Ensemble data assimilation for regional reanalysis

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Thanks to U.Schättler[2], R.Potthast[2], K.Stephan[2], H.Reich[2], A.Rhodin[2], A.Cress[2], A.Kaiser-Weiss[2] and F.Kaspar[2]

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Cosmo User Seminar

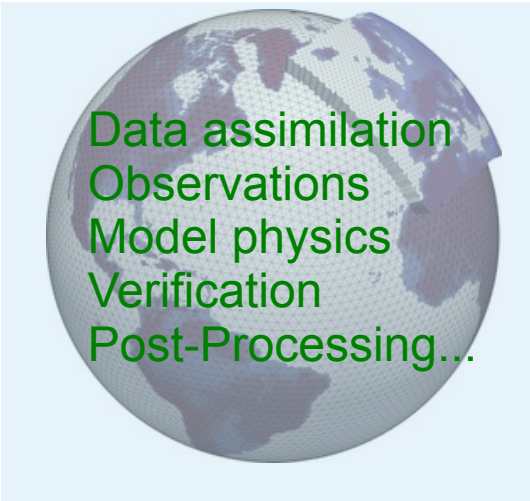
universitätbonn

UERRA Uncertainties in Ensembles of Regional ReAnalyses

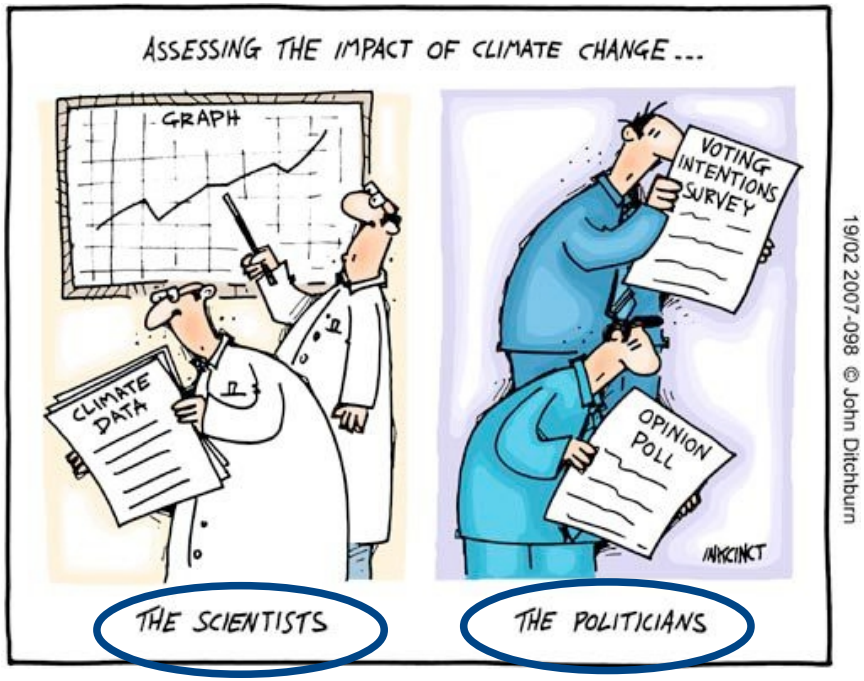
Reanalysis is so interesting because ...

… Numerical weather prediction methods meet climate science

NWP



Users/ CLIMATE SCIENCE



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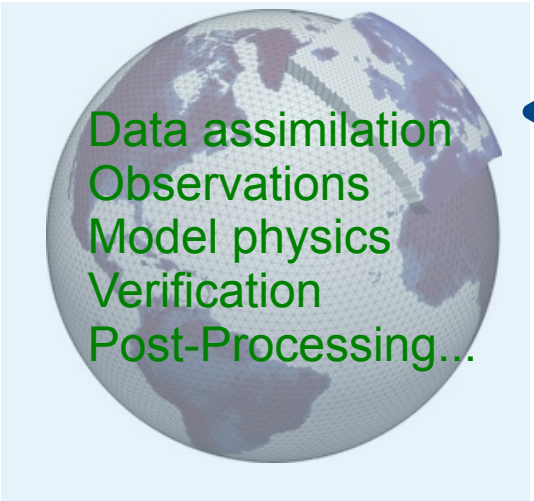

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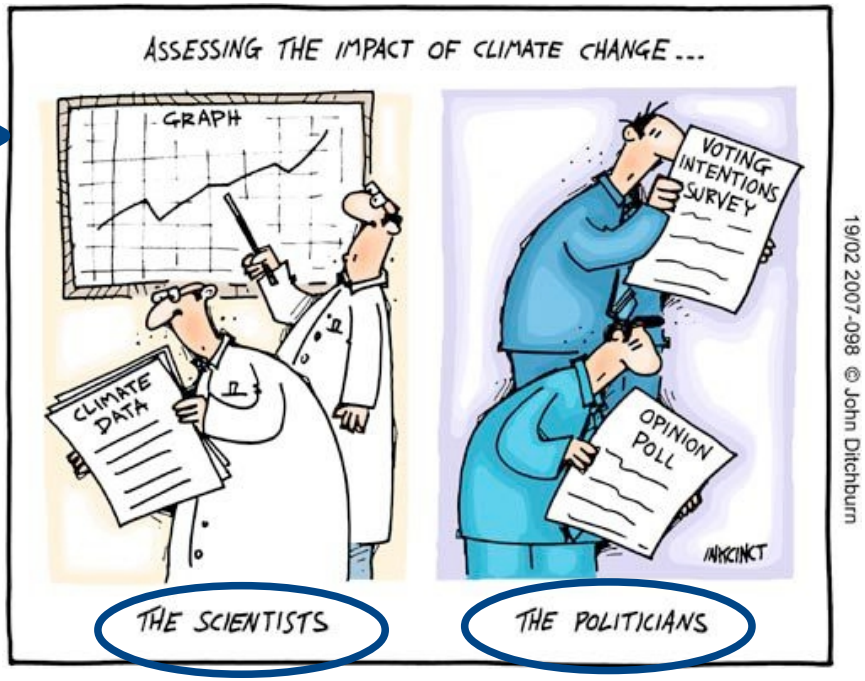

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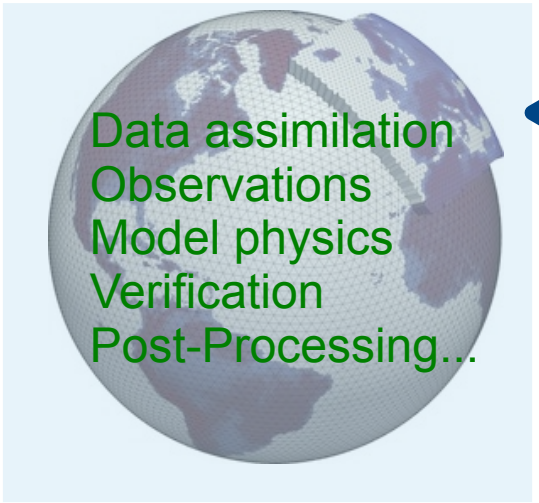

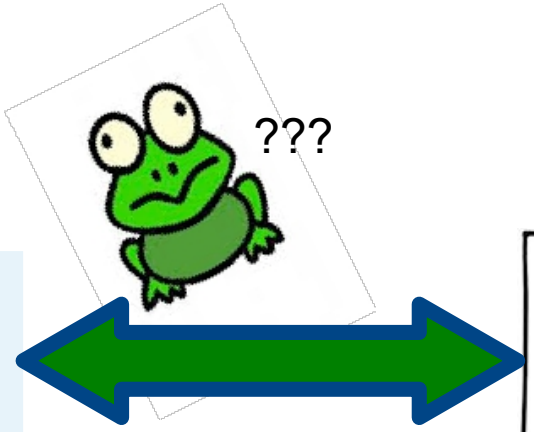

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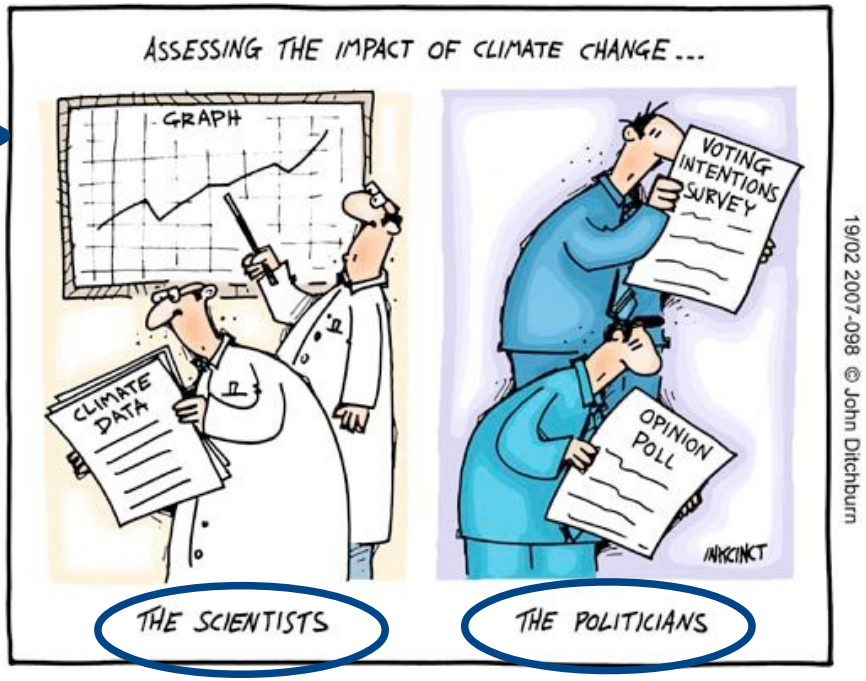

