Evaluation of Measurements of Coarse Mode Aerosol Particle and Cloud Droplet Size Spectra from Aircraft: Setting Fundamental Uncertainties

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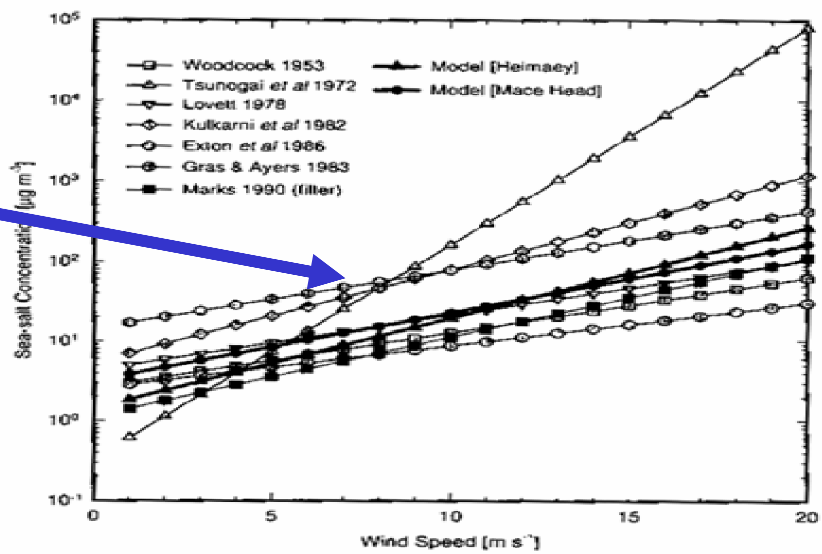
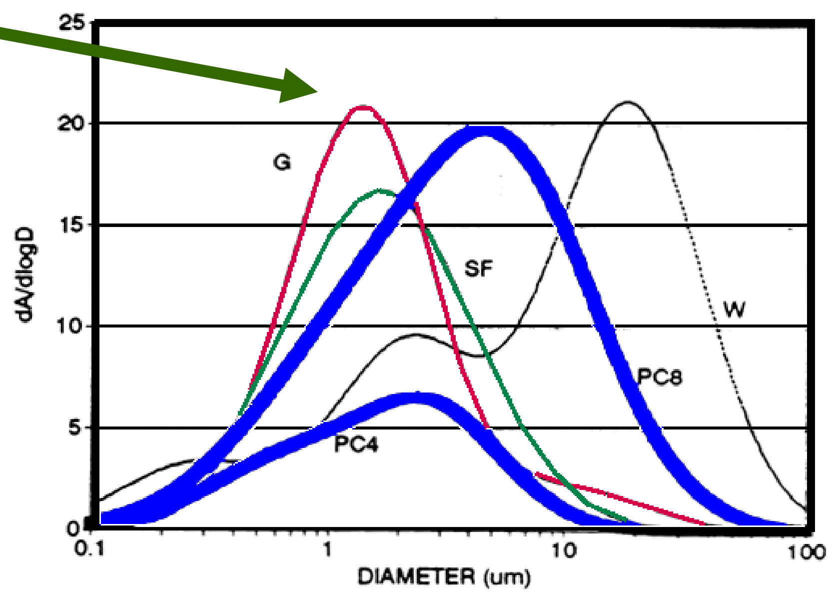
The State of Sea Salt Particle Size

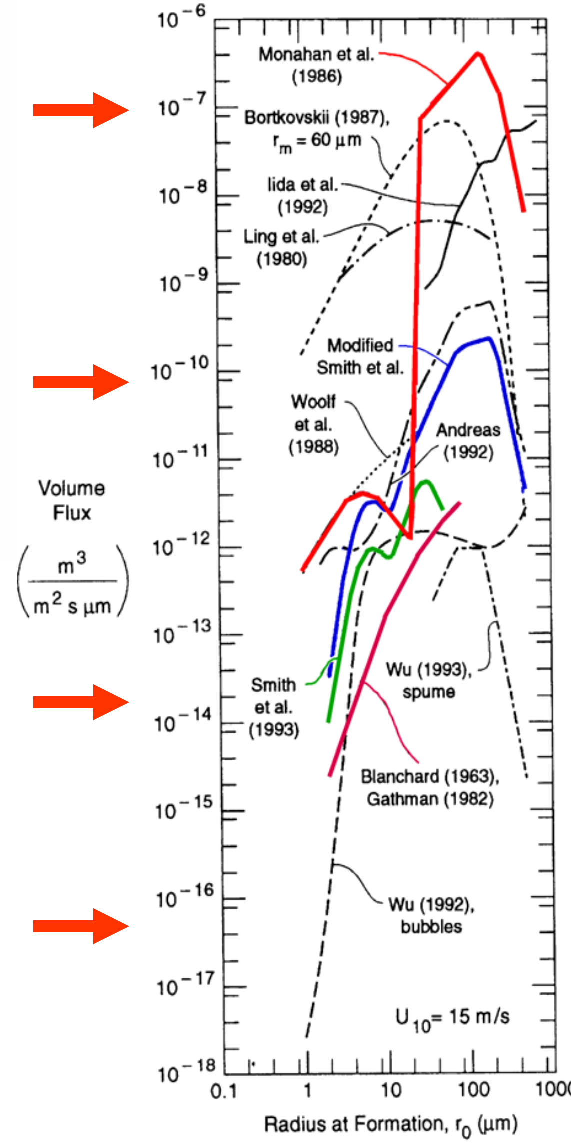
Gong et al., [1997]
Order of magnitude uncertainty in concentration

