

CHEMICAL MANUFACTURERS ASSOCIATION
FLUOROCARBON PROGRAM PANEL

Recent Research Results and Future Directions

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INTRODUCTION

In 1972, chlorofluorocarbon (CFC) manufacturers began supporting research to investigate the effects of CFCs on the environment. This program has been expanded greatly to help determine the extent to which these compounds may affect the stratospheric ozone layer. The Fluorocarbon Program Panel (FPP), administered by the Chemical Manufacturers Association (CMA), is supported by 19 CFC manufacturers from North America, Europe, Japan, and Australia.

FPP has reviewed to date about 580 research proposals, and projects totalling about \$18 million have been funded worldwide. Calendar 1986 commitments are expected to total about \$1.8 million. This summary describes some of the recent and ongoing work supported by FPP. A more detailed research summary can be obtained from the CMA.*

SCOPE OF PROGRAM

FPP sponsored research has made a major effort toward estimating and interpreting changes in total column ozone, the ozone profile, and the temperature profile over the last decade and a half. This research has been an interdisciplinary effort involving statisticians, meteorologists, and modelers. Sensitivity analyses of trends to data quality concerns (e.g., instrument calibrations), natural events (e.g., solar variability, volcanic aerosol), statistical model formulation, and bias correction factors have been done in part and will be a focus of future work. Discrepancies and similarities between

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trend estimates and chemical model calculations have been flagged for further study.

FPP continues to sponsor three one-dimensional (1-D) modeling programs as well as a two-dimensional (2-D) model development program. Capabilities of 1-D models include fully coupled radiative-convective/chemistry models, diurnal models, and models capable of time-dependent/multiple perturbation scenario calculations as well as the standard diurnally averaged 1-D chemical models. A 2-D model has the additional capability of simulating the latitudinal and seasonal distribution of stratospheric trace gases. The goal of the 2-D model development program is to develop a fully coupled stratospheric 2-D model with interactive dynamics, radiation and chemistry.

The FPP supported chemistry program is designed to improve understanding of the kinetic and photochemical data base needed to calculate possible changes to stratospheric ozone. To these ends, FPP supports studies of reactions already included in models as well as exploratory studies of reactions that could affect calculated ozone alterations but are not currently included in models.

The atmospheric measurements program of FPP sponsors research to obtain observational data that test and extend knowledge of atmospheric processes related to the stratospheric ozone layer. These data play a crucial role in testing atmospheric models and hence in understanding the present day atmosphere and assessing the reliability of predictions of its future composition.

FPP also reports production data for CFCs 11 and 12, sponsors climate modeling, and follows research on biological effects that may result from altered ozone levels.

1. OZONE TREND ANALYSIS

The FPP continues to fund statistical analyses of atmospheric ozone measurements for evidence of ozone changes. Based on the total column ozone measurements recorded at 36 Dobson stations since as early as 1958, trend determinations of globally-averaged ozone for the period 1970-1982 yield values that are not distinguishable from a zero trend in terms of statistical significance. However, the analyses for long term trends have been complicated by effects possibly due to volcanic aerosols from the El Chichon eruption in March-April of 1982, an anomalously warm sea-surface temperature effect in the equatorial Pacific (El Nino phenomenon) in 1982-1983, and the effect of the quasi-biennial oscillation (QBO). Estimated trends in total column and profile ozone may well be distorted by lower ozone values following these events.

The focus of the FPP sponsored program is to carry out competent, credible, and critical analyses: 1) to quantify any changes or trends in total column ozone, the ozone profile, and the temperature profile; 2) to compare results with chemical model calculations; 3) to estimate the early warning capability and thresholds of trend detection (i.e., the 95% confidence limits); 4) to evaluate problems in data quality and assess approaches to account for measurement biases and natural perturbations; 5) to bring together scientists responsible for obtaining data and for its statistical analysis; and, 6) to develop and extend the methodology needed for spatial and time dependent trend analyses.

