A modelling case-study of a tropical tropopause layer cirrus : roles of dynamics and microphysics and cirrus impacts

Aurélien Podglajen (*apodgla@lmd.ens.fr*), Riwal Plougonven, Albert Hertzog,
Laboratoire de Météorologie Dynamique, Ecole Polytechnique, Palaiseau, France

Bernard Legras,
Laboratoire de Météorologie Dynamique, Ecole Normale Supérieure, Paris, France

Introduction

Cirrus formation :

in situ formation (uplift in altitude) or convection

Introduction

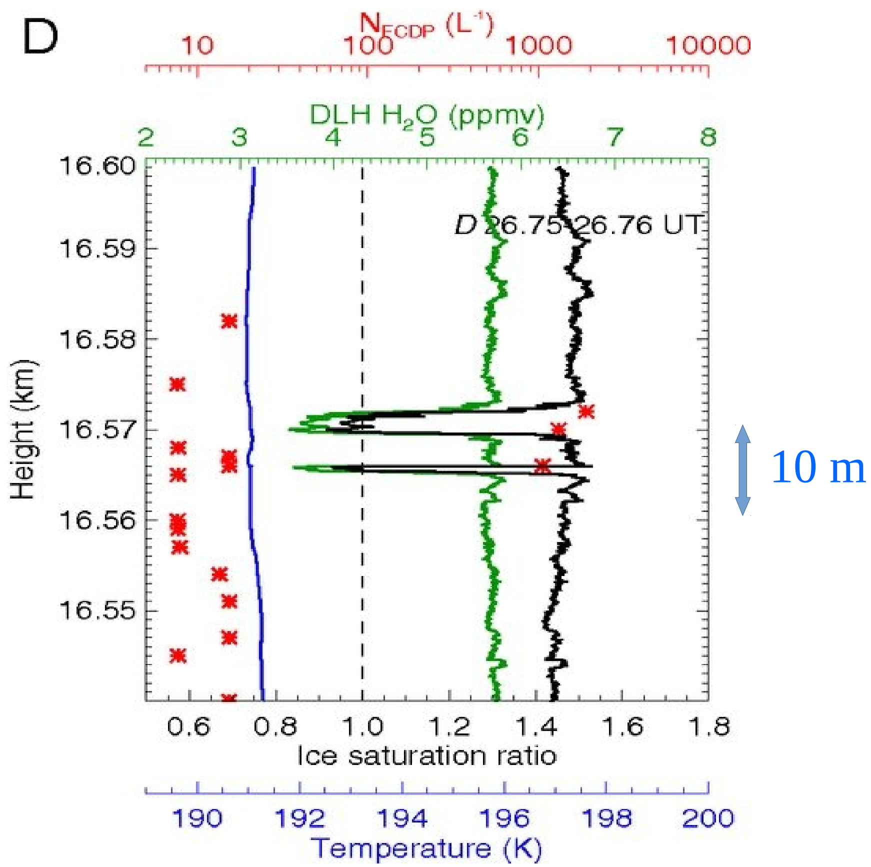
In situ cirrus:

- sensitive to different types of atmospheric waves (e.g. Kelvin waves, inertio-gravity waves) *Immler et al. 2008*

- can be very large-scale clouds

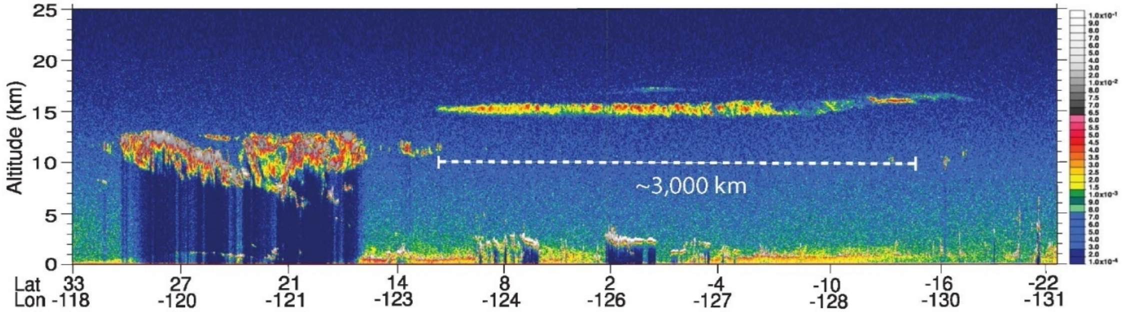
- can show very small scale features (a few meters, at least!)

We will focus on the large-meso scale



From Jensen et al., 2013

Presentation of the case study

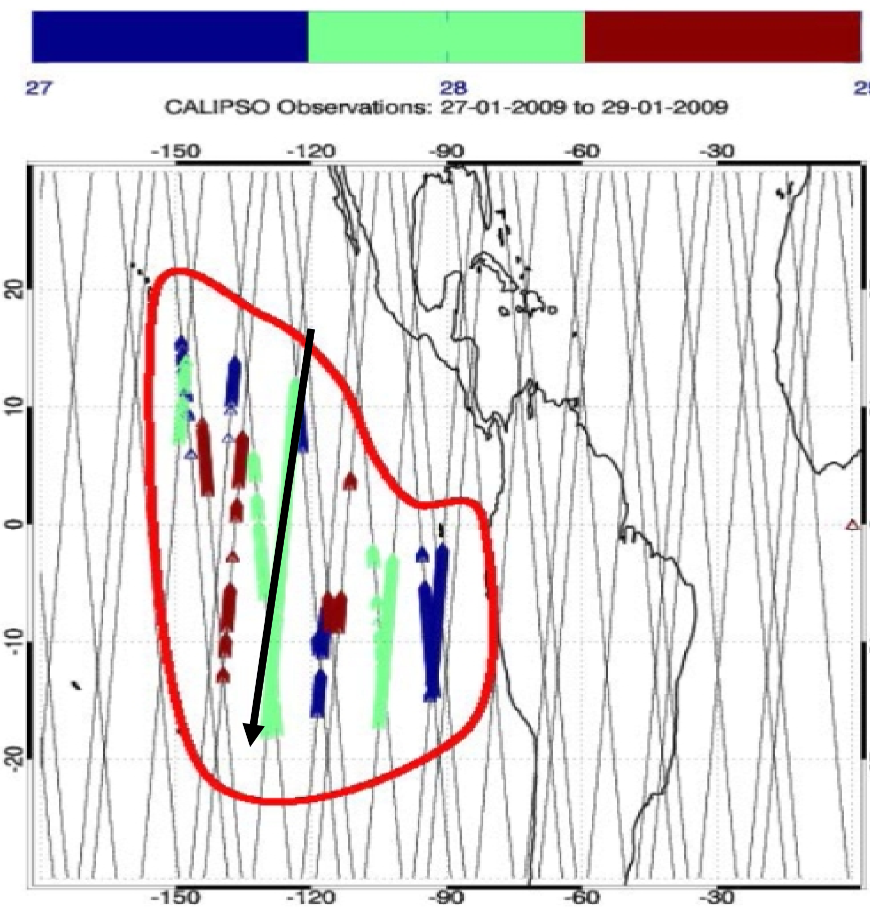


Backscatter along CALIOP track

Large-scale, apparently long-lasting cirrus in the tropical Eastern Pacific in late January 2009

Described from satellite observations by Taylor et al., 2011

Timing and location of cirrus formation



From Taylor et al., 2011

Problematic

*Is the mesoscale WRF model in a "**default configuration**" able to reproduce a **realistic cirrus** event? How does it compare to CALIPSO **observations**?*

*Why does the **cloud form**?*

*To what choices in the **parametrizations/initial conditions** is the simulated cirrus sensitive ?*

*What are the **impacts** of this cirrus event on the TTL?*

Outline

- Model setup and model evaluation
- Cloud formation
- Sensitivity of cloud modelling
- Cloud impact

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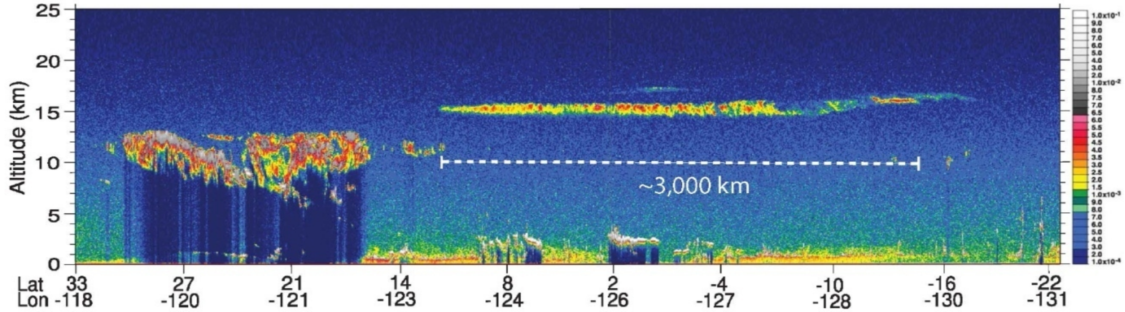

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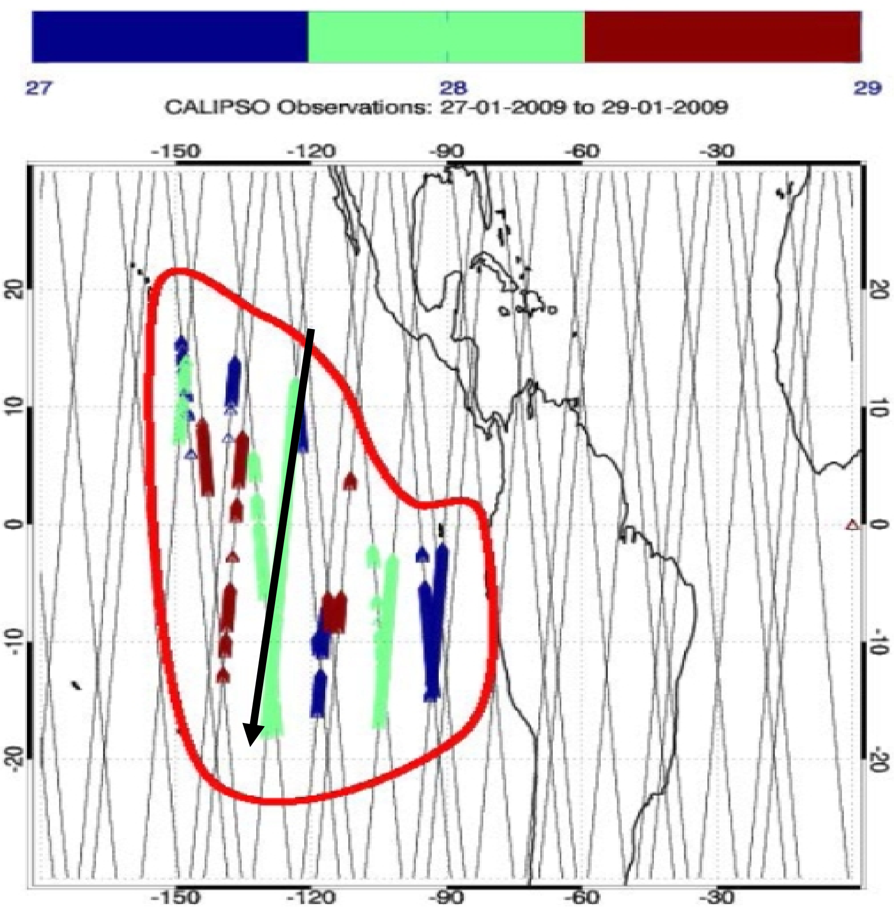
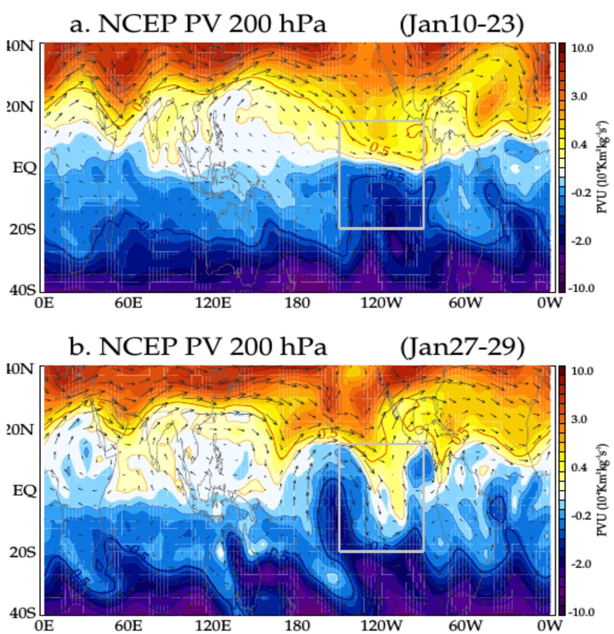


