Global Assessment of Carbon Export Using Satellite Observations: New Approaches & A Plan for the Future

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Help from …

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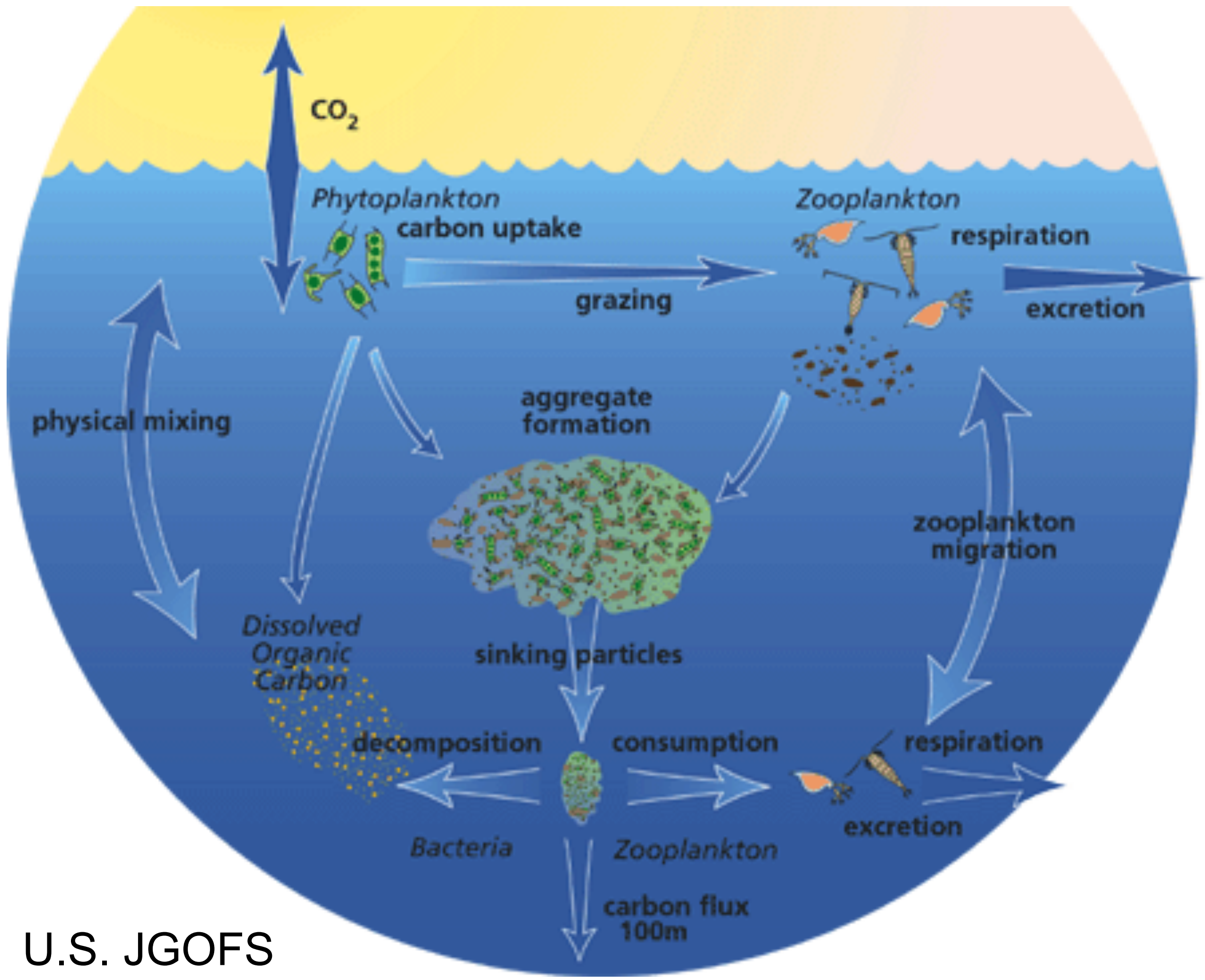
Support from NASA Ocean Biology & Biogeochemistry Program

The Biological Pump



U.S. JGOFS

Food web processes transfer organic matter to depth

pathway for rapid C sequestration

Quickly remove C from surface ocean

turn off bio pump & atm. CO_2 increases by 200 ppmv

Global C Export estimates range from ~4 to ≥12 GtC y^{-1}

we must do better

Global Extrapolation of Carbon Export

- Export modeled as e-ratio * NPP

  We can estimate NPP globally - but need e-ratio

- Empirical modeling for e-ratio

  f(SST) - Laws et al. [2000] GBC; Henson et al. [2011] GRL

  f(SST & Chl) - Dunne et al. [2004] GBC

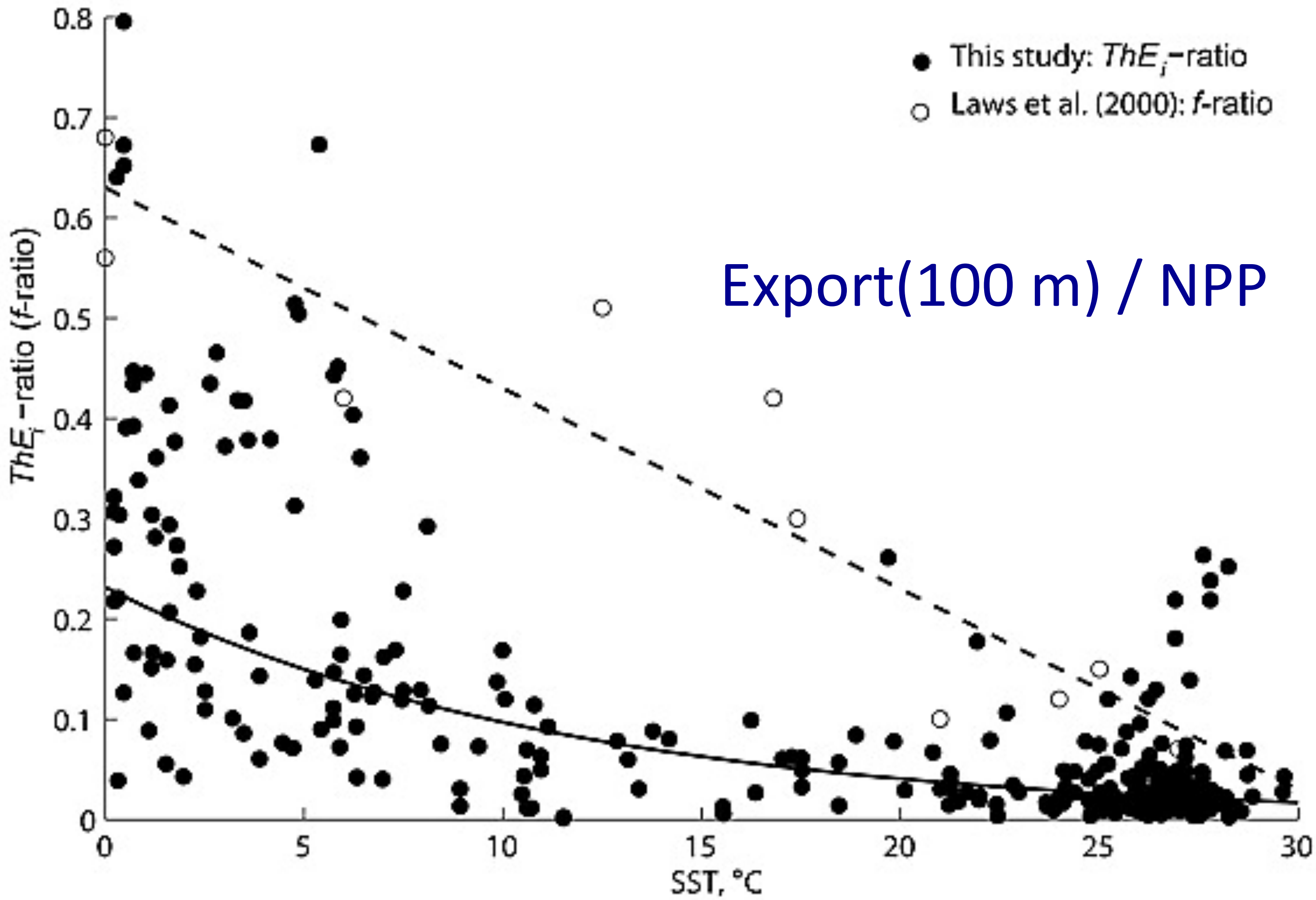
- Problems

  Not mechanistic

  Tuned for a single depth – not export at Z_{eu}

  Not very good…

E-Ratios vs. SST



Export(100 m) / NPP

Henson et al. GRL [2011]