Analyses have been made on total column ozone data from: 36 Dobson stations through 1984; balloon ozonesonde profile data through 1983 from 13 geographical sites (12 in the N. Hemisphere and 1 in the S. Hemisphere); and Umkehr ozone profile data through 1984 at 11 N. Hemisphere stations (through 1981 at 13

stations of which one was in the S. Hemisphere). In these studies the Dobson total ozone records range from 15 to 27 years in length. The records for stations in the Umkehr network range in length from 10 to 24 years and in the ozonesonde network from 7 to 17 years.

Total Column Ozone: Nimbus 4 satellite data for 1970-1977 show that the current 36 station Dobson network used in these analyses has adequate global representation for trend analysis. The average satellite trend result over the 36 locations is similar to the globally averaged satellite trend estimate.

Low total ozone values of about 5% below normal in the winter of 1982-1983 appear to have affected the trend estimates. For example, trend estimates by a team of researchers at the Universities of Chicago and Wisconsin were $+0.02 \pm 0.94\%$ /decade (95% confidence limits) for the period 1970-1982, $-0.17 \pm 1.10\%$ /decade for 1970-1983, and $-0.26 \pm 0.92\%$ /decade for 1970-1984. Although none of these estimates was statistically different from a zero trend, natural events in 1982-1983 such as the El Chichon volcanic eruption, equatorial sea-surface warming, and QBO appear to have had some effect.

The trend modeling approach by Princeton University statisticians appears to be even more sensitive to these events. For example, their total ozone trend estimates were $-0.67 \pm 1.02\%$ /decade for the period 1970-1982, $-1.10 \pm 0.94\%$ /decade for 1970-1983, and $-0.70 \pm 0.82\%$ /decade for 1970-1984.

Including data through 1984, neither group finds evidence of a statistically significant change in total column ozone. This is consistent with chemical model calculations that take into account all trace gases.

Sensitivity studies now in progress examine the differences in approach between the two research groups. These differences include the time period covered prior to 1970, regional weighting factors, methods of adjustment for solar and seasonal variations, and analysis method. These studies indicate that the generally more negative trend values from the Princeton group can be explained in large part by the shorter length data set used. The Wisconsin/Chicago team include data taken as early as 1958 at some stations, whereas the Princeton work has used only data after 1963. When the Princeton analysis is modified to include 1960-63 data, the trend estimates become less negative by about 0.5%/decade.

It will be important to continue trend analyses, given that the anomalously low ozone values may represent a transient excursion due to natural effects which temporarily obscures any longer term trend in the ozone layer. Work is underway to reexamine recent data and continue to improve the methodology for its statistical analysis. Future work includes expanding the data base to include Russian stations and more Dobson stations and evaluating six years of Nimbus 7 satellite SBUV data (1978-1984).

Profile Ozone: FPP supports studies on statistical analysis of ozone profile data from the Umkehr network, balloon ozonesondes, and the Nimbus 7 satellite. Since the original Nimbus 7 data set includes only four years of data -- barely adequate for trend analyses -- and has recently been reprocessed with another two years of data, only the Umkehr and ozonesonde studies have been analyzed beyond the preliminary stage so far.

A joint research team of statisticians and atmospheric scientists from the Universities of Wisconsin and Chicago, the U.S. National Aeronautics and Space Administration (NASA), the U.S. National Oceanic and Atmospheric Administration (NOAA), and

the Canadian Atmospheric Environment Service has analyzed the Umkehr and balloon ozonesonde profile data. Umkehr measurements range from the lower troposphere (0-5km) to the upper stratosphere (43-48km), with the best trend precision between 25 and 40km. The ozonesonde data are collected from the lower troposphere up to a height of approximately 30-35km, with the best precision in the 15-28km region.

Statistical trend analyses have been made using the Umkehr data between Umkehr layer 5 (24-29km) and Umkehr layer 9 (43-48km). Layer 8 (38-43km) has been of particular interest since it is the region of the stratosphere calculated by chemical models to show the largest percentage effect from chlorinated compounds such as CFCs. The trend analysis models have used terms to adjust for instrumental recalibrations, solar variation, and volcanic aerosol interferences. Written correspondence with the ozone recording stations confirmed that all known updates and corrections were included in the data analyzed.

