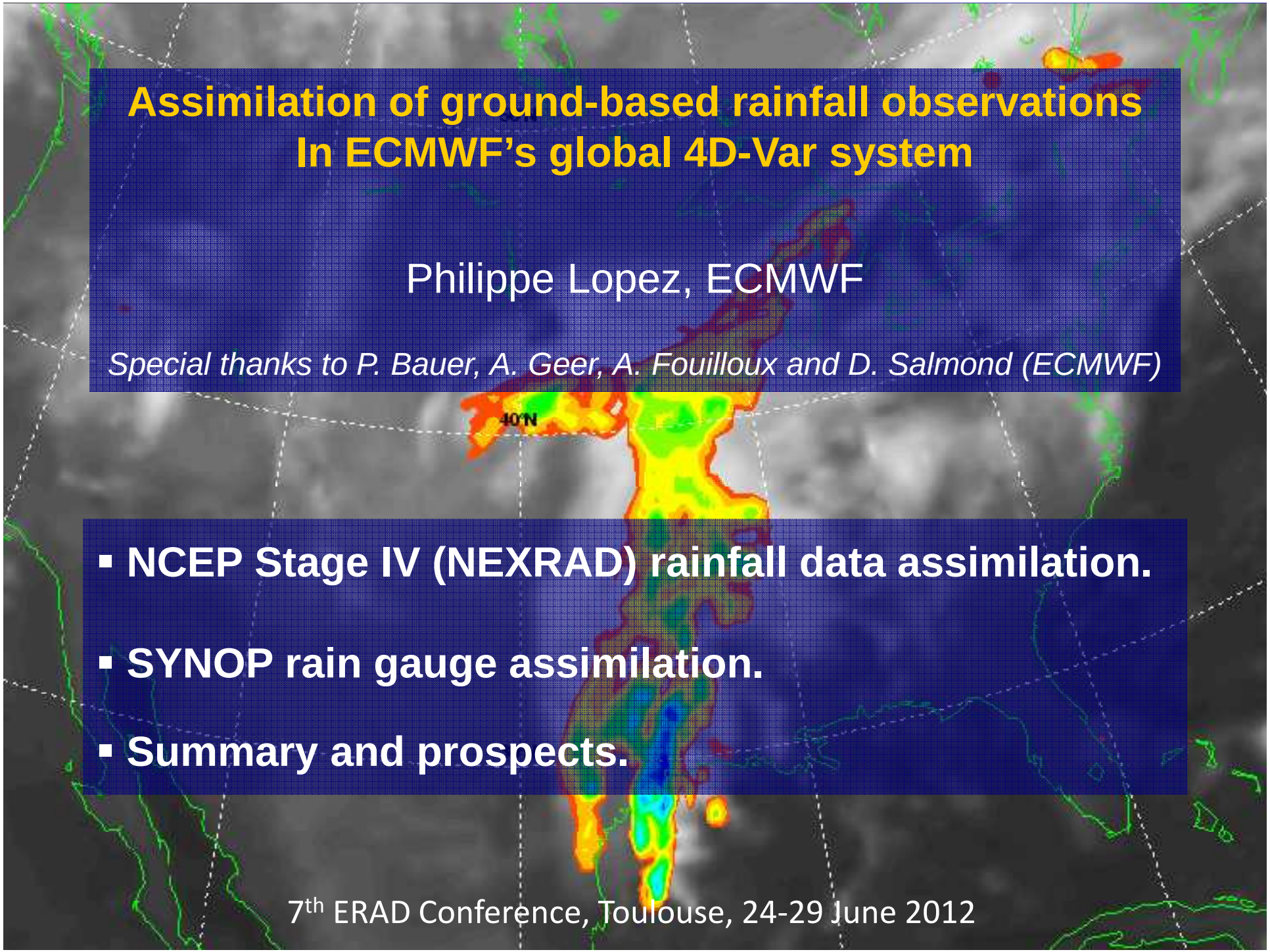


Assimilation of ground-based rainfall observations In ECMWF's global 4D-Var system

Philippe Lopez, ECMWF

Special thanks to P. Bauer, A. Geer, A. Fouilloux and D. Salmond (ECMWF)

- **NCEP Stage IV (NEXRAD) rainfall data assimilation.**
- **SYNOP rain gauge assimilation.**
- **Summary and prospects.**

7th ERAD Conference, Toulouse, 24-29 June 2012

Direct 4D-Var assimilation of NCEP Stage IV rain data

(Lopez 2011, MWR)

Observations:

- **NCEP Stage IV radar + gauge precipitation product** (4-km resol.).
- **Data are averaged to model resolution** prior to the assimilation.
- **Domain: eastern USA.**
- **6-hour accumulations** are assimilated → smoother & more linear (4D-Var).
- **Ln(RR_{6h}[mm h^{-1}]+1) transform** (background departures closer to Gaussian).

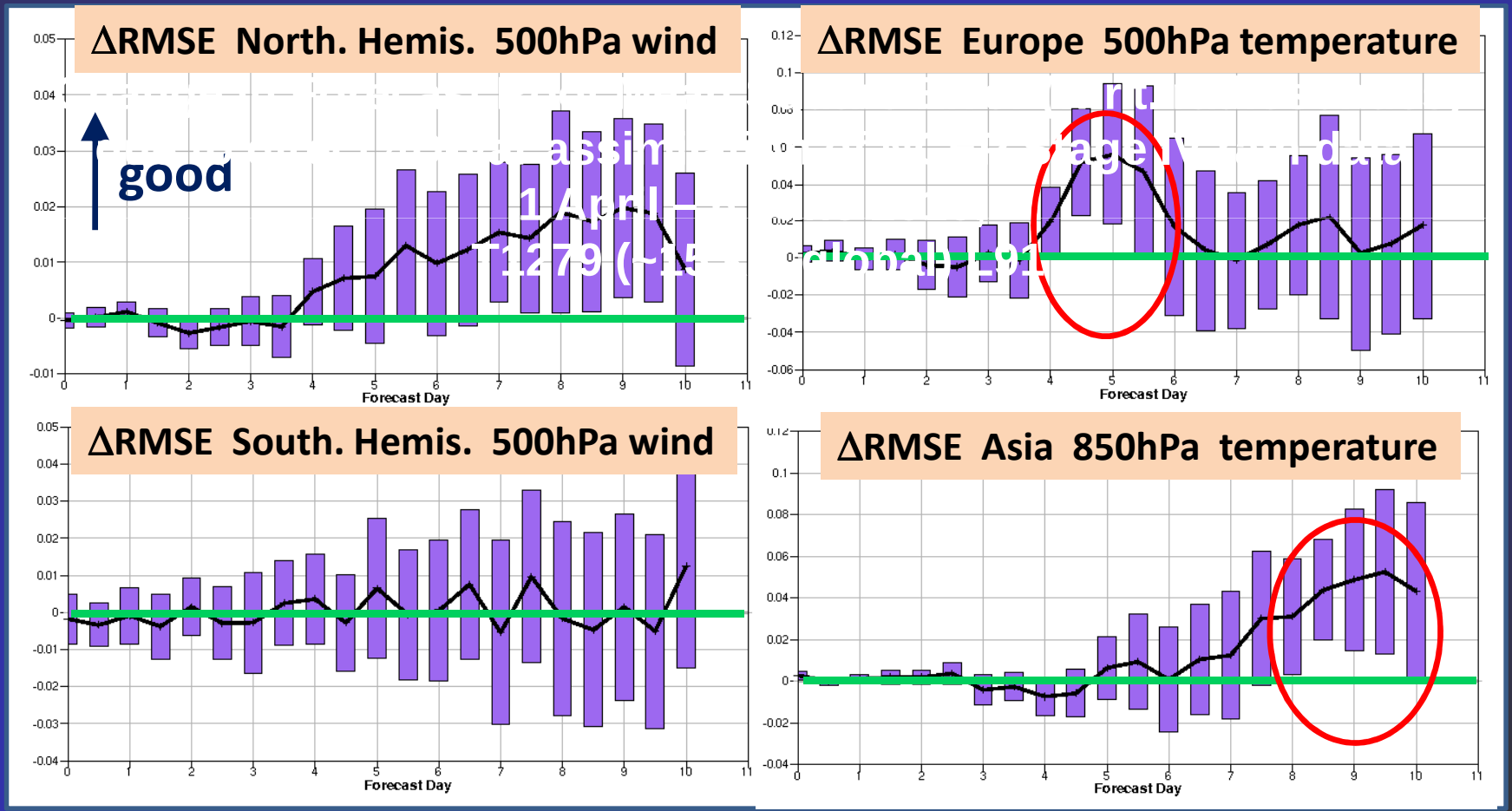
Quality control:

- **Obs rejected** in regions with either **rugged orography, surface snowfall** or **ducting**.
- **Only points that are rainy in both background and obs are assimilated.**
- Fixed **observation error**: σ_o = 0.18 (in log-space).
- **Variational bias correction** applied (Dee and Uppala, 2009).

