TOWARDS A REGIONAL ENSEMBLE REANALYIS

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2016 November, 22nd
4th UERRA GM Reading

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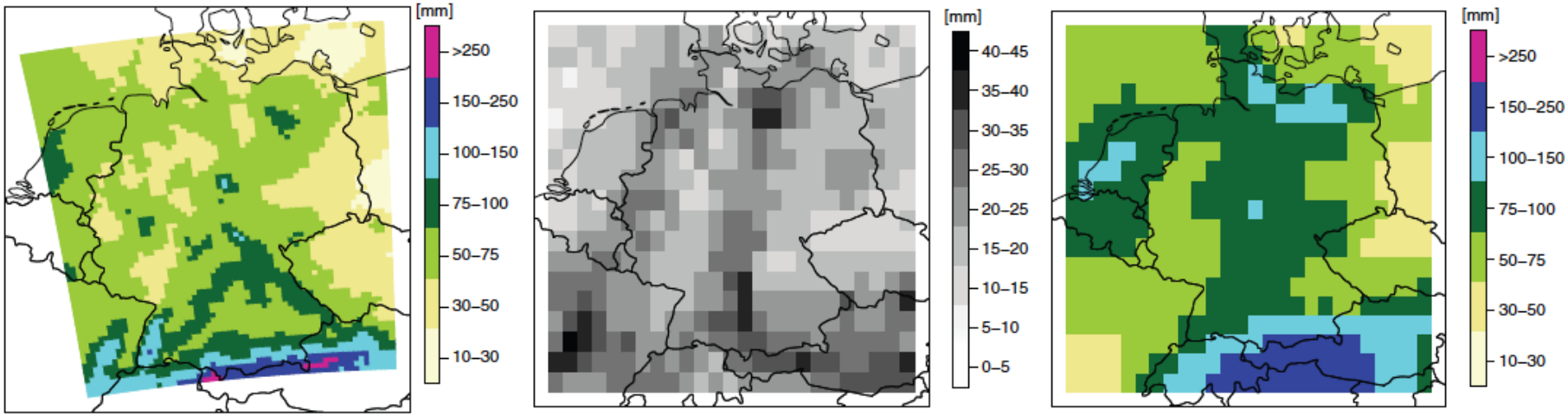
UERRA Uncertainties in Ensembles of Regional ReAnalyses

WHY REGIONAL REANALYSES?

COSMO-EN-REA12 VARIANCE ERA-INTERIM



Monthly integrated precipitation in June 2011

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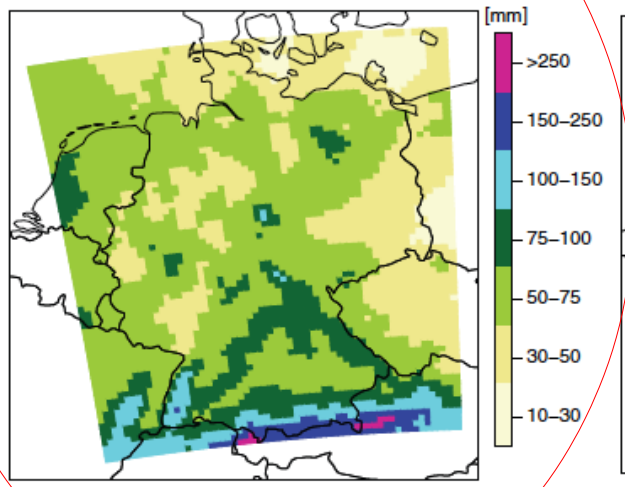
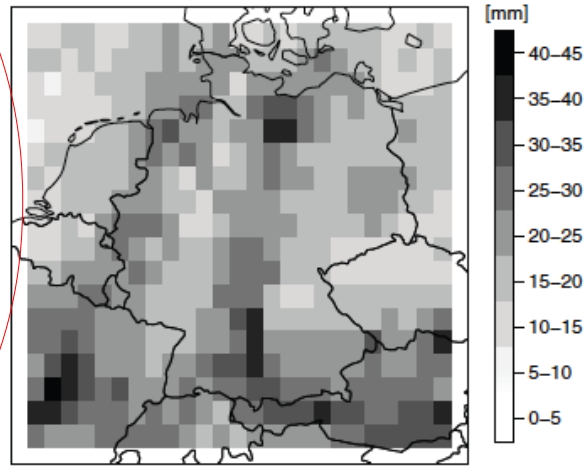
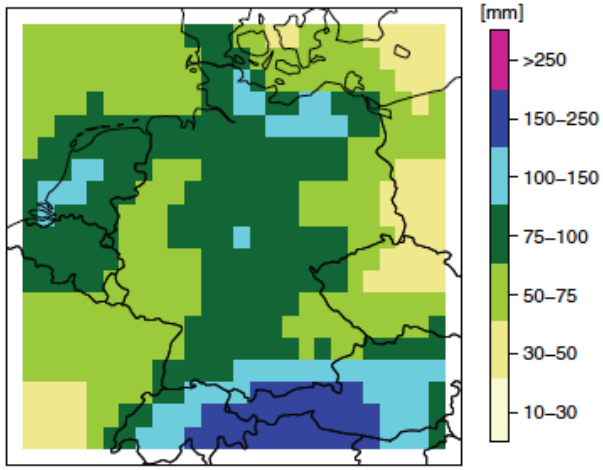
COSMO-EN-REA12



VARIANCE



ERA-INTERIM

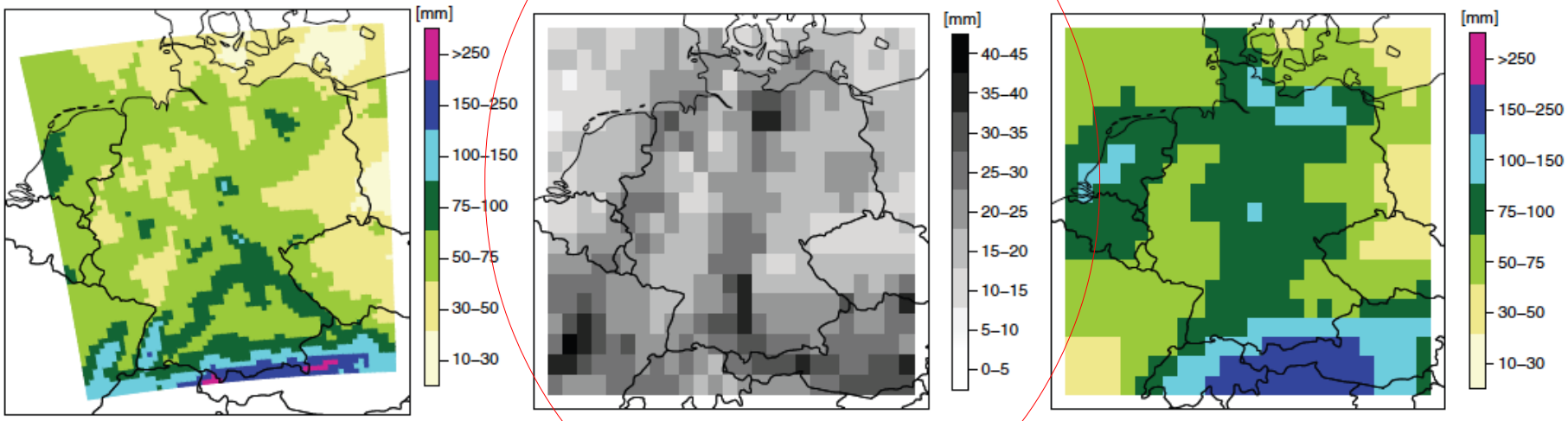


Monthly integrated precipitation in June 2011

Motivates regional reanalyses!

WHY REGIONAL REANALYSES?

COSMO-EN-REA12 | VARIANCE | ERA-INTERIM



Monthly integrated precipitation in June 2011

Motivates ensembles!

HIGH-RESOLUTION REGIONAL REANALYSES IN BONN

- Regional reanalyses in the Hans-Ertel Centre for Weather Research
  - COSMO-REA6
    - Europe, 6km
    - COSMO+nudging
    - 20 years

    Bollmeyer et. al, 2015
  - COSMO-REA2
    - Germany, 2km
    - COSMO+nudging+lhn
    - 8 years

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What are the uncertainties underlying the system?

Bach et. al, 2016

OBJECTIVE

Develop probabilistic reanalysis suite

based on COSMO (at bisection of grid spacing)

and produce 5 test years

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STEPS AND STATUS

- Implementation of ensemble nudging technique
- Evaluation of test periods (2 months)
- Combination with LETKF (did not work well)
- Integration into COSMO-REA6 suite in ecflow
- Extension of the suite by further uncertainty sources
- Working on variables, post-processing and archiving

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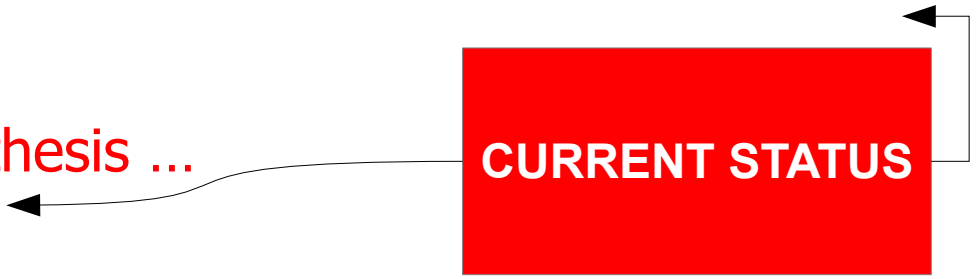
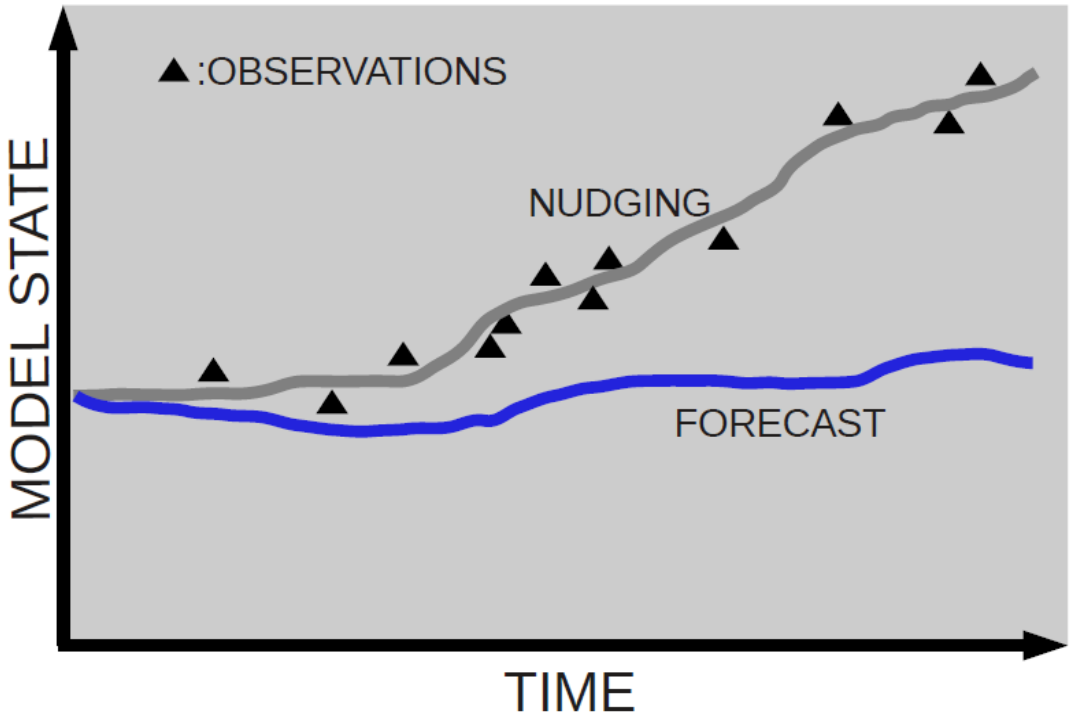
- PhD thesis ...



