What bout water vapor and condensation at Dome C

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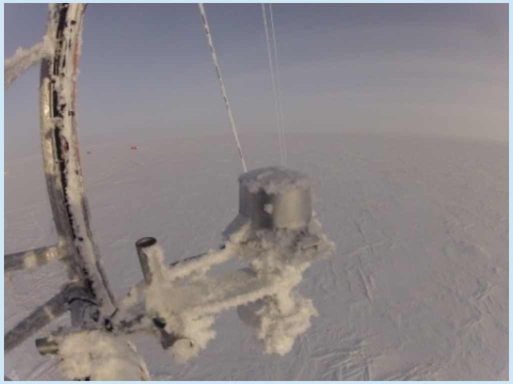
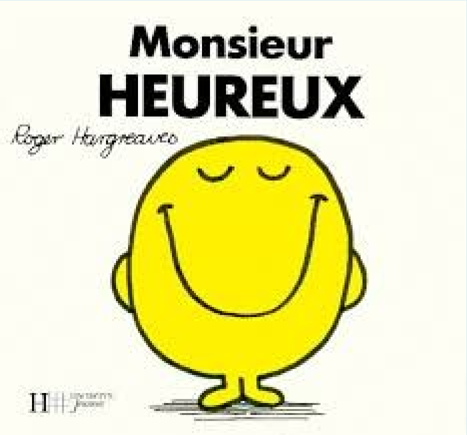
Little atmospheric moisture (T° ~ -30 / -70°C), yet a lot of frost => necessarily near or above saturation ?



There used to be a time when climate modeling was simple.



For instance, basic equilibrium thermodynamics would apply:

With good old FORTRAN 77

IF

partial pressure of water vapor .GT. saturation partial pressure

THEN

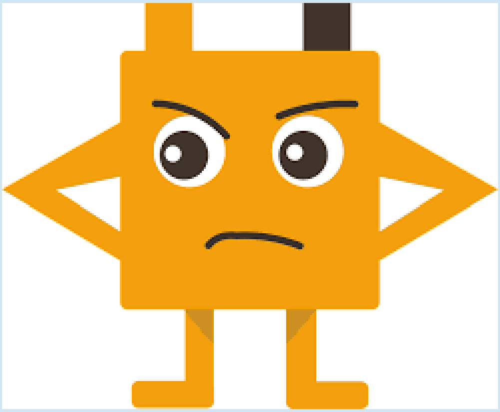
Dump excess water, make cloud and rain (T>0°C) or snow (T <°C),

ELSE

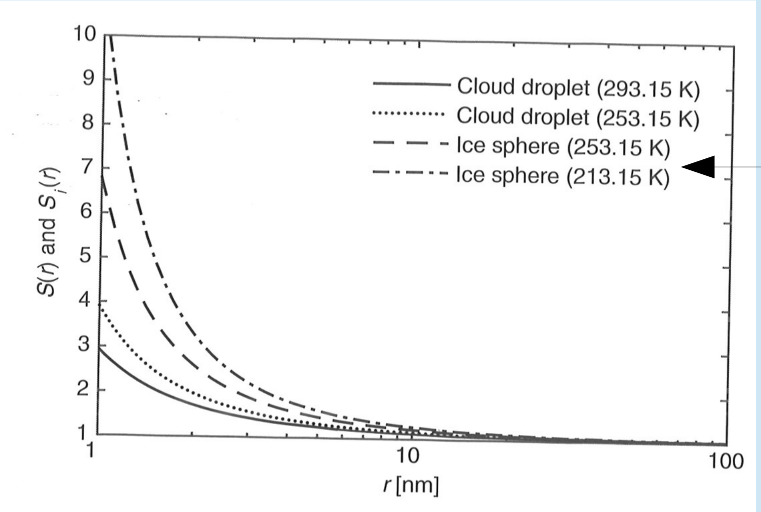
Clear sky, no precip

END IF

Good old time. Until we found (or accepted) that supersaturation exists in the atmosphere.



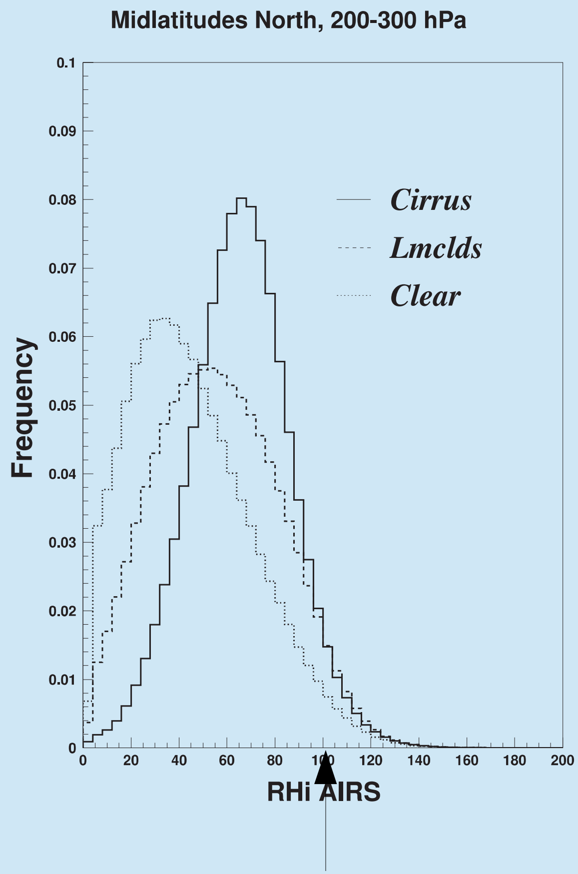
Enhanced thermodynamics: Supersaturation is required for homogeneous nucleation to spherical droplet / ice crystal to occur (Kelvin effect). The required supersaturation is larger as temperature is colder.



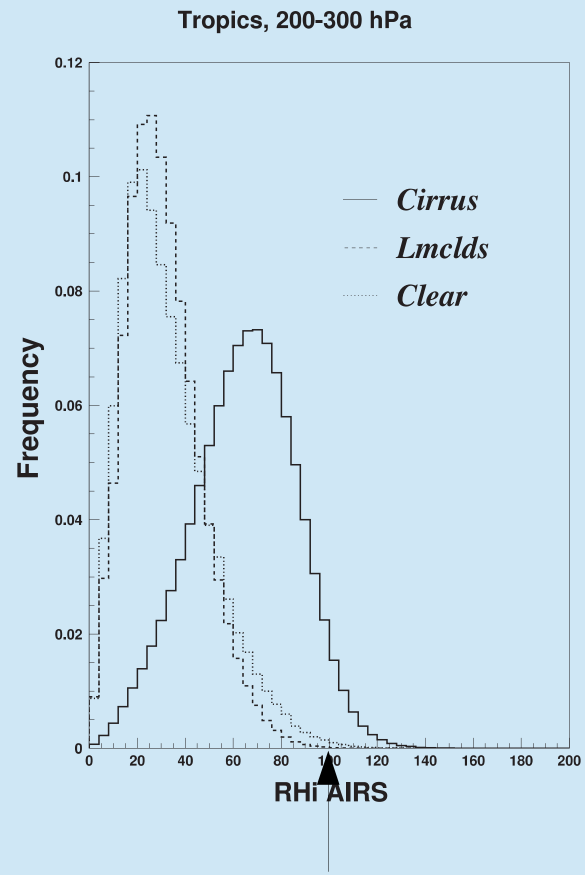
Upper troposphere
Antarctic surface

From Lohmann, Lüönd and Mahrt, 2016. An Introduction to clouds, Cambridge University Press, Fig 8.1

In addition, if supercooled water, then humidity >~ supersaturation with respect to liquid => largely supersaturated with respect to ice



100 %
With respect to ice
(wri)



100 %
With respect to ice
(wri)

From Atmospheric InfraRed Sounder (AIRS)

Lamquin et al., A global climatology of upper-tropospheric ice upersaturation occurrence inferred from atmospheric infrared sounder calibrated with MOZAIC, 2012, doi:10.5194/acp-12-381-2012

Good old time. Until we found (or accepted) that supersaturation exists in out atmosphere.

