Karlsruhe Institute of Technology | NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH | Universität Augsburg University | KIT-Campus Alpin IMK-IFU: Atmospheric Environmental Research

Aerosol-aware, convection-resolving climate modelling

Regional and global modelling approaches with WRF and MPAS

Contact: heinzeller@kit.edu

Towards convection-resolving, global atmospheric simulations

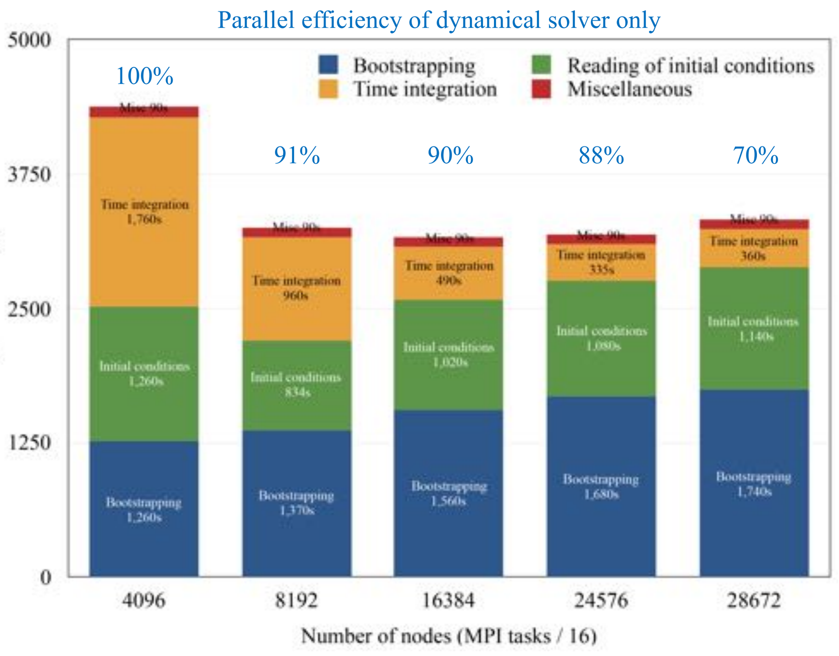
D. Heinzeller, M.G. Duda, H. Kunstmann, 2016: Geosci. Model Dev., 9, 77-110, http://www.geosci-model-dev.net/9/77/2016

MPAS Model for Prediction Across Scales

Convection-permitting global model applications are the next grand challenge in NWP and on the horizon of next-generation, massively parallel HPC systems.

Extreme scaling experiment with MPAS on FZJ JUQUEEN (IBM Bluegene /Q) :

- Regular 3km mesh, 65 Mio grid cells
- 41 vertical levels, double precision
- 1hr model integr., no disk output
- Initial conditions: 1.1TB netCDF3
- Min. 4096 nodes, 65TB memory
- Max. 28672 nodes (458752 cores)
- Fastest run: 6.3 x real-time, 1.6 Mio CPUh/24h integr.



The dynamical solver of MPAS scales up 400000 MPI tasks (160 cells/task) as on smaller meshes. The bottlenecks are model initialisation and disk I/O.

Step 1. Addressing the disk I/O performance

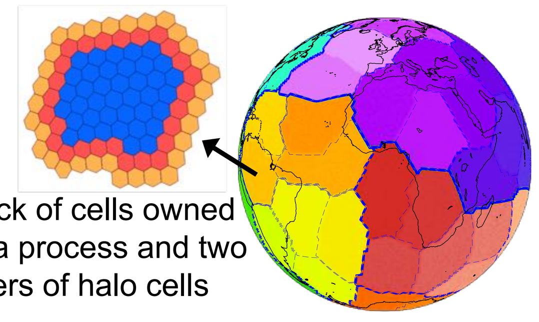
- SIONlib I/O layer for massively parallel I/O, internal + external data (http://www.fz-juelich.de/jsc/sionlib)
- Post-processor core to convert to netCDF and more

Time required to write 1.2TB restart file on LRZ SuperMUC (16384 tasks)

I/O format	Write time
pHDF5/netCDF4	607 s
pnetCDF (CDF5)	133 s
SIONlib	12 s

Step 2. Reducing model initialisation times

- Hybrid MPI+OpenMP parallelisation to speed up bootstrapping and decrease MPI comm.
- Focus on dynamical solver
- Maintain scaling of MPAS

