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**Bundesamt für Meteorologie und Klimatologie MeteoSchweiz**

# Statistical Characteristics of High-Resolution COSMO Ensemble Forecasts in view of Data Assimilation

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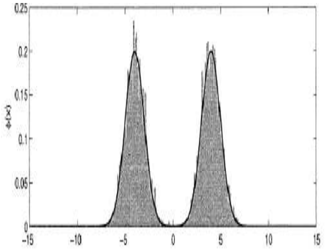
# Introduction

- New data assimilation scheme for high-res COSMO
- Local Ensemble Transform Kalman Filter (Hunt et al., 2007)
- General assumption in Ensemble Kalman Filter Methods: „Errors are of Gaussian nature and bias-free“
- Prerequisite for
  - „optimal“ combination of model fc and observations or
  - easily finding a minimum of the cost function

$$J(\mathbf{x}) = \underbrace{\frac{1}{2}\left(\mathbf{x}-\bar{\mathbf{x}}_b\right)^T \mathbf{P}_b^{-1}\left(\mathbf{x}-\bar{\mathbf{x}}_b\right)}_{\text{Background term}} + \underbrace{\frac{1}{2}\left[\mathbf{y}-H(\mathbf{x})\right]^T \mathbf{R}^{-1}\left[\mathbf{y}-H(\mathbf{x})\right]}_{\text{Observation term}}$$

# Non-Normality in EnKF



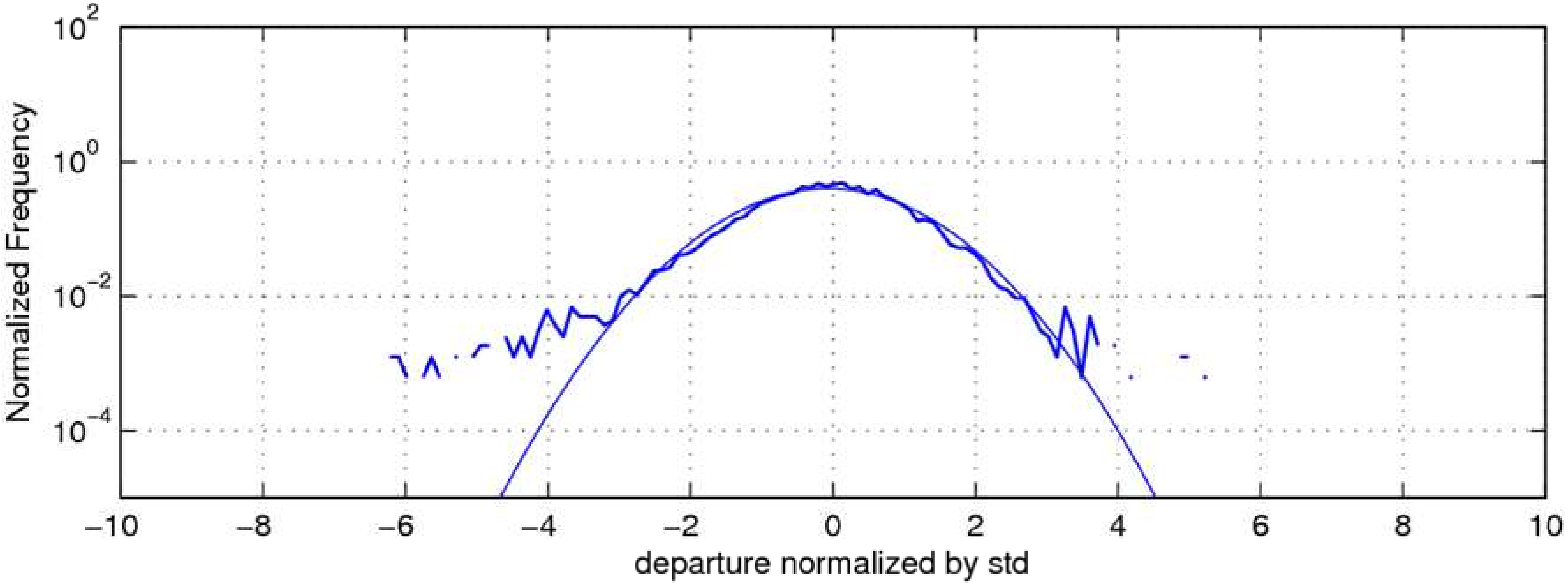
Background pdf

Lawson and Hansen, MWR (2004)

# Data

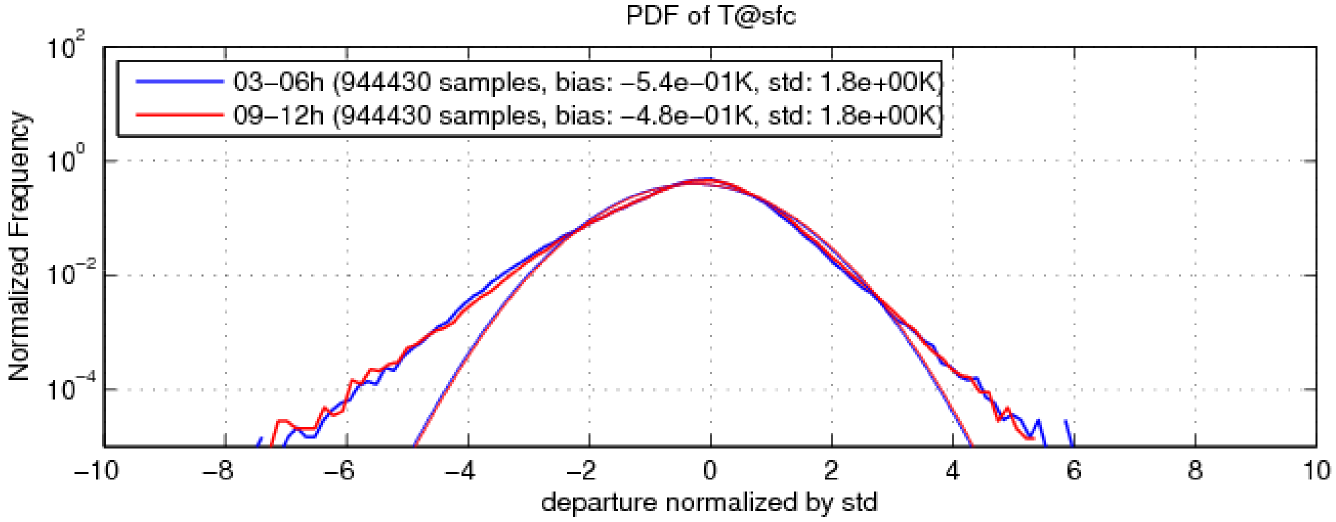
- Forecast departures (observation term)
  - Different variables, observation systems, heights, lead times and seasons
  - Based on a 3 month summer (2008) and winter (2007/2008) period of operational COSMO-DE forecasts
- Ensemble anomalies (background term)
  - Different variables, levels, lead times and days
  - Based on 9 days (Aug. 2007) of the experimental COSMO-DE EPS

