Recent developments in high-resolution NWP

30th WGNE-meeting
23-26 March 2015, NCEP, Washington

Michael Baldauf (DWD) with material from the WGNE members

Forecast Centre (Country)	# gridpoints, resolution, # layers	EPS	DA system
ECMWF	-	-	-
Met Office (UK)	744x928; 1.5km vrb L70	2.2km vrb L70; M12; 1.5 days	3D-Var 1.5km
Météo France (France)	1536x1440; 1.3 km; L90	10km; M35; 4	3D-Var 1.3 km
DWD (Germany)	zooming 6.5 km; L60 651x716; 2.2 km; L65	2.2 km, L65; M40; 1.125	Nudging; 2.8 km
HMC (Russia)	1000x500; 13.2km, L40 800x700, 6.6km, L40 3 dom.: 420x470 , 2.2km, L50 190x190, 1.1km, L50		Nudging; 6.6 km
NCEP (USA)	935x835; 12 km; L60 1371x1100; 4 km; L60 595x625; 6 km; L60 373x561; 3 km; L60 401x325; 3 km; L60 375x375; 1.333km; L60 758x567; 13 km; L50 1799x1059; 3 km; L50	16km M26 3.5day 4cyc 3-4 km M4 1.5day 2cyc	Hybrid enKF-3dvar 12km / 3km for nests
Navy/FNMOC/NRL (USA)	45/15/5km L60	45/15 km, 3 day	3D-Var variable, nested
CMC (Canada)	- 3000x2400; 2.5 km; L80	15 km; M21; 5	En-Var; 10 km
CPTEC/INPE (Brazil)	500x600, 15 km, L60; 1360x1480, 5km, L60	40 km x 40km, L38, M7	3D-Var; 10 km
JMA (Japan)	817x661; 5 km; L50 1581x1301, 2km, L60	T_L479 L100; M25; 4 times/day; 5.5	4D-Var, 15 km 3D-Var, 5km
CMA (China)	750x500,10km; L60 1000x750,3km; L90	10km L40 M30, 3	hybrid 3dvar, 10km
KMA (Korea)	~12km L70 1.5km L70	3kmL70;M12	36km 4D-Var 3km 3D-Var
NCMRWF (India	-		
BoM (Australia)	1088x746; 12km L70 816x668; 1.5km, L70 816x668; 1.5km, L70 300*300; 12km, L70	-	4D-Var, 24km downscaled downscaled 4D-Var, 24km

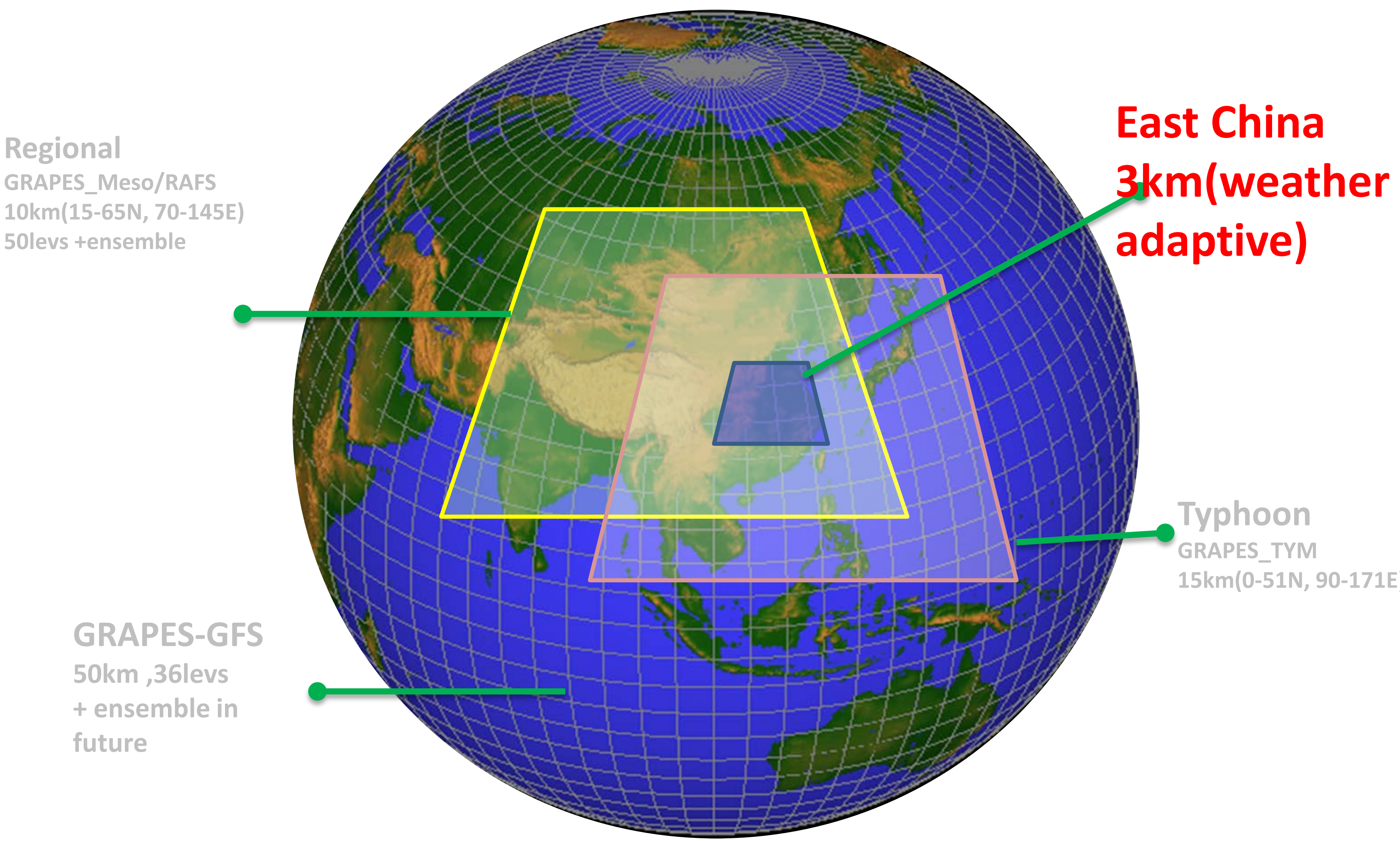
High-resolution NWP systems, planings for 2015

from the ‚WGNE-table about the centre computing resources and model configurations’

CMA high resolution NWP

slides by Sun Jian (CMA)

3km-resolution GRAPES implemented in 2015



GRAPES-Meso upgraded in June 2014

V3.3 upgraded by V4.0

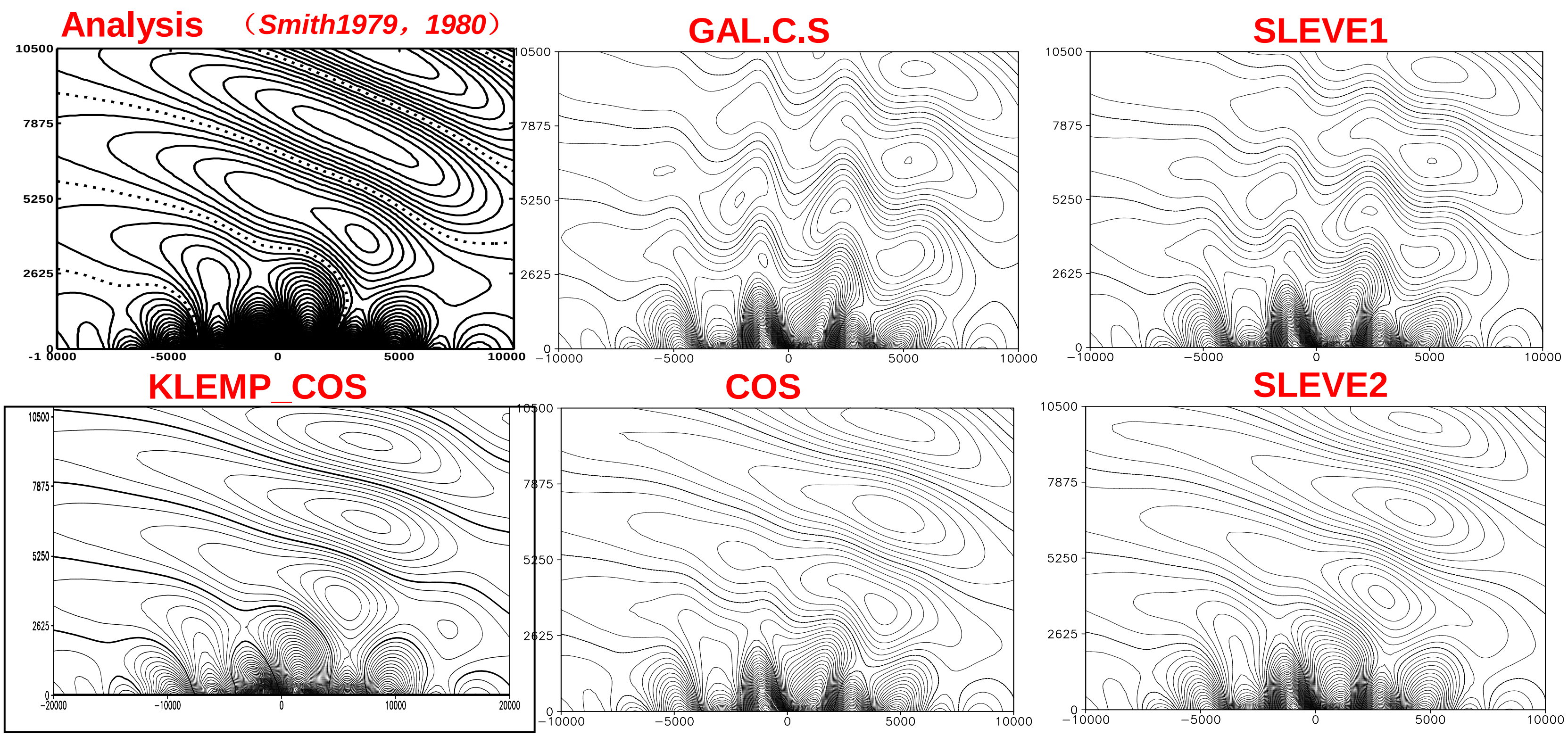
- Initial condition improved
- Precipitation prediction error reduced
- Near surface temperature prediction improved
- Diurnal cycle improved

- Data assimilation
  - More data used such as GPS/PW, FY_2E-AMV, GNSS
  - Variational QC
  - BC on TEMPS-humidity
  - Unified RAFS and Meso flow charts

- Model
  - Updated PBL, radiation and convection schemes
  - Increasing resolutions in vertical and in horizontal (15kmL31 to 10kmL50)

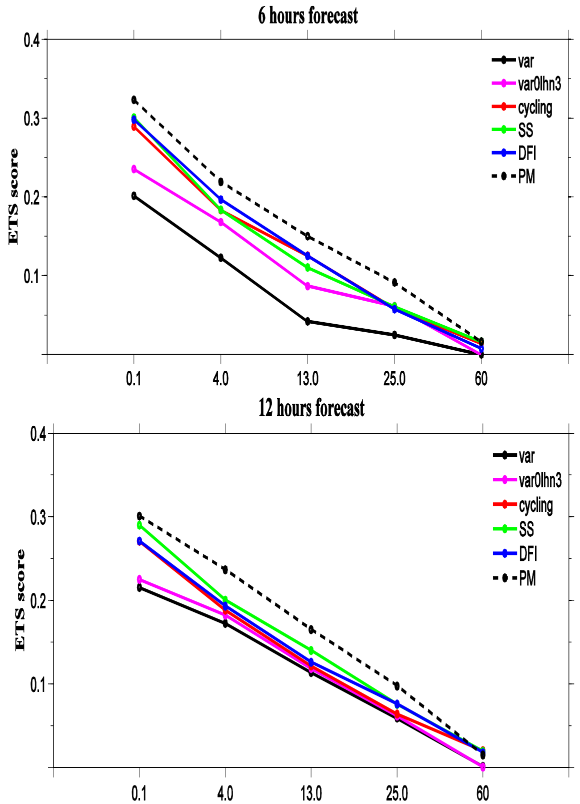
High resolution NWP

- Inter-comparison of different vertical coordinates

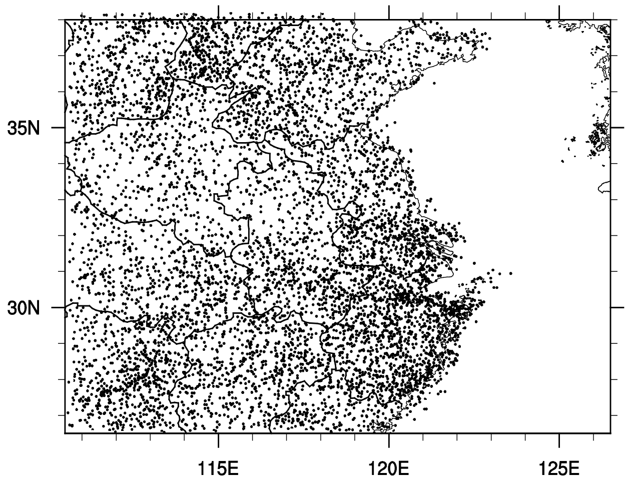


mountain wave: Cross-section of vertical velocity W after 10 hours integration

- LHN（Latent Heat Nudging）
  - precipitation observation on surface AWS



ETS-verification
(one month averaged)



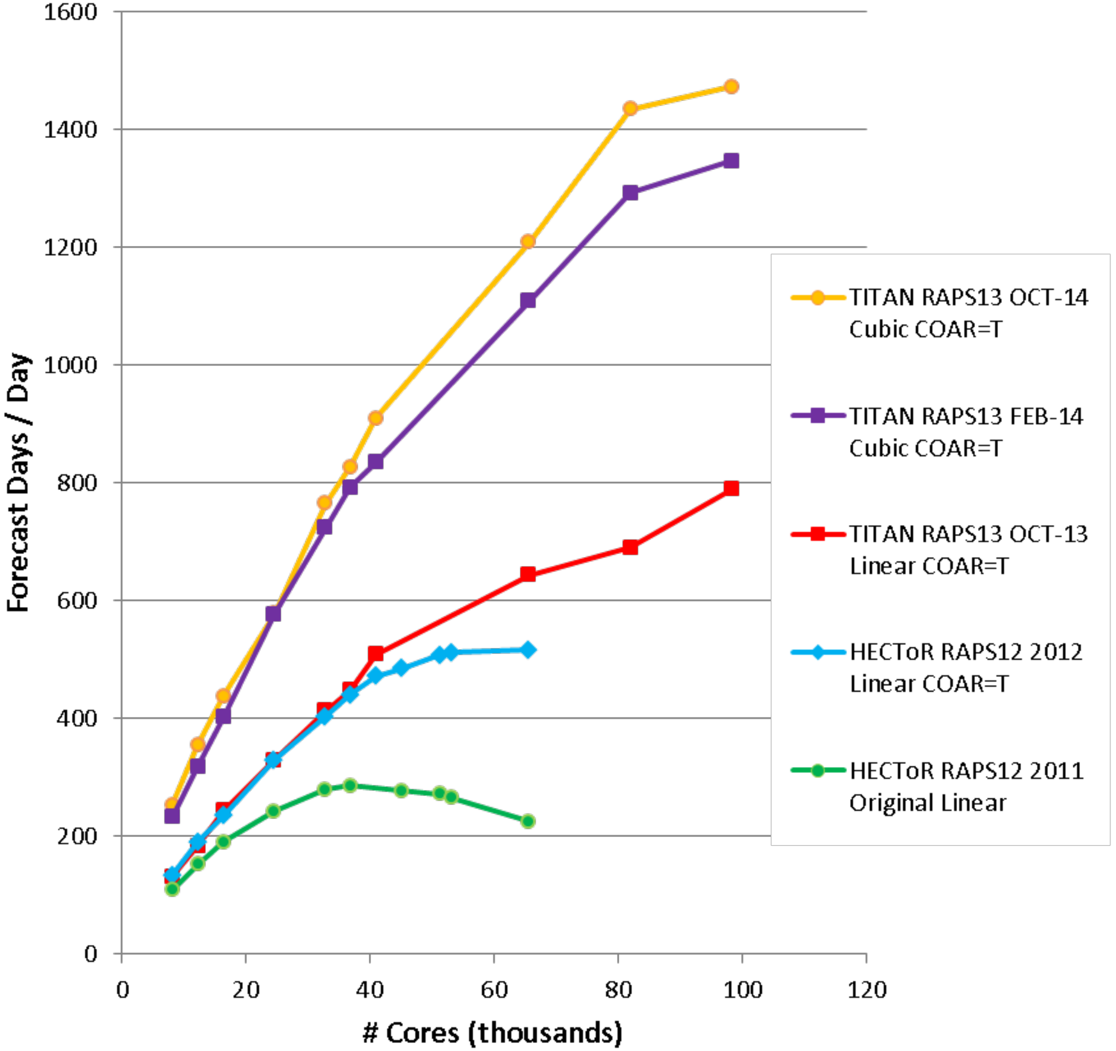
Test-domain and AWS

"VAR": 3DVAR, non-cycling;
"var0lhn3": after 3DVAR, non-"Cycling"
"Cycling": before 3DVAR, cycling;;
"SS": with Schuman-Shapiro filter;
"DFI": with Digital Filter
"PM": Prob. Matching on 5 runs

