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# Towards operational postprocessing of temperature at MeteoSwiss

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# Key points

Goal: probabilistic and seamless post-processing for arbitrary locations

Requirement: set-up that allows for an operational implementation (efficiency and interpretability)

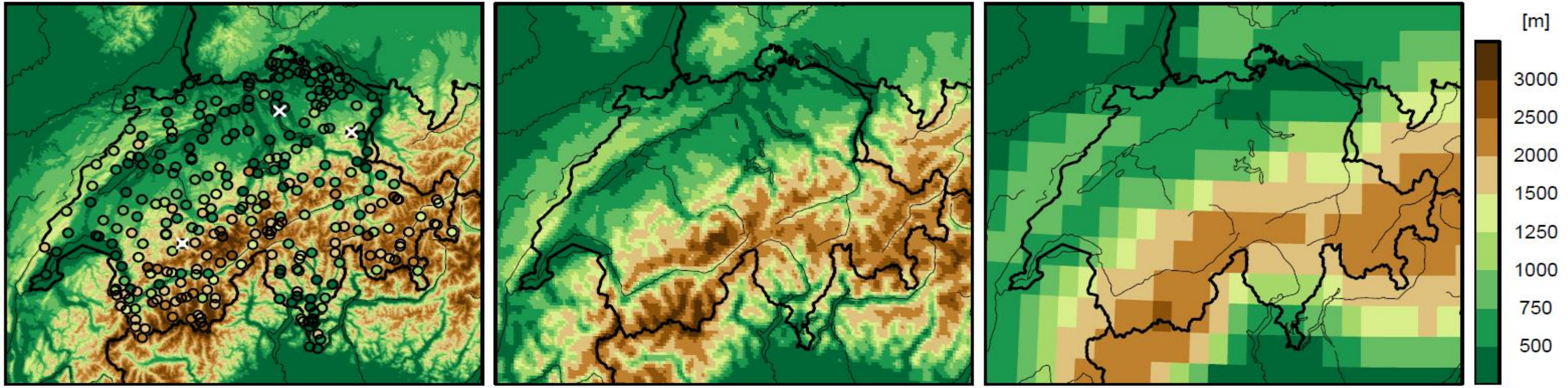
- EMOS approaches improve NWP temperature forecasts substantially
  - CRPSS between 0.2 and 0.5, depending on (a) location (most within complex topography where NWP misses many sub-grid processes) (b) day-time (c) season (in winter more than in summer) and (d) lead-time (decrease towards larger lead-times).

- Multi-model EMOS allows to (a) merge several NWP models (e.g. a high-resolution short-range forecast and a coarse-resolution medium-range forecast), (b) further improve skill of predictions (by up to 10-20%) and (c) provide seamless short- to medium-range forecasts (constrained by NWP system with the longest lead-time).

