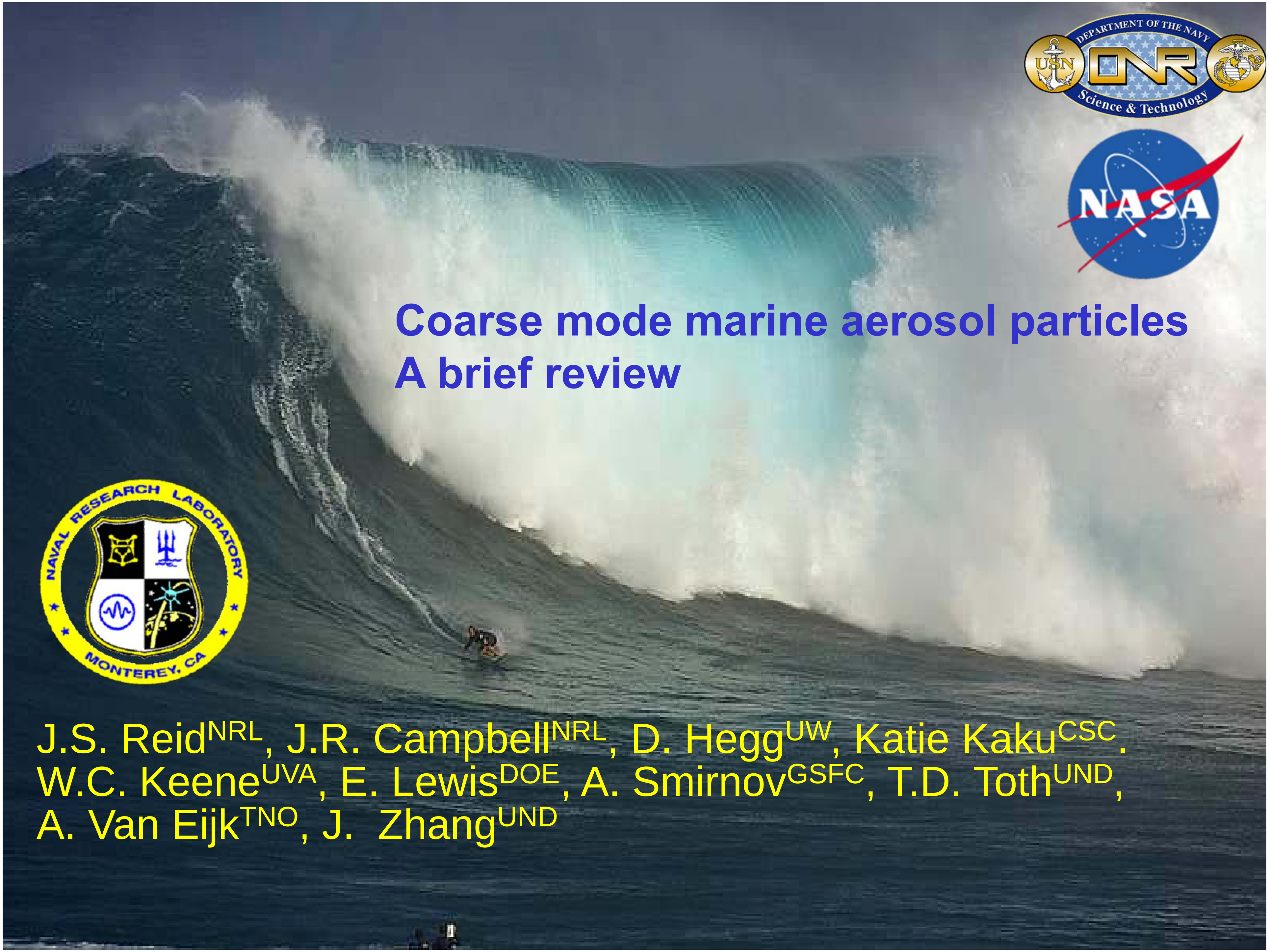
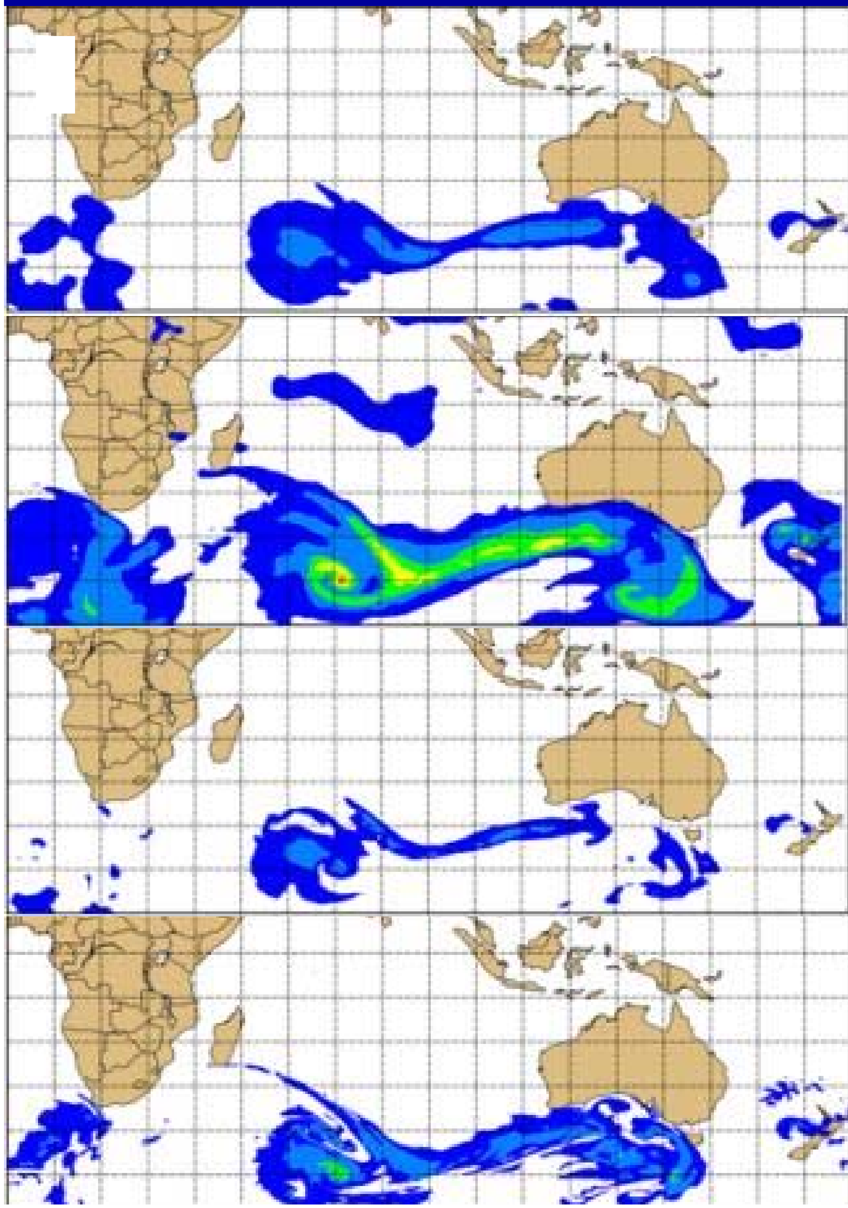


Coarse mode marine aerosol particles
A brief review

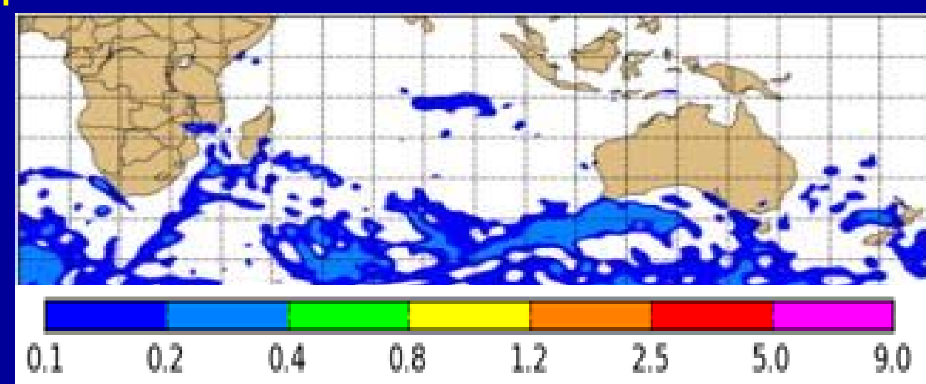
J.S. Reid[NRL], J.R. Campbell[NRL], D. Hegg[UW], Katie Kaku[CSC].
W.C. Keene[UVA], E. Lewis[DOE], A. Smirnov[GSFC], T.D. Toth[UND],
A. Van Eijk[TNO], J. Zhang[UND]

Rationale

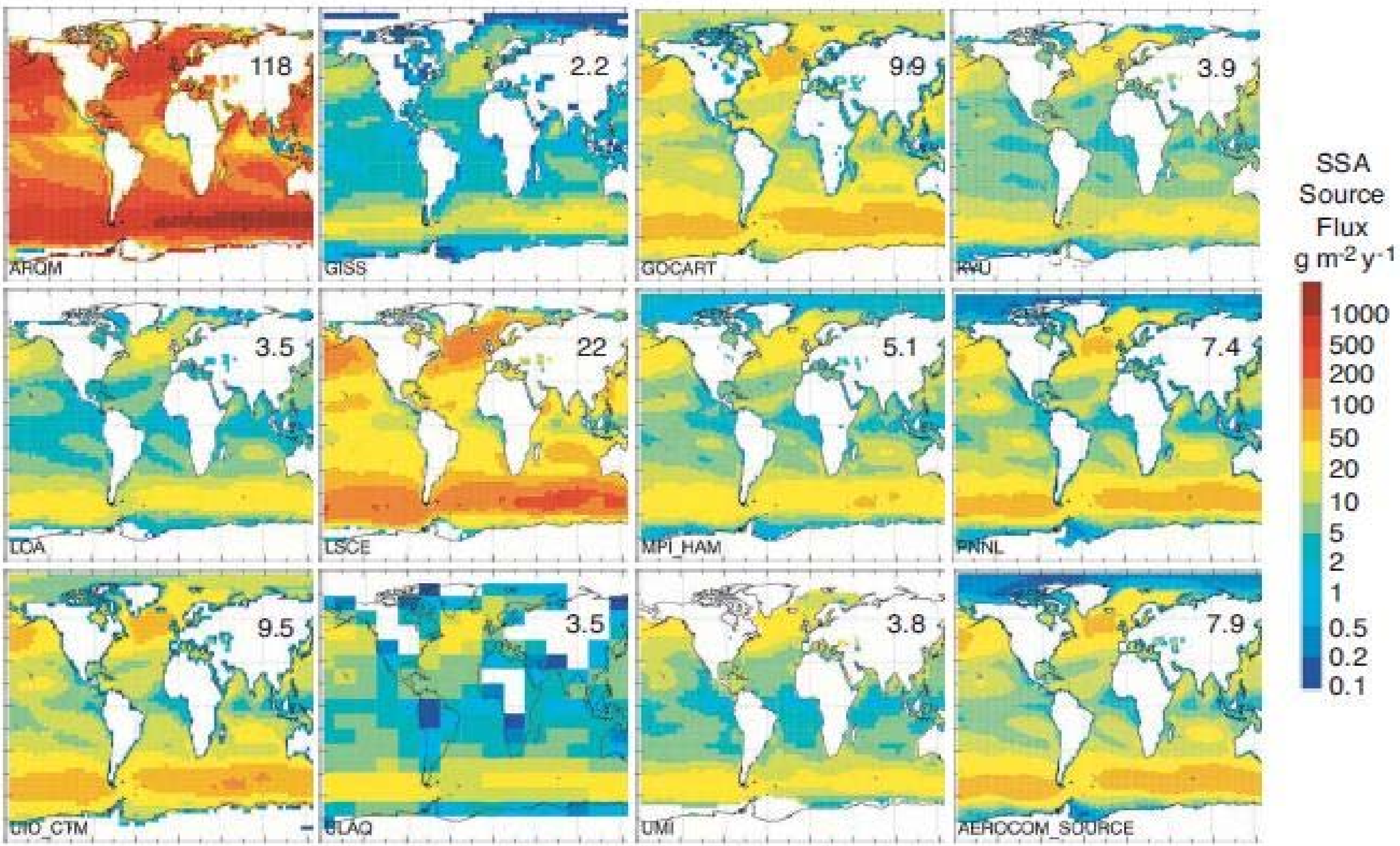
ICAP Ensemble Sea Salt AODs



- Despite being one of the oldest areas of aerosol research, there is much divergence in published measurements and model results.
- Despite similarities in source functions and meteorology, there is more spread/mean diversity in sea salt components in the ICAP multi-model ensemble than any other specie.
- “Closure” of sea salt observations with optics is thwarted by large measurement uncertainty on both the microphysical and optical side.



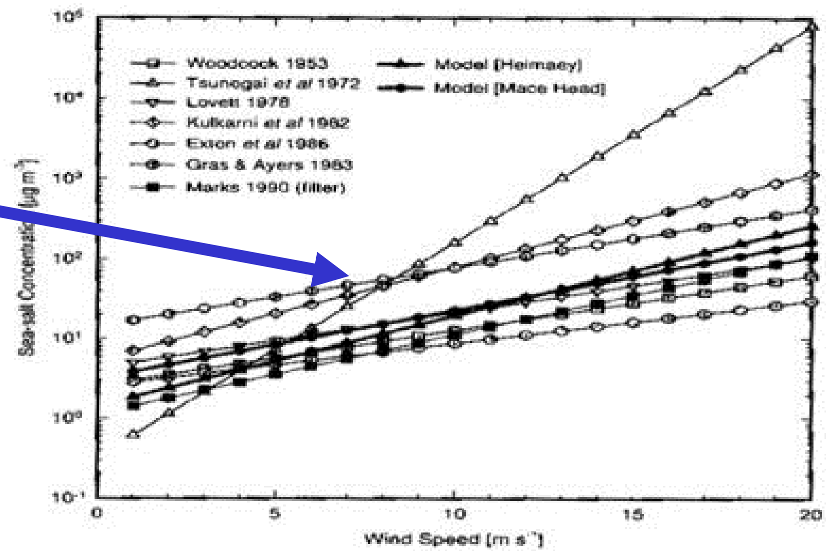
AEROCOM Sea-Salt Emissions
Climate models are in worse shape.



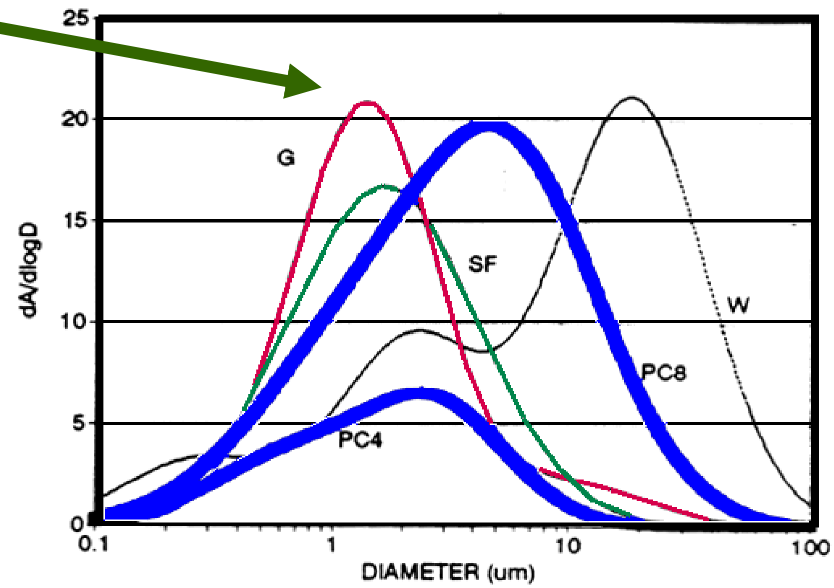
How about field measurements?

The State of Sea Salt Particle SizeFrom my 2002 talk. Not too much has changed. But see Reid et al., 2006 and Jaegle et al, 2011 for latest synopsis.

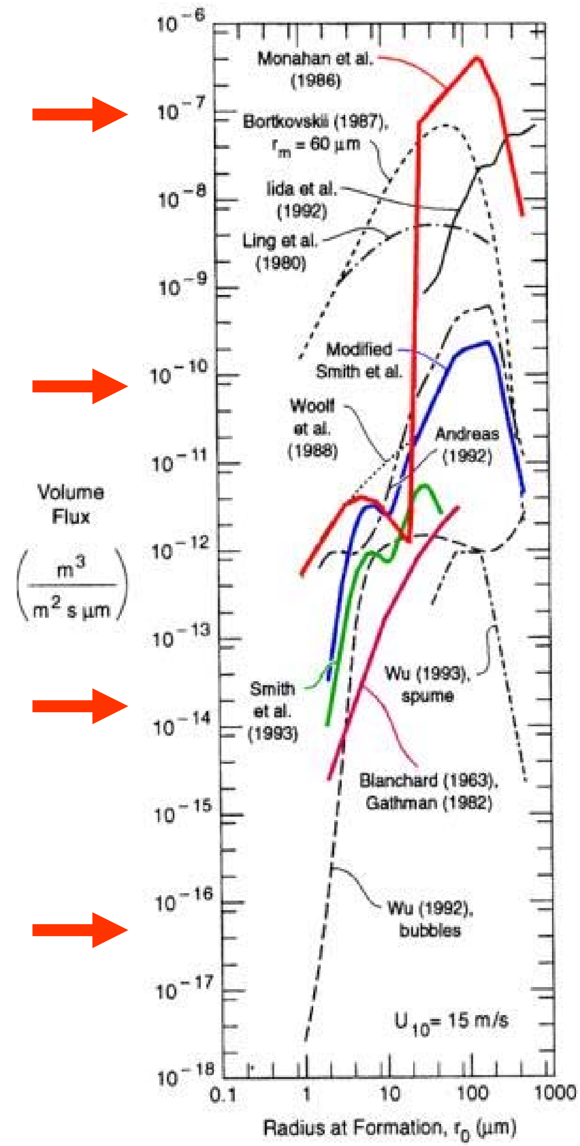
Gong et al., [1997]
Order of magnitude uncertainty in concentration