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

Andreas [1998]
Don't even think about flux







All Coarse Mode Measurements Have Issues

Dust size distributions vary systematically by technique

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 Gillette, [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 Reports in the Literature are not as Systematic as Dust

- The few open ocean APS are consistent
- Impactor data consensus ~4-5 μm, but some variance

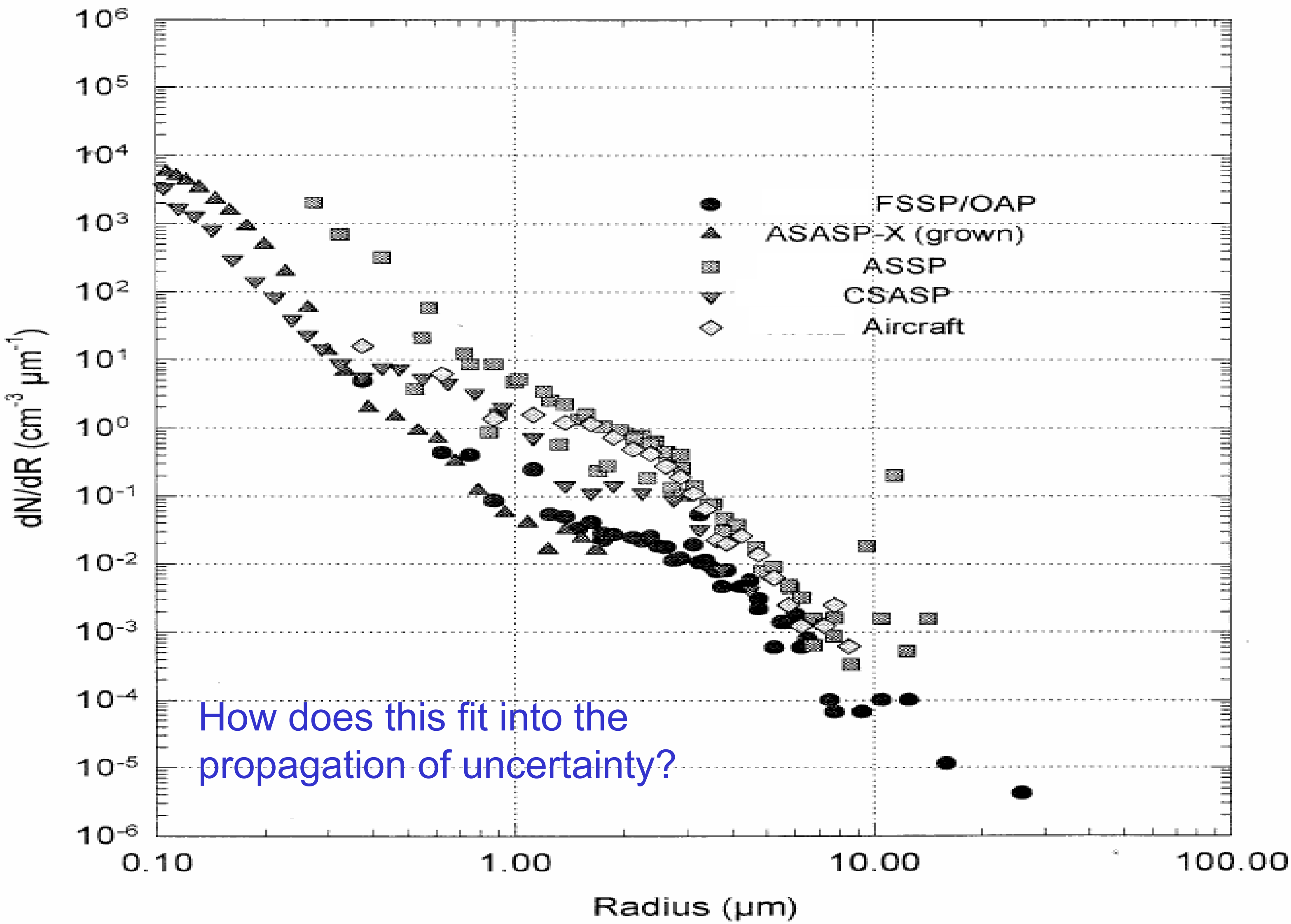
OPC Data: A very mixed bag

- Inversions? In the middle

	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/Atlantic	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]	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

Reconcile Optical Particle Counters

Old data from …



How does this fit into the propagation of uncertainty?

