Intercomparison of Atmospheric Water Balance over Indian monsoon region using Major Reanalysis Datasets

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ABSTRACT

The atmospheric water balance over different domains within the South Asian Monsoon region has been studied using moisture convergence (C) computed from JRA-25, ERA-40 and NCEP/NCAR reanalysis datasets, GPCP precipitation data (P) and evaporation (E) as a residual of these two parameters. The seasonal climatology of P, C, and E for the selected regions shows generally large contribution of E to P. The inter-annual characteristics of P, C and E over selected key domains with in the South Asian Monsoon region have also been examined for both early (JJ) and late summer (AS) monsoon periods from 1979 to 2000. The spatial and temporal characteristics of the hydrological cycle and the contribution of E and C to P are discussed in detail.

1. Introduction

In this study, we compared the characteristic features of seasonal and interannual variations of atmospheric water balance over the Indian monsoon region using major reanalysis datasets during satellite observation period (1979-2000). There are a few previous regional studies which uses observed precipitation to obtain atmospheric water balance (Oki et al., 1995; Fukutomi et al., 2003; Marengo, 2005). The evaporation obtained as a residual from the water balance method suffers from substantial errors; the accuracy of (E) depends on the accuracy of observed (P) as well as the accuracy of computed (C). In this paper, we tried to exploit the advantages of atmospheric water budget analysis for understanding precipitation generation over different sub-domains within Indian monsoon region using GPCP dataset and major reanalysis datasets.

2. Data and Methodology

The Global Precipitation and Climatology Project (GPCP) Precipitation (Adler et al. 2003), NCEP/NCAR (Kalnay et al. 1996), ERA-40 (Uppala et al. 2005) and JRA-25 reanalysis datasets (Onogi et al. 2005) daily and 6 hourly dataset from 1979-2000 period are used for this investigation.

Following the seminal works on global water budget studies (Trenberth, 1991; Oki et al., 1995; Trenberth and Guillemot, 1998; Trenberth, 1999), we have attempted to understand the atmospheric water balance over South Asia. The total vertically integrated moisture convergence is computed for all the datasets. Evaporation is obtained as a residual from the precipitation and the convergence.

The atmospheric water budget equation can be written as (Peixoto and Oort 1992),

$$< \partial W/ \partial t > + < \nabla . \mathbf{Q} > = < E - P > \text{ ...... (1)}$$

On longer timescales (monthly to seasonal)

$$< \partial W/ \partial t > \sim 0 \text{ ....(2)}$$

Vertically integrated moisture flux vector (**Q**) is given by,

$$\mathbf{Q} = 1/g \int_{Pt}^{Ps} q\mathbf{v}dp \text{ ....(3)}$$

There fore we can approximately write,

P ~ C + E ....(4)

3. Results

The interannual variability of early and late summer precipitation over the Indian monsoon region using atmospheric water balance method elucidates the relative role of C and E contribution to P variability. Especially results are in good agreement over the central Indian domain (CEN) in all the reanalysis datasets. However, notable differences in the vertically integrated moisture convergence are seen over domains like, (NWI), (ARS) and (BOB) (Figure 2). Generally, moisture convergence is stronger in JRA25 which uses high-resolution model (T106) than those from the other two reanalysis. We further assessed the different characteristics and features of the three reanalysis data in terms of atmospheric water budgets. However, for the sake of brevity we show only results from the atmospheric water budget analysis based on JRA-25 dataset. The JRA-25 reanalysis dataset is better compared to other two reanalysis datasets. Still, large differences are noted in the monthly mean annual cycle of convergence over most of the domains. But all the reanalyses agree over Central Indian domain, where observations are dense. Though there are discrepancies in the monthly mean convergence, most reanalyses capture the interannual signatures quite well (Figure 3).

The JRA-25 reanalysis products are used to study atmospheric water budget over Indian monsoon domain due to the higher correlation of moisture convergence with observed precipitation. The monthly mean annual cycle of water budget components are brought out over most of the regions using JRA-25 reanalysis datasets (Figure 4). Seasonal and interannual variability for early (JJ) and late (AS) seasons do exhibit differences in terms of atmospheric water budget components suggesting that the mechanism of precipitation generation for early and late seasons are quite different over some regional domains.

