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The Aurora as a Source of Planetary-Scale Waves in the Middle Atmosphere

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Photographs of global-scale auroral forms taken by scanning radiometers onboard U.S. Air Force weather satellites in 1972 show that auroral bands exhibit well-organized wave motion with typical zonal wave number of 5 or so. The scale size of these waves is in agreement with that of well-organized neutral wind fields measured by the 1967–50B satellite in the 150- to 220-km region during the geomagnetic storm of May 27, 1967. Further, the horizontal scale size revealed by these observations is in agreement with that of high-altitude traveling ionospheric disturbances. It is conjectured that the geomagnetic storm is a source of planetary and synoptic scale neutral atmospheric waves in the middle atmosphere. Although there is, at present, no observation of substorm-related waves of this scale size at mesospheric and stratospheric altitudes, the possible existence of a new source of waves of the proper scale size to trigger instabilities in middle atmospheric circulation systems may be significant in the study of lower atmospheric response to geomagnetic activity.

The dynamics of the upper stratosphere, and perhaps the lower thermosphere as well, have been shown to be strongly affected by the interaction of mean zonal winds with planetary Rossby waves (Charney and Drazin, 1961; Dickinson, 1968; Finger et al., 1966; Matsuno, 1970; Newell and Dickinson, 1967). Clearly, a source of Rossby waves in the stratosphere would be associated with large-scale tropospheric weather systems. However, if a second source of such planetary or synoptic scale waves were to exist, then it would be of considerable interest to workers concerned with upper atmospheric dynamics. In particular, if such a second source of neutral atmospheric waves were related to geomagnetic activity, and if such waves were of the proper dimensions to interact with the upper atmospheric circulation, then they may act as the initiating perturbations to trigger latent aerodynamic instabilities in the upper atmosphere.

In this paper, we would like to suggest, by invoking recent satellite observations of planetary-scale variations of auroral forms (Morse et al., 1973), as well as direct satellite observations of polar upper atmospheric winds during magnetic storms (Feess, 1968; Chiu, 1972), that auroral substorms may be a source of planetary waves in the 100-km altitude region. It is understood that numerous observations of ionospheric and atmospheric disturbances associated with geomagnetic activity have been reported from time to time; however, upon examination, most of these are either in the high-altitude regions (~350 km) or of such local nature that the lateral extent of the disturbance cannot be ascertained.

Traveling ionospheric disturbances occurring in the 200- to 800-km altitude region have been observed for many years (Davis and daRosa, 1969; Thome, 1968). Well-correlated ionospheric disturbances of ~ 2000-km horizontal scale and of ~1- to 2-hr periods have been observed to propagate from the auroral zone at speeds of ~500 m/s. These disturbances have been interpreted generically as due to the passage of gravity waves. Because the horizontal scale and wave speed are so large, being reminiscent of longwaves in the ocean, at least two intriguing questions must be raised. First, because auroras occur at

