International Association of Meteorology and
Atmospheric Physics (IAMAP)

Collection of Extended Summaries of Contributions Presented at Joint IAGA/IAMAP Assembly Seattle, Washington

JOINT SYMPOSIUM C
INFLUENCE OF SOLAR ACTIVITY AND GEOMAGNETIC CHANGE ON WEATHER AND CLIMATE

22 August - 3 September 1977

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SEATTLE, WASHINGTON U.S.A.

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Joint Symposium C

Influences of Solar Activity and Geomagnetic Changes on Weather and Climate

Preface

The main emphasis in Joint Sympoisum C held at the IAGA/IAMAP General Assemblies in August 1977 was on mechanisms that might be involved in the connection between weather and solar activity or geomagnetic changes. It is clear that the most popular concept among symposium participants involved ozone changes, usually as influenced by nitrogen oxide chemistry. However, changes in solar ultraviolet flux, changes in the electrical properties of the atmosphere, and even small periodic (27 day) changes in the solar constant, were concepts that also received attention.

A considerable quantity of evidence has now been gathered by many scientists around the world demonstrating the existence of connections between (a) solar phenomena (ranging from short-lived events such as sector boundary crossings, solar flares, and the 27-day solar rotations to long-lasting phenomena such as the 11-year and 22-year solar cycles) and (b) various aspects of the weather such as tropospheric pressure and circulation patterns, temperature and rainfall. Some of the now established sun-weather relationships appear to be not only statistically significant, but also of practical importance in that they include meteorologically significant variations of parameters such as the zonal index and the occurrence of blocking anticyclones. Several authors have claimed that relationships also exist between the weather and geomagnetic variations on various time scales; the reality of these relationships has yet to be proved and, indeed, it is not yet clear whether, if they are real, they result from geomagnetic influences on the weather or vice-versa.

The solar-cycle variation in galactic cosmic radiation modulates NO_x (i.e., NO and NO_2) production in the atmosphere, and this is believed to produce a solar-cycle variation in total ozone. Solar-flare proton events sporadically produce NO_x and reduce ozone. Precipitation of radiation belt particles during magnetic disturbances provides still another means of producing additional NO_x. Thus ozone amounts on earth are expected to vary both with the solar cycle and with the solar flares that eject energetic protons or that produce geomagnetic disturbances. Just how changes in ozone amount can lead to changes in weather remains speculative, although several candidate mechanisms exist; ozone changes should lead to changes in the thermal structure of the stratosphere and hence in the radiation balance of the lower atmosphere, in the wind patterns of the upper stratosphere, and in the reflective properties of the stratosphere for upward propagating waves that originate in the troposphere.

The relative popularity of the concept that ozone changes constitute a vital link in sun-weather relationships does not mean that the concept is without difficulties. J. Zinn, using a one-dimensional model, found that the changes in thermal structure associated with ozone changes caused by cosmic radiation changes were too small to be credible as a factor in influencing weather. He considered changes in solar ultraviolet radiation at a level described by D. F. Heath (1% at 295 nm increasing to 5% at 175 nm) to be more promising for production of a change in the thermal structure of the stratosphere. A. J. Theobald, M. J. Rycroft, and R. G. Williams considered the combined effects of solar ultraviolet changes on ozone and on thermal structure and found these to be of possible significance, although still rather small. However, the uncertainties in the models are such that the possibility of ozone changes as a link in the relationship should continue to be regarded seriously.

R. Markson considered the possibility that the overall electrical structure of the atmosphere might be changed as a result of ionization changes in the atmosphere due to changes in cosmic radiation or solar flare protons. The change in electrical structure might in turn affect thunderstorm development and cloud formation. Though not much discussed at this symposium, the possibility of modulation effects on cirrus clouds remains a candidate mechanism for relating weather to solar events.

J. M. Mitchell reported new results showing that the double sunspot cycle influences the occurrence of droughts in the U.S.A., and suggesting that short-term geomagnetic variations and the solar cycle both modify the circulation of the troposphere and stratosphere in various ways. The double sunspot (twenty-two year) cycle in weather is especially puzzling, as no mechanism by which the atmosphere can discriminate between successive eleven-year sunspot cycles has been identified.

