Effective Assimilation of Global Precipitation: Simulation Experiments

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Introduction

- Past attempts to assimilate precipitation by nudging or 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.
  - The change in moisture is not an efficient way to update the potential vorticity field, which is the "master" dynamical variable that primarily determines the evolution of the forecast in NWP models.
- Major difficulties in the current status of precipitation assimilation (Bauer et al. 2011):
  - (1) The linear representation of moist physical processes required for the assimilation stage.
  - (2) The non-Gaussianity of both precipitation observations and model perturbations.
- ***Objective***: Observation system simulation experiments (OSSE) with a simplified, but realistic atmospheric GCM.
  - Use an ensemble Kalman filter (EnKF) to avoid the problem (1): The EnKF does not require linearization of the model.
  - Propose and test several changes in the precipitation assimilation process to overcome the problem (2):
    - Transform the precipitation variable into a Gaussian distribution based on its climatological distribution.
    - Only assimilate precipitation at the location where some ensemble members have positive precipitation.

Transformation method

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

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

  y : Precipitation variable.

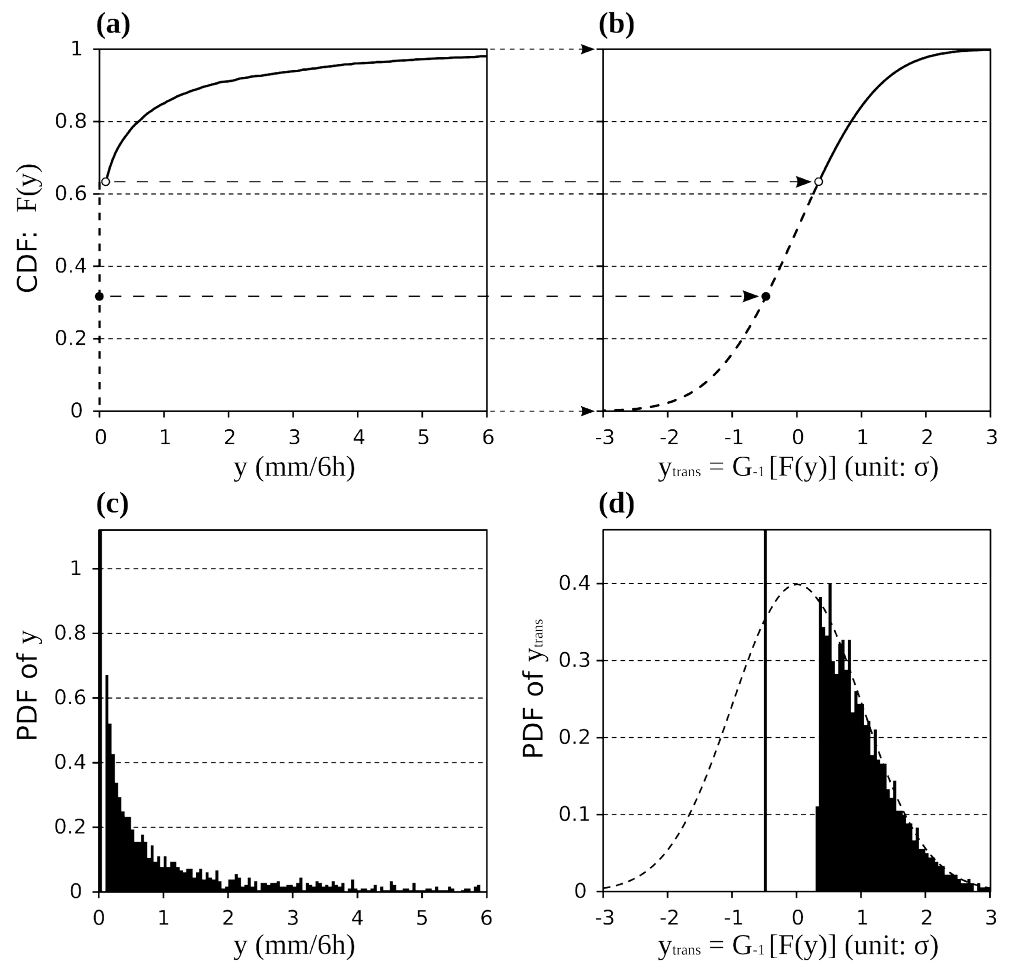
  F : Cumulative distribution function (CDF) of precipitation variables based on the 10-year model climatology at each grid and each season.

  G^{-1} : Inverse CDF of normal distribution.

