OCEAN COLOUR AND BIOGEOCHEMICAL/ECOSYSTEM MODELS

Stephanie Dutkiewicz
Massachusetts Institute of Technology

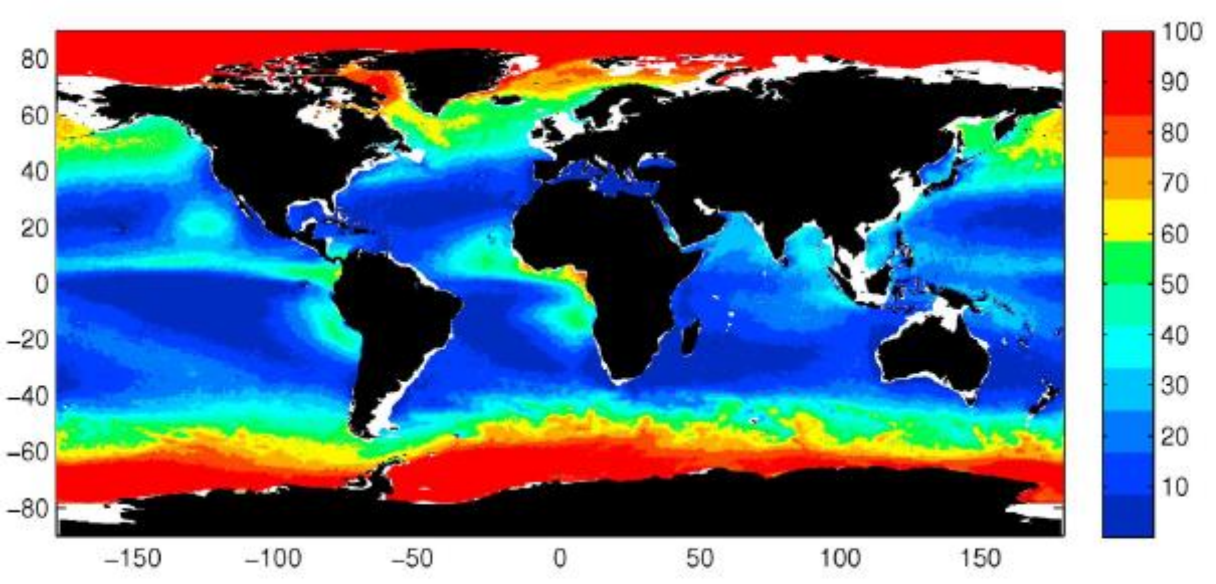
MODIS TRUE COLOUR IMAGE 02/02/2011:

Tropical cyclone Yasi 2011

What is happening to Great Barrier Reef?

Baird et al, ESM, 2015

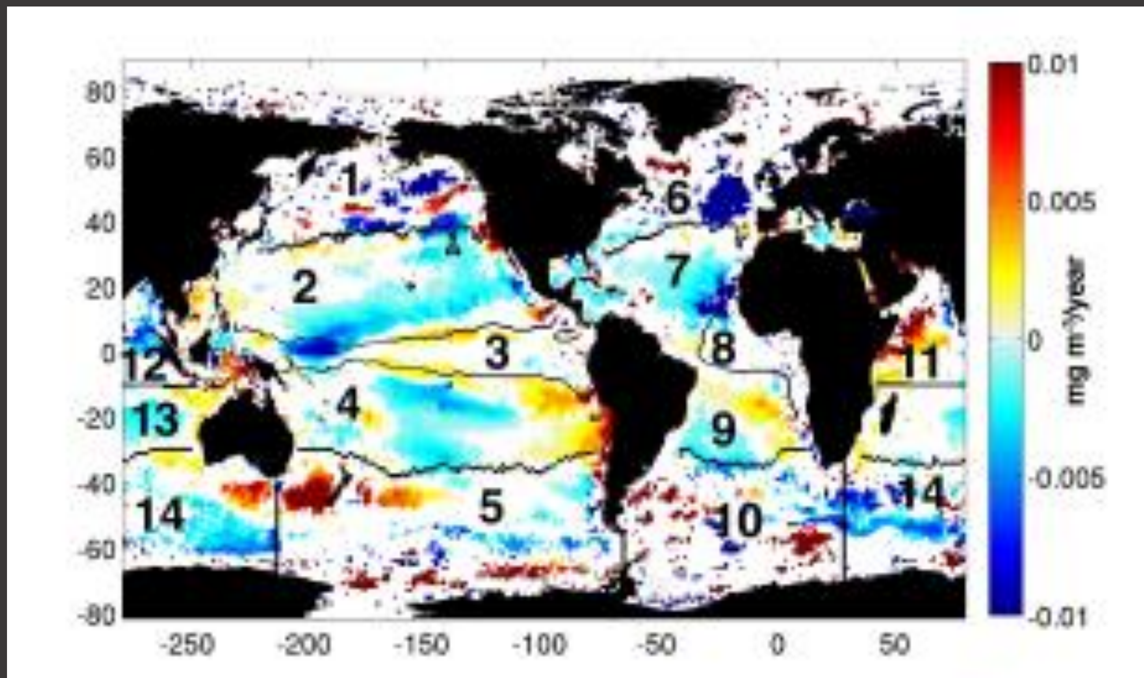
% time that there is missing data in GlobColor (2002-2006)



What is impact of this missing data?
e.g. on calculating spring bloom metrics?

Coles et al, JGR, 2012

Trend in SeaWiFs Chl 1997-2007

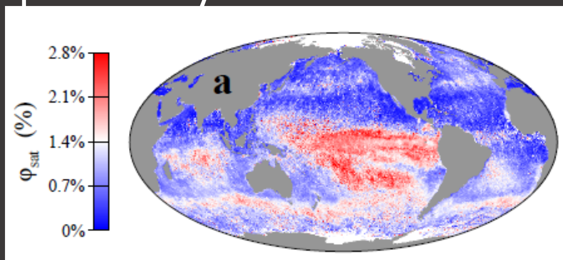


mgChl/m3/year

Is this "trend" a signature of anthropogenic driven climate change?

Henson et al, BG, 2010

What causes differences in quantum yield?



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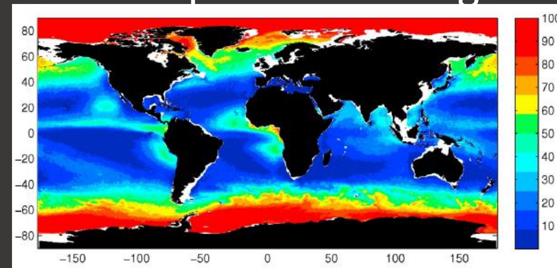
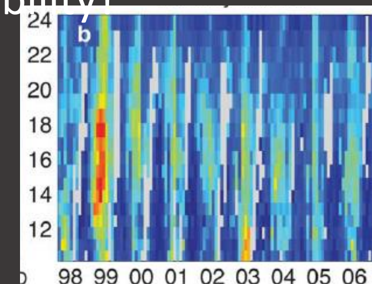
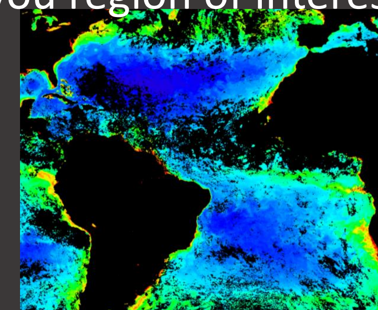


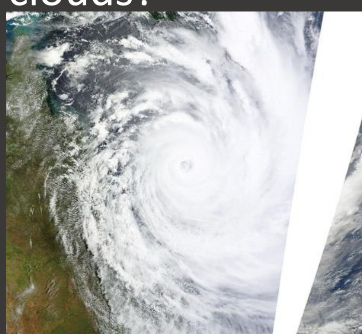
What drives the interannual variability?



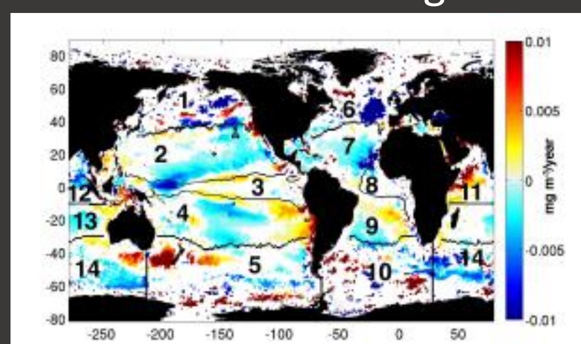
What if clouds cover you region of interest?



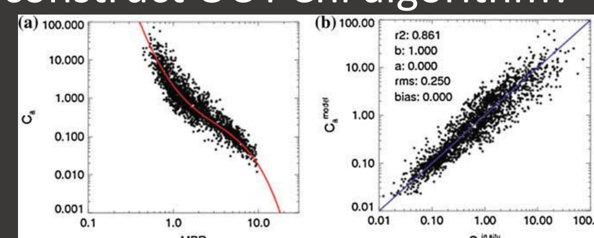
How to maintain monitoring under clouds?



Is this a climate change trend?

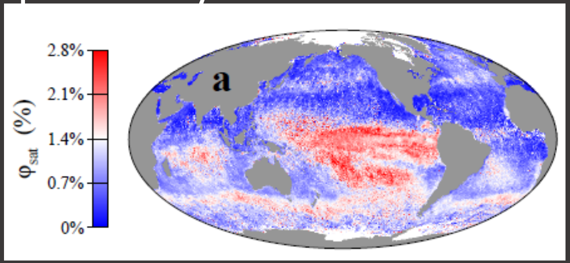


Uncertainty from limited data to construct OC4 Chl algorithm?



NUMERICAL MODELS CAN BE USEFUL

What causes differences in quantum yield?



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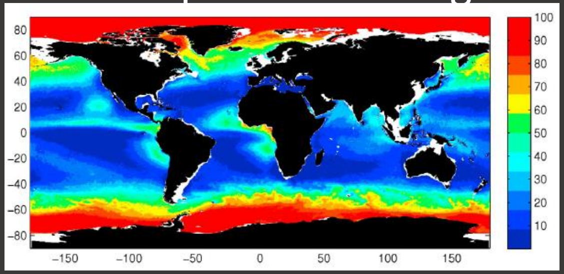

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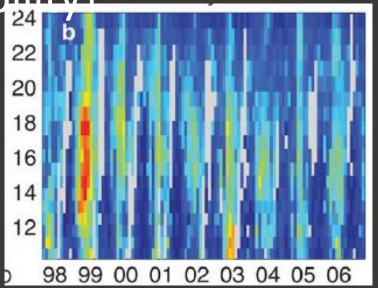

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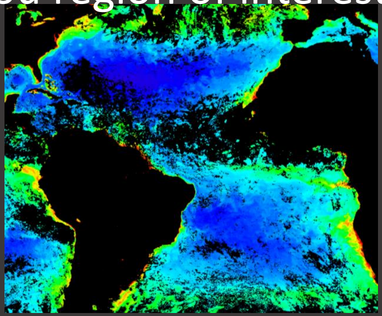

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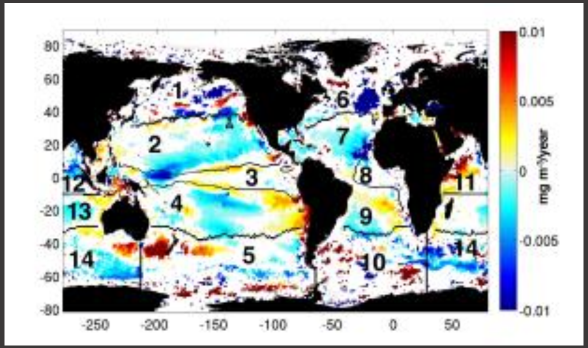

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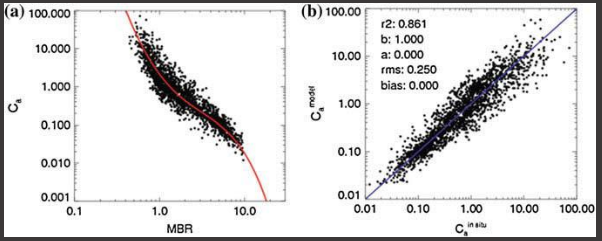

Bachelor of Science (Physics) – University of Miami, FL, USA

PhD (Physical Oceanography) – University of Rhode Island, RI, USA

Post-doc – MIT, USA

ecosystem model, SeaWiFs output

carbon cycle, coupled climate modelling, iron cycle, adjoint modeling

more complex ecosystem modeling, ecological theory –
biodiversity, biogeographical provinces

Improving treatment of light/pigments in ecosystem model ....

OUTLINE

- Introduction to forward numerical biogeochemical /ecosystem models

- Why/How to use model output
  (OC example studies)

- Introduction to data assimilation
  (OC example studies)

- Capturing phytoplankton diversity

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BASICS

Model:

"simplified representation of real system or process"

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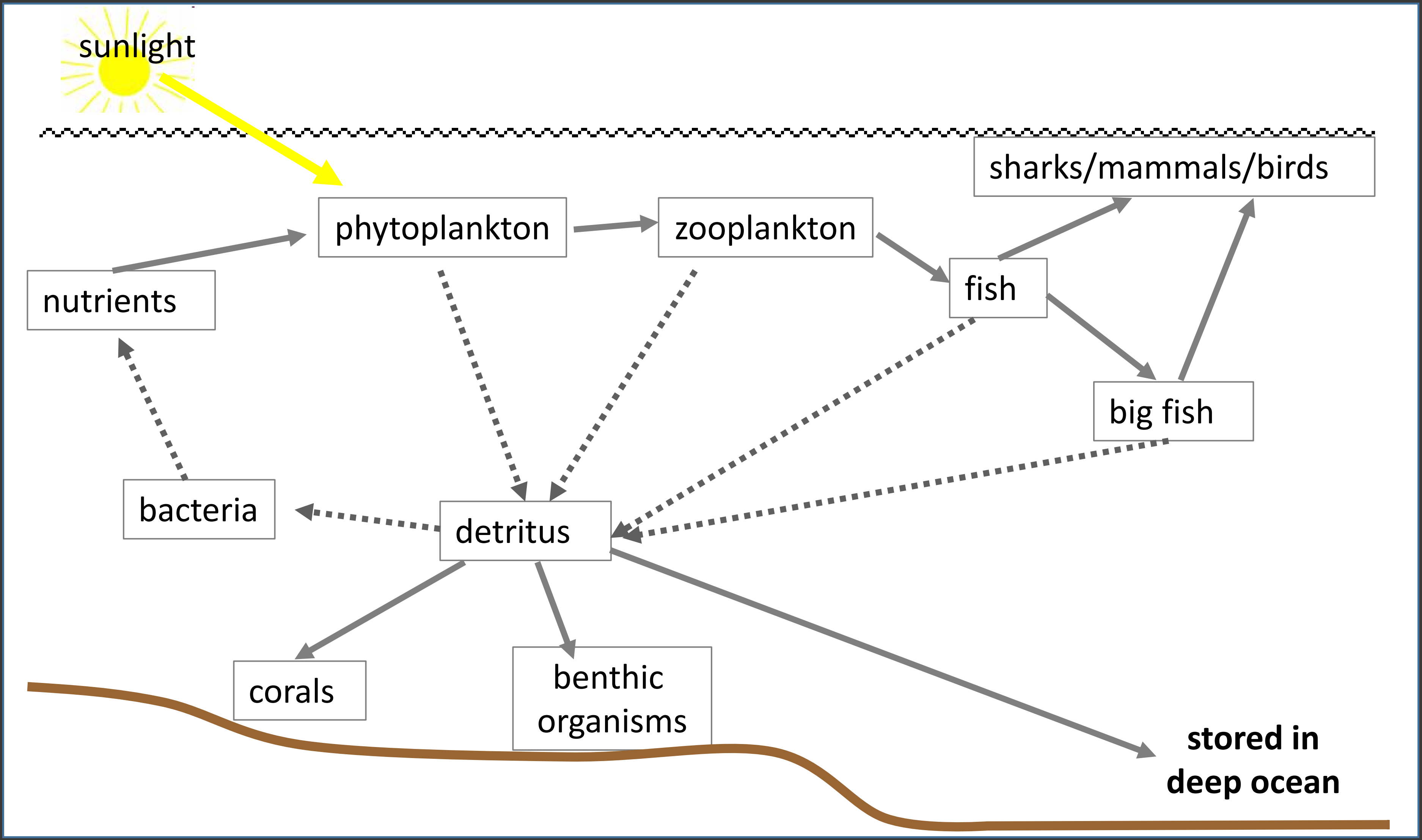
"simplified representation of real system or process"

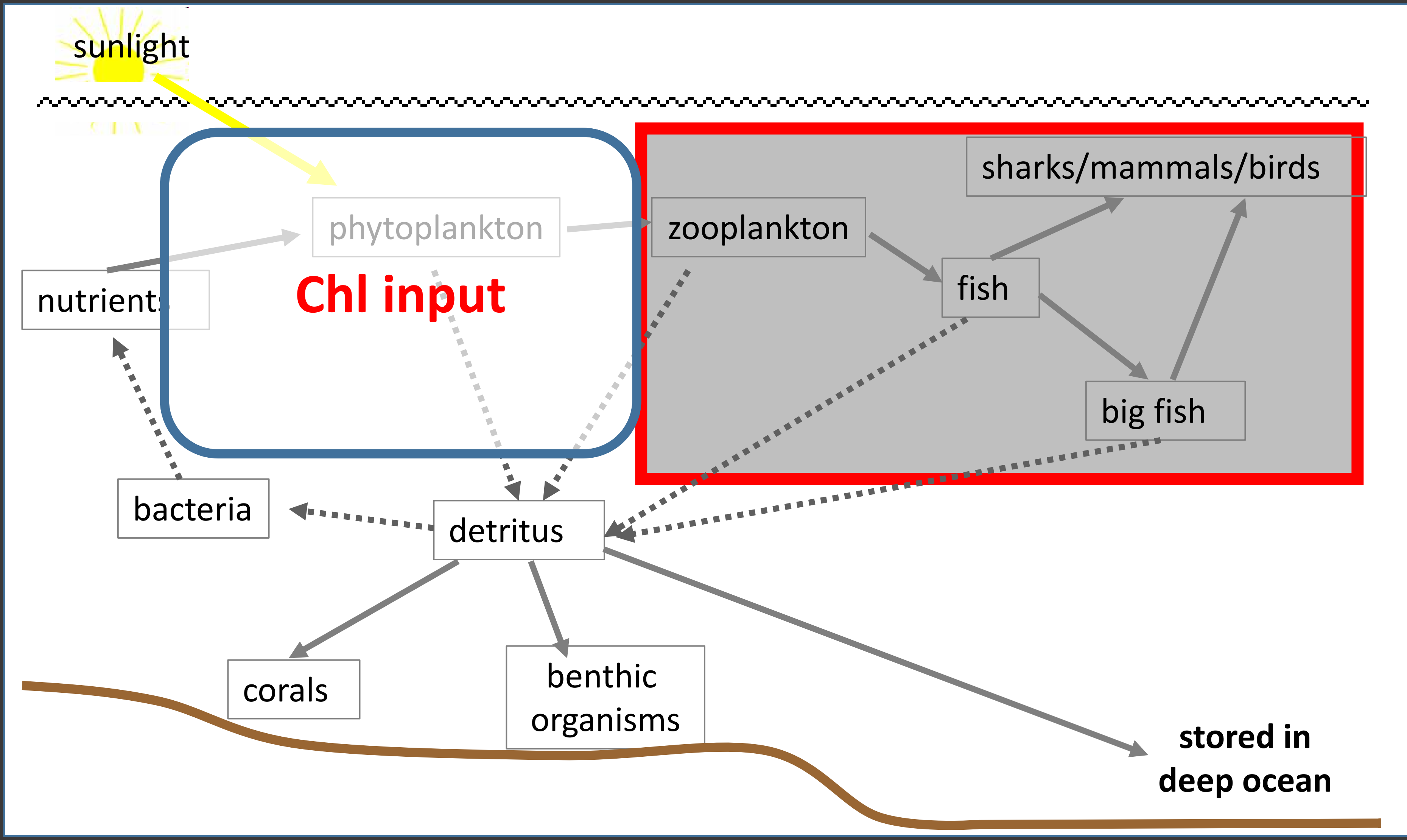
often described by a set of equations

BASICS



sunlight
sharks/mammals/birds
phytoplankton
zooplankton
nutrients
fish
big fish
bacteria
detritus
corals
benthic organisms
stored in deep ocean

BASICS



sunlight
phytoplankton
Chl input
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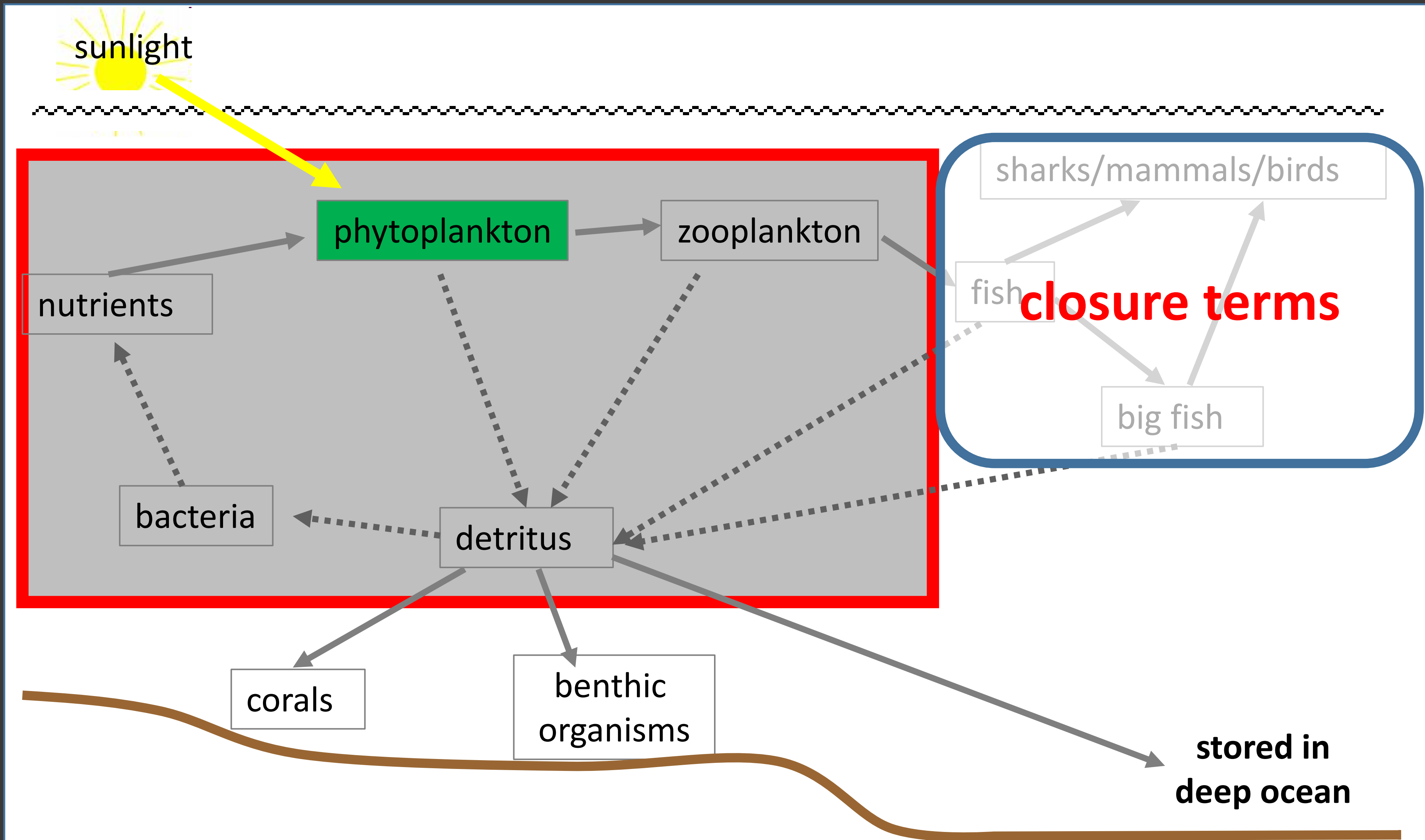

sunlight
phytoplankton
zooplankton
sharks/mammals/birds
fish
closure terms
big fish
nutrients
bacteria
detritus
corals
benthic organisms
stored in deep ocean

BASICS

Time-stepping

Scale:	Trophic Level:	Dimension:
cell level	Lower trophic	0-D
individual based	Higher trophic	1-D
continuum	End-to-end	2-D
		3-D (regional/global)

MODELLING PHYTOPLANKTON

Biomass of Phytoplankton (B):

$B_{at\ time\ 2} = B_{at\ time\ 1} + (\textbf{growth} - \textbf{losses} + \textbf{transport}) * timestep$

growth: nutrient limitation, light, temperature, ….

losses: grazing, viruses, respiration, cell death, sinking, ….

transport: advection by currents, vertical mixing, ….