# Evaluation Method

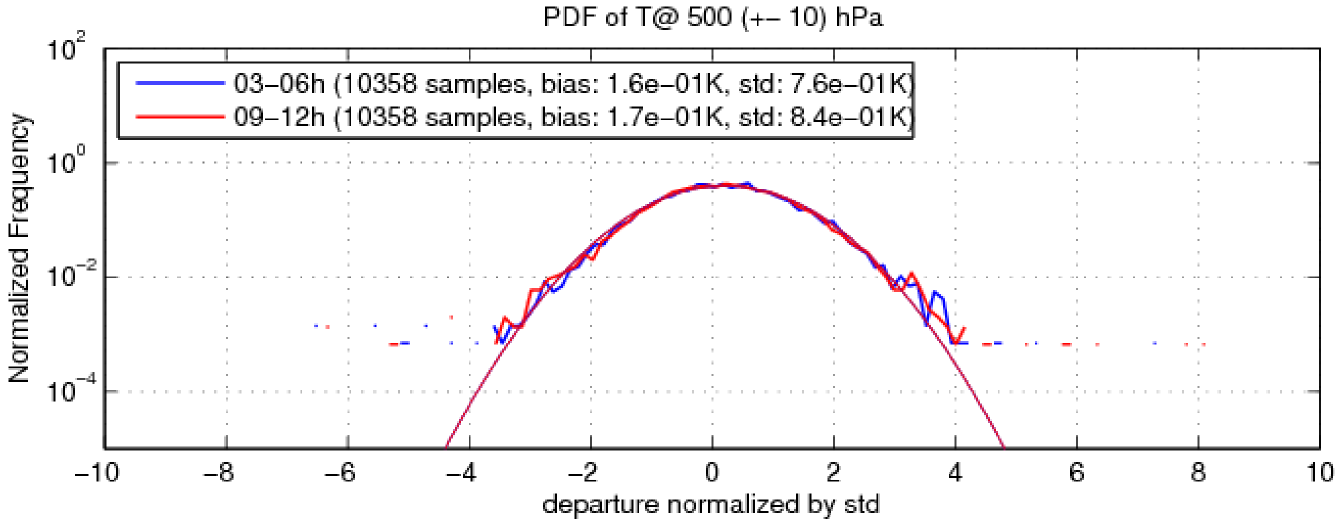


# Example I: Temperature

T2m from SYNOP

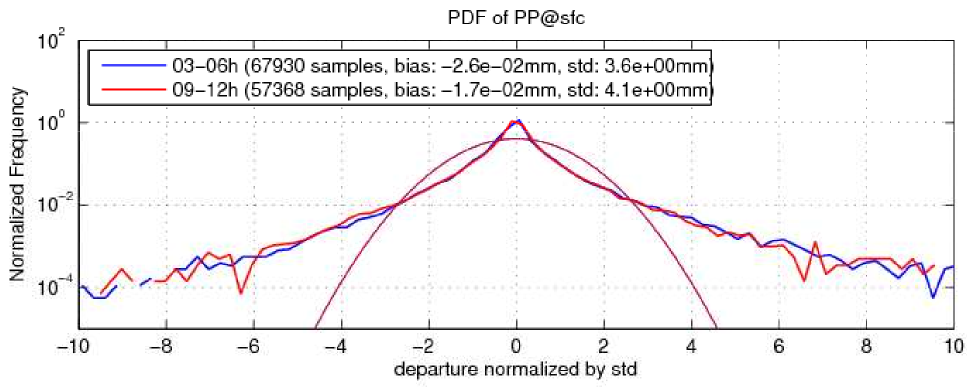



T@500hPa
from aircraft obs

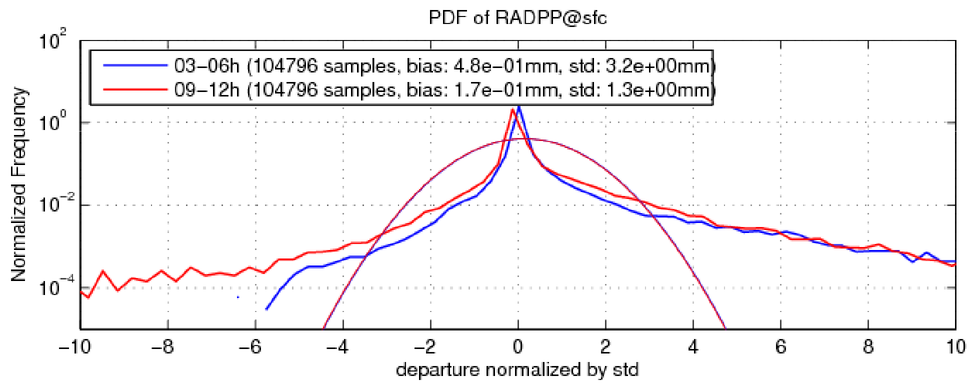


# Example II: Rainfall

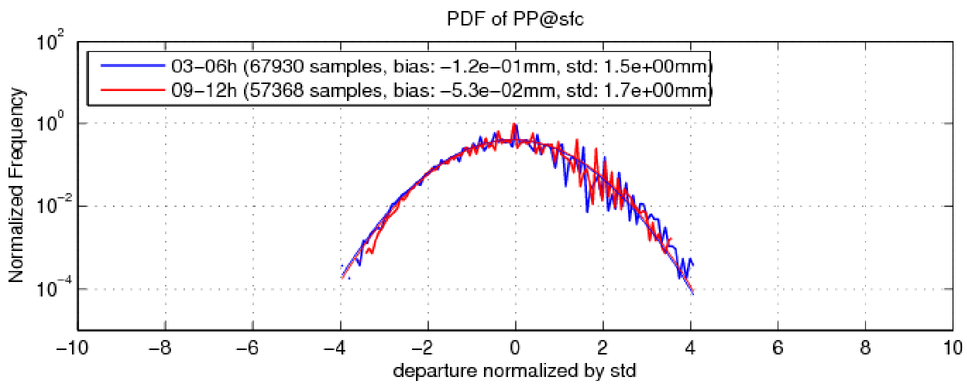
pp from SYNOP



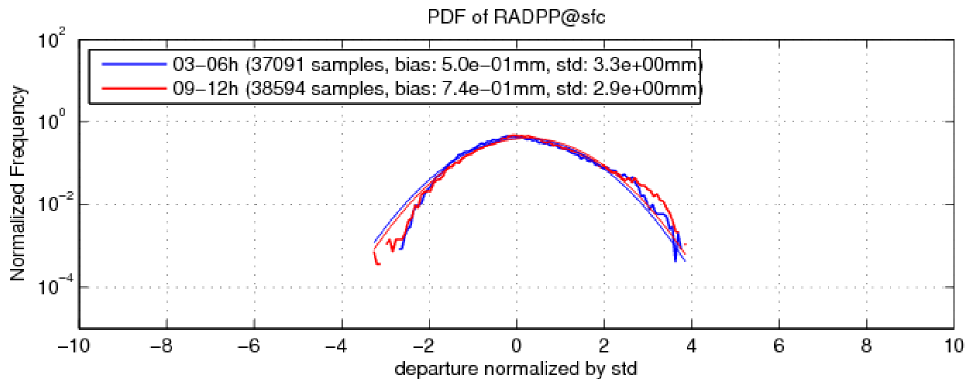

pp from radar




log(pp) from SYNOP




log(pp) from radar



# General Findings for Observation Term

- Small deviations from normality around mean in COSMO-DE for forecast departures of temperature, wind and surface pressure out to 12h lead time
- „Fat tails“, i.e. more large departures than expected in a Gaussian distribution
- Better fit in free atmosphere than near surface
- Deviation from normality in humidity and precipitation
- Transformed variables (e.g. log(pp)) have better properties concerning normality