ENSEMBLE NUDGING

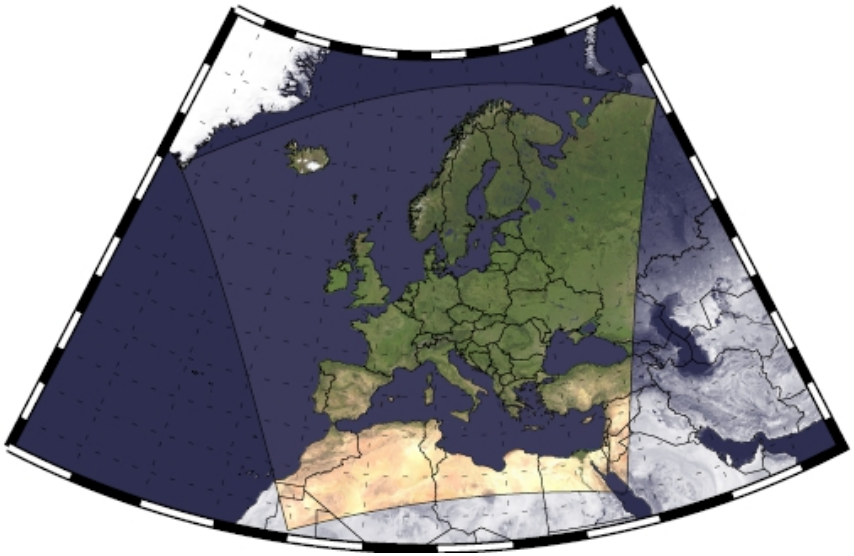
$$\frac{\partial}{\partial t}\psi(\mathbf{x},t) \;=\; F(\psi,\mathbf{x},t) \;+\; G_\psi \cdot \sum_{k_{(obs)}} W_k(\mathbf{x},t) \cdot [\psi_k^{obs} - \psi(\mathbf{x}_k,t)]$$

- Perturb the observations assuming
  - normally distributed
  - stationary
  - spatio-temporally uncorrelated
  - unbiased *obs errors*



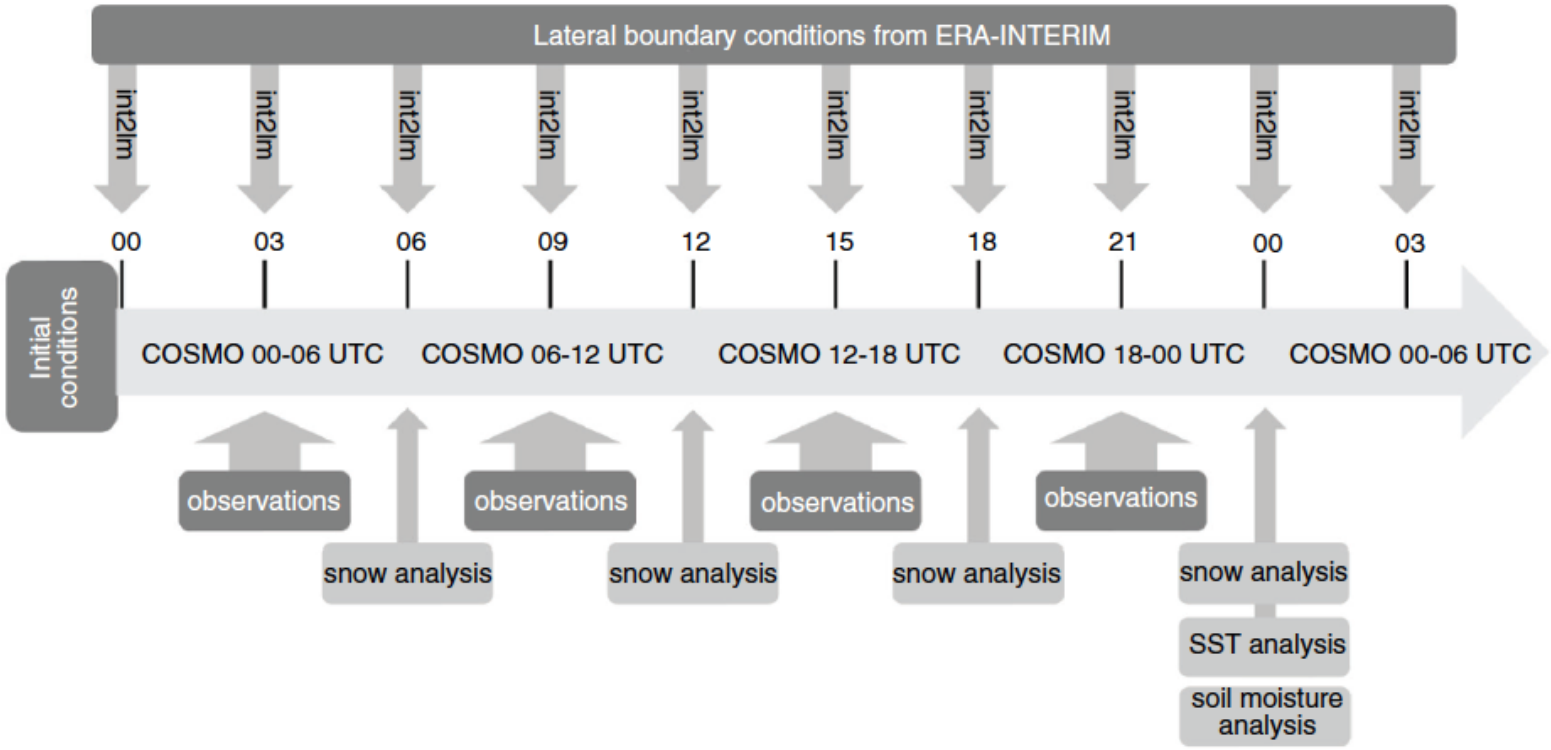
REANALYSIS SET-UP

- COSMO-EU set-up of model version 5.0 (extended)
- Conventional observations & wind profilers
- 3-hourly LBCs from ERA-Interim
- 21 ensemble members
- Hourly analysis output



Observing system	Report type	Observed variable
Radiosondes	PILOT	Upper-air wind
	TEMP	Upper-air wind, temperature, humidity
		Surface-level wind temperature, humidity, geopotential
Aircraft	AIREP	Wind, temperature
	AMDAR	Wind, temperature
	ACARS	Wind, temperature
Wind profiler		Upper-air wind
Surface systems	SYNOP	Screen level pressure, wind, humidity
	SHIP	Screen level pressure, wind, humidity
	DRIBU	Screen level pressure, wind, humidity

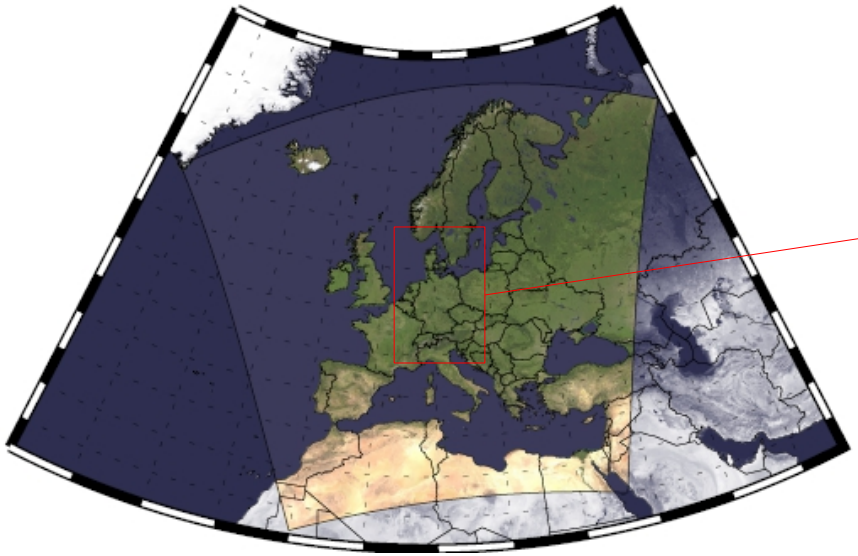
PRODUCTION CYCLE



VERIFICATION OF PRECIPITATION

PILOT STUDIES

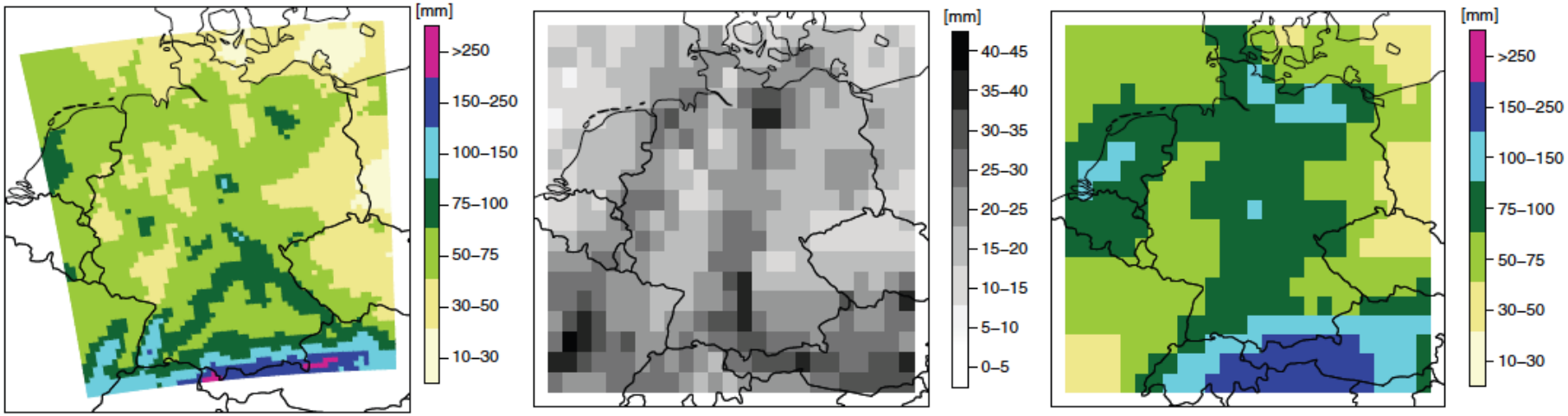
- Suite for COSMO-EN-REA12
- 12 km grid spacing
- 21 ensemble members (1 control run)
- June / December 2011



1000 rain gauges

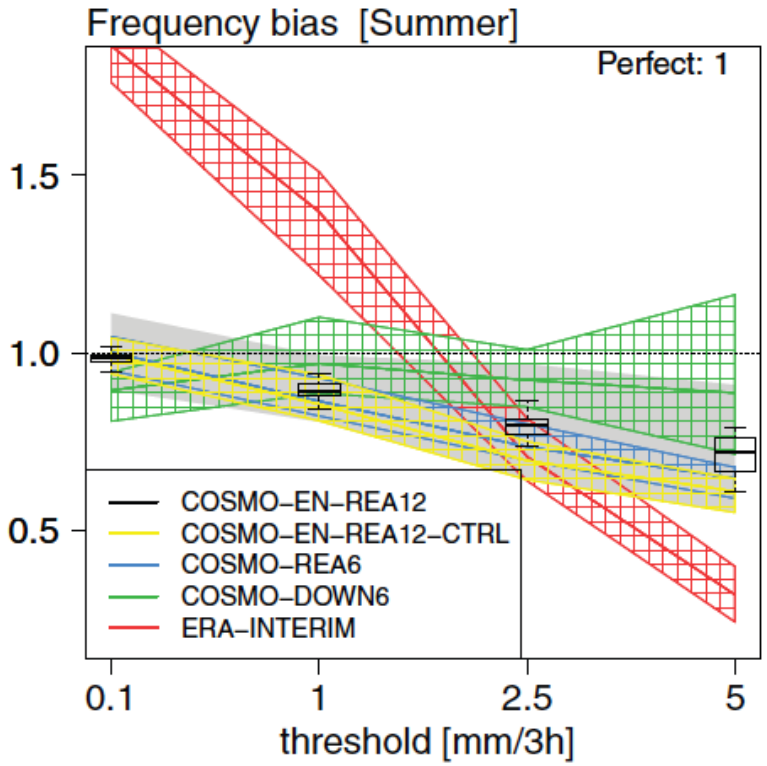
PRECIPITATION AS ESSENTIAL CLIMATE VARIABLE

