Circulation characteristics associated with the Inter-Tropical Convergence Zone during northern winter

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In this study, circulation characteristics associated with the ITCZ during the winter are examined by using the archives of National Centre for Medium Range Weather Forecasting (NCMRWF). To this end, some of the mean large scale basic meteorological and derived fields surrounding the ITCZ are analysed to examine the ITCZ circulation. It would be expected that during the INDOEX field phase experiment, several remote sensing and special observations be generated. To assess the impact of new remote sensing data in maintaining the structure and intensity of ITCZ circulation, an assimilation experiment is conducted using the high resolution TOVS temperature profile data of NOAA over the Indian Ocean for March 1996. An assimilation for the forthcoming INDOEX field phase duration in 1999 is planned by incorporating all satellite and observational data to be collected to study the dynamics of ITCZ.

THE Inter-Tropical Convergence Zone (ITCZ) is a region of wind discontinuity in the lower troposphere, the wind discontinuity being between the westerlies in the near equatorial region and the easterlies on either side of it. On a planetary scale, the ITCZ can be regarded as a zone of horizontal velocity convergence associated with ascending motion and rainfall. At times, this belt appears as an east–west elongated shear zone having westward moving cloud clusters embedded in its structure. Several studies suggest that over the tropical oceans the climatological positions of the ITCZ are found in the vicinity of the relatively higher sea surface temperature (SST) belts and away from the equator as well[1,2]. Further, it was demonstrated that the eddy kinetic energy along the ITCZ is primarily maintained by vertical overturning ($-w'T' > 0$) with a conversion from the eddy available potential energy, the latter being maintained by the cumulus heating.

In this study we examine the large scale basic meteorological fields associated with the ITCZ during the winter. Also, the impact of high resolution TOVS temperature profile data, NOAA satellite data retrieved and processed locally by the high resolution picture transmission (HTRT) station at India Meteorological Department, New Delhi, on the analysis-forecast system of NCMRWF in maintaining the structure of ITCZ would be examined.

Details of the analysis-forecast system

The NCMRWF was formed with an objective to provide medium range forecasts over monsoon regions and to provide agro-meteorological advisory services to the farming community in India. The global data assimilation and forecasting system (GDAFS) of the NCMRWF comprises a global spectral model adapted from NCEP (National Centers for Environmental Prediction), USA which is currently implemented at T-80/L-18 resolution and an intermittent data assimilation scheme involving Spectral Statistical Interpolation (SSI)[3]. In the assimilation cycle, however, six-hour forecasts of the global model are utilized to serve as first guess for the subsequent analysis. The GDAFS was installed on a CRAY XMP/216 computer system in 1993 and, after extensive experimentation and testing, it was made operational on 1 June 1994. Five-day forecasts are produced daily on real time based on 00UTC analysis. Details of the global spectral model are described in Kanamitsu[4]. A brief description of the model is presented in Table 1.

The model uses a simple land-surface scheme which includes: (i) exchange coefficient computations based on Monin–Obukhov similarity theory, (ii) Penman-Monteith method of evapotranspiration over land which includes vegetation effects, (iii) prognostic surface temperature equation, (iv) 3-layer of surface and soil temperature prediction, (v) interactive bucket hydrology, (vi) evaporation by bulk method over ocean, and (vii) Charnock's roughness length computation of ocean.

Detailed examination of onset of the summer monsoon over the southern tip of Indian peninsula, and its advancement and withdrawal over the Indian subcontinent was carried out using analyses/forecasts of the model for three successive monsoon seasons (1994–97). All types of conventional and non-conventional data as available on the GTS are utilized in the assimilation scheme.

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Climatological features associated with the ITCZ

In this section we present the mean monthly fields of winds, temperature and moisture associated with the ITCZ over the Indian Ocean region at 1000 hPa.

