Seasonal Variability Of Warm Clouds and Precipitation in the Southern Oceans as Diagnosed from A-Train

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Stephanie Avey

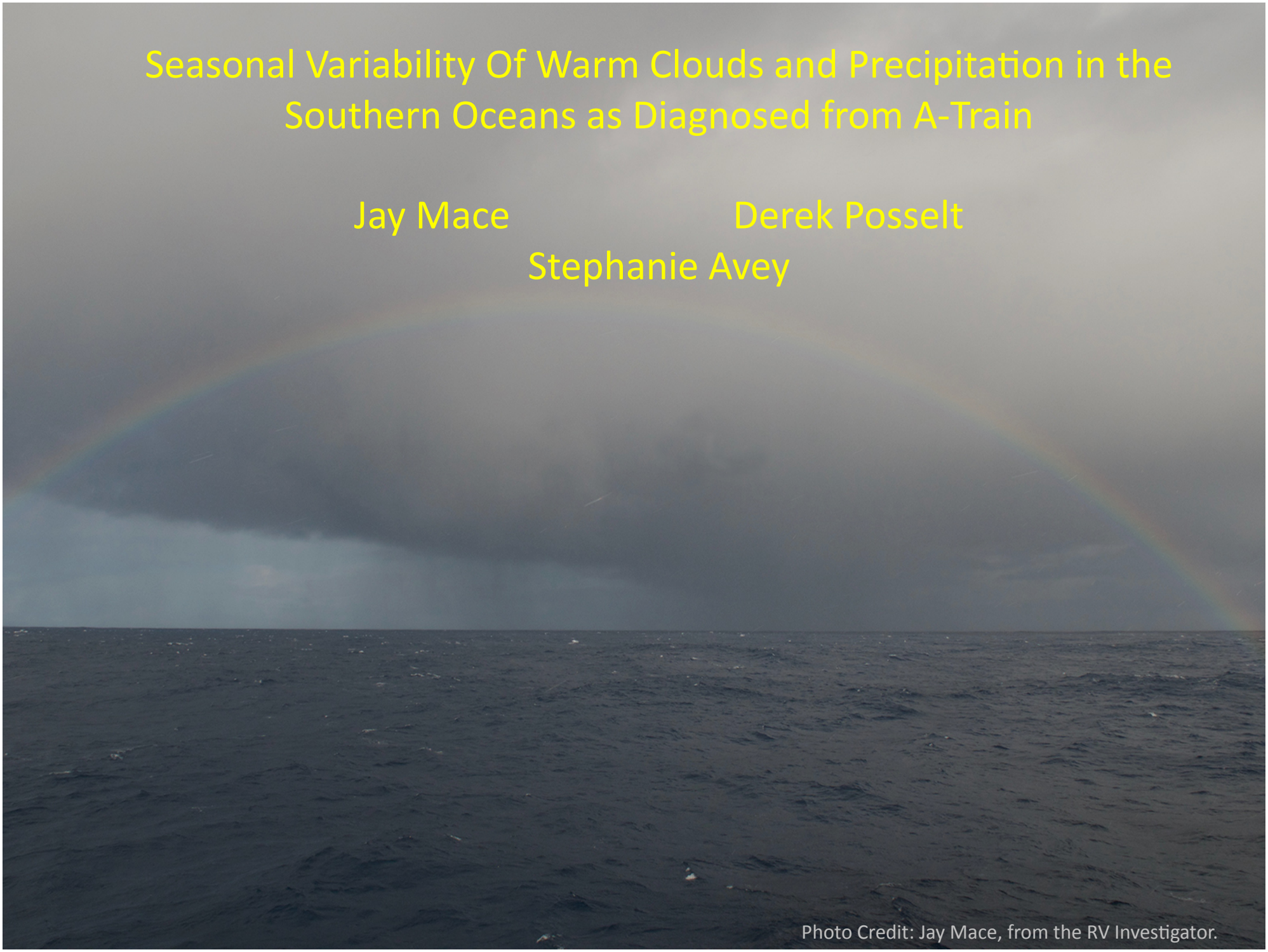
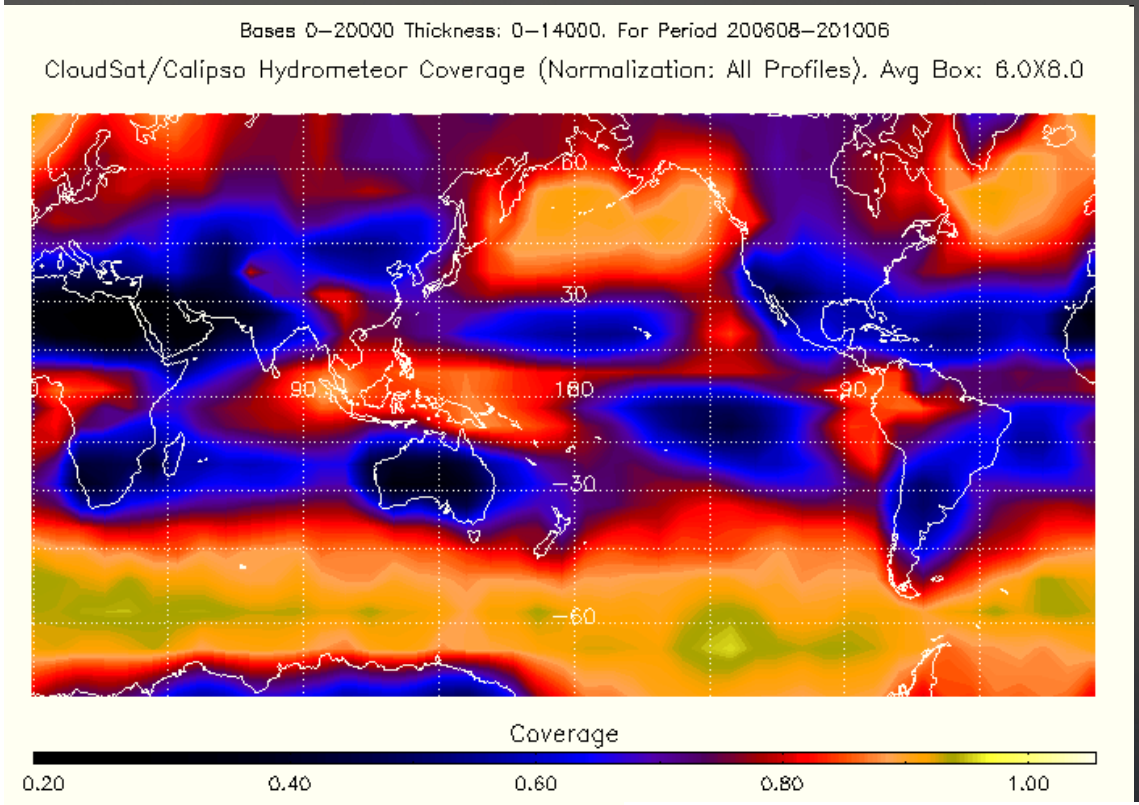
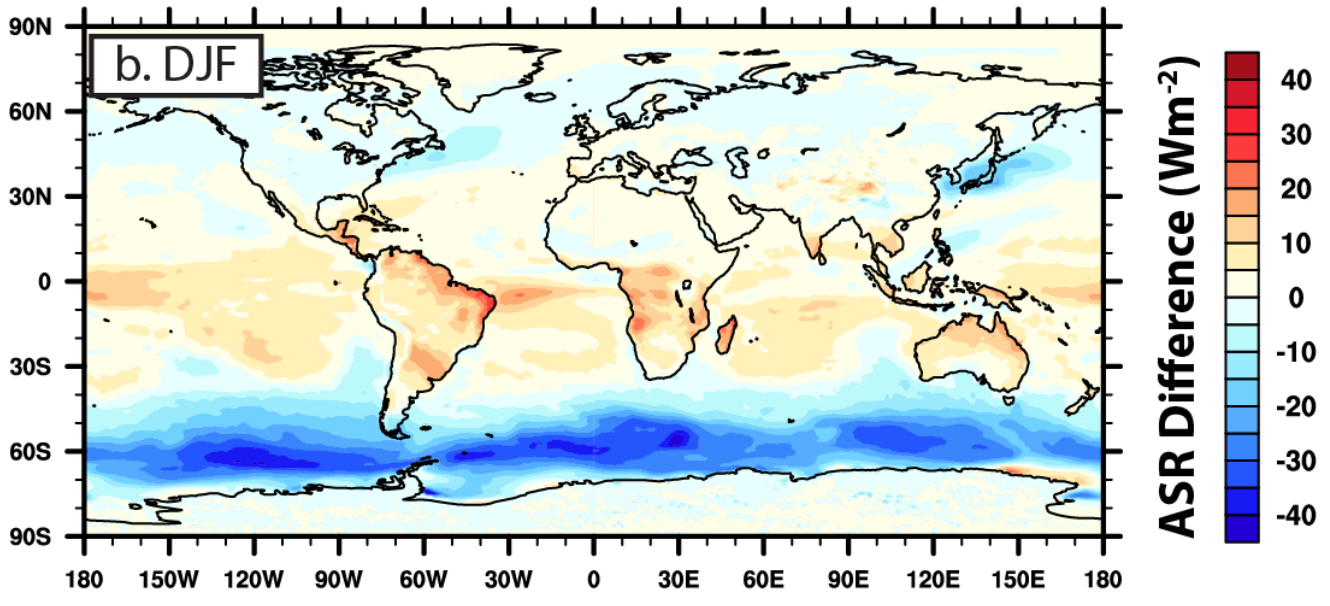


Photo Credit: Jay Mace, from the RV Investigator.