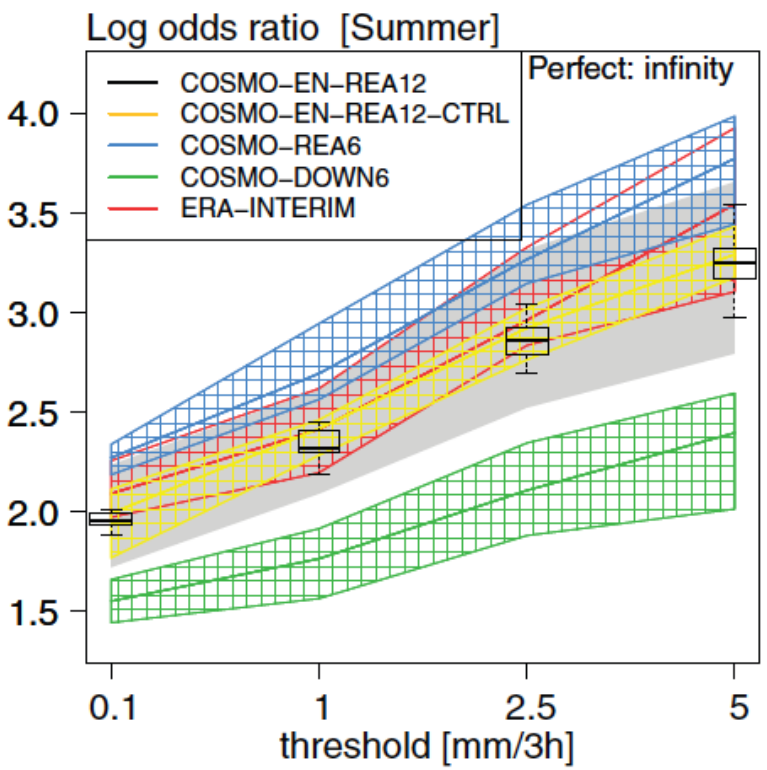
COSMO-EN-REA12 VARIANCE ERA-INTERIM



Monthly integrated precipitation in June 2011

COMPARISON TO ERA-INTERIM (yellow vs red)

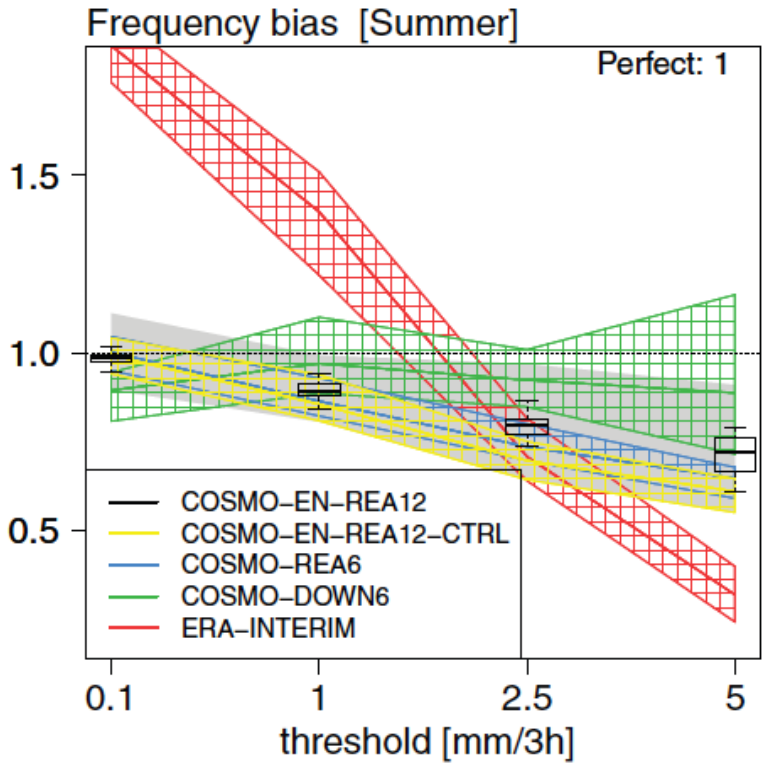


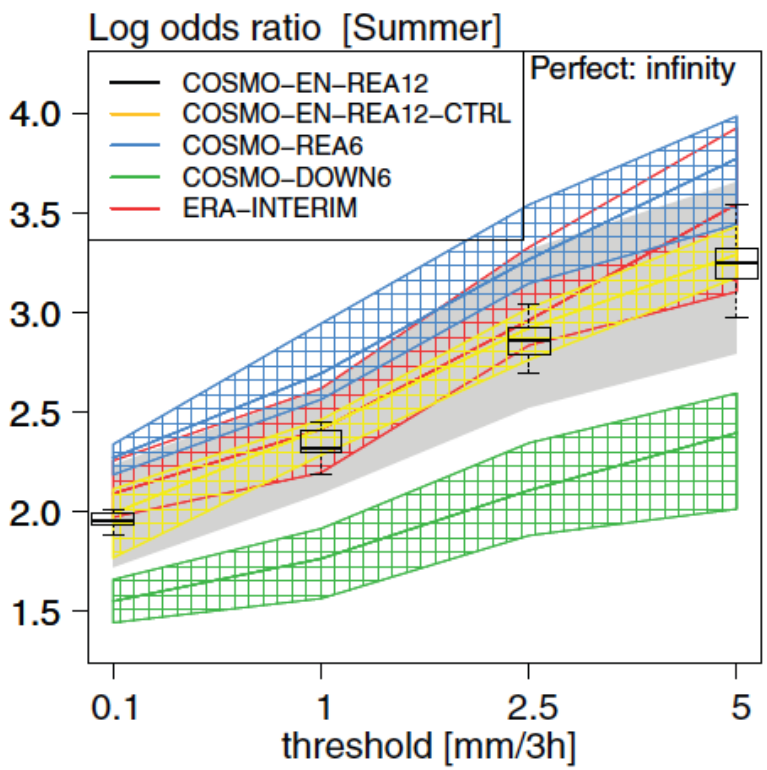


Much better frequency bias!
No change compared to REA6

Comparable accuracy
Loss compared to REA6

COMPARISON TO DOWNSCALING (yellow vs green)





Worse frequency bias

Much better accuracy!

WHAT DO WE NEED?

- More accuracy than ERA-Interim?

  → compute 6km reanalysis

- Better climatological scores than ERA-Interim?

  → compute dynamical downscaling

- Uncertainty estimation?

  → compute ensemble with reduced grid spacing

  → if frequency distributions should be better represented on local scale regional ensemble recommendable

PROBABILISTIC

CAPABILITIES

VERIFICATION

Probabilistic attributes: *Does the ensemble work technically?*

- Consistency
- Accuracy
- Resolution
- Reliability
- Sharpness

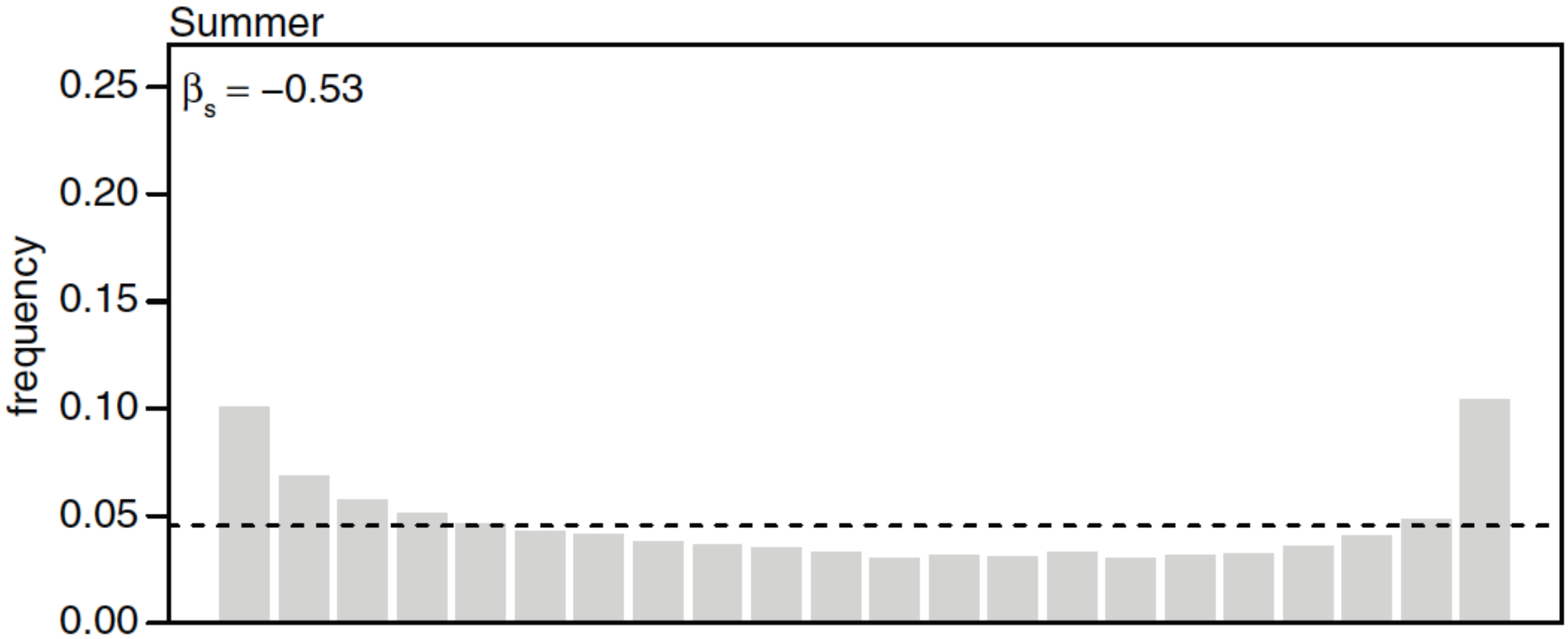
Uncertainty estimation: *Does it measure the right uncertainty?*

