Chapman Conference on The Role of the Stratosphere in Climate and Climate Change

The Petros M. Nomikos Conference Center
Santorini, Greece
24–28 September 2007

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CONVENERS

- ■ Mark P. Baldwin, Northwest Research Associates, Bellevue, Wash., USA
- ■ Emily F. Shuckburgh, University of Cambridge, U.K.
- ■ David W. J. Thompson, Colorado State University, Fort Collins, Colo., USA

PROGRAM COMMITTEE

- ■ Bo Christiansen, Danish Meteorological Institute, Denmark
- ■ Martin Dameris, DLR-Institut für Physik der Atmosphäre, Germany
- ■ Nathan P. Gillett, University of East Anglia, U.K.
- ■ Lesley J. Gray, University of Reading, U.K.
- ■ Peter H. Haynes, University of Cambridge, U.K.
- ■ Paul J. Kushner, University of Toronto, Canada
- ■ Warwick A. Norton, University of Reading, U.K.
- ■ Judith Perlwitz, CIRES, University of Colorado, USA
- ■ Theodore G. Shepherd, University of Toronto, Canada
- ■ Shigeo Yoden, Kyoto University, Japan

CONFERENCE COSPONSORS

- ■ European Office of Aerospace Research and Development, Air Force Office of Scientific Research, United States Air Force Research Laboratory
- ■ NorthWest Research Associates, Inc., Bellevue, Washington
- ■ World Meteorological Organization/SPARC

Cover: Santorini at sunset.

MEETING AT A GLANCE

Monday, 24 September 2007

8:40 a.m. – 9:00 a.m.	Conference Introduction
9:00 a.m. – 10:10 a.m	Oral Sessions
10:10 a.m. – 10:40 a.m.	Coffee Break
10:40 a.m. – 12:10 p.m.	Oral Sessions
12:10 p.m. – 2:30 p.m.	Lunch
2:30 p.m. – 3:40 p.m.	Oral Sessions
3:40 p.m. – 4:10 p.m.	Coffee Break
4:10 p.m. – 5:20 p.m.	Poster Summaries
5:30 p.m. – 7:00 p.m.	Poster Viewing and Refreshments
7:00 p.m. – 9:00 p.m.	Reception (*open to conference registrants*)

Tuesday, 25 September 2007

9:00 a.m. – 10:10 a.m.	Oral Sessions
10:10 a.m. – 10:40 a.m.	Coffee Break
10:40 a.m. – 12:10 p.m.	Oral Sessions
12:10 p.m. – 2:30 p.m.	Lunch
2:30 p.m. – 3:40 p.m.	Oral Sessions
3:40 p.m. – 4:10 p.m.	Coffee Break
4:10 p.m. – 5:20 p.m.	Poster Summaries
5:30 p.m. – 7:00 p.m.	Poster Viewing and Refreshments

Wednesday, 26 September 2007

9:00 a.m. – 10:10 a.m.	Oral Sessions
10:10 a.m. – 10:40 a.m.	Coffee Break
10:40 a.m. – 12:00 p.m.	Oral Sessions

Thursday, 27 September 2007

9:00 a.m. – 10:10 a.m.	Oral Sessions
10:10 a.m. – 10:40 a.m.	Coffee Break
10:40 a.m. – 12:10 p.m.	Oral Sessions
12:10 p.m. – 2:30 p.m.	Lunch
2:30 p.m. – 3:40 p.m.	Oral Sessions
3:40 p.m. – 4:10 p.m.	Coffee Break
4:10 p.m. – 5:20 p.m.	Oral Sessions
5:30 p.m. – 7:00 p.m.	Poster Viewing and Refreshments
7:00 p.m. – 9:00 p.m.	Reception (*open to conference registrants*)

Friday, 28 September 2007

9:00 a.m. – 10:10 a.m.	Oral Sessions
10:10 a.m. – 10:40 a.m.	Coffee Break
10:40 a.m. – 12:10 p.m.	Oral Sessions
12:10 p.m. – 2:30 p.m.	Lunch
2:30 p.m. – 3:40 p.m.	Synthesis Presentations and Discussion
3:40 p.m. – 4:10 p.m.	Refreshments
4:10 p.m. – 5:20 p.m.	Synthesis Presentations and Discussion

SCIENTIFIC PROGRAM

MONDAY, 24 SEPTEMBER 2007

Note: Registration will be available during coffee breaks. Please visit the Ground Floor.

8:40 A.M. – 9:00 A.M. **INTRODUCTION** **LOCATION: MAIN HALL**

OVERVIEW AND GENERAL DYNAMICS
M. BALDWIN: SESSION CHAIR

9:00 a.m. – 9:30 a.m. **Alan Plumb**, *(INVITED) Annular Modes, the Fluctuation-Dissipation Theorem, and the Dynamical Response of the Atmosphere to Climate Perturbations*

9:30 a.m. – 9:50 a.m. **A. O'Neill**, A. J. Charlton, *A Paradigm for Variability in the Troposphere-Stratosphere System*

9:50 a.m. – 10:10 a.m. **P. H. Haynes**, S. C. Hardiman, *Downward Penetration of Dynamical Perturbations to the Upper Stratosphere*

10:10 a.m. **Coffee Break** **10:40 a.m**

B. CHRISTIANSEN: SESSION CHAIR

10:40 a.m. – 11:10 a.m. (*INVITED*) **G. Vallis**, *The NAO, Annular Patterns and All That: Is the Troposphere All We Need?*

11:10 a.m. – 11:30 a.m. **C. J. Chan**, R. A. Plumb, *The Effect of Poleward Propagation on the Stratospheric-Tropospheric Coupling in a Simple GCM*

11:30 a.m. – 11:50 a.m. **D. W. J. Thompson**, *The Balanced Response to Stratospheric Wave Drag and Diabatic Heating*

11:50 a.m. – 12:10 p.m. **T. R. Nathan**, E. C. Cordero, J. Albers, *Planetary Wave Induced Ozone Heating and its Effect on Troposphere-Stratosphere Communication*

12:10 p.m. **Lunch** **2:30 p.m.**

Y. YAMASHITA: SESSION CHAIR

2:30 p.m. - 3:00 p.m. *(INVITED)* **P. J. Kushner**, *Overview of Stratospheric Impacts on the Troposphere/DynVar*

3:00 p.m. – 3:20 p.m. **A. J. Charlton**, A. O`Neill, *What Controls Dynamical Timescales Near the Tropopause?*

3:20 p.m. – 3:40 p.m. **T. Kunz**, K. Fraedrich, R. J. Greatbatch, *Dynamical Time Scales in the Extratropical Lowermost Stratosphere*

3:40 p.m. Coffee Break 4:10 p.m.

4:10 p.m. – 5:20 p.m. *Poster Summaries: all posters will be on display in the Gallery for the duration of the conference*.

5:30 p.m. – 7:00 p.m. *Poster Viewing and Refreshments*.

7:00 p.m. – 9:00 p.m. *Reception to be held in Banquet Area and Courtyard; reception open to all conference registrants*.

TUESDAY, 25 SEPTEMBER 2007

CLIMATE CHANGE AND THE STRATOSPHERE LOCATION: MAIN HALL

D. THOMPSON: SESSION CHAIR

9:00 a.m. – 9:30 a.m**.** *(INVITED)* **D. J. Seidel**, W. J. Randel, *Observed Recent Changes in the Tropopause*

9:30 a.m. – 9:50 a.m. **M. P. Baldwin,** *Stratospheric Climate Change and its Effect on the Troposphere*

9:50 a.m. – 10:10 a.m. **E. C. Cordero,** *Temperature Trends in the Upper Troposphere and Lower Stratosphere as Revealed by CCMs and AOGCMs*

10:10 a.m. Coffee Break 10:40 a.m.

T. SHAW: SESSION CHAIR

10:40 a.m. – 11:10 a.m. *(INVITED)* **J. Perlwitz**, S. Pawson, J. E. Nielsen, P. A. Newman, R. S. Stolarski, W. Neff, M. Hoerling*, Past and Future Changes of Southern Hemisphere Tropospheric Circulation and the Impact of Stratospheric Chemistry-Climate Coupling*

11:10 a.m. – 11:30 a.m. **N. P. Gillett**, S. Keeley, *Antarctic Tropospheric Response to Ozone Depletion is Dominated by Ozone Changes in the Mid-Stratosphere*

11:30 a.m. – 11:50 a.m. **K. Sato**, Y. Tomikawa, H. Nakajima, T. Sugita, *Longitudinally-Dependent Ozone Recovery in the Antarctic Polar Vortex Revealed by Satellite-Onboard ILAS-II Observation in 2003*

11:50 a.m. – 12:10 p.m. **K. M. Grise**, D. W. J. Thompson, *Dynamical Impacts of Antarctic Stratospheric Ozone Depletion on the Extratropical Circulation of the Southern Hemisphere*

12:10 p.m. **Lunch** **2:30 p.m.**

S. YODEN; SESSION CHAIR

2:30 p.m. – 3:00 p.m. (*INVITED*) **N. Butchart**, *Stratospheric Climate and Circulation Changes in the CCM Simulations Used for the 2006 Ozone Assessment*

3:00 p.m. – 3:20 p.m. **T. G. Shepherd**, *How will Climate Change Affect Ozone Recovery?*

3:20 p.m. – 3:40 p.m. **M. Dameris**, R. Deckert, *Investigation of Brewer-Dobson Circulation Changes in a Future Climate*

3:40 p.m. **Coffee Break** **4:10 p.m.**

4:10 p.m. – 5:20 p.m. *Poster Summaries: all posters will be on display in the Gallery for the duration of the conference*.

5:30 p.m. – 7:00 p.m. *Poster Viewing and Refreshments*.

WEDNESDAY, 26 SEPTEMBER 2007

THE TROPICS, TRANSPORT, AND STATISTICS **LOCATION: MAIN HALL**

K. NISHII: SESSION CHAIR

9:00 a.m. – 9:30 a.m. (*INVITED*) **W. J. Randel**, R. R. Garcia, *Dynamical Balances and Tropical Stratospheric Upwelling*

9:30 a.m. – 9:50 a.m. **K. Labitzke**, *Winter Variability in the Stratosphere: Coupling Between the Arctic and the Tropics*

9:50 a.m. – 10:10 a.m. **M. A. Giorgetta**, E. Manzini, M. Esch, E. Roeckner, *Role of the Stratosphere in Climate Modelling: The Connection Between the Hadley and the Brewer-Dobson Circulation*

10:10 a.m. **Coffee Break** **10:40 a.m.**

E. SHUCKBURGH: SESSION CHAIR

10:40 a.m. – 11:10 a.m. *(INVITED)* **S. Fueglistaler**, *Open Problems of Transport into the Stratospheric Overworld: New Insights from Measurements of Deuterated Water?*

11:10 a.m. – 11:30 a.m. **K. Krüger**, S. Tegtmeier, M. Rex, *Interannual Variability of Transport Processes in the TTL During NH Winter*

11:30 a.m. – 12:00 p.m. *(INVITED)* **M. E. McIntyre***, On Thinking Probabilistically*

Sessions Resume on Thursday at 9:00 a.m.

THURSDAY, 27 SEPTEMBER 2007

GENERAL DYNAMICS **LOCATION: MAIN HALL**
T. SHEPHERD: SESSION CHAIR

9:00 a.m. – 9:30 a.m. (*INVITED*) **R. K. Scott**, L. M. Polvani, D. W. Waugh, *The Circulation Response to Time-Dependent Tropospheric Wave Forcing in a Simple General Circulation Model of the Stratosphere*

9:30 a.m. – 9:50 a.m. **C. G. Fletcher**, P. J. Kushner, J. Cohen, *Can the Stratosphere Control the Extratropical Circulation Response to Surface Forcing*?

9:50 a.m. – 10:10 a.m. **A. J. Haklander**, P. C. Siegmund, H. M. Kelder, *Interannual Variability of the Stratospheric Wave Driving During Northern Winter*

10:10 a.m. **Coffee Break** **10:40 a.m.**

P. HAYNES: SESSION CHAIR

10:40 a.m. – 11:10 a.m. (*INVITED*) **T. Birner**, *Stratospheric Residual Circulation and Tropopause Structure*

11:10 a.m. – 11:30 a.m. **R. X. Black**, B. A. McDaniel, *Sub-Monthly Polar Vortex Variability and Stratosphere-Troposphere Coupling in the Arctic*.

11:30 a.m. – 11:50 a.m. **P. O. Canziani**, E. Agosta, E. Castañeda, *The Interannual Spatial Variability of the Southern Hemisphere Total Ozone Column Midlatitude Maximum*

11:50 a.m. – 12:10 p.m. **L. Sun**, W. A. Robinson, *Modeling the Downward Influence of Stratospheric Final Warming Events*

12:10 p.m. **Lunch** **2:30 p.m.**

PREDICTION AND THE STRATOSPHERE
N. OMRANI: SESSION CHAIR

2:30 p.m. – 3:00 p.m. (*INVITED*) **T. Reichler**, J. Kim, A. Kumar, S*hort-Term Climate Predictability Associated With Stratospheric Influences in Operational Forecast Systems*

3:00 p.m. – 3:20 p.m. **T. Hirooka**, T. Ichimaru, H. Mukougawa, *Predictability of Stratospheric Sudden Warming Events and Associated Stratosphere-Troposphere Coupling System*

3:20 p.m. – 3:40 p.m. **Y. Kuroda**, *The Role of the Stratosphere on the Seasonal Forecast Using MRI/JMA-Climate Model*

3:40 p.m. **Coffee Break** **4:10 p.m.**

N. GILLETT: SESSION CHAIR

4:10 p.m. – 4:40 p.m. (*INVITED*) **B. Christiansen**, *Stratosphere-Troposphere Coupling in Dynamical Seasonal Prediction*

4:40 p.m. – 5:00 p.m. **S. Ineson**, A. A. Scaife, *Influence of ENSO on European Climate via the Stratosphere*

5:00 p.m. – 5:20 p.m. **K. Kodera**, H. Mukougawa, Y. Kuroda, *A Numerical Forecast Study of the Impacts of a Stratospheric Sudden Warming on the Equatorial Troposphere*

5:30 p.m. – 7:00 p.m. *Poster Viewing: all posters will be on display in the Gallery for the duration of the conference*.