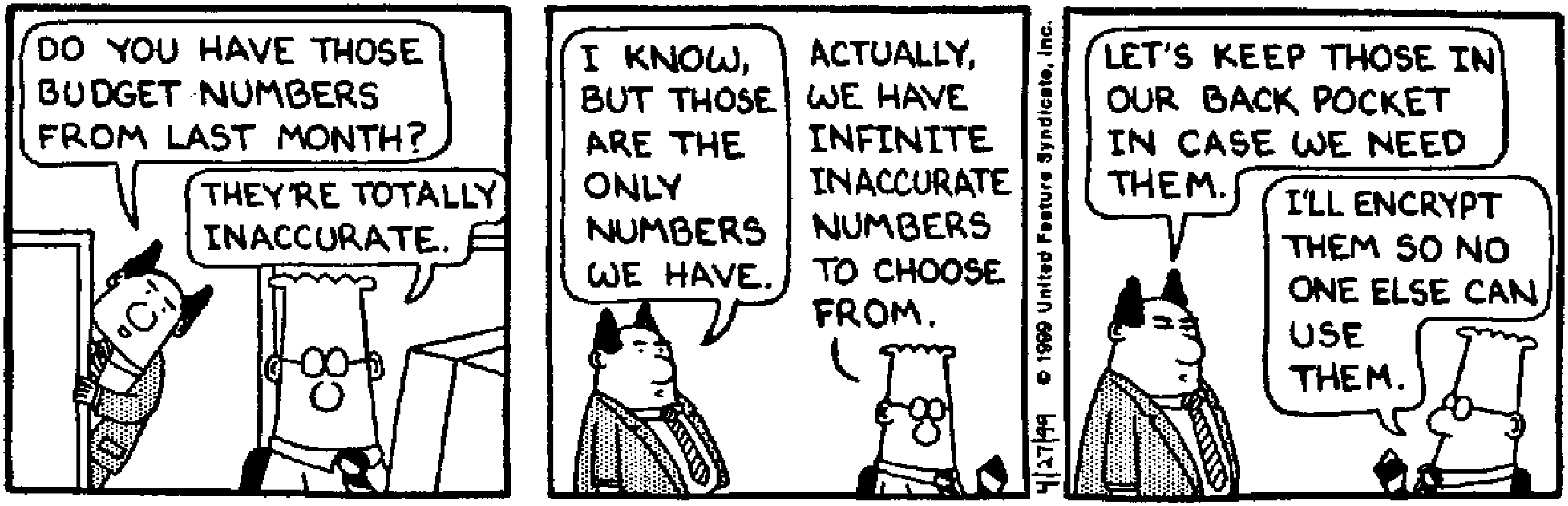
Porter and Clarke [1997]
Factor of 10 uncertainty in size



Andreas [1998]
Don't even think about flux



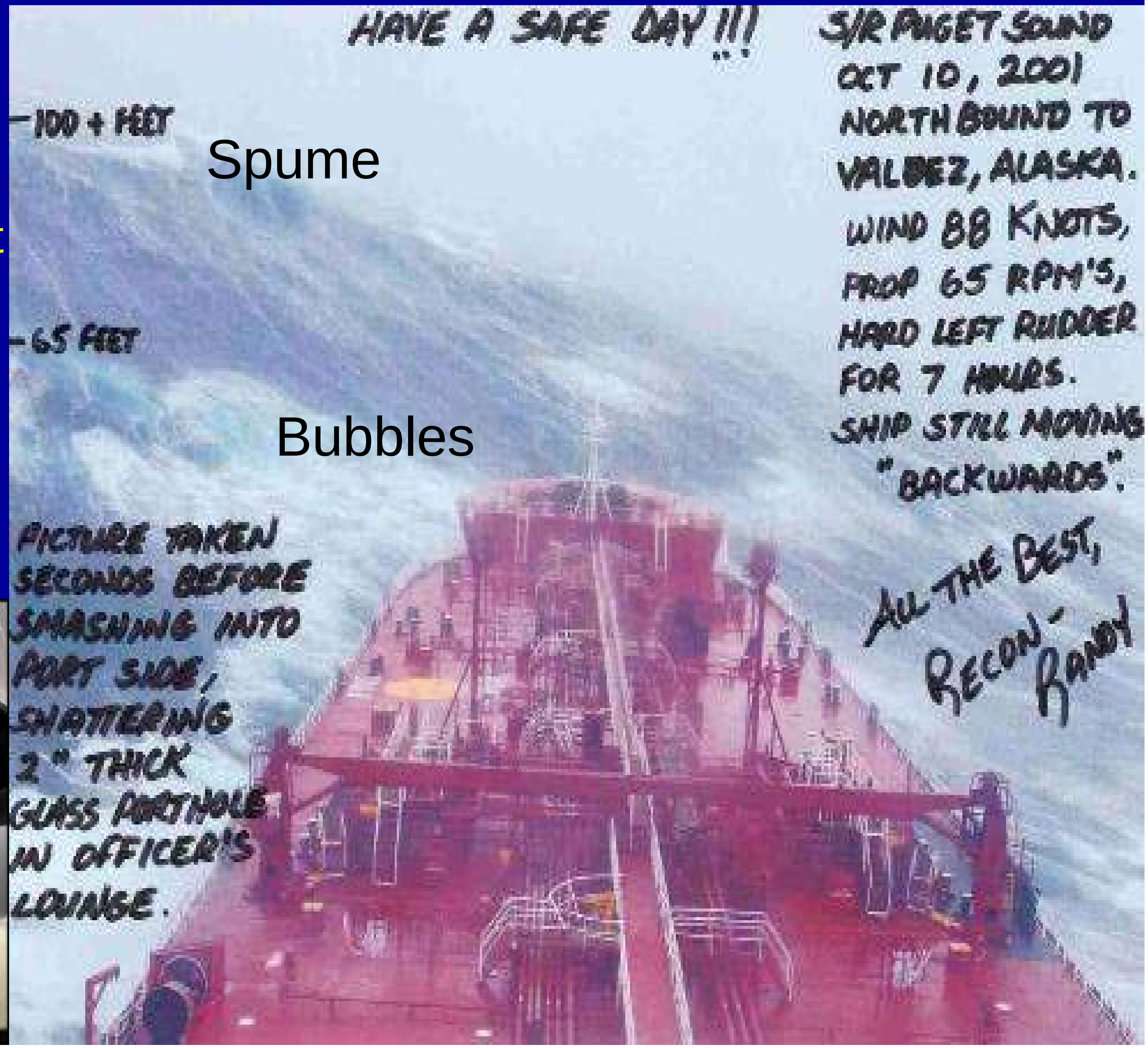
Sometimes Dilbert is a bit close to home.....



What does it look like at the surface for a large sea salt emissions event???

- Extra tropical cyclones drive global sea salt verification statistics in aerosol models, but maybe not most relevant global sea salt budgets.
- But, these are the most challenging regions to measure, or even define.

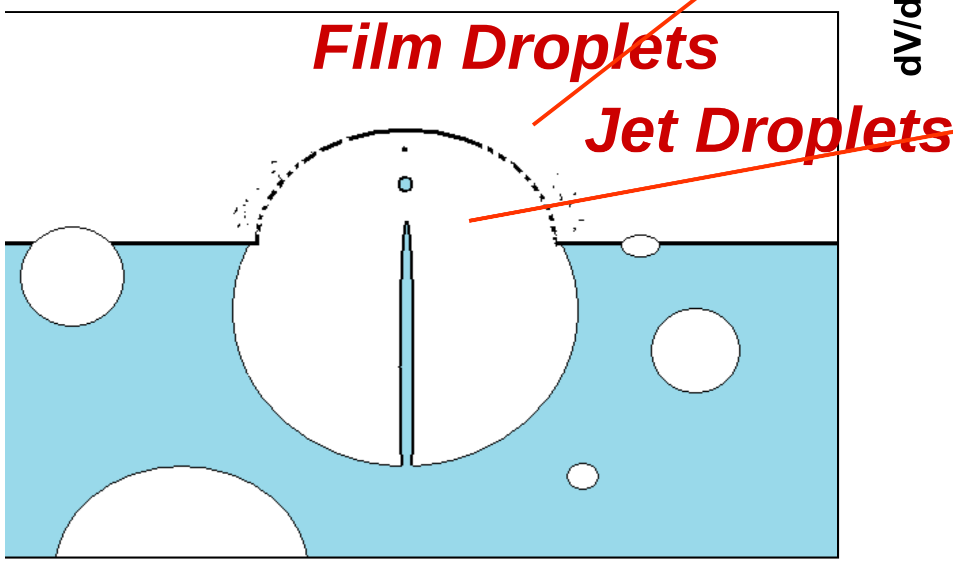

NOAA P-3 on landing

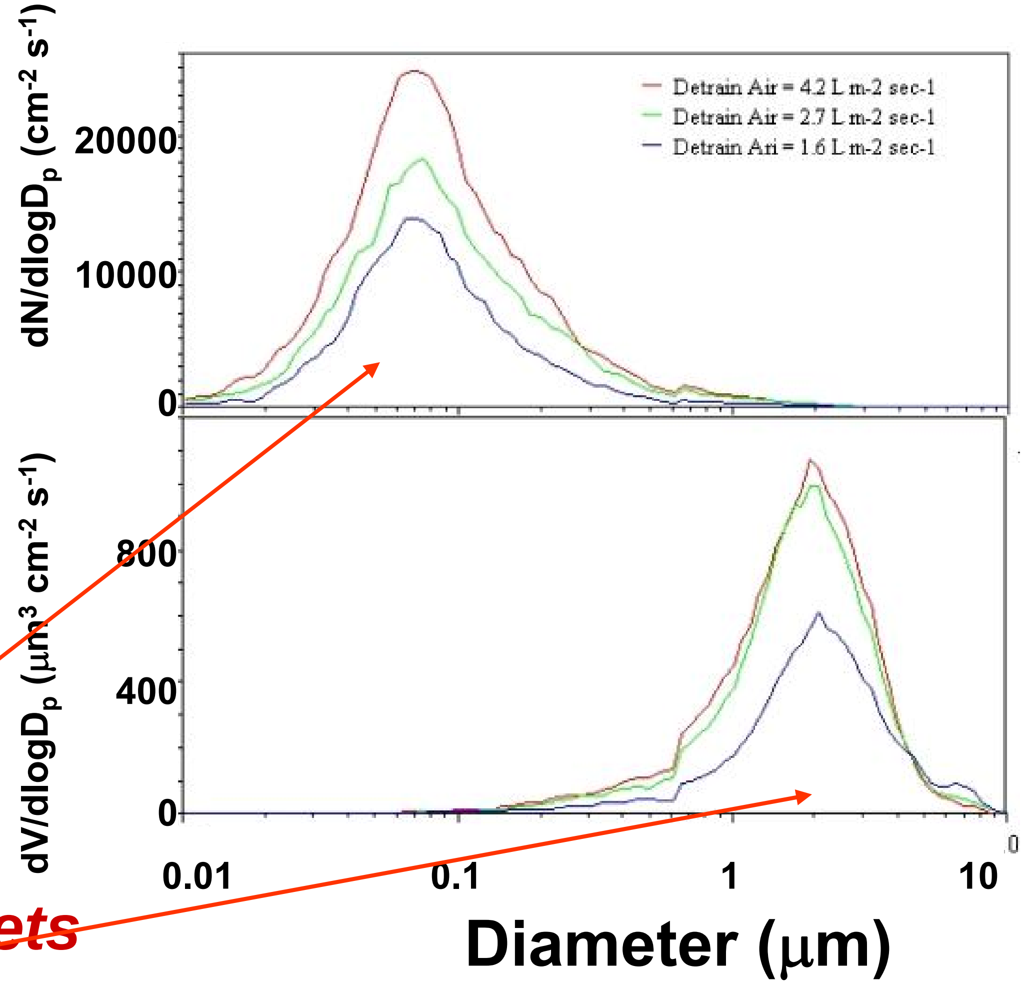


Particle Formation

Is it as simple as this?

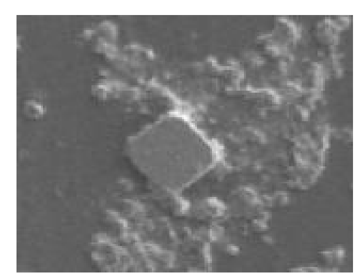
Regardless, volume and number controlling processes are likely decoupled.





Adapted from Bill Keene

Dry Spume



A Current Challenge: Reconcile microphysical and optical properties

First we must come to grips that coarse mode marine aerosol systems are perhaps the most complex observability problems in aerosol science. Ask yourself what problem are you trying to solve? Because right now one size fits none.

For ICAP's problems, at the moment we need to reconcile remote sensing and model views of the coarse mode sea salt aerosol system. Questions include:

- What are we measuring? In situ measurements of particle size, chemistry, source/sink.
- What are we seeing? Satellite and surface remote sensing of aerosol properties.

How do we bridge the two? Thermodynamics.

These will be demonstrated through examples from ONR field campaigns. Usually I am not so Navy centric, but this is the stuff you need to know.

Start with measurements:

All Coarse Mode Measurements Have Issues

See Reid et al., 2006 for a full discussion.

Dust: Reid et al, 2003

Reference	Region	MMD/VMD (μm)	Geo. St Dev. (σ_g)
Aerodynamic Methods			
D'Almeida et al., [1987]	Sahara	3±1	2.1
Gomes et al., [1990]	Algeria	3±0.5	1.8
Gomes and Gillete, [1993]	Tadzhikistan	3-6	–
Gullu et al., [1996]	Turkey (from Libya)	7±1	–
Maenhaut, et al., [1999]	Negev Desert	5±1	–
Maring et al., [2000]	Canary Islands	5±1	
Patterson and Gillette [1977]	Texas	6±1	2.2
Reid et al., [1994]	Owens (Dry) Lakebed	4±1	2.3
Sviridenkov et al., [1993]	Tadzhikistan	5±1	1.9±0.3
Talbot et al., [1986]	Barbados	3.2±0.8	2.5
PRIDE Study	*Puerto Rico (Saharan)*	*3.5±1*	*2.0*
Mean		**4.4±1.2**	**2.1±0.2**
Optical Methods			
Ackerman and Cox [1982]	Arabian Sea	12±2	~2
Cahill et al. [1994]	Owens (Dry) Lake	>5	–
Carlson and Caverly [1977]	Capo Verde	13±2	2.1
Collins et al., [2000]	Tenerefe	>8	–
Levin et al., [1980]	Israel	>5	–
Porter and Clarke [1997]	Hawaii (Asian)	6.5±1*	2.2
Sviridenkov et al., [1993]	Tadzhikistan	9±1*	2.0
PRIDE Study	*Puerto Rico (Saharan)*	*9±1*	1.5
Mean		**>9**	**2.0**

*Estimated from given surface median diameter and geometric standards deviation using Hatch-Choat equations

Sea Salt: Reid et al, 2006

	Location	RH	Height	VMD (μm)	σ_{gv}
Aerodynamic Particle Sizers(dry)					
Maring et al., [2003]	Puerto Rico	dry	10 m	**4/5**	2
Quinn et al., [1996]	S. W. Pacific	55%	10 m	**3/4**	1.8
This study	Hawaii	dry	15 m	**2.9/4**	1.7
Cascade Impactors					
Hoppel et al. [1989]	Tenerife	Amb	10 m	**9**	2.1
Howell and Huebert [1998]	ASTEX/Atlanic	Amb	Cliff	**7**	~1.9
Marks [1990]	Ireland	Amb	10 m	**4.5**	~2.2
McGovern, et. al., [1994]	Ireland	Amb	10 m	**5**	~2.2
Quinn et al., [1996]	SE Pacific	55%	10 m	**2.7/4**	1.82
Quinn et al., [2001]	ACE-1&2	55%		**2.5/4**	2
Reid et al., [2003]	Puerto Rico	Amb	~10 m	**~4**	2
Savoie (unpublished)*	Puerto Rico	Amb	10 m	**4**	2
Optical Particle Counters					
Clarke et al., [2003]	Hawaii	dried	5&20 m	**7/12**	1.8
Exton et al., [1986]	Outer Hebrides	Amb	10 m	**6**	~2.2
Gathman [1982]	variable	Amb	10 m	**2**	2.0
Gras and Ayers [1983]	Cape Grim		10 m	**2**	~2
Fairall et al. [1983]/Schacher et al., [1981]	Monterey/JASIN	Amb.	10 m	**4**	~2.2
Gerber, [1985]	Azores	Amb	15 m	**6**	2.0
Horvath et al., [1990]	Bermuda	Amb	250 m	**5**	1.7
Horvath et al., [1990]	US East Coast	Amb	variable	**7.5**	2.1
Kim et al., [1995]	ASTEX	dry	10 m	**1/2**	1.5
Reid et al., [2001]	Outer Banks, NC	Amb	30-100 m	**10**	1.8-2.2
Sievering et al., [1987] Kim et al., [1990]	Outer Banks	Amb	variable	**8**	2.1
Shettle and Fenn[1979]	Composite	Amb	variable	**8**	2.5
Sievering et al., [1987]/ Kim et al., [1990]	Bermuda	Amb	variable	**5.6**	1.7
Smith et al.,[1993]	Outer Hebrides	Amb	14 m	**8**	~2
van Eijk and De Leeuw [1992][bc]	North Sea	Amb	10 m	**2**	2.0
van Eijk and De Leeuw [1992]*	North Sea		10 m	**8**	2.0
This study	Hawaii	Amb	variable	**8**	1.5
Inversions (ambient)					
Smirnov et al., [2003]	Midway, Lanai, Tahiti	Amb	Integrated	6	2

RED Aerosol Flux Game Plan

Deploy EC instruments to starboard boom on FLIP

Campbell Sonic, LICOR H_2O/CO_2, FSSP, PCASP

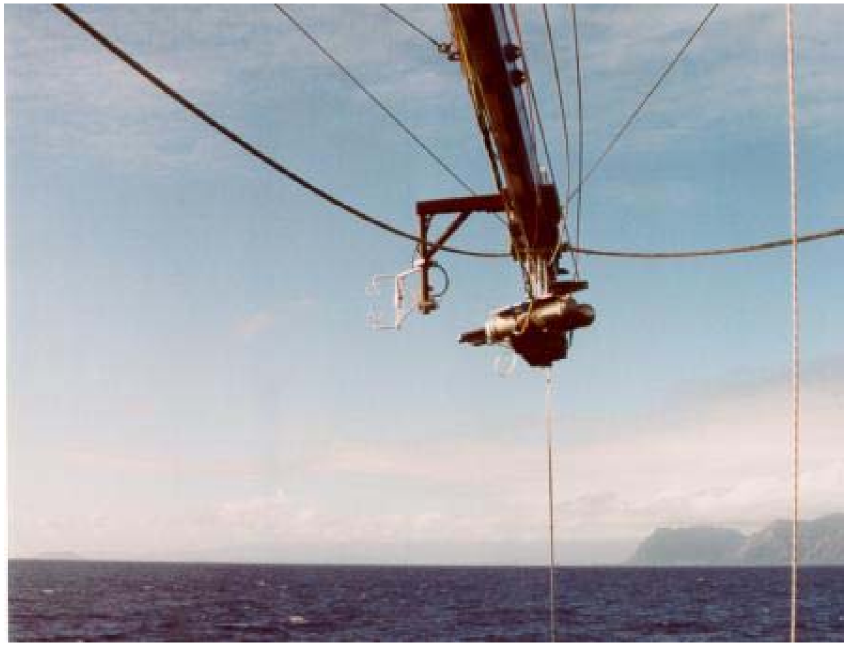
Deploy mean aerosol instruments to upper deck