- Spread-skill ratio / correlation

DATA

- ERA5 not yet available
- Compare COSMO-EN-REA12 to ECMWF-EPS

ANALYSIS RANK HISTOGRAM



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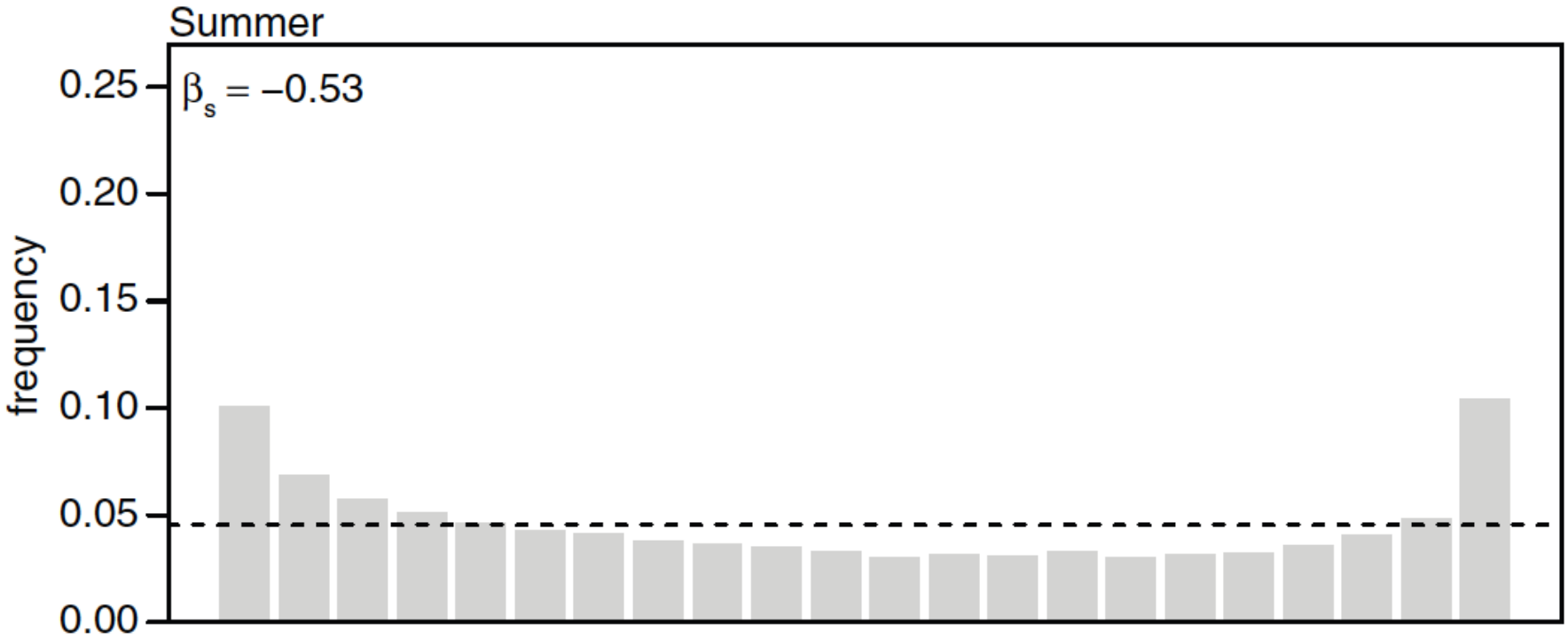
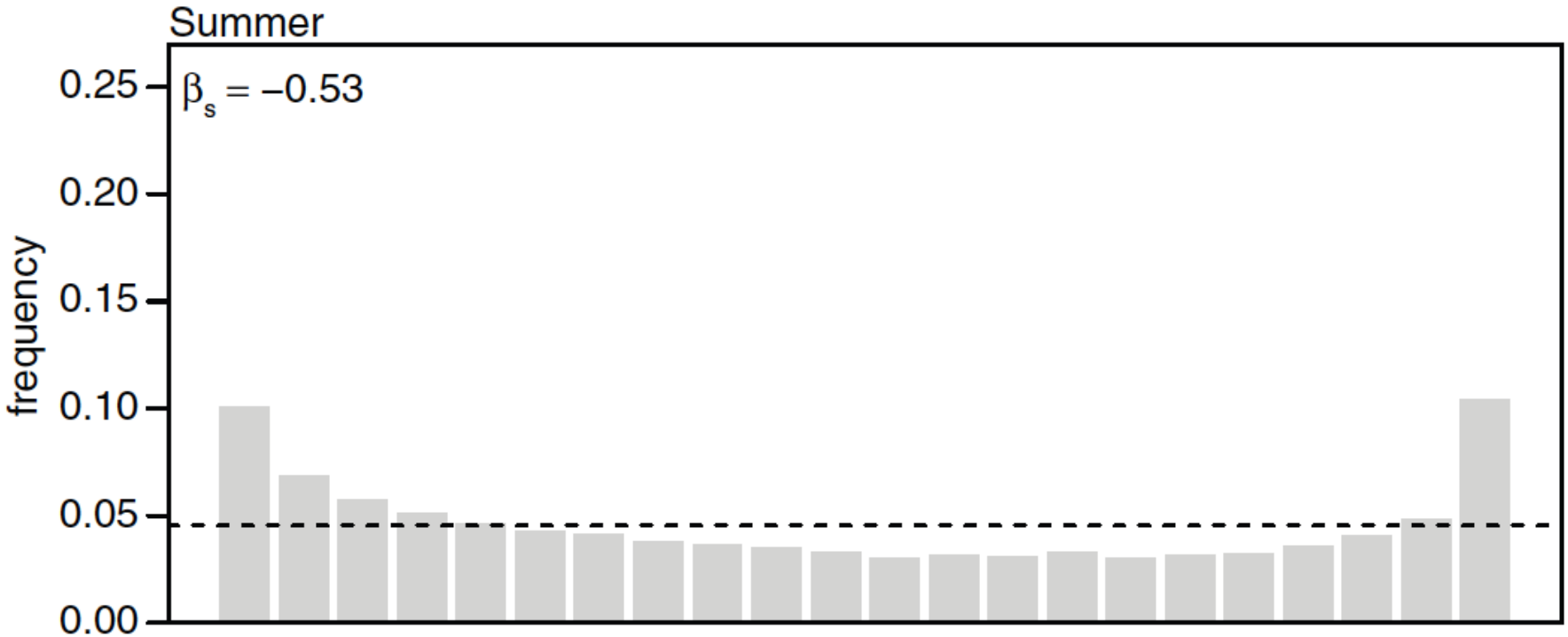


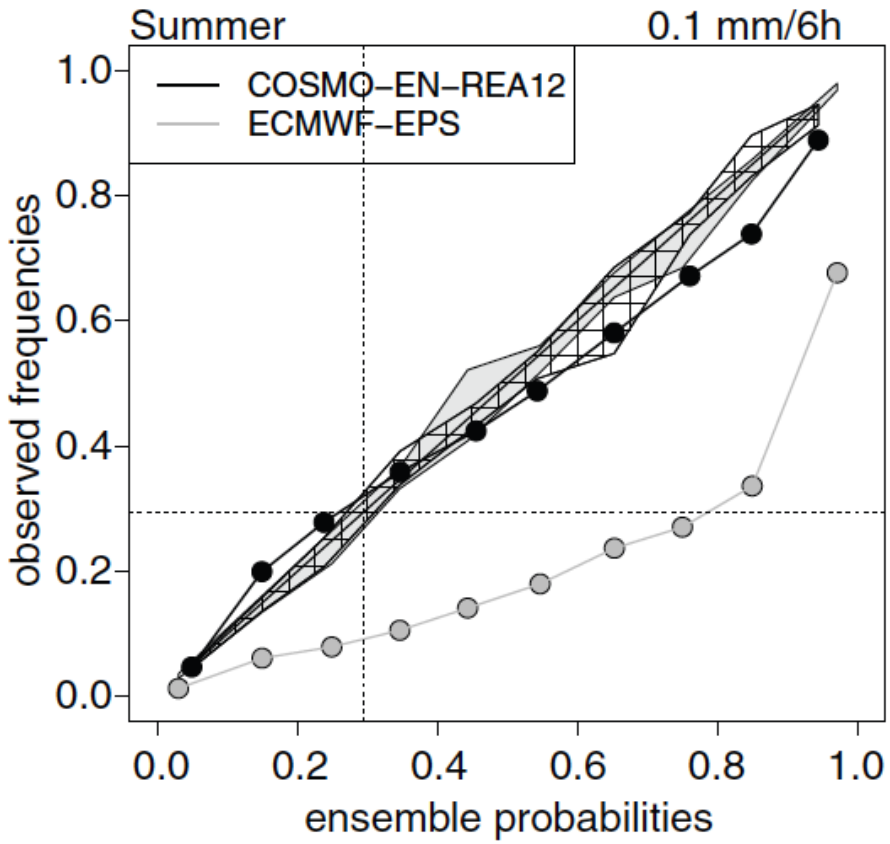
Consistency *Are members and obs drawn from same pdf?*
Sharpness *Is ensemble pdf too sharp or too wide?*
Bias *Is there a model bias?*

ANALYSIS RANK HISTOGRAM



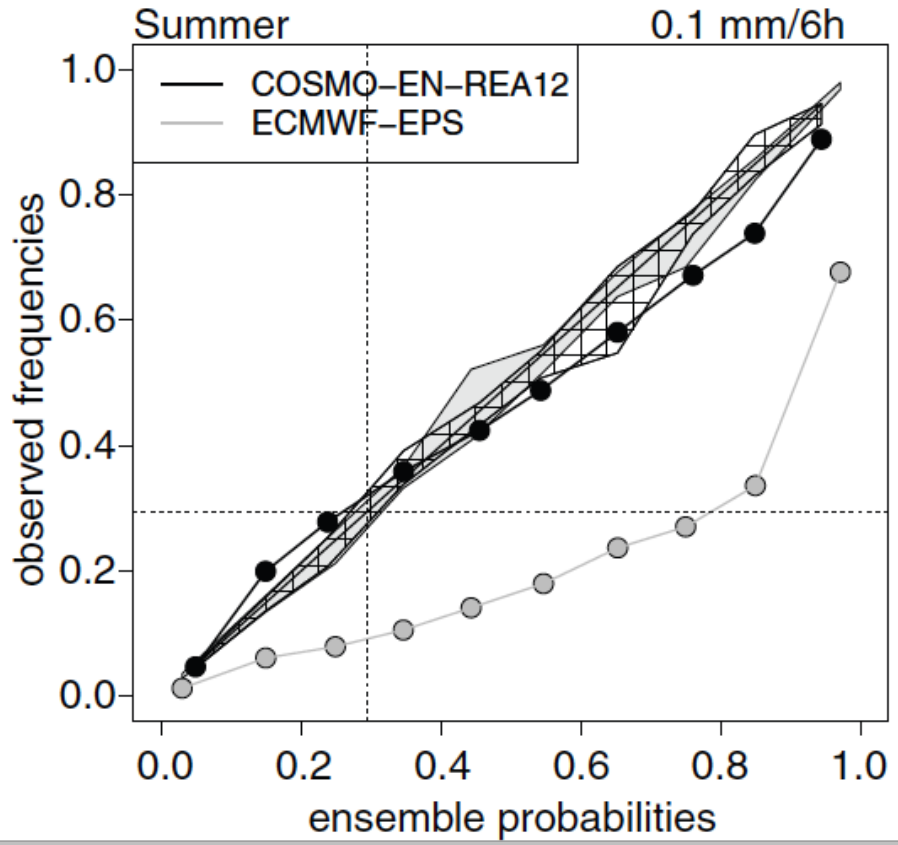
- **Overweighting of lowest rank**
  whole ens overestimates precipitation (e.g. displacement error)
- **Overweighting of highest rank**
  whole ens underestimates precipitation (e.g. limited eff. resolution)
- **Negative beta-score**
  Underdispersiveness, too sharp pdf and bias

RELIABILITY DIAGRAM



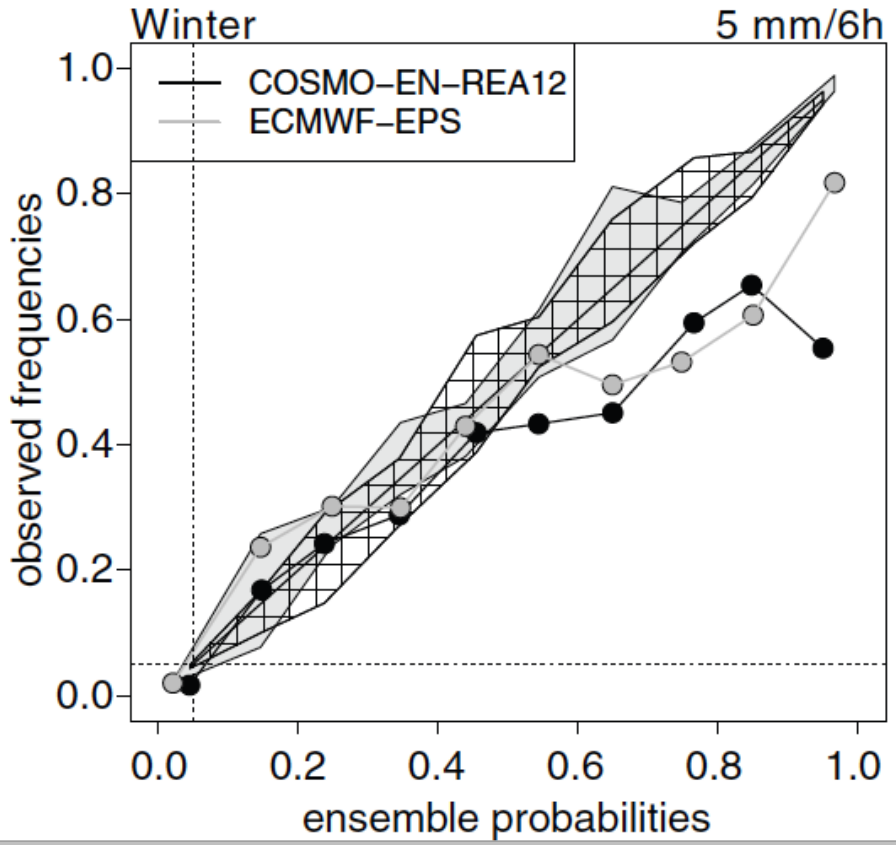
Reliability *Do conditional observed frequencies agree with the issued ensemble probabilities?*

RELIABILITY DIAGRAM



- COSMO ensemble is quite well calibrated
- ECMWF-EPS overforecasts observed frequencies

RELIABILITY DIAGRAM



- Conditional bias at high probability thresholds
- Ensembles are over-confident → members agree about error

BRIER SCORE

- Measures **probabilistic accuracy**
- Is negatively oriented (BS=0 is best)

$$BS = \frac{1}{n} \sum_{k=1}^{n} (p(y_k) - o_k)^2$$

- The higher the probability issued by the ensemble is for an event, if the observation says it occurs, the better is the Brier score!