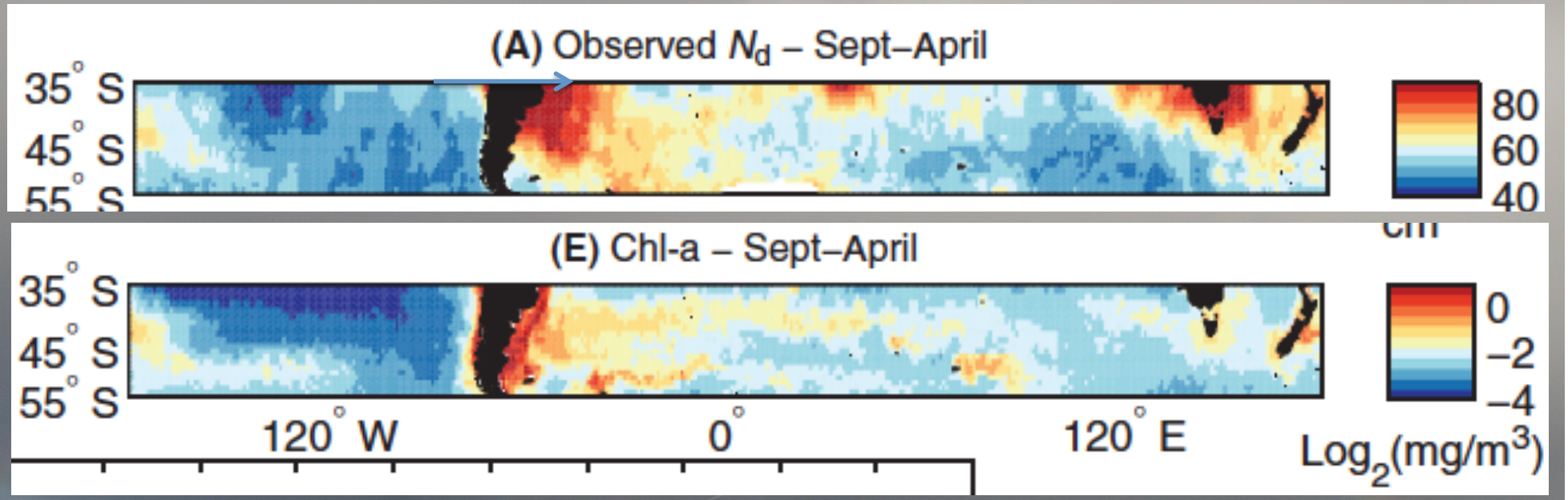


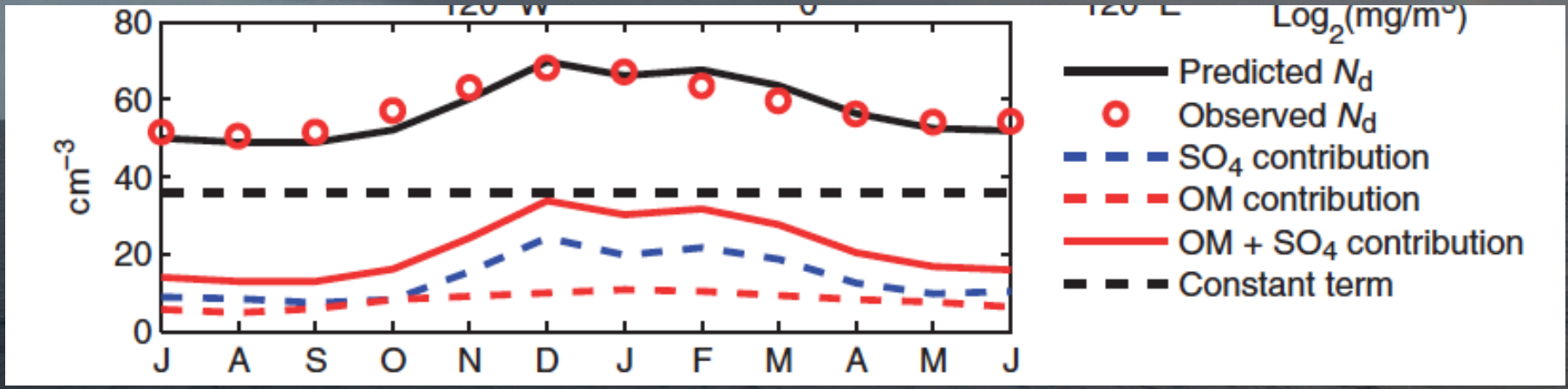
The Southern Oceans are the cloudiest regions on Earth (Mace et al, 2009; Mace and Zhang 2014)…

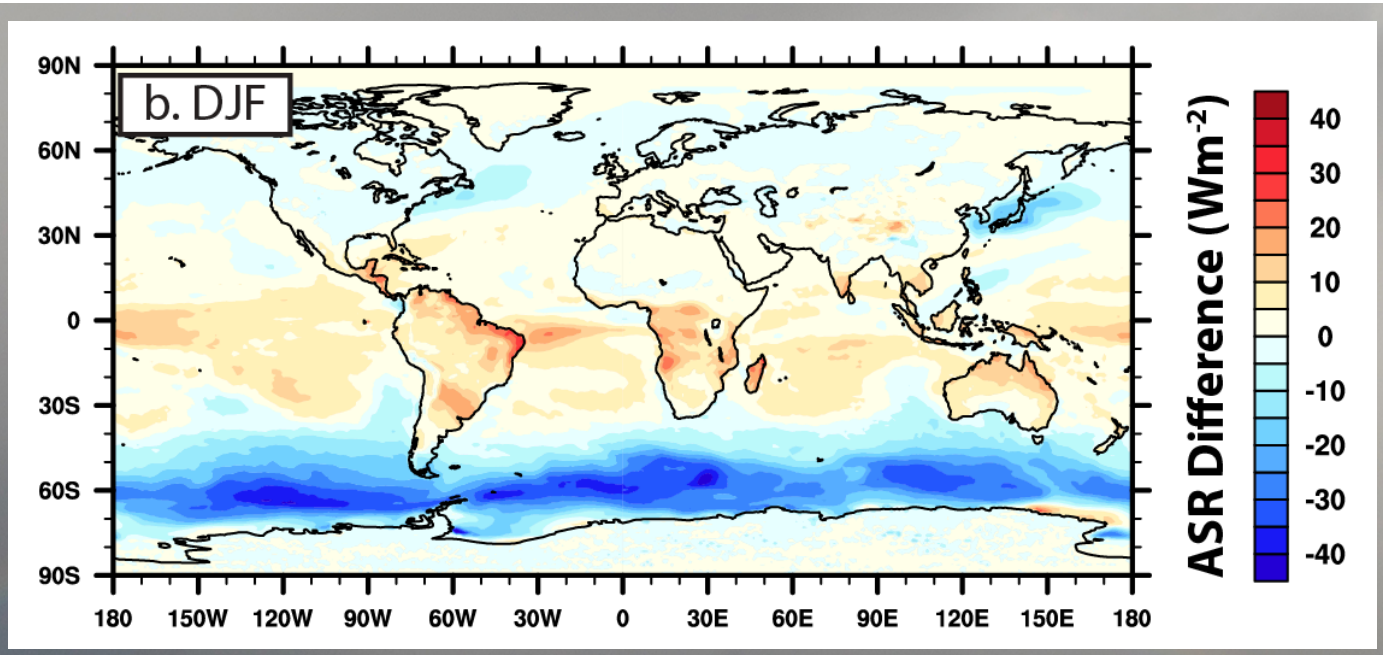
… and one of the regions with the most significant abosrbed shortwave biases (obs-models) on earth (from Kay et al., 2016)

