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ABSTRACT. Ion drift measurements were made by the incoherent scatter radars at Saint-Santin, France and at Millstone Hill, Massachusetts, during the 26-28 June 1984 Global Thermospheric Mapping Study (GTMS) campaign. These measurements have been decomposed in terms of electric field components and meridional neutral wind velocities in the ionospheric *F*-region. The electric field results from both stations for 26 June reveal a pattern characteristic of quiet geomagnetic conditions, consistent between the two stations, in contrast to the results for the geomagnetically disturbed day of 28 June which exhibit large electric fields that differ substantially at the two stations. A comparison is made with average electric field models and with convection models to delineate the source of the observed effects. The meridional neutral winds derived from the ion-drift component parallel to the magnetic field at the two stations under the same model assumptions agree well, and show strong southward winds at night, weaker in the daytime, and large oscillations during magnetic disturbances. Closer agreement with the NCAR thermospheric global circulation model is found for Millstone Hill than Saint-Santin suggesting deeper penetration of the magnetospheric convection cell with latitude in the European sector due to larger magnetic activity in that sector than was assumed in the model calculations.

Key words : ionospheric electrodynamics, thermospheric neutral winds, incoherent scatter radar.

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INTRODUCTION

The Global Thermospheric Mapping Study (GTMS) campaign of 26-28 June 1984 provided an excellent opportunity to investigate the electrodynamic behavior of the midlatitude ionosphere using incoherent scatter radar data gathered at Saint-Santin, France ($2°$ E, $45°$ N) and at Millstone Hill, Massachusetts ($71.5°$ W, $42.6°$ N). These two stations, although close in geographic latitude, differ substantially in geomagnetic coordinates, with Saint-Santin apex latitude being $40°$ N compared to Millstone Hill's apex latitude of $55°$ N. Thus one would expect some differences in the electrodynamics observed at the two stations particularly during geomagnetic disturbances, and such data could be useful in determining the influence of ionospheric dynamo fields and the penetration of magnetospheric convection. These topics have been the subject of interest in many studies, for example Axford and Hines (1961), Vasyliunas (1972), Richmond and Matsushita (1975), Blanc (1978), Wand and Evans (1981) and Mazaudier (1985).

The overall GTMS campaign effort and the results obtained at Millstone Hill have been described by Oliver and Salah (1987) ; the ion drift measurements made at Saint-Santin have been described by Mazaudier (1986). Both papers outline the geomagnetic conditions that prevailed during the 26-28 June 1984 period. These may be characterized as being quiet on 26 June, moderate on 27 June, and disturbed on 28 June. Quantitatively, the A_p index increased from 8 to 10 to 21 on the three consecutive days. The variation of the K_p index is shown in figure 1, together with a history of the precipitating particle power input as measured by the NOAA/TIROS satellite (D. S. Evans, private communication). Magnetometer traces of the horizontal component of the magnetic field measured at Tromsø, Norway ($69.7°$ N, $19°$ E) and Narssarssuaq, Greenland ($61.2°$ N, $45.4°$ W) are also shown for the three days of the campaign ; these two magnetometer stations are located in the same longitude sector but northward of each of the radars. Note that the magnetometer at Tromsø indicates a higher degree of disturbance in the European longitude sector on 28 June than indicated by the Narssarssuaq magnetometer for the eastern American sector. We also examined the magnetometer record for Thule, Greenland ($76.5°$ N, $68.7°$ W) and this
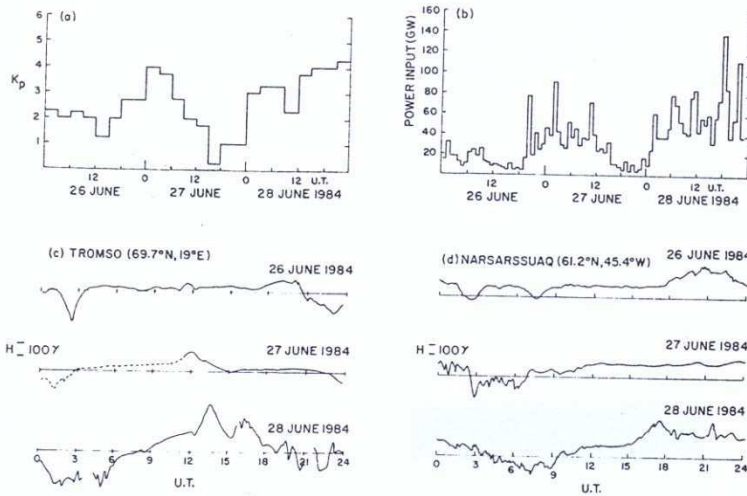
Figure 1