MODELING PLANKTON

rate of change biomass = *growth* - *loss* - *transport*

growth *grazing* *mortality* *advection* *diffusion*

$$\frac{dB}{dt} = \mu B - gZ - mB - \nabla \cdot \vec{u}B + \nabla \cdot (\vec{K}\nabla B)$$

MODELING PLANKTON

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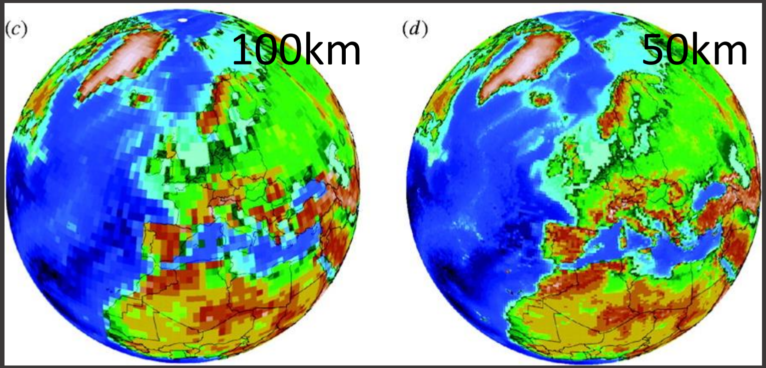
$$\frac{dB}{dt} = \mu B - gZ - mB - \nabla \cdot \vec{u}B + \nabla \cdot (\vec{K}\nabla B)$$

functional forms for each biological term are "approximations"; there is considerable research in how to parameterize each

MODELING PLANKTON

RESOLUTION:
Horizontal: Coarse: > 1 degree
Fine: 10’s km



Vertical: usually finer in surface (m’s, and coarser 100m at depth)

(also different types of grids – isopynal etc)

Grid size: “resolution” depends on model purpose

MODELLING PHYTOPLANKTON

computer code

```
      gTr(iPO4 )=gTr(iPO4 ) - consumPO4
      gTr(iSiO2)=gTr(iSiO2) - consumSiO2
      gTr(iFeT )=gTr(iFeT ) - consumFeT

      reminDOC  = reminTempFunc*KDOC *DOC
      reminDON  = reminTempFunc*KDON *DON
      reminDOP  = reminTempFunc*KDOP *DOP
      reminDOFe = reminTempFunc*KDOFe*DOFe
      reminPOC  = reminTempFunc*KPOC *POC
      reminPON  = reminTempFunc*KPON *PON
      reminPOP  = reminTempFunc*KPOP *POP
      reminPOSi = reminTempFunc*KPOSi*POSi
      reminPOFe = reminTempFunc*KPOFe*POFe
      disscPIC = Kdissc*PIC

 nitrogen chemistry
 NH4 -> NO2 -> NO3 by bacterial action
      prodNO2 = knita*NH4
      prodNO3 = knitb*NO2
      IF (PAR_oxi .NE. 0.0 _d 0) THEN
         print*,'prod',prodNO2,PARtot,PAR_oxi
        prodNO2 = prodNO2*MAX(0.0, 1.0 - PARtot/PAR_oxi)
        prodNO3 = prodNO3*MAX(0.0, 1.0 - PARtot/PAR_oxi)
      ENDIF

ifdef GUD_ALLOW_CDOM
      reminPOP_CDOM = fracCDOM*reminPOP
```

equations

uptake remineralization advection diffusion

$$\frac{dR}{dt} = -\mu \frac{R}{R+\kappa_R} B + rD - \nabla \cdot \vec{u}R + \nabla \cdot (\vec{K}\nabla R)$$

growth grazing mortality advection diffusion

$$\frac{dB}{dt} = \mu \frac{R}{R+\kappa_R} B - g \frac{B}{B+k_B} Z - mB - \nabla \cdot \vec{u}B + \nabla \cdot (\vec{K}\nabla B)$$

grazing mortality closure advection diffusion

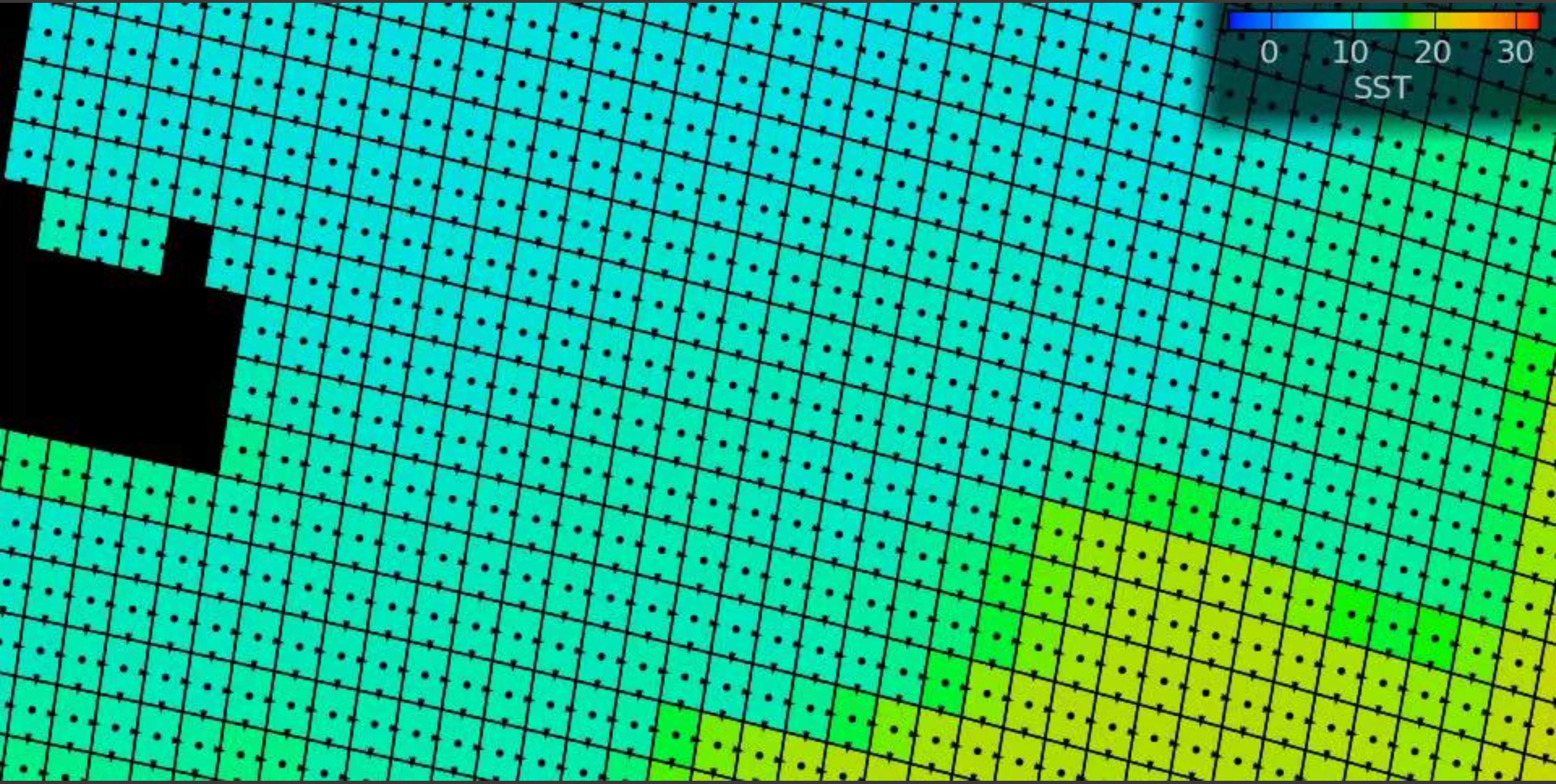
$$\frac{dZ}{dt} = \gamma g \frac{B}{B+k_B} Z - mZ - cZ^2 - \nabla \cdot \vec{u}Z + \nabla \cdot (\vec{K}\nabla Z)$$

source remineralization advection diffusion

$$\frac{dD}{dt} = S(D) - rD - \nabla \cdot \vec{u}D + \nabla \cdot (\vec{K}\nabla D)$$

computers

MODELING PLANKTON



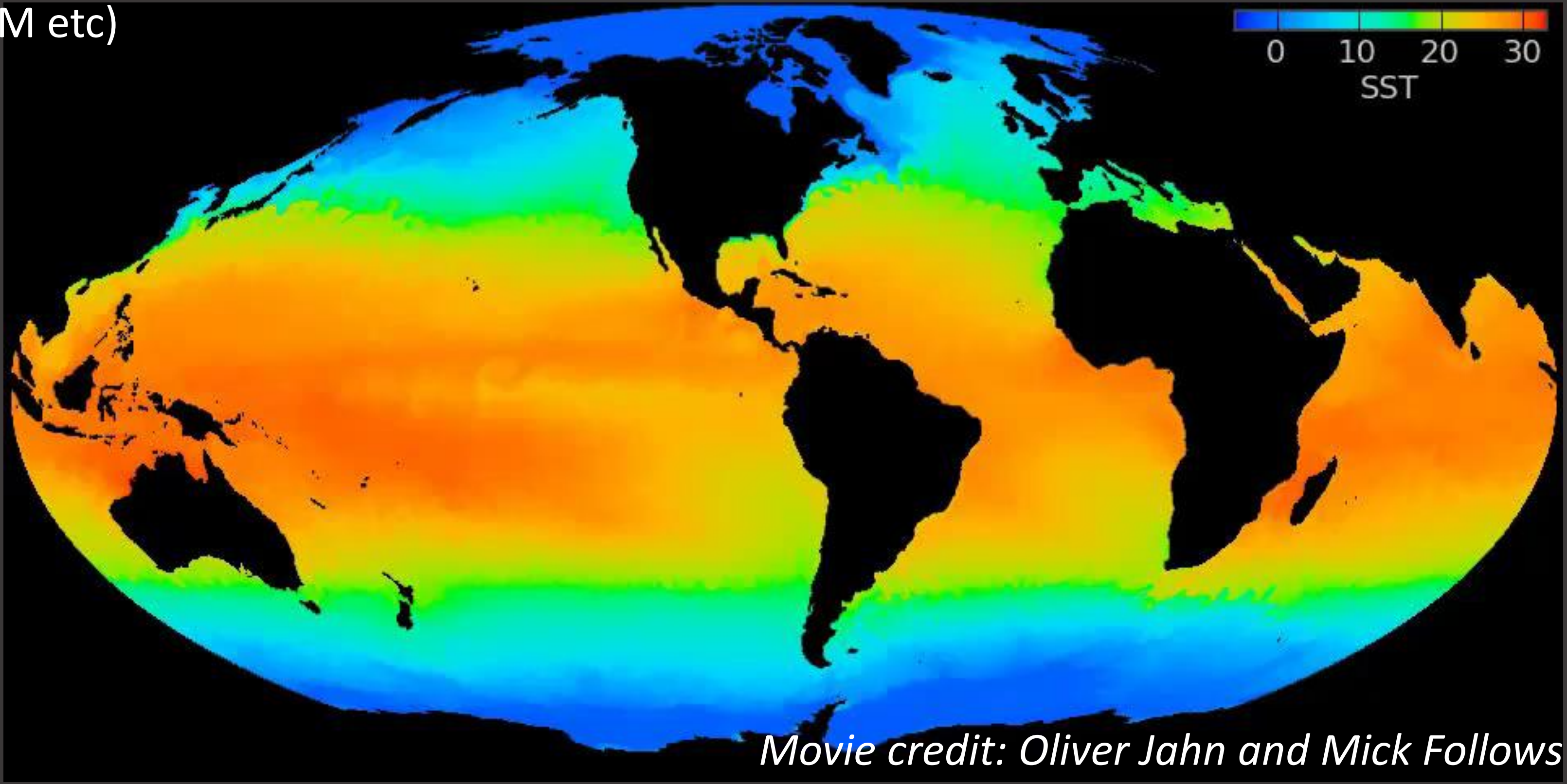
Movie credit: Oliver Jahn and Mick Follows

MODELLING PHYTOPLANKTON

Physics: e.g velocity, mixing, temperature (e.g. MITgcm, ROMS, MOM etc)

Biogeochemistry: e.g. Carbon, nutrients, DOM, POM

Ecosystem: e.g. Phytoplankton (C, Chl), zooplankton



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SUMMARY (1)

- Modeling phytoplankton
  - equations, parameterization
  - grid, computer code, computer simulations

- Biogeochemical/Ecosystem models include:
  - physics
  - biogeochemistry
  - ecosystem

SOME TERMINOLOGY (1)

- Physical model – temperature, velocities, mixing
- Biogeochemical model – cycling of elements such as C,N,P
- Ecosystem model – life and death of organisms

- State Variable – things (“concentrations”) that the model steps forward in time (e.g. phytoplankton biomass)

- Grid resolution - spatial size of grids (horizontal/vertical)

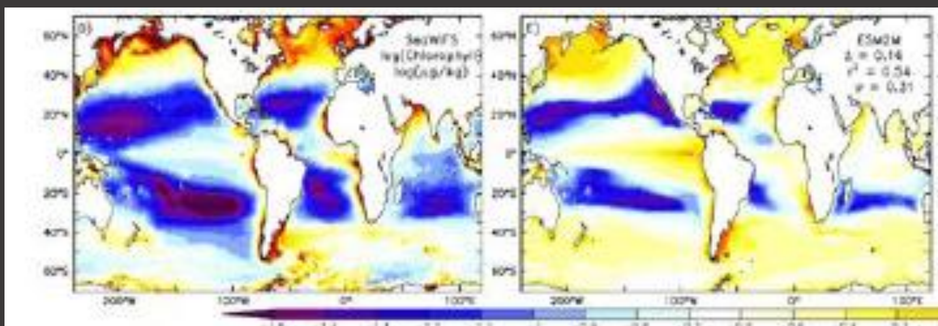
- Initial conditions – state the model starts from (usually climatologies)
- Forcing fields – boundary conditions, incoming conditions that are assumed as knowns

- Hindcast model – simulates last few decades
- Climate model – usually has hindcast and future components (CMIP5 / CMIP6)

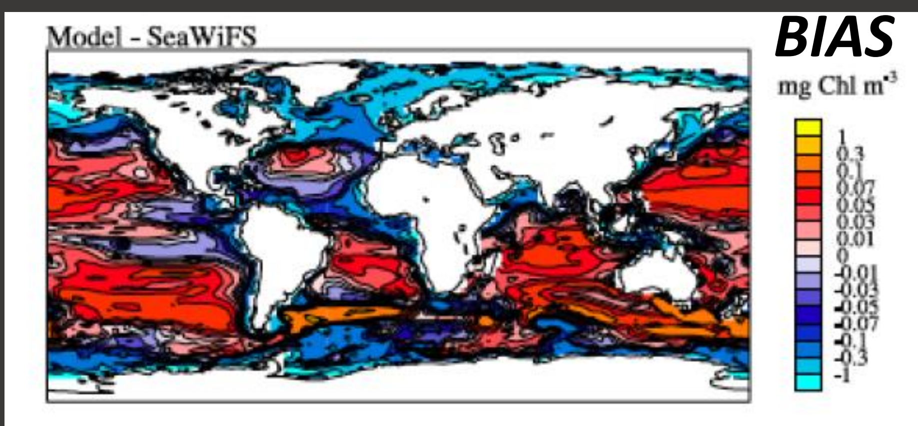
EVALUATION OF MODEL WITH OCEAN COLOUR

Model's evaluated output against ocean colour products –

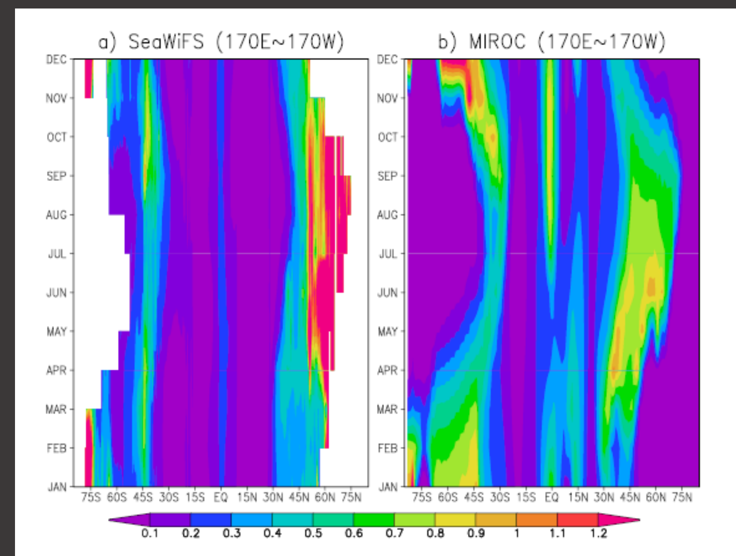
particularly Chl (Level 3, gridded), but also primary production, sometimes Kd, PFTs



GFDL's ESM2: Dunne et al, JClim, 2011



BOGM, Doney et al, JMS, 2008



MIROC-ESM: Watanabe et al, GMD, 2011

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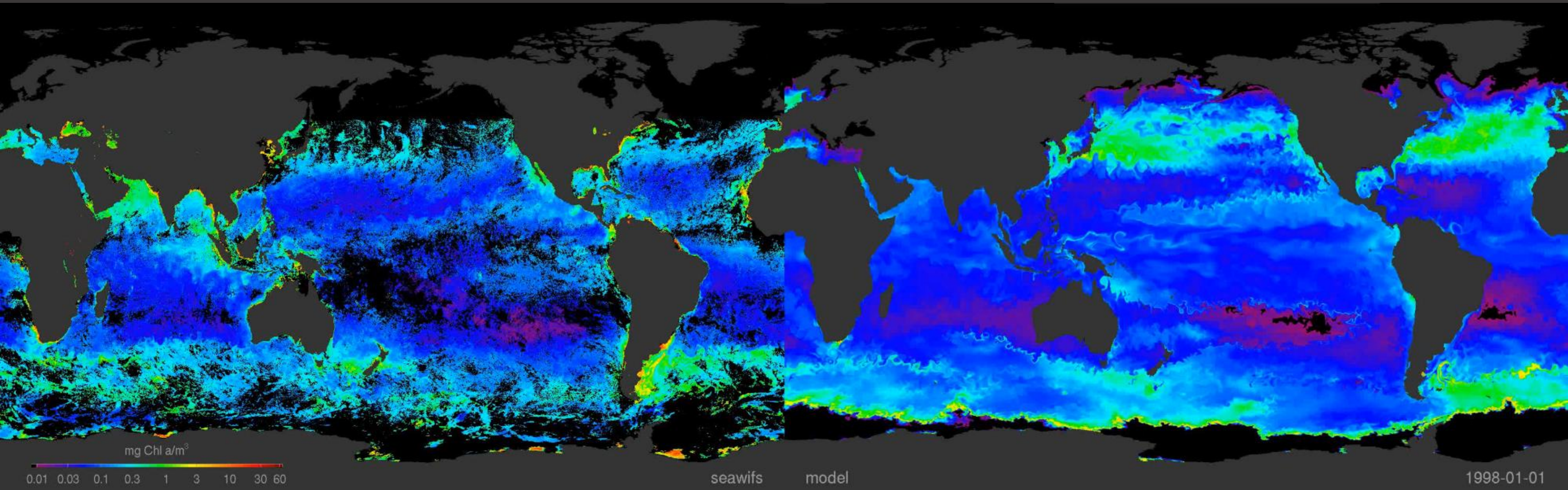
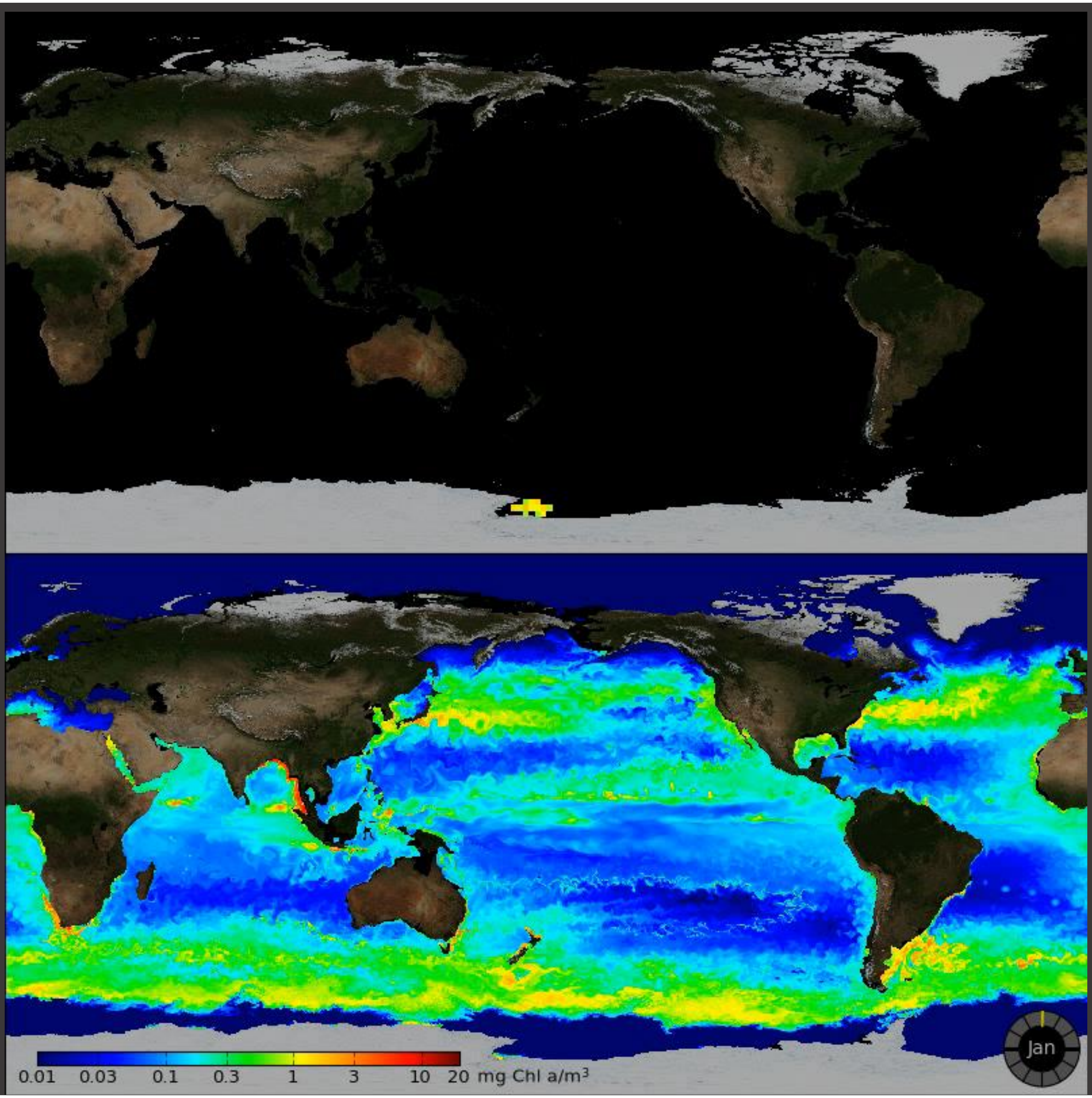
WHY USE MODEL OUTPUT

