Global retrospective analysis using NGFS for the period 2000–2011

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The National Centre for Medium Range Weather Forecasting (NCMRWF) conducted its first global data retrospective analysis (reanalysis) for the period 1 January 2000–31 March 2011 using its GFS based system (NGFS). This reanalysis is called NGFS-R and the main objectives of this effort are to address issues for studying decadal variability of the Indian summer monsoon, high-resolution global analysis fields to study the Indian monsoon and to provide short-term mean fields for its seasonal/long-term forecasts by ensemble methods. NGFS-R has been conducted with the T574L64 version of the Global Data Assimilation and Forecasting System of NCMRWF that is operational as of May 2015, and using CFS-reanalysis data dump. With this effort, a high-resolution global data analysis at 6 h intervals is made available for about 16 years (2000–2015) for various uses and applications.

Keywords: Global data assimilation and forecasting, monsoon season, numerical weather prediction models, retrospective analysis.

THE objective of data assimilation methods is to provide an estimate of the state of the atmosphere at any particular time by combining information from *in situ* and remote sensing observations with an a priori estimate of that state obtained from a short-term forecast generated using numerical weather prediction (NWP) models. The quality of these analyses depends on data assimilation methods and NWP models used to generate the a priori 'first guess' analysis estimates[1]. Operational runs of Global Data Assimilation and Forecasting (GDAF) system at National Centre for Medium Range Weather Forecasting (NCMRWF), have been started since 1994 and this system has been upgraded from time to time for incorporating the latest advances in model physics, analysis schemes and skills to assimilate new types of datasets into the model[2]. These changes were made with an aim to increase the forecast skill of the GDAF system. The latest significant change in the system is the enhancement of the model resolution to T574L64 and other relevant changes that are reported in detail by Prasad *et al.*[3]. This upgraded system produces model forecasts at about 23 km horizontal resolution and the skill of the useful forecast increased by about 24 h. The analysis and forecasts generated by this system are in turn used in mesoscale models, coupled atmospheric models and with ocean state forecast models in India. Using these improved GDAF outputs also improved the user model systems[4]; however, some of the systems require long-term GDAF outputs. The GDAF analysis is crucial for generating accurate real-time forecasts, but it has limited utility in studying trends over longer period and in climate change research due to artificial variability associated with the above-mentioned frequent changes. Modern reanalyses have been proposed as a remedy for this problem, with an emphasis on regenerating the synoptic analyses over several decades using a fixed data assimilation system and NWP model[1,5–7]. By adopting the same strategy, NGFS-R reanalysis has been initiated for the period 1 January 2000–31 March 2011. NGFS-R took about nine months to be completed (in January 2016) and was run using the new High Power Computing (HPC) system (Bhaskara 350 terraflop IBM idataplex system).

Before the 2010 period, the main source of global meteorological observations at NCMRWF was Regional Telecommunication Hub (RTH), India Meteorological Department (IMD), New Delhi, which in turn receives data through the Global Telecommunication System (GTS) of World Meteorological Organisation (WMO). The volume of these data is comparatively less than the contemporary operational NWP centres and it mainly consists of conventional data. The satellite and other remote sensing data were almost absent, except for few datasets like atmospheric motion vector (AMV) winds from geostationary satellites and scatterometer winds, etc. Thus, for maximizing data usage in reanalysis data dumps in CFS-analysis system are used. In these data dumps global conventional dataset and wind observations from geostationary satellites (AMV) and scatterometers are available in the PREPBUFR format (Figure 1). They are compared with current operational conventional observations (Figure 2). It clearly shows that the distribution of observations that are ingested is similar to most of the observations. The number of ship observations increased and additional ship routes have also been added over the years. The number of land synoptic observations over Amercian and European continents is more in CFS-observational data, as India is not receiving METAR-type of observations in real time. Further, it can be clearly seen that CFS-observational dataset contains a good number of observations over the Indian region as well. Figure 3 shows increase in conventional observations over the reanalysis period. This increase is mainly due to increase in satellite-based wind products such as AMV winds, scatterometer ocean surface wind, and rain observations like SSM/I and TRMM precipitation rates. Even though these are satellite-based datasets, they are retrieved geophysical products and are considered as conventional observations only and packed in PREPBUFR format. The satellite direct radiance datasets are packed in separate files in NCEP-BUFR format. Figures 4 shows