Francis S. Johnson

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Bates, J. R., Stratospheric influence on heat transfer by ultra-long stationary waves in the troposphere - a mechanism for climate change. (Published Quart. J. Roy. Met. Soc., 103, p.397, 1977.)

Borisenkov, E. P., Energetic aspects of solar activity effect on weather and climate.

Chamberlain, J. W., A mechanism for inducing climatic variations through ozone destruction: Screening of galactic cosmic rays by solar and terrestrial magnetic fields. (Published J. Atmos. Sci., 34, p. 737, 1977.)

Davydov, V. M., On the role of magnetosphere-ionosphere processes in formation of atmosphere electricity variations.

Hale, L. C., Particulate transport through the mesosphere and stratosphere, (Published Nature, 268, p. 710, 1977.)

Hampson, J., A model for iterative interaction between atmospheric chemistry, heating and circulation to explain perturbation of weather and climate by solar activity and anthropogenic change.

Kondratovich, K. V., On the relation between present oscillations of climate and changes of geomagnetic field.

Larsen, M. F., and M. C. Kelley, A study of an observed and forecasted meteorological index and its relation to the inter-planetary magnetic field. (Published Geophys. Res. Letters, 4, p. 337, 1977.)

Mass, C., The influence of sunspots on long term temperature records. (Published J. Atmos. Sci., 12, 1977.)

Mitchell, J. M., Jr., Drought cycles in the United States and their relation to sunspot cycles since 1700 A.D.

Mustel, E. R., The morphological properties of solar-atmospheric effects.

Plachotnjuk, V. N., About the relationship between the variations of geomagnetic field, the earth's rotation and parameters of interplanetary environment.

Rakipova, L. R., Ozone mechanism of the effect of solar activity on climate.

Ramakrishna, S., and D. F. Heath, Temperature changes associated with geomagnetic activity at Wallops Island.

Reiter, R., Solar events increase the frequency of stratospheric intrusions.(Published Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie A, Springer Verlag, 1977.)

Reiter, R., The electric potential of the ionosphere as controlled by the solar magnetic sector structure.(Published Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie A, Springer Verlag, 1977.)

Theobald, A. G., M. J. Rycroft, and R. G. Williams, Calculation of the effects of variations of solar cosmic rays and UV radiation on the middle atmosphere.

Vorobjeva, E. V., Space-time structure of some long period variations in meteorological and geophysical parameters and their relation with geomagnetic activity.

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4	Volland, H.	Periodic variations of the solar radiation - a possible source of solar activity-weather effects
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6	Geller, M. A. Avery, S. K.	Calculations of solar activity effects on planetary wave propagation
7	Banerjee, S. K. Lund, S. P. Eyster-Smith, N. Wright, H. E., Jr. Long, A.	Correlation between paleoclimate and paleomagnetism for the last 9,500 years
8	Brown, G. M. John, J. I.	Solar cycle influences in tropospheric circulation
9	Olson, R. H. Sawyer, C. B.	A comparison of solar sector boundaries, high-speed streams, and flares as they affect vorticity in the earth's atmosphere
10	Wilcox, J. M. Scherrer, P. H. Svalgaard, L. Gustafson, E. K.	Morphology of a sun-weather effect

COMPUTATIONS OF SOLAR CYCLIC VARIATIONS
OF TEMPERATURE AND PRESSURE IN THE POLAR STRATOSPHERE

J. Zinn (University of California, Los Alamos Scientific Laboratory, Los Alamos, NM 87545)

By way of introduction I have to say that our original abstract should be largely disregarded. This was intended to be a talk about the computed effects of changes in solar activity on atmospheric temperatures by way of the time-varying production of NO_x by solar protons and galactic cosmic rays, and the variations in ozone concentrations arising from the variations in $[NO_x]$, and, finally, the variations in stratospheric temperatures arising from the variations in ozone. We have now done the calculations, and we found some of the effects that we expected, but they are an order of magnitude weaker than we expected.

It is of course well known that the fluxes of galactic cosmic rays show an anticorrelation with the solar activity index, and there have been several papers on the effects of the cosmic rays on ozone concentrations. However, the rates of production of NO_x by cosmic rays are very small at all altitudes, relative to the normally existing NO_x concentrations. At altitudes above 20 km the NO_x doubling time by cosmic rays is longer than the eleven-year solar period. Even at 15 km altitude it is 2 to 4 years. So it is hard to imagine that variations in direct NO_x production by galactic cosmic rays can have much to do with any observed variations in O_3 concentrations or temperatures.

