Study of trace gas species including greenhouse gases over the Indian Ocean during INDOEX precampaign cruises of 1996, 1997 and 1998 on *Sagar Kanya*

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Measurements of surface concentration of trace gas species including greenhouse gases, viz. CO, CH_4, CO_2, N_2O have been carried out over the Indian Ocean region on board the research vessel *Sagar Kanya* (*SK*) from 4 January to 7 February 1996, 27 December 1996 to 31 January 1997 and 18 January to 31 March 1998, respectively. The positive latitudinal gradient from south to north has been observed for various measured trace species during the above pre-campaigns. It could be attributed to the continental air-mass flow across the Inter-Tropical Convergence zone (ITCZ).

THE gaseous pollutants and continental aerosols from the northern hemisphere encounter the relatively pristine air from the southern hemisphere in the vicinity of The Inter-Tropical Convergence Zone (ITCZ). The rapid vertical transport within the deep convective-cirrus cloud systems of the ITCZ and their subsequent horizontal distribution by fast zonal upper air flows provide a fundamental link between regional emissions of reactive gases and their global impacts on the radiatively active species such as ozone and aerosols. It is important to examine how continental aerosols particularly dust, black carbon and organics including soluble species modify the cloud solar absorption in the tropics. Tropical latitudes are rich sources of ozone precursors[1], viz. CO, CH_4 and NO_x. There are few measurements of trace chemical species from the Indian Ocean, viz. Soviet American Gases and Aerosols (SAGA)[2] in 1987 along 90°E longitude and between 5°N and 30°S and during World Ocean Circulation Experiment (WOCE)[3] in 1995 on board NOAA *RV Malcolm Baldrige* from (30°S) Durban (SA) to (7°N) Colombo. Indian Ocean Experiment (INDOEX) campaigns have been carried out to study/estimate the extent and role of aerosols (continental and marine), trace gas species, (viz. SO_2, NO_x, O_3, CO and greenhouse gases, etc.) and their reaction products in the radiative forcing of the atmosphere near the ITCZ of the Indian Ocean.

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INDOEX main field phase has been planned during the period between January and April in 1999. The INDOEX precampaigns, generated data for aerosols, CO, NO_x, O_3, GHGs, precipitation, and solar radiation, etc. during 1996 (cruise #109), 1997 (cruise #120) and 1998 (cruise # 133) on board Indian Ocean research vessel *Sagar Kanya* (*SK*). It also included the first field phase of INDOEX (FFP-98) campaign of *SK* cruise #133 during 18 January to 31 March 1998. The results of trace gas species, viz. CO and GHGs, viz. CH_4, CO_2, and N_2O measurements during the above precampaigns are presented in this paper.

Experimental techniques

In all the three cruises instruments were installed on board *SK* from the Department of Ocean Development, Govt of India. These *SK* cruises, numbered 109, 120 and 133 of the INDOEX precampaigns, were from 4 January to 7 February 1996, 27 December 1996 to 31 January 1997 and 18 January to 31 March 1998, respectively. During each cruise, the *SK* was used for oceanography, meteorology and atmospheric science studies which required the ship to remain stationary for some time at various locations along the track daily.

GHG measurements

During cruise #109, monitoring of methane was done using a portable gas chromatograph (model 511-A of AID, USA). Methane was separated on a 10′ long 1/8″ O.D. stainless steel column filled with 80–100 mesh molecular sieve-5A, nitrogen carrier gas flow of 15 c.c. min^{-1} and detected by the flame ionization detector (FID). Methane standard of 2 ppmv in nitrogen from ECM Speciality Gases Ltd, UK, was used for GC calibration. Ambient air samples from the bow of the ship facing upwind were also collected in stainless steel samplers using oil-free compressors (KNF, Germany) at various locations in *SK* cruise nos. 109, 120 and 133. These samples were analysed for GHGs, viz. CH_4, CO_2 and N_2O in the laboratory at NPL, New Delhi by gas chromatograph

(model Sigma-2000 of Perkin-Elmer, USA) with FID/ECD. FID with methanizer was used to analyse CO_2.

