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

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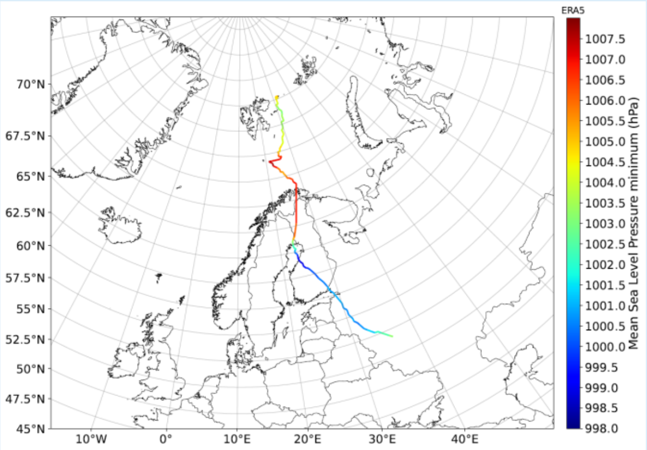
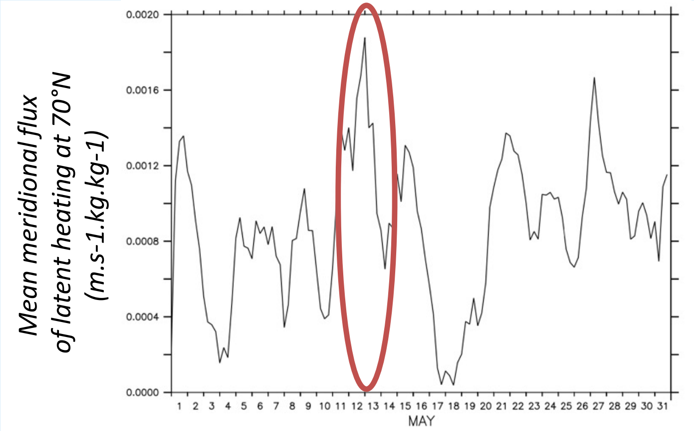
Study Case:
Arctic Cyclone in May 2019

- 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



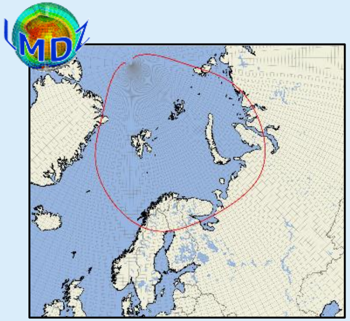
Minimum of MSLP during the Arctic cyclone trajectory (ERA5 data)



Mean meridional flux of latent heating at 70°N (ERA5 data)

Atmospheric models

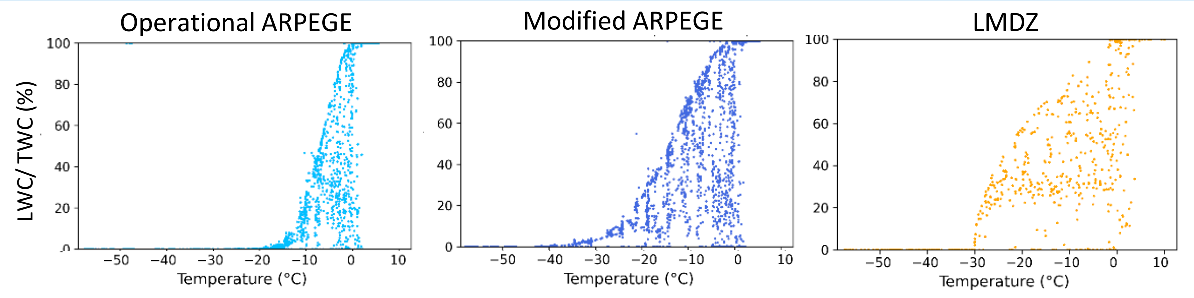
ARPEGE
Resolution: 5-24km, 105 levels
Initialisation: 4DVar analysis
(2019-05-12 at 00UTC)
Type of simulation: “Free” Forecast



