Assessing the cloud representation of two global atmospheric models using multiple overpasses of CloudSat-CALIPSO over an Arctic cyclone

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Study Case:
Arctic Cyclone in May 2019

- Born: 2019-05-09 in Russia
- End: 2019-05-16 near Svalbard
- Characteristics:
  - Long life
  - Small deepening (near 998hPa)
  - Brings humidity in Arctic Area
  - 20 overpasses of CloudSat and CALIPSO
  - Availability of DARDAR products and model simulation
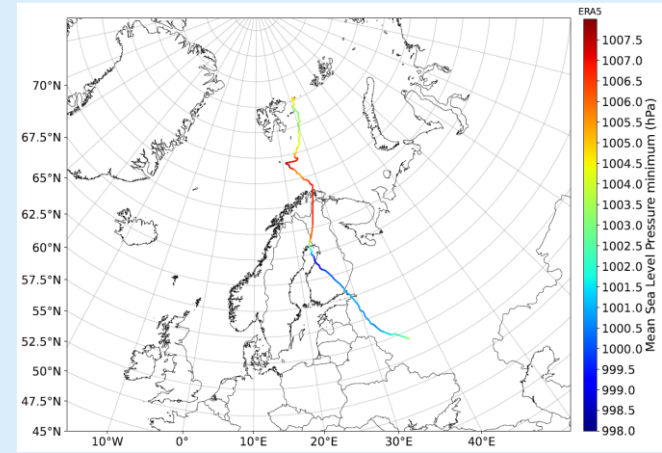
Minimum of MSLP during the Arctic cyclone trajectory (ERA5 data)
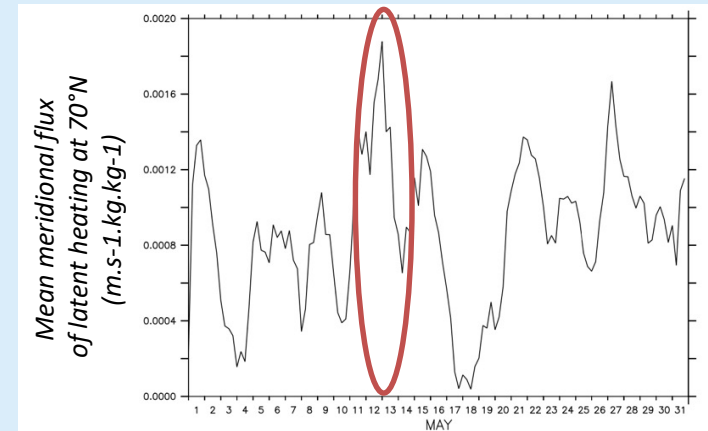
Mean meridional flux of latent heating at 70°N (ERA5 data)
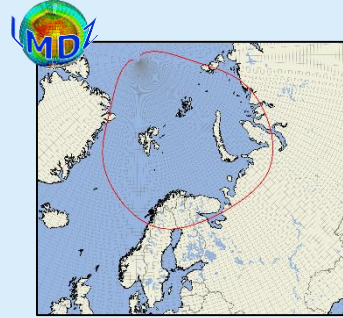
Atmospheric models

ARPEGE
Resolution: 5-24km, 105 levels
Initialisation: 4DVar analysis
                (2019-05-12 at 00UTC)
Type of simulation: "Free" Forecast

Simulations:
- Operational liquid/ice partition function
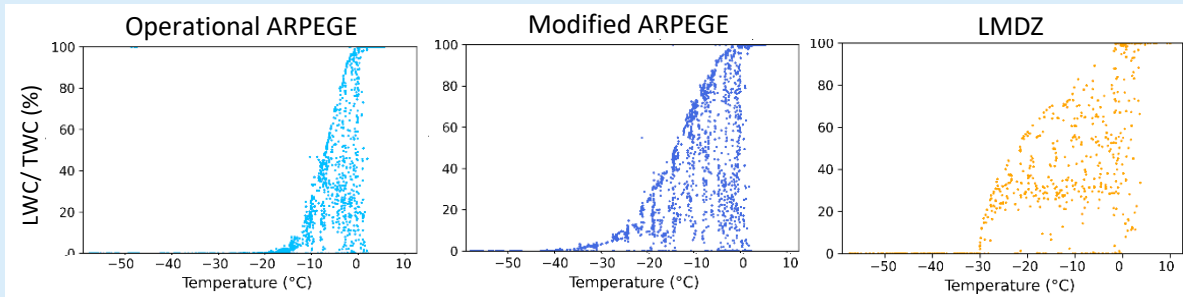- liquid/ice partition function tested in Ricaud et al. (2020)

