Overview on satellite experiments which measure atmospheric water vapor

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Abstract

Environmental satellites with the capability of measuring atmospheric water water have been launched since the early seventies. The measurement method, latitudinal coverage, data quality and availability have to be taken into account before choosing a particular experiment. An overview of the main experiments which measure water vapor with the principal characteristics is compiled here. Links to main references are given. The experiments are classified into three categories, the experiments sounding the lower part of the atmosphere in the first part, the experiments sounding the upper part of the atmosphere in the second part, and the experiments sounding both the lower and the upper atmosphere in the third part.

Chapter 1

Introduction

Water vapor plays a very important role in the climate system. In the atmosphere, its concentration varies vertically and horizontally and represents approximately 0% to 4% of the atmospheric composition. The vertical distribution of water vapor roughly follows an exponential decrease from the earth surface up to the lower stratosphere, then remains at relatively low values, as illustrated in Fig. 1.1. Therefore, water vapor is mostly situated in the troposphere (0–10 km altitude). Horizontally, water vapor is heterogeneously distributed, depending on the latitude and on the weather conditions. Its concentration is higher in the hot, humid tropical regions, and lower in the cold, dry polar regions. In the atmosphere, water vapor is a strong greenhouse gas, with many absorption lines in the longwave range of the frequency spectrum. It has also a large latent heat. These properties make water vapor a key player in the earth energy transport and in the earth energy budget.

Therefore, measuring the amount and the distribution of water vapor in the atmosphere is of major importance. Three main methods are used to routinely measure atmospheric water vapor: (i) *In-situ* measurements, i.e., radiosounding, (ii) remote sensing from the ground, i.e., ground-based radiometry, and (iii) remote sensing from space, i.e., satellite radiometry. *In-situ* measurements using radiosondes have the main advantage of a high vertical resolution, but the disadvantages of being expensive on the long run, have a low temporal resolution (usually 1-2 launches/day), a low spatial distribution (point measurement), a questionable accuracy, and are sparsely distributed on the earth surface. From the ground, ground-based radiometers have the advantage of continuous and reliable measurements, working on most weather conditions. The main disadvantage being the low spatial resolution. From space, satellite-based radiometers have the advantages of allowing global coverage of the earth and reliable measurements. Satellite-based radiometry have some disadvantages, amongst: integrated water

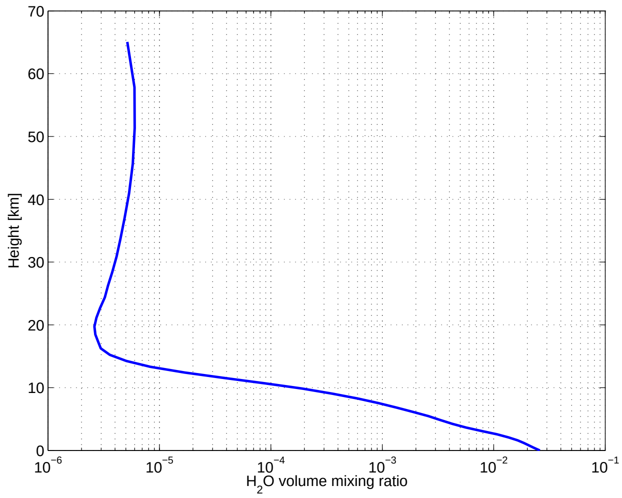

Figure 1.1: Vertical distribution of water vapor for a standard atmosphere (Source: US Standard Atmosphere 1976).

vapor is measured accurately only over the oceans, where the ground emissivity is known, the vertical resolution is rather coarse, and there are difficulties to obtain profiles of the lower layers of the atmosphere, especially the first few kilometers of the troposphere.

Satellite-based instruments use different observing geometries in order to sound different altitude ranges. Two observing geometries are commonly used, the downlooking geometry on the one hand, and the limb geometry on the other hand (See schematic in Fig. 1.2). In downlooking geometry, the radiometer points at the atmosphere with the earth in the background and measures the atmospheric emissions. Different frequencies are used to sound different altitude ranges. Usually, the radiance is measured along the satellite track in a continuous mode. This technique allows the sounding of the stratosphere and the troposphere. It gives best results over the oceans. In limb geometry, the radiometer points at a known source of radiation, usually the sun or the moon, and monitor the radiance while the source sets behind the horizon. From the attenuation of the transmitted signal one can retrieve the water vapor concentrations at the sampled altitudes. This technique is primary used to retrieve profiles in the stratosphere, but is not appropriate to retrieve profiles at the lower altitudes. The sampled path becomes too opaque. In limb geometry, only a maximum of 2 or 4 profiles per orbits are produced.