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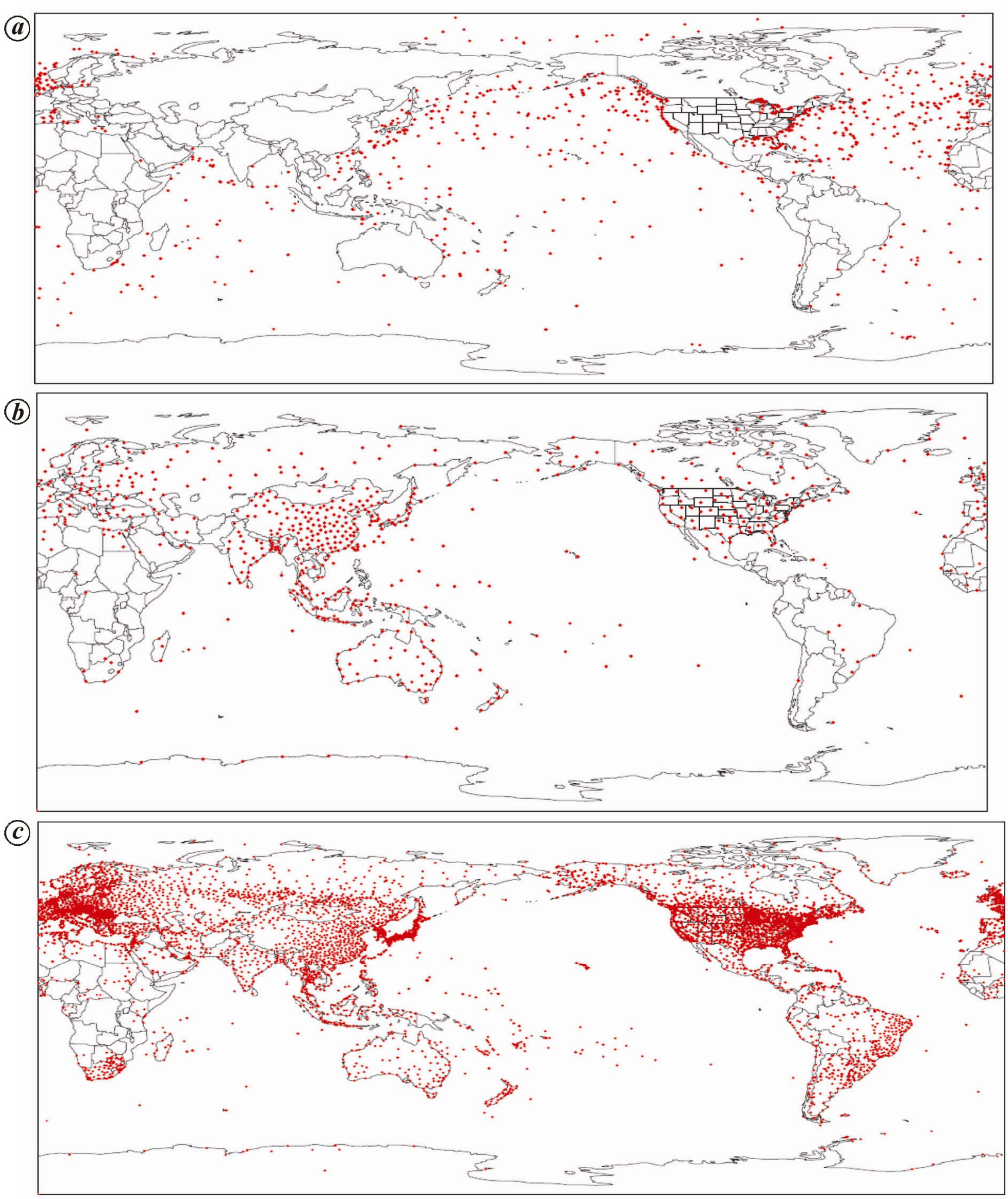

Figure 1. Distribution of conventional observations for a typical cycle (20050511 00Z) during reanalysis: ***a***, surface ship; ***b***, radiosonde and pilot ballon; ***c***, land synoptic.

year-wise availability of different satellites in terms of volume per observation per month and these datasets are assimilated according to this availability. Table 1 presents data counts, rejection rates and difference of observations with first guess for each type of conventional observation used in NGFS-R for a typical cycle. It can be clearly observed that a good percentage of data is accepted and the quality of analysis is satisfactory.

