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LOWER THERMOSPHERE (80-100 km) DYNAMICS RESPONSE TO SOLAR AND GEOMAGNETIC ACTIVITY
(Overview)

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ABSTRACT: The variations of solar and geomagnetic activity may affect the thermosphere circulation via plasma heating and electric fields, especially at high latitudes. The possibility exists that the energy involved in auroral and magnetic storms can produce significant changes of mesosphere and lower thermosphere wind systems. A study of global radar measurements of winds at 80-100 km region has revealed the short-term effects (correlation between wind field and geomagnetic storms) and long-term variations over a solar cycle. It seems likely that the correlation results from a modification of planetary waves and tides propagated from below, thus altering the dynamical regime of the thermosphere. Sometimes the long-term behavior points rather to a climatic variation with the internal atmospheric cause than to a direct solar control.

The variations of solar and geomagnetic activity may affect the thermosphere circulation via plasma heating and electric fields, especially at high latitudes. The 80-100 km layer, occuring at the lower thermosphere, is a transition layer between an upper ionized region where motions are strongly influenced by electromagnetic processes and a lower neutral region where motions are controlled primarily by dynamics resulting from internal atmospheric causes. It is important to determine the maximum depth in the atmosphere to which the direct and indirect effects of solar and geomagnetic activity and variability penetrate. There are two main classes of processes to be considered: those associated with the variability of solar irradiance in various wavelength bands and those associated with the corpuscular radiation of the Sun.

The effects generated by solar wind variability and high-energy particles are well developed and fairly well understood in the lower ionosphere, whereas they are not much known and understood in the lower-lying layers and the neutral middle atmosphere.

The search for a coupling of solar and geomagnetic activity changes with middle atmosphere and lower thermosphere dynamics has been the subject of investigations for decades. Short-duration effects (correlation with geomagnetic storms, current intensity variations in the auroral electrojet, etc.) and long-term variations over a solar cycle were extensively investigated. There are some theoretical and numerical models of the lower thermosphere dynamics response to solar and geomagnetic activity. Nevertheless the results still remain rather ambiguous and controversial.

A zonally averaged chemical-dynamical model of the thermosphere (ROBLE and KASTING, 1984) was used to examine the effect of high-latitude particle and Joule heating on the lower thermosphere neutral composition, temperature and winds at solstice for solar minimum conditions. It was found that high-latitude heat sources drive mean circulation cells that reinforce the solar-driven circulation in the summer hemisphere and oppose this circulation in the winter hemisphere.

Using a three-dimensional, time-dependent global model the response of the lower thermosphere to an isolated substorm was simulated (FULLER-ROWELL and REES, 1984). It was found that in the lower thermosphere (~120 km) a long-lived vortex phenomenon is generated. Initially two oppositely rotating vortices are generated by the effects of ion drag during the period of enhanced high-latitude energy input centred on the polar cap/auroral oval boundary, one at dusk and the other at dawn. After the end of substorm the dawn cyclonic vortex dissipates rapidly while the dusk anti-cyclonic vortex appears virtually self-sustaining and survives many hours after the substorm input has ceased.

Possible effects of solar variability on the middle atmosphere have been discussed (COLE, 1984; GARCIA et al., 1984) - solar variability in emission in the UV and EUV, variability of cosmic rays and auroral ionization rates, solar proton events, corpuscular heating in auroras, Joule heating by auroral electrojet, auroral NO production and gravity wave emission by the auroral electrojet.

GARCIA et al. (1984) examined the global response of the middle atmosphere (16-116km) to the solar variability between the maximum and minimum of the 11-year cycle of solar activity. In the upper mesosphere and lower thermosphere a temperature increase was found to occur, but for the most part this increase did not bring about any large changes in the zonal winds because the temperature increases are nearly uniform in latitude and do not affect the horizontal temperature gradient.