Flow characteristics

During the winter season an anti-cyclonic circulation forms over central India and Arabian Sea (Figures 1 *a–c*). The outflow from these high pressure cells generates the north-easterly flow (north-easterly trade wind regime) over the Bay of Bengal and Arabian Sea. The north-easterlies over the Arabian Sea are particularly stronger among them and are strongest in January. The ITCZ is located around 8°S in December and moves to around 10°S in January and February. Another interesting feature is the presence of cyclonic eddies over the equatorial regions of the east Indian Ocean during the entire winter season which may be a hindrance to the transport of pollutants from the northern to southern hemisphere.

Temperature and moisture

Figures 2 *a–b* shows the seasonal mean (December–February) temperature and moisture field. In general the temperature field over the Indian Ocean region does not show much variation during the winter season. The ITCZ region shows a temperature of about 298 K and specific humidity in excess of 16 g/kg.

Impact of high resolution TOVS data in NCMRWF analysis-forecast system

On a regular basis coarse resolution (500 km) TOVS temperature profile data (CRTOVS) as available on GTS is incorporated in the data assimilation scheme. TOVS temperature profile data at its full resolution of 85 km (HRTOVS) produced by the NOAA HRPT station at New

Table 1. Brief description of global spectral model

Model elements	Components	Specifications
Grid	Horizontal	Global Spectral-T80 (256 × 128)
	Vertical	18 Sigma Layers (s = 0.995, .0.981, 0.960, 0.920, 0.856, 0.777, 0.688, 0.594, 0.497, 0.425, 0.375, 0.325, 0.275, 0.225, 0.175, 0.124, 0.074, 0.021)
	Topography	Mean
Dynamics	Prognostic variables	Relative vorticity, divergence, virtual temp., log (surface pressure), water vapour mixing ratio
	Horizontal	Orszag's technique
	Transform	
	Vertical differencing	Arakawa's energy conserving scheme
	Time differencing	Semi-implicit with 900 sec of time step
	Time filtering	Robert's method
Physics	Horizontal diffusion	Second order over quasi-pressure surfaces, scale selective
	Surface fluxes	Monin–Obukhov similarity
	Turbulent diffusion	K-theory
	Radiation	Short wave (Lacis and Hansen)
		Long wave (Fels and Schwarzkopf)
	Deep convection	Kuo scheme modified
	Shallow convection	Tiedtke method
	Large scale condensation	Manabe-modified scheme based on saturation
	Cloud generation	Slingo scheme
	Rainfall evaporation	Kessler's scheme
	Land surface processes	Pan scheme having 3-layer soil model for soil temperature and bucket hydrology of Manabe for soil moisture prediction
	Air–sea interaction	Roughness length over sea computed by Charnock's relation. Climatological SST, bulk formulae for sensible and latent heat fluxes
	Gravity wave drag	Lindzen and Pierrehumbert scheme

Delhi was available for March 1996. An assimilation experiment including this data was carried out for March 1996 to study its quality and impact in maintaining the structure of the ITCZ over the conventionally data void oceanic sectors of Indian Ocean.

A preliminary assessment of the HRTOVS was made by verification against collocated reference RS/RW observations. The collocation statistics in terms of RMSE and bias in the mean sense showed that the quality of HRTOVS retrievals was generally better than that of CRTOVS. In view of this, it was concluded that HRTOVS can be used in the GDAFS on real-time basis if made available.

The impact of HRTOVS is examined in terms of sectoral mean (30°–120°E) vertical cross-sections of the divergent circulation in the meridional plane. The divergent

