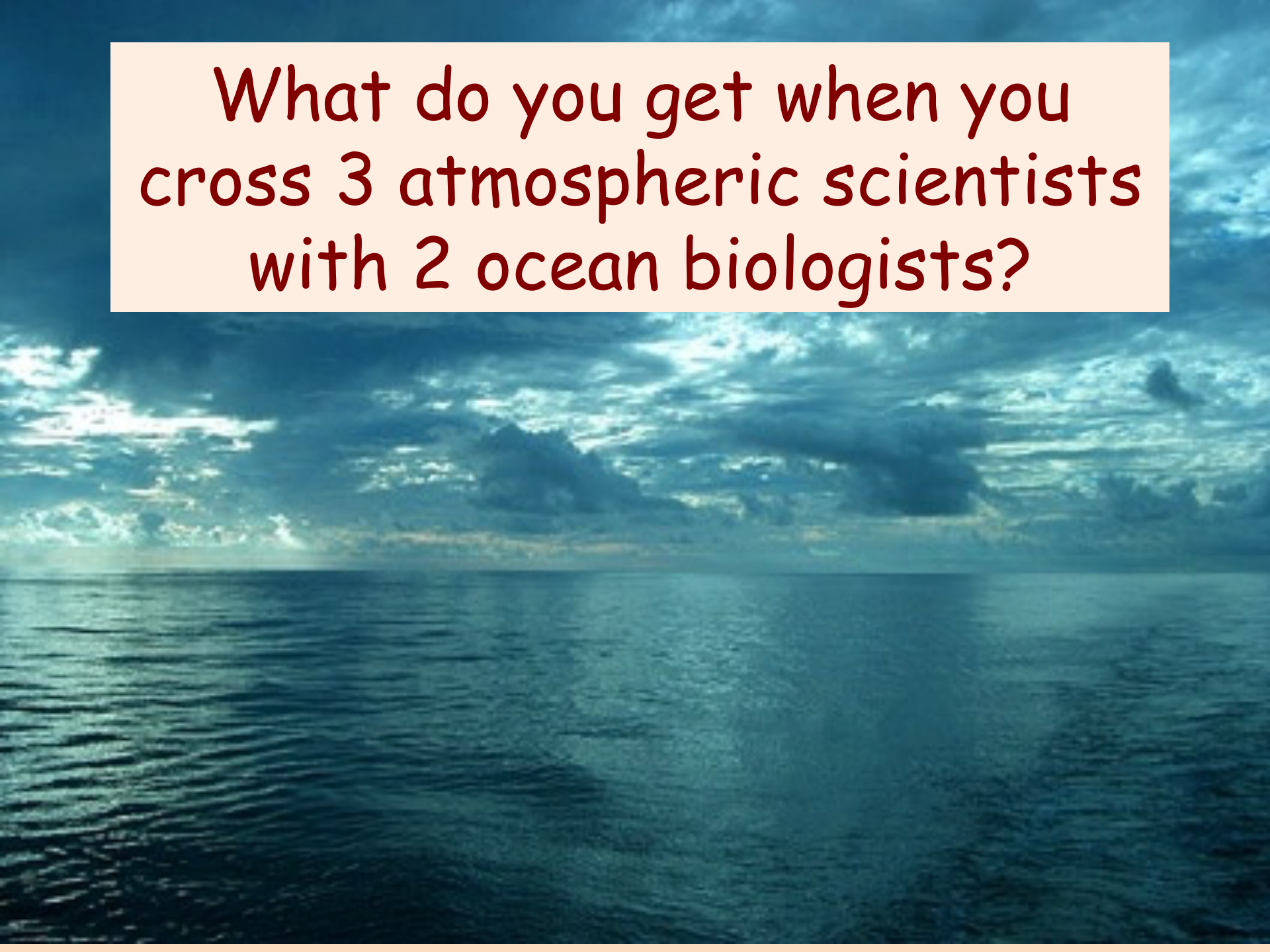
What do you get when you cross 3 atmospheric scientists with 2 ocean biologists?

Understanding airborne fertilization of oceanic ecosystems using MODIS, VIIRS and CALIPSO

Lorraine Remer, Yingxi Shi, Hongbin Yu
(the atmospheric scientists)

Toby Westberry and Michael Behrenfeld
(the ocean biologists)

Characterizing Dust, Dust Deposition and Ocean Response in the North Pacific

Lorraine Remer, Yingxi Shi, Hongbin Yu
(the atmospheric scientists)

Toby Westberry and Michael Behrenfeld
(the ocean biologists)

Our first paper was published this year

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL083977

Key Points:

- The ash deposition from Aleutian volcanic eruptions in 2008 provides a case study for remote sensing

Citation:
Westberry, T. K., Shi, Y. R., Yu, H., Behrenfeld, M. J., & Remer, L. A. (2019). Satellite-Detected Ocean Ecosystem Response to Volcanic Eruptions in the Subarctic Northeast Pacific Ocean. *Geophysical Research Letters*, *46*. https://doi.org/10.1029/2019GL083977

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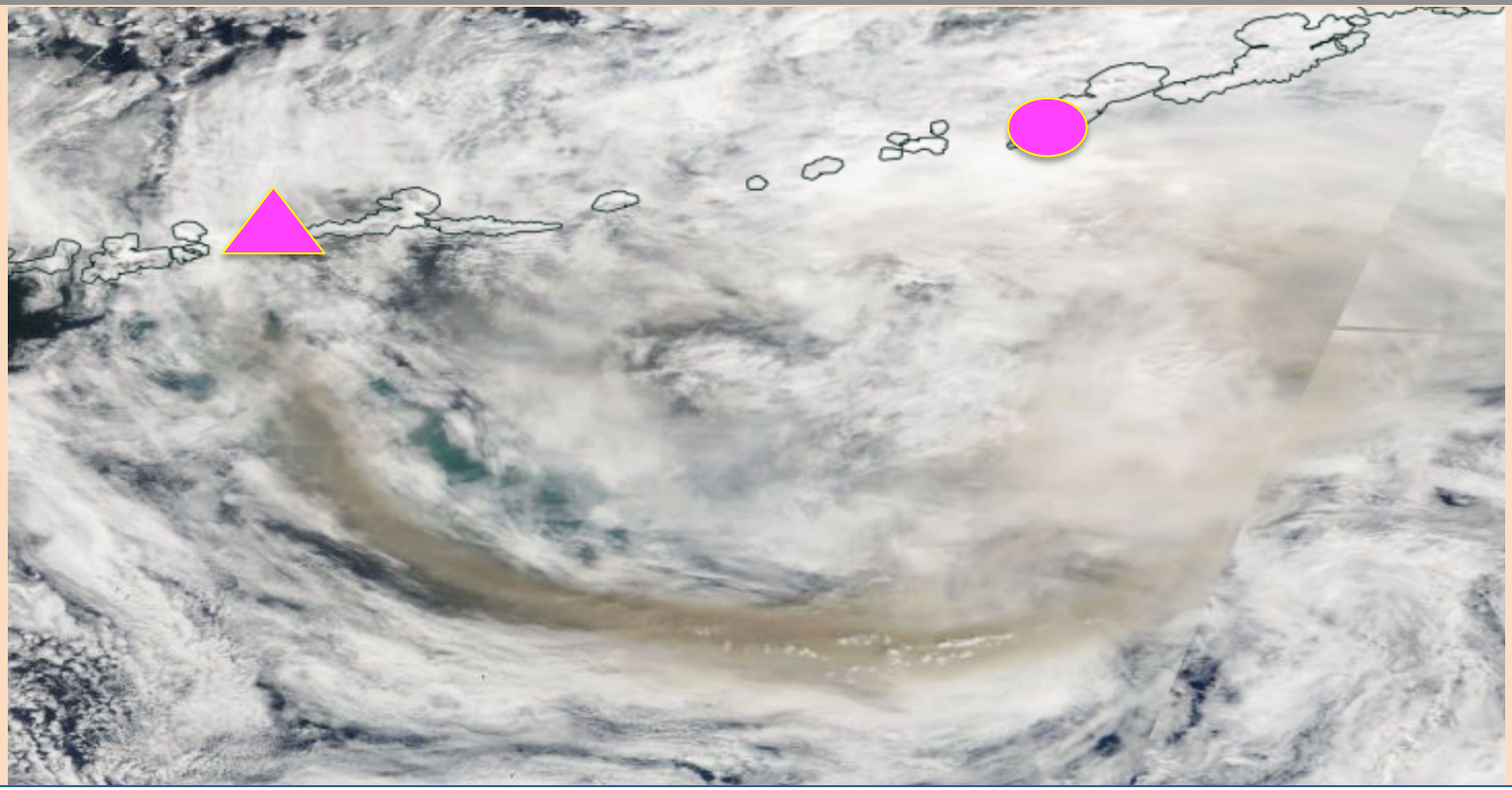
Satellite-Detected Ocean Ecosystem Response to Volcanic Eruptions in the Subarctic Northeast Pacific Ocean

