POLAR SCIENCE
FOR PLANET EARTH

The Microphysics of Clouds over the Antarctic Peninsula
Observation & Modelling

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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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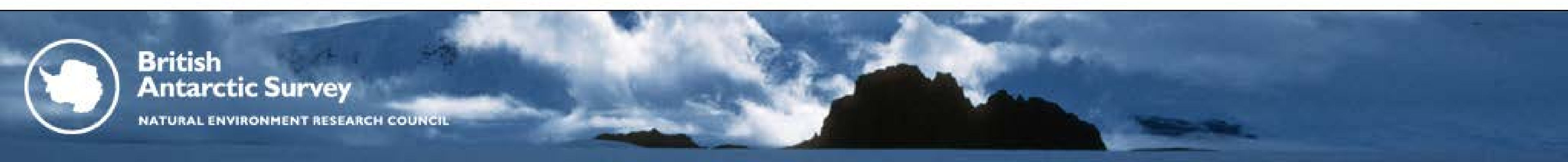


General Context

Clouds are collection of liquid droplets or/and water ice crystals (hydrometeors) that…

… contribute to the water cycle **by redistributing water vapour** (condensation-advection-sedimentation-evaporation)

… affect the **ice mass balance** at the surface through **precipitation** (albedo)

… affect the **energy budget** by reflecting shortwave and longwave radiations (temperatures)

… Impact **safety of aircraft and ground operations** (visibility, icing, precipitation)

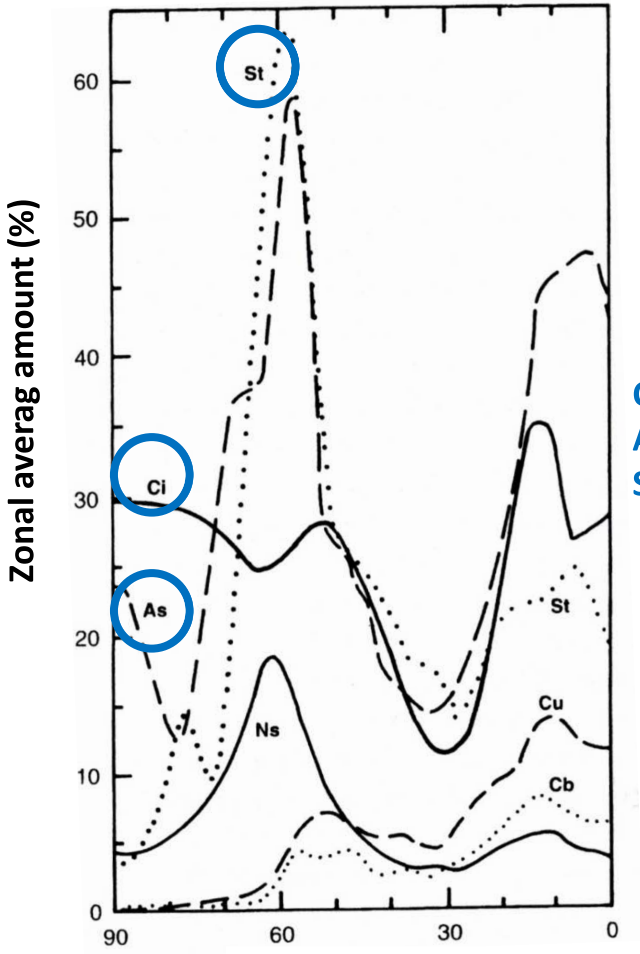
From Global Modelling studies:

Changes in Local/regional cloud properties can have a **global impact** (Gordon et al. 2000)

Change in Antarctic clouds properties can **affect regions at southern mid-latitudes (and up to the Northern hemisphere)** by impacting the North-South temperature gradient (Lubin et al. 1998).

Context: Antarctica

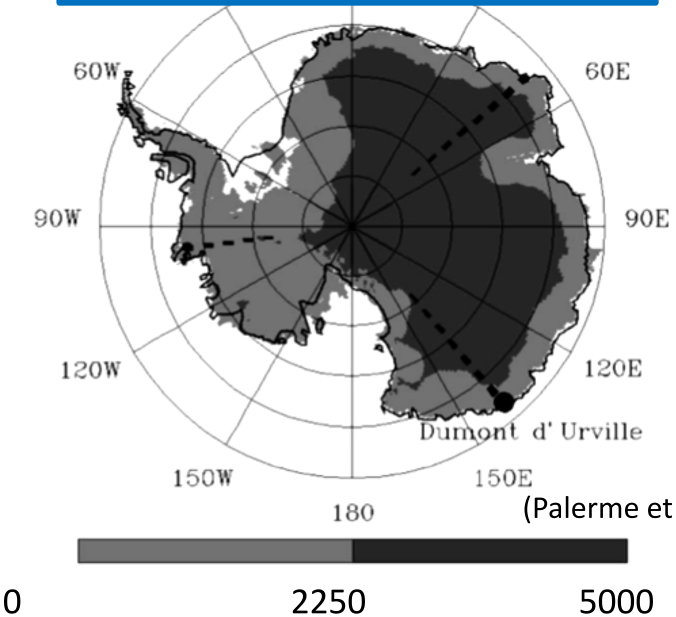
Cloud types



King & Turner, 1997 (after Warren et al., 1986)

Ci: Cirrus (high)
As: Altostratus (med)
St: Stratus (low)

Coastal regions / Interior



(Palerme et al., 2014)

Ice crystals (100s µm) + Drops/ice crystals (<5-30 µm)

(Lachlan-Cope, 2010)

Synoptic scale-driven precip./Clear-sky precip

75% precipitations / 25% of precipitations

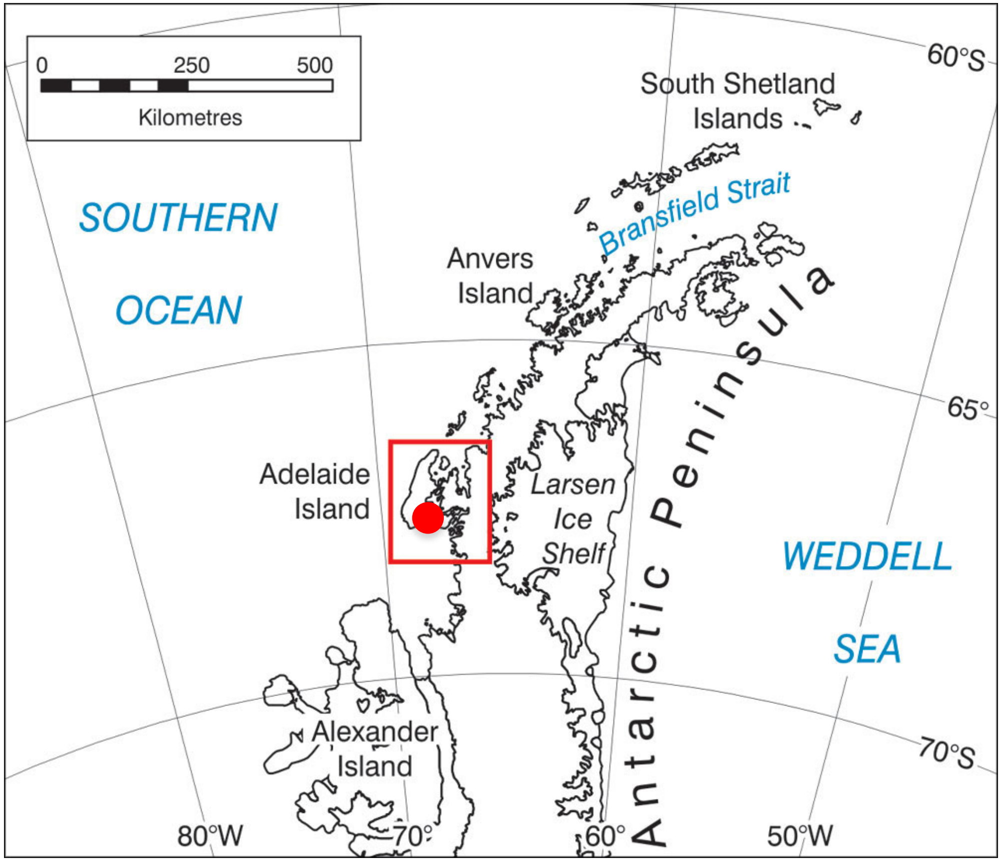
100s mm yr^{-1} accumul./<100 mm yr^{-1} accumul.

(Bromwich, 1988)

Snow grains /Diamond dust

(Walden et al., 2003)

Context: Antarctica Peninsula



Credit: BAS

WEST / EAST

West: Maritime (cyclonic) influence
East: Continental influence
(prevailing easterlies)

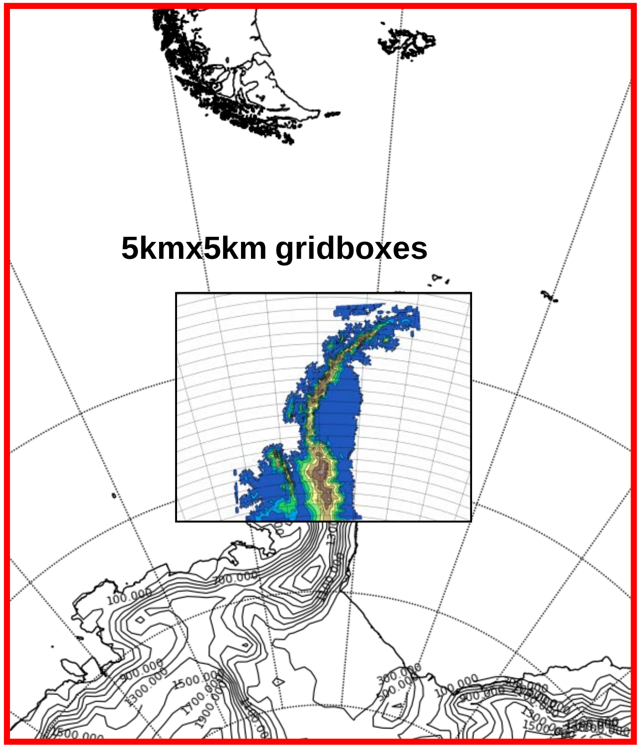
Western surface temperatures are **3-5°C warmer** than eastern ones. (Morris and Vaughan, 2003)

More Precipitations (mm water/year)
West (1260 ± 390) than East (310 ± 80).
(Peel, 1992a)

On coastal regions: precipitations produced by **adiabtic cooling of air** rising up the **steep topography** or brought by **declining depressions** (small intensity) – King&Turner, 1997

Using Polar WRF (v3.5.1) (Hines and Bromwich 2008)

45kmx45km gridboxes



Simulation settings

Boundary conditions at the 45x45km coarse domain:
European Centre for Medium-Range Weather Forecasts (ECMWF)
ERA-Interim data (0.7◦ x 0.7 ◦ resolution)
Two nests: 15kmx15km intermediate domain
5kmx5km highest resolution domain
Number of levels: 30 levels (up to 20 km asl - ≈5000 Pa)
Time of simulation: 40 days
1st Jan 2011 – 9th Feb 2011 (Austral Summer)
Topography: Bedmap2 products 1km resolution (Fretwell et al.2013)
- built for Polar WRF by Pranab Deb, Tony Phillips (BAS)

King et al. 2015 –Validation of surface summertime energy budget (Larsen C shelf – East of AP)
(AWS14 & Camp: 9 Jan – 8 Feb2011)

Deficiencies in cloud microphysics modelling rather than in cloud cover would Explain >0 SW bias and <0 LW bias in high resolution models (AMPS,Met-Office, RACMO2)

(also emphasized in reviews on Antarctic clouds: Lachlan-Cope,2010; Bromwich et al. 2013)

Microphysical schemes

Vocabulary

Non-precipitable: Liquid droplets (liquid)/Ice crystals (ice)
Precipitable: rain drops/snow/graupel

Single-moment (SM): predicts mass (kg/kg)
Double-moment (DM): predicts mass AND number density (#/kg) – more realistic behavior

WRF single moment 5 (**WSM5**) – Default scheme in (Polar) WRF
<u>used in Antarctic Mesoscale Prediction System</u>
SM for liquid droplets, rain, ice, snow

WRF Double moment 6 (**WDM6**) – “Upgrade” of default scheme wsm5.
DM for liquid and predicts Cloud Condensation Nuclei (CCN)