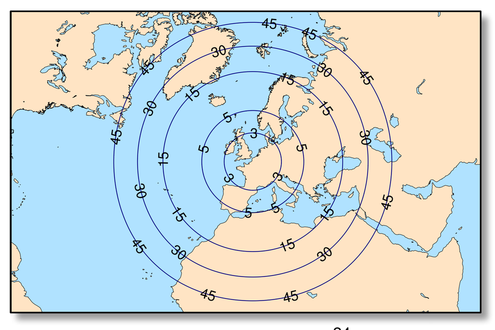


Block of cells owned by a process and two layers of halo cells

Nodes/MPI/OMP	Solver/h [s]	Init [s]	I/O [s]
4096 x 16 x 1	350	830	33
4096 x 8 x 2	323	258	39
4096 x 2 x 8	407	222	21
4096 x 1 x 16	689	162	5

1hr model integration of 3km mesh on SuperMUC

MPAS allows variable-resolution meshes with smooth transitions to address limitations of limited area models.



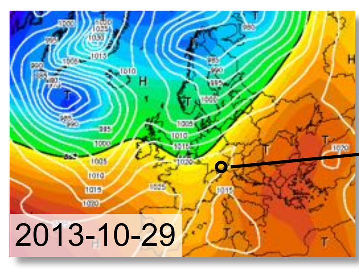
60-3km mesh with high-res. area centred over Europe

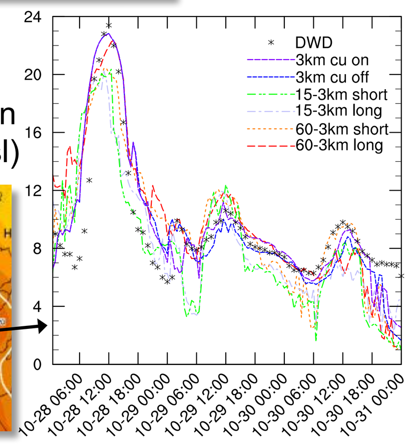
Putting it to the test: an NWP study over Europe

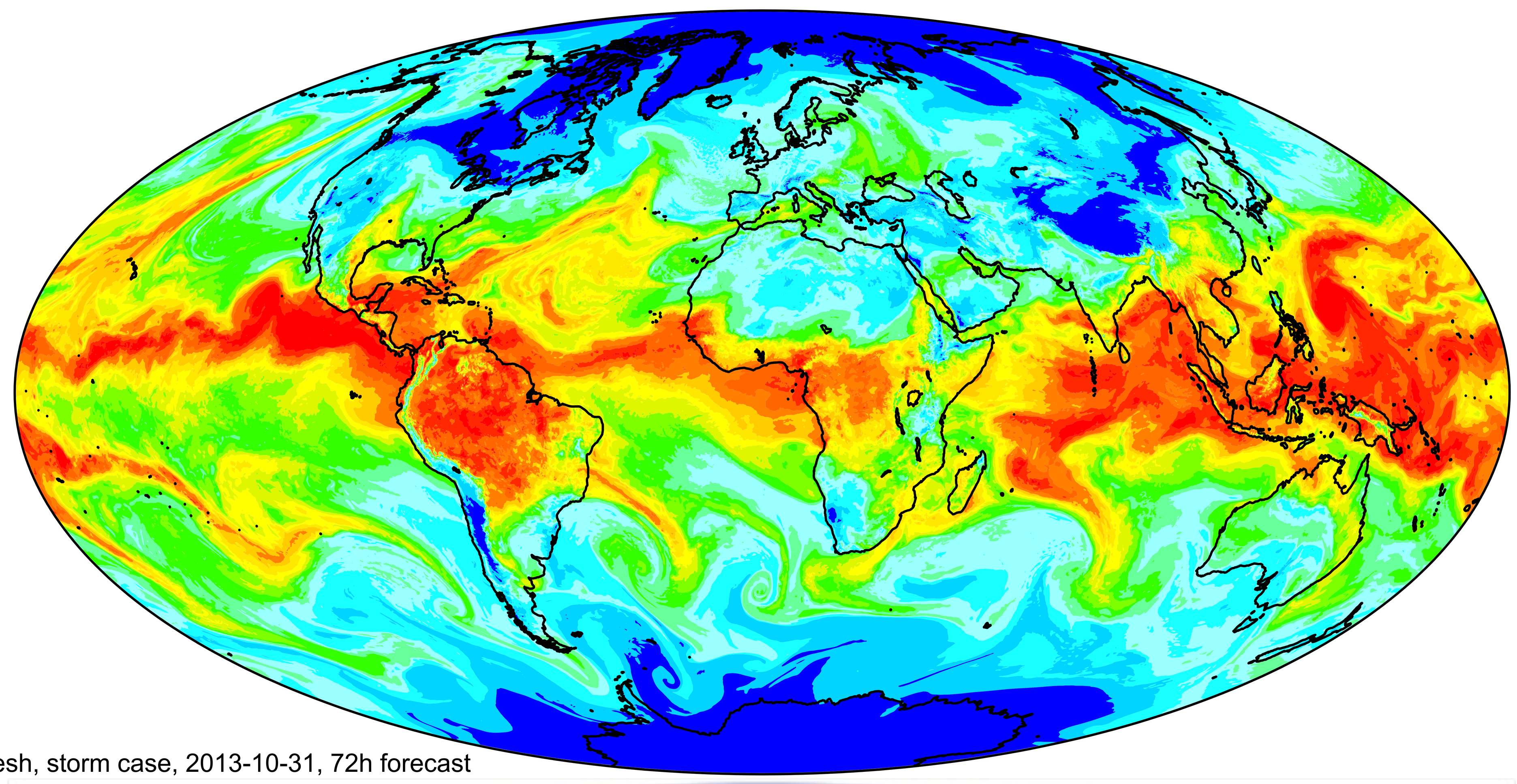
- Three selected events, 72h and 84h forecasts
- Variable-resolution meshes transitioning the grey zone, using the Grell & Freitas (2014) cu scheme
- Regular 3km mesh as reference model
- (to come) Validation against operational WRF forecasts at MeteoGroup (with Wageningen Univ.)