T.K. Westberry[1], Y.R. Shi[2,3], H. Yu[2], M.J. Behrenfeld[1], and L.A. Remer[3]

[1]Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR, USA, [2]Earth Science Division,

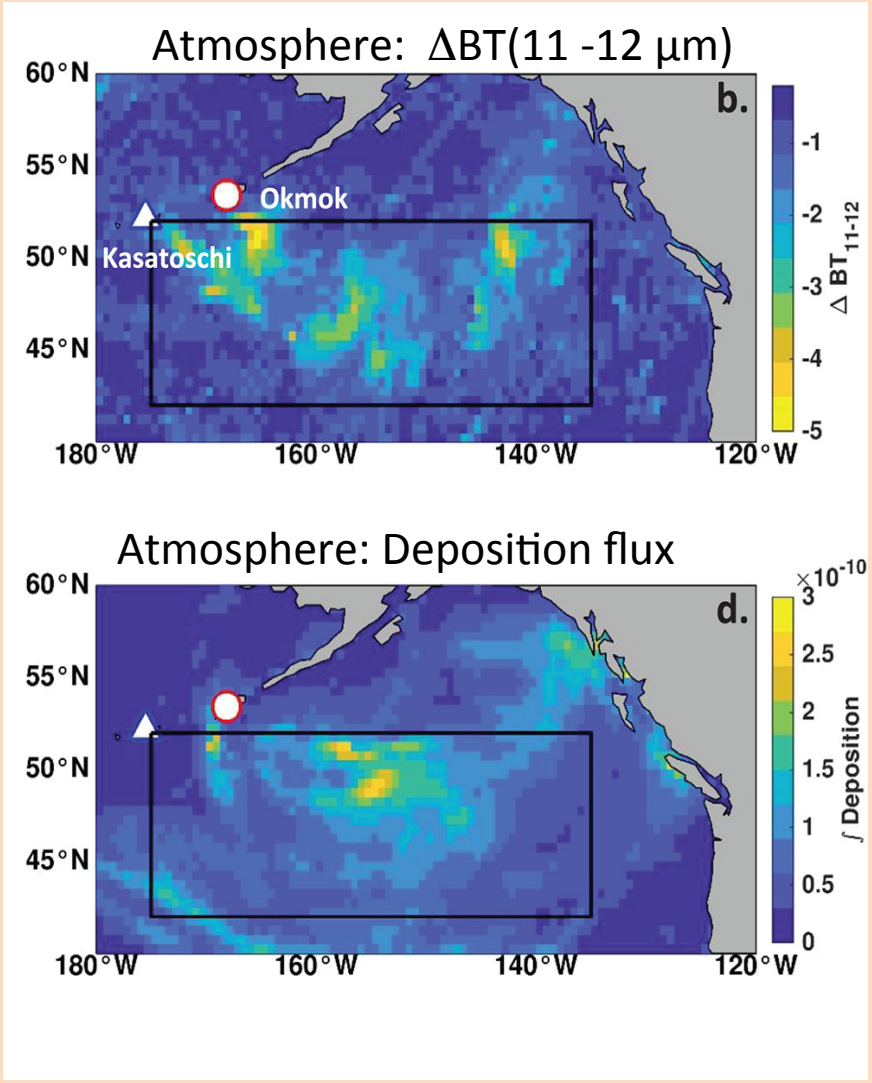
Plain Language Summary Phytoplankton growth in nearly one third of the global ocean is limited by the micronutrient iron. Outside the influence of continental margins, the only mechanisms to introduce new iron to the surface ocean are mixing up from the deep ocean (such as during winter storms) and through airborne deposition of desert dust. However, every once in a while large volcanic eruptions can provide a temporary source of iron to the ocean through deposition of volcanic ash. The effects of this "fertilization" are nearly impossible to measure in the field because of the unpredictability of volcanic eruptions. Satellite platforms provide the necessary coverage for this scale of event but have been woefully underutilized to date. We revisit a pair of well-documented volcanic eruptions from the Aleutian Archipelago and describe their impact on the surface ocean ecosystem of the subarctic North Pacific Ocean using novel satellite–derived products supplemented by model output. We are able to characterize the ecosystem response in terms of both increased phytoplankton growth and adjustments in their physiology. The latter is often neglected yet can be of equal or greater magnitude than changes in growth rate.

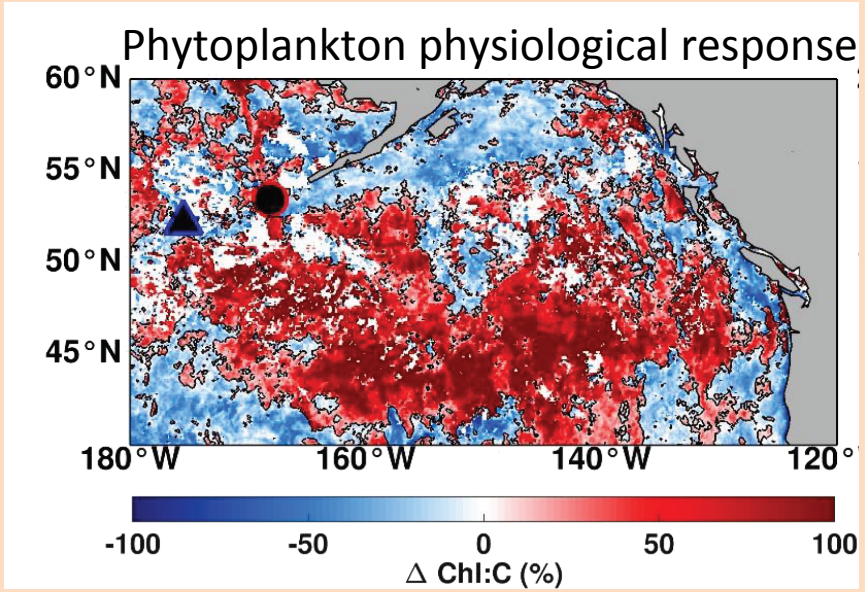
Kasatochi eruption. Terra MODIS 8 August 2008

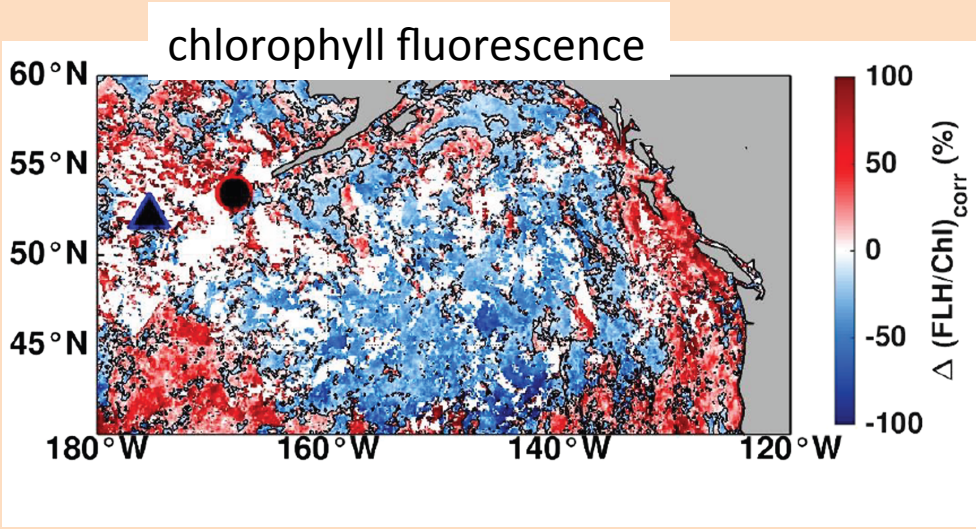


2 active Aleutian volcanoes produced ash in 2008 and deposited mineral-rich ash into an iron-limited ocean

