ANALYSIS OF DATA FROM
SPACECRAFT (STRATOSPHERIC WARMINGS)
Quarterly Progress Report, Sep. - Nov. 1973 (Lockheed Missiles and Space Co.)

MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA
QUARTERLY PROGRESS REPORT NO. 1

ANALYSIS OF DATA FROM SPACECRAFT
(STRATOSPHERIC WARMINGS)

NASA CONTRACT NASW-2553

NASA HEADQUARTERS, WASH. D.C.

COVERING THE PERIOD SEPTEMBER-NOVEMBER, 1973

CONTRACT MONITOR: H. D. CALAHAN
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1. INTRODUCTION

The primary objectives of the study are to establish the details of the stratospheric warming processes as to time, area, and intensity and to correlate the warmings with other terrestrial and solar phenomena occurring at satellite platform altitudes or observable from satellite platforms. Early correlations will be statistical and are expected to point to the mechanisms that are connected or are unconnected.

Stratospheric warmings are large-area phenomena containing large amounts of energy. They probably have major influence on the weather over large areas, on observations from satellites and high-altitude platforms, on the dynamics of the upper and lower atmospheres, on atmospheric chemistry, on air pollution observations and on backgrounds for surveillance and earth resources observations.

Little correlative data has been brought to bear on defining the relationship between energetic events above 50 km and the warmings at about 40 km. Current rocket and balloon-borne IR sounding instruments do not provide good coverage on a global basis. It is difficult to provide dynamic readings throughout a warming by means of ground based instrumentation. Satellite and other high altitude data, therefore, need to be applied to the problem.

One purpose of the study is to determine if there are links between the ionosphere and the stratosphere which could explain the physics of the sudden stratospheric warmings, to describe the mechanics of energy transfer if such links exist, and
to extend our vertical models of the disturbed atmosphere to high altitudes during the perturbation. In the search for higher altitude phenomena which might be a direct cause of stratospheric warmings, it is necessary to assess the total energy available to see whether or not there is sufficient energy. If no direct causes are found then it may be possible to find higher altitude phenomena which can serve as initiators or trigger mechanisms which cause the release of large amounts of energies stored over appreciable periods of time in special areas.

Existing data and literature have been searched to find the identified cases of stratospheric warmings. Six case histories of these events have been chosen by assembling correlative high altitude satellite, rocket, and ground based measurements, geophysical characteristics and solar activity data. Existing data from NIMBUS spacecraft sensors such as the MRIR, SIRS, IRIS and SCR are being used to define the existence and characteristics of the warming in the 20-50 km-altitude regime. Data from various particle and radiation experiments on ALOUETTE, ISIS, OGO and OGO satellites are being used to determine some of the energetic conditions existing in the upper atmosphere prior to and during the warming events. The correlation of the particle data with the lower altitude radiance data may lend some insight into the physical mechanism of sudden warmings. Then statistical analyses will be carried out with various influencing factors and effects to see if a cause and effect relationship is discernible. Finally, comparison of results will be made with existing spatial and temporal models of warming events. It is hoped that the models may be extended as a result of this study.
2. SUMMARY OF ACTIVITIES

The main effort during this period involved a search through existing literature and data to obtain case histories for the six or more stratospheric warmings that occurred in April - May 1969, June - July 1969, August 1969, December 1969 - January 1970, December 1970 - January 1971, and January 1973 - February 1973. For each of these warmings the following steps have been taken in preparation for analysis:

1. Defining the nature of the problem (see Appendix A).

2. Literature search of stratumwarmings and solar-terrestrial phenomena (See Appendix B).

3. File of data sources, especially stratospheric temperatures (radiances) and geophysical indices (Appendix C).

Contacts were made with NSSDC and NOAA personnel and a number of orders for data executed. Data received is being reduced to a form usable for correlation studies.
A preliminary survey of recorded major and minor stratospheric warmings shows that in January of every year between 1966 and 1971 at least one event occurred in the Northern Hemisphere between 45° and 80° latitude. These same years produced events in the Southern Hemisphere in July and August. One such sequence of events was recorded in 1969. Six stratospheric events in both the Northern and Southern Hemispheres have been selected for detailed analysis.