Potential vorticity at 200 hPa, NCEP



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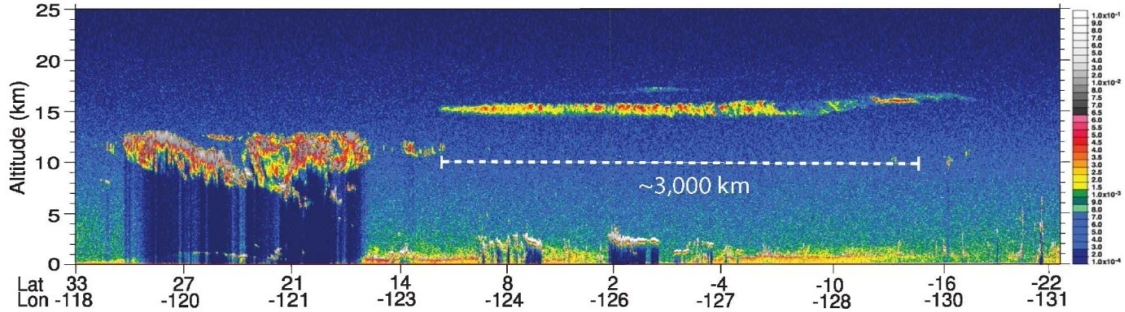

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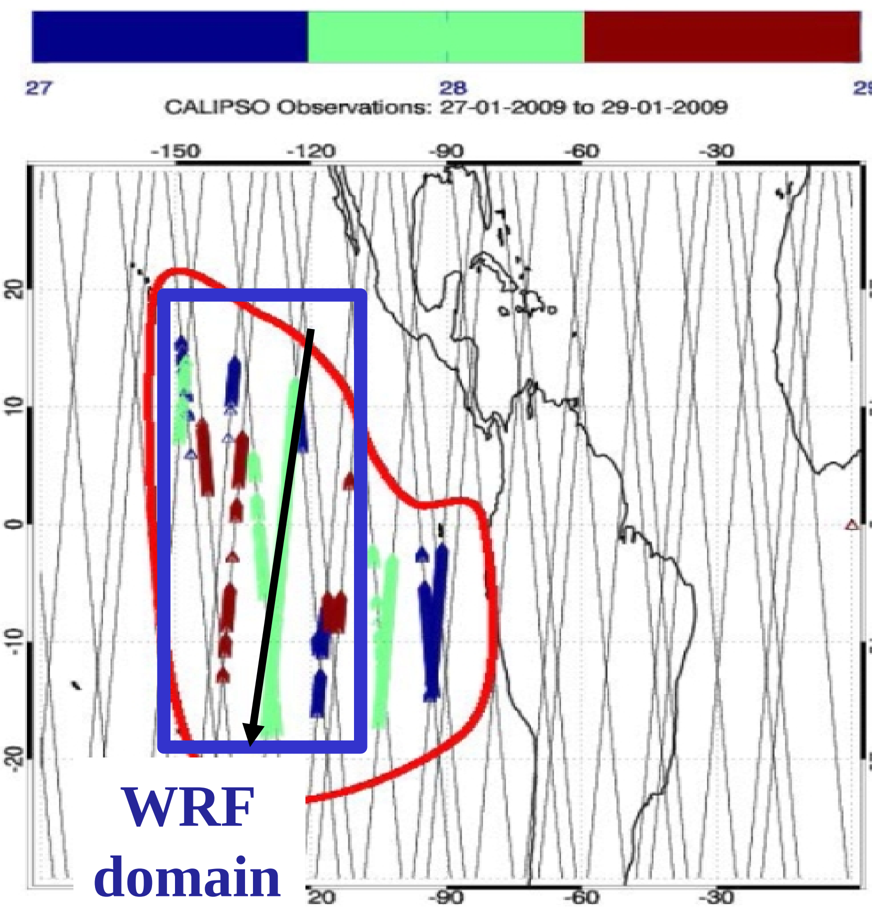

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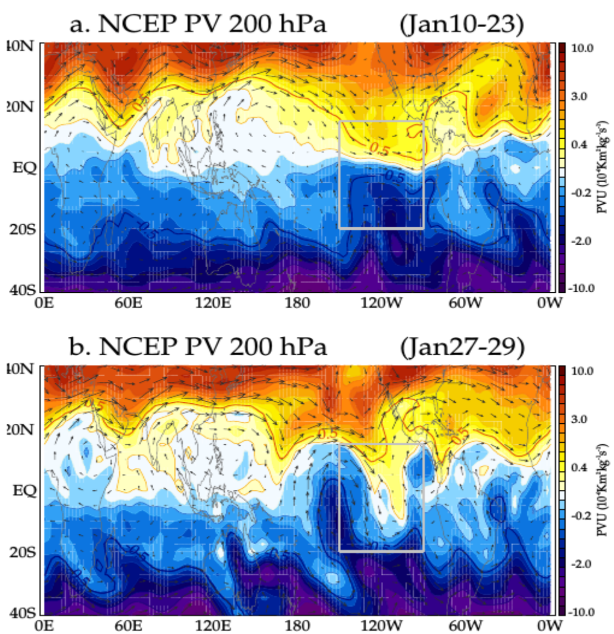

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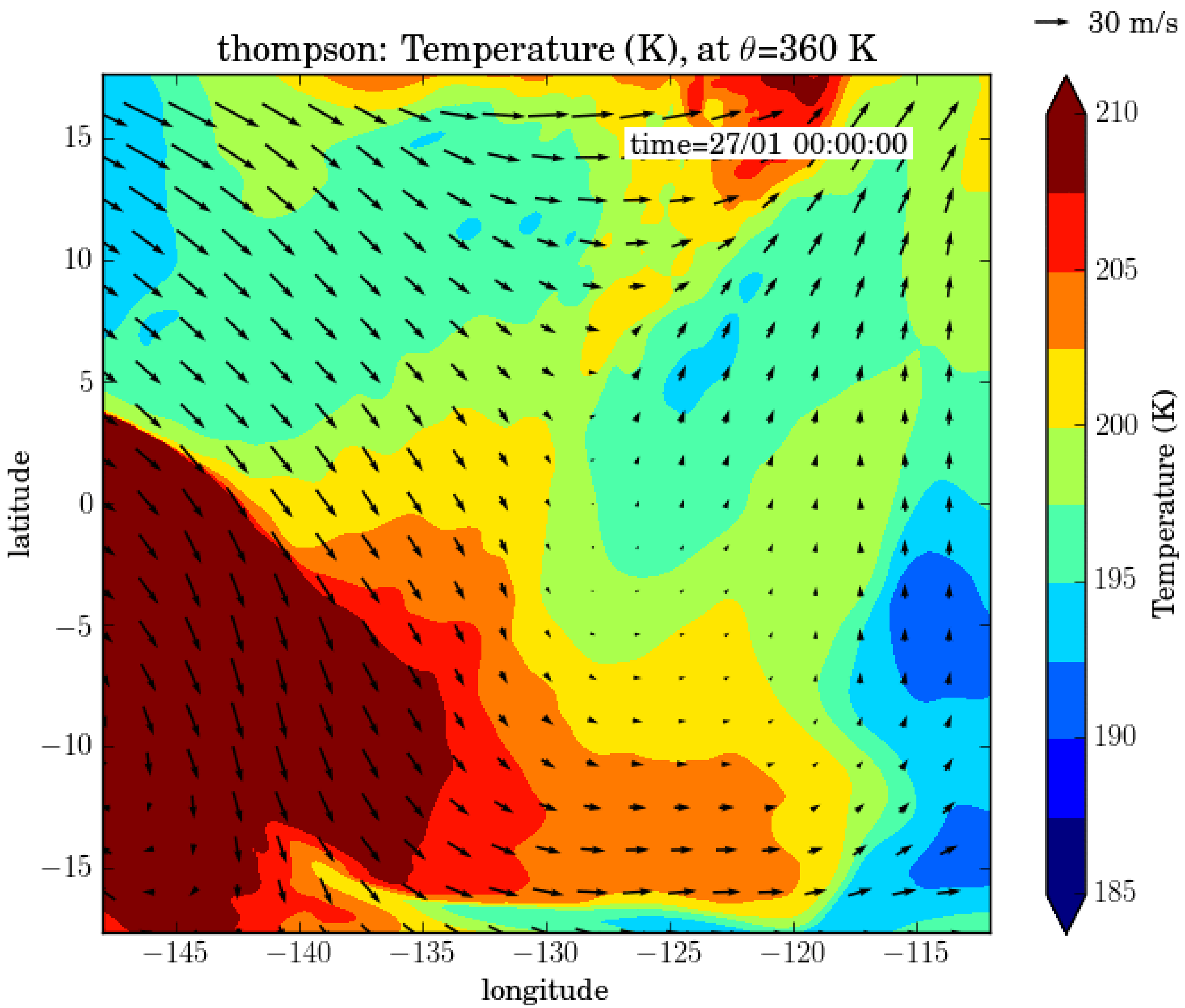
Modelling set-up

- Mesoscale modeling with the NCAR Weather Research and Forecast model v3, in January 27-29, 2009
- Thompson scheme (2 moments for ice), (and different sensitivities)
- 10 km horizontal resolution (tests with 4 km), about 250-300 m vertical resolution
- Initial and boundary conditions taken from ECMWF operational analyses (including water vapor)