- Okmok: intermittently between 22 Jul to 18 Aug 2008
- Kasatochi: 7-8 Aug 2008

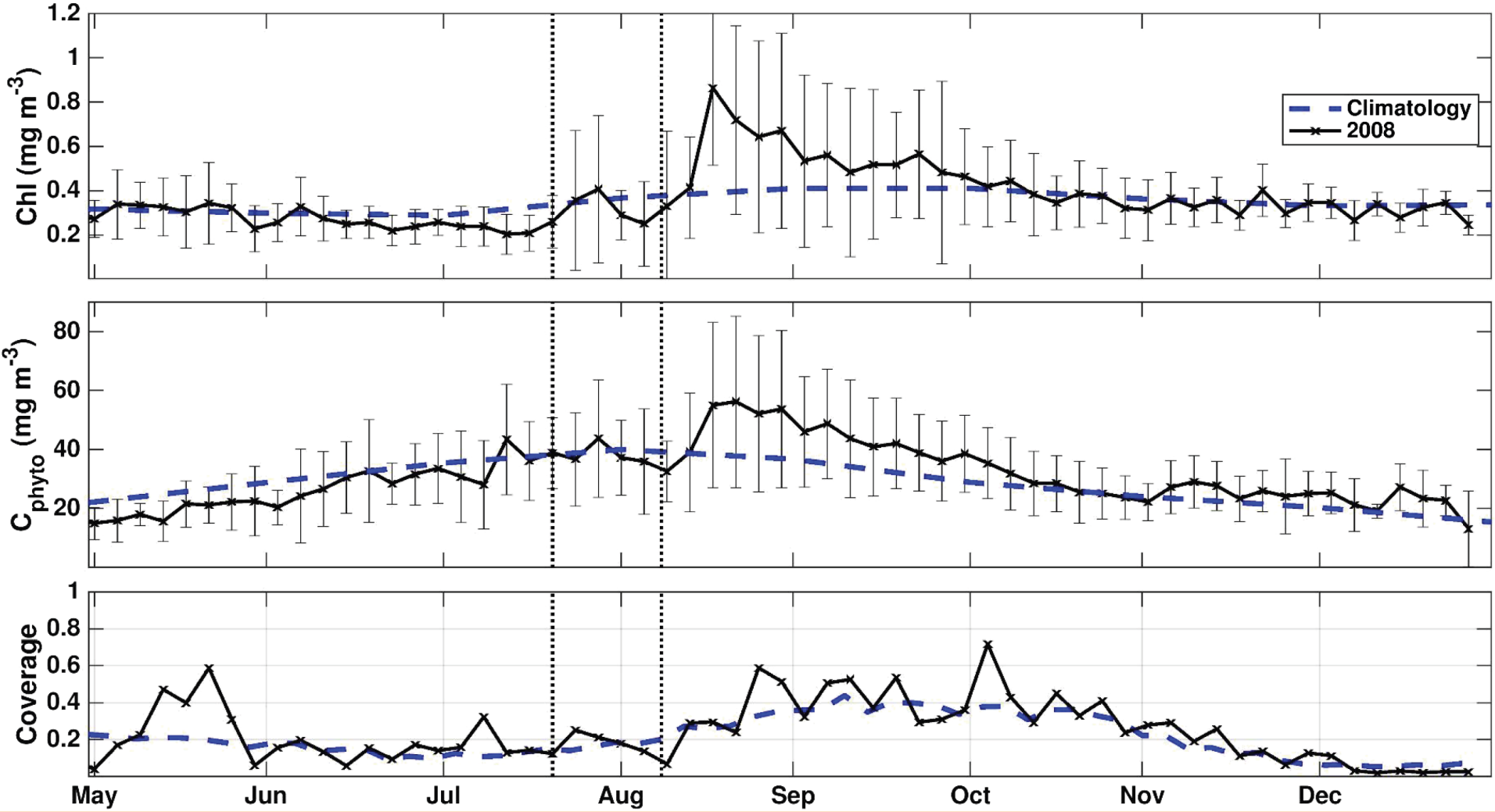






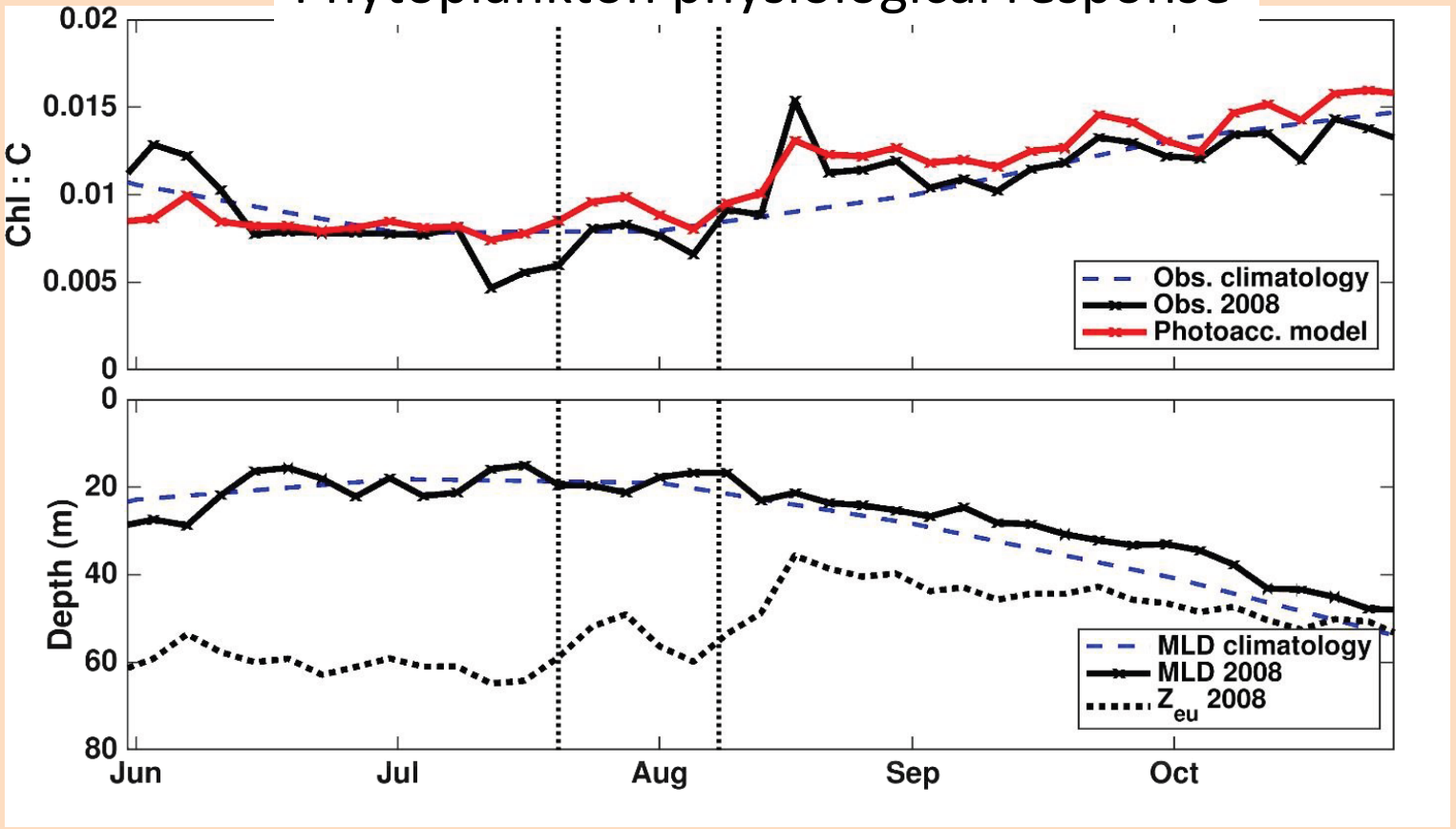
Westberry et al., 2019

Bulk ocean color properties during 2008 from satellite remote sensing.



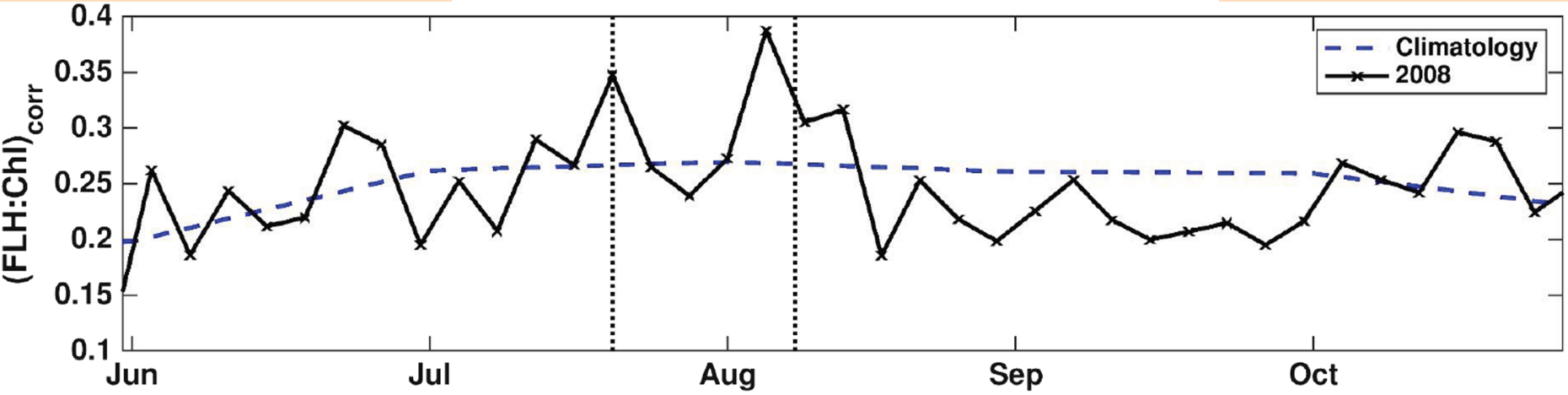
Westberry et al. (2019)

Phytoplankton physiological response



Westberry et al., 2019

Satellite chlorophyll fluorescence



Westberry et al., 2019

Now what?

