Journal of Atmospheric and Solar-Terrestrial Physics 102 (2013) 125–139

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

A ground-based spectrometer equipped with an InGaAs array for routine observations of OH(3-1) rotational temperatures in the mesopause region

Carsten Schmidt [a,*], Kathrin Höppner [a], Michael Bittner [a,b]

[a] German Aerospace Center (DLR-DFD), German Remote Sensing Data Center, 82234 Wessling, Germany
[b] Augsburg University (UNA), 86135 Augsburg, Germany

ARTICLE INFO

Article history:
Received 13 July 2012
Received in revised form
25 March 2013
Accepted 6 May 2013
Available online 14 May 2013

Keywords:
Airglow
MLT region
Instrumentation
NDMC

ABSTRACT

We present a new spectrometer with high temporal resolution for the observation of OH Meinel band emission dynamics in the spectral range between 1.5 μm and 1.6 μm. The instrument was developed and is now in operation at the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) in Oberpfaffenhofen (11.27°E, 48.08°N), Germany—a measurement station of the international Network for the Detection of Mesosphere Change (NDMC). It is equipped with a thermoelectrically cooled 512 element InGaAs-photodiode array (PDA) and a polychromator with a grating blazed for 1.6 μm. During routine operation one spectrum is obtained every 15 s, originating from a field of view of approximately $15^\circ \times 15^\circ$ corresponding to $\sim 24 \times 24\,km^2$ in 87 km height, the peak height of the OH emission layer. The covered wavelength range allows the observation of the OH(3-1) Q- and P-branches as well as of the OH(4-2) R- and Q-branches. Rotational temperatures are calculated using OH(3-1) P-branch emissions between 1.52 μm and 1.55 μm. Being the successor of the older scanning grating spectrometers of the GRIPS type it is named Ground-based Infrared P-branch Spectrometer (GRIPS 6).

A fully automated data acquisition and analysis scheme has also been developed, that covers the complete processing chain from data recording to derivation of rotational temperatures and to long-term archiving. For the estimation of a nocturnal mean value all samples of the nightly temperature time series are weighted according to their individual precision. Thus, mean temperatures between 1 and 2 K are lower compared to the unweighted arithmetic mean. Data products are archived at the World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT) and results are displayed at the website of the Network for the Detection of Mesosphere Change (NDMC). A summary of the data obtained during the first 40 months of operation at the German Remote Sensing Data Center as well as aspects of data processing efforts are presented.

1. Introduction

The observation of airglow features by spectroscopic methods is a widely used method for the determination of upper mesospheric parameters. In particular, rotational temperatures and brightness variations derived from emission spectra of excited hydroxyl- or oxygen-molecules are commonly studied (e.g., López-González et al., 2007; von Savigny et al., 2004; Bittner et al., 2002; Scheer and Reisin, 2000). The derived quantities allow the determination of long-term trends (e.g., Beig et al., 2003; Beig, 2006) and the investigation of upper mesospheric dynamics such as planetary waves (e.g., López-González et al., 2009; Höppner and Bittner, 2007; Murphy et al., 2007; Buriti et al., 2005; Takahashi et al., 2002), gravity waves (e.g., Offermann et al., 2009; Simkhada et al., 2009; Reisin and Scheer, 2001) or infrasound (Bittner et al., 2010).

OH airglow features can be observed from the visible wavelength range up to beyond 2 μm in the infrared, with its brightest emissions occurring between 1.4 μm and 1.7 μm (OH(2-0), OH(3-1) and OH(4-2) vibrational transitions (e.g., Leinert et al., 1998, Rousselot et al., 1999)). However, certain spectral regions are favoured for ground-based observation of the nightglow, one in the visible range around 730 nm for the observation of OH(8-3), one around 860 nm for simultaneous observation of the OH(6-2) and O_2(0-1) transitions and one beyond 1.5 μm for the observation of the bright OH(3-1) and OH(4-2)-bands. Although intensities in the shorter wavelength region are lower, these transitions can be recorded with sensitive silicon-based detectors (e.g., Scheer, 1987; Wiens et al., 1997). Observations of the brighter emissions between 1.5 μm and 1.7 μm are more difficult, since they require

* Corresponding author. Tel.: +49 8153 28 1335; fax: +49 8153 28 1363.
E-mail address: carsten.schmidt@dlr.de (C. Schmidt).

1364-6826/$ - see front matter
http://dx.doi.org/10.1016/j.jastp.2013.05.001

the application of low noise Germanium or InGaAs-photodiodes mostly integrated in scanning or Fourier transform spectrometers (e.g., Bittner et al., 2000; Mulligan et al., 1995). On the one hand the temporal resolution of scanning spectrometers is limited by the time needed for the scan of one spectrum, the operation of interferometers on the other hand demands precise calibration and environmental stabilization of the complete instrument.

To our knowledge Suzuki et al. (2008) were the first to utilize an InGaAs-photodiode array (PDA) for the study of airglow and aurora between 850 nm and 1000 nm to overcome decreasing responsivity of silicon-based detectors in the long wavelength regime. Here we present a medium resolution grating spectrometer with an InGaAs-PDA specifically utilized for the observation of the bright OH-airglow emissions between 1.5 μm and 1.6 μm. The high temporal resolution of only 15 s per spectrum, which can be achieved with this instrument, is significantly higher than the atmospheric Brunt-Väisälä frequency. This is considerably higher than the temporal resolution achieved by most scanning grating spectrometers, making it well suited for the study of short periodic atmospheric waves, e.g., gravity and even infrasonic waves (see Bittner et al., 2010). The overall setup of the instrument is relatively simple, robust and compact compared to, e.g., Fabry-Pérot- or Fourier-Transform spectrometers. Together with its low maintenance requirements, these features make the instrument ideally suited for routine observation of nightglow parameters.

