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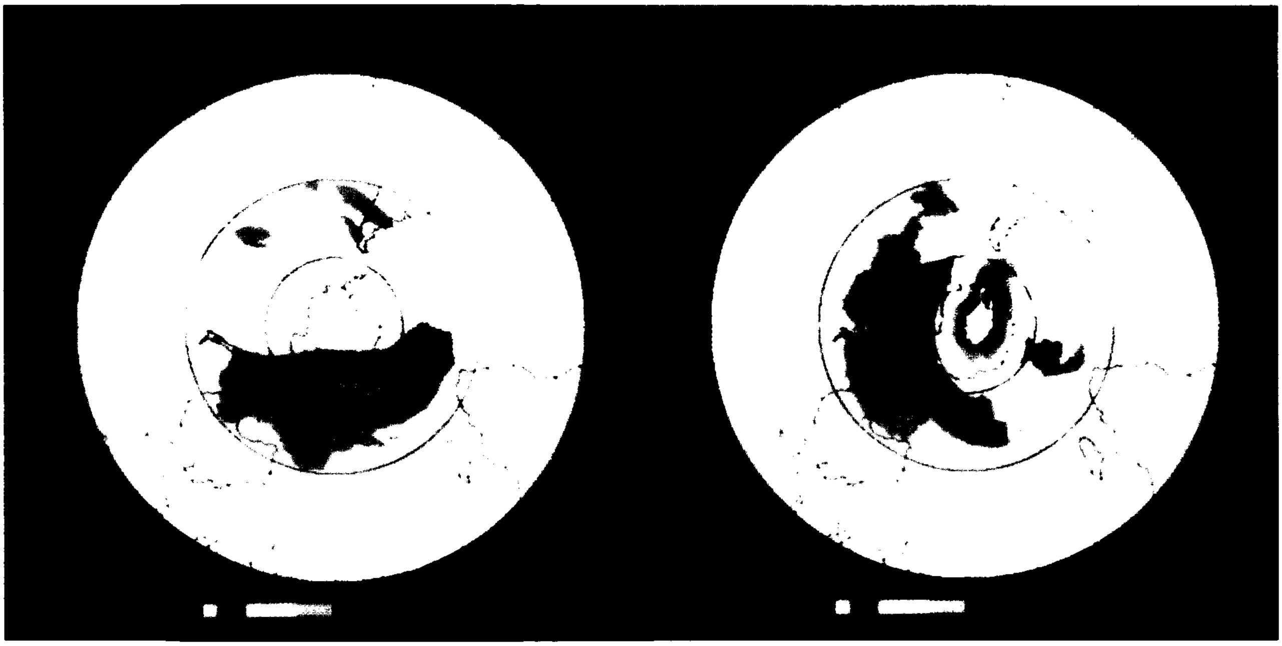
CHAPTER 14

OZONE AND TEMPERATURE TRENDS



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CHAPTER 14

OZONE AND TEMPERATURE TRENDS

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14.0 INTRODUCTION

Within this chapter we discuss the measurements of temporal changes in ozone and temperature. Our responsibility is to examine the data within the context of natural atmospheric variability and data problems and compare the results to numerical model calculations. In addition, we define the major issues of what is required to achieve the goals.

We note that ozone and temperature are considered within the one chapter in that they are very closely coupled via radiative, dynamic and photochemical processes, e.g. Chapter 8. Changes in one result in changes in the other such that a complete examination of trends must verify both parameters in a consistent system against a unified fully coupled predictive model. As we will see, below, the history of this subject is such that sophisticated statistical trend analyses have been accomplished first on the ozone data such that we can present quantitative results. Similar analyses for temperature, however, are only just beginning so that the results are more qualitative although prevocative.

For each parameter the initial consideration is by instrument type as each system has its unique elements that must be considered in long-term trend evaluation. Within each instrument discussion further breakdown is accomplished by altitude.

14.1 OZONE TRENDS

14.1.1 Total Ozone

Over the past several years there have been several studies conducted in an attempt to detect any evidence of a total ozone trend (e.g. Hill *et al.*, 1977; Reinsel, *et al.*, 1981; St. John *et al.*, 1982, Angell and Korshover, 1983b; Bloomfield *et al.*, 1983). Most recent statistical analyses have adopted a time domain approach to estimating a global trend. The ozone value $X_{t,j}$ at time t and observing station j is represented by $X_{t,j} = \omega_j h_t + \varepsilon_{t,j}$ where h_t represents a predicted global trend, e.g. one caused by CFC's; ω_j is a multiplier that indicates the magnitude of the observed trend at station j; and $\varepsilon_{t,j}$ represents an error process to account for other influences on ozone. The $\varepsilon_{t,j}$ series is typically assumed to be an autoregressive process (e.g., Hill *et al.*, 1977; Reinsel *et al.*, 1981; St. John *et al.*, 1982). This model is fit separately to the ozone record from each station, and a global trend estimate is obtained by combining the station values ω_j. Bloomfield *et al.*, (1983), on the other hand, introduce a frequency domain statistical model. This model extends variance-components analysis to the time series case and incorporates both temporal and spatial association found in the ozone data. A key feature of this model is the inclusion of a common global term representing natural global variations in ozone.

Reinsel *et al.* (1981) found an increase of 0.28% in global total ozone over the period 1970-1978 with a standard error of 0.67%, while St. John *et al.* (1982) found an increase of 1.5% with a standard error of 0.5% from '70 - '79 and Bloomfield *et al.* (1983) found an increase of 0.1% for the same period with a standard error of 0.55%. Thus, there is little overall support for the suggestion of a statistically significant trend in total ozone.

Reinsel *et al.* (1985 - personal communication) have recently extended the analysis using data through 1983. Time series models were used to obtain a trend estimate for each station, where level shifts to account for instrument recalibration were also included in the model for five stations (Mt. Louis, Mt. Abu, Lisbon, Buenos Aires, and Hradec Kralove). The overall trend estimate for total ozone change over the entire period 1970-1983, with associated 95% confidence limits, is (-0.003 ± 1.12) % per decade.

Trend analyses were also performed using the f10.7 solar flux series and the sunspot number series separately as explanatory variables for the total ozone series at each station. Results were quite similar in both cases, and the overall total ozone trend estimates for the period 1970-1983 are summarized as follows:

(-0.00 ± 1.12) % per decade with no solar effect in model
(-0.17 ± 1.10) % per decade with f10.7 solar flux in model
(-0.14 ± 1.08) % per decade with sunspot series in model

The f10.7 solar flux series (as well as the sunspot series) was found to be mildly related to total ozone overall, with the estimated effect of f10.7 solar flux on total ozone (averaged over 36 stations) equal to (0.63 ± 0.53)% ozone change per 100 units of f10.7 solar flux. This estimate corresponds to about a one percent change in total ozone from solar cycle minimum to maximum.

These analyses all indicate no significant overall trend in total ozone during the fourteen year period 1970-1983, and suggest a mild relation between total ozone and f10.7 solar flux. The trend estimates are about 0.2% per decade more negative with the inclusion of data for 1983 than comparable estimates based on data through 1982.

A major question of the statistical analyses has been the general lack of global coverage of the ground-based observations suggesting possible spatial biases. For the most recent trend estimates given above by Reinsel *et al.* (1985, personal communication), Figure 14-1 shows a plot of the trend estimates as a function of latitude. Altogether, there does not seem to be any latitudinal effect, but if we examine this diagram by region we see an interesting pattern. For example, all of the North American stations are below the Indian network as are 6 of 7 European stations. While the analysis of Reinsel *et al.* (1981) takes this type of regional networking into consideration, it suggests that more consideration should be given to the representativeness of the data set. This will be discussed further below.

One element that deserves further discussion is the above observation that the total ozone trend through 1983 is more negative than the earlier results. This is related, at least, in part, to the strong ozone minimum seen in the winter period 1982-1983. This effect is shown in Figure 14-2 for the global scale where we present the monthly average total ozone integrated over the domain 60N to 60S for the period May '79 through November '83 as measured from the operational TOVS system (Planet, *et al.*, 1984). We see that in the early part of the record the ozone values were higher than the general average level then seemed to level off until the winter of '82-'83 when the values dropped to their lowest level. This period of "ozone hole" is currently being examined in great detail and appears to be related possibly to two events. The first is the volcanic eruption of El Chichon (Mexico) in April '82 which spewed large amounts of material into the stratosphere (McCormick and Swissler, 1983); the second is the El Nino event of '82-'83 which was accompanied by large-scale circulation changes in the atmosphere. Quiroz, (1983a) through examination of stratospheric temperatures, has shown the difficulty of separating the signals from these events. As the record continues, the ozone values appear to be returning slowly to their previous levels. We might expect, then, that the ozone trend extended through 1984 will be slightly more positive than that for 1983. One additional point is that the above decrease does not appear to be caused by the volcanic cloud in an instrument sense (i.e. Mateer and Asbridge, 1980, Angell *et al.*, 1985).

We might also ask the question as to how often major perturbations such as the 82-83 phenomena occur and what will be their impact on a near real-time trend assessment. In Figure 14-3 we show the average monthly deseasonalized total ozone values for North America and Europe for the periods from the late 50's through 1983 (Reinsel *et al.*, personal communication). Taken in this context the '82-'83

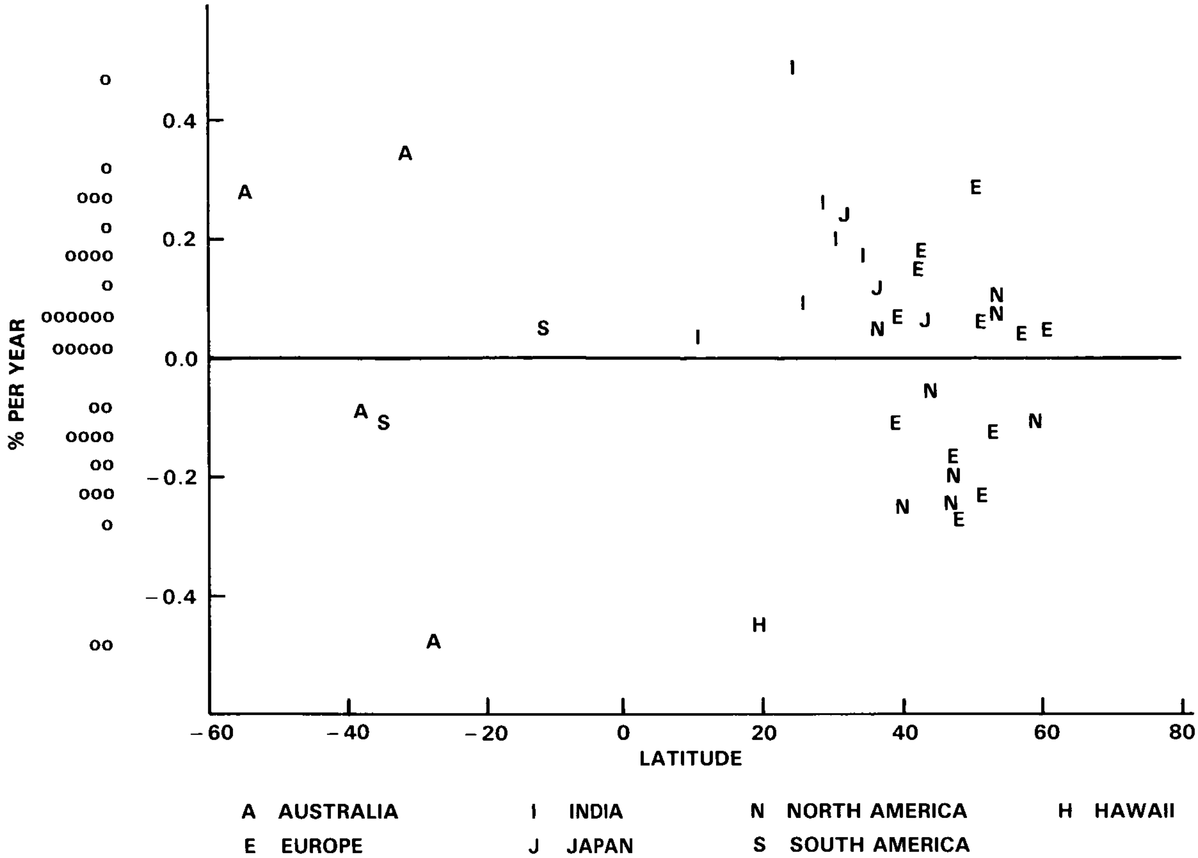

Figure 14-1. Histogram and scatter plot of total ozone trend estimates using data through 1983. (Reinsel *et al.,* personal communication).

winter results do not look all that remarkable and we can see major perturbations at not infrequent intervals. Taking the results of Figures 14-2 and 14-3 together, it appears that real-time assessment of the total ozone variation may be easily influenced by current conditions and that this will require further analysis of the data.

Recently Farman *et al.* (1985) have published the data in Figure 14-4 showing a large secular decrease in total ozone for the month of October over their station at Halley Bay, Antarctica. Since 1957 the total ozone over Halley Bay has decreased during the month of October by about 40%. Other months show significantly less trend. Satellite data from the Nimbus 7 TOMS instrument and the SBUV instrument confirm these findings and show a minimum which is spatially confined to the high south polar latitudes. As is shown in Figure 14-5 (taken from Bhartia *et al.*, 1985) the minimum is surrounded by a large maximum which displays some wave structure. The minimum is distorted into an oblong shape and rotates along with the maximum. Figure 14-5 shows a 5-day sequence in October of 1983 in which the rotation is about 50°. There is a marked tendency for the minimum to be displaced off the pole towards the direction of Halley Bay. For comparison, Figure 14-6 (Bhartia *et al.*, 1985) compares October 3, 1979 to October 3, 1983 showing that 1979 had a similar structure to 1983 except that the deep minimum was missing. These data indicate that some mechanism is at work in the cold southern polar night or polar twilight that is not generally included in models. This clearly warrants further investigation.