The interannual variability of early and late summer precipitation over the Indian Monsoon region studied using atmospheric water balance method and the relative role of C and E contribution to P variability differ between early and late summers (Figure 5).

To study the precipitation variability on interannual time scale, the interannual variations of water budget components are plotted for both early and late summer for each domain. The correlation coefficient (CC) between ΔP and ΔC, ΔP and ΔE are used to understand the relationship of these three components in the interannual variability. Since E is obtained as a residual from P and C, E contains the P signature when C does not vary, so care has been taken while interpreting correlation between P and E. For understanding the interannual variability of P, C and E over domains like NWI, NEI and CEN only land grid points are considered for area average.

Though the contribution of evaporation to mean seasonal precipitation is high over the Northwest Indian region both in early and late summer monsoon period, the correlation between (ΔP) and (ΔC) are 0.86 and 0.81 (exceeds 95% significant level) for early and late summer, respectively, and correlation between (ΔP) and (ΔE) are 0.05 and 0.22 (Figs. 5a and 5b). Therefore (ΔC) affects the year-to-year variability of (P) over NWI monsoon region.

NEI monsoon region shows correlation coefficients of 0.49 and 0.54 between (ΔP) and (ΔC) (at just above 95% of significant level) for early and late summer respectively, JJ (0.63) and AS (0.59) between (ΔP) and (ΔE) (above 95% of significant level) respectively (Figs. 5e and 5f). These results suggest that evaporation also partly play a role in modulating the precipitation anomalies.

Similarly, over the CEN region precipitation (ΔP) is highly correlated with convergence (ΔC) (above 95% of significant level) for both early and late summer monsoon periods (Figs. 5c, 5d) and the CC between ΔP vs. ΔE in

CEN considerably changes from JJ (0.41) to AS (0.08) suggesting that though C > E in the early summer and E > C in the late summer, while the interannual variability for respective seasons are reversed, i.e., ΔE contributes to ΔP for early summer and ΔC contributes to ΔP for late summer respectively.

Large discrepancies in the moisture convergence (Figure 6) are noticed over Bay of Bengal and Arabian Sea domains due to lack of observations over oceans. Large discrepancies are also noted in the vertically integrated moisture fluxes. For example, differences among the reanalyses are higher for 850hpa humidity (Figure 8) than for the 850hpa wind fields (Figure 7). Mostly the difference in the moisture flux vectors stem from discrepancies in the humidity (Figure 9). Therefore, proper representation of upper level humidity is crucial for studies related to hydrological cycle using reanalysis datasets.

4. Precipitation variability over CEN domain with respect to atmospheric water balance

Precipitation (P), large-scale convergence (C), winds, moisture transport vectors and evaporation (E) are regressed with the averaged GPCP precipitation index over each domain in order to understand the structure of (P) variability, over the CEN domain. A test of local statistical significance for spatial correlation coefficient was performed using standard t-test for plotting above 95% significance level (Figures 10).

Interannual variability over Central India (CEN) during early and late summer largely driven by large scale moisture convergence and evaporation from the surface also contribute to the (P) variability(Figure 10).

5. Conclusions

The interannual variability of early and late summer precipitation over the Indian monsoon region using atmospheric water balance method elucidates the relative role of C and E contribution to P variability. Especially results are in good agreement over the central Indian domain (CEN) in all the reanalysis datasets. However, notable differences in the vertically integrated moisture convergence are seen over domains like, (NWI), (PEN) and (ARS).

On the interannual time scales, the NEI domain precipitation anomalies are not directly influenced by large-scale convergence both in early and late summers, whereas the evaporation is likely to play at least partly a role in modulating the anomalies over NEI. These results suggest that some surface hydrological processes are responsible for modulating monsoon over NEI domain during summer season. Still, this is a tentative result, as the accuracy of computed (C) and observed (P) over this region has known limitations.

Large discrepancies are noted in the moisture fluxes. Differences among the reanalyses are higher for humidity than for the wind fields. Mostly the difference in the moisture flux vectors stem from discrepancies in the humidity.

Thus proper representation of upper level humidity and moisture divergence field is crucial for studies related to hydrological cycle using reanalysis datasets.

