The GEWEX water vapor assessment (G-VAP) - results from inter-comparisons and stability analysis

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Thomas August, Ralf Bennartz, Bojan Bojkov, Eva Borbas, Xavier Calbet, Heather Cronk, Frank Fell, John Forsythe, Antonia Gambacorta, Kathrin Graw, Ben Ho, Heidrun Höschen, Julian Kinzel, Robert Kursinski, Anthony Reale, Remy Roca, Noelle Scott, Jörg Schulz, Tim Trent, Thomas Vonder Haar, Andi Walther

Overview

- **Background**
- **Considered data records**
- **Approach**
- **Results (focus on total column water vapour):**
  - **Trend estimation**
  - **Intercomparison**
  - **Global**
  - **Regional**
- **Conclusions**
- **Outlook**

Overview
G-VAP

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

- **Overall scope:**
  - **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, profiles and stability/variability. No ranking. Assessment plan available at http://gewex-vap.org, WCRP report on G-VAP currently under review.**

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

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
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www.gewex-vap.org
→ Data Records

With support from F. Fell

- 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
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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-	global	daily, monthly	1°,	WEB
AIRS, AMSU-, CPR, MODIS							
AMSR-E	REMSS	TCWV	06/2002-09/2011	global ocean	monthly	0.25°	WEB Hilburn and Wentz, 2008
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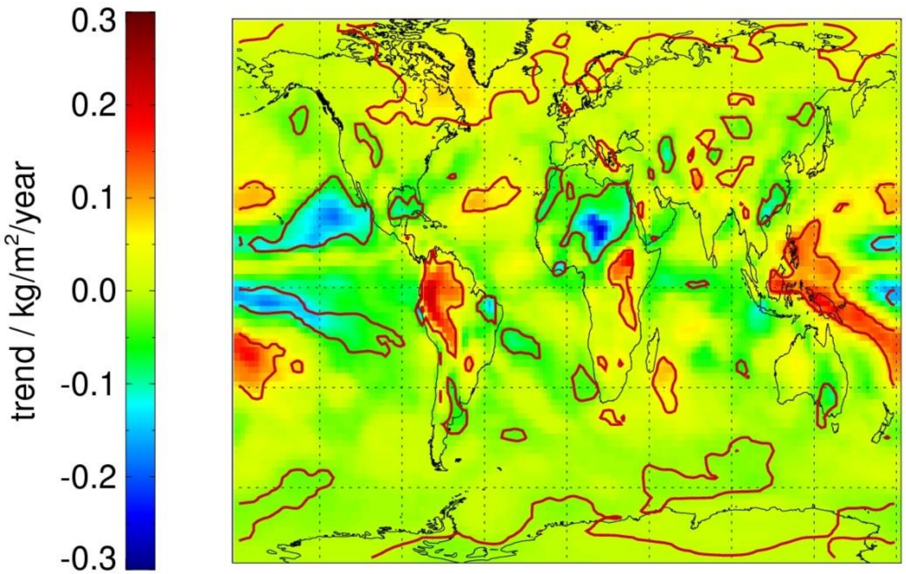
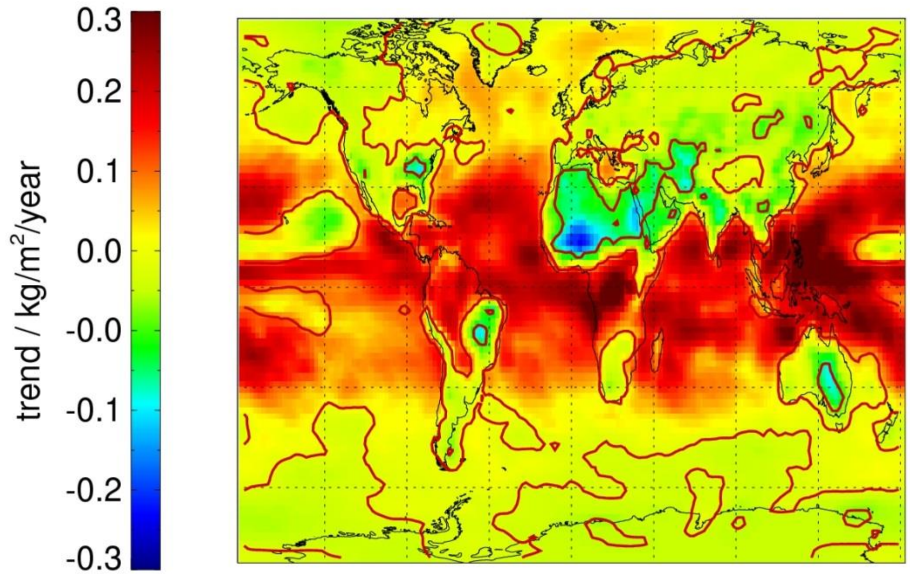
AMSU-B	LTU	UTH	01/1999-05/2008	global, 60°N-60°S	monthly	2.5°	WEB

- **22 data records used within G-VAP.**

Science questions
(subset)

How large are the differences in observed temporal changes in long-term satellite data records of water vapour? Are the observed temporal changes and anomalies in line with theoretical expectations? Are the differences in observed temporal changes within uncertainty limits? What is the degree of homogeneity (breakpoints) and stability of each long-term satellite data record?





Data records

Long-term data records: more than 20 years of coverage and available at start of analysis.

TCWV: CFSR, ERA20C, ERA-Interim, HOAPS, JRA55, MERRA, MERRA2, nnHIRS', NVAP-M, NVAP-O, REMSS

Methods, results and conclusions are largely based on Schröder et al. (2016, JAMC) and Schröder et al. (2017, WCRP report on G-VAP).

Methods
(TCWV)

Data has been aggregated onto common grid of 2°x2° for the common period from 1988 – 2008.