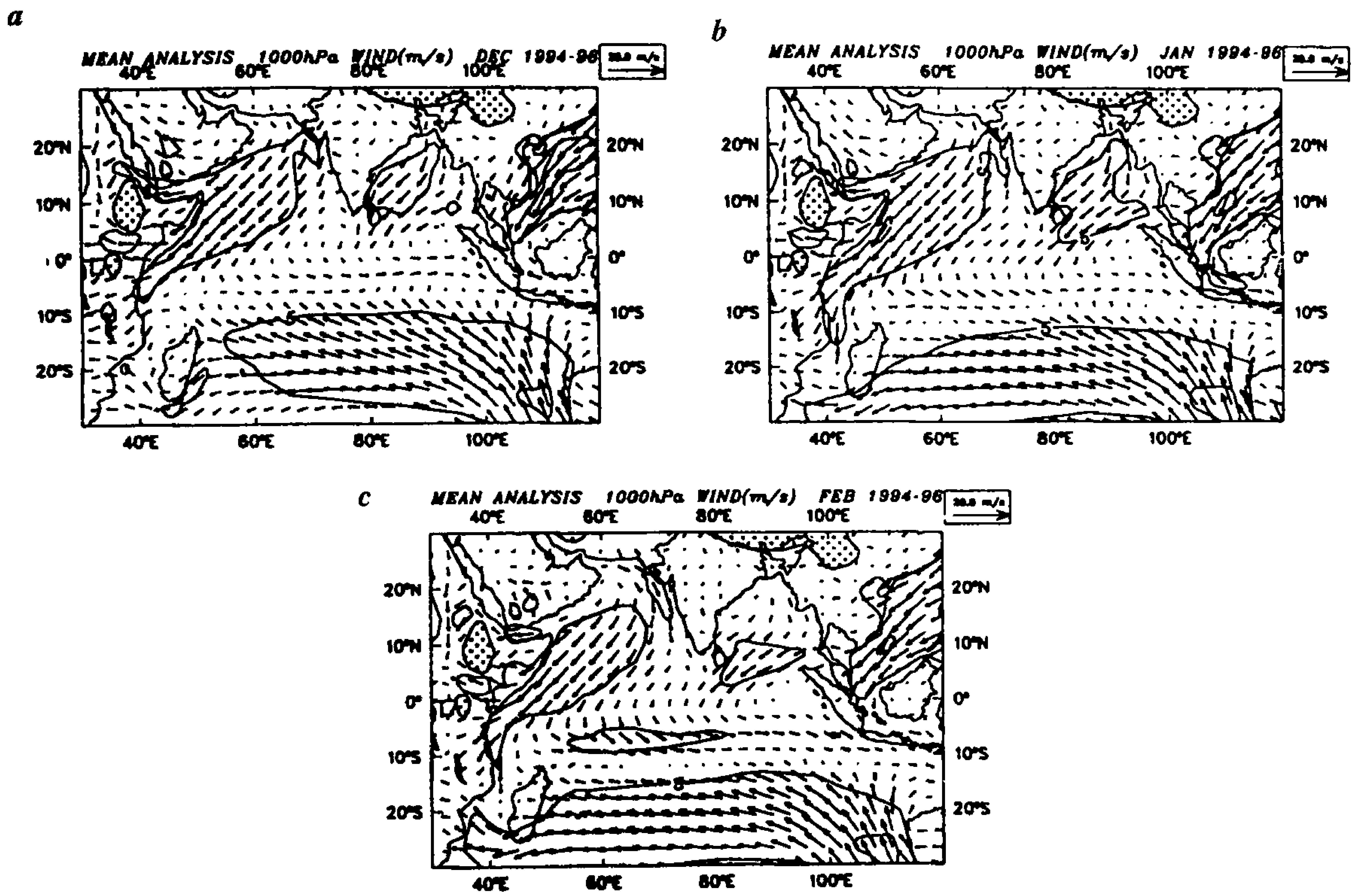

Figure 1. Mean wind fields at 1000 hPa (*a*) December, (*b*) January and (*c*) February (units: m/s, contour interval: 5 m/s).