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Figures

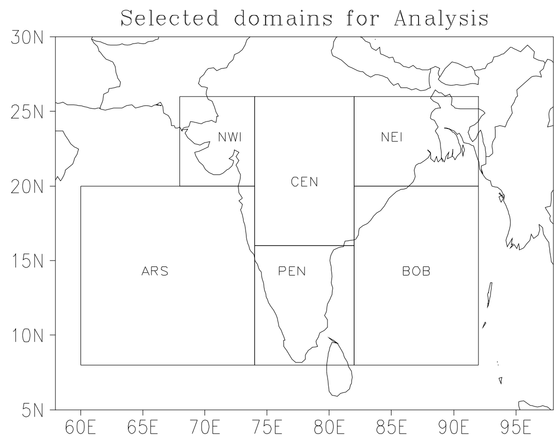

Figure 1. Selected boxes over South Asia for analysis of atmospheric water balance.(NWI: North West India) (NEI: North East India) (CEN: Central India) (PEN: Peninsular India) (ARS: Arabian Sea) (BOB: Bay of Bengal)

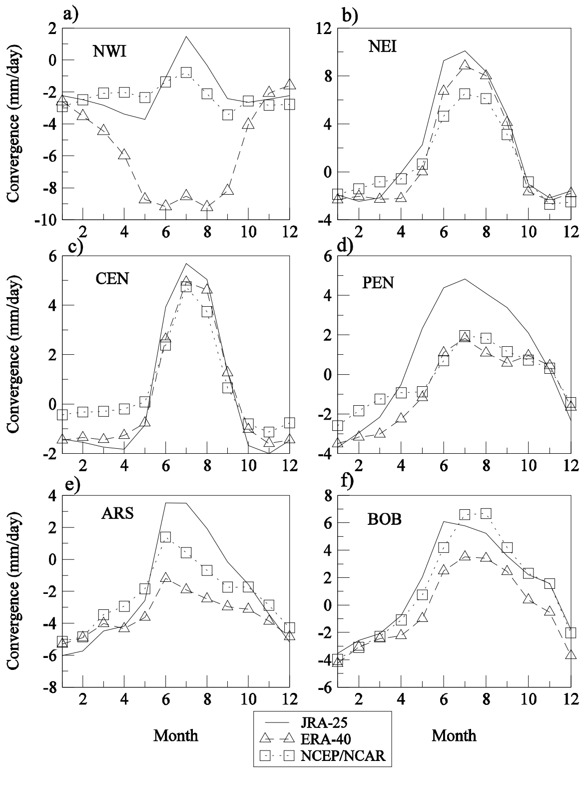

Figure 2. Monthly mean annual cycle of vertically integrated moisture convergence. (NWI: North West India) (NEI: North East India) (CEN: Central India) (PEN: Peninsular India) (ARS: Arabian Sea) (BOB: Bay of Bengal). [Convergence: + ; Divergence: -]

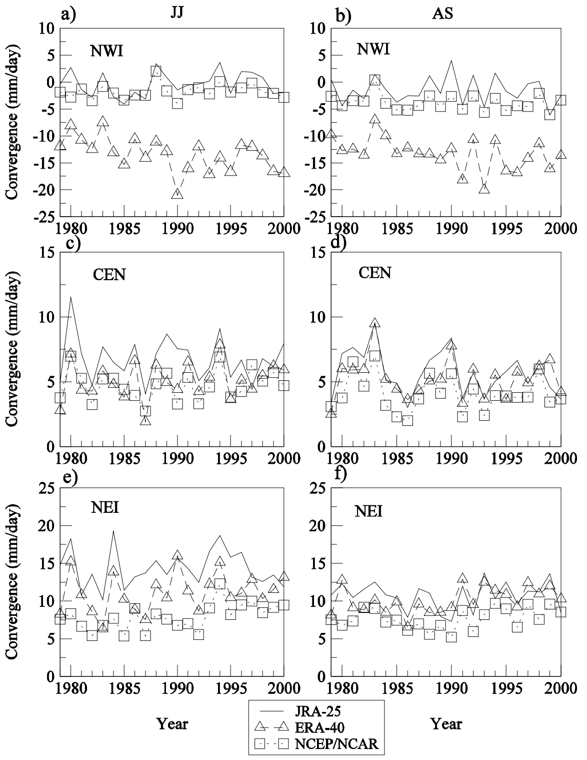

Figure 3. Interannual variations of convergence (C) over different domains of South Asia in three major reanalysis (JRA-25, ERA-40 and NCEP/NCAR) datasets. [Top Panel] for NWI domain a) early summer (JJ) and b) late summer (AS), [Middle Panel] for CEN domain c) early summer (JJ) and d) late summer (AS). [Bottom Panel] for NEI domain e) early summer (JJ) and f) late summer (AS).