Dried inlet, APS 3320, TSI Neph, CSASP DOA

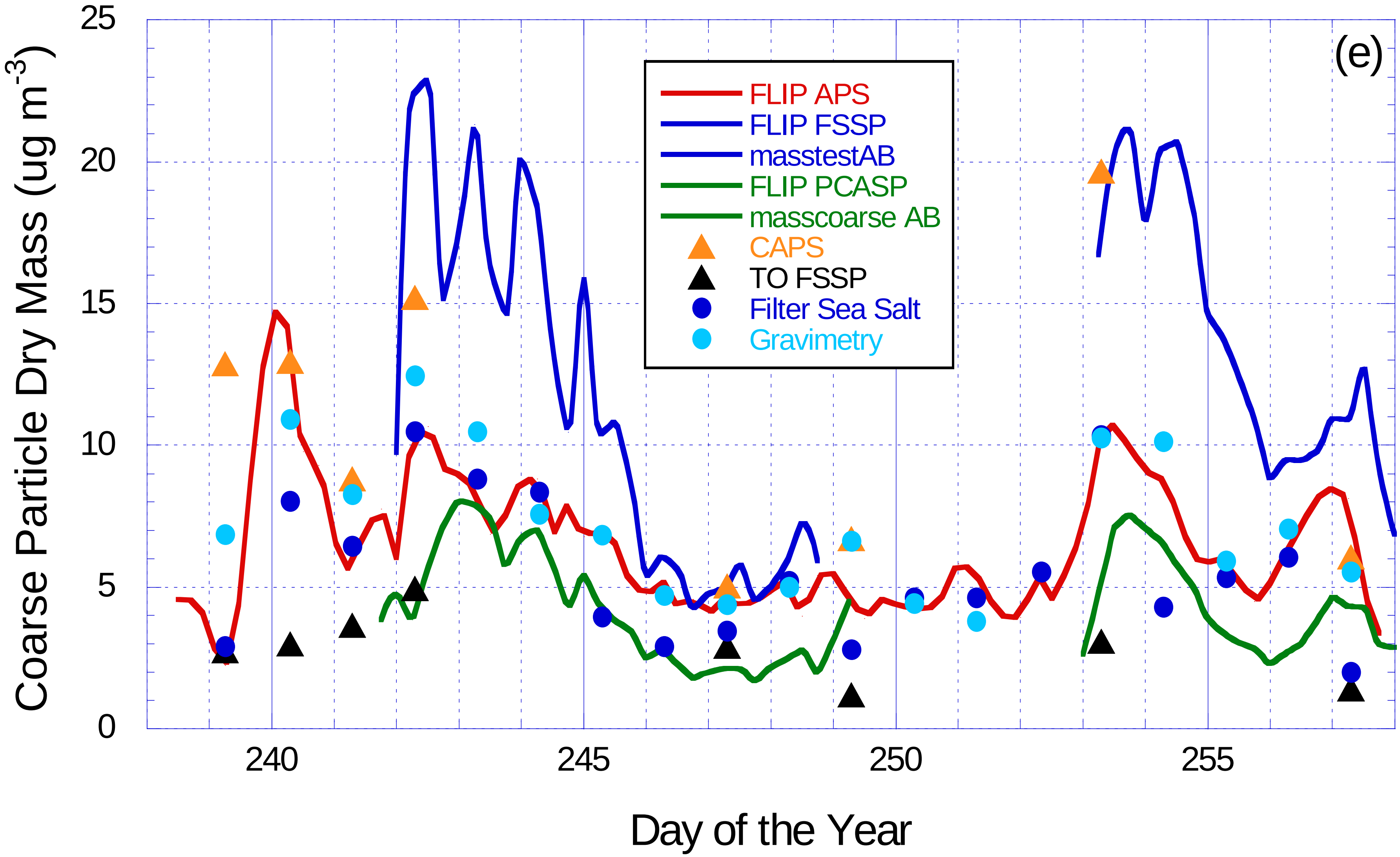
Use CIRPAS Twin Otter for vertical distribution

Use site as receptor for Hoppel and Co.

Advantages: Stable platform, long fetch



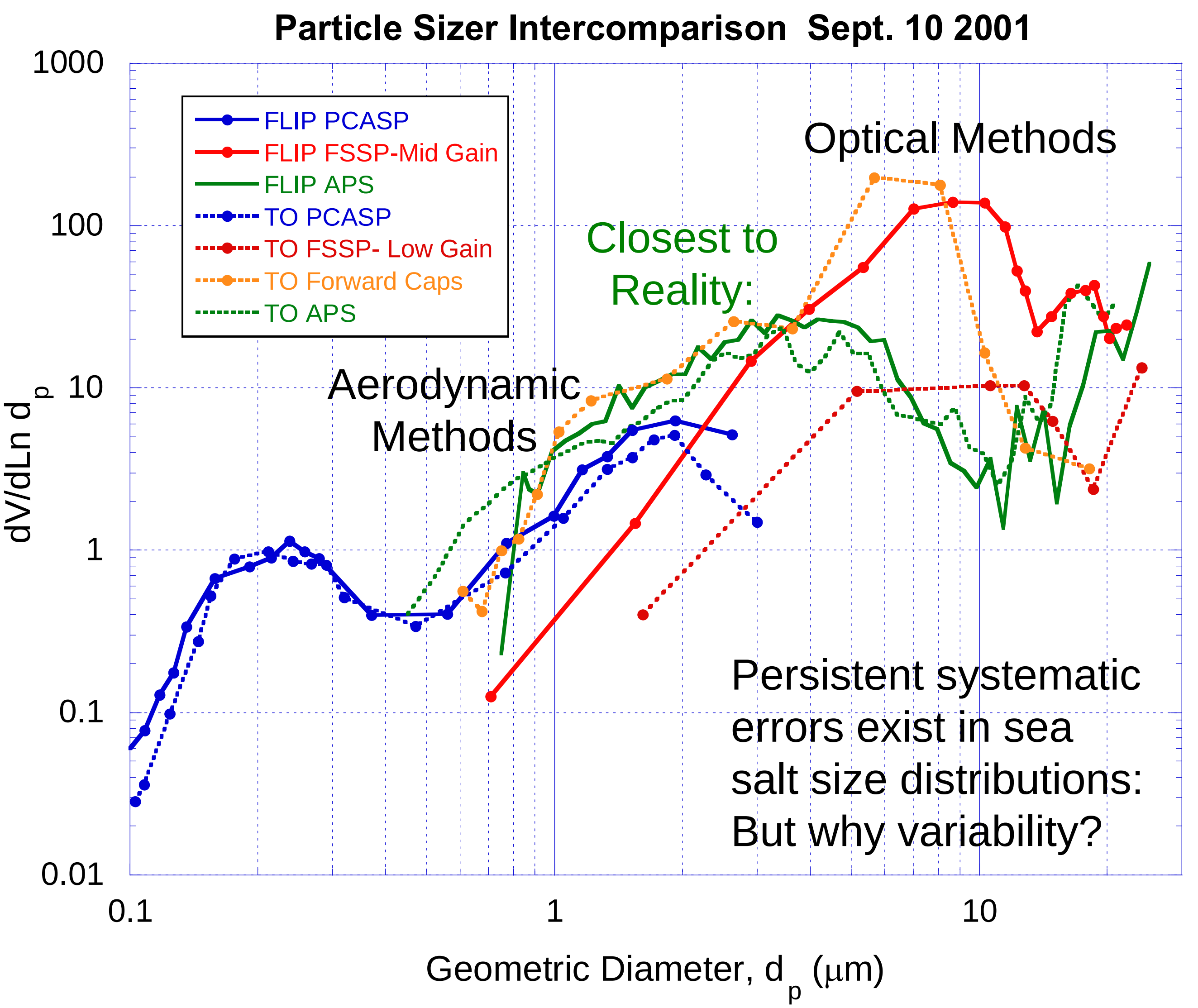
Marine Aerosol Implications
Geochemical Cycles/Model Validation



Marine Aerosol Size Distribution Issues

Do the sizing biases we found for dust extend to sea salt?

Most OPC data in the literature cannot be trusted at face value.



Optical Particle Counter Biases

Probably needs to be excluded in review paper "means"

See Reid et al., 2006/2007

Response Curve Degeneracy

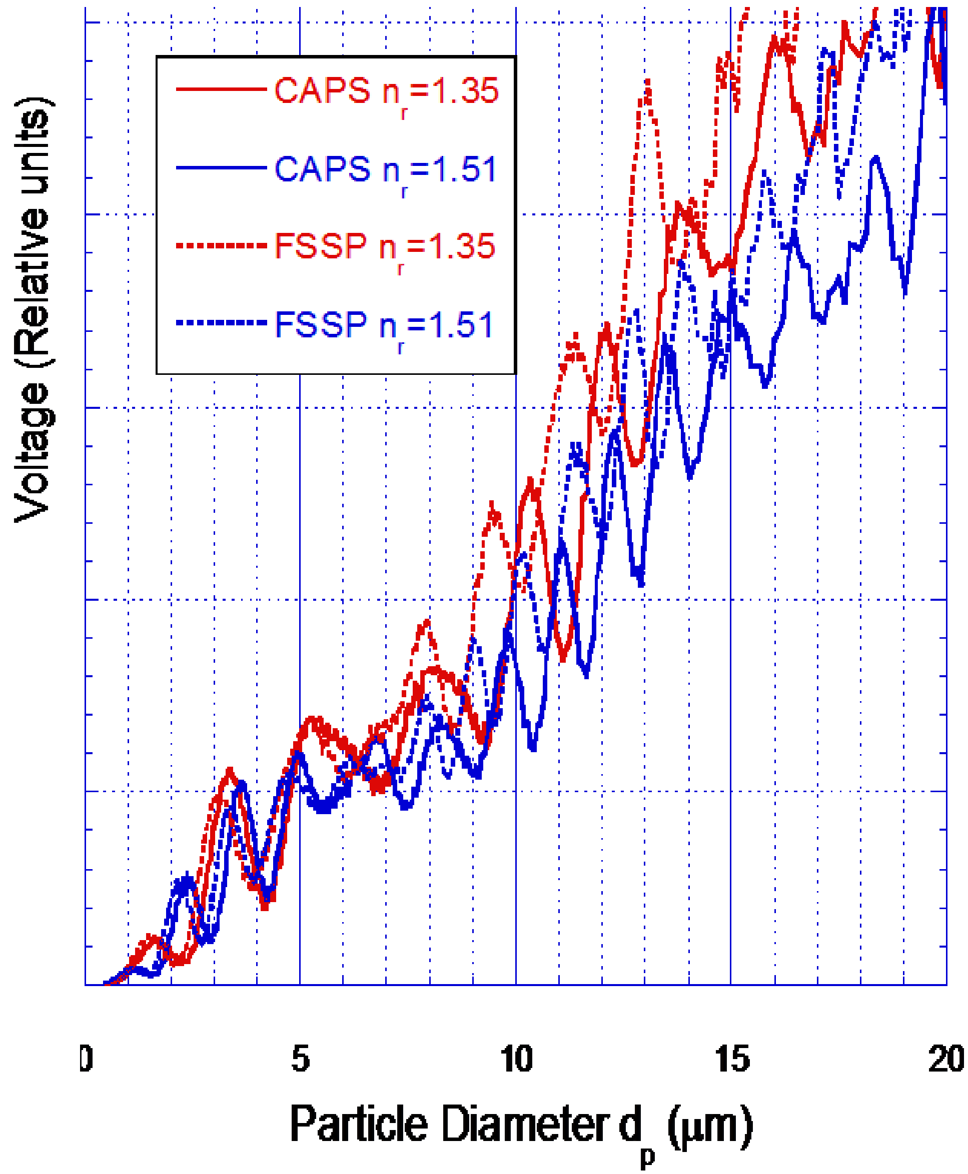
Channel/Gain Bias

Reporting/Curve Fit Bias

Inlet/Humidity Bias

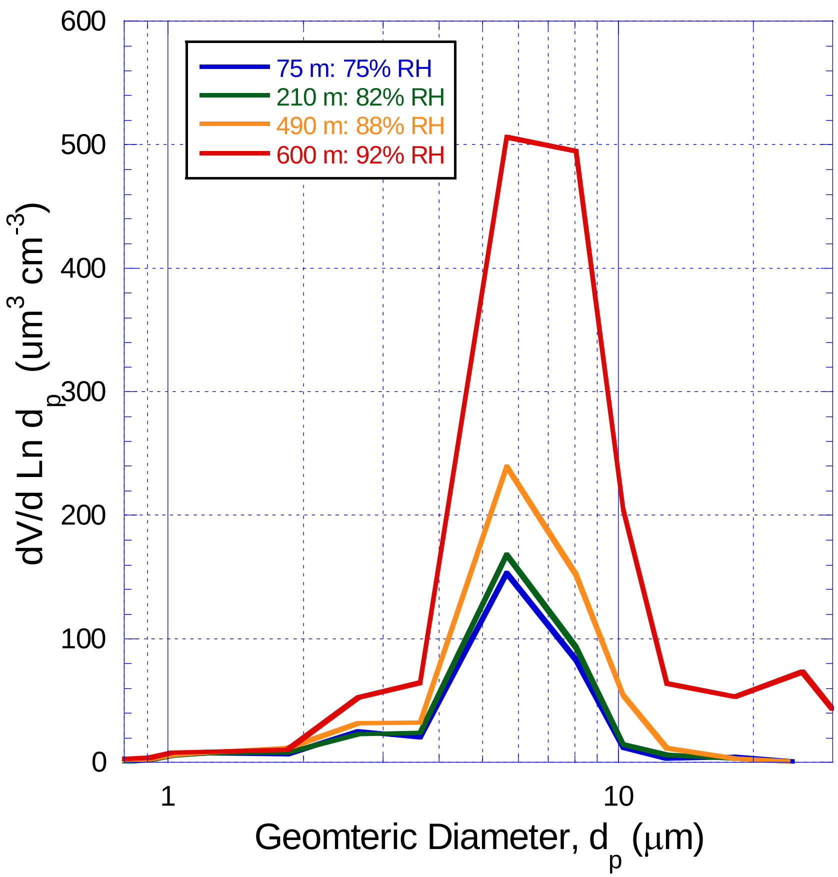
Sample Volume

Please show me how you can calibrate around this!

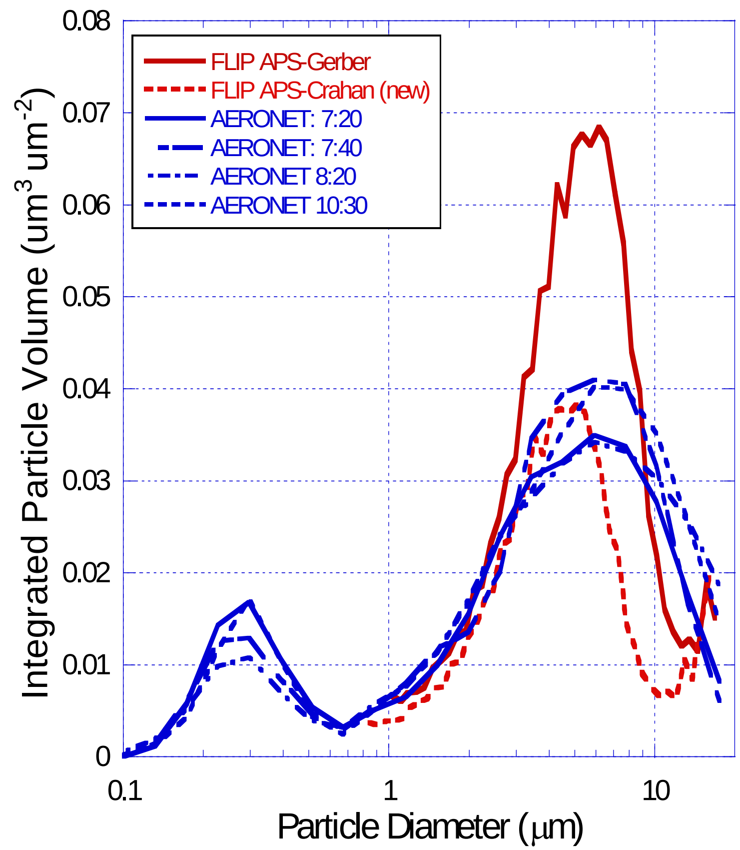


Marine Aerosol Measurement Implications:
Extinction/Column Closure Failures for Cleaner Background Environments

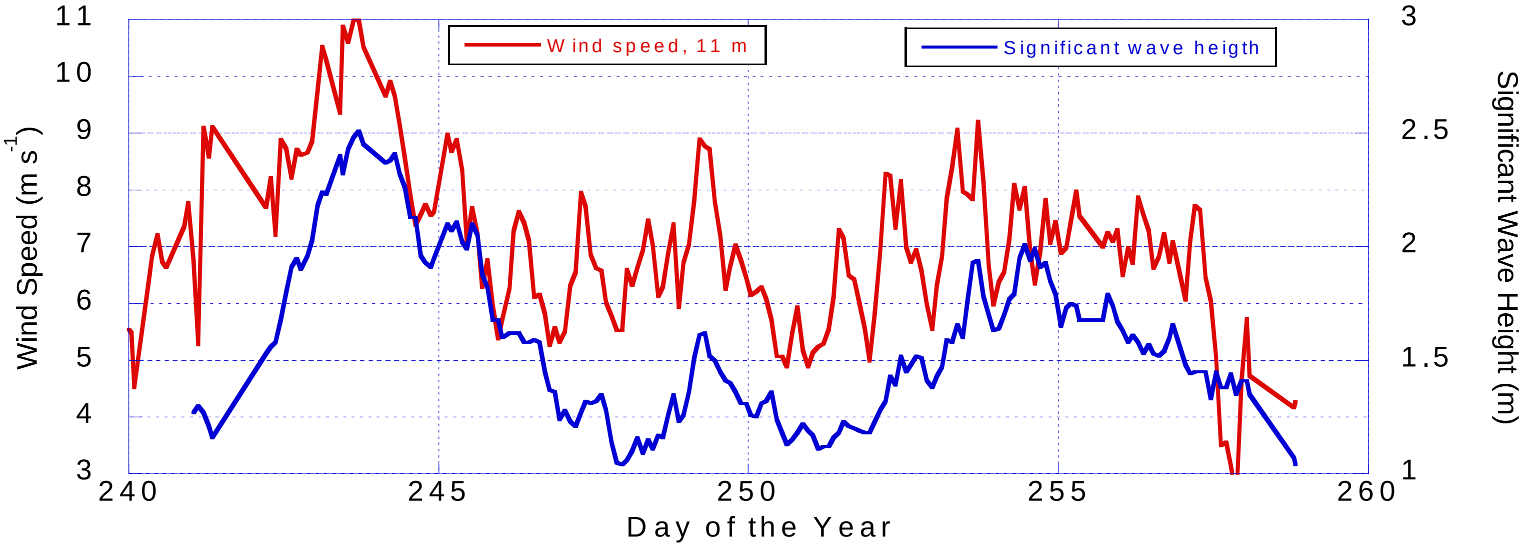
Vertical Profile/Column Closure Bias: FSSP: Instrument response to increasing humidity unphysical. We are getting an image of the response function back.

