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# COSMO-E - status and developments

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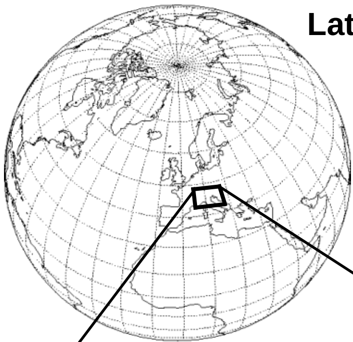
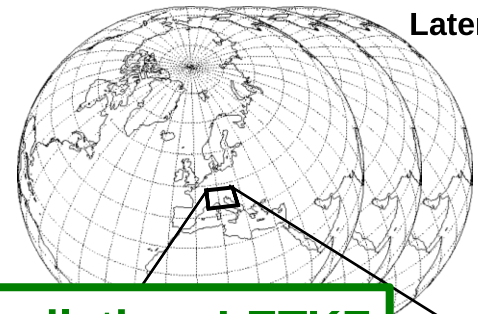
COSMO General Meeting
8 September 2014, Eretria

# Project COSMO-NExT



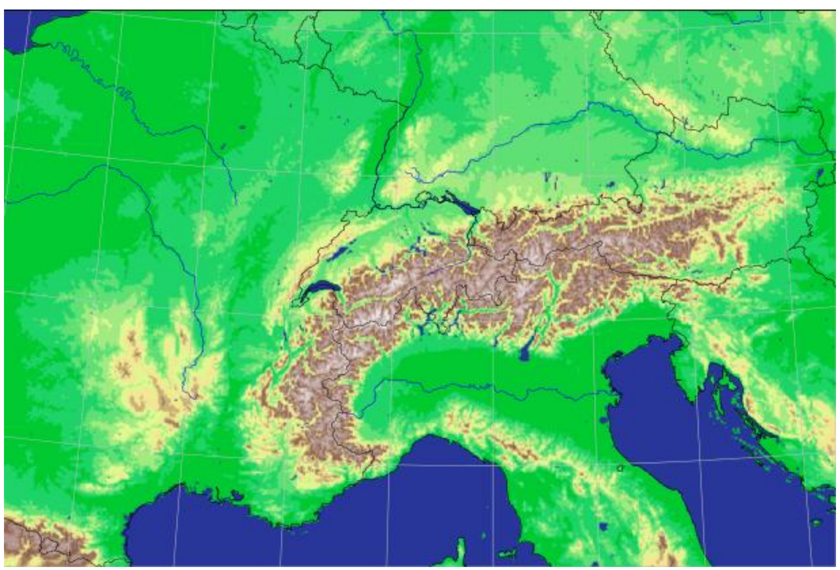
Lateral boundary conditions:
IFS-HRES
10km
4x per day



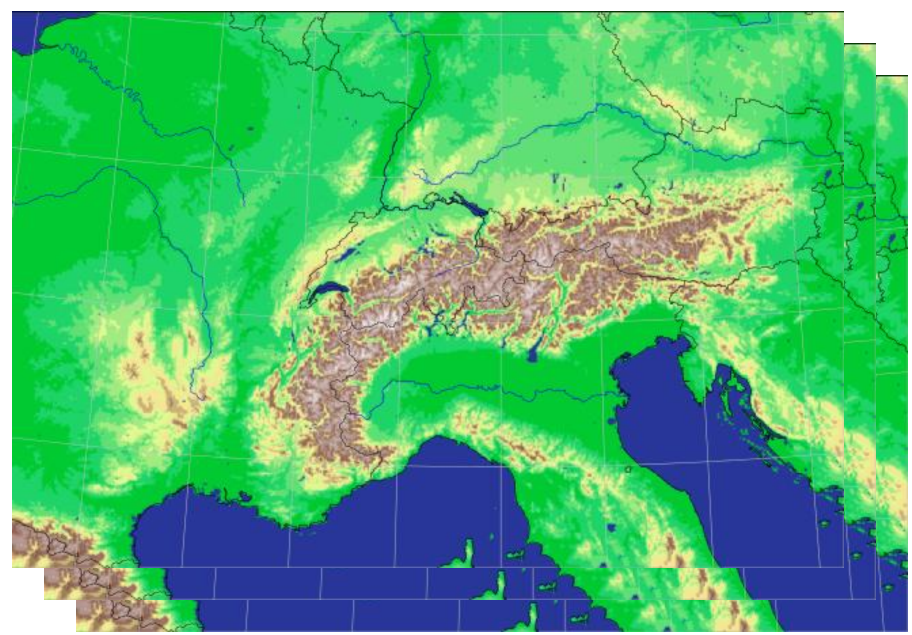
Lateral boundary conditions:
IFS-ENS
20km
2x per day

**ensemble data assimilation: LETKF**

**COSMO-1**: O(24 hour) forecasts, 8x per day
1.1km grid size (convection permitting)



**COSMO-E**: 5 day forecasts, 2x per day
2.2km grid size (convection permitting)
O(21) ensemble members



# Outline

- Sampling model errors:
  - **Stochastic Perturbation of Physical Tendencies (SPPT)**
  - Stochastic Kinetic Energy Backscatter Scheme (SKEBS)

- COSMO-E regular runs: Status and verification

- Outlook

# COSMO-E experimental setup

- Ensemble forecasts with **convection-permitting resolution** (2.2 km mesh-size, 60 vertical levels)
- **21 members, forecasts up to +120h, Alpine area**
- ICs:
  - perturbations: **KENDA/LETKF analysis**
  - no perturbations: operational COSMO-2 analysis
- LBCs:
  - perturbations: **IFS-ENS members 1-20**
  - no perturbations: IFS-ENS member 0
- COSMO version 5.0 (single precision)

# SPPT: Stochastic Perturbation of Physical Tendencies

$$\frac{\partial X}{\partial t} = D^X + K^X + (1 + rand) \sum_{i=1}^{N} P_i^X$$

dynamics

random pattern

local tendency

horizontal diffusion

physics

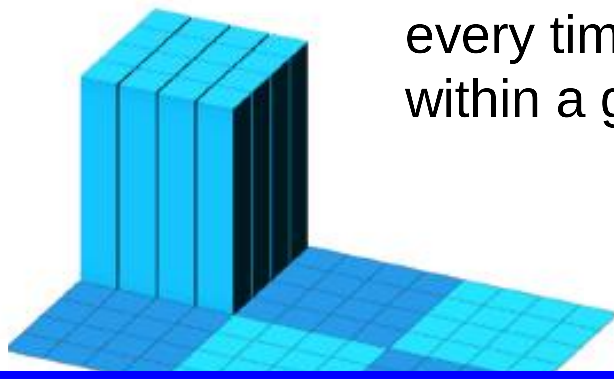
$X$ prognostic variable (u, v, T, $q_v$, $q_c$, $q_i$, $q_r$, $q_s$, $q_g$)

$P_i^X$ physical parameterisation scheme *i*

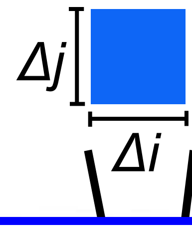
(turbulence, radiation, microphysics, shallow convection, …)

*copied and adapted from Shutts*

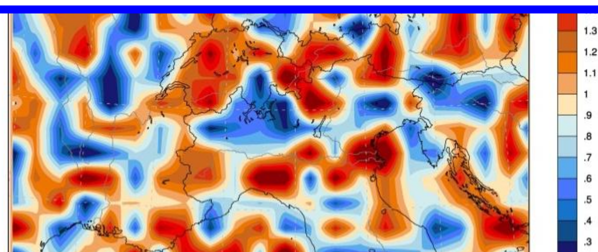
# SPPT: Generation of random pattern



every timestep *Δt* draw N(0,*σ*) random numbers within a given *range* on coarse grid *Δi, Δj*

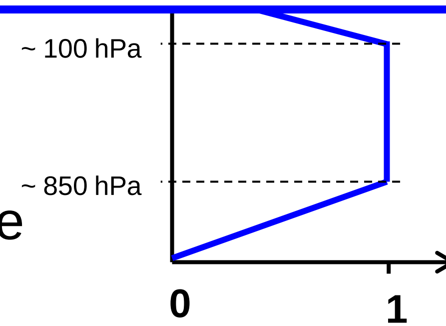



**will be available with COSMO 5.1**
**(many thanks to Lucio & Christoph!)**




random pattern (1+*rand*)

if required:
vertical tapering at model top and close to the surface




*copied and adapted from Torrisi*

# Sensitivity: SPPT perturbations only

| name | *Δt* | *Δi=Δj* | *σ* | *range* |
|---|---|---|---|---|
| **12** | **1h** | **0.5°** | **0.5** | **1.0** |
| 14 | 6h | 5.0° | 0.5 | 1.0 |
| **19** | **6h** | **5.0°** | **1.0** | **0.9** |
| 20 | 6h | 2.5° | 1.0 | 0.9 |

- **no tapering in lower troposphere**
  - main motivation to taper SPPT in PBL are **stability** issues; **COSMO-E runs did not show any stability problems**
- **no humidity limiter**
- **no IC and LBC perturbations**
  - ICs: COSMO-2 analysis, LBCs: IFS-ENS control

# Sensitivity: results

- larger correlation-lengths in space and time lead to (substantially!) larger spread
- larger random numbers produce larger spread and faster spread growth
- spread decreases with increasing height above surface
    - turning tapering off has significant (positive) impact on spread in PBL

# Validation: deterministic runs

- SPPT **must not** degrade (deterministic) quality of ensemble members
- **deterministic runs (1 month each in summer and winter 2012)** for different SPPT parameter settings

➢ no significant quality degradation observed with SPPT, even for very strong stochastic perturbations of physical tendencies

➢ choose (aggressive) SPPT parameter settings “19” for subsequent tests

| **name** | ***Δt*** | ***Δi=Δj*** | ***σ*** | ***range*** |
|---|---|---|---|---|
| **12** | **1h** | **0.5°** | **0.5** | **1.0** |
| 14 | 6h | 5.0° | 0.5 | 1.0 |
| **19** | **6h** | **5.0°** | **1.0** | **0.9** |
| 20 | 6h | 2.5° | 1.0 | 0.9 |

# Verification: COSMO-E for Aug 2012

- 1 month period (26.07.-25.08.2012), one run at 00 UTC every second day (results in 16 runs per setup)
- experiments:

| name | *ICs* | *LBCs* | *Δt* | *Δi=Δj* | *σ* | *range* |
|---|---|---|---|---|---|---|
| **19e111** | **LETKF** | **ENS** | **6h** | **5.0°** | **1.0** | **0.9** |
| **19e110** | **LETKF** | **ENS** | **---** | **---** | **---** | **---** |
| **19e011** | **COSMO-2** | **ENS** | **6h** | **5.0°** | **1.0** | **0.9** |
| | *COSMO-LEPS (ICs & LBCs: IFS-ENS)* | | | | | |

for SPPT: no tapering near the surface, no humidity limiter

→ spread / error relation against COSMO-2 analysis

→ BS and BSS against surface observations

# Verification: scores (I)

- 
- spread: Root Mean Ensemble Variance (RMEV) with respect to ensemble mean

$$RMEV^2 = \frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{i=1}^{N}(f_{ij} - \bar{f}_j)^2 \quad ; \quad \bar{f}_j = \frac{1}{N}\sum_{i=1}^{N} f_{ij}$$