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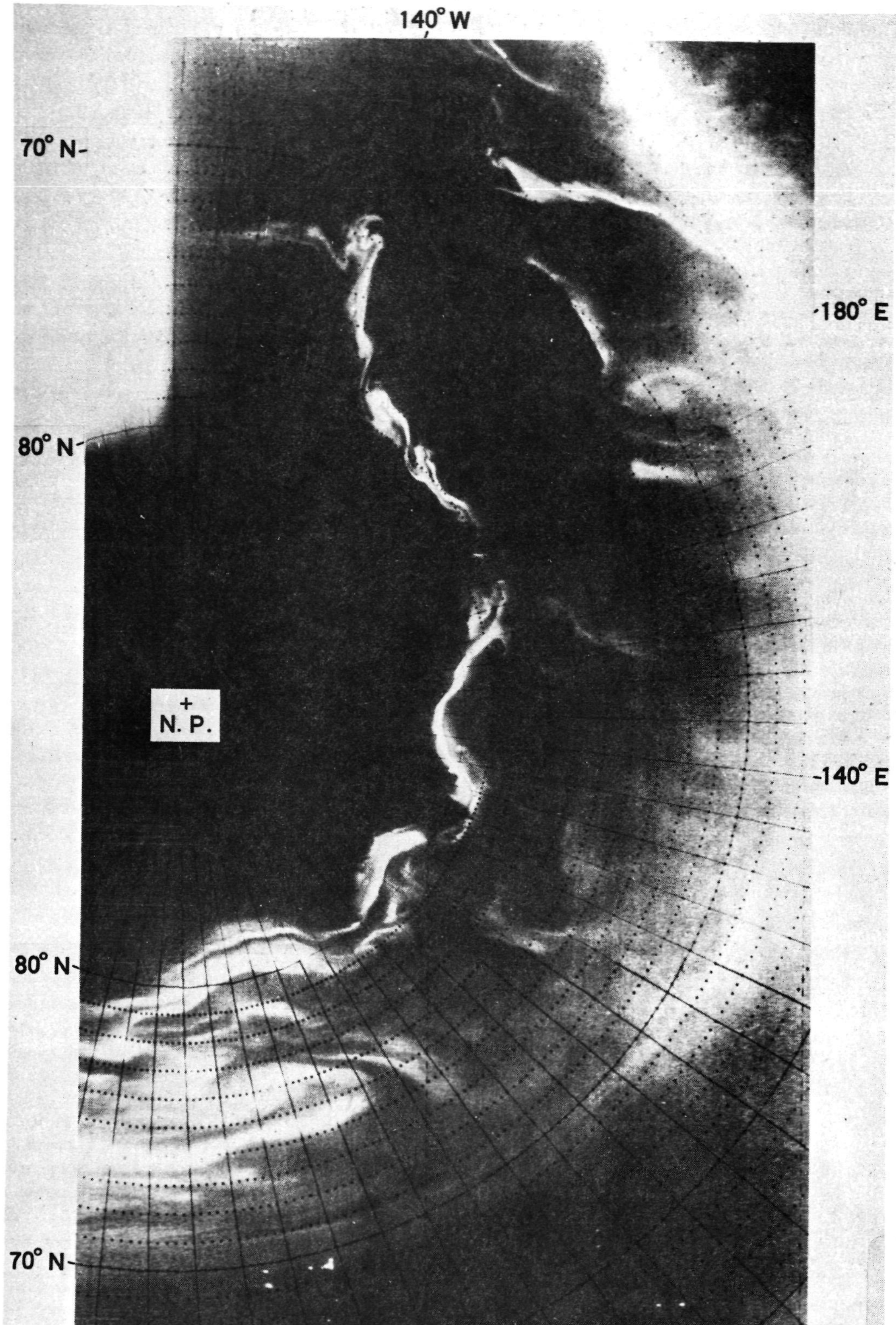
the 100-km level, it would be of interest to ask if these high-altitude ionospheric disturbances may be related to variations of the low-altitude auroras and associated neutral disturbances. Second, if such large scale disturbances were indeed neutral waves, then it would be of interest to investigate the effects of sphericity and the latitudinal variation of the Coriolis force on their propagation. These questions will be considered in some detail here in order that the peculiar properties of these waves in the auroral region may be exploited for observational purposes. In this respect, it is perhaps relevant to note that, whereas meridional propagation of ionospheric disturbances has been studied thoroughly in the midlatitude region, observations of the horizontal scale and propagation of such disturbances in the auroral region do not seem to be available.

Figure 1 shows an extensive auroral form detected by scanning radiometers on board a U.S. Air Force weather satellite (Morse et al., 1973). The most important feature revealed by this unique observation of planetary-scale auroral forms is that the aurora shows *coherent* spatial variations typical of a wave with zonal wave number of 3 to 6. Because auroral substorms show typical temporal variations of, say, 1 to 2 hr, these observations suggest clearly that auroral substorms, as a source of atmospheric heating in the vicinity of 100 km, must be rich in Fourier components of these zonal wave numbers and wave periods. Indeed, there is theoretical reason to believe that such spatial and temporal variations of the aurora are related to waves in the auroral current (Hasegawa, 1970). Given the existence of such wavelike variations of auroral heating, it is reasonable to consider meridional and vertical propagation of such planetary waves, to lower latitudes and to higher altitudes, in the interpretation of traveling ionospheric disturbances.

Despite the observation of clearly wavelike variation of planetary scale auroral heating, direct observations of the neutral wind field associated with such wave motion would be desirable to substantiate the suggested relation between the characteristics of auroral forms and traveling ionospheric disturbances. In short, are there in situ satellite observations of upper atmospheric wind fields in the auroral region directly related to specific geomagnetic storms? In this regard, we wish to point out that the pattern of crosstrack wind components, deduced from accelerometer and attitude control activity onboard the 1967–50B satellite at altitudes between 150 and 220 km before and after the onset of a very large geomagnetic storm on May 27, 1967, is of particular interest (Feess, 1968). Figure 2 shows data from selected orbits in which well-organized crosstrack wind variations were encountered. Although the major stationary structure near the pole may involve convective overturning of the atmosphere (Chiu, 1972), the coherent wind variations of smaller magnitude, which change from orbit to orbit, are likely to be propagating waves of ~ 2000-km horizontal scale. These structures are particularly evident at or near satellite orbits 51 and 53.

The next question then, is how the stratosphere responds to the same magnetic storm. In this regard, it is a fortunate coincidence that detailed radiosonde data exist for Berlin during the same period (Scherhag, 1967). Figure 3 shows Scherhag's data for the period March to June 1967. The top three curves show the stratospheric temperature at 30, 35, and 37 km. The bottom curve shows the thickness between the 5- and 10-millibar levels in decameters. Scherhag noted that all four curves show a rapid rise to a peak during the period May 25 to 26, 1967. This becomes somewhat more evident if we take the sum of all four curves so that the random signal

