Effective Assimilation of Global Precipitation: Simulation Experiments

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Introduction

- Precipitation has long been one of the most important and useful meteorological observations.
- Many efforts to assimilate precipitation observations have been made (e.g., Tsuyuki 1996; Mesinger et al. 2006).
  - Most of them used nudging / variational methods.
  - Succeeded in forcing the model precipitation to be close to the observed values.
  - However, the model forecasts tend to lose their additional skill after few forecast hours.
- Major difficulties in the current status of precipitation assimilation (Bauer et al. 2011):
  - (1) The linear representation of moist physical processes required for variational data assimilation.
  - (2) The non-Gaussianity of precipitation observations.

Objectives

- Use an ensemble Kalman filter (EnKF) to avoid the problem (1) (linearization of the model).
- Propose and test several changes in the precipitation assimilation process to overcome the problem (2) (non-Gaussianity):
  - Transform the precipitation variable into a Gaussian distribution based on its climatological distribution.
  - Assimilate both positive precipitation and zero precipitation using a new observation selection criterion.
- Observing system simulation experiments (OSSEs) in SPEEDY, a simplified but realistic atmospheric GCM.

Gaussian transformation

- The “Gaussian anamorphosis” (also used by Schöniger et al. 2012 in hydrology):

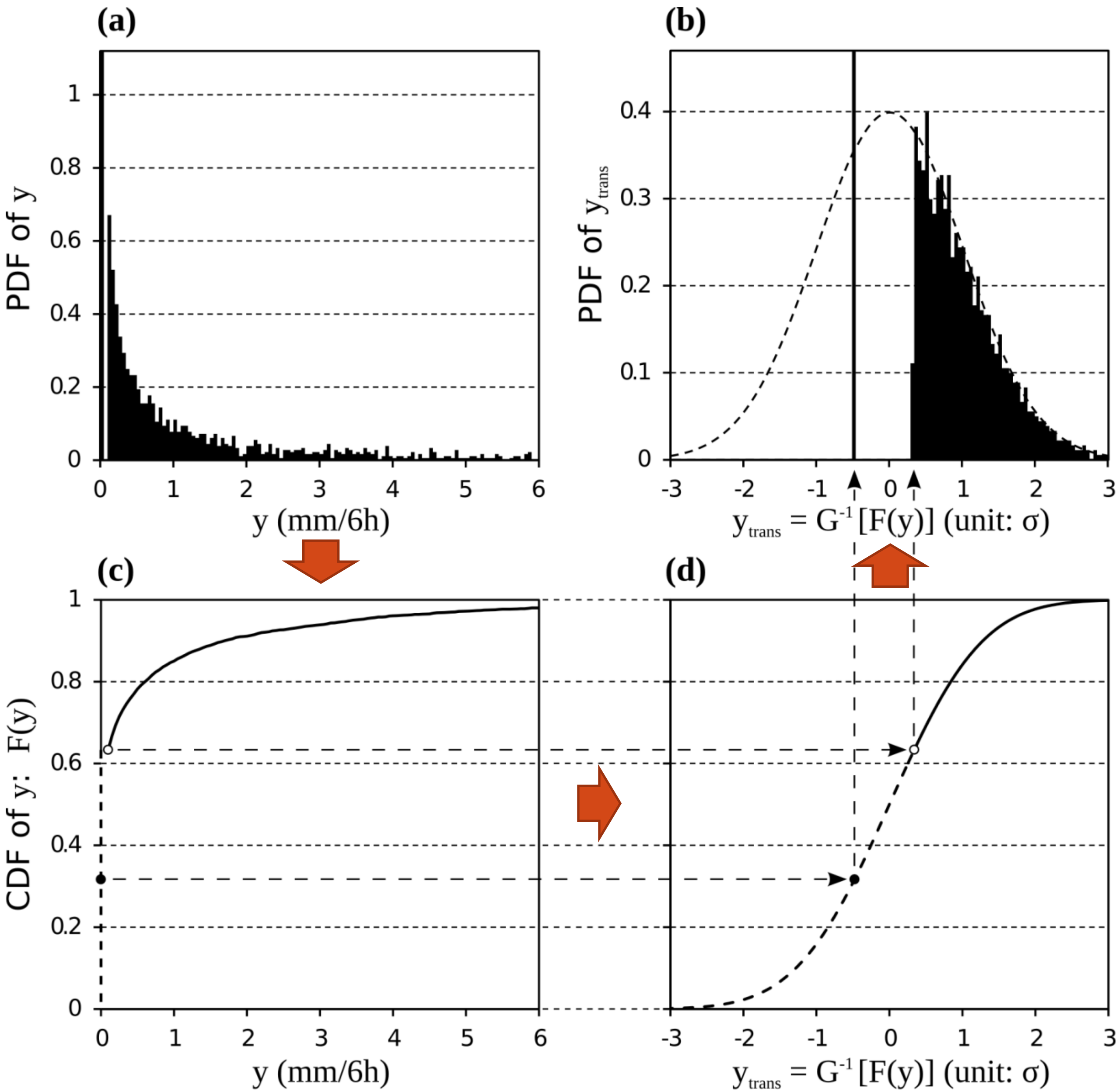
$$y_{\text{trans}} = G^{-1}[F(y)]$$

  - y : Precipitation variable.
  - F : Cumulative distribution function (CDF) of precipitation variables based on the model climatology at each grid point and in each season.
  - G^{-1} : Inverse CDF of a normal distribution. In the case with zero mean and standard deviation one:

$$G^{-1}(x) = \sqrt{2}\,\mathrm{erf}^{-1}(2x - 1)$$

- Precipitation variables contain a large portion of zero values.
  - Zero precipitation values have to be considered in the transformation.
  - A natural choice: assigning the middle value (i.e., *median*) of zero-precipitation cumulative probability to $F(0)$.

Example of precipitation distribution in DJF near Maryland



Observation selection criteria

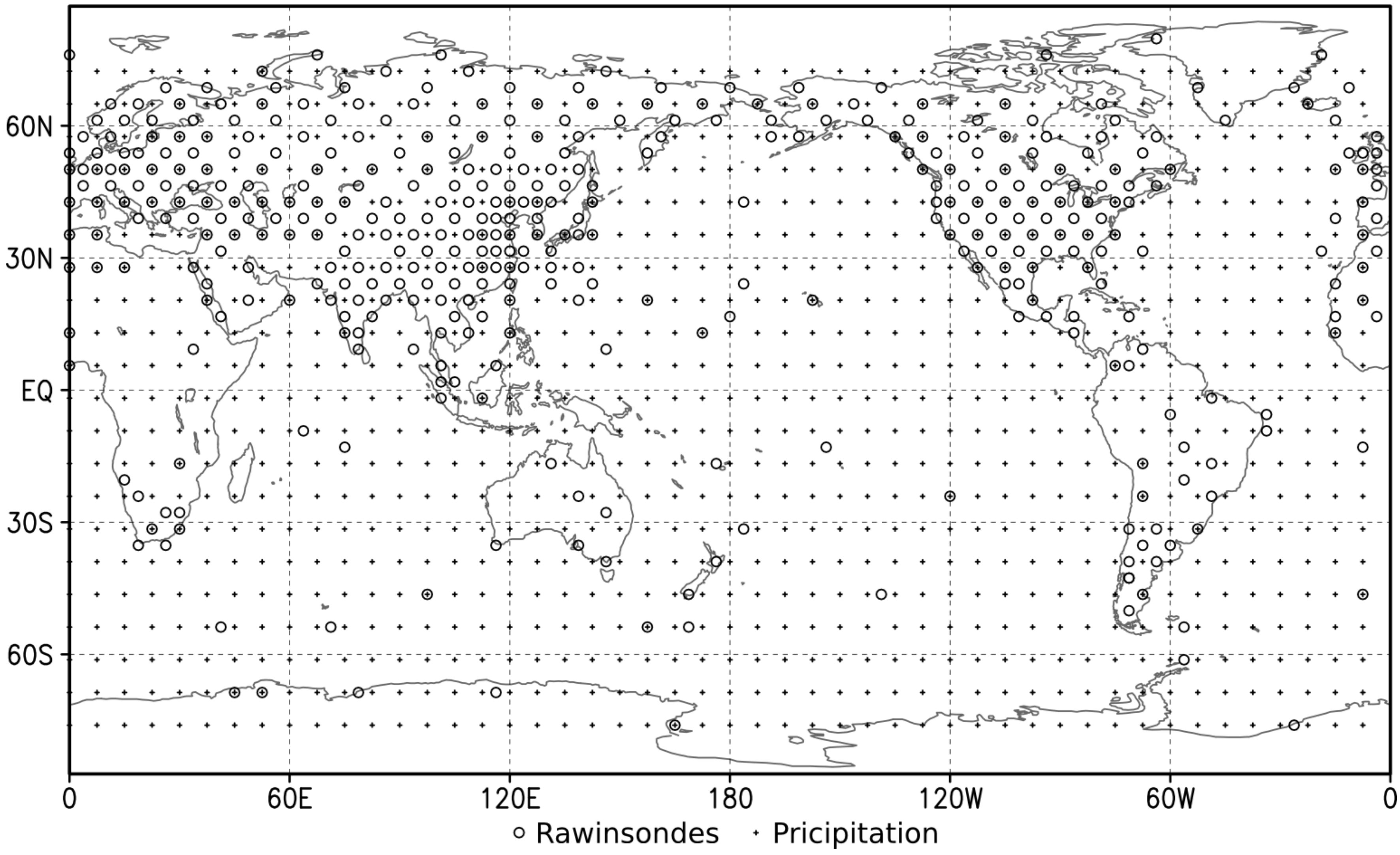
- Observation selection criteria for precipitation assimilation:
  - (i) The "***ObsR > 0*** criterion": only assimilating precipitation when positive precipitation is observed.
    - Discard all zero precipitation observations.
  - (ii) The "***10mR*** criterion": only assimilating precipitation at the location where more than 10 (half of ensemble size) background members have positive precipitation.
    - Allow to assimilate some zero precipitation observations if the background ensemble spread of precipitation is sufficient.

