# Incorporating Satellite Time-Series data into Modeling

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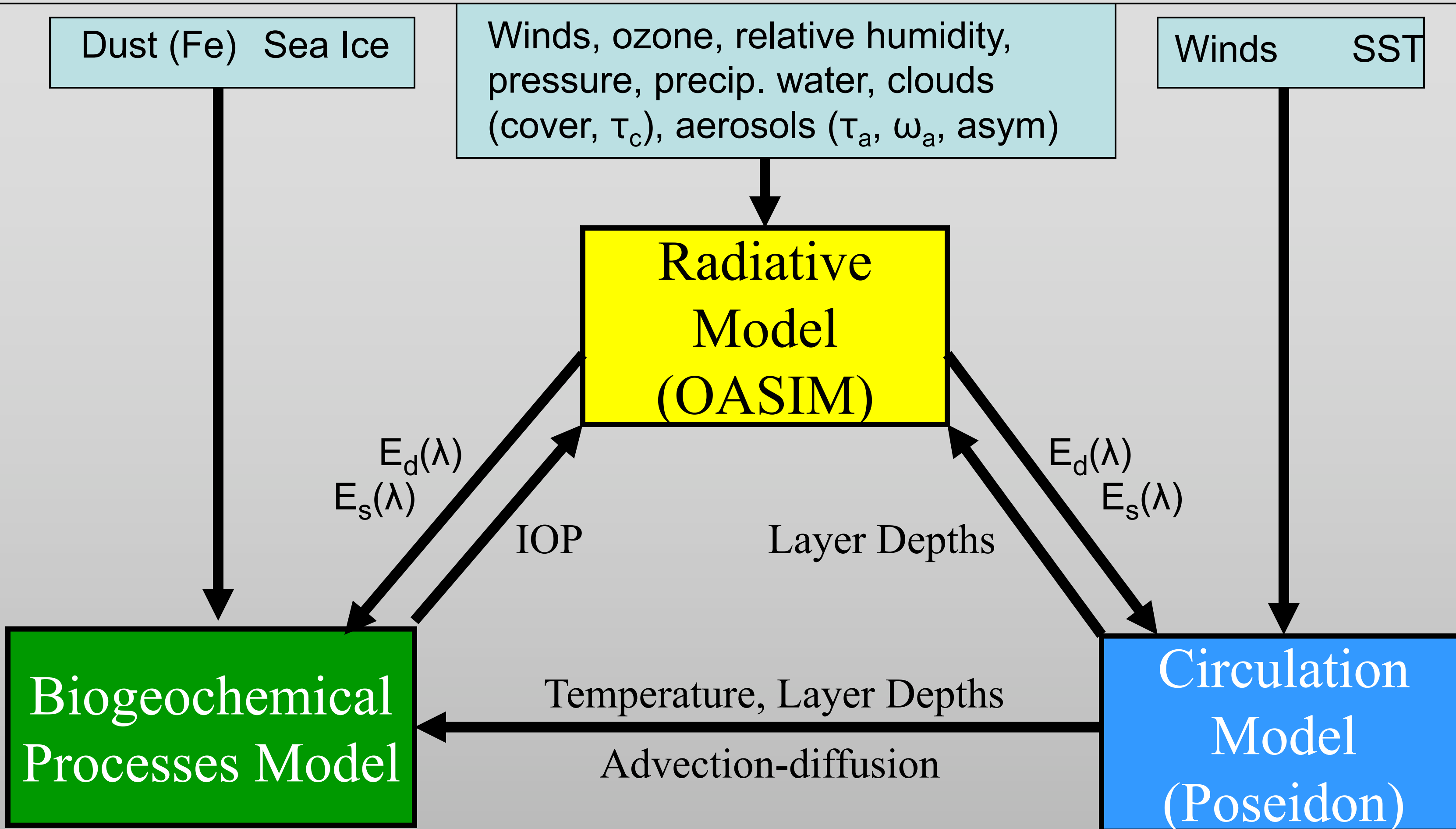
Topics:
Models, Satellite, and In situ representations of

- 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)



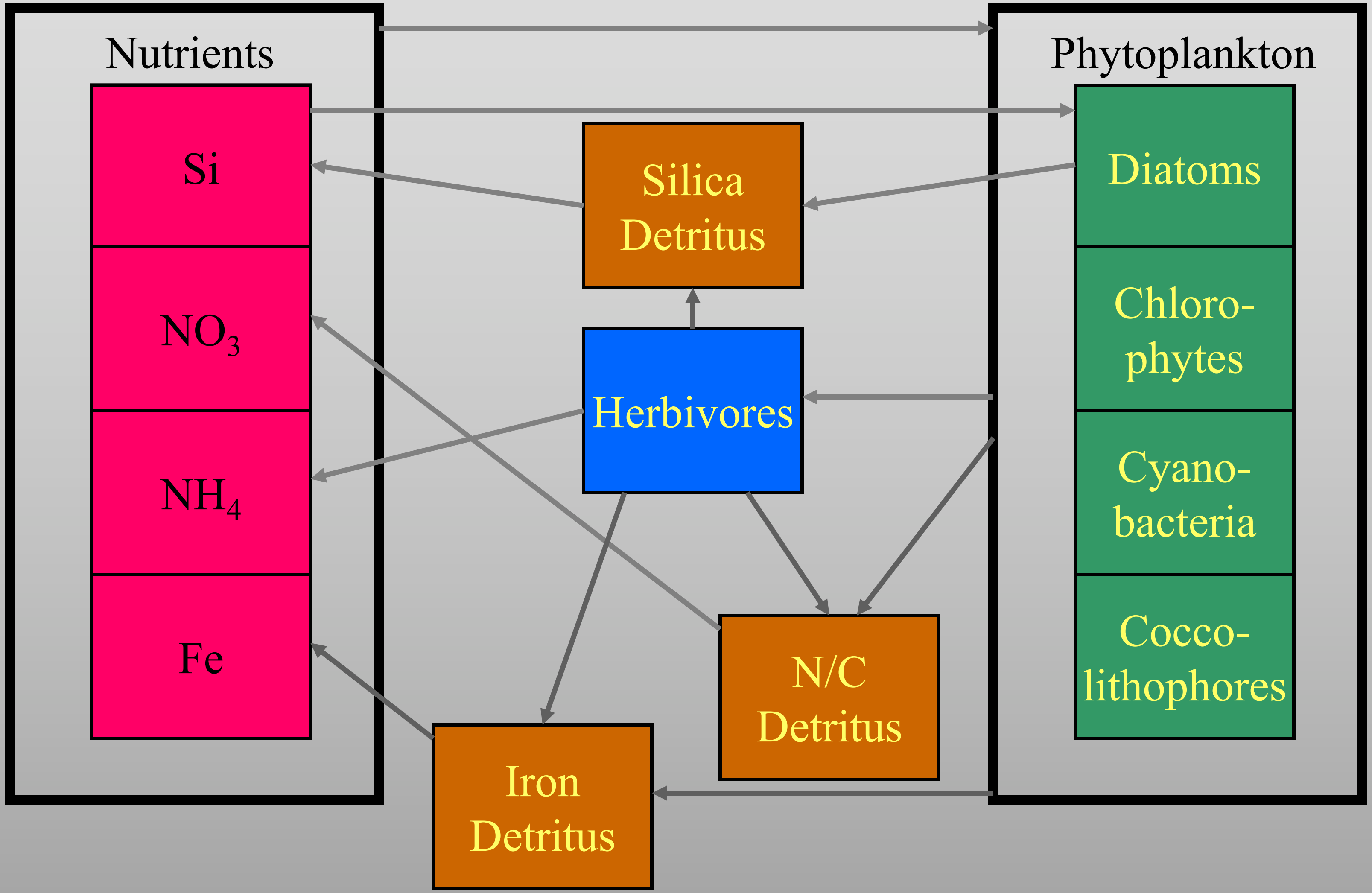

Outputs:

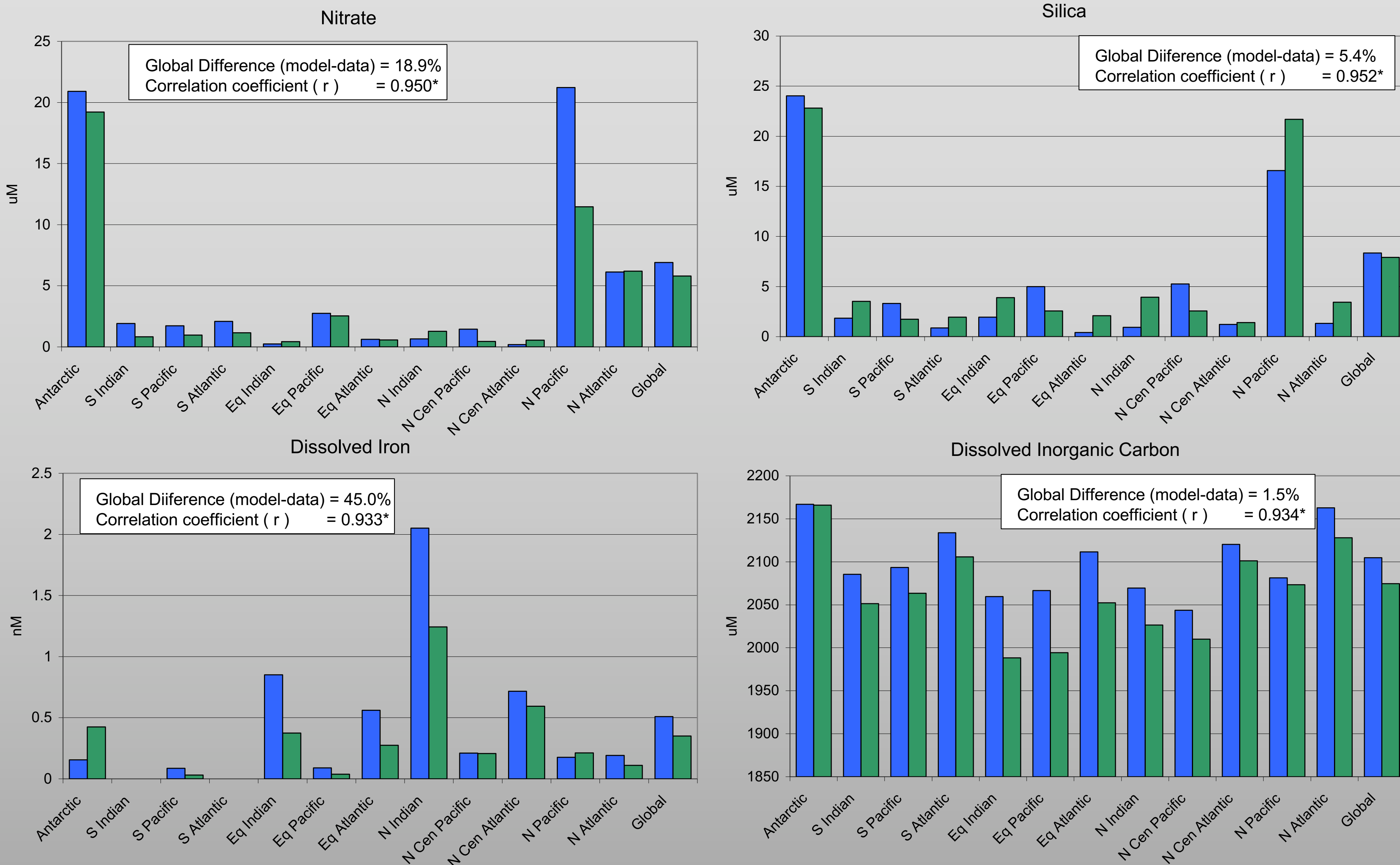
- Chlorophyll, Phytoplankton Groups
- Primary Production
- Nutrients
- DOC, DIC, $pCO_2$
- Spectral Irradiance/Radiance