ECMWF

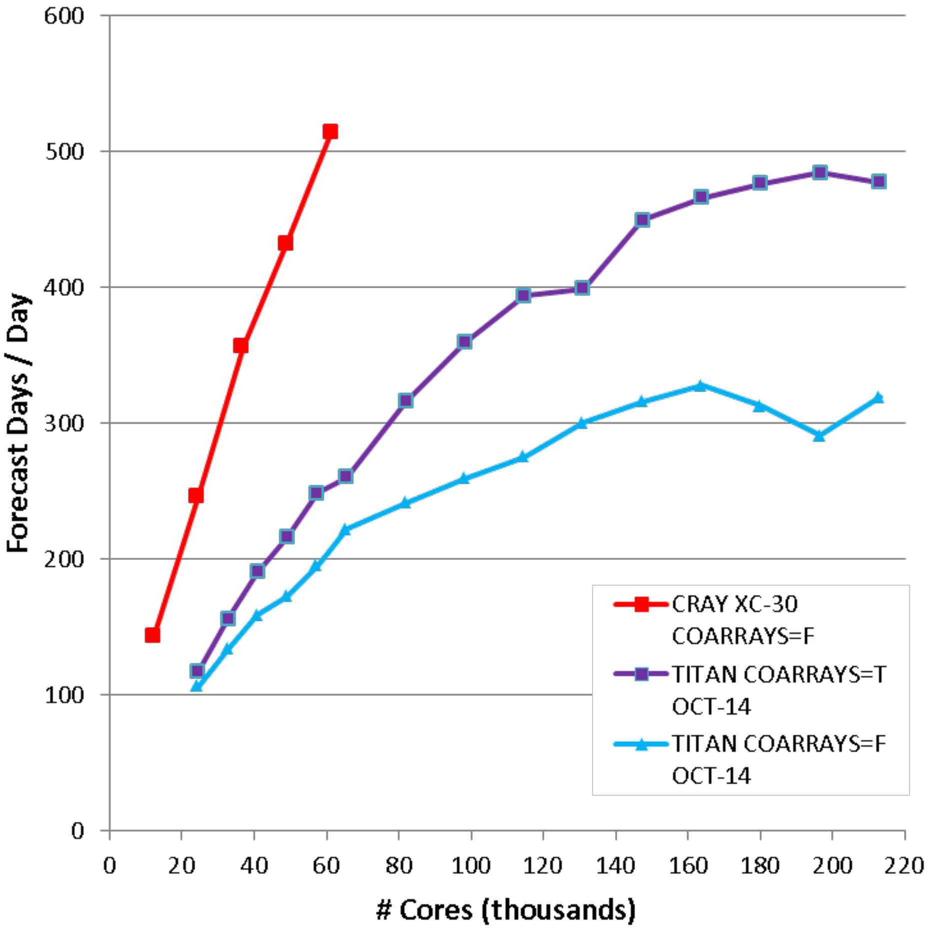
slides by Jean-Noel Thepaut (ECMWF)

10 km IFS model performance evolution in CRESTA

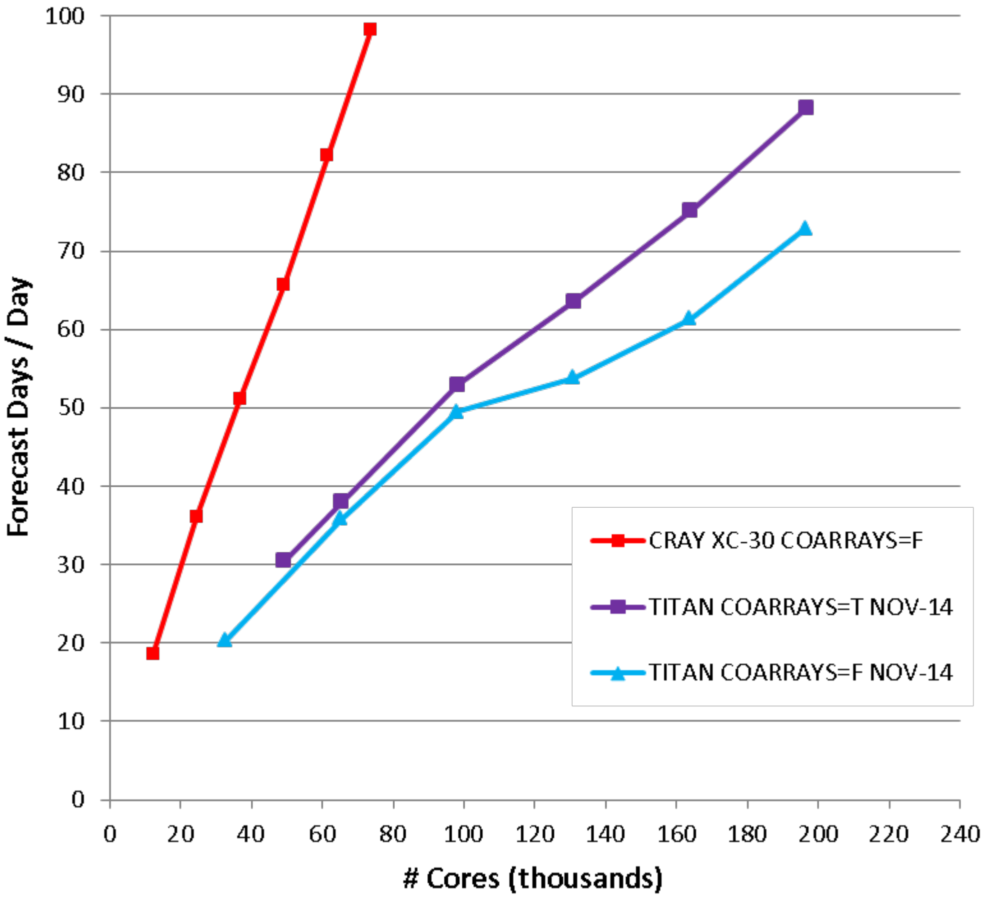


CRESTA

T_c1999 5 km (~2023) IFS model scaling



T_c3999L137 2.5 km (~2032) IFS model scaling



US Navy / NRL

slides by Carolyn Reynolds (NRL)

NEPTUNE

Navy Environmental Prediction sysTem Using the NUMA corE

WSM6 (cold-phase) microphysics

- **Single moment, 6 species (cloud water/ice, water vapor, rain, snow, graupel)**
- **Used in NWP regional models (e.g. WRF) as well as in New Generation global models with fine horizontal resolution (e.g. MPAS)**

- **Test Case: Splitting supercell on a reduced radius planet (X=120), no rotation, free-slip; $<\Delta x>=<\Delta y>=1$ km, $<\Delta z>=200$ m ($z_{top}=20$ km); $t_{final}=2$ h; mid-latitude based vertical sounding perturbed by a warm bubble to trigger convection.**

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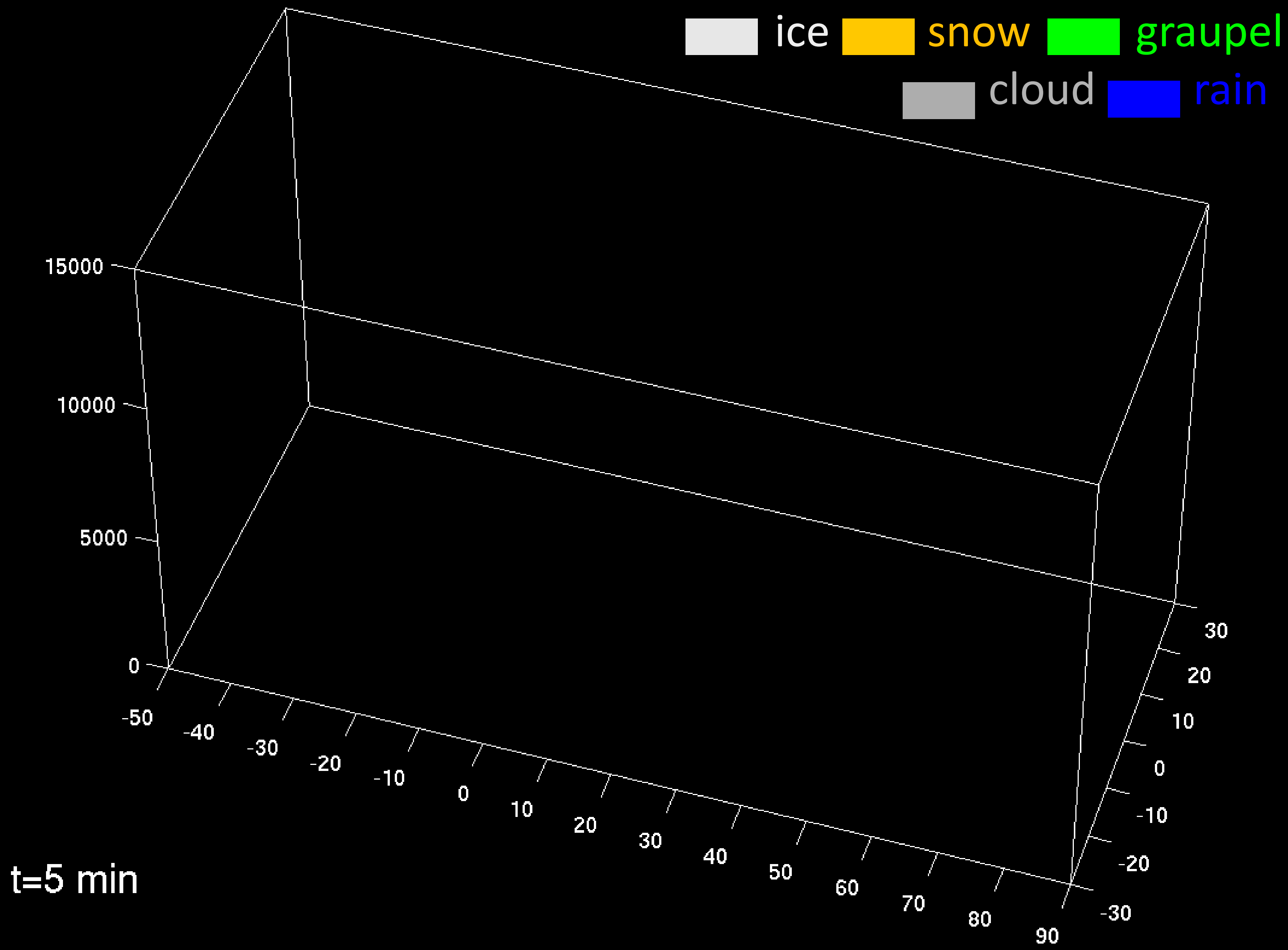
ice
snow
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70
80
90
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10
0
-10
-20
-30
t=5 min

CMC Canada

slides by Ayrton Zadra (CMC)

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Environment Canada Environnement Canada

Canada

Numerical Environmental Prediction Systems for the 2015 Pan Am Games

(Photograph: Sylvie Leroyer)

Stephane Belair
Sylvie Leroyer
Craig Stroud
Vincent Fortin
Greg Smith
Natacha Bernier

Meteorological Research Division
Atmospheric Science and Technology Directorate

March, 2015, EC Dorval, QC

Environnement Canada Environment Canada

EC's Science Project for the 2015 Pan Am Games (in Toronto)

The Pan American Games are **the world's third largest international multi-sport Games**

Enhanced local forecasts:
Weather, air quality, hydrology and lakes

Observational networks:
surface observations, mobile platforms, air quality, lightning

Linkages:
Weather, health, air quality, hydrology, UV

Numerical Modeling for Pan Am: Systems

Continental 2.5-km atmospheric model

10-km air quality model

MSC Pan Am Operations Desk

1.0-km and 0.25-km atmospheric models

2.5-km air quality model

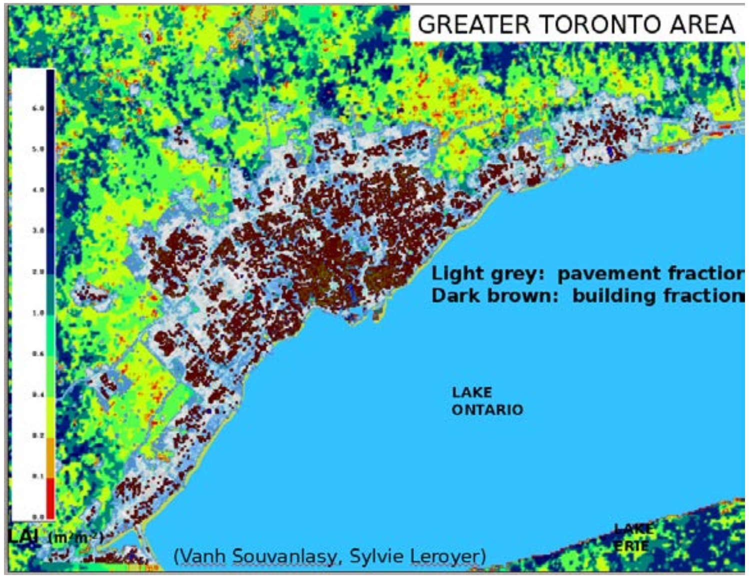
2.0-km Lake model (Lake Ontario)

1.0-km wave model

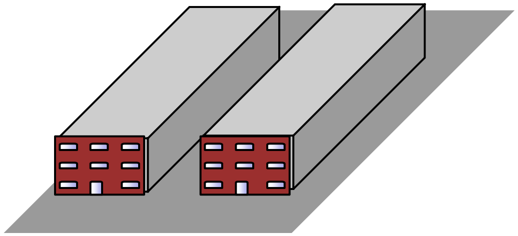
MSC Pan Am Research Desk

Other client:
Public Health Ontario

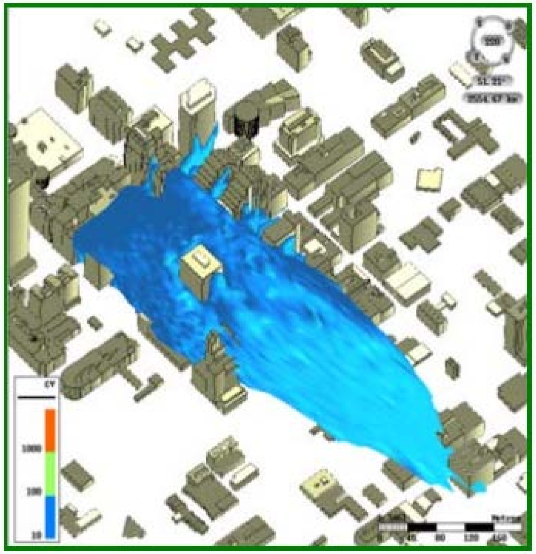
Urban Modeling for Pan Am



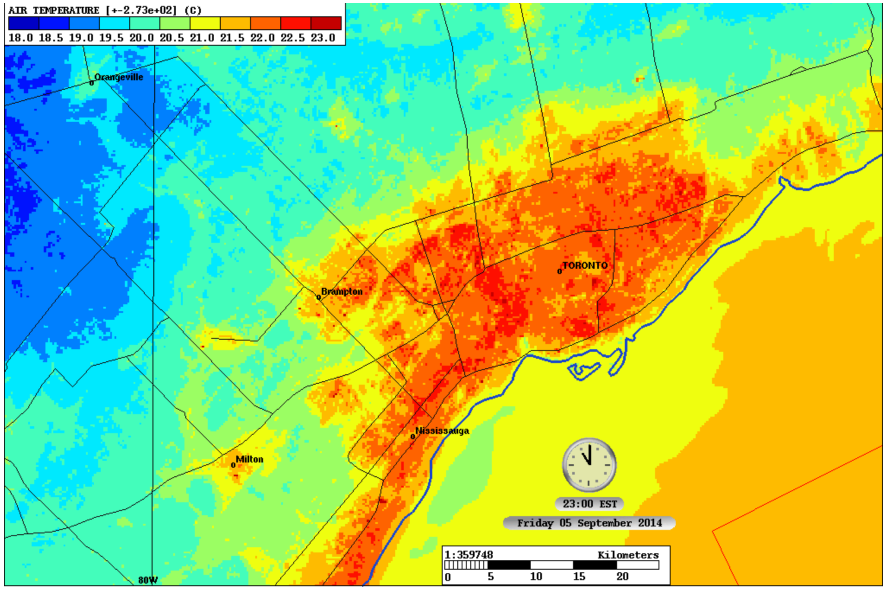
Urban representation as part of the atmospheric model



