CHAPMAN CONFERENCE ON ATMOSPHERIC WATER VAPOR AND ITS ROLE IN CLIMATE

Kailua-Kona, Hawaii, USA

20–24 October 2008

AGU Chapman Conference on
Atmospheric Water Vapor and Its Role in Climate
Kailua-Kona, Hawaii, USA, 20–24 October 2008

Conveners

- **Steven Sherwood**, Yale University, New Haven, Connecticut, USA
- **Natalia Andronova**, University of Michigan, Ann Arbor, Michigan, USA
- **Ray Pierrehumbert**, University of Chicago, Chicago, Illinois, USA

Program Committee

- **Dieter Kley**, Forschungszentrum Juelich, Juelich, Germany
- **Liz Moyer**, University of Chicago, Chicago, Illinois, USA
- **Joyce Penner**, University of Michigan, Ann Arbor, Michigan, USA
- **Rémy Roca**, LMD/IPSL, Paris, France
- **Karen Rosenlof**, NOAA Aeronomy Laboratory, Boulder, Colorado, USA
- **Masato Shiotani**, Kyoto University, Kyoto, Japan
- **Brian Soden**, RSMAS/MPO, University of Miami, Coral Gables, Florida, USA
- **Tammy Weckwerth**, NCAR, Boulder, Colorado, USA

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NSF (Climate and Large-Scale Dynamics: CLD): The goals of the Program are to (i) advance knowledge about the processes that force and regulate the atmosphere's synoptic and planetary circulation, weather and climate, and (ii) sustain the pool of human resources required for excellence in synoptic and global atmospheric dynamics and climate research.
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Cover Caption: Photograph from the summit of Mauna Kea, Hawaii, looking out toward Maui; courtesy of J. Galewsky. Inset photos cover the broad spectrum of the Earth sciences.

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MEETING AT A GLANCE

Sunday, 19 October

5:30 p.m. – 7:00 p.m.	Aloha Reception and Registration

Monday, 20 October

8:00 a.m. – 8:45 a.m.	Registration
9:00 a.m. – 10:45 a.m.	Oral Discussions
10:45 a.m. – 11:05 a.m.	Morning Refreshments
11:05 a.m. – 11:35 a.m.	Poster Summaries
11:35 a.m. – 1:15 p.m.	Lunch on own
1:15 p.m. – 2:35 p.m.	Oral Discussions
2:35 p.m. – 2:55 p.m.	Afternoon Refreshments
2:55 p.m. – 3:45 p.m.	Poster Summaries
3:45 p.m. – 6:00 p.m.	Poster Viewings

Tuesday, 21 October

8:00 a.m. – 8:45 a.m.	Registration
9:00 a.m – 10:40 a.m.	Oral Discussions
10:40 a.m. – 11:00 a.m.	Morning Refreshments
11:00 a.m. – 11:30 a.m.	Poster Summaries
11:30 a.m. – 1:00 p.m.	Lunch on own
1:00 p.m. – 2:20 p.m.	Oral Discussions
2:20 p.m. – 2:40 p.m.	Afternoon Refreshments
2:40 p.m. – 3:30 p.m.	Poster Summaries
3:30 p.m. – 6:00 p.m.	Poster Viewings

Wednesday, 22 October

All-Day Field Trips; No Scientific Sessions

Thursday, 23 October

8:00 a.m. – 8:45 a.m.	Registration
9:00 a.m. – 10:40 a.m.	Oral Discussions
10:40 a.m. – 11:00 a.m.	Morning Refreshments
11:00 a.m. – 11:35 a.m.	Poster Summaries
11:30 a.m. – 1:00 p.m.	Lunch on own
1:00 p.m. – 2:20 p.m.	Oral Discussions
2:20 p.m. – 2:40 p.m.	Afternoon Refreshments
2:40 p.m. – 3:45 p.m.	Poster Summaries
3:45 p.m. – 6:00 p.m.	Poster Viewings
6:30 p.m. – 9:00 p.m.	A hui hou Banquet

Friday, 24 October

8:00 a.m. – 8:45 a.m.	Registration
9:00 a.m. – 10:40 a.m.	Oral Discussion
10:40 a.m. – 11:00 a.m.	Morning Refreshments
11:00 a.m. – 12:00 noon	Poster Viewings
12:00 noon – 1:15 p.m.	Lunch on own
1:15 p.m. – 3:00 p.m.	Oral Discussions

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SCIENTIFIC PROGRAM

Note: Oral Discussions and Poster Summaries will be held in Keauhou II. Poster Viewings will be held in Keauhou I.

SUNDAY, 19 OCTOBER 2008

5:30 p.m. – 7:00 p.m. Registration, Crystal Blue Terrace I
5:30 p.m. – 7:00 p.m. Aloha Reception, Crystal Blue Terrace I

MONDAY, 20 OCTOBER 2008

8:00 a.m. – 8:45 a.m. Registration, Foyer, Keauhou I and II

OPENING SESSION
9:00 a.m. Conveners' Welcome (S. Sherwood)

KEYNOTE SESSION
Chair: Natasha Andronova
9:15 a.m. Keynote Talk - Implications of Increased Water Vapor in a Warmer World (B. Soden)

10:15 a.m. Open Discussion

10:45 a.m. **BREAK** **FOYER**

WATER VAPOR IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE
Chairs: Karen Rosenlof, Masato Shiotani

11:05 a.m. Upper Troposphere/Lower Stratosphere Poster Summaries (*2 minutes each*): P. Baines, J. Barnes, R. Boers, I. Cionni, A. Gettelman, J. Gille, D. Hofmann, V. John, S. Khaykin, E. Kursinski

11:35 a.m. **LUNCH (on your own)** **1:15 p.m.**

UPPER TROPOSPHERE/LOWER STRATOSPHERE I

1:15 p.m. Ice Nucleation in Tropical Tropopause Layer Thin Cirrus and Implications for Dehydration of Air Entering the Stratosphere (E. Jensen)

1:45 p.m. Supersaturation: Experimental Evidence or Instrumental Artifacts? Classical Explanations or New Microphysics? (C. Schiller)

2:15 p.m. Discussion

2:35 p.m. **BREAK** **FOYER**

2:55 p.m. Upper Troposphere/Lower Stratosphere Poster Summaries (*2 minutes each*): A. Lambert, N. Lamquin, E. Larroza, B. Legras, C. Liu, D. Livings, Z. Luo, E. Martins, G. Nedoluha, J. Penner, L. Pfister, K. Rosenlof, W. Read, R. Schofield, J. Schulz, H. Su, H. Vomel, D. Whiteman, L. J. Wilcox, J. Wrotny

3:45 p.m. – 6:00 p.m. Upper Troposphere/Lower Stratosphere Poster Viewings

TUESDAY, 21 OCTOBER 2008

8:00 a.m. – 8:45 a.m. Registration, Foyer, Keauhou I and II

UPPER TROPOSPHERE/LOWER STRATOSPHERE II

9:00 a.m. Water Vapor in the Upper Troposphere and the Stratosphere (B. Legras)

9:30 a.m. Convective Troposphere-Stratosphere Transport in the Tropics and Hydration by Ice Crystals Geysers (J.-P. Pommereau)

10:00 a.m. Open Discussion

10:40 a.m. **BREAK** **FOYER**

CONVECTION AND WATER VAPOR

Chairs: Tammy Weckwerth, Remy Roca

11:00 a.m. Convection Poster Summaries (*2 minutes each*): L. Back, M. Bosilovich, H. Brogniez, D. Brown, E. Fetzer, E.-H. Jung, B. Kahn, T. Koshiro, D. Kley, A. Kursinski, J. R. Lawrence, T. Logan, E. Monier

11:30 a.m. **LUNCH (on your own)** **1:00 p.m.**

CONVECTION I

1:00 p.m. Water Vapor and the Initiation of Deep Convention (R. Wakimoto)

1:30 p.m. Climatology of Deep Convection in the Tropics from a Decade of TRMM Observations (E. Zipser)

2:00 p.m. Discussion

2:20 p.m. **BREAK** **FOYER**

2:40 p.m. Convection Poster Summaries (*2 minutes each*): P. Mote, T. Ning, S.-J. Park, V. Phillips, M. Previdi, F. Robertson, C. Risi, J.-M. Ryoo, M. Schroder, J. Schulz, R. Singh, B. J. Sohn, B. Tian, K. Young, T. Vonder Haar, J. Wang, T. Weckwerth, J. Wright, V. Wulfmeyer, M. Zelinka, L. Zhang, X. Zhang

3:30 p.m. – 6:00 p.m. Convection Poster Viewings

WEDNESDAY, 22 OCTOBER 2008

ALL-DAY FIELD TRIPS; NO SCIENTIFIC SESSIONS

THURSDAY, 23 OCTOBER 2008

8:00 a.m. – 8:45 a.m. Registration, Foyer, Keauhou I and II

CONVECTION II

9:00 a.m. Feedback Among Convection, Water Vapor, and Climate (K. Emanuel)

9:30 a.m. On the Potential of Water Stable Isotopes for the Study of Convection - Water Vapor Interactions (S. Bony)

10:00 a.m. Discussion

10:40 a.m. BREAK FOYER

CLIMATE, HUMIDITY, AND THE GLOBAL WATER CYCLE

Chairs: Brian Soden, Joyce Penner

11:00 a.m. Climate/Hydrology Poster Summaries (*2 minutes each*): R. Allan, N. Andronova, M. D. Alexandrov, H. Brogniez, A. Dai, I. Durre, A. Dessler, J. Evans, C. Garrity, G. Gastineau, G. Guerova

11:30 a.m. LUNCH (on your own) 1:00 p.m.

CLIMATE I

1:00 p.m. Where Hope is Coldest: Understanding Tropospheric Water Vapor With Last-Saturation Analysis (J. Galewsky)

1:30 p.m. Tropospheric Water Vapor and the Hydrological Cycle in Today's Climate (R. Allan)

2:00 p.m. Discussion

2:20 p.m. BREAK FOYER

2:40 p.m. Climate/Hydrology Poster Summaries (*2 minutes each*): Y. Huang, M. Huber, J. Hurley, W. Ingram, A. H. Jahren, S. Krishnan, M. Lachniet, J.-E. Lee, A. LeGrande, J.-H. Lu, J. Ma, C. Mears, S. Mieruch, B. Music, P. O'Gorman, I. Richter, R. Roca, M. Roderick, B. Santer, U. Seibt, S. Sherwood, H. Sodemann, A. Swann, F. Wentz, K. Willett, Y. Wu, I. Zveryaev

3:45 p.m. – 6:00 p.m. Climate/Hydrology Poster Viewings

6:30 p.m. A hui hou BANQUET CRYSTAL BLUE POINT

FRIDAY, 24 OCTOBER 2008

CLIMATE II

8:00 a.m. – 8:45 a.m. Registration, Foyer, Keauhou I and II

9:00 a.m. The History of the Atmospheric Hydrological Cycle in Past and Present Climates Captured by Water Isotopes (D. Noone)

9:30 a.m. Hydrological Cycle Feedbacks in the Eocene UltraGreenhouse: Heat Death, Hyperthermals, and Heat Transport (M. Huber)

10:00 a.m. Discussion

10:40 a.m.	**BREAK**	**FOYER**
11:00 a.m. Second Viewing of Climate/Hydrology Posters		
12:00 noon	**LUNCH (on your own)**	**1:15 p.m.**

PANEL DISCUSSION SESSION
Chair: Liz Moyer

1:15 p.m. Panel Discussion: What is Needed for Future Observing Systems?

1:45 p.m. Questions/Discussion/Closing Remarks

3:00 p.m. Conference Adjourns

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POSTER SESSIONS

Posters will be on display in Keauhou I. Posters are listed below in alphabetical order based on day of presentation.

MONDAY, 20 OCTOBER

Upper Troposphere/Lower Stratosphere Posters *3:45 p.m. - 6:00 p.m.*

M01 Baines, P. *The Interannual Variability of Upper Tropospheric Water Vapor and its Connection with Tropical Dynamics*

M02 Barnes, J. *Raman Lidar Water Vapor Measurements in the Upper Troposphere Above Mauna Loa Observatory*

M03 Boers, R. *Accuracy Requirements for Water Vapor Measurements in the Upper Troposphere Based on 1950 – 2100 Simulations of Future Climate*

M04 Cionni, I. *The Role of Stratospheric Water Vapor in Global Climate Models*

M05 Gettelman, A. *Water Vapor Ice Supersaturation and Its Effect on Climate*

M06 Gille, J. *HIRDLS Observations of Water Vapor in the Upper Troposphere-Lower Stratosphere Region*

M07 Hofmann, D. *Decadal Trends in Stratospheric Water Vapor and Background Sulfate Aerosol – Are They Related?*

M08 John, V. *Upper Tropospheric Humidity Data Set From Operational Microwave Sounders*

M9 Khaykin, S. *Water Vapor in the Tropical UT/LS From Balloon Observations With FLASH-B Hygrometer.*

M10 Kursinski, E. *A New Method of Remotely Sensing Tropospheric and Middle Atmospheric Water Vapor: the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS)*

M11 Lambert, A. *Aura Microwave Limb Sounder Measurements of Upper Tropospheric Cloud Ice-Water Content, Water Vapor and Relative Humidity*

M12 Lamquin, N. *Upper Tropospheric Humidity and Cirrus Clouds: Relationships Inferred by Combined AIRS and CALIPSO Data, Evaluation of ECMWF Forecasts and Influence of Vertical Resolution on ice Supersaturation Larroza, E. Sub-Visual Cirrus LIDAR Measurements for Satellite Masking Improvement*

M13 Legras, B. *Water Vapor Transport and Dehydration Above Convective Outflow During Asian Monsoon*

M14 Liu, C. *Diurnal Cycles of Water Vapor, Clouds and Deep Convection Near the Tropical Tropopause*

M15 Livings, D. *What Is the Right Way to Compare Solar Occultation Soundings to an NWP System?*

M16 Luo, Z. *Ten Years of Measurements of Tropical Upper-Tropospheric Water Vapor by MOZAIC: What Do We Learn From Them?*

M17 Martins, E. *Water Vapor, Ice Phase and Thin Cirrus at the Tropical Tropopause Layer (TTL)*

M18 Nedoluha, G. *A Comparison of Measurements from Ground Based Radiometers, Aura MLS, and ODIN*

M19 Penner, J. *Effects of Anthropogenic Aerosols on Cirrus Clouds, Tropopause Temperatures, and Water Transport to the Stratosphere*

M20 Pfister, L. *Water Vapor and Clouds in the Tropical Tropopause Layer as Simulated by a Microphysical Model*

M21 Rosenlof, K. *Related Changes in Tropical Tropopause Temperatures and Stratospheric Water Vapor Input*

M22 Read, W. *Convection Extratropical Mixing and In Situ Freeze Drying in the Tropical Tropopause Layer*

M23 Schofield, R. *Microphysical Model Details for Trajectory Studies of Water Vapor Transport Across the Tropical Tropopause Layer*

M24 Schulz, J. *Characterising Satellite Infrared Water Vapour Radiances Utilising Ground-based Reference Observations and Radiative Transfer Simulations*

M25 Su, H. *Pollution Influence on Tropopause Water Vapor*

M26 Vomel, H. *A Review of Balloon Borne Observations of Supersaturation in the Tropical Tropopause Transition Layer*

M27 Whiteman, D. *Upper Tropospheric and Lower Stratospheric Measurements of Water Vapor using Raman Lidar and Radiosondes*

M28 Wilcox, L.J. *The Impact of Aviation on Climate: Water Vapour Emissions From Aircraft*

M29 Wrotny, J. *Interpretation of HALOE and ACE Water Vapor and Methane data in the Equatorial Upper Stratosphere*

TUESDAY, 21 OCTOBER 2008

Convection Posters *3:30 p.m. - 6:00 p.m.*

T1 Back, L. *Water-Vapor-Convection Feedback and the Diurnal Cycle in an Idealized Cloud-Resolving Model Study*

T2 Bosilovich, M. *The Impact of Water Vapor Observations in Global Data Assimilation*

T3 Brogniez, H. *Long Term Measurements of Free Tropospheric Humidity From Space: Where Do We Stand?*

T4 Brown, D. *Using Measurements of the Isotopic Composition of Water Vapor to Model Regional Moisture Exchange*

T5 Fetzer, E. *AIRS Temperature and Water Vapor Climatologies Based on CloudSat Cloud Classes*

T6 Jung, E.-H. *Suggestion for the Precipitation Index Using the Precipitable Water and Variation of GPS Data*

T7 Kahn, B. A. *Global Climatology of Temperature and Water Vapor Variance Scaling From the Atmospheric Infrared Sounder*

T8 Koshiro, T. *Relationship Between Low Stratiform Cloud Amount and Lower-Tropospheric Stability Over the Ocean in Terms of Cloud Types*

T9 Kley, D. *Relative, Specific Humidity and Temperature in the Outflow of Deep Convection: Relation to Sea Surface Temperature*

T10 Kursinski, A. *A New El Niño Atmospheric Perspective via GPS Radio Occultation*

T11 Lawrence, J. R. *Stable Isotopes of Water Vapor and Climate Change*

T12 Logan, T. *Tracking of Aerosol and Chemical Pollutants From Asia to the United States Across the Pacific Ocean: A Validation of an in Depth Case Study Using Data From the April-May 2006 INTEX-B Experiment*

T13 Monier, E. *Madden-Julian Oscillation Convection-Wind Coupling in the MM5 Model and the Role of Moisture*

T14 Mote, P. *The Role of Water Vapor in the Energetics of the Madden-Julian Oscillation*

T15 Ning, T. *Atmospheric Water Vapor Content Inferred From GPS Data and Compared to a Global NWP Model and a Regional Climate Model*

T16 Park, S-J. *Calculating Eddy Diffusivity of Water Vapor in the Atmospheric Surface Layer: from the CASES-99 Experiment*

T17 Phillips, V. *Observational Study of the Relation Between Sea Surface Temperature and Water Vapour in Atlantic Region*

T18 Previdi, M. *Changes in the Atmospheric Energy Budget With Global Warming: Role of Water Vapo*r

T19 Robertson, F. *Water Vapor Feedback and Links to Mechanisms of Recent Tropical Climate Variations*

T20 Risi, C. *The Influence of Convection on the Isotopic Composition of Precipitation and Water Vapor in the Tropics*

T21 Risi, C. *Influence of Large Scale Climate Variations on the Isotopic Composition of Tropical Precipitation and Water Vapor*

T22 Ryoo, J-M. *PDFs of Tropical Tropospheric Humidity with Generalized Statistical Model*

T23 Schroder, M. *Diurnal Cycle and Spatial Distribution of Outgoing Longwave Radiation in the (Sub)Tropics and the Dependence on Deep Convection and Humidity*

T24 Schroder, M. *Long-Term Application and Evaluation of IAPP Using Global Radiosonde and CHAMP Measurements*

T25 Schulz, J. *The First Long-Term Satellite-Derived Total Water Vapour Column Climatology From CM-SAF: Intercomparison Results*

T26 Singh, R. *Enhancement of Water Vapor and Its Relation with the Observed Climatic Changes over the Indo-Gangetic Plains*

T27 Sohn, B. J. *Moistening Processes in the Tropical Upper Troposphere and Their Implication in Water Vapor Feedback*

T28 Tian, B. *On the Low-level Moisture Preconditioning of the Madden-Julian Oscillation*

T29 Young, K. *Development of a High-Quality, Long-Term Dropsonde Climatology and Characterization of the Thermodynamic Profiles in Hurricanes*

T30 Vonder Haar, T. *Variability of Water Vapor Observations on Daily to Decadal Timescales from the Global NVAP Dataset*

T31 Wang, J. *Climate Applications of Ground-Based GPS Measurements of Water Vapor*

T32 Weckwerth, T. *Water Vapor DIAL and DOW Observations and Comparisons with Mesoscale Models in COPS*

T33 Wright, J. *The Role of Condensate Evaporation in Setting Water Vapor, HDO, and H2O18 amounts in a GCM*

T34 Wulfmeyer, V. *World Weather Research Program Activities in 2007 for Studying Quantitative Precipitation Forecasting in Complex Terrain*

T35 Zelinka, M. *Sensitivity of Tropical Deep Convection to SST and the Large-Scale Circulation*

T36 Zhang, L. *A Near-Global, 2-Hourly Data Set of Atmospheric Precipitable Water from Ground-Based GPS Measurements*

T37 Zhang, X. *Simulation of Radiation Fog: Numerical Model and Sensitivity Analysis*

THURSDAY, 23 OCTOBER 2008

Climate Posters *3:45 p.m. - 6:00 p.m.*

TH01 Allan, R. *Tropospheric Water Vapor and the Hydrological Cycle in Today's Climate*

TH02 Allan, R. *Evaluation of Links Between Clear-sky Radiation, Water Vapor and the Hydrological Cycle in Models, Reanalyses and Observations*

TH03 Andronova, N. *Constraining The Tropical Mean Atmospheric Water Vapor Feedback From Observations And Model Simulation*

TH04 Alexandrov, M.D. *Retrieval of Columnar Water Vapor from Sun-Photometric Measurements*

TH05 Brogniez, H. *Free Tropospheric Humidity From METEOSAT: Link to Large-Scale Dynamics*

TH06 Dai, A. *Global Changes in Atmospheric Water Vapor Content During 1976-2007: Observations vs. Models*

TH07 Durre, I. *Radiosonde-Based Trends in Precipitable Water over the Northern Hemisphere: An Update*

TH08 Dessler, A. *Global Cooling During 2007: An Examination of the Water-Vapor Feedback*

TH09 Evans, J. *Using Regional Climate Models and Lagrangian Back Trajectories to Estimate the Source Areas of Water Vapor*

TH10 Garrity, C. *Linking Water Vapor Climatology to Extreme Surface Moisture Conditions in the Western United States – A Comparison of GIS-Based Methods*

TH11 Gastineau, G. *Relation Between Atmospheric Energy Transport and Hadley Cell Strength in Aquaplanet Simulations*