# Ensemble Anomalies

- Background error calculated from ensemble spread (anomalies around mean)

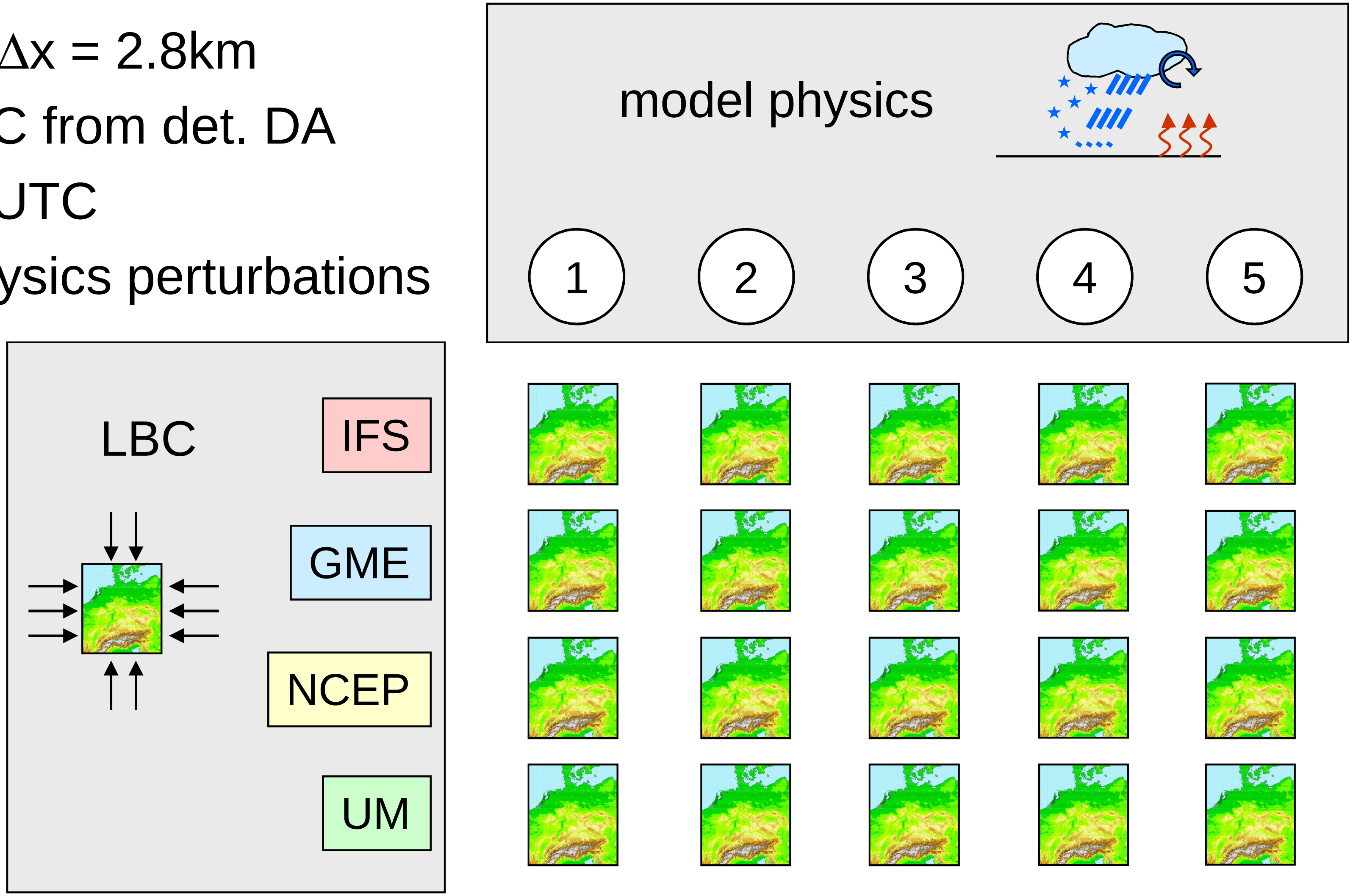
$$\mathbf{x}_b^k - \overline{\mathbf{x}}_b$$

- Look at distribution of ensemble anomalies of COSMO-DE EPS forecasts
  - at +3h, +9h, +12h and +24h
  - near surface and at ~5400m above surface

- Two localized regions in Germany
  - Northern Germany (flat terrain)
  - Black Forest (moderately complex terrain)