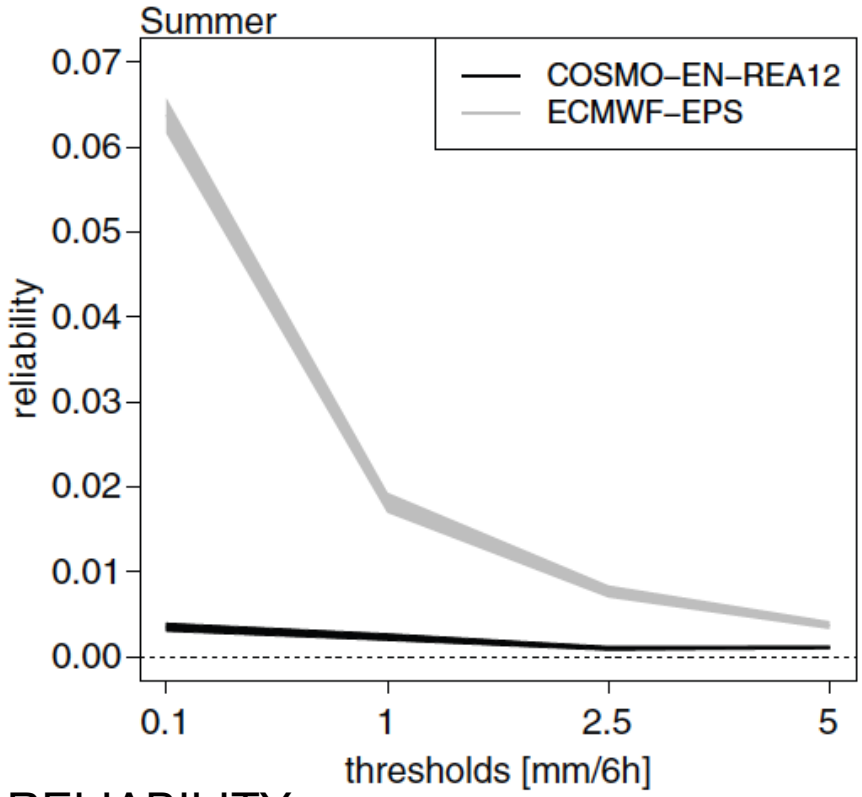
DECOMPOSITION OF THE BRIER SCORE

- BRIER SCORE = RELIABILITY – RESOLUTION + UNCERTAINTY

- Perfect ensemble system
  - RELIABILITY=0
  - RESOLUTION=UNCERTAINTY

$$BS = \underbrace{\frac{1}{n}\sum_{i=1}^{N} N_i(y_i - \overline{o}_i)^2}_{Reliability} - \underbrace{\frac{1}{n}\sum_{i=1}^{N} N_i(\overline{o}_i - \overline{o})^2}_{Resolution} + \underbrace{\overline{o}(1-\overline{o})}_{Uncertainty},$$

DECOMPOSITION OF BRIER SCORE



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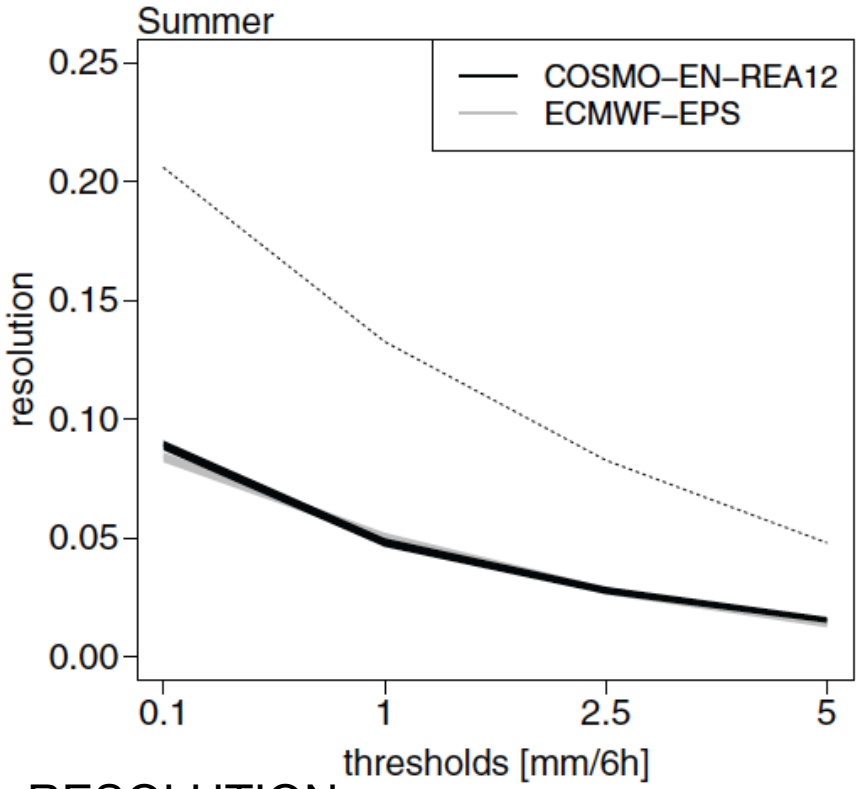
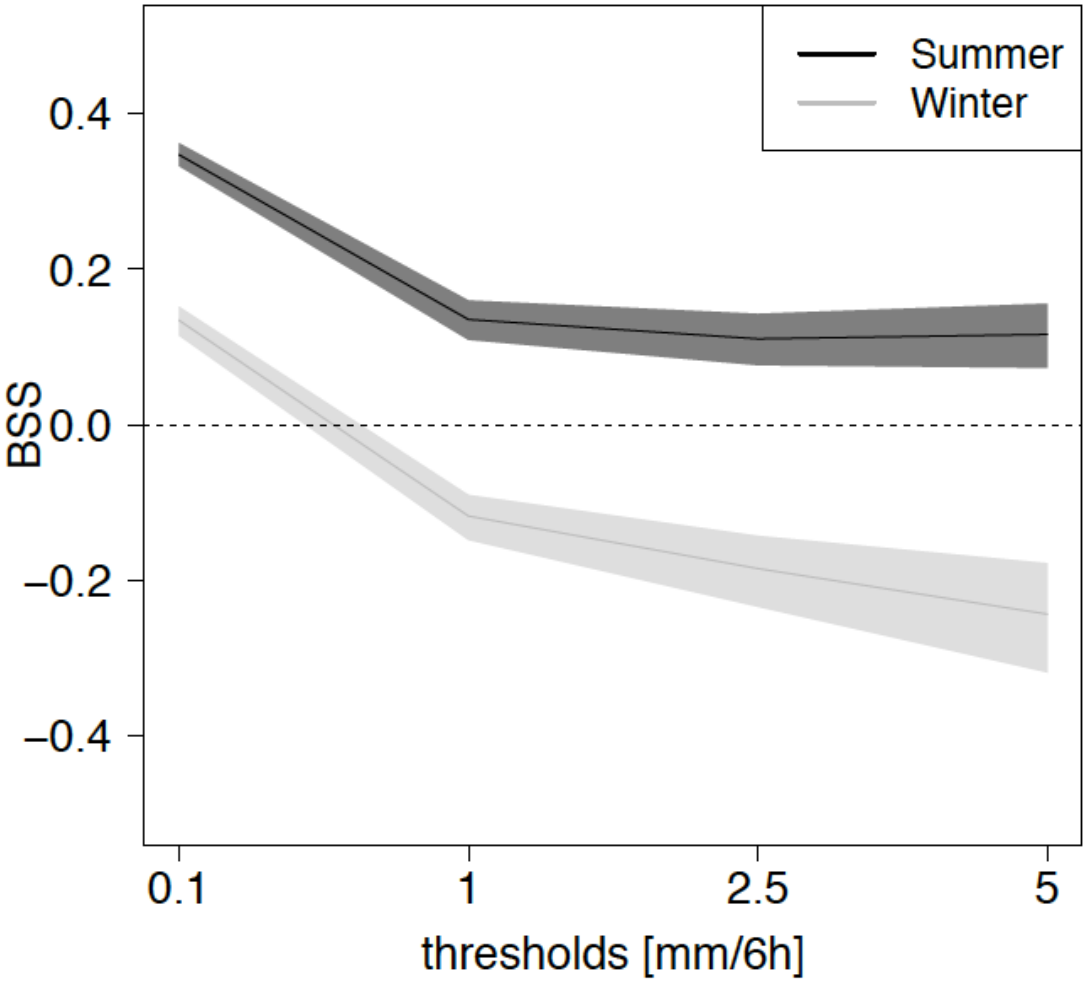


RESOLUTION

- Ensemble nudging has very good reliability
- Resolution comparable to ECMWF

BRIER SKILL SCORE



Summer

$CRPSS \in [-0.01, 0.00, 0.012]$

$CRPSS \in [-0.02, 0.00, 0.016]$

Winter

SUMMARY PRECIPITATION

- Slightly underdispersive analysis rank histogram
- Reliability better than ECMWF-EPS
- Resolution comparable
- BSS better in summer
- CRPSS ~0 in both seasons
- CRPSS >> 0 in convective weather
- Discrimination has added value at higher thresholds

→ Pilot studies indicate good probabilistic capabilities with respect to precipitation

UNCERTAINTY ESTIMATION CAPABILITIES

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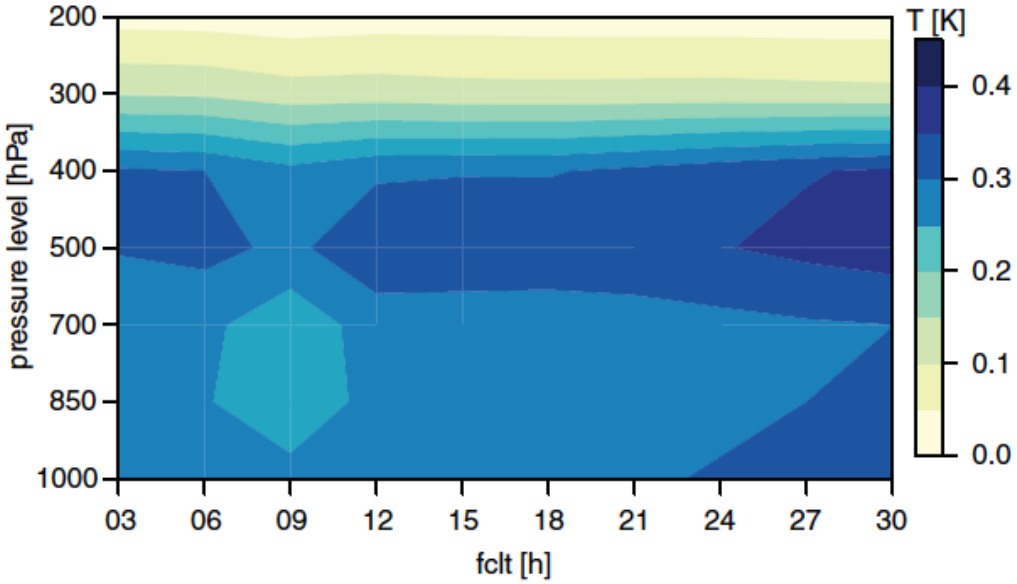
We have the spread of the ensemble (standard deviation)



