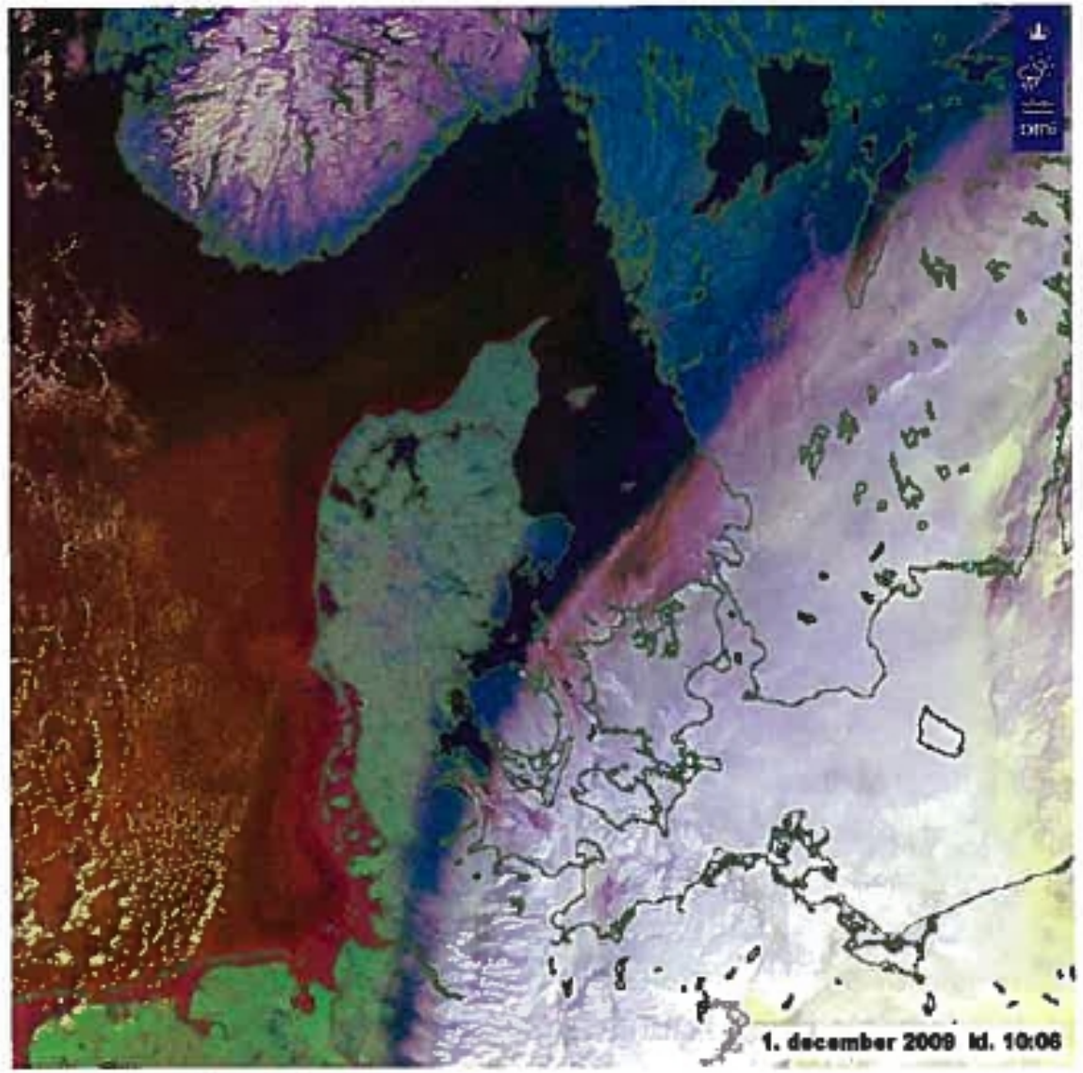
3D radiation and cloud-radiation modelling
2022-04-05

Kristian P. Nielsen, Bent Hansen Sass,
Bjarne Stig Andersen & Peter Ukkonen
The Danish Meteorological Institute (DMI)

