WORKSHOP ON EARLY DETECTION OF STRATOSPHERIC CHANGES

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POSITION PAPER: **Sampling Frequency & Required Network Size**

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What should be the location, size and sampling frequency for a network of stations designed to give an early warning of stratospheric changes? In lieu of providing immediate answers to this question, let us examine some of the problems which might obscure the detection of trends in the stratosphere and, therefore, some of the sampling strategies which may allow extraction of trends from the natural atmospheric variance. I will try to point to necessary research--both theoretical & observational--which is needed to answer better this primary question. I shall focus on *the middle to upper stratosphere (above 30 km)* where chemistry plays an active role on dynamical time scales, and where the photochemical perturbations to ozone are predicted to be greatest (Antarctica aside).

**1. What atmospheric conditions should we expect in 10-20 years?**

Chemical composition:

Extrapolation of current trends is too simple a model for atmospheric changes, but it may suffice for the next decade or so. The table below is my rough estimate of the changing atmospheric composition (loosely derived from Chapter 3, NASA Assessment). A look at the RAND assessment of halocarbon growth over the next two decades gives a similar estimate of $Cl_x$ increases. Verification of these trends in the long-lived trace gases will come about mainly through tropospheric monitoring; trends unique to the stratosphere (HCl and $C_2H_6$ are discussed by Sze et al) represent important confirmation of the atmospheric models.

| | Observed trends (Chapter 3) | | | | | Rand scenario (1986) |
|---|---|---|---|---|---|---|
| year | $Cl_x$ | $Br_x$ | $CH_4$ | $N_2O$ | $CO_2$ | $Cl_x$ |
| 1980 | 2.77 | 28.1 | 1.62 | 296 | 343 | 2.8 |
| 1985 | 3.23 | 29.2 | 1.70 | 300 | 350 | 3.2-3.2 |
| 1990 | 3.85 | 31.2 | 1.79 | 304 | 357 | 3.6-3.9 |
| 1995 | 4.70 | 35.2 | 1.88 | 308 | 364 | 4.1-4.7 |
| 2000 | 5.87 | 42.7 | 1.97 | 311 | 372 | 4.5-5.7 |
| 2005 | 7.51 | 57.2 | 2.07 | 315 | 379 | 5.0-6.8 |

Climate:

We expect a detectable change in global climate within the next 2 decades (due mainly to increases in $CO_2$). The direct stratospheric effects of $CO_2$ increases are small (cooling of less than 0.5°C), but the tropospheric climate during this period is expected to undergo substantial warming ( > 0.5°C). The climate change is likely to result in significant reductions of long-wave eddy kinetic energy as the pole-to-equator gradient in temperature is reduced. These planetary waves have a major impact on the forcing of the mean stratospheric circulation. This impact is a topic of current research and its effect on stratospheric monitoring strategies is unknown.

## 2. What should we try to measure: $O_3$, T, ClO, NO, $H_2O$, ...?

This topic is discussed by others, and I include only the following comments: Simultaneous observation of several variables would definitely aid in the interpretation of trends. Furthermore, the observed correlations of ozone with temperature ( etc.) would allow some of the atmospheric "noise" to be removed (e.g., ozone values corrected to a standard temperature), perhaps even the interannual variability & solar variability. Current photochemical models are capable of predicting such correlations.

Systematic errors or signals specific to a $Cl_x$ perturbation:

Do the correlations of ozone with temperature change with $Cl_x$? Does the altitude dependence of this correlation change at high levels of $Cl_x$? (Can we sample so as to eliminate this atmospheric noise?)

Will elevated levels of $Cl_x$ and $CH_4$ affect the diurnal cycles and therefore possibly corrupt or disguise the signal of a trend? (In 30-50 km range: no)

Can we adequately interpret solar occultation data today? (Systematic errors in the inferred abundance of $NO$-$NO_2$ occurs below 35 km and for $O_3$ above 55 km.)

Can we remove the effect of atmospheric tides which have a large diurnal amplitude in the tropics? (Systematic differences of at least 10% in ozone concentrations are predicted for the tropical stratopause.)