→ **In ECMWF's operations since 15 November 2011.**

Direct 4D-Var assimilation of NCEP Stage IV rain data

- **Improvement in short-range precipitation forecasts** (up to 24h range).
- **Impact on forecast scores for atmospheric parameters** (Z, **T, wind**, RH):
  - **neutral or slightly positive impact on the global scale**.
  - some hint of a downstream positive impact over Europe and Asia.



Direct 4D-Var assimilation of SYNOP rain gauges

(Lopez 2012, MWR, submitted)

- **Based on the developments made for radar rain data assimilation (e.g. possibility to assimilate accumulated rainfall obs.).**

Observations:

- **SYNOP station 6-hour precipitation accumulations.**
- **Data are superobbed to model resolution prior to the assimilation.**
- **Domain: extratropics (too large errors in the tropics?).**
- **$Ln(RR_{6h}[mm\ h^{-1}]+1)$ is actually assimilated in 4D-Var.**

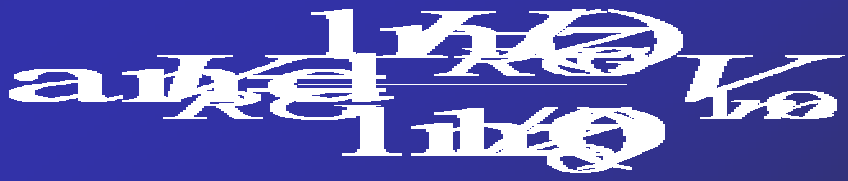
Direct 4D-Var assimilation of SYNOP rain gauges

Quality control:

- **Obs rejected** in regions with **rugged orography, snowfall** or **strong winds**.
- **All points that are rainy in either background or obs are assimilated.**

- **Crude parametrization of representativity error (seasonal variations).**
- **Fixed contribution from other sources:** $\sigma_{other} = 0.05$ (in log-space).

- **Wind-induced error bias correction** (based on Nešpor and Sevruk, 1999):



- **Fixed bias correction** $BC = f(RR)$**, for other sources of bias.**

Direct 4D-Var assimilation of SYNOP rain gauges

Experimental set-up:

Two 4D-Var assimilation global experiments were run:

Experiment	Resolution	Period	Observational coverage
ERA_CTRL	T511 L91 (~40 km)	Apr-Jun 2011	SYNOP Psurf only
ERA_NEW	T511 L91 (~40 km)	Apr-Jun 2011	SYNOP Psurf + RGs (6h)

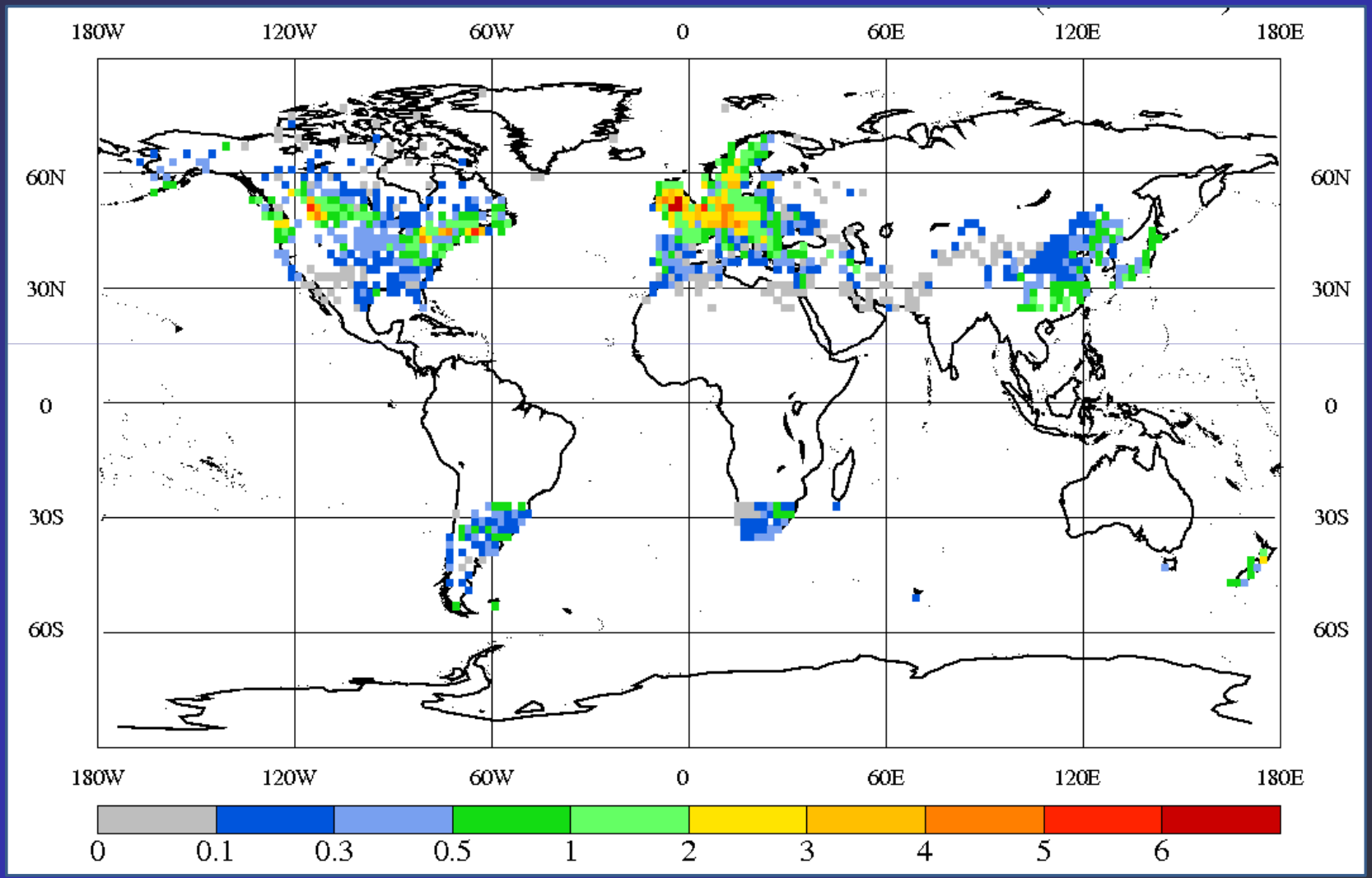
→ to mimic ECMWF's future reanalysis of the early 20th century.

→ to assess the potential impact of rain gauge assimilation when the coverage in other observations is sparse.

~ 600 rain gauge superobs were assimilated per 4D-Var cycle (every 12 h).