The results of the preliminary survey are depicted in chart form in Figure 1. The lower field depicts the approximate latitude and time of occurrence of stratospheric warmings during 1962 through 1972. Plotted above in the form of bar charts are a number of satellite instruments and their approximate times of operation. Dashed bars represent periods when either instrument coverage or data quality restricted the availability of usable data. Six representative events were chosen - three Southern Hemisphere events occurring in May, July, and August 1969 and three Northern Hemisphere events occurring in January 1970, January 1971, and January-February 1973. This set of representative cases with a list of available data is summarized in Table I.
Figure 1 - Location and dates of reported warming events during 1962 through 1973, with indication of concurrently available satellite scientific data for selected warmings.
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Warming Date</th>
<th>Journal Reference</th>
<th>Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May 1969</td>
<td>Fritz 1970a</td>
<td>Nimbus 3 SIRS Channel 8 radiance maps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fritz 1972a</td>
<td>Nimbus 3 MRIR Channel 3 radiance maps</td>
</tr>
<tr>
<td>2</td>
<td>July 1969</td>
<td>Finger 1970</td>
<td>Nimbus 3 SIRS Channel 8 radiance maps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fritz 1970b</td>
<td>and derived 10 mb temperature maps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Miller 1970d</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Aug. 1969</td>
<td>Finger 1970</td>
<td>Nimbus 3 SIRS Channel 8 radiance maps</td>
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<tr>
<td></td>
<td></td>
<td>Miller 1970d</td>
<td>and derived 30 mb temperature maps.</td>
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<tr>
<td></td>
<td></td>
<td>Smith 1970a</td>
<td>Time-height section at Mirnyj</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Miller 1972</td>
<td>2- and 10-mb analyses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quiroz 1971</td>
<td>Time-height sections at selected stations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labitzke 1972a</td>
<td>A and B radiance maps. 30-, 45- and 60-mb</td>
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<tr>
<td></td>
<td></td>
<td>Labitzke 1973</td>
<td>analyses. Selected rocketsonde profiles</td>
</tr>
<tr>
<td>6</td>
<td>Jan.-Feb. 1973</td>
<td>Anon 1973</td>
<td>Nimbus 5 SCR Channel B radiance maps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quiroz 1973</td>
<td>NOAA 2 VTPR Channels 1 and 2 radiance maps</td>
</tr>
</tbody>
</table>
Initially it was proposed to use the data from various experiments on some of the research satellites (ALOUETTE, ISIS, OGO and OSO) to determine some of the energetic conditions existing in the upper atmosphere prior to and during the warming events. Although a major effort has been made to obtain such data, the results have been discouraging for several reasons:

a. There is a tremendous volume of data from any one satellite (experiment).

b. It is not easy to locate the data, especially recent data.

c. Normally, it takes several years for research data to be placed in the National Space Science Data Center (NSSDC).

d. If data is in NSSDC, it is not easy to find if it is available at location and time desired (this may involve sending for many rolls of tape or film and making a time consuming search).

e. Data may not be in a format to give desired parameter or in desired form (much more computer processing may be necessary to get it in desired form for analysis).

The above situation does not hold for operational type data. Operational data has been put in a form that makes it readily available on a timely basis to outsiders. Therefore, although further attempts will be made to get research data, especially that data in a convenient format, the main emphasis will be on obtaining and plotting operational type data.

There is a wealth of operational data on solar and geophysical indices. The main problem is determining which data are pertinent for correlation analysis involving the upper atmosphere and the warmings. In view of the fact that no definite correlations have been found between stratwarmings and the upper atmosphere phenomena represented by the indices, the selection of the indices to be used must be made on the basis of a possible connection and not a probable one. In other words, we are dealing with a strictly exploratory situation inasmuch as no connection may exist between stratwarmings and upper atmosphere phenomena. Although meteorological research to date indicates that stratospheric warmings are caused entirely by a
transfer of energy from the troposphere to the stratosphere, nevertheless
the possibility has not been completely ruled out that such events are
triggered or enhanced by certain conditions occurring in the upper atmo-
sphere. The solar and geophysical indices used are listed in Table II;
in-house values are indicated by a X mark for the months containing
warmings. These particular indices were selected on a preliminary basis
because they all appear to be correlated with upper-atmospheric heating
phenomena. All of the indices, except the HeII flux, are available from
the Environmental Data Service, NOAA, National Geophysical and Solar-
Terrestrial Data Center, Boulder, Colorado, in the monthly publication
"Solar-Geophysical Data." Each index in Table II will now be discussed in
turn.

