21 December, 2010

WRF LES simulations – Status report

Introduction

Uni BCCS (Uni) in Bergen and Institute for Meteorological Research (IMR) have made an agreement regarding development of a system to run the atmospheric model AR-WRF in LES mode. IMR is to set up and run AR-WRF in LES mode for three different regions:

- Utsira municipality in Rogaland county, Norway
- Havsul area, outside Møre county, Norway
- Bolund, Risø, Denmark

The final horizontal resolution is to be 50 meters and input data are to be from ECMWF.

Deliverables

IMR is going to develop a software suite that makes it easy for user's to set up, and run, AR-WRF in LES mode. The software suite will be tailored for use on the Hexagon super computer in Bergen, but the resulting executable scripts can be modified for use on other machines. In addition to this, IMR will download high resolution terrain data (ASTER) for the regions in question, and make the necessary modifications to the AR-WRF pre-processing system for the data to be used. In short, what will be done is this:

- Download ASTER data for a region that will cover all three sites mentioned in the contract. Do the necessary modifications to `GEOGRID.TBL` and `METGRID.TBL` in order to use this data.
  - Document how this is done so as to make it simple to get high resolution ASTER data for other regions of the world and use with WRF.
- Write a stand alone python software suite (i.e. one that can be used anywhere) that makes it straight forward to run AR-WRF in mixed PBL/LES mode. This would be a command line interface (at least to begin with) where the user either defines a central point and radius, or two corner points of the innermost (50 meter) domain. The system would than set up all the necessary namelist files and line up the WRF modeling system. The end result would be a PBS file ready to be submitted (via "qsub") by the user.
  - Note that the user can still modify the resulting `namelist.wps` and `namelist.input` files manually in order to modify the proposed domain setup.

The simulation philosophy is as follows:

- Run WRF in normal (i.e. PBL) mode at 8100m and 2700m resolution.
- Use NDOWN to create IC/BC data at a 1350m resolution.
- Run WRF in LES mode at 1350, 450, 150, and 50m resolution.

The description regarding `ndown` in the WRF on-line manual is somewhat lacking in detail. There is for example no mentioning lower boundary data. What we are doing now is to have a six domain setup like this:

8100	2700	1350	450	150	50	resolution [m]
1:3	1:3	1:2	1:3	1:3	1:3	nesting ratio
PBL	PBL	NDOWN/LES	LES	LES	LES	PBL vs. LES

- Create the `met_em.d0?` and `wrf*d0?` input files for all six domains.
- Run the WRF model in PBL mode for `Domain01` and `Domain02` with five minute history interval. For comparison purposes, one can also run for `Domain03`.
- Run NDOWN to create `wrfinput_d01` and `wrfbdy_d01` for the outermost LES domain (1350 m resolution).
- Link `wrflowinp_d01` to the original `wrflowinp_d03` (i.e. 1350m resolution), `wrflowinp_d02` to the original `wrflowinp_d04`, etc., etc.
- Run WRF in LES mode with an outermost domain of 1350m and three nested domains (450, 150, and 50m resolution).

Status

AR-WRF has been set up and run for the Utsira region with two different horizontal model setups:

- Resolution of 8100m, 2700m, 900m, 300m, 100m, 50m (unstable)
- Resolution of 8100m, 2700m, 1350m, 450m (unstable)

The original plan was to start the LES simulations (MOAD of the LES runs) at 900 meter resolution. There seems however to be a bug in WRF with respect to the `adaptive_time_step` option. When the grid resolution of the inner domains multiplied with the time ratio between the domain and the one “above”it becomes less than one, the model bombs immediately when it starts running this domain. Initially we believed the bug was manifested in that the outermost domain could not be less than 1000m resolution. The reason for this misunderstanding was that the MOAD was 900m (this is a LES simulation) and `domain02` was 300m. Hence, the time ratio was 1:3 → 3*300m = 3*0.3km = 0.9 “sec” → model bombs when entering the 300m domain.