TH12 Guerova, G. *Water Vapor Feedback During the 2003 Heat Wave in Europe*

TH13 Huang, Y. *Impact of Water Vapor on the Earth's Radiative Energy Budget Analyzed from Longwave Radiation Spectra*

TH14 Huber, M. *Importance of Changes in Extreme Weather Events for the Maintenance of Past Warm Climates*

TH15 Hurley, J. *Circulation and Temperature Influences on Subtropical Humidity: Last Saturation Water Vapor Tracers and ENSO*

TH16 Ingram, W. *A Very Simple Model for the Water Vapour Feedback on Climate Change*

TH17 Ingram, W. *A New Way to Quantify Water Vapour Feedback in GCMs*

TH18 Jahren, A. H. *Reconstruction of Relative Humidity using Fossil Cellulose Derivatives; Seasonal Patterns from The middle-Eocene (45 Ma)*

TH19 Krishnan, S. *Hydrological Characteristics During CO2 Induced Warm Events Using Organic Compound-Specific Proxies*

TH20 Lachniet, M. *Stable Isotopes in Modern Water and Ancient Stalagmites from Central America: Implications for Moisture Transport and Tropical-Extratropical Climate Teleconnections*

TH21 Lee, J-E. *Water Isotopes During the Last Glacial Maximum: New GCM Calculations*

TH22 LeGrande, A. *Controls on Water Isotope Variability on Millennial and Abrupt Time Scales Over the Last 21,000 Years – General Circulation Model results from GISS ModelE-R*

TH23 Lu, J-H. *Representing the Role of Water Vapor in Climate Feedback by Coupled Surface-Atmosphere Climate Feedback-Response Method (CFRAM)*

TH24 Ma, J. *Sensitivity of Global Warming to Surface Latent Heat Flux: Relative Humidity*

TH25 Mears, C. *Correlation of Water Vapor and Temperature Anomalies in the Climate System*

TH26 Mieruch, S. *Global Water Vapor Trends From Satellite Data Compared With Radiosonde Measurements*

TH27 Music, B. *Investigation of the Sensitivity of Water Cycle Components Simulated by the Canadian Regional Climate Model (CRCM) to the Land Surface Parameterization, the Lateral Boundary Data and the Internal Variability*

TH28 O'Gorman, P. *The Response of Mean and Extreme Precipitation to Global Warming and Increased Atmospheric Water Vapor Content*

TH29 Richter, I. *The Muted Precipitation Increase in Global Warming Simulations: A Surface Evaporation Perspective*

TH30 Roca, R. *On the Distribution of the Free Tropospheric Humidity in the Intertropical Belt*

TH31 Roderick, M. *Evaporative Demand and Terrestrial Water Resources under a Changing Climate*

TH32 Santer, B. *Identification of Human-Induced Changes in Atmospheric Moisture Content: Sensitivity of Results to Model Quality*

TH33 Seibt, U. *The "Flood of the Century" as Isotopic Fingerprint in Canopy d18O Signatures*

TH34 Sherwood, S. *Relative Humidity Change*

TH35 Sodemann, H. *Atmospheric Transport of Water to the European Arctic Simulated with a Mesoscale Model with Water Vapor Tracers: Sources, Structure, and Energy Considerations*

TH36 Swann, A. *Arctic Vegetation Changes Induce High Latitude Warming Through Greenhouse Effect*

TH37 Wentz, F. *The Impact of Water Vapor on Precipitation and Evaporation Trends*

TH38 Willett, K. *HadCRUH: Analysis of Recent Changes in Surface Humidity and Underlying Causes with a New Global Dataset*

TH39 Willett, K. *Modelling Heat Stress in Warmer and More Humid Climates*

TH40 Willett, K. *Humidity and Human Health – Implementing a Universal Heat Stress Product for both Historical Analyses and Forecasting on Daily to Multi-decadal Scales*

TH41 Wu, Y. *Storm Tracks Changes and Their Impacts on Hydrological Cycle*

TH42 Zveryaev, I. *Seasonality in Interannual Variability of Atmospheric Moisture Over Europe*

ABSTRACTS

Oral discussions: listed in order of daily presentation.

Monday, 20 October

UPPER TROPOSPHERE/LOWER STRATOSPHERE I

Session Chairs: Karen Rosenlof, Masato Shiotani

Ice Nucleation in Tropical Tropopause Layer Thin Cirrus and Implications for Dehydration of Air Entering the Stratosphere

E. Jensen (NASA Ames Research Center, MS 245-4, Moffett Field, CA 94035 303-704-3039, email: eric.j.jensen@nasa.gov); Leonhard Pfister, (NASA/Ames Research Center , MS 245-5 , Moffett Field, CA 94035-1000 , 650 604 3183 , FAX: 650 604 3625 , E-mail: Leonhard.Pfister-1@nasa.gov); Daniel Murphy, (NOAA ESRL Chemical Sciences Division, 325 Broadway, R/CSD6, Boulder, CO 80305; email: daniel.m.murphy@noaa.gov)

Recent in situ measurements of subvisible cirrus from the CRAVE and TC4 field experiments indicate ice number concentrations less than 100/L that are far lower than homogeneous-freezing nucleation theory predicts. In addition, the measured size distributions are much broader than theoretical models predict. Consistent with the apparent overestimate of ice concentrations by numerical models, we find that simulated extinctions are substantially larger than those indicated by CALIPSO. All of this evidence points to a fundamental problem with our theoretical understanding of ice cloud formation processes at low temperature with important implications for cloud radiative properties and dehydration of air entering the stratosphere. Recent laboratory evidence indicating formation of glassy states in organic-containing aerosols at low temperatures presents a possible explanation for the low ice concentrations. We will use numerical simulations of TTL transport, cloud formation, and water vapor to evaluate the implications of uncertainties in cloud formation processes at low temperatures for TTL cirrus properties and dehydration of air entering the stratosphere.

Supersaturation: Experimental Evidence or Instrumental Artifacts? Classical Explanations or New Microphysics?

C. Schiller (Forschungszentrum Jülich, 52425 Jülich, Germany; ph. +49-2461-615272; fax +49-2461-615346; email c.schiller@fz-juelich.de); M Krämer (Forschungszentrum Jülich, 52425 Jülich, Germany; ph. +49-2461-613238; fax +49-2461-615346; email m.kraemer@fz-juelich.de); T. Peter (ETH Zürich, Switzerland; ph. +41-44-633-2756; fax +41-44-633-1058; email thomas.peter@env.ethz.ch)

Massive supersaturation in cloud-free air exceeding the homogeneous ice nucleation threshold has been derived from numerous data airborne and balloon-borne data sets. Also inside clouds, significant supersaturations have been reported. Many of these observations, most strikingly those at lowest temperatures, seem to contradict our conventional understanding of the formation and the life cycle of cirrus clouds.

Measurements of water vapor using different hygrometers have shown discrepancies, in particular in the critical mixing ratio range of only a few ppmv. Therefore, the involved hygrometers have been recently intercompared in an AIDA chamber experiment and re-characterized in the home laboratories in order to get a better understanding of potential experimental biases and uncertainties. Part of the unexpected field data have therefore been revised recently or have to be used with corrected uncertainties. However, there seem to remain many observations which still require new explanations.

Model calculations in comparison with field data imply that the `supersaturation puzzle' may turn into a `freezing puzzle' with new questions (i) Are there only very small temperature fluctuations or (ii) Are there new mechanisms that suppress or slow down

the homogeneous formation of ice crystals at temperatures below 200 K?

Tuesday, 21 October

UPPER TROPOSPHERE/LOWER STRATOSPHERE II
Session Chairs: Karen Rosenlof, Masato Shiotani

Water Vapor in the Upper Troposphere and the Stratosphere

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Fresh tropospheric air enters the stratosphere across the tropical tropical tropopause, where motion is ascending, and is then pumped into the Brewer-Dobson circulation above. Because of the extremely cold temperature of the tropical tropopause (190-200K), the mixing ratio of water vapor is limited to a few ppmv at the entry to the stratosphere, setting the conditions for the stratospheric chemistry and composition. The detailed mechanism of water vapor injection is , however, a matter of discussion about the respective roles of the fast pathway across the tropopause due to intense penetrative convection and the the slow pathway where air detrained by convection below the tropopause is lifted across it by the ambient heating. In the first part of this talk, we will review the state of our understanding of these processes and the insights from recent modelling studies, campaigns and satellite observations. In the second part, we will focus on the summer season and we will discuss the strong interaction between localized convection and the large-scale Asian monsoon circulation which leads to a maximum of water vapor in the lower stratosphere within the monsoon anticyclone.

Convective Troposphere-Stratosphere Transport in the Tropics and Hydration by ice Crystals Geysers

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Twenty-five years ago the suggestion was made by Danielsen of direct fast convective penetration of tropospheric air in the stratosphere over land convective systems. Although the existence of the mechanism is accepted, it was thought to be rare and thus its contribution to Troposphere-Stratosphere Transport (TST) of chemical species and water vapor at global scale unimportant at global scale. In contrast to this assumption, observations of temperature, water vapour, ice particles, long-lived tropospheric species during HIBISCUS, TROCCINOX and SCOUT-O3 over Brazil, Australia and Africa and more recently CALIPSO aerosols observations suggest that it is a general feature of tropical land convective regions in the summer. Particularly relevant to stratospheric water vapour is the observation of geyser like ice crystals in the TTL over overshooting events which may result in the moistening of the stratosphere. Although such events successfully captured by small scale Cloud-Resolving Models may have a significant impact on stratospheric ozone chemistry and climate, they are currently totally ignored by NWPs, CTMs and CCMs. Several recent balloon and aircraft observations of overshoots and CRM simulations will be shown illustrating the mechanism, as well as observations from a variety of satellites suggesting a significant impact at global scale.

CONVECTION I
Session Chairs: Tammy Weckwerth, Remy Roca

Water Vapor and the Initiation of Deep Convention

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The initiation of deep convection during the summer months when large-scale forcing is weak remains a challenging forecast problem. It is well known that a forecaster's skill score declines rapidly during the time of the year when precipitation totals are the greatest. Researchers have made important progress in recent years by recognizing that storm initiation, in a convectively unstable environment, is often focused in regions where surface-based convergence boundaries develop. However, the lack of knowledge of the 4-dimensional distribution of water vapor has proven to be a limiting factor in these studies. Indeed, numerical simulations have suggested that variations as small of 1 g/kg can have a significant impact on a developing storm storm. Examples of instruments that measure water vapor in the convective boundary layer are presented. In addition, recent studies documenting the variation of moisture near convergence boundaries and its impact on the development of convection are presented.

Climatology of Deep Convection in the Tropics from a Decade of TRMM Observations

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Since the TRMM satellite was launched in December, 1997, it has been successfully acquiring observations of clouds, precipitation and lightning over the tropics and subtropics. Using this decade of observations, climatologies of seasonal, diurnal and geographical distributions of deep convection and cold clouds are derived and made available on line. Since deep convection is directly related to the moistening the tropical upper troposphere, and likely to have impact on the water vapor budget in the tropical stratosphere as well, these climatologies should be optimized for use in water vapor studies.

Geographic, seasonal, and diurnal distributions of deep convection reaching near the tropical tropopause are quite different, depending upon the metrics we use to define "deep convection". For example, using coverage by high cold clouds, the western Pacific Ocean has the highest occurrence. But using metrics related to convective intensity, the continents have the highest occurrence. In this presentation, we show seasonal and diurnal cycles of precipitation features defined by area of IR Tb < 210K, and contrast that with those defined by 20 dBZ radar echo areas above 14 and 16 km. Another interesting contrast is between the 100 largest cold cloud systems observed in the 10-year period, with the 100 most intense convective systems defined by using metrics from the precipitation radar or lightning data.

Thursday, 23 October

CONVECTION II

Session Chairs: Tammy Weckwerth, Remy Roca

Feedback Among Convection, Water Vapor, and Climate

K Emanuel (Program in Atmospheres, Oceans, and Climate, Massachusetts Institute of Technology, Rm 54-1620 MIT, 77 Mass Ave, Cambridge, MA 02139; ph. 617-253-2462; email: emanuel@texmex.mit.edu)

I will review what is known about the complex interdependencies of atmospheric convection, radiative transfer, water vapor, and climate, focusing on the role of convection in regulating atmospheric water vapor and the role of the latter in regulating convection itself. Phase transitions from disordered convection to tropical cyclones will also be discussed, emphasizing the effect of such transitions on water vapor and climate.

On the Potential of Water Stable Isotopes for the Study of Convection - Water Vapor Interactions

S. Bony, C. Risi (LMD/IPSL, CNRS, Université Pierre et Marie Curie, 4 Place Jussieu, F75252 PARIS cedex 05; France; ph. +33 1 4427 5014; fax +33 1 4427 6272; email: bony@lmd.jussieu.fr); F. Vimeux (IRD-UR Great Ice, LSCE/IPSL, CE Saclay, Orme des Merisiers, F91191 Gif-sur-Yvette cedex, France; email: vimeux@lsce.saclay.cea.fr).

Cumulus convection constitutes a key process in the control of tropical precipitation and the vertical transport of atmospheric water. However, questions remain about issues such as the relative role of convective and non-convective processes in the transport of water vapor to the upper troposphere, or the importance of rain reevaporation in the tropics.
Also, the evaluation of these processes in general circulation models has been hampered by the lack of appropriate observational tests.

Using observations together with a hierarchy of numerical models, we will discuss the potential of water stable isotopes (oxygen 18, deuterium) for studying convection - water vapor interactions. For this purpose, we will discuss the information about convective variability and processes that may be inferred from the isotopic composition of tropical water vapor and precipitation at different space and time scales, ranging from the convective scale to the climatic scale.

CLIMATE I
Session Chairs: Brian Soden, Joyce Penner

Where Hope is Coldest: Understanding Tropospheric Water Vapor With Last-Saturation Analysis

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Our understanding of tropospheric humidity dynamics has been advanced in recent years by thinking about the coldest point encountered by air parcels as they wander between the subtropics and the extratropics and back again. In particular, this framework has elucidated the importance of extratropical processes in controlling the humidity of the subtropics. The changes in large-scale temperature and circulation associated with ENSO provide a natural test-bed for exploring such links and preliminary results from an Eulerian last-saturation analysis indicate a prominent role for ENSO-related changes in the Pacific and Atlantic storm tracks in controlling subtropical humidity variability. Additionally, water vapor isotope ratios provide unique insight into the history of moist processes affecting air parcels, and data from Hawaii indicates that subtropical water isotopologues may be understood largely in terms of last-saturation analysis, providing a new probe of the atmospheric water cycle and potentially making a link between studies of modern and ancient climates.

Tropospheric Water Vapor and the Hydrological Cycle in Today's Climate

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Tropospheric water vapor is crucial in determining the response of global temperature and the hydrological cycle to a radiative forcing of the climate system through greenhouse gas increases. In climate model simulations, water vapor increases with temperature at roughly the rate expected from assuming constant relative humidity (~7%/K); this is backed up by present-day satellite observations although the response in the upper troposphere remains under scrutiny. Of more concern to climate prediction is the uncertainty in how clouds and their radiative properties change with warming and moistening. While the bulk of water in the atmosphere is of the gaseous form, the subtle links between temperature, water vapor and cloud are crucial yet these processes and their importance for climate feedbacks are difficult to illuminate using remote sensing data. Monitoring changes in components of the hydrological cycle is a further challenge for observational datasets and reanalyses. Satellite measurements appear to suggest that climate models are underestimating present day changes in precipitation; understanding how the Earth's radiative energy balance and water vapor determine changes in the hydrological cycle are of utmost importance to society.

Friday, 24 October

CLIMATE II
Session Chairs: Brian Soden and Joyce Penner

The History of the Atmospheric Hydrological Cycle in Past and Present Climates Captured by Water Isotopes

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The records of climate captured in the isotopic composition of ice cores from the polar ice sheets and temperate alpine glaciers provide unique insight into the role of the atmospheric water cycle in the climate system. The isotopic composition of these proxy archives reflects the history of balance between atmospheric water vapor transport, cloud processes and the conditions during the supply of water to the atmosphere by evaporation and evapotranspiration. Time series of the three most abundant stable isotopes in water (2H, 18O and 17O) exist and comprise an invaluable resource for understanding the variations in climate, yet there remains some uncertainty in exactly which aspects of the hydrologic cycle they measure, and thus the ability to use the isotope data to their full potential remains elusive. With comprehensive models and detailed observations from the contemporary era, the ways in water isotopes capture the linkages between the large-scale atmospheric circulation and characteristics of the water sources can be established. Armed with this knowledge, the paleoclimate record is seen to provide clues as to the function of the hydrologic cycle and its dependence on the general circulation and other aspects of the climate system.

Hydrological Cycle Feedbacks in the Eocene UltraGreenhouse: Heat Death, Hyperthermals, and Heat Transport

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Tropical temperatures are arguably the most important aspect of the climate system to characterize in early Paleogene greenhouse climates. Half of the Earth's surface is between 30° N and 30°S and tropical to subtropical sea surface temperature gradients must be weak because of large Rossby radius of deformation in the tropics. Hence tropical temperatures dominate any estimate of past global mean temperature change and sensitivity. They almost play a key role in determining the meridional temperature gradient which plays a co-dominant role (with mean temperature) in determining latent heat transports. Lastly, tropical sea surface temperatures have frequently been conjectured to be limited to near-modern values by 'thermostats' of various types--evidence for such a phenomenon has been lacking. Here we describe what is known about tropical and extratropical climates in past greenhouse climates and show the important role that changes in atmospheric water vapor, especially in the upper troposphere, play in determining climate sensitivity and in meridional temperature gradient alterations at very high pCO2 levels. Better reconstruction of paleo-tropical SSTs is found to be the crucial variable in determining how early Paleogene climate functioned.

ABSTRACTS

Poster Sessions: listed in alphabetical order by last name of First Author by day of presentation.

Monday, 20 October

The Interannual Variability of Upper Tropospheric Water Vapor and its Connection with Tropical Dynamics

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The radiative properties of upper tropospheric water vapor are very important for climate dynamics, and its behaviour is still controversial. It is also a useful variable for the monitoring and interpretation of dynamics, particularly in the tropics. Here observations from the high-resolution infrared sounder (HIRS) of the upper tropospheric water vapor brightness temperature band (Channel 12) from 1979 to 2007 are analysed to describe seasonal and interannual variability. This analysis is based on the decomposition of the data into empirical orthogonal functions. Data from the ECMWF ERA-Interim reanalysis are also used to to describe the associated atmospheric flow field. Results include the effects of the various manifestations of El Nino and other variations of the Hadley circulation on upper tropospheric water vapor over this period.

Raman Lidar Water Vapor Measurements in the Upper Troposphere Above Mauna Loa Observatory

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Measurements of upper tropospheric (UT) water vapor have been made with the Mauna Loa Observatory Raman lidar. The lidar also measures aerosol backscatter from the station altitude (3.4 km) through the stratospheric layer. The data have been used for NASA/Aura/MLS validation and as well to develop a climatology. Both MLS version 1.5 results and MLS version 2.2 results show the MLS has a dry bias compared to the lidar in the UT. The lidar has been calibration with RS80-H Vaisala radiosondes launched from the observatory. The integrated precipitable water is well correlated with the NOAA GPS measurement. Results from over 100 measurements from 2005 to 2008 indicate a drier UT during the winter and wetter during the summer and fall. There was an increasing trend in water vapor during 2006 and 2007 followed by a sharp decrease in the winter of 2007/2008. The average 1/e folding of the mixing ratio is -0.523/km between 6 and 12 km, although this may be biased towards the clearer conditions needed for lidar observations.

Accuracy Requirements for Water Vapor Measurements in the Upper Troposphere Based on 1950 – 2100 Simulations of Future Climate

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Changes in water vapor in the upper troposphere and lower stratosphere have a comparatively large impact on the radiative balance of the atmosphere. It is thus important to measure the long term change in water vapor at those altitudes with enough accuracy so that it can be used as a climate record from which trends can be derived. The question of how precise those measurements should be made cannot be answered because it is not *a priori* known by how much water vapor will change over climatic time scales. The only relevant in situ observations in the upper troposphere are provided by very

expensive reference humidity sondes, which are notorious for their lack of accuracy at low humidity. Here, we use an ensemble of runs made by a regional climate model to estimate the expected change in humidity in the atmosphere between 1950 and 2100. Model output includes daily profiles of water vapor up to 30 km altitude, and contains high resolution temporal and vertical variability in addition to long term trends. The model output is used as a proxy for a climate record of atmospheric moisture from which the requirements for accuracy of atmospheric measurement can be obtained. The two critical question are 1) If measurements could perfectly reproduce the climate record of atmospheric humidity, how long are such measurements necessary before a trend unambiguously shows up in the record, and 2) Given the inherent limitations in the measurements from the currently available instrumentation, how long do we have to do such measurements ' in reality'. Results for mid latitude European sites suggest that if such measurements were started today using currently available best practices and radiosonde equipment, it would be necessary to conduct continuous observations over a period of at least three decades.

The Role of Stratospheric Water Vapor in Global Climate Models.

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Two 20 year global, general circulation model (GCM) runs have been completed to investigate the role of interactive chemistry and in particular, stratospheric water wapor on modelled tropospheric trends and variability. The first model simulation used a full coupled chemistry-climate model (UMETRAC). The underlying GCM that is the basis of UMETRAC is the Unified Model (UM), the climate model developed by the Hadley Centre and the MetOffice (UK). The second simulation used the tropospheric/stratospheric configuration of the UM without interactive chemistry. Identical external forcings (GHG, SST, sea ice) and ozone concentrations calculated by UMETRAC run were used in the second (UM) simulation. Results from the two model simulations and from NCEP/NCAR reanalyses are compared. UMETRAC tropospheric temperature trends reproduce the trends from the reanalyses better than the GCM without interactive chemistry. Second order analysis using the fluctuation dissipation theorem between temperature and SST time series has been performed to investigate the differences in the way the two models dissipate natural perturbations.