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

# Biogeochemical Processes Model

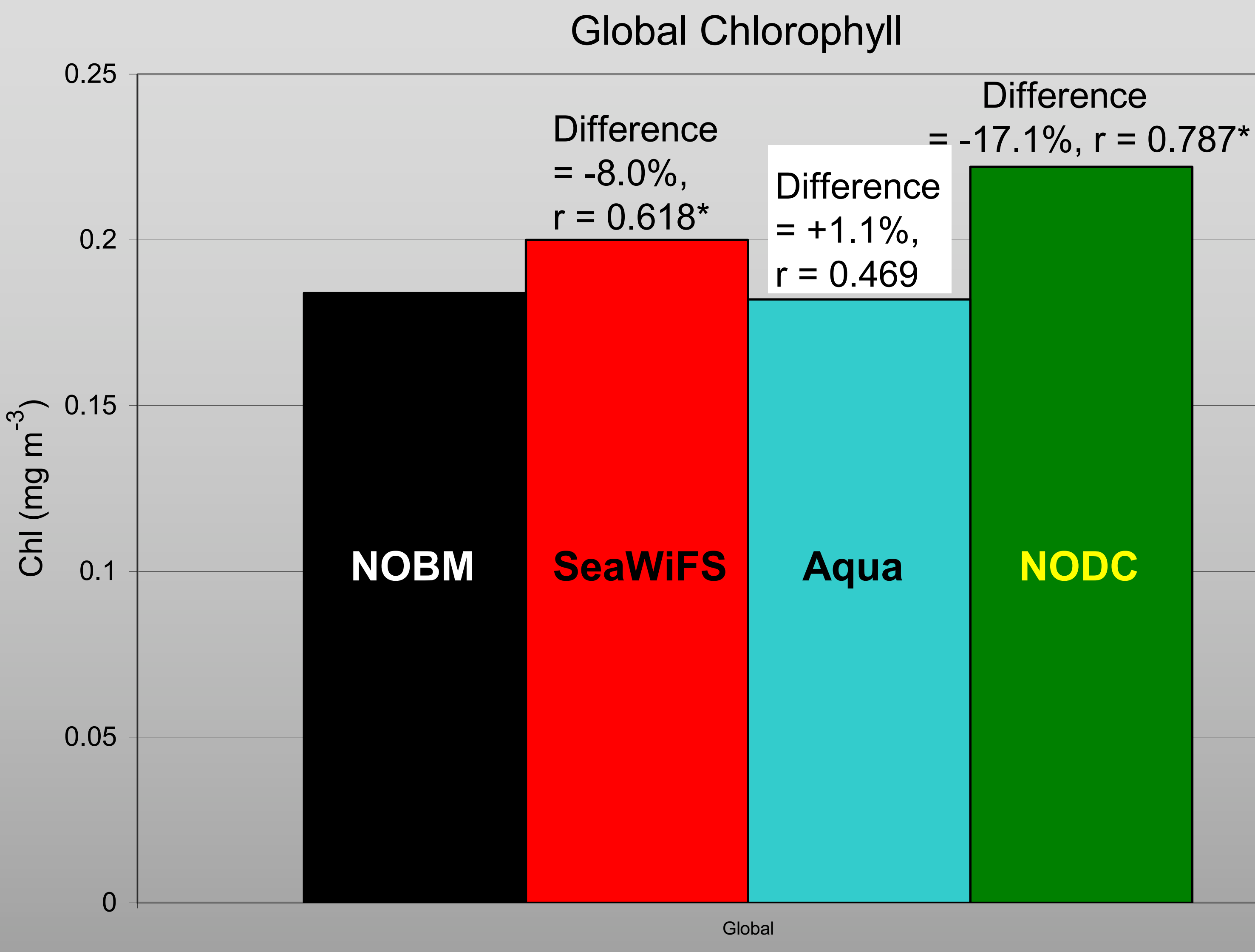
## Ecosystem Component






Blue = NOBM; Green = Data

Gregg and Casey, 2007, Deep-Sea Research II


Global Chlorophyll
Chl (mg m$^{-3}$)
0.25
0.2
0.15
0.1
0.05
0
Difference
= -8.0%,
r = 0.618*
Difference
= +1.1%,
r = 0.469
Difference
= -17.1%, r = 0.787*
NOBM
SeaWiFS
Aqua
NODC
Global

# 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

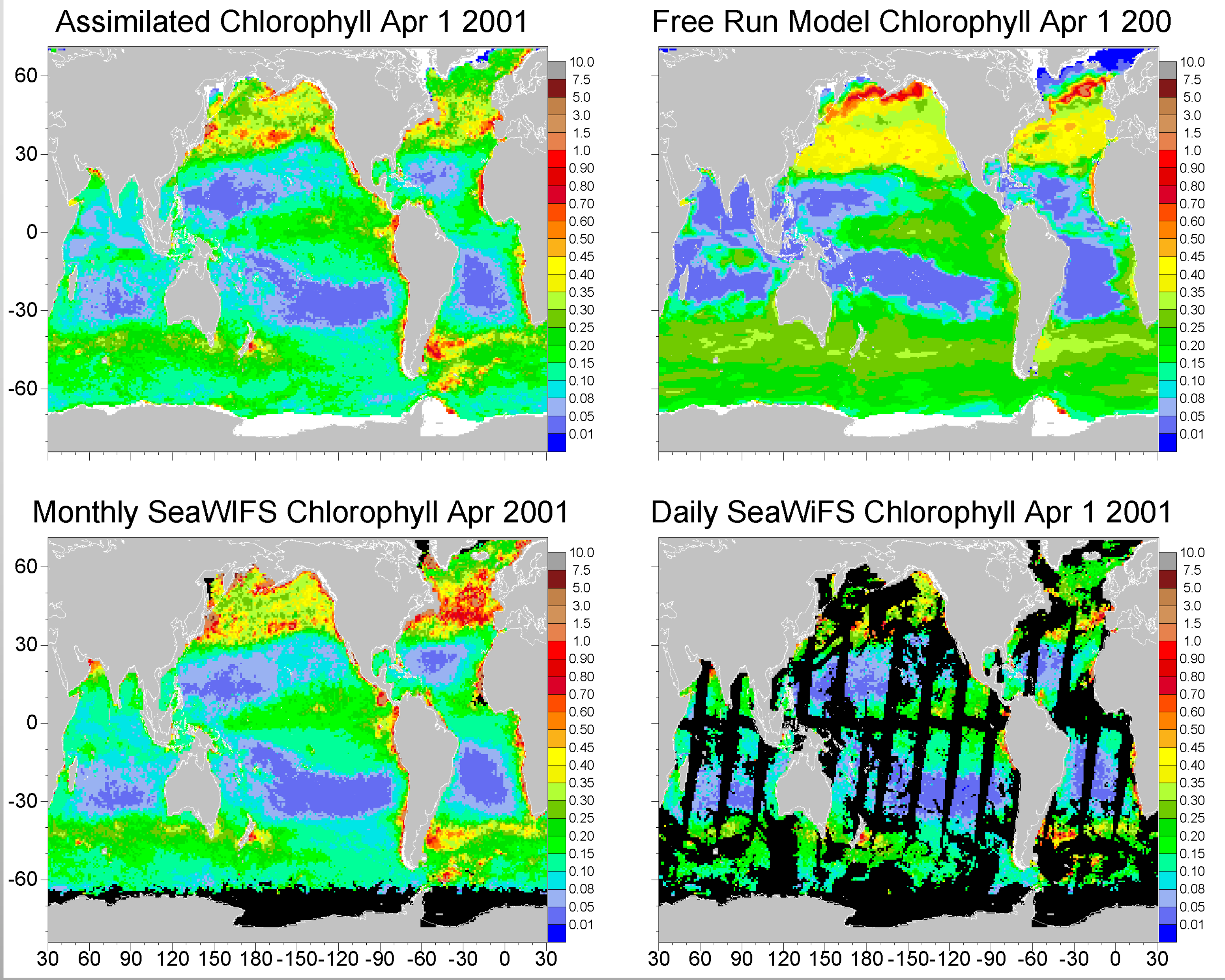
**Daily assimilation** of gridded data into surface layer