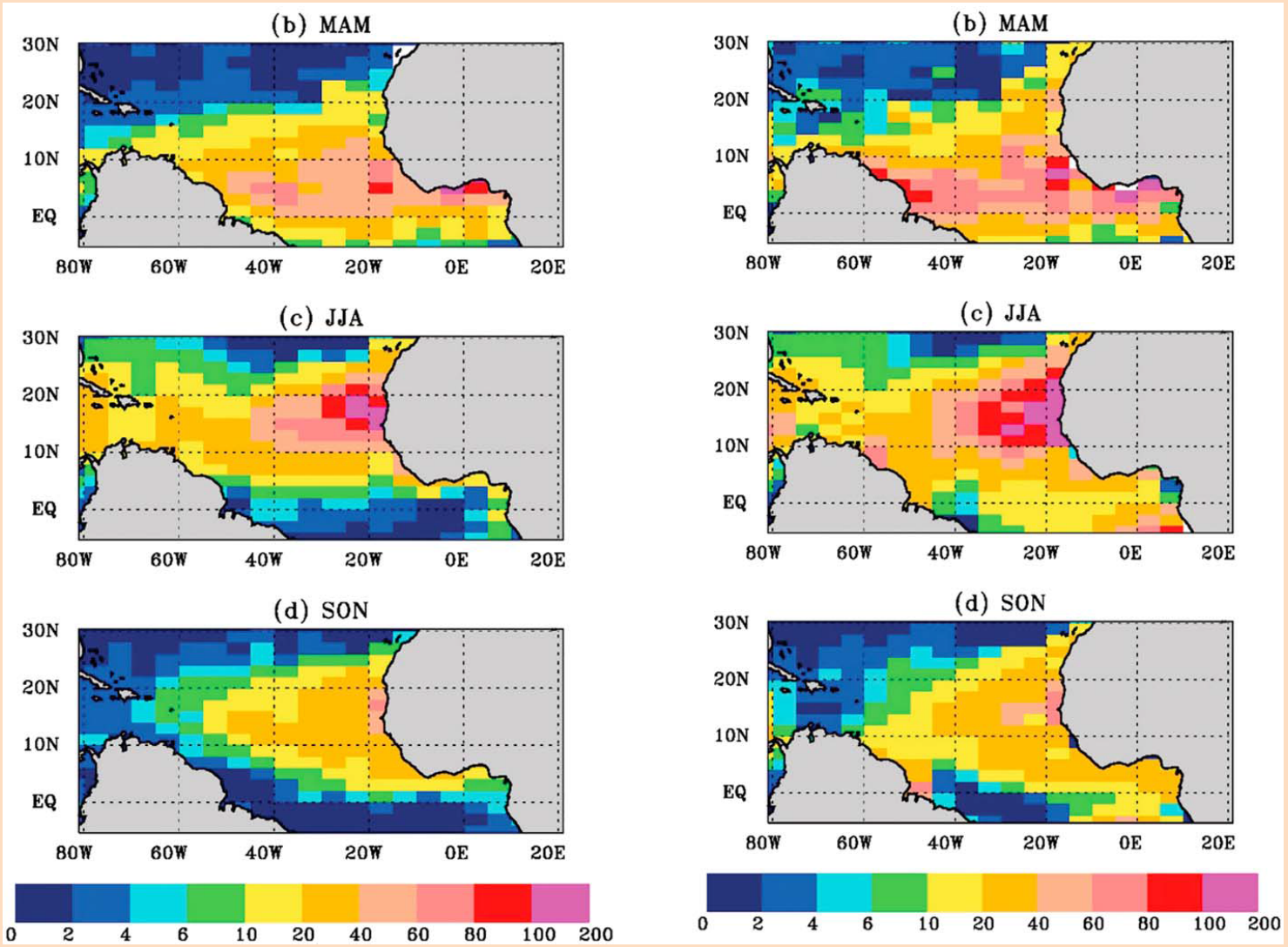
The atmospheric scientists:

Let’s look at the Atlantic!

Seasonal dust deposition rate ($mg \cdot m^{-2} \cdot day^{-1}$)

MODIS

CALIOP



Yu et al. 2019

The atmospheric scientists:

Let's look at the Atlantic!

The ocean biologists:

The Atlantic is exactly the WRONG place to look for a response

The ocean biologists:

Let’s look at the North Pacific!

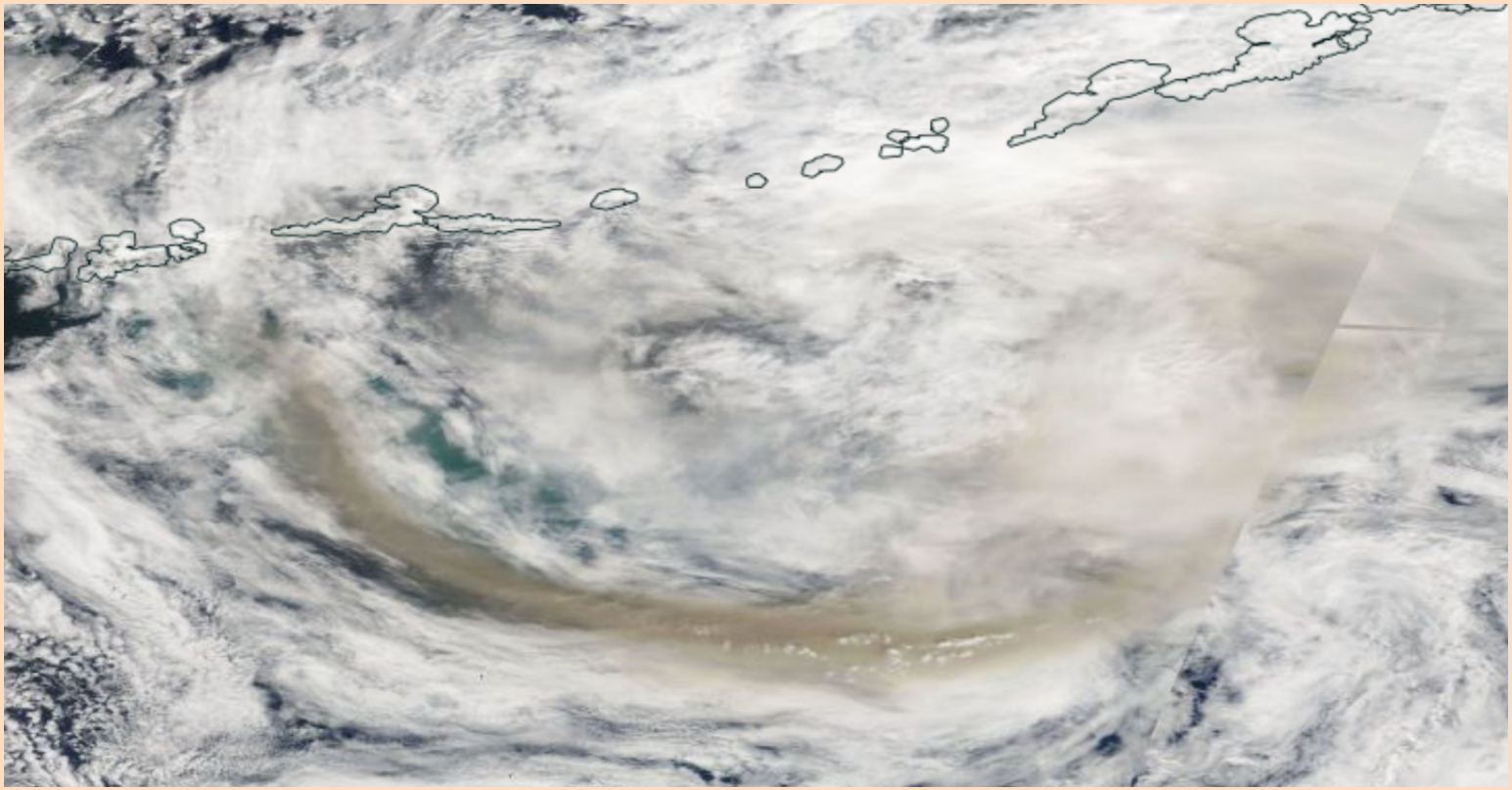
The atmospheric scientists:

That's the worst place for satellite retrieval of aerosol.

