Mausam, (1996), **47**, 1, 47-52

551.524.73 (203.31.51.7)

Non-uniformity of the long-term trends in some tropospheric, stratospheric and mesospheric parameters

R. P. KANE

Instituto Nacional de Pesquisas Espaciais-INPE
C.P. 515, 12201/970-Sao Jose dos Campos, SP, Brasil
(*Received 10 November 1994, Modified 6 April 1995*)

सार — पिछले तीन दशकों के दौरान हरित गृह गैसों की सांद्रता समानरूप से बढ़ गई है। इनसे क्षोभमंडल में उष्णता तथा उच्च तुंगता में आर्द्रता उत्पन्न होने की अपेक्षा की जाती है। विभिन्न वायुमंडलीय प्राचलों के प्रयोगात्मक प्रेक्षणों की जांच की गयी है। यह पाया गया कि सभी प्राचलों की प्रवृत्ति एक जैसी नहीं है। कुछ मामलों में, 1970-75 के आस-पास पहले तथा बाद की प्रवृत्ति विपरीत थी। अथवा केवल 1970-75 के बाद ही बढ़ने की प्रवृत्ति पाई गई। इस संक्रमण के कारणों का पता लगाने की आवश्यकता है। हाल के वर्षों में सी० एफ० सी० की सांद्रता में अधिक तीव्रता से वृद्धि इसका एक संभावित कारण हो सकता है। इसके अतिरिक्त, मौसम विज्ञानिक कारकों का प्रभाव, विशेषकर 1975 के पहले और बाद में, समुद्र-सतह तापमान में परिवर्तन भी एक अन्य संभावित कारण हो सकता है। इस प्रकार से इसे हरितगृह गैसों के स्तर में वृद्धि से संबद्ध माना जा सकता है।

ABSTRACT. During the last 3 decades, the concentrations of greenhouse gases have increased monotonically. These are expected to produce warming in the troposphere and cooling at higher altitudes. Experimental observations of various atmospheric parameters were examined. It was noted that not all parameters showed monotonic trends. In some cases, the trends before and after about 1970-75 were opposite; or, the trends developed only after 1970-75. The reason for this transition needs to be explored. A possible cause could be a more rapid increase of CFC concentrations in recent years. Also, effect of meteorological factors, specially sea-surface temperature changes before and after 1975, could be a possible cause, though this, in turn, may be related to increasing levels of greenhouse gases.

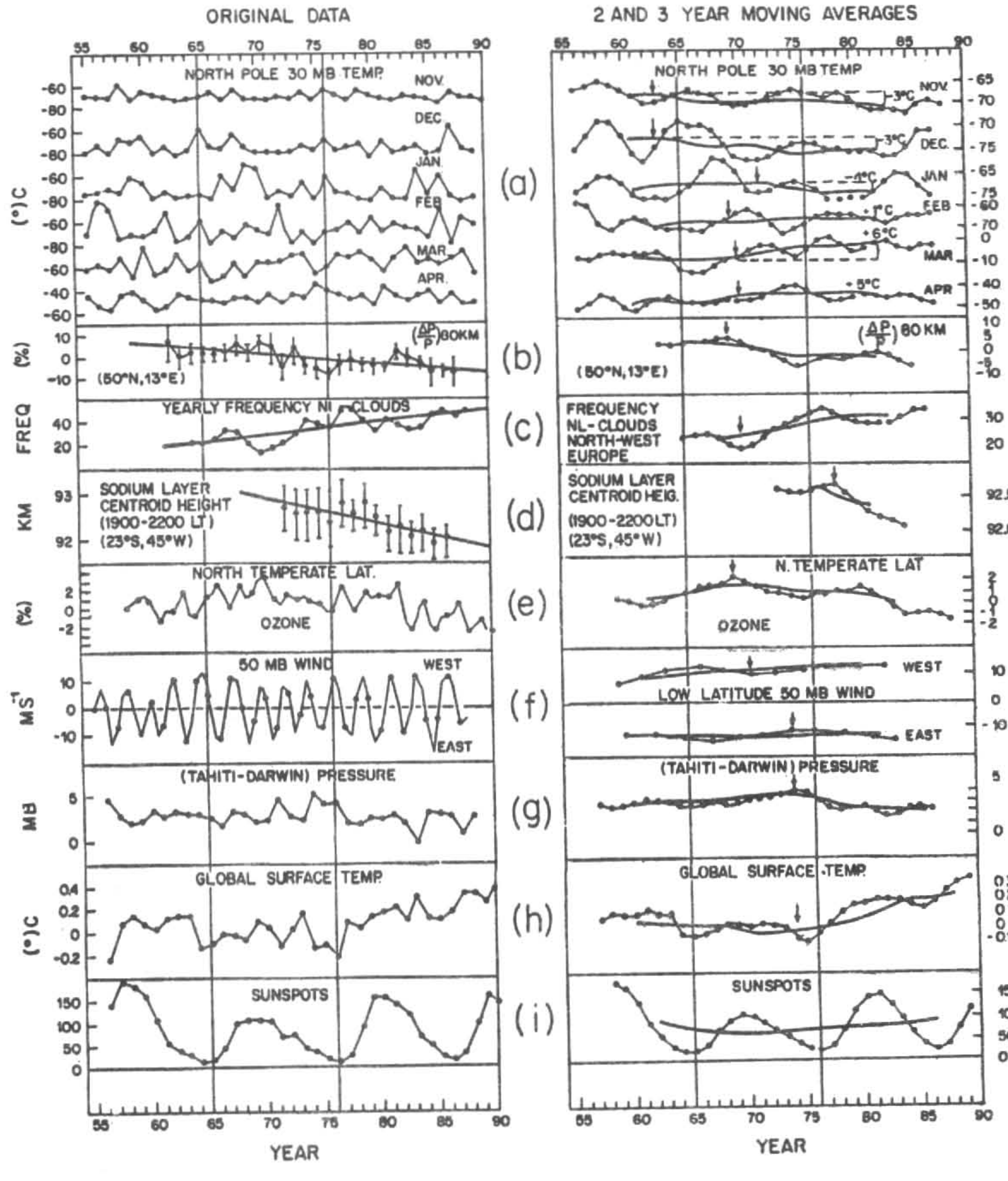
Key words — Greenhouse gases, Trends, CFC, Linkage, QBO, SST.

