First High Time Resolution FPI Observations of the Daytime Thermosphere During the Eclipse Over Svalbard on 20th March 2015

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Abstract Daylight observations of the upper atmosphere have long been a goal of the ground-based optical community. Fabry-Perot Interferometer observations of the airglow emission of atomic oxygen at 630.0 nm are used as a measure of thermospheric winds and temperatures at an altitude of around 240 km. However, airglow is only about 10 times the intensity of starlight. Adding extra etalons (up to a triple etalon FPI) to filter out sunlight has been attempted by a few groups, including ours, over the decades. However, the alignment of multiple etalons is extremely tricky, and long exposures (several minutes) are required, which reduces the capacity to observe the dynamic behaviour of the upper thermosphere.

Here we show FPI observations made during the solar eclipse on the 20th March 2015. A total eclipse occurred over Svalbard for 2 minutes 27 seconds from 10:10 – 10:13 UT. This is within the time window when Svalbard passes under the magnetic cusp. There are 24 hours of darkness at Svalbard during the period November to January, which allows continuous FPI observations, including cusp measurements. However, by the time of the March equinox, the hours of darkness have reduced significantly to give an observing period of 18:55-10:16 UT. During the tiny window of time of darkness due to the eclipse, we measured the vertical winds at very high time resolution using a 5 second exposure with our narrow angle FPI; and we were able to make a single exposure for 104 seconds with our Scanning Doppler Imager (SCANDI). The SCANDI provided an all-sky observation, divided into 61 sectors, of horizontal winds and temperatures as a context for the high time resolution vertical winds. The observations are compared with FPI-SCANDI December cusp measurements; and the UCL Coupled Middle Atmosphere Thermosphere (CMAT2) global circulation model simulations. This is an opportunity to test the model daylight winds with direct observations. Determining the day and night upwelling mechanism remains a challenge.