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

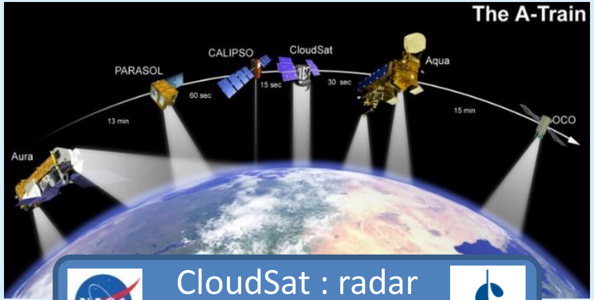
Simulations:
- Operational liquid/ice partition function
- liquid/ice partition function tested in Ricaud et al. (2020)

Simulations:
- CMIP7.1b version



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

Observations: DARDAR products



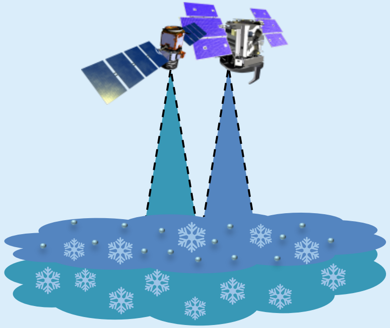
CloudSat : radar
CALIPSO : lidar

VarPy

- IWC, LWC
- Hydrometeores categorization

Radar:

- Sensitive to diameter of particules
- Detects ice cristals
- Use to determine IWC



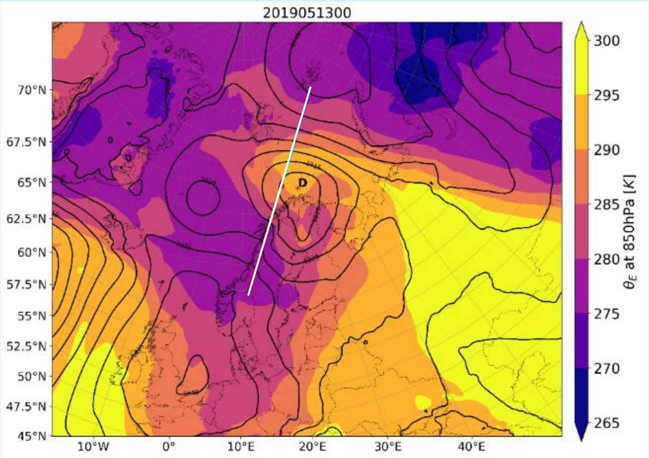
Lidar:

- 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

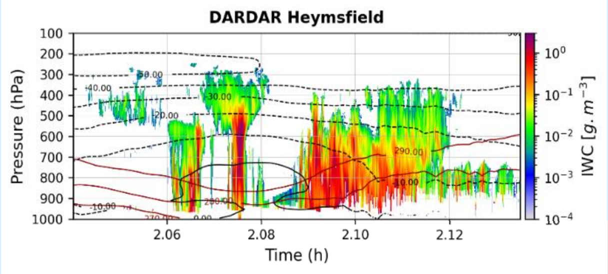
Example of one satellites overpass:
#2019133004652_69455 crossing warm and cold front

ERA5 : 20190513 00UTC

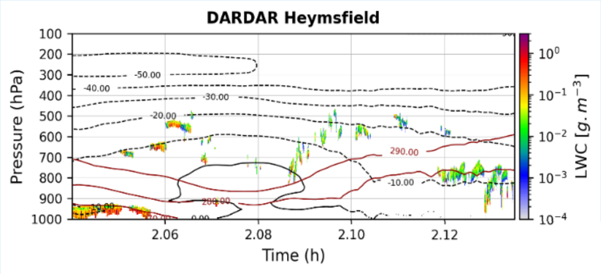


Shading: θ_E at 850hPa (K) ; black contours: MSLP (hPa) ;
white line: time along satellites overpass

DARDAR Products : 20190513 02UTC



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



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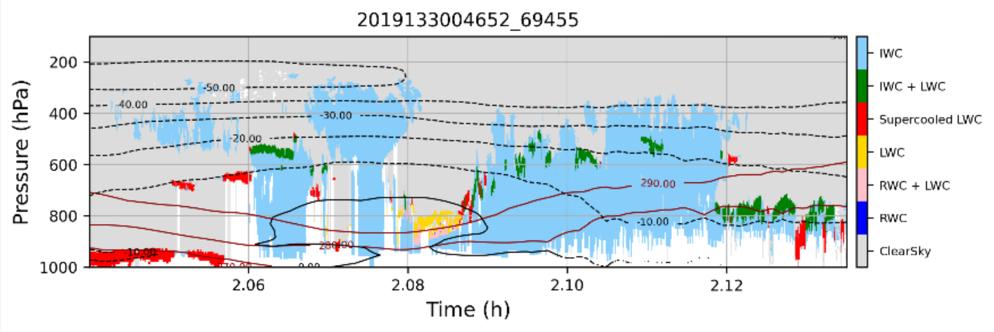