The so-called Ground-based Infrared P-branch Spectrometer instrument (GRIPS 6) located at Oberpfaffenhofen (11.27°E, 48.08°N), Germany, is one of a series of new instruments and it is integrated in the Network for the Detection of Mesosphere Change (NDMC), a global program with the mission to promote international cooperation among research groups investigating the mesopause region (80–100 km). The initial focus of NDMC is the early identification of changing climate signals. The international network consists of currently 50 globally distributed measurement stations (http://wdc.dlr.de/ndmc).

The overall question addressed by NDMC focuses on global change: “Is the climate of the mesopause region (80–100 km) changing and if so, how and why?” Consequently, NDMC must meet the following objectives: (1) Identification and quantification of climate change by monitoring key parameters such as temperature and airglow brightness in the mesopause region to enable the early characterization of climate signals and the identification and quantification of variability at different time scales, such as seasonal variations and solar cycle effects. (2) Detection of solar activity effects at all time scales (so-called space weather related phenomena). (3) Addressing other scientific challenges related to atmospheric dynamics at different time scales including the description and the causes of the variability of periodic and quasi-periodic processes such as acoustic and gravity waves, tides and planetary waves as well as seasonal and interannual variations. In addition, episodic events caused by external forcing must be monitored. (4) Validation of satellite instruments and their use for intercomparison with ground-based instruments. (5) Participation in the development of future instrumentation.

The initial investigations of NDMC focus on mesopause region airglow techniques utilizing the existing ground-based and satellite measurement capabilities. Collaboration with researchers using other techniques in the mesopause and mesosphere region are strongly encouraged. NDMC is affiliated with the Global Atmosphere Watch (GAW)-program of the World Meteorological Organization (WMO) and with the Network for the Detection of Atmospheric Composition Change (NDACC). NDMC has established a central data management platform hosted by the WMO/ICSU - World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT), which also acts as NDMC's communication platform.

The paper is organized as follows. First we describe the instrument including the calibration activities. The operational concept is presented in Section 2, followed by a description of the routine operating mode and data analysis scheme in Section 3. In Section 4 the results are discussed in more detail. These include the considerably high data quality, which is characterized by an average completeness of the dataset of 80% during the first three years of operation, as well as the low uncertainty of the derived rotational temperatures, which make the instrument well suited for the study of atmospheric dynamics on many time scales from the infrasonic frequency regime to the study of planetary waves on time scales from days to weeks.

2. Instrumentation and concept of operation

2.1. Instrumentation

The GRound-based Infrared P-branch Spectrometer instrument (GRIPS 6) is equipped with a thermoelectrically cooled 512 pixel InGaAs-photodiodearray (PDA) and a polychromator with 163 mm focal length, both manufactured by ANDOR™ Technology. It is mounted in an upright position allowing observations in the zenith direction. The field of view is mainly governed by the F-number of the polychromator, because the instrument is operated with no further objective lenses or mirrors (see Fig. 1). Thus we get an entrance angle of 15.5°, which corresponds to a field of view of approximately 24 km × 24 km at the peak height of the emitting OH layer of 87 km ± 4 km (e.g., Baker and Stair, 1988). The reflection grating is blazed for 1.6 μm and the entrance slit width is set to 300 μm, yielding a resolving power of $\lambda/\Delta\lambda = 505$ corresponding to a spectral resolution of ~3.1 nm at a wavelength of $\lambda = 1550$ nm. The maximum spectral resolution is limited by the finite extent of the single pixels of 25 μm, which was determined to translate into 0.195 nm per pixel. Therefore, the instantaneous wavelength range covered during a single exposure is about 99.8 nm, covering the wavelength regime from 1502 nm to 1602 nm. This enables the measurement of the OH(3-1) Q- and P-branches and the OH(4-2) R- and Q-branches up to the first line of the OH(4-2) P-branch (see Fig. 2). The slit width of 300 μm for the system was chosen, because it yields the best trade-off between spectral resolution and the amount of collected light. Table 1 presents a short overview of the key parameters of the complete instrument.

2.2. Calibration

The wavelength range covered by the instrument is determined by measuring the spectrum of an OSRAM cd/10 cadmium lamp for all reflection grating angles allowed by the mechanical layout of the polychromator. The coverage extends from the grating's zero order reflection to well beyond 2 μm, as can be seen in Fig. 3. The complete spectrum was obtained from 36 exposures at different grating angles, with an average spectral overlap of one third during successive exposures. These single spectra have been put together to form one virtual spectrum consisting of 12,000 pixels. These pixels have then been transformed into wavelengths using a fifth order polynomial fit to 48 emission lines and their higher orders, which could be identified in this spectrum. The shortest line identified in the spectrum is the 325.25 nm Cadmium emission; wavelengths beyond 1648.2 nm are all higher orders of shorter wavelengths. The wavelengths of the Cadmium emission lines are taken from Kayser and Ritschl (1939) and Zaidel' et al. (1970).

During routine operation – with the grating set to a fixed position – the validity of the wavelength calibration is assured by