3D effects of solar radiation

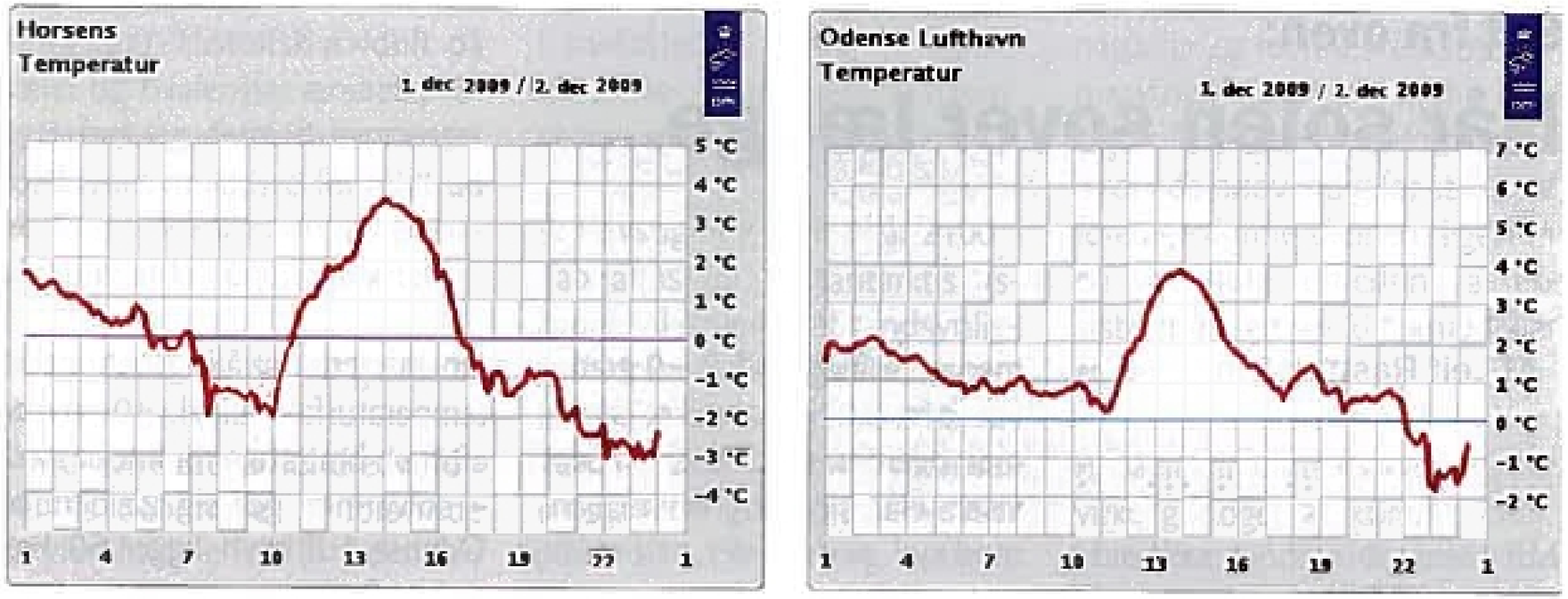


Visuelt NOAA-billede fra dmi.dk.

Vejret, **122**, februar 2010 • side 37

L. Rasmussen, Vejret 122: 37.

3D effects of solar radiation

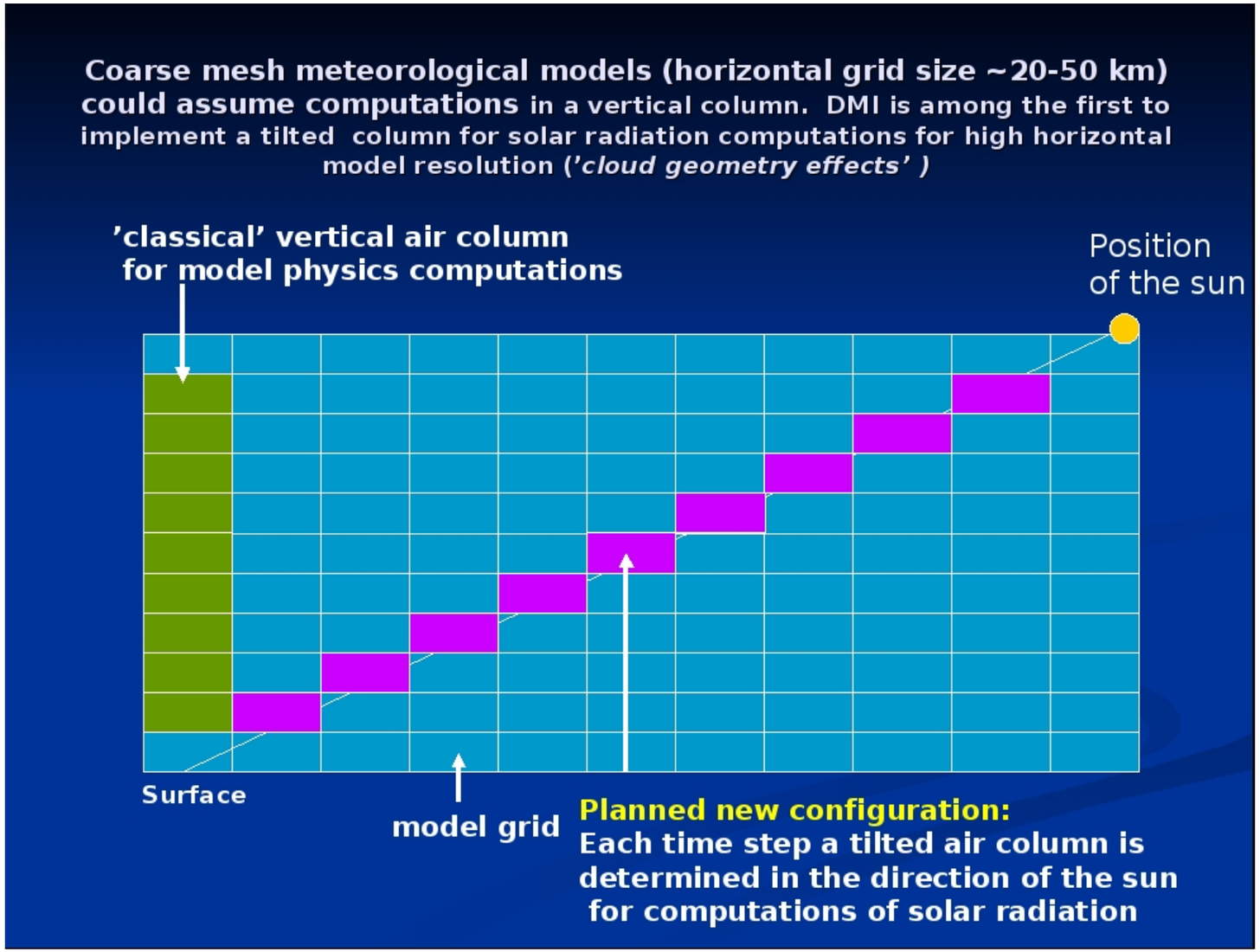


Til venstre et termogram fra Horsens. Til højre et termogram fra Beldringe ved Odense.

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

3D effects of solar radiation



Bent Hansen Sass

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

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.

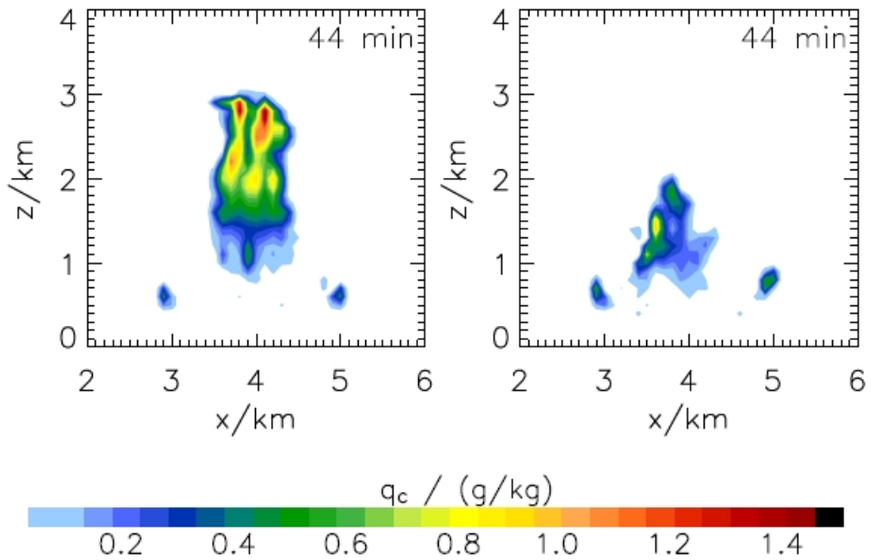


Abbildung 4.5: Vertikalschnitt des Wolkenwassermischungsverhältnisses nach 44 *min* der Simulationen mit EULAG (links) und mit EULAG-TICA30 (rechts).

