The GEWEX water vapor assessment (G-VAP)

Marc Schröder, Maarit Lockhoff, Kathrin Graw, Lei Shi

Thanks goes to

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

- Short introduction to G-VAP
- Last workshops
- Output
- A few results
- Topics for the future

Motivation

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 and will fully document each step of the analysis and related results.

- GDAP (GEWEX Data and Assessments Panel) perspective:

Support for the selection process of suitable water vapour products by GDAP for its production of globally consistent water and energy cycle products.

- User perspective:

Overview of available data records and enable users to judge the quality and fitness for purpose of CDRs.

- PIs and agencies:

Valuable information on strength and weakness of data records, aiming at recommendations for improvement.

Background

The GEWEX Data and Assessments Panel (GDAP) initiated G-VAP in 2011:

- **First workshop**:
  Hosted in March 2011 by ESA-ESRIN with support from the ESA DUE GlobVapour project. Summary in GEWEX Newsletter, May 2011.

- **Second workshop**:
  Hosted in September 2012 by DWD and CM SAF. Summary in GEWEX Newsletter, November 2012.

- The outputs form the basis of the assessment plan (scope, science questions, activities, responsibilities, time line, data policy) – see www.gewex-vap.org for details.

- Summary of results in a WCRP report on G-VAP and a summary paper to be submitted to, e.g., BAMS

- **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.

- **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.**

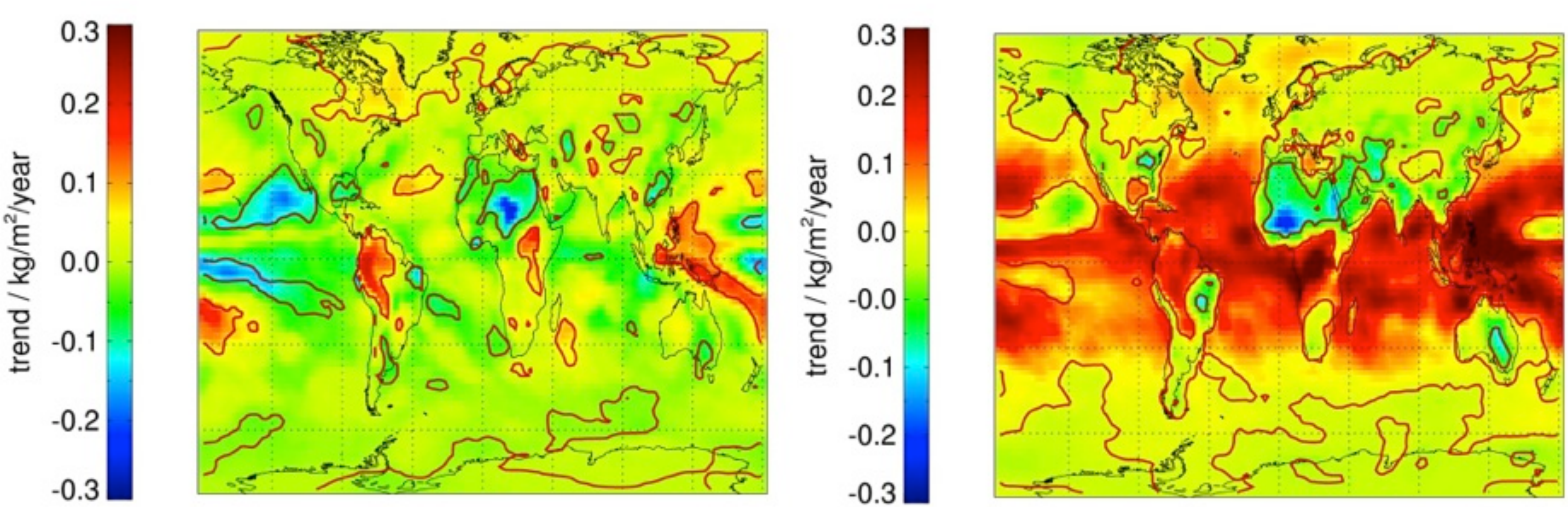
- **G-VAP informs on advantages and common features, e.g., to „benchmark" climate models and inconsistencies of/among data records and provides explanations for inconsistencies.**

- **The assessment will provide an overview on available data records, collects detailed meta data and provides comparable evaluation results.**

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

Science questions
(condensed)

Q1) 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?



Science questions
(condensed)

Q2) What is the degree of consistency among the products?

Q3) Do the satellite data records exhibit areas of distinct quality and how can the distinct differences and limitations be explained? What is the quality of long-term satellite WV products in the lowermost part of the atmosphere and in the upper troposphere? What is the quality of long-term satellite TCWV and WV products over ocean?

Q4) What are the differences in quality between satellite products and products from reanalysis and are the observed differences significant?

Q5) How easily can the satellite data records be downloaded, read and understood?

www.gewex-vap.org

→ 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

⋮ ⋮ ⋮

With support from F. Fell

Last Workshops

Place: University of Wisconsin's Lowell Centre, Madison, WI, USA
Date: 04+05 November 2015
Summary: GEWEX Newsletter, February 2016, http://www.gewex.org/resources/gewex-news/ (G-VAP on front page!)

~25 participants from various nations and institutions.

All presentations are available online.

Last Workshops

Place: EUMETSAT HQ, Darmstadt, Germany
Date: 22+23 September 2016
Summary: available at http://www.gewex-vap.org

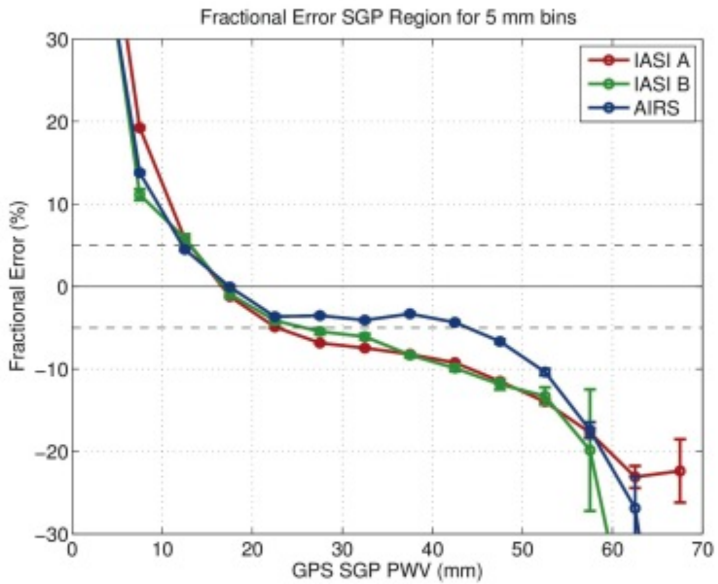
~25 participants from various nations and institutions.

All presentations are available online.

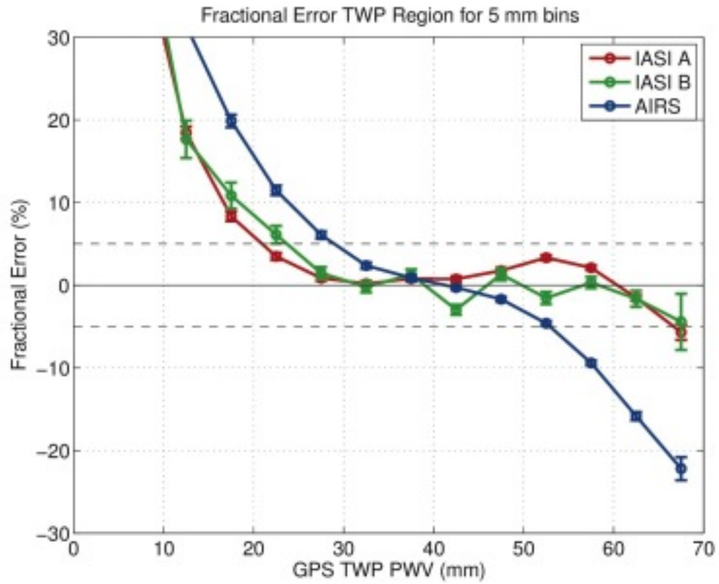
Last Workshop
exemplary result

IASI / AIRS versus GPS ARM at SGP and TWP,
(see presentation by Roman at 5th G-VAP workshop, GEWEX Newsletter)

SGP



TWP



Courtesy: J. Roman

Main outcome

- Series of interesting presentations and very valuable discussions.
- Constructive meetings with many ideas to improve G-VAP activities.

- The recommendation list has been updated.

- It was agreed to release regridded data records on common grid (no free access though!)
- and collocated data records (ARSA with HomoRS92, long-term validation data).

- The time line for drafting the WCRP report on G-VAP was agreed upon.

- It was consensus to continue G-VAP beyond submission of final report.

Summary from last workshop

Activity	Responsible	Status	Until
Prepare MoM and provide talks	M. Schröder, L. Shi, M. Lockhoff	Done	Mid October
Update web page (a.o., agenda, talks, data record overview)	F. Fell, M. Schröder	Done*	30 November 2016
G-VAP presentation at SPARC WAVAS-2	M. Lockhoff	Done right now	November/ December 2016
Overview slides on links/complementarity between WAVAS-2 and G-VAP for GEWEX and SPARC	G. Stiller, M. Schröder	Done (see later)	October 2016
Prepare draft of overview paper and distribute among authors	M. Schröder		Early 2017
Prepare for discussions of future science topics for G-VAP	M. Schröder (talk at GDAP), all	Partly done (see later)	November 2016 (GDAP meeting), Oct 2017 (G-VAP meeting)

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*.

Publications
(plans)

- Paper on G-VAP **data archive** (doi, ESSD):
  sensors, abstracts, tables, intercomparison results

- G-VAP **overview** paper (BAMS, consensus from 6th WS):
  authors: all first authors from sectional reports or co-authorship in case figures are part of submitted version
  title: "Assessment of global water vapour and temperature data records from satellites and reanalyses"*
  structure: as in Stubenrauch et al. (2013), with details on data records "outsourced"

- Plan to contribute to SPARC WAVAS-II special issue with **UTH** results (consistency and sampling uncertainties)

Links between SPARC WAVAS-II and GEWEX G-VAP

Overview

- Two WAVAS-II team members (Bill Read and Gabi Stiller) attended the latest GEWEX G-VAP meeting at EUMETSAT HQ (activity overview and UTH results from WAVAS-II).
- M. Lockhoff will attend the WAVAS-II meeting at KIT (this week). M. Schröder presented G-VAP results at the SPARC/GAW/NDACC UTLS observation workshop at WMO.

- SPARC WAVAS-2 and GEWEX G-VAP activities are complementary with respect to vertical coverage.
- Overlap is at in the upper troposphere. Here, different variables from different sensors are considered, thus again, complementary. However, there are several communalities in general approaches and applied methodologies identified.
- The cooperation between SPARC WAVAS-2 and G-VAP is considered to be beneficial and will be continued.