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

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

Also available:

- Absolute and relative uncertainty
- Coverage probability, extended uncertainty

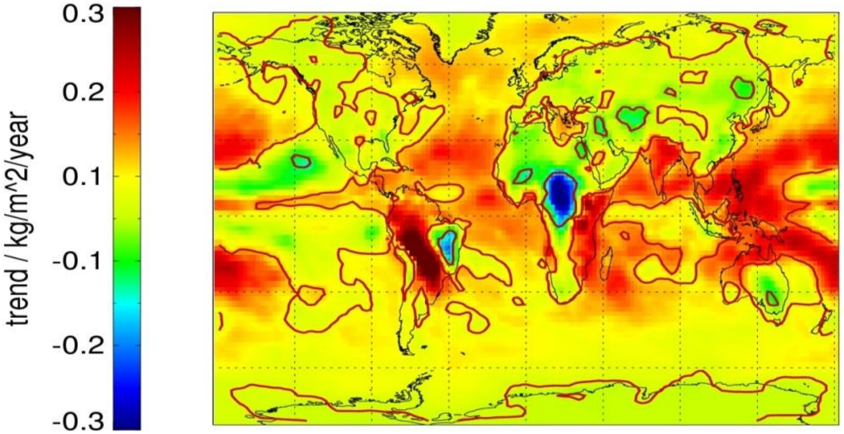
Regression after Dessler and Davis (2010) and Mears et al. (2007).

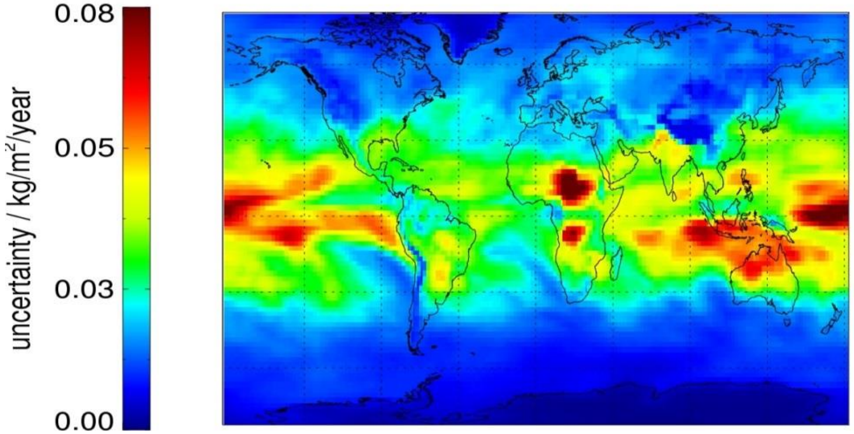
Time-to-detect (TTD) after Weatherhead et al. (1998).

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

Trend estimation as a tool

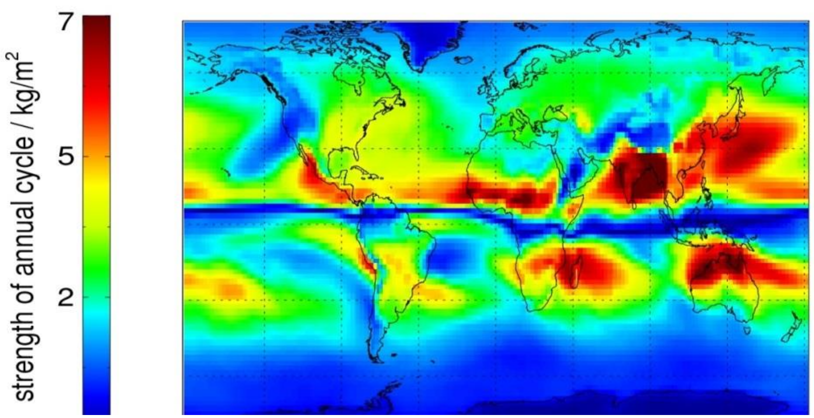
also: relative values, autocorrelation, ext. uncertainty

