Remote sensing observations and climate modeling of snowfall in Antarctica.

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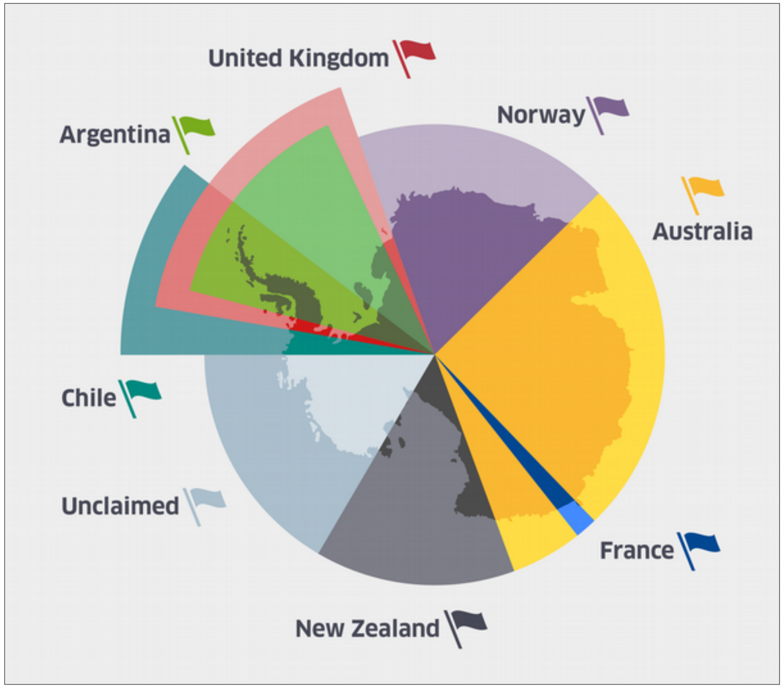
LMD

APRES3

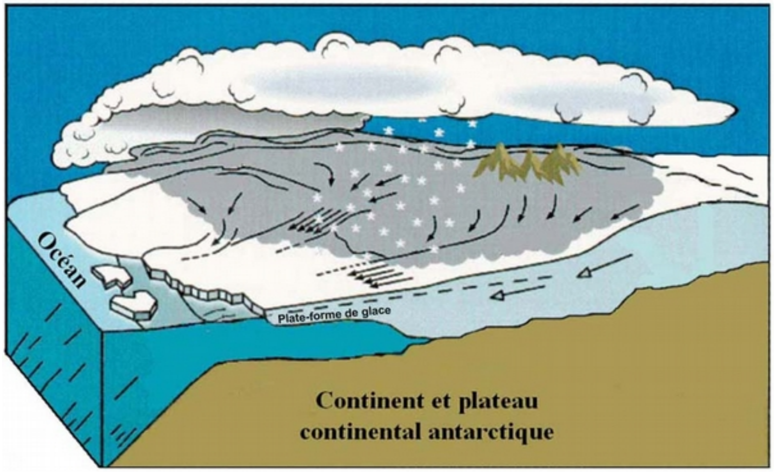
Introduction : Terra Australis Incognita

- Envisioned since the 16th century.
- Discovered in 1820.
- Dedicated to Science, Peace and Preservation since 1959.



Introduction : Why studying Antarctica ?

- Resources :
  - 75 % of the global fresh water.
- Surface mass balance :
  - Snow precipitation and accumulation over the ice cap.
  - Glacier calving, sublimation and meltwater runoff.
  - Wind erosion and drifting snow.
- Major focus : Global warming :
  - Constrain the contribution of the precipitation.
  - Predict the evolution of the ice-cap.



Introduction : Precipitation in Antarctica before 1990

→ **Coastal areas :**

- Episodic events due to cyclones, oceanic fronts and storms *[Astapenko, 1964]*.
- Always "solid precipitation".
- Hard to measure due to the strong winds.

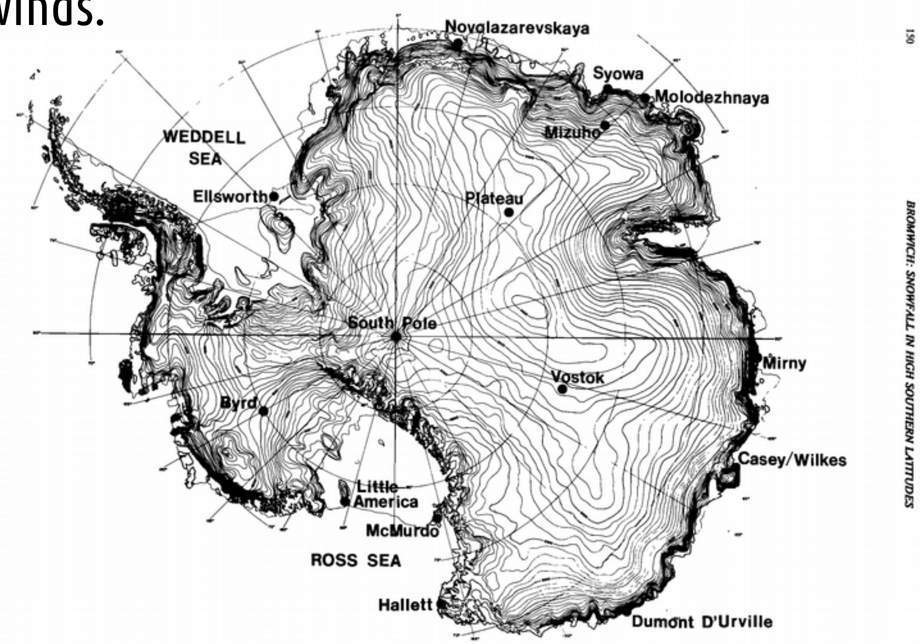


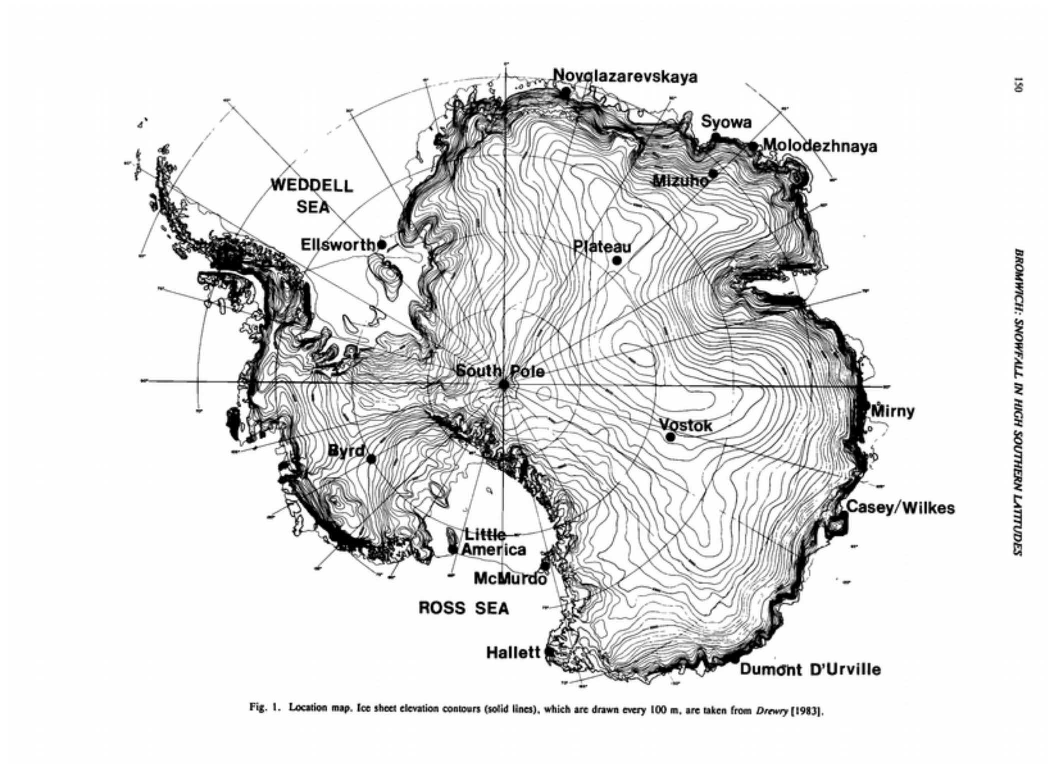
Fig. 1. Location map. Ice sheet elevation contours (solid lines), which are drawn every 100 m, are taken from *Drewry* [1983].

Elevation map from Drewry, 1983.