- Global EMOS allows to provide forecasts at arbitrary points and

# NWP models

Reality + Obs. Stations | COSMO-E | ECMWF-IFS

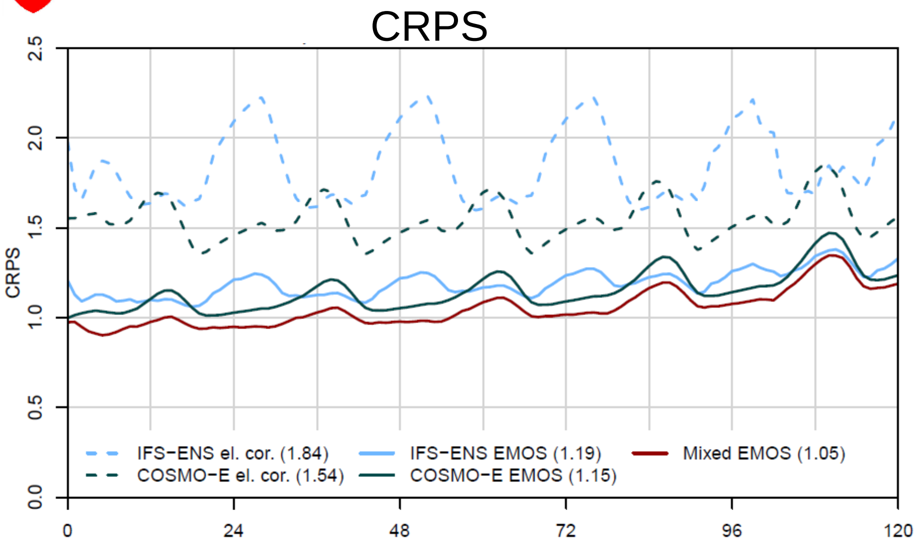


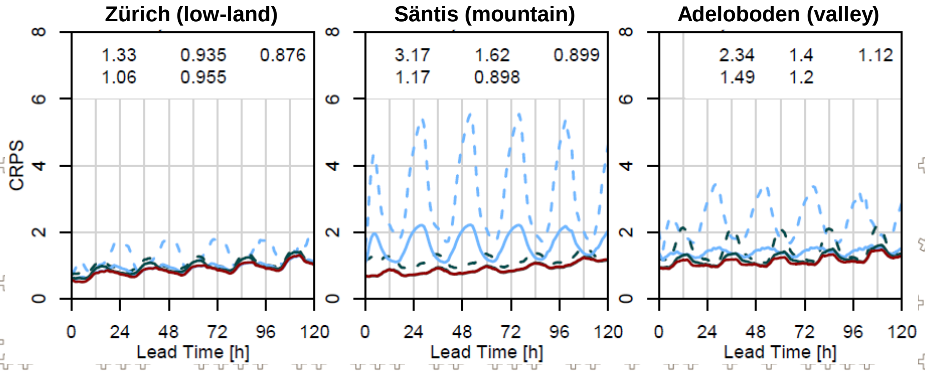

- Several hundred stations within Switzerland (shown, 296) and from surrounding countries and networks (not shown, used in global EMOS approaches).

- Limited-area model for the greater Alpine region at 2.2 km resolution.
- Operational weather forecasting model of MeteoSwiss.
- 21-member ensemble.
- Hourly up to 120h.
- Initialized 2 (4) times a day.

- Global model at 18 km resolution
- 51-member ensemble.
- At different granularity up to 360h (linearly interpolated to hourly resolution)
- Initialized 2 (4) times a day.