Rough Evaporation Duct Experiment (RED)

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 and fluxes

Use site as receptor for Hoppel and Co.

Advantages: Stable platform, long fetch

Particle Sizer Intercomparison
Participants

Measurements

Brooks (Univ. of Leeds), Crahan (UW), de Leuuw (TNO), Eck (GEST/GSFC), Hegg (UW), Jonsson (NPS/CIRPAS), O'Neill (Sherbrook), Reid (NRL), van Eijk (TNO)

FLIP
- APS
- CSASP (2)
- PCASP-100X
- Filter Chemistry

Twin Otter
- APS (Wing)
- CAPS Backwards
- CAPS Forward
- PCASP-100X

AERONET
- Coconut Island
- Lanai
- Dubovik Inversion
- O'Neill Analytical

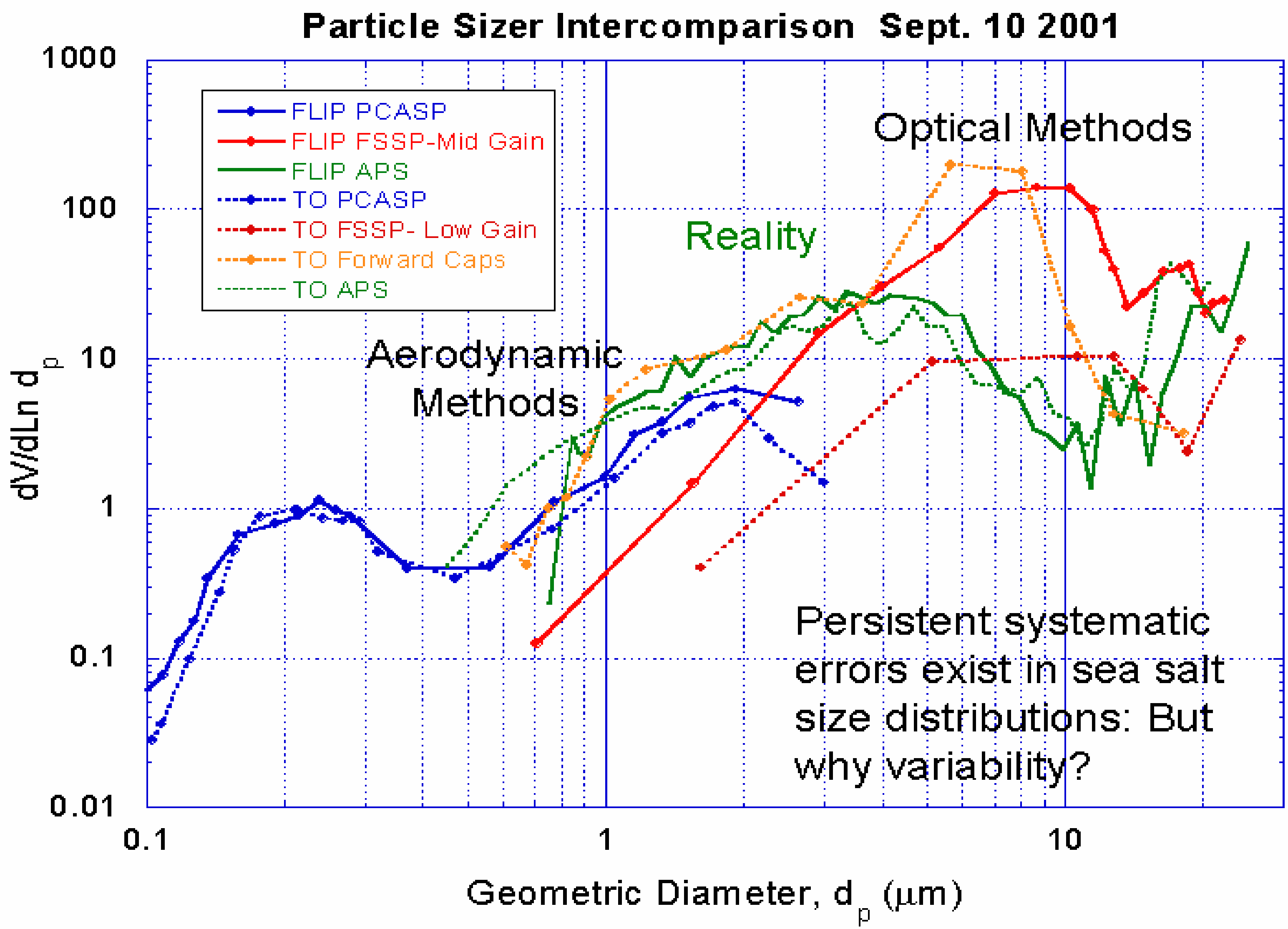
Modeling