Introduction : Precipitation in Antarctica before 1990

→ High plateau area :

- Essentially snowfall under clear skies.
- 87 % of the 1967 annual precipitation consisted of ice crystals *[Kuhn, 1970; Radok and Lile, 1977]*.



Elevation map from Drewry, 1983.

Introduction : Precipitation in Antarctica before 1990

→ **First estimates of Antarctic precipitation** ***[Bromwhich, 1990]*** **:**

- Based on atmospheric water balance : from 44 mm/yr up to 77 mm/yr.
- Based on glaciological accumulation measurements : 153 mm/yr.

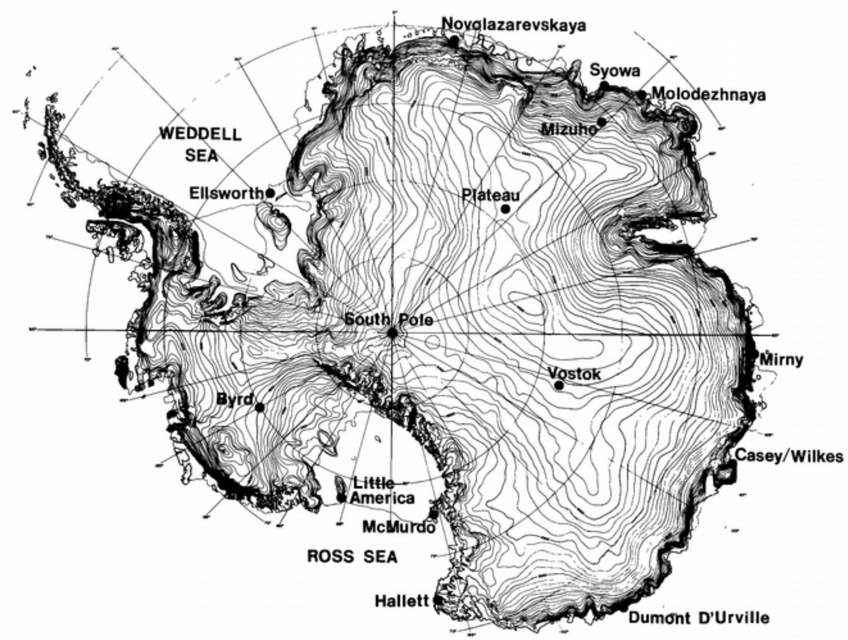
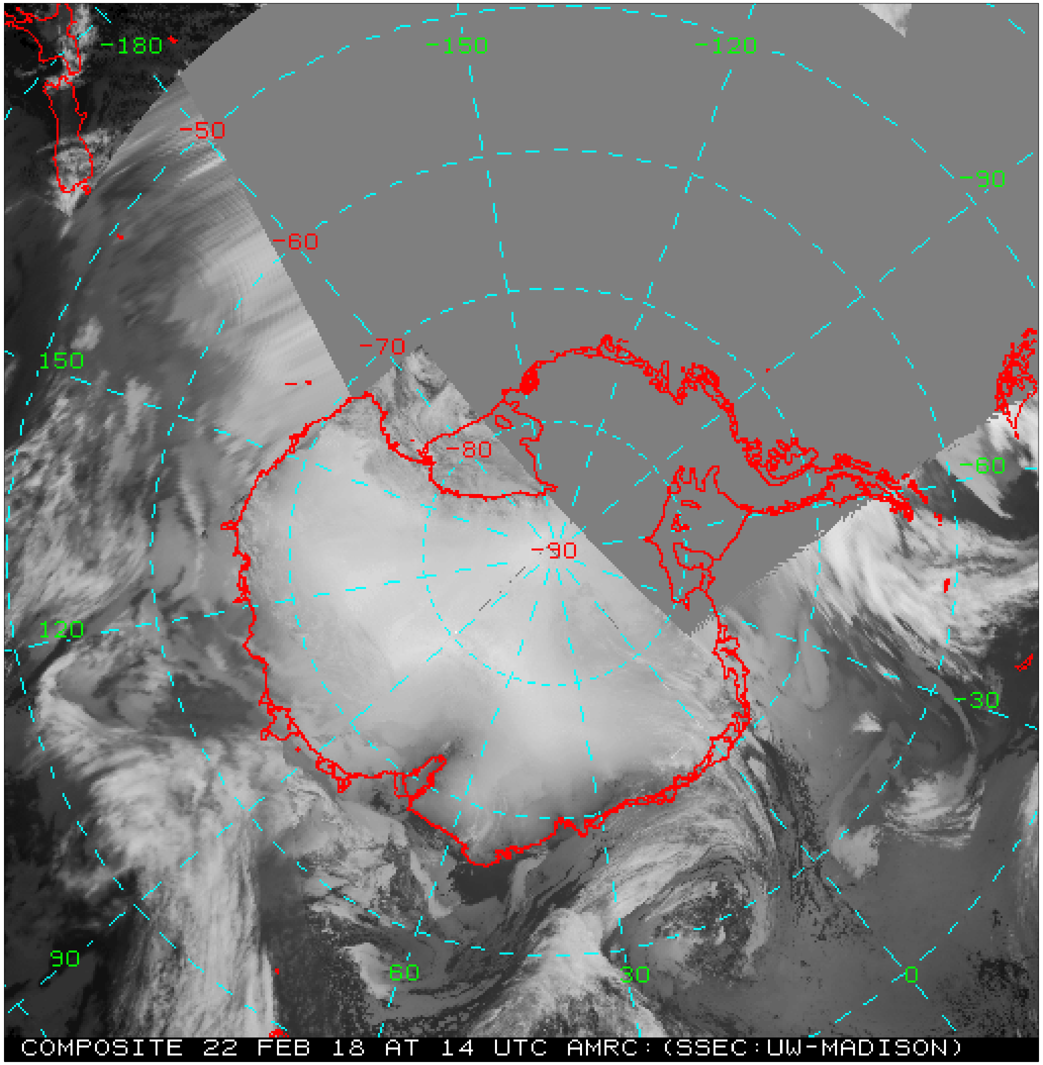


Fig. 1. Location map. Ice sheet elevation contours (solid lines), which are drawn every 100 m, are taken from *Drewry* [1983].

Elevation map from Drewry, 1983.

Introduction : Precipitation in Antarctica since 1990

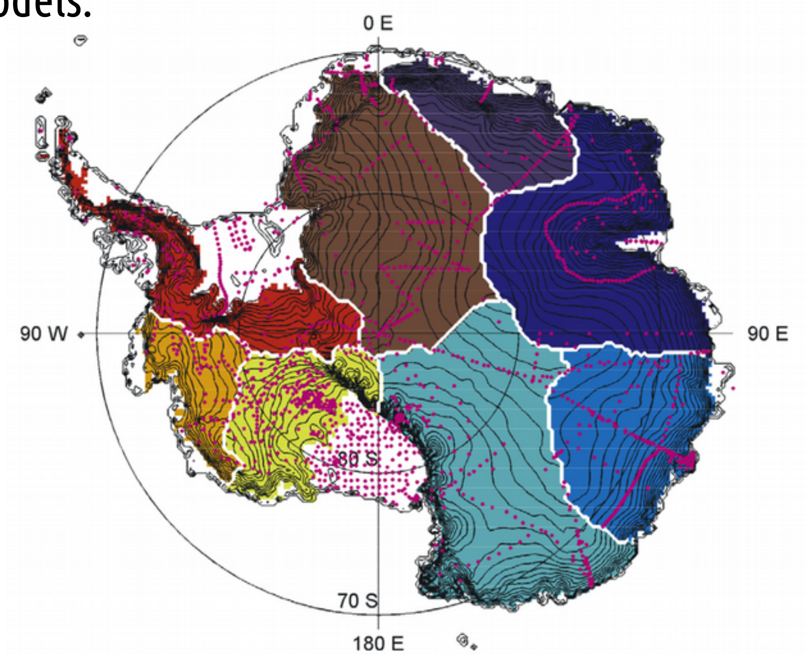


Infrared composite

Introduction : Precipitation in Antarctica since 1990

- Data acquirement are enhanced and multiplied over the ice-sheet.
  - Snowpits, snow-stakes, ice-cores…
  - Remote sensing observations.