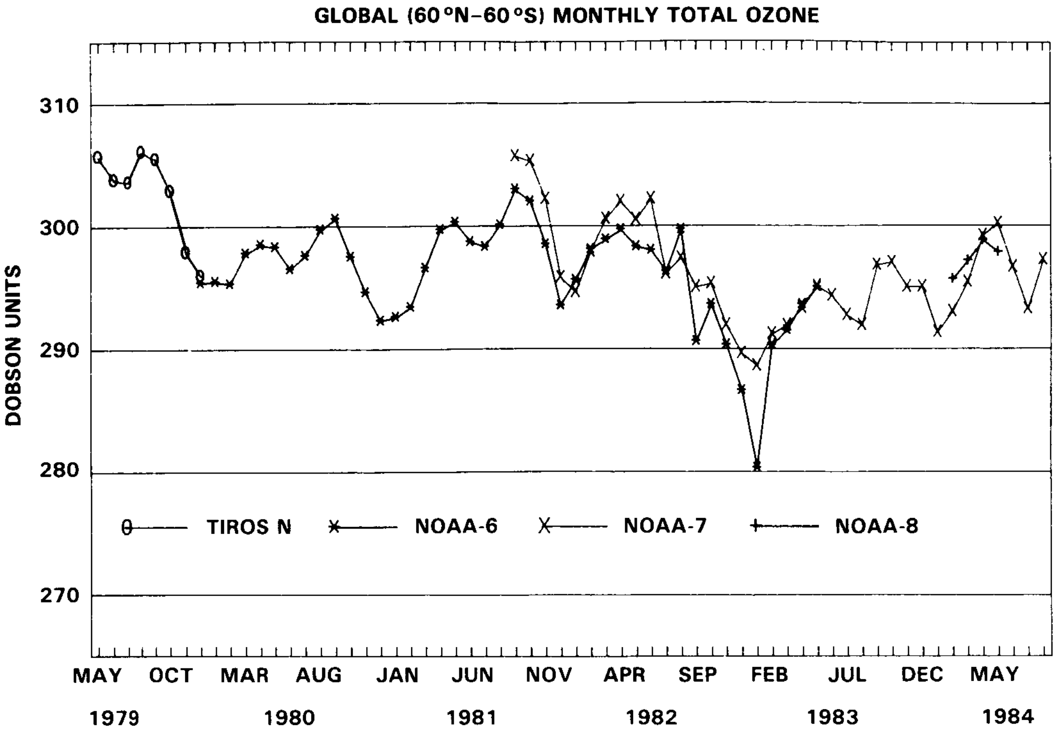

Figure 14-2. Global (60°N-60°S) monthly total ozone determined from NOAA TOVS system. (Planet *et al.*, 1984.)

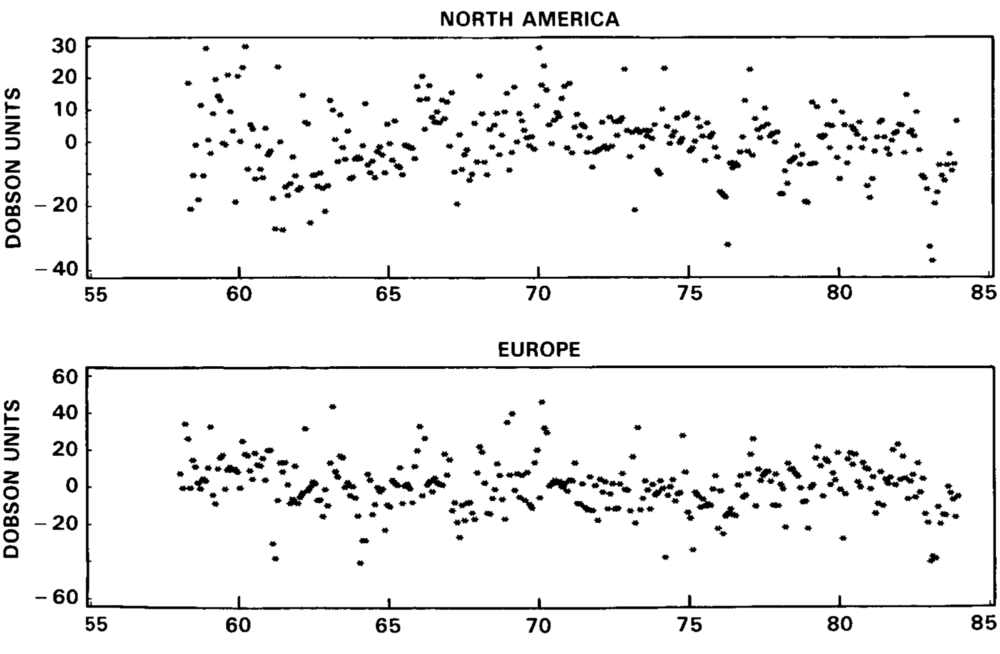

Figure 14-3. Monthly average deseasonalized total ozone; North America (top), Europe (bottom). Units: Dobson units. (Reinsel *et al.*, personal communication).

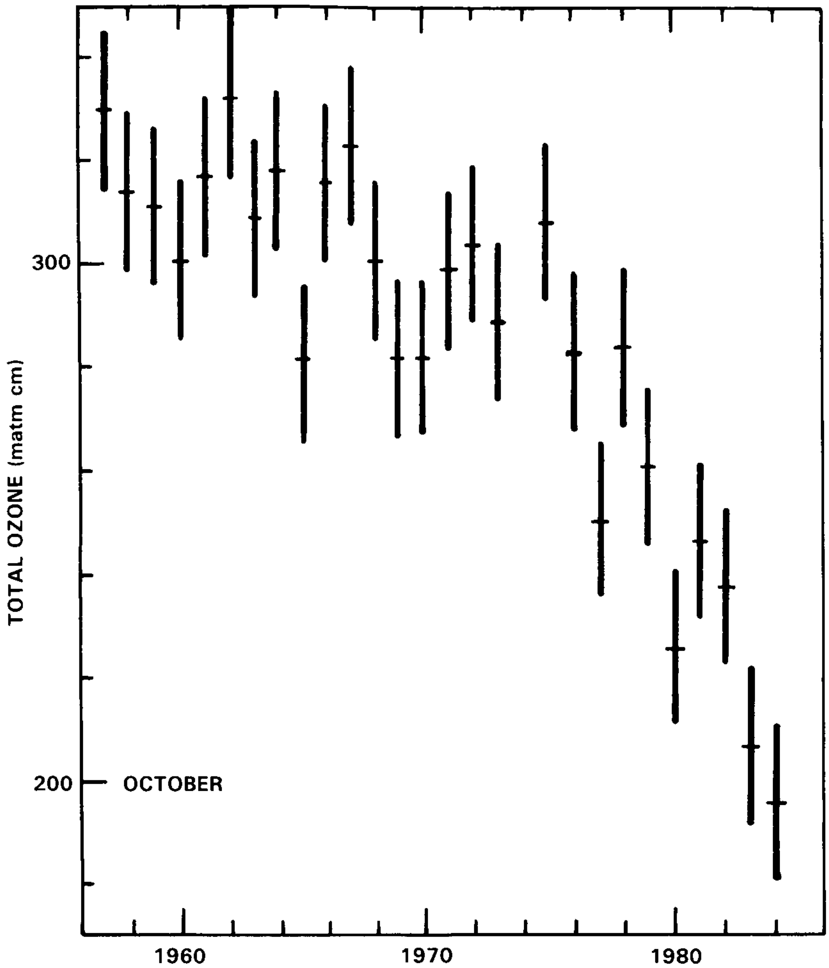

Figure 14-4. Monthly means of total ozone at Halley Bay for October of the years 1957 through 1984. (Farman *et al.,* 1985.)

14.1.2 OZONE PROFILES

14.1.2.1 Ozone Balloonsonde

In a recent update of ozone variations determined from balloonsondes, Angell and Korshover (1983b) determined that in the tropospheric layer of north temperature latitudes, 2-8 km, the data suggest a 12% increase in ozone between 1970 and 1981. This is accompanied by a 1-3% decrease in the region 16-32 km. Since then, several on-going studies have focused on the quality of the ozonesonde data for trend detection (Tiao *et al.*, personal communication; Logan, 1985) and the discussion is presented here with the authors' kind permission. Formal publication is planned for the near future. From Tiao *et al.*, Ozonesonde data from 13 stations have been processed to obtain monthly averages of ozone in 14 fractional Umkehr layers, (1A, 1B, 1C, 1D, 2A, 2B, 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B), (e.g. Table 14-3) and an additional layer above 6B. For each station, the daily sonde data (in partial pressure) were first integrated into ozone readings (in Dobson units) within each layer, and monthly averages for each layer were then computed from the integrated readings. The data were screened to meet the following criteria:

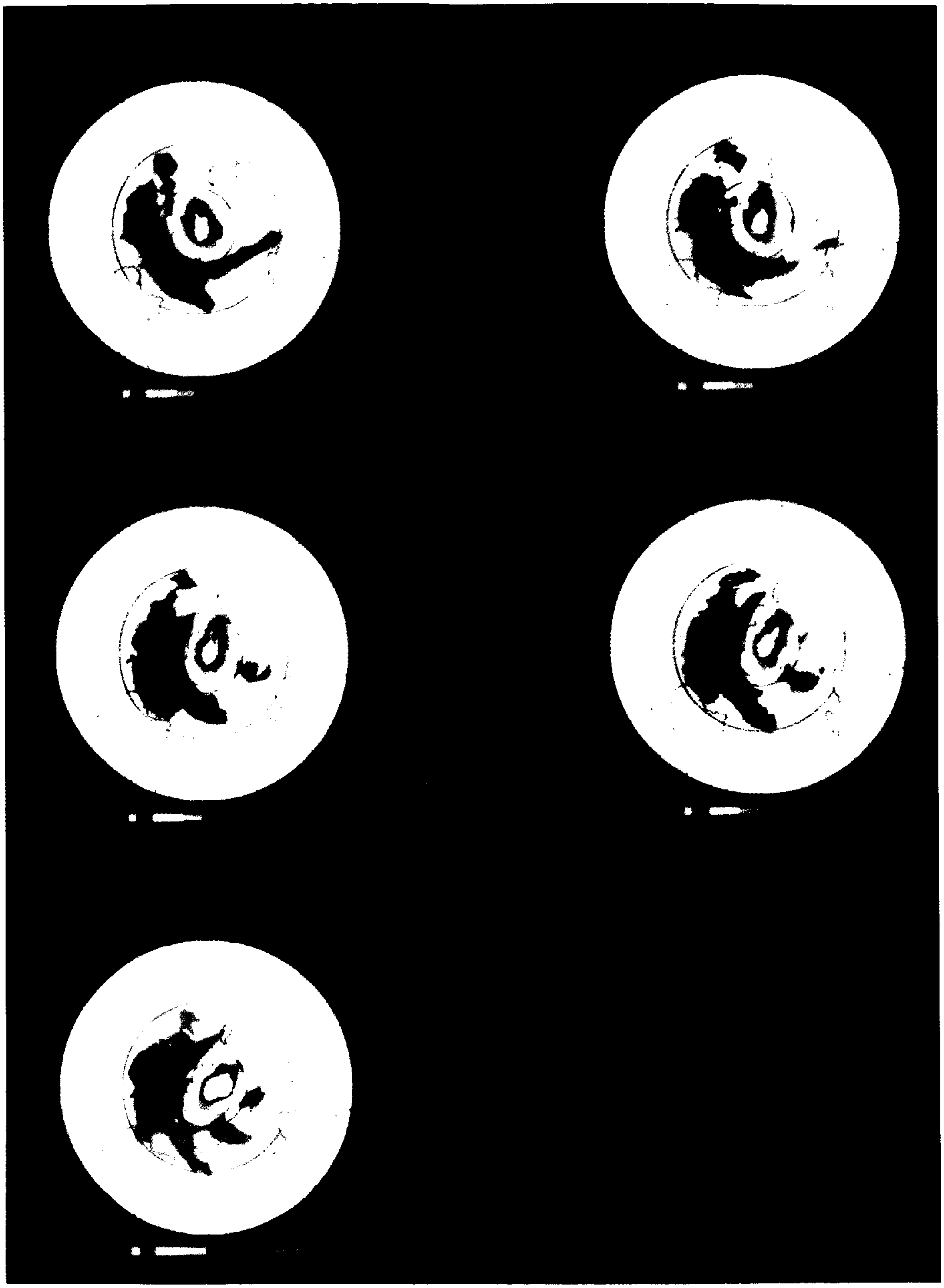

Figure 14-5. Sequence of 5 days (October 1, 1983-October 5, 1983) of total ozone measurements from the Nimbus 7 TOMS instrument. (Bhartia *et al.*, 1985.)