Chlorophyll distribution log-normal

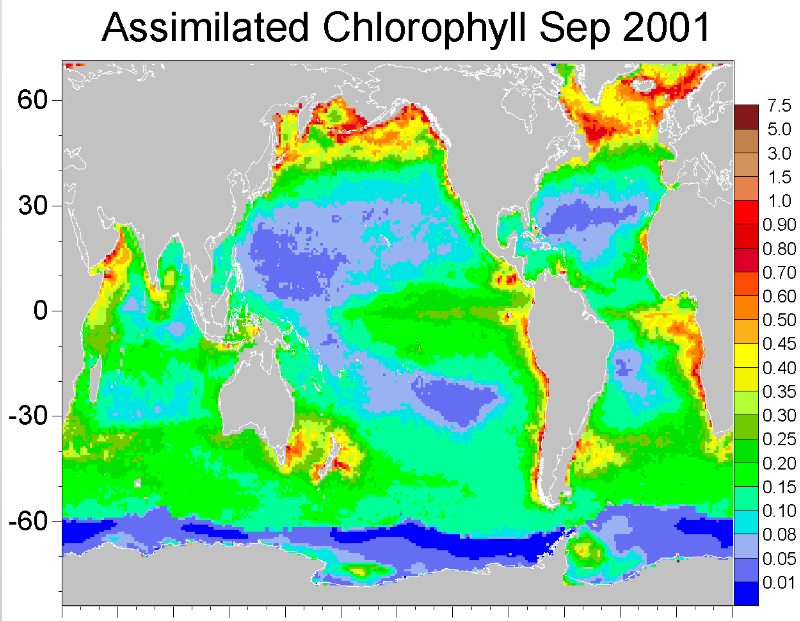
**assimilate logarithmic quantities**

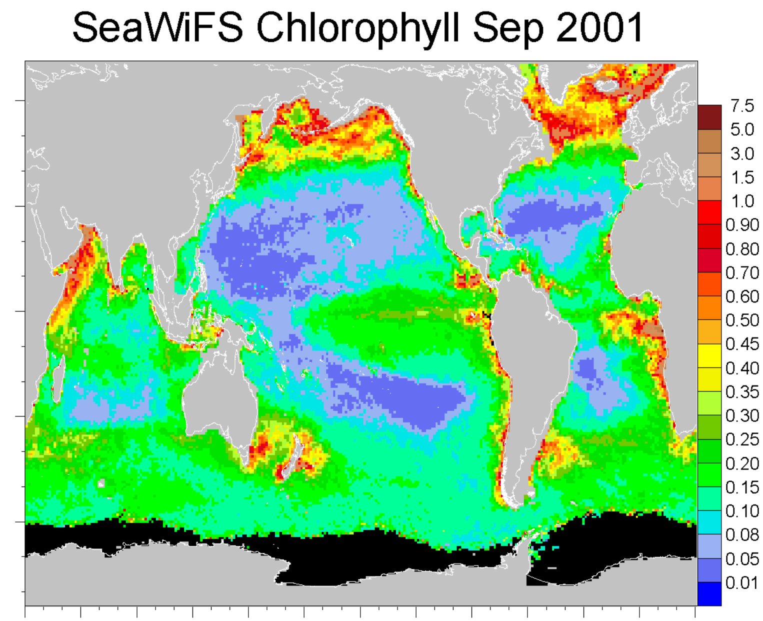
Satellite errors can affect results

**explicitly define regional satellite errors** estimated from global analysis of in situ data

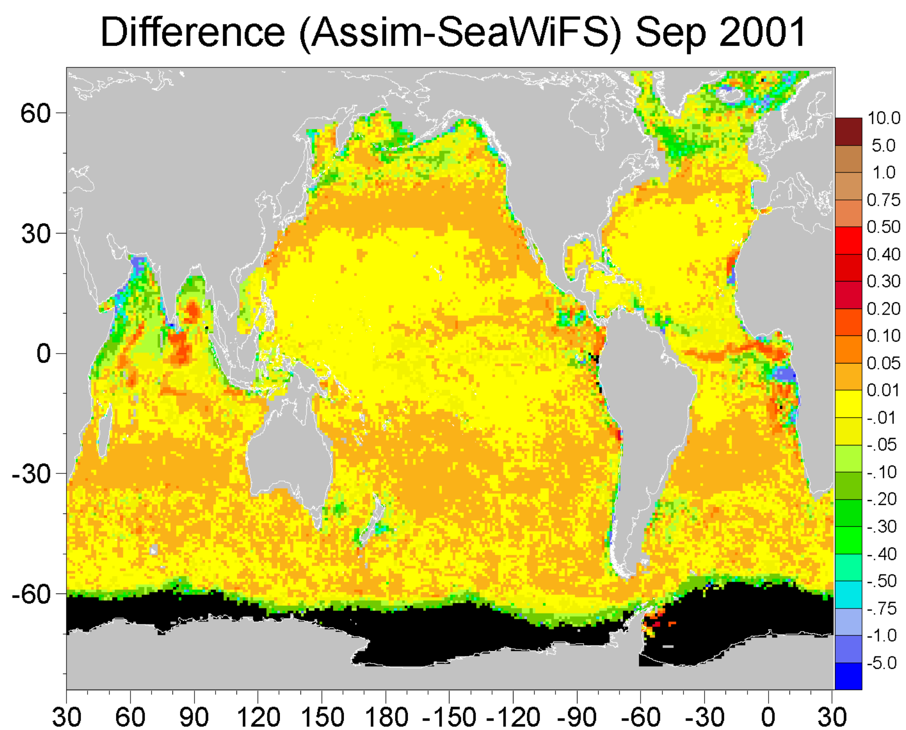



Gregg, 2008. Journal of Marine Systems 69: 205-225.
Nerger and Gregg, 2008. Journal of Marine Systems, in press.
Nerger and Gregg, 2007. Journal of Marine Systems 68: 237-254.




# NASA Ocean Biogeochemical Model (NOBM)




Assim Model vs. SeaWiFS:

Bias = +5.5%

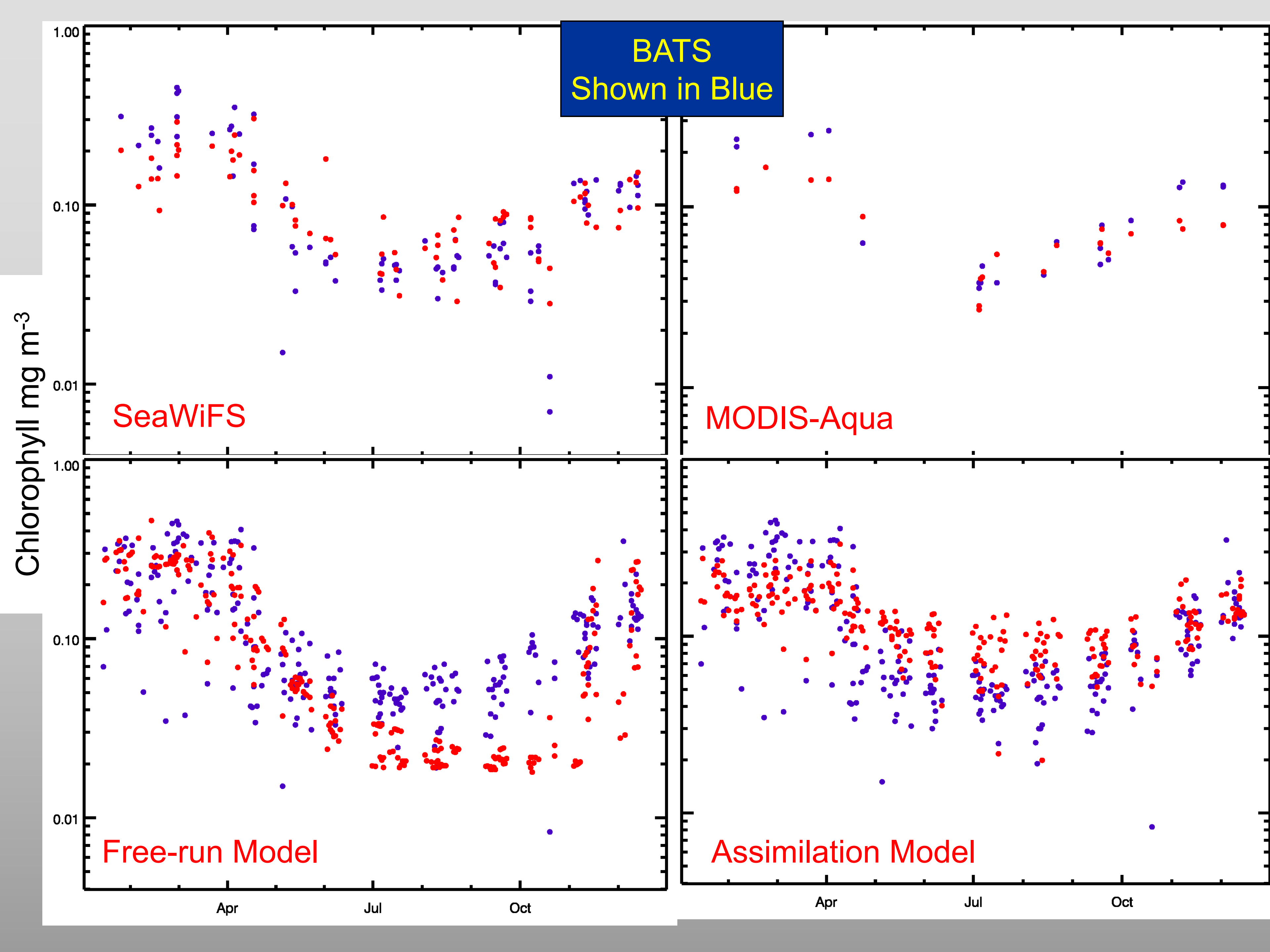
Uncertainty = 10.1%

# Compared to In situ Data

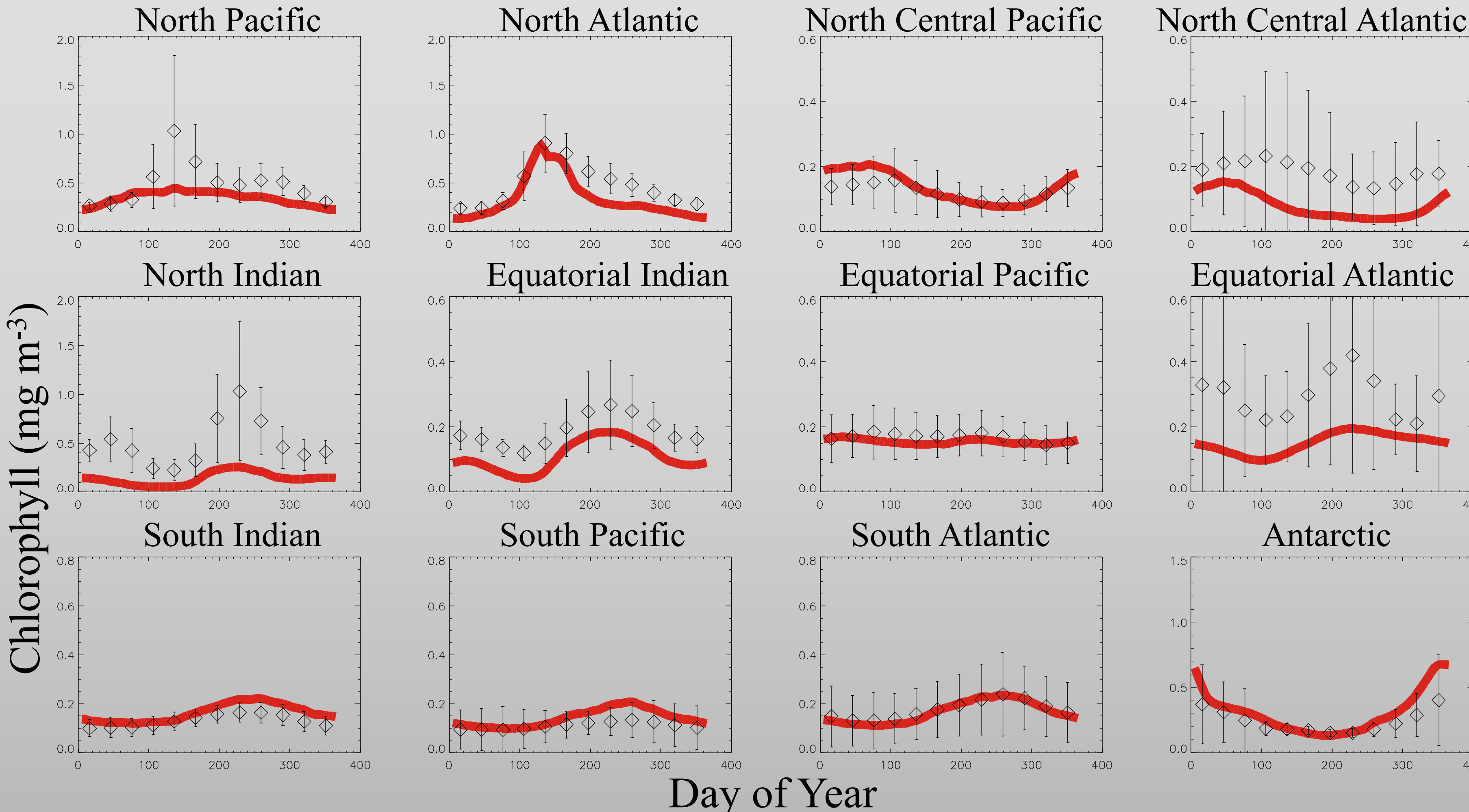
| | Bias | Uncertainty | N |
|---|---|---|---|
| **SeaWiFS** | **-1.3%** | **32.7%** | **2086** |
| **Free-run Model** | **-1.4%** | **61.8%** | **4465** |
| **Assimilation Model** | **0.1%** | **33.4%** | **4465** |

Estimate of in situ data uncertainty: 22%

# Seasonal Variability



BATS
Shown in Blue
Chlorophyll mg m-3
1.00
0.10
0.01
SeaWiFS
MODIS-Aqua
Free-run Model
Assimilation Model
Apr
Jul
Oct



