ERA report series

5 Evaluation of ERA-Interim and ERA-Interim-GPCP-rescaled precipitation over the U.S.A.

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Abstract

A 3-hourly global precipitation dataset extracted from the European Centre for Medium range Weather Forecasts (ECMWF) - Interim Reanalysis (ERA-Interim) is validated against different precipitation datasets and accumulation periods over the U.S.A.: the Global Precipitation Climatology Project - Global Monthly Merged Precipitation Analysis (GPCP v2.0 and v2.1), the U.S.A. Department of Agriculture (USDA) official precipitation climatology (PRISM) for annual and monthly accumulations and the National Centers for Environmental Prediction precipitation dataset (NCEP Stage IV) for daily amounts. The results show that, over the U.S.A., the ERA-Interim precipitation has comparable quality to GPCP v2.1 for annual averages and a spatial correlation of 0.85 with respect to the PRISM dataset (2000-2008). A scale-selective rescaling procedure is also proposed to re-calibrate the ERA-Interim reanalysis with GPCP product. The annual spatial correlation of ERA-Interim-GPCP-rescaled precipitation versus PRISM increases up to 0.90. Benefits of the rescaling method are confirmed also at monthly and daily time-scales.

1 Introduction

Multi-model land surface simulations, such as those performed within the Global Soil Wetness Project-Second initiative (GSWP2, Dirmeyer et al., 2006, 2002), coupled with seasonal forecasting systems have been crucial in triggering advances in soil moisture predictability as documented in GLACE (Koster et al. 2006) and GLACE-2 (Koster et al. 2009) experiments. Therefore a state-of-the-art near-surface forcing dataset covering the most recent decades is highly relevant to foster research into intra-seasonal forecasting in a changing climate. While in re-analyses and operational weather forecasting near-surface atmospheric fields such as 2m temperature are rather tightly constrained by observations and with documented errors (Richardson et al. 2007), precipitation products are more difficult to constrain and often discarded by land surface modellers owing to their relatively large errors that would dominate offline driven land surface simulations. These errors are attributed to the weak constraint in humidity and precipitable water in the data assimilation process, particularly over continents, and to the fact that ground-based precipitation observations are not yet assimilated. On the other hand, long-term observation-based precipitation dataset do either not have the global coverage or sufficient horizontal and temporal resolution to be used directly in land surface modelling applications.

Caveats of using precipitation from a re-analysis in the case of GSWP2 have been shown by Descharme and Douville (2006) when comparing to a high resolution network over France. These concerns are also justified for modern re-analyses. Significant efforts have been devoted in various centres to improve the quality of precipitation in modern reanalysis as shown in Bosilovich et al. (2008). In recent years, Lopez and Bauer (2007) have proposed to assimilate a combined radar and gauge precipitation dataset and such a method might be beneficial in future atmospheric re-analyses.

ECMWF precipitation forecasts have been recently evaluated for hydrological applications in Pappenberger and Buizza (2009) showing meaningful skill up to 3 days ahead.

A well-known precipitation dataset for climatological applications is for instance the Global Monthly Merged Precipitation Analyses produced within the Global Precipitation Climatology Project (GPCP). It provides a long time series covering 1979 to present, which is ideally suited for land surface climatological studies. However it does have a limited spatial resolution (2.5°x2.5°) and temporal resolution (monthly). A re-analysis has the advantage of providing global data at higher resolution with a 3-hourly frequency.

In this study, we first evaluate the ECMWF ERA-Interim precipitation at various time-scales from annual to daily. We then demonstrate that ERA-Interim precipitation can be improved by applying a scale-selective rescaling method, based on GPCP, which basically “calibrates” the monthly precipitation amount addressing the issue of non-conservation typical of data assimilation systems.

A similar rescaling method was applied to obtain the GSWP2 precipitation forcing as described in Dirmeyer et al. (2002), however with a few additional refinements. In the next sections, we present the datasets used, the rescaling method, and its validation. Results are evaluated over 9 years (2000-2008) with an independent high-resolution dataset covering the U.S.A. only.