Solar protons arising from solar flares can have a stronger effect. Some comparisons of NO_x production by solar protons vs galactic cosmic rays have been made by Crutzen. Crutzen showed that above 25 km altitude the NO_x produced by a large solar proton event is larger than that produced in a year by cosmic rays.

Taking Crutzen's calculations of the NO_x produced by the November 1960 solar proton event we made a computation of the effects that the added NO_x would have on atmospheric temperatures (at 65° latitude). In the computation we assumed that the solar proton event occurred in July. Figure 1 shows a comparison of computed concentration profiles 10 days after the solar proton event and profiles for the same time with no solar proton event. One can see that the NO_x concentrations are changed quite a bit above 30 km; however the O_3 concentrations are changed very little. This is because at 40 km and above the NO_x catalytic cycle doesn't have much to do with concentrations of ozone.

Figure 2 shows a set of computed profiles of atmospheric heating and cooling rates (in degrees per day) from various processes. The most important are the solar UV absorption by ozone and the 15 μm emission by CO_2.

Figure 3 shows the comparison of computed temperature profiles 10 days after the proton event and at the same time without the event. The two profiles differ by only 1 °K at the stratopause. So we have computed what amounts to a non-effect.

Before this conference I was unaware of the data on solar cycle changes in UV flux. As Dr. Callis showed on Friday, a change in UV flux has much better possibilities for causing changes in stratospheric temperatures.

THE MODEL

I would like to talk a little bit about the model. This is an extension of our atmospheric chemistry model, which now includes interactive heating and cooling terms. See Fig. 4. It is time dependent and 1-dimensional, and it covers the range from zero to about 60 km, although the top boundary is allowed to move as the atmosphere expands or contracts. It includes quite detailed chemistry and quite detailed radiation transport. It includes vertical hydrodynamic motions, and includes heating terms arising from precipitation of water. The precipitation also interacts directly with the chemistry by washing out soluble species.

The thing that has caused us the most difficulty is the eddy heat conduction, which of course is the dominant factor in determining the thermal structure of the troposphere. See Fig. 5. For a quasi-hydrostatic equilibrium situation one can cast the eddy diffusion equation in the very simple form

$$F_i = - nD \frac{\partial f_i}{\partial z}$$

where F_i is the diffusive flux of the i^{th} species relative to the fluid as a whole, n is the total molecular density, f_i is the mole fraction of the species i, and D is the same thing as K_z, the vertical eddy diffusion coefficient.

In the absence of water condensation effects one can write the eddy heat flux equation in a fairly analogous form, namely

$$\phi = - nD_c\left(\frac{\partial H}{\partial z} + \bar{m}g\right) \qquad erg/cm^2s$$

where H is the enthalpy per molecule, $\bar{m}$ is the average molecular mass and g is the acceleration due to gravity. D_c is again a diffusion coefficient, which I originally took to be the same as the ordinary eddy diffusion coefficient D.

However, if one uses any of the published estimates of eddy diffusion coefficients in this equation one gets tropopause temperatures that are very much too low. In regions that are convectively stable, i.e. where $\frac{\partial H}{\partial z} + \bar{m}g > 0$, we find that we need to use values of D_c that are much smaller than D.

The reasons for the difference between the eddy diffusion coefficient and the thermal diffusion coefficient have been stated in the literature, originally by Priestley and Swinebank in 1947, although I was slow to accept them. They have to do with the fundamental distinction between free and forced convection. In this context free convection is that which arises, from the buoyant motion of local hot or cold volumes of air, while forced convection as associated with purely mechanical turbulence arising from processes such as wind shears or flow over rough terrain. As far as eddy diffusion of chemical species is concerned, it doesn't matter whether the convection is free or forced. However for heat transfer the distinction is very important. If the atmosphere is in a convectively stable condition, that is if $\frac{\partial H}{\partial z} + \bar{m}g > 0$ then one can show that to a first approximation free convection cannot produce any heat transfer. Only the forced convection leads to heat transfer. Therefore D_c has to be only that part of D that comes from purely forced convection. Thus $D_c \leq D$. We do not have any good a priori way of estimating the relative amounts of free and forced convection. However we have found that the best computed temperature profiles were obtained when D_c was set to zero. This tends to imply that the actual eddy diffusion process is dominated by free convection.