1. Introduction

Since regular measurements started in 1958, the concentration of atmospheric CO_2 has increased steadily from ~315 ppm in 1958 to ~350 ppm in 1988. Other greenhouse gases like methane, nitrous oxide, CFC compounds have also increased in recent years and all these are expected to have potential climatic effects (Mitchell 1989). The troposphere is expected to warm (Ramanathan 1988, Hansen *et al.* 1988) and the stratosphere is expected to cool (Brasseur and Hitchman 1988, Rind *et al.* 1990). The mesosphere and thermosphere are also expected to cool (Roble and Dickinson 1989). Global warming in the past decade was demonstrated by Jones *et al.* (1988). For the 30 hPa temperatures, Labitzke *et al.* (1988) reported long-term trends (cooling) of about −0.03°K/decade at 80°N, −(0.5-0.7) at 40°-70°, −0.22 at 30°N and +0.03 at 20°N. Using the 30 hPa temperatures at the North Pole for winter months (November-February) for the period 1955-1985 (31 winters) as given by Labitzke (1987) and further data kindly sent by Dr. Labitzke, Kane (1992) reported declines of ~3°C from 1962 to 1984 (22 year), *i.e.*, a negative trend of ~1.4°K/decade for November and December. However, for January, the temperature level was constant upto about 1976 and fell rapidly, thereafter, by ~4°C in the next 3-4 years and then remained constant. On the other hand, for February, March and April, there were no temperature drops and even increases occurred. Thus, a transition near about 1976 was indicated. In this note, we examine whether similar abrupt changes could be discernible in some other parameters, for which data were available in recent publications.

2. Data

Data for North Pole stratospheric winter temperatures are the same as used in Kane (1992). In



Figs. 1. (a-i). Plots for 1955-90 for several parameters. Left half-Original values. Right half-Moving averages over 2 and 3 consecutive values and 11-year averages. (a) North Pole 30 hPa winter temperatures (Labitzke 1987, Kane 1992); (b) 80 km pressure changes (yearly mean) at (50°N, 13°E) (Taubenheim *et al.* 1990); (c) Frequency of occurrence of noctilucent clouds northwest Europe (Gadsden 1990); (d) Sodium layer centroid height (yearly mean) at (23°S, 45°W) (Clemesha *et al.* 1992); (e) Average ozone for north temperate latitudes (Dobson) (Angell and Korshover 1983, updated); (f) Low latitude 50 hPa wind (9°N-3°S, Venne and Dartt 1990); (g) Tahiti minus Darwin, barometric pressure difference (Parker 1983, updated); (h) Global surface temperature (Jones *et al.* 1988, updated); and (i) Sunspot number (Solar Geophysical Data).