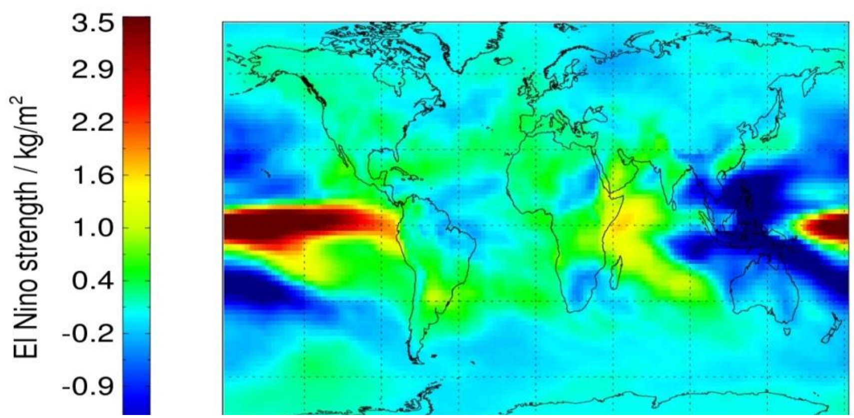




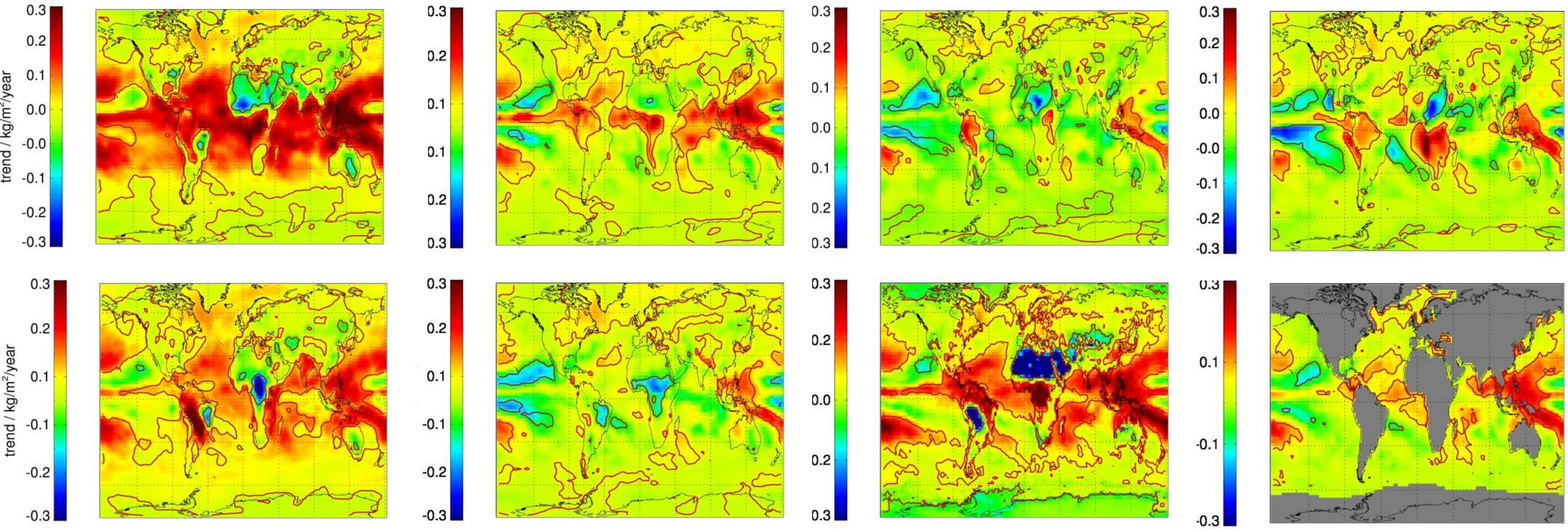
trend **uncertainty**

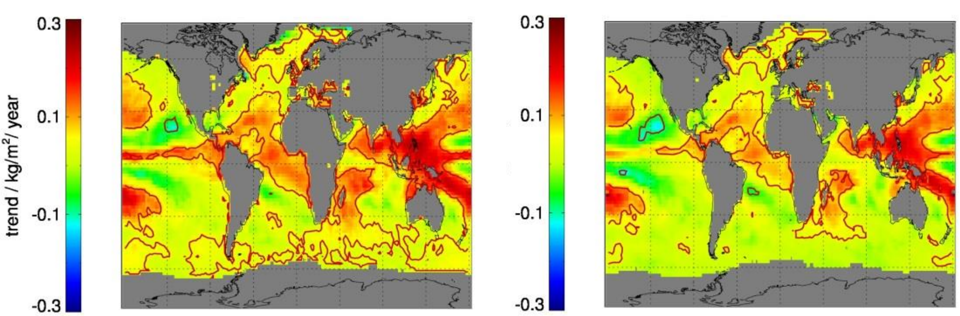
annual cycle strength **El Nino strength**





Trend estimates

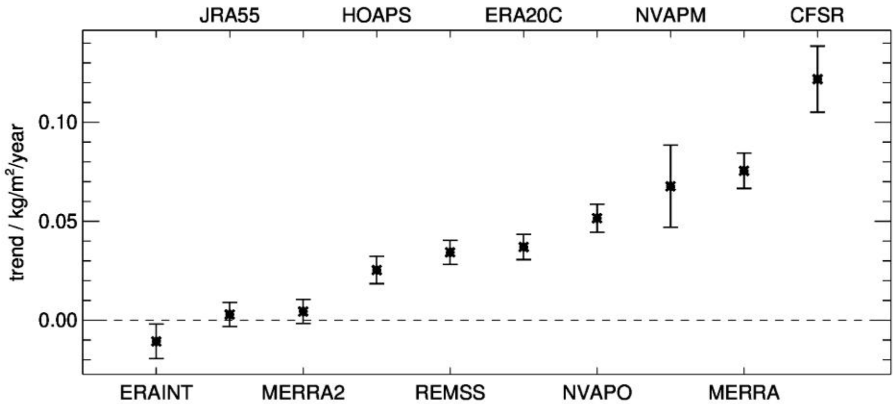


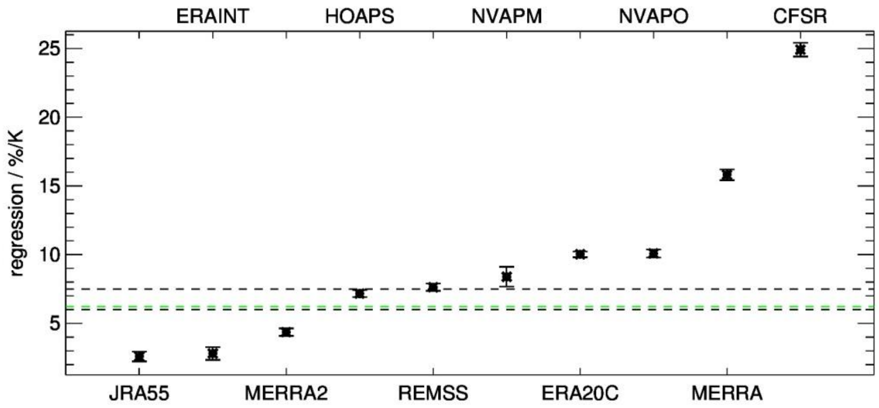


- **CFSR, ERA20C, ERA-Interim, JRA55, MERRA, MERRA2, NVAP-M (Climate), HOAPS, NVAP-M (Ocean), REMSS**

Updated from Schröder et al. (2016)

Trends + expectation





Schröder et al. (2017)

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

- **Large diversity in trends.**
- **Often significantly different.**

- **Typically outside of the theoretical expectation.**

Time-to-detect

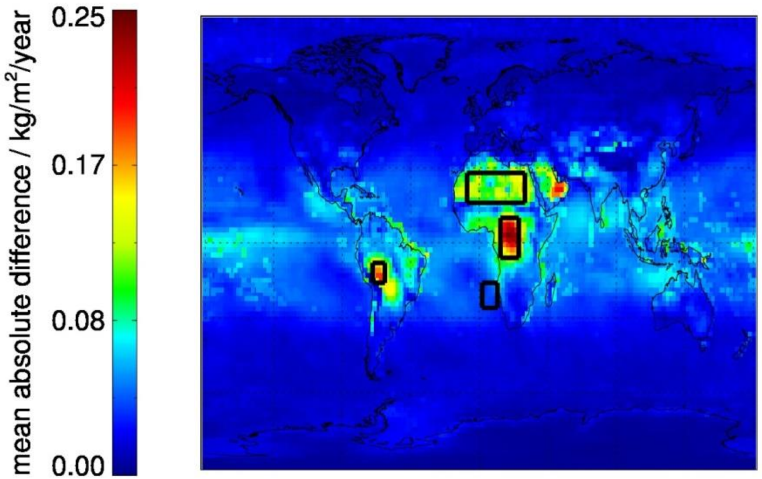
	Trend kg/m^2/decade	Regression % / K	TTD* years
CFSR	1.21 ± 0.16	24.9 ± 0.5	33
ERA-Interim	-0.11 ± 0.09	2.9 ± 0.5	22
ERA20C	0.37 ± 0.06	10.0 ± 0.2	18
HOAPS	0.25 ± 0.07	7.2 ± 0.3	18
JRA55	0.03 ± 0.06	2.6 ± 0.4	17
MERRA	0.75 ± 0.09	15.8 ± 0.3	22
MERRA2	0.04 ± 0.06	4.4 ± 0.3	17
NVAP-M Climate	0.68 ± 0.20	8.4 ± 0.7	37
NVAP-M Ocean	0.52 ± 0.07	10.1 ± 0.3	18
REMSS	0.34 ± 0.06	7.6 ± 0.3	17