G. Stiller, M. Schröder

Results from SPARC WAVAS-II (G-VAP) UTH work

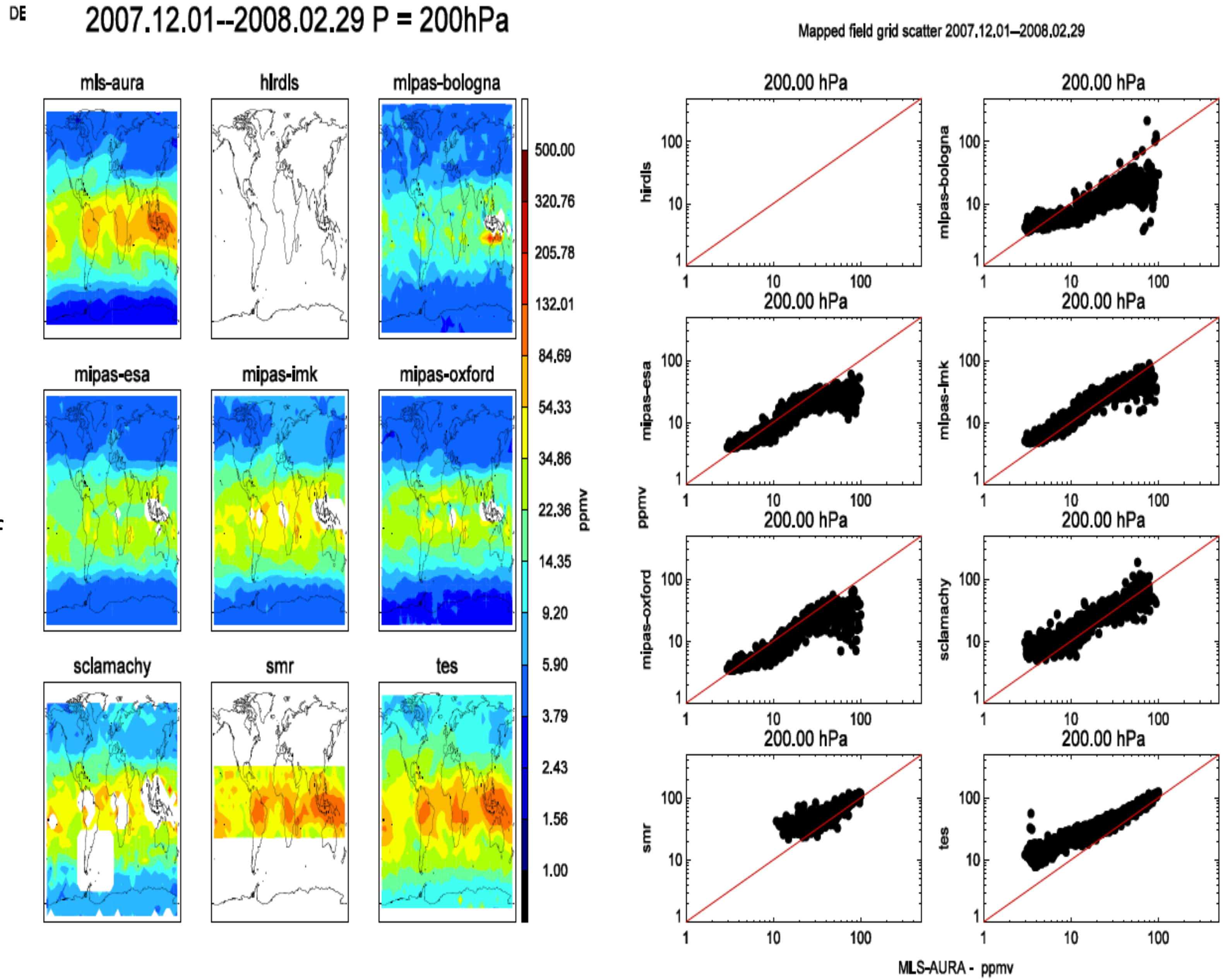
- Goal: Assess the quality of water vapor data from limb-sounding (imagers+sounders+reanalysis) satellites in the upper troposphere
- Quantity to be assessed: water vapor mixing ratio (upper tropospheric humidity, mixing ratio up to 200 hPa)

- Approach (WAVAS-II):
  - Compare to co-incident radiosonde data and frost point hygrometer data
  - Assess correlation of co-located satellite data (limb and nadir sounders)
  - Assess correlation from gridded maps at several pressure levels

G. Stiller, M. Schröder

Example: Comparison of satellite data on basis of gridded data

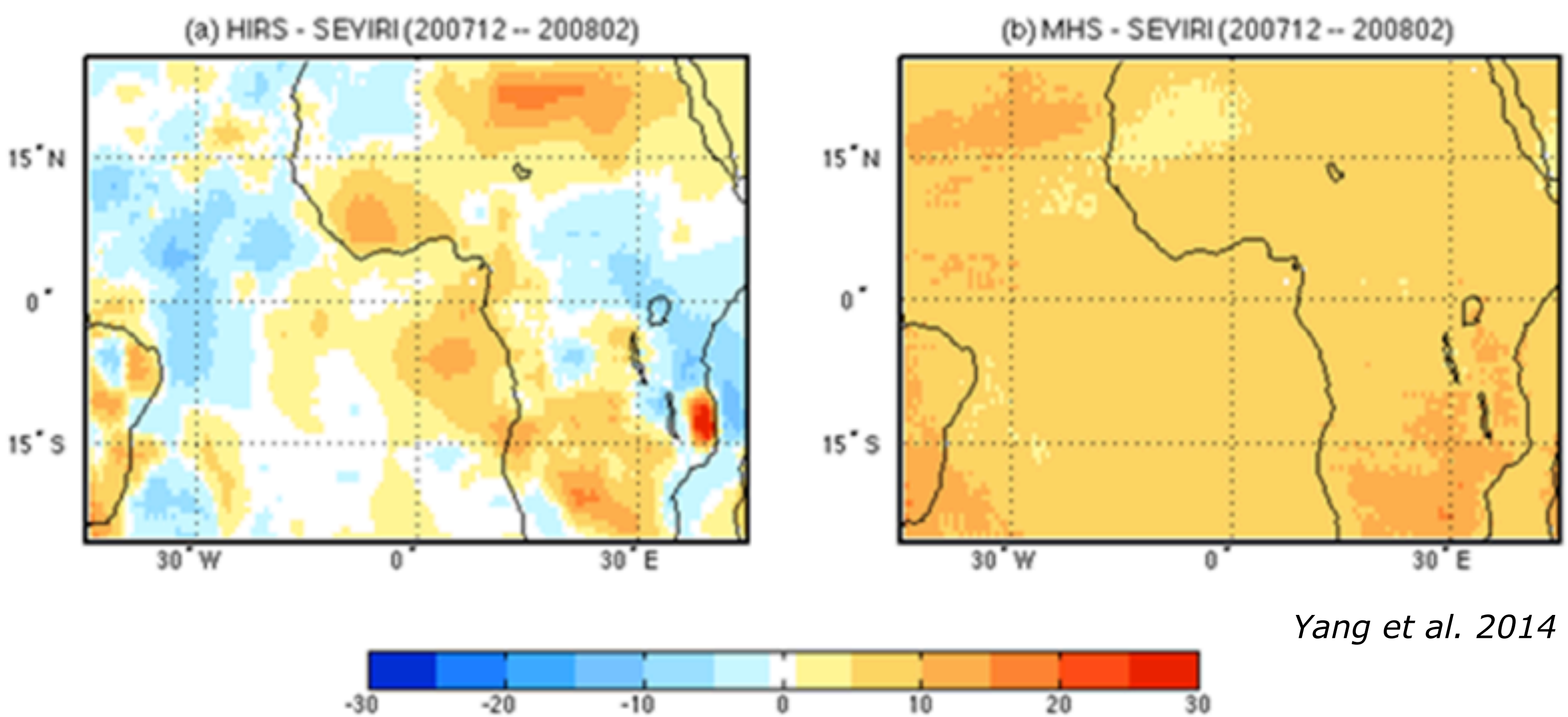
Courtesy:
G. Stiller



Comparison of limb sounders vs. one limb-sounding reference instrument at 200 hPa

G-VAP: Climatological differences in UTH

HIRS – SEVIRI **MHS - SEVIRI**



Yang et al. 2014

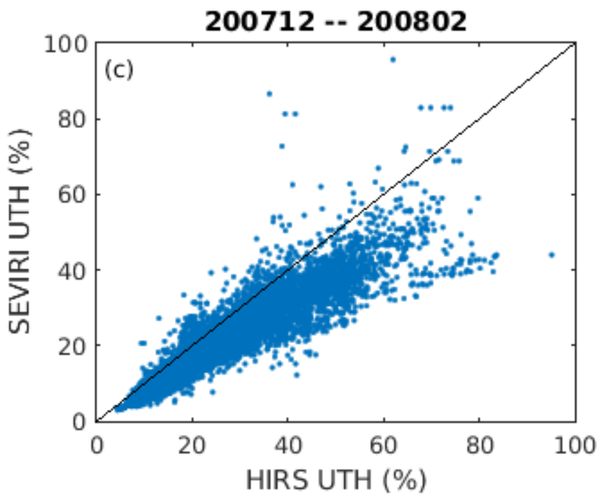
- **Clear sky bias (~25%, microwave – IR(HIRS, SEVIRI)) John et al. (2011),**
- **Difference between HIRS and SEVIRI is small (~4%).**

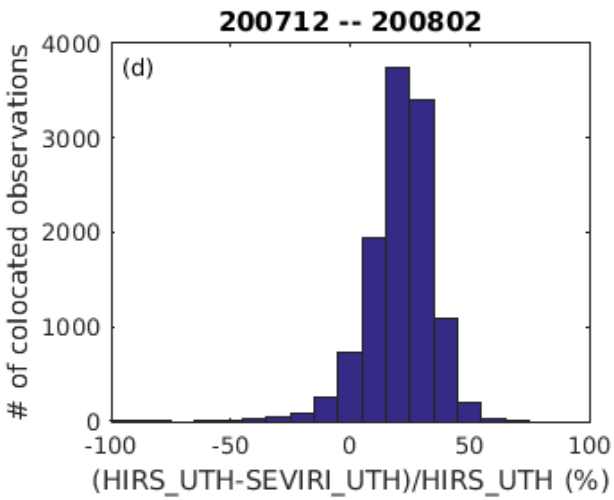
UTH

We found an average difference of 21% between collocated HIRS and Meteosat UTH products (Yang et al., 2014).

Reasons:

- **Different spectral response function (SRF) and thus different vertical sampling.**
- **Different weighting function during retrieval design (HIRS: after Soden and Bretherton, 1996 and Meteosat: Jacobians with respect to relative humidity).**
- **Potential differences in absolute calibration.**





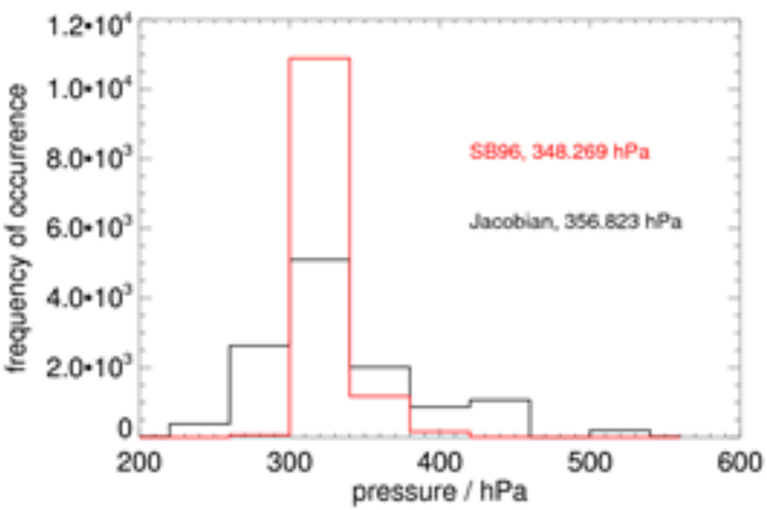
FTH

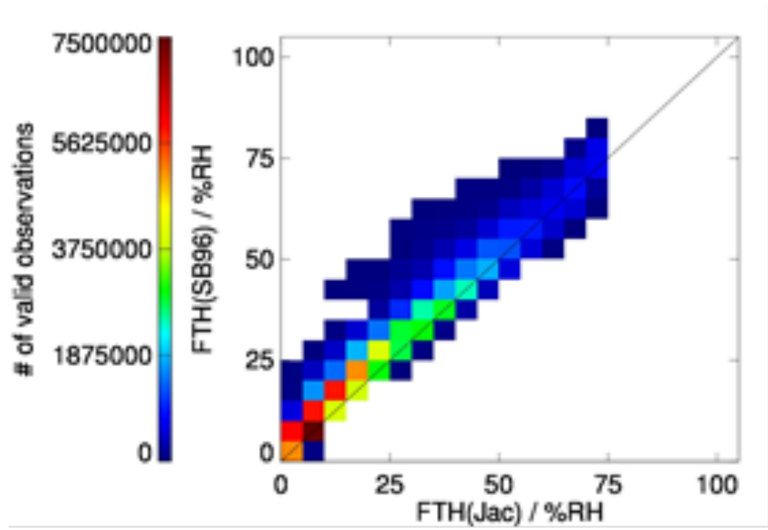
Analysis:

- **Use training data base from CM SAF UTH retrieval and RTTOV.**
- **Compute Jacobian as function of HIRS and Meteosat.**
- **Compute UTH using Soden and Bretherton approach and Jacobians per satellite.**

Results:

- **Difference between UTH(Jacobian) and UTH(SB96): 23%, independently from satellite.**
- **Difference between UTH(Jacobian, HIRS) and UTH(Jacobian, Meteosat): 0.0%.**





GEWEX

Report:
Overview

(provided to GDAP for review on 18 November 2016)

Overview

Section	Lead author	Contributing author
1. Summary	M. Schröder	L. Shi, lead authors
2. Introduction		
2.1 Overview	M. Schröder	
2.2 Scope	M. Schröder	
2.3 Questions	M. Schröder	
2.4 Definitions	M. Lockhoff	Lead authors
2.5 Information and avk	T. August, T. Trent	
3. Data records		
3.1 Overview of sensors	J. Forsythe	A. Gambacorta, R. Kursinski, M. Schröder
3.2 Uncertainties	A. Gambacorta	H. Brogniez
3.3 Inventory	F. Fell	M. Schröder
3.4 Overview of reference observations	M. Schröder	F. Fell, N. Scott
4. Analysis of gridded data		
4.1 Intercomparison	M. Lockhoff (TCWV, WV), L. Shi (UTH)	M. Schröder, A. Walther (U. Wisconsin)
4.2 Variability	R. Bennartz (TCWV), L. Shi (UTH)	A. Walther, F. Fell, M. Schröder, U. Willen (SMHI)
4.3 Homogeneity and trend analysis	M. Schröder	M. Lockhoff, J. Roman, L. Shi
4.4 Stability	T. Trent	M. Schröder
4.5 Consistency	L. Shi	M. Lockhoff, M. Schröder
5. Full archive: Intercomparison		
6. Analysis of instantaneous data		
6.1 Sampling	B. Ho	J. Forsythe, H. Höschen, M. Lockhoff, M. Schröder
6.2 PDF	R. Kursinski	M. Lockhoff, A. Löw
6.3 Collocation	X. Calbet	S. Eikenberg, J. Kinzel, B. Sun, T. Trent
6.4 Intercomparison	A. Reale	T. August, A. Gambacorta, T. Reale, M. Schröder, B. Sun, T. Trent
6 Conclusions	M. Schröder	L. Shi, lead authors

Oriented at Cloud assessment report

Several volunteers

- **T. August, T. Trent**
- **J. Forsythe**
- **A. Gambacorta**
- **F. Fell**
- **R. Bennartz**
- **T. Trent**
- **S.-P. Ho**
- **R. Kursinski**
- **X. Calbet**
- **A. Reale**

Overview
(information)

- **Executive summary:**
  - each conclusion is linked to the corresponding section,
  - Recommendations with link to corresponding section.

- **Introduction:**
  - Overall output,
  - Scope, GEWEX needs and requirements
  - Science Questions, …

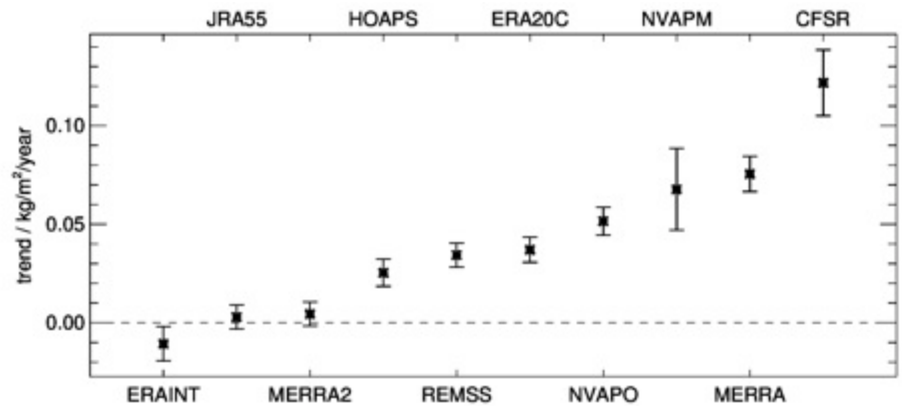
- **Data records:**
  - Overview tables,
  - Contains links to section where data is analysed,…

Technique	Dataset	Parameters	More Information	Utilisation
(A)ATSR	AIRWAVE	TCWV	Castelli et al., 2015	Section 5
AATSR, HIRS, SSM/I, GNSS	NVAP-M Climate	TCWV, WV	DFS	Sections 4.1, 4.2 (TCWV), 4.3 (TCWV, WV), 4.5, 5, 6.1 (TCWV)
AIRS, AMSU, HSB	NASA	TCWV, WV, T	WEB	Sections 6.2 (WV) and 6.4 (WV, T)

- **Conclusions:**
  - Answers to Science Questions and links to corresponding sections.

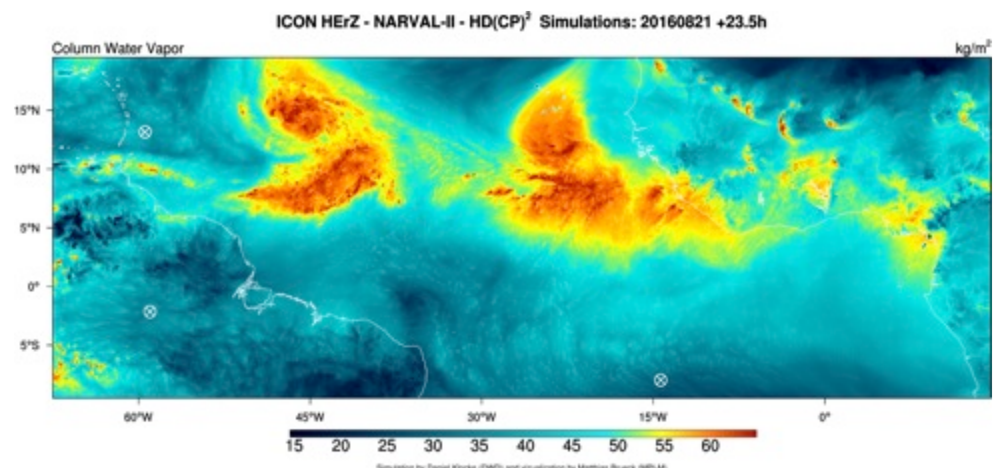
Overview
(science)

- **Analysis of long-term gridded data records**
  - Hovmöller
  - Intercomparison
  - Homogeneity testing
  - Trend estimation
  - Comparison to in-situ data



- **Analysis of data from full archive**
  - Intercomparison
  - Weather type analysis

- **Analysis of instantaneous data**
  - Sampling
  - PDF
  - Collocation
  - Comparison to radiosondes



Time line (?)

- **The time line for drafting the WCRP report on G-VAP was agreed upon:**

(until/at)	
31 Oct 16	Provide final input to chairs (sectional reports, comments to full report)
14 Nov 16	Implement input (DWD) and final iteration among authors
18 Nov 16	Editorial work (DWD)
18 Nov 16	Submission of final draft to GDAP
29 Nov 16	GDAP Meeting with presentation of G-VAP results
6 Jan 17	Implement feedback from GDAP and provide elements to chairs
31 Jan 17	Merging (DWD), final consolidation
	Inform PIs of all data records that have been analysed
06 Feb 17	Final editorial work (DWD), resubmission
Mid Feb 17	GEWEX JSC meeting subsequent release

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: Provide uncertainty information and assess uncertainty as function of total amounts and other dependent parameters (sections 3.2, 4.3.1.4, 6.4).

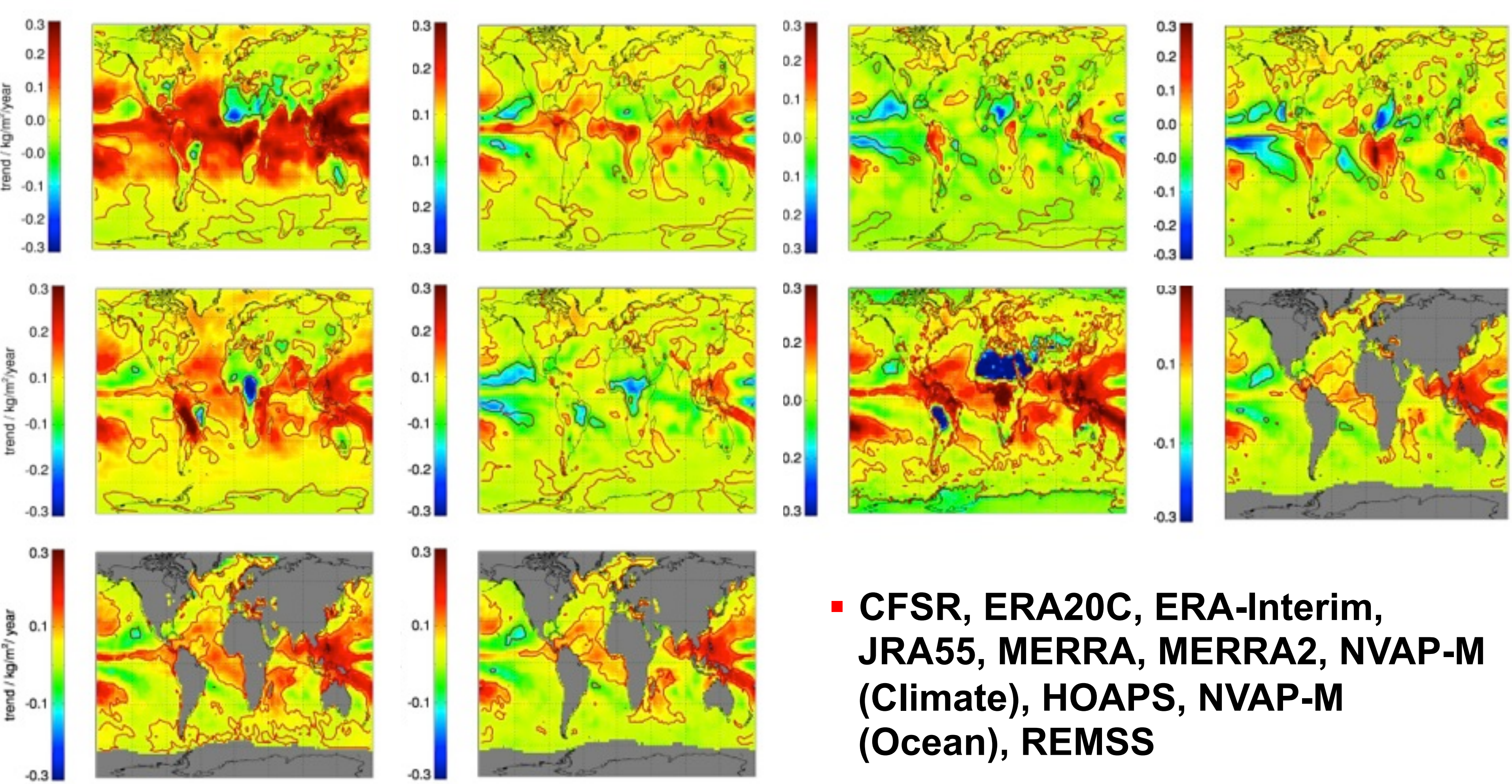
Recommendation

- 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).
- 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.