Water Vapor Ice Supersaturation and Its Effect on Climate

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Ice supersaturation in the atmosphere is explored from analysis of observations, and compared to global climate model simulations. Observations from satellites (AIRS), aircraft (commercial aircraft in the US and Europe, as well as some research aircraft) and balloon borne sensors (frost-point hygrometers) are compared. Observations indicate frequent and coherent regions of ice supersaturation in the upper troposphere in the mid-latitudes and in the tropics. These results are compared to new global climate model simulations of (a) diagnostic and (b) process based representations of ice supersaturation. Changes to supersaturation can have large effects on ice nucleation and clouds, which in turn affect water vapor in the upper troposphere and the stratosphere. Conclusions will discuss how anthropogenic perturbations to supersaturated regions by changing background temperatures, humidity and aerosols may affect surface climate and stratospheric chemistry.

HIRDLS Observations of Water Vapor in the Upper Troposphere-Lower Stratosphere Region

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The High Resolution Dynamics Limb Sounder (HIRDLS) on NASA's Aura satellite is designed to measure water vapor, temperature, ozone, and 8 other trace gases with higher vertical resolution (~ 1km) than previously available, from the upper troposphere into the mesosphere. Here we emphasize the distributions in the upper troposphere-lower stratosphere region, where a thin layer of dry air (the hygropause) is seen a few km above the tropopause over a wide latitude range. The data show events during which there is transport of low-latitude air from the UT into the LS, and transport of LS air in the reverse direction. These transports take place in thin layers, or laminae, created during the evolution of baroclinic instabilities in the troposphere. These laminae closely match the positions of similar laminae of low or high ozone and nitric acid. These features also follow the distributions of potential temperature and potential vorticity in this region. The number of laminae is largest in late winter and early spring. Understanding the transport and mixing of water vapor in this region will be important for developing models that correctly predict the water vapor distribution around the tropopause.

Decadal Trends in Stratospheric Water Vapor and Background Sulfate Aerosol – Are They Related?

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It is well-known that stratospheric water vapor has undergone long-term changes since measurements with a balloon-borne frost-point hygrometer began at Boulder, Colorado in 1980. Since both stratospheric water vapor and background sulfate aerosol precursor gases originate in the troposphere, with stratospheric entry in the tropics, it is interesting to compare their long-term trends. The Boulder water vapor measurements indicate an increasing trend from 1980 to about 2000 with a flattening or decreasing trend thereafter. Measurements with satellite instruments with shorter records, such as HALOE and MLS, have qualitatively confirmed these changes which are larger than expected from methane oxidation and the increase in methane over this time period.

Changes in stratospheric background sulfate aerosol have also been observed. The aerosol measurements are made with Nd(YAG) lidars at Boulder and at Mauna Loa Observatory, Hawaii. Since the eruption of the volcano Pinatubo in June 1991, there have been no major eruptions capable of perturbing the stratosphere above 20 km. This has provided an unusual opportunity to study the background aerosol, free of volcanic effects. The period following the decay of the Pinatubo aerosol, from about 1996 to the present, is the longest period without a volcanic stratospheric aerosol perturbation since the sulfate layer was discovered by Junge in 1959. Both sites show a well-defined annual variation in the background aerosol with a maximum in winter associated with transport from the tropical reservoir. At Boulder, where aerosol lidar measurements began about 2000, an increasing trend of about 10% per year in the integrated stratospheric lidar backscatter has been observed in the 20-25 km layer. At Mauna Loa, where the lidar record extends back to the 1970's, an identical increase in background aerosol backscatter, beginning in about 2000, has been observed in the 20-25 km layer. These decadal trends are being compared with the water vapor trends in a search for a common cause.

Upper Tropospheric Humidity Data Set From Operational Microwave Sounders

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183.31 GHz observations from the Advanced Microwave Sounding Unit B (AMSU-B) instruments onboard the NOAA 15, 16, and 17 satellites were used to derive a new data set of Upper Tropospheric Humidity (UTH). The data set consist of monthly median and mean data on a 1.5 degree latitude-longitude grid between 60S and 60N and covers the time period of January 2000 to February 2007. The data from all three instruments are very consistent, with relative difference biases of less than 4% and relative difference standard deviations of 7%. Radiometric contributions by high ice clouds and by the Earth's surface affect the measurements in certain areas. The uncertainty due to clouds is estimated to be up to approximately 10 %RH in areas with deep convection. The uncertainty associated with contamination from surface emission can exceed 10 %RH in midlatitude winter, where the data therefore should be regarded with caution. Otherwise the surface influence appears negligible. The paper also discusses the UTH median climatology and seasonal cycle, which are found to be broadly consistent with UTH climatologies from other sensors. Finally, the paper presents an initial validation of the new data set against IR satellite data and radiosonde data. The observed biases of up to 9 %RH (wet bias relative to HIRS) were found to be broadly consistent with expectations based on earlier studies. The observed standard deviations against all other data sets were below 6 %RH.

Water Vapor in the Tropical UT/LS From Balloon Observations With FLASH-B Hygrometer

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We present a series of in-situ water vapour measurements using balloon FLASH-B Lyman-alpha hygrosonde flown during SCOUT-AMMA balloon campaign in Niger in 2006, TC4 campaign in Costa-Rica in 2007 and the most recent SCOUT sondes campaign in Niger, 2008.

Vertical profiles of water vapour obtained with FLASH-B above Western Africa in August 2006 during SCOUT-AMMA and accompanying them backscatter and ozone measurements clearly indicate signatures of cross-tropopause transport of ice particles hydrating lowermost stratosphere. Cases of supersaturation inside and outside the clouds in the upper troposphere are considered. Frequent humid layers above the cold point tropopause observed in the profiles suggest that deep overshooting convection could detrain humid tropospheric air directly into the lower stratosphere up to 450 K potential temperature level and enhance its water vapour content. This assumption is supported by evident correlation between the observed moist layers in the lower stratosphere to convective overshoots upwind detected using Meteosat Second Generation brightness temperature images and backward trajectory analysis.

Also presented here are the results of simultaneous water vapour soundings with FLASH-B and CFH hygrometers during NASA TC4 campaign held in August 2007 in Costa-Rica. The measurements reveal good agreement between the hygrometers and point out various processes in the tropopause layer and lower stratosphere. The stratospheric profiles ranging up to 30 km carry the signature of "tape recorder" signal and differ from the SCOUT-AMMA observations obtained during the same season.

Finally, we present the most recent results of a series of water vapour and backscatter soundings conducted in Western Africa in August-September 2008.

A New Method of Remotely Sensing Tropospheric and Middle Atmospheric Water Vapor: the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS)

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To address fundamental observational needs for climate monitoring and constraining processes related to water vapor, we are developing a cm and mm wavelength satellite-to-satellite occultation instrument called the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS). ATOMMS actively probes absorption lines that the Microwave Limb Sounder (MLS) probes passively and is thus essentially a cross between GPS radio occultations (RO) and MLS. ATOMMS overcomes several key limitations of GPSRO such as simultaneously profiling water and temperature. Probing via occultation offers several key advantages relative to probing via emission including vertical resolution (100-200 m vs. 2-3 km), simple and unique retrievals, very high SNR and precision to capture variability and signatures of processes, all-weather sampling eliminating clear sky-only biases and self-calibration which eliminates long term drift. Estimates of typical precisions of the ATOMMS observations of temperature, geopotential height and moisture profiles are ~0.4 K, 10 m and 1-3% respectively extending from near the surface to the mesopause (ionosphere effects at mm-wavelengths are negligible). Similar performance for ozone profiles will extend from the upper troposphere into the mesosphere. Performance in cloudy conditions will be within a factor of 2 of clear sky performance. With additional signal frequencies, other trace constituents such as water isotopes can be measured in the upper troposphere and above with similar performance.

NSF has funded the demonstration of the ATOMMS concept and performance in the 1st half of 2009 using two high altitude NASA aircraft and an instrument built at the University of Arizona. Ultimately we are working toward a microsatellite constellation that will provide full sampling of the diurnal cycle each orbit as the COSMIC GPSRO mission does. The unique coverage and performance of this system would fill many of the critical needs defined for a global climate observing system.

Aura Microwave Limb Sounder Measurements of Upper Tropospheric Cloud Ice-Water Content, Water Vapor and Relative Humidity

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The Aura Microwave Limb Sounder has been operating as a key instrument in the NASA Afternoon 'A-Train' Satellite Constellation since July 2004. New cloud products are being developed from MLS using a tomographic retrieval of cloud structure with 50 km horizontal and 2 km vertical resolution from simultaneous measurements at 240 and 640 GHz which provide information on cloud ice-water content (IWC) and bulk cloud particle size (Dmn). Complementary cloud and aerosol measurements obtained from the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat instruments combined with MLS measurements of atmospheric composition (e.g. temperature, water vapor, relative humidity, ozone, nitric acid and carbon monoxide) allow the properties of upper tropospheric clouds to be investigated for different physical environments e.g. under polluted and clean conditions and for variations in aerosol loading.

Upper Tropospheric Humidity and Cirrus Clouds: Relationships Inferred by Combined AIRS and CALIPSO Data, Evaluation of ECMWF Forecasts and Influence of Vertical Resolution on Ice Supersaturation

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Profiles of relative humidity with respect to ice (RHice) determined from spaceborne passive remote sensing suffer a lack of vertical and spatial resolutions. RHice distributions show dry biases compared to in situ observations because geometrically thin moist layers are integrated within coarser vertical resolutions, a direct effect being the underestimation of ice supersaturation (RHice>100%) occurence. Collocated data from the Atmospheric Infrared Sounder (AIRS) and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) provide an opportunity to investigate relationships between RHice and geometrical thickness and optical depth of high clouds near the tropopause. Our analysis has shown that cloud geometrical thickness has a greater influence on RHice (determined at coarse vertical resolution) than cloud optical depth. Both datasets have then been used to evaluate upper tropospheric humidity forecasts from the European Centre of Medium-Range Weather Forecasts (ECMWF). The comparison of RHice between AIRS and ECMWF distinguishes two modes: 1) a dry mode in which ECMWF predicts RHi<80% (and mainly cloud free) and in which the relative humidities show a good agreement and 2) a moist mode in which ECMWF predicts values around ice saturation and AIRS provides a range of RHi values with a peak probability around 80%. The better vertical resolution of CALIPSO is further explored to evaluate the ECMWF forecasts. The RHice from ECMWF matches well high cloud features in terms of altitude and occurence. The influence of vertical resolution on the detection of ice supersaturation is also studied with high and low-resolution ECMWF forecasts and an algorithm is proposed for a more reliable determination of ice supersaturation occurence at low resolution.

Sub-Visual Cirrus LIDAR Measurements for Satellite Masking Improvement

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Understanding the impact of cirrus cloud on modifying both the solar reflected and terrestrial emitted radiations is crucial for climate studies. Unlike most boundary layer stratus and stratocumulus clouds have a net cooling effect on the climate, high-level thin cirrus clouds have a warming effect on our climate. However, the satellites as GOES or NOAA are limited to the cloud top and its reflectivity or brightness temperature, without assessing accurately the optical depth or physical thickness. Other more recent sensors as MODIS are able to determine optical depths for aerosols and clouds, if related to cirrus, they are still inaccurate. Research programs as First ISCCP, FIRE, HOIST, ECLIPS and ARM have concentrated efforts in the research of cirrus, being based mainly on the observations of combined terrestrial remote sensing and airplanes instruments. LIDAR's are able to detect sub-visual cirrus cloud in altitudes above 15 km and estimate exactly their height, thickness and optical depth, contributing with information for satellites sensors and radiative transfer models. In order to research characteristics of SVCs, the LIDAR system at Instituto de Pesquisas Energ ́ticas e Nucleares has as objective to determine such parameters and implement a cirrus cloud mask that could be used in the satellite images processing as well as in the qualitative improvement of the radiative parameters for numerical models of climate changes. The first preliminary study shows where we compare the data Lidar with Brightness temperature
differences between the split-window data from GOES-10(DSA/INPE) and CALIPSO.

Water Vapor Transport and Dehydration Above Convective Outflow During Asian Monsoon

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We investigate the respective roles of large-scale transport and convection in determining the water vapor maximum at 100 hPa in the Asian monsoon region. The study uses backward trajectories with ECMWF ERA-Interim heating rates. It includes simple microphysics with supersaturation and takes into account convective sources based on CLAUS data with a simple parameterization of overshoots. A good agreement between reconstructed water vapor and observations is obtained over Asia. It is found that parcels belonging to the water vapor maximum have been first lifted by convection over the Bay of Bengal and the Sea of China and then transported through the tropical tropopause layer (TTL) via the monsoon anticyclonic circulation towards North-West India, where they are eventually dehydrated, avoiding the coldest temperatures of the TTL. Convective moistening accounts for about 0.3 ppmv in the Asian monsoon region and overshoots do not have a significant impact on the water vapor budget.

Diurnal Cycles of Water Vapor, Clouds and Deep Convection Near the Tropical Tropopause

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Cloud Features (CFs) are defined by vertically grouping the pixels with cloud mask and cloud radar reflectivity greater than -28 dBZ from two year (July 2006 - June 2008) of CloudSat GeoProf-2B products. The along-track distance, maximum reflectivity profile and other properties for each CF are summarized. Since CloudSat has a sun synchronous orbit and only observes at two local times, the global distribution of cloud occurrence from CFs are compared at different altitudes near 1:30 AM and 1:30 PM local time over tropical land and ocean respectively.

As another member of the A-Train, AURA shares the same sun synchronous orbit as CloudSat. Using 3 years of AURA MLS water vapor observations, it is found that there are some interesting correlations between the patterns of day vs. night differences in the geographical distributions of water vapor and that of clouds near the tropical tropopause. To interpret these differences, the diurnal cycles of deep convection and clouds derived from a decade of TRMM observations are presented.

What Is the Right Way to Compare Solar Occultation Soundings to an NWP System?

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Retrievals from satellite solar occultation soundings provide a useful source of independent data for the validation of stratospheric and upper tropospheric humidity in Numerical Weather Prediction (NWP) systems. It is conventional to treat such retrievals as though they were point values and to interpolate the gridded NWP field to the retrieval tangent point. This poster presents an improved comparison methodology that takes account of the nature of the retrieval as a weighted average over the region of the atmosphere seen by the sounder during the occultation event. Applications include validation of humidity in a reanalysis dataset and testing of a new humidity control variable in a data assimilation system.

Ten Years of Measurements of Tropical Upper-Tropospheric Water Vapor by MOZAIC: What Do We Learn From Them?

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Ten years (1994-2004) of measurements of tropical upper-tropospheric water vapor (UTWV) by the Measurement of Ozone and Water Vapor by Airbus In-Service Aircraft (MOZAIC) are investigated over three regions – the tropical Atlantic, tropical Africa, and the Asian monsoon region – to determine the UTWV climatology and variability on multiple scales, to understand them in relation to moisture transport and deep convection, and to assess the ECMWF humidity analysis. Several new insights were gained: 1) The probability density functions of tropical upper-tropospheric humidity (UTH) are almost always bimodal with the two modes staying rather constant; differences in the mean values are largely due to the variations in the proportions of the two modes as opposed to changes in the modes themselves. 2) In response to the 1997/1998 ENSO event, both temperature and specific humidity increase over the upper troposphere, but the increase in temperature outweighs that in specific humidity such that RH decreases by 5 – 15%. 3) UTH generally increases with height by 10-20% RH from 300 to 200 hPa, but this increase is largely missing in the ECMWF analysis (which has a roughly constant RH profile). This bias is attributed to the deficiency of the model representation of deep convective detrainment.

Water Vapor, Ice Phase and Thin Cirrus at the Tropical Tropopause Layer (TTL)

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The Tropical Tropopause Layer (TTL) is the boundary in the tropics (30S-30N) between the troposphere below and the stratosphere above. Water vapor is a thousand times less concentrated in the stratosphere (~5 ppmv) than in the troposphere. In the tropics, the variation of lower stratospheric water vapor concentration is due in part to vertical transport of lower tropospheric air masses meeting the TTL cold temperatures, and implies the creation of high ice clouds. The relation between cirrus clouds formation and water vapor transport is still not well understood and two competing mechanisms are considered up to now: [1] the fast injection (overshoots) of tropospheric wet air masses passing through the TTL or [2] the slow drying at large scale of these tropospheric wet air masses before their entrance in the lowermost stratosphere.

In order to study the effects on cirrus cloud formation of the tropical troposphere-to-stratosphere transport of water vapor, two instruments from the A-Train satellites constellation have been used: MLS (Microwave Limb Sounder on Aura platform) retrieves the relative humidity with respect to ice (RHice) near the tropopause with a vertical resolution of ~5 m and CALIOP (on the CALIPSO platform) is a lidar measuring cloud top altitude with great accuracy and microphysical cloud properties, even for optically thin clouds. The distributions of cirrus properties will be presented, e.g. temperature, altitude, optical and geometric thickness, depolarization and color ratio, including their seasonal variabilities. Moreover cirrus clouds properties will be correlated with RHice fields at the cloud level in an effort to characterize and better understand the interactions between cirrus and water vapor in the tropics.

A Comparison of Measurements from Ground Based Radiometers, Aura MLS, and ODIN

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Several ground-based microwave radiometers have measured middle atmospheric water vapor for extended periods since 2004. In this work we evaluate the ability and the consistency of these instruments, some of which are part of the Network for the Detection of Atmospheric Composition Change (NDACC). A unique feature of the period since 2004 is the availability of global stratospheric and mesospheric measurements of both temperature and water vapor from the Aura MLS instruments. We will make use of the global measurements of stratospheric and mesospheric temperatures of the Aura MLS instrument, along with a common a priori, in the water vapor retrievals for the ground-based radiometers. We will then perform a cross validation between the ground-based instruments from 2004 to the present using the water vapor data sets from MLS and ODIN as references and investigate the latitudinal and temporal variations of the ground-based instruments.

Effects of Anthropogenic Aerosols on Cirrus Clouds, Tropopause Temperatures, and Water Transport to the Stratosphere

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Anthropogenic aerosols may alter clouds by acting as ice nuclei (IN). An increase in cirrus cloud ice crystals, may increase cloud fraction, and, in thin cirrus near the tropopause, may act to warm the tropopause. Here, we examine the possible effects of anthropogenic aerosols on cirrus clouds. The effect of aerosols on cirrus clouds depends on the relative abundance of homogeneous and heterogeneous ice nuclei present in the upper troposphere as well as on the relative humidity distribution and updraft velocity distribution. We use the NCAR CAM3 model to examine the change in cloud fraction, tropopause temperatures and the transport of water to the stratosphere. The effects of anthropogenic aerosols depend on the mode of nucleation in the atmosphere and are highly uncertain.

Water Vapor and Clouds in the Tropical Tropopause Layer as Simulated by a Microphysical Model

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The Tropical Tropopause Layer (dubbed the TTL), roughly between 13 and 18 km altitude, is one of the coldest parts of the earth's atmosphere. In contrast to the rest of the global tropopause region, radiative heating rates are positive and mean vertical motion is upward. It is thus the pathway for constituents into the stratosphere, and the cold temperatures lead to the well-known very dry stratospheric conditions. This simple picture is made more complicated by the interaction of convective injection, horizontal advection through cold regions (and consequent dehydration), slow ascent, and constraints on the nucleation of ice crystals. All these processes have significant effects on the water vapor distribution.

The advent of detailed water and cloud measurements in the TTL provides new constraints on models and the processes that they purport to simulate. We present results from simulations using a trajectory-based full microphysical model, with observational convective injection, temperatures from analyses corrected using radiosondes, and a realistic spectrum of subgrid scale motions. A number of simulations for three different boreal winter seasons have been done, and the results show good agreement with measured water vapor values within the TTL, including most aspects of the horizontal distribution. These simulations also show that inclusion of detailed micrphysics and convective injection add about .8 ppmv to water vapor at 100mb (as opposed to simply removing water above saturation). New simulations for the boreal summer season, where convection plays a more important role, will be presented.

Related Changes in Tropical Tropopause Temperatures and Stratospheric Water Vapor Input

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In this paper, we will discuss changes in temperature near the tropical tropopause, emphasizing recent anomalous variations. These changes have important implications for the minor constituent compositions of the stratosphere, and in particular, water vapor. A drop in near tropopause temperature in the tropics, and a concomitant drop in stratosphere water vapor is noted at the end of 2000. This feature has no parallel in earlier periods; at least since regular radiosonde measurements of tropical straton in the 1950s. A possible link to variations in the sea surface temperature in the western tropical Pacific will be examined and discussed.

Convection Extratropical Mixing and In Situ Freeze Drying in the Tropical Tropopause Layer

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Mechanisms for transporting and dehydrating air across the tropical tropopause layer (TTL) are investigated with a conceptual two dimensional model. This poster is a follow-on of the Read et al. ACPD 8, 3961—4000 (2008) study now using MLS v2.2 data and extending the time series from 2.5 to 4 years. We will investigate different convective processes such as dehydrating convection with direct ice injection versus direct injection of 100% relative humidity with respect to ice air without ice. We will compare results from our convection cold trap tropical tropopause model to the improved v2.2 MLS data with its longer time series. We will also show some initial comparisons between modeled ice and measurements by Calipso. California Institute of Technology and Government sponsorship acknowledged.

Microphysical Model Details for Trajectory Studies of Water Vapor Transport Across the Tropical Tropopause Layer

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Water vapor is one of the strongest greenhouse gases and its detailed path into the stratosphere is critical to determining how water vapor concentrations can be expected to respond to a changing climate. In this paper we detail the microphysical model developed to calculate the water vapor entering the stratosphere from the tropical troposphere. Back trajectories are calculated using ECMWF winds with vertical winds calculated using the thermodynamic energy equation as detailed by Wohltmann, et al. ACP [2008]. The microphysical model is then run along the trajectories. Binary (H_2SO_4 + H_2O) and ternary (H_2SO_4 + NH_3 + H_2O) gas to particle conversion as well as ion induced nucleation are included. The role of mesoscale temperature fluctuations is determined and included. Homogeneous ice nucleation, as well as a simple heterogeneous ice nucleation scheme are included. Growth by vapor diffusion, sedimentation, and coagulation are included and the size distribution is represented by bins that are transported along each trajectory. The isotopic fractionation of the water signal that results is also calculated and preliminary results are presented.