- Including supersaturation with respect to ice (wri)

- Not only exists but also is frequent

- Not only in clear sky but also in cloudy conditions

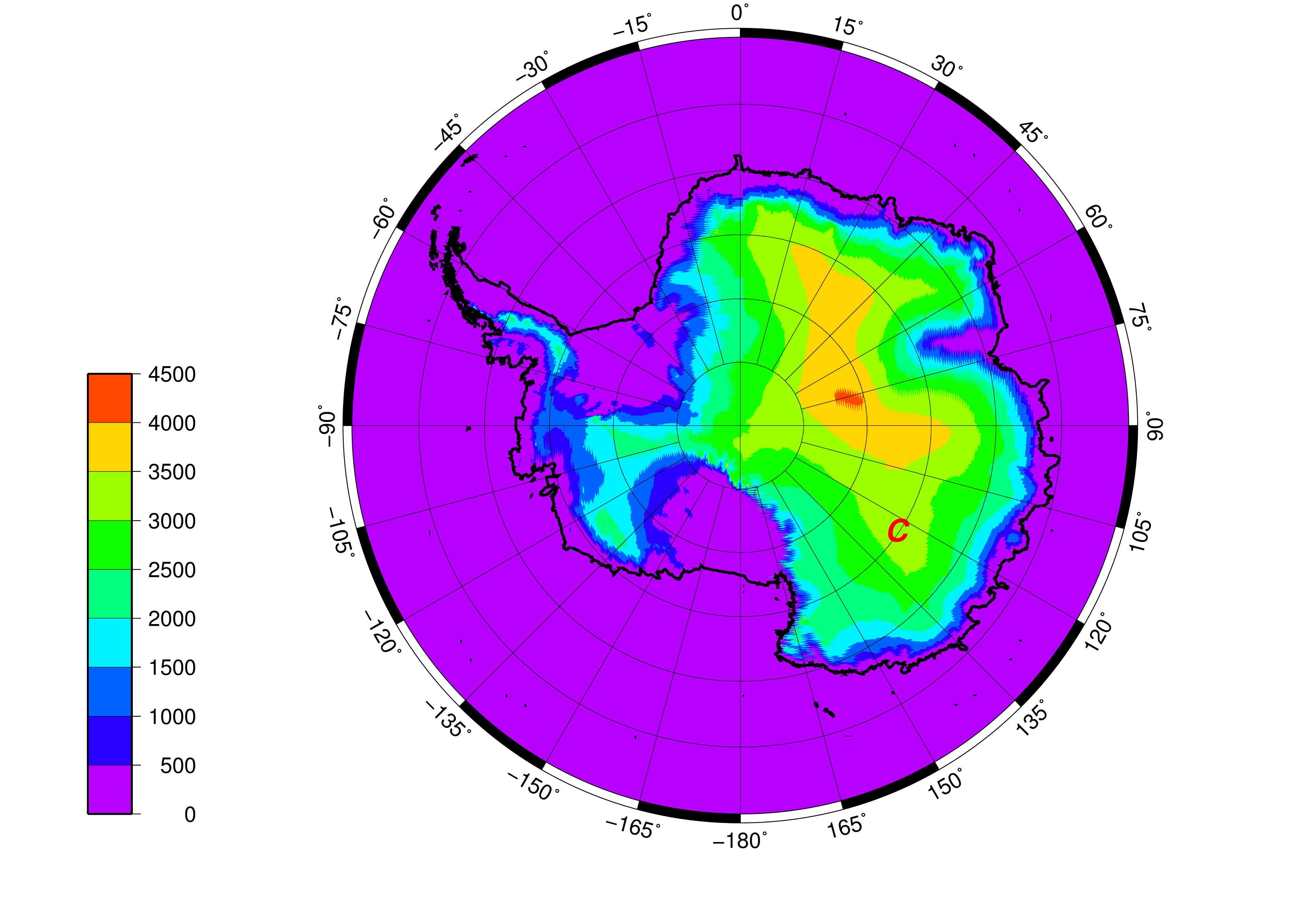
And it must be accounted / parameterized in meteorological and climate models to account for such highly sensitive clouds as the high altitude cirrus

Cold temperature + low CCN / IN => high altitude, not at the surface

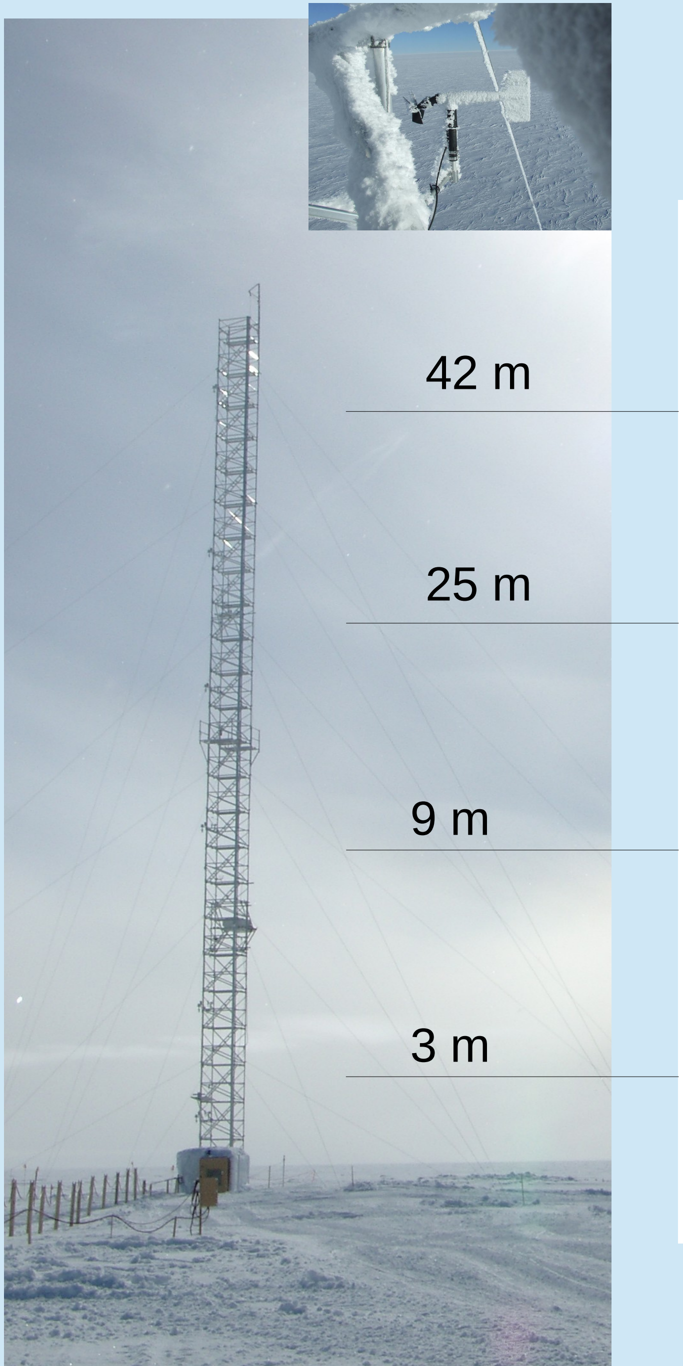
=> An issue for high altitude clouds (cirrus) only
=> Obtain in situ observation to verify parameterization is difficult

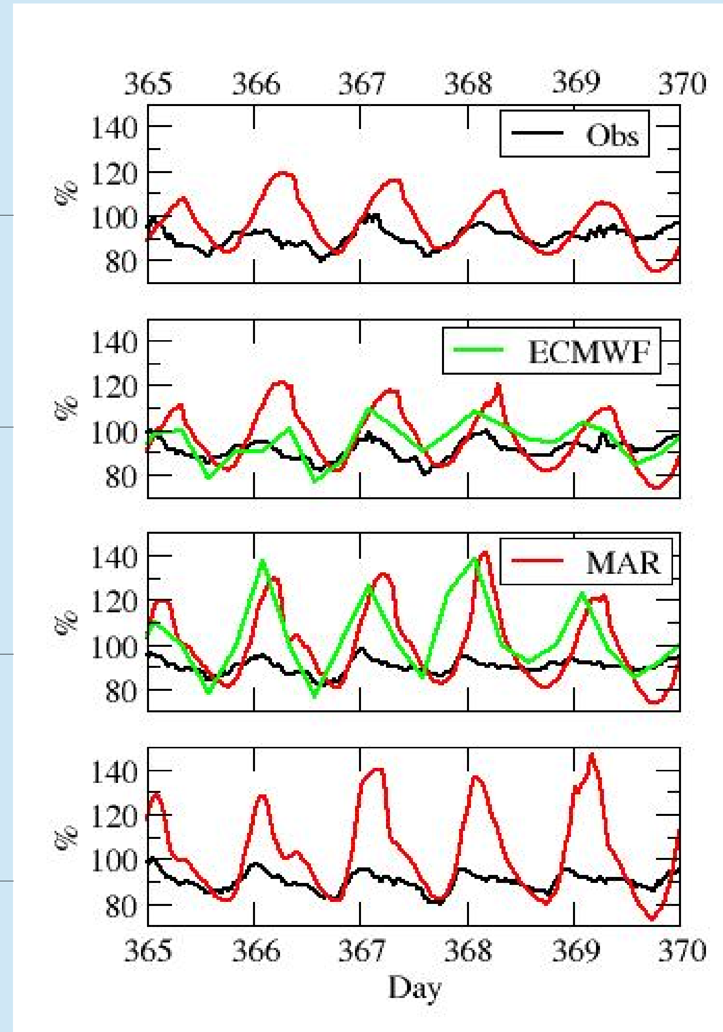
Where do we have cold temperature, low CCN/IN, right at the surface?

