Aircraft induced cloudiness in the regional climate model CCLM

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Meteoclim PhD symposium 28/01/2009

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CLM

Outline

- Motivation: Impacts of aviation on climate
- Theory of contrail formation and representation in the model
- Some preliminary results
- Next steps
- ABCi project

Climate impacts of aviation

Factor of : climate warming   climate cooling

- $NO_x + C_xH_y + \mathbf{CO_2} + H_2O + CO + C_{BC} + SO_x$ (Direct emissions)

  (Transformation in the Wake of planes)

- $\mathbf{O_3}$ CH_4 (cooling because concentration diminishes)

- Condensation trails (Contrails)

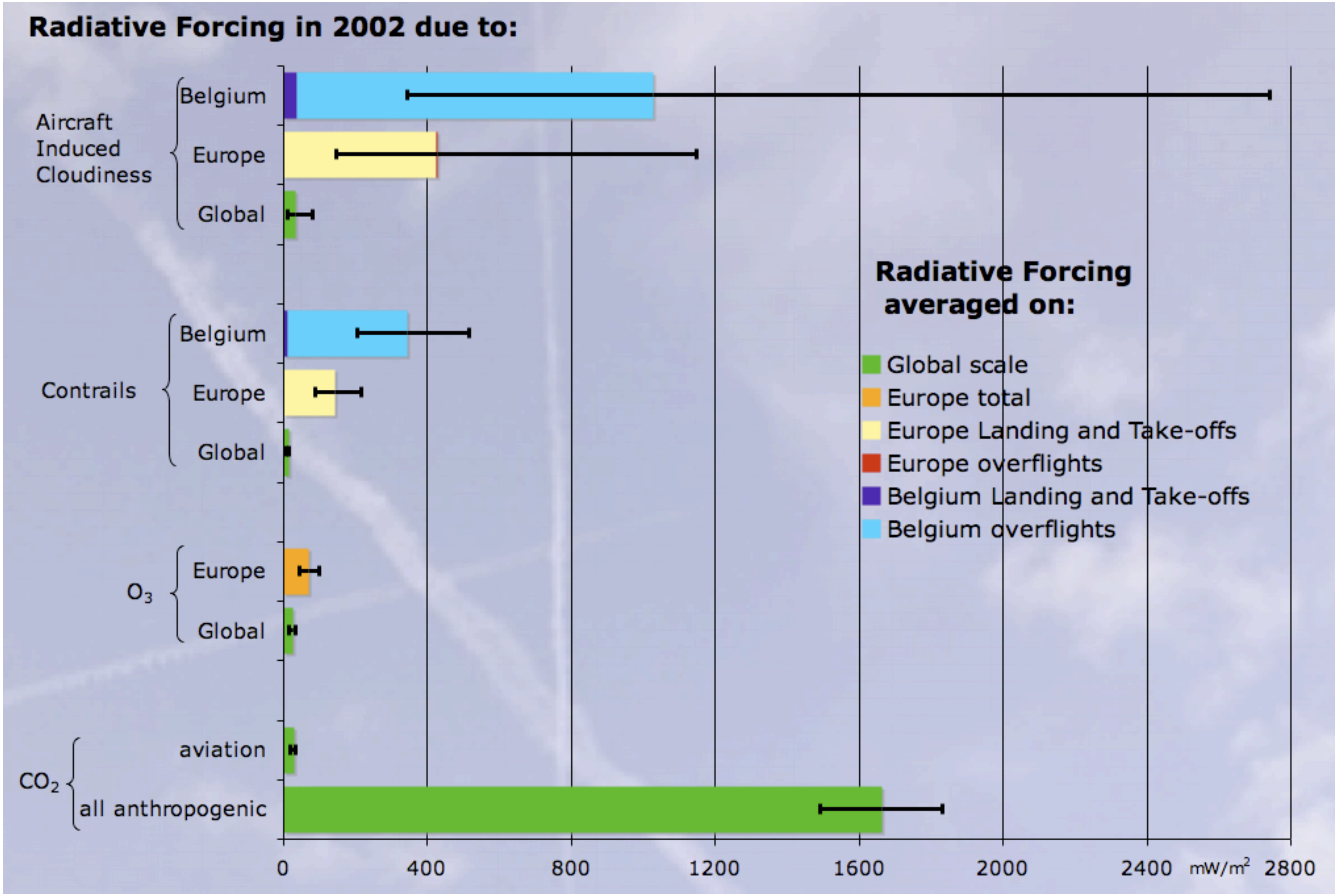
if air is supersaturated

Reflexion of incoming solar light

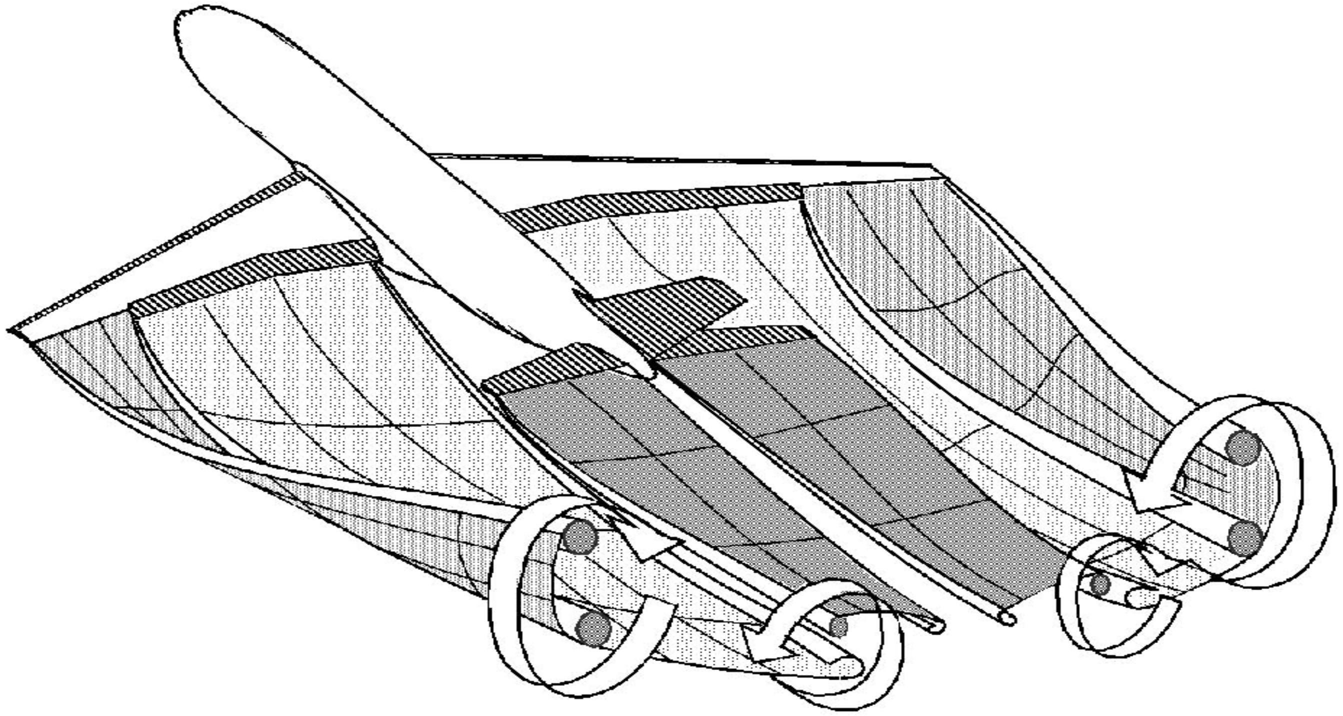
Absorbtion of outgoing long wave terrestrial radiation

Mean dirumal effect
=
Climate warming

Local radiative forcing

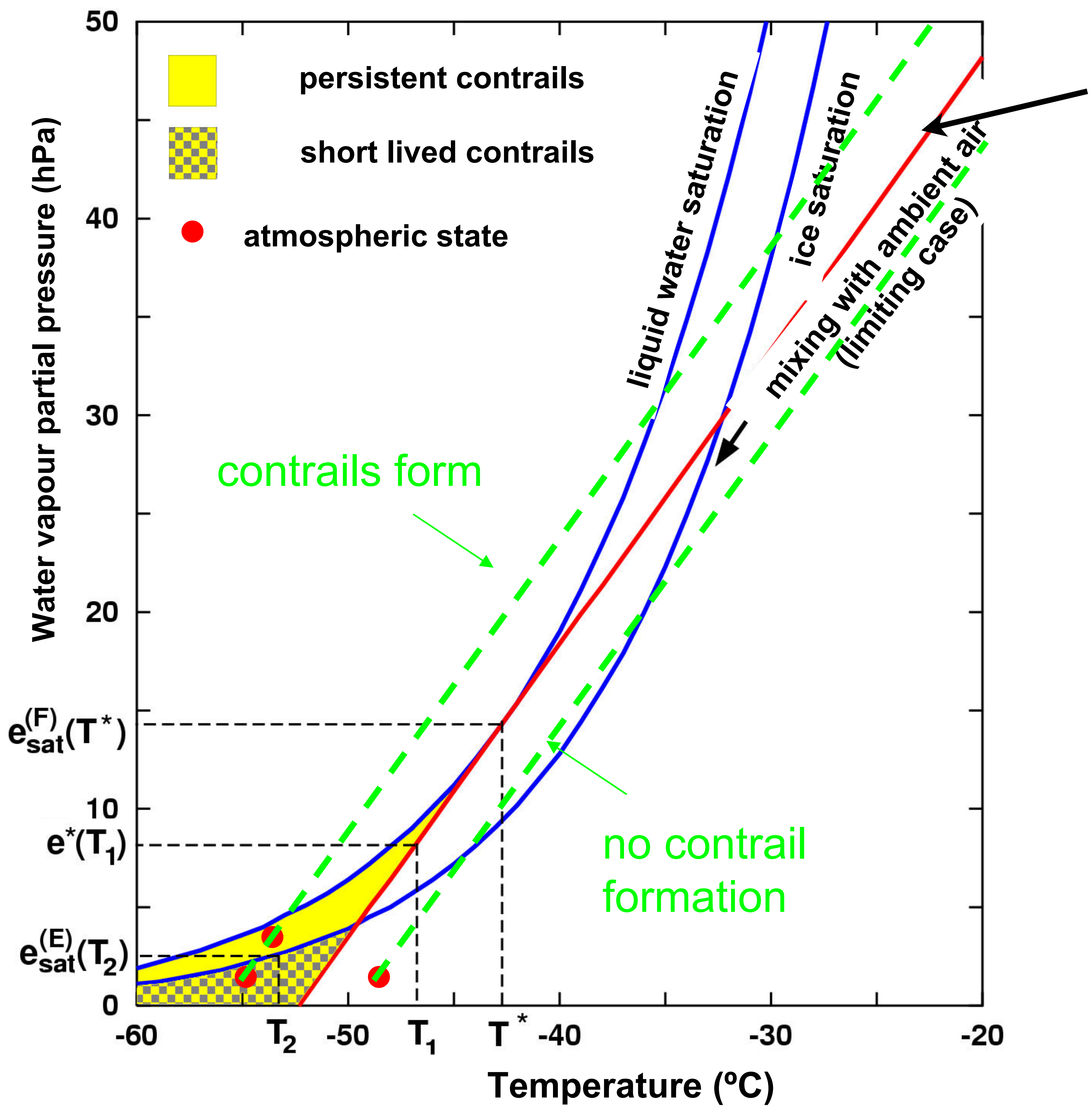


Theory of contrail formation and representation in the model



Source: S. Unterstrasser (2008)

Schmidt Appleman criterion



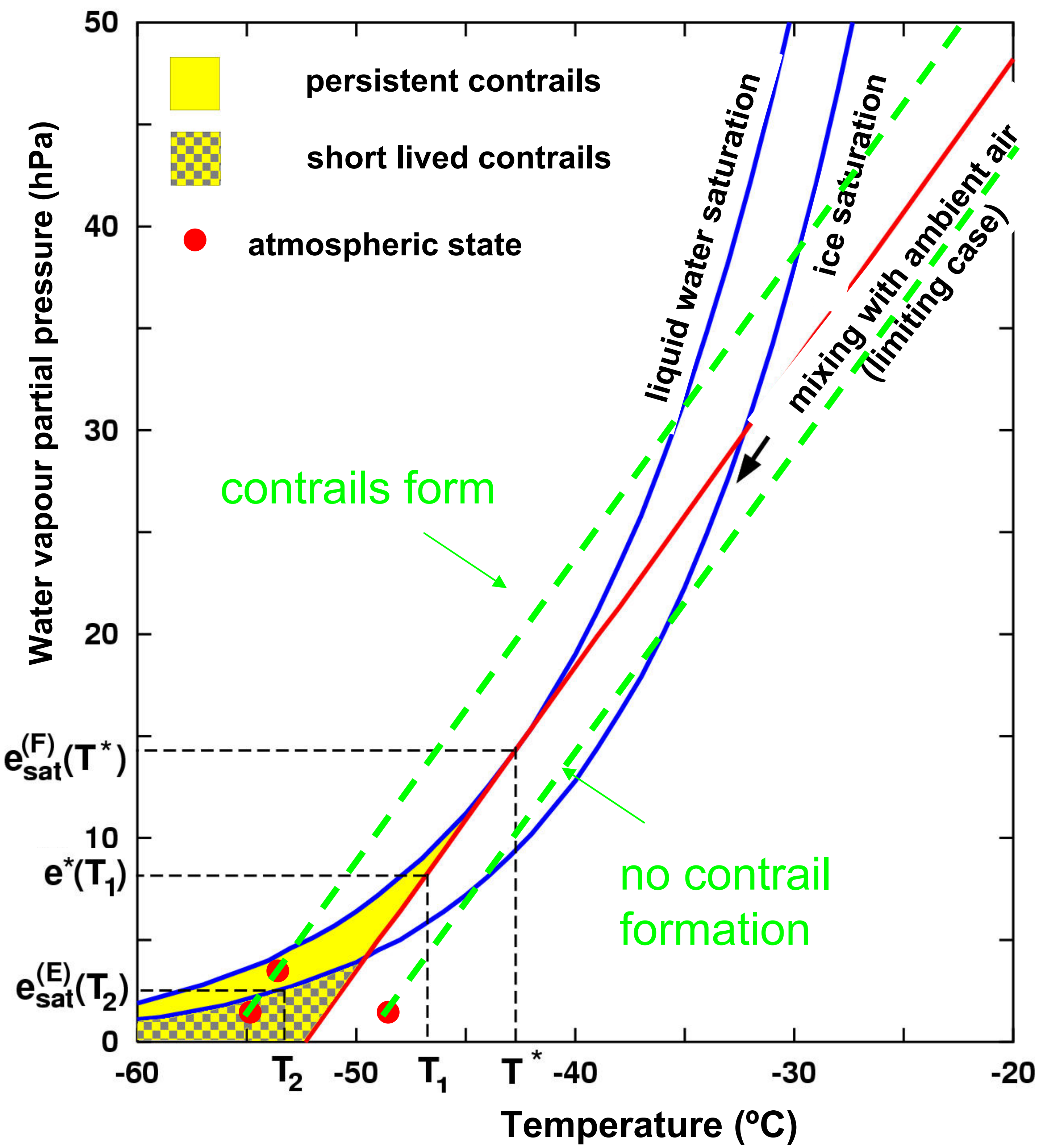
Source: S. Marquart (2003)

Isobaric mixing of air emitted by the reactor with surrounding air. The slope is given by:

$EI(H_2O)\ c_p\ P\ /[0.622\ Q\ (1\text{-}\eta)]$,

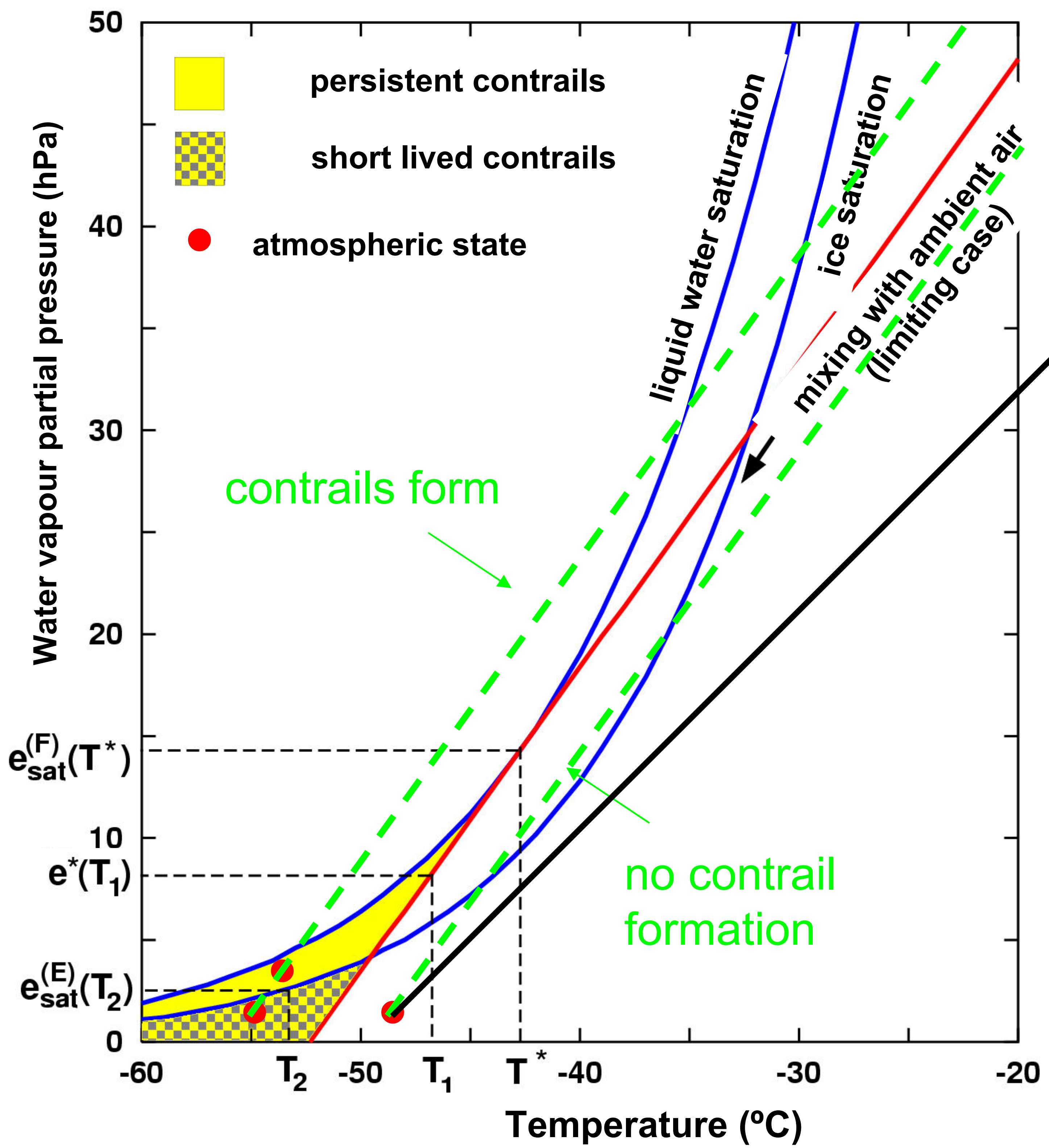
where $EI(H_2O)$ emission water vapor index, c_p is the specific thermal capacity of water, P the ambient pressure, 0.622 the molar ratio of air and water molecules, Q the specific combustion heat of kerosene and η total efficiency of the airplane.

Schmidt Appleman criterion



Source: S. Marquart (2003)

Schmidt Appleman criterion



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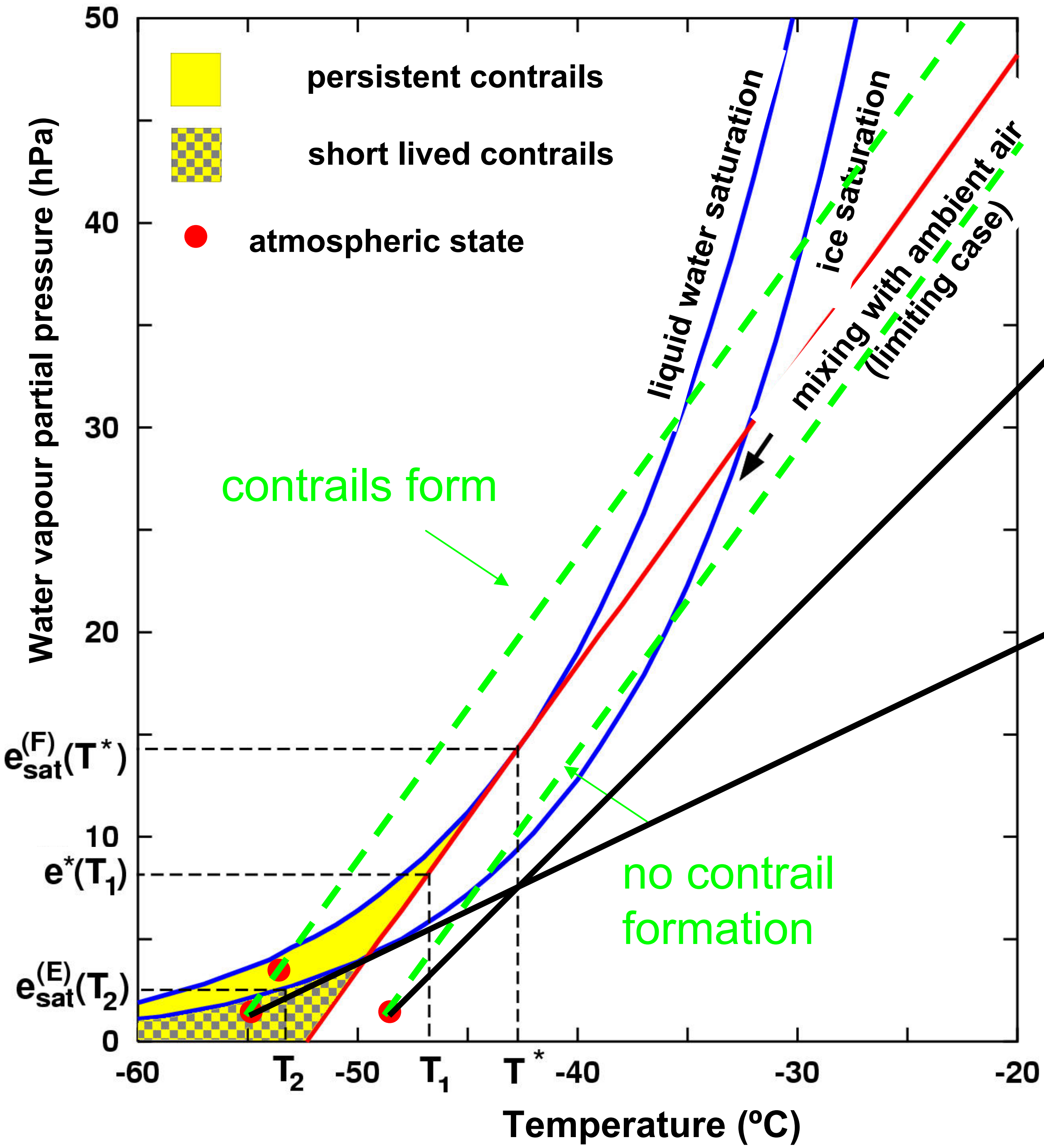

