Cloud/Radiation parameterization issues in high resolution NWP

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As the horizontal grid size in atmospheric models is reduced the assumptions made in connection with vertical column physics becomes more and more incorrect

Outline of presentation

- Simple computation examples illustrating the basic problems associated with radiation processes in column physics for a cloudy atmosphere.

  Sensitivity of solar- and thermal radiation to column physics computations

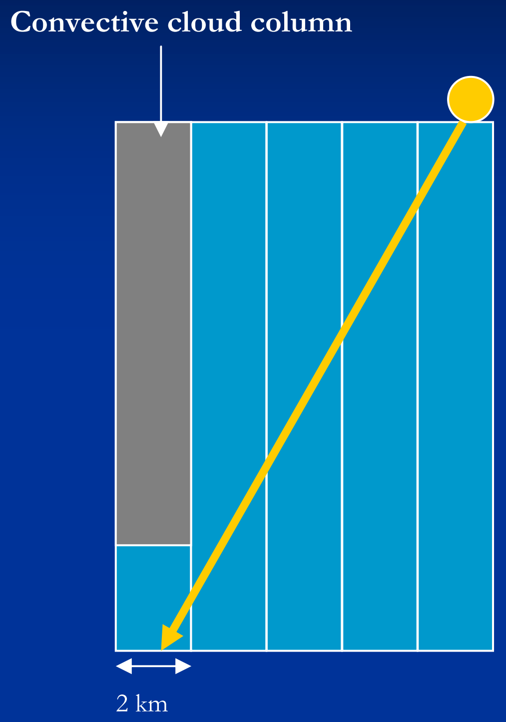
- Satellite pictures

  Shadows from clouds are often visible in satellite pictures: examples are shown

- Past and ongoing modelling studies investigating effects of 3-dimensional cloud/radiation interaction.

- Concluding remarks

Test examples for solar radiation



Example 1a:

Solar zenith angle= 30 deg
Observational facts: Solar constant ~1370 W/m2

Actual situation: Direct sunshine reaches the ground without penetrating the deep convective cloud. However: in Column physics only a small fraction of solar radiation will reach the ground due to a high cloud albedo.

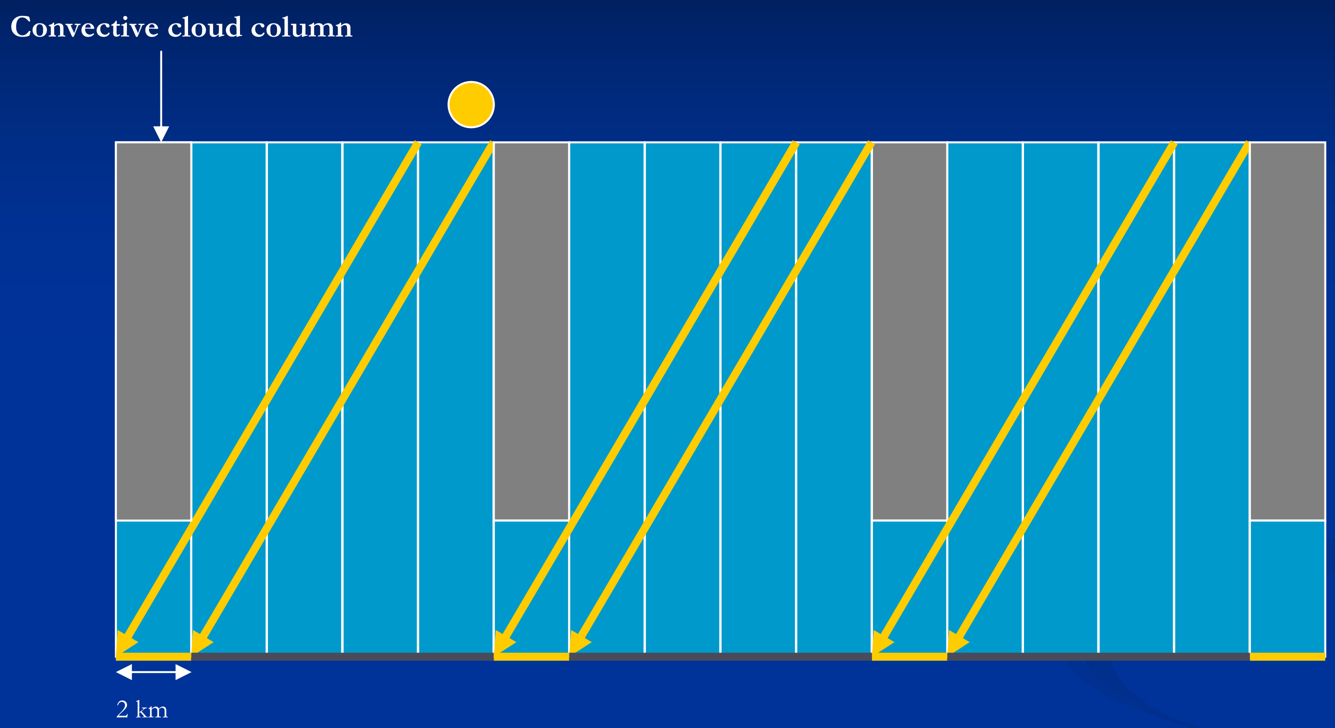
Solar radiation F at the ground:

A) Column physics: F~1370*cos (30)*0.10 =119 W/m2

B) 'Slant' column: F~1370*cos (30)*0.75 =890 W/m2

Difference = 890 – 119 W/m2 = 771 W/m2

Test examples for solar radiation



Example 1b: As the deep convective clouds are expanded to a larger area

the domain area average influx to the ground is much in error for the case of vertical column physics

Column physics: F(column mean) = (4*890 +1*119)*0.20 = 736 W/m2

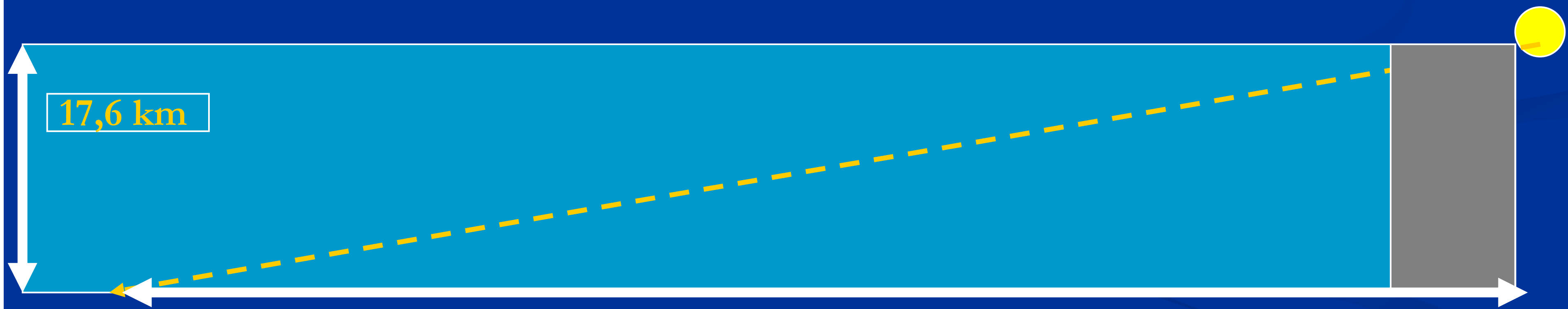
Realistic computation: F (area mean) = (4*119 +1*890)*0.20 =273 W/m2

Difference = 463 W/m2

Example 2:

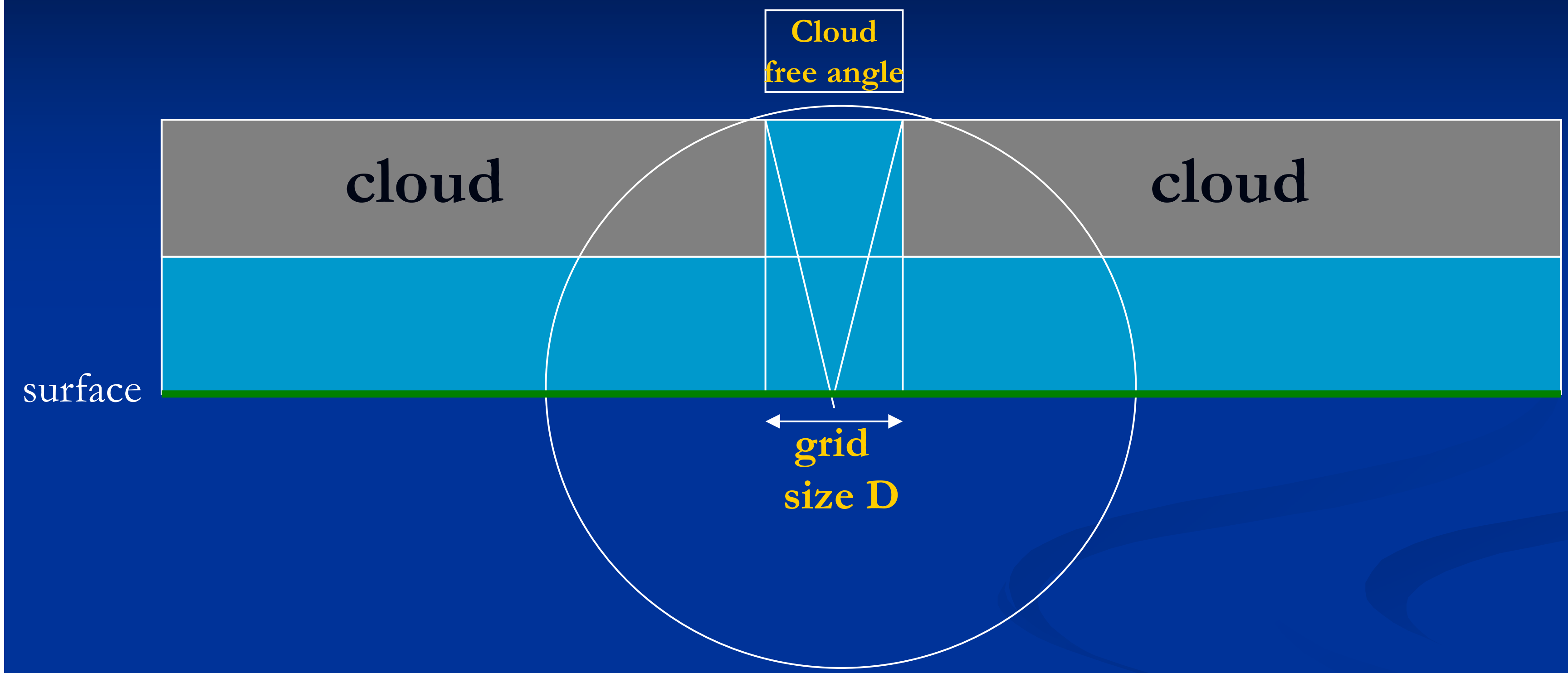
How long can the shadows from clouds be ?