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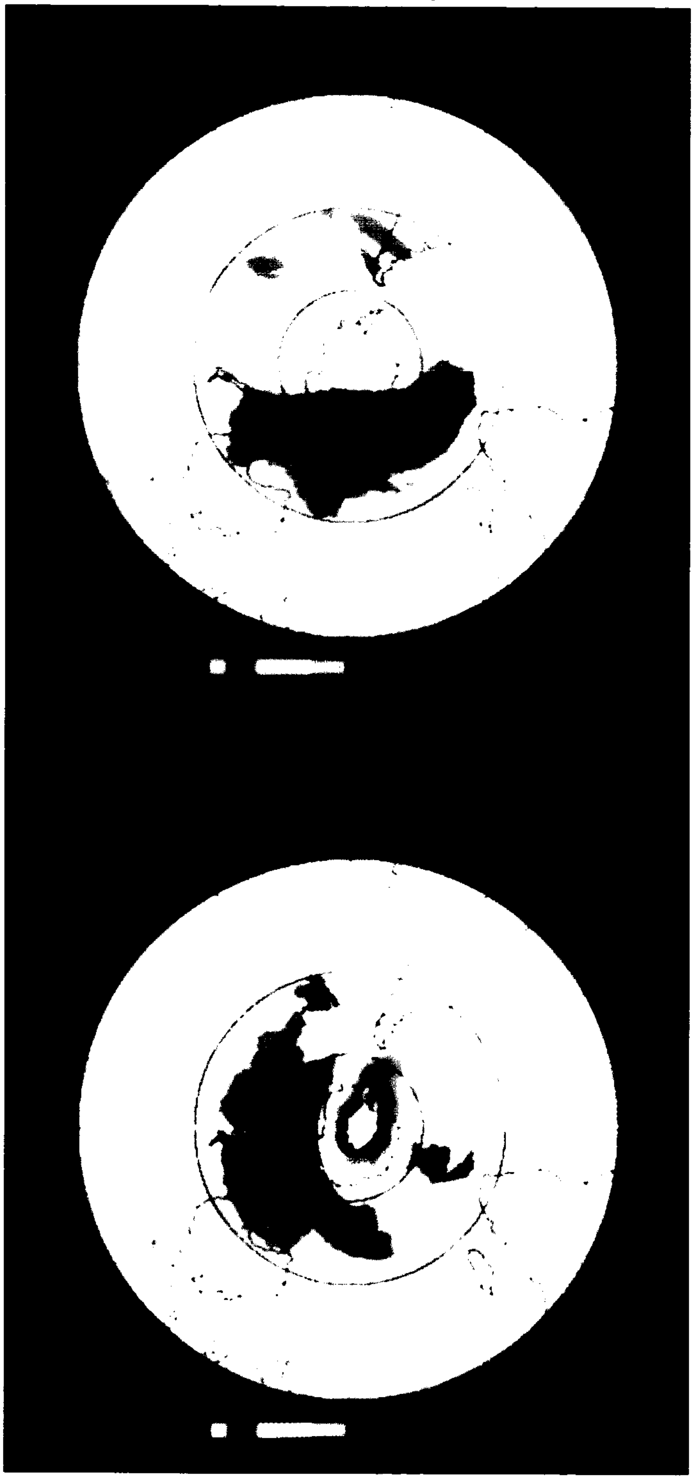

Figure 14-6. Comparison of October 3, 1979 with October 3, 1983 total ozone measurements from the Nimbus 7 TOMS instrument. (Bhartia *et al.*, 1985.)

- The correction factor (Chapter 8) was between .8 to 1.3 for ECC and .8 to 1.4 for Brewer.
- The balloon reached a burst level of 15.8 mbar (top of layer 5B).
- There were no zero partial pressure readings recorded in each daily sondes.
- The total ozone reading for the daily sonde data had a nonzero value.

The station locations, data span and methods of measurement are given in Table 14-1 (Tiao *et al.*, personal communication), where the Canadian stations changed from the Brewer system to the ECC at the designated times.

One of the first elements examined were the correction factors for the various instruments and, as examples of this parameter, we present in Figure 14-7 (Reinsel *et al.*, personal communication), the results at Goose Bay, and Hohenpeissenberg. At Goose Bay we see that the individual months show large variations with a small tendency for decrease till 1980 where the change to ECC was effected. The impact of this change will be discussed further below. For Hohenpeissenberg the diagram also shows some interesting month-to-month variations and we note, in particular, the tendency for the corrections to increase during the first few years followed by the strong minimum in the late '70's.

The cause of these tendencies in the correction factors is unclear and may be related to instrument manufacture, personnel changes or changes in the Dobson system. The major point is that we can not expect the correction factors to be random about some average value and that we will have to consider, in detail, the possible impacts of these variations. As Hilsenrath *et al.* (1985) have indicated, this brings into question whether or not the factors should be applied as they are, as a percentage change to the profile, or in some height dependent manner.

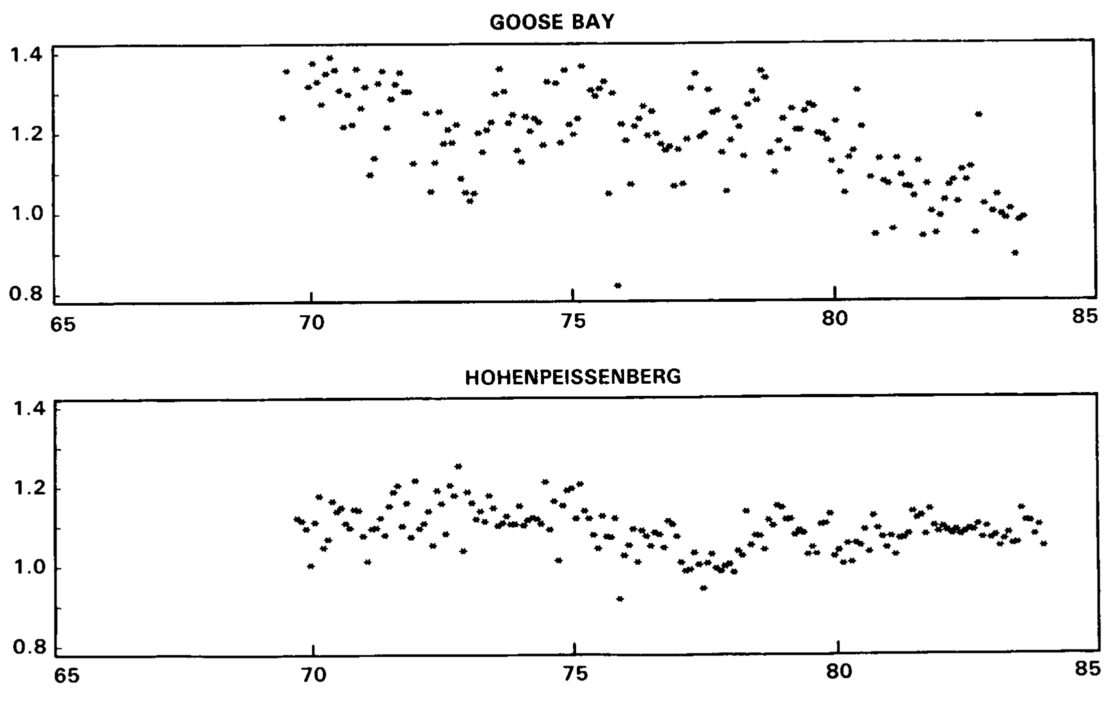

Figure 14-7. Monthly average ozone balloonsonde correction factors at Goose Bay (top), Hohenpeissenberg (bottom). (Reinsel *et al.*, personal communication)

Table 14-1. Ozone Balloonsonde Stations

Station	Data Span	Methods
Hohenpeissenberg	1/70 - 2/83	Brewer
Biscarrosse	3/76 - 1/83	Brewer
Lindenberg	1/75 - 2/83	Brewer
Payerne	9/68 - 12/81	Brewer
Aspendale	6/65 - 5/81	Brewer
Churchill	10/73 - 1/83	Brewer/ECC 9/79
Edmonton	10/70 - 12/82	Brewer/ECC 9/79
Goose Bay	6/69 - 12/82	Brewer/ECC 12/80
Resolute	1/66 - 1/83	Brewer/ECC 12/79
Wallops Island	5/70 - 4/82	ECC
Kagoshima	1/70 - 12/82	ECC
Sapporo	12/68 - 12/82	ECC
Tateno	3/68 - 12/82	ECC

The above notwithstanding, trend estimates (1970) have been obtained from the monthly averages using standard models reported previously with and without an intervention at the 4 Canadian sites for the changes of measurement method. As a cross-validation an overall trend estimate for each station was obtained by calculating a weighted average of the individual estimates of the 15 layers. These estimates may then be compared with the corresponding trend estimates obtained from the Dobson total ozone reading on the ozonesonde file. The results are shown in Table 14-2 (Tiao *et al.*, personal communication). For the nine non-Canadian stations, the trends from weighted averages are in close agreement with those from Dobson total ozone readings on the sonde file. For Churchill, Edmonton and Resolute, the agreement seems much better without the intervention level adjustments. This is in direct contrast to what we would expect and reflects, again, the question as to whether the correction factors between the Brewer Mast and ECC sondes are applied in a consistent manner.

Finally, in Table 14-3 (Tiao *et al.*, personal communication) we present the combined ozone trend estimates (Table 14-2) in the various layers along with their 95% confidence limits. We see that with and without the data intervention at the 4 Canadian sites the negative trends in the lower stratosphere appear statistically significant and of the same magnitude, about − 5% per decade. In the lower troposophere, however, the values are very different although they remain positive. Thus, there is evidence to suggest the existence of overall negative trends at layers 3A and 3B, and perhaps also at 2B and 4A.

The results for the troposphere have recently been examined by Logan (1985) and her analysis indicates that the surface ozone at mid-latitudes displays two modes of seasonal behavior: a broad summer maximum within a few hundred kilometers of populated and industrialized regions in Europe and the United States; and a summer minimum in sparsely populated regions remote from industrial activity, in Canada and Tasmania, for example. She argues, in addition, that the current data base for different regions, in combination with limited historical data indicates that summertime concentrations of ozone near the surface in rural areas of Europe and the central and eastern U.S. may have increased by approximately 10-20 ppb (30-100%) since the 1940's. The seasonal cycle of ozone in the middle troposphere over Europe, the United States, and northern Japan is very similar to that at the surface, with a summer maximum,

Table 14-2. Ozone Trend Estimates (% Per Year) As Determined from Balloon Ozonesondes versus Those Determined from Dobson Measurements. (Tiao *et al.*, personal communication.)

Station	Ozonesonde		Total Ozone Readings on Sonde File
Aspendale (6/65-5/82, Brewer)	−.115 (.055)		−.162 (.075)
Biscarrosse (3/76-1/83, Brewer)	−.416 (.114)		−.587 (.185)
Hohenpeissenberg (1/70-2/83, Brewer)	−.174 (.052)		−.220 (.088)
Lindenberg (1/75-2/83, Brewer)	−.287 (.128)		−.269 (.266)
Payerne (9/68-12/81, Brewer)	−.149 (.045)		−.181 (.074)
Kagoshima (1/70-12/82, ECC)	.136 (.090)		.215 (.155)
Tateno (3/68-12/82, ECC)	.085 (.082)		−.055 (.094)
Sapporo (12/68-12/82, ECC)	.148 (.103)		.203 (.138)
Wallops Isl. (5/70-4/82, ECC)	.034 (.075)		.037 (.122)
Churchill (10/73-1/83, Brewer/ECC 9/79)	.473* (.118)	−.310** (.197)	.282 (.234)
Edmonton (10/70-12/82, Brewer/ECC 9/79)	.405* (.095)	.027** (.152)	.360 (.149)
Goose Bay (6/69-12/82, Brewer/ECC 12/80)	.029* (.060)	−.095** (.077)	−.123 (.099)
Resolute (1/66-1/83, Brewer/ECC 12/79)	−.194* (.045)	−.240** (.070)	−.164 (.074)

* without intervention adjustment.
** with intervention adjustment.

Table 14-3. Ozone Trend Estimates and 95% Confidence Intervals

Layer	KM	95% Interval (%/yr.) (w/o Intervention)	95% Interval (%/yr.) (with Intervention)
Above 6B	35+	−.05 ± .38	.22 ± .56
6B	30-35	.04 ± .33	.27 ± .54
6A		.22 ± .31	.46 ± .51
5B	25-30	.15 ± .17	.18 ± .21
5A		.05 ± .18	−.02 ± .27
4B	20-25	−.07 ± .15	−.16 ± .22
4A		−.21 ± .22	−.30 ± .21
3B	15-20	−.33 ± .25	−.48 ± .26
3A		−.56 ± .31	−.71 ± .27
2B	10-15	−.30 ± .53	−.48 ± .49
2A		−.17 ± .67	−.64 ± .75
1D	5-10	.93 ± 1.04	.08 ± .88
1C		1.44 ± 1.23	.57 ± .74
1B	0-5	1.43 ± .87	.66 ± .53
1A		1.72 ± 1.17	.75 ± .83

but it is quite different from that at 300 mb, which is characterized by a maximum in spring. There is good evidence for an increase in ozone in the middle troposphere over Europe during the past 15 years, and weaker evidence for a similar increase over Northern America and Japan. From this she argues that the summer maximum in ozone and the observed trends are due to photochemical production associated with anthropogenic emissions of NO_x, hydrocarbons and CO from combustion of fossil fuels. A strong seasonal variation in ozone observed at Natal, Brazil (6°S) may also result from emissions of NO_x and hydrocarbons, in this case from agricultural burning. Maximum concentrations at Natal are similar to values found at mid-latitudes in summer.

With the limited network of ozonesonde stations, however, the question remains as to whether the tropospheric ozone increase is due to local pollution effects or is symptomatic of a more general atmospheric behavior.

14.1.2.2 Umkehr Measurements.

Although there have been several recent analyses of Umkehr data (eg Angell and Korshover, 1983b; Reinsel *et al.*, 1983; Bloomfield *et al.*, 1982), these have been limited in that they did not consider the impact of stratospheric aerosols on the observations. This has been discussed by DeLuisi (1979) and Dave *et al.* (1979) and it has been concluded that aerosols tend to induce significant negative errors in the Umkehr measurements in the uppermost layers 7-9, with the largest percentage error occurring in layer 9.