Mesh	nCells	Conv
60-3km	835586	GF
15-3km	6488066	GF
3km	65536002	GF/off

Storm case Oct 2013, 2m temperature [°C] in Garmisch-Partenkirchen (WMO 10963, 730m asl)







Precipitable water content 15-3km mesh, storm case, 2013-10-31, 72h forecast

Anthropogenic aerosol emissions and rainfall decline in South-West Australia

WRF Weather Research & Forecasting

D. Heinzeller, W. Junkermann, H. Kunstmann, 2016: Journal of Climate, http://dx.doi.org/10.1175/JCLI-D-16-0082.1

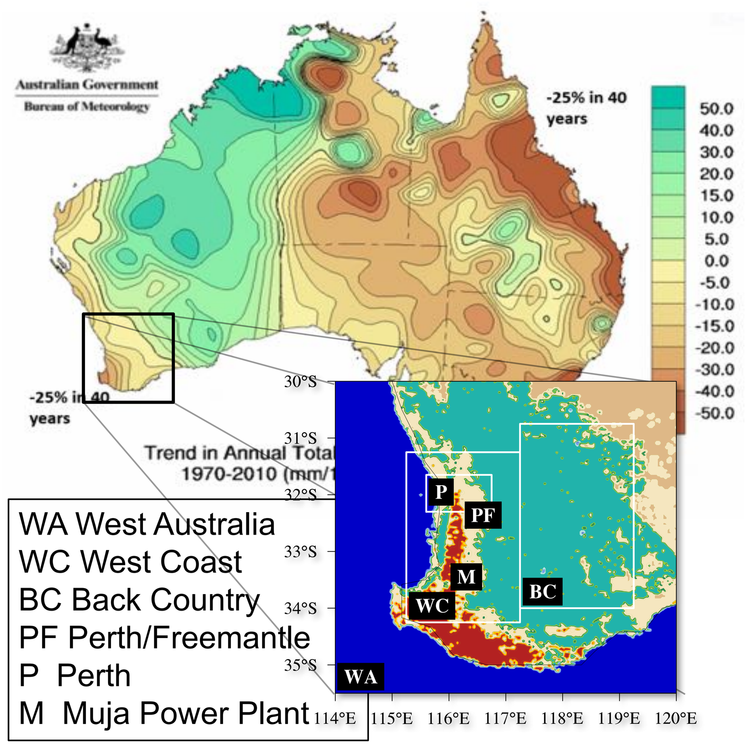
Significant decline in precipitation in SW Australia in the 20th century