- error: Root Mean Squared Error (RMSE) of ensemble mean

$$RMSE^2 = \frac{1}{M}\sum_{j=1}^{M}(\bar{f}_j - o_j)^2$$

# Verification: scores (II)

- 

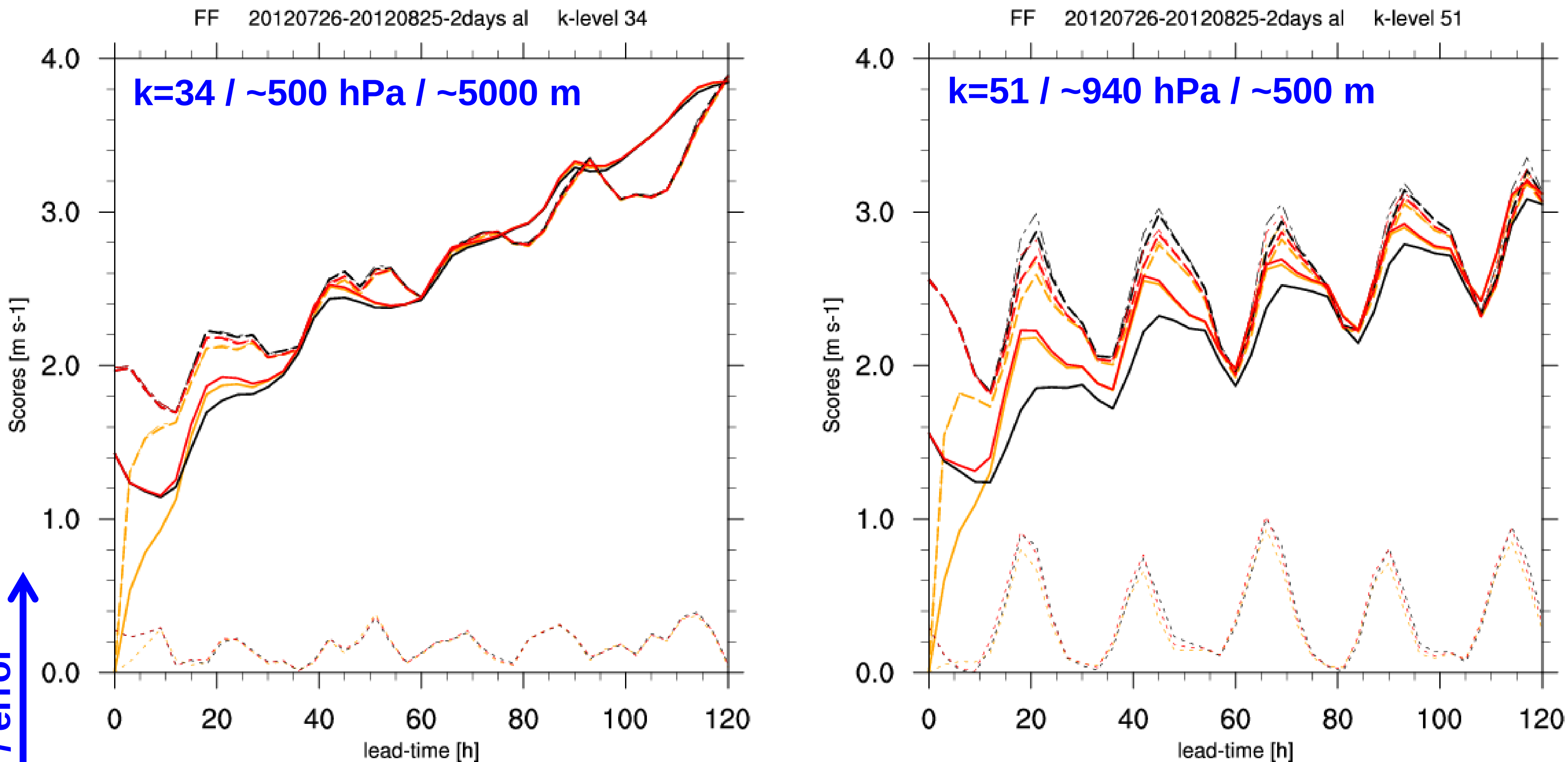
- bias: BIAS of ensemble mean

$$BIAS = \frac{1}{M}\sum_{j=1}^{M}(\bar{f}_j - o_j)$$

- (de-biased) error: STandard Deviation of Error (STDE) of ensemble mean

$$STDE^2 = \frac{1}{M}\sum_{j=1}^{M}(\bar{f}_j - o_j - BIAS)^2 = RMSE^2 - BIAS^2$$

# spread / error: wind speed




spread / error

lead-time [h]

ICs plus LBCs plus SPPT

ICs plus LBCs

LBCs plus SPPT

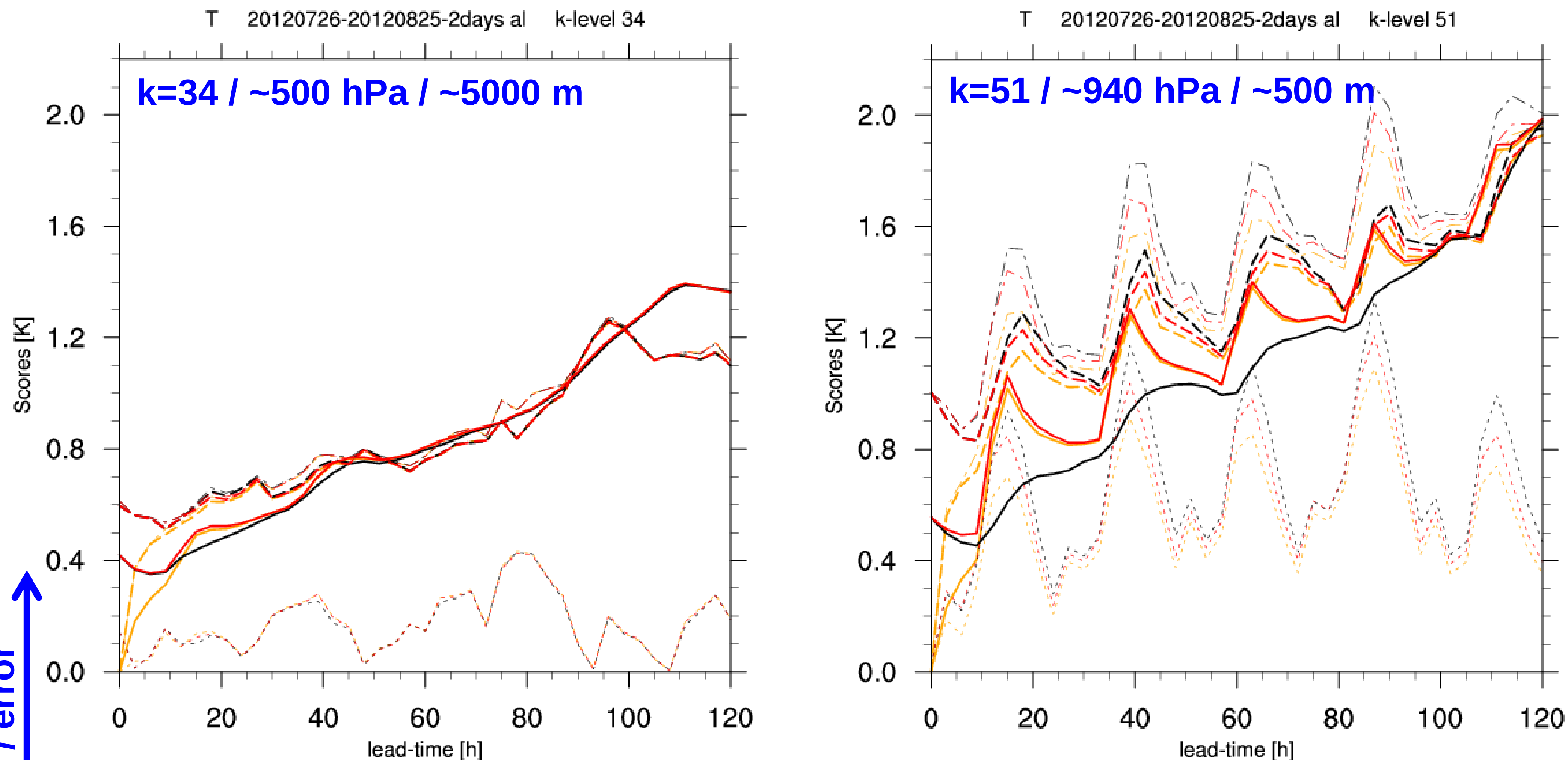
**RMEV**

**STDE**

RMSE

abs(BIAS)

# spread / error: temperature

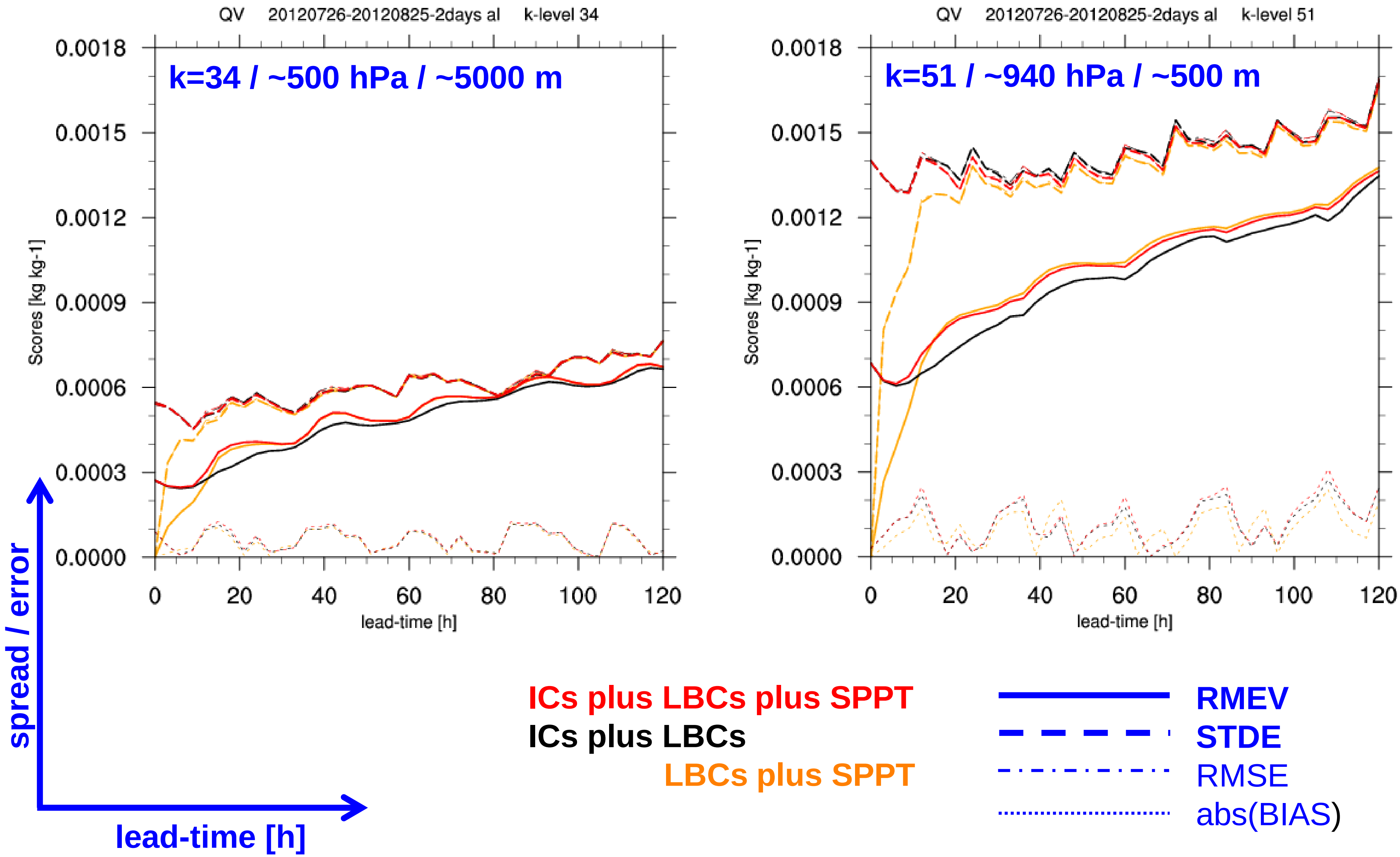



ICs plus LBCs plus SPPT
ICs plus LBCs
LBCs plus SPPT

**RMEV**
**STDE**
RMSE
abs(BIAS)

spread / error
lead-time [h]