Schröder et al. (2017)

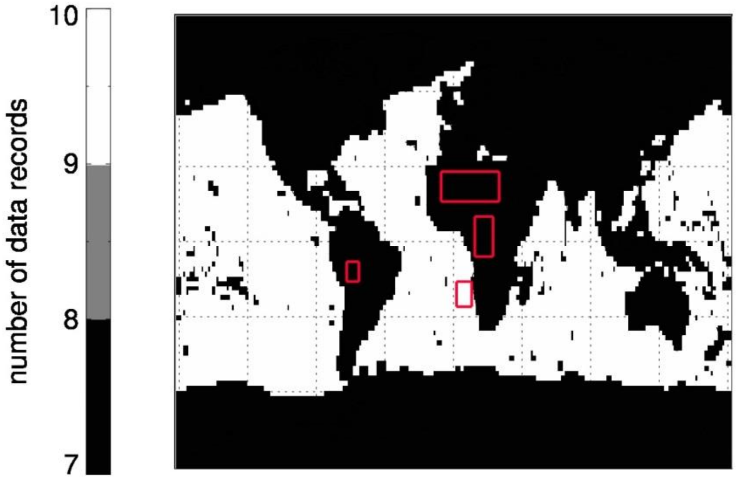
- **Trend and regression values for previous slide.**
- **Large diversity in TTD (time-to-detect: function of noise and autcorrelation).**
- **Extremes values dominated by noise.**

Differences in trend estimates

- **Mean absolute difference in trend estimates and number of data records.**



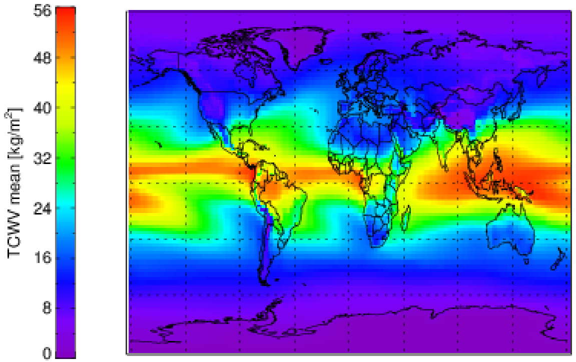
Updated from Schröder et al. (2016)



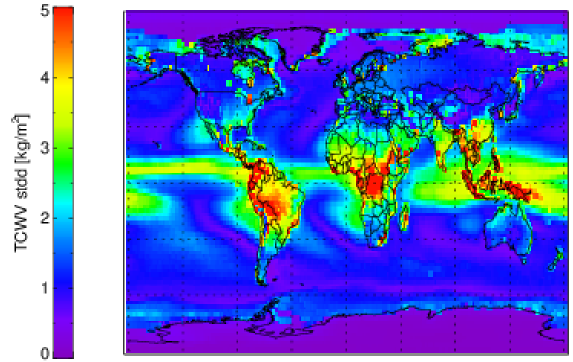
- **Maxima: South America, Central Africa, Sahara.**