Report:
A few results

G-VAP
continued

Trend estimates



Updated from Schröder et al. (2016)

- **CFSR, ERA20C, ERA-Interim, JRA55, MERRA, MERRA2, NVAP-M (Climate), HOAPS, NVAP-M (Ocean), REMSS**
- **Mostly statistically significantly different, e.g. on global ocean scale.**

Regression, Time-to-detect

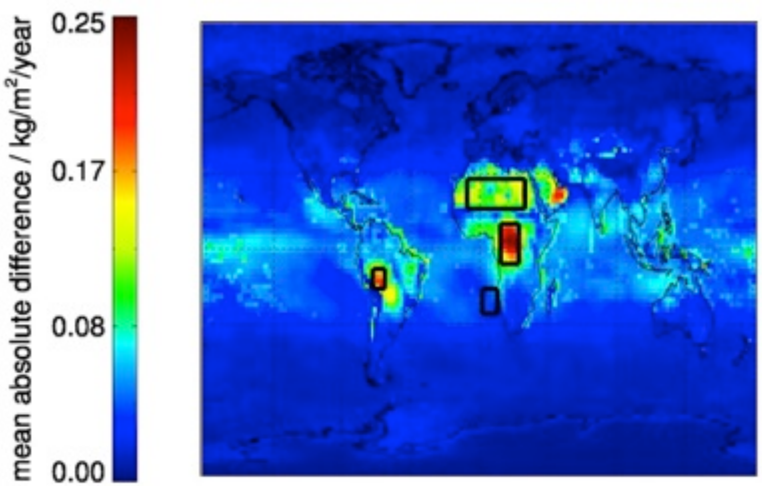
	Trend kg/m²/decade	Regression % / K	TTD* years
CFSR	1.21 ± 0.16	24.9 ± 0.5	33
ERA-Interim	-0.11 ± 0.09	2.9 ± 0.5	22
ERA20C	0.37 ± 0.06	10.0 ± 0.2	18
HOAPS	0.25 ± 0.07	7.2 ± 0.3	18
JRA55	0.03 ± 0.06	2.6 ± 0.4	17
MERRA	0.75 ± 0.09	15.8 ± 0.3	22
MERRA2	0.04 ± 0.06	4.4 ± 0.3	17
nnHIRS	-1.51 ± 0.17	14.2 ± 1.3	35
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

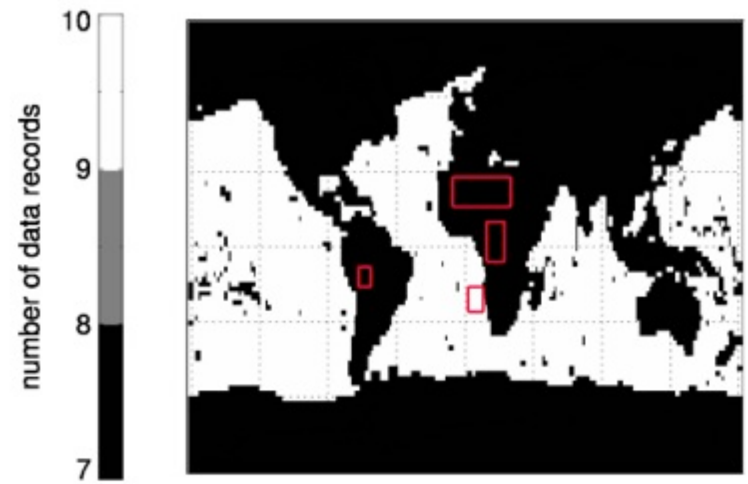
- **Trend and regression values for previous slide.**
- **Largely no match with theory.**
- **Large diversity in TTD (function of noise and autcorrelation).**
- **Extremes values dominated by noise.**

Differences in trend estimates

- Mean absolute difference in trend estimates and number of data records.
- Maxima: South America, Central Africa, Sahara.

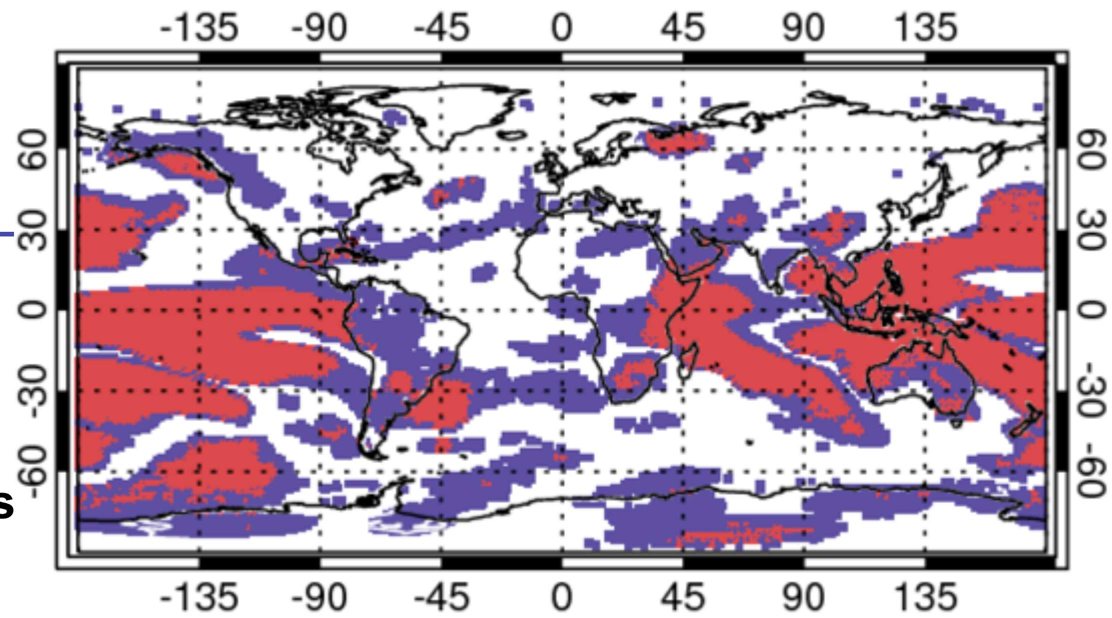
Updated from Schröder et al. (2016)





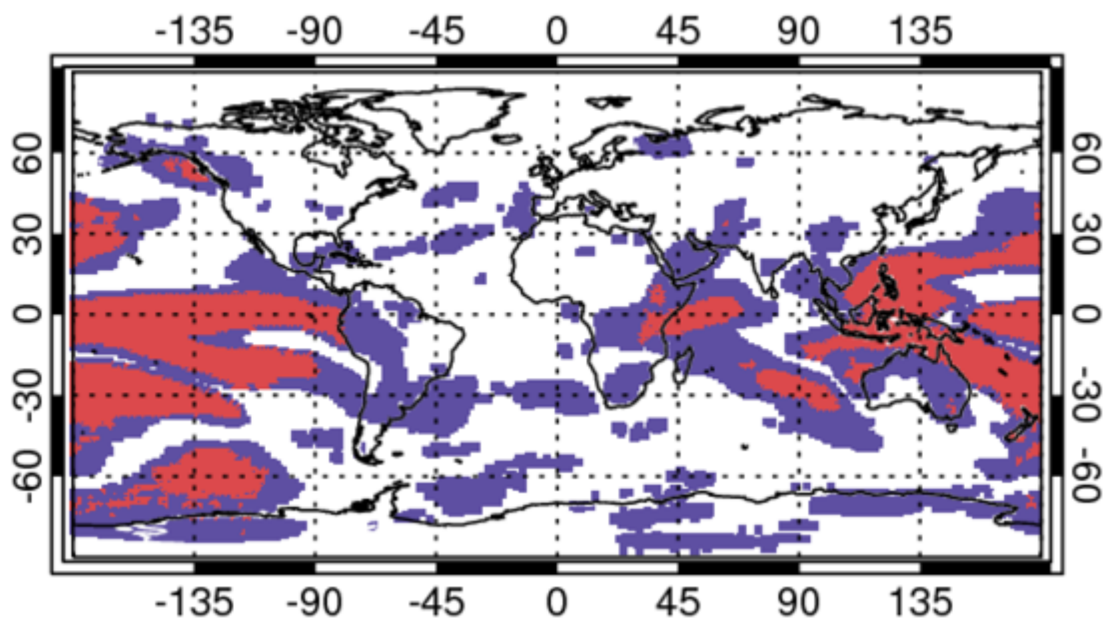
- Most large scale and regional differences are caused by breakpoints. These coincide with changes in the observing system.
- Breakpoints are a function of region and data record.

Variability Applications?



- Correlation of 6(8) data records with climate indices
- Shown here: ENSO

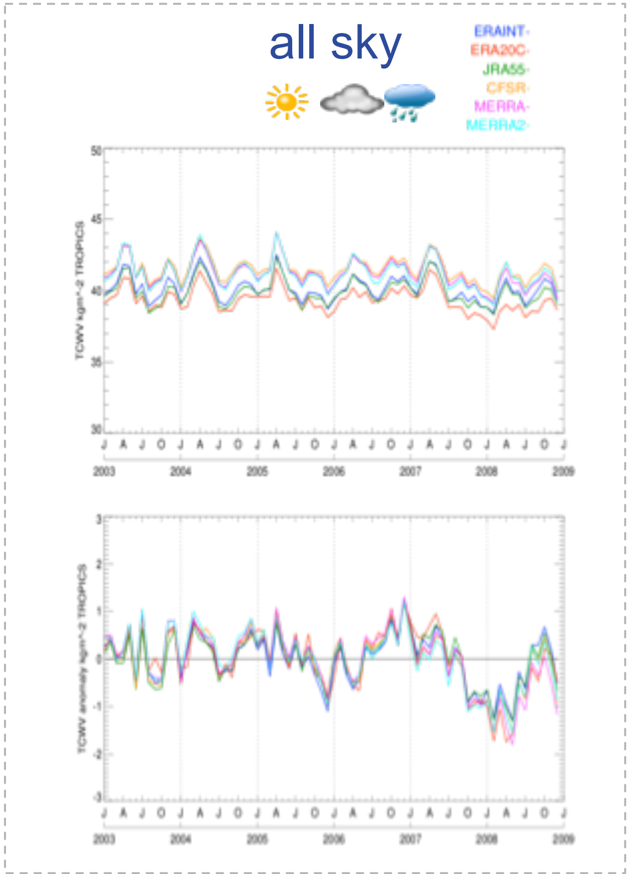
- 6 data records
- 6 data records + 2 climate models