Volcanic aerosols interfere with the Umkehr measurements, leading to apparent lower ozone values in the upper Umkehr layers. The volcanic aerosol loading has been approximated by using the Mauna Loa solar transmission data with different terms in the statistical models for before and after the El Chichon volcanic eruption. Both the Mt. Agung eruption in 1963 and the El Chichon eruption in 1982 added significant aerosol loadings to the atmosphere as reflected in the Mauna Loa solar transmission data. In order to be meaningful, trend analysis must accurately adjust for this type of event. An apparent ozone increase in the 1960's, as derived from Umkehr measurements, correlates with a diminishing aerosol effect, as seen in the Mauna Loa transmission data following the M. Agung eruption. Thus, whether the Mauna Loa transmission data are globally representative is important to the accuracy of the correction procedure. There is evidence that they are not. Peak aerosol loadings measured by Lidar and

satellite at other locations were much higher than those measured at Mauna Loa after the Mt. St. Helens and El Chichon events. Aerosol particle size and altitude profile distribution may also cause biases in the correction procedure that are not yet accounted for in the analyses. Intensive work is in progress to include post El Chichon Umkehr data in ozone trend analyses.

With these caveats, for the aerosol-corrected data from 12 N. Hemisphere Umkehr stations and 1 S. Hemisphere station studied by the above team of scientists, trend estimates of the average ozone change for the period 1970-1981 (prior to the El Chichon eruption) are:

| | |
|-------------------|---------------------|
| Layer 9 (43-48km) | -0.32 ± 0.33 %/year |
| Layer 8 (38-43km) | -0.32 ± 0.17 %/year |
| Layer 7 (34-38km) | -0.26 ± 0.17 %/year |
| Layer 6 (29-34km) | +0.04 ± 0.16 %/year |
| Layer 5 (24-29km) | -0.03 ± 0.16 %/year |

The error bars are the 95% confidence limits from the statistical analysis, revealing that the trend estimates in layers 7 and 8 are statistically significant. Aerosol and solar adjustments were done using the Mauna Loa transmission series and the f10.7cm solar flux data respectively.

The addition of 1982-84 data, which are highly affected by volcanic aerosol interference, makes the preliminary trend estimates in layers 8 and 9 slightly more negative. The adjustment for the volcanic aerosol after the El Chichon eruption is complicated by the amount and location of the aerosol burden and there is a reluctance by the researchers to report quantitative trend results until these effects are more thoroughly studied.

Future FPP sponsored studies will focus on how well the Mauna Loa transmission data represent the aerosol loading for each of the Umkehr stations. The FPP has sponsored a study to acquire astronomical extinction data collected since 1960 at 14 locations which may be used to evaluate aerosol global distribution for Umkehr data correction. In addition, efforts will be made to determine how other Umkehr layers affect the 40km trend estimate since the amounts of ozone in the different layers obtained from the Umkehr retrieval algorithm are highly correlated, and hence the layer trend estimates do not provide truly independent pieces of information. Also, trend estimates will be further compared with model calculations to determine critical areas of agreement or disagreement with respect to solar, temporal, and geographical factors. Calculations with 2-D models for the coupled scenarios (e.g., CFCs, CO₂, N₂O, NO_x, and CH₄) will be of crucial importance here.

A recently installed automated Dobson network of seven stations, the installation co-funded by FPP, will enhance the Umkehr analyses in the years to come by providing more frequent, higher quality Umkehr observations and better global coverage. Continued government funding support is, therefore, essential.

The joint research team has analyzed balloon ozonesonde data from 13 locations. A total of 15 layers or height regions ranging up to 33km were considered. The team is addressing a number of possible sources of error in the measurements which may introduce errors in the analyses. Work to date using different correction procedures gives estimates suggesting an increase in ozone in the 0-5km region and a decrease at 15-21km. However, this does not agree with 1-D model multiple perturbation calculations which indicate a negligible change at 15-21km and a much smaller increase than observed at 0-5km. Inclusion of data from 1983 made the estimates for 15-21km more negative, indicating a possible effect due to natural events such as the El

Chichon eruption. Further analyses and comparison with 2-D model multiple perturbation calculations are needed.

