Exploring influences of deep convection and cloud processes on tropical stratospheric water vapor

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Stratospheric Water Vapor

Water vapor is of central importance to both chemical and radiative processes in the stratosphere. An increase of water vapor in the stratosphere:

1. cools the stratosphere
2. warms the surface
3. enhances ozone destruction
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Introduction

Stratospheric Water Vapor

The Stratospheric Tape Recorder

Stratospheric water vapor is primarily controlled by temperatures at the tropical tropopause. The imprint of the seasonal cycle of tropical tropopause temperatures propagates upward over time.
The Brewer-Dobson Circulation

This upward propagation occurs in the tropical component of the stratospheric Brewer-Dobson Circulation: the 'tropical pipe'.
Contributions from Tibet?

Fu et al. (PNAS 2006) showed that deep convection over the Tibetan Plateau moistens the local lower stratosphere.
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Introduction

Transport From Southeast Asia
Contributions from Tibet?

Does this water vapor reach the tropical pipe? What is its contribution relative to tropical convection?
Contributions from Tibet?

Climate model simulations suggest that this pathway is important (Lelieveld et al., ACP 2007); however, other results cast doubt (Park et al., JGR 2007; James et al., ACP 2008).

Contributions from South-East Asia

Substantial transport from South-East Asia during summertime.
The influence of summertime convection over Southeast Asia on water vapor in the tropical stratosphere


J. S. Wright, R. Fu, S. Fueglistaler, Y. S. Liu, and Y. Zhang
Hypothesis #1
Transport from convective events over the Tibetan Plateau and South Slope of the Himalayas is moister than transport from other convective events within Southeast Asia.

Hypothesis #2
This transport makes a substantial contribution to the annual maximum of water vapor in the tropical lower stratosphere.
Experimental design

Lagrangian back trajectories from Aura MLS observations of water vapor in the tropical lower stratosphere (68 hPa) to identify the relative importance of different convective source regions.
Focus on Annual Maximum

Initialize back trajectories during OND, and trace backward to summertime convection over South-East Asia.
Trajectory Analysis

Trajectories are driven using reanalysis winds and diabatic heating rates. Independent simulations are performed using three different reanalysis datasets to drive the trajectories:

1. NCEP/NCAR Reanalysis1
2. GMAO MERRA (NASA)
3. ERA-Interim (ECMWF)

Focus on points of consistency within the results.

Convective Sources

Convective source locations are identified by matching observations of cloud top pressure (derived from CLAUS 11μm brightness temperatures) with all trajectory locations.
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Transport from Southeast Asia
Study Design

**Advection-Condensation Simulations**
Identify the transport of water vapor into the tropical lower stratosphere according to the advection-condensation paradigm.

**Stratospheric Water Vapor**
This paradigm works for stratospheric water vapor for the same reason that the tape recorder exists: stratospheric water vapor depends on tropical tropopause temperatures.
Convective Sources in Southeast Asia

Summertime convective sources in Southeast Asia are concentrated in the South Asian and South China Sea monsoon regions.
Results

Distribution of Convective Sources

There are three geographically distinct convective source regions within Southeast Asia.
Results

Distribution of Convective Sources

These three regions account for a substantial fraction of summertime convective source events.

- **GMAO MERRA**
  - SCS: 25%
  - MON: 24%
  - TIB: 10%
  - Other: 41%

- **ERA Interim**
  - SCS: 20%
  - MON: 16%
  - TIB: 6%
  - Other: 58%

- **NCEP/NCAR**
  - SCS: 33%
  - MON: 27%
  - TIB: 21%
  - Other: 19%
Water Vapor Transport

The magnitude of water vapor transport into the tropical LS differs by convective source region. These regional differences are qualitatively consistent in all three trajectory ensembles.
These differences in water vapor transport are related to systematic differences in preferred transport pathways.
Lagrangian Dry Points

LDPs are shifted northward and westward for trajectories from TIB convection relative to those from MON convection.
Lagrangian Dry Points

LDPs are shifted northward and upward for trajectories from TIB convection relative to those from MON convection.
Bypassing the Cold Trap

Shifting of cold points northward, westward, and upward bypasses ‘freeze-drying’ at the coldest temperatures.
Bypassing the Cold Trap

Higher detrainment potential temperatures.
Bypassing the Cold Trap

Tighter confinement to the monsoon anticyclone.
Results

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Transport from Southeast Asia
Results

The Big Picture

Transport from convection over the Tibetan Plateau and South Slope of the Himalayas appears to have only a small impact on the tropical lower stratosphere water vapor maximum.
Hypothesis #1

Transport from convective events over the Tibetan Plateau and South Slope of the Himalayas is moister than transport from other convective events within Southeast Asia.