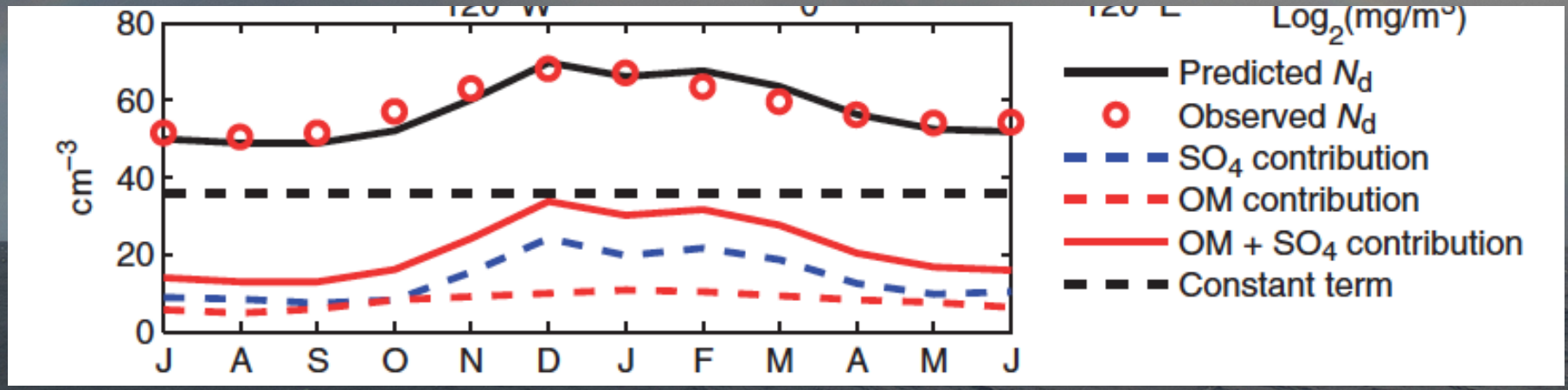


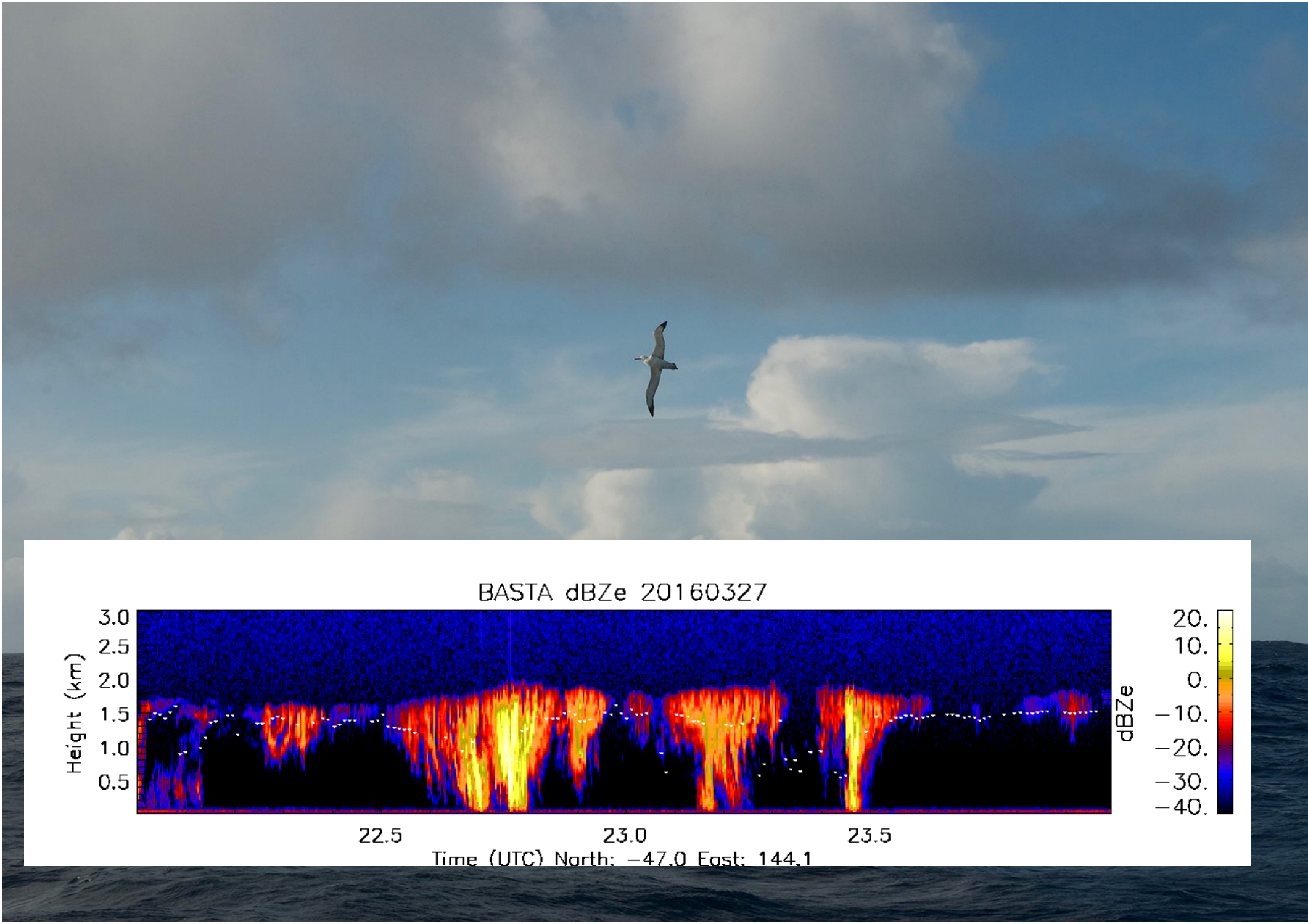
Recent work (McCoy et al., Nature, 2015) suggest how biogenic aerosol precursors and cloud properties change seasonally in the Southern Ocean….

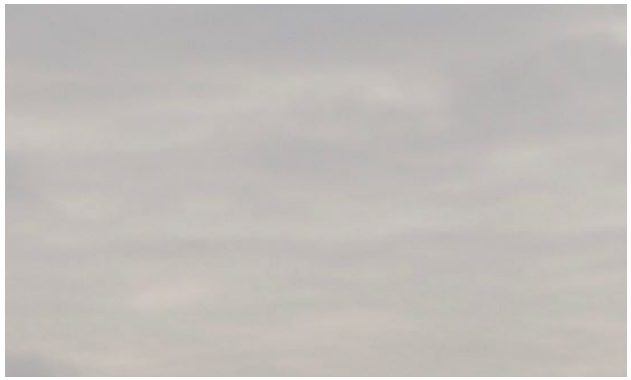


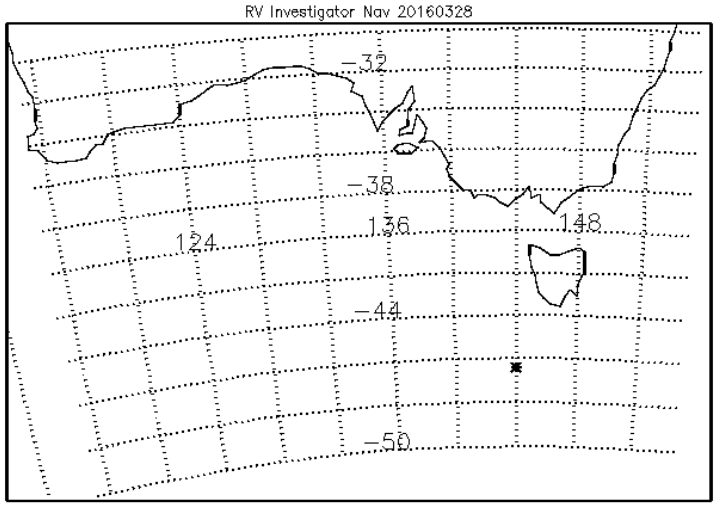


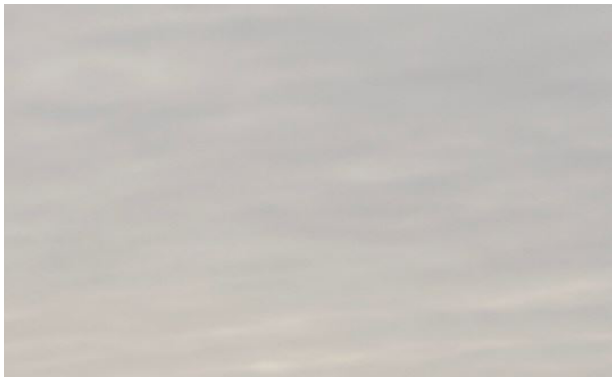

b. DJF
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
ASR Difference (Wm-2)
40
30
20
10
0
-10
-20
-30
-40

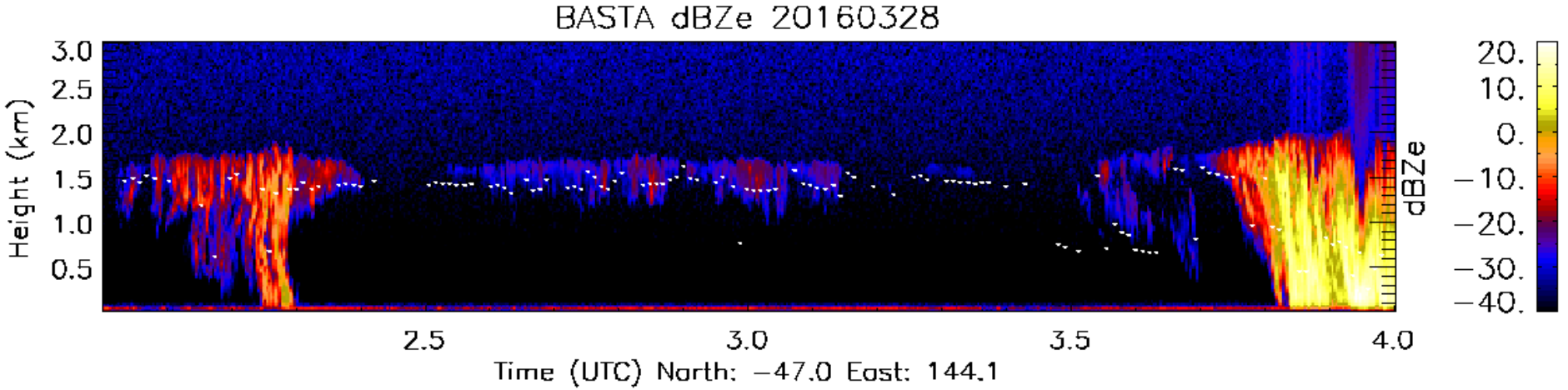

80
60
40
20
0
cm-3
J
A
S
O
N
D
J
F
M
A
M
J
Log2(mg/m3)
Predicted Nd
Observed Nd
SO4 contribution
OM contribution
OM + SO4 contribution
Constant term

