# Modeling and Data Assimilation of Ocean Biology Using MODIS Data

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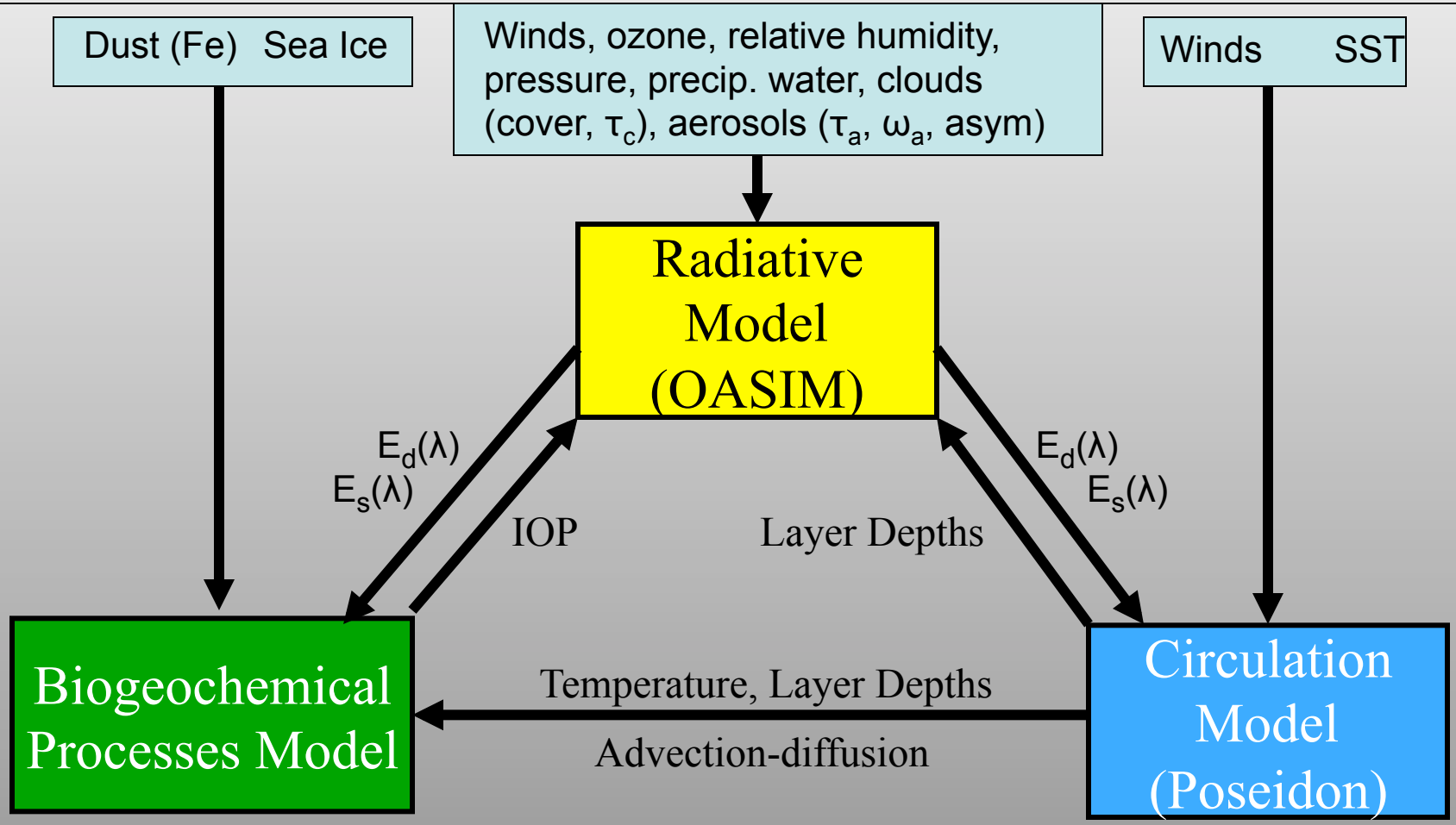
Surface Spectral Irradiance

Model Validation

Data Assimilation

# NASA Ocean Biogeochemical Model (NOBM)

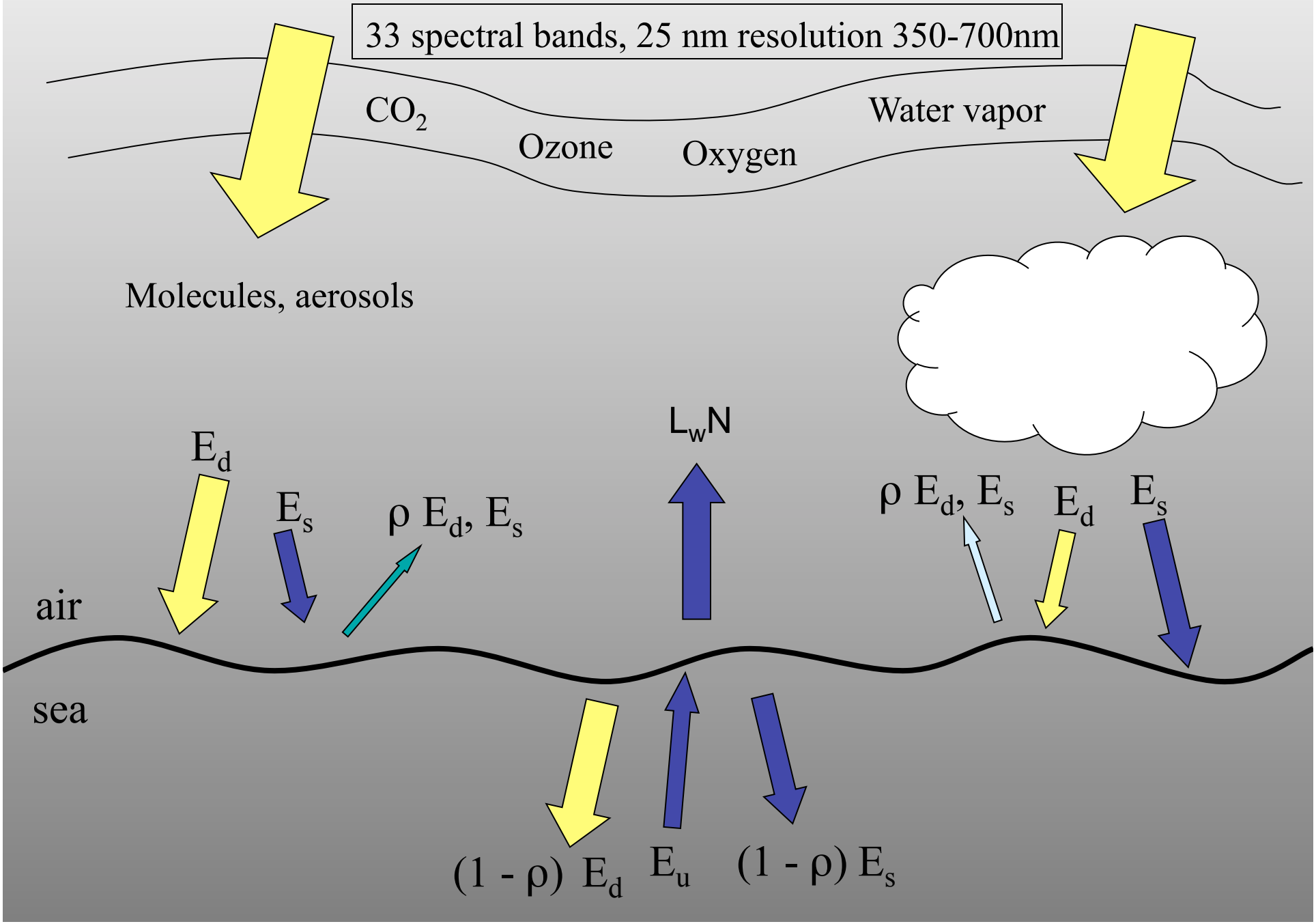



Outputs:

