosystem and Optical models not as mature as physical model and assimilation

- Representativeness errors –
- Sensor errors
- Physics and bio-optical model errors
- Complexity of the model

Characterizing the uncertainty of ocean bio-optical data

- Spatial and Temporal data uncertainty – non static and spatial variant
- Data inconsistencies – satellite and insitu and intra satellite
- How physical models impacts bio-optical models .

Different model types (physical and bio optical)

- Importance 1) Initialization field 2) physical field 3) boundary conditions
- 4) constraining and assimilation using observations 5) fluxes .
- Growth and decay models - many approaches to assimilation

- Optimization approach using combined satellite, insitu and physical models
  - Capture the real time ecosystem – Extending the satellite surface optics

Role of models and ensembles for use in adaptive sampling

- Setting in the observatory based on uncertainty with the environment .

Robert Arnone