CO measurements

Sample air from 10 m level at A-deck of the starboard side of ship was drawn through a 3 mm i.d. teflon tube, for continuous CO measurements through a PTFE filter. An infra-red gas-filter correlation CO analyser (Model 300, Advanced Pollution Instruments Inc., USA) was used for CO monitoring. The 5-min average values were used to calculate hourly averages for the above measurements. Calibration standards procured from Scott Marrin Inc., Riverside California, USA, for CO (28 ppmv in nitrogen) has been used for the analyser.

Results and discussion

Figure 1 shows all the ambient methane concentration data, from above the three cruises, plotted with respect to latitudes. Average methane concentration during cruise #109, was 1.81 and ranged from 1.72 to 2.02 ppmv. During cruise #120, it was 1.94 and ranged from 1.76 to 2.27 ppmv and during cruise #133, it was 1.79 and ranged from 1.62 to 2.03 ppmv. Values of ambient methane were generally higher near the Indian sub-continent and ITCZ region. There is a positive gradient of methane concentration from south to north of latitudes in the Indian Ocean region. Similar positive gradient is observed from the data during the cruise #120 and 133 for ambient carbon dioxide (Figure 2) and nitrous oxide (Figure 3) concentrations. During cruise #133, peak of CO_2 around the equator could be due to ocean upwelling of CO_2-rich watermass and hence high CO_2 emissions. However in the case of nitrous oxide, latitudinal gradient is not much. The results are comparable with GHG measurements by PRL on *SK* during INDOEX pre-campaigns[4].

Figure 4 shows the variations of ambient CO concentrations for onward (Goa–Mauritius) and return track of *SK* cruise #133. In general, return lag ambient CO concentrations are lower. During the onward track, after about 5°N, the CO concentrations ranging between 120 and 200 ppbv increased two-fold with large variations. Its concentration decreased to nearly 100 ppbv after about 12°S, which probably indicates the pristine air parcels coming from the southern part of ITCZ whose approximate position was between 10°S and 15°S. During the return track, a positive gradient with latitude in CO concentration was observed on going from about 18°S to about 13°N. Across the ITCZ at about 5°S, four-fold increase in ambient CO concentrations was observed. Figure 5 shows the diurnal behaviour of hourly averaged ambient CO concentrations for data on all the days, for the onward and return journey. The trend in CO concentration variation for onward (higher value compared to in the return lag) and return journey was similar, except between 3 and 7 h in the morning. This could be due to