7:00 – 9:00 p.m. Reception to be held in Banquet Area and Courtyard; reception open to all conference registrants.

FRIDAY, 28 SEPTEMBER 2007

SOLAR VARIABILITY **LOCATION: MAIN HALL**
J. PERLWITZ: SESSION CHAIR

9:00 a.m. – 9:30 a.m. (*INVITED*) **S. Yoden**, K. Ito, Y. Naito, *Parameter Sweep Experiments on the Remote Influences of the Equatorial QBO and Solar Heating Around the Stratopause With a Mechanistic Stratosphere-Troposphere Coupled Model*

9:30 a.m. – 9:50 a.m. **I. Simpson**, J. D. Haigh, M. Blackburn, *Solar Influence on Stratosphere-Troposphere Dynamical Coupling*

9:50 a.m.– 10:10 a.m. **L. L. Hood**, *Solar Forcing of Climate Through the Stratosphere: Understanding the Observed Ozone and Thermal Response to 11-Year Solar Variability*

10:10 a.m. **Coffee Break** **10:40 a.m.**

MODELING/OZONE ASSESSMENTS
P. KUSHNER: SESSION CHAIR

10:40 a.m. – 11:10 a.m. (*INVITED*) **E. Manzini**, M. A. Giorgetta, M. Esch, E. Roeckner, *Extratropical Climate and the Modelling of the Stratosphere in Coupled Atmosphere Ocean Models*

11:10 – 11:30 a.m. **Y. Kawatani**, M. Takahashi, K. Sato, S. Miyahara, S. Watanabe, *3-D Activities of Equatorial Gravity Waves Simulated in a High-Resolution AGCM*

11:30 – 11:50 a.m. **M. Sigmond**, J. F. Scinocca, P. J. Kushner, *The Effect of Removing a Well-Resolved Stratosphere on the Simulation of the Tropospheric Climate, and Climate Change*

11:50 a.m. – 12:10 p.m. **A. R. Ravishankara**, *Assessments of the Stratospheric Ozone Layer: Past and Future*.

12:10 p.m.	**Lunch**	**2:30 p.m.**

2:30 p.m. – 3:40 p.m. *Synthesis Presentations and Discussion*

3:40 p.m.	**Refreshments**	**4:10 p.m.**

4:10 p.m. – 5:00 p.m. *Synthesis Presentations and Discussion*

Poster Sessions

All posters will be on display in the Gallery for the duration of the conference. Note: Posters are listed below in alphabetical order by last name of First Author; each listing begins with Poster Number.

A01 E. Agosta, P. O. Canziani, *A Case Study of Tropospheric Synoptic-Scale Wave Incursion into Lower Stratosphere*

A02 J. A. Añel, J. C. Antuña, L. de la Torre, J. M. Castanheira, L. Gimeno, *Climatic Aspects of Multiple Tropopauses from Radiosonde Data*

A03 J. A. Añel, L. de la Torre, L. Gimeno, *Changes in Tropopause Presssure and Temperature from Homogeneized Radiosonde Data*

B01 C. J. Bell, L. J. Gray, *The Response of Sudden Stratospheric Warmings to Increased* CO_2

B02 T. Birner, P. D. Williams, *Sudden Stratospheric Warmings as Noise-Induced Transitions*

C01 C. Cagnazzo, E. Manzini, *ENSO Teleconnections and Impact of Modeling the Stratosphere*

C02 P. O. Canziani, P. del V Repossi, *Interannual and Interdecadal Climatic Variations over the Southern Hemisphere: An Analysis of Climatic Shifts in Zonal Mean Geopotential Height Through the Troposphere and Stratosphere*

C03 J. M. Castanheira, M. R. L. Liberato, L. de la Torre, H.-F. Graf, A. Rocha, *Tropospheric Planetary Wave Excitation and Baroclinic Wave Energy Bursting Into the Stratosphere*

C04 H. Chepfer, P. Dubuisson, P. Minnis, M. Chiriaco, E. Riviere, *On the Characterization of Very Small Particles Observed in the Upper Troposphere/Lower Stratosphere at Global Scale with A-train Observations*

C05 A. A. Cheremisin, *Photophoretic Effects in the Stratosphere and Mesosphere*

C06 M. Chiriaco, H. Chepfer, C. David, V. Noël, *The Coupling of CALIPSO Lidar and Infrared Imager to Retrieve the Particle Size in Polar Stratospheric Clouds*

G01 J. C. Gille, J. J. Barnett, T. Eden, C. Hartsough, R. Khosravi, B. Nardi, *The Application of HIRDLS Data to Studies of the TTL and Stratosphere-Troposphere Exchange*

G02 M. Giorgetta, C. Timmreck, M. Thomas, M. Esch, H. Haak, J. Jungclaus, W. Müller, E. Roeckner, H. Schmidt, H.-F. Graf, G. Stenchikov, *Volcanic Eruptions and ENSO: Studies with a Coupled Atmosphere-Ocean Model*

G03 R. J. Greatbatch, S. Blessing, K. Fraedrich, *Unravelling the Role of the Stratosphere in the Atmospheric Circulation Trend During the Last Half of the 20th Century*

G04 S. Gupta, S. Lal, S.Venkataramani, Y. B. Acharya, *Enhancement in Ozone Concentration During the Pre-Monsoon Season (MAM), 2006 over the Arabian Sea; Stratosphere-Troposphere Coupling*

H01 Y. B. L. Hinssen, A. J. van Delden, *Mid-latitude Westerly Flow and Global Change*

H02 P. Hitchcock, T. Shepherd and C. McLandress, *Are the Coldest Winters Getting Colder?*

H03 K. Hocke, *Atmospheric Trends and Annual Oscillations Observed over Europe*

H04 J.-O. Hooghoult, J. Barkmeijer, *The Stratosphere-Troposphere Coupling During the Occurrence of Stratospheric Sudden Warmings Studied With the aid of Singular Vectors*

I01 S. Ineson, A. A. Scaife, J. Knight, *European Winter Climate and Stratosphere-Troposphere Interaction*

I02 Y. Izrael, I. I. Borzenkova, A. G. Ryaboshapko, D. A. Severov, E. A. Chayanova, *Possibility of Maintenance of Present-Day Climate Using Properties of Stratospheric Aerosol*

K01 P. Kenzelmann, S. Fueglistaler, T. Peter, M. Schraner, E. Rozanov, *The Impact of Increasing Methane Concentration on Stratospheric Chemistry and Dynamics and its Feedback on Troposphere*

K02 N. A. Kilifarska, *A Nature of Solar-QBO Interactions and their Role in the Tropical-Polar Teleconnections*

K03 P. Konopka, *Transport Across the Tropical Tropopause Layer (TTL) and its Role for the Troposphere-Stratosphere Coupling in a Changing Climate*

K04 K. Krüger, R. Hand, C. Timmreck, *Combined Effects of Volcanic Eruptions and ENSO in IPCC AR4 Experiments*

K05 P. Kushner, *Stratosphere-Troposphere Coupling and Links with Eurasian Land-Surface Variability*

K06 J. Kuttippurah, F. Lott, F. Vial, *Equatorial Waves in the Stratospheric Version of LMDz Model and in the NCEP Reanalysis*

L01 Q. Li, H.-F. Graf, M. A. Giorgetta, *Different Roles of Stationary and Transient Planetary Wave in Maintaining Stratospheric Polar Vortex Regimes in Northern Hemisphere Winter*

L02 G.-H. Lim and W. Choi, *The Three Dimensional Structure and Evolution of the Decadal Variability in the ECMWF Reanalyses*

L03 J. A. Lopez-Bustins, *Stratospheric Temperature in the North Pole and Iberian Peninsula Rainfall in March*

L04 H. Lu, *Middle to Late Winter Atmospheric Wind and Temperature Responses to Solar Irradiance and Geomagnetic Activity in the Northern Hemisphere*

M01 S. McDermid, M. Kurylo, G. Braathen, *Network for the Detection of Atmospheric Composition Change (NDACC)*

M02 R. Mizuta, *Transport Across the Extratropical Tropopause in an AGCM with the Horizontal Grid Size of 20 km*

M03 R. Mo, *Recent Stratospheric Temperature Trends in NCEP-DOE and NCEP-NCAR Reanalysis, with Dynamical Implications*

N01 K. Nishii, H. Nakamura, *Climatology and Interannual Variability of Upward and Downward Propagation of Rossby Wave Activity Across the Tropopause*

N02 N. E. Omrani, M. Latif, M. A. Giorgetta, *Dynamics of the Coupled System Stratosphere/Troposphere at Strong Polar Vortex*

P01 C. Pena-Ortiz, R. García-Herrera, P. Ribera, N. Calvo, *The Extratropical QBO Signature in the Northern Winter Hemisphere*

P02 D. H. W. Peters, A. Gabriel, *The Influence of Zonal Asymmetry in the Polar Vortex on Upper Tropospheric Rossby Wave Breaking Events*

R01 M. K. Reszka, S. M. Polavarapu, L. Fillion, *New 3D-Var Dynamical Constraints at Environment Canada*

R02 J. L. Russell, P. J. Goodman, *Southern Ocean Carbon Source or Sink?: The Role of Southern Hemisphere Westerlies*

R03 I. I. Rypina, M. G. Brown, F. J. Beron-Vera, H. Kocak, M. J. Olascoaga, A. Udovydchenkov, *On the Lagrangian Dynamics of Atmospheric Zonal Jets and the Permeability of the Stratospheric Polar Vortex*

S01 T. A. Shaw, M. Sigmond, J. F. Scinocca, T. G. Shepherd, *Spurious Sensitivity of Middle Atmospheric Climate Simulations to Model Lid Height due to Nonconservation of Angular Momentum*

S02 M. Sprenger, H. Wernli, *Diabatic Processes Associated with Stratosphere-Troposphere Exchange and Their Link*

S03 A. Stickler, A. Fischer, A. Lustenberger, S. Brönnimann, T. Griesser, E. Rozanov, *Variability of the Northern Polar Vortex During the Past 100 Years*

S04 J. Syktus, *The Impact of Stratospheric Ozone Depletion and CO2 on Southern Annular Mode and Regional Climate: Implications for Water Resources in Australia*

T01 M. A. Thomas, C. Timmreck, M. Giorgetta, H.-F. Graf, G. Stenchikov, *The Climate Impact of Mt. Pinatubo Eruption: Sensitivity to SSTs in a Middle Atmosphere Model*

T02 Y. Tomikawa, S. Watanabe, Y. Kawatani, K. Miyazaki, M. Takahashi, K. Sato, *A Mechanism for the Wintertime Temperature Maxima at the Subtropical Stratopause in a T213L256 AGCM*

W01 S. Watanabe, *Development of an Atmospheric General Circulation Model of an Integrated Earth System Model on the Earth Simulator*

Y01 Y. Yamashita and M. Takahashi, *Solar Cycle Modulation of Wave Forcing over Troposphere Related to the Annular Mode over Stratosphere*

ABSTRACTS

Monday, 24 September

Overview and General Dynamics

Annular Modes, the Fluctuation-Dissipation Theorem, and the Dynamical Response of the Atmosphere to Climate Perturbations

R. Alan Plumb [* R. Alan Plumb*] (Massachusetts Institute of Technology, Cambridge, MA 02139; Tel 617 253 6281; Email: rap@rossby.mit.edu) Michael J. Ring (Massachusetts Institute of Technology, Cambridge, MA 02139; Tel (617) 253-1541 Email: mring@mit.edu) Cegeon J. Chan (Massachusetts Institute of Technology, Cambridge, MA 02139; Tel 617939-6498 Email: cegeon@mit.edu

It is now well established that the structures classified as “annular modes,” characterizing variability of the zonal jets are also apparent as dominant components of the response to certain climate perturbations (such as increased CO_2 and depleted polar ozone). In fact, the fluctuation-dissipation theorem of Leith predicts such an outcome, with the response to imposed perturbations being proportional to the imposed forcing and to the autocorrelation time scale of the unforced fluctuations. By linearizing about the time-averaged climatological state and making a few further assumptions, we formulate the problem in terms of a single governing equation for the perturbed zonal mean flow, thus allowing straightforward analysis. Amongst other things, this approach makes explicit the way in which forcings of various kinds project onto the modes. Experiments with a simplified GCM produce responses to both imposed torques and thermal perturbations that are broadly in agreement with the theory, but with some significant quantitative discrepancies that are currently unresolved. It has been noted before (e.g., by Vallis and Gerber) that annular modes in some simplified GCMs may have autocorrelation times much longer than their observed counterparts. We argue that some previous studies of the impact of stratospheric perturbations may, for this reason, greatly exaggerate the tropospheric response.