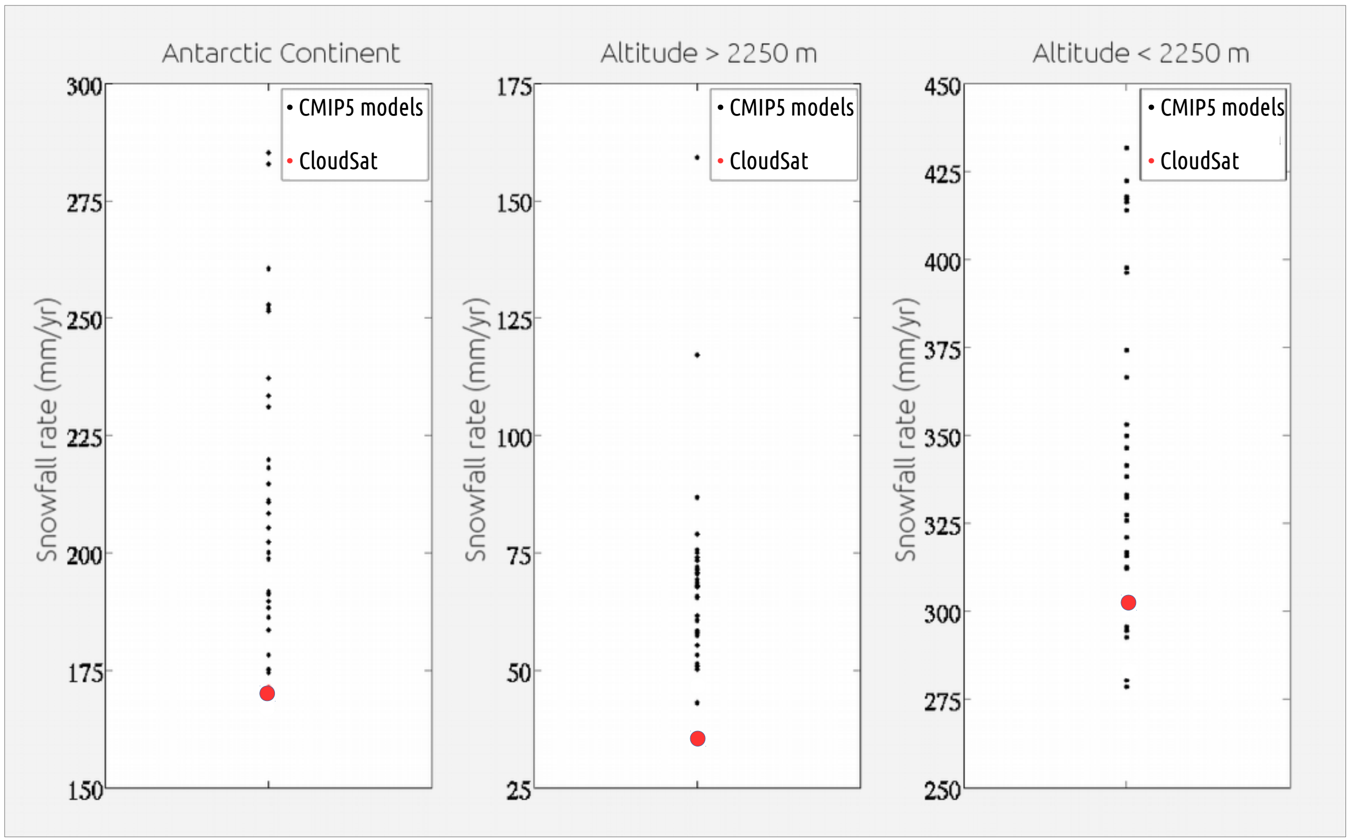
- Accumulation error calculated by comparing models and in-situ data.
  - Accumulation maps from compilation of collected data.
  - General Circulation Models and Meso-Scale Models.
  - Both present large errors.



In situ observations (in pink) and major drainage sectors from Arthern et al., 2006.

Introduction : Antarctica today

- Precipitation prediction still remains doubtful.
- Model are ranging snowfall rate from 160 mm/yr up to 300 mm/yr.



Palerme et al., 2014.

Outstanding questions

- Amount of precipitation over Antarctica ?
- Geographical and seasonal distribution of precipitation ?
- Processes controlling snowfall ?

In-situ precipitation

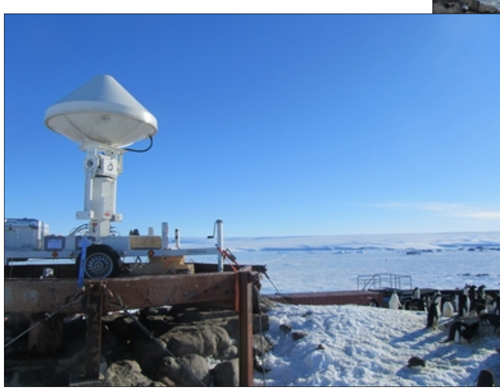
The APRES3 project

- **A**ntarctic **P**recipitation, **Re**mote **S**ensing from **S**urface and **S**pace project from the National Research Agency.
- France-Switzerland collaboration.
- **Goal** : Improve Antarctic precipitation.

The APRES3 project : a local precipitation study

- Two phases :
  - Snowfall observations.
    → Field campaigns and remote sensing observations.

  - Polar climate modeling.
    → With a global climate model (LMDz) and a mesoscale model.



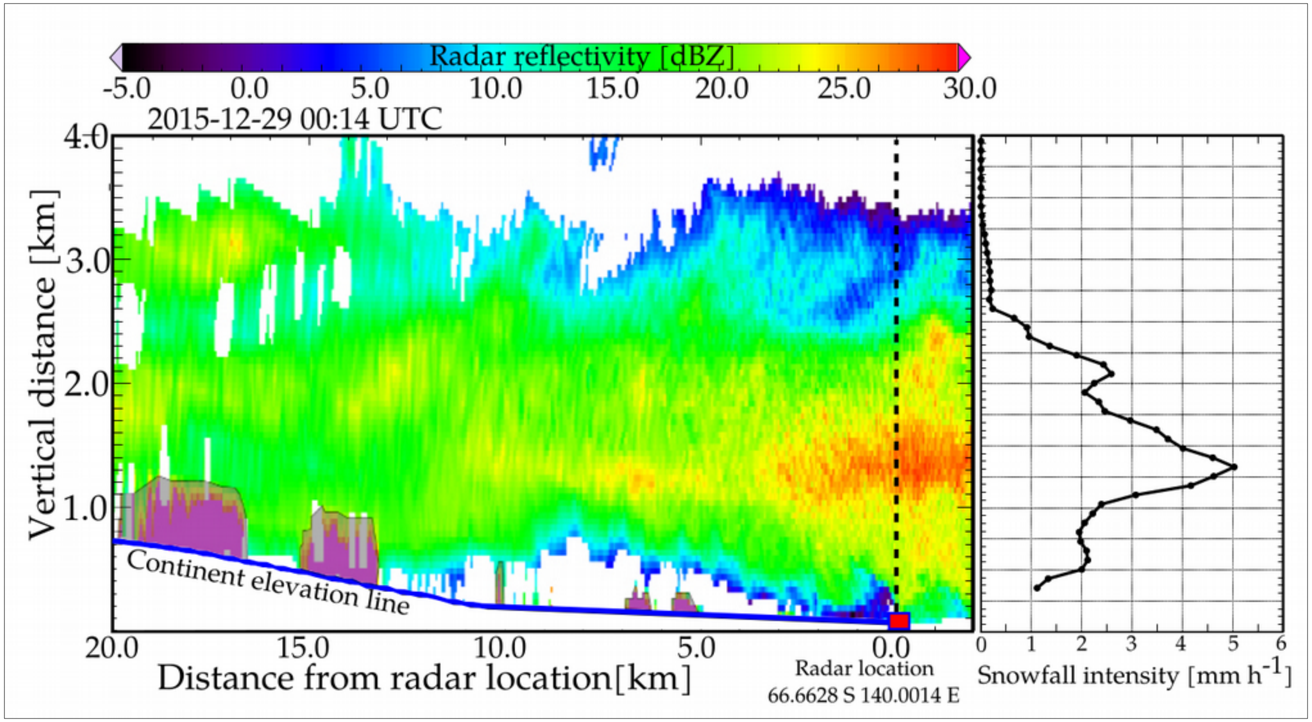
Introduction : the APRES3 project

- **MxPol :** High-resolution dual-polarization radar with “3D” scanning.
- **MRR :** Vertically profiling radar with a 100 m resolution from 300 until 3000 m high.
- Conversion of radar reflectivity into snowfall rate by Ze/Sr relation :
    - At Dumont d’Urville : 95% confidence by Grazioli et al., 2017.



