monitoring middle atmospheric water vapour at polar latitudes

Pietro Paolo Bertagnolio[1,2] and Giovanni Muscari[1]

1 - Istituto Nazionale di Geofisica e Vulcanologia - Via di Vigna Murata 605, 00143 Roma, Italy
2 – Dipartimento di Scienze della Terra - University of Siena – Via Laterina 8, 53100 Siena, Italy
pietropaolo.bertagnolio@ingv.it

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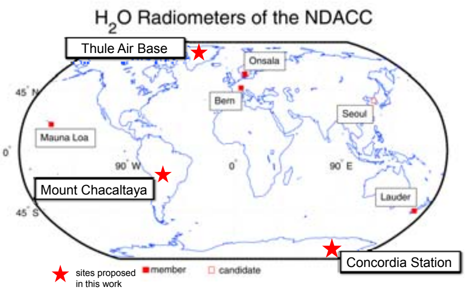
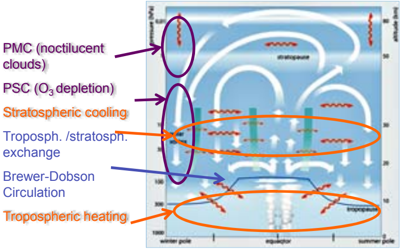


Water vapour in the middle atmosphere

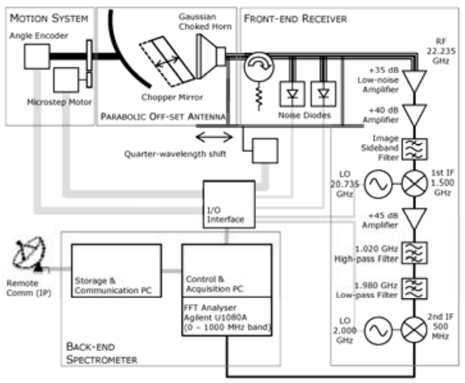
Water vapour is a crucial element of the climate system. Accurate observations of stratospheric humidity are needed in the equatorial belt, where water vapour crosses the tropopause, and in the polar regions, that are affected the most by climate change trends [IPCC, 2007; Solomon et al., 2010]. Satellite-based observations provide atmospheric composition data with extensive spatial and temporal coverage, but these need to be validated and integrated by ground-based networks like GAW and NDACC. Changes in middle atmospheric water vapour on time scales longer than the duration of a satellite mission have been successfully observed by ground-based instruments [Nedoluha et al., 2009]. Several ground-based spectrometers have been developed in the last decades to detect the water vapour rotational emission line at 22.235 GHz with heterodyne microwave receivers [e.g., Nedoluha et al., 2009; Straub et al., 2011, Forkman et al., 2003, De Wachter et al., 2011] (see map on the left). The proposed sites for long-term installation of the new spectrometer are Concordia Station, Antarctica (3233 m asl 75.10°S, 123.3°E, NDACC site) or Thule Air Base, Greenland (76.5°N, 68.8°W; NDACC site) for polar monitoring, or Mount Chacaltaya, Bolivia (5.320 m asl, 16.2ºS, 68.1ºW, GAW site) for tropical observations.

Climate impact of middle atmospheric water vapour



A new instrument: VESPA-22 (water Vapour Emission SPectrometer for Antarctica at 22 GHz)

Instrument design



The water Vapour Emission SPectrometer for Antarctica at 22 GHz (VESPA-22) has two main science objectives: provide long-term (decadal time scale) as well as short-term (diurnal) observations of water vapour variations from observatories at high altitude/high latitude (characterized by low atmospheric opacity).

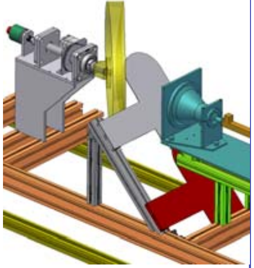
The radiation emitted by water vapour molecules in the atmosphere is collected, through an off-axis parabolic reflector and a feedhorn antenna, by a single side-band uncooled heterodyne receiver (front-end). Once the signal is properly amplified and down converted in frequency, a high resolution FFT spectrometer (back-end) is used for digital acquisition.

The need to maximise the effective observation time led us to adopt a balanced beam-switching configuration with a chopper mirror sliding at ~1 Hz.

The sky is observed at two different angles:

- the "signal beam" 10-20° above the horizon
- the "reference beam" near the zenith direction (a weak grey-body is added to balance the wide-band power.)

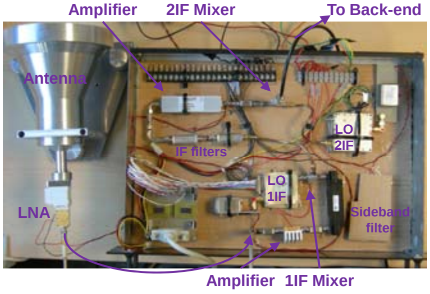
The difference spectrum (signal – reference / reference) is then independent from gain variations in the receiver.