Shading: Hydrometeors categorization ; black contours: Temperature (°C) ; red contours: θ_E (K)

Comparison of IWC

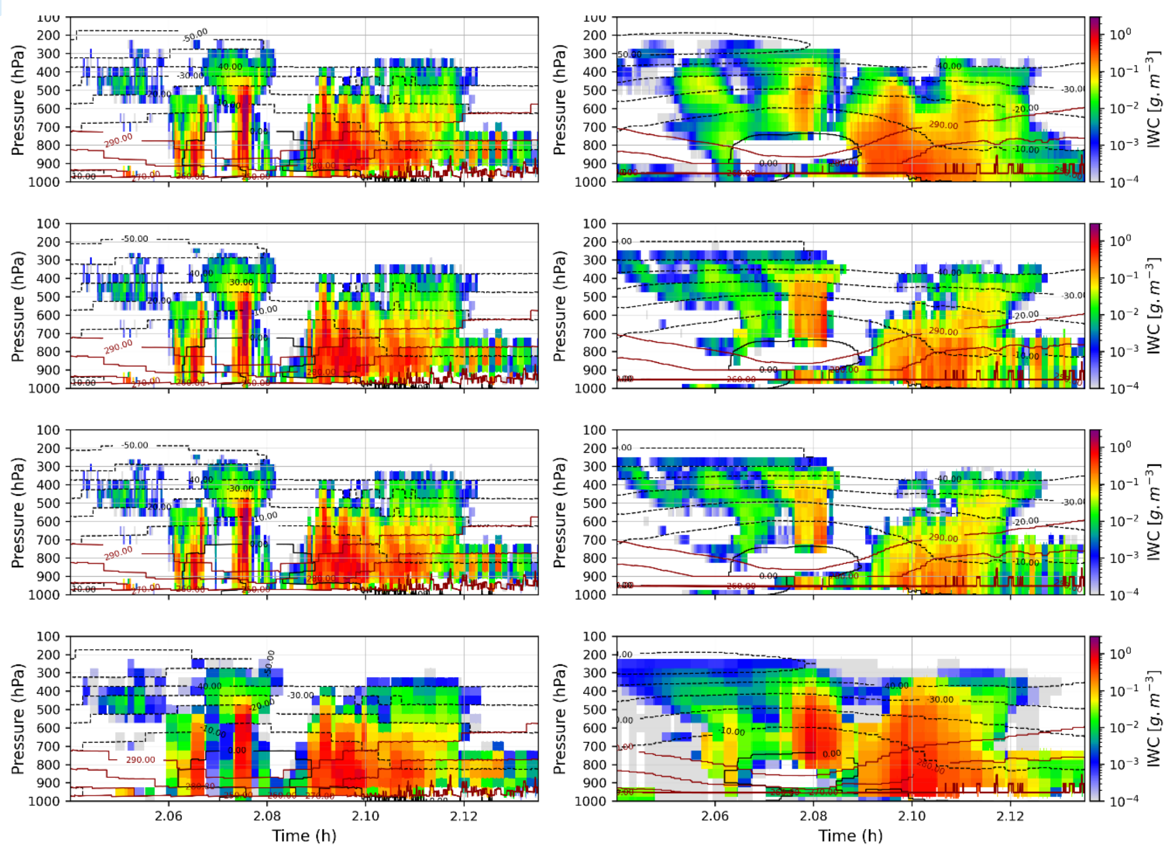
Shading: IWC ($g.m^{-3}$) ; black contours: Temperature (K) at 2019-05-13 0UTC