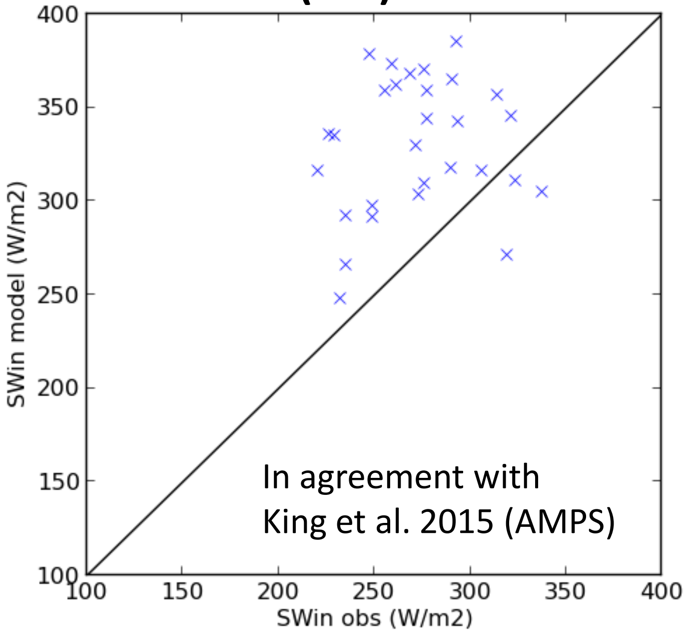
Morrison scheme (**MDM**) – DM for all icy hydrometeors and rain / SM for liquid droplets
<u>used in Arctic System Reanalysis</u>

Thomson scheme **(Thom) –** DM for ice, with state of the art parameterization for snow
(fractal-like snow)

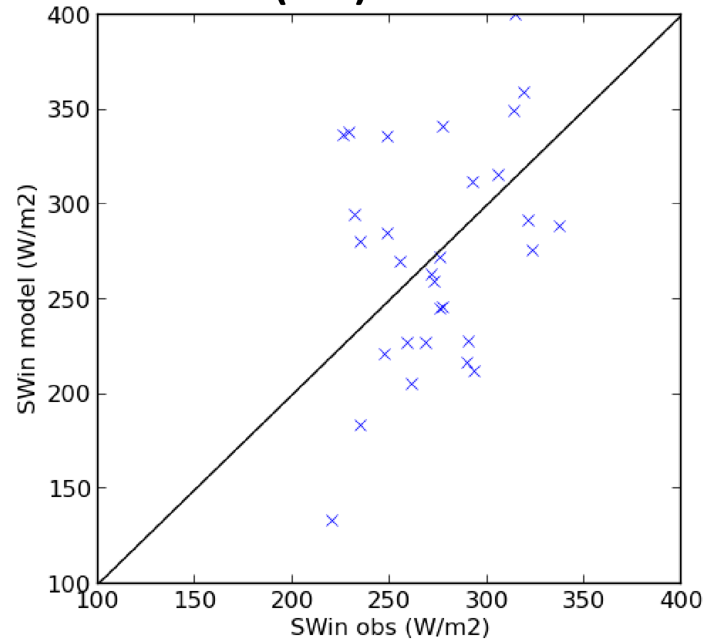
Monthly radiation biases (W/m2) over Jan 2011

	Rothera (SW/LW)	AWS14 (SW/LW)
WSM5	52/26	53/-20
Morrison	49/26	**-5/1**

AWS14 (SW) – WSM5



AWS14 (SW) – Morrison



Cloud Microphysics scheme → Info? → Radiative scheme → Surface bias

Conclusions?

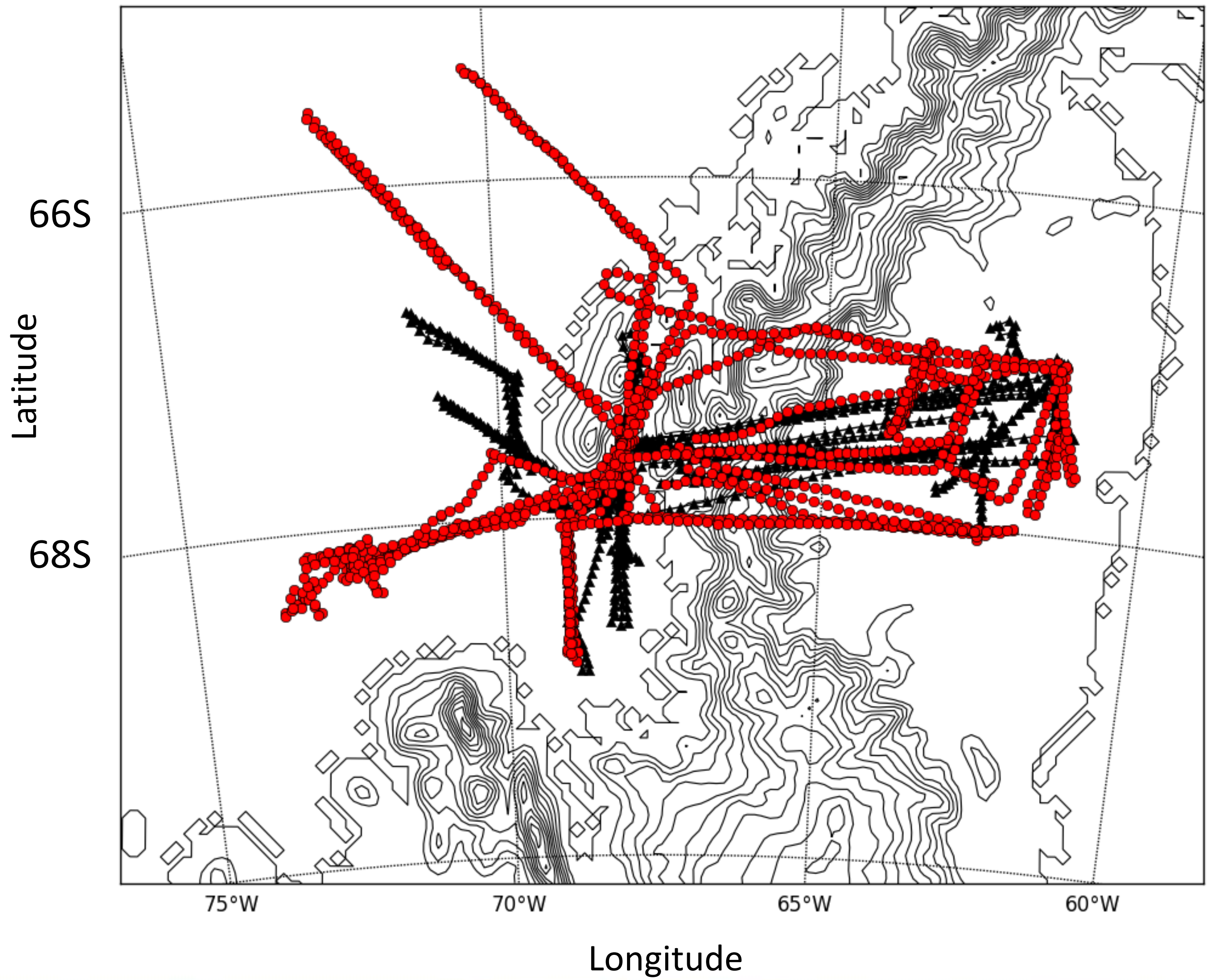
2010 & 2011 Campaigns

"First time clouds have been directly sampled by aircraft in Antarctica since 2 flights in November 1980 [near the Ross ice shelf]described in Saxena and Ruggiero (1990)..."
(Grosvenor et al., 2012)

Credit: Russ Ladkin (BAS)

Cloud probe
2D imaging probe (25-1550µm)
Aerosol spectrometer (0.5-50 µm)
Liquid water content probe (0.01-3.0 g/m3)

Flights tracks

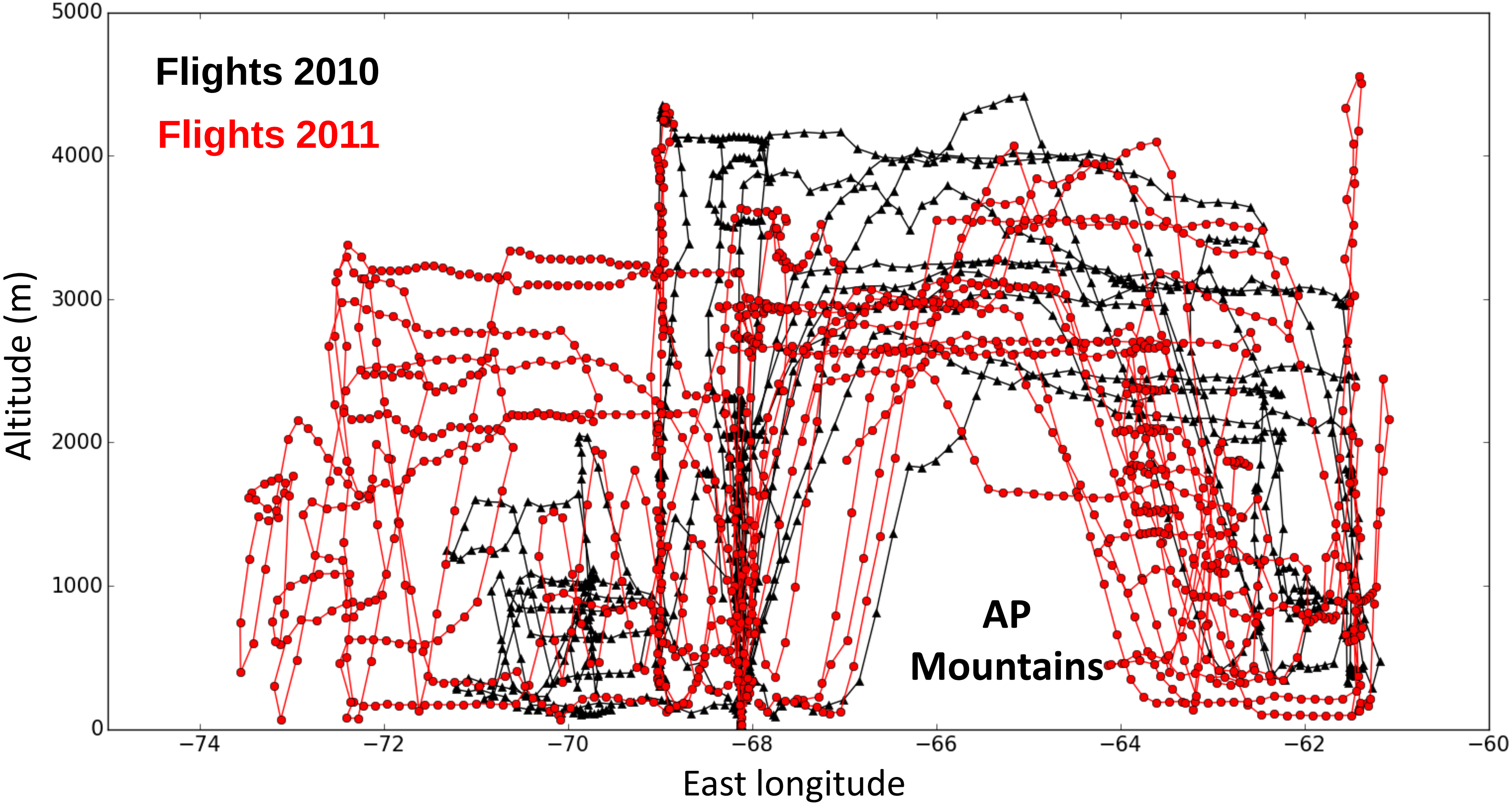


Flights 2011
11Jan – 6 Feb 2011
(11 flights)

Flights 2010
3Feb – 4March 2010
(11 flights)