Experimental setup

- 1-year OSSE.
- Ensemble size = 20
- Adaptive inflation (Miyoshi 2011)

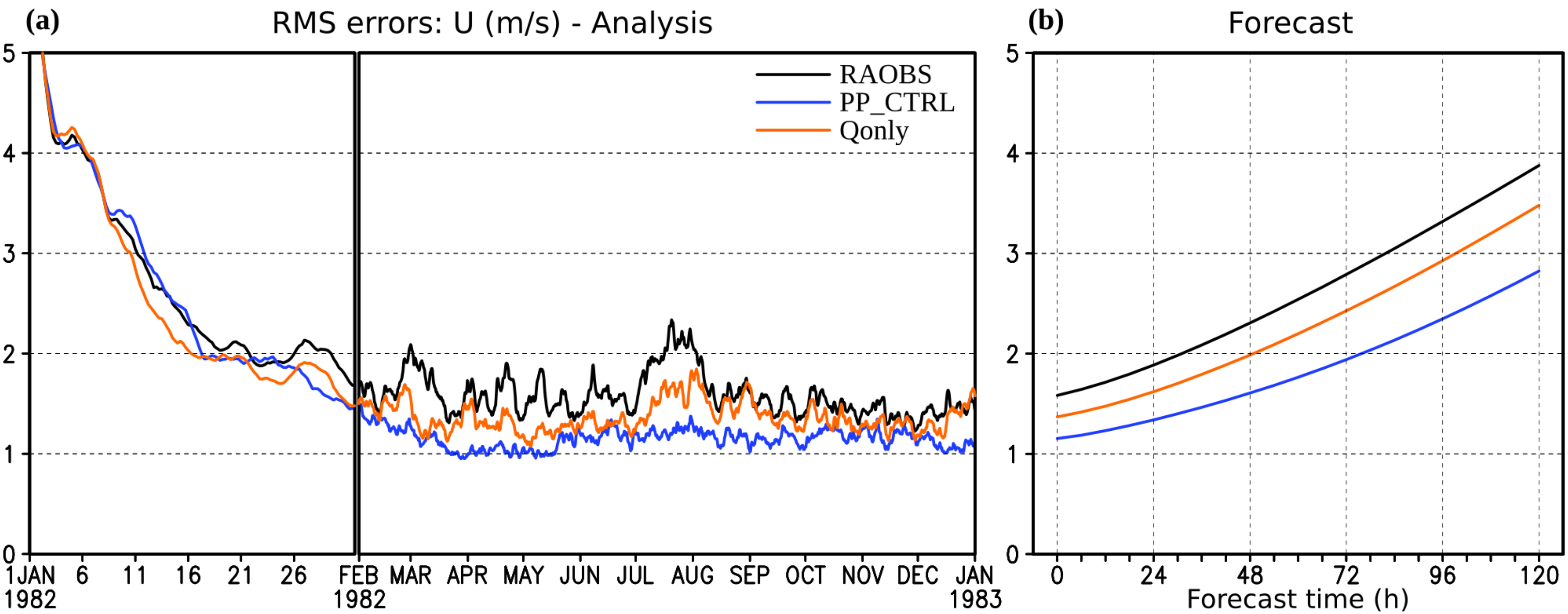
Experiment	Observations		Gaussian transf.	Criteria for prcp. assimilation	Obs. error of prcp. obs.
	Raws.	Prcp.			
RAOBS	X				
PP_CTRL	X	X	X	(ii) 10mR	20%
Qonly	X	X (only updating Q)	X	(ii) 10mR	20%
noGT	X	X		(ii) 10mR	20%
ObsR	X	X	X	(i) ObsR	20%
50%err	X	X	X	(ii) 10mR	50%
50%err_noGT	X	X		(ii) 10mR	50%

