Limitations of ’column physics’ for radiation computations in atmospheric models

Bent H Sass
Danish Meteorological Institute
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As the horizontal grid size in atmospheric models is reduced the assumptions made in connection with column physics becomes more and more incorrect

Outline of presentation

- Radiative processes considered

It is argued that the accuracy problem for solar radiation is an order of magnitude bigger than for thermal longwave radiation computatons.

- Simple computation examples

Sensitivity of solar- and thermal radiation to the limitations of doing physics in a vertical column is demonstrated

- Satellite pictures

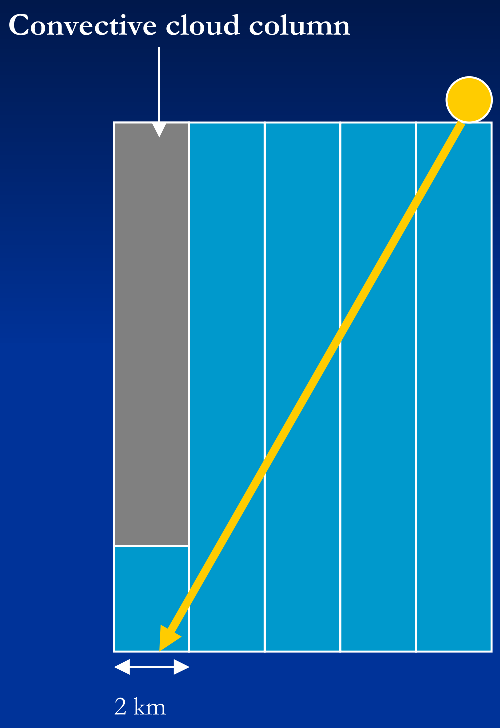
Shadows from clouds are often visible in satellite pictures: examples are shown

- Method to compute solar radiation in the direction towards the sun.

  A method is outlined, at present for HIRLAM, to treat solar radiation in a tilted column to avoid computations in a vertical column.

- Discussion and conclusions

Test examples for solar radiation



Example 1:

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:

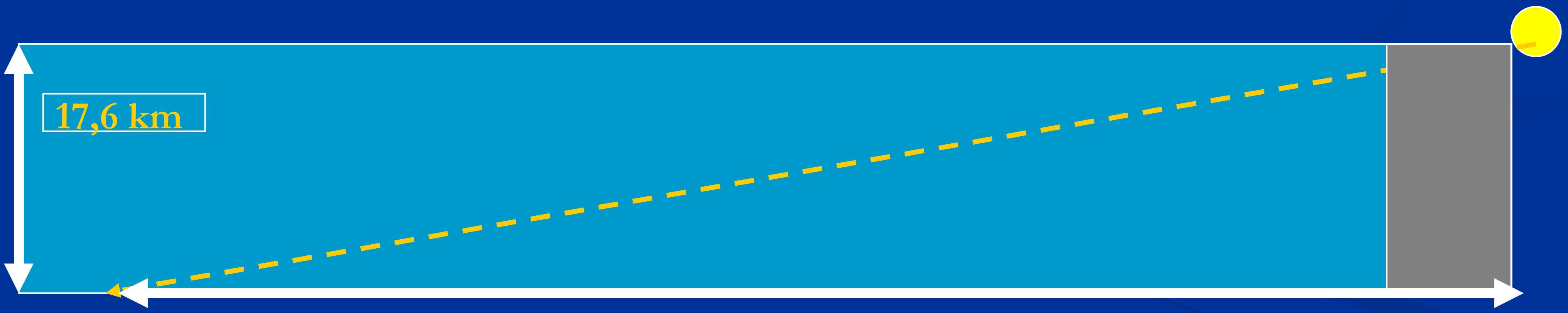
- Column physics: F~1370*cos (30)*0.10 =119 W/m2
- 'Slant' column: F~1370*cos (30)*0.75 =890 W/m2

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

Example 2 :