LMDZ
Resolution: Zoom configuration with 50km in Svalbard, 95 levels
Initialisation: ERA5
                (2019-05-12 at 00UTC)
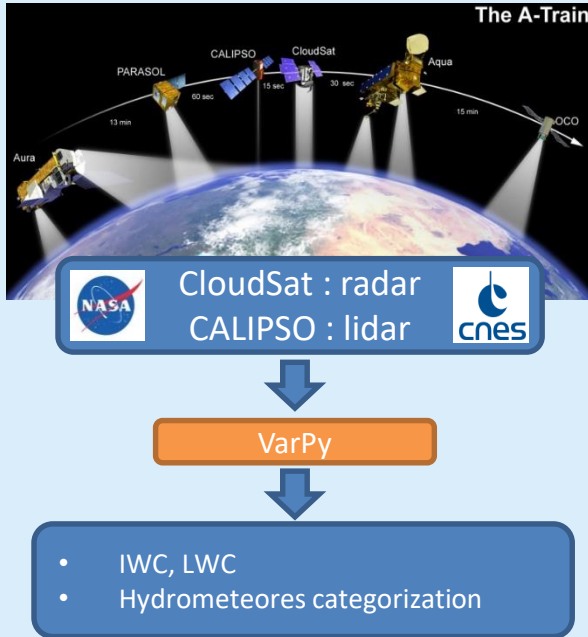Type of simulation: nudging to ERA5 outside the zoom

Simulations:
- CMIP7.1b version
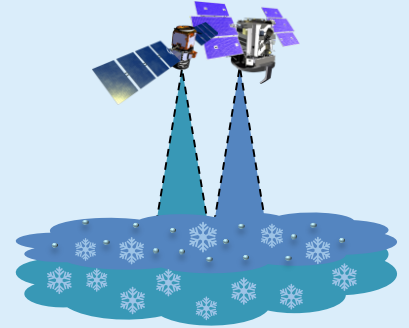

Operational ARPEGE — Modified ARPEGE — LMDZ

Outputs:
- time: 3h
- lonxlat : 0,5° x 0,5
- 18 pressure levels (50hPa resolution)

Observations: DARDAR products

CloudSat : radar
NASA
CALIPSO : lidar
cnes

VarPy

- IWC, LWC
- Hydrometeores categorization

Radar:

- Sensitive to diameter of particules
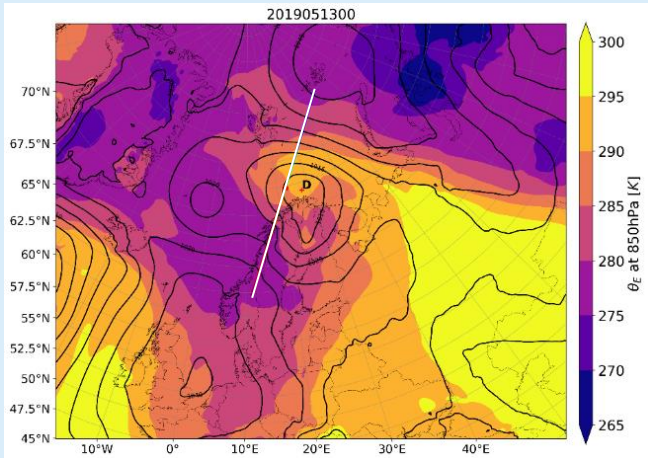
- Detects ice cristals