# CRPS (296 stations)

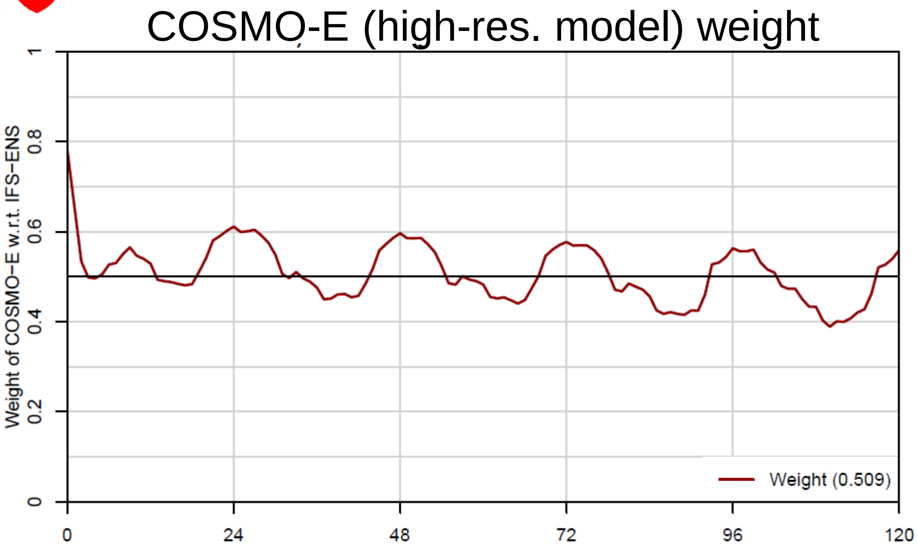


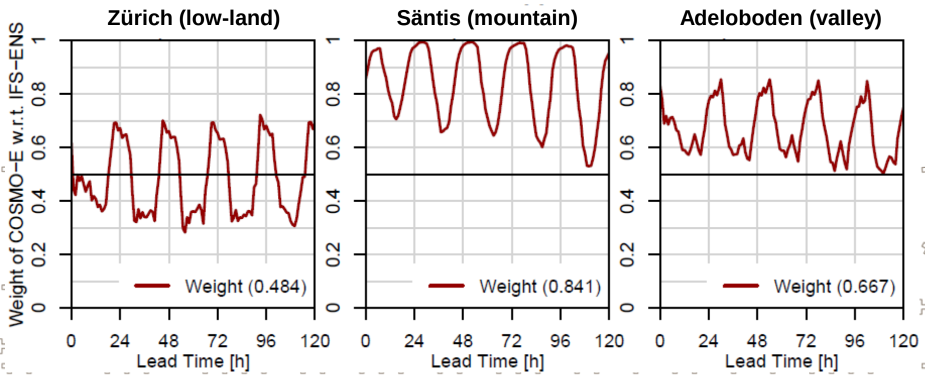

- High-resolution (COSMO-E) outperforms coarse-resolution (ECMWF-IFS) DMO
- Applying EMOS to both NWP systems improves forecasts substantially (still COSMO better than IFS)
- Processing both NWP systems using Mixed EMOS outperforms all approaches.

- Skill and Improvement for characteristic Swiss station sites in the low-land (Zurich-Airport) and mountain (Säntis) and valley-location (Adelboden).
- Note the distinct biases of DMO in complex terrain (middle and right column)

# COSMO-E Model Weight (296 stations)



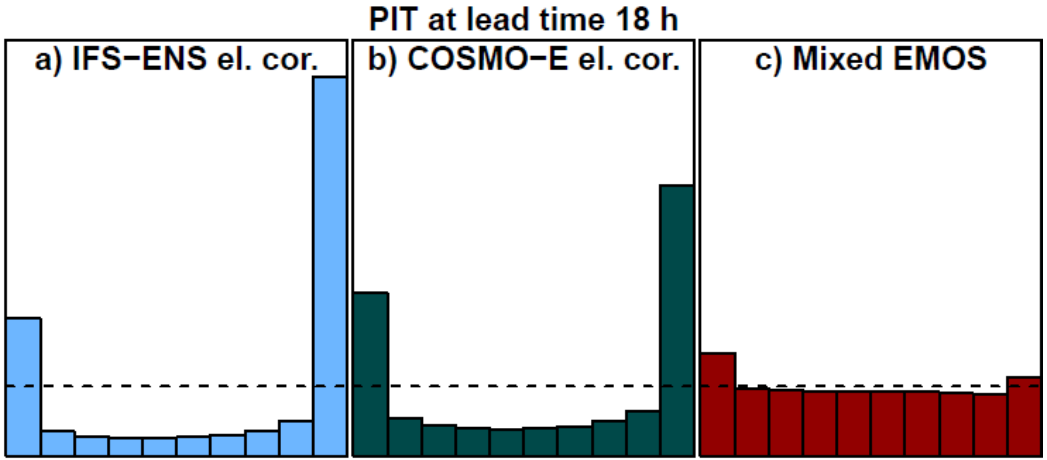

- Weight or importance of COSMO-E within the Mixed EMOS approach at roughly 50% (with diurnal variations)




- Weight / Importance at the three characteristic Swiss sites
- Note the importance of COSMO-E within complex terrain (middle and right column).

# PIT Histogram of Mixed EMOS

- NWP models elevation-corrected, EMOS (mixed-model version)

