Impact of cirrus clouds on tropopause structure and tracer distributions

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Outline

- Motivation
  - Stratosphere-Troposphere exchange (STE)
  - STE and cyclones
  - Cirrus clouds
- Input data and EULAG setup
- First Results
  - Reference case
  - Influence of updraught velocity
- Conclusion and Outlook

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Stratosphere-**T**roposphere **E**xchange (STE)

Exchange of air masses through tropopause plays important role for chemical composition of stratosphere and troposphere, e.g.

- **STT** ↓ (**S**tratosphere-to-**T**roposphere **T**ransport) can enhance ozone concentration in troposphere.
- **TST** ↑ (**T**roposphere-**S**tratosphere-**T**ransport) can increase the amount of water vapour in the stratosphere.

STE occurs in different meteorological environments, such as:

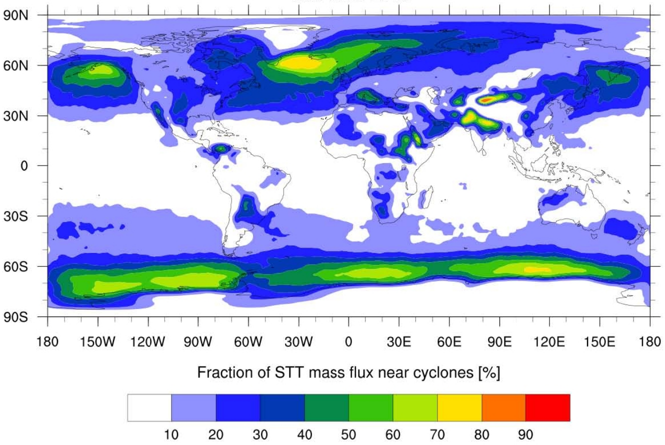
- tropopause-level jet stream
- overshooting deep convective systems
- tropopause folds connected to extra-tropical cyclones

STE and cyclones I

- Until now only case studies of STE events connected to a cyclone are published (e.q. Lamarque & Hess (1994), Bourqui (2006)).
- Hence, to investigate the influence of cylcones on STE events a 20 year climatology of STE in the vicinity of cyclones was obtained (Uni Mainz, ETH Zurich)
- 20 years of ERA-Interim data
- Research question: how many STE events are associated with cyclones compared to all STE events?

STE and cyclones II

In the vicinity of cyclones an increased exchange of air masses through the tropopause can be observed (here: STT).



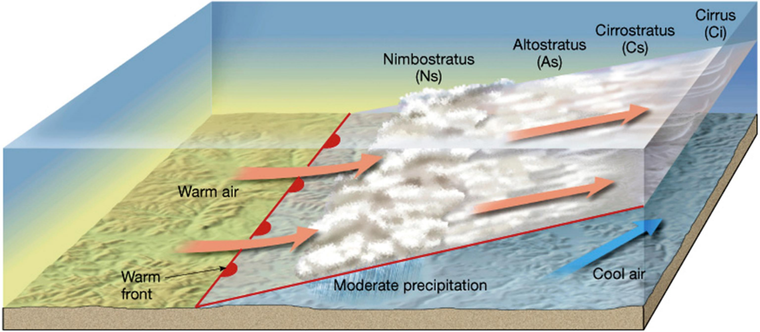
Data obtained by a 20-year climatology using backward trajectories, by B. Skerlak, ETH Zurich

STE and cyclones III

Warm front is the first sign of an approaching low pressure system, with cirrus clouds as first visible sign.

Warm front

Source: Lutgens and Tarbuck, 2004



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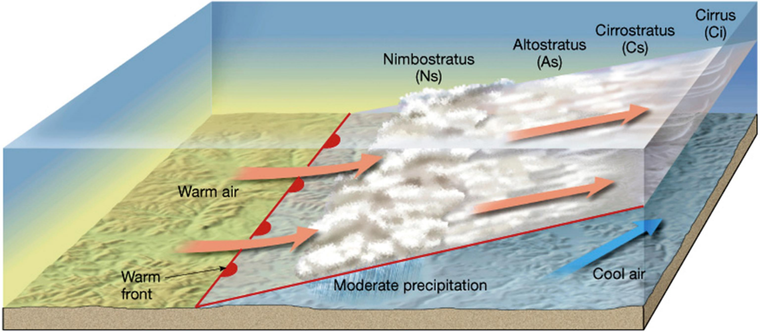


- Question: How do cirrus clouds influence the tropopause region?

Cirrus clouds I

- Cirrus clouds are purely made of ice crystals
- High internal variability of microphysical and thermodynamic properties leading to *patchiness* of cirrus clouds

Cirrus clouds II

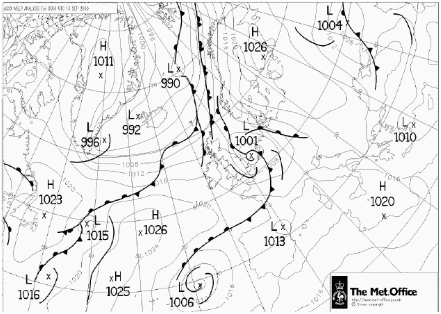
Cirrus clouds are an important factor in the Earth's climate system.

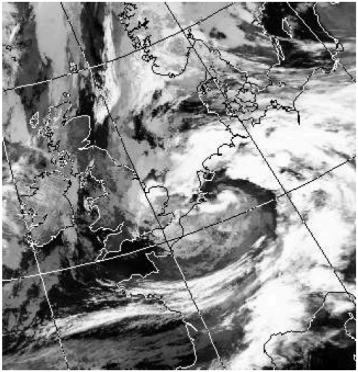
- Changing of the radiation budget
  - they scatter / reflect incoming solar radiation
  - they absorb thermal radiation from Earth's surface
- Modification of the chemical composition of the tropopause region
- Modification of the water budget in the upper troposphere.
  - regulating the humidity of air entering the stratosphere

Low pressure system

Find suitable boundary conditions for idealized EULAG simulations.

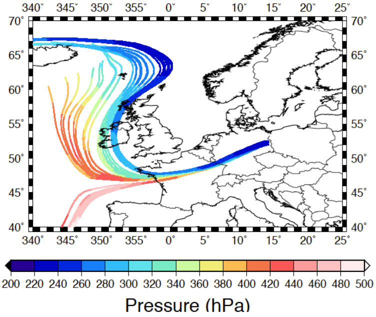
- weak low pressure system over central Europe (16 Sept 2000).
- warm front extends from southern Denmark to Czech Republic.

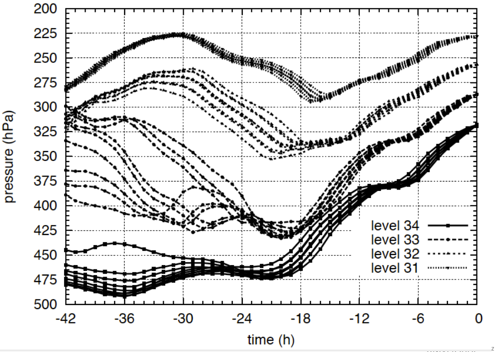




backward trajectories

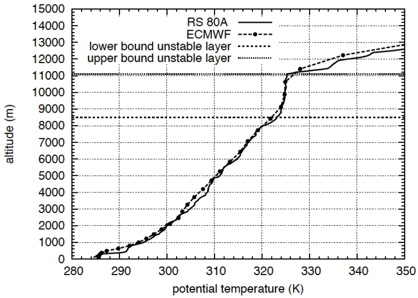
- main flow dominated by low pressure system
- equal flow in different levels
- ascending trajectories for the last 18 hrs
- median updraught: $w = 0.03\,\mathrm{m\,s^{-1}}$
- behaviour of a lifted layer

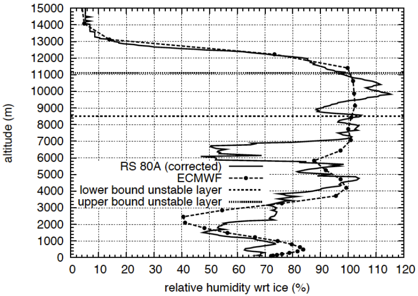




vertical profiles

- vertical profiles obtained from
  - radiosonde data (Lindenberg, Germany)
  - ECMWF data
- ice supersaturated region (ISSR) close to the tropopause