Observation distribution



Results

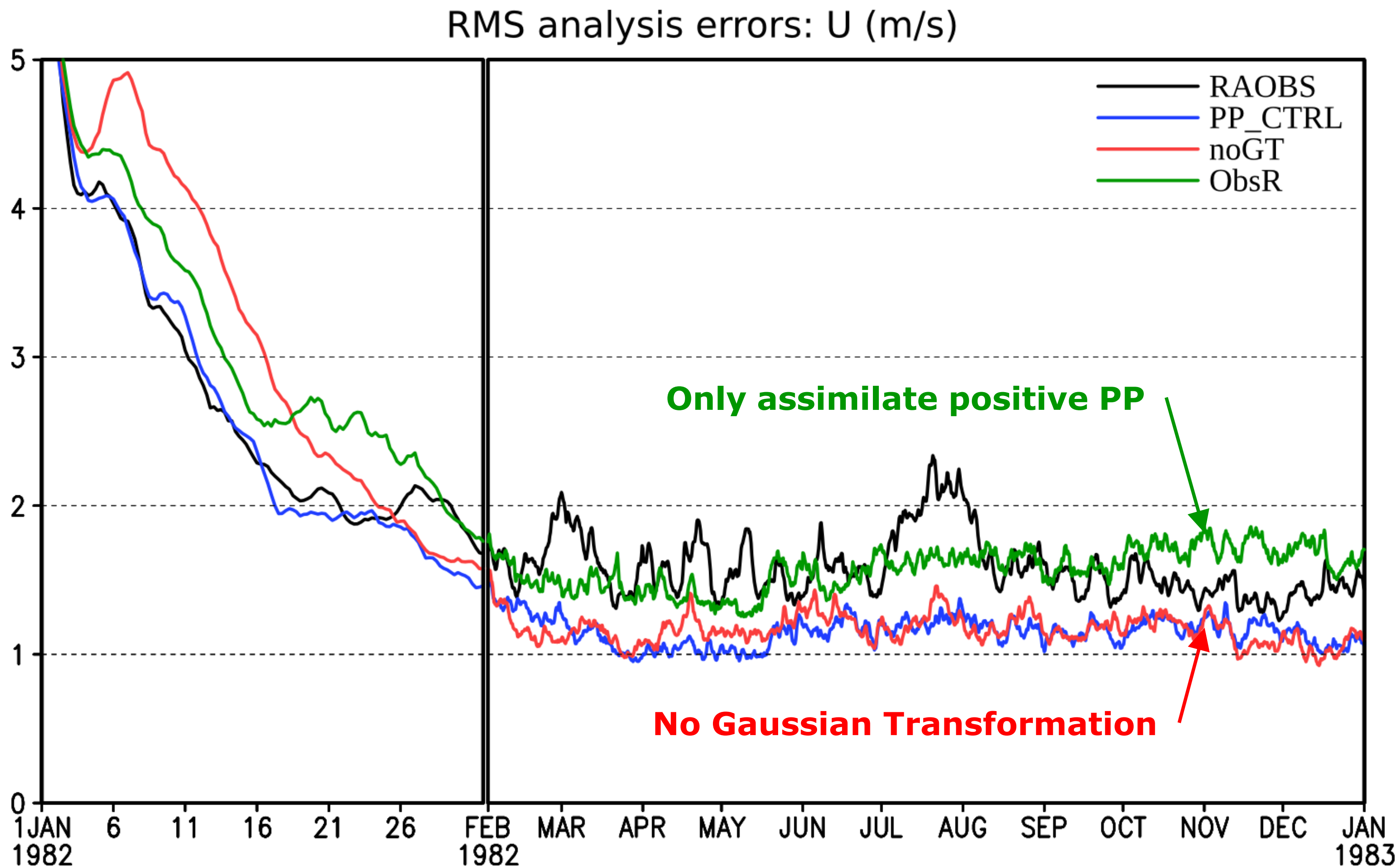
Improvement on analyses and medium range forecasts by precipitation assimilation