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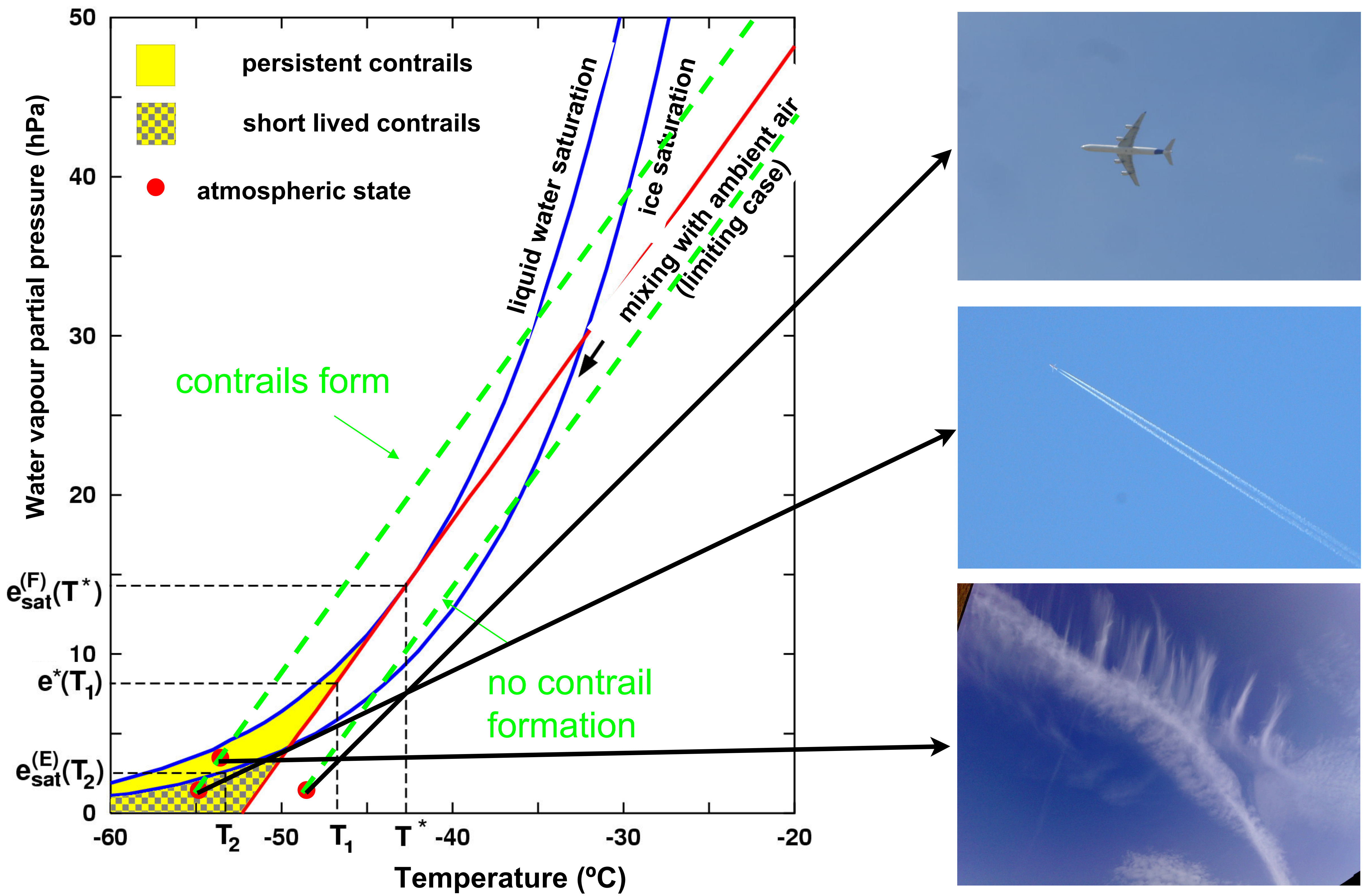
Schmidt Appleman criterion



Source: S. Marquart (2003)

Ice microphysic scheme in CLM

Climate version derived from the NWP model **COSMO** (formerly **LOKAL** modell) developed by DWD

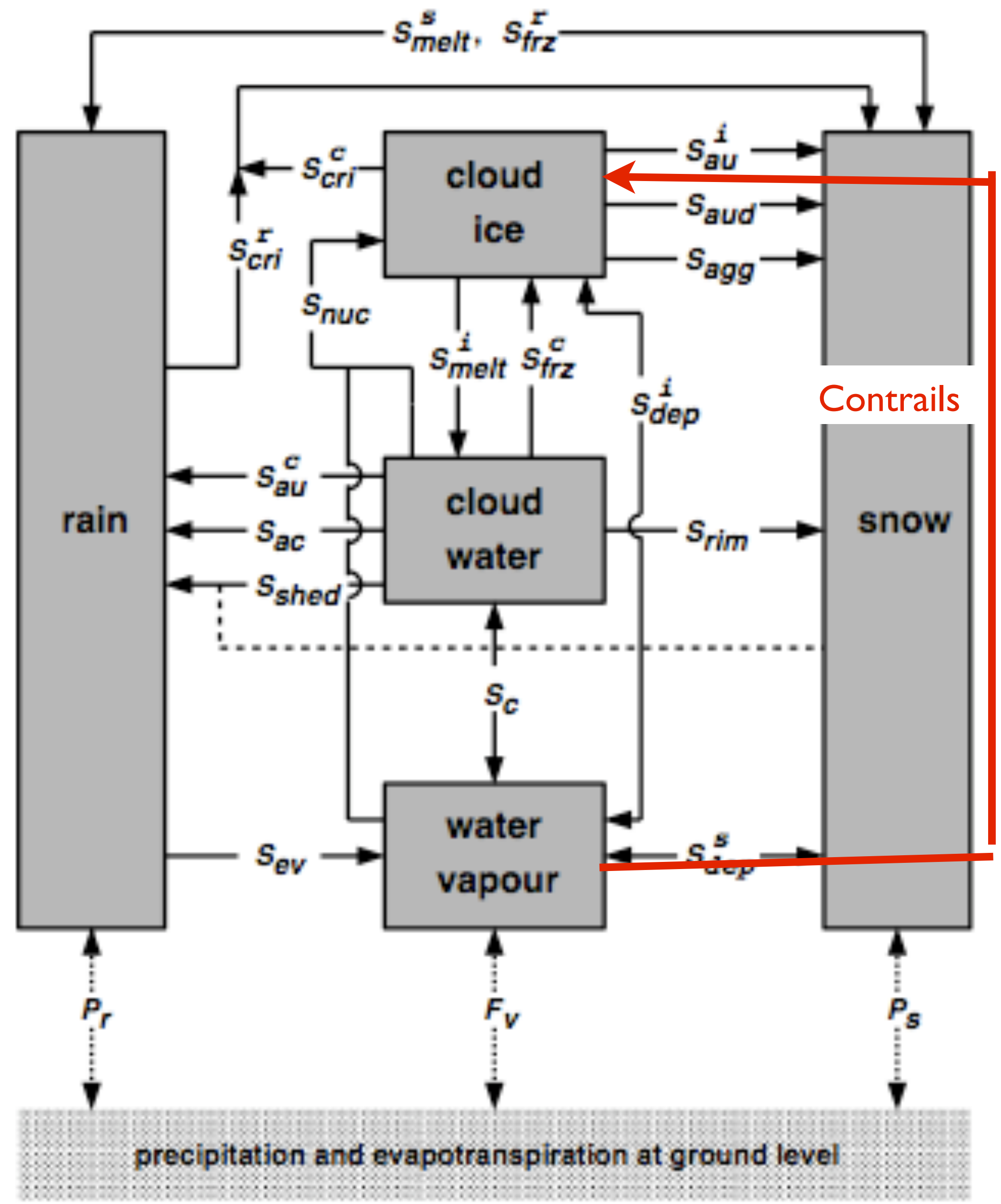
CLM includes a **2 category** (rain and snow are diagnostic) and **1 moment** (only mixing ratio are prognostic, particle number are diagnostic) microphysics scheme

The model **forms** ice via

- nucleation
- deposition
- freezing

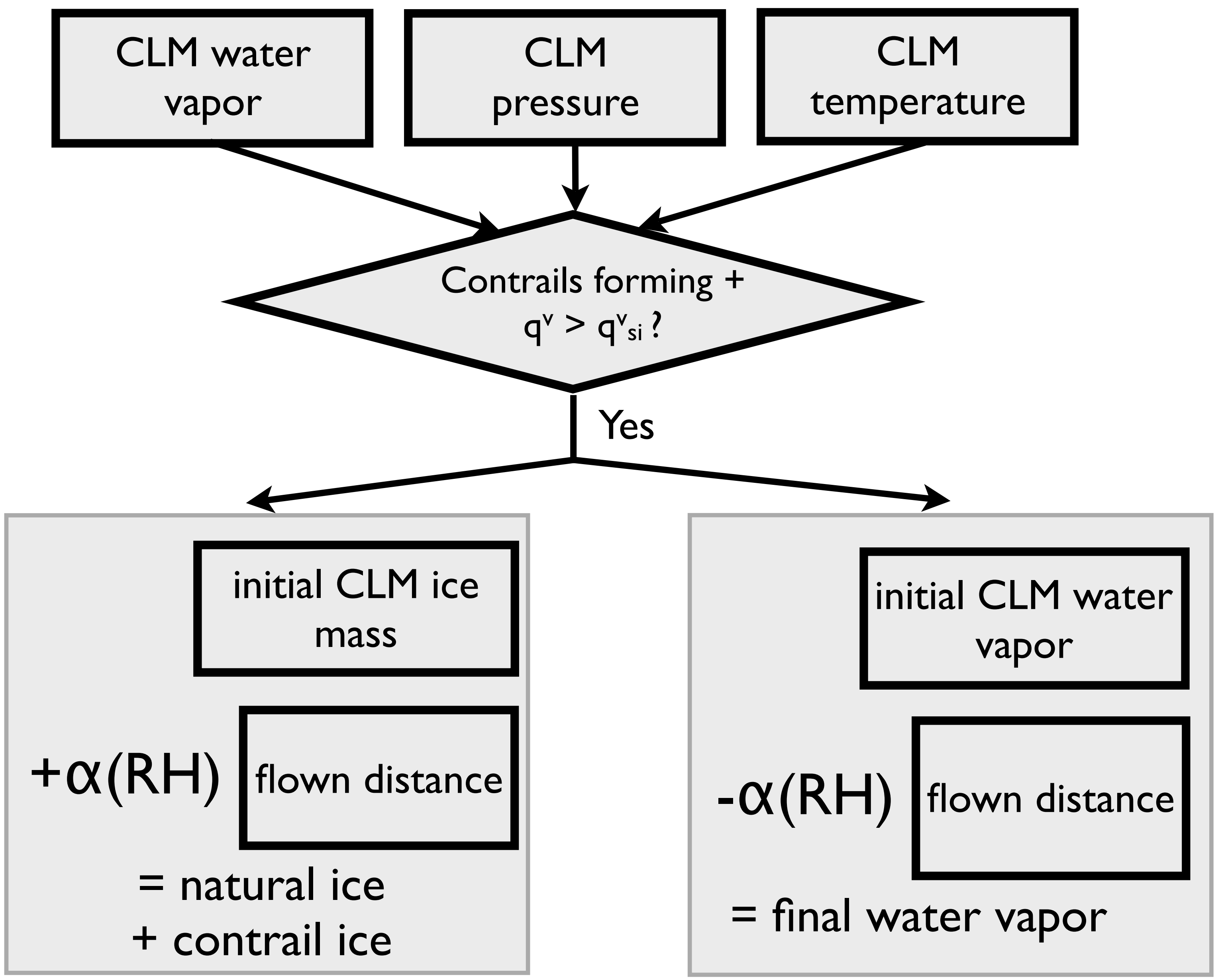
Sinks of ice crystals are

- agregation
- autoconversion
- fusion



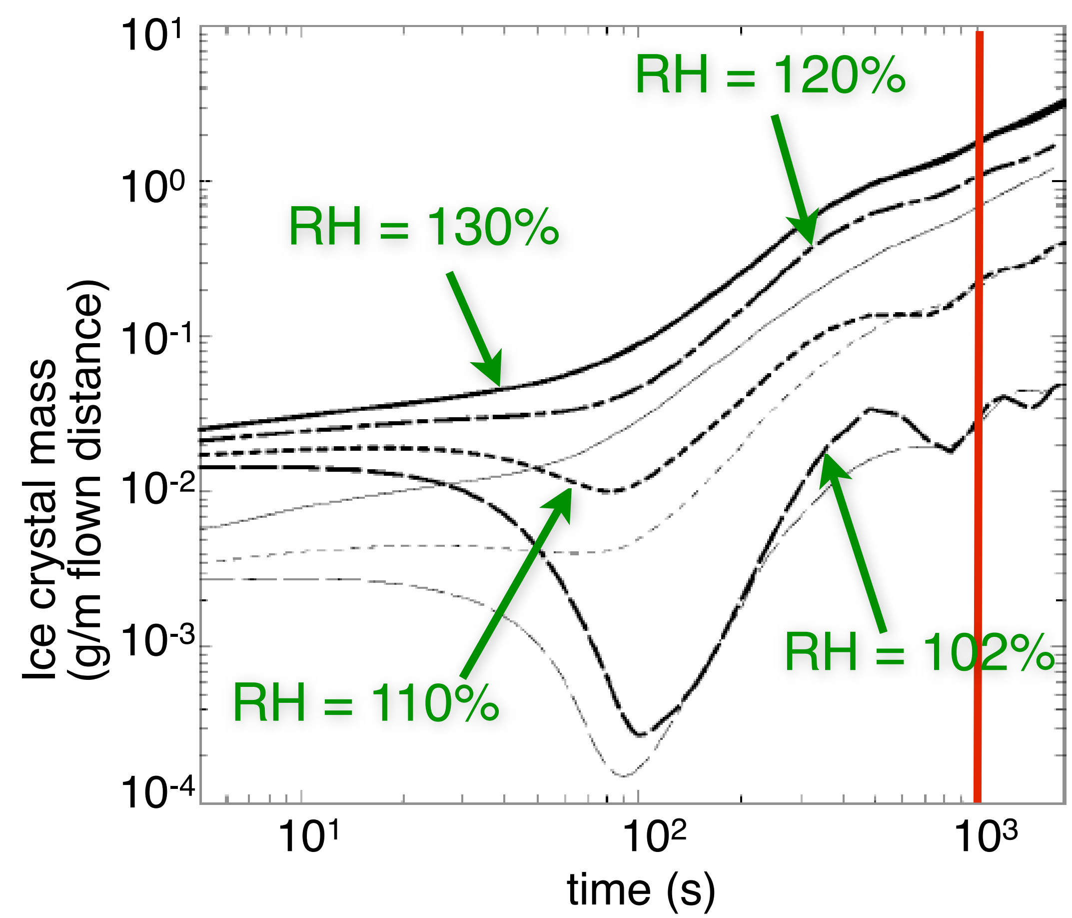
Source: C.Doms and U. Schättler: Scientific Documention of LM,1999

Parametrization of contrails



q^v: specific humidity calculated by CLM
q^v_{si}: specific ice saturation humidity
α : parameter to account for the sub-grid scale growth of contrails
RH: relative humidity

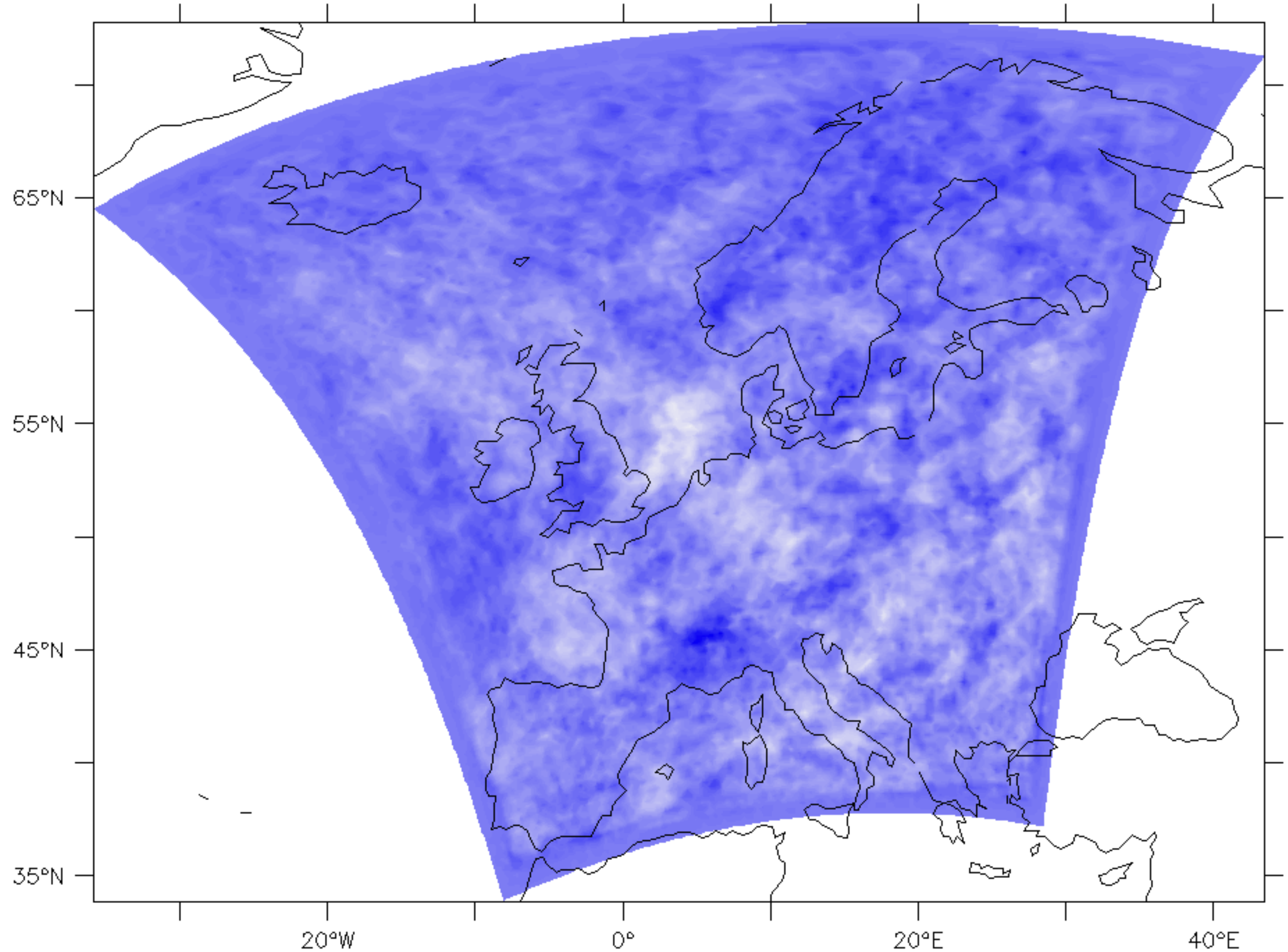
Determination of α based on LES numerical simulation of contrails



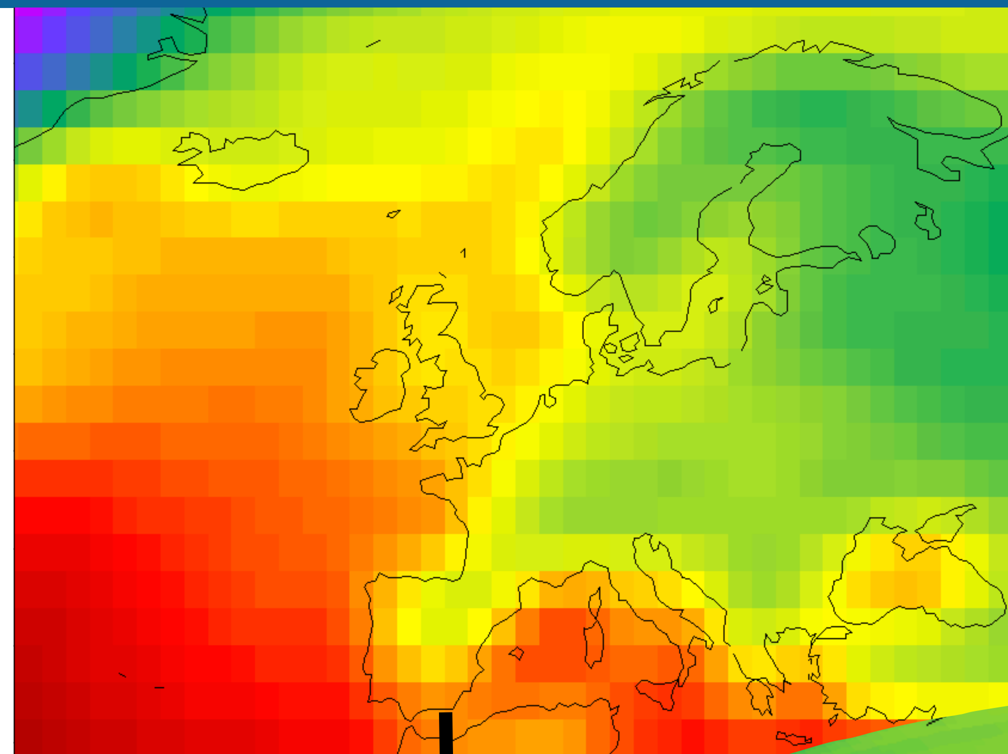
for two types of planes :
four-engined e.g. B747 (**tick lines**)
two-engined e.g. B737 (**thin line**)