- Use to determine IWC

Lidar:

- Sensitive to concentration of small particules

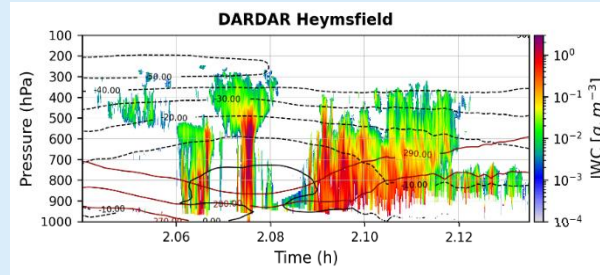- Detects small cristals and liquid droplets

- Use to determine LWC and IWC

Delanoë and Hogan (2008, 2010), Clémantyne AUBRY's PhD

Example of one satellites overpass:
#2019133004652_69455 crossing warm and cold front

ERA5 : 20190513 00UTC

Shading: θ_E at 850hPa (K) ; black contours: MSLP (hPa) ;
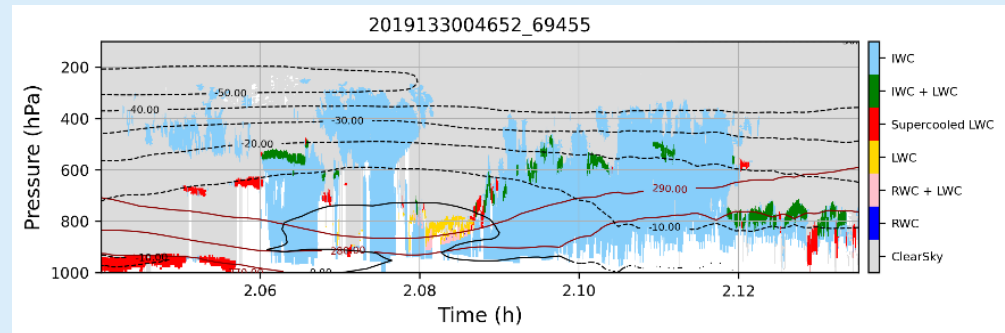white line: time along satellites overpass

DARDAR Products : 20190513 02UTC

Shading: IWC (g.m^{-3}) ;
black contours: Temperature (°C) ; red contours: θ_E (K)
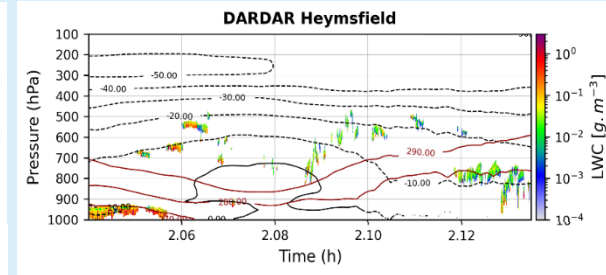
Shading: LWC (g.m^{-3}) ;
black contours: Temperature (°C) ; red contours: θ_E (K)

Shading: Hydrometeors categorization ; black contours: Temperature (°C) ; red contours: θ_E (K)
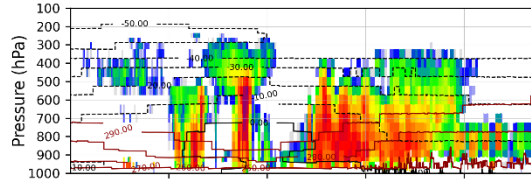
Comparison of IWC