The APRES3 project : a local precipitation study

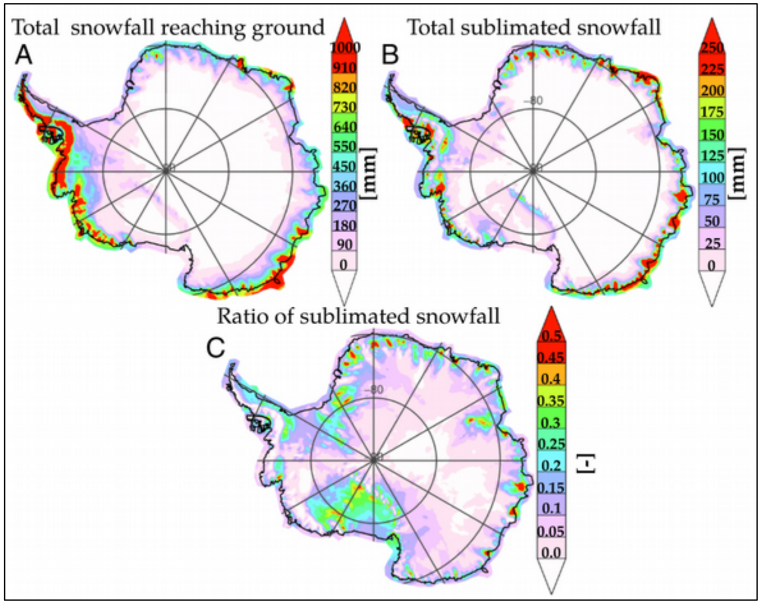
- Using dual polarization radar and micro-rain radar we highlighted the processes of low-level snow sublimation.

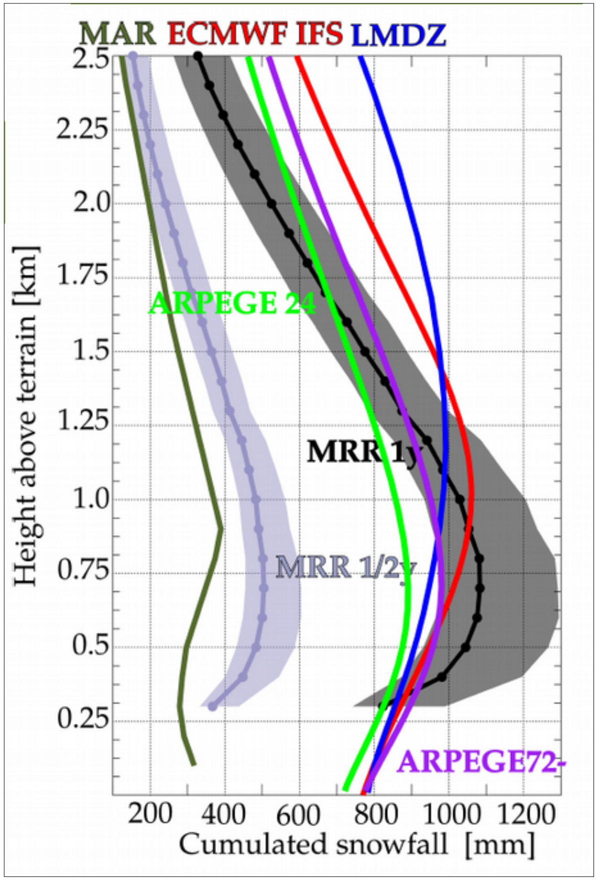


Radar time series over DDU area on December 29, 2015.
Grazioli et al., 2017.

The APRES3 project : a local precipitation study

- After one year of continuous acquisition over Dumont d'Urville and comparison with models.
- Models are simulating sublimation too.

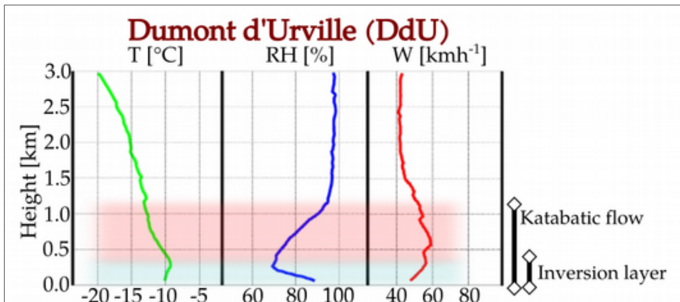


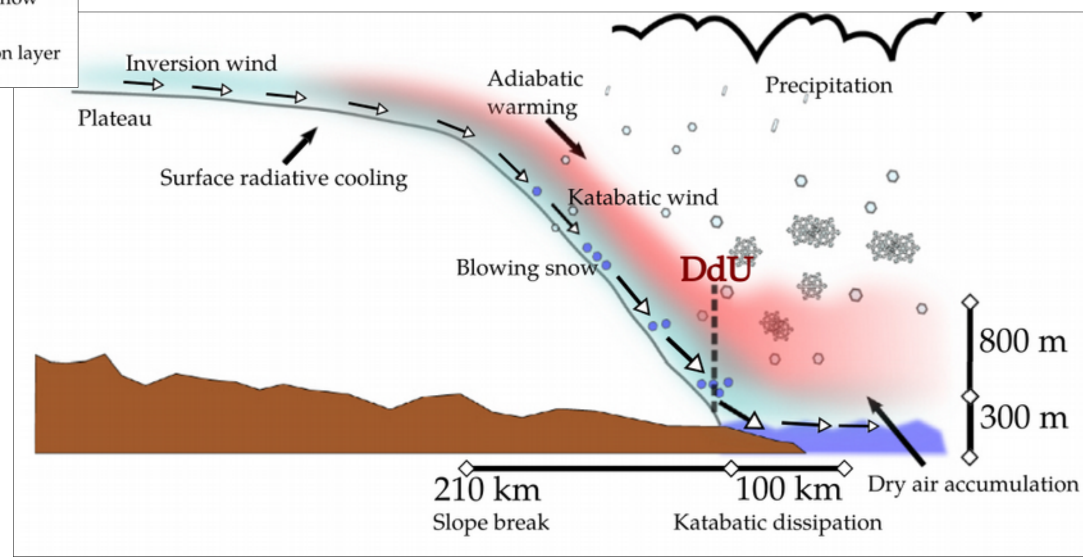


ECMWF model | MRR annual precipitation profile over DDU . November 2015 – October 2016. Grazioli et al., 2017.

The APRES3 project : a local precipitation study

- Katabatic winds are controlling low-levels sublimation over the coastal regions at the margin of the Antarctic ice-sheet.





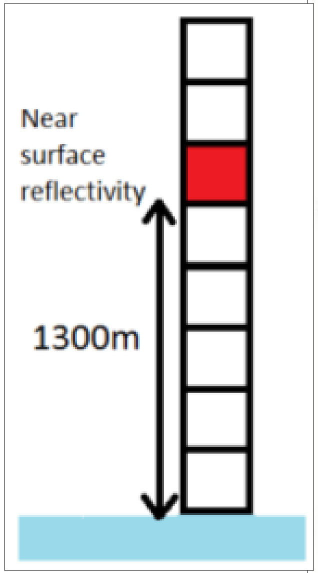
Meteo-station data.
November 2015 – October 2016.

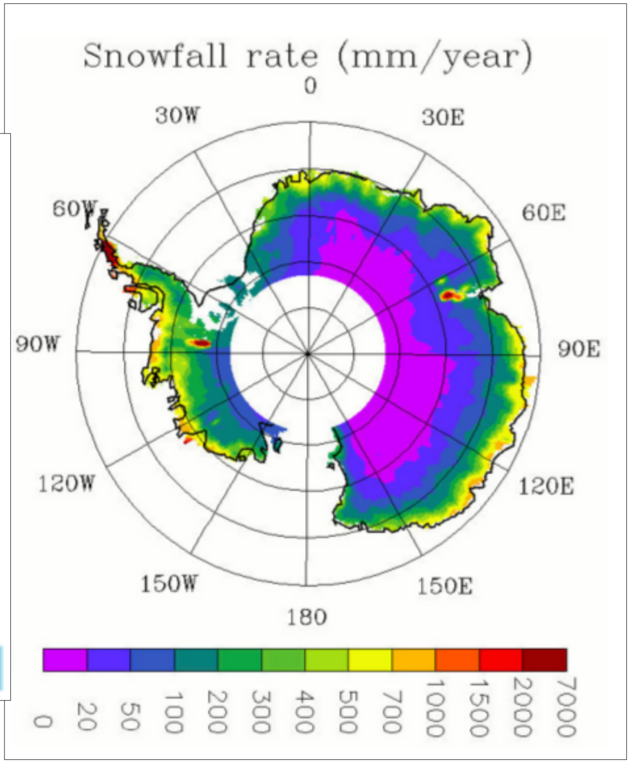
Grazioli et al., 2017.