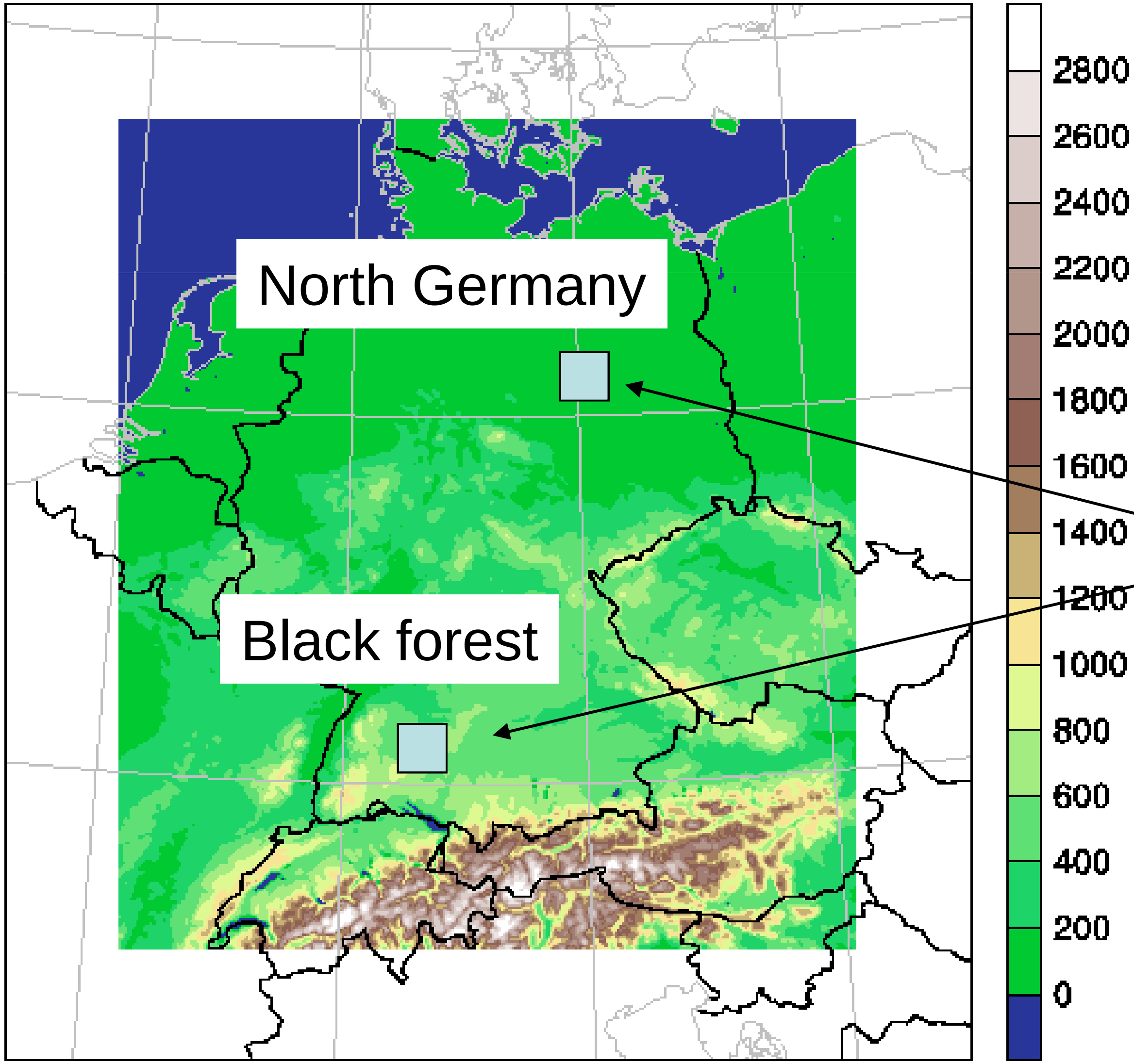
# COSMO-DE EPS

- Mesh size Δx = 2.8km
- Common IC from det. DA
- Start at 00UTC
- BC and physics perturbations




Susanne Theis, DWD

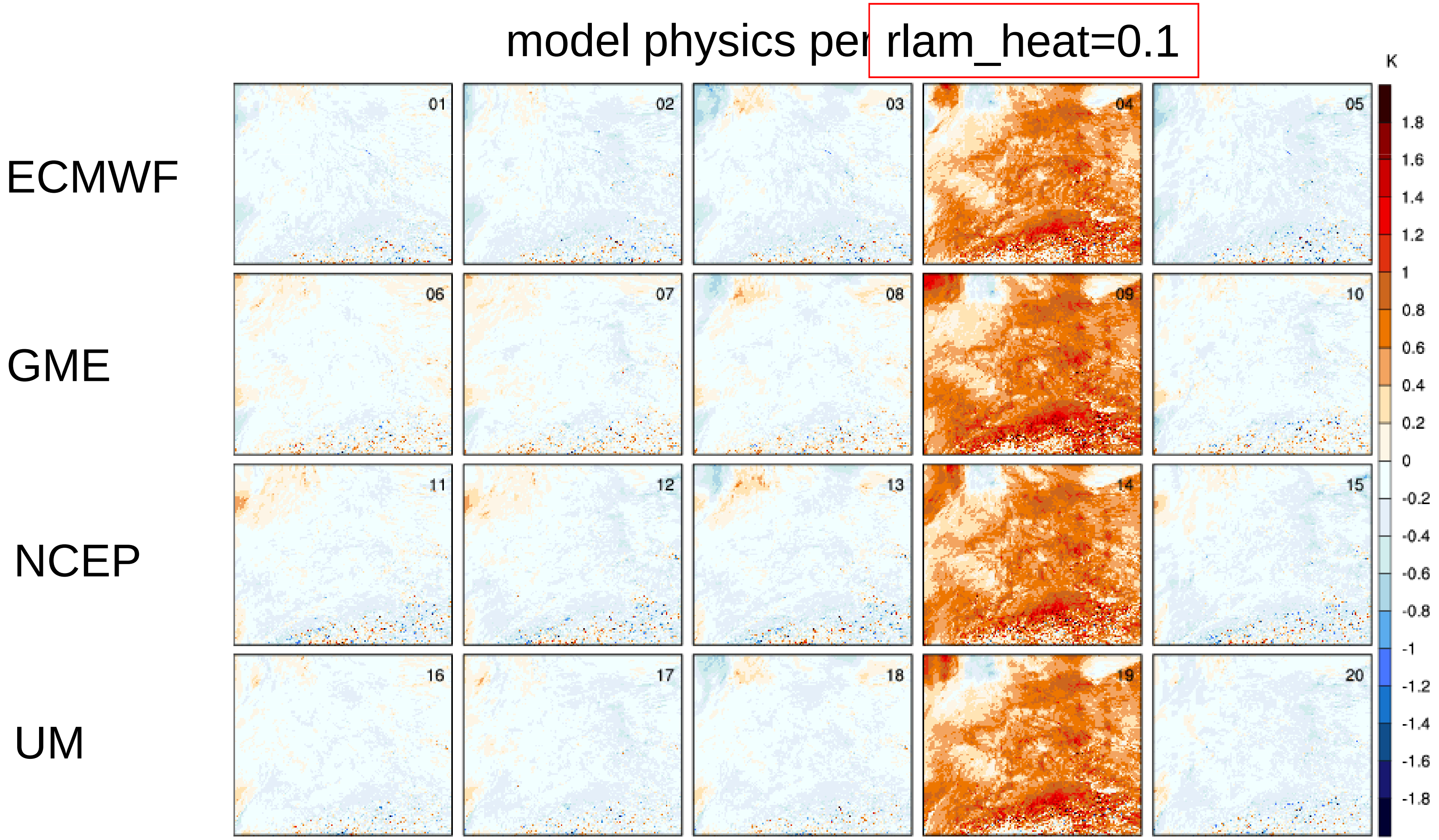
# COSMO-DE EPS




Verification regions (10x10 gridpoints)