## 3. How frequently should we sample, over what spatial scales?

High frequency variability at a fixed location is directly related to the spatial scales of inhomogeneous air parcels. We see spatial variability in the stratosphere on vertical scales of 100 m and (as inferred from ascent and descent data several hours apart) on horizontal scales of 100 km. Does a "stratospheric-trends" network need to resolve and individually average over these lamina? Or can we effectively average over them by integrating the "signal" over 1 km in altitude and half the day? This problem is unresolved.

We need to develop new types of theoretical models which are able to infer the source of the different composition of these layers and the impact of this small scale structure on average ozone concentrations (at the 5% level). Is there any hope of modelling these vertical scales in current or projected 2/3-D models? (probably not) Are the 100m lamina essential to the chemistry, or can we calculate the photochemical response of the system on the average of conditions, or will they be mixed with their environs in relatively short time scales? (probably not)

(Example: In the lower troposphere we need to resolve the spatial/temporal scales of the event/parcels which we are measuring. For example, at Cape Grim, Tasmania 'polluted' air parcels from the mainland of Australia sweep over the observing station in less than 24 hours; but at Adrigole, Ireland, events with elevated levels of CFCs typically last from 3 to 6 days. This difference is predicted by 3-D tracer models and can be identified with the relatively small extent of the Australian source region (Melbourne) as compared with that of Europe.)

Is there a measurement problem in averaging over these layers? Is a "mean" value correct? For example, when we integrate thermal emissions over a large volume, is it homogeneously weighted as in temporal averaging? Or does it disproportionately weight the hotter parcels? (It is likely that temperature will be correlated with some concentrations.)

## 4. Where should we locate ground stations?

If we are limited in spatial sampling to a few fixed locations (i.e., ground stations) then the choice should be made so as (1) to enable effective spatial sampling through a time series and (2) to eliminate noise associated with natural atmospheric variability.

(1) The location should not preferentially sample air with respect to longitude. If all air parcels in a given latitude/altitude range are equally likely to pass over the station then a good time series of observations gives effective spatial sampling. (This is clearly a problem in the troposphere where we have strong longitudinal gradients associated with continental vs. oceanic sources.) At mid-latitudes the large planetary waves in the troposphere might create standing waves in the middle stratosphere, but this seems less a problem in summer than winter. A more serious problem may occur in the tropics where there is major forcing at the tropopause due to deep convection over the continents. Depending upon the zonal winds (which change seasonally and quasi-biennially), this signal may propagate through the stratosphere and create a systematic, standing disturbance in temperature which would bias the observations over one station.

(2) The location should avoid strong gradients in chemical concentrations because it would be difficult to extract chemical trends from atmospheric variability in dynamical transports. Thus 40°N is a less desirable location because of the strong, observed latitudinal gradients.

(Example: The tropospheric monitoring station at Cape Meares, Oregon sits at the edge of a large gradient in anthropogenic gases between the North American continent and the Pacific Ocean. Khalil and Rasmussen (Science, 1984) reported large seasonal variations in CO and a trend based on 3 years of nearly continuous monitoring. The large rate of increase first reported (+6%/yr) has not been confirmed by two subsequent years of observation. Although many interpretations are possible, one candidate could be the interannual variations in transport of CO near the vicinity of these large gradients.)

(added note)

5. **Correlations of trace gases in the lower stratosphere:**

Following on a point emphasized by Sze, the concentration of $C_2H_6$ in the lower stratosphere reflects the concentration of active chlorine: atomic Cl. The profile of this species is expected to show a more rapid fall-off with height as total $Cl_x$ increases in the next decades. The actual change in the mean profile may be difficult to observe accurately because of the small scale height. However the effect of an increase in $Cl_x$ would be evident in the changing correlation of $C_2H_6$ with other gases which are mainly photolyzed ($CFCl_3$) or destroyed by reaction with OH ($CH_3CCl_3$, $CH_4$). It should be emphasized again that *$C_2H_6$ responds not just to the total chlorine in the stratosphere, but particularly to the active form (Cl/ClO)* which we predict will become increasingly important in the destruction of ozone in the lower stratosphere. If these correlative measurements are made with grab samples then it would be important also to measure $H_2O$ simultaneously!

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