Identification of satellite CDR capability

The upper tropospheric humidity (UTH) (also named as free tropospheric humidity (FTH)) is one of the Global Climate Observing System (GCOS) atmospheric Essential Climate Variables (ECVs). The datasets have been derived from the High Resolution Infrared Radiation Sounder (HIRS) since late 1978, from the Advanced Microwave Humidity Unit-B (AMSU-B) and the Microwave Humidity Sounder (MHS) since late 1998, and from Meteosat Visible and InfraRed Imager (MVIRI) and Spinning Enhanced Visible and InfraRed Imager (SEVIRI) since 1983. These satellite records have been improved by newly developed bias correction and improved homogenization procedures. Multiple sensors from different space agencies provide over three decades of daily data with near-global coverage.

For much of this period, there are multiple sensors in operation and this redundancy is critical to identify and correct for artifacts which arise from orbital drift and sensor calibration drift. Data sets from multiple sensors are complementary with varying strengths and weaknesses. For example, the infrared datasets cover longer time periods, starting from late 1978 for HIRS and from 1983 for Meteosat imagers, for long-term climate studies, however their clear-sky requirements for water vapor measurement can lead to dry biases for certain applications. The microwave sensors, on the other hand, affected by only ice clouds in upper troposphere, provide much better spatial coverage, however the data records are shorter, starting from late 1998. The UTH/FTH data from these three major sources complement each other in providing a full picture of the upper tropospheric water vapor. The good redundancy of these records from multiple sensors in recent years facilitates the examination of the homogeneity and stability of each satellite data record and to explain the differences among data records.

Justification of project

UTH plays a significant role in the radiative and hydrological feedback in the climate system. The dataset provides important information on the variability and change of large-scale atmospheric circulations. Studies have shown that UTH variations are closely associated with the
El Niño – Southern Oscillation and are closely correlated with major climate indices. UTH datasets also facilitated evaluation of climate model simulations. In recent years considerable work has been put into inter-satellite calibration to form homogenized time series from polar orbiting infrared and microwave sensors and from geostationary satellite sensors. Time series independently generated from each sensor and measurements from Global Positioning System (GPS) Radio Occultation (RO) provide means for inter-checking potential problems in certain time periods or certain areas in each sensor’s dataset. Inter-comparison of data from different sensors can also lead to a better understanding of the differences. As this proposal is a coordinated activity among several government agencies and universities, we will exchange standards on software coding, metadata, and other data generation practices developed in each institution and strive to confirm to common standards.

Under the SCOPE-CM framework, the UTH project will follow SCOPE-CM’s guidance on archiving satellite metadata, maintain appropriate data format for archived data, ensure accessibility, perform re-processing with improved inter-satellite calibration, and maintain sustained generation of UTH products for climate monitoring. The process aims at advancing maturity levels established by the SCOPE-CM Maturity Matrix Model.

**Current and targeted maturity level**

UTH datasets are derived from three groups of satellite sensors: HIRS, SSM-T2/AMSU-B/MHS, and MVIRI/SEVIRI. The following tables list the current maturity level for each dataset, where maturity levels are defined as in “Bates, J. J., and J. L. Privette (2012), A maturity model for assessing the completeness of climate data records, Eos Trans. AGU, 93(44), 441”. In the tables, 1 represents minimum and 6 represents maximum maturity.

Current maturity level for HIRS upper tropospheric water vapor (UTWV, i.e., HIRS channel 12 brightness temperature; UTH is derived from UTWV):

<table>
<thead>
<tr>
<th>Software Readiness</th>
<th>Metadata</th>
<th>Documentation</th>
<th>Product Validation</th>
<th>Public Access</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
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Current maturity level for SSM-T2/AMSU-B/MHS UTH:

<table>
<thead>
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<th>Software Readiness</th>
<th>Metadata</th>
<th>Documentation</th>
<th>Product Validation</th>
<th>Public Access</th>
<th>Utility</th>
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</thead>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
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Current maturity level for METEOSAT MVIRI/SEVIRI FTH:

<table>
<thead>
<tr>
<th>Software Readiness</th>
<th>Metadata</th>
<th>Documentation</th>
<th>Product Validation</th>
<th>Public Access</th>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
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</table>

We propose that each of these datasets will reach the following maturity level at the completion of the project:

**Targeted maturity level**:

<table>
<thead>
<tr>
<th>Software Readiness</th>
<th>Metadata</th>
<th>Documentation</th>
<th>Product Validation</th>
<th>Public Access</th>
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<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Expected results, challenges and potential contributions**
Software Readiness: We will process HIRS, SSM/T-2, AMSU-B, MHS, and ATMS FCDR in an operational environment and ensure that the processing is stable and reproducible. It is expected that the METEOSAT FCDR will be provided by EUMETSAT. A fall back solution is an improved homogenization tool. Software will be developed for release of METEOSAT datasets with increased spatial and temporal resolution as well as coverage. In developing software we will strive to confirm to common program coding standards.

In cooperation with French partners, a geo-ring FTH demonstrator product will be developed which will cover the tropics and subtropics (within 45°N/S, all longitudes) and a short period in recent years. This activity contributes to the SCOPE-CM activity ICoG.

Metadata: The datasets will comply with netCDF CF format. We will consider following the same naming conventions where applicable and same gridding resolution where reasonable, thus products derived among different sensors can be easily analyzed and compared.

Documentation: We will complete C-ATBD for FCDR and TCDR products where applicable describing the correction procedures, for example, inter-satellite biases, scan-dependent biases, orbit drift correction. DOI numbers will be assigned to the products.

Product Validation: We will leverage efforts from our involvement with other programs such as the GEWEX Water Vapor Assessment and other projects. The UTH datasets will be validated using independent measurements including GPS RO data. UTH products as well as level 2 brightness temperatures among infrared and microwave observations and among polar-orbiting and geostationary data will be inter-compared. We will document the consistency and differences among UTH datasets.

Public Access: Data and source codes will be archived. We will follow perspective agency’s policies in making data and source code publicly available. Where available, uncertainty estimates and known issues will be provided.

Utility: We will do comparisons with reanalyses and climate model simulations. Also, we will use the data for studies such as monsoon variability, MJO. Further analysis to enhance usability by climate modelers and elsewhere is planned. One of such activities is to assess the possibility to jointly contribute relevant UTH/FTH data sets for the Observations for Model Intercomparison Projects (obs4MIPs) project.

The following flowchart provides a schematic view of the data flow of the targeted UTH/FTH CDRs.
Expected project duration and tentative schedule

The duration for this proposal is expected to be 4-years (mid-2013 to mid-2017). Tentative schedule is provided in the following.

Year 1
- Please see the work plan for the first year.

Year 2
- Improve software coding to conform to common program coding standards.
- Coordinate metadata standards.
- Complete C-ATBD for both FCDR and TCDR products describing the correction procedures, for example, inter-satellite biases, scan-dependent biases, orbit drift correction.
- Adapt METEOSAT processing to new cloud mask and FCDR.
- Inter-compare both level 2 and UTH among several sensor sources.
- Validate UTH using independent measurements such as GPS RO data.
- Add capabilities in Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package (COSP) for Tb to UTH conversion for all the sensors we are proposing.

Year 3
- Improve operational processing capability of UTH.
- Partly re-process UTH using up-to-date FCDRs.
- Document validation findings.
- Compare satellite derived UTH with climate model simulations.
- Use the data for studies such as monsoon variability and MJO.

Year 4
- Re-process full time series UTH using up-to-date FCDRs.
- Regularly process polar-orbiting UTH.
- Continue inter-comparison of UTH datasets from different sensors and other independent measurements.
- Submit papers for publications.
- Archive data and source codes. Data and sources codes are in version control.
- Follow perspective agency’s policies in making data and source code publicly available.