# spread / error: humidity




ICs plus LBCs plus SPPT

ICs plus LBCs

LBCs plus SPPT

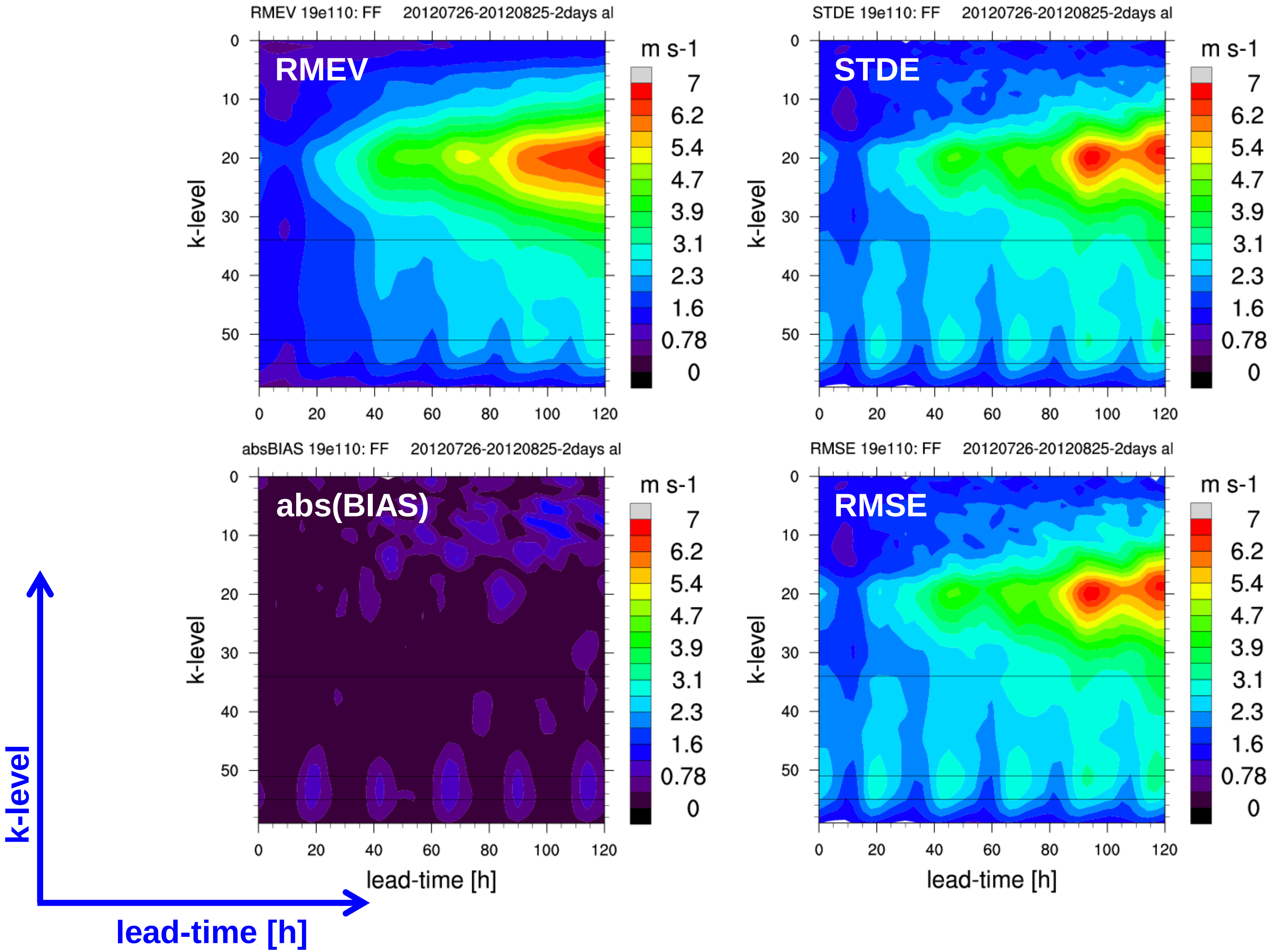
RMEV

STDE

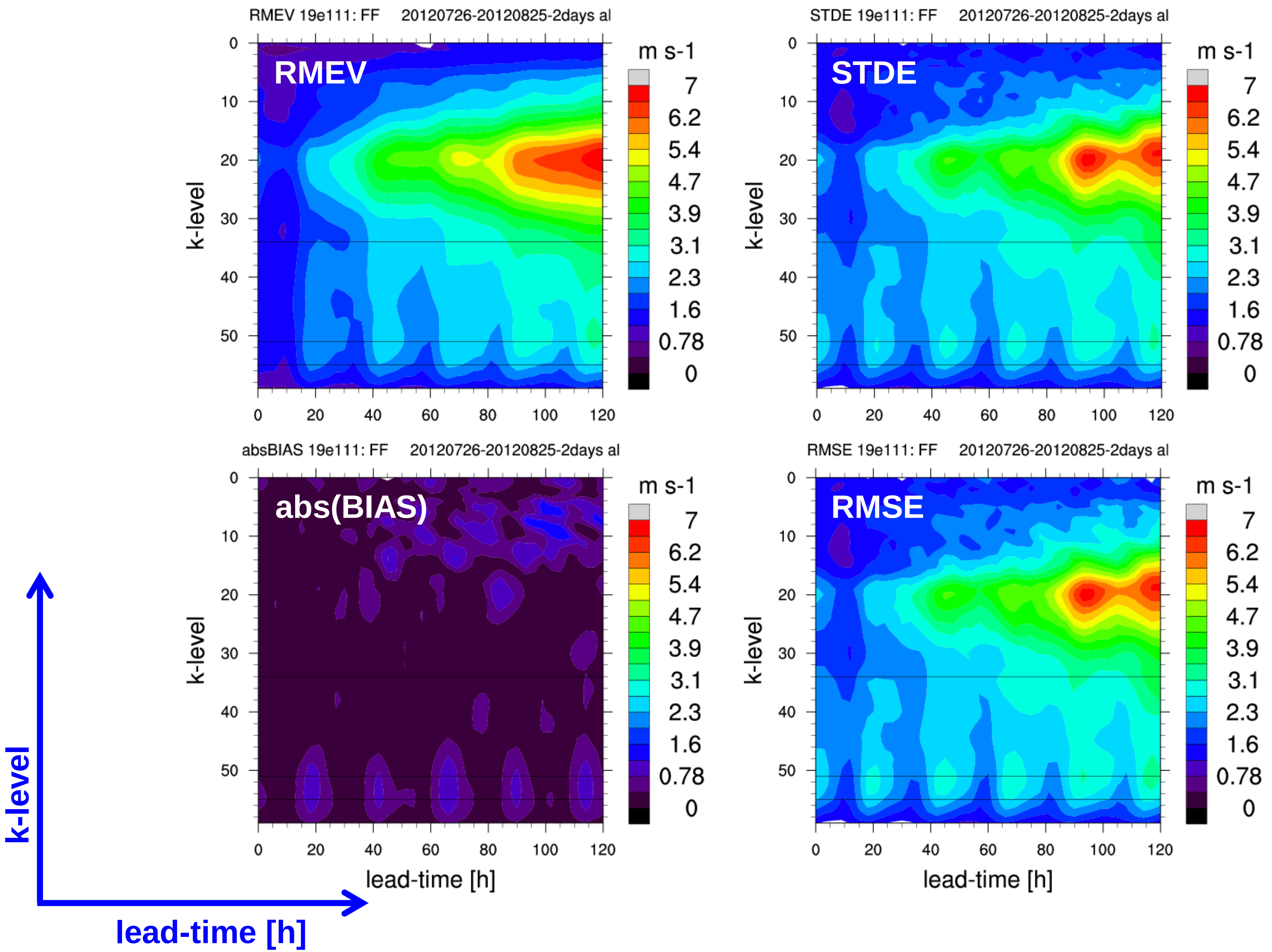
RMSE

abs(BIAS)