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

Thermal 3D radiation aspects

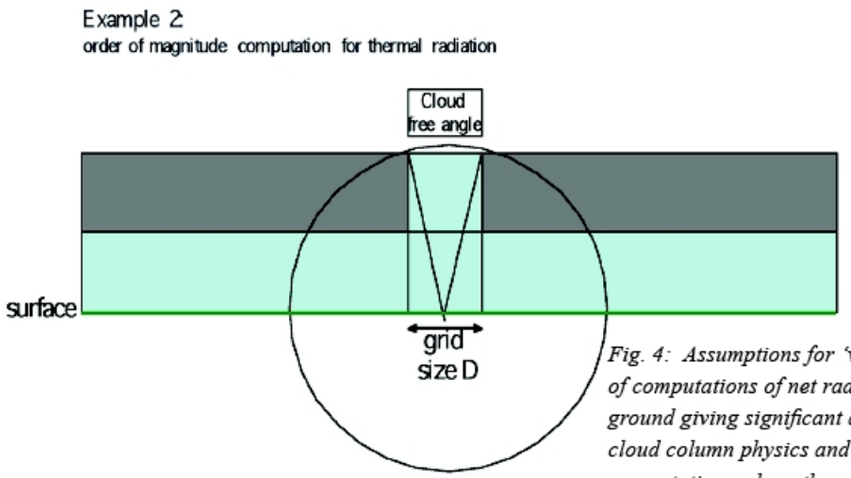


Fig. 4: Assumptions for 'worst case' type of computations of net radiation at the ground giving significant differences between cloud column physics and more realistic computations where the actual sky view (cloud free cone) is taken into account, integrating radiance over the half sphere above the ground – cloud layers of big horizontal extent exist outside the vertical 'column' (cylinder) !

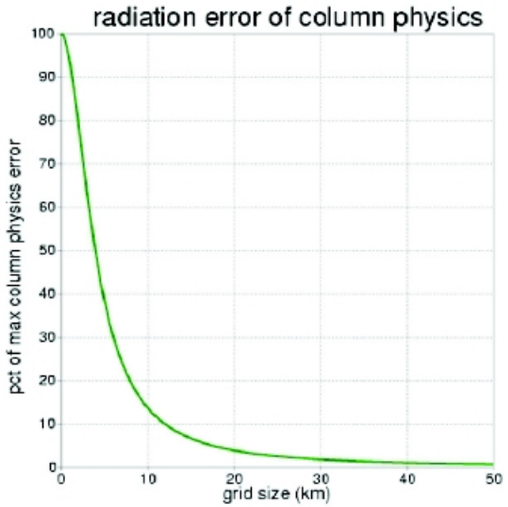


Fig. 5: Results for thermal radiation in stratifom cloud conditions.
Maximum error occurs when the grid size goes to very small values considering a cloud free column while in reality the surroundings are covered by a large cloud sheet radiating like a black body towards the ground. The figure shows the percentage of the maximum error (~98 W/m²) as a function of grid size, arising from executing column physics under the specified conditions.

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

The SPARTACUS solver (ecRad)