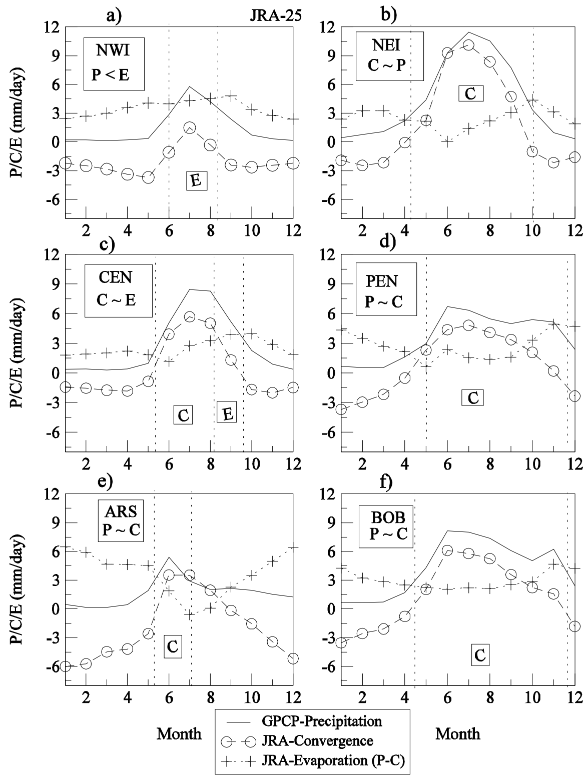

Figure 4. Observed monthly mean annual cycle of P, C and E over South Asia using JRA-25 dataset. (NWI: North West India) (NEI: North East India) (CEN: Central India) (PEN: Peninsular India) (ARS: Arabian Sea) (BOB: Bay of Bengal). (Dominance of convergence or evaporation is shown as C or E in boxes). Vertical dotted lines delineate the summer months from the rest of the months where dominance of E or C is valid. Box in the left top shows the relationship among P, C, and E during the monsoon season over the respective domains.

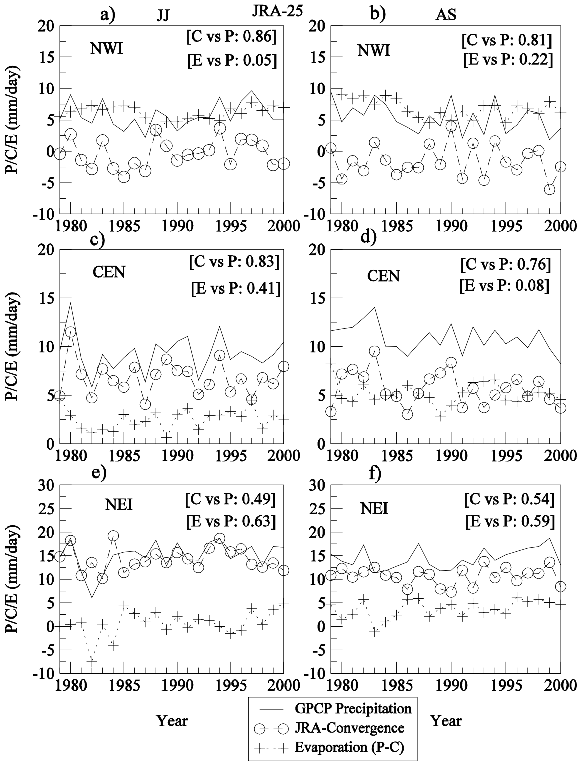

Figure 5. Interannual variations of P, C and E over south Asia from JRA-25 dataset. [Top Panel] for NWI domain a) early summer (JJ) and b) late summer (AS), [Middle Panel] for CEN domain c) early summer (JJ) and d) late summer (AS). [Bottom Panel] for NEI domain e) early summer (JJ) and f) late summer (AS). (Value of correlation coefficient between P and C & P and E are shown in each graph) [95% significant level is +/- 0.42]