Based on this, Reinsel *et al.* (1984) have completed a statistical analysis of the Umkehr data where atmospheric aerosols are taken into account. In the statistical trend analysis, time series models have been estimated using monthly averages of Umkehr data over the past 15 to 20 years through 1980 at each of 13 Umkehr stations and at each of the five highest Umkehr layers, 5-9, which cover an altitude range of approximately 24-48 km. The time series regression models incorporate seasonal, trend, and noise factors and an additional factor to explicitly account for the effects of atmospheric aerosols on the Umkehr measurements. At each Umkehr station, the explanatory series used in the statistical model to account for the aerosol effect is a 5 month running average of the monthly atmospheric transmission data at Mauna Loa, Hawaii, the only long running aerosol data available. A random effects model is used to combine the 13 individual station trends for each Umkehr layer. The analysis indicates statistically significant trends in the upper Umkehr layers 7 and 8 of the order of −0.2 to −0.3% per year over the period 1970-1980, with little trend in the lower layers 5 and 6.

The results are shown graphically in Figure 14-8 (Reinsel *et al.*, 1984) where we have added, for comparison numerical model calculations from Wuebbles *et al.* (1983). We see that there is substantive agreement between the observations and the model calculations.

There are several points to be raised on these results of the Umkehr analysis. The first is that the results, including the sign, are very sensitive to the inclusion of a stratospheric aerosol impact (i.e. Reinsel *et al.*, 1983, 1984). For this data record, the major impact is due to the volcanic eruption at Mt. Agung in 1963 and to lesser extent that of Tiera Del Fuego in 1974 and possibly Mt. St. Helens in 1980. The

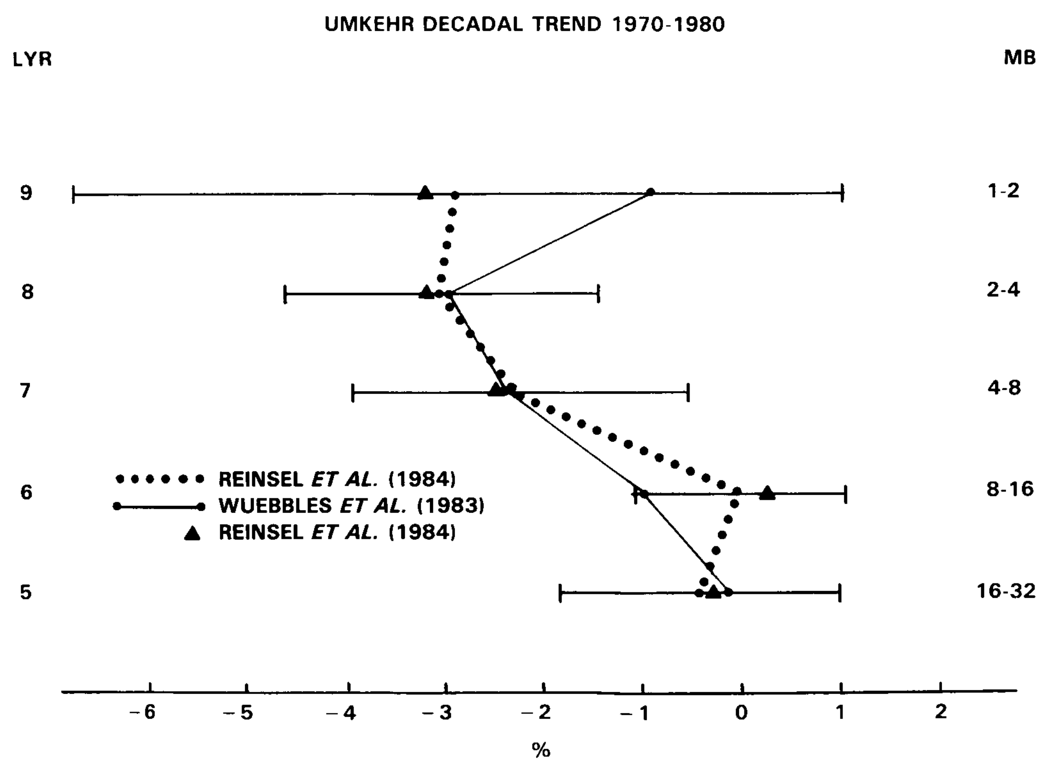

Figure 14.8. Umkehr decadal trend 1970-1980. Units: percent per decade. (Reinsel *et al.,* 1984.)

use of a single station such as Mauna Loa to account for the aerosol on a global basis is fraught with difficulty and great care must be taken on the interpretation of the results. This was evidenced most recently by the events of the volcanic eruption of El Chichon. Attempts (DeLuisi, personal communication) to consider this event within the framwork of the previous analysis have not been free of difficulty. One suggestion by DeLuisi is that there existed an actual decrease of ozone associated with the volcanic debris, possibly due to heterogeneous chemistry or injected chlorine, but this is still quite uncertain. Considerably more work will be required before we will be able to utilize the Umkehr data through the El Chichon event with some confidence.

Another point for consideration is the global representativeness of the 13 station network, an element touched on in the total ozone trend section. For the Umkehr data, Reinsel *et al.* (personal communication) have examined the spatial sampling by examining the approximate 4 year period of the global SBUV data. Their results are presented in Figure 14-9 where the trends over the period November '78 - April '82 have been determined from SBUV zonal averages. Superposed on these curves are the values determined in $10° \times 10°$ longitude/latitude boxes from the SBUV data that includes the Umkehr site. In layer 8, for example, we see that the North American and European stations are biased on the high side of the curve and that Japanese stations tend to bring the overall average into line. Thus, the overall results can be very sensitive to the availability of the stations. This is taken to extreme in the Southern Hemisphere where we see that the Australian station happens to coincide with the relative peak in the zonal average. Because of this fortuitous sampling the overall station average is rather close to the total SBUV area weighted trend. That the ground-based results are so sensitive to the spatial sample is, of course, precisely why the NOAA operational satellite ozone measurement program was initiated. This will be discussed further below.

As the final element in this section we discuss the inclusion of a solar flux variation within the trend analysis. For the Umkehr data, Reinsel *et al.* (personal communication) have included the f10.7 cm solar radio flux as an additional independent variable.

For each Umkehr layer, 5 to 9, and for a given Umkehr station, the model was used:

$$Y_t = \mu + S_t + \omega X_t + \gamma_1 V_{1t} + \gamma_2 V_{2t} + N_t$$

where

Y_t =monthly average for month t of a station's observations at a given layer
S_t =seasonal component (annual and semi-annual)
x_t =0 for $t < T$ (T denotes 12/1969)
=$(t - T)/12$ for $t > T$
ω =annual rate of change parameter (trend)
V_{1t} =a smoothed version of the transmission data at Mauna Loa
γ_1 =a parameter providing an empirical measure of the aerosol effect on Umkehr data
V_{2t} =monthly mean of 10.7 cm solar radio flux (2800 MHz)
γ_2 =a parameter for an empirical measure of the solar effect on Umkehr data
N_t =an autocorrelated noise term, modelled as an autoregressive process to account for non-independence of data
μ =intercept which is very close to the average value

A term to account for a shift in mean level due to instrument recalibration was also included in the model for some stations, as described above.

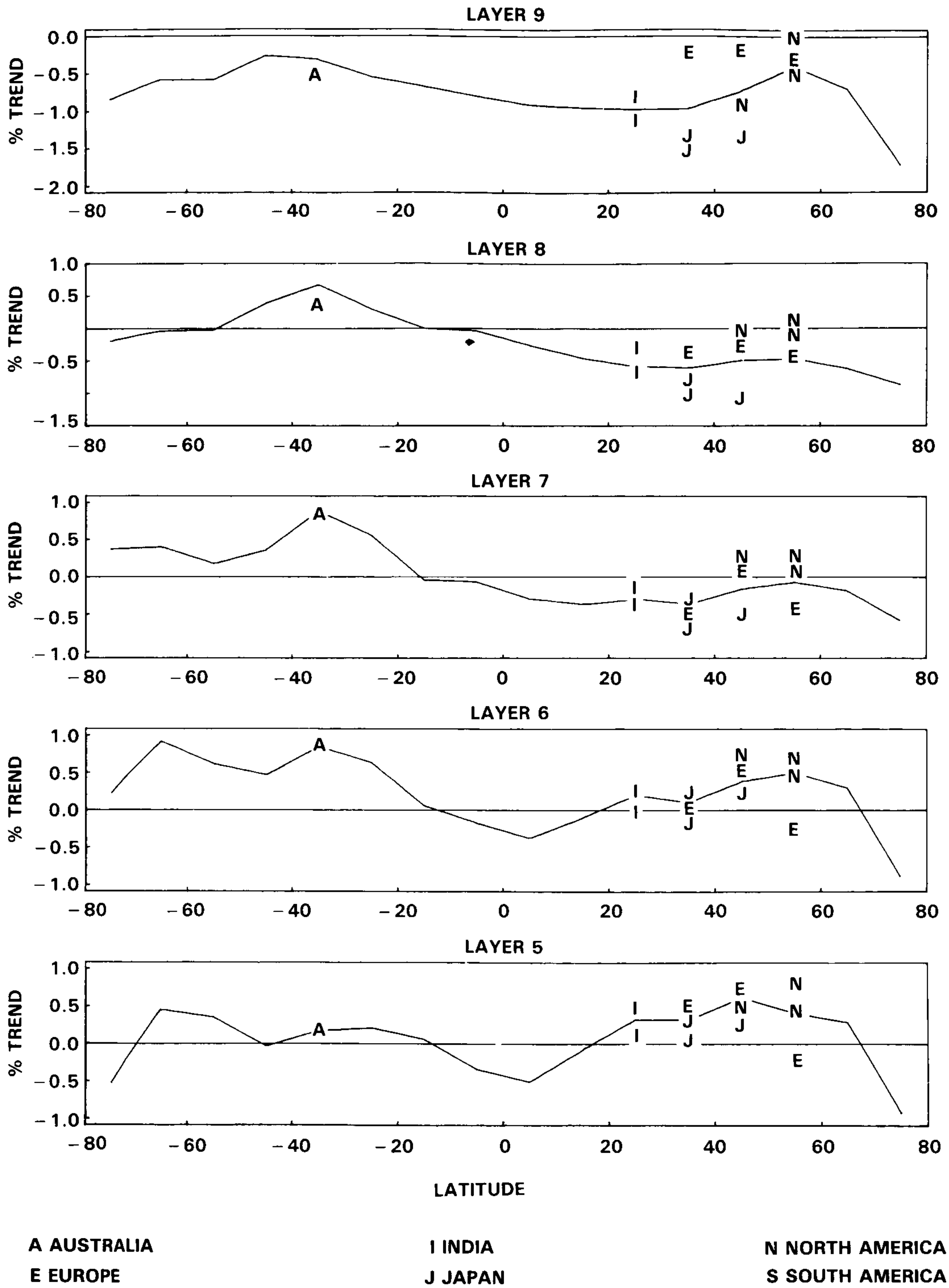

Figure 14-9. SBUV zonal trend estimates in Umkehr layers compared to "Umkehr station blocks" for period November 1978-April 1982. (Reinsel *et al.*, personal communication)

The trend estimates including the solar flux series are shown in Figure 14-8 as the solid triangles (Reinsel *et al.*, personal communication). We see that there is very little impact on the decadal trend with this term added. The overall estimates for the regression coefficients of the solar flux series with accompanying 95 percent confidence intervals are 0.81 ± 2.56, 0.46 ± 1.80, 2.04 ± 1.32, 1.53 ± 0.78 and 1.18 ± 0.86 percent, respectively, for layers 9 through 5. These coefficient estimates represent percentage change in ozone per 100 units change in solar flux. The solar effect is largest in layer 7, and statistically significant in layers 7 to 5. The estimates correspond to a solar effect on ozone from solar cycle minimum to maximum of about 1.3, 0.8, 3.4, 2.5, and 2.0 percent, respectively, for layers 9 through 5.

It is not at all clear as to why the solar flux term should have a significant regression coefficient in layers 7 and 6 and not in layers 9 and 8, and raises serious questions on the effect of the solar flux variations.

14.1.2.3 Satellite Measurements

Although the ozone satellite data are not yet of sufficient length to be able to examine decadal trends, the Solar Backscatter Ultraviolet system (SBUV-2) is now operational on the NOAA satellite series. We may expect, then, that these data will take their place among the long-term data sets such as Umkehr, ozonesondes etc., and in this section we will outline the basic operational program including validation. This will be compared to current estimates of anthropogenic impact such that the capabilities of early ozone trend detection will be delineated. We note that the SBUV-2 satellite measurements are restricted to daytime only total ozone and vertical profiles in the stratosphere above the ozone concentration maximum. There is no satellite profile capability for the troposphere anticipated for the near future.

14.1.3 OPERATIONAL SBUV-2 OZONE MONITORING SYSTEM

A critical issue in the search for long term ozone trends using satellite-based sensors concerns the separation of instrument sensitivity changes from true atmospheric variability. A thorough examination of this requires careful characterization of the instrument over its entire lifetime. A significant improvement in the new SBUV-2 as compared to previous system is the inclusion of an onboard calibration lamp to assist in tracking any instrument-related changes in the ratio of backscattered ultraviolet radiance to incident solar irradiance. This ratio is the fundamental measurable upon which the derived ozone abundance depends. However, the new calibration check is only one of several evaluations that must be conducted on a regular basis toward reaching the goal of obtaining a long term data base with negligible instrumental drift. Additional support in this regard will be provided by NASA's Shuttle-borne SBUV (SSBUV). Regular flights of this freshly calibrated instrument in coincidence with measurements from a free-flying SBUV-2 have the objective of detecting and correcting for possible sensitivity drifts in the long term measurements.

When we incorporate the above internal calibrations at a rate of twice per week, and include effects for daily sampling fluctuations, instrument noise and absolute calibration differences between operational instruments launched over two years, the operational system is determined to be able to detect a global ozone change of about 1.5% per decade at the 95% confidence level. This is considerably less than the 2.8% per decade estimate as predicted by Wuebbles *et al.* (1983) for Umkehr level 8.

