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Thermospheric Neutral Temperature Measurements from the University College London Fabry-Perot Interferometers

E. M. Griffin[1], A. L. Aruliah[1], I. McWhirter[1], and T. Yeoman[2]

[1]Atmospheric Physics Laboratory, University College London, UK
[2]Radio and Space Plasma Physics Group, University of Leicester, UK

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Abstract.
The ionosphere responds almost immediately to magnetospheric forcing, however, the neutral atmosphere has inertia owing to its far greater mass density. As a consequence the neutral atmosphere can significantly modify the ionosphere-magnetosphere coupling processes such as the energy transferred between them. Thermospheric neutral temperatures measured by Fabry-Perot Interferometers (FPI) from airglow are presented from both auroral and polar cap sites. These are compared to both Incoherent Scatter Radar (ISR) derived values and modelled temperatures from MSIS. The large differences evident in the comparison to model results are discussed and the reaction of the measured values to geomagnetic conditions are demonstrated from both sites. We also demonstrate the importance of accurate neutral temperatures in monitoring the dissipation of energy and in the derivation of ionospheric parameters.

1 Introduction

The techniques available to provide thermospheric neutral temperatures include direct measurements from FPI (e.g. Killeen et al., 1995), measurements derived from ISR (e.g. Alcaydé et al., 1983) and modelled values from both empirical models such as MSIS (Hedin, 1987) and calculated values from numerical models such as CTIM (e.g. Codrescu et al., 1997). The FPI technique derives temperatures from Doppler Broadening of observed emission lines. For the upper thermosphere the 630 nm atomic oxygen emission is observed which has a peak emission altitude of 240 km. The technique has allowed thermospheric temperatures to be measured from both ground-based and satellite borne instruments but there are a limited number of such instruments and in ground-based systems they require dark, clear conditions to operate. The ISR technique uses electron and ion temperatures in the F region ion energy balance equation for quiet geomagnetic conditions together with input from the MSIS model to derive neutral temperatures. These measurements can have very high time resolution but there are few ISRs and the conditions for which the temperatures are valid is limited. Model neutral temperatures at high latitudes are typically too low due to a lack of consideration of mesoscale variability which leads to larger Joule heating. Meanwhile the empirical MSIS model has poor data coverage at high latitudes. In the high latitude thermosphere there is therefore a lack of a credible source of neutral temperatures when direct measurements are not available. The measurements that are available, however, may be used to test and improve the performance of both modelled and derived values in this region.

Correspondence to: E. M. Griffin. Author

2 Fabry-Perot Interferometer Measurements

The FPI technique for determining temperatures from observed atomic oxygen emission profiles requires an accurate description of the instrument function. This is obtained by sampling a stabilised He-Ne laser and scanning the instrument by changing the pressure, and hence the refractive index, inside the Fabry-Perot etalon. Until recently the APL used a manual technique to obtain these instrument functions but in the winter of 2000 a new system to provide an automatic laser calibration capability for the FPI was tested at Longyearbyen. This provided improvements in the scope and resolution of the instrument functions derived for the FPI compared to the manual technique, as demonstrated in Figures 1a (manual) and 1b (automatic). The figures show the progression of the reduced laser profile as the pressure is increased for both the manual and automatic systems.

When a profile is observed from the emission of interest it is possible to work out the extent of the Doppler broadening, and hence the temperature, by deconvolving the instrument function from the measured profile, as shown in Figure 2. In the current analysis regime we perform a non-linear least-squares fit to the measured profiles. Changes to the instrument over time will change the form of the instrument function and also affect the measured profiles. This leads to the necessity of making regular calibrations. To date the manual process has been used whenever possible during routine maintenance visits to the FPI sites. This however only provided one calibration per FPI season.