Future efforts include comparisons of Umkehr and ozonesonde profiles below 30km on a regional and station-by-station basis to check for consistency in the lower stratosphere trends. Seasonal variation in trends will also be evaluated. The six years (1978-1984) of Nimbus 7 ozone profile data will be used to determine the global representativeness of the ozonesonde network.

Temperature: Princeton University scientists have analyzed 1964-1979 atmospheric temperature data (radiosondes) at nine altitude levels ranging from 1 to 24km. Data from a total of 154 stations were used and the data were divided into nine latitudinal zones. Trend estimates for each pressure (or height) level were fitted, with adjustments for station-to-station and within-station variation. The characteristic shape of the estimated trend profile through 1979 was a cooling above 16km and a warming below. Another study is currently being done by the Wisconsin/Chicago research team using data through 1983.

2. MODELING

Time-dependent calculations which account for changes in concentrations of the potential ozone modifying source gases (CFCs, CH₄, N₂O, and CO₂ in multiple scenario calculations) provide the best available estimate of near term changes in the ozone layer. However, the limitations of the calculations due to uncertainties in model formulations, chemical data, and future concentrations of source gases must be realized. The program results have identified two requirements:

- o periodic updating of the multiple scenario/time-

dependent calculations, and

- o calculations based on future scenarios should not be extended beyond the next few decades (except for model intercomparison purposes) to avoid introducing overwhelming uncertainties in projected future source gas concentrations.

Multiple scenario/time-dependent calculations have been made using a 1-D model to estimate future changes in the ozone layer. These calculations continue to show that total column ozone is not likely to change significantly during the next few decades for reasonable assumptions of future source gas concentrations. The scenario chosen for this study, and discussed in WMO 1986, was: 1.0%/year increase in CH₄ concentration, 0.25%/year increase in N₂O concentration, 0.5%/year increase in CO₂ concentration, and 1.5%/year increase in the release rate of CFCs for 1980-2000 and constant release thereafter. The resulting changes in total column ozone are given for several years in the table.

| <u>Year</u> | <u>O₃%</u> |
|-------------|-----------------------|
| 1985 | 0.0 |
| 1990 | -0.13 |
| 1995 | -0.26 |
| 2000 | -0.40 |
| 2005 | -0.54 |

The FPP second generation 2-D model, based on diabatic circulation formulated on isentropic coordinates, has been further refined. Compared to the first generation 2-D model it provides a more realistic treatment of transport since it involves only observed temperature fields and one small eddy diffusion term. The transport in the model has been tested with

long lived trace gases involving simple chemistry, such as the upward diffusing species N_2O and CFC 11, and the downward diffusing species, HF, with satisfactory results. The complete photochemical scheme, including a diurnal code, has been successfully interfaced with the advective transport code. As a result of these model developments and refinements, the calculated seasonal and latitudinal zonal mean distribution of total column ozone are in reasonable agreement with observations. However, there are important differences between model calculated and observed local densities of ozone at certain altitudes, i.e., 40-50km.

The capability to couple feedback effects from chemistry, dynamics, and radiation will be incorporated into the 2-D advective transport model in the coming year. Ongoing activities include: the development of an efficient radiation scheme to calculate the solar and thermal radiation budget; diabatic heating rates from the temperature and ozone fields; and the development of a dynamical model to calculate zonal wind. Longer range plans call for establishing the feasibility of coupling a tropospheric climate model to the stratospheric model; determining the importance of tropospheric/stratospheric interactions; and, if feasible and necessary, development of a coupled 2-D tropospheric/stratospheric model.

Incorporation of the most recently revised rate data and physical constants into 1-D and 2-D models has not resolved many of the discrepancies between observed and calculated values of important trace species. Significant differences still exist between observed and calculated ozone values above 40 km. Since this is a region in which transport does not play an important role and the ozone chemistry is relatively simple, it suggests that resolution of these differences may require the introduction of new chemistry into the model.