DARDAR obs at ERA5 resolution

DARDAR obs at ARPEGE resolution

DARDAR obs at ARPEGE modified resolution

DARDAR obs at LMDZ resolution



ERA5

ARPEGE

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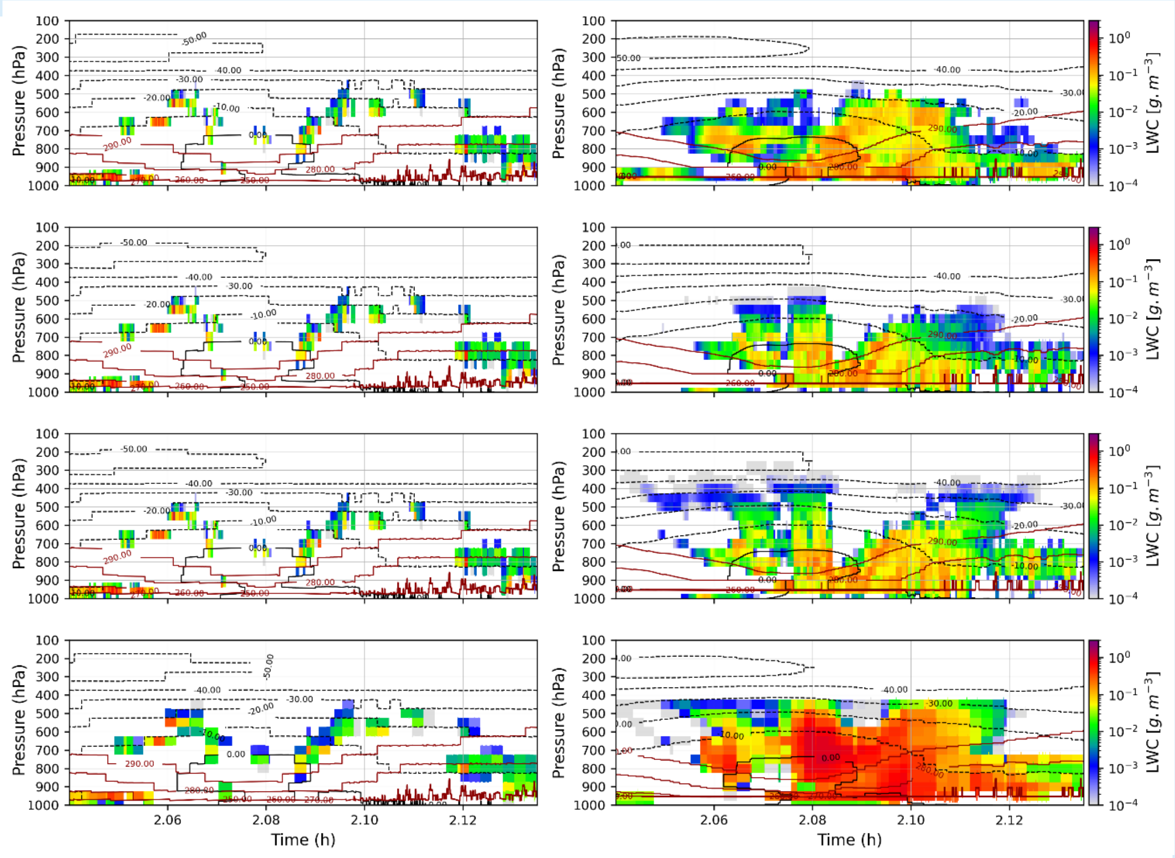

ERA5

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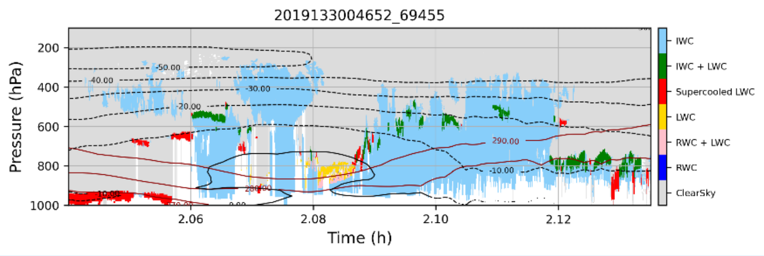
Comparison of hydrometeors categorization

DARDAR's categorization

Model categorization (ex : LMDZ)



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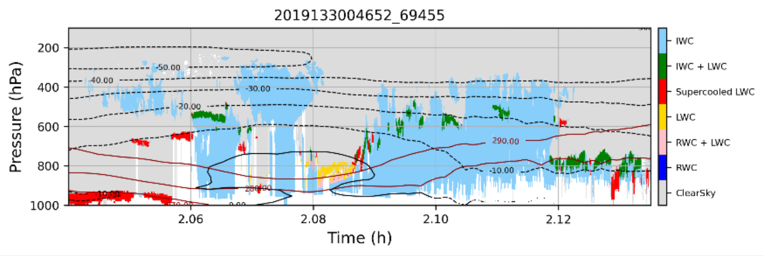