Vertical lines mark sunspot minima. Vertical arrows indicate possible changes (or commencement) of trends. Thick lines represent 11-year moving averages.

addition, we examine the changes in the height of the atmospheric sodium layer (~90 km) at Sao Jose dos Campos (23°S, 45°W), reported by Clemesha *et al.* (1992), pressure changes at 80 km at Kuhlungsborn (51°N, 13°E) derived from reflection heights of long radio waves (Taubenheim *et al.* 1990) and secular changes in noctilucent cloud occurrence as observed from northwest Europe (Gadsden 1990). Low latitude stratospheric (50 hPa) winds (Venne and Dartt 1990), Tahiti minus Darwin barómetric pressure difference (Parker 1983, updated) and global surface temperature (Jones *et al.* 1988) are also examined. The ozone data are an average of 58 ground-based Dobson spectrophotometers in north temperate latitudes (Angell and Kroshover 1983 and further private communication from Dr. Angell). Sunspot data were obtained from Solar Geophysical Data.

3. Results

Fig. 1 (left half) shows a plot of the various parameters. For some parameters, the scatter is large and the authors seem to have preferred to fit only a straight line trend as indicated in Figs. 1 (b), (c) and (d). However, at least in one case, *viz*, Fig. 1 (b) for the 80 km air pressure, the authors (Taubenheim *et al.* 1990) hinted at "an apparent quasi-cyclic shape rather than a monotonic trend". In some of the other cases, there seems to exist an indication of a QBO (Quasi-Biennial Oscillation, period 2-3 years). To minimize the same, moving averages were calculated first over two successive (yearly) values and then, for the so-smoothed series, further over three successive values. This is equivalent to applying a 1, 2, 2, 1 filter. The results are shown in the right half of Fig. 1. The following may be noted :

(1) In some cases, notably the North Pole 30 hPa winter temperature, there is probably an 11-year solar cycle effect. Sunspots are plotted in Fig. 1(i) and the vertical lines mark sunspot minima. The solar cycle effect can be minimized by calculating moving averages over 11 consecutive yearly values. The thick lines show the 11-year averages.

(2) In the North Pole 30 hPa winter temperatures [Fig. 1(a)], the 11-year averages of November and December temperatures seem to have an almost uniform downtrend from about 1960 onwards (−3°C in ~25 years). For January, there is no downtrend during 1960-70. Only later, there is a downtrend of −4°C in about 10 years. For February, March and April, trends are positive, +1, +6 and +5°C respectively in about 10 years, starting near about 1970. The vertical arrows indicate the approximate beginning or change of a trend in the 11-year averages only, in a qualitative and subjective way.

(3) For the atmospheric pressure changes [Fig. 1 (b)] at 80 km at 51°N, 13°E [(Taubenheim *et al.* (1990)], the 3-year averages indicate a non-uniform trend. For 1962-69, the trend is slightly upward and thereafter, downward. However, there is a possibility of a solar cycle effect, as both 1969 and 1982 (years of sunspot maxima) show maxima. In that case, the downward trend could be considered as having started near 1965, the beginning of the data. According to Taubenheim *et al.* (1990), the 10% decrease in pressure from 1963 to 1985, would correspond to an average mesosphere cooling of 4°K, *i.e.*, 1.6°K/decade. This is much smaller than the 4°K/decade cooling in the mesosphere reported by Hauchecorne *et al.* (1991), but for 1978 onwards only. Part of this discrepancy could be because of non-uniformity of the trend. For Taubenheim data, trend for 1970-85 may still be ~4°K cooling (in 15 years instead of 22 years).

(4) For the frequency of occurrence (nights per year) of noctilucent clouds as observed from northwest Europe, Gadsden (1990) mentioned a solar cycle effect with an amplitude of about 10 nights per year, superposed on a steady increase during 1964-82. In Fig. 1(c), there appear two minima, one at 1969 and another at 1982. Even if these are ignored, it seems that an uptrend started near about 1970.

(5) For the yearly mean sodium layer centroid height for 1900-2000 hr L.T. observed above Sao Jose dos Campos (23°S, 45°W) by Clemesha *et al.* (1992), Fig. 1(d) shows a probable non-uniform trend, *viz.* a slight uptrend during 1972-78 and a large downtrend thereafter.