Presentation of the simulation



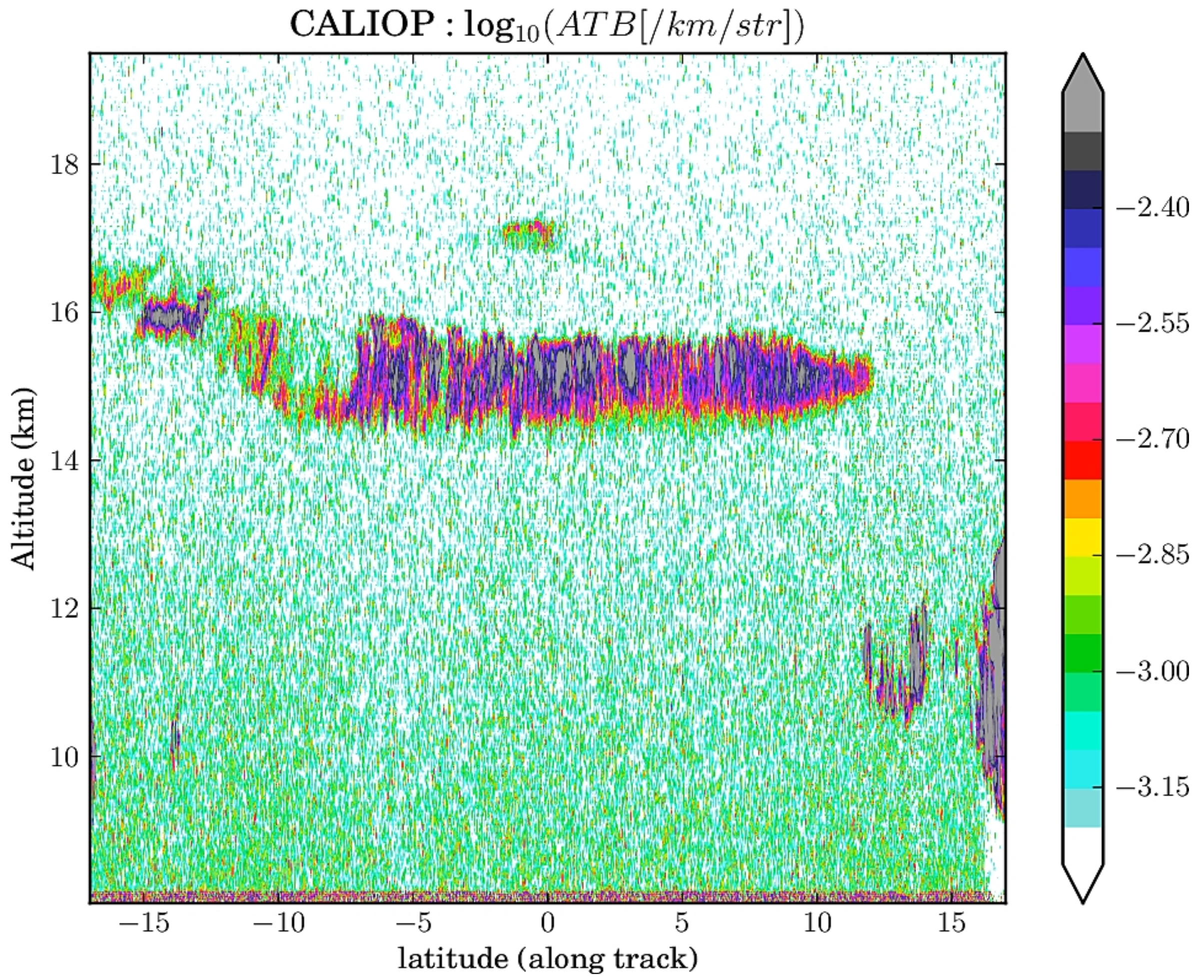
Black contours = cirrus

Model Evaluation

Comparison of the simulation to CALIPSO Lidar observations :

Use of a "Lidar simulator" COSP to compare the simulated and observed cloud induced backscatter at 532 nm

Comparison with a "night profile" on January 28th



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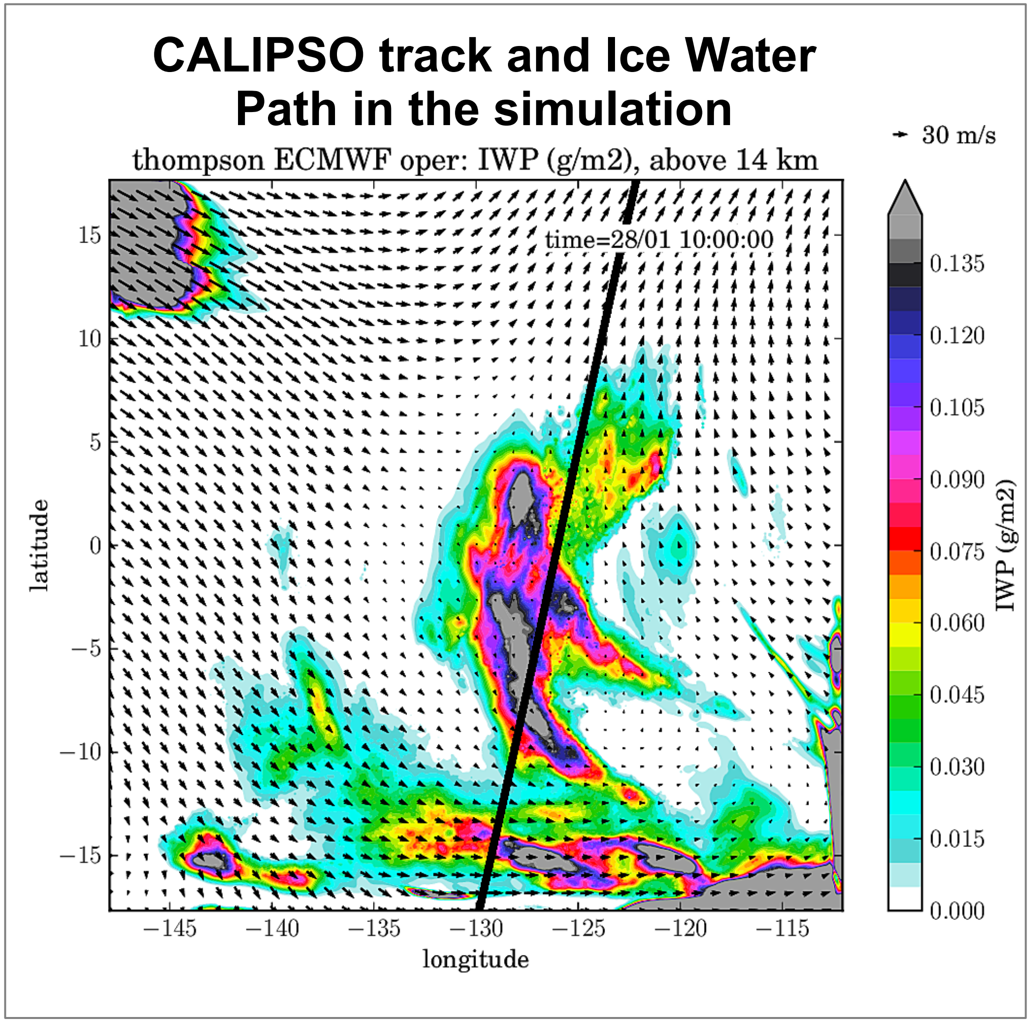
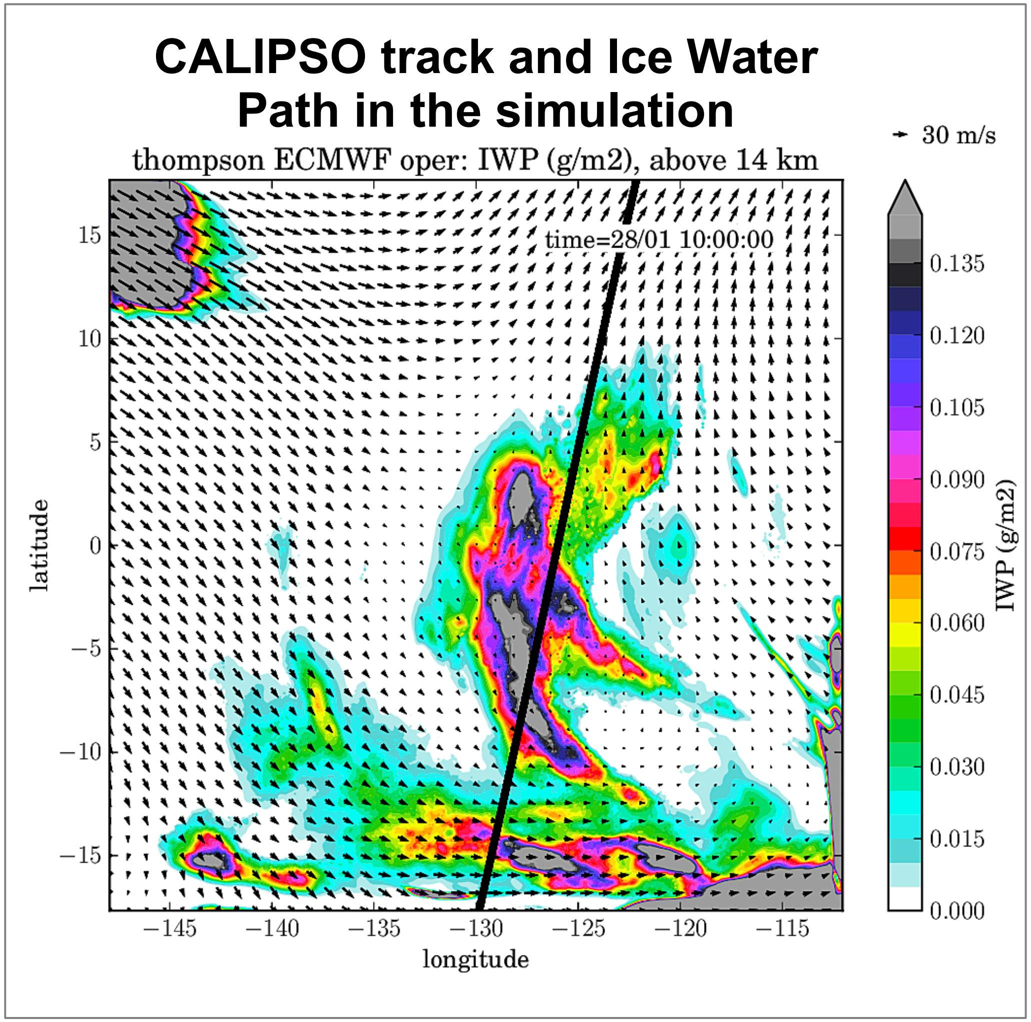
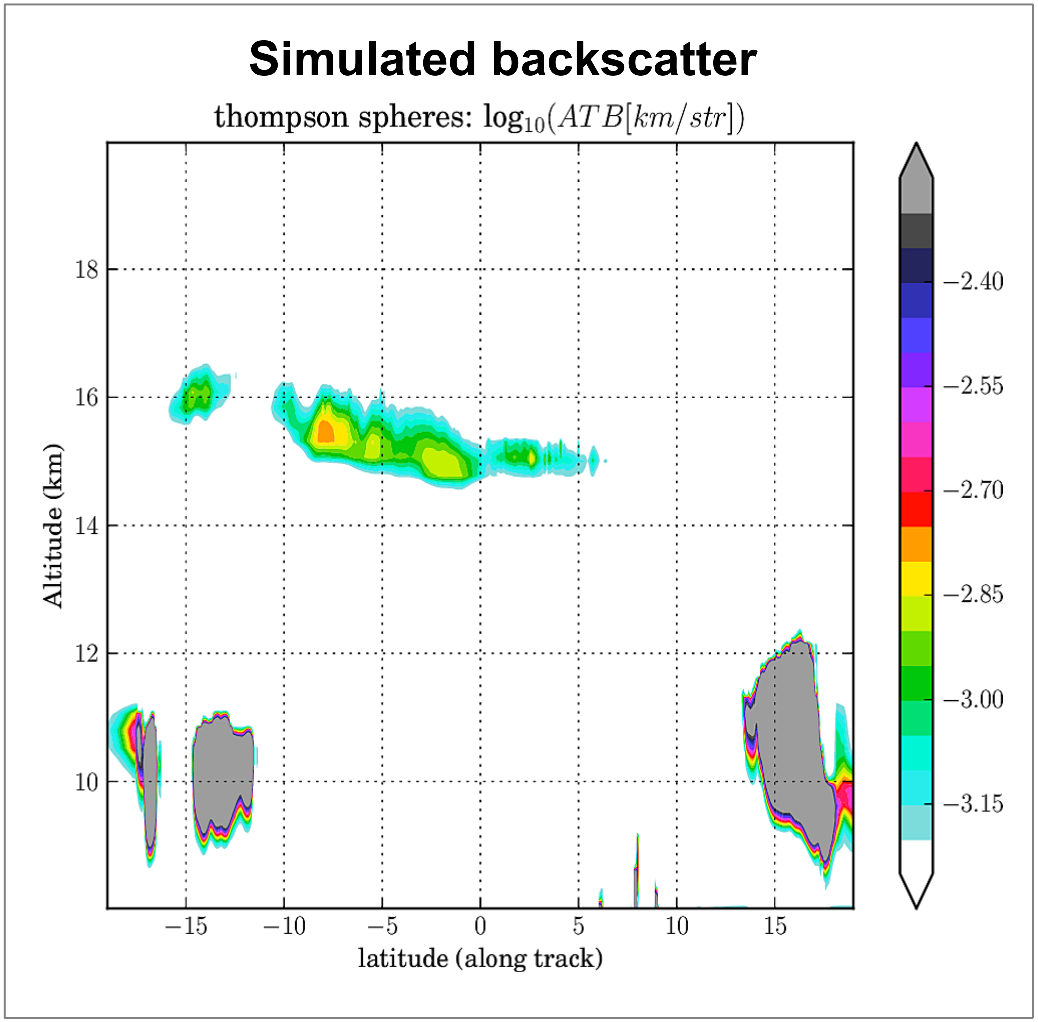