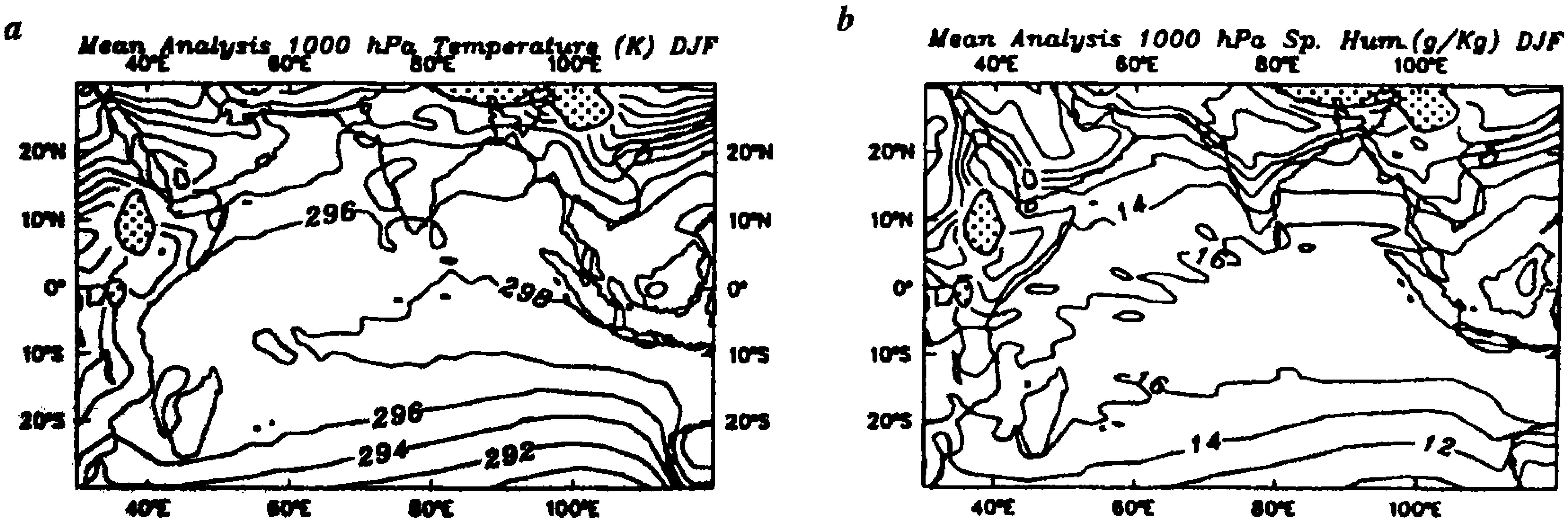

Figure 2. Mean seasonal (December–February) 1000 hPa analysis, (*a*) Temperature (units: K, contour interval: 2 K) and (*b*) Specific humidity (units: g/kg, contour interval: 2 g/kg).