Shading: IWC (g.m^{-3}) ; black contours: Temperature (K) at 2019-05-13 0UTC

DARDAR obs at ERA5 resolution
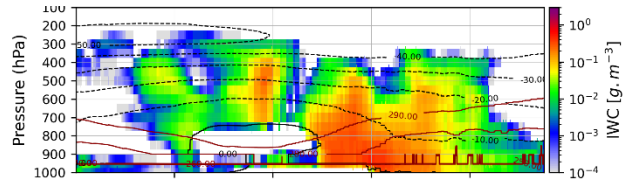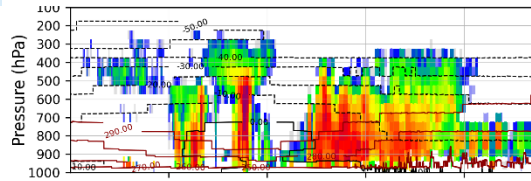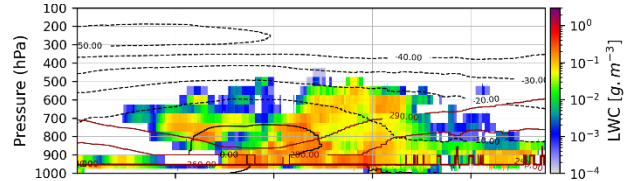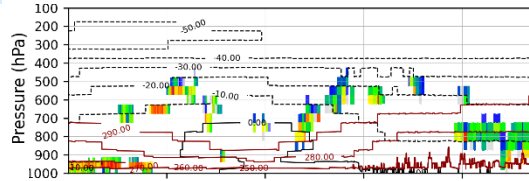
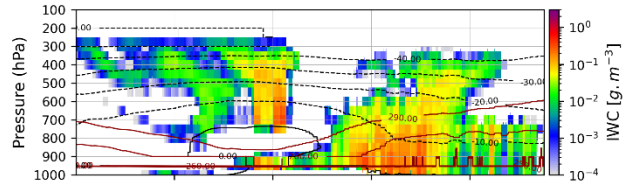**DARDAR obs at ARPEGE resolution**

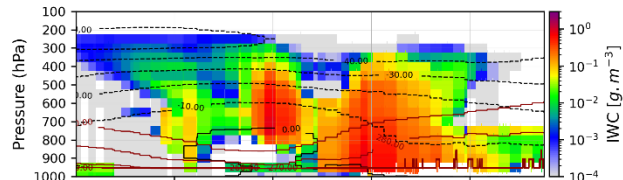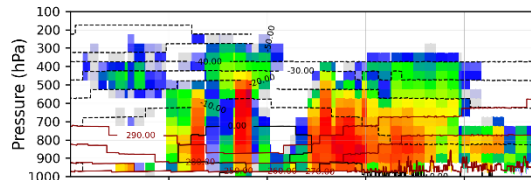**DARDAR obs at ARPEGE modified resolution**
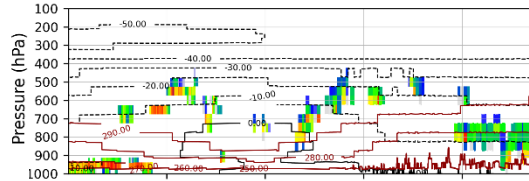
DARDAR obs at LMDZ resolution

ERA5

ARPEGE

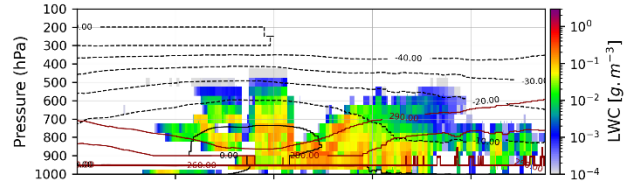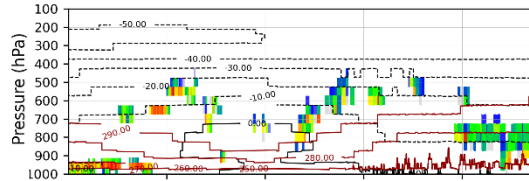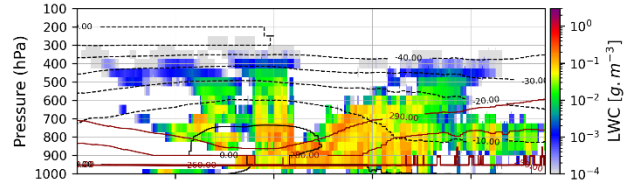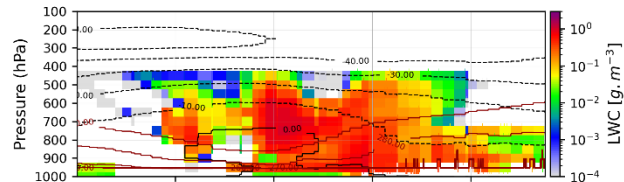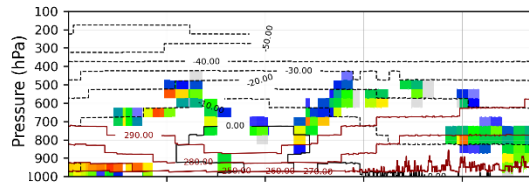**ARPEGE modified**