Urban Dispersion of materials

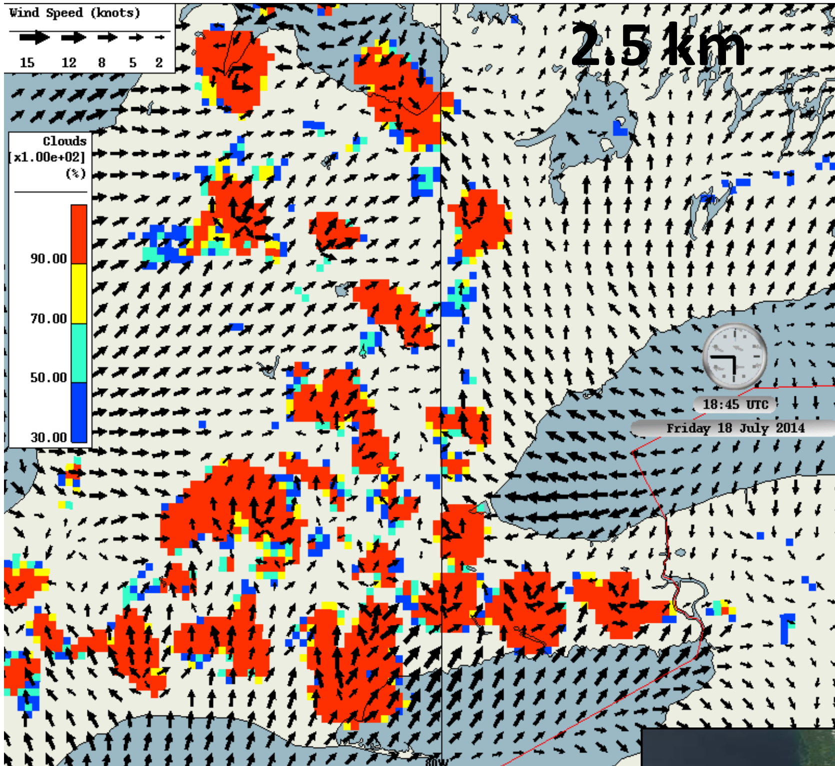


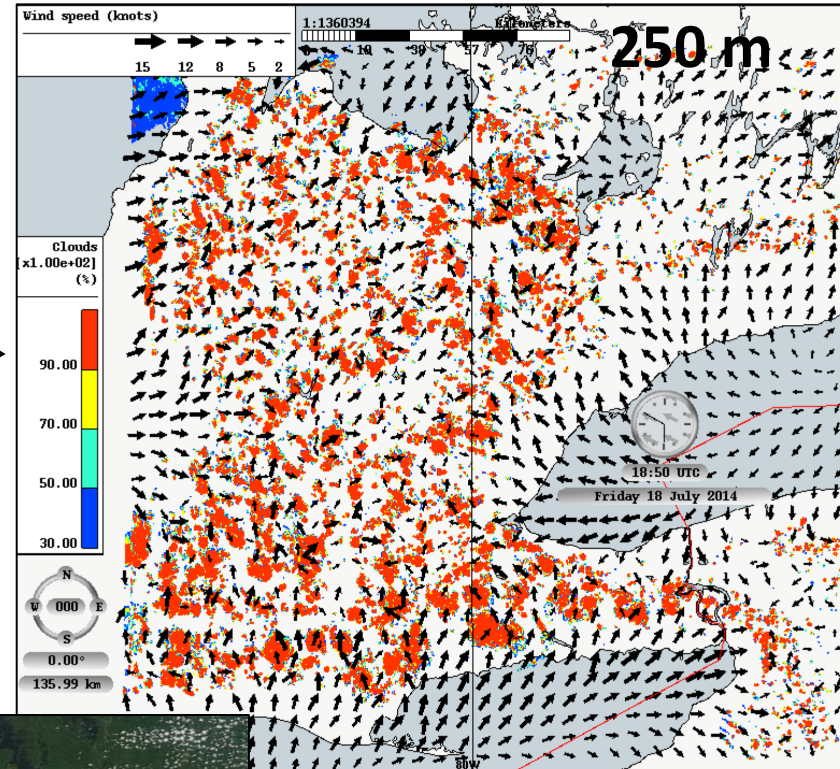
Urban heat island – Air temperature



Environnement Canada Environment Canada

Example of Daytime Convective Activity



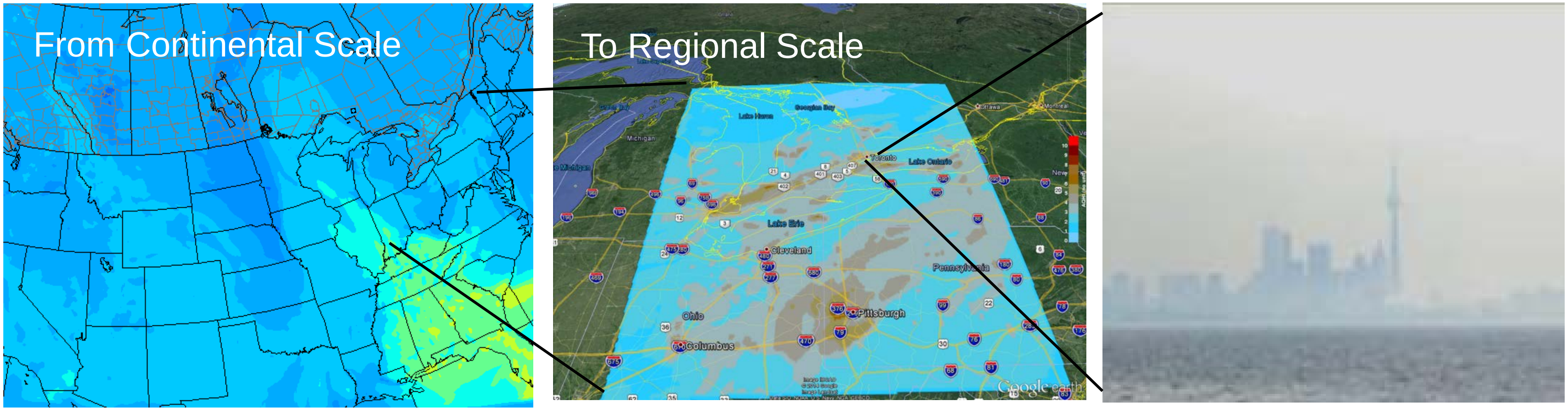


Cloud coverage and near-surface winds Valid at 1850 UTC 18 July 2014

MODIS (Aqua satellite)

Environnement Canada Environment Canada

High-Resolution Air Quality Forecasts



Focus on direct / indirect impacts of aerosols on weather and air quality

High-resolution (2.5-km grid spacing) GEM-MACH will be used in real time

Lake prediction system based on NEMO model

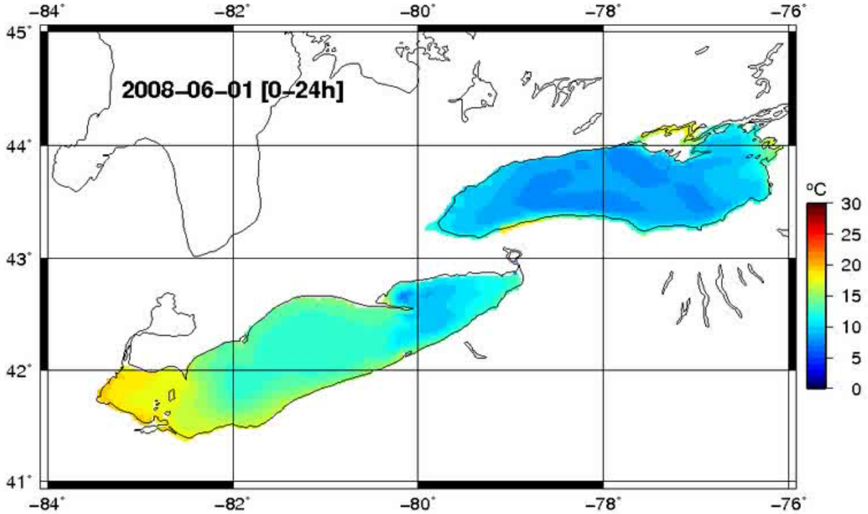
- 2-km resolution
- 2-day forecast launched once per day
- Hourly outputs

Main surface variables:

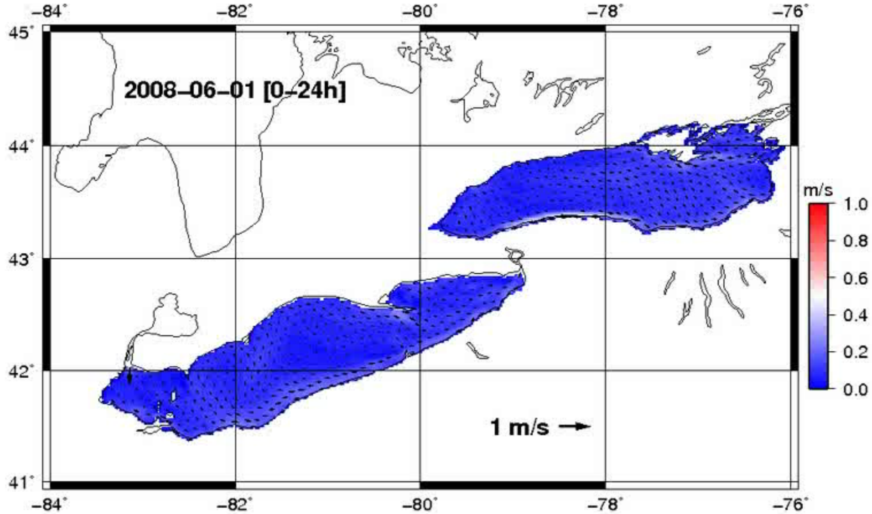
- Water temperature
- Surface currents
- Water levels
- Ice cover

Applications

- Weather forecasting
- Support for search and rescue operations
- Particle tracking (drifting boat, oil spill)
- Forecasting storm surge and coastal inundations
- Optimization of hydropower production



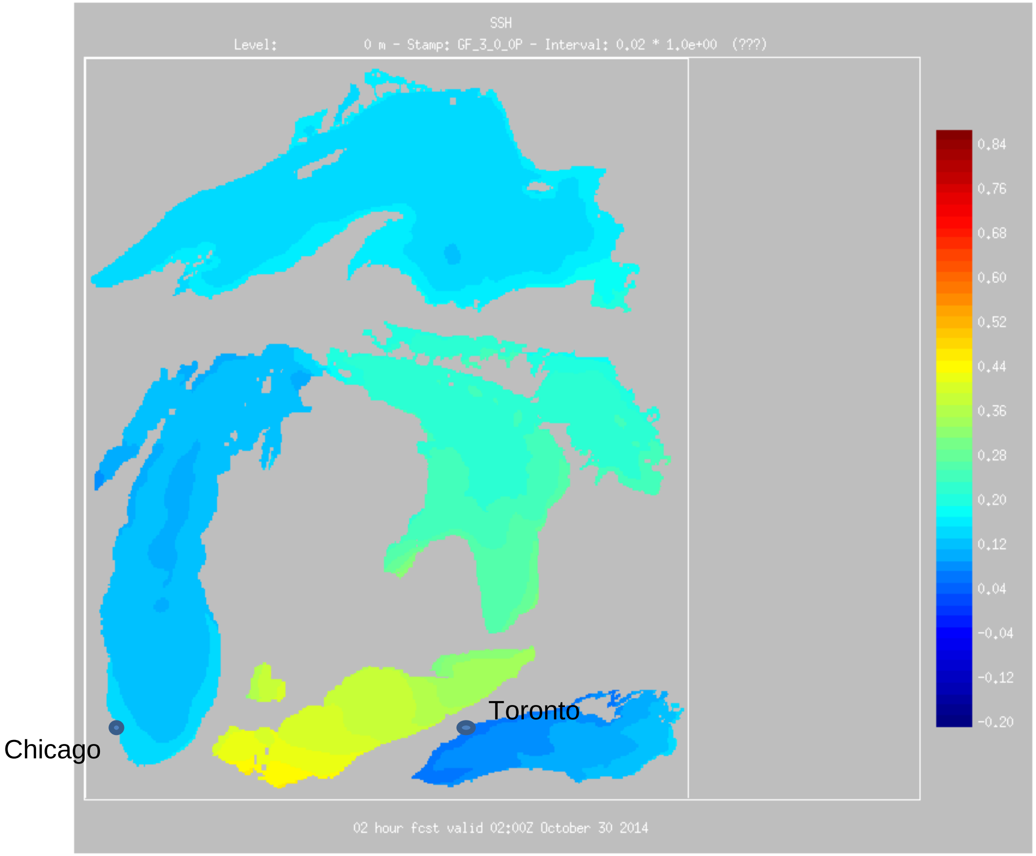
Water temperature [C]

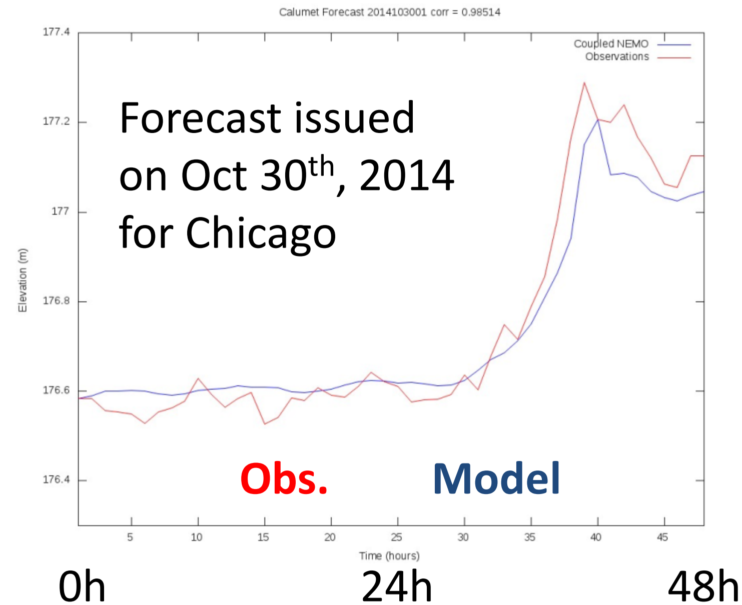


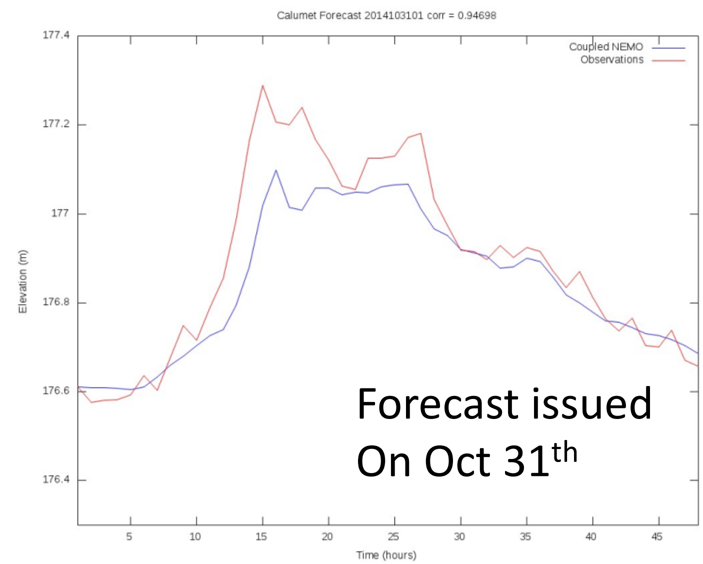
Surface currents [m/s]

