



**Sixth workshop
on the
GEWEX water vapor assessment**

Workshop summary

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1. Overview

The GEWEX Data and Assessments Panel (GDAP) has initiated the GEWEX Water Vapor Assessment (G-VAP) in 2011. The major purpose of G-VAP is to quantify the state of the art in water vapour products being constructed for climate applications, and by this supports the selection process of suitable water vapour products by GDAP for its production of globally consistent water and energy cycle products. Workshops are carried out on an annual basis to discuss recent findings, to further refine the plan and to draft and consolidate the assessment reports. The 6th G-VAP workshop was hosted by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Darmstadt, Germany and took place at EUMETSAT Headquarters in Darmstadt on 22 and 23 September 2016. Approximately 25 participants from research institutes, universities and SME (Small and Medium-sized Enterprises, Colorado State U, FU Berlin, informus GmbH, KIT, MPI-C, SSE, UCAR, U. Albany, U. Cologne, U. Leicester, U. Wisconsin), from weather services (AEMET, DWD, NOAA), from the ground-based and in-situ measurement communities (GFZ, U. Albany) as well as from space agencies (EUMETSAT) attended the workshop. A list of participants, their affiliations and email addresses are given in Appendix D. The presentations of the 6th G-VAP workshop are available at www.gewex-vap.org.

The main objectives of the 6th meeting were to

- present and discuss results achieved thus far,
- discuss the feedback from GDAP on the first draft of the WCRP report on G-VAP,
- discuss the finalization of the G-VAP report and the /finalisation of other output from G-VAP (e.g., recommendations, data on common grid, collocated data),
- discuss structure and content of the overview paper,
- further discuss and shape future activities - beyond the release of the report.

The workshop started with an overview of G-VAP including the outcomes of the last workshop and on the aims of the current meeting. Furthermore, an update of the status of the report was given including the feedback received from GDAP and report co-authors. Updates were given on G-VAP activities and related work, together with proposals on how to proceed in order to finalise the WCRP report in time. Data records were introduced and results from various evaluation and analysis studies have been presented and discussed. In particular, the SPARC WAVAS-2 activity in general and results from an analysis of water vapour in the upper troposphere were introduced and discussed. Finally, recommendations, the replanning and the new time line and the future of G-VAP have been presented and discussed.

The main outcomes of the 6th workshop are summarized as follows:

- The time lines for the finalization of the G-VAP report and the implementation of feedback from GDAP were agreed upon.
- The structure of the overview paper, the authorship and the way forward was discussed and agreed upon.

- It was consensus to continue G-VAP beyond the finalization of the G-VAP report and the overview paper. Science topics will be defined at G-VAP workshops and in close contact with GDAP.
- The cooperation between SPARC WAVAS-2 and G-VAP is considered to be beneficial and will be continued.

The following recommendations have been formulated:

- **GRUAN:** Provide estimates of the uncertainty correlation between levels or guidance on how to compute it from information already available (ideally the covariance matrix of uncertainties is provided).
- **WMO, GCOS:** Oppose and balance user, scientific and product requirements with focus on climate analysis.
- **G-VAP:** Assess the joint effect of orbital drift, clear sky sampling/bias and the diurnal cycle of clouds on biases and how this might change with climate change.

Recommendations from previous workshops are recalled in Appendix B. Activities from this and from last workshops are recalled in Table 1 and Appendix A, respectively.

2. Background

This year's 6th GVAP workshop builds upon five previous workshops held on an annual basis since 2011. The 1st workshop was hosted by the European Space Agency's European Space Research Institute (ESA-ESRIN) with support from the ESA DUE GlobVapour project in March 2011. This workshop set the general framework for the assessment by agreeing on variables, data records and general procedures to be considered. The workshop summary was published in the GEWEX Newsletter¹. The 2nd workshop, hosted by Deutscher Wetterdienst and EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) in September 2012 aimed at the consolidation of the G-VAP strategy and the technical implementation. The results of the 2nd GVAP workshop were presented to the first GDAP meeting in Paris, October 2012, where further recommendations were received. The major outcomes of the 2nd workshop and feedback from the first GDAP meeting have also been summarized in the GEWEX Newsletter². Results from these workshops and feedback from GDAP were used for setting up the G-VAP assessment plan. The plan is available at the G-VAP webpage (www.gewex-vap.org).