Comparison to CALIOP Lidar observations :

1) Interpolation along the satellite track

Model Evaluation





Comparison to CALIOP Lidar observations :

1) Interpolation along the satellite track

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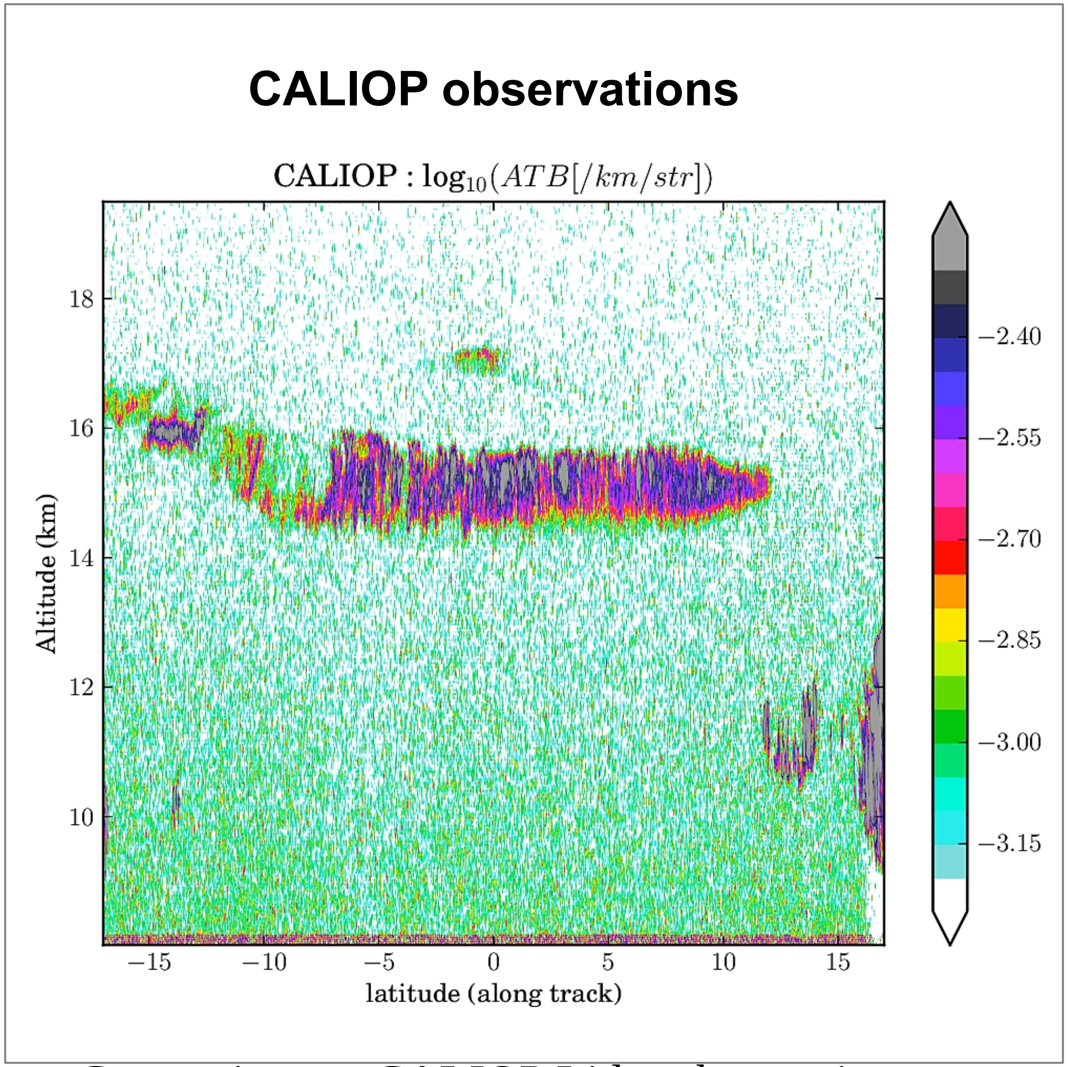