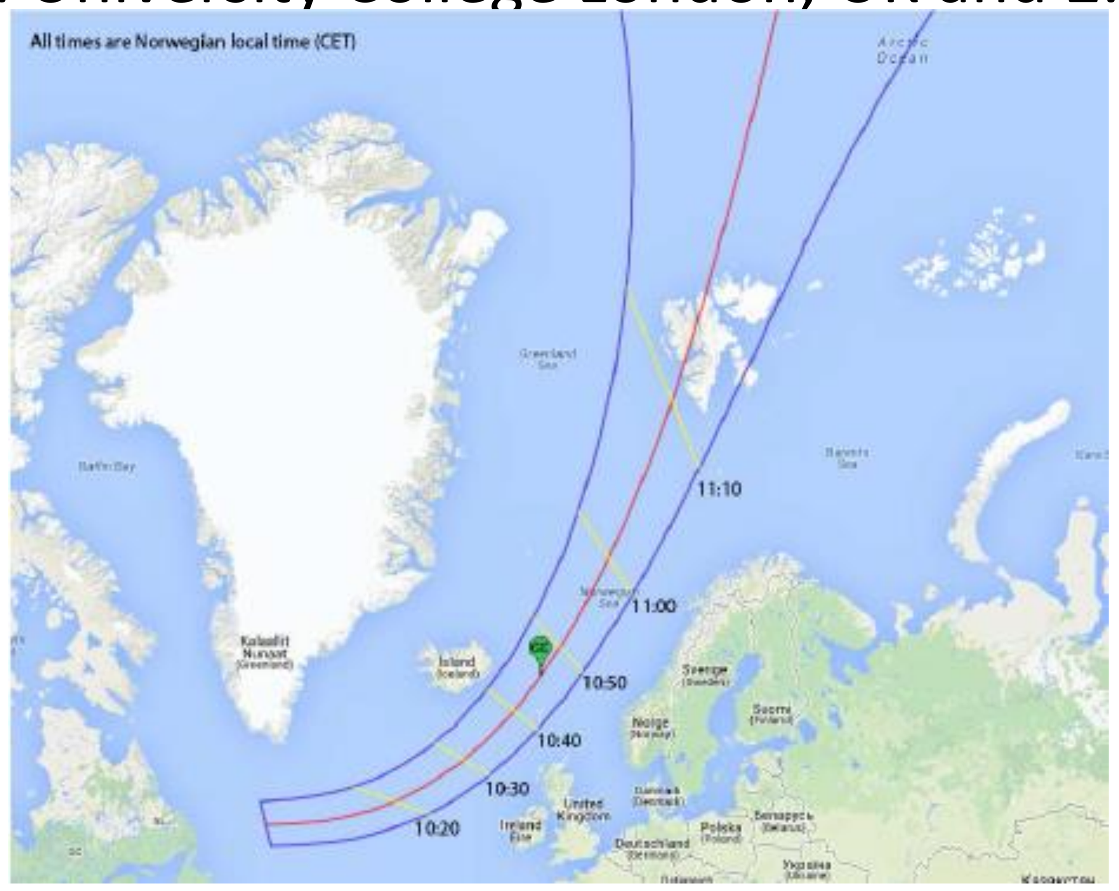

Figure 1: Path of the eclipse courtesy Kjellmar Oksavik, University of Bergen and University Centre in Svalbard (UNIS)

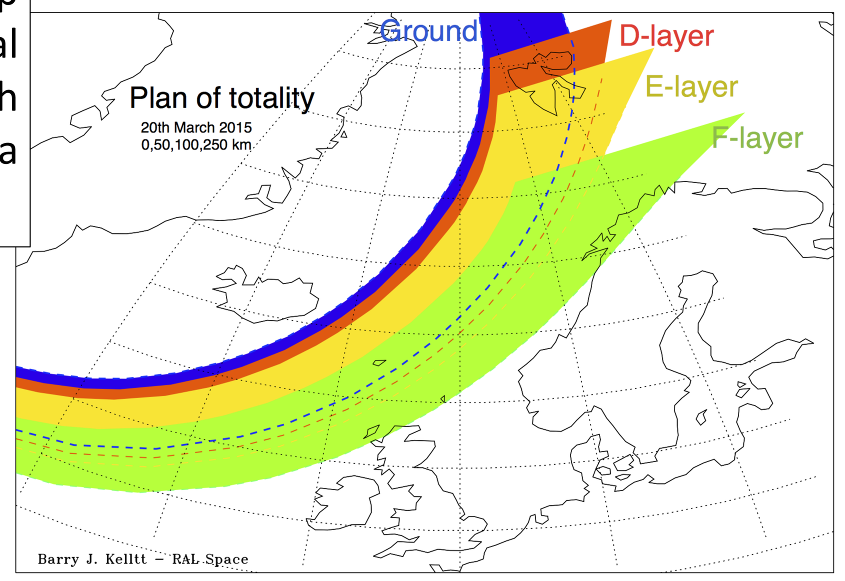

Figure 2: Path of the eclipse showing the path of totality at different altitudes: ground; D-layer (~90km); E-layer (~120km) and F-layer(~300km) (Barry Kellitt, RAL Space)