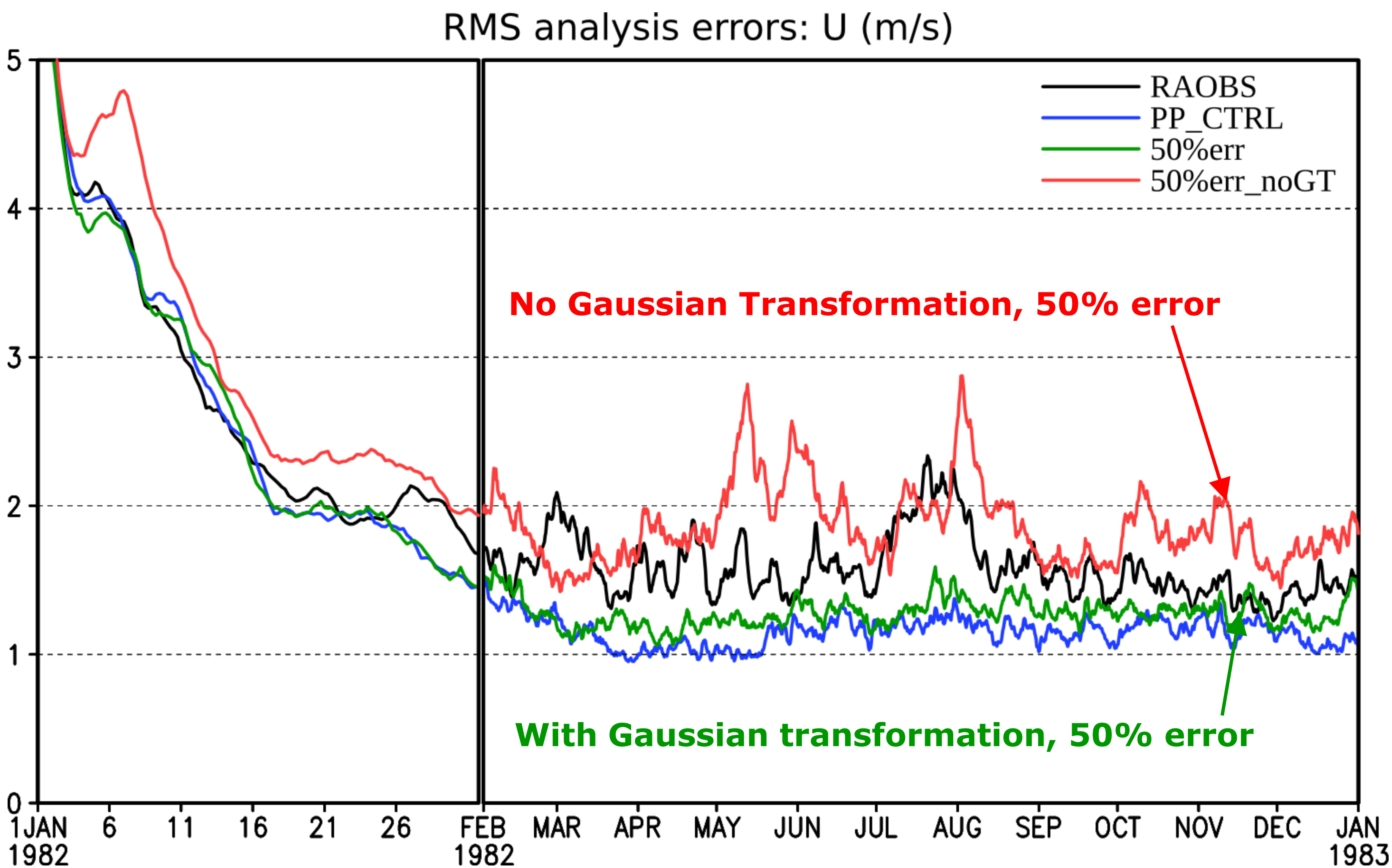
(Spin-up) (After the spin-up) (11-month average after the spin-up period)