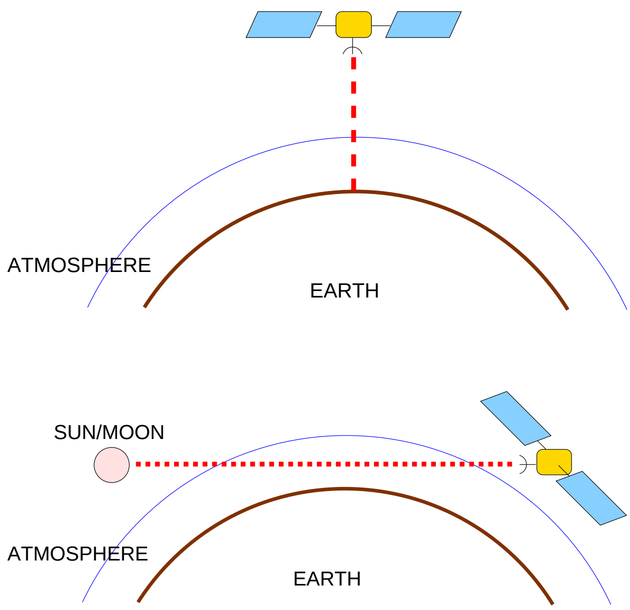

Figure 1.2: Schematic of two observation geometries. Top: downlooking geometry, the radiometer points at the atmosphere with the earth in the background. Bottom: limb geometry, the radiometer points at a known source of radiation.

The applications of satellite-based water vapor measurements is large. It covers climate research and monitoring of the atmospheric parameters, for weather forecast and meteorology for instance. The data on water vapor can also be used for validation experiments using surface-based sensors (radiometers, radiosondes), for the extension of water-vapor database like Startwave [Morland et al., 2006] or for the extension of satellite-derived profiles to surface with surface-based instruments.

In this report, we review the satellite experiments measuring atmospheric water vapor. The experiments are classified into three categories: The experiments sounding the troposphere in Chapter 2 , the experiments sounding the stratosphere in Chapter 3, and the experiments sounding both the troposphere and the stratosphere in Chapter 4. Chapter 5 shows a summary of the experiments characteristics. Chapter 6 presents the conclusions.

Chapter 2

Sensors measuring water vapor in the troposphere

2.1 AMSU-B

- Platform: NOAA 15, 16 and 17
- Launch: May 1998
- Orbit: 850 km, polar orbit
- Inclination: 98.7°
- Period: 101 min
- Latitudinal coverage: Global
- Sounding altitude: Lower troposphere to lower stratosphere
- Measurement method: Cross-track microwave radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 1998 – present
- Data availability: Data to be ordered from NOAA CLASS (http://www.class.noaa.gov/nsaa/products/welcome)

The Advanced Microwave Sounding Unit (AMSU) instrument was meant for temperature and water vapor sounding of the atmosphere. This unit is composed of two distinct parts: AMSU-A and AMSU-B. AMSU-A was made for the sounding of atmospheric temperatures, from surface to about 45 km altitude, whereas AMSU-B was made for the sounding of atmospheric humidity. The instrument is aboard three satellites on polar orbit (NOAA-15, -16 & -17), which have approximate observing times (at the equator) of 0700/1900, 0200/1400, and 1000/2200 LST. There are 14 rotations per day; it has a large time and space coverage.

AMSU-B has three channels sounding tropospheric water vapor, they are centered around the strong 183.31 GHz water vapor line. The footprints of AMSU-B vary from $20{\times}16\,\mathrm{km}^2$ at the innermost scan position to $64{\times}27\,\mathrm{km}^2$ at the outermost scan position. Data are available at the NOAA's Comprehensive Large Array-data Stewardship System (CLASS).

References:
Saunders et al. [1995]
Weng et al. [2003]

2.2 AIRS

- Platform: AQUA
- Launch: May 2002
- Orbit: 705 km, sun-synchronous
- Inclination: 98.2°
- Period: 98.8 min
- Latitudinal coverage: Global
- Sounding altitude:
- Measurement method: Infrared spectrometer
- Vertical resolution: N/A
- Error: N/A
- Data: 2002 – present
- Data availability:

The Atmospheric Infrared Sounder (AIRS) was launched in May 2002 aboard NASA's weather and climate research satellite Aqua.

AIRS retrieves Earth's atmospheric temperature and water vapor in 3D on a global scale every day. It has been specifically designed to measure global water vapor and greenhouse gases. AIRS is a grating array spectrometer, which covers the 640 – 2700 cm^{-1} region of the infrared spectrum (3.7 – 15.4 $\mu\mathrm{m}$). Absolute radiometric accuracy between 220K and 320K at all scan angles is better than 0.2K. Online visualization and analysis tools are available.