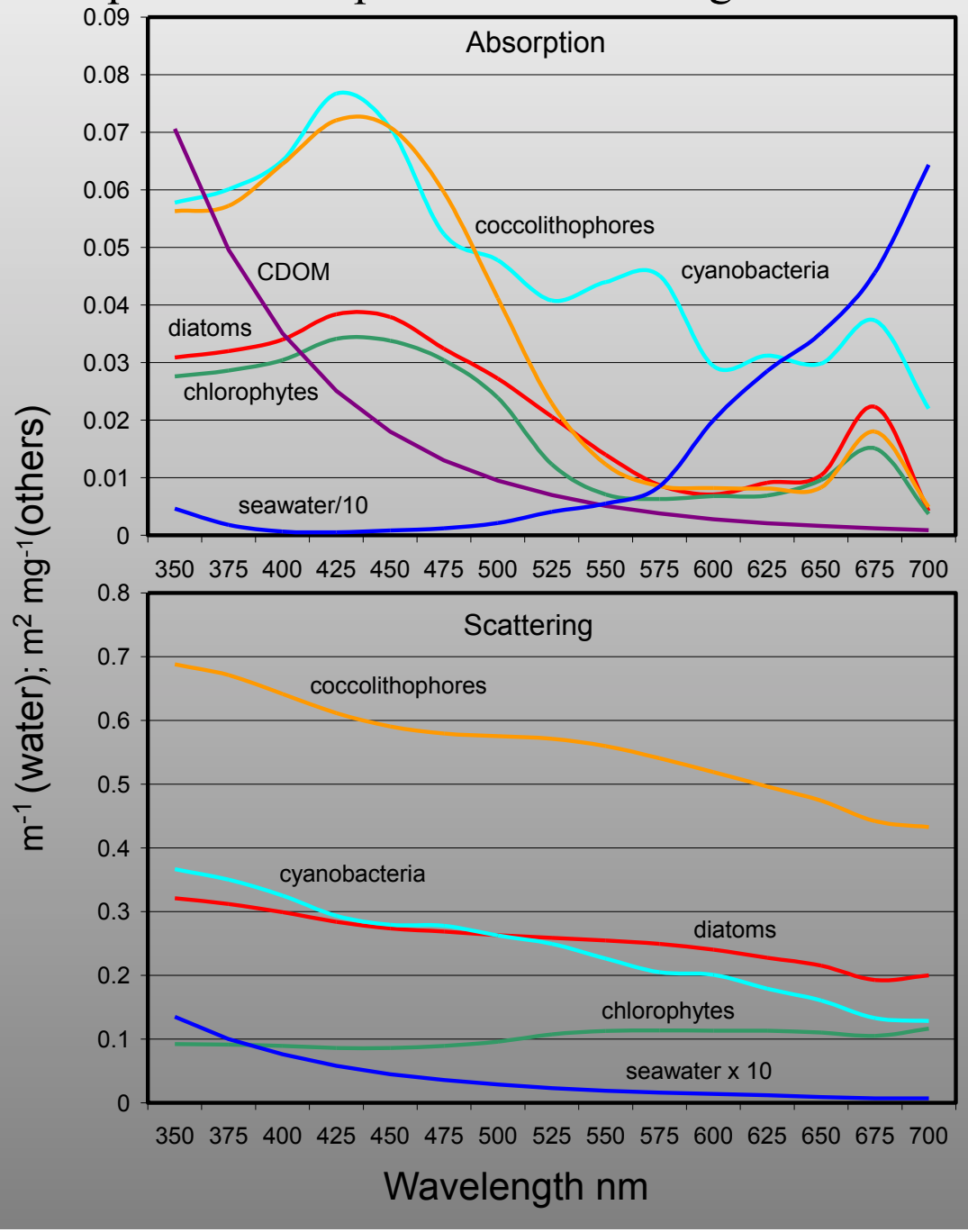
- Chlorophyll, Phytoplankton Groups
- Primary Production
- Nutrients
- DOC, DIC, $pCO_2$
- Spectral Irradiance/Radiance

