Results from the second SPARC water vapour assessment (WAVAS-II) on (limb) satellite data quality

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Report structure

1. Introduction (Rosenlof)
2. Data characterisation (Walker & Stiller)
3. Comparison to frost point hygrometers (Kiefer, Hurst & Vömel)
4. Comparison to ground-based microwave radiometers (Kiefer & Nedoluha)
5. Inter-comparison of co-located satellite data (Lossow)
6. Comparison of satellite time series (Lossow & Khosrawi)
7. Comparison of derived quantities (Lossow & Khosrawi)
8. Representation of UTH by the limb instruments (Read)
9. Minor water vapour isotopologues (Walker, Lossow, Bauer & Högberg)
10. Discussion (Rosenlof & Stiller)
11. Summary, conclusions and recommendations (Stiller)
Data sets

- Data sets from 13 satellite instruments:
  - ACE-FTS, GOMOS, HALOE, HIRDLS, MAESTRO, MIPAS, MLS (Aura), POAM III, SAGE II, SAGE III, SCIAMACHY, SMR and SOFIE

  - 42 data sets for the main isotopologue $\text{H}_2^{16}\text{O}$ (7 UTH data sets)
  - 5 data sets for $\text{H}^{16}\text{D}$
  - 2 data sets for $\text{H}_2^{17}\text{O}$
  - 2 data sets for $\text{H}_2^{18}\text{O}$

- different retrieval versions, data processors, measurement geometries and spectral signatures to derive the water vapour information
- focus on the time period from 2000 on
A few results
FPH comparisons

Bandung
Beltsville
Biak
Boulder
Fort Sumner
Hanoi
Hawaii
Heredia
Huntsville
Kiruna
Kototabang
Kunming
La Reunion
Lauder
Lhasa
Lindenberg
Ny Alesund
RV Mirai
San Cristobal
Sodankyla
So.Gr.Planes
Table Mountain
Tarawa
Tengchong
Watukosek
Yangjiang
FPH comparisons

MLS−Aura_V3.3_fAK_pressure

MIPAS−IMK_V5R_fAK_pressure

Bandung (28)
Beltsville (1266)
Blauf (738)
Boulder (5296)
Fort Sumner (84)
Hanoi (712)
Hawai (684)
Kototabang (310)
Kunming (1105)
La Reunion (226)
Lindenberg (2682)
Table Mountain (1296)
Tarawa (206)

Beltsville (6)
Blauf (104)
Boulder (28)
Hanoi (12)
Hawai (12)
Heredia (378)
Kototabang (202)
Kunming (118)
La Reunion (22)
Lauder (438)
Lhosa (56)
Lindenberg (16)
RV Mirai (8)
San Cristobal (72)
Sodankyla (36)
Table Mountain (236)
Tarawa (38)
Tengchong (6)
Yangjiang (22)
FPH comparisons

![Graph showing FPH comparisons over different sites and periods.](image)

Hurst et al., Atmospheric Measurement Techniques Discussions 2016
Comparisons to ground-based radiometers
Comparisons to ground-based radiometers
Satellite profile-to-profile comparisons
Satellite time series comparison

Absolute data @ 10 hPa

De-seasonalised data @ 10 hPa

Water vapour / ppmv

Water vapour residual / ppmv

15°S - 15°N

ACE–FTS v2.2 (0.5 S)
ACE–FTS v3.5 (0.2 S)
GOMOS–LATMOS (1.7 N)
HALOE v19 (0.5 S)
HALOE v20 (0.1 S)
HIRDLS (0.1 S)
ILAS–II (no overlap)
MAESTRO (0.4 N)
MIPAS–Bologna V5H (1.2 S)
MIPAS–Bologna V5R MA (Equator)
MIPAS–ESA V5H (1.2 S)
MIPAS–ESA V5R NOM (0.1 N)
MIPAS–ESA V5R MA (0.1 N)
MIPAS–ESA V7R (0.1 N)
MIPAS–IMKIAA V5H (1.2 S)
MIPAS–IMKIAA V5R NOM (0.1 N)
MIPAS–IMKIAA V5R MA (0.1 N)
MIPAS–Oxford V5H (1.2 S)
MIPAS–Oxford V5R NOM (0.1 N)
MIPAS–Oxford V5R MA (0.2 N)
MAESTRO (0.4 N)
MIPAS–Bologna V5H (1.2 S)
MIPAS–Bologna V5R MA (Equator)
MIPAS–ESA V5H (1.2 S)

SAGE II (0.3 S)
SAGE III (no overlap)
SCIAMACHY limb (2.6 S)
SCIAMACHY lunar (no overlap)
SCIAMACHY solar OEM (no overlap)
SCIAMACHY solar Onion (no overlap)
SMILES–NICT band A (0.2 N)
SMILES–NICT band B (0.2 N)
SMR 544 GHz (0.1 N)
SMR 489 GHz (1.0 S)
SOFIE (no overlap)
Satellite time series correlation