Selected geophysical indices for the period 26-28 June 1984. (a) Variation of K_p, (b) variation of the hemispheric power input due to precipitating particles, (c) the horizontal component of the geomagnetic field strength at Tromsø, Norway and (d) at Narssarssuaq, Greenland.

record similarly indicates a relatively quieter geomagnetic behavior at longitudes west of the Tromsø magnetometer.

The following two sections deal, respectively, with the electric field components determined from the ion drifts perpendicular to the magnetic field and with the meridional neutral winds determined from the ion drifts measured parallel to the field.

ELECTRIC FIELDS

The method of determining the horizontal electric fields from ion-drift measurements by incoherent-scatter radar at Saint-Santin have been discussed by Blanc *et al.* (1977) and at Millstone Hill by Evans *et al.* (1979). At the latter station, the technique was

modified for the GTMS campaign to maximize the latitudinal coverage of neutral atmosphere parameters, and two north-south elevation scans offset in azimuth by a wedge of 30° were utilized (Oliver and Salah, 1987). For the analysis described in this paper, the ion doppler velocity from three antenna positions (north, south and south-west of Millstone Hill) at an elevation of 45° were selected to decompose the ion drifts at 300 km into three components : two orthogonal and one parallel to the magnetic field line. The orthogonal $\mathbf{E} \times \mathbf{B}$ drift components are then used to describe the electric field in the *F*-region over Millstone Hill.

Figure 2 presents the observed eastward and northward ion drifts (southward and eastward electric field components, respectively) superimposed for the two

Figure 2

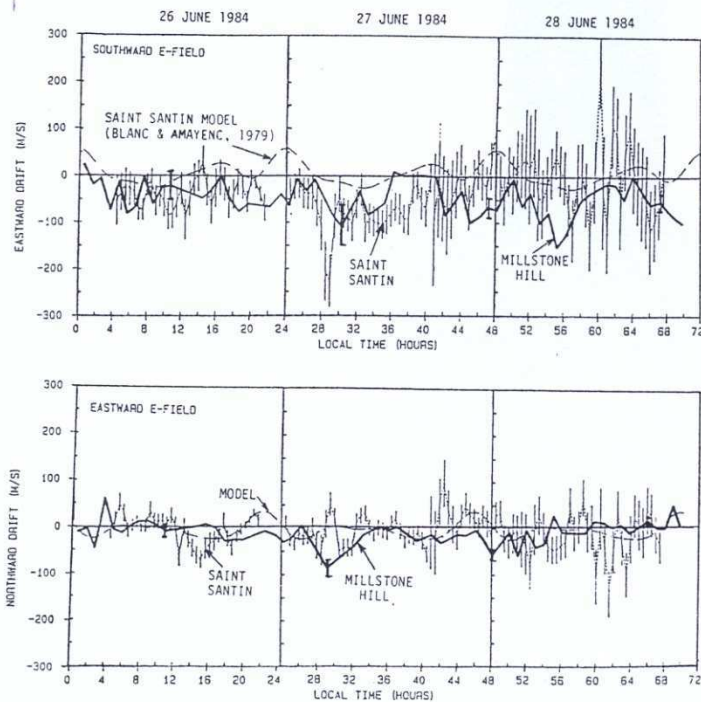*Comparison of electric field observations in the F-region at Saint-Santin (1 mV/m = 25 m/s) and at Millstone Hill (1 mV/m = 21 m/s) for June 26-28, 1984. Also shown is the model based on Saint-Santin data from solar cycle 20 (Blanc and Amayenc, 1979).*