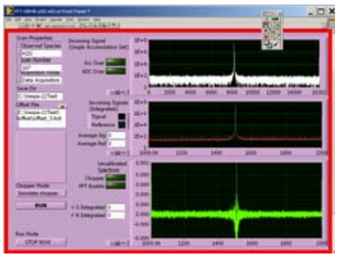
3D model of the VESPA-22 optical system. On the lower right the chopper mirror is shown in "signal" position (red) and "reference" position (grey). On the left is the parabolic mirror axle with the high precision motion control system. A 51200-microstep motor is linked to the axle by high precision aluminium gears with a ratio of 1:5. The angle is tracked by a 13-bit absolute encoder, resulting in an overall precision on the elevation angle of 0.07°.

Observation goals		Instrument specifications	
Observation angle	10°-15°	Spectral resolution (B)	61 kHz
Signal-to-noise ratio (SNR)	115	Spectrometer bandwidth	1 GHz
Total integration time (ttot)	12 hrs (1 h if binned)	Antenna beamwidth (HPBW)	3.5°
Altitude range of profiles	20 - 80 km	Effective observation time (t / ttot)	40%
Profile accuracy	15%	System temperature (Tsys)	≈ 165 K

Front-end receiver test with artificial source

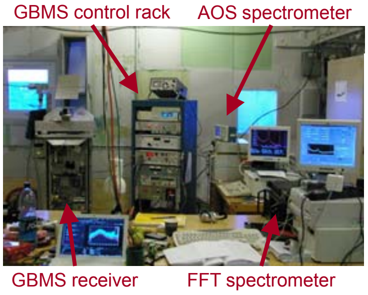


Front-end receiver test setup. The low-noise amplifier (LNA) has a 125 K noise temperature. When observing the sky, the system has an output power of -30 dBm.



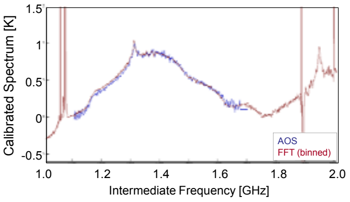
The horn antenna, front-end receiver and back-end spectrometer the have been tested with an artificial signal at 22.235 GHz emitted with a calibrated antenna (photo on the left, source in the foreground, receiver in the back). On the right, screenshot of the acquisition software with the signal measured by the FFT spectrometer.

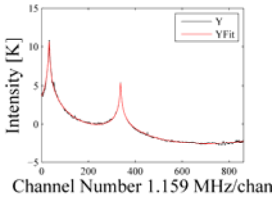
Back-end FFT spectrometer comparison with AOS at Thule Air Base



The GBMS setup at Thule Air Base during the comparison between the FFT back-end spectrometer of VESPA-22 (61 kHz resolution, 1 GHz bandwidth) and the wideband AOS back-end of GBMS (1.176 MHz resolution, 600 MHz bandwidth).

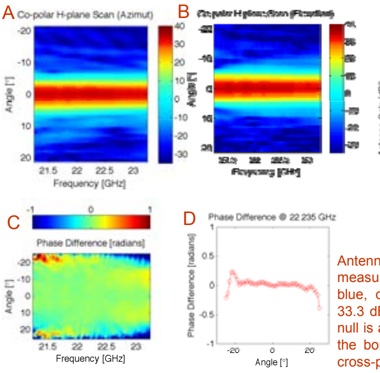
The back-end spectrometer (an Agilent U1080A FFT Analyser) has been tested on a field campaign at Thule Air Base during winter 2011. The Ground Based Microwave Spectrometer (de Zafra, 1995) measured stratospheric trace gases emission spectra between 230 and 280 GHz. The spectra have been acquired with both the wideband AOS spectrometer of GBMS and the new FFT spectrometer of VESPA-22.



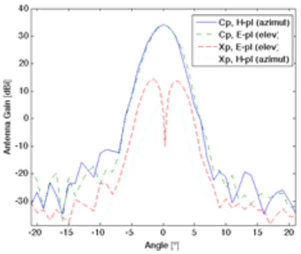


Nitric acid (left) and ozone (right) emission lines observed by GBMS using the FFT spectrometer. Comparison with the AOS spectrometer (left, blue) shows a good agreement between them regarding both linearity and noise. The wider spectral range of the FFT system, which allows the simultaneous retrieval of different emission lines, can be noticed. On the right the forward-model spectrum used for O_3 retrievals is shown together with the measurements.

Characterization of the optical system



The whole optical system (horn antenna + reflector) has been characterized in a semi-anechoic chamber at the Microwave Eurolab (ISCTI, Roma) – see photo above. The far-field spectral-dependent antenna pattern for all principal planes doesn't show significant spectral features (figures A and B). Near-field phase measurements of the feedhorn show that the wave front of the beam matches the curvature of the spherical reflector (figures C and D).



Antenna pattern of the whole optical system measured at 22.235 GHz. On the co-polar plane (solid blue, dashed green) the boresight antenna gain is 33.3 dBi, the half-power beamwidth is 3.5°. The first-null is at ~7.5°, with a sidelobe level 45 dB lower than the boresight maximum. The maximum gain on the cross-polar plane (dashed red, dotted blue) is 24 dB lower than the boresight maximum.

Further development goals

- Measurement of the effective receiver temperature with a hot-cold calibration
- Study of the different materials for housing, shielding and calibration
- First atmospheric tests planned for Winter 2011-2012
- First field campaign planned for Summer 2012

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R. de Zafra, State University of New York, Stony Brook, NY, USA.

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