Caffrey, Hoppel & Shi: MARBLES/COAMPS

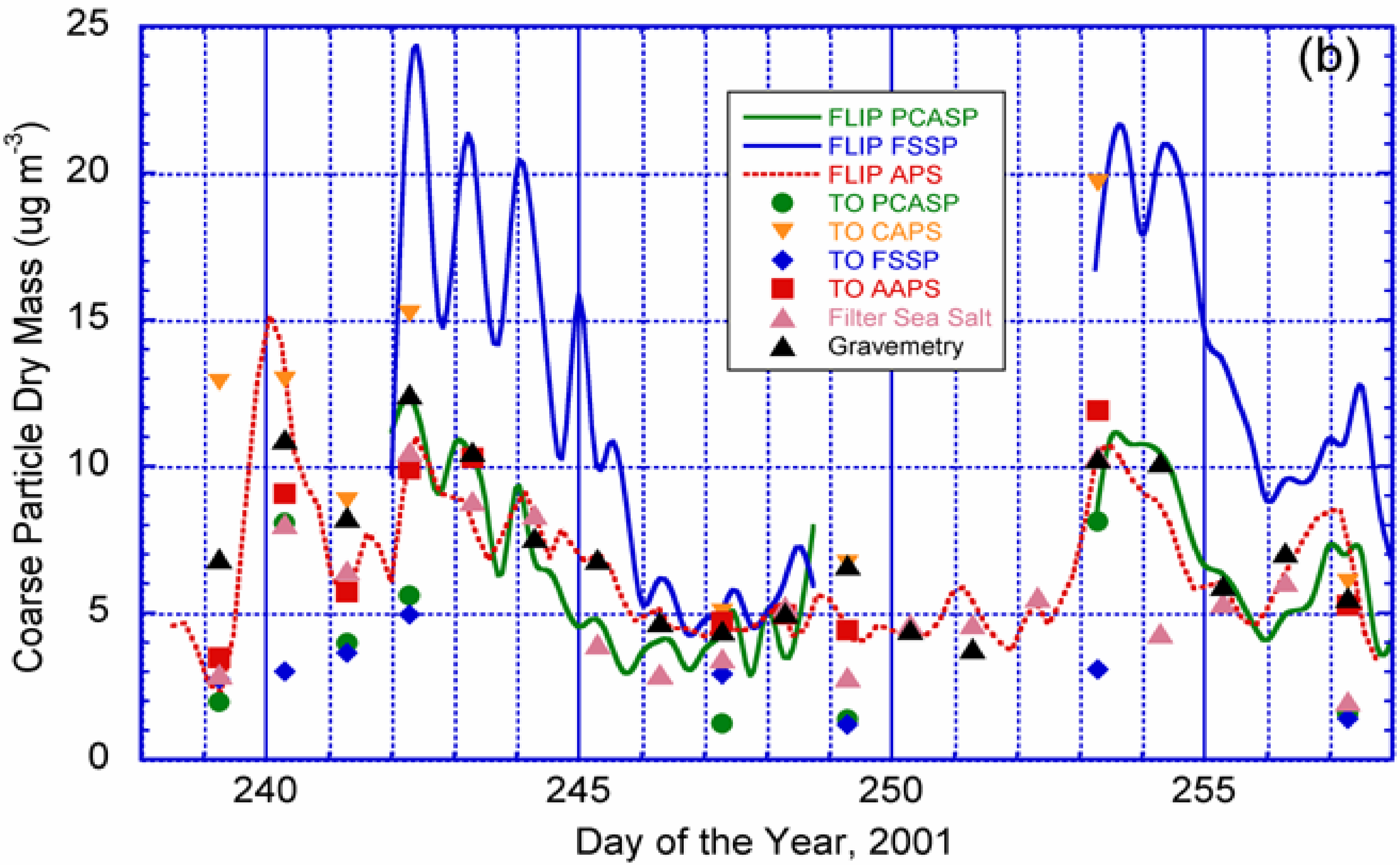
Westphal, Flatau, Liu, & Reid: NAAPS/COAMPS

Marine Aerosol Size Distribution Issues

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



Sea Salt Time Series



Optical Particle Counter Biases

Response Curve Inhomogeneity

•Known for some time, but not dealt with properly
•Previous solutions include average response function, larger bins, ignoring region.
•None of these ultimately deal with the problem at hand, and true uncertainty not propagated correctly.
•Even using “minimum possibility” approach does not correct enough.
•How well do we know these response functions?