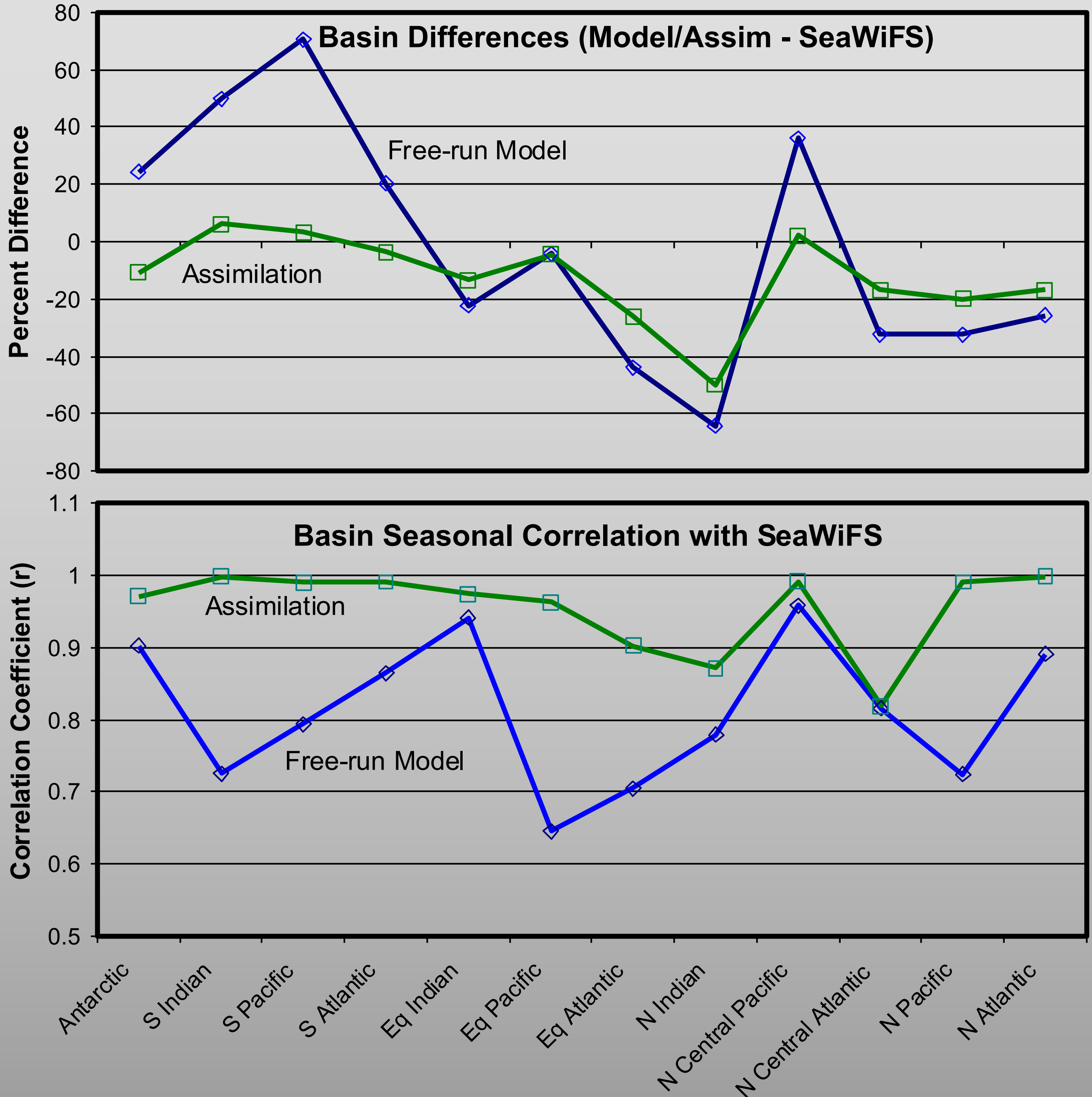

Statistically positively correlated ($P < 0.05$) all 12 basins

Red = model

Diamonds = SeaWiFS monthly mean

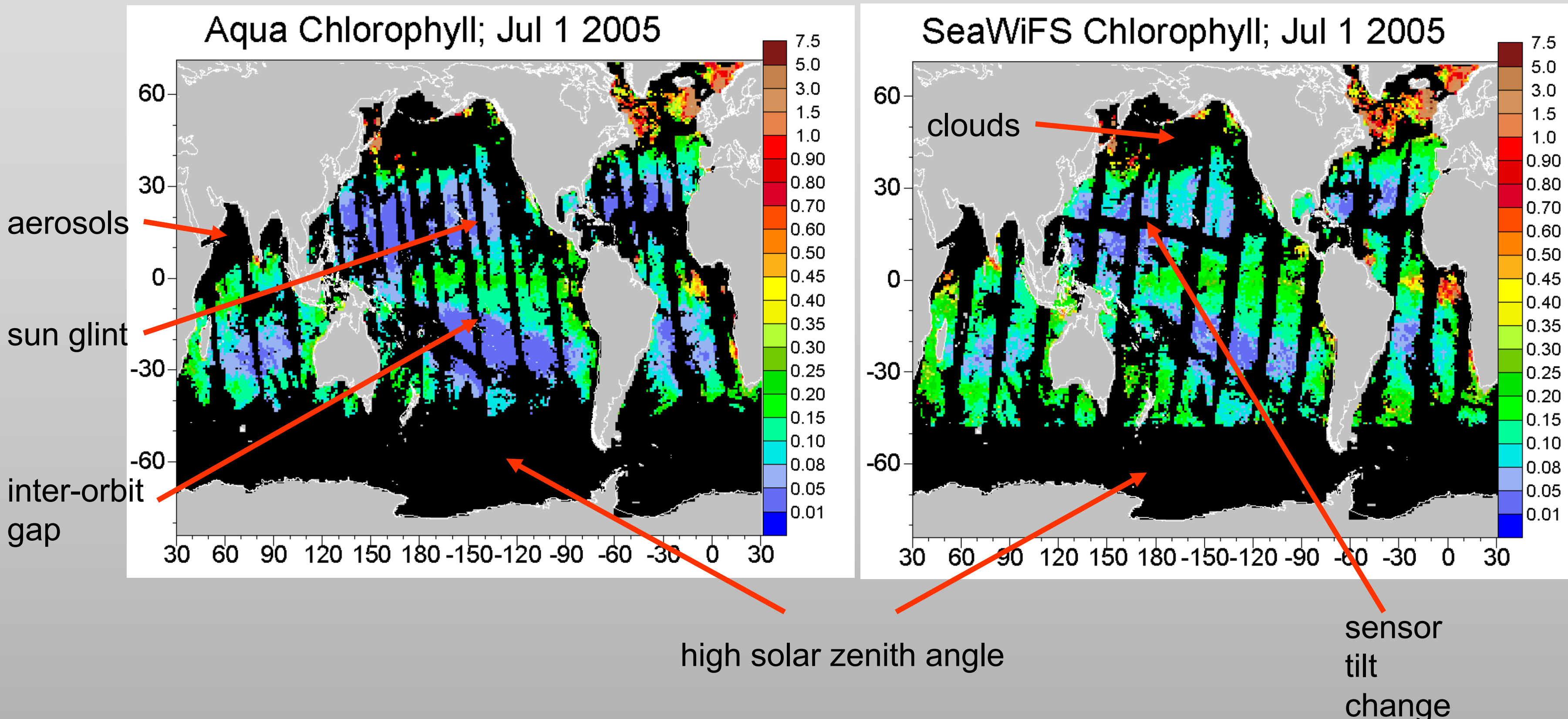
Gregg, 2002, Deep-Sea Research II

Gregg et al., 2003, Deep-Sea Research II

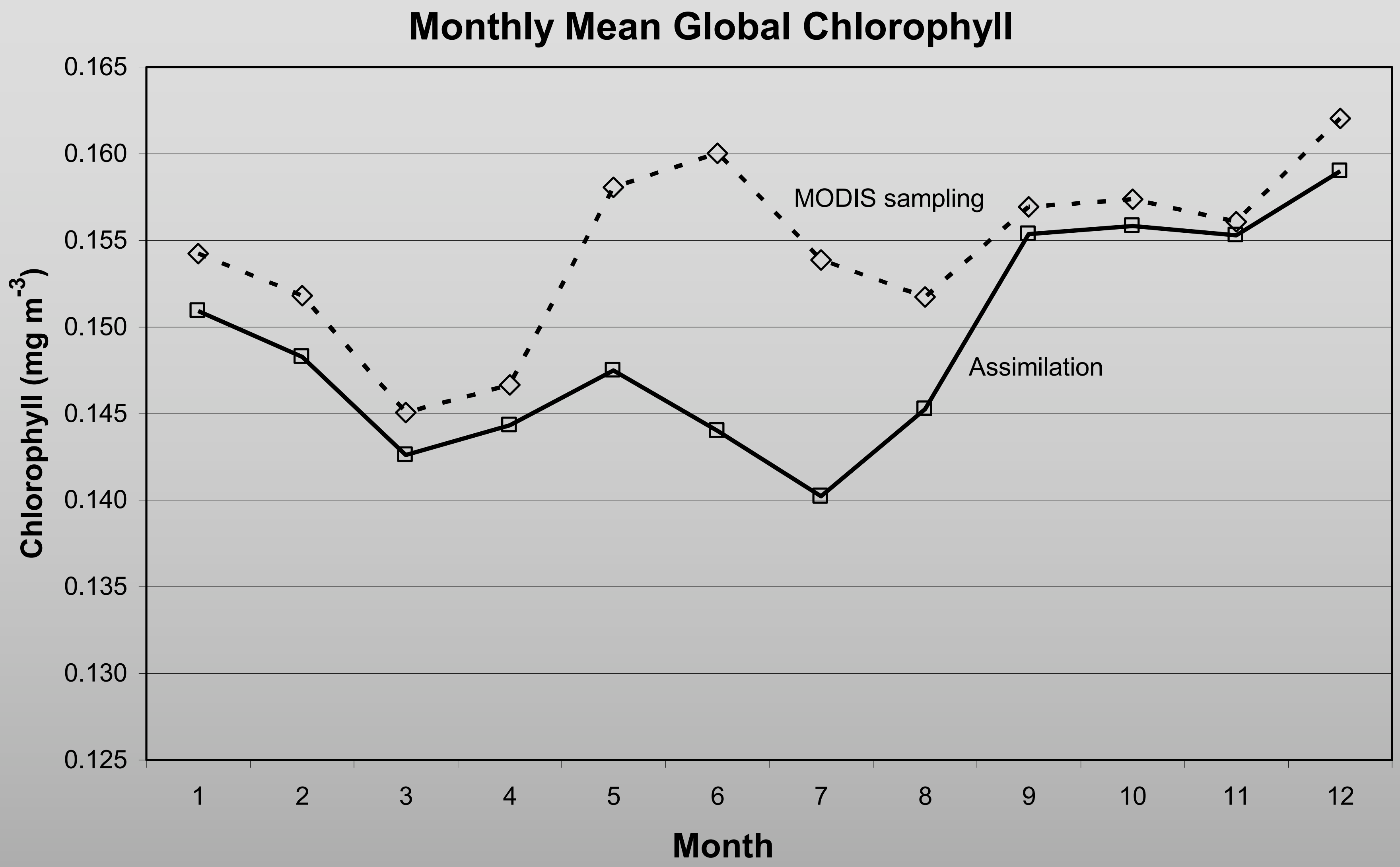


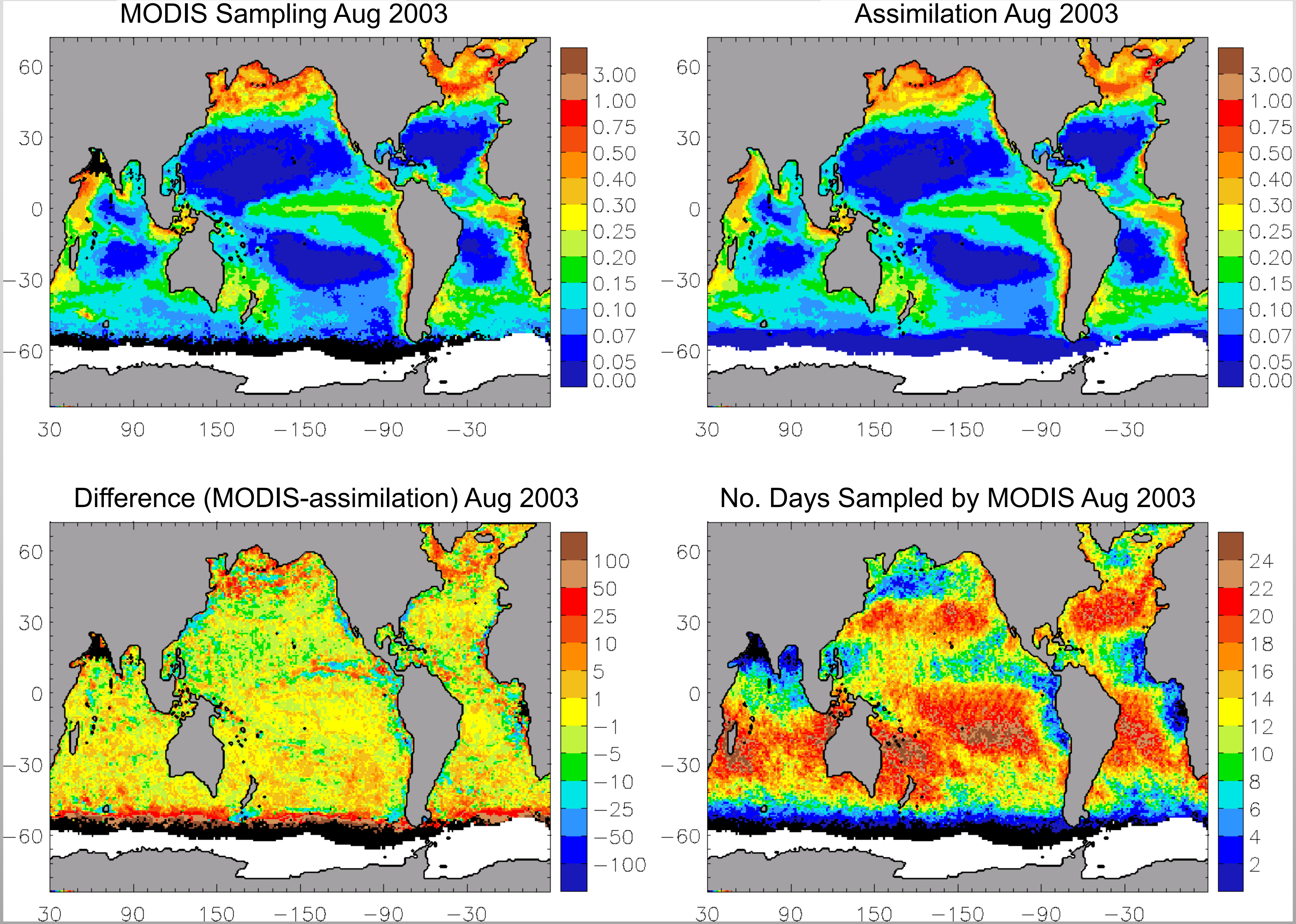
Basin Differences (Model/Assim - SeaWiFS)
Percent Difference
80
60
40
20
0
-20
-40
-60
-80
Free-run Model
Assimilation
Basin Seasonal Correlation with SeaWiFS
Correlation Coefficient (r)
1.1
1
0.9
0.8
0.7
0.6
0.5
Assimilation
Free-run Model
Antarctic
S Indian
S Pacific
S Atlantic
Eq Indian
Eq Pacific
Eq Atlantic
N Indian
N Central Pacific
N Central Atlantic
N Pacific
N Atlantic

Daily ocean coverage by MODIS-Aqua and SeaWiFS.