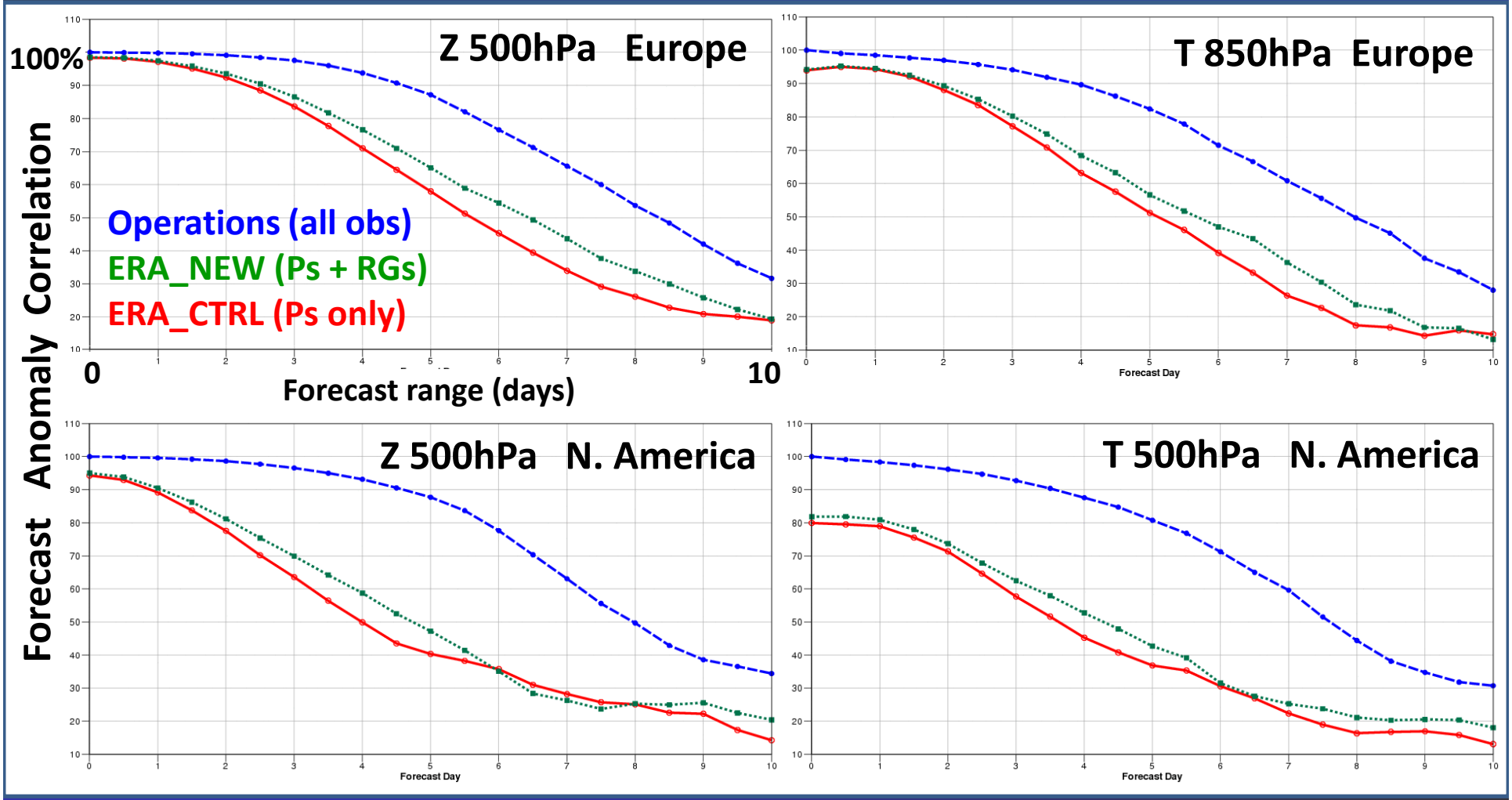
4D-Var assimilation of SYNOP rain gauges

Number of used RG superobs per 2°x 2° box and per 4D-Var cycle
T511 L91 experiment ERA_NEW (Apr-Jun 2011)



Results from pseudo-ERA experiments with RGs (1)

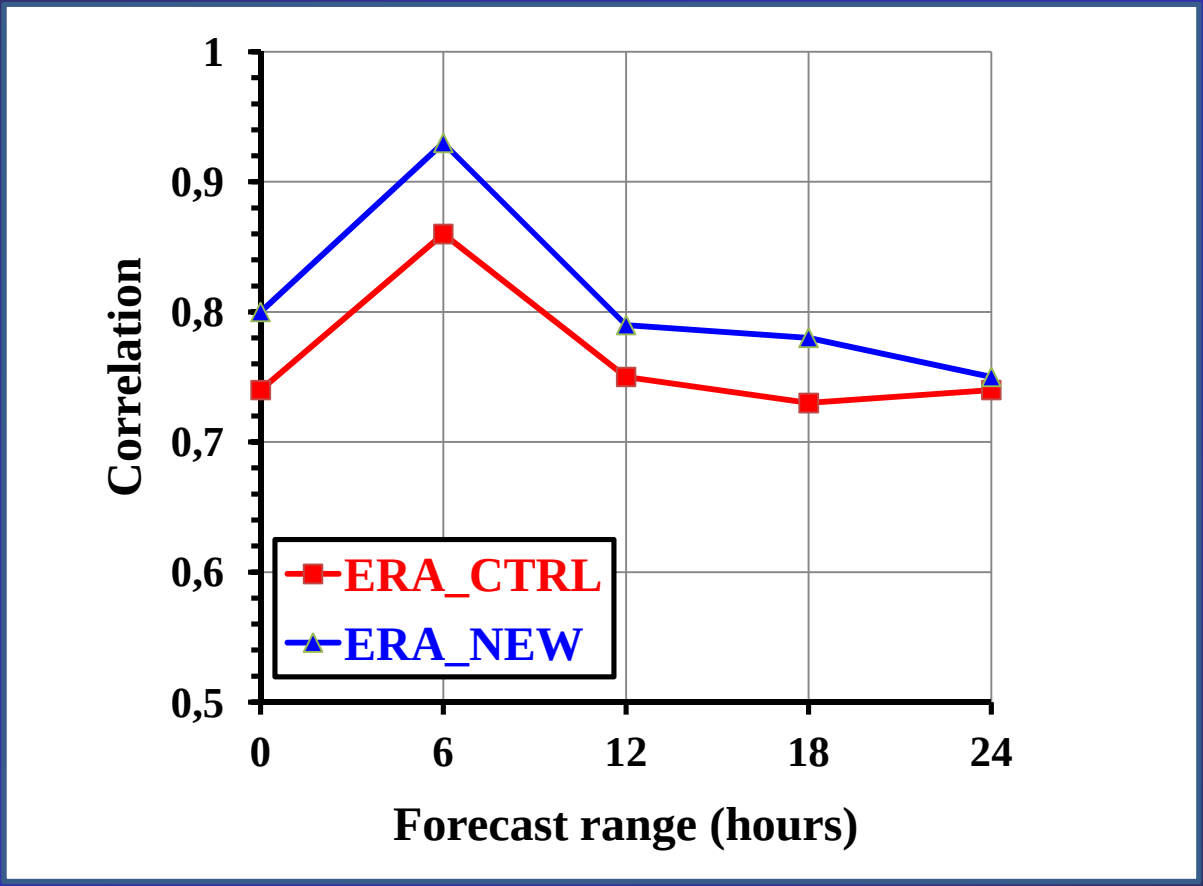
Forecast anomaly correlation (w.r.t. operational analyses) as a function of forecast range (0 to 10 days) (Apr-Jun 2011).



→ Positive impact of RG assimilation, esp. over Europe.

Results from pseudo-ERA experiments with RGs (2)

Correlation of short-range forecast 10.8 μm brightness temperatures with Meteosat-9 imagery over Europe (Apr-Jun 2011):



Higher correlations → improved spatial distribution of clouds when SYNOP RGs are assimilated.

Summary and prospects

Ground-based precipitation radars:

- NCEP Stage IV 6-hourly rainfall accumulations are now assimilated in ECMWF's operational 4D-Var.
- Plans: to use other radar networks (Europe, Japan, China,…) (issue of data policy).