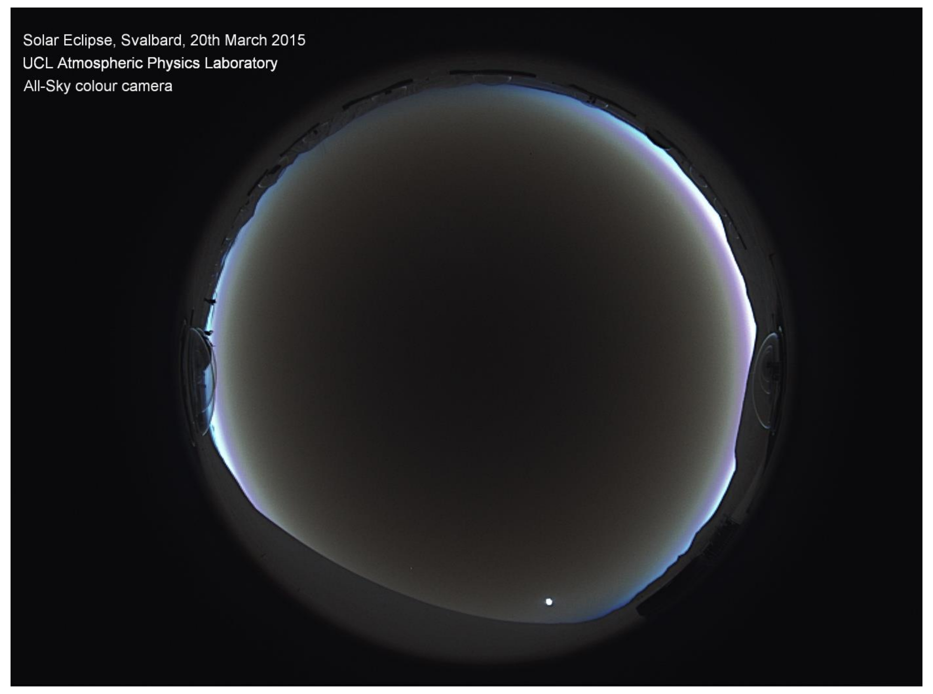

Figure 3: The sky during the eclipse, as seen by the UCL All-Sky Camera at Svalbard. The Earth's shadow does not completely fill the horizon. The domes of the Kjell Henriksen Observatory can be seen around the edge of the image. We were very lucky, as it had been cloudy during the previous night. We were remotely controlling the FPIs from London (UK) where it was totally clouded over.

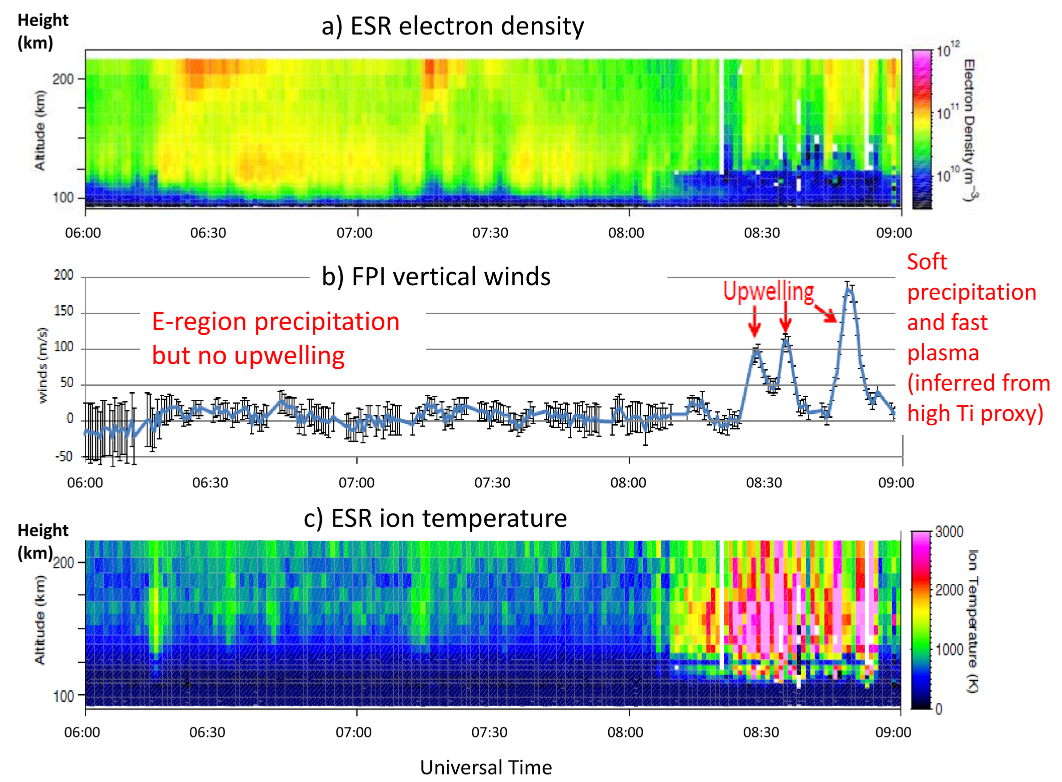

Figure 4: Comparison with the first cusp upwelling campaign at Svalbard from 06-09UT on 22 January 2012 when there were 24 hours of darkness. b) FPI measurements of unexpectedly large vertical winds of up to 200 ms^{-1}. during periods of a) soft precipitation and c) fast plasma velocities inferred from ion temperatures measured by the EISCAT Svalbard Radar.