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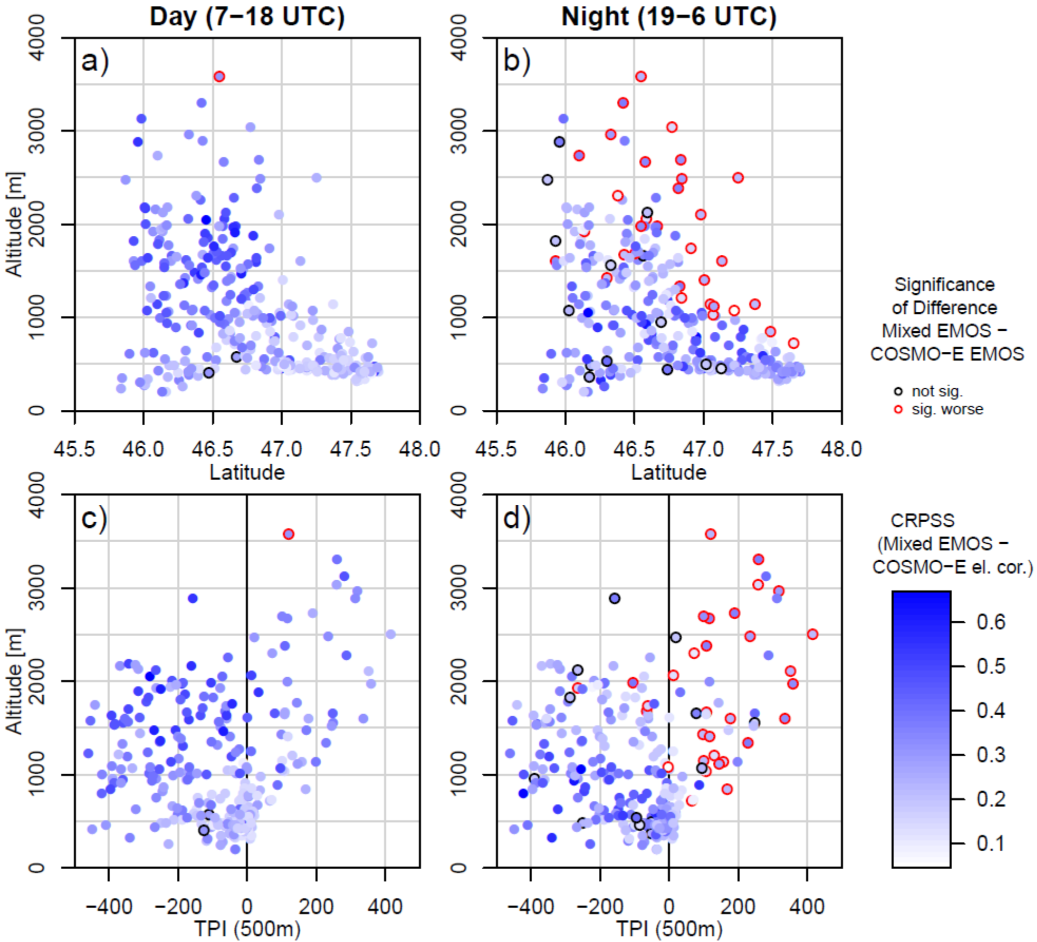
# A detailed look at mixed EMOS improvement