Source: Lewellen &Lewellen, 2001

Model configuration and some preliminary results



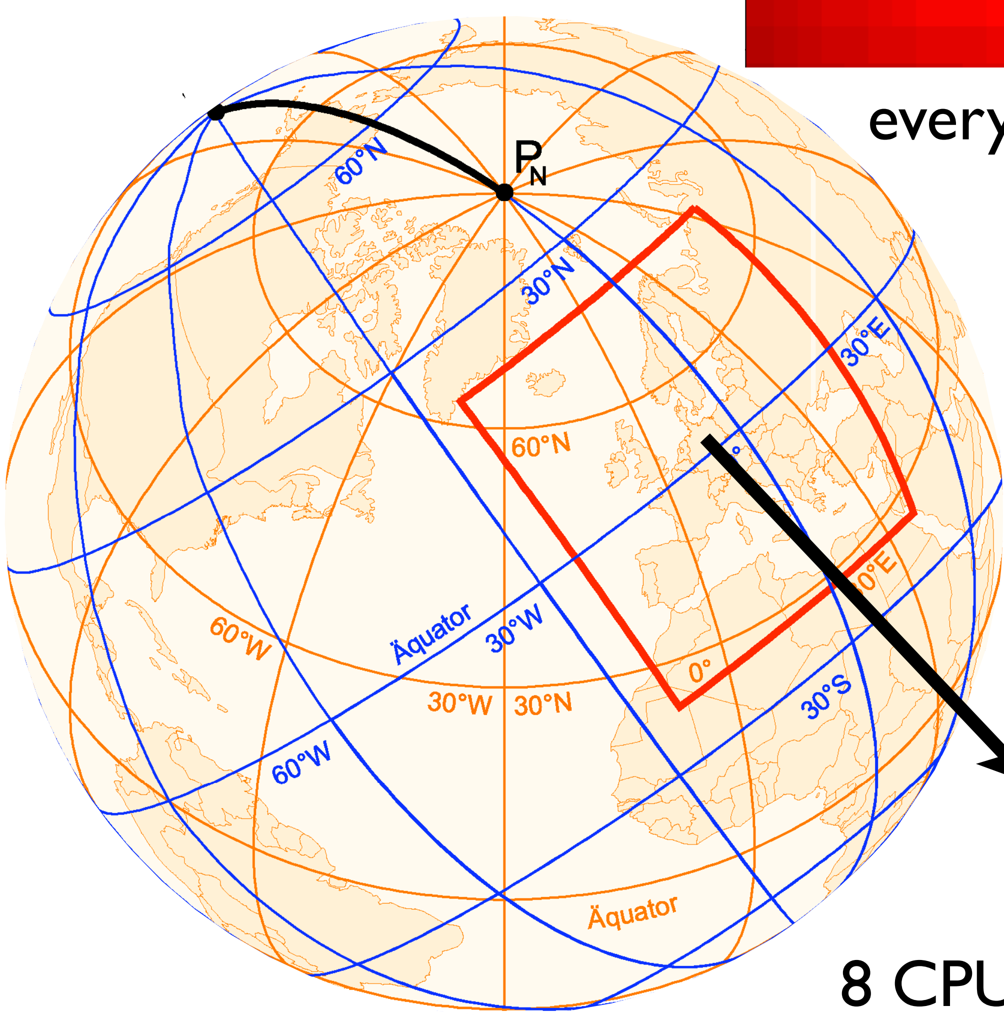
Model configuration



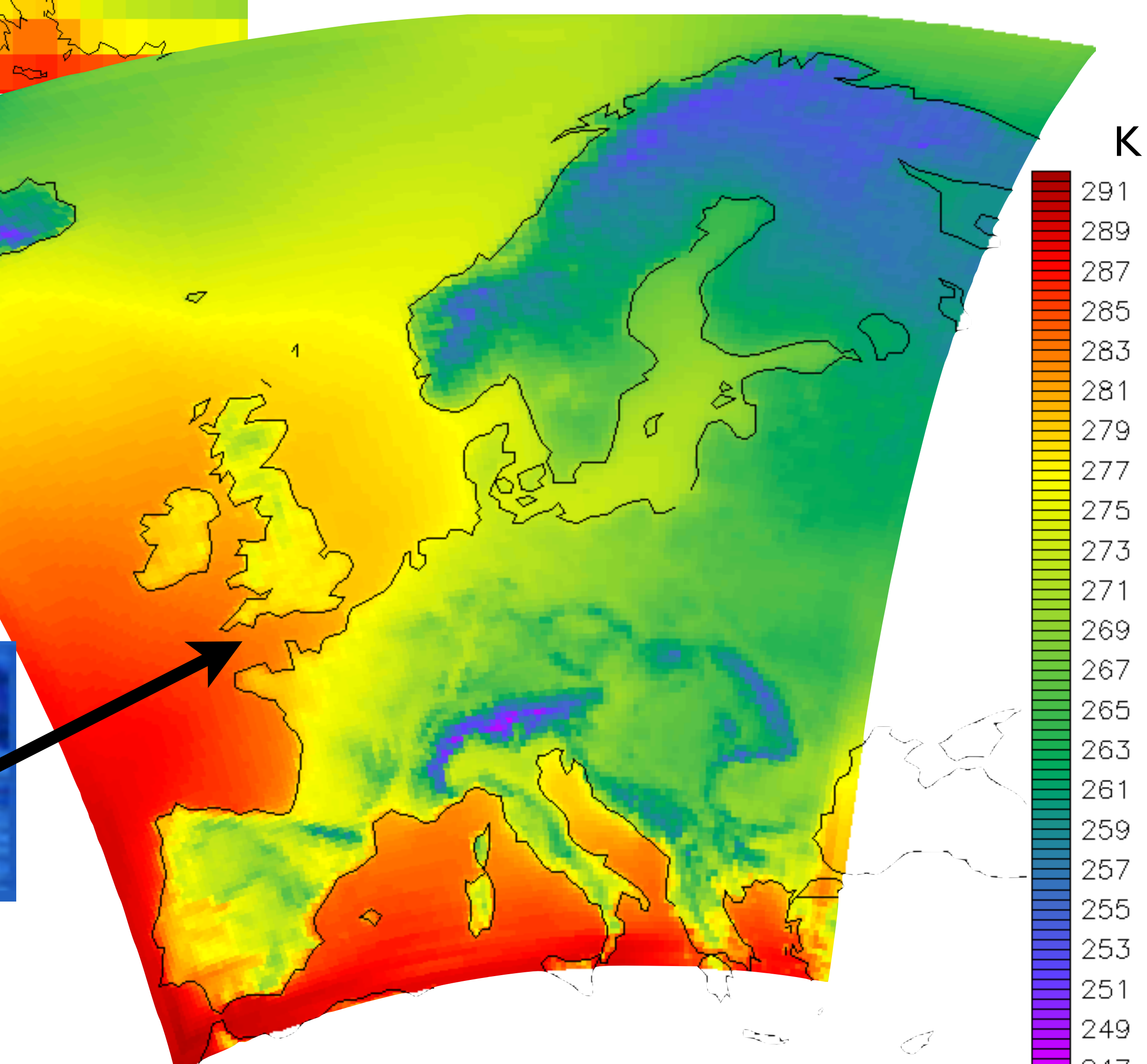
Forcing:
NCEP reanalysis for 2005
~2°x2°

Model grid:
0.22°x0.22° (20x20 km)
on a rotated lon/lat grid

Example:
Surface temperatures for
february 2005



every 6 h

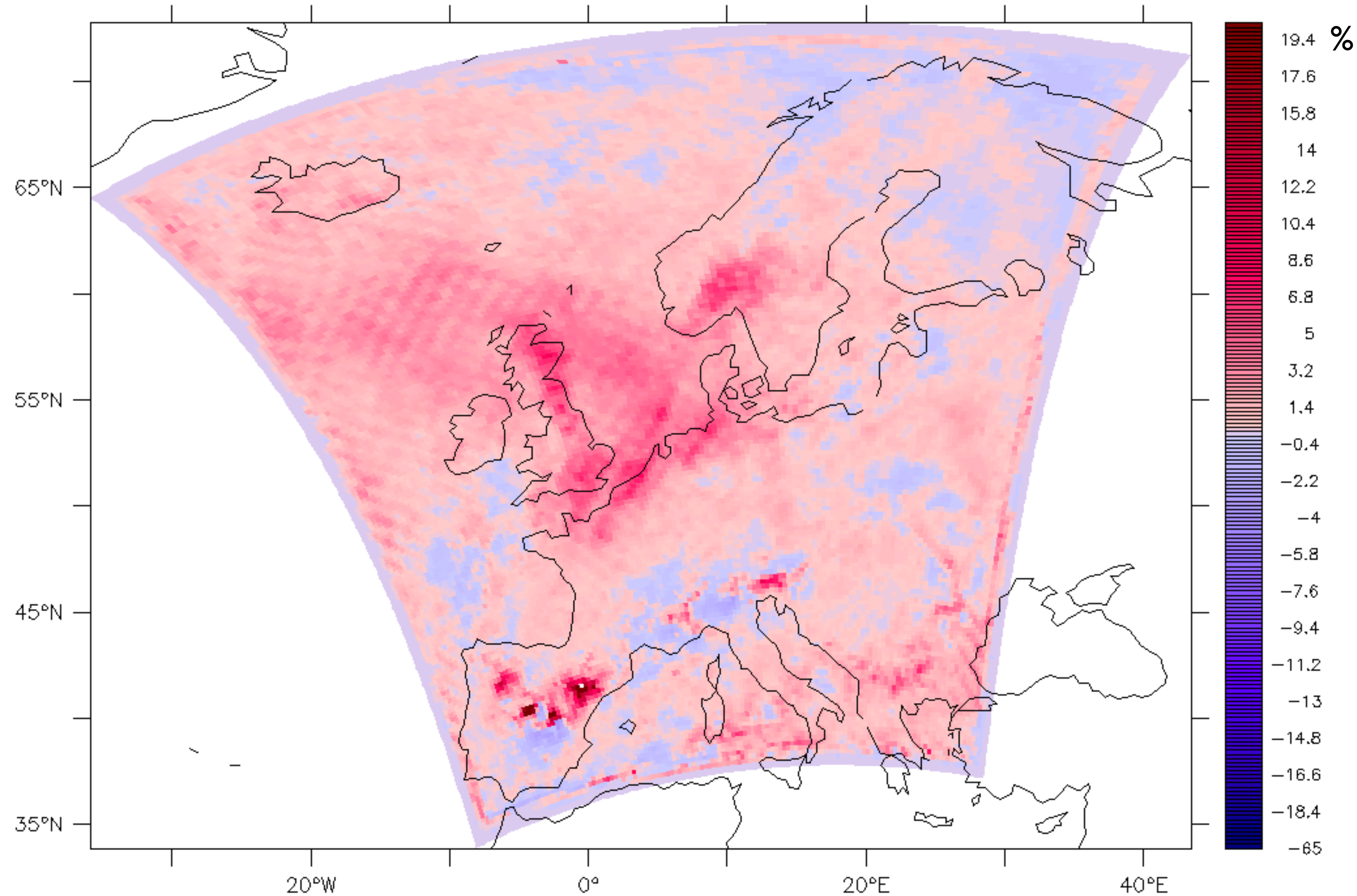


8 CPUs

time step: 80s

Additional ice due to aviation in CLM

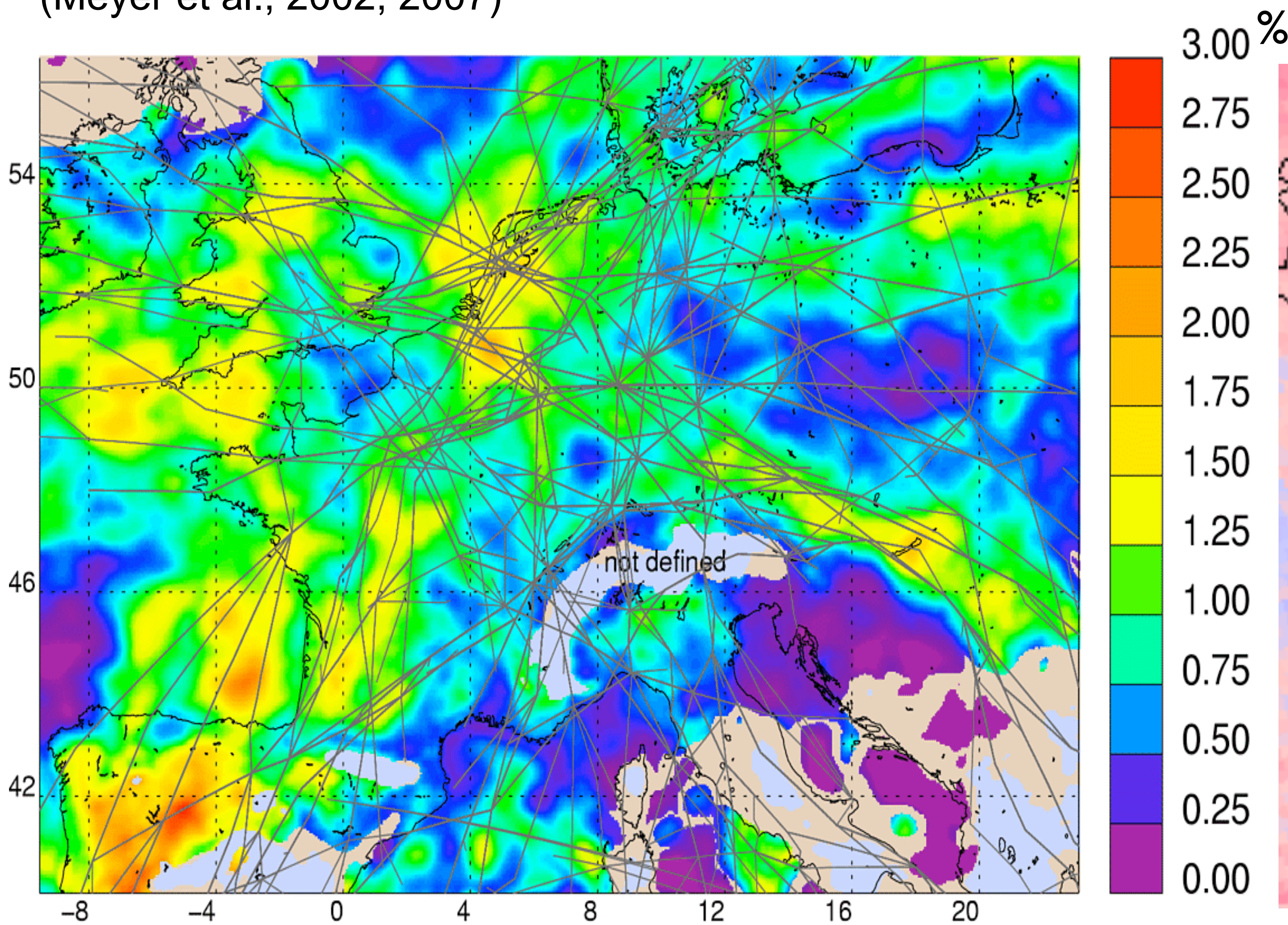
Aviation forcing: The flown distance is homogeneous in every girdcell and is the average on one year based on AERO2k.
This simulation does NOT CONTAIN FLIGHT ROUTE INFORMATION

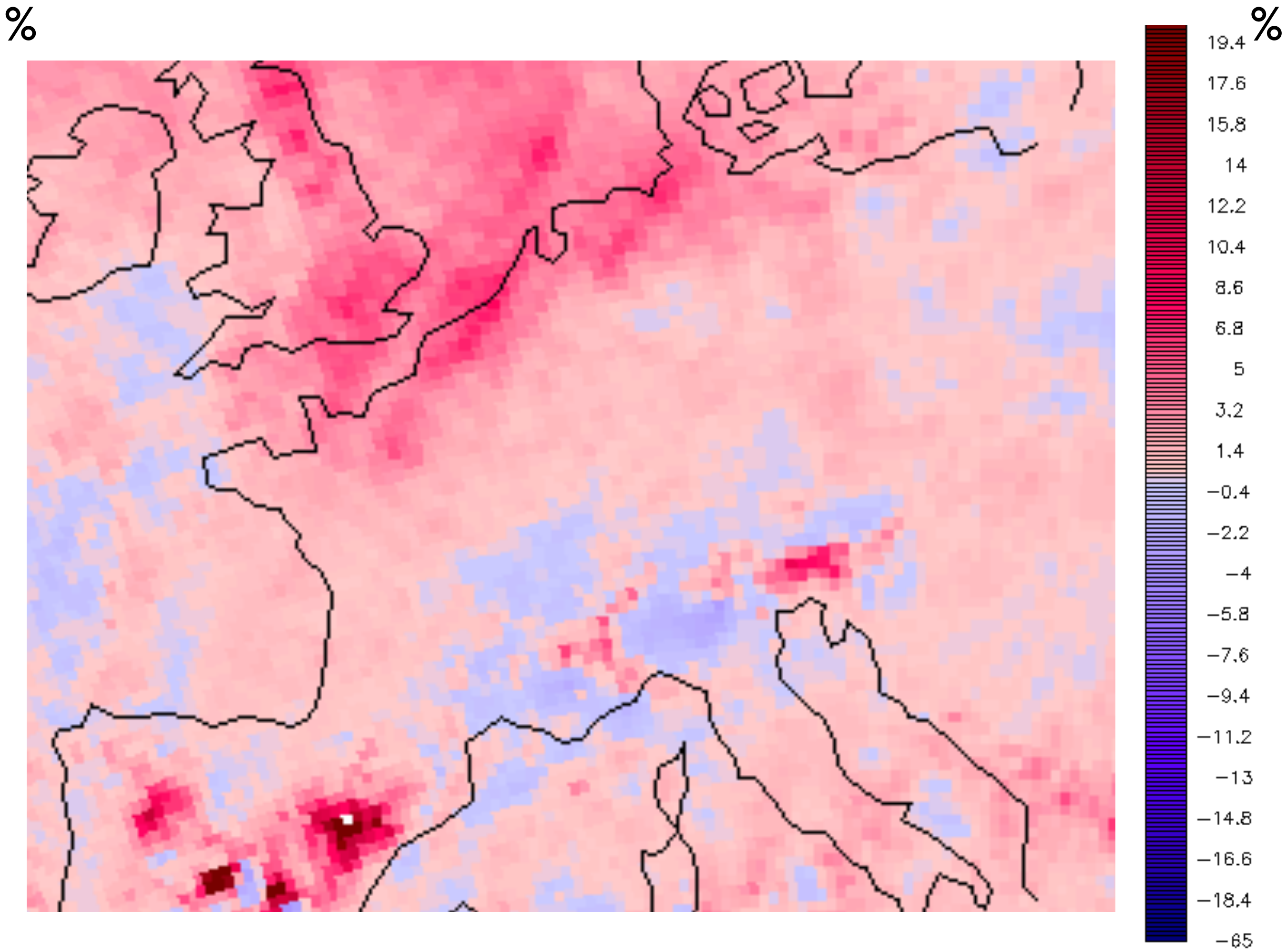


Relative difference (in %) of ice mass between the the reference simulation and the simulation with contrails averaged on every model levels and for January 2005

Comparaison with observations

(Meyer et al., 2002, 2007)

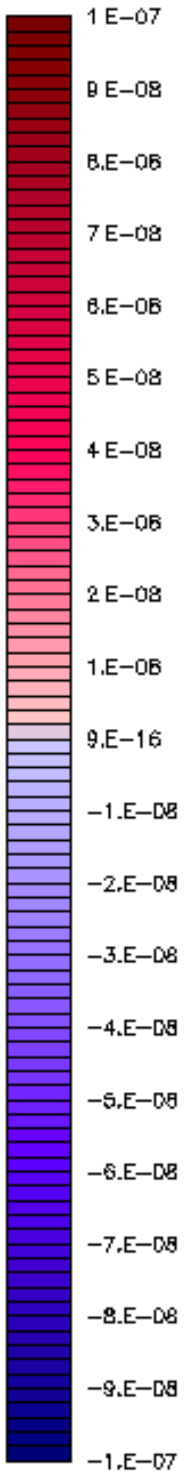


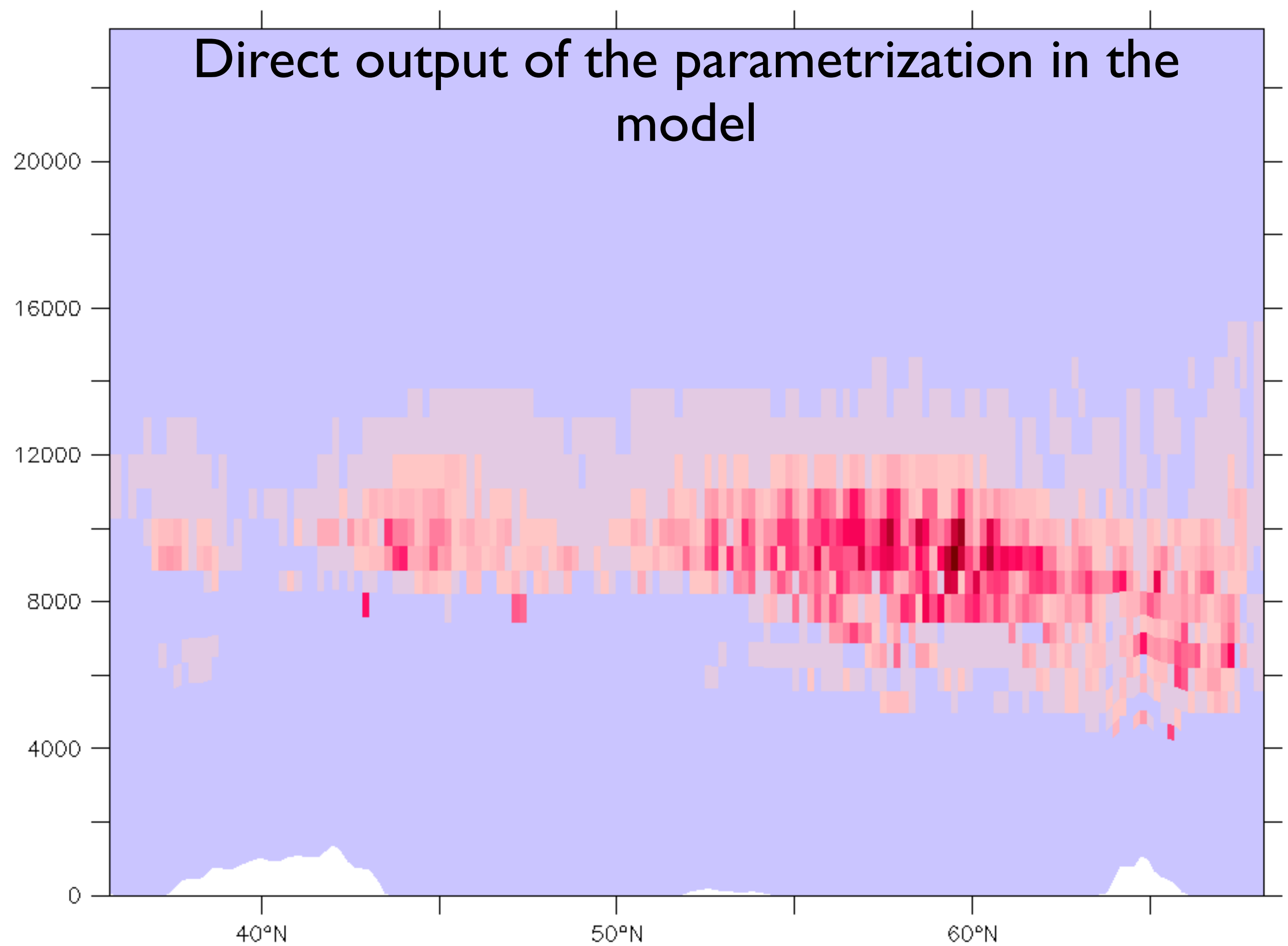


Cloud cover (in % of sky covered) of linear contrails, as detected on satellite images for 2000-2005, with principal flight routes (in grey)

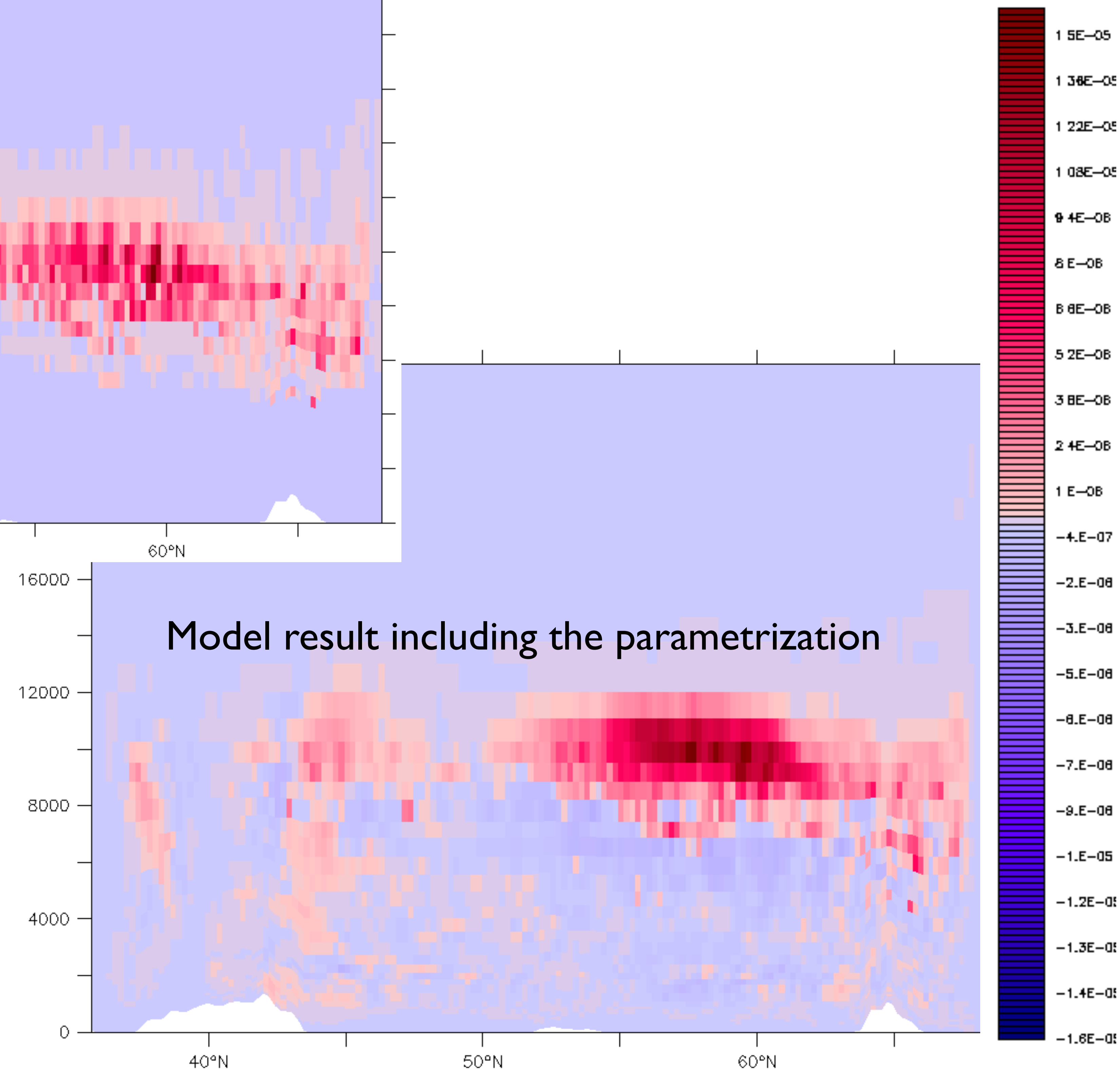
Relative difference (in %) of ice mass between the the reference simulation and the simulation with contrails averaged on every model levels and for January 2005