Intercomparison

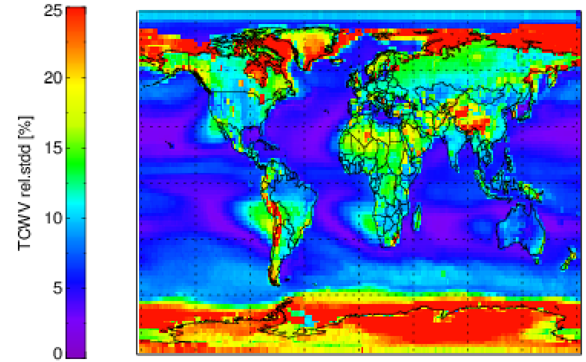
mean



standard deviation



relative standard deviation

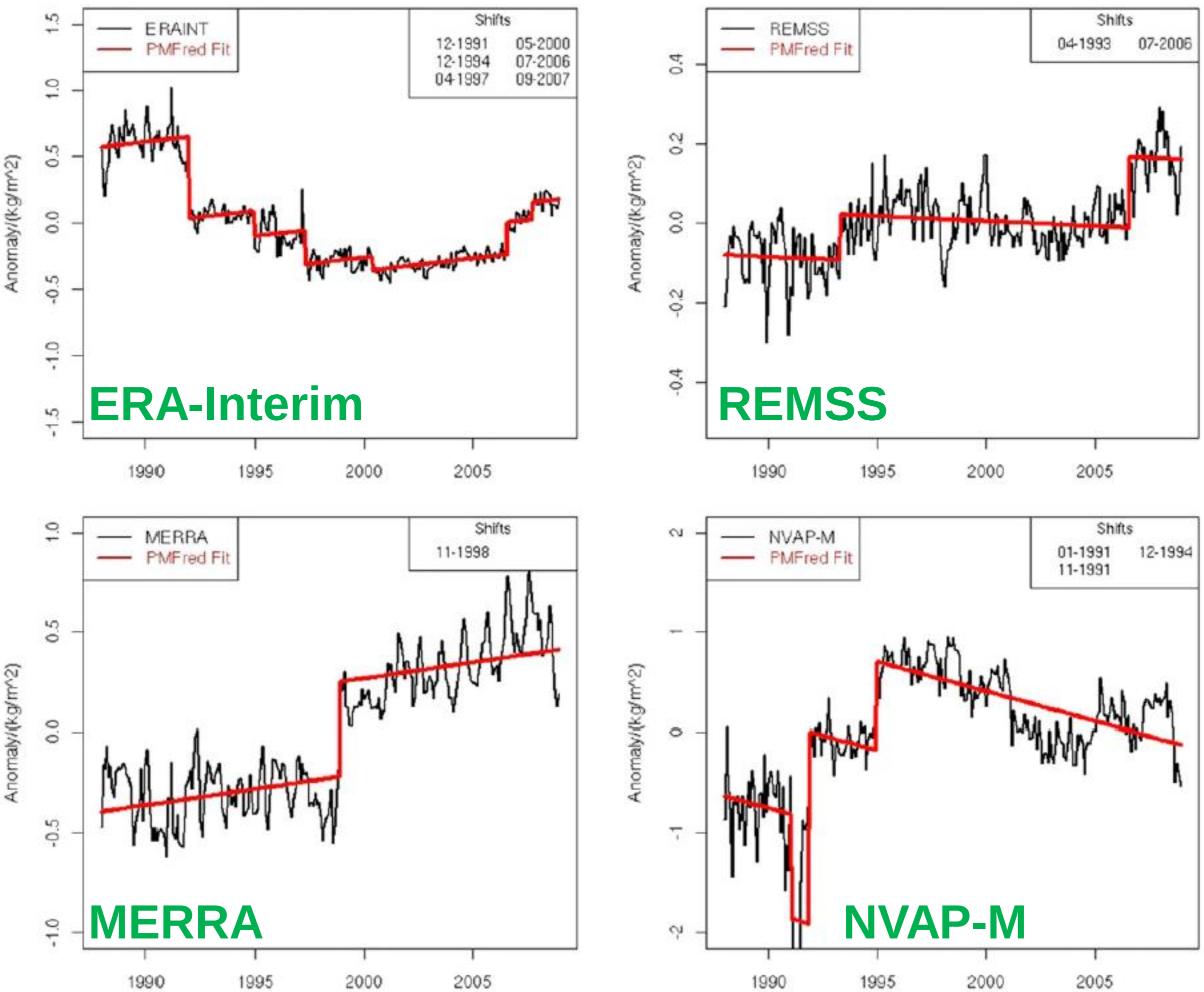


Schröder et al. (2017)

- **Largest standard deviations over land areas.**
- **Distinct features over South America, Central Africa, mountainous areas, Sahara, and the poles.**

- **With large overlap to mean absolute differences in trend estimates.**

Homogeneity
(global ice-free ocean)



- **Global ice-free ocean.**
- **Anomaly difference, reference is HOAPS-3.2.**

Schröder et al. (2016)

Homogeneity

Date	Break size (kg m^{-2})	Dataset	Event
Jan 1991	−1.05	NVAP-M	Launch *F-10*: Dec 1990
Nov 1991	1.92	NVAP-M	Launch *F-11*: Dec 1991 Stop date *F-08*: Dec 1991
Dec 1991	−0.62	ERA-Interim	See Nov 1991
Apr 1993	0.11	REMSS	See text
Dec 1994	−0.19	ERA-Interim	Launch of *NOAA-14*: Dec 1994, approx stop of assimilation of *NOAA-11* data (see Dee et al. 2011)
	0.88	NVAP-M	
Apr 1997	−0.26	ERA-Interim	Approx change from assimilation of data from *NOAA-12* to *NOAA-11* (see Dee et al. 2011)
Oct 1998	1.31	CFSR	Begin of assimilation of *NOAA-15* data in Oct 1998 (Chelliah et al. 2011); approx end of assimilation of *NOAA-11* and *NOAA-14* data; change from assimilation of data from *GOES-9* to *GOES-10* (Saha et al. 2010)
Nov 1998	0.47	MERRA	Start of assimilation of *NOAA-15* data (Rienecker et al. 2011)
May 2000	−0.10	ERA-Interim	Approx start of assimilation of *F-15* data and end of *NOAA-11* and *NOAA-15* data (see Dee et al. 2011)
Jul 2006	0.24	ERA-Interim	Close to end of assimilation of *F-15* data, close to change from *GOES-10* to *GOES-11*, start of *Meteosat-5* and *Meteosat-8*, approx end of assimilation of *NOAA-14* data (see Dee et al. 2011)
	0.18	REMSS	See text
Sep 2007	0.13	ERA-Interim	Approx end of assimilation of *NOAA-16* data (see Dee et al. 2011)

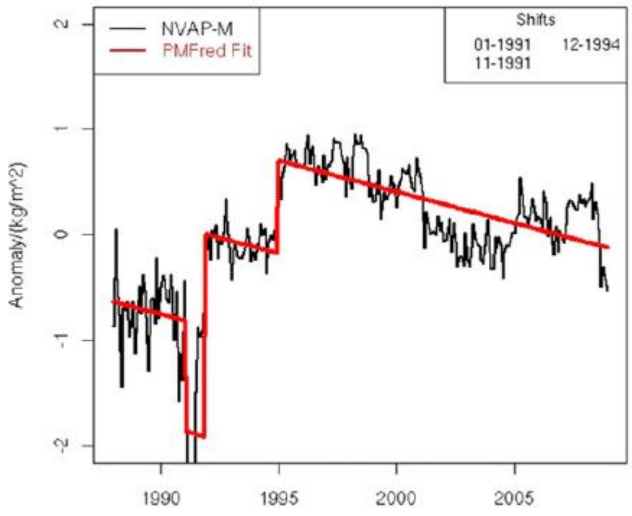
Schröder et al. (2016)

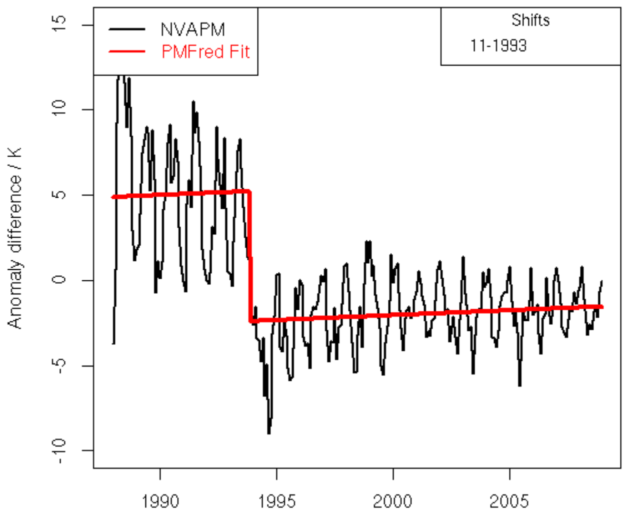
Homogeneity

global ice-free ocean

Sahara

Schröder et al. (2016)

