The GEWEX water vapor assessment (G-VAP): final results from first phase

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Thanks goes to

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Overview

- Background
- Overview of available data records
- G-VAP data archive
- Results
  - Trend estimation
  - Homogeneity analysis
  - Global and regional analysis
  - total column water vapour, water vapour and temperature profiles
- Summary and outlook
- Appendix

Webpage: http://gewex-vap.org

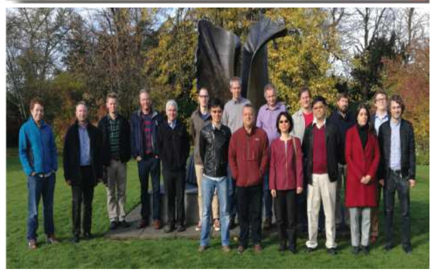
Overview on G-VAP

Until recently a comprehensive and consistent assessment of long-term satellite based water vapour data records has not been carried out. G-VAP fills this gap.

- **GDAP initiated G-VAP in 2011 with the overall scope to:**
  - **Quantify the state of the art in satellite water vapour products being constructed for climate applications, and by this;**
  - **Support the selection process by GDAP (GEWEX Data and Assessments Panel).**

- **Main approach: consistent inter-comparison and comparison to ground-based and in-situ observations with focus on gridded data, troposphere and stability/variability. No ranking.**

- **Considered ECVs (Essential Climate Variables): Total column water vapour (TCWV), upper tropospheric humidity (UTH), tropospheric water vapour and temperature profiles.**



Overview of available water vapour data records

- Satellite and reanalysis data records
- **Operational satellite data**
- **Ground-based/in-situ data records**

TECHNIQUE	DATASET	PARAMETERS	TEMPORAL COVERAGE	SPATIAL COVERAGE	TEMPORAL RESOLUTION	SPATIAL RESOLUTION	MORE INFORMATION
(A)ATSR	AIRWAVE	TCWV	08/1991-03/2012	global	monthly	0.25°	Castelli et al., 2015
AATSR, HIRS, SSM/I, GNSS	NVAP-M Climate	TCWV, WV	01/1988-12/2009	global	daily, monthly	1.0°	DFS
AIRS, AMSU, HSB	NASA	TCWV, WV, T	09/2002-present	global	daily, monthly	1°, 12 levels	WEB
AIRS, AMSU-A, CPR, MODIS	WVCC	WV, T	07/2006-11/2012	global	daily-weekly	45 km	WEB
AMSR-E	REMSS	TCWV	06/2002-09/2011	global ocean	monthly	0.25°	WEB Hilburn and Wentz, 2008
AMSR-E	JAXA	TCWV	06/2002-10/2011	global ocean	monthly	0.25°	WEB
AMSU-B	U Miami	UTH	01/1999-12/2014	global, 60°N-60°S	monthly	1.5°	Chung et al., 2013
AMSU-B	LTU	UTH	01/1999-05/2008	global, 60°N-60°S	monthly	2.5°	WEB

www.gewex-vap.org
→ Data Records

With support from F. Fell

G-VAP data archive

- **22 data records comprise the G-VAP data archive,**
- **Data has been aggregated onto common grid of 2°x2° for the common period from 1988 – 2008 (TCWV) and 1988 – 2009 (WV).**
- **doi: http://dx.doi.org/10.5676/EUM_SAF_CM/GVAP/V001,**
- **Abstracts per data record, intercomparison based on full archive.**

Folder	Temporal coverage	Data records
Specific_humidity	01/1988 – 12/2009	CFSR, ERA-20C, ERA-Interim, JRA55, MERRA, MERRA-2, nnHIRS
Temperature	01/1988 – 12/2009	CFSR, ERA-20C, ERA-Interim, JRA55, MERRA, MERRA-2, nnHIRS
TCWV/long	01/1988 – 12/2008	CFSR, ERA-20C, ERA-Interim, HOAPS, JRA55, MERRA, MERRA-2, nnHIRS, Merged Microwave REMSS, NVAP-M, NVAP-O
TCWV/short	01/2003 – 12/2008	AIRWAVE, AMSR-E JAXA, AMSR-E REMSS, ATOVS, CFSR, EMiR, ERA-20C, ERA-Interim, GOME/SCIAMACHY/GOME-2 GlobVapour, HIRS UWisc, HOAPS, JRA55, Merged Microwave REMSS, MERIS GlobVapour, MERRA, MERRA-2, MODIS AQUA, nnHIRS, NVAP-M, NVAP-O, SSM/I+MERIS GlobVapour, TMI REMSS

Schröder, M., et al., Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2017-128, in review, 2018.

Science questions
(subset)

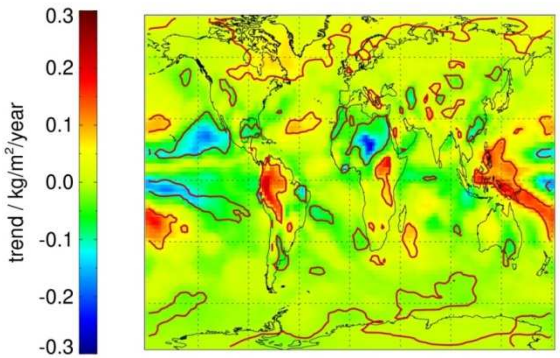
a) How large are the differences in observed temporal changes in long-term satellite data records of water vapour?