Shadow for deep convective clouds
Extending to 17.6 km at a solar height of
10 deg. = 100 km !



Length of shadow = 100 km

Example 3: order of magnitude computation for thermal radiation



Assumptions for 'worst case' type of computations of net radiation at the ground giving siginicant differences between column physics and more realistic computations where the actual sky view (cloud free cone) is taken into account, integrating radiance over the half sphere above the ground – cloud layers of big horizontal extent outside the vertical column (cylinder) !

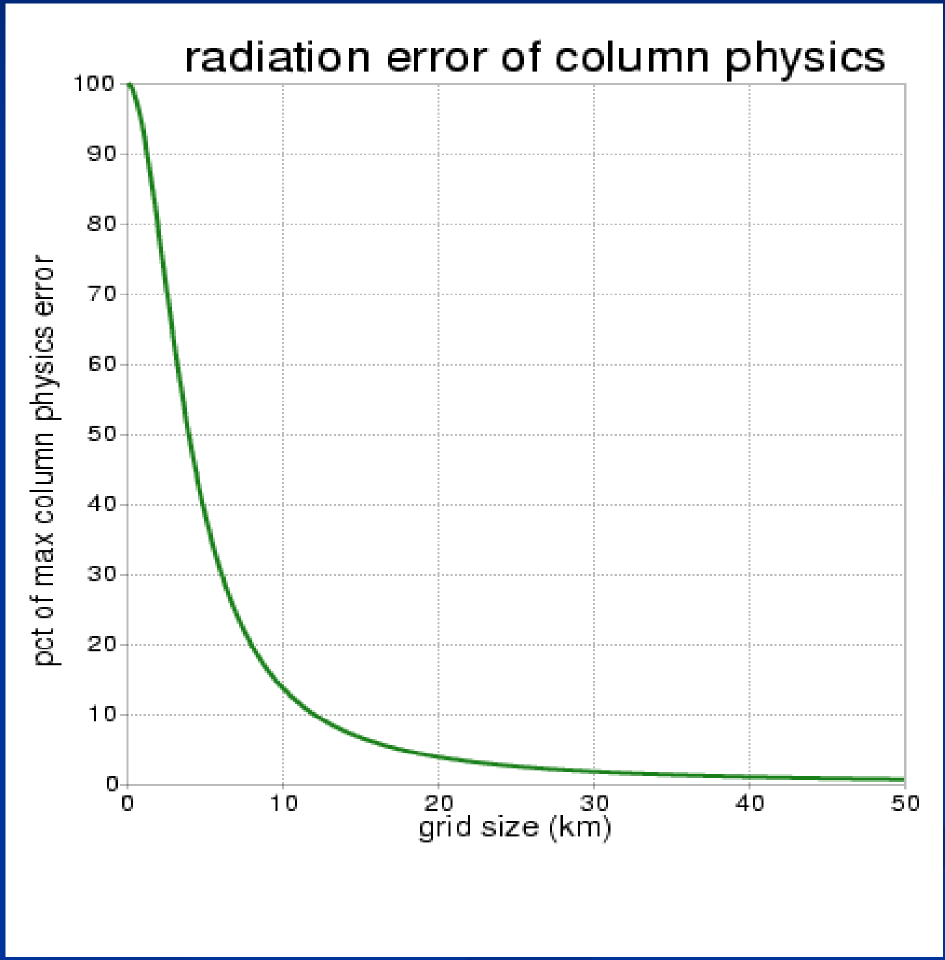
Assumptions for simplified LW computations:

- Surface: black body (absorbing all incoming radiation)
- Isothermal atmosphere with temperature = 288 K
- Only the effect of boundary layer clouds between 1000m and 2000m is considered. The rest of the atmosphere is cloud free
- Radiation from clear sky atmosphere towards the ground is ~75 percent of the black body radiation
- Radiation from clouds to the ground is exchanged through 'atmospheric window' by 25 percent of the black body radiation at the atmospheric temperature.