LMDZ

Comparison of LWC

Shading: LWC (g.m⁻³) ; black contours: Temperature (K) at 2019-05-13 0UTC
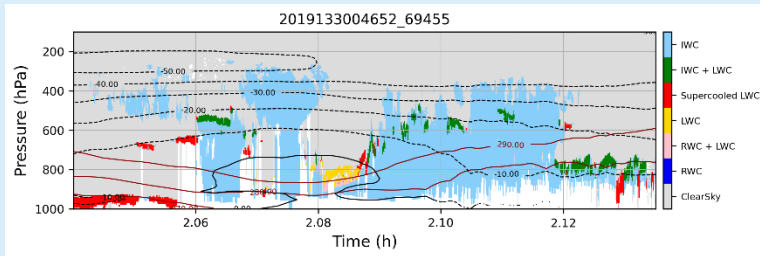
Comparison of hydrometeors categorization

DARDAR's categorization

Model categorization (ex : LMDZ)
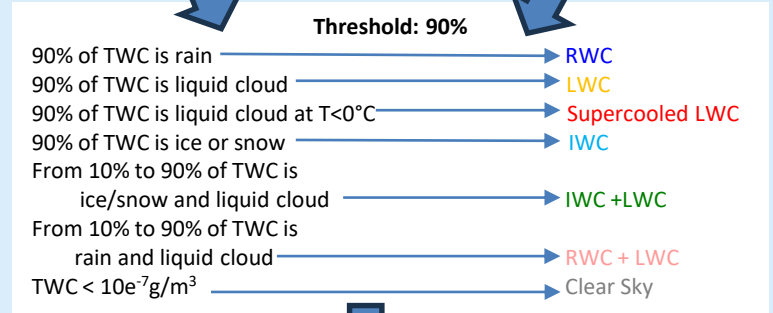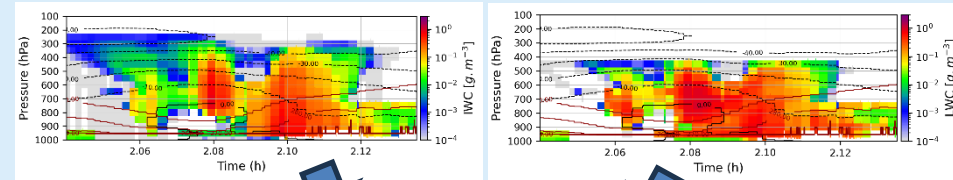
Threshold: 90%

90% of TWC is rain ⟶ RWC
90% of TWC is liquid cloud ⟶ LWC
90% of TWC is liquid cloud at T<0°C ⟶ Supercooled LWC
90% of TWC is ice or snow ⟶ IWC
From 10% to 90% of TWC is
    ice/snow and liquid cloud ⟶ IWC +LWC
From 10% to 90% of TWC is
    rain and liquid cloud ⟶ RWC + LWC
TWC < 10e^{-7}g/m^3 ⟶ Clear Sky