Contrail to cirrus evolution

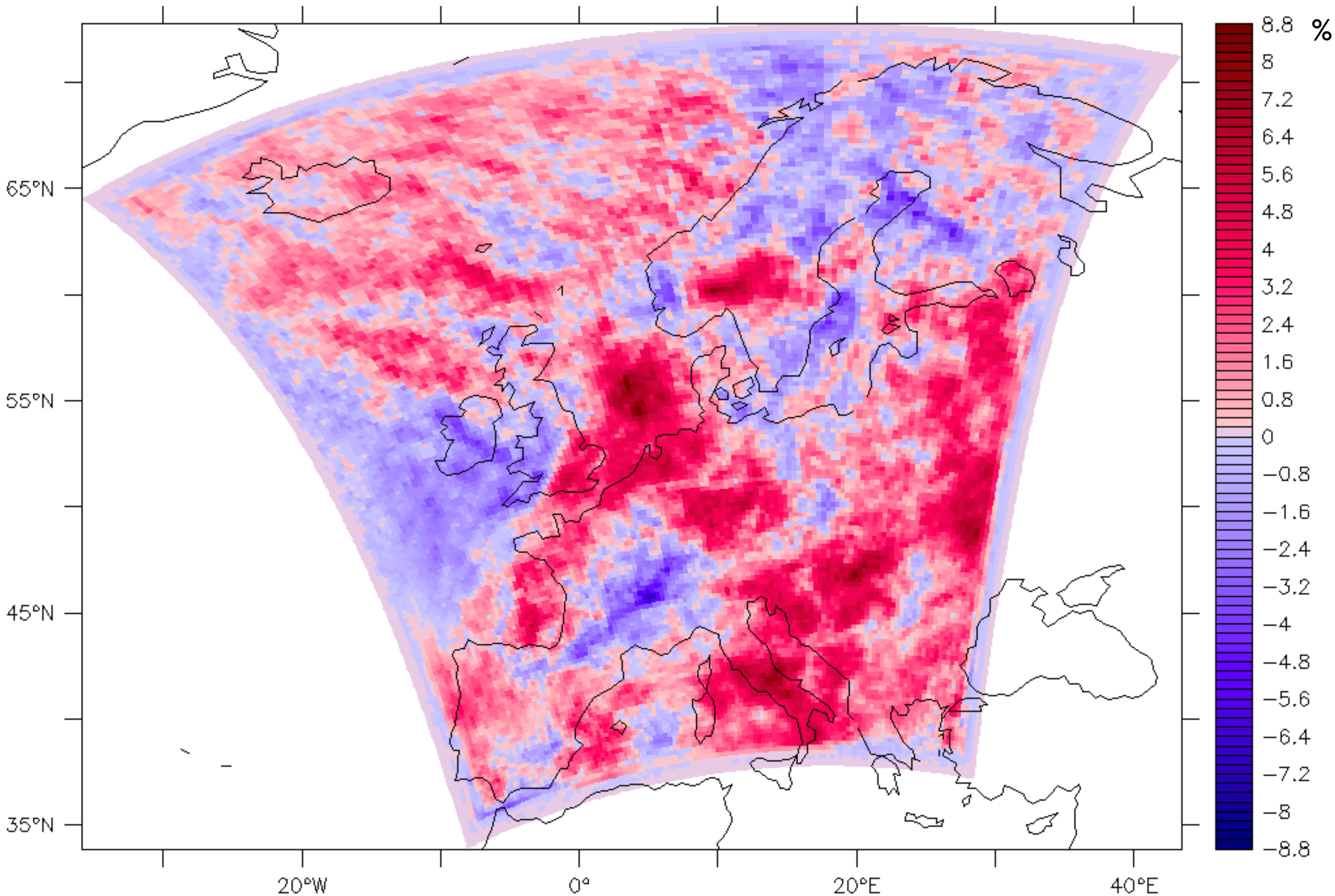




Absolute difference (in kg/kg) of ice mass between the the reference simulation and the simulation with contrails averaged on every model levels and for January 2005



Impact on cloud cover



Absolute difference (in % of coverage) of high clouds (> 8km) between the reference simulation and the simulation including the contrail parameterization, averaged on january 2005

Next steps

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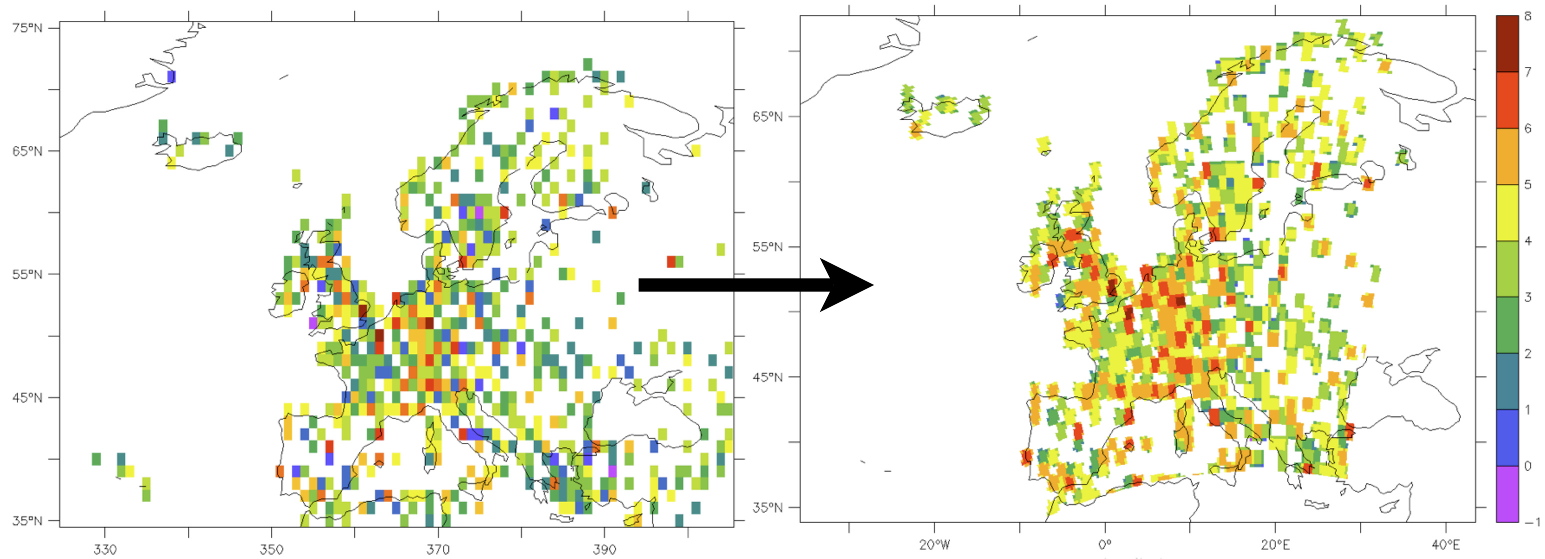
Finalizing the parameterization implementation

- Interpolate the AERO2k database (1°x1°) on the model grid (0.2°x0.2°)



log de la quantité de kérosène utilisée (en kg) au niveau du sol

- Compare the results obtained with the homogeneous forcing with those based on the forcing based on real flight data

Analysis of radiative forcing of contrails

Validation of cirrus clouds and contrails

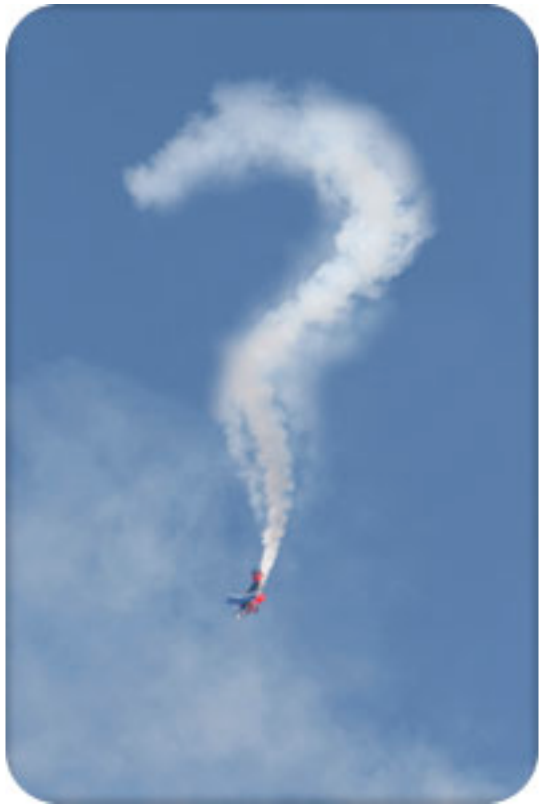
Quantification of impacts and sensitivity tests

- Quantification of the impact of aircraft induced cloudiness on the total cloud cover as well as the diurnal temperature range (DTR)

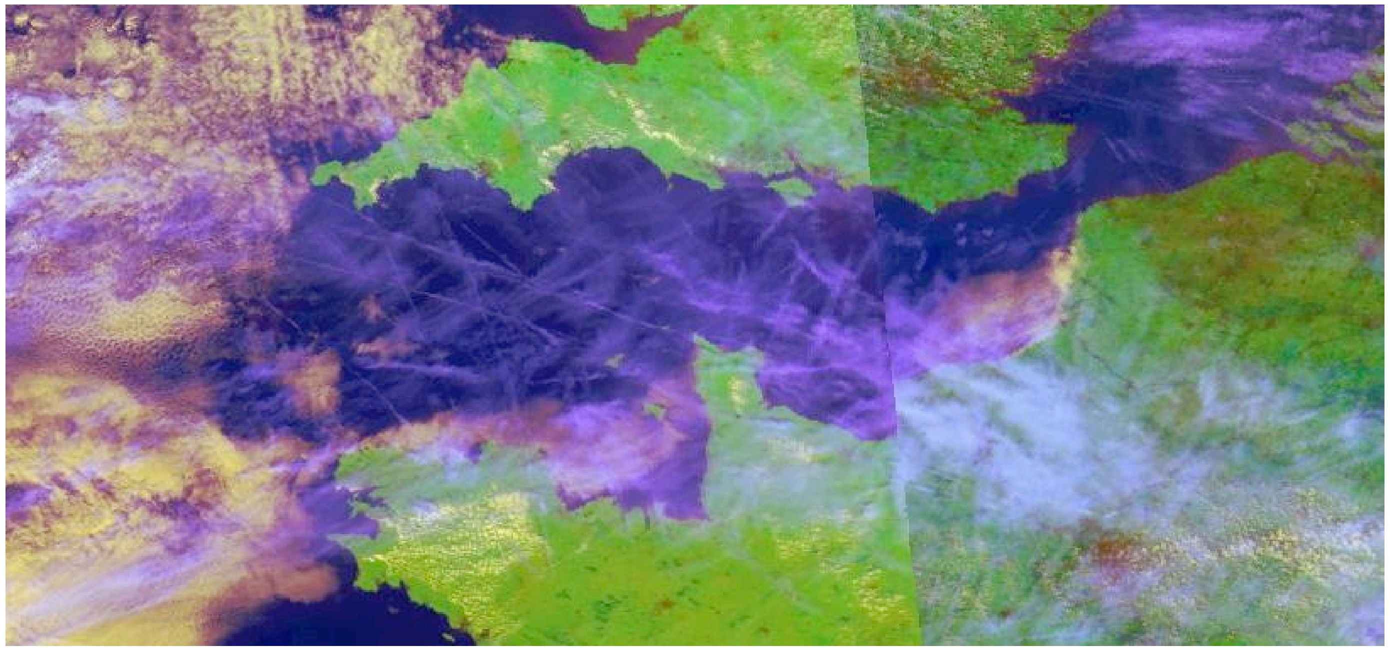
- Sensitivity test of cruise altitudes

Thank you for your attention

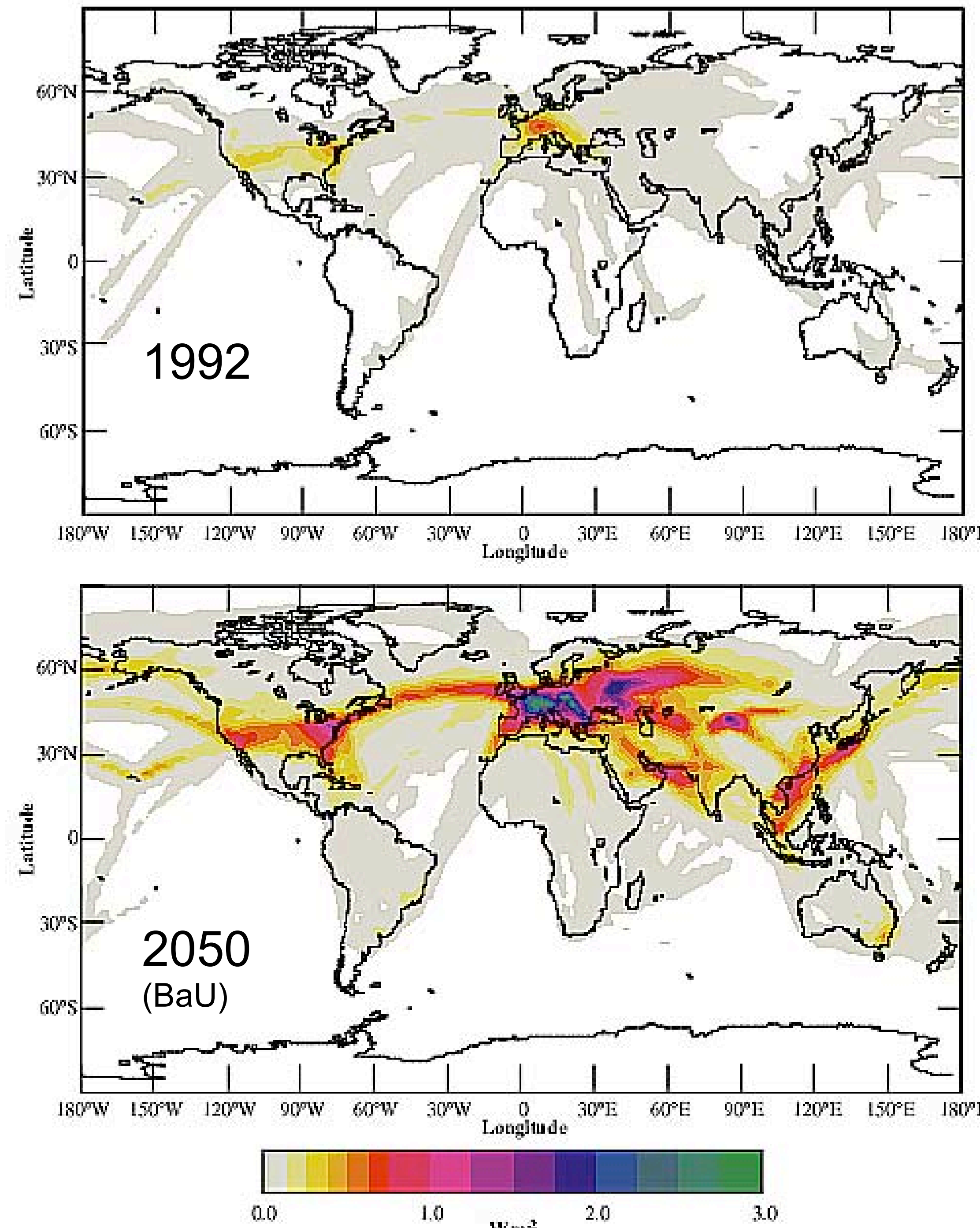
Questions?



Condensation trails

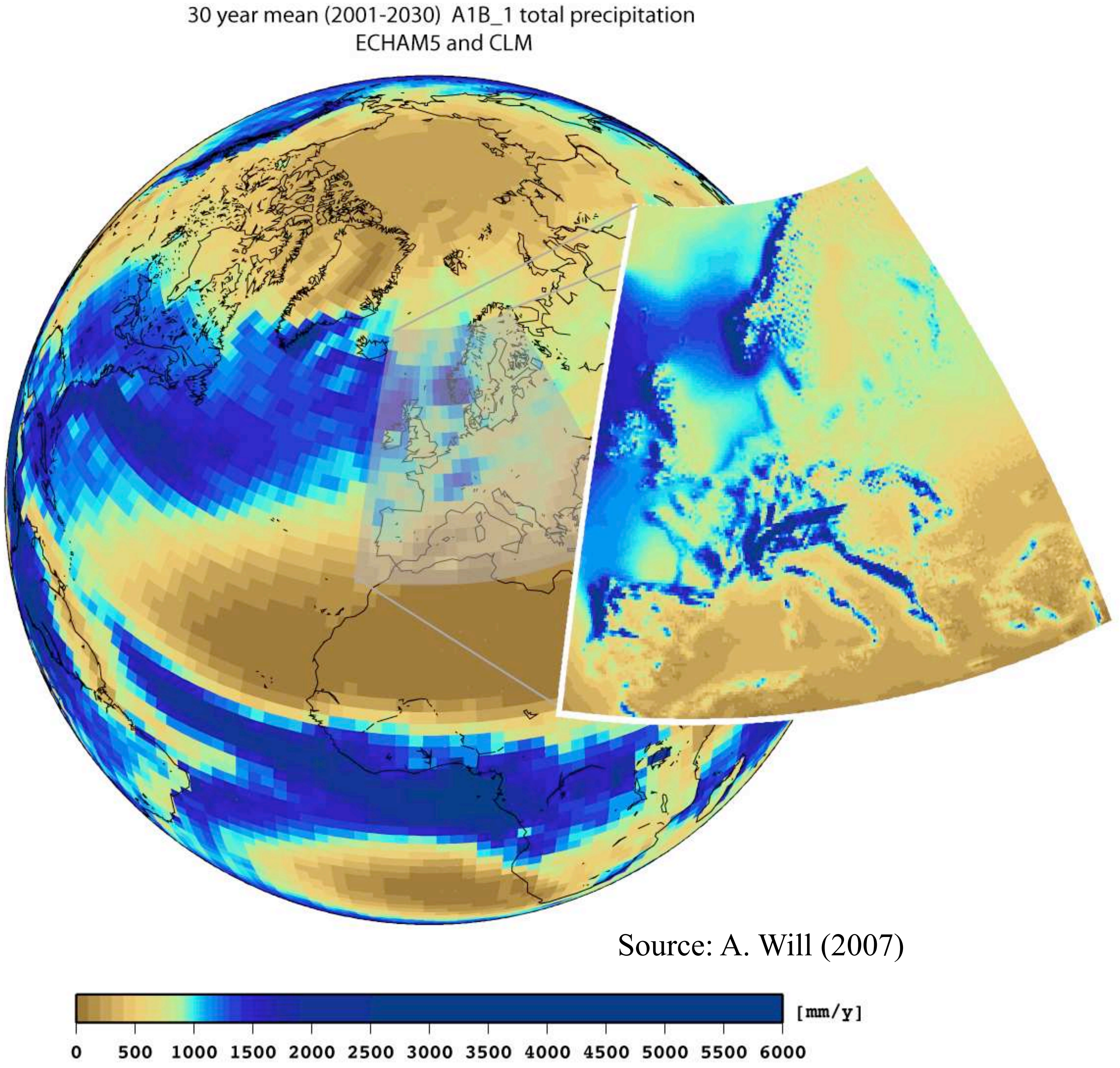


Forçage radiatif des traînées de condensation (Wm^{-2})



Source : IPCC, 1999.

Model choise and desciption of CCLM



Source: A. Will (2007)

Model choice

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Out of a choice of 10 models the foloowing 3 were analysed in more detials

	Cloud microphysics parametrization	Validation in Europe	User group	Paralelization Installation
MAR Modèle Atmosphérique Regional	detailed microphysics, prognostic calculation of cloud ice mass	incomplete validation in Europe	limited	no runs on our computers
CLM COSMO Model in Climate Mode	detailed microphysics, prognostic calculation of cloud ice mass	validated for the 20^{th} century in Europe; 21^{th} century projections done	European group with many interactions	yes runs on our computers
UM Unified Model	less detailed microphysics, diagnostic calculation of cloud ice mass	validated for the 20^{th} century in Europe; 21^{th} century projections done	international group, but limited support as available version in old	yes installation problems on our computers

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The CLM community

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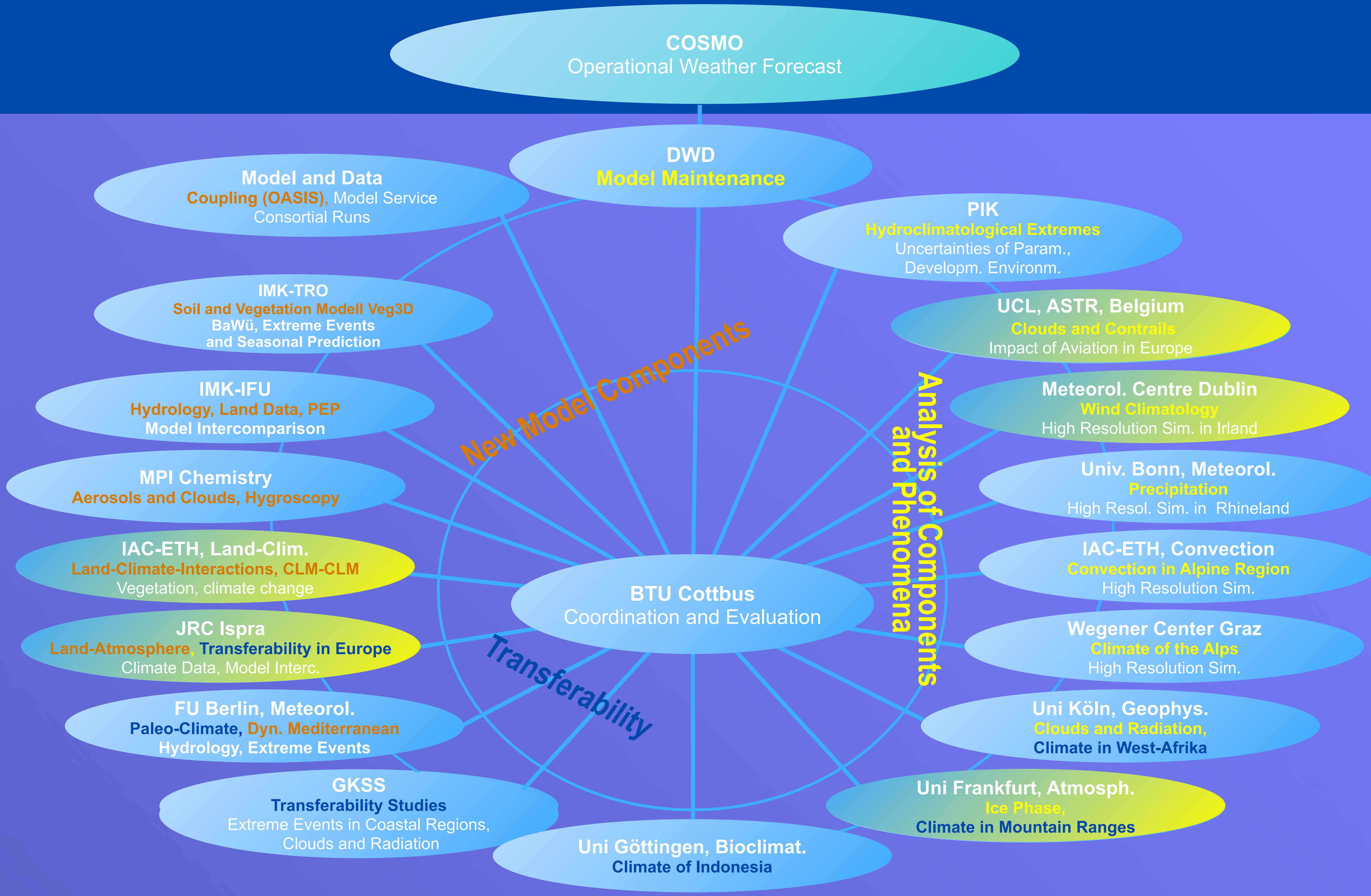

Model dynamics and numerics

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Climate version derived from the NWP model COSMO (formerly LOKAL modell) developed by DWD

Model Equations

- Basic hydro-thermodynamical equations in advection form,
- no scale approximations (i.e. fully compressible and non-hydrostatic)

Prognostic Variables

- Horizontal and vertical wind components (u,v,w), temperature (T), pressure (P),
- specific humidity, specific cloud water content, cloud-ice

Spatial Discretization

- Second-order horizontal and vertical differencing (centered)

Time Integration

- 3 time-level (Leapfrog) split explicit using extensions proposed by Skammarock and Klemp (1992).