Summer of 2008 (system running daily since the fall of 2014)

Water level forecast







HMC Russia

slides from Elena Astakhova (HMC)

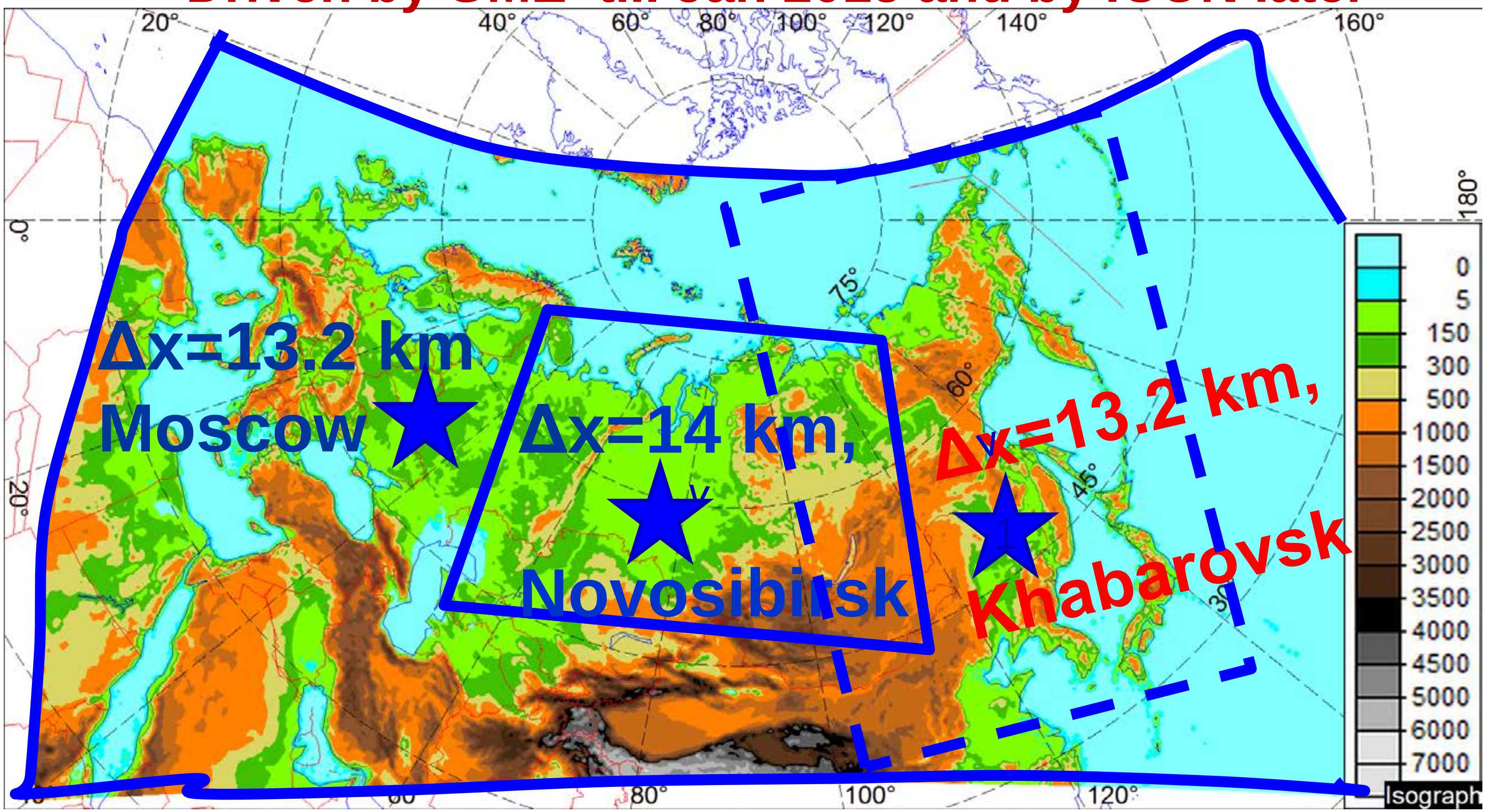
“Large” COSMO-Ru domains

COSMO-Ru13/6 для ENA (Europe & North Asia) – NEW!

Now: 13.2 км – 1000 x 500. Planned: 6.6 km - 2000 x 1000.

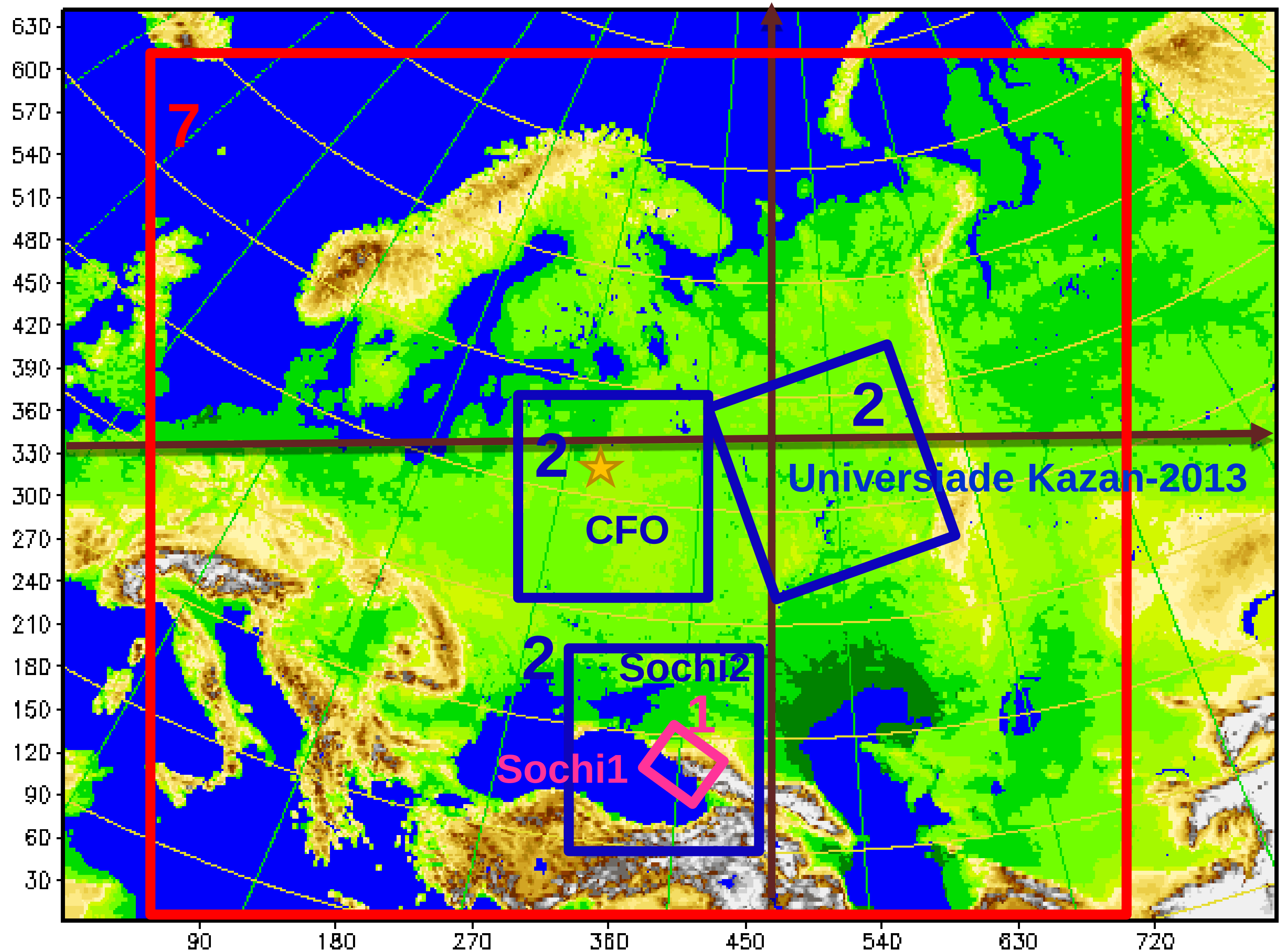
COSMO-Ru14 for Siberia: 14 km - 360 x 250

Driven by GME till Jan 2015 and by ICON later



A new domain around Khabarovsk is planned (dashed rectangle)

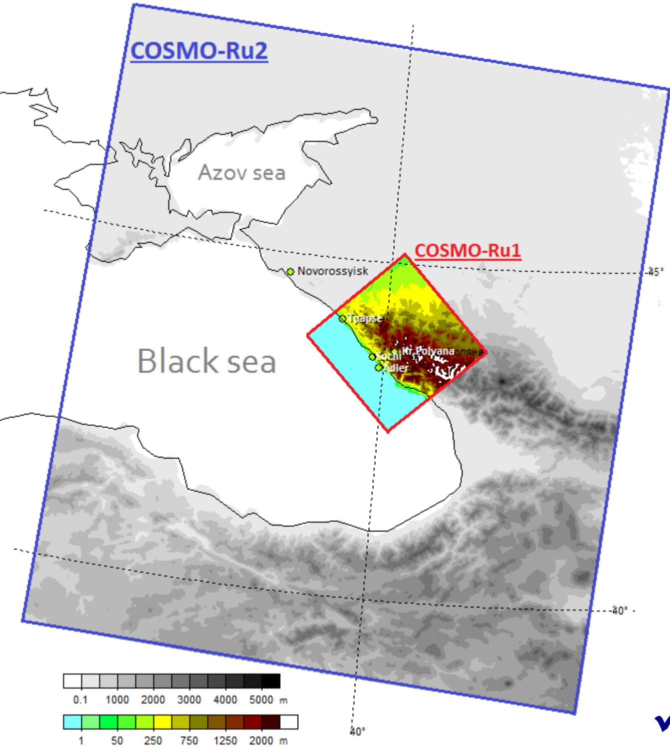
Operational mesoscale forecasting COSMO-Ru domains in 2014



COSMO-Ru7, Δx = 7 km   COSMO-Ru1, Δx = 1.1 km

COSMO-Ru2 (CFO, Universiade, Sochi-2014), Δx =2.2 km

High-resolution model COSMO-Ru1



COSMO-Ru1 model's grid is nested to **COSMO-Ru2 for SFO** (region around Sochi)

COSMO-Ru2
(for the **S**outhern **F**ederal Area)
Domain: 900 km x 1000 km
Grid: 420 x 470 x 50
Space step: **2.2 km**
Time step: 20 s
Lead time: 48 h

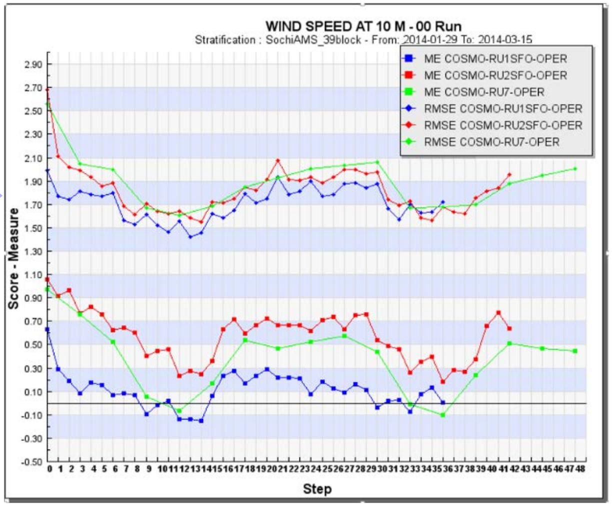
IC&BC

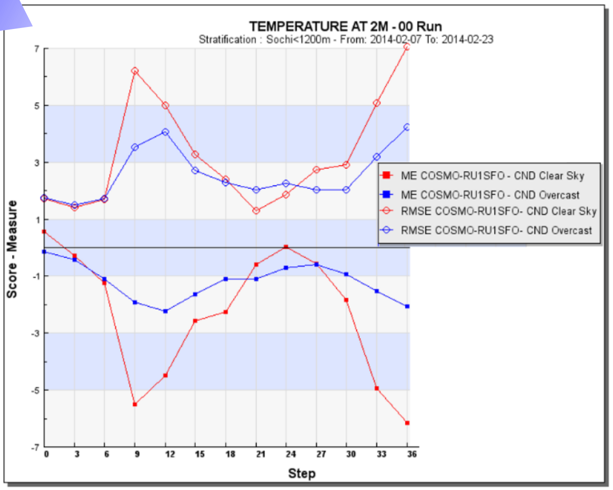
COSMO-Ru1
Domain: 210 km x 210 km
Grid: 190 x 190 x 50
Space step: **1.1 km**
Time step: 5 s
Lead time: 36 h

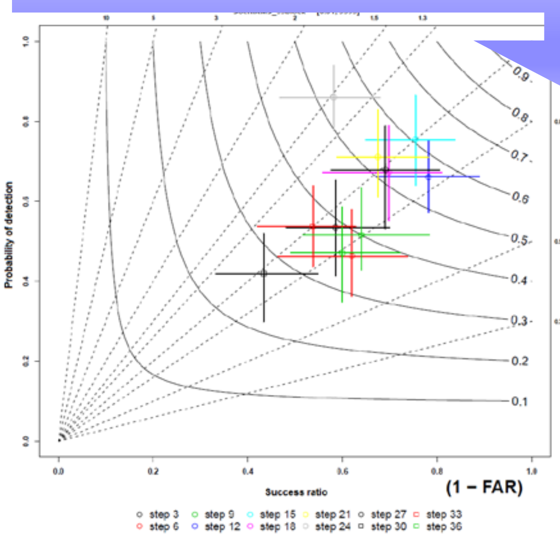
- ✓ A detailed orography based on ASTER data (Advanced Spaceborne Thermal Emission and Reflection Radiometer, resolution 1'' (~30m)
- ✓ A dynamic core with modifications by M. Baldauf
- ✓ Assimilation of HMS & AMS data using ***nudging method***

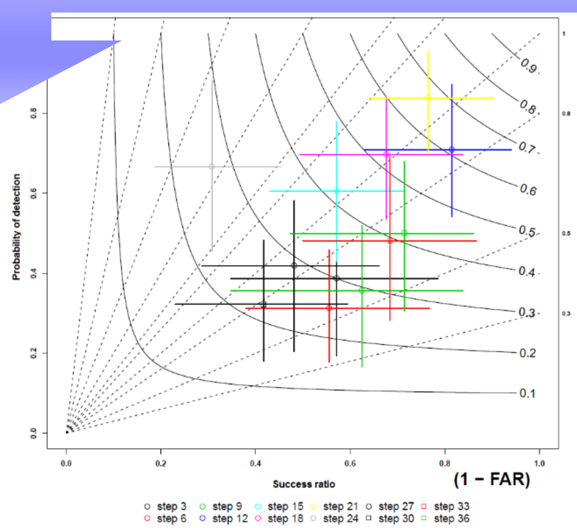
COSMO-Ru1 vs COSMO-Ru2

- Wind direction, wind speed and wind gusts are better predicted by COSMO-Ru1. There is no evident effect on temperature and relative humidity forecast.
- *Conditional verification* of temperature forecast for the points located below 1200 m shown higher errors for Clear sky cases. More conditional verifications are needed.
- Traditional *point-to-point precipitation scores* are rather high for COSMO-Ru1. Several cases of intense precipitation were forecasted well.









For February-March, 2014.

FURTHER WORK

1. Increase the resolution of COSMO-Ru7 from 700x620,7km, L40 to 800x700, 6.6km, L40 in 2015
2. Increase the vertical resolution to L60 in all versions in 2016
3. COSMO-Ru1 forecasts for the extended area and estimation the wind speed and wind gust forecast for the Novorossiysk bay (bora forecast) and Kerch Strait
4. Case studies for high resolution models (COSMO-Ru2, COSMO-Ru1) using observations archived during the Olympics / Paralympics (1.5 month) and trial period (2 previous years).
5. COSMO-Ru1 for Moscow region coupled with COSMO-ART.
6. COSMO-Ru1 for Moscow region coupled with URBAN model.