2 Datasets

2.1 GPCP v2.0 (1979-2008)

The GPCP version2.0 data is a monthly climatology provided globally at 2.5°x2.5° resolution and covering the period between 1979 and 2008. The GPCP dataset merges satellite and rain gauge (SG) data from a number of satellite sources including the Global Precipitation Index (GPI), the Outgoing Longwave Radiation (OLR), Precipitation Index (OPI), the Special Sensor Microwave/Imager (SSM/I) emission, the SSM/I scattering, and the TIROS Operational Vertical Sounder (TOVS). In addition, rain gauge data from the combination of the Global Historical Climate Network (GHCN) and the Climate Anomaly Monitoring System (CAMS), as well as the Global Precipitation Climatology Centre (GPCC) dataset which consists of approximately 6700 quality controlled stations around the globe interpolated into monthly area averages, are used over land. More details on the datasets and the method used to merge these data are provided by Adler et al. (2003). Although this dataset is superseded by v2.1 it is still included here for reference because it used in several studies.

2.2 GPCP v2.1 (1979-present)

Version 2.1 of the GPCP data had the same processing strategy as Version 2.0 described by Adler et al. (2003), and it takes advantage of the improved GPCC gauge analysis and the usage of the OPI estimates for the new SSM/I era. Thus, the main differences between the two versions are introduced by the use of the new GPCC full data reanalysis (Version 4) for 1997-2007, the new GPCC monitoring Product (version 2) thereafter and the recalibration of the OPI data to a longer 20-year record of the new SSM/I-era GPCP data. Further details on the new version can be found in Huffman et al. (2009).

2.3 ERA-Interim (1989-present)

ERA-Interim covers the period January 1989 to present (with approximately 1 month real time delay). The atmospheric forcing data was gridded on the original T255 reduced Gaussian grid (resolution of 0.7° at the Equator) with a 3-hour time interval. Precipitation data within ERA-Interim represent 3-hour averages, and to avoid the initial spin-up the 3-hourly forcing surface fluxes correspond to the 09-21h forecast interval from initial conditions at 00 and 12 UTC. The monthly mean is computed from the original 3-hourly model output at T255 resolution. Further details of the full ERA-Interim reanalysis products can be found in Simmons et al. (2007).

2.4 PRISM (1997-present)

As reference data for validation of the rescaling method/outputs, we use the PRISM (Parameter-elevation Regressions on Independent Slopes Model) monthly High-Resolution (4km) precipitation products over the conterminous U.S.A. PRISM is the USDA's official climatological data set and is widely considered as the major high-quality spatial climate data set currently available (Daly et al. 1994, 2000).

2.5 NCEP Stage IV (2002-present)

The NCEP Stage IV precipitation dataset contains precipitation analyses obtained from approximately 150 high-resolution Doppler NEXRAD radars and about 5500 hourly rain gauge reports over the continental U.S.A. (Baldwin and Mitchell, 1996; Lin and Mitchell 2005). The mainland U.S.A. Stage IV data is available hourly on a 4-km resolution polar-stereographic grid. We use this dataset for its high temporal and spatial resolution. However, this dataset is conceived for real-time use and it comes with missing data which make accumulation impossible for a direct comparison with monthly datasets.

3 Methodology

This study focuses on the validation of ERA-Interim short-term precipitation forecasts and a rescaled version. The 9-21h forecasts from 00 and 12 UTC are used to build a continuous 3-hourly precipitation time-series (1989-present). Interpolation of precipitation fields is a delicate issue since conservation should be imposed. All datasets considered in this study are interpolated with a conservative bilinear interpolation method in which the flux is computed according to the areal weight of each high resolution grid-box. Afterwards the conservation is re-established on the output resolution grid and the adjacent land grid-points having the largest weights get the excess (or deficit) of precipitation.