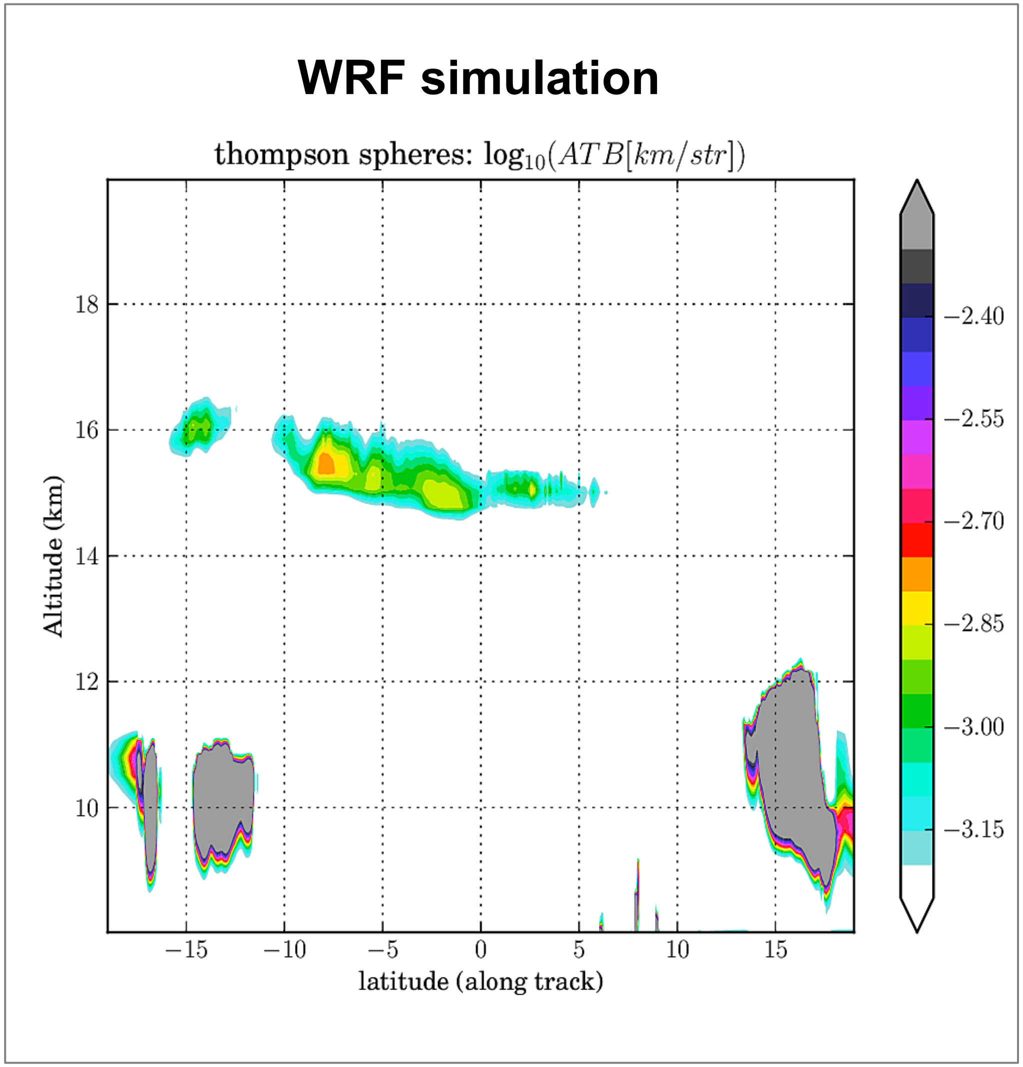

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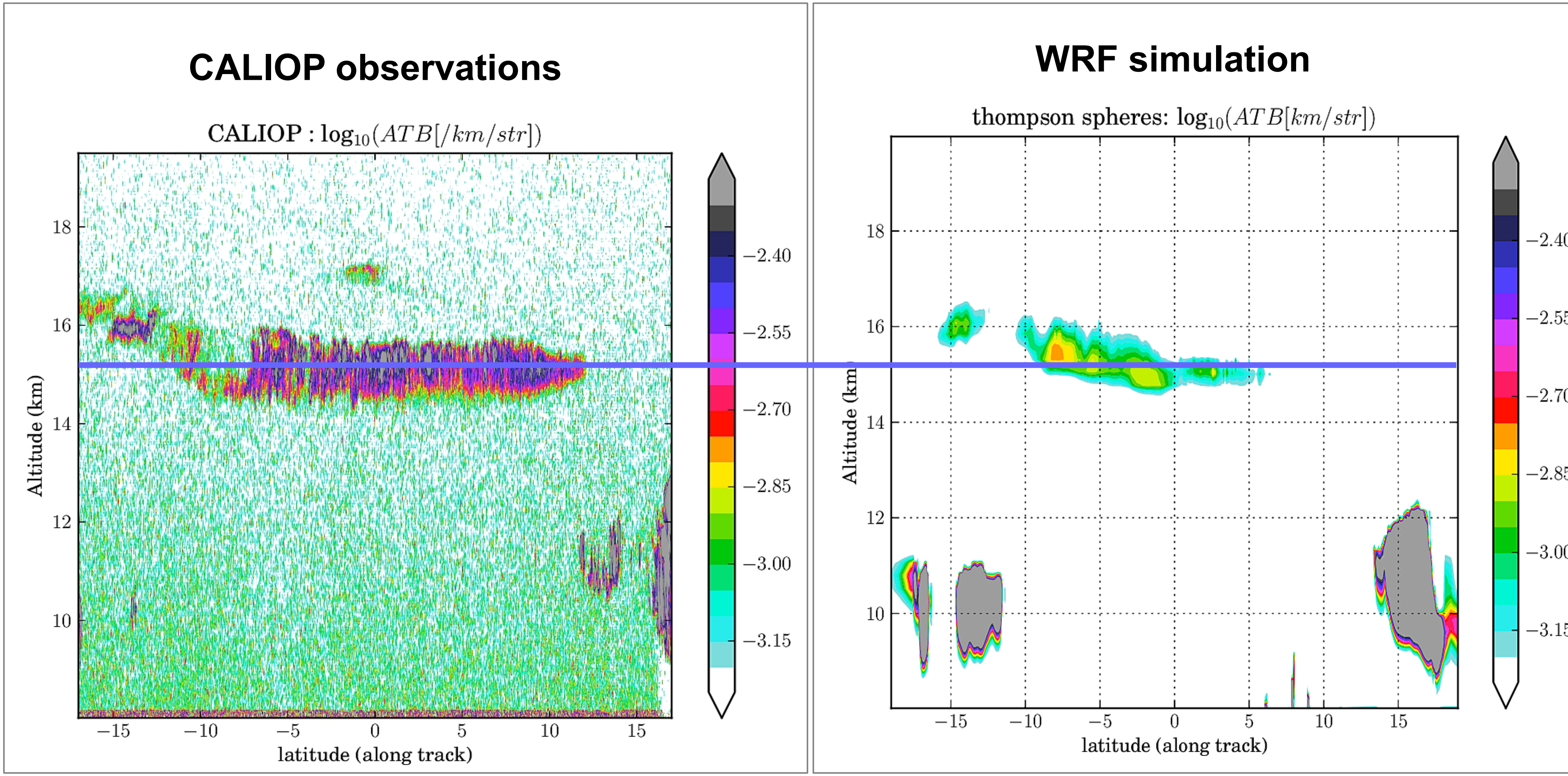
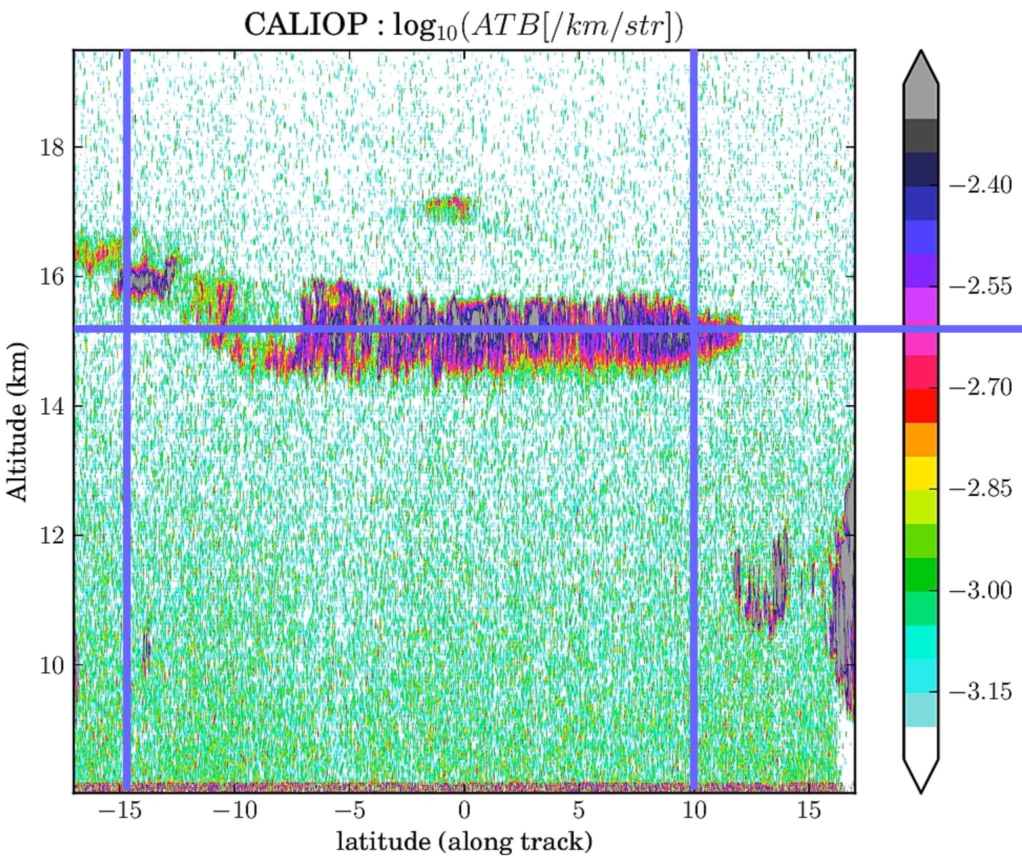


Points to be compared :

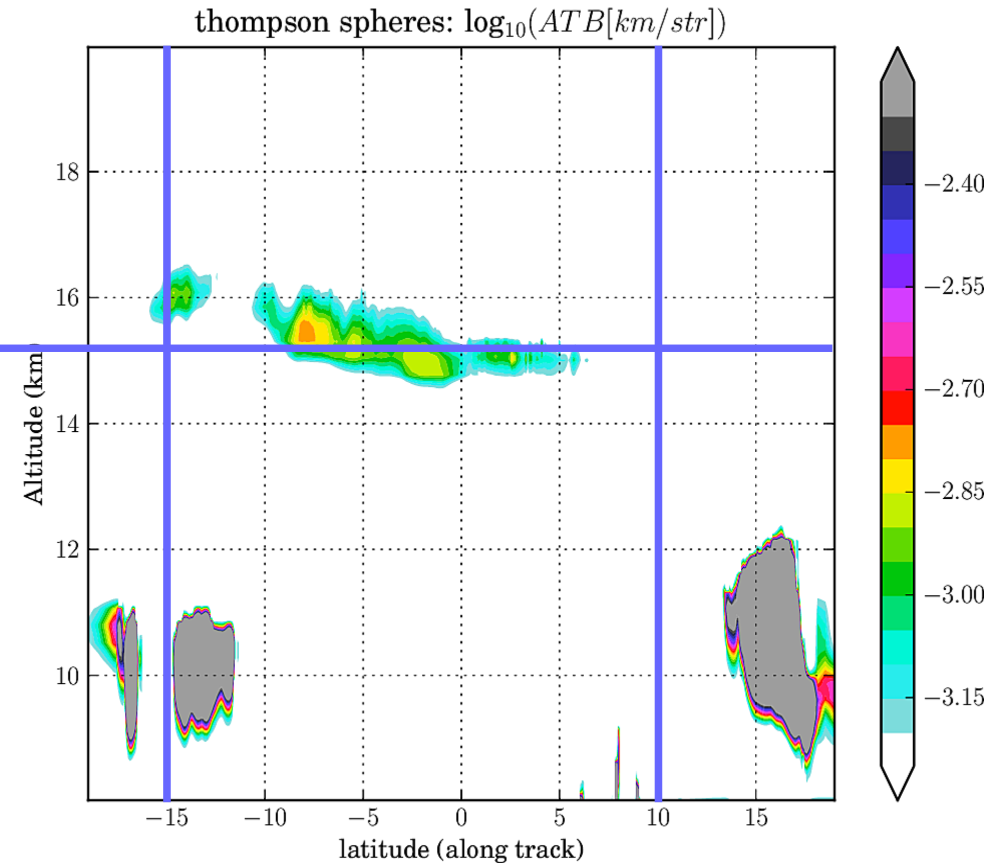
- Amplitude of the returned signal ("optical depth") ; can be misleading for those thin clouds (because of instrumental noise, etc.)
- Spatial characteristics : location (altitude), extension, thickness, optical thickness

Model Evaluation

CALIOP observations



WRF simulation



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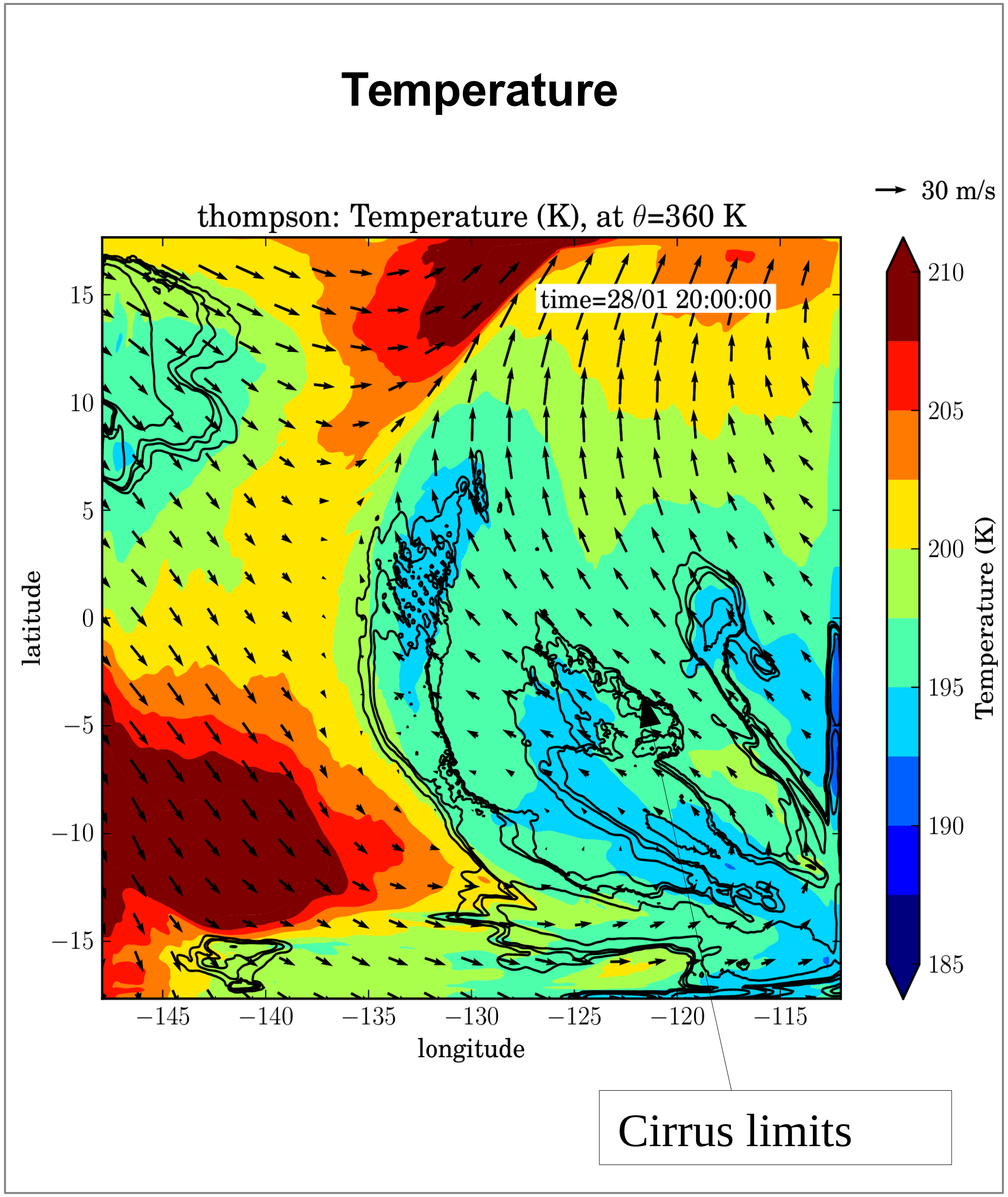
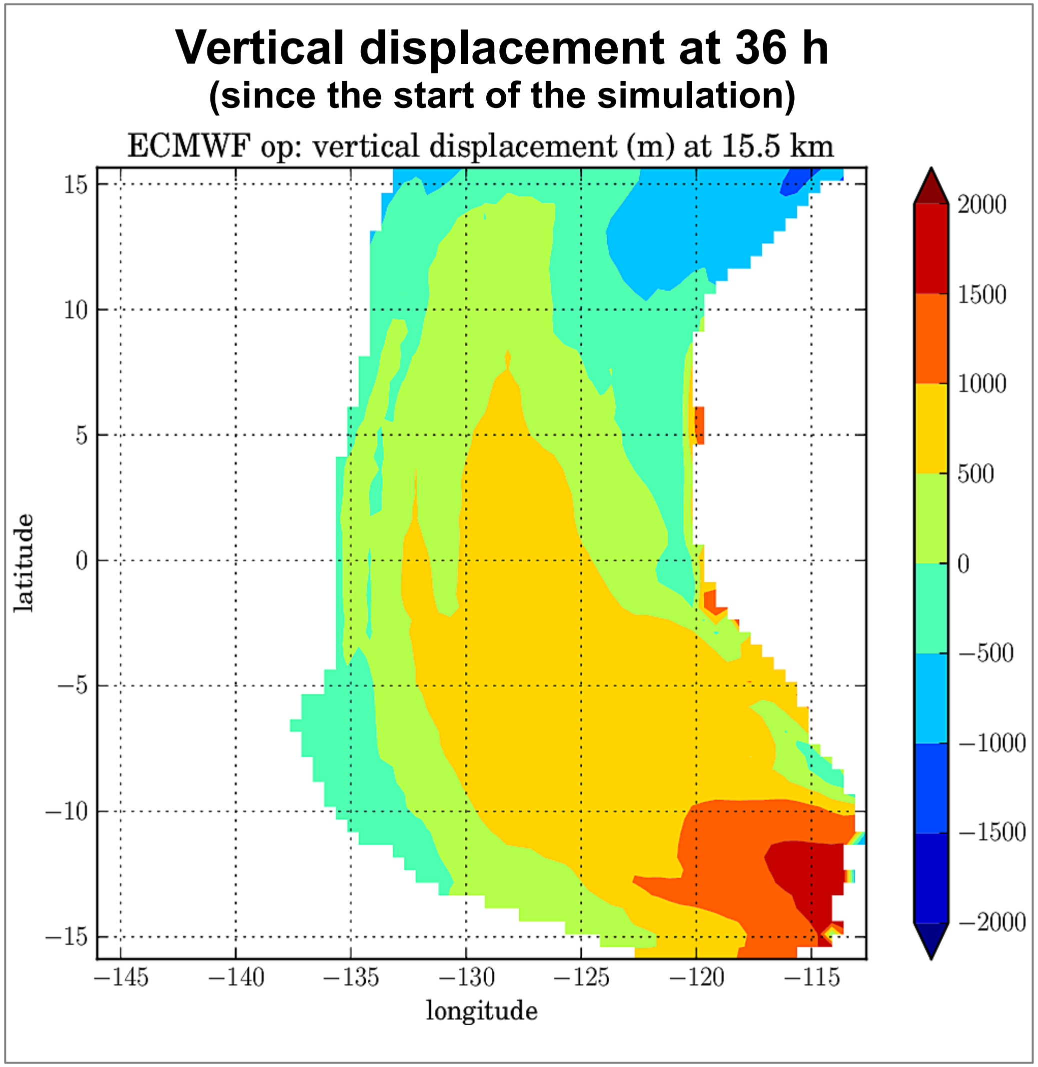
- Model setup and model evaluation
- **Cloud formation**
- Sensitivity of cloud modelling
- Cloud impact