As for the experimental evidence, a solar-cycle dependence of LF drift wind (90-100 km) was for the first time found by SPRENGER and SCHMINDER (1969). For the years 1957-68 they obtained, for the winter period, a positive correlation of the prevailing wind with solar activity (represented by the 10.7 cm radio emission of the Sun) whereas the amplitude of the semidiurnal tidal wind showed a negative correlation. This result was emphasized in the COSPAR International Reference Atmosphere 1972 (CIRA 72). It was confirmed by meteor radar wind measurements (PORTNYAGIN et al., 1977; BABAJANOV et al., 1977). Further, GREGORY et al. (1980, 1981, 1983) on the basis of an analysis of partial reflection wind data, 60-110 km, have inferred the 11-year cycle response of seasonal zonal flow which varies with altitude. Saskatoon data have been reviewed to determine whether a solar cycle modulation exists in them. It has been found that all circulation regimes in the mesosphere and lower thermosphere, i.e., both summer and winter, above and below ~95 km, show such a modulation, and that is as large as, if not larger than the effect at Kuhlungsborn, which was described as "considerable". Let us remember that much of data used in the CIRA-72 model for latitudes about 50°N were obtained during a solar minimum. Prevailing winds at Saskatoon increase from solar minimum to solar maximum by factors of up to 2-4. A comparison of trends in mean winds over Canada with those over Central Europe and East Siberia with the difference of about 20° geomagnetic latitude reveals that the effect of solar and geomagnetic activity is stronger for higher geomagnetic latitudes.

The data collected from experimental ground-based remote measurements of 80–110 km winds were analyzed in terms of seasonal and long-term solar cycle behavior (DARTT et al., 1983). The annual variations depend on solar activity rather weakly, but the occurence of stronger westerlies (at 90 km during winter) in solar maximum than those in solar minimum years was confirmed with independent data at 50°N and 35°S. In addition, it appears that zonal winds are more southerly in spring and early summer in solar maximum years than in solar minimum years in the northern hemisphere. There are enough discrepancies between experimental data and theoretical models, though the stronger winter westerlies and summer easterlies during solar maximum are predicted by theory.

An analysis of long term meteor radar wind measurements for three midlatitude stations (D'YACHENKO et al., 1986) shows the significant solar cycle oscillations with periods of not only the 11 years but also the 22 year cycles. The variations of the prevailing winds with 22 year period are approximately in phase or antiphase with the 22 year solar activity cycle depending on the season. The variations with 22 year period dominate for variations of zonal prevailing wind velocities during the cold periods and meridional winds in autumn months. Meridional prevailing winds in November-February vary mainly with the 11-year cycle. In other months of the year the amplitudes of the 22 and 11 year velocity variations of prevailing winds are commensurable. For amplitudes of a semidiurnal tide the oscillations with the 22-year period prevail for all seasons. The authors noted that solar activity dependence of zonal and meridional component amplitudes of semi-diurnal tide are quite similar, whereas the character of corresponding dependences of zonal and meridional prevailing wind is different.

It may be noted that the results concerning a solar dependence of wind parameters below 100 km are controversial to date. The above-mentioned positive correlation of prevailing wind with solar activity (SPRENGER and SCHMINDER, 1969) may be changed by a negative correlation with an indication of a new change after 1983 (GREISIGER et al., 1987). The negative correlation with solar activity of the semi-diurnal tidal wind in winter remained unchanged (as late as 1984) and proved also to be the same in summer and for annual averages. Nevertheless the authors concluded that long-term behaviour points rather to a climatic variation with an internal atmospheric cause than to a direct solar control. This conclusion was made on the basis of continuous wind observations in the upper mesopause region over more than twenty years.

ZIMMERMAN and MURPHY (1977) plotted yearly averaged occurence rates of turbulence and turbulent diffusivity summed over the altitude region 70 to 90 km and compared them with solar activity indices. These data suggest a correlation with a two year time lag. ZIMMERMAN comments that it is fairly apparent that this occurence is wave induced and that one should look into the lower atmosphere for the source mechanism of these waves to understand more properly the solar relationship.