Dome C, East Antarctic plateau, 75°060S, 123°200E, 3233 m a.s.l.



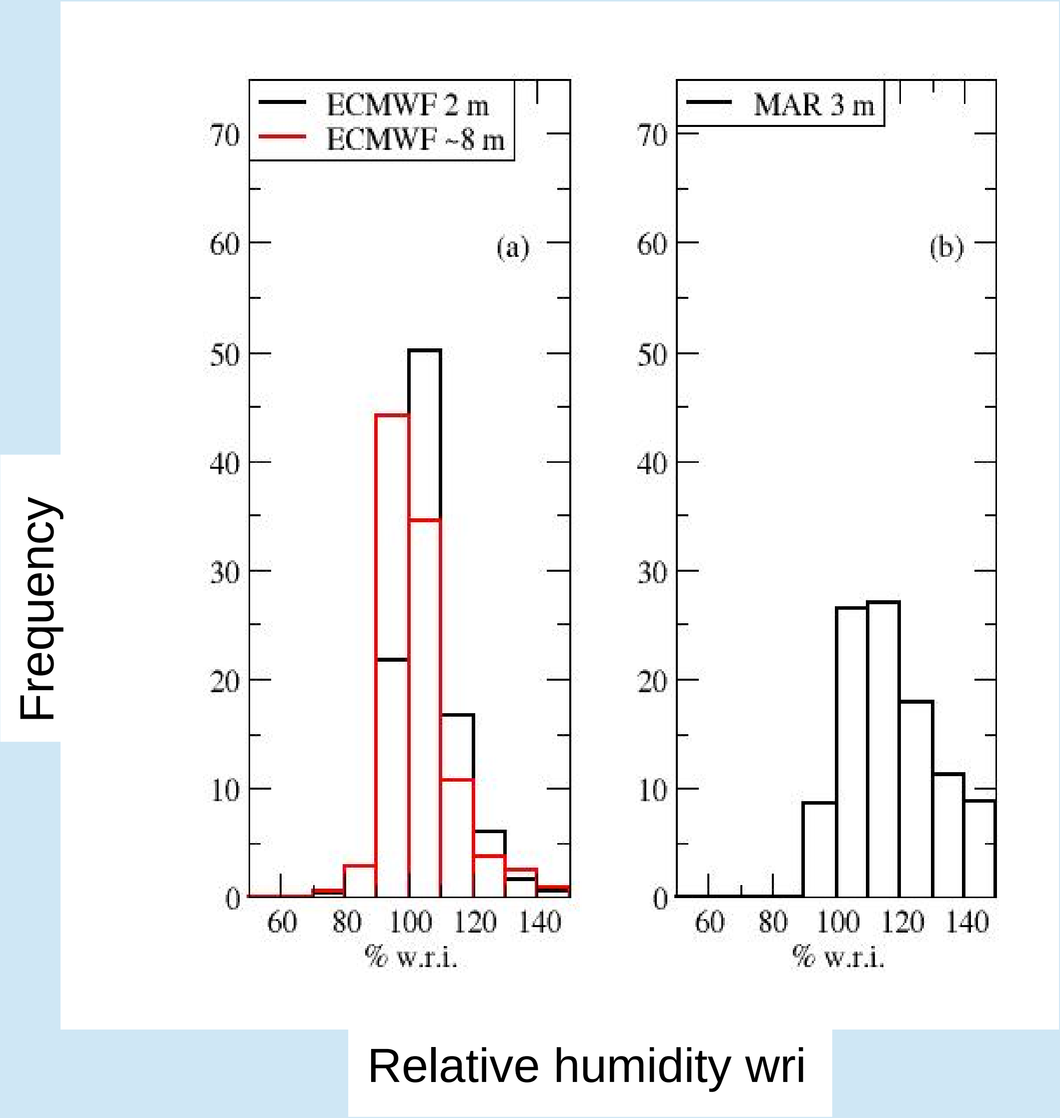
=> Standard (incl. WMO approved) instruments do not report supersaturation





OBS
ECMWF
MAR

The models (with cold microphyics) suggest that supersaturation is very frequent

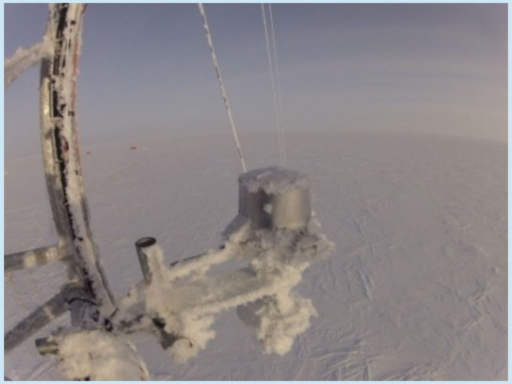


Where moisture is measured

Where frost deposits / excess moisture is dumped

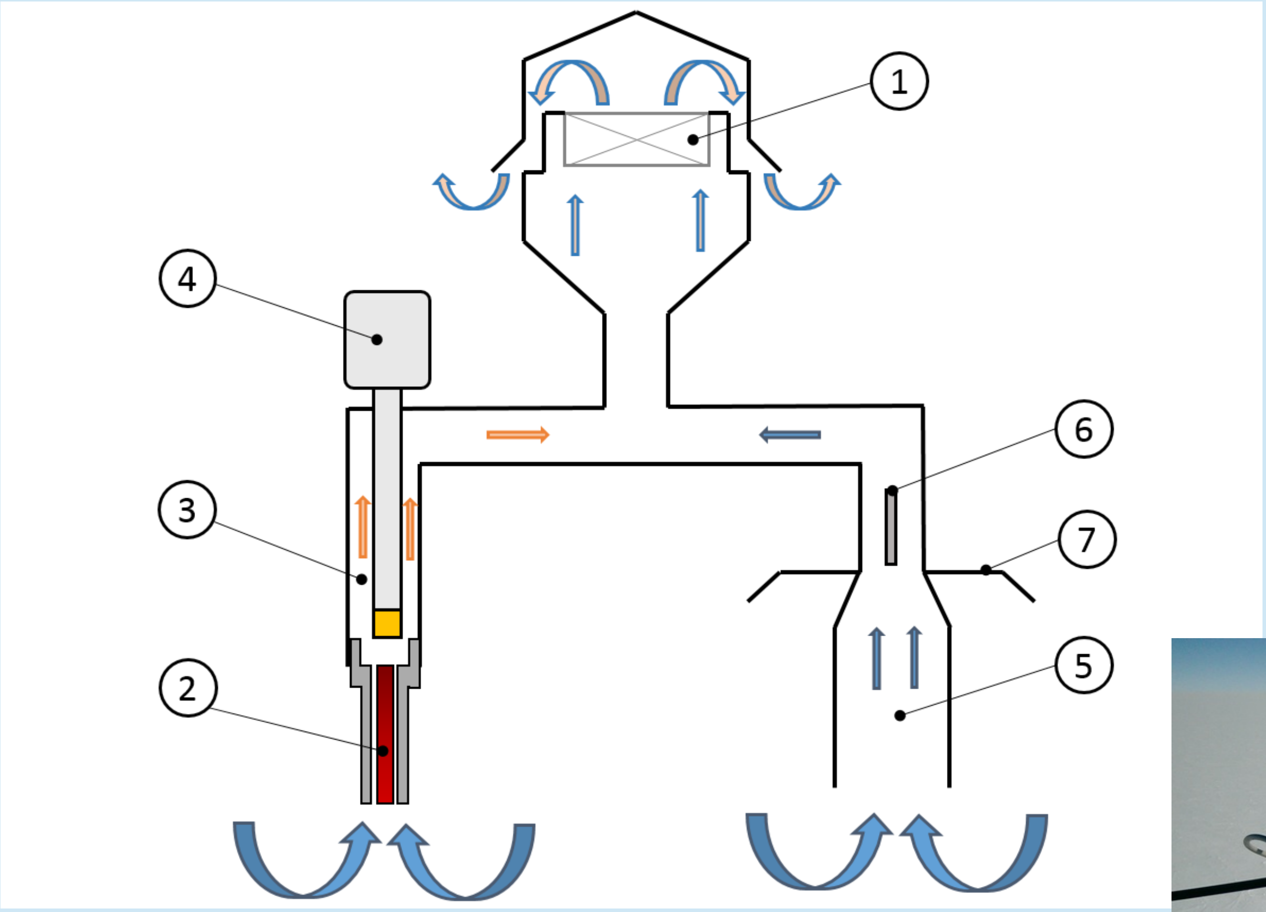
A typical commercial hygrometer (Vaisala HMP155)