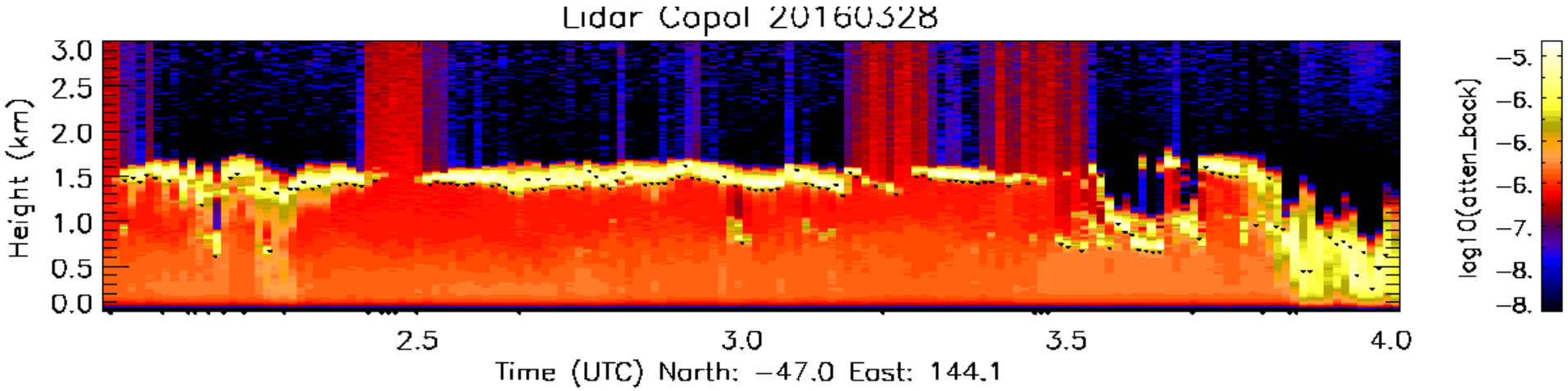

BASTA dBZe 20160327
Height (km)
3.0
2.5
2.0
1.5
1.0
0.5
22.5
23.0
23.5
Time (UTC) North: −47.0 East: 144.1
dBZe
20.
10.
0.
−10.
−20.
−30.
−40.




RV Investigator Nav 20160328
-32
-38
-44
-50
124
136
148

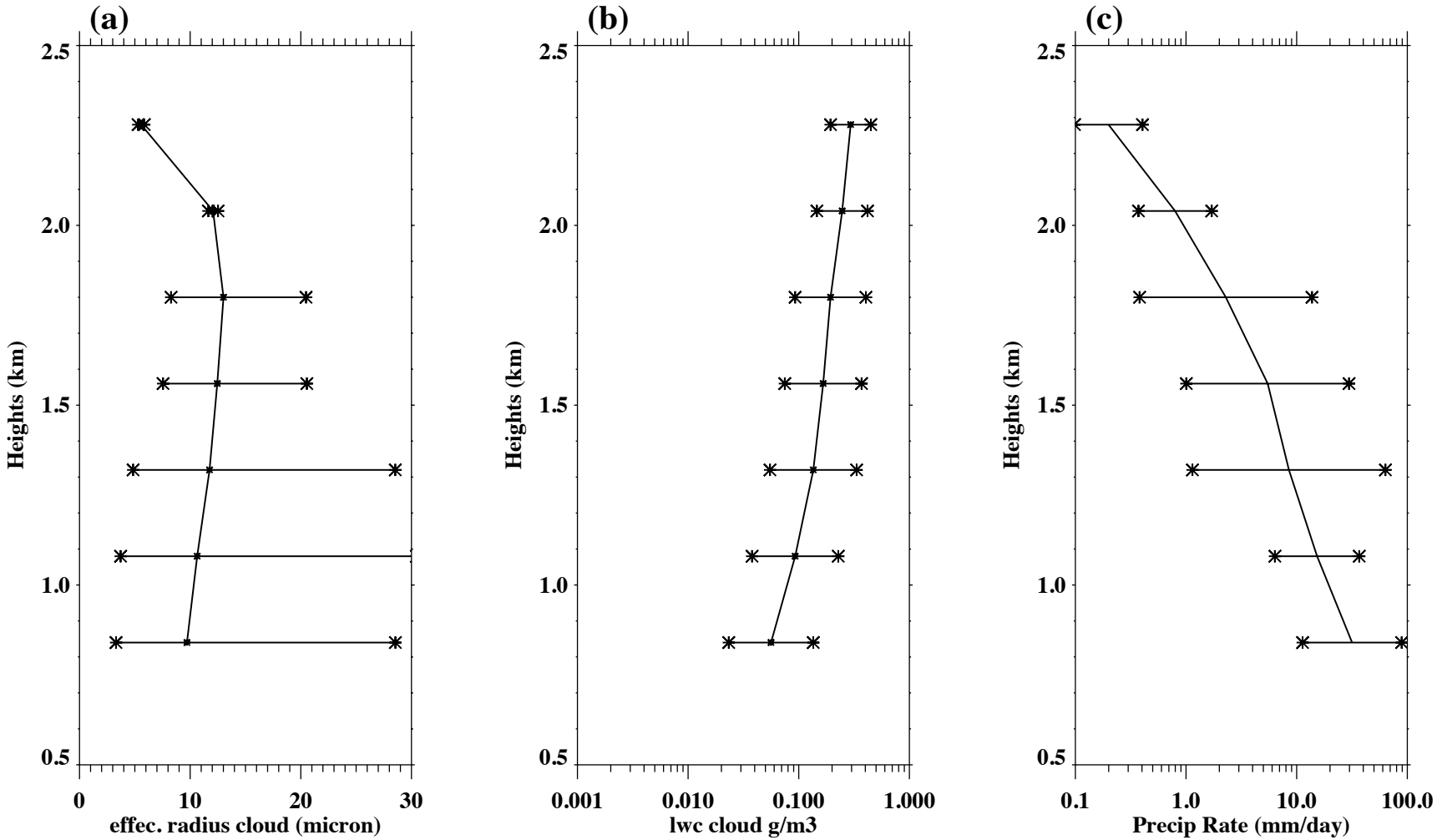



BASTA dBZe 20160328
Height (km)
3.0
2.5
2.0
1.5
1.0
0.5
2.5
3.0
3.5
4.0
Time (UTC) North: -47.0 East: 144.1
dBZe
20.
10.
0.
-10.
-20.
-30.
-40.

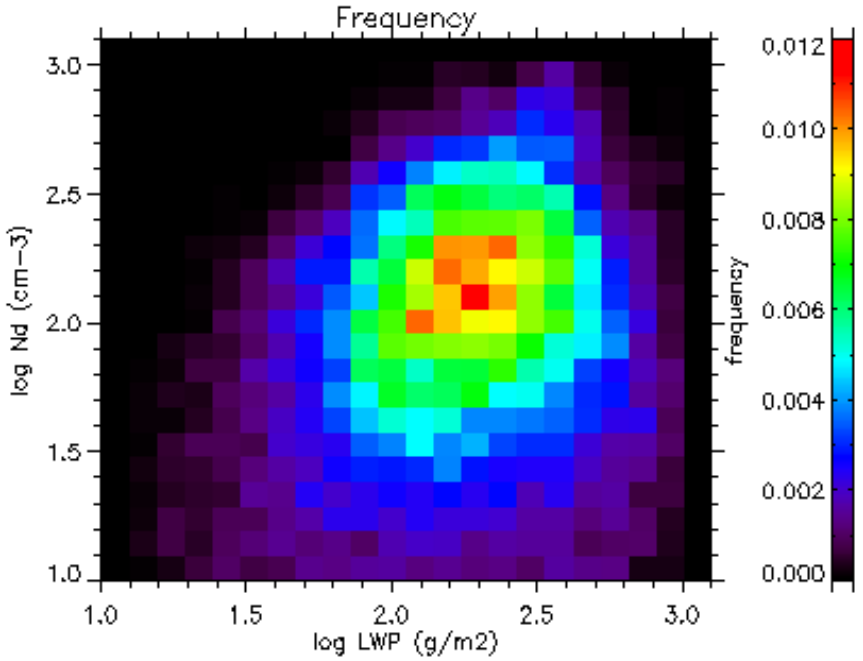

Lidar Copol 20160328
Height (km)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2.5
3.0
3.5
4.0
Time (UTC) North: -47.0 East: 144.1
log10(atten_back)
-5.
-6.
-6.
-6.
-7.
-8.
-8.