In unstable regions where $\frac{\partial H}{\partial z} + \bar{m}g < 0$ (that is, where the vertical temperature gradient exceeds the adiabatic lapse rate) the situation is very different. In such regions it is impossible to distinguish free convection from forced convection; however both kinds of convection lead to heat transfer, and it is appropriate to set

$$D_c = D \quad .$$

The net result is that eddy heat conduction can only be upward. I should also note that D tends to be very large in unstable regions.

To show where we are now with the model, Fig. 6 is a set of computed 24 hour average volume mixing ratios of various trace constituents for 45° latitude on July 1. The overlay shows a collection of observational data for summer at temperate latitudes. The phenominal agreement with respect to the ozone profiles is mostly accidental, since we are actually not able to predict correctly either the seasonal or latitudinal variations of ozone concentrations. The comparisons of methane and H_2 profiles shows that we should probably be somewhat larger eddy diffusion coefficients at high altitudes.

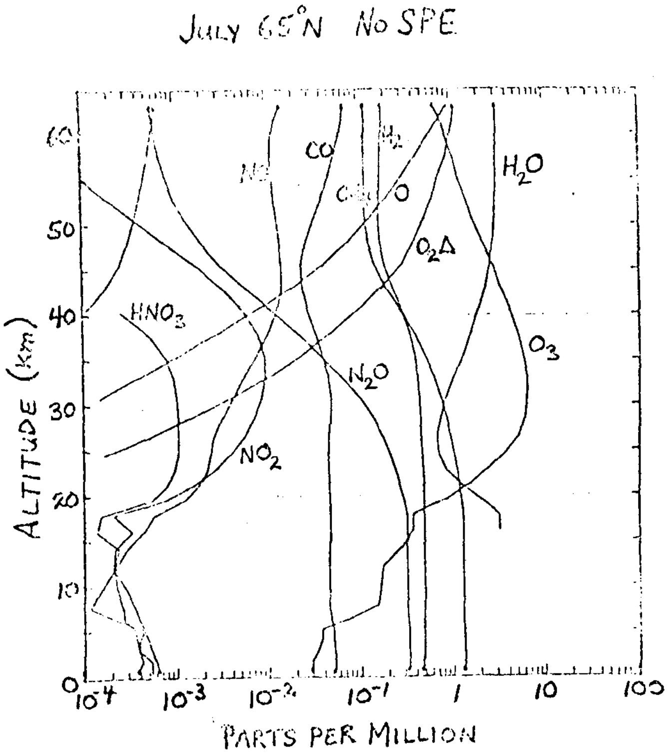
Figure 7 shows a comparison between a computed temperature profile and some experimental data.

Figure 8 shows the contributions of various individual processes to the overall heating and cooling rates.

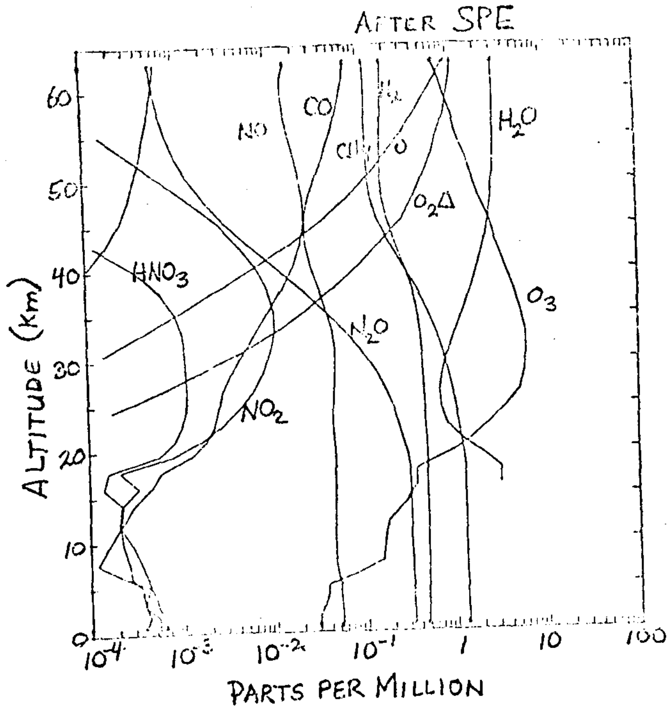
Notes added in proof:

1. In response to a question by Julius London I should point out that the solar proton effect calculations were done for a moderately large event but not nearly as large an event as that of 4 August 1972. An actual measured decrease in O_3 concentrations after the 1972 event has been reported recently by Heath, Krueger and Crutzen [Science 197, 886, (1977)].