Extrapolated Global Fluxes

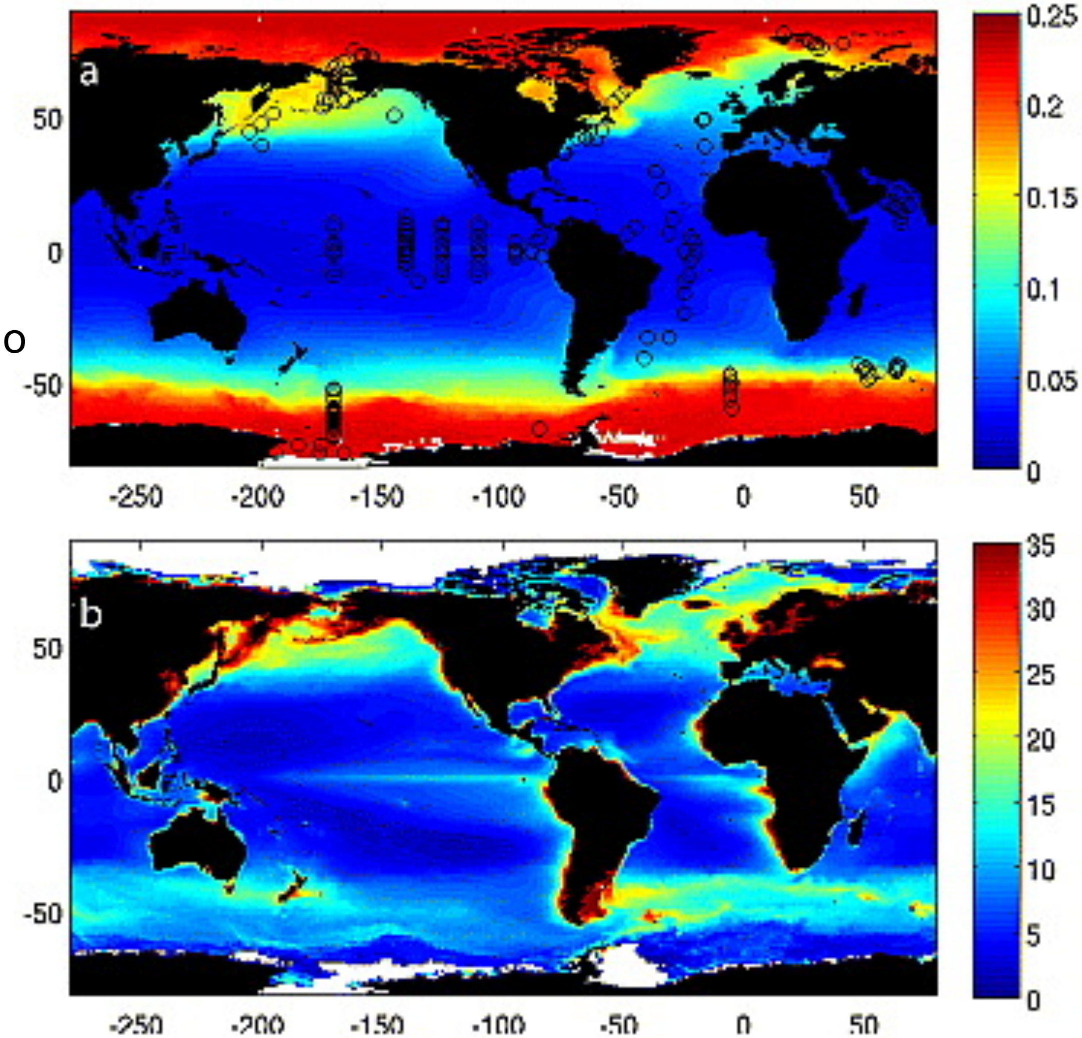
e-ratio @100m

>0.05 equatorward of 40^{o}

Export @100 m

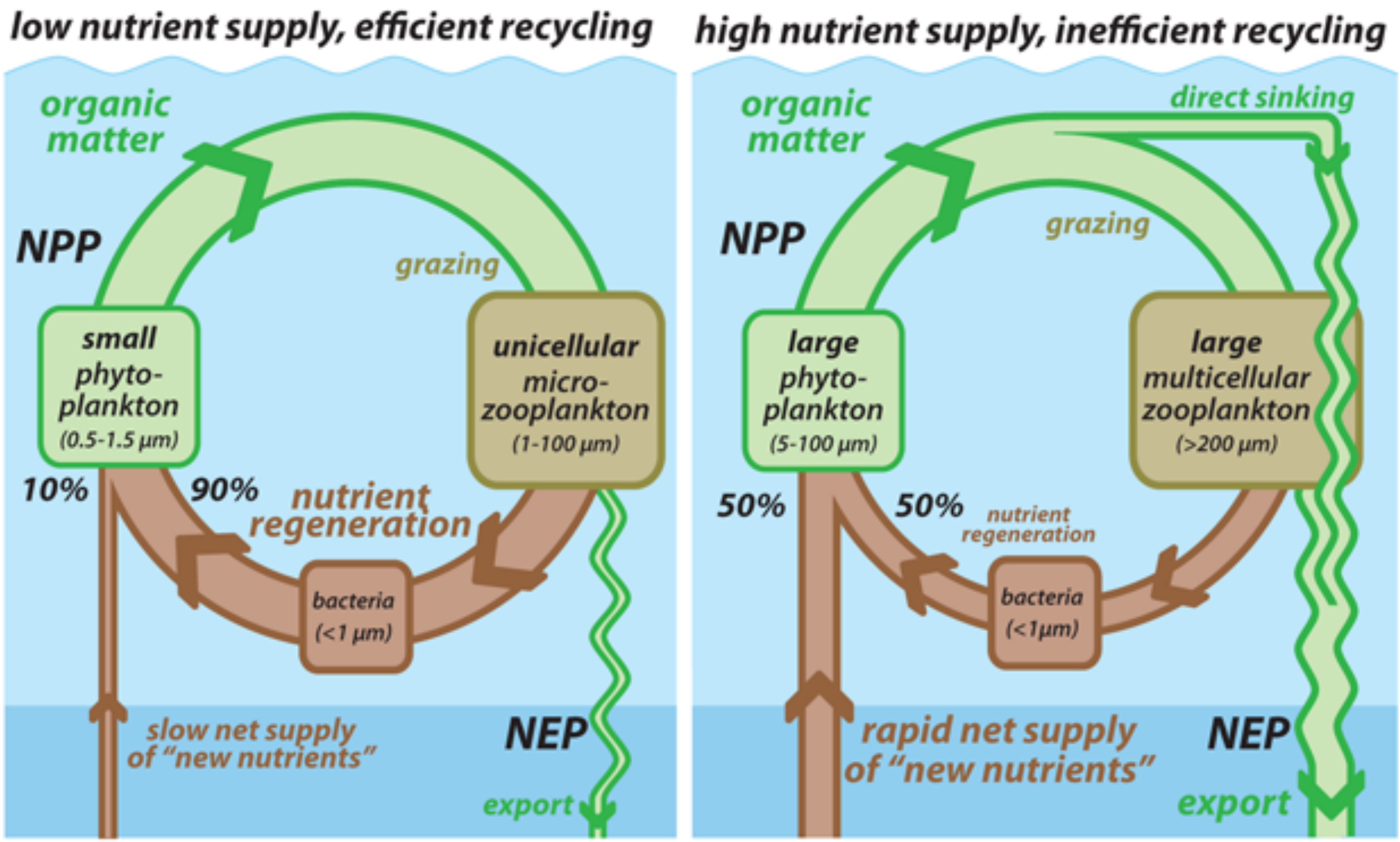
(gC m^2 y^{-1})