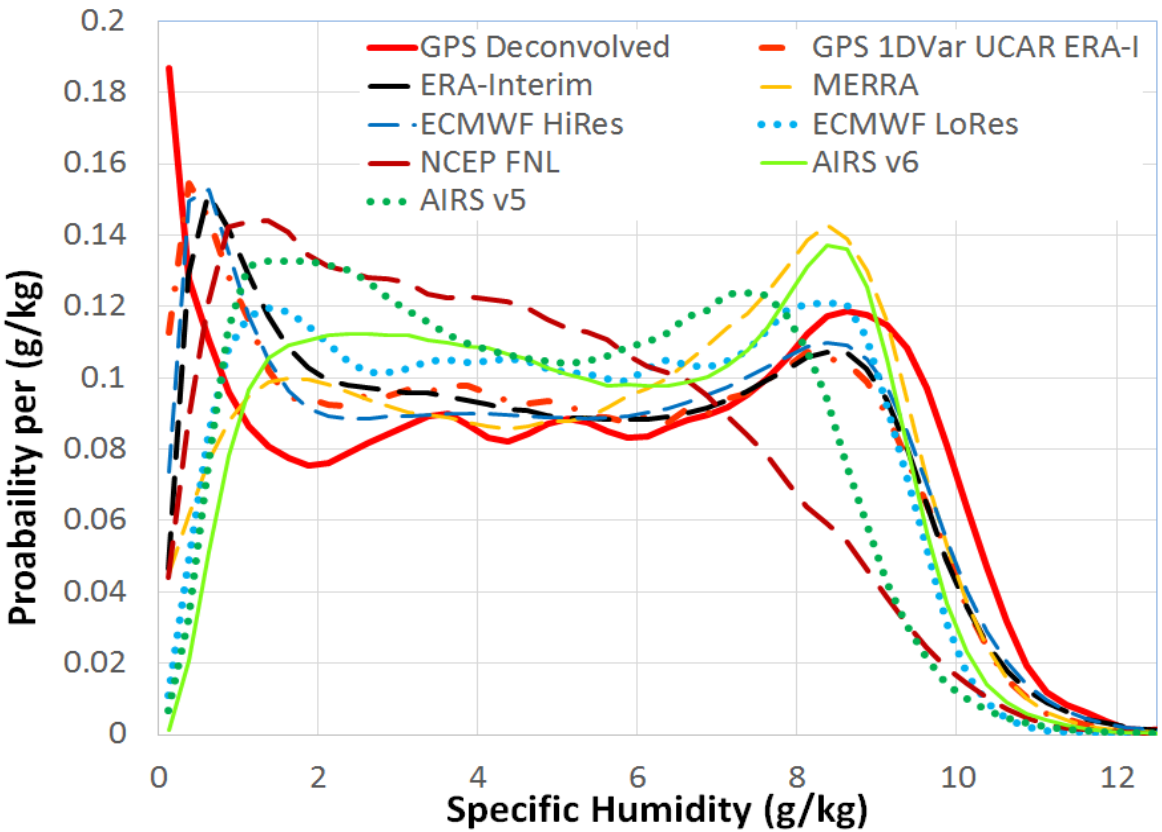




- Results based on NVAP-M.
- Inhomogeneities explain maxima in mean absolute differences in trends and in standard deviation among the data records.
- The break points temporally coincide with changes in the observing system.
- The time, sign and the step size of break points are a function of region and data record.

Specific humidity, profiles PDFs

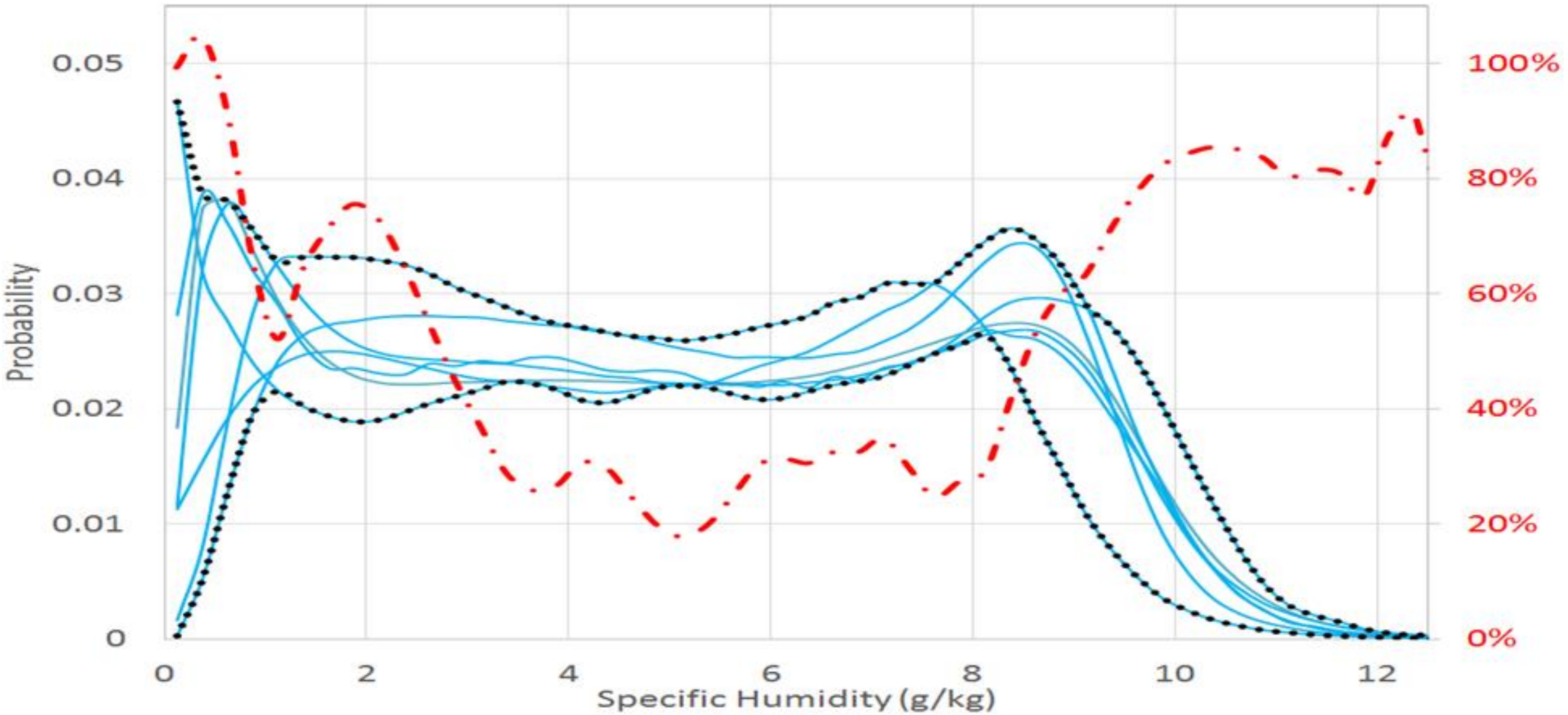
- **Specific humidity at 725 hPa.**
- **Tropics (within 30°N/S) from 2007.**