A Paradigm for Variability in the Troposphere-Stratosphere System

A. O'Neill [*A O'Neill] (Department of Meteorology, University of Reading, PO Box 243, Reading, Berks., UK, RG6 6BB; ph. +44 1183788317; e-mail: alan@met.reading.ac.uk); A J Charlton (Department of Meteorology, University of Reading, PO Box 243, Reading, Berks., UK, RG6 6BB; ph. +44 1183786023; e-mail: a.j.charlton@reading.ac.uk)

The talk will present an alternative view to the traditional one of the dynamics of large-scale variability in the stratosphere. The traditional picture, which is often implicitly assumed if not explicitly acknowledged, is that large-scale dynamical variability in the stratosphere is driven by the upward propagation of transient planetary waves generated in the troposphere. The Eliassen-Palm flux near the tropopause is frequently presented as a diagnostic of this tropospheric "wave driving". The dynamical framework based on such such thinking is that of wave, mean-flow interaction. A refinement on this picture considers the feedback of the stratosphere on the troposphere, the two regions of the atmosphere now being considered as two interacting systems. Evidence from previous research with simplified models as well as observational evidence point to an alternative dynamical view. It is proposed that the variability arises from coherent non-linear vacillations in the troposphere-stratosphere, considered as a single system, rather than by external generation in a tropospheric "wavemaker" followed by vertical propagation. It is further proposed the variability may be more appropriately understood in terms of vortex-vortex interactions rather than in terms of wave, mean-flow interactions. An embellishment on this different paradigm considers the role of smaller scale eddies in the troposphere arising from baroclinic instability.

Downward Penetration of Dynamical Perturbations to the Upper Stratosphere

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Mechanisms whereby dynamical perturbations in the upper stratosphere can lead to a significant response in the lower stratosphere are considered, considering particularly at how this response is determined by the dynamics of the extratropical stratosphere. In a one-dimensional Holton-Mass type mode the lower stratospheric response is larger when the external parameters are such that the flow has multiple stable states. Correspondingly in a three-dimensional model the lower stratospheric response is much larger when the extratropical dynamics exhibits multiple steady states, vacillation or some other kind of strongly nonlinear behaviour. The implication is that dynamical sensitivity of the lower stratosphere to upper stratospheric perturbation might be peculiar to the actual state of the stratosphere in Northern Hemisphere winter and might not, for example, be exhibited if both hemispheres were 'Southern-hemisphere' like. Similar ideas are investigated in the context of the tropospheric response to stratospheric perturbation -- i.e. whether the actual tropospheric circulation is peculiarly sensitive and whether it might not be so sensitive if external parameters were different.

The NAO, Annular Patterns and All That: Is the Troposphere All We Need?

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We will review and discuss the underlying dynamics underlying the production of the main extra-tropical patterns of climate variability on intra-seasonal to inter-annual timescales. The primary dynamics resides, uncontroversially, in the troposphere, in the sense that a model atmosphere with specified surface conditions and essentially no stratosphere can readily produce NAO-like and annular mode-like patterns. Furthermore, almost uncontroversially, annular modes do not require annular dynamics; that is to say, purely annular patterns such as annular EOFs may be constructed from dynamics that is essentially zonally local. However, the above assertions do not mean that the stratosphere is not important in modulating the dynamics of the NAO and annular modes, nor do they mean that the dynamics of the NAO and annular modes is in fact zonally local. The stratosphere may bring zonal coherence at upper levels as well as longer timescales (as also may the ocean), and dynamics of a near hemispheric scale may be needed for the NAO.

The Effect of Poleward Propagation on the Stratospheric-Tropospheric Coupling in a Simple GCM

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Observations have shown that changes in the stratospheric Northern Annular Mode can sometimes be precursors to same-signed changes in the troposphere. Furthermore, numerical modeling studies have shown externally-forced stratospheric perturbations being capable of affecting the tropospheric climate (e.g. Song and Robinson 2004; Kushner and Polvani 2004). However, a theory describing this coupling remains incomplete. Stratospheric extratropical variability is generally dominated by the vertical propagation of planetary waves originating from the troposphere. Nonetheless, prior studies have omitted any topography that strongly contribute in generating these waves. Although the above studies have examined how downward control, eddy feedback and a combination of both in describing the stratospheric influence onto the troposphere, the focus here is to examine the role of planetary waves and how it fits into the above context. Using a simple AGCM, we investigate how topographically-forced stationary waves can impact the stratosphere in such a way to subsequently affect the troposphere. In addition, the effects of changing the location and amplitude of the artificial mountains will also be discussed.

The Balanced Response to Stratospheric Wave Drag and Diabatic Heating

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The amplitude of the observed tropospheric response to vacillations in the stratospheric flow is shown to be quantitatively similar to the zonal-mean balanced response to the anomalous wave forcing at stratospheric levels. The persistence of the tropospheric response is further shown to be consistent with the impact of anomalous diabatic heating in the polar stratosphere as stratospheric temperatures relax to climatology. The results suggest that variations in stratospheric wave drag are sufficiently large to account for the attendant changes in the tropospheric flow, but that stratospheric processes alone cannot account for the observed meridional redistribution of momentum within the troposphere.

Planetary Wave Induced Ozone Heating and its Effect on Troposphere-Stratosphere Communication

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Stratosphere-troposphere communication is an integral part of the climate system. Essential to this communication is a faithful representation of the interactions between dynamics, radiation and chemistry in the stratosphere. In this study linear and nonlinear mechanistic models are constructed that self-consistently couple dynamics, radiative transfer, and the transport and photochemistry of ozone. Central to these models is planetary wave-induced ozone heating. This wave-induced ozone heating mechanism hinges on wave-like perturbations in the wind and temperature fields producing wave-like perturbations in the ozone field. The phasing and structure of these three wave fields, which are coupled to each other as well as to the background distributions of wind, temperature and ozone, directly affect wave transience and wave dissipation, processes vital to the driving of the zonal-mean circulation. Here we focus on how planetary wave-induced ozone heating affects planetary wave drag (PWD), "downward control, and the reflection of vertically propagating planetary waves. Using Nathan and Cordero's (2007, J. Geophs. Res.) recently derived expression for an ozone-modified refractive index, analytical expressions are obtained for both PWD and downward control. These expressions clearly show the important connection between planetary wave-induced ozone heating and planetary wave reflection, which can combine to communicate natural and human-caused changes in stratospheric ozone to the troposphere. Using a mechanistic model of wave-mean flow interaction, the planetary wave-induced ozone heating is shown to significantly affect the period and intensity of the wave-mean interaction, which manifests in the frequency and strength of the model's stratospheric sudden warmings. These results are discussed in light of natural (e.g., solar cycle) and human-caused (e.g., CFCs) changes in stratospheric ozone.

The SPARC Dynamics and Variability Project

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Although we have known for some time that the tropospheric circulation influences the stratosphere, we have more recently learned that the stratosphere can in turn influence the tropospheric circulation all the way to the surface. This two-way stratosphere-troposphere coupling, which involves dynamical links between the stratospheric circulation and the tropospheric circulation, implies that the stratosphere can significantly influence the global climate system and the pattern and magnitude of global climate change. The goal of the Dynamics and Variability Project for SPARC (DynVar, www.sparcdynvar.org) is to approach the question of the dynamical influence of the stratosphere on the troposphere in a systematic way, proceeding from intraseasonal to climate timescales. The main activity for this effort will be to compare "high-top" atmospheric general circulation models (AGCMs) with good stratospheric representation against standard "low-top" AGCMs with the stratospheric representation typical of current climate models. A novel aspect of DynVar is that we will include ocean models coupled to these AGCMs to investigate in a more realistic setting the two-way troposphere-stratosphere coupling. In addition, DynVar will include a significant component devoted to the use of simplified models and more theoretical approaches to build our understanding of stratosphere-troposphere coupling.

What Controls Dynamical Timescales Near the Tropopause?

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The region of the polar Stratosphere just above the Tropopause (100-300hPa) has a decorrelation time of around 40 days, the largest in the extra-tropical atmosphere. Some recent efforts to improve seasonal forecasting in the extra-tropics have focussed on exploiting this long decorrelation timescale. However, it is unclear if the long decorrelation timescales in the lower Stratosphere are determined solely by long local radiative timescales, or are related to Stratospheric dynamics. A simple dynamical core which parametrises radiation physics using a Newtonian cooling scheme is used to investigate dynamical timescales in the lower Stratosphere. Several experiments, with different Newtonian cooling timescales in the Stratosphere but identical Newtonian cooling timescales in the Troposphere are conducted. Two regimes of dynamical behaviour in the lower Stratosphere are found. In one regime, decorrelation timescales are equal to the very short Newtonian cooling timescales. In a second regime, long decorrelation timescales related to Stratospheric dynamics occur, which exceed the input cooling rates by 30-40 days. The second regime only occurs when we include orography in the model. As in previous studies, dynamical timescales above the tropopause are shown to have significant impacts on dynamical behaviour in the troposphere.

Dynamical Time Scales in the Extratropical Lowermost Stratosphere

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The dynamical coupling of the wintertime extratropical stratosphere and troposphere is of great interest and has consequences not only for climate change but also tropospheric intraseasonal predictability. The potential for additional predictive skill comes from longer stratospheric dynamical time scales compared to the troposphere. Observational data as well as modeling studies also show significantly longer dynamical time scales in the lowermost stratosphere than at higher levels. This may be caused by the combined effect of longer radiative damping times there, non-linear wave-mean flow interactions, and the dynamics of the zonally symmetric part of the circulation.

This study investigates the role of the zonally symmetric circulation for the long dynamical time scales in the lowermost stratosphere in a dry primitive equation model in the quasi-linear (small amplitude) regime. Two sets of experiments are carried out, both including surface friction and a uniform radiative damping time throughout the model domain: (i) Stratospheric vertically deep zonal flow anomalies with their maximum in the upper stratosphere are radiatively damped towards a state of rest, and the effective decay time scales are determined. (ii) Stochastic zonal momentum forcing (zero mean AR(1)-process) is applied to an initially resting atmosphere, again with its maximum in the upper stratosphere, and the decorrelation time scales of the forced zonal flow anomalies are calculated. Both sets of experiments exhibit the following results: (a) At upper stratospheric levels of maximum initial anomaly/forcing amplitude the relevant dynamical time scales (decay and decorrelation times, respectively) are 2 to 3 times the radiative damping time, and (b) the dynamical time scales are found to be longer in the lowermost stratosphere, by about 30% to 40%, compared to upper levels. The dynamics of the zonally symmetric circulation is presented and discussed as well as the sensitivity of the results to changes in model parameters, in particular, the decorrelation time scale of the stochastic forcing. Furthermore, implications of these results for the role of downward control in stratosphere-troposphere coupling are made.

Tuesday, 25 September

Climate Change and the Stratosphere

Observed Recent Changes in the Tropopause

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Previous investigators have suggested that tropopause height may be a sensitive indicator of anthropogenic climate change, rising in association with both tropospheric warming and stratospheric cooling. Using radiosonde and reanalysis data, we examine changes in the tropopause over the past several decades and their relationship to temperature changes in the troposphere and stratosphere. Tropopause height trends over 1980-2004 are upward at almost all of the radiosonde stations analyzed, yielding an estimated global trend of 64 ± 21 m/decade (and corresponding tropopause pressure and temperature trends of -1.7 ± 0.6 hPa/decade and - 0.41 ± 0.09 K/decade, respectively). Tropopause height increases are spatially correlated with stratospheric temperature decreases but are uncorrelated with tropospheric temperature trends. This association of tropopause height and stratospheric temperature trends suggests that multi-decadal tropopause changes are primarily coupled with stratospheric temperatures. This behavior contrasts with tropopause variability on shorter (synoptic and monthly) time scales, when tropopause height variations are both anticorrelated with stratospheric temperature variations and positively correlated with tropospheric temperature variations. We also explore the details of tropopause changes in the subtropics, where the tropopause exhibits a bimodal height distribution, with maxima in occurrence frequency near 16-17 km (characteristic of the tropical tropopause) and below 13 km (typical of the extratropical tropopause). Both the radiosonde and reanalysis data show that the frequency of occurrence of high tropopause days in the subtropics of both hemispheres has systematically increased during 1979-2005, so that tropical characteristics occur more frequently in recent years. This behavior is consistent with a widening of the tropical belt, and the data indicate an expansion of 1.7± 0.8 degrees latitude per decade. This trend is consistent with recent findings by other investigators using different, independent indicators of the width of the tropical belt.

Stratospheric Climate Change and its Effect on the Troposphere

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During northern winter large amplitude anomalies in the strength of the stratospheric polar vortex frequently precede long-lived (up to ~two months) changes to the tropospheric circulation that resemble the Arctic Oscillation (AO). The same mechanisms that couple stratospheric variability to surface weather would also couple stratospheric long-term changes to surface climate. This is perhaps the most important, but least understood aspect of stratosphere-troposphere coupling. Perhaps the largest problem to be solved is predicting the future evolution of the stratosphere as greenhouse gases increase and the ozone layer recovers.

Temperature Trends in the Upper Troposphere and Lower Stratosphere as Revealed by CCMs and AOGCMs

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Simulations of 20th century temperatures from coupled chemistry-climate models (CCMs) used for the 2006 WMO/UNEP Ozone Assessment and atmosphere ocean general circulation models (AOGCMs) used for the 2007 IPCC Fourth Assessment Report are studied to better understand the role of interactive chemistry on temperature variability and trends in the upper troposphere and lower stratosphere. Climatological mean temperatures from the two model datasets are compared with observations to investigate annual and seasonal biases. Trend calculations between 1960-2000 are then examined to determine if CCMs are better constrained to observations in the stratosphere and upper troposphere than the AOGCMs. Trends in the 21st century are also investigated, and the relationship between these results and simulated fields of ozone will be discussed.

Past and Future Changes of Southern Hemisphere Tropospheric Circulation and the Impact of Stratospheric Chemistry-Climate Coupling

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The Goddard Earth Observing System-Chemistry-Climate model GEOS-CCM is used to investigate the impact of anthropogenic changes in atmospheric composition on the tropospheric Southern Hemisphere circulation. We will compare changes between the periods from 1971 to 2000 and from 2000 to 2099. We will describe the impact of polar ozone changes and increasing greenhouse gases, and will discuss possible mechanisms for tropospheric circulation changes. These include the impacts of both sea surface temperature changes due to increasing greenhouse gases and stratospheric circulation changes due to ozone depletion and eventual recovery.

