Incorporating Satellite Time-Series data into Modeling

Watson Gregg
NASA/GSFC/Global Modeling and Assimilation Office

Topics:
Models, Satellite, and In situ representations of
Seasonal Variability
Interannual Variability
Decadal and Longer Trends

Supporting data and publications: Google gmao, click Research, then Ocean Biology Modeling (http://gmao.gsfc.nasa.gov/research/oceanbiology)
NASA Ocean Biogeochemical Model (NOBM)

- **Radiative Model (OASIM)**
  - \( E_d(\lambda) \)
  - \( E_s(\lambda) \)
  - IOP
  - Layer Depths

- **Biogeochemical Processes Model**
  - Dust (Fe)
  - Sea Ice
  - Winds, ozone, relative humidity, pressure, precip. water, clouds (cover, \( \tau_c \)), aerosols (\( \tau_a, \omega_a, \text{asym} \))

- **Circulation Model (Poseidon)**
  - Winds
  - SST
  - Advection-diffusion

**Outputs:**
- Chlorophyll, Phytoplankton Groups
- Primary Production
- Nutrients
- DOC, DIC, pCO\(_2\)
- Spectral Irradiance/Radiance

**Global model grid:**
- Domain: 84°S to 72°N
- 1.25° lon., 2/3° lat.
- 14 layers
Diatoms

Biogeochemical Processes Model
Ecosystem Component

Chlorophytes
Cyano-bacteria
Cocco-lithophores

Phytoplankton

Nutrients

Si
NO₃
NH₄
Fe

Herbivores

Silica Detritus

Iron Detritus

N/C Detritus

Detritus

Iron
Blue = NOBM; Green = Data

Gregg and Casey, 2007, Deep-Sea Research II
Global Chlorophyll

Difference = -8.0%, \( r = 0.618^* \)

Difference = +1.1%, \( r = 0.469 \)

Difference = -17.1%, \( r = 0.787^* \)
Data Assimilation

Time has finally come

>50 papers using data, 12 using satellite data
(Gregg et al., Journal of Marine Systems, in press)

In ocean biology, Two Classes:
  Variational (e.g., adjoint)
  Sequential (e.g., Kalman Filter)

Here we used Sequential Methodologies,
  Conditional Relaxation Analysis Method
  Ensemble Kalman Filter
Application to Ocean Color

**Daily assimilation** of gridded data into surface layer

Chlorophyll distribution log-normal

**assimilate logarithmic quantities**

Satellite errors can affect results

**explicitly define regional satellite errors** estimated from global analysis of in situ data
Assimilated Chlorophyll Apr 1 2001

Free Run Model Chlorophyll Apr 1 2000

Monthly SeaWiFS Chlorophyll Apr 2001

Daily SeaWiFS Chlorophyll Apr 1 2001

Assim Model vs. SeaWiFS:
Bias = +5.5%
Uncertainty = 10.1%

NASA Ocean Biogeochemical Model (NOBM)
## Compared to In situ Data

<table>
<thead>
<tr>
<th></th>
<th>Bias</th>
<th>Uncertainty</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>SeaWiFS</td>
<td>-1.3%</td>
<td>32.7%</td>
<td>2086</td>
</tr>
<tr>
<td>Free-run Model</td>
<td>-1.4%</td>
<td>61.8%</td>
<td>4465</td>
</tr>
<tr>
<td>Assimilation Model</td>
<td>0.1%</td>
<td>33.4%</td>
<td>4465</td>
</tr>
</tbody>
</table>

Estimate of in situ data uncertainty: 22%
Seasonal Variability
Statistically positively correlated (P < 0.05) all 12 basins

Red = model  
Diamonds = SeaWiFS monthly mean

Gregg, 2002, Deep-Sea Research II  
Gregg et al., 2003, Deep-Sea Research II
Basin Differences (Model/Assim - SeaWiFS)

Percent Difference

Free-run Model

Assimilation

Correlation Coefficient (r)

Basin Seasonal Correlation with SeaWiFS

Assimilation

Free-run Model

Antarctic  S Indian  S Pacific  S Atlantic  Eq Indian  Eq Pacific  Eq Atlantic  N Indian  N Central Pacific  N Central Atlantic  N Pacific  N Atlantic
Daily ocean coverage by MODIS-Aqua and SeaWiFS.