Results for thermal radiation

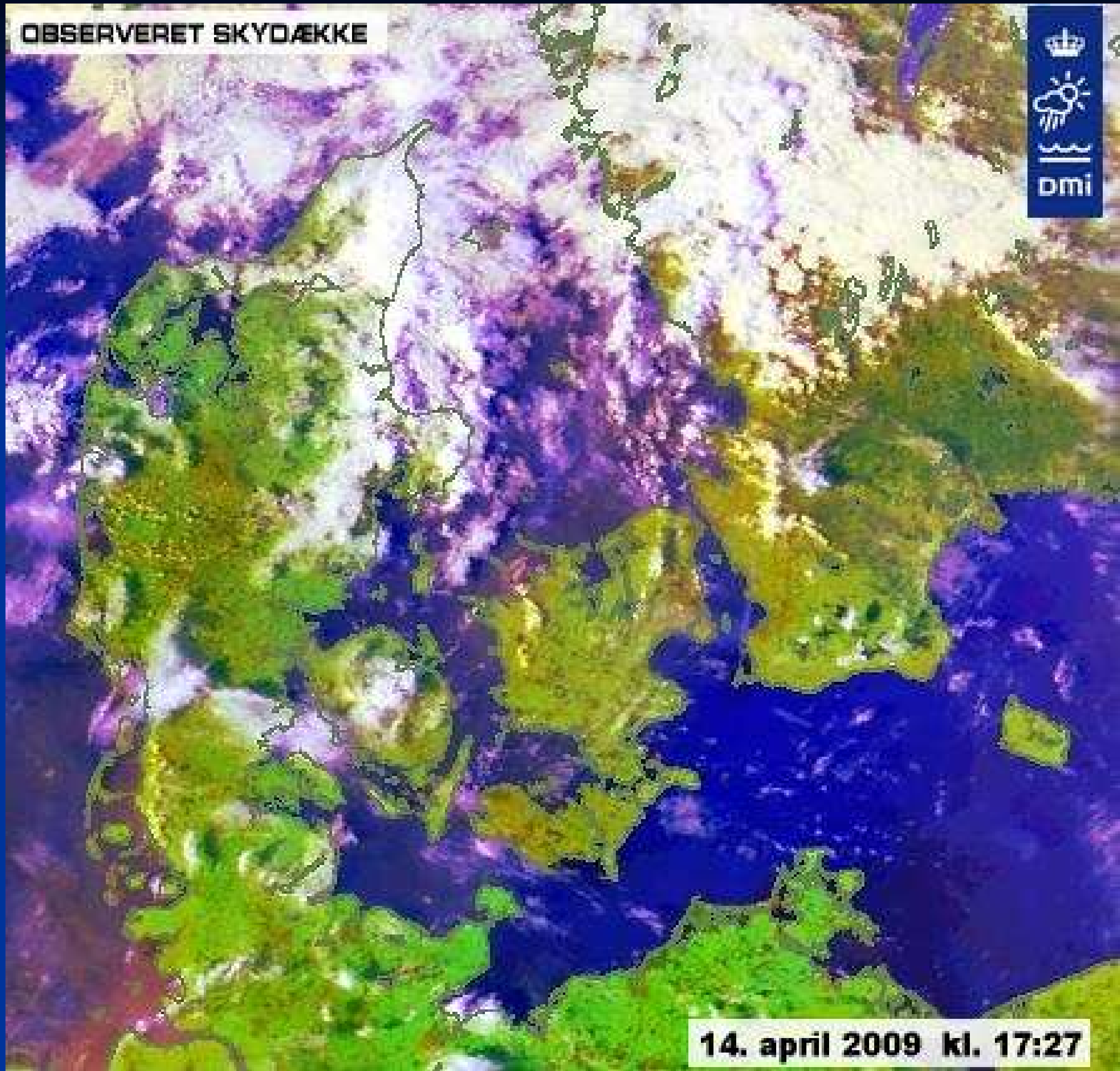
Maximum error occurs when the grid size goes to very small values considering cloud free column while in reality the surroundings are covered by a large cloud sheet radiating like a black body towards the ground.

The figure shows the percentage of the maximum error (~98 W/m2) as a function of grid size arising from executing column physics under the specified conditions



Satellite evidence for significant shadow effects from clouds.