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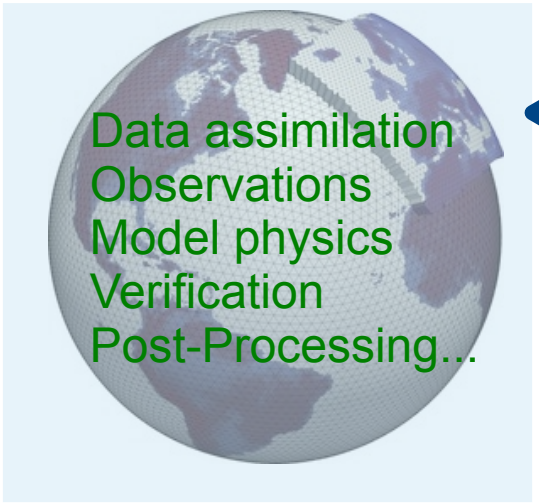
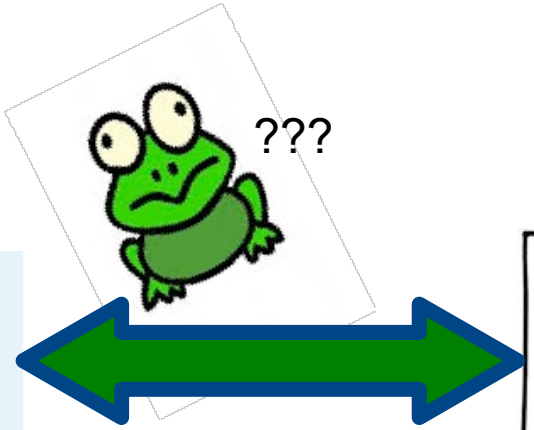
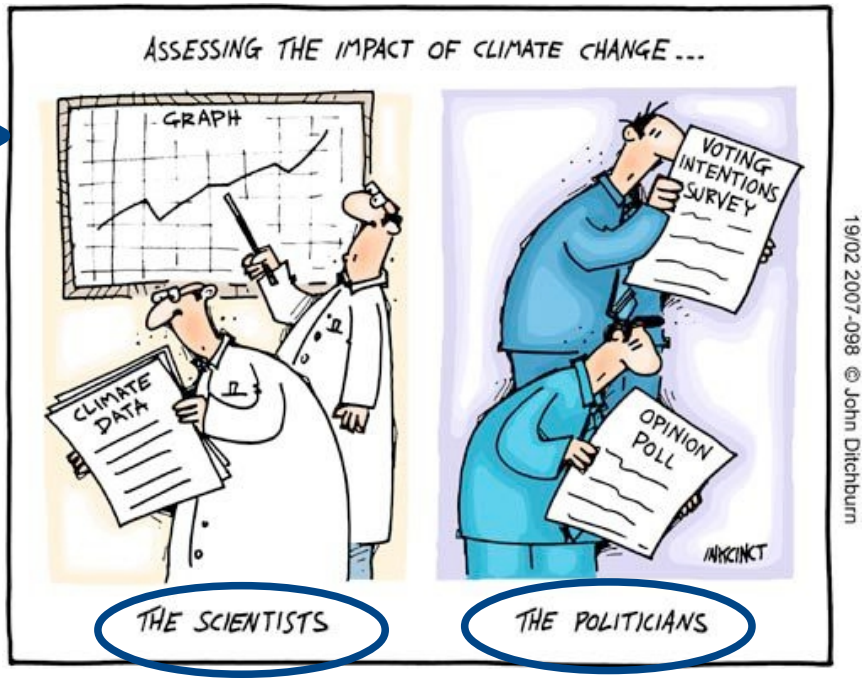




What do the users need?
How will they use the data?

Users/ CLIMATE SCIENCE



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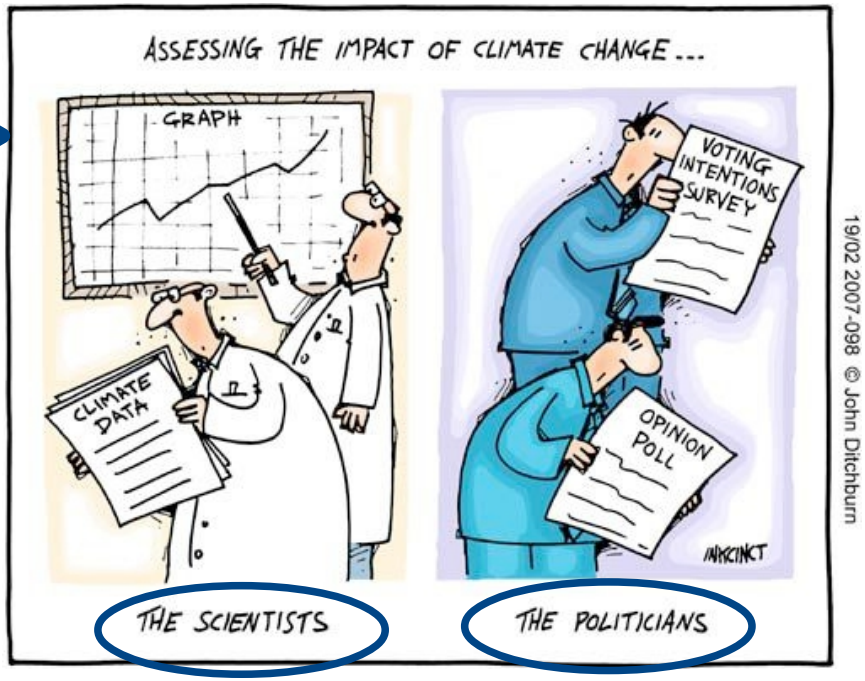
What do the users need?
How will they use the data?

What is different from NWP?

Users/ CLIMATE SCIENCE



Users of reanalyses

- Water management
- Energy
- Agriculture and forestry
- Health
- Tourism
- Infrastructure
- Insurance
- Disaster risk reduction
- Transport
- Coastal areas

- Political decision makers
- Met services
- Hydrological services
- Climate (change) services
- Research institutions

DWD

opernicus
Europe's eyes on Earth
Climate Change Service

European Parliament

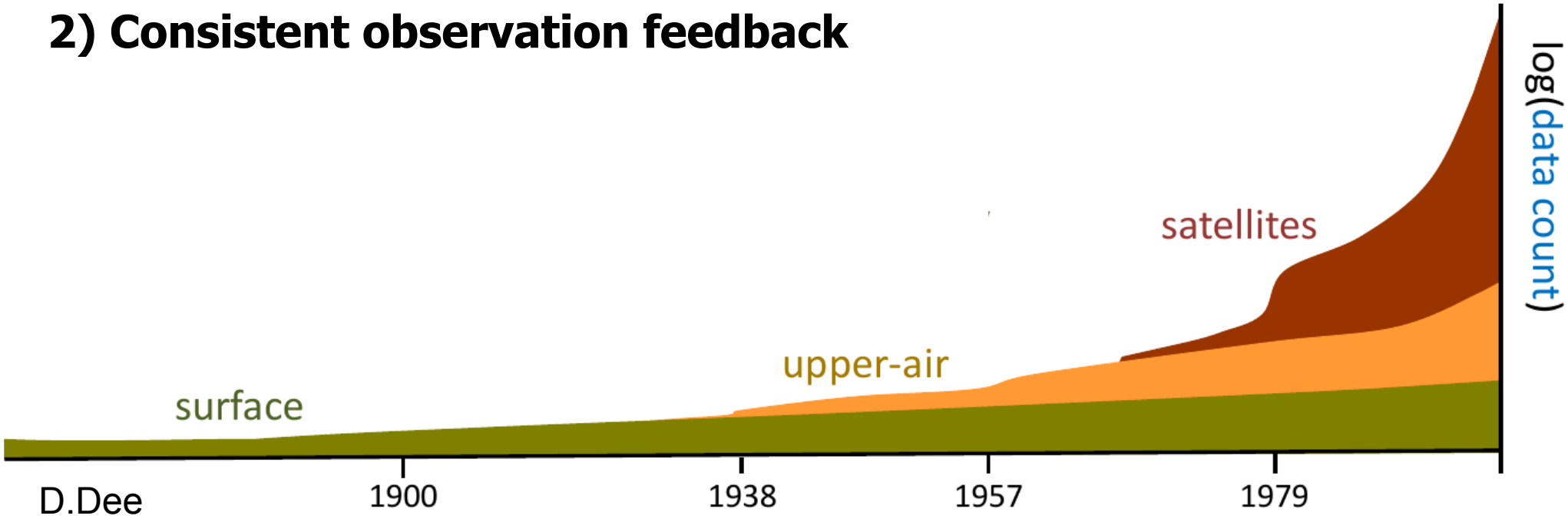
European Environment Agency

The user's needs and our challenges

1) Spatio-temporal consistency and homogeneity

- Evolution of the observing system
- Changing number, distribution, quality, observation biases

2) Consistent observation feedback



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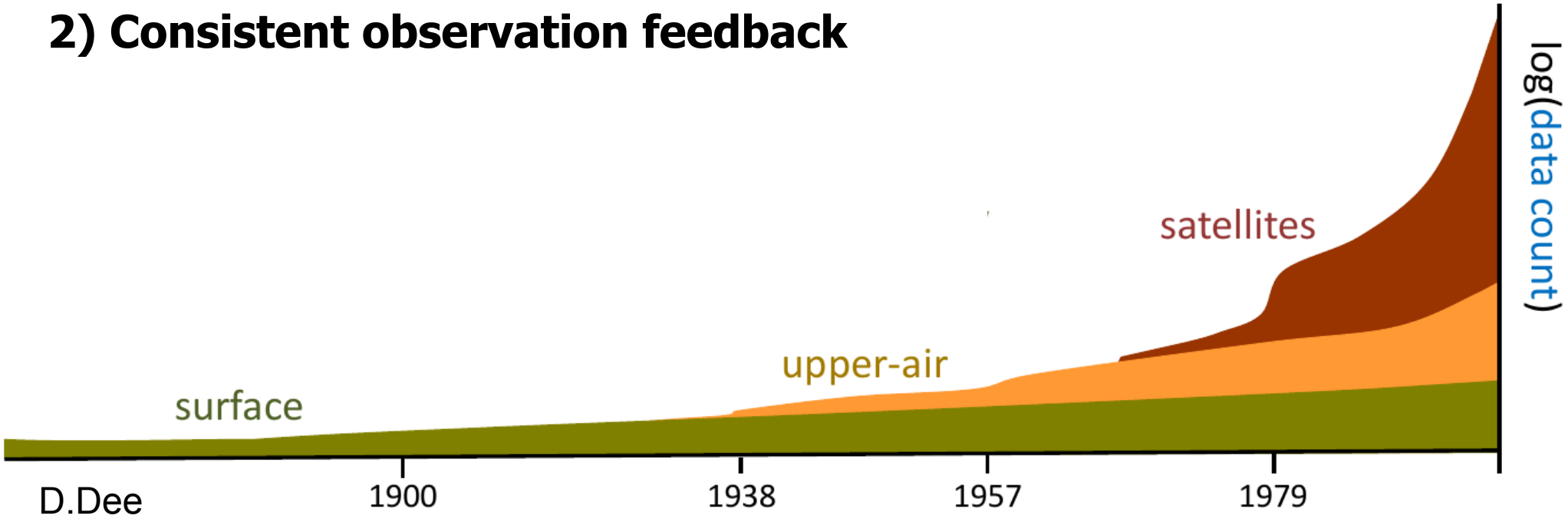