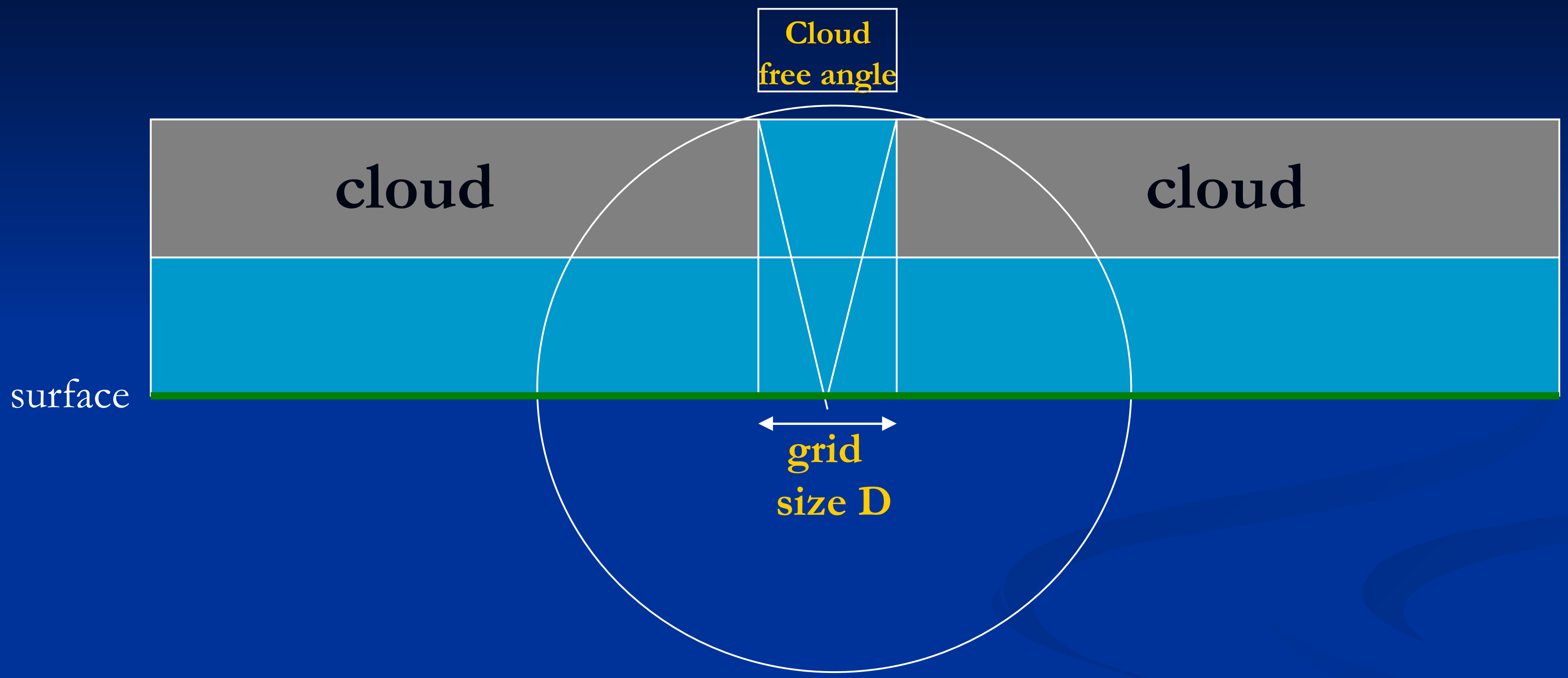
How long can the shadows from clouds be ?

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) !