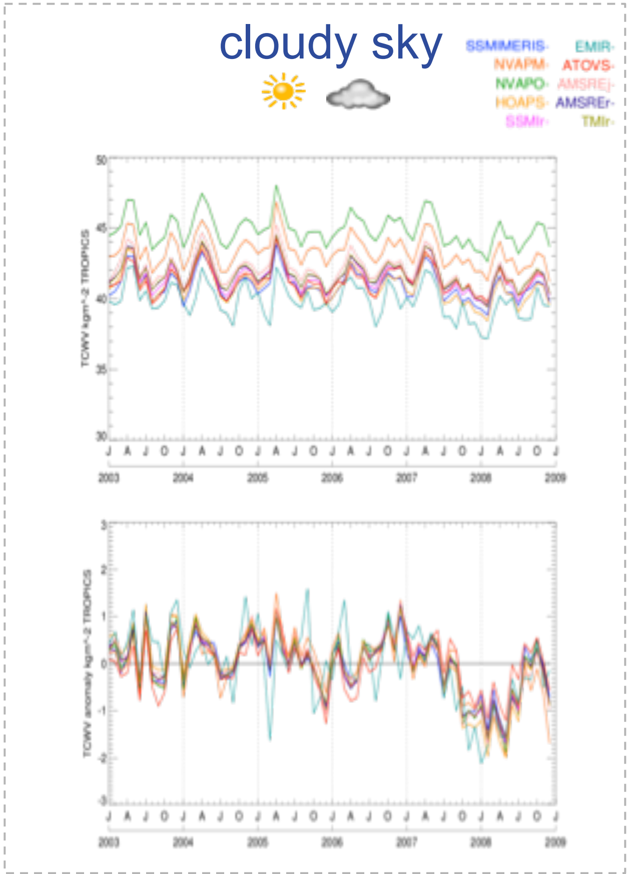


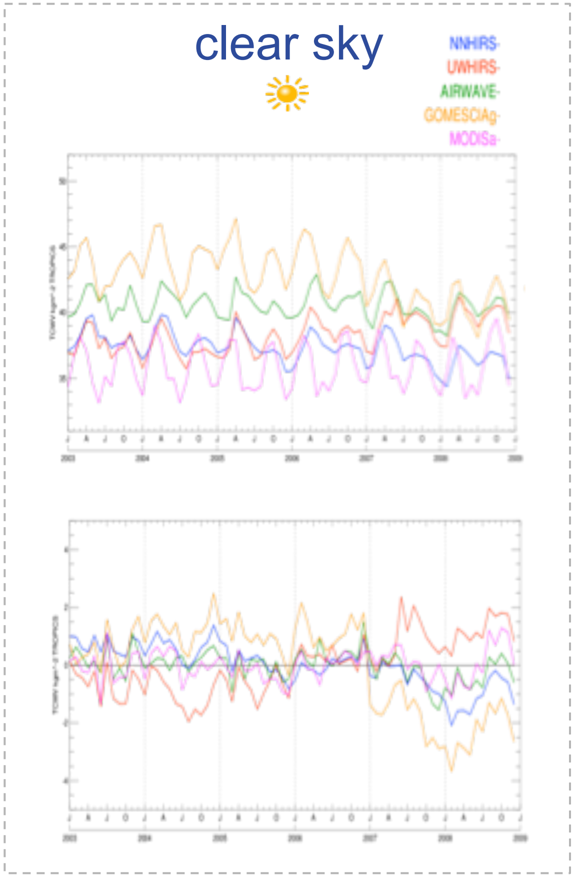
- Climate modelling unit of DWD interested in G-VAP data archive.

Intercomparison
Weather type

- TCWV for the tropics (±20°), over ocean



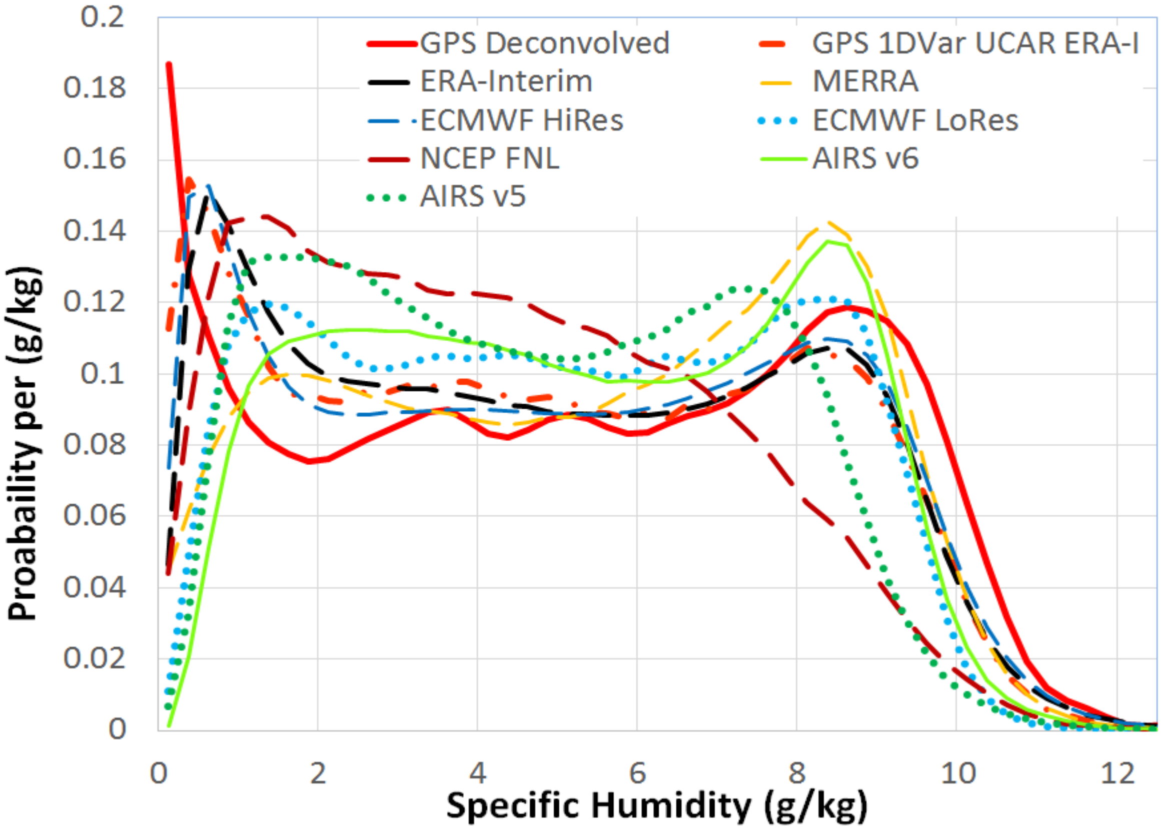




- **Internal weather type variance larger than differences between types.**
- **Differences are likely not caused by weather type but by retrieval class.**

PDFs

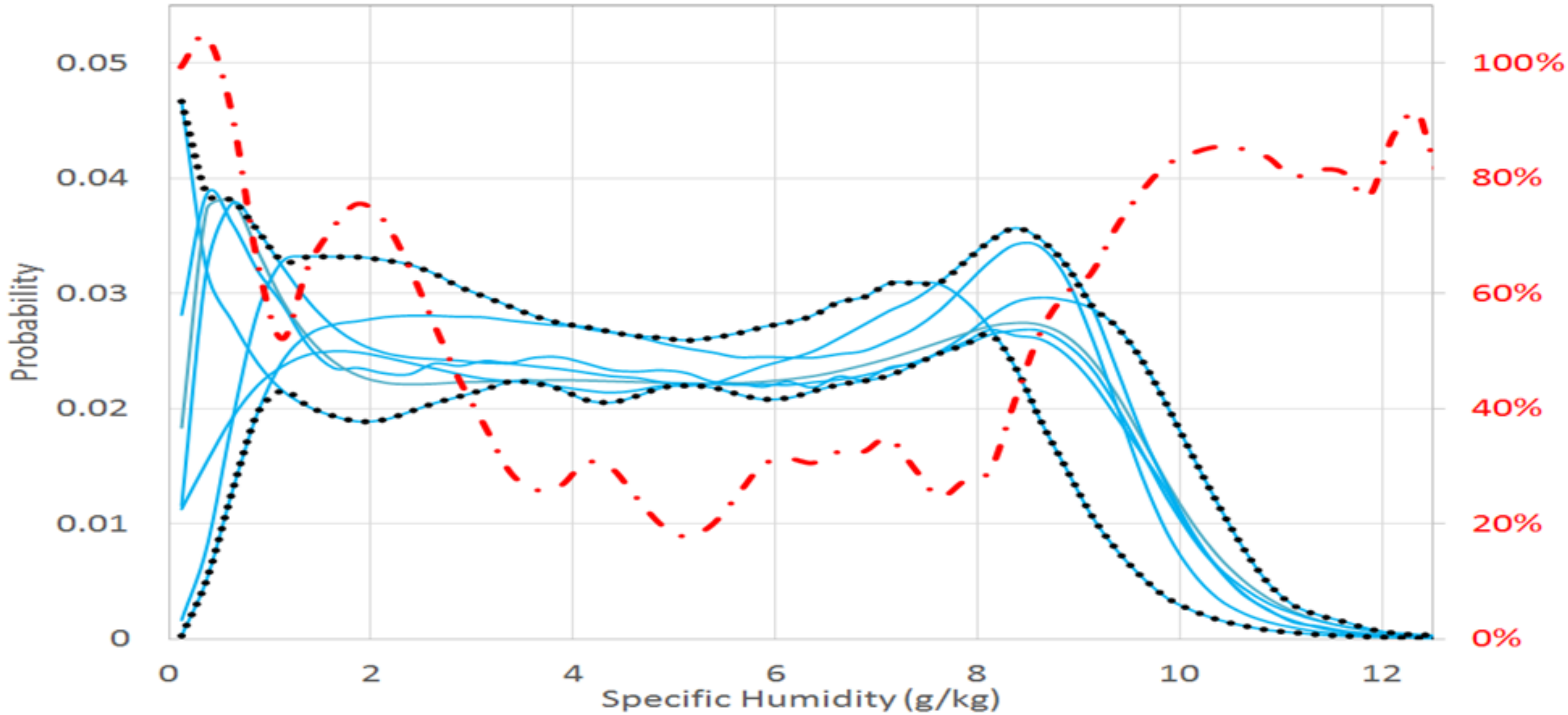
- Specific humidity at 725 hPa.
- Tropics (within 30°N/S) from 2007.



Courtesy: R. Kursinski

PDFs structural uncertainty

- **Specific humidity at 725 hPa.**
- **Dashed – min/max values.**
- **Dashed-dotted: relative spread within each bin.**



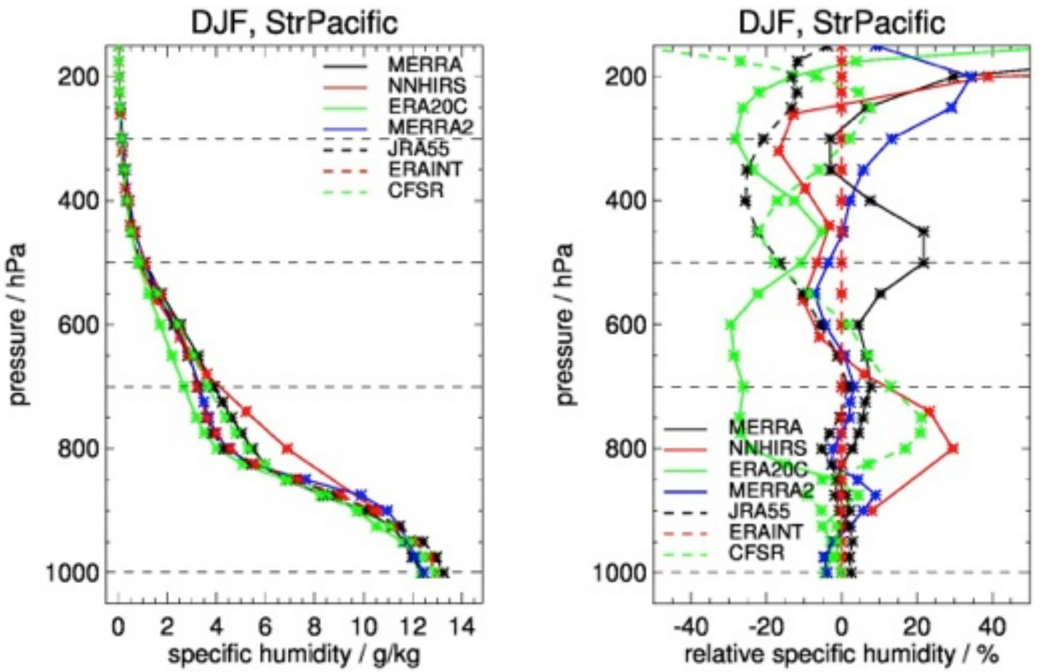
Courtesy: R. Kursinski

Profile intercomparison

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

- Below: intercomparison at 700 hPa.