Surface Chl (mg/m3)



Movie credit: Oliver Jahn

WHY USE MODEL OUTPUT



Chl at 50m (mg/m3)

Movie credit: Oliver Jahn

HOW TO USE MODEL OUTPUT

Just like any other "dataset"

- gridded and no missing points
- but with caveats

HOW TO USE MODEL OUTPUT

"… all models are wrong, but some are useful"
George Box

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

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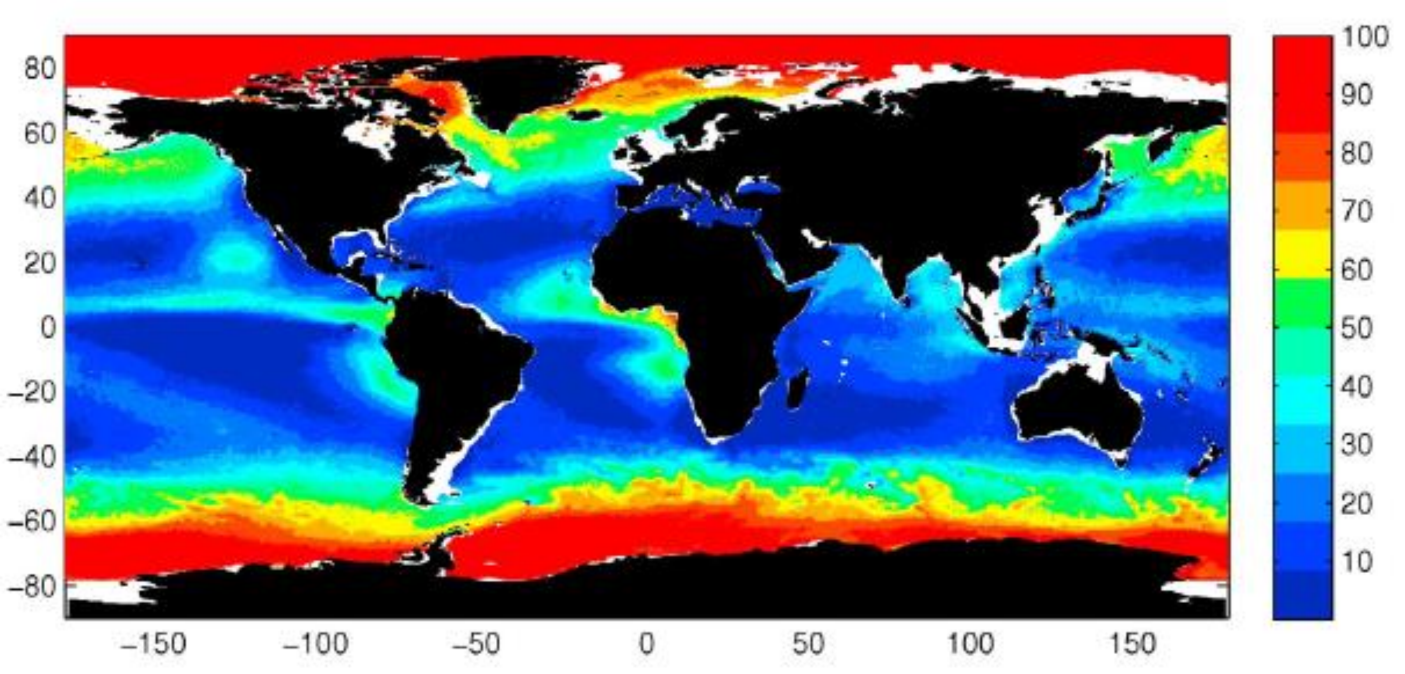
% time that there is missing data in GlobColor (2002-2006)



What is impact of this missing data?
e.g. on calculating spring bloom metrics?

Coles et al, JGR, 2012

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, C08030, doi:10.1029/2012JC008249, 2012

Mind the gap: The impact of missing data on the calculation of phytoplankton phenology metrics

Harriet Cole,[1] Stephanie Henson,[2] Adrian Martin,[2] and Andrew Yool[2]

Observations: GlobColor (SeaWiFS, MERIS, MODIS synthesis)

Model: NOBM

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

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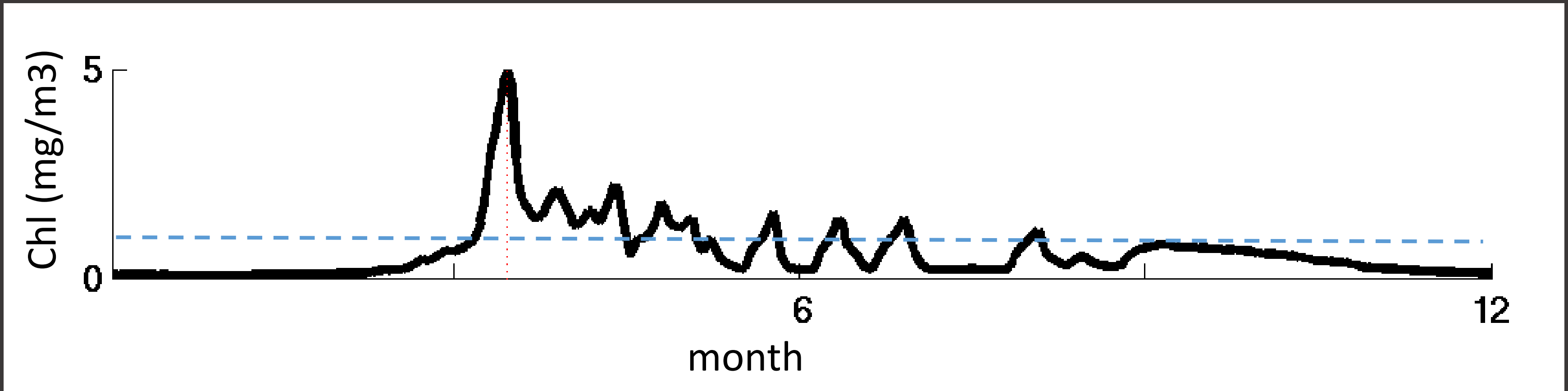
Spring Bloom Metrics:

Peak (maximum)
Initiation (5% above annual median)

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

Why are timing metric different when calculated with gappy data?



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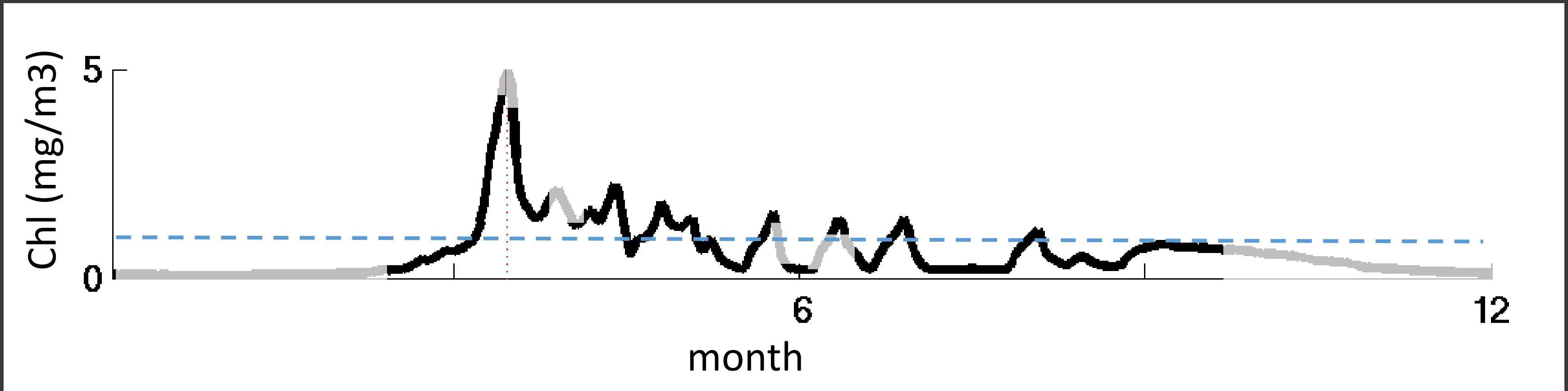
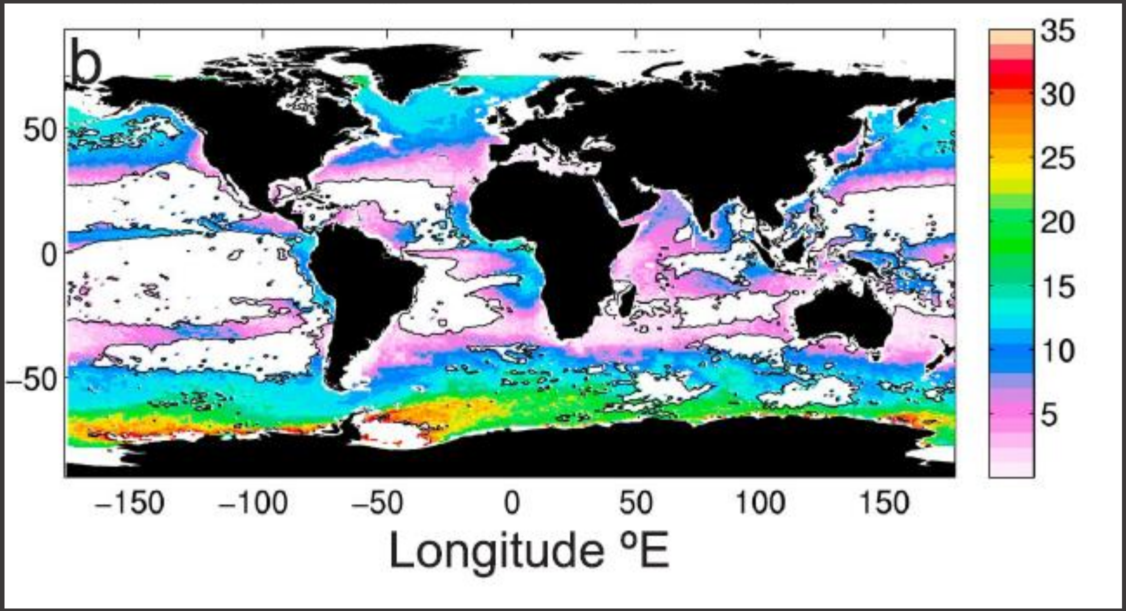


Peak: will be when highest Chl is captured, not necessarily highest actual

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



white areas: no discernable seasonal cycle

Uncertainty (in days) of bloom peak

Uncertainty (in days) of bloom initiation much worse

Coles et al, JGR, 2012

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

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What does this study indicate?

- Will be tough to understand interannual variability of timing spring bloom
  (and accompanying recruitment, export etc issues)
- Trends in phenology could be missed (within uncertainty estimates)

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

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Take home:

- Model can help understand uncertainty in ocean colour timeseries studies (i.e. not just spring bloom) from lack of data

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

Biogeosciences, 6, 779–794, 2009
www.biogeosciences.net/6/779/2009/

Biogeosciences

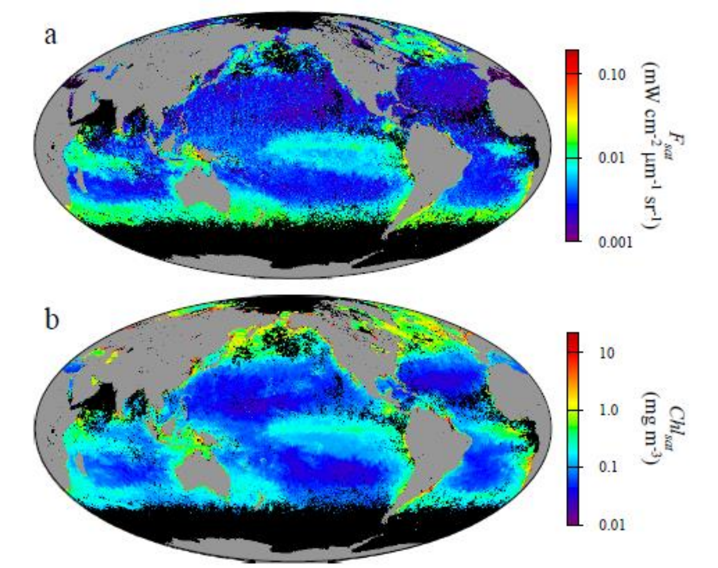
Satellite-detected fluorescence reveals global physiology of ocean phytoplankton

M. J. Behrenfeld[1], T. K. Westberry[1], E. S. Boss[2], R. T. O'Malley[1], D. A. Siegel[3], J. D. Wiggert[4], B. A. Franz[5], C. R. McClain[5], G. C. Feldman[5], S. C. Doney[6], J. K. Moore[7], G. Dall'Olmo[1], A. J. Milligan[1], I. Lima[6], and N. Mahowald[8]

Chlorophyll fluorescence

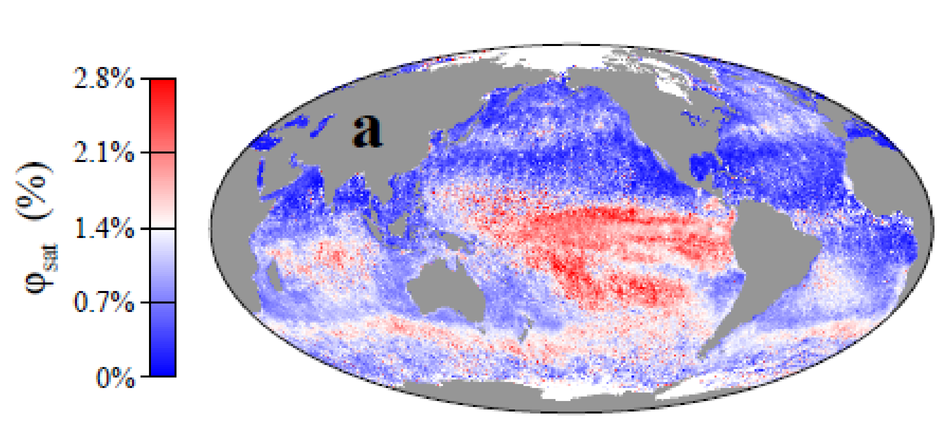
$$F = Chl \times \langle a^*_{\mathrm{ph}} \rangle \times iPAR \times \phi$$

Estimate quantum yield ϕ



WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

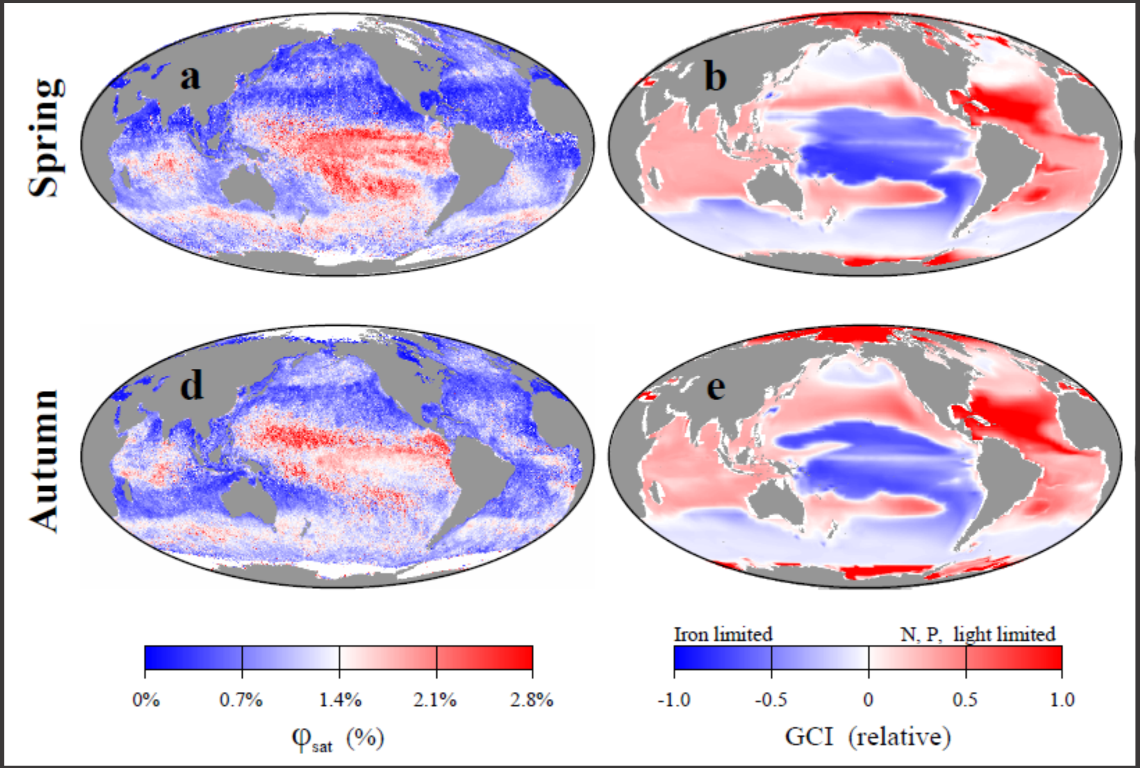
Ocean Colour Derived Quantum Yield



Suggests difference in physiological state:
But what causes this?

Behrenfeld et al., BG, 2009

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



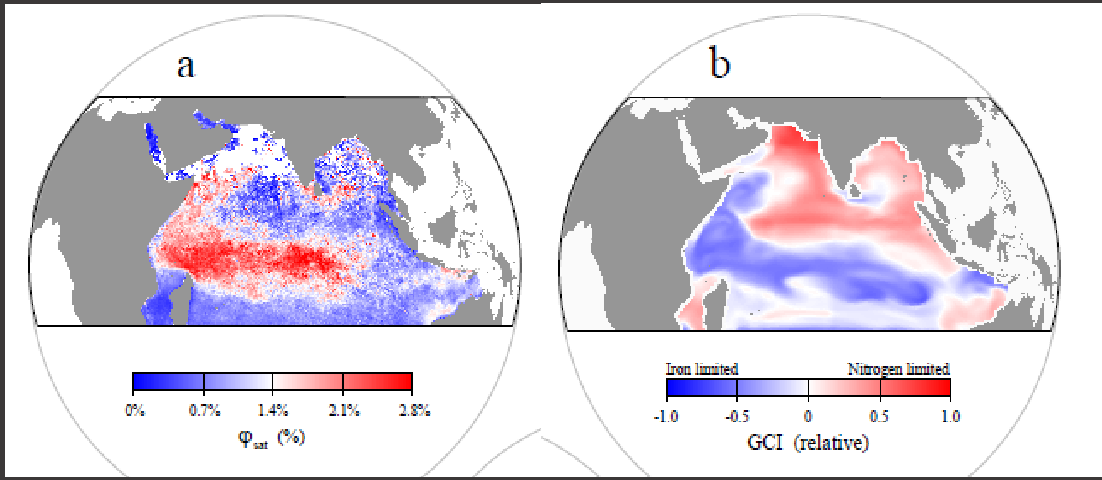
BOGM model (Moore et al 2006):

Global, coarse resolution

$$\mu = \mu_{\max} f(T, I) \min\left(\frac{NO_3}{NO_3 + \kappa_{no3}}, \frac{PO_4}{PO_4 + \kappa_{po4}}, \frac{Fe}{Fe + \kappa_{fe}}\right)$$

Behrenfeld et al., BG, 2009

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



Higher resolution
Indian Ocean model

(Wiggert et al 2006)

Behrenfeld et al., BG, 2009

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Take home:

- By having more mechanistic details (here growth limitation) models can help understand ocean colour results

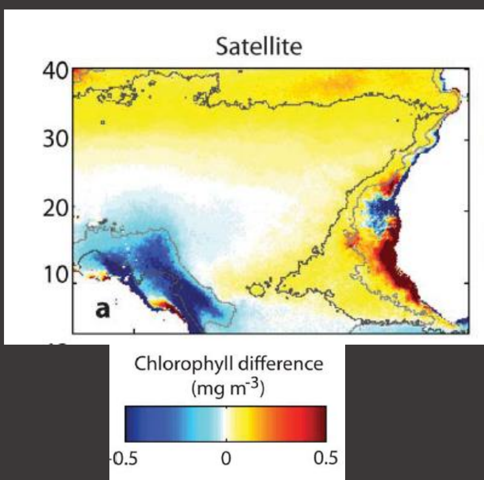
- Models do not work as well in all locations – using multiple models can be useful.