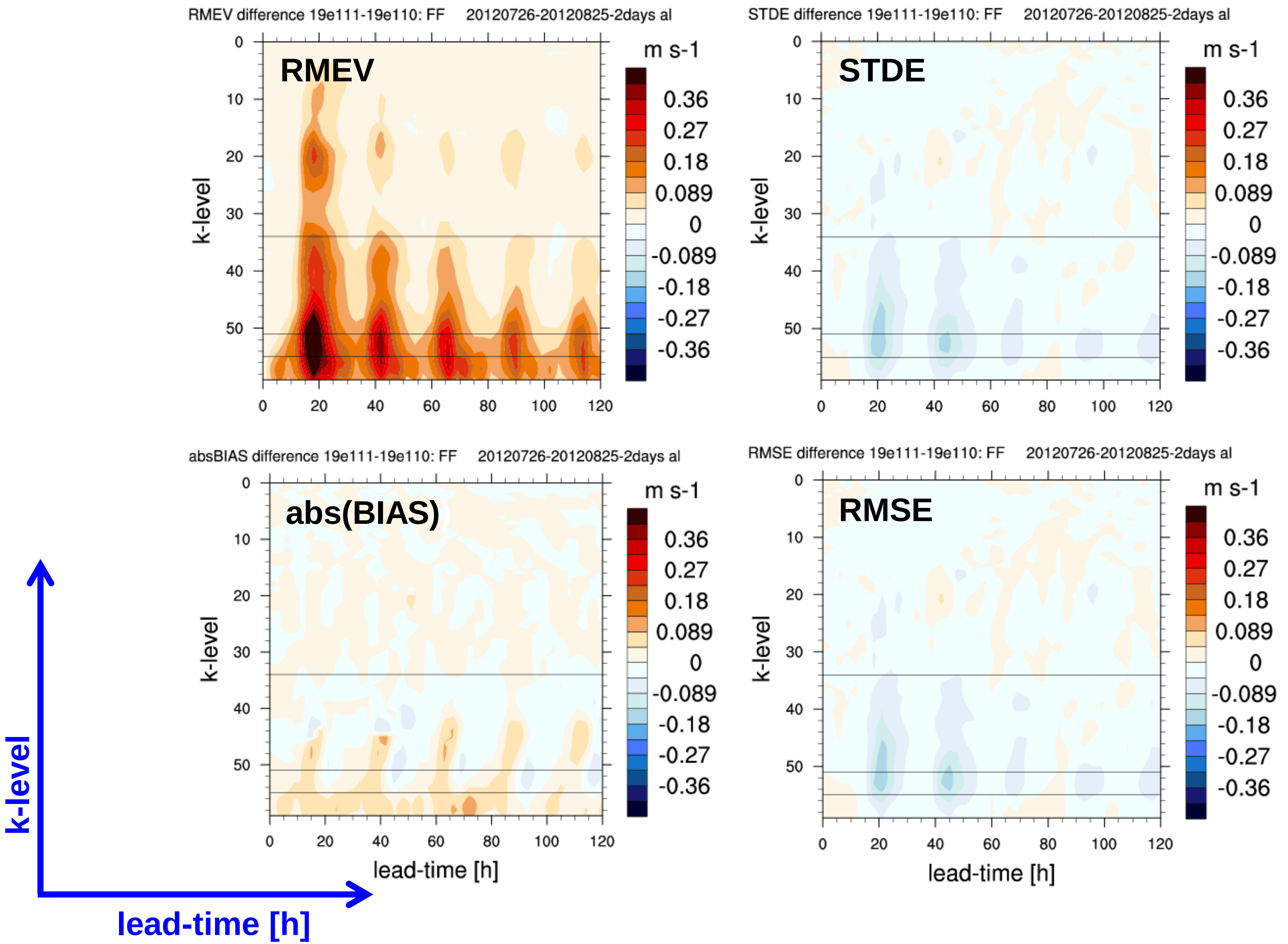
# spread / error: wind speed, 19e110



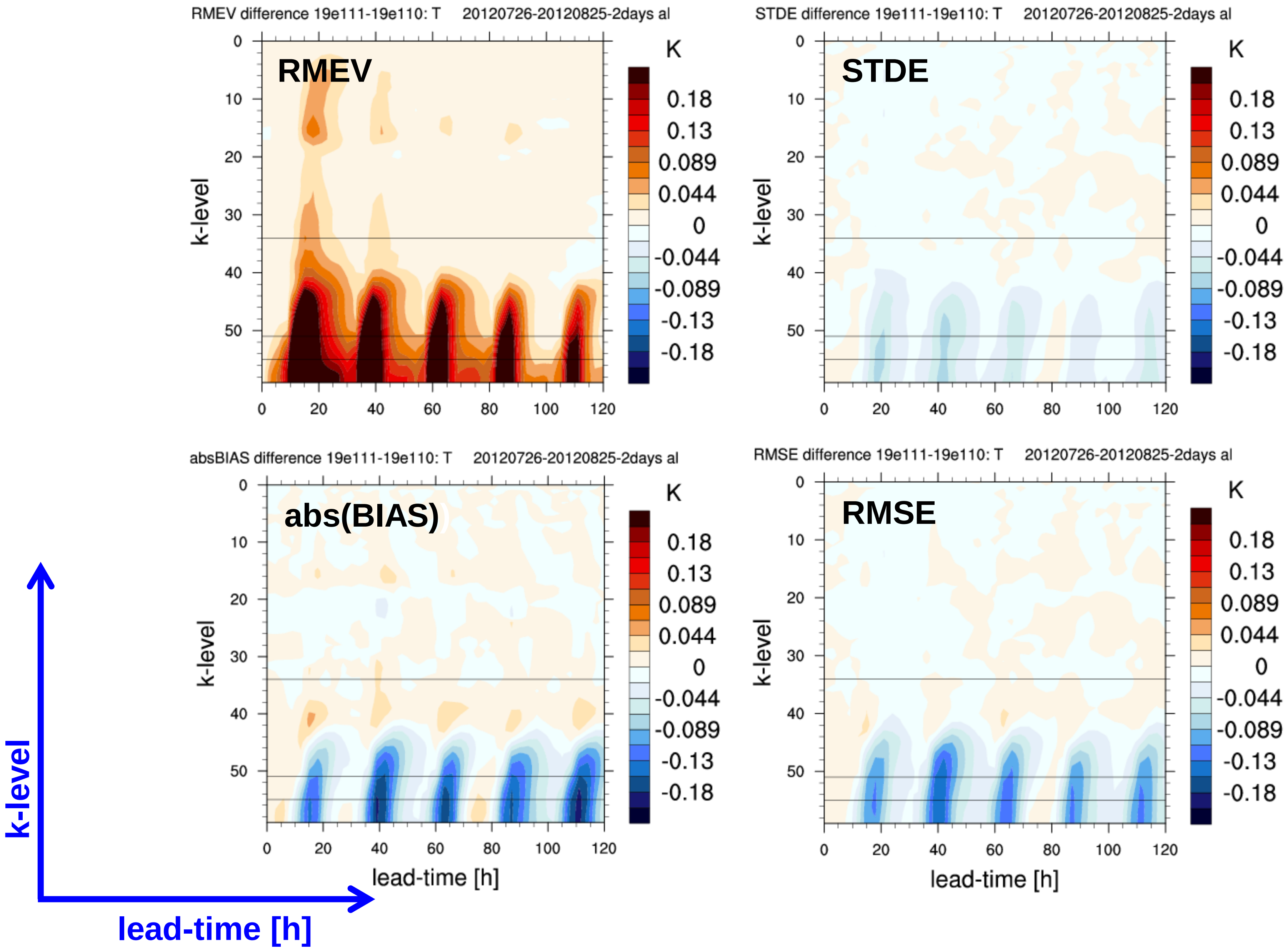
# spread / error: wind speed, 19e111



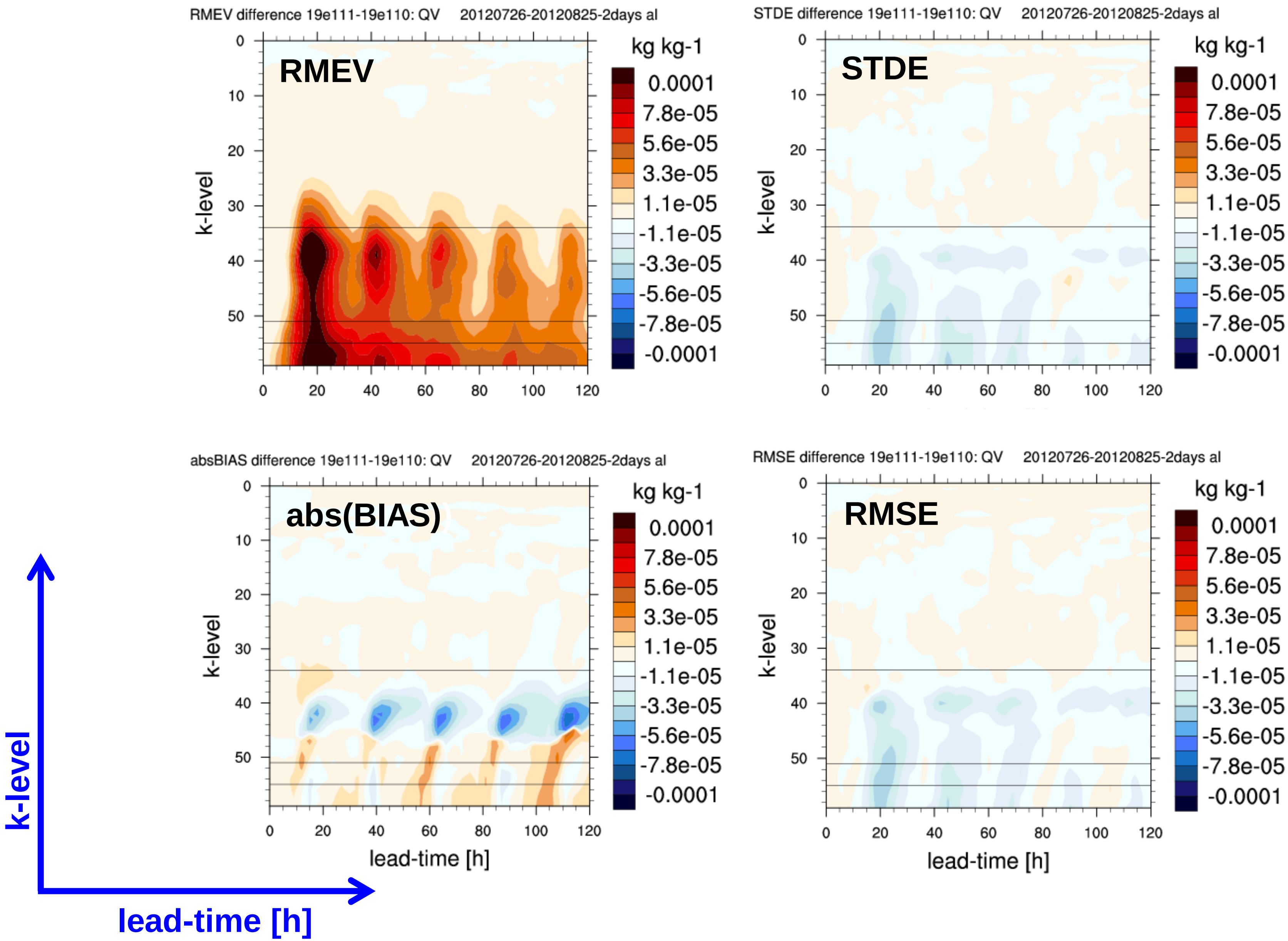
# spread / error: FF, 19e111-19e110



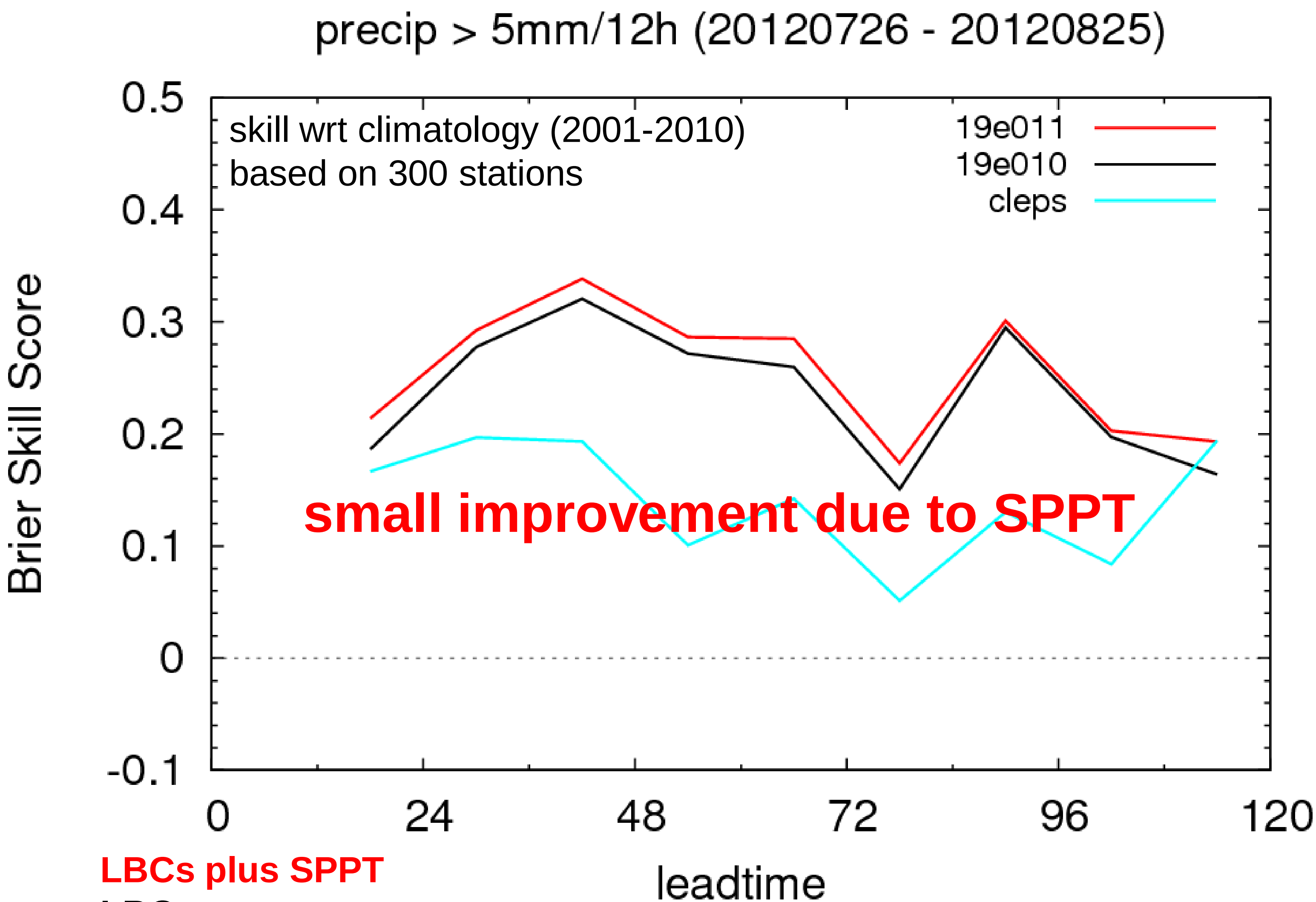
# spread / error: T, 19e111-19e110



# spread / error: QV, 19e111-19e110



# Verification against observations:
# BSS: precip, > 5mm/12h, Aug




LBCs plus SPPT
LBCs
COSMO-LEPS

# Verification: COSMO-E for Dec 2012

- 1 month period **(03.12.-31.12.2012),** one run at 00 UTC every second day **(results in 15 runs per setup)**
- experiments:

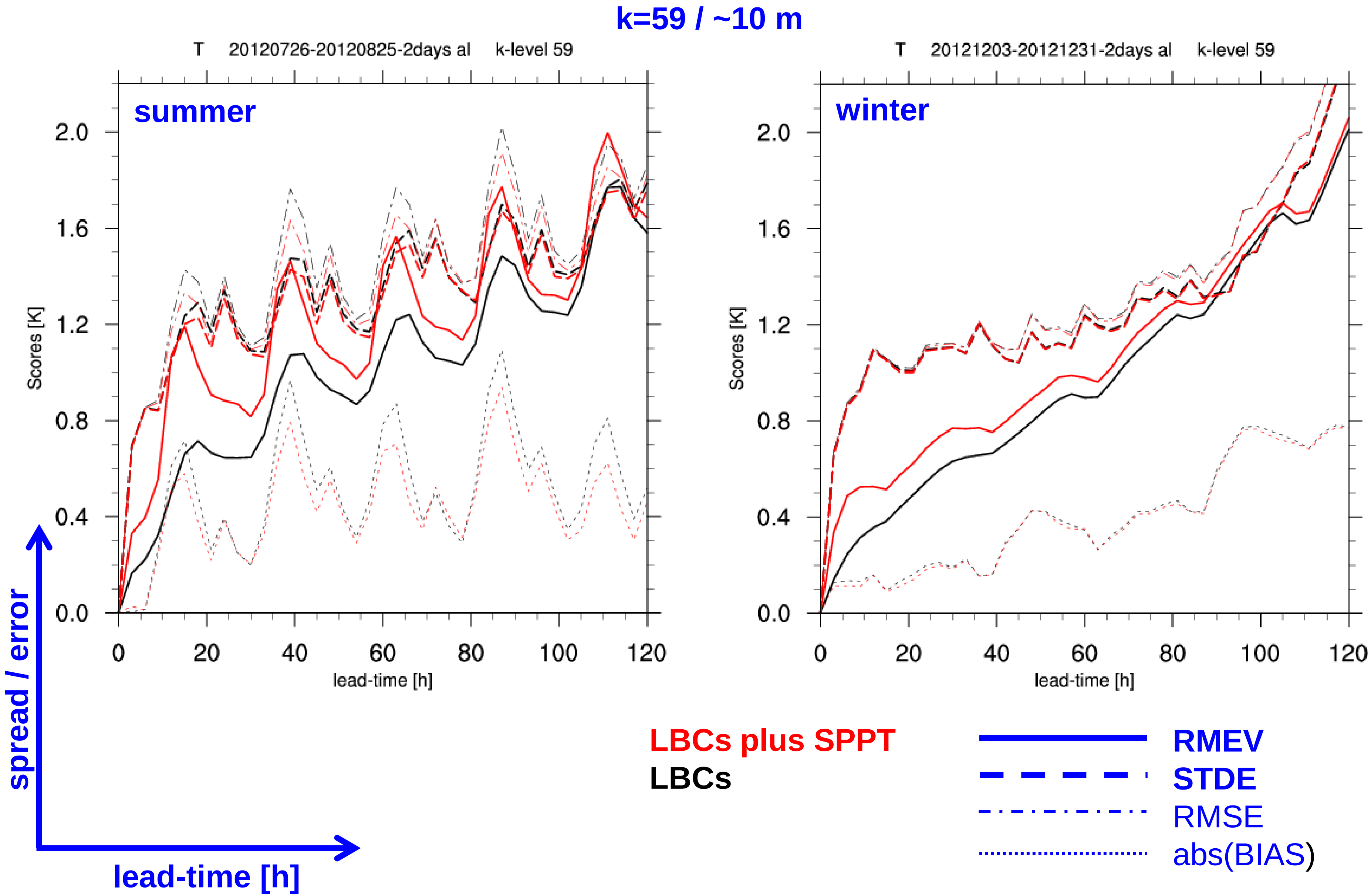
| name | *ICs* | *LBCs* | *Δt* | *Δi=Δj* | *σ* | *range* |
|---|---|---|---|---|---|---|
| **19e011** | **COSMO-2** | **ENS** | **6h** | **5.0°** | **1.0** | **0.9** |
| **19e010** | **COSMO-2** | **ENS** | **---** | **---** | **---** | **---** |
| | *COSMO-LEPS (ICs & LBCs: IFS-ENS)* | | | | | |