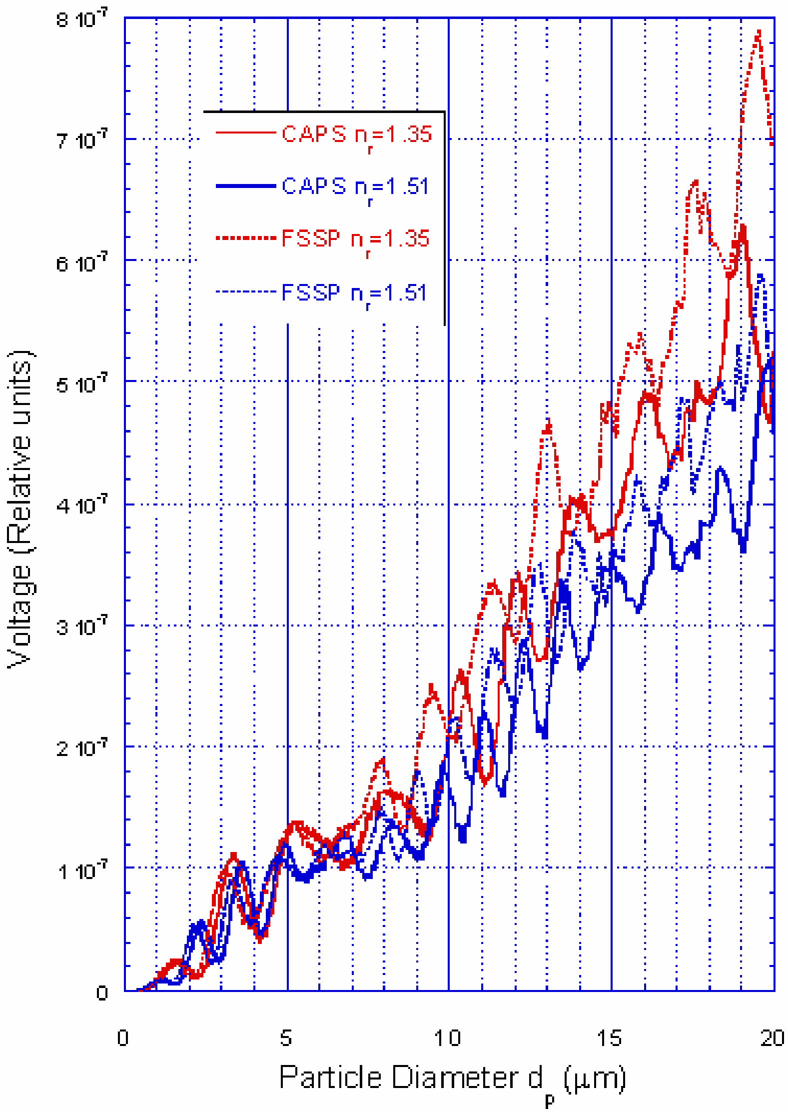
Channel/Gain Bias

•NOBODY trusts first and last channel in an OPC
•But, this error certainly includes channel 2, and in part channel 3.
•Multi-gain “inversions” treat all data on an equal footing. ASASPs look particularly bad. Gain failures?