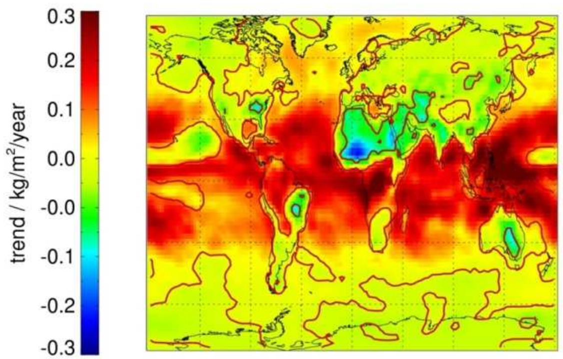
b) Are the differences in observed temporal changes within uncertainty limits?

c) Are the observed temporal changes in line with theoretical expectations?

d) What is the degree of homogeneity (breakpoints) and stability of each long-term satellite data record?

e) Do the satellite data records exhibit areas of distinct quality and how can the distinct differences and limitations be explained?





Methods

Trends estimation after Weatherhead et al. (1998) and Mieruch et al. (2014):

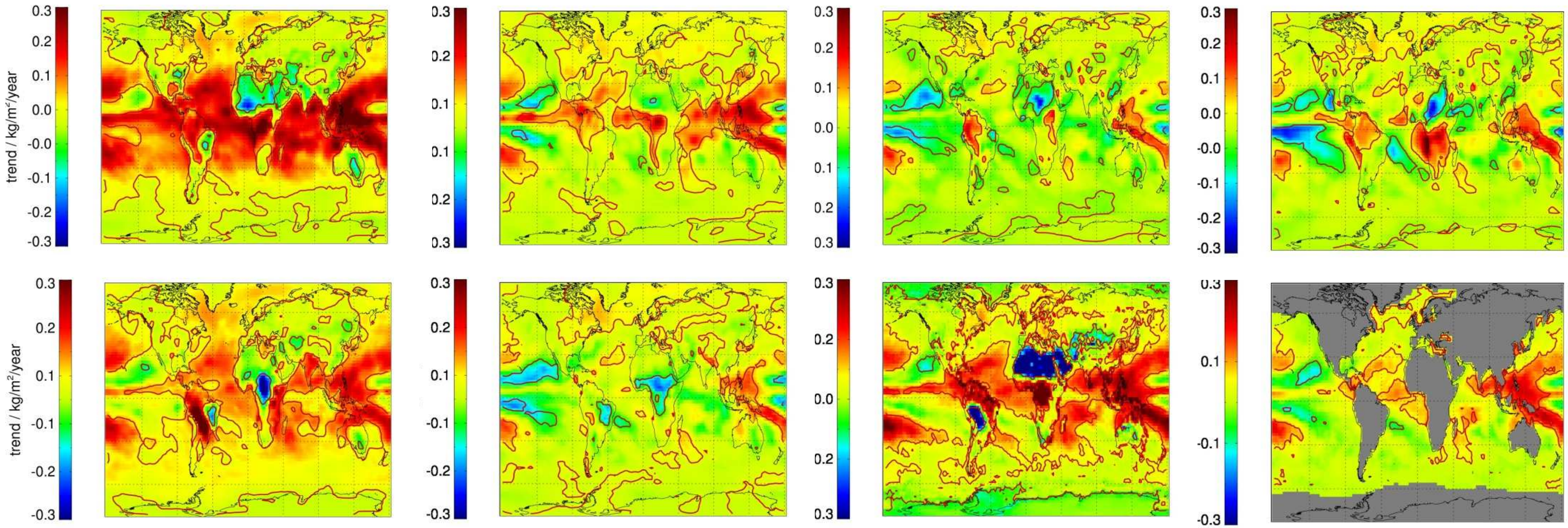
- **Signal from El Nino, annual cycle and other frequencies removed,**
- **Considers autocorrelation.**

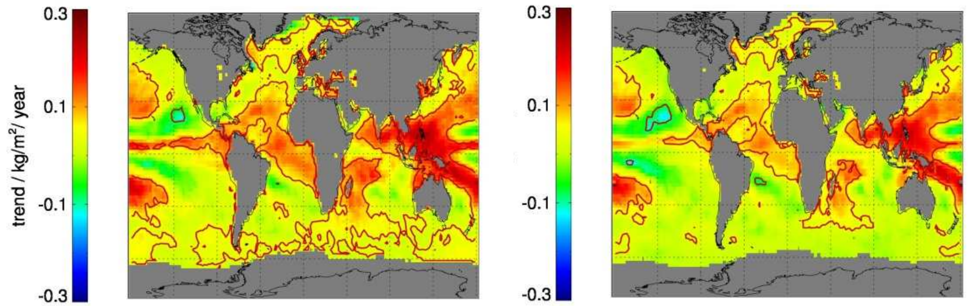
Regression after Dessler and Davis (2010) and Mears et al. (2007).