The main outcome of the 3rd Workshop was the consensus about the way forward: finalization of the intercomparison, of the comparison to ground-based and in-situ observations, of the homogeneity, trend and stability analysis using gridded data and of the identification of strengths and reasons for inconsistencies. Additionally, several refinements were suggested in particular the analysis of PDFs using instantaneous data. The major outcomes of the 3rd workshop were summarized in the GEWEX Newsletter³. The 4th workshop was hosted by FU Berlin in October 2014. Its main outcome was the definition of the structure of the WCRP report on G-VAP and of the ToR for lead and contributing authors. Many participants volunteered to lead and contribute to sections of the report such that the majority of sections

¹ <http://www.gewex.org/resources/gewex-news/>

² <http://www.gewex.org/resources/gewex-news/>

³ <http://www.gewex.org/resources/gewex-news/>

are covered. Several refinements and the next steps have been presented, discussed and agreed upon, in particular the consideration of the nnHIRS data record. The 5th GVAP workshop took place at the University of Wisconsin's Lowell Centre in Madison, Wisconsin, USA on 04 and 05 November 2015. The main outcomes were the refinement of the current activities and discussion and agreement on the next steps. The latter included the time line for drafting the G-VAP report and for finalising G-VAP. Furthermore, it was agreed to release regridded and collocated data records. The major outcomes of the 5th workshop were summarized in a GEWEX Newsletter⁴.

3. Major results

After D. Klaes welcomed the participants of the 6th workshop, M. Schröder gave an overview on G-VAP, recalling the overall goal of G-VAP, its dedicated science questions, the results from the last workshop as well as the feedback on the draft G-VAP report provided by GDAP and co-authors.

T. August, on behalf of L. Schüller, continued with an overview on water vapour products at EUMETSAT Central Facility and within the SAF network, which cover a wide range of satellite sensors and applications. Updates on candidate data records were given by F. Fell (EMiR-MWR), P. Menzel (HIRS), T. August (IASI), R. Preusker (MERIS, MODIS) and T. Wagner (GOME/SCIAMACHY/GOME-2). The talks included results from evaluation and partly also from analysis. Among others, the year to year variability per satellite was analysed on basis of HIRS data. F. Alshawaf presented current atmospheric monitoring activities based on GNSS data conducted at the GFZ in Potsdam. She showed results from an analysis of decadal variations and trends in Germany using a combined time series based on radiosondes, ERA-Interim and GNSS data. S. Crewell presented results from studies investigating the impact of temporal and spatial sampling on water vapour products using IASI, MODIS and GNSS data. Results show that sampling difference due to atmospheric conditions (all-sky, cloudy-sky, clear-sky) and time of the day (daytime/nighttime) have an impact on the PDF. Limitation to clear-sky and daytime samples leads to a loss of high values and to a change from single modal to bimodal distribution. B. Ho presented results on the impact of sampling on the retrieval uncertainty, the sampling bias in rainy conditions and the impact of a priori information using TCWV data from SSM/I with COSMIC data serving as reference. No dependency on a priori information was found, whereas a positive (wet) retrieval bias was found for cloudy and precipitating conditions. R. Kursinski gave an update on comparisons of PDFs of various products to those from GPS-RO data. R. Nelson introduced a TCWV product derived from OCO-2 and showed first evaluation results. M. Lockhoff and M. Schröder showed final results from the intercomparison of data from the full G-VAP archive and from assessing the homogeneity of long-term TCWV data records, respectively. It was discussed that the assessment of physical consistency relative to the theoretical expectation can also be carried out using the SST used during generation of the different data records. J. Wang showed results from an analysis of the trends in precipitable water and the effect of diurnal sampling on trends. It was shown that the assumption of a constant relative humidity in a

⁴ <http://www.gewex.org/resources/gewex-news/>

warming climate is not valid, at least not over land. Also, the observed trends are larger during night than during day for unclear reasons.