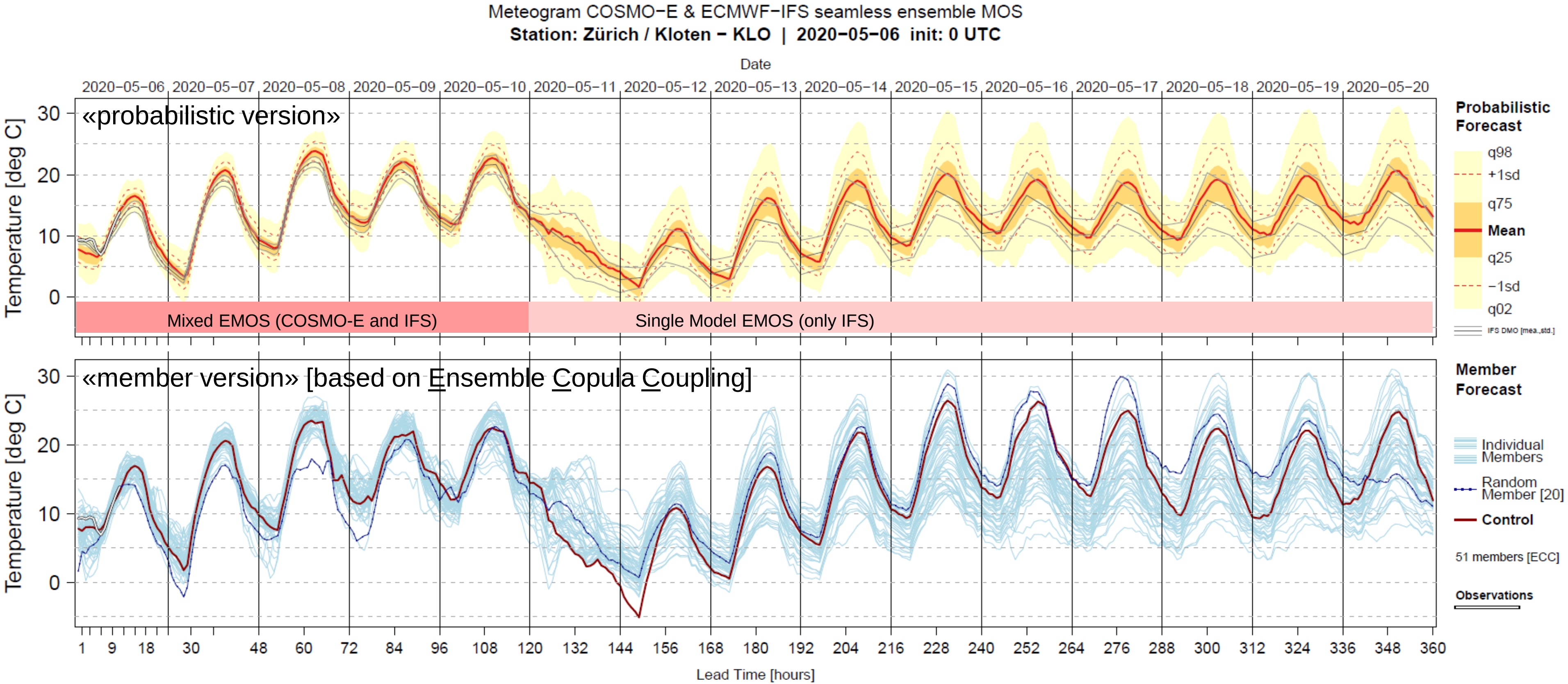



- Mixed EMOS (multi-model) improves forecasts over direct model output (DMO) at all stations (denoted by color-code)
  - In particular at valley stations, indicated by a negative TPI (500m).

- Mixed EMOS (multi-model) is especially at night-time not necessarily better than COSMO-E EMOS, especially along mountain (ridges), indicated by a positive TPI (500m) – coarse resolution of ECMWF-IFS may distort quality at night-time when boundary layer processes are important, in particular in complex terrain.

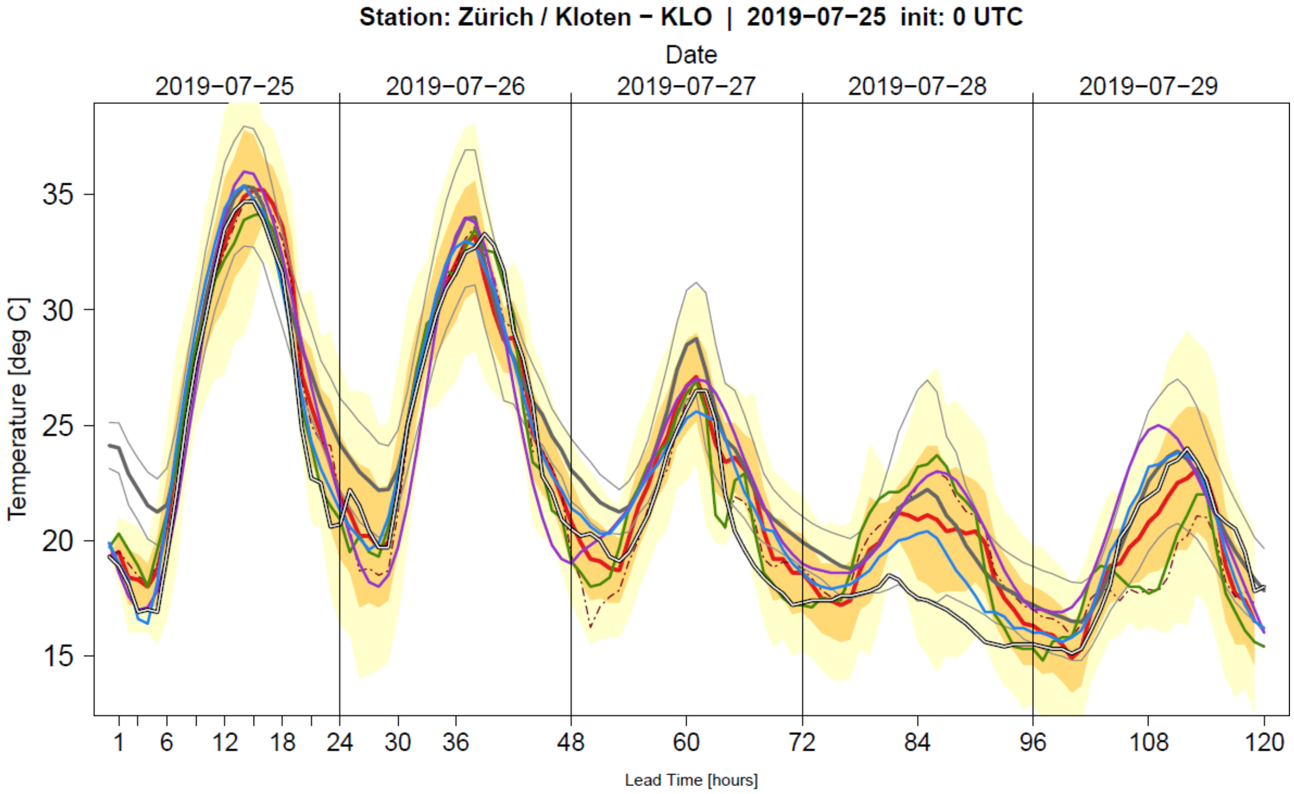
# Seamless medium-range forecast prototype