This bug will be reported to the WRF community.

Running with fixed timestep can be troublesome as:

- One misses out the flexibility of the adaptive time step.
- Write-to-file times drifts for MOAD if the time step is not an integer ratio of the history interval. This can lead to that the final step is not written to `domain01` output file.

Now, we have done a 27 hour simulation for Utsira at a resolution of 8100, 2700 (output written every 5 minutes) and 900 meters using the MYJ PBL scheme. Than we did NDOWN from the 2700 domain down to 900 and ran again with one 900 meter domain, using both the MYJ scheme and the 3dTKE method. The result from the NDOWN/PBL simulation are very similar to that of the regular one-way-nesting simulation, indicating that a 5 minute update of input on the boundaries is sufficient.

We then did one simulation in LES mode with a 900-300-100m resolution setup (the 50m domain crashed with CFL errors when we had the outermost timestep=2.7 sec). It took about 27 hours to run a 27 hour simulation, using 32 cpu's on Hexagon. We have not spent much time on the results as we're still using the USGS 30sec terrain data. Hence, the topography at higher resolution is just showing a hill that looks like it was created by huge Lego-chips.

We then changed the domain setup, starting the LES simulations at 1350m resolution instead of 900m. As with the former setup, the three model simulations at 1350m (i.e. one-way-nesting, NDOWN/PBL, and NDOWN/3dTKE) showed very similar behavior (cf. Figs. 1 to 4).