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

# OASIM (Ocean-Atmosphere Spectral Irradiance Model)

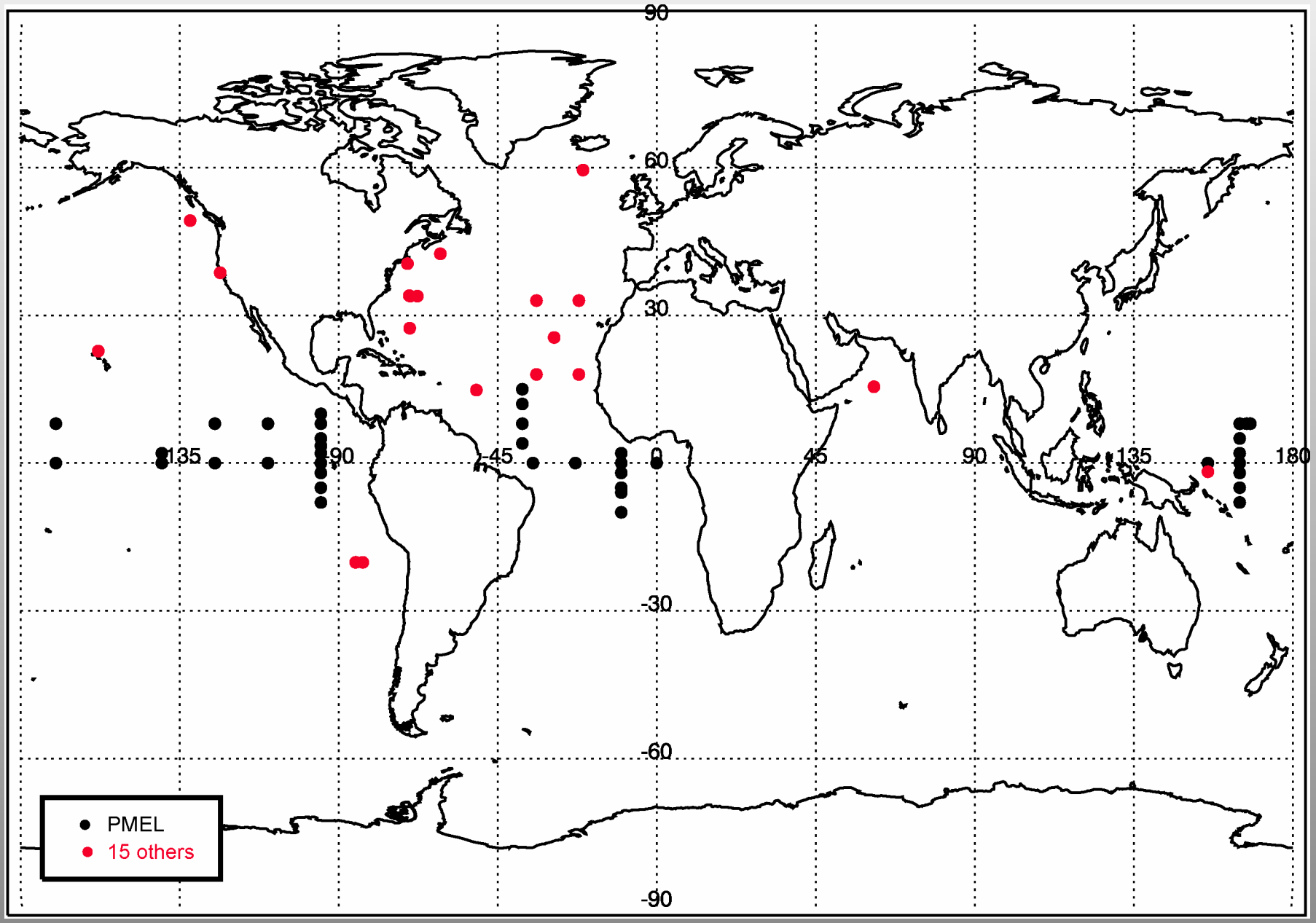


# Spectral absorption and scattering coefficients

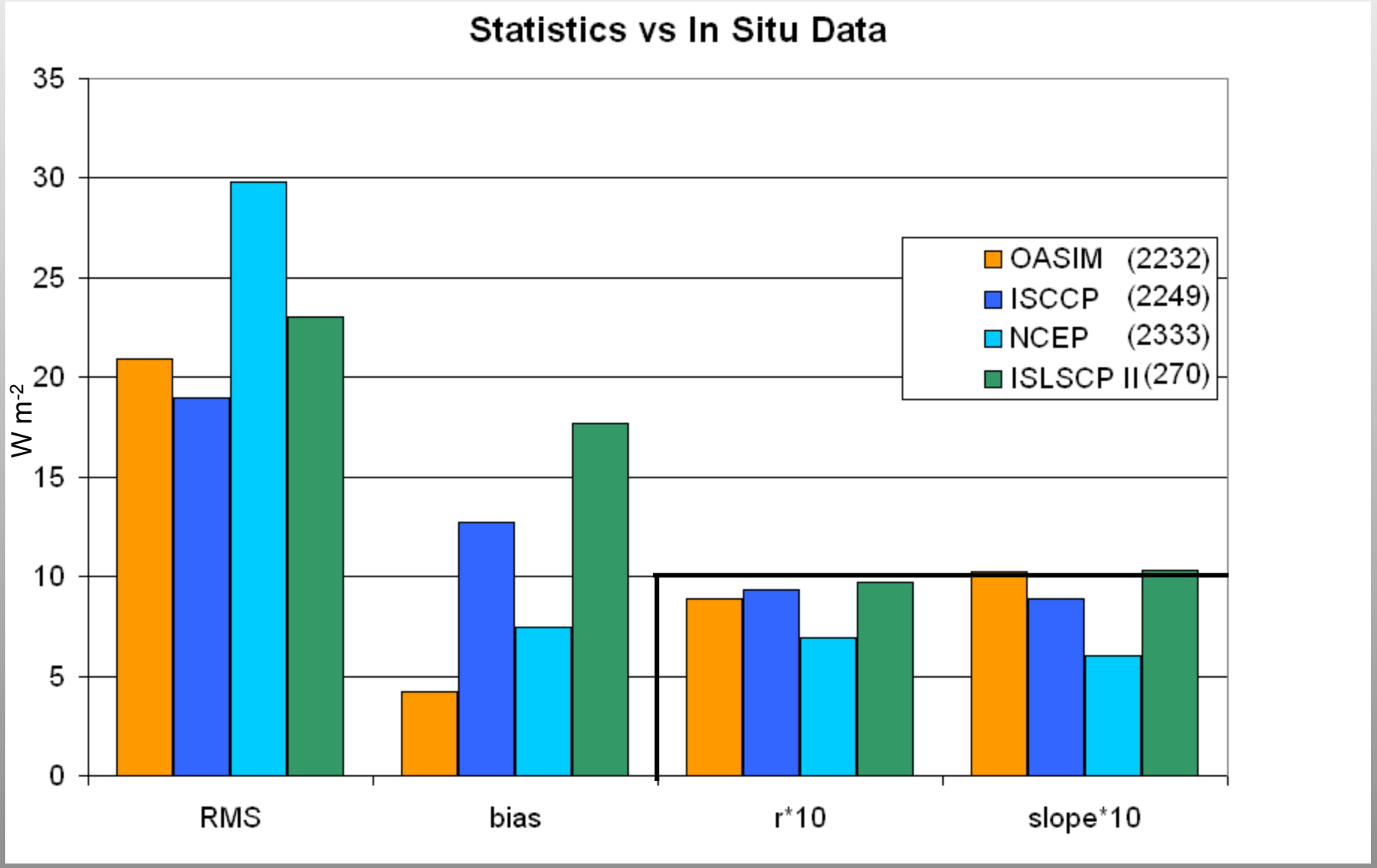


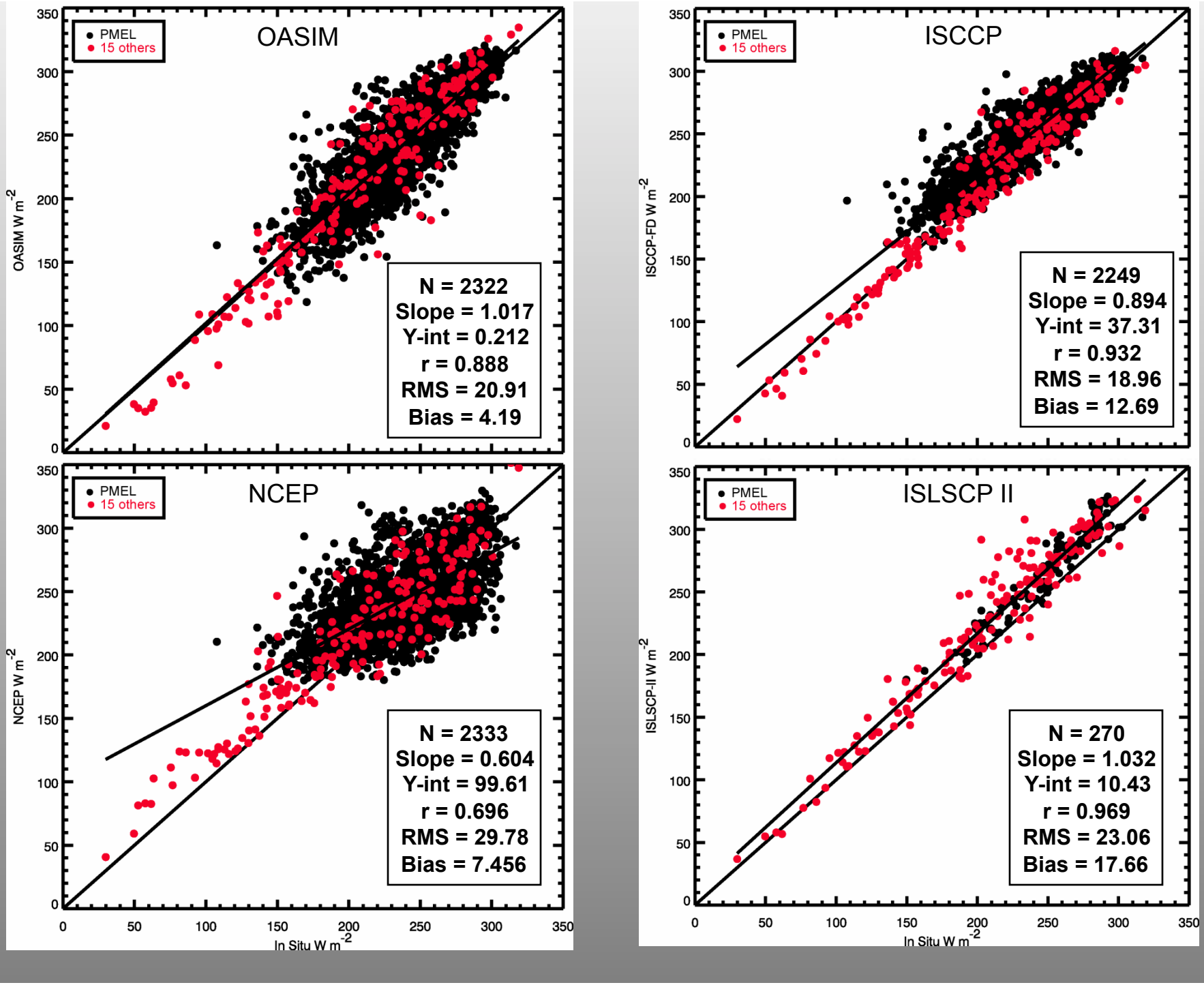
Data sets needed for OASIM and dates available. ISCCP is the International Satellite Cloud Climatology Project; MODIS is the Moderate Resolution Imaging Spectroradiometer (Terra and Aqua are spacecraft); AVHRR is the Advanced Very High Resolution Radiometer; TOMS is the Total Ozone Mapping Spectrometer (Nimbus-7 and EP (Earth Probe) are spacecraft); and MERRA is the Modern-Era Retrospective analysis for Research and Applications .

| | 1981 | 1983/06 | 1993/05 | 1996/07 | 2000/03 | 2002/07 |
|---|---|---|---|---|---|---|
| **Clouds** | | | | | | |
| **Cover** | ISCCP climatology | ISCCP → | → | → | → | → |
| **LWP** | ISCCP climatology | ISCCP → | → | → | → | → |
| **$r_e$** | **MODIS climatology** → | → | → | → | **MODIS-Terra** → | **MODIS-Terra+Aqua** |
| **Aerosols** | | | | | | |
| **$\tau_a$** | AVHRR → | → | → | → | **MODIS-Terra** → | **MODIS-Terra+Aqua** |
| **$\omega_a$** | **MODIS climatology** → | → | → | → | **MODIS-Terra** → | **MODIS-Terra+Aqua** |
| **asymmetry** | **MODIS climatology** → | → | → | → | **MODIS-Terra** → | **MODIS-Terra+Aqua** |
| **Ozone** | Nimbus-7 TOMS → | → | Climatology → | EP-TOMS → | → | → |
| **Sfc Pressure** | MERRA → | → | → | → | → | → |
| **Wind Speed** | MERRA → | → | → | → | → | → |
| **Rel. humidity** | MERRA → | → | → | → | → | → |
| **Precip. water** | MERRA → | → | → | → | → | → |




In situ observations of total surface irradiance. (>2000 observations)