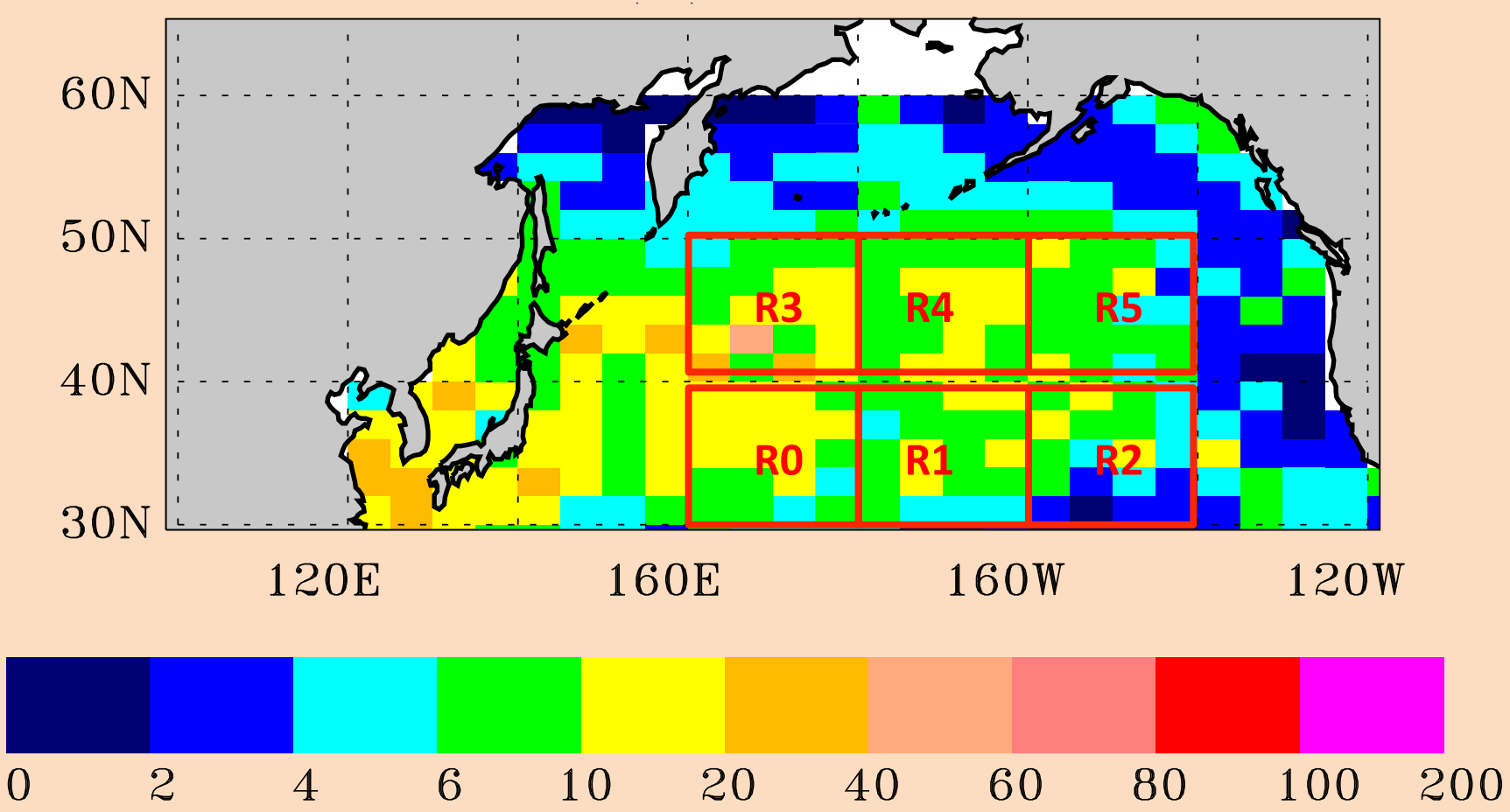
The ocean biologists:

Let's look at the North Pacific!

The North Pacific



Areas of interest in the North Pacific



Climatological annual dust deposition rate
from MODIS ($mg \cdot m^{-2} \cdot day^{-1}$)