G. Stiller gave an introduction to the SPARC WAVAS-2 activity which is a similar activity to G-VAP but focused on the upper troposphere and stratosphere. An overview of utilised data records, applied methodologies and results was given. The limb sounders are beyond life time and no follow-up missions are currently planned. W. Read showed results from the assessment of humidity in the upper tropospheric conducted within the SPARC WAVAS-2 context. The analysis focuses on absolute humidity values and not on UTH. Potential issues with corrected radiosonde data in the UT were presented. L. Shi continued with a presentation of intercomparison results focused on UTH products, achieved within G-VAP. It was summarised that the SPARC WAVAS-2 and GEWEX G-VAP activities are complementary with respect to vertical coverage, except at UT where different variables from different sensors are considered. At the same time there are several communalities in particular in terms of general approaches and applied methodologies.

X. Calbet summarized best practices and information on uncertainties gained through collocation exercises using radio sondes. In order to achieve consistency among references systems dual radiosondes are needed. It was concluded that a RAOB observation can not be replaced by data from NWP and the collocation uncertainty can also not be estimated from NWP data. In his presentation, T. Trent showed results from an assessment of AIRS tropospheric humidity profiles using radiosonde soundings. M. Lockhoff completed the update on results based on G-VAP candidate data records by presenting results from the intercomparison of long-term humidity and temperature profile products and from the assessment of their degree of homogeneity. As for the long-term TCWV records distinct regions of differences with respect to climatological means and trends were found. These differences often result from breaks in the time series. Most of these breaks can be linked to changes in the satellite observing system (except for ERA-20C which does not assimilate any satellite observations). The divergence in breaks and the strong regional imprint was considered to be highly interesting.

Results based on instantaneous comparisons were presented by T. Reale and T. Trent. T. Reale showed comparison results for humidity profiles using the NPROVS software and GRUAN as a source of fully characterized temperature and humidity profiles including uncertainty information. HIRS was found to have slightly higher mixing ratios than AIRS and IASI. ECMWF assimilates radiosonde data from stations which also form the basis of this analysis. It might thus not be surprising that uncertainties for the ECMWF model were found to be lower than for satellite products. T. Trent gave an update on the analysis of the stability of the NOAA HIRS TCWV data record.

Several talks triggered discussions about the temporal change in TCWV. Among others, it was discussed that aggregated convection in combination with clear sky sampling leads to specific trend features which might change with climate change due to changes in convection and associated cloud area coverage. Also, the sampling effect of cloudy vs rainy skies was discussed. Contrary results have been presented: a decrease in TCWV if rainy pixels are removed and an increase in TCWV if rainy pixels are included. The final example is on

requirements from a climate perspective. Requirements from GCOS are available, and GRUAN defined requirements from a scientific point of view. The open question is how user and scientific requirements relate to product requirements, i.e., to requirements that are within reach depending on the observing system.

Finally, M. Schröder presented status and last steps to finalise the G-VAP report. The expected output from G-VAP was discussed and agreed upon. Among others collocated data will not be released due to concerns about property rights. Also, the recommendations have been slightly adapted and extended (see Appendix B and section 1, respectively). The data on common grid will be released in netCDF format, compliant with CF standard. The output will be aligned with output from the GEWEX cloud assessment where feasible. Last steps related to the finalization of the G-VAP report and the associated time line have been discussed and agreed upon. The implementation of feedback received thus far is straightforward. B. Ho, R. Kursinski and M Schröder are interested to analyse profile data using GPS RO over stratus regions in the future. All authors agreed to provide final feedback until 31 October 2016. Then, after a final iteration the report will be send to GDAP for review in mid-November 2016. It is expected that final feedback from GDAP will be implemented in December 2016 and January 2017 so that the final report can be presented by GDAP at the next GEWEX JSC in February 2017. The way forward and the structure of the overview paper (uncontroversial, see talk by M. Schröder) on G-VAP was also discussed and agreed upon. The draft will be submitted to BAMS, authors will be all lead authors of the report and those who significantly contribute with e.g. figures. Finally, he also presented ideas for how to continue the G-VAP activity. As at the last workshop it was consensus to continue G-VAP, with L. Shi (requires confirmation from management) and M. Schröder as co-chairs, and to carry out annual meetings. Topics will be defined during workshops in close dialogue with GDAP. For the upcoming GDAP meeting a talk will be prepared which links recommendations to science results to start discussions about future directions. The goal is to draft publications and it is foreseen to publish in a special issue.