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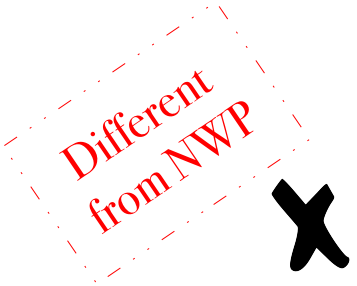

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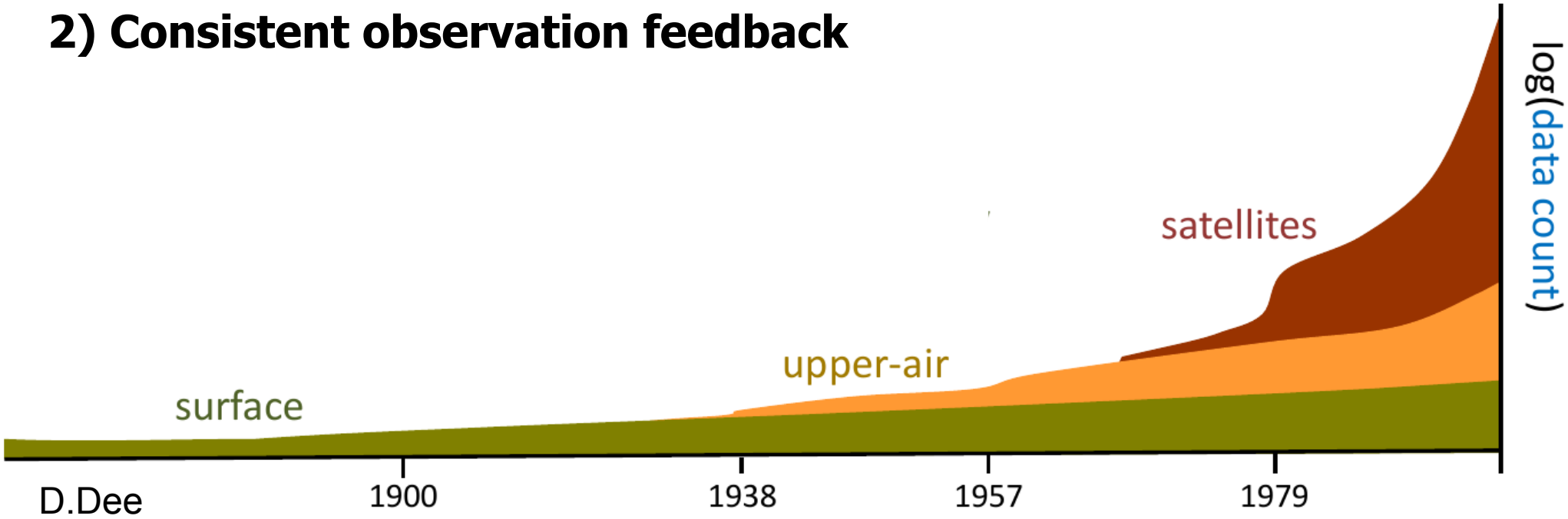

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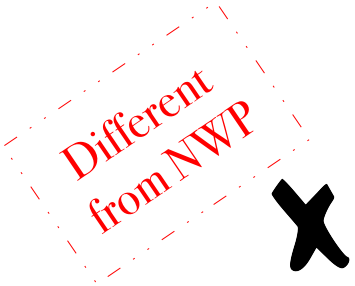
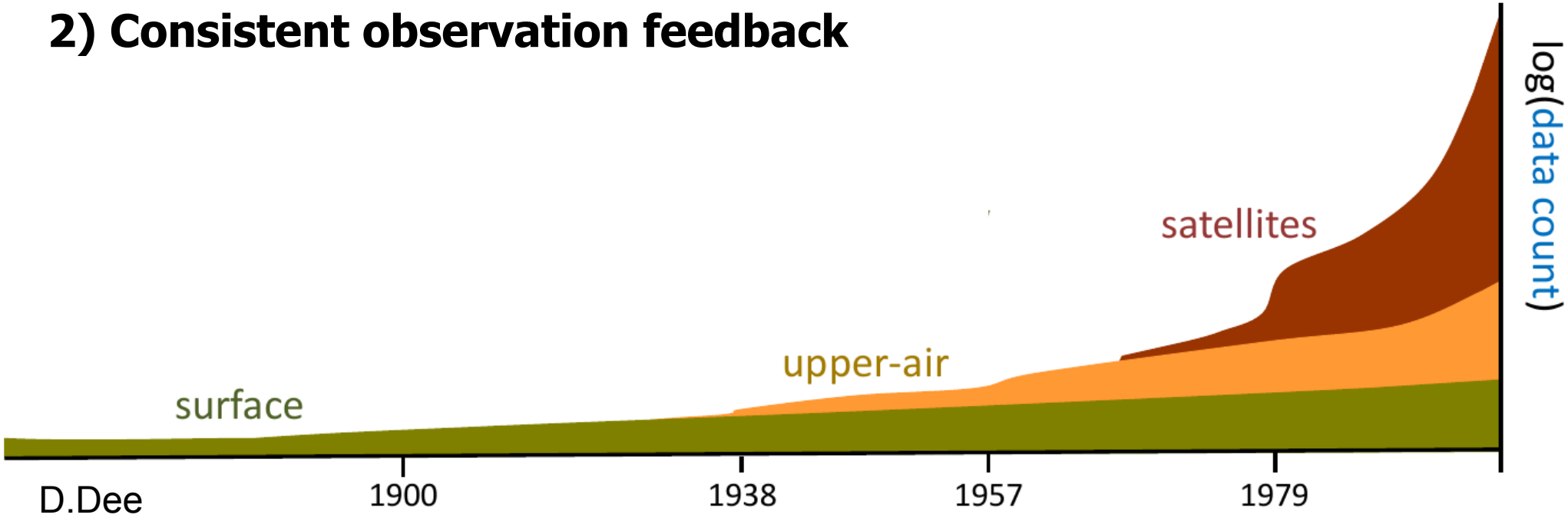


Not relevant for short time span...

2) Consistent observation feedback



The user's needs and our challenges

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Different from NWP

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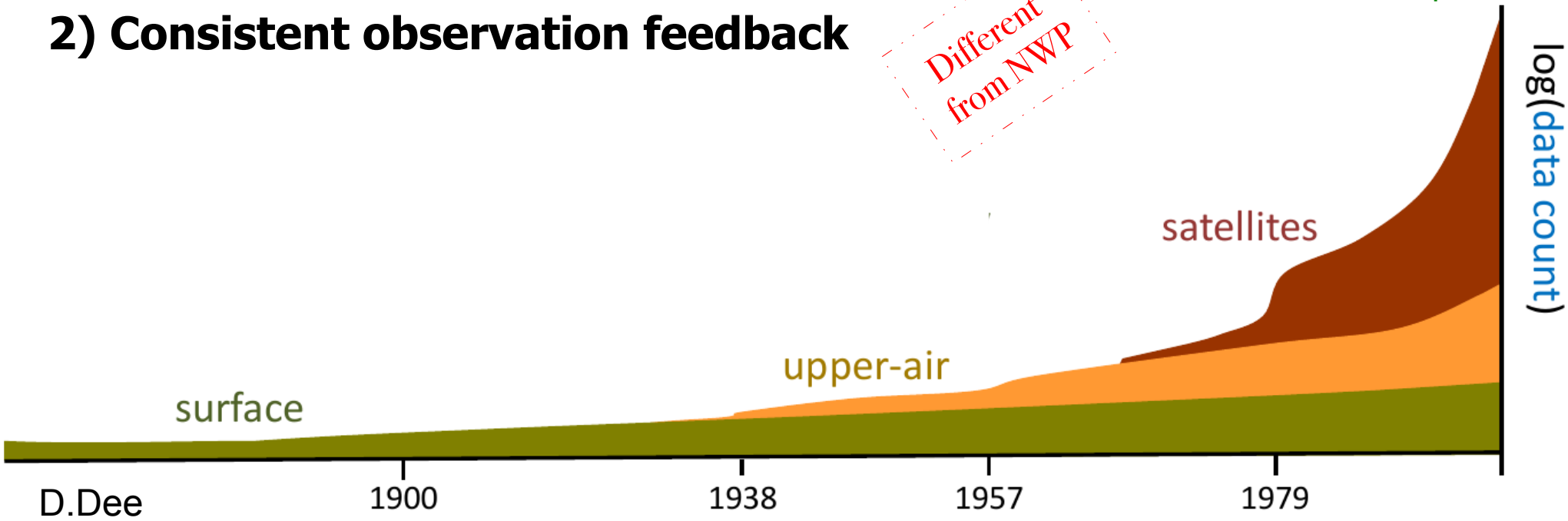

The user's needs and our challenges

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Different from NWP ✗

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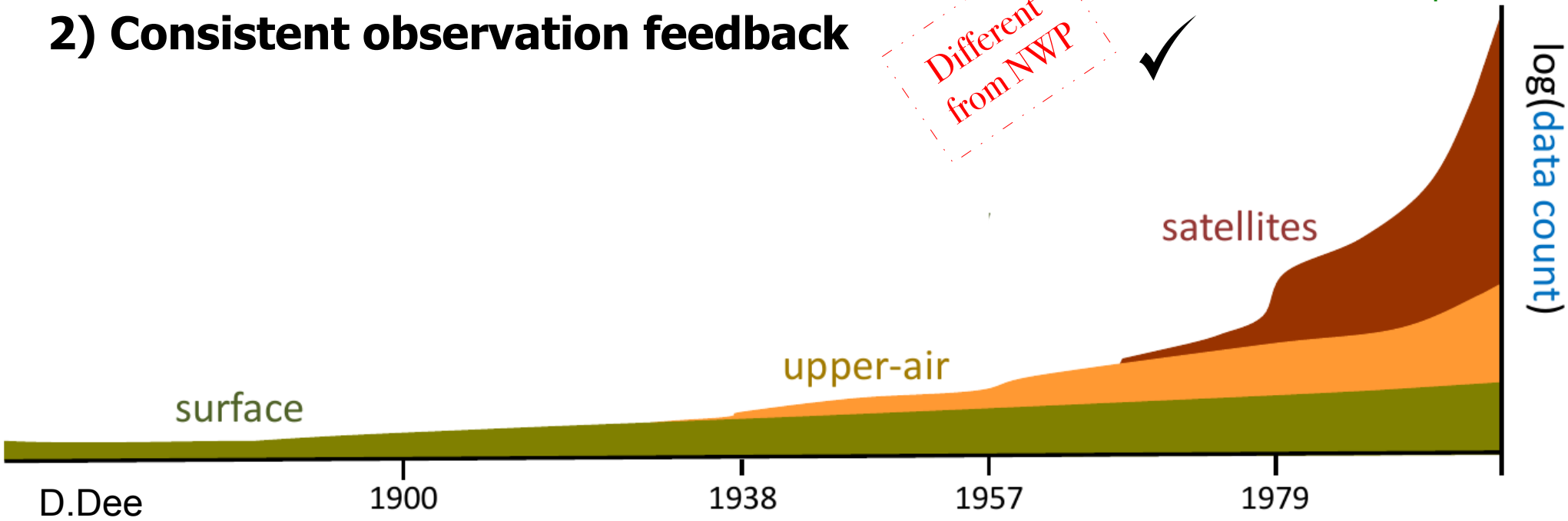
Different from NWP ✓