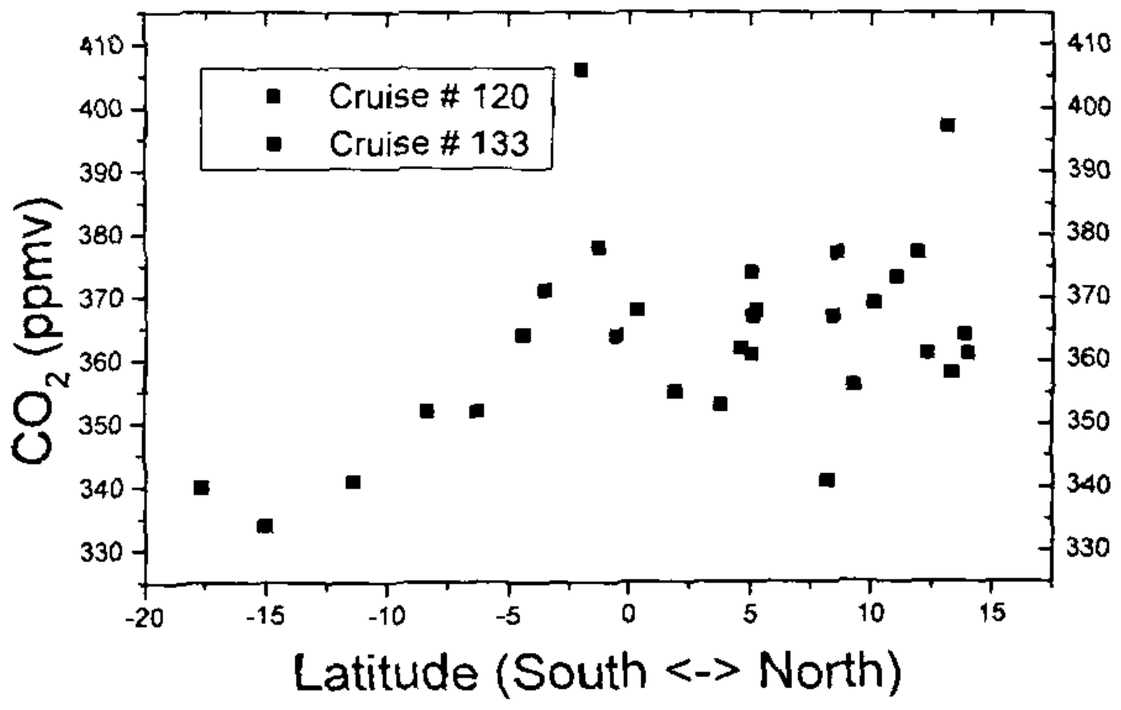

Figure 2. Variations in ambient carbon dioxide concentration with latitudes during SK #109, 120 and 133 INDOEX campaign cruises.

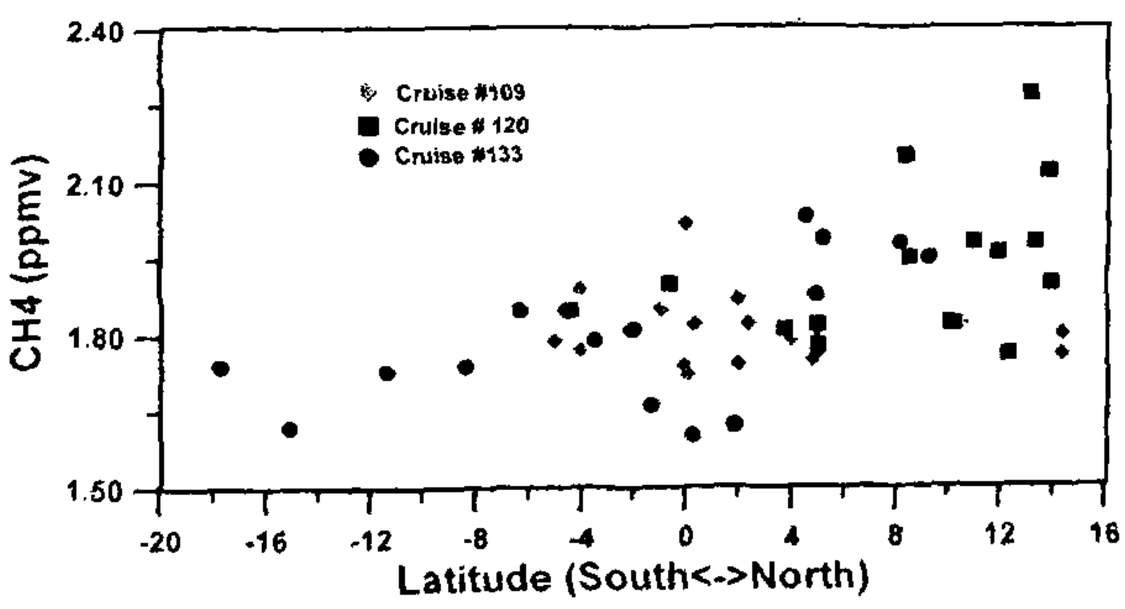

Figure 1. Variations in ambient methane concentrations with latitudes during SK #109, 120 and 133 INDOEX campaign cruises.