Shading: Hydrometeors categorization ;
black contours: Temperature (°C) ; red contours: θ_E (K)
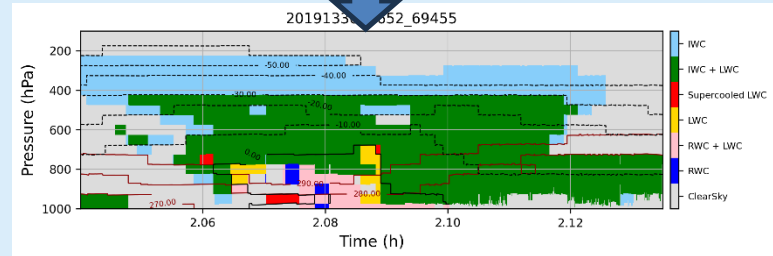
Shading: Hydrometeors categorization ;
black contours: Temperature (°C) ; red contours: θ_E (K)

Over-representation of ice in mid-troposphere in observation
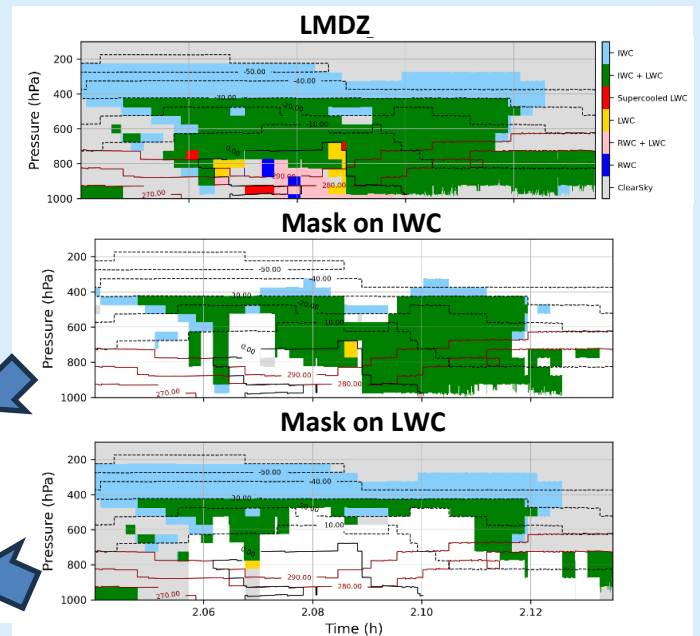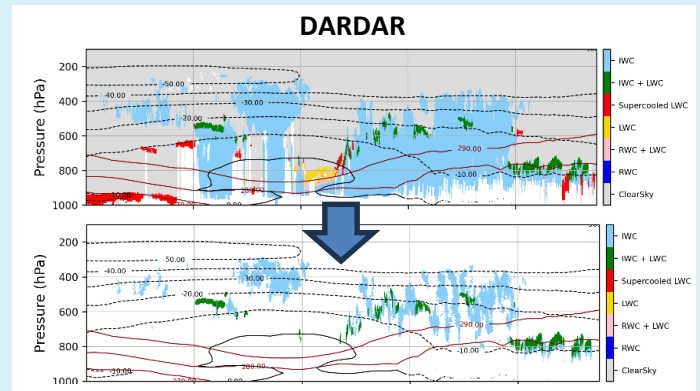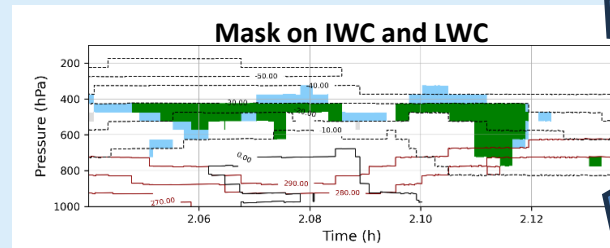
Observations :
Delete some data in order to keep data only where there are signals from radar and lidar simultaneously, namely :
 - where lidar signal is extinguished or attenuated
 - where there is a clutter in radar signal