Hypothesis #2

This transport makes a substantial contribution to the annual maximum of water vapor in the tropical lower stratosphere.
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Continuing Exploration
Motivation
Advection-Condensation is Biased Dry

Recent results indicate that advection-condensation simulations of water vapor transport into the tropical lower stratosphere are biased dry, especially during boreal summer.

Liu et al., JGR 2010
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Continuing Exploration

Motivation

modified from Steinwagner et al., 2010
Biases in Cloud Top Height

Estimates of cloud top height using 11 µm brightness temperatures tend to be biased low (Sherwood et al., 2004; Minnis et al., 2008). Adjusting cloud tops upwards affects the distribution of convective sources to the LS within the global tropics.
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Continuing Exploration

Motivation

Biases in Cloud Top Height

Such biases affect the simulated water vapor transport.

![Graph showing water vapor VMR (ppmv) distribution with different cloud top heights.

Legend:
- MLS
- ORIG
- CORR

Water Vapor VMR [ppmv]

1 2 3 4 5 6 7

20%
15%
10%
5%
Experimental design

Lagrangian back trajectories from Aura MLS observations of water vapor in the tropical lower stratosphere to identify the relative importance of different convective source regions.
Experimental design

Identify the transport of water vapor into the tropical lower stratosphere according to the advection-condensation paradigm – then add various cloud processes.
Experimental design

Evaluate whether biases in convective detrainment height may contribute to the dry bias by misidentifying convective source regions or by supplying anvil ice directly to the LS.
Experimental design

Evaluate sensitivity to the underlying meteorological fields using four different reanalyses:

- GMAO MERRA (NASA)
- ERA Interim (ECMWF)
- JRA-25/JCDAS (JMA)
- CFSR (NOAA/NWS)
Advection-condensation (ADVCON)

Condensation/deposition occurs at 100%RH with respect to ice, and all condensate falls out immediately.
Parameterized supersaturation (SUPSAT)

Condensation occurs at a temperature-dependent threshold supersaturation (Kärcher et al., 2002). All condensate falls out.
Parameterized cirrus clouds (CIRRUS)

Condensation/deposition occurs at 100%RH with respect to ice, but condensate falls out over time and may re-evaporate.
Parameterized cirrus clouds (CIRRUS)

Condensation/deposition occurs at 100%RH with respect to ice, but condensate falls out over time and may re-evaporate.
Cloud model setup

Assume a log-normal distribution of particle masses at cloud formation, distributed evenly within the parcel volume.
Cloud model setup

The sedimentation velocity of cloud particles out of the parcel volume is mass-dependent (Spichtinger and Gierens, 2009).
Parameterized supersaturation and cirrus clouds (SSCIRR)

Condensation/deposition occurs at a threshold supersaturation. Condensate falls out over time and may re-evaporate.
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Continuing Exploration

Early Results: GMAO Seasonal Cycle
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Continuing Exploration

Early Results: ERAI Seasonal Cycle

![Graphs showing simulated water vapor vs. MLS observed water vapor at different pressures (100 hPa, 83 hPa, 68 hPa, 56 hPa).]
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Continuing Exploration

Early Results: CFSR Seasonal Cycle
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Continuing Exploration

Early Results: JRA-25/JCDAS Seasonal Cycle
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Early Results: GMAO Tape Recorder
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Convective Detrainment Height
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Early Results: GMAO/ERAI Convective Source Distributions
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Continuing Exploration

Early Results: GMAO Seasonal Cycle

![Graphs showing simulated vs. observed water vapor at different pressures (100 hPa, 83 hPa, 68 hPa, 56 hPa).]
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Continuing Exploration

Early Results: GMAO Tape Recorder
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Continuing Exploration

Inclusion of Isotopes

- **Water**
  - $^{1}H_{2}^{16}O$
  - 1,000,000

- **Deuterated Water**
  - $^{1}HD^{16}O$
  - 311

- **$^{18}O$ Water**
  - $^{1}H_{2}^{18}O$
  - 2,005
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Continuing Exploration

Inclusion of Isotopes

Steinwagner et al., *Nature Geoscience, 2010*
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Inclusion of Isotopes

Steinwagner et al., 2010

(a) ppm x 100
(b) %o
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Continuing Exploration

Inclusion of Isotopes
There are systematic differences in water vapor transport into the stratosphere from different convective source regions in Southeast Asia.

These differences are related to systematic differences in transport pathway characteristics, particularly the likelihood of experiencing the coldest temperatures during transit.

These differences do not appear to have a significant impact on the seasonal cycle of water vapor at 68 hPa.

Advection-condensation simulations of tropical stratospheric water vapor are too dry, perhaps due to neglected or misrepresented cloud processes.

No improvement with inclusion of evolving cirrus clouds: condensate evaporation during transit is unimportant.

Inclusion of supersaturation with respect to ice and accounting for biases in cloud top height do improve the results, particularly in the mean and amplitude of the seasonal cycle.