stations, aligned as a function of local time. As a general conversion rule, an electric field strength of 1 millivolt/meter is equivalent to 25 m/s drift as Saint-Santin and 21 m/s at Millstone Hill. For 26 June, there is an overall consistency of the drift magnitude and direction : westward with a magnitude of 50 m/s (a northward electric field of about 2 mV/m), and oscillating around a near-zero mean in the northward component. While the small scale oscillations are not statistically significant since they are of the order of the precision in the measurements, there is a measurable difference between the two stations during the few hours following local noon. Aligning the measurements as a function of universal time by shifting the Millstone Hill data by 5 h later does not remove the differences. We consider the observations on this day to be indicative of the quiet time midlatitude behavior of the electric fields generated through E-region dynamo effects, and the variations between the two stations to reflect local variation in the neutral winds over each station that generate the dynamo field.

On 27 June, the electric field strengths increase relative to the previous day at both stations. The large westward surge equivalent to 10 mV/m at 5 LT at Saint-Santin is not seen at Millstone Hill but an increase of the westward ion-drift is observed 2 h later at Millstone Hill to levels of about 5 mV/m. It should be noted that the time resolution available from the Millstone Hill GTMS experiment is about 60 min due to the emphasis in the planning on wide latitude and altitude coverage, so that the surge may not have been detected or was reduced by temporal or spatial smearing of the data. Examination of ion drift measurements from the Millstone Hill steerable antenna at other nearby latitudes for that time period (both in universal as well as local time) however failed to reliably detect a large westward surge at 5 LT. We note a similarly large difference in the direction of the north-south drift velocity at that time. Following the surge, there is better correspondence between eastward drifts at the two stations when aligned in universal time. In particular, the reduced eastward drifts after 16 UT at the two stations (16 LT at Saint-Santin and 11 LT at Millstone Hill) correlate well with the reduced magnetic activity represented by the small K_p values during that interval.

Finally, on the most magnetically active day, 28 June, the Saint-Santin data reveal larger oscillations in the electric field components than observed at Millstone Hill, and the predominant short period south-eastward drift surges are not distinct in the Millstone Hill data. The chief feature in the Millstone Hill data is the systematic increase in the westward drift velocity corresponding to an equivalent northward electric field of 7 mV/m at 7 LT. The presence of the large oscillations in the Saint-Santin measurements suggests that the effects of the geomagnetic disturbance are observed at Saint-Santin's apex latitude which is 15° further south than Millstone Hill's, and that the signature of these effects is different in the European longitude sector than in the American sector. As previously noted, the magnetometer record from Tromsø for that day (fig. 1) similarly revealed large oscillations in comparison with the records from the stations in Greenland.

A comparison made by Mazaudier (1986) of the ion drifts observed at Saint-Santin during June 1984 GTMS campaign with the average model derived from similar measurements during the previous solar cycle (Blanc and Amayenc, 1979) indicated an overall westward shift of the east-west drifts relative to the model. The comparison is reproduced in figure 2 where the average model is shown as a dashed curve. Mazaudier (1986) has interpreted this westward shift to be due to solar cycle variations. A similar comparison of the observed GTMS horizontal ion drifts with the average model by Wand and Evans (1981) for Millstone Hill based on data collected in 1976-1977 is shown in figure 3. This indicates continued consistency with the average Summer westward drifts during quiet periods at Millstone Hill. In previous comparisons of electric field models based on measurements at Saint-Santin and Millstone Hill (e.g. Wand and Evans, 1981), the diurnal variations of the east-west ion drifts were found to be in opposite phase at the two stations, and necessitated taking into account conjugate point electric fields to explain the differences (Richmond et al., 1976). This does not appear to be required to explain the quiet time electric fields during GTMS. During disturbed periods, the enhanced westward drifts observed during GTMS at Millstone Hill are again consistent with the observations by Wand and Evans (1981).