In order to improve ERA-Interim precipitation we propose a scale-selective rescaling procedure that corrects ERA-Interim 3-hourly precipitation in order to match the monthly accumulation provided by the GPCP v2.1 product at grid-point scale. This method uses the information from GPCP v2.1 at the scale for which this dataset is provided (for a spatial resolution of 2.5°x2.5°) and rescales the ERA-Interim precipitation at full resolution (about 0.7°x0.7°). The advantage of this procedure is that small scale features of ERA-Interim (for instance related to orographic precipitation enhancement) can be preserved while the monthly totals are rescaled to match GPCP. The latter is believed to be better calibrated due to use of rain-gauge observations.

The ERA-Interim precipitation rescaling factor is obtained by:

- interpolating conservatively the GPCP 2.5°x2.5° grid to its equivalent T95 Gaussian grid,
- interpolating conservatively the ERA-Interim T255 Gaussian grid to T95 Gaussian grid
- computing the rescaling factor at the T95 resolution (the observation resolution)
- interpolating bi-linearly the rescaling factor from the T95 to the T255 resolution.

This procedure is not new to Numerical Weather Prediction and mimics the idea of spectral blending introduced by Brožková et al. (2001) in order to retain small scale features of a Limited Area Model while initializing large-scale patterns from coarser resolution global analyses.

A formula for the rescaling factor, *Rf*, can be written as

$$Rf = \{ [GPCPv2.1]_{T95} / [ERA\text{-}Interim\_MM\ ]_{T95} \}_{T255} \qquad (1)$$

where *GPCPv2.1* and ERA-Interim_MM are the precipitation monthly means for a given month. The $[]_{95}$ and $\{\}_{255}$ denote conservative interpolation steps to T95 and T255 resolution respectively. The rescaled precipitation, *ERA-Interim_res*, can be obtained for each temporal resolution (from 3-hourly to monthly) as

$$ERA\text{-}Interim\_res = ERA\text{-}Interim * Rf \qquad (2)$$

This method can be applied globally and at each ERA-Interim grid point for which the monthly mean precipitation exceeds a minimum threshold (set to 0.005 mm/day). No attempt is made to correct the frequency of precipitation events. To evaluate this procedure, and its outputs, a dense observation dataset over the U.S.A. (PRISM) is used.

4 Results

The rescaling procedure is applied to ERA-Interim and evaluated against PRISM and NCEP Stage IV, respectively for the monthly and daily time-scales. Merits and limitation of this method are illustrated in the comparison of ERA-Interim and ERA-Interim-GPCP-rescaled precipitation. For monthly and annual verification, the GPCP (v2.0 and v2.1) are also shown as benchmark. Results are presented for annual, monthly and daily timescales as follows.

4.1 Annual precipitation

The mean annual ERA-Interim precipitation bias for the whole U.S.A. against PRISM is remarkably low (-0.01 mm/day) on the considered period and equal to -0.63 % of the mean annual precipitation. The geographical distribution of the annual mean results show that, in general, rescaling the precipitation has a positive effect over most of the conterminous U.S.A., especially over the Mississippi Valley and Gulf Coast where most of the precipitation occurs, as shown in Figure 1.

Rescaling by GPCP v2.1 brings an improvement for the large scale which is particularly important for flat areas. It is also noticeable when comparing Figure 1 (c) and (d) that the rescaled products can retain the information proper to the high spatial resolution of ERA-Interim while reducing the local bias, and greatly improved interannual variability as shown in Figure 1 (f) and (g). The mean annual bias of the ERA-Interim-GPCP-rescaled is slightly increased to 0.1 mm/day. Note that the bias in ERA-Interim-GPCP-rescaled cannot match exactly the bias of GPCP v2.1 due to differences in spatial resolution that affects the value of mean precipitation when re-mapped onto the verification area.