A requirement to detect long term ozone trends of the magnitude predicted by theoretical scenarios for chlorofluoracarbon chemistry places strict performance requirements on the operational SBUV-2 sensors. To ensure a data base of the highest possible quality from the long term measurements program it is necessary to examine continuously the performance of the SBUV-2 instruments and to compare the output products with independent measurements of high accuracy and precision. These procedures should, in principle, allow detection and removal of any instrument anomalies, provide support for the validity of the SBUV-2 inversion procedure, and will allow estimates of the ozone trend from independent data sets.

14.1.4 GROUND-BASED VALIDATION SYSTEM

14.1.4.1 Dobson/Umkehr Data

The basic NOAA satellite ozone validation program contains the following elements:

- 16 Primary Dobson stations - triennial calibration against Boulder standard instrument
- Other Dobson and M-83 sites with oversight via satellite consistency, WMO, U.S. and AES calibration programs
- 16 primary Umkehr sites - includes 7 automated instruments
- Other Umkehr sites as available
- Aerosol impact evaluation by GMCC
- Balloonsonde measurements monitored by GMCC at 3 sites on a once-per-week schedule
- Other balloonsonde as available
- SSBUV
- Other sources as available:
    - Ozone rocketsondes
    - Solar observations

Within previous studies of ground-based data and comparisons with satellite data, several elements that have been clearly exhibited are the variability between stations and that instruments change in time. Based on this experience, it is clear that we must utilize a small subset of data sites that are well coordinated and able to be recalibrated at regular intervals such as three years. Within the limitations of personnel and resources NOAA has selected 16 Dobson/Umkehr sites as this primary data base.The stations are:

1) Fairbanks, Alaska
2) Mauna Loa, Hawaii
3) Boulder, Colorado
4) Huancayo, Peru
5) Haute Province, France
6) New Zealand (tentative)
7) Perth, Australia
8) Edmonton, Canada
9) Goose Bay, Canada
10) Arosa, Switzerland
11) New Delhi, India
12) Varanasi, India
13) Sapporo, Japan
14) Tateno, Japan
15) Aspendale, Australia
16) Invercargill, New Zealand

Of these, sites 1-7 are the recently automated Dobson stations and stations 8-15 have long-term records extending at least to the mid 60's.

When a matchup of satellite and ground-based data at individual points is considered, two major sources of error are included. The first involves the noise characteristics of the individual instruments plus any space-time window involved in the matchups; the second is the difference in calibration between instruments at individual stations. We define the first to have a variance of σ_1^2 where σ_1 is a representative value at a station for η_1 matchups. For the second source, we define σ_2^2 as the variance of the average difference (satellite minus station) at η_2 stations.

The combined variance for the two errors is then:

$$\text{var} = \frac{\frac{\sigma_1^2}{\eta_1} + \sigma_2^2}{\eta_2}$$

The standard deviation, SD, is $(\text{Var})^{1/2}$ and the 95 percent confidence level is given by twice the standard deviation.

Total Ozone

Based on the results of comparisons of Bhartia *et al.* (1984) for comparisons of Dobson with SBUV for '79-'80, we find the following representative values:

$\sigma_1 \sim 5\%$ $\quad\quad \sigma_2 \sim 2.5\%$
$\eta_1 \sim 100$ $\quad\quad \eta_2 \sim 58$

with the result that

$\text{var} = 0.11$
$\text{SD} = 0.33\%$ $\quad\quad 2\times\text{SD} = 0.67\%$

Thus, for a yearly average, SBUV can be compared to the Dobson network to an overall 95 percent confidence precision within one percent.

One caveat with the above is that there is an implicit assumption that each station is independent of the others and that no latitudinal biases exist. Both assumptions appear reasonable based on the results presented by Bhartia *et al.* (1984).

Vertical Profiles

Umkehr - SBUV

Based on the results of Bhartia *et al.* (1984) for '79-'80 the following values are representative:

$\sigma_1 \sim 8\%$ $\quad\quad \sigma_2 \sim 7\%$
$\eta_1 \sim 36$ $\quad\quad \eta_2 \sim 11$

Consequently:

var = 4.62
SD = 2.15% 2×SD = 4.3%

Therefore, as shown in the two year SBUV data comparisons, on a yearly basis the SBUV can be compared to the Umkehr observations to within five percent.

The above, however, is somewhat misleading in that it does not address two concerns for long-term measurements. The first is that with a small number of co-location stations, particular emphasis must be placed on station history and performance; the second is the impact of stratospheric aerosols on the data. The approach to the former is that the ARL-GMCC group in Boulder, who maintain the Dobson international standard instrument, has been tasked to develop a cross-calibration program for a set of Umkehr stations on a three-year rotating basis. This, in conjunction with the added automated Dobson instruments funded by EPA would increase the number of available sites to about 16 and decrease the σ_2 standard deviation to about four percent. This changes the previous statistics to:

var = 1.11
SD = 1.05% 2×SD = 2.11%

an improvement of about a factor of two.

On the question of the aerosol impact, there has been considerable recent effort by John DeLuisi (ARL/GMCC) and Carl Mateer (AES, Canada) on determining correction factors for the Umkehr measurements. This is an on-going project and the principal thrusts have been along two lines. The first is the accumulation of precise lidar measurements; the second has been simple statistical regression of the Umkehr data against the long-term atmospheric transmission data (solar radiation) at Mauna Loa as presented by Reinsel *et al.* (1984). This latter approach is expected to be less precise than the former in that we would expect some natural region-to-region variation of aerosols and the record includes stations with modifications in time. The above not withstanding, if we examine the transmission record, (which does not include the recent El Chichon event) we can ask how great an error would result with a 16 station network if the Mt. Agung eruption was not recognized and no adjustments were made for stratospheric aerosols. Utilizing these measurements and the results from Reinsel *et al.* (1984), we would expect a bias in layer 9 of about 11.2 percent with a 95 percent confidence limit of ~ 4.8 percent and a bias in layer 8 of about 7.3 percent with a 95 percent confidence limit of ~ 3.1 percent.

The implication of the above is that if we do not recognize an aerosol impact at all, then a significant error results in the Umkehr estimates. On the other hand, if we do recognize the event even in as course a manner as making lidar measurements at one site such as Mauna Loa, then the combined 95 percent confidence limits of the SBUV and Umkehr comparisons (assuming no aerosol impact on the high level SBUV data, which is rather reasonable) for a calibrated 16 station network are:

Layer 8	Layer 9
±3.79%	±5.24%

Within the above scenario the results can be translated to our ability to detect a trend utilizing the 16 station network as a calibration mechanism for the SBUV-2 system assuming that the latter had no internal calibration mechanism. The 95% confidence limits for a decadal trend over various periods are:

10 years	4.2%
15 years	2.3%
20 years	1.5%

Thus, while this system is not expected to provide trend estimates over 10 years to within the model calculations of 2.8%, it does become sufficient at 15 years and beyond. We note that to be able to discuss a 2.4% decadal trend within 10 years would require about 45 observing stations.

14.1.4.2 Balloon Ozonesonde Data

For the low altitude, routine ozonesonde balloon program, again based on the results of Bhartia *et al.* (1984) for '79-'80, the following values are representative, noting that in their comparisons they reference all data to the Umkehr layers (i.e., they integrate the balloon ozone profile within the Umkehr layers):

$\sigma_1 \sim 11\%$ $\quad \sigma_2 \sim 5\%$
$\eta_1 \sim 20$ $\quad \eta_2 \sim 10$

var = 3.1
SD = 1.76%
2×SD = 3.52%

For Umkehr layer 6, this translates to a 95% trend detection capability of about 3.9% per decade.

In the case of upper altitudes, ARL-GMCC has developed a high altitude system capable of utilization to about 40 km and these are being launched in support of SBUV-2 about once-per-week. Sites selected are:

Hilo, Hawaii
Boulder, Colorado
Poker Flat, Alaska or Edmonton, Canada

Note that these data are coincident with Umkehr observations and will serve as an additional check on these systems and the impact of aerosols.

Assuming a 15% noise value for the ozonesonde at 40 km and a 10% value for SBUV-2 with a 1.2% standard deviation between stations, the 95% confidence limits for a *decadal* trend over various periods are:

10 years	3.5%
15 years	1.9%
20 years	1.2%

Thus, as for the Umkehr observations, the data base is within the model trend estimates at 15 years and beyond.

14.2 TEMPERATURE TRENDS

14.2.1 Troposphere

In the troposphere the trend evaluation is based on 63 selected radiosonde stations. The impact of including satellite data to supplement the rawinsondes is currently being evaluated.

Figure 14-10 (which is an update of earlier work, Angell and Korshover, 1983a; personal communication by authors) shows the time variation of the mean temperature in the tropospheric 850-300 mbar layer for climatic zones, hemispheres and world (climatic zone boundaries at 10°, 30° and 60°) as estimated from radiosonde data. A 1-2-1 weighting has been applied twice to successive seasonal deviations from long-term seasonal means. The variation in sea-surface temperature (SST in the eastern equatorial Pacific) is shown at the bottom, and the arrows show the dates of Mt. Agung and El Chichon volcanic eruptions. Tick marks are in June-July-August of indicated years. In the Northern Hemisphere the temperature is indicated to have decreased from 1958 to about 1965, remained approximately constant from 1965 to 1975, and increased thereafter, so that the temperature in 1983 is comparable to the temperature in 1958. In the Southern Hemisphere, however, this temperature is indicated to have decreased from 1958 to about 1965, and increased thereafter, so that the temperature in 1983 is higher than in 1958. Because of the close relation between sea-surface temperature in the eastern equatorial Pacific (bottom trace of Figure 14-10) and tropospheric temperature in the tropics a few seasons later, there is also a good relation between this SST and global tropospheric temperatures a few seasons later. The pronounced increase in this SST (El Nino) two seasons after the El Chichon volcanic eruption makes it difficult to detect any cooling effect of the eruption.

14.2.2 Lower Stratosphere

Based on the same rawinsonde stations which have been used for the troposphere, the time variation in the mean temperature in the 100-30 mbar layer has been prepared, Figure 14-11, (update of Angell and Korshover, 1983a; personal communication by authors). The evidence for a long-term cooling of this layer is better in the Southern Hemisphere than in the Northern Hemisphere. A temperature increase is apparent following the eruptions of Agung and El Chichon, but there is no obvious association with SST in eastern equatorial Pacific. We note also the pronounced cooling in polar latitudes in 1982 and 1983 following the El Chichon volcanic eruption. However, no generally accepted hypothesis is yet available to explain it.

We should stress that the 63 station data base was selected on the basis of global coverage, albeit with some gaps over the ocean areas and the southern Hemisphere. In addition, Angell and Korshover (1983a) have compared their statistical methodology for surface temperature against independent gridded analyses with quite favorable results.

For the investigation of long-term temperature changes in the lower stratosphere another series of temperature data for the Northern hemisphere is available from the Stratospheric Research Group, Free University Berlin. This data set which starts in July 1964 for most pressure levels, consists of daily hemispheric analyses of temperatures (and geopotential heights), based largely on radiosonde observations. The daily hemispheric analyses have been analyzed by hand and have been digitized into a latitude-longitude grid. Monthly mean statistics have been derived afterwards.

Figure 14-12 shows filtered zonal mean 30-mbar temperatures (°C). A 39 point filter has removed the annual and the quasi-biennial cycles (Labitzke *et al.*, 1985). Looking at these curves, several features can be noticed:

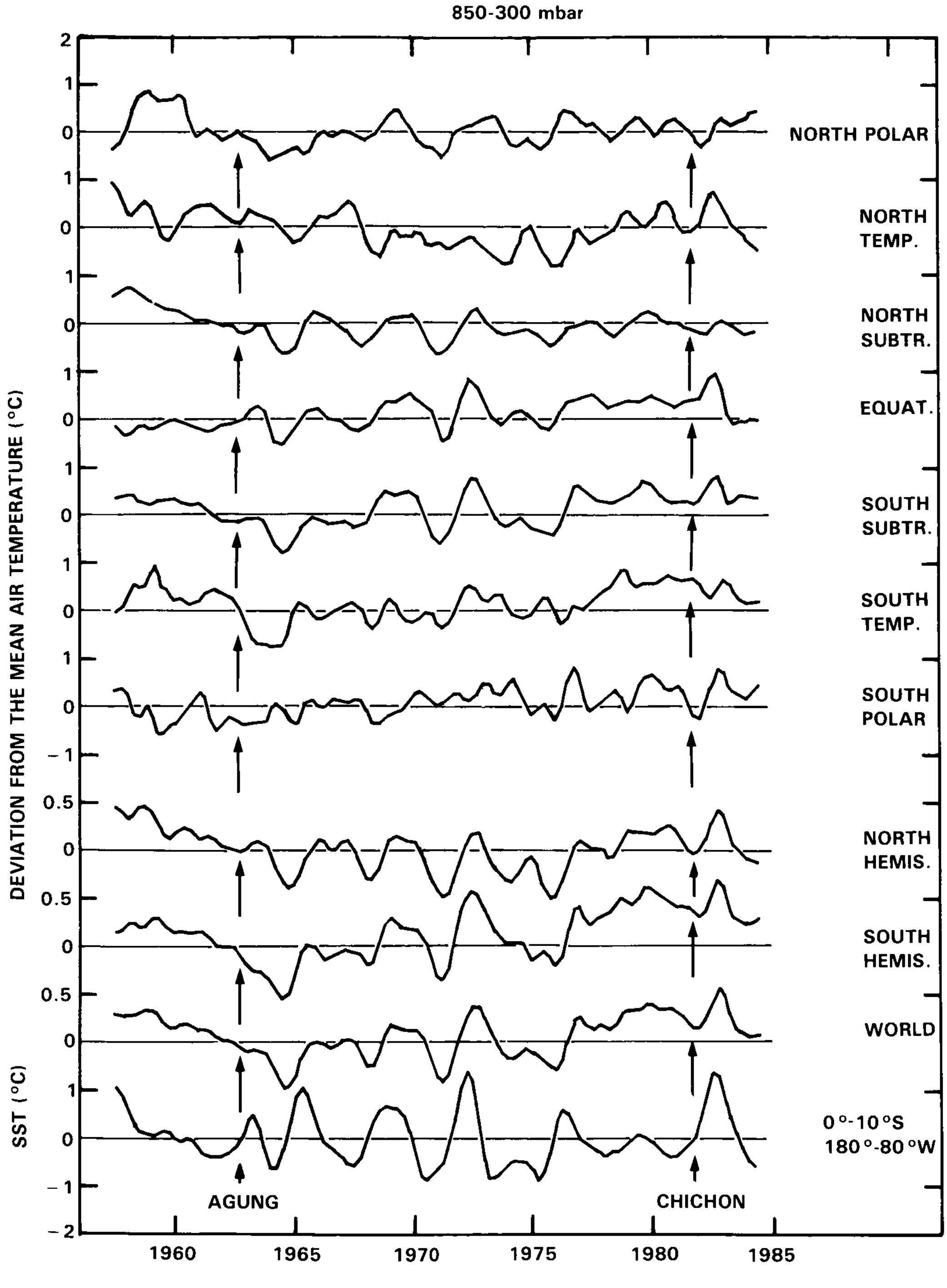

Figure 14-10. Time variation of the mean temperature in the tropospheric 850-300 mbar layer for climatic zones, hemispheres and world (climatic zone boundaries at 10°, 30° and 60°) as estimated from radiosonde data. A 1-2-1 weighting has been applied twice to successive seasonal deviations from long-term seasonal means. The variation in sea-surface temperature (SST in the eastern equatorial Pacific) is shown at the bottom, and the arrows show the dates of Agung and El Chichon volcanic eruptions. Tick marks are in July-June-August of indicated years. (Update Angell and Korshover, 1983a; personal communication).

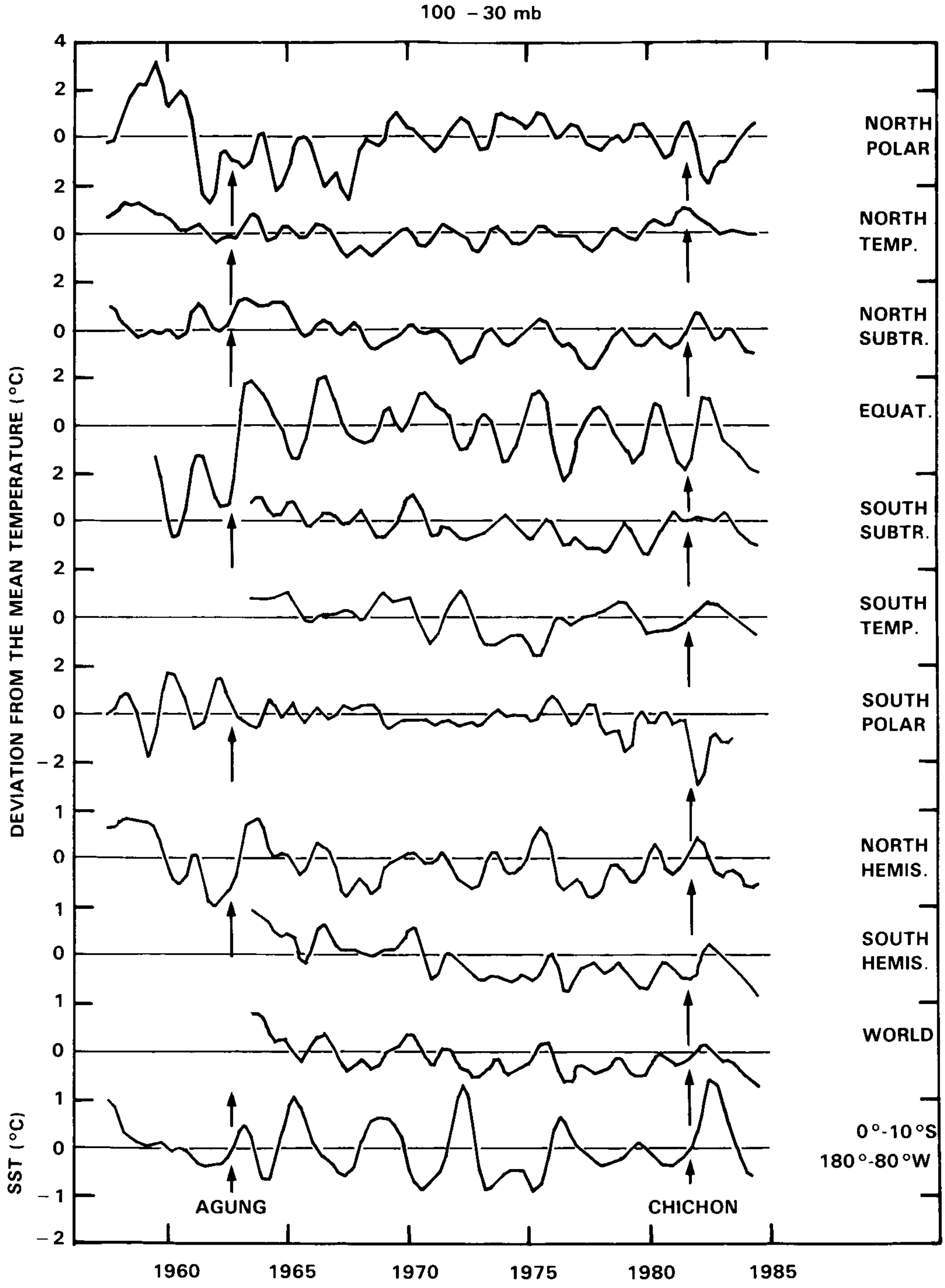

Figure 14-11. Time variation of the mean temperature in stratospheric 100-30 mbar layer for climatic zones, hemispheres and world as estimated from radiosonde data. Otherwise, see legend of Figure 14-10.

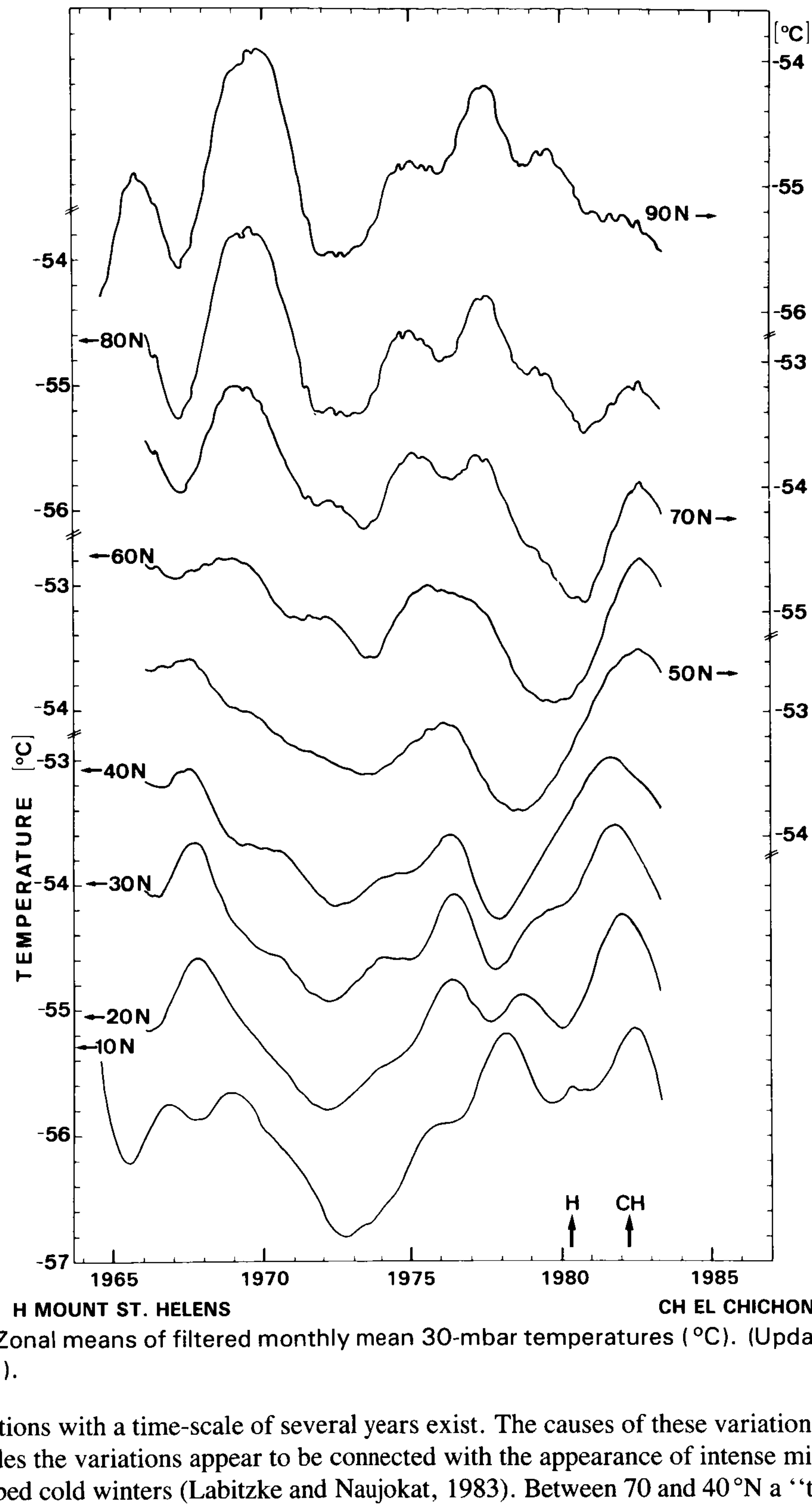

Figure 14-12. Zonal means of filtered monthly mean 30-mbar temperatures (°C). (Update of Figure 7, Naujokat, 1981).

Large variations with a time-scale of several years exist. The causes of these variations are not clear. At higher latitudes the variations appear to be connected with the appearance of intense midwinter warmings or undisturbed cold winters (Labitzke and Naujokat, 1983). Between 70 and 40°N a "trend" of about −0.6°/10 years can be seen from 1965 to 1979 in the data, if maxima or minima are considered. This "trend" is interrupted after 1979 at 40 °N, after 1980 at 50 °N, and after 1981 at 60 °N. The interruption was earlier over low latitudes where the "cooling" stopped in 1972.

The cause of the warming over the tropics from about 1972 to 1979 is not clear at this time. However, a warming attributed to the increased aerosol load after volcanic eruptions was demonstrated for the summer and fall of 1963 and 1982, when the stratosphere warmed markedly over the tropics from the eruptions of Agung and El Chichon, Figure 14-13. (Labitzke *et al.*, 1983; Quiroz, 1983a; Parker and Brownscombe, 1983).

The departures of the annual mean temperatures, averaged over 2 years, are summarized in a time-latitude cross-section, Figure 14-14. The warming episode in 1982 appears to be related to the increased volcanic aerosol load. Labitzke (1985) has associated the continued cooling over high latitudes, Figure 14-14, to be a result of extremely low winter values which may be connected with a cooling due to the increased aerosols in the polar night region and the formation of polar stratospheric clouds.

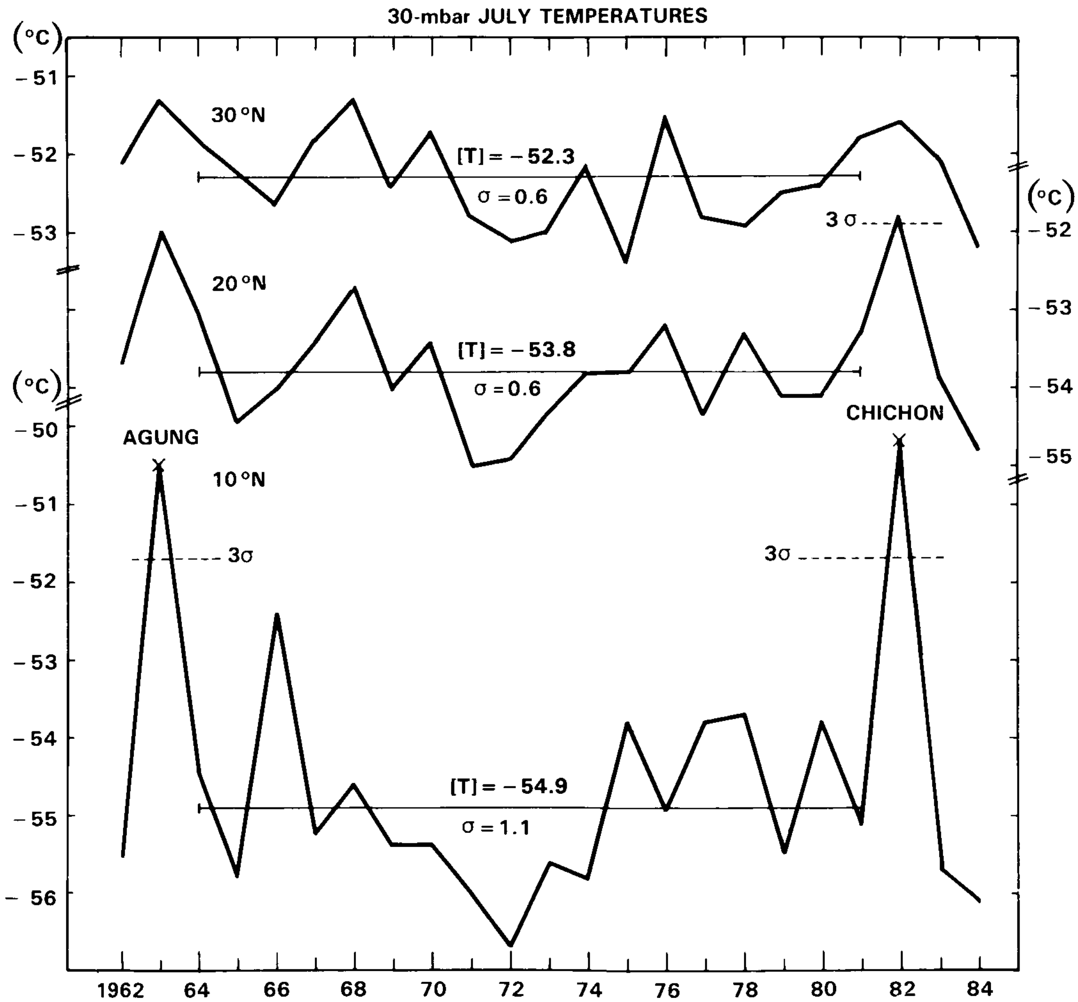

Figure 14-13. Zonal mean 30-mbar temperatures (°C) during July at 10, 20, and 30 °N, for the period 1962 through 1984. The 18-year average [T] is for the period 1964-1981. (Update of Figure 11, Labitzke and Naujokat, 1983).