- Based on COSMO-E (21 members, 5 days) & ECMWF-IFS (51 members, 15 days)



# Operational monitoring of EMOS vs. other products

- Operational monitoring of EMOS and a set of other post-processing tools (see legend) at several locations in Switzerland allows to spot major differences, problems and issues and helps improving the PP system in general.




EMOS (1h)
q98
+1 stdev
Mean
−1 stdev
q02
ctrl

COSMO−E (DMO)
+1 stdev
Mean
−1 stdev
direct model output (DMO)
nearest neighbor
not corrected for elev. diff.

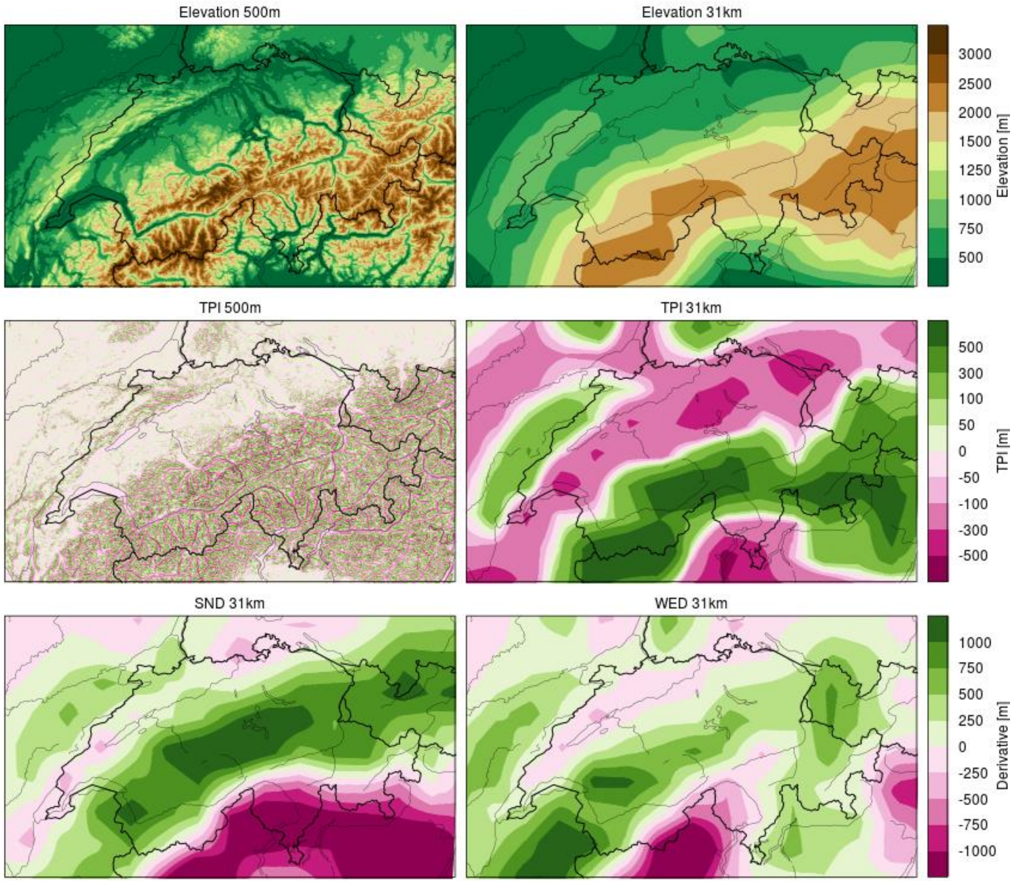
Other Products
Kalman−Filter
data4web
MOSMIX
Observations