The total nitrogen (NO_y) concentration in the lower tropical stratosphere calculated in the 2-D model is considerably lower than the concentration deduced from satellite HNO_3 and NO_2 observations. A trace gas budget study reveals that the abundance of NO_y in the lower tropical stratosphere is maintained by transport of NO_y from the upper troposphere rather than by in situ production processes. If lightning is included as a source of tropospheric NO_y , the calculated concentrations of NO_y in the lower tropical stratosphere are in much better agreement with observations.

Model simulation of the observed diurnal behavior of stratospheric reactive species (e.g., ClO) is important for understanding their short term response to diurnal variations of solar insolation. Model calculations have been carried out to determine the effect of the revised reaction rate and physical constant data on the diurnal variation of ClO . The calculated day to night ratio of ClO is about the same as previous results and in good agreement with observations. Previous conclusions about the roles of ClONO_2 and HOCl in modulating the diurnal variation of ClO remain valid. The large diurnal variation of ClO in the mid-stratosphere (30-40km) is mainly due to rapid exchange between ClO_x ($\text{Cl} + \text{ClO}$) and ClONO_2 , whereas the diurnal variation in the upper stratosphere (40-50km) is due to exchange between ClO_x and HOCl . However the new calculated daytime column density of ClO is about 12×10^{13} molecules cm^{-2} and is almost a factor of two higher than the mean of observed values.

Vertical profiles of HCl and ClONO_2 have been calculated and compared with recent observations. The calculated ClONO_2 agrees well with observations but the calculated HCl concentrations at around 25-35km is about a factor of two lower than observed. A comparison of the calculated values to observations shows that the models may be overestimating the ratio of ClO/HCl (by approximately a factor of four) in the lower stratosphere, a

discrepancy suggesting that the partitioning of Cl_y is not correctly calculated by current photochemical models. These and other discrepancies between model calculations and atmospheric measurements show that significant uncertainties remain in understanding the processes controlling stratospheric ozone and other trace gases. Hence there is a need to continue research to improve understanding of the current atmosphere and to improve capabilities to forecast future ozone levels.

The steady state 2-D model calculations including growth only in CFC emissions have been carried out to evaluate the effects of high chlorine scenarios on ozone levels. The initial results show that even at three times current emission levels there is no indication of a non-linear effect. In contrast to 1-D model calculations, the calculated amount of ozone change at each latitude and season is found to be in direct proportion (linear) to the stratospheric chlorine abundance. This underscores the importance of meridional transport and self healing processes, i.e., increases in ozone production in the tropics due to ozone reduction in the stratosphere. It also confirms the continuing value of statistical techniques of ozone trend analysis to provide early detection of ozone change.

Detailed steady state and time dependent calculations with a 1-D model have shown that the magnitude and onset of the calculated non-linear effect is a function of present day total nitrogen concentration in the stratosphere; the rate of growth of not only CFC emissions, but of CH_4 , N_2O , and CO_2 ; and transport effects. Time dependent coupled 1-D calculations incorporating consensus growth scenarios for the other key trace species show that, at double present CFC production rates/emissions, the calculated effect of CFCs on ozone is significantly moderated, i.e., from about -15% for CFCs only to about -6.6% for the more realistic multiple perturbation scenario case.

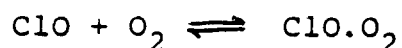
The 2-D high chlorine scenario calculations have been extended to coupled steady state calculations. The initial results show that the calculated effects of CFCs are significantly moderated by the calculated effects due to increases in the atmospheric concentrations of CH₄ and N₂O. The calculated reductions in column ozone vary strongly with latitude and seasons. The largest ozone change is calculated to occur in winter at high latitudes.