UK Met Office

slides by Keith Williams (UK MO)

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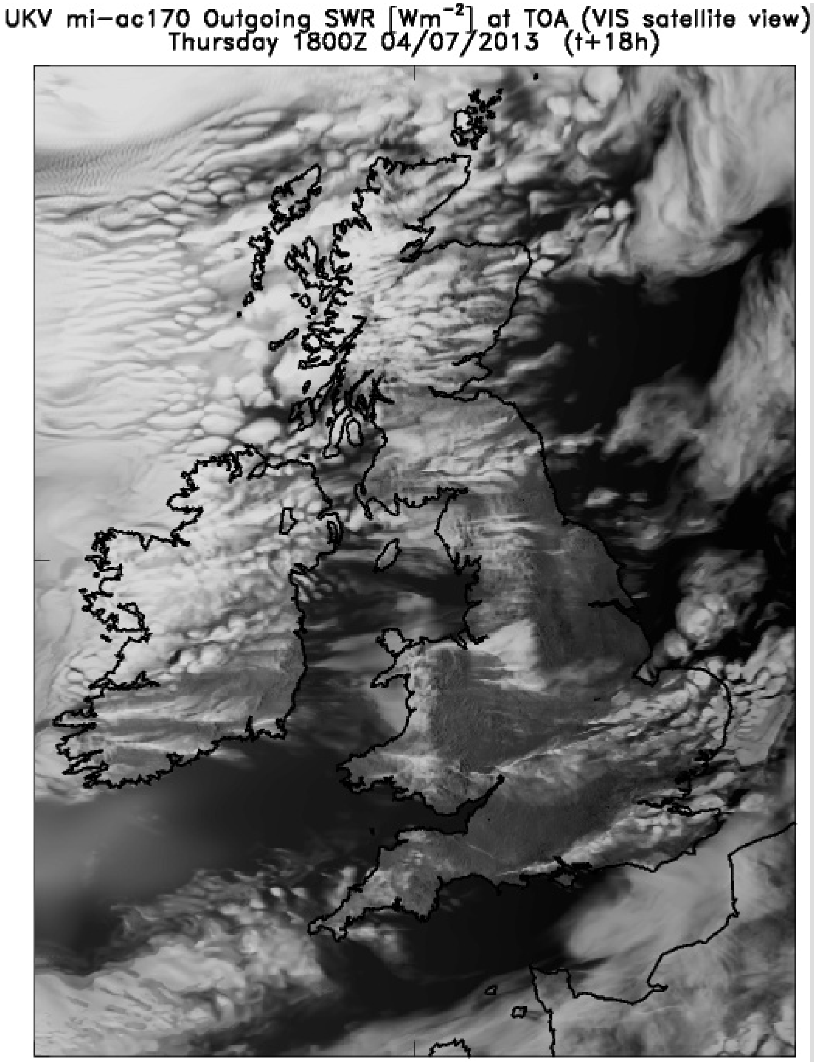
Recent convective permitting model upgrade

- Operational Feb 2015
    - ENDGame dynamical core
    - Improvements to physics – greyzone “blended” turbulence, warm rain microphysics, cloud assimilation,…

ENDGame in UKV: Improved accuracy enabling gravity wave activity

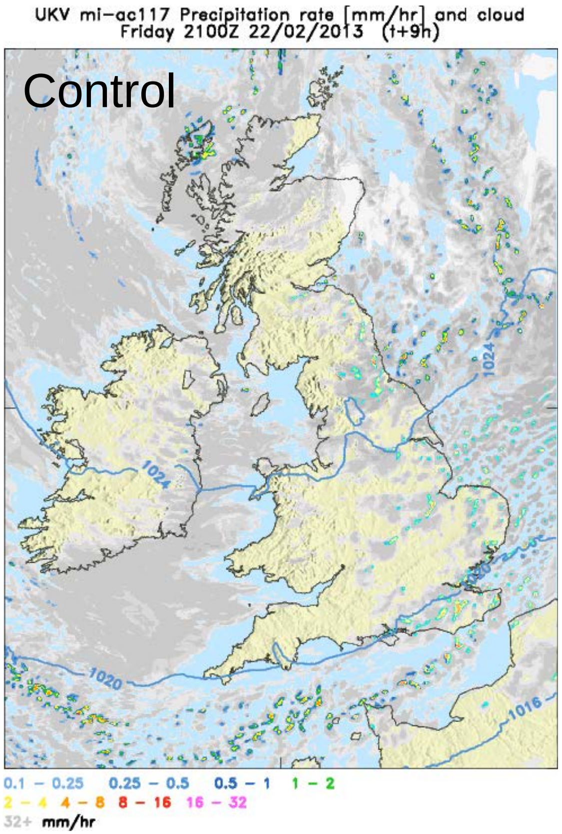
Control

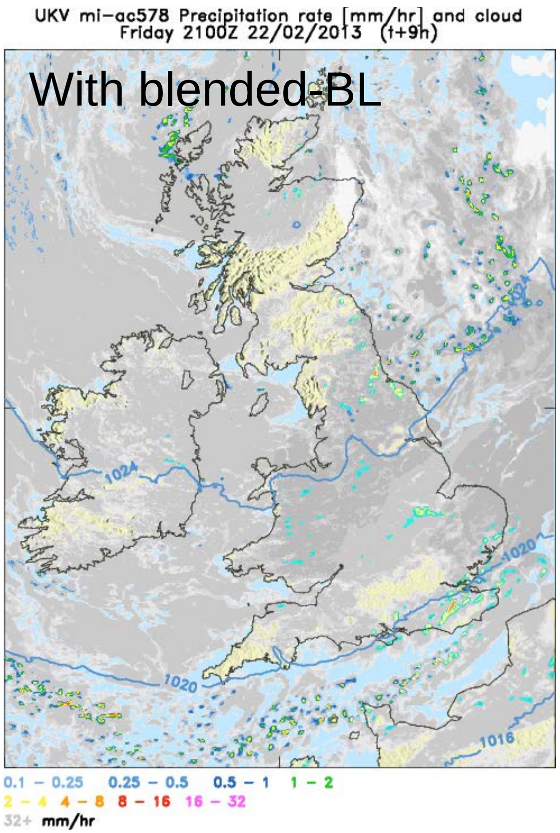


ENDGame

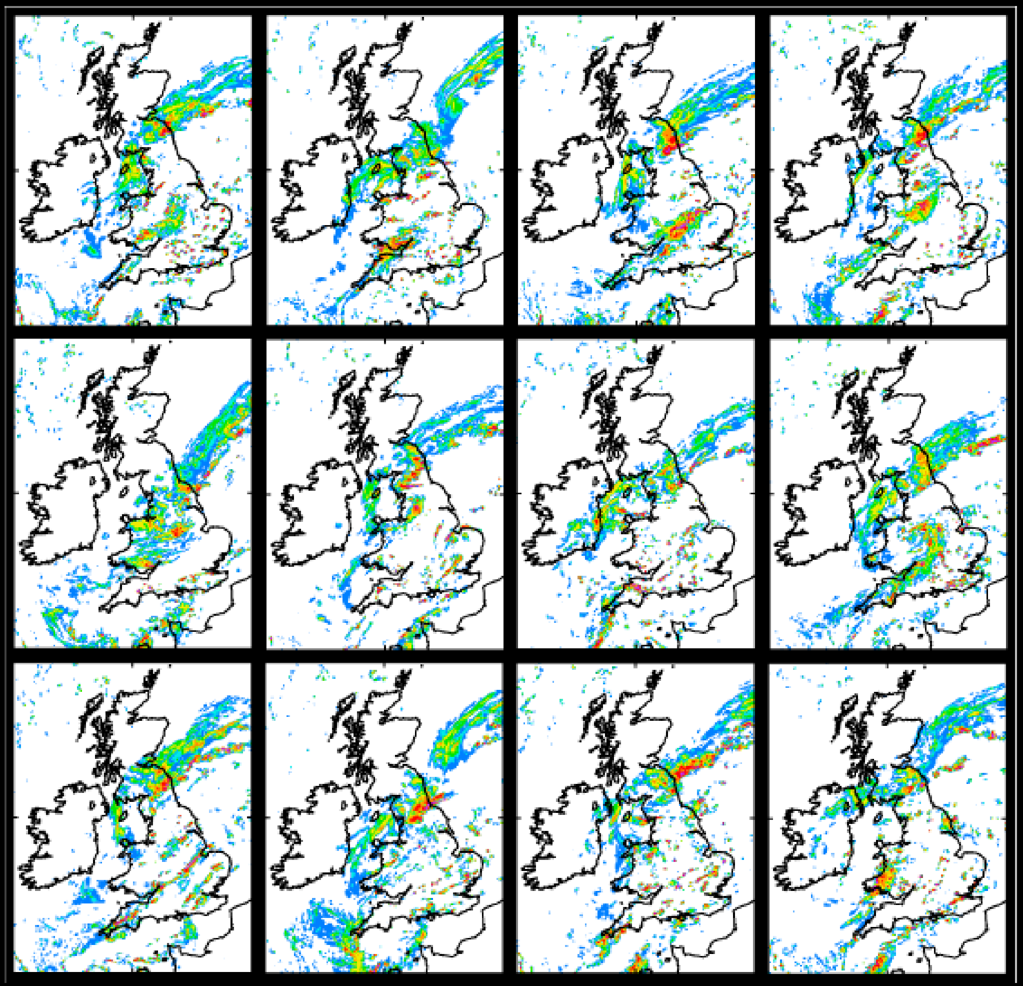
Blended-BL scheme

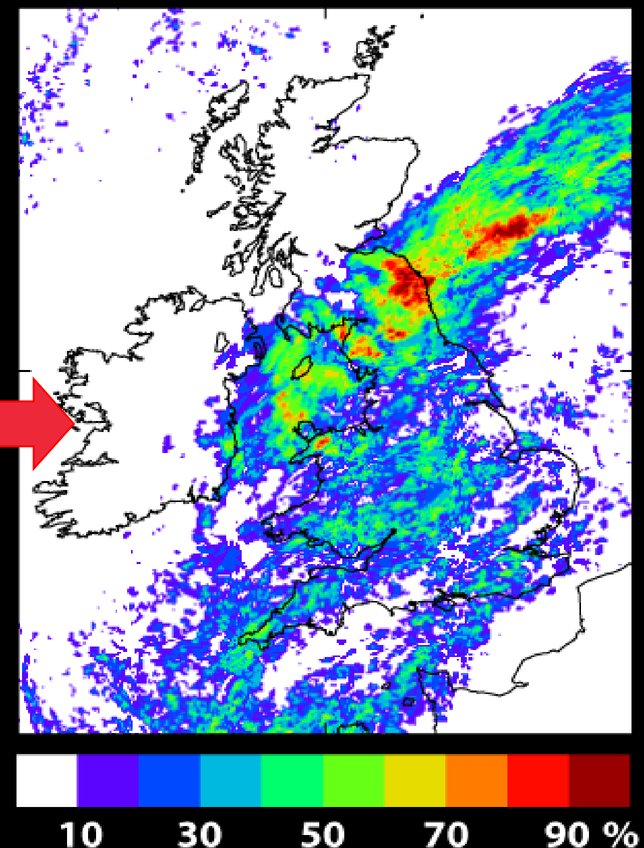
- Scale-aware blending of boundary-layer and Smagorinsky turbulence schemes
- Gives a scale-dependent blend as the flow transitions from unresolved to resolved turbulence
- Self-adapting for all high resolution configurations
- In UKV tends to suppress spin-up of near grid-scale circulations which, in stratocumulus, helps to suppress spurious break-up





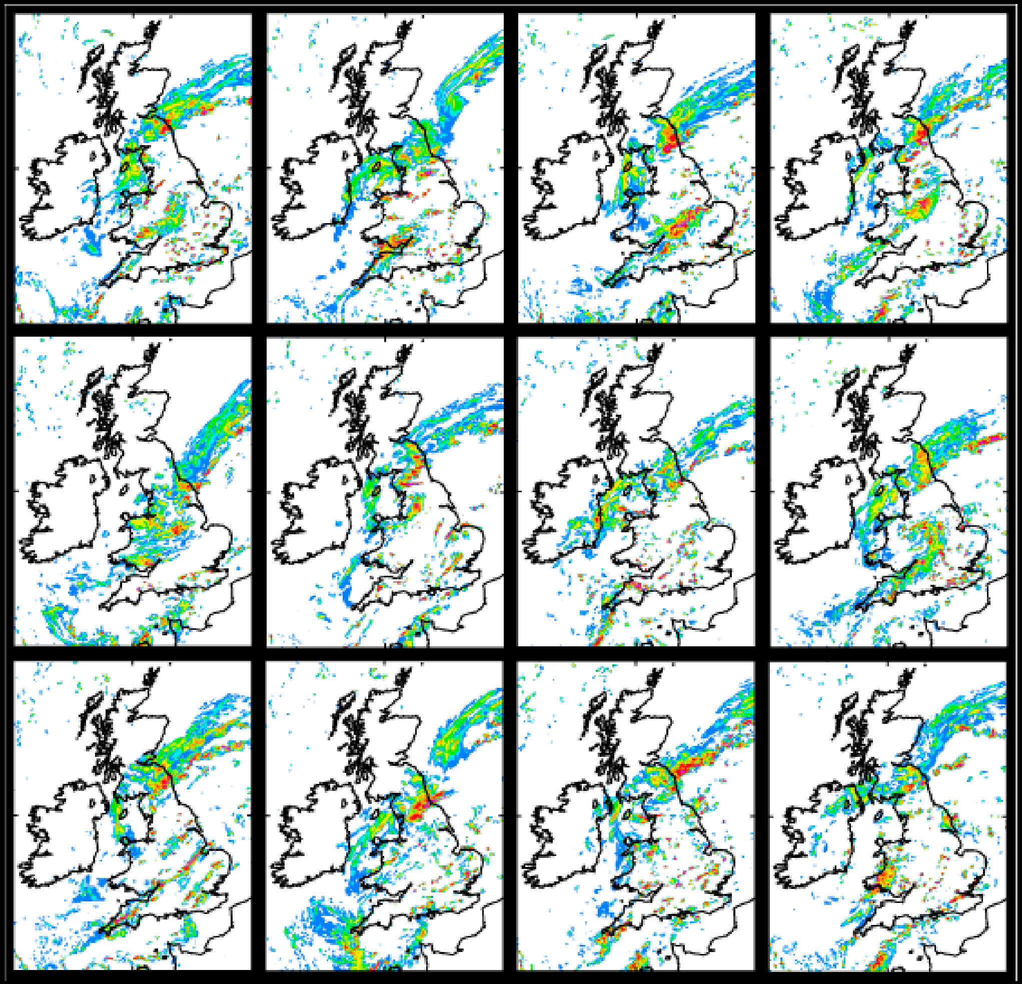
MOGREPS-UK
2.2km ensemble

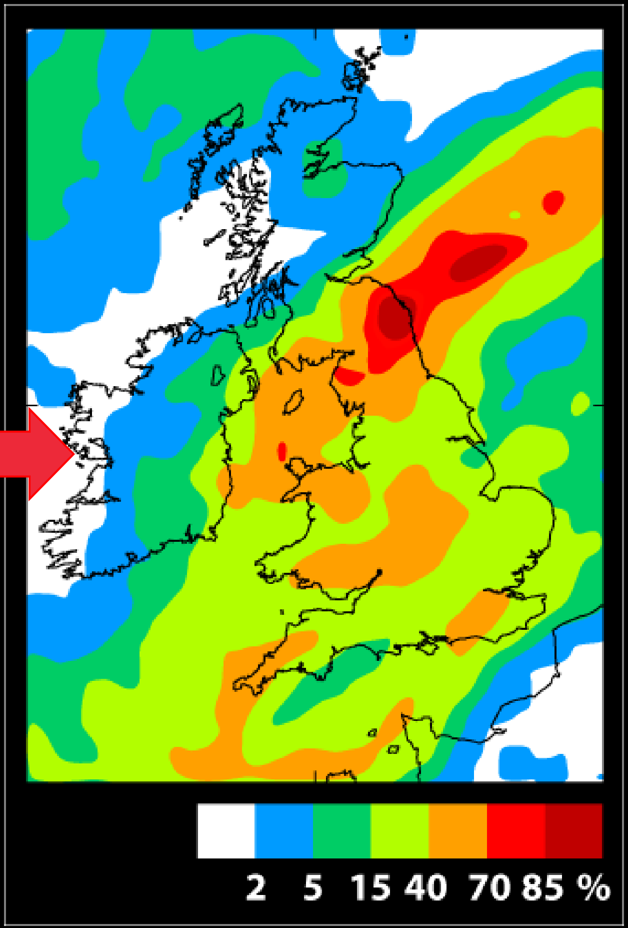




Undersampling leaves "holes" of zero-probability where showers could still occur

MOGREPS-UK … with Neighbourhood processing





Holes filled in

MOGREPS-UK plans

Short-term

- Use UKV analysis combined with perturbations from MOGREPS-G.
- First phase of stochastic physics – version of "random parameters" scheme suited for MOGREPS-UK.