Precipitation at continental scale

CloudSat : Continental remote sensing data

- Earth observation satellite belonging to the A-train (NASA).
- Meteorological radar :
  - Clouds and precipitation observations → 153 mm/yr over 2007-2010 period.
  - Altitude limit for observation : ~ 1,2km.
  - 94 GHz frequency.





Haynes et al., 2009
Palerme et al., 2014

CloudSat : Continental remote sensing data

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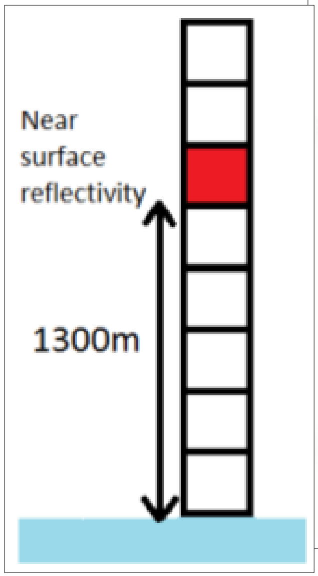
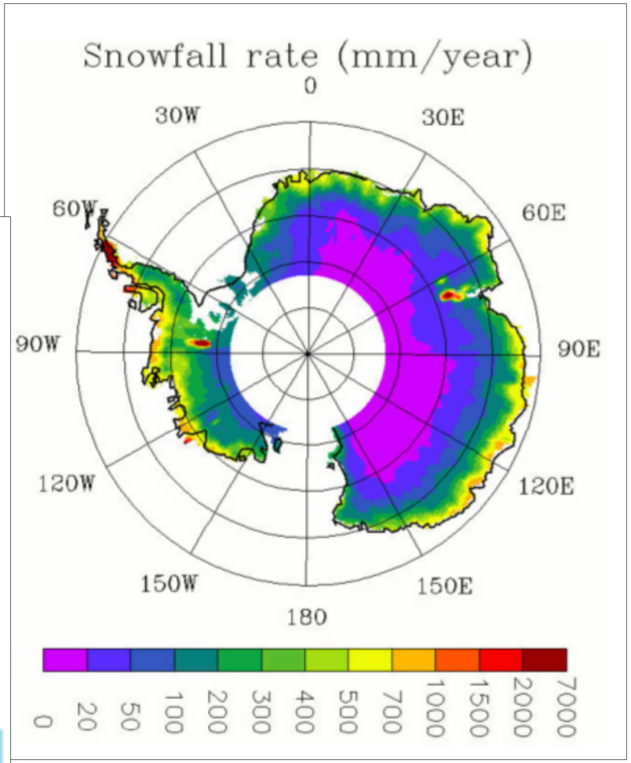
- Meteorological radar :
  - Clouds and precipitation observations → 153 mm/yr over 2007-2010 period.
  - Altitude limit for observation : ~ 1,2km.
  - 94 GHz frequency.
- Uncertainties : from 50 up to 175% *[Wood, 2011]*





Haynes et al., 2009
Palerme et al., 2014

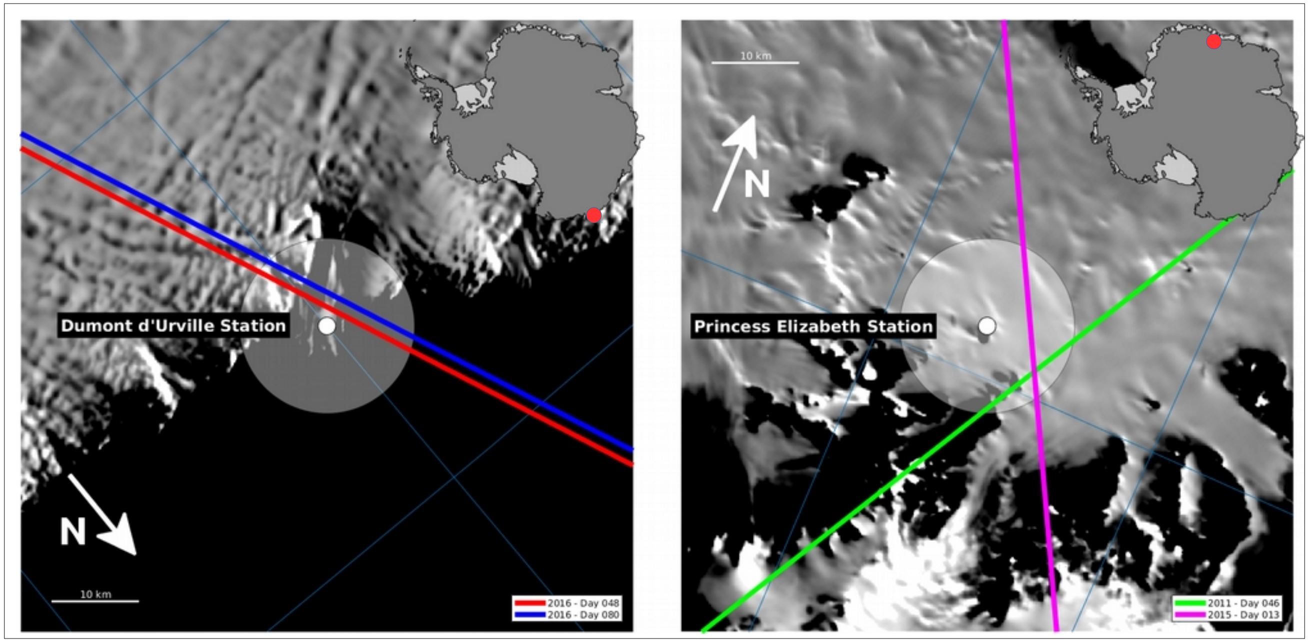
Outstanding questions

- Agreement between in-situ data and CloudSat data ?

CloudSat : Continental remote sensing data

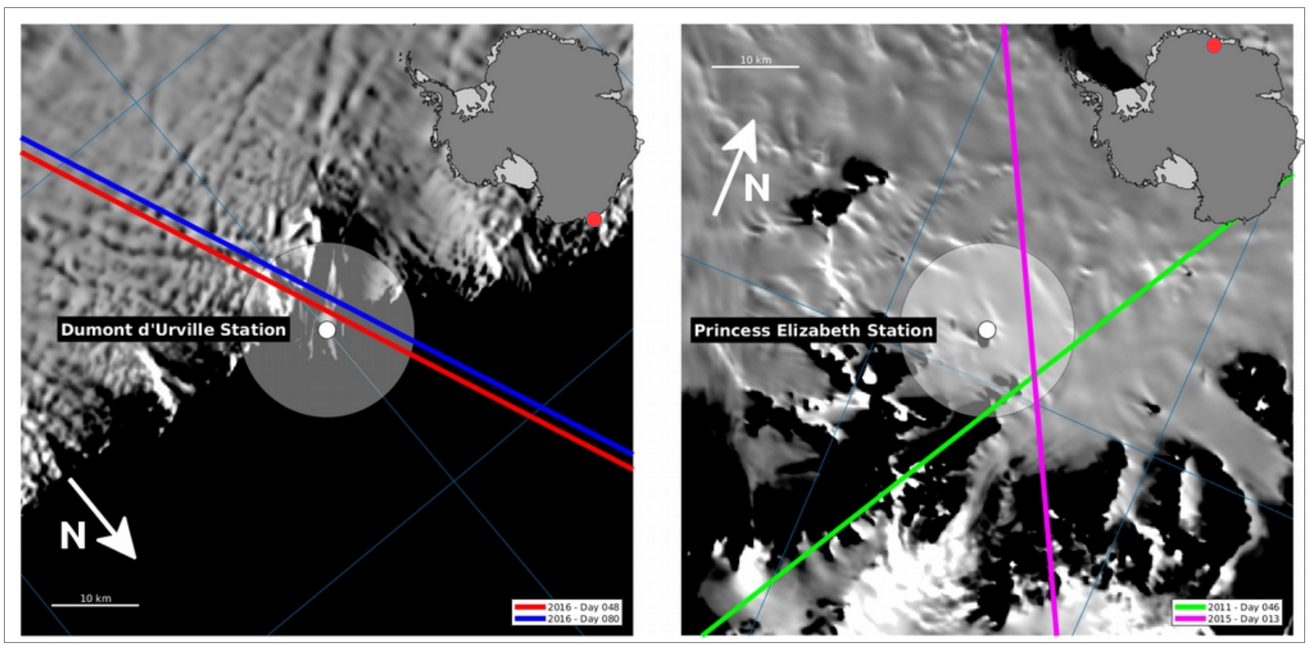
- Two MRR used :
  - At Dumont d'Urville station – APRES3 project.
  - At Princess Elizabeth station – additional data.