The user's needs and our challenges

3) Accuracy

- Best as possible, increased by regional additionally to global reanalyses
- Essential Climate Variables different from variables that are important for NWP!
- Limited accuracy due to
  - Model biases, error growth on non-resolved scales
  - Observation errors
  - Errors in lateral boundary conditions

The user's needs and our challenges

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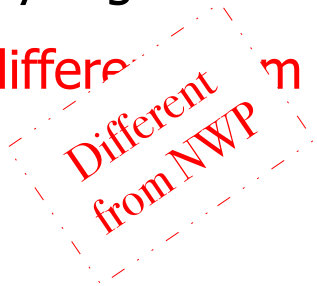

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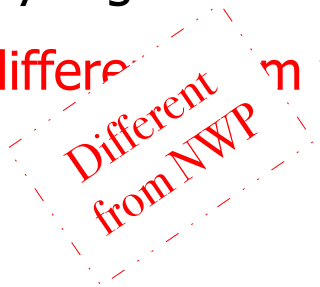

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✓ In the future…

The user's needs and our challenges

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Different from NWP

✓ In the future...

Same as NWP

The user's needs and our challenges

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✓

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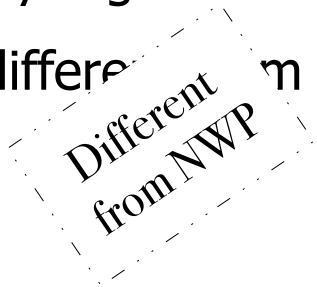
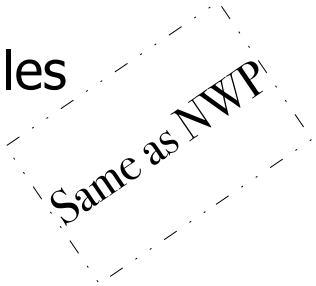


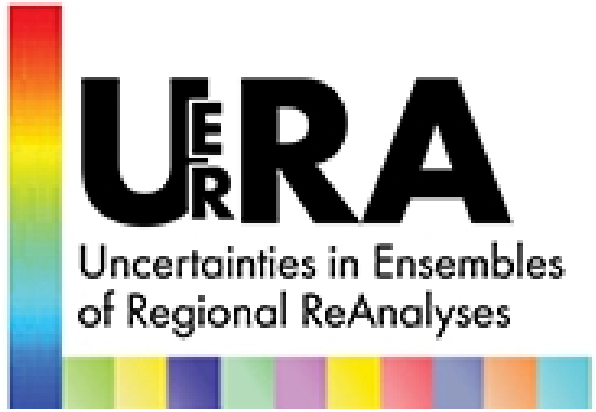


→ Quantify the uncertainties by means of ensembles!

Uncertainties in ensembles of regional reanalyses

- Regional ensemble reanalysis systems and production by
  - Met Office
  - SMHI
  - Meteo France
  - Bonn/DWD

→ *Copernicus Climate Change Service / ECMWF & European Comission*



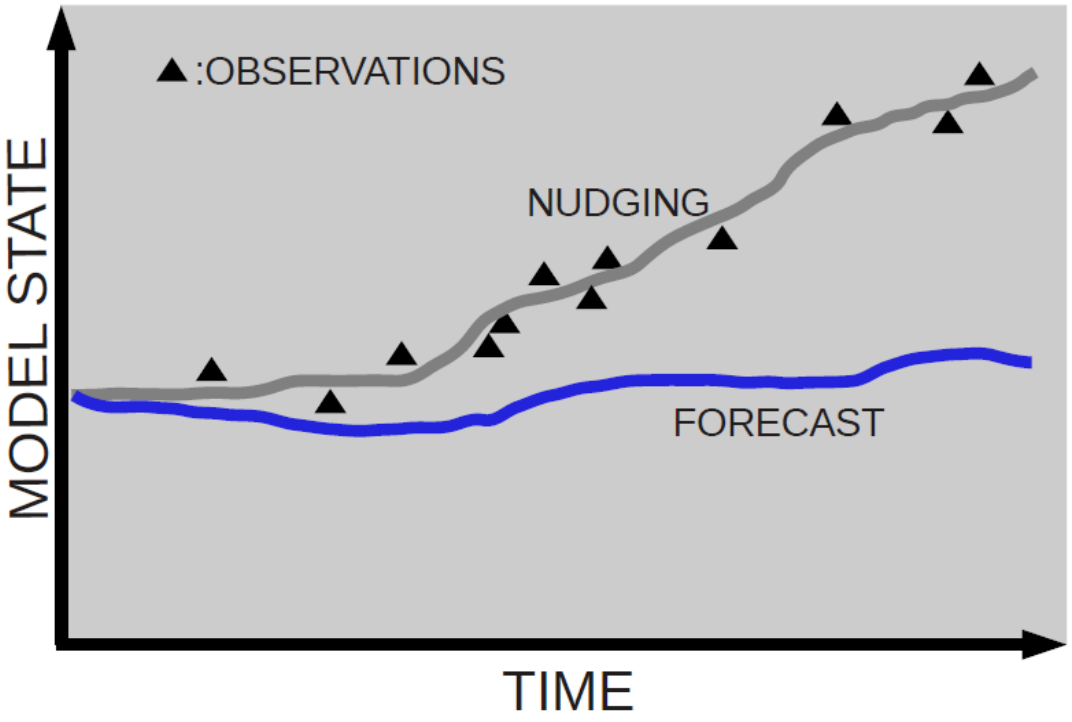
Starting with

observation uncertainty...

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*

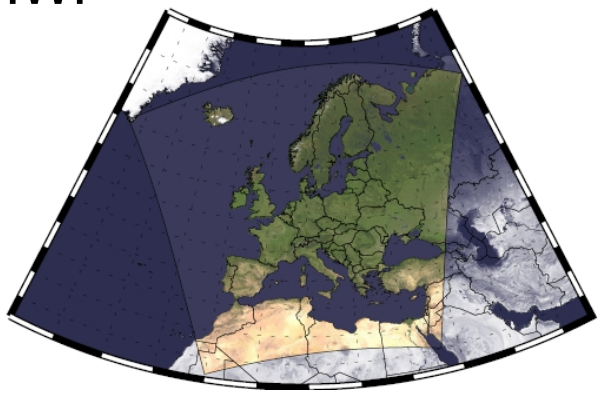


Spread ~ Uncertainty arising from errors in the assimilated observations

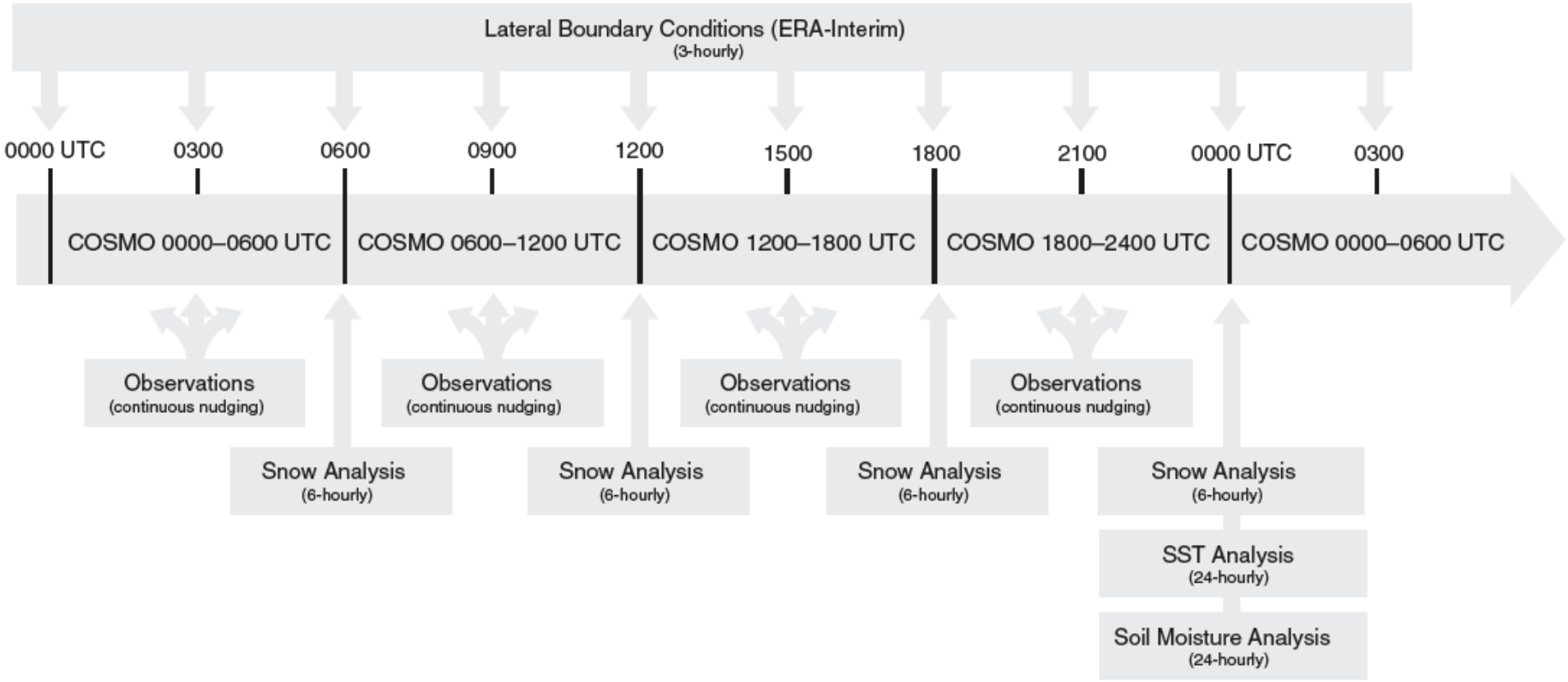
Set-up of the reanalysis suite

- COSMO-EU set-up adapted to 12 km grid, V5.0
- Conventional observations
- 3-hourly LBCs from ERA-INTERIM
- Reanalysis + reforecasts
- 20 + 1 members
- 2006 to 2010
- Stored in MARS/ECMWF

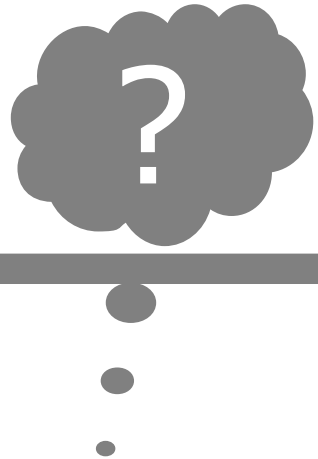
Observing system	Report type	Observed variable
Radiosondes	PILOT	Upper-air wind
	TEMP	Upper-air wind, temperature, humidity Surface-level wind temperature, humidity, geopotential
Aircraft	AIREP	Wind, temperature
	AMDAR	Wind, temperature
	ACARS	Wind, temperature
Wind profiler		Upper-air wind
Surface systems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



Production cycle



Scientific questions



- How good is our regional reanalysis ensemble?
  - Added value compared to ERA-INTERIM
  - Comphrehensive uncertainty estimation

- What are really the uncertainties in ensembles of regional reanalyses?
  - How do we best generate the ensemble in the future?