  $G^{-1}(x) = \sqrt{2}\,\mathrm{erf}^{-1}(2x-1)$
- 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 of zero-precipitation cumulative probability to $F(0)$.
- LETKF is performed on the transformed space.
  - Variables transformed: $\mathbf{y}^{b(i)}_{pp}$, $\bar{\mathbf{y}}^{b}_{pp}$, $\mathbf{y}^{o}_{pp}$.
  - The observation errors associated with each observation also have to be transformed. Conceptually:

  $\sigma^o_{trans} \simeq (y^o+\sigma^o)_{trans} - y^o_{trans} \simeq y^o_{trans} - (y^o-\sigma^o)_{trans}$

Example of prcp. distribution in DJF near Maryland

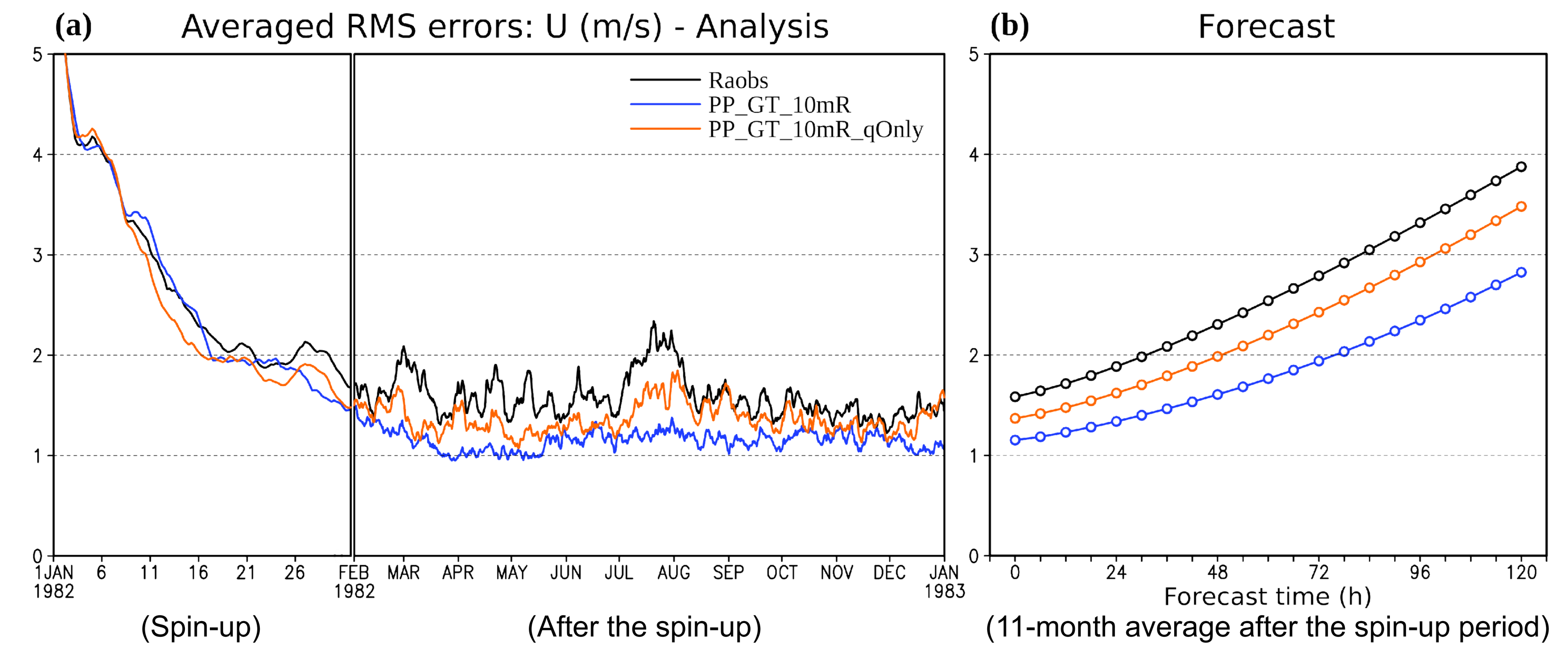


Experimental setup

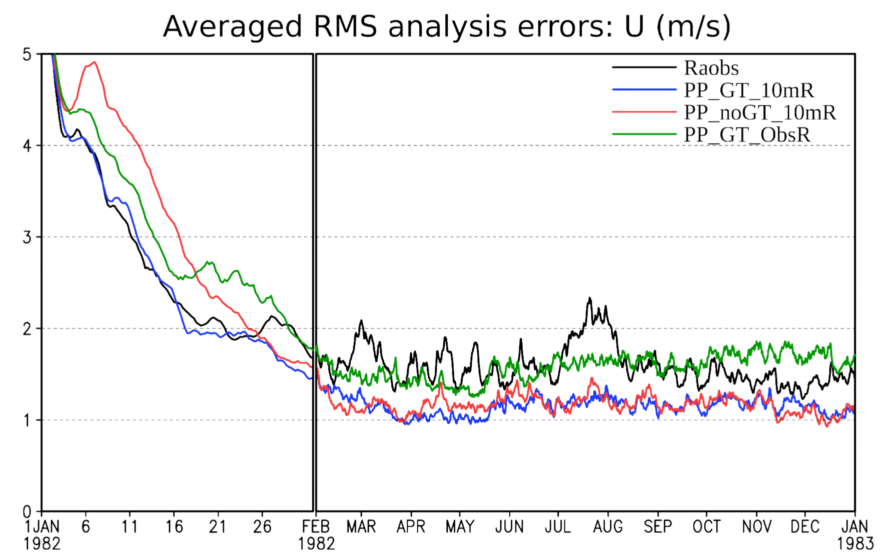
- Ensemble size = 20 / Horizontal localization length scale = 500 km / Adaptive inflation (Miyoshi, 2011)
- Observation selection criteria for precipitation assimilation:
  - (i) The traditional "***ObsR*** criterion": only assimilating precipitation at the location with observed positive precipitation (> 0.1 mm/6h).
  - (ii) The "***10mR*** criterion": only assimilating precipitation at the location where more than 10 (half of ensemble size) background members have positive precipitation.

Experiments	Assimilated observations		Gaussian transf.	Criteria for prcp. assimilation	Obs. error of prcp. obs.
	Rawinsondes	Global prcp.			
Raobs	X				
PP_GT_10mR	X	X	X	(ii) 10mR	20%
PP_GT_10mR_qOnly	X	X (only updating Q)	X	(ii) 10mR	20%
PP_noGT_10mR	X	X		(ii) 10mR	20%
PP_GT_ObsR	X	X	X	(i) ObsR	20%
PP_GT_10mR_50%err	X	X	X	(ii) 10mR	50%
PP_noGT_10mR_50%err	X	X		(ii) 10mR	50%

