The Microphysics of Clouds over the Antarctic Peninsula
Observation & Modelling

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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

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

Zonal average amount (%)

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

Coastal regions / Interior

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)
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

Context: Antarctica Peninsula

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)
**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)

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King et al. 2015 – Validation of surface summertime energy budget (Larsen C shelf – East of AP)
(AWS14 & Camp: 9 Jan – 8 Feb 2011)

**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

*used in Antarctic Mesoscale Prediction System*

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

*used in Arctic System Reanalysis*

**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

<table>
<thead>
<tr>
<th></th>
<th>Rothera (SW/LW)</th>
<th>AWS14 (SW/LW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSM5</td>
<td>52/26</td>
<td>53/-20</td>
</tr>
<tr>
<td>Morrison</td>
<td>49/26</td>
<td>-5/1</td>
</tr>
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</table>

In agreement with King et al. 2015 (AMPS)

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

Flights 2010

Flights 2011

Mountains

East longitude

Altitude (m)
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 $\approx 200\mu m$
- Snow $\approx 200\mu m$

**Measurements:**
- 20$\mu m$-1mm
Liquid Phase & Ice phase where clouds form, **on Flight tracks only**

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Flights (2011)</td>
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</table>
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

Hallett-Mossop zone
Triggering of (primary) ice prod. in microphysics

Scheme is done thanks to Ice Nuclei Parameterizations: \( \text{IN} = f(T) \)

\( \text{PIP} \rightarrow \text{SIP} \)

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

Legend:
- Fletcher
- Fletcher as in wsm5
- Cooper
- Meyers at \( S_w = 1 \)
- De Mott at naer=0.05/cc
- De Mott at naer=0.1/cc
- De Mott at naer=1/cc
- De Mott at naer=10/cc
- De Mott at naer=50/cc
- De Mott at naer=100/cc

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 11-21 Jan 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 realistic).

**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?)
2010 flights
(cf. Grosvenor et al. 2012)

Ice crystals (#/g)

Temperature (C)

> ≈2000 m  < ≈2000 m

2011 flights

Ice crystals (#/g)

Temperature (C)

> ≈2000 m  < ≈2000 m
## Liquid Phase & Ice phase in Clouds on Flight tracks only

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