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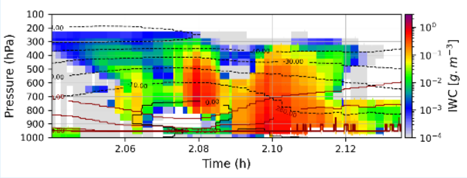

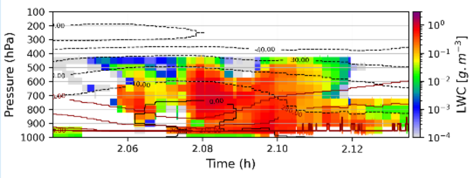

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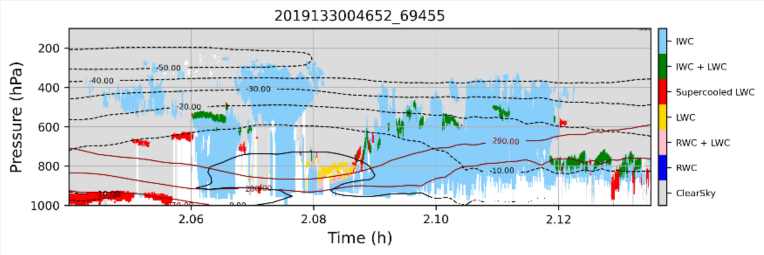

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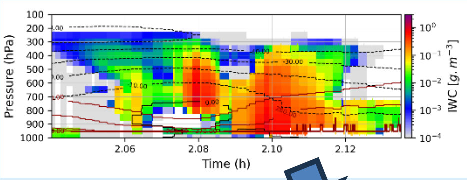

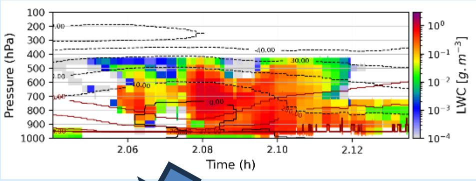

Threshold: 90%

- 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

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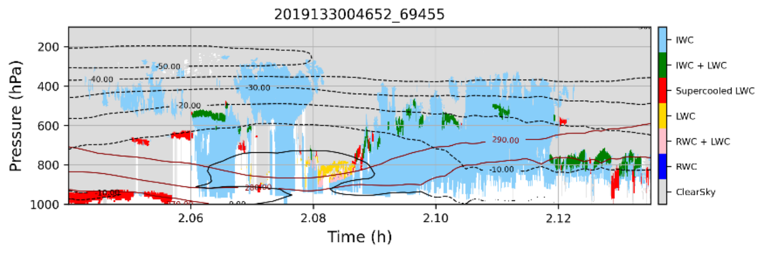

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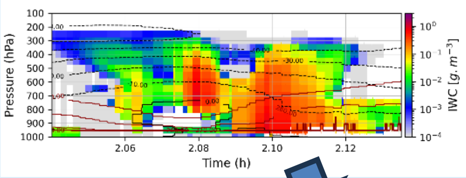

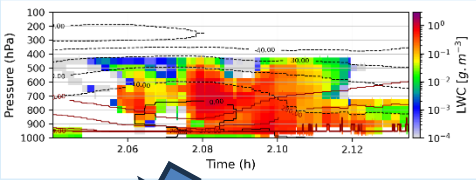

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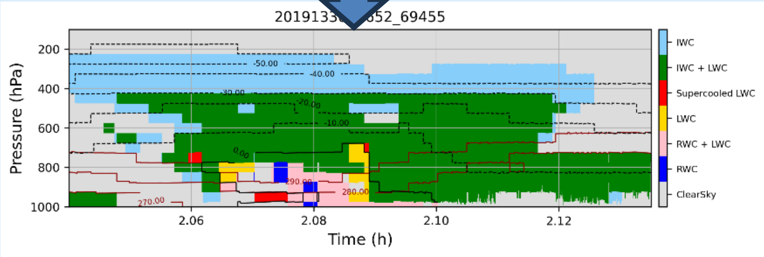