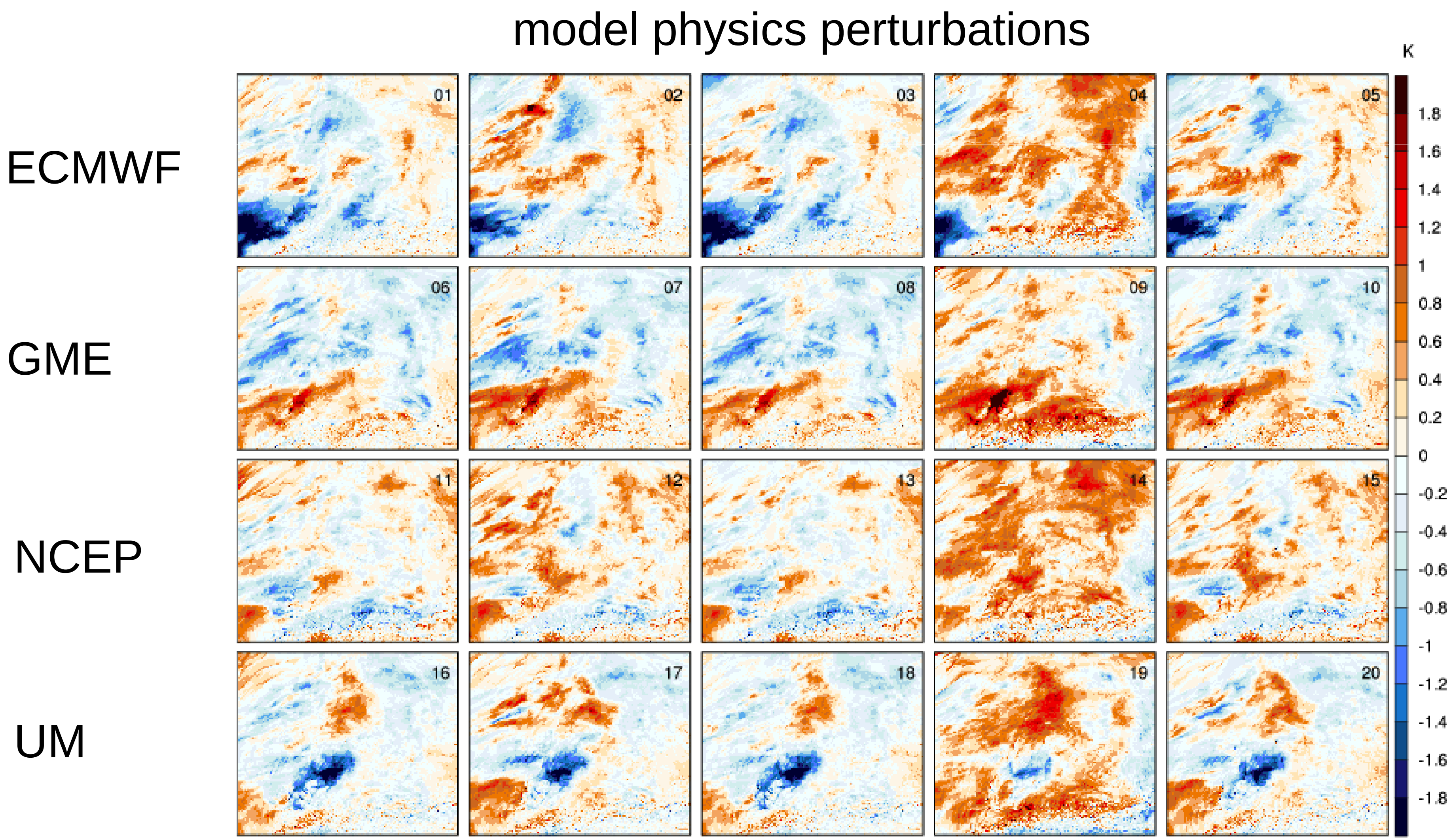
# Ensemble Anomalies

## Temperature at ~10m, +3h (03UTC)



# Ensemble Anomalies

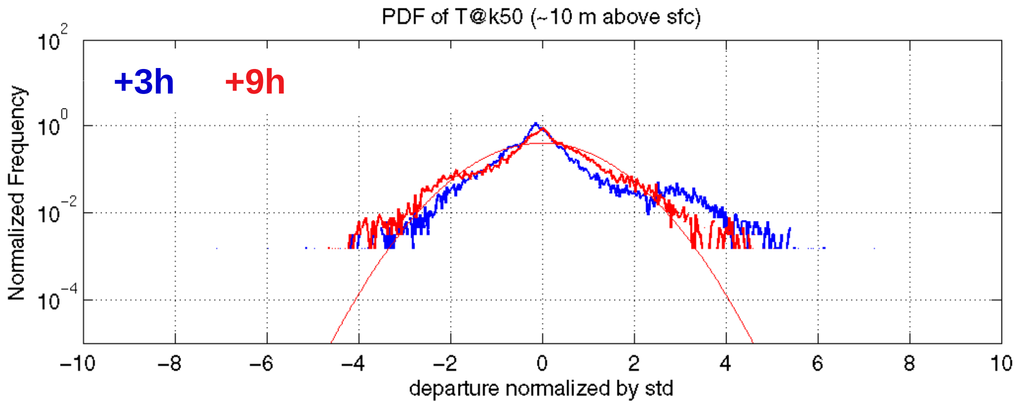
## Temperature at ~10m, +9h (09UTC)