Rain gauges:

- 4D-Var data assimilation of SYNOP 6-hour RG accumulations can have a significant positive impact on medium-range forecast scores when coverage in other observations is sparse.
- This might be beneficial in the context of future 20th century reanalyses.
- Plans: to test 4D-Var with 24h accumulations and relax screening of snowfall and tropical observations.

+ Hints of an improvement of surface analyses (e.g. soil moisture).

Thank you!

Early developments

- At ECMWF, work on the assimilation of ground-based precipitation radar data started in **2005**, taking advantage of the developments for satellite microwave imager observations in rainy regions (Mahfouf, Marécal, Moreau, Bauer, Geer, Lopez).

- First, an **indirect 1D+4D-Var approach** was tested with **NCEP Stage IV hourly radar + gauge rain product** over the USA:

→ **slightly positive impact** on both analyses and forecast scores (up to 24h range only).

- Limited impact ← **competition with other observations** (TEMP, SYNOP).

- **Some limitations of 1D+4D-Var were identified → try direct 4D-Var instead.**

1D+4D-Var assimilation of NCEP Stage IV rain data

(Lopez and Bauer, 2007, MWR)

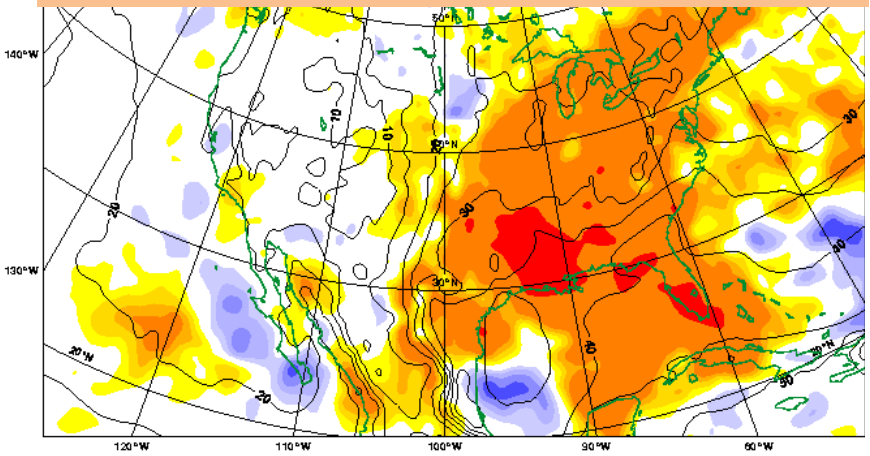
Three global assimilation experiments (20 May - 15 June 2005; T511 L60):

CTRL = all standard observations (ECMWF operational 4D-Var).
CTRL_noqUS = CTRL – no moisture obs over US (from SYNOP, TEMP, satellites).
NEW_noqUS = CTRL_noqUS + NCEP Stage IV hourly rain rates over US (1D+4D).

Mean differences of TCWV analyses at 00UTC

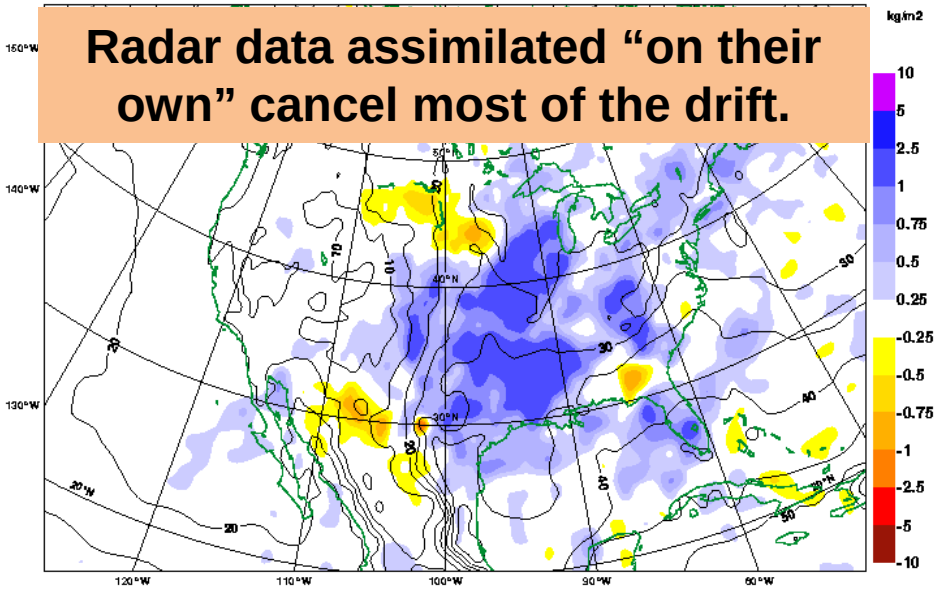
CTRL_noqUS – CTRL

No moisture obs. over USA → strong drying (down to –5 kg m^{-2})



NEW_noqUS – CTRL_noqUS

Radar data assimilated "on their own" cancel most of the drift.

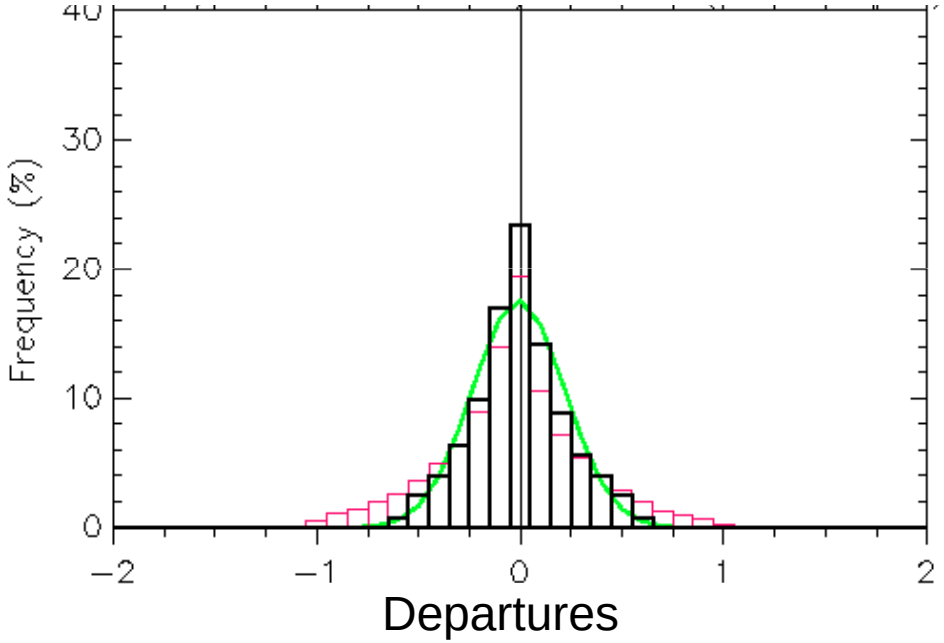


→ Rain data alone can have a substantial positive impact on analyses and forecasts.

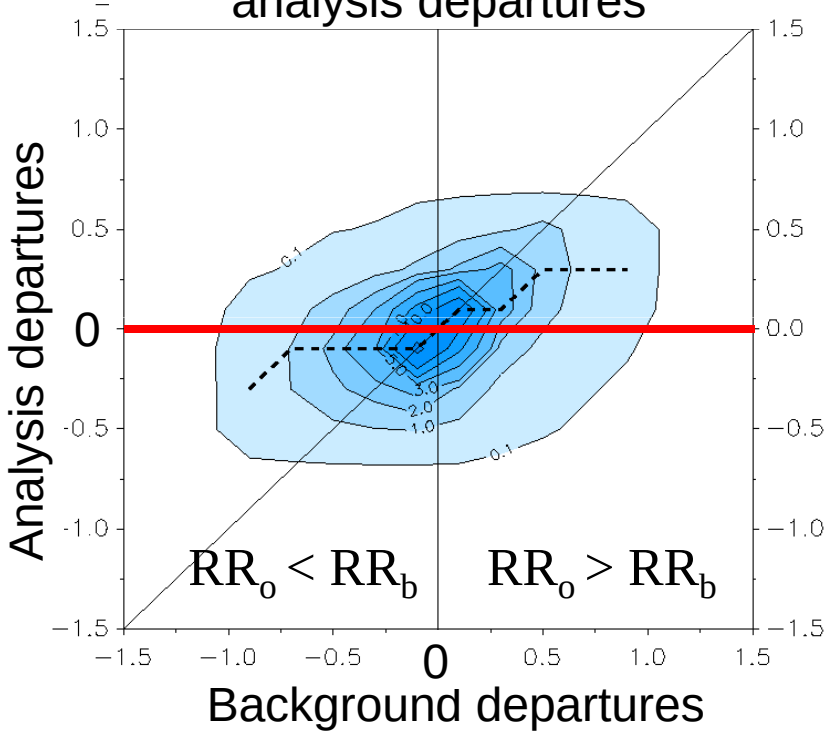
Asymmetry of rain analysis increments

Statistics of direct 4D-Var assimilation of NCEP Stage IV data over eastern half of the USA in April-May 2009 (T511 L91; CY35R2).