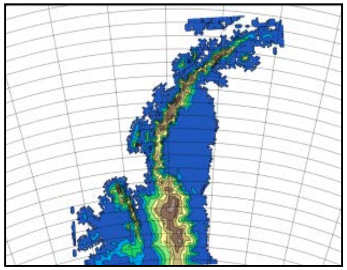
Modelling
1st Jan – 9th Feb 2011

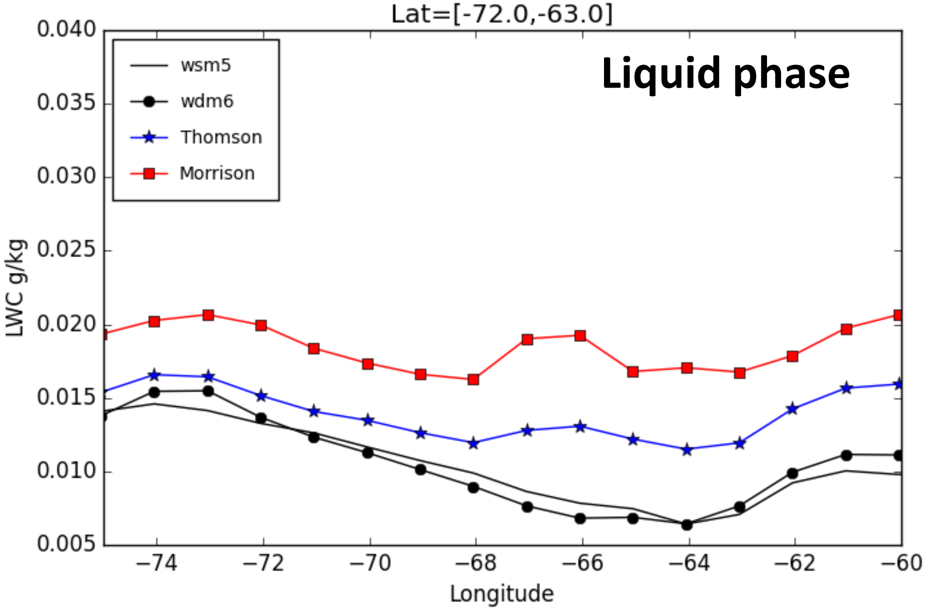
Altitudes of Flights

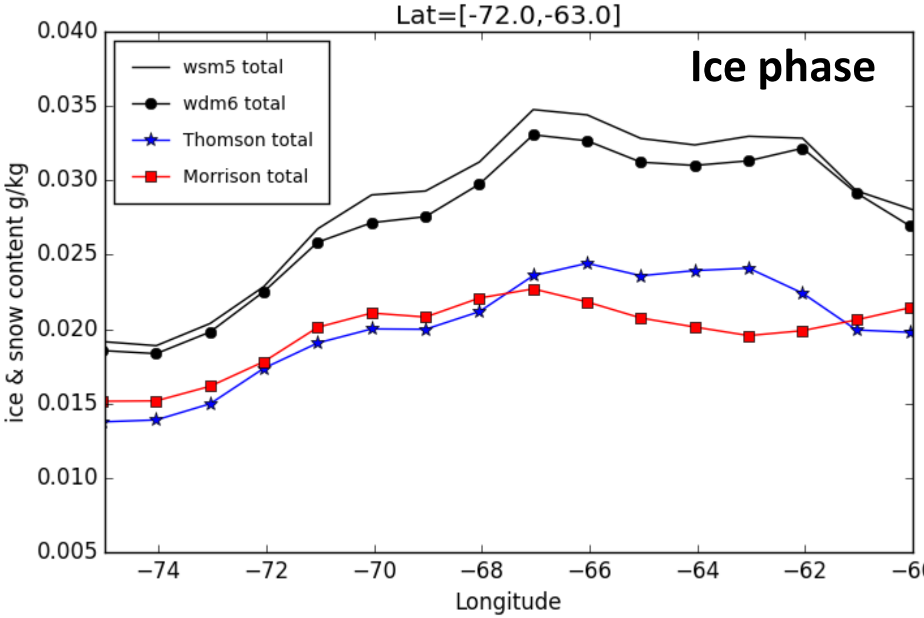


Zonal distribution of liquid/ice phase in model

In the entire high resolution domain

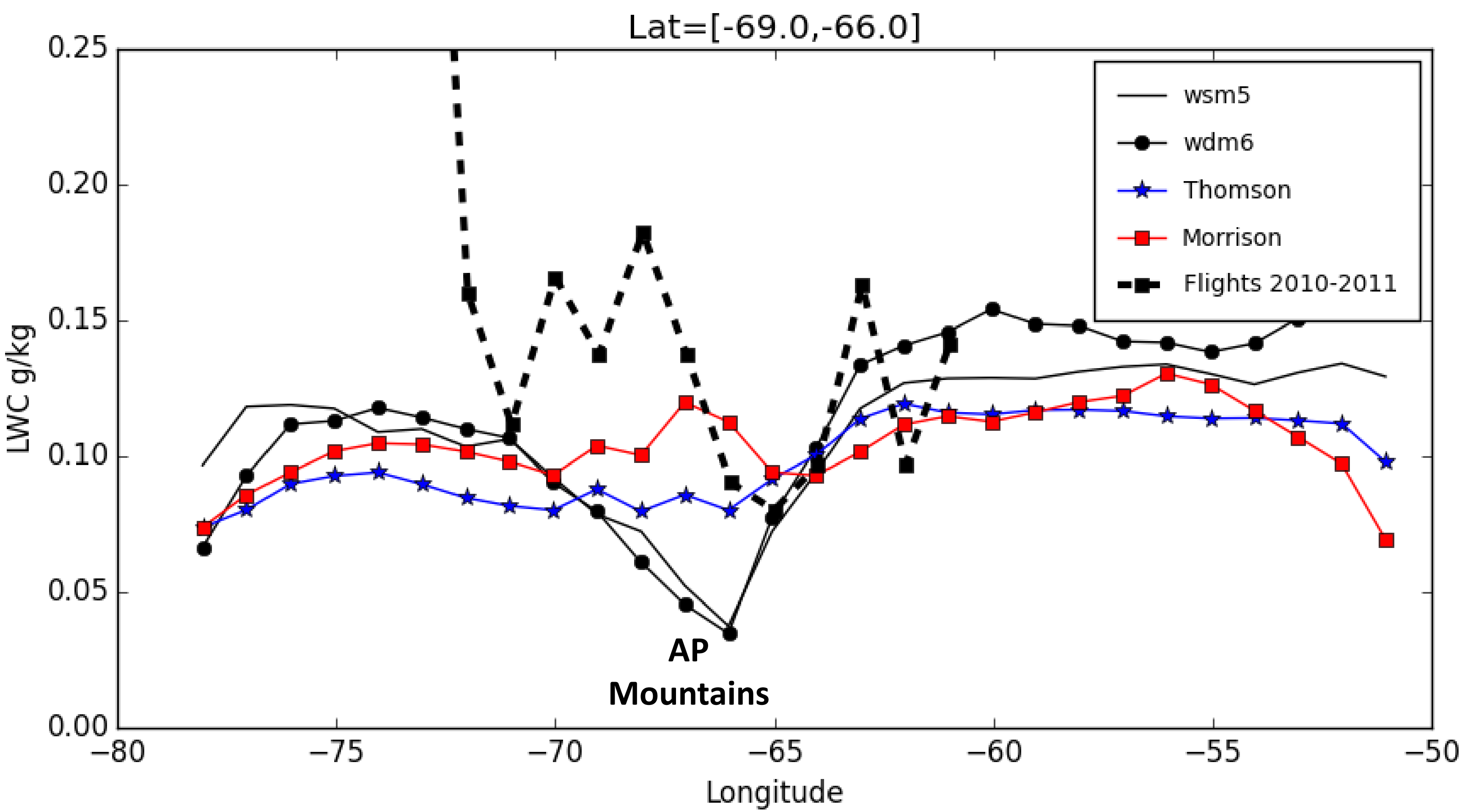






WSM5/WDM6 form
less liquid mass and more ice mass than
Morrison/Thomson

Zonal distribution of Liquid Water Content (LWC, g/kg) where cloud forms



Zonal distribution of ice and snow (g/kg) where ice cloud forms

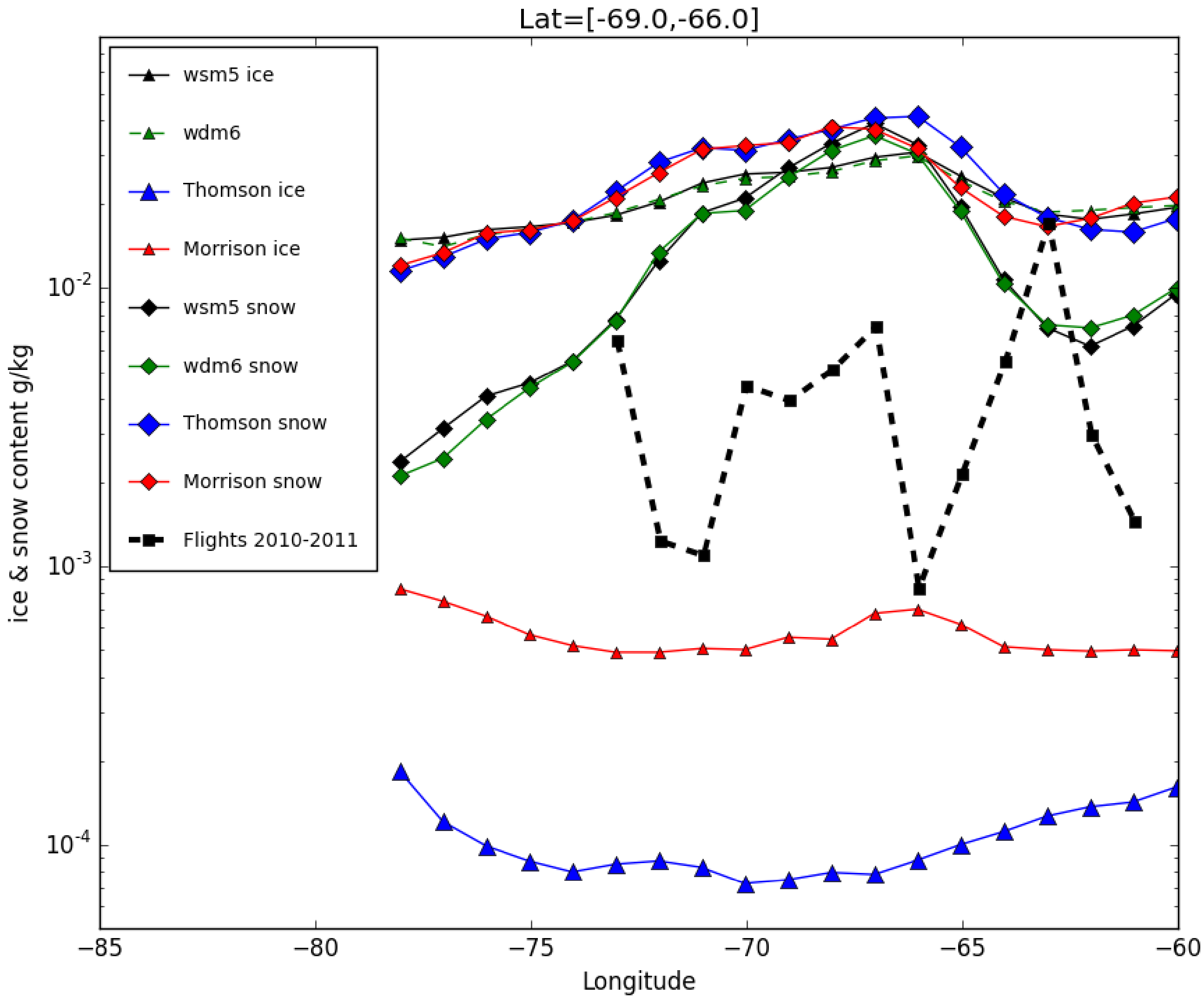
Microphysics Schemes:

Ice <≈200µm

Snow> ≈ 200µm

Measurements:

20µm-1mm

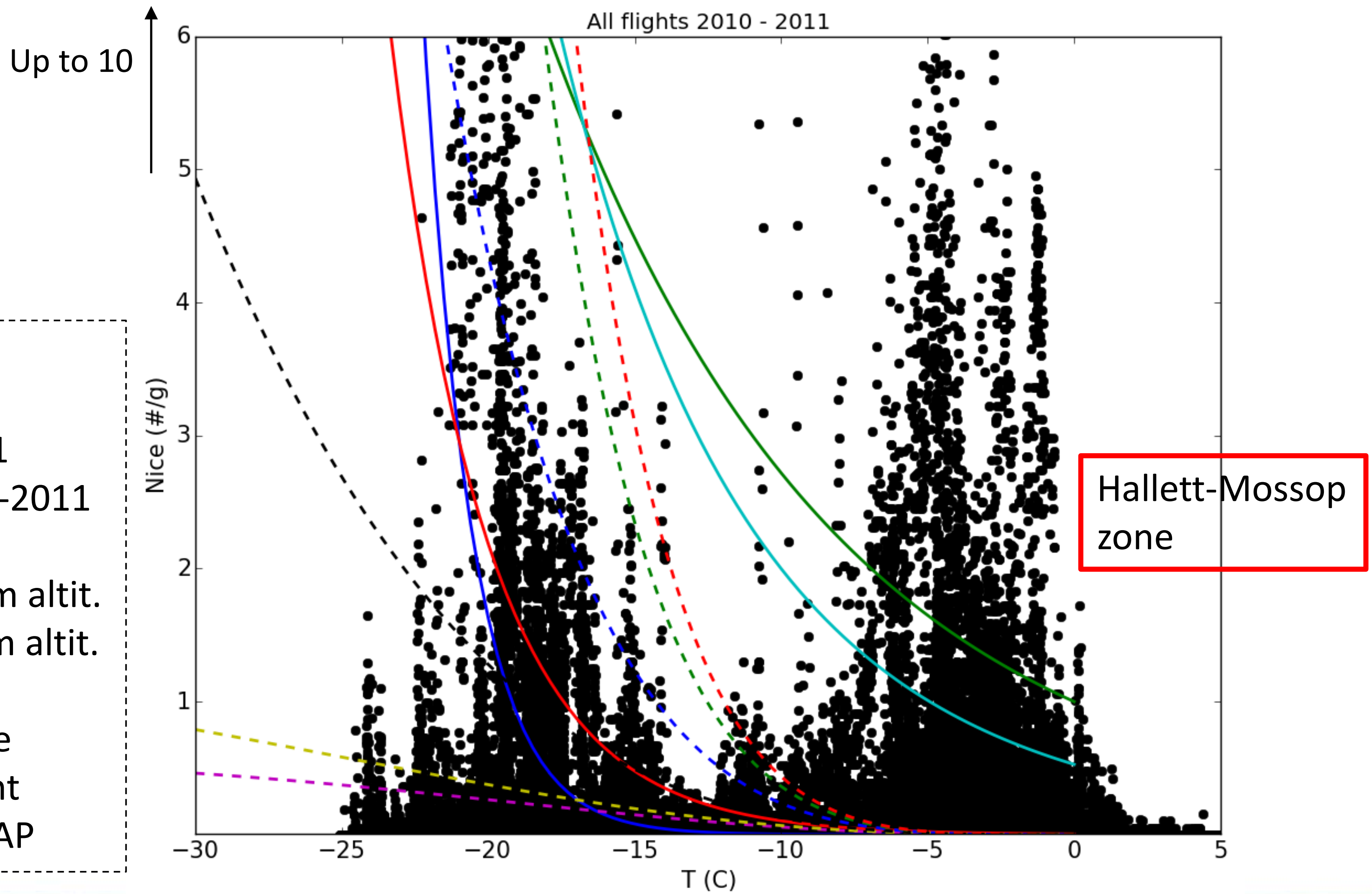


Liquid Phase & Ice phase where clouds form, on Flight tracks only

	Liquid (g/kg)	Ice (g/kg)	mixed phase	
			Liquid (g/kg)	Ice (g/kg)
WSM5	0.065	0.017	0.065	0.012
WDM6	0.059	0.017	0.059	0.0065
Morrison	**0.129**	**0.006**	**0.129**	**0.004**
Thomson	0.080	0.014	0.075	0.018
Flights (2011)	**0.15**	**0.005**	**0.17**	**0.004**

Ice particles in all observed clouds : 2010-2011 flights

Primary/Secondary ice production? (PIP or SIP?)



Stats:

PIP: 2011
SIP:2010-2011

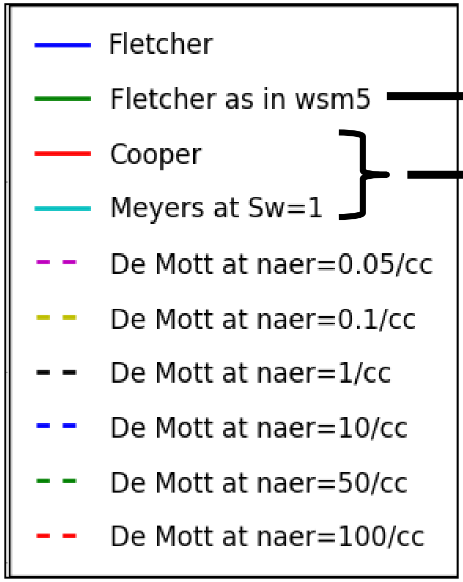
PIP: >2km altit.
SIP: <2km altit.

SIP: more important West of AP

Triggering of (primary) ice prod. in microphyiscs Scheme is done thanks to
Ice Nuclei Parameterizations: IN=f(T)

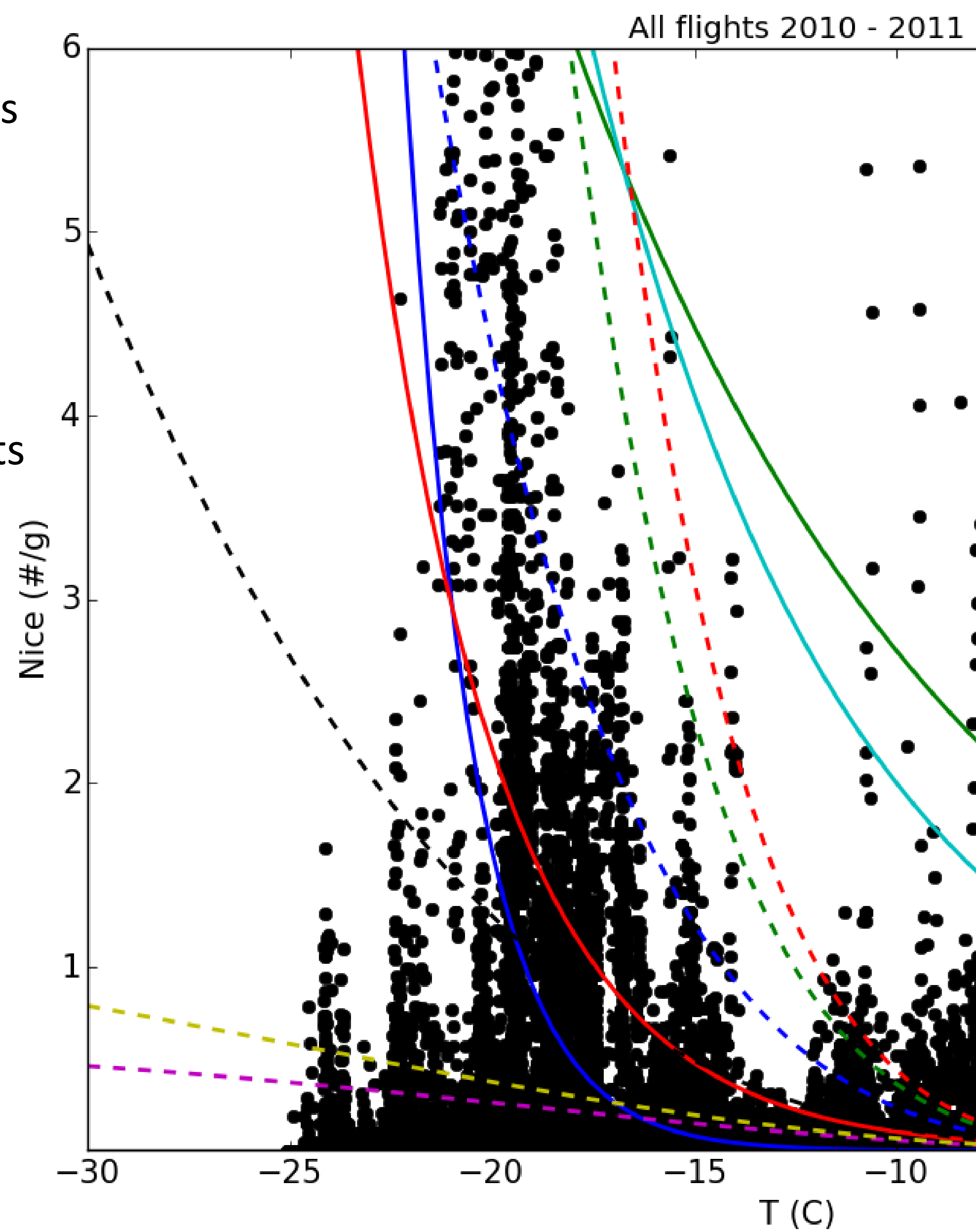
PIP → SIP

Currently, all rely on mid-latitude measurements
And cause overestimations of IN.



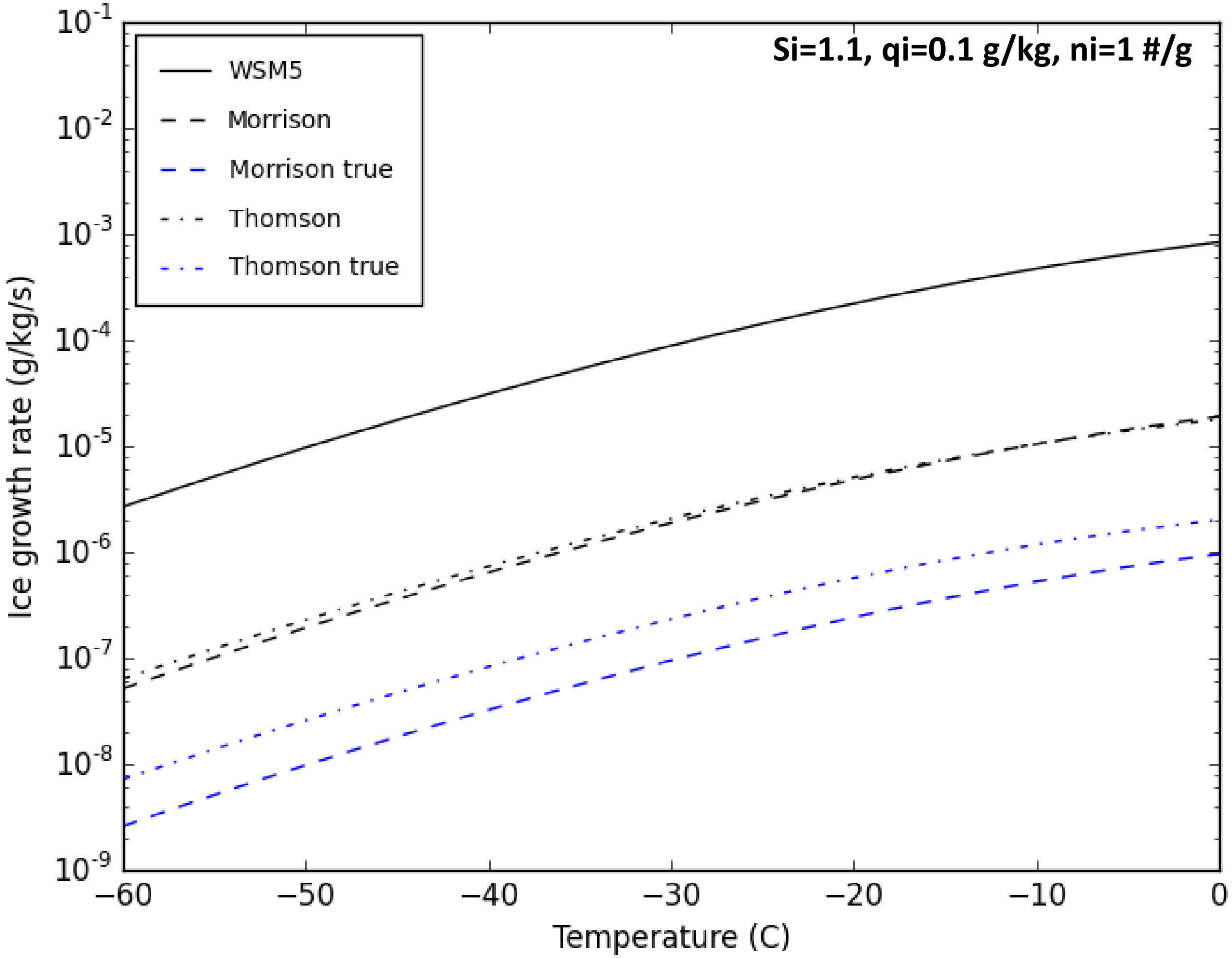
wsm5/wdm6

Morrison/Thomson



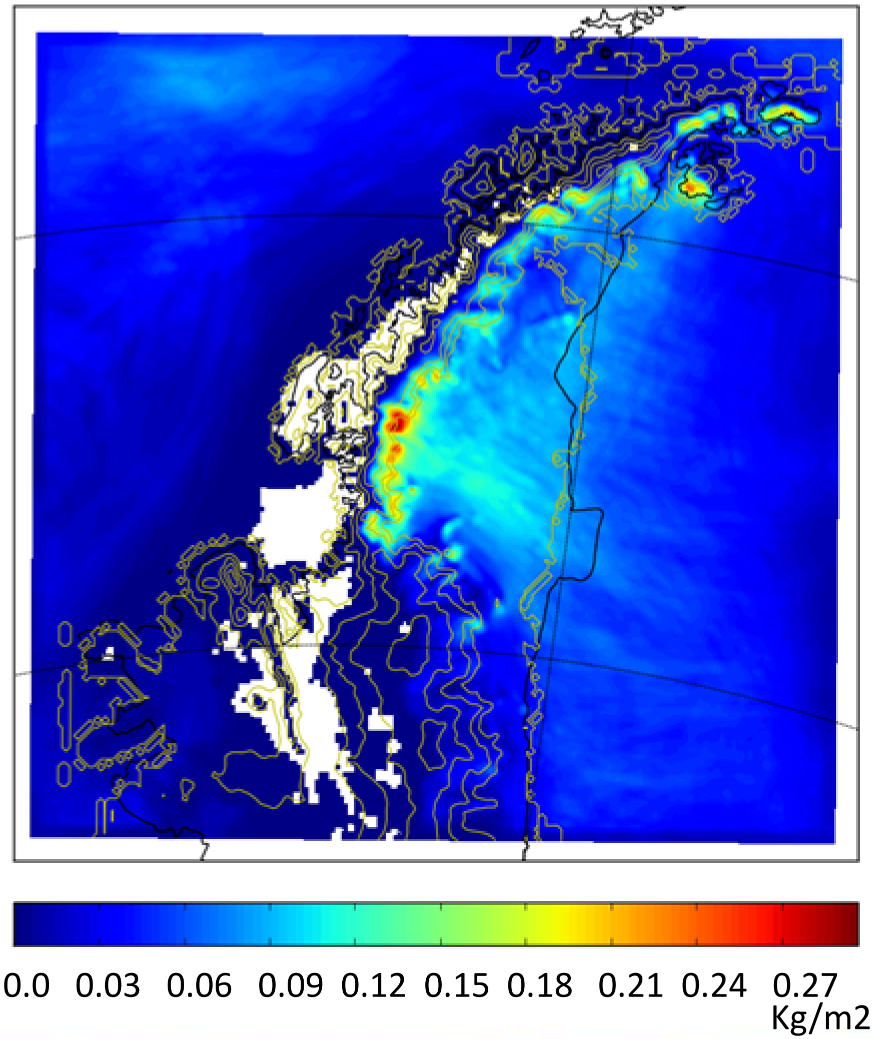
Ice Microphysics: ice growth rate

WSM5 form ice faster and depletes vapour faster so that not enough liquid can form