Numerical Smoothing

- Rayleigh damping layer at upper boundary
- 4th order linear horizontal diffusion
- 3-D divergence damping in split steps

Model physical parametrization

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Grid-Scale Clouds and Precipitation

- Cloud water formation dissipation by saturation adjustment
- Cloud scheme including ice-clouds, precipitation and snow

Subgrid-Scale Clouds

- Subgrid-scale cloudiness (fractional cloud cover) is interpreted by an empirical function depending on relative humidity.

Moist Convection

- Mass-flux convection scheme after Tiedtke (1989) with closure based on moisture convergence.

Radiation

- δ-two stream radiation scheme based on Ritter and Geylen (1989) for short- and longwave fluxes; full cloud-radiation feedback.

Turbulent Diffusion

- Diagnostic K-closure (at hierarchy level 2 following Mellor and Yamada (1982)) for vertical diffusion.

Surface Layer

- Constant flux layer parameterization based on the Louis (1979) scheme.

Soil Processes

- Multi-layer soil model.

Formation on a contrail

The formation of a contrail can be decomposed in 3 phases:

1) **Jet regime** (~20s) The wingtip vortices roll up mutually, ice nucleation is starting and the crystals are trapped in the vortices

2) **Vortex regime** (2 to 3 minutes) The vortices start to descend and the adiabatic warming influences the growth of the crystals

3) **Dispersion regime**(several minutes /hours) turbulent mixing with ambient air, dispersion and growth of crystals

LES simulation of a contrail

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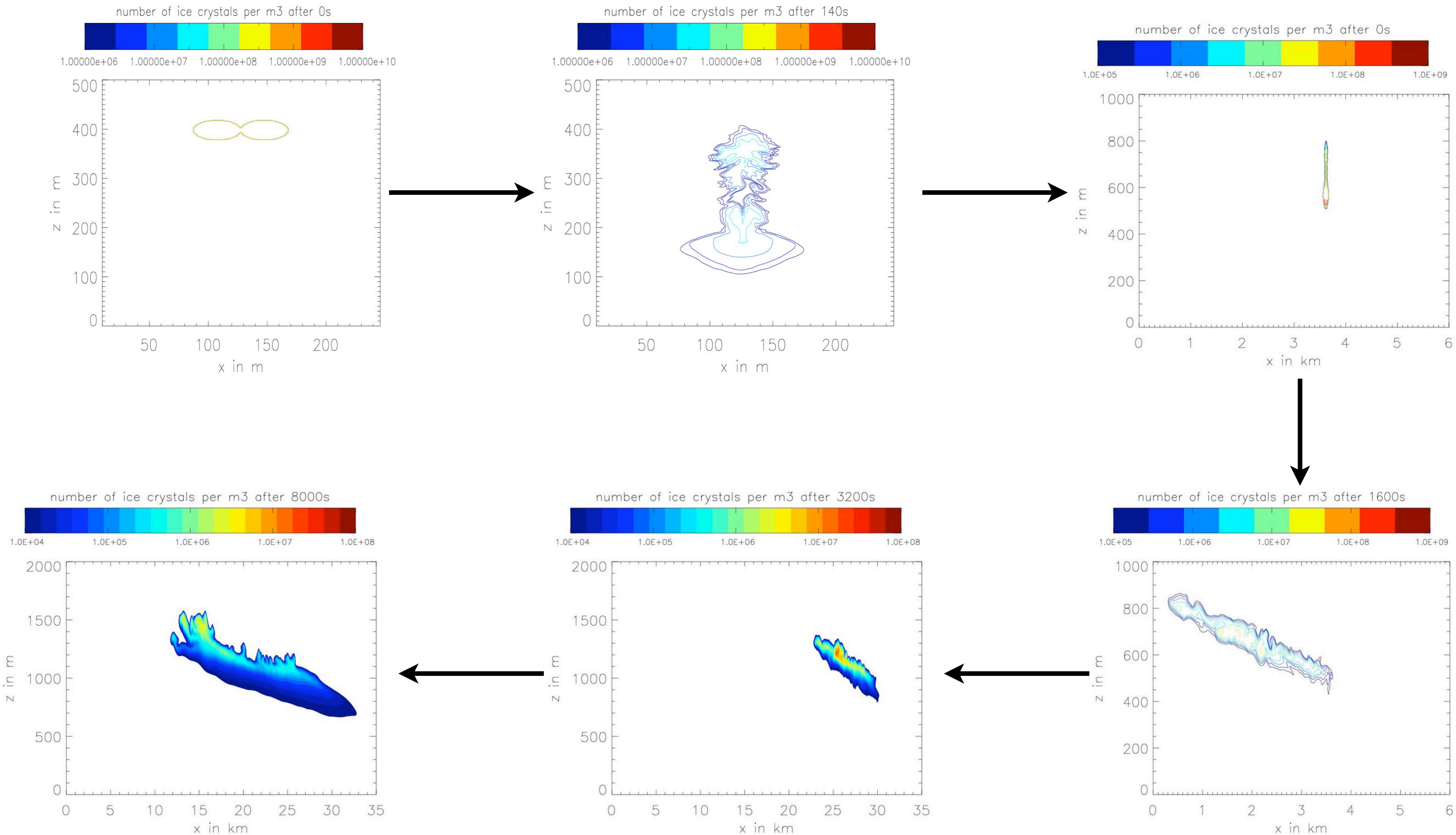
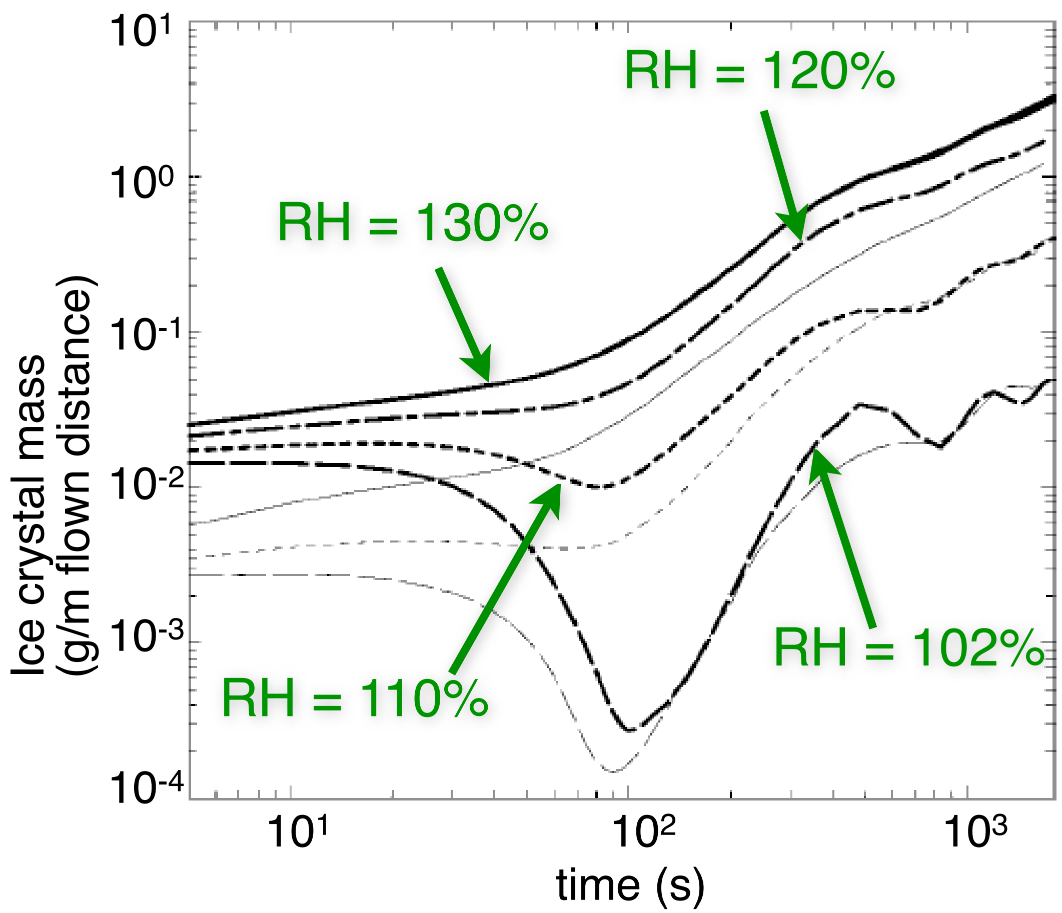
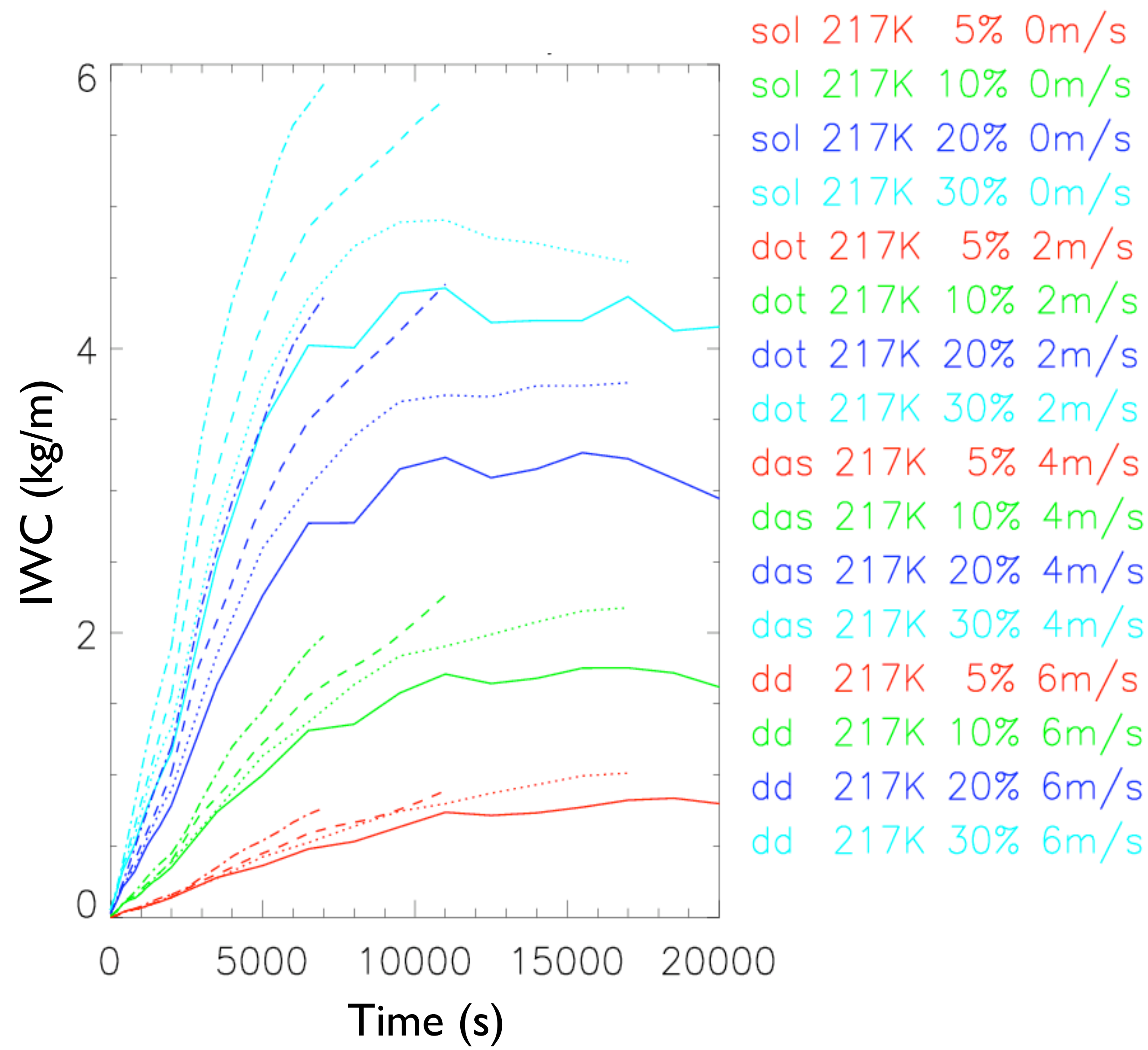


Ice crystal number in a LES simulation of a contrail done by (S. Unterstrasser et al., 2008) with T=217K, Rhi=130% and u=6 m/s

Ice crystal mass produced



for two types of planes :
four-engined e.g. B747 (**thick lines**)
two-engined e.g. B737 (**fine lines**)



ambiant relative humidty is the main parameter governing the ice mass growth in the dispersion phase

CLM-COSMO Model in Climate Mode

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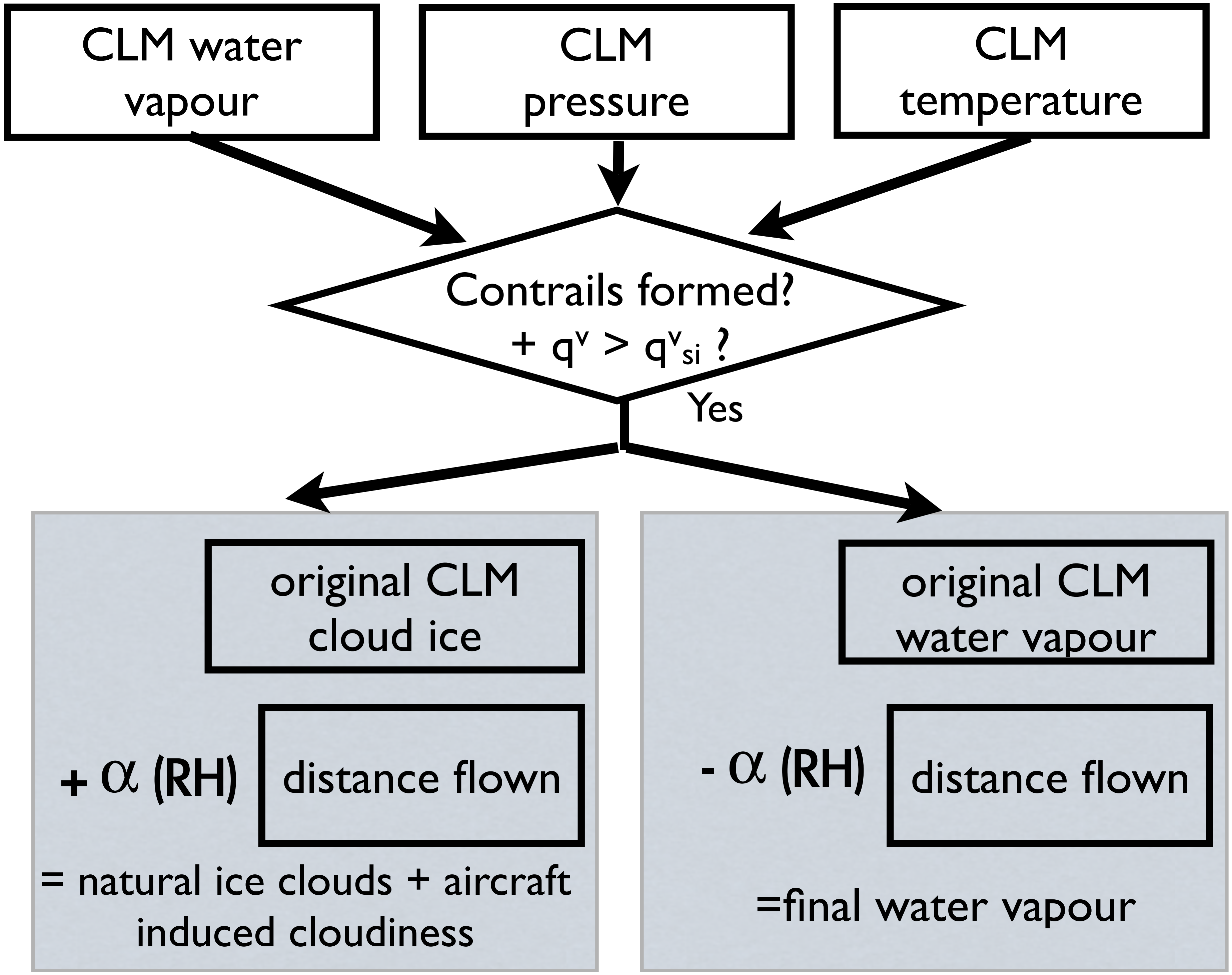
Climate version derived from the NWP model **COSMO** (formerly **LOKAL** modell) developed by DWD

Features:

- non-hyrostatic
- massively parallized
- codage clair et standardisé
- potentiel à long-terme assuré

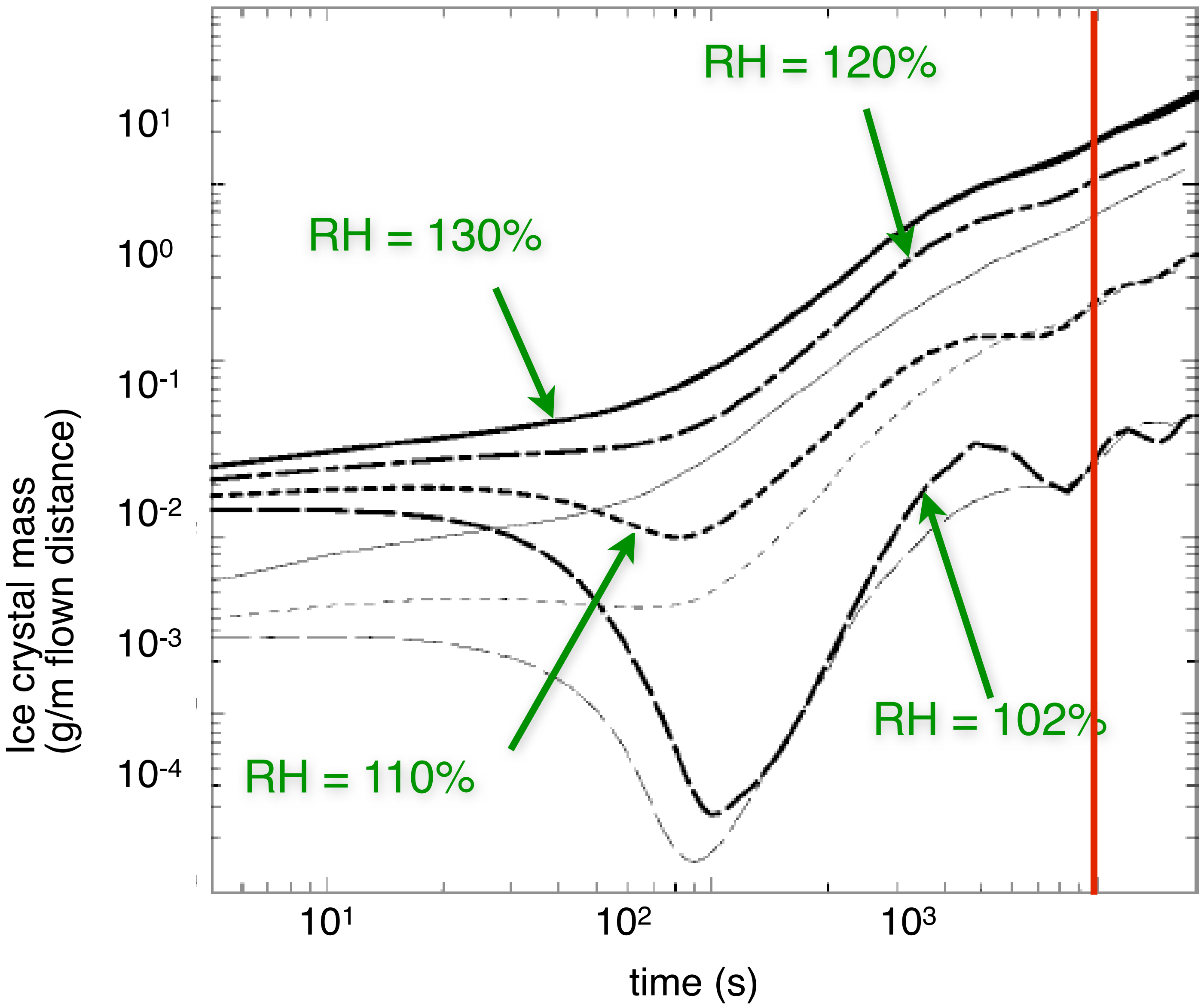
Parametrisation of contrails



q^v: specific humidity

q^v_{si}: ice saturation specific humidty

Sob-gridscale growth of contrails



for two types of planes :
four-engined e.g. B747 (**thick lines**)
two-engined e.g. B737 (**fine lines**)

For the following simulations the dependence on growth of contrails at a time of 1000 s has been taken into account, as a function of supersaturation

