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C2SM Center for Climate Systems Modeling

CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

How does MeteoSwiss serve society with better weather forecasting information?

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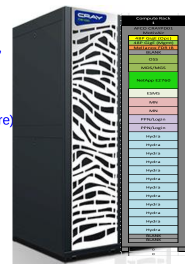
Operational NWP forecasting system implemented in 2016 with the introduction of ensembles

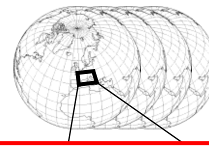
- **Prognostic variables of the COSMO model** (Baldauf et al., 2011)
  pressure, 3 wind components, temperature, specific humidity, cloud water, cloud ice, graupel, rain, snow, turbulent kinetic energy (TKE), 4 different pollen species
- **Coordinates** general terrain-following height-based vertical levels (SLEVE for COSMO-1), Lorenz staggering; Arakawa-C, rotated Lat/Lon horizontal grid
- **Dynamics:** 2-timelevel 3rd order Runge-Kutta, Bott 2[nd] order for tracer advection
- **Physics:** bulk microphysics for atmospheric water content, multilayer soil module, radiation, turbulence
  COSMO-E: shallow Tiedtke mass flux convection scheme, model uncertainty from **Stochastic Perturbations of Physical Tendencies (SPPT)** (Buizza et al., 1999; Maurer et al., 2014)
  COSMO-7: Tiedtke mass flux convection scheme, SSO

- **Computers**
  2 (production + R&D) CS Storm Cray Hybrid system with 12 "fat" computational nodes per rack with:
  - 8 dual **GPU** cards (Tesla K80)
  - 2 Intel Haswell (2.6GHZ,12-core)

- **Time to solution**
  ~1:20h after analysis time (AT) for +72h COSMO-7
  ~1:40h after (AT) for +33h COSMO-1
  ~4h after (AT) for +120h disseminated COSMO-E



IFS-HRES
9km / 0.1°
4x per day



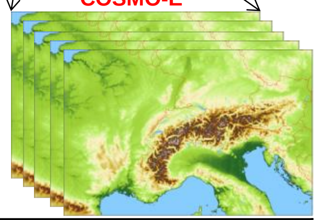
IFS-ENS
18km / 0.2°
4x per day

Ensemble Data Assimilation: LETKF

COSMO-7

COSMO-1

COSMO-E



Mesh size	6/100°, **~6.6km,** Δt = 60 s	1/100°, **~1.1km,** Δt = 10 s	1/50°, **~2.2km**; 20+1 ensemble members
Domain	393 x 338 x 60 = 7'970'040 grid points	1158 x 774 x 80 = 71'703'360 grid points	582 x 390 x 60 = 13'618'800 grid points
Forecasts	+72h at 00, 06, 12 and 18 UTC	+33h at 00, 06, 09, 12, 15, 18 and 21UTC +45h at 03 UTC	+120h at 00 and 12 UTC
Boundary conditions	Hourly update from IFS-HRES (0.1°)		Perturbations: IFS-ENS 18 & 06 UTC: - IFS-ENS control for control & IFS-ENS members 1-20 (out of 50)
Initial conditions	Newtonian relaxation (nudging) to surface and upper air observations, intermittent cycle of 3h assimilation **2018**: LETKF (downscaling from 2.2km) for COSMO-1		**Local Ensemble Transform Kalman Filter (LETKF)** intermittent 1h assimilation cycle (Hunt et al., 2007, Schraff et al., 2016) - LETKF mean for control member & 20 out of 40 members from LETKF

- **References**

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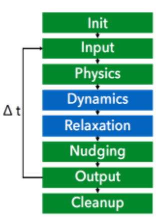
Buizza, R. et al.,1999: Stochastic representation of model uncertainties in the ECMWF ensemble prediction system. *Quart. J. Roy. Meteor. Soc.*, **125**, 2887–2908
Hunt, B. et al., 2007: Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter. *Physica D*, **230**: 112–126
Maurer, D. et al., 2014: First COSMO-E Experiments with the Stochastically Perturbed Parametrization Tendencies (SPPT) Scheme, COSMO Newsletter No. 14, available at http://www.cosmo-odel.org
Schraff, C. et al., 2016: Kilometer-scale ensemble data assimilation for the COSMO model (KENDA), *Quart. J. Roy. Meteor. Soc.*, **142**, 1453-1472

High-Performance Implementation



Programming Languages
Fortran: OpenACC
C++: CUDA

C++ dynamical core rewriting using STELLA (Dycore)

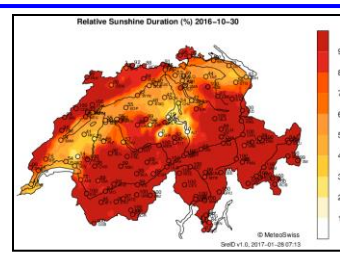
STELLA is a domain specific language directly embedded in C++ geared towards stencil computations. STELLA can generate CUDA, OpenMP and X86 code.

For a 2 hour forecast with one COSMO-E member:

CPU: 100x Haswell cores **GPU**: 8x Kepler sockets (4x NVIDIA K80 cards)

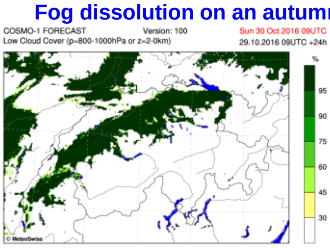
DP: double **SP:** single precision	**CPU** perf. COSMO **DP** Fortran	factor	**CPU** perf. COSMO **DP** C++ Dycore	**GPU** perf. **DP**	factor	**GPU** perf. **SP**
Dynamics & Relaxation	280s	**1.35**	207s	98s	**1.6**	63s
Physics	80s		80s	38s	**1.4**	27s
Other	14s		12s	34s		21s
Total	**374s**	**1.21**	**309s**	**169s**	**1.5**	**110s**

Total Speedup: 3.4

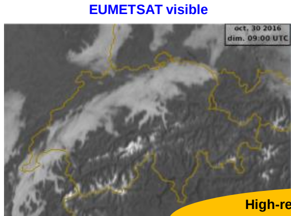


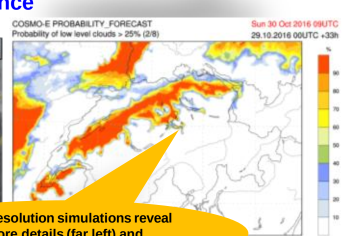
Observations (above) have 4 stations below 15% which are not present in any of the members below

Fog dissolution on an autumn day more than 24h in advance

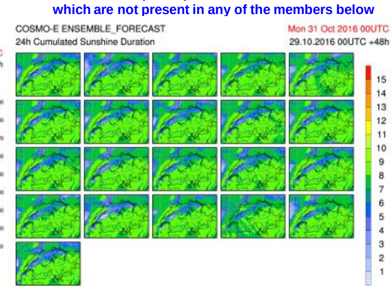


EUMETSAT visible





High-resolution simulations reveal more details (far left) and ensemble gives a better reliability



- **References**

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Gysi, T. et al. 2015: STELLA: A Domain-specific Tool for Structured Grid Methods in Weather and Climate Models. In Proc. of the Intl. Conf. for High Performance Computing, Networking, Storage and Analysis (SC '15). ACM, New York, NY, USA, Article 41, 12 pages.

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