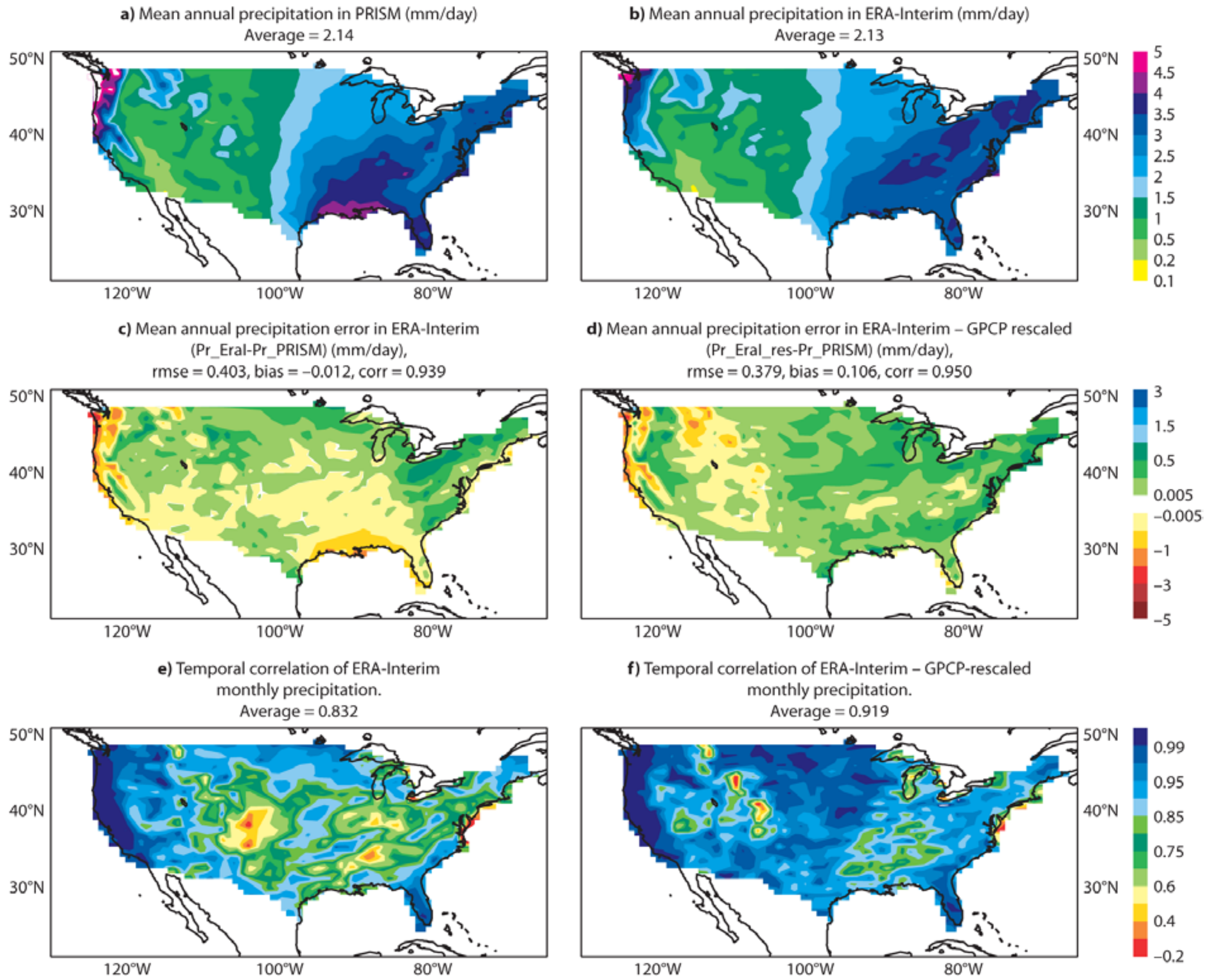

Figure 1: Annual precipitation calculated over the 2000-2008 period and expressed in mm/day for a) PRISM dataset, b) ERA-Interim. Panels c) and d) show the mean annual precipitation biases, and panels e) and f) show the temporal correlations of the monthly precipitation, for ERA-Interim and ERA-Interim-GPCP-rescaled, respectively.

4.2 Monthly precipitation

The RMSE, bias and correlation calculated on monthly means over the period 2000-2008 show a general increase in skill of the ERA-Interim-GPCP-rescaled precipitation indicating that with such method the output can benefit from both observation and reanalysis input data (Table 1 and Fig. 2).