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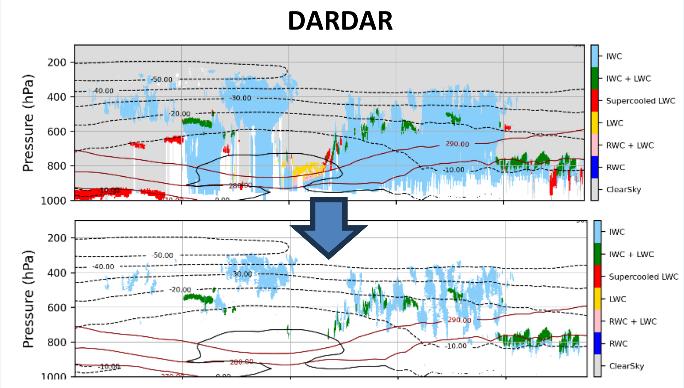
Over-representation of ice in mid-troposphere in observation



Observations :
Delete some datas 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

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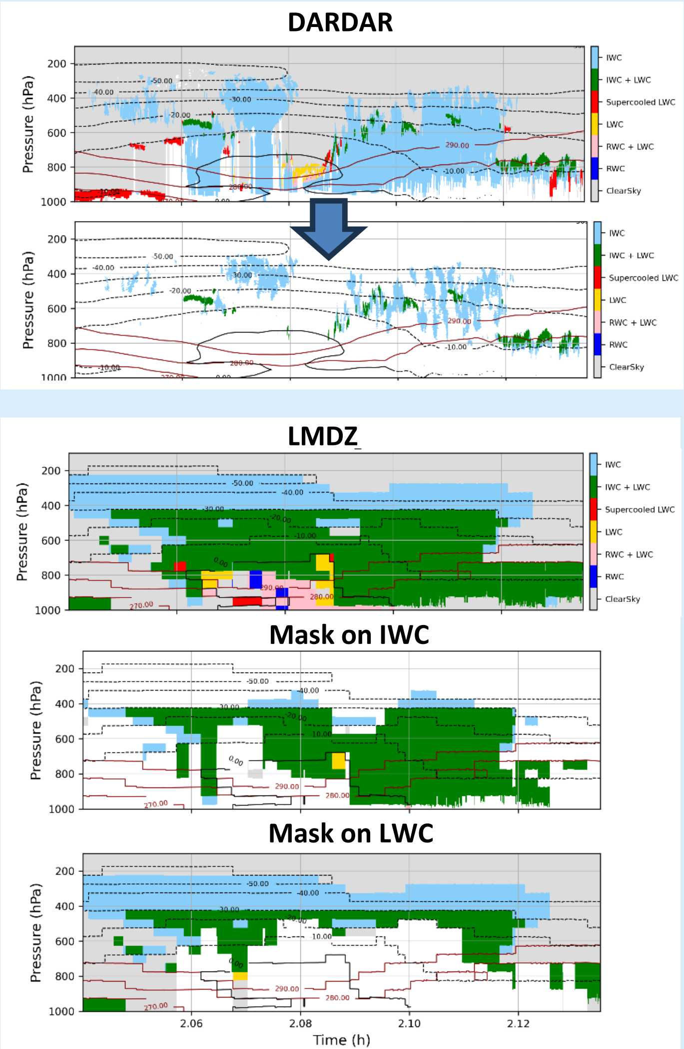
- $LWC > 1 \times 10^{-1} g.m^{-3}$ where lidar is attenuated