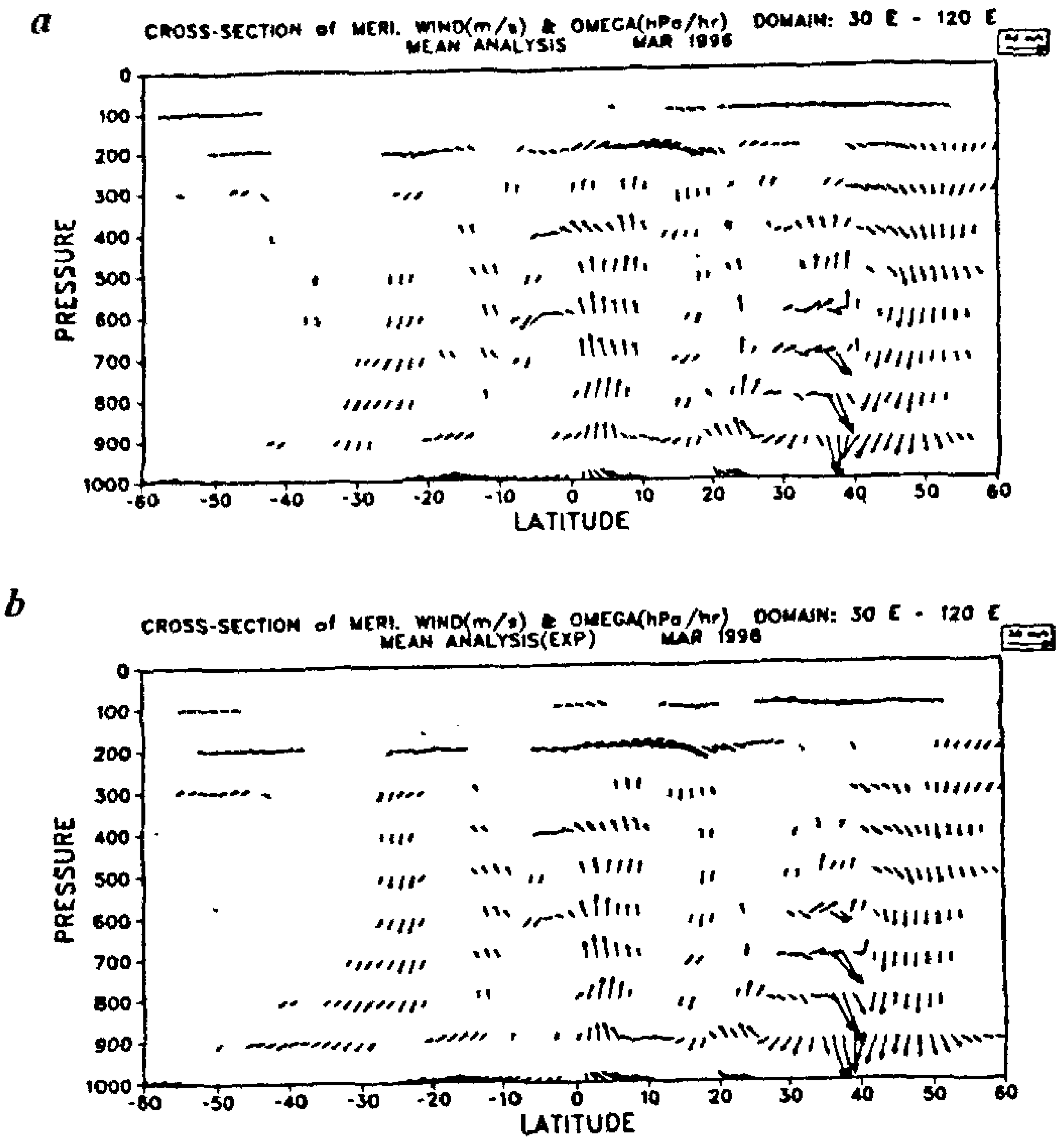

Figure 3. Pressure–latitude (30E–120E) cross-sections of mean monthly analysis of divergent circulation for March 1996: (*a*) operational analysis and (*b*) experimental analysis.

circulation is represented by the vectors of combined vertical velocity and divergent meridional wind. Figure 3 *a–b* shows the divergent circulation for the control analyses (assimiliated with CRTOVS data) and experimental analyses (assimilated with HRTOVS data over the Indian seas only) respectively. It can be clearly seen that the ascending motion around 10°S is amplified and pronounced in the experimental analyses. Moreover the whole cell of rising and sinking motion in the southern hemisphere is well defined.

The impact of HRTOVS on GDAFS is also examined in terms of various objective scores, viz. anomaly correlation, RMSE, skill scores (figures not shown). Improvements in the forecast skill are seen up to 120 h all through the middle and upper tropospheric levels (700–200 hPa) over the data void equatorial regions of Indian Ocean.

Summary

It is expected that during the 1999 INDOEX field phase experiment several satellite and surface based special data sets will be generated to carry out the research on the specified objectives of the programme. Further assimilation and forecast experiments which incorporate the data collected during INDOEX are planned.

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