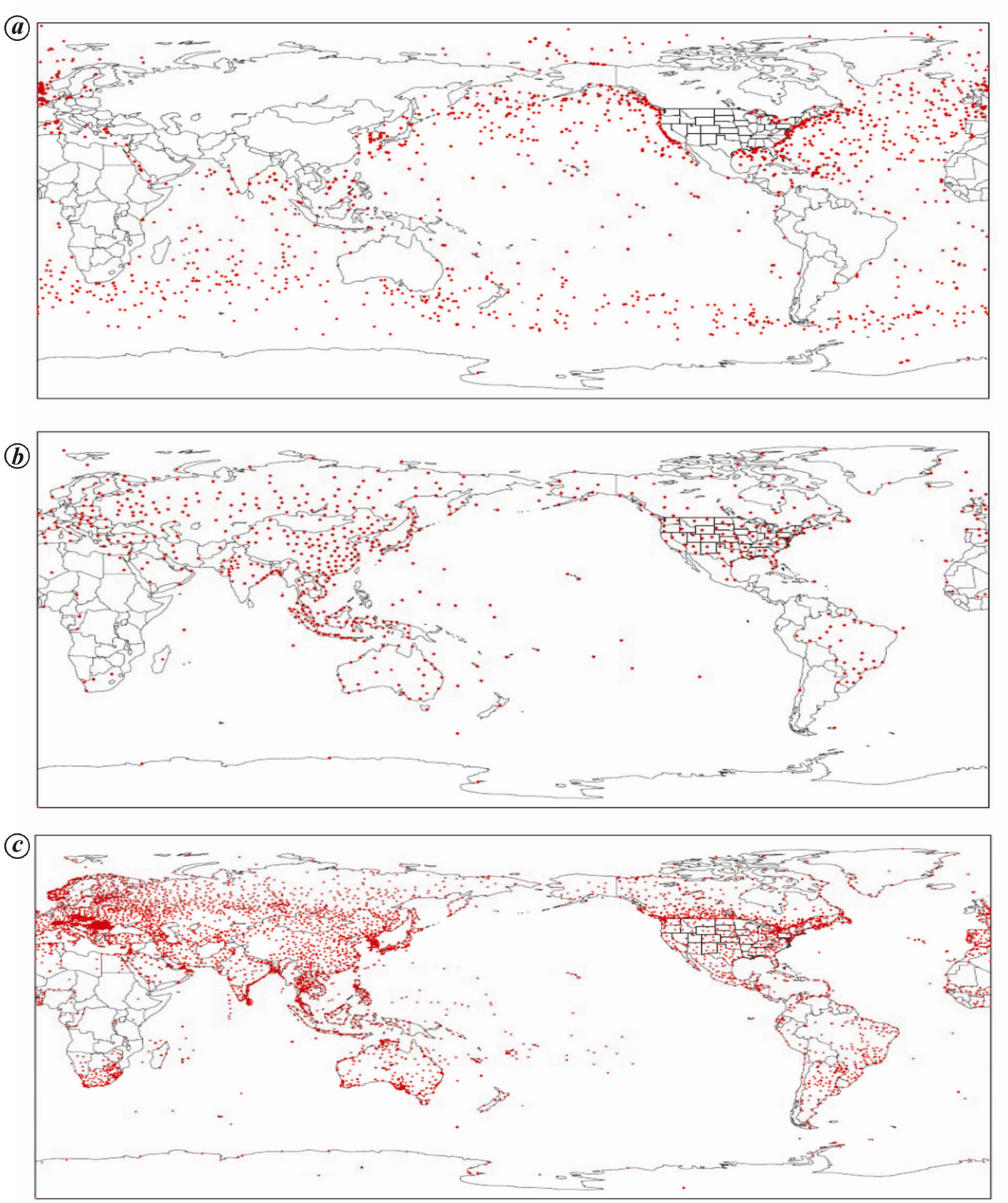

Figure 2. Same as Figure 1, but for a typical cycle (20150511 00z) in NCMRWF operational GDAF system.

NCMRWF started assimilating direct satellite radiances from 2006 onwards and the same are implemented in the total NGFS-R period. The cloud-cleared radiances from different satellite sensors depending on their availability (as shown in Figure 2) are assimilated in NGFS-R system. The GNSS-RO refractivities have been used since July 2006 in NGFS-R. The assimilation of GNSS-RO observations does not require any bias correction because they are derived from atmospheric time delays of radio signals, which can be measured by an atomic clock with high accuracy. Further, the quality of GNSS-RO observations is hardly affected by surface and weather conditions. NGFS-R assimilates an average of approximately 500 refractivity profiles from the entire globe in every analysis cycle. Therefore, GNSS-RO observations together with radiosonde observations are important for constraining model biases and for the anchoring analysis system.