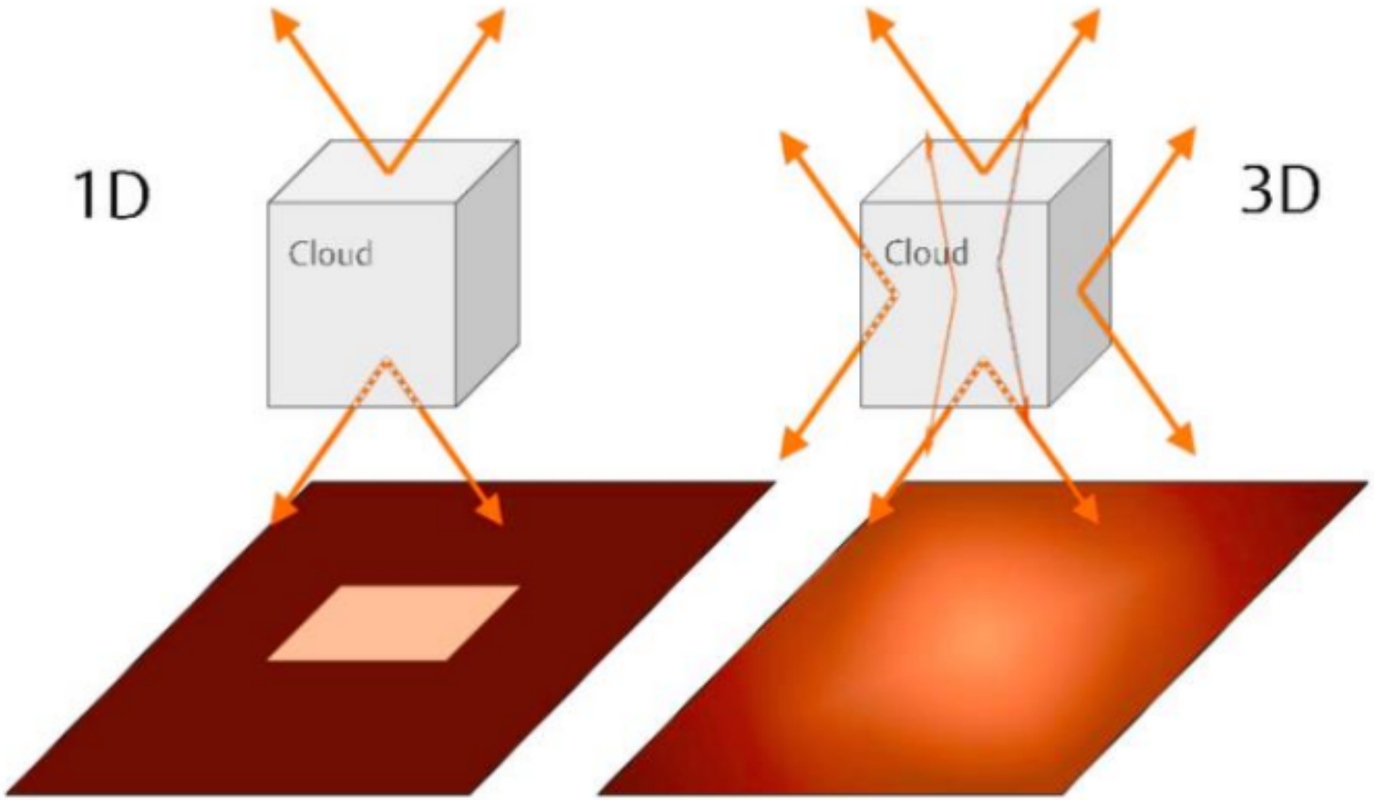


Figure 1. Schematic of outgoing fluxes and their contributions to total downwelling flux in 1-D and 3-D schemes for a cubic cloud. Because of symmetry, the total outward flux G through every cloud face is the same, as discussed in section 2. Every arrow symbolizes a flux of $G/2$ through the respective face. At cloud sides, half of the outgoing radiation is at an upward angle, the other half at a downward angle. The distribution of downwelling flux at the surface is shown below: in a 1-D scheme, we only see downwelling flux directly underneath the cloud, while in a 3-D scheme, cloud side fluxes result in a more spread-out distribution as well as in higher total downwelling flux.

Schäfer, Hogan et al. (JGR 2016)

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

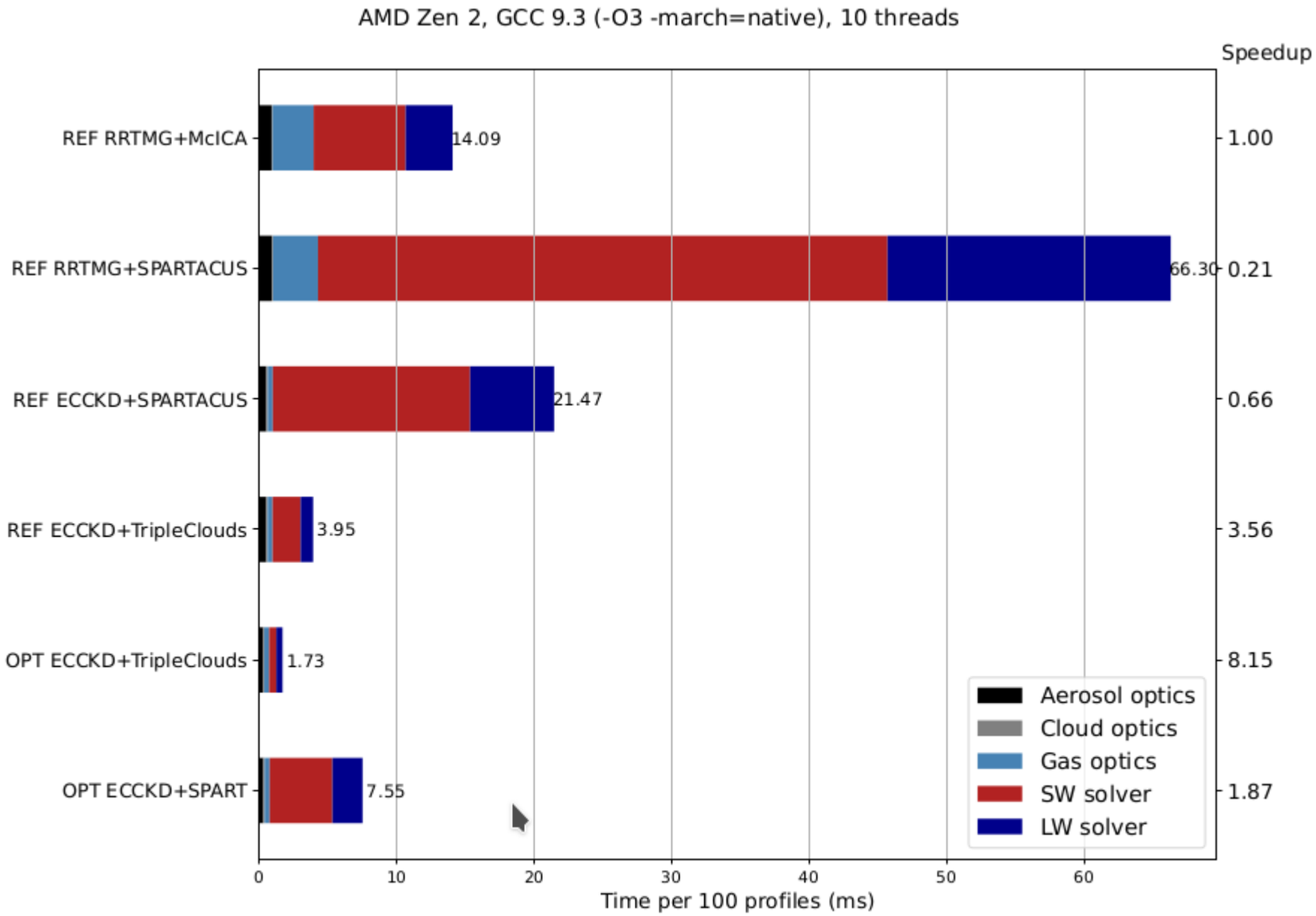
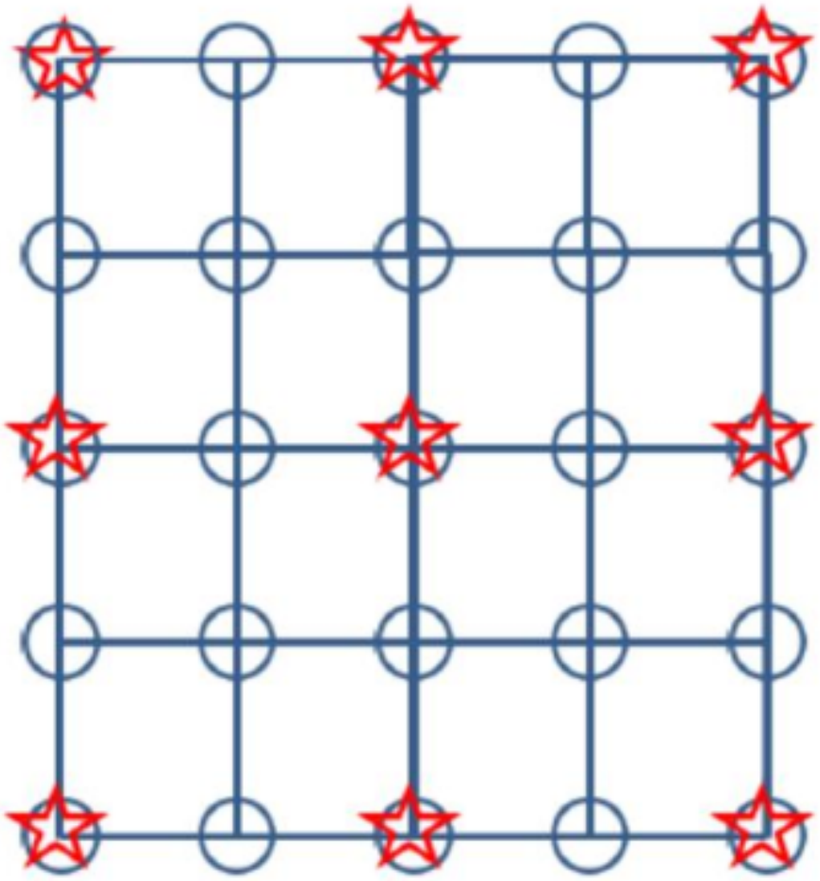