Courtesy: R. Kursinski

PDFs structural uncertainty

- **Specific humidity at 725 hPa.**
- **Dashed – min/max values.**
- **Dashed-dotted: relative spread within each bin.**
- **See also Thorne et al. (2006).**



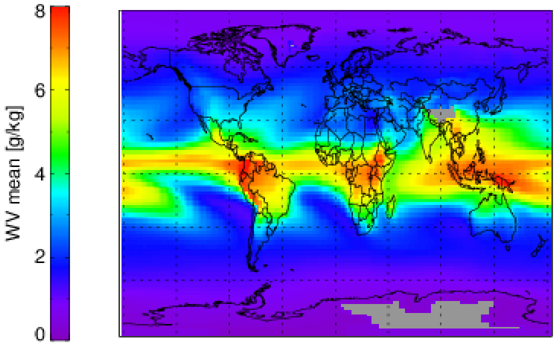
Courtesy: R. Kursinski

Profile intercomparison

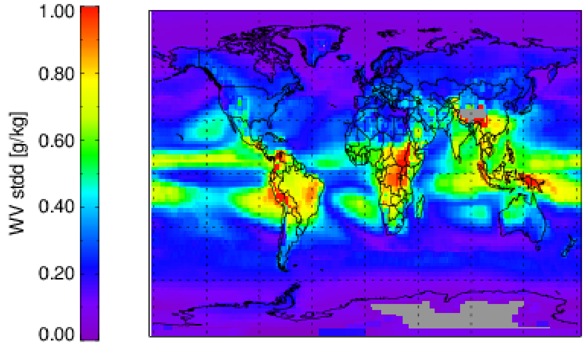
- **Specific humidity**
- **7 data records (6 reanalyses).**
- **Common grid: 2°x2°.**
- **Common period: 1988-2009.**

- **Intercomparison at 700 hPa.**

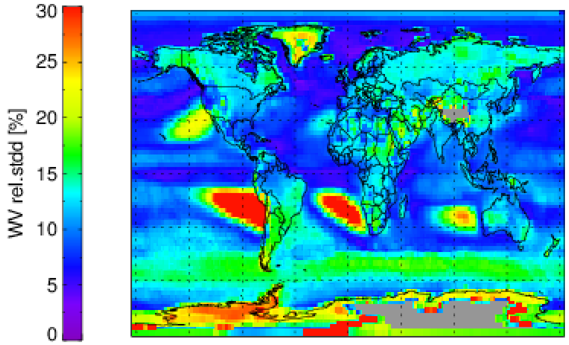
mean



standard deviation



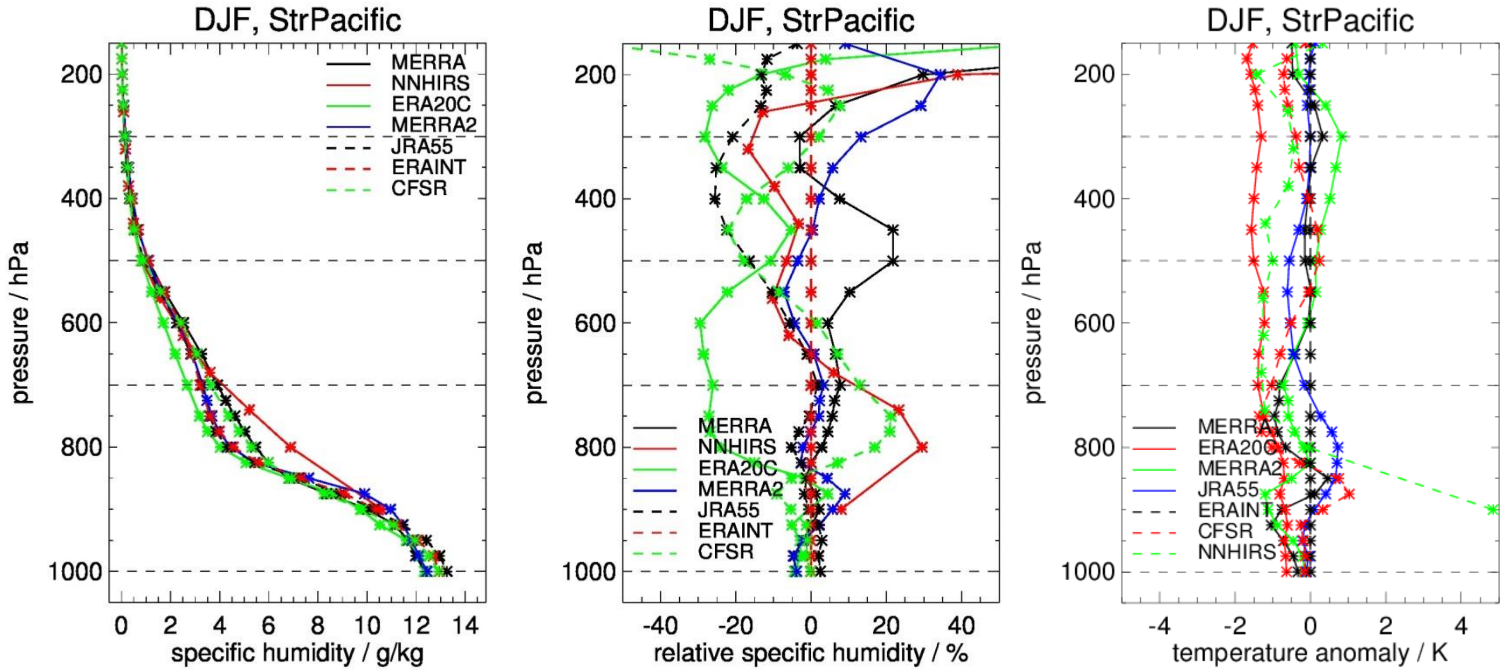
relative std. dev.