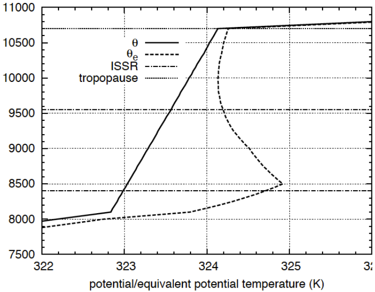




stability

- Potentially stability is important for lifting of whole layers

$$\frac{\partial \theta_{eq}}{\partial z} \begin{cases} > 0 & \text{potentially stable} \\ = 0 & \text{potentially neutral} \\ < 0 & \text{potentially unstable} \end{cases}$$



- Potentially unstable layer and ISSR close to the tropopause

EULAG setup I

- 2D model simulation in the x-z-plane.
  - horizontal extension: $L = 51.1\,\mathrm{km}$
  - horizontal resolution: $\Delta x = 100\,\mathrm{m}$
  - vertical extension: $4 \leq z \leq 14\,\mathrm{km}$
  - vertical resolution $\Delta z = 50\,\mathrm{m}$

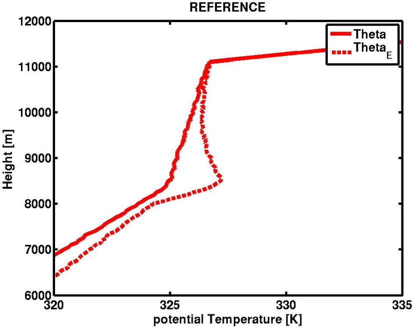
- total simulation time: $t_{tot} = 400\,\mathrm{min}$
  - dynamical time step: $\Delta t = 1\,\mathrm{s}$
  - optional microphysical time step: $\Delta t_{mp} = 0.1\,\mathrm{s}$

- two moment bulk microphysical scheme (Spichtinger and Gierens, 2009):
  - number concentration of sulfuric acid droplets: $n_a = 300\,\mathrm{cm}^{-3}$
  - homogeneous ice crystal nucleation, diffusional growth/evaporation and sedimentation.

EULAG setup II

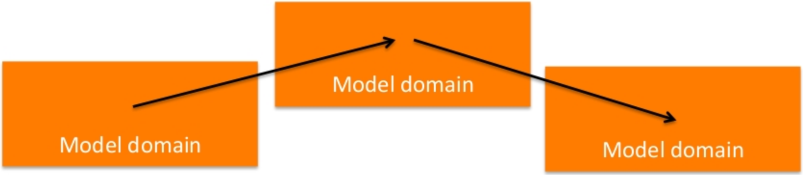
Initialization of the model:

- realistic case of a potentially unstable layer near the tropopause
- Θ is superimposed by a Gaussian noise ($\sigma = 0.05\,\mathrm{K}$)
- constant background horizontal wind shear
- no radiation



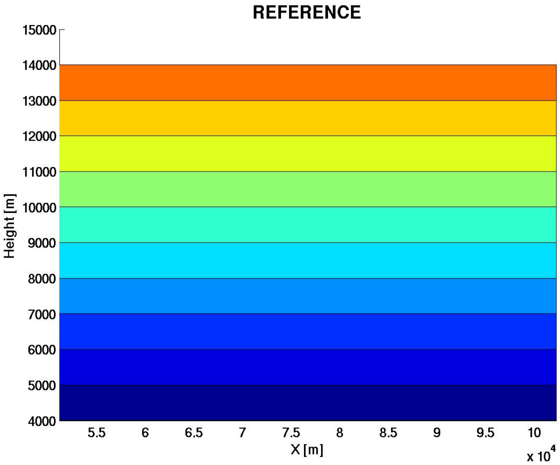
EULAG setup III

- Idealized warm front is simulated by lifting the complete model domain with a synoptic updraught of $0.03\,\mathrm{m\,s^{-1}}$
- After $t = 200\,\mathrm{min}$ the model domain descents with a velocity of $-0.03\,\mathrm{m\,s^{-1}}$



REFERENCE CASE

To visualize the vertical mixing, the model is initiated with a height dependent passive tracer



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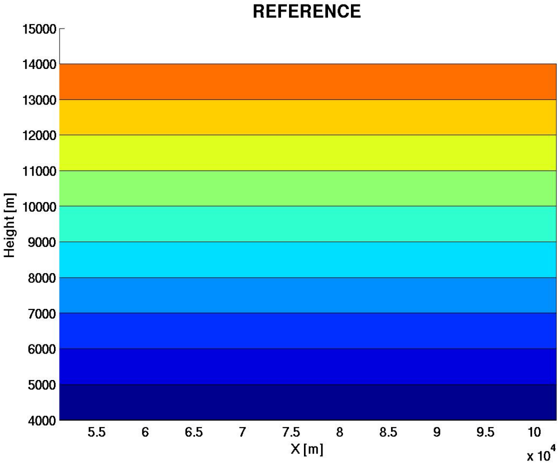
t= 000 min, black isolines: Ice water content, colour: Tracer



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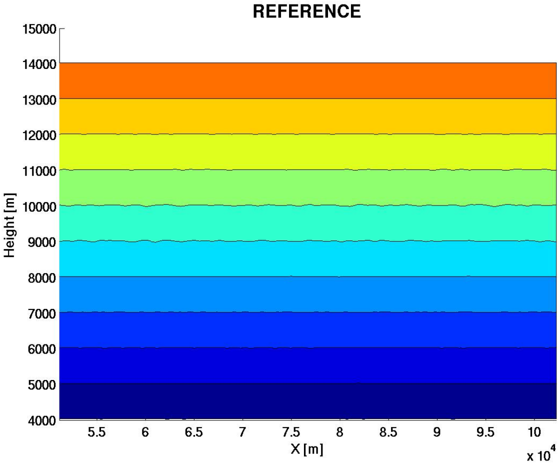

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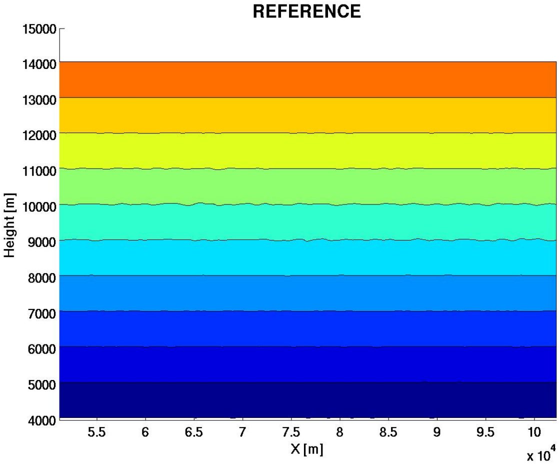
t= 033 min, black isolines: Ice water content, colour: Tracer



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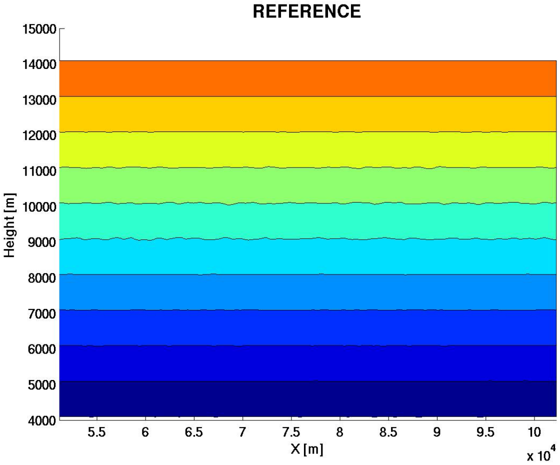