Figure 6.2: Time per profile for different configurations and code versions of ecRAD. "REF" = reference code, "OPT" = optimized code.

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

Reduced radiation grid



Used for instance in IFS. RADHEAT could be used intermittently.

Reduced radiation grid results

ACRANEB2 version 2 (expensive)

KNUM / KFAC	1	2	4	7	10
2	N_f=9 N_c=4 E=0.1007s F=2.13	N_f=25 N_c=9 E=0.2862s F=2.70	Nf=81 Nc=25 E=0.9107s F=3.14	Nf=225 Nc=64 E=2.4154s F=3.29	Nf=441 Nc=121 E=4.6700s F=3.61
4	N_f=25 N_c=4 E=0.2858s F=5.41	Nf=81 Nc=9 E=0.9114s F=8.45	Nf=289 Nc=25 E=3.0696s F=10.99	Nf=841 Nc=64 E=9.0692s F=12.81	Nf=1681 Nc=121 E=17.697 F=13.64
7	N_f=64 N_c=4 E=0,6850s F=12.71	Nf=225 Nc=9 E=2.361s F=21.61	Nf=841 Nc=25 E=8,899s F=31.54	Nf=2500 Nc=64 E=26.24s F=36.85	Nf=5041 Nc=121 E=53.021s F=39.61
10	N_f=121 N_c=4 E=1.351s F=28.42	Nf=441 Nc=9 E=4.685s F=43,76	Nf=1681 Nc=25 E=17.62s F=61.05	Nf=5041 Nc=64 E=52.94s F=71.76	Nf=10201 Nc=121 E=107.03s F=76.25

Table 2: Results of ACRANEB2 version 2

Results of one time step test based on ALADIN-HIRLAM CY40 h1.1 code of ACRANEB2, computed on a single CPU, GNU 4.8.4 compiler, intel processor COREi5 1.70 GHz using the full version of the ACRANEB2 scheme.

This means that computation of optical depths (solar plus thermal) are included. Also the exact computation of non statistical weights in the thermal radiation is included.
Namelist options : NSORAYFR=1, NTHRAYFR=1 and NRAUTOEV=1 respectively.

The table shows in black

$N_f = (1 + KFAC * KNUM)^2$ (fine mesh) ,
$N_c = (1 + KNUM)^2$ (coarse mesh)

In blue: execution time of ACRANEB2 using N_f grid points.

In light brown: F is relative speed up factor, reducing execution time, between execution of `acraneb2´ and `acraneb2c´ schemes, for different choices of KFAC and KNUM.

Sass & Nielsen (2017) from the ESCAPE FP7 project

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

Why to run with a coarser radiation grid?

- **With progressively smaller columns 3-D radiative effects introduce larger and larger errors at higher and higher costs**