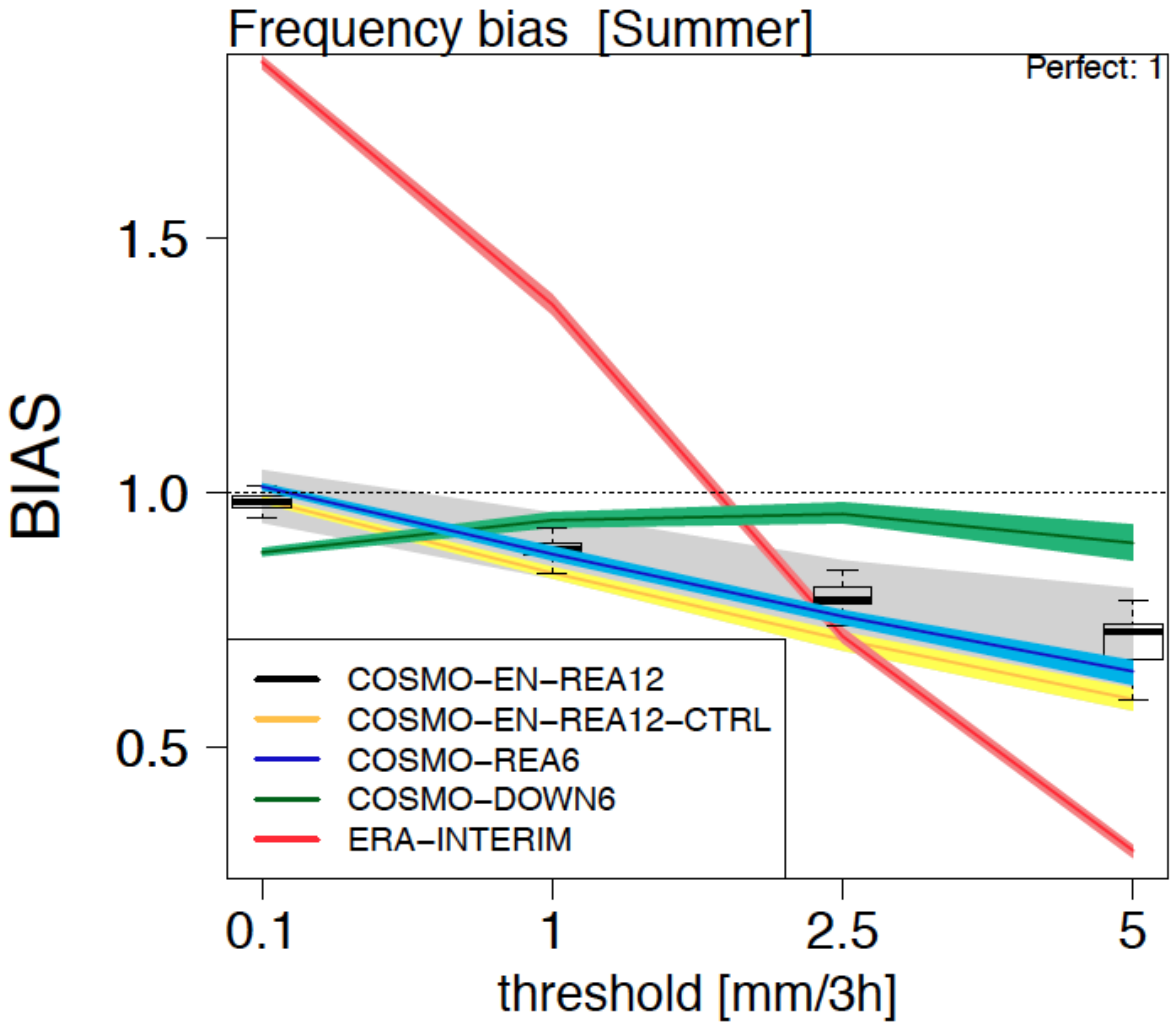
How good is the ensemble for precipitation?

- Experiments for June / December 2011
- Verification of reanalyses using ~1000 rain gauges in Germany

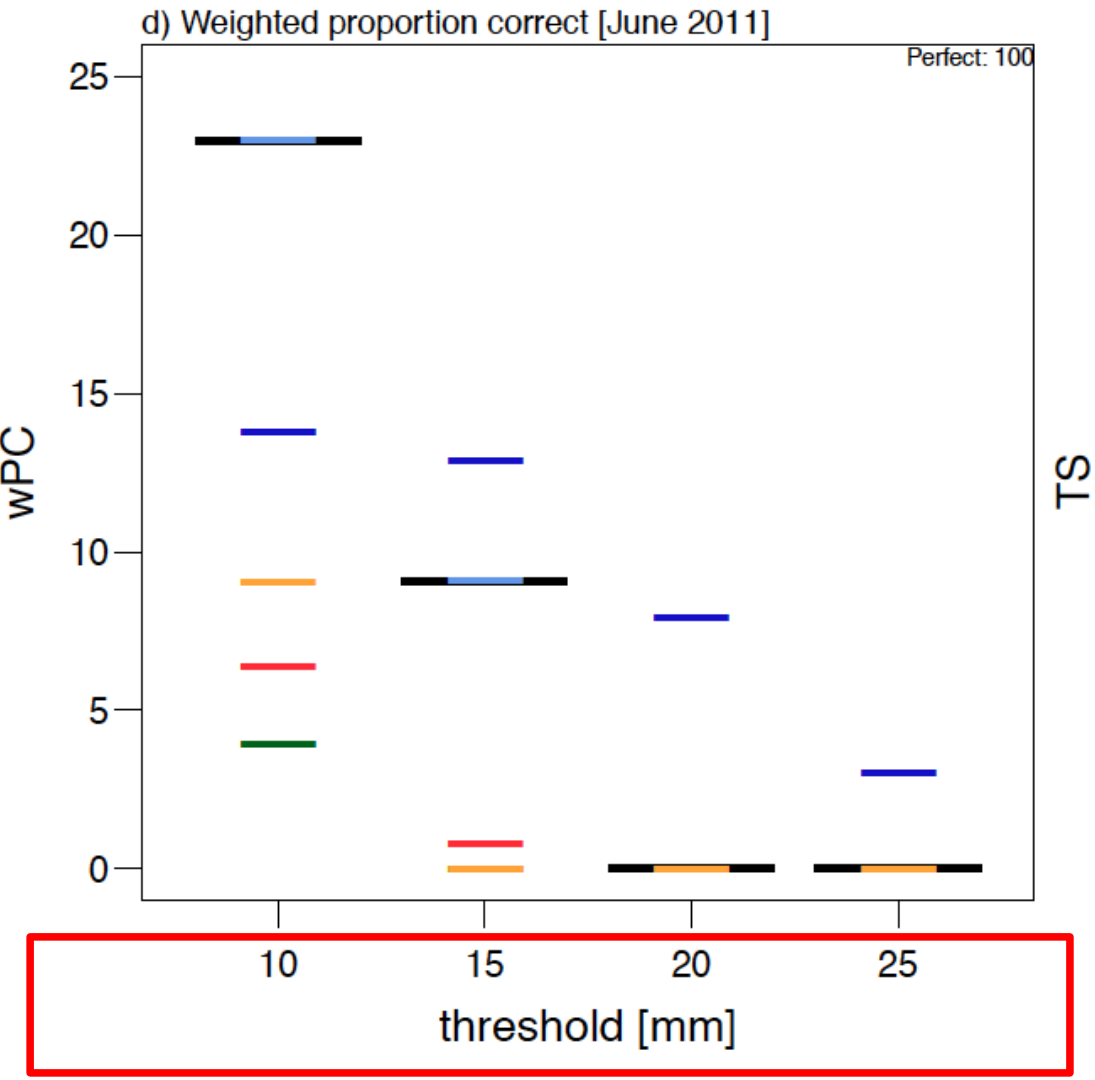
- Probabilistic verification compared to