- Vertically profiling radar with a 100 m resolution from 300 until 3000 m high.

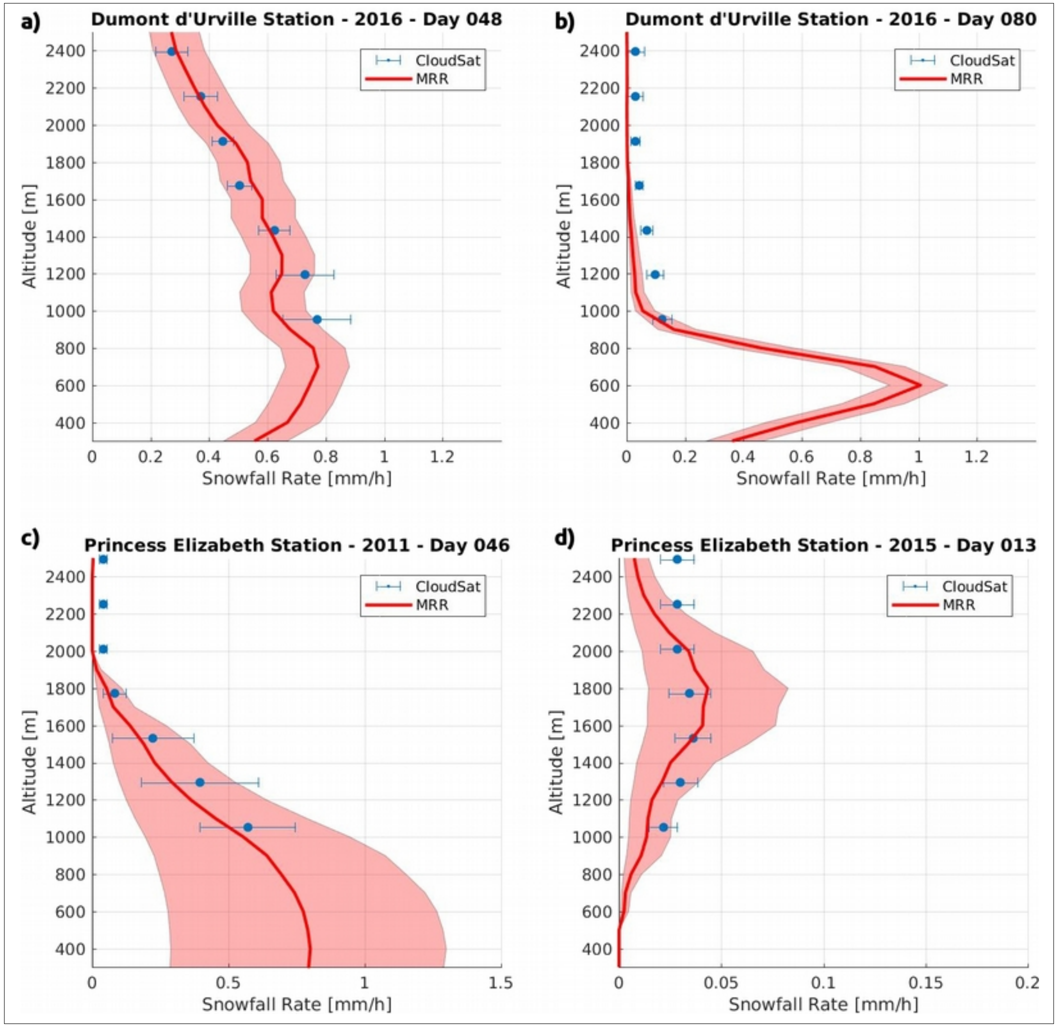


Events and data selection

- 4 precipitation events, 2 per station.
- CloudSat data passing through a 10 km – radius around stations.
    - About 20 profiles per track.

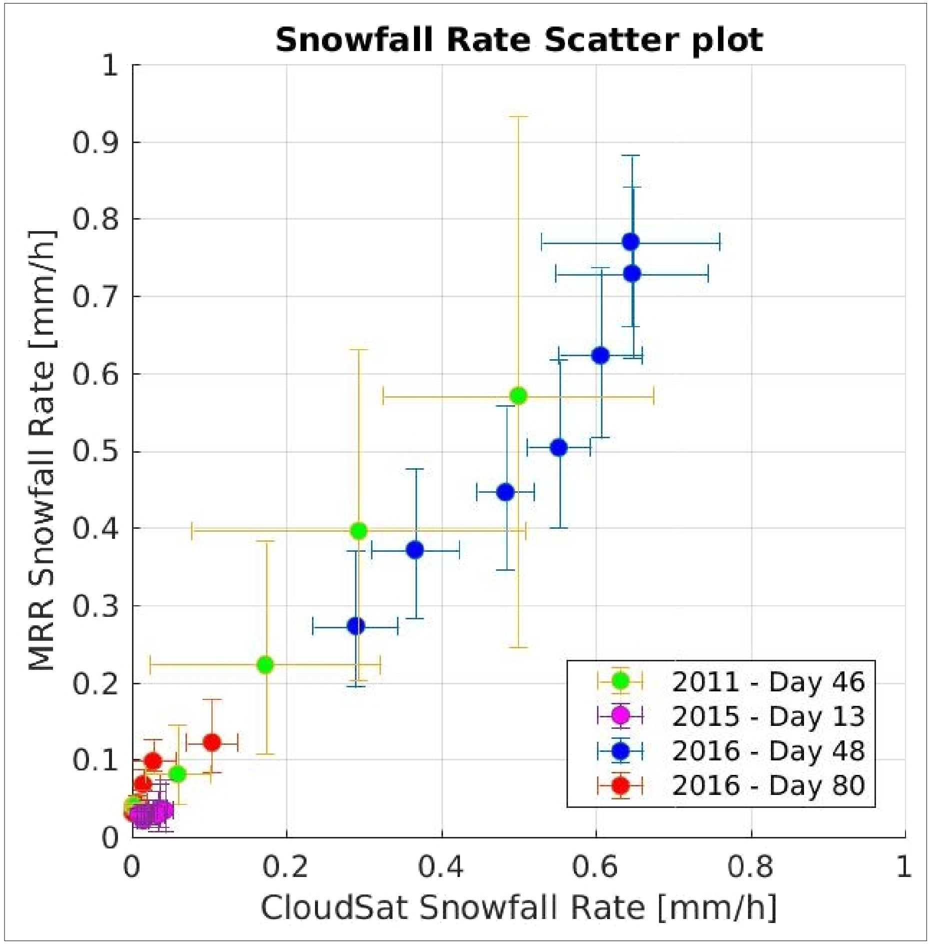


CloudSat : Precipitation profiles comparison with MRR



- Cases **a** & **c** : good agreement.
- Cases **b** & **d** : Snowfall rate too weak.

Precipitation profiles comparison



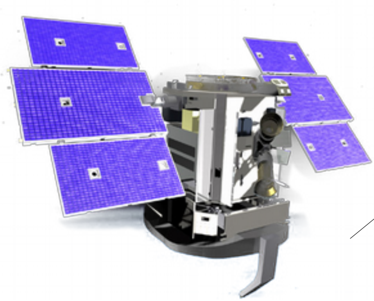
- Correlation coefficient of 99,41 %.
- Reassessment of uncertainties by calculating CloudSat deviation from MRR :

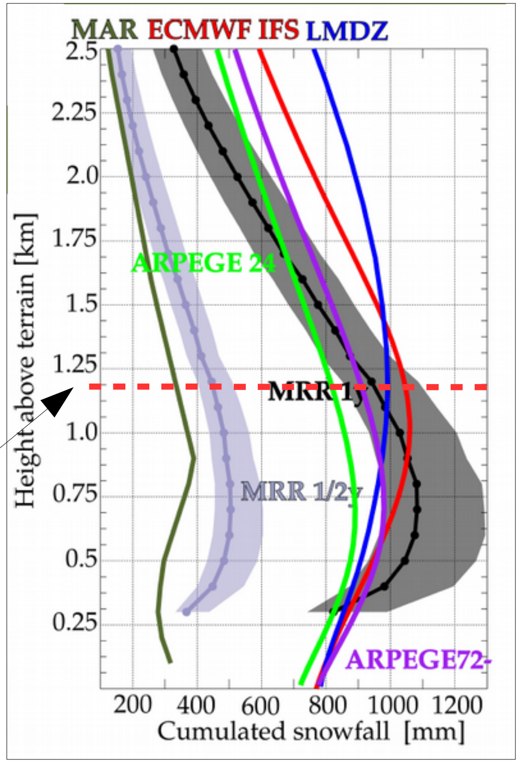
  → [-21,20% ; +25,43%]

Conclusion.