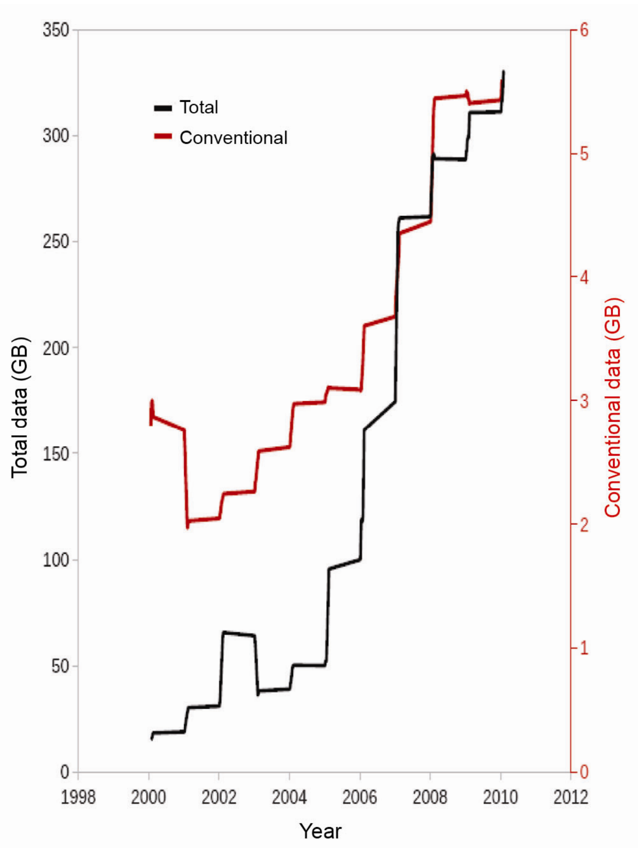

Figure 3. Changes in the monthly mean volume of conventional and satellite datasets during the period 2000–2010.

This high-resolution reanalysis product is mainly expected to be used in the study of decadal variability of Indian summer monsoon and also in ocean surface state modelling. In Figure 5, the mean seasonal flow (JJAS) at lower troposphere for a typical year, i.e. 2000 is plotted and compared with that of ERA-i reanalysis. There is clearly good comparison between them. Figure 6 depicts the mean difference between zonal wind buoy observations over oceans and those of the model generated fields for this analysis period. It clearly shows that the quality of surface wind output is satisfactory and can be used.

Wang and Fan[8] used a dynamical index based on horizontal wind (*U*) shear at 850 hPa as a circulation index for representing variations of the strength of Indian monsoon circulation. They also recommend that the circulation index be computed with the mean difference of the zonal winds (*U*) between the two boxes; one for the southern region and the other for the northern region, i.e. 5°N–15°N, 40°E–80°E and 20°N–30°N, 70°E–90°E can be used as the criteria for identifying the onset date also. The southern region box is taken over the South Arabian Sea and the northern region box is taken over the northern land region. This circulation index describes the variability of the low-level vorticity over the Indian monsoon trough, thus realistically reflecting the large-scale circulation it is also correlated with monsoon rainfall over India. To study the inter-annual variability during NGFS-R period, this circulation index for all 122 days of monsoon season for each year is calculated and compared with that of the area mean of daily grided rainfall over Indian land (Figure 7). The rainfall considered here is taken from NCMRWF-IMD observed rainfall analysis product[9]. It clearly shows good match between variations. Further, the correlation between observed daily mean rainfall over the Indian land and the circulation index is calculated and presented in Table 2. It clearly shows that the relation between them is very high (up to 60%) during strong

Table 1. Volume of main synoptic observations ingested and accepted in a typical cycle during the reanalysis period

Observation type	Total ingested observations	Assimilated observation	O–B
RAOB	33,310	32,554	0.204811
PIBAL	1008	870	0.087816
NOAA Profiler	8786	8357	–0.39195
VAD Wind	16,527	16,017	–0.30413
AIREP/PIREP	1017	1009	0.534727
AMDAR	13,343	12,411	0.714024
DROP Sonde	27	27	–1.32963
ACARS	36,603	36,518	–0.15601
Surface Marine	4972	4613	0.163915
Atlas Buoy	126	126	1.19095
Windsat Scat.	6009	5672	0.193211
Metar	34,491	34,485	0.58436

Table 2. Correlation coefficient values between rainfall and monsoon index

Year	Correlation
2000	0.43
2001	0.44
2002	0.32
2003	0.49
2004	0.31
2005	0.33
2006	0.37
2007	0.34
2008	0.52
2009	0.68
2010	0.52