Question: Can A-Train data provide unique information regarding cloud-precipitation *process* information (in warm liquid phase clouds)?

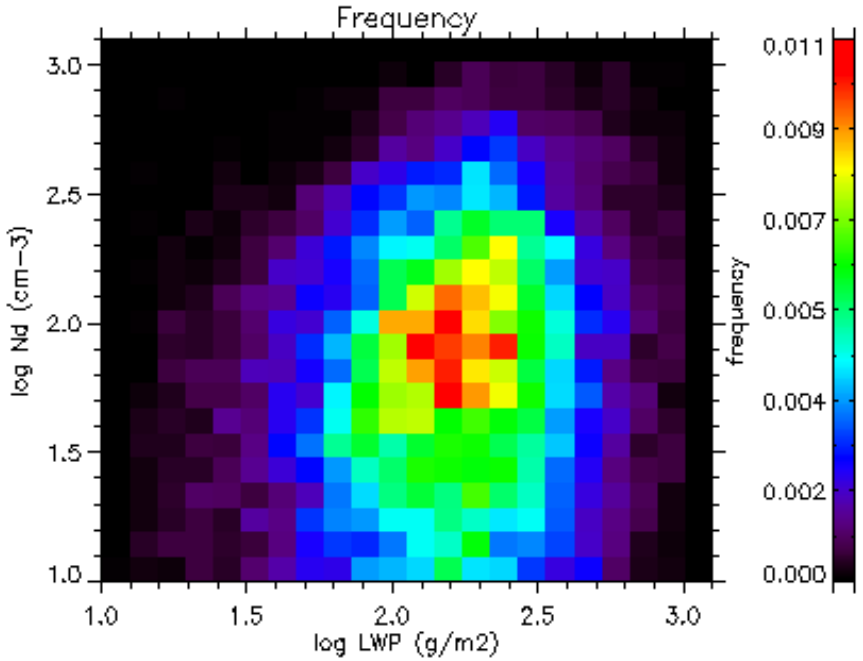
By optimally combining CloudSat Z, Tb, and MODIS 2.1 and 0.8 micron Reflectances process information is weakly constrained and requires significant input from empirical constraints (i.e. aircraft statistics) (Mace et al., 2016, Posselt et al., 2016)