Monthly Mean Global Chlorophyll

Chlorophyll (mg m$^{-3}$)

Month
Interannual Variability
Regression statistics are for log-transformed data.
Interannual Variability, SeaWiFS and Assimilation

Red = Assimilation model
Diamonds = SeaWiFS monthly mean

Nerger and Gregg, 2007, Journal of Marine Systems
Gregg, 2008, Journal of Marine Systems
Monthly Mean Percent Difference Aqua-MODIS and Assimilation

North Pacific

North Atlantic

Antarctic

North Indian
Decadal and Longer Trends
Global Annual Anomaly Trends with SeaWiFS, and SeaWiFS/Aqua

Same calibration, same algorithms, same processing
Linear trends using 7-year average/composite images were calculated, and when significant (P < 0.05), shown here.
Global Annual Anomaly Trends, with Data Assimilation

SeaWiFS Assimilation = -1.90% (NS)
SeaWiFS/Aqua Assimilation = 0.42% (NS)
Conclusions

Assimilation improves representation of seasonal, interannual, and decadal chlorophyll

Satellite data provide good representation of local and most regional seasonal variability, but global seasonal variability is poor.

Global and regional satellite data provide good representation of interannual variability.

Model and assimilation do not represent local temporal variability well, but better on regional and global scales (better than satellite for global seasonal variability)

Extending satellite time series into decadal and longer time scales is problematic due to inconsistencies between sensors/missions. Data assimilation can alleviate these problems but relies upon the model for chlorophyll abundance (not spatial and temporal variability)
Assimilation: Challenges

New work on assimilation methods needed and ongoing multi-variate assimilation (nutrients)
dynamic state covariance matrix
multi-dimensional assimilation
Can we fill a gap in satellite data using enhanced ship observations and data assimilation?

<table>
<thead>
<tr>
<th>Sampling %</th>
<th>Global Difference</th>
<th>Maximum difference by basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% sampling (about 1500 obs/day)</td>
<td>-2.3%</td>
<td>-7.6% North Pacific</td>
</tr>
<tr>
<td>1% sampling (about 150 obs/day)</td>
<td>1.4%</td>
<td>-21.9% North Indian</td>
</tr>
</tbody>
</table>
Using targeted sampling by basin and month, we can refine our sampling strategy, and reduce the required amount. Shown below is targeted sampling as a percent of SeaWiFS, by month.

<table>
<thead>
<tr>
<th>Basin</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Atlantic</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>10%</td>
<td>10%</td>
<td>2%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>North Pacific</td>
<td>2%</td>
<td>1%</td>
<td>5%</td>
<td>5%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>North Central Atlantic</td>
<td>5%</td>
<td>1%</td>
<td>5%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>North Central Pacific</td>
<td>2%</td>
<td>5%</td>
<td>1%</td>
<td>0%</td>
<td>5%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>5%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>North Indian</td>
<td>2%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>2%</td>
<td>2%</td>
<td>10%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Equatorial Atlantic</td>
<td>5%</td>
<td>10%</td>
<td>2%</td>
<td>10%</td>
<td>2%</td>
<td>10%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>5%</td>
<td>1%</td>
<td>5%</td>
</tr>
<tr>
<td>Equatorial Pacific</td>
<td>5%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Equatorial Indian</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>South Pacific</td>
<td>2%</td>
<td>2%</td>
<td>5%</td>
<td>0%</td>
<td>1%</td>
<td>5%</td>
<td>5%</td>
<td>2%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>South Indian</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>2%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Antarctic</td>
<td>2%</td>
<td>2%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>2%</td>
</tr>
</tbody>
</table>