PDF of background (red) and analysis (black) departures (Gaussian fit)



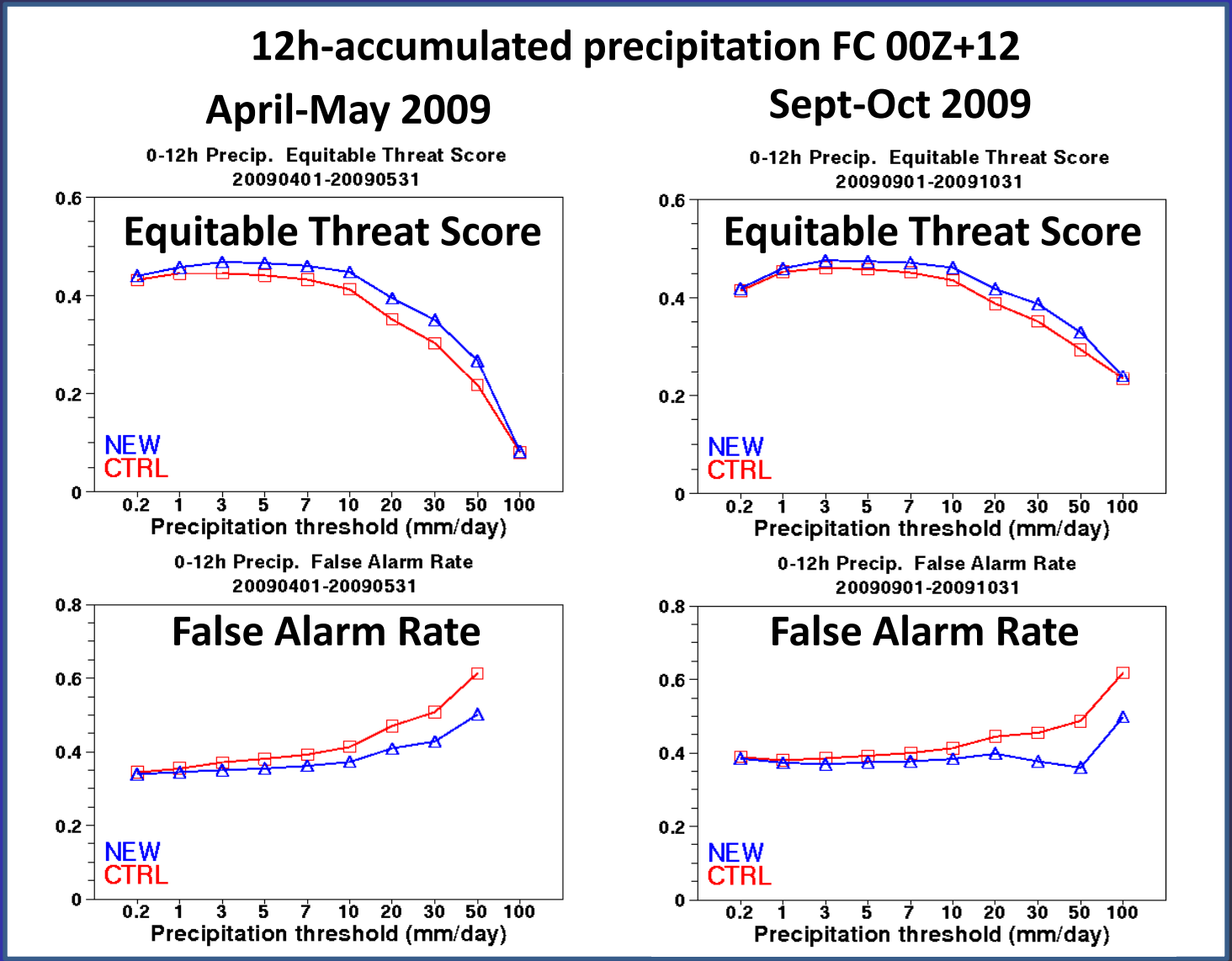
2D PDF of background and analysis departures



Always **easier to reduce precipitation than to increase it** during assimilation, mainly as a result of the limiting effect of saturation.

Direct 4D-Var assimilation of NCEP Stage IV rain data

Short-range precipitation forecast is significantly improved.

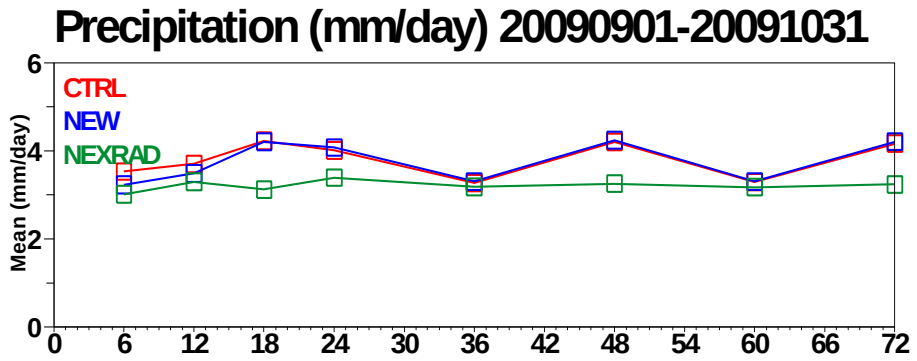


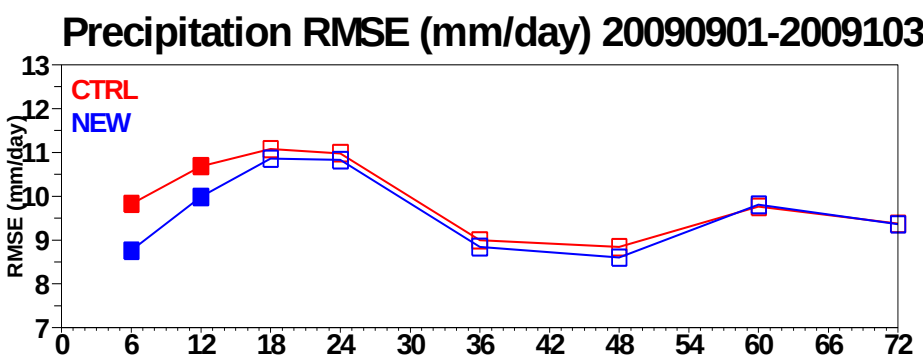
Direct 4D-Var assimilation of NCEP Stage IV rain data