- **All other variables (V, T, P_{sfc}) show similar results!**

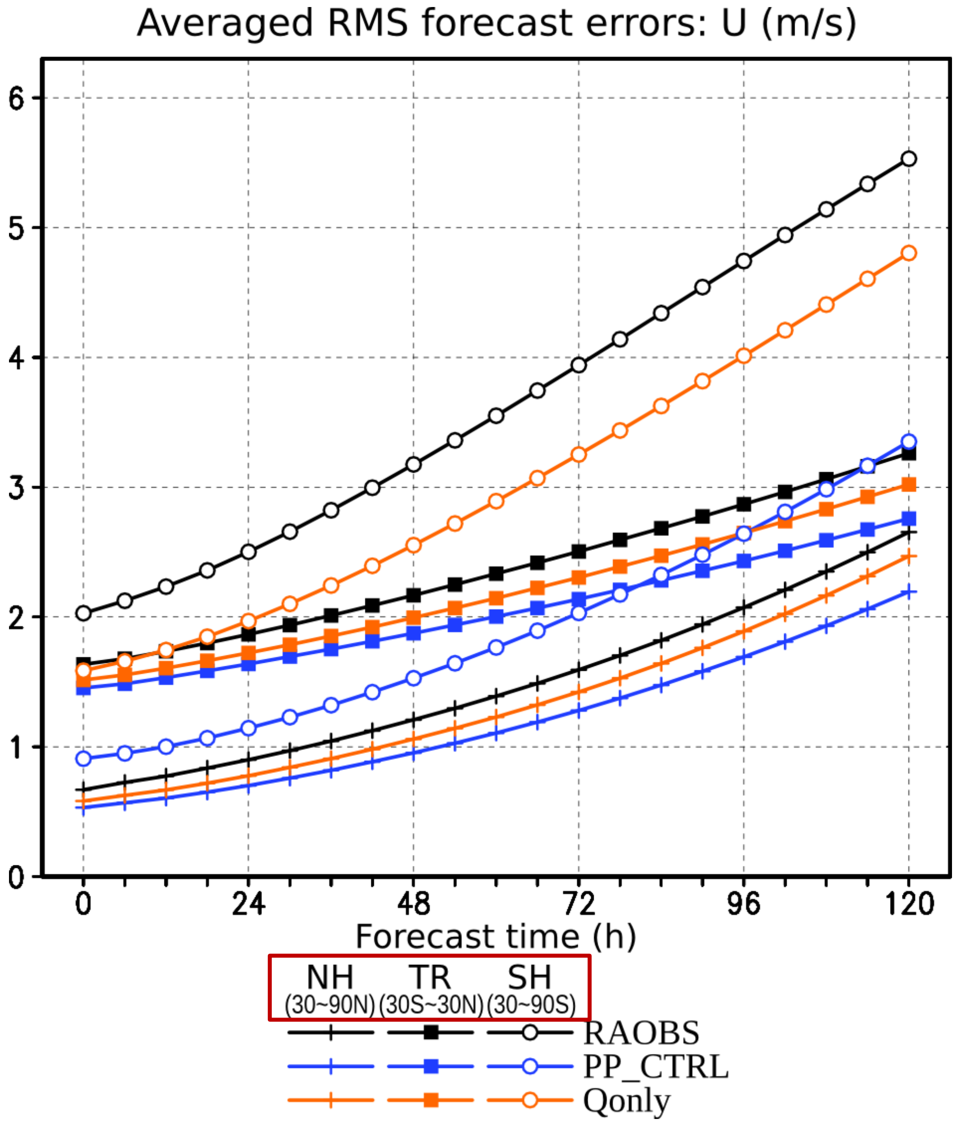
Impact of Gaussian transformation and observation selection criteria



Impact of observation errors



Regionally averaged medium range forecast errors



- A large portion of improvement by precipitation assimilation comes from southern extratropical regions.