- Continuous decline by about 15% for entire region (WA)
- Sudden drop by further 15% for Perth/Freemantle (PF) in the 70s

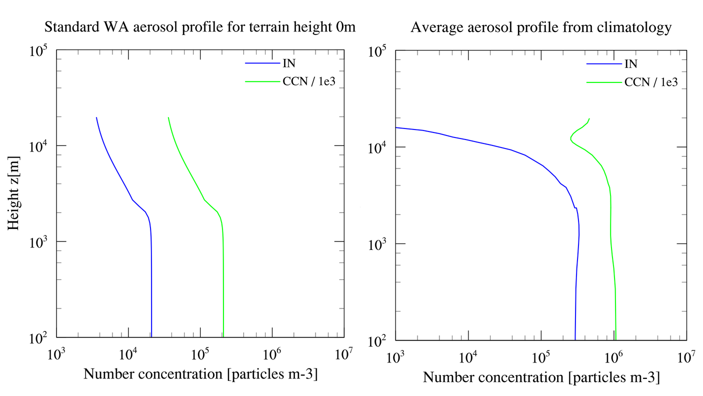
Possible reasons are:

- Continuous changes due to large scale circulation (slow)
- Deforestation, irrigation (fast)
- Anthropogenic aerosols from power plants/smelters (fast)

Anthropogenic aerosol emissions and rainfall decline – coincidence or causality?

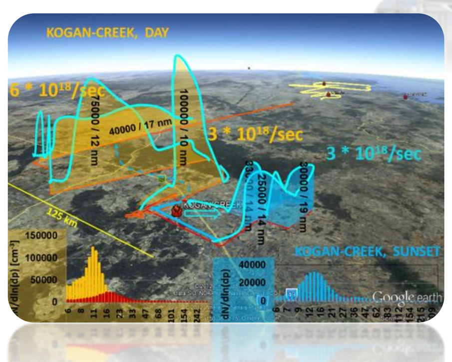


A high-resolution (3.3km) regional climate modelling study using WRFV3.6.1 with a new aerosol-aware microphysics scheme (Thompson and Eidhammer, 2014) for 1970-1974.



Pre-industrial CCN/IN emissions from 1970s observations and current (2000-07) climatology

Muja Power Station, commissioned 1966, 974MW, ≈10^{19}CCN/s



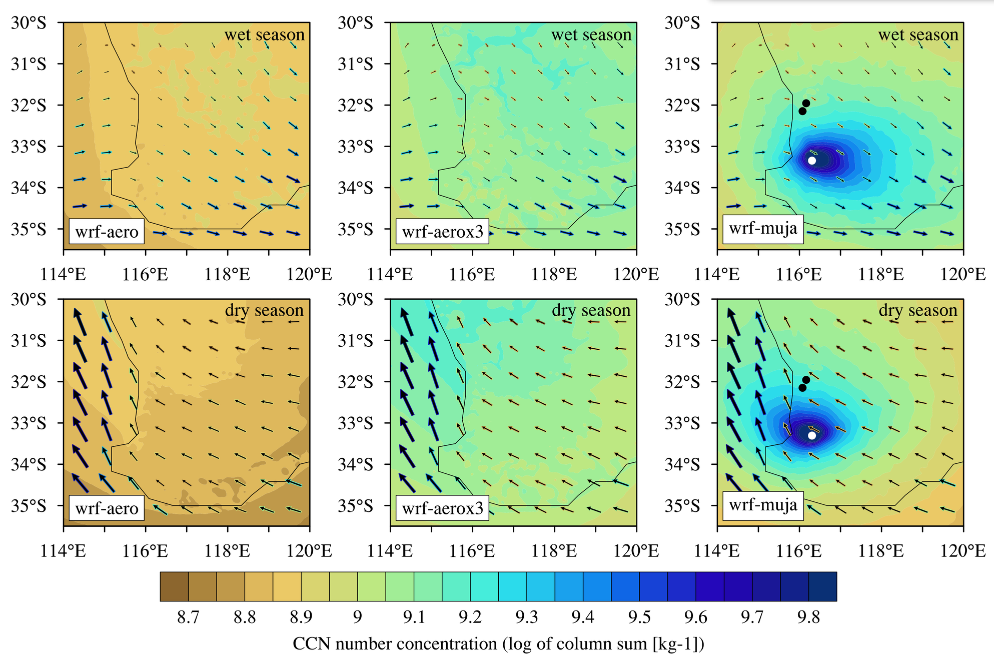
Airborne measurements of CCN emission rates of coal power plants in East Australia w/ similar size (Junkermann and Hacker, 2015).