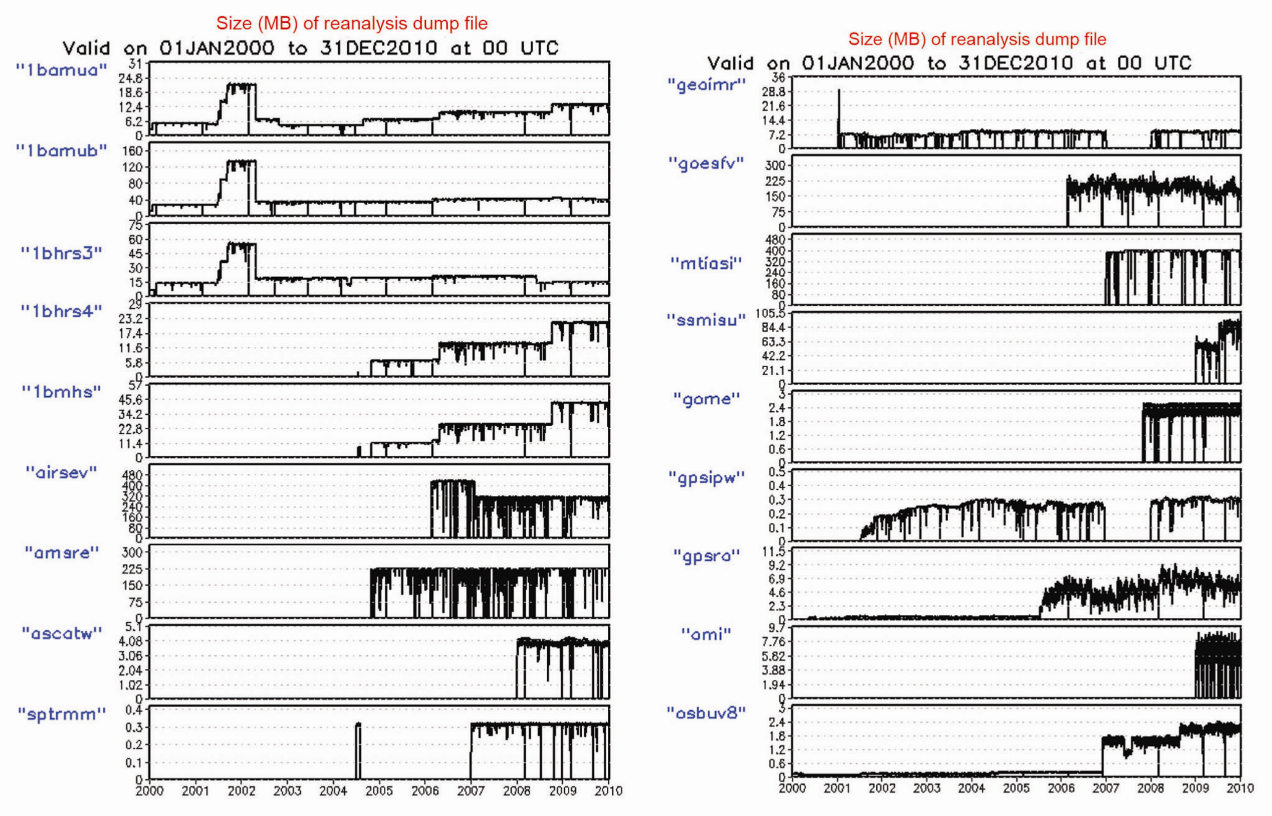

Figure 4. Volume of various satellite datasets per cycle used in the assimilation system for different years (***a***); and for some more products (***b***).

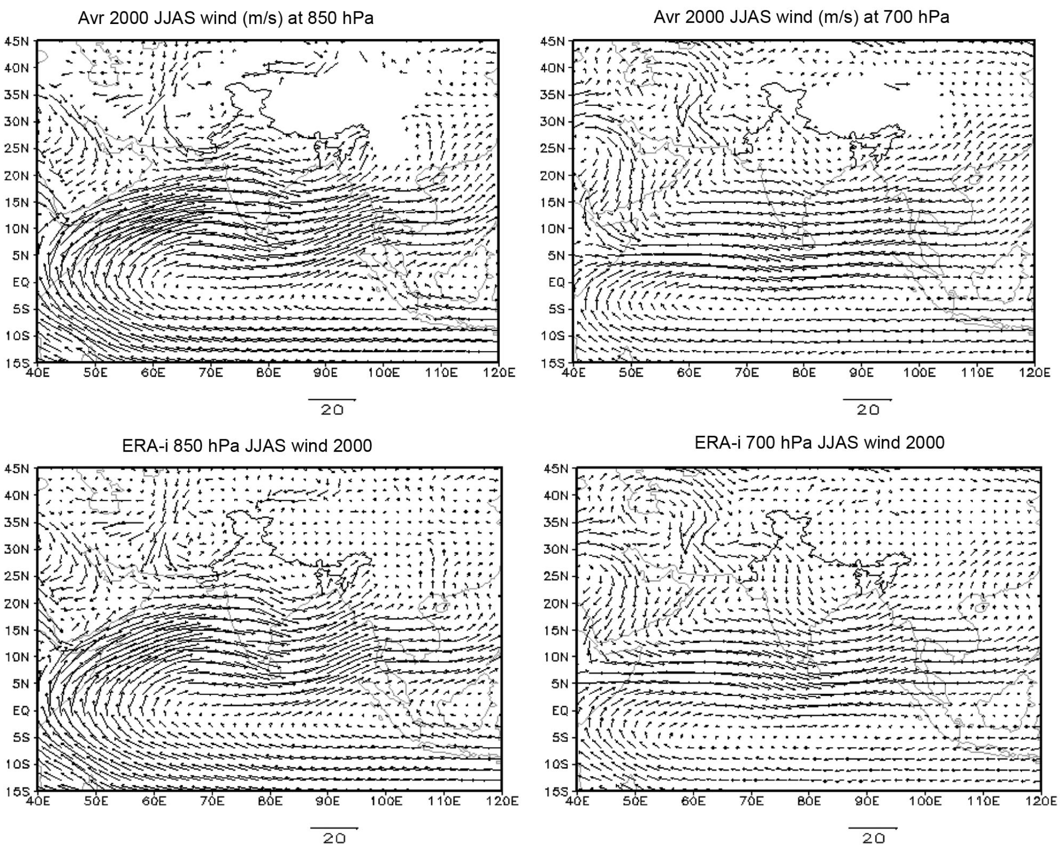

Figure 5. Mean seasonal flow (JJAS) at the lower troposphere for a typical year, i.e. 2000 with NGFS-R and ERA.