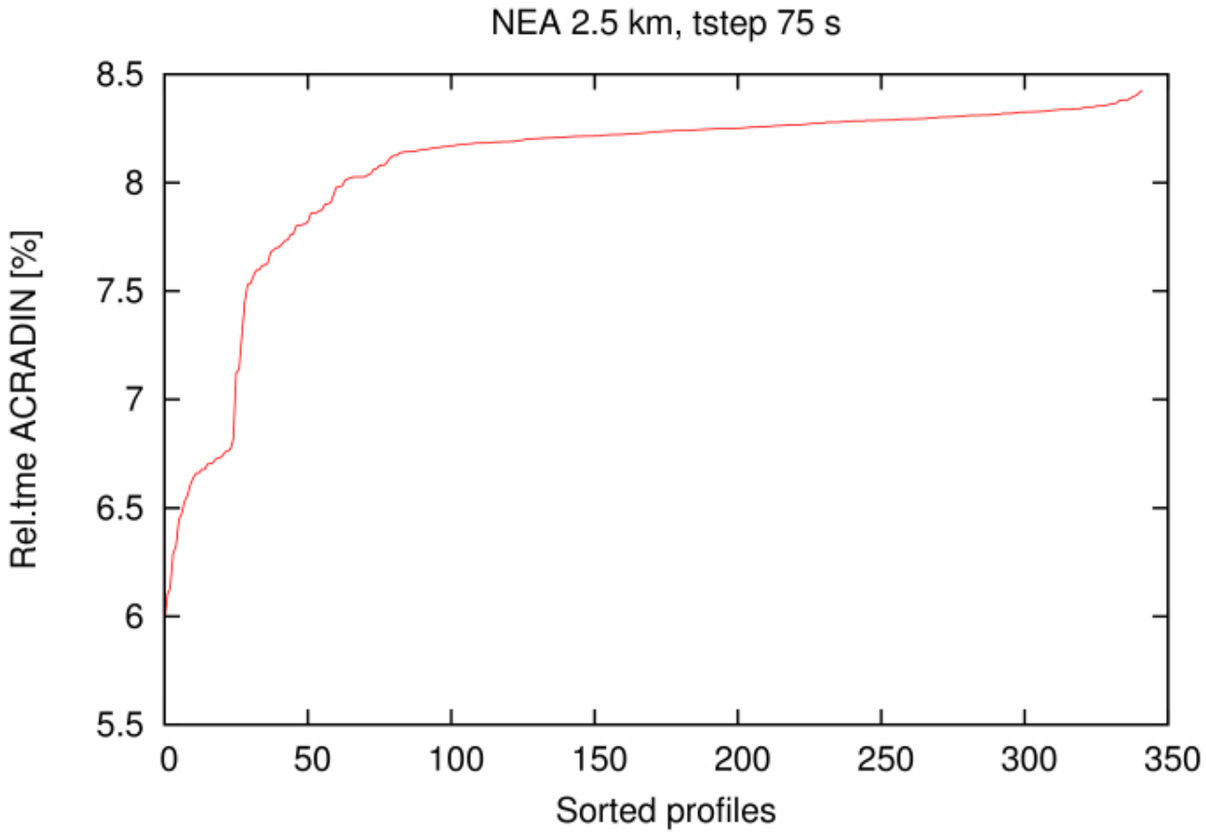
- Full resolution surface temperature variations and solar zenith angle changes could be accounted for with existing intermittent computation (RADHEAT)

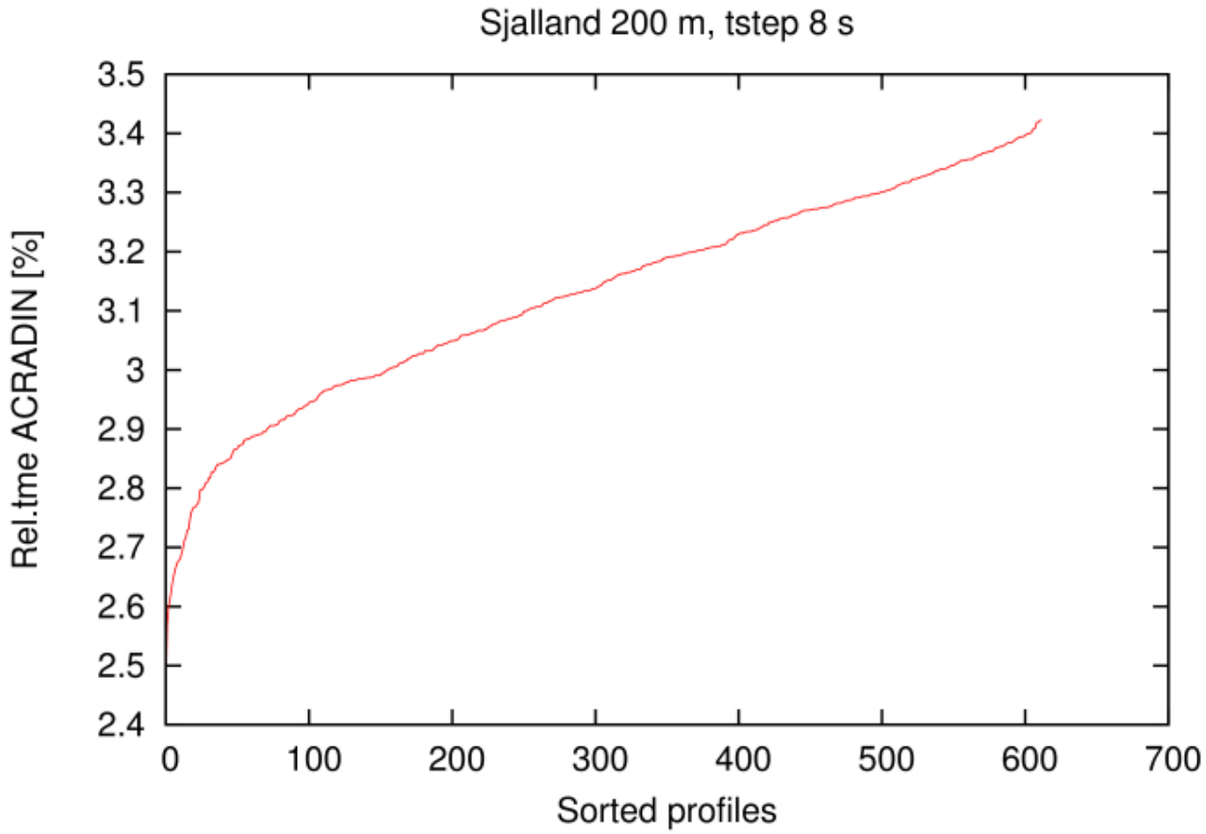
- **This will also work with the ecRad sub-grid 3D SPARTACUS solver**