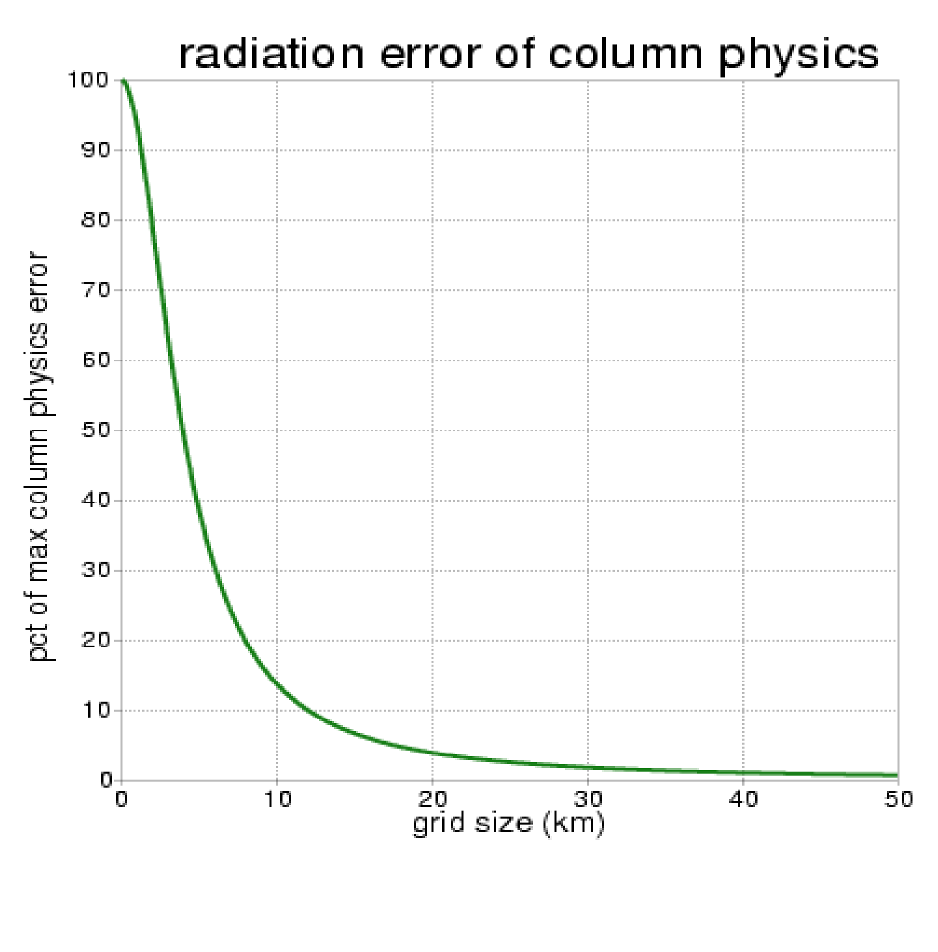
Assumptions for simplified LW computations:

- 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

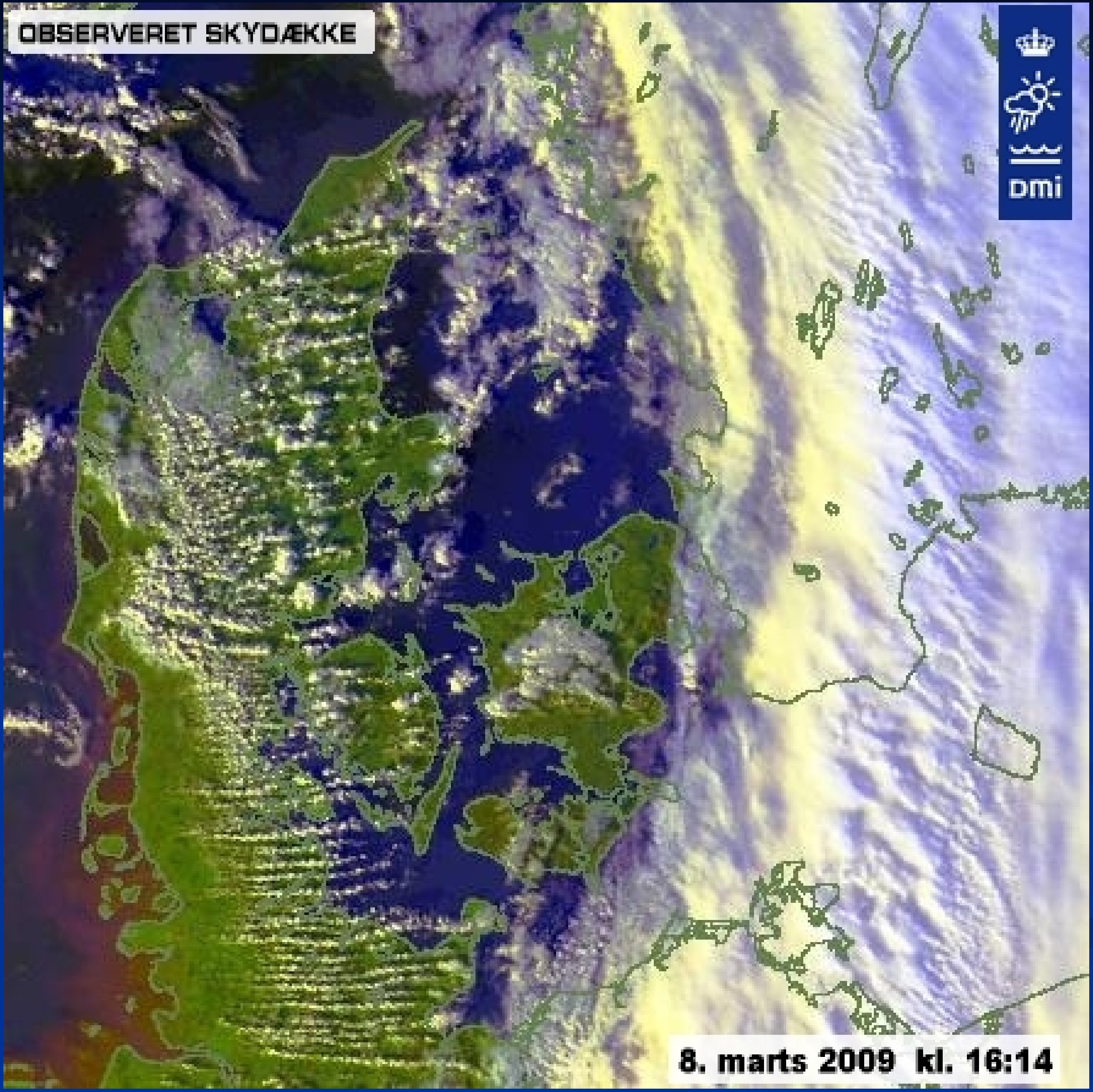
Maximum error occurs when the grid size goes to very small values considering cloud free column while in reality the surroundings are covered by a large cloud sheet radiating like a black body towards the ground.