Characterising Satellite Infrared Water Vapour Radiances Utilising Ground-based Reference Observations and Radiative Transfer Simulations

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The establishment of high quality long-time series of atmospheric water vapour for climate monitoring requires known error characteristics and temporal stability. The provision of homogeneous, inter-calibrated radiances from satellites is the primary mission of the Global Space-based Inter-Calibration System (GSICS) and is a challenging task in view of various aspects like technical improvements, calibration issues and different spatial coverage of present and upcoming satellites. We present a comprehensive approach to the evaluation of GSICS type inter-calibrated satellite radiances demonstrated on the example of the Meteosat SEVIRI and MetOp IASI water vapour channels. Ground-based observations from GCOS Reference Upper-Air Network (GRUAN) sites perform long-term measurements of the atmospheric state with high accuracy employing different instruments, e.g., lidars, microwave radiometers and research quality radiosondes. Utilising a fast radiative transfer model (RTTOV) these measurements can be operationally used to infer residual biases before and after applying the GSICS inter-calibration by comparing simulated and observed radiances. Additionally, a line-by-line radiative transfer model is utilised in an off-line mode to estimate uncertainties of the fast RTTOV model. In this way operationally provided (inter-)calibration of satellites is tested with independent observations.

Pollution Influence on Tropopause Water Vapor

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Sherwood (2002) has postulated that aerosols may be responsible for stratospheric water vapor trends through their impact on ice cloud number concentration and ice particle size and subsequently tropopause moisture. Climate model simulations also show that aerosols can act as ice nuclei and thus impact tropopause temperature and humidity (Liu et al. 2007). Recent observations from NASA's A-train satellites provide an excellent opportunity to investigate the role of aerosols in water vapor transport from the troposphere to the stratosphere. We use water vapor, cloud ice and carbon monoxide measurements from Aura MLS, aerosol and clouds from Aqua MODIS, AIRS and CALIPSO, along with other related satellite measurements to examine the influence of pollution on tropopause water vapor. In particular, we use carbon monoxide observed by MLS as an index for aerosol pollution and compare tropical tropopause layer water vapor differences between “polluted” and “clean” regions, where ice clouds also exist. Our results suggest that there is a microphysical connection between pollution and tropopause water vapor, although dynamics also come into play, complicating their relationships.

A Review of Balloon Borne Observations of Supersaturation in the Tropical Tropopause Transition Layer

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Water vapor and ozone in the tropical upper troposphere and lower stratosphere play an important role in climate; however, their distribution and correlation in this region have not been well characterized. Several hundred of profiles of water vapor and ozone have been measured by balloon borne soundings during a number of tropical campaigns over the last years using the Cryogenic Frostpoint Hygrometer (CFH) and the Electrochemical Concentration Cell (ECC) ozone sonde. These soundings provide a distribution of water vapor, relative humidity over ice, and ozone in the tropical tropopause transition layer (TTL).

The observations at Costa Rica cover 3 years of nearly continuous measurements and are the only tropical data set of high resolution profiles of TTL water vapor and ozone covering all seasons. Observations in Indonesia and Tarawa were taken only during the Northern winter season and show some of the largest supersaturations at the coldest temperatures found in the TTL.

Observations of cirrus clouds were obtained by lidar at some sites and by balloon borne backscatter sonde for two soundings. Despite strong differences in the seasonal and geographical variation of water vapor and ozone in the tropical TTL, the distribution of relative humidity shows only a weak dependency on the geographical and seasonal variation. The observations are discussed in the context of the accuracy of CFH water vapor measurements and temperature measurements.

Upper Tropospheric and Lower Stratospheric Measurements of Water Vapor using Raman Lidar and Radiosondes

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Upper tropospheric and lower stratospheric water vapor concentrations are important for reasons of atmospheric radiation and composition but the measurement challenge of quantifying concentrations at these altitudes is significant. We review recent measurements of upper tropspheric and lower stratospheric water vapor involving the NASA/GSFC ALVICE Raman lidar, Vaisala RS-92 radiosondes and Cryogenic Frostpoint Hygrometer. The measurements were acquired both at the Howard University Beltsville Campus in Beltsville, MD and the Table Mountain Facility of the Jet Propulsion Laboratories, Wrightwood, CA during 2007 and 2008. Recent advances in Raman lidar technology permit retrievals of water vapor well into the lower stratosphere under clear, nighttime conditions. We show comparisons of these measurements with Crygenic Frostpoint

Hygrometer. We also show the current status of an empirical correction to Vaisala RS-92 radiosonde that permits useful measurements in the upper troposphere and lower stratosphere.

The Impact of Aviation on Climate: Water Vapour Emissions From Aircraft

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Water vapour emissions from subsonic aircraft can cause a radiative forcing of several mWm-2. Despite being treated as negligible in many studies, this forcing is comparable to recent estimates of radiative forcing due to line-shaped contrails. As water vapour emissions are longer lived than contrails, especially in the stratosphere, they are a potentially potent source of radiative forcing.

The lifetime of stratospheric water vapour emissions is dependent on their height above the tropopause. As the height of the tropopause can vary dramatically with individual weather systems, the lifetime of emissions is difficult to define. This height dependence also makes the radiative impact of water vapour emissions sensitive to flight path.

The aim of this project is to quantify the dependence of the climate impact of water vapour emissions from aircraft on the variability of the atmospheric circulation, and also the dependence of this impact on flight path. Attention will be given to atmospheric variability associated with individual weather systems, and also variability associated with the North Atlantic Oscillation. The project will focus on the North Atlantic region.

Preliminary results, using the ERA-40 reanalysis and AERO2K emissions inventory, have shown that more than 90% of water vapour emissions in the North Atlantic region directly enter the stratosphere under certain meteorological conditions. There is a strong annual cycle in the percentage of emissions entering the stratosphere in this region, with a maximum in February or March. It has been shown that the percentage of emissions directly entering the stratosphere has an annual average in excess of 60%; this is significantly higher than previous estimates.

Interpretation of HALOE and ACE Water Vapor and Methane data in the Equatorial Upper Stratosphere

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Water vapor and methane data measured by the Halogen Occultation Experiment (HALOE) and the Atmospheric Chemistry Experiment are used to study time series of H2O+2*CH4 in the equatorial upper stratosphere. Recent studies [e.g. Nassar et. al., 2005] have shown that, generally, H2O+2*CH4 is a conserved quantity. However, multi-year time series of H2O+2*CH4 show unexpected time variations which occur even during periods of relative long-term stability in water vapor and methane entering the stratosphere. These variations are evident in both the HALOE and ACE time series, are QBO and seasonal in nature, and peak near 2 mb with a magnitude of 2-3 % of the H2O+2*CH4 mixing ratio. The H2O +2*CH4 time variations are anti-correlated with the CH4 variations suggesting a connection to local transport. We address the potential causes of the variations in H2O+2*CH4 and rule out several possibilities such as QBO and seasonal (e.g. H2O tape recorder) variations from the lower stratosphere and variations in H2O from photodissociation. By using a common analysis approach to study water vapor and methane variations [e.g. Hansen and Robinson, 1989; Remsberg et. al., 1996], we calculate beta, also called the net chemical yield factor of water vapor from methane. Modeling studies of water vapor chemistry in the stratosphere [LeTexier et. al., 1988] found beta values >2 in the upper stratosphere and suggested that oxidation of molecular hydrogen must also be considered in the water vapor budget to explain these values. Using several approaches, we find beta values consistently >2 over the entire equatorial upper stratosphere using both HALOE and ACE data. We then use this value of beta to calculate a time series which should better reflect the tropopause entry levels of water vapor and methane, and discuss the implications of this for the early 1990s increase in water vapor.

Tuesday, 21 October

Water-Vapor-Convection Feedback and the Diurnal Cycle in an Idealized Cloud-Resolving Model Study

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The diurnal cycle of rainfall provides an interesting test of our understanding of how free tropospheric moisture modulates deep convection. In the case of the diurnal cycle, as well as many tropical convective phenomenon, understanding how moisture and convection interact is difficult because moisture anomalies are both cause and consequence of deep convection. Observations show that statistically, the diurnal rainfall maximum over land occurs 4-5 hours after local noon. In contrast, in large-scale numerical models, deep convection often erupts earlier in the day. It has been speculated this is due the incorrect representation of moisture-convection relationships in numerical models.

In this study, I examine the results of simple experiments using a cloud resolving model, the System for Atmospheric Modeling (SAM), which are designed to study the diurnal cycle of deep convection over a tropical island in a highly idealized setting. The case studies provide a setting in which some degree of causality in the relationship between free tropospheric moisture anomalies and precipitation can be inferred. Results show that including interactions with the ``large-scale dynamics" that are often externally specified in cloud resolving model studies is crucial to reproducing the correct timing of the diurnal precipitation maximum. I discuss the reason for this result and the implications for how moisture can modulate deep convection.

The Impact of Water Vapor Observations in Global Data Assimilation

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Global water vapor observations are assimilated from both conventional and radiance observations. The intended effect of the assimilation is to provide a better initial condition for the subsequent numerical prediction. The magnitude of the change due to assimilation of water vapor is often large, and affects the mass balance of the system. This can lead to strong feedback in other terms of the water cycle when using analyses in climate studies. The latest version of the GEOS5 data assimilation system is intended to perform a retrospective

analysis of the satellite era (1979-present). Here, we test the sensitivity of the system to the assimilation of water vapor observations. A one year experiment without water vapor observations is compared against a control including the water vapor. We focus the discussion on the impact on total column water, water vapor profile, precipitation, evaporation, clouds and radiation in comparison with retrieved observations, as well as the impact on the analyzed Hadley circulation. Withholding the water vapor increments allows the water budget to balance in the system. The mean water vapor increments were not large to begin with, so effect on global precipitation is generally small, with a decrease of tropical precipitation when removing the water analysis. The feedback of the water analysis also extends to the Hadley circulation.

Long Term Measurements of Free Tropospheric Humidity From Space: Where Do We Stand?

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The free troposphere is usually considered as one of the most sensitive region for the effect of the water vapour on the climate. Monitoring and documenting the distribution of humidity there hence became of importance to constrain and test our current understanding of the water vapour feedback. This key variable is very well observed by the fleet of operational meteorological satellite since the last part of the 70's thanks to a suite of infrared radiometers observing in the 6.3 µm strong water vapour absorption band. Discussing the difficulty to extract from these meteorological satellites a useful climate series and reviewing the available dataset with their strength and weaknesses is the aim of the present contribution.

A quick overview of the existing database and associated products will be proposed together with the relevant intercalibration and/or homogenization techniques information. Then the precise case of METEOSAT will be presented in the details. The methodology used for linking one spacecraft radiometer to another over the period 1983:2005 will be presented together with some comparisons with radiosondes data over the whole period. Then on-going analysis dedicated to the adjustement of the meteosat first generation up to 2005 with the most recent meteosat second generation data will be discussed with emphasis on the calibration issues and the envisioned reprocessing technique.

Since the mid-90's, a series of observations is also available from passive microwave captors sensing in the 183GHz water vapour band nicely completes the IR based archive. A quick review and perspective on these more recent instruments and derived products will also be given.

Using Measurements of the Isotopic Composition of Water Vapor to Model Regional Moisture Exchange

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There is a need for further understanding of the seasonal variations in the sources of atmospheric moisture, including the contributions from evapotranspiration and re-evaporation of falling rain. Stable water isotope measurements from the Tropospheric Emission Spectrometer (TES) are useful in this regard since isotopic fractionations occurring during evaporation and condensation give rise to measurable variations in the isotopic composition of water vapor, which can be used to estimate the strength of regional hydrologic processes. The present study uses TES isotopic values and one to three day back trajectories to constrain a Lagrangian isotopic exchange model that estimates the regional supply of water vapor from evapotranspiration, the loss of moisture via precipitation, and the rainfall evaporation fraction for the 500-825 hPa layer. Given the advection pathways found from NCEP/NCAR Reanalysis wind fields, the isotopes allow the balance of these moisture exchange processes to be found. The zonal mean values of the supply of moisture via evaporation minus the losses of moisture through precipitation (E-P) in the isotopic exchange model are in reasonable spatial agreement with the surface-based values of E-P from the NCEP/NCAR Reanalysis. However, the isotopic model finds more vigorous moisture exchange occurring over land surfaces in monsoonal regions and over the tropics in general. Additionally, the rainfall evaporation fraction is found to be an important parameter for constraining the model's isotopic budget over tropical regions. The timescale for refreshment of the moisture in the parcels via surface evaporation is found to vary from 4 days over land surfaces in the tropics to 10 days over oceanic surfaces in the wintertime mid-latitude regions. The minimum timescale for the complete loss of initial moisture in the parcels via precipitation is 2.5 days, which occurs over land surfaces during the monsoonal season. Using the isotopic measurements from TES, this study provides unique diagnostics of mechanisms that control the seasonal distribution of water vapor.

AIRS Temperature and Water Vapor Climatologies Based on CloudSat Cloud Classes

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Two of the standard data sets from the NASA A-Train satellite constellation are CloudSat cloud classes and Atmospheric Infrared Sounder (AIRS) moist thermodynamic observations. We describe AIRS temperature and water vapor climatologies conditional on CloudSat cloud classes. Because different cloud classes represent fundamentally different physical processes, each scene type has a unique temperature and water vapor signature. We focus on the transition from the subtropical to tropical eastern Pacific Ocean, where the AIRS performance is well understood and several cloud classes from stratocumulus to deep convection are prevalent.

Suggestion for the Precipitation Index Using the Precipitable Water and Variation of GPS Data

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Recently, Ground based GPS has been considered as a strong tool deriving the precipitable water which indicates integration of column of water vapor. One of the characteristics of precipitable water is rapid increase before the precipitation. Therefore, the slope of precipitable water can be related with precipitation. In 2006, de Haan Suggested P(t) which is obtained from power of GPS data variation. In detail, he thought that GPS signals are affected by convective motion, when atmosphere is convectively unstable. Therefore, if convectively available potential energy increase, variation of GPS signals are also increased, then power of variation of GPS data is also large. Then using time window, power of variation of GPS data is integrated this is P(t). In this study, using the slope of precipitation and P(t), precipitation index is obtained. This value is not always highly correlated with real precipitation. However, similar pattern is showed. If more accuracy is guaranteed, this value is used as a index of precipitation. And If this data assimilated, positive effect is expected.

A Global Climatology of Temperature and Water Vapor Variance Scaling From the Atmospheric Infrared Sounder

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We present results of variance length scaling within the troposphere in three-dimensional space and time using derived temperature and water vapor profiles from the Atmospheric Infrared Sounder (AIRS). We show that temperature has a power law exponent closer to -3 in Mid-latitudes at length scales > 500 km or so, but closer to -5/3 at scales < 500 km, as has been observed by various aircraft campaigns and simulated in numerical modeling studies (e.g., Charney 1971; Nastrom and Gage 1985). A larger negative exponent in the power law implies dominance by larger spatial scales. The temperature exponent in the Tropics at all length scales becomes less negative and is larger than -5/3, and a similar pattern emerges near the boundary layer in some regions. For water vapor, the scaling relationships vary differently from temperature with -5/3 observed in the Mid-latitudes, and exceeding -2 in parts of the Tropics and Subtropics, with little to no scale break observed. Some differences between land and ocean, pressure levels, as well as cloud and clear sky pixels are observed. We also show seasonal variations of temperature and water vapor scaling, with a stronger seasonal cycle in the power law exponent observed over land than ocean, especially for temperature. Implications for climate model cloud parameterizations will be briefly highlighted.

Relationship Between Low Stratiform Cloud Amount and Lower-Tropospheric Stability Over the Ocean in Terms of Cloud Types

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Surface cloud observations in several marine subtropical regions show that the low stratiform cloud (LSC) amount is strongly correlated with the lower-tropospheric stability (LTS), defined as the difference in potential temperature between 700-hPa level and the surface (Klein and Hartmann 1993). Recently, a new formulation called the estimated inversion strength (EIS) was proposed, as a refinement of LTS, to estimate the strength of the temperature inversion within the planetary

boundary layer (PBL) given the temperatures at 700hPa and at the surface without inversion height information (Wood and Bretherton 2006). In this study, synoptic ship cloud observations, ERA-40 temperatures and sea level pressure data are used to construct seasonal climatology for the time period 1958-1997 and to examine the relationship between LSC amount and EIS over the global ocean.

It is found that seasonal LSC amounts in 5 x 5 degree grid boxes are well correlated with EISs all over the ocean areas between 60N and 60S. A linear regression indicates that LSC amounts increase about 5% per 1K increase in EIS, which supports the previous studies about several LSC regions in the subtropics and midlatitudes. LSC consists of three low cloud types: Stratocumulus (Sc), stratus (St), and fog. Their amounts are all correlated with EIS, but sensitivity and regionality of these relationships are quite different. These differences are attributed to the vertical structure of potential temperature within the PBL, which is related to sea surface temperature (SST).

If the difference in potential temperature between 850hPa and 925hPa is greater than EIS, where SST is greater than about 18 deg C, EIS can be considered as strength of the capping inversion at around 1km. In this condition, the difference in potential temperature between 925hPa and 2m is small, which corresponds to a well-developed mixed layer. Sc is the only dominant type and its amount is in proportion to EIS. EIS generally increases as SST decreases. In regions where SST is colder than the former case, the difference in potential temperature between 850hPa and 925hPa is less than EIS, and capping inversion does not exist. Maxima in Sc, St, and fog amounts occur progressively as EIS increases. This cloud type transition corresponds to the change of the vertical temperature structure within the PBL; a well-developed mixed layer becomes gradually stratified, and finally a surface-based inversion occurs, though SST does not fully correspond to this transition. The amount of fog is related to rather the sea-air temperature difference than SST itself.

Relative, Specific Humidity and Temperature in the Outflow of Deep Convection: Relation to Sea Surface Temperature

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Relative humidity and temperature was measured from passenger aircraft in the outflow of deep convection at 238 and 262 hPa over the central Atlantic ocean between 1994 and 2001. Observations within 100 km to the cores of convection are analyzed with regard to the underlying ocean suface temperature. Specific humidity (q) increases with SST by 65 ppmv/K at 238 hPa and 79 ppmv/K at 262 hPa. Relative humidity (RHi) increases by 9.9 %/K at 238 hPa and 5.7%/K at 262 hPa. The mean RHi over ice increases to > 100% with SST > 301 K.

A New El Niño Atmospheric Perspective via GPS Radio Occultation

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Because water vapor is so fundamental to the thermodynamic and dynamical coupling of the tropical ocean and atmosphere, water vapor observations are critical to understanding and predicting modes of variability such as the El-Nino-Southern Oscillation (ENSO) that dominates atmosphere-ocean climate system variations at low latitudes. We present initial results of a study on ENSO focusing on free tropospheric water vapor derived from Global Positioning System Radio Occultation (GPSRO) observations made by the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC). The COSMIC dataset, which spans mid-2006 to the present, provides far denser coverage than previous GPSRO datasets, enabling this study. While far too short for a climatology, the tropical system has experienced both warm (fall 2006- spring 2007) and cold (fall 2007-spring 2008) ENSO phases over this short interval. The contrast between the two phases has allowed us to extract spatio-temporal patterns associated with ENSO. To expose links between water vapor and other key ENSO variables such as SST, clouds and OLR and search in particular for those that may improve predictive skill, we have created a new vertically-resolved, gridded water vapor dataset via a cluster analysis. We will summarize our approach and some of key spatio-temporal patterns and correlation that we have found in this study.

Stable Isotopes of Water Vapor and Climate Change

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Water vapor samples collected during tropical field experiments at Puerto Escondido, Mexico, near Kwajalein (KWAJEX), and near Key West, FL (CAMEX 4) were analyzed for their stable isotope contents, O18/O16 and D/H. Highest delta 18-O values approached isotopic equilibrium with seawater during quiescent weather or in regions of isolated or disorganized convection. Lowest delta 18-O values occurred in or downwind from regions of organized mesoscale weather disturbances (MCS) and ranged as low as 15‰ below isotopic equilibrium with seawater. The mean delta 18-O value of vapor over the sea surface therefore decreases as storm activity and organization increases.

Mesoscale Convective Systems (MCS) "make a significant contribution to tropical rainfall despite the fact that they account for only about 10%-20% of their precipitating systems" (Zolman et al, 2000 from Mohr et al, 1999). These systems charge the lower to mid levels of the low latitude troposphere with moisture and thereby have a significant impact on the isotopic composition of water vapor. Isotopic measurements of rain and water vapor in hurricanes collected from NOAA research aircraft within the 850 to 700 mb range exhibit significant lower isotope values than a simple Rayleigh model would produce (Lawrence et al, 2002, Gedzelman et al, 2003). Measurements of D/H ratios of water vapor made between 550 and 850 mb in the tropics by the Tropical Emission Spectrometer (TES) aboard the AURA spacecraft show "that moist tropical points are more depleted than dry tropical points" (Worden et al (2007) demonstrating that this depletion is a tropical global phenomenon.

Isotopic analyses of ice cores from both low latitude glaciers and the polar ice caps have been used to reconstruct past climates. Rayleigh distillation models are commonly utilized to make climatic interpretations. One of the basic assumptions of these models is that the isotopic composition of water vapor at the oceans surface is in near isotopic equilibrium with the sea surface. Lawrence and Gedzelman (2003) and Lawrence et al (2004) have shown that in areas of organized mesoscale weather disturbances in the low latitudes isotope values of water vapor are markedly lower than those assumed in the above models. Thus, the interpretation of isotopic analyses of low latitude ice cores and perhaps even southern Greenland ice cores must take this into account.

