WINDS IN THE UPPER MESOSPHERE AT MID-LATITUDE:
FIRST RESULTS USING AN IMAGING FABRY-PEROT INTERFEROMETER.

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Abstract. The first stage of a new midlatitude facility at the Hardware Ranch Observatory near Bear Lake (41.93°N, 111.42°W, 1970 M elevation), for studies of the aeronomy of the middle and upper atmosphere, was completed during early September 1989. An Imaging Fabry-Perot interferometer (IFPI) (Rees et al., 1982; Rees et al., 1990), was commissioned with a special Imaging Photon Detector (IPD) (McWhirter et al., 1982), equipped with a Gallium Arsenide (GaAs) photocathode. Wind and temperature structure can be deduced from observations of the Doppler shift and Doppler broadening of airglow and auroral emissions from the mesosphere and thermosphere. The near infra-red Meinel bands from near 86 km in the upper mesosphere were observed with the IFPI and show 40 ms⁻¹ amplitude wind oscillations, consistent with a semi-diurnal tidal mode.

Introduction

The wind and temperature structure of the upper mesosphere and lower thermosphere is very complex with rapid variations (Rosenberg, 1968; Groves, 1968; von Zahn and Kurzawa, 1989). The complexity and variability results from the interplay of propagating tides, generated in the troposphere and stratosphere (Lindzen, 1970), gravity waves of multiple origin (Chanin and Hauchecorne, 1981), planetary waves within the mesosphere and in-situ forcing from solar heating and possibly also of magnetospheric origin. Amplification of the upward propagating waves and tides causes non-linear interactions in the presence of background mean flows, (Garcia and Solomon, 1985). Wave breaking occurs either when wave amplitudes approach the local speed of sound, or when their phase velocity approximates the background wind speed (including all important wave modes). Eddy dissipation of propagating waves and tides may generate a major fraction of the total energy budget of the upper mesospheric and lower thermospheric region, often exceeding heating from the direct absorption of residual solar UV and EUV sources (Hines, 1965).

The IFPI observes the (P₁(3)) emission line in the (6,2) Meinel band of OH at 843 nm. The emission region is centred near 86 km which corresponds to the upper mesosphere, covering a region of 6 km Full Width Half Maximum (FWHM), (Thomas and Young, 1981; Baker and Stair, 1988); the mesopause is usually at 90 - 95 km (von Zahn and Kurzawa, 1989). The individual lines of the (6,2) OH band are weak (of order 100 Rayleighs), and have been difficult to observe with traditional Fabry-Perot interferometers and detectors (Smith et al., 1987). Photomultipliers and earlier versions of the IPD with S-25

photocathodes have a very low detective quantum efficiency (DQE) beyond 800 nm. The GaAs photocathode of the IFPI at Bear Lake has a high peak DQE of 20%, and its useful sensitivity extends to beyond 950 nm. The thermionic emission of the entire device (256 * 256 pixels) at -25°C is only 80 counts per s⁻¹.

Instrument

The IFPI (Rees et al., 1990) used a 15 cm clear aperture Fabry-Perot etalon, with a fixed etalon gap of 20.49 mm, designed to overlap the lambda-doubled (6,2) OH line at 843 nm. A scanning mirror system selected a sequence of seven views of the sky at 60° zenith angle, and a view of a spectral calibration lamp. A PC-compatible computer controlled the sequence and also integrated, photon by photon, two-dimensional images of the fringe pattern derived by the IFPI. After an integration period of 240 seconds the image, consisting of 256 * 256 pixels, was reduced to a 1-dimensional spectrum by a sample-weighted algorithm (Lloyd, 1985) which counts the photons in a series of 256 equal-area annular rings starting at the centre of the fringe pattern. These annulae correspond to equal increments of wavelength. The complete sequence was repeated throughout the night when the sun was more than 9° below the geometric horizon. The IFPI was entirely automated, limited only by the need for data back-up.

Hydroxyl emissions

The Meinel emissions of the hydroxyl radical result from a photochemical sequence where:

creates OH in an excited state with vibrational levels up to 9. The full photochemical scheme involves the minor mesospheric constituents hydrogen, ozone, atomic oxygen and hydrogen dioxide, and the major constituents molecular oxygen and molecular nitrogen. The hydroxyl photochemistry is discussed in Walterscheid et al., (1987), Walterscheid and Schubert, (1987) and McDade and Llewellyn, (1987).