Funding situation
John Bates and Lei Shi are funded by an NCDC internal operation fund. Viju John is funded by the Met Office Hadley Centre climate program and EUMETSAT CM SAF. Marc Schröder is funded by DWD and EUMETSAT CM SAF. Stefan Buehler is funded by internal University resources. Funding is needed to carry out the UTH evaluation using GPS RO data.

Needed and available processing capabilities
NCDC has an archive of HIRS level1b data from 1978 to present. Current computer capability is sufficient for HIRS UTH processing. Lulea University of Technology has all AMSU-B/MHS data and the computer capability for UTH processing. The university also currently offers gridded UTH data products for public download. DWD has an archive of METEOSAT SEVIRI level1.5 data. Current computer capability is sufficient for METEOSAT FTH processing. The FTH edition 1 data record will be released in February 2013, after close out and will be available free of charge at www.cmsaf.eu/wui.

Curriculum vitae

Curriculum vitae for the following key investigators are attached.

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Telephone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Brian Soden</td>
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<td><a href="mailto:b.soden@miami.edu">b.soden@miami.edu</a></td>
</tr>
</tbody>
</table>
Dr. John J. Bates
151 Patton Ave, Asheville, NC 28801 828-271-4378 John.J.Bates@noaa.gov

Education

Ph.D.  Meteorology, 1986, University of Wisconsin, Madison

M.S.  Meteorology, 1982, University of Wisconsin, Madison

B.S.  Meteorology, 1976, Florida State University

Professional Societies and Awards

Board of Directors, American Geophysical Union, 2013-2014

Chairman, American Geophysical Union (AGU) Meetings Committee and Member AGU Council, 2010-2012

1998 Editors’ Citation for Excellence in Refereeing, Geophysical Research Letters – “for thorough and efficient reviews of manuscripts on topics related to the measurement and climate implications of atmospheric water vapor”

Employment

Principal Scientist for Remote Sensing, National Climatic Data Center, NOAA/NESDIS, Asheville, NC, 5/2012-present


Reviewed Publications


Stefan Buehler  
SRT, Division of Space Technology  
Lulea University of Technology, Box 812, 98128 Kiruna, Sweden  
Phone: +46 980 7 9177  
email: sbuehler@ltu.se

EDUCATION:
- University of Bremen  Physics  Ph.D. 1998
- SUNY at Stony Brook  Physics  M.A. 1994
- University of Tübingen  Physics  Vordiplom (comparable to B.S) 1993

EXPERIENCE:
- Since September 2006: Professor chair, Lulea University of Technology, Department of Space Science, Kiruna, Sweden
- 2005-2006: Privatdozent (associate professor) University of Bremen
- 2001-2004: Assistant professor (C2) University of Bremen
- 2000-2001: Senior working group leader (BAT Ia) University of Bremen
- 1998-2000: Working group leader (BAT IIa) University of Bremen

RELEVANT RESEARCH EFFORTS:
Prof. Buehler has more than 10 years of experience in the satellite remote sensing of water vapor, mainly from microwave sensors. His other research interests include the remote sensing of clouds and radiative transfer modeling. Recent water vapor research focused on the development of inter-satellite calibration of AMSU-B measurements, cloud clearing, comparison to other measurements (in particular radiosondes), and diurnal cycles. He has published over 60 peer-reviewed articles and according to Web of Science has a Hirsch index of 15 (researcher ID: A-4056-2009).

SELECTED PUBLICATIONS:

SELECTED PROFESSIONAL SERVICE/ACTIVITIES:
- 2010: Lead scientist of CloudIce ESA Earth Explorer mission proposal.
- Since 2007: Swedish delegate of COST Action ES0604 "Water Vapor in the Climate System".
- Since 2008: Editor for Atmospheric Chemistry and Physics (ACP) and Atmospheric Measurement Techniques (AMT).
- 2010: Lead-organizer of COST WaVaCS final workshop, focus on science theme 1, water vapor time series and trends.
Shu-Peng Ben Ho
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Tel:(303)497-2922, Fax:(303)497-2920, Email: spho@ucar.edu