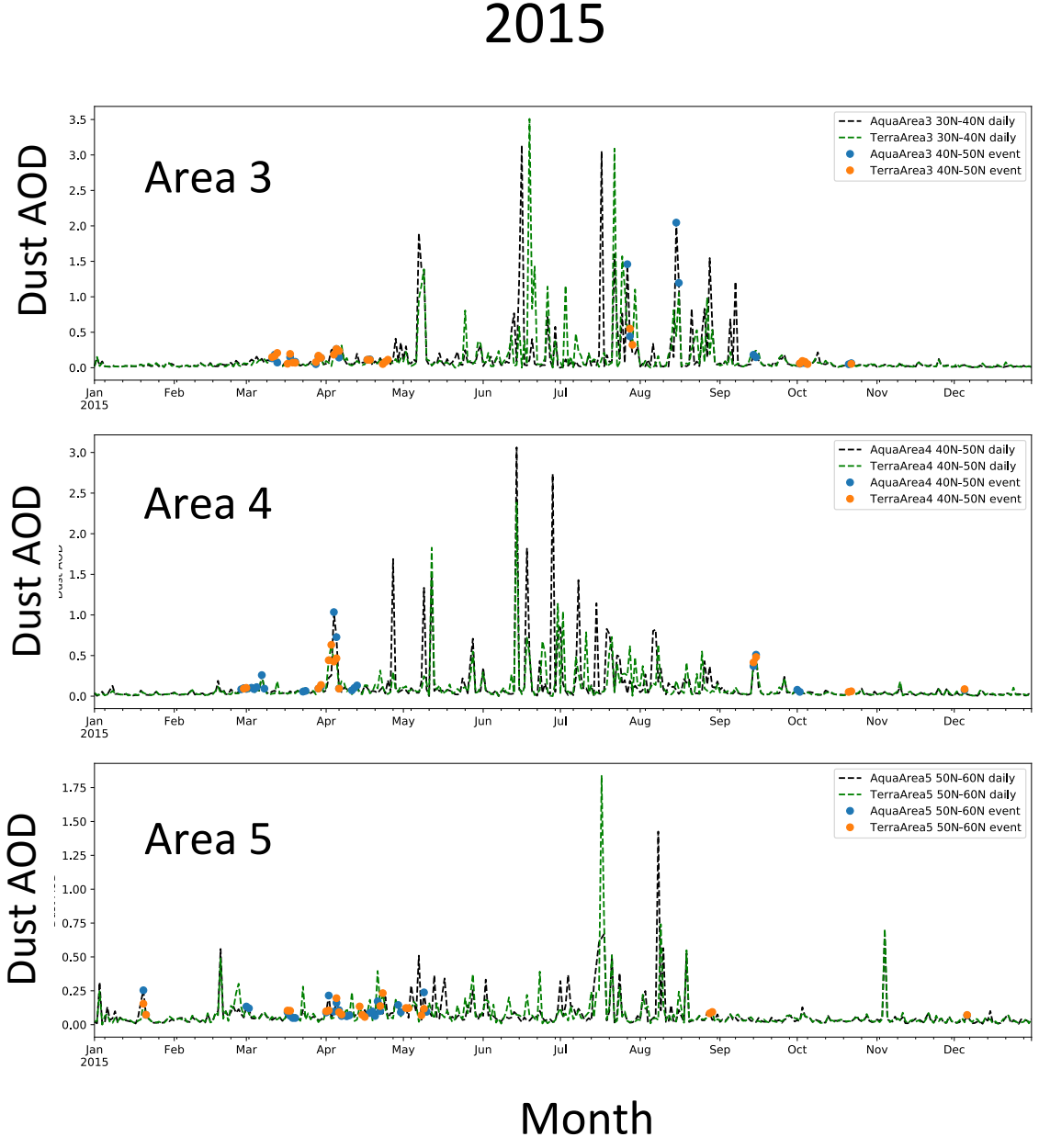
Identify Dust Events

-------- Aqua Dust AOD

-------- Terra Dust AOD

● Aqua dust event

● Terra dust event



Identify Dust Events

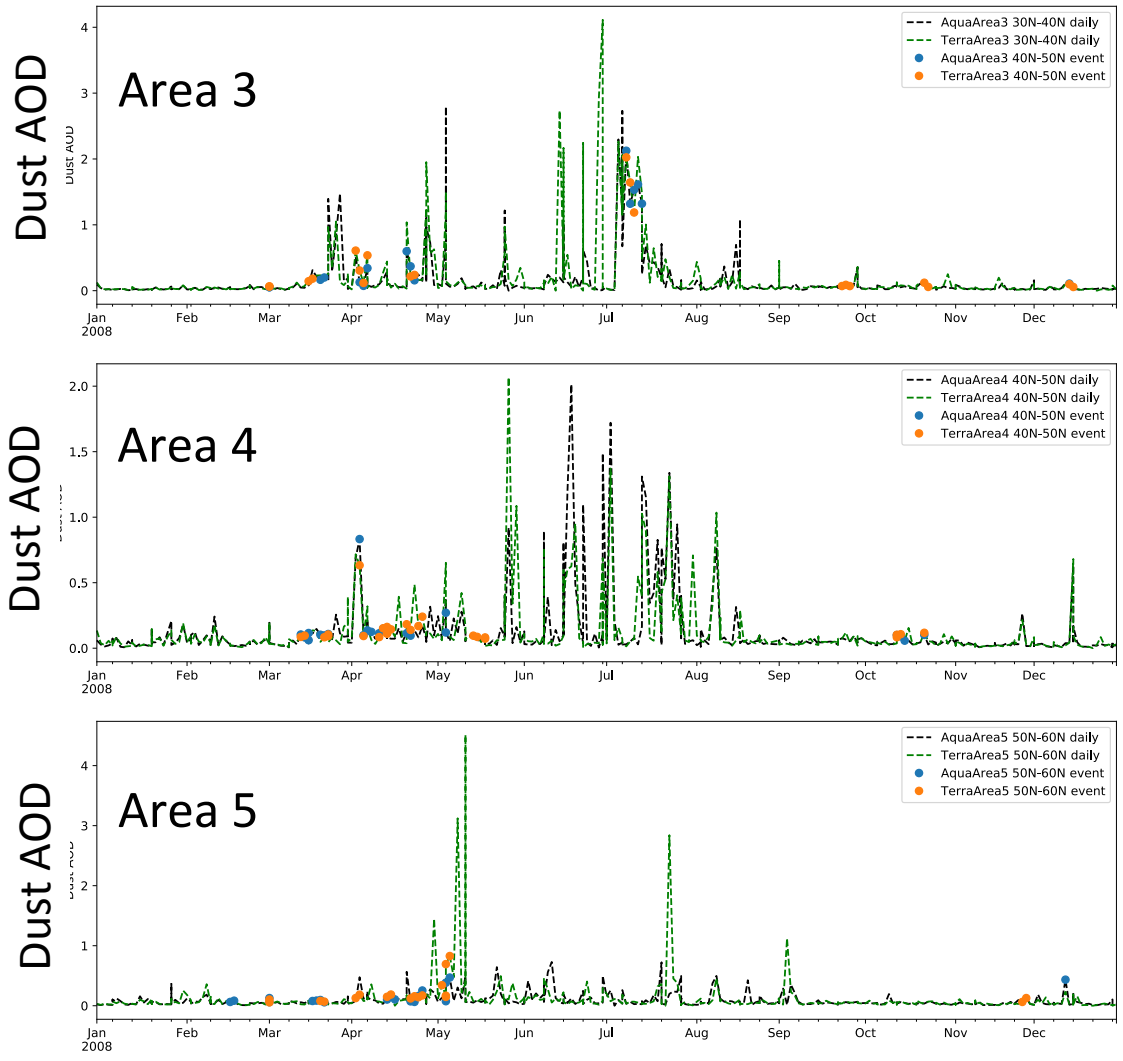
-------- Aqua Dust AOD

-------- Terra Dust AOD

● Aqua dust event

● Terra dust event

2008



The atmospheric scientists:

Despite the clouds, (take THAT Steve Platnick!) we have confidence that we have found the dust events in the North Pacific.

The ocean biologists:

That's nice, friends, but we want a more *quantitative* measure of the dust.

The ocean biologists:

….On a time scale of a few days…

The ocean biologists:

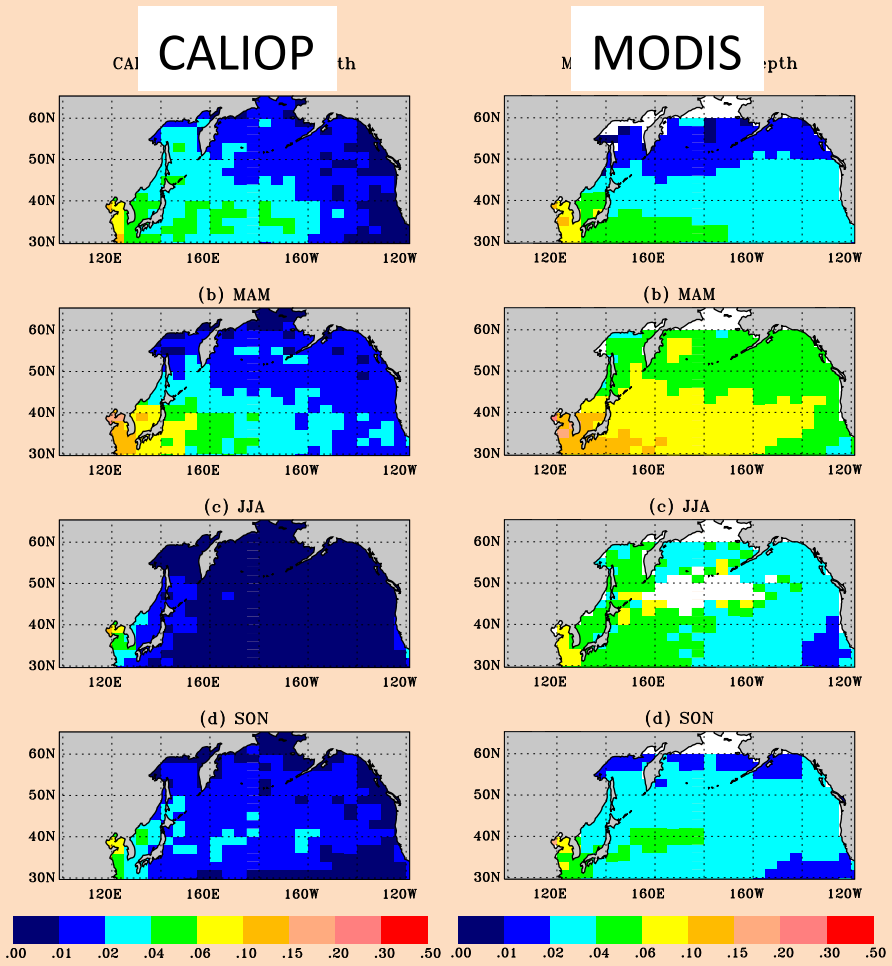
…. And no cloud effects …

The ocean biologists:

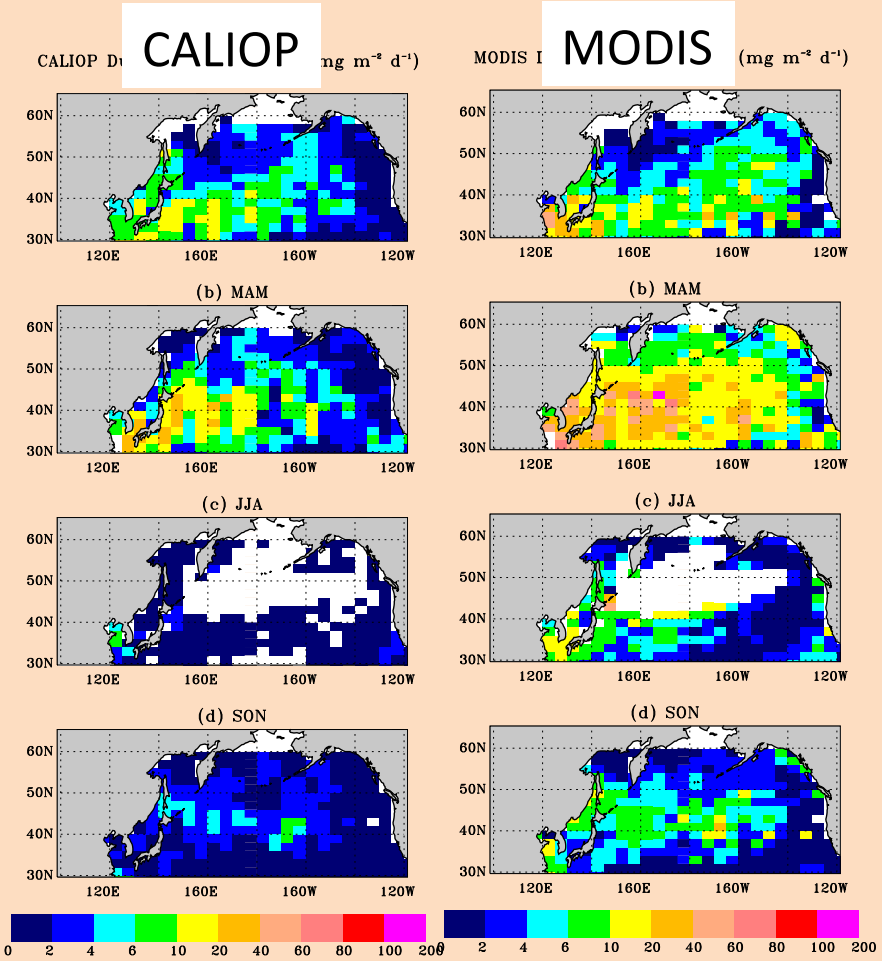
Something we can put on an x-axis when we put the ocean biology quantities on the y-axis