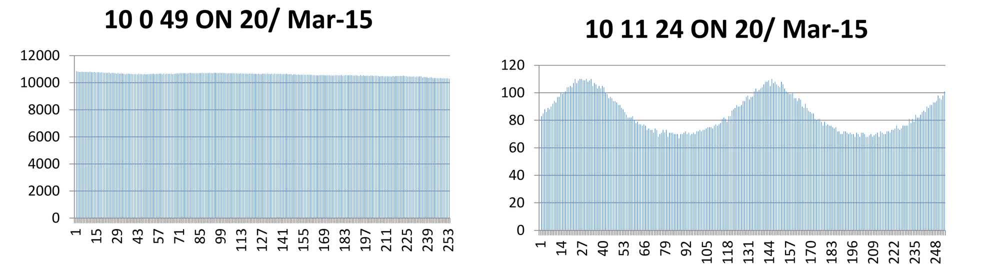

Figure 5: On the left, sunlight overwhelms the weak airglow emission which is a 2-dimensional FPI intensity image (see Figure 7) reduced to a radius-squared plot. During the eclipse, the 630nm peaks are clearly seen as shown by the figure on the right.

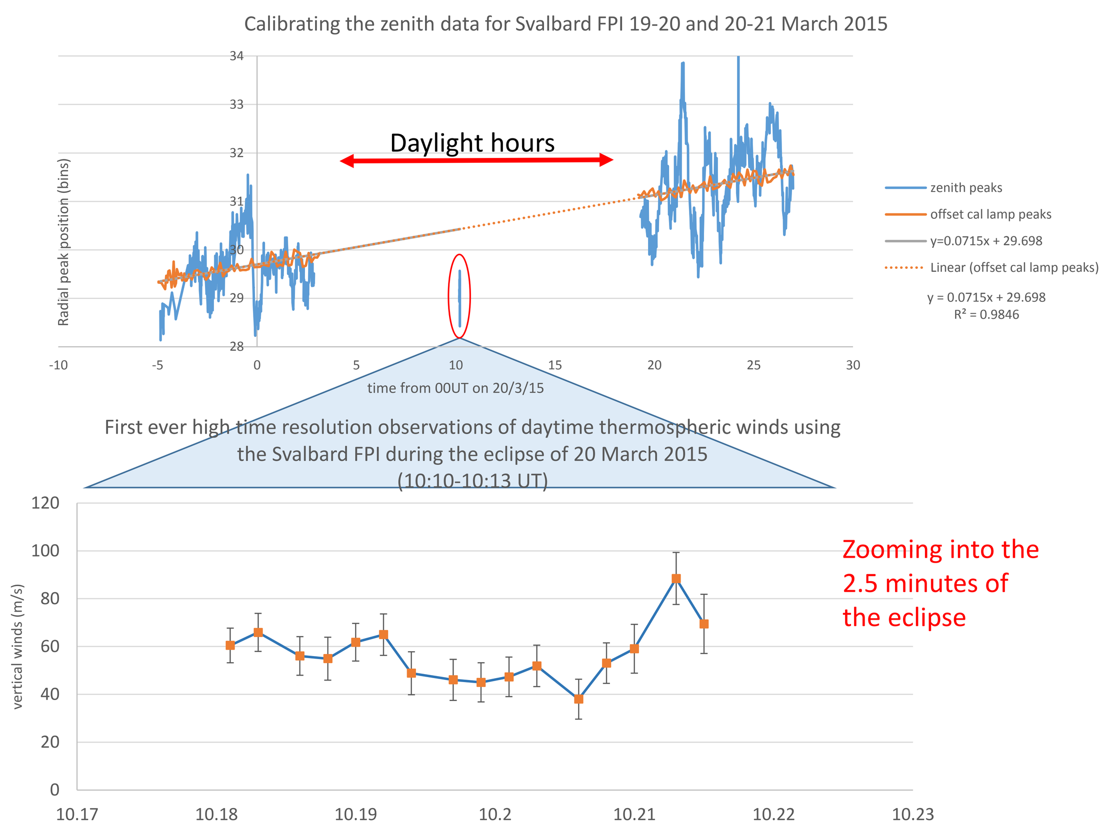

Figure 6: With only 2.5 minutes to observe, we decided to limit to zenith measurements at high time resolution 7.2 seconds (5 second exposures). ***These are the first ever high time resolution measurements of daytime winds measured directly by an FPI.*** Large, and variable, upward winds of between 40-90 ms^{-1} were observed as shown in the lower plot. The high intensities gave errors of the order of ±5 ms^{-1}. The winds are calculated from the Doppler shift of the 630nm emission. The upper plot shows how careful calibration is required to determine the zero Doppler shift baseline since there is no laboratory source of excited atomic oxygen O(^{1}D). This is achieved using a helium-neon calibration lamp (630.2nm) from the period of darkness before and after the daytime, as there was no time for the calibration during the eclipse. Determining the upwelling mechanism remains a challenge.