(6) For average total ozone for North temperate latitudes shown in Fig. 1(e) (Angell and Korshover 1983, Kane 1988, updated),

there is an uptrend for 1960-70 and a downtrend thereafter. There is a small solar cycle effect. But the 11-year averages also show a slight uptrend upto about 1970, followed by a downtrend.

(7) The 50 hPa low latitude wind velocities (Venne and Dartt 1990) have a very strong QBO [Fig. 1(f), left half]. Positive values represent westerlies and negative values represent easterlies. The trends in westerlies and easterlies (peak values) were considered separately. In Fig. 1(f), right half, the 11-year averages of the westerlies show increasing values from 1960 to 1980. The easterlies remained almost constant.

(8) For the Tahiti minus Darwin barometric pressure (Parker 1983, updated), Fig. 1(g) shows an uptrend during 1955-75 and a downtrend thereafter. No solar cycle effect is discernible.

(9) For the global surface temperature (Land + Marine, Jones *et al.*, 1988 and private communication), Fig. 1(h) shows a slight downtrend during 1957-75 and an uptrend thereafter.

(10) Aikin *et al.* (1991) have reported temperature decreases (~3°K per decade) in the lower mesosphere (55 km and 0.4 hPa) at Haute Provence (44°N, 6°E), using ground-based lidar and satellite techniques. However, these data refer to only 10 years (1980-90). For these years, results in our Fig. 1 show clear trends. For the same location and for 60-70 km altitude, Hauchecorne *et al.* (1991) reported a cooling of about ~4°K per decade but only since 1978 onwards. However, it is difficult to say whether this is a part of a secular trend or a component of decadal-scale variability.

4. Conclusions and discussion

It would, thus, seem that long-term trends in atmospheric parameters in the last 2-3 decades have not always been uniform. For some parameters, trends started in early sixties. But for some others, there were up (down) trends upto about 1970-75 and reverse trends thereafter, with magnitudes larger in the last few years. Thus, some extra factors seem to have come into play during 1970-75. Generally, apart from a solar cycle effect, which seems to be rather small in most of the cases, the changes are attributed to *changes in greenhouse gas concentrations.* The most important greenhouse gas is water vapour. It is highly variable in space and time, but to a first approximation, the relative humidity of the troposphere has remained constant (Mitchell 1989), and hence, could not have contributed to the long-term trends. Carbon Dioxide (CO_2) showed an almost monotonic increase from 1958 onwards when the first regular measurements started (Keeling *et al.* 1989). For Methane (CH_4), amounts seem to have increased by about 1% per year (Blake and Rowland 1988). However, regular measurements seem to be available only for the last 10-15 years. The same seems to be true for Nitrous oxide (N_2O) (Weiss 1981) as also for chlorofluoromethanes (CFC-11 and CFC-12) (Bodhaine 1989). The CFC's have increased and are increasing very rapidly in the last few years but the observations date back only to about 1978 (Cunnold *et al.* 1986). Could it be that their role became significant only since about 1975 ? Or, could it be that the various greenhouse gases have a *threshold* concentration, only above which significant climatic changes could occur, and these thresholds were reached only after 1970 ? This needs further exploration.

Model calculations give estimates of expected changes in the troposphere, stratosphere, mesosphere and thermosphere. Thus, when greenhouse gases increase, the tropospheric temperature is expected to increase (Ramanathan 1988, Hansen *et al.* 1988), while the stratospheric temperatures are expected to decrease (Brasseur and Hitchman 1988, Rind *et al.* 1990) and the mesosphere and thermosphere are also expected to cool (Roble and Dickinson 1989). For other parameters, *viz.*, noctilucent clouds and sodium layer heights, the trends should be due to variations in temperature. For ozone, the downtrend is attributed to destruction by CFC compounds. What we are emphasizing in this paper is that, while comparing these with experimental observations, *the changes of trends in 1970-75* demonstrated in this paper should be taken into consideration.