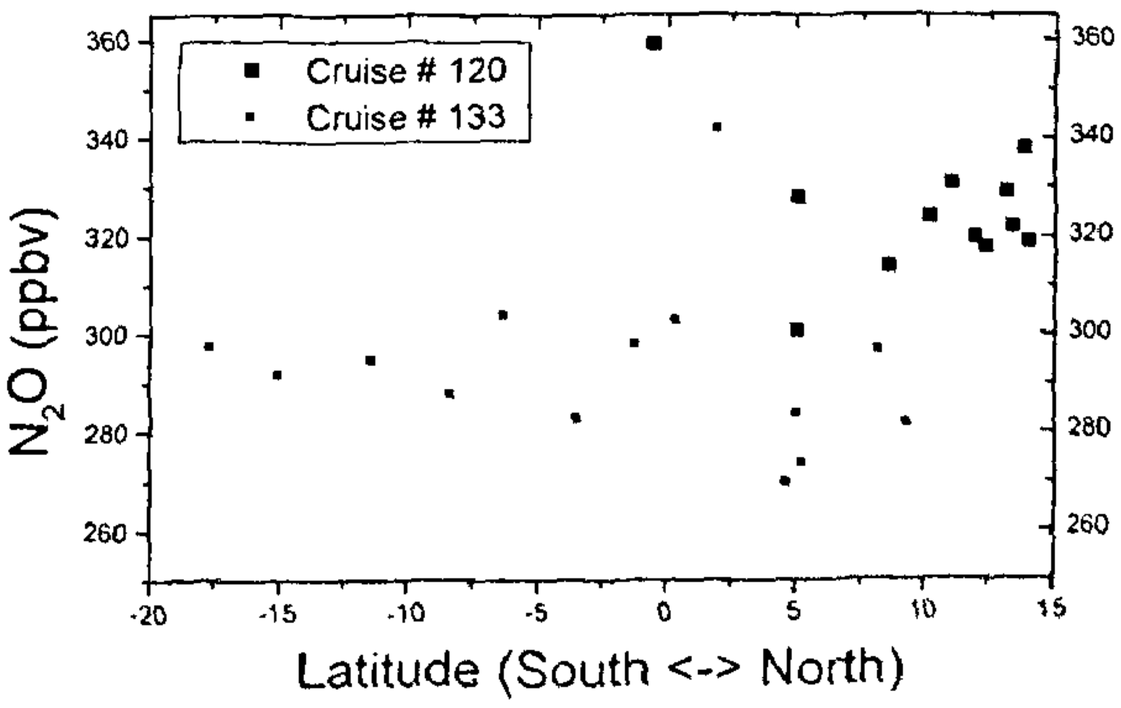

Figure 3. Variations in ambient nitrous oxide concentration with latitudes during SK #109, 120 and 133 INDOEX campaign cruises.

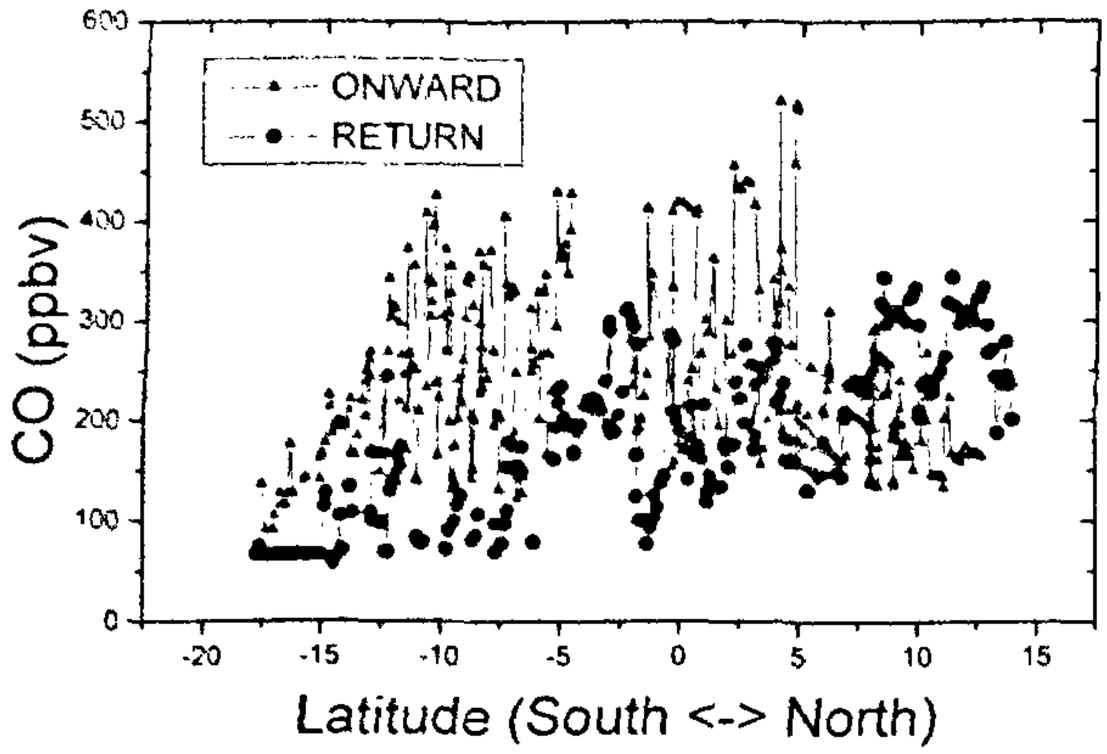

Figure 4. Variations in ambient hourly average carbon monoxide concentration with latitudes during SK #133 INDOEX campaign cruise for both onward and return journey.