The average intensity of the OH (6,2) band Meinel mesospheric emission is around 400 - 600 Rayleighs, with extreme variations between 100 and 1000 Rayleighs. Wave structures are frequently observed in wide-angle images of the sky (Peterson and Kieffaber, 1973; Herse et al., 1980; Taylor, 1986). In mesospheric temperature studies (a spectroscopic method based on determining the intensity ratio of various rotational levels within the Meinel bands (Sivjee et al., 1987), quasi-periodic temperature fluctuations have been related to the thermodynamic effects of propagating gravity waves (Hines, 1960; 1965).

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Paper number 90GL00739
0094-8276/90/90GL-00739\$03.00

Altitude Range

The Meinel emissions of OH come from a narrow emission layer at 86 km. The vertical sample of wind and temperature is heavily weighted to the 4 - 6 km region of peak volume emission rate with smaller contributions from above and below.

Near 86 km the major semi-diurnal tidal modes have a vertical wavelength greater than 30 km and the propagating diurnal tidal mode (1,1) has a wavelength of about 20 km, greater than the FWHM of the emission layer and such tides are therefore well sampled. Gravity waves often have vertical wavelengths of the order of 5-10 km and, although tides and waves with longer wavelength components can be resolved clearly, those with shorter vertical wavelengths will be heavily smeared (Hines and Tarasick, 1987). The extent of smearing cannot be estimated (Schubert and Walterscheid, 1988) so that only a lower limit of the wave amplitude can be determined.

Data

Observations of wind from the OH Meinel bands were made from the Centre for Atmospheric and Space Science (CASS, Logan, Utah) for three nights from 30/31 August 1989. The instrument was moved to the Bear Lake Station on 2nd September and run in fully automated mode on the night of September 3/4, and subsequently. The repetitive sequence of sky observations was: North, Northeast, East, Calibration, South, Southwest, West, Northwest, and back to North. With an integration time of 240 seconds, the entire sequence took approximately 33 minutes, including delays for data storage and azimuthal scanning of the mirror (Rees et al., 1990).

In 240 sec., the IFPI typically detected 200,000 signal photons per free spectral range (FSR), giving a wind error estimate due to the statistical fluctuation of integrated photons of around 2 ms^{-1} (Hernandez, 1986). Figure 1 shows the raw data of an interferogram plotted as photon counts versus spectral interval. The average curve-fitting error in the data analysis of these data is about 1 ms^{-1} . The instrument has short to medium term drifts of optical path difference (or zero velocity base-line) equivalent to $5 - 10\text{ ms}^{-1}$, routinely monitored by a R-F excited neon discharge lamp.

Two lines from the neon lamp are transmitted by the pre-filter used to select the OH line at 843 nm. The two neon lines overlap within the free spectral range, reducing the accuracy with which the instrument baseline can be monitored.

Fig. 1. The raw data of an interferogram plotted as photon counts versus spectral interval.

Ultimately, a single-mode stabilised He-Ne laser will be used to monitor the instrument line profile, and the instrument zero velocity base-line. The zero velocity base-line has been defined by presuming that, on an average of a number of clear nights, the paired velocity observations in North and South; East and West, Northeast and Southwest directions should be the same. For monitoring short term behaviour, the average peak position of the Neon calibration lamp obtained for an entire night's observations has been used, in combination with the average offset between the long-term averages of the calibration peak position and OH peak position.

Figures 2 and 3 show, respectively, the meridional and zonal neutral wind components obtained from the IFPI for six consecutive nights. These components were taken from an average wind vector calculated for every 15 minute interval from the observations obtained in all seven azimuthal directions. The wind vector rotated clockwise from southward to westward to northward to eastward during the night and exhibited the phase quadrature expected for a semi-diurnal tide, with the southward wind lagging the westward wind by about 3 hours. There was a night by night variability of the order of $20 - 50\text{ ms}^{-1}$ and phase variability of the order of 1 - 2 hours.

Fig. 2. Meridional neutral wind components obtained from the IFPI for 6 consecutive nights in September 1989.

Fig. 3. Zonal neutral wind components obtained from the IFPI for 6 consecutive nights in September 1989.