A possible contribution due to meteorological changes should also be considered. In a recent communication, Komhyr *et al.* (1991) pointed out that the June-August sea surface temperature (SST) in the eastern equatorial Pacific (6°N-6°S, 150°-90°W) were anomalously warmer by 0.67°C during 1976-87 compared with 1962-75. Also, QBO easterly winds in the equatorial Pacific stratosphere were generally *stronger* after 1975 than before 1975. Since the global ozone increased from 1960 to about 1970-75 and decreased thereafter up-to-date [Fig. 1 (e)], these authors suggested a possible *linkage* between long-term SST changes in the tropics and global ozone variations. The mechanisms they proposed are "modulation, by variations in convective activity associated with changes in SST, of the interaction between equatorial QBO winds and extratropical planetary waves that disperse ozone from the tropical stratospheric ozone source region to other parts of the globe; SST modulation of Hadley cell circulation; and SST changes in the equatorial Pacific and elsewhere in the tropics that, through teleconnections, affect planetary activity at higher latitudes" They also pointed out that the water vapour mixing ratios in the stratosphere at 80 hPa were different before and after 1975 (*e.g.* Mastenbrook and Oltmans 1983).

Nagatani and Miller (1987) and Newman and Randel (1988) reported a large decrease in lower stratosphere planetary wave activity in the Southern Hemisphere after 1979. Trenberth (1990) reported an increase in the intensity of the Aleutian low in the Northern Hemisphere during November-March of 1977-87, an eastward displacement of the low and reduced sea level pressures in the central and north Pacific and attributed these to atmospheric and underlying SST changes (El Nino). Komhyr *et al.* (1991) have themselves demonstrated the increasing geostrophic wind flow intensity east and west of the Baffin island low.

Recently, Gutzler (1992) reported temperature indices for the tropical western pacific (~7°N, 135°-170°E). For these, the 3-year averages showed a rising trend from 1974 to 1979-80 and a decrease thereafter. Thus, the changes before and after 1975 may have a possible meteorological origin, due to underlying SST changes. The SST changes may be related to the changes of greenhouse gas levels. In their global climatic model experiments, Hansen *et al.* (1988) show that the warming due to increase of greenhouse gases may appear first in low-latitude oceans.

The present results are only roughly indicative of a possible *transition during 1970-75* in large parts of the atmosphere. Since the temperature changes are mostly due to increase in the concentration of greenhouse gases (notably CO_2), one would expect a transition for greenhouse gases also in 1970-75. In a recent communication (Kane 1994), the interannual variability of some trace elements (including CO_2) during 1970-90 were examined. The CO_2 plots did show an *extra* increase (superposed on a general rising trend) during 1973-74. The CFC-11 compounds also showed an *extra* increase during 1977-78. Thus, the transitions of temperature trends in 1970-75 could be attributed to similar transitions in greenhouse gases.

References

Aikin, A. C., Chanin, M. L., Nash, J. and Kendig, D. J., 1991, "Temperature trends in the lower mesosphere," *Geophys. Res. Lett.*, **18**, 416-419.

Angell, J. K. and Korshover, J., 1983 "Global variation in total ozone and layer-mean ozone; An update through 1981," *J. Clim. Appl. Meteor.*, **22**, 1611-1627.

Blake, D. R. and Rowland, F. S., 1988, "Continuing worldwide increase in tropospheric methane 1978 to 1987," *Science*, **239**, 1129-1131.

Bodhaine, B. A., 1988, Geophysical Monitoring for Climate Change No. 16, Summary Report 1987, Air Resources Laboratory, Boulder, Colorado.

Brasseur, G. and Hitchman, M. H., 1988, "Stratospheric response to trace gas perturbations : Changes in ozone and temperature distribution," *Science*, **240**, 634-637.

Clemesha, B. R., Simonich, D. M. and Batista, P. P., 1992, "A long-term trend in the height of the atmospheric sodium layer : Possible evidence for global change," *Geophys. Res. Lett.*, **19**, 457-460.

Cunnold, D. M., Prinn, R. G., Rasmussen, R. A., Simmonds, P. G., Alyea, F. N., Cardelino, C. A., Crawford, A. J., Fraser, P. J. and Rosen, R. D., 1986, "Atmospheric lifetime and annual release estimates for $CFCl_3$ and $CFCl_2$ from 5 years of ALE data," *J. Geophys. Res.*, **91**, 10797-10817.

Gadsden, M., 1990, "A secular change in noctilucent cloud occurrence," *J. Atmos. Terr. Phys.*, **52**, 247-251.

Gutzler, D. S., 1992, "Climatic variability of temperature and humidity over the tropical western Pacific," *Geophys. Res. Lett.*, **19**, 1595-1598.