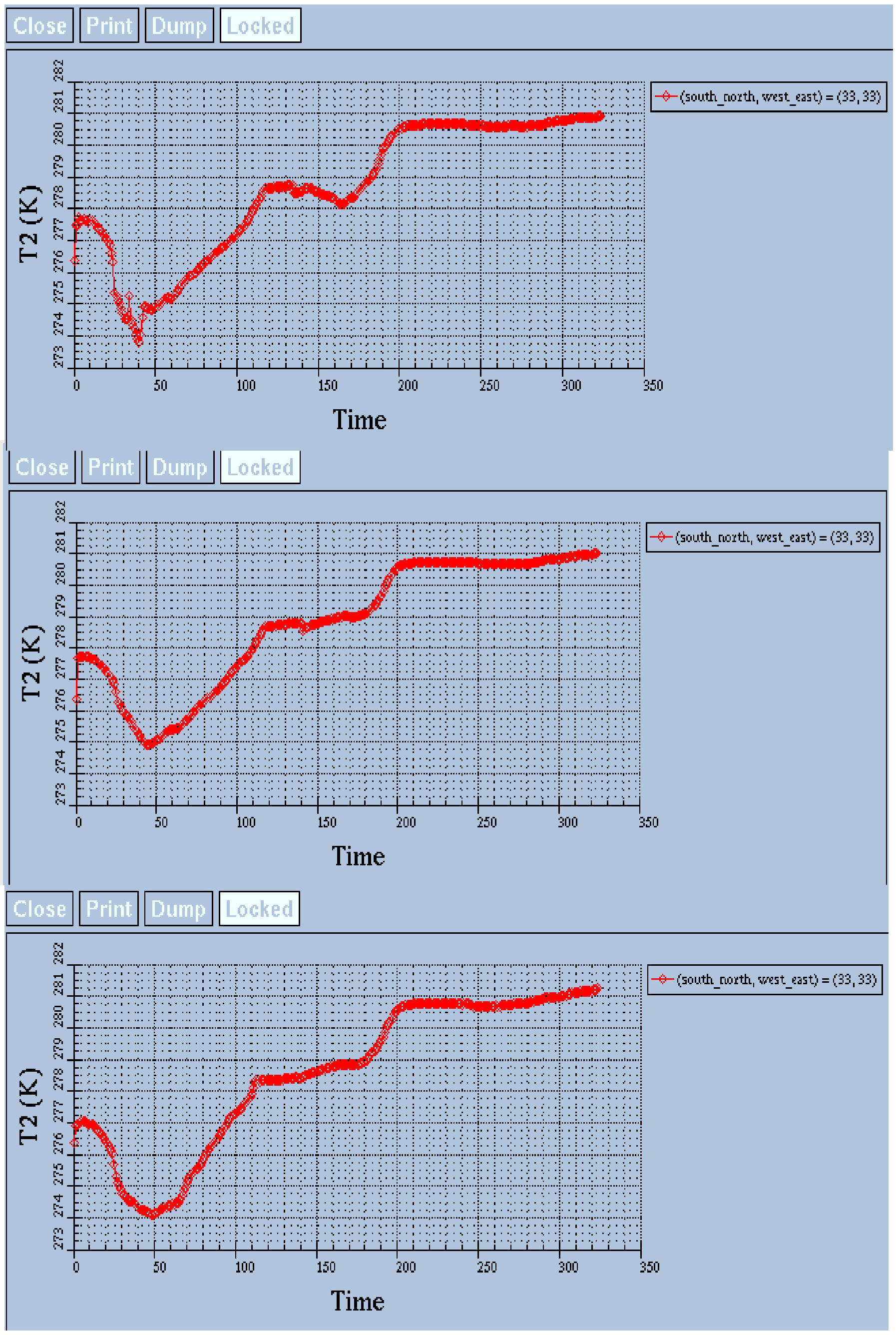

Figure 1: *Timeseries of variable T2 [K] at point (33,33) for the 1350m domain. One-way-nesting (top), NDOWN/PBL (middle) and NDOWN/3dTKE (bottom). Time is shown on horizontal axis, each "step" is five minutes.*