DEPARTURES ($\frac{1}{10}$ K) OF THE 30-mbar TEMPERATURES, AVERAGED OVER 2-YEARS, FROM THE 17-YEAR MEAN 1965-1981

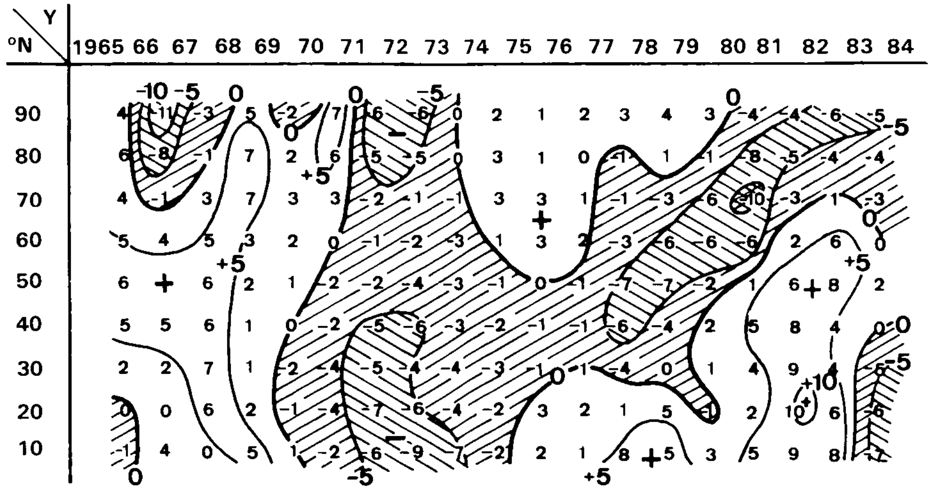

Figure 14-14. Time-latitude distribution of the deviations (1/10 K) of the annual averages, smoothed over 2 years, from the 17-year mean 1965-1981. (Update of Figure 9, Labitzke and Naujokat, 1983).

An even clearer picture emerges, if only July, i.e., a relatively quiet summer month, is considered, Figure 14-15. The data series for July starts in 1962 and the time-latitude section shows clearly the warming after Agung (March 1963) and after El Chichon (March 1982).

A serious difficulty that must be addressed is that the results from Figure 14-11 and 14-12 are inconsistent. For example, in the North Temperate regions of the former there is virtually no trend indicated

DEPARTURES ($\frac{1}{10}$ K) OF THE 30-mbar JULY TEMPERATURES, AVERAGED OVER 2-YEARS, FROM THE 18-YEAR MEAN 1964-1981

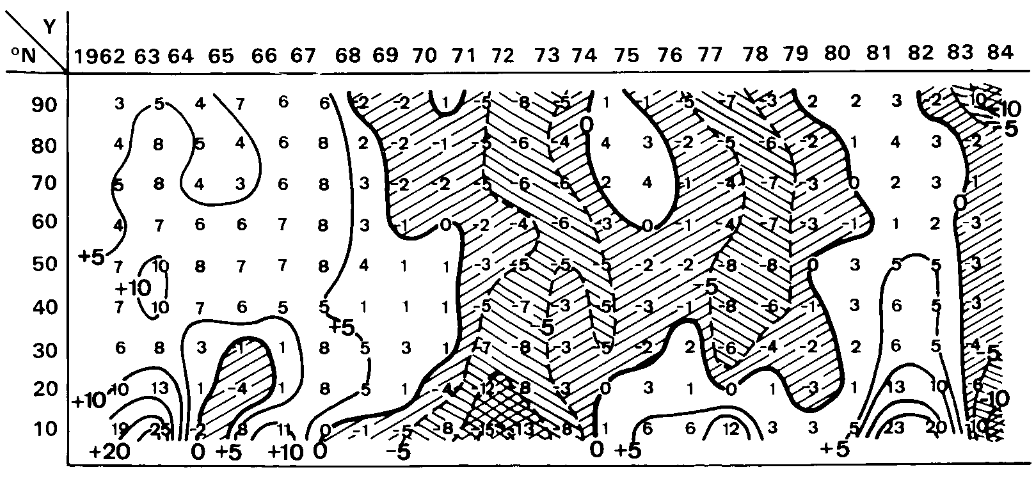

Figure 14-15. Time latitude distribution of the deviations (1/10 K) of the July averages, smoothed over 2 years, from the 18-year mean 1964-1981. (Update of Figure 9, Labitzke and Naujokat, 1983).

for the period 1965-1979, while a pronounced negative trend exists in the latter. Examination of similar diagrams for the 100-and 50-mbar levels (not shown) shows that the cause is not simply thc difference between thickness and on-level temperature and this question must be resolved by further analysis.

14.2.3 Upper Stratosphere

Recent calculations, (e.g., Wuebbles, 1983b; de Rudder and Brasseur, 1985) with fully coupled one-dimensional models suggest that a 1.5 °C decrease should have been observed from 1970-1980 in upper stratospheric temperature. There have been several studies seeking this effect in available observational data. Angell and Korshover (1978) found a 3 to 5 °C decrease in mean annual temperatures in the middle and upper stratosphere (26-55 km) between 1970 to 1976. This cooling was found at Western Hemisphere rocketsonde stations at all latitudes. Quiroz (1979a) restricted his study to summer (June, July, and August), seasonal mean temperatures at 35 and 50 km from 1965 to 1977 at seven Western Hemisphere rocketsonde stations. This study used summer data because of the well-known reduced daily temperature variability during that season. In addition to many careful quality control procedures, Quiroz applied adjustments for solar radiation of as much as 3.0 °C where necessary. This study also showed a decline in temperature of 3 to 6 °C between 1970 to 1976.

In a more recent study by Johnson and Gelman (1985) the Western Hemisphere rocketsonde network reports were again the primary data base, but the period of record was extended to include 1965 to 1983 and additional quality control procedures to the data were used.

Quiroz (1979a) has discussed some of the problems involved in using rocketsonde data as published by World Data Center A for Meteorology, Ashville, N.C., (in print through 1976 and extended on microfilm through 1983). Quiroz points out that the published monthly averages may include data from falling sphere sondes, and may also need to have appropriate adjustments (''correction'') applied, based on the work of Ballard (1967), Krumins (1972), or Staffensen *et al.* (1972). In addition, some observations are reported to have abnormally high or abnormally low fall velocities, which render the observational data from these soundings suspect.

Within Johnson and Gelman (1985) June monthly mean values for the 40-45 km layer were calculated for all Western Hemisphere rocketsonde stations for which data were available. The quality control scheme was as follows: (1) All falling sphere or experimental sensor soundings were rejected. (Quiroz and Gelman (1976) discuss the problems in using the data from sphere soundings.) (2) Any soundings flagged in the data books as having doubtful or missing temperatures in the 40 to 45 km region were rejected. (3) All soundings with a 43-km fall velocity more than two standard deviations from the mean June 43-km fall velocity for the station were rejected. (4) Adjustments for radiation were applied in a similar manner to that used by Quiroz (1979a). (5) If fewer than three soundings were available for a station for the month, or if the soundings were all at the beginning or end of the month, the mean was not included.

Mean temperatures for each June were then used to calculate linear least-squares regression coefficients with latitude of the stations as the independent variable. The resulting coefficients were used to calculate area-weighted mean temperatures for 25 °N to 55 °N. Results are displayed in Figure 14-16. A 2 to 3 °C temperature drop in the early 1970s is indicated in this diagram similar to the findings by Quiroz (1979a) and Angell and Korshover (1978a). We note, however, that this temperature decline coincides with a change in the principal observing system for the Arcasonde system to the Datasonde system.

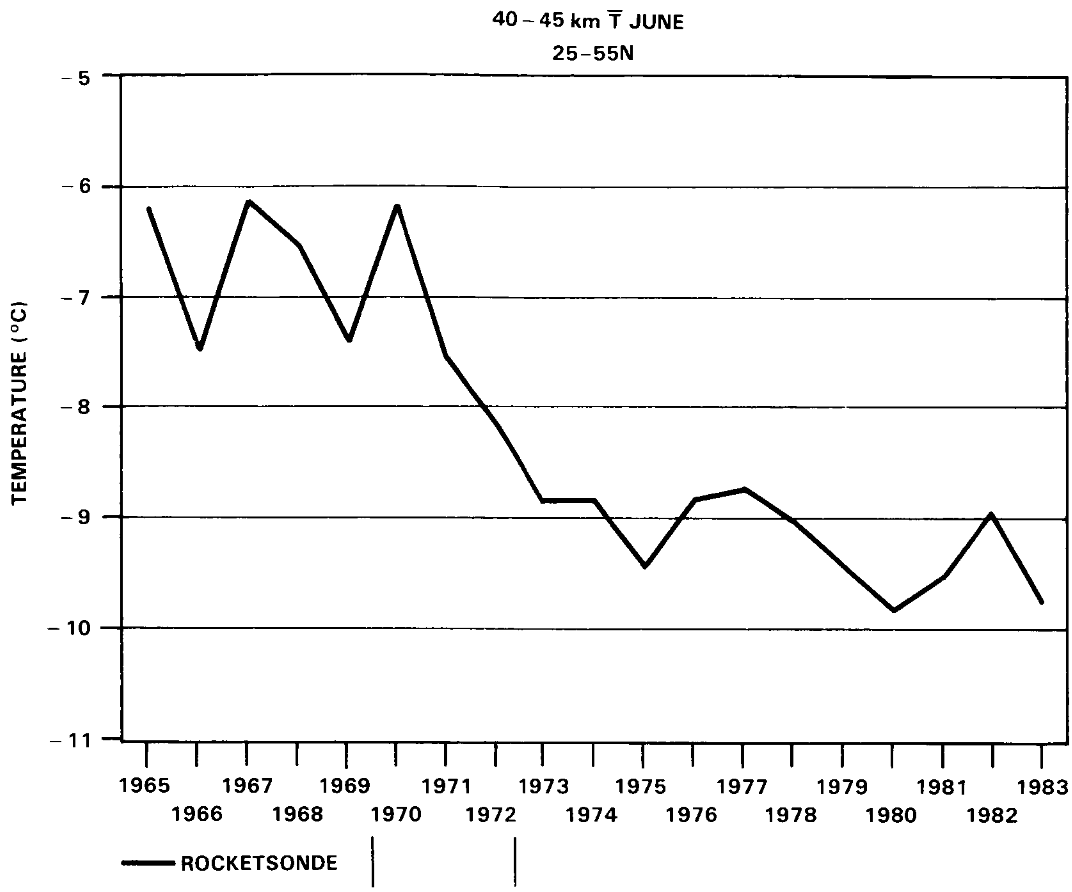

Figure 14-16. 40-45 km layer mean rocketsonde temperatures averaged over the north America (25-55 north latitude) for June in years 1965 to 1983. Heavy ticks indicate beginning and end of transition from Arcasonde to Datasonde observing systems.

In order to study this temperature decrease more closely, similar mean temperatures were calculated for the 25-30 km layer using both rocketsondes and support radiosondes. Results are displayed in Figure 14-17. There is no discernable long-term trend in radiosonde temperatures for this limited data sample and period; however, in the 1965-1971 time period the rocketsonde temperatures averaged 1.11 °C higher than the radiosonde means while in the 1972-1978 time period the rocketsondes averaged 1.06 °C lower than the radiosonde temperatures. This approximately 2 °C decrease in rocketsonde mean temperatures again corresponds to the change in observing systems.

From this, Johnson and Gelman (1985) conclude that the change in rocketsonde temperatures in the early 1970s simply reflects a previously uncompensated change in the rocketsonde temperature measurement system. It remains, then, to determine the true temperature variation taking the above into consideration. As a simple exercise to determine a possible order of magnitude effect, we have fitted a linear regression model to the 40-45 km temperature data for the limited period 1973-1983. This is after the major instrument transition and the data should be uniform in quality. The results indicate a negative trend of -0.75 °C/decade with a standard error of $\pm$ 0.34 °C/decade. Wuebbles (1983b), although not for this specific time period, suggests that a temperature decrease should exist on the order of -0.9 °C/decade at about 45 km. Thus, substantive agreement at this altitude is suggested.