The evolution of contrails before this time is thus not explicitly simulated

Vertical coordinate

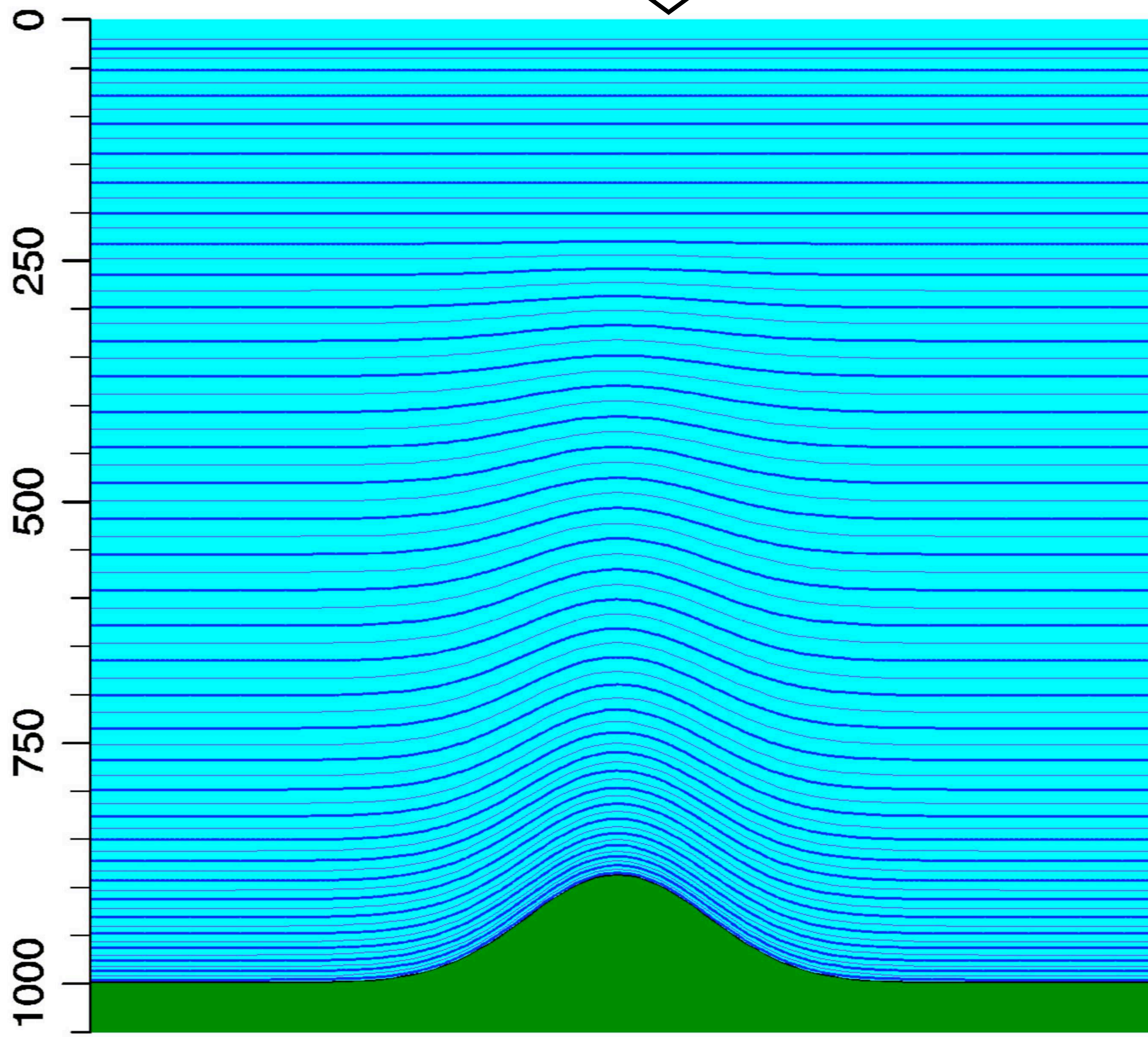
NCEP forcing

Hybrid pressure based with 40 vertical levels

highest level at 20 hPa

NCEP forcing

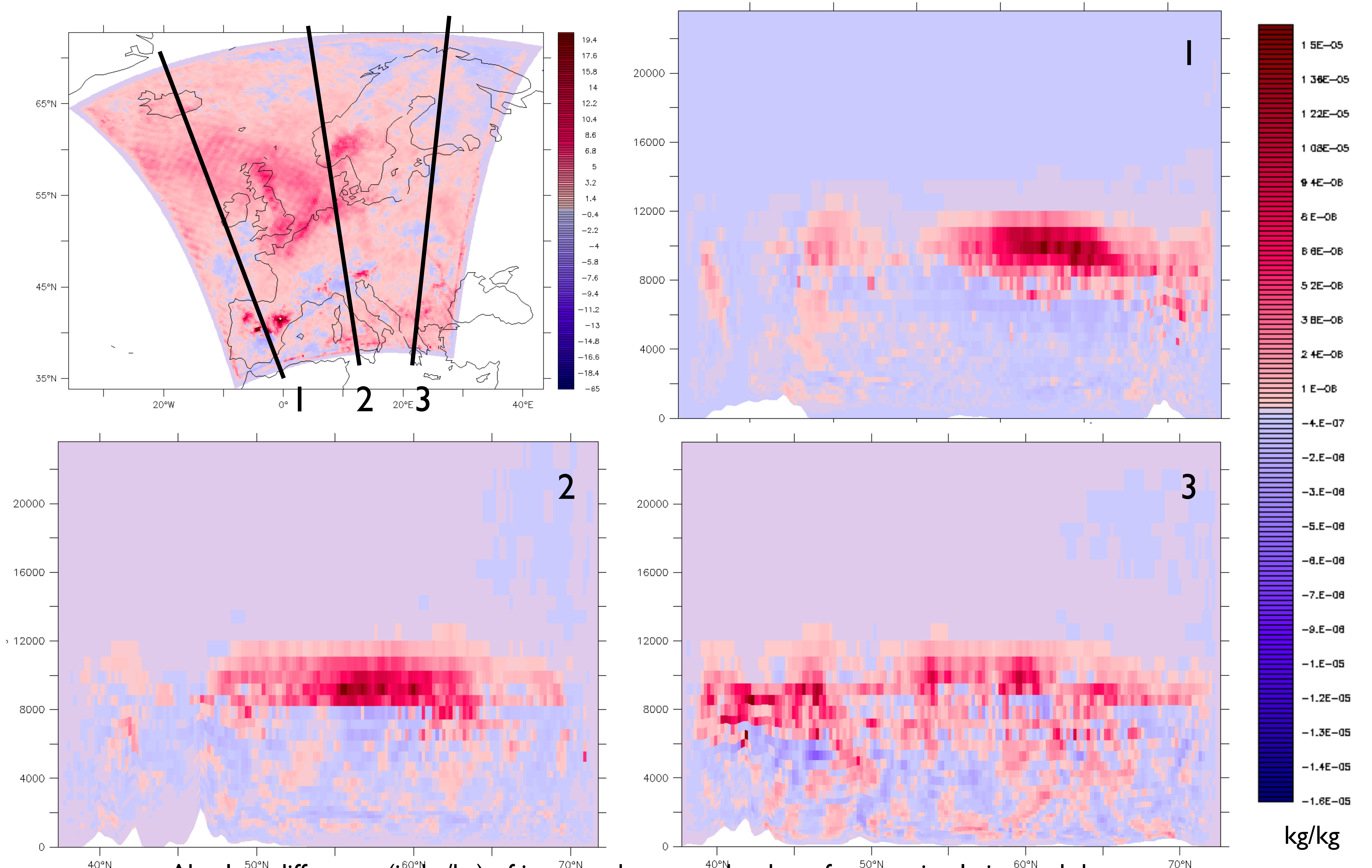
NCEP forcing



soil model with 9 levels

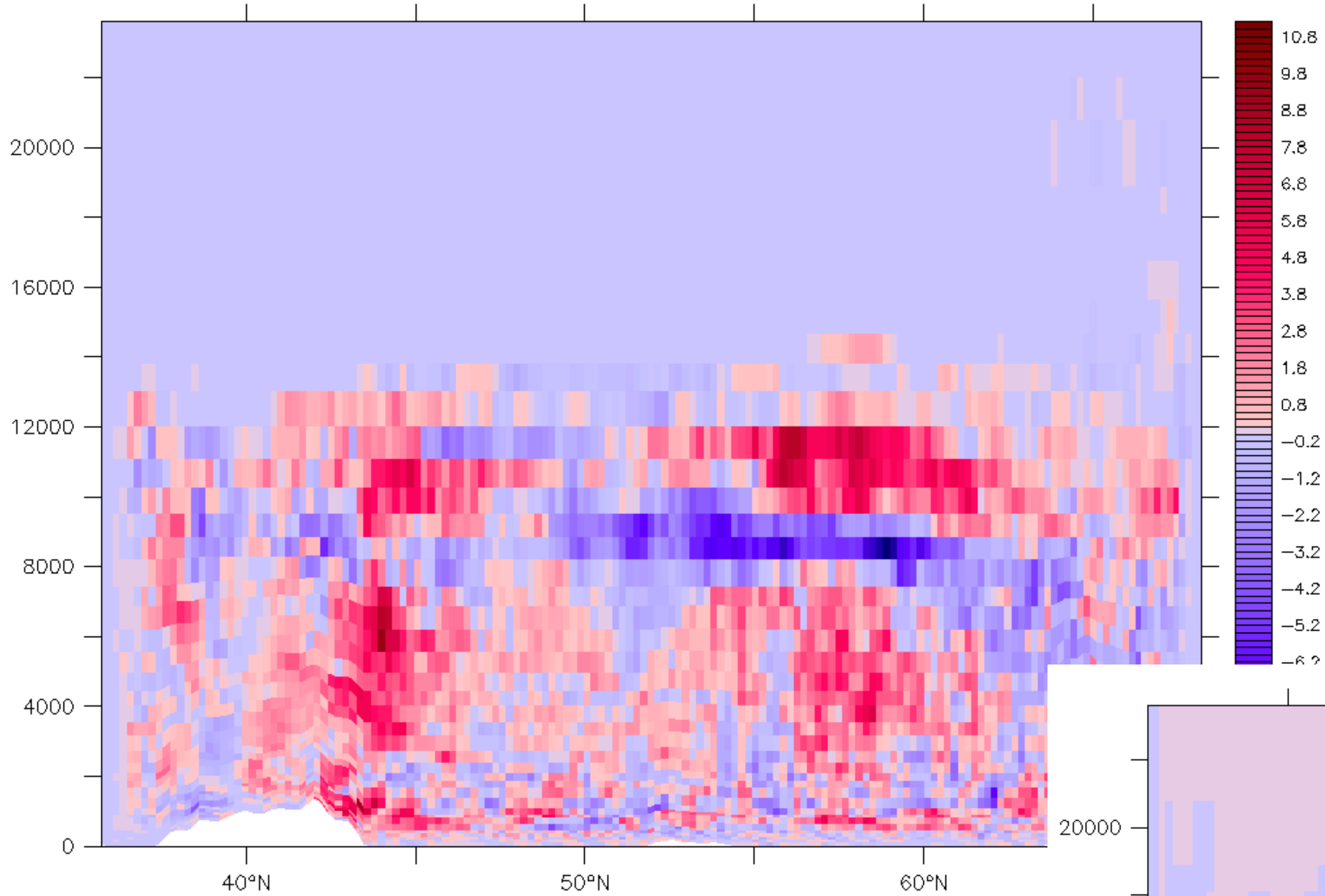
LAI, vegetation type, deep soil humidity and temperature

Vertical distribution

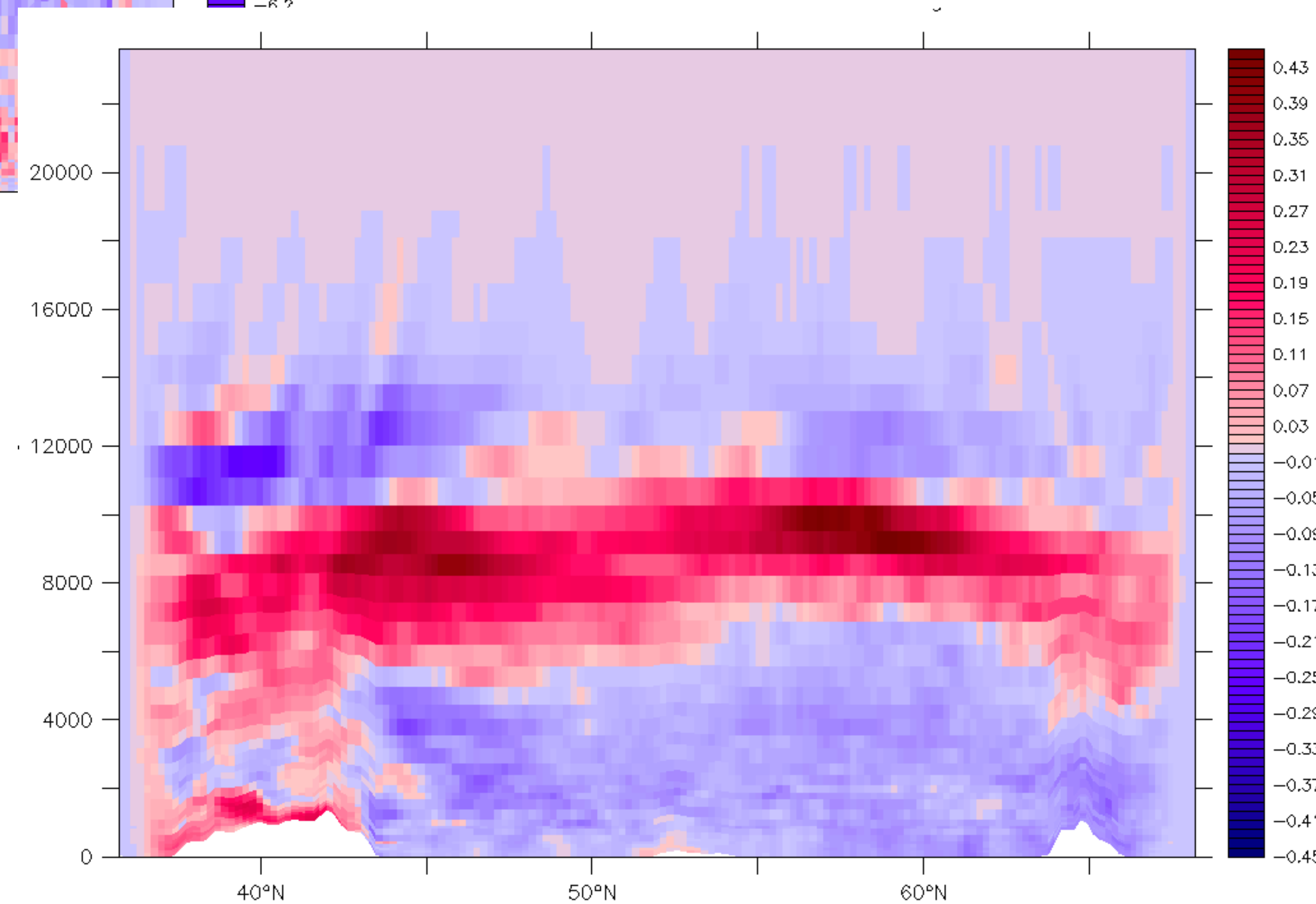


Absolute difference (in kg/kg) of ice mass between the the reference simulation and the simulation with contrails averaged on every model levels and for January 2005

Vertical slice



Absolute difference (in % of coverage) of high clouds (> 8km) between the reference simulation and the simulation including the contrail parameterization, averaged on january 2005



Absolute difference (in K) of the temperature between the reference simulation and the simulation including contrails averaged on January 2005

Next steps (2)

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Validation of cirrus clouds and contrails

- for the validation of contrails the data of (Meyer et al., 2002) covering the period 2000 to 2005 can be used
- The supersaturation in the model needs to be compared to satellite and other observational data

Quantification of impacts and sensitivity tests

- Quantification of the impact of aircraft induced cloudiness on the total cloud cover as well as the diurnal temperature range (DTR)
- Sensitivity test of cruise altitudes
- Influence of a warmer climate on the production of contrails

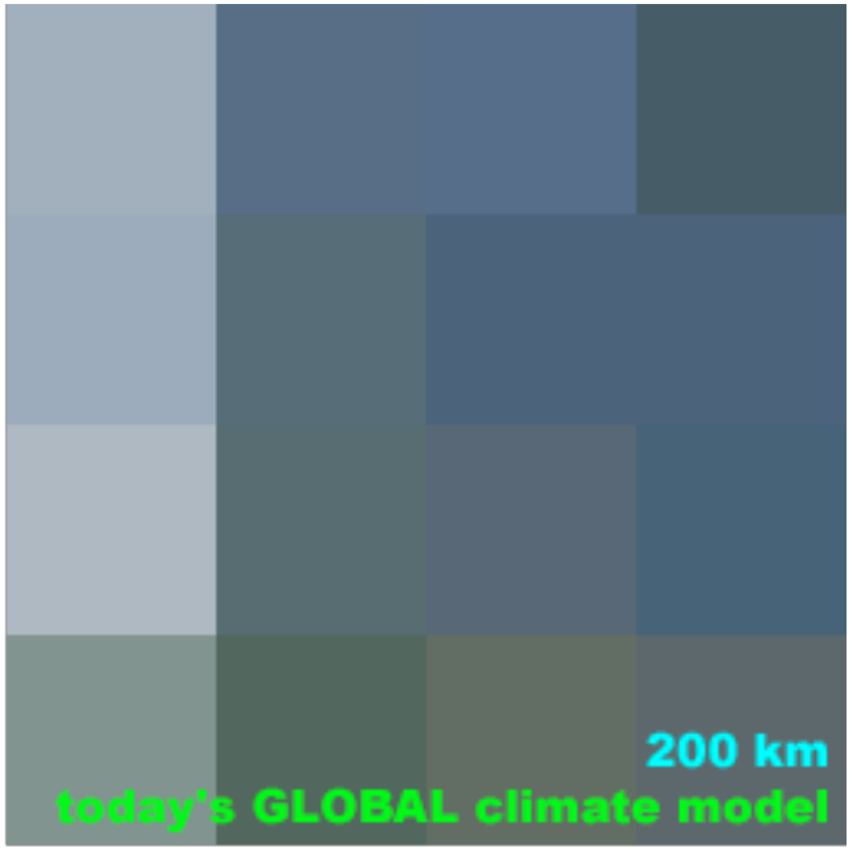
Why use a regional climate model?

Satellite Image

GCM

Source: presentation of B. Rockel (2007)

What about regional features ?



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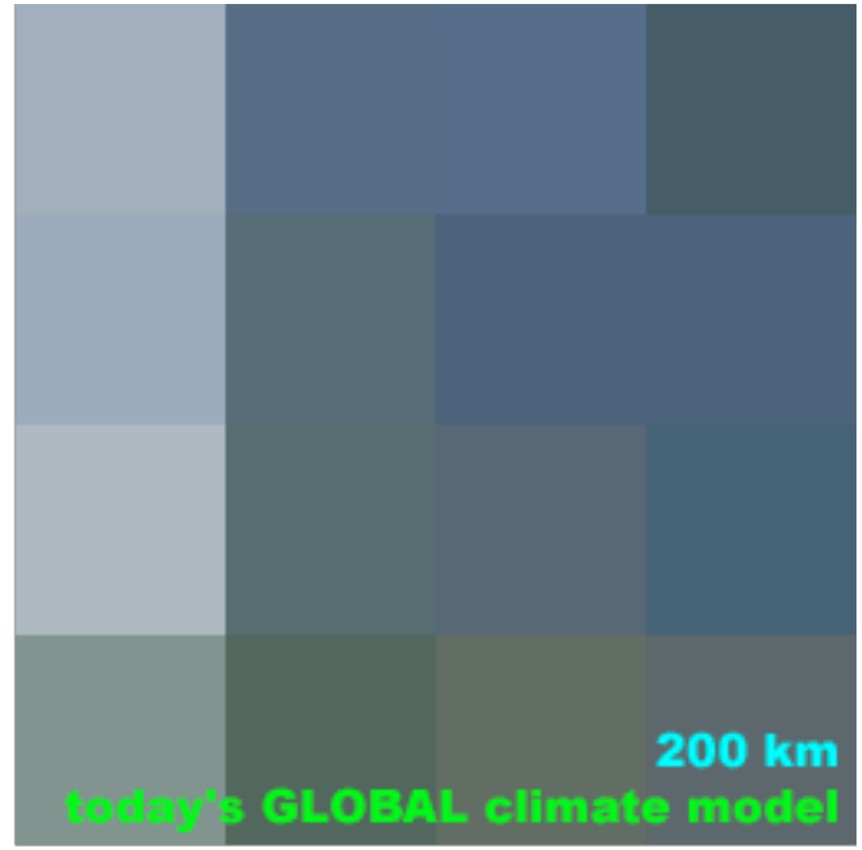

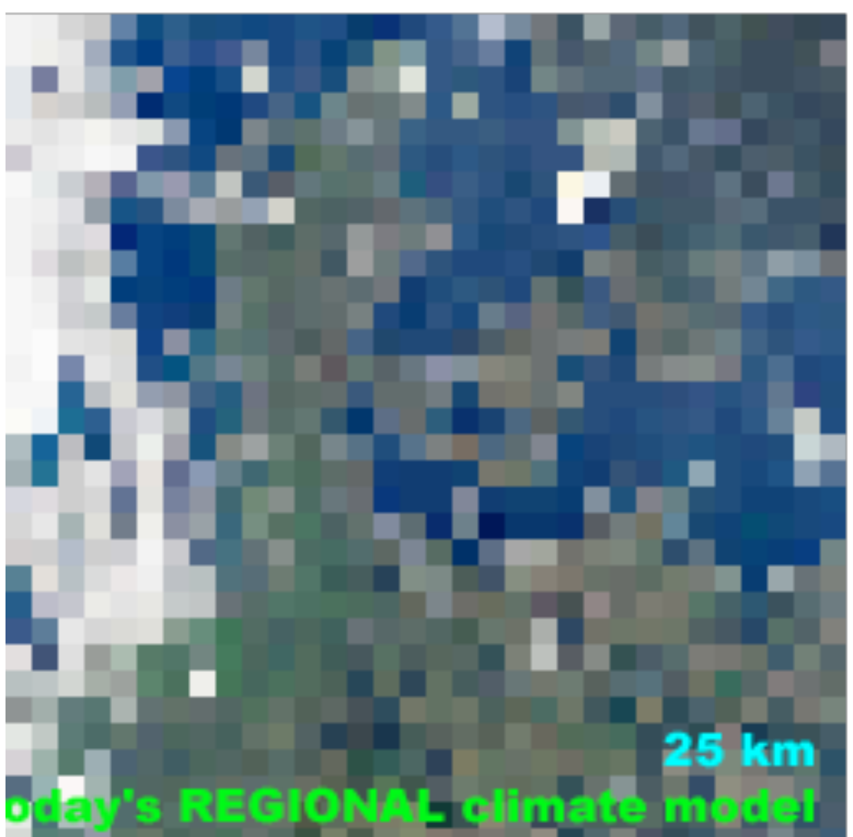

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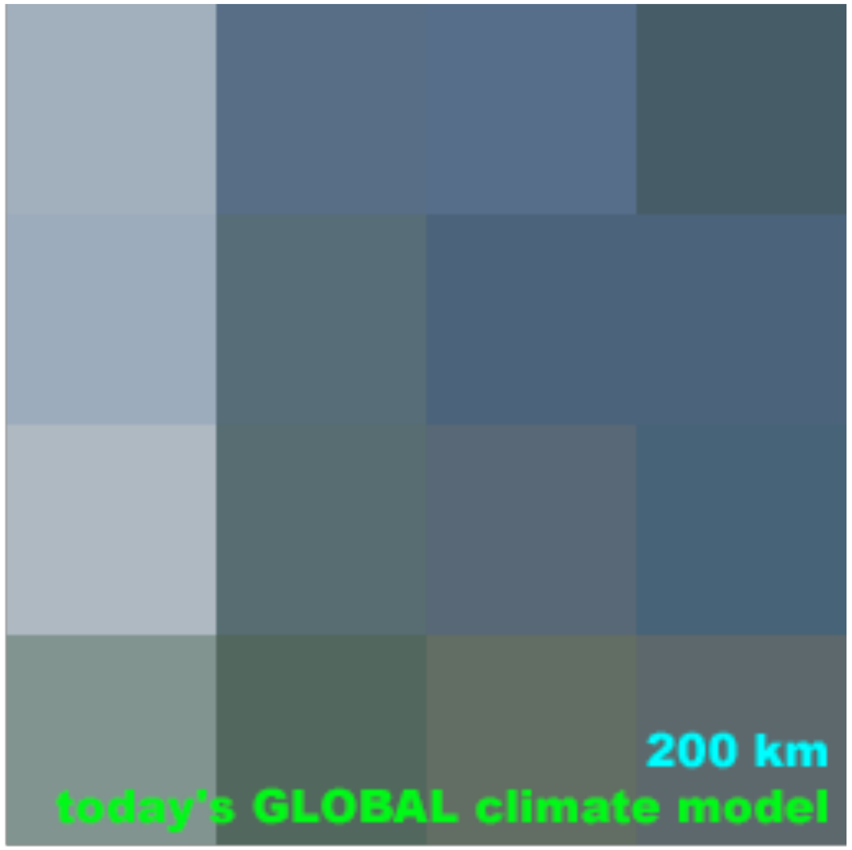