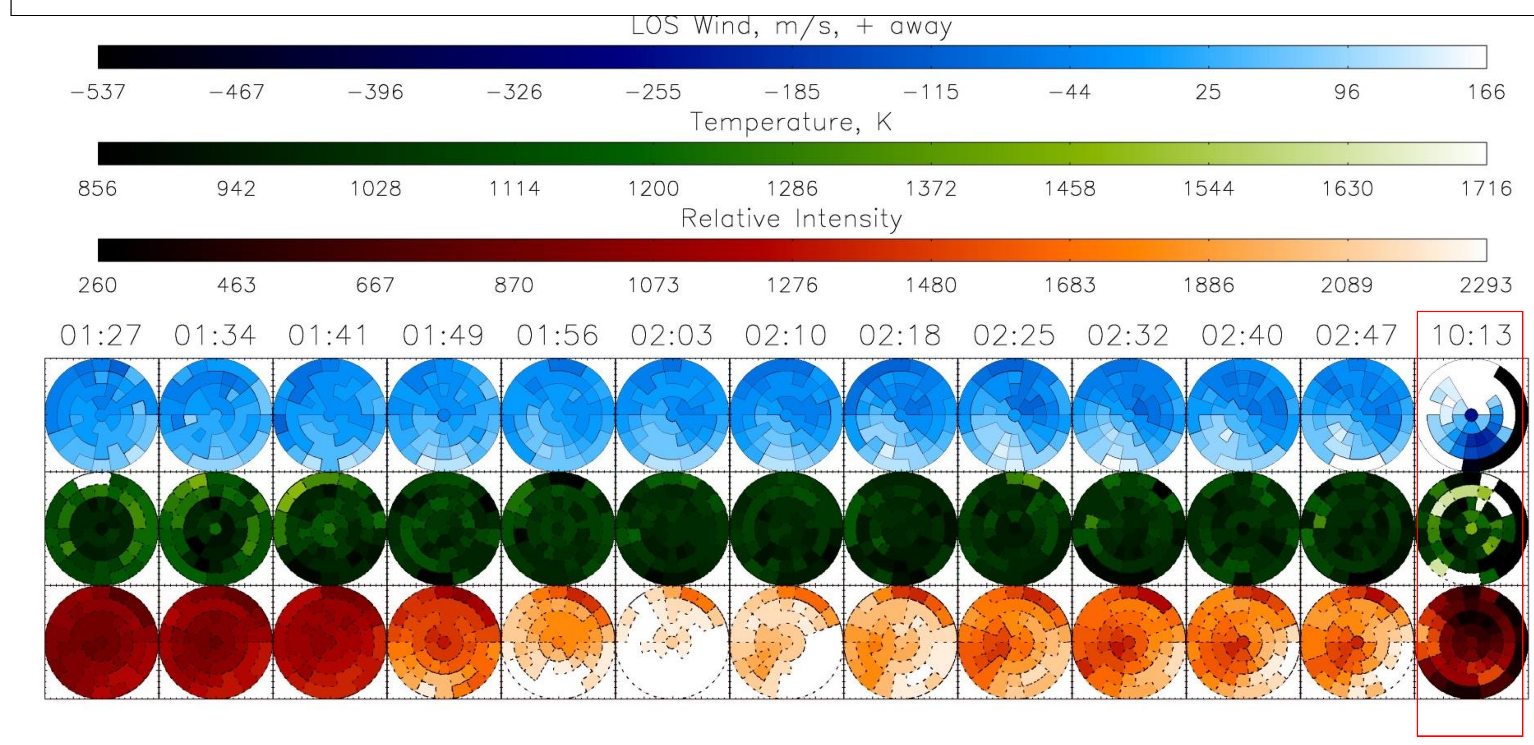

Figure 9: SCANDI all-sky nighttime measurements of line-of-sight winds (blue), neutral temperatures (green) and 630nm intensities (red) between 2343 UT on 19 March to 0247UT on 20 March 2015. The last column of plots shows "day-time" images during the eclipse at 10:13UT on 20 March 2015 with an average temperature of 1200 K and north east winds of around 600 ms^{-1}.