In an attempt to determine the extent of the penetration of the magnetospheric convection patterns to midlatitudes, we compare the GTMS electric field measurements with the empirical model for Millstone Hill developed by Foster et al. (1986), based on the particle precipitation index representing high-latitude energy flux measured by the NOAA/TIROS satellite (see fig. 1). The comparison is shown in figure 4. The large westward surges observed at 7 LT on June 26 and 27 are not reproduced by the convection model at that time. There are however large predicted westward surges just prior to local midnight that are consistent with observed increases at that time. Such large westward drifts are expected from an ionospheric disturbance dynamo (Blanc and Richmond, 1980). This suggests that the observations at Millstone Hill during June 27 are most likely due to disturbed ionospheric dynamo effects caused by the winds generated by auroral heating during the magnetic storm activity. This same interpretation has been made by Mazaudier (1986) for this day at Saint-Santin with the additional evidence of observed southward neutral winds in the dynamo region.

On June 28, the same effects are seen at Millstone Hill as the previous day except with enhanced intensities, but at Saint-Santin the strong eastward oscillations suggest that the effects are due to a combination of the disturbance ionospheric dynamo together with a penetration of the convection electric fields (Mazaudier, 1985) due to the larger magnetic activity in the European sector.

MERIDIONAL NEUTRAL WINDS

The meridional component of the F-region neutral wind velocity in the geomagnetic horizontal plane is
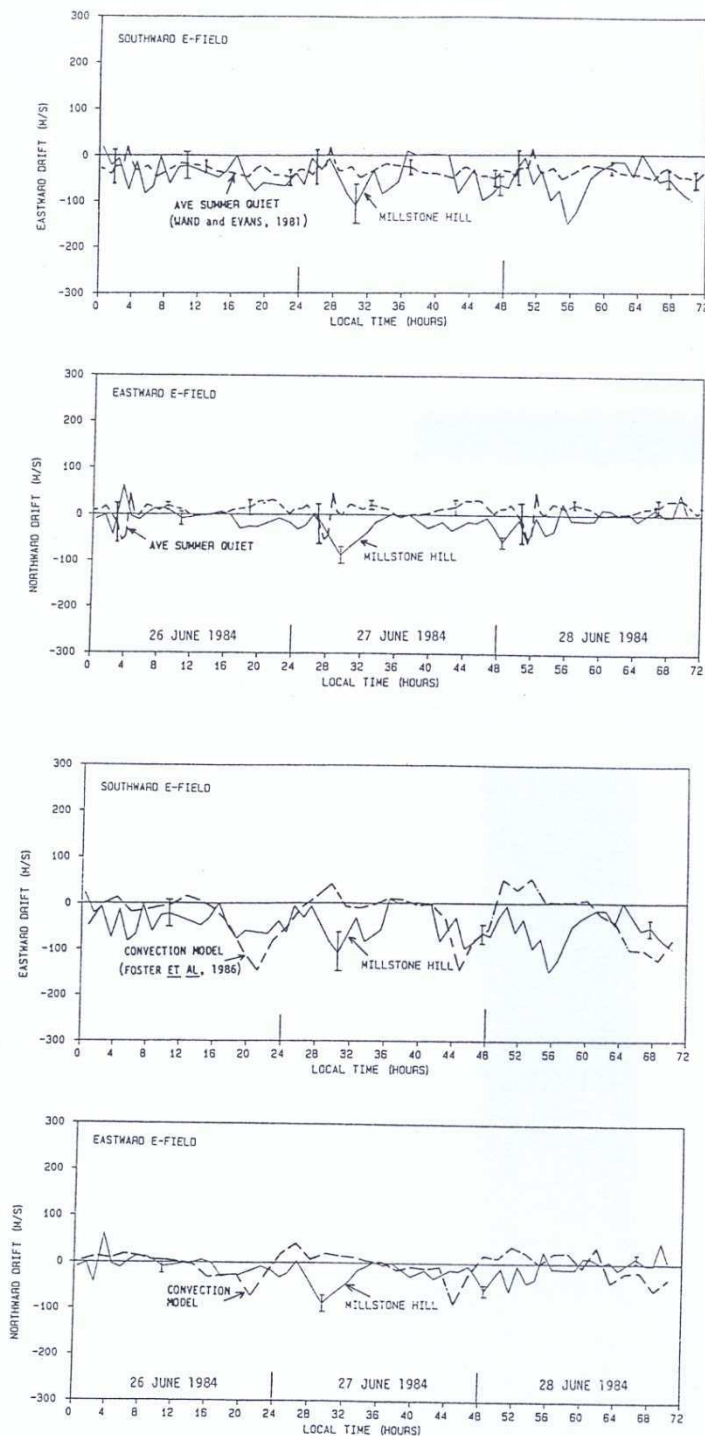
Figure 3