Global Σ ~4 Pg C y^{-1}



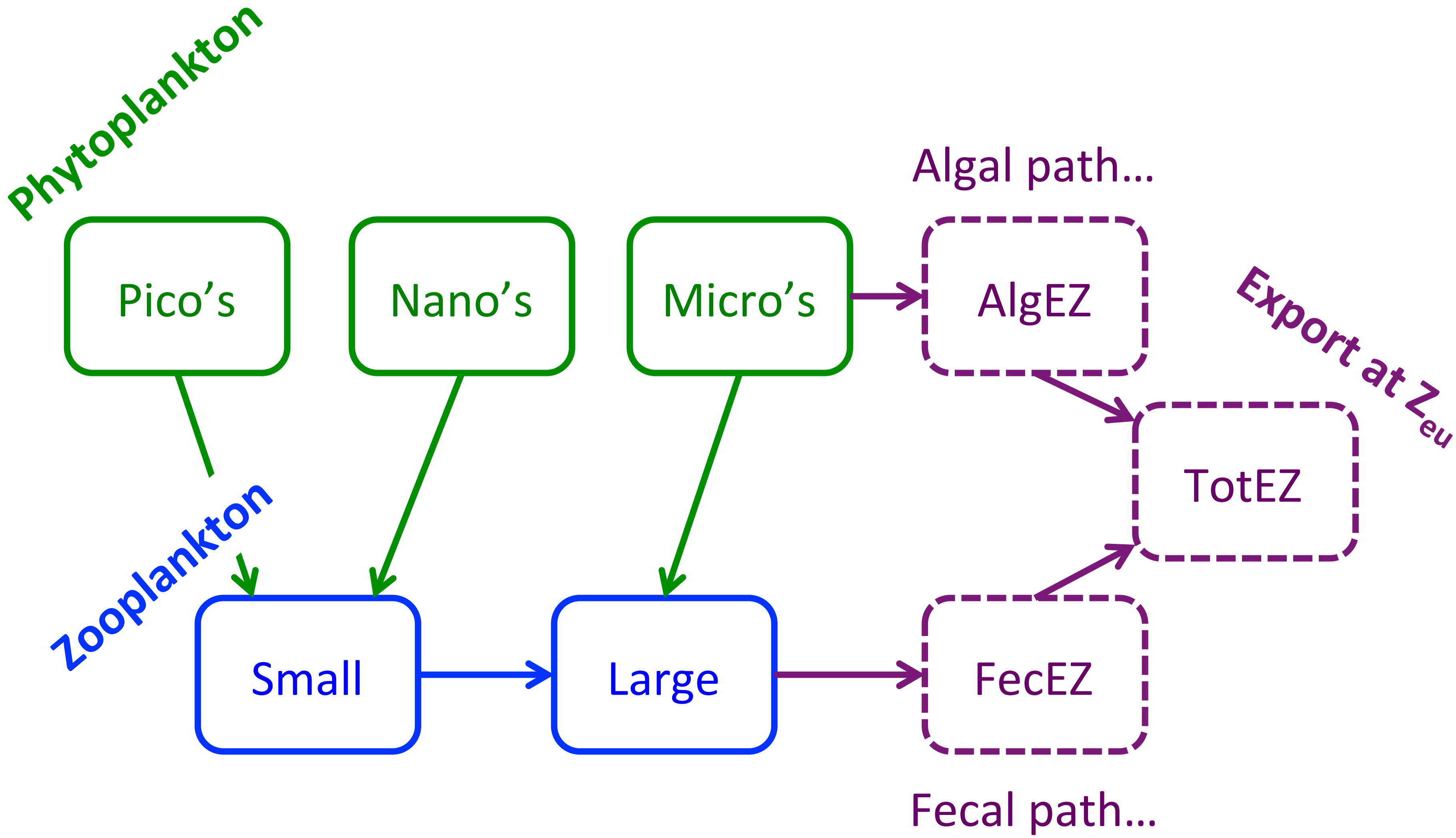
Henson et al. GRL [2011]

Food Web & Export



Sigman & Hain [2012] *Nature Education*

A Mechanistic Approach…



Following Michaels & Silver (1988), Boyd & Stevens (2002) & many more…

New Satellite Tools…

- Carbon-based NPP (CbPM)

  Phytoplankton Carbon & NPP using obs Chl:C ratio

  Behrenfeld et al. (2005; *GBC*) & Westberry et al. (2008; *GBC*)

- Particle-size distribution

  Partitioning of NPP & C stocks by biovolume fraction

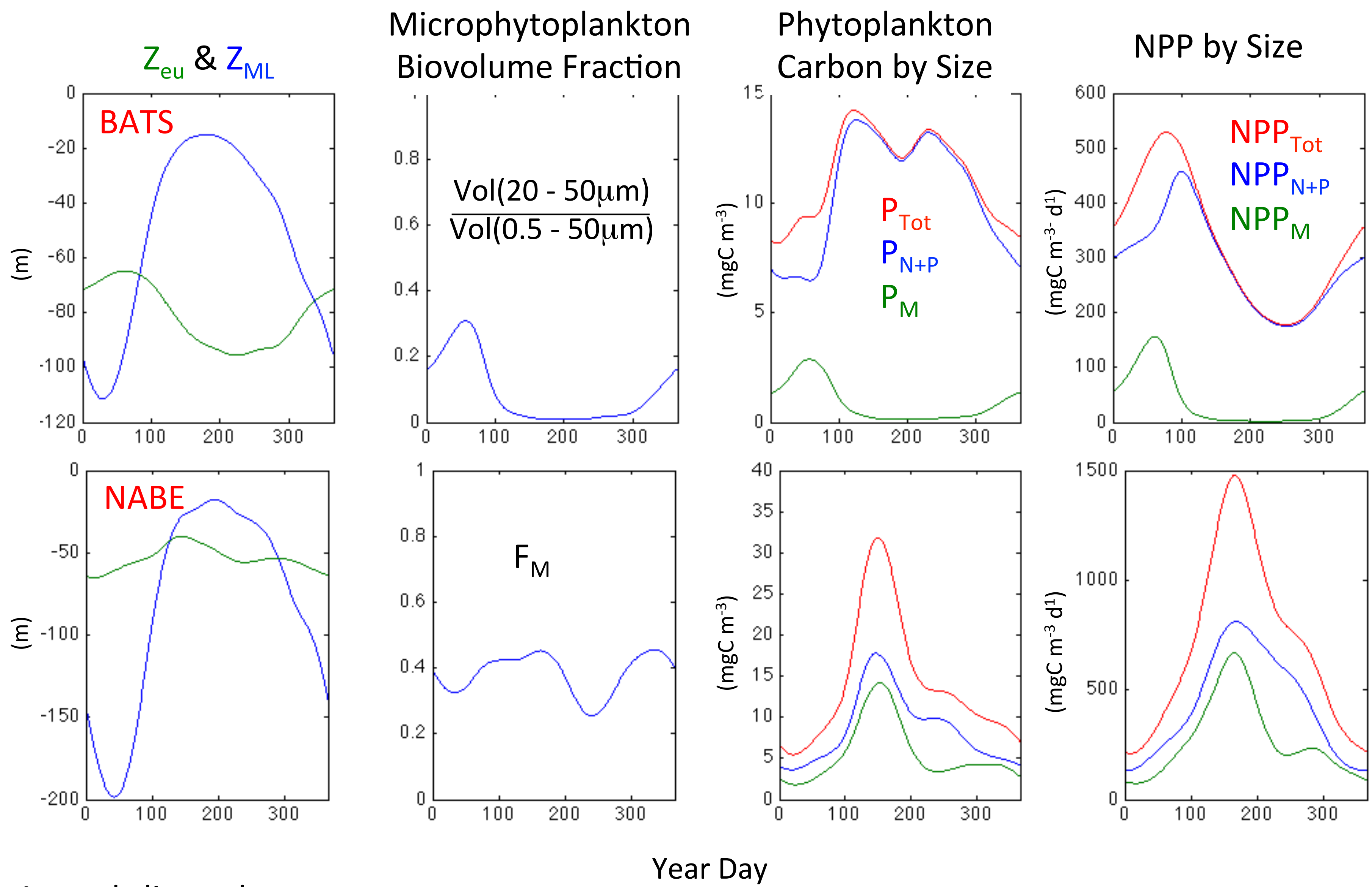
  Kostadinov et al. (2009; *JGR*) & (2010; *Biogeosci.*)