Seasonal Variations
Satellite observations

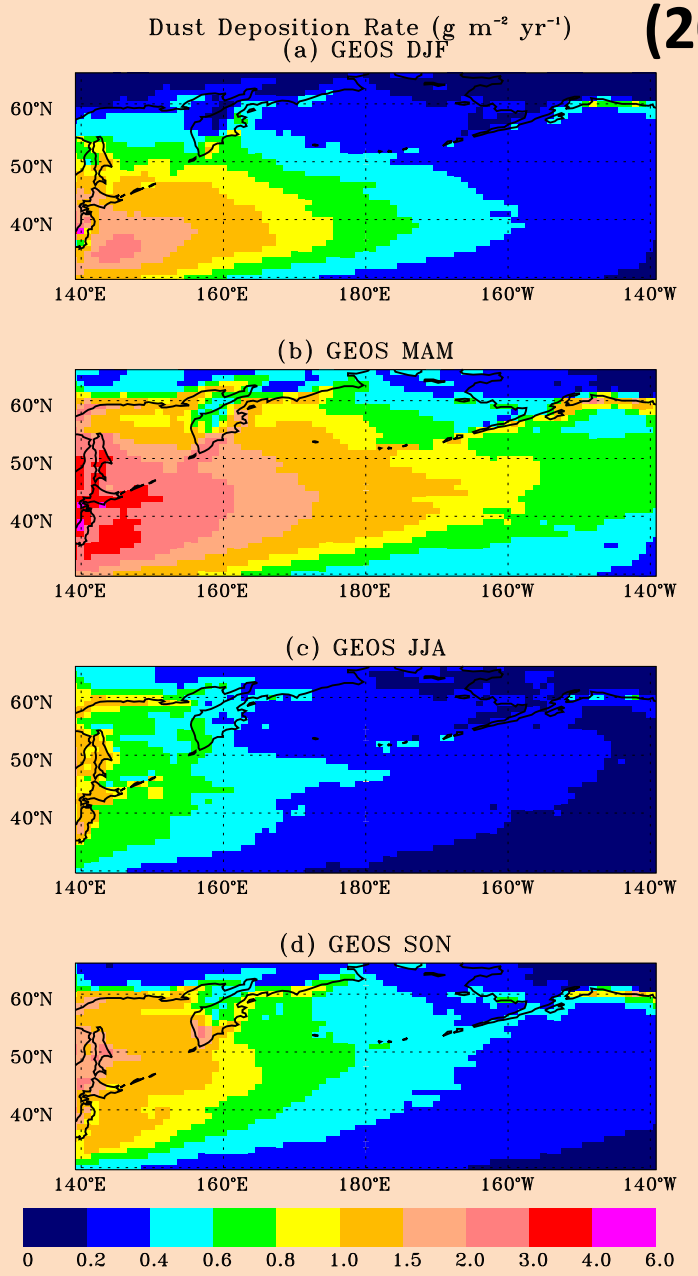
Dust Optical Depth



Dust Deposition Flux



GEOS-5 Dust Deposition into subarctic North Pacific Ocean (2003-2016)



DJF

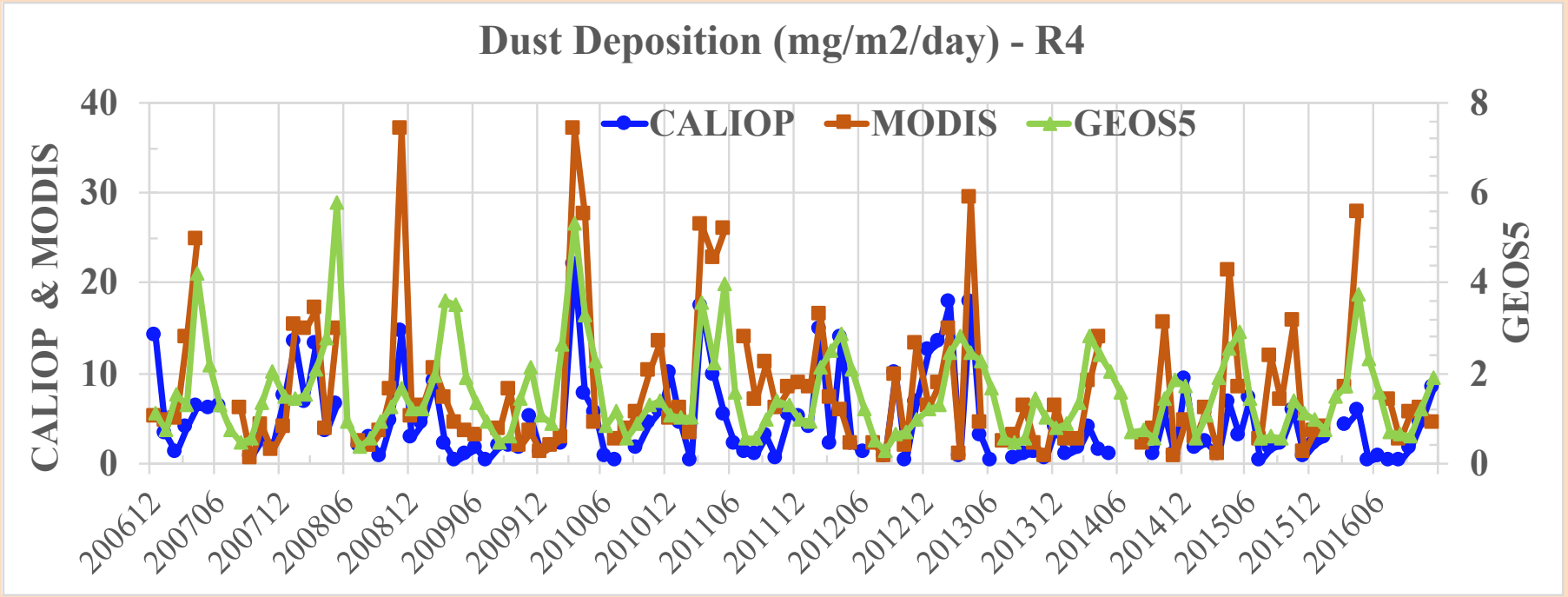
MAM

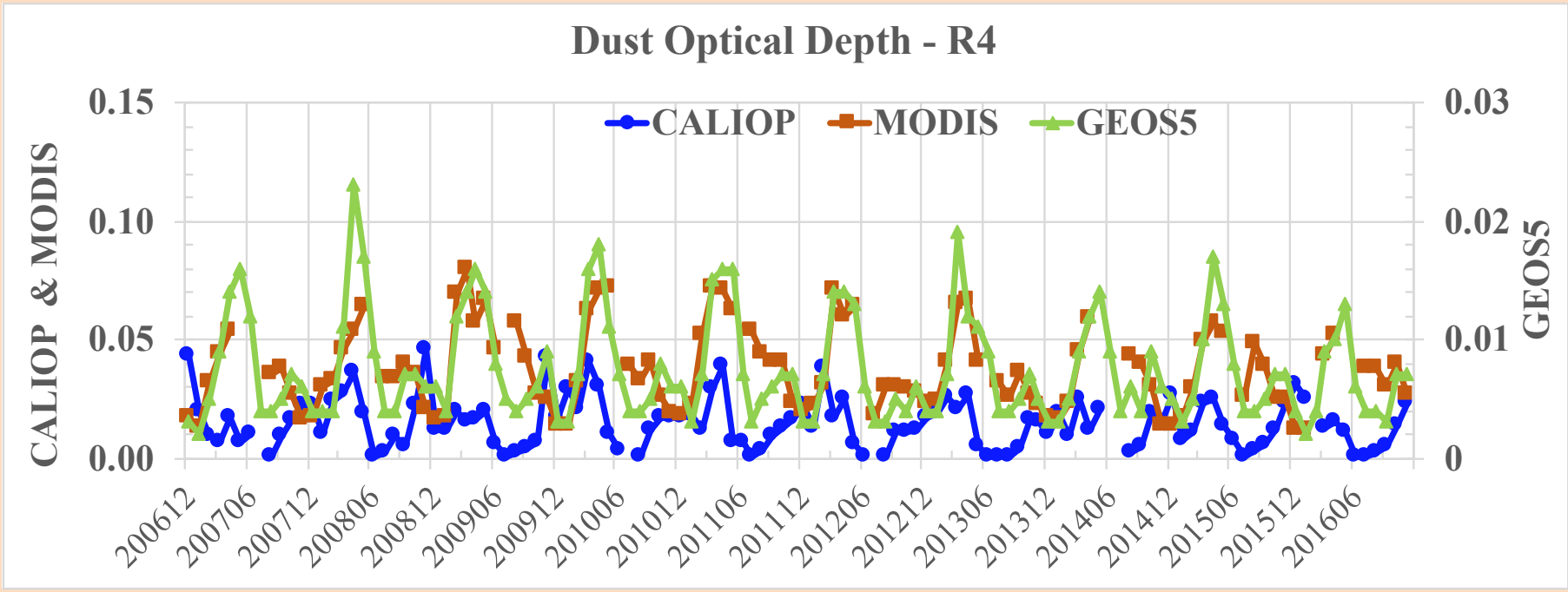
JJA

SON

Dust deposition rate ($g\ m^{-2}\ y^{-1}$)