Reporting/Curve Fit Bias

Inlet/Humidity Bias

Sample Volume

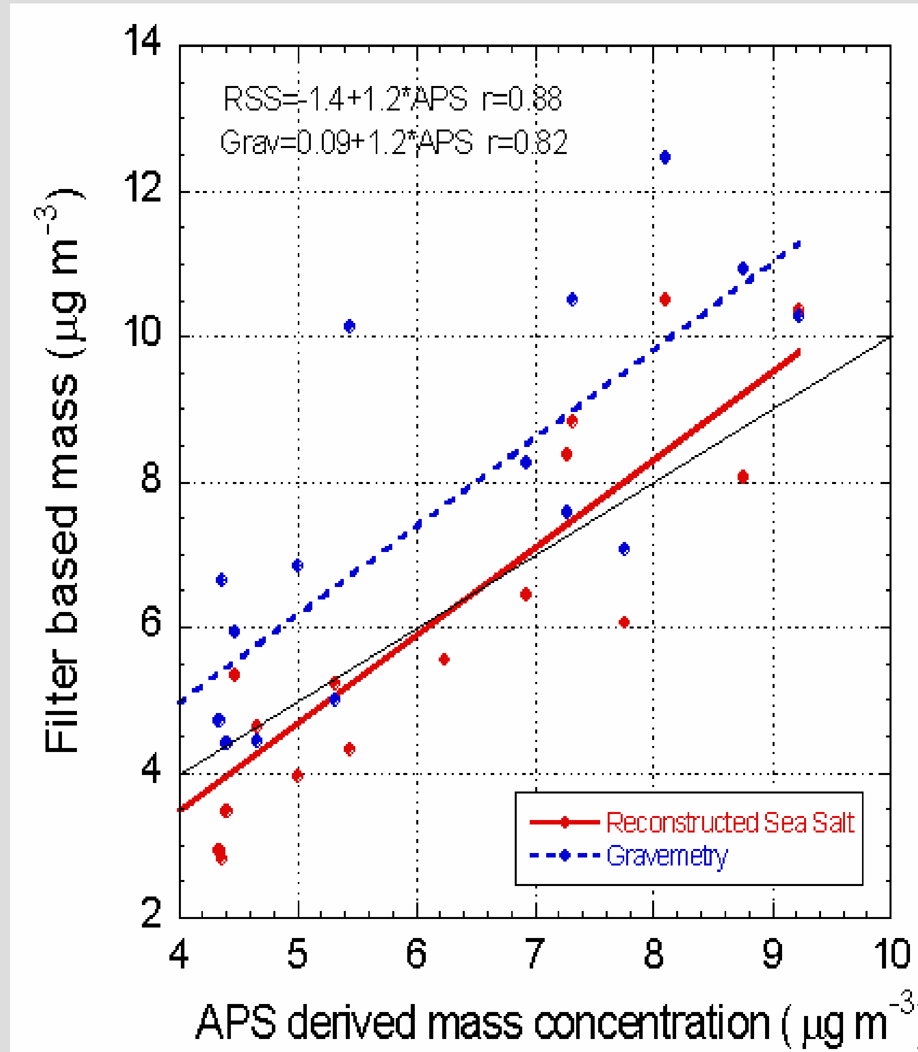


APS Performance

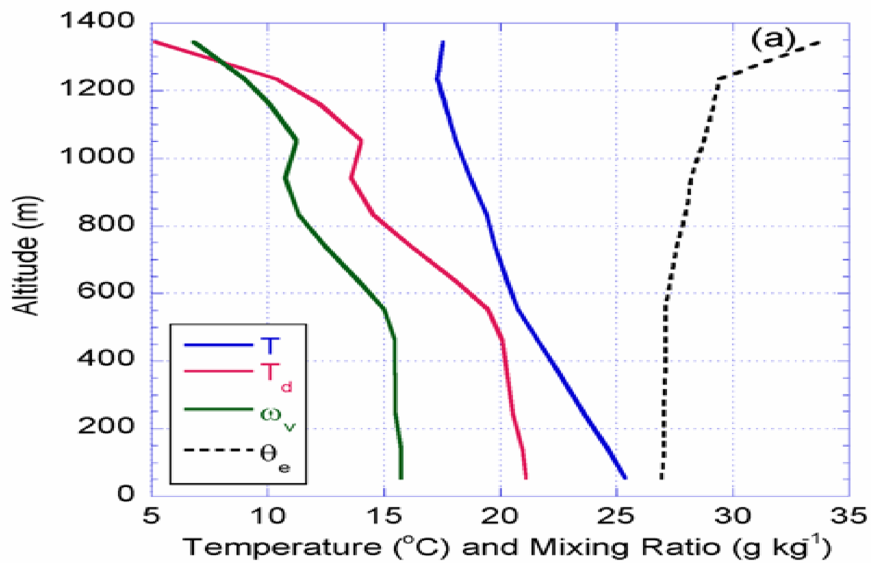
- Surface APS was the only instrument that tracked with filters.

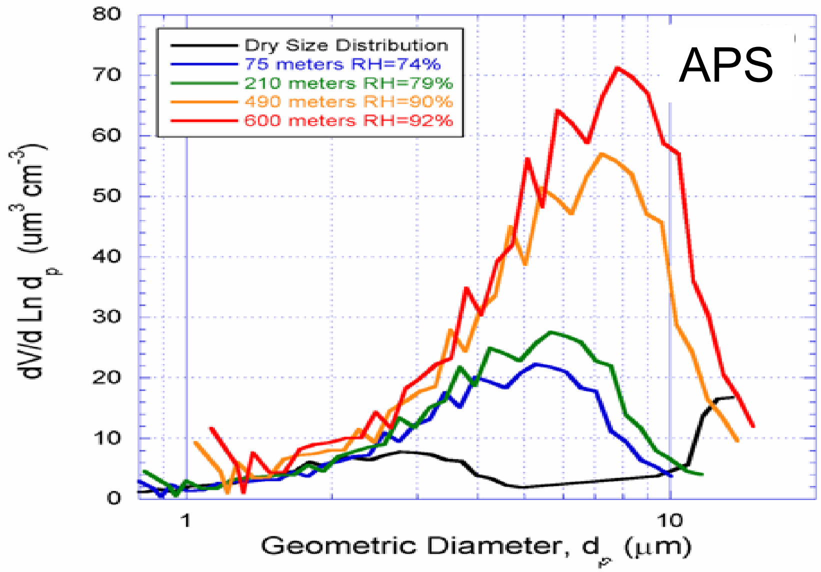
- “Drying” is key. APS systems host 50% losses for “wet” particles.

