Computationally efficient tilted independent column calculations of surface radiation
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Kristian P. Nielsen & Bent Hansen Sass
The Danish Meteorological Institute
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Tilted array modeling: Introduction
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Coarse mesh meteorological models (horizontal grid size $\sim 20$-$50$ km) could assume computations in a vertical column. DMI is among the first to implement a tilted column for solar radiation computations for high horizontal model resolution ("cloud geometry effects").

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

Previous works

Varnai and Davies (1999)
Markowski and Harrington (2005)

Kathrin Wapler, PhD Thesis, München, 2007:

- TICA is a very good approximation for surface solar radiation, when compared to exact 3D-modeling.
- When TICA is not applied, convective clouds have shorter lifetimes.
- The cloud shadows significantly affect the pattern of convection.

*Abbildung 4.5:* Vertikalschnitt des Wolkenwassermischungsverhältnisses nach 44 min der Simulationen mit EULAG (links) und mit EULAG-TICA30 (rechts).
Tilted array modeling: Theory

\begin{align*}
    x_{\text{tilt}}(x, y, z) &= \frac{Z(x, y, z) \tan(\theta_0(x, y))}{\lambda(x, y, z)} \sin(\phi_0(x, y) - \rho_{\text{grid}}(x, y)) \\
    y_{\text{tilt}}(x, y, z) &= \frac{Z(x, y, z) \tan(\theta_0(x, y))}{\phi(x, y, z)} \cos(\phi_0(x, y) - \rho_{\text{grid}}(x, y)) \\
    \rho_{\text{grid}}(x, y) &= -\tan^{-1}\left(\frac{\phi(x + 1, y) - \phi(x - 1, y)}{\cos(\phi(x, y)) (\lambda(x + 1, y) - \lambda(x - 1, y))}\right)
\end{align*}

Here, \((x, y, z)\) are the regular array indices, \((x_{\text{tilt}}, y_{\text{tilt}}, z)\) are the array indices of the tilted array, \(\rho_{\text{grid}}\) is the local rotation between the modeling grid and the geographical grid, \(Z\) is the geopotential height, \(\theta_0\) is the solar zenith angle, \(\phi_0\) is the solar azimuth angle, \(\phi\) is the latitude and \(\lambda\) is the longitude.
Tilted arrays

- Cloud cover
- Cloud water
- Cloud ice
- Specific humidity
- Temperature

...used to calculate

- Surface short wave radiation
Results for clear sky conditions


[Graph showing accumulated surface flux]
Results for overcast conditions

Station 6156: Holbæk, 2009-11-23.
Results for mixed cloud conditions

Station 6068: Isenvad, 2009-11-23.
Problem with tilted arrays

How to use tilted arrays on a parallel-processing computer?
Tilted array modeling - SLSWAP

Fig. 4.0 - Halo zone exchange in north-south and east-west direction

Boerhut (2003).
With tilted array modeling
Without tilted array modeling
Without tilted array modeling

24-hour precipitation 2010-08-14 0 UTC +24h
With tilted array modeling

24-hour precipitation 2010-08-14 0 UTC +24h
Tilted array modeling difference

24-hour precipitation 2010-08-14 0 UTC +24h
Further aspects of 3D-radiation

Example 2
order of magnitude computation for thermal radiation

Fig. 4: Assumptions for ‘worst case’ type of computations of net radiation at the ground giving significant differences between cloud 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 exist outside the vertical ‘column’ (cylinder).

Fig. 5: Results for thermal radiation in stratus/fog cloud conditions. Maximum error occurs when the grid size goes to very small values considering a 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.
Concluding remarks

- We have deviced a method for implementing tilted array modeling, which is only 1.09 times slower than a regular NWP run;
- Tilted array modeling significantly affects the strength and distribution of convective precipitation;
- Further aspects of 3-D radiative transfer could also be implemented;
- How to proceed?