UNCERTAINTY ESTIMATION CAPABILITIES

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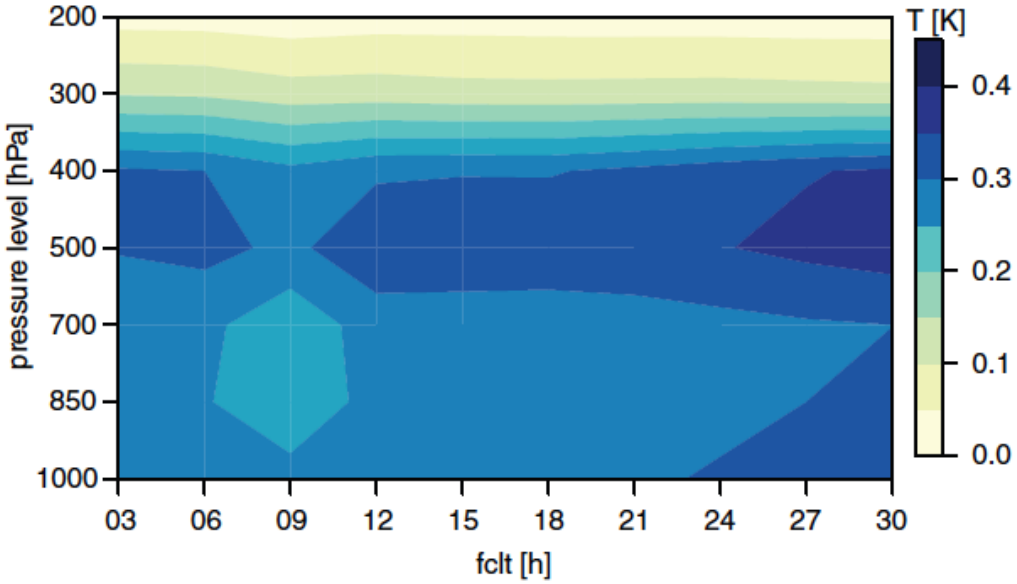

But is the spread a reliable estimate of the real reanalysis uncertainty?

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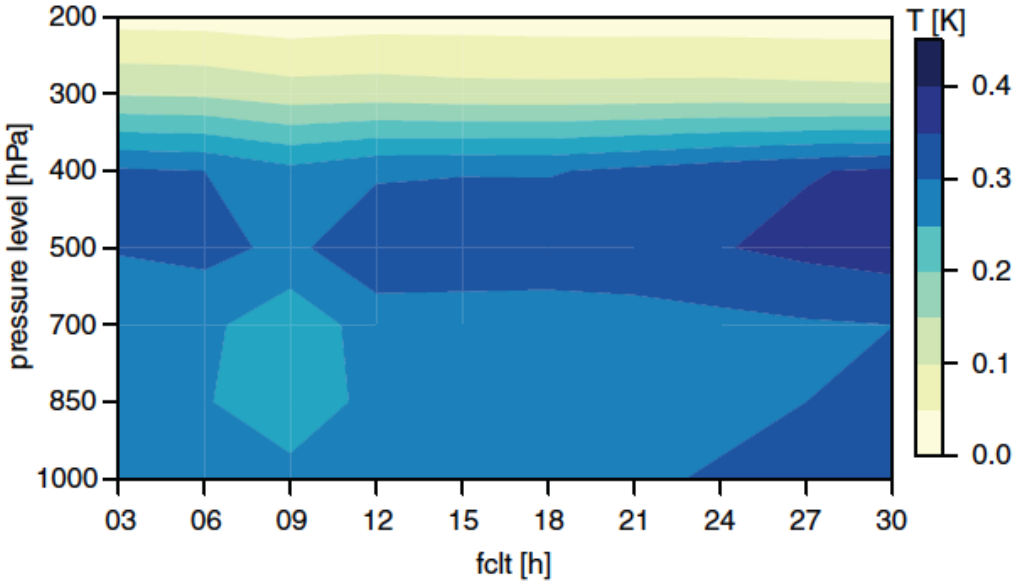

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→ compute spread-skill ratio

SPREAD-SKILL RATIO

- Does the average spread measure the average error?

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$$sr = \frac{RMSE(m,t)}{\sigma_{ens}} = \frac{\sqrt{MSE(m,o) - Var(o) - BIAS^2(m)}}{\sigma_{ens}}$$

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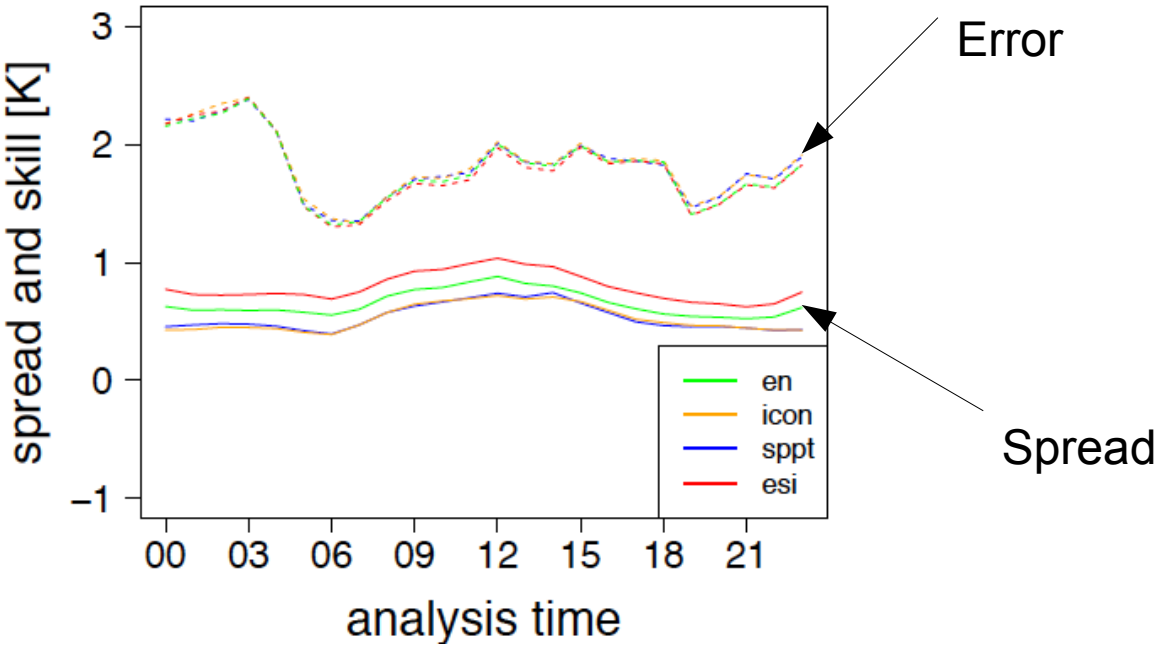

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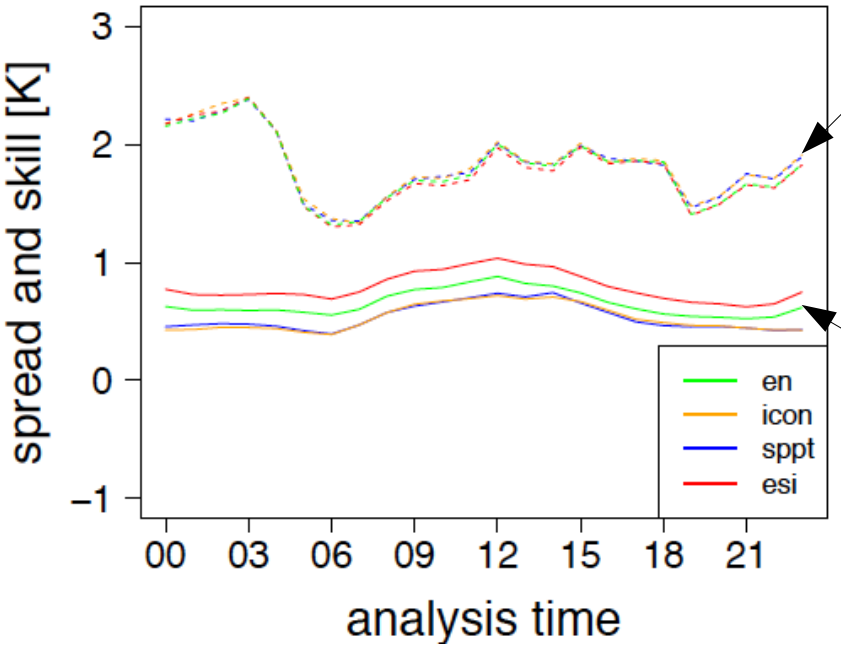

Error

The spread strongly underestimates the error!

Spread

HOW CAN THE UNCERTAINTY ESTIMATION BE ENHANCED?

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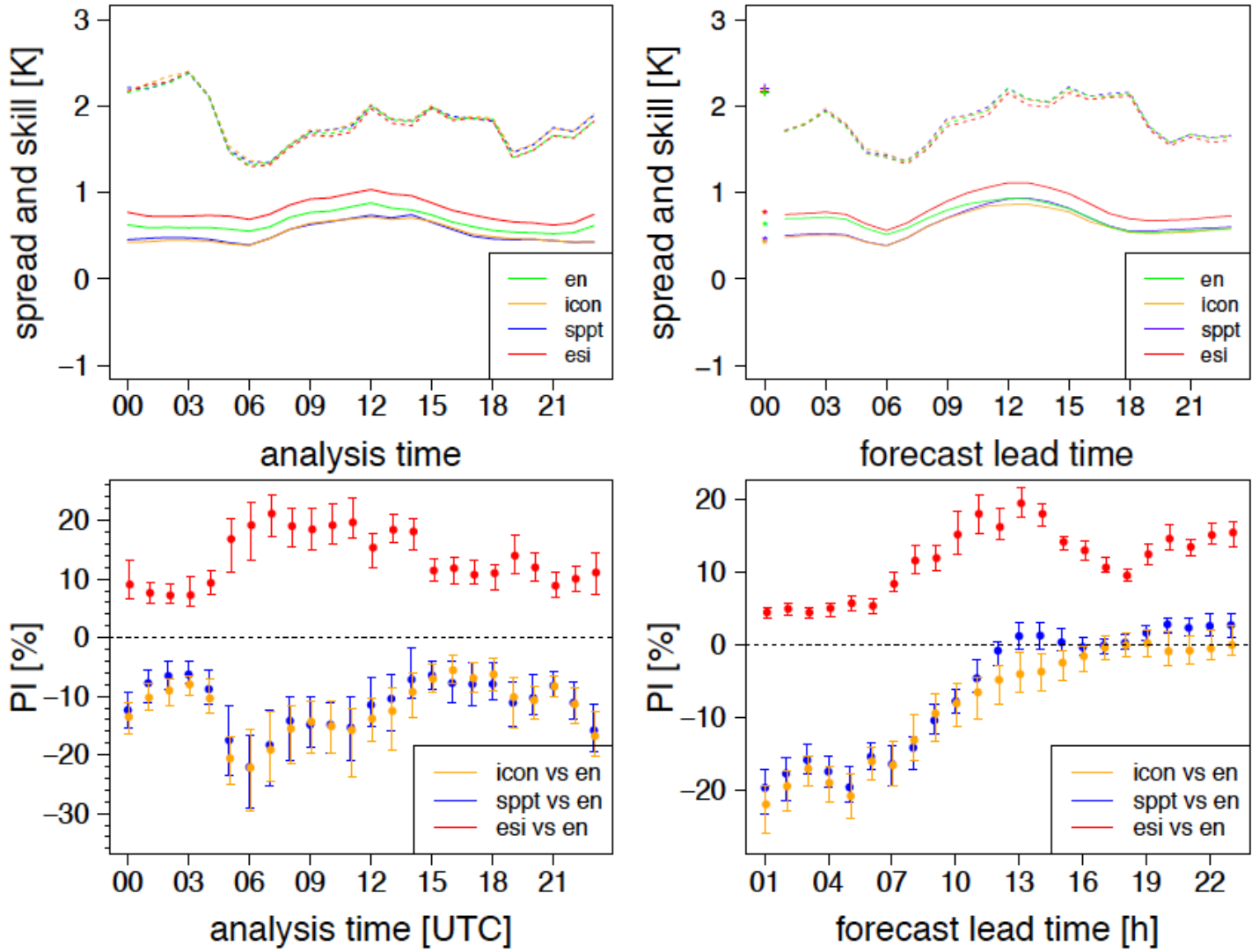
Combine techniques that account for