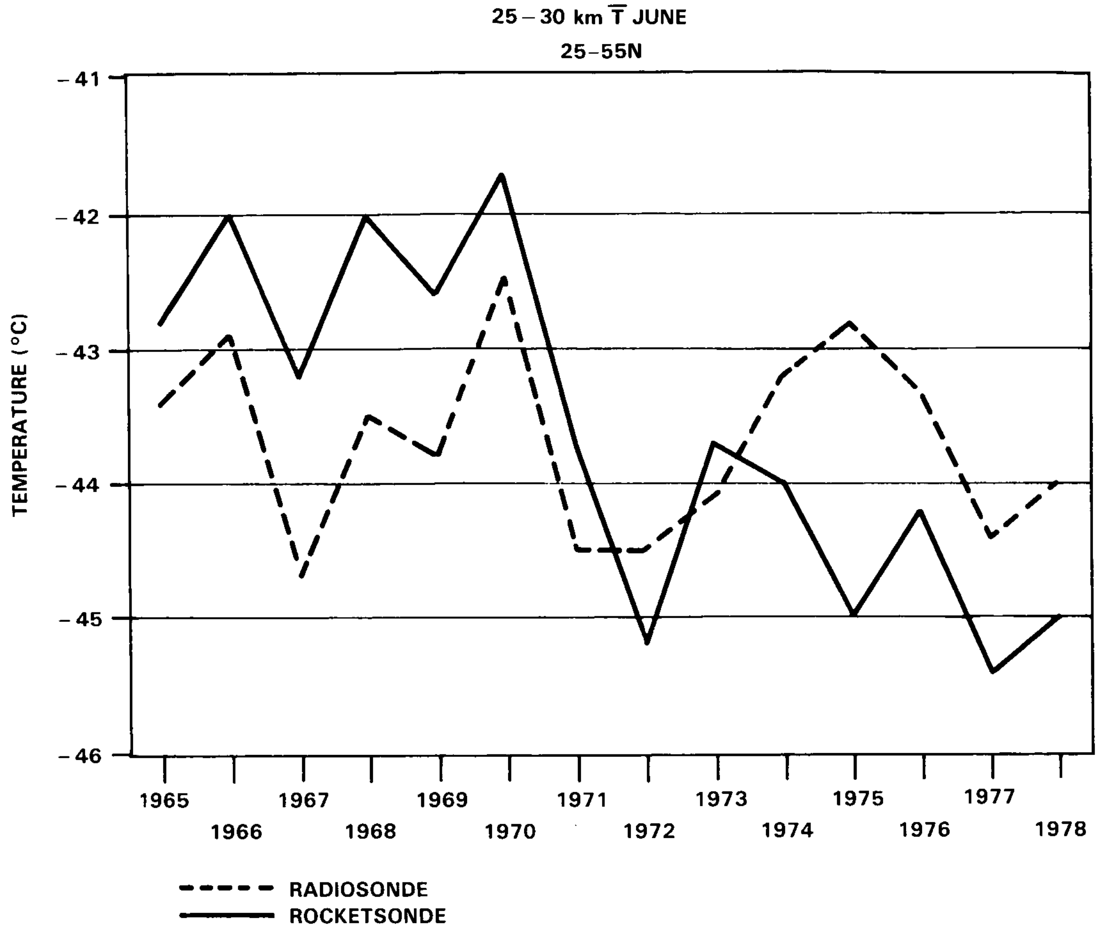

Figure 14-17. As in Figure 14-16, except for 25-30 km. Solid line indicates mean temperatures derived from support radiosondes; dashed line for corresponding rocketsondes.

Clearly, the above will have to be examined further with the more complete data sets in order to verify these preliminary findings. We note especially that the results presented above for the lower stratosphere summertime only can be quite different from yearly averages, Figures. 14-12–13.

14.2.4 Capability of Satellites to Measure Trends

As for the ozone trend section described above, the data of the long-term measurement program of statospheric temperature within the NOAA operational satellite program are not yet of sufficient length to determine decadal trends. We will discuss here, then the potential of this system and its capability to meet the monitoring requirements. Following Wuebbels *et al.* (1983b), a 3% decrease in ozone at about 2 mbar should be associated with about a 1.5 °C decrease in temperature. Following the notation in the Ozone Section, 14-1, the combined variance for a satellite-rocketsonde comparison is

$$\text{variance} = \frac{\dfrac{\sigma_1^2}{\eta_1} + \sigma_2^2}{\eta_2}$$

In contrast to the ozone comparisons when the different instruments are independently operated, the U.S. meteorological rocketsonde program utilizes a single instrument type with consistent manufacture. In theory, then, if the errors are purely random, σ_2 is zero and the relationship changes to

$$\text{variance} = \frac{\sigma_1^2}{\eta_1 \eta_2}$$

In practice, σ_2 is not zero. This may be due to essentially non-random errors in the satellite data or to possibly some particular equipment feature at a specific site. Gelman (private communication) has indicated that a representative value of σ_1, is about 4 °C and η_1 about 50. Depending on the particular period of study, however, σ_2 can range from 1.6 to 2.5 °C with a value for η_2 of 10. Note that the goal is to be able to discern a trend of 1.5 °C/10 years or 0.15 °C/year - at the 95% confidence limit. In Table 14-4 we see the results of the computation with varying values of σ_2. The worse case scenario suggests that we will be able to detect the temperature impact within 15 years. In the theoretical extreme, if we can achieve a lower value of σ_2, to the value of 1.6, then we will be able to detect a change of 1.2 °C over ten years and if we can ultimately bring it to zero, the value is 0.4 °C over a decade.

The nature of the problem is depicted in Figure 14-18, where we show the period Sept. 1981-Oct. 1983. We note that at the time of this document the data from the Eastern Test Range (Cape Kennedy, Antigua, Ascension Island) were being reprocessed and were not available for this analysis. The data from these sites should be forthcoming in the near future. We also note that the data from Shemya indicated an inconsistency with time that precluded their usage. The σ_2 value at 1 mbar is 1.9 °C while that at 2 mbar is 1.0 °C. In both cases, however, it is clear that it is the value at Primrose Lake that is the major departure from the average and, hence, to the standard deviation. The question is whether the values at Primrose Lake are part of a pattern of satellite bias with latitude or are merely a reflection of some difficulty at site. That there are no other U.S. run sites at these latitudes makes the interpretation extremely difficult. Data from the USSR network are currently under examination.

Finally, we point out that at 2 and 1 mbar, the average value of the TOVS-rocketsonde difference at low to mid-latitudes is about −1 °C and −9 °C, respectively. For the NOAA-6 period Oct. 1980-Sept-1981, not shown, a similar pattern of difference with latitude is indicated, but the average in low latitudes is about −5 °C and −8 °C. Thus a substantive change of about 4 °C is indicated at 2 mbar and about 1 °C at 1 mbar between the operational instruments. This is thought to be caused by the use of filters in the TOVS system that are not exactly reproducable one-to-the-other and stresses the need for a long-term validation/calibration program.

Table 14-4. 95% Confidence Estimates of 10 Year Trends (K/10 Years), as Determined from TOVS Satellite Data with Rocketsonde Verification: σ_2 is the Between Station Standard Deviation (See Text) and t is the Length of the Data Series (Years).

σ_2 (K) t(Years)	2.50	1.60	0
10	1.78	1.19	0.4
15	0.97	0.64	0.2

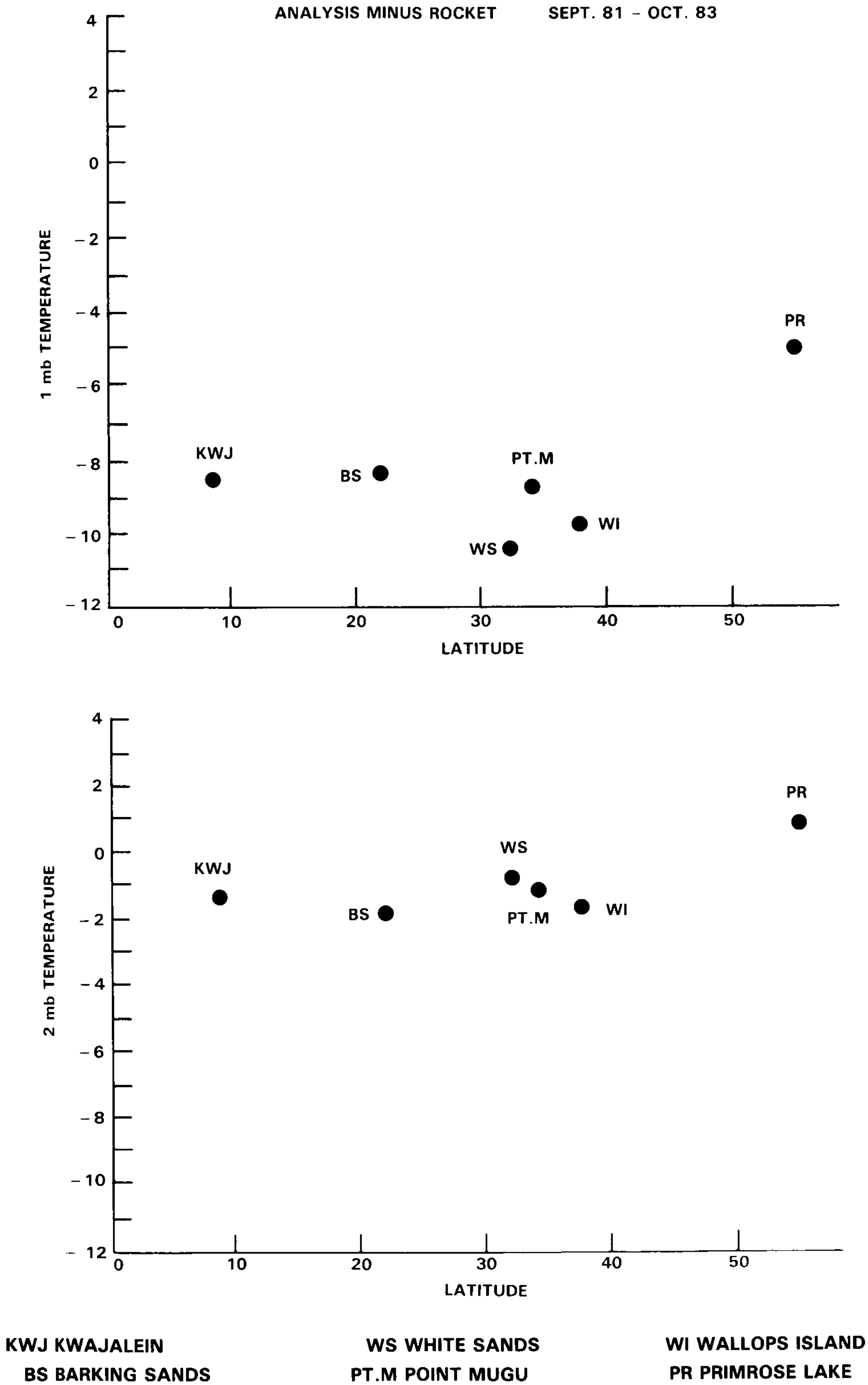

Figure 14-18. NOAA-7 TOVS analysis minus rocketsonde at 2- and 1-mbar for the period Sept. 1981-Oct. 1983.

As stated at the outset, the ozone and temperature are so intimately coupled through radiation, photochemistry and dynamics that any monitoring program must include both parameters as essential components. Toward this, we have indicated above that the requirement exists for a high quality, independent stratospheric temperature measurement system with which to verify the satellite instrument-to-instrument consistency. Such a system does not exist and is a major weakness of the monitoring program.

14.3 SUMMARY

14.3.1 Ozone

- Global trend estimates of total ozone determined from the Dobson spectrophotometer network indicate little overall support for the suggestion of a statistically significant trend during the fourteen year period 1970-1983.

- Trend estimates from 13 ozone balloonsondes indicate statistically significant positive trends in the lower troposphere and negative trends in the lower stratosphere. The interpretation of these results, however, is clouded by uncertainties in instrument behavior and the lack of a global station network.

- Ozone trend estimates from 14 Umkehr stations indicate significant negative trends from 1970 to 1980 in the middle stratosphere that are in substantive agreement with results from one-dimensional numerical models. The observational results are sensitive to the inclusion of a term to account for stratospheric aerosol impact on the measurements and the spatial distribution of the sites, but do not appear sensitive to the inclusion of a 10.7 cm flux variation (an indicator for solar flux variation).

- Examination of the NOAA SBUV-2 satellite measurement program indicates that if the system operates as designed, it is capable of global ozone trend detection in the middle to upper stratosphere as well as total ozone to within about 1.5% over a period of one decade at the 95% confidence level. This is an estimate for the measuring system only, and does not include consideration of natural atmospheric variation which can be quite complex.

- As with other long-term measurement programs, however, it is necessary to examine continually the SBUV-2 instrument performance and satellite products and compare them with independant data. We note, moreover, that the SBUV-2 are inherently limited to total ozone and ozone profiles between 25 and 55 km. If we are to be able to determine ozone trends, unambiguously, from the surface to the overlap region with the SBUV-2 profiles, a high-quality measurement program must exist.

14.3.2 Temperature

- The large cooling in rocketsonde temperatures reported for the early 1970's appears now to be due to a change in the rocketsonde temperature measurement system. Taking this into account, statistically significant negative trends are observed in June rocketsonde data at 40-45 km from 1973-1983 that are in substantive agreement with results from one-dimensional numerical models. These preliminary results will have to be examined further with a more complete data set.

- Examination of the NOAA TOVS stratospheric satellite temperature measurement program indicates that it is essential that the instrument-to-instrument consistency be verified by a high quality, independent data system. Such a system does not exist.

OZONE AND TEMPERATURE TRENDS

• Two independent analyses of lower stratospheric temperatures during the period 1965-1979 are suggestive of a downward temperature trend. Inconsistencies between the two analysis, however, preclude firm conclusions.