Comparison of the Millstone electric field observations with the average Millstone model for Summer quiet conditions (Wand and Evans, 1981).

Figure 4

Comparison of the Millstone electric field observations with the Millstone plasma convection model (Foster et al., 1986).

derived from the measured ion drift component parallel to the field line by suitably accounting for ion diffusion effects. These latter effects are computed from the altitude gradients of the measured plasma density and temperature as described by Salah and Holt (1974) for Millstone Hill and by Vasseur (1969) for Saint-Santin, and require knowledge of the ion-neutral collision frequency and, therefore, the neutral gas composition. Since there is uncertainty in the collision frequency cross-sections for ion-neutral collisions, particularly for O^+ ions with atomic oxygen, we have standardized these terms in the analysis of the Millstone Hill and Saint-Santin data in this paper by using a consistent set of coefficients (Dalgarno, 1964 ; Banks, 1966). We used the MSIS-83 model (Hedin, 1983) to represent the neutral composition at the two radar stations. This allows relative comparisons between the two stations to be confidently made.

The results shown here all correspond to an altitude of 300 km. Statistical uncertainties in the winds resulting from these calculations are about 20-30 m/s, but the total accuracy of the technique given the model assumptions is of the order of 50-70 m/s during quiet geomagnetic conditions. Under disturbed conditions, the errors are likely to be larger and depend primarily on the ability of the MSIS model to represent the neutral gas composition accurately. Comparison of exospheric temperatures from the MSIS model with those derived from the radar data during the June 1984 GTMS period, together with a sensitivity analysis of the error sources on the wind calculations, indicate that the accuracy of the winds is of the order of 100 m/s during moderately disturbed conditions.

Figure 5 shows the measured ion drift velocity along the field line at 300 km over Saint-Santin and Millstone Hill for the three days in the GTMS June campaign. The drift velocities are very consistent in magnitude and direction at most times, with the exception of the early hours on June 28, when strong upward drifts are observed over Saint-Santin in contrast to the typically downward drifts over Millstone Hill. The derived meridional neutral winds for the two radar stations are compared in figure 6, which shows an excellent overall agreement. Strong southward winds of about 300 m/s are observed at night, which weaken during the daytime and reverse direction briefly at some times. There are differences in the winds at particular times that are larger than the above-quoted accuracy and these most likely reflect local differences. The strong southward winds near

local midnight appear to remain strong for a longer interval at Millstone Hill than at Saint-Santin. The large upward ion velocity and concomitant oscillations mentioned above for Saint-Santin at about 4 LT on June 28 are caused by the neutral wind pattern rather than by diffusion effects, since diffusion velocities are similar to those calculated for Millstone Hill. We note that the large oscillations in the winds observed at both stations on the geomagnetically disturbed 28 June are somewhat offset in phase.