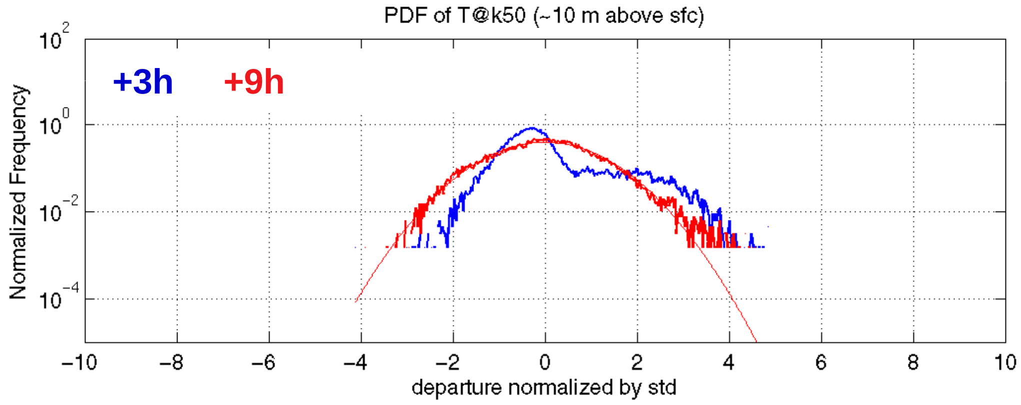


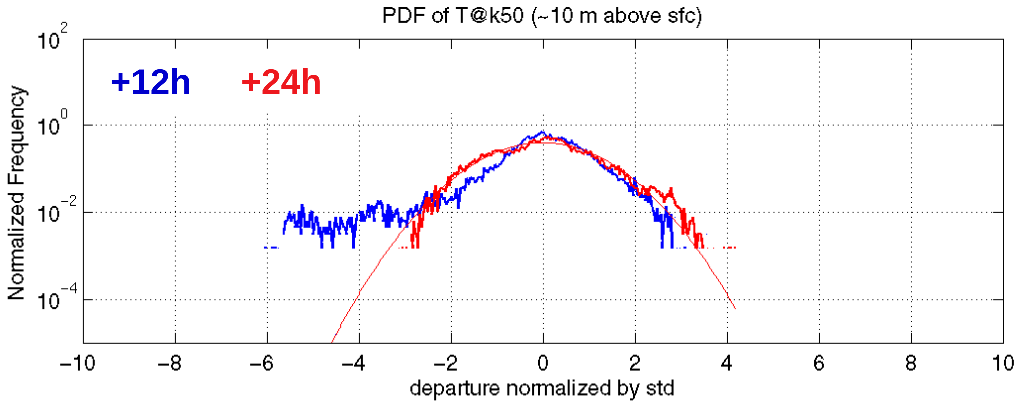
# Ensemble Anomalies – T@10m

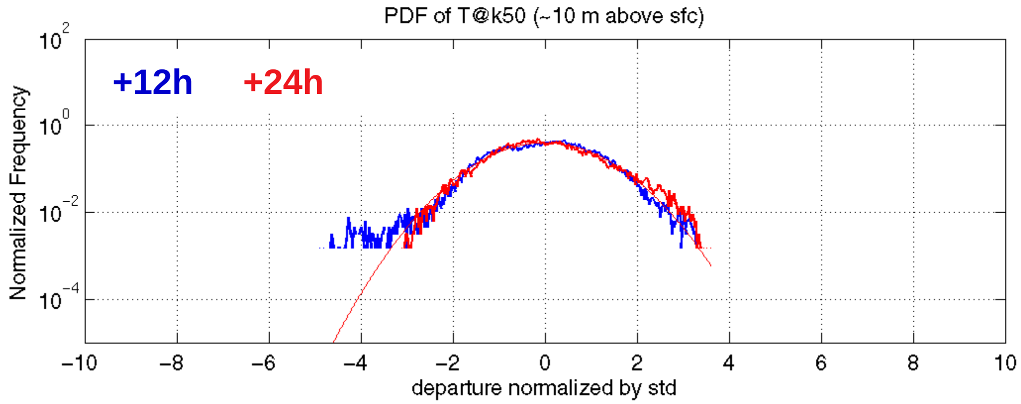
Black forest

North Germany



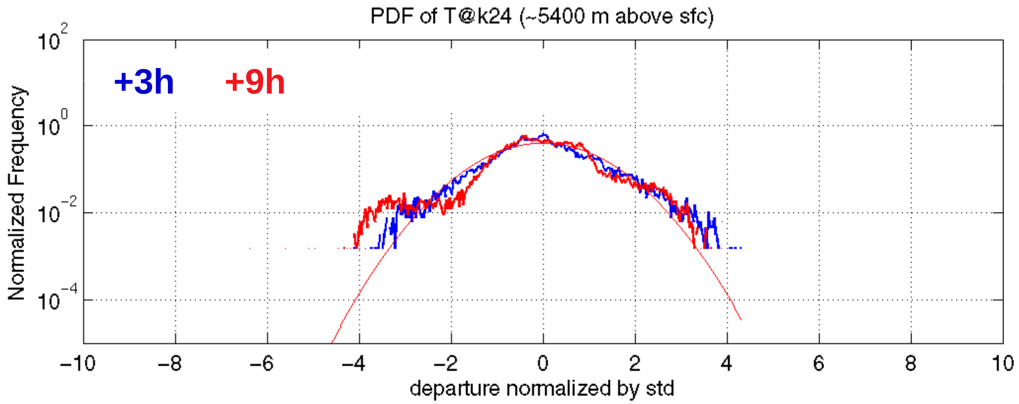



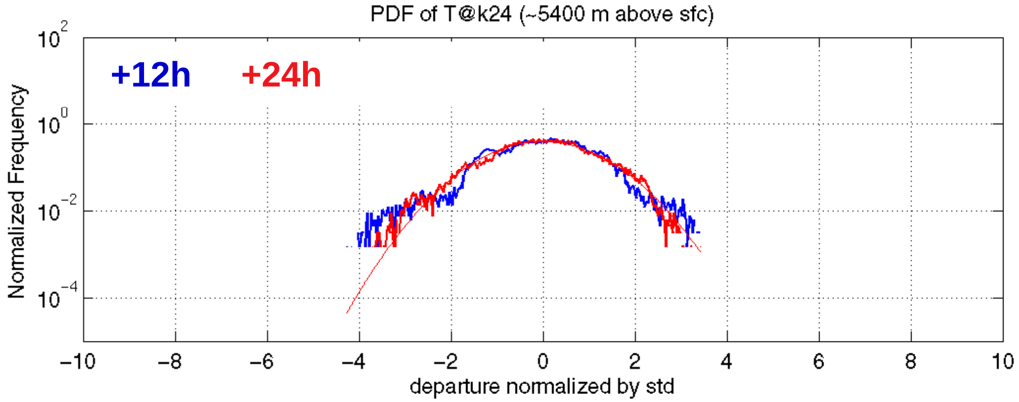



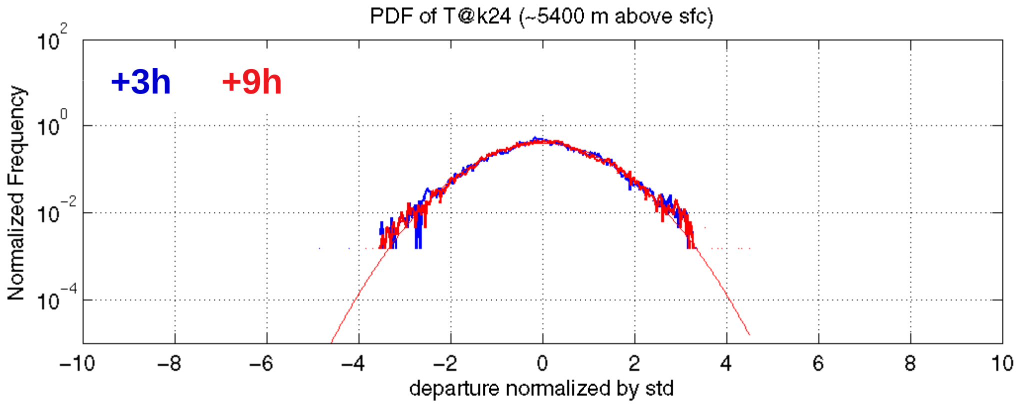
# Ensemble Anomalies – T@5400m

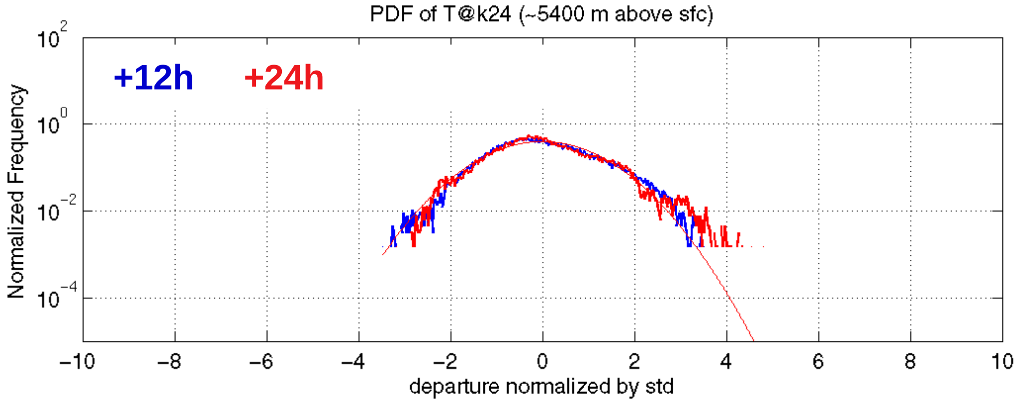
## Black forest




## North Germany



# General Findings for Background Term

- May deviate significantly from Normality
- Largest deviations
  - for temperature
  - at early forecast times
- Deviations larger in complex terrain
- Consistently better fit at longer lead times
- Tendency for better fit in free atmosphere than near surface

- Largely determined by physical perturbation technique

# Discussion

- LETKF ensemble will differ from the current setup of COSMO-DE EPS
  - Gaussian spread in initial conditions
  - Non-gaussianity will grow during non-linear model integration
  - For data assimilation more gaussian (physical) model perturbations would be favourable