Absolute data

De-seasonalised data

Pressure / hPa

Correlation coefficient

ACE–FTS v2.2
ACE–FTS v3.5
GOMOS–LATMOS
HALOE v19
HALOE v20
HIRDLS

MIPAS–Bologna V5H
MIPAS–Bologna V5R NOM
MIPAS–Bologna V5R MA
MIPAS–ESA V5H
MIPAS–ESA V5R NOM
MIPAS–ESA V5R MA

MIPAS–ESA V7R
MIPAS–IMKIAA V5H
MIPAS–IMKIAA V5R NOM
MIPAS–IMKIAA V5R MA
MIPAS–Oxford V5H
MIPAS–Oxford V5R NOM
MIPAS–Oxford V5R MA

MLS v3.3/3.4
MLS v4.2
SAGE II
SCIAMACHY limb
SMR 544 GHz
Annual variation in the tropics

Amplitude / ppmv

Pressure / hPa

Time of first maximum / month

ACE–FTS v2.2
ACE–FTS v3.5
HALOE v19
HALOE v20
HIRDLS
MIPAS–Bologna V5H
MIPAS–Bologna V5R NOM
MIPAS–Bologna V5R MA
MIPAS–ESA V5H
MIPAS–ESA V5R NOM
MIPAS–ESA V5R MA
MIPAS–ESA V7R
MIPAS–IMKIAA V5H
MIPAS–IMKIAA V5R NOM
MIPAS–IMKIAA V5R MA
MIPAS–Oxford V5H
MIPAS–Oxford V5R NOM
MIPAS–Oxford V5R MA
MLS v3.3/3.4
MLS v4.2
SAGE II
SCIAMACHY limb
SMR 544 GHz
SMR 489 GHz
Standard deviation for annual variation

- Standard deviation of amplitude / ppmv
- Standard deviation of amplitude / percent
- Standard deviation of phase / month

[Graph showing the standard deviation for annual variation with data points at different pressures and latitudes.]

Atmospheric Composition Validation and Evolution Workshop, 18 - 20 October 2016, Frascati/Italy
UTH comparisons

Binned means lng:180W-180E lat: 10S-10N

H2O (ppmv)

Year
Seasonal latitudinal cross section for δD, HDO & H₂O

[Graph showing seasonal variations of δD, HDO, and H₂O across different latitudes for MAM, JJA, SON, and DJF.]

- MAM / 10 hPa
- HDO / ppbv
- δD / ppm
- H₂O / ppm

Instruments used:
- Odin/SMR v2.1
- Envisat/MIPAS v5
- Envisat/MIPAS v2.0
- SCISAT/ACE-FTS v2.2
- SCISAT/ACE-FTS v3.5
δD-H$_2$O tape recorder amplitude

![Graph showing δD-H$_2$O tape recorder amplitude with different datasets and their phases.](image)
The vertical resolution issue

- Odin/SMR v2.1
- Envisat/MIPAS v5
- Envisat/MIPAS v20
Comparisons of $\delta^{18}$O-H$_2$O and $\delta^{17}$O-H$_2$O

- Average of the $\delta^{18}$O values from collocated profiles.
- Noisier profiles for SMR lead to larger standard deviations.
- Data points in this figure only included for averaging if both ACE-FTS and SMR match their quality criteria.
- Data after 2010 discarded due to drift in SMR.

Number of avg. profiles:

- $\delta^{18}$O
- $\delta^{17}$O

- Decreasing number of valid data points below 25 km and above 55 km.
Conclusions

- 0.5 ppmv/10% deviation are still the typical benchmarks in the stratosphere as concluded from the last WAVAS report
- larger biases and uncertainties in the upper troposphere and lower mesosphere
- overall good consistency of the time series, but clear offsets exists as well as differences in the size of the anomalies
- some drifting data sets have been detected
- variability patterns largely agree, differences in details and the absolute values
- isotopologue comparisons show larger differences
Special issue

Water vapour in the upper troposphere and middle atmosphere: a satellite data quality assessment including biases, variability, and drifts (ACP/AMT/ESSD inter-journal SI)

Editor(s): J. Russell, K. Rosenlof, S. A. Buehler, and G. P. Stiller

Special issue jointly organized between Atmospheric Chemistry and Physics, Atmospheric Measurement Techniques, and Earth System Science Data

More Information

Download citations of all papers: Bibtex  EndNote  Reference Manager

28 Sep 2016

The Stratospheric Water and Ozone Satellite Homogenized (SWOOSH) database: a long-term database for climate studies


Summary

08 Sep 2016

Recent divergences in stratospheric water vapor measurements by frost point hygrometers and the Aura Microwave Limb Sounder


Summary

05 Sep 2016

Advancements, measurement uncertainties, and recent comparisons of the NOAA frost point hygrometer

Emrys G. Hall, Allen F. Jordan, Dale F. Hurst, Samuel J. Oltmans, Holger Vömel, Benjamin Kühnreich, and Volker Ebert


Summary

Webpage: http://www.atmos-meas-tech.net/special_issue10_830.html

Atmospheric Composition Validation and Evolution Workshop, 18 - 20 October 2016, Frascati/Italy
Thank you for your attention
Key findings

- A significant increase in the number and quality of stratospheric water vapour measurements has occurred over the past 25 years, particularly with the advent of satellite observations. Stated accuracy of most in situ and remote instruments as well as direct or indirect comparisons of coincident field measurements cluster within a ±10% range.