- Mass budgets for phytoplankton C stocks

  Enables upper layer grazing rates to be estimated

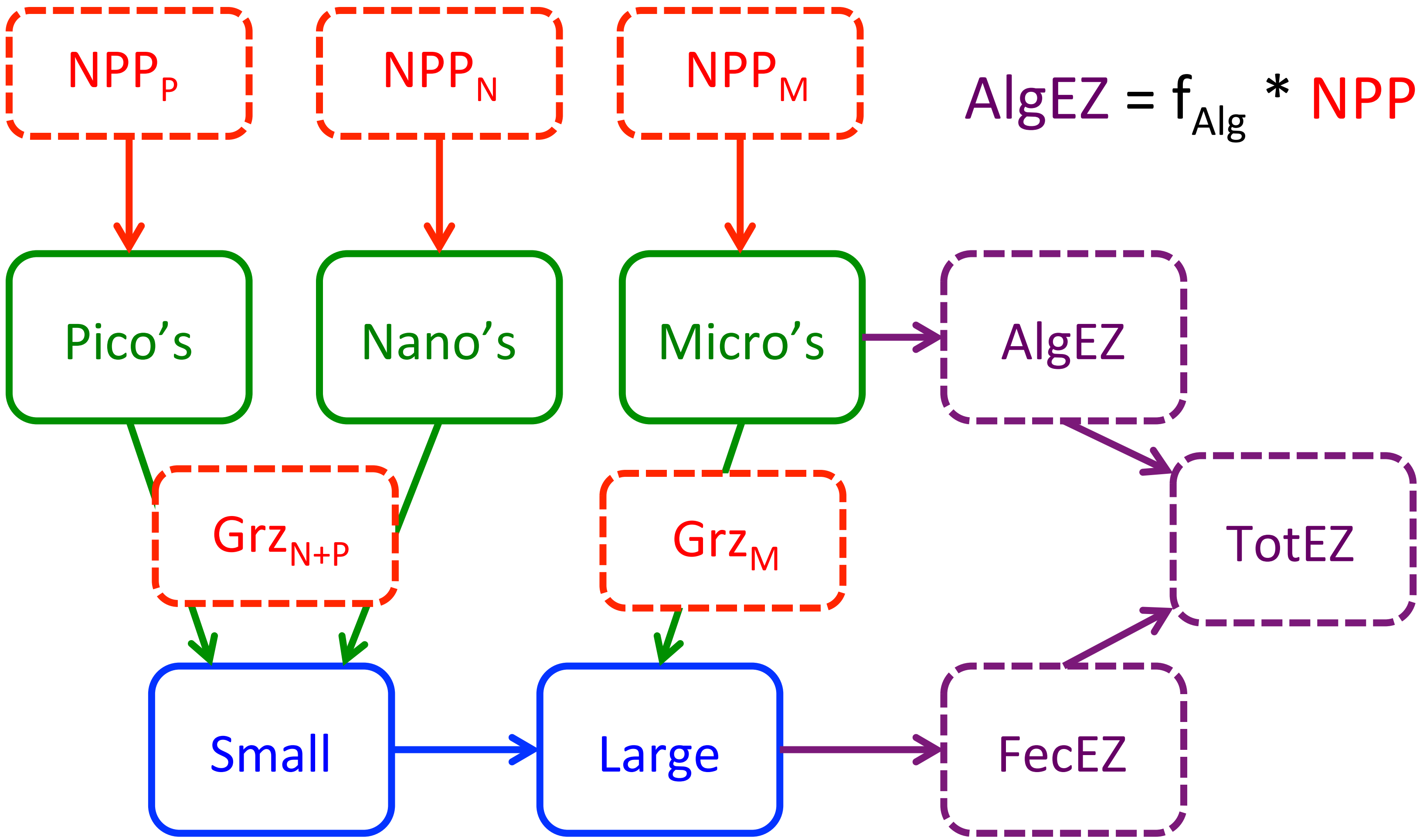
  Behrenfeld (2010; *Ecology*) & Behrenfeld et al. (2013; *GBC*)

New Satellite Tools…



Annual climatology

A Mechanistic Approach…



$AlgEZ = f_{Alg} * NPP_M$

$FecEZ = (f_{FecN+P} * Grz_{N+P} + f_{FecM} * Grz_M) * Z_{eu}$

Siegel et al. in review

Diagnosing Grazing Rates

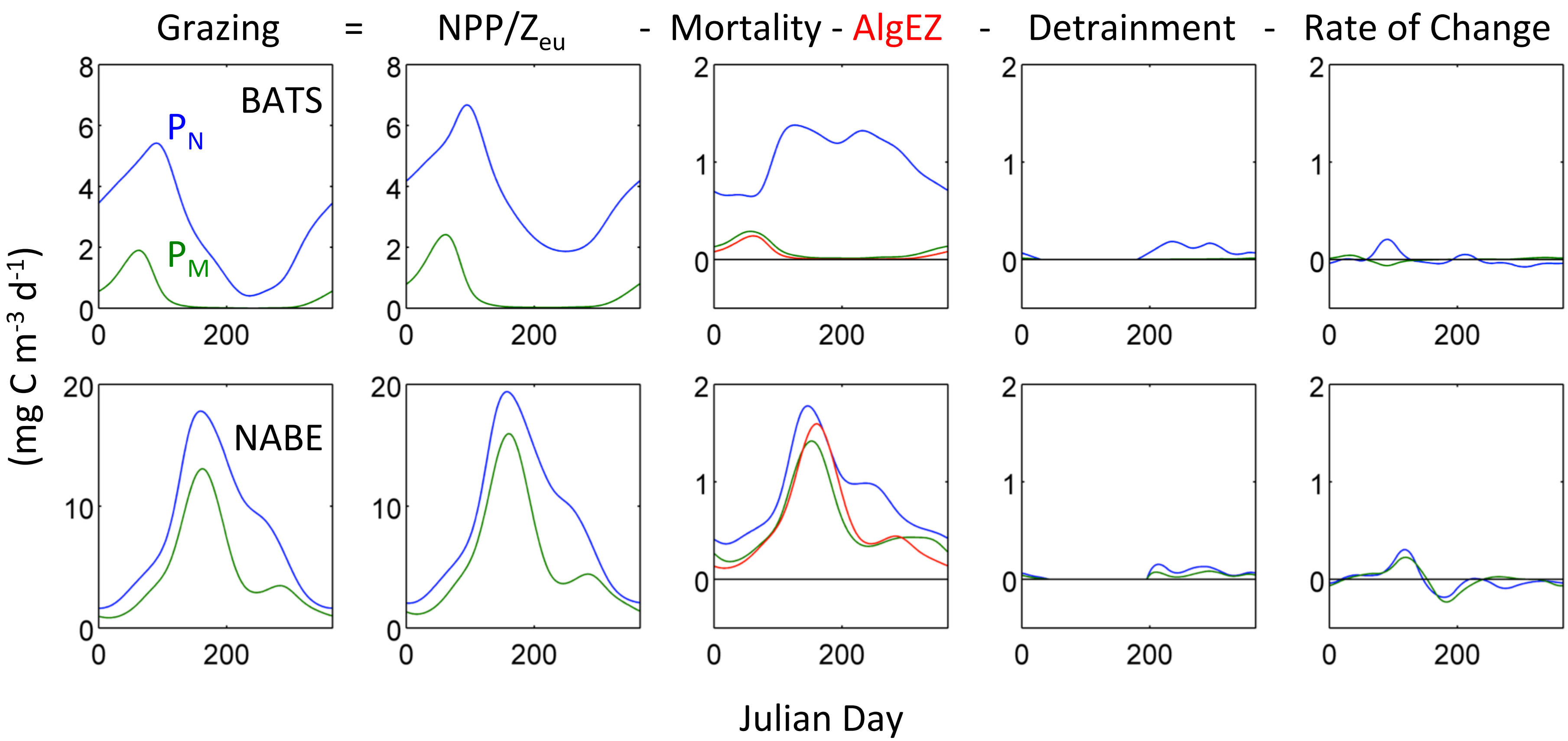
- Upper layer (Z_{ML}) phytoplankton biomass budget