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


OBSERVERET SKYDÆKKE
DMI
8. marts 2009 kl. 16:14


OBSERVERET SKYDÆKKE
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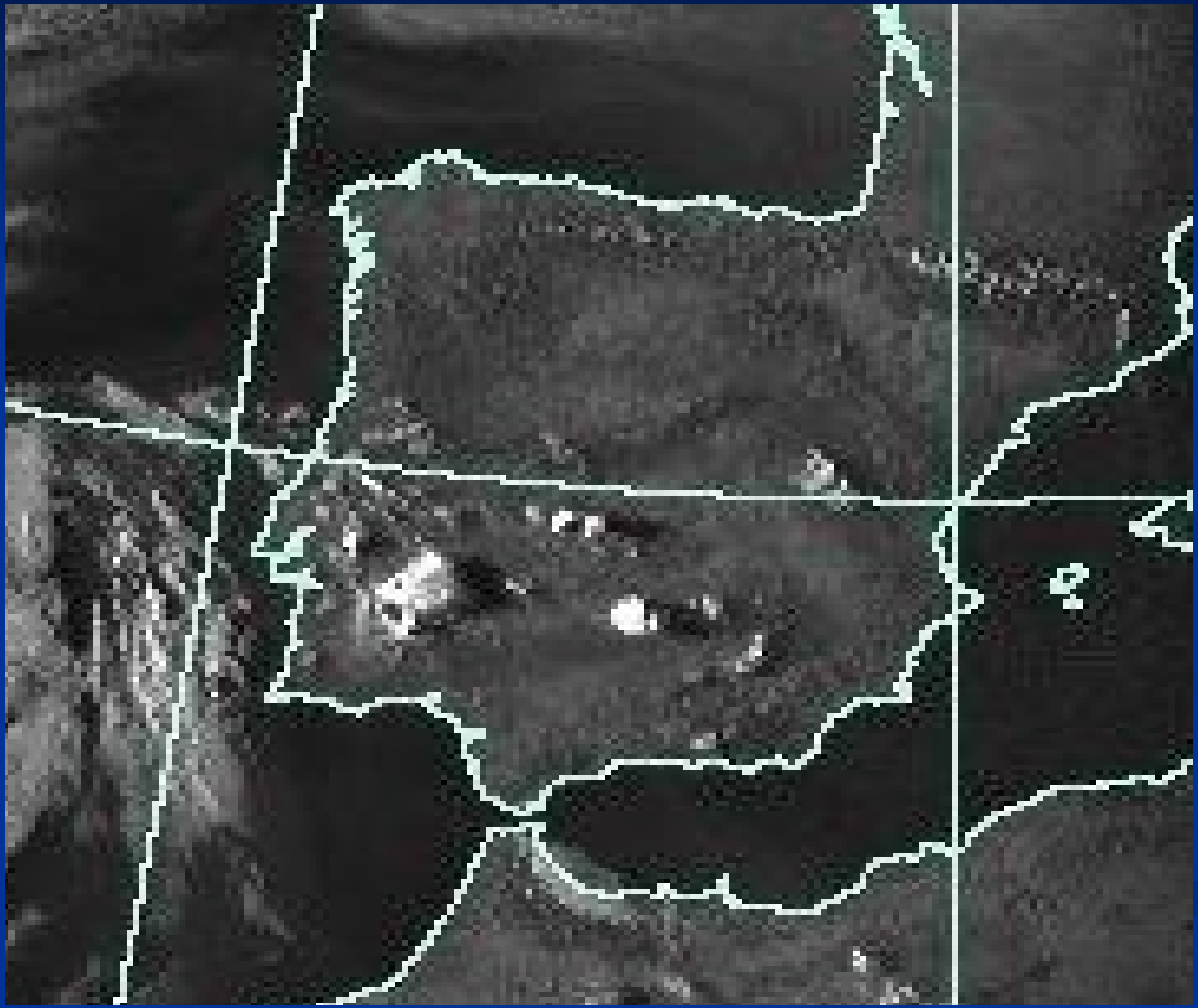
14. april 2009 kl. 17:27