Longer term – (on new HPC)

- Hourly UK ensemble; combine several runs to make larger lagged ensemble
- Higher resolution (horizontal and vertical)
- Convective-scale ensemble data assimilation (needing much larger ensemble for DA cycling).

MOGREPS-UK
Initial conditions

- Experience with the old regional ensemble (MOGREPS-R) showed benefit of using a higher resolution regional (NAE) analysis, plus global perturbations.
- Does the same carry over to MOGREPS-UK?

Downscaled:

Currently each MOGREPS-UK (2.2km) member starts from a reconfigured MOGREPS-G (N400, 32km) 3-hour forecast.

$$x_{UK}=R(x_G)$$

Re-centred:

An alternative is to re-centre the MOGREPS-G perturbations around the UKV (1.5km) analysis.

$$x_{UK}=x_a+R(x_G)-R(x_G^0)$$

Random Parameters in MOGREPS-UK

- A first step to representing the uncertainties in convective-scale forecasts
- Motivation: to better represent uncertainties in low cloud and visibility

  - Targeting appropriate BL / microphysics parameters.
  - Combining associated parameters so that they vary together.
  - Improved algorithm for time variation of parameters

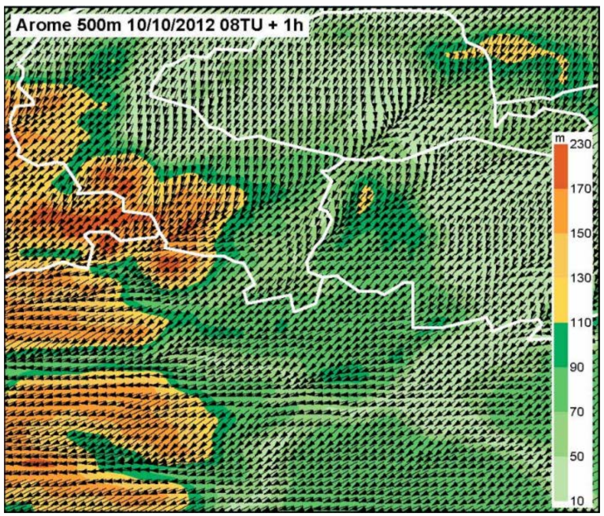
Meteo France

slides by Francoid Bouyssel (MeteoF)

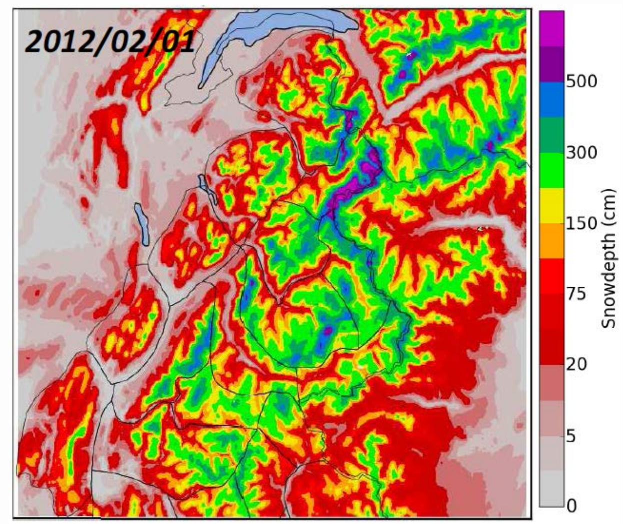
Simulations at 500m resolution

Current operational resolution is 1.3 km on a large domain over western europe (1536x1440)

500m simulations are regularly performed on small domains for research and development activities :



500m simulation in Paris area to provide wind and turbulence related parameters to a wake-vortex prediction model (here wind field over surface orography)



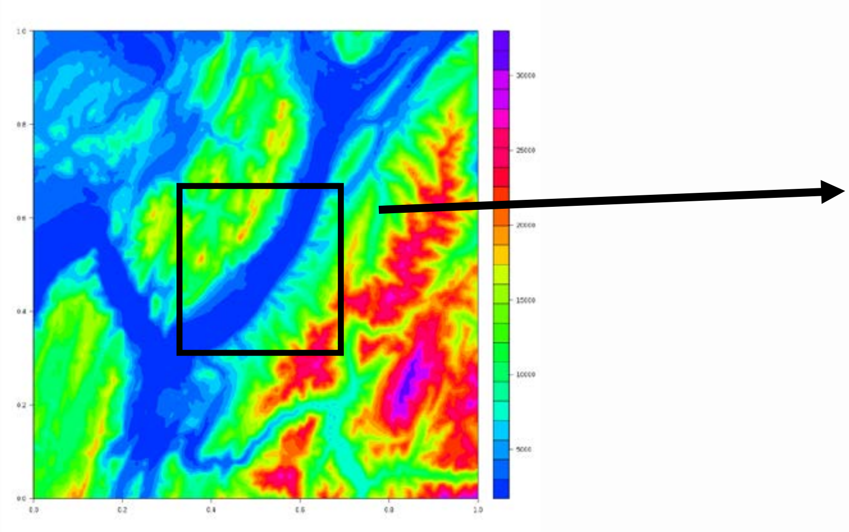
500m simulations over a whole winter period to force the snow model CROCUS (here snow depth at a particular time)

slides by F. Bouyssel

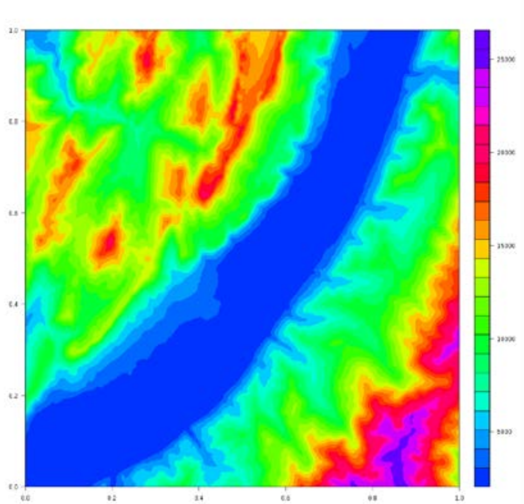
METEO FRANCE

Simulations at 500m resolution

- 500m resolution forecasts experiments done to prepare the future resolution of operational regional forecast model



Chartreuse I domain, dx=250m, maximum slope is 61 ° .



Chartreuse II domain, dx=100m and dx=50m maximum slope is 67 ° and 76° .

500m domain seems to be ok with 15 s time-step, but there are some problems with 250m and 100m resolution domains due to steep slopes (less issues on a flat terrain !)

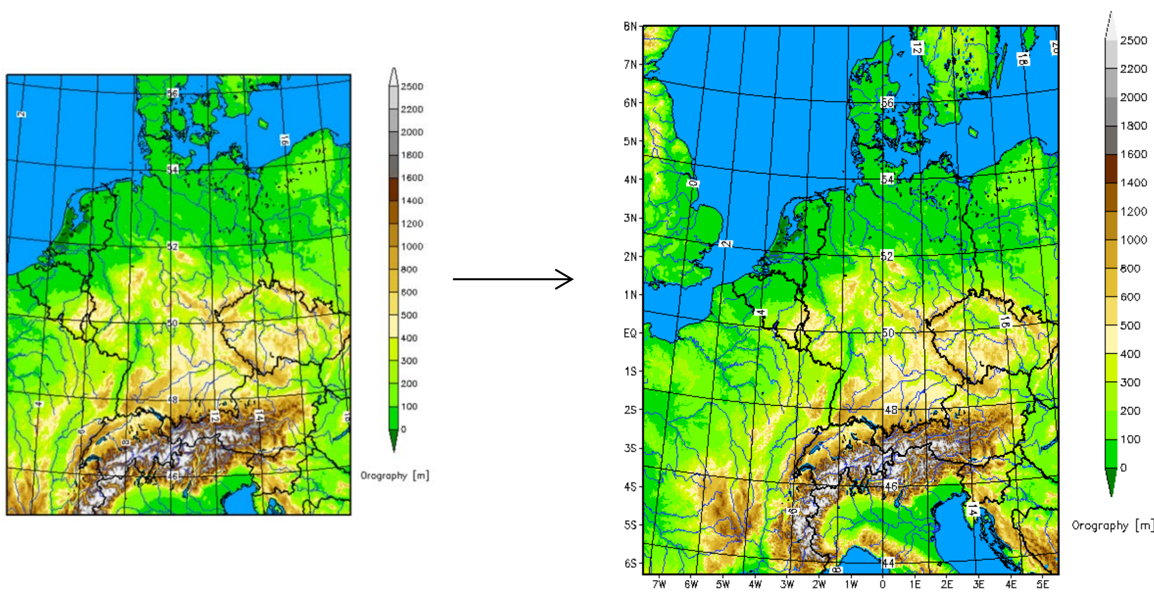
DWD

DWD plans to extend the current convection permitting model-setup COSMO-DE in the following respects (~end 2015):

➔ increase horizontal resolution from 2.8 km to 2.2 km

➔ increase number of vertical levels from 50 to 65

➔ increase area from 10.5° * 11.5° to 13° * 14.3°



Test case: 09. June 2014

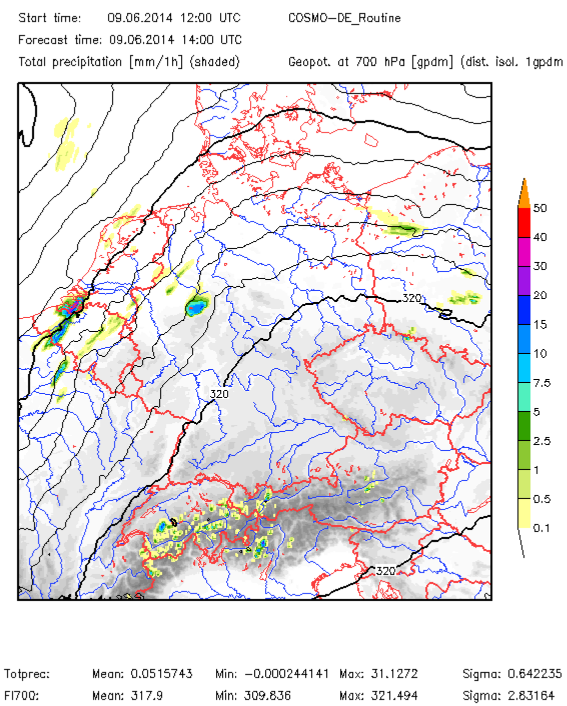
At this day, an MCS moving over Germany at the afternoon produced several super cells. At the evening an additional squall-line produced heavy rain and strong winds (144 km/h at Düsseldorf)

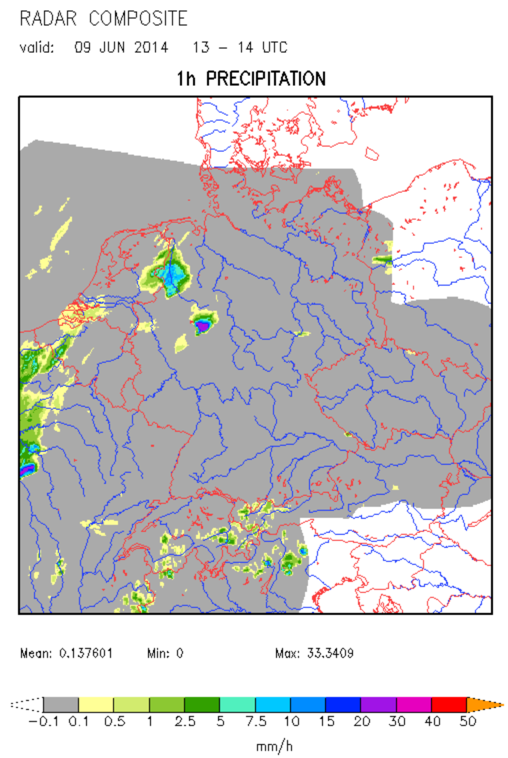
source: *Sofortbericht, 10.06.2014*

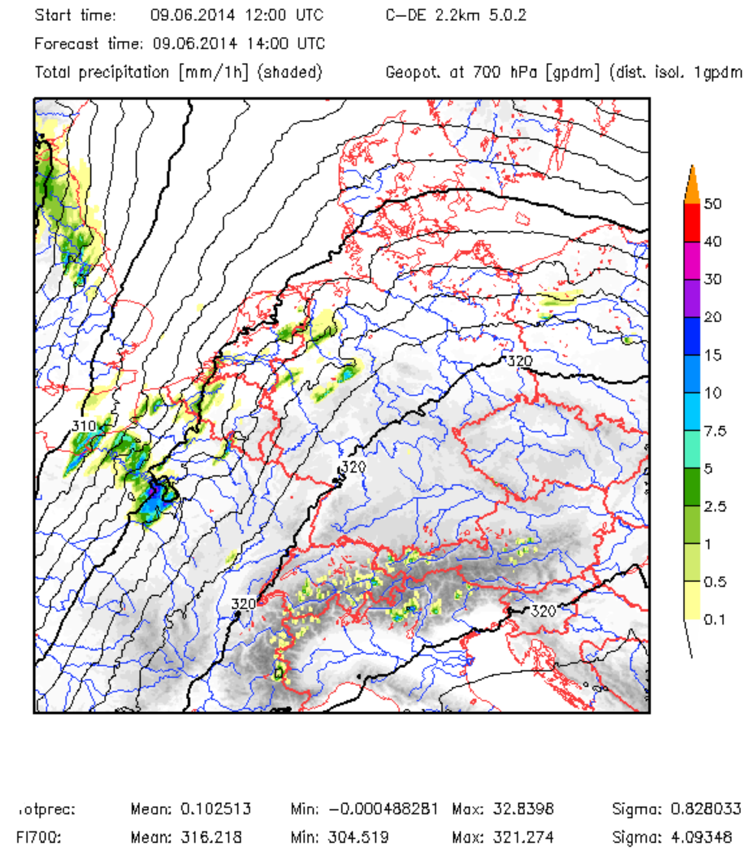
Unfortunately, even the 12 UTC and 15 UTC runs of COSMO-DE didn‘t produce a signal for this event. Only the COSMO-DE ensemble at 15 UTC delivered signals due to the later model start and therefore with the use of more radar information.

Demonstration: the planned new model setup of COSMO-DE delivers a much better (but still not entirely satisfying) forecast, mainly due to the larger domain and the use of radar data (via latent heat nudging) in the extended domain.

COSMO-DE, 06.09.14 12 UTC-run, 1h precipitation sum + radar obs.