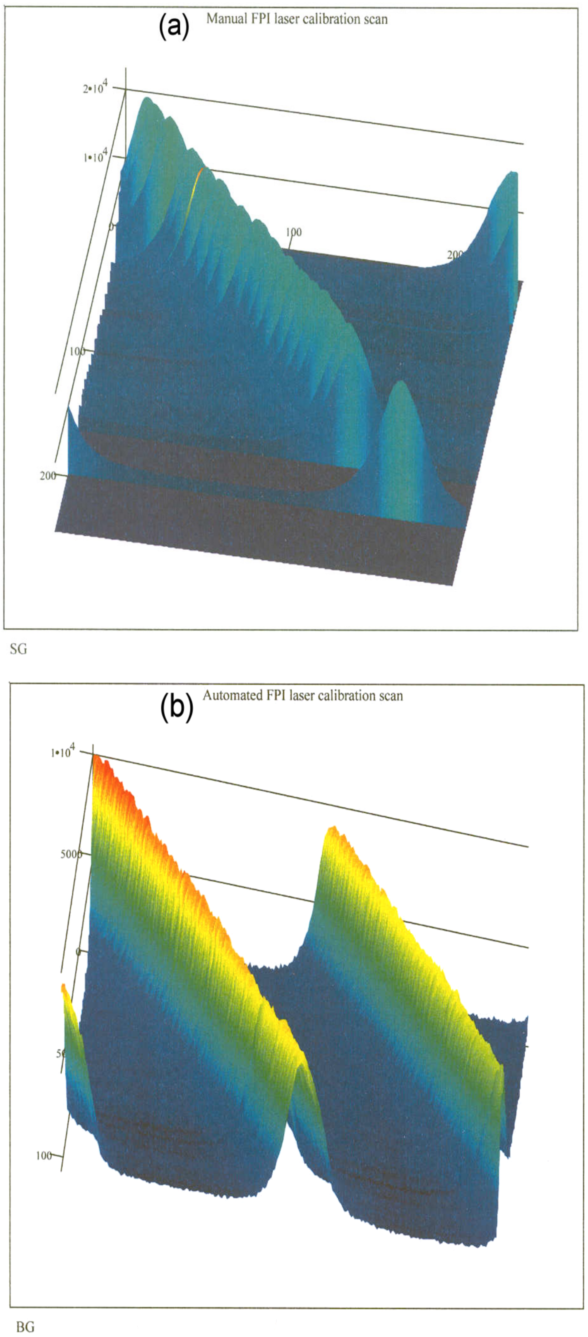

Fig. 1. Laser calibration profiles using both manual (top) and automatic (bottom) scanning of the FPI

Our Kiruna FPI has recorded data for two decades, without laser calibration. These may be analysed for relative temperature changes but the absolute value of these measurements is not available without external corroboration due to the lack of an appropriate instrument function. Thus trends in the temperatures and reactions to individual conditions may be demonstrated but the absolute values are unknown.

However, temperatures derived from EISCAT measurements may be used to normalise the FPI measurements. The EISCAT database is almost as extensive as that for the Kiruna FPI and provides a valuable source of comparative neutral temperatures. Using the EISCAT temperatures in quiet times can provide valuable normalisation to the FPI temperatures which have not been laser calibrated. Conversely the technique for deriving neutral temperatures from EISCAT data can then be tested under active conditions by comparison with the measured FPI data to see how the technique works and establish the limits in its application.

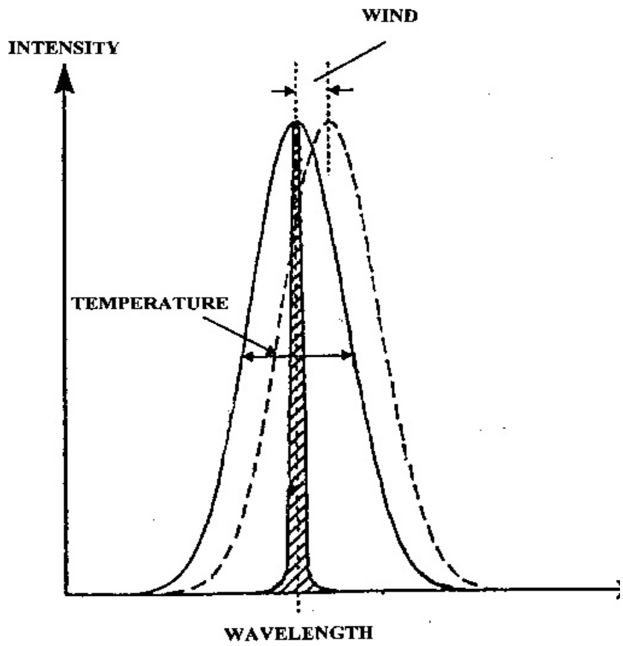

Fig. 2. Schematic of the observed FPI profile.

3 Auroral zone temperatures from Kiruna

The common sample volume of the EISCAT UHF system with the FPI at Kiruna allows comparisons to be made between the neutral temperatures derived from the radar with those measured by the FPI. During the period from 8th March 1999 to 12th March 1999 an EISCAT CP2 experiment was run at Tromso and the ion and electron temperatures from the 8th March, during quiet conditions, were used to derive neutral temperatures which in turn were used to normalise the FPI temperatures at the start of this run. Figure 3a shows the neutral temperatures produced for the night of the 9th March from the FPI using this technique, with the UT hours starting at 00UT on 9th March. Also shown (Figure 3b) are the A_p values for the period plotted. The temperature variations may be attributed to the changes in geomagnetic conditions during the night. There is a lag of 3-4 hours following the decrease and increase of A_p which corresponds to a temperature drop of 200 K and rise of up to 500 K respectively. EISCAT derived neutral temperatures would be unreliable for the larger A_p values and are at best reliable only up to an A_p of 16.