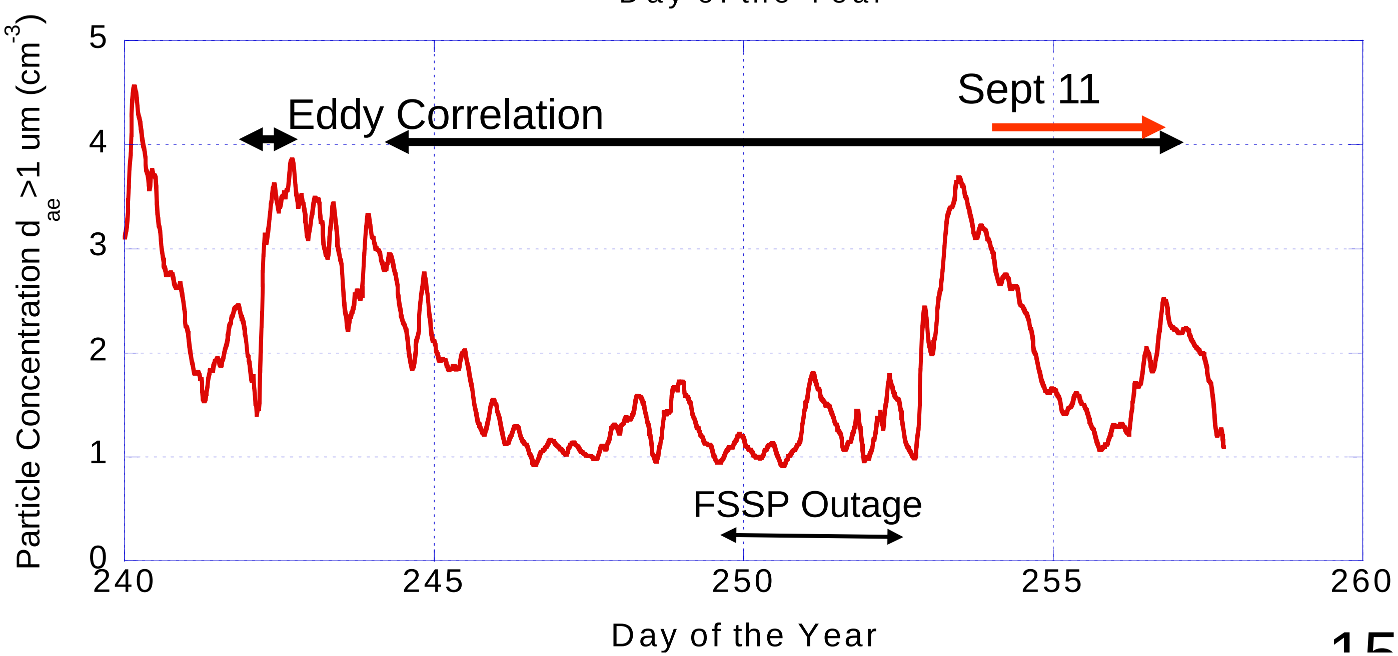


Hygroscopicity Bias: Organics need to be accounted for. Current algorithms (such as Gerber or Tang) overestimate hygroscopicity. Crahan's results from RED make more sense. Difference in AOT can be a factor of 2

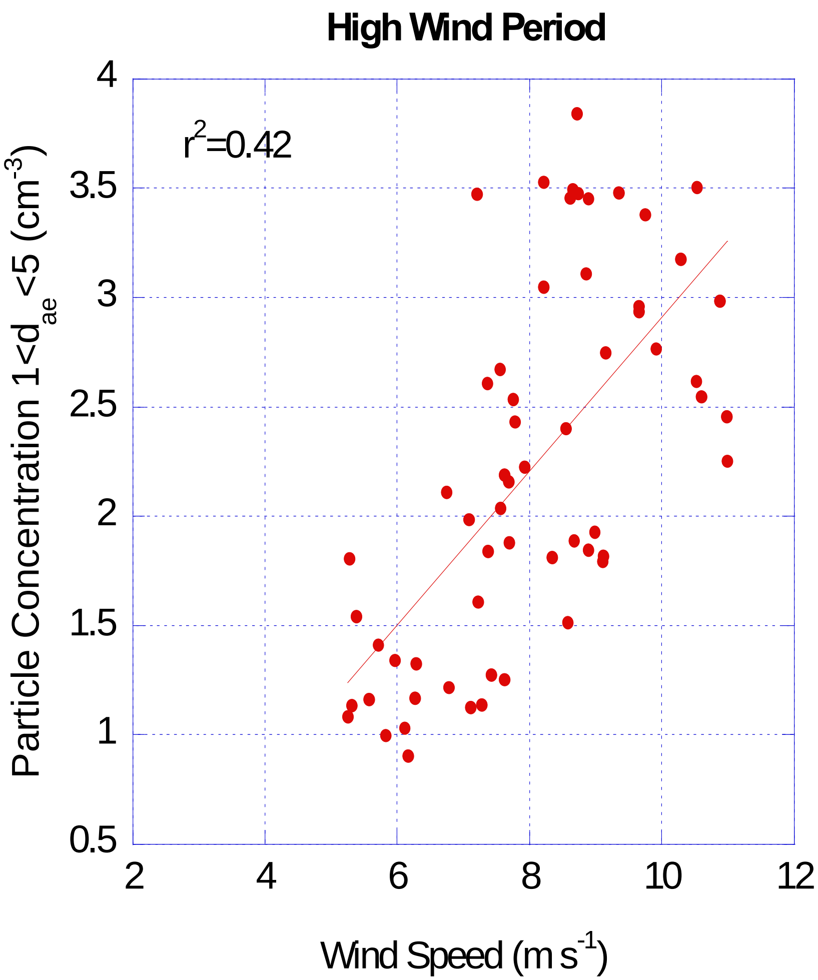


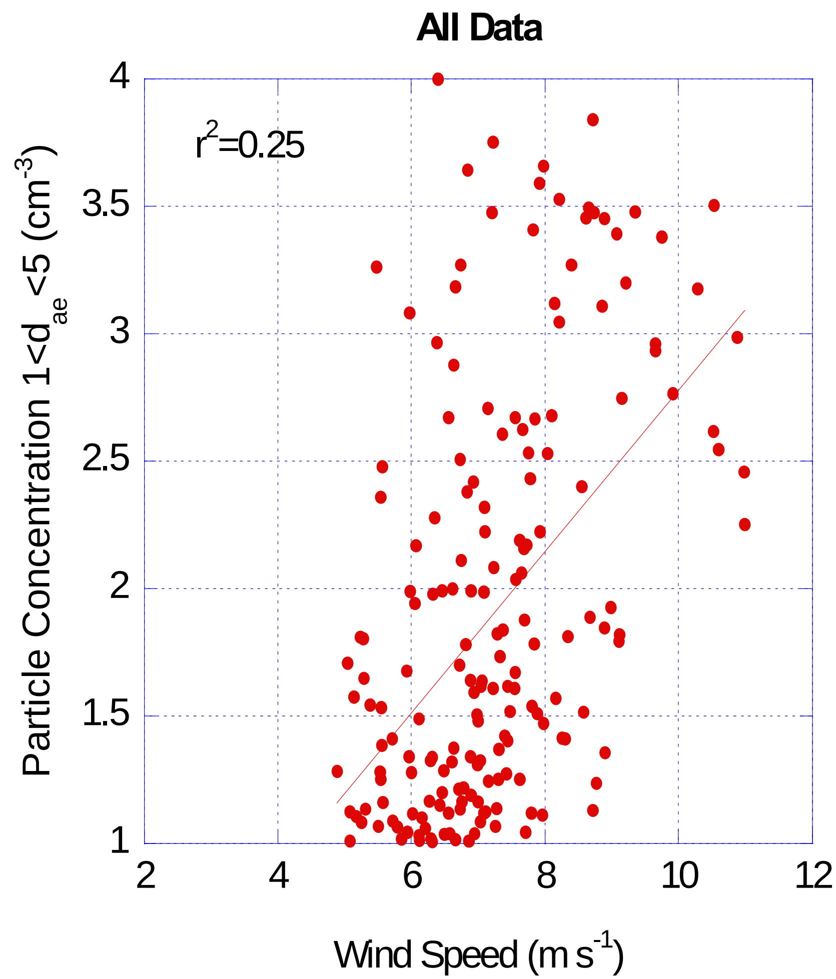
RED: Environmental Conditions



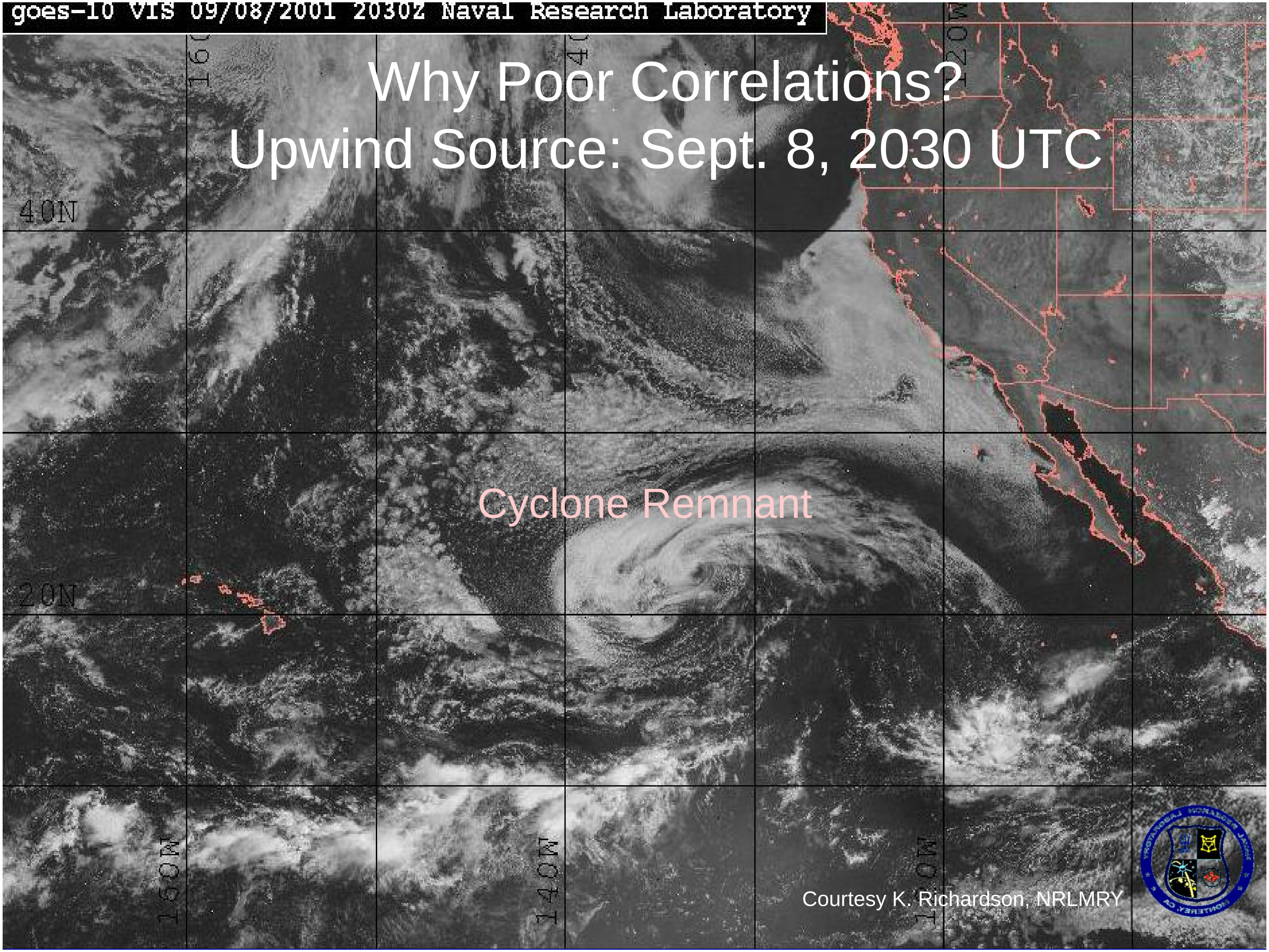


A Word on Wind- Sea Salt Regressions
High winds imply high particle concentrations. But low wind does not imply low concentrations