Visualisation tools:
http://acdisc.sci.gsfc.nasa.gov/Giovanni/haloe/

References:
http://www-airs.jpl.nasa.gov/
http://airs.jpl.nasa.gov/researchers/publication_list.html

2.3 NEMS

- Platform: Nimbus 5
- Launch: 1972
- Orbit: 1110 km, sun-synchronous
- Inclination: 99.8°
- Period: 107 min
- Latitudinal coverage: Near global
- Sounding altitude: N/A
- Measurement method: Nadir radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 1972 – 1983
- Data availability: N/A

The Nimbus E Microwave Spectrometer (NEMS) experiment was among the first application of microwave techniques for the remote sensing of atmospheric temperatures from an earth-orbiting satellite. NEMS provided atmospheric temperature profiles in the presence of clouds. NEMS was the forerunner of the AMSU on the NOAA operational satellites (see Section 2.1).

The NEMS views nadir continuously with a spatial resolution of approximately 200 km, and, at two-second intervals, measures microwave radiation at five wavelengths near the 5 mm oxygen resonances and the 1.35 cm water vapor resonance. The center-frequencies are 22.235, 31.4,53.65,54.9 and 58.8 GHz. It views nadir with half-power beam widths of 10 degrees. Each channel is an independent super-heterodyne, load-switched radiometer with pass bands from 10 to 110 MHz on each side of its center-frequency.

The relative calibration of the instrument from one day to the next is believed to be better than 0.2 K, and the absolute accuracy is believed to be approximately 2 K. On the ground the data are averaged over time intervals of 16 seconds, which yields a root-mean-square sensitivity of 0.1 to 0.2 K.

Reference:
Staelin et al. [1972]

2.4 SSM/I

- Platform: DMSP series (F08, F10, F11, F12, F13, F14, F15)
- Launch: 1987 (F08)
- Orbit: 850 km, near-circular, sun-synchronous, and near-polar
- Inclination: 98.8°
- Period: 102 min
- Latitudinal coverage: Near-global
- Sounding altitude: N/A
- Measurement method: Conical scan microwave radiometer
- Vertical resolution: N/A
- Error: Absolute accuracy IWV 2.0 $\mathrm{kg/m^2}$
- Data: 1987 to present
- Data availability: National Snow and Ice Data Center DAAC (NSIDC DAAC) http://www.earth.nasa.gov/data/daac/nsidc_daac.html http://www.earth.nasa.gov/data/daac/nsidc_daac.html

The SSM/I is a seven-channel, four-frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0, and 85.5 GHz. Each of the seven channels of SSM/I is measured from a separate total-power radiometer. All radiometers simultaneously measuring the microwave emission coming from the Earth and the intervening atmosphere. Dual-polarization measurements are taken at 19.35, 37.0, and 85.5 GHz, and only vertical polarization is observed at 22.235 GHz. Spatial resolutions vary with frequency.

Observations at the lower frequencies are only taken every other scan and are sampled 64 times over the arc. This sampling pattern results in a 12.5 km pixel spacing at 85 GHz and a 25 km pixel spacing at the lower frequencies.

Data available at the National Snow and Ice Data Center DAAC (NSIDC DAAC) as daily binary data files on a 0.25 x 0.25 degree grid. Well documented Matlab reading routines provided on the website.

References:
http://podaac.jpl.nasa.gov:2031/sensor_docs/ssmi.html
http://dmsp.ngdc.noaa.gov/html/sensors/doc_ssmi.html
http://www.ssmi.com

2.5 MERIS

- Platform: Envisat
- Launch: March 2002
- Orbit: 800 km, sun-synchronous
- Inclination: 98°
- Period: 100.6 min
- Latitudinal coverage: Global
- Sounding altitude: N/A
- Measurement method: Passive nadir spectrometer
- Vertical resolution: Better than 2 km
- Error: N/A
- Data: 2002 - present
- Data availability: http://envisat.esa.int/dataproducts/meris/

The MEdium Resolution Imaging Spectrometer Instrument (MERIS) was primarily dedicated to Ocean Color Observations. It has in the past broadened its scope of objectives to atmospheric and land surface related studies. This instrument has measurements in 15 spectral bands, in the visible and near infrared. MERIS allows global coverage of the Earth in 3 days. The FOV is 68°, swath width of 1150 km centered around the sub-satellite point. Resolution on the ground at nadir: 260x290m^2.

Channels used for water vapor measurements: (i) Channel 13 (Band center: 865 nm, band width: 20 nm), (ii) Channel 15 (Band center: 900 nm, band width: 10 nm). The MERIS water vapor product is a measurement of the concentration in g.m^{-2} of water vapor found in the total atmospheric column.

Water vapor data available at Level2 (referred to as MER_RRC_2P). The MERIS retrieval algorithm for total water vapor content reaches a radiometric accuracy of 2–4%, and for the geophysical product: 10% relative to amount of water vapor over land surfaces and sun glitter, less than 20% over water surfaces.