$$\frac{dP_i}{dt} = \frac{NPP_i}{Z_{eu}} - Grz_i - m_i P_i - \frac{AlgEZ_i}{Z_{eu}} - Detrn(Z_{ml}, P_i)$$

unsteady | NPP/vol | grazing | mortality | direct sinking loss | detrainment

- Grz_i & $AlgEZ_i$ are the only unknowns
- Model $AlgEZ_M = f_{Alg} * NPP_M$ where $f_{Alg} = 0.1$
- Let $m_i = 0.1\ d^{-1}$ (non-grazing, biological losses)
- Solve for Grz_{N+P} and Grz_M

Diagnosing Grazing Rates



- NPP roughly balances grazing mortality
- All other terms are much smaller

Modeling Export Flux

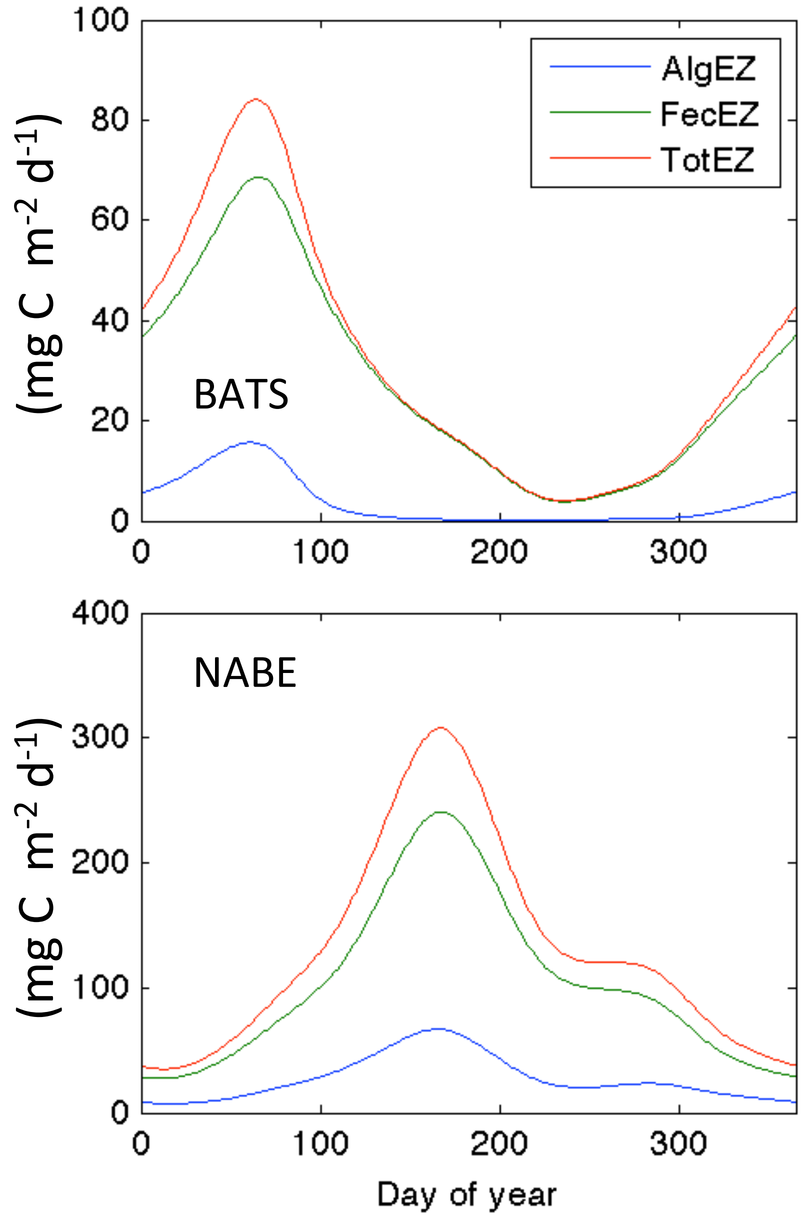
$$AlgEZ = f_{Alg} * NPP_M$$

$$f_{Alg} = 0.1$$

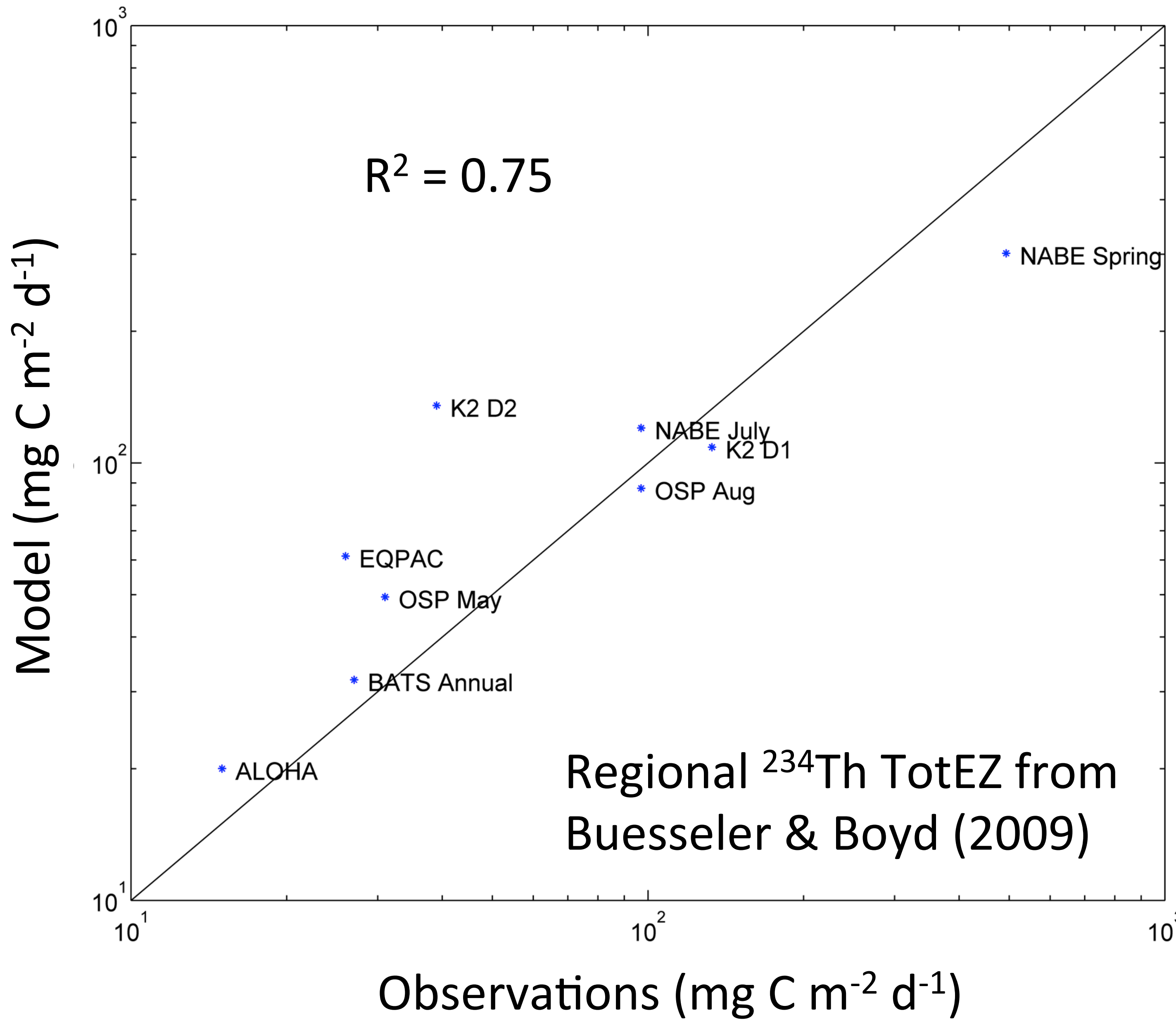
$$FecEZ = (f_{FecM} * Grz_M + f_{FecN+P} * Grz_{N+P}) * Z_{eu}$$