This effect is clearly non-negligible when computing solar radiation at the ground in high resolution models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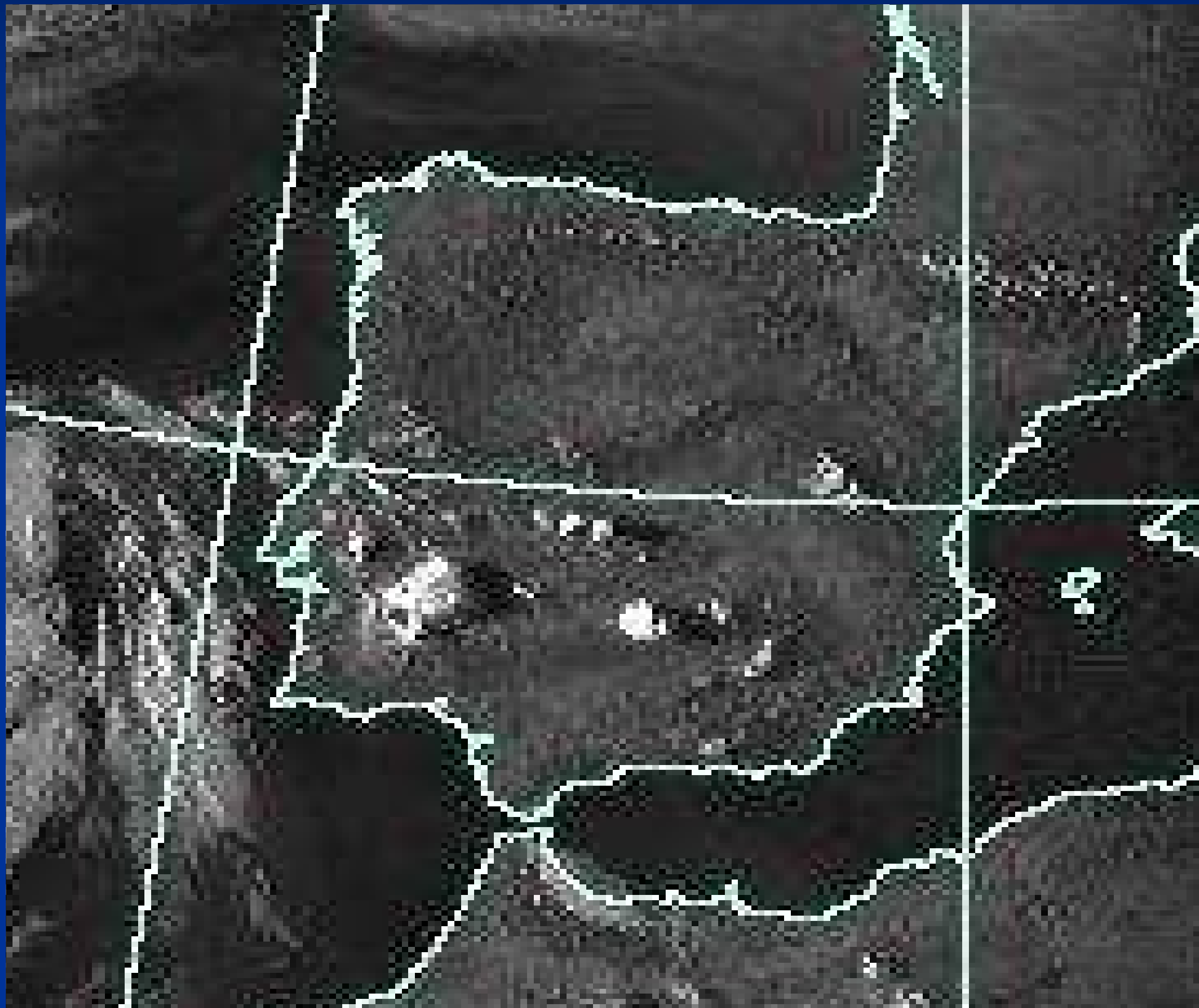
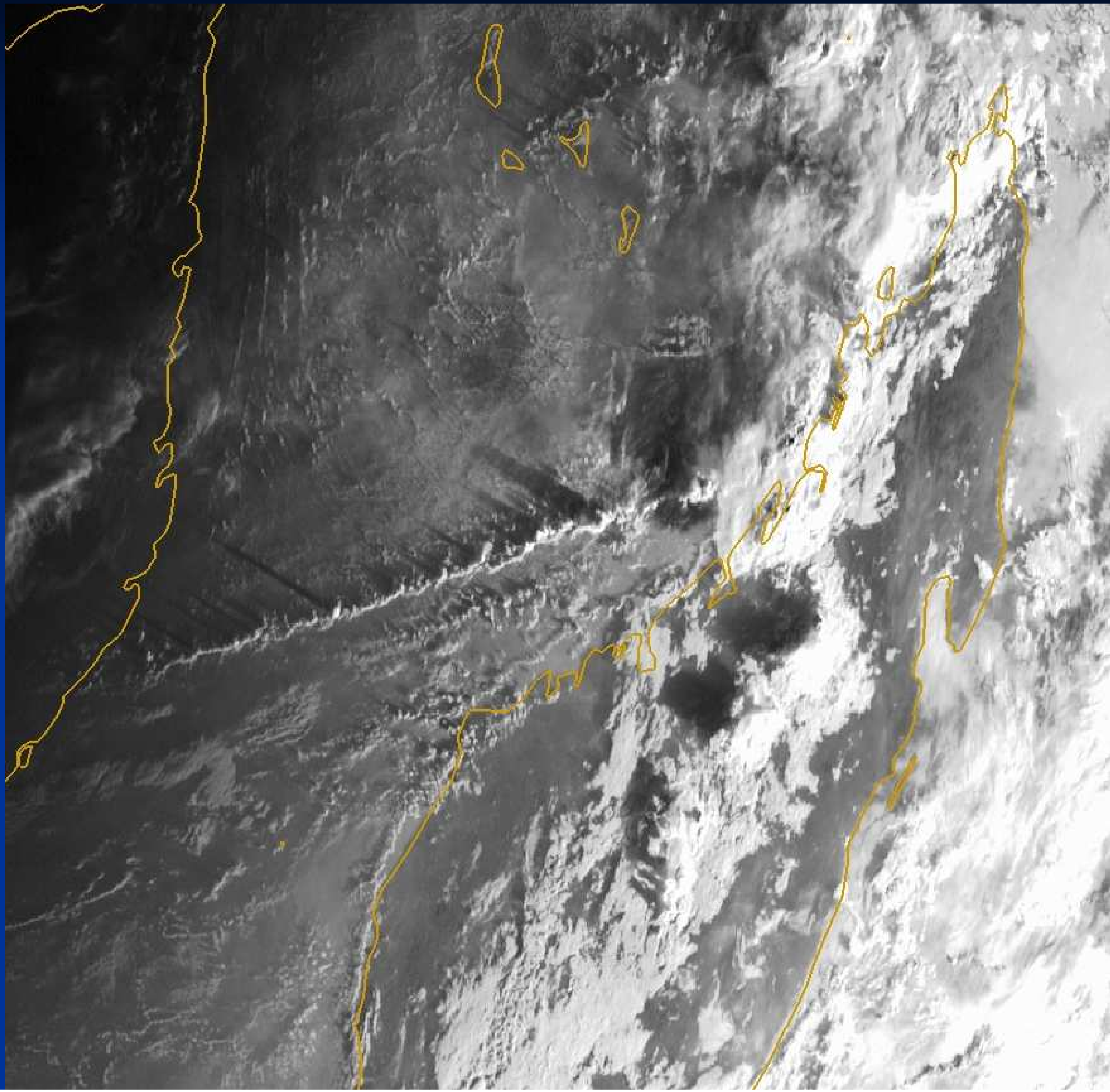
Clouds over Spain 22 marts 2009 late in the afternoon