| MAE in 6h−period | −6 | −12 | −18 | −24 | −30 | −36 | −42 | −48 | −54 | −60 | −66 | −72 | −78 | −84 | −90 | −96 | −102 | −108 | −114 | −120h | mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EMOS mean | 0.8 | 0.8 | 0.8 | 2.5 | 0.7 | 0.3 | 1.5 | 0.8 | 0.6 | 1 | 1.3 | 2.2 | 0.5 | 2.2 | 3.6 | 2.7 | 0.4 | 1 | 1 | 1.4 | **1.3** |
| EMOS ctrl | 1.1 | 0.9 | 0.7 | 2.2 | 1.6 | 0.6 | 1 | 1.1 | 2.2 | 0.3 | 1.5 | 1.5 | 0.6 | 2.7 | 5.3 | 3.2 | 1.2 | 2 | 3.8 | 1.8 | **1.8** |
| COSMO−E mean | 4.8 | 1 | 0.5 | 2.9 | 2.2 | 0.5 | 1.8 | 1.7 | 2.1 | 2 | 2 | 3.1 | 1.9 | 2.3 | 4.2 | 2.6 | 1.5 | 0.4 | 0.5 | 0.5 | **1.9** |
| KalmanFilter | 1.5 | 0.9 | 0.9 | 0.7 | 1.1 | 0.6 | 0.4 | 1.1 | 1.4 | 1.4 | 1.6 | 0.9 | 0.3 | 3.6 | 5.8 | 1.8 | 0.7 | 2.2 | 3.4 | 2.4 | **1.6** |
| MOSMIX | *0.5* | *1.6* | *0.5* | *1* | *1* | *0.6* | *1.2* | *1.1* | *0.9* | *1.1* | *1.3* | *2.2* | *0.7* | *1.3* | *2.5* | *1.2* | *0.6* | *0.8* | *0.6* | *1.3* | **1.1** |
| data4web | 0.4 | 0.6 | 1.1 | 2.6 | 1.8 | 1.9 | 1.5 | 2.5 | 1 | 1.7 | 1.8 | 2.9 | 1.3 | 2.3 | 5.6 | 3.7 | 1.8 | 2.4 | 1.5 | 0.9 | **2** |

# Going into (unobserved) space

## ..or from local EMOS to global EMOS

- Incorporate static predictors *(see right)*
  - At high and coarse spatial resolution [elevation, topographic position (valleyy vs. mountains), derivatives of orientation (too which direction one is facing)]
- Train coefficients using all forecast-observation pairs in one model.
  - Pros: computationally extremely efficient solution to provide calibrated forecasts at arbitrary locations, a larger set of potential predictors can be exploited.
  - Cons: forecast quality degrades with respect to local approaches.