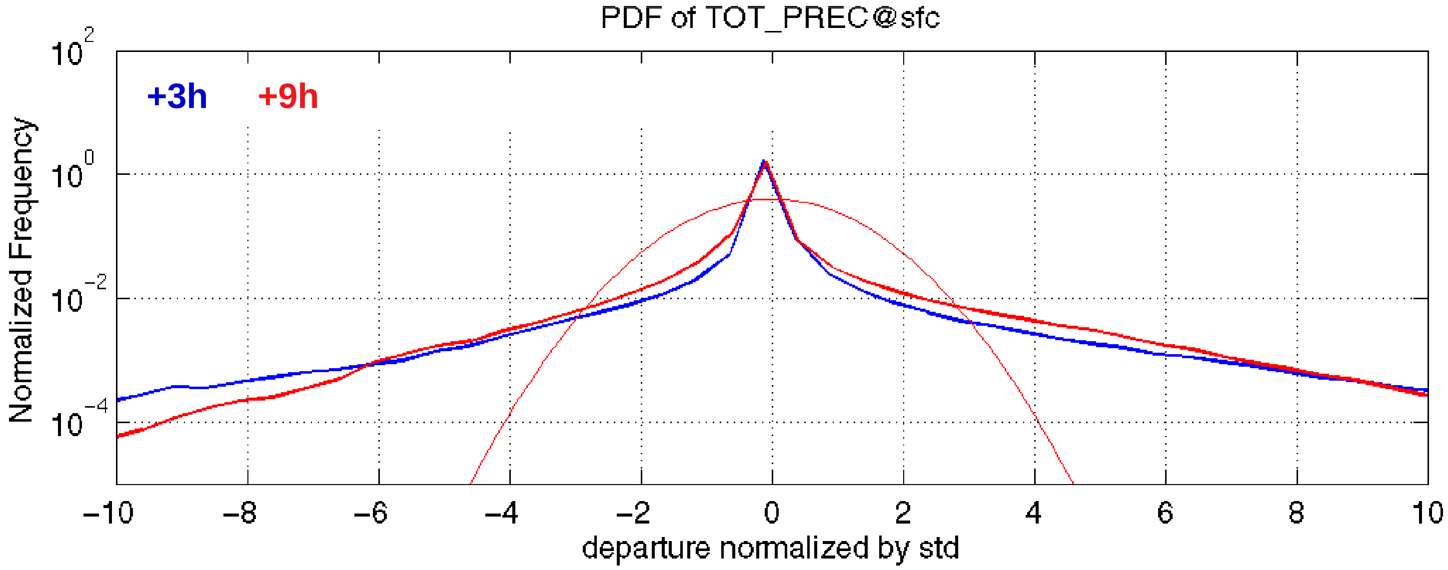
# Conclusions

- Observation term seems to be reasonably normally distributed averaged over many cases, except for humidity and precipitation
- Transformation of variables can improve normality
- High-resolution COSMO EPS might produce non-normal anomalies in some cases
- COSMO is implementing the LETKF
- Ways to improve the LETKF in highly nonlinear / non-normal conditions are currently being investigated

# Thank you for your attention

# Ensemble Anomalies

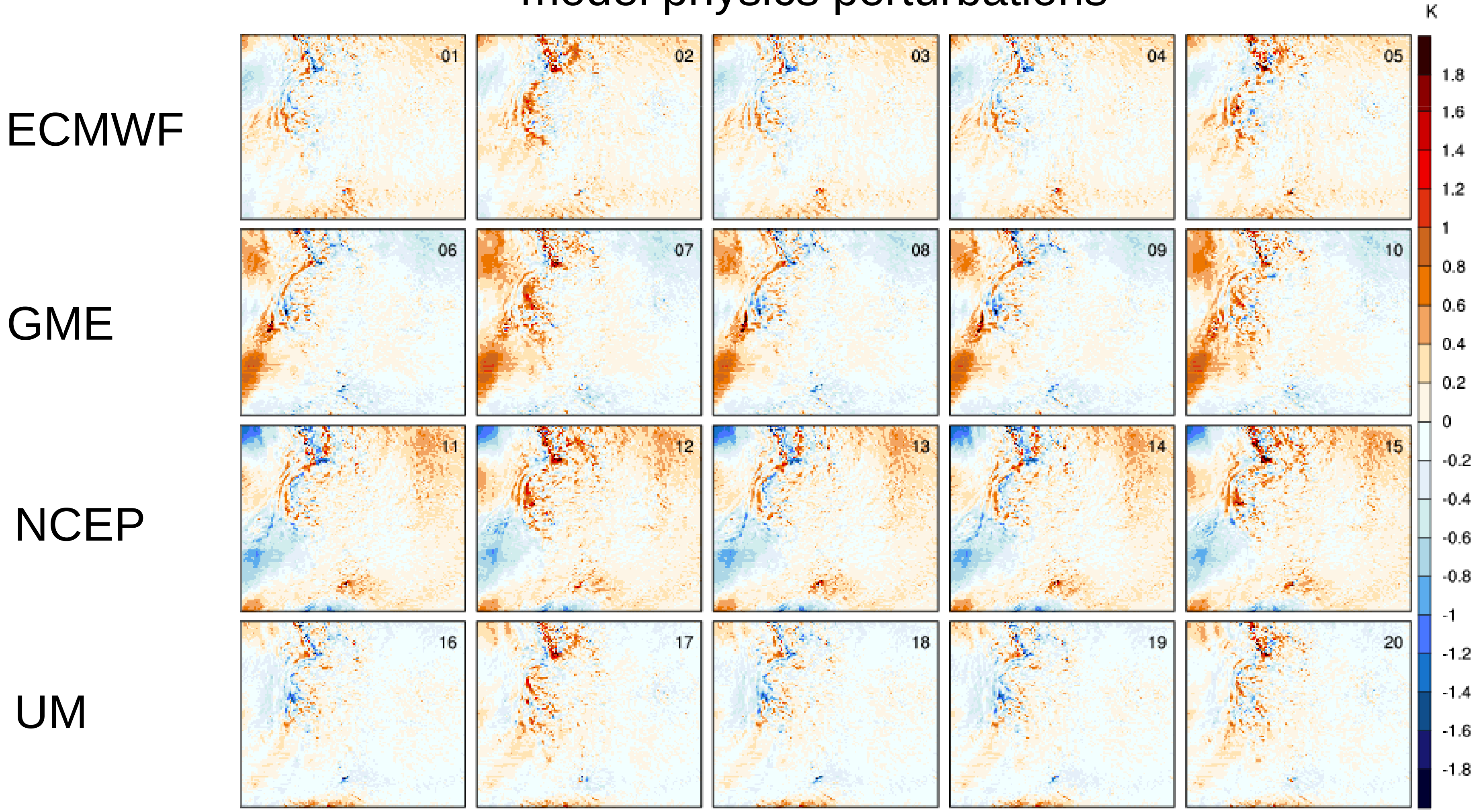
Hourly Precipitation



# Ensemble Anomalies

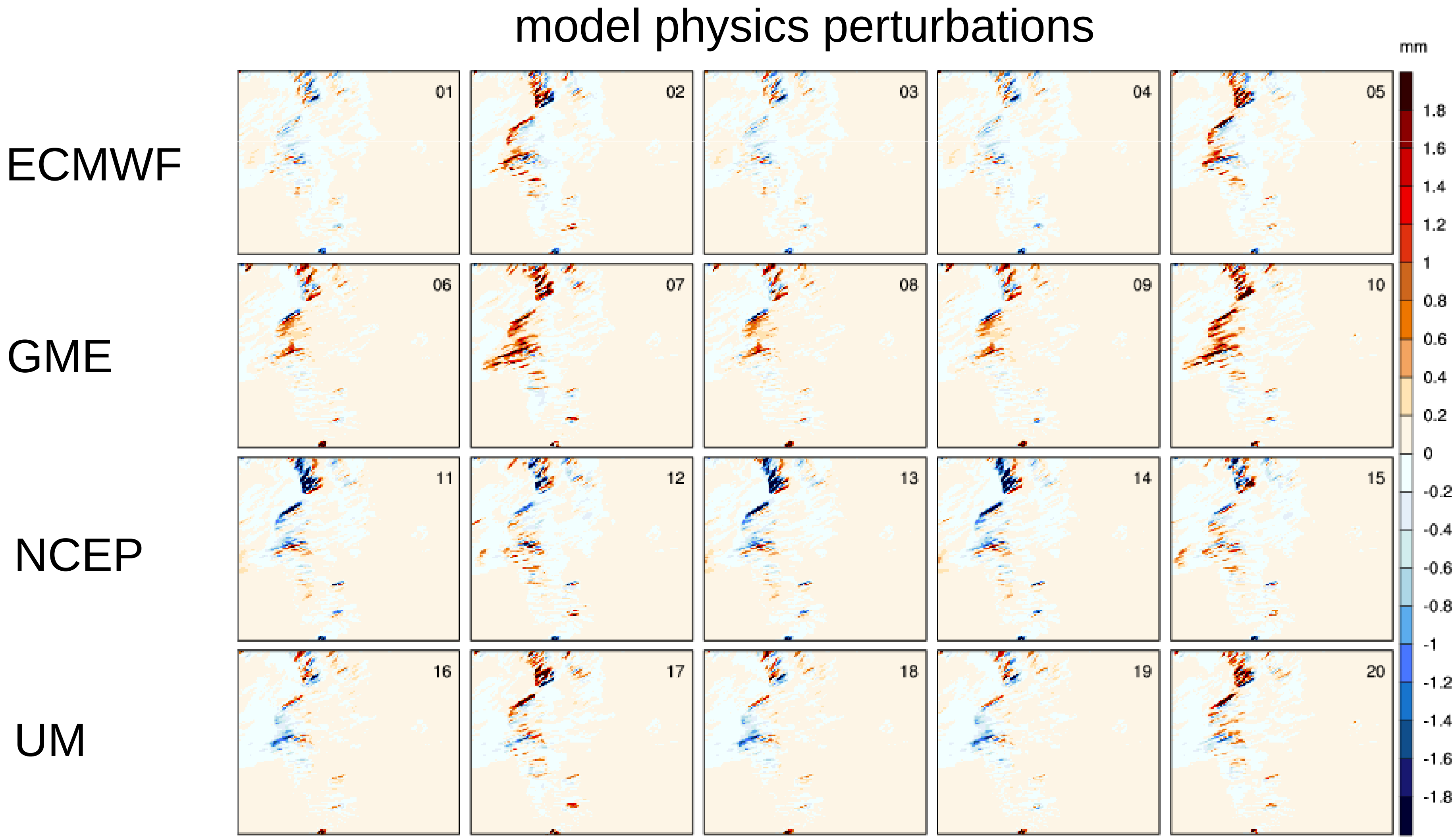
## Temperature at ~5400m, +3h (03UTC)

model physics perturbations



# Ensemble Anomalies

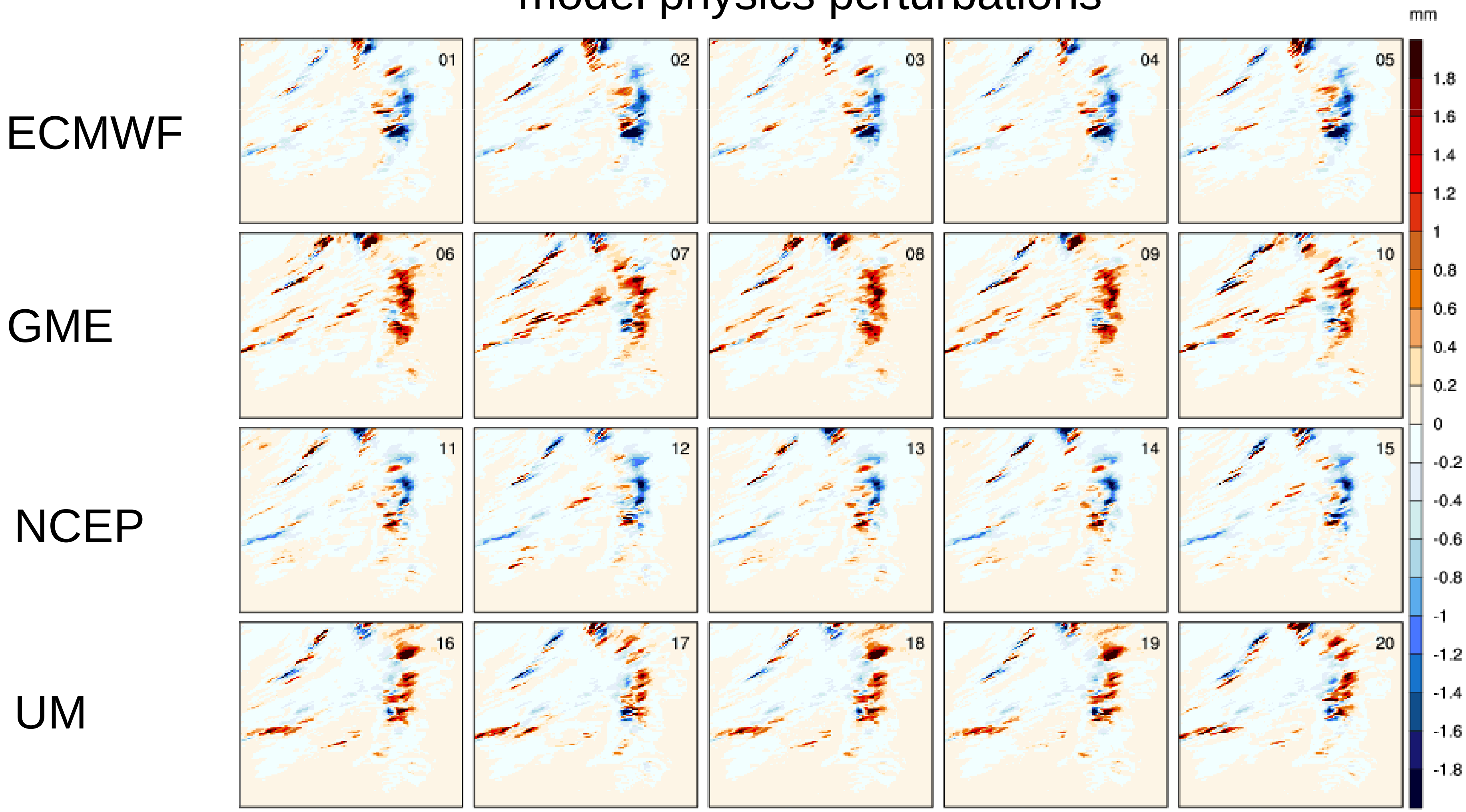
## Hourly Precipitation, +3h (03UTC)



# Ensemble Anomalies

## Hourly Precipitation, +9h (09UTC)

model physics perturbations



# Methods to deal with Nonnormality

- „No cost smoother“ (Kalnay et al., 2007)
  - Apply weights from time t+1 at time t
- „Running in place“
  - Use observations more than once by iterating several times over same assimilation window using the no cost smoother until convergence
- „Outer loop“ in LETKF
  - Bring analysis mean closer to observations by iteration of update step (inner loop)
  - Advance to next assimilation time by using nonlinear model (outer loop) using better guess of mean analysis from inner loop
- Have proven to improve LETKF in presence of nonlinearity / non-Gaussianity in Lorenz model (Yang and Kalnay, 2008)