Antarctic Tropospheric Response to Ozone Depletion is Dominated by Ozone Changes in the Mid-Stratosphere

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Simulations of the response to Antarctic stratospheric ozone depletion show a strengthening of the zonal circulation from the stratosphere to the troposphere and an accompanying summer cooling over Antarctica, consistent with observed changes. While the large mid-stratospheric ozone depletion is at a maximum in October-November, the smaller ozone depletion near the tropopause occurs around one month later, concurrent with the maximum tropospheric response. These results have prompted discussion over whether ozone depletion in the mid-stratosphere or in the lowermost stratosphere has been dominant in forcing observed surface climate changes. Two simulations with a high vertical resolution version of the Met Office Unified Model, in which ozone depletion was restricted to above and below 160 hPa indicate that the Antarctic tropospheric response is dominated by ozone depletion in the mid- and upper-stratosphere. An analysis of the components of the thermodynamic equation indicates an important contribution of dynamical heating changes to the stratospheric temperature response.

Longitudinally-Dependent Ozone Recovery in the Antarctic Polar Vortex Revealed by Satellite-Onboard ILAS-II Observation in 2003

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An analysis was made of horizontal structure of the ozone recovery in 2003 using data from satellite-onboard Improved Limb Atmospheric Spectrometer-II (ILAS-II), which were distributed uniformly in the zonal direction. In 2003, the Antarctic ozone hole was developed into one of the largest in the past. The analysis was focused on the period from late September to late October which was before the polar vortex breaking, and on the height of about 20 km corresponding to the top of the region where a severe ozone destruction occurred in August and early September. First, the decent rate of a level of a particular ozone mixing ratio near 20km in the polar vortex was estimated with the unit of (km/month). The obtained descent rate significantly depends on longitude. It was shown using ECMWF operational data that this feature was "roughly" explained by the longitudinally-dependent decent rate of isentropes caused by the evolution of a dominant wavenumber 1 "quasi"-stationary planetary wave. It is worth noting that the decent rate is fundamentally different from the vertical wind component of the planetary wave. One of the interesting and new findings is that the longitudinal dependence still remains for the decent rate of ozone estimated relative to the isentropes, namely, with the unit of (K/month). In other words, the ozone mixing ratio and its increase on an isentrope are not uniform in the polar vortex. Results of a backward trajectory analysis suggest that the air parcels having large ozone mixing ratio in the longitudinal sector around 180 degrees were mostly transported from the polar vortex edge region, while the trajectories of air parcels with small mixing ratio in the sector around 0 degree remain inside the polar vortex. This fact indicates that the lateral transport/mixing is important even in the time period when the polar vortex is stable. Another interesting result is that the decent rate of a level of N_2O (one of a long-lived species) mixing ratio was only a half of that of ozone around 20 km. This result means that the ozone was recovered faster than expected by the diabatic transport, and is consistent with the importance of lateral transport of ozone-rich air for the ozone recovery as suggested by the trajectory analysis.

Dynamical Impacts of Antarctic Stratospheric Ozone Depletion on the Extratropical Circulation of the Southern Hemisphere

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Southern Hemisphere springtime polar stratospheric zonal wind trends associated with the Antarctic ozone hole couple into the troposphere during December and January. Concurrent linear trends in both stratospheric and tropospheric variables are consistent with a delayed seasonal breakdown of the Southern Hemisphere stratospheric polar vortex and a positive tendency in the phase of the Southern Annular Mode (SAM). Decomposing these linear trends into a component linearly congruent with the SAM and its residual hints at the potential forcing mechanism behind the recent bias toward the positive phase of the SAM in the troposphere. Observations suggest that this bias has a direct link with the diabatic cooling of the stratosphere associated with the Antarctic ozone hole and, in particular, the reduction of downwelling radiation near the tropopause. Stratospheric linear trends in temperature are largest in November, but the temperature and downwelling longwave radiation trends near the tropopause strongly peak in December when the stratospheric zonal wind anomalies first couple to the troposphere. This dramatic decrease in downwelling longwave radiation at the tropopause may be essential to understanding the mechanism underlying stratospheric-tropospheric coupling. However, preliminary modeling results imply that other processes are more important.

Stratospheric Climate and Circulation Changes in the CCM Simulations Used for the 2006 Ozone Assessment

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In support of the 2006 WMO/UNEP Scientific Assessment of Ozone Depletion the Chemistry-Climate Model Validation Activity for SPARC (CCMVal) performed a coordinated set of reference simulations for the past and future. Thirteen chemistry-climate models (CCMs) participated. Using the meteorological output from these CCM simulations we will analyse and compare the predicted changes in the stratospheric climate and circulation for the 21st century. In particular we will investigate the role of long-term changes in dynamical (wave) forcing from the troposphere on the stratosphere and use the multi-model comparisons to assess the robustness (model independence) of the processes involved. The relative contributions in the models of low-frequency variability and anthropogenically forced trends to stratospheric change on the decadal time-scale will be considered.

How will Climate Change Affect Ozone Recovery?

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The recovery of stratospheric ozone as ozone-depleting substances decline through the 21st century will be affected by climate change. There is particular interest in the possibility of a circulation change - i.e. change in the Brewer-Dobson circulation - which would affect the ozone distribution as well as tropopause height. We have recently performed an ensemble of three simulations with the Canadian Middle Atmosphere Model (CMAM) from 1950-2100, which allows a detailed statistical assessment of this issue. The recovery of global ozone essentially follows the chlorine loading, suggesting there is no super-recovery in global ozone. However there is a strengthened Brewer-Dobson circulation - seen also in a decrease in age of air - most notably in the Northern Hemisphere. This leads to a persistent decrease in tropical ozone of about 2%, and to a dynamical super-recovery of about 4% in northern midlatitudes and about 8% in the Arctic. The changes occur principally in the lowermost stratosphere, and appear to be associated with changes in subtropical wave drag in the lower stratosphere. Possible reasons for this are discussed. The tropical changes are consistent with recent observations of ozone and temperature decreases just above the tropopause.

Investigation of Brewer-Dobson Circulation Changes in a Future Climate

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Climate-Chemistry Models (CCMs) include sophisticated representations of the stratosphere and interactive ozone chemistry and can therefore simulate changes to chemical composition (e.g. the ozone layer) and their coupling to climate change. There are clear indications derived from climate models as well as CCMs that stratospheric circulation is expected to change in a future climate due to enhanced greenhouse gas concentrations (see Chapter 5 in UNEP/WMO Ozone Assessment 2007). The exchange of air between the troposphere and the stratosphere is predicted to increase due to climate change, which will also decrease the average time that air remains within the stratosphere. The strengthening of the Brewer-Dobson circulation seems robust as a result of increased generation of planetary waves. Currently, we do not know the cause(s) or mechanism(s) for increased planetary wave-driving that modify stratospheric circulation. There is a strong need for improved understanding of the general stratospheric circulation. In this presentation we will discuss first results of long-term simulations carried out with the CCM E39C where we try to identify and quantify relevant processes as well as feedback effects which affect the Brewer-Dobson circulation and determine the predicted changes.

Wednesday, 26 September

The Tropics, Transport, and Statistics

Dynamical Balances and Tropical Stratospheric Upwelling

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The dynamical balances associated with upwelling in the tropical lower stratosphere are investigated, based on analysis of momentum and thermodynamic budgets. We focus on mechanisms that control the seasonal cycle of tropical upwelling, based on NCEP and ERA40 reanalysis data sets. Estimates of upwelling derived from momentum balance (or 'downward control') are in reasonable agreement with estimates estimated from thermodynamic balance, and the momentum balance calculations can be separated to isolate the influences of tropical versus extratropical forcing. We show that the time mean upwelling is primarily forced by extratropical eddy fluxes (associated with the equatorward propagation of midlatitude baroclinic waves), while the large seasonal cycle in upwelling is mainly driven by equatorial planetary waves forced by tropical convection. We extend the analyses to examine the mechanisms that produce increased stratospheric upwelling in long-term climate change simulations.

Winter Variability in the Stratosphere: Coupling Between the Arctic and the Tropics

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Large effects of solar variability related to the 11-year sunspot cycle (SSC) are seen in the stratosphere, especially over the Arctic, but only if the data are grouped according to the phase of the QBO. New results based on an extended, 65-year long data set fully confirm earlier findings. By means of teleconnections the dynamical interaction between the Arctic and the Tropics in the stratosphere and in the troposphere is shown for the whole data set and compared with the anomalies of single events. The results suggest strongly that during the northern winter the teleconnections between the Arctic and the Tropics were determined by the Major Midwinter Warmings (MMWs) and very cold winters, respectively. These events in the stratosphere depend, however, on the 11-year SSC and on the QBO.

Role of the Stratosphere in Climate Modelling: The Connection Between the Hadley and the Brewer-Dobson Circulation

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Coupled climate models do not generally include a proper representation of the stratosphere. Although such models may simulate the lower stratospheric response to tropospheric dynamical forcing, they likely distort any influence of the stratosphere on the troposphere. To evaluate the systematic influence of the stratosphere on the modeling of climate, two coupled atmosphere ocean models that differs only in their representation of the stratosphere and mesosphere have been assembled: the first is the ECHAM5/MPIOM (T63L31) model with 5 levels from 100 hPa to 10 hPa; the second is the MAECHAM5/MPIOM (T63L47) model with 21 levels from 100 hPa to 0.01 hPa (11 levels from 100 hPa to 10 hPa). Results are reported for multi-decadal simulations performed with both models. To investigate the causes and the direct and indirect (via coupling to the ocean) effects of the atmospheric model top and physics on the simulated climate, some of the results of the coupled models are intercompared with AMIP simulations performed with the respective atmospheric components. Results are presented for global mean aspects of the sensitivity of the climate system to the representation of the stratosphere. In particular a nearly uniform warming is found in the troposphere, largest in the tropics (~0.5 K) and a cooling (~2 K) in the lower tropical stratosphere. The associated vertical velocity differences in the tropical troposphere and stratosphere suggest a role of wave drag and convective processes for the coupling between the Hadley and the Brewer-Dobson circulations and hence for the sensitivity of the modelled climate to the representation of the stratosphere.

Strategies to Isolate the Impact of Changes in Stratospheric Chemistry on Climate due to Trends in Atmospheric Methane Concentrations

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Atmospheric methane concentrations have strongly increased since preindustrial times. Methane is a strong greenhouse gas, and this trend induces a strong climate forcing, leading to a warming of the troposphere. In the stratosphere, methane is oxidized to water, and a trend in methane entry mixing ratios induces a change in the radiative balance that has a characteristic latitudinal structure. Consequently, increasing methane concentrations may induce changes in the stratospheric meridional temperature gradient, and, coupled via thermal wind balance, zonal winds. The latter, in turn, may feed back on tropospheric dynamics. Because of the strong greenhouse forcing in the troposphere, the climate response to increasing methane concentrations is likely dominated by the changes in tropospheric dynamics, which also induce changes in stratospheric dynamics. Consequently, isolating the impact on climate due to changes in stratospheric composition is a challenge. Here, we present an approach to describe the response of this complex system with a set of partial derivatives, and strategies to evaluate these derivatives using a coupled chemistry climate model.

Interannual Variability of Transport Processes in the TTL During NH Winter

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Recent investigations of transport processes in the tropical tropopause region have shown that the interaction between vertical and horizontal transport plays an important role in dehydrating air while entering the stratosphere. Uncertainties in the formulation of vertical transport typically limit our understanding of the dynamical processes in the tropical tropopause layer (TTL). In this paper we present results of multi-year calculations covering the ERA40 and operational ECMWF analyses period. For this purpose we have developed a different approach to better constrain the vertical velocities in trajectory models of this region of the atmosphere: a reverse domain filling trajectory model driven by diabatic heating rates from the ECMWF's radiative transfer model. We focus on the northern hemispheric winter months which show the lowest temperatures during the seasonal cycle and hence the lowest stratospheric water vapour mixing ratios.

The analysis will focus on Lagrangian cold point tropopause (LCPT) temperatures, diabatic ascent rates and residence time within the TTL region, which have a strong impact on reliable studies of transport processes of e.g. very short live substances traveling from the surface to the stratosphere. The differences which arise from this new approach will be discussed in context with previous studies that relied on the noisy assimilated vertical wind fields. NH winter also shows a strong interannual variability in the LCPT, which will be investigated in more detail taking care of the most prominent dynamical mechanisms such as the influence of ENSO, QBO, solar cycle and volcanoes in driving this variability.

On Thinking Probabilistically

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Statistical inference is too important a topic to be left to the warring tribes of specialists. It's basic to all of science, as well as to related societal issues such as risk assessment. Most of us were taught to think of probabilities primarily as absolutes -- `the' probability of this or that -- thanks to the standard `frequentist' education in probability theory which, however, restricts attention to a tiny artificial category of thought-experiments. (Its influence still looms large in, for instance, this year's IPCC Chapter 9 on the attribution of climate change. There, the frequentist approach -- which conceals most of the relevant information on spurious grounds of `objectivity' -- is given equal weight with far more advanced, e.g., `Bayesian' and group-theoretic, approaches as if they were rivals on the same footing. That's like saying that one can see one's way equally well with and without blindfolding.) A clear light is thrown on all these issues by the theorems of Richard T. Cox, the statements and proofs of which I propose to discuss carefully since some authors still consider them controversial. (For more background see my short essay available here and its bibliography: http://www.atm.damtp.cam.ac.uk/ people/mem/#thinking-probabilistically)

Thursday, 27 September

General Dynamics

The Circulation Response to Time-Dependent Tropospheric Wave Forcing in a Simple General Circulation Model of the Stratosphere

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Using a simple, stratosphere-only GCM, we have recently shown that robust coherent, internal modes of stratospheric variability, (observed earlier in highly truncated models) exist when all forcings are time-independent. These purely internal modes of stratospheric variability consist of downward propagating patterns of zonal wind anomalies that closely resemble observations and are associated with large variability in the upward EP fluxes into the stratosphere. The nature of the variability places a strong constraint on the strength of the Brewer-Dobson circulation and the transport of chemical species within the stratosphere.