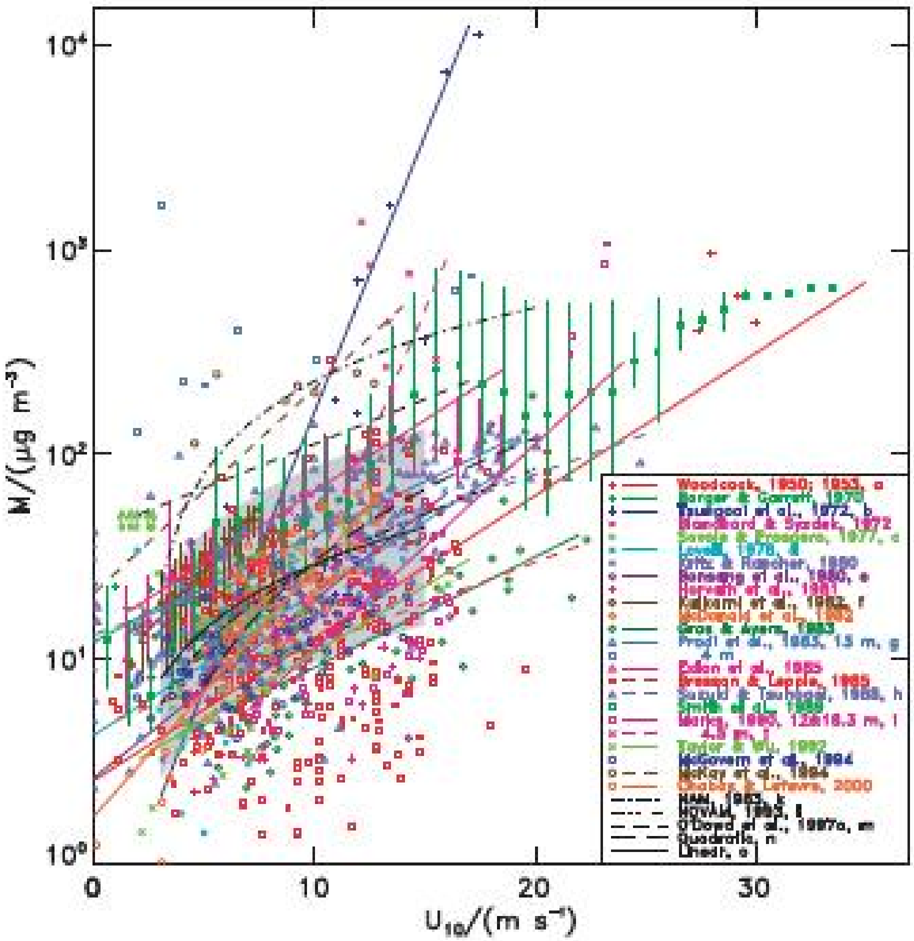


Why Poor Correlations?
Upwind Source: Sept. 8, 2030 UTC

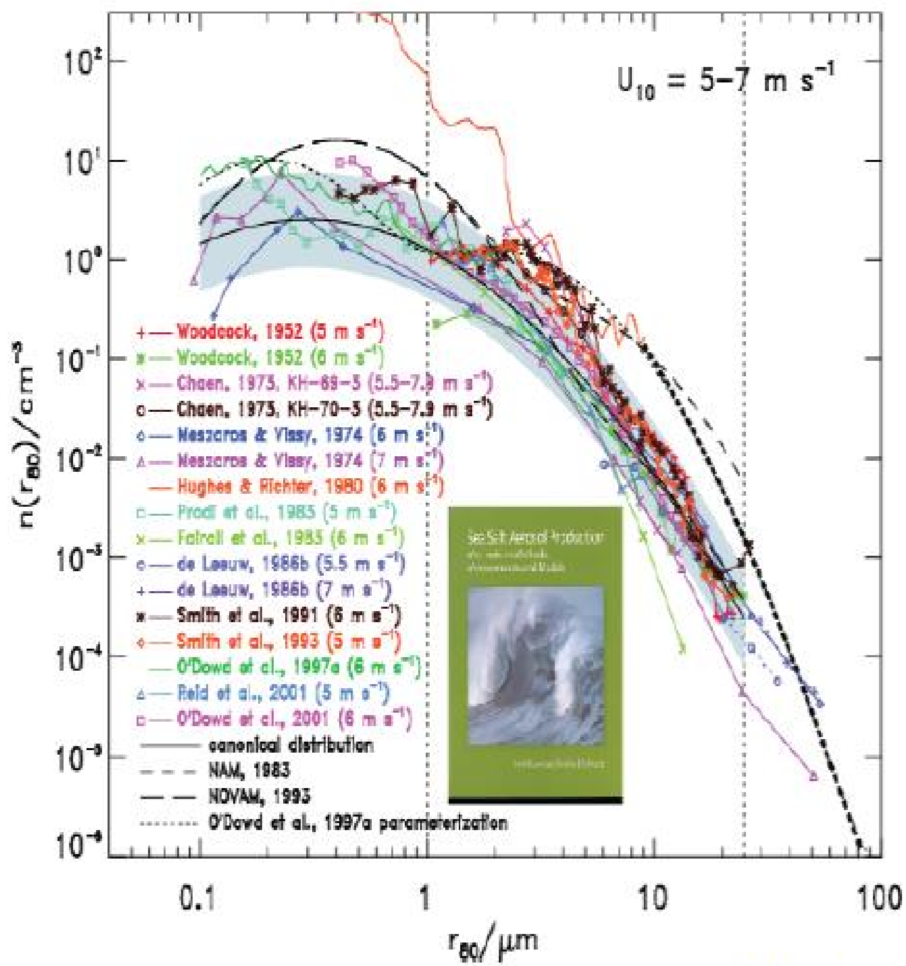


So how about source fluxes? Lewis and Schwartz Wind Regressions and Fluxes

Cm versus Wind



Fluxes



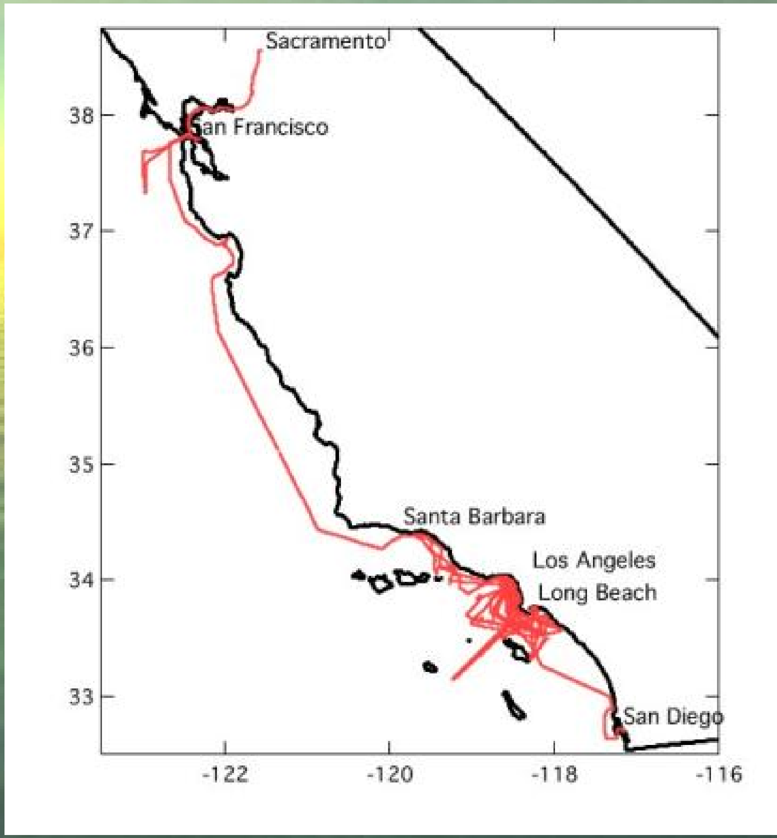
Example Methods

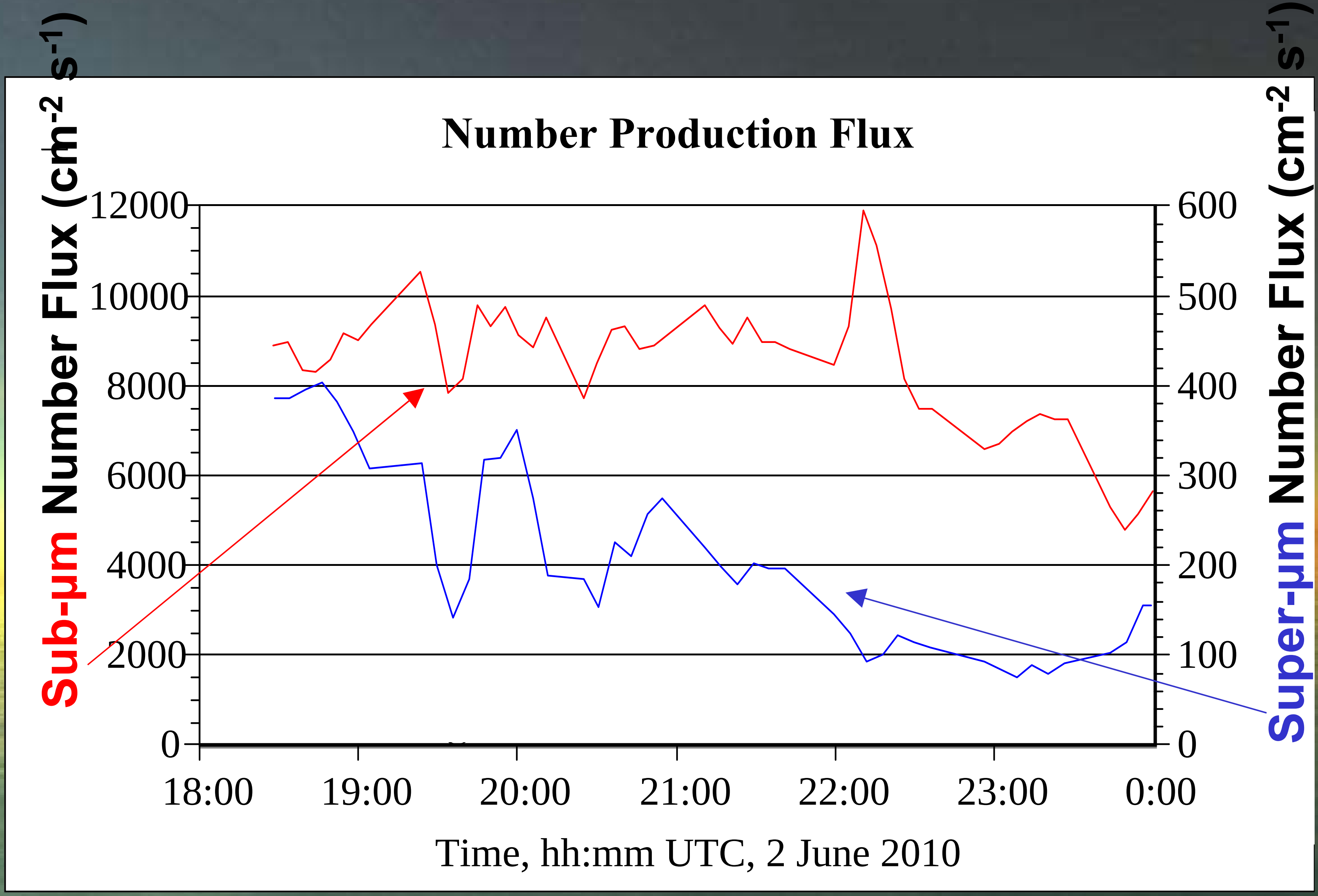
- Flavors of lab or field whitecap scaling
- Gradient
- Eddy correlation
- Box method
- Model tuning

Hypothesized Dependencies

- Stability/momentum flux
- Organic component/Chl a
- Wind-wave direction differences
- SST

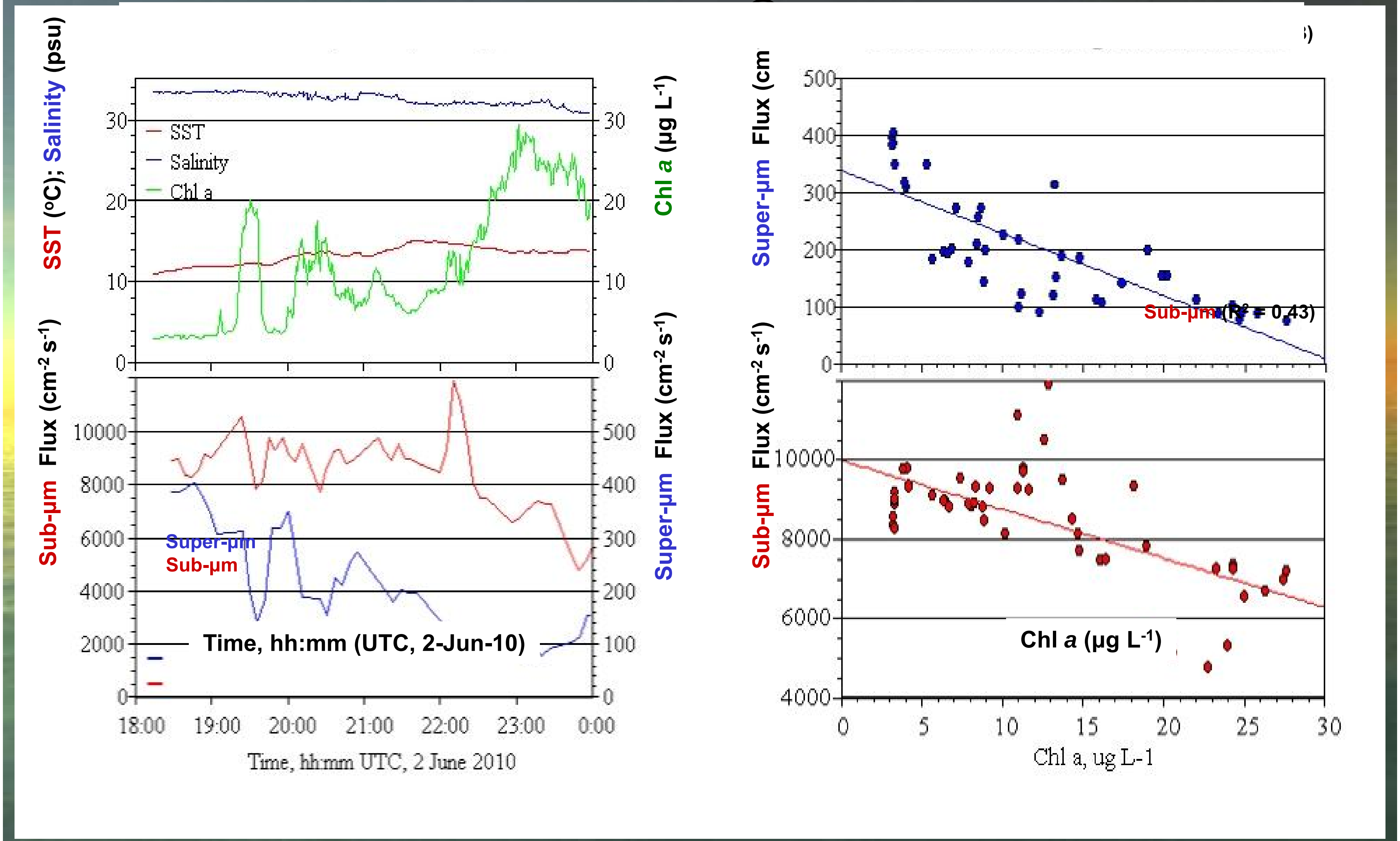
Bill Keene's Bubble Maker: Looking at how ocean properties influences production



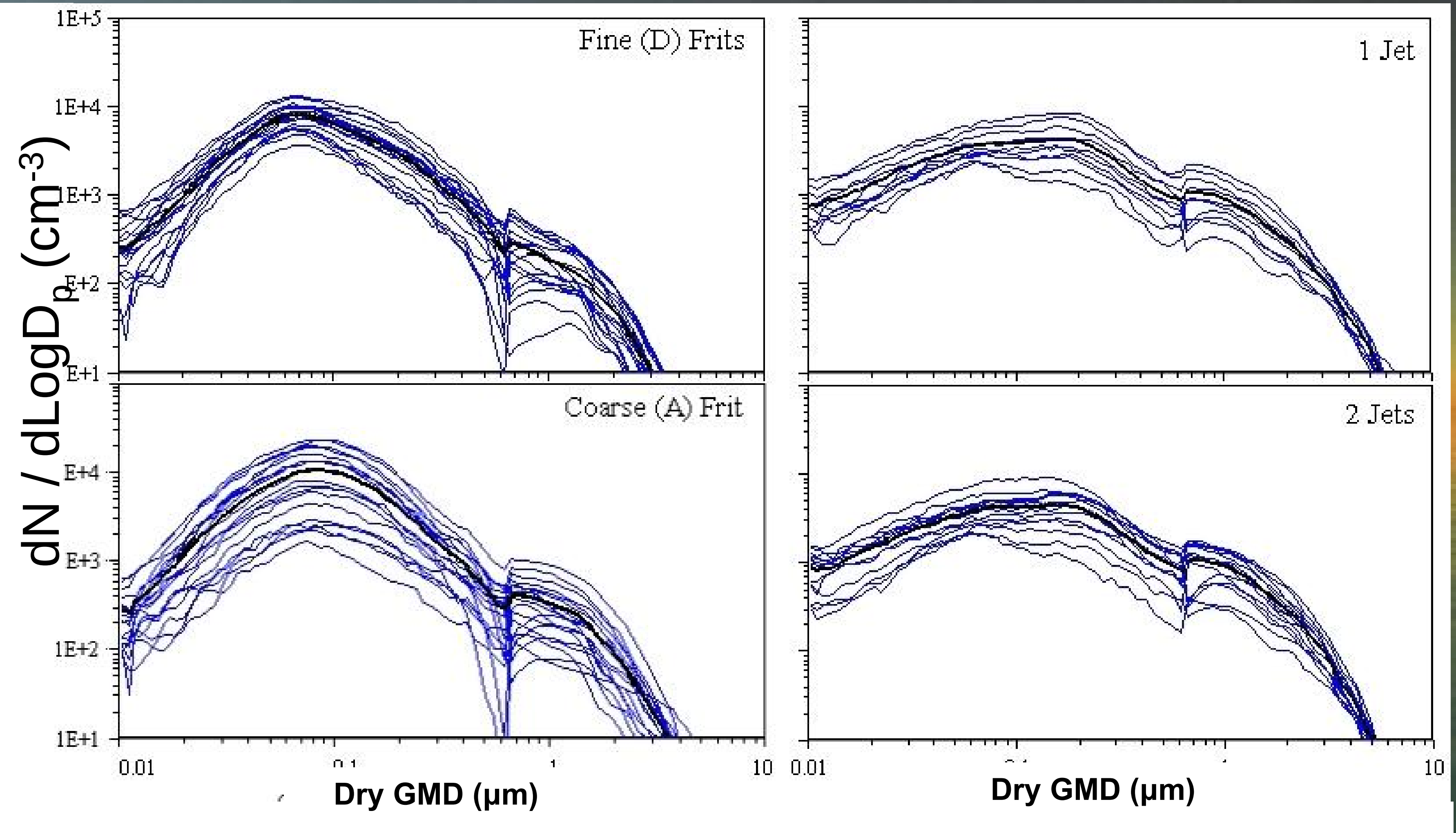


* Diameters at 80% RH.

Number Production Flux vs. Seawater Characteristics
Keene et al., 2010 AGU



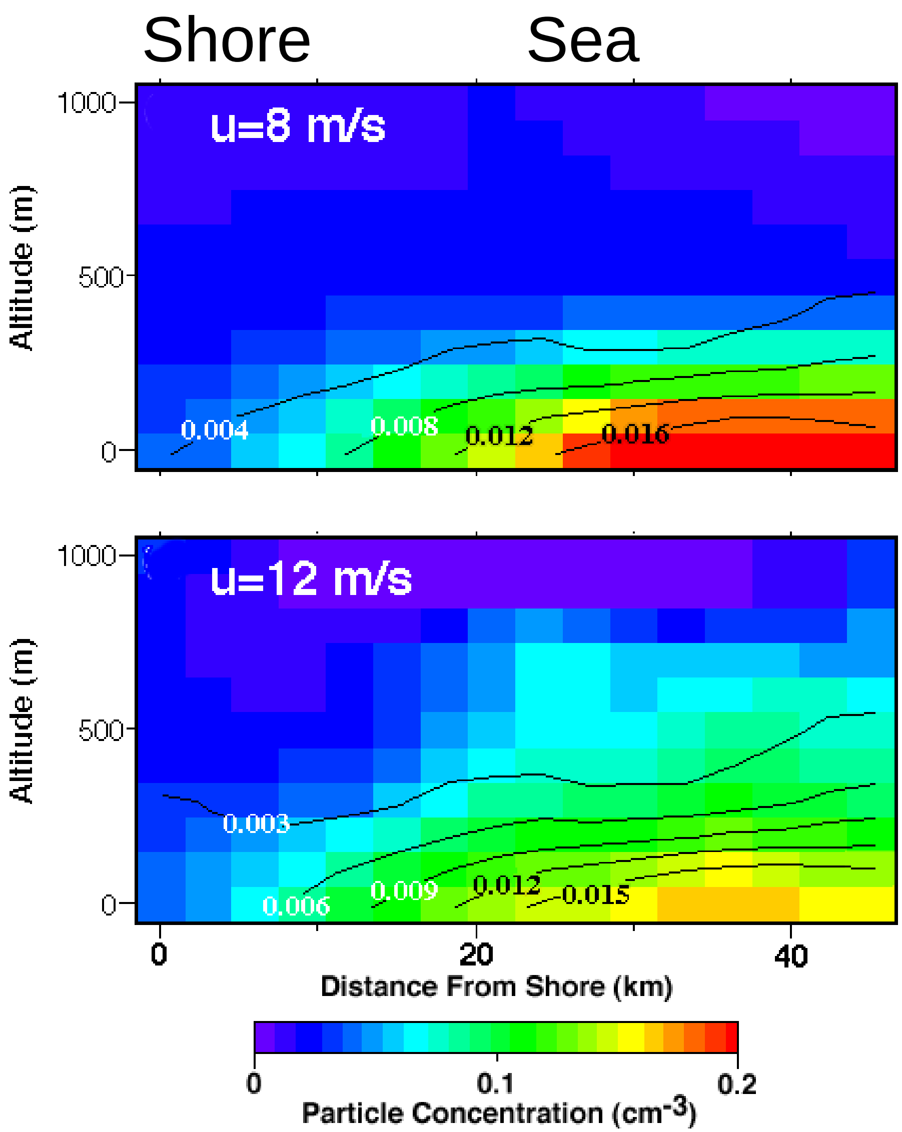
Number Size Distributions in Head Space
Do bubble dynamics converge to stabilize coarse mode size?

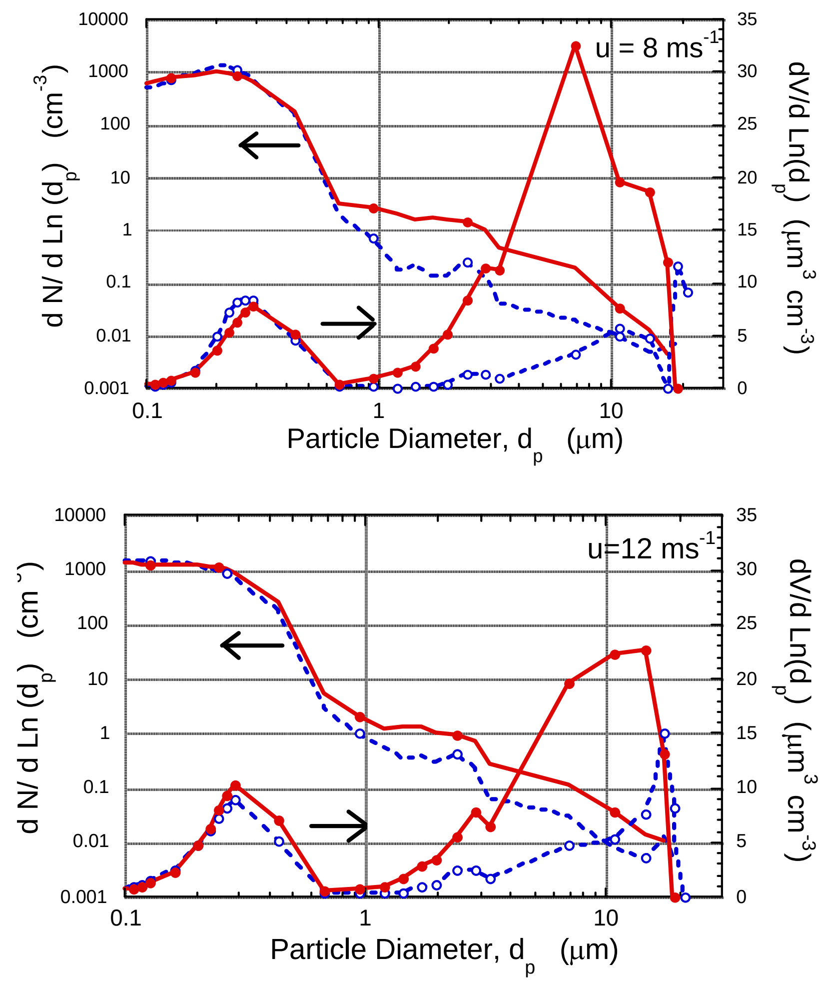


Dry Deposition

- Slinn: “This is an algorithm o be tested, not a parameterization to be used….”
- Need to distinguish between production and net flux.
- Dry deposition is as much as the source problem as the source.
- From a measurement point of view it is seldom considered.
- From a modeling point of view it equally defines MBL concentrations as the source.
- I still do not know what to think about Hoppels source function, but in modeling space his logic seems sound.

Measuring flux: EOPACE Duck is still the only actual measurement of source flux in the literature.