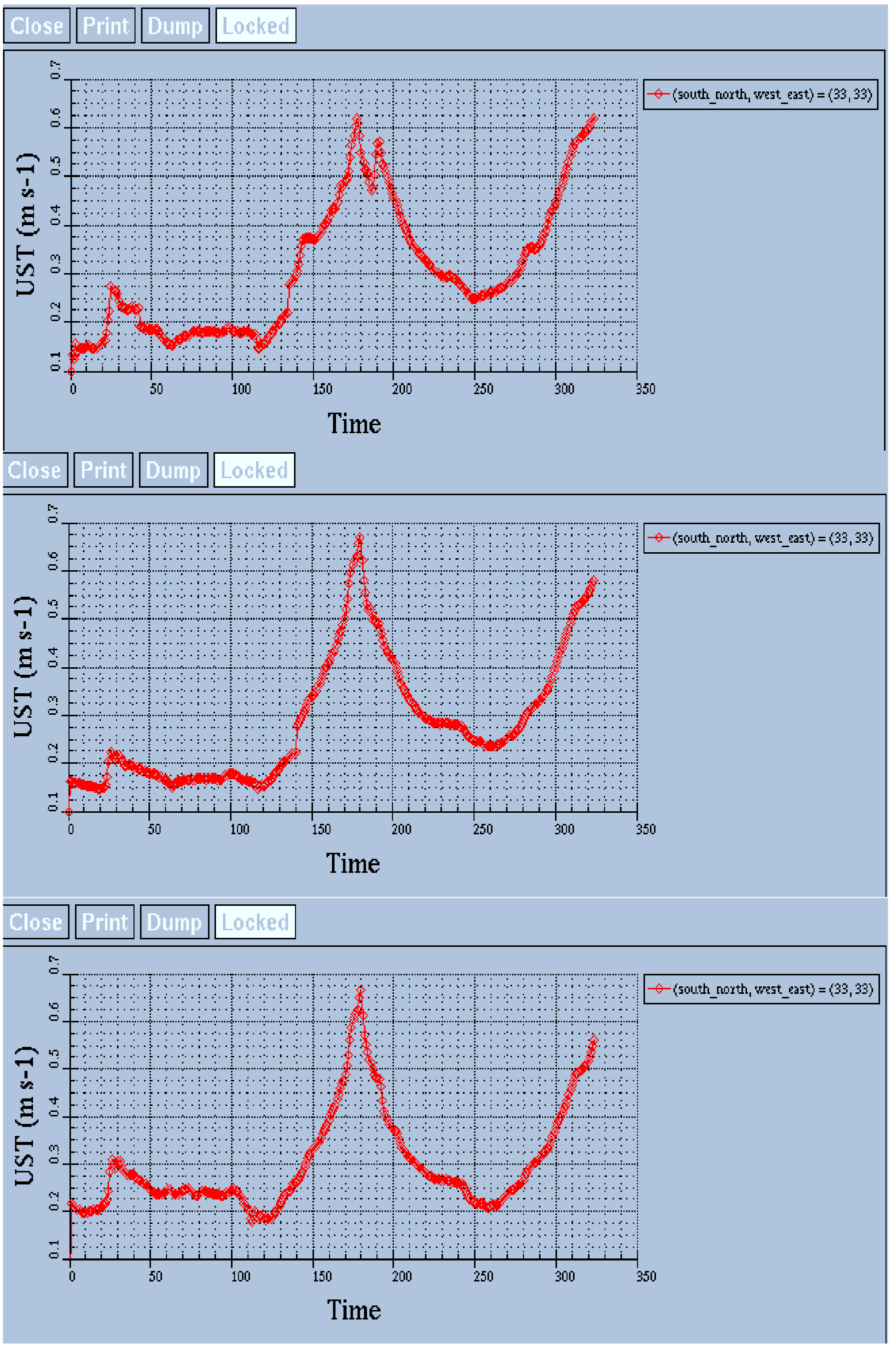

Figure 2: *Timeseries of variable UST [m/s] at point (33,33) for the 1350m domain. One-way-nesting (top), NDOWN/PBL (middle) and NDOWN/3dTKE (bottom). Time is shown on horizontal axis, each "step" is five minutes.*