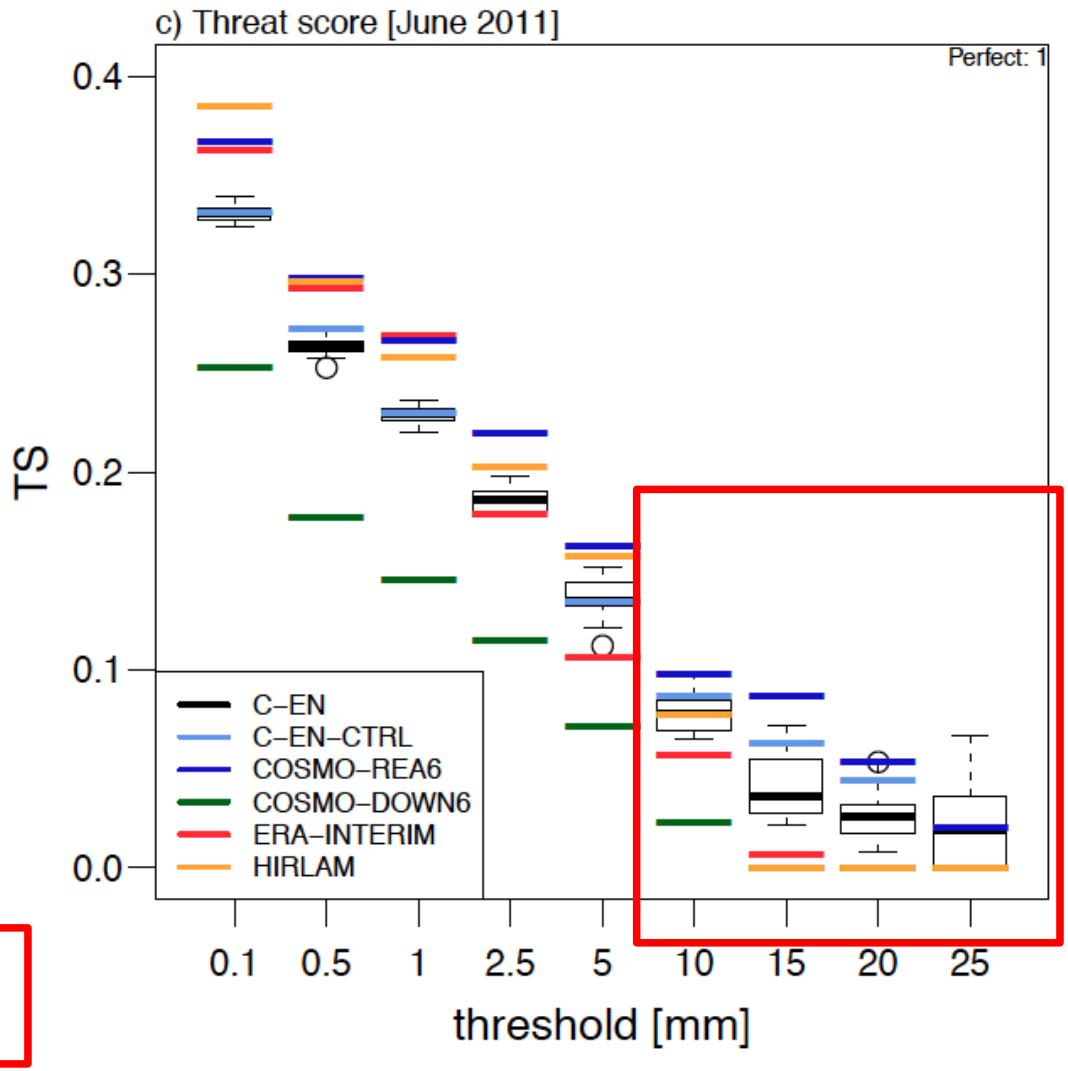
  +06 forecasts of ECMWF-EPS

Agreement of marginal distributions

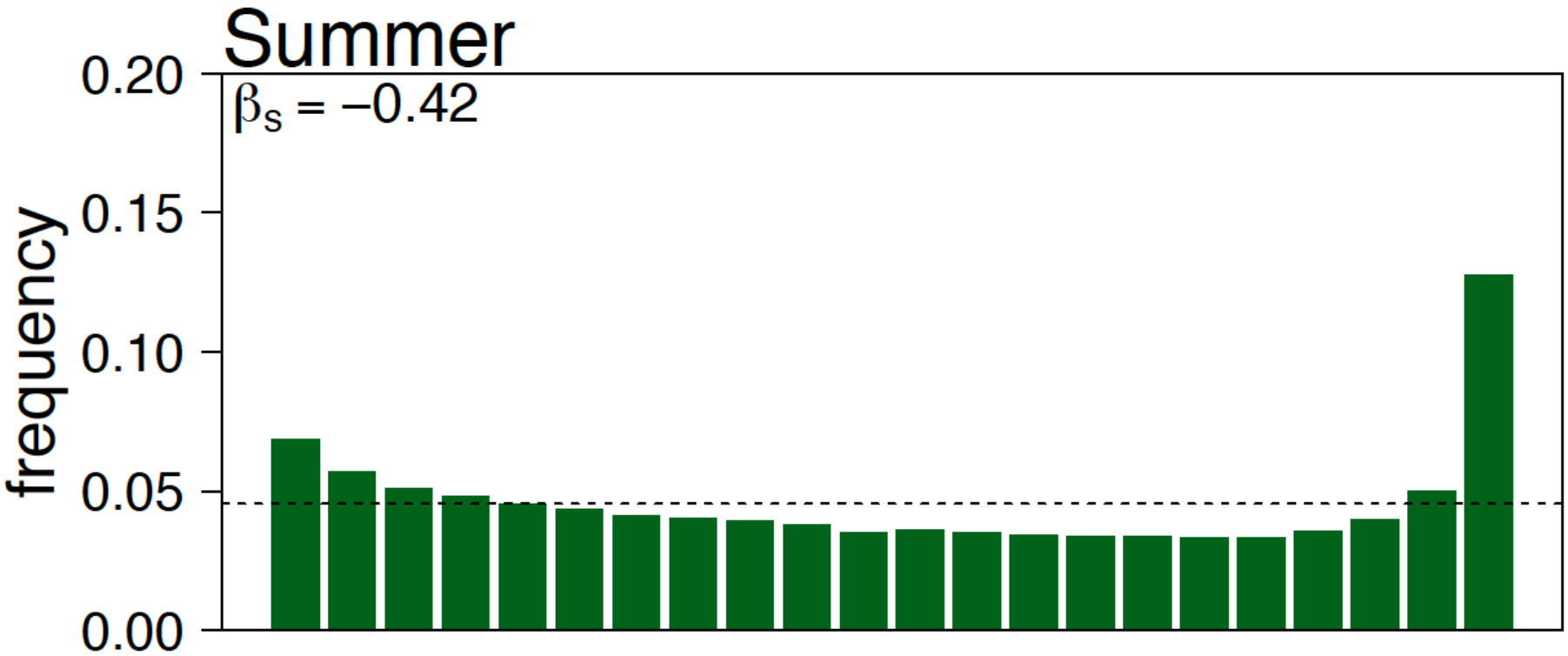


Agreement of conditional distributions



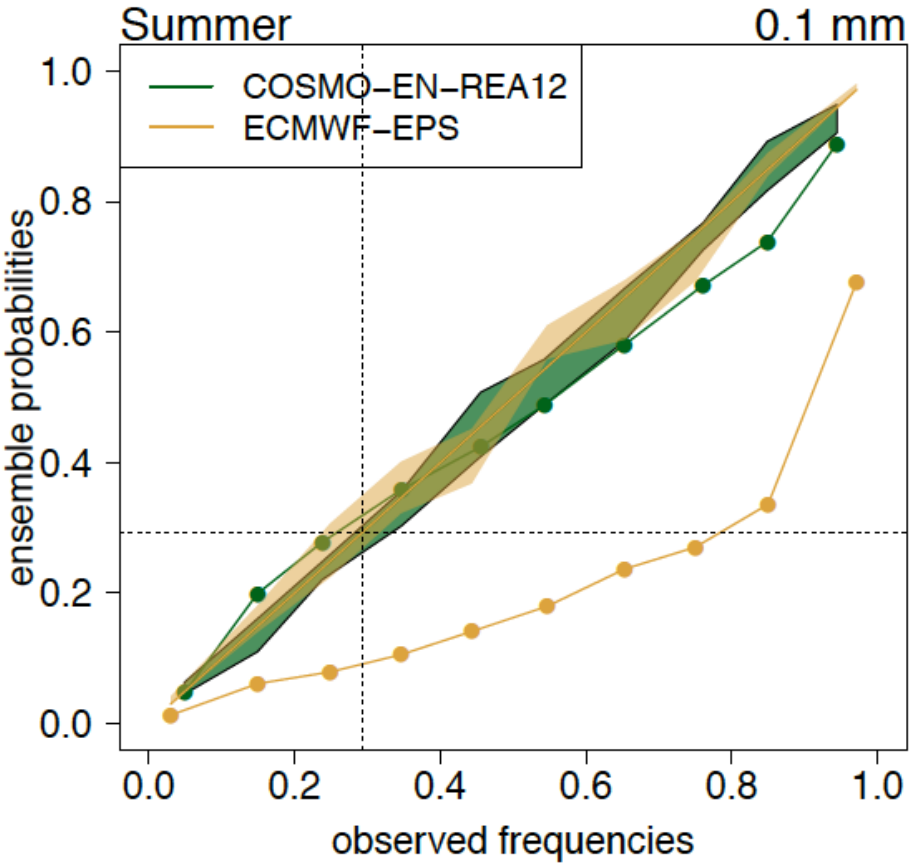


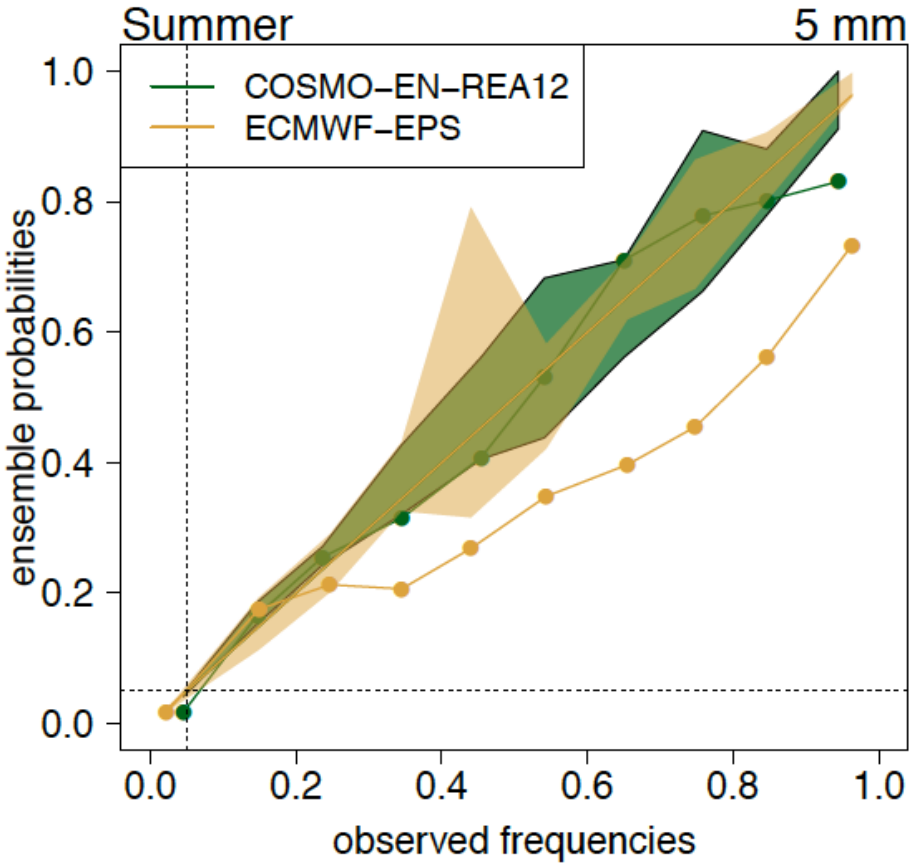
Equal-likelihood



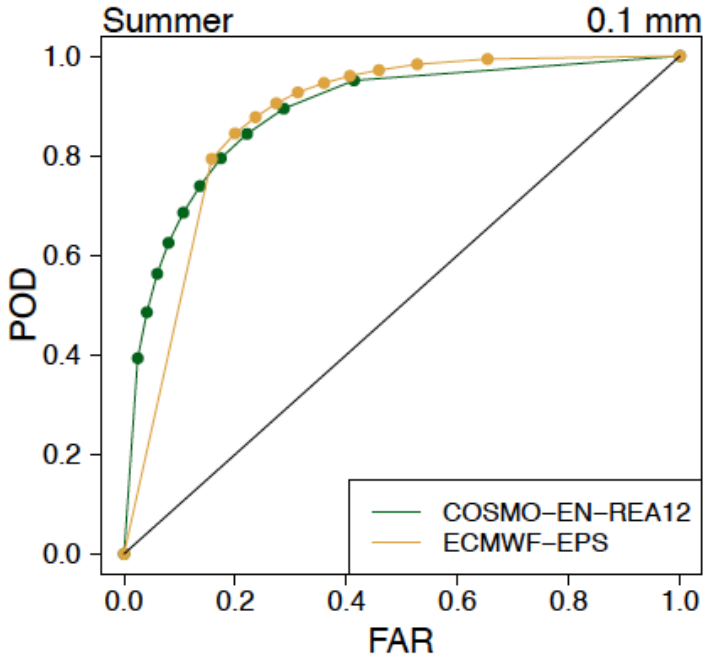
$$SSR \in [0.784, 0.794, 0.805]$$

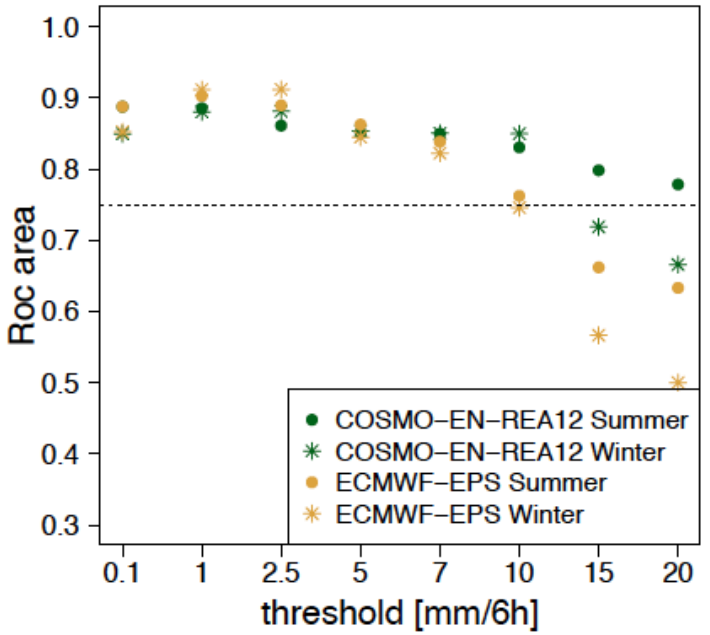
Reliability





Resolution / discrimination





How good is the ensemble for precipitation?

- Added value in frequency bias
- Added value at high precipitation thresholds
- Uncertainty estimation for 12 km model set up given observation uncertainties (~80 %)
- Quite well-calibrated ensemble (analysis rank histogram)
- Reliability win compared to ECMWF-EPS (reliability diagrams, BS)
- Resolution/discrimination (roc curve, BS)
- Probabilistic accuracy comparable to ECMWF-EPS (CRPSS)

  → 1 – CRPS(EN)/CRPS(ECMWF-EPS) ~ 0

Scientific questions

- How good is our regional reanalysis ensemble? ✓

- What are really the uncertainties in ensembles of regional reanalyses?
  - How do we best generate the ensemble in the future?

Uncertainties in ensembles of regional reanalyses