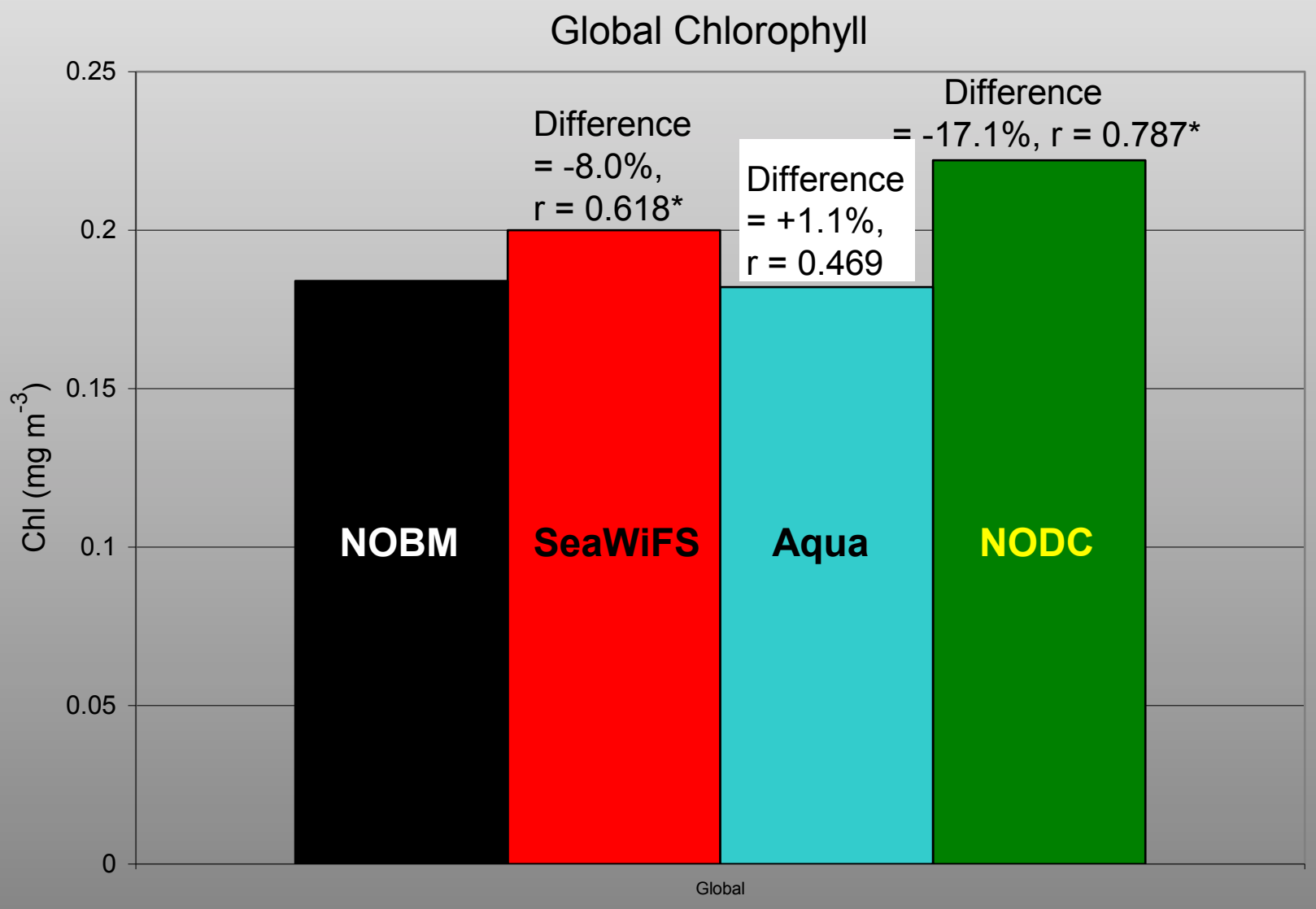

Statistics vs In Situ Data
35
30
25
20
15
10
5
0
W m-2
OASIM (2232)
ISCCP (2249)
NCEP (2333)
ISLSCP II (270)
RMS
bias
r*10
slope*10


OASIM
PMEL
15 others
N = 2322
Slope = 1.017
Y-int = 0.212
r = 0.888
RMS = 20.91
Bias = 4.19
OASIM W m-2
ISCCP
PMEL
15 others
N = 2249
Slope = 0.894
Y-int = 37.31
r = 0.932
RMS = 18.96
Bias = 12.69
ISCCP-FD W m-2
NCEP
PMEL
15 others
N = 2333
Slope = 0.604
Y-int = 99.61
r = 0.696
RMS = 29.78
Bias = 7.456
NCEP W m-2
ISLSCP II
PMEL
15 others
N = 270
Slope = 1.032
Y-int = 10.43
r = 0.969
RMS = 23.06
Bias = 17.66
ISLSCP-II W m-2
In Situ W m-2

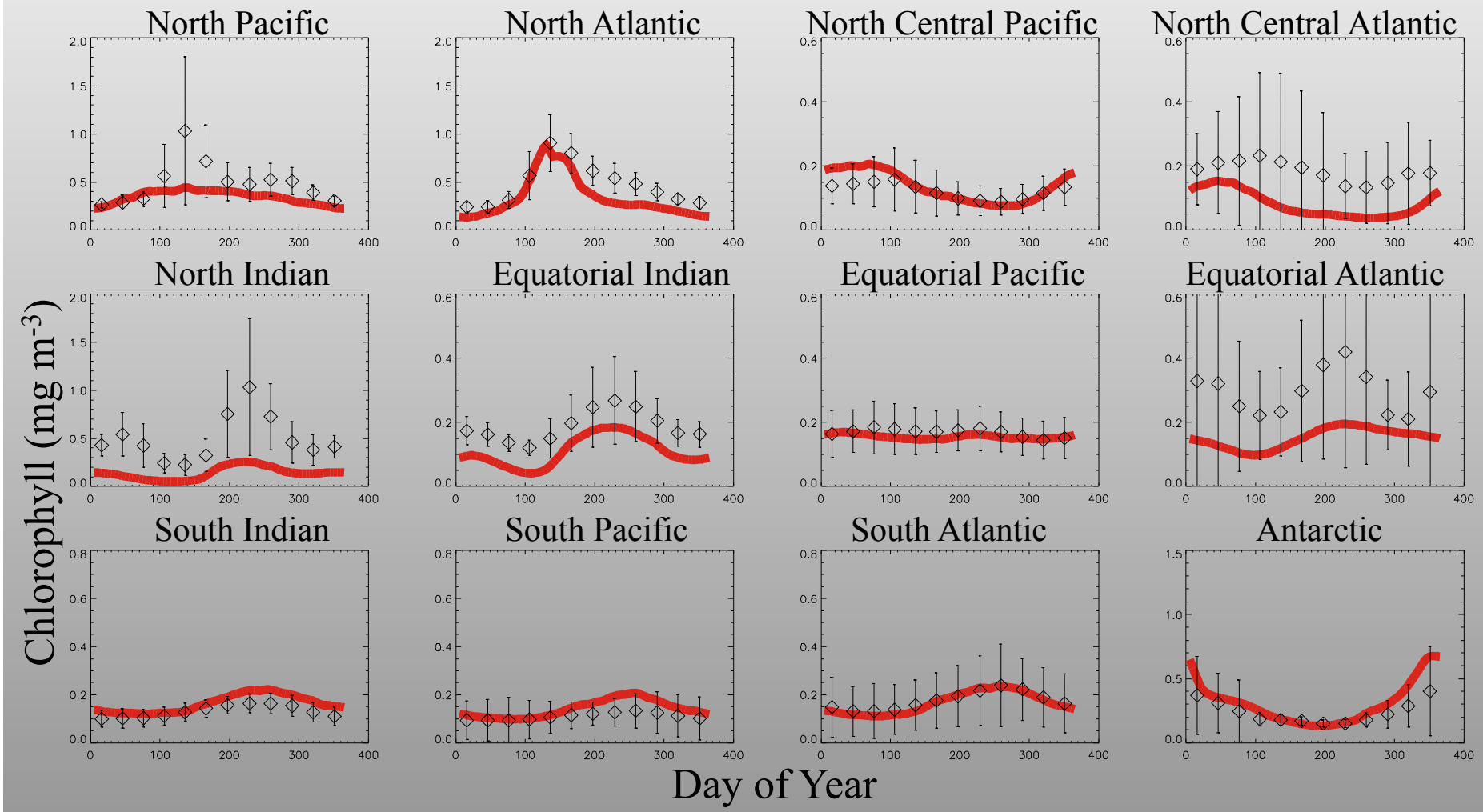
# Model Validation

Most common use of MODIS data

How well does the model perform?


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

# Seasonal Correlation




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

Red = model

Diamonds = MODIS monthly mean

# Data Assimilation

Incorporation of data into a model via constant confrontation

Now becoming established in ocean biology
>50 papers using data, 12 using satellite data
(Gregg et al., Journal of Marine Systems, 2009)

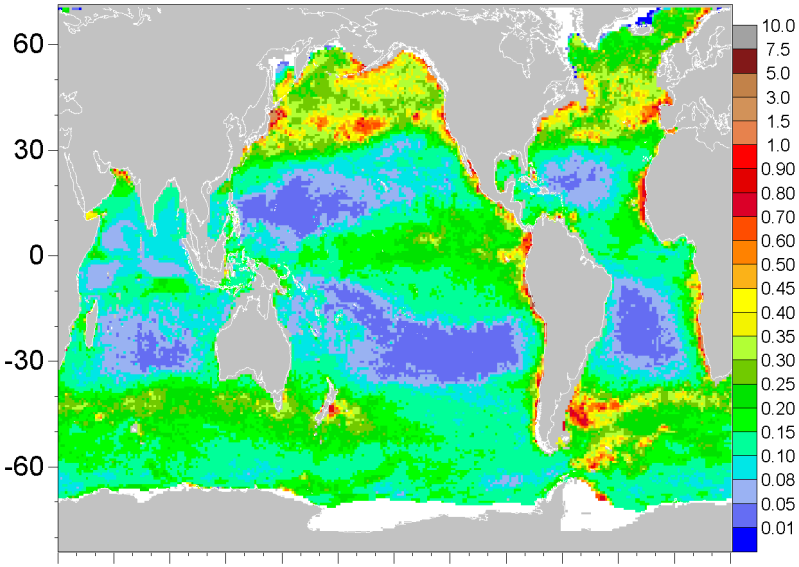
In ocean biology, Two Classes:

- Variational (e.g., adjoint, 4DVar)
- Sequential (e.g., Kalman Filter)