3.1 Spatial structure in FPI field of view

Figure 4 shows the temperatures derived for Kiruna for 25th Dec. 2000. The temperatures are smoothed with a 5 point running average, which corresponds to a window of around 1 hour, to emphasise a separation in the results from the individual look directions shortly after 20 UT. Temperature observed in the north direction rises the most, the zenith and zonal directions by an intermediate amount and the south by the least. This would indicate that there is a heating source to the north of Kiruna which is sufficiently localised both spatially and temporally to allow the temperature gradient to be observed by the FPI.

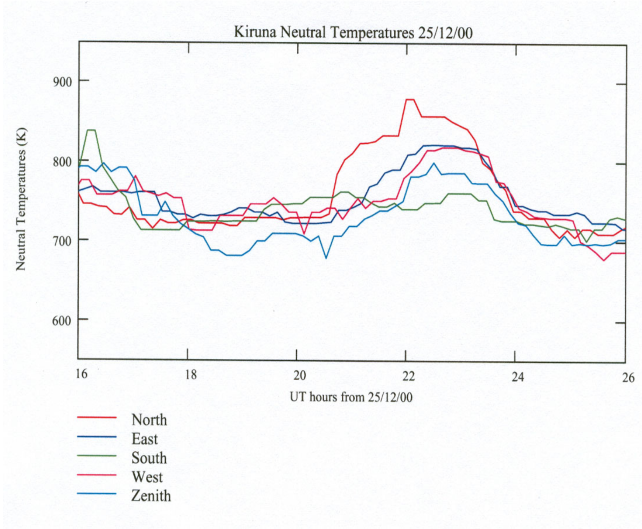

Fig. 4. Smoothed Kiruna FPI neutral temperatures for 25th Dec. 2000

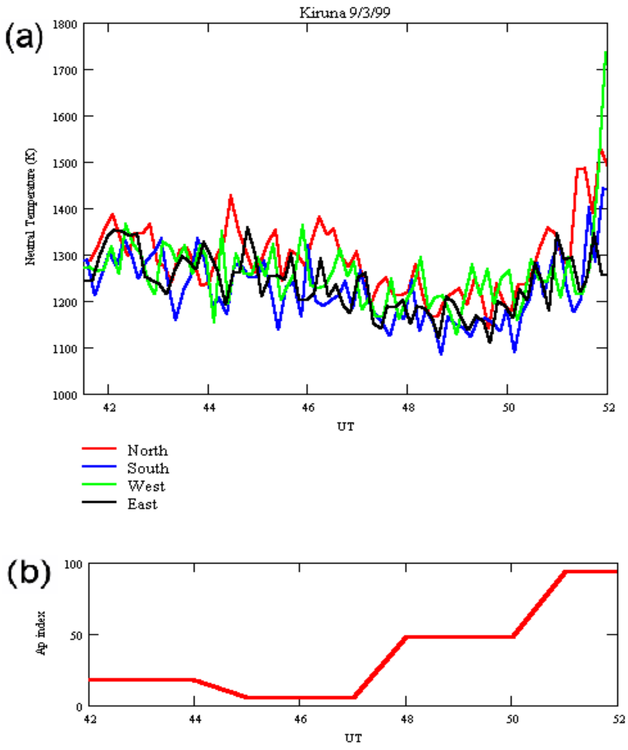

Fig. 3. (a)Kiruna FPI temperatures for 9/3/99 using EISCAT measurements for normalisation (b) Corresponding variation in A_p

4 Polar cap temperatures from Svalbard

In Figure 5 we show the temperatures from the Svalbard FPI at Longyearbyen for 25/12/98. The results demonstrate the consistency between the look directions over this period with a large temperature increase over a very short period of time. This FPI has a field of view which overlaps with both of the CUTLASS radars. In Figure 6 below we see the ion velocities from beam 5 of the Iceland East CUTLASS radar for 25/12/98 in a plot by magnetic latitude and UT. This beam is directed closest to Longyearbyen, which is at a magnetic latitude of 74^o. Figure 6 demonstrates strong flow reversals associated with cusp transient features at the same time (07.30 - 08.30 UT) as the FPI shows the largest gradient in neutral temperature. This implies that the large rise in temperature (about 800 K) seen until 09 UT is caused by Joule heating due to the ion velocity reversal.