FIGURE 1.—An extensive auroral form observed by scanning radiometers onboard a U.S. Air Force weather satellite near the north auroral zone at 13.51 GMT on August 1, 1972. The origin of the grid on the photograph is the north geographic pole. It is seen that, aside from small scale variations of <100-km horizontal scale, the auroral form exhibits planetary-scale variations with zonal wave number of approximately 3 to 6. The coherent extensiveness of the associated auroral heating is particularly significant. (Courtesy of E. H. Rogers and D. F. Nelson, The Aerospace Corp.)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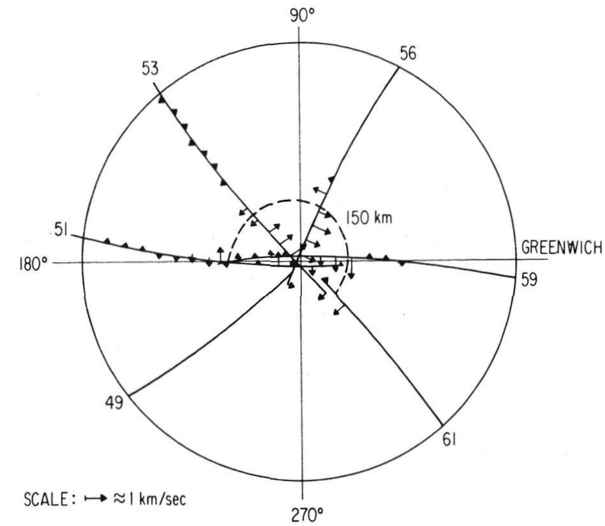

FIGURE 2.—Lower thermospheric winds deduced from accelerometer and attitude control activity onboard the satellite 1967–50B on May 27, 1967, near the north geographic pole, the origin of the figure. The satellite paths are labeled by the orbit numbers (49–61), and the dashed curve indicates the locus of points for which the satellite altitude is 150 km. The polar plot shows the measurements for the northern hemisphere. The magnetic storm onset was at the 50th orbit. It is seen that well-organized wind components with a horizontal scale of $\sim$2000 km seem to be associated with an extremely disturbed but stationary structure at the pole. These features are particularly well illustrated on orbits 51, 53, and 59. It should be noted that both features are coherent and planetary in scale. (After Feess, 1968; for summary see also Chiu, 1972.)

is reduced. Indeed, the sum shows three clear events (April 24, May 3, and May 26) which interestingly occurred during the most magnetically disturbed days of the period ($\Sigma K_p = 32$, 47, and 51, respectively; K_p is the geomagnetic activity index).

In conclusion, there seems to be some in situ evidence that the auroral substorm is a source of planetary waves in the 100-km region *neutral* atmosphere. These neutral wind disturbances may have caused some stratospheric response although data from a wider area would be required to confirm it. In any event, we emphasize that detailed testing of any theoretical mechanism reduces, in the final analysis, to an *in situ* layer by layer correlation study of the responses from thermospheric levels to the stratospheric levels.

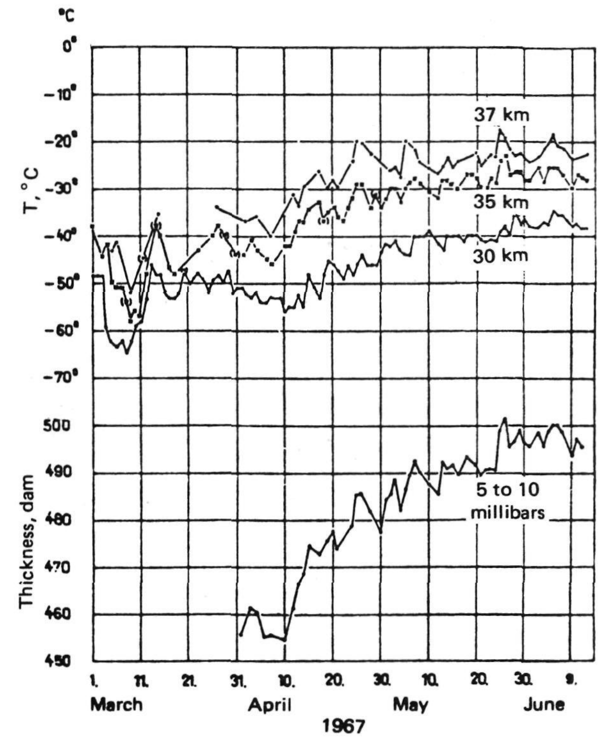

FIGURE 3.—Stratospheric temperatures at 30, 35, and 37 km and the 5- to 10-millibar thickness for the period March to June 1967 (Scherhag, 1967).

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DISCUSSION

AKASOFU: I do not think you can associate that type of picture of the aurora with Rossby waves because in a matter of 10 min, the pattern of the aurora might change drastically. I understand that Rossby waves are a much more stable phenomenon. These are very high-latitude phenomena at geographic latitudes above approximately 70; I am sure that Rossby waves are at something like latitude 50.

CHIU: I agree that the phenomenon is not a Rossby wave. The point, however, is that the auroral heating would have a spatial structure of 2000 km, even though it changes in a few minutes. If you consider the aurora, or the particle deposition associated with it, as a heating source that produces waves, then it would be rich in the Fourier components in spatial structure of 2000 km. I am not trying to associate Rossby waves with the auroral waves.