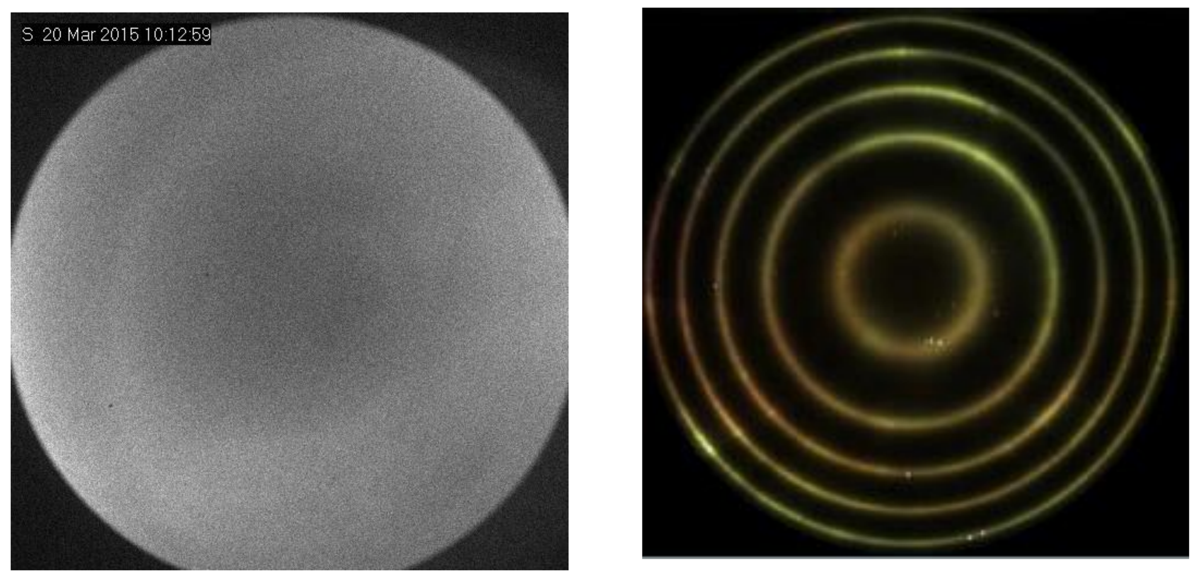

Figure 7: The imaging logistics were extremely tightly planned. The normal nighttime SCANDI scan takes 7-8 minutes, which includes 5 successive rampings up of the etalon gap. The figure on the right shows the Airy Function of a Fabry-Perot Interferometer. As the etalon gap increases, the rings shrink inwards. During the eclipse, only 1 scan (lasting 104 seconds) was possible, because it was imperative that the sky was as uniformly dark as possible throughout the scan. Thus we could see true Doppler shifts, rather than intensity gradients as the Earth's shadow crossed the Sun. The left figure shows the SCANDI 'raster scan' image made from all the scan images added together. The date-stamp is 10:12:59, which shows that the scan finished well before totality ended. This is confirmed by the fairly uniform intensity across the field-of-view, which is nearly 1000 km in diameter.