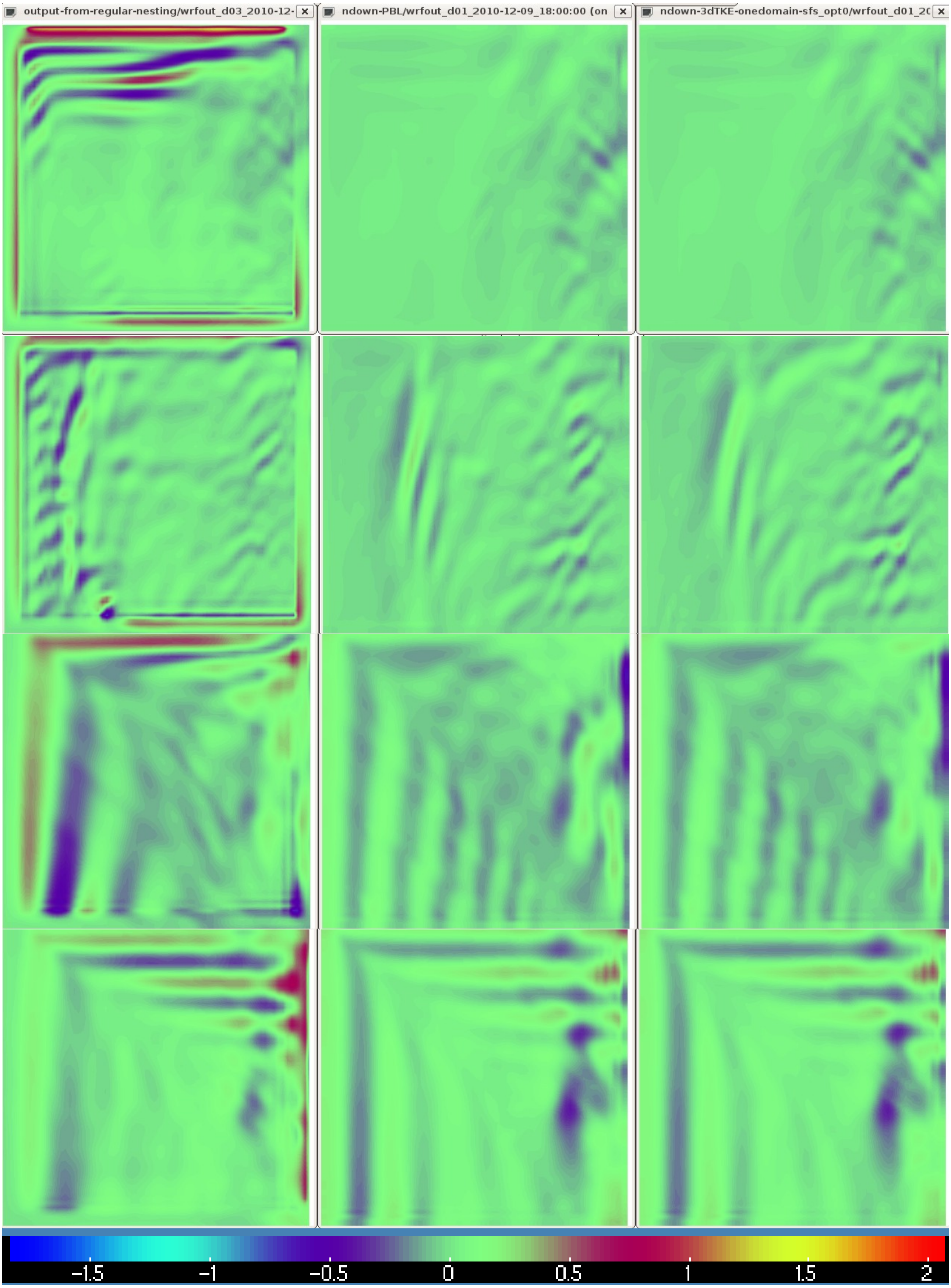

Figure 3: *Vertical velocity [m/s] at vertical level 20 for the 1350m domain. One-way-nesting run (left), NDOWN/PBL (middle), and NDOWN/3dTKE (right) after 1 hour (top), 3 hours (second from top), 22.5 hours (second from bottom), and 27 hours (bottom) of simulation time. Color scale at bottom shows wind speed in m/s.*