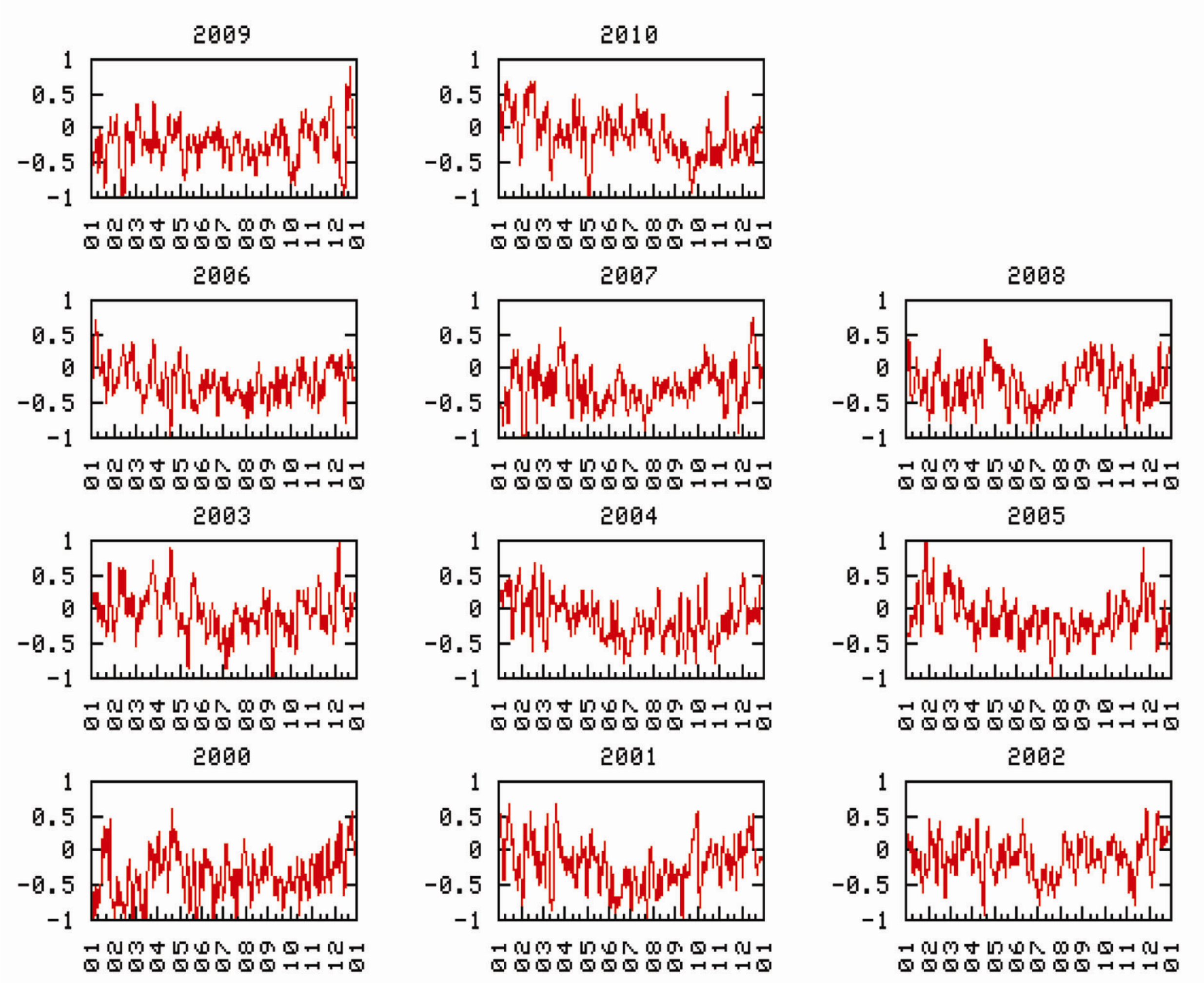

Figure 6. Daily global mean difference of ocean surface horizontal wind between model and *in situ* buoy observations.