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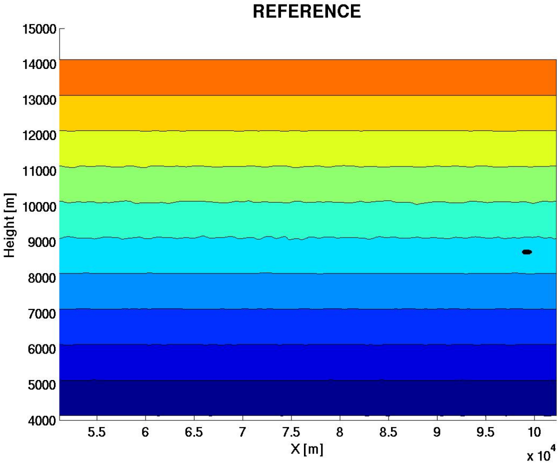

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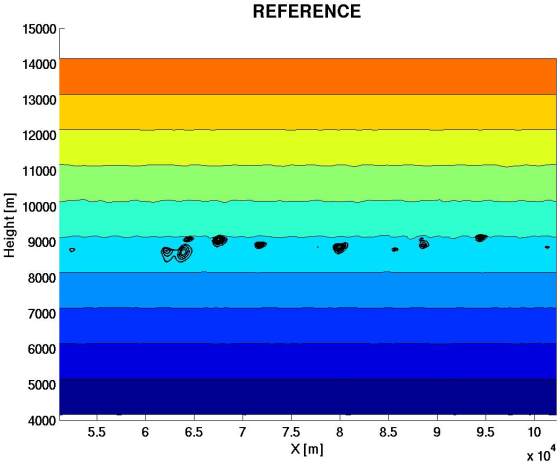
REFERENCE CASE

t= 082 min, black isolines: Ice water content, colour: Tracer



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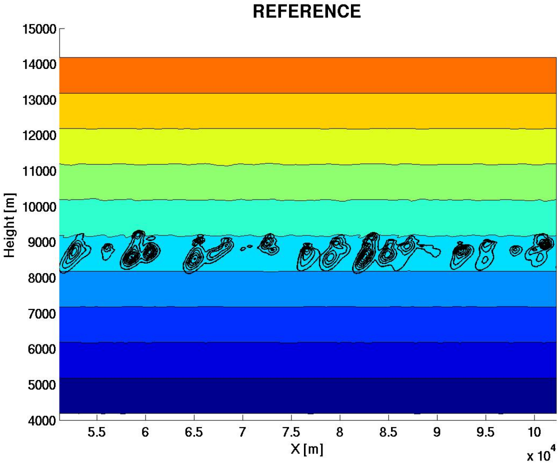
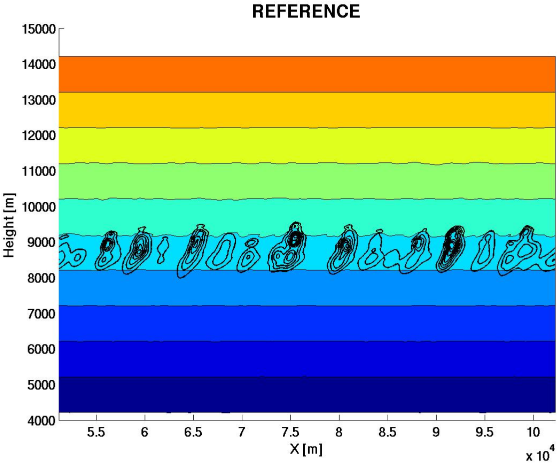
t= 099 min, black isolines: Ice water content, colour: Tracer



REFERENCE CASE

t= 115 min, black isolines: Ice water content, colour: Tracer



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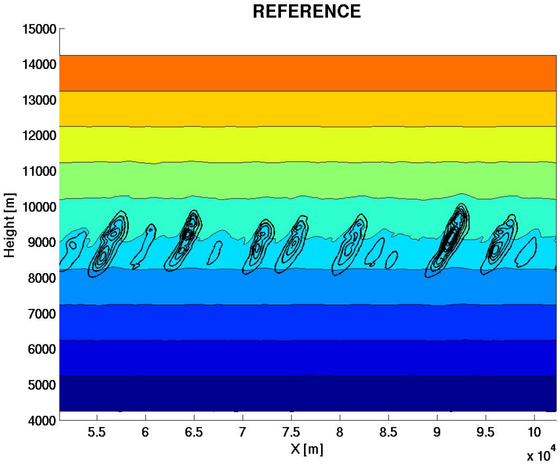
t= 132 min, black isolines: Ice water content, colour: Tracer



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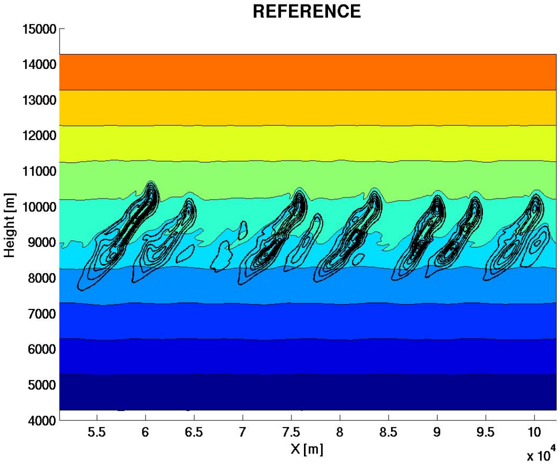
t= 148 min, black isolines: Ice water content, colour: Tracer



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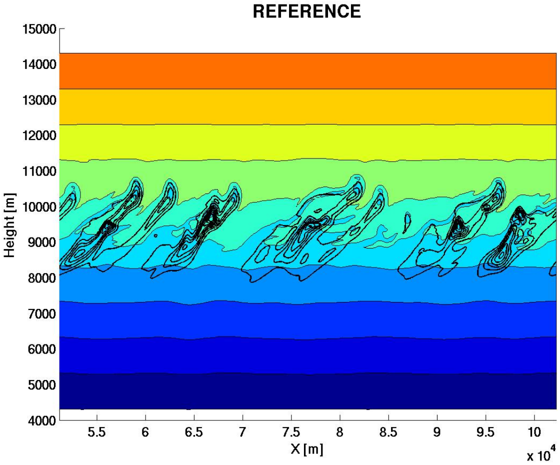
t= 165 min, black isolines: Ice water content, colour: Tracer



REFERENCE CASE

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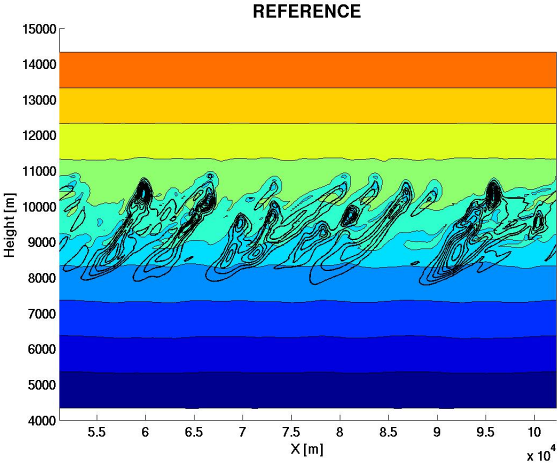

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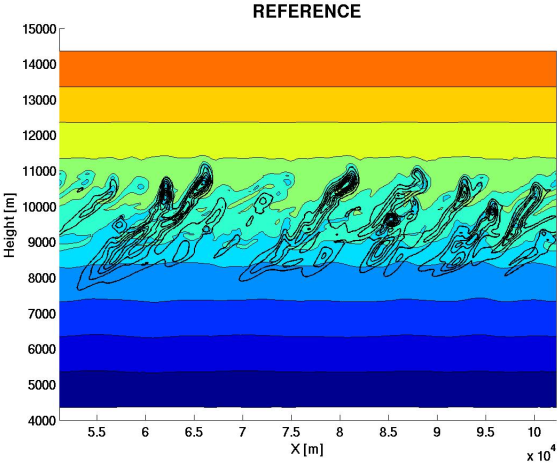
t= 200 min, black isolines: Ice water content, colour: Tracer