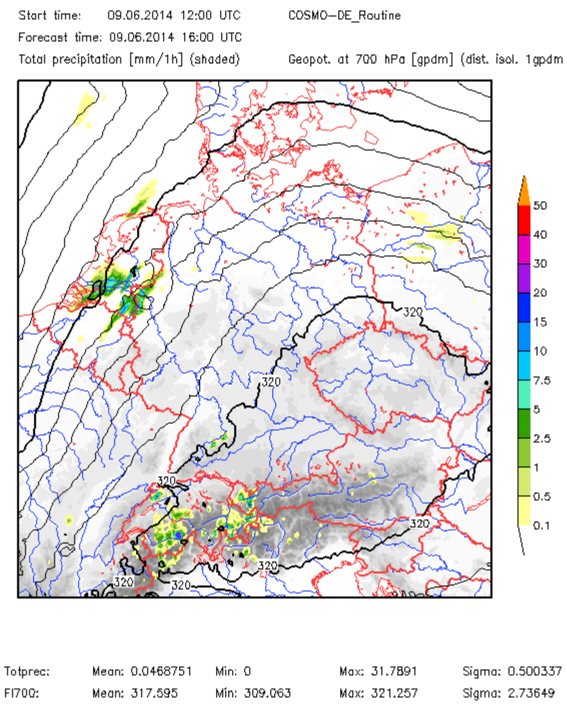


operational run

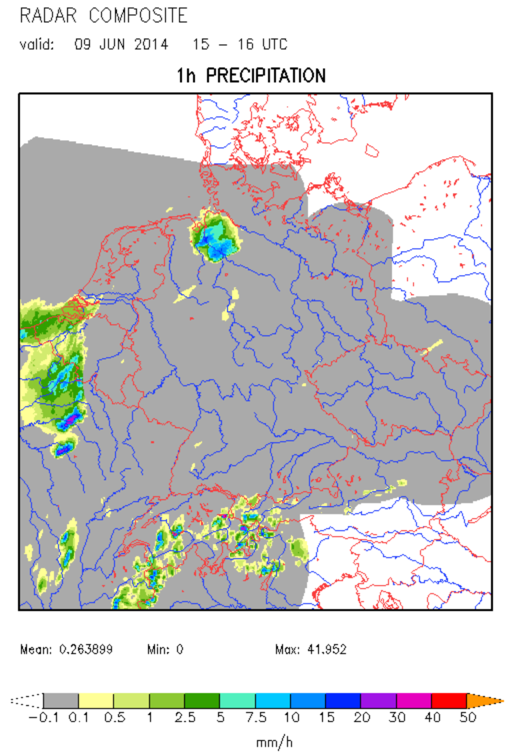
Radar

new setup (2.2km, L65, …)

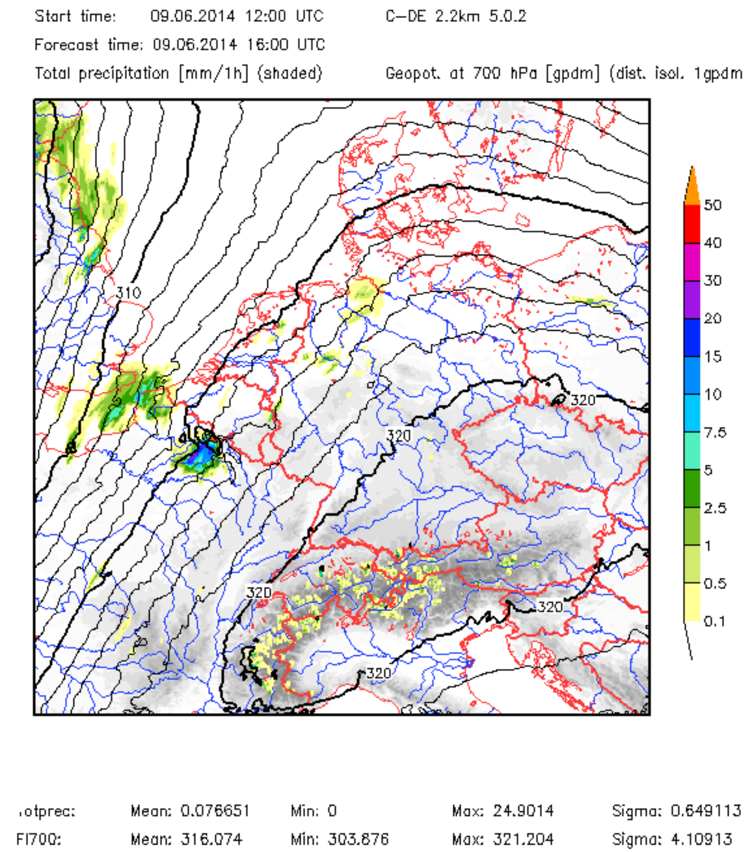
COSMO-DE, 06.09.14 12 UTC-run, 1h precipitation sum + radar obs.



operational run



Radar



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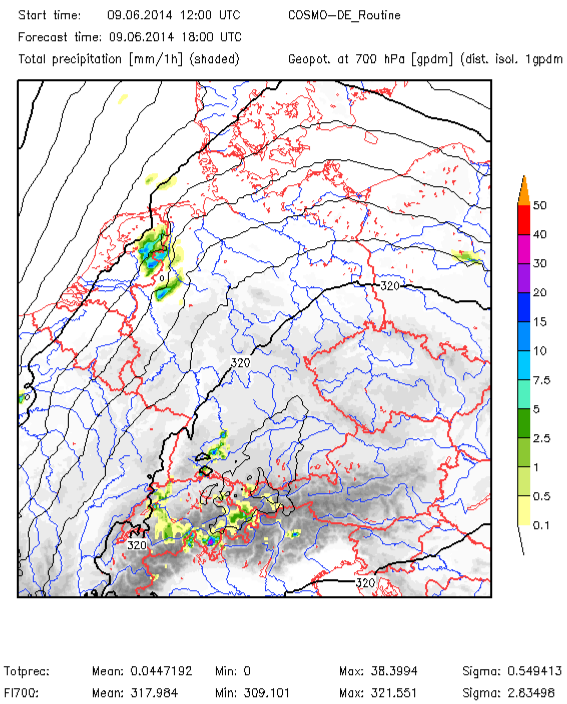
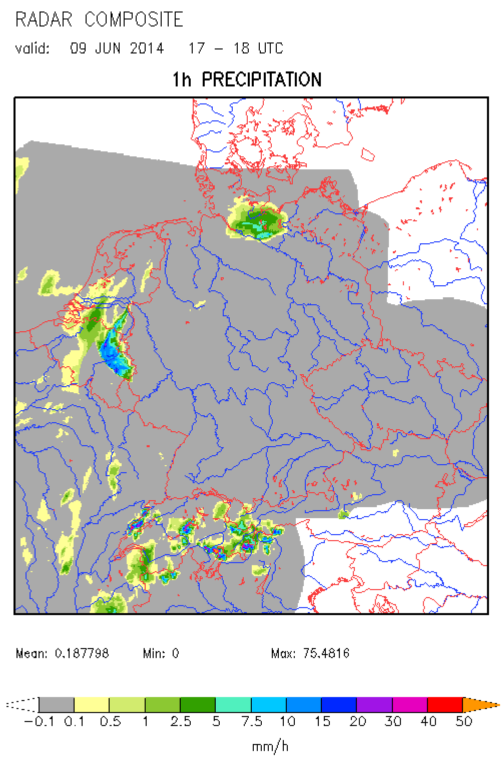
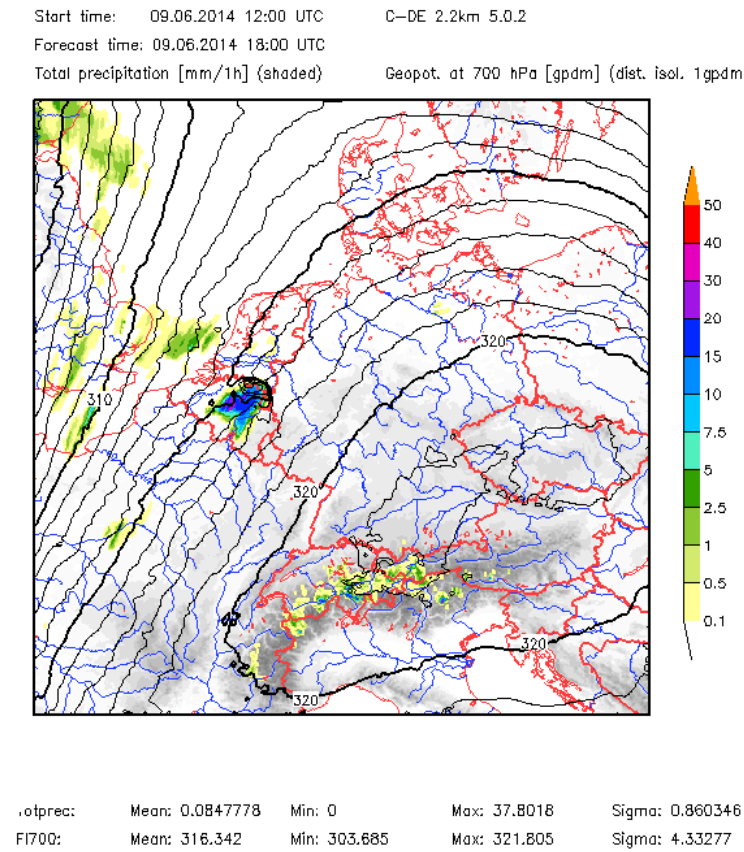


operational run



Radar



new setup (2.2km, L65, …)

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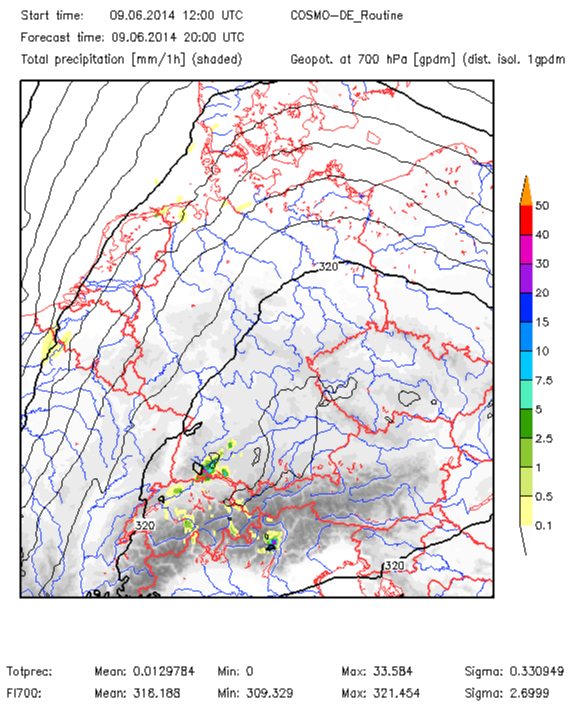
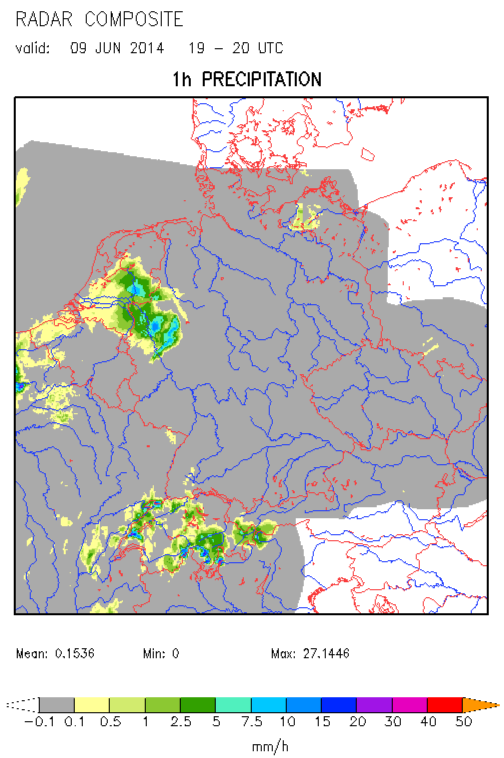
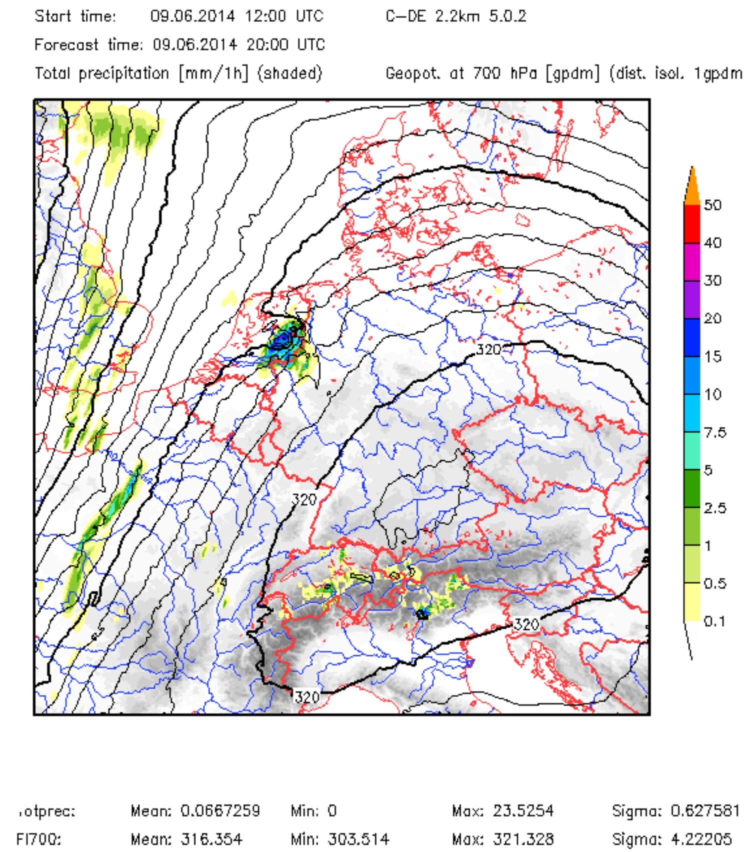


operational run



Radar



new setup (2.2km, L65, …)

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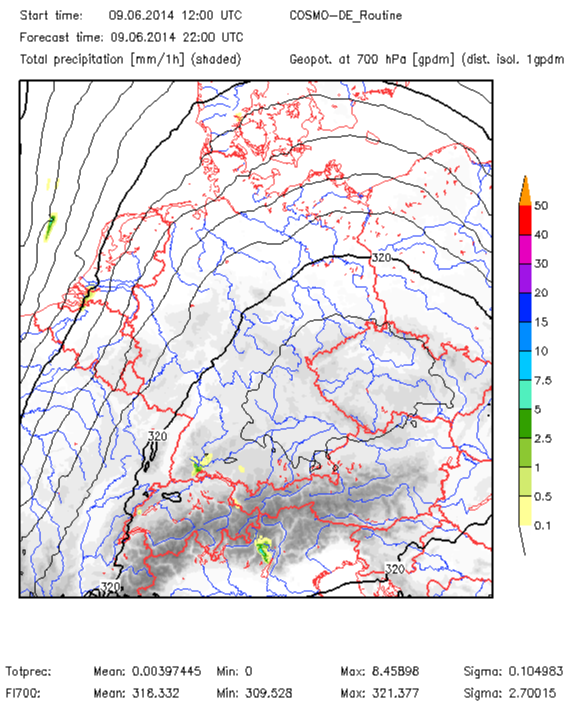
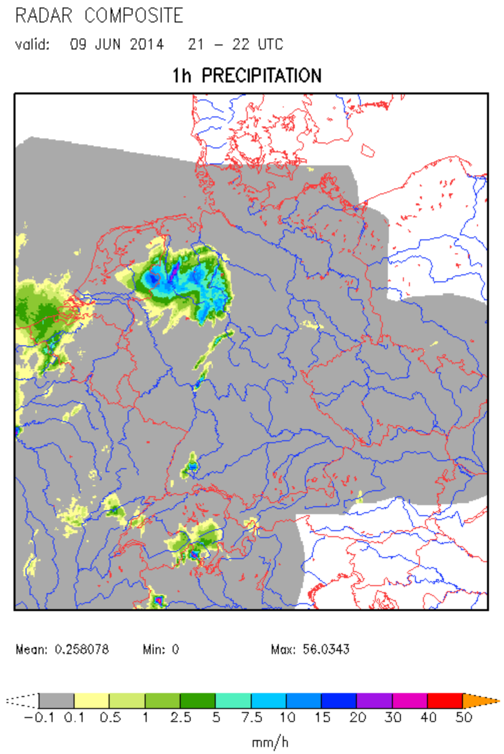
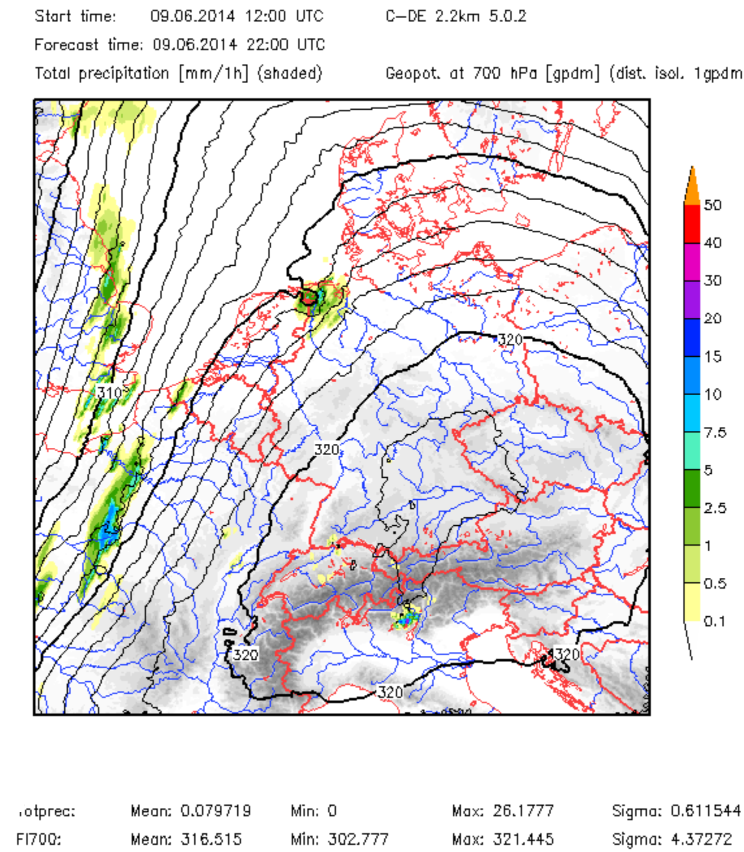


operational run



Radar



new setup (2.2km, L65, …)