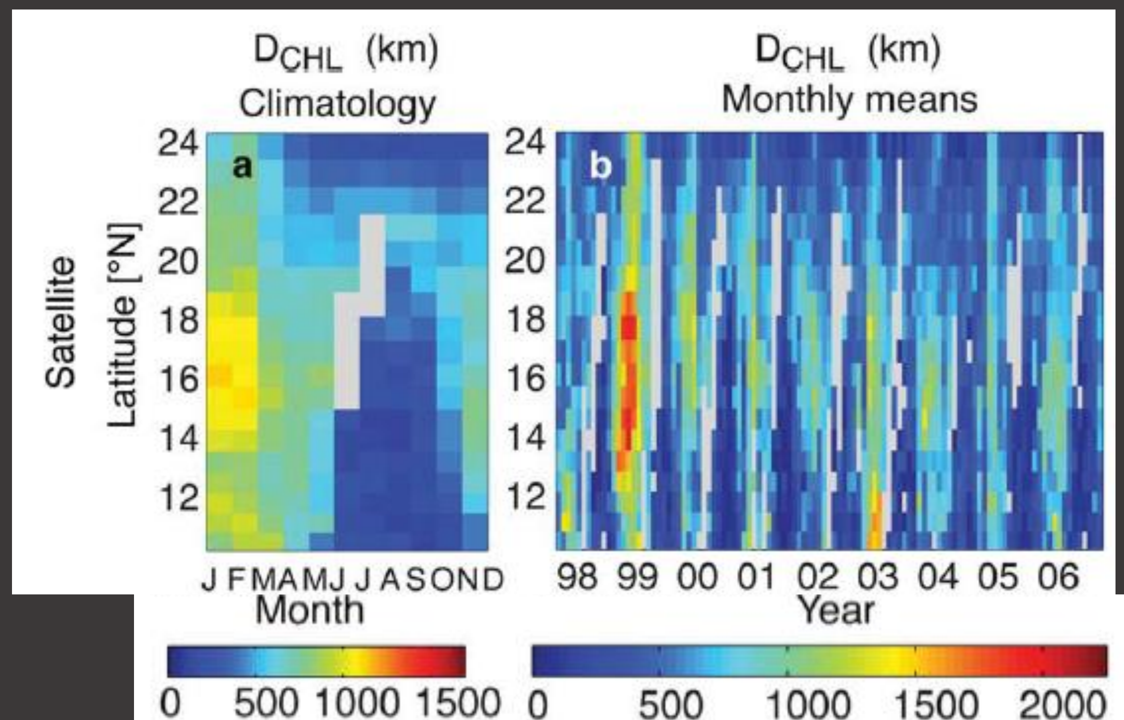
WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

JOURNAL OF GEOPHYSICAL RESEARCH: OCEANS, VOL. 118, 3871–3886, doi:10.1002/jgrc.20254, 2013

Physical drivers of interannual chlorophyll variability in the eastern subtropical North Atlantic

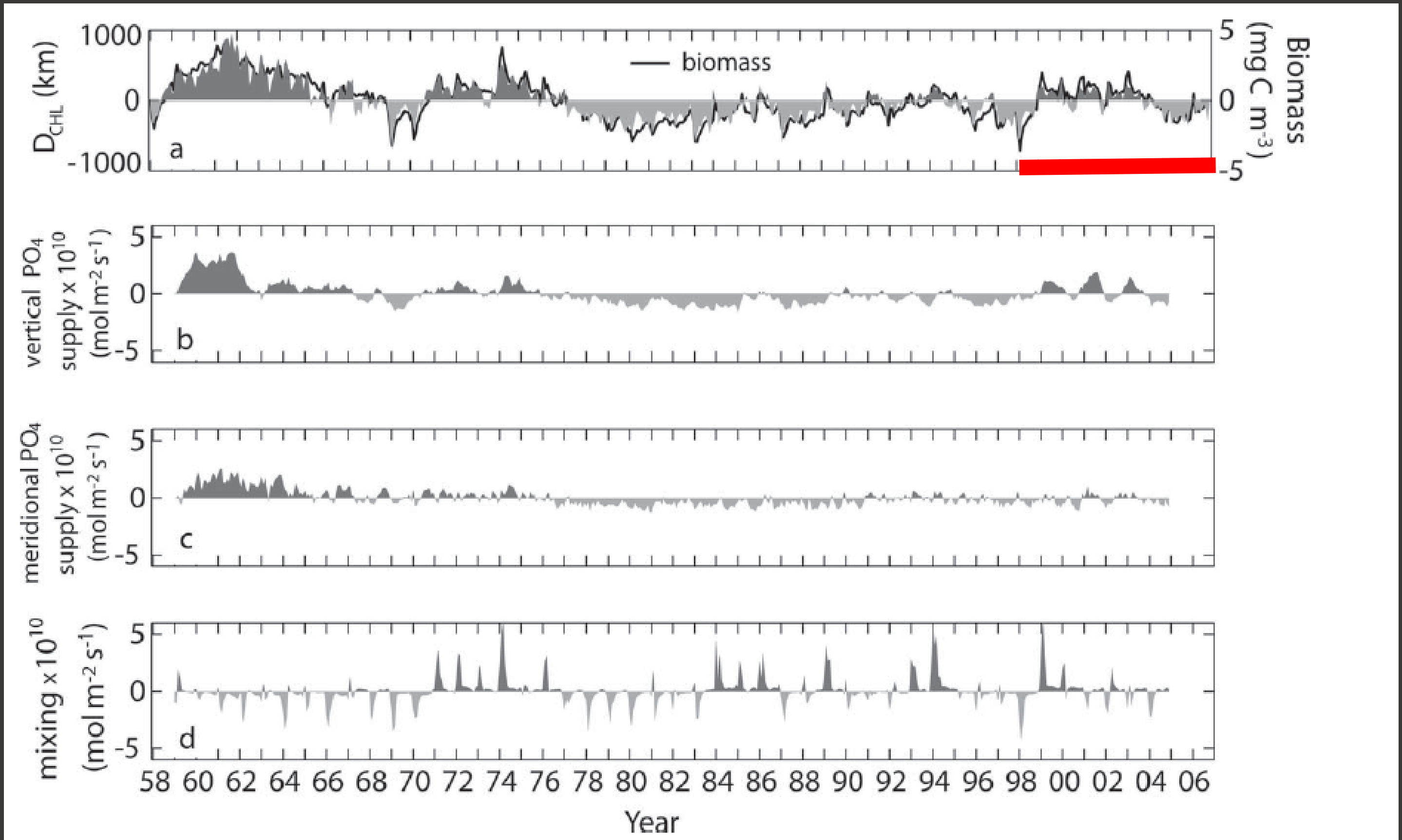
M. V. Pastor,[1] J. B. Palter,[2] J. L. Pelegrí,[1] and J. P. Dunne[3]





What drives the interannual variability?

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



Pastor et al, JGR, 2013

TOPAZ model

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

JOURNAL OF GEOPHYSICAL RESEARCH: OCEANS, VOL. 118, 3871–3886, doi:10.1002/jgrc.20254, 2013

Physical drivers of interannual chlorophyll variability in the eastern subtropical North Atlantic

M. V. Pastor,[1] J. B. Palter,[2] J. L. Pelegrí,[1] and J. P. Dunne[3]

Take home:

- Interannual variability embedded in multidecadal oscillation
  (need the model simulation to extend the "observations")

- Variability is driven by alterations in nutrient supply which in turn is driven by changes in upwelling water
  (processes that can not be detected using satellite observations)

SUMMARY (2)

Potential for models to inform ocean colour community:

- Uncover processes driving observations
- Explore uncertainties in observations (gaps in data etc)
- Extend dataset in space and time
- Place variability in large context

Debunk Model Myths:

- *You do not need to understand all equations and output*
- *Output is (or can be made) available*
- *Models are inherently wrong – but they can be useful*

OUTLINE

- Introduction to forward numerical biogeochemical /ecosystem models

- Why/How to use model output
  (OC example studies)

- Introduction to data assimilation
  (OC example studies)

- Capturing phytoplankton diversity

DATA ASSIMILATION

- Combine observation with model
- Bring model into consistency with observations
- “Best” of model and observations

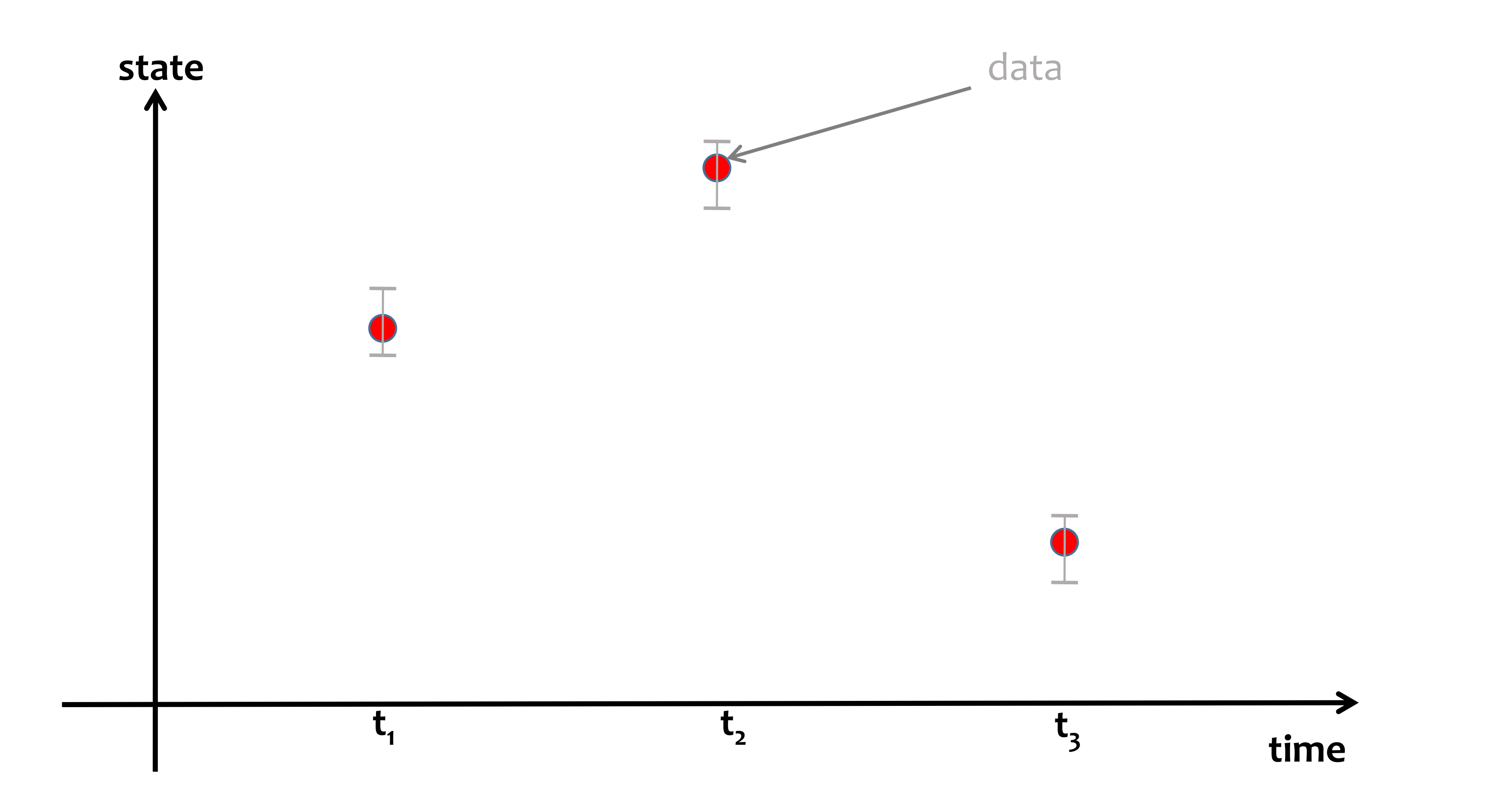
DATA ASSIMILATION

Some different types of data assimilation:

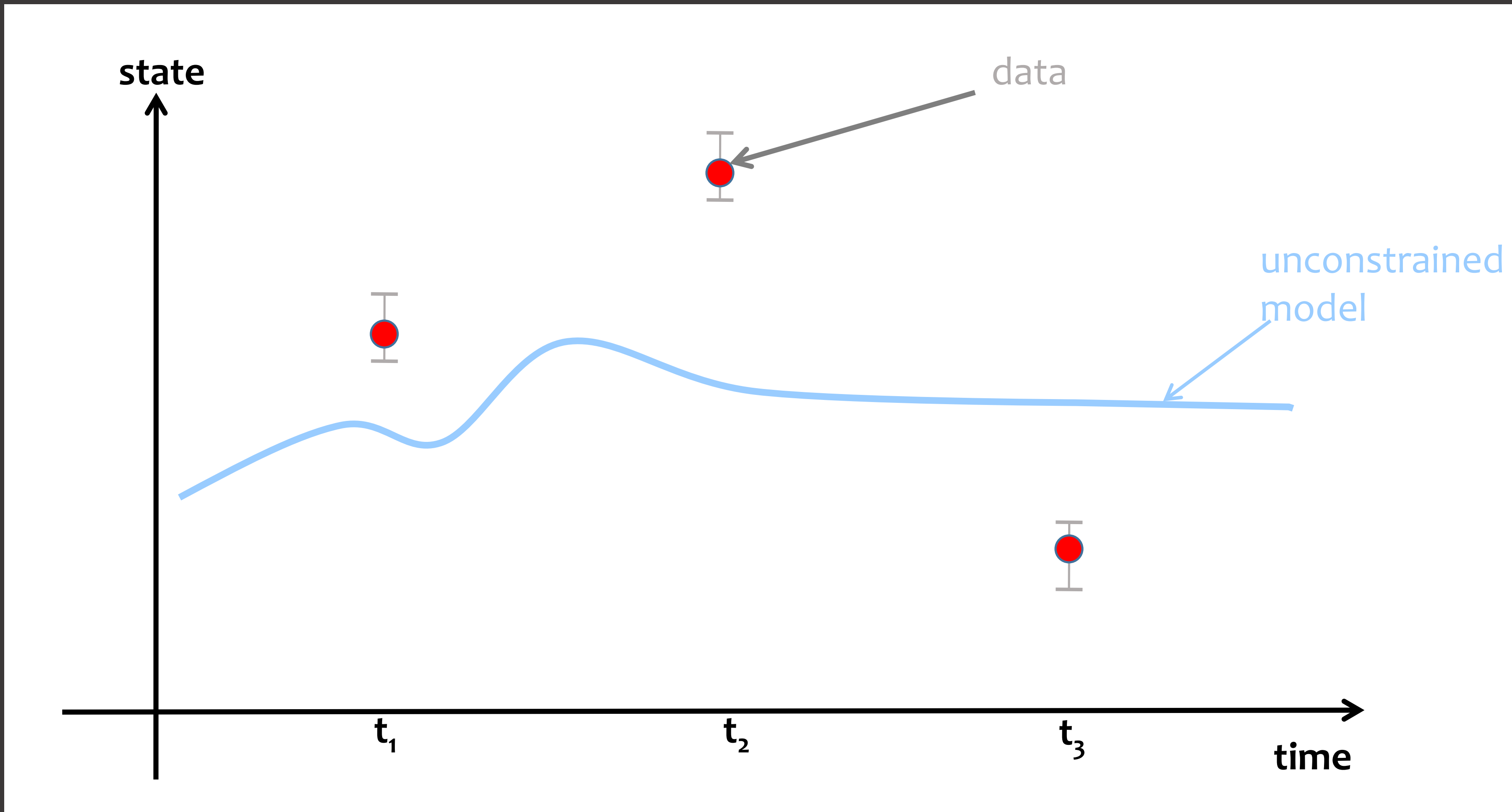
- Sequential methods
  (e.g. Kalman Filter, Ensemble Kalman Filter)

- Variational methods
  (e.g. Adjoint, 4D Var)

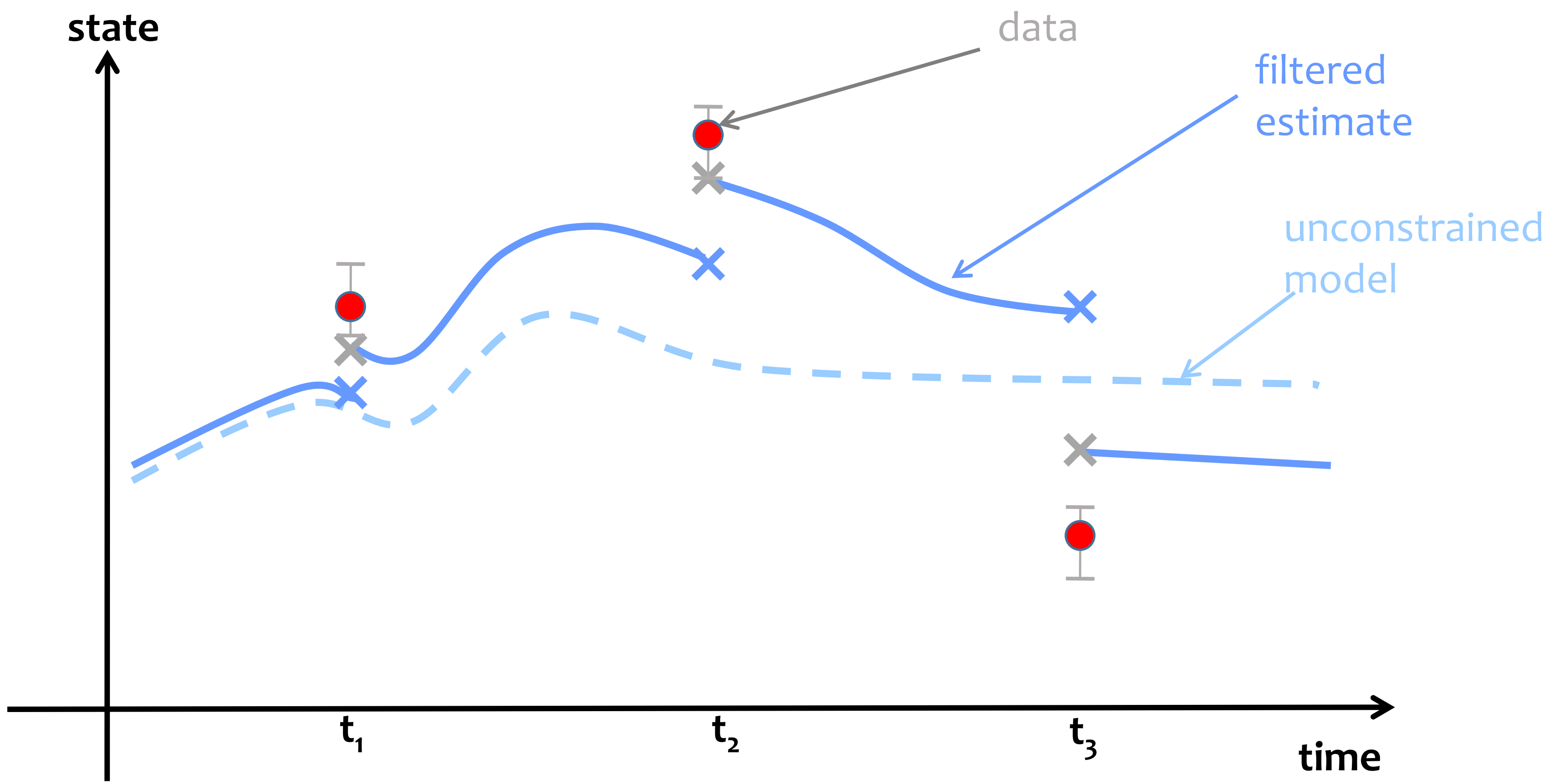
DATA ASSIMILATION



DATA ASSIMILATION



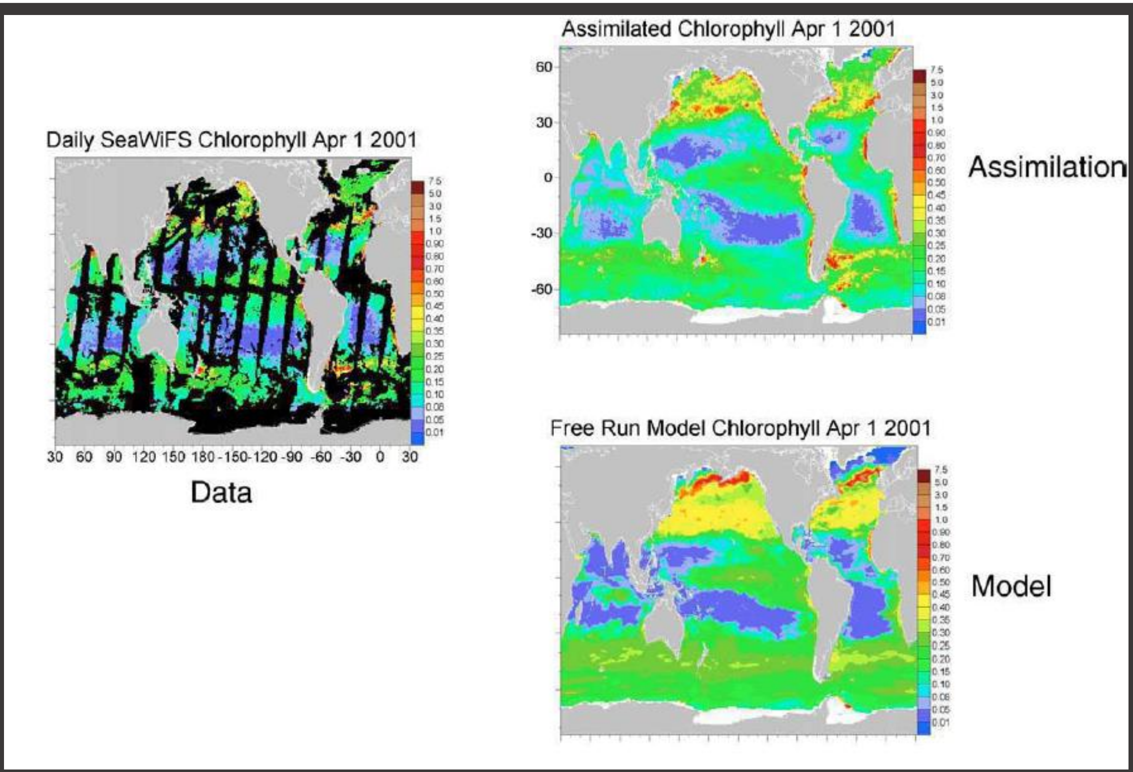
DATA ASSIMILATION



Assimilation: Sequential Method

(e.g. Kalman Filter)

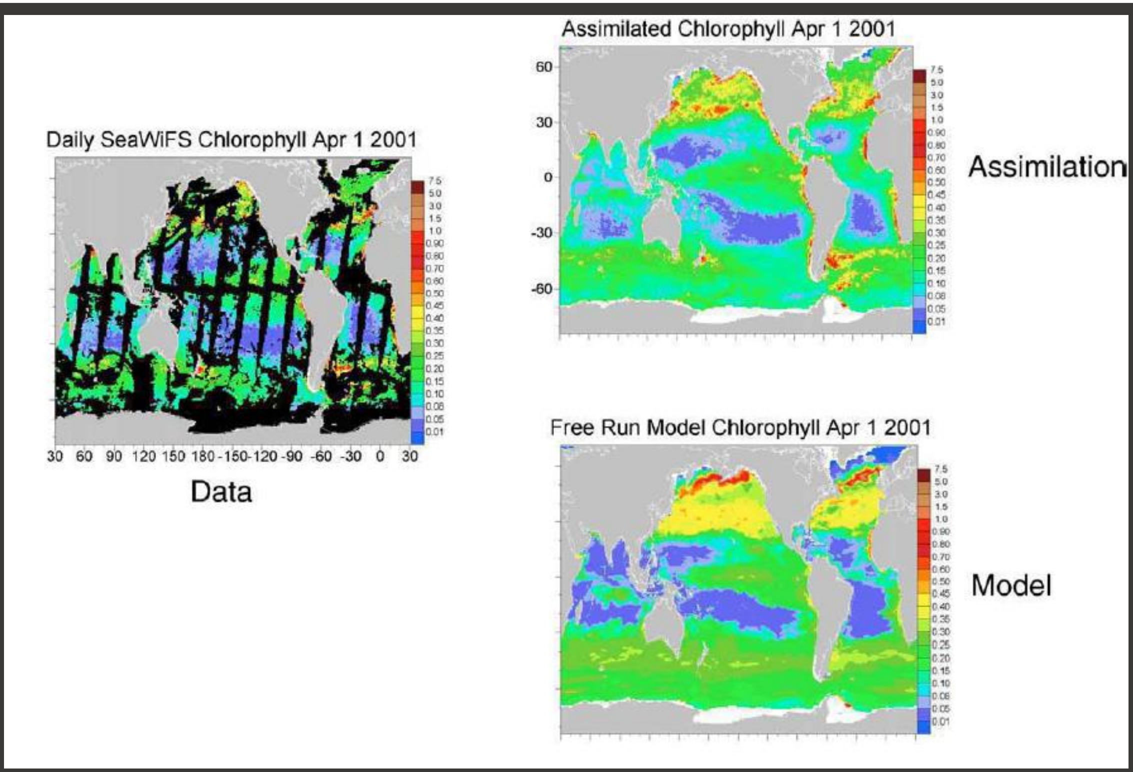
DATA ASSIMILATION: EXAMPLE



NOBM, Gregg, JMS, 2008

- 4 fold decrease in bias;
- Improves non-assimilated processes such as primary production