Models :
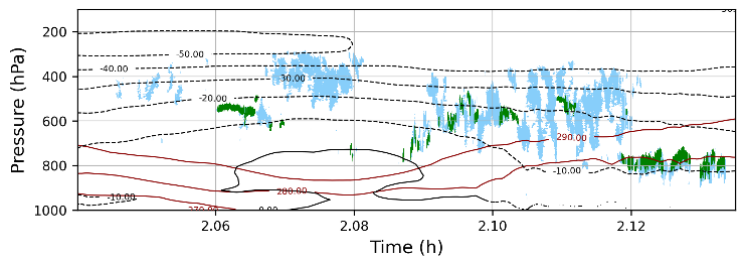Delete datas where:
- $IWC < 5 \times 10^{-2} g.m^{-3}$ where radar cannot detect
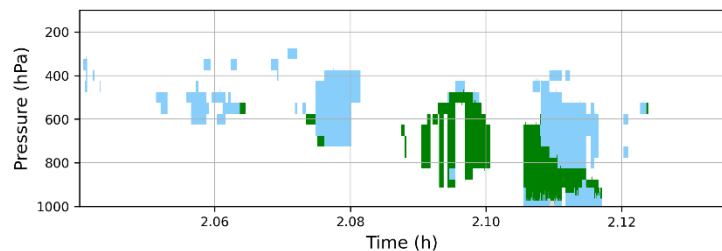- $LWC > 1 \times 10^{-1} g.m^{-3}$ where lidar is attenuated

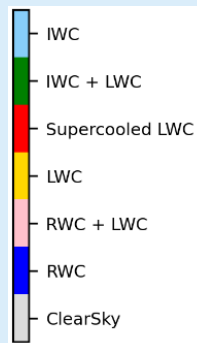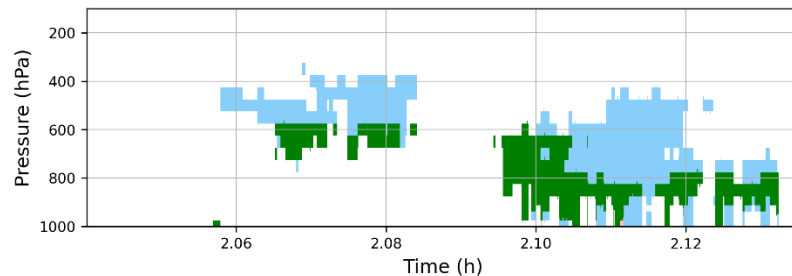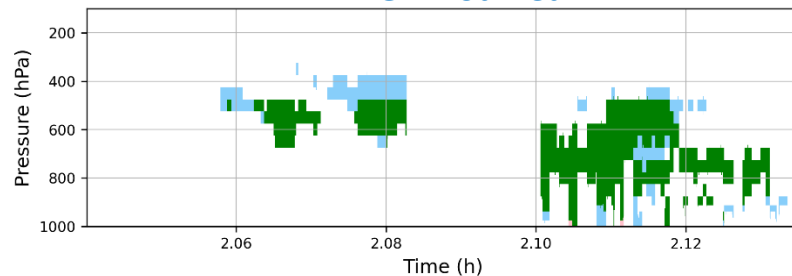# Sensitivity to ice/liquid partition function and ratqs

DARDAR

ERA5

Shading: Hydrometeors categorization ;
black contours: Temperature (°C) ;
red contours: θ_E (K)