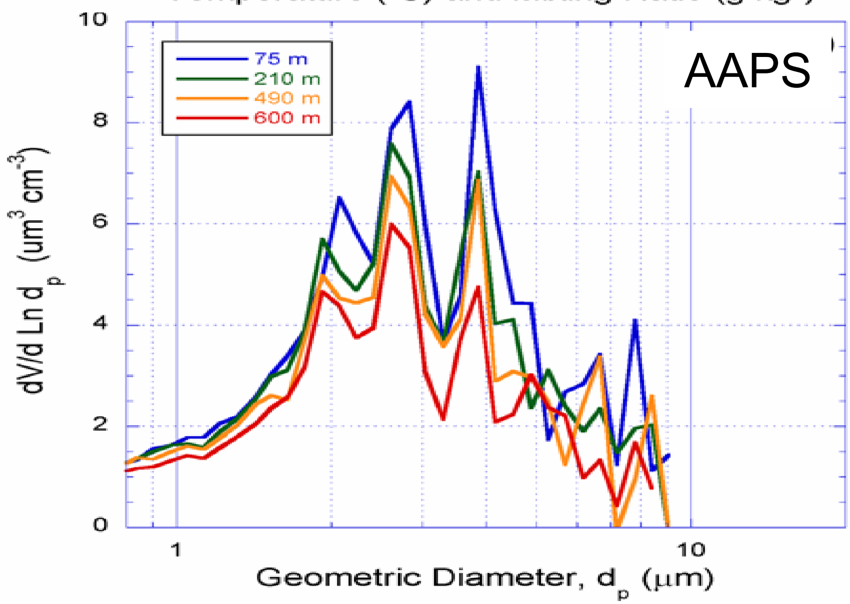
- Operating at ambient humidity CIRPAS wing mounted APS yields very “unphysical” results.