**Solar Flares**: Some solar flares result in significant effects on
the earth's upper atmosphere. Solar flares of importance 2 or greater
are used in this study.

**SID (Sudden Ionospheric Disturbance)**: Attributed to solar flare
electromagnetic radiation incident on the earth's ionosphere. SID's are
observed on the sulit hemisphere and occur almost simultaneously with visual
flare observations.

**Magnetic Condition**: This includes magnetically quiet and disturbed
days from the Abbreviated Calendar Record and Principal Magnetic Storms.

**2800 MHz Solar Flux**: This index is used to indicate the solar ex-
treme ultraviolet radiation incident on the upper atmosphere and responsible
for heating near 140 km.

**HeII Solar Flux**: This extreme ultraviolet line at 304A contains much
of the energy involved in heating the atmosphere near 140 km. This index
was obtained from Timothy (JGR 34, 6950) for April - August 1969. It is a
more accurate measure than the 2800 MHz solar flux of the upper atmospheric
EUV heating.
**TABLE II**

**INDICES USED FOR STRATWARM ANALYSIS**

<table>
<thead>
<tr>
<th>INDEX</th>
<th>Apr '69</th>
<th>May '69</th>
<th>June '69</th>
<th>July '69</th>
<th>Aug '69</th>
<th>Dec '69</th>
<th>Jan '70</th>
<th>Dec '70</th>
<th>Jan '71</th>
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<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>S.I.D.</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>Magnetic Condition</td>
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<td>X</td>
<td>X</td>
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<td>X</td>
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<td>2800 MHz Solar Flux</td>
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<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>HeII Solar Flux</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$A_p$</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>$D_{st}$</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Solar X-Rays (1-8A)</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>
$A_p$: This is a planetary index commonly used as a measure of the global average magnetic activity although it is obtained by averaging values from 12 observatories located between 47.7 and 62.5°N geomagnetic latitude, averaging 56°N. Higher values of this index are definitely associated with upper-atmospheric heating although the mechanism is not understood.

$D_{st}$: This index is a measure of the low latitude magnetic activity; negative values have been found to be correlated with upper-atmospheric heating.

$AE$: This index measures the contribution of geomagnetic activity from the auroral electrojet which is believed to be responsible for upper-atmospheric heating between 100-150 km by means of joule dissipation.

Solar X-Rays (1-8A): This index is used to indicate the magnitude of the x-ray flux between 1-8A which can cause heating between 55-105 km.

Many of the above indices are, of course, somewhat correlated with each other. The important thing to determine is how many of these indices are correlated, if any, with the onset or maximum of the stratospheric warmings. The indices listed in Table II have all been plotted in graphs and charts on a daily basis so that this phase of the analysis can commence for those warmings for which 10-mb daily temperatures are available in-house (December 1969 - January 1970, December 1970 - January 1971, January - February 1973).
3.1 Task A - Development of Case Histories. The starting point for the development of cast histories of warmings is the body of previously-published data in the technical journals (Appendix B). Contact has been made with various experimenters and researchers in the field with the intention of obtaining supplementary data from which more detailed descriptions of each case may be developed. These contacts, most notably with Dr. Sigmund Fritz, Chief, Space Scientist NESS; Mr. Roderick S. Quiroz, Research Meteorologist, Upper Air Branch, NMC, NWS; and Dr. E. J. Williamson, Clarendon Laboratory, Oxford University, are expected to yield additional data in the near future. The available maps for each case have been chronologically arranged in the process of developing a time history of the identified warmings.

Available data is sparse for the first of the identified cases, and has been supplemented with a set of Nimbus 3 MRIR Channel 3 digital maps over the warmed region. These single passes over the area of interest were spaced on a daily basis at the reported time of warming, and include a map a week prior to the warming. This data has recently been received from NSSDC and has not yet been plotted.