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

Intermittent physics runs example: Radiation drhook profiles

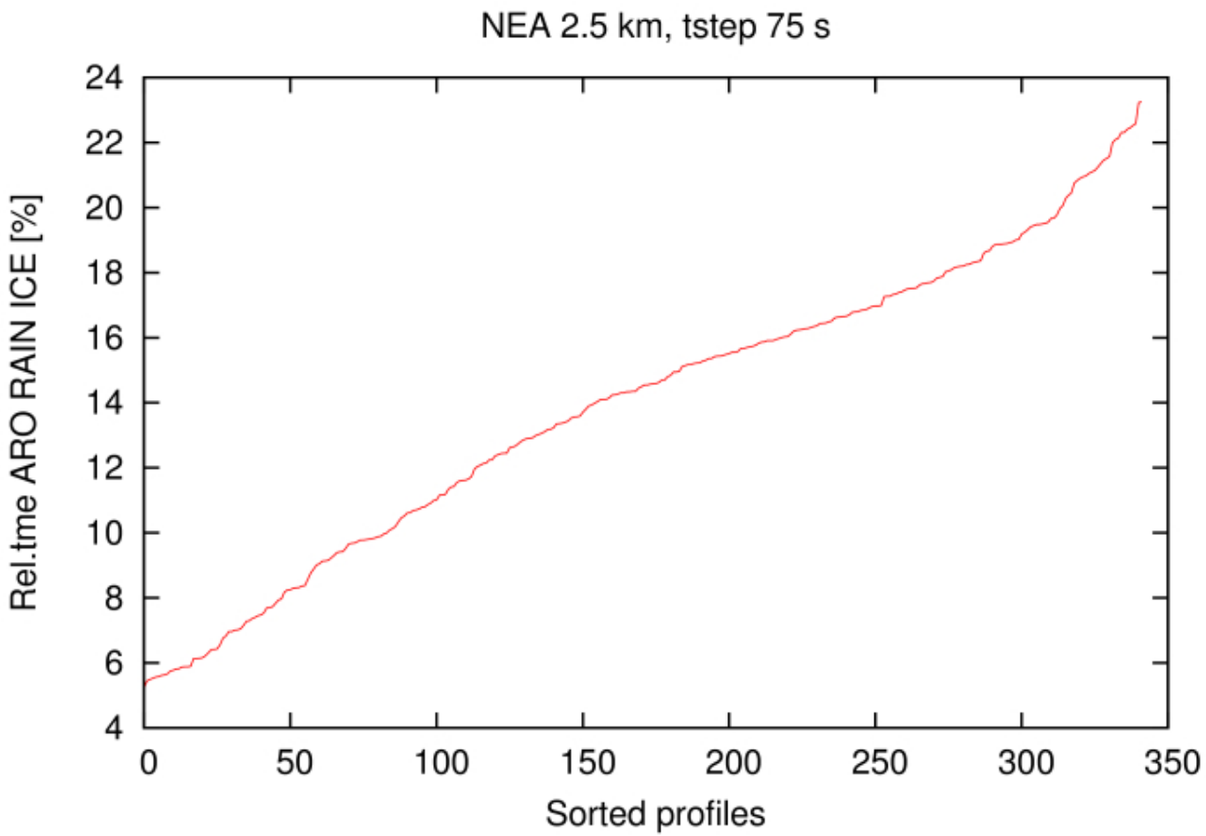


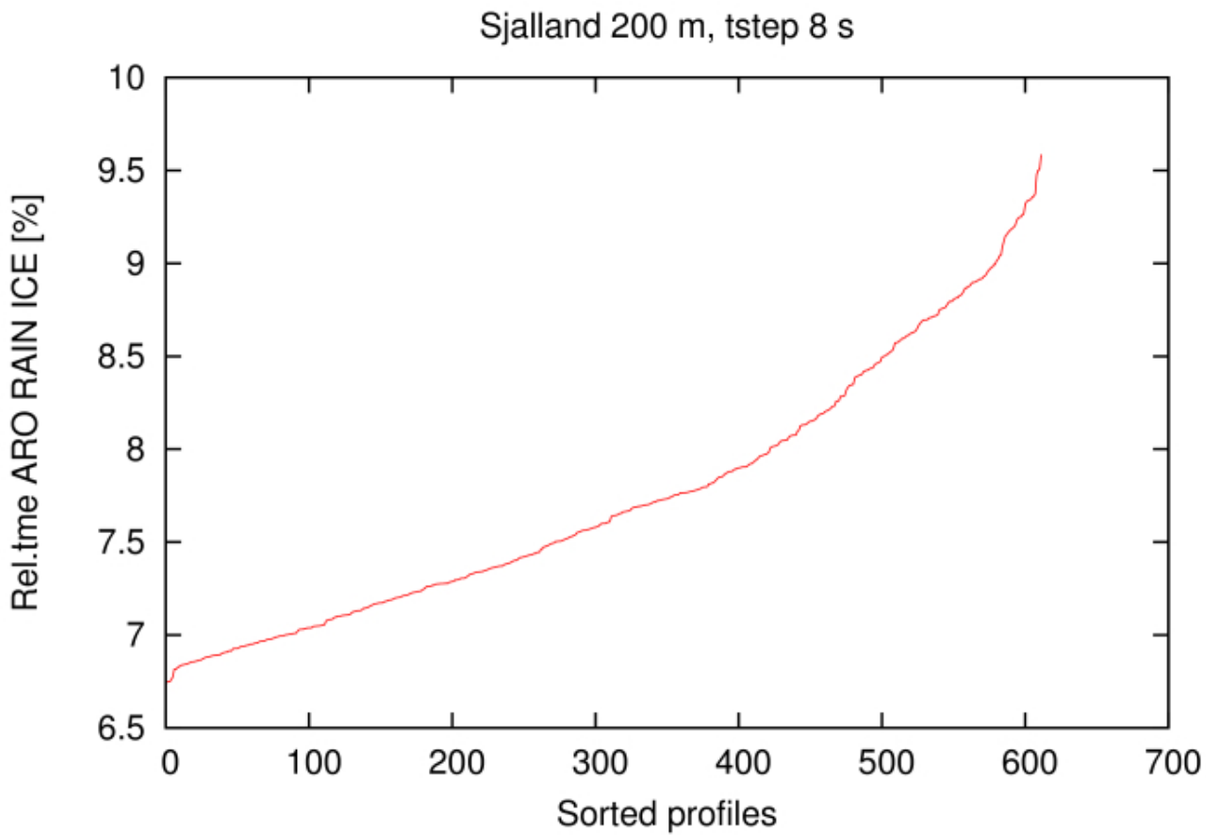


Only run every 15 minutes.

RADHEAT (<0.1% rel. time) is run intermittently.