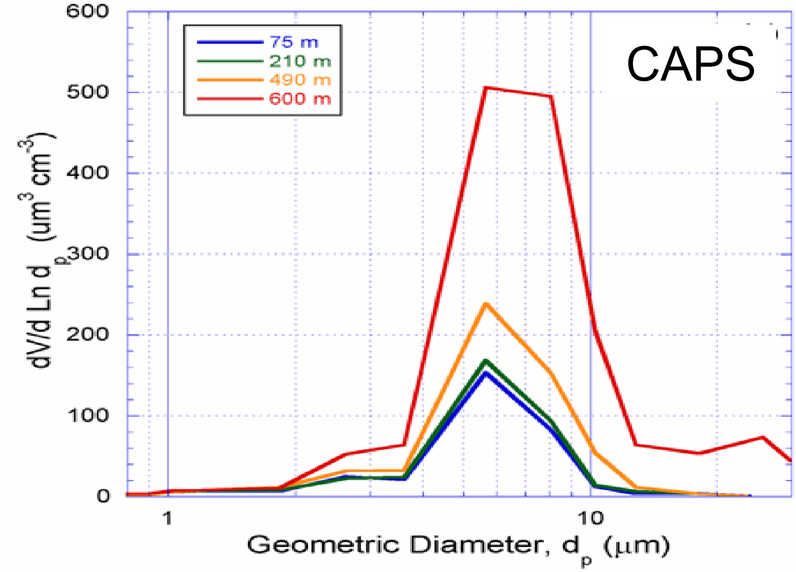


Unphysical Behavior in MBL





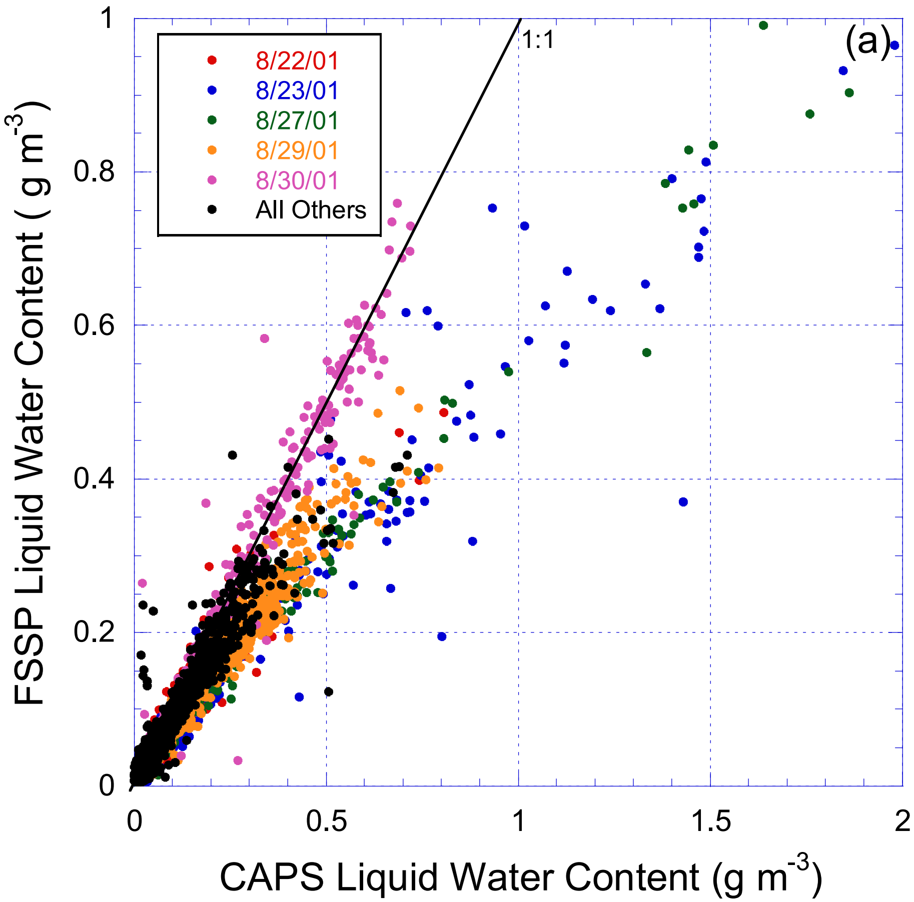




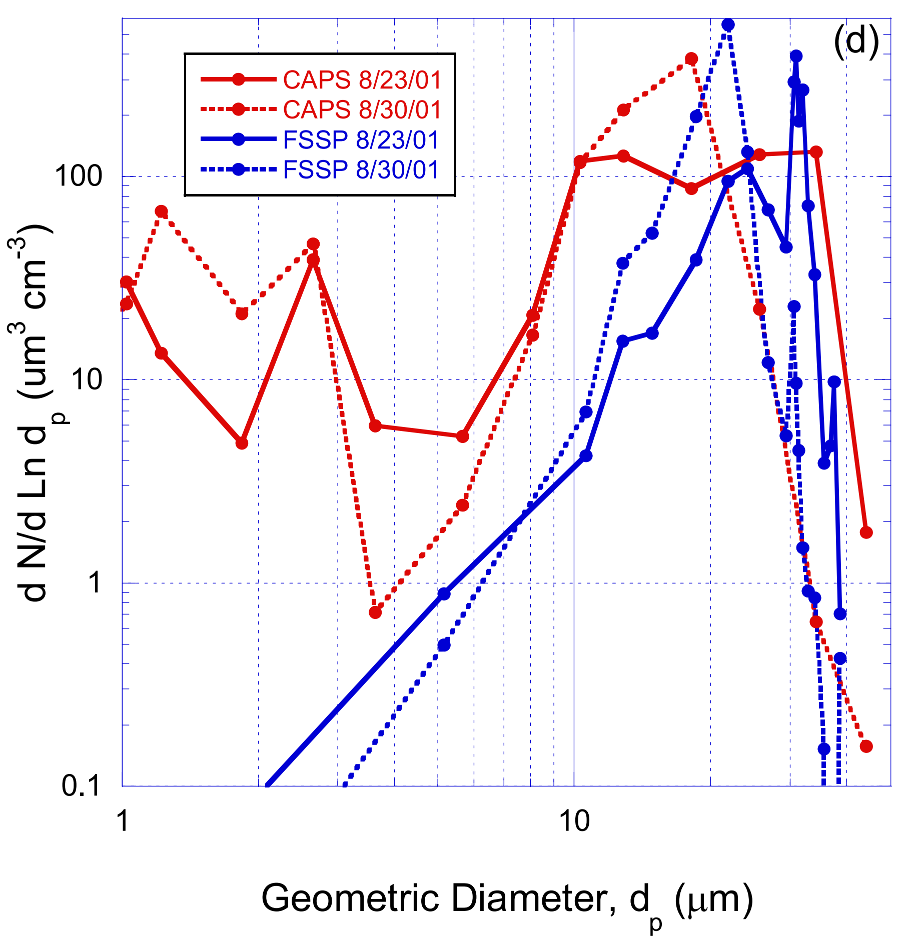
Issues With Clouds Mode?

All previous intercomparisons deal with integrated quantities in clouds

Variability between integrated quantities are consistent by cloud type



Large systematic differences in size+aliasing



Bottom Line Uncertainties

- Because these instruments are ubiquitous on airborne campaigns, the propagation of error can be shown to be massive.
- Most airborne sea salt measurements yield a factor of 2 bias in volume median diameter.
- In reality, common mode variability in volume median diameter is probably around 20% for dry particles, and 40% for ambient.
- Total volume bias is as large as a factor of 5. However, how this propagates into other areas such as light scattering is likely to be significantly less.
- For clouds, effective radius cannot be justified better than +/- 3 μm. Cloud liquid water for marine clouds is probably on the order of >30%. Size errors for specific channels can be an order of magnitude, but most often are around a factor of two.
- Bottom line: There (still) does not exist an airborne system that has proven itself to be able to measure the coarse mode. But, white light systems are showing promise. We'll see….

Summary

•Despite being one of the oldest fields of aerosol research, the educated uncertainty in sea salt particle size is about a factor of two, and for fluxes is about a factor of 5

•Based on the RED, PRIDE, and now retrospective analysis of EOPACE data, we have found that most of these uncertainties can be traced back to specific systematic errors in particle sizing and thermodynamics

•These uncertainties propagate strongly throughout the system. This inevitably leads to unphysical tuning in models and inconsistent results as a function of wavelength

•Clouds are equally problematic, but the prevalent use of integrated quantities have lessened the impact.

•Do not treat all measurements equally! On the other hands, don't disregard data just because they are outliers