References:
http://envisat.esa.int/instruments/meris/
http://envisat.esa.int/dataproducts/meris/toc.htm

Retrieval of Total Water Vapor Content from MERIS measurements:
http://naftali.meteor.wisc.edu/ ralf/atbd_2_04.pdf

2.6 TMI

- Platform: TRMM
- Launch: November 1997
- Orbit: 350 km
- Inclination: 35°
- Period: 90 min
- Latitudinal coverage: 40°S to 40°N
- Sounding altitude: N/A
- Measurement method: Conical scan microwave radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 1997 to spring 2005 (subject to further extension)
- Data availability: Orders at NASA's GES DISC DAAC (http://daac.gsfc.nasa.gov/)

The TRMM Microwave Imager (TMI) is a 9-channel/dual-polarized passive microwave radiometer that provides data related to rainfall rates over the oceans. It is aboard the Tropical Rainfall Measuring Mission (TRMM). TMI is a conical scan radiometer (49°), similar to SSM/I (see Section 2.4), and contains lower frequency channels required for sea surface temperature retrievals. The entire data set includes sea surface temperatures, surface wind speeds derived using two different radiometer channels, atmospheric water vapor, liquid cloud water and rain rates. Only data over the oceans are processed.

The TMI observed brightness temperatures are sensitive to integrated quantities of water vapor, liquid water, and ice in the atmosphere, as well as surface temperature and wind speed over ocean regions. The root-mean-square retrieval accuracy for columnar water vapor is 1.2 mm. Horizontal resolution: 5 km (highest frequencies) to 40 km (lowest frequency channels).

TRMM was launched in 1997, and originally designed as a three-year research mission. Following four years of extension, the TRMM program was due to end in spring 2005.

References:
http://trmm.gsfc.nasa.gov/
Kummerow et al. [1998]
Kummerow et al. [2000]

2.7 AMSR

- Platform: ADEOS II
- Launch: December 2002
- Orbit: 803 km, sun-synchronous sub-recurrent orbit
- Inclination: 98.6°
- Period: 101 min
- Latitudinal coverage: Global
- Sounding altitude: N/A
- Measurement method: Conical scan microwave radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 2002 - present
- Data availability: Available from the Earth Observation Center, JAXA

The Advanced Microwave Scanning Radiometer (AMSR) is aboard the Advanced Earth Observing Satellite-II (ADEOS-II). AMSR is an eight-frequency, total-power microwave radiometer with dual polarization (except two vertical channels in the 50GHz band). Conical scanning is employed to observe the Earth's surface with a constant incidence angle. Calibration counts are obtained every scan by using the hot load target (around 300K) and the cold-sky mirror to introduce the temperature of deep space (around 3K).

Range of the water vapor retrieval is between 0 and 70 kg/m^2. Retrieval error was estimated within 2.5 kg/m^2 by using match-up dataset of radiosonde-derived water vapor and AMSR estimates.

Data can be obtained from:
Order desk, Earth Observation Center, JAXA
Tel: +81-49-298-1307
Fax: +81-49-298-1398
E-mail: orderdesk@eoc.jaxa.jp

References:
http://sharaku.eorc.nasda.go.jp/ADEOS2/sensor/sensor.html
http://sharaku.eorc.jaxa.jp/AMSR/data_re/amsr/wv031224_e.htm

2.8 AMSR-E

- Platform: AQUA
- Launch: May 2002
- Orbit: 705 km
- Inclination: 98.2°
- Period: 98.8 min
- Latitudinal coverage: Global
- Sounding altitude: N/A
- Measurement method: Conical scan microwave radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 2002 - present
- Data availability: Data available at: ftp://ftp.ssmi.com/amsre/
  and at http://daac.gsfc.nasa.gov/

The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) is a passive microwave radiometer, modified from the ADEOS-II AMSR (see Section 2.7).

The AMSR-E is a conically scanning total power passive microwave radiometer sensing microwave radiation (brightness temperatures) at 12 channels and 6 frequencies ranging from 6.9 to 89.0 GHz. Horizontally and vertically polarized radiation are measured separately at each frequency. The incidence angle is 55°. Precision of 1K. Channels frequencies: 6.93, 10.65, 18.7, 23.8, 36.5 and 89.0 GHz.

Atmospheric integrated water vapor is measured over ocean with a spatial resolution of 24 km. The accuracy of the oceanic integrated water vapor product is 1.0 mm.