Over the last few decades an increasing number of meteorological studies including field programs and satellite data have contributed significantly to the understanding of tropical precipitating systems (Zipser, 2003). The most abundant greenhouse gas in the atmosphere is water vapor. Kummerow et al (1998) pointed noted "The atmosphere gets 3/4 of its heat energy from the release of latent heat by precipitation, and an estimated 2/3 of this precipitation falls in the tropics". These facts show that the study of the isotopic composition of water vapor both from satellite platforms and at the Earth's surface represents an important component in our evaluation of "global warming". The potential for success will best be accomplished by joint studies that incorporate both meteorological and isotopic data.

Tracking of Aerosol and Chemical Pollutants From Asia to the United States Across the Pacific Ocean: A Validation of an in Depth Case Study Using Data From the April-May 2006 INTEX-B Experiment

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Asian dust events occur frequently during the northern hemisphere spring season on average. Some of these events can transport dust downwind to North America within 7 days' time and turn a regional impact into one of a much larger scale. To further quantify the transpacific transport and evolution of Asian dust to North America and assess the impact on regional climate, NASA led a field experiment called the Intercontinental Chemical Transport Experiment – Phase B (INTEX-B) during April-May 2006 over the eastern Pacific Ocean. This poster documents a case study of how chemical species are transported across the Pacific along with Asian dust. Chemical tracking is being added to a former study already completed on dust transport in order to validate whether both Asian dust and pollution from the source region follow one another across the Pacific to North America. Chemical species such as calcium, sulfate, and ammonium are being evaluated. These act as tracers of anthrop ogenic as well as natural pollution sources. A total of 10 dust events have been identified and summarized.

Madden-Julian Oscillation Convection-Wind Coupling in the MM5 Model and the Role of Moisture

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The Madden-Julian Oscillation (MJO) is the dominant component of intraseasonal variability in the Tropics. Since the 1980s, the MJO has received a great deal of attention in part because of its impact on weather systems around the globe. A lot of work has been devoted in the accurate simulating and forecasting of the MJO, which has become the holy grail of tropical atmospheric dynamics and has not ceased to be a challenge for the modeling community. Various studies have focused on comparing or evaluating models, whether global climate, regional and multiscale models, as well as analyzing the effectiveness of their parameterizations and schemes. For example, the MM5 v.3 regional model was shown to capture the dominant features of the MJO, such as the observed location of convection, its eastward propagation and the strong first baroclinic structure of the MJO.

However, in this previous study, the statistical techniques used to analyze the model results did not follow any systematic and standardized diagnostics, developed in subsequent years. Besides, the width of the domain allowed only waves up to a size of global wavenumber 3 to develop without crossing the boundaries, while the observed MJO is dominated by wavenumbers 1-3. At last, a single dataset, the NCEP/NCAR reanalysis, was used to force the initial and boundary conditions of the model. Since uncertainties in the accuracy of the input data could impact on the simulated MJO, the use of another dataset could yield interesting results. For these reasons, in this study, the MM5 model was ran with the ECMWF ERA-40 reanalysis dataset for a time period of 26 months, over the tropics (25S-25N) and half the globe in longitude (10E- 200E). The aim of this study is to use a standardized statistical procedure to assess the realism of the simulated MJO, in particular the MJO convection-wind coupling.

Results show that upper- and lower-level zonal winds are very well reproduced, as they display the correct MJO spatial and vertical structure, phase speed and space-time power spectrum. In addition, the proper eastward propagation and phase speed in also present in the specific humidity over the Indian Ocean, breaking down when it reaches the Maritime Continent. On the other hand, the model output exhibits a weak propagation in the OLR, decoupled from the circulation, and a lack of organization in the precipitation. Overall, this study shows that the MM5 model is able to effectively reproduce the MJO circulation without the associated convection. Therefore this would indicate that an MJO signal over the Indian Ocean in the moisture and wind fields is sufficient to produce the correct MJO circulation over the whole domain.

The Role of Water Vapor in the Energetics of the Madden-Julian Oscillation

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Water vapor plays several key roles in the four-dimensional structure and evolution of the MJO. Using a variety of data sources to provide an integrated view of clouds, water vapor, moist static energy, and atmospheric dynamics, we examine the structure of the eastward-propagating tropical Madden-Julian Oscillation (MJO). Passage of convective anomalies associated with the MJO have clear signatures in water vapor, surface and lower tropospheric winds, cloud top temperature, cloud fraction, and more. Aspects of the three-dimensional structure confirm the notion of low-level "preconditioning" through a buildup of moist static energy to the east of the MJO convection, perhaps related to anomalies in cloudiness, evaporation, and low-level winds.

Atmospheric Water Vapor Content Inferred From GPS Data and Compared to a Global NWP Model and a Regional Climate Model

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Radio based space geodetic methods, such as the Global Positioning System (GPS), are affected by the water vapor in the atmosphere. The velocity of radio signals in the atmosphere is lower than that in vacuum since the refractive index is larger than one. Since the refractive index depends on the humidity, it is possible to infer the atmospheric water vapor content, sometimes also called Integrated Water Vapor (IWV), from the estimations of these propagation delays (or the excess propagation path often expressed in units of length). The observations are relative measurements of time, which makes the method interesting from a calibration point of view - since time is the physical parameter that we can measure with the highest accuracy over long time scales.

Water vapor is difficult, and costly, to measure with a high temporal and spatial resolution due its large variability. Hence, researchers in the atmospheric sciences have shown interest in using data from already existing ground-based continuously operating GPS receivers. Time series of the IWV from specific sites are now longer than ten years. For example, 20 sites in the Swedish GPS network have produced continuous data since 1993/1994. Additional global navigational satellite systems (GNSS), such as the European Galileo and the finalization of the Russian GLONASS, will in the future significantly improve the spatial sampling of the atmosphere, and also reduce the relative influence of orbit errors for individual satellites.

We have analyzed ground-based GPS data acquired in Europe and Africa over the period 2001-2006. IWV results from the GPS data analysis are compared to the global Numerical Weather Prediction (NWP) model from the European Center for Medium Range Weather Forecasting (ECMWF) as well as the regional climate model of the Rossby Center.

The overall goal for the possible use of GNSS data in climate research is to determine to which extent these independent data can be used to discriminate between different climate models - both in terms of absolute values as well as long term trends - thereby improving the quality of the models and increasing the probability to produce realistic scenarios of the future climate.

Calculating Eddy Diffusivity of Water Vapor in the Atmospheric Surface Layer: From the CASES-99 Experiment

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For the past few decades, the eddy diffusivity of moisture is assumed to be equal to the eddy conductivity of heat. However, some studies reported a dissimilarity of eddy diffusivities between humidity and temperature, and this discrepancy may be associated with different features in the horizontal advection and/or the dissimilarity of source and sink. So, the turbulent transport of moisture may be different from that of heat. This motivated the present study. Here, the eddy diffusivity of the moisture in the atmospheric surface layer is obtained from the Cooperative Atmosphere-Surface Exchange Study–99 (CASES-99) field experiment. It is newly found that the obtained eddy diffusivity of moisture is smaller than 2/3 of the eddy conductivity in the unstable atmosphere. By contrast, in the stable atmosphere, the eddy diffusivity of moisture is comparable to the eddy conductivity. These results indicate that the magnitudes of eddy diffusivities of moisture and heat are different each other and the discrepancy mainly depends on the atmospheric stability. As a result, it is proposed that the calculation of the surface fluxes (e.g., energy balance Bowen ratio method) may overestimate the evaporation in the unstable atmosphere. Further re-evaluation of evaporation schemes using bulk exchange coefficients or resistances may be examined as a separate study.

Observational Study of the Relation Between Sea Surface Temperature and Water Vapour in Atlantic Region

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Water vapor is a major factor in climate change, and its response to global warming provides an important positive climate feedback. It has been commonly observed that zonally averaged relative humidity with respect to water, when averaged over a few months, does not change much during seasonal transitions. However, on shorter time and spatial scales, there is significant variability of relative humidity. For instance, cloud simulations have shown that in meso-scale regions of deep convection, environmental humidity is higher than elsewhere. In particular, much meridional transport of vapor is done by tropical storms in the atmosphere at low latitudes. Consequently, it would be expected that the longterm variability of column averaged water vapor, SST and tropical cyclone frequency are statistically related. Here the longterm trends in such quantities are presented. Possible hypotheses for how tropical cyclones modify local distributions of vapor and SST are discussed.

Changes in the Atmospheric Energy Budget With Global Warming: Role of Water Vapor

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Water vapor strongly impacts the energy budget of Earth's atmosphere. Its concentration and vertical distribution help shape the profiles of radiative and latent heating, with the latter being closely related to the vertical distribution of cloud cover. The current work analyzes changes in the atmospheric energy budget that occur in association with global mean surface warming using a series of observational datasets. Changes in radiative heating and cooling are examined using monthly radiative heating profiles from CloudSat and ISCCP. The contribution of water vapor changes to the radiative heating changes is assessed and compared with other (e.g., temperature) effects using a stand-alone radiative transfer code. Additionally, TRMM data are employed to investigate variations in atmospheric latent heating occurring with global warming, with the goal of better understanding cloud feedback.

Water Vapor Feedback and Links to Mechanisms of Recent Tropical Climate Variations

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Recent variations of tropical climate on interannual to near-decadal scales have provided a useful target for studying feedback processes. A strong warm / cold ENSO couplet (e.g. 1997-2000) along with several subsequent weaker events are prominent interannual signals that are part of an apparent longer term strengthening of the Walker circulation during the mid to late1990's with some weakening thereafter. Decadal scale changes in tropical SST structure during the 1990s are accompanied by focusing of precipitation over the Indo-Pacific warm pool and an increase in tropical ocean evaporation of order 1.0 % / decade. Here we use a number of diverse satellite measurements to explore connections between upper-tropospheric humidity (UTH) variations on these time scales and changes in other water and energy fluxes. Precipitation (GPCP, TRMM), turbulent fluxes (OAFlux), and radiative fluxes (ERBE / CERES, SRB) are use to analyze vertically-integrated divergence of moist static energy, divMSE, and its dry and moist components. Strong signatures of MSE flux transport linking ascending and descending regions of tropical circulations are found. Relative strengths of these transports compared to radiative flux changes are interpreted as a measure of efficiency in the overall process of heat rejection during episodes of warm or cold SST forcing. In conjunction with the diagnosed energy transports we explore frequency distributions of upper-tropospheric humidity as inferred from SSM/T-2 and AMSU-B passive microwave measurements. Relating these variations to SST changes suggests positive water vapor feedback, but at a level reduced from constant relative humidity.

The Influence of Convection on the Isotopic Composition of Precipitation and Water Vapor in the Tropics

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The stable isotopic composition of precipitation and atmospheric water is a promising tool to better constrain the present and past water cycle. Numerical simulations are performed and observations collected during the AMMA campaign are analyzed to better understand what information is recorded by water stable isotopes (oxygen 18 and deuterium), and in particular how convection impacts the isotopic composition of precipitation and water vapor.

By fitting the Emanuel convection scheme with water stable isotopes and by using it in a single-column model or a general circulation model (LMDZ), we show that deep convection strongly influences the isotopic composition of the upper tropospheric water vapor, and can produce an isotopic enrichment with height that starts well below the tropopause. We show that convective processes are also responsible for the amount effect, which is the anti-correlation that has long been observed at the monthly scale between precipitation and the isotopic composition of precipitation, and that rain reevaporation and the recycling of the boundary layer air by convective fluxes are the two processes that primarily explain the amount effect. Finally, we show that in the model, the isotopic composition of the precipitation records the convective activity integrated over the few previous days, due to the residence time of the vapor in the lower atmosphere.

The isotopic analysis of precipitation samples collected in Niamey (Niger) all along the 2006 monsoon season during AMMA confirms these findings. Consistently with the amount effect, the monsoon onset is recorded as a sudden drop in the heavy isotope content of the precipitation. After the onset, the isotopic composition is related to the average convective activity over the nine previous days, and records the intra-seasonal mode of variability of convection over the Sahel.

To investigate how the different convective processes impact the isotopic composition of precipitation, we also sampled at high frequency (5 to 10 minutes) the precipitation from several squall lines propagating over Niamey. For each system, the time evolution of the isotopic composition exhibits robust features that can be related to the spatial organization of the squall lines. Using observed atmospheric profiles and radar data together with a stationary 2D isotopic model of squall line, we highlight the major impact of rain reevaporation and of isotopic exchanges between rain drops and water vapor, and discuss the potential of water stable isotopes to better constrain the water budgets of squall lines.

Influence of Large Scale Climate Variations on the Isotopic Composition of Tropical Precipitation and Water Vapor

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Water stable isotopes constitute a promising tool to reconstruct past climate variations. In the tropics, however, the interpretation of isotopic composition changes in terms of climate variations is debated. By analyzing simulations of a single-column model run in radiative-convective equilibrium and of a general circulation model (LMDZ GCM) equipped with water stable isotopes (oxygen 18 and deuterium), we investigate the impact of large-scale climate variations on the isotopic composition of the tropical precipitation, at the interannual time scale and in climate change.

Idealized 1D radiative-convective equilibrium simulations suggest that the isotopic composition of the tropical precipitation is mainly controlled by changes in convective activity and large-scale vertical motion, and that surface temperature changes have, in comparison, a much weaker influence. Idealized GCM simulations performed with prescribed sea surface temperature variations, as well as climate simulations of the last glacial maximum, show consistent results. By analyzing pluri-annual simulations, we investigate the relative contributions of regional dynamical changes and of coherent tropical temperature changes to the inter-annual variability of the isotopic composition of tropical precipitation and water vapor. The climate information recorded, in different locations of the tropics, by the isotopic composition of precipitation and water vapor is discussed.

PDFs of Tropical Tropospheric Humidity with Generalized Statistical Model

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We examine the spatial variations in the probability distribution functions (PDFs) of relative humidity (RH) in the tropical and subtropical troposphere using observations from the Atmospheric Infrared Sounder (AIRS) and the Microwave Limb Sounder (MLS) instruments together with a simple statistical model. We generalize the model of Sherwood et al (2006), in which the RH is determined by a combination of drying by uniform subsidence and random moistening events. The generalized model has two parameters: *r*, the ratio of the drying time by subsidence to the time between moistening events, and *k*, a measure of the randomness of the moistening events. The model fits the observed PDFs well, which show that the characteristics of the PDFs vary between the tropics and subtropics and with altitude. The model parameters concisely characterize variations in the PDFs and provide information on the processes controlling the RH distributions. In tropical convective regions, the model PDFs that match the observations have large *r* and small *k*, indicating rapid random remoistening, which is consistent with direct remoistening in convection. In contrast, in the non-convective regions there are small *r* and large *k*, indicating slower, less random remoistening, consistent with remoistening by slower, quasi-horizontal transport. The statistical model derived here may be useful for quantifying differences between, or temporal changes in, RH distributions from different datasets or models. This also may

give some insights to understand how changes in physical processes could alter the RH distribution.

Diurnal Cycle and Spatial Distribution of Outgoing Longwave Radiation in the (Sub)Tropics and the Dependence on Deep Convection and Humidity

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There is a controversial and ongoing discussion about the link between deep convection, water vapour transport into the upper troposphere/lower stratosphere, and the combined effect on outgoing longwave radiation (OLR) and related physical processes. We analyse the spatial distribution and the diurnal cycles of deep convection, upper troposheric humidity (UTH), and OLR over the tropics and subtropics in June 2006 and utilise SEVIRI and GERB observations, both instruments onboard Meteosat-8. Convective activity is defined by BT10.8<230 K. UTH and OLR are retrieved following EUMETSAT, 2007 and Harries et al., 2005, respectively. Diurnal cycles are determined as domain averages, on pixel basis and as function of distance to nearest convection. The analysis further separates pixels affected and unaffected by deep convection. Pronounced minima in the spatial distribution of OLR correlate with maxima of convective activity and orography. The analysis of OLR also shows distinct diurnal cycles over coastal areas and lakes, in agreement with observations related to deep convection. The domain average diurnal cycle of OLR exhibits a maximum around noon. While the maximum of the diurnal cycle stems from the contributions of land surfaces, the average level of the diurnal cycle is dominated by ocean pixels. The effect of deep convection on the domain average diurnal cycle is ~2% or ~5.3 W/m2. In the tropics maxima of UTH correlate with minima of OLR, in several regions in conjunction with orography and maxima of convective activity. UTH and OLR exhibit an exponential decrease, respectively increase, with distance from nearest deep convection. The time shift between the maximum of the diurnal cycle of convective activity and of UTH is ~4 hours and increases with increasing distance from convection. Furthermore, minima of OLR occur at later times of the day with increasing distance from deep convection, with very similar temporal sequence as it is observed for the maxima of the diurnal cycle of UTH. The release of water vapour into the upper troposhere / lower stratosphere by deep convection leads to a traceable signal in OLR that vanishes at a distance of ~700-1000 km.

Long-Term Application and Evaluation of IAPP Using Global Radiosonde and CHAMP Measurements

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The major objective of the Satellite Application Facility on Climate Montoring (CM-SAF) is the exploitation of satellite observations to derive information on key climate variables of the Earth system. The CM-SAF focuses on the atmospheric part of the Essential Climate Variables defined within the framework of the Global Climate Observing System (GCOS). Among other methods the CM-SAF operationally applies the International ATOVS Processing Package (IAPP) to retrieve humidity and temperature profiles from ATOVS observations onboard NOAA-15, -16, and -18. A kriging routine is applied to the swath based retrievals in order to determine daily and monthly averages on a global grid. Furthermore, the profiles are vertically integrated and averaged to provide column integrated water vapour as well as humidity and temperature values for 5 layers and at 6 layer boundaries. Currently the years 2004-2007 had been processed, and a reprocessing event will go back to 1998 in the near future. The evaluation of temperature and humidity Climate Data Records (CDRs) for the period 2004-2007 is carried out using global radiosonde observations that meet the quality standards of the GCOS Upper Air Network (GUAN). The evaluation is extended by utilising CHAllenging Minisatellite Payload (CHAMP) observations for the years 2004 and 2005. The evaluation considers biases, RMSE, and mean absolute deviations and separates between global and zonal values. The maximum average bias of column integrated and layer integrated water vapour between ATOVS and GUAN radiosondes is 0.5 kg/m2 and 0.8 kg/m2 (850-700 hPa), respectively. For the layer averaged temperatures we find a maximum bias of -1.1 K (300-200 hPa). The RMSE of water vapour exhibits an annual cycle with a maximum in summer months and a maximum of zonal RMSE around the equator with some variation depending on the month. The exemplary comparison of ATOVS and CHAMP data confirms above findings. When future progress in intercalibration efforts leads to improved homogenised radiances, reprocessing of ATOVS observations can be carried out easily and will lead to CDRs with at least the accuracy as presented above.

The First Long-Term Satellite-Derived Total Water Vapour Column Climatology From CM-SAF: Intercomparison Results

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The production of climate data records (CDRs) for variability and trend monitoring is one of the major objectives within the Continuous Development and Operations Phase (CDOP) of the Satellite Application Facility on Climate Monitoring (CM-SAF). In this study, the first such CDR from CM-SAF, a total water vapour column climatology, is presented and compared to various data sources to increase confidence in consistency and accurateness of such a climatology. Based on intercalibrated brightness temperatures from the SSM/I sensors on board the DMSP satellite platforms, a climatology of total water vapour column content over global ice-free oceans has been compiled within the Hamburg Ocean-Atmosphere Fluxes and Parameters from Satellite (HOAPS) framework. The climatology covers the period 1987 - 2006. A recently developed geostatistical interpolation technique using the Kriging approach has been applied to the swath-based total column water vapour retrievals from the HOAPS data set. The resulting climatology consists of daily and monthly mean fields of the column water vapour itself and an uncertainty estimate from the Kriging technique. The climatology has been compared to different types of meteorological analyses from the ECMWF (ERA40, ERA INTERIM and operational analyses) and other centers (JRA, NCEP). This comparison shows an overall good agreement of the climatology and the analyses fields. Regarding the biases to the ECMWF data sets, one finds that ERA INTERIM performs significantly better than ERA40 and the operational analyses over time. Only from 2003 on, the operational analysis reaches comparably low biases as ERA INTERIM. In order to show the robustness of the SSM/I-based climatology it has also been compared to other independent data sets (as SSM/I channels are assimilated in all ECMWF analyses used): (a) a second CM-SAF total water vapour climatology based on ATOVS from the NOAA polar orbiting satellites for one selected year and (b) time series of instantaneous column water vapour values as obtained from the integration of radiosonde profiles. The latter mentioned data sources agree reasonably well with the climatology. Existing distinctions may be traced back e.g. to the different spectral channels of the SSM/I and AMSU instruments used. Finally, as an application of the produced CDR, interannual variability patterns and trends have been calculated and compared to various recently published other trend estimates.

Enhancement of Water Vapor and Its Relation with the Observed Climatic Changes over the Indo-Gangetic Plains

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The dust events are very common over the Indo-Gangetic plains during pre-monsoon season, which are found to originate from the Arabia peninsula and sometimes crosses over the Arabian ocean and Afghanistan, Pakistan to reach over the Indo-Gangetic plains. Due to the towering Himalayan range in the north, dust subsides in the plains and also on the surface of the Himalayan range. The Himalayan snow cover and its characteristics are found to be highly variable in space and time. We have analyzed daily TOMS aerosol parameters, total ozone column and water vapor from NCEP and MODIS satellites for the period 1978-2007 and recent AIRS data during pre-monsoon season (April – June). An enhancement of total water vapor is inferred soon after the dust events which may be the reason to give rise to an enhanced water vapor in the north-western parts of India. The recent AIRS data have shown pronounced enhancement of water vapor up to 500 hPa level. The increasing water vapor is found to show warming of the tropospheric temperature. The detailed analysis of multi sensor data and effect of the enhancement of water vapor will be presented in monsoon rainfall, declining of snow surface in the Himalayan region and on total ozone column. The total ozone column is found to decline in the Indo-Gangetic plains which will be discussed in view of the enhanced water vapor during pre-monsoon season especially in view of the observed changes in tropospheric and stratospheric temperature. The long term trend of water vapor will be discussed in the observed recent climatic changes over the Indo-Gangetic plains.