	ERA-I	**ERA-I rescaled**	GPCP_V2.1	GPCP_V2.0
BIAS	-0.013	**0.101**	0.081	-0.068
RMSE	0.852	**0.687**	0.675	0.889
Correlation	0.853	**0.902**	0.899	0.816

Table 1: Average of 2000-2008 monthly bias, RMSE (mm/day) and correlation coefficient with respect to PRISM data.

The marked seasonal cycle for ERA-Interim bias (Figure 2b), with positive and negative peaks exceeding +/- 0.2 mm/day in April and July respectively, has been eliminated in the bias correction procedure. The RMSE also showing a pronounced seasonal cycle indicate a marked improvement from the bias correction. The corrected ERA-Interim product has better skill in winter and worse in summer compared to GPCP v2.1. We speculate that dynamic weather systems in winter are “easier” to simulate in NWP than convective systems in summer. The improvement of GPCP v2.1 in comparison to v2.0 is confirmed on a monthly basis and the higher monthly average of the GPCP V2.1 (reported in Huffman et al. 2009) is confirmed by the bias which went from -0.07 to +0.08 mm/day affecting on the same way the rescaled precipitation bias (Figure 2b). Such relatively low biases may be related to the precipitation analysis method (e.g. differences in wind corrections).

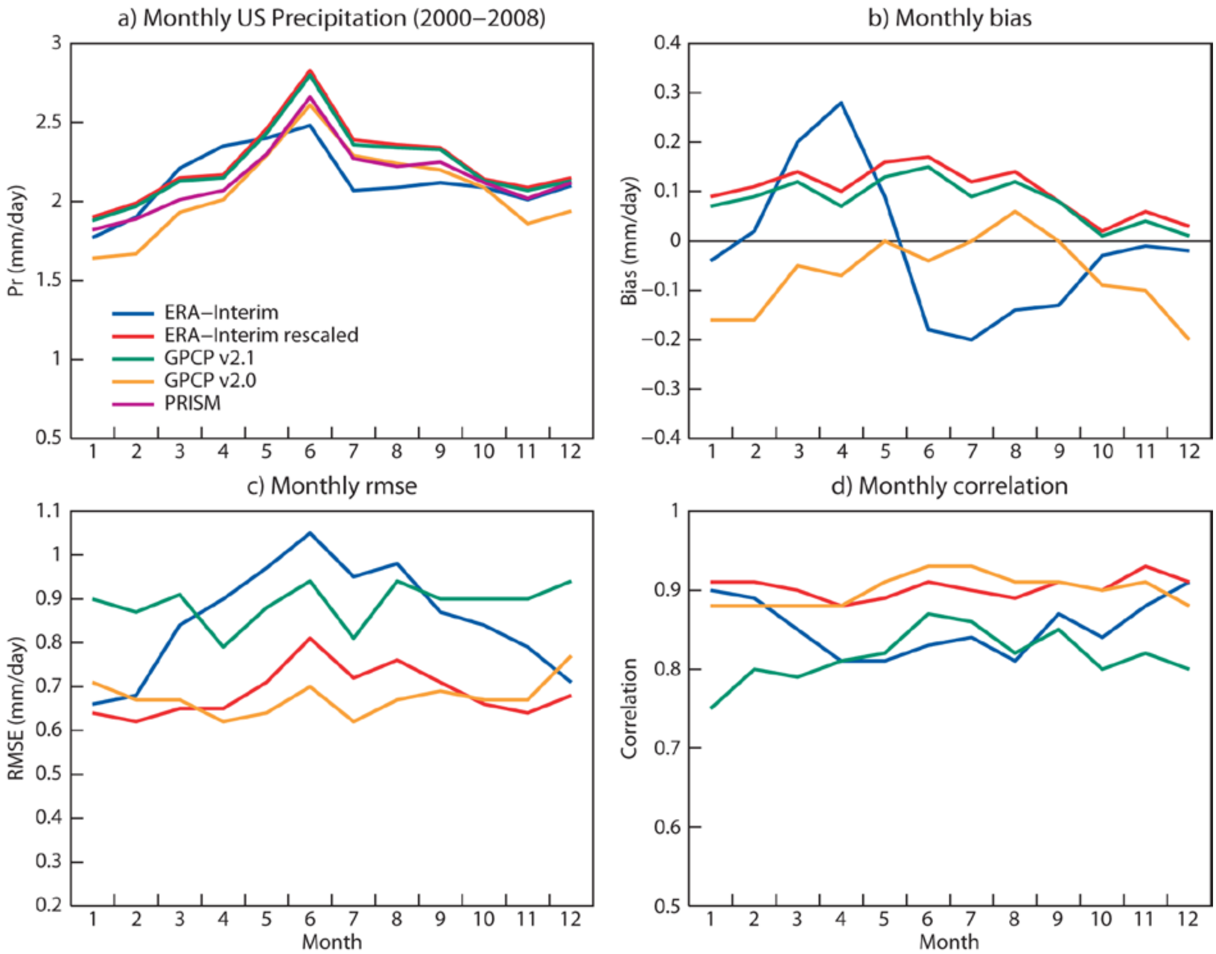

Figure 2: a) Average of monthly precipitation: ERA-Interim (blue), PRISM (violet), GPCP_V2.1 (light green), GPCPv2.0 (green); b) Monthly bias: ERA-Interim (blue), ERA-Interim-GPCP-rescaled (red), GPCPv2.1 (light green), GPCP_V2.0 (green), c) same as (b) but for RMSE, d) same as (b) but for correlation with PRISM data.