Early morning in tropical summer at Madagaskar

8 January 2008
0300 UTC
(~ 6.00 local time)

Note the long convective band between Madagaskar and Mozambique with shadows of order 100 km long



Radiative heating of the atmosphere due to cloud geometry effects :

Summary:

Deep cumulus cloud fields : Very substantial effects

e.g. Qiang Fu et al. , (2000)

Shallow cumulus cloud fields: Significant effects in some cases

e.g. Qiang Fu et al. (2000) , Guan et al. (1997)

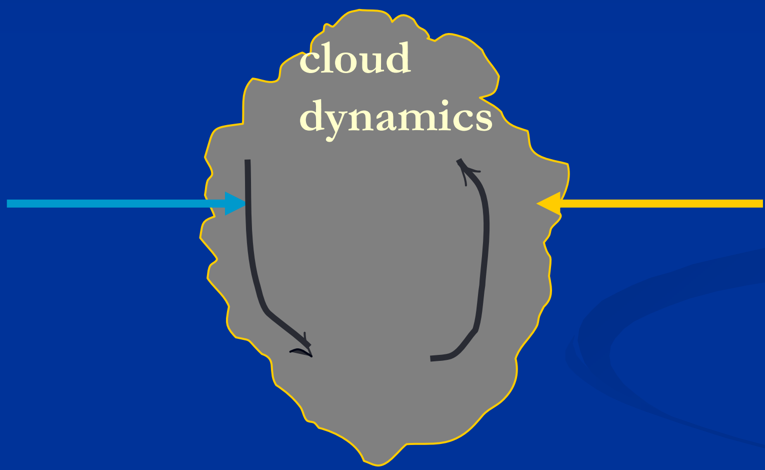
Stratocumulus cloud fields: Some effects at cloud tops, otherwise small

e.g. Mechem et al. (2002), Guan et al. (1995)

Modelling studies of 3D radiation impacts on clouds

Cumulus cloud

Raditive longwave cooling at the sides of the cloud



solar absorbtion

at the sides of the cloud

Guan et al. (1997) document 3D-radiation effect caused by longwave cooling at the sides of the cloud leading to increased downdrafts

3D cloud geometry effects on surface solar radiation

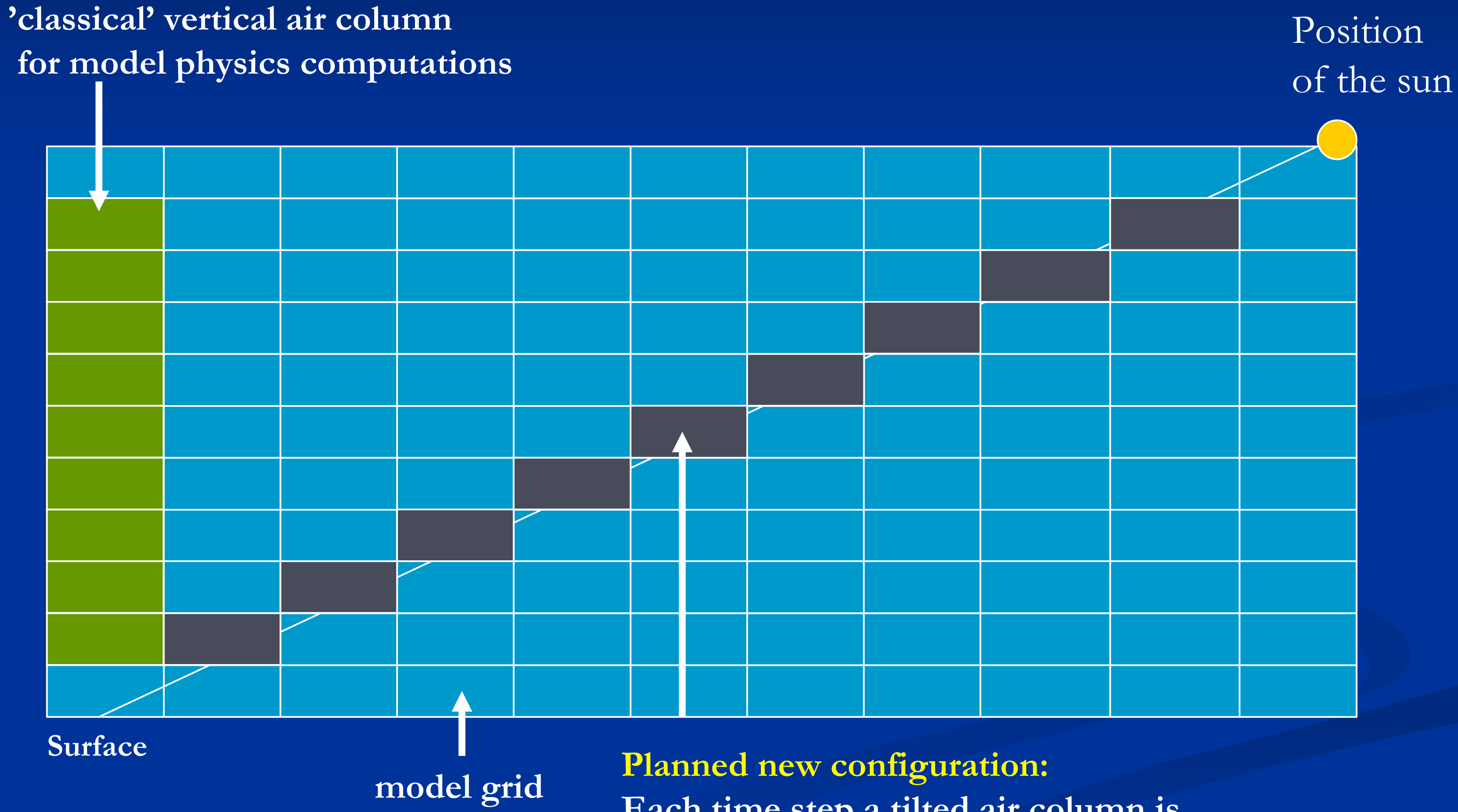
Wapler and Mayer, 2008 (a, b)
have developed a solar radiation scheme which calculates a tilted optical thickness for each surface pixel that is then used as input to a one-dimensional radiative transfer code.