Hansen, J., Fund, I., Lacis, A., Rind, D., Lebedeff, S., Ruedy, R., Russel, G. and Stone P., 1988, "Global climate changes as forecast by Goddard Institute for Space Studies three dimensional model," *J. Geophys. Res.*, **93**, 9341-9364.

Hauchecorne, A. H., Chanin, M. L. and Keckhut, P., 1991, "Climatology and trends of the middle atmospheric temperatures (33-87 km) as seen by Rayleigh radar over the South of France", *J. Geophys. Res.*, **96**, 15297-15309.

Jones, P. D., Wigley, T.M.L., Folland, C. K. Parker, D. E., Angell, J. K., Lebedeff, S. and Handsen, J. E., 1988, "Evidence for global warming in the past decade," *Nature*, **332**, 790.

Kane, R. P., 1988, "Long-term variation of total ozone," *Pure and Appl. Geophys.*, **127**, 143-154.

Kane, R. P., 1992, "Long-term variation of stratospheric temperature at the North Pole," *J. Atmos. Terr. Phys.*, **54**, 1139-1148.

Kane, R. P., 1994, "Interannual variability of some trace elements and surface aerosol," *Int. J. Clim.*, **14**, 691-704.

Keeling, C. D., Bacastow, R. B., Carter, A. F., Piper, S. C., Whorf, T. P., Heimann, M., Mook, W. G. and Roeloffzen, H., 1989, "A three-dimensional model of atmospheric CO_2 transport based on observed winds : 1. Analysis of observational data". In "Aspects of climate variability in the Pacific and the western Americas" (ed. Peterson D. H.), *Geophys. Monogr.*, **55**, 165-235.

Komhyr, W. D., Oltmans, S. J., Gras, R. D. and Leonard, R. K., 1991, "Possible influence of long-term sea surface temperature anomalies in the tropical Pacific on global ozone," *Canad. J. Phys.*, **69**, 1093-1102.

Labitzke, K., 1987, "Sunspots, the QBO and the stratospheric temperature in the North Pole region", *Geophys. Res. Lett.*, **14**, 535-537.

Labitzke, K., Brasseur, G., Naujokat, B. and De Rudder, A., 1988, "Long-term temperature trends in the stratosphere : Possible influence of anthropogenic gases," *Geophys. Res. Lett.*, **13**, 52-55.

Mastenbrook, H. J. and Oltmans, S. J., 1983, "Stratospheric water vapour variability for Washington DC/Boulder, Colorado", *J. Atmos. Sci.*, **40**, 2157-2165.

Mitchell, F. B., 1989, "The greenhouse effect and climate change", *Rev. Geophys.*, **27**, 115-139.

Nagatani, R. M. and Miller, A. J., 1987, "The influence of lower stratospheric forcing on the October Antarctic ozone decrease", *Geophys. Res. Lett.*, **14**, 202-205.

Newman, P. A. and Randel, W. J., 1988, "Coherent ozone-dynamical changes during the Southern Hemisphere spring, 1979-1986", *J. Geophys. Res.*, **93**, 12585-12606.

Parker, D. E., 1983, "Documentation of a Southern Oscillation index", *Met. Mag.*, **112**, 184-188.

Ramanathan, V., 1988, "The greenhouse theory of climate change : A test by an inadvertent global experiment", *Science*, **240**, 293-299.

Rind, D., Suozzo, R., Balchandran, N. K. and Prather, M. J., 1990, "Climate change and the middle atmosphere : The doubled CO_2 climate," *J. Atmos. Sci.*, **47**, 475-494.

Roble, R. G. and Dickinson, R. E., 1989, "How will change in carbon dioxide and methane modify the mean structure of the mesosphere and thermosphere ?", *Geophys. Res. Lett.*, **16**, 1441-1444.

Taubenheim, J., Von Kossart, G. and Entzian, G., 1990, "Evidence of CO_2-induced progressive cooling of middle atmosphere derived from radio observations", *Adv. Space Res.*, **10(10)**, 171-174.

Trenberth, K. E., 1990, "Recent observed inter-decadal climate changes in the Northern Hemisphere", *Bull. Amer. Met. Soc.*, **71(7)**, 988-993.

Venne, D. E. and Dartt, D. G., 1990, "An examination of possible solar cycle-QBO effects in the Northern Hemisphere troposphere", *J. Clim.*, **3**, 272-281.

Weiss, R. F., 1981, "The temporal and spatial distribution of tropospheric Nitrous Oxide," *J. Geophys. Res.*, **86**, 7185-7195.