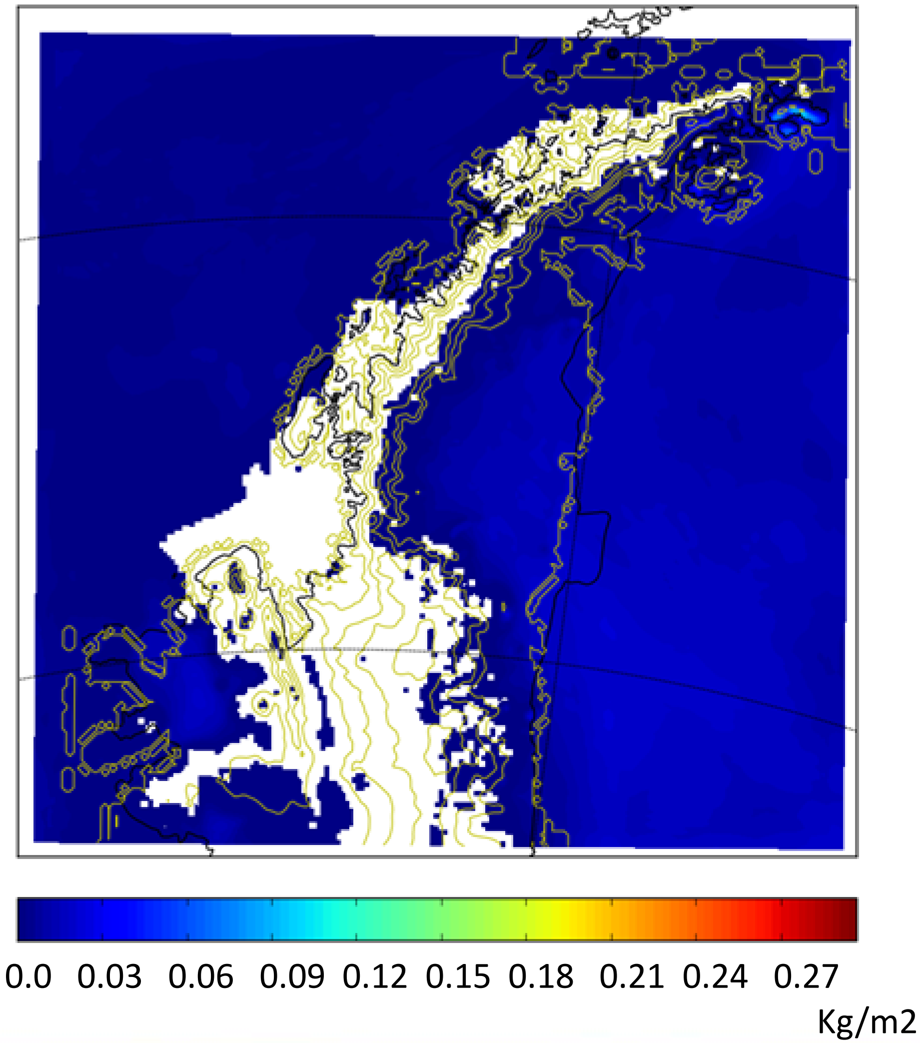


Mapping of average liquid water column density over 11-21Jan 2011

Morrison scheme



WSM5 scheme



Conclusion

Morrison scheme is the scheme which better agrees with flight data
Both for liquid and ice phases over the AP during January 2011.

Morrison scheme, then Thomson, then WSM5/WDM6 produce
The more liquid and less ice (in that order) over the entire domain

Morrison might be the best candidate to lower SW/LW biases (East. However: West?)

WSM5 & WDM6 behaves in very similar ways (nor particular improvements)

WSM5 & WDM6 ice growth rate are much larger than Morrison's and Thomson's
(rely on strong hypothesis of Ni propto qi^3/4 – not realisitc).

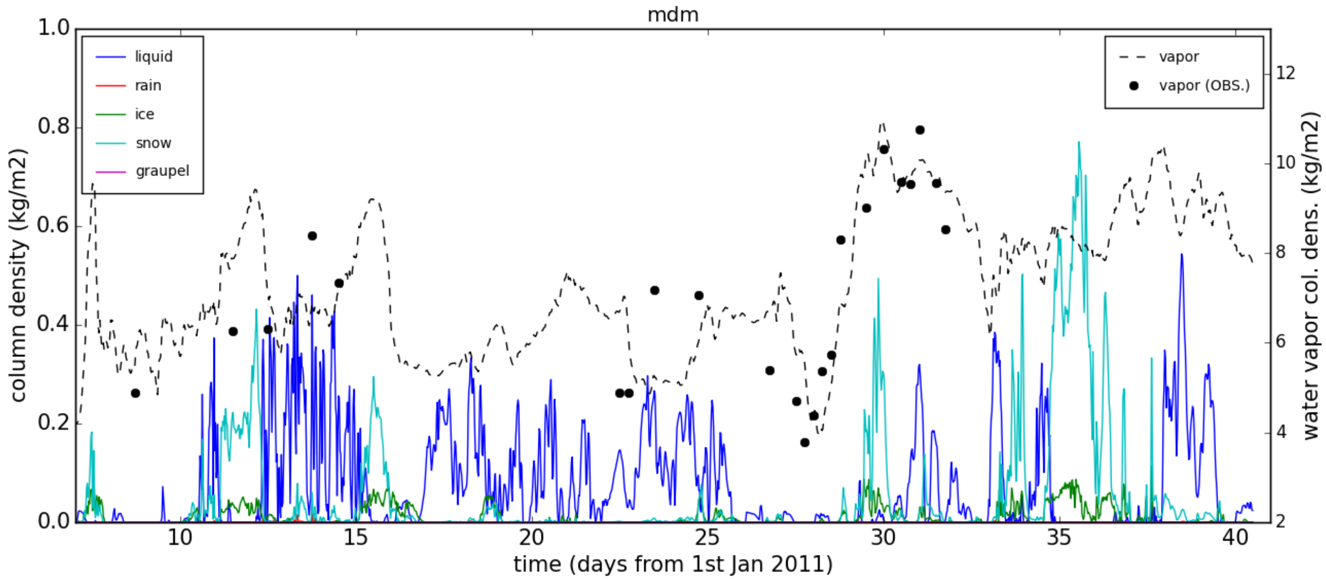
No Particular West/East differences in microphysical properties of clouds LWC, ice, and droplet number (not shown) from data on the two sides of AP.
Although **more SIP West of AP and below 2km, than East of AP. More PIP East of AP.**

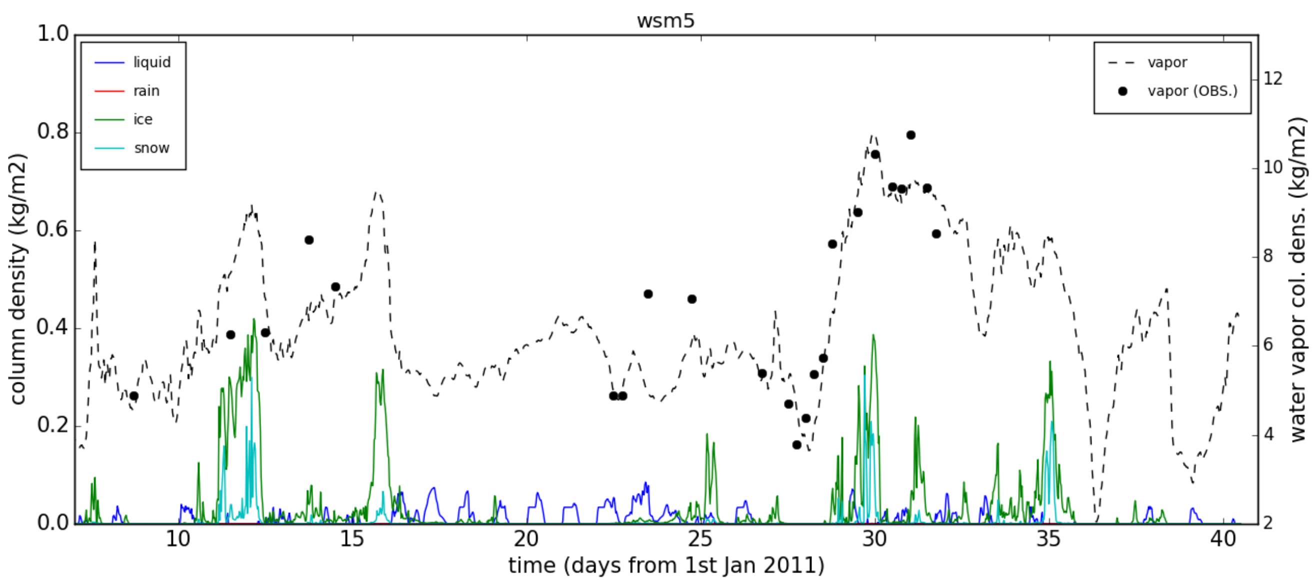
Both **primary and secondary ice production peaks appear in data** Nice=f(T) with values up to 10 #/g. (**Morrion & Thomson do include SIP**, not WSM5/WDM6)

None of current parameterization represent the ice data (including the most recent DeMott et al. 2010 which tends to overestimate IN –not shown)
However there is a possibility to build a new parameterization (would it be representative?)