Moistening Processes in the Tropical Upper Troposphere and Their Implication in Water Vapor Feedback

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In order to investigate processes of moistening the upper troposphere (UT), we examined Lagrangian evolutions of deep convection index, cloudiness, UTH tendency, and condensation/evaporation rate of the convective cloud system observed by Meteosat-8 infrared measurements over tropical Africa and the Atlantic Ocean. Condensation/evaporation rates were inferred from the imbalance between cloud expansion rate and wind divergence which were directly determined from the Meteosat-8 measurements.

It was found that wind divergence corresponds much more with UTH tendency, in comparison to the poor correlation found between evaporation rate of cloud condensates and UTH tendency. Because water vapor concentrations in the UT are nearly an order of magnitude larger than ice water concentrations, the transport of moist air associated with the formation and vertical growth of clouds and the subsequent upper-tropospheric divergence should be primarily responsible for moistening the UT. On the other hand, the role of evaporation of detrained hydrometeors from the convection center appears to be secondary, as indicated by less coherent relationship between UTH tendency and evaporation rate, and in a much smaller amount of ice water. Results strongly support the notion that the UT is predominantly moistened by water vapor advected to drier surroundings from the diverging cloud top areas, and further support that results of water vapor feedbacks in GCM simulations, in which the UTH relies much on the large-scale advection, are likely reasonable.

On the Low-level Moisture Preconditioning of the Madden-Julian Oscillation

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The Atmospheric Infrared Sounder data have revealed the low-level moisture preconditioning of the Madden-Julian Oscillation (MJO), but the cause of this preconditioning remains unknown. The present study addresses this issue by analyzing the latest satellite-based total-column moisture transport from QuikSCAT/Tropical Rainfall Measurement Mission Microwave Imager and surface evaporation from Objectively Analyzed Air?Fluxes project. Our analysis indicates that this low-level moisture preconditioning of the MJO is due primarily to the moisture convergence anomaly instead of surface evaporation anomaly associated with the MJO. Furthermore, the moisture convergence anomaly is mainly from the zonal component rather than the meridional component and should also be largely in the lower troposphere. These satellite-based results are more consistent with the frictional wave-conditional instability of the second kind theory instead of the wind-evaporation feedback theory.

Development of a High-Quality, Long-Term Dropsonde Climatology and Characterization of the Thermodynamic Profiles in Hurricanes

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The primary application of dropsonde data is use in studying and helping predict the path and intensity of hurricanes. Dropsondes are deployed from aircraft, most commonly over oceans, and they collect data at a half second rate as they descend, measuring pressure, temperature, relative humidity, and GPS winds. The objective of this research is to gather together high resolution dropsonde profiles collected over a twelve year period (1996-2007) by NOAA's Hurricane Research Division (HRD), NCAR's Earth Observing Laboratory (EOL), the United States Air Force, and NASA, and to apply consistent quality-control in order to produce a high-quality, long-term dropsonde climatology for hurricane research. Special attention will be paid to improve the dropsonde water vapor profile. The data will be used to characterize the thermodynamic structure of different regions within a hurricane. The raw data files will be uniformly processed and separated into distinct groups based on drop location relative to the eye of the hurricane. The categories will include: dropsondes deployed within the eyewall, those made in the rain bands surrounding the eyewall, dropsondes deployed in the outer environment, and possibly others. Each group of dropsonde will then be examined and the thermodynamic characteristics will be documented in order to a present a generalization of features unique to each region.

Variability of Water Vapor Observations on Daily to Decadal Timescales from the Global NVAP Dataset

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The NASA Water Vapor Project (NVAP) dataset is examined to address variability in water vapor on a variety of time and space scales. Specific questions addressed are: What is the daily, interannual, and decadal variability of water vapor? What is the structure of its vertical distribution? Are there decadal trends in total column water vapor based on the NVAP dataset?

The NVAP record of atmospheric water vapor shows a global, annual mean of 24.5 mm with an annual cycle of about 10% of the total value. Considerable interannual variability has also been observed. During 1988-2001, atmospheric water vapor responded to both the eruption of Mount Pinatubo and El Nino events in step with the record of tropospheric temperature. A study of daily water vapor variability shows that on a percentage basis water vapor content from 300 – 700 hPa in the midlatitudes shows the largest variability. This result could be a useful comparison point for general circulation models to assess the vigor of their water vapor circulation.

Trend analysis of a 12-year record of NVAP reveals no robust statistically significant trend in global total precipitable water. There are significant regional trends, some of which are due to atmospheric processes and some of which are likely due to known time-dependent biases in NVAP. The status of the NVAP reprocessing and extension beyond 2001 will be discussed.

Climate Applications of Ground-Based GPS Measurements of Water Vapor

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Since the AGU Chapman Conference on Water Vapor in the Climate System held October 25-28, 1994 , at Jekyll Island , Georgia , there have been significant progresses made to GPS measurements of water vapor. They include increased accuracy in raw GPS measurements, significant improvements in techniques to map zenith wet delays onto precipitable water, the dramatic growth of global and regional GPS networks, the increasing of the GPS data period (longer than 10 years) and the broader applications of GPS water vapor data. We have produced a global, 2-hourly atmospheric precipitable water (PW) dataset from ground-based GPS measurements of zenith tropospheric delay (ZTD) using the International GNSS (Global Navigation Satellite Systems) Service (IGS) tropospheric products (~80-370 stations, 1997-2007), U.S. SuomiNet product (169 stations, 2003-2006) and Japanese GEONET data (1223 stations, 1997-2007). This study takes advantage of availability under all weather conditions, high accuracy, long-term stability and high temporal resolution of the GPS-derived PW data and utilizes the 2-hourly GPS PW data for various climate applications. They consist of (1) identifying and quantifying systematic errors in the global radiosonde humidity data, (2) validating three reanalysis humidity products (the NCEP-NCAR, ECMWF 40-year and Japanese 25-year reanalyses) and (3) studying PW diurnal and long-term variations. The dataset and first two applications will be reviewed. The focus will be on studying and comparing diurnal variations of PW in U.S. and over Europe where dense GPS stations exist from the GPS data and the reanalysis products, and understanding the variations and differences by co-relating with precipitation diurnal cycle and other parameters.

Water Vapor DIAL and DOW Observations and Comparisons with Mesoscale Models in COPS

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The World Weather Research Program (WWRP) Research and Development Project (RDP) Convective and Orographically-induced Precipitation Study (COPS) occurred during the summer of 2007 in southwestern Germany and eastern France. COPS was aimed at advancing the quality of forecasts of orographically-induced convective precipitation with the use of 4-D observations and modeling of its life cycle. One of the components of improving quantitative precipitation forecasting skill is better understanding of convection initiation processes. A unique combination of pre-convective measurements was obtained during COPS with two Doppler on Wheels (DOW) mobile radars and a high-powered water vapor Differential Absorption Lidar (DIAL). The combination of these wind velocity and water vapor measurements in the pre-convective environment may enable better understanding of low-level boundaries in orographic terrain and their associated influence on the distribution of the 3-D moisture field. This is expected to be important for convection initiation applications.

The DIAL and DOW observations will be compared with an ensemble of convection-permitting models, which were available by collaboration with the WWRP Forecast Demonstration Project (FDP) D-PHASE. The comparisons will be performed either with a model forward operator simulating the DOW performance around its site or by profiling of mixing ratio over the DIAL site. Preliminary results indicate that most models suffered from a strong positive moisture bias in the boundary layer, which may have negative implications on their capability to simulate convection initiation. It will be discussed whether these comparisons can be used to investigate the parameterization of land-surface processes and the ABL in atmospheric models.

The Role of Condensate Evaporation in Setting Water Vapor, HDO, and H2O18 Amounts in a GCM

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The standard configuration of the Goddard Institute for Space Studies ModelE contains two parallel hydrologic cycles. The primary hydrologic cycle interacts with the model physics, while the other is implemented "offline" and used as a carrier for stable water isotopes. These two cycles are normally identical, but their separation allows the offline cycle to be modified without affecting model physics and dynamics. We have performed two model simulations, one in which cloud and precipitation can evaporate in the offline cycle and one in which it cannot. The resulting differences in atmospheric humidity and stable water isotope content can be directly attributed to condensate evaporation. We find that the suppression of condensate evaporation leads to specific humidity decreases of between 5% and 25% in this model. Furthermore, condensate evaporation is found to generally deplete the HDO and H2O18 content of vapor in the lower and middle troposphere, while it enriches vapor in the upper troposphere and high latitudes in the winter hemisphere. The locations that are most sensitive to the suppression of condensate evaporation are identified, and the contributions of different components of the model atmospheric hydrologic cycle are examined.

World Weather Research Program Activities in 2007 for Studying Quantitative Precipitation Forecasting in Complex Terrain

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During summer 2007, extensive research activities have been executed in connection with quantitative precipitation forecasting (QPF) in complex terrain. Three experiments were coordinated and performed: i) The Research and Development Project (RDP) Convective and Orographically-induced Precipitation Study (COPS) of the World Weather Research Program (WWRP). Its main goal is to "advance the quality of forecasts of orographically-induced convective precipitation by 4D observations and modeling of its life cycle". During COPS, which was executed in southwestern Germany/eastern France, extensive measurements were performed by enhanced ground-based networks, remote sensing synergy operated along a transect of supersites, and 9 airborne platforms. The Atmospheric Radiation Measurement (ARM) program Mobile Facility (AMF) was operated in the COPS domain from April – December 2007. Furthermore, the Rapid Scan Service (RSS) of the Meteosat Second Generation (MSG) satellite was provided by EUMETSAT. ii) The WWRP Forecast Demonstration Project (FDP) Demonstration of Probabilistic Hydrological and Atmospheric Simulations of Flood Events in the Alpine Region (D-PHASE). This project provided in the D-PHASE domain, which covered a region around the Alps, a large suite of ensembles forecasts and of deterministic forecasts using convection permitting models and models with convection parameterizations. iii) The first summertime THORPEX European Regional Campaign (ETReC07). Various types of targeting methods were studied and upstream conditions were observed by airborne measurements and/or additional AMDAR and EUCOS soundings.

For certain COPS Intensive Observation Periods (IOPs), it will be demonstrated how these research programs complement each other to identify and separate errors in QPF due to large-scale and initial conditions as well as model physics. By observations of the chain of processes leading to precipitation, different forcing mechanisms are

discussed leading to convection initiation. In all cases, the role of land-surface processes, e.g., leading to thermally induced slope flows and convergence lines, could not be neglected. Extensive comparisons with the D-PHASE model ensemble demonstrate the performance of the current generation of convection-permitting mesoscale models. This is very promising, as in the future, these models will be used both for high-resolution limited area modeling of weather and climate.

Sensitivity of Tropical Deep Convection to SST and the Large-Scale Circulation

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Deep convection is the dominant means by which water vapor is taken from the boundary layer to the free troposphere in the tropics. A number of studies have investigated the relationship between tropical deep convection and sea surface temperature (SST) and the implications of these relationships for climate and climate change. However, it is necessary to note that deep convection and SST are rather indirectly related to each other through their individual relationships with the large-scale circulation; thus the intrinsic sensitivity of convection to SST is somewhat less apparent. Many previous studies use outgoing longwave radiation as a proxy for deep convection, but the ubiquity of thin cirrus disconnected from active deep convection in the tropics makes interpretation of observed relationships difficult. In this study we use rainfall data from the TRMM Multisatellite Precipitation Analysis as direct measures of deep convective events, SST from AMSR-E, cloud fraction as a function of cloud top temperature and visible optical thickness from MODIS and CERES, and vertical velocity from NCEP/NCAR reanalysis to address a number of questions: Within a given circulation regime (as determined by the large scale vertical motion), does the number of deep convective events systematically increase with SST? Is this relationship robust for both spatial increases in SST and temporal increases in SST? How sensitive is the relationship to the underlying SST gradient? How do the properties of the ensemble of clouds and their associated radiative forcings change with SST in a given regime? Likewise, how does the large-scale circulation respond to a change in SST gradient, and how does this circulation change impact the cloud properties and their associated radiative forcings? Finally, how do these results vary between synoptic and climatologic scales? Implications of these results for tropical climate, with specific focus on the observed net radiative neutrality of the ensemble of high clouds will be discussed.

A Near-Global, 2-Hourly Data Set of Atmospheric Precipitable Water from Ground-Based GPS Measurements

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Atmospheric water vapor varies significantly in both time and space. Radio soundings as a traditional observing system are inadequate to monitor water vapor properly with only once or twice daily observations. An analysis technique is developed to estimate precipitable water (PW) on a global scale from ground-based GPS estimated zenith path delay (ZPD). A global, 2-hourly PW data set has been produced from 1997 to 2007. The ZPD data are from both global GPS network of International GNSS Service (IGS) and regional networks such as SuomiNet in North America and

GEONET (GPS Earth Observation Network) in Japan. They are converted into PW using surface pressures (Ps) adjusted from WMO surface synoptic observations and water-vapor-weighted atmospheric mean temperature (Tm) derived from Japanese 25-year Reanalysis. Theoretical error analysis concludes that total PW error associated with errors in ZPD (4 mm), Tm (1.3K) and Ps (1.65hPa) is less than 1.5mm. The GPS PW data are validated by comparing with radiosonde, microwave radiometer and satellite data and show no systematic errors. The GPS PW data set provides a new source of atmospheric water vapor data. Because of its high accuracy, high-temporal-resolution and long-term stability, the data set is useful for various scientific applications.

Simulation of Radiation Fog: Numerical Model and Sensitivity Analysis

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Fog begins to form when water vapor condenses into tiny liquid water droplets in the air. And radiation fog appears in the surface boundary layer, and its evolution is driven by the interactions between the surface and lower layers of the atmosphere.

A single-column model (SCM) designed to study the formation, growth, and dissipation of radiation fog is described. The SCM is a diagnostic model resembling a single vertical column of a three-dimensional computational fluid dynmaics (CFD) model. The one-dimensional SCM is compared with deteiled obserations made at SIRTA, located 20 km south of Paris, in the France. This study we use observations made in a shallow radiation fog that formed on the night of 18/19 February 2007. The one-dimensional SCM is forced with horizontal advection terms derived from the observations by using the Cressman method. The model seems to be able to describe the most important mechanisms occurring during the fog evolution. In this study special attention is given to the parameterization of the cloud microphysics, which is important for a good representation of the air temperature and the cloud droplet spectrum. The influence of the main parameters of the model (turbulence transport, longwave radiative cooling, and droplet deposition, etc.) on the fog evolution is described.

Thursday, 23 October

Tropospheric Water Vapor and the Hydrological Cycle in Today's Climate

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Tropospheric water vapor is crucial in determining the response of global temperature and the hydrological cycle to a radiative forcing of the climate system through greenhouse gas increases. In climate model simulations, water vapor increases with temperature at roughly the rate expected from assuming constant relative humidity (~7%/K); this is backed up by present-day satellite observations although the response in the upper troposphere remains under scrutiny. Of more concern to climate prediction is the uncertainty in how clouds and their radiative properties change with warming and moistening. While the bulk of water in the atmosphere is of the gaseous form, the subtle links between temperature, water vapor and cloud are crucial yet these processes and their importance for climate feedbacks are difficult to illuminate using remote sensing data. Monitoring changes in components of the hydrological cycle is a further challenge for observational datasets and reanalyses. Satellite measurements appear to suggest that climate models are underestimating present day changes in precipitation; understanding how the Earth's radiative energy balance and water vapor determine changes in the hydrological cycle are of utmost importance to society.

Evaluation of Links Between Clear-sky Radiation, Water Vapor and the Hydrological Cycle in Models, Reanalyses and Observations

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Satellite measurements of column water vapor (CWV) and clear-sky radiation are used in conjunction with reanalysis products and CMIP3 climate models to evaluate relationships between the Earth's radiation and water budgets. Despite discrepancies between products, relating to changes in the observing system and satellite calibration errors, a consistent increase in the longwave radiative cooling of the clear-sky atmosphere with surface warming (3-5 Wm-2K-1) is evident, partly relating to the enhanced cooling to the surface with CWV at the rate of 1-1.5 Wkg-1 and an increase in CWV with warming at around the rate expected from the Clausius Clapeyron equation. The changes in the atmospheric longwave radiative balance imply precipitation increases that are smaller than the Clausius Clapeyron rate. The relationship between precipitation, temperature and water vapor is investigated.

Constraining The Tropical Mean Atmospheric Water Vapor Feedback From Observations And Model Simulation

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We apply the Cause-and-Effect nomenclature to estimate the tropical mean atmospheric water vapor feedback and the climate system total feedback effect from observations and the AR4 model simulations. For this we use the observed and simulated monthly mean changes in radiative fluxes at the top of the atmosphere, the near-surface temperature and the total water vapor content over ocean for two nearly distinct periods: (i) the Pinatubo eruption period (1991-1993) when we can assume that the disturbance of the variables came from a modification of the net radiative fluxes at TOA by the volcanic aerosol; and (ii) two strong ENSO periods (1987-1989 and 1997-1998) when we assume that the main short term "external" disturbance to the climate system occurred via a modification of the sea-surface temperature. We show that the total feedback effect can also serve as another useful metric for model-to model and model-to-observations intercomparisons.

Retrieval of Columnar Water Vapor from Sun-Photometric Measurements

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We will present our retrievals of precipitable water vapor (PWV) column amounts from the 940 nm spectral channel of the Multi-Filter Rotating Shadowband Radiometer (MFRSR). The HITRAN 2004 spectral database was used in our analysis to model the water vapor absorption. We will discuss the influence of uncertainties in instrument calibration and spectral response, as well as those in available spectral databases, on the retrieval results. The results of our PWV retrievals from the Southern Great Plains (SGP) site operated by the DOE Atmospheric Radiation Measurement (ARM) Program were compared with correlative standard measurements by Microwave Radiometers (MWRs) and a Global Positioning System (GPS) water vapor sensor, as well as with retrievals from other solar radiometers (AERONET's CIMEL, AATS-6). Some of these data are routinely available at the SGP's Central Facility, however, we also used measurements from a wider array of instrumentation deployed at this site during the Water Vapor Intensive Observation Period (WVIOP2000) in September-October 2000. The WVIOP data show better agreement between different solar radiometers or between different microwave radiometers (both groups showing relative biases within 4%) than between these two groups of instruments, with MWRs values being consistently higher (up to 14%) than those from solar instruments (especially in the large PWV column amount range). We also demonstrate the feasibility of using MFRSR network data for creation of 2D datasets comparable with the MODIS satellite water vapor product.

Free Tropospheric Humidity From METEOSAT: Link to Large-Scale Dynamic

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Satellite remote sensing of water vapor in the 6.3µm strong water vapor absorption band, offers a unique observational estimate of the free tropospheric relative humidity (FTH). A database of clear sky radiances from the METEOSAT series, spanning July 1983 – June 2005 with a 3 hourly time step and a spatial resolution of 0.625°, has been developed and is exploited to document the variability of the water vapor content of the free troposphere. A particular effort has been done on the dry subtropical highs that play a key role in the water vapor feedback through a significant impact on the longwave cooling to space.

The region of the Eastern Mediterranean reveals strong inter-annual features such as an extreme dryness during the summer (~6%) and a higher

relative variability (~50%) than the convectively active regions of the African monsoon (~20%) that underlines it's importance in the Earth's radiative balance. The link between such inter-annual variations and large-scale dynamic is performed with a lagrangian transport model. This technique, applied onto the whole set of summers, reveals a complex scheme of mixing between air masses of tropical (<25ºN) and/or extra-tropical (>25ºN) origins that explains for a large part the variability of FTH at the inter-annual scale. Hence, the tropical air ending its trajectory over the Eastern Mediterranean high has mainly a drying influence while extra-tropical parcels generally moisten the free troposphere.

Global Changes in Atmospheric Water Vapor Content During 1976-2007: Observations Versus Models

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Atmospheric water vapor is the single largest greenhouse gas. All models predict a strong positive feedback by water vapor in response to CO_2 and other anthropogenic forcing. Validating and quantifying this water vapor feedback under global warming is thus vital for climate predictions. Efforts to quantify decadal and long-term changes in global atmospheric water vapor content have been hampered by a lack of atmospheric sounding data over the oceans and many land areas (while satellite records are still relatively short). Here we attempt to quantify atmospheric water vapor response to global temperature increases during the last three decades, and compare that to model-simulated responses. We first analyze the relationship between near-surface water vapor content and the total water vapor contents in the lower and whole troposphere at locations where atmospheric sounding data are available, and apply this relationship to derive atmospheric water vapor contents from surface observations of specific humidity from weather stations and ships and buoys around the world for areas without sounding data. These derived water vapor contents are then combined with quality-controlled sounding data to derive global estimates of changes in atmospheric water vapor contents (dPW) during 1976-2007 in relationship to observed surface warming (dT). The global and regional dPW/dT rates on decadal time scales are then compared with those from NCEP-NCAR and ERA-40 reanalyses, and many IPCC AR4 climate models during the same periods. The models' strength of water vapor feedback is compared and validated against the observed values. The results help quantify the recent changes in atmospheric water vapor content over the globe, the strength of the water vapor feedback, and any model deficiencies related to the water vapor feedback.

Radiosonde-Based Trends in Precipitable Water over the Northern Hemisphere: An Update

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In an effort to update previous analyses of long-term changes in column-integrated water vapor in the lower to middle troposphere, we have analyzed trends in surface-to-500-hPa precipitable water (PW) calculated from radiosonde measurements of dewpoint depression, temperature, and pressure at approximately 300 stations in the Northern Hemisphere for the period 1973-2006. Inhomogeneities were addressed by applying a homogenization algorithm that adjusts for both documented and undocumented changepoints. The

trends of the adjusted PW time series are predominantly upward, with a statistically significant trend of 0.37 mm decade^{-1} for the Northern Hemisphere land areas included in the analysis. particularly significant increases are found in all seasons over the islands of the western tropical Pacific whose time series are also characterized by anonymously low PW values during years influenced by the El Niño/Southern Oscillation phenomenon and volcanic eruptions. Other areas where trends are statistically significant in at least one season are Japan and the United States. These results indicate that the widespread increases in tropospheric water vapor since the early 1970s, which earlier studies had shown to be physically consistent with concurrent increases in temperature and changes in moisture transport, have continued in recent years.