Data available at:
ftp://ftp.ssmi.com/amsre/
http://daac.gsfc.nasa.gov/

References:
http://www.ghcc.msfc.nasa.gov/AMSR/
http://www.remss.com/amsr/amsr_browse.html
http://sharaku.eorc.nasda.go.jp/AMSR/index_e.htm

2.9 SMMR

- Platform: Nimbus 7
- Launch: 1978
- Orbit: 955 km, sun-synchronous
- Inclination: 99.1°
- Period: 104.2 min
- Latitudinal coverage: Near-Global
- Sounding altitude: N/A
- Measurement method: Conical scan microwave radiometer
- Vertical resolution: N/A
- Error: N/A
- Data: 1978 – 1987
- Data availability: Available on 8 mm tapes

The Scanning Multichannel Microwave Radiometer (SMMR) measures dual-polarized microwave radiance from the earth's atmosphere and surface. It's purpose is primarily of deriving global and nearly all-weather measurements of sea surface temperature, wind speed, and atmospheric liquid water and water vapor.

The instrument obtained near-global coverage at five frequencies (6.63, 10.69, 18.0, 21.0, and 37.0 GHz) in both horizontal and vertical polarizations, every six days. Equatorial crossings are local noon for ascending and local midnight for descending nodes. A parabolic antenna reflected microwave emissions into a five-frequency feed horn. The antenna beam was at a constant nadir angle of 42 degrees, resulting in an incidence angle of 50.3 degrees at the Earth's surface. The antenna was forward-viewing and rotated equally (+/− 25 degrees) about the satellite subtrack. The 50 degree scan provided a 780 km swath of the Earth's surface.

Data are stored as daily orbit files in compressed Hierarchical Data Format (HDF) and are available on 8mm tape. Each level 1B orbit file covers a time period of approximately 104.16 minutes.

References:
http://podaac.jpl.nasa.gov:2031/SENSOR_DOCS/smmr.html
Gloersen and Barath [1977]
Gloersen and Hardis [1978]

Chapter 3

Sensors measuring water vapor in the stratosphere

3.1 HALOE

- Platform: Upper Atmosphere Research Satellite (UARS)
- Launch: September 1991
- Orbit: 575 km
- Inclination: 57°
- Period: 96.2 min
- Latitudinal coverage: 80° S to 80° N
- Sounding altitude: 15 km to 80 km for H_2O
- Measurement method: Solar occultation technique
- Vertical resolution: approx. 0.3 km
- Error: N/A
- Data: October 91 - Present
- Data availability: Public download from Internet, and from DAAC center

The Halogen Occultation Experiment (HALOE) was launched on the Upper Atmosphere Research Satellite (UARS) spacecraft September 12, 1991, it began science observations on October 11. The experiment uses solar occultation to measure vertical profiles of H_2O, O_3, HCl, HF, CH_4, NO, N_2O and aerosol extinction at 4 infrared wavelengths, and temperature versus pressure with an instantaneous vertical field of view of 1.6 km at the Earth's limb. Latitudinal coverage is from 80° S to 80° N over the course of 1 year. The altitude range of the measurements extends from about 15 km to 60-130 km, depending on the species. Internal data consistency checks, comparisons with correlative measurements including satellite, in situ and ground-based observations are in good agreement.

Online visualization and analysis tools are available.

Water vapor profiles obtained from Haloe data have been compared with the MIAWARA instrument. The mean difference was generally better than 10% in all altitude regions [Deuber, 2005].

Visualisation tools:
http://acdisc.sci.gsfc.nasa.gov/Giovanni/airs/

Data:
http://haloedata.larc.nasa.gov/download/index.php
http://daac.gsfc.nasa.gov/data/dataset/UARS/HALOE/

References:
http://haloedata.larc.nasa.gov/
http://haloedata.larc.nasa.gov/publications/index.php
Deuber [2005]

3.2 SAGE II

- Platform: Earth Radiation Budget Satellite (ERBS)
- Launch: October 1984
- Orbit: 650 km (non-sun synchronous)
- Inclination: 57°
- Period: 96.8 min
- Latitudinal coverage: 80° S to 80° N
- Sounding altitude: 10 – 40 km
- Measurement method: Solar occultation technique
- Vertical resolution: N/A
- Error: N/A
- Data: 1984 - Present
- Data availability: Free download from the Internet, binary format. Reading routine for IDL and Fortran90 language provided.

The Stratospheric Aerosol and Gas Experiment (SAGE II) is a seven-channel Sun photometer using a Cassegrainian-configured telescope, holographic grating, and seven silicon photodiodes, some with interference filters, to define the seven spectral channel bandpasses.

During each sunrise and sunset encountered by the orbiting spacecraft, the instrument uses the solar occultation technique to measure attenuated solar radiation through the Earth's limb in seven channels centered at wavelengths ranging from 0.385 to 1.02 micrometers. Data are available to download from the Internet on binary format. An online software calculates occurrences at latitude-longitude.