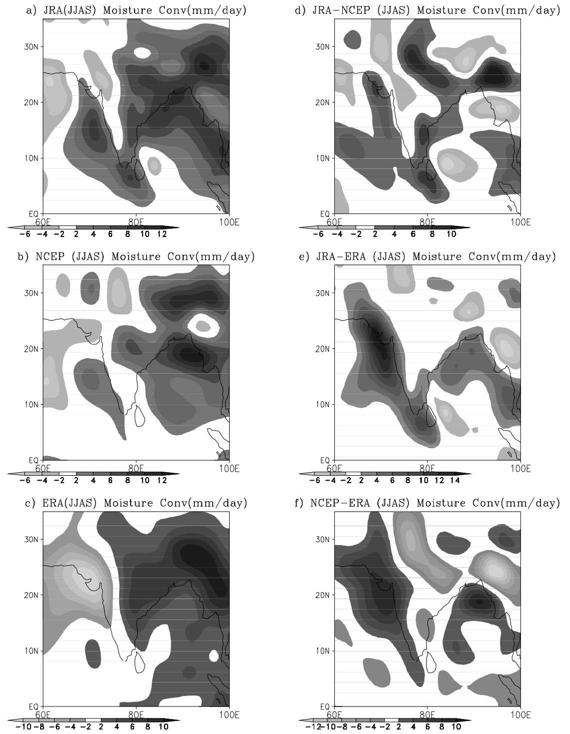

Figure 6. Observed monthly mean spatial pattern of Convergence over Indian monsoon region among the datasets and their differences.

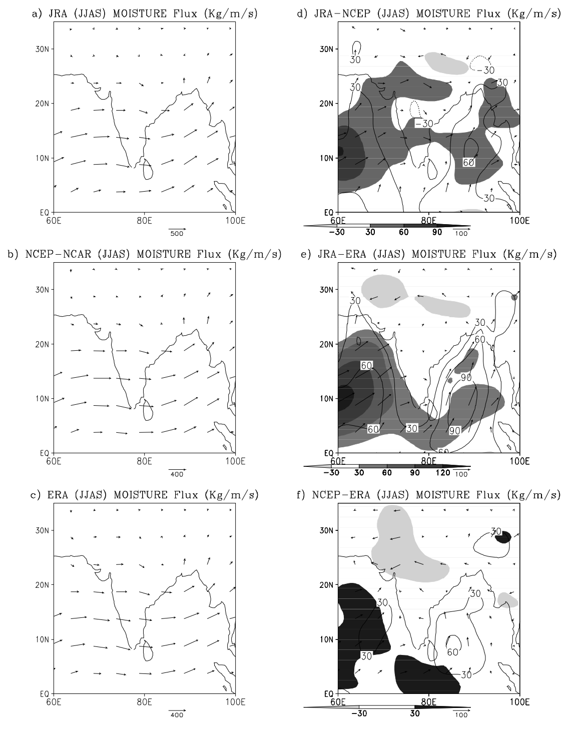

Figure 7. Observed monthly mean spatial pattern of Moisture fluxes over Indian monsoon region among the datasets and their differences.

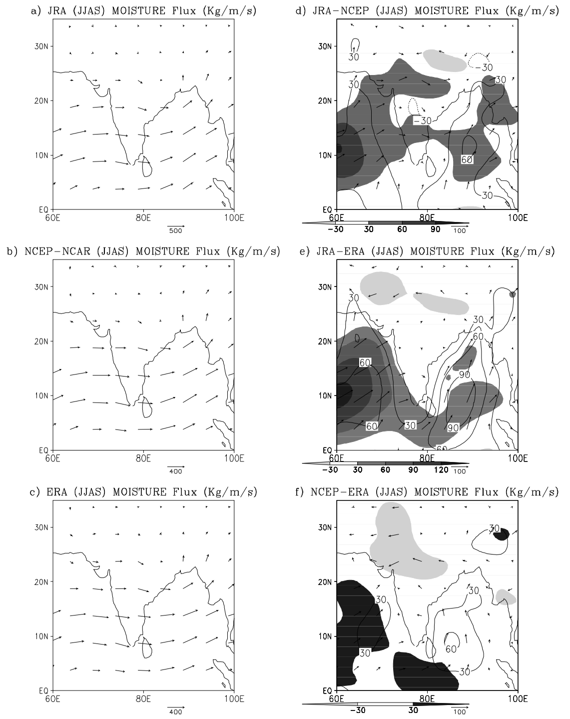

Figure 8. Observed monthly mean spatial pattern of 850hpa winds over Indian monsoon region among the datasets and their differences.