We further extended these results to the case when the forcing at the lower boundary of the model is time dependent, to assess the importance of internal stratospheric variability relative to variability forced by the active troposphere. We consider both periodic and random modulations of the tropospheric wave forcing, with the modulation period and amplitude as external control parameters. For periodic modulation, although the response can become frequency locked, the character of the variability strongly resembles the internal variability found in the absence of tropospheric modulation. Similarly, with random tropospheric modulation, significant power again persists at the internal frequency, even for large modulation amplitudes. In general, the stratospheric response appears to depend on an effective steady forcing equal to the root mean square of the time varying forcing, with the response period and amplitude similar to the corresponding internal mode. Our results suggest that, even in the presence of large time-dependent external forcing, internal dynamical modes play a fundamental role in determining the total stratospheric variability.

Can the Stratosphere Control the Extratropical Circulation Response to Surface Forcing?

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Snow extent anomalies over Siberia have been proposed as potential precursors to stratosphere-troposphere interaction events. However, often these events occur without a clear tropospheric precursor. We assess the role of snow cover in initiating such events in a 100-member ensemble of autumn-winter transient integrations using the Geophysical Fluid Dynamics Laboratory atmosphere/land GCM AM2/LM2. The forcing is a prescribed Siberia region snow mass perturbation, which does indeed induce a stratosphere-troposphere interaction response. On seasonal timescales we demonstrate that the coupling of the stratospheric response to the surface depends on the state of the stratosphere prior to the initiation of the forcing. An initially weak stratospheric polar vortex increases the likelihood of a negative Northern Annular Mode response at the surface. This result could have practical implications for the general problem of the prediction of circulation anomalies arising from surface forcing in the extratropics.

Interannual Variability of the Stratospheric Wave Driving During Northern Winter

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The strength of the stratospheric wave driving during northern winter is often quantified by the January–February mean poleward eddy heat flux at 100 hPa, averaged over 40°–80° N (or a similar area and period). Despite the dynamical and chemical relevance of the wave driving, the causes for its variability are still not well understood. In this study, ERA-40 reanalysis data for the period 1979–2002 are used to examine several factors that significantly affect the interannual variability of the wave driving. The total poleward heat flux at 100 hPa is poorly correlated with that in the troposphere, suggesting a decoupling between 100 hPa and the troposphere. However, the individual zonal wave-1 and wave-2 contributions to the wave driving at 100 hPa do exhibit a significant coupling with the troposphere, predominantly their stationary components. The stationary wave-1 contribution to the total wave driving significantly depends on the latitude of the stationary wave-1 source in the troposphere. The results suggest that this dependence is associated with the varying ability of stationary wave-1 activity to enter the tropospheric waveguide at mid-latitudes. The wave driving anomalies are separated into three parts: one part due to anomalies in the zonal correlation coefficient between the eddy temperature and eddy meridional wind, another part due to anomalies in the zonal eddy temperature amplitude, and a third part due to anomalies in the zonal eddy meridional wind amplitude. It is found that year-to-year variability in the zonal correlation coefficient between the eddy

temperature and the eddy meridional wind is the most dominant factor in explaining the year-to-year variability of the poleward eddy heat flux.

Stratospheric Residual Circulation and Tropopause Structure

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The effect of the stratospheric residual circulation on the thermal structure of the tropopause is studied. As is generally accepted, the cooling associated with the upward branch of the stratospheric residual circulation is at least partly responsible for the extremely low temperature of the tropical tropopause and its separation from the top of convection (i.e. the existence of the tropical tropopause layer). On the other hand, the warming associated with the downward branch of the stratospheric residual circulation lowers and warms the extratropical tropopause. The above described relationships lead to anticorrelated tropical and extratropical tropopause variability. This anticorrelation is quantified using output from the Canadian Middle Atmosphere Model (CMAM) and ERA40. Furthermore, upper tropospheric residual velocities are predominantly poleward in midlatitudes (near-zero vertical residual velocity). It is shown that this translates into a vertical gradient in vertical residual velocity in the midlatitudinal lowermost stratosphere. This vertical gradient is associated with a positive forcing of static stability in the lowermost stratosphere, which effectively enhances the sharpness of the extratropical tropopause by creating a layer of strongly enhanced static stability just above the tropopause - a layer that has recently been described in observational studies.

Sub-Monthly Polar Vortex Variability and Stratosphere-Troposphere Coupling in the Arctic

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The annual breakdown of the stratospheric polar vortex is known as the stratospheric final warming [SFW]. A recent observational study of boreal SFW events found that these events are associated with a vertically coherent north-south dipole pattern in the zonal wind anomaly field extending from the mid-stratosphere downward to Earth's surface at mid to high latitudes. However, this pattern is distinct from the canonical Northern Annular Mode (NAM) structure as the primary centers in the north-south anomaly dipole are retracted northward compared to NAM. These results suggest that SFW events are associated with distinct and previously unrecognized annular modes of variability at high latitudes. Here we explore this idea with a general characterization of the primary modes of intraseasonal variability in the wintertime stratospheric polar vortex. In contrast to previous studies, the current analysis concentrates on zonal-mean variability on short [daily] time scales within a limited spatial domain [the lower stratosphere at high latitudes] encompassing the stratospheric polar vortex.

An empirical orthogonal function analysis is used to characterize daily variability in the boreal stratospheric polar vortex. The leading EOF modes consist of vertically coherent north-south dipoles in the zonal-mean zonal wind extending through the mid to lower stratosphere. The first mode represents variability in the polar vortex strength and is highly correlated with the stratospheric NAM [or SNAM]. The second mode, referred to here as the Polar Annular Mode [PAM], represents variability in the latitudinal position of the polar vortex and is structurally and statistically distinct from SNAM, with the former having a northward retracted spatial structure. Composite analyses indicate that large amplitude PAM events are relatively short-lived [1-2 weeks] compared to their SNAM counterparts [1 month or longer]. Furthermore, trend analyses reveal that recent decadal trends in the boreal stratospheric polar vortex project more strongly onto PAM than SNAM.

Composite analyses illustrate that the time evolution of sudden stratospheric warming events is dominated by SNAM variability whereas both

SNAM and PAM play first-order roles in SFW events. Linear regression analyses reveal that SNAM and PAM are associated with circumpolar circulation and temperature anomalies of similar magnitudes within the high latitude troposphere. However, in both cases the regressed tropospheric circulation anomaly structures differ from the canonical tropospheric NAM structures identified elsewhere. It is concluded that PAM represents a previously unrecognized annular mode that is orthogonal to SNAM and strongly couples the stratosphere and troposphere on submonthly time scales at mid to high latitudes. We further posit that the SNAM/PAM framework provides a means for isolating the proximate tropospheric response to respective variations in the strength and position of the stratospheric polar vortex.

The Interannual Spatial Variability of the Southern Hemisphere Total Ozone Column Midlatitude Maximum: An Indicator of Tropospheric-Stratospheric Coupled Dynamics

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Several studies link the intraseasonal-to-interannual variability in Total Ozone Column (TOC) observed over the Southern Hemisphere to the atmospheric circulation coupling induced on the lower stratosphere by the tropospheric/stratospheric Southern Annual Mode (SAM). An interesting, though not much studied feature, of the low-frequency TOC variability is the slow eastward motion of the TOC maximum horseshoe-like structure at mid to high southern latitudes and the Atlantic Ocean TOC trough during winter and spring, observed in monthly fields over the last 20 years. The TOC horseshoe is similar in shape to the atmospheric circulation anomalies imposed by the SAM. However this eastward migration would appear to suggest either an eastward migration of the SAM mode or the existence of another source of variability in the lowers stratosphere during spring.

The aim of the work is to explore potential tropospheric-stratospheric mechanisms other than SAM that could explain this low-pfrequency variability in the TOC monthly fields. The interannual variability of the SAM in troposphere shows a more coherent structure with the stratosphere during January and June. However, this variability is less linked to the stratosphere's polar gradient in spring (Sep-Oct). This suggests that different coupling mechanisms are involved. The eastward evolution of the TOC for October can be related to a quasi-wave 1 anomaly imposed on the polar vortex variability, the latter controlled mainly by SAM, which could be related to a combination of tropospherically generated planetary waves and wave trains.

The analysis shows that the SAM has no eastward spatial evolution in the troposphere along the annual cycle and over the years sampled, with a barotropic structure at interanual scales; the horseshoe interannual-to-decadal variability can not be explained by the SAM alone. The results suggest significant contribution from tropospheric anomaly patterns over the southern Pacific and Atlantic Oceans.

Modeling the Downward Influence of Stratospheric Final Warming Events

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The Stratospheric Final Warming (SFW) is the final transition of the zonal winds from wintertime westerlies to summertime easterlies as the solar heating of the high latitude stratosphere increases in springtime. Recently, composite analyses of observations indicate that the SFW events may influence the tropospheric circulation: In the northern hemisphere (NH), a coherent pattern of significant zonal wind anomalies is observed to extend downward into the surface, while in the southern hemisphere (SH), only marginally significant anomalies are found in the troposphere. Understanding the physical mechanisms for this downward influence is essential if it is to be exploited to enhance atmospheric predictability during spring onset. Here an idealized atmospheric dynamical-core model is used to simulate SFW events, focusing on the mechanisms for stratosphere-troposphere coupling during spring onset. When the radiative equilibrium temperature in the stratosphere is gradually changed from a winter to a summer state, the model generates realistic SFW events. As in the observations, the simulated SFWs occur at different "dates". Thus we can form a climatological springtime transition and composite anomalies from this climatology. Our simulations for both non-topography and topography cases show that starting five days before the SFW, the stratosphere zonal wind rapidly decelerates, in association with a strong upward Eliassen-Palm flux anomaly Eliassen-Palm flux convergence. There are earlier events of wave driven zonal-wind deceleration, but their timing is different in simulations with and without topography. The composite zonal wind anomaly for these two types of SFWs are compared with each other and with observations of NH and SH events. For both of the SFW cases; a statistically significant zonal wind anomaly extends downward to the surface, similar to the NH observations. These tropospheric zonal wind anomalies are stronger in the simulations with topography. The composite of 1000hPa geopotential height anomaly and change pattern for topography SFW cases are also investigated.

Prediction and the Stratosphere

Short-Term Climate Predictability Associated With Stratospheric Influences in Operational Forecast Systems

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The majority of current forecast systems does not have an adequate stratospheric component to faithfully simulate the dynamical coupling between the stratosphere and the troposphere. This may lead forecast systems to not realize the full potential of short-term climate predictability related to stratospheric coupling. In this talk, we investigate this issue by analyzing how much practical forecast skill is associated with stratospheric influences in the current generation of operational models. In particular, we study long histories of sub-seasonal reforecast data sets generated by those models. By comparing the results from two different reforecast systems we will show (1) how much useful forecast skill of the surface AO is associated with dynamical coupling with the stratosphere and (2) how important a good representation of the stratosphere is for achieving such skill.

Predictability of Stratospheric Sudden Warming Events and Associated Stratosphere-Troposphere Coupling System

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Recently the predictability of stratospheric sudden warming events has attracted much attention by upsurging interests on stratosphere-troposphere dynamical coupling. Among them, sudden warming events after a cold and undisturbed early winter often show simpler time evolution than those in mid or late winter. In this study, we examine predictability of sudden warming events occurring in and after the 2001/02 winter using the Japan Meteorological Agency ensemble one-month forecast data. It is found that they showed various features of time changes of the polar vortex and accompanying anticyclones, contributed to by planetary waves and stratosphere-troposphere coupling; predictable periods of the sudden warming events change in a fairly wide range from one to three weeks. In case of a simple warming in December 2001 caused by amplified zonal wavenumber-1 planetary waves, the predictable period is estimated at least to be 16 days; such wavenumber-1 activity was closely associated with a persistent blocking over the Atlantic sector. On the other hand, the predictability is relatively low in other warming events, due mainly to the complicated time evolution of the warming episodes with significant contribution of smaller-scale planetary waves.

The Role of the Stratosphere on the Seasonal Forecast Using MRI/JMA-Climate Model

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The role of the stratosphere on the seasonal forcast of the tropospheric climate in winter is examined through ensemble forcast of the MRI/JMA climate model. The target periods we had examined are winters of 2002/3 and 2003/4. In the case of winter of 2002/3, the predictability of the tropospheric Arctic Oscillation (AO)-like variability was found to be relatively short (about 10 days) even after occurence of the stratospheric sudden warmings is well predictable. Note that in winter of 2002/3, the activity of the Polar-night Jet Oscillation (PJO) is relatively weak. In the case of winter of 2003/4, on the other hand, the tropospheric AO-like variability is well predictable after when occurence of the stratospheric sudden warmings is well predictable. In this case, the predictabity is found to be very long (one to few months). Note that in winter of 2003/4, the activity of the PJO is very strong. These suggest that the occurence and reproductability of the PJO play a important role for seasonal forcasting in winter. To examine the role of stratosphere on the predictablity of the seasonal forcast, we had performed the same ensemble forcast using the same model except without the stratosphere. It is found that the predicatability of the forcast is drastically reduced by this procedure. There experiments show that the stratosphere, especially the reproductability of the PJO, play an important role for long-range forcasting of the tropospheric climate.