The rescaling method increased the spatial correlation to PRISM up to 0.90, with a net increase of 6% on average comparing to ERA-Interim. Although the benefit is found throughout the year, the largest impact on RMSE and correlation occurs in June and July with a 9% increase in correlation.

The average of grid-point based temporal correlations is enhanced from 0.83 in ERA-Interim to 0.92 in ERA-Interim-GPCP-rescaled.

4.3 Daily precipitation

The daily accumulated precipitation is verified against the NCEP Stage IV dataset using daily 24-h accumulation from 12h-UTC. The aim of this comparison is to verify that the rescaling procedure does not alter the synoptic variability of ERA-Interim. A set of daily accumulation is extracted for 2008 and bias, RMSE and correlation coefficient are calculated and reported in Table 2. However, in this case general considerations on the biases are limited by the presence of missing values in NCEP Stage IV data (which lead to an observational bias with respect to the true precipitation). The correlation coefficient is considered the most reliable metric of improvement and therefore average daily correlations calculated for each month are shown in Figure 3. The largest impact is confirmed to be in June and July with improvements in correlation of +8.7% and +6.8 %, respectively, while December is marginally deteriorated (-1.5 %). The annual average daily correlation of ERA-Interim precipitation is 0.546 and is slightly improved by the rescaling method (+2.8%). Changes in bias and RMSE, although positive, are negligible as reported in Table 2.

	ERA-I	ERA-I rescaled
BIAS	0.546	0.566
RMSE	4.797	4.711
Correlation	0.560	0.575

Table 2: Average of 2008 daily bias, RMSE (mm/day) and correlation coefficient with respect to NCEP Stage IV data.