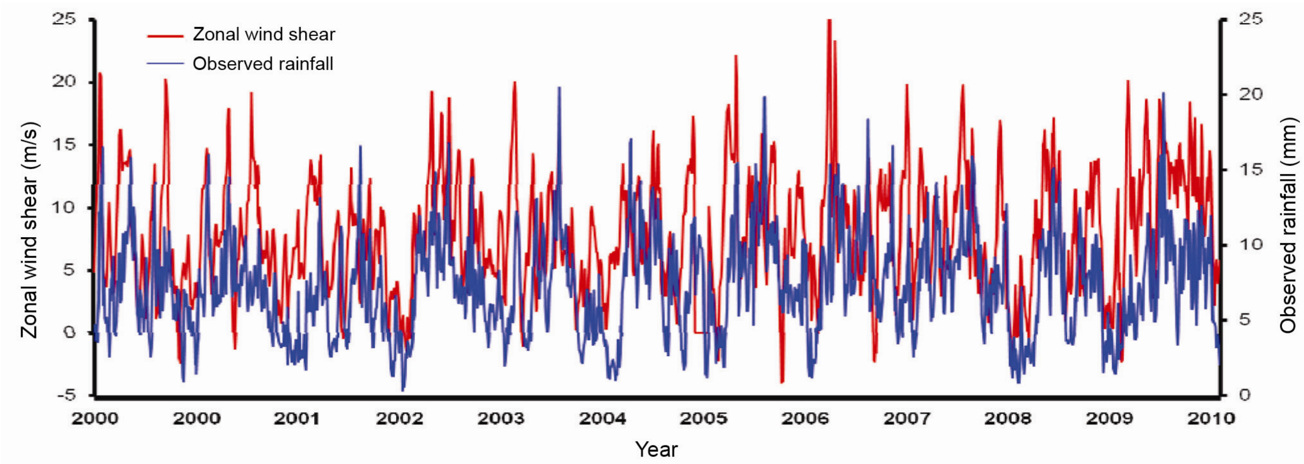

Figure 7. Trends in analysed daily rainfall over the Indian land mass and monsoon index during the Indian summer monsoon season for reanalysis years.

monsoon years and is less during week and normal monsoon years.

To study inter-annual variability in the NGFS-R products, 2 m temperature is taken as a field representative. The same is plotted in Figure 8 and compared with those from ERA-40 and CRUTM reanalysis projects. It clearly shows that the pattern of changes (trends) in NGFS and ERA-40 is similar to that of CRUTM but differs in

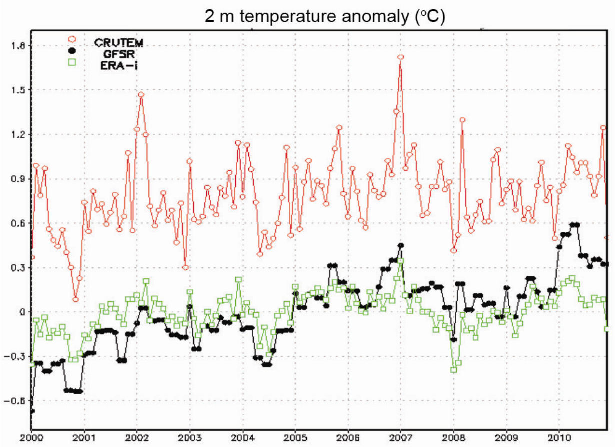

Figure 8. Trend of 2 m surface temperature during reanalysis period.