In general, it has been found that a series of daily radiance maps are to be preferred to objective analyses, which tend to be overly smooth. This is a problem when one is trying to plot the course of a perturbation to an ambient field, which is the case in a stratospheric warming. The 10-mb objective analyses are useful, however, to plot the course of major warmings, and have been obtained from the Environmental Data Service on microfilm for the three Northern Hemisphere warmings, Cases 4, 5 and 6.
3.2 Task B - Examination of Correlations. Examination of the available data has been started. Correlative data has been plotted on a time scale appropriate for a comparison with the time history of the warming. One minor problem concerns definition of the time history of the warming which is moving in space. Typically a warming is described in terms of temperature change at a fixed altitude and over a fixed Earth location, e.g., a warming of 80°C occurred at West Geirinish at 40 km in late December. Since satellite radiance data for a given sensor originates predominantly from a constant altitude band, this data represents single-level data. And rocketsondes expand the reported levels, but yield only single-location data, such as time-height sections for a given station. Eventual availability of operational stratospheric maps based on satellite soundings will be a great boon to a study of this kind. For preliminary searches for correlations, the time history of maximum temperature at a given level is used to define a warming. Later analysis of correlations will account for the location and altitude of the warming in seeking to explain physical effects. Examples of plotted correlative data are shown in Appendix C. No positive correlations have been found during this reporting period.

3.3 Task C - Extension of Existing Models. This task is contingent upon positive findings of Task B and has not been started.
4. PROGRAM STATUS

The study has been configured as a six-month study (Fig. 2 and 3) with a relatively high level of activity for the first two months for data ordering and preliminary analysis and for a detailed literature survey. The middle three months were planned to be a somewhat lower level of effort with data analysis and correlations study occurring as the data is collected. Detailed analysis, extension of existing models, and drafting of the final report were scheduled for the last month.

Expenditures have been at a lower-than-planned rate since some of the ordered data has not yet arrived. A new forecast based upon a longer study span within the contractual nine-month period will be developed during the next quarter.

As of the end of the first quarter of activity (December 1, 1973) 39 percent of the total activity has been completed. The expended 512 man-hours is 29 percent less than the projected 720 man-hours for the period (Fig. 3). Accumulated expenditures against the study are tracking the man-hour expenditure, and are now at 37 percent of the contract total.
### MASTER CONTRACT SCHEDULE

**TECHNOLOGY SUPPLEMENT**

**TITLE:** ANALYSIS OF DATA FROM SPACECRAFT-STRATOSPHERIC WARMINGS

**CONTRACT TYPE:** CPFF

**VALUE (LESS FEE):** $30K

**START:** 8-27-73  
**COMPL:** 5-26-73

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**CONTRACT PERFORMANCE PERIOD**

1. **QUARTERLY PROGRESS REPORT**
2. **DEVELOP CASE HISTORIES**
3. **ANALYZE CORRELATIONS**
4. **EXTEND EXISTING MODELS**
5. **DRAFT - FINAL REPORT**
6. **FINAL REPORT**

* CONTINGENT ON POSITIVE CORRELATION RESULTS

### LEGEND

- **CONTRACT**
- **ECO**
- **INTERNAL MILESTONE**
- **EXTENDED EFFORT**

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Figure 2 Master Contract Schedule
### Figure 3: Program Status - End of First Quarter

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<td>Dec</td>
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<tr>
<td>Feb</td>
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</tbody>
</table>

- 720 (Projected)
- 512 (Actual)
5. **PLANNED ACTIVITIES**

The following activities are planned for the coming quarter:

1. A revised program schedule will be generated reflecting actual data availability.

2. Additional data will be obtained through a visit to R. S. Quiroz and Dr. S. Fritz.

3. Additional data will be ordered to fill in holes in the available case studies, and to obtain vertical profiles through warmed areas.

4. Correlation analyses will be continued.

5. Case studies will be completed.
APPENDIX A

SOLAR-TERRESTRIAL LINKS AND STRATOSPHERIC WARMINGS

1. Introduction

Solar radiation near 1216Å and also at wavelengths under 100Å vary by large amounts at certain times. These radiations penetrate to levels between 60-100 km in the atmosphere of the earth. Before physical theories can be invented to explain certain suspected solar-weather relations, including stratospheric warmings, several links must be filled in. Some of the principal missing links in the development of such theories are as follows:

Thorough knowledge of incident solar flux - Long-term accurate measurements are needed at all wavelengths, including Lyman-alpha (1216Å), EUV (100-900Å) and x-rays (< 100Å). Most of the Lyman-alpha is absorbed below 100 km. Its flux varies from about 6 to 3 ergs cm\(^{-3}\) sec\(^{-3}\) between high to low solar activity. Changes during flare periods are not significant geophysically. The x-rays should be measured globally, since the greatest variation in solar photon output occurs in the x-ray region (up to 3 orders of magnitude with periods of minutes to hours. It is necessary to separate out the ionizing effect of the x-rays from that of longer wavelengths. The main action of x-rays is to create ionization between 120 km (100Å) and 55km (1Å). However, they are not the sole ionizing agent in this altitude range nor is their contribution to heating the major one.
Appropriate data on the primary photon interactions - Quantitative data on the rate coefficients of various types of transitions for all the important constituents at all important wavelengths so that the consequential effects of the primary photon interactions, such as ionization of atoms and molecules, dissociation of molecules, etc., can be assessed.