They conclude:

” It has been shown that the consideration of three dimensional radiative effects can have a significant impact on the formation and development of convective clouds ”.

Modelling of a tilted solar radiation in HIRLAM

(ongoing work since 2009)



Planned new configuration:
Each time step a tilted air column is determined in the direction of the sun for computations of surface solar radiation

Simplified implementation of 3D- cloud geometry effects in HIRLAM.

- Determine an alternative column in the direction of the sun based on the knowledge of solar height, azimuth angle and the horizontal plus vertical grid spacing.

- The essential variables (specific humidity, cloud water, cloud ice, cloud cover and temperature) of the new columns are passed to the ’physics’ in the normal way as is done for other global arrays.

- The values of the new arrays should not be time stepped or remembered to the next time step.

- The heating rates of the atmosphere (longwave and shortwave) could in a first implementation be computed in vertical columns as usual. However the 3D cloud geometry effects are taken into account with regard to incoming surface radiation.

CONCLUSIONS

- Numerical modelling studies show that 3D cloud geometry effects on atmospheric heating rates can be significant both with regard to longwave and shortwave radiation. The effects can be very significant for deep convective cloud fields while more modest effects are seen for shallow cumulus or stratocumulus.

- For high resolution NWP models (~ below 5 km grid size) the radiative downward flux to the ground can become seriously in error when using vertical column physics as an effect of cloud geometry effects. The errors associated with solar radiation seem to be significantly larger than for thermal radiation.

CONCLUSIONS

- Numerical studies indicate that shading effects can have a significant effect on the evolution of the model's cloud field
- The future will reveal the possible fruits of introducing simplified 3D radiation -effects in operational NWP models.