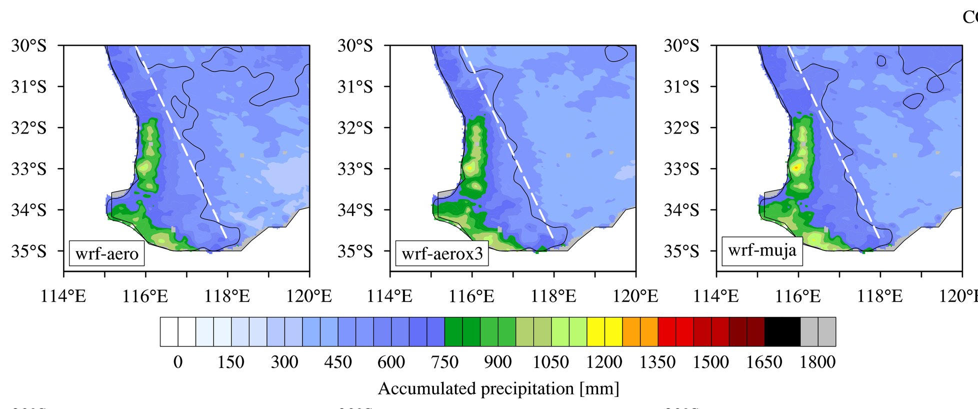
Three different aerosol model runs

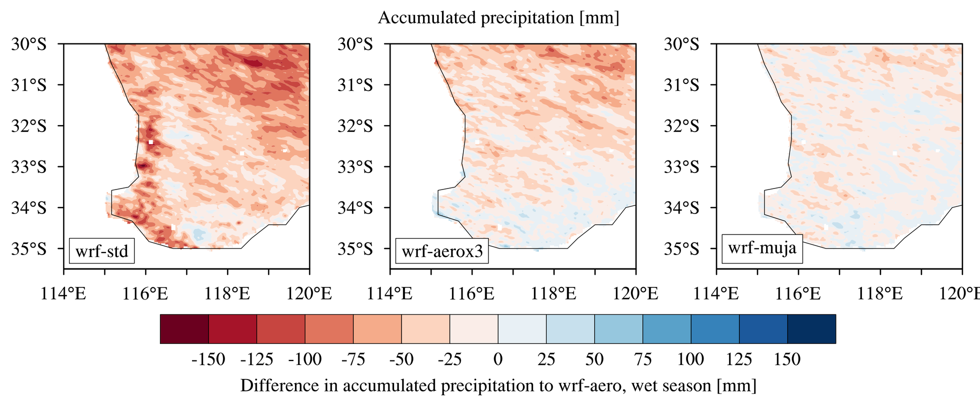
- Pre-industrial CCN/IN levels, std. aerosol profile (wrf-aero)
- Post-1970s CCN/IN levels, 3x std. aerosol profile (wrf-aerox3)
- Pre-industrial CCN/IN levels + Muja Power Station (wrf-muja)

Muja Power Station emissions:

- 4.6x10^8 particles/kg/s, added to surface emissions at location of Muja Power Station (M) within first 1500m above ground







1970-1974 means of CCN number concentration and surface wind (top) and rainfall Apr-Sep (left); wet season: Apr-Sep, dry season: Oct-Mar

Decline in precipitation for increasing aerosol concentrations, strongest effect on the back country. CCN are advected by near-sfc wind, seasonal variation in wrf-muja rainfall decline.

	wrf-muja >3xCCN	wrf-muja dry/wet	wrf-aerox3 3xCCN/IN
WA	-2.0%	3.1	-5.3%
WC	-1.7%	3.3	-3.1%
BC	-2.8%	2.9	-6.5%
PF	-1.7%	11.0	-4.0%