→ Snow sublimation processes were observed for the first time in Antarctica.

→ We can trust observed precipitation by using CloudSat. → **153** [-32 +38] **mm/yr at 1,2 km over surface.**





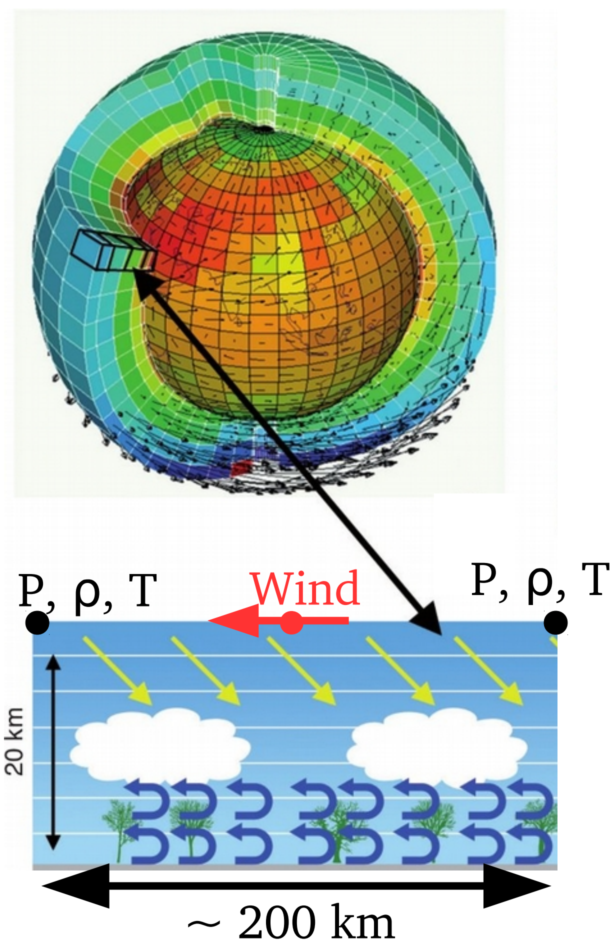
[Grazioli et al., 2017]

Modelling

Outstanding questions

- ➔ Precipitation prediction over Antarctica ?
- ➔ Processes controlling snowfall ?

Modelling : LMDz



- Dynamical core.
  → Primitive hydrostatic equations of meteorology.

- Radiative transfer model.
  → RT equations (plane-parallel approximation).

- Physical parameterizations.
  → Large scale and shallow convection clouds.
  → Cloud scheme.
  → Conversion to rain and snowfall.

Modelling : Simulations using ERA-Interim nudging

- Nudged simulations – relaxation term toward ERA-I reanalysis with a time constant τ of 3 hours.
  - Wind. → Nudged dynamics.
  - Wind & temperature.
  - Wind, temperature and humidity. → Nudged physics.

- 96x71 points grid.

- 79 vertical levels.

$$\frac{\partial u}{\partial t} = \frac{\partial u}{\partial t}_{GCM} + \frac{u_{analysis} - u}{\tau}$$

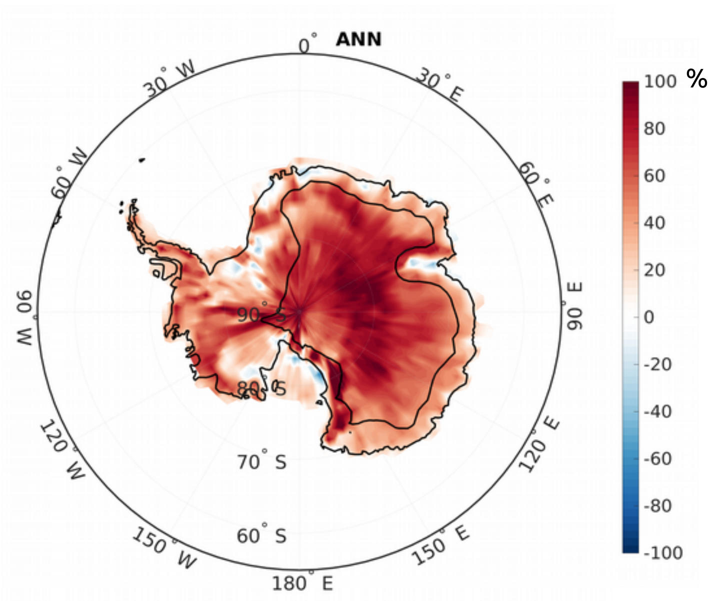
$$\frac{\partial v}{\partial t} = \frac{\partial v}{\partial t}_{GCM} + \frac{v_{analysis} - v}{\tau}$$

τ Time constant for the relaxation of the model wind toward analyses

Coindreau, 2007

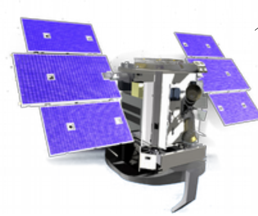
Modelling : Comparison between CloudSat and LMDz

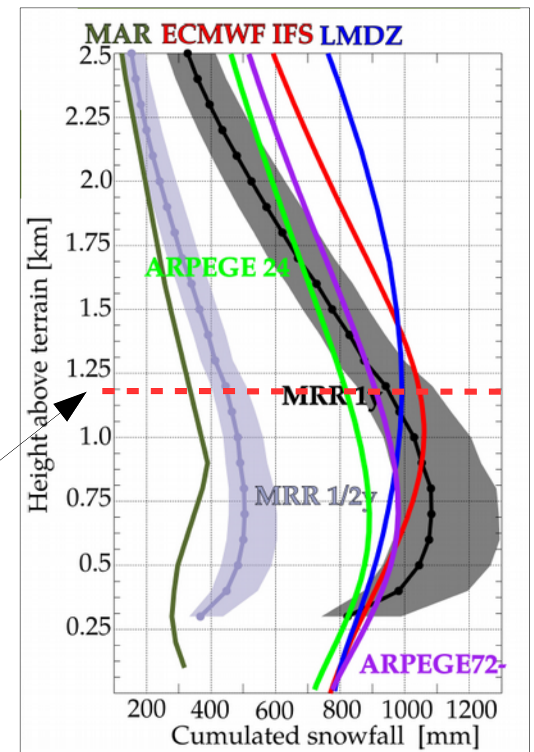
- Comparison with CloudSat made at the same altitude.



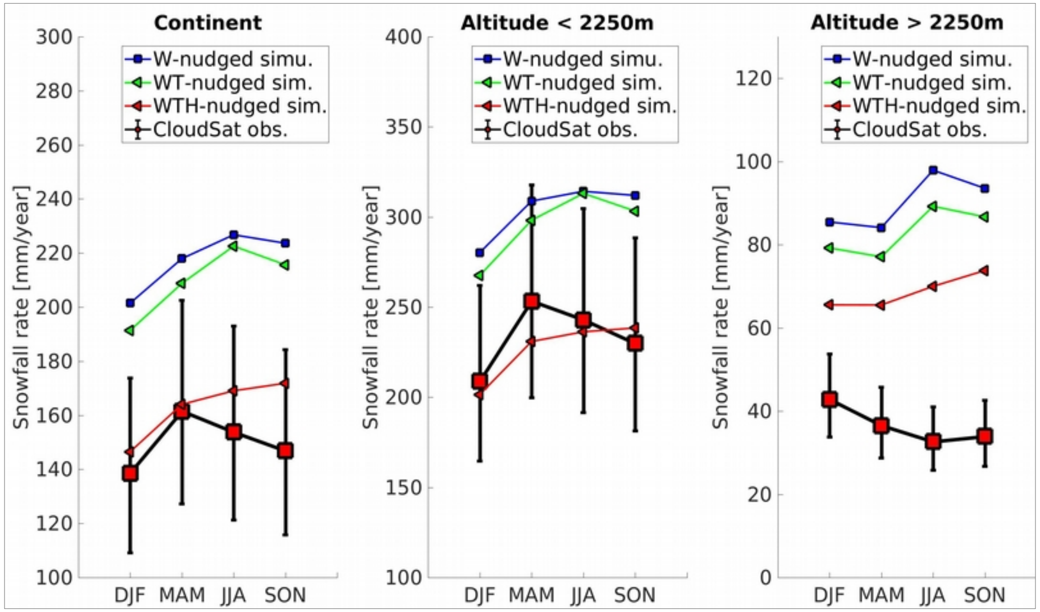
Relative difference between surface precipitation and 1,2km-high precipitation.