Stratosphere-Troposphere Coupling in Dynamical Seasonal Prediction

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It is now well known that in winter mid-latitudes statistically significant correlations can be found between the stratospheric circulation and surface weather parameters when the stratosphere leads with 5-60 days. This coupling promises a potential for increased skill of extended range forecasts and season prediction in the mid-latitudinal region where such skills are notoriously small or even non-existent. We have previously shown that the skill of simple statistical forecasts utilizing the stratospheric information compares well to a state-of-the-art dynamical prediction system on lead times larger than 5 days. However, it is not clear to which extent the relevant stratospheric processes and the stratosphere-troposphere coupling are already represented in current dynamical seasonal prediction systems.

In this study we analyze the stratosphere-troposphere coupling in ECMWFs new dynamical seasonal prediction model (system 3). With this system re-forecasts are available for 25 years starting in 1980. We will investigate the connection between the stratospheric vortex (at 10 and 50 hPa) and both the large scale surface circulation (AO, NAO indices) and local surface parameters such as temperature and wind. The results will be compared to a similar study based on observations.

Influence of ENSO on European Winter Climate

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The existence of an extratropical ENSO signal in the stratosphere has been demonstrated in a number of observational and modelling studies. Filling of the polar cyclone and a weakening of the polar night jet during El Nino is likely due to an increase in the level of stratospheric wave driving by Rossby waves from the troposphere. A number of recent studies have looked at the effect of the stratosphere on the troposphere with a weakening of the polar night jet being associated with a surface response resembling the negative phase of the North Atlantic Oscillation. Consistent with these studies, recent observational results also indicate a link between El Nino and cold late winter European surface temperature in some but not all events.

Here we present results from a 4-member ensemble of experiments using an extended (60-level) version of the Hadley Centre climate model, HadGAM1. The model uses observed sea surface temperatures at its lower boundary and has been run from 1960 to 2002. A composite of El Nino events shows both an infilling of the winter polar vortex and a late winter negative NAO signal, indicating a potential source of seasonal predictability for Europe in winter.

A Numerical Forecast Study of the Impacts of a Stratospheric Sudden Warming on the Equatorial Troposphere

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Previous observational studies revealed that the equatorial convective activity is influenced by the stratospheric sudden warmings. In the present study the impact of the sudden warming of December 2001 is investigated by means of numerical forecast experiments. The forecast skill of the sudden warming was controlled by the small perturbations to the initial conditions. The impact of the sudden warming was then investigated by calculating the difference between the ensemble mean of successful warming runs and that of failed warming runs. The results showed that the amplification of the planetary waves produced a warming in the polar stratosphere and a cooling in the tropical stratosphere. Adding to that impacts are also found in the tropical troposphere. Zonaly averaged precipitation increased at the beginning of the stratospheric warming in the off equatorial region around 5N-10N, but it shifted southward over the equator during the mature phase of the warming.

Friday, 28 September

Solar Variability

Parameter Sweep Experiments on the Remote Influences of the Equatorial QBO and Solar Heating Around the Stratopause With a Mechanistic Stratosphere-Troposphere Coupled Model

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We have used mechanistic global circulation models with simplified physical processes in order to obtain deeper understanding of the dynamical coupling between the stratosphere and troposphere. We investigated the internal interannual variability of the coupled system (Taguchi et al., 2001; Taguchi and Yoden, 2002a,b), the effect of the equatorial quasi-biennial oscillation (QBO) on the global circulation (Naito et al., 2003; Naito and Yoden, 2006), and the detectability of a linear trend in a finite-length dataset with natural internal variability (Nishizawa and Yoden, 2005; Nishizawa et al., 2007). Stratospheric sudden warming (SSW) is a major event to produce the interannual variations of winter stratospheric circulation in the Northern Hemisphere and also an important candidate to cause the vertical linkage between the upper stratosphere and the lower parts of the atmosphere.

In this study, we use a mechanistic circulation model to study a possible downward influence of temperature variations around the stratopause that mimic the 11-year modulations of solar heating, in association with a particular phase of the equatorial QBO. Long time integrations over 10,000 days under a perpetual winter condition are made for 66 runs with the combinations of external parameters that control the QBO and the solar heating, and a statistical significance test on the difference of the time mean states is made based on such a large number of samples. A relationship of the occurrence frequency of SSWs and the temperature modulation of the winter polar stratosphere is obtained for the combination of the stratopause temperature variations and the equatorial QBO, consistent with the observed relationship (Labitzke, 1987; Labitzke and van Loon, 1988). However, the statistical significance is much lower than that for the difference between westerly and easterly QBO phases for the same data length. A possible explanation of the relationship will be given by the dynamics of planetary waves associated with SSW events.

Solar Influence on Stratosphere-Troposphere Dynamical Coupling

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There is increasing evidence that changing solar activity over the 11-year solar cycle influences the Earth's climate. However, as yet the mechanisms involved remain uncertain. One of the main problems is that the observed tropospheric response appears to be too large and too non-uniform to be explained by changes in the direct radiative forcing of the troposphere due to primarily changes in visible and infra-red radiation over the solar cycle. The temperature changes observed in the troposphere over the solar cycle are non-uniform and these are accompanied by variations in tropospheric circulation. A weakening and poleward shift of the mid-latitude jets along with a weakening and expansion of the Hadley cells and a poleward shift of the Ferrell cells is found at solar maximum compared to solar minimum. These circulation changes along with the non-uniform temperature changes points towards a dynamical response rather than simply altered direct radiative forcing. With the now widely accepted view that there is a two way dynamical coupling between the stratosphere and troposphere a possible explanation for these tropospheric temperature and circulation changes is through a dynamical response to stratospheric heating by increased UV absorption by stratospheric ozone. This work follows on from some previous modelling results (Haigh et al (2005)) which have shown that similar circulation and temperature changes to those found over the solar cycle can by produced by a dynamical response to increased heating of the equatorial stratosphere. We review that work and present a spin-up ensemble experiment using a simplified general circulation model to investigate the mechanisms by which altered stratospheric heating could produce such a response in tropospheric circulation. Results suggest that changes in eddy propagation are important in transmitting the effect of altered stratospheric heating to the troposphere below.

Solar Forcing of Climate Through the Stratosphere: Understanding the Observed Ozone and Thermal Response to 11-Year Solar Variability

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Reconstructions of global mean temperature records and total solar irradiance suggest a detectable solar influence on tropospheric climate occurring on decadal to millennial time scales (for a review, see J. D. Haigh, Phil. Trans. R. Soc. Lond. A, 2003). Estimated changes in total solar irradiance on these time scales are relatively small (e.g., ca. 0.1 per cent on decadal time scales) suggesting that an amplification mechanism is needed to explain the apparent surface temperature response. One such amplification mechanism involves solar-induced changes in stratospheric ozone and solar UV variations, which can affect the radiative forcing of the troposphere and, additionally, may modify stratosphere-troposphere dynamical interactions through changes in stratospheric thermal and zonal wind structure (e.g., Kodera and Kuroda, JGR, 2002). Currently, solar-induced changes in stratospheric ozone, temperature, and zonal winds occurring on decadal and longer time scales are not well understood; this limits the ability of climate models to simulate the tropospheric consequences of solar forcing.

In this paper, recent attempts to characterize and understand the stratospheric ozone and temperature response to solar forcing occurring on the 11-year time scale are reviewed. In the tropics, statistical analyses of satellite ozone data sets with lengths extending up to 25 years (Soukharev and Hood, JGR, 2006) confirm that statistically significant positive ozone responses exist in the upper and lower stratosphere but that the response in the middle stratosphere (about 28 to 38 km altitude) is not statistically significant. This vertical structure differs from that simulated by most models. A similar vertical structure is obtained for separate time intervals and is therefore difficult to explain by random interference from the equatorial quasi-biennial wind oscillation (QBO) and volcanic eruptions in the statistical analysis. The observed increase in tropical total ozone approaching the cycle 23 maximum during the late 1990's occurred primarily in the lower stratosphere below the 30 hPa level. Evidence for a corresponding solar cycle variation of tropical lower stratospheric temperature has also been reported based on analyses of Microwave Sounding Unit Channel 4 data and ERA-40 Reanalysis data. Possible origins for the lower stratospheric ozone and temperature response center on changes in the tropical upwelling rate driven by solar-induced changes in the thermal and zonal wind structure of the extratropical upper stratosphere (Hood and Soukharev, JAS, 2003; McCormack et al., JGR, submitted, 2007). Possible origins for the tropical minimum in the ozone response center on solar-induced perturbations of the QBO and consequent physical decadal ozone variations opposite in phase to those produced by solar UV variations.

Modeling/Ozone Assessments

Extratropical Climate and the Modelling of the Stratosphere in Coupled Atmosphere Ocean Models

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Simulations of the climate system with coupled atmosphere ocean models have been found to be sensitive to the modeling of the stratosphere for mean global aspects, such has the tropospheric temperature and the meridional circulation. Here the focus is on the role of the representation of the stratosphere in coupled atmosphere ocean models at high latitudes, during the Northern hemisphere winter and spring seasons. Making use of the availability of multi-decal simulations for fixed past climate conditions with a "high top" model (explicitly including the representation of the stratosphere, MAECHAM5) and a "low top" model (standard climate model with top somewhere in the stratosphere, ECHAM5), this analysis is a prerequisite for the use of middle atmosphere models in climate change studies. Previous observational and modeling works have provided evidence that the stratosphere may play an active role in hemispheric tropospheric variations on intraseasonal timescales. By comparing standard measures of tropospheric variability and its connection to the lower stratosphere in AMIP simulations as well as the simulations with coupled atmosphere ocean models for the "high top" and the "low top" atmospheric models, respectively, the role of the stratosphere on surface characteristics such as sea level pressure, surface air temperature and sea ice concentration is reported.

3-D Activities of Equatorial Gravity Waves Simulated in a High-Resolution AGCM

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Numerous observational, theoretical and modeling studies have shown that the energy and momentum transports by gravity waves (GWs) have important effects on the large-scale circulation and thermal structures of the middle atmosphere. Due to relatively small temporal and spatial scales, it is difficult to investigate global characteristics of GWs with the observed data alone. Atmospheric General Circulation Model (AGCM) is one of the effective tools to study GWs globally (cf. Sato et al. 1999; Kawatani et al. 2003, 2004, 2005; Watanabe et al. 2006). CCSR/NIES/FRCGC AGCM with resolution of T213L256 is used in the present study. The vertical resolution is set about 300 m with top boundary of ~80km. Although no gravity wave drag parameterization is included in the model, the QBO-like oscillation is clearly simulated with periods of ~16 months. The amplitude of easterly (westerly) phase is ~30m/s (20m/s) with bottom levels around 80 hPa. Amplitudes and bottom levels of QBO-like oscillation are quite realistic, which could not be well simulated in T106L60 AGCM by Kawatani et al. (2005). Recently, Miyahara (2006) derived a three dimensional wave activity flux applicable to inertio-GWs. The flux gives the wave-action density flux relative to the local time mean flow. GW components are extracted with a cut-off periods of 3days. Results using this flux show that in the equatorial upper troposphere, convectively generated GWs which large vertical flux of eastward (westward) momentum is associated with are excited in the Eastern (Western) Hemisphere. The Walker circulation which has different direction of zonal wind between the Eastern and Western Hemisphere plays crucial roles on selective filtering of GWs. Spectrum analysis reveals that in the upper troposphere and lower stratosphere, strong eastward (westward) forcing due to GWs is formed over easterly (westerly) of the Walker circulation. In the altitude where the phase of QBO changes from easterly to westerly, eastward forcing in the Eastern Hemisphere is much greater than that in the Western Hemisphere. 3-D distribution of Equatorial waves and its roles on QBO will be also discussed.

The Effect of Removing a Well-Resolved Stratosphere on the Simulation of the Tropospheric Climate, and Climate Change

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It is well known that the troposphere influences the stratosphere through angular momentum transfer mediated by upwardly propagating planetary and gravity waves. In recent years, evidence has mounted for a downward influence of the stratosphere on the troposphere, primarily through interactions of the planetary waves with the mean flow. Thus, for example, the effects of ozone depletion can interact with those of climate change. An important question is how high the model domain needs to be in order to correctly represent these effects.

In this study we employ a comprehensive GCM to first investigate the magnitude and direct impact of this downward influence on present-day climate and its variability. We undertake a series of AGCM simulations employing "low-top" (troposphere only) and "high-top" (well resolved stratosphere) configurations of the Canadian Middle Atmosphere Model (CMAM) and discuss some of the difficulties in performing controlled experiments of this sort. The results indicate that there can be significant artifacts arising in the low-top configuration. We consider the impact of these artifacts on the climate change response of the model by performing a series of CO2 doubling experiments.

Assessments of the Stratospheric Ozone Layer: Past and Future

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The science of the stratospheric ozone layer continues to progress. In the process, the scientific efforts have contributed to decision-making on a major societal issue- the depletion of the ozone layer due to human-induced emissions and how to deal with it. The decision-making has at its very foundation the science findings as derived from the assessment of the knowledge by the scientists working in this field. Now that this process of assessment has been taking place for more than two decades, it is a god time to ask: what next? I will describe the science issues that have dominated the past assessments and speculate on what is likely to follow. A few organizational issues such as better coordination, or joint ventures, with the IPCC process will also be noted.