- Take into account uncertainty in
  - **Lateral boundary conditions**
    - ICON-Ensemble
    - New ECMWF global ensemble reanalysis ERA-5
  - **Model physics**
    - Perturbed physics ensemble
    - SPPT

First experiment

- Do we get a better uncertainty estimation if we (additionally) account for model error?
- Perturbed physics ensemble similarly to COSMO-LEPS

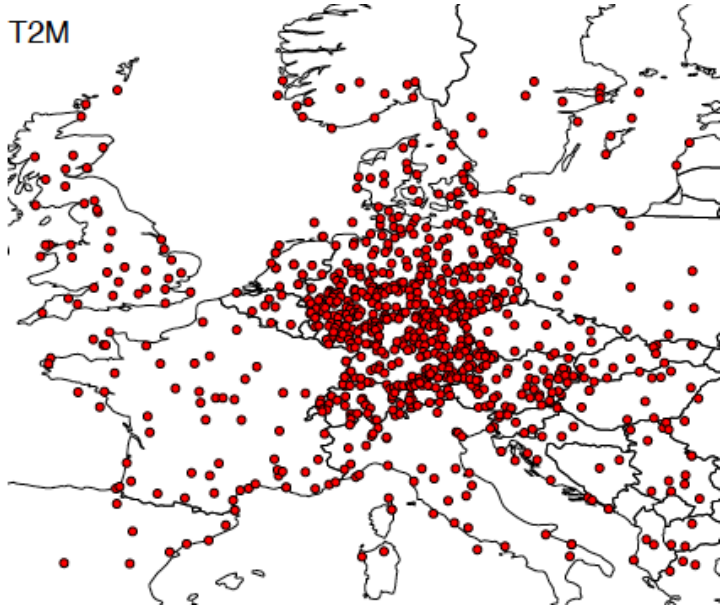
tur_len	150	500*	2000
pat_len	500	2000	
crsmin	50	150	200
rat_sea	1	20	40
rlam_heat	0.1	1	5
mu_rain	0.5	0.0	
cloud_num	$5*10^8$	$5*10^7$	

```
&TUNING
  c_soil   =   1.0,
  clc_diag =   0.5,
  crsmin   = 150.0,
  qc0      =   0.0,
  q_crit   =   4.0,
  qi0      =   0.0,
  rat_can  =   1.0,
  rat_lam  =   1.0,
  tur_len  = 500.0,
  v0snow   =  25.0,
  wichfakt =   0.0,
  tkhmin   =   0.4,
  tkmmin   =   0.4,
```

- Control run + 20 unique parameter combinations

Verification of screen level temperatures

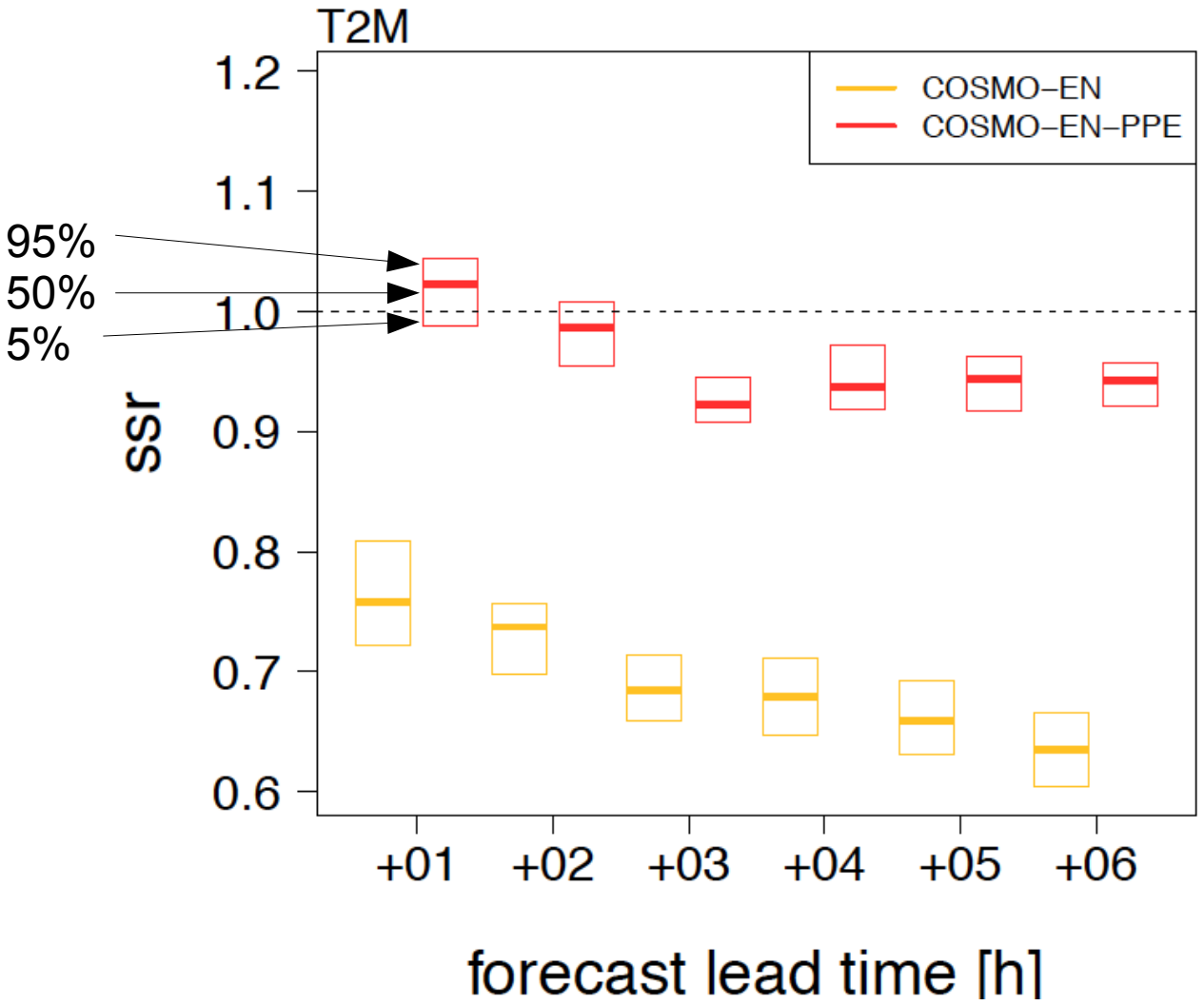
- Ensemble nudging vs PPE
- Ensemble nudging vs ensemble nudging + PPE
- Experiment for May/June 2014
- Verification of reforecasts until +06h using ~1000 stations in Europe



Can the spread explain more of the RMSE(reanalysis, observations)?