In addition to solar cycle variations short-term response of lower thermosphere dynamics to geomagnetic storm or current intensity variations in the auroral electrojet were inferred. Several mechanisms through which a short-term response may develop are provided by ion-neutral frictional coupling. The ion-drag momentum and Joule heat sources may either directly drive motions of the neutral gas or launch atmospheric waves that propagate to lower latitudes. At high latitudes particle precipitation and magnetospheric convection may influence the internal atmospheric waves upward propagation from the lower atmosphere and thereby affect the mesosphere. As altitude increases from the mesosphere to the thermosphere, at some point the additional influence of auroral processes is superposed on this complex collection of interacting waves and turbulent motions. Hence the geomagnetic activity affects both boundaries of the middle atmosphere - the turbopause (upper) and the tropopause (lower).

In order to investigate the response of neutral winds at the lower thermosphere to variations in magnetospheric forcing, it is necessary to have observational techniques with reasonably continuous measurement capability at this altitude.

There are some recent experimental results. The geomagnetic control of ionospheric D-region dynamics was revealed and confirmed on the basis of continuous LF drift measurements (1978-1983) over East Siberia (KAZIMIROVSKY et al., 1986; VERGASOVA, 1988a, 1988b). The monthly mean parameters of the wind system are different for quiet ($Kp \leq 3$) and disturbed ($Kp > 3$) conditions. There is an increase in stability of the meridional wind with increasing level of geomagnetic activity. On the basis of 31 events the influence of geomagnetic storms on the winds was considered, and it became apparent that the variation of zonal and meridional winds during geomagnetically disturbed nights differs from those for undisturbed nights before and after the storm. Calculations made by the superposed epoch method for weak ($Ap < 50$), moderate ($50 \leq Ap < 100$) and strong ($Ap > 100$) storms show that the zonal wind during weak and strong storms decreases but increases for moderate storms. The meridional wind increases during weak and strong storms, while after the storm there is a reverse of meridional wind. We did not find conclusive evidence for geomagnetic effects on semi-diurnal tides, except for a decrease of tidal phase during disturbed nights.

We may compare our results with recent findings of other investigators. SCHMINDER and KURSCHNER (1978, 1982) found the influence of geomagnetic storms on the measured wind in the Central Europe upper mesopause region deduced from ionospheric drift measurements. But they interpreted the disturbances of the wind field as an effect of increasing in the reflection level, so that the measurements during a geomagnetic storm relate to a different altitude with different wind conditions. Nevertheless we may note the increased zonal wind variability including possible reversals. LASTOVICKA and SVOBODA (1987) found some correlation (~ -0.4) of 5-day medians of Collm mean winds and $\sum Kp$ for winter.

At Saskatoon (subauroral zone) MANSON and MEEK (1986) observed small but significant cross correlations between semidiurnal tidal amplitudes from 90 to 105 km and the Ap index. Tidal amplitudes remained reduced from time lags of zero to about 5 days following the interval of increased Ap. Reduced diurnal tidal amplitudes were also found in the lower E-region, at 105 km. It may be noted that small increases in eastward and equatorward mean winds (incoherent scatter, Millstone Hill) as well as reduced semidiurnal tidal amplitudes at 105 km during geomagnetically disturbed conditions were reported by WAND (1983) some years ago.

Some of these effects might be explained by geomagnetic-activity induced changes in lower thermosphere temperature and density, which alter the dissipation of the upward propagating tides. MAZANDIER and BERNARD (1985) also found the effect of geomagnetic storm on the meridional circulation and semidiurnal tide, especially the phase of tide at 90-180 km, revealed by incoherent scatter measurements at midlatitude station Saint-Santin.