REFERENCE CASE

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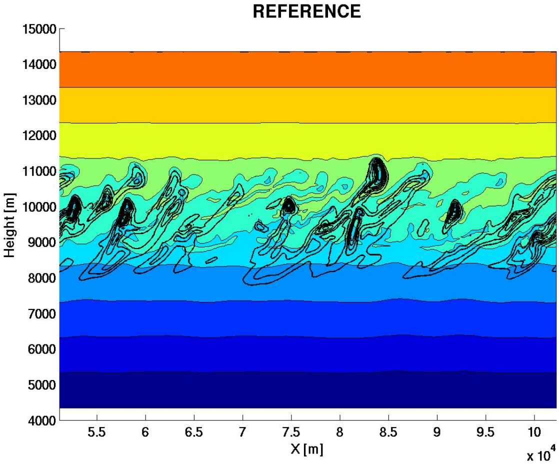

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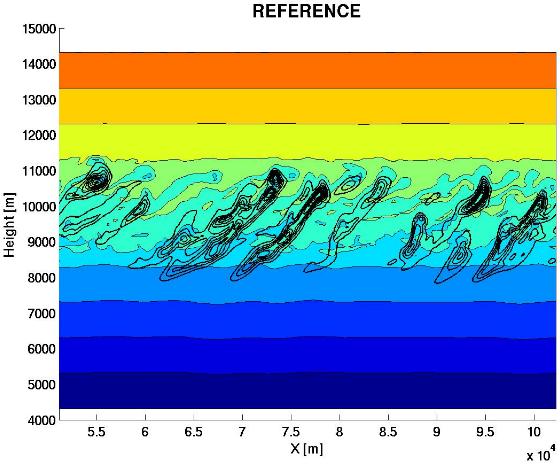

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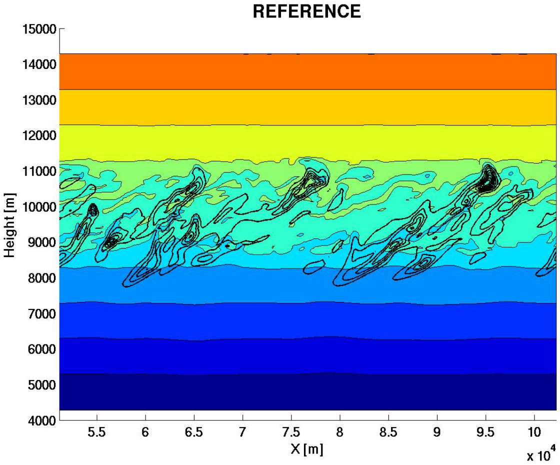
t= 249 min, black isolines: Ice water content, colour: Tracer



REFERENCE CASE

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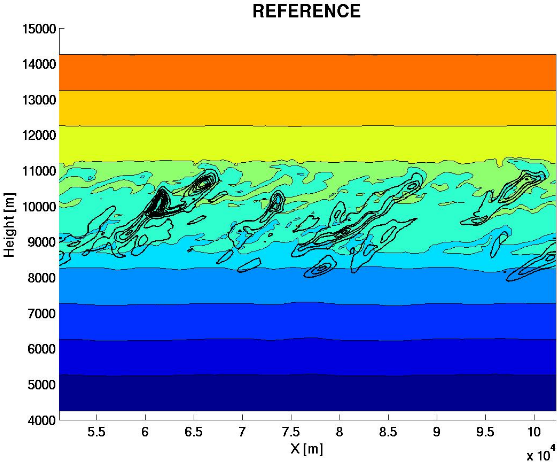

REFERENCE CASE

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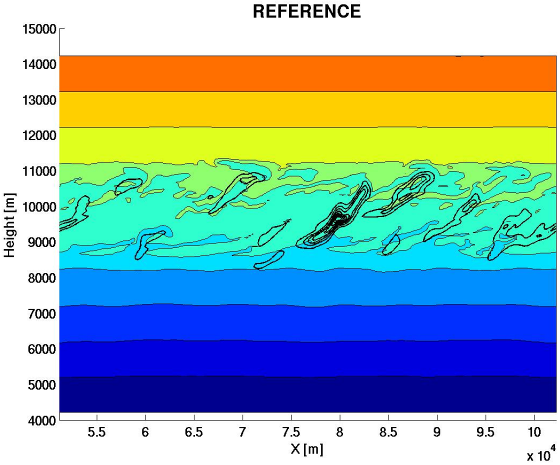

REFERENCE CASE

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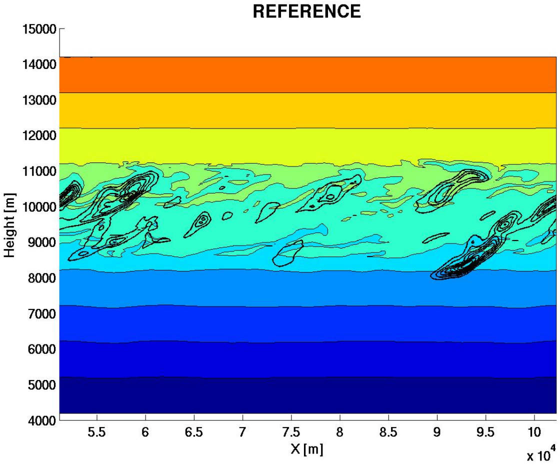

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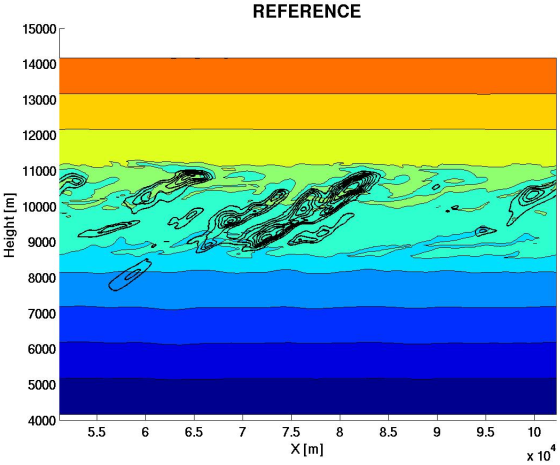
REFERENCE CASE

t= 315 min, black isolines: Ice water content, colour: Tracer



REFERENCE CASE

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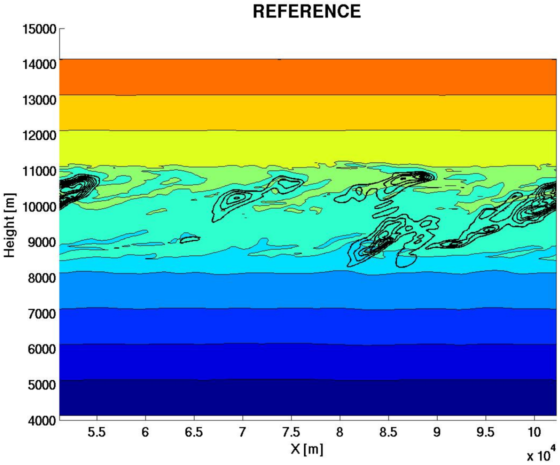

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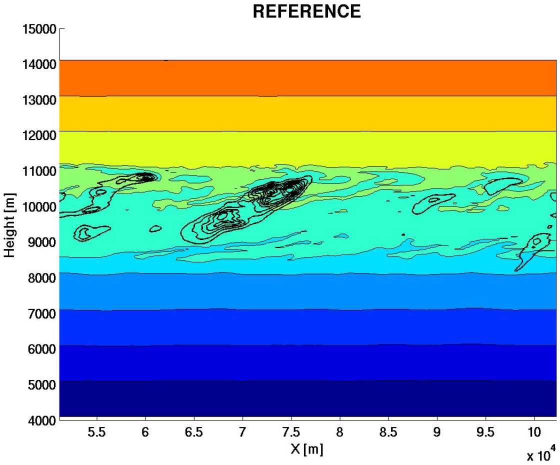