$$f_{FecM} = 0.3 \ \& \ f_{FecN+P} = 0.1$$

$$TotEZ = AlgEZ + FecEZ$$

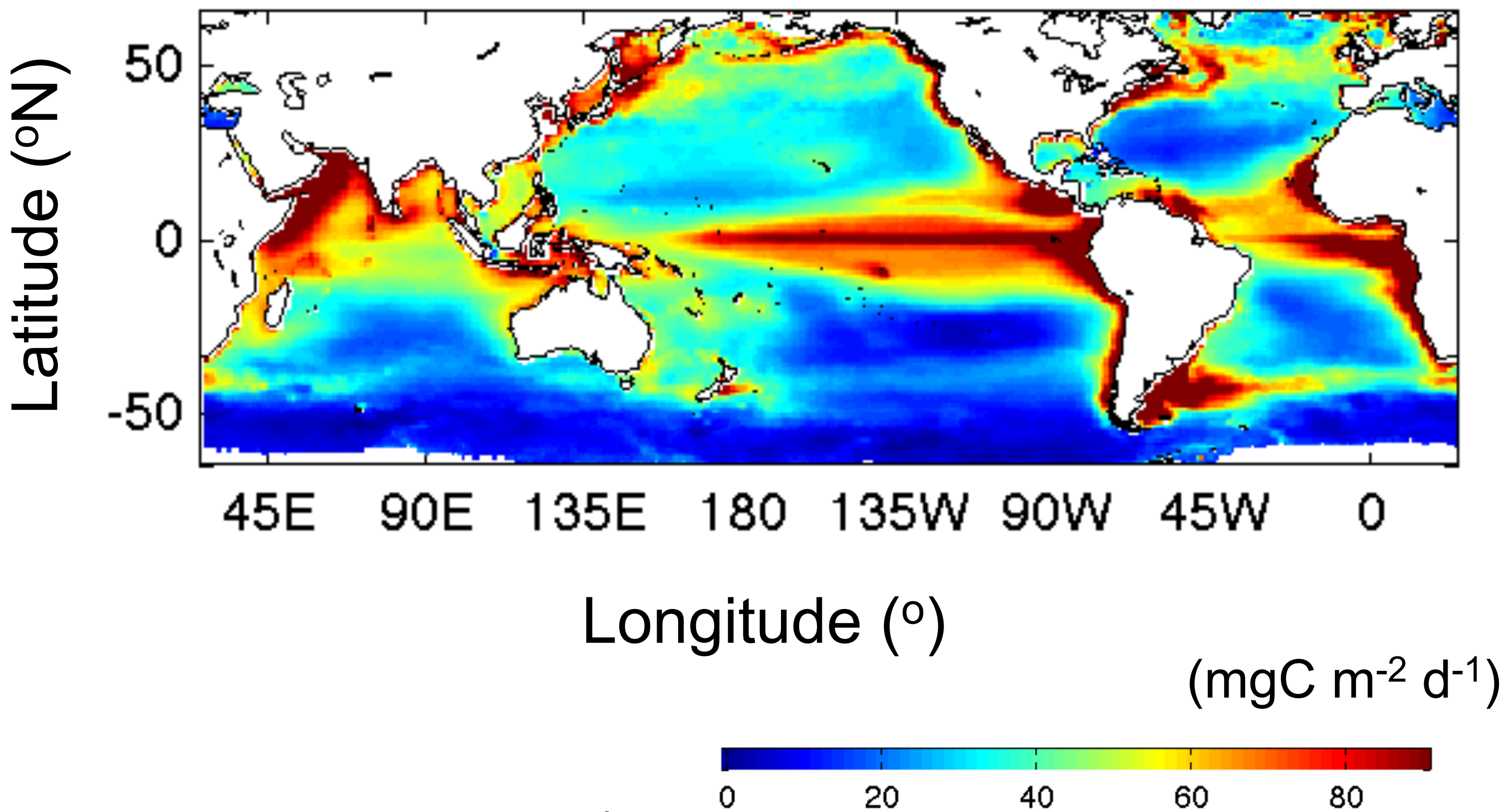


So, Does It Work??



*Not completely fair as model is a climatology and the observations are not

Annual TotEZ



Total = 5.7 Pg C y^{-1}

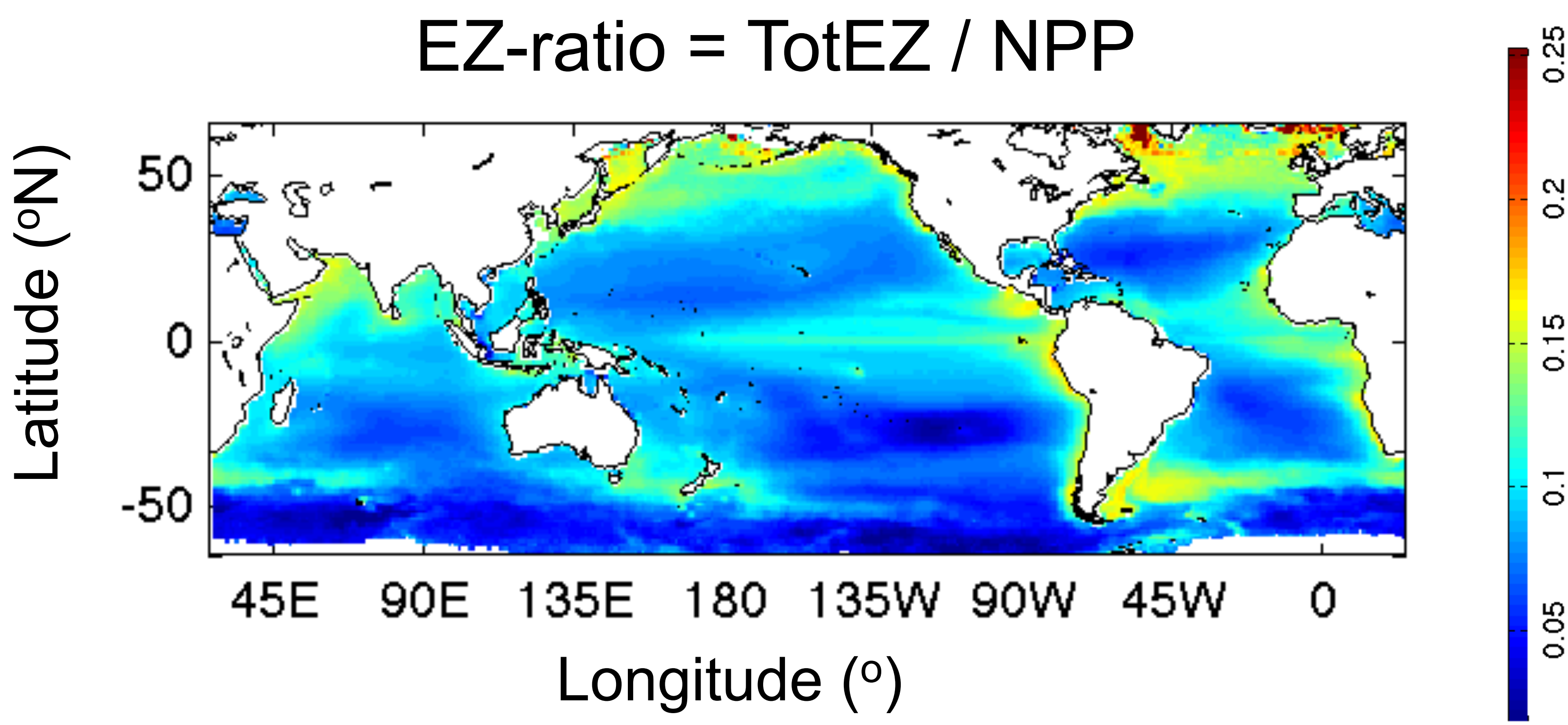
So, Is It Robust??