Schröder et al. (2017)

Profile intercomparison

- **Average profiles and relative differences (to ERA-Interim), here: stratus region over southern Pacific.**
- **Obvious issues at cloud top.**

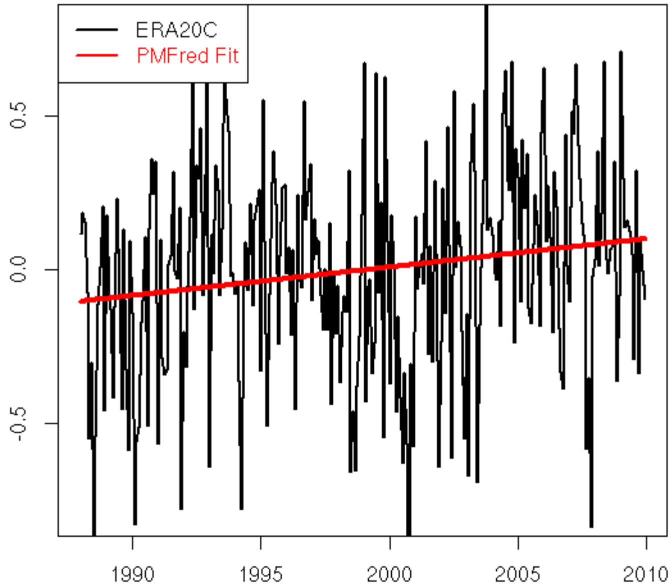


Schröder et al. (2017)

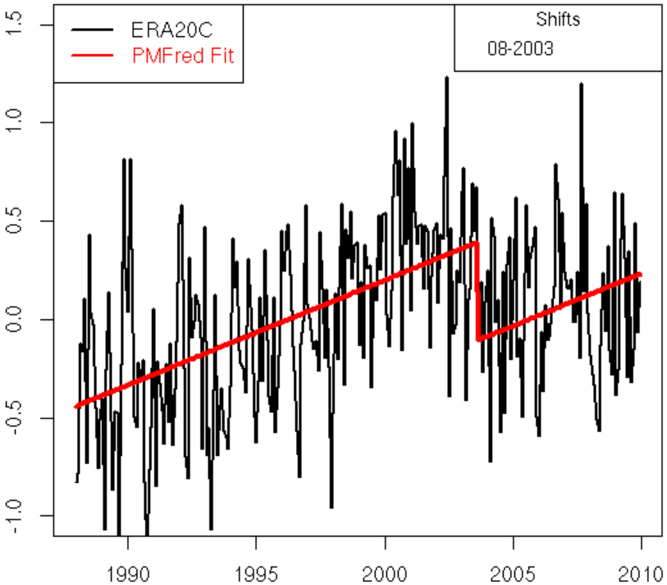
Profile intercomparison

- **Anomaly difference time series (versus ERA-Interim) over stratus regions of the Pacific.**

Temperature



Specific humidity



Schröder et al. (2017)

- **Breakpoints are a function of region, data record and parameter.**

Recommendation (subset)

- CGMS, Space Agencies: Dedicated validation archive for all water vapour sensors, also including ship based RS.
- CGMS, WMO, GRUAN: Aim at the sustained generation and development of a stable, bias corrected multi-station radiosonde archive including reprocessing of historical data.
- CGMS, WMO: Achieve consistency among reference observing systems and sustain corresponding services.
- Space Agencies: Need for inter-calibrated radiance/brightness temperature data records and homogeneously reprocessed instantaneous satellite data records.
- 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.
- GRUAN: Include station over tropical land.
- 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.
- 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.

Conclusions

- **In general, trends in TCWV are very different and often significantly different. Generally the trends do not match the theoretical expectation.**
- **TCWV: The differences in trends and maxima in standard deviation are frequently caused by changes in the observing system. A strong regional imprint is observed.**
- **Profiles: Breaks have largely impact stability. Other factors like vertical resolution and other structural differences affect the standard deviation as well.**
- **Break points are a function of data record, region and parameter!**
- **Intercomparison to station data does typically not exhibit the observed break points because regions with distinct features are often not covered with long-term reference data.**

Outlook

- **WCRP report on G-VAP under review by GDAP.**
- **G-VAP will be continued as agreed upon at the last G-VAP workshop and supported by GDAP.**
- **Finalise ESSD paper on G-VAP data archive and overview paper for submission to BAMS.**
- **Next G-VAP workshop will be at the University of Leicester, UK on 25+26 October 2017.**

Publications related to G-VAP
(subset)

- **Courcoux, N. and Schröder, M.:** The CM SAF ATOVS data record: overview of methodology and evaluation of total column water and profiles of tropospheric humidity, Earth Syst. Sci. Data, 7, 397-414, doi:10.5194/essd-7-397-2015, 2015.
- **Kinzel, J., K. Fennig, M. Schröder, A. Andersson, K. Bumke, and R. Hollmann, 2016**: Decomposition of Random Errors Inherent to HOAPS-3.2 Near-Surface Humidity Estimates Using Multiple Triple Collocation Analysis. Accepted by JAOT.
- **Mieruch, S., M. Schröder, S. Noel, and J. Schulz, 2014:** Comparison of decadal global water vapor changes derived from independent satellite time series. *J. Geophys. Res. Atmos*., 119, doi:10.1002/2014JD021588.
- **Schröder, M., M. Jonas, R. Lindau, J. Schulz, and K. Fennig, 2013**: The CM SAF SSM/I-based total column water vapour climate data record: methods and evaluation against re-analyses and satellite. *Atmos. Meas. Tech.*, 6, 765–775, doi:10.5194/amt-6-765-2013.
- **Schröder, M., R. Roca, L. Picon, A. Kniffka, and H. Brogniez, 2014:** Climatology of free tropospheric humidity: extension into the SEVIRI era, evaluation and exemplary analysis. Atmos. Chem. Phys., 14, 11129-11148, doi:10.5194/acp-14-11129-2014.
- **Shi, L., C. J. Schreck III, and V. O. John:** HIRS channel 12 brightness temperature dataset and its correlations with major climate indices, *Atmos. Chem. Phys.*, 13, 6907-6920, doi:10.5194/acp-13-6907-2013, 2013.
- **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.
- **Trent, T., M. Schröder, J. Remedios,** 2016**:** Assessment of AIRS tropospheric humidity profiles with characterised radiosonde soundings within the GEWEX water vapor assessment. Submitted to JGR.