3. ATMOSPHERIC CHEMISTRY

During the last year, FPP-funded studies have helped to show that the homogeneous reactions of ClONO₂ with both HCl and H₂O are too slow to be important in stratospheric chemistry. One study gave an upper limit of $2 \times 10^{-21} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$ for the rate constant for the reaction of ClONO₂ with H₂O. Another study supported the conclusion that the rate constant for the reaction between ClONO₂ and HCl is slower than $10^{-18} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$. Both studies were conducted at 298K. If the rate constants for these reactions had been faster, as tentatively reported at the time of the last CCOL meeting, the calculated effect of CFCs on ozone in atmospheric models would have increased.

The UV absorption cross section of NaCl has recently been measured at 300K in an FPP supported study. The results lead to a calculated photolysis rate for NaCl at 40km of $(1.9 \pm 0.8) \times 10^{-4} \text{ s}^{-1}$, a factor of 10 smaller than previously estimated using high temperature cross section data. This value limits, but does not eliminate, the possibility that sodium chemistry may play a role in partitioning chlorine between Cl/ClO and HCl in the upper stratosphere. More work is needed to determine the role of both heterogeneous and homogeneous processes that could remove sodium compounds from the stratosphere.

If a sufficient fraction of the modeled ClO were to exist as the adduct ClO.O₂, the calculated effect of CFCs on stratospheric ozone could be significantly changed. The effective rate constants as well as the products of reactions involving ClO could be different. More importantly, ClO.O₂ could photolyze to produce ozone. To determine the potential importance of ClO.O₂, the FPP is sponsoring a study of the equilibrium constant for the reaction:



One of the most significant sources of uncertainty in chemical modeling is the degree of penetration of solar ultraviolet radiation into the atmosphere, a process which is controlled primarily by absorption by oxygen. FPP funded a recently completed study of the Herzberg continuum absorption cross section of oxygen in the 194-240nm region. The results confirmed the conclusion drawn from in situ solar irradiance measurements that the previously accepted cross sections were about 35% too large. A project to parameterize the detailed laboratory oxygen absorption cross section data for use in atmospheric models is in progress. The goal of this project is to provide an accurate parameterization of the new high quality laboratory data, thus reducing the uncertainty that exists and encouraging the use of a single state-of-the-art parameterization by modelers.

The HO_x family is probably the most important group of compounds in the stratosphere because reactions involving these compounds control the partitioning between the active, or potentially ozone depleting, and inactive compounds of the other groups. The reaction between OH and HO₂NO₂ is responsible for removing about half of the HO_x in model calculations for the lower stratosphere. Yet the uncertainties in the reaction parameters that control the HO₂NO₂ concentrations are very large. The level of uncertainty is increased by the fact that there have

been no measurements of atmospheric concentrations of HO_2NO_2 . The FPP is supporting studies of two of the more important reactions involving HO_2NO_2 whose rate parameters are still very uncertain, namely the photolysis of HO_2NO_2 and its reaction with OH.

The FPP sponsored a workshop on atmospheric chemistry at Göttingen, FRG, in October 1984. Leading atmospheric scientists from the United States and Europe met to discuss outstanding questions on the chemistry of stratospheric ozone. Copies of the proceedings of this workshop can be obtained from CMA.

4. ATMOSPHERIC MEASUREMENTS

The FPP continues to support research projects aimed at expanding the observational data base and developing or improving instruments to measure stratospheric composition more accurately.

The results of five years of measurements by the Atmospheric Lifetime Experiment (ALE) will be published soon. They provide information on the concentration trends of the source gases (including methane, nitrous oxide, and CFCs) needed as input for model calculations. The atmospheric lifetimes of 75 years for CFC 11 and 110 years for CFC 12 provide a constraint for the models. The ALE program has now been succeeded by the Global Atmospheric Gases Experiment (GAGE) which is co-funded by NASA, NOAA, the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, and the FPP.