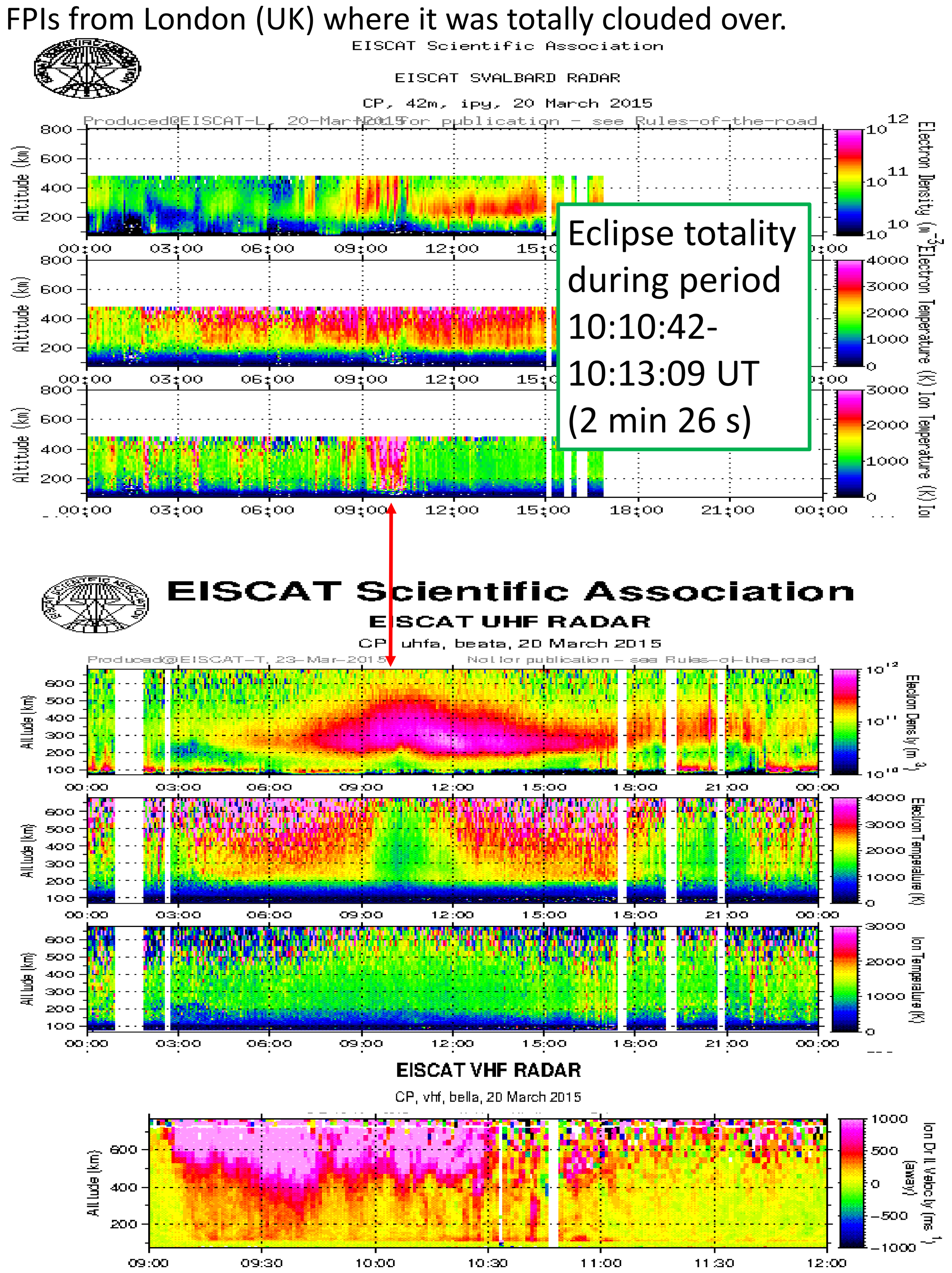

Figure 11: All the EISCAT radars were operating during the eclipse. The top plot shows height profiles of electron densities (Ne); electron temperatures (Ti) and ion temperatures (Ti) from the Svalbard field-aligned radar. The middle plot shows the equivalent for the UHF radar at Tromsø, which was also field-aligned. The "bite-out" caused by the lack of ionising solar flux is strongly apparent in the Tromsø Te at all altitudes. The bottom plot shows the strong meridional plasma velocities ~1200 ms^{-1} measured by the VHF radar pointing northward at elevation 30 deg. The eclipse occurred a couple of days after one of the largest geomagnetic storms, where the maximum Kp= 7-8 for the second half of 17 March 2015, hence the label the "St Patrick's Day storm".