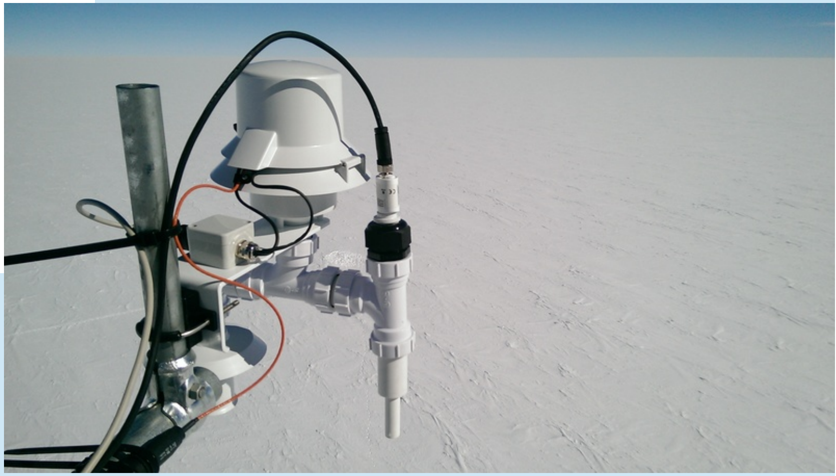
In its radiation shield



Challenge : how to measure moisture content of a supersaturated atmosphere?

Since any surface – including measuring device – acts as IN?



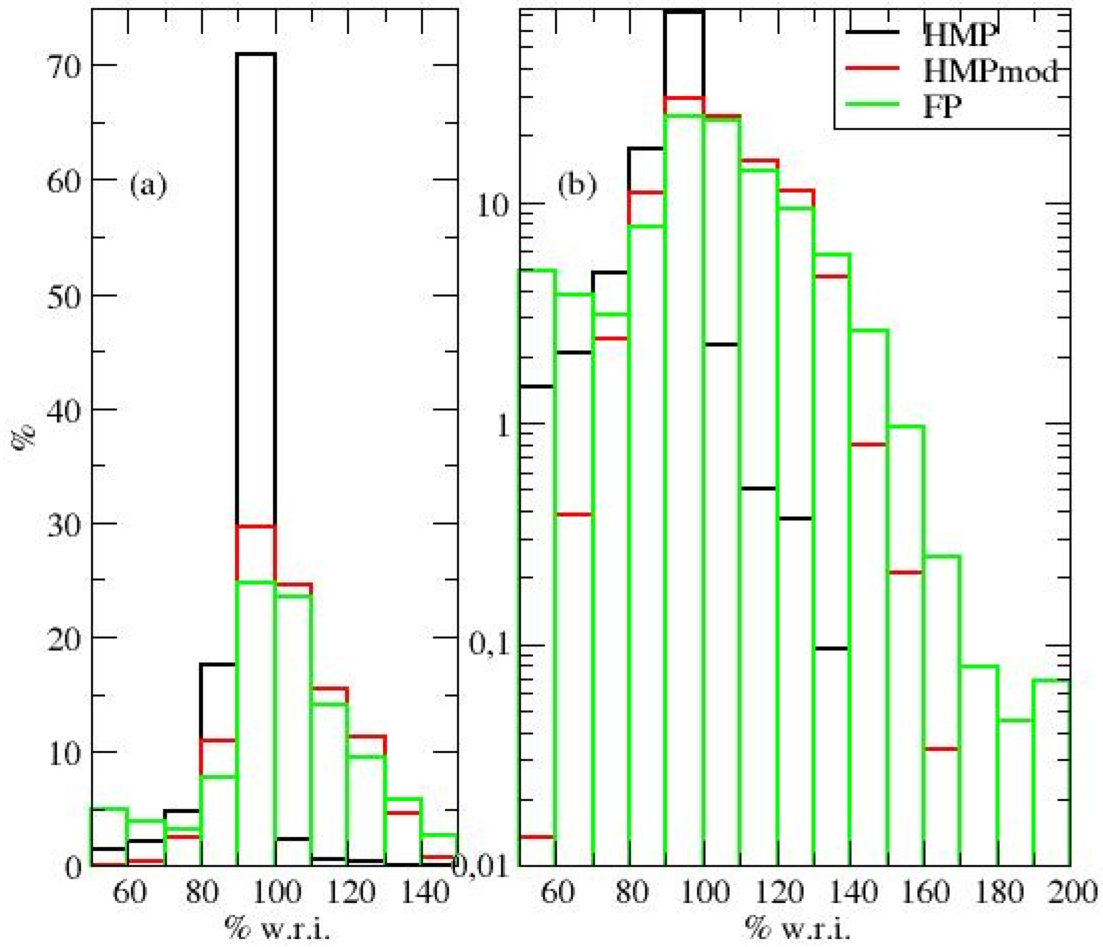


- Simple (use commercial sensors)

- Robust (deploy, operate in extreme environment)

- Affordable (can deploy multiple units , e.g. for vertical gradients)

Observation confirm that supersaturation is very frequent, the norm rather than the exception