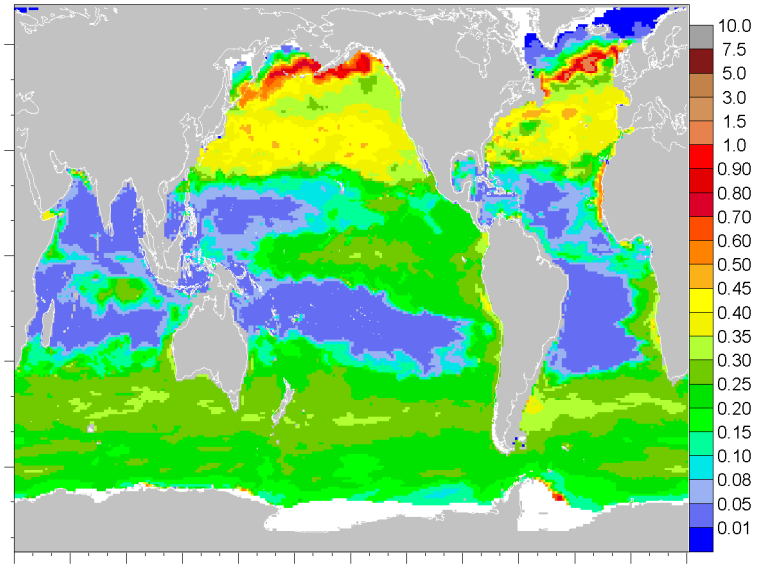
Here we used Sequential Methodologies,

- Conditional Relaxation Analysis Method
- Ensemble Kalman Filter

Assimilated Chlorophyll Apr 1 2001




Free Run Model Chlorophyll Apr 1 2001




Data Assimilation: NASA Ocean Color Sensors (SeaWiFS and MODIS-Aqua)

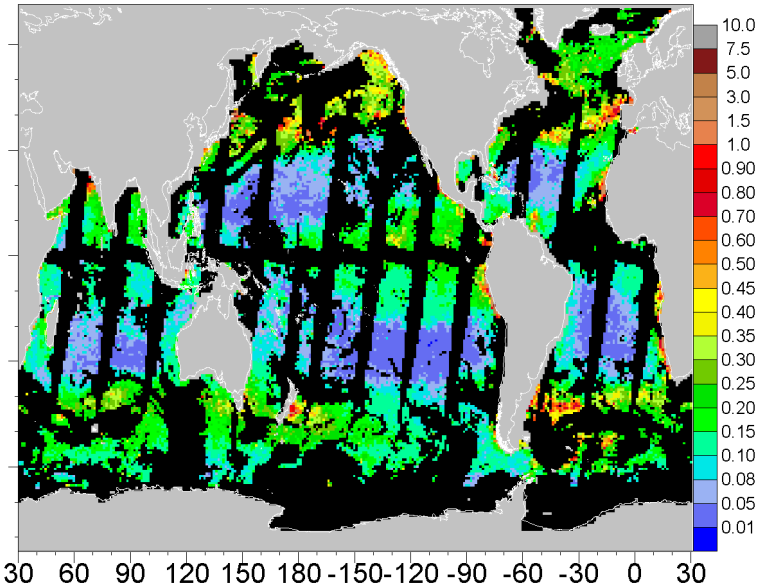
Assimilation variable: chlorophyll

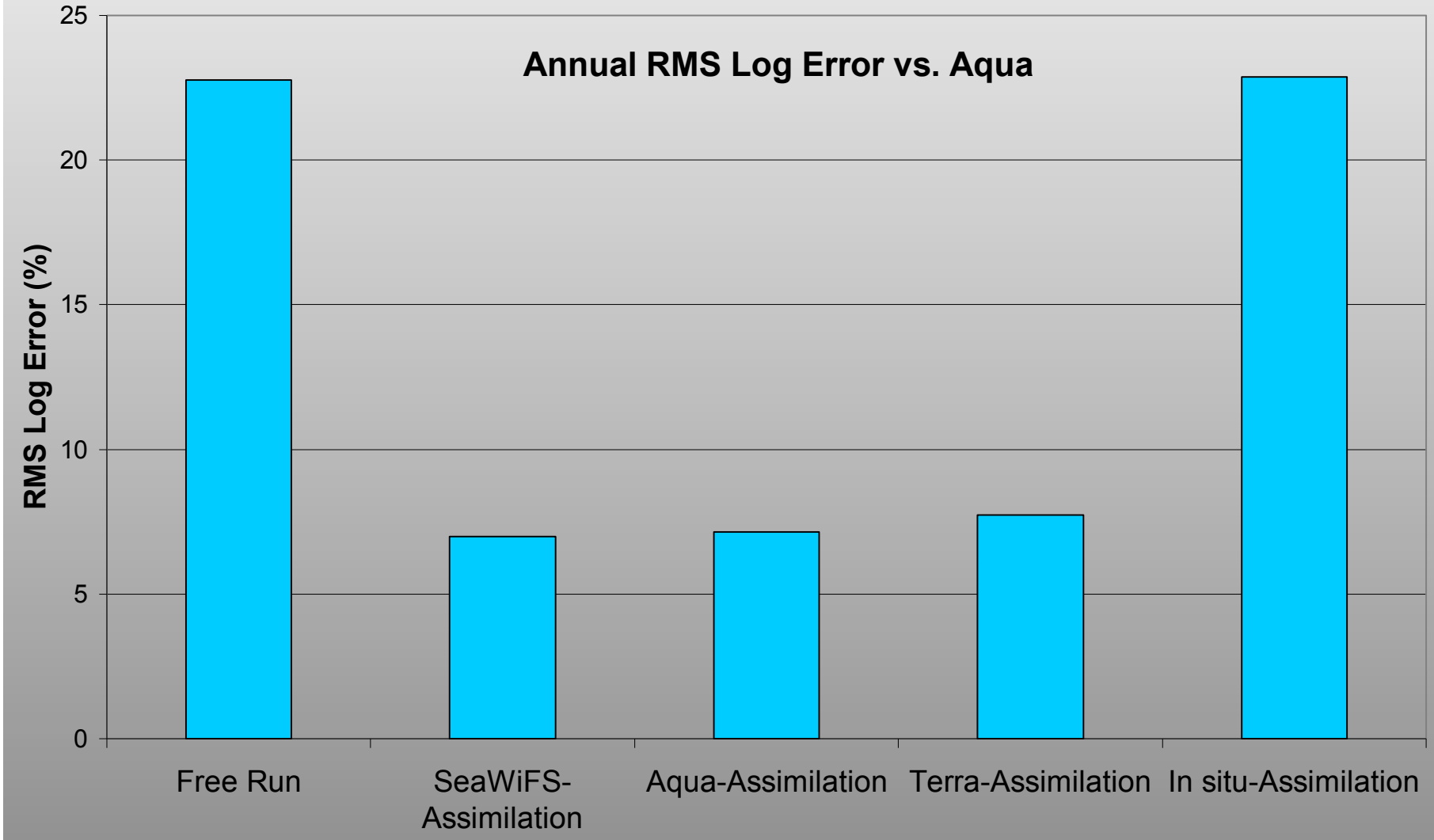
Conditional Relaxation Analysis Method (sequential method)

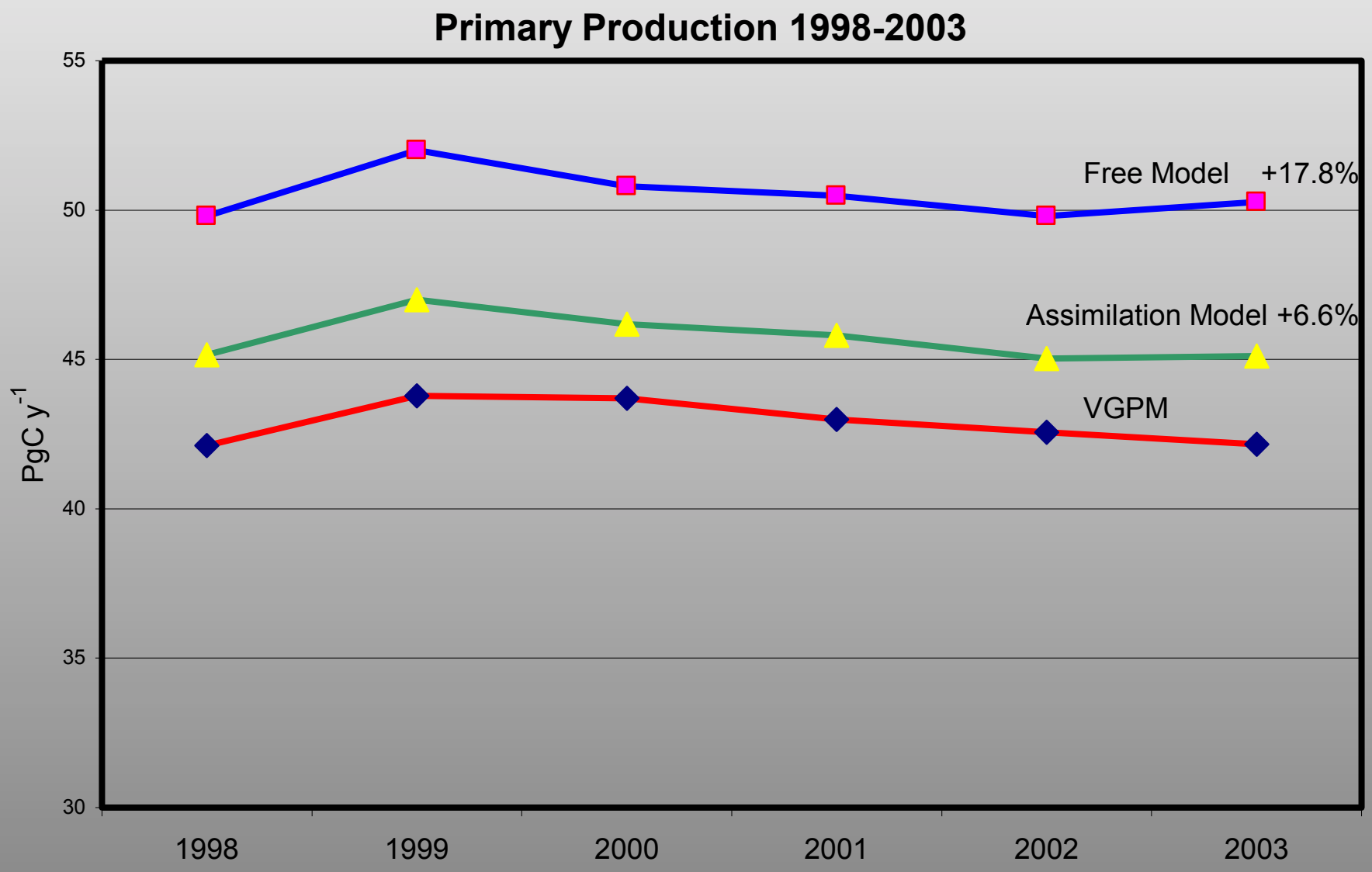
Comparison with in situ data:

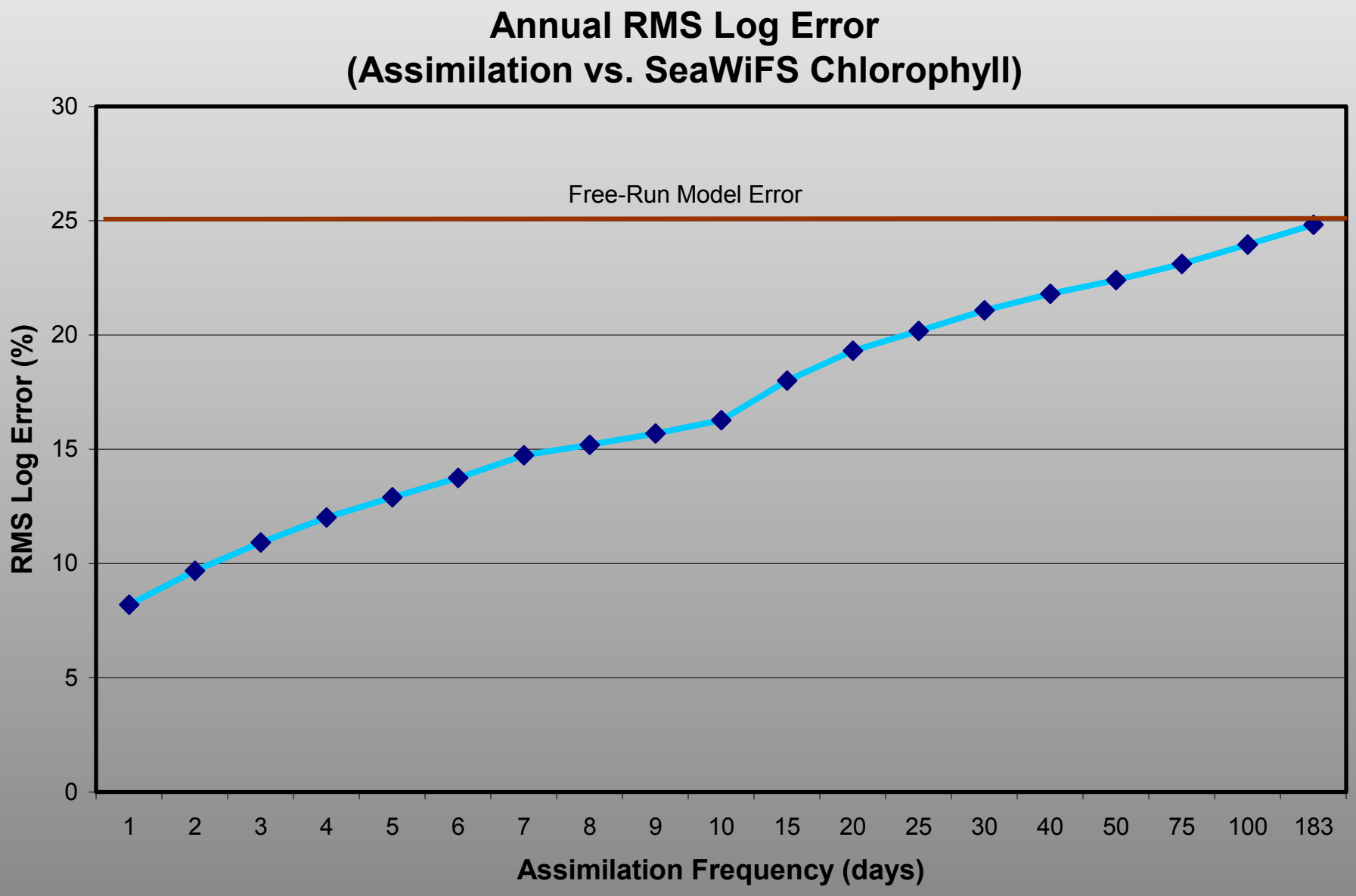
| | Bias | Uncertainty | N |
|---|---|---|---|
| **SeaWiFS** | **-1.3%** | **32.7%** | **2086** |
| **Assimilation Model** | **0.1%** | **33.4%** | **4465** |

Daily SeaWiFS Chlorophyll Apr 1 2001



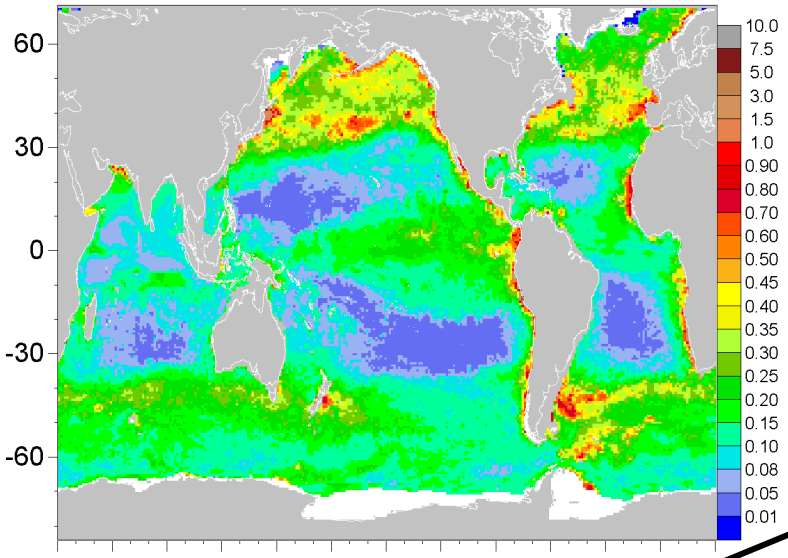

Annual RMS Log Error vs. Aqua
RMS Log Error (%)
25
20
15
10
5
0
Free Run
SeaWiFS-Assimilation
Aqua-Assimilation
Terra-Assimilation
In situ-Assimilation


Primary Production 1998-2003
55
50
45
40
35
30
PgC y-1
Free Model +17.8%
Assimilation Model +6.6%
VGPM
1998
1999
2000
2001
2002
2003

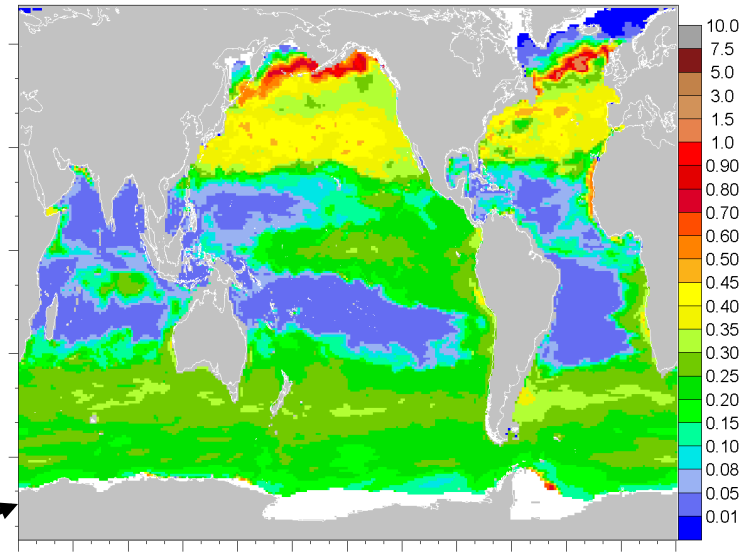

Annual RMS Log Error
(Assimilation vs. SeaWiFS Chlorophyll)
Free-Run Model Error
RMS Log Error (%)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
15
20
25
30
40
50
75
100
183
Assimilation Frequency (days)