During the wrap-up the following was agreed upon: M. Lockhoff will present G-VAP results at the upcoming SPARC WAVAS-2 meeting at KIT, Karlsruhe, Germany in November 2016. G-VAP intends to submit draft publications on UTH results to the SPARC special issue. 1-2 overview slides will be prepared to highlight the cooperation between SPARC WAVAS-2 and G-VAP, the communalities and the complementarity. It is planned to invite T. Trent to the GAIA-CLIM project.

Finally, the activities listed in Table 1 were agreed upon.

Table 1: List of new activities.

Activity	Responsible	Comment	Until
Prepare MoM and provide talks	M. Schröder, L. Shi, M. Lockhoff		Mid October
Update web page (a.o., agenda, talks, data record overview)	F. Fell, M. Schröder		30 November 2016

G-VAP presentation at SPARC WAVAS-2	M. Lockhoff		Mid December 2016
Overview slides on links/complementarity between WAVAS-2 and G-VAP for GEWEX and SPARC	G. Stiller, M. Schröder		October 2016
Prepare draft of overview paper and distribute among authors	M. Schröder		Early 2017
Prepare for detailed discussions of future science topics for G-VAP	M. Schröder (talk at GDAP), all		November 2016 (GDAP meeting), Oct 2017 (G-VAP meeting)

4. Conclusions

The 6th G-VAP workshop was hosted by EUMETSAT and took place at the EUMETSAT headquarters in Darmstadt, Germany on 22 and 23 September 2016. More than 25 scientists from all over the world participated and nearly everybody contributed with a presentation. The presentations were very interesting and relevant to G-VAP and triggered intense, valuable and constructive discussions. The strong support of the community in terms of report drafting, dedicated analysis and strategic considerations and the continued participation in the workshops is highly acknowledged.

The plan to continue G-VAP beyond the acceptance of the WCRP report on G-VAP continues to find support among the participants. It was agreed to continue with regular meetings on an annual basis where dedicated science questions will be discussed.

The contribution of SPARC WAVAS-2 representatives is highly acknowledged and was very valuable. It was agreed to maintain close contact. Among others G-VAP will contribute to the SPARC WAVAS-2 special issue.

The next workshop will tentatively take place at the University of Leicester, Leicester, United Kingdom in October 2017.

Appendix A List of activities from previous workshops

The list has been updated according to progress and decisions from G-VAP workshops.

Activity	Responsible	Comment	Until
Finalise minutes and submit letter to GEWEX Newsletter as well as provide talks	Marc Schröder with support from Frank Fell and K. Graw		closed
Finalise sections of WCRP report and provide the draft to co-chairs	Lead authors	With support from contributing authors	October 2016
Include HIRS record from U Wisconsin and remove MODIS TERRA from archive	M. Schröder, K. Graw, E. Borbas		closed
Release of data records on common grid and common period.	M. Schröder, M. Lockhoff, T. Reale, T. Trent		October 2016
Prior to data release contact SPARC and C. Stubenrauch to exchange ideas on format and type of data.	Co-chairs		closed
Implement a document repository for report drafting	Co-chairs		closed
Provide template of WCRP report sections and structure of report to lead and contributing authors	Co-chairs	Provided end of 2014	closed
Draft WCRP report on G-VAP and provide the draft to reviewers/GDAP	Co-chairs	With support from lead and contributing authors	November 2016
Extend long-term (>20yrs) analysis with JRA55 and nnHIRS (expected to be available in October 2014)	Maarit Lockhoff, Marc Schröder	JRA55 and nnHIRS included	closed
Include presentations of previous G-VAP workshops on G-VAP webpage	Frank Fell, Marc Schröder	Continuous	open
Compare breakpoint positions to changes in observing system and gradients in major climate indices, relate breakpoint strength to variance before and after breakpoint time and inform PIs	Maarit Lockhoff		November 2016
Draft summary report on information content description, value averaging kernels and collocation uncertainty	Thomas August, Tim Trent		October 2016
Address diurnal sampling issues using GNSS data	Heidrun Höschen, Marc Schröder		closed