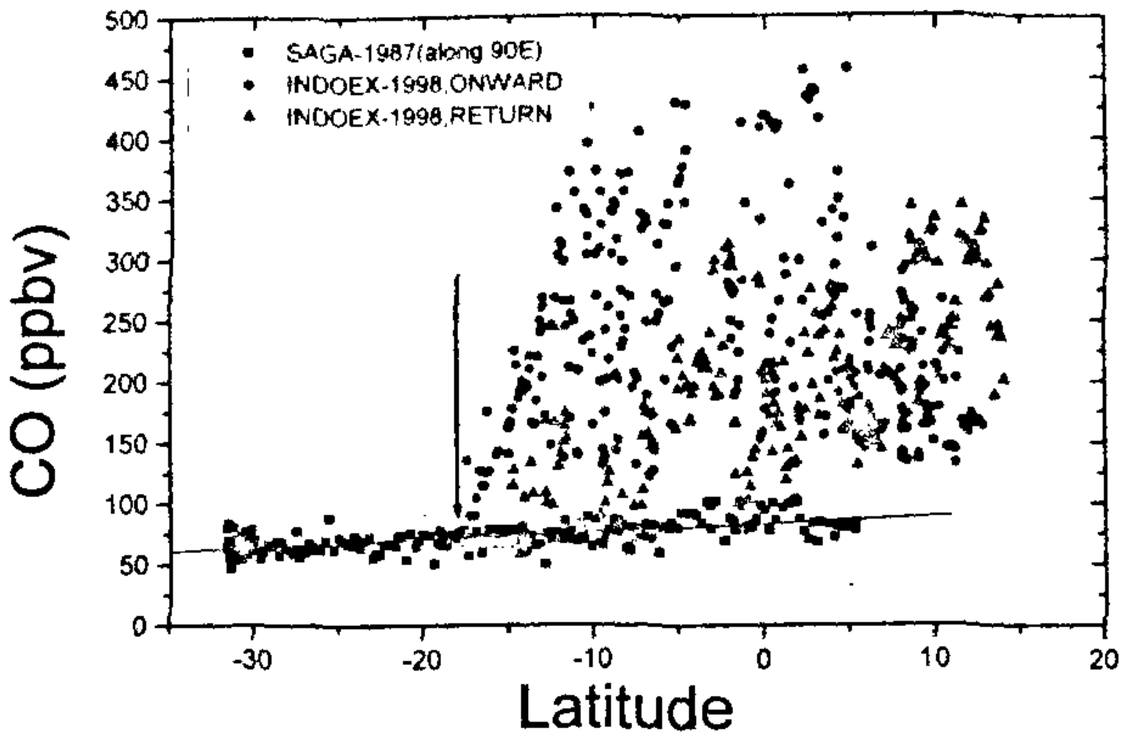

Figure 6. Comparison of carbon monoxide data with latitudes for SAGA-1987 and INDOEX SK #133 campaigns.