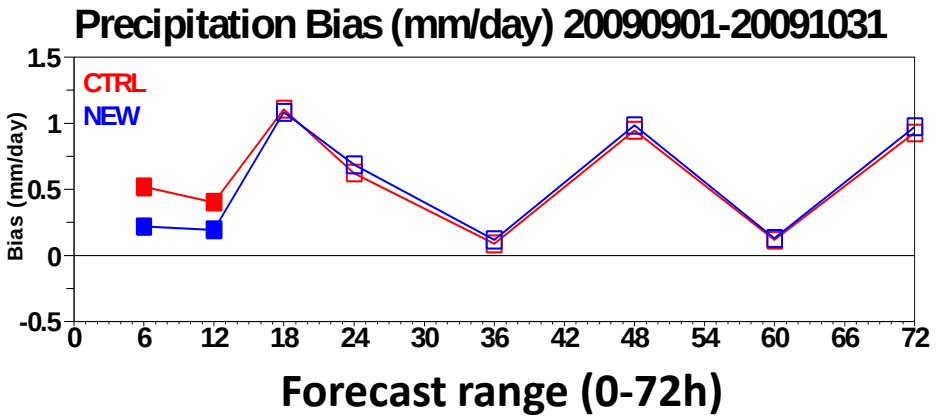
Impact on precipitation FC as a function of FC range (6-72h)

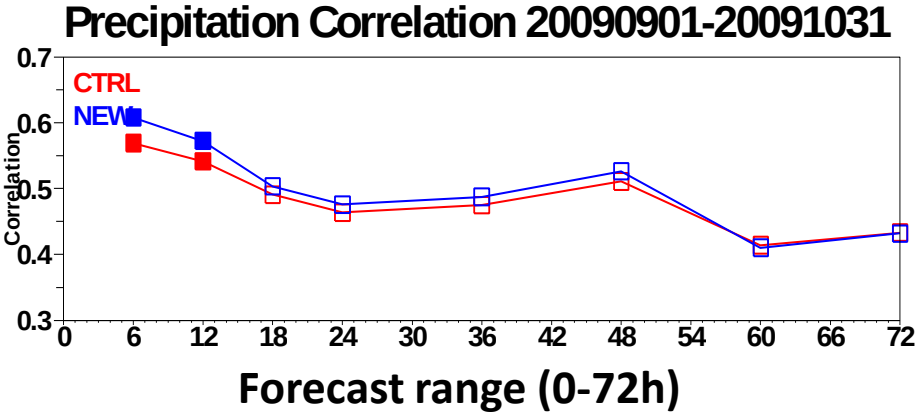
Sept-Oct 2009 average
(CY35R2; T511 L91 ≈ 37 km)

Filled symbols indicate significant differences (at 95% level)



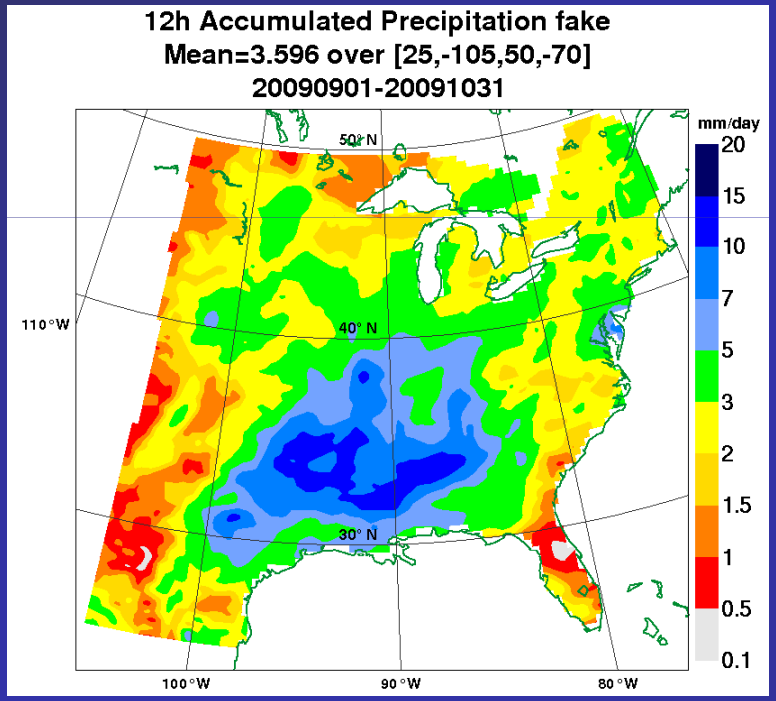


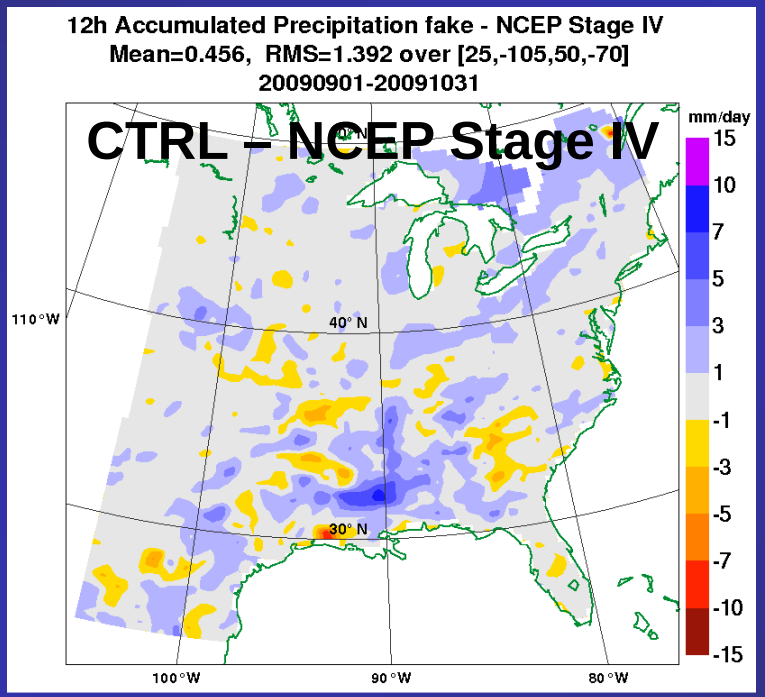


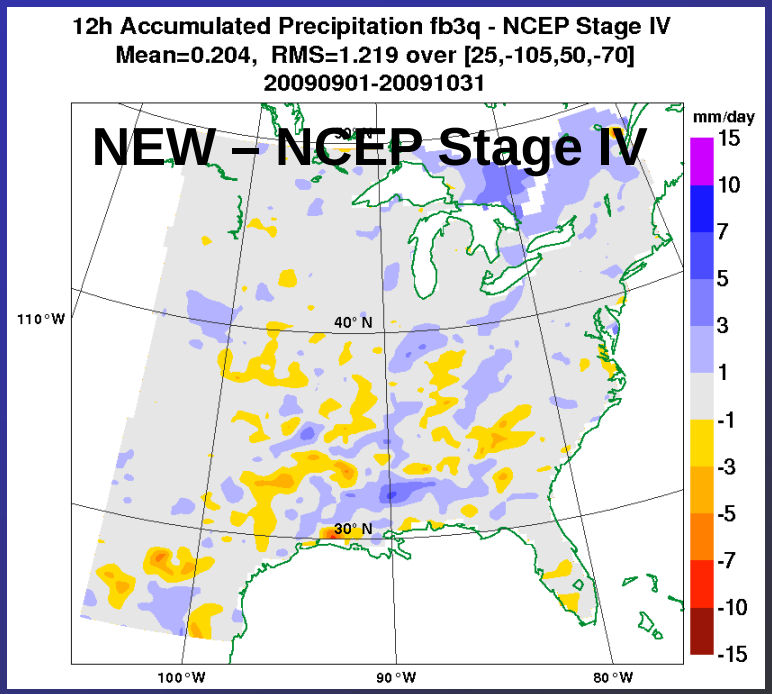


Impact of NCEP Stage IV assimilation on 12h forecasts of precipitation. Sept-Oct 2009 average (T511 L91 ≈ 40km)