We have had an opportunity in this study to compare the neutral wind results with predictions made from the NCAR Thermospheric General Circulation Model (Roble et al., 1982) for the GTMS June 1984 period (R. Roble and B. Emery, private communication). The global wind distribution was derived from the model using measured indices to determine the auroral convection patterns and a model ionosphere. We show in figure 7 a time slice from the model at 45° N latitude and at an altitude of 300 km for the longitudes of Millstone Hill and Saint-Santin. Comparison with figure 6 shows overall agreement between the predicted wind pattern and general magnitude of the Millstone Hill observations. The model, however, does not reproduce the equally strong nighttime winds observed at Saint-Santin. Working with the NCAR group in this comparison, it has been determined that the convection electric fields modeled for this GTMS period at Saint-Santin's longitude were roughly one-half those at Millstone Hill, and therefore reduced the effects of convection driven winds at that longitude. It has already been shown above that the electric fields

Figure 5

Measurements of the ion velocity component parallel to the magnetic field line at 300 km altitude at Saint-Santin and Millstone Hill for the GTMS June 1984 campaign.
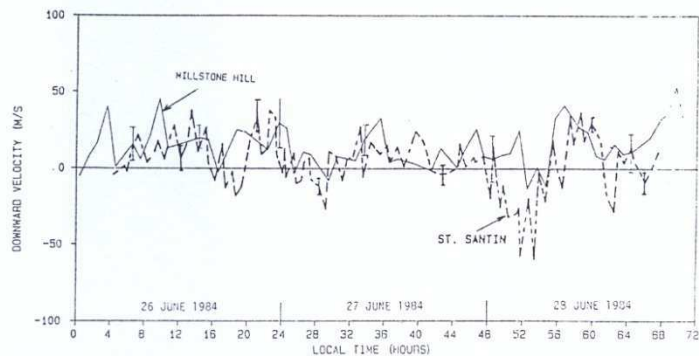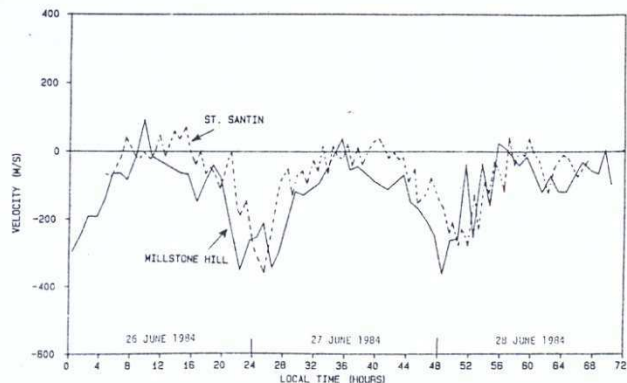

Figure 6

Derived meridional neutral wind velocities (positive northward) at 300 km at Saint-Santin and Millstone Hill for the June 26-28, 1984 period.

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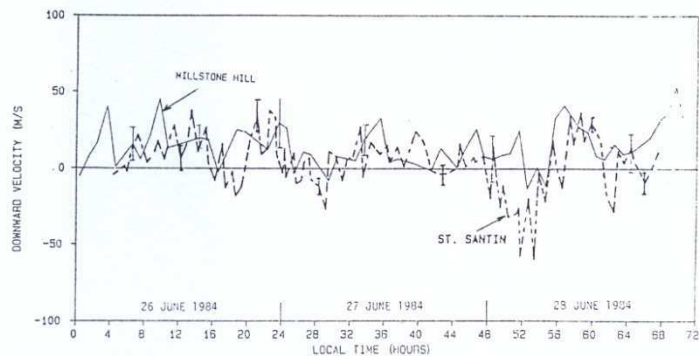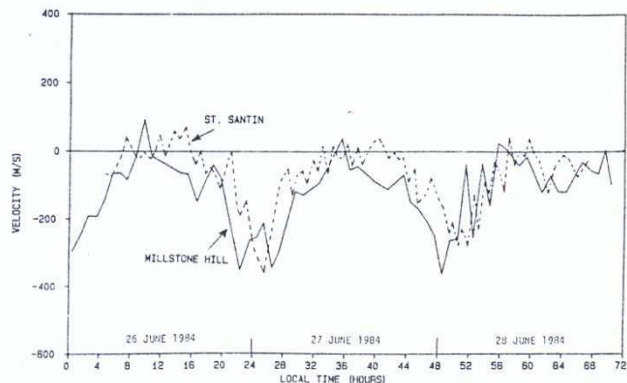