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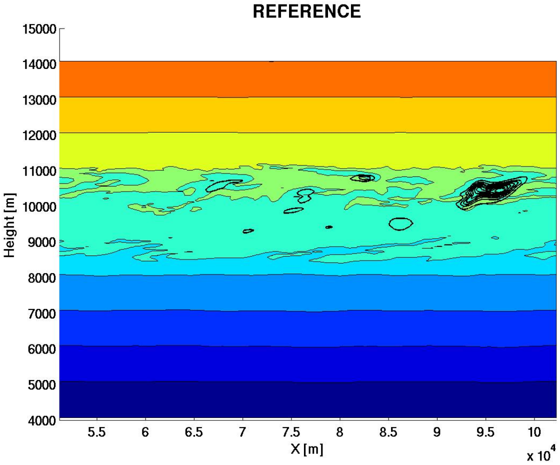
t= 365 min, black isolines: Ice water content, colour: Tracer



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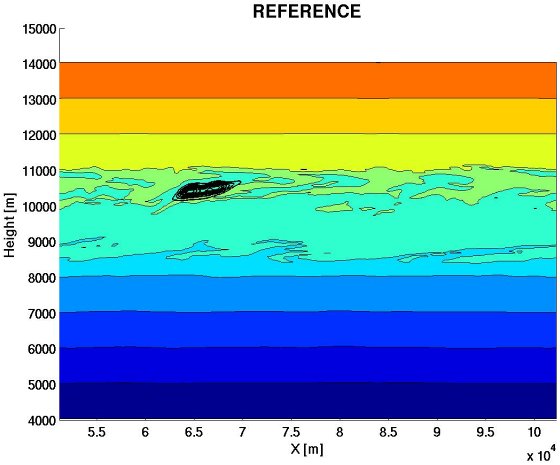
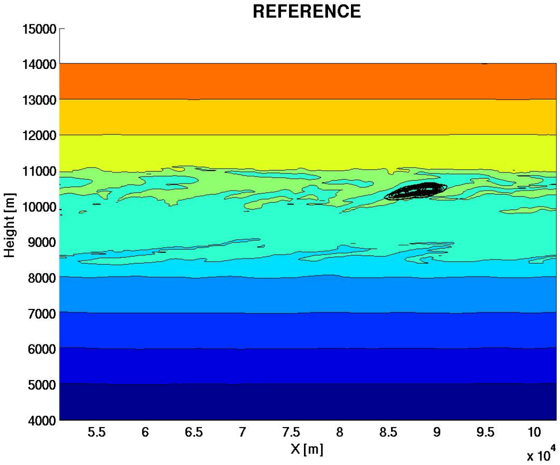


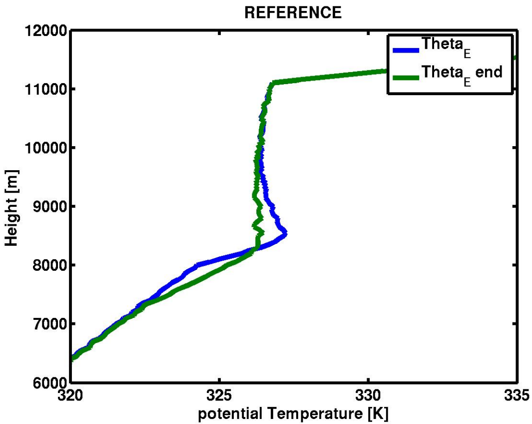
REFERENCE CASE

t= 400 min, black isolines: Ice water content, colour: Tracer



equivalent potential temperature (horizontally averaged)

- potentially unstable layer is transformed into a potentially neutral layer
- no changes in tropopause height and sharpness



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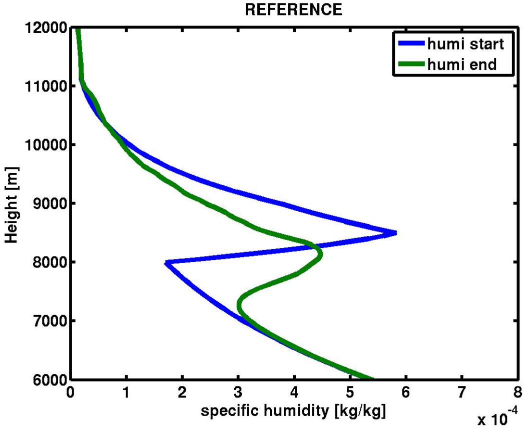
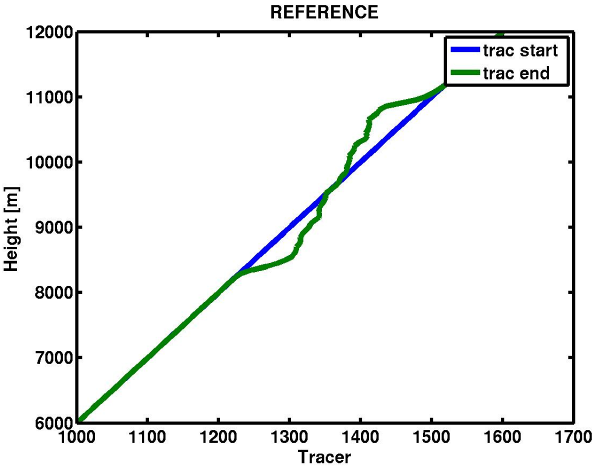
specific humidity (horizontally averaged)

- humidity is brought into lower layers of the atmosphere
- air becomes drier close to the tropopause



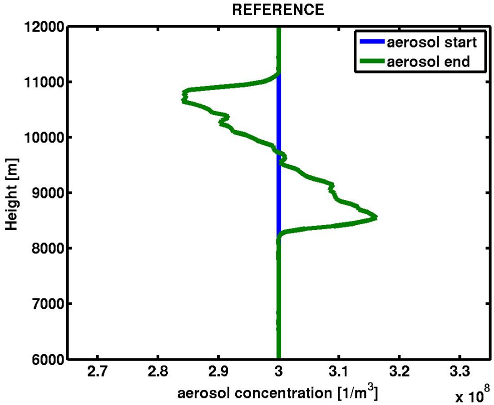
tracer distribution (horizontally averaged)

- lower air layers are mixed into higher regions and vice versa



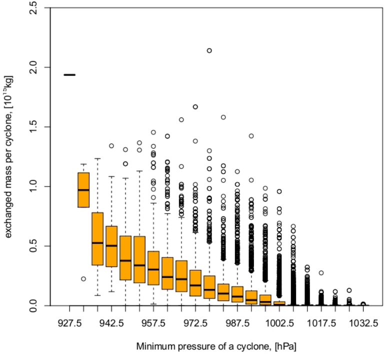
aerosol concentration (horizontally averaged)

- aerosol concentration close to the tropopause is reduced and increased in the lower parts due to mixing



INFLUENCE OF UPDRAUGHT VELOCITY

Exchanged mass per cyclone is increasing with decreasing minimum pressure of a cyclones lifetime



- 20 years of cyclone and STE data of the northern hemisphere extra tropics (here: STT)
- more intense cyclones often show a rapid development

INFLUENCE OF UPDRAUGHT VELOCITY

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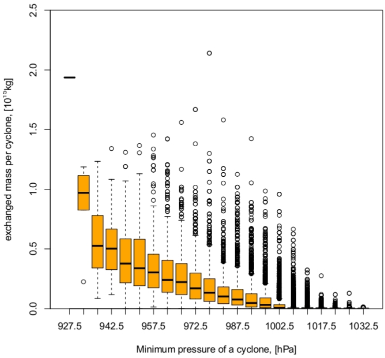
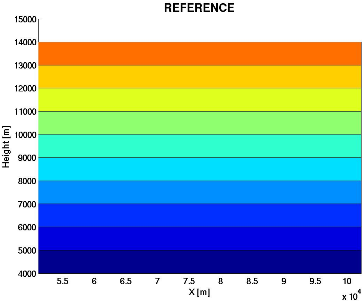
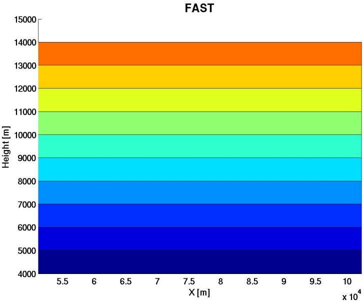