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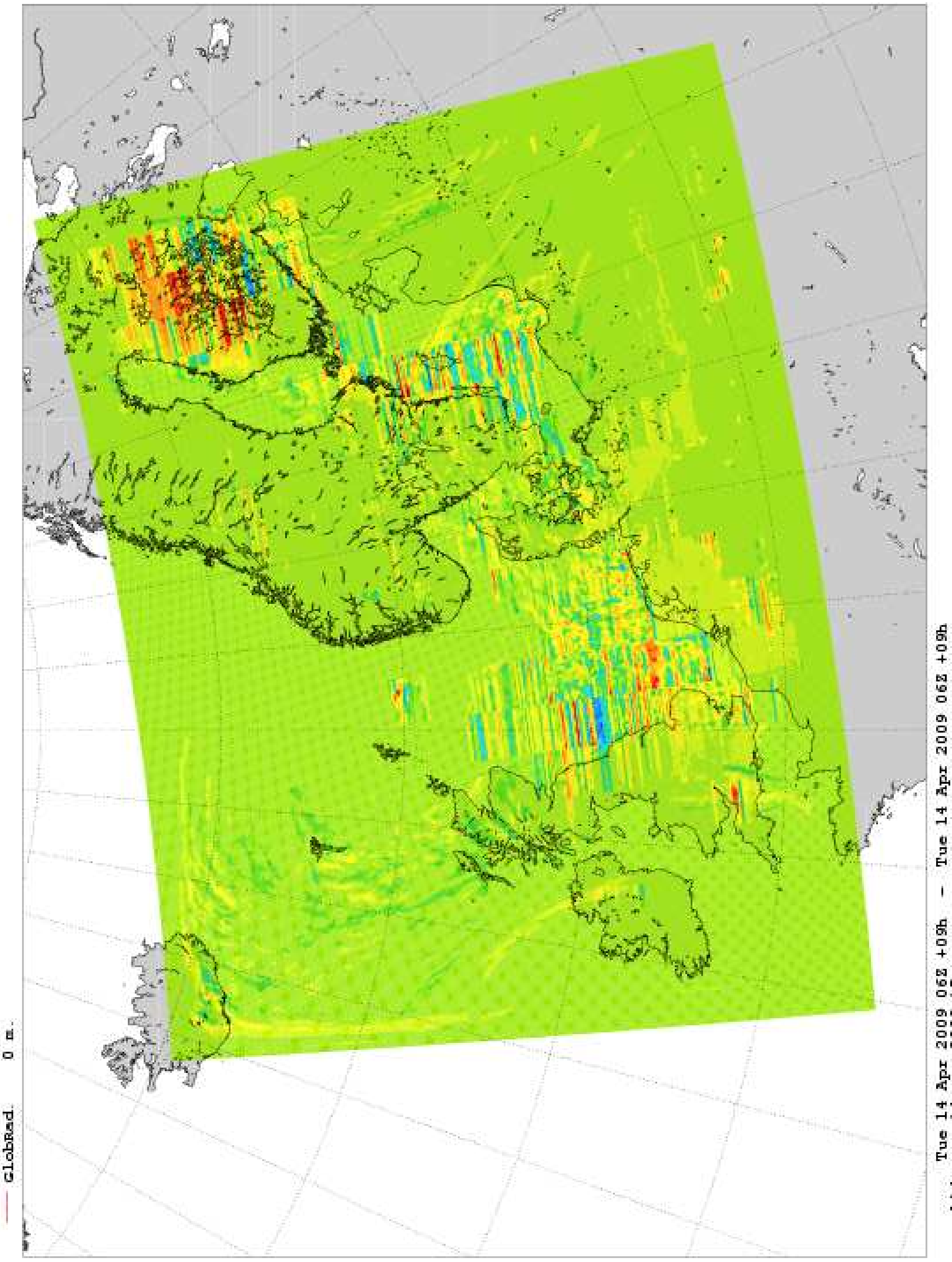
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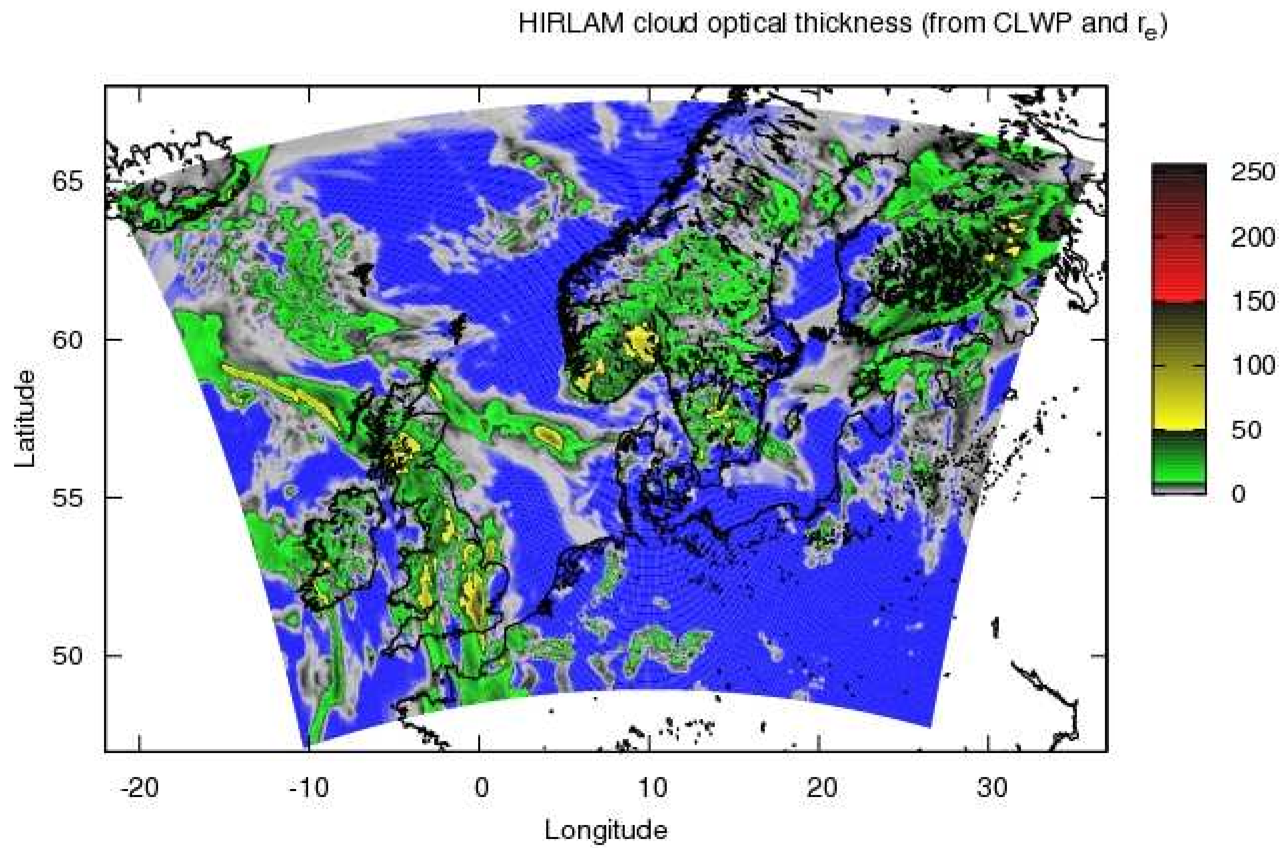
HIRLAM cloud optical thickness (from CLWP and r_e)
Latitude
65
60
55
50
-20
-10
0
10
20
30
Longitude
250
200
150
100
50
0