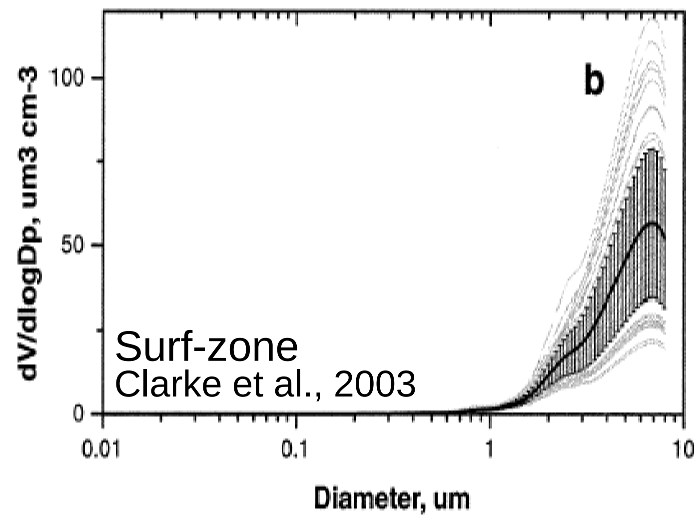




The Null Hypothesis. Regional variability

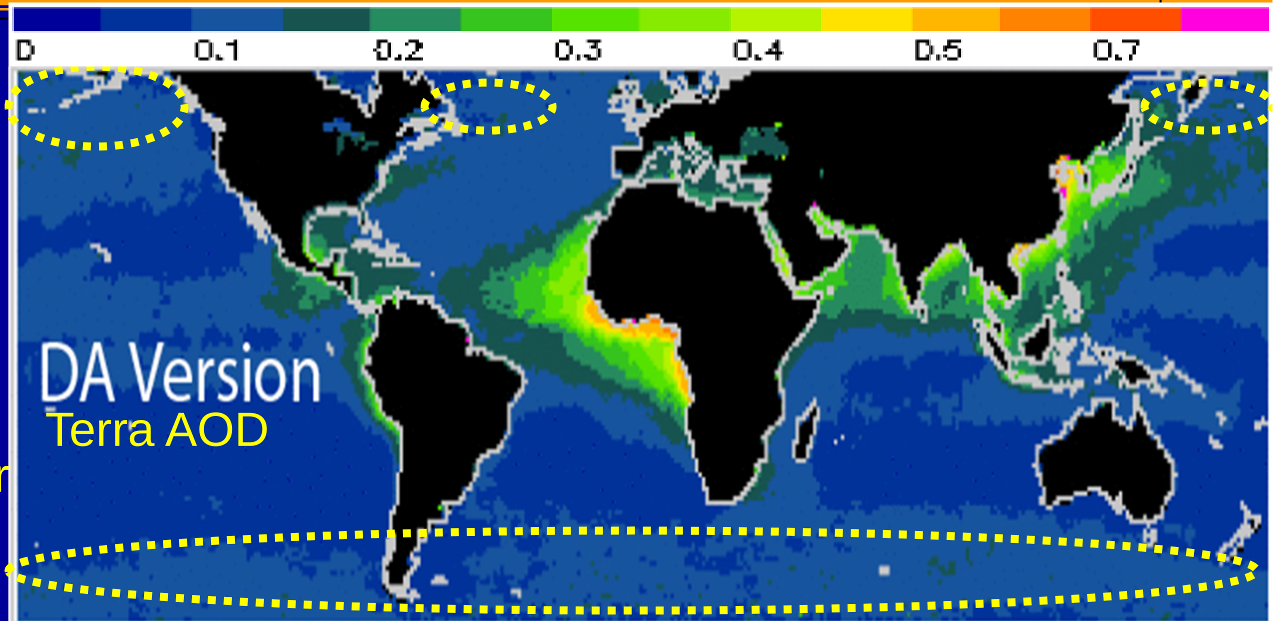
Do different parts of the world create different particles? Are surf zone particles like open ocean particles?

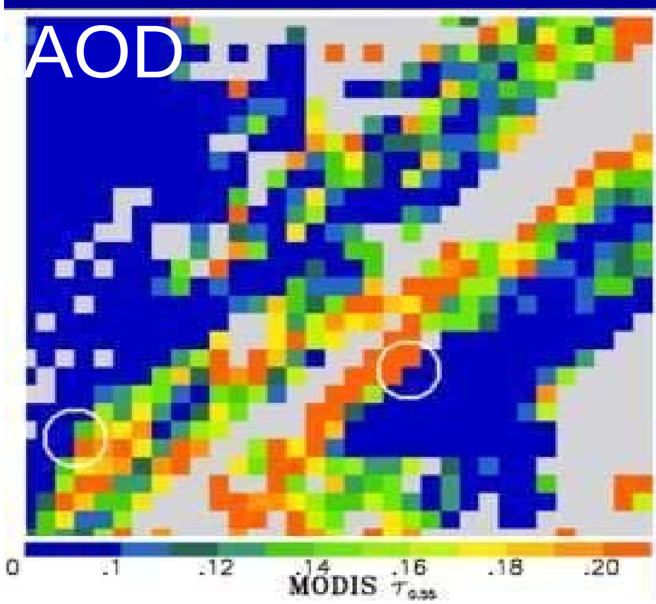
- Differences by "investigator" is consistent between regions of the world.
- Very few measurements at high wind speeds and variable ocean/wave conditions.
- There are physical reasons why open ocean and surf particle fluxes *could* be different.
- If they are different, then surf would probably be larger.
- Does relative comparability (order of magnitude) of recent fluxes imply everything comes out in the wash? Is this really something we can forward model?

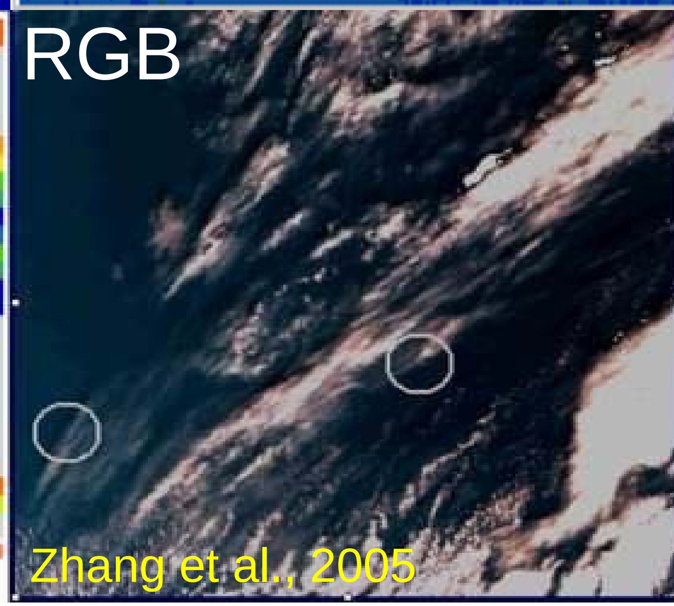


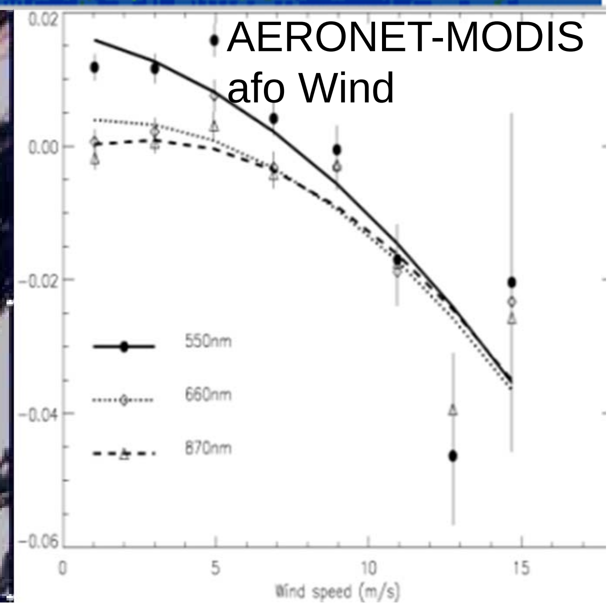
High AODs in the high mid-latitude oceans. Cloud and lower boundary condition biases are a big problem for data assimilation

- S. ocean aerosol anomaly: Fact or cloud bias?
- N. oceans have same problem, but often attributed to pollution.
- Cloud issues: Masks, 3d radiation effects, pixel sampling, and some reality.
- Model winds helps with lower boundary condition.
- Microphysics? Sampling?





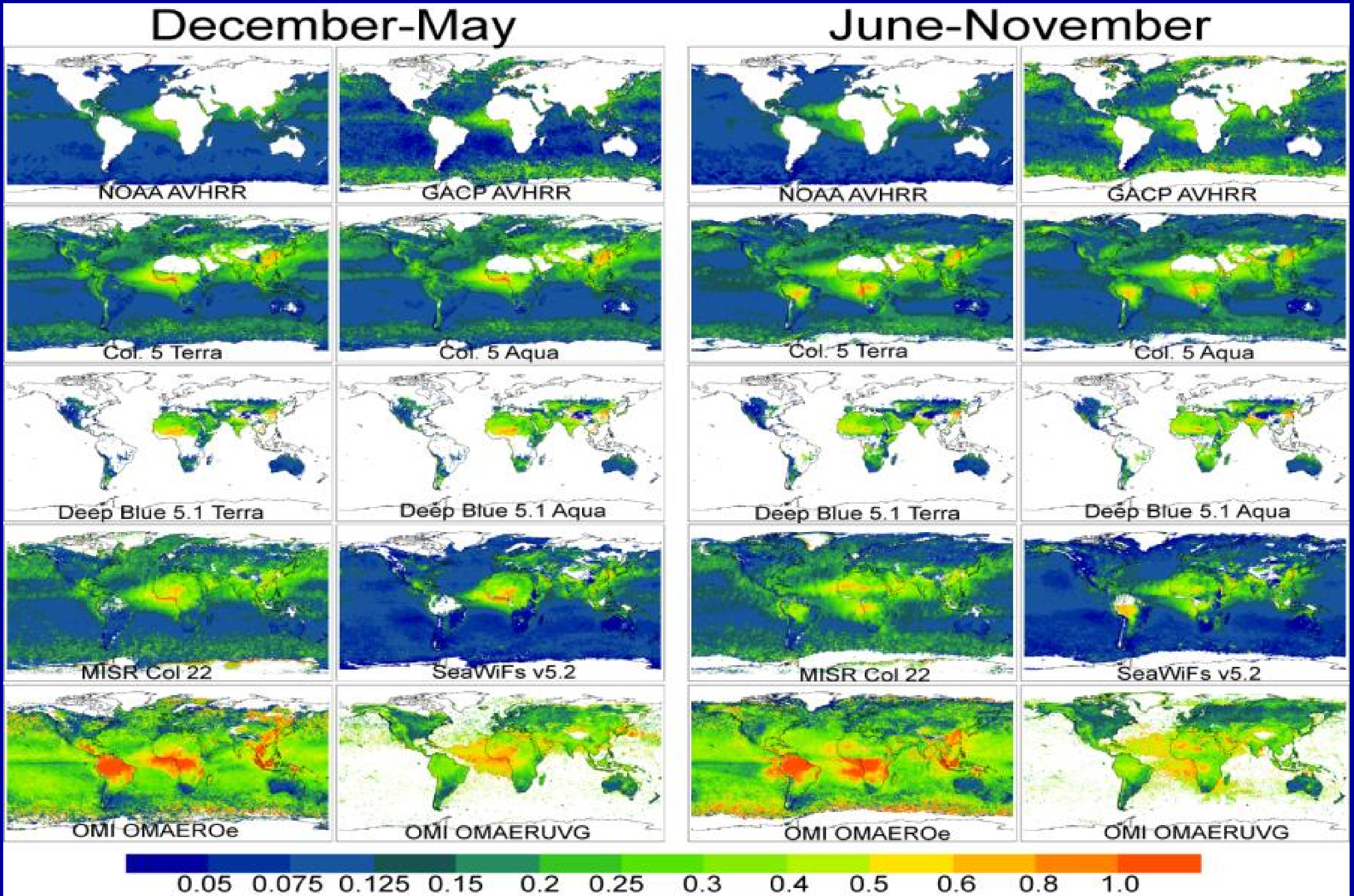




Marine AOD- A Satellite Perspective

Who's satellite obs do you trust?

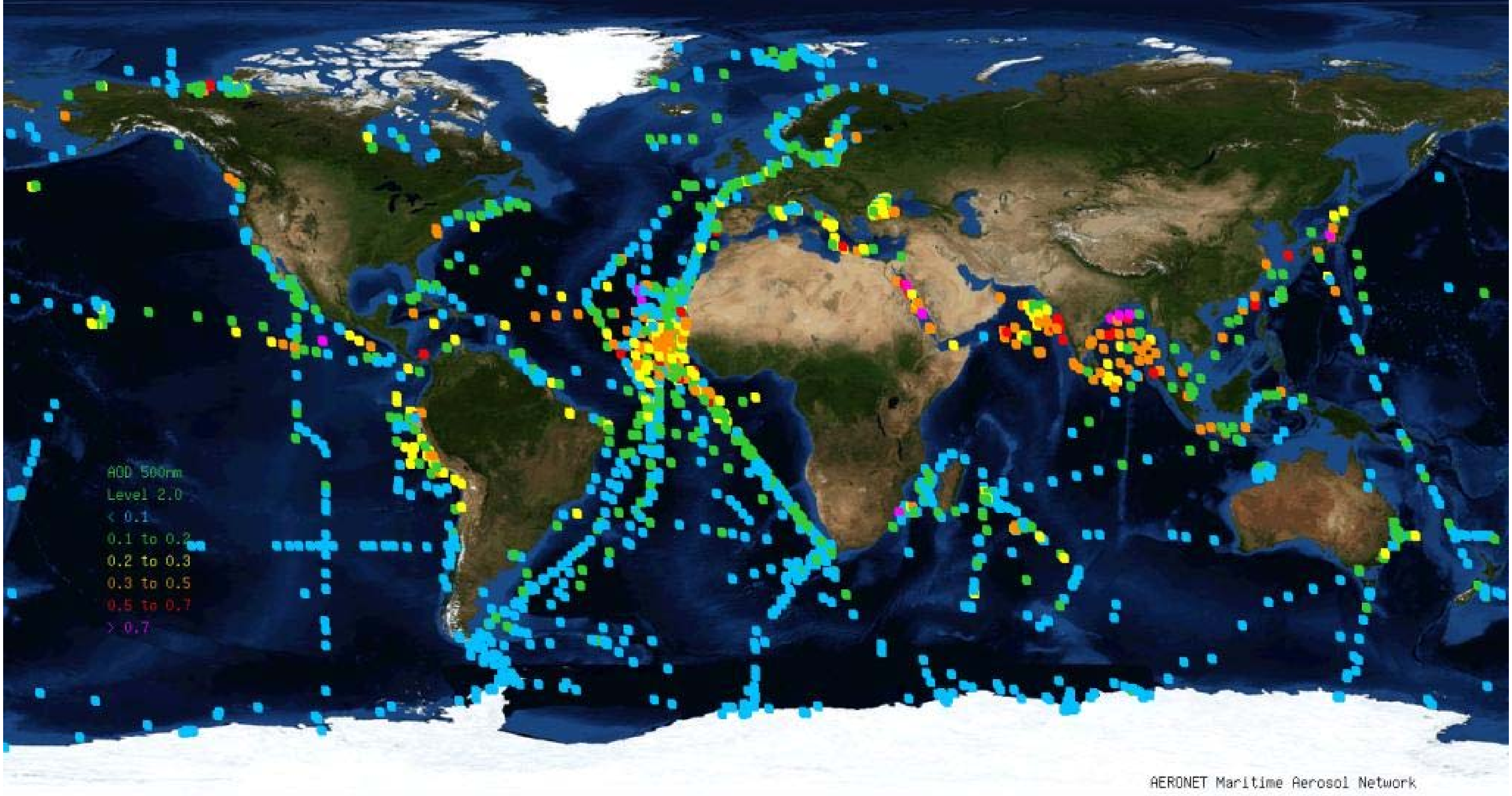
It is easy to say it is just cloud bias, but there is more to it than that.



2005 Aerosol Optical Depths

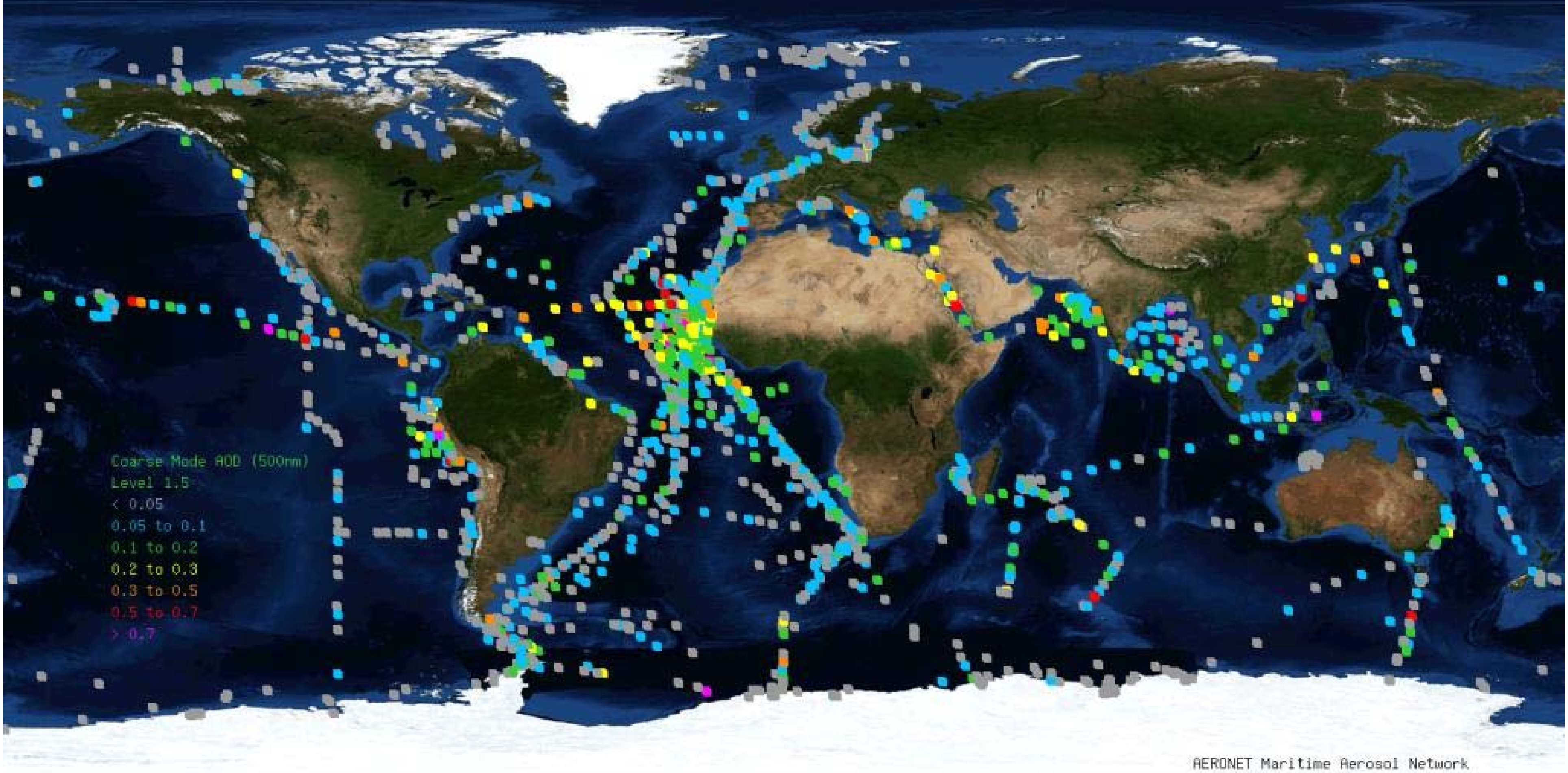
AVHRR (670 nm), MODIS Col 5, Deep Blue SeaWiFs (550 nm), OMI (500 nm)

Maritime Aerosol Network global coverage (as of September 2011)