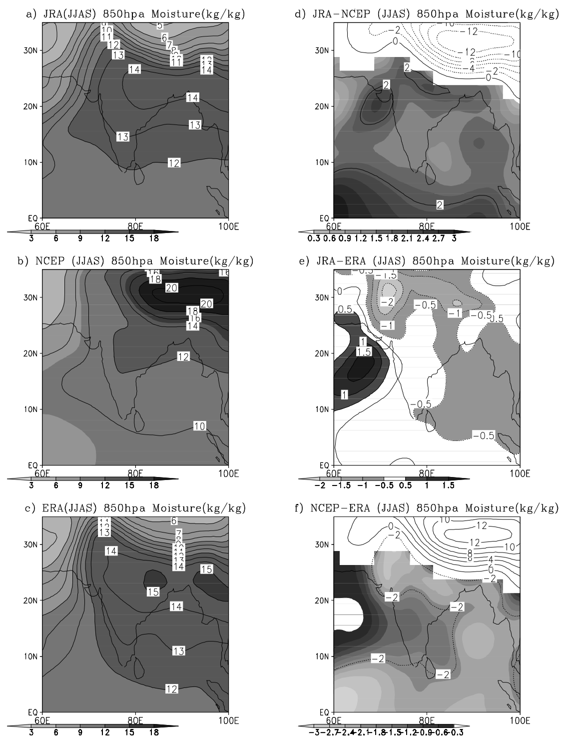

Figure 9. Observed monthly mean spatial pattern of 850hpa Specific humidity over Indian monsoon region among the datasets and their differences.

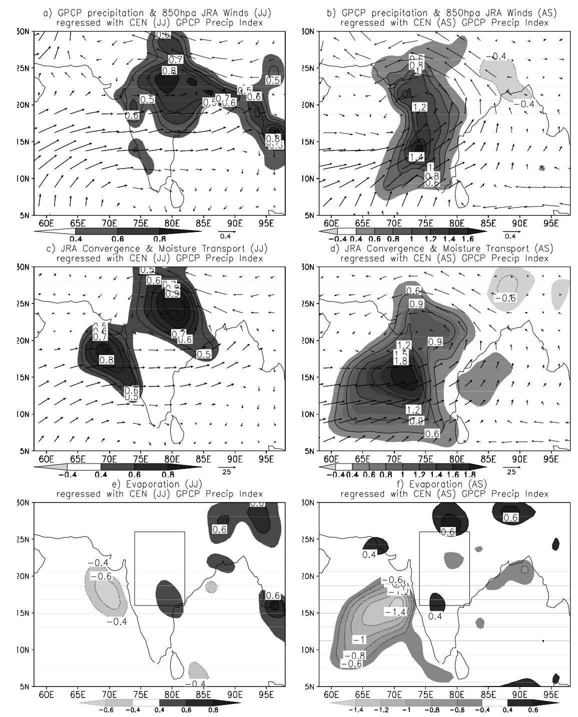

Figure 10. Regression maps based on Central India (CEN) domain averaged GPCP precipitation for JRA-25 dataset. [Top panel] GPCP Precipitation and 850hpa winds, a) for early summer (JJ) b) for late summer. [Middle Panel] Moisture Convergence and moisture flux transport, c) for early summer d) for late summer. [Bottom Panel] Evaporation, e) for early summer f) for late summer. [Domain for precipitation index is shown by a box in the Bottom panel. Shaded values and thick arrows are significant at 95% level]. (Shaded bar indicates regression coefficient), (Units for precipitation & convergence: mm/day, winds: m/sec, moisture flux: kg $m^{-1} s^{-1}$).