During the night of September 1 several rapid oscillations were observed in all viewing directions. In the southwest and northeast directions (Figure 4) there was a particularly

Fig. 4. A large (20 ms^{-1}) coherent oscillation around 0640 UT observed in the southwest and northeast directions, September 1, 1989.

large (20 ms^{-1}) coherent oscillation around 0640 UT (max. flow to the northeast). This flow was consistent with a propagating wave crossing the entire field of view (approximately 300 km diameter, assuming a mean emission altitude of 86 km). A delay of 30 minutes between the observation of this wave in the northeast and later in the southwest, corresponded to an apparent phase velocity of 200 ms^{-1} . There was, however, quite inadequate information to determine the full 3-dimensional characteristics and direction of propagation of this wave.

Transient disturbances have also been observed, for example in the data of 9 Sept 1989, (Figure 5). A short period transient northeastward flow was observed briefly at 0517 UT in the south and at 0522 UT in the southwest direction. This disturbance was not observed in other directions.

It is not clear if these disturbances were caused by a localised source, a compressive wave, or some class of 'front' with an abrupt discontinuity. Possibly, the disturbances were due to a propagating wave, with a tilted surface of propagation, viewed where it intercepted the observing screen of the OH emission layer, near 86 km altitude.

Discussion

On any given night, the winds observed by the IFPI from the Meinel emissions near 86 km have usually been consistent with a semi-diurnal variation, with a typical amplitude around 40 ms^{-1} . The wave phase is consistent with predictions of theoretical models, (Forbes, 1985). Amplitudes predicted by the theoretical model of the semi-diurnal tide are, however, only some $5 - 10 \text{ ms}^{-1}$ at 86 km (rather than the observed 40 ms^{-1}

Fig. 5. Transient disturbances observed briefly at 0517 UT in the south and at 0522 in the southwest directions, September 9, 1989.

1), increasing rapidly to $20 - 30 \text{ ms}^{-1}$ around 100 km altitude. Wind data averages over periods of 16 nights (the initial data set available from Bear Lake), give a mean semi-diurnal amplitude around 20 ms^{-1} , still considerably larger than theoretical model predictions.

The mean average semi-diurnal phase is similar to that obtained from individual nights, although the phase varies typically by 1 - 3 hours from night to night. The day to day phase variability appears to be responsible for the reduction in the average semidiurnal tidal amplitude from 40 ms^{-1} to 20 ms^{-1} .

In the region from 80 to 100 km, there are several other sources of observational wind data. Rocket-borne chemical and chaff releases have provided the best quality instantaneous wind profiles in this region, while Meteor radar, MST radar, HF Doppler and incoherent scatter radar have provided the majority of data on tidal amplitude and phase. Peak instantaneous winds around 86 km in the range $50 - 80 \text{ ms}^{-1}$ have often been reported. More rarely, peak values of the order of 100 ms^{-1} , or larger, have been reported (Rosenberg 1968). The H.F. Doppler radar at Saskatoon rarely shows semidiurnal wind amplitudes in excess of $20 - 30 \text{ ms}^{-1}$ below 90 km (Manson and Meek, 1986).

Two particular classes of short period disturbances occurred within the data sets. On September 1, a disturbance crossed the entire field of view (300 km diameter) observable by the IFPI with an apparent phase velocity of 200 ms^{-1} or 720 km.hr^{-1} . On other occasions, quite large temporary wind disturbances have been limited to only a part of the observed region, and it has not been possible to determine the source or direction of propagation of the disturbance.

The IFPI is now in regular operation, and is expected to provide a large data base over several years. The stabilised single-mode He-Ne laser will calibrate the instrument function, permitting routine temperature as well as wind measurements. As additional optical and radar facilities are commissioned at the Hardware Ranch a series of cooperative and comparative measurements using the combined facilities will be conducted for a range of studies of the mesosphere and lower thermosphere, as part of the STEP programme.

Acknowledgements: The Hardware Ranch (Bear Lake) Facility of CASS, Utah State University is supported by grants from the National Science Foundation. Further general assistance with the project was made available by grants to University College London from the UK Science and Engineering Research Council.

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(Received January 29, 1990;
revised March 20, 1990;
accepted March 26, 1990)