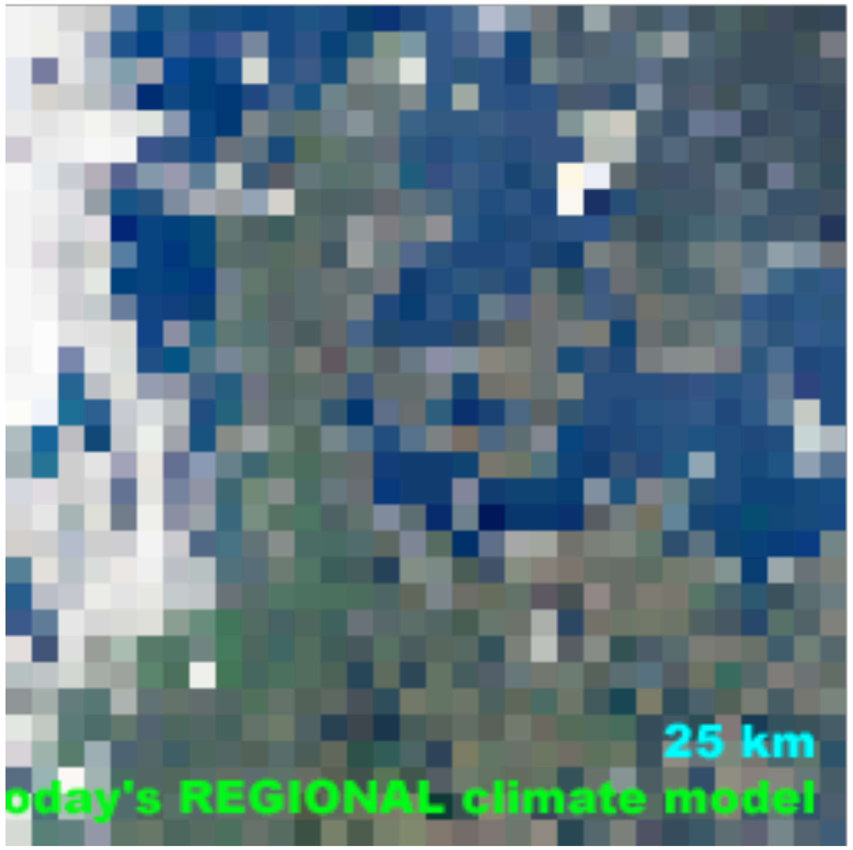

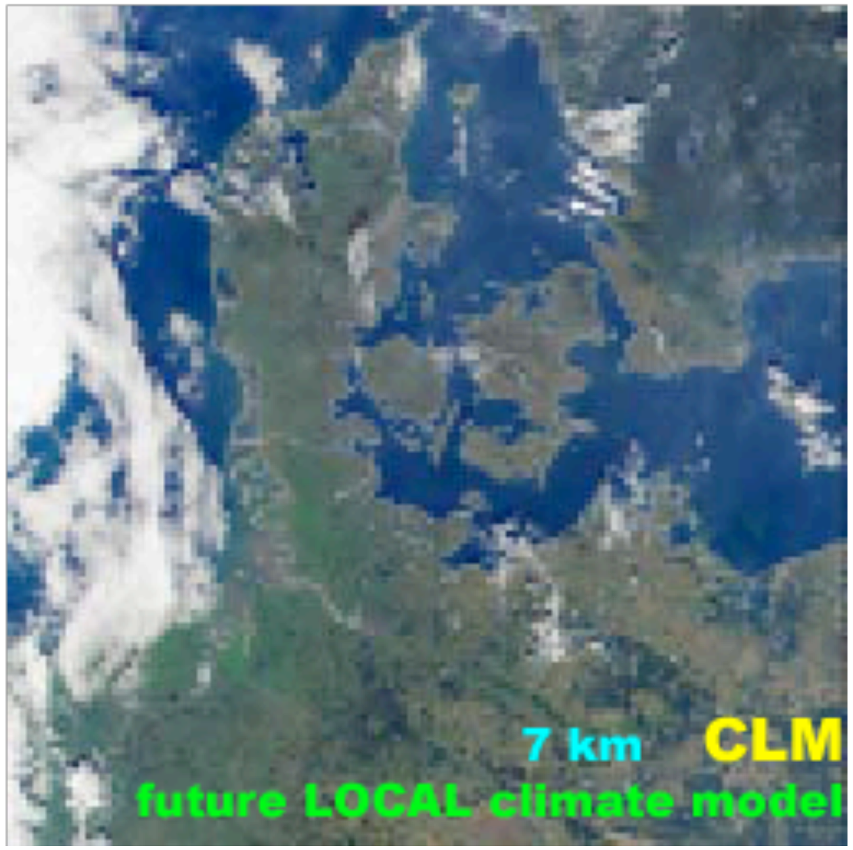

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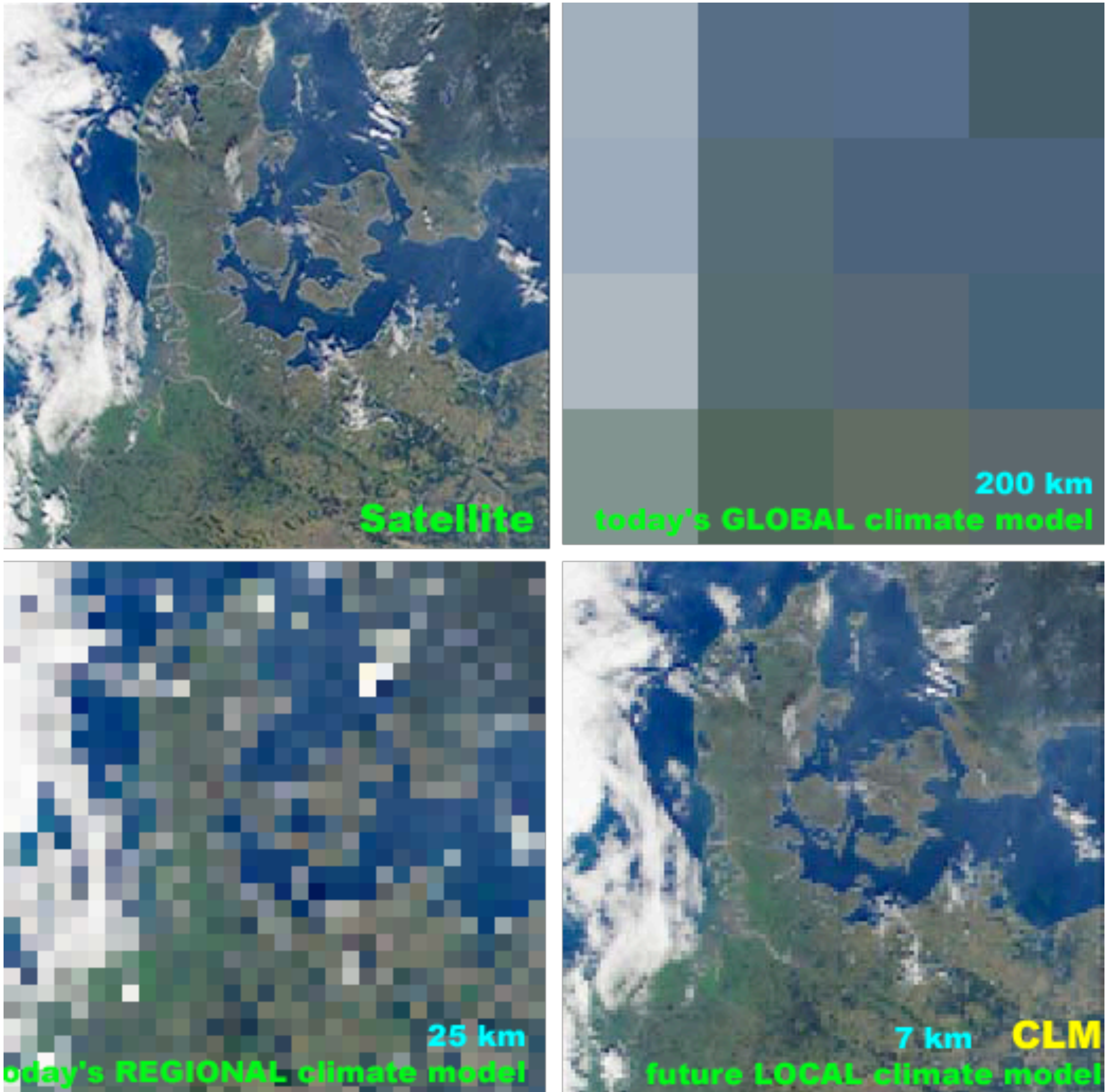

Source: presentation of B. Rockel (2007)

Differences between CLM and COSMO

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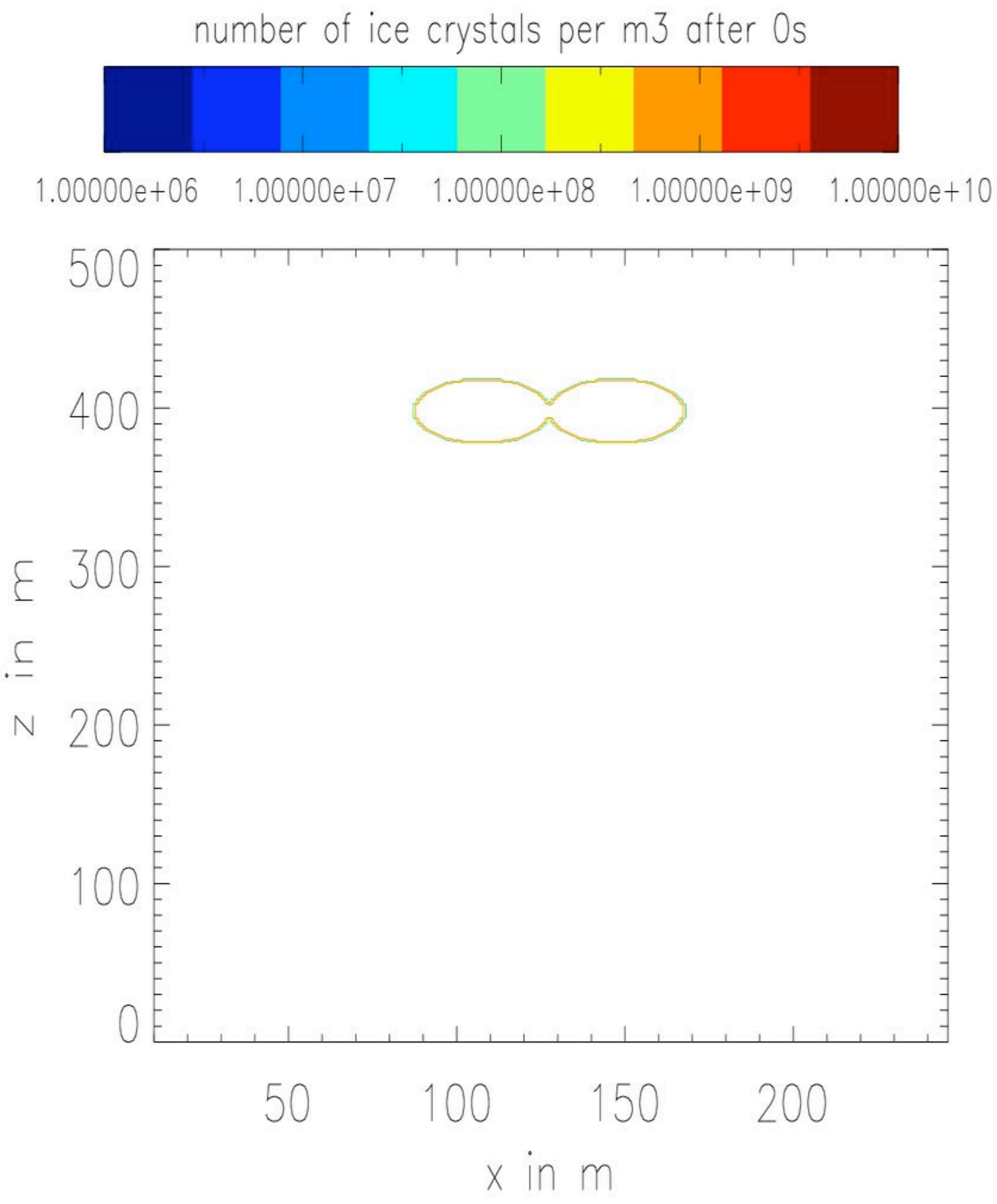
Le modèle climatique et le modèle de prévision numérique du temps (NWP) ont le même code avec des différences d'utilisation

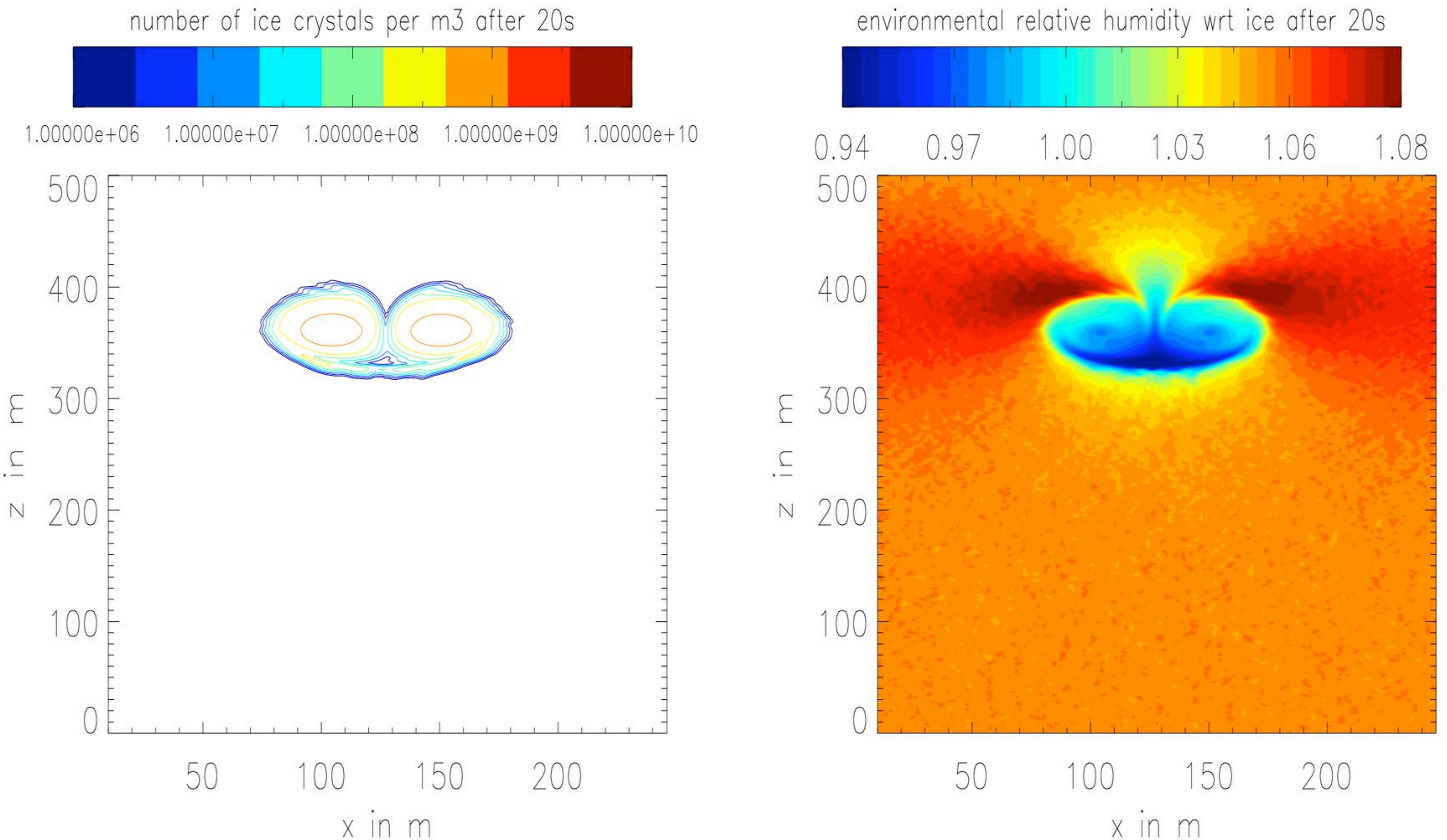
	Climate Mode	**NWP mode**
Time integration	up to100s of year	several days
Dependency on inital state	weak (after spin-up)	strong
assimilation of obs data	no	yes
vegetation, CO_2, ozone, SST	temporal variable, prescriped	constant
possibilty of restart	yes	no

Vortex regime



Numerical simulation with T=217K , Rhi=105% done by S. Unterstrasser et al. (2008)

Vortex regime



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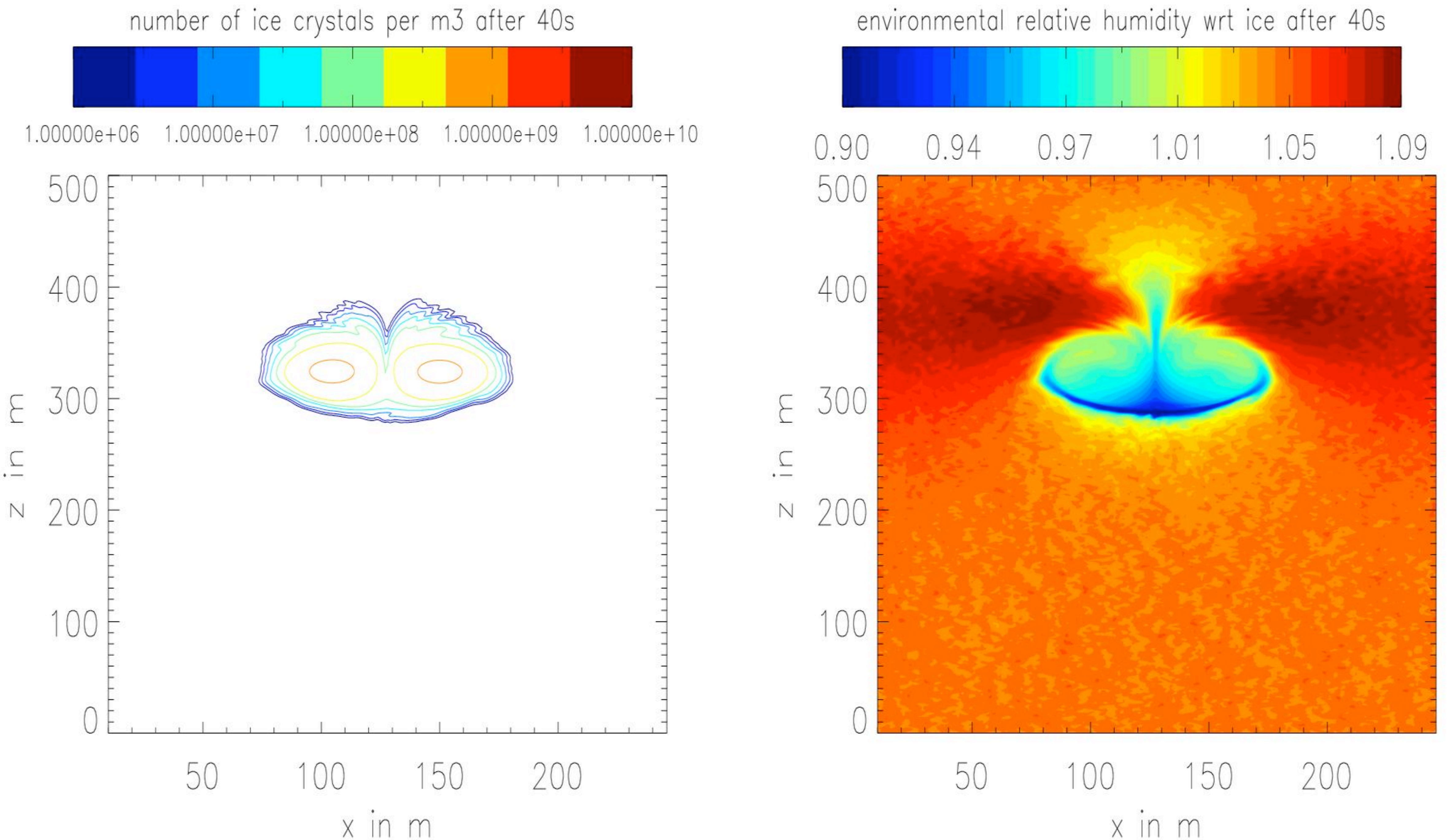
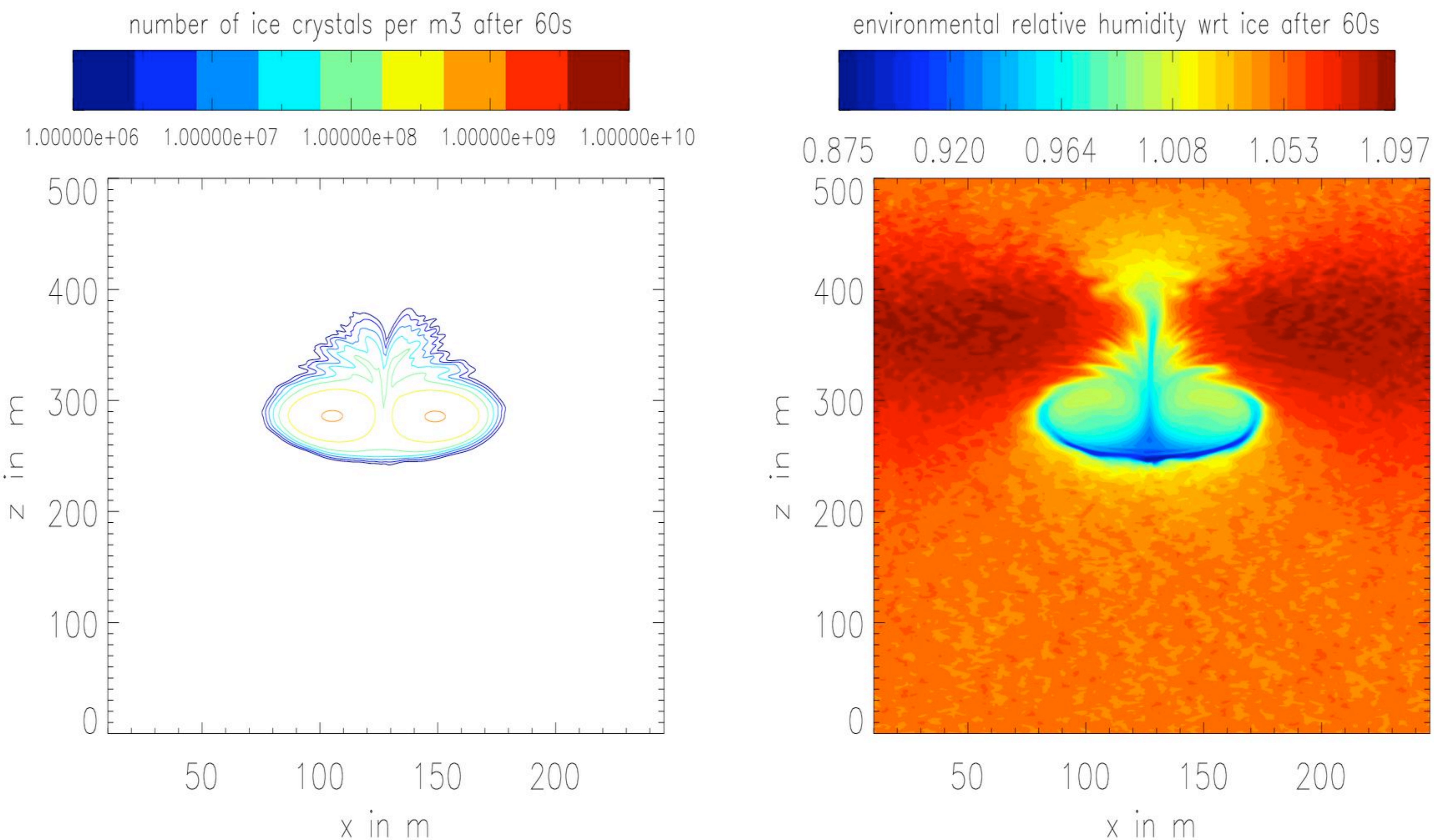