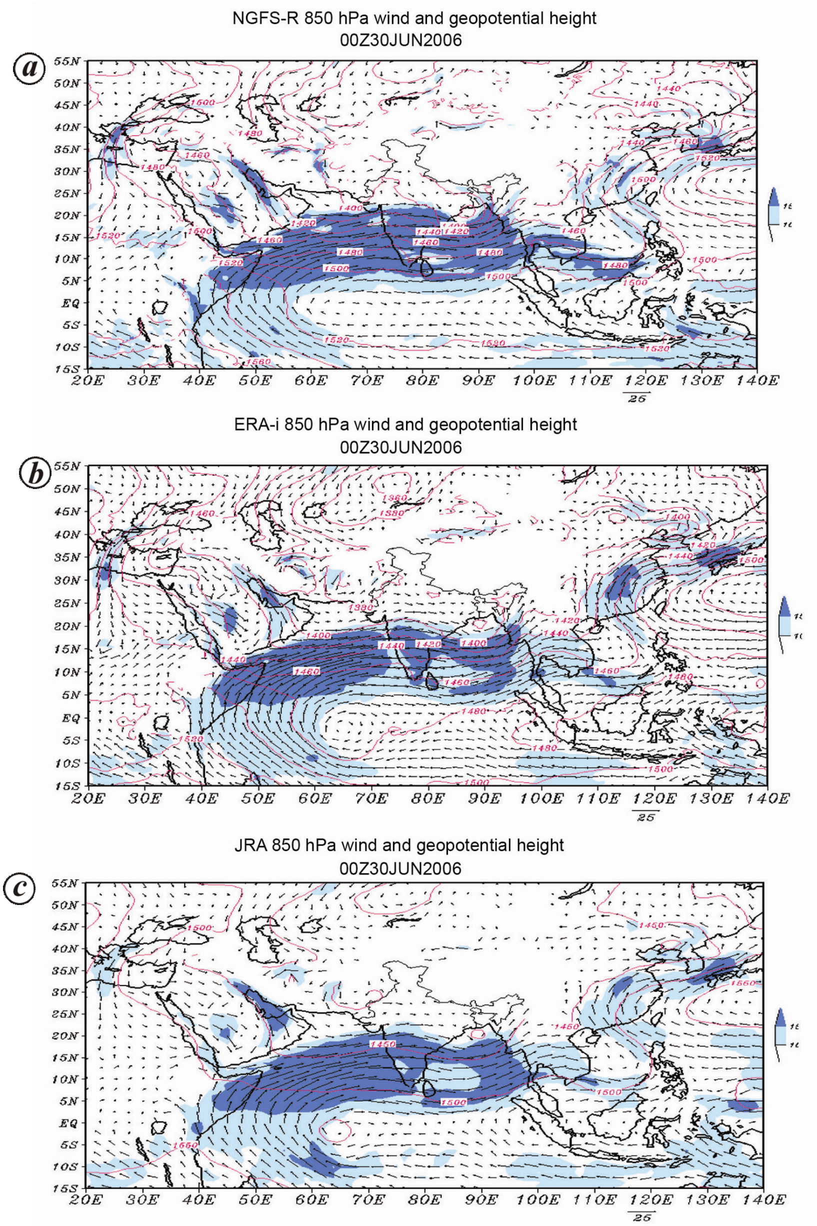

Figure 9. Comparison of flow pattern along with geopotential height at 850 hPa for a typical day (30 June 2006): ***a***, NGFS-R; ***b***, ERA-40; ***c***, JRA-55.

magnitude. A clear rise in temperature for the year 2010 is observed in the case of NGFS-R and CRTUM, but ERA-40 fails to simulate this rise. To compare the ISM circulation feature between NGFS-R, JRA-55 and ERA-40 reanalysis for typical day, 30 June 2006 is chosen at random and plotted in Figure 9. It is clearly observed that there is agreement between major global scale circulation features; but there are small differences in synoptic scale details. These may be due to the difference in model resolution and physical parameterization schemes. Hence, these NGFS-R data can be utilized for summer monsoon studies.

High-resolution global analysis at T574L64 resolution (about ~27 km) was made for the years 2000 to 2011. Further, by taking into account similar operational products generated at NCMRWF, these high-resolution data are available for total 16 years. The quality of this product is found satisfactory. It simulated interannual variations in the Indian summer monsoon well. It also generated good-quality ocean surface winds as a co-product for use in ocean surface state models.

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Assessment of climate change impact on water diversion from the Bago River to the Moeyingyi wetland, Myanmar

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Originally built for flood control, the Moeyingyi wetland, Myanmar now provides valuable resources such as fishery, irrigation water and tourism, and is also home to many rare species and migratory birds. This is the only wetland in Myanmar listed as a Ramsar Site. Bias-corrected climate data from three general circulation models under two emission scenarios of IPCC Assessment Report 5 (AR5), namely RCP 4.5 and RCP 8.5 were used to forecast temperature and rainfall. Future climate scenarios were predicted for three future periods as 2020s (2021–30), 2030s (2031–40) and 2040s (2041–50). The Soil Water Assessment Tool (SWAT) was used for hydrological analysis to predict water availability. Analysis suggests that the discharge is expected to decrease during dry season, which can have a negative impact on the diversion of water from the Bago River to the Moeyingyi wetland. On the other hand, discharge is likely to increase during July and can further worsen the recurring floods. Similarly, inflow at the Moeyingyi wetland is expected to decrease in future. Hence, robust adaptation strategies should be formulated to cope with the negative impact of climate change.

Keywords: Climate change, hydrological analysis, water diversion, wetlands.

WETLANDS are important natural resources and are considered as natural heritages in Myanmar; they play a vital role in the economy of the country. Migratory birds are dependent upon these areas, especially on coastal and inland mangrove wetlands; therefore, they are of international importance[1]. In addition, wetlands act as natural barriers against sea water intrusion into the agricultural areas, preventing floods and coastal land from erosions.

The Moeyingyi wetland was constructed in 1978 and was originally built as a reservoir for flood control. This wetland is also used to supply water to the Bago–Sittaung canal during the dry season as a source of irrigation water for rice (*Oryza sativa* L.) farmers. In addition, it also serves as a habitat for various species and acts as a resting place for migratory birds. Thousands of tourists visit

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