NCEP Stage IV observations

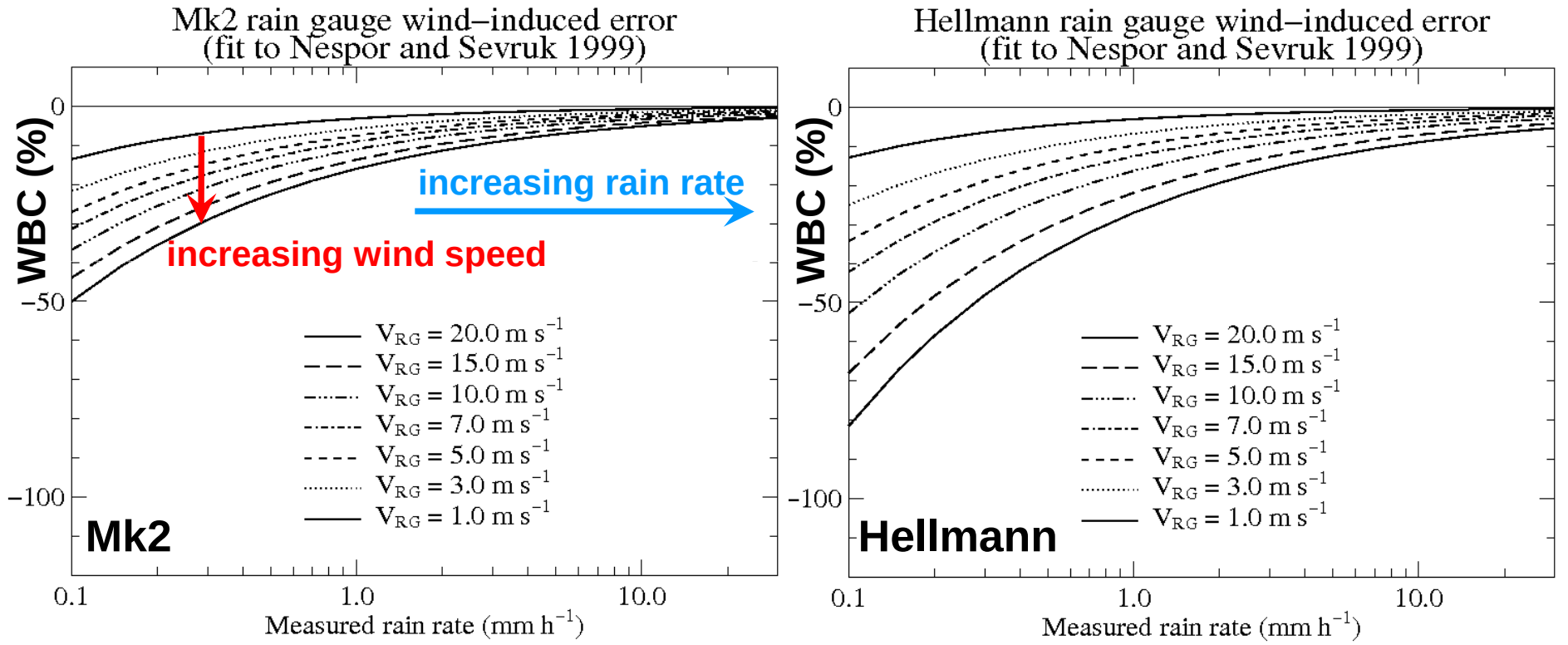






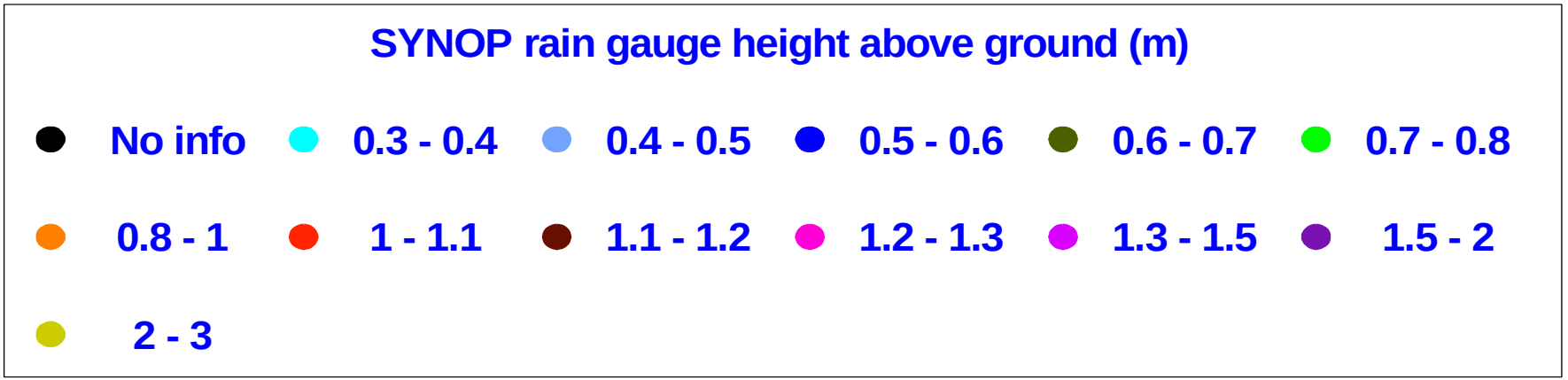
Wind-induced error bias correction (3)

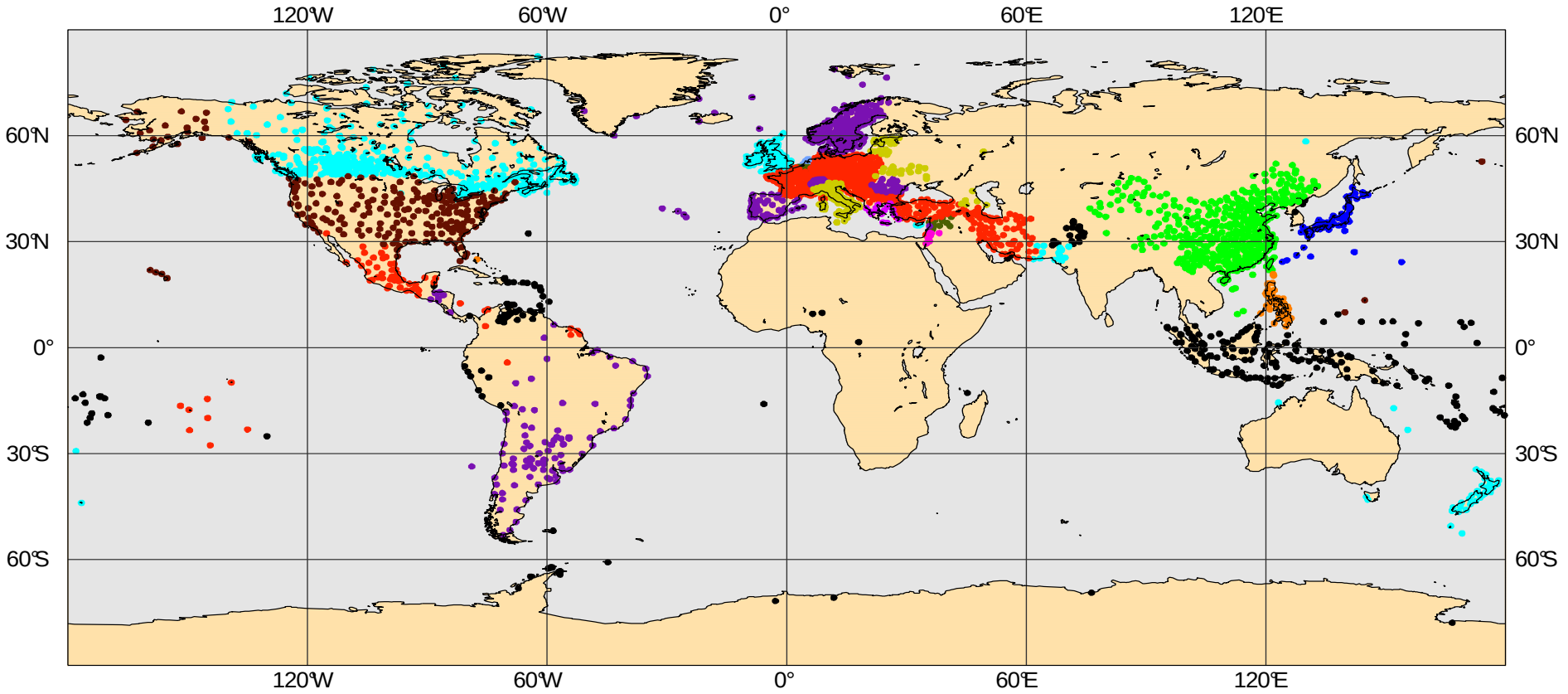
- Fitted curves of relative wind-induced error (%) against measured rain rate and wind speed at gauge top for Mk2 and Hellmann gauges:



Hellmann larger than Mk2 gauge in size ⇒ stronger undercatch.