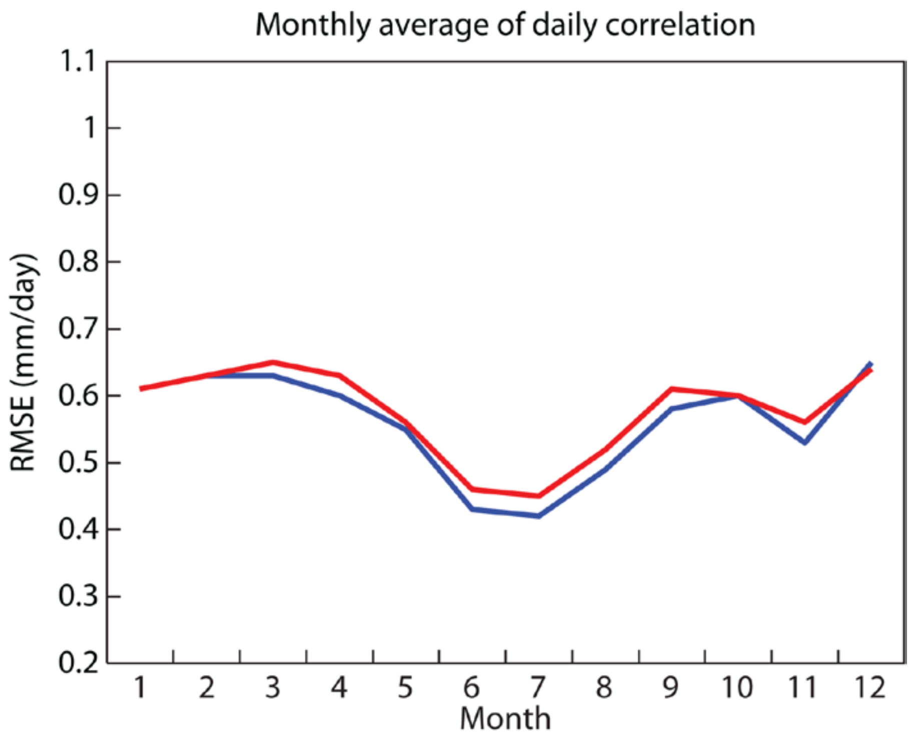

Figure 3: Monthly average of daily correlations for ERA-Interim-GPCP-rescaled (red) and ERA-Interim (blue) with respect to NCEP Stage IV dataset in 2008.

5 Conclusions

This study assesses the value of ERA-Interim precipitation over U.S.A. and proposes a methodology to rescale the re-analysis precipitation using GPCP v2.1 to construct a long forcing dataset for land surface multi-model intercomparison projects such as the Water and Global Change (WATCH) project and the follow-on to Global Soil Wetness Project. The method is validated for monthly and annual means through a comparison with PRISM used as an independent high resolution dataset. The validation has shown that the original ERA-Interim products have reasonable skills over the selected time period (2000-2008), with low annual bias and quite remarkable skill, especially in winter. The ERA-Interim rescaling improves RMSE and spatial/temporal correlations by combining the advantages of the observation-based GPCP v2.1 product with those of the original high resolution ERA-Interim data. Skills in daily precipitation, evaluated with respect to NCEP Stage IV data, are also improved by the rescaling method, especially in the summer months. The rescaled precipitation remains meteorologically consistent with all the other ERA-Interim forcing for land surface modelling applications. Overall the rescaling methodology proves to be positive on all considered time-scales and adds information to the ERA-Interim precipitation. These results are encouraging for the future assimilation of ground-based precipitation data into atmospheric models.

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References

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, E.J. Nelkin, 2003: The Version 2.1 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979 -Present). *J. Hydrometeor*., **4**(6), 1147-1167.

Baldwin M. E., and K. E. Mitchell, 1996: The NCEP hourly multi-sensor U.S.A. precipitation analysis. *Preprints, 11th Conf. on Numerical Weather Prediction*, Norfolk, VA, Amer. Meteor. Soc., J95–96.

Bosilovich, M.G., J. Chen, F.R. Robertson, and R.F. Adler, 2008: Evaluation of Global Precipitation in Reanalyses. *J. Appl. Meteor. Climatol.*, **47**, 2279-2299.

Brožková, R., Klaric, D., Ivatek-Sahdan S., Geleyn, J.-F., Cassé, V., Široká, M., Radnóti, G., Janoušek, M., Stadlbacher, K., Seidl, H., 2001, DFI Blending: an Alternative Tool for Preparation of the Initial Conditions for LAM. *SAC/JSC WGNE Report* No. 31, WMO/TD-No. 1064, 1, 7-8.

Daly, C., Neilson, R.P. and Phillips, D.L., 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology*, **33**, 140-158.