- Model error (stochastic perturbation of physical tendencies)
- Observation error (ensemble nudging)
- Uncertainties in the lateral boundary conditions (ICON ensemble)

Yields equally likely ensemble members

- Same bias
- Same accuracy

SPREAD-SKILL RATIO
T2M



WHICH TECHNIQUE IMPROVES UNCERTAINTY ESTIMATION?

- **As many uncertainty sources as possible!**
- COSMO ensemble better, but still underdispersive

In general

- Uncertainty estimation depends on **correct estimates** of obs error, spread in global ensemble etc.
- Problem is overconfident ensemble, e.g. about position of frontal systems

OUTLOOK

- Finish post-processing and archiving tools
- Produce 2006 to 2010
- Compute longer ensemble with ERA5 as lateral boundary conditions?

- Possibly update of COSMO-REA6 by new suite

- Implementation of COSMO reanalysis suite with ICON / LETKF

Tellus
SERIES A
DYNAMIC
METEOROLOGY
AND OCEANOGRAPHY
PUBLISHED BY THE INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

Towards a probabilistic regional reanalysis system for Europe: evaluation of precipitation from experiments

By LISELOTTE BACH[1]*, CHRISTOPH SCHRAFF[2], JAN D. KELLER[2,3] and ANDREAS HENSE[1], [1]*Meteorological Institute of the University of Bonn, Auf dem Hügel 20, Bonn, Germany*; [2]*Deutscher Wetterdienst, Offenbach, Germany*; [3]*Hans-Ertel-Centre for Weather Research, Germany*

(Manuscript received 10 May 2016; in final form 16 October 2016)

ABSTRACT

A new development in the field of reanalyses is the incorporation of uncertainty estimation capabilities. We have developed a probabilistic regional reanalysis system for the CORDEX-EUR11 domain that is based on the numerical weather prediction model COSMO at a 12-km grid spacing. The lateral boundary conditions of all ensemble members are provided by the global reanalysis ERA-Interim. In the basic implementation of the system, uncertainties due to observation errors are estimated. Atmospheric assimilation of conventional observations perturbed by means of random samples of observation error yields estimates of the reanalysis uncertainty conditioned to observation errors. The data assimilation employed is a new scheme based on observation nudging that we denote ensemble nudging. The lower boundary of the atmosphere is regularly updated by external snow depth, sea surface temperature and soil moisture analyses. One of the most important purposes of reanalyses is the estimation of so-called essential climate variables. For regional reanalyses, precipitation has been identified as one of the essential climate variables that are potentially better represented than in other climate data sets. For that reason, we assess the representation of precipitation in our system in a pilot study. Based on two experiments, each of which extends over one month, we conduct a preliminary comparison to the global reanalysis ERA-

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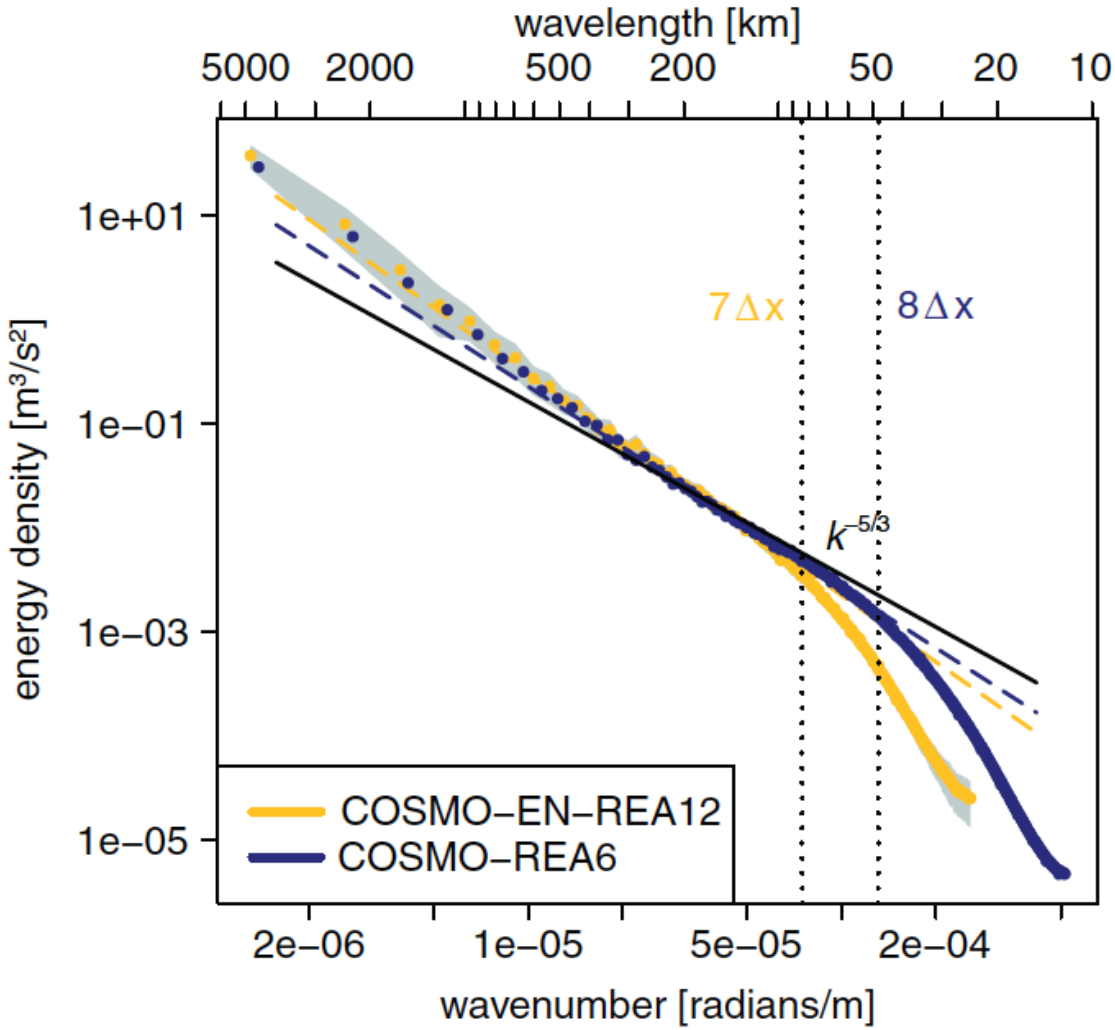
UERRA Uncertainties in Ensembles of Regional ReAnalyses