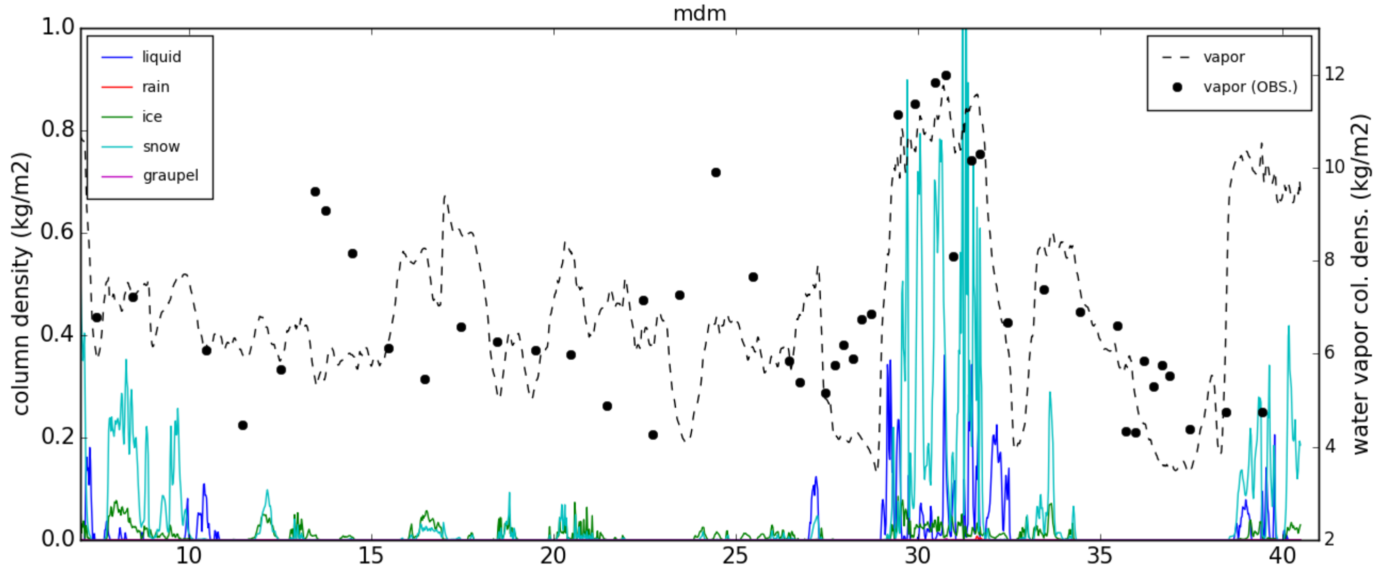
Extra slides

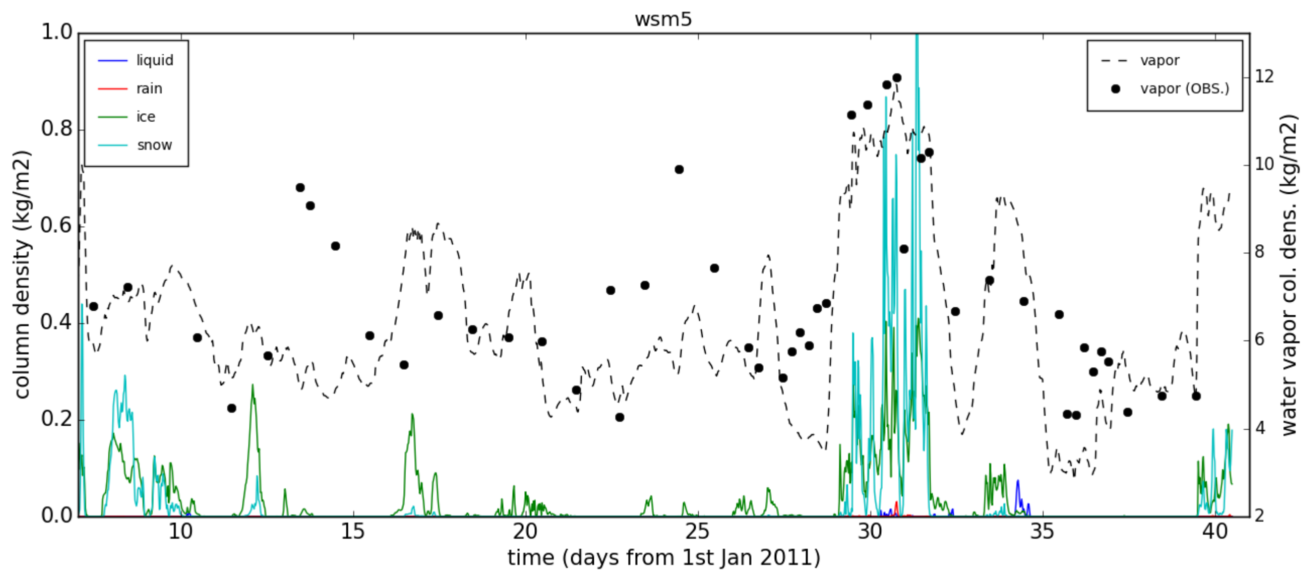
AWS14

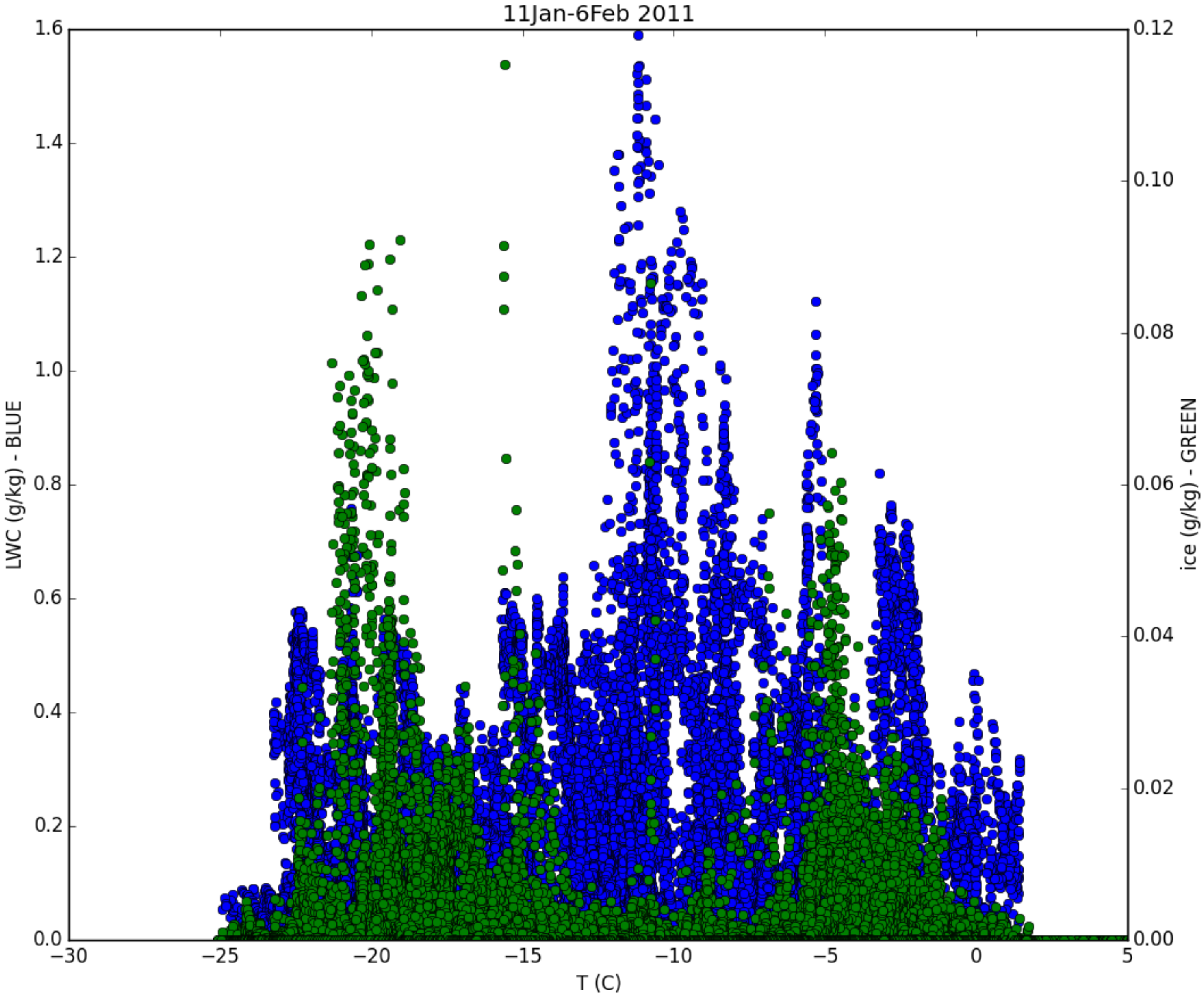

mdm
liquid
rain
ice
snow
graupel
vapor
vapor (OBS.)
column density (kg/m2)
water vapor col. dens. (kg/m2)
time (days from 1st Jan 2011)
1.0
0.8
0.6
0.4
0.2
0.0
12
10
8
6
4
2
10
15
20
25
30
35
40

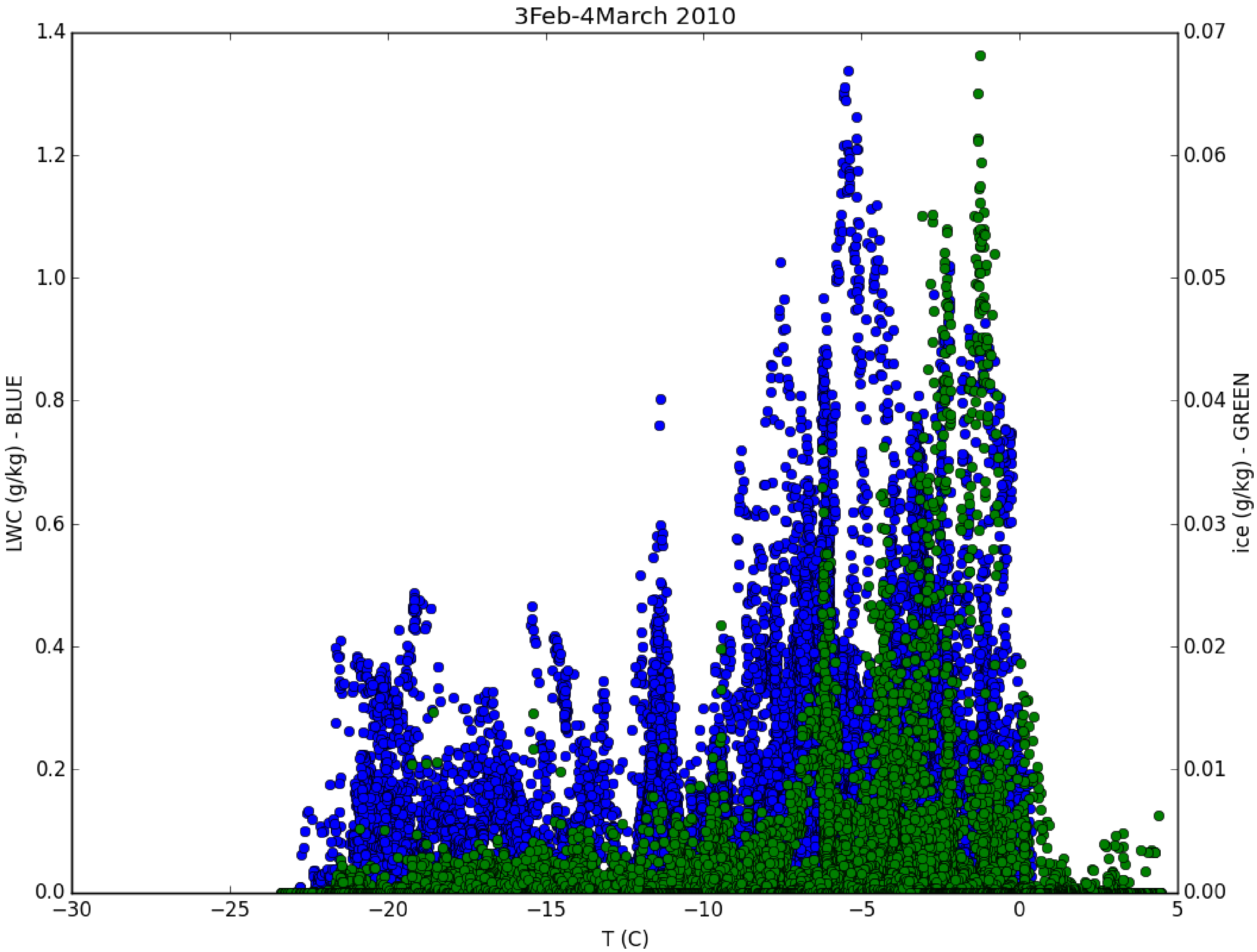

wsm5
liquid
rain
ice
snow
vapor
vapor (OBS.)
column density (kg/m2)
water vapor col. dens. (kg/m2)
time (days from 1st Jan 2011)
1.0
0.8
0.6
0.4
0.2
0.0
12
10
8
6
4
2
10
15
20
25
30
35
40