Numerical simulation with T=217K , Rhi=105% done by S. Unterstrasser et al. (2008)

Vortex regime



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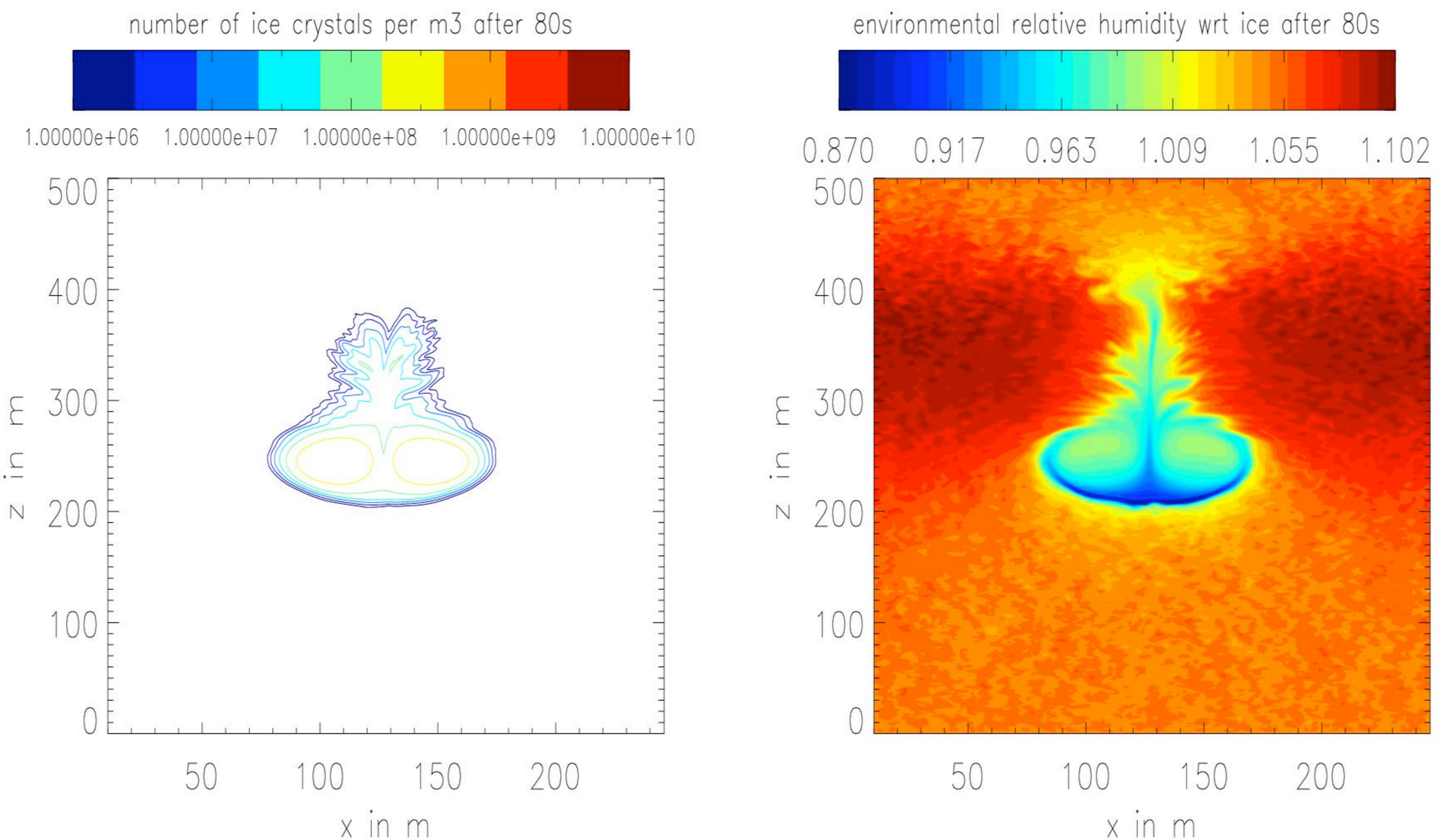
Vortex regime



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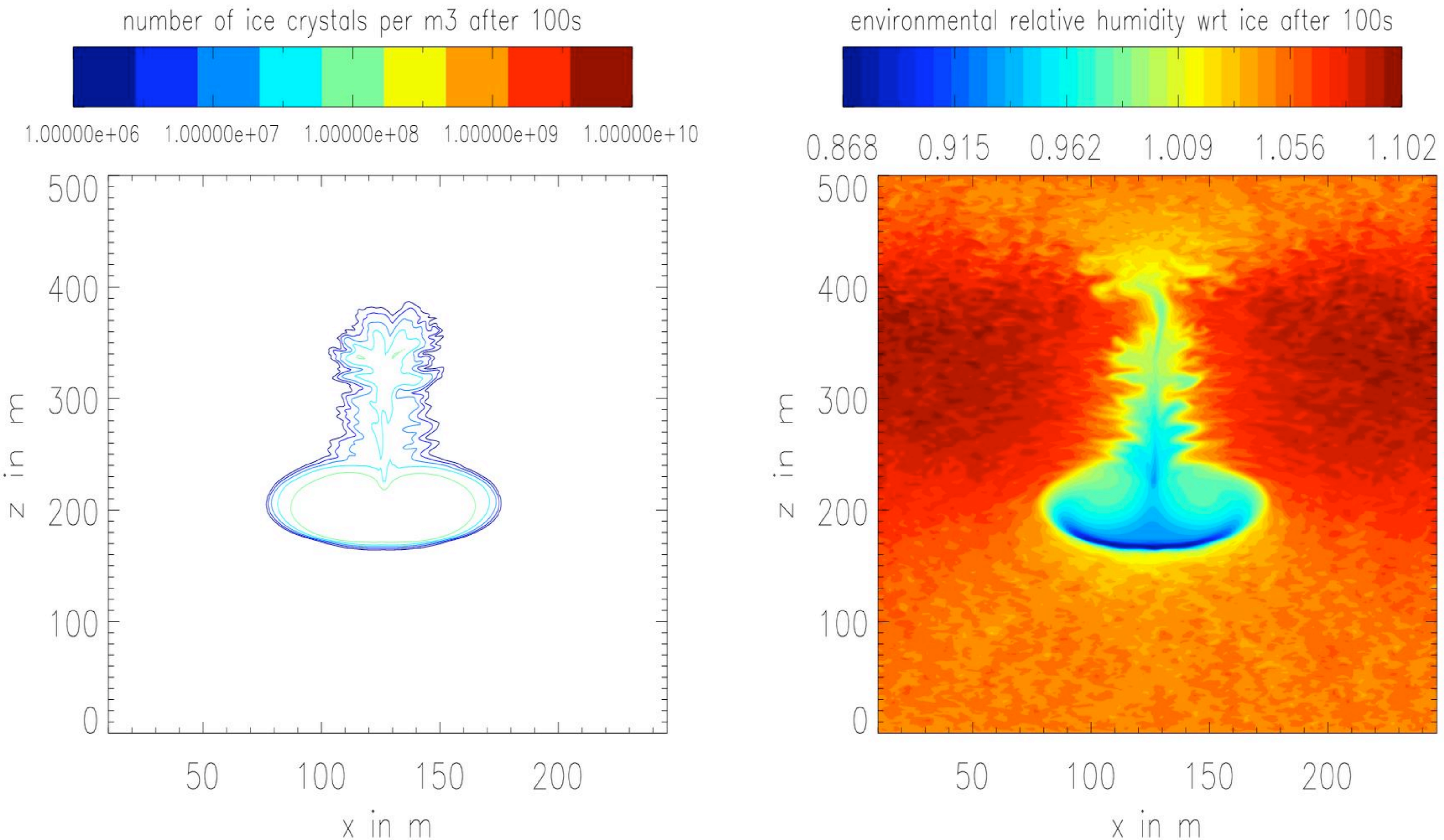
Vortex regime



Numerical simulation with T=217K , Rhi=105% done by S. Unterstrasser et al. (2008)

Vortex regime

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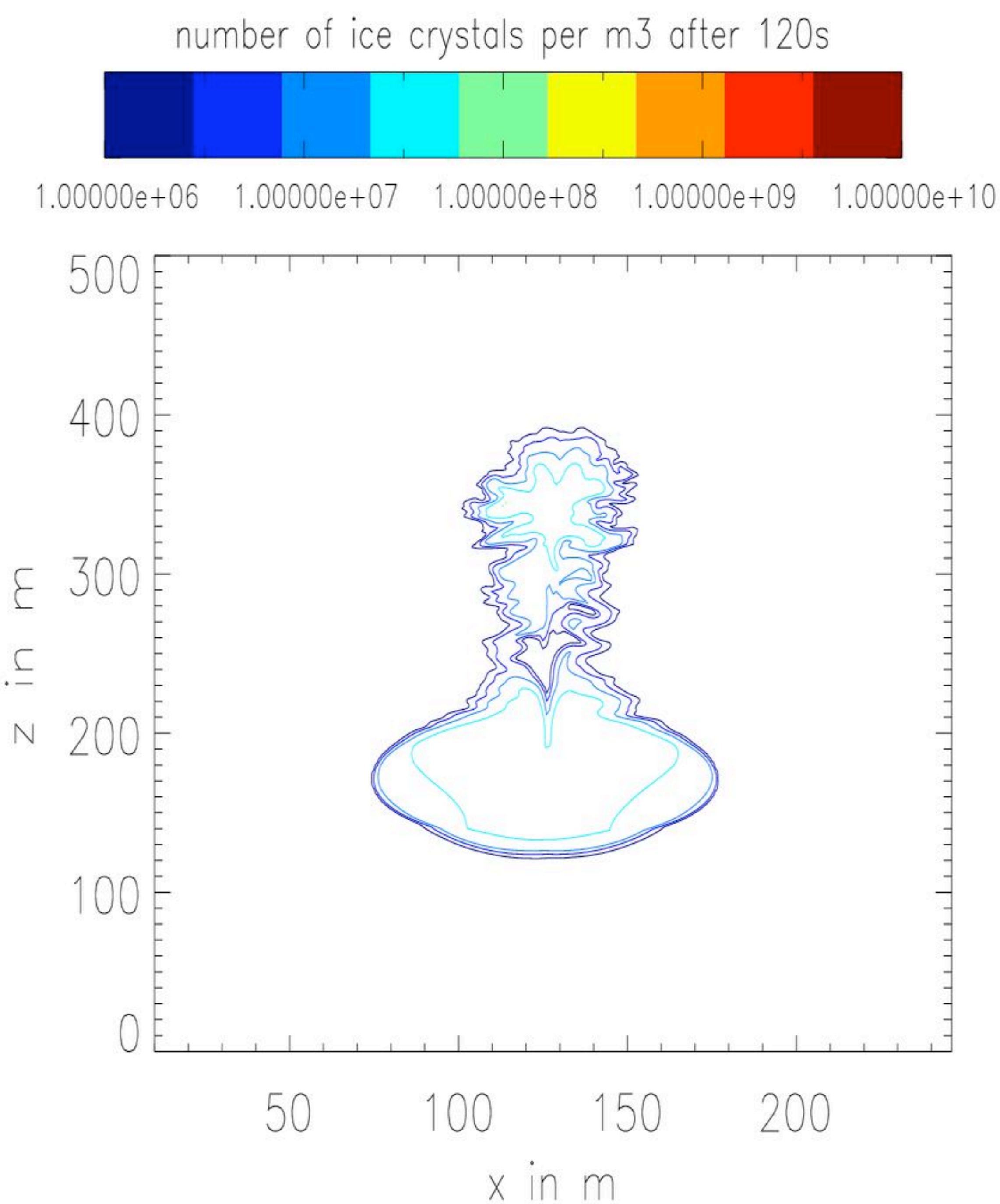

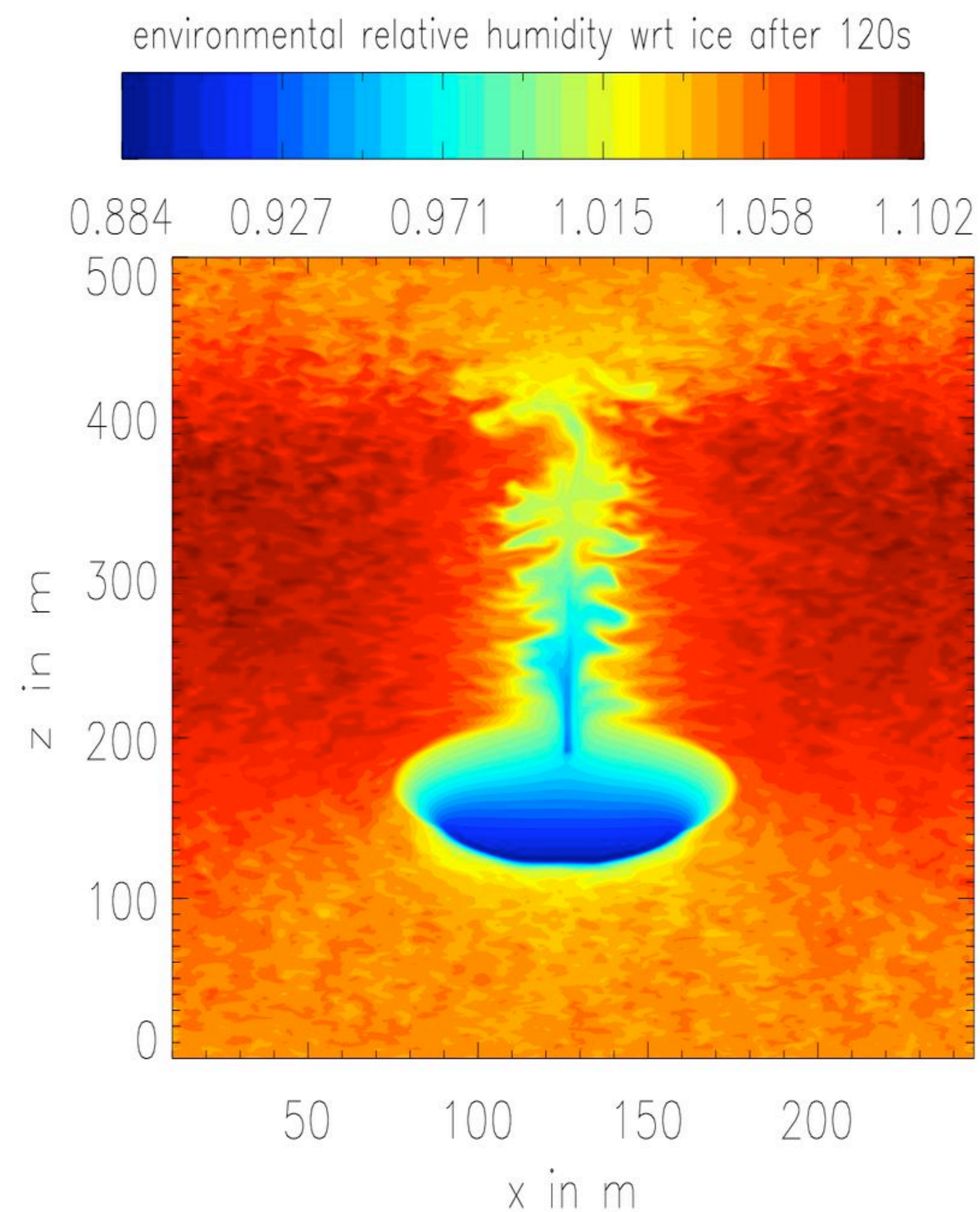

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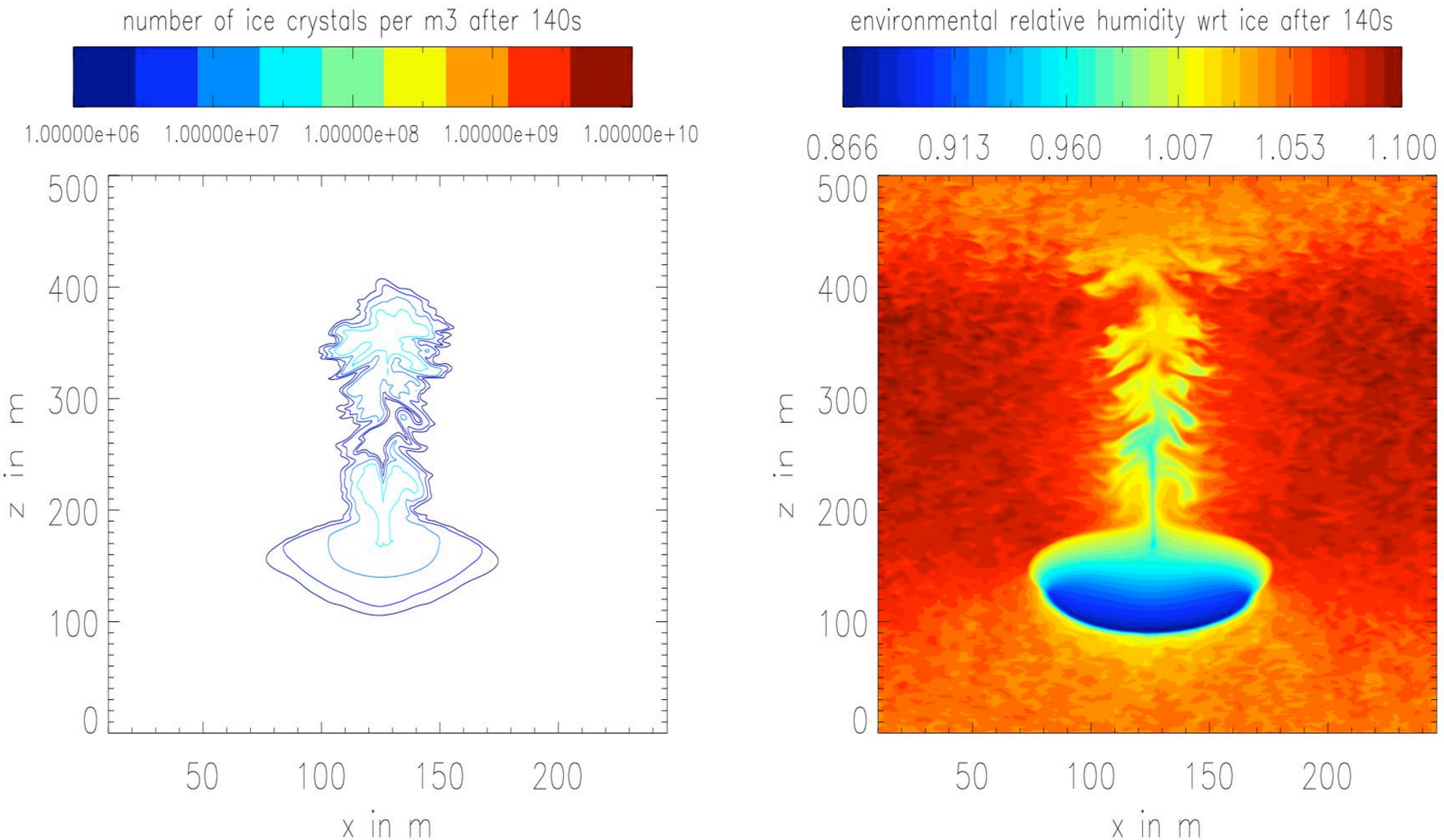
Vortex regime



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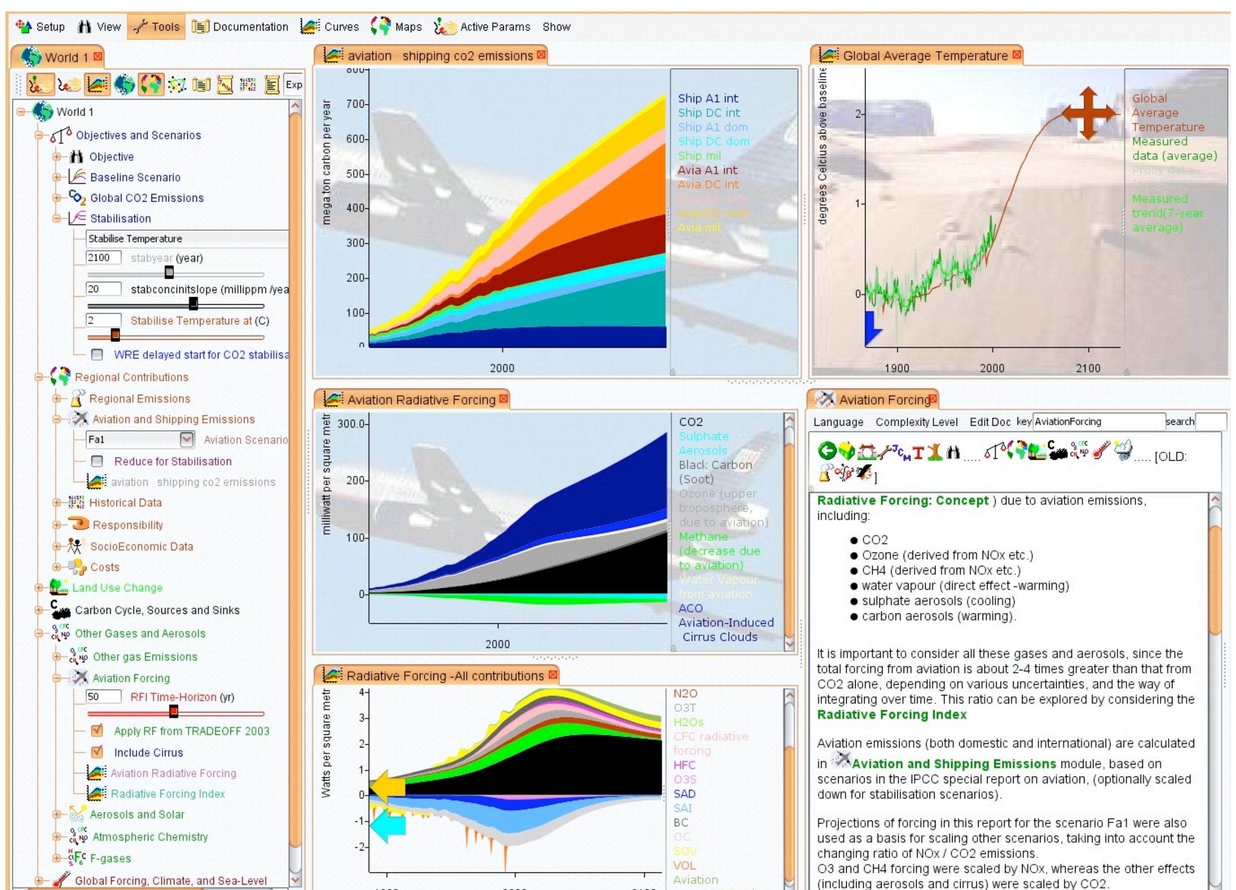
Main conclusions of first phase

One focus for Belgian policy makers could be to reduce the impacts from transit aviation, especially via operational measures targeting non-CO_2 gases, as well as shift to other transport modes.

In a scenario limiting global temperature rise to 2°C (EU policy), but with unmitigated aviation (Fa1), aviation (including CO2, ozone, cirrus etc.) adds about 15-20ppm CO_{2eq} in 2050

To compensate for this unmitigated aviation forcing, CO_2 emissions from all other sectors must be about 30% lower in 2050, in order to reach the 2°C target.



http://www.climate.be/abci