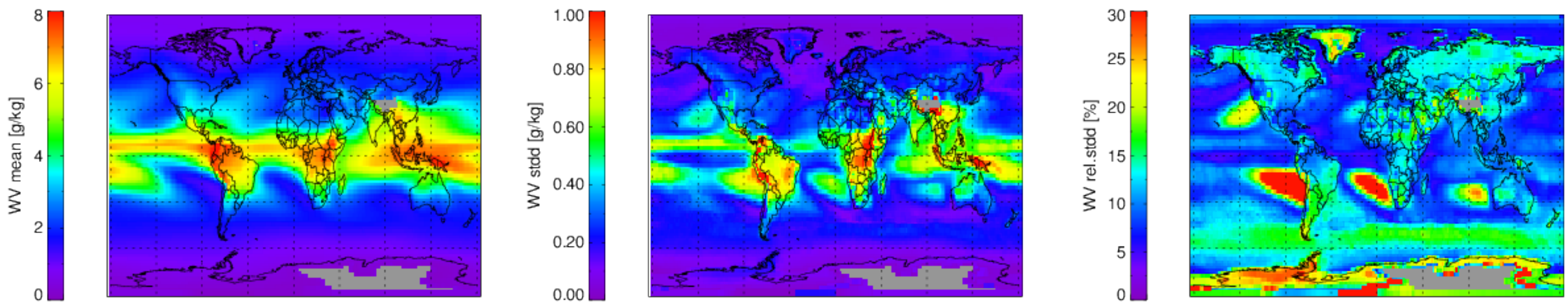
- Right: average profiles and relative differences (to ERA-Interim).



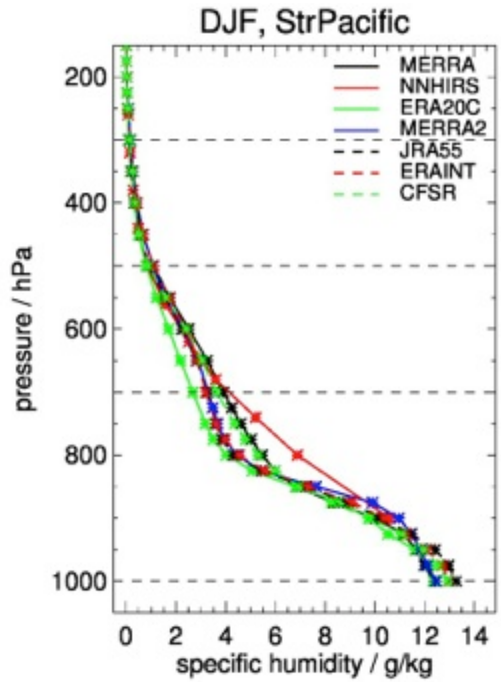
mean

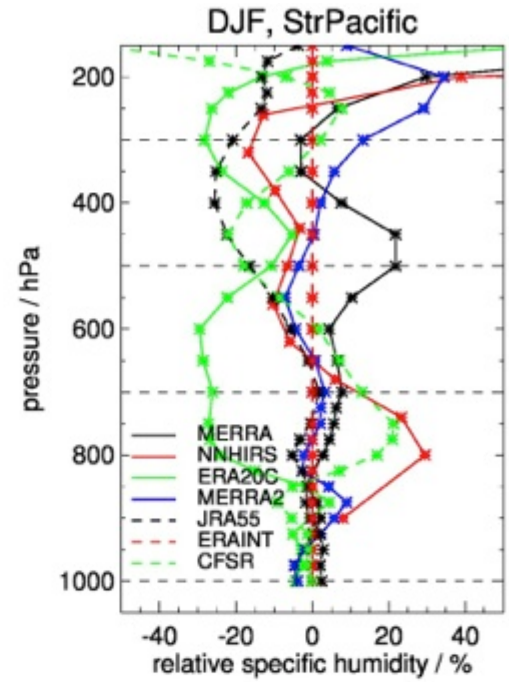
standard deviation

relative std. dev.

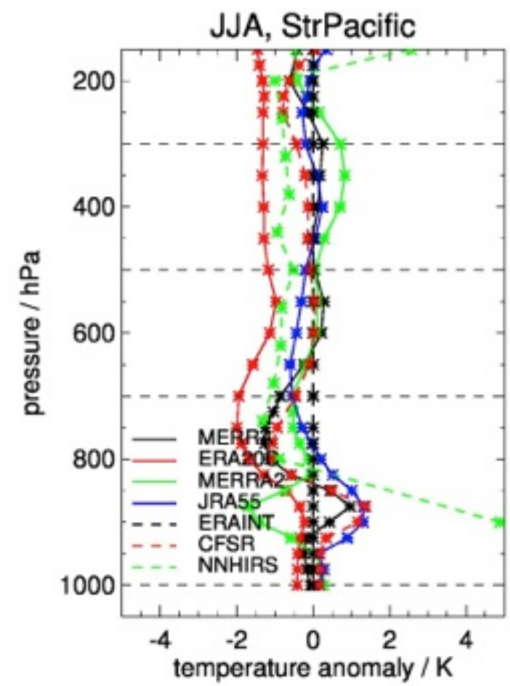


Profile Intercomparison





- Specific humidity and temperature.



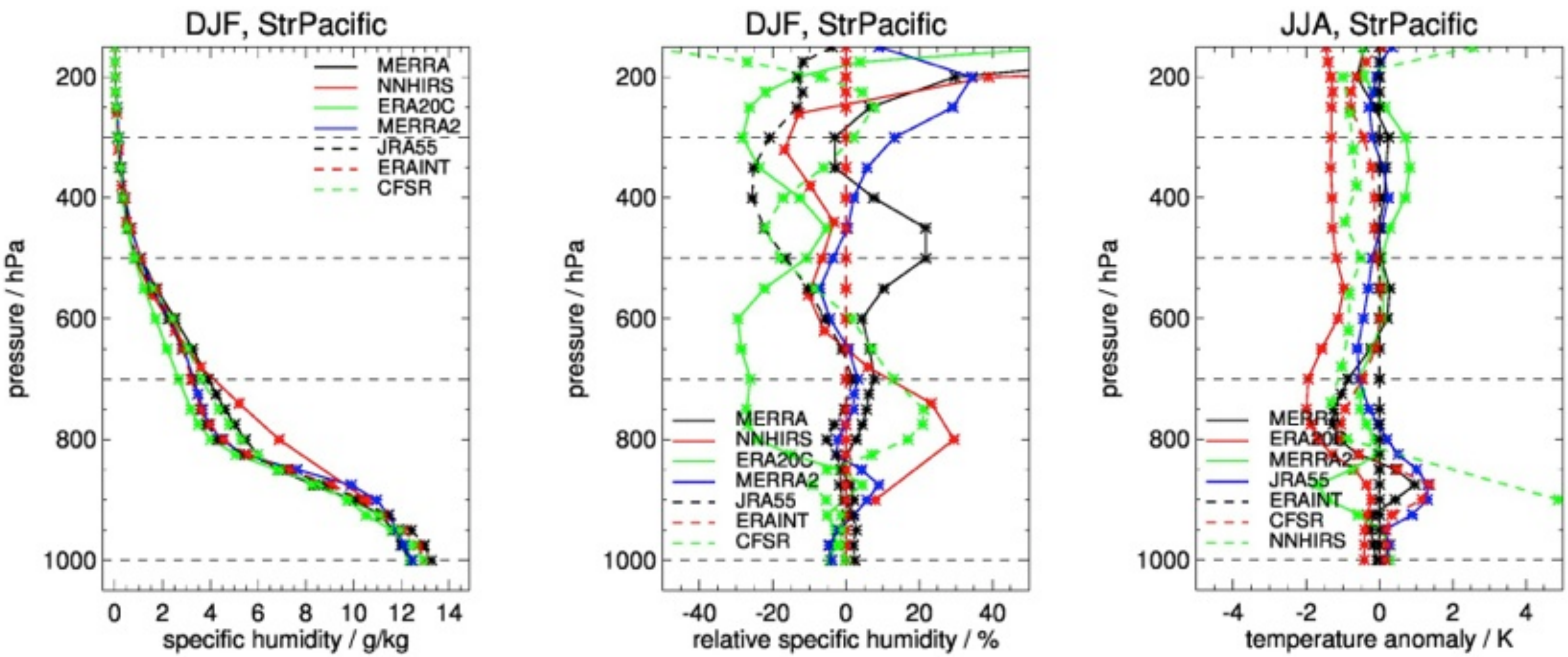
- Breakpoints are a function of region, data record and parameter.

Good news

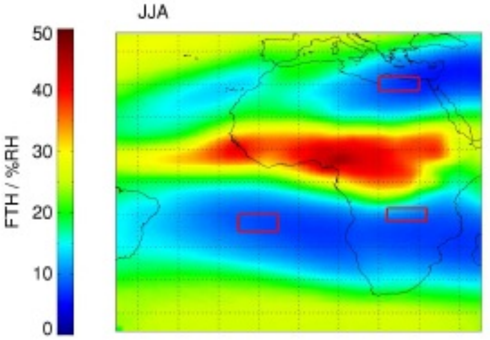
- **Financial support for G-VAP via EUMETSAT's CM SAF (very likely).**
- **Covered:**
  - Coorganise G-VAP workshops
  - (Re-)assess the quality of water vapour CDRs using (existing) G-VAP tools
  - Participate in GDAP meetings
  - Draft reports on reassessed quality.

Enhance quality analysis of profile data records over open ocean, in particular over high pressure areas/ subsidence areas and stratus

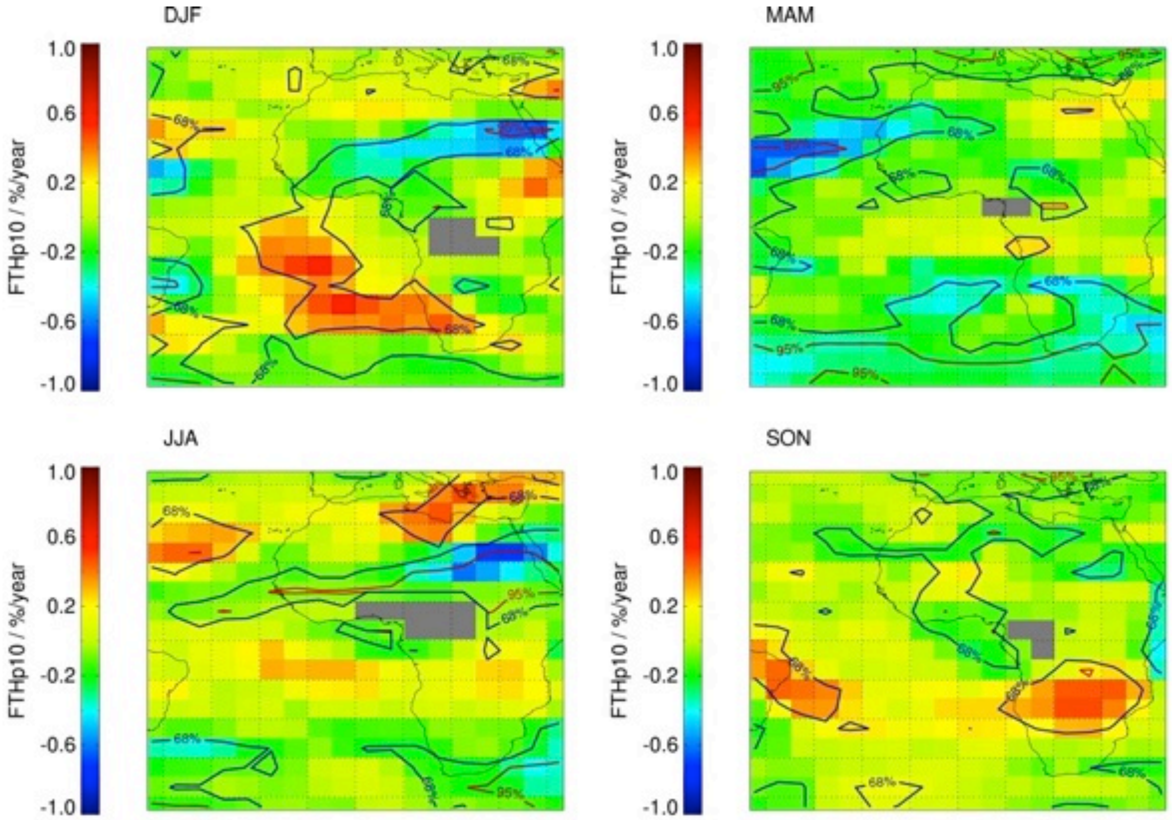
- **Large differences among data records over stratus regions.**
- **Use GPS RO data to better constrain the evaluation.***