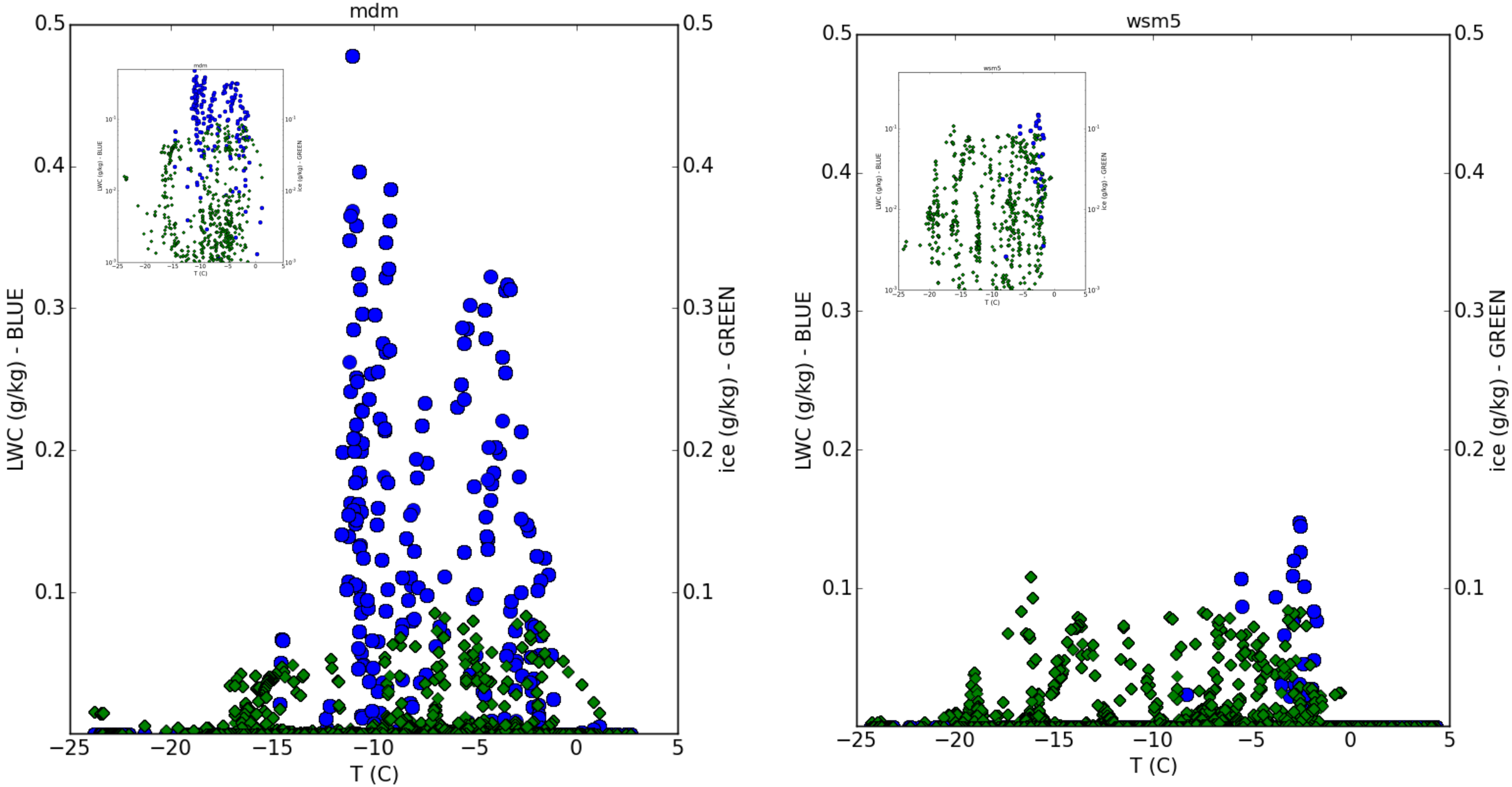
Rothera

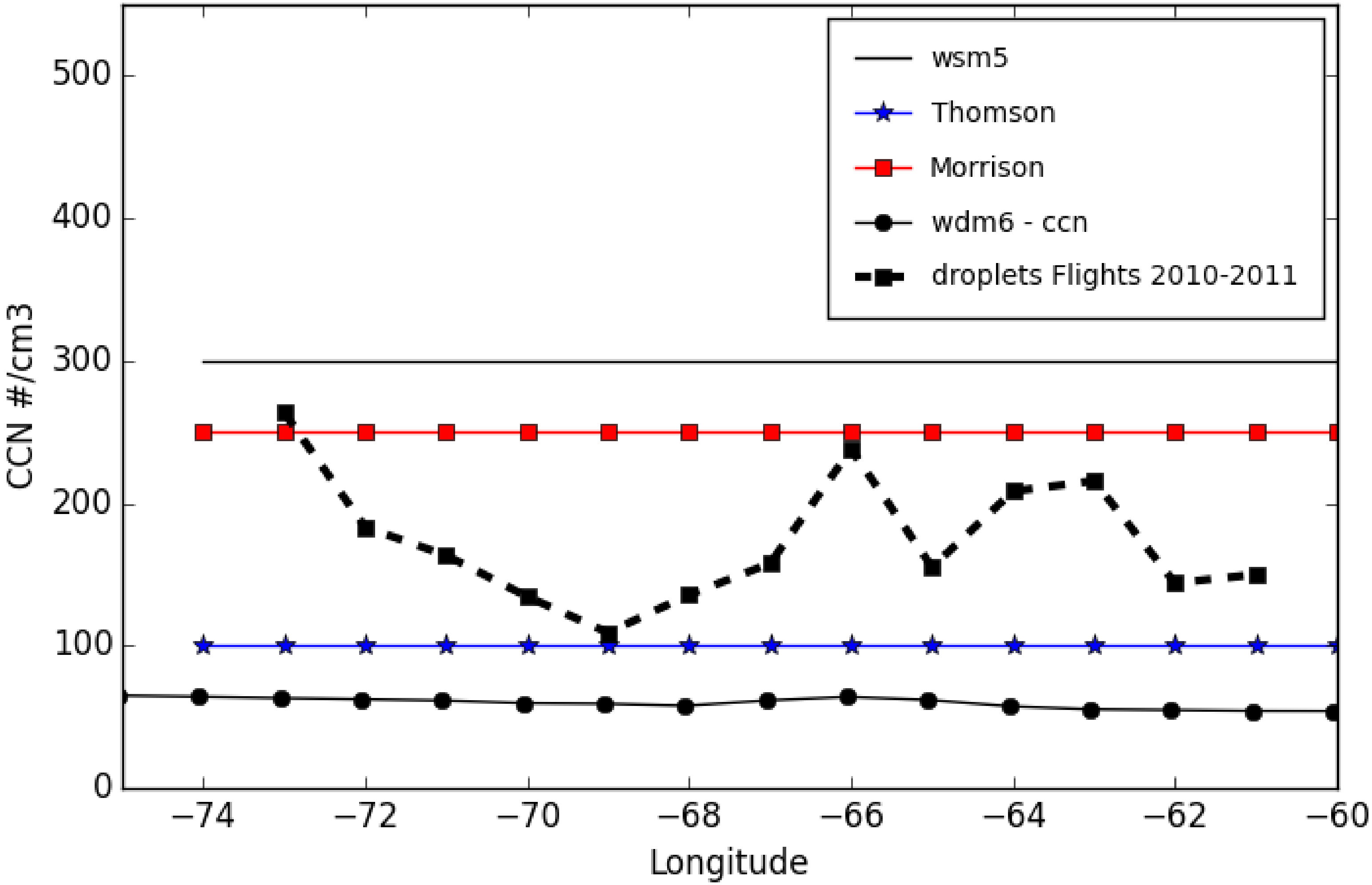

mdm
liquid
rain
ice
snow
graupel
vapor
vapor (OBS.)
column density (kg/m2)
water vapor col. dens. (kg/m2)
1.0
0.8
0.6
0.4
0.2
0.0
12
10
8
6
4
2
10
15
20
25
30
35
40


wsm5
liquid
rain
ice
snow
vapor
vapor (OBS.)
column density (kg/m2)
water vapor col. dens. (kg/m2)
1.0
0.8
0.6
0.4
0.2
0.0
12
10
8
6
4
2
10
15
20
25
30
35
40
time (days from 1st Jan 2011)

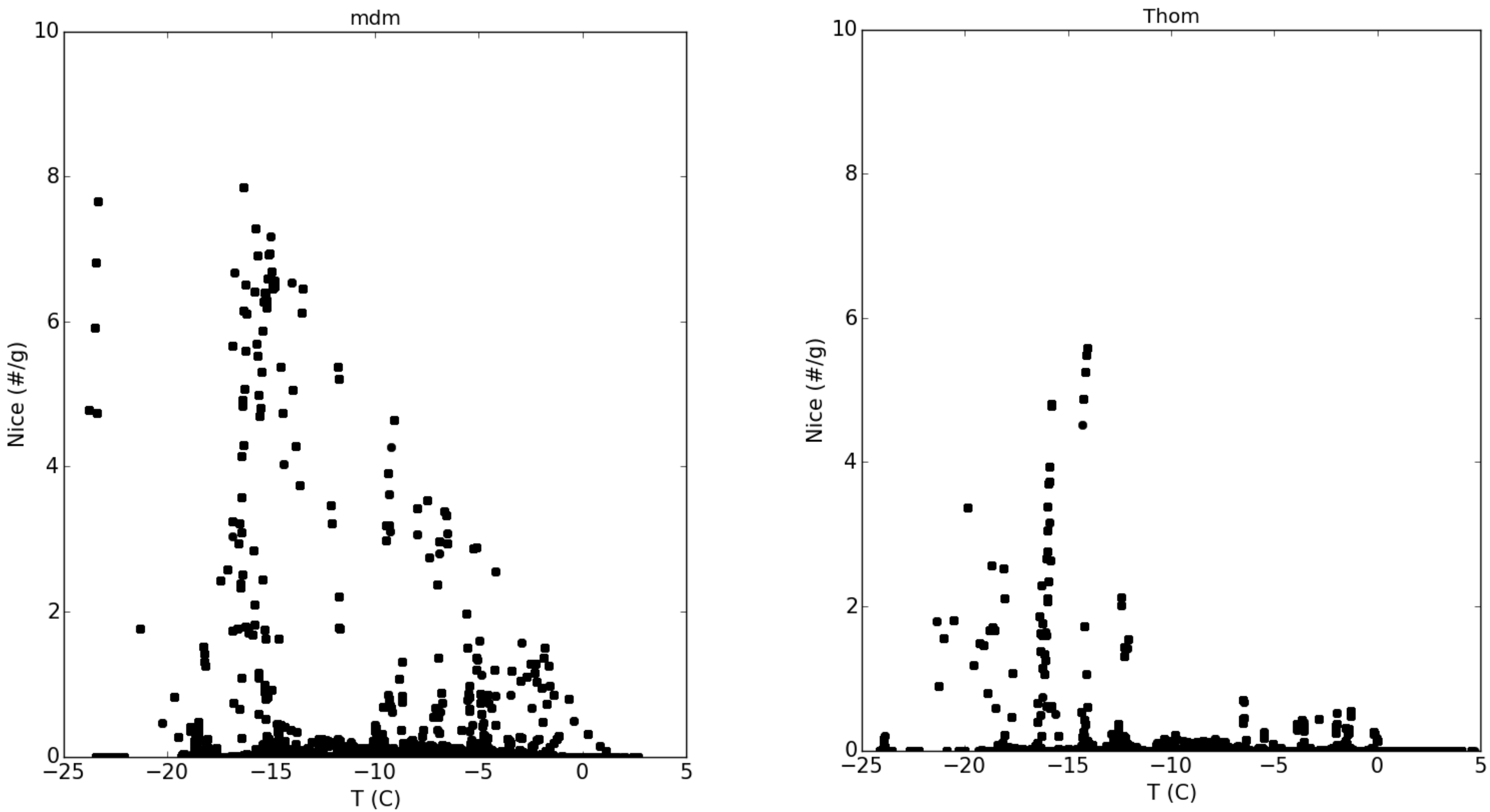

11Jan-6Feb 2011
LWC (g/kg) - BLUE
ice (g/kg) - GREEN
T (C)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.12
0.10
0.08
0.06
0.04
0.02
0.00
−30
−25
−20
−15
−10
−5
0
5

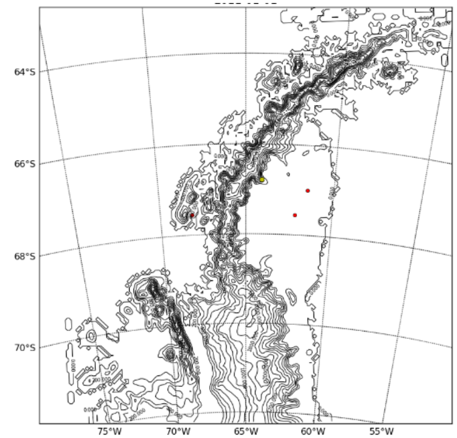

3Feb-4March 2010
LWC (g/kg) - BLUE
ice (g/kg) - GREEN
T (C)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−30
−25
−20
−15
−10
−5
0
5


mdm
LWC (g/kg) - BLUE
ice (g/kg) - GREEN
T (C)
0.5
0.4
0.3
0.2
0.1
−25
−20
−15
−10
−5
0
5
wsm5
LWC (g/kg) - BLUE
ice (g/kg) - GREEN
T (C)



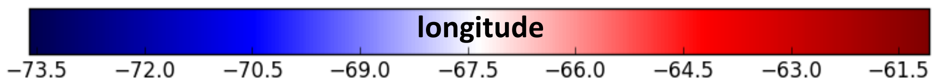
wsm5
Thomson
Morrison
wdm6 - ccn
droplets Flights 2010-2011
CCN #/cm3
Longitude
0
100
200
300
400
500
−74
−72
−70
−68
−66
−64
−62
−60


mdm
Nice (#/g)
T (C)
Thom
Nice (#/g)
T (C)