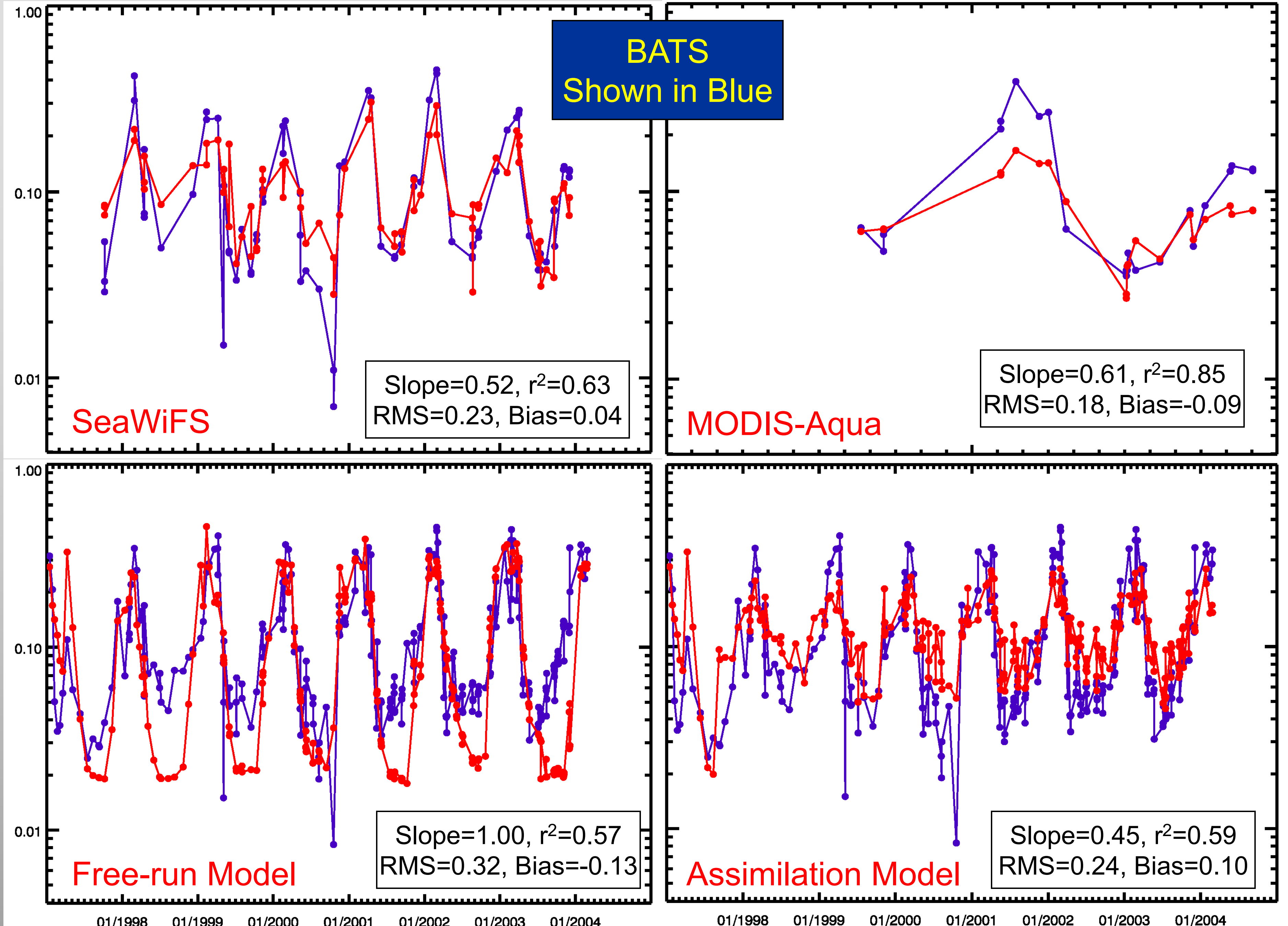

Gregg and Casey, 2007. Remote Sensing of Environment 111: 25-35.


Monthly Mean Global Chlorophyll
Chlorophyll (mg m-3)
0.165
0.160
0.155
0.150
0.145
0.140
0.135
0.130
0.125
MODIS sampling
Assimilation
1
2
3
4
5
6
7
8
9
10
11
12
Month



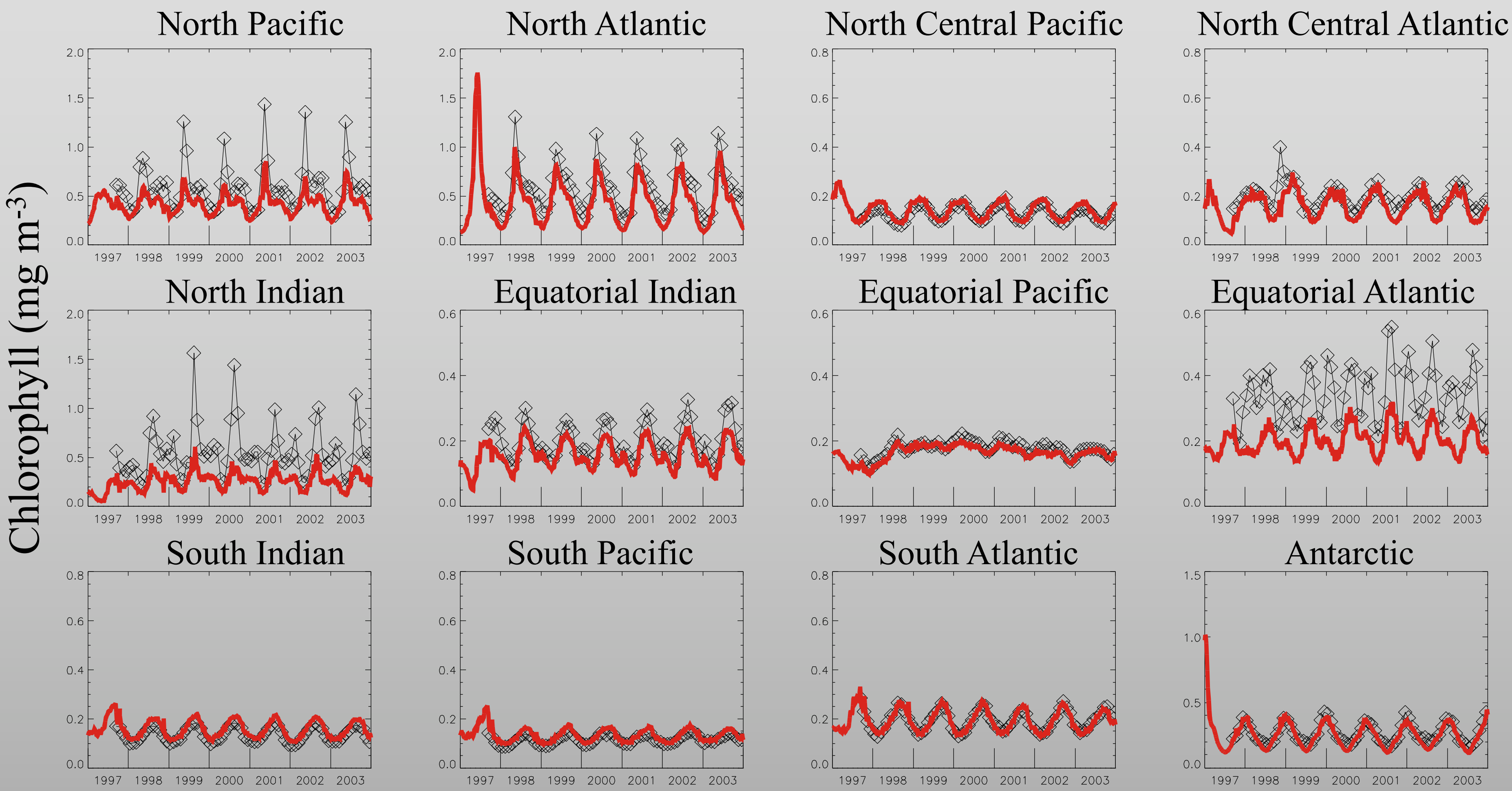
MODIS Sampling Aug 2003
Assimilation Aug 2003
Difference (MODIS-assimilation) Aug 2003
No. Days Sampled by MODIS Aug 2003
60
30
0
−30
−60
30
90
150
−150
−90
−30
3.00
1.00
0.75
0.50
0.40
0.30
0.25
0.20
0.15
0.10
0.07
0.05
0.00
100
50
25
10
5
1
−1
−5
−10
−25
−50
−100
24
22
20
18
16
14
12
10
8
6
4
2