Homogeneity tests (break point detection) after Wang (2008a, b).

A summary on the applied methodologies is given in Schröder et al. (2016) in JAMC.

Trend estimates (TCWV)



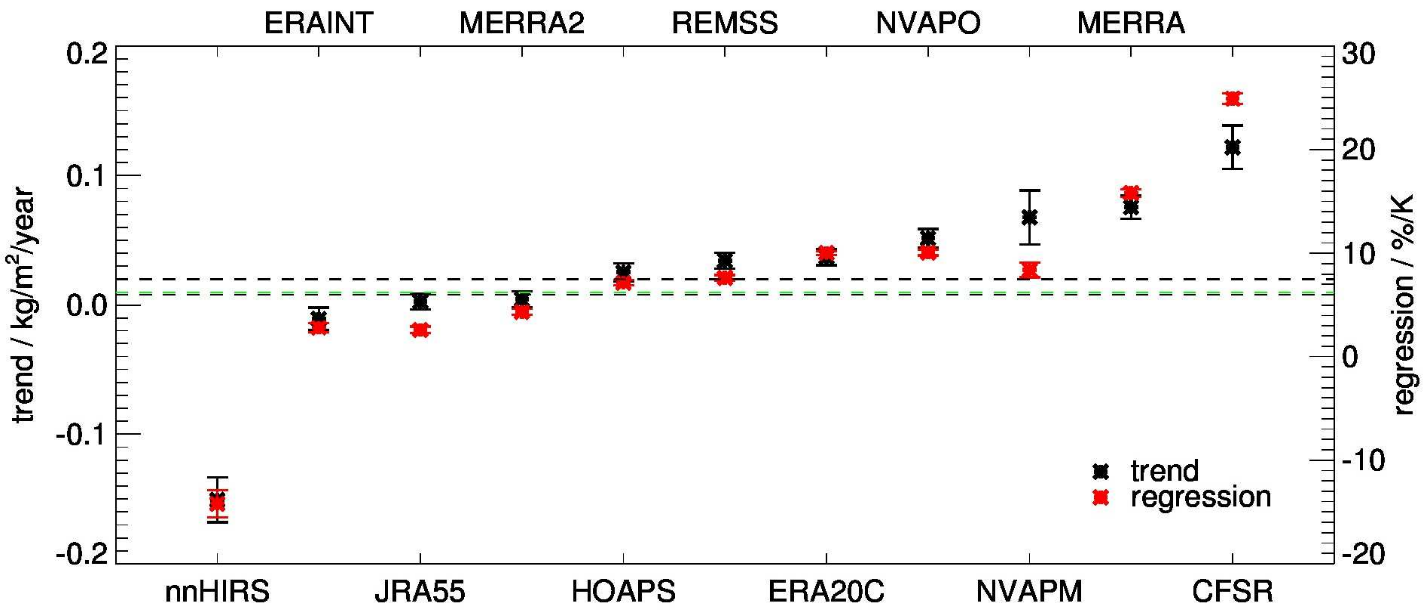


- **CFSR, ERA20C, ERA-Interim, JRA55, MERRA, MERRA2, NVAP-M (Climate), HOAPS, NVAP-M (Ocean), REMSS**

Updated from Schröder et al. (2016) in JAMC

Trends + expectation (TCWV)

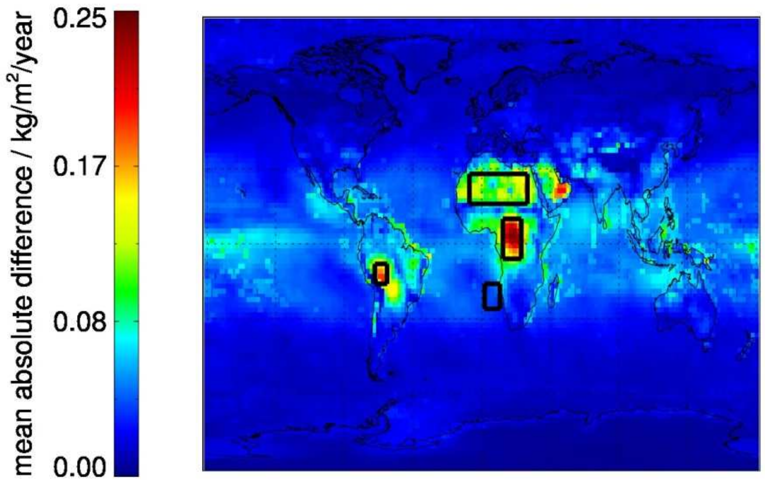
- Trends and expectation over global ice-free ocean (±60°N/S).