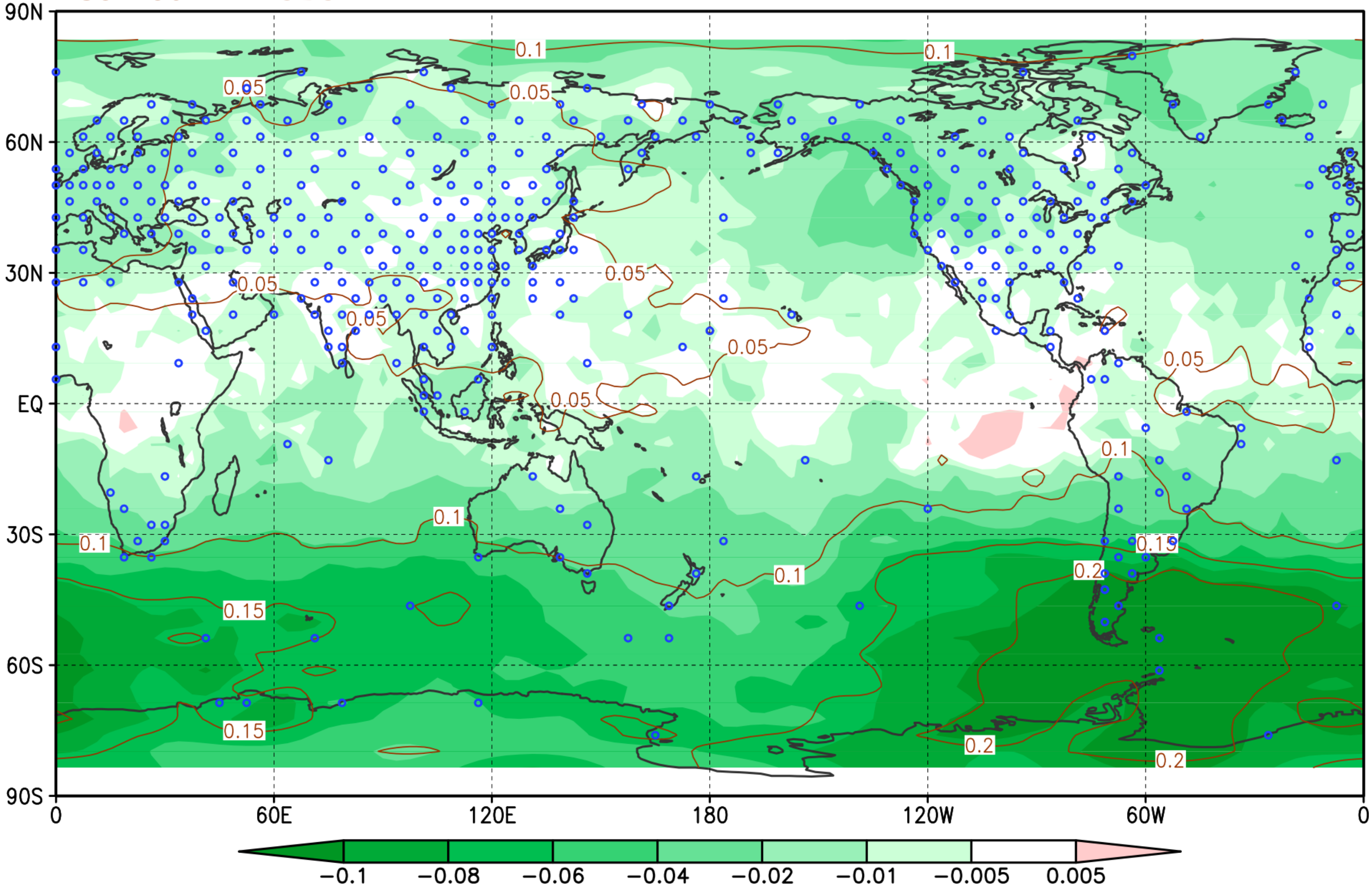
Map of averaged 72-h forecast improvement

RMS errors of 72-hour forecasts: vorticity at σ=0.51 (10^{-4} s^{-1})

Shade: (PP_CTRL - RAOBS)

Contour: RAOBS

∘ Radiosonde observation location



Conclusion

- Precipitation assimilation using an EnKF and with several changes can significantly improve the analyses and medium range forecasts in the SPEEDY model.
  - In the "Qonly" experiment only modifying the moisture field by precipitation observations, the improvement is much reduced.
- Applying the Gaussian transformation in precipitation assimilation is beneficial, which is even emphasized in the case with large observation errors.
- Allowing to assimilate zero precipitation data with the "10mR criterion" also results in better analyses.
- The experimental setting is too ideal compared to real systems with real precipitation data. We are going to test these ideas in a more realistic system.