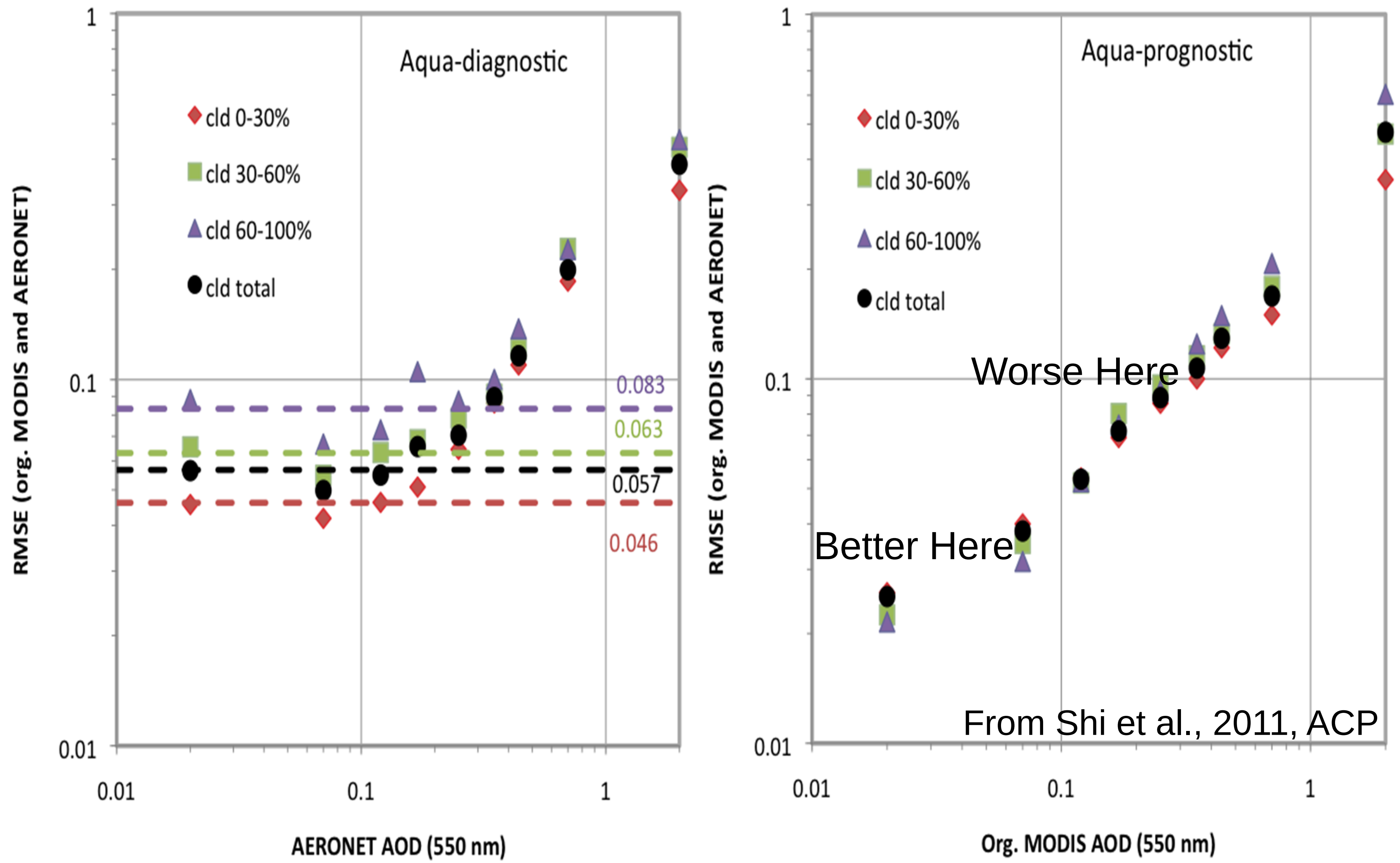
Cruise tracks and daily averages of aerosol optical depth at 500 nm (squares are colored with respect to AOD values, i.e. blue – AOD<0.10, green – 0.1≤AOD<0.2, yellow – 0.2≤AOD<0.3, orange – 0.3≤AOD<0.5, red – 0.5≤AOD<0.7, purple – AOD≥0.7).

Coarse mode AOD

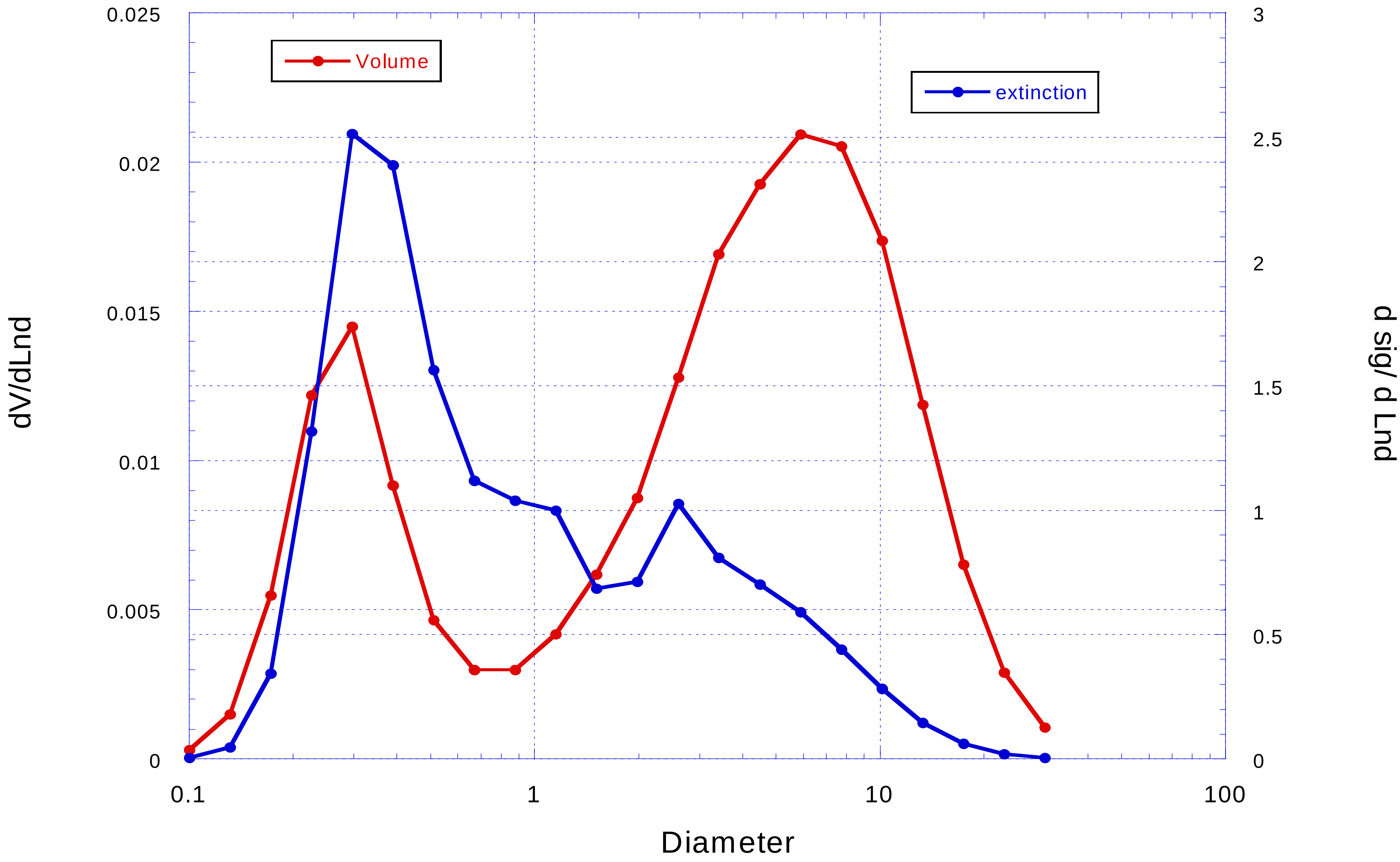


Cruise tracks and daily averages of coarse mode aerosol optical depth at 500 nm (squares are colored with respect to coarse AOD values, i.e. grey – AOD<0.05, blue – 0.05<AOD<0.10, green – 0.1≤AOD<0.2, yellow – 0.2≤AOD<0.3, orange – 0.3≤AOD<0.5, red – 0.5≤AOD<0.7, purple – AOD≥0.7).

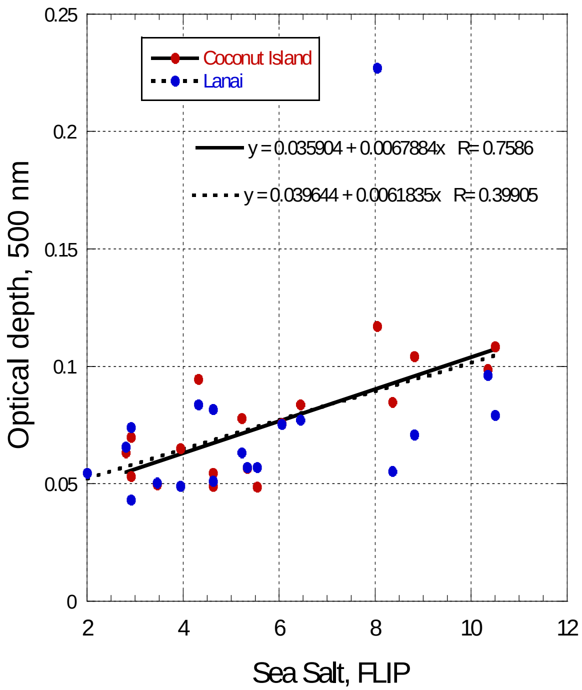
Over most of the ocean, the AOD is at the satellite retrieval noise floor.

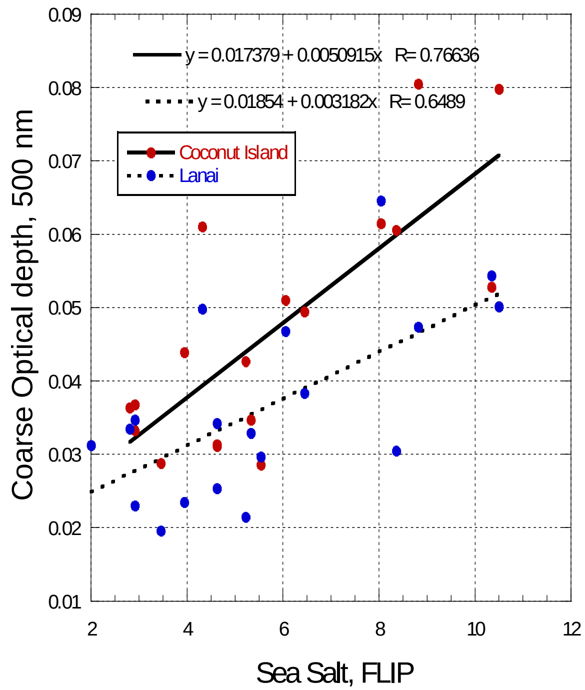


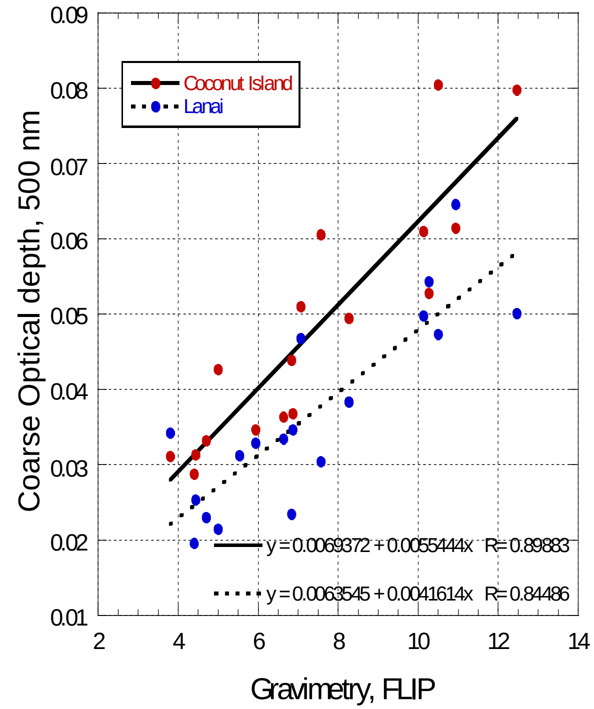
Relating Mass to Extinction: Odds are in favor of the fine mode than the coase mode.



But there are good relationships between AOD and mass for simple MBL conditions. But, you have to actually measure mass.



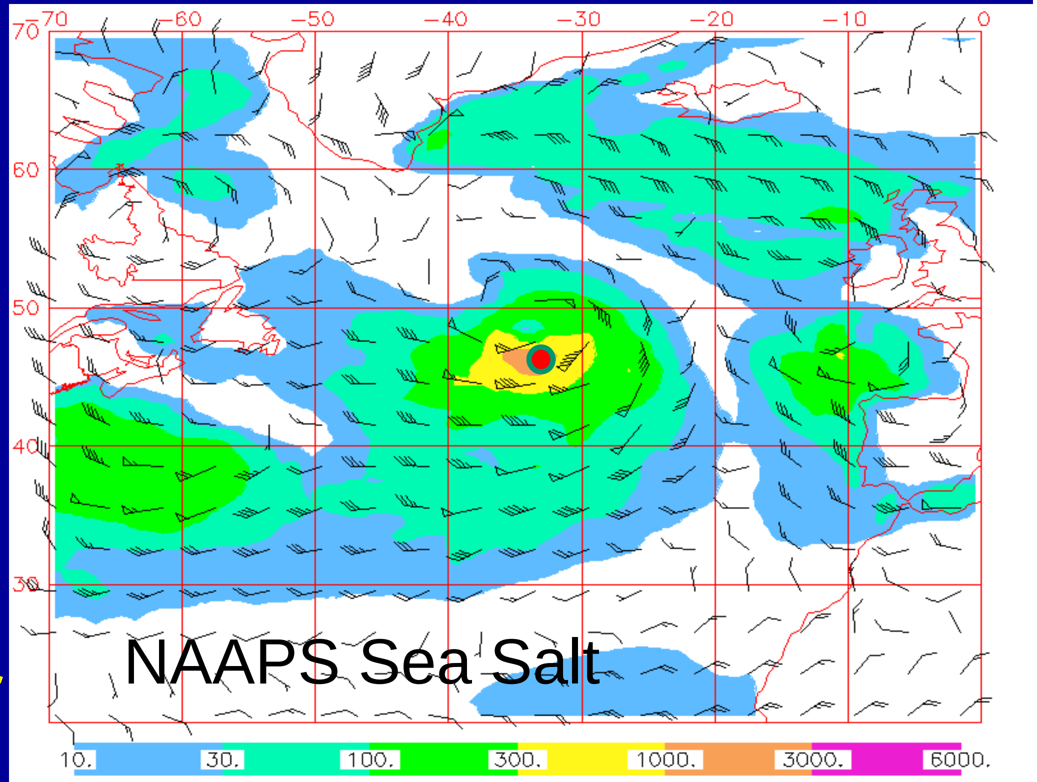




Lets look at more extreme events!
This is your lower boundary condition.

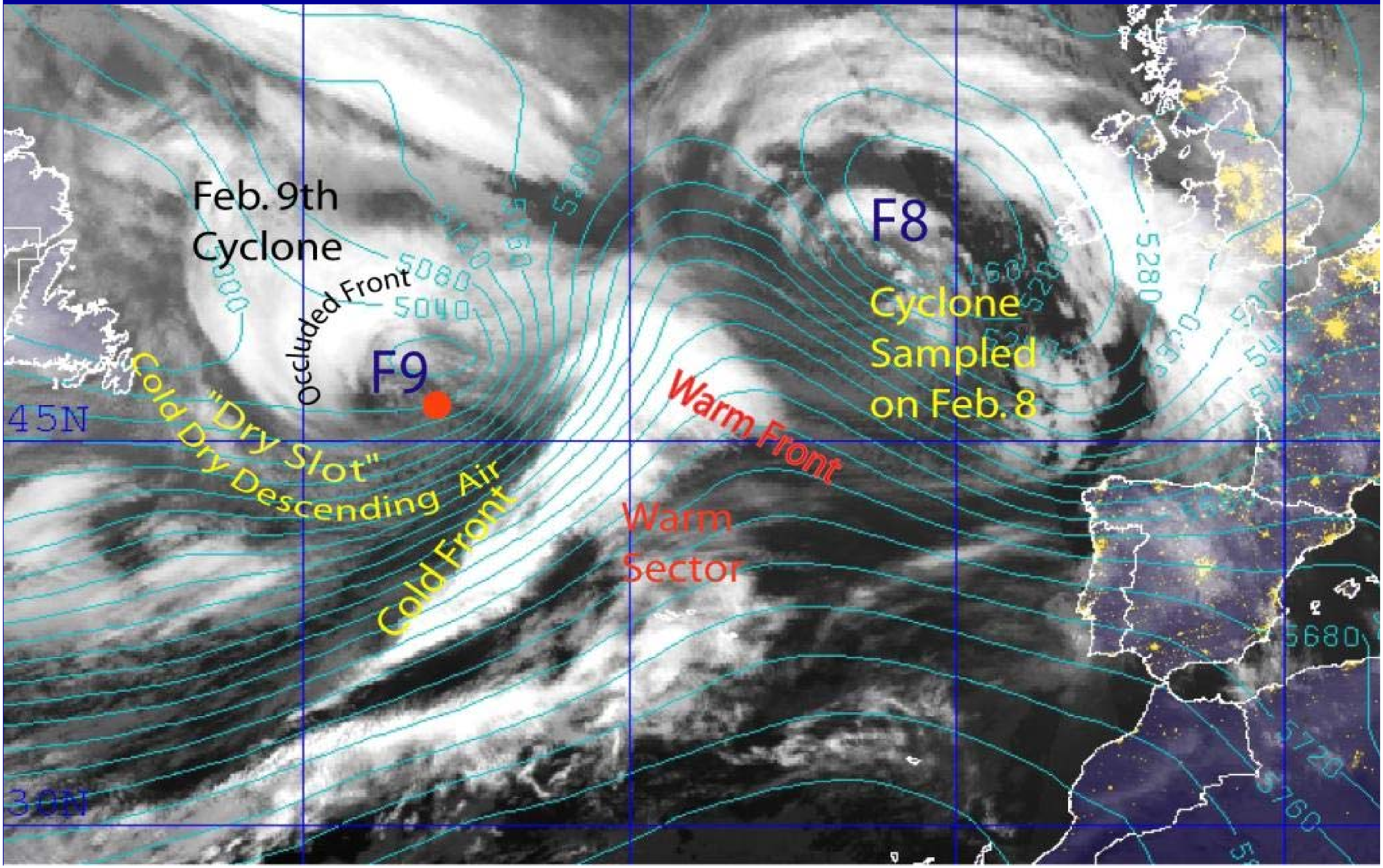
Close with a fun case: Known Facts of NOAA WP-3D aircraft N42RF February 9th Event

- Power loss power to three of four engines over the northern Atlantic Ocean at ~800 m altitude in a powerful extra-tropical cyclone.
- These failures left insufficient power for sustained flight and crew prepared to perform an in-water emergency landing.
- After passing though a minor one-minute long rain band, pilots were able to restart the engines and return home safely.
- Preliminary investigation suggested that sea salt aerosol particles generated in the high winds and seas coated the aircraft, leading to severe engine fouling and ultimately compressor stalls.