DATA ASSIMILATION: EXAMPLE



NOBM, Gregg, JMS, 2008

- Does not necessarily conserve mass; can also lead to misfits between nutrients and Chl (though see Rousseaux et al 2012)

DATA ASSIMILATION

- For providing state estimates/re-analyses

- For parameter optimization

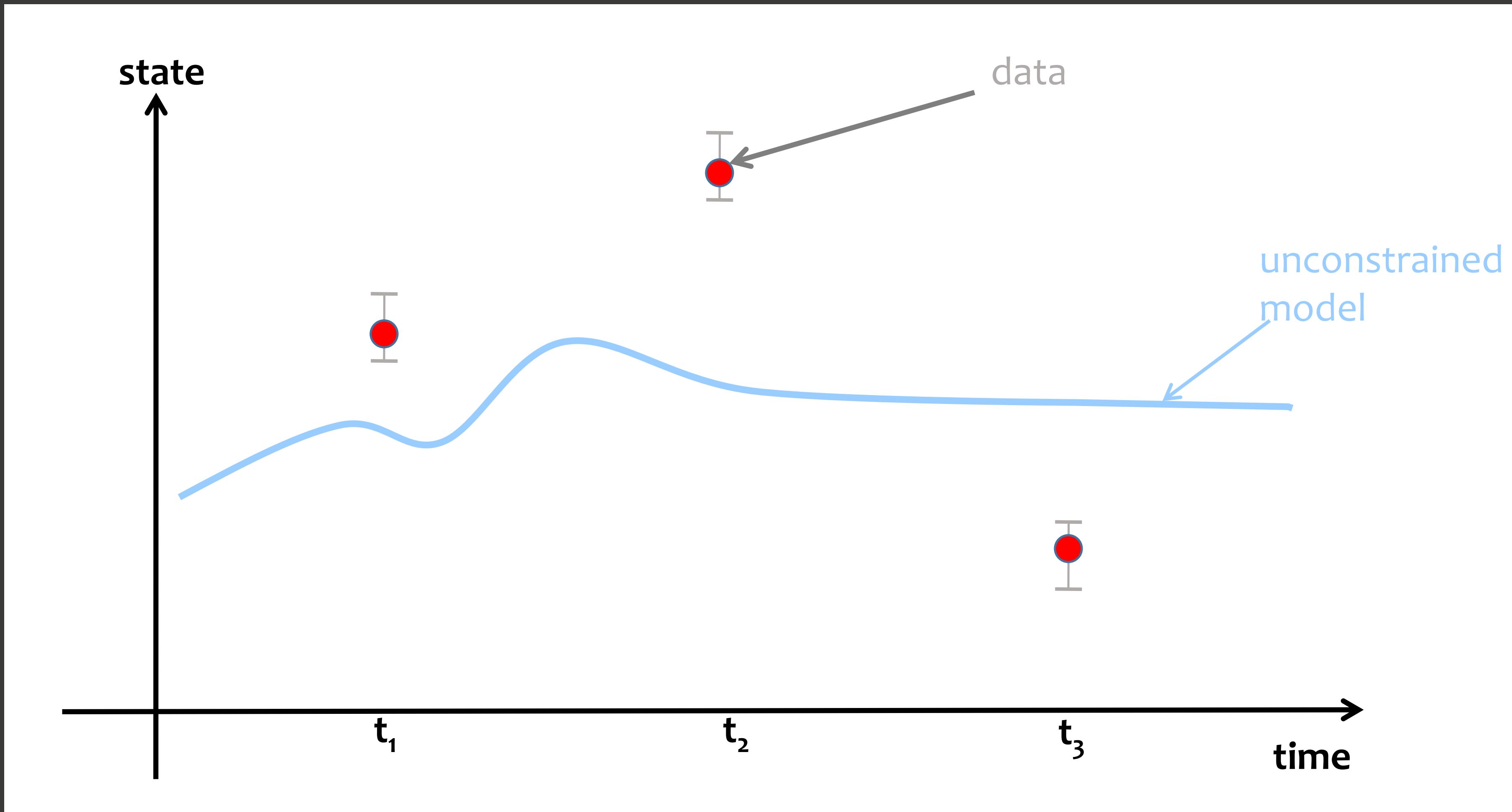
DATA ASSIMILATION

Some different types of data assimilation:

- Sequential methods
  (e.g. Kalman Filter, Ensemble Kalman Filter)

- Inverse methods
  (e.g. Adjoint, 4D Var)

DATA ASSIMILATION



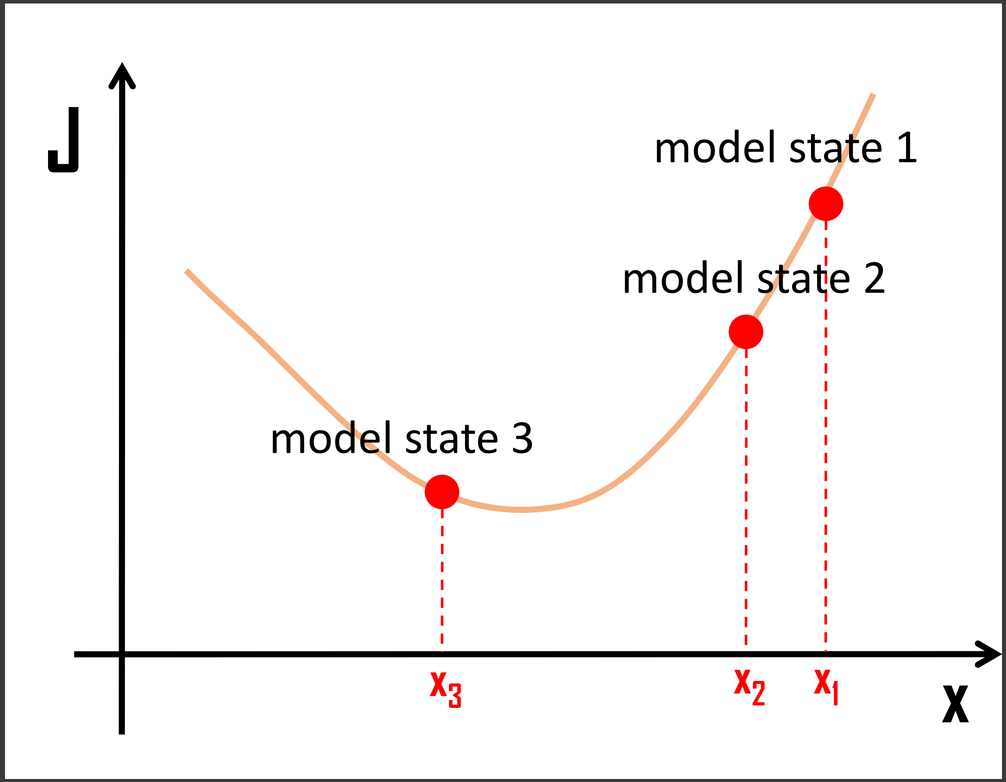
least square fit of model to observations: $J=\Sigma_i W_i^2(\text{model}_i-\text{data}_i)^2$

J - cost function; W_i - weighting function (error estimates)

DATA ASSIMILATION

State Estimation: Adjoint Method

- essentially the “backward” model
- efficiently computes sensitivity of model (cost function) to perturbations in parameters/initial conditions/forcing fields

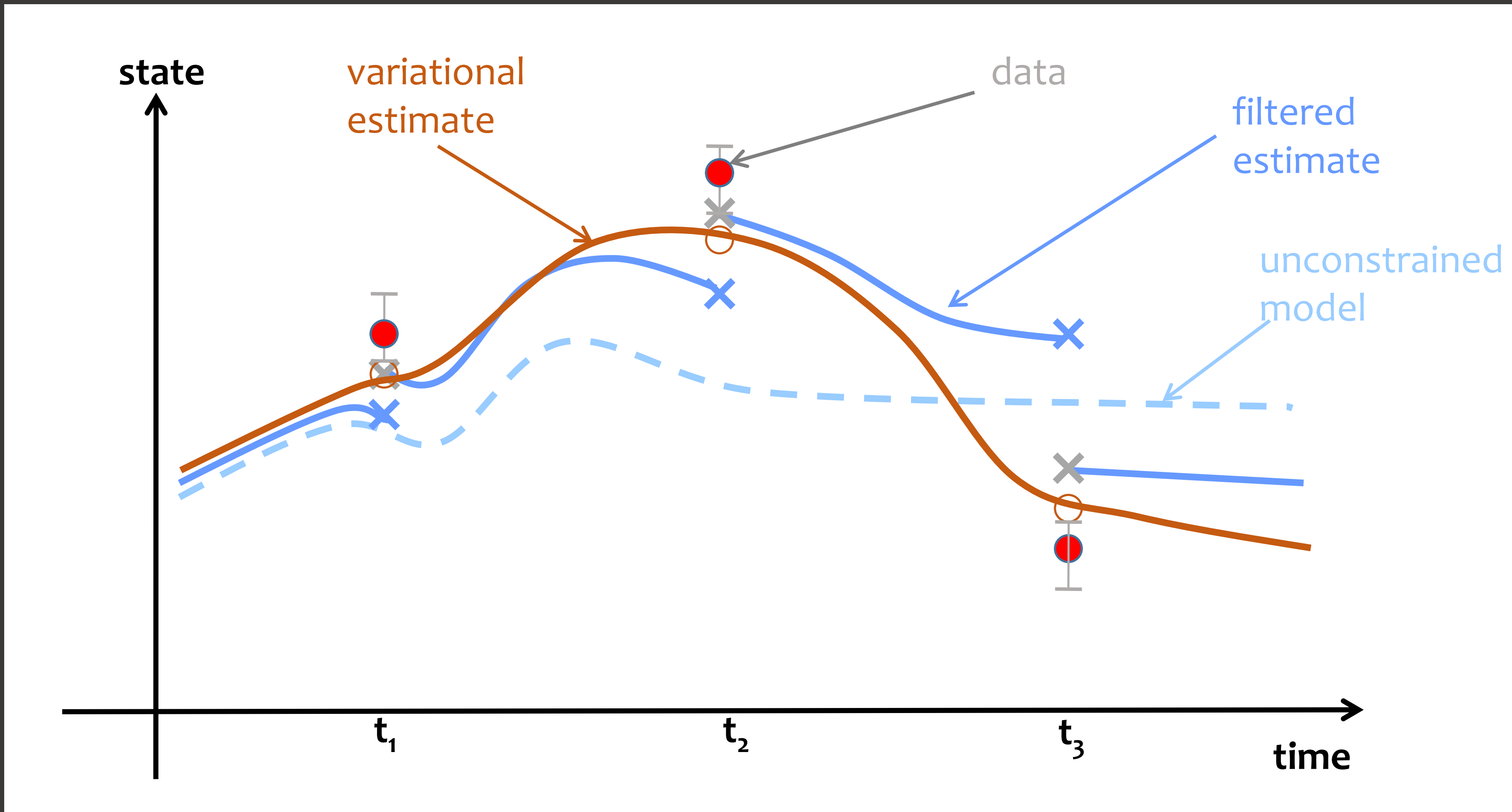


$$J=\Sigma_i W_i^2(model_i-data_i)^2$$

Use adjoint to find gradient **dJ/dx** to iteratively minimize **J**

x can be:
- initial conditions
- forcing fields
- model parameters

DATA ASSIMILATION



Assimilation: Variational Method (e.g. Adjoint)

DATA ASSIMILATION: EXAMPLE

AGU PUBLICATIONS

JGR

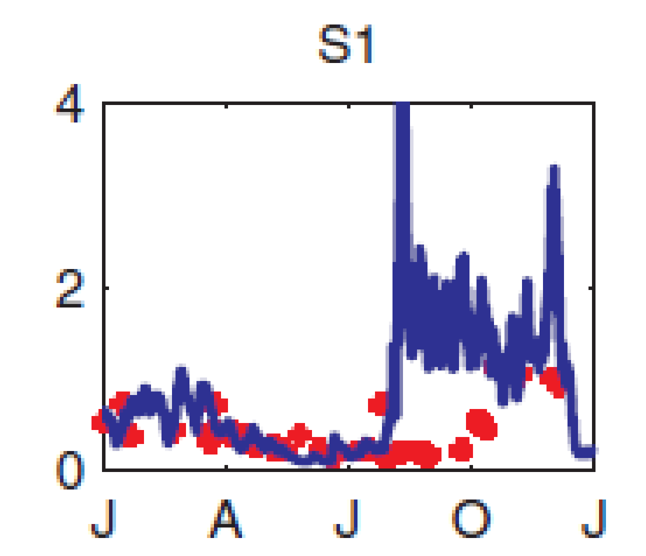
Journal of Geophysical Research: Oceans

The assimilation of satellite-derived data into a one-dimensional lower trophic level marine ecosystem model

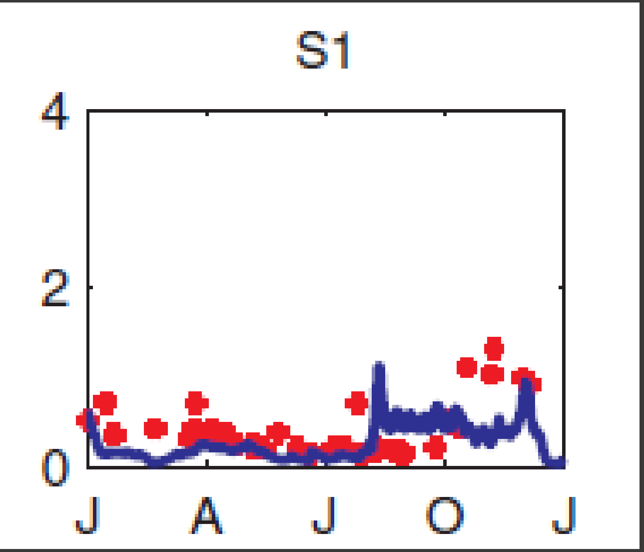
Yongjin Xiao[1] and Marjorie A. M. Friedrichs[1]

DATA ASSIMILATION: EXAMPLE

Forward Model



Adjoint Model after parameter estimation to be consistent with ocean colour data

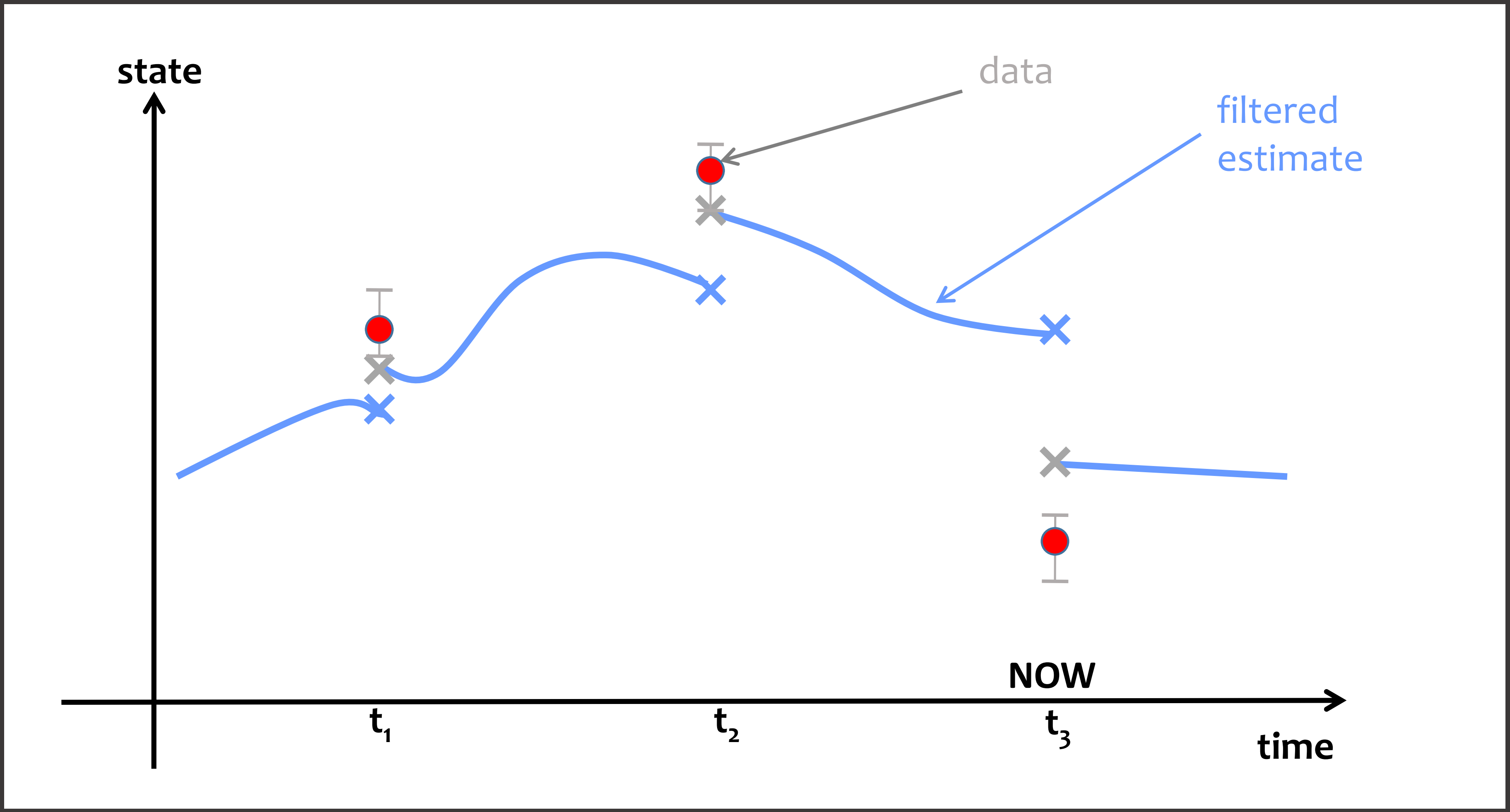


Xiao and Friedrichs, JGR, 2016

SOME TERMINOLOGY (3)

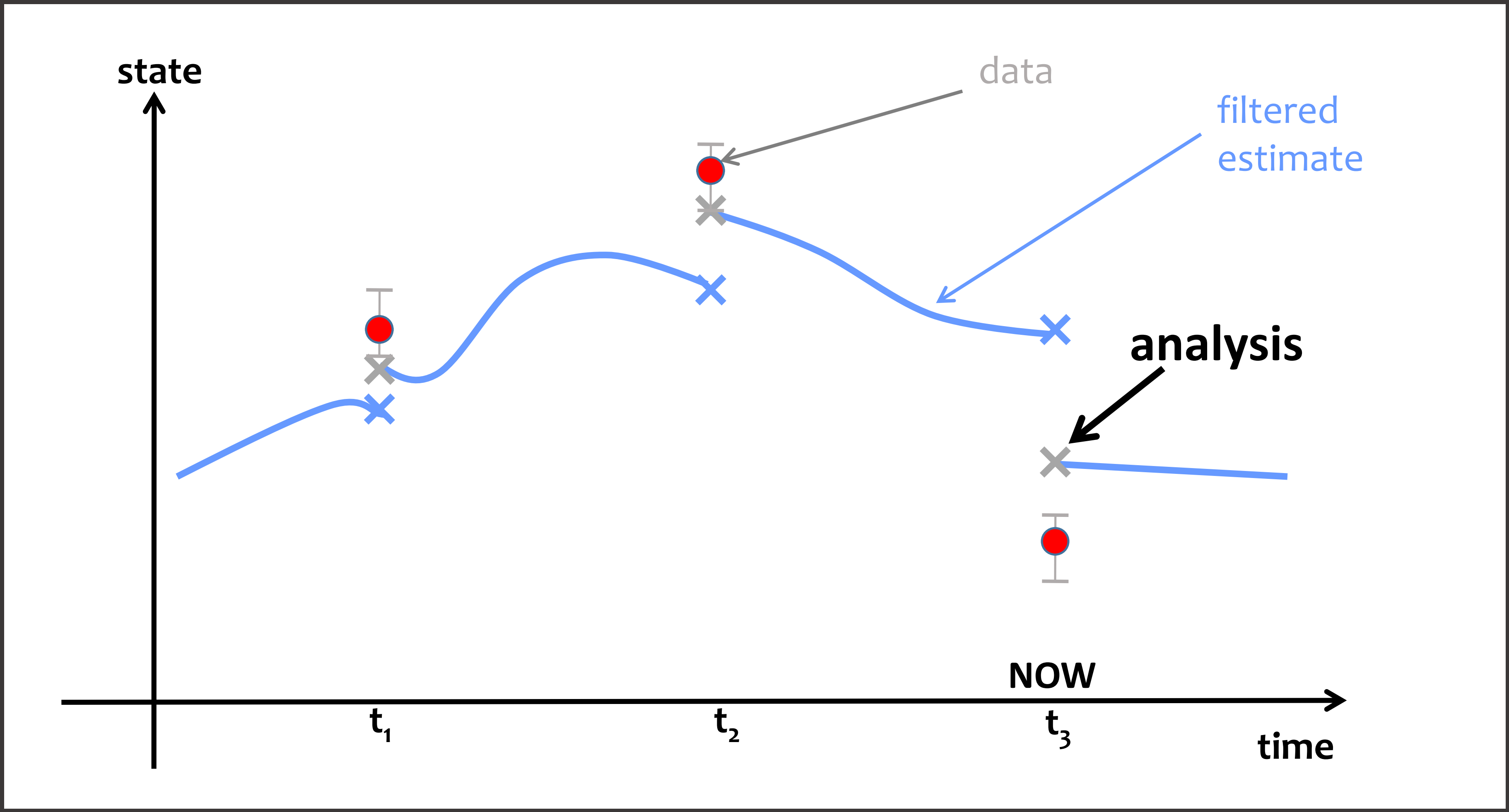
- Forward model – not data assimilation
- Data Assimilation – produces "analysis", "re-analysis" and/or parameter estimations
- Operational modelling – produce "products" for real-time or short term uses
- Inverse modeling – know the results, figure out parameters/initial conditions/forcing fields to get there (e.g. adjoint)
- Cost function – least square difference between model and data (goal of assimilation is to reduce cost function)
- Forecast: after re-initializing for "today" run forward (days) for prediction
- Reanalysis/State Estimation - data assimilated fields (e.g. Chl)