- The concentration of stratospheric water vapour in the "overworld" ($\Theta \geq \sim 380$ K) is determined by dry air upwelling through the tropical tropopause, methane oxidation in the stratosphere, and transport by the poleward-and-downward (Brewer-Dobson) mean circulation. At the tropical tropopause, air transported into the stratosphere is dried by a complex combination of processes that act on a variety of spatial and temporal scales. Water vapour in the upper troposphere is controlled by local and regional circulation patterns and seasonal changes of upper tropospheric temperature.

- There has been a 2 ppmv increase of stratospheric water vapour since the middle 1950s. This is substantial given typical current stratospheric values of 4-6 ppmv. Photochemical oxidation of methane in the stratosphere produces approximately two molecules of water vapour per molecule of methane. The increase in the concentration of tropospheric methane since the 1950s (0.55 ppmv) is responsible for at most one half of the increase in stratospheric water vapour over this time period. It is not clear what is responsible for the remainder of the observed increase in stratospheric water vapour.

- Upper tropospheric relative humidity (UTH) has been monitored for about 20 years by instruments on operational satellites. In the upper troposphere, no major inconsistencies were found between existing satellite-based measurements that would preclude their use in describing the long-term behaviour of upper tropospheric humidity. The data are also of sufficient quality for climatological and process studies.

- Assessing long-term changes in the UTH is difficult because of high variability during El Niño - Southern Oscillation events, other natural modes of variability in the large-scale circulation, and the competing effects of changes in water vapour concentration and temperature. Although both positive and negative statistically significant long-term changes can be found in different latitudinal bands, no striking global trend emerges from preliminary analyses.

- The operational radiosonde network does not produce water vapour data that can be used for either analyses of long-term change, process studies in the upper troposphere, or for validation of UTH measurements. However, emerging data sets from improved quality, quasi-operational aircraft and ground-based instrumentation show promise and should be used more extensively for process studies, climate analyses and validation of satellite data.
Motivation & Goals

- Water vapour is the most powerful greenhouse gas in the atmosphere
- Exact causes of trends and variability (and the exact trends and variability) are not completely understood.

- Provide quality assessment of upper tropospheric to lower mesospheric satellite records since the early 2000s
- Provide, as far as possible, absolute validation against ground-truth instruments (FPH, MW radiometers)
- Assess inter-instrument biases, depending on altitude, location, and season
- Assess representation of temporal variations on various scales
- Include data records on isotopologues
- Provide recommendations for usage of available data records and for future observation systems
Satellite profile-to-profile comparisons

Comparisons with Aura/MLS v4.2 as reference – mean relative bias

Considered: Day of year: Entire year  Latitude: Global  Longitude: 180 W – 180 E  Obs: at least 20
Satellite profile-to-profile comparisons

Water vapour comparisons with Aura/MLS v3.3/3.4 as reference – relative bias histograms

Considered: Day of year: entire year  Latitude: global  Longitude: 180 W – 180 E  Obs: at least 20

Creation Time: 19-05-2015 08:06:24 LT
Semi-annual variation in the Arctic

![Graph showing semi-annual variation in the Arctic with different data sets and parameters such as amplitude, pressure, and time of first maximum.](image-url)
Standard deviation for semi-annual variation
Standard deviation for QBO variation
UTH comparisons

Mean Profiles

Mean % differences

Variability

Pressure (hPa)

H2O (ppmv)

100 *(FP - sat inst) / FP (%)

Stdev of differences (%)
Seasonal latitudinal cross section for δD, HDO & H2O
Tropical monthly averages

February / 15 S – 15 N

April

August

October

Pressure / hPa

δD / per mille

Odin/SMR v2.1
Envisat/MIPAS v5
Envisat/MIPAS v20
SCISAT/ACE–FTS v2.2
SCISAT/ACE–FTS v3.5
HDO and H$_2$O tape recorder amplitude

- **HDO**
  - Pressure / hPa
  - Amplitude / ppmv

- **H$_2$O**
  - Pressure / hPa
  - Amplitude / ppmv

Legend:
- Odin/SMR v2.1
- Envisat/MIPAS v5
- Envisat/MIPAS v20
- SCISAT/ACE–FTS v2.2
- SCISAT/ACE–FTS v3.5
- Envisat/MIPAS v20 (only Feb/Apr/Aug/Oct)
- EMAC