Exchange information on metrics, data records and general approaches and include B. Read (L. Shi and M. Schröder) in activity on UTH analysis (UTLS analysis) – joined SPARC and G-VAP activity	Lei Shi, Marc Schröder		December 2016
Summarize recommendations and needs as input to a GEWEX letter to agencies	Jörg Schulz, Marc Schröder	After report acceptance	open
Draft assessment plan	Co-chairs	Available online	closed
Clarify framework of potential cooperation with ICARE	Co-chairs	Not needed at present, can be an option for the future.	closed
Establish formal communication link to SPARC	Co-chairs	See summary from 3 rd workshop	closed
Establish group to initiate technical implementation	Co-chairs	IDL-based G-VAP tool was set up by A. Walter and R. Bennartz	closed
Prioritise data records	Co-chairs	See assessment plan and minutes of 3 rd and 4 th workshop	closed
Update data fact sheets according to workshop discussions	F. Fell with support from co-chairs	Updated	closed
Set-up G-VAP webpage	Co-chairs	www.gewex-vap.org	closed
Establish group to advise long-term analysis	M. Schröder, R. Bennartz	Covered by discussion letters in future	closed
Draft data policy	M. Schröder, R. Bennartz	See assessment plan	closed
Analyse trend as function of temporal coverage for exemplary data record (e.g., HOAPS)	Marc Schröder	December 2013	closed
Consolidate details of profile evaluation	Marc Schröder, Tony Reale, Antonia Gambacorta	TR takes the lead, following the assessment plan, limited number of records	closed
Set-up password protected ftp server	Maarit Lockhoff, Marc Schröder	Server has limited space	closed

Contact PIs to get information on long-term calibration uncertainty and number of valid observations per month for full record length	Marc Schröder	Will be formulated as recommendation	closed
Contact data providers to join effort (continuous activity)	Co-chairs	Last update in December 2015	closed

Appendix B List of recommendations and needs from previous workshops.

The list has been adapted according to discussions at the previous workshops. In case of analysis the recommendation is also of relevance to assessments.

- **Space Agencies, PIs:** Develop and provide PDF based climatology of satellite-based radio-occultation data.
- **Space Agencies, PIs:** Analyse differences between observations under all-sky as well as cloudy and clear sky conditions.
- **Space Agencies:** Need for continental high quality satellite data records.
- **Space Agencies:** Need for inter-calibrated radiance/brightness temperature data records and homogeneously reprocessed instantaneous satellite data records.
- **Space Agencies, PIs:** Enhance quality analysis of profile data records over open ocean, in particular over high pressure areas/subsidence areas and stratus.
- **CGMS/WMO:** Achieve consistency among reference observing systems and sustain corresponding services.
- **Space Agencies, GEWEX:** Provide water vapour transport product in order to analyse atmospheric dynamics and to evaluate the constancy of relative humidity.
- **GRUAN:** Include station over tropical land.
- **GRUAN:** Reassess the uncertainty estimates at large humidity values.
- **CGMS/WMO, GRUAN:** Aim at the sustained generation and development of a stable, bias corrected multi-station radiosonde archive including reprocessing of historical data.
- **Space Agencies, PIs:** Provide information on input to data records such as precise start and stop dates and number of observations as function of time and input data type.
- **Space Agencies, PIs:** Provide uncertainty information and assess uncertainty as function of total amounts and other dependent parameters.
- **CGMS, Space Agencies:** Dedicated validation archive for all water vapour sensors, also including ship based RS.
- **GEWEX:** Continuous support to G-VAP, beyond acceptance of first report.
- G-VAP supports the ITSC-20 recommendation on the reinstallation of the TPW ARM station.
- G-VAP supports the ITSC-20 initiative to collect SRF data in common format at a common location.
- G-VAP supports the concluding remarks from the workshop on Joint workshop on uncertainties at 183 GHz.