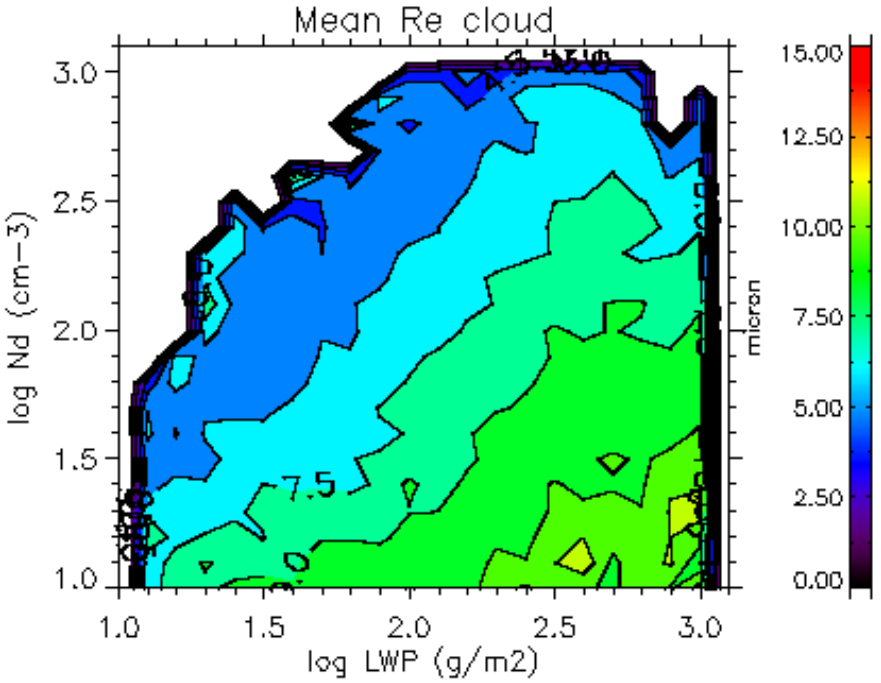


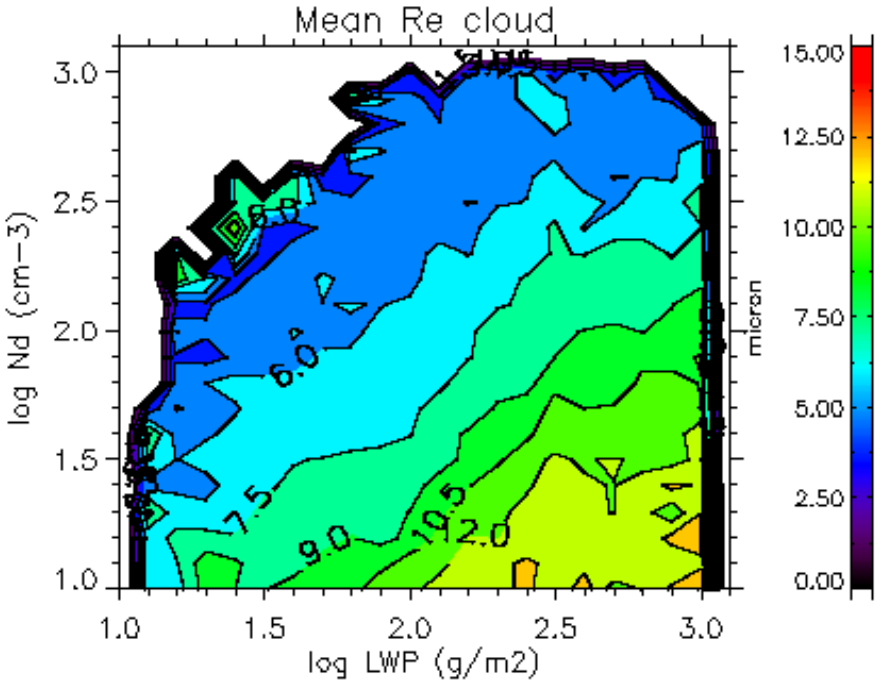
Retrieval stats for summer



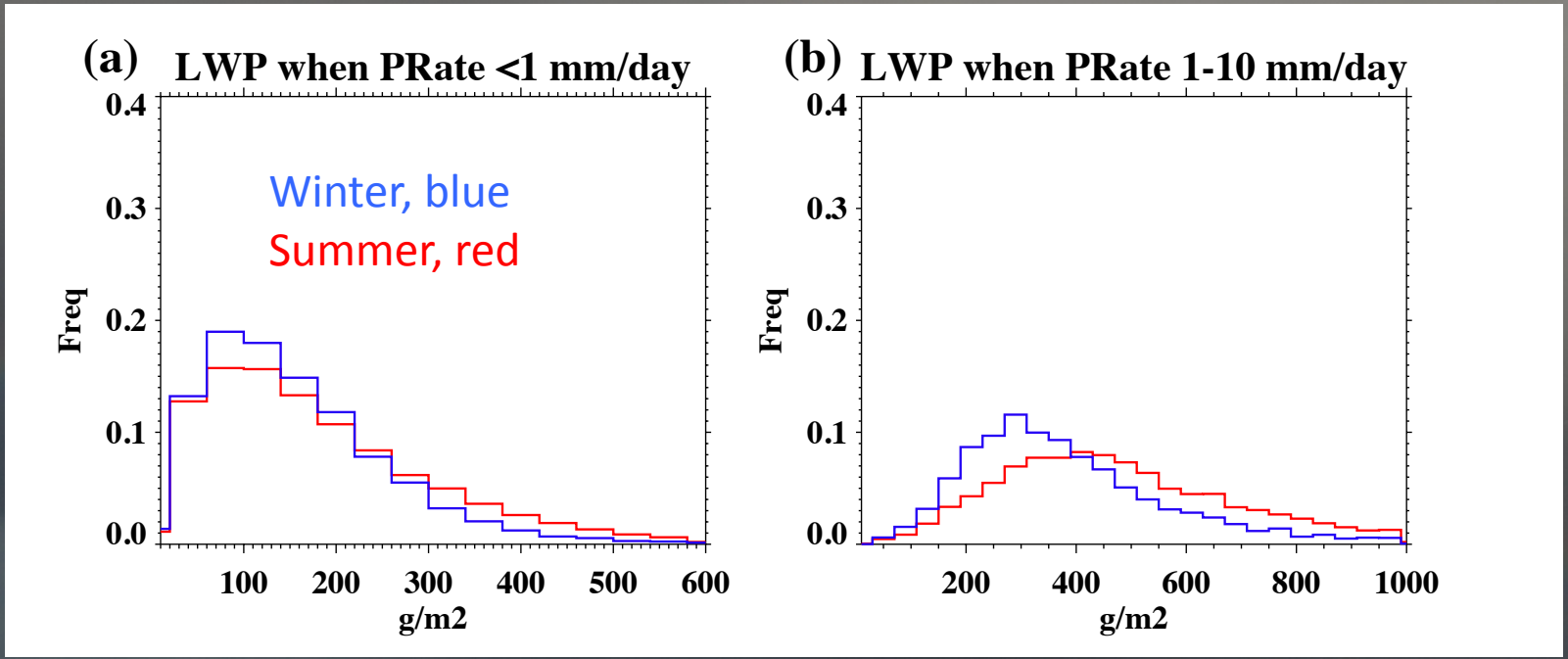
Retrieval stats for winter







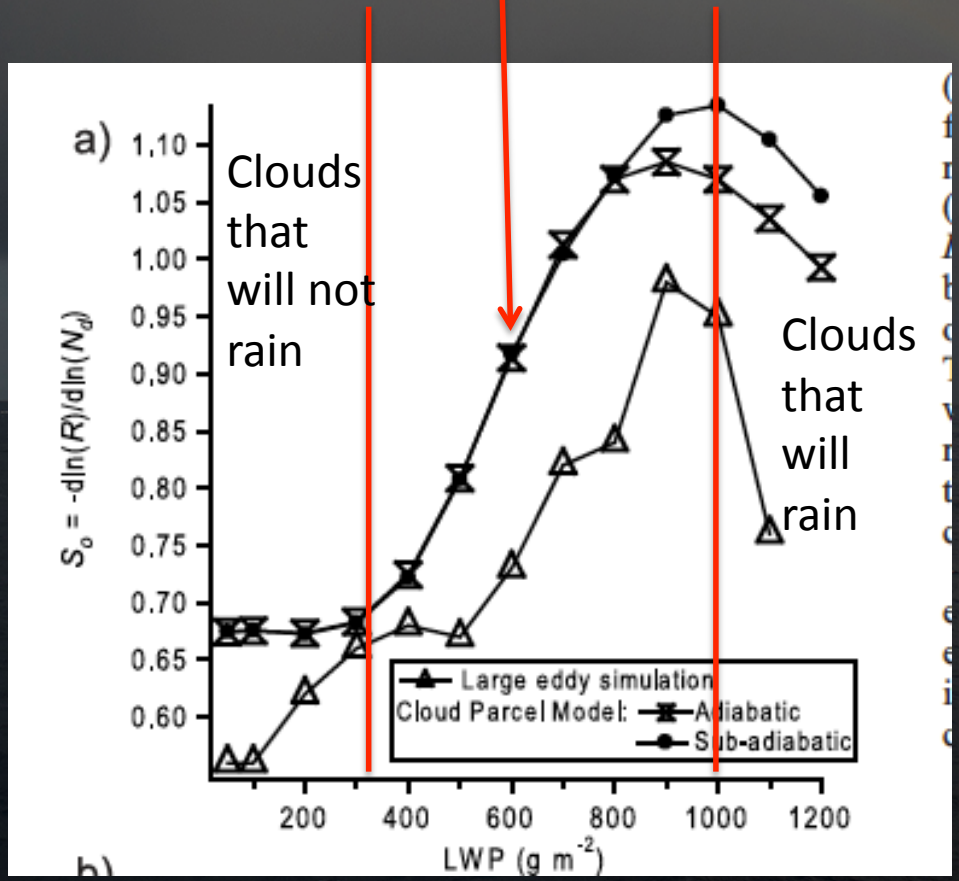
What are the implications for precipitation?
Mace and Avey (2016, under revision in JGR)

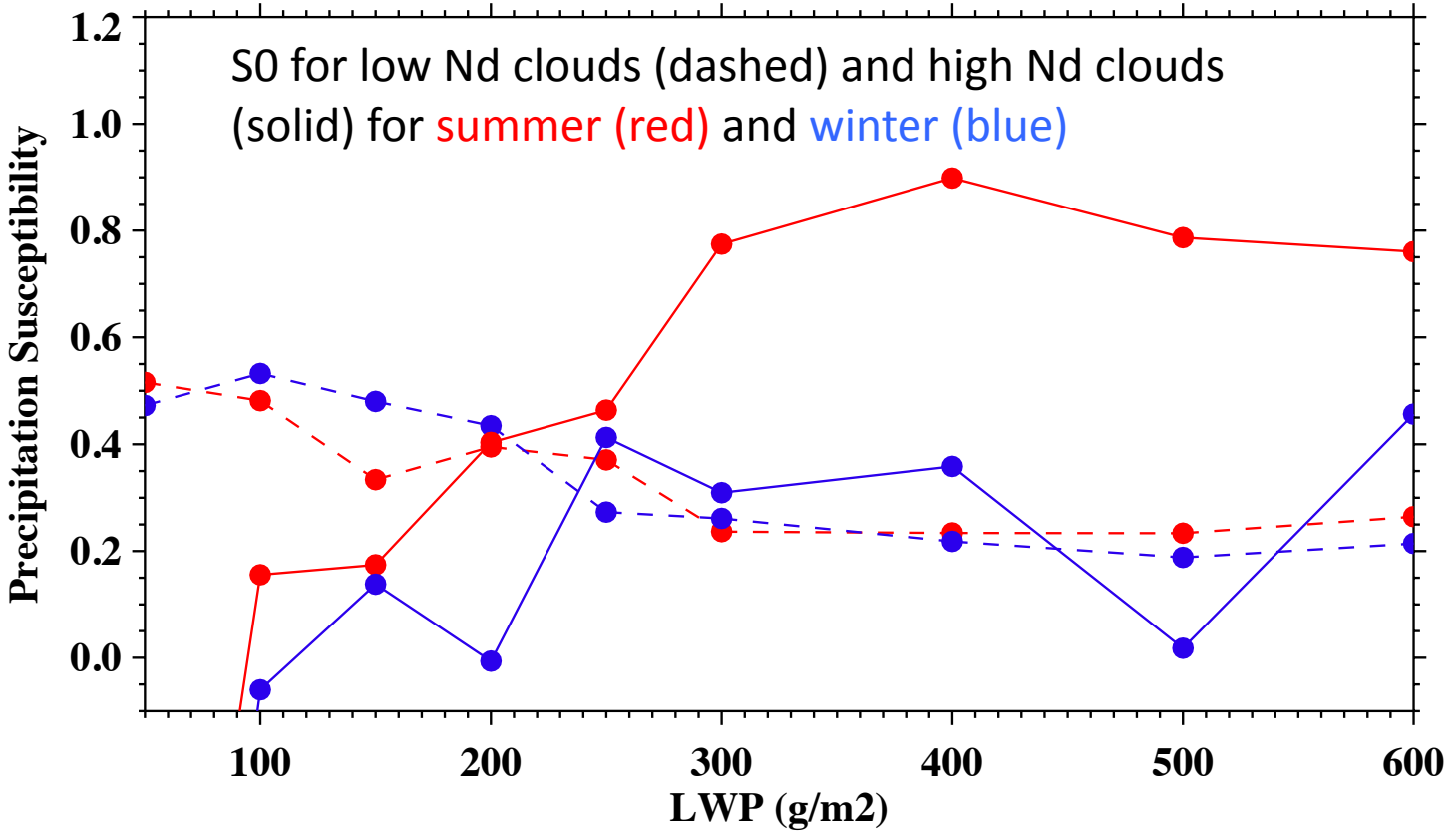


In other words, it takes more water path for warm clouds to rain the same amount in summer!

A formalism for investigating the relationship between LWP, Cloud Droplet Number and Precipitation was introduced by Feingold (2009)…

$$S_o = -\frac{\mathrm{d}\ln R}{\mathrm{d}\ln N_d}$$





- Low Nd clouds behave similarly with season – they rain regardless of LWP and are not susceptible to Nd
- High Nd clouds show significant differences between summer and winter with summer clouds more susceptible to Nd – i.e. require higher water path to rain.

Winter Cloud Properties compared to Summer Cloud Properties

Two modes of seasonal variability of WARM low level clouds.