DATA ASSIMILATION



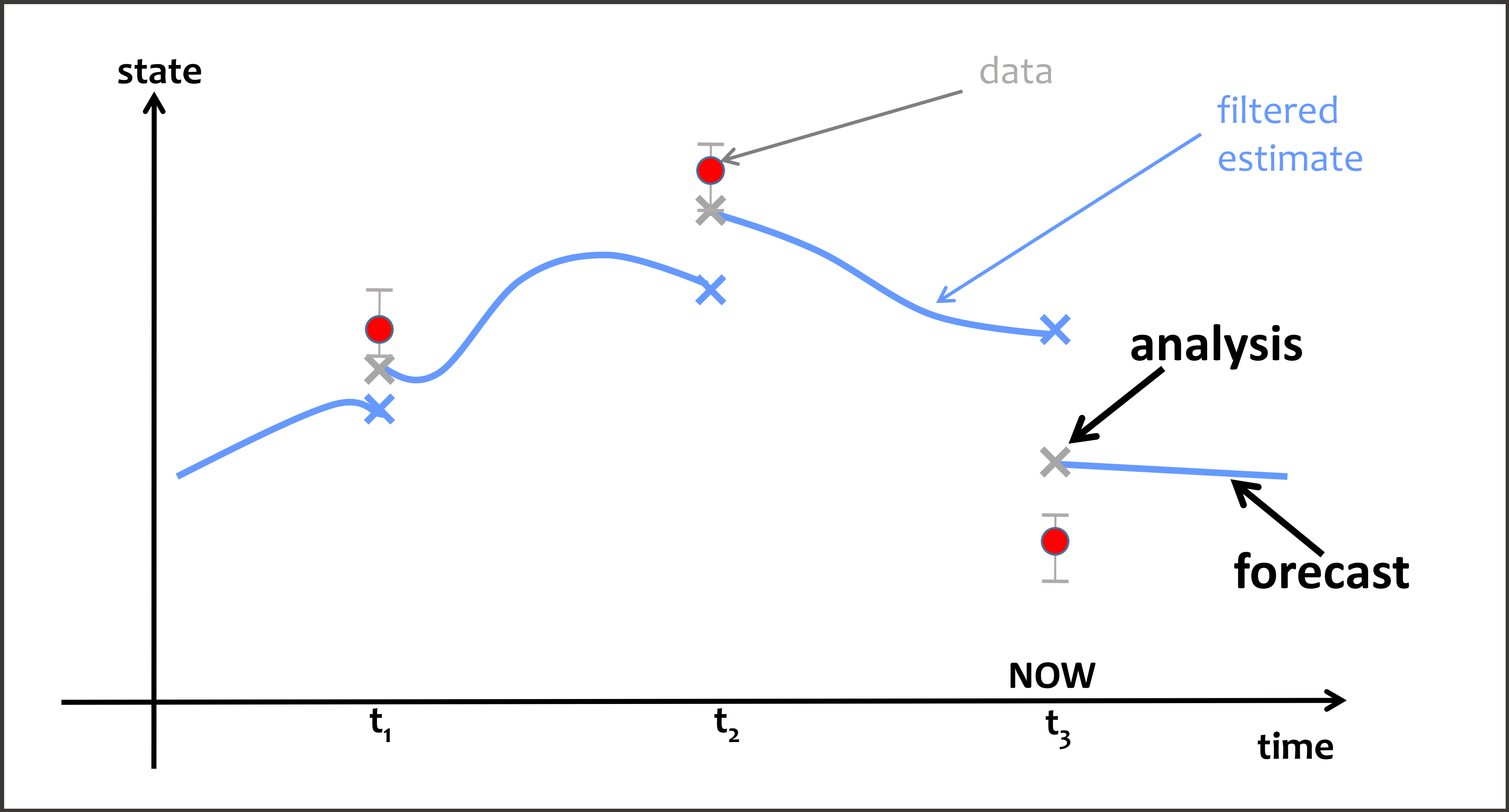
Assimilation: Sequential Method (e.g. Kalman Filter)

DATA ASSIMILATION



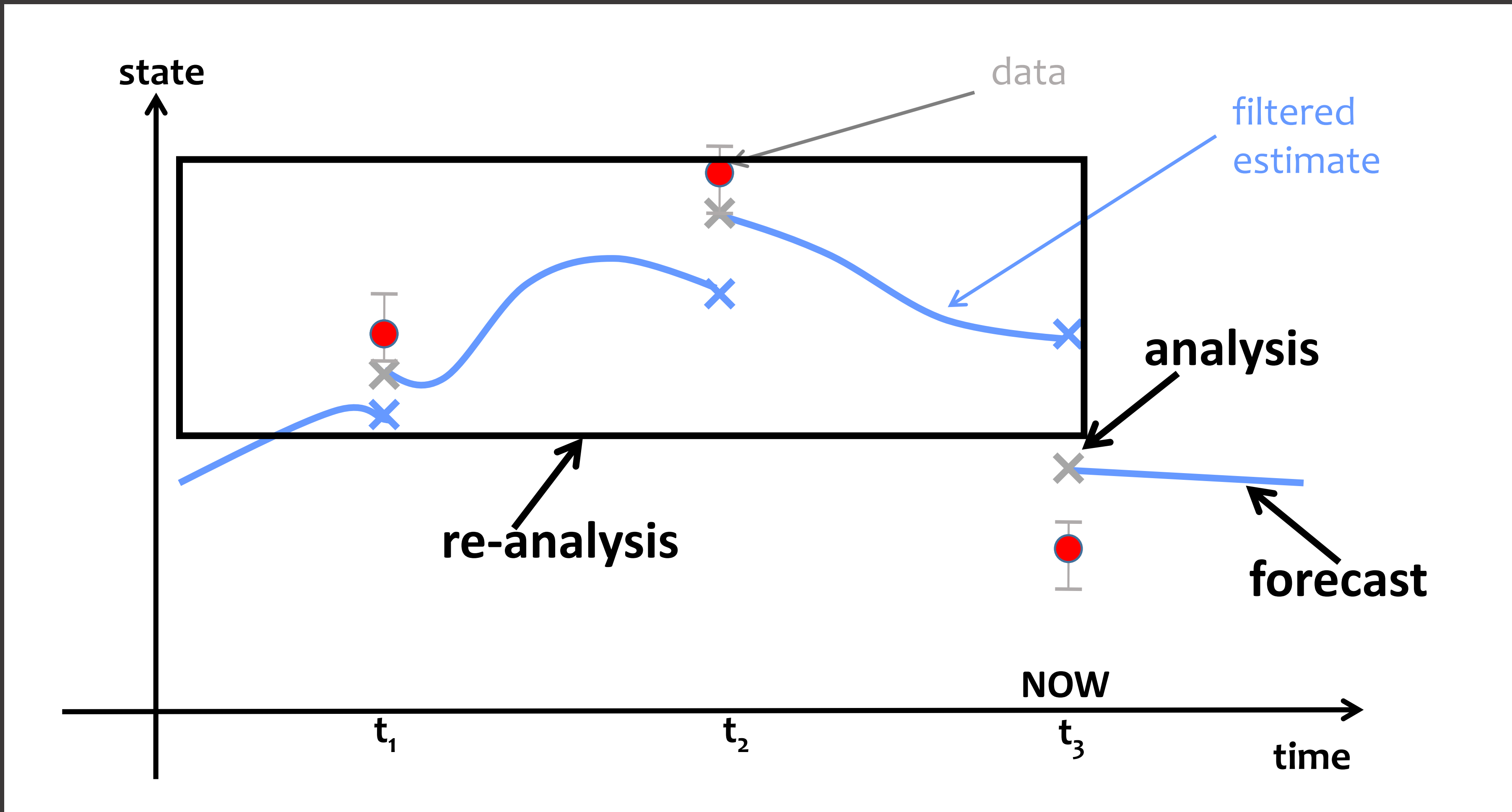
Assimilation: Sequential Method (e.g. Kalman Filter)

DATA ASSIMILATION



Assimilation: Sequential Method (e.g. Kalman Filter)

DATA ASSIMILATION



Assimilation: Sequential Method

SUMMARY (3)

- Types of data assimilation:
  - sequential methods
  - inverse methods (e.g. adjoint)

- Provide analysis/re-analysis/forecast: but know limitations

- Can also provide parameter estimates

- Physical fields from data assimilation:

  ECCO (adjoint)

  OTHERS…..

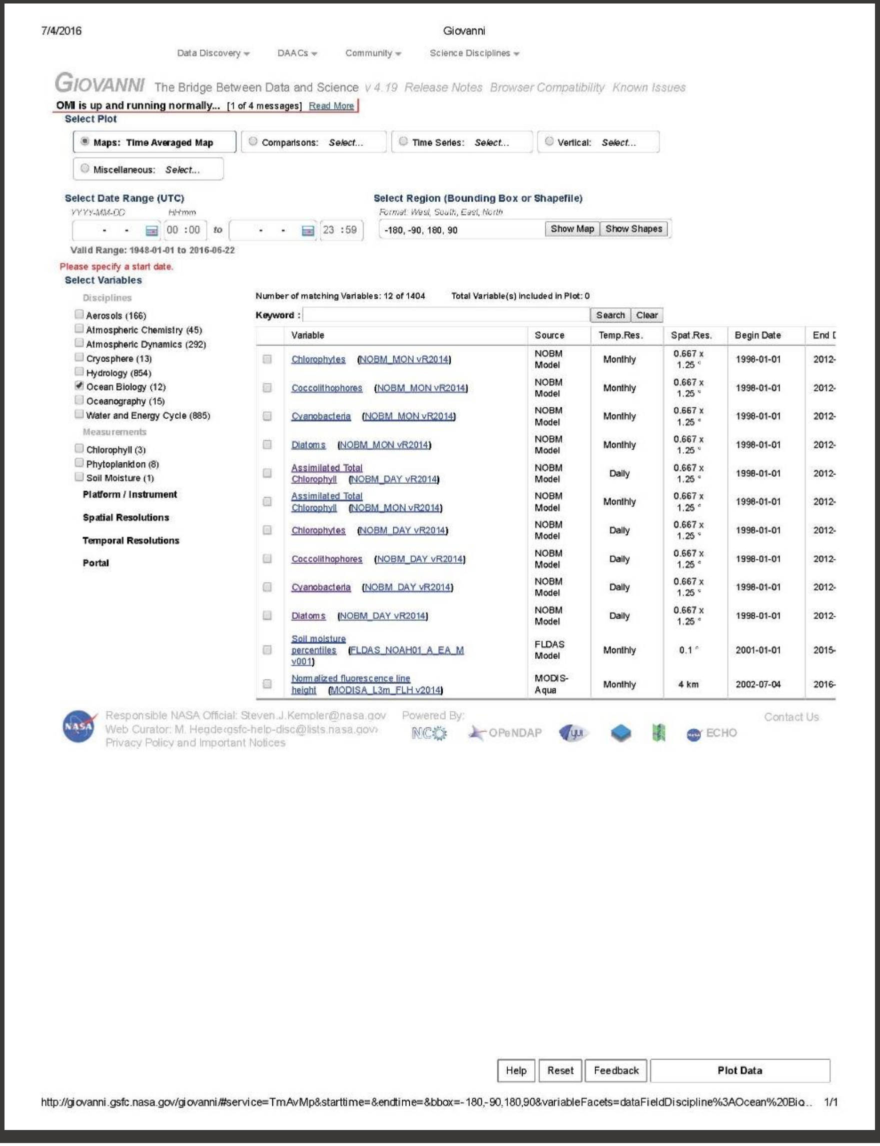
- Physical and biogeochemical/ecosystem assimilation eventually

HOW TO GET MODEL OUTPUT: EXAMPLES

HOW TO GET MODEL OUTPUT: EXAMPLES

And what sort is more appropriate for my question/interest?

HOW TO GET MODEL OUTPUT: EXAMPLES



7/4/2016 Giovanni

Data Discovery ▾ DAACs ▾ Community ▾ Science Disciplines ▾

GIOVANNI The Bridge Between Data and Science *V 4.19 Release Notes Browser Compatibility Known Issues*

OMI is up and running normally... [1 of 4 messages] Read More

Select Plot

Maps: Time Averaged Map | Comparisons: *Select...* | Time Series: *Select...* | Vertical: *Select...* | Miscellaneous: *Select...*

Select Date Range (UTC)

YYYY-MM-DD *HH:mm*

- - 00 :00 to - - 23 :59

Valid Range: 1948-01-01 to 2016-06-22

Select Region (Bounding Box or Shapefile)

Format: West, South, East, North

-180, -90, 180, 90 Show Map Show Shapes

Please specify a start date.

Select Variables

Disciplines

- Aerosols (166)
- Atmospheric Chemistry (45)
- Atmospheric Dynamics (292)
- Cryosphere (13)
- Hydrology (854)
- Ocean Biology (12)
- Oceanography (15)
- Water and Energy Cycle (885)

Measurements

- Chlorophyll (3)
- Phytoplankton (8)
- Soil Moisture (1)

Platform / Instrument

Spatial Resolutions

Temporal Resolutions

Portal

Number of matching Variables: 12 of 1404 Total Variable(s) included in Plot: 0

Keyword : Search Clear

Variable	Source	Temp.Res.	Spat.Res.	Begin Date	End D
Chlorophytes (NOBM_MON vR2014)	NOBM Model	Monthly	0.667 x 1.25 °	1998-01-01	2012-
Coccolithophores (NOBM_MON vR2014)	NOBM Model	Monthly	0.667 x 1.25 °	1998-01-01	2012-
Cyanobacteria (NOBM_MON vR2014)	NOBM Model	Monthly	0.667 x 1.25 °	1998-01-01	2012-
Diatoms (NOBM_MON vR2014)	NOBM Model	Monthly	0.667 x 1.25 °	1998-01-01	2012-
Assimilated Total Chlorophyll (NOBM_DAY vR2014)	NOBM Model	Daily	0.667 x 1.25 °	1998-01-01	2012-
Assimilated Total Chlorophyll (NOBM_MON vR2014)	NOBM Model	Monthly	0.667 x 1.25 °	1998-01-01	2012-
Chlorophytes (NOBM_DAY vR2014)	NOBM Model	Daily	0.667 x 1.25 °	1998-01-01	2012-
Coccolithophores (NOBM_DAY vR2014)	NOBM Model	Daily	0.667 x 1.25 °	1998-01-01	2012-
Cyanobacteria (NOBM_DAY vR2014)	NOBM Model	Daily	0.667 x 1.25 °	1998-01-01	2012-
Diatoms (NOBM_DAY vR2014)	NOBM Model	Daily	0.667 x 1.25 °	1998-01-01	2012-
Soil moisture percentiles (FLDAS_NOAH01_A_EA_M v001)	FLDAS Model	Monthly	0.1 °	2001-01-01	2015-
Normalized fluorescence line height (MODISA_L3m_FLH v2014)	MODIS-Aqua	Monthly	4 km	2002-07-04	2016-

Responsible NASA Official: Steven.J.Kempler@nasa.gov
Web Curator: M. Hegde<gsfc-help-disc@lists.nasa.gov>
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Contact Us

Help Reset Feedback Plot Data

http://giovanni.gsfc.nasa.gov/giovanni/#service=TmAvMp&starttime=&endtime=&bbox=-180,-90,180,90&variableFacets=dataFieldDiscipline%3AOcean%20Bio... 1/1

NASA MODEL:

NOBM (Gregg, JMS, 2008)

Assimilates Chl,

Hindcast available

Data available from Giovanni

HOW TO GET MODEL OUTPUT: EXAMPLES

COPERNICUS
MARINE ENVIRONMENT MONITORING SERVICE

http://marine.copernicus.eu/web/69-interactive-catalogue.php

HOW TO GET MODEL OUTPUT: EXAMPLES

COPERNICUS
MARINE ENVIRONMENT MONITORING SERVICE

ERSEM

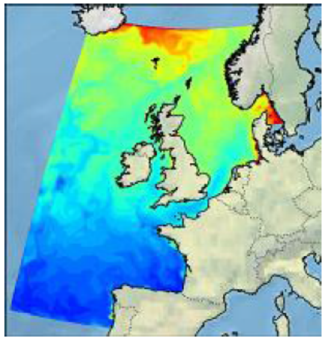
NORTHWESTSHELF_ANALYSIS_FORECAST_BIO_004_002_b

Atlantic - European North West Shelf - Ocean Biogeochemistry Analysis and Forecast

The Forecasting Ocean Assimilation Model 7km Atlantic Margin model (FOAM AMM7) is a coupled hydrodynamic-ecosystem model, nested in a series of one-way nests to the Met Office global ocean model. The hydrodynamics are supplied by the Nucleus for European Modelling of the Ocean (NEMO) with the 3DVar NEMOVAR system used for the assimilation of sea surface temperature data. This is coupled to the European Regional Seas Ecosystem Model (ERSEM), developed at Plymouth Marine Laboratory (PML). ERSEM based models have been used operationally to forecast biogeochemistry in the region for a number of years (Siddorn et al., 2006).

MORE INFO

NORTHWESTSHELF_REANALYSIS_BIO_004_011



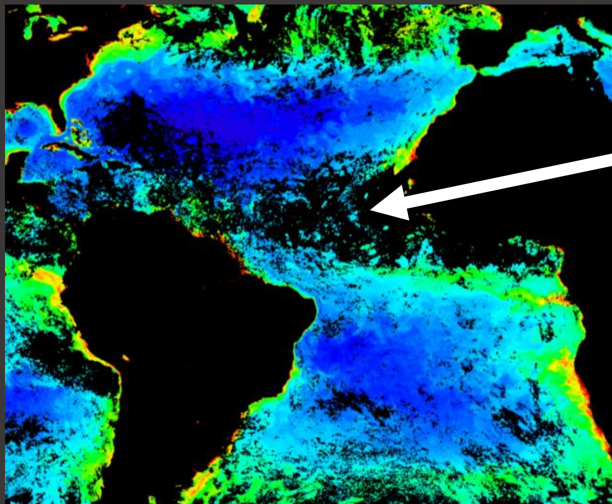
Atlantic- European North West Shelf- Ocean Biogeochemistry Reanalysis from METOFFICE (1985-2012)

The reanalysis covers the period January 1985 until July 2012 and is based upon the
Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM7). This is a coupled hydrodynamic-ecosystem model of the North West European shelf forced at the surface by ERA-interim winds, atmospheric temperature, and precipitation fluxes. Horizontal boundary conditions were provided by the NOC global reanalysis prior to 1989 and by the GloSea reanalysis thereafter. Boundary conditions in the Baltic sea came from the IOM-GETM model. E-Hype data were used for river inputs. Hydrodynamic calculations were performed by the Nucleus for European Modelling of the Ocean (NEMO) system, while the 3DVar NEMOVAR system was used for the assimilation of sea surface temperature data. This is coupled to the European Regional Seas Ecosystem Model (ERSEM), developed at Plymouth Marine Laboratory (PML) (Blackford et al., 2004). ERSEM based models have been used operationally to forecast biogeochemistry in the region for a number of years (Siddorn et al., 2007). Nutrient boundary conditions are provided by World Ocean Atlas climatology (Garcia et al., 2010) and river nutrient and sediment concentrations from the operational climatology. Outputs are provided both as monthly means and as daily 25 hour, de-tided, averages.

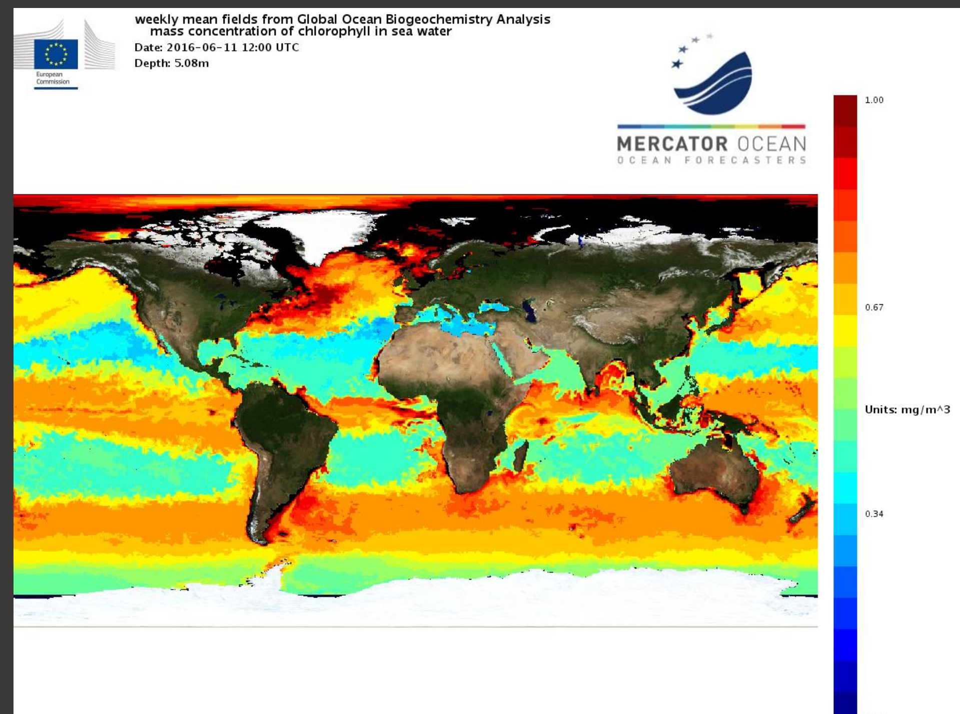
MORE INFO

http://marine.copernicus.eu/web/69-interactive-catalogue.php

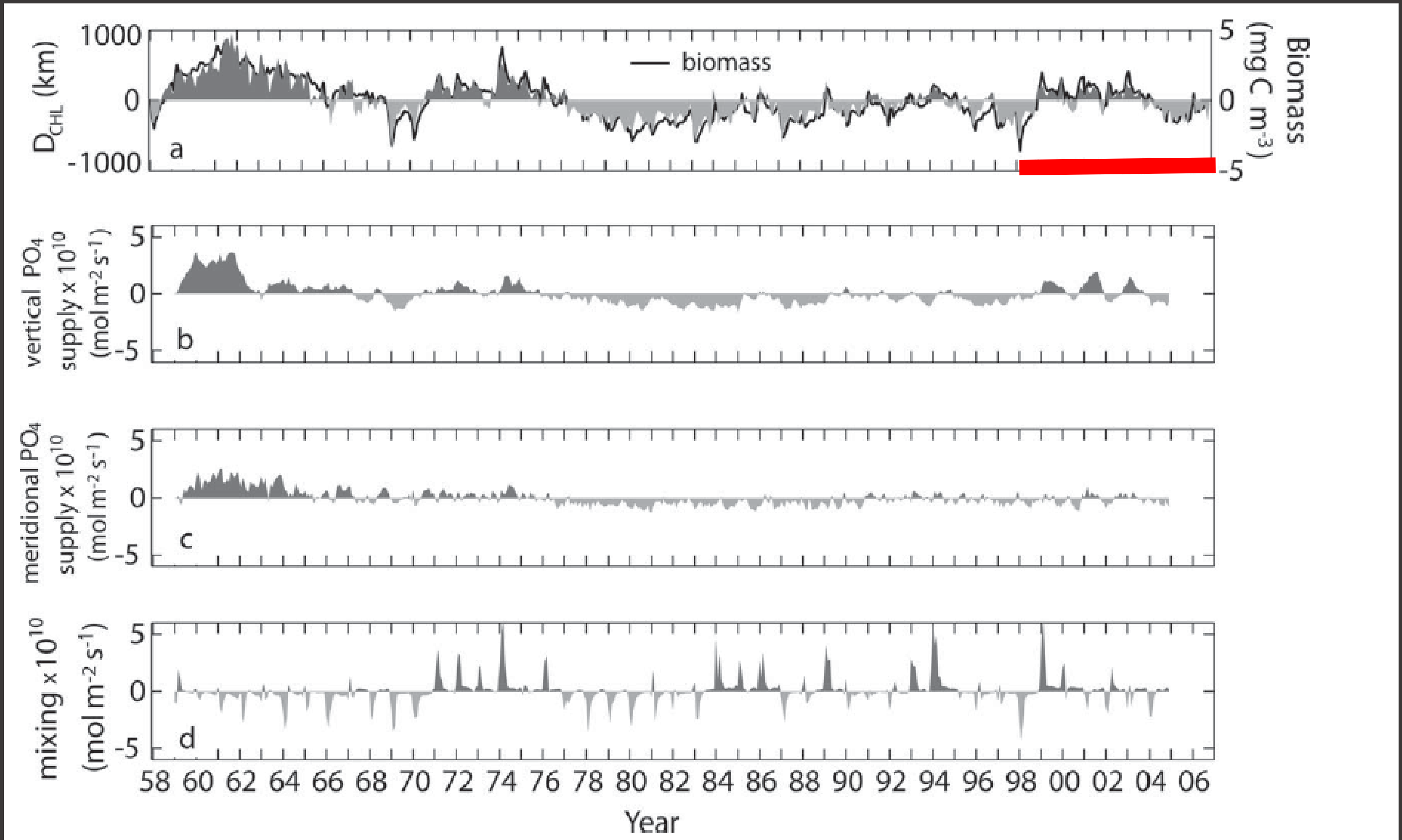
WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



What happens if you want to go fishing today here?