ABSTRACTS

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

A Case Study of Tropospheric Synoptic-Scale Wave Incursion into Lower Stratosphere

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The stratospheric polar vortex is the dominant feature in the Antarctic stratosphere during the wintertime and spring. Its yearly evolution and dynamics are crucial in determining the size and depth of the Antarctic ozone hole as has been dramatically demonstrated by the 2002 polar vortex early break-up.The daily overall evolution of the polar vortex/ozone-hole system has been linked to the evolution of the planetary wave structures during winter and spring. However, the relationship between the wave forcing originating from the troposphere and the polar vortex/ozone hole system deformation is not yet well understood. Canziani and Legnani (2003) have shown that over the Southern Hemisphere (SH) sizeable synoptic scale waves can be present even up to 50hPa, noting their presence in the vicinity of the storm track at mid to high latitudes, depending upon the background wind conditions. Some of the most significant stratospheric penetrations occurred directly in the vicinity of the Antarctic polar vortex edge. Hence, the research aims to deep in understanding the coupling dynamics observed during two case studies: in the period 6-9 Oct 1990 (event I, E-I) and 17-18 Oct 1990 (event II, E-II). The case of E-I corresponds to strong quasi-stationary planetary waves and limited baroclinic waves while E-II corresponds to weakening planetary waves and fairly strong synoptic-scales signatures. The daily atmospheric reanalysis fields are smoothed using a 7-term gaussian filtering function in time in order to separate quasi-stationary planetary waves (over 8 days) and short-scale synoptic waves (below 7 days). The stratosphere/troposphere coupling dynamics is investigated through the diagnostic basic-flow-wave interaction flux W proposed by Takaya and Nakamura (2001). This is a phase-independent wave-activity flux for stationary and migratory quasi-geostrophic waves on a zonally varying basic flow suitable for a comparative study between these two events. The preliminary results suggest that the daily polar vortex/ozone hole evolves in accordance to lower troposphere baroclinic surfaces. The short-scale baroclinic wave penetration into the stratosphere seems not to contradict the Charney-Drazin theory, but rather leads to its generalization for regional flow conditions.

Climatic Aspects of Multiple Tropopauses From Radiosonde Data

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In the last years, the research on tropopause and multiple tropopause events had gained an increasing interest. In this paper we show several climatological features of these events, such as the occurrence frequency and its trends, pressure levels, temperature and thickness of multiple tropopause. The events were studied separately of each season of the year. The relationship between tropopuase features and low frequency variability modes is also studied. Centres of multiple tropopause occurrences are detected and increasing trends in the percentage of multiple tropopause cases are found out for all the globe and for each hemisphere separately. Differences in tropopause parameters were found between single, double or triple tropopause events and considerable seasonal and latitudinal influence. The relationship with low frequency variability modes shows clear influence of QBO, SOI and NAM 50 hPa on the multiple tropopause. Possible mechanisms explaining some of the observed features are suggested.

Changes in Tropopause Presssure and Temperature from Homogeneized Radiosonde Data

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Changes in the tropopause pressure have been previously addressed as a promising climate change fingerprint by several authors. In this work we studied variations in the tropopause pressure and temperature using radiosonde data for a global subset of stations from the Integrated Global Radiosonde Archive (IGRA), the most comprehensive radiosounding database. This subset gives us an optimal spatial and temporal coverage. Finally homogeneization procedures are applied to the data series in order to remove possible inhomogeneities, using both computational methods and metadata.

The Response of Sudden Stratospheric Warmings to Increased CO2

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GCM studies of the NH winter stratosphere under $2xCO_2$ and $4xCO_2$ will be described. These enhanced levels of CO_2 are employed to gain statistical significance of the results. Similar experiments have also been carried out using a model of intermediate complexity that allows extremely long runs, which is an alternative method of ensuring statistical significance. The expected global stratospheric cooling is modified by a warming of the NH Arctic winter lower stratosphere. This is shown to be associated with an increase in the number and timing of stratospheric sudden warmings, as found by other authors. The impact of these vortex changes on the underlying tropospheric circulation will be described, with particular emphasis on the AO/NAO signature and the height distribution of the autocorrelation timescale, which is a useful indicator of stratospheric impact on the troposphere. Results from similar experiments in which an El Nino-like tropical SST forcing has been applied will also be presented. The behavior and tropospheric impact of the modified polar vortex will be described and compared with the CO_2 results.

Sudden Stratospheric Warmings as Noise-Induced Transitions

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Sudden stratospheric warmings (SSWs) are usually considered to be associated with planetary wave activity. Here it is asked whether small-scale variability, e.g. related to gravity waves, can lead to SSWs given a certain amount of planetary wave activity that is by itself not able to cause a SSW. A recently proposed highly truncated version of the Holten-Mass model of stratospheric wave-mean flow interaction (Ruzmaikin et al., 2003) is extended to include stochastic forcing. In deterministic setting, this low-order model exhibits multiple stable equilibria corresponding to the undisturbed vortex and SSW-state, respectively. Momentum forcing due to quasi-random gravity wave activity is introduced as an additive noise term in the zonal momentum equation. Two distinct approaches are pursued to study the stochastic system. First, initialized at the undisturbed state the system is numerically integrated many times in order to derive statistics of first passage times of the system undergoing a transition to the SSW-state. Second, the Fokker-Planck equation corresponding to the stochastic system is solved numerically in order to derive the stationary probability density function of the system. Both approaches show that even small to moderate strengths of the stochastic gravity wave forcing can be sufficient to cause a SSW for cases where the deterministic system would not have predicted a SSW.

ENSO Teleconnections and Impact of Modeling the Stratosphere

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The impact of the ENSO warm events on the Northern Hemisphere winter polar stratospheric circulation has been documented in several works. These works reported a general polar warming of a few degrees in the lower stratosphere in late winter and spring, with a weakened polar vortex due to enhanced planetary-wave vertical propagation from the troposphere. The purpose of this work is to investigate the possible role of the stratosphere-troposphere coupling in the ENSO teleconnections to the Northern Hemisphere extratropics in late winter / early spring through the analysis of the ENSO signal from the troposphere to the stratosphere and possibly from the stratosphere to the surface. In order to achieve this aim, we analyse a set of ensemble simulations performed with the MAECHAM5 and ECHAM5 Models, respectively including and not including a well resolved stratosphere, forced with observed SSTs during the 20-yr period from 1980 to 1999.

Interannual and Interdecadal Climatic Variations over the Southern Hemisphere: An Analysis of Climatic Shifts in Zonal Mean Geopotential Height Through the Troposphere and Stratosphere

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The aim of this study is to evaluate the climate disturbances detected through abrupt variations in geopotential height over the Southern Hemisphere, between 20°S and 70°S, both in the troposphere and the stratosphere, in zonal-mean monthly mean anomalies, using techniques as Yamamoto´s method. Such an approach has been used in the past only to detect climatic jumps using annual means anomalies. In this work we also discuss possible causes for such behaviour. By considering both tropospheric and stratospheric discontinuities it is possible to assess their extent and the degreee of coupling between these two atmospheric layers layers. Starting with the well established 1976/77 Pacific climatic shift, associated with pronounced changes in the ocean circulation as noted by various authors, its impac on the overlying atmosphere is

analyzed as well as subsequent climatic disturbances. A number or disturbances following that major shift are detected with differencial response in the region, many of which can be associated with ENSO events. Each Niño event has characteristics in common as well as its own evolution/signature. In general the disturbances associated with ENSO in the 1980s reach the stratosphere from September to November. Meanwhile in the 1990s it happens between January and March. A disturbance probably associated with the Benguela Niño phenomenon is also detected. There are few studies looking into the vertical coupling mechanisms for such processes. About the SAO, a disturbance is detected in the troposphere (until 300 hP) at 10/79 equatorward 50°S, and in the troposphere and lower stratosphere at 9/79 poleward 60°S. the date of the disturbance detected and the range of latitudes involves is coherent with previous studies.

Tropospheric Planetary Wave Excitation and Baroclinic Wave Energy Bursting Into the Stratosphere

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A study of the energy associated with planetary waves, during rapid stratospheric vortex decelerations and rapid accelerations, is presented. Positive energy anomalies associated with tropospheric planetary waves are observed during the phases of strong stratospheric vortex. High peak maxima of the energy associated with baroclinic planetary waves are observed during vortex decelerations. The vertical propagation of planetary waves requires they have a baroclinic structure (they must have a westward phase tilting with height) and the energy peaks suggest energy wave burstings into the stratosphere. During the weak vortex periods the energy associated with tropospheric planetary waves is generally smaller than the climatologic values, and the vortex accelerations are accompanied by noticeable negative anomalies of the energy associated with baroclinic planetary waves. Results give clear evidence of the troposphere-stratosphere wave driven coupled variability: The vortex variability is forced by baroclinic planetary wave burstings. On the other hand, the tropospheric wave energy content seems to respond to the vortex status. Results suggest that the response is mediated by changes of the topographic forcing due to zonal mean zonal wind anomalies which progress downward from the stratosphere.

On the Characterization of Very Small Particles Observed in the Upper Troposphere/Lower Stratosphere at Global Scale with A-train Observations

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Negative brightness temperature differences between 11 and 12 µm have been observed with MODIS above cold thick ice cloud in tropical convection regions. These spectral signatures suggest that very small particles appear in the upper troposphere / lower stratosphere. The signatures of those small particles are associated to very low temperature in the tropics over convective clouds and over Antarctica during the PSC season. These particles maybe partially composed of nitric acid trihydrate due to local HNO3 increase coming from lightning and/or zonal transport. They may contribute to the regulation of water vapour in UTLS. The study presented here will focus on the characterization of those particles at global scale using A-train observations: the CALIPSO lidar (attenuated backscatter profile) allow detecting optically thin particle layers above convection regions, and describing their properties (depolarization and color ratio signals), and MODIS (negative brightness temperature differences) allow detecting the presence of very small particles above thick clouds.

Photophoretic Effects in the Stratosphere and Mesosphere

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Stratospheric aerosol can play an essential role in the climate processes. Stable aerosol layers are observed at different altitudes in the stratosphere and the mesosphere of the earth. However an interpretation of these and other known facts of stratification in the atmosphere meets certain difficulties. Basically, the gravito-photophoresis allows to explain existence of observed layers at altitudes about 20, 50, 70 and 80-83 km (Cheremisin A.A., Vassilyev Yu.V., Horvath H., 2005). Two different photophoretic forces can occur- caused by the temperature variation over the particle surface and induced when there is sufficient difference in the values of a thermal accommodation coefficient. There are three mechanisms of lifting force inducing-classical photophoretic effect and gravito-photophoresis of two different types (Rohatschek, 1996; Cheremisin, Vassilyev and Kushnarenko, 2002). It was shown that the altitudes at which gravito-photophoretic forces balance the gravities correspond to ones at which the observed aerosol layers exist in the real atmosphere. This investigation is supported under grant 07-05-00734 by the Russian Fund of Basic Research.

The Coupling of CALIPSO Lidar and Infrared Imager to Retrieve the Particle Size in Polar Stratospheric Clouds

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Polar Stratospheric Clouds (PSC) can be separated into two categories: type I, that contain condensate nitric acid, and type II that contain ice water and that are closed to cirrus clouds. In 2002, the WMO (World Meteorological Organization) has noticed that one of the main uncertainties in the prevision of polar ozone, a capital chemical and radiative component, is associated to the future evolution of PSC in a changing climate. Actually, PSC play a major role on the destruction of polar ozone, with a positive feedback: the stratospheric ozone decrease induces a temperature decrease in the polar low stratosphere that favours the PSC formation, and so favours the ozone destruction processes. Because of their sedimentation, PSC are also responsible of the dehydration of the polar low stratosphere in Antarctic. PSC have not been observed so much, except from ground-based stations, and so a better characterization of their properties is necessary, especially at large scale. For example, the PSC particle size (i) determines the available area for heterogeneous chemical reactions that induce the chlorinate activation and so the ozone destruction; (ii) informs on the cloud particle sedimentation, hence on the dehydration of the polar low stratosphere.

In the Aqua-Train, the instruments on-board CALIPSO satellite offer the possibility of characterizing the PSC particle size, based on the method developed in Chiriaco et al. (2004) that combine 532-nm lidar measurements and the so-called split window technique based on the infrared spectral information contained at 8.7-, 10.5- and 12 µm bands. The lidar returns are employed to detect PSC. The optical properties of several PSC particles sizes and the cloud altitude (from lidar) are used in radiative transfer simulations that fully account for both gaseous absorption and multiple scattering processes in the atmosphere, to calculate the brightness temperatures in the three infrared channels. Brightness temperatures differences are then compared to their measured counterparts (from CALIPSO infrared imager) for the different particle models. The best agreement between simulations and observations leads to the particle size. With this particle size, it is possible to calculate the particle area and so the quantity of activated chlorinate, for finally estimate the quantity of destructed ozone.

The Application of HIRDLS Data to Studies of the TTL and Stratosphere-Troposphere Exchange

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The High Resolution Dynamics Limb Sounder (HIRDLS) instrument on NASA's EOS Aura satellite was designed to make observations of temperature, ozone, water vapor, thin cirrus, and 8 other trace species from the upper troposphere up to the stratopause and above, with high vertical resolution. Although the instrument performance was degraded by an unexpected event during launch, a great deal of progress has been made in correcting for its effects. At this time measurements of temperature, ozone and water vapor with 1 km resolution can be achieved in the UT/LS region as well as measurements of thin cirrus. In this presentation we will show examples of these data, with some initial applications to show the temporal and spatial variations in the tropopause region. Particular emphasis will be placed on indications of strat-trop exchange and its spatial patterns. Attention will focus on the tropics, but results from initial looks at mid-latitude data will also be described. Finally, some thoughts on further applications will be presented.

Volcanic Eruptions and ENSO: Studies with a Coupled Atmosphere-Ocean Model

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Large volcanic eruptions have a significant impact on stratospheric and tropospheric climate, atmospheric composition and circulation. After large tropical eruptions observations and subsequent years model simulations show abnormally warm winters over the Northern Hemisphere continents in years following the eruption. During the winters following the three biggest eruptions in the last decades (Agung, El Chichon and Pinatubo) El Ninos took place. It is currently uncertain to what degree ENSO influences the atmospheric response to volcanic forcing and or in which way a volcanic eruption influences the strength and the timing of an El Nino event.