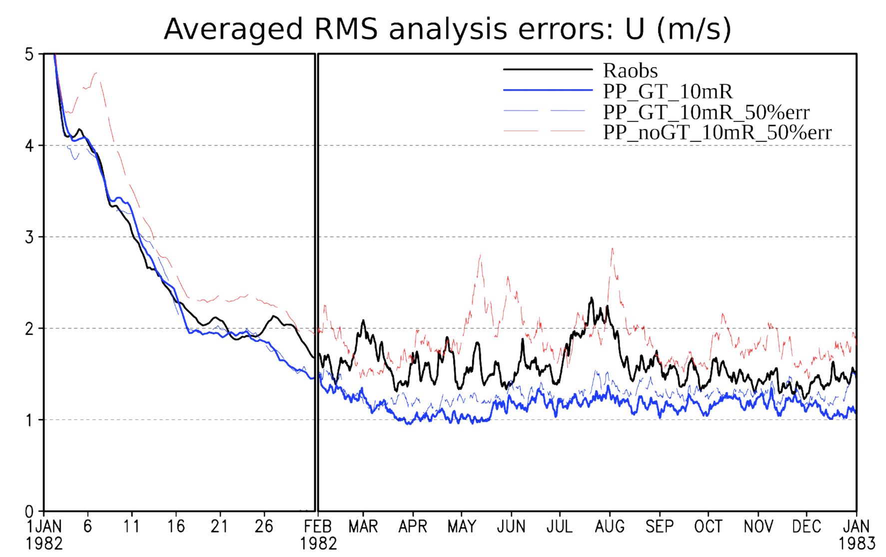
Results



Impact of Gaussian transf. and obs. selection criteria

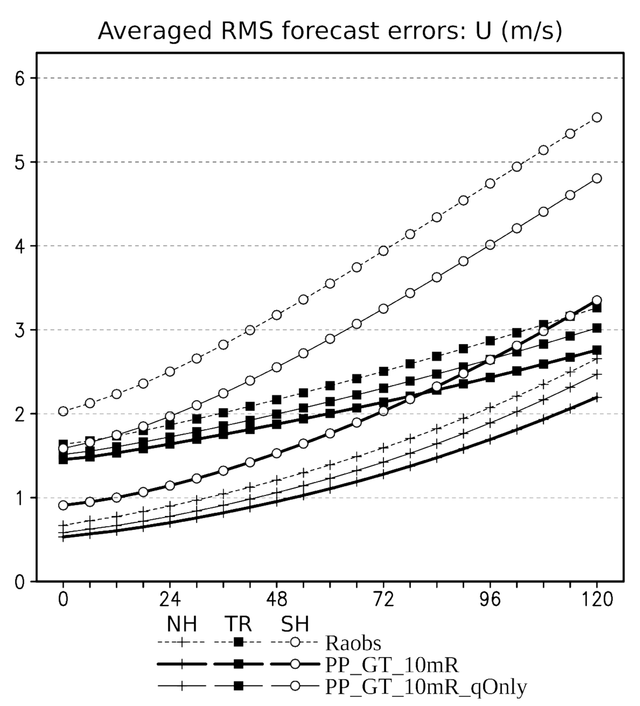


Impact of observation errors



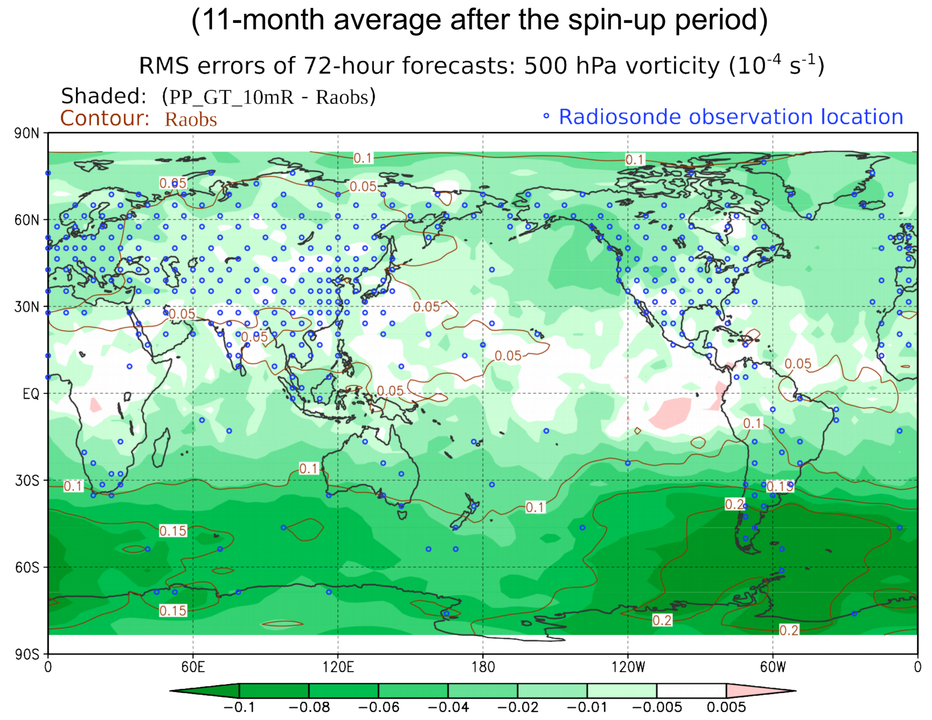
- Other variables show similar results.

Regional average



Map of 72-h forecast improvement

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



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

Conclusion

- Precipitation assimilation using an EnKF and with several changes significantly improve the analyses and medium range forecasts in the SPEEDY model.
  - The improvement is much reduced when only modifying the moisture field by precipitation observations with the same approach: Covariances between precipitation variable and mass/wind fields contain important information.
- Applying the Gaussian transformation in precipitation assimilation lead to a faster spin-up and slightly better analyses and forecasts.
  - The benefit is much larger in the case with large observation errors.
- Allowing to assimilate zero precipitation data with the "10mR criterion" also results in better analyses.
- Regional dependency:
  - A large portion of improvement by precipitation assimilation comes from the southern extratropical regions. It prevents the initial errors over the radiosonde-sparse areas from spreading out to the entire southern hemisphere.
  - The northern extratropical region is also improved, while the improvement in the tropical region is the smallest.
- Ongoing work:
  - Assimilation of precipitation using the GFS model and with high-resolution TRMM Multi-satellite Precipitation Analysis (TMPA) data.