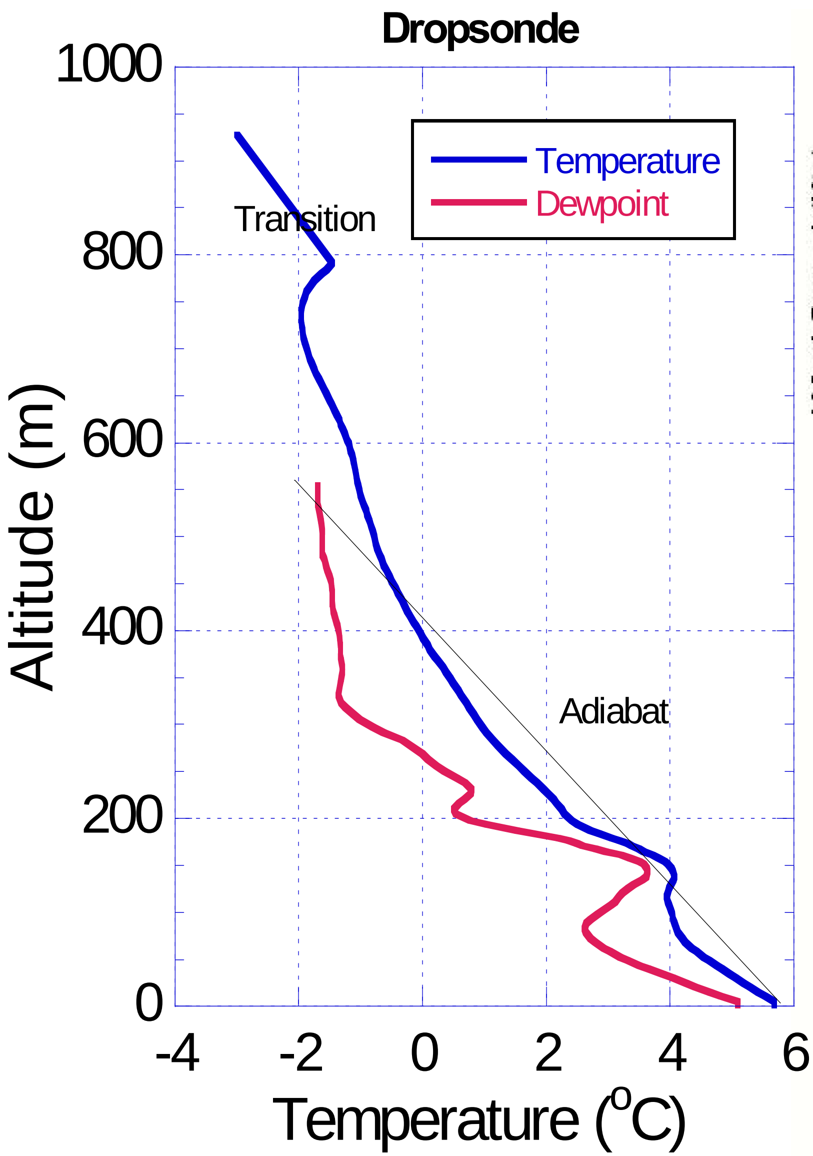


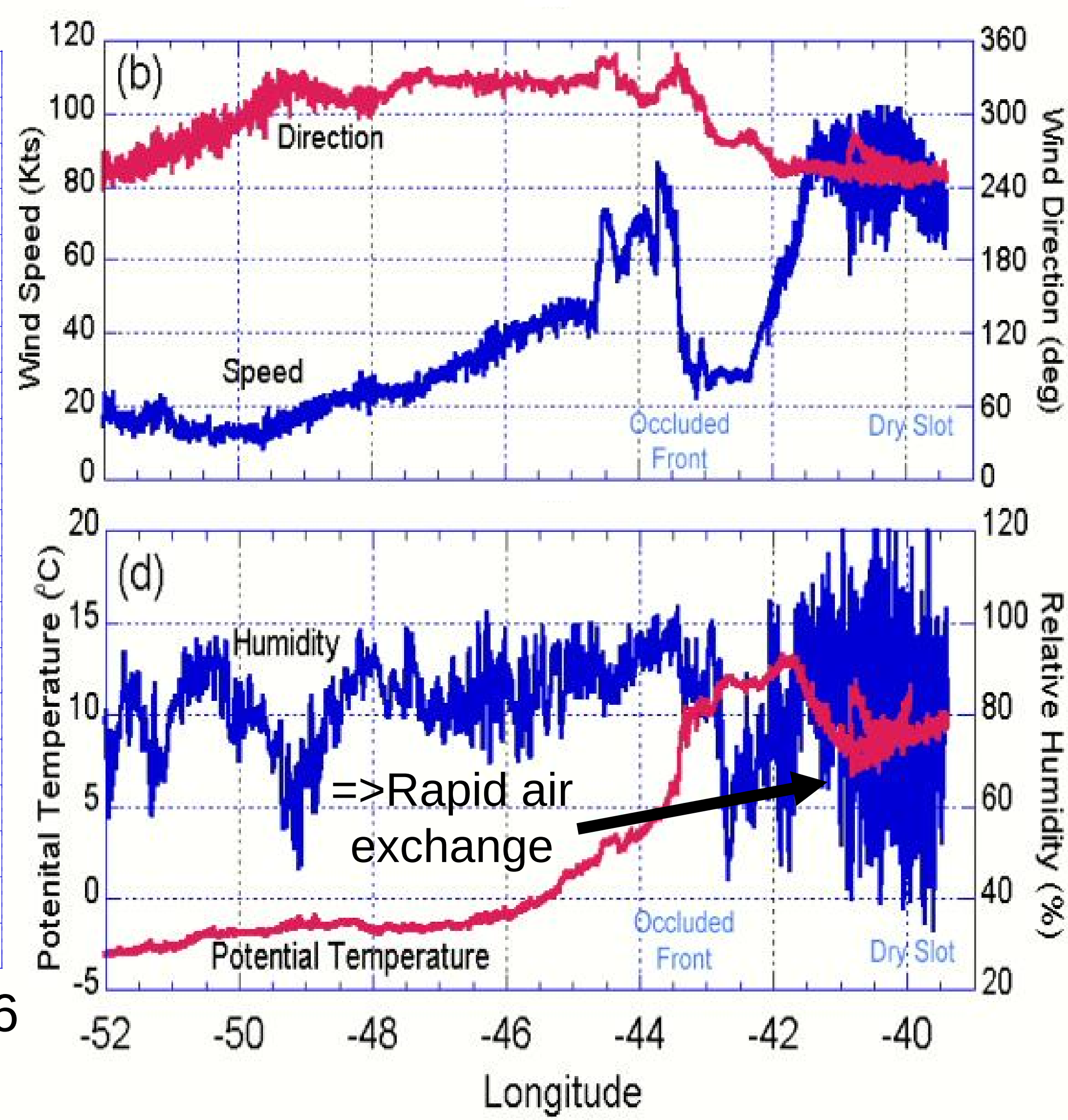
Salt on a P3 after flying into a North Atlantic bomb…

NOGAPS/ IR Image
A classic extra tropical bonb

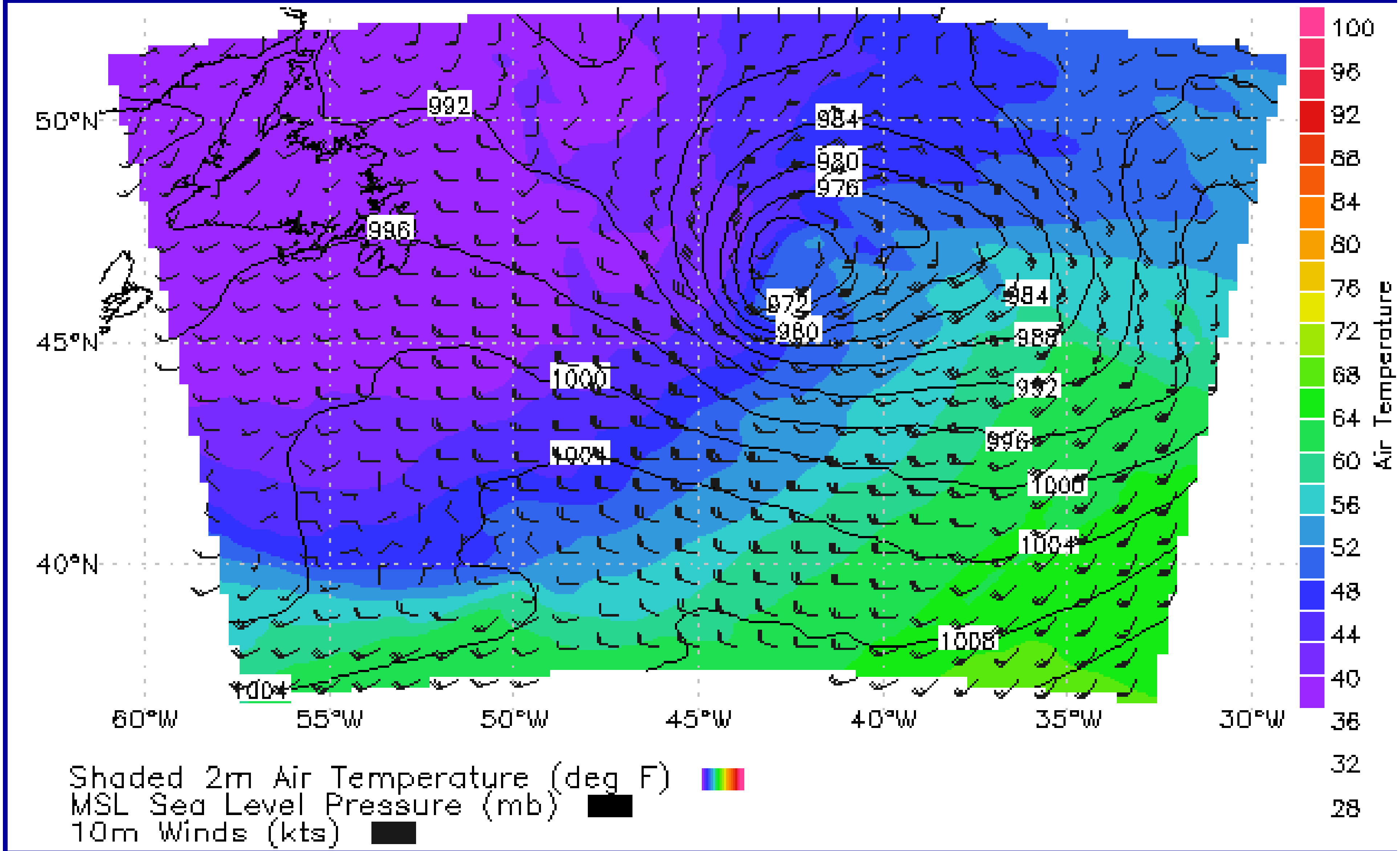


Aircraft Obs in the Dry Slot

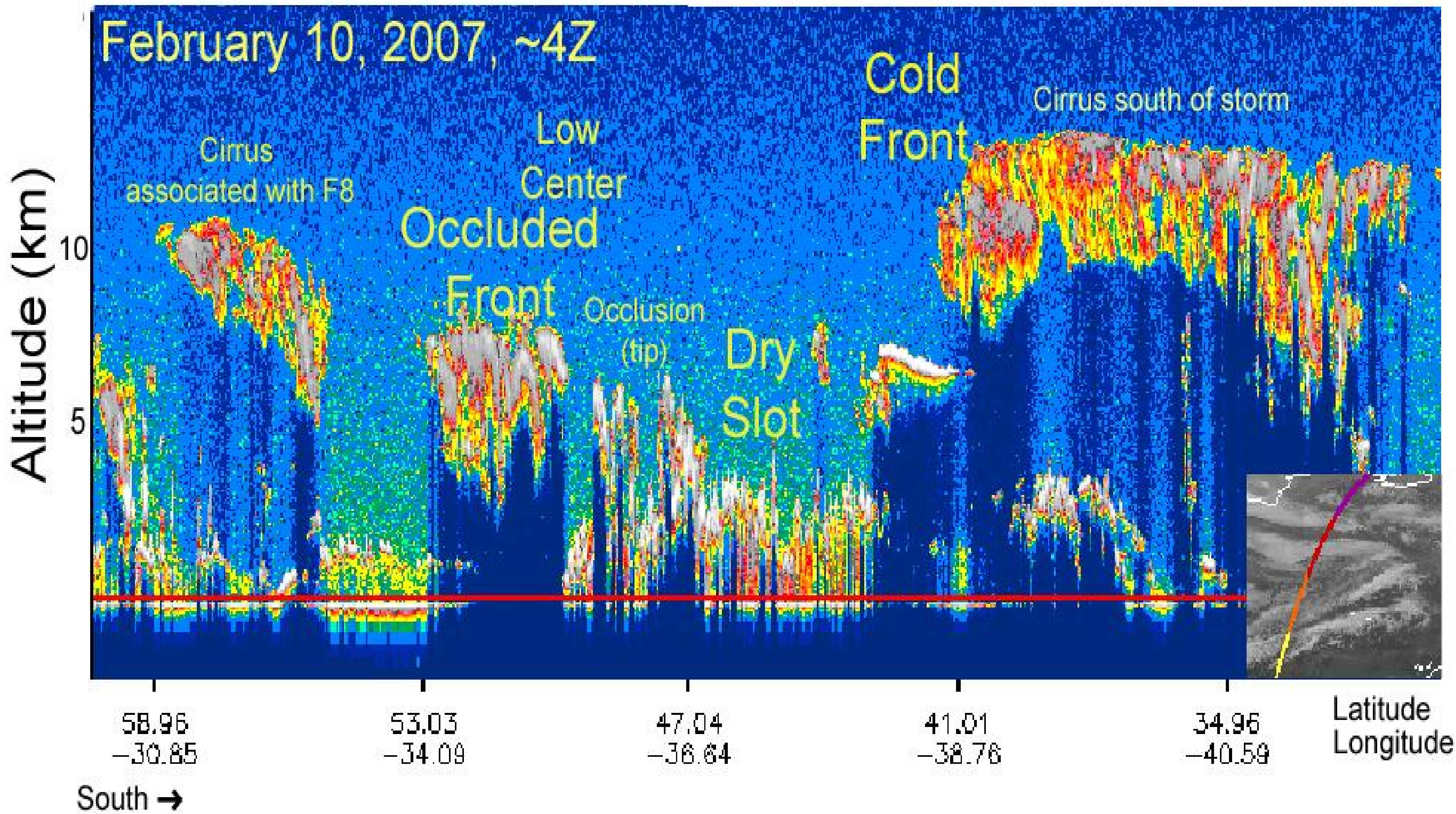




Cold air over the gulf stream enhanced mixing further



A Two Dimensional View: CALIPSO
Maximum salt altitude 1.5-2 km



Summary and Closing Thoughts

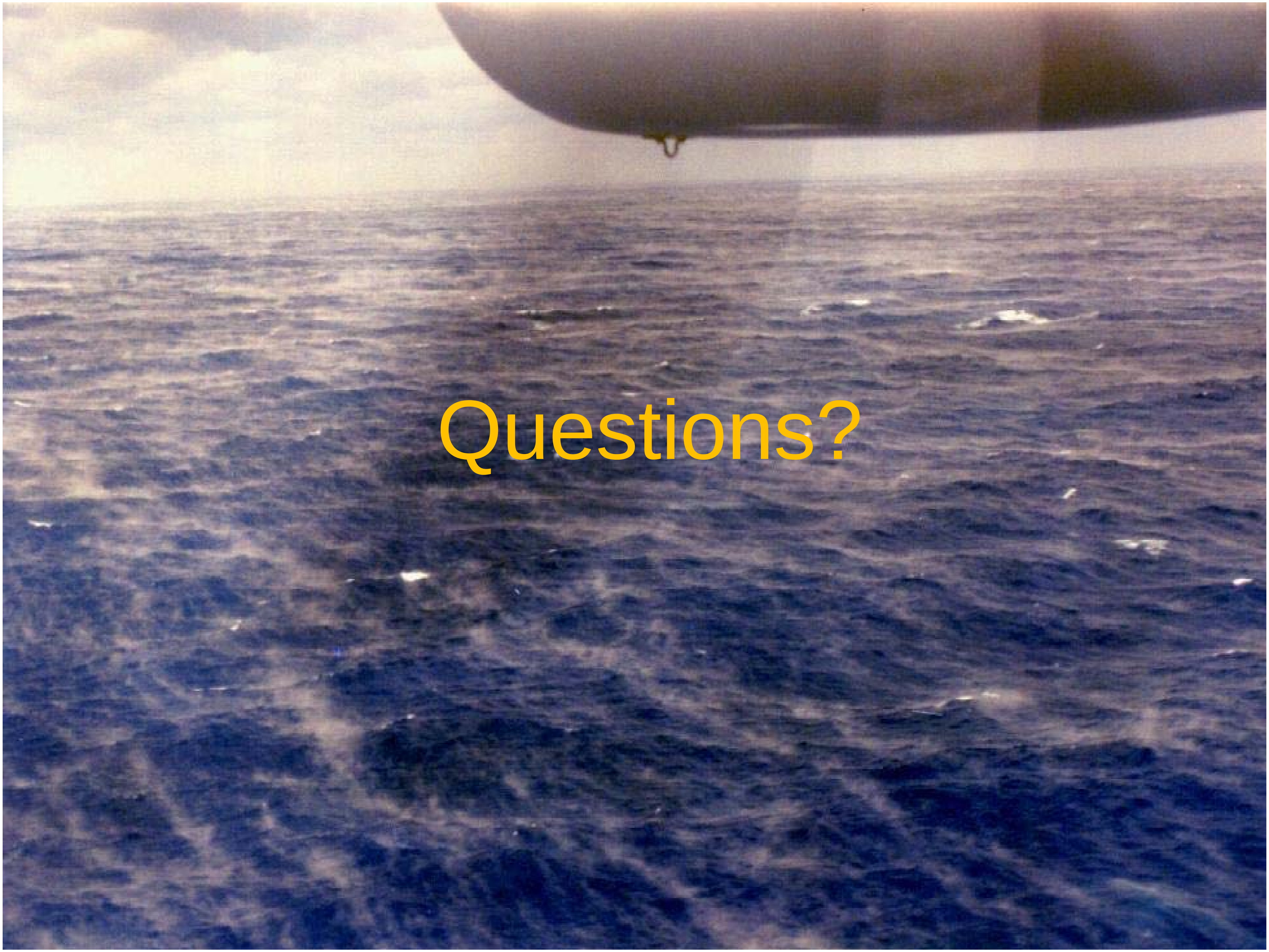
•Despite being one of the oldest fields of aerosol research, uncertainties on many basic sea salt parameters and hence models remains high.

•Verification statistics are driven in extreme event where measurement is difficult, and even common definitions break down. In many cases, they may not even be relevant.

•Based on field data, we have found that most of these uncertainties can be traced back to specific systematic errors in particle sizing and thermodynamics. The question is how much legacy data is correctable? Can this lead to something that can improve prediction?

•Remote sensing is a powerful tool (see Travis Toth's Poster Friday), but errors are equally large and tend to be positive definite (LBC, Clouds, Microphysics). Lots of good work has been done studying the effects, but the native product may not be appropriate.

•But there is hope! Modeling capability and new observations are making headway.


Questions?