Global Cooling During 2007: An Examination of the Water-Vapor Feedback

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Between January 2007 and January 2008, the Earth cooled 0.6°C, the proximate cause of which was a shift from El Niño to La Niña conditions. We analyze here the response of atmospheric water vapor to this cooling in order to examine and quantify the water-vapor climate feedback. Height-resolved measurements of water vapor are obtained from NASA's satellite-borne Atmospheric Infrared Sounder (AIRS) between 2003 and 2008. We find that relative humidity (RH) did not remain constant, but increased in some regions and decreased in others. In the global average, there is cancellation between regions of increasing and decreasing RH, so that the change in global average RH was near zero over most of the troposphere. The water-vapor feedback implied by these observations is strongly positive, with a magnitude of 1.6-1.7 W/m2/K, similar to that simulated by climate models. The magnitude is also similar to that obtained by assuming that the atmosphere maintains constant RH, even though the atmosphere did not actually maintain constant RH. We find that the water-vapor feedback arises primarily from changes in water vapor in the tropical upper troposphere, so it is the tropical surface temperature that primarily controls the global water-vapor feedback.

Using Regional Climate Models and Lagrangian Back Trajectories to Estimate the Source Areas of Water Vapor

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Where did the water vapor that rained here, come from? This is the basic question behind studies into water vapor source regions and precipitation recycling. Estimates of precipitation recycling using highly simplified bulk formulations have existed for some time. Over the last decade, attempts to estimate water vapor source regions more generally using back trajectories have appeared. Some fairly strong and often broken assumptions are required by these back trajectory methods. In this study I use the output from a regional climate model simulation to calculate back trajectories and estimate water vapor source regions. This is done multiple times, each time further relaxing the assumptions involved. The impact this has on the water vapor source regions, precipitation recycling and the limitations of the method are explored.

Linking Water Vapor Climatology to Extreme Surface Moisture Conditions in the Western United States – A Comparison of GIS-Based Methods

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This research investigates the climatology of atmospheric moisture and extreme surface moisture conditions, both drought and wet, in the western United States. Methods of investigating water vapor climatology using spatial analysis and Geographic Information Systems (GIS) tools are new and not well established. A major difficulty posed in solving such spatial problems lies in comparing data composed of different spatial units; this is termed the "Modifiable Areal Unit Problem" in spatial analysis literature. In this case, gridded atmospheric data is compared to surface polygon data. This research examines the use of two types of irregular surface polygons: climate divisions and amalgamated climate divisions. Comparison of these two illustrates the effects of generalizing the surface moisture conditions. In both cases, extreme surface conditions are identified using monthly Palmer Drought Severity Index (PDSI) data (drought PDSI < -3; wet PDSI > +3). Using GIS tools, monthly atmospheric moisture profiles are created for each of the extreme surface moisture polygons. Gridded specific humidity data from the NCEP/NCAR Reanalysis (NNR) are used to quantify atmospheric moisture. Moisture profiles are generated at 4 pressure surfaces, 850, 700, 600, and 500 hPa. Once extreme surface moisture conditions are identified and their atmospheric moisture profiles are generated in a GIS, discriminant analysis examines whether the extreme surface moisture conditions can be identified by their moisture profiles. Data are stratified for annual and seasonal analysis. The effects of generalizing the surface data are demonstrated in the comparison.

Relation Between Atmospheric Energy Transport and Hadley Cell Strength in Aquaplanet Simulations

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Water vapor transport and distribution within the atmosphere are closely linked with the characteristics of the large scale circulation. In this paper, we study the relationships between the mean meridional circulation strength and the poleward energy transport, using prescribed SST aquaplanet simulations. In the tropical region, an increase in the meridional SST gradient increases the equatorward heat and water vapor transport, compared to the poleward geopotential transport. As a consequence, in simulations with strong meridional SST gradient, the total energy transport is less efficient and the mean meridional circulation strength needs to increase. To measure the efficiency of the atmospheric energy transport, we define a parameter called the "Efficient Specific Energy" that is closely related with the SST meridional profile. The Efficient Specific Energy of the atmospheric energy transport is suggested to determine part of the interactions between large scale circulation and water vapor, in simulations of future climate.

Water Vapor Feedback During the 2003 Heat Wave in Europe

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Both climate models and observations indicate that globally the column-integrated water vapor

increases by about 7 % for every 1 K increase of temperature in agreement with the Clausius-Clapeyron (C-C) equation. Over Europe no evident positive water vapor trend was found, despite the large positive trends over the North Atlantic. The 2003 summer heat wave when the temperature in Switzerland was on average 3 K higher than the 2001-2006 mean, provided an opportunity to test the temperature/water vapor feedback. During the 2003 summer, the column-integrated water vapor increased by 7%, which is a factor of three less than the expected from C-C equation. This weak response of water vapor to temperature forcing is found to be due to the rainfall deficit in the 2003 spring. An increase in evapotranspiration in June 2003 facilitated the soil moisture depletion and further heating went into raising temperature hence the heat wave in August 2003.

Impact of Water Vapor on the Earth's Radiative Energy Budget Analyzed from Longwave Radiation Spectra

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Water vapor is a critical variable that influences the radiative energy budget of the climate system. Outgoing Longwave Radiation (OLR) spectra measured at the top-of-the-atmosphere (TOA) provides an excellent way to analyze the effect of water vapor on radiation energy budget in that the roles of water vapor at different altitudes can be inferred from their distinctly different spectral signatures and thus separated from the effects due to other geophysical variables (e.g. clouds). For the same reason, such measurements afford a new and integrative perspective for verifying climate model simulations. Combining satellite observations and model simulations, we investigate how water vapor, in conjunction with other geographical variables (temperature, clouds, etc.), influences the longwave spectra on different time scales (seasonal, interannual and decadal). We also explore methods where spectral observations are applied to better understand climate feedbacks and monitor climate change. Moreover, OLR spectra at TOA are used together with downward radiation spectra at the surface to analyze how the adjustments occur in the atmosphere in response to various forcings; this analysis offers insights into the changes in hydrological cycle that accompany the energy balance considerations at the surface.

Importance of Changes in Extreme Weather Events for the Maintenance of Past Warm Climates

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Changes in the frequency and intensity of extreme weather events are a likely result of climate change. Here we present results showing changes in the frequency and intensity of extreme weather events, including hurricanes, in past greenhouse climates such as the Eocene and Miocene. We present analyses of paleo-hurricanes from simulations and show some of the potential impacts of hurricane induced mixing on oceans. Our modeling supports to some degree the hypothesis that increase integrated intensity of tropical cyclones may have placed some constraints on tropical temperatures and helped to warm the poles during periods of past climatic warmth.

Circulation and Temperature Influences on Subtropical Humidity: Last Saturation Water Vapor Tracers and ENSO

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Recent studies have suggested that extratropical processes exert an important influence on the aridity of the subtropical free troposphere, but the details of these influences, and how they change as a function of the large-scale climate state, remain poorly understood. The goal of this study is to use the temperature and circulation changes associated with ENSO as a test-bed for evaluating the links and feedbacks between the subtropics and extratropics. Tracers of last saturation for dry subtropical air were determined through simulations of northern hemisphere winters using the MATCH tracer transport model with NCEP-NCAR reanalysis. Fifteen November through March winters were simulated, including five El Nino, five La Nina, and five ENSO-neutral periods. Relative humidity reconstructions from the last-saturation tracer fields capture not only the first order observed boreal winter humidity structure but also the observed ENSO-related humidity changes in the subtropical free troposphere.

Relative and specific humidity both decrease across the subtropical Pacific during El Nino and the corresponding last saturation tracers for the region are consistent in that tracer-weighted latitudes of last saturation are further (less) poleward during El Nino (La Nina) and atmospheric pressure levels and temperatures of last saturation are lower (higher) during El Nino (La Nina). Preliminary results on the longitude of last saturation, completed for the 1997-98 El Nino and the 1988-89 La Nina, are that the longitude of last saturation for air in the central Pacific subtropical mid-troposphere is dominantly to the west (east) during El Nino (La Nina). Relative humidity fields were also constructed using El Nino water vapor tracer fields applied to La Nina temperature fields, and vice versa, and the difference between these constructed humidity fields match in sign and structure the observed ENSO humidity variability. Results of these relative humidity constructions, using the swapped El Nino-La Nina water vapor tracer-temperature fields, suggest that circulation changes, at least to a first degree, determine the ENSO variability in subtropical humidity. Finally, ENSO related temperature field variability was evaluated as it relates to the relationship between last-saturation region and subtropical dry air saturation specific humidity. Preliminary results of these analyses relate ENSO-variable structure in the temperature field to the potential for the generation of dry air. ENSO variability of the potential to generate dry air, combined with the water vapor tracer results will further help distinguish the influences that temperature and circulation can have on subtropical humidity.

A Very Simple Model for the Water Vapour Feedback on Climate Change

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Climate sensitivity is often said to be doubled by water vapour feedback. From simple physical arguments, confirmed by the most detailed physical models we have, and consistent with the limited observational evidence, we expect the distribution of RH to change little under climate change. A substantial positive feedback on climate change must then be expected, and an approximate doubling is well established numerically. However, no physical explanation has yet been put forward for the size of this effect - the fact that water vapour feedback makes the climate around 100% more sensitive, rather than, say, 10% or 1000%, has been treated as an "emergent constraint" from detailed models rather than as calling for physical explanation.

Simpson's idealized numerical model of the LW component of climate sensitivity gave the counter-intuitive result that this component is zero: OLR does not change as climate warms. This result is shown to be more general than often thought, though still clearly not applicable to our planet. However, with certain physical approximations a "partly-Simpsonian" generalization can be derived: that the component radiated by water vapour does not change as the climate system warms, while that radiated by everything else - the surface and other atmospheric absorbers - increases following Planck's Law. While very simple, and still not quantitatively accurate, this does provide a physical explanation for the general size of the water vapour feedback.

The "partly-Simpsonian" approach also suggests an alternative way of breaking down the overall response of LW emission under climate change into feedback components, explains the robustness of modelled water vapour feedback, provides some physical limits on the possibility of a run-away water vapour greenhouse effect, and explains physically the long-known fact that in water-vapour-dominated regions of the spectrum the heat radiated by the climate system is a function primarily of RH, not temperature.

A New Way to Quantify Water Vapour Feedback in GCMs

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The water vapour feedback is probably the largest contribution to climate sensitivity, and the second-largest contribution to uncertainty in climate sensitivity (in the sense of disagreement between GCMs). Yet we have no useful way of quantifying it, essential if we are to explain these differences between GCMs with the aim of constraining the true value. The IPCC judge that the conventional diagnosis of a "water vapour feedback" is not worth doing. This poster shows that it is also formally useless - the anticorrelation between conventional "water vapour feedback" and "lapse rate feedback" makes that between the "water vapour feedback" and their sum insignificant and negative: i.e. knowing this "feedback" allows one to conclude nothing about the sum, but, if there is any effect, it is probably that strengthening this positive feedback reduces sensitivity - and discusses how this is effectively true by construction.

The "partly-Simpsonian" model of water vapour feedback suggests an alternative breakdown of the tropospheric LW response. Now the largest term, the "partly-Simpsonian" term, is essentially a function of control climate, not climate change, and so in a sense is observable and verifiable. Three other terms arise from the change under climate change of relative humidity, lapse rate and pressure, each considered as a function of temperature. While various technical issues arise, a workable implementation has been applied to 4 GCMs.

The results show, rather than just the cancellation between the "water vapour feedback" and "lapse rate feedback" that dominates the conventional analysis, much more similarity between the GCMs, in line with our physical expectations - and the differences in feedback terms that remain can be related to physically meaningful differences between the GCMs. For this (not necessarily representative) set of GCMs, these are different subtropical RH responses, differences in the latitudinal distrbution of the warming due to other feedbacks, and differences in the LW schemes' treatments of water vapour absorption, in particular the pressure broadening.

Reconstruction of Relative Humidity using Fossil Cellulose Derivatives; Seasonal Patterns from The Middle-Eocene (45Ma)

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Water capture by plants is offset by water loss out through leaves absorbing carbon dioxide. Atmospheric relative humidity is a powerful modulator of water loss, and ultimately governs the O and H isotopic composition (or "isotopic labeling") of leaf water. The isotopic label is then transfered to carbohydrates during photosynthesis. Later, when cellulose is synthesized from carbohydrates, some of the O and H is "relabeled" by water drawn directly from the soil. Hydroponic experiments have quantified exactly how much of the H and O in cellulose has been isotopically labeled by leaf water, and how much has been relabeled by soil water. Therefore, by performing both oxygen and hydrogen isotopic analysis on fossil cellulose, we may use two equations to solve for two unknowns: the composition of leaf water and the composition of soil water. We then invoke equilibrium and kinetic isotopic fractions to solve for the ratio of atmospheric vapor pressure outside:inside the leaf. By assuming leaf temperature to be nearly equal to that of the atmosphere, we use this ratio to conservatively approximate relative humidity. In this way, the paleo-relative-humidity can be determined by analyzing the O and H isotope signature of fossil plant cellulose, such as that found within fossil tree rings.

The above technique is often applied to Holocene (i.e., < 10 ka) plant fossils; our work represents the first effort to extend this technique to "old" fossils, and we have focused on the spectacularly preserved Metasequoia wood recovered from Axel Heiberg Island, Nunavut, Canada. These fossils are interesting not only because of their exquisite preservation, but also because they represent deciduous conifer forests that grew north of the Arctic Circle during the middle Eocene (45 Ma). By microsampling within fossil tree rings, we observe a consistent seasonal pattern in relative humidity, increasing from ~50% to ~100% during each growing season. Bulk measurements across many tree individuals indicate an average growing season relative humidity = ~67%. Taken in conjunction with mean annual temperature estimates based on soil carbonates, this implies at least double the amount of atmospheric water content in the Eocene polar atmosphere, relative to today. We are eager to explore the possible sources of this enhanced polar water-delivery, and the global climate consequences of elevated atmospheric water content in polar regions during the middle Eocene.

In addition, we report on recent work further investigating the intramolecular and biosynthetic controls on isotope fractionation during cellulose synthesis. For example, we have shown that the isotopic fractionation of the O attached to C-2 of the glucose moities differs from the average fractionation of O attached to C 3-6 by at least 9 permil. In addition, we have shown that cellulose synthesized from starch carries a different isotopic signature than cellulose synthesized from lipid, demonstrating the importance of biosynthetic pathway over the control of isotope fractionation. We have proposed a new specific compound, phenylglucazone, as an improved paleoindicator of soil water O isotope composition. Phenylglucazone may be derived from cellulose hydrolysate via phenylhydrazine, thereby removing the problematic O attached to C-2 mentioned above. Analyses of modern plants confirmed that phenylglucazone allows for a much more precise determination of soil water O isotope composition over whole cellulose, thus opening the door to a new generation of cellulosic paleo-relative-humidity indicators.

Hydrological Characteristics During CO2 Induced Warm Events Using Organic Compound-Specific Proxies

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Paleoclimate reconstructions are becoming increasingly focused on how global warming impacts the hydrological system. Extreme warming events ~55 million years ago (Paleocene Eocene Thermal Maximum—PETM, and Eocene Thermal Maximum—ETM 2 and 3) are particularly relevant to our modern predicament given evidence that each period of rapid global warming was induced by a massive release of carbon dioxide. A previous PETM study focused on the North Pole hydrology argued that a shift to deuterium-enriched precipitation near the onset of warming resulted from a decreased meridional temperature gradient, reduced rainout of subtropical water vapor, and net increase in water-vapor transport to the extreme high latitudes (Pagani et al., 2006) — an interpretation consistent with evidence for Arctic Ocean freshening during the PETM. This present study further evaluates regional characteristics of hydrological cycle during these ancient warming events using biomarker distributions and hydrogen isotope records of specific lipids obtained from the IODP 302 Arctic core (ETM 2) and Contessa (Italy) section (ETM 3). These data allow interpretations of changes in terrestrial ecosystems and the hydrogen isotopic composition of source water (precipitation and ocean water) used during photosynthesis. Our goal is to develop globally dispersed isotope records during warm intervals during the Eocene (~50 million years ago) to evaluate how hydrological changes are regionally and latitudinally expressed. Existing literature on changes in the hydrological cycle during these intervals will also be summarized.

Stable Isotopes in Modern Water and Ancient Stalagmites from Central America: Implications for Moisture Transport and Tropical-Extratropical Climate Teleconnections

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The role of the tradewinds in the transport of atmospheric water vapor from the Atlantic to the Pacific Ocean across Central America is an important control on the ocean's thermohaline circulation. Yet little is known about removal of this moisture as rainfall upon its traverse of the isthmus. We present stable isotopic data from several hundred surface water samples collected from across the isthmus that shows a decrease in oxygen isotope values from the Caribbean Sea to the Pacific Ocean. Such a decrease reflects progressive rainout of Atlantic-sourced air masses. Our samples from Guatemala, Costa Rica, and Guatemala, are a good stable isotopic proxy for spatial gradients in rainfall, and by inference atmospheric moisture, because of their concordance with the local and global meteoric water lines. As such, our data are useful for estimating rainout efficiency due to orographic effects and convection within the Intertropical Convergence Zone, and for estimating the isotopic composition of atmospheric moisture as it reaches the Pacific Ocean basin. Paleoclimatic variations in the stable isotopic composition of rainfall on the isthmus, as revealed by analysis of absolutely dated stalagmites, may thus serve as a proxy for past variations in cross-isthmian water vapor transport. Such proxy suggest a link to variations in poleward heat transport, via a correlation with isotopic data for variable moisture source contribution to the Greenland Ice Sheet. The data indicate a possible tropical forcing and/or positive feedback on global climate changes.

Water Isotopes During the Last Glacial Maximum: New GCM Calculations

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The application of water isotopes to estimate the glacial-interglacial cycle of temperature (T) assumes the validity of the present-day spatial relationship between T_a and $d^{18}O$ in precipitation ($d^{18}O_p$) to estimate temporal changes of the temperature at a fixed location. We explored how and why the spatial relationship between annual mean T_a- $d^{18}O_p$ is different from the temporal relationship at one location. Our GCM-isotope model exhibits a spatial slope of 1.22‰/°C between annual mean temperature at the top of the inversion layer (T_i) and $d^{18}O_p$ over Antarctica, comparable to the observed value of 1.25‰/°C from Dahe et al. (1999) and using the Phillpot and Zillman (1990) relationship between surface temperature and the temperature of the inversion layer). Over the southern ocean (45°-60°S), local evaporation accounts for 50% of precipitation, and this evaporative flux (mean $d^{18}O_e$ of ~-1‰) increases the $d^{18}O$ of vapor (mean $d^{18}O_v$ of -16‰). During the Last Glacial Maximum (LGM: 21,000 years ago), the isotopic composition of the vapor near the ice edge (~60°S) is calculated to be similar to the present values because evaporative recharge also accounts for ~50% of the precipitation over the southern ocean. As a result, the isotopic composition of vapor during the LGM is close to the present values at the ice edge. The apparent temporal slope over eastern Antarctica is half of the observed spatial slope, and our LGM experiment estimates an Antarctic mean annual temperature decrease of 13°C at Vostok, much colder than previous estimates. Our results show that the magnitude of the temporal slope on Antarctica is dependent on |DSST|, the cooling in the Southern Ocean poleward of 40ºS.

Controls on Water Isotope Variability on Millennial and Abrupt Time Scales Over the Last 21,000 Years – General Circulation Model results from GISS ModelE-R

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Water isotopes records collectively provide some of the most extensive proxy evidence for past climate. Required for the interpretation of these records is a known or assumed relationship between water isotopes and climate. However, on orbital timescales and during abrupt climate change events, the climate goes under significant reorganization, impacting the hydrologic cycle and influencing water isotope distribution. As such, the relationship between water isotopes and climate may not remain constant through time.

We assess the relationship between water isotopes and climate and infer the primary mechanisms controlling water isotope variability on various time scales using different simulations of Holocene and glacial climate using GISS ModelE-R, a fully coupled atmosphere-ocean GCM equipped with water isotope as well as other tracers, ideal for making exact comparisons with the proxy record of past climate change.

We find that the relationships between water isotopes climate (i.e., surface air temperature, salinity, precipitation, etc.) are different at decadal timescales than at orbital (millennial) timescales and that this relationship also changes during abrupt climate change events. In particular, the modulation of the amount of water exported from the tropics, as well as exchanged between ocean basins, has profound impacts on the relationship between water isotopes and climate. We find that the relationship between water isotopes and climate is likely not constant through time, possibly altering the interpretation of past climate based on water isotope reconstructions.

Representing the Role of Water Vapor in Climate Feedback by Coupled Surface-Atmosphere Climate Feedback-Response Method (CFRAM)

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We propose using the coupled surface-atmosphere climate feedback-response method (CFRAM) to study the role of water vapor in climate change. There are some new features in representing the role of water vapor by the CFRAM: (1) In the CFRAM, the water vapor feedback is not only the change in radiation perturbation at the top of the atmosphere (TOA) due to the change in water vapor, but also the change in the vertical structure of radiative heating/cooling effect in the atmosphere-surface column. The change in water vapor induces radiative heating at the surface and radiative cooling in the atmosphere, especially in the lower troposphere. We suggest this would affect the global hydrological cycle response to the global warming; (2) In the CFRAM, the changes in the dynamic transport, both large-scale and convective, of water vapor are explicitly included as feedback agents. This may help us better understand the uncertainty in estimate of climate feedback and climate sensitivity. We illustrate these two features of the CFRAM with the results from a 4-box model, which includes the meridional transport of water vapor, and from an idealized CGCM. We will also discuss the influence of meridional water vapor transport on the spatial pattern of global warming based on the analysis of CMIP3 model outputs.