Heat budget of the mesosphere near 80 km - What are the altitude, latitude, temporal, diurnal, and seasonal variations of mesospheric temperatures? How are the temperatures related to the intensity and variations of the solar Lyman-alpha and x-rays? Are there other important heat sources for the mesosphere, such as particle influx, and how do they contribute to the temperature structure? What is the energy balance of the mesosphere as a function of height, and what are its global variations? A difficult aspect of this problem is the transfer of energy as a result of radiative processes and various circulation processes. The altitude at which energy is absorbed need not in general correspond to the altitude at which it is converted into thermal energy.

Circulation in the Mesosphere - It is necessary that the temperature, density or pressure, and composition of the mesosphere be measured as functions of altitude, location, and time, in sufficient detail to disclose the general patterns and systematic variations that occur with (a) time, (b) season, (c) sun-spot cycle, (d) location, and (e) the condition of other parameters (meteorological, auroral, geomagnetic, etc.). The limits and characteristics of random variations that cannot be associated with other geophysical parameters should also be determined. Thus, it is necessary
to establish the inherent variability of the mesosphere, both short term (to determine possible effects due to x-rays) and long term (to find possible effects due to Lyman-alpha).

**What are the vertical distributions of the chemically active atmospheric species?** What processes control those distributions? The most important species are ozone, nitric oxide, carbon dioxide, hydrogen and its compounds, atomic oxygen, argon, methane, and excited atoms and molecules. These minor constituents need to be measured as function of latitude and time. Water vapor and methane dissociate in the 60-100 km region, and the dissociation and recombination rates are so poorly known that a direct measurement of their concentration is needed. Accurate measurements of the vertical profile of some or all of these species will be interpretable in terms of the large-scale circulation in the mesosphere.

**Laboratory measurements of reaction rate coefficients** - While some of the chemistry of the mesosphere is understood, there are serious gaps in our knowledge of the chemical processes involved, and many of the needed rate coefficients are missing.

**How is turbulence generated in the mesosphere?** - If waves are responsible, what are their origins, and are their amplitudes sufficient to cause nonlinearities?
How does eddy diffusion affect the distribution of atmospheric gases and the transport of heat? - This is an important question near 80 km. It is necessary to determine the value of the eddy diffusion coefficient as a function of height and time from 60-100 km.

What are the physical mechanism(s) responsible for interaction(s) between the mesosphere and lower atmosphere (troposphere and stratosphere)? - How does their relative importance vary with altitude, location and time? Statistical studies indicating correlation between upper and lower atmospheric phenomena have little validity unless backed up by physical mechanisms. For example, the statistical correlation between the international magnetic character index C (which is correlated with solar activity) and lower atmosphere circulation systems may result from dynamic interconnections between lower and upper atmosphere circulation systems rather than of solar emission.

Hydrodynamic theory of atmospheric perturbations - This theory needs to be developed in order to find the influence of upper atmospheric solar heating, etc., upon the circulation in the atmosphere. How is the general circulation influenced by irregular changes in the sun's emissivity or by variations of the reflectivity of the earth-atmosphere system? The physical basis for changes in lower atmosphere circulation patterns is not fully understood.

Development of techniques to evaluate the significance of weak relationships or relationships exposed from a small number of cases - Only about .01 percent of the solar radiation is in the wavelengths considered. Even if this energy absorbed near 80 km does influence the earth's lower atmosphere, how could this be detected?
APPENDIX B

LITERATURE SEARCH

STRATOSPHERIC WARMINGS


LITERATURE SEARCH STRATOSPHERIC WARMINGS


Staff, Upper Air Branch, NMC, NOAA, Weekly Synoptic Analyses, 5-, 2-, and 0.4 Millibar Surfaces for 1968.


Appendix C

Correlative Data Plots and
Preliminary Correlation Search
MAGNETOGRAMS OF GEOMAGNETIC STORMS

1-3 JANUARY 1970

LT = UT - x

11
-9
-7
1
4

Figure C-8
Figure C-9 Preliminary Correlation Search