Free climate simulation in annual mean.





Modelling : Comparison between CloudSat and LMDz



Nudged dynamics (blue & green) :

- Over-estimation of snowfall over both coastal and high continental areas.
- Wrong seasonal variability over the whole continent.

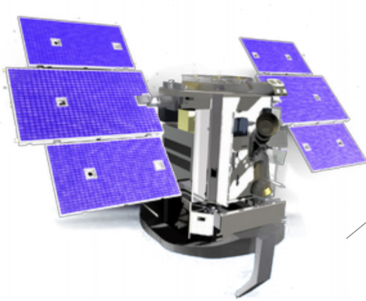
Nudged physics (red) :

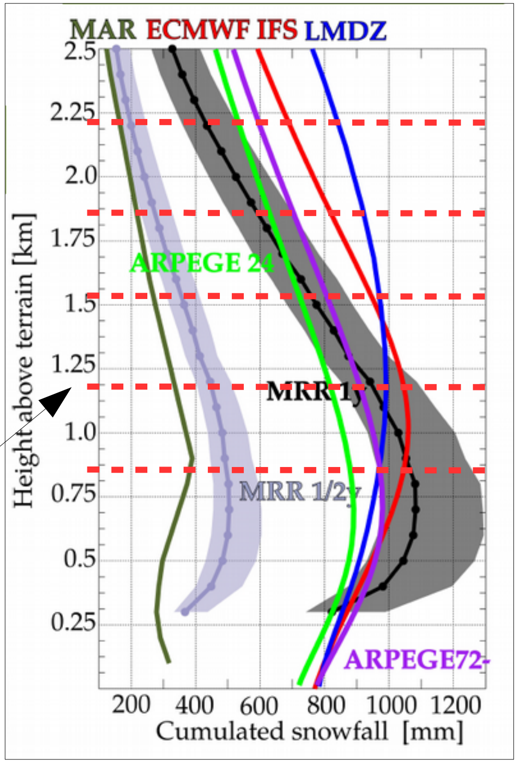
- Good agreement between LMDz and CloudSat observations in annual mean.
- Over-estimation of snowfall over the high continental plateau
- Wrong seasonal variability.

Modelling : Conclusions

- Overestimation of the precipitation over the high plateau area by all simulations due to a continuous over-saturation of relative humidity controlling continental snowfall.

  → Zoomed simulations over DDU.

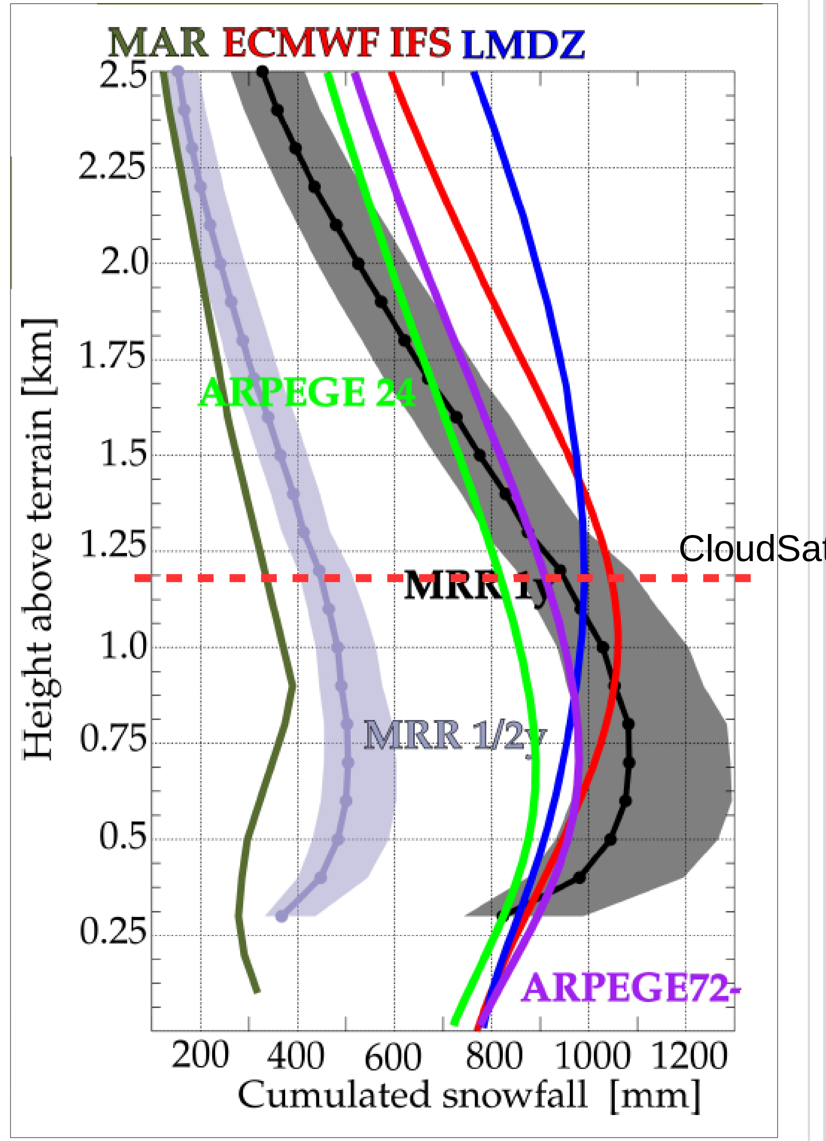




Modelling : Outlooks I – modelling

- New simulations :
  - → Horizontal resolution ?
  - → Vertical resolution ?

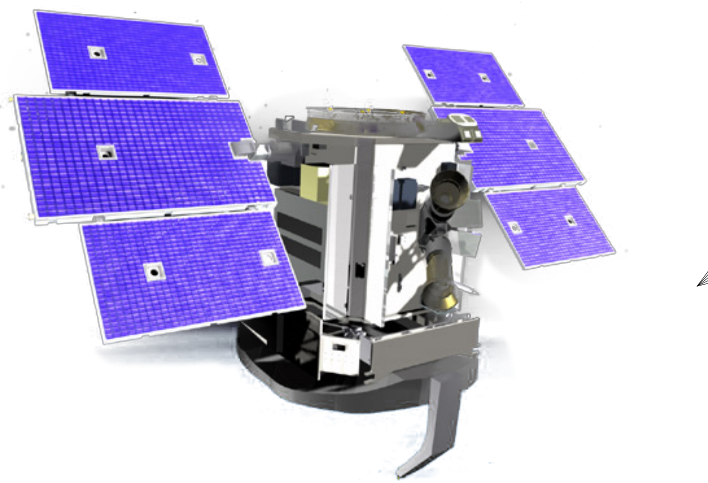
- New parametrisations :
  - → Auto-conversion of the precipitation ?
  - → Sedimentation ?
  - → Advection ?
  - → Wind velocity ? Katabatics ?
  - → Subgrid precipitation ?

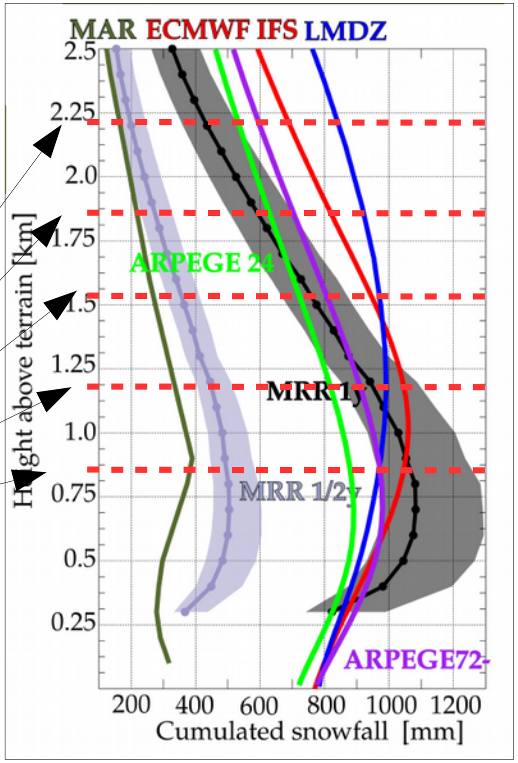


Modelling : Outlooks II – data comparison

→ Multi-vertical levels comparison.

→ A 3D comparison between CloudSat and LMDz model would improve our knowledge about precipitation processes over Antarctica.





Questions ?

Thank you !