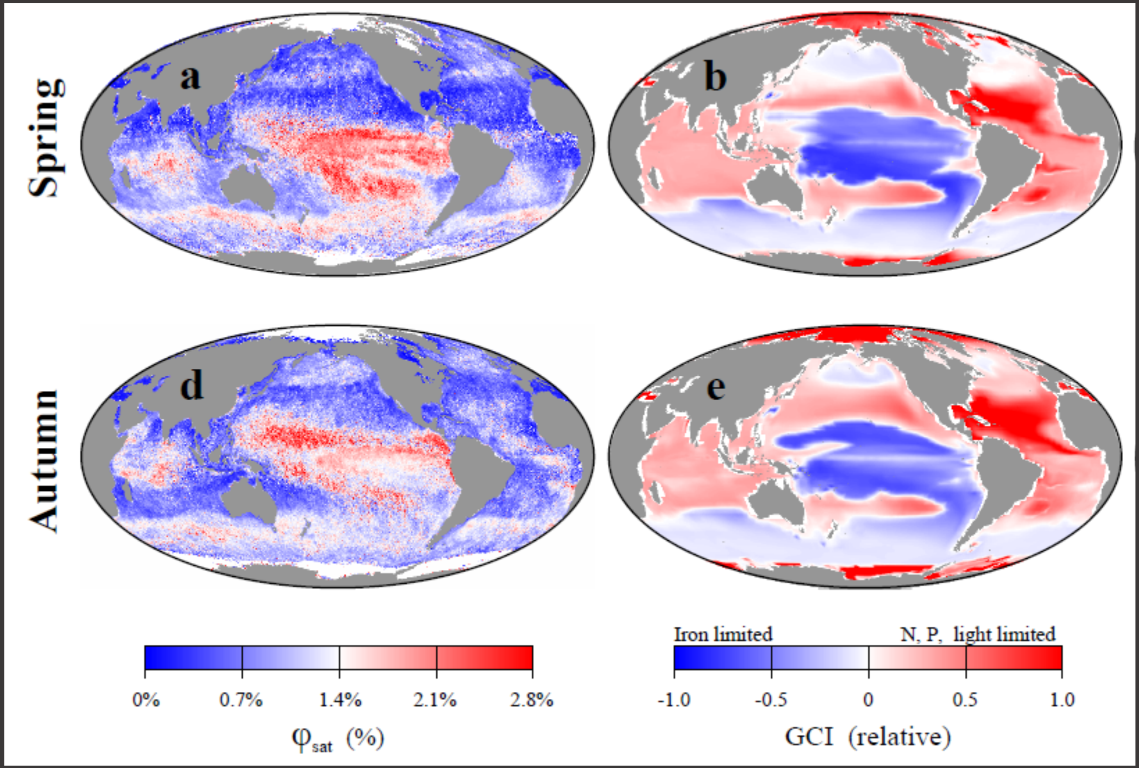
WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



Pastor et al, JGR, 2013

TOPAZ model

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES

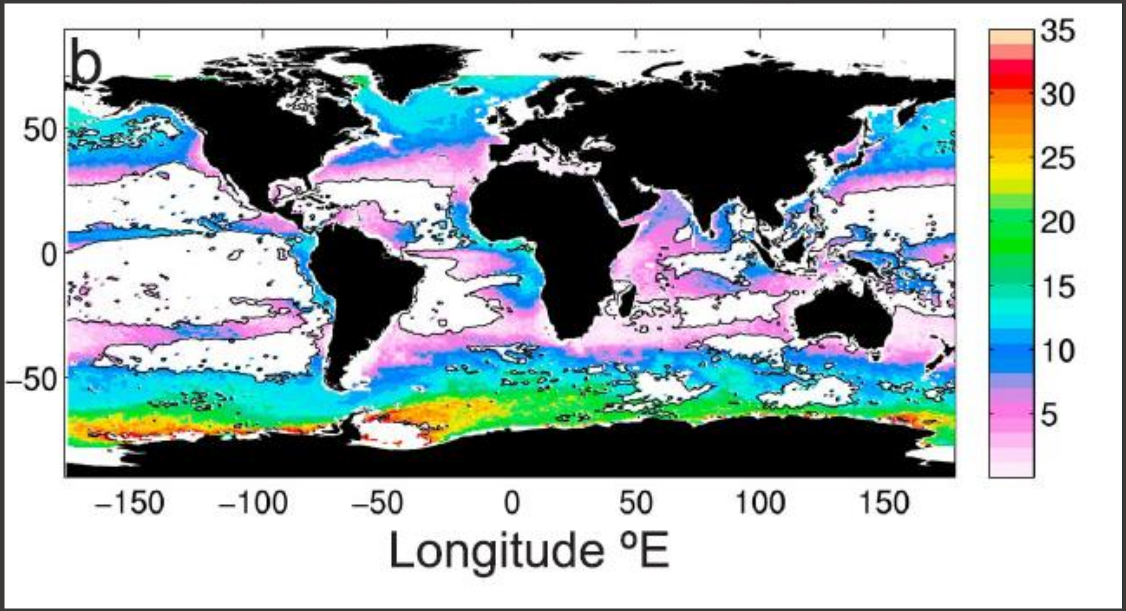


BOGM model (Moore et al 2006):

$$\mu = \mu_{max} f(T, I) \min\left(\frac{NO_3}{NO_3 + \kappa_{no3}}, \frac{PO_4}{PO_4 + \kappa_{po4}}, \frac{Fe}{Fe + \kappa_{fe}}\right)$$

Behrenfeld et al., BG, 2009

WHY/HOW TO USE MODEL OUTPUT: EXAMPLES



white areas: no discernable seasonal cycle

Uncertainty (in days) of bloom peak

Uncertainty (in days) of bloom initiation much worse

Coles et al, JGR, 2012

HOW TO GET MODEL OUTPUT: EXAMPLES

Example of non-assimilated models:

BOGM (Moore et al., 2007) -- NCAR

PISCES (Aumont et al, GMD, 2015)

Darwin (Dutkiewicz et al, BG, 2015)

Topaz (Dunne et al, JClim, 2011) – GFDL

(Kearney et al, Ecol Model., 2012) – GFDL (end to end foodweb model)

…. many others…..

OUTLINE

- Introduction to forward numerical biogeochemical /ecosystem models

- Why/How to use model output
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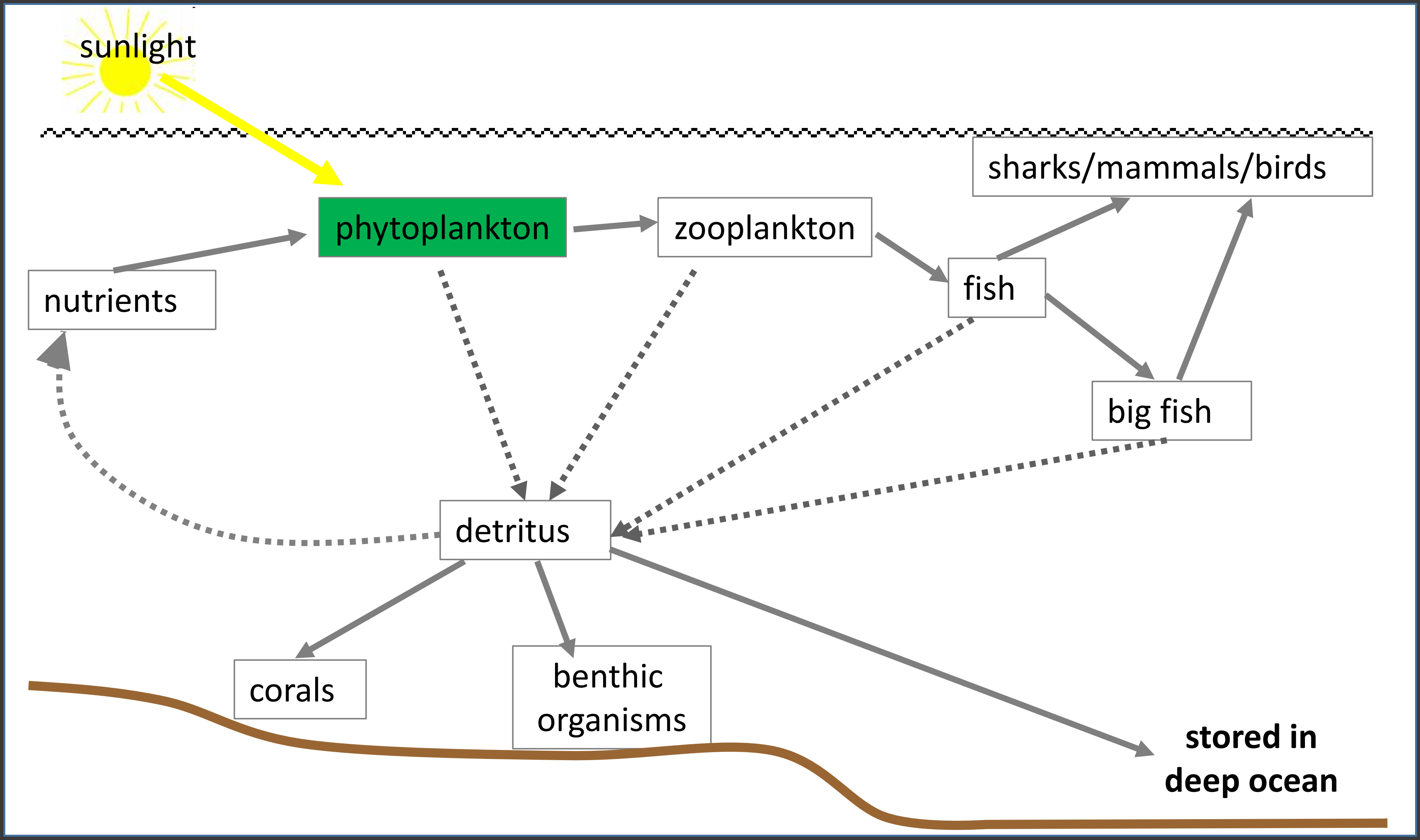
- Capturing phytoplankton diversity

MODELING DIVERSITY OF PHYTOPLANKTON



MODELING DIVERSITY OF PHYTOPLANKTON

Phytoplankton diversity matters:

- As base of foodweb
- For carbon cycling
- For resilience of ecosystem

MODELING DIVERSITY OF PHYTOPLANKTON

Phytoplankton differ in terms of:

- size
- nutrient uptake
- biogeochemical function
- temperature tolerance
- pigment
- predation avoidance
- morphology
- chain/colony formation
- symbiosis

MODELING DIVERSITY OF PHYTOPLANKTON

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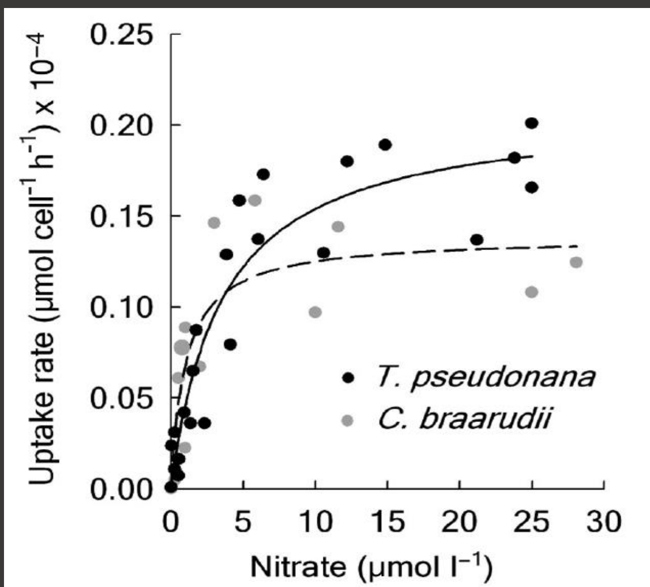
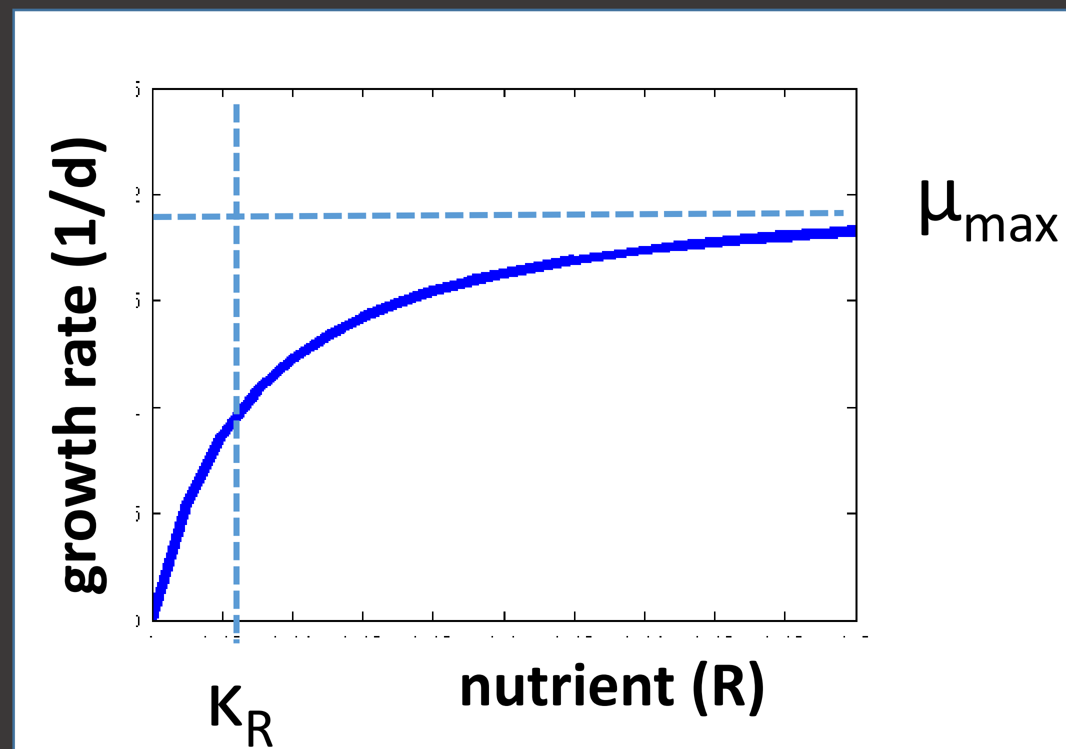
MODELING DIVERSITY: NUTRIENT UPTAKE

$$\mu_{\max} \frac{R}{R+\kappa_R}$$



Cermeno et al, MEPS, 2011



MODELING DIVERSITY: NUTRIENT UPTAKE

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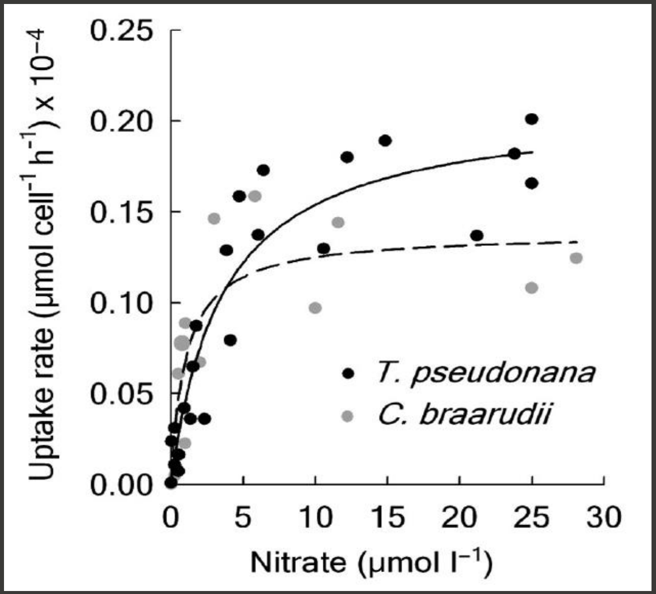
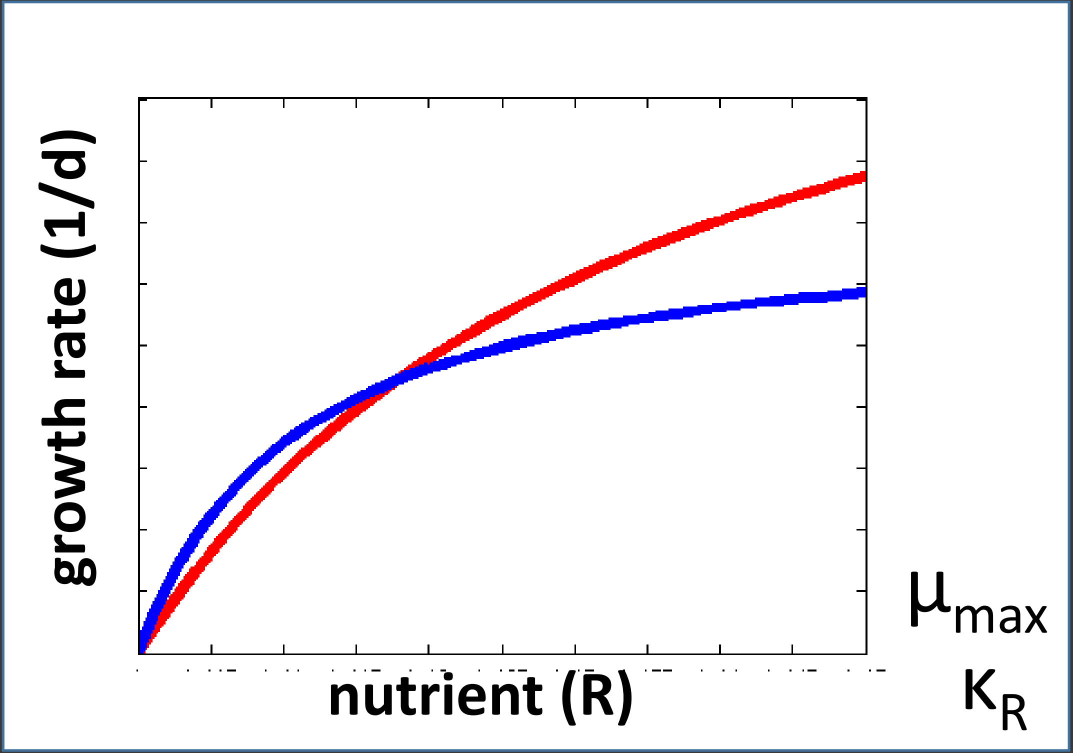
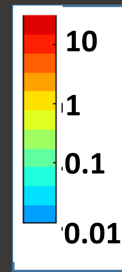
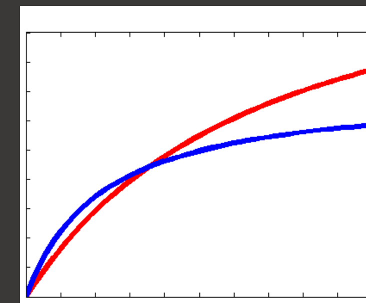


Cermeno et al, MEPS, 2011

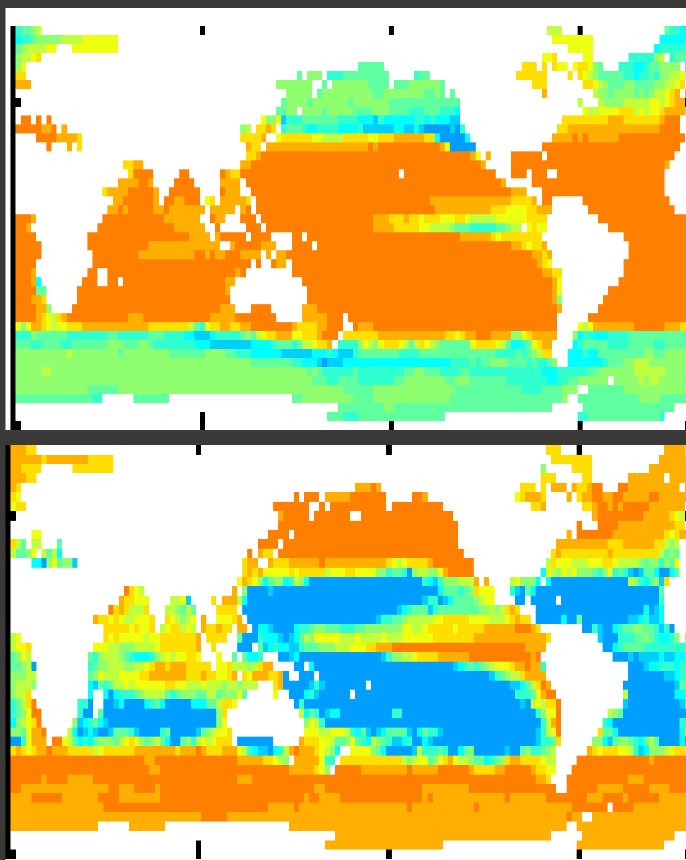


MODELING DIVERSITY: NUTRIENT UPTAKE





Biomass (mgC/m3)

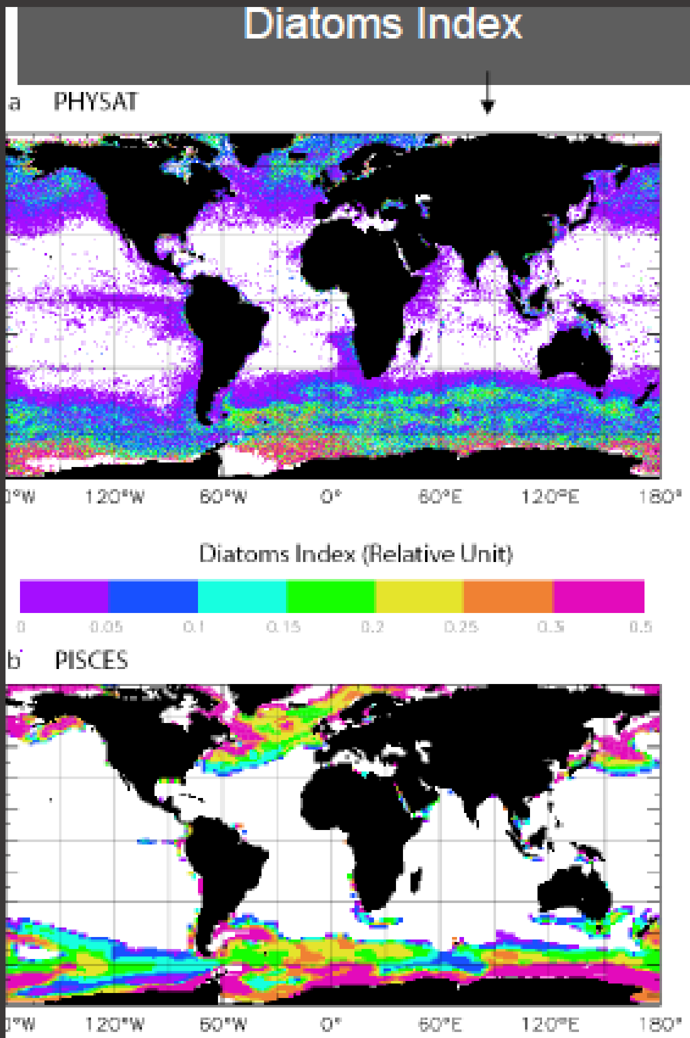


- K-strategist (gleaner)
- dominates in stable, low nutrient conditions (resource control theory)