- 20 years of cyclone and STE data of the northern hemisphere extra tropics (here: STT)
- more intense cyclones often show a rapid development
- **Same simulation with an updraught of** $0.06\,\mathrm{m\,s^{-1}}$
- same Θ-profile as in **REFERENCE**

Influence of updraught velocity

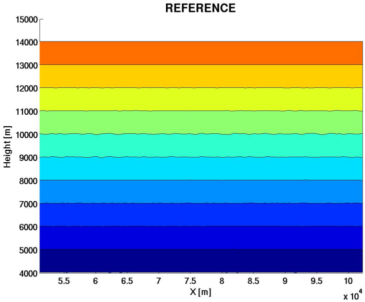
t= 000 min, black isolines: Ice water content, colour: Tracer

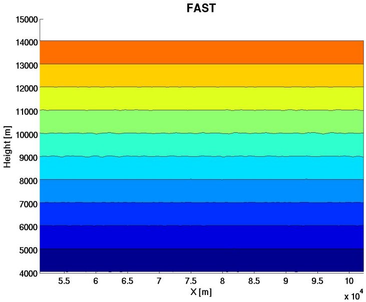




Influence of updraught velocity

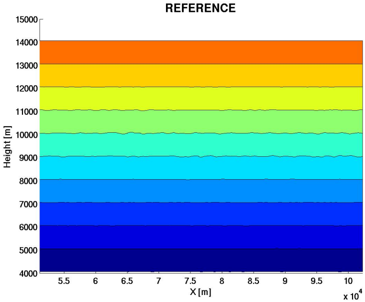
t= 016 min, black isolines: Ice water content, colour: Tracer

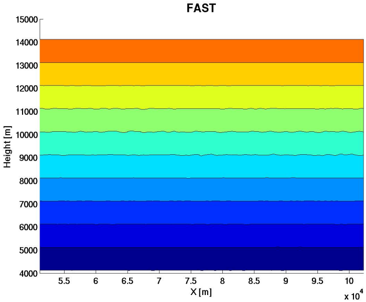




Influence of updraught velocity

t= 033 min, black isolines: Ice water content, colour: Tracer





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Influence of updraught velocity

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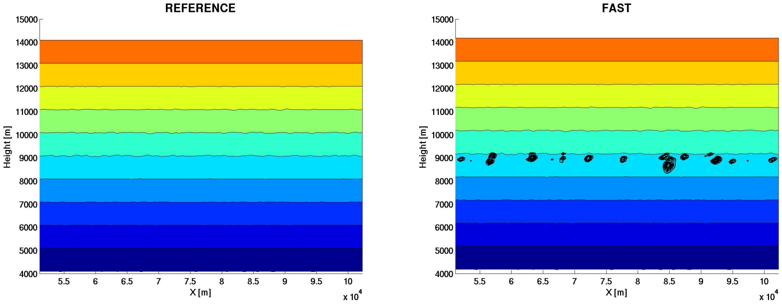
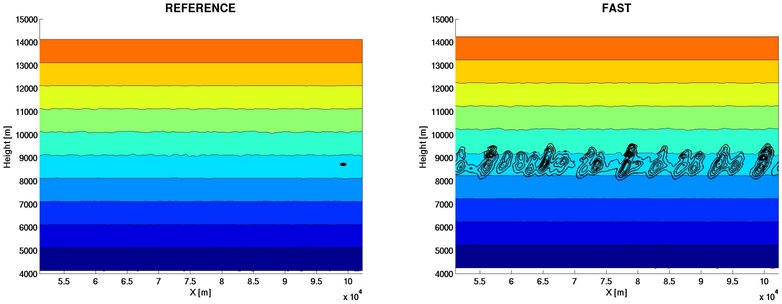


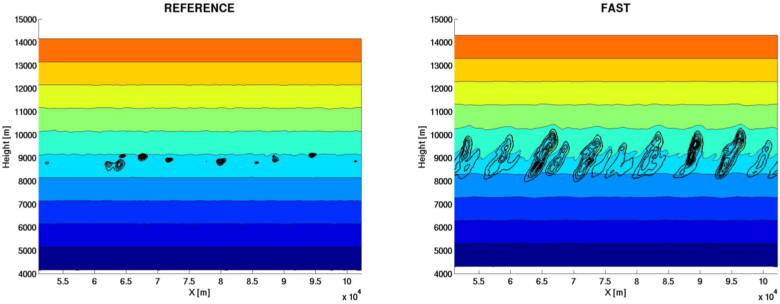
Influence of updraught velocity

t= 066 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

t= 082 min, black isolines: Ice water content, colour: Tracer



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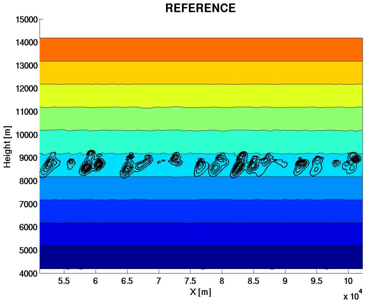
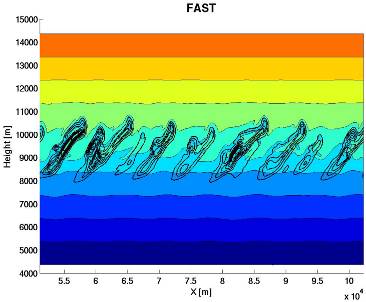
Influence of updraught velocity

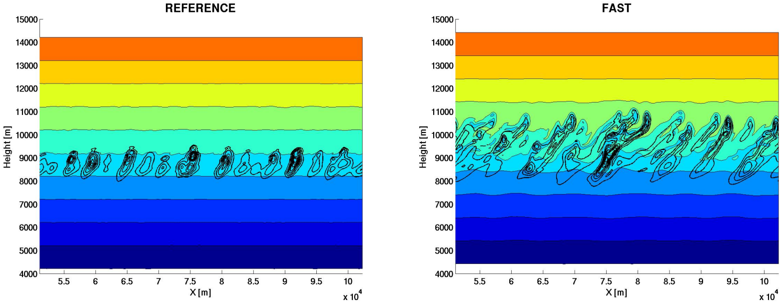
t= 099 min, black isolines: Ice water content, colour: Tracer





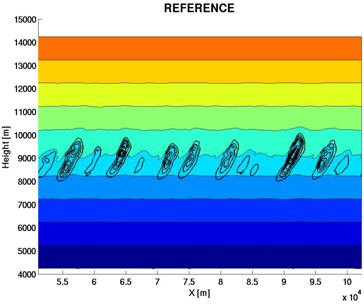
Influence of updraught velocity

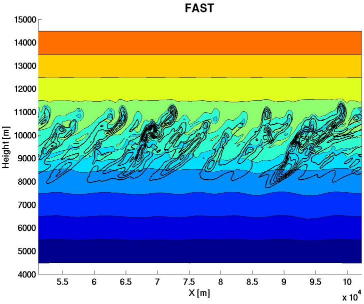
t= 115 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

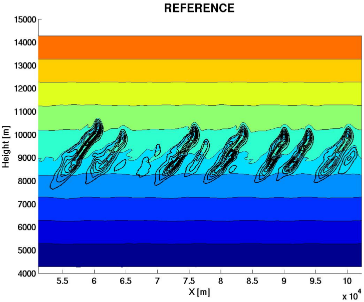
t= 132 min, black isolines: Ice water content, colour: Tracer