Schröder et al. (2018), in preparation for BAMS

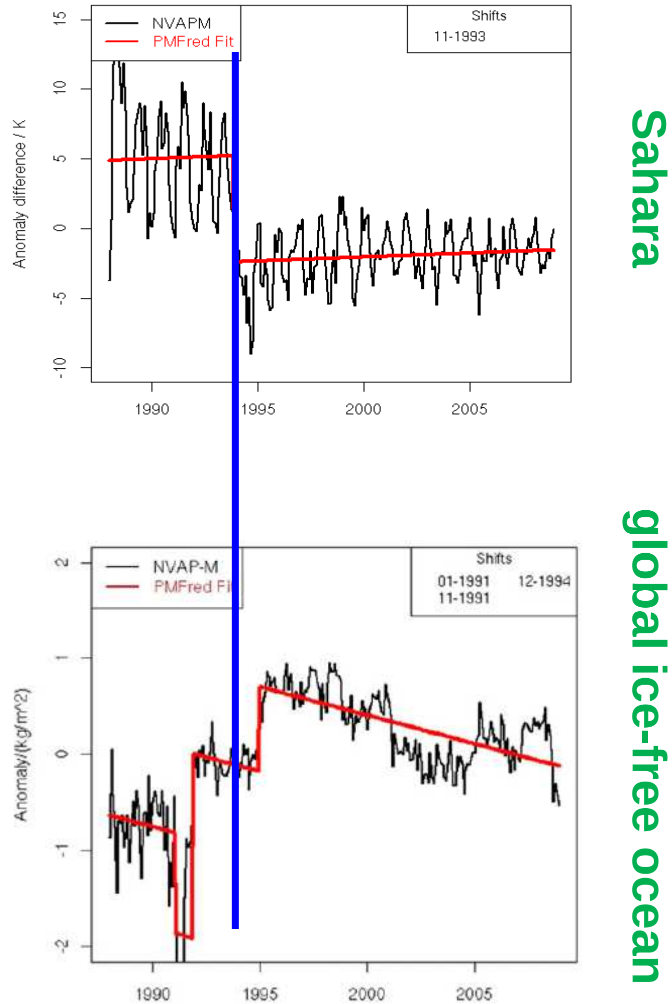
- Large diversity in trends.
- Often significantly different.
- Typically outside of the theoretical expectation.

Homogeneity
(regional dependence, TCWV)



***Top**: mean absolute difference in trend estimates (based on 11 data records).*

***Right**: anomly differences at two regions, based on NVAP-M.*



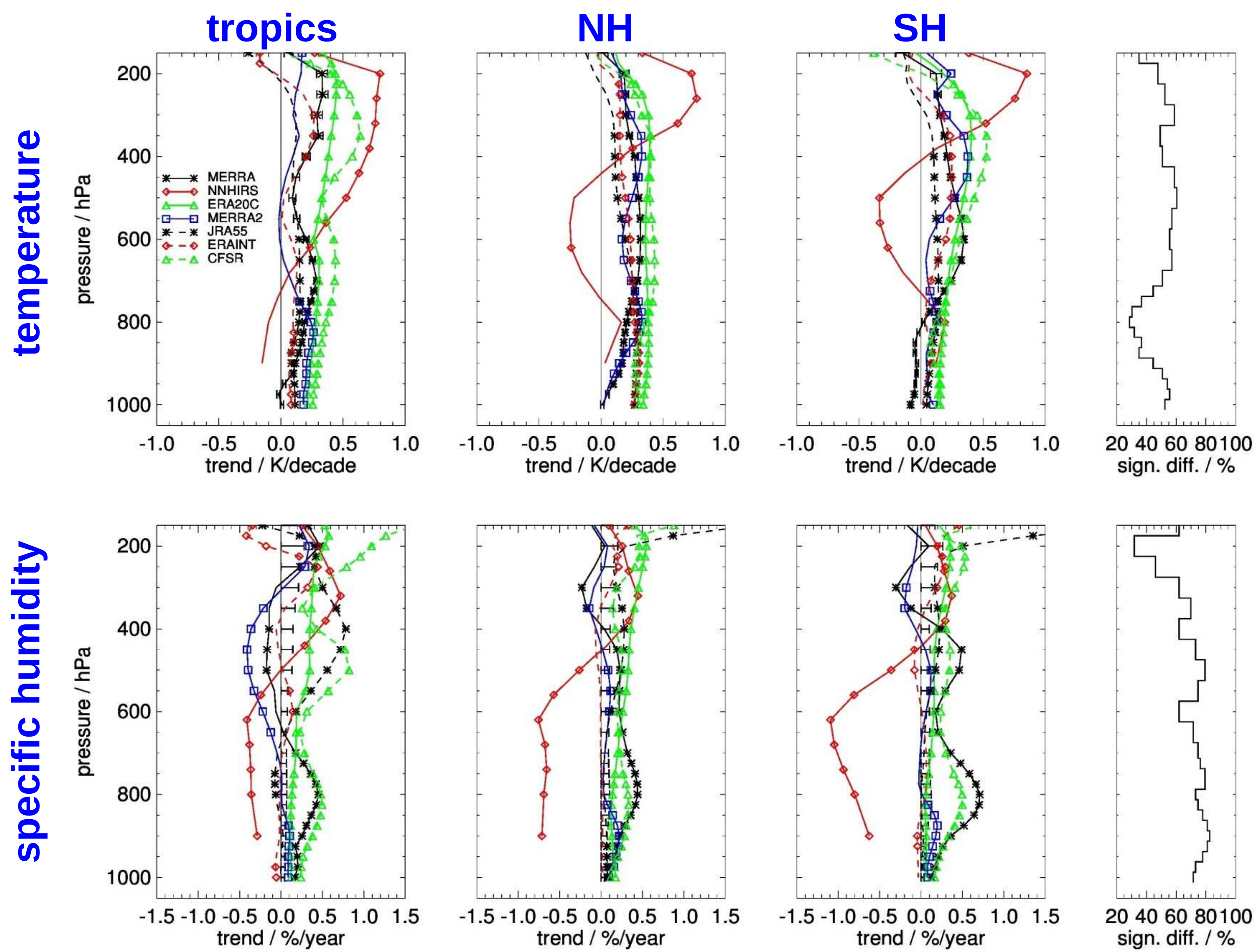
- **(All) data records exhibit break points.**
- **The time, sign and the step size of break points are a function of data record and region.**
- **The break points temporally coincide with changes in the observing system (see Schröder et al., 2017, 2018).**