BASIC

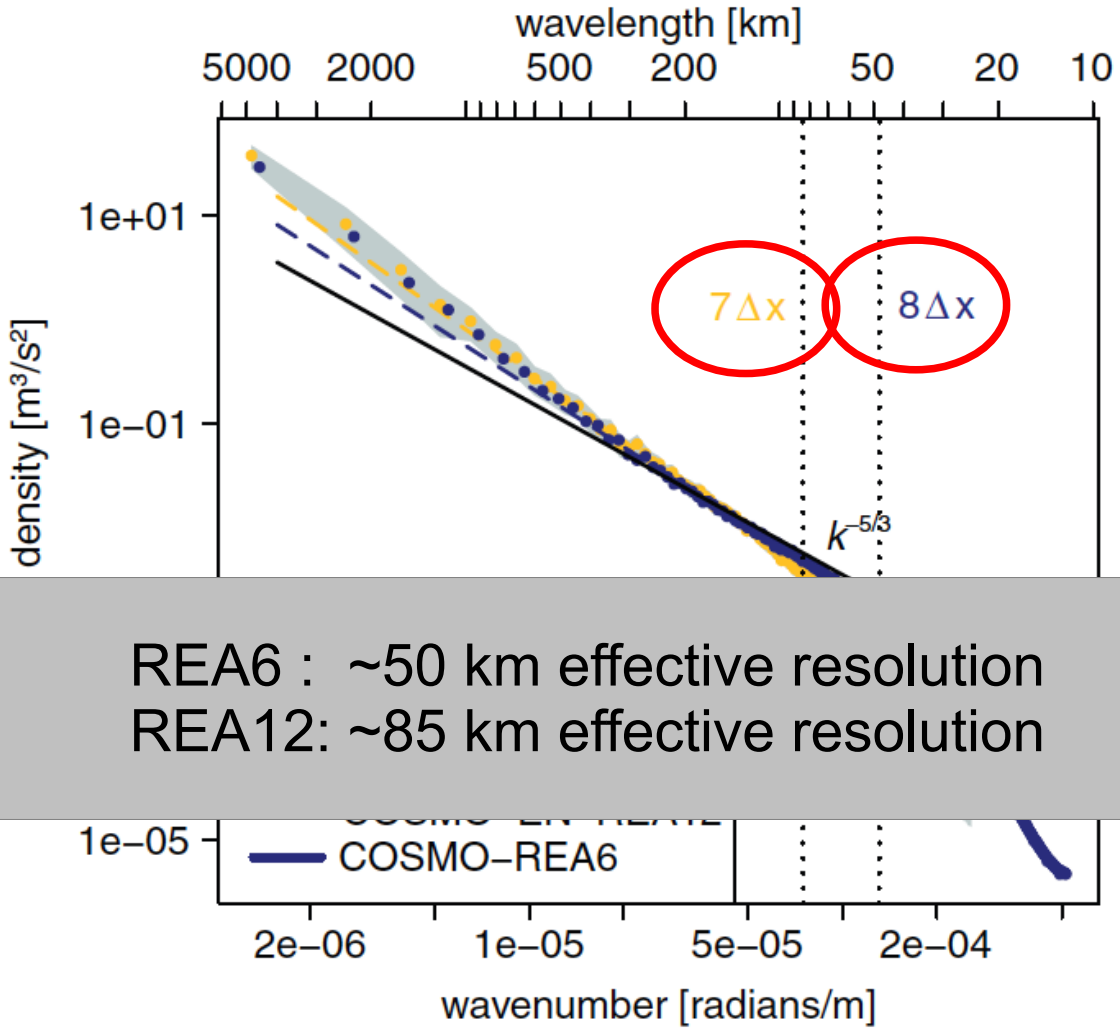
DIAGNOSTICS

EFFECTIVE RESOLUTION



KINETIC ENERGY SPECTRA

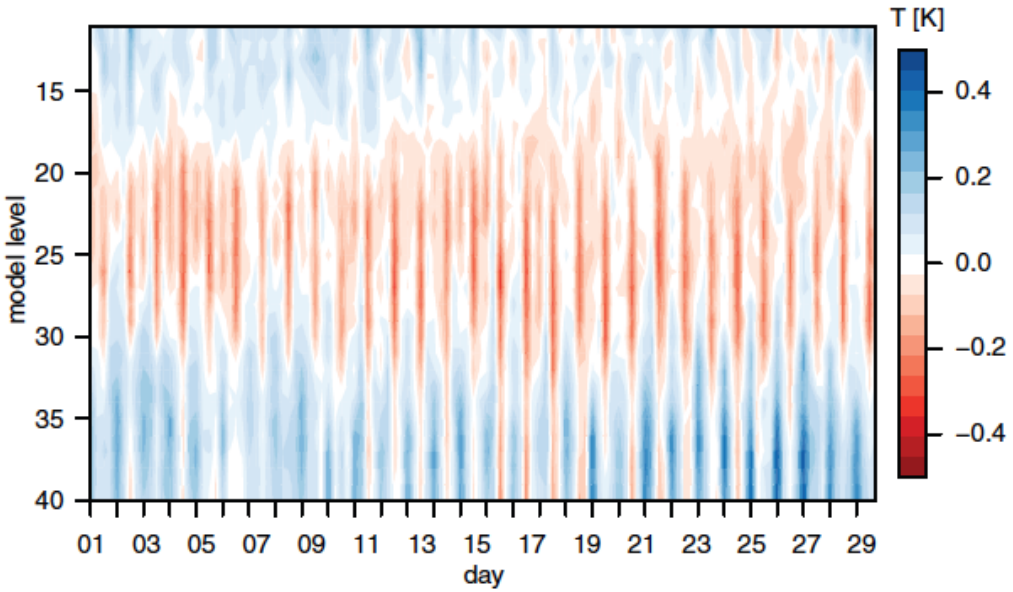
EFFECTIVE RESOLUTION



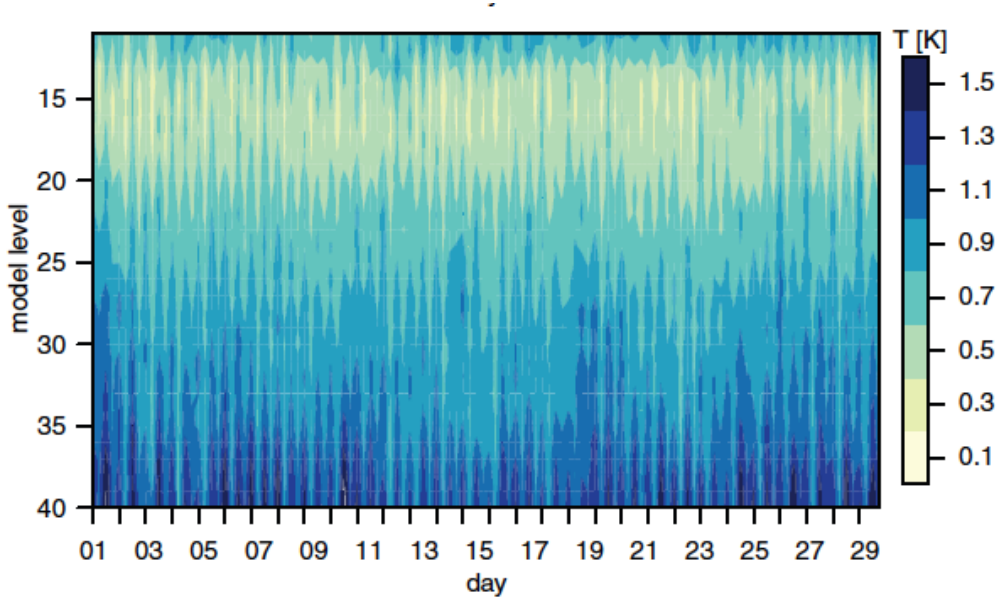
KINETIC ENERGY SPECTRA

REA6 : ~50 km effective resolution
REA12: ~85 km effective resolution

TEMPERATURE ANALYSIS INCREMENTS (JUNE 2011)

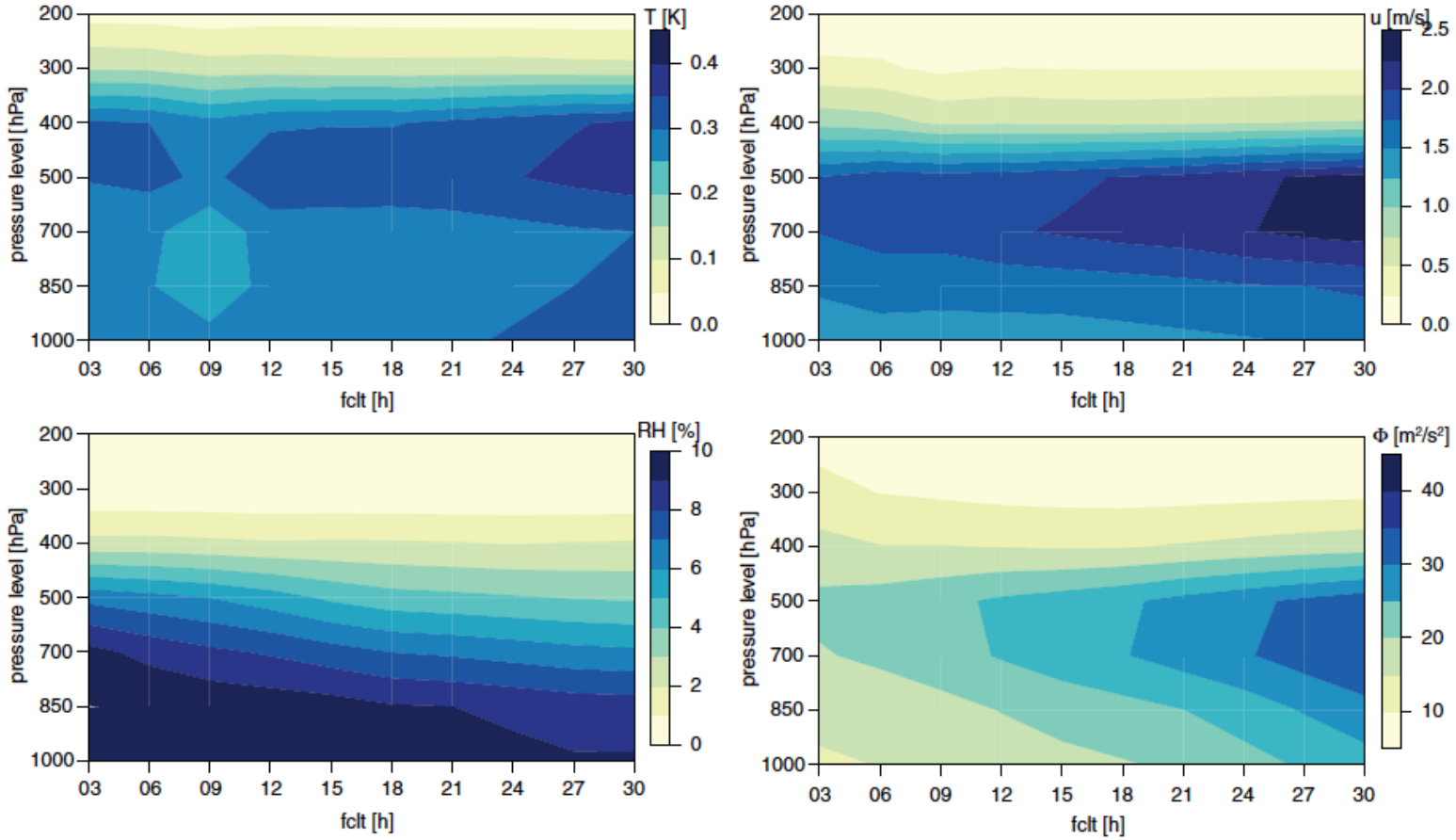


Domain averaged increments aggreagated over 6h

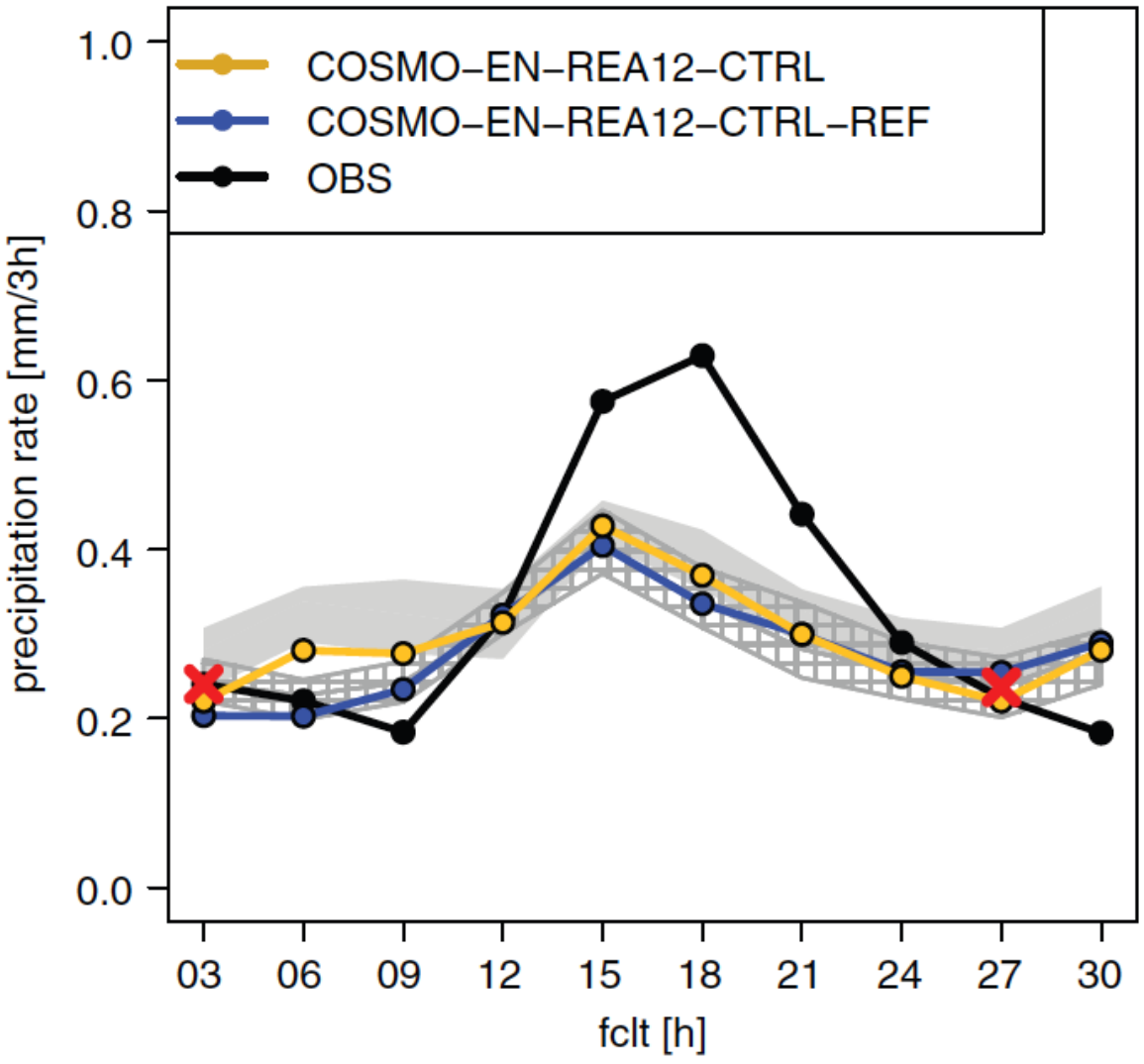


Standard deviations

UNCERTAINTY REPRESENTED BY ENSEMBLE SPREAD



IS THERE A SPIN-UP EFFECT?



IS THERE A SPIN-UP EFFECT?

Ensemble median precipitation at +03 h agrees with observations and with precipitation at +27 h
→ hardly any spin-up effect