Figure 6

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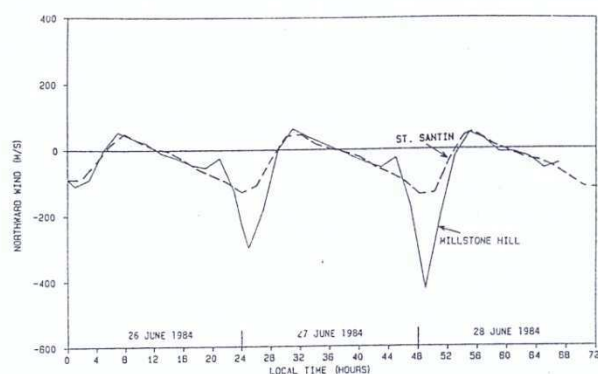
Figure 7

Prediction of the NCAR *Thermospheric General Circulation Model of neutral winds over Saint-Santin and Millstone Hill for the* GTMS *June* 1984 *campaign period.*

at Saint-Santin were at least equal and often exceeded those observed at the higher magnetic latitude of Millstone Hill for this period. Thus it is believed that a suitable adjustment of the convection field penetration in the European longitude sector would enhance the winds to be more consistent with those at the American longitude.

A few other less prominent features may be noted from this comparison. The strengthening of the model nighttime winds at Millstone Hill from June 27 to June 28 is not apparent in the data and is perhaps due to reduced ion drag obtained from the ionospheric model used in the calculation or from an overestimation of the electric field convection penetration. The repeatable northward early morning maximum in the model is also not seen in the measurements. Additional iterations of the model are presently underway to reconcile these results and determine the factors that influenced the thermospheric circulation for this GTMS period. Through such iterations we will learn more about the electrodynamic coupling of the ionosphere with the thermosphere, which has been the prime goal of the GTMS campaign.

CONCLUSIONS

The 26-28 June 1984 GTMS campaign provided an interesting opportunity with geophysically quiet and disturbed conditions to study the electrodynamic behavior of the midlatitude ionosphere simultaneously at two longitudes. The first day of the campaign was geomagnetically quiet and provided a good reference day to compare the progressively more disturbed conditions that prevailed on the next two days. The quiet electrodynamic pattern at midlatitude is represented by a westward ion drift corresponding to a northward electric field with a mean value of 1-2 mV/m and a north-south ion drift corresponding to an east-west electric field component that oscillates with an amplitude of about 1 mV/m around a zero mean. The meridional wind velocity pattern in the F-region is driven by solar pressure gradients that at midlatitudes result in nighttime southward winds of 200-300 m/s. These southward winds weaken in the daytime to magnitudes of 50-100 m/s oscillating between northward and southward directions.

During the more disturbed conditions of 27-28 June, electrodynamic effects were more prevalent at Saint-

Santin than at Millstone Hill. This was unexpected because of the latter stations's relatively much higher magnetic apex latitude. On the disturbed day of June 27, the northward electric field component, which is most affected by the enhanced geomagnetic activity, strengthens and produces increased westward plasma drifts at both stations, including a short-lived westward surge at Saint-Santin. Comparison with the plasma convection model of Foster *et al.* (1986), driven by high-latitude particle precipitation, indicates that at Millstone Hill the disturbed effects are due to an ionospheric dynamo driven by storm induced wind disturbances. This is similar to the conclusion reported by Mazaudier (1986) for Saint-Santin on the basis of an observed southward neutral wind disturbance in the E-region dynamo layer. On the last day of the campaign, June 28, a continued strengthening of the westward drifts is observed at noon UT at Millstone Hill (7 LT) and very large south-eastward oscillations in the plasma drift are observed at Saint-Santin. This indicates that the effects of the geomagnetic disturbances on that day were more concentrated in the European longitude sector, as suggested by the magnetometer records. The observations at Saint-Santin are likely a result of a combination of both the magnetospheric convection and the disturbance dynamo fields.