Spread-skill ratio

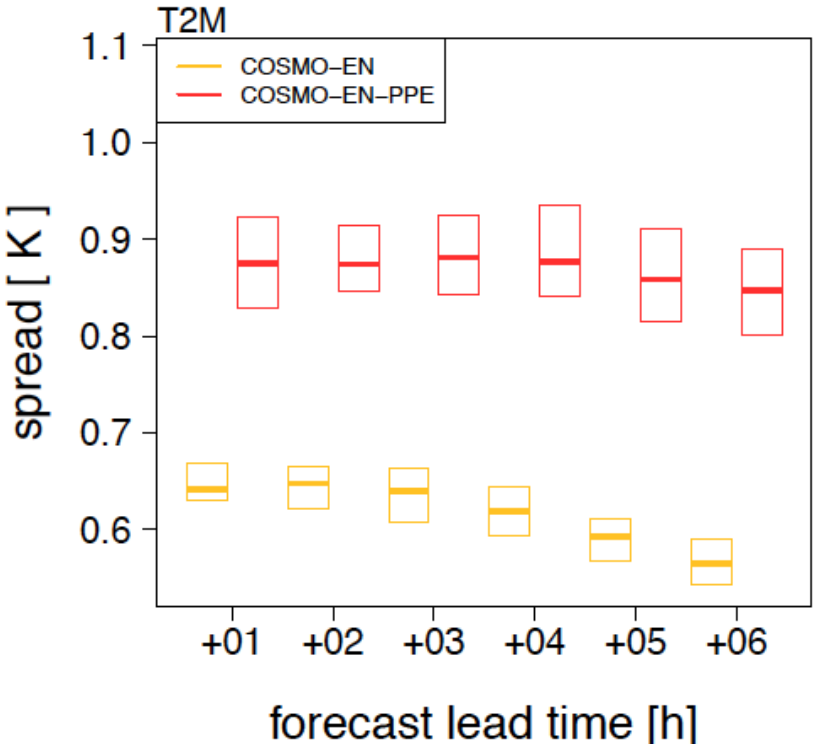
Spread-skill ratio, T2M

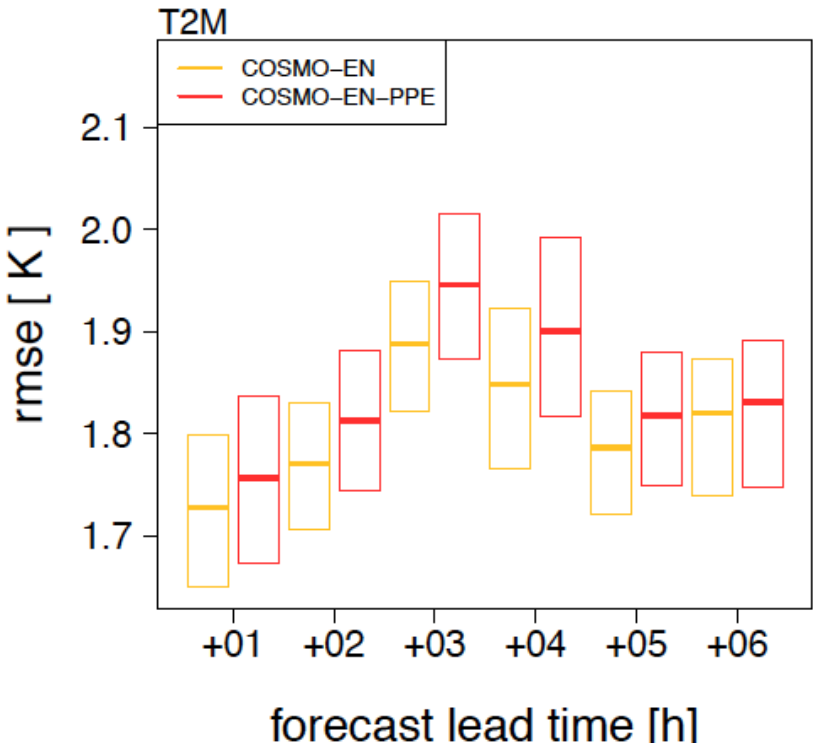


Spread-skill ratio averaged over all locations and points of time

Nboot=100

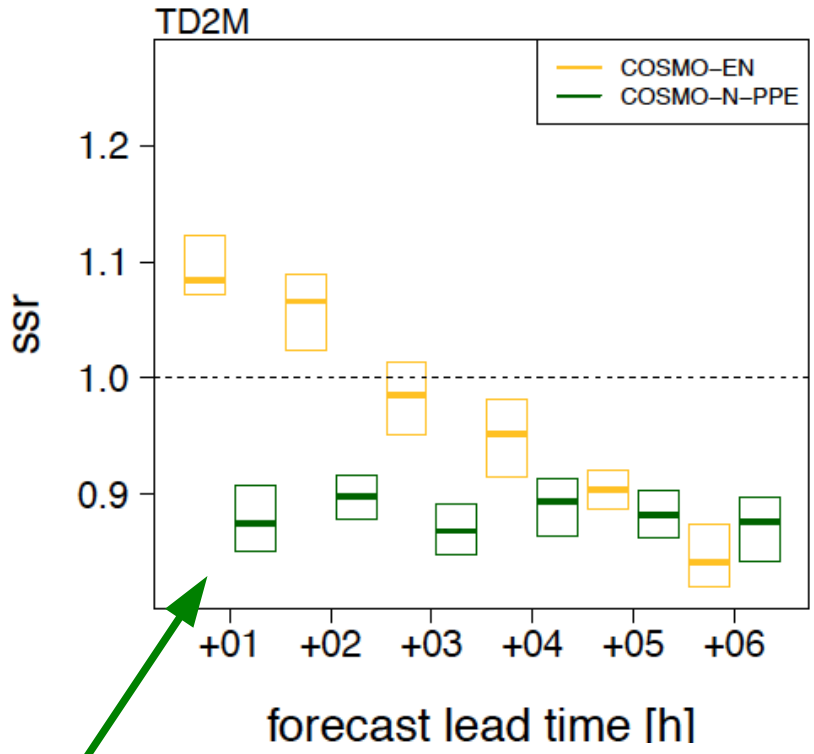
Spread and RMSE, T2M

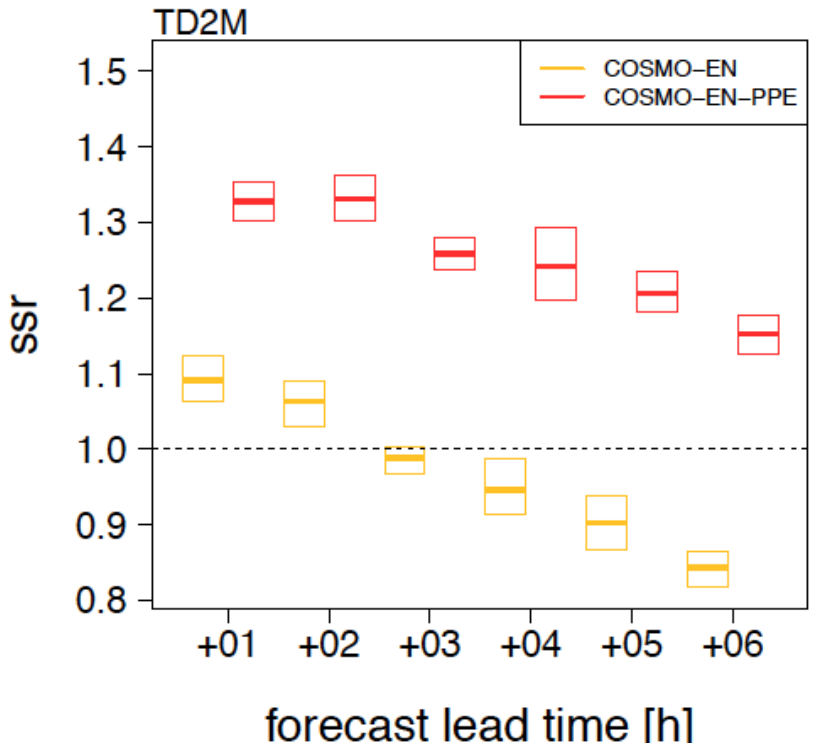




Spread and rmse averaged over all locations and points of time, Nboot=100

Spread-skill ratio, TD2M





Nudging + PPE → just model error!

Better uncertainty estimation accounting for model error?

Measured by means of screen level temperatures in reforecasts

T2M

- Very positive impact of PPE additionally to EN

TD2M

- EN + PPE leads to overestimation

Better uncertainty estimation accounting for model error?

Measured by means of screen level temperatures in reforecasts

T2M

- Very positive impact of PPE additionally to EN

TD2M

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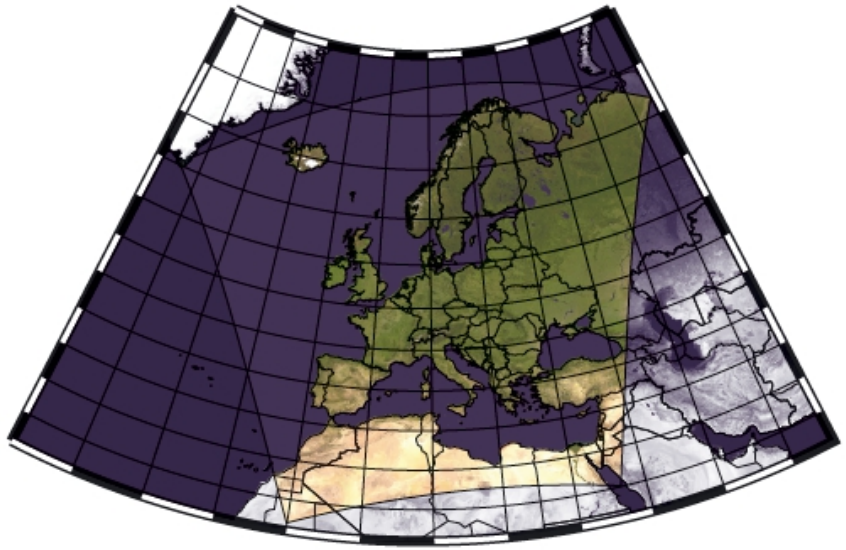
$$1_{(EN)} : 1_{(EN+PPE)}$$

High-resolution regional reanalyses

- Regional reanalyses in the Hans-Ertel Centre for Weather Research
  - COSMO-REA6
    - Europe, 6km
    - COSMO+nudging
    - 1994 - 2014
  - COSMO-REA2
    - Germany, 2km
    - COSMO+nudging+lhn
    - 2007 - 2014

Bollmeyer et. al, 2015



- Very comprehensive data sets
- Do not hesitate to contact us for data requests!

Ensemble data assimilation for regional reanalysis

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UERRA Uncertainties in Ensembles of Regional ReAnalyses