Data:
ftp://ftp-rab.larc.nasa.gov/pub/sage2/v6.20

References:
http://www-sage2.larc.nasa.gov/
http://www-sage2.larc.nasa.gov/references/
Thomason et al. [2004]
Taha et al. [2004]
Rind et al. [1993]
Chu et al. [1993]

3.3 SAGE III

- Platform: Meteor-3M
- Launch: December 2001
- Orbit: 1018 km, sun synchronous
- Inclination: 99.6°
- Period: 105 min
- Latitudinal coverage: 50° to 80° North and 30° to 50° South
- Sounding altitude: Cloud-top – 50 km for H_2O
- Measurement method: Solar occultation technique
- Vertical resolution: 0.5 km
- Error: N/A
- Data: 05/07/2002 - Present
- Data availability: Langley Atmospheric Sciences Data Center http://eosweb.larc.nasa.gov/PRODOCS/sage3/table_sage3.html

The Stratospheric Aerosol and Gas Experiment (SAGE III) instrument was designed to provide long-term measurements of ozone, aerosol, water vapor, and other gases in the atmosphere. It was launched on-board the Russian spacecraft Meteor 3M on December 10, 2001.

The spacecraft is placed into a sun-synchronous orbit with an inclination of 99.6° , an ascending node crossing time of 9 am, and an orbital height of 1018 km. The SAGE III mission is part of NASA EOS program, and is a collaborative mission between NASA and the Russian Aviation and Space Agency (RASA). Routine measurement operations began in March 2002.

The data are available from a public ftp server at Level 1B and Level 2. Profiles of water vapor are provided in units of concentration from the cloud-top to an altitude of 50 km. A temperature profile retrieved from SAGE III measurements or from a gridded analysis will facilitate computation of relative humidity. The water vapor products are retrieved using a nonlinear least squares approach from the solar occultation measurements of slant path absorption.

References:
http://www-sage3.larc.nasa.gov/
http://www-sage3.larc.nasa.gov/library/references.php

3.4 POAM III

- Platform: SPOT4
- Launch: March 1998
- Orbit: 833 km, Sun-synchronous polar orbit
- Inclination: 98.7°
- Period: 101.5 min
- Latitudinal coverage: 54.5 - 71.1° North ; 62.6 - 88.2° South
- Sounding altitude: 5 to 50 km for H_2O
- Measurement method: Solar occultation technique
- Vertical resolution: 1-3 km
- Error: Random error: 5%
- Data: 98 - present
- Data availability: available on request (www.cpi.com/products/poam/download.html)

The Polar Ozone and Aerosol Measurement III (POAM III) experiment was launched on the SPOT 4 spacecraft on 24 March, 1998, in an orbit and measurement coverage nearly identical to that of POAM II. The POAM III instrument is very similar in design and operation to POAM II, but has been substantially improved in several areas. Among the most important of these is a large increase in the measurement signal-to-noise (especially in the three bluest channels), and greater sun tracker sensitivity enabling measurements to be made (in cloud free conditions) well into the troposphere.

The POAM III measurement complement includes ozone, water vapor (which was not provided with POAM II), N_2O, and aerosol extinction. H_2O is measured with channels 7 and 8, respectively at 922.4nm and 935.8nm. A more detailed description of the POAM III instrument, and early validation results is given by Lucke at al. [1999]. Version 2 is the current retrieval version, and the POAM III data are publicly available through the POAM web page.

At the 833 km altitude of the SPOT4 satellite, the distance to the tangent point is about 3400 km, so the 0.013 ° FWHM of the PSF results in an instantaneous vertical resolution of 0.77 km at the tangent altitude.

Data validation:
Status of POAM III Version 3 Retrievals: Water vapor errors are on the order of 5-8 % from the tropopause to 50 km. Between 5 and 10 km, errors increase to 10-20 %.
Validation Summary for H_2O: Agrees to within 10 % with HALOE from 14 to

45 km. POAM is significantly higher than HALOE at lower altitudes, generally consistent with a higher hygropause in the POAM profiles.

Water vapor measurements above 20 km altitude from POAM III and MIAWARA have been compared during the LAUTLOS campaign. Agreement is better than 8% (Deuber et al. [2004]).

References:
http://wvms.nrl.navy.mil/POAM/poam.html
http://wvms.nrl.navy.mil/solve/
Lucke et al. [1999]
Deuber et al. [2004]

3.5 SCAMS

- Platform: Nimbus 6
- Launch: 1975
- Orbit: 1098 km, sun-synchronous
- Inclination: 99.8°
- Period: 107 min
- Latitudinal coverage: Near global
- Sounding altitude: N/A
- Measurement method: Solar occultation technique
- Vertical resolution: N/A
- Error: N/A
- Data: 1975 to 1976
- Data availability: N/A

The Nimbus 6 SCAnning Microwave Spectrometer (SCAMS) was designed to map tropospheric temperature profiles, water vapor abundance, and cloud water content to be used for weather prediction even in the presence of clouds.