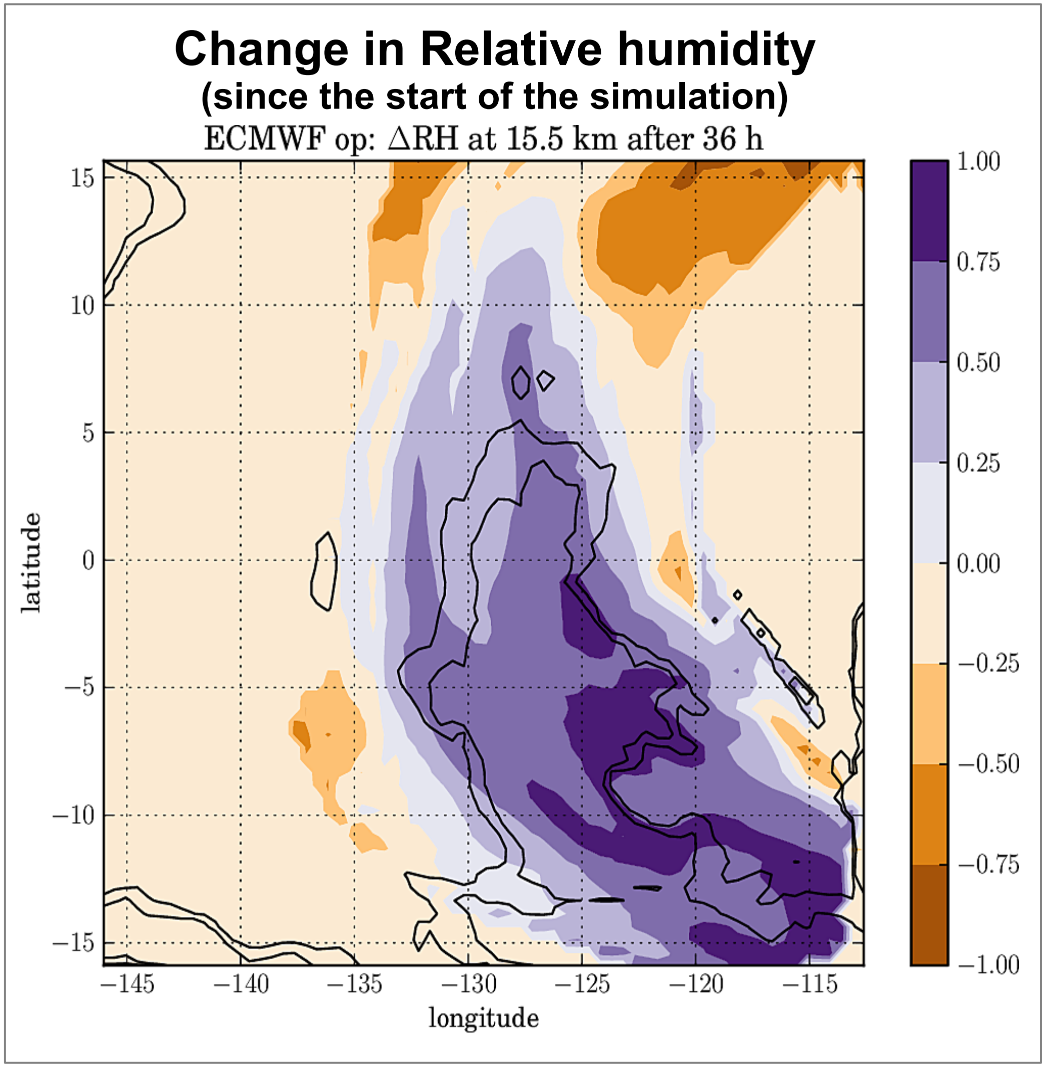
Dynamics of cloud formation



Correlation of the cirrus with low temperature

Cause of cloud formation



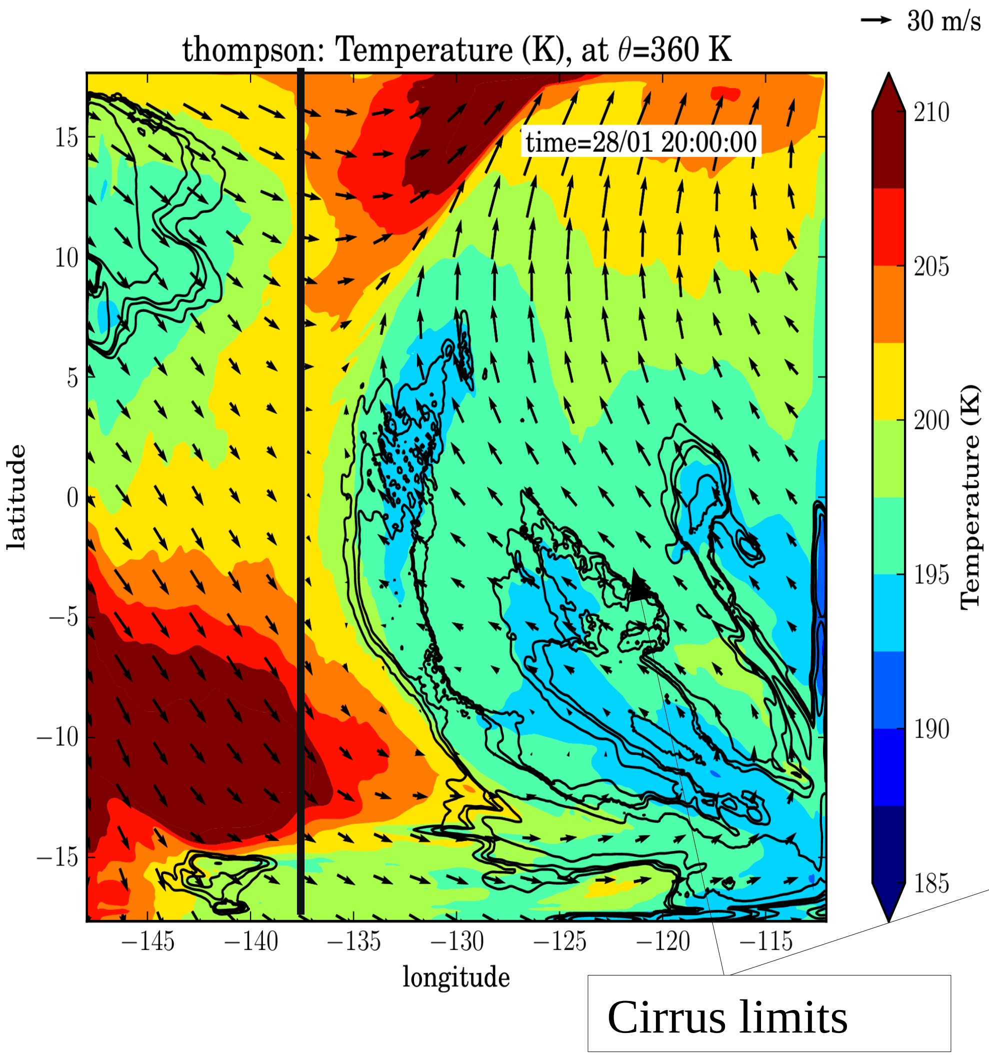


The temperature decrease causes a relative humidity increase along air parcel trajectory, which in turn causes the cloud to form.