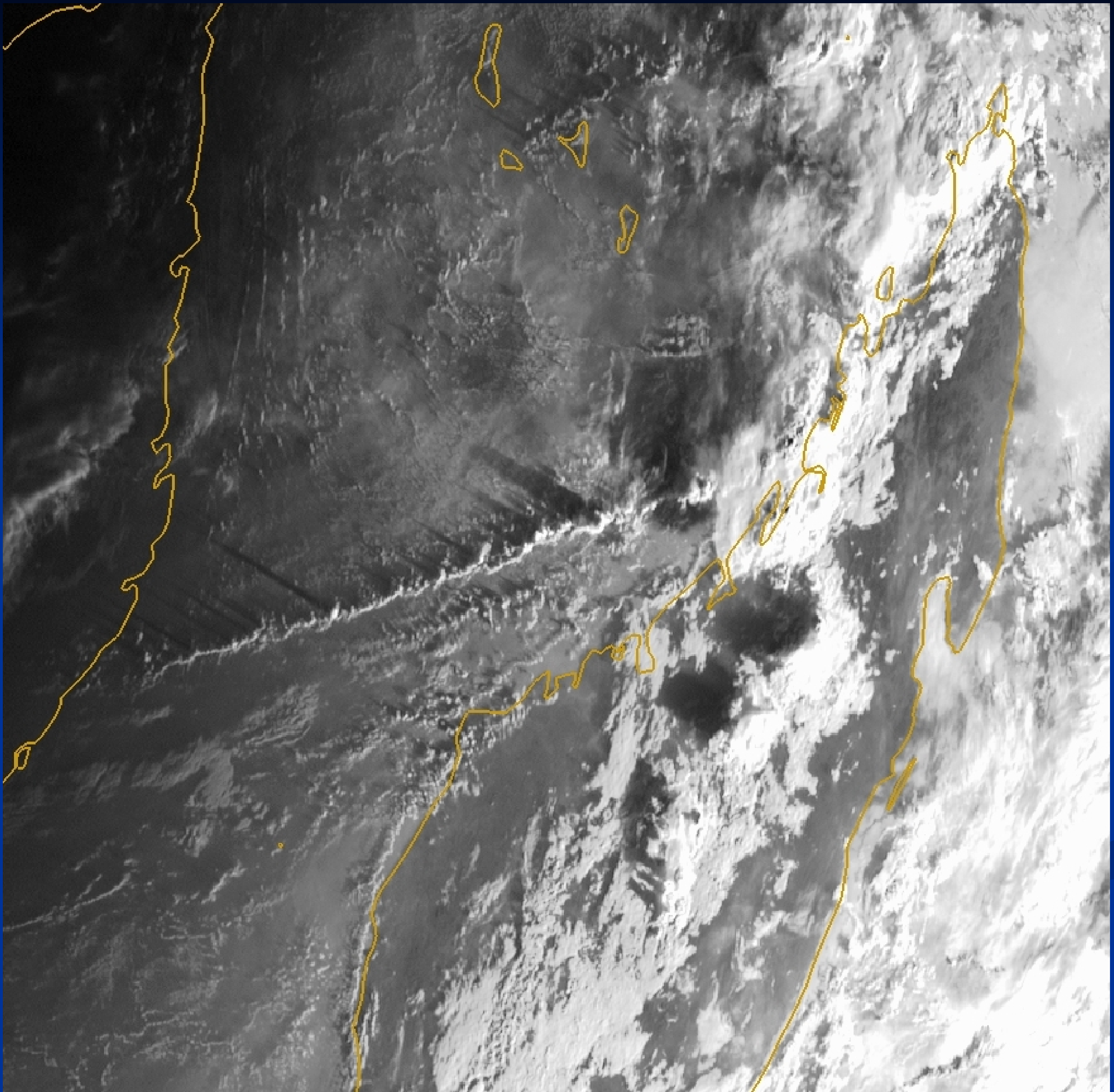
Clouds over Spain 22 marts 2009 late in the afternoon