The instrument was an advancement of the Nimbus E microwave spectrometer (NEMS) on Nimbus 5 (see Section 2.3). The SCAMS continuously monitored emitted microwave radiation at frequencies of 22.235, 31.65, 52.85, 53.85 and 55.45 GHz. The three channels near the 5.0 mm oxygen absorption band were used primarily to deduce atmospheric temperature profiles. The two channels near 10 mm permitted water vapor and cloud water content over calm oceans to be estimated separately. The instrument, a Dicke-superheterodyne type, scanned +/− 45 ° normal to the orbital plane with a 10° field of view. The three oxygen channels shared common signal and reference antennas. Both water vapor channels had their own signals and reference antennas.

The absolute root-mean-square accuracy of the oxygen channels was better than 2 K and that of the water vapor channels better than 1 K. The dynamic range for all channels was 0-400 K. The ground resolution was approximately 145 km near nadir and 330 km at the scan limit. The instrument ceased functioning on May 31, 1976, due to jamming of the scan mechanism.

References:

"The Nimbus 6 User's Guide" (TRF B23261), available from NSSDC.
http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1975-052A&ex=10

3.6 MIPAS

- Platform: Envisat
- Launch: March 2002
- Orbit: 800 km, sun-synchronous
- Inclination: 98°
- Period: 100.6 min
- Latitudinal coverage: Global
- Sounding altitude: 5 – 150 km
- Measurement method: Michelson interferometer, infrared emission limb sounder
- Vertical resolution: about 3 km
- Error: N/A
- Data: 2002 to present
- Data availability: http://envisat.esa.int/dataproducts/

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is a Fourier transform spectrometer for the measurement of high-resolution gaseous emission spectra at the Earth's limb.

MIPAS operates in the near to mid infrared where many of the atmospheric trace-gases playing a major role in atmospheric chemistry have important emission features. The instrument measures in two directions: Rearwards within a 35° wide range in the anti-flight direction, and sideways within a 30° wide area in the anti-sun direction. The first viewing range gives good earth coverage, including the earth's polar regions. The sideways range allows special measurements relevant to specific atmospheric chemistry issues e.g. volcanism and air traffic. In the rearwards viewing geometry, the distance between instrument and tangent point is about 3300 km. At this range, MIPAS can scan between 5 and 150 km, in variable or even steps with a vertical resolution of about 3 km. For water vapor, the altitude of sounding at maximum is down to the tropopause (10–13 km). Profiles of atmospheric constituents are available at level 2 (MIP_NL__2P), with water vapor as VMR. MIPAS as been validated with MIAWARA and radiosondes, see: http://www.iapmw.unibe.ch/publications/pdffiles/879.pdf

References:
http://envisat.esa.int/instruments/mipas/
http://envisat.esa.int/instruments/mipas/related.html

Data available at:
http://envisat.esa.int/dataproducts/
http://envisat.esa.int/dataproducts/mipas/CNTR6-2.htm#eph.mipas.mipasdf.1p

Chapter 4

Sensor measuring water vapor in the troposphere and stratosphere

4.1 SCIAMACHY

- Platform: Envisat
- Launch: March 2002
- Orbit: 800 km, sun-synchronous
- Inclination: 98°
- Period: 100.6 min
- Latitudinal coverage: Global
- Sounding altitude: troposphere and stratosphere
- Measurement method: Nadir, limb and solar/lunar occultation measurements
- Vertical resolution: N/A
- Error: N/A
- Data: 2002 to present
- Data availability: Available at http://envisat.esa.int/

The Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY) experiment is a spectrometer designed to measure sunlight, transmitted, reflected and scattered by the earth atmosphere or surface in the ultraviolet, visible and near infrared wavelength region (240 nm - 2380 nm) at moderate spectral resolution (0.2 nm – 1.5 nm). SCIAMACHY has a typical spatial resolution of $30 \times 60\,\mathrm{km}^2$.

SCIAMACHY offers the possibility to observe the same atmospheric volume first in limb and then after about 7 minutes in nadir geometry.

Water vapor column density is available at level 2 (Referred to as 'SCI_NL__2P at Level 2 NRT').

References:
http://envisat.esa.int/instruments/sciamachy/
http://envisat.esa.int/instruments/sciamachy/related.html
http://envisat.esa.int/instruments/sciamachy/data-app/dataprod.html
http://www-iup.physik.uni-bremen.de/sciamachy/index.html

Chapter 5

Summary of the experiment characteristics

Table 5.1 summarizes the instruments characteristics.