Cloud microphysics drhook profiles



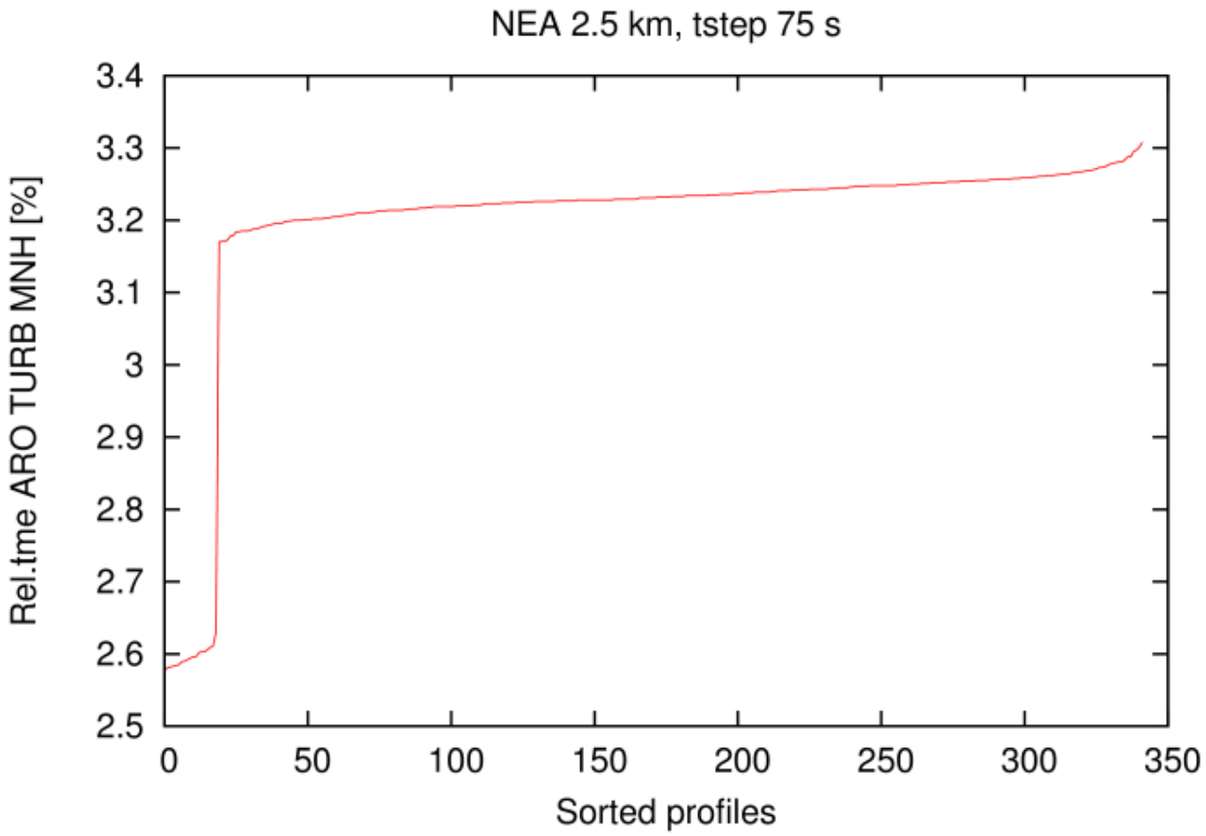


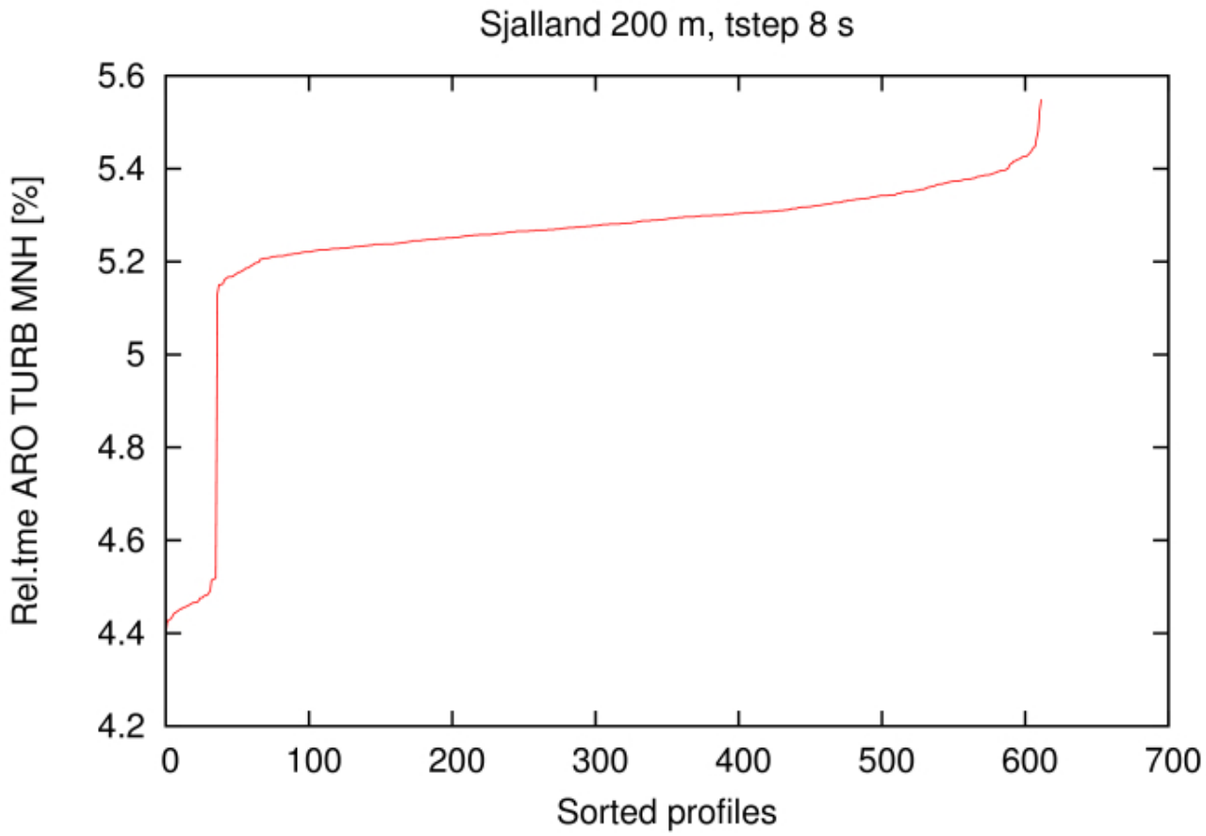
Notice the large spread in ARO_RAIN_ICE relative times!

DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development

Turbulence drhook profiles





DMI

ACCORD
A Consortium for COnvection-scale modelling Research and Development