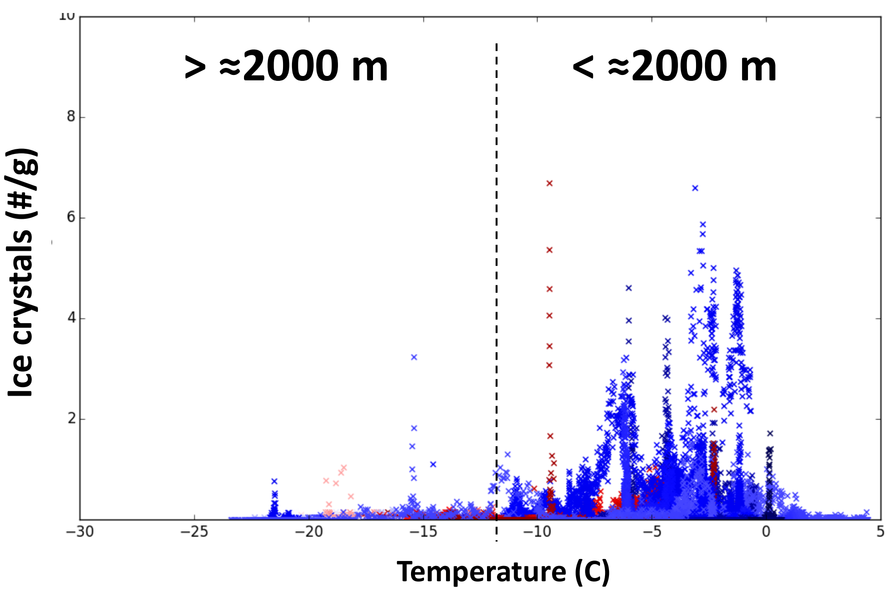


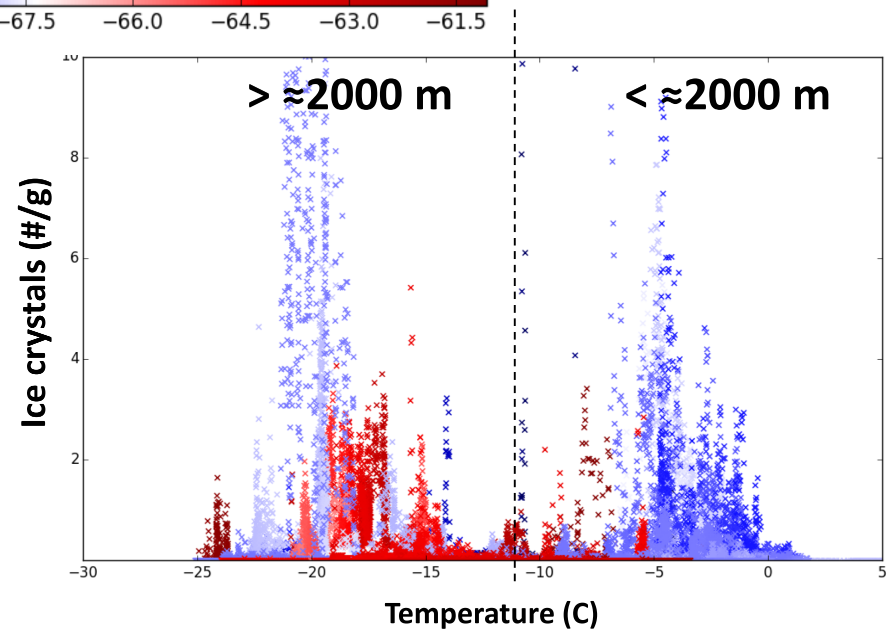
2010 flights

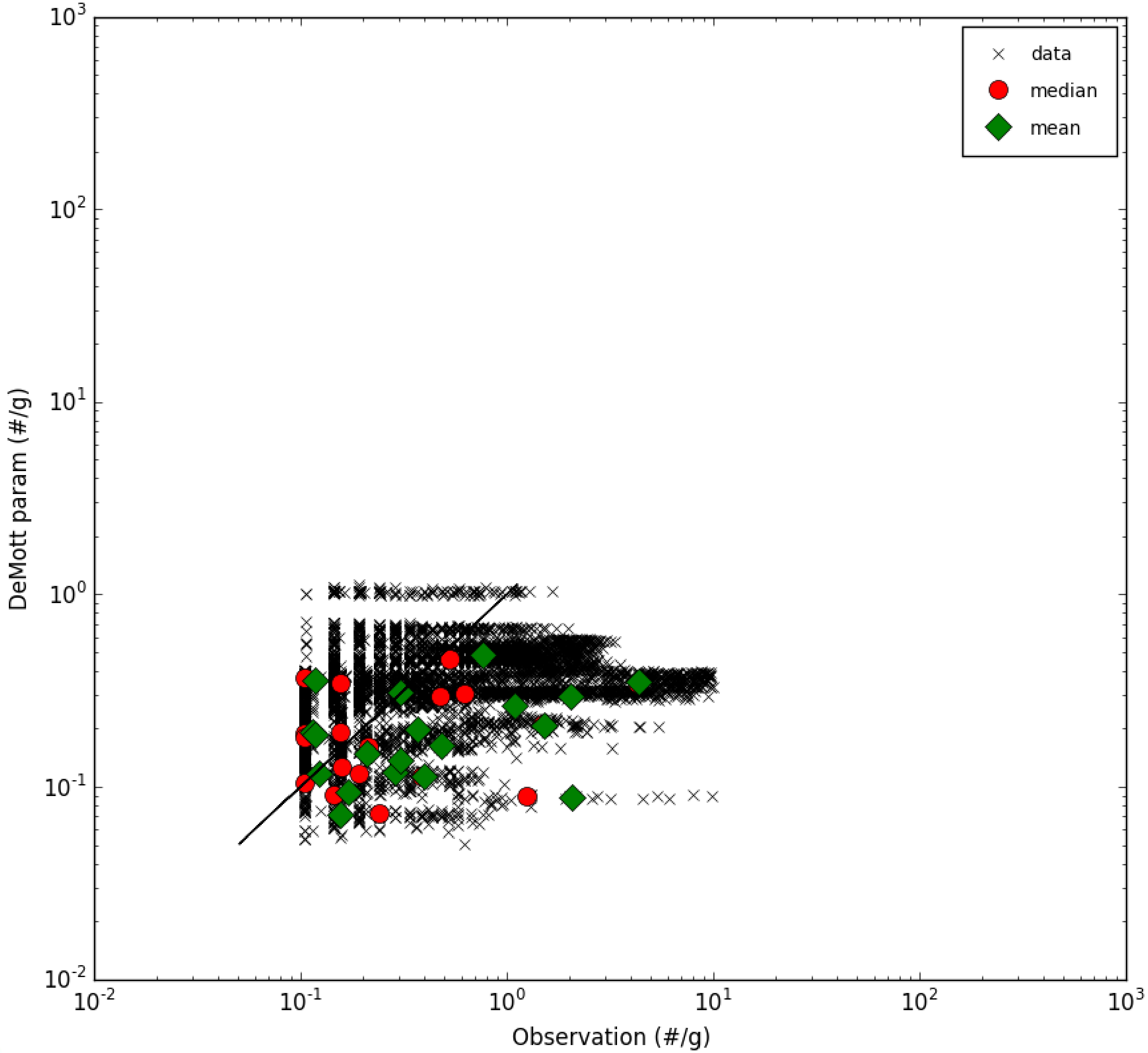
(cf. Grosvenor et al. 2012)



2011 flights

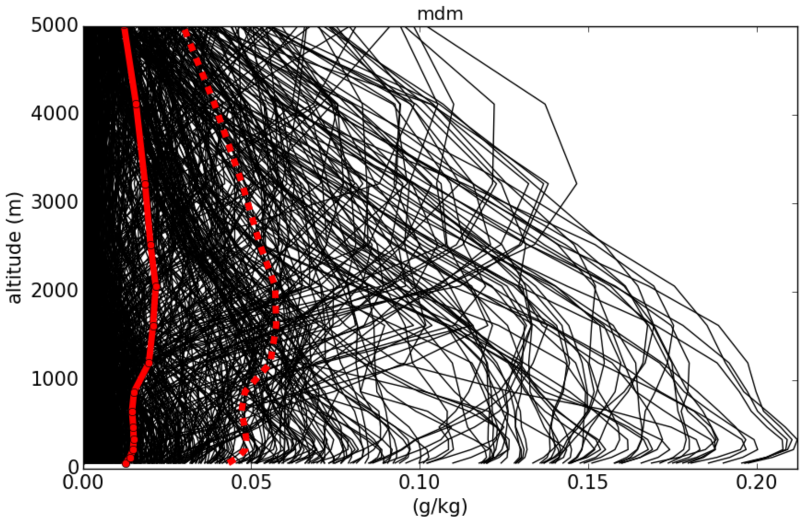


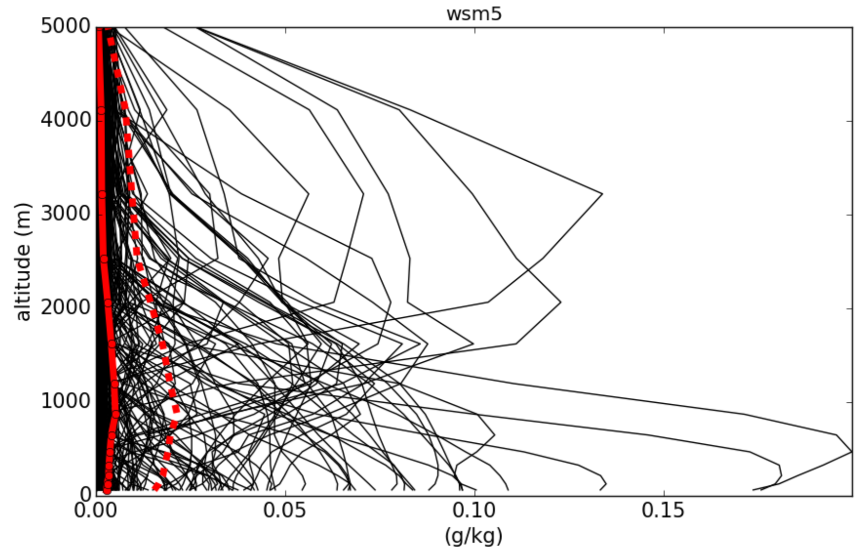




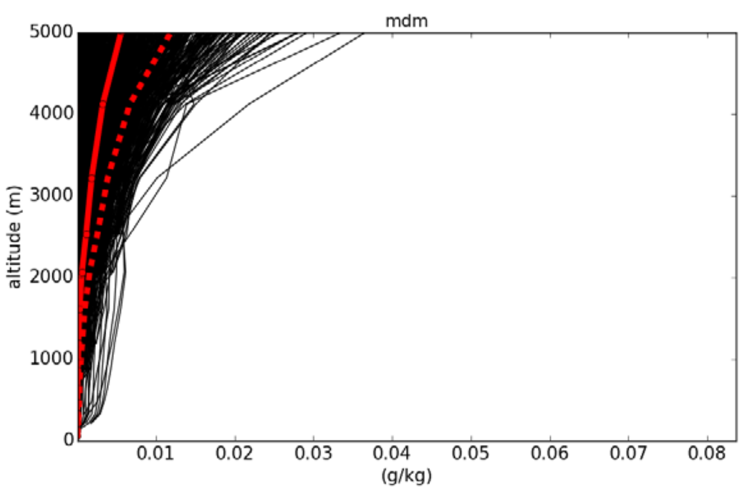
data
median
mean
DeMott param (#/g)
Observation (#/g)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

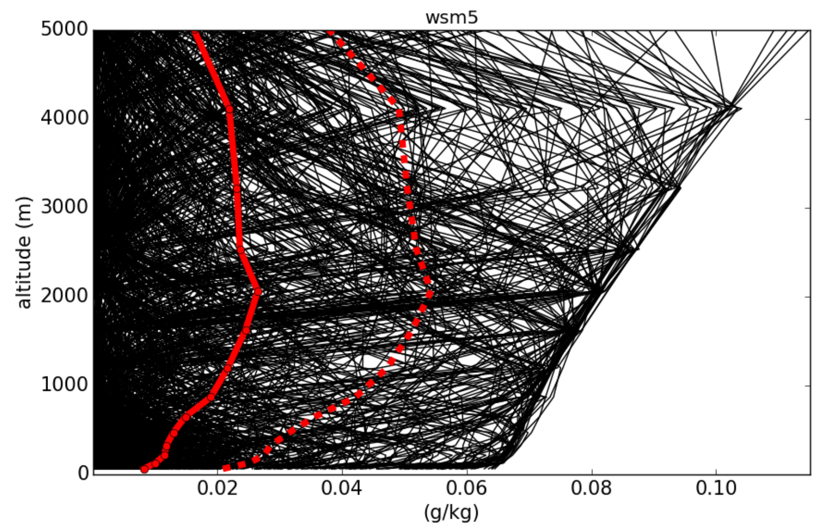
Aws14 - snow





Aws14 - ice





Liquid Phase & Ice phase in Clouds on Flight tracks only

	Liquid (g/kg)	Ice (g/kg)	mixed phase		Phase ratio (Liq/Ice)	Mixed Phase Ratio
			Liquid (g/kg)	Ice (g/kg)		
WSM5	0.065	0.017	0.065	0.012	3.8	5.4
WDM6	0.059	0.017	0.059	0.0065	3.5	9.1
Morrison	**0.129**	**0.006**	**0.129**	**0.004**	**21.5**	**32.2**
Thomson	0.080	0.014	0.075	0.018	5.7	4.2
Flights (2011)	**0.15**	**0.005**	**0.17**	**0.004**	**30**	**42.5**