Trend estimates
FTHp10: frequency of occurrence of FTH<10%



- **Positive trends largely coincide with dry regions but are hardly significant.**
- **This caused mainly by interannual variability.**
- **An indication of a poleward shift of the dry region.**

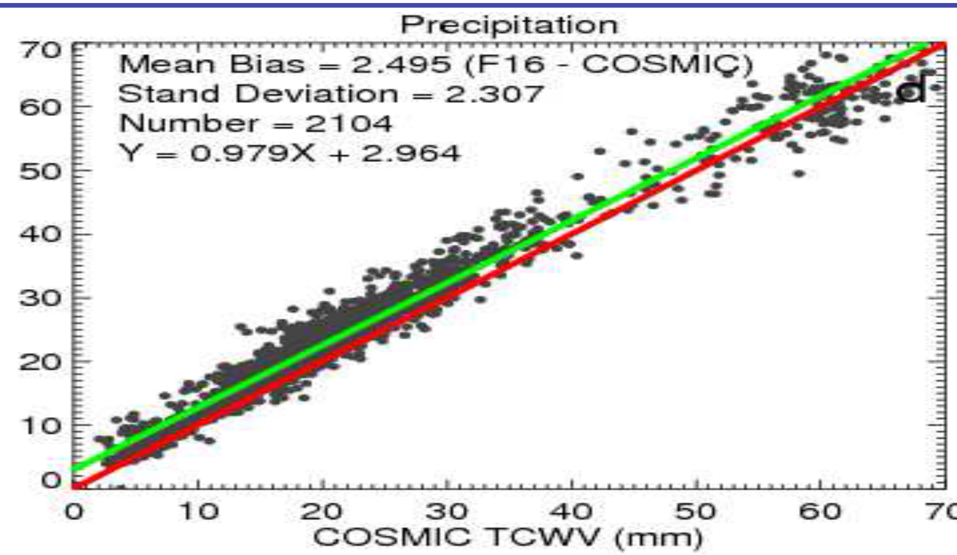


Schröder et al. (2014)

- **Future: climate process related study.**

Analyse differences between observations under all-sky as well as cloudy and clear sky conditions

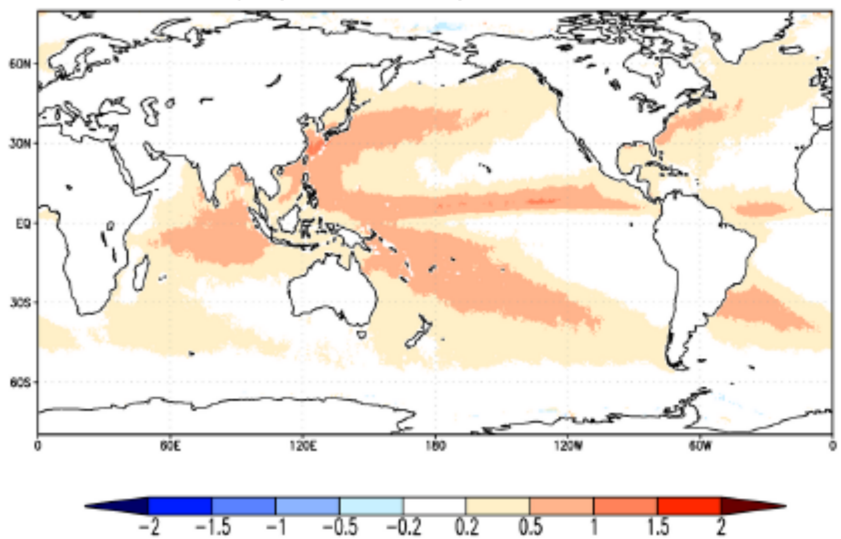
- **Retrieval uncertainty in presence of rain**
  bias in clear sky: 0.02 mm
  bias in cloudy sky: 0.4 mm

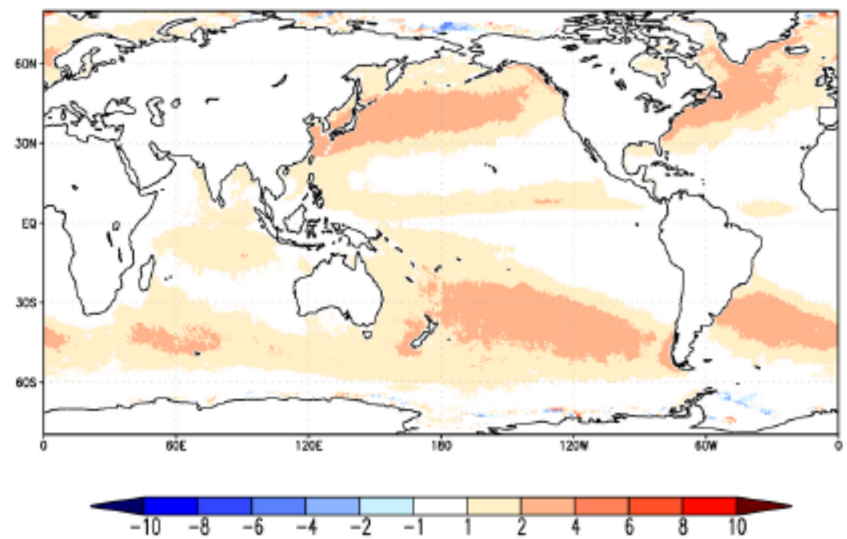


- **Bias induced by gap-filling.**

H
O
A
P
S

absolute difference

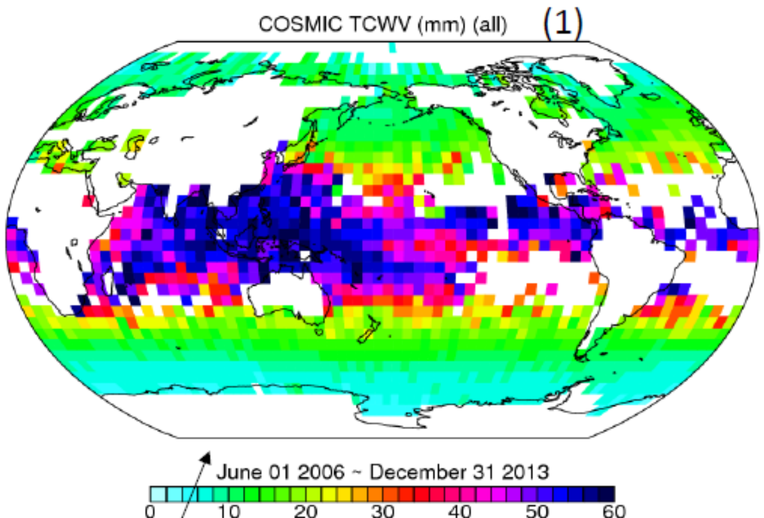


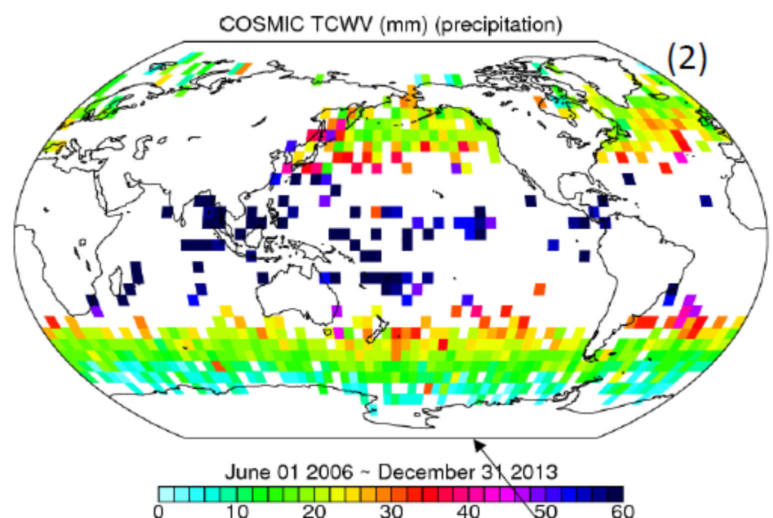


relative difference

Schröder et al., 2013

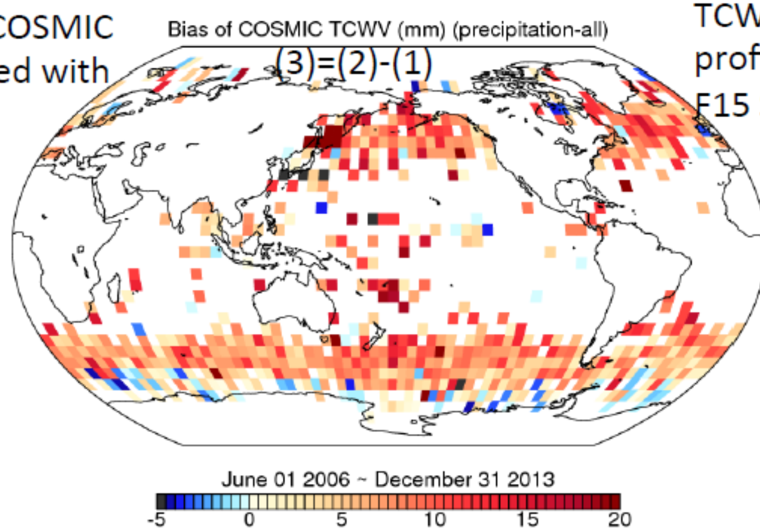
Potential systematic difference in presence of rain?





TCWV generated by COSMIC profiles which matched with all F15 SSMI data.

TCWV generated by COSMIC profiles which matched with F15 SSMI precipitation data.