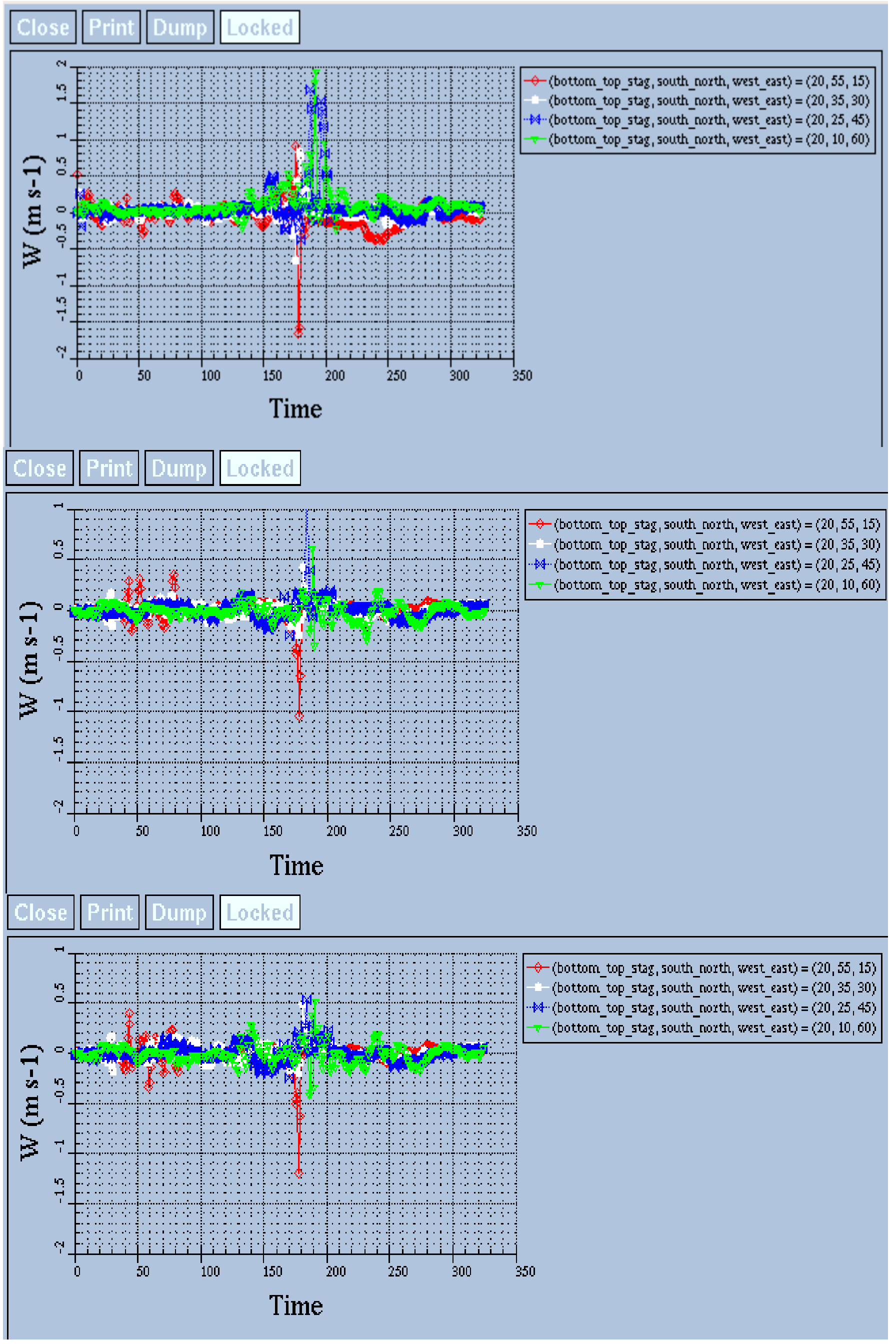

Figure 4: *Timeseries of vertical velocity [m/s] at vertical level 20 at four different points (15;55 – red, 30;35 – white, 45;25 – blue, 60;10 – green). The points are roughly along the diagonal line from the upper left corner to the lower right corner of the domain shown in Fig. 3. Simulations are One-way-nesting (top), NDOWN/PBL (middle) and NDOWN/3dTKE (bottom). Note the different vertical scale for top panel. Time is shown on horizontal axis, each "step" is five minutes.*

It is interesting to note that effects of the lateral boundaries seem to be less prominent for the NDOWN simulations (PBL and 3dTKE) than for the regular One-way nesting (cf. Fig. 3). All three simulations show similar results, especially the two simulations where the NDOWN technique was used.

Unsolved problems

There are downsides using the `adaptive_time_step` option, in particular it appears that when estimating whether or not the time step should be reduced the model only estimates the horizontal CFL value and not the vertical. We have been experiencing simulation crashes where the vertical CFL value is very large. This matter will be brought to the attention of WRF help.

Possible solutions to these numerical instabilities could also lie in increasing the number of vertical levels and/or increasing the `smooth_passes` for the highest resolution domains.

Miscellaneous

We have downloaded ASTER data for the region shown in Fig. 5. The data needs to be post-process the data in order to use them in AR-WRF.