The Dome C surface atmosphere is characterized by

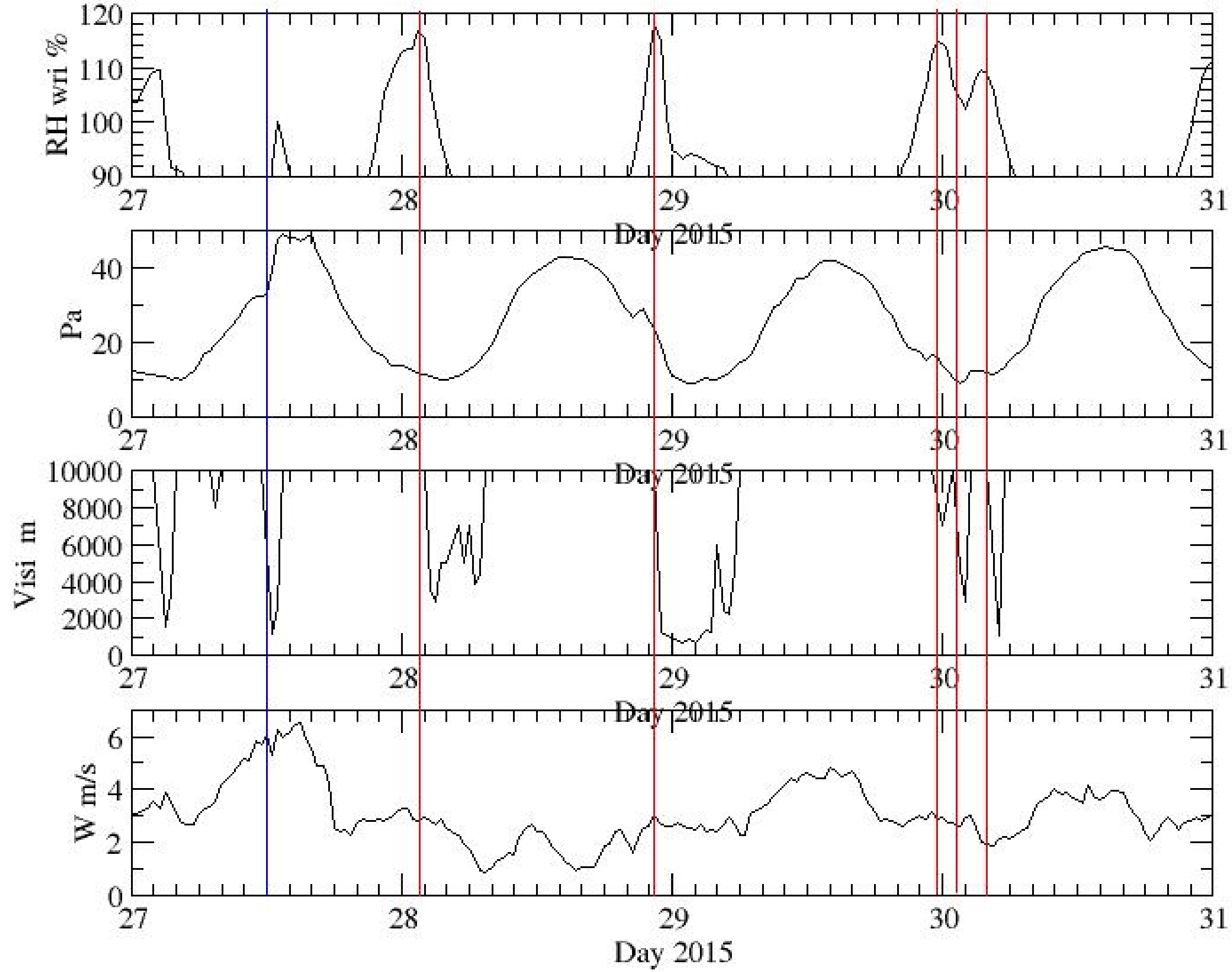
- Frequent supersaturations

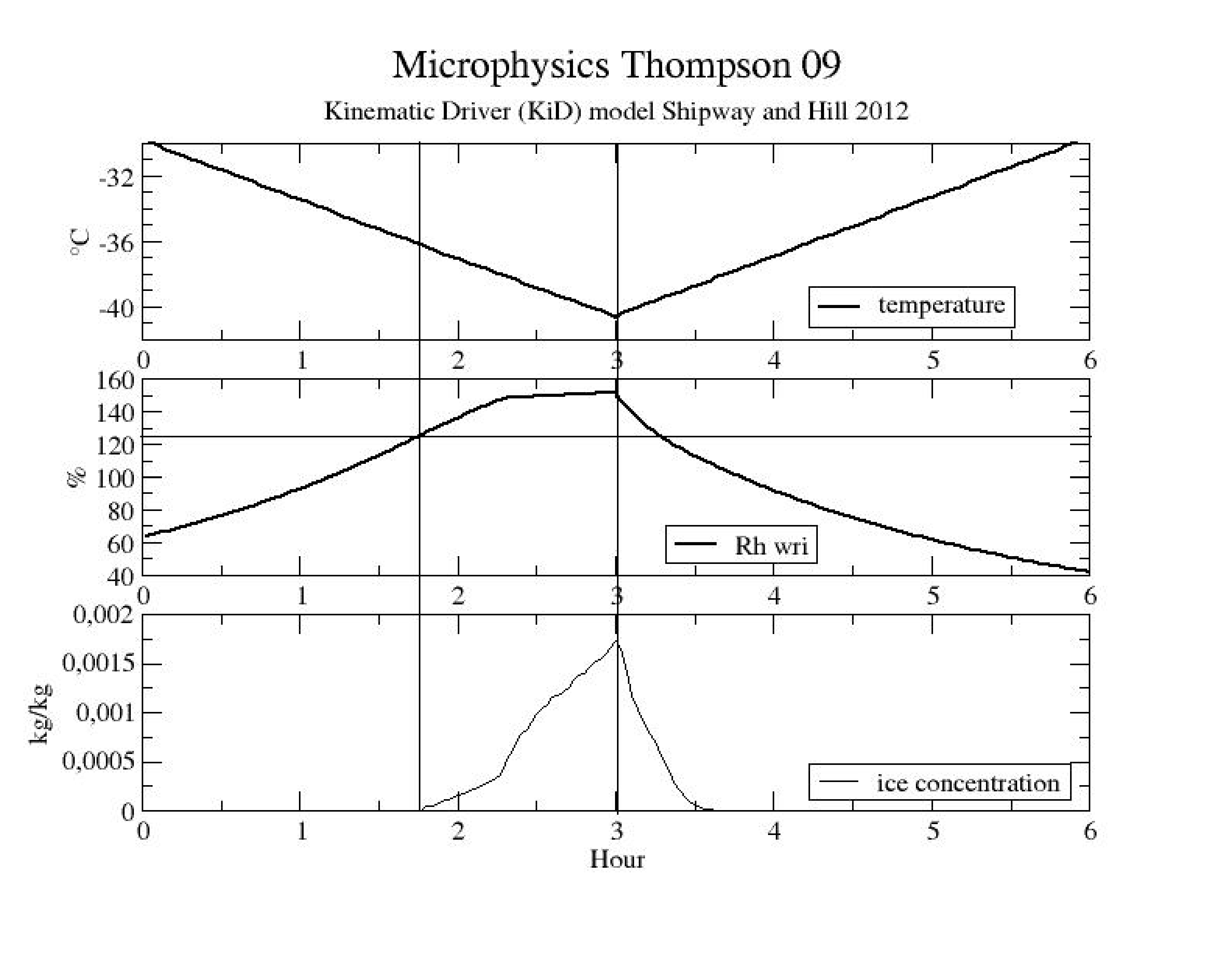
- In conditions similar to high troposphere regarding temperature, moisture content, CCN and IN content

- But comparatively more accessible for in situ measurement (e.g. long continuous series)

Could it be used as a natural laboratory to test / evaluate / develop cold microphysics parametrizations of cold clouds an precipitation ?

Visibility from METAR (Meteorological Airport Reports) : diurnal haze formation in summer



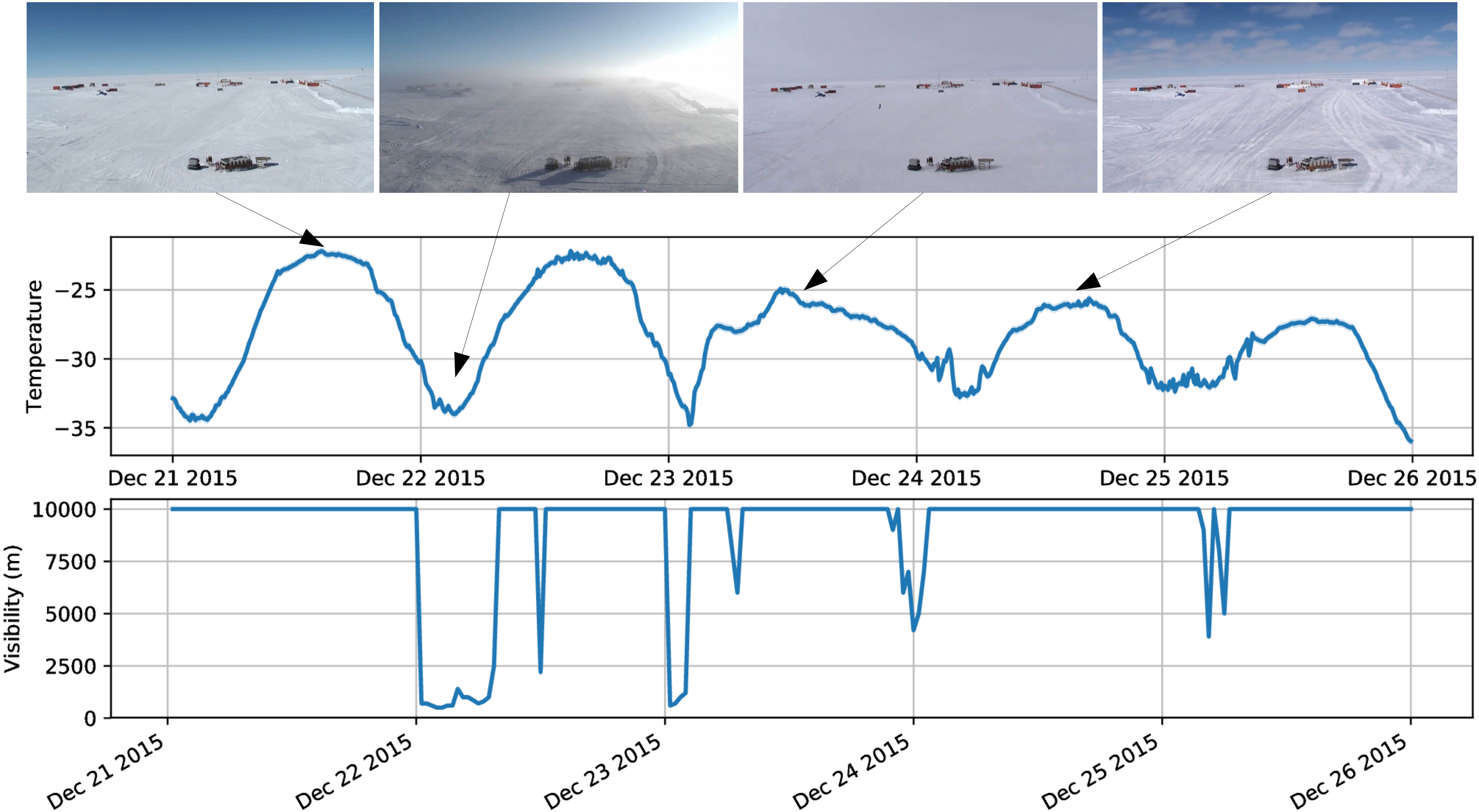


Microphysics Thompson 09
Kinematic Driver (KiD) model Shipway and Hill 2012
°C
-32
-36
-40
temperature
%
160
140
120
100
80
60
40
Rh wri
kg/kg
0,002
0,0015
0,001
0,0005
0
ice concentration
0
1
2
3
4
5
6
Hour

A model evaluation / intercomparison (GAWS?)