1. Winter has a population of very low Nd clouds compared to summer (McCoy et al. and others).

2. Low Nd clouds behave similarly between summer and winter – they rain and they are not susceptible to Nd

3. **Higher Nd clouds behave differently in summer and winter**:
    - Winter clouds are less susceptible to Nd than in summer.
    - Or – winter clouds rain more easily at lower LWP.
    - Winter clouds are able to overcome the autoconversion barrier more easily than in summer.
    - Why? We do not know (weaker updrafts, longer cloud residence times…)

Only the A-Train would allow us to dive this deeply into cloud processes – the power of measurement synergy is the ONLY way to address Aerosol-Cloud-Precipitation processes

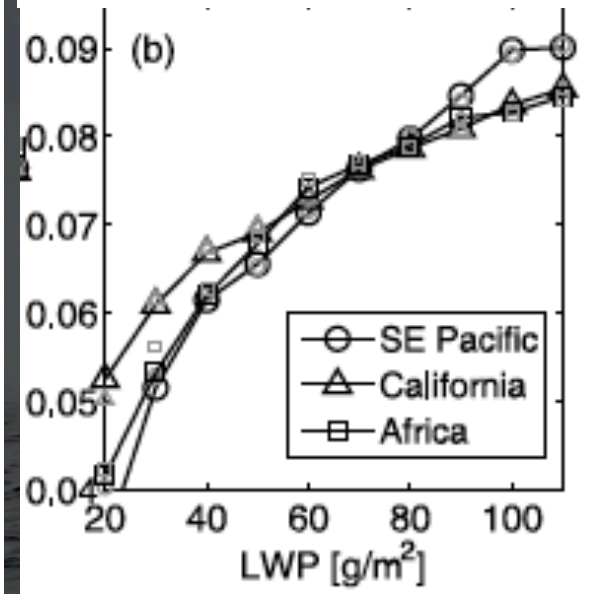
Southern Travelers. Water color on paper. Jay Mace.

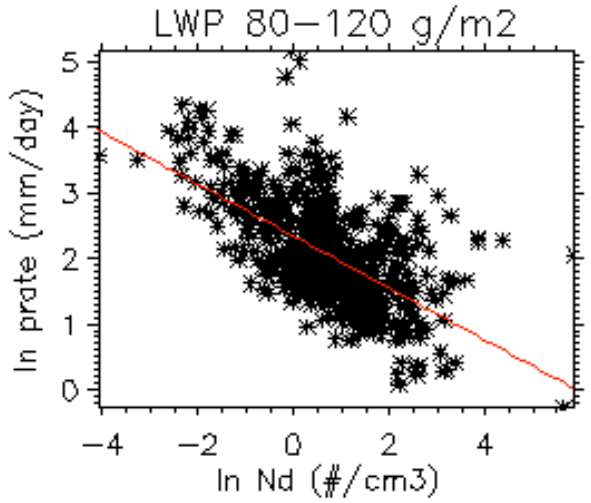
Examine the Co-Dependence of Albedo and Precipitation Susceptibility in Warm Shallow Clouds of the Southern Ocean

Albedo Susceptibility (Platnick and Twomey, 1994):
$S_A = dA/d\ln N$

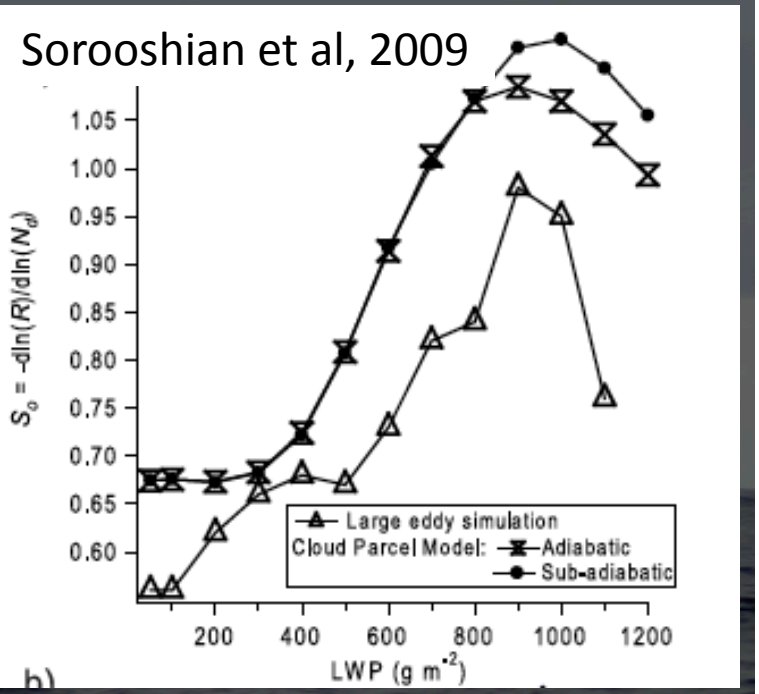
Precipitation Susceptibility (Feingold and Stevens, 2009):
$S_A = d\ln P/d\ln N$

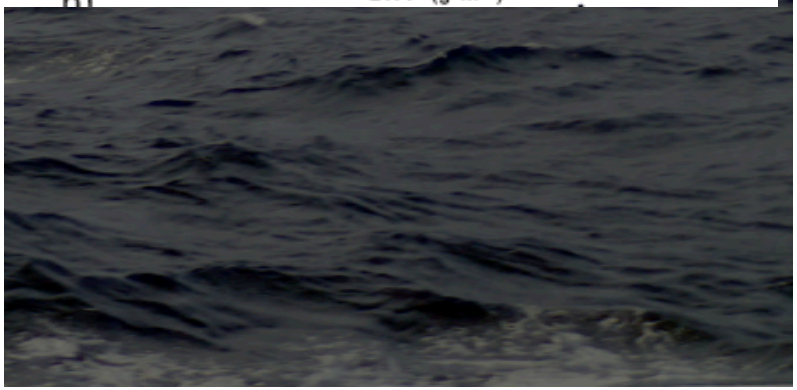
Painemal and Minnis, 2012



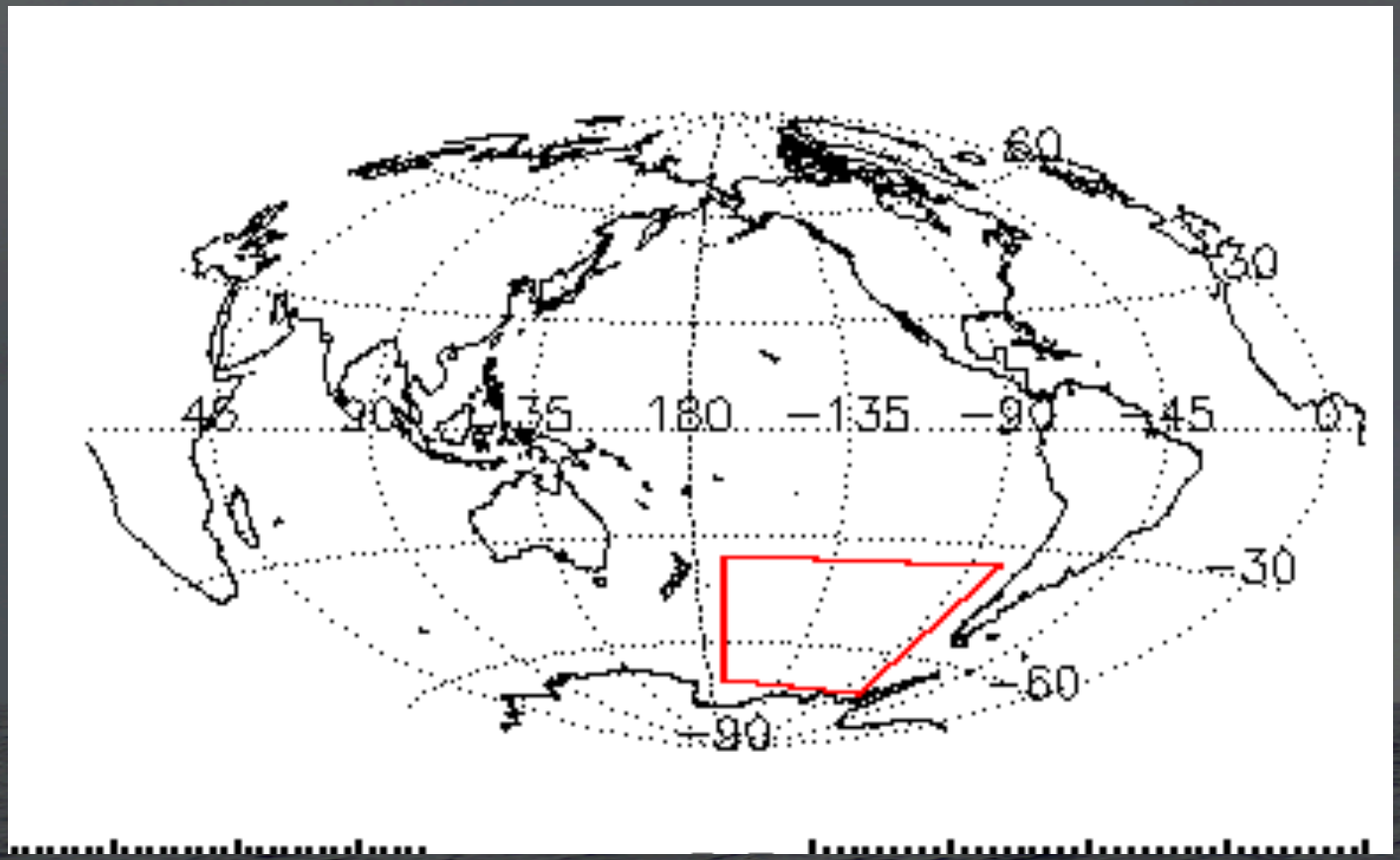


Sorooshian et al, 2009





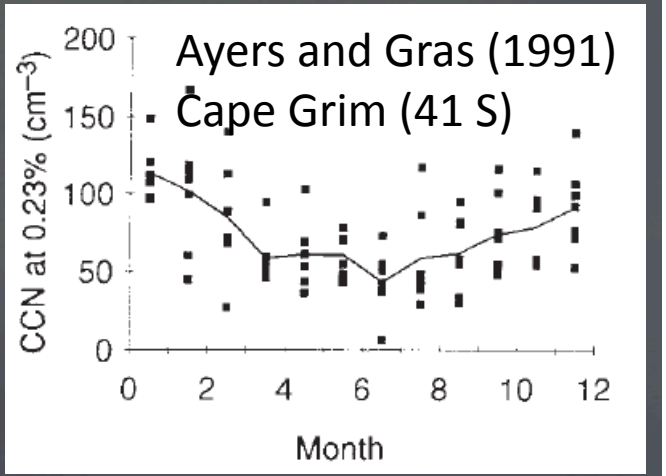
Examine the Co-Dependence of Albedo and Precipitation Susceptibility in Warm Shallow Clouds of the Southern Ocean