Schröder et al. (2016, 2017) in JAMC and WCRP report

Profiles: trends

Schröder et al. (2018) in prep. for BAMS

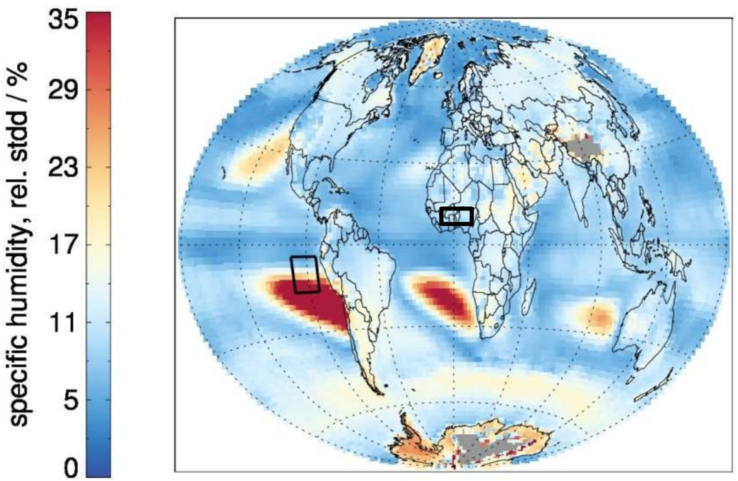
- **7 data records.**
- **Common period: 1988-2009.**
- **Data has not been regridded here.**



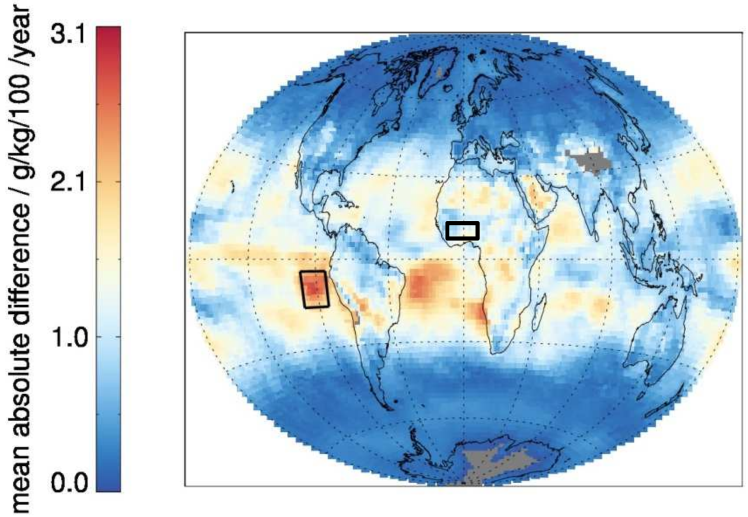
Profiles: regional aspects

- Analysis on global scale, focus at levels 1000, 700, 500, 300 hPa.
- Results shown here: specific humidity at 700 hPa.

Intercomparison: std. dev.



mean differences in trends



Schröder et al. (2018) in prep. for BAMS

Profiles homogeneity

- **Break points observed over stratocumulus (eastern Pacific) at 700 hPa and over western Africa at 300 hPa.**
- **Results are shown for** *specific humidity* **and for** *temperature*.
- **Break points are a function of region, data record and parameter.**