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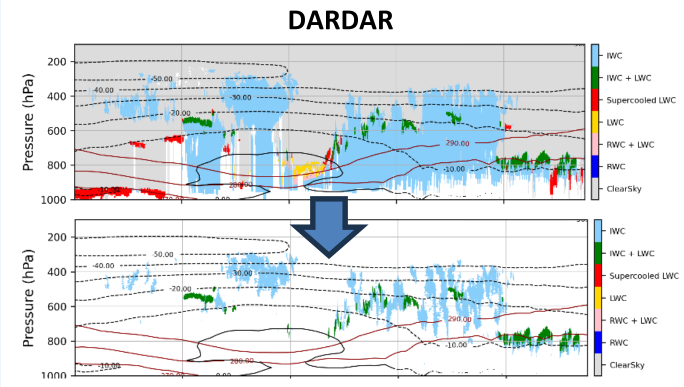
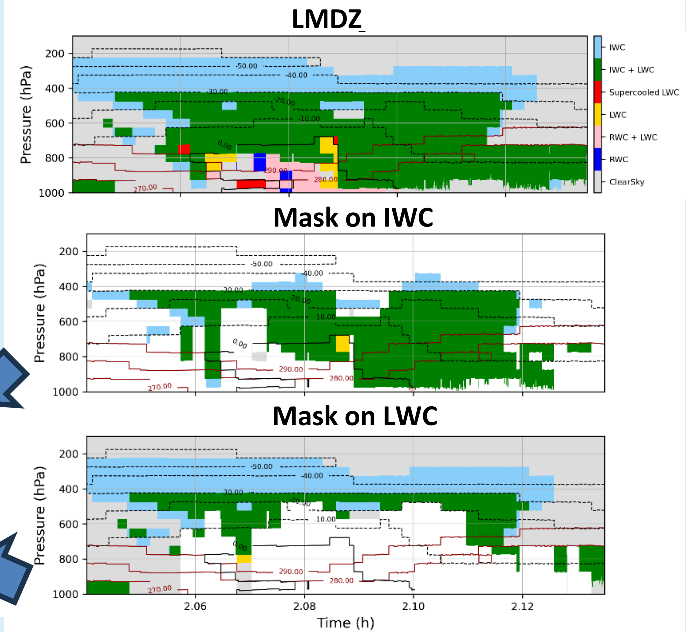
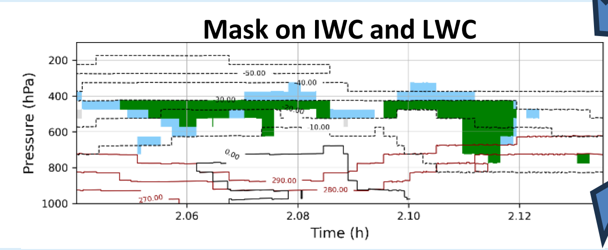
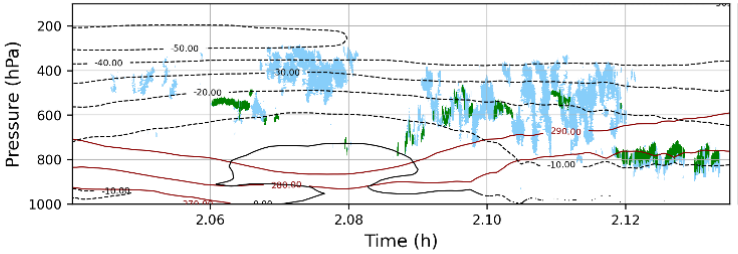




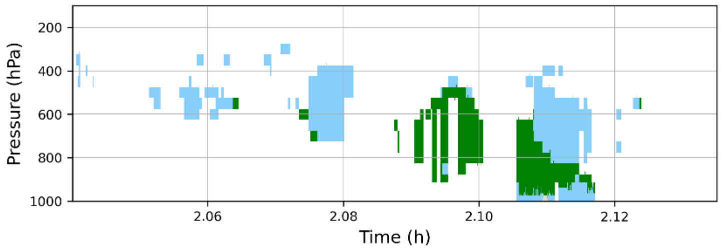


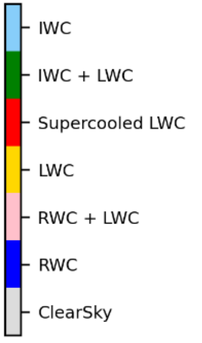
Sensitivity to ice/liquid partition function and ratqs