# Interannual Variability




Regression statistics are for log-transformed data

# Interannual Variability, SeaWiFS and Assimilation



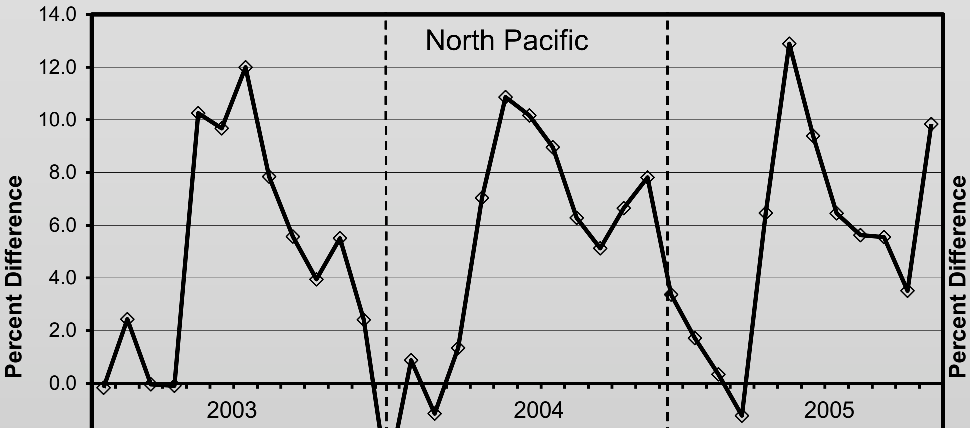

**Red = Assimilation model**

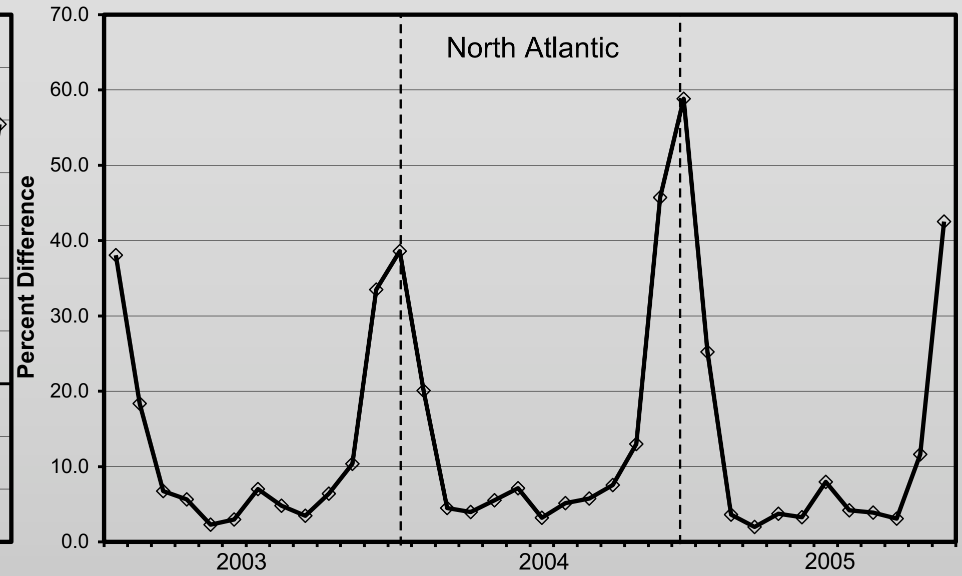
Diamonds = SeaWiFS monthly mean

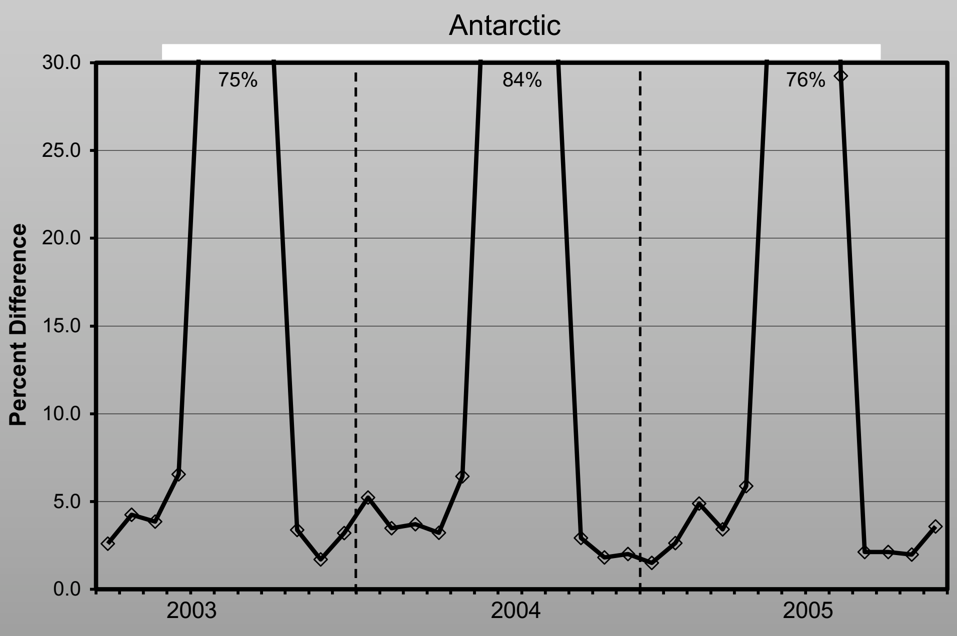
Gregg, 2008, Journal of Marine Systems

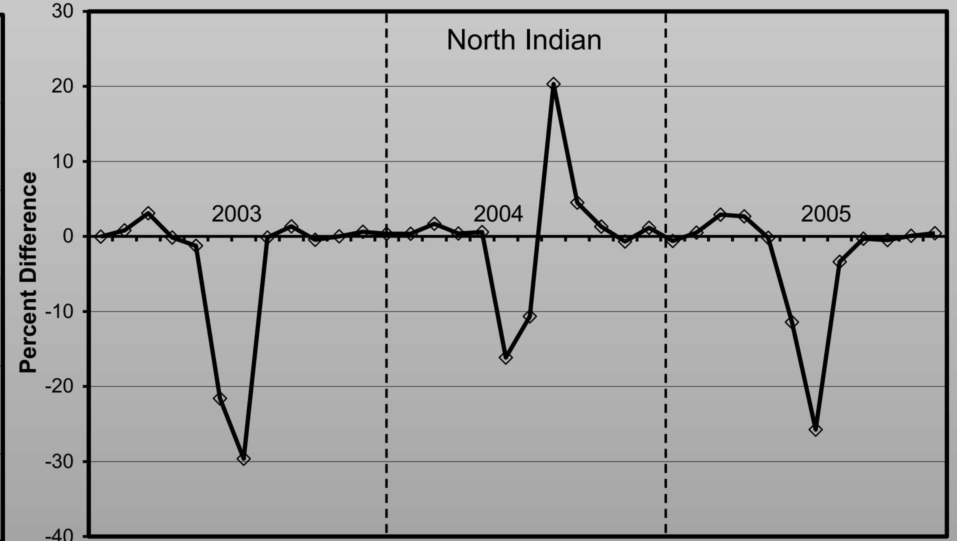
Nerger and Gregg, 2007, Journal of Marine Systems