# Assimilation of Satellite Chlorophyll

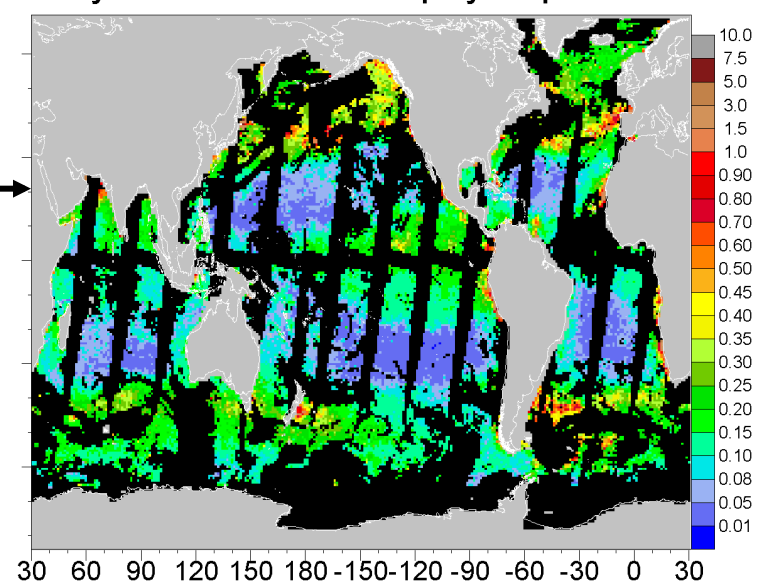
Assimilated Chlorophyll Apr 1 2001




Free Run Model Chlorophyll Apr 1 2001




Daily SeaWiFS Chlorophyll Apr 1 2001

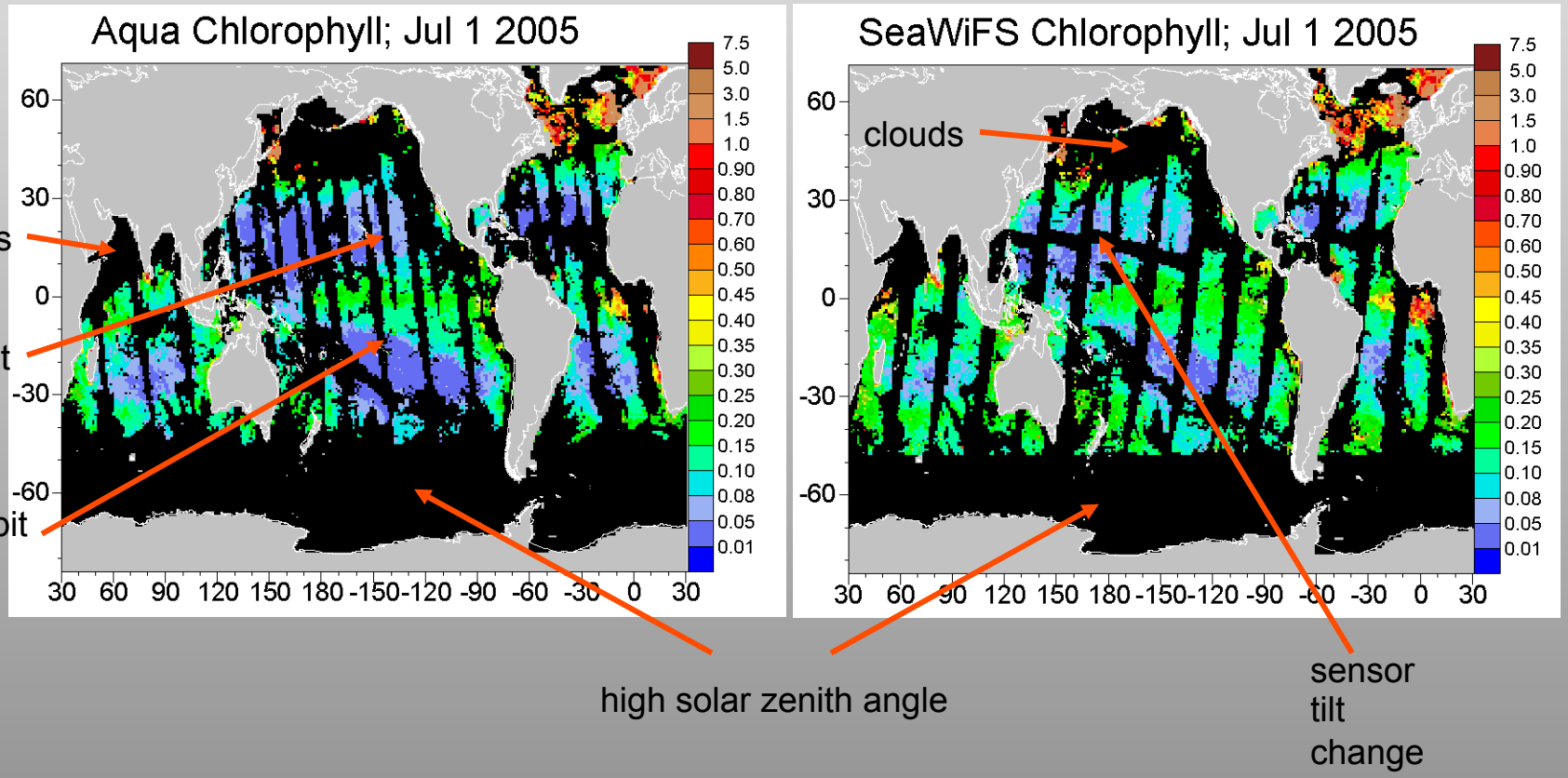



mg m$^{-3}$

Data assimilation **improves a model** by forcing agreement with data and reducing model biases.

It also **improves the data** by filling in missing data and reducing sampling biases.