Early morning in tropical summer at Madagaskar

8 January 2008
0300 UTC
(~ 6.00 local time)

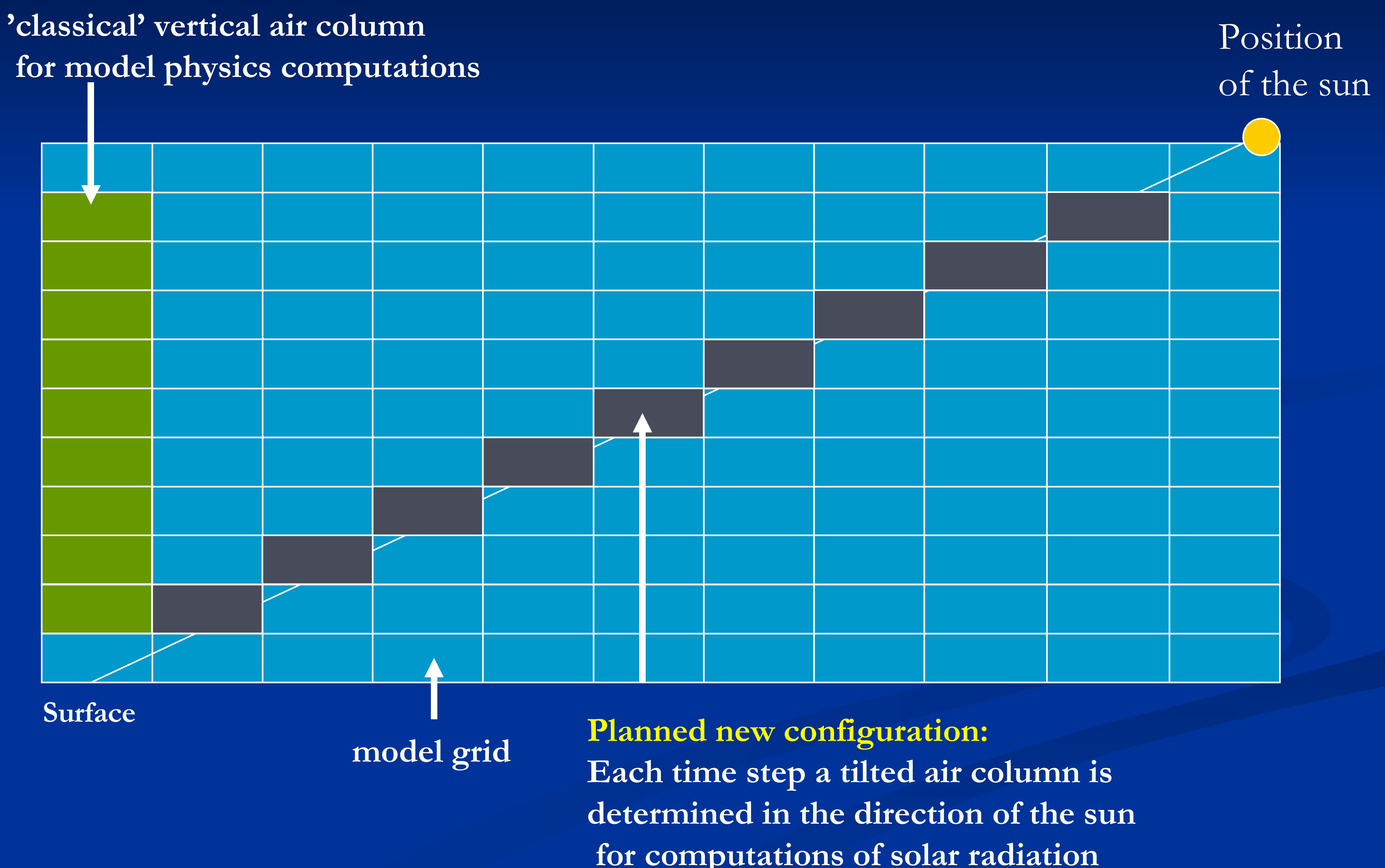
Note the long convective band between Madagaskar and Mozambique with shadows of order 100 km long



Computational method for HIRLAM to avoid column physics in solar radiation computations

- 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.
- A procedure in the radiation scheme checks that no grid volume is updated more than once with solar radiation process
- Longwave (thermal) radiation is still done in vertical columns

Coarse mesh meteorological models (horizontal grid size ~20-50 km) could assume computations in a vertical column. At higher resolution a tilted column for solar radiation computations should be used to include the effect of cloud geometry.



Discussion and conclusions (1)

As far as surface radiation budget is concerned :

- Simple test computations indicate that it is an order of magnitude more important to avoid ’column physics’ for solar radiation than for thermal radiation

- For both solar radiation and thermal radiation the limitations of column physics becomes more serious for clouds extending to great heights in the atmosphere while shallow clouds close to the ground tends to be not problematic in the same context.

Discussion and conclusions (2)

- The shadows from clouds are easily visible in satellite images and may in extreme situations for tropical convection exceed 100 km.

- A method has been outlined for treating solar radiation parameterization in `tilted´ columns in the direction of the sun while still doing thermal radiation in vertical columns.

- The effect of tilted columns is expected to be significant when decreasing grid size in mesoscale models and in the case of quasi-stationary cloud bands extending to great heights.