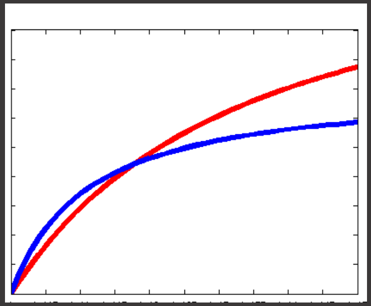
- r-strategist (opportunist)
- dominates in high nutrient conditions (fastest net growth important)

Dutkiewicz et al, GBC, 2005

MODELING DIVERSITY: NUTRIENT UPTAKE



PICES, Bopp et al, 2005



<u>Model Examples</u>:

Chai et al, 2002

Moore et al, 2002

Aumont et al, 2005

Dutkiewicz et al, 2005; 2009

most CMIP5 models

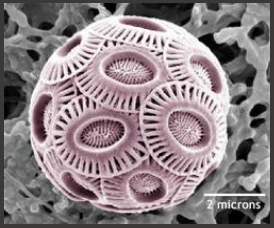
MODELING DIVERSITY: BIOGEOCHEMICAL FUNCTION

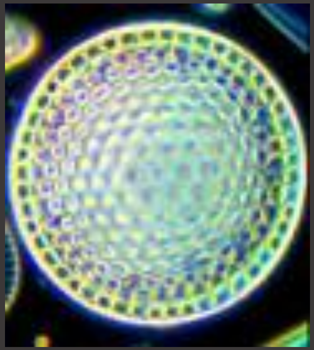
Phytoplankton functional types (PFT)

N_2 fixers

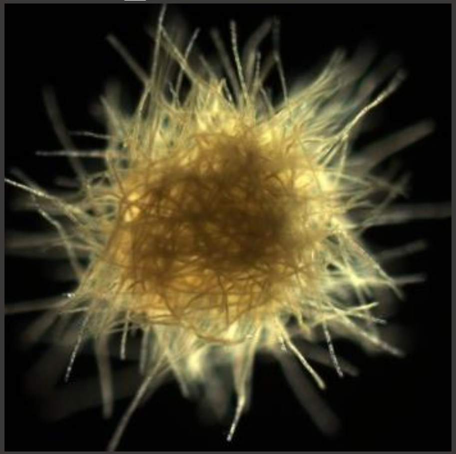
calcifiers

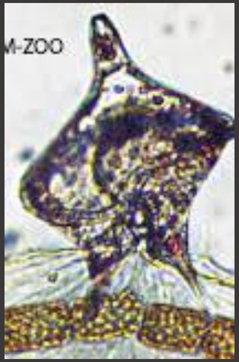
pico





silicifiers





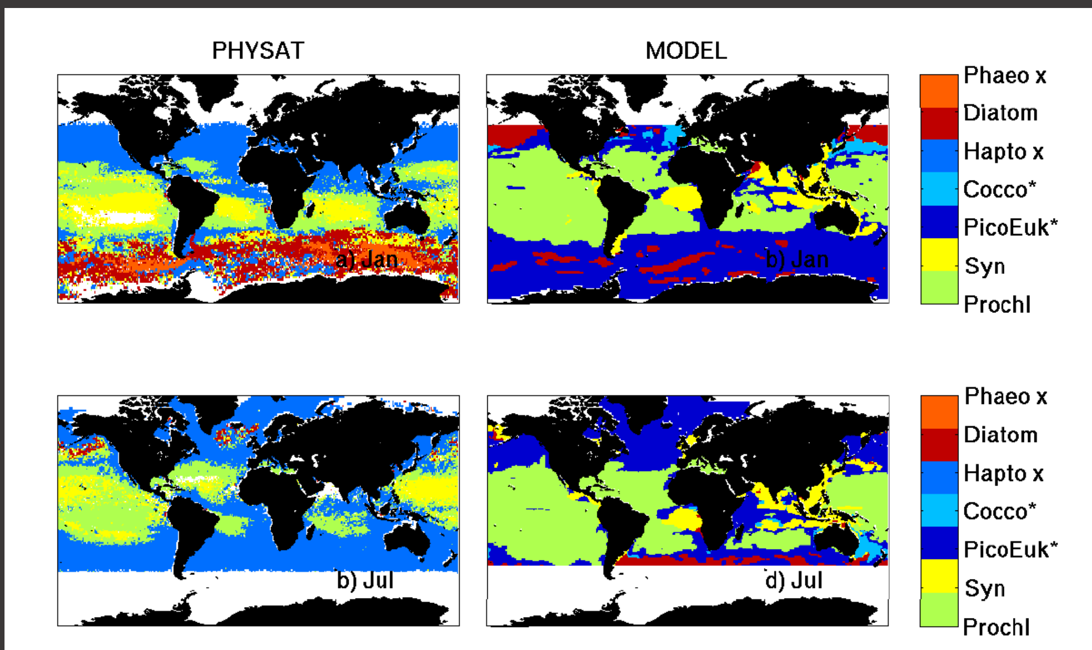
mixotrophs

References: Hood et al, Deep Sea Res, 2006

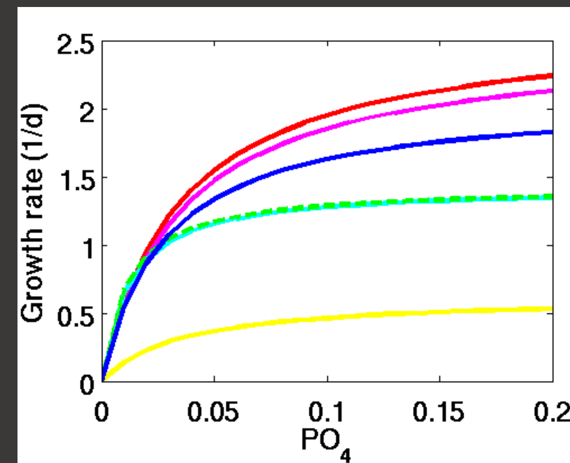
Le Quere et al, Glob Change Bio, 2005

MODELING DIVERSITY: BIOGEOCHEMICAL FUNCTION

Phytoplankton functional types (PFT)



Dutkiewicz et al, BG, 2015



Model Examples:

Gregg and Casey, DSR, 2007

Le Quere et al, 2005

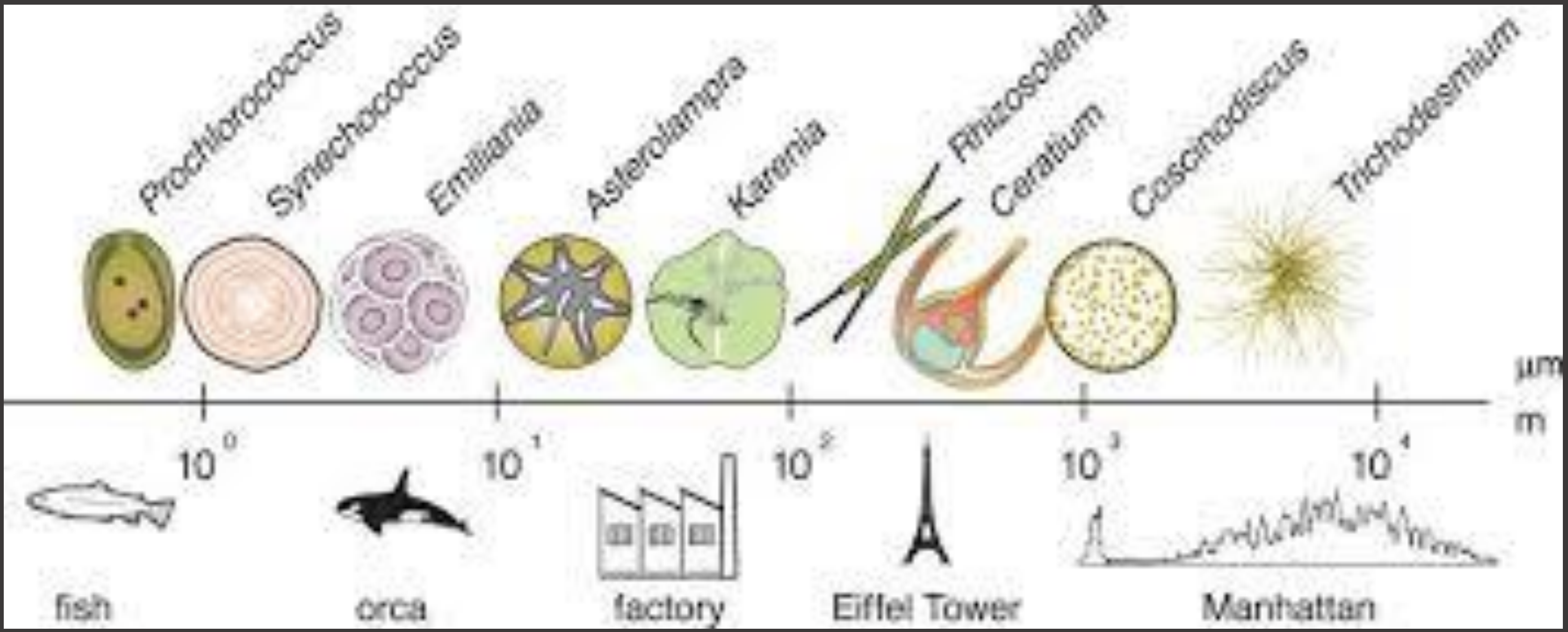
Moore et al, 2004

Hood et al, 2004

Dutkiewicz et al, 2015

MODELING DIVERSITY: SIZE

SIZE:

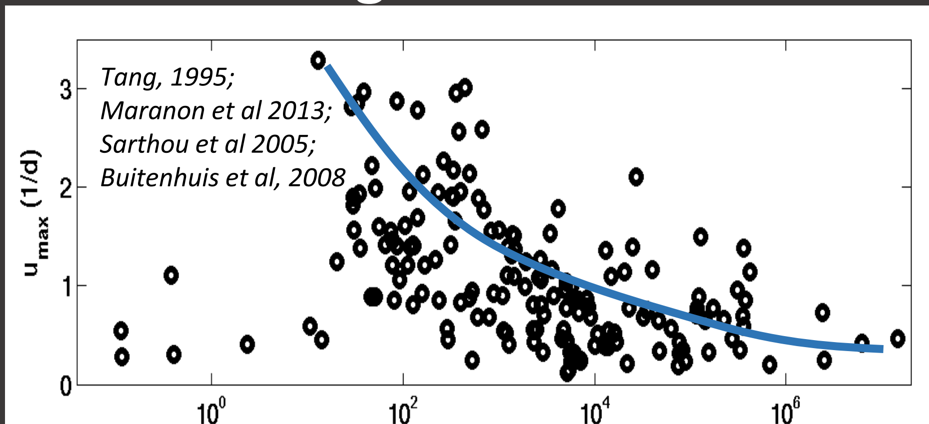


Finkel et al, JPR, 2009

MODELING DIVERSITY: SIZE

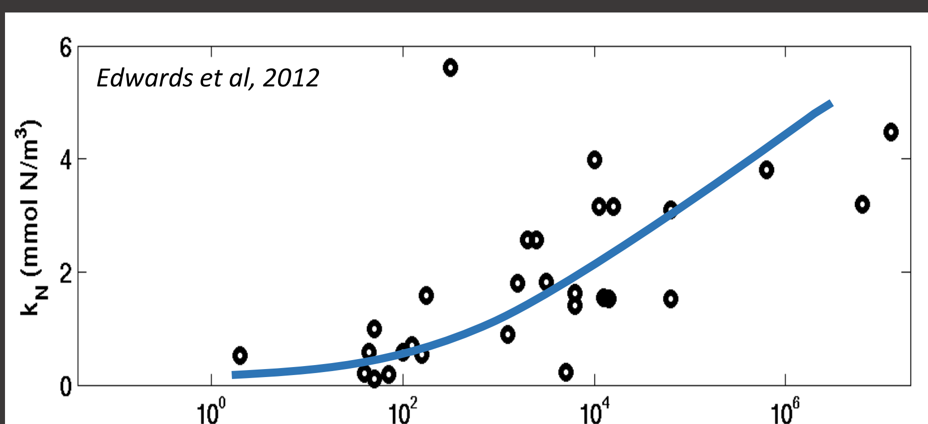
SIZE.

maximum growth rate



Volume (um3)

nutrient half saturation



Volume (um3)

$a\ V^b$

<u>Model Examples</u>:

Moloney and Fields, 1991

Armstrong, 1999

Baird and Suthers, 2007

Banas et al, 2011

Ward et al, 2012, 2013

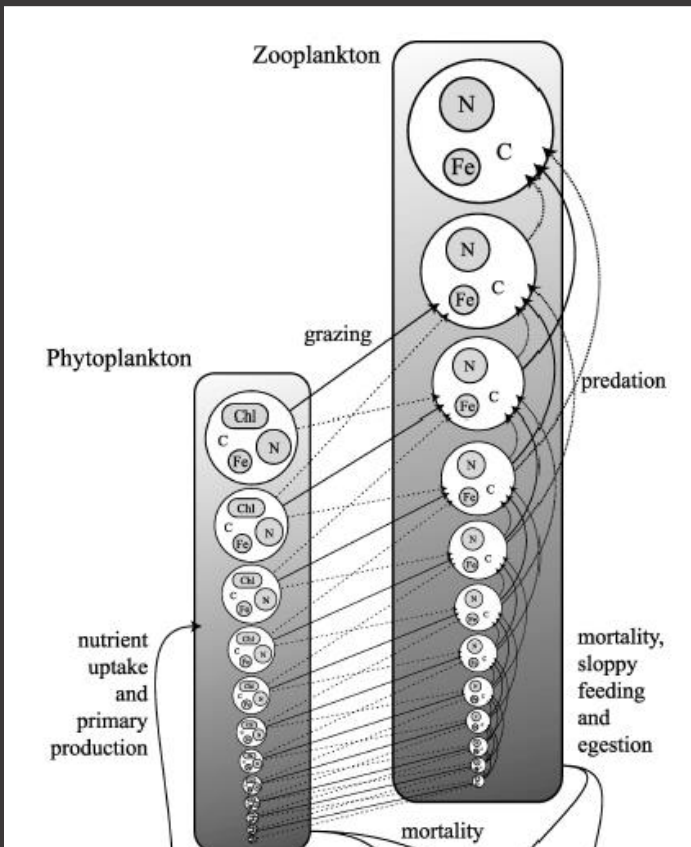
MODELING DIVERSITY: SIZE

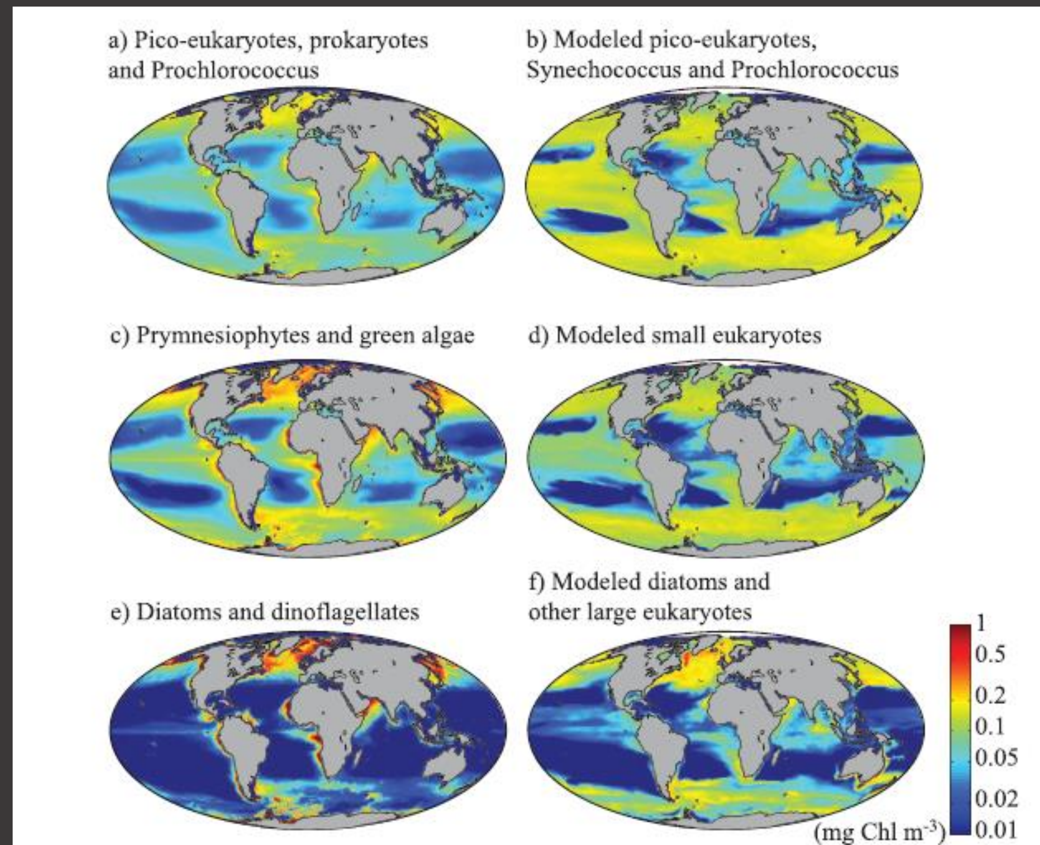
SIZE.

Satellite derived

(Hirata et al, 2011)

model



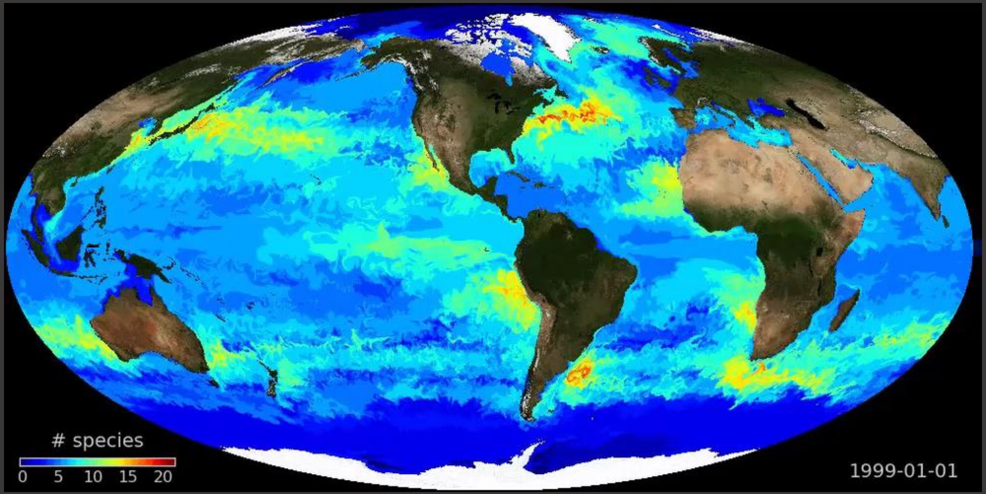


Ward et al, L+O, 2012

MODELING DIVERSITY OF PHYTOPLANKTON

Phytoplankton differ in terms of:

- size
- nutrient uptake
- biogeochemical function
- temperature tolerance
- pigment
- predation avoidance
- morphology
- chain/colony formation
- symbiosis



Clayton et al, L+OFE, 2014
Movie credit: Oliver Jahn

SUMMARY (4)

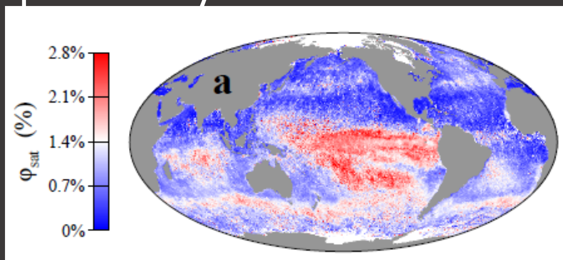
Phytoplankton diversity matters for foodweb, carbon cycle

Most models include between 2 and 6 “phytoplankton functional types” (PFTs) – thus link to some OC estimates (but may not be the same choices)

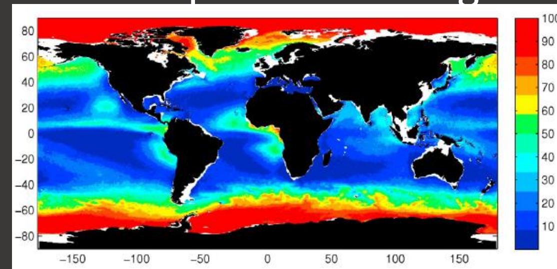
Some models model range of sizes using allometric scaling with volume of various traits – thus link to other OC estimates (e.g. abundance based)

But there are sizes within functional groups (e.g. diatoms), and many other reasons for phytoplankton diversity

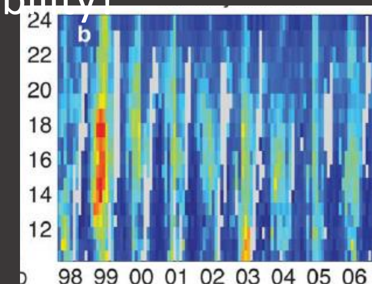
What causes differences in quantum yield?



What is impact of missing data?

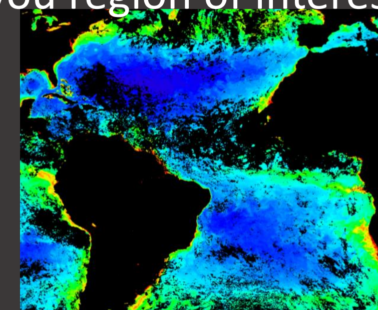


What drives the interannual variability?

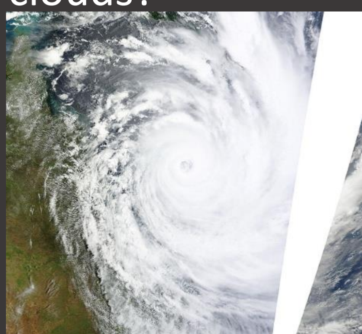


NUMERICAL MODELS CAN BE USEFUL

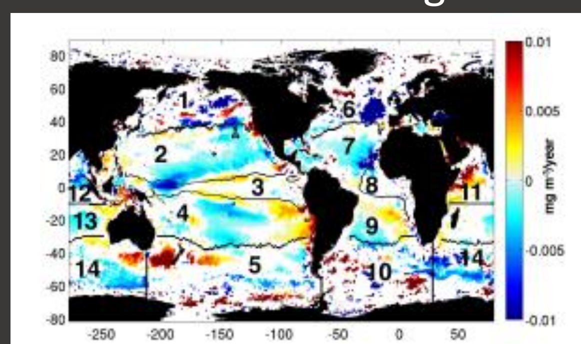
What if clouds cover you region of interest?



How to maintain monitoring under clouds?



Is this a climate change trend?



Uncertainty from limited data to construct OC4 Chl algorithm?