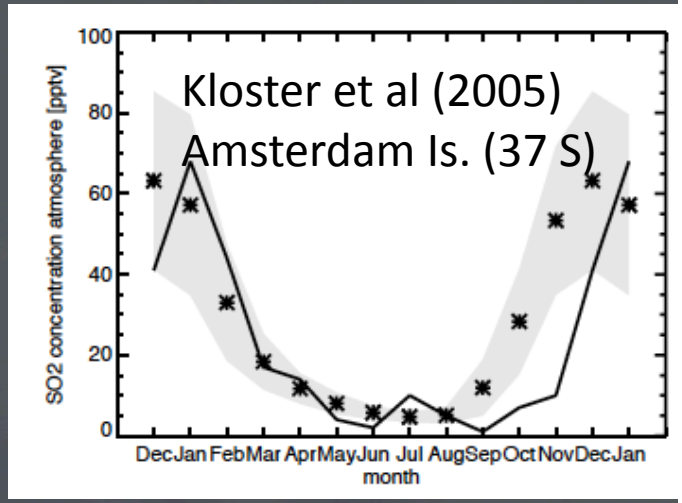


Periods Considered: Winter, 2008, ~11,000 Profiles
Summer, 2007, ~32,000 Profiles

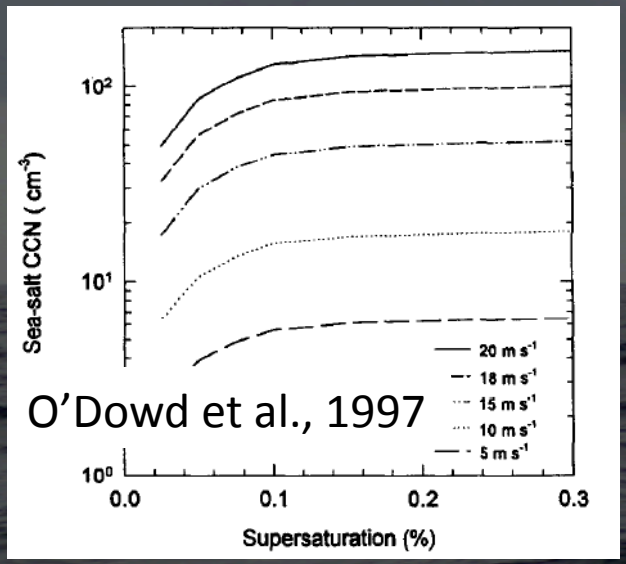
So, What is going on?

- Sulfate aerosol decreases significantly from Summer to Winter



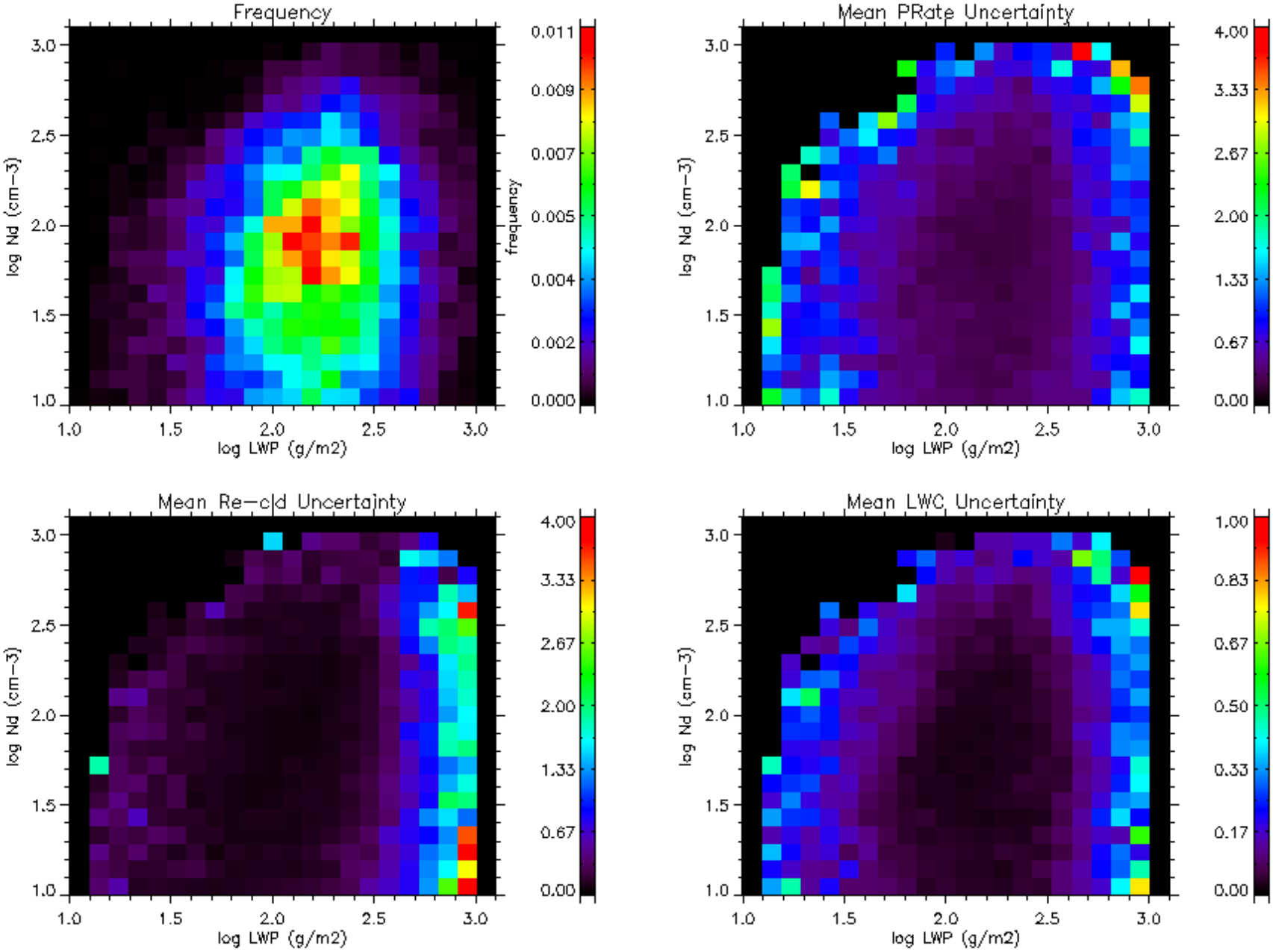


- Sea salt aerosol increases with wind speed



Feingold et al., 2013: Is the precipitation process dominated by autoconversion (Nd dependent) or accretion? LES suggest that **S diminishes with decreasing Nd** at a given LWP.

Retrieval Uncertainty stats for winter – southern_ocean



Cloud and Precipitation Property Retrieval Algorithm (Mace et al., 2016):

- Cloudsat CPR is sensitive to precip when precip is present but cloud otherwise
- MODIS Vis and NIR Reflectances sensitive to Cloud properties primarily but precip contributes
- Passive Microwave (from Cloudsat Noise - New!) responds to water path – mostly cloud but precip contributes

Together these measurements have independent (but tangled) information on the cloud and precipitation coexisting within a profile.

The Inversion Algorithm

- Assumption: Bimodal PSD– cloud mode and precipitation modes
- Input: CloudSat Z Profile, 94 GHz Tb (New Product!), MODIS 0.55, 1.6, 2.1 um reflectances
- Output: Cloud LWC, re, Nd, and Precip LWC, re, Nd in each range bin.
- Prior data from RICO and MASE

Forward Models:

Radar Forward Model: Posselt and Mace (2013). Mie backscatter and extinction. Direct integration of modified gamma PSD's. Accounts for air and droplet attenuation.

MODIS reflectances simulated using Radiant 2.0 eigenmatrix solver (Christi and Gabriel, 2004)

Microwave: Kummerow et al. (1993) with modifications by Lebsock. W-Band ocean emissivity developed by Greg Elsaesser at CSU.