Daly, C., Taylor, G.H., Gibson, W. P., Parzybok, T.W., Johnson, G. L., Pasteris P., 2001. High-quality spatial climate data sets for the United States and beyond. *Transactions of the American Society of Agricultural Engineers*, **43**, 1957-1962.

Descharme, B.,Douville, H., 2006: Uncertainties in the GSWP-2 precipitation forcing and their impacts on regional and global hydrological simulations. *Clim. Dyn*. **27**, 695-713.

Dirmeyer, P.A., Gao, X. and Oki, T., 2002. The Second Global Soil Wetness Project - Science and Implementation Plan, *IGPO Int. GEWEX Project Office Publ. Series* 37, 65 pp.

Dirmeyer, P.A., X. Gao, M. Zhao, Z. Guo, T. Oki, and N. Hanasaki, 2006: GSWP-2: Multimodel Analysis and Implications for Our Perception of the Land Surface. *Bull. Amer. Meteor. Soc*., **87**, 1381–1397.

Huffman G. J., R. F. Adler, D. T. Bolvin, G. Gu (2009), Improving the global precipitation record: GPCP Version 2.1, *Geophys. Res. Lett*., **36**, L17808, doi:10.1029/2009GL040000

Koster, R.D., Z. Guo, P.A. Dirmeyer, G. Bonan, E. Chan, P. Cox, H. Davies, C.T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C.H. Lu, S. Malyshev, B. McAvaney, K. Mitchell, D. Mocko, T. Oki, K.W. Oleson, A. Pitman, Y.C. Sud, C.M. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2006: GLACE: The Global Land-Atmosphere Coupling Experiment. Part I: Overview. *J. Hydrometeor*., **7**, 590-610.

Koster, R., S. Mahanama, T. Yamada, G. Balsamo, M. Boisserie, P. Dirmeyer, F. Doblas-Reyes, T. Gordon, Z. Guo, J.-H. Jeong, D. Lawrence, Z. Li, L. Luo, S. Malyshev, W. Merryfield, S. I. Seneviratne, T. Stanelle, B. van den Hurk, F. Vitart, and E. F. Wood, 2009: The Contribution of Land Surface Initialization to Subseasonal Forecast Skill: First Results from the GLACE-2 Project, *Geophys. Res. Lett*., 2009GL041677R.

Lin Y., and K. E. Mitchell, 2005: The NCEP stage II/IV hourly precipitation analyses: Development and applications. *Preprints, 19th Conf. on Hydrology*, San Diego, CA, Amer. Meteor. Soc., CD-ROM, 1.2.

Lopez, P., and P. Bauer, 2007: 1D+4DVAR Assimilation of NCEP Stage IV Radar and Gauge Hourly Precipitation Data at ECMWF. *Mon. Wea. Rev*., **135**, 2506-2524.

Pappenberger, F., and R. Buizza, 2009: The Skill of ECMWF Precipitation and Temperature Predictions in the Danube Basin as Forcings of Hydrological Models. *Wea. Forecasting*, **24**, 749-766.

Richardson, D.S., Bidlot, J., Ferranti, L. , Ghelli, A., Janousek, M., Leutbecher, M., Prates, F., Simmons, A.J., Uppala, S.M., Dee, D. and Kobayashi, S., 2007. ERA-Interim: New ECMWF reanalysis product from 1989 onwards. *ECMWF Newsletter*, 110: 25-35 (Available from http://www.ecmwf.int/publications/newsletters/).

Simmons A.J., Uppala S.M., Dee D. & Kobayashi S., 2007: ERA-Interim: new ECMWF reanalysis product from 1989 onwards. *ECMWF Newsletter,* 110, 25–35. (Available from http://www.ecmwf.int/publications/newsletters/).

See also:

ERA-Interim dataset: http://data-portal.ecmwf.int/data/d/Interim_daily/

GPCP dataset: http://precip.gsfc.nasa.gov/

PRISM dataset: http://www.prism.oregonstate.edu/

NCEP Stage IV dataset: http://wwwt.emc.ncep.noaa.gov/mmb/ylin/pcpanl/stage4/

WATCH project web-site: http://eu-watch.org/