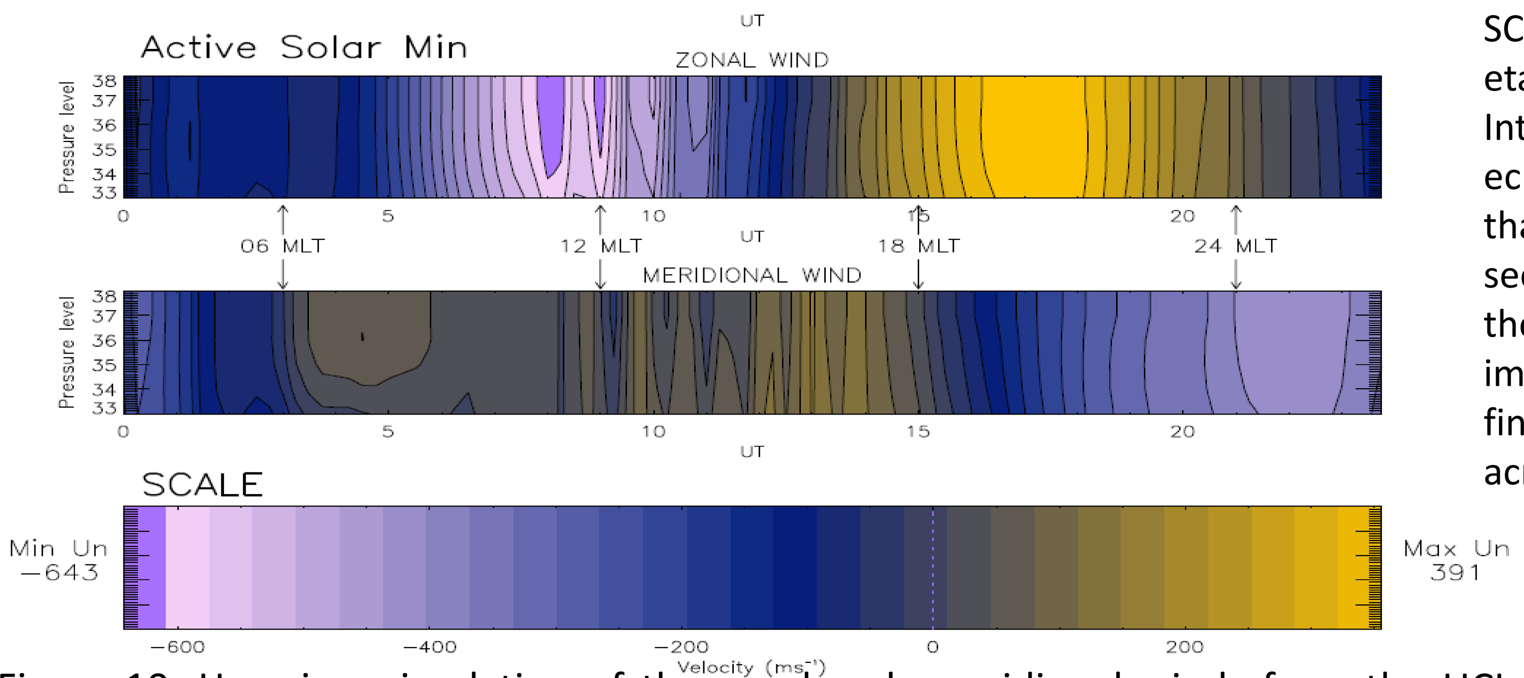

Figure 10: Here is a simulation of the zonal and meridional winds from the UCL Coupled Middle Atmosphere Thermosphere model (CMAT2). The figure shows a height profile (given in terms of pressure levels) over 24 hours at Svalbard for active solar minimum conditions. The f10.7 for March 2015 = 125, and the Kp for the 24 hours before the eclipse varied between 2$^+$ and 5$^-$. The CMAT2 winds for 10UT are zonal winds ~ 400 ms^{-1} and meridional winds ~ 100 ms^{-1}. CMAT2 assumes hydrostatic equilibrium, so its vertical winds are never more than ~ 30 ms^{-1}. The neutral temperatures are around 750K. So larger winds, but lower temperatures than measured by the FPI and SCANDI.

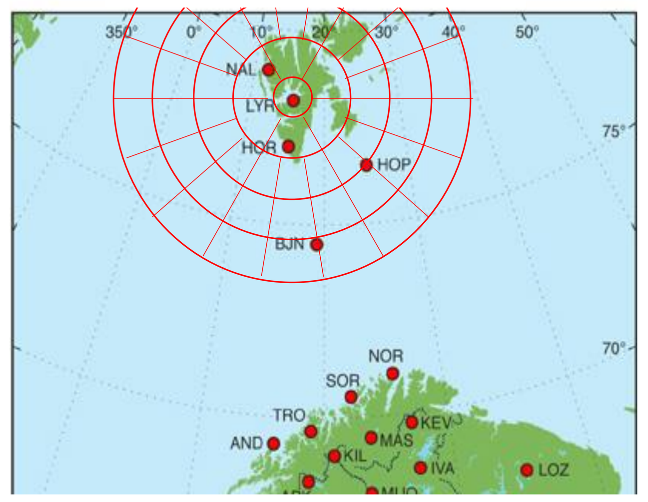

Figure 8: The sky maps down onto the detector and winds and temperatures can be measured for each zone simultaneously, as shown by Figure 9.