J.-B. Madeleine, With R. Forbes, H. Gallée, E. Vignon, F. Hourdin, F. Lemonnier

Selected period – Dome C obs.



Concordia video 2015-12-22 00:22:39

Concordia video 2015-12-22 01:21:01

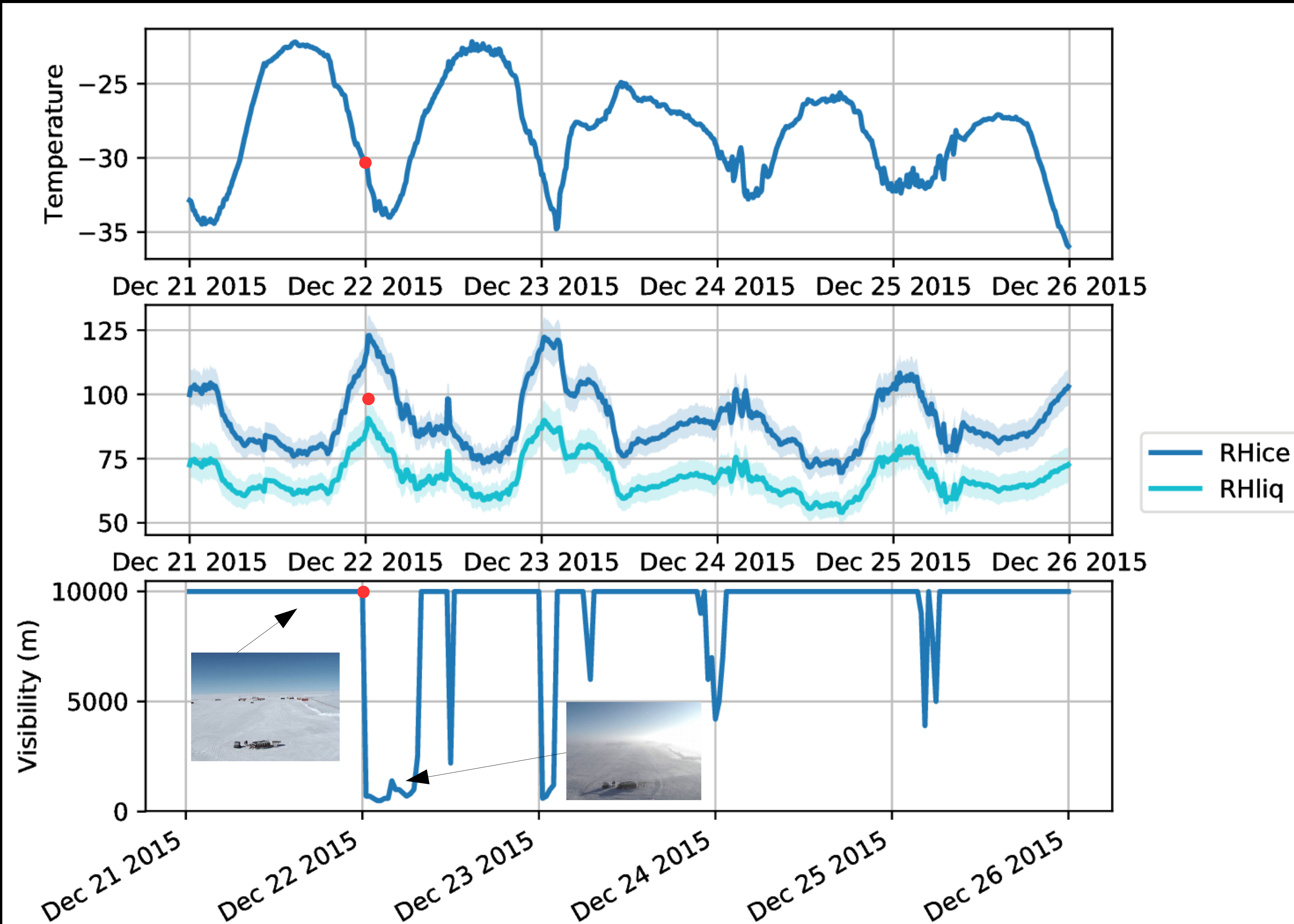
Concordia video 2015-12-22 02:32:58

Concordia video 2015-12-22 03:16:32

Concordia video 2015-12-22 07:41:01

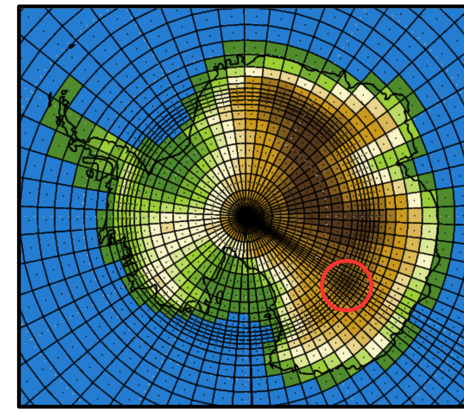
Concordia video 2015-12-22 10:02:44

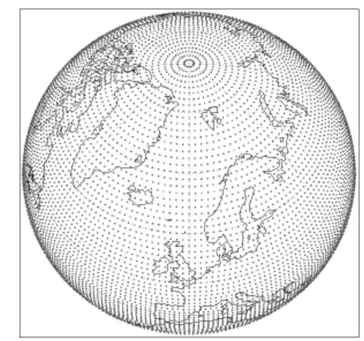
Ice haze formation

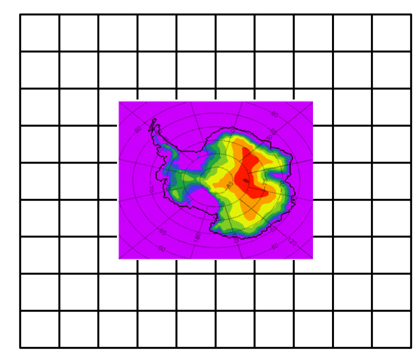


Model intercomparison

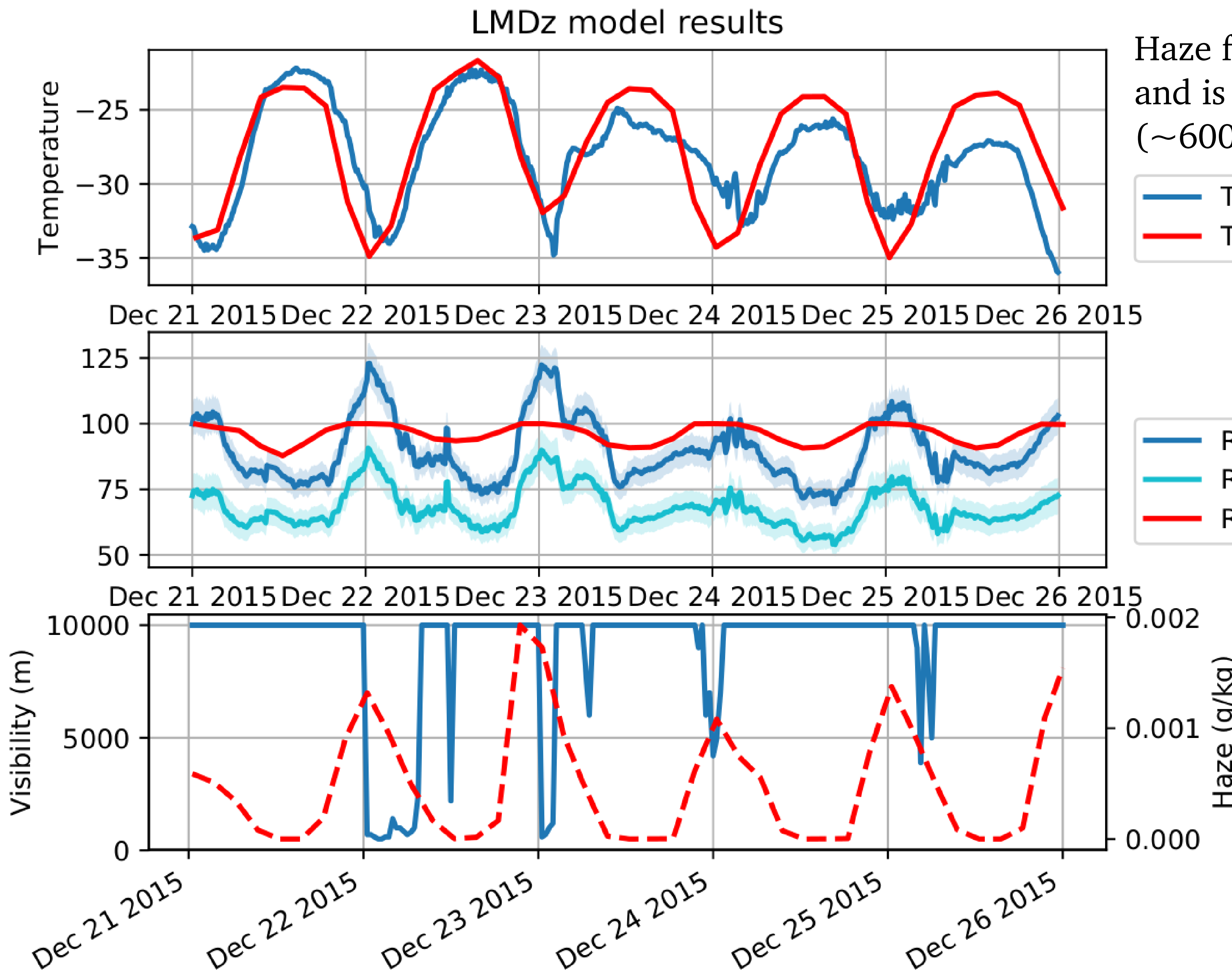
- **IPSL-CM** (global, zoom) : no supersaturation → ice condenses when $RH_i = 100\%$ and $\text{Cloud liquid fraction} = \left(\frac{T - T_{min}}{T_{max} - T_{min}}\right)^n$
- **IFS** (global, high resolution) : microphysical scheme → crystal growth by deposition for T > -38°C and homogeneous freezing for T < -38°C
- **MAR** (limited area model) : microphysical scheme and blowing snow, 6 prognostic equations