Instrument	Launch year	Operational period	Latitude coverage (°)	Incl. (°)	Period (min)	Sounding alt.(H_2O)	Resol. (km)	Sounding method
NEMS	1972	72–83	near-global	99.8	107	troposphere	N/A	Nadir radiometer
SMMR	1978	78–87	near-global	99.1	104.2	troposphere	N/A	Conical scan radiometer
SSM/I	1987	87-present	near-global	98.8	102	troposphere	N/A	Conical scan radiometer
TMI	1997	97-present	40S–40N	35	90	troposphere	N/A	Conical scan radiometer
AMSU-B	1998	98-present	global	98.7	101	0–12	N/A	Cross-track radiometer
MERIS	2002	02-present	global	98	100.6	troposphere	2	Nadir Spectrometer
AMSR	2002	02-present	global	98.6	101	troposphere	N/A	Conical scan radiometer
AMSR-E	2002	02-present	global	98.2	98.8	troposphere	N/A	Downlooking radiometer
SCAMS	1975	75–76	near-global	99.8	107	stratosphere	N/A	Solar Occultation
SAGE II	1984	84-present	80S–80N	57	96.8	10–40	N/A	Solar Occultation
Haloe	1991	91-present	80S–80N	57	96.2	15–80	0.3	Solar Occultation
POAM III	1998	98-present	54.5–71.1N + 62.6–88.2S	98.7	101.5	5–50	1-3	Solar Occultation
SAGE III	2001	02-present	50-80N + 30-50S	99.6	105	cloud-top–50	0.5	Solar Occultation
MIPAS	2002	02-present	global	98	100.6	5–150	3	Michelson interferometer
SCIAMACHY	2002	02-present	global	98	100.6	troposphere +stratosphere	N/A	Solar/Lunar Occultation

Table 5.1: Characteristics of the instruments

Chapter 6

Conclusion

In this report, we compiled the characteristics of the main experiments measuring water vapor in the atmosphere. Each experiment offers its own features, in terms of sounding method, sounding altitude, resolution, spatial and temporal coverage, availability of the dataset.

One of the main difference between the experiments is the technique of measurement. The technique used is usually related to the sounding altitude to which the experiment is dedicated. The most common techniques used include solar (and/or lunar) occultation (SCAMS, SAGE-II, -III, Haloe, POAM III, SCIAMACHY) and downwards looking radiometry (NEMS, SMMR, SSM/I, TMI, AMSU-B, AMSR, AMSR-E, SCIAMACHY). In the occultation method, the antenna points at a known source of radiation (Sun/Moon) while moving along its orbit. Atmospheric absorption is measured while the target sets behind the horizon. Information on vertical distributions of atmospheric constituents is retrieved. The occultation technique is mostly used to sound the stratosphere. In the downlooking radiometry technique, the antenna points downwards to the earth and measures radiance along the path, with the possibility of a moving mirror to scan a wider area. When associated to a conical scan, the sampling is made at a constant incidence angle with the Earth surface. The downlooking radiometry technique is mostly used to sound the troposphere. The other techniques include Nadir Spectrometry (MERIS) and Michelson interferometry (MIPAS).

The temporal and spatial coverage of an experiment is an important parameter as well. Some experiments were on orbit only for a limited time (NEMS, SCAMS, SMMR), others measured only for a given latitude range, with a specific orbit inclination (TMI) or because of the technique used (POAM III, SAGE III).

The data from the experiments shown here presented a good level of quality, they are widely used and recognized in the community (e.g. AMSU-B, SSM/I). Some have been compared to MIAWARA (HALOE, POAM III, MIPAS).

Most of the data products are accessible to download online or have to be ordered through the Internet. A comprehensive search of NASA products is available at the Goddard Earth Sciences Data and Information Service Center (GES DISC[1]) and at the NASA Langley Atmospheric Sciences Data Center (LARC DAAC[2]). For the ESA data products, they are accessible separately from each experiment's homepage.

Using this report, one can select the most suitable experiment for one's purpose. For example, if we are looking for an experiment to make a comparison with the humidity profiles produced by ASMUWARA, we would consider the following steps:

1. ASMUWARA measures in the troposphere, therefore we have to choose an experiment that measures down into the troposphere.

2. ASMUWARA measures accurate humidity profiles in the first 4-5 km of the troposphere, therefore we have to choose an experiment that measures down to, or near to the surface.

3. As ASMUWARA is a campaign instrument, large latitude range is needed and frequent overpasses as well. Ideally, it's an instrument mounted on several platforms (AMSU-B, SSM/I).

4. Regarding the dates, ASMUWARA started measurements in 2002, we therefore need an experiment that was launched in 2002 or before, and that is still in orbit.

5. On the view of these requirements, the experiments AMSU-B and SSM/I are best suited.

[1] http://disc.gsfc.nasa.gov/index.shtml
[2] http://eosweb.larc.nasa.gov/

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