Fully coupled Atmosphere-Ocean GCMs are therefore an important tool to improve our current understanding of the atmosphere and ocean response to the combined effects of El Nino and large tropical volcanic eruptions. We have carried out a series of Pinatubo experiments with the coupled atmosphere ocean circulation model, the ECHAM5/MPIOM. The volcanic radiative forcing is calculated online in the model using a realistic spatial-temporal distribution of aerosol optical parameters derived from satellite observations. We present results of ensemble simulations when the volcanic eruption appears for different states of ENSO: before the onset and during an El Nino event, during a La Nina episode and for a climatological mean. Each ensemble run has been performed for two years.The discussion includes the changes in atmospheric and ocean circulation and in planetary wave propagation. Special emphasis will be placed on the circulation changes in Northern Hemisphere winter and the role of the stratosphere.

Unravelling the Role of the Stratosphere in the Atmospheric Circulation Trend During the Last Half of the 20th Century

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A tangent linear adjoint model is used to determine the optimal forcing perturbation to a dynamical model required to excite the northern hemisphere winter tropospheric circulation trend during the last half of the 20th century. A significant feature is forcing for the top model level resembling the annular mode. When the optimal forcing perturbation is applied to the top level of a nonlinear version of the model with a realistic climate, the model successfully reproduces the atmospheric circulation trend over the Euro-Atlantic sector. We argue that the top level optimised forcing mimics the influence of the stratosphere on the tropospheric circulation trend, lending support to previous work by Scaife et al. (2005).

Enhancement in Ozone Concentration During the Pre-Monsoon Season (MAM), 2006 over the Arabian Sea; Stratosphere-Troposphere Coupling

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Tropospheric ozone concentrations have increased since the preindustrial era due to antropogenic emissions of the ozone precursors, such as nitrogen oxides (NOx), carbon mono-oxide (CO), methane (CH4) and non -methane hydrocarbons (NMHCs) (Kley,1988). In the Stratosphere, ozone depletion has occured during the last few decades, primarily through catalytic cycles involving chlorine and bromine species,both of which have been enhanced by human activity (WMO, 2003). In the future, tropospheric ozone is expected to increse furthur due to enhanced ozone precursor emissions (Parther et al., 2001). Stratospheric ozone is expected to recover as a result of the Montereal protocol and its amendments (WMO, 2003). Ozone a ects the raditive budget of the atmosphere through its interction with both shortwave (SW) and Longwave(LW) radiation and its chemical influence on other radioactively active trace gases. Reductions in lower stratospheric ozone imply a positive SW and negative LW raditive forcing while tropospheric ozone increase leads to a positive radiative forcing in both SW and LW spectral regions. There are inadequate observations of the changes in tropospheric ozone on a global scale. Northern and western Arabian Sea is the least studied region of the Indian ocean as most of the earlier studies (e.g. INDOEX) have focused on the eastern / Southern Arabian Sea. Furthermore, the winter season (NE monsoon) periods have received much attention since they involve planetary scale atmospheric changes and transport from Indian sub continent. In contrast, the pre monsoon transition periods in March-May and Sep-Nov have not been studied in detail. Although they are main rainy season for eastern Africa. Winds are strongest during monsoon transition period. To study this transition period, Indian Space Research Organization Geosphere Biosphere Programme (ISRO GBP) has made a measurement campaign over the Bay of Bengal region and the Arabian Sea region during spring (MAM), 2006 to provide a comprehensive data set for tracegases and aerosol study and their chemistry from a combination of aircraft, ground based and shipboard platforms. In this paper, we first describe the ozonesonde observations and characterize the campaign periods in terms of the ozone concentration over the Arabian Sea. After that we focused on the cases of ozone structured layer observed in the troposphere.

Experimental Setup: We have launched 15 Balloon flights from Arabian Sea during April May 2006. Most of the balloons have crossed up to 30 km except few of them which could cross only up to 25km. Vertical profiles of ozone were measured using balloon-borne electro chemical ozonesondes. Relative humidity, air temperature and pressure were measured with RS-80 Vaisala radiosondes. Each ozonesonde has an Electrochemical Concentration Cell (ECC), which serves as ozone sensor, a non-reactive air pump and an electronic interface board (Komhyr, 1969). Further, ozone ECC consists of two platinum electrodes immersed in potassium iodide (KI) solution.

Results and Conclusions: Surface CO and CH4 were found to be in the range of (0-120 ppbv) and (1.70 1.86 ppmv) respectively. South AS shows higher concentrations of CO and CH4 as compared to north AS. Both CO and CH4 were found to be highest in the latitude range (812 N) because of the winds prevailing from gulf and African countries. While in the other latitude range (12-16 N and 16-20 N) due to the transition period the wind pattern was mainly from oceanic region. Profile of 5 May 06 shows long range transport of ozone from Pacific Ocean via united state, Atlantic Ocean and Africa up to 16 km of altitude. So this high ozone could be because of transport from the higher latitudes. Potential Vorticity at 200hPa also shows subsidence over this region on 5th May. These results will be presented and discussed in detail during the poster session.

Mid-latitude Westerly Flow and Global Change

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In this research we investigate if the observed temperature increase at the Earth's surface in winter in Western Europe is related to changes occurring in the potential vorticity distribution in the stratosphere over the North pole (due to more greenhouse gases in the stratosphere). We first show that the North Atlantic Oscillation (NAO-) index is correlated with winter temperatures in Western Europe. We then show that a high (low) NAO-index is associated with high (low) potential vorticity over the pole in the stratosphere. Finally, by solving the invertibility principle for potential vorticity over the northern hemisphere, we find, for January, that the monthly average westerly component of the balanced wind associated with the potential vorticity in the positive NAO-phase is up to 10 m/s larger than the monthly average westerly component of the balanced wind associated with the potential vorticity in the negative NAO.

Are the Coldest Winters Getting Colder?

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Observations of the Arctic stratosphere suggest that the volume of air below the thermodynamic threshold for the formation of Polar Stratospheric Clouds during the coldest winters has been steadily increasing since the 1960s (Rex et al. 2004 GRL), despite any apparent cooling trend in mean temperatures. It has been argued that this is a sign of climate change. In hopes of understanding possible mechanisms for such a trend, we present an analysis of polar stratospheric temperatures in an ensemble of three 150-year integrations of the Canadian Middle Atmosphere Model which include the combined effects of ozone depletion/recovery and climate change. While the distinct radiative impacts of ozone depletion and carbon dioxide increase are clearly seen in the southern hemisphere in terms of changes in temperature extremes, in the northern hemisphere any such signal is overwhelmed by the strong variability of the Arctic vortex.

Atmospheric Trends and Annual Oscillations Observed over Europe

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The annual oscillation transports energy and momentum from the tropics to middle and high latitudes. The atmospheric composition over Europe experiences variations due to the seasonal change of the solar zenith angle and associated advection of tropical and polar air masses. The observed rapid increase of temperature and water vapor in the troposphere over Europe during the past decades might be partly due to changes of the atmospheric circulation. The meridional circulation is strongly forced by solar heating of atmospheric water vapor at low latitudes. Water vapor, sea surface temperature, and atmospheric temperature of the tropics depend on natural oscillations of the ocean-atmosphere system (e.g., ENSO, QBO) but also on long-term influences by anthropogenous emissions of greenhouse gases. Analyzing time series of wind, temperature, water vapor, and ozone over Switzerland, we find a large increase of the annual oscillation (AO) of water vapor. The AO amplitude of the meridional wind of the upper troposphere, lower stratosphere, and the stratopause region is modulated by ENSO, so that the AO possibly interacts with equatorial oscillations as assumed by Mayr et al. (2007). We find upward and downward propagation of anomalies in the time-height cross-sections of the AO amplitudes of various parameters. The observed linear trends and anomalies of atmospheric composition, energetics, and dynamics are discussed with consideration of meridional and vertical coupling processes of the mid-latitude atmosphere.

The Stratosphere-Troposphere Coupling During the Occurrence of Stratospheric Sudden Warmings Studied With the aid of Singular Vectors

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In order to get insight in the instability mechanisms in the stratosphere and the dynamical processes that play a role in the interaction between the stratosphere and troposphere during the occurrence of stratospheric sudden warmings (SSW's), we have calculated and studied stratospheric singular vectors (SV's). To that end we have used a recent version of the ECMWF model with 60 levels in the vertical and the top level at 0.1 hPa. We will discuss the results we have obtained for two experimental set-ups. For both set-ups, the SV's are located initially in the low stratosphere (between 10 and 100 hPa). In the first set-up the SV's are constructed to mainly amplify in the stratosphere (above 100 hPa). In the second set-up the SV's are forced to propagate downward to the low troposphere (below 500 hPa). Calculations are done for optimization times of 2 and 5 days. The properties of both types of SV's will be discussed in terms of amplification, preferable geographical position, possible mechanism for perturbation growth and their relation with tropospheric SV's. Results will also we discussed in terms of potential vorticity (PV).

European Winter Climate and Stratosphere-Troposphere Interaction

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A combination of modelling experiments and observational datasets is used to estimate the influence of stratospheric variability on surface European climate in winter. Stratospheric changes appear to be important for the very rapid warming of Europe in winter between the 1960s and 1990s and associated changes in the frequency of climate extremes. The winter of 2005/6 is used as a case study to illustrate how this influence occurs in individual years.

Possibility of Maintenance of Present-Day Climate Using Properties of Stratospheric Aerosol

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One of the most important tasks of present-day is a necessity of climate maintenance on its modern level. It is assumed that one of the most effective methods of climate maintenance could be usage of stratospheric aerosol layer, which is able to reflect a part of solar radiation back to the space. In the work, available information on quantitative relations between mass of stratospheric aerosol of volcanoes origin and global near-surface atmospheric temperature has been analyzed. The data on temporal variations of aerosol optical depth for vertical atmospheric column after Pinatubo eruption are discussed. Evaluation of possible reduction of solar radiation by artificial sulfate aerosol in the size range of 0.3-2.5 um introduced into the low stratosphere was done on the base of Mie theory of light scattering. Optimal size of the particles, which can provide maximum scattering of solar radiation to the space was determined. Using semi-empirical theory of thermal atmospheric regime, an estimate of change of average Earth temperature has been done for mass of 1 Mt of aerosol in the stratospheric layer. Possibilities to use different sulfur-containing gases as precursors of additional sulfate stratospheric layer have been investigated, and it has been shown that the injection of hydrogen sulfide can be the most effective. Some possible negative ecological effects of the proposed method like precipitation acidification, stratospheric ozone depletion, and reduction of solar radiation flux for ecosystems have been considered. It is assumed that the method can be used in the case of beginning of really dangerous and even catastrophic consequences of climate change, when the warming will threaten to exceed a certain critical value. Some first results of the work were published in: Yu.Izrael, 2005. Effective way to preserve climate on the current level - the basic task of solving the climate problem. Meteorology and Hydrology, 10, pp. 5-9 (in Russian); Yu.Izrael, I.Borzenkova, and D.Severov, 2005. Role of Stratospheric Aerosols in the Maintenance of Present-Day Climate. Russian Meteorology and Hydrology, Vol. 32. No. 1, pp. 1-7 (Allerton Press Inc., 2007).

The Impact of Increasing Methane Concentration on Stratospheric Chemistry and Dynamics and its Feedback on Troposphere

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We present model calculations of the impact of the strong increase in methane concentrations since preindustrial times on climate. We seek to separate the effect of increasing methane concentrations in the stratosphere from that of the troposphere. The changes in stratospheric methane entry concentrations are among the best established trends in stratospheric composition over the past 200 years or so. Methane is of particular interest because it oxidizes to water in the stratosphere and influences the ozone chemistry. Hence a trend in methane induces a systematic change in the latitudinal structure of radiative absorption and emission in the stratosphere. These, in turn, may induce latitudinal temperature trends, and coupled via thermal wind relation, changes in zonal winds that eventually may feed back on tropospheric dynamics. Using a global coupled chemistry - climate model, we perform a suite of experiments designed to isolate the impact on global climate from changes in stratospheric chemistry. The experiments are designed to answer the following questions: (1) Is the main impact due to changes in the CH4-H2O/radiative balance, or is the impact on O3-chemistry, and associated changes in radiative budgets, overwhelming? Do highly non-linear effects, e.g. arising from heterogeneous chemistry on PSCs despite minute chlorine loading, play a role? (We deliberately exclude the impact of changes in chlorine loading, and assume climatological background concentrations.) (2) Is there a systematic change in latitudinal temperature- and zonal wind structure of the stratosphere? (3) If yes - are there patterns of change in the troposphere that could be related (following recent work on stratosphere-troposphere coupling) to the changes observed in the stratosphere? (4) Is the impact of changes in stratospheric chemistry robust if we allow changes in tropospheric methane, or do corresponding tropospheric changes, e.g. in planetary wave activity, induce changes in stratospheric circulation that overwhelm any signature of the impact of changes in stratospheric chemistry? Preliminary analysis suggests that changes in methane concentrations in the range of 0.7 ppmv to 2.7 ppmv do not significantly affect the methane to water vapour ratio, and that methane-induced changes in stratospheric water vapour can be well estimated from today's ratio. Increasing stratospheric methane concentrations lead to significant cooling of the mesosphere. Changing methane concentrations have an impact on active chlorine, nitrate and hydrogen, all of which induce systematic, latitude-dependent (including hemispheric asymmetries) changes in ozone.

A Nature of Solar-QBO Interactions and Their Role in the Tropical-Polar Teleconnections

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It will be presented a unified concept aimed to interpret the horizontal (tropics-pole) and vertical