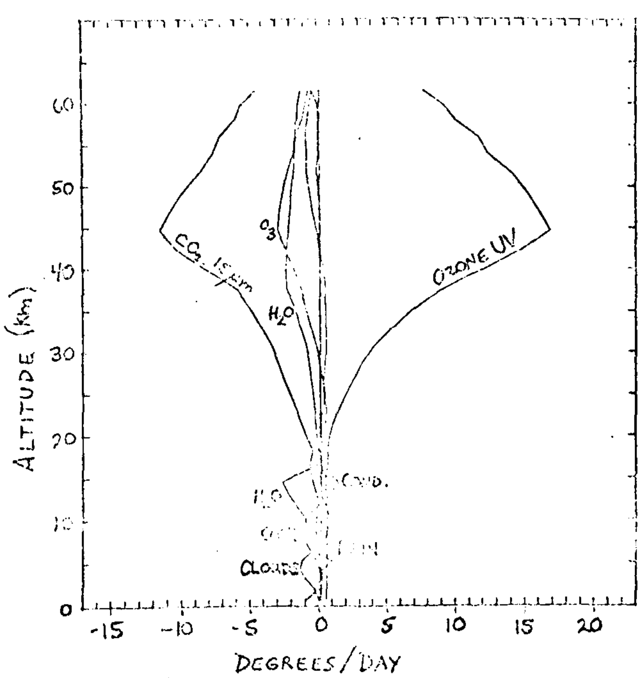
2. Our current model attempts to represent the eddy diffusion coefficient as a dynamically varying function of the local air density and relative convective stability, rather than as a function of altitude. These numerical experiments are not yet finished.



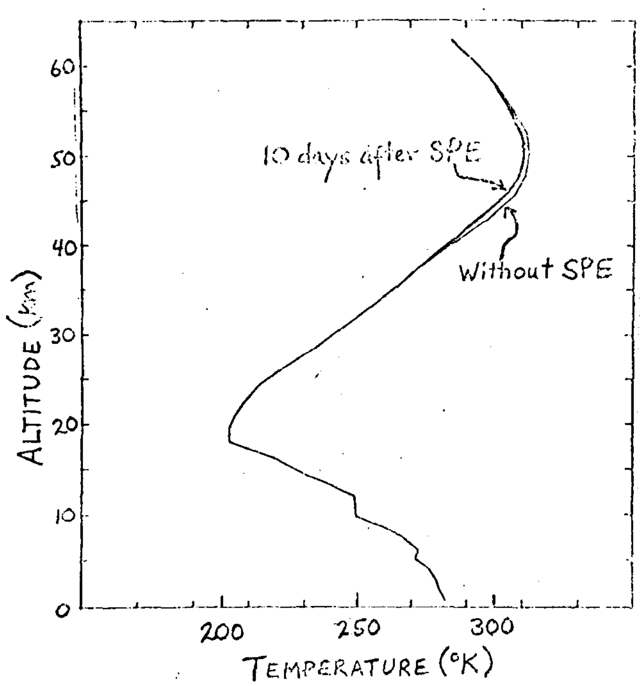
1a. Computed volume mixing ratios for July 10 at 65° north latitude under "normal" conditions without solar proton event.



1b. Computed volume mixing ratios 10 days after moderately large solar proton event, which was assumed to have occurred on July 1 (65° north latitude).



2. Computed heating and cooling rates from individual processes (July, 45° latitude).



3. Comparison of computed temperature profiles with and without the solar proton event.

ATMOSPHERIC HEATING & COOLING

1. PHOTOCHEMISTRY (UV ABSORPTION)
2. SWIR ABSORPTION BY WATER
3. LWIR EMISSION & ABS BY CO_2, O_3, H_2O, CLOUDS
4. THERMAL CONDUCTION (EDDY)
5. PRECIPITATION
6. VERTICAL EXPANSION & CONTRACTION

Fig. 4