EDUCATION:
Feng Chia University, Taichung, Taiwan, Computer Science, B.A., 1987
Rutgers—the State University of New Jersey, Meteorology, M.S., 1992
University of Wisconsin-Madison, Atmospheric Science, M.S., 1995
University of Wisconsin-Madison, Atmospheric Science, Ph. D., 1998

EXPERIENCE:
2008-current UCAR/COSMIC, NCAR/ACD, Project scientist II
2005-2008: UCAR/COSMIC, NCAR/ACD, Project scientist I
2002-2005: NCAR/ACD, Project scientist I
2001-2002: NCAR/ACD, Associate Scientist III

RELEVANT RESEARCH EFFORTS:
Dr. Shu-peng Ho is currently a Research Scientist in the UCAR COSMIC program. He is an expert in satellite remote sensing. Dr. Shu-peng Ho has more than 12 years of experience in developing and testing retrieval algorithms and radiative transfer models for high spectral resolution instruments including AIRS, HIS, AMSR-E, and TES. Dr. Ho is a remote sensing expert and is a member of GEWEX water vapor assessment group, and a member of the Stratospheric Processes and their Role in Climate (SPARC). He is also a contributing author to the IPCC 5th assessment report. His recent works include the development of the combined AIRS, AMSU, and GPS RO retrieval algorithm for global temperature and water vapor profiles for data assimilation system. Dr. Ho published over 37 refereed journal papers. He is a regular reviewer for several remote sensing related Journals.

SELECTED PUBLICATIONS:
Viju Oommen John
Met Office Hadley Centre
FitzRoy Road, Exeter, UK, EX1 3PB
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EDUCATION:
University of Bremen, Germany  Physics  Ph.D.  2005
CUSAT, India  Atmospheric Sciences  M. Tech.  2000
CUSAT, India  Physics  M. Sc.  1998

EXPERIENCE:
Jan., 2008 – present  Scientist, Met Office, UK
Feb., 2006 – Dec. 2007  PDRA, RSMAS, Uni. of Miami, USA

RELEVANT RESEARCH EFFORTS:
Viju has more than 10 years of experience in the satellite remote sensing of temperature and water vapor from both infrared and microwave sensors. Recent research focused on the development of inter-satellite calibration of microwave humidity sounding measurements since 1993, development of upper tropospheric humidity dataset for climate studies, and evaluating climate models using observations.

SELECTED PUBLICATIONS:


Marc Schröder  
Deutscher Wetterdienst, Satellite-based Climate Monitoring  
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EDUCATION:  
Freie Universität Berlin, Berlin, Germany  
Natural sciences  
Ph.D.  
2004  
Carl von Ossietzky Universität Oldenburg, Germany  
Physics  
Diploma.  
1999  

EXPERIENCE:  
Jul. 2007 – present  
Scientist, DWD, Germany  
May 2006 – June 2007  
Consultant/Visiting Scientist at EUMETSAT, Darmstadt, Germany  
Postdoc, FU Berlin, Berlin, Germany  
April 2000 – August 2004  
Research Assistant, FU Berlin, Berlin, Germany  
Research Assistant, University of Wisconsin, Madison, Wisconsin, USA  

RELEVANT RESEARCH EFFORTS:  
Marc Schröder is leading the CM SAF water vapour activities and is currently involved in the retrieval of global water vapour and temperature profiles from ATOVS observations, the retrieval of free tropospheric humidity from MVIRI/SEVIRI observations and the continuation and improvement of the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data (HOAPS), which - among others – include a total column water vapour product. Besides activities in geophysical space he is also working on the homogenisation of the METEOSAT time series and is involved in the generation of a SSM/I FCDR.  