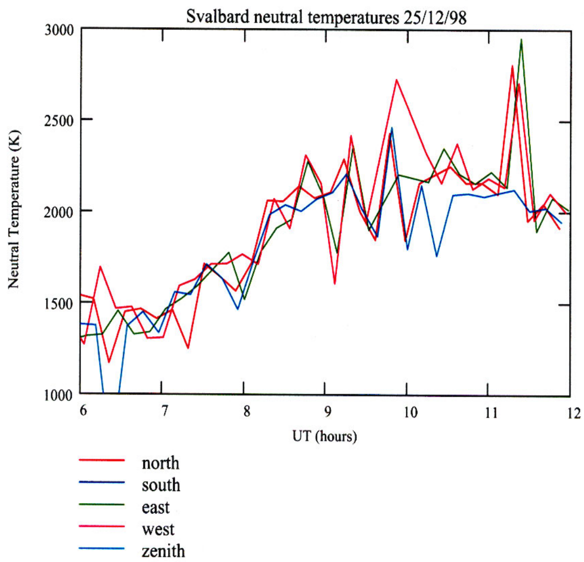

Fig. 5. Plot of Svalbard FPI neutral temperatures for 25/12/98

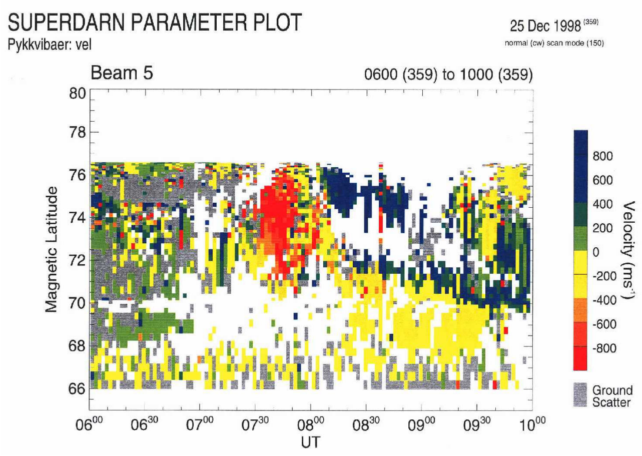

Fig. 6. Ion velocities from Iceland East Cutlass radar for 25/12/98

4.1 Climatological behaviour of polar cap thermospheric temperatures

Killeen et al. (1995) demonstrate polar cap neutral temperatures, measured by FPI, from Thule in northern Greenland, using 5 seasons of data from 1986 to 1991 to produce a climatology of neutral winds in both geomagnetic activity, by Ap, and solar activity, by F10.7. They compared their results with the output from the MSIS model for the same location and conditions and found large discrepancies (see Table 1). These discrepancies become more pronounced at high values of solar and geomagnetic activity with MSIS underestimating the temperatures significantly. A similar climatology has not yet been possible for the Svalbard temperatures, however results from December 1998, when there was a single calibration done, have been compared to the Killeen climatology and produce temperatures that are on average just under 200 K higher than those calculated for the same conditions at Thule. The MSIS output are also several hundred degrees K lower than those measured in this location, as was found at Thule. The results are summarised in Table 1.

As the database of temperatures grows from Svalbard more detailed comparisons can be undertaken with the Thule results.

5 Future work

Kiruna FPI winds and temperatures are being used in a modelling study for the 8th March 12th March 1999 period in conjunction with the EISCAT data. The combined EISCAT and Kiruna FPI databases will be searched for similar periods when the neutral temperatures may be normalised. The Eiscat Svalbard Radar database will also be searched to normalise Svalbard FPI data when calibrations are not available. This will lead to an empirical database of thermospheric neutral temperatures for both the auroral zone and polar cap becoming available to support the large number of ionospheric instrumentation in the European sector. The detailed reaction of neutral temperatures to solar and geomagnetic variability will then be quantified for this region.

The new automatic system to allow regular accurate calibrations using an automatic pressure scanning system was successfully tested at Svalbard in October/November 2000 and will be installed on all the FPIs for the 2001/2002 season. The specific neutral heating event from the Svalbard FPI and CUTLASS data is being further investigated using ion convection plots in combination with neutral winds.

Table 1. December 1998 Neutral Temperatures

Location	MSIS	FPI
Svalbard	886.7 K	1476.6 K
Thule	890.6 K	1278.1 K

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