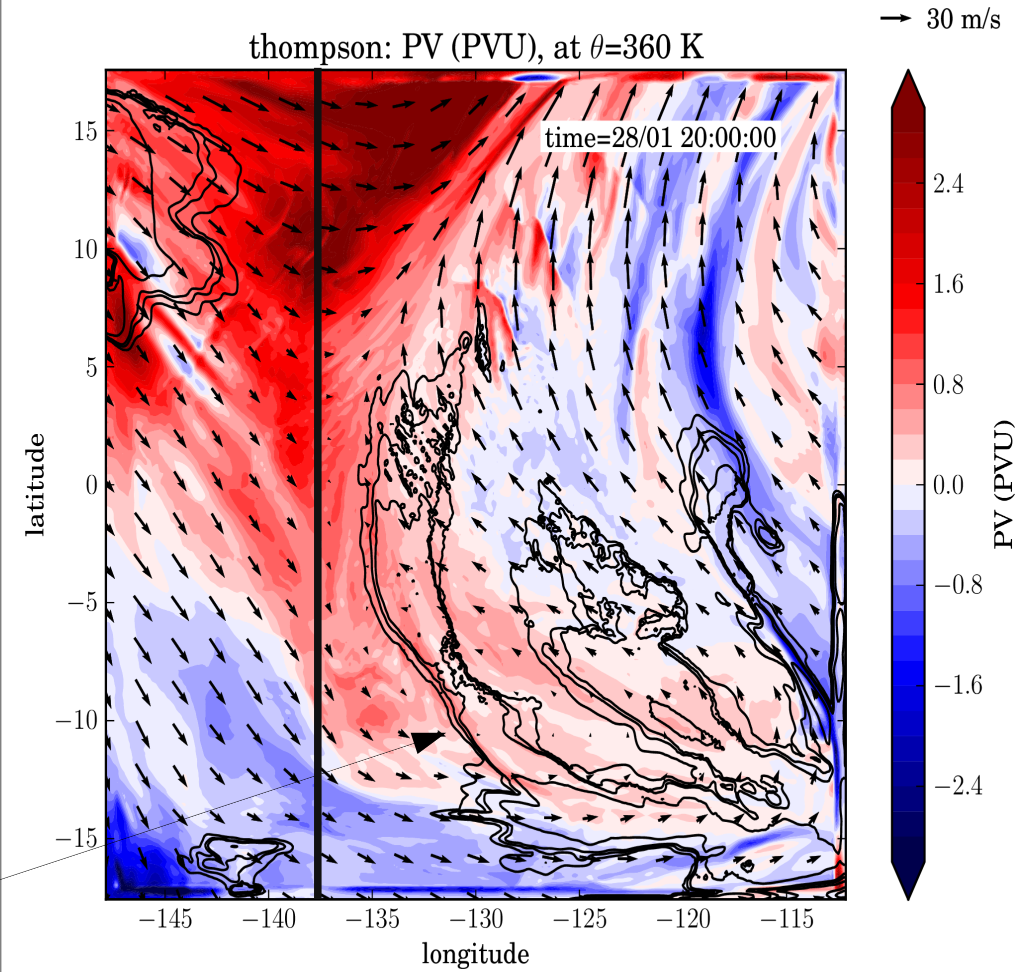
In a Lagrangian perpective, the decrease in temperature is due to adiabatic cooling forced by a large-scale vertical uplift. *Cause of the uplift ?*

Dynamical structures in the simulation

Temperature

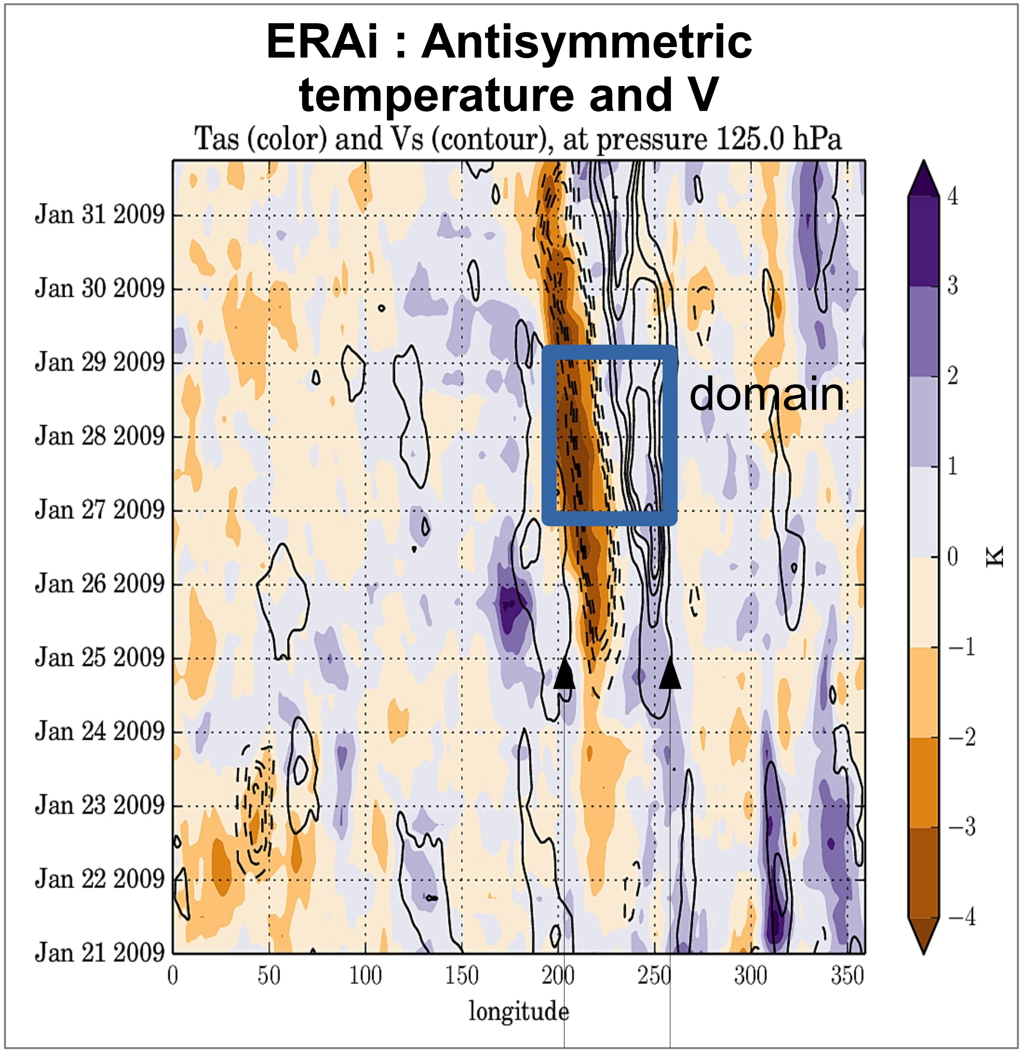


Potential vorticity



Antisymmetric temperature and symmetric Potential Vorticity in quadrature phase relationship

Global equatorial structure- ERA interim



Temperature signature of a Yanai (Mixed Rossby-gravity) wave during the simulation : explains the overall geometry of the cirrus in WRF

Outline

- Model setup and model evaluation
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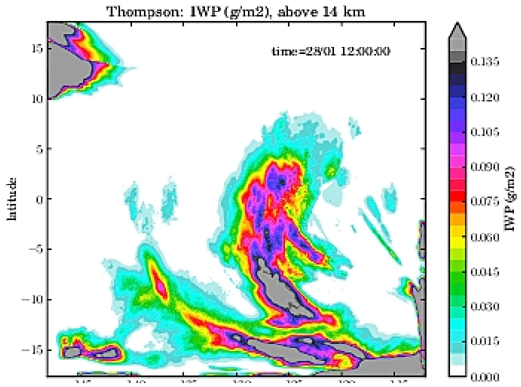
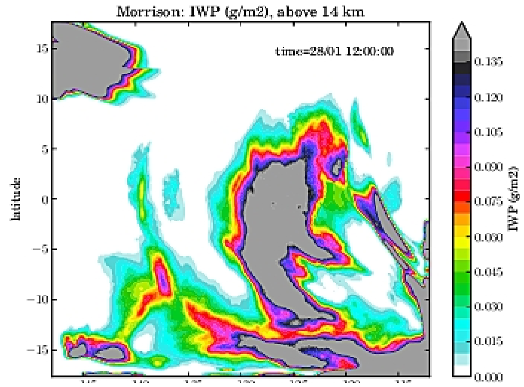
Sensitivity of the simulated cirrus (36 hours)

Thompson microphysics

Morrison microphysics

ECMWF op. an.





Sensitivity :

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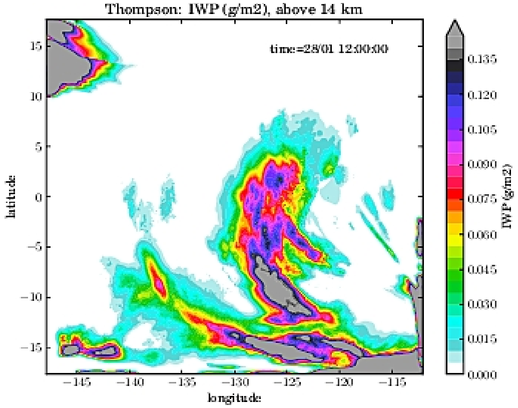
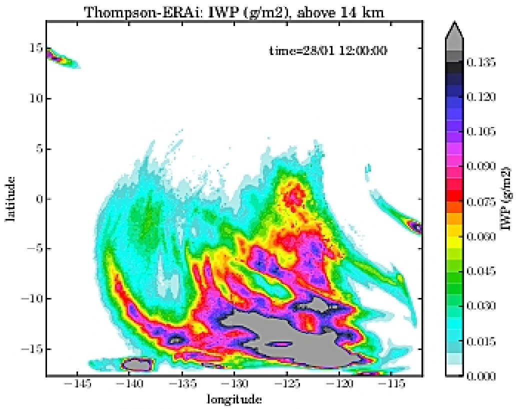


ERA interim



No cloud radiative heating

Sensitivity :

-microphysics scheme (2 moments Morrison vs. 2 moments Thompson)

-initial and boundary conditions (ECMWF op. an. vs. ERA interim)

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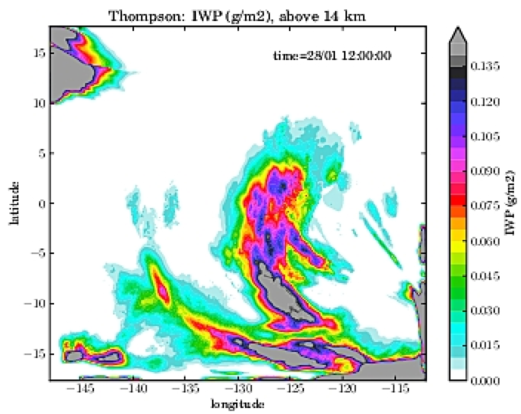

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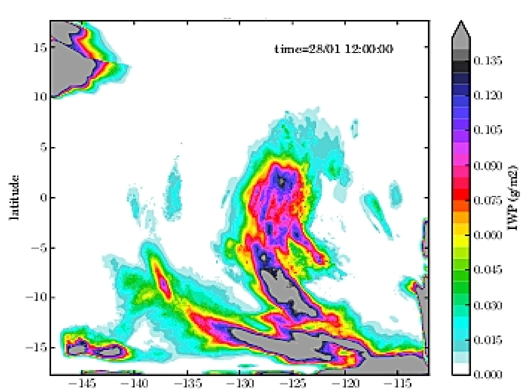

Sensitivity :

-microphysics scheme (2 moments Morrison vs. 2 moments Thompson)

-initial and boundary conditions (ECMWF op. an. vs. ERA interim)

-cloud induced radiative heating (with vs. without cirrus radiative heating included)