# Monthly Mean Percent Difference Aqua-MODIS and Assimilation



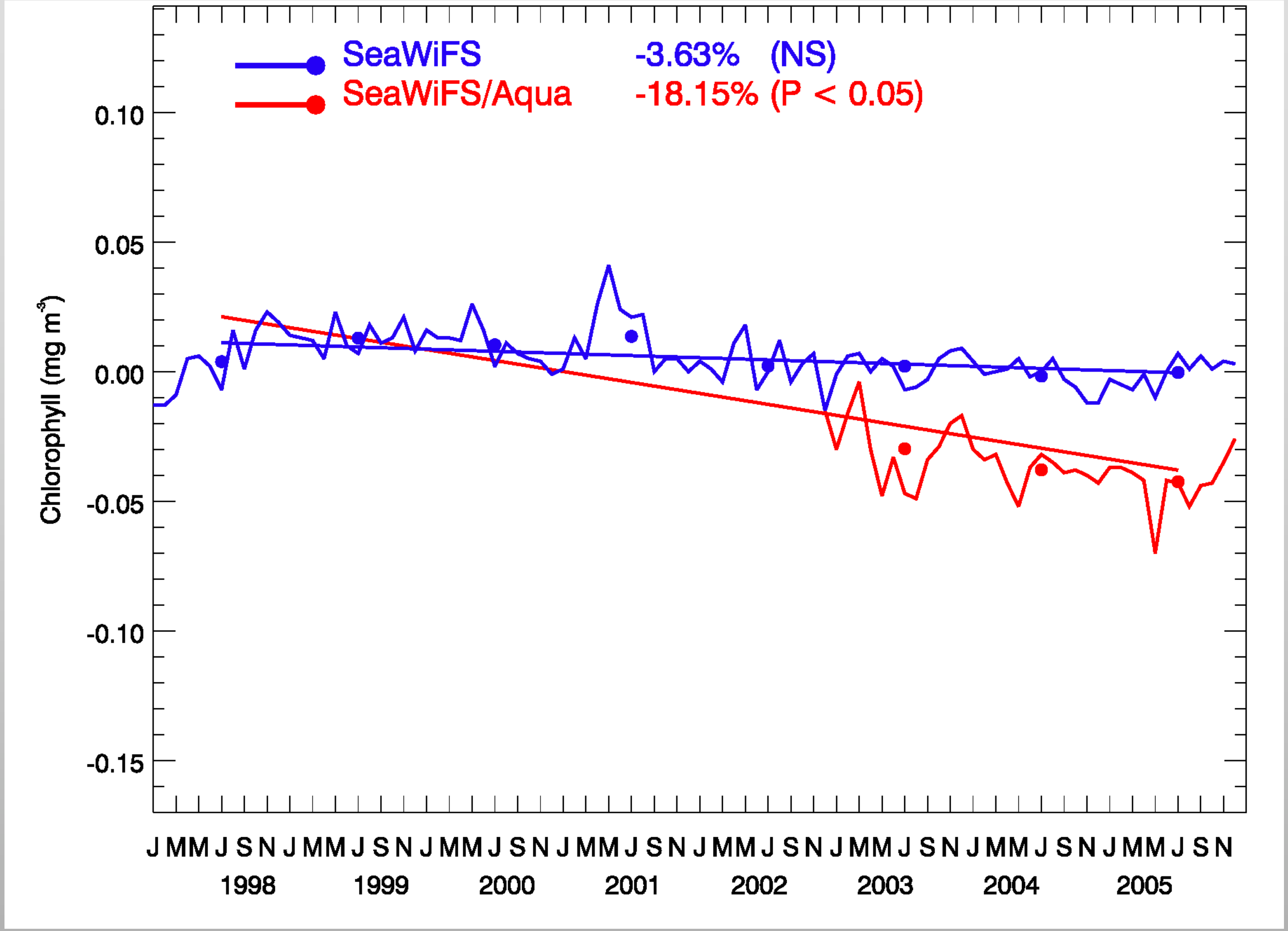



# Decadal and Longer Trends

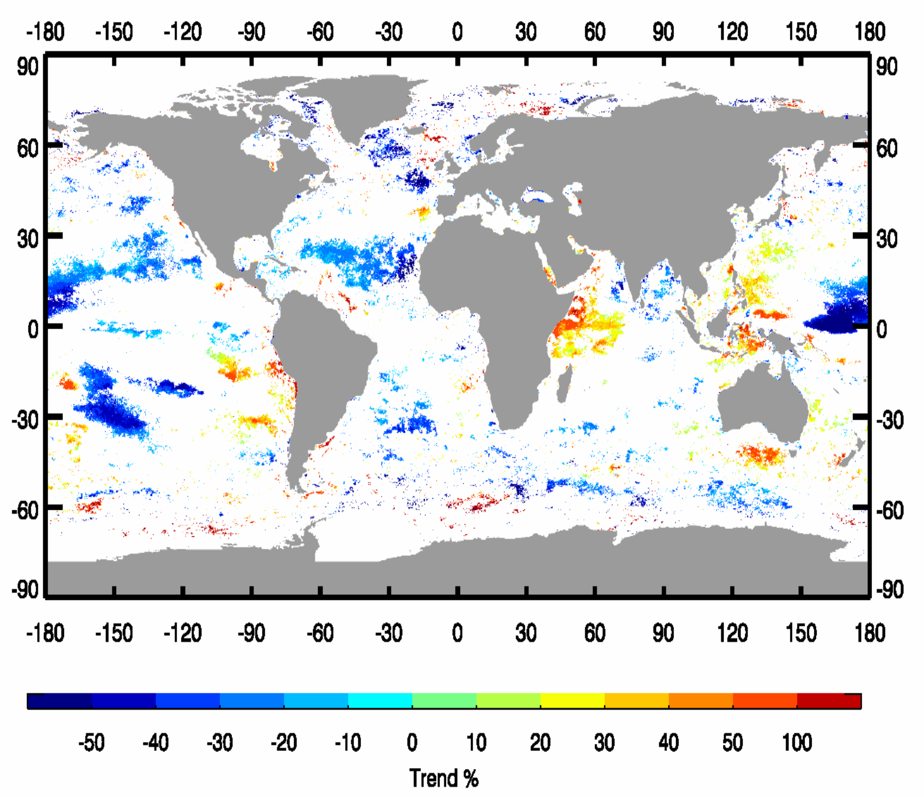
# Global Annual Anomaly Trends with SeaWiFS, and SeaWiFS/Aqua



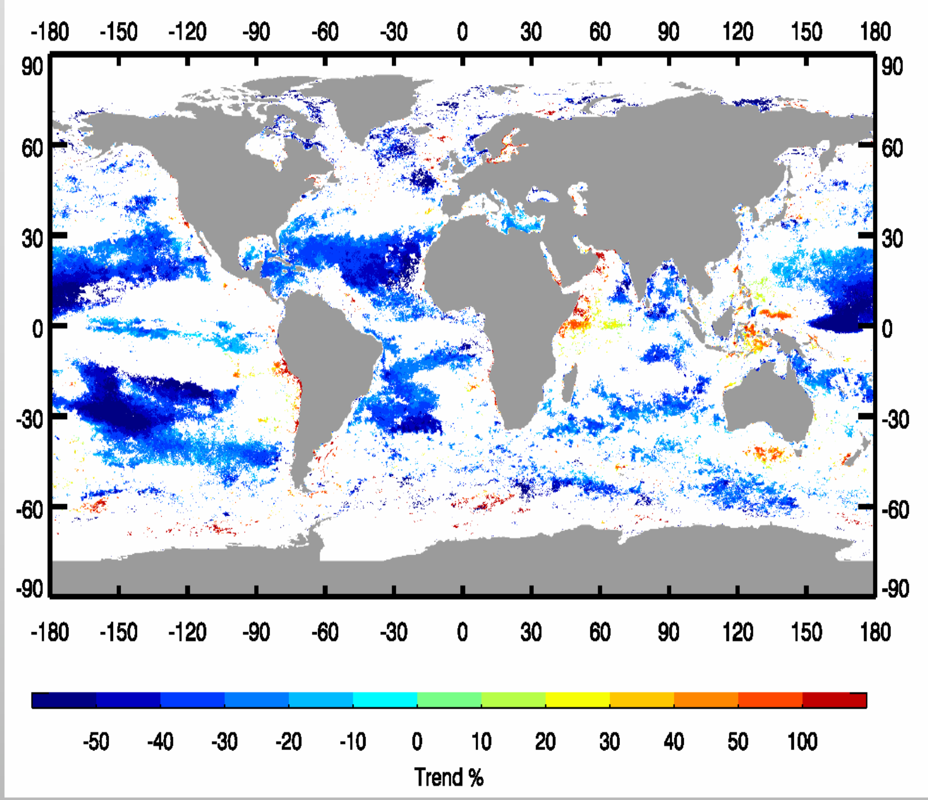

Same calibration, same algorithms, same processing

# Regional Annual Trends

SeaWiFS

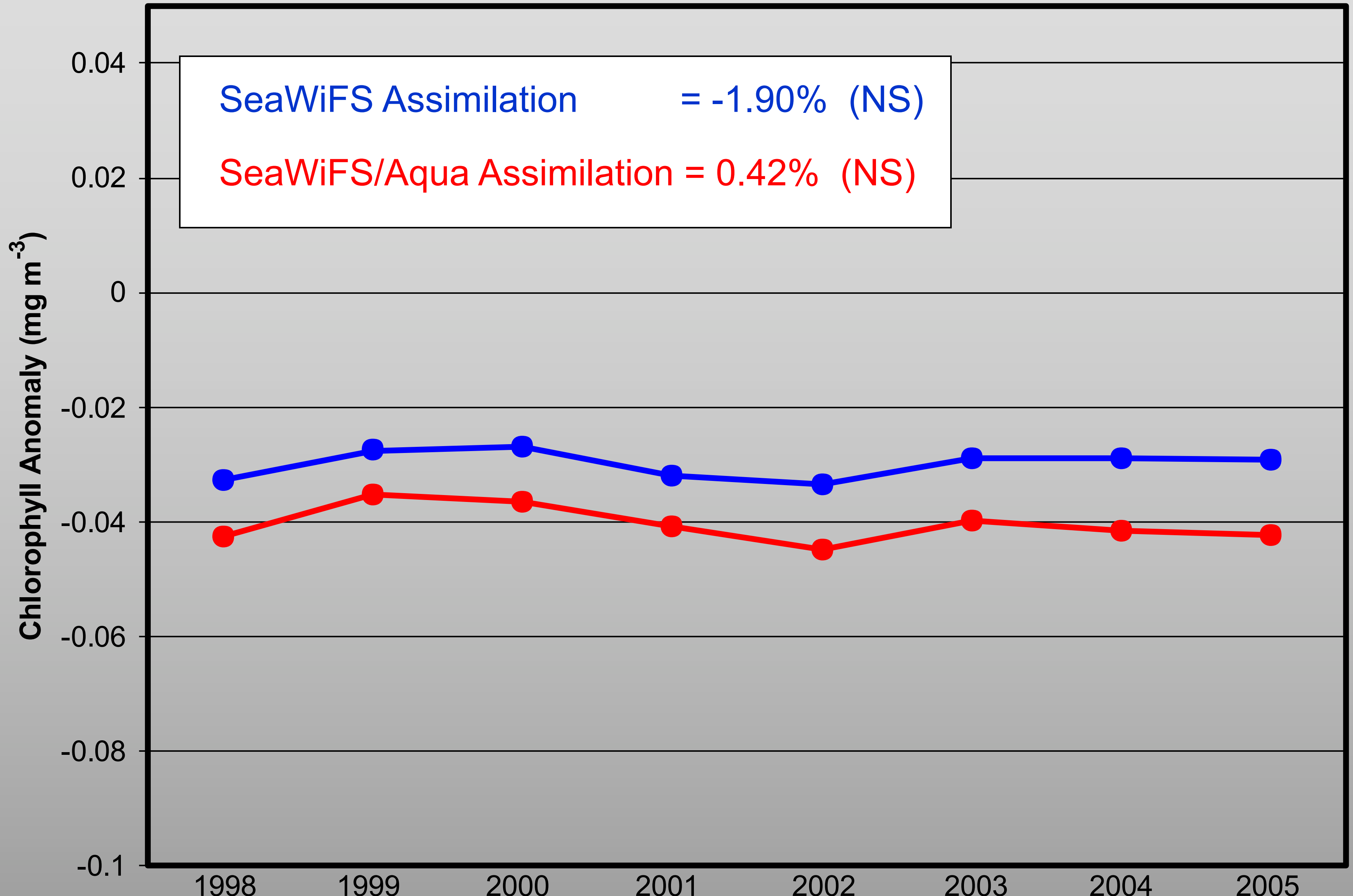



SeaWiFS/Aqua




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



# 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?

| Sampling % | Global Difference | Maximum difference by basin |
|---|---|---|
| 10% sampling (about 1500 obs/day) | -2.3% | -7.6% North Pacific |
| 1% sampling (about 150 obs/day) | 1.4% | -21.9% North Indian |

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.

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basin | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| North Atlantic | 2% | 1% | 1% | 2% | 1% | 1% | 2% | 10% | 10% | 2% | 10% | 5% |
| North Pacific | 2% | 1% | 5% | 5% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 2% |
| North Central Atlantic | 5% | 1% | 5% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| North Central Pacific | 2% | 5% | 1% | 0% | 5% | 1% | 1% | 1% | 1% | 5% | 5% | 1% |
| North Indian | 2% | 10% | 10% | 10% | 10% | 2% | 2% | 10% | 2% | 2% | 2% | 2% |
| Equatorial Atlantic | 5% | 10% | 2% | 10% | 2% | 10% | 2% | 2% | 2% | 5% | 1% | 5% |
| Equatorial Pacific | 5% | 5% | 0% | 0% | 0% | 0% | 1% | 1% | 1% | 1% | 1% | 1% |
| Equatorial Indian | 1% | 2% | 2% | 2% | 1% | 1% | 5% | 5% | 5% | 1% | 1% | 5% |
| South Atlantic | 0% | 0% | 0% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 5% | 2% |
| South Pacific | 2% | 2% | 5% | 0% | 1% | 5% | 5% | 2% | 5% | 5% | 5% | 5% |
| South Indian | 10% | 0% | 0% | 0% | 1% | 1% | 1% | 1% | 1% | 5% | 2% | 2% |
| Antarctic | 2% | 2% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 2% |