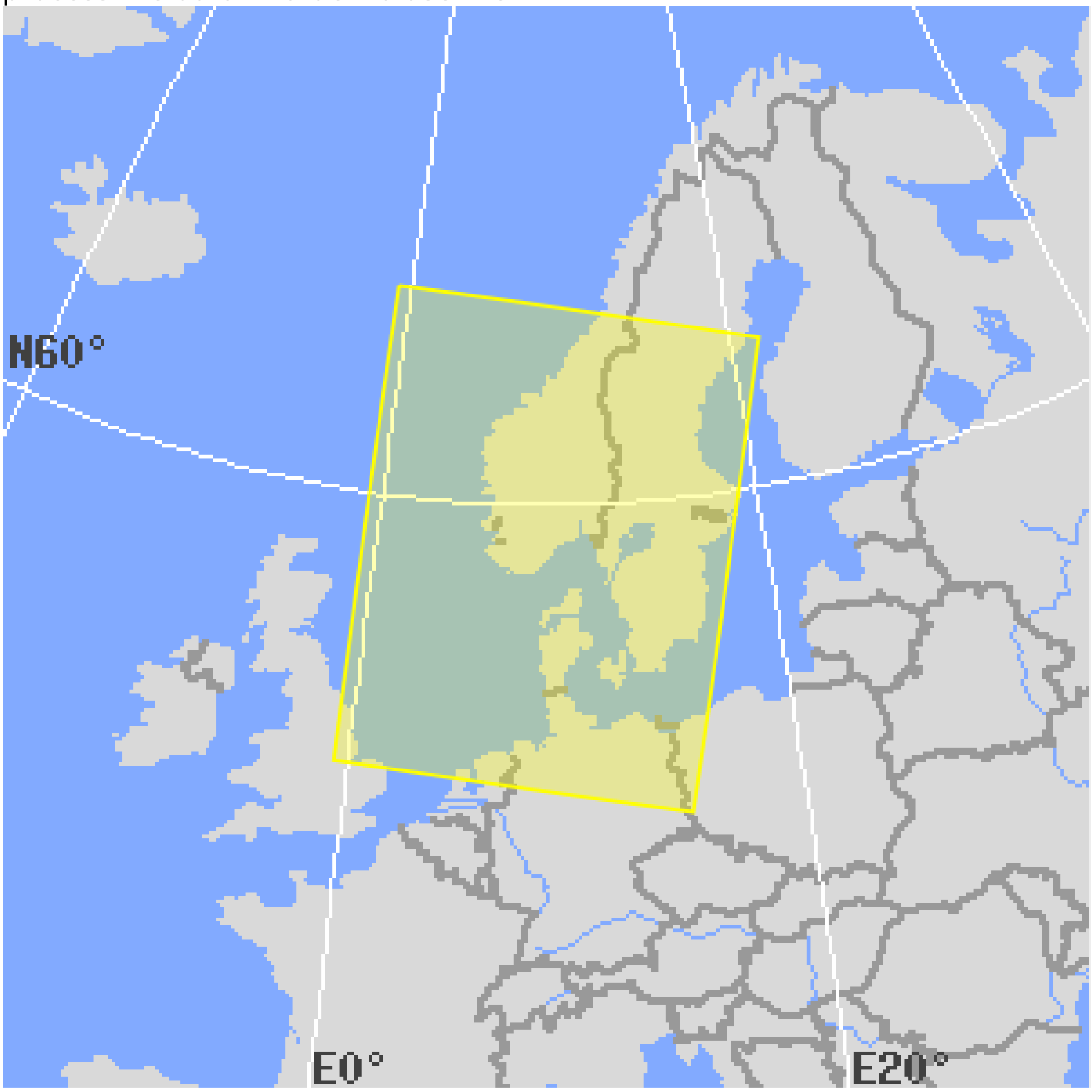

Figure 5: *High resolution ASTER data have been downloaded for the shaded area.*

We strongly recommend to use ECMWF data with full vertical resolution. This requires the data to be downloaded on model levels and to be converted to pressure levels using the `CDO` software package. In order for the interpolation to work, one also needs to download geopotential height on at least one pressure level (preferable between 700 and 850hPa, depending on local orography).