SELECTED PUBLICATIONS:  
B. Dürr, M. Schröder, R. Stückli, and R. Posselt: HelioFTH: Combining cloud index principles and aggregated rating for cloud masking using infrared observations from geostationary satellites.  
Submitted to AMT, 2013.  
Schröder, M., Jonas, M., Lindau, R., Schulz, J., and Fennig, K.: The CM SAF SSM/I-based total column water vapour climate data record: methods and evaluation against re-analyses and satellite, Atmos.  

SELECTED PROFESSIONAL SERVICE/ACTIVITIES:  
Co-Chair for GEWEX Water Vapor Assessment,  
2011-present  
Coordinator for SCOPE-CM SSM/I pilot project  
2008-2012  
Member of the Post-EPS Mission Expert Team  
2010-present  
Member of the GRUAN Task Team 5  
2010-present
Lei Shi  
NOAA National Climatic Data Center  
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EDUCATION:
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Meteorology  
Ph.D. 1992
Florida State University  
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M.S. 1988
Zhongshan University  
Meteorology  
B.S. 1984

EXPERIENCE:
Aug., 2003 – present Meteorologist, NOAA National Climatic Data Center  
Asheville, NC, USA
Dec., 1993 – Aug. 2003 Staff Scientist, SeaSpace Corporation  
San Diego, CA, USA
Apr., 1992 – Nov. 1993 Post-doctoral Researcher, Scripps Institution of Oceanography,  
San Diego, CA, USA

RELEVANT RESEARCH EFFORTS:
Dr. Shi has more than 20 years of experience in the satellite remote sensing of temperature and water vapor from both infrared and microwave sensors. Recent research focused on the development of intersatellite calibration of HIRS measurements since 1978, development of upper tropospheric water vapor dataset for climate studies, retrieval of global temperature and water vapor profiles from HIRS, and retrieval of temperature and humidity from AMSU-A and AMSU-B.

SELECTED PUBLICATIONS:

SELECTED PROFESSIONAL SERVICE/ACTIVITIES:
Co-Chair for GEWEX Water Vapor Assessment, 2011-present
Coordinator for SCOPE-CM UTH pilot project 2008-2012
Voting Member representing NOAA’s climate goal in Low-Orbiting Satellite Requirement Working Group (LOW WG), 2007-2011
Team Lead for IJPS NOAA Archive and Access, 2003-2007
Brian J. Soden

EDUCATION:
June 1993  Ph. D. University of Chicago
March 1990  M.S. University of Chicago
May 1988  B.S. University of Miami

RESEARCH EXPERIENCE
8/04 -  Professor, Rosenstiel School for Marine and Atmospheric Science
        University of Miami, FL.
6/94 – 7/04  Physical Scientist, Geophysical Fluid Dynamics Laboratory,
            National Oceanic and Atmospheric Administration, Princeton, NJ.
6/94 - 7/04  Lecturer with Rank of Associate Professor, Atmospheric and Oceanic
            Sciences Program, Princeton University.

RELEVANT RESEARCH EFFORTS:
Prof. Soden has more than 20 years of experience in the satellite remote sensing of water vapor and
clouds, and their application for climate monitoring and model evaluation. He has been involved in the
development of retrieval algorithms, detection and correction of satellite orbital and calibration drifts, and
the application of these data sets for climate change detection and attribution. He has published over 90
peer-reviewed articles and according to Google Scholar has an H-index of 42.

SELECT PROFESSIONAL ACTIVITIES:
Chairman, AMS Committee on Atmospheric Radiation (1998-2000).
Editor, Journal of Climate (2009-).

SELECT PUBLICATIONS:
Chung, E. S., and B. Soden, 2009: A satellite-based asessment of upper tropospheric water
humidity-temperature covariance using AIRS, *Geophysical Research Letters*, 35, L10814,
Jackson, D. L., and B. J. Soden, 2007: Detection and correction of diurnal sampling bias in
Soden, BJ, DL Jackson, V Ramaswamy, MD Schwarzkopf, and X. Huang, 2005: The radiative
Env.*, 25, 441-475.
Soden, B. J., and F. P. Bretherton, 1993: Upper tropospheric relative humidity from the GOES