IWC
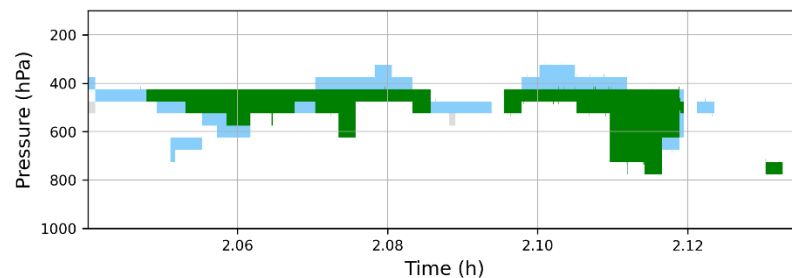IWC + LWC
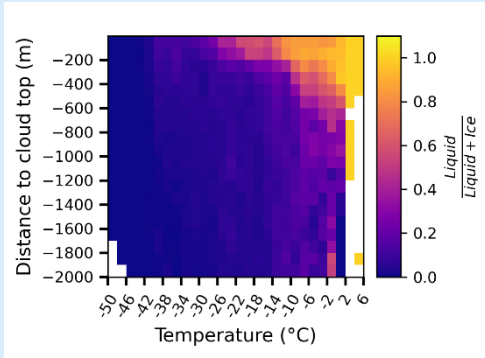Supercooled LWC
LWC
RWC + LWC
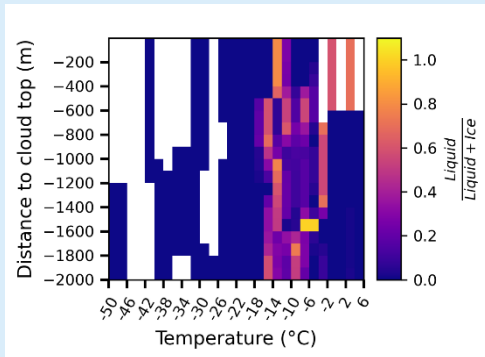RWC
ClearSky

ARPEGE

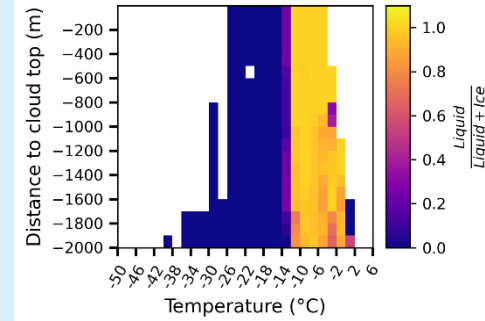**ARPEGE modified**

LMDZ

Ice/liquid partition function on occurrence:
according to temperature and distance to cloud top
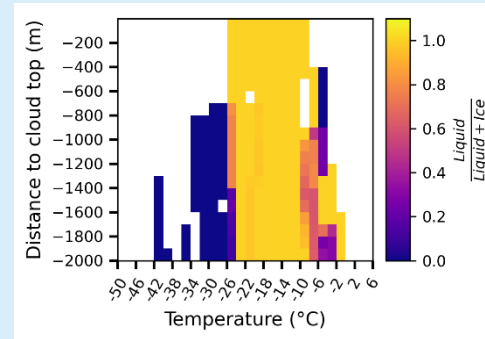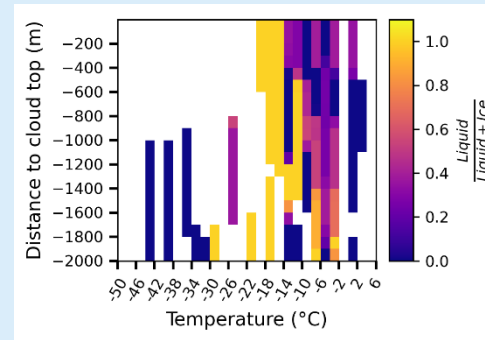## Statistics on all satellite overpasses

DARDAR

ERA5

ARPEGE

ARPEGE modified

LMDZ

Conclusion and outlooks

Conclusion:

- Higher **IWC** with **LMDZ**, closer to DARDAR observation
- **LWC** in models is very **far away** from observation
- Liquid water **occurrences**:
  - Over-estimation at low temperature (-20° - 0°)
  - Under-estimation at very negative temperature (-40°C)
  - Models do not consider a dependence on **distance to cloud top**
- Changing the **ice/liquid partition function**:
  - Decreases IWC
  - Allows supercooled liquid water at higher altitude

Outlooks:

- Look at LMDZ simulation with a **new ice/liquid partition function** depending on temperature and distance to cloud top
- Look at ice/liquid partition function according to **content** and not only occurrences
- Use mask based on radar reflectivity and lidar backscatter with **COSP simulator**

Thank you for your attention