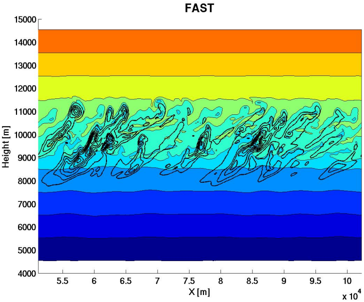




Influence of updraught velocity

t= 148 min, black isolines: Ice water content, colour: Tracer





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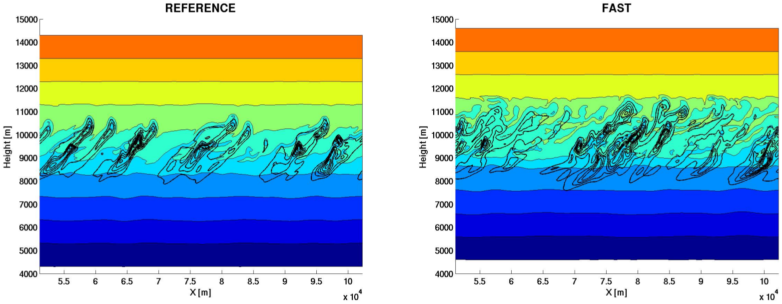
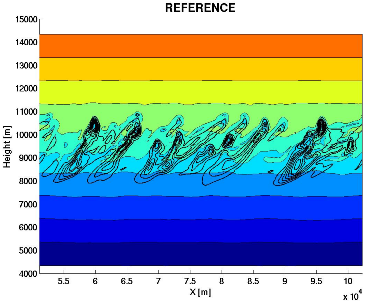
Influence of updraught velocity

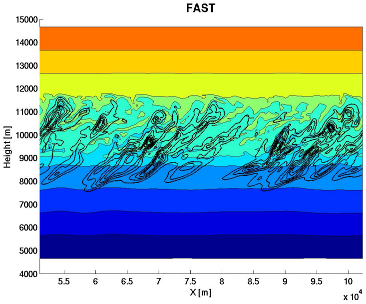
t= 165 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

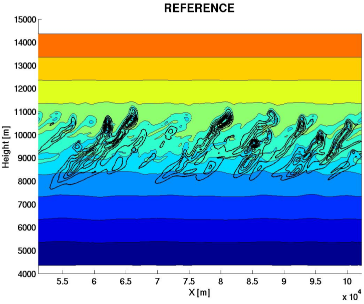
t= 181 min, black isolines: Ice water content, colour: Tracer

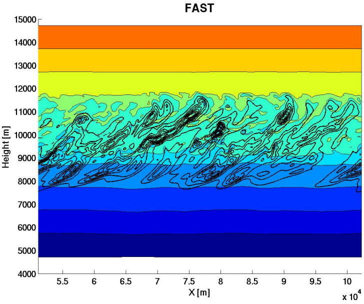




Influence of updraught velocity

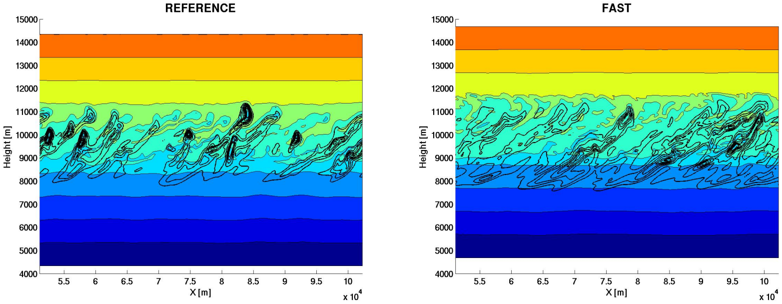
t= 200 min, black isolines: Ice water content, colour: Tracer





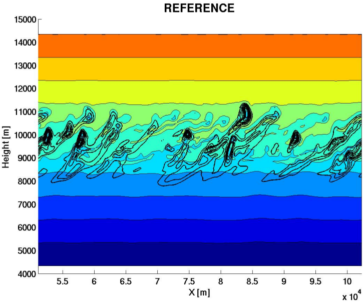
Influence of updraught velocity

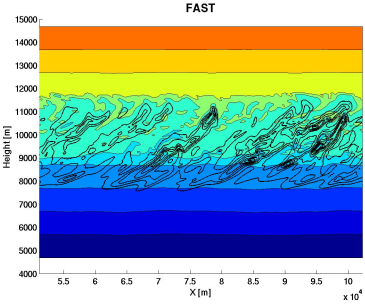
t= 216 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

t= 233 min, black isolines: Ice water content, colour: Tracer





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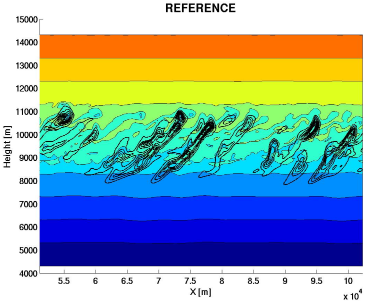
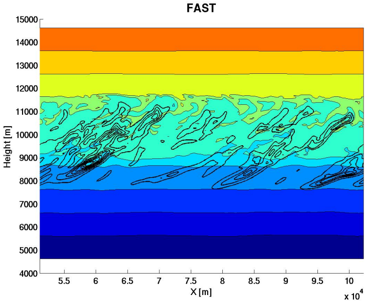
Influence of updraught velocity

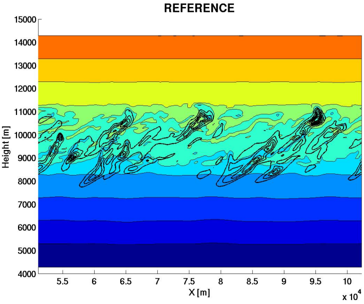
t= 249 min, black isolines: Ice water content, colour: Tracer

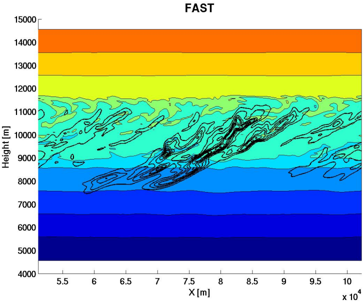




Influence of updraught velocity

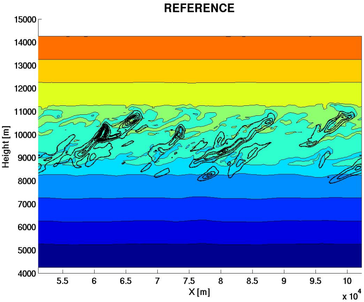
t= 266 min, black isolines: Ice water content, colour: Tracer

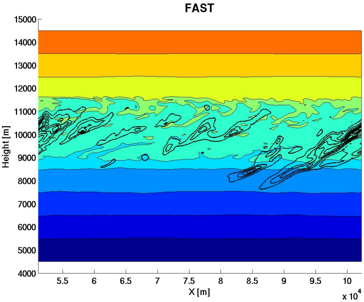




Influence of updraught velocity

t= 282 min, black isolines: Ice water content, colour: Tracer





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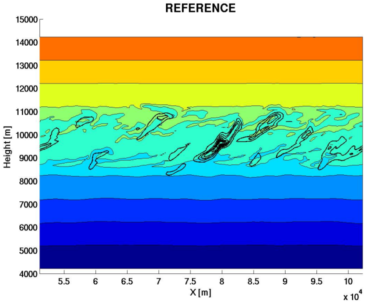
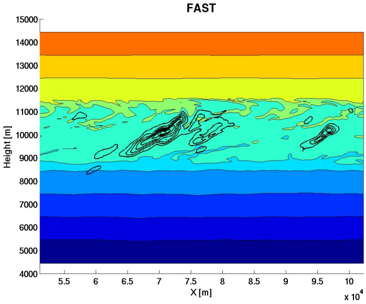
Influence of updraught velocity

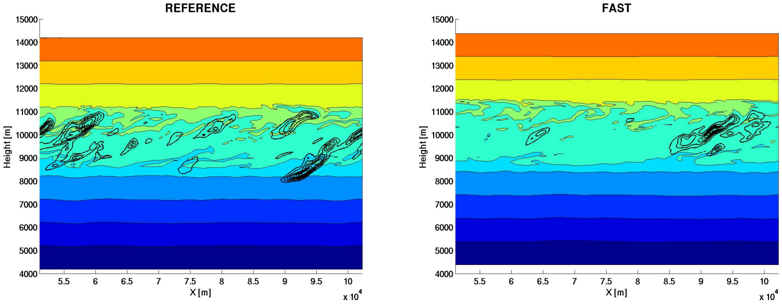
t= 299 min, black isolines: Ice water content, colour: Tracer