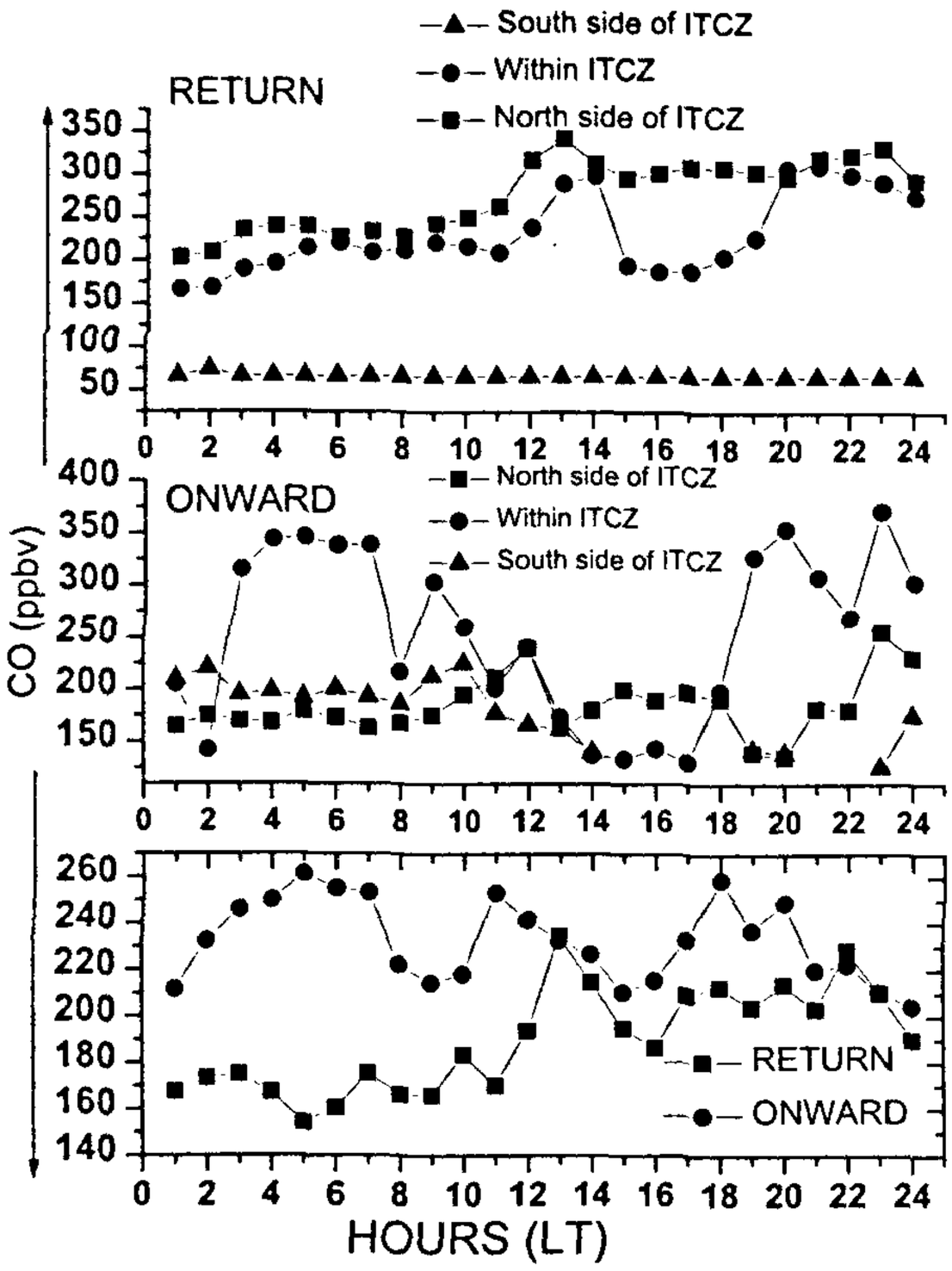

Figure 5. Variations in ambient hourly average for data on all days for carbon monoxide concentrations with latitudes during SK #133 INDOEX campaign cruise including hourly average for data within ITCZ, north of ITCZ and south of ITCZ for both onward and return journey.

high CO concentrations observed within the ITCZ during the onward journey in this time period. This figure also supports the fact that there are polluted air-parcels coming from north of the ITCZ, intermixing with the southern pristine air-mass having low concentrations of pollutants in the ITCZ region, which indicate in-between concentrations. A comparison of INDOEX *SK* #133 with SAGA-*1987, which took place along 90°E and between 5°N and* 30°S is shown in Figure 6. This also indicates positive gradient in CO concentrations from south to north of latitudes.

A negative gradient in concentration for GHGs and trace gas species has been observed from north to south of *latitudes and positive gradient from south to north of* latitudes, during the measurements over the Indian Ocean across the ITCZ, during 1996, 1997 and 1998 INDOEX campaign *SK* cruises.

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