MODEL Results


Dust Deposition (mg/m2/day) - R4
CALIOP
MODIS
GEOS5
CALIOP & MODIS
GEOS5
40
30
20
10
0
8
6
4
2
0
200612
200706
200712
200806
200812
200906
200912
201006
201012
201106
201112
201206
201212
201306
201312
201406
201412
201506
201512
201606


Dust Optical Depth - R4
CALIOP
MODIS
GEOS5
CALIOP & MODIS
GEOS5
0.15
0.10
0.05
0.00
0.03
0.02
0.01
0
200612
200706
200712
200806
200812
200906
200912
201006
201012
201106
201112
201206
201212
201306
201312
201406
201412
201506
201512
201606

Correlations for Dust Deposition (DD) and Dust Optical Depth (DOD) - Sensitivity to MODIS data screening

Daily 1° x 1 ° → Monthly 5° x 2° →Monthly 20° x 10°

Monthly coverage >30% for 5° x 2° grid (figures shown earlier are based on this criterion)

Region	R0		R1		R2		R3		R4		R5	
Variable	DD	DOD	DD	DOD	DD	DOD	DD	DOD	DD	DOD	DD	DOD
CALIOP_MODIS	0.677	0.419	0.563	0.434	0.713	0.540	0.673	-0.034	0.667	0.011	0.459	0.096
CALIOP_GEOS	0.514	0.539	0.279	0.422	0.289	0.480	0.604	0.256	0.403	0.331	0.390	0.337
MODIS_GEOS	0.611	0.901	0.396	0.907	0.443	0.909	0.560	0.755	0.558	0.777	0.433	0.814

MONTHLY Correlations

5 day running mean correlation between Dust Deposition and Dust optical depth MODIS and GEOS

Daily 1° x 1 ° → 5 Day running mean 20° x 10°

Daily number > 25% for 10° x 20° grid plus spatial thresholds. All DOD > 1. removed.

Correlation Coeff.	R0	R1	R2	R3	R4	R5
AOD (Aqua vs GEOS)	0.74	0.7	0.7	0.37	0.25	0.38
DOD (Aqua vs GEOS)	0.74	0.74	0.76	0.37	0.4	0.51
GEOS (DOD vs Dep)	0.61	0.61	0.6	0.59	0.64	0.68
Aqua DOD vs GEOS Dep	0.39	0.45	0.52	0.11	0.17	0.3

5-DAY correlations

5 day running mean correlation between Dust Deposition and Dust optical depth MODIS and GEOS

Daily 1° x 1 ° → 5 Day running mean 20° x 10°

Daily number > 25% for 10° x 20° grid plus spatial thresholds. All DOD > 1. removed.

Correlation Coeff.	R0	R1	R2	R3	R4	R5
AOD (Aqua vs GEOS)	0.74	0.7	0.7	0.37	0.25	0.38
DOD (Aqua vs GEOS)	0.74	0.74	0.76	0.37	0.4	0.51
GEOS (DOD vs Dep)	0.61	0.61	0.6	0.59	0.64	0.68
Aqua DOD vs GEOS Dep	0.39	0.45	0.52	0.11	0.17	0.3

5-DAY correlations

Summary Thoughts

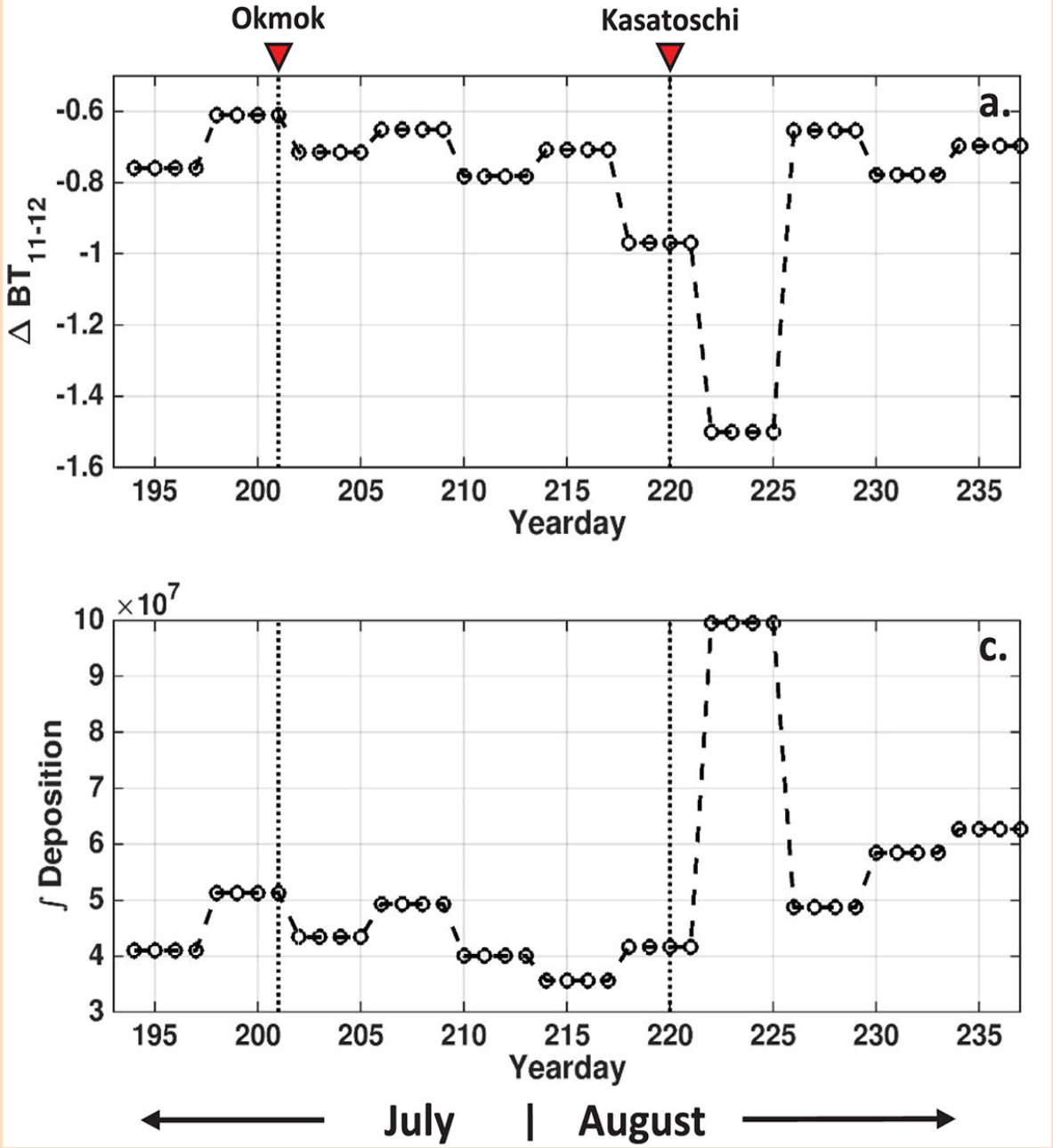
Pilot study published (Gulf of Alaska, summer of 2008).

- Definite ocean response to mineral-rich volcanic ash
- *Observed* both airborne and ocean components from satellite
- More chlorophyll (bulk response)
- Also physiological response and changes to fluoresence yield
- Effect lasted months over a wide area

Expanding to North Pacific and 11 years of observations

- Clouds
- Difficult to *quantify* airborne component from satellite
- Satellite AOD and dust AOD poor measure of deposition
- High confidence in *identifying* "dust events"
- Confidence in *quantifying* monthly and seasonal deposition
- For daily-weekly time scales will need constrained model

Let’s give three cheers for interdisciplinary science!



Time series of 4-day mean ΔBT (11 -12 μm) And dust deposition flux

Westberry et al. (2019)