DARDAR



ERA5





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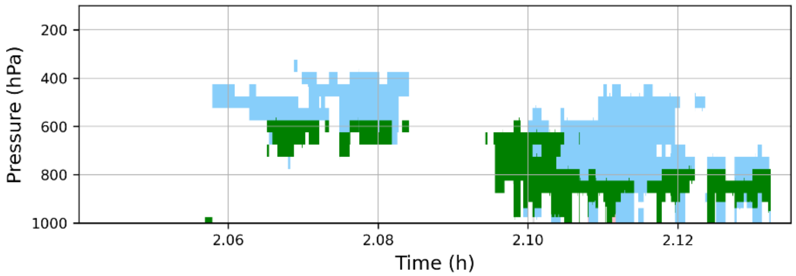
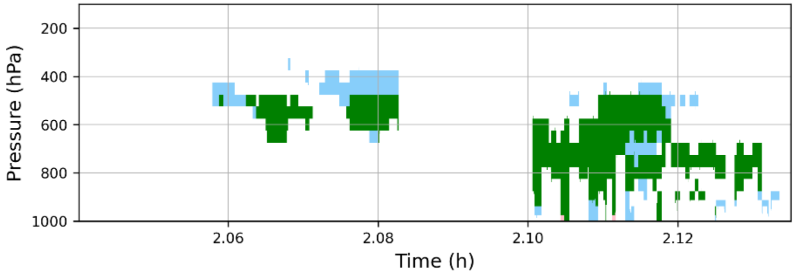
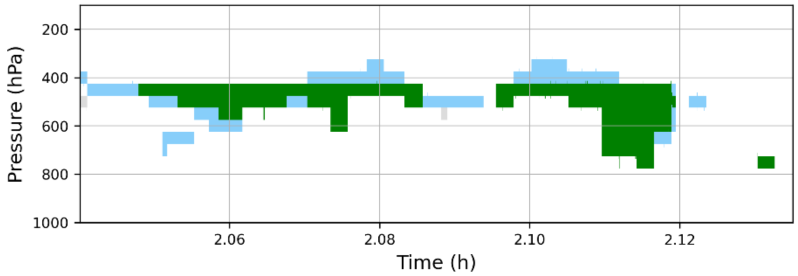
ARPEGE



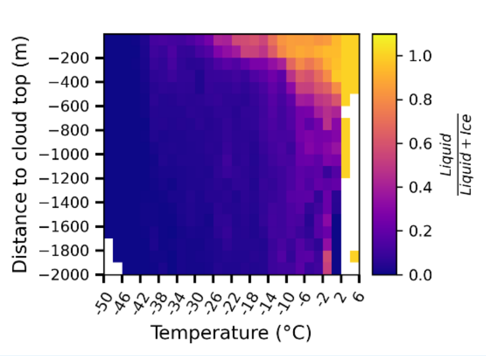
ARPEGE modified



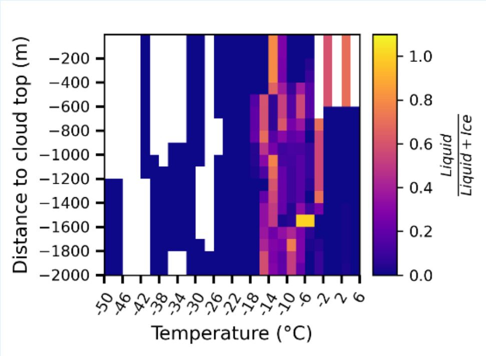
LMDZ



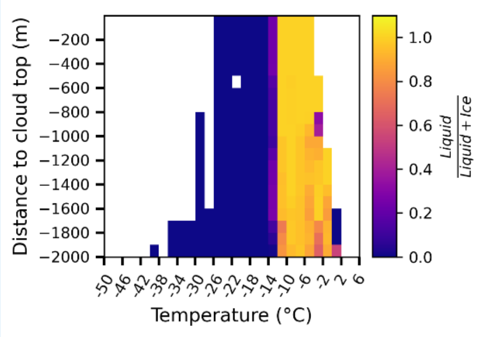
Ice/liquid partition function on occurrence: according to temperature and distance to cloud top
Statistics on all satellite overpasses



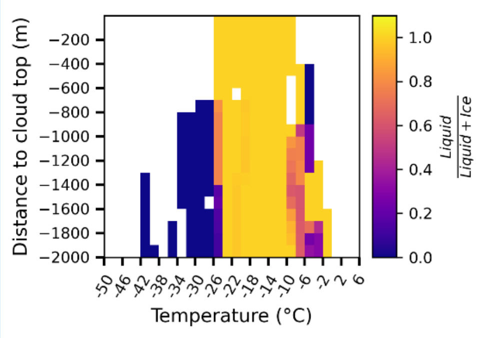
DARDAR



ERA5



ARPEGE



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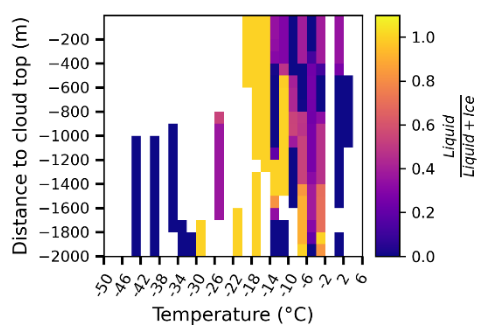

LMDZ

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