Date yyyy-mm	Region	Break size g kg^{-1}	Break size K	Data record	Event
1988-10	stratus Pacific	-0.76		nnHIRS	NOAA11 declared operational on 1988-11-08
1990-10	western Africa		-0.36	CFSR	Unclear , see text
1991-08	stratus Pacific	0.53		JRA-55	NOAA12 declared operational on 1991-09-17
1991-08	western Africa		0.16	MERRA	Start of assimilation of NOAA12 data on 1991-08-18, end of assimilation of NOAA10 on 1991-09-17 (Rienecker et al. 2011)
1991-12	stratus Pacific	0.26		MERRA-2	Start of assimilation of F11 data in 1991-12-05, end of assimilation of F08 data in 1991-12-04 and of NOAA10 data on 1991-09-01 (McCarty et al. 2016)
1995-02	western Africa	-0.03		nnHIRS	NOAA14 declared operational on 1995-04-10
1995-04	western Africa		-0.23	MERRA-2	Start of assimilation of F13 data on 1997-05-03 and of NOAA14 data on 1995-04-01, end of assimilation of NOAA11 data on 1995-04-10 (McCarty et al. 2016)
1997-03	stratus Pacific		-0.62	CFSR	Approx. stop of assimilation of NOAA12 data (Saha et al. 2010)
1998-06	stratus Pacific	0.41		JRA-55	Approx. start of assimilation of NOAA15 data (Fig. 4, Kobayashi et al. 2015)
1998-09	western Africa	0.05		nnHIRS	Launch of NOAA15 on 1998-05-13, NOAA15 declared operational on 1998-12-15
1998-10	stratus Pacific		0.87	CFSR	Approx. start of assimilation of NOAA15 data, change from assimilation of GOES09 to GOES10 data (Saha et al. 2010)
2001-03	stratus Pacific	-0.55		MERRA	Start assimilation of NOAA16 on 2001-03-02 (Rienecker et al. 2011)
2001-04	stratus Pacific	-0.67		CFSR	Approx. start of assimilation of NOAA16 data (Saha et al. 2010)
2003-08	stratus Pacific	-0.50		ERA-20C	See text
2004-02	western Africa		-0.22	MERRA-2	End of assimilation of NOAA16 data on 2004-05-20, strong change in number of assimilated AMV data from MODIS in early 2004 (McCarty et al. 2016)
2006-04	western Africa		-0.2	MERRA-2	Start of assimilation of COSMIC GPS RO data on 2006-07-13 and of GOES11 data on 2006-06-22, end of assimilation of NOAA14 data on 2006-05-04 and of NOAA15 data on 2006-02-16, (McCarty et al. 2016; see Fig. 10 in Gelaro et al. 2017 on impact of GPS RO on temperature increments in 2006), change in source of sea surface temperature on 2006-04-01 (Gelaro et al. 2017)

Schröder et al. (2018) in prep. for BAMS

Summary

- In general, trends in TCWV, q and T are significantly different and the regression values do not match the theoretical expected value.
- Distinct regional maxima in standard deviation and differences in trends occur over South America, central Africa, Sahara, stratocumulus regions and the poles.
- The data records exhibit break points. These are a function of data record, region and parameter and largely coincide with changes in the observing system.

- Demonstrating stability is challenging on global scale.

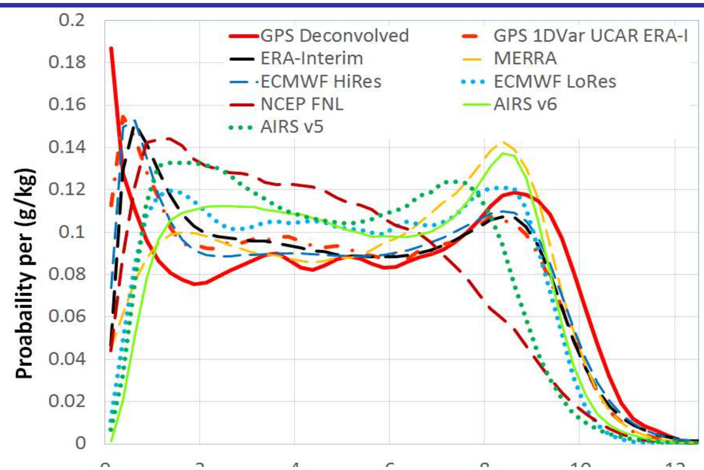
- Recommendations can be found in the appendix and in the WCRP report on pages 10+11.

Outlook:
G-VAP phase 2

Continuity in terms:

- **Scope and objectives, science questions, methodologies/approaches, variables**

- **G-VAP data archive**
- **Workshop series (every 1.5 years with half yearly telecons)**
- **Reassess data records, e.g., use existing break points tables as baseline**
- **Governance (under umbrella of GDAP)**

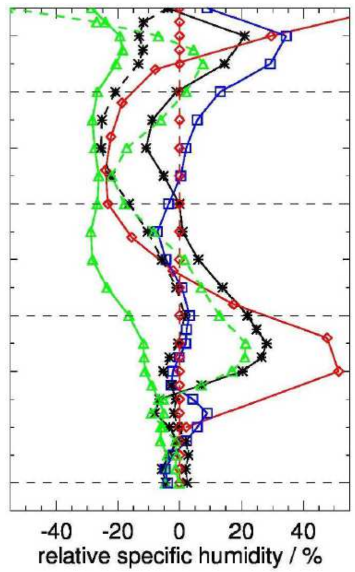


Courtesy: R. Kursinski (SSE)
(taken from WCRP report)

New aspects:

- **Co-chairs:** **H. Brogniez (UVSQ),**
  S.-P. Ho (UCAR)
- **Activities:** **a.o., assess quality over stratocumulus regions, oriented at science questions or at G-VAP recommendations**

Schröder et al. (2018)



Acknowledgement

Appendix

Publications related to G-VAP

- Schröder, M., M. Lockhoff, J. Forsythe, H. Cronk, T. Vonder Haar, R. Bennartz, 2016: The GEWEX water vapor assessment: Results from intercomparison, trend and homogeneity analysis of total column water vapour. J. Applied Meteor. Clim., 1633-1649, 55 (7), doi: /10.1175/JAMC-D-15-0304.1.
- Loew, A., Bell, W., Brocca, L., Bulgin, C., Burdanowitz, J., Calbet, X., Donner, R., Ghent, D., Gruber, A., Kaminski, T., Kinzel, J., Klepp, C., Lambert, J.C., Schaepman-Strub, G., Schröder, M., Verhoelst, T., 2017: Validation practices for satellite based earth observation data across communities. Reviews of Geophysics, 55 (3), 779-817, https://dx.doi.org/10.1002/2017RG000562.
- Schröder, M., Lockhoff, M., Shi, L., August, T., Bennartz, R., Borbas, E., Brogniez, H., Calbet, X., Crewell, S., Eikenberg, S., Fell, F., Forsythe, J., Gambacorta, A., Graw, K., Ho, S.-P., Höschen, H., Kinzel, J., Kursinski, E.R., Reale, A., Roman, J., Scott, N., Steinke, S., Sun, B., Trent, T., Walther, A., Willen, U., Yang, Q., 2017: GEWEX water vapor assessment (G-VAP). WCRP Report 16/2017; World Climate Research Programme (WCRP): Geneva, Switzerland; 216 pp.
- Schröder, M., Lockhoff, M., Fell, F., Forsythe, J., Trent, T., Bennartz, R., Borbas, E., Bosilovich, M. G., Castelli, E., Hersbach, H., Kachi, M., Kobayashi, S., Kursinski, E. R., Loyola, D., Mears, C., Preusker, R., Rossow, W. B., and Saha, S.: The GEWEX Water Vapor Assessment archive of water vapour products from satellite observations and reanalyses, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2017-128, in review, 2018.
- Trent, T., M. Schröder, J. Remedios, 2018: GEWEX Water Vapor Assessment: Validation of AIRS Tropospheric Humidity Profiles with Characterised Radiosonde Soundings. Submitted to JGR.
- Shi, L., C. J. Schreck III, M. Schröder, 2018: Assessing the consistency between satellite-observed upper tropospheric humidity and total column water vapor during major El Niño events. In preparation for Rem. Sens.
- M. Schröder, M. Lockhoff, L. Shi, T. August, R. Bennartz, X. Calbet, F. Fell, J. Forsythe, A. Gambacorta, S.-P. Ho, E. R. Kursinski, A. Reale, T. Trent, Q. Yang, 2017: The GEWEX water vapor assessment of global water vapour and temperature data records from satellites and reanalyses. In preparation for BAMS.

Recommendation

- CGMS, Space Agencies: Improve upon current satellite profiling capabilities with goals of providing high precision and long term stability, with sufficient vertical resolution, complete, unbiased global sampling and independency of models (sections 4.3.2.3 and 6.2).
- CGMS, Space Agencies: Dedicated validation archive for all water vapour sensors, also including ship based RS (sections 4.1, 6.4).
- CGMS, WMO, GRUAN: Aim at the sustained generation and development of a stable, bias corrected multi-station radiosonde archive including reprocessing of historical data (section 6.4).
- CGMS, WMO: Achieve consistency among reference observing systems and sustain corresponding services (section 6.3).
- WMO, GCOS: Oppose and balance user, scientific and product requirements with focus on climate analysis.
- 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 (sections 4.2.2, 4.3, 4.4).
- Space Agencies, GEWEX: Provide water vapour transport product in order to analyse atmospheric dynamics and to evaluate the constancy of relative humidity.
- Space Agencies, PIs: Develop and provide PDF based climatology of satellite-based radio-occultation data (section 6.2).
- Space Agencies, PIs: Provide averaging kernels, a priori state vectors and associated error covariance matrices together with the release of profile products (section 2.5).
- Space Agencies, PIs, G-VAP: Estimate and provide uncertainty information and assess uncertainty estimates, also as function of total amounts and other dependent parameters (sections 3.2, 4.3.1.4, 6.4).