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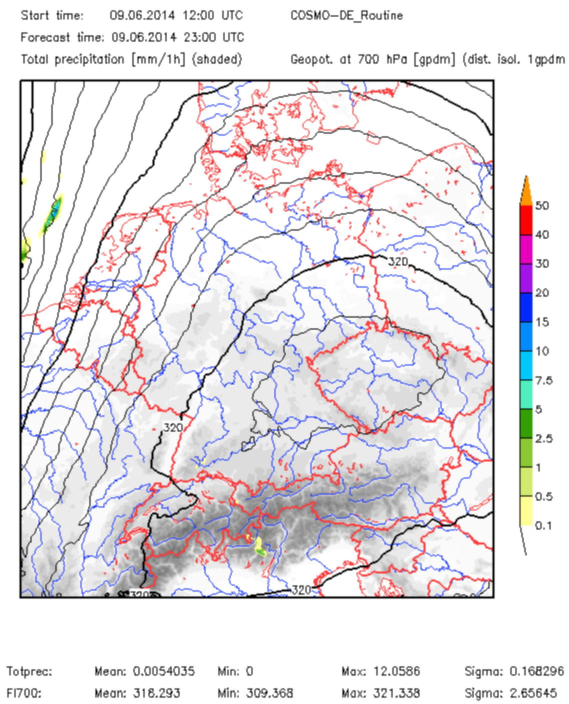
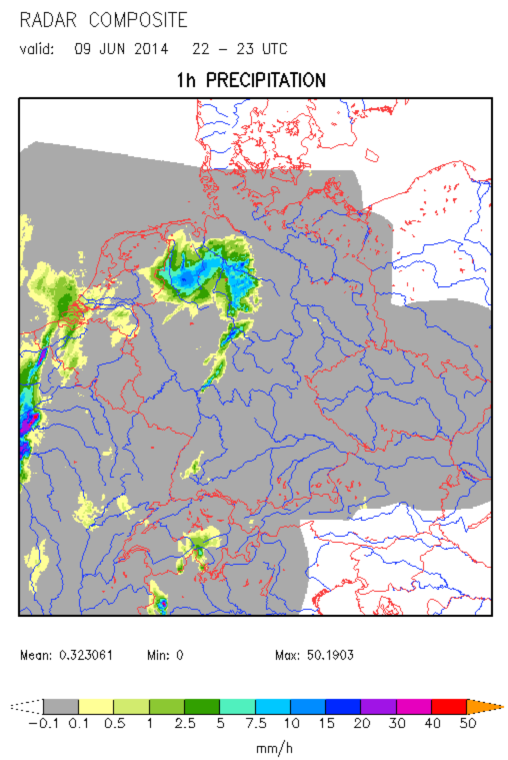
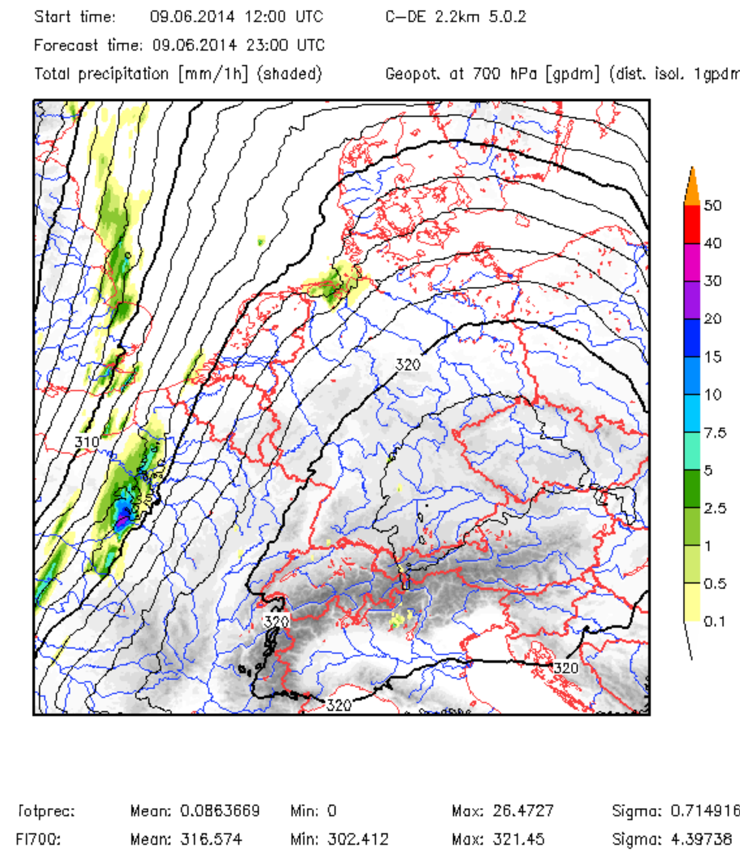


operational run

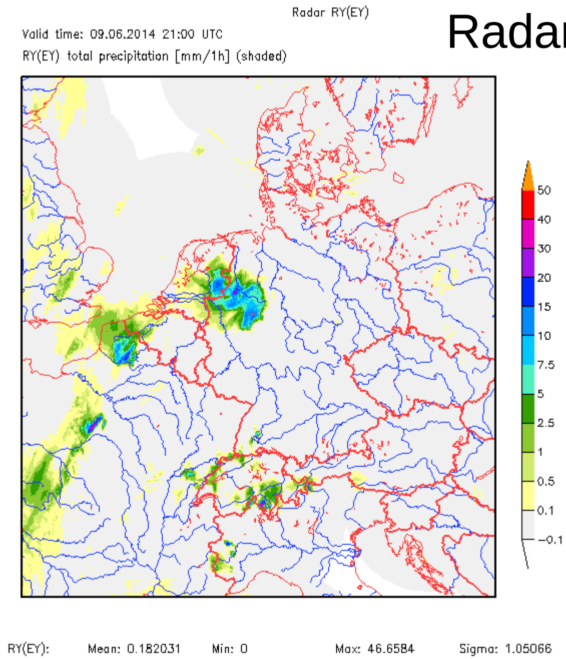


Radar

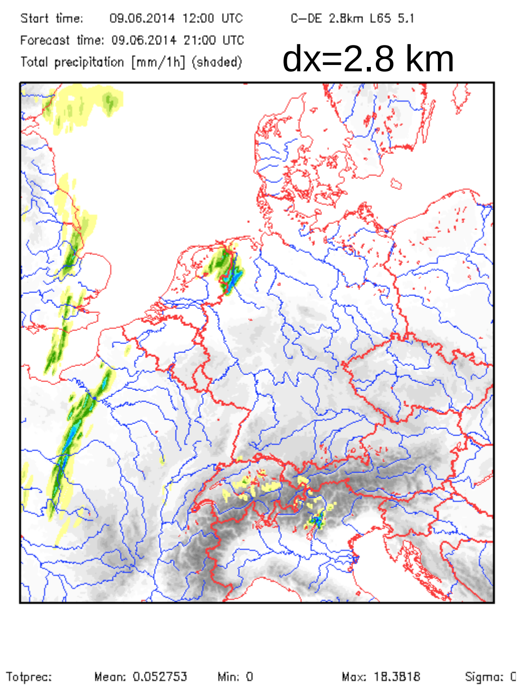


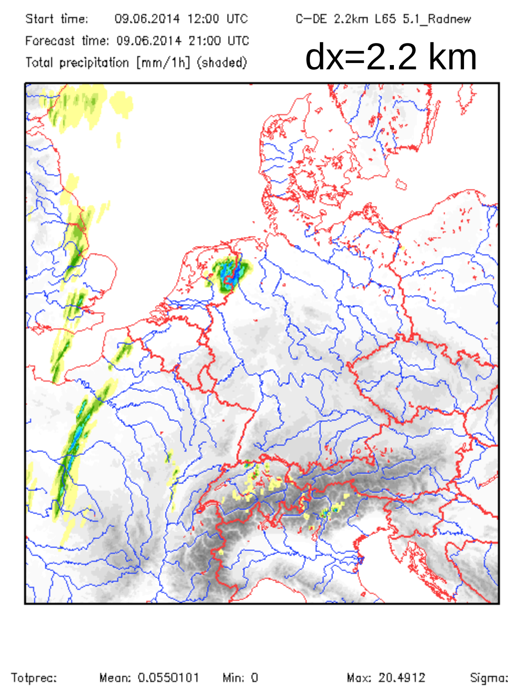
new setup (2.2km, L65, …)

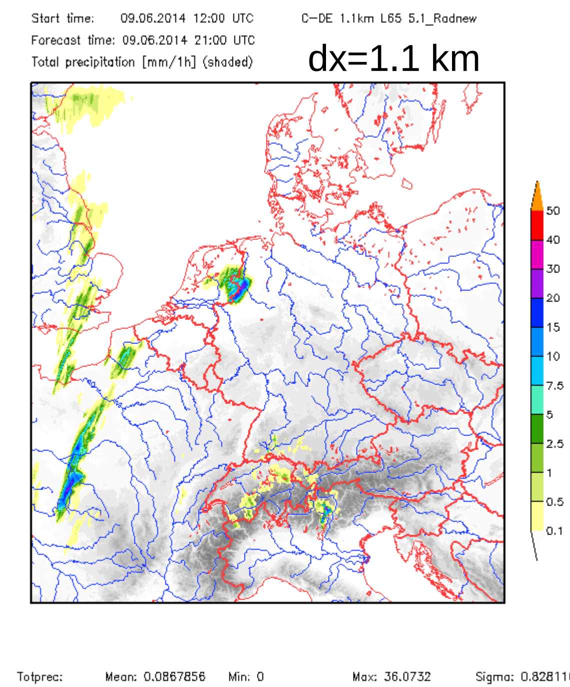
Radar obs.



impact of different resolutions





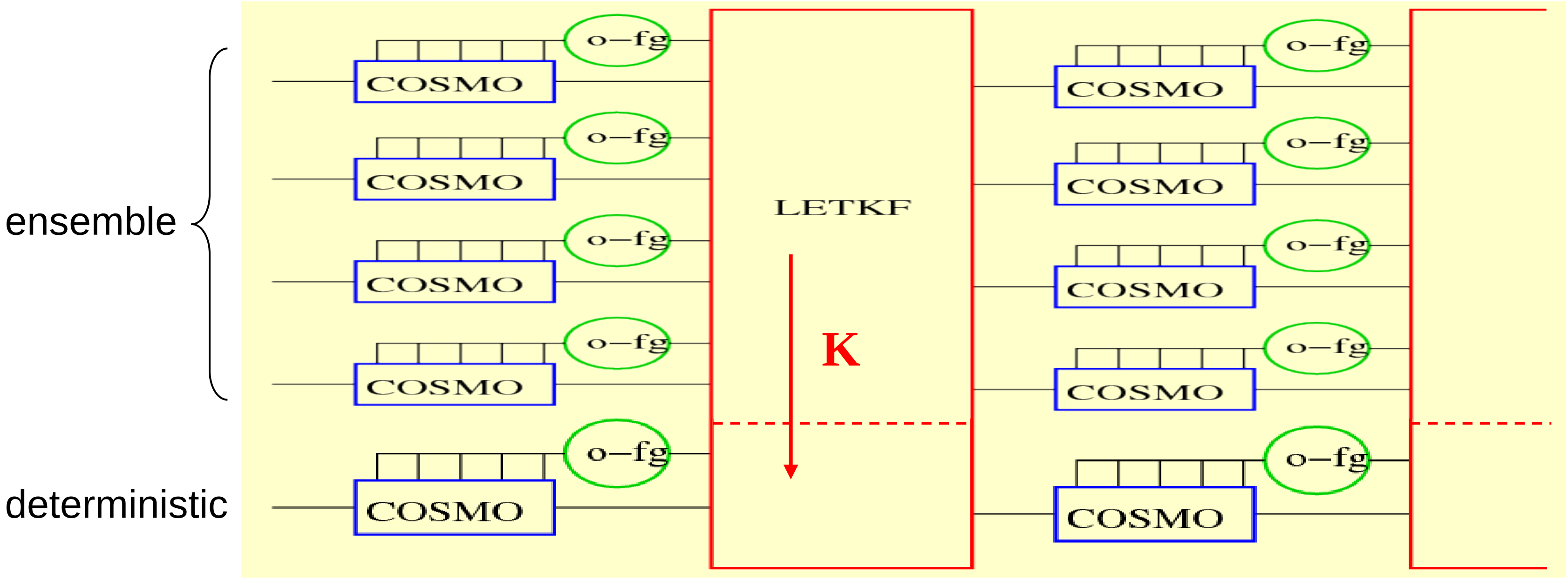


Further investigations in

- turbulence parameters:
    - Blackadar length scale
    - effect of new unified turbulence shallow convection (UTCS) scheme (Mironov et al.)
- cloud microphysics parameters

LETKF (km-scale COSMO) : implementation

- analysis step (LETKF) outside COSMO code
  - → ensemble of COSMO runs, collecting obs – f.g. → **4D** -LETKF
  - → separate analysis step code, LETKF included in 3DVAR package of DWD



- analysis for a deterministic forecast run : use Kalman Gain **K** of analysis mean

$$\mathbf{x}^A = \mathbf{x}^B + \mathbf{K}\,[y^o - H(\mathbf{x}^B)]$$

  - → deterministic run must use same set of observations as the ensemble system !
  - → deterministic run may have higher resolution (not optimal if deterministic f.g. deviates strongly from ensemble mean f.g.)

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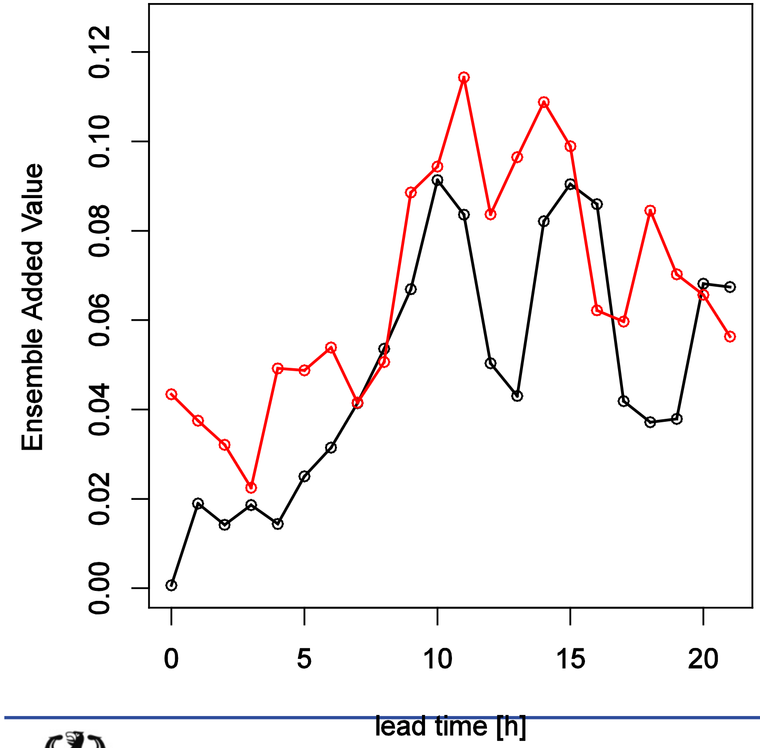
Current Research:

Use of IC from the Kilometer scale ENsemble Data Assimilation (KENDA) based on the LETKF scheme (Hunt et al., 2007)

Results: Ensemble Added Value

2m temperature



operational
KENDA IC

10m wind gusts