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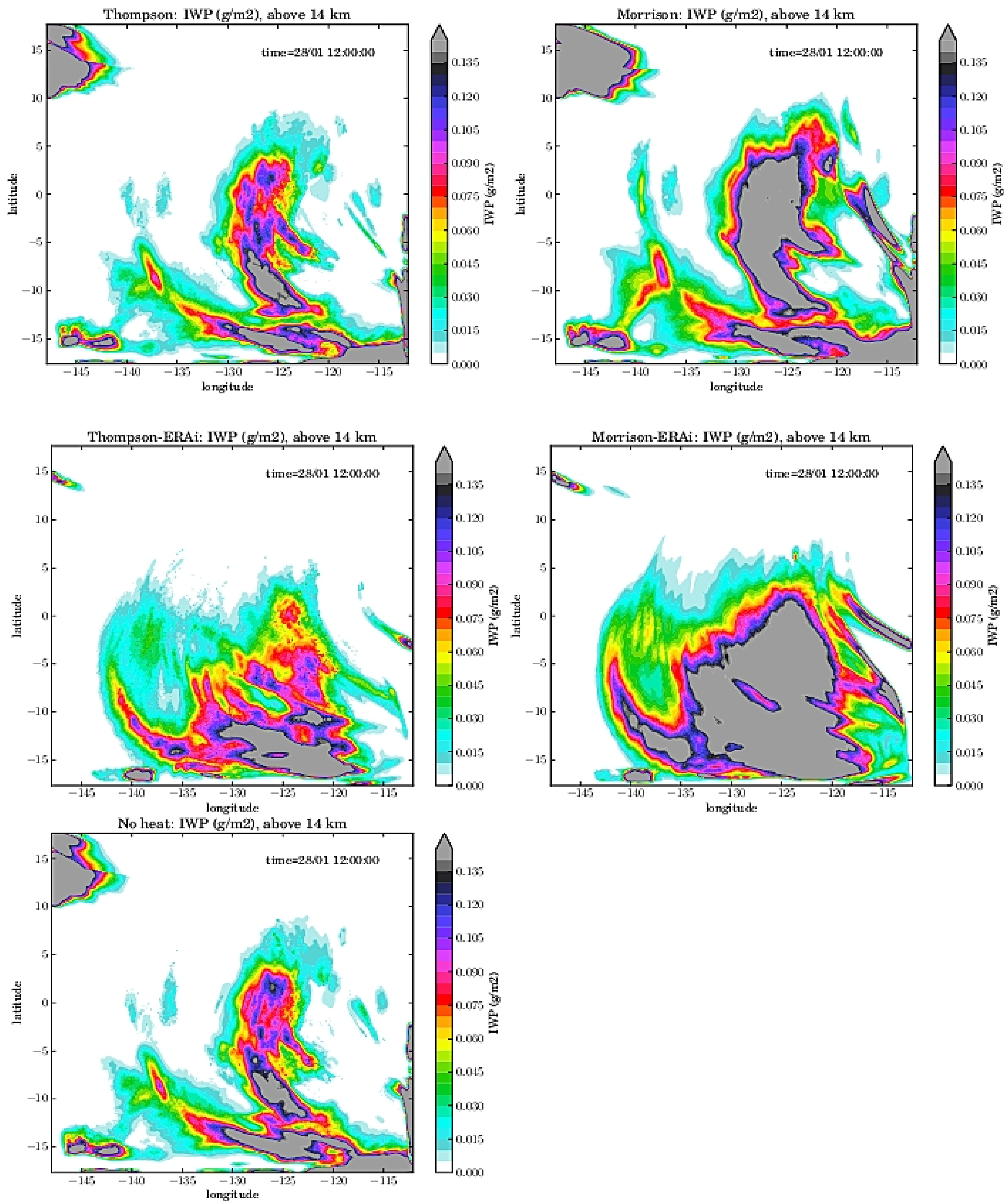

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Summary of sensitivities at 36 hours

	Amplitude (IWC)	Horizontal position	Vertical position	Structure
Microphysics	++	no	+	no
Initial and boundary conditions	++	++	++	++
Radiation	no	no	no	no

Differences in the large-scale dynamics and water vapor (as can be found in different analysis systems) are as important as the microphysics. They play more role to determine the geographic structure and evolution of the cloud field, when the microphysics and the initial water vapor essentially act on the amplitude.

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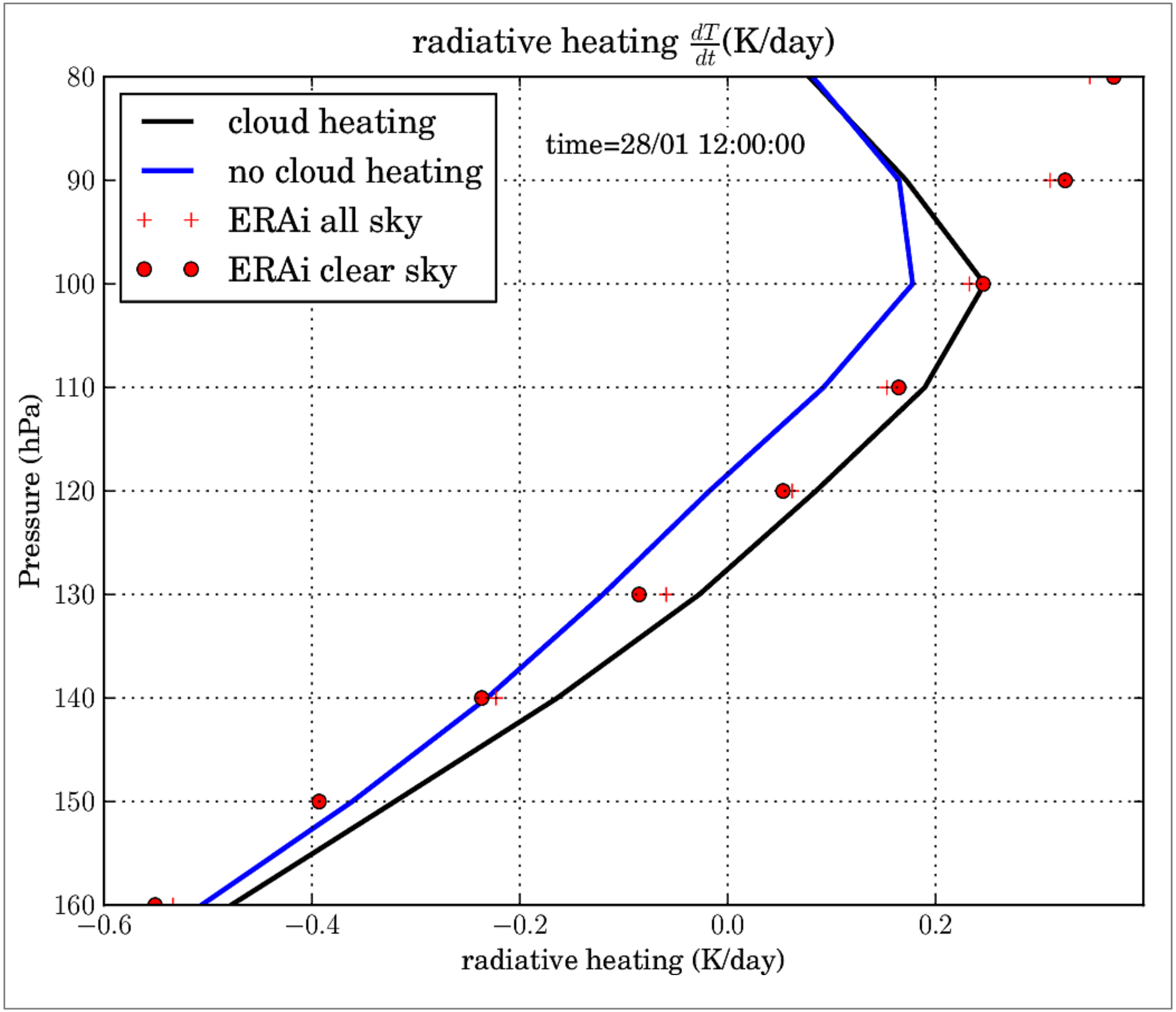
Cirrus impact : radiative heating

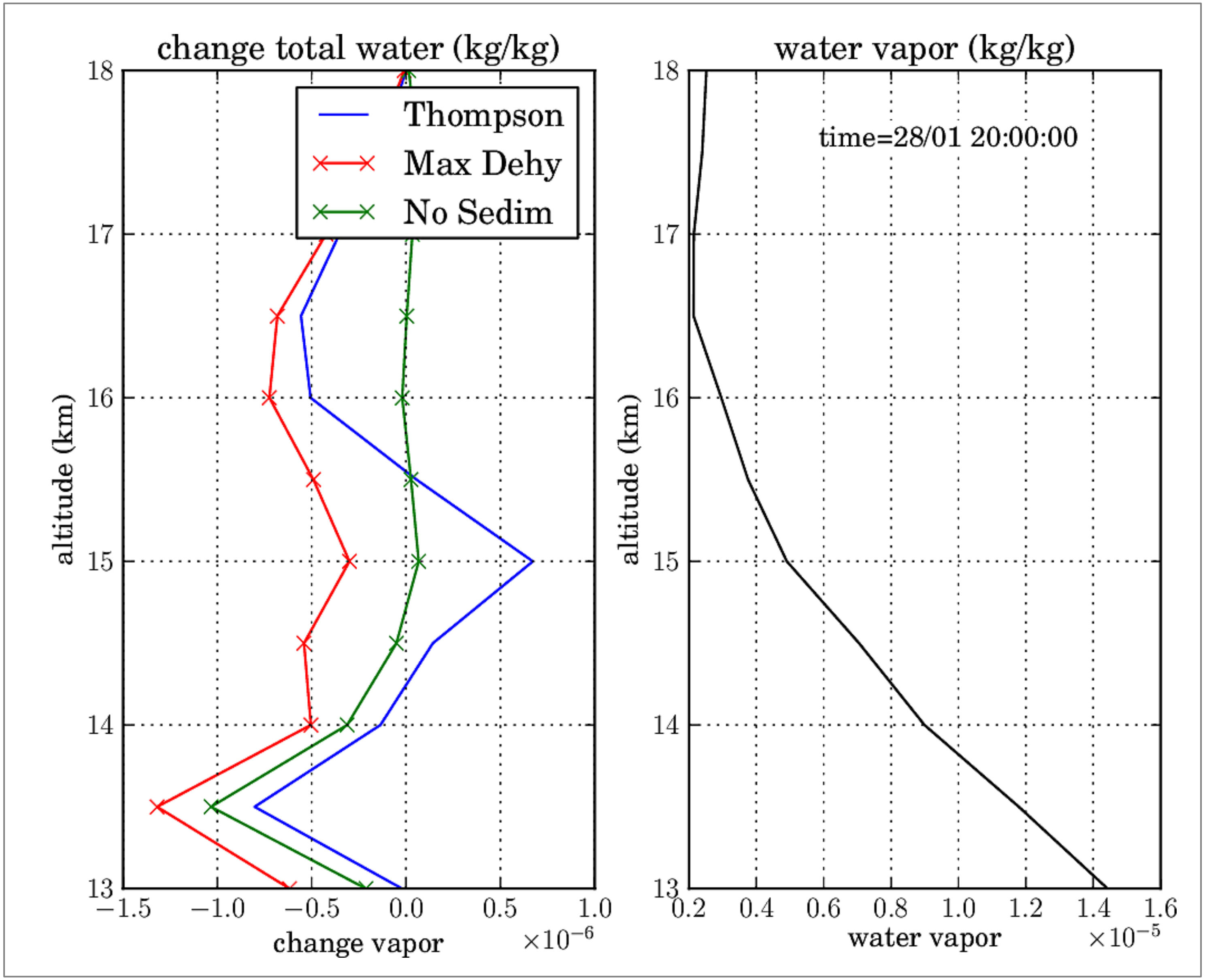


Cirrus radiative impact estimate from simulations with and without cloud radiative heating included (RRTMG scheme):

- Mean heating in the domain of the order of 0.1 K/day by the cirrus

- Cloud radiative effect absent in the ERA interim : bias

Cirrus impact : water redistribution



Water vertical transport (through sedimentation):

- Thompson : reference

- Max Dehy :

$q_v = \min(q_v, q_{v\ SAT})$

- No Sedim : sedimentation suppressed (for temperature below 210 K)

Rough estimate of cloud effect, but illustrates the role of the cloud in dehydrating AND rehydrating different layers

Conclusions

- Default WRF able to reproduce the main cirrus characteristics
- Cirrus formation due to large-scale dynamics : equatorial wave response excited by interaction with the midlatitudes (PV intrusion)
- Strong sensitivity of the modelled cloud to the initial dynamics (U, T). Initial and boundary conditions in dynamics and in water vapor, and choices for the microphysics parametrization affect different characteristics of the cloud field.
- Cirrus impact : 0.1 K/day in radiative heating, water vertical redistribution with de and re-hydration (- 0.5 ppm / + 0.5 ppm) (emphasized with a single column model by Ueyama et al., 2014 or idealized simulations by Dinh et al. 2014))

Thank you for your attention