	f_{alg} (-)	m_{ph} (d^{-1})	f_{fecM} (-)	f_{fecN+P} (-)	Global TotEZ ($Pg\ C\ y^{-1}$)
Baseline	0.1	0.1	0.3	0.1	5.69
Alter f_{alg}	0.2	0.1	0.3	0.1	6.20
	0.05	0.1	0.3	0.1	5.43
Alter m_{ph}	0.1	0.2	0.3	0.1	4.52
	0.1	0.1	0.2	0.1	5.16
Alter f_{fecN+}	0.1	0.1	0.3	0.05	4.00
	0.1	0.1	0.3	0.2	9.07

Ensemble mean = 5.9 Pg C y^{-1}

Using VGPM for NPP model, we get 5.4 Pg C y^{-1}

Export Efficiency



- EZ-ratio patterns have an "oceanographic logic"
- Global mean = 0.10 (± 0.05)

Summary of Results

- Mechanistic model for global C export on sinking particles from the euphotic zone
  - Four parameters – make sense physically
  - Model successfully recreates regional-scale observations
  - Global summary statistics are robust to large changes in parameter values
  - Improvement over correlative methods

Next Steps…

- Improve remote sensing data products
  - PhytoC, PSD, NPP, etc.
- Advance food-web modeling
  - What really are f_{AlgM}, f_{FecM}, f_{FecN+P}, etc.?
  - Is food-web model framework used appropriate?
- Model transfer efficiency below euphotic zone
  - Critical for assessing C sequestration
- Need field data...
  - Need obs under differing “states” of the pump

EXport Processes in the Ocean from RemoTe Sensing

EXPORTS

An Opportunity to Help Plan a Major Field Campaign for NASA

Dave Siegel (UCSB), Ken Buesseler (WHOI)
and the EXPORTS Science & Implementation Plan Writing Team

Support from NASA Ocean Biology & Biogeochemistry Program

What is EXPORTS?

- First *competed* scoping study for NASA OBB
- <u>Focus</u>: Surface ocean plankton patterns & the functioning of the biological carbon pump
- EXPORTS Science & Implementation Plan to be delivered to NASA HQ early 2014
- If NASA HQ selects it, SciDefTeam call 2015, ROSES call 2016, Fieldwork starts 2017

EXPORTS Goal & Rationale

Goal: *Predict the consequences of changing plankton patterns on strength & efficiency of the biological pump*.

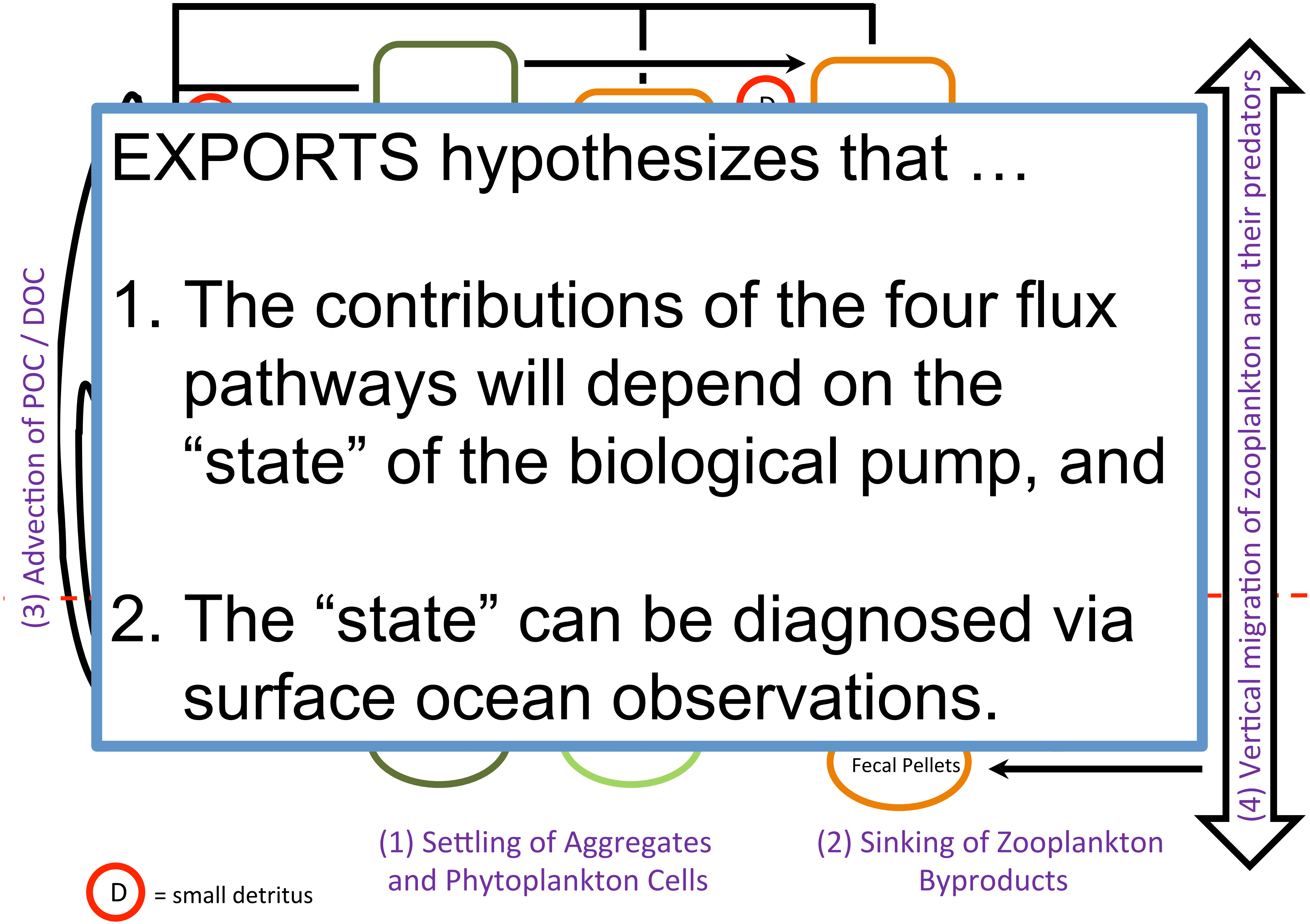
- *Plankton patterns* include food web structure & their spatiotemporal variability
- Recent advances in the remote sensing of plankton patterns (PFT, PSD, C export?, etc.) & autonomous in situ tools make achieving our goal possible

Hypothesis: The biological pump can be quantified by observing surface ocean plankton patterns

EXPORTS hypothesizes that …

1. The contributions of the four flux pathways will depend on the "state" of the biological pump, and

2. The "state" can be diagnosed via surface ocean observations.



Three Science Questions

1. How do plankton community composition & ecological-physical interactions determine the vertical transfer of organic matter from the well-lit surface ocean?

2. What controls the efficiency of vertical transfer of organic matter below the well-lit surface ocean?

3. Can this process-level knowledge be used to reduce uncertainties in contemporary & future estimates of the biological pump?