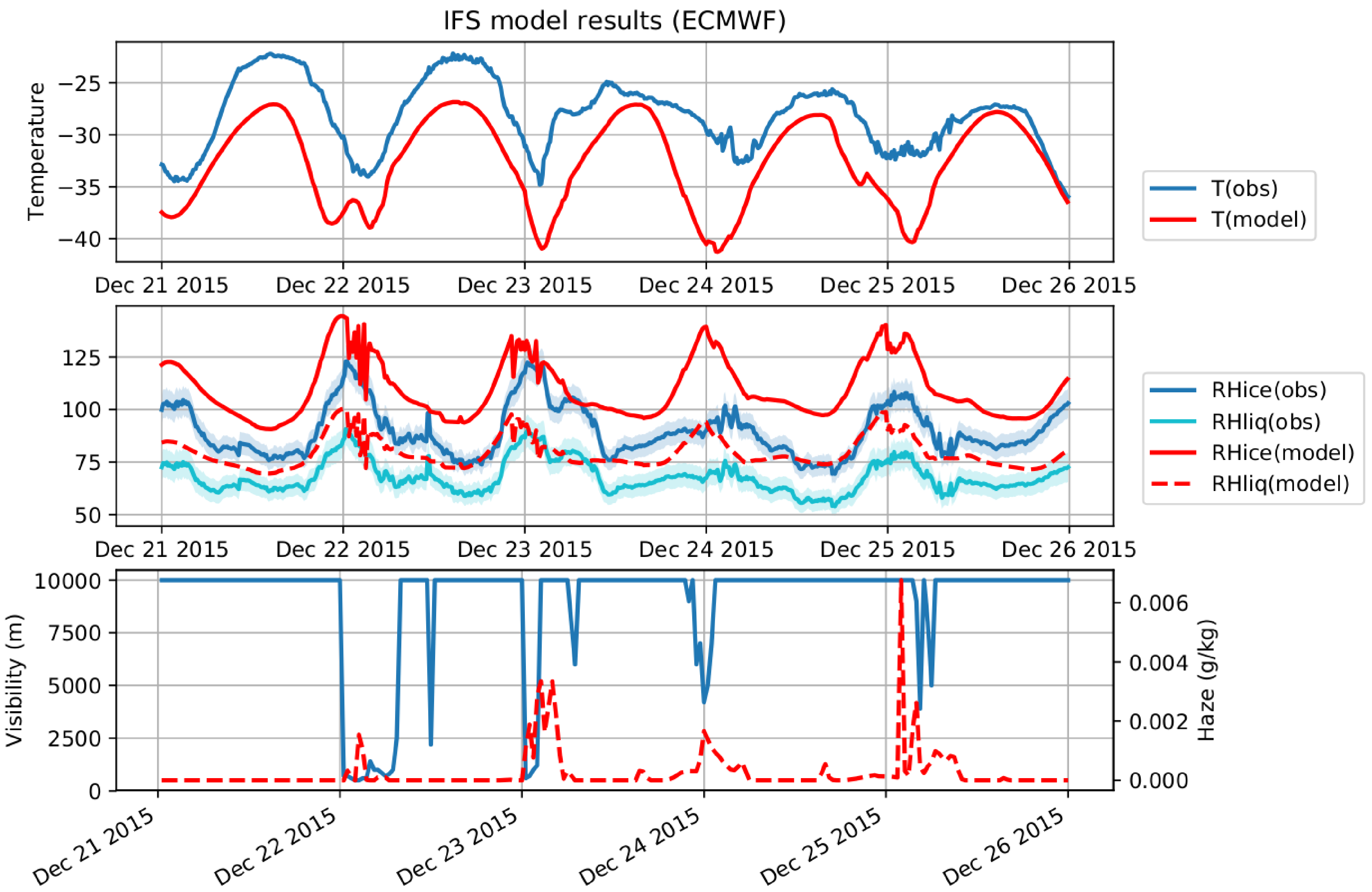


Results without supersaturation

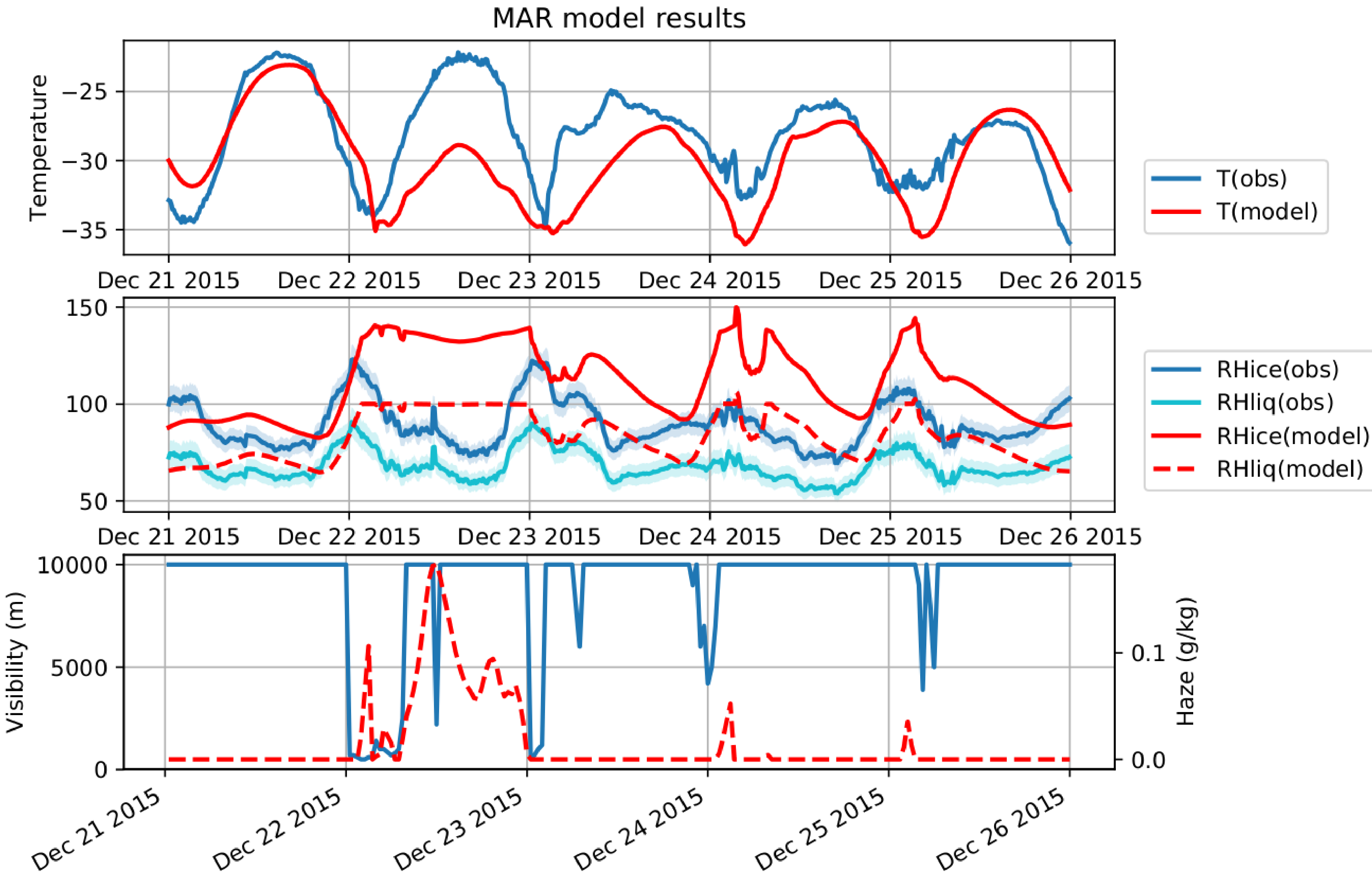


Haze forms too often and is too thin (~6000m visibility)

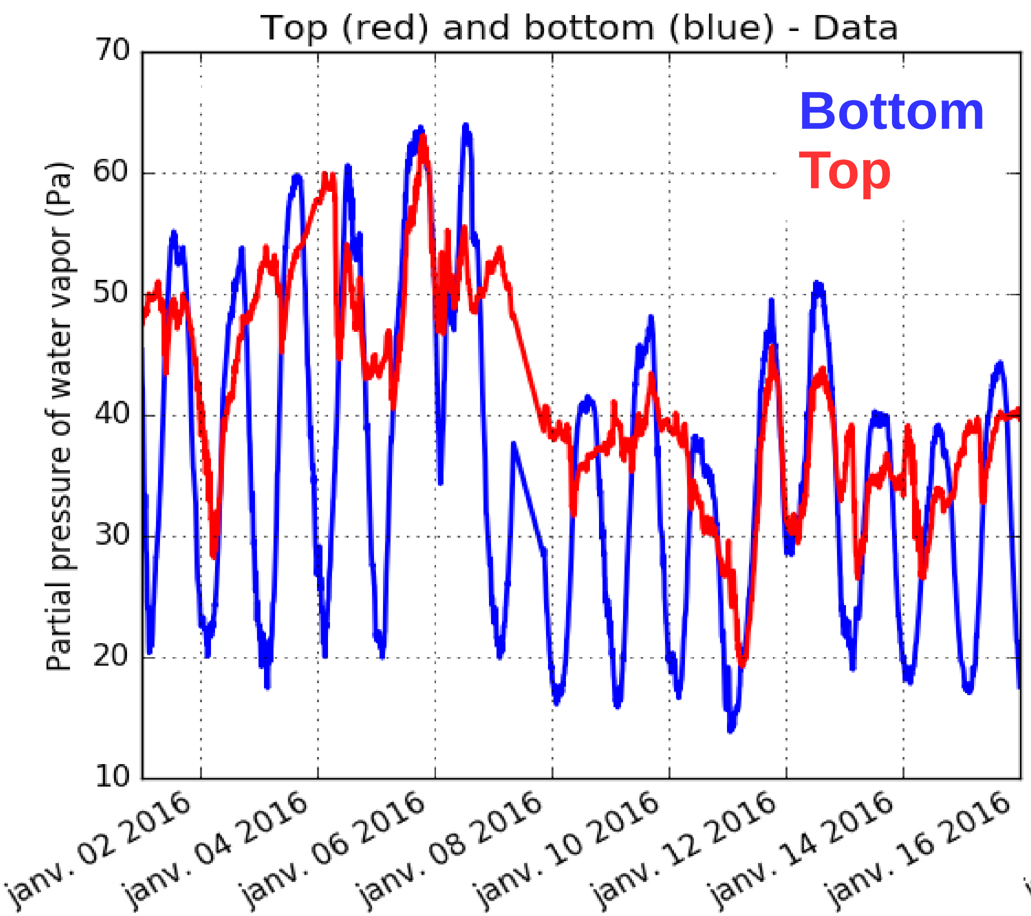
IFS results (includes supersaturation)

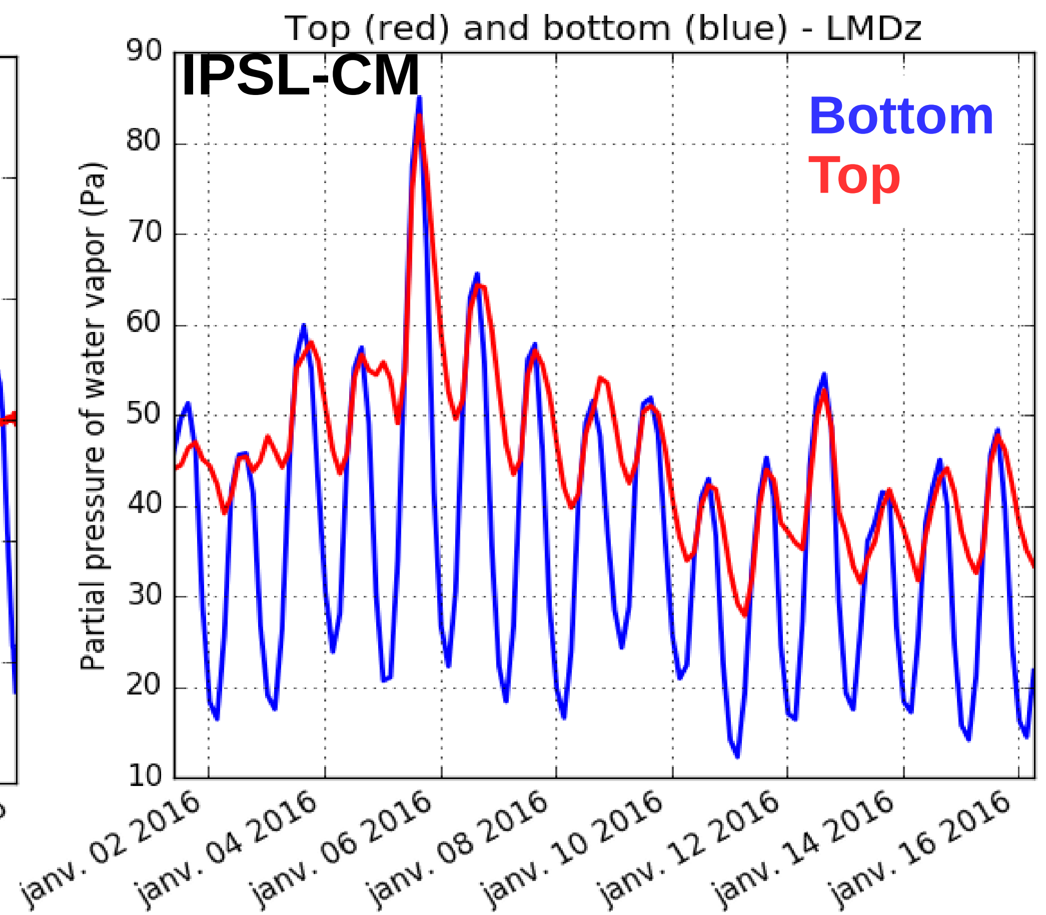


MAR results (40 km resolution)



Vapor partial pressure along the mast





Turbulent diffusion in the boundary layer can be validated using the multiple hygrometers along the mast (gives access to the water vapor

Conclusions

- IPSL-CM temperatures are in good agreement with the observations if albedo / heat capacity tuned, but the model underestimates haze opacity
- IFS shows good agreement with both the observed humidities and haze opacities despite a cold bias
- MAR overestimates supersaturation and haze opacity → fails to dissipate the haze → cold bias

These microphysical observations at Dome C are very promising
→ work is underway to further constrain microphysics (amount of ice nuclei, microphysical properties of the fog)


THANK YOU