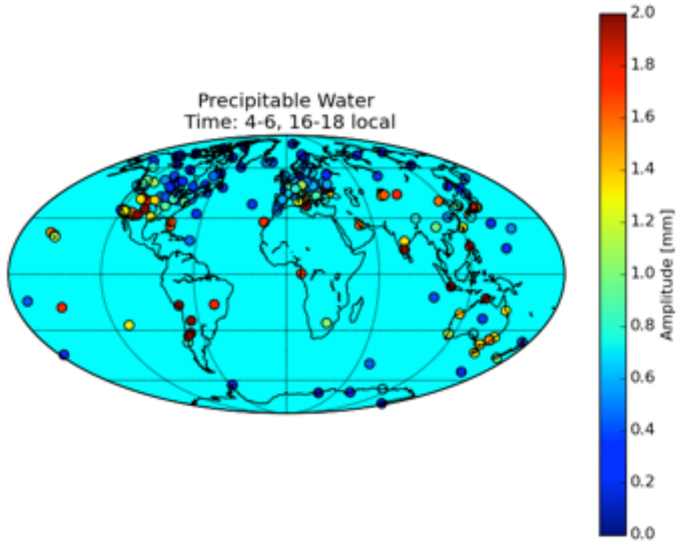


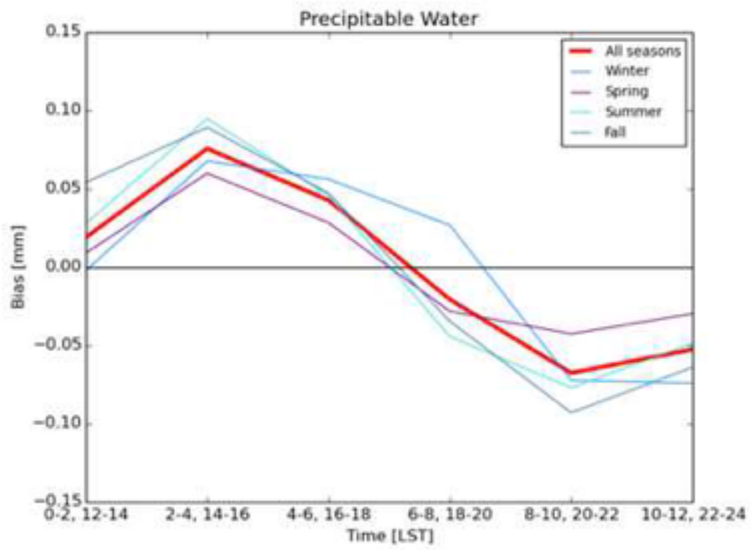
Courtesy: S.-P. Ho at 6th G-VAP WS

- **Future: avoid mixture and look at difference between rainy and cloudy sky?**

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

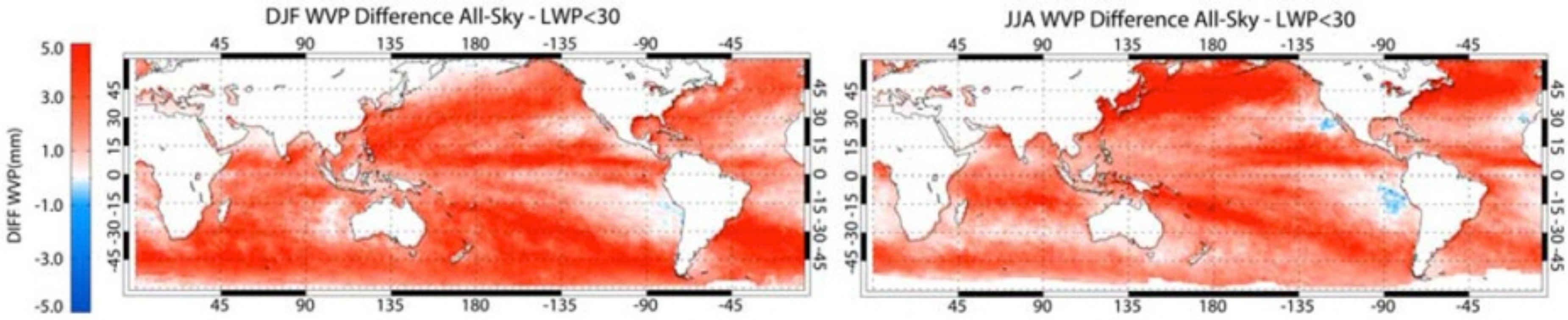
- **Diurnal cycle of water vapour might lead to sampling biases.**
- **Diurnal cycle impact assessed using ground-based GNSS data.**





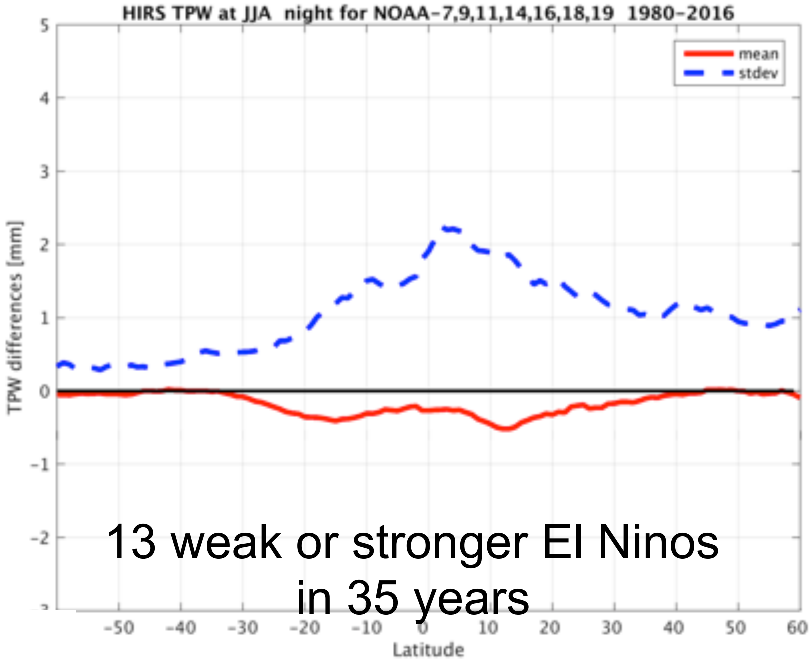
Assess the joint effect of orbital drift, clear sky sampling/ bias and the diurnal cycle of clouds on biases and how this might change with climate change

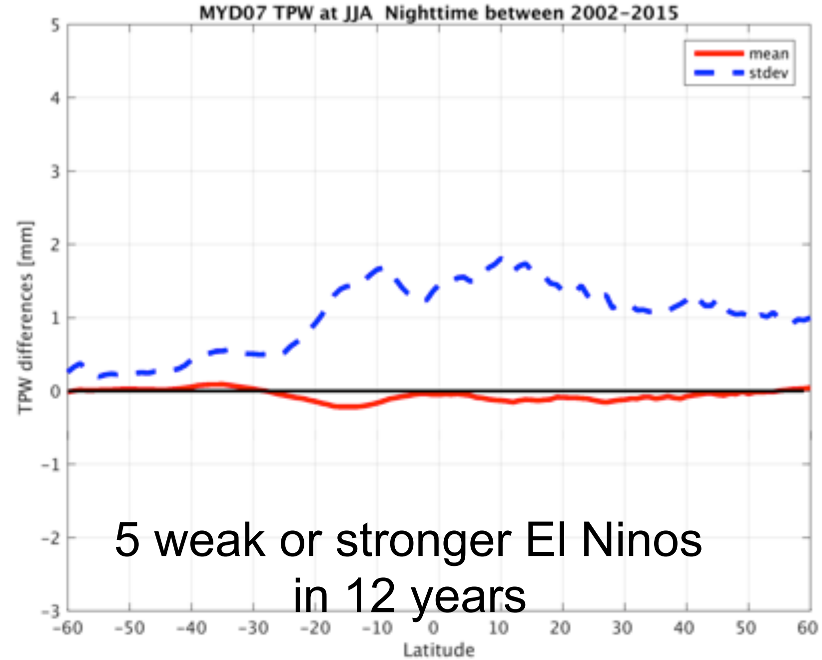
AMSR-E TPW



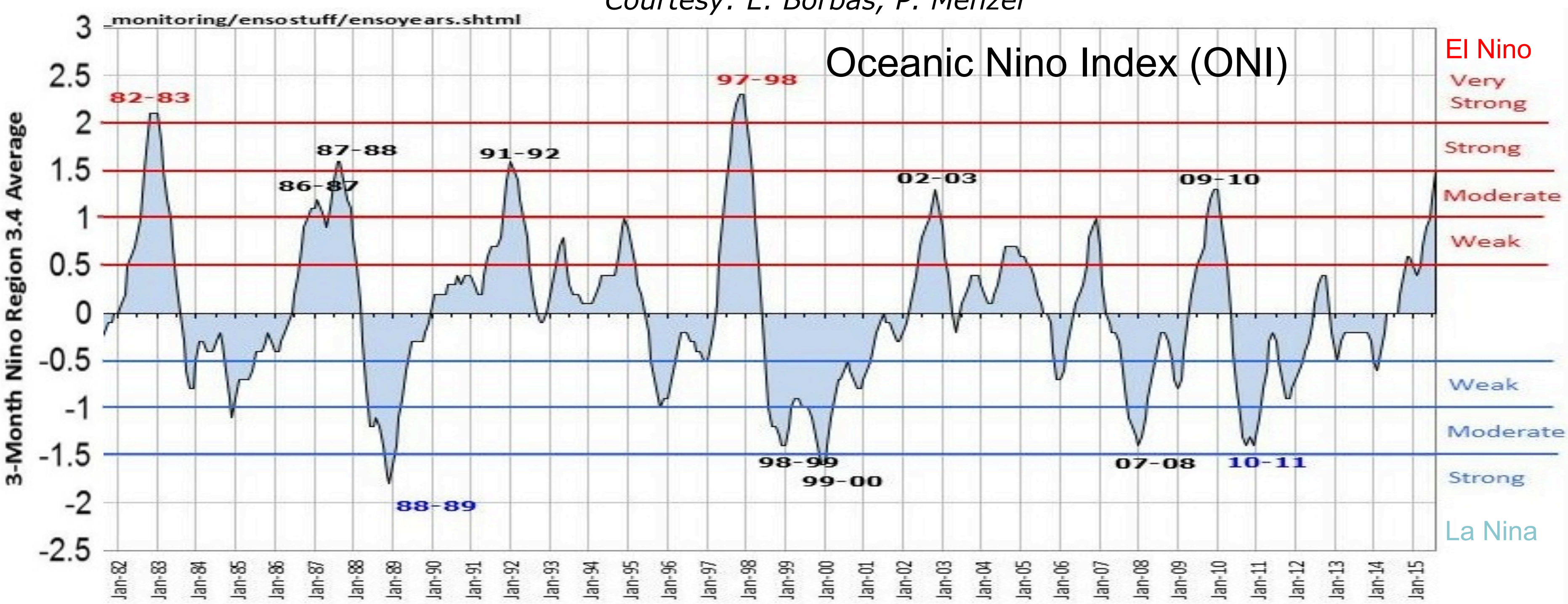
Sohn and Bennartz, 2008

- **Sample clear sky sampling bias which is linked to the diurnal cycle of clouds!**





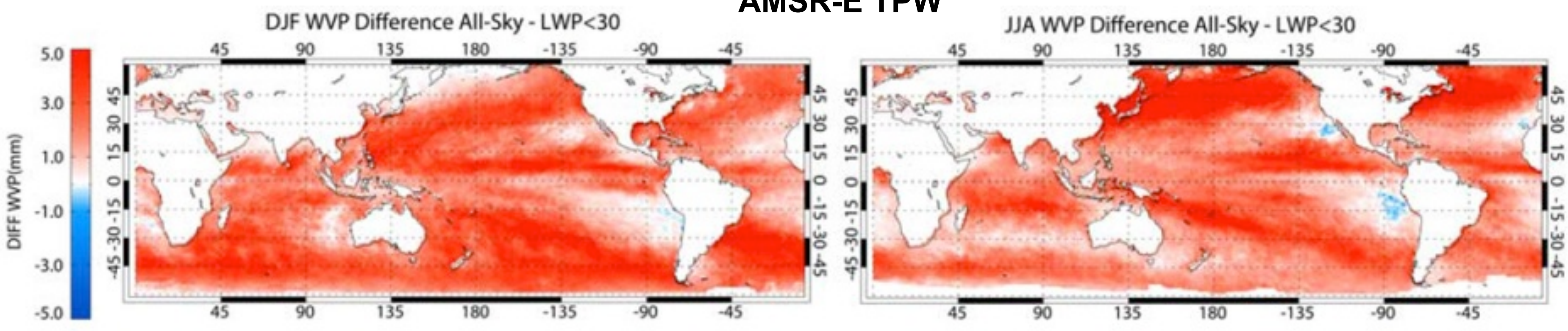
Courtesy: E. Borbas, P. Menzel



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

- **Clear sky sampling bias and the diurnal cycle of clouds!**

AMSR-E TPW



Sohn and Bennartz, 2008

- **Impact of orbital drift on water vapour sampling bias through sampling of clear sky bias, itself linked to the diurnal cycle of clouds.**

- **Impact of climate change on diurnal cycle of clouds (amplitude, area coverage, moisture convergence/divergence,…).**

- **In addition: retrieval issues, cloud mask issues, mountains,…**

Acknowledgement

GEWEX

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CM SAF
Climate Monitoring

Deutscher Wetterdienst
DWD

esa

EUMETSAT

INFORMUS

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U.S. DEPARTMENT OF COMMERCE

University of Leicester

Thank you very much!