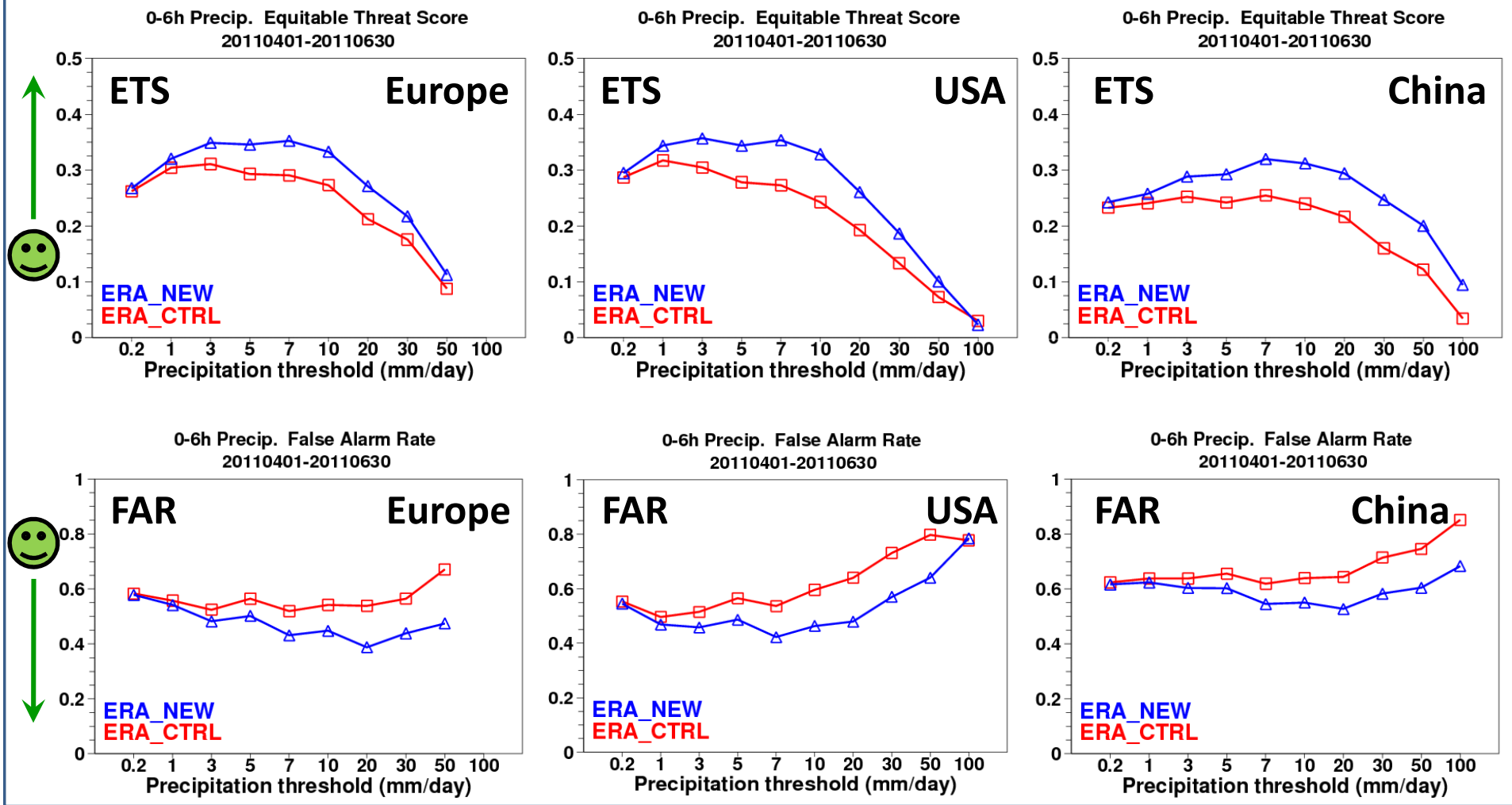
SYNOP rain gauge height above ground (m)





Results from pseudo-ERA experiments with RGs (3)

0-6h precipitation forecast scores against SYNOP RG themselves: Equitable Threat Score (ETS) and False Alarm Rate (FAR) (Apr-Jun 2011).



→ 4D-Var “precipitation analysis” is successful.

Results from pseudo-ERA experiments with RGs (4)

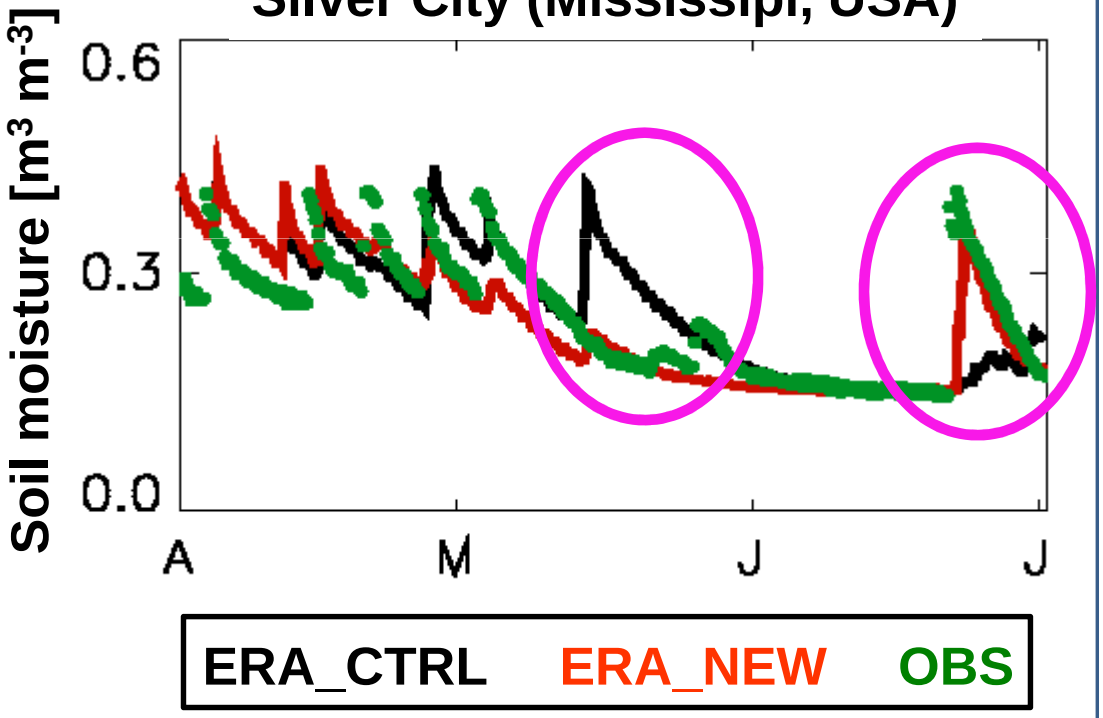
Comparison of top-layer soil moisture analyses (6-hourly) with in-situ NCRS-SCAN observations over the USA (from Clément Albergel)

Statistics over 101 stations

	ERA_CTRL	ERA_NEW
Correl.	**0.615**	**0.644**
Bias	-0.060	-0.058
RMSD	0.128	0.124

(Bias and RMSD in $m^3\ m^{-3}$)

Example of Silver City (Mississipi, USA)



Higher correlations → improved spatial distribution of soil moisture when SYNOP RGs are assimilated.