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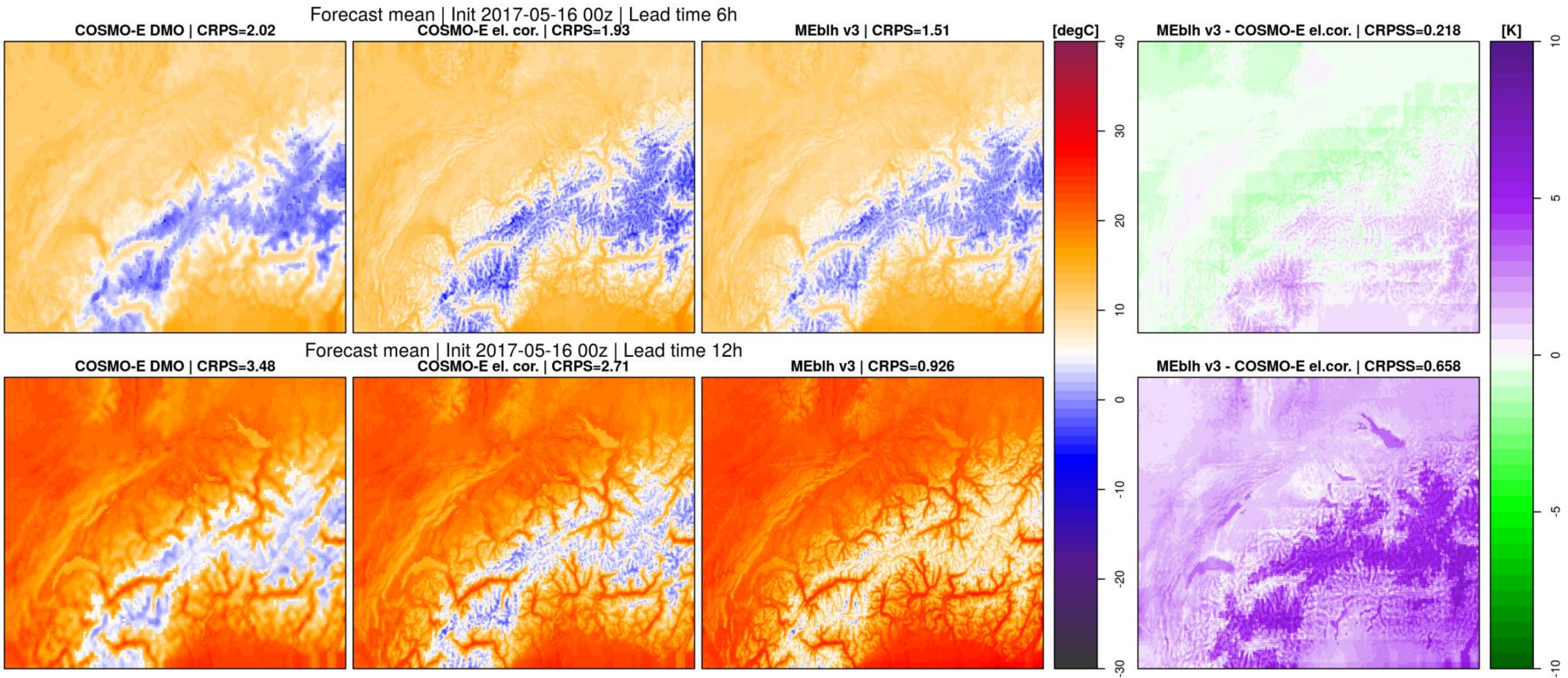
# gEMOS example forecast at 500m resolution

- (1) COSMO-E DMO (2) COSMO-E elevation-corrected (3) gEMOS output (4) Difference of *(3)* and *(2)*
- *Note, the reduction of CRPS (based on point-observations) at the top of each panel.*



# Ensemble Model Output Statistics (EMOS)

- EMOS corrects for errors in the mean (e.g. model biases) and variance (e.g. underdispersion)
- Requires distributional assumption about the target variable (output is a predictive distribution and its parameters)
- For temperature: normal / Gaussian distribution (i.e. mean and standard deviation)

**Local EMOS** (for each location and lead time separately)

$$y = a + b_1 x_1 + \ \dots + b_n x_n \qquad \sigma = \sqrt{c + d s_1}$$

CRPS minimization using a rolling archive of 50 days.
Predictors: ensemble_mean of COSMO-E and ECMWF-IFS, ensemble_std of COSMO-E, mean atmospheric boundary layer height of COSMO-E
Framework following approach of Gneiting et al (2005): *Calibrated Probabilistic Forecasting Using Ensemble Model Output Statistics and Minimum CRPS Estimation*

**Global EMOS (or gEMOS)** (for all locations at once and each lead time separately)

Local framework is adjusted such that it allows to additionally incorporate static predictors

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