High-Level Experimental Approach

- Focus on contrasting states of the biological pump
- Resolve range of conditions (multiple observations)
- Balance scientific returns & project efficiency ($'s)
  - Leverage on-going programs & establish new partners
- Multiscale sampling using BGC proxies to resolve submesoscale process (floats, gliders, ship & satellite)
- Measure the "right things" too (process cruises)
- Integrate modeling (eco/bgc, SMS, process, RS algo)
- Document measurement protocols & uncertainties

EXPORTS – Experimental Plan (1)

- 2 Station P cruises (each with 2 ships!!)
  - Two BCP states (30d [40d survey] - April/May & 30d - Aug)
  - Leverage OOI StaP node, Canada's Line P, etc.
- 2 North Atlantic cruises (each with 2 ships)
  - 1 longer (45 d; April-May Bloom) & 1 shorter (30 d; Aug)
  - Leverage PAP & other international collaborations
- Data mining
  - Compile secondary data sets of more BCP states
  - BATS, HOT, CARIACO, VERTIGO, MAREDAT, etc.
  - Each will not have everything…

EXPORTS – Experimental Plan (2)

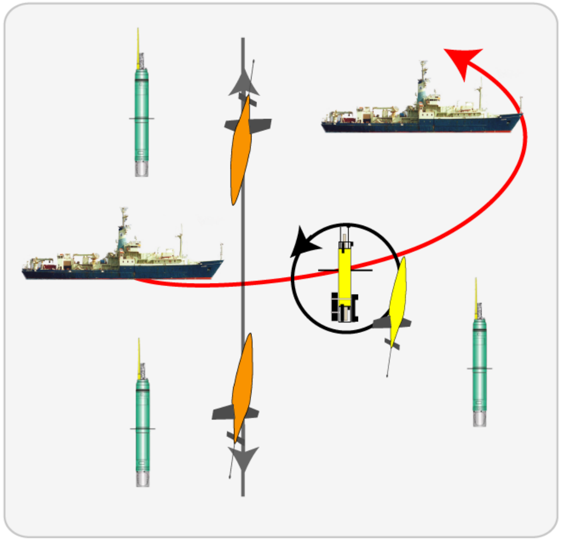
- Track highly-instrumented mixed layer float(s?)
- Follow particles from production to trap (measure export profile to 500 mm, which corresponds to a station duration of ~20 days)
- Process ship focused on rates & transformations
- Survey ship sampling sub- & meso-scale patterns about the process ship & ML float (scales ~10 to 200 km)
  - Collect spatial data around the Process Ship
  - Deploy short-term autonomous assets (traps, optical buoys, etc.)
- Multiple gliders supplement survey sampling (~100 km)
- Maintain long-term presence with floats
  - Supplement with gliders & traps between cruises

Autonomous Sampling

- Many parameters are now accessible

  T, S, O_2, Chl, NO_3, POC, IOPs, PSD, export proxy, …

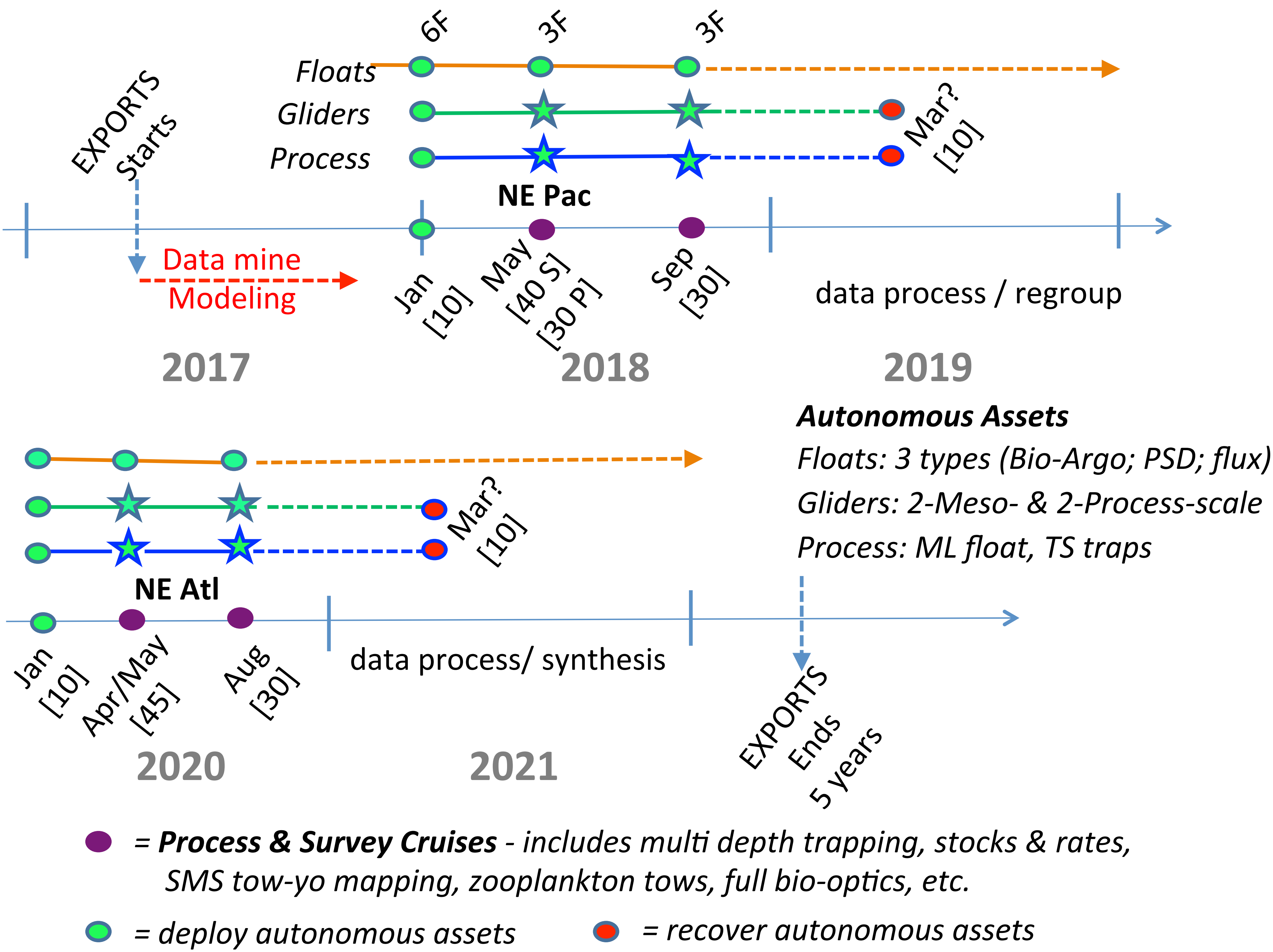
  Must plan for their inter-calibration!



- Lagrangian stations follow well-instrumented mixed layer float
- Gliders sample spatially
- Floats provide long-term context

  Bio-Argo, flux proxy, PSD, spectral irradiance, etc.

- Time-series sediment trapping


6F
3F
3F
Floats
Gliders
Process
Mar?
[10]
EXPORTS
Starts
NE Pac
Data mine
Modeling
Jan
[10]
May
[40 S]
[30 P]
Sep
[30]
data process / regroup
2017
2018
2019
Autonomous Assets
Floats: 3 types (Bio-Argo; PSD; flux)
Gliders: 2-Meso- & 2-Process-scale
Process: ML float, TS traps
Mar?
[10]
NE Atl
Jan
[10]
Apr/May
[45]
Aug
[30]
data process/ synthesis
EXPORTS
Ends
5 years
2020
2021
= Process & Survey Cruises - includes multi depth trapping, stocks & rates,
SMS tow-yo mapping, zooplankton tows, full bio-optics, etc.
= deploy autonomous assets
= recover autonomous assets

EXPORTS Progress

- Writing team formed in the scoping proposal

  Responsible for completion of the plan

  Behrenfeld, Benitez-Nelson, Boss, Brzezinski, Buesseler, Burd, Carlson, D'Asaro, Doney, Perry, Siegel, Stanley, Steinberg

- June meeting at UCSB addressed Goals, Questions & Experimental Plan (23 invitees)
- Remember, this is a work in progress…

  We are writing the report now

  Inputs are VERY welcome and timely!

Next Steps…

- Continue collecting input from the community
  - There will be a public comment period…
  - Town Hall at 2014 Ocean Sciences Meeting
  - Remember, EXPORTS will be competed…
- Finalize measurement & product lists, sampling plan, cost estimates & science traceability matrix
- Establish the scientific trades with possible de- & re-scope options
- Address required technology developments
- Finish the #@$^*& report…


Thank you for your attention!!