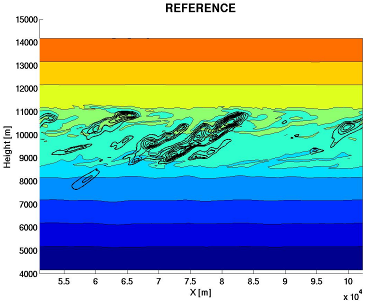
Influence of updraught velocity

t= 315 min, black isolines: Ice water content, colour: Tracer



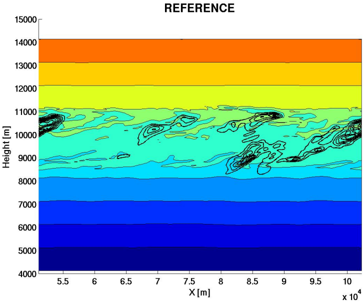
Influence of updraught velocity

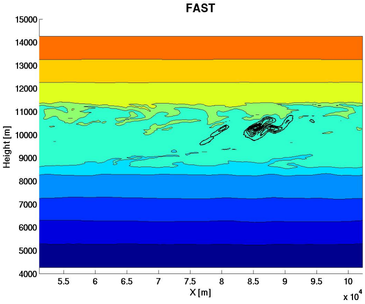
t= 332 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

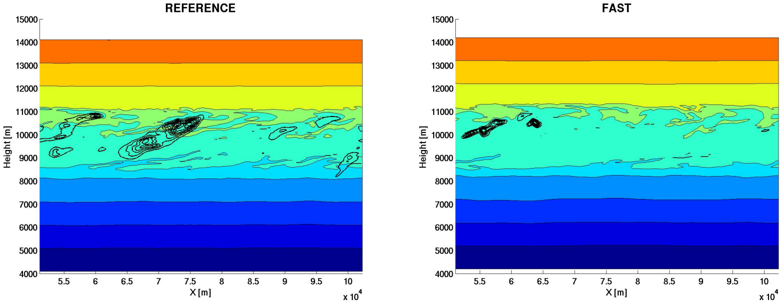
t= 349 min, black isolines: Ice water content, colour: Tracer





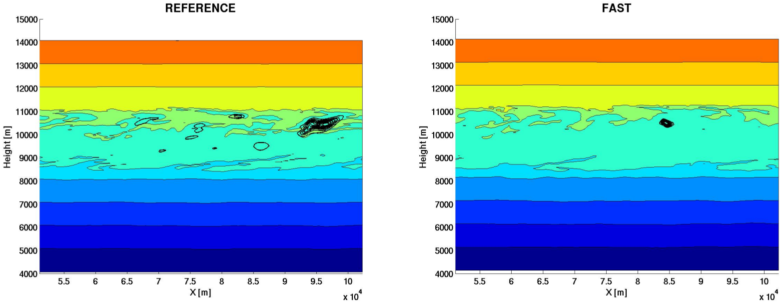
Influence of updraught velocity

t= 365 min, black isolines: Ice water content, colour: Tracer



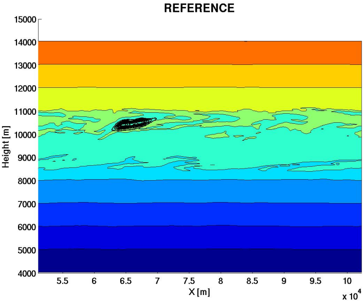
Influence of updraught velocity

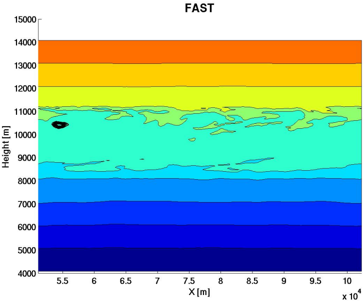
t= 381 min, black isolines: Ice water content, colour: Tracer



Influence of updraught velocity

t= 400 min, black isolines: Ice water content, colour: Tracer





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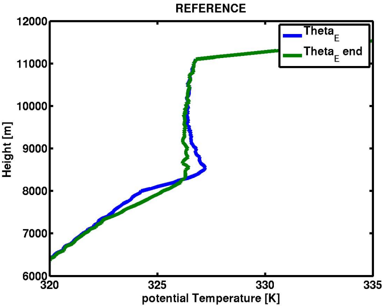
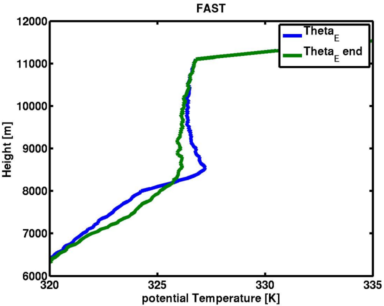
equivalent potential temperature (horizontally averaged)

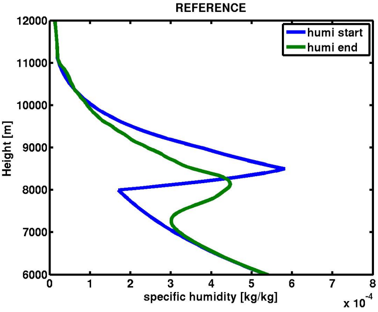
- The potentially unstable layer in the beginning is converted into a weak potentially stable layer in **FAST** in contrast to **REFERENCE**.
- increased depth of mixed layer for **FAST**.





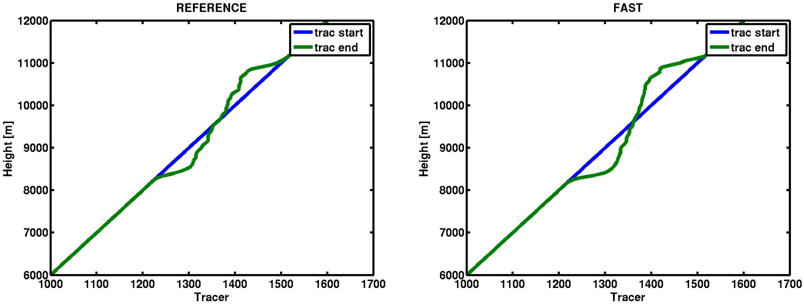
specific humidity (horizontally averaged)

- The maximum of the humidity in the **FAST** case is redistributed into lower heights compared to the **REFERENCE**.



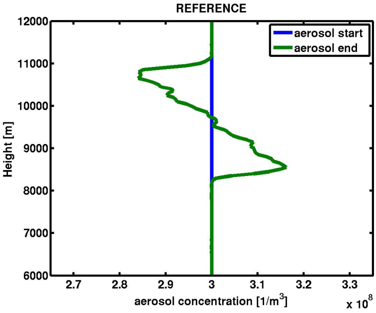
tracer distribution (horizontally averaged)

- In **FAST** higher amount of lower air masses is mixed into higher regions and vice versa compared to **REFERENCE**.



aerosol concentration (horizontally averaged)

- The reduction of aerosol particles close to the tropopause and the increase of particles at the bottom of the previously potenatially unstable layer is significantly enhanced in **FAST**.



Conclusion

- Cirrus clouds are important for the Earth's climate and weather system.
- In the vicinity of cyclones an enhanced exchange between stratosphere and troposphere can be observed.
- First results indicate that cirrus clouds alter the tropopause region by:
  - changing the potential stability close to the tropopause
  - reducing the humidity close to the tropopause
  - mixing lower air up to higher regions and vice versa
- Hence, cirrus clouds can affect the air, which is exchanged through the tropopause.

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Outlook

Further investigation on this topic:

- introduction of realistic chemical tracers,
- influence of tropopause shape,
  - find more realistic Θ-profiles,
- idealized 3D simulations,
- introducing radiation,
- realistic 3D simulations.

Outlook

Further investigation on this topic:

- introduction of realistic chemical tracers,
- influence of tropopause shape,
  - find more realistic Θ-profiles,
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- realistic 3D simulations.

Thank you!

with special thanks to Matthias and Peter!