Finally, the F-region meridional neutral winds are in reasonable agreement at both stations, and a comparison of the results with the general circulation model at NCAR suggests that a reconciliation of the results requires a deeper penetration of the convection pattern at Saint-Santin's longitude due to the large observed magnetic activity in the European sector, consistent with the above conclusions. The southward nighttime winds are observed to reach strengths of 300-400 m/s during 27-28 June at both stations, and large oscillations in the wind velocity are observed on the most disturbed night of 28 June.

REFERENCES

Axford W. I., Hines C. O., 1961. A unifying theory of high-latitude geophysical phenomena and geomagnetic storms. *Can. J. Phys.*, **39**, 1433-1464.

Banks P., 1966. Collision frequencies and energy transfer-ions. *Planet. Space Sci.*, **14**, 1105-1122.

Blanc M., 1978. Midlatitude convection electric fields and their relation to ring current development. *Geophys. Res. Lett.*, **5**, 203-206.

Blanc M., Amayenc P., 1979. Seasonal variations of the ionospheric E × B drifts above Saint-Santin on quiet days. *J. Geophys. Res.*, **84**, 2691-2704.

Blanc M., Richmond A., 1980. The ionospheric disturbance dynamo. *J. Geophys. Res.*, **85**, 1669-1686.

Blanc M., Amayenc P., Bauer P., Taieb C., 1977. Electric field induced drifts from the French incoherent scatter facility. *J. Geophys. Res.*, **82**, 87-97.

Dalgarno A., 1964. Ambipolar diffusion in the F-region. *J. Atmos. Terr. Phys.*, **26**, 938.

Evans J. V., Holt J. M., Wand R. H., 1979. Millstone Hill incoherent scatter observations of auroral convection over 60°-75°. 1. Observing and data reduction procedures. *J. Geophys. Res.*, **84**, 7059-7074.

Foster J. C., Holt J. M., Musgrove R. G., 1986. Ionospheric convection associated with discrete levels of particle precipitation. *Geophys. Res. Lett.*, **13**, 656-659.

Hedin A. E., 1983. A revised thermospheric model based on mass spectrometer and incoherent scatter data : MS15-83. *J. Geophys. Res.*, **88**, 10170-10188.

Mazaudier C., 1985. Electric currents above Saint-Santin. 3. A preliminary study of disturbances : June 6, 1978 ; March 22-23, 1979. *J. Geophys. Res.*, **90**, 1355-1366.

Mazaudier C., 1986. Saint-Santin observations of electric fields and neutral winds in the dynamo layer during the GTMS period of June 1984. XXVIth COSPAR, Toulouse, France (in press).

Oliver W. L., Salah J. E., 1987. The global thermospheric mapping study. (Submitted to *J. Geophys. Res.*)

Richmond A. D., Matsushita S., 1975. Thermospheric response to a magnetic substorm. *J. Geophys. Res.*, **80**, 2839-2850.

Richmond A. D., Matsushita S., Tarpley J. D., 1976. On the production mechanism of electric currents and fields in the ionosphere. *J. Geophys. Res.*, **81**, 547-555.

Roble R. G., Dickinson R. E., Ridley E. C., 1982. Global circulation and temperature structure of the thermosphere with high-latitude plasma convection. *J. Geophys. Res.*, **87**, 1599-1614.

Salah J. E., Holt J. M., 1974. Midlatitude thermospheric winds from incoherent scatter radar and theory. *Radio Sci.*, **9**, 301-313.

Vasseur G., 1969. Vents dans la thermosphère déduits des mesures par diffusion de Thomson. *Ann. Géophys.*, **25**, 517-524.

Vasyliunas V. M., 1972. The interrelationship of magnetospheric processes. In : Earth's Magnetospheric processes. Ed. B. M. McCormac, D. Reidel, Hingham, Mass., 60-70.

Wand R. H., Evans J. V., 1981. Seasonal and magnetic activity variations of ionospheric electric fields over Millstone Hill. *J. Geophys. Res.*, **86**, 103-118.