The FPP continues to co-fund balloon campaigns aimed at simultaneous measurements of a wide range of stratospheric compounds and intercomparisons of different techniques for measuring the same compound. The simultaneous measurements provide information to test the model chemistry. The

intercomparisons determine what portion of the previously measured atmospheric variability of compounds is due to instrument error as opposed to real variability. Two recent campaigns of this type are the Balloon Intercomparison Campaign (BIC) and the Middle Atmosphere Program (MAP/GLOBUS) NO_x campaign. These intercomparison campaigns have undoubtedly improved the quality of measurement data by revealing unsuspected deficiencies that could be corrected. Results from BIC for certain key molecules (HCl, HF, HNO₃) give confidence in the stratospheric vertical distributions obtained. More work is needed to understand the discrepancies among instruments for other gases such as CH₄ and NO₂.

FPP provides co-funding of projects to measure HO_x compounds and total chlorine by balloon-borne instruments. Recent results of HO_x measurements provide conflicting information about their concentrations and partitioning. Thus it is critical to continue these programs to determine if the conflicting information is a result of instrumental problems or deficiencies in the understanding of stratospheric chemistry. The total chlorine measurements are expected to provide a test for the completeness of model input data.

FPP has co-funded several instruments that measure the abundance, vertical distribution, and diurnal variability of ClO. Although there is now reasonable agreement between theory and observations for the average altitude profile and diurnal behavior, existing data are inadequate to test the calculated seasonal, latitudinal, or long-term trends.

Although direct involvement in satellite based measurement programs is beyond the scope of the FPP activities, funding is provided to assist in the interpretation of the atmospheric composition data that are now becoming available from satellite

instruments. These types of projects are particularly important to provide tests for 2-D models. One such project has derived OH fields using several approaches.

FPP is funding work in several laboratories to measure pressure-broadening coefficients and line positions of key trace species as well as spectra of species that may cause interferences in the measurement of minor trace gases. These results will support measurements made by the ATMOS instrument on board the Space Shuttle, the far infrared Fourier Transform emission spectrometers, and other instruments. Infrared band strength data needed to assess the significance of CFCs to the radiative balance of the atmosphere are being obtained.

The FPP atmospheric measurements program has strongly supported ground-based measurements systems by co-funding millimeter-wave, infrared, and Lidar projects. The developmental work resulting from these projects is expected to play a key role in an Early Detection Workshop, co-sponsored by NASA, NOAA, and FPP and scheduled for March 5-7, 1986. The goal of the workshop is to set priorities and determine capabilities for measuring atmospheric parameters in order to determine trends in atmospheric composition well before changes in stratospheric ozone concentrations could become significant. An early detection network could then be designed to augment and strengthen existing "early warning" measurement programs. Future FPP funding for atmospheric measurements will take into account the need for implementation of such a network.

5. OZONE MEASUREMENTS

FPP has co-funded a project to establish automated Dobson ozone monitoring stations in strategic locations around the world. Since the last CCOL report additional stations have been

established in Australia and Peru, and a third S. Hemisphere site in New Zealand is under evaluation. Further information is in "1. OZONE TREND ANALYSIS" above.

6. PRODUCTION AND RELEASE OF CFC 11 and CFC 12

FPP has continued to collect and report production, sales, and release data for CFC 11 and CFC 12. The latest report, recently made available to CCOL, covers production, sales, and releases through 1984. Efforts to obtain reliable data from the U.S.S.R., Eastern Europe, and P.R.C. have been unsuccessful but continue. Therefore, the last two reports contain data from reporting companies only.

7. CLIMATIC AND BIOLOGICAL EFFECTS

FPP is concerned with the effect of possible changes in solar UV radiation on terrestrial and aquatic biological systems, including the human race, and on world climate.

FPP sponsored a sophisticated statistical analysis of the available epidemiological data on the incidence of non-melanoma skin cancer (NMSC). The purpose of the project was to provide scientific perspective as to the validity of predictions of the change in incidence of NMSC with various postulated changes in solar UV-B radiation.

FPP is also sponsoring a two-year program, now in its second year, with the objective of developing a 2-D climate model.

In 1985, FPP sponsored a workshop in Arles, France, on the scientific status of climate modeling and possible effects on world climate due to changes the global average temperature. Copies of the proceedings of this workshop can be obtained from CMA.