The amplitude of gravity waves was found to be positively correlated with intervals of increased Ap near zero time lag at heights from 90-105 km (MANSON and MEEK, 1986). Rocket measurements of turbulent transport in the lower ionosphere collected by ANDREASSEN et al. (1983) confirm the increase of turbulence for high geomagnetic activity. But the vertical turbulent diffusivity in the lower thermosphere above 110 km deduced from ionospheric sporadic E parameters by BENCZE (1983) decreases during geomagnetic storm. This would mean that the height of the turbopause increases. ZIMMERMAN et al. (1982) found a strong correlation of Ap with deviations of the turbopause height from mean diurnal variation (but not with the height itself). THRANE et al. (1985) found that it is not possible to determine whether or not a direct relation exists between the energy input during geomagnetic disturbances and the turbulent state of the high-latitude mesosphere.

Extensive investigations have been made at auroral zone observatories Poker Flat (MST-radar) by BALSLEY et al. (1980, 1982, 1983), JOHNSON et al. (1984), JOHNSON and LUHMAN (1985a, 1985b, 1988) and Chatanika by JOHNSON et al. (1987). The results were controversial. Initially it was found that zonal winds in the 80-90 km altitude region were enhanced toward the west while intensified electrojet currents flowed overhead. It appeared that the enhancement in the zonal wind amounts to some tens of meters per seoond and the wind field variations may lag behind the electrojet variations by between 2 and 4 hours (BALSLEY et al., 1980, 1982, 1983). The incoherent scatter measurements would show enhanced eastward winds above 100 km on disturbed day, as well as reduced semidiurnal and increased diurnal tidal amplitudes (JOHNSON et al., 1987). These results are not in conflict with those of MANSON and MEEK (1986) since a lower altitude range has been addressed in this study. But recently (JOHNSON and LUHMAN, 1988) it was shown that the presence of like frequencies in the available geomagnetic activity indices and in the neutral wind data makes the detection of any small neutral wind response to changes in the level of activity extremely difficult. Examination of all Poker Flat and Chatanika results suggested the conclusion that the 90 to 100 km altitude region constitutes the altitude range in which the effects of magnetospheric forcing begin to be detectable observationally in horizontal neutral winds at high to midlatitudes. Below this altitude significant and consistent responses are not evident. In order to alter the neutral dynamics at lower altitudes drastically more energetic inputs are required.

LASTOVICKA (1988) proposed that the apparent difference between North American (weaker effect) and European (stronger effect) results may be partly explained by the use of winter or late autumn data in Europe versus summer data in North America (Poker Flat and Chatanika) and by the fact that particularly strong events (e.g. geomagnetic storms - mainly studied in Europe) but not short-term weaker fluctuations (mainly studied in North America) can affect wind fields. Sometimes the longitudinal effect (KAZIMIROVSKY et al., 1988) may be significant.

It should be noted in conclusion that the solar and geomagnetic activity variations are important but not dominant in the upper mesosphere-lower thermosphere circulation (wind system). Incorrect application of statistical methods to experimental data sets may lead to artifacts and misunderstanding.

At present we can only speculate about a suitable physical process. The lack of reasonably reliable mechanisms is a problem of vital importance. It may be a common reason for variations of the wind regime at the lower thermosphere and magnetic activity - the dissipation of energy from external sources at high latitudes and its transfer equatorward. A change in the wind system may exert an influence on the density and structure of the middle atmosphere and on conditions of internal waves propagation from below. Hence the variability may be changed. It is quite possible too that the change in the 80-100 km wind system associated with geomagnetic activity variations is caused by enhanced electron concentrations in the ionospheric D-region. Also, magnetic activity induced by disturbances in the wind field of the neutral atmosphere should not be ruled out as a possibility.

The most difficult problem which will limit our progress is that of understanding the cumulative interaction of small- and large-scale dynamics occuring within the lower atmosphere, the coupling between the thermosphere and lower atmosphere from below. Of course, these studies are needed, in order to determine whether all the highly variable middle atmospheric dynamical processes can influence processes within our lower atmosphere and thus affect our immediate environment.

There is a need to organize an effective monitoring system that would be reasonably intensive and extensive. What is desired from future research is a qualitative assessment of all the significant couplings, trigger mechanisms and feedback processes. Many problems are largely to be solved.

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