Sensitivity of Global Warming to Surface Latent Heat Flux: Relative Humidity

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Predicted by the IPCC AR4 models, the global mean precipitation and evaporation pursue a muted response (~2% /K) to the water vapor content (~7% /K) during global warming. Based on the bulk expression of the latent heat, a linear diagnostic study on the results of IPCC AR4 models shows that surface evaporation response is reduced mainly by feedbacks on wind speed, relative humidity (RH), and air-sea temperature difference. Simulated small increase of RH (1%) during the 21st century contribute to 1/3 of these feedbacks, equivalent to 1/5 of Newtonian cooling. In this study, we adopted the NCAR CAM 3.0 with a slab ocean to study the sensitivity of surface warming and evaporation to RH. In our equilibrium global warming experiments, doubling CO2 concentration causes 2.50 K warming in SAT and 2.11 K in SST. 1% increase in RH contribute 0.49 K warming to SST, 1/5 of total warming while evaporation is hardly affected. This shows a RH feedback, in which global warming-caused RH increase prohibit the latent heat release, which would in turn warm the ocean. With warmed RH, strong warming occurs in subtropical cloud deck region, showing positive feedback in shortwave radiation. That is, SST warming induced by RH increase reduces low cloud fraction. Less low cloud decreases planetary albedo, causing more solar insolation. On the other hand, SST warming plus low cloud reduction increase surface long wave output, nearly balancing the enhancement of solar insolation globally, but not locally.

Correlation of Water Vapor and Temperature Anomalies in the Climate System

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On large spatial scales, we expect water vapor anomalies and temperature anomalies to be tightly correlated due to the Clausius-Clapeyron relationship. This is confirmed by analyzing satellite measurements of water vapor and lower tropospheric temperature in the tropics to find a scaling relationship in agreement with both Clausius-Clapeyron and simulations from the CMIP-3 set of climate models. On smaller spatial scales, the situation is more complex as the water vapor anomalies tend to depend on local-scale dynamics, leading to areas where temperature and water vapor are anti-correlated. We compare patterns of change in water vapor and temperature satellite measurements and climate models, with particular emphasis on separating signals associated with long term change with those caused by year-to-year variability. Over the past 20 years we find significant moistening in a number of regions, including the Western Pacific, and significant drying in the subtropical subsidence regions, in contrast to the nearly global-scale warming of the lower troposphere.

Global Water Vapor Trends From Satellite Data Compared With Radiosonde Measurements

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An analysis and intercomparison of trends from column integrated water vapor data, retrieved by satellite observations and radiosonde measurements, has been performed. The global satellite water vapor time series are provided by the Global Ozone Monitoring Experiment (GOME) on ERS-2 (European Remote-Sensing satellite) from January 1996 to December 2002 and are extended by measurements of the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) onboard ENVISAT (ENVironmental SATellite) up to December 2007. The combination of the two sets of data results in a long-term time series of 12 years on the basis of monthly means covering the Earth on a 0.5 degree grid. The global radiosonde data are supplied by the German Weather Service/Deutscher Wetterdienst (DWD) under the framework and the high quality standards of the World Meteorological Organisation (WMO). Monthly mean radiosonde water vapor column data from January 1996 to December 2007 have been selected for the comparison with the satellite observations. For the detection of trends or changes in the water vapor column over the time period of 12 years we use the same linear least square regression algorithm for all sets of data. Special emphasis is placed on the estimation of the errors and therefore the significance of the trends, which also includes the consideration of autocorrelations in the data. The intercomparison of the trends from independent measurements is performed by a Bayesian model selection approach.

Investigation of the Sensitivity of Water Cycle Components Simulated by the Canadian Regional Climate Model (CRCM) to the Land Surface Parameterization, the Lateral Boundary Data and the Internal Variability

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This study investigates the sensitivity of components of the hydrological cycle simulated by the Canadian Regional Climate Model (CRCM) to lateral boundary forcing, the complexity of the land-surface scheme (LSS) and internal variability arising from different model initial conditions. This evaluation is a contribution to the estimation of the uncertainty associated to RCM simulations. The analysis was carried out over the period 1961-1999 for three North American watersheds, and looked at climatological seasonal means, mean (climatological) annual cycles and interanual variability. The three watersheds (the Mississippi, the St.-Lawrence and the Mackenzie River basins) were selected to cover a large range of climate conditions. An evaluation of simulated water budget components with observations was also included in the analysis. Numerous information such as vertically integrated moisture flux convergences and precipitable water tendencies from reanalyses as well as precipitation and runoff data from different sources were brought together in order to quantify all the water budget components and to close the water budget over a river basin.

Results indicated that the response of climatological means and annual cycles of water budget components to land surface parameterisations and lateral boundary conditions varied from basin to basin. Sensitivity to lateral boundary conditions is in general smaller than sensitivity to LSS and tends to be stronger for the northern basins (Mackenzie and St. Lawrence). Inter-annual variability was unaffected by changes in LSS and driving data. Internal variability triggered by different initial conditions and the non-linear nature of the climate model did not significantly affect either the 39-year climatology, the climatological annual cycles or the inter-annual variability. Comparison with observations suggests that while the simple Manabe-based LSS may be adequate for simulations of climatological means, skilful simulation of annual cycles require the use of a state-of-the-art LSS.

The Response of Mean and Extreme Precipitation to Global Warming and Increased Atmospheric Water Vapor Content

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Climate warming is associated with increases in atmospheric water vapor content and major changes in the hydrological cycle. We probe the response of the hydrological cycle to climate change using a combination of theory and simulations with idealized and comprehensive general circulation models (GCMs). In particular, we analyze the changes that occur in mean and extreme precipitation. By considering a wide range of climates, we show that energetic constraints play a role in the behavior of global-mean precipitation. It has been suggested that the intensities of precipitation extremes should increase proportional to increases in water vapor, but our results show that this is not the case. Changes in latent heating, circulation strength, and the temperature when the precipitation extremes occur must also be taken into account. We will discuss how the growth in precipitation extremes varies seasonally and how it differs in the tropics and high latitudes.

The Muted Precipitation Increase in Global Warming Simulations: A Surface Evaporation Perspective

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Both observations and climate simulations suggest an increase of atmospheric moisture content by 7% per degree surface warming. The simulated precipitation, on the other hand, increases at a much slower rate. This muted response of the hydrological cycle to increased greenhouse gas forcing is investigated from a surface evaporation perspective, using simulations participating in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) under the A1B forcing scenario. A 90-year analysis of surface evaporation based on a standard bulk formula reveals that the following atmospheric changes act to slow down the increase in surface evaporation over ice free oceans: surface relative humidity increases by 1.0%, surface stability, as measured by air-sea temperature difference, increases by 0.2 K, and surface wind speed decreases by 0.02 m/s. As a result of these changes, surface evaporation increases by only 2% per Kelvin of surface warming rather than 7%/K. The increased surface stability and relative humidity are robust features among models. The former is nearly uniform over ice-free oceans (60S-60N) whereas the latter features a subtropical peak on either side of the equator. While relative humidity changes are positive almost everywhere in a thin surface layer, changes aloft show negative trends in the subtropics and positive ones in the deep tropics. The changes in the free troposphere are on the order of 5% and thus significantly stronger than surface trends. Our results call for observational efforts to detect and monitor changes in surface relative humidity and stability over the World Ocean.

On the Distribution of the Free Tropospheric Humidity in the Intertropical Belt

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While the importance of the humidity in the mid troposphere in the intertropical region to the earth radiative budget is well recognized, the detailed interaction of the outgoing long wave radiation and water vapour remains to be clarified. In this contribution it will be argued that the arithmetical average, the mean is not appropriate to characterize the humidity radiation-wise and that the full probability distribution function should be used instead. The first part of the poster will hence be dedicated to the presentation of idealized profiles of humidity and radiative computations in support of the above. The second part will focus on the humidity field of well known atmospheric reanalysis. The distribution humidity is build for key sub regions for a twenty year period. The departure from Gaussian statistics will be quickly shown. The first four moments are calculated from instantaneous fields during a season and are shown to complement each other in describing the interannual variability of the distribution of humidity. The contribution of the variation of temperature to the change of relative humidity will be evaluated in light of this 4-moments description of the relative humidity PDF. The dynamical process through which the full distribution of RH evolves from one year to another will be exemplified with the use of a climatology of back trajectory covering the same 20 years period. The final part will extend the reasoning and approach to satellite derived layered relative humidity estimates from the METEOSAT suite of 6.3 microns with emphasis on the recently available 24 years time series.

Evaporative Demand and Terrestrial Water Resources under a Changing Climate

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Changes in the availability of water represent one of the basic challenges arising from the enhanced greenhouse effect. One of the most interesting observations has been the decline in evaporative demand (as measured by pan evaporation) observed in many parts of the world. In this talk we first describe the underlying physics and show how the decline in pan evaporation can be decomposed into separate contributions due to changes in radiation, temperature, vapour pressure deficit and windspeed. We then show how most of the observed declines in evaporative demand can be attributed to declines in radiation and/or windspeed. There is little change due to vapour pressure deficit, which implies that near-surface relative humidity has remained nearly constant as warming has occurred. We then use the knowledge of trends in evaporative demand to make an assessment of expected changes in terrestrial water resources out to 2100 using the IPCC AR4 model archive. The results of that assessment will be described.

Identification of Human-Induced Changes in Atmospheric Moisture Content: Sensitivity of Results to Model Quality

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In a recent multi-model detection and attribution ("D&A") study using the pooled results from 22 different climate models, the simulated "fingerprint" pattern of anthropogenically-caused changes in water vapor was identifiable with high statistical confidence in satellite data. This preliminary investigation relied on a "one model, one vote" approach, in which equal weight was given to the water vapor data obtained from each model. There are however, large differences in the skill with which these 22 models simulate key aspects of the observed mean state and variability of water vapor. Here, we examine whether the results from our initial D&A study are sensitive to model quality. We calculate various statistical measures of model performance relevant to the water vapor D&A problem. Our focus is on model skill in simulating the mean state and variability of water vapor and SST in a number of different regions (AMO, PDO, ENSO, etc.). The amplitude and pattern of the simulated variability is compared with observations on multiple timescales. In three separate sensitivity tests, we define the "top ten" models based on measures of mean state alone, variability alone, and mean state plus variability. The entire D&A analysis is repeated with each of these three different sets of more skillful models. Results indicate that our ability to identify an anthropogenic fingerprint in observed water vapor data is not impaired by inclusion of some form of "screening" based on model quality.

The "Flood of the Century" as Isotopic Fingerprint in Canopy d18O Signatures

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The d18O composition of water and CO2 exchange at smaller scales (leaf and ecosystem) can be affected by changes in atmospheric water vapour at larger (regional) scales. During a sampling campaign in a beech forest in Germany in August 2002, we encountered such a large scale change when dry sunny weather was followed by a large storm system with heavy rains leading to floods across Europe. During the transition, canopy vapour d18O decreased at least 2 permil, and the d18O composition of leaf water then reflected isotopic exchange with this depleted vapour due to the high humidity. Hence, bulk leaf water was substantially more depleted at night compared to the first, sunny period, and showed virtually no evaporative enrichment during the day. Values of 18O discrimination during CO2 exchange for photosynthesis strongly decreased from the sunny to the wet period, whereas those for nocturnal respiration increased by a factor of 2 to 4. Model simulations indicated that the small positive foliage isoflux during the day was offset by the negative isoflux at night. As a consequence, the d18O of CO2 in canopy air decreased by about 3 permil. The d18O signatures of canopy water and CO2 thus reflected the transition from local water to the regional regime of depleted water deposited across the area by the storm.

Relative Humidity Change

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Relative humidity is widely expected to remain roughly constant in changing climates. However, climate models run for the IPCC 2007 report consistently predict changes in relative humidity of order 1-4\% per C of warming, with increases near the tropopause, decreases throughout the midlatitude troposphere and tropical upper troposphere, and increases in the tropical lower troposphere. We offer explanations for each of these changes, which may soon become observable. While they approximately cancel with respect to water vapor's greenhouse effect, they cause changes in the cloud distribution that contribute to the overall positive cloud feedback in the models. The magnitude of these relative humidity changes increases with model resolution, and does not converge until resolution is 2 degrees or better, which was attained only by a minority of the AR4 models. Significantly coarser grids, especially those employed in paleoclimate models, are insufficient to predict even qualitatively most of the changes shown.

Atmospheric Transport of Water to the European Arctic Simulated with a Mesoscale Model with Water Vapor Tracers: Sources, Structure, and Energy Considerations

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Coastal areas at the end of the storm track, such as Norway and the American west coast, are prone to heavy precipitation associated with moisture conveyor belts or atmospheric rivers. Previous studies have shown that both, remote and local moisture transport contribute to such heavy precipitation events. During winter 2006/2007, a series of mid-latitude cyclones brought above-average precipitation to southern Norway. We present an analysis of the transport processes and the evaporation sources of the tropospheric water vapor in the European North Atlantic for this period, using a mesoscale model with water vapor tracers. Water vapor tracers allow to tag water vapor by source region, and to follow its movement throughout the model's hydrological cycle, including parameterized diabatic processes. A one-month model simulation was carried out for December 2006, using ECMWF's high-resolution operational data as initialization and boundary conditions.

We use a new composite visualization to reveal the horizontal and vertical structure of the moisture transport associated with several mid-latitude cyclones. Our results confirm that the tropospheric water transport is strongly inter-related with the upper-level circulation, in particular with respect to the formation of tropospheric rivers. For the cases analyzed here, it is shown that water vapor is transported over longer distances within such filaments, and that different sources contribute to the total water vapor at different altitudes. Heavy precipitation events in southern Norway contain more moisture from long-range transport than average precipitation events. In addition, we quantify the meridional transport of water and energy associated with several cyclones during the study period, separated into the contributions of different moisture sources. Our results provide detailed insight into the mechanisms of moisture transport in and precipitation from mid-latitude cyclones. Water tracers in mesoscale model simulations offer new possibilities for the quantification of mass and energy transport, for understanding the processes leading to heavy precipitation events, and for the validation of a model's hydrological cycle with observations.

Arctic Vegetation Changes Induce High Latitude Warming Through Greenhouse Effect

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Conversion of bare ground to trees at high northern latitudes (above 60 degrees) changes not only springtime albedo but also transpiration. In the NCAR climate model we find the greenhouse effect due to additional water vapor is amplified by ice albedo feedback. The radiative consequences of enhanced transpiration may not be significant at lower latitudes but could cause significant temperature changes at high latitudes through its link to ice albedo feedbacks.

The Impact of Water Vapor on Precipitation and Evaporation Trends

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Climate models and satellite observations both indicate the total amount of water vapor in the atmosphere will increase substantially due to global warming at a rate of 7%/K. However, the climate models predict global precipitation will increase at a much slower rate of 1-3%/K. A recent analysis of satellite observations does not support this prediction of a muted response of precipitation to global warming. Rather, the observations suggest that precipitation and total atmospheric water have increased at about the same rate over the last two decades. These satellite results are supported to some degree by the 75-year record of precipitation measurements from the Global Historical Climatology Network. The difference between a subdued increase in rainfall as compared to a Clausius-Clapeyron increase has enormous impact with respect to the consequences of global warming. Can the total water in the atmosphere increase 15% with CO_2 doubling, but precipitation only increase 4%?

HadCRUH: Analysis of Recent Changes in Surface Humidity and Underlying Causes with a new Global Dataset

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Humidity is fundamental to understanding recent climate change, but until now no truly global high quality dataset has existed with which to assess surface humidity changes. HadCRUH, provides a homogenized quality-controlled near-global 5° by 5° gridded monthly mean anomaly dataset in surface specific and relative humidity from 1973 to 2003. It consists of land and marine data, and is geographically quasi-complete over the region 60° N to 40° S.

Between 1973 and 2003 surface specific humidity has increased significantly over the Globe, Tropics and Northern Hemisphere. Global trends are 0.11 and 0.07 g kg-1 10yr-1 for land and marine components respectively. Trends are consistently larger in the Tropics and in the Northern Hemisphere during summer, as expected: warmer regions exhibit larger increases in specific humidity for a given temperature change under conditions of constant relative humidity, based on the Clausius-Clapeyron equation. Relative humidity trends are not significant when averaged over the landmass of the Globe, Tropics and Northern Hemisphere, although some seasonal changes are significant.

A strong positive bias is apparent in marine humidity data prior to 1982, likely due to a known change in reporting practice for dewpoint temperature at this time. Consequently, trends in both specific and relative humidity are likely underestimated over the oceans.

Modelling Heat Stress in Warmer and More Humid Climates

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The weather and climate pose many challenges to human health with high temperature and high humidity combined, creating increased heat stress (physiological strain). Given recent trends in both atmospheric temperature and humidity it follows that heat stress, and likely extremes of heat stress, will also increase. This paper investigates the potential changes in heat stress threshold exceedances in a warming climate for the contiguous USA, Europe and Australia.

There are many different indices for quantifyinsg heat stress. The ISO standard (7243) is the WBGT (wet-bulb globe temperature). It is used during military operations by the USA and UK, for athletics and sports events in Australia and in many work places where heat stress is an issue. Here we use the global surface humidity dataset HadCRUH (Willett et al. in press) to create an summertime equivalent WBGT outdoor daytime, outdoor nighttime and indoor nighttime dataset. We show that over recent decades WBGT is increasing significantly over France and the south-eastern quadrant of the US. Elsewhere, increases are widespread but lack significance and decreases are found over most of Australia.
Exceedances of lower thresholds (26°C, 28°C) are commonplace for most regions WBGT outdoor daytime.

Work is ongoing to model these exceedances over recent climate change and use this model to project likely future threshold exceedance under 1°, 2°, 3° and 5° of warming under constant relative humidity. To date, the model appears to represent current exceedances satisfactorily.

Humidity and Human Health – Implementing a Universal Heat Stress Product for Both Historical Analyses and Forecasting on Daily to Multi-decadal Scales

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Heat affects human comfort, productivity and health. The sudden onset of sustained high temperatures triggers stress in the elderly, very young and infirm, which can lead to mortality, most commonly by respiratory, cardio or cerebral complications. The addition of high humidity makes temperatures feel higher because of the reduced ability for the body to keep cool due to evaporation. For the active healthy population who have to perform physical work (labourers, military personnel, athletes) this can lead to lowered productivity and in severe cases heat stress or heat stroke and possible death. Given likely future trajectory towards a warmer, moister climate, it is critical to be able to quantify, understand historically and forecast heat stress at a range of scales in a simple, consistent and meaningful way.

There are many different methods for quantifying heat stress (the combined effect of temperature, humidity, radiation and wind) on humans. The ISO standard (7243), the WBGT (wet-bulb globe temperature), although in use by the US and UK military, is not universally used. It is inconvenient to measure and impossible to forecast because it utilizes non-standard meteorological variables to take into account temperature, radiation, wind speed and humidity. Thus quantifying heat stress in a universally consistent way has, to date, not been possible.

This project aims to compare all current heat stress indices for their compatibility with the ISO standard in order to define a single ideal measure of heat stress that can be measured synoptically. This will then enable coherent analysis of heat stress from historical timeseries to forecasts from daily to multi-decadal scales.

Storm Tracks Changes and Their Impacts on Hydrological Cycle

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Storm tracks play a major role in regulating the precipitation and hydrological cycle in midlatitudes. The changes in the location and amplitude of the storm tracks in response to global warming will have significant impacts on the poleward transport of heat, momentum and moisture and on the hydrological cycle. Recent studies have indicated a poleward shift of the storm tracks and midlatitude precipitation zone in the warming world that will lead to subtropical drying and higher latitude moistening. This study confirms this key feature for not only the annual mean but also different seasons based on the analysis of multiple climate models. Further analyses show that the meridional sensible and latent heat fluxes associated with the storm tracks shift poleward and intensify in both boreal summer and winter in the late 21st century (2081-2100) relative to the 20th century (1961-2000) from the Geophysical Fluid Dynamics Laboratory (GFDL) model simulations. The maximum dry Eady growth rate and its moist generalization by Emanuel et. al (1987) are analyzed to determine the effect of global warming on baroclinic instability. The trend in maximum Eady growth rate, especially its moist version, is consistent with the poleward shift and intensification of the storm tracks, indicating the relevance of the changing characteristics of baroclinic instability in driving the trend in storm tracks. A diagnosis of the latitude-by-latitude energy budget for the current and future climate is underway to further unravel the interplay among the eddy heat and moisture transport and the radiative and surface heat fluxes in shaping the midlatitude weather activities and hydrological cycle in future climate.

Seasonality in Interannual Variability of Atmospheric Moisture over Europe

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Seasonality in the interannual variability of atmospheric moisture over Europe is investigated using precipitable water (PW) from the NCEP/NCAR Reanalysis dataset for 1979-2004. Over Europe the summer PW and its interannual variability (expressed by standard deviations) are essentially larger than those of the winter season. The largest seasonal differences are found over eastern Europe and European Russia, where the summer PW climatology and magnitudes of its interannual variability exceed respective winter characteristics by a factor of 2.5-3.8. The first and second EOF modes of winter PW over Europe are associated, respectively, with the North Atlantic Oscillation (NAO) and the East Atlantic teleconnection pattern. During summer the leading EOFs of PW are not linked to the known regional teleconnection patterns. Our analysis revealed that EOF-1 of summer PW is associated with sea level pressure (SLP) pattern characterized by two action centres of opposite polarity over northwestern Siberia and over a broad region including southern Europe, the Mediterranean Sea and part of northern Africa. The EOF-2 of summer PW is associated with cyclonic/anti-cyclonic SLP anomalies over Scandinavia and southwestern Europe. It is shown that PW and precipitation variability are positively coupled during the cold season but not for the warm season. Instead, during the warm season we found a significant link between regional PW and air temperature variability, indicating an important role of local heating in variability of summer PW over Europe.

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