Recommendation

- Space Agencies, PIs, G-VAP: Improve stability of long-term data records and (re)assess improvement in stability (sections 4.3, 4.4).
- 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 (section 4.3).
- GEWEX, SPARC, G-VAP, WAVAS: Joint WAVAS and G-VAP analysis of data records covering the upper troposphere and lower stratosphere using the same methodology.
- GRUAN: Include station over tropical land (sections 4.1, 4.3, 6.4.2).
- GRUAN: Reassess the uncertainty estimates at large humidity values (section 6.4).
- GRUAN: Provide estimates of the correlation uncertainty between levels or guidance on how to compute it from information already available (ideally the covariance matrix of uncertainties is provided, section 6.3).
- GEWEX: Continuous support to G-VAP, beyond acceptance of first report.
- G-VAP, Space Agencies, PIs: Enhance quality analysis of profile data records over open ocean, in particular over high pressure areas/subsidence areas and stratus (sections 4.1.2, 4.3.2).
- G-VAP, Space Agencies, PIs: Analyse differences between observations under all-sky as well as cloudy and clear sky conditions (sections 4.1.1, 4.1.2, 6.1).
- G-VAP: Reassess the TTD of humidity profile data by taking into account the vertical resolution and sensitivity and the characteristics of the PDF at certain levels/layers (section 2.5, section 6.2).
- 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 (section 6.1).
- 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 Joint workshop on uncertainties at 183 GHz.

Other activities

T. August (EUMETSAT), T. Trent (U Leicester): Information content, value of averaging kernels.

T. Trent (U Leicester: stability.

B. Ho (UCAR), J. Forsythe (CSU) et al.: Sampling biases.

R. Bennartz (Vanderbilt U, U Wisconsin), A. Walther (UW) et al.: Temporal variability in satellite data records and climate model simulations.

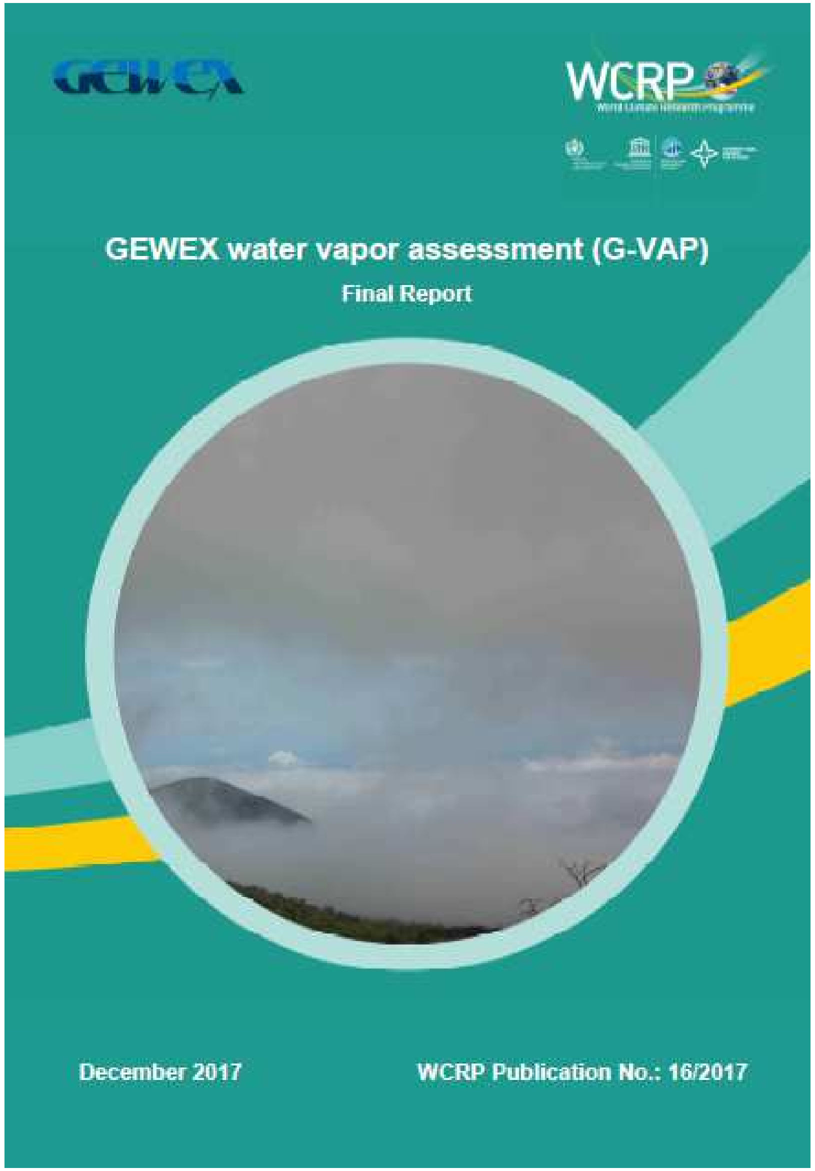
J. Forsythe (CSU) et al.: Overview on sensors

A. Gambacorta (NOAA), H. Brogniez (UVSQ/LATMOS): sources of uncertainties

A. Reale (NOAA) et al.: Validation of vertical profiles y.

X. Calbet (AEMET et al.: Colocation.

L. Shi (NOAA) et al: Intercomparison of UTH products, consistency



Schröder et al., 2017: GEWEX water vapor assessment (G-VAP). WCRP Report 16/2017; World Climate Research Programme (WCRP): Geneva, Switzerland, available at https://www.wcrp-climate.org/WCRP-publications/2017/WCRP-Report-16-2017-GVAP-v1.3_web.pdf