Appendix C Workshop Agenda



G-VAP – Workshop

22 - 23 September 2016

Agenda

Venue:

**EUMETSAT Headquarters,
Eumetsat Allee 1,
D-64295 Darmstadt, Germany**

*Version 1.2
23 September 2016*

Thursday, 22nd Sep 2016

- 09:00 – 09:10 Welcome
Klaes
- 09:10 – 09:25 Overview on G-VAP
Schröder, Shi
- 09:25 – 09:35 Aims of meeting
Schröder, Shi
- 09:35 – 09:50 G-VAP report: status and feedback
Schröder, all
- 09:50 – 10:10 Overview of water vapour products at EUMETSAT
August

Discussion

10:30 – 11:00 Coffee break

11:00 – 12:00 An intercalibrated dataset of TCWV and Wet Tropospheric Correction
(15 min each) based on MWR on board ERS-1, ERS-2 and Envisat
Fell

Update on the UW SSEC/CIMSS Global Clear Sky IR Moisture
Products derived from HIRS and MODIS data
Menzel

Decadal variations in IWV time series estimated using GNSS
Alshawaf

Discussion

12:00 – 13:30 Lunch break

13:30 – 15:30 Impact of temporal and spatial sampling on water vapor products
(15 min each) *Crewell*

Vertical resolution and sensitivity in IASI sounding products at
EUMETSAT
August

The impact of sampling on the uncertainty
Ho

Water vapor histograms from GPS RO
Kursinski

Discussion

15:30 – 16:00 Coffee break

16:00 – 17:30
(15 minutes each) TCWV from OCO-2: methodology and evaluation
Nelson (remote)

TCWV from MERIS and MODIS and results from analysis
Preusker (remote)

Results from intercomparison of full G-VAP archive
Lockhoff

Assessing the homogeneity of long-term TCWV
Schröder

Trends in precipitable water and their diurnal asymmetry
Wang

Discussion

17:30 Adjourn

Dinner at Bockshaut (own expense)

Friday, 23rd Sep 2016

09:00 – 09:20 An introduction to the SPARC WAVAS2 activity
Stiller

09:20 – 09:40 SPARC WAVAS2: Assessment of Upper Tropospheric Humidity
measurements from Satellite
Read

09:40 – 10:00 G-VAP: Intercomparison of UTH products, climate variability and
consistency analysis
Shi

Discussion

10:30 – 11:00 Coffee break

11:00 – 12:30
(15 min each) Collocation: best practices and related uncertainties
Calbet

Assessment of AIRS tropospheric humidity profiles with characterised
radiosonde soundings
Trent

Intercomparison of humidity and temperature profile products
Lockhoff

Assessment of the degree of homogeneity in humidity and temperature profiles products
Lockhoff

Discussion

12:30 – 14:00 Lunch break

14:00 – 14:20 Evaluation of humidity profiles using NPROVS
Reale (remote)

14:20 – 14:35 Evaluating the stability of the NOAA HIRS TCWV record
Trent

14:35 – 14:50 Recent advances in the retrieval of TCWV from GOME: results from the GOME EVL project
Wagner

14:50 – 15:15 Finalising the G-VAP report: feedback implementation and last steps
Schröder, Shi, all

15:15 – 15:25 Further output: data, recommendations,...
Schröder

15:25 – 15:35 G-VAP continuation
Schröder

Discussion

16:00 – 16:30 Coffee break

16:30 – 16:45 Preparing the G-VAP overview paper
Schröder

16:45 – 17:15 Wrap-up, next meeting

17:15 – 17:30 AoB

17:30 Expected end

Appendix D List of participants

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