# Daily ocean coverage by MODIS-Aqua and SeaWiFS.



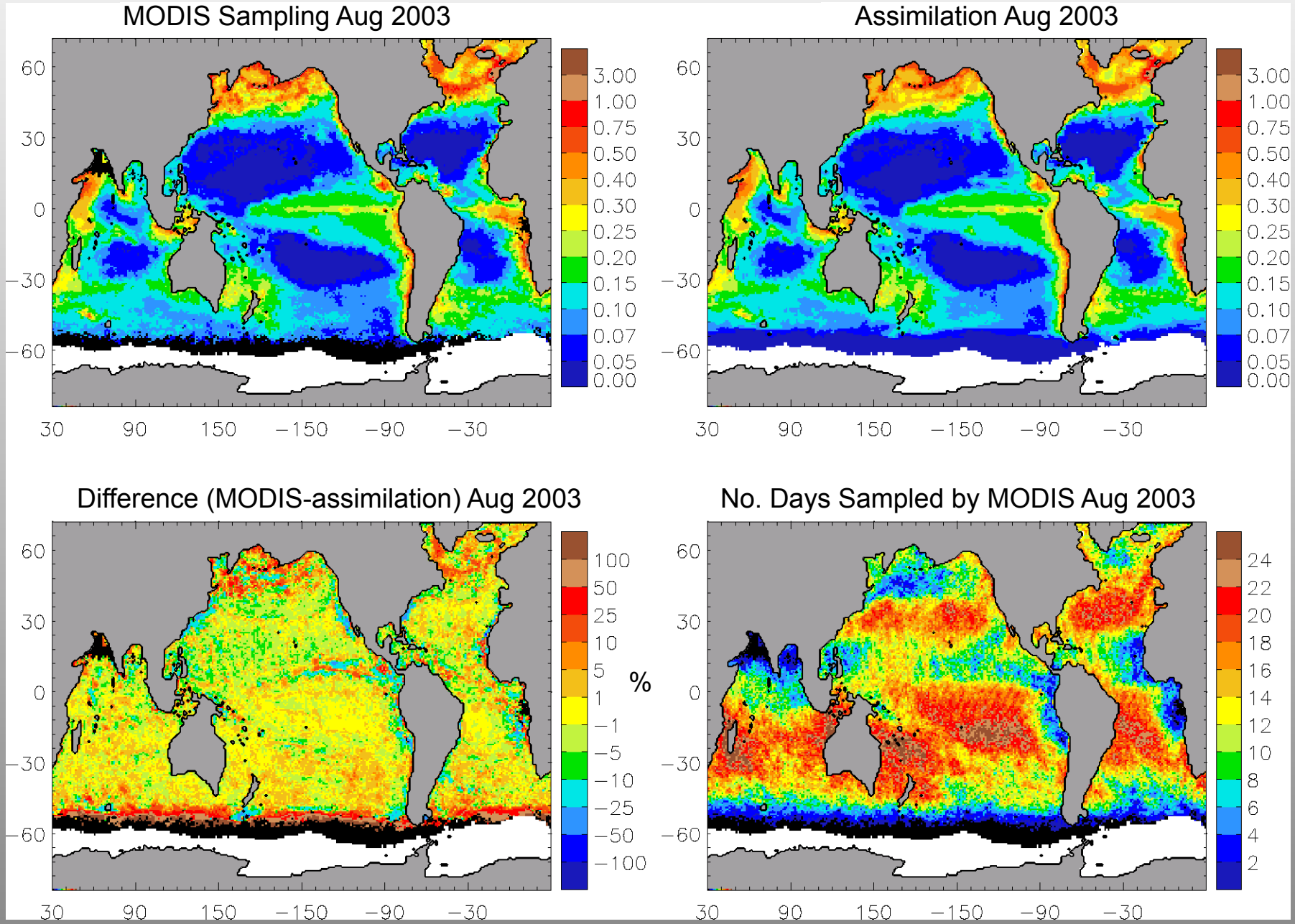

aerosols

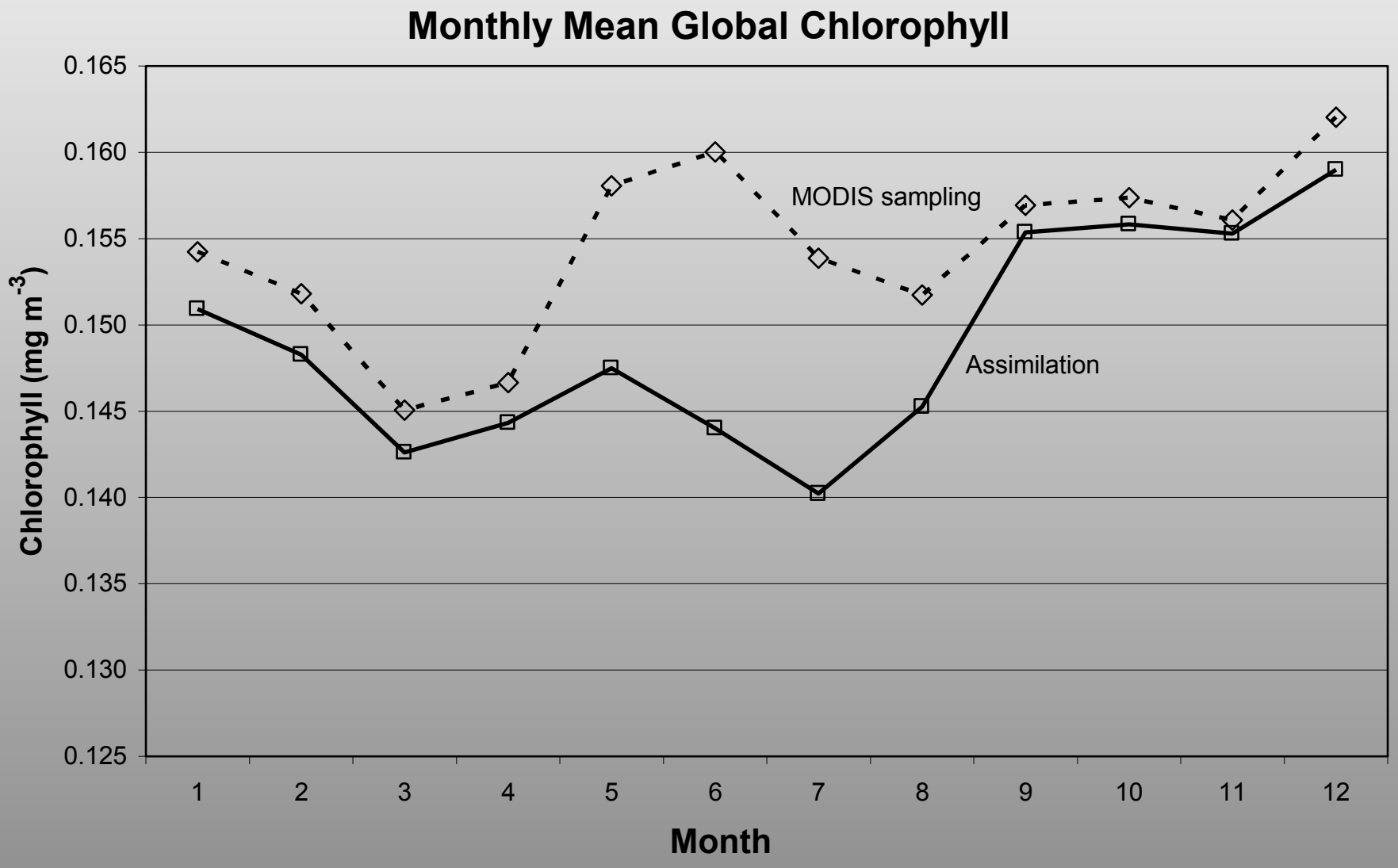
sun glint

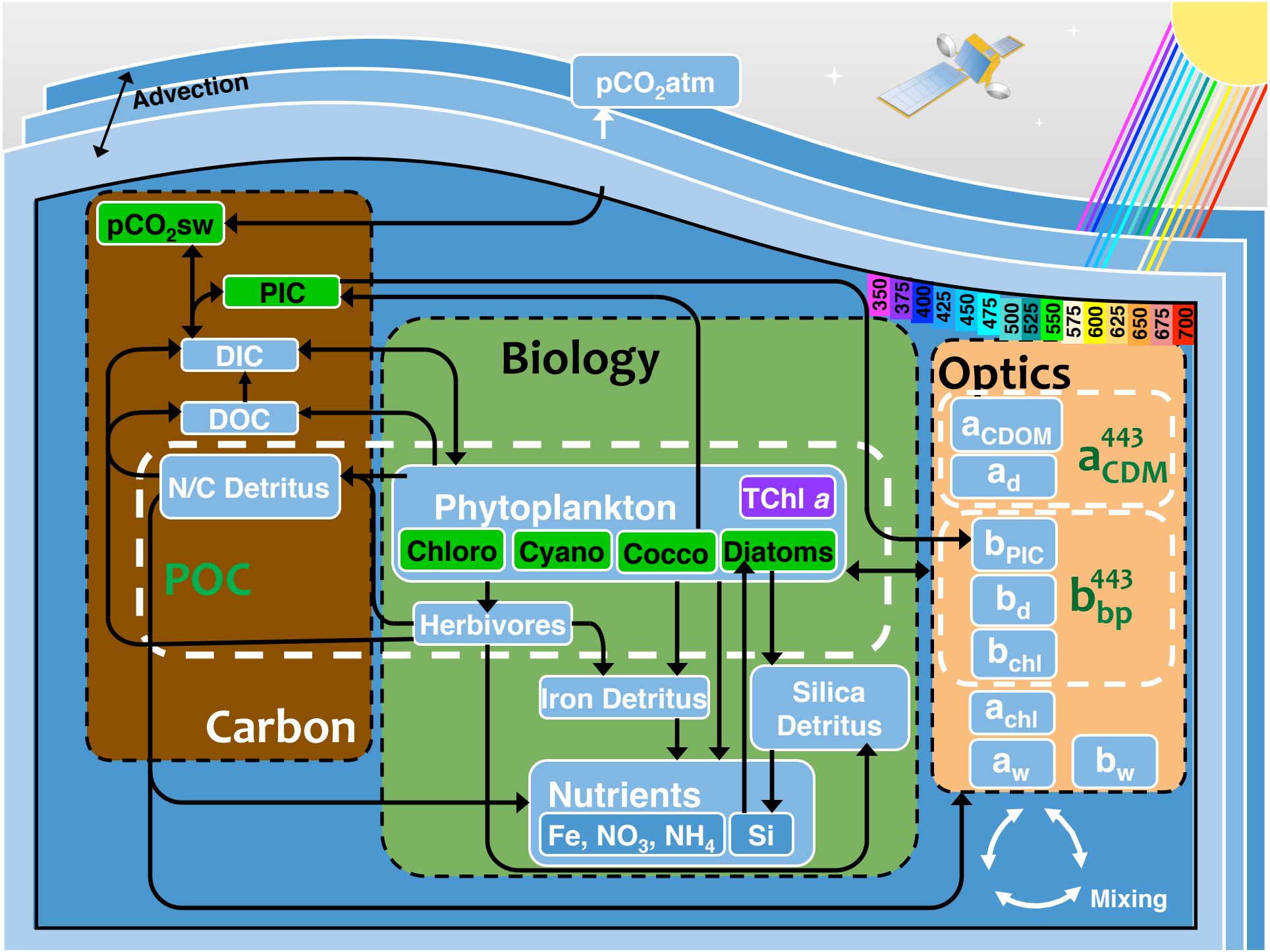
inter-orbit gap

high solar zenith angle

sensor tilt change


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
mg m-3
100
50
25
10
5
1
−1
−5
−10
−25
−50
−100
%
24
22
20
18
16
14
12
10
8
6
4
2
Number


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


Advection
pCO2atm
pCO2sw
PIC
DIC
DOC
N/C Detritus
POC
Carbon
Biology
Phytoplankton
TChl a
Chloro
Cyano
Cocco
Diatoms
Herbivores
Iron Detritus
Silica Detritus
Nutrients
Fe, NO3, NH4
Si
350
375
400
425
450
475
500
525
550
575
600
625
650
675
700
Optics
aCDOM
ad
a443CDM
bPIC
bd
bchl
b443bp
achl
aw
bw
Mixing

# Summary

•MODIS data find multiple uses for ocean biology modeling, from radiative transfer to ocean modeling validation to data assimilation

•MODIS atmospheric and ocean color data are useful for ocean biology modeling

•Data assimilation not only improves models but also improves data representations