for SPPT: no tapering near the surface, no humidity limiter

→ spread / error relation against COSMO-2 analysis

→ BS and BSS against surface observations

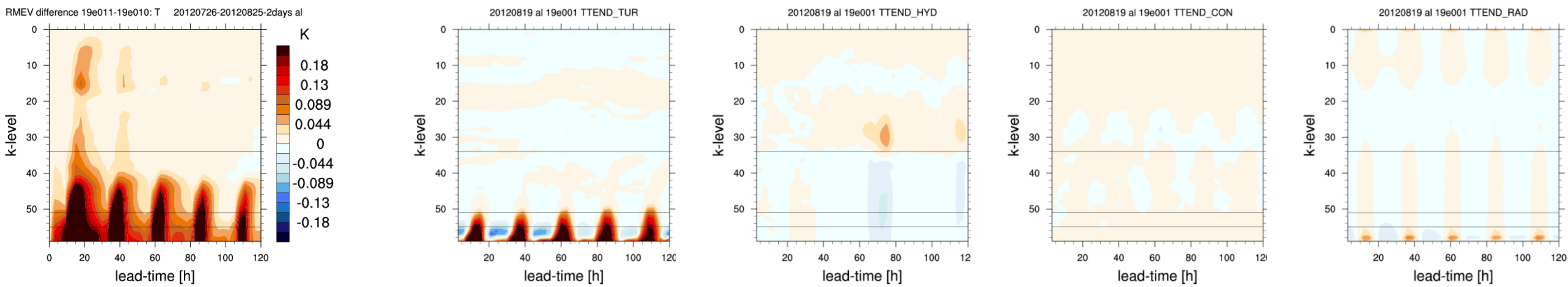
# spread / error: temperature



# Tendencies: vertical, temperature

RMEV Diff, Aug 2012

tendencies for 19.08.2012

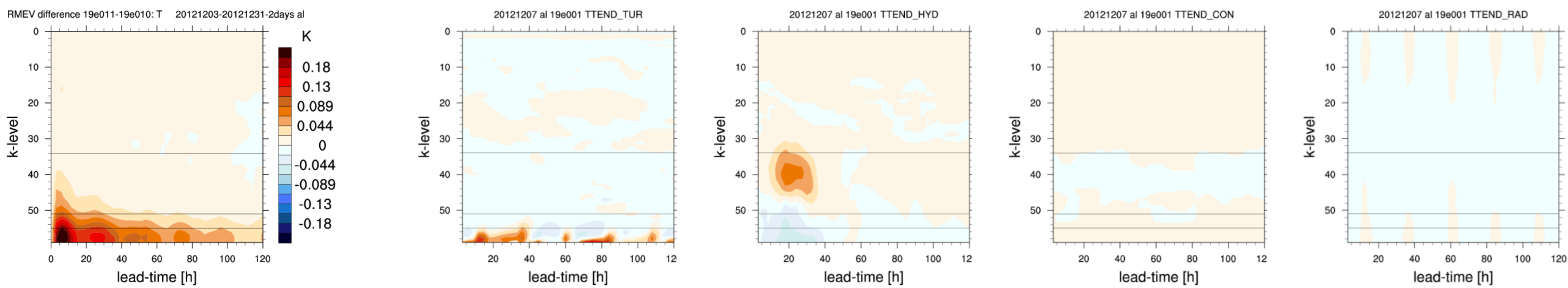



turbulence

micro-physics

shallow convection

radiation



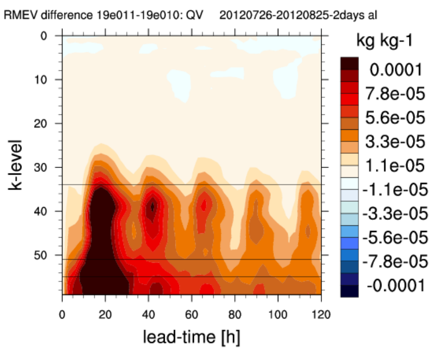

RMEV Diff, Dec 2012

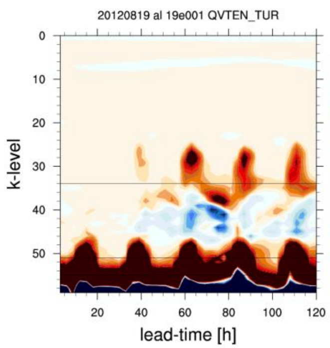
tendencies for 07.12.2012

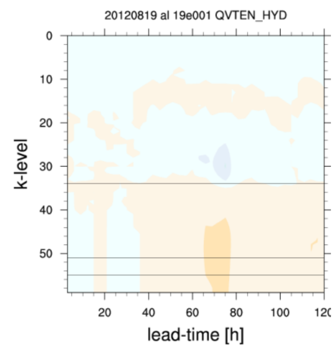
# Tendencies: vertical, humidity

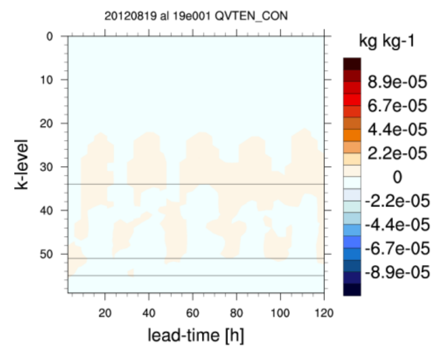
**RMEV Diff, Aug 2012**

**tendencies for 19.08.2012**



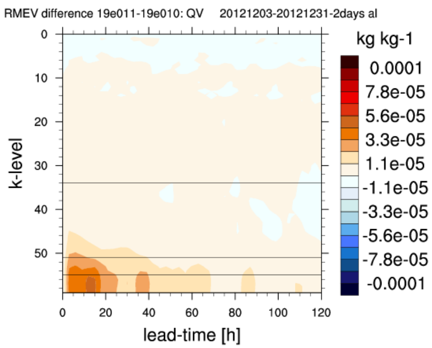



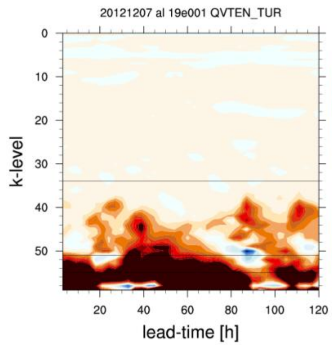



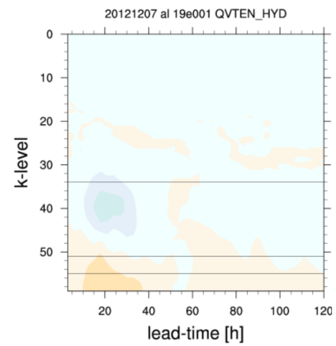

**turbulence**

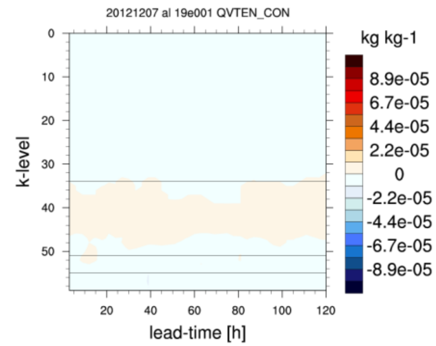
**micro-physics**

**shallow convection**



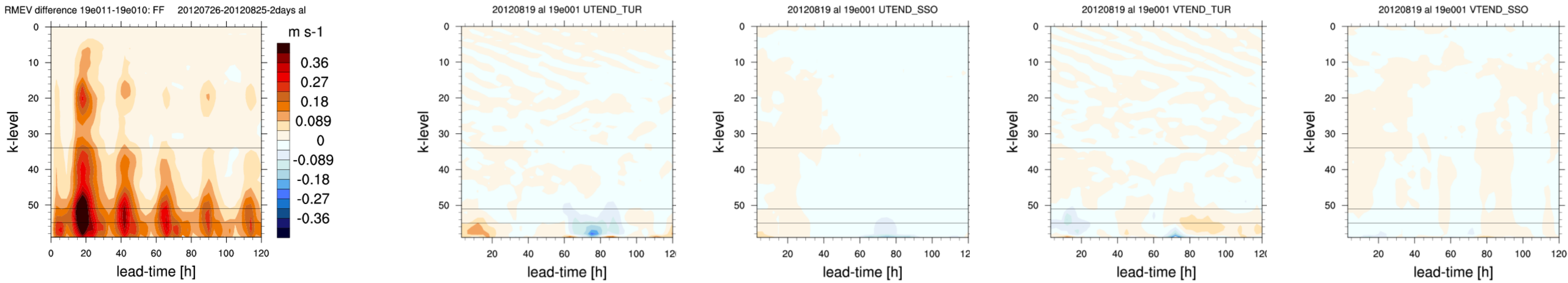




**RMEV Diff, Dec 2012**

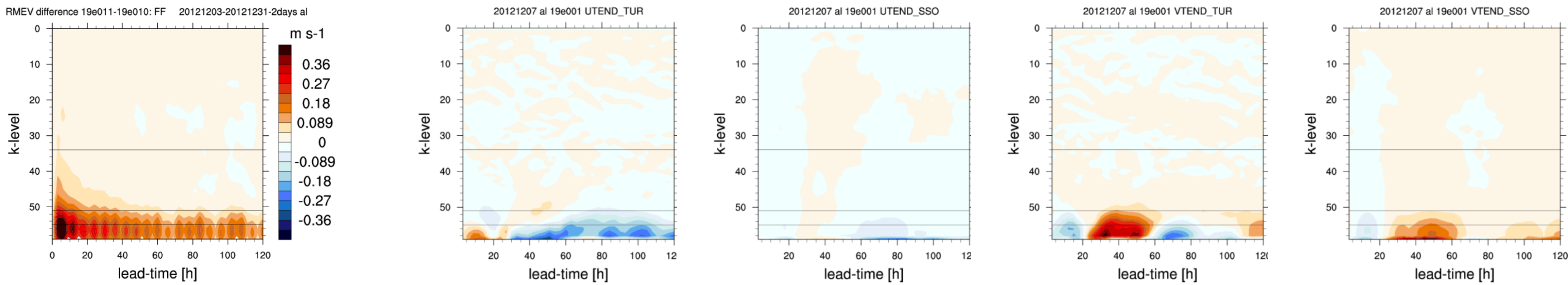
**tendencies for 07.12.2012**

# Tendencies: vertical, wind speed

**RMEV Diff, Aug 2012** **tendencies for 19.08.2012**




**turbulence** **SSO** **turbulence** **SSO**




**RMEV Diff, Dec 2012** **tendencies for 07.12.2012**

# Verification: general conclusions

- **middle and upper troposphere:** spread dominated by LBC perturbations, **generally satisfactory** spread-error relation
- **lower troposphere: considerable improvement** of RMEV, STDE, and BIAS **due to SPPT**, larger in summer, but still lacking spread, in particular for humidity
- **SYNOP verification**: **small improvements** in probabilistic scores for precipitation and 2m temperature **due to SPPT**
- **Turbulence scheme** shows largest physics tendencies and hence contributes strongest to SPPT impact

# Stochastic Kinetic Energy Backscatter Scheme (SKEBS)

- Assumption: *fraction of dissipated kinetic and potential energy is available as forcing for the resolved flow leading to streamfunction tendency and temperature tendency forcings*
- SKEBS implemented in IFS-ENS and WRF (author: Judith Berner, NCAR)
- Prototype implementation in COSMO during 2 days visit of Judith Berner (COSMO Activity Proposal) based on WRF implementation that uses flow-independent dissipation rates

➢ **perturbations for U, V and T with a prescribed energy spectrum and auto-correlation in time**

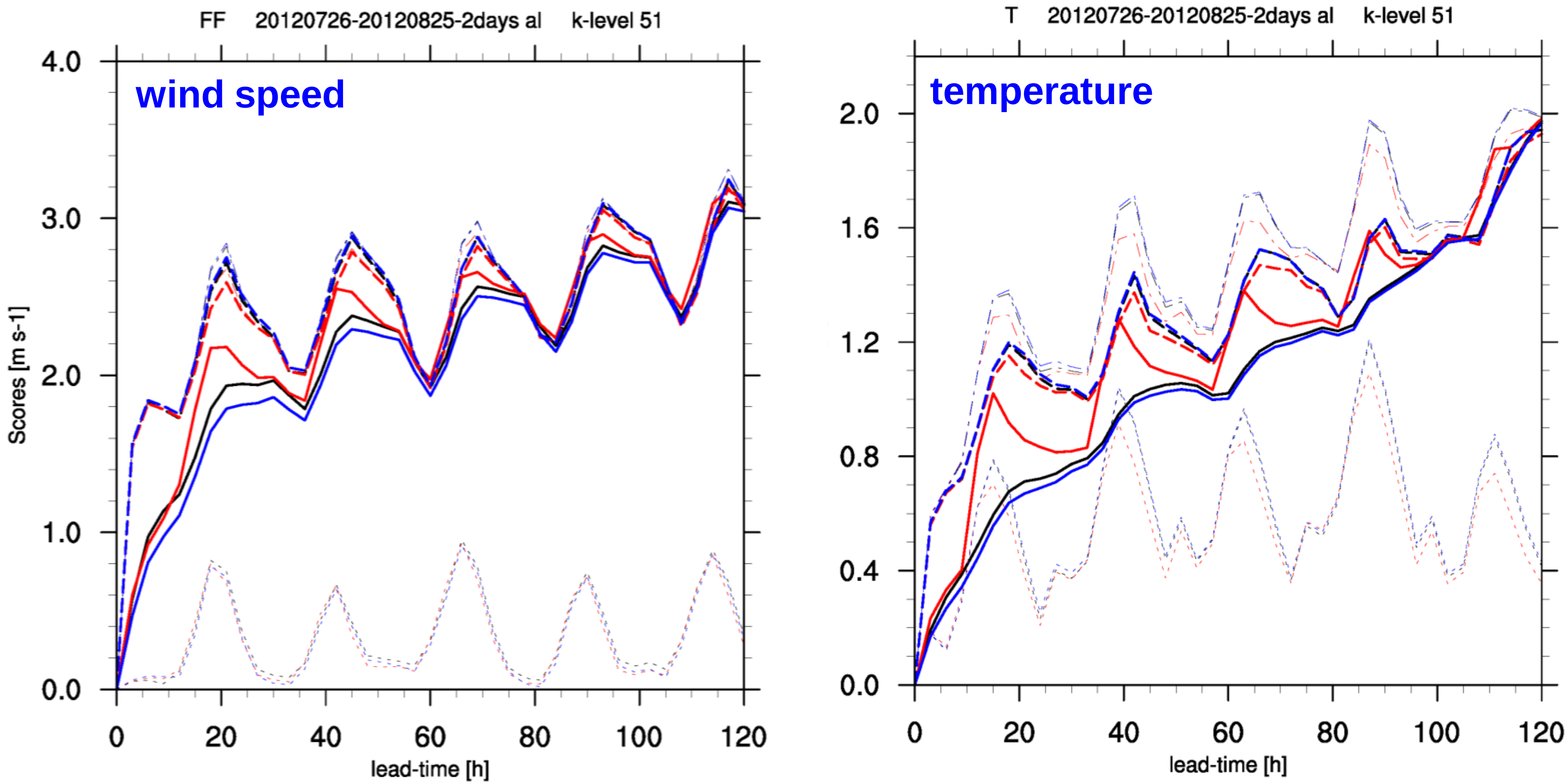
➢ perturbations are defined in the spectral space and thus require backward FFTs to add them to the tendencies in the grid-point space

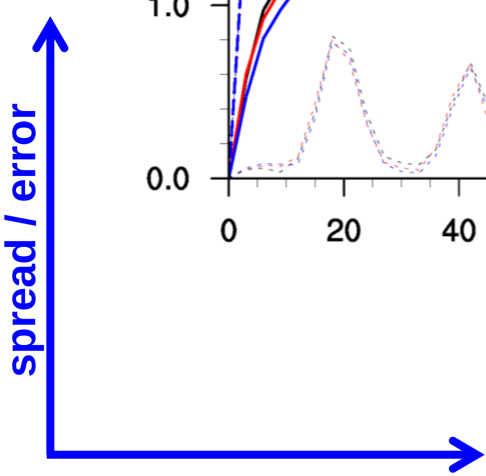
# SKEBS experiments

- SKEBS experiments for ‘SPPT summer period’: 1 month period (26.07.-25.08.2012), 00 UTC runs every second day
- LBC perturbations (IFS-ENS), no IC perturbations
- SKEBS settings used as suggested for WRF
- identical perturbations at all model levels

# spread / error: FF and T

## k=51 / ~940 hPa / ~500 m




LBCs plus SPPT
LBCs plus SKEBS
LBCs only

**RMEV**
**STDE**
RMSE
abs(BIAS)

# SKEBS results

- in experiments with LBC perturbations, largest impact of SKEBS on spread found for wind speed in lower troposphere
- only small increase in spread as compared to SPPT
- no reduction of error

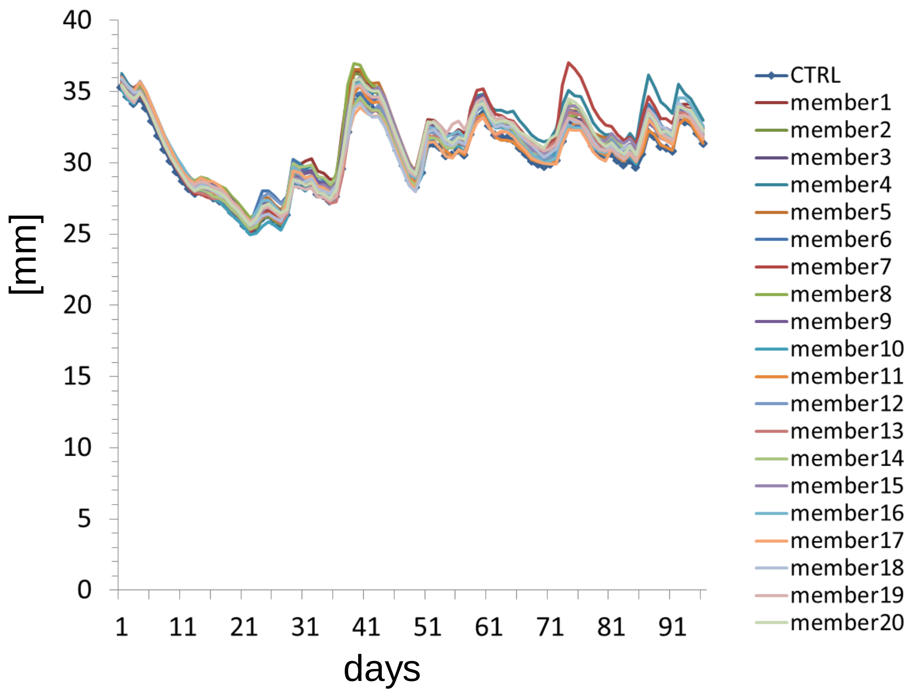
- ➢ tuning required for COSMO-E
- ➢ parallelization of FFTs to reduced the CPU costs
- ➢ pattern generator developed at RHM (Michael and Dmitriy) seems to be valuable alternative for this kind of perturbations

# COSMO-E regular runs

- Ensemble forecasts with convection-permitting resolution (2.2 km mesh-size, 60 vertical levels)
- 21 members, forecasts up to +120h, Alpine area (domain 25% larger as for COSMO-2)
- regular runs once per day started end of May, stable as of mid of June
- perturbations:
  - IC: downscaled/re-cycled soil (later KENDA)
  - LBC: IFS-ENS (members 0-20)
  - model errors: Stochastic Perturbation of Physical Tendencies (SPPT)
- COMO version 5.0 (single precision)

# Current IC perturbations

- KENDA not ready yet, a temporary solution required
- similar approach as COSMO-LEPS, merge of:
  - downscaled atmosphere of IFS-ENS members
  - soil fields from COSMO-E members of previous forecast (i.e. forecast step +24h)
    → soil perturbations (moisture, temperature)




domain-averaged soil moisture evolution @9-27 cm, June-August 2014

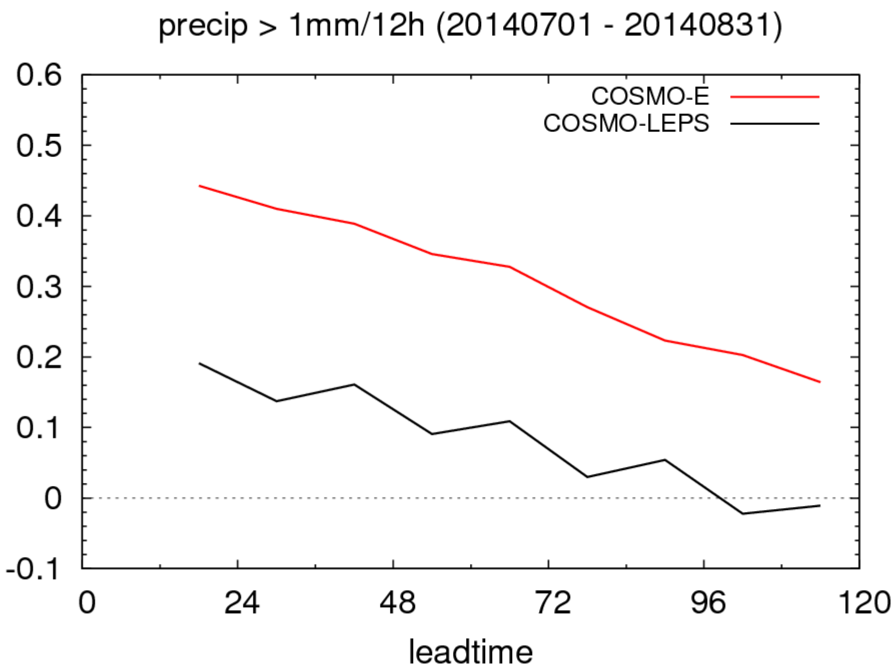
# Verification regular runs

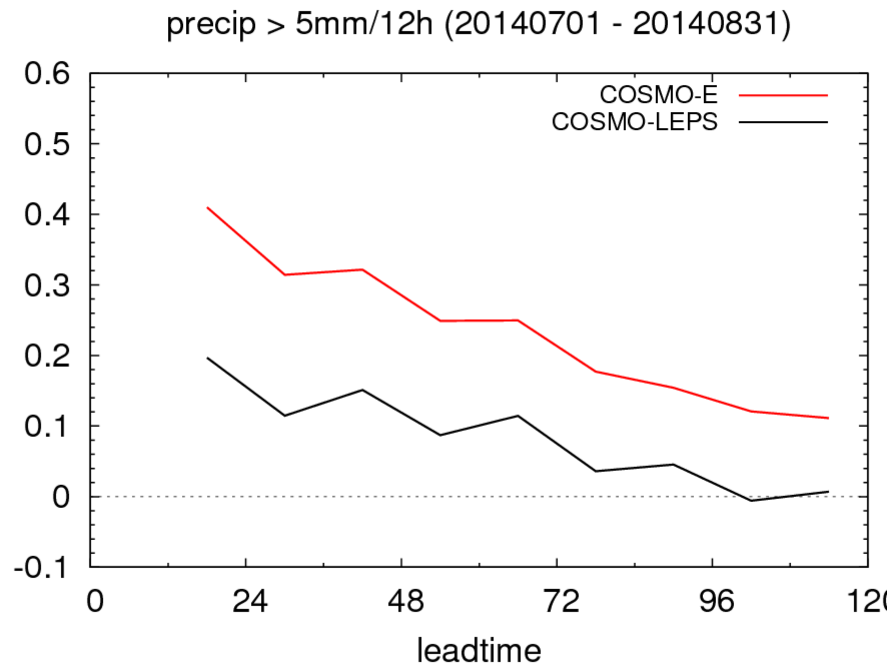
- comparison of COSMO-E vs. COSMO-LEPS
- comparison of COSMO-E median vs. COSMO-1

# Brier Skill Score (BSS)

skill wrt climatology (2001-2010) based on 300 stations

COSMO-E
**COSMO-LEPS**



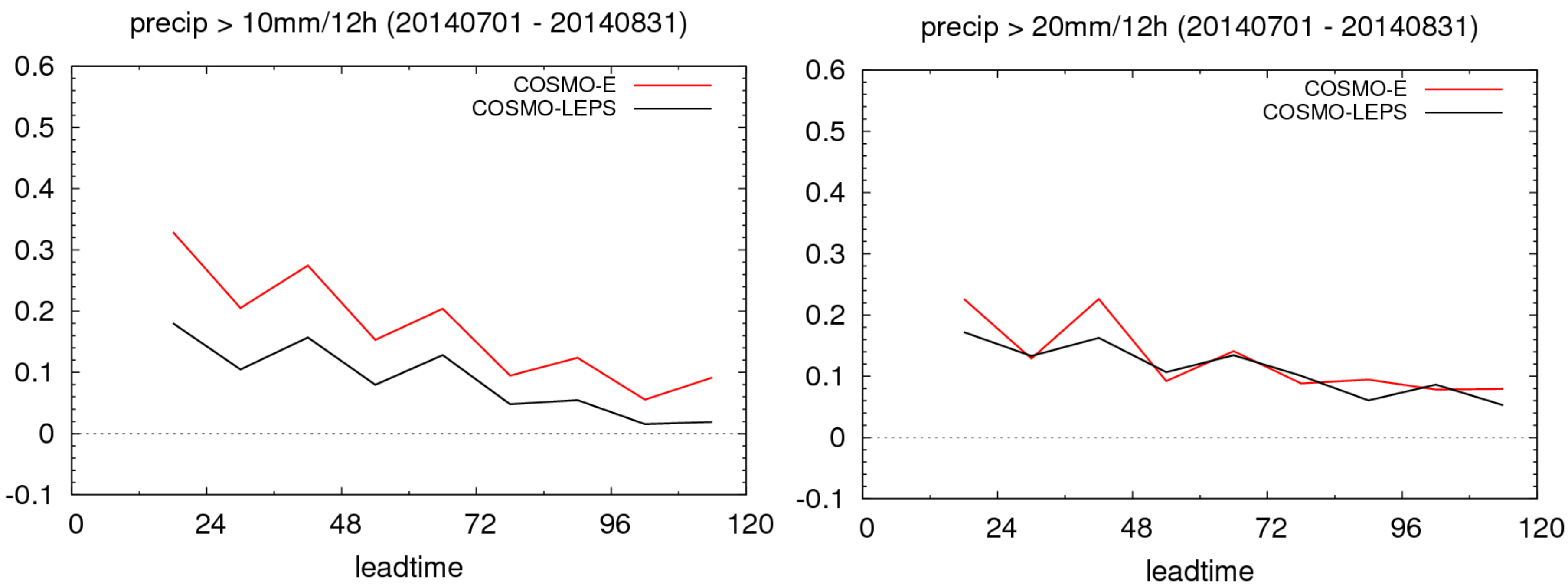




- COSMO-E shows significant skill until end of forecast range
- clearly better than COSMO-LEPS, even though 9 grid-points averages used for both

# Brier Skill Score (BSS)

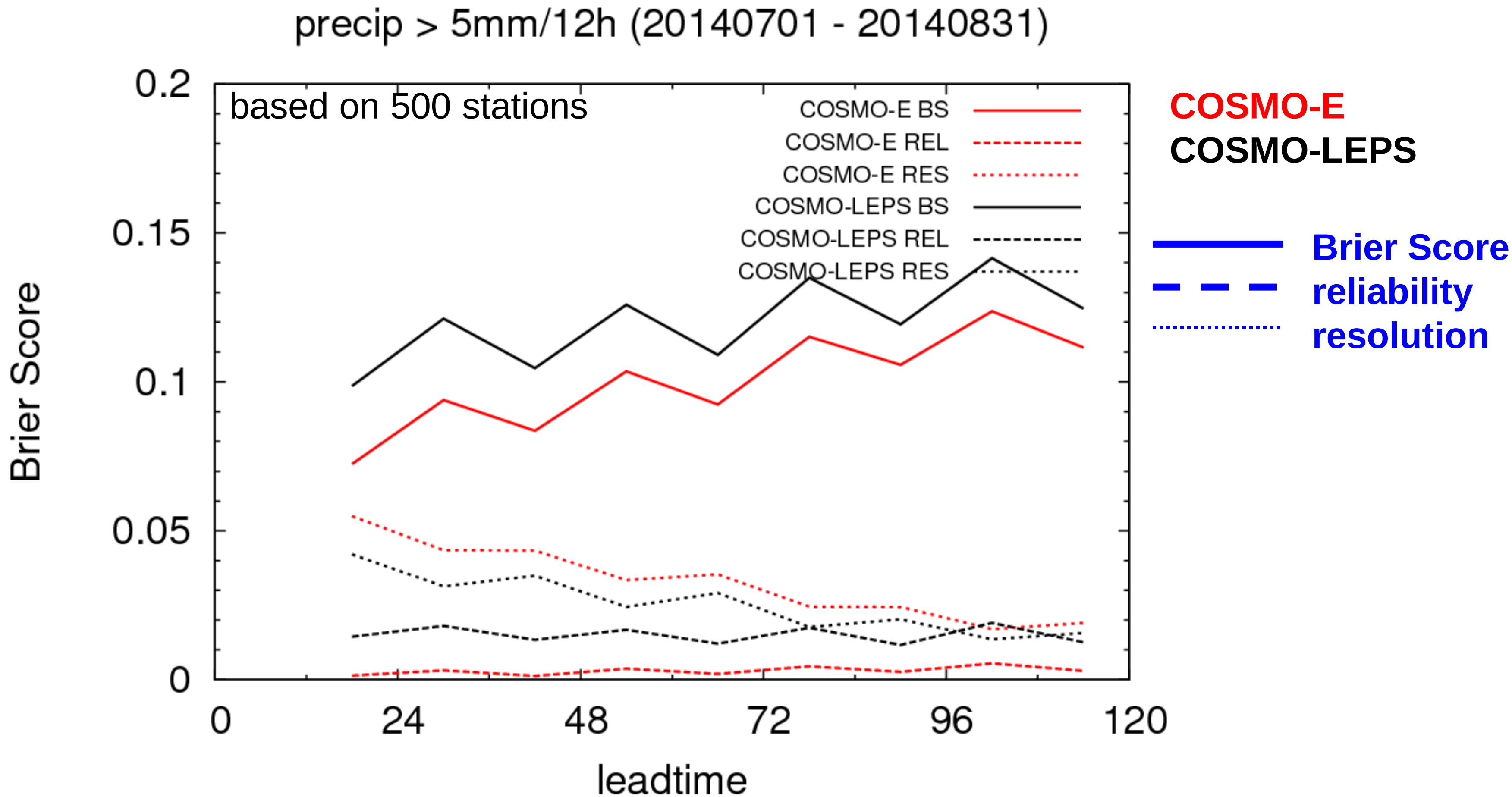
skill wrt climatology (2001-2010) based on 300 stations

COSMO-E
**COSMO-LEPS**




- COSMO-E shows significant skill until end of forecast range
- For large precipitation COSMO-E only slightly better than COSMO-LEPS

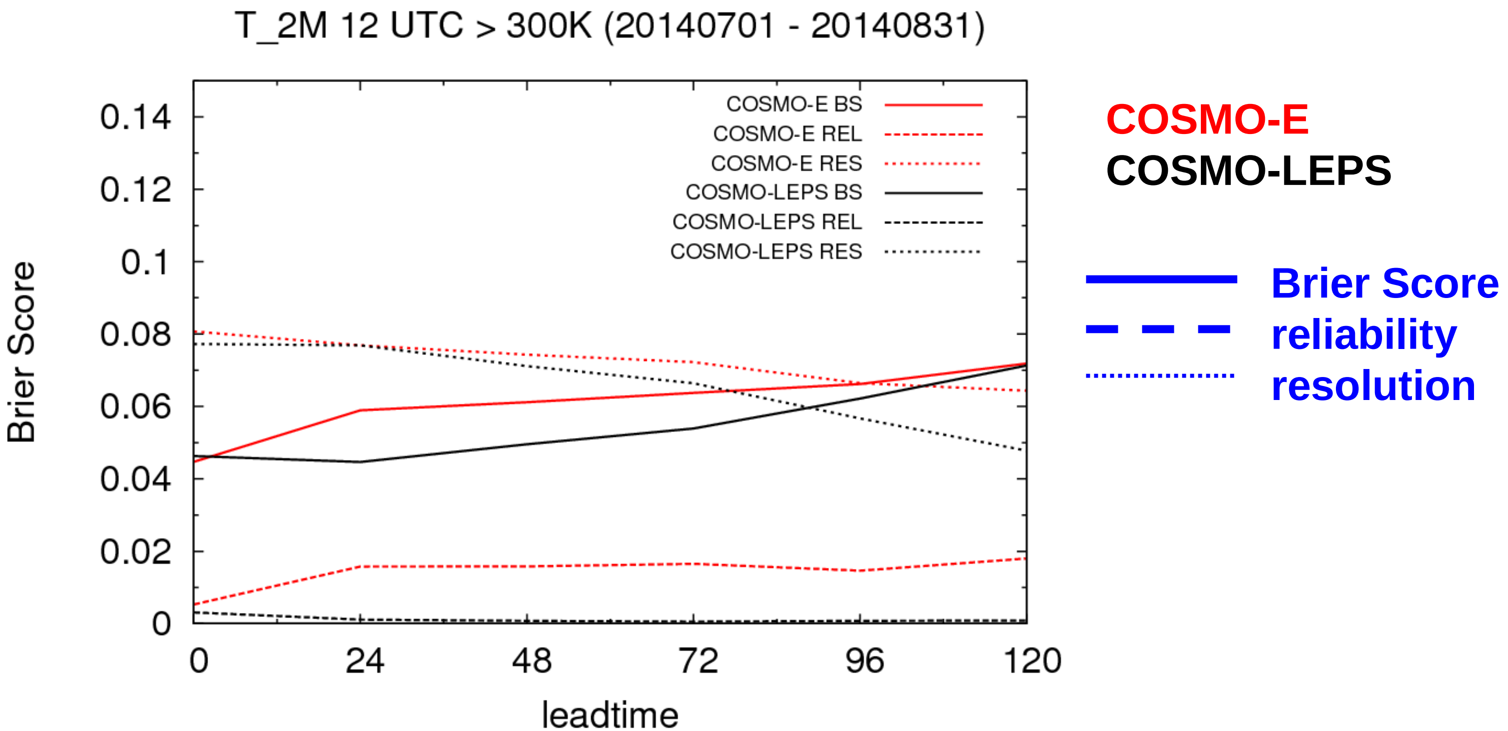
# Brier Score: precip > 5mm/12h




- reliability and resolution better in COSMO-E

# Wind gusts and 2m temperature

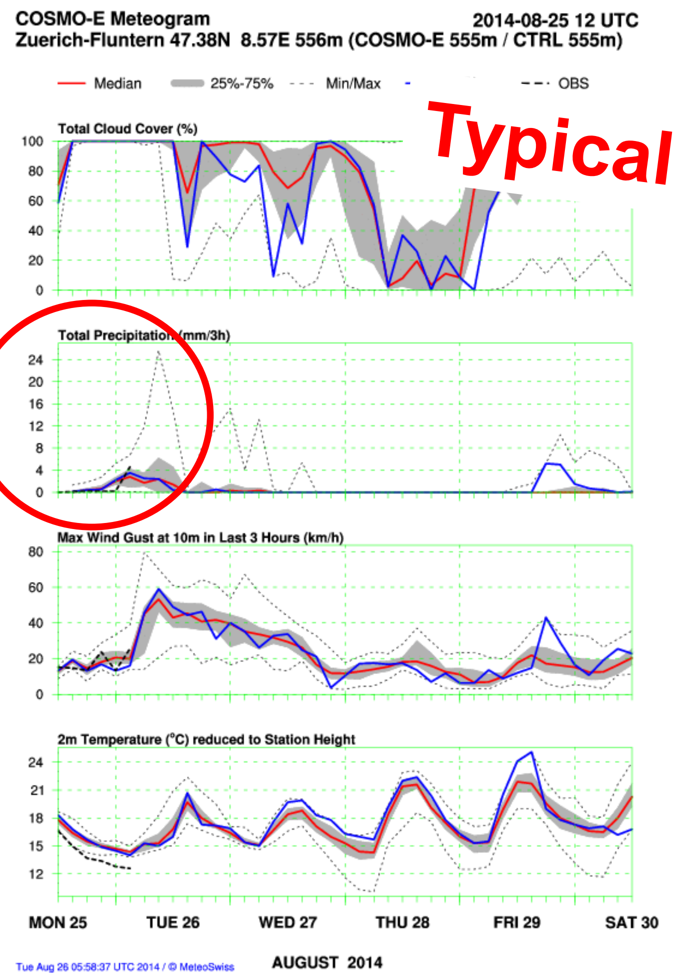
- no benefit found for wind gusts
- for T_2M COSMO-LEPS even better than COSMO-E (→ warm bias!), in particular for high thresholds




- bad reliability due to COSMO-E warm bias

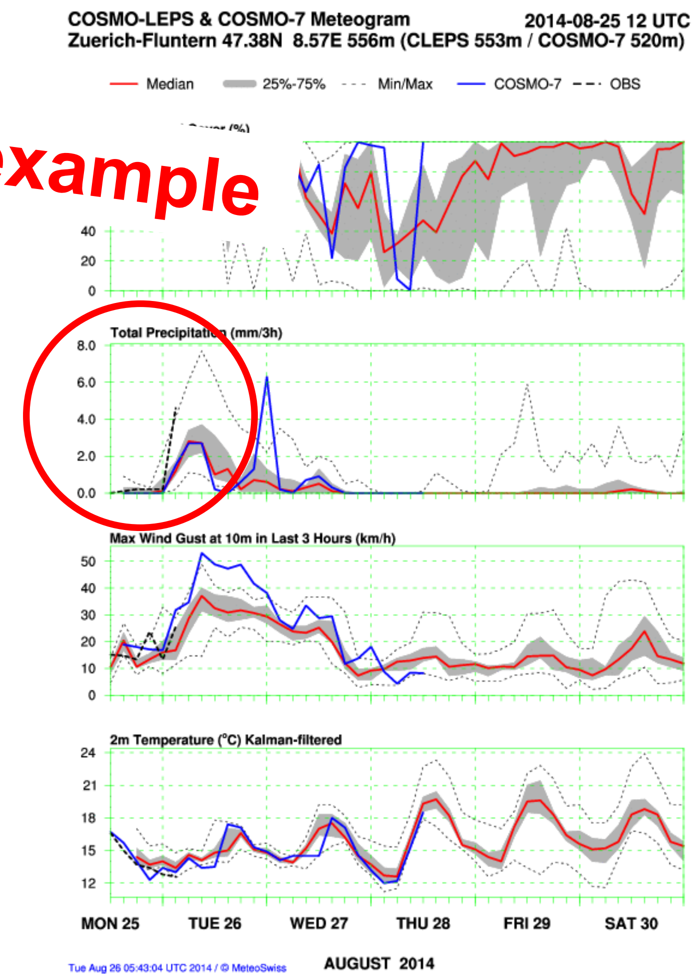
# Scale issue only or does SPPT lead to higher precipitation intensities?

## COSMO-E



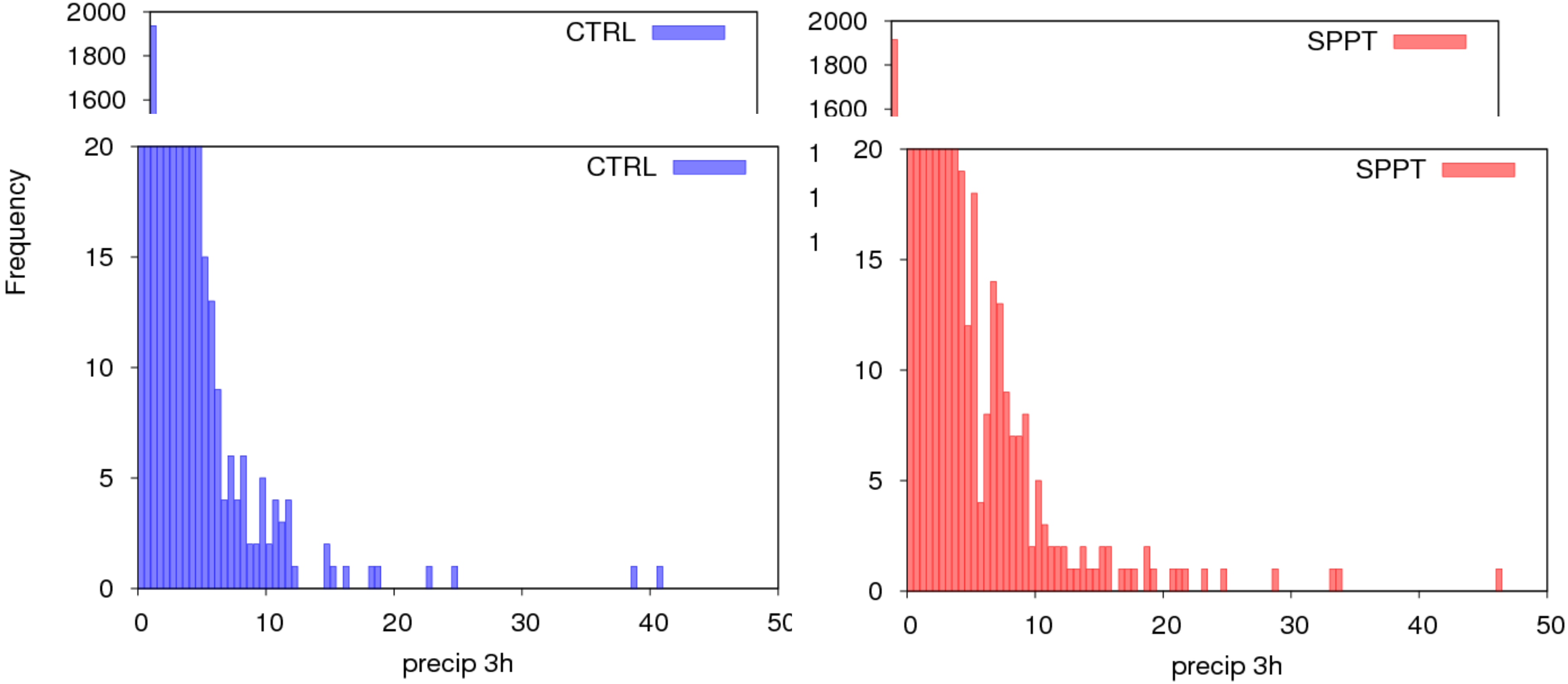

**Typical example**

## COSMO-LEPS



# Frequency distribution for Zurich

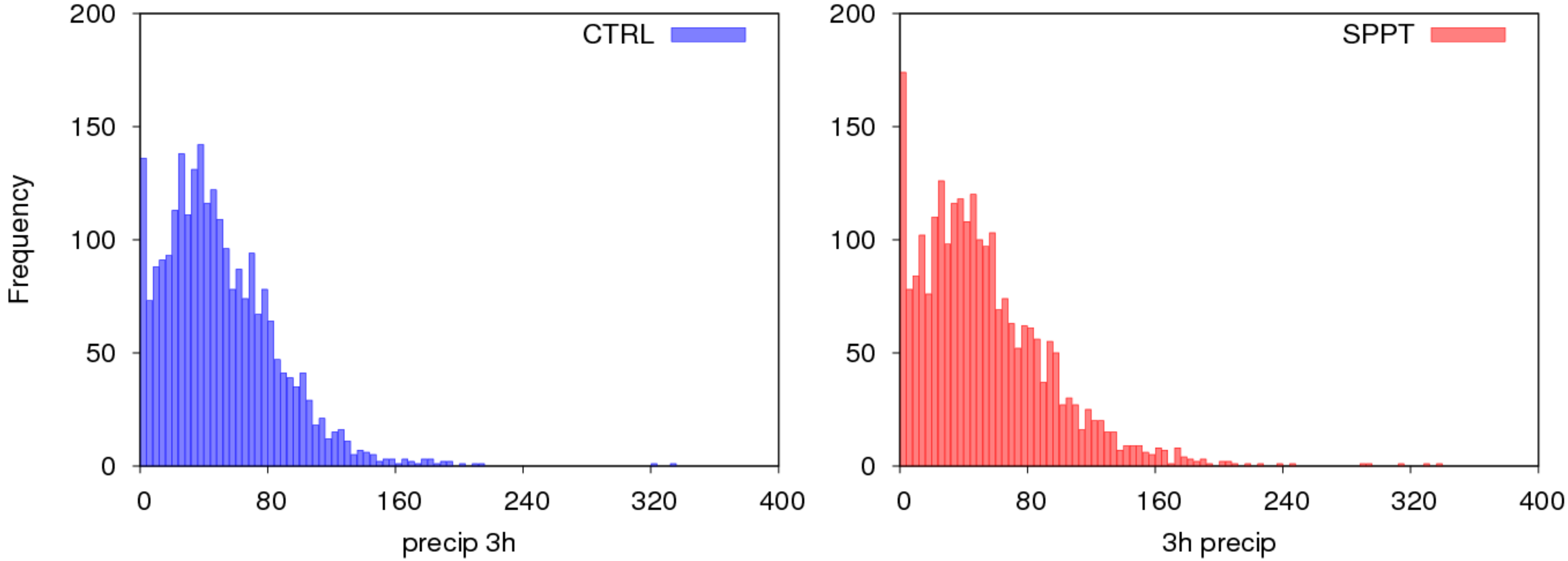
3h precipitation sums for grid-point Zurich for all lead-times:




- no-rain events unchanged
- slight shift towards higher intensities

# Frequency distribution domain-max

domain-maximum 3h precipitation sums for all lead-times (without 20 grid-points frame)



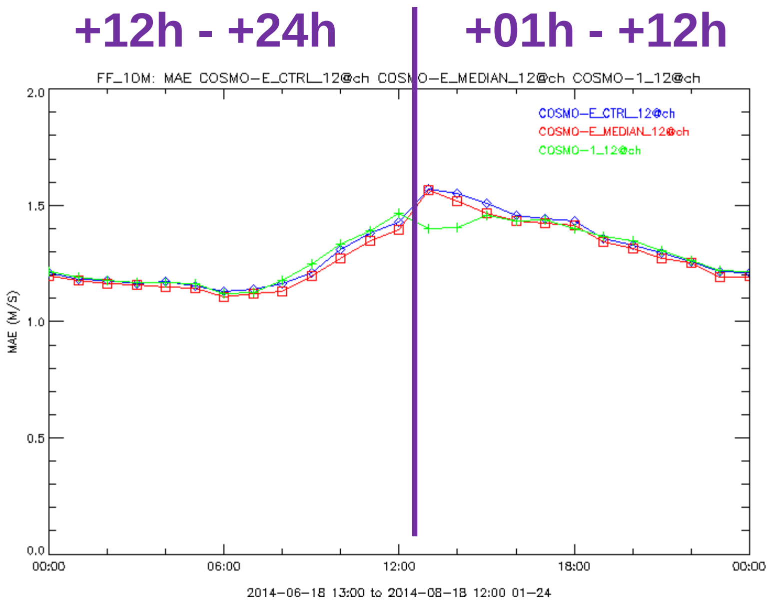

- more no-rain events in SPPT member (!)
- slight shift towards higher intensities
- CTRL and SPPT member show unrealistic extremes and of same amplitude (330 mm/3h!!)

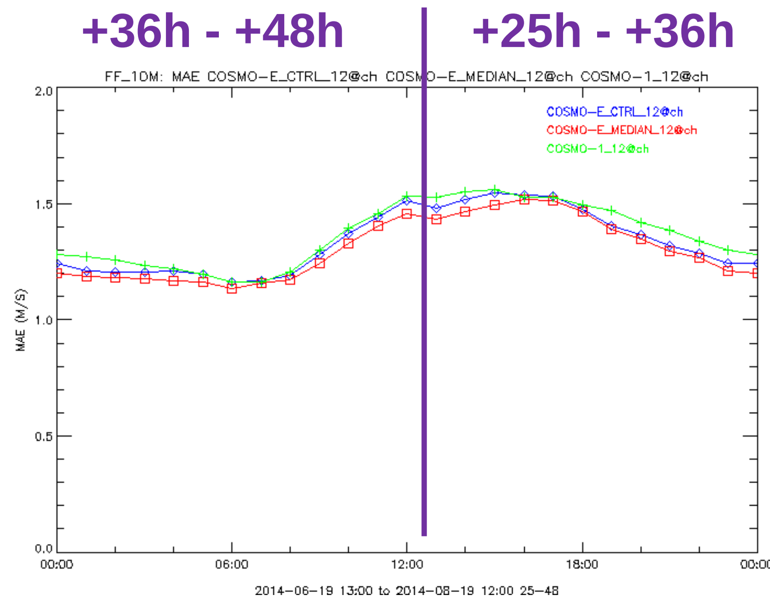
# COSMO-E median vs. COSMO-1

- Until what lead-time does COSMO-1 outperform COSMO-E median?
- Standard verification for 12 UTC +48h forecasts for two months (mid June – mid August) over CH

- Caveats:
  - COSMO-E uses 6 hours newer IFS LBCs than COSMO-1 → small advantage for the entire forecast range
  - COSMO-E has no assimilation cycle (KENDA) yet → obvious disadvantage in the short-range

# Wind speed at 10m: daytime scores




COSMO-E better as from +7h, but differences are small

# Overview cross-over lead-time

- preliminary results
- depends strongly on parameters: for some already in the first 12h (DD, FF, CLCT, TOT_PREC), for others only after +48h (PS, TD_2M)
- only mean absolute error considered so far
- update frequency of both models has to be considered as well
- too early to draw conclusions

# Outlook

- Improve ICs and IC perturbations (KENDA/LETKF)
- Test **“additional” perturbations at/in the surface** consistent with LETKF (e.g., soil moisture based on COTEKINO results)
- Look into **Stochastic Pattern Generator** of RHM
- Test **stochastic boundary layer parameterization scheme** (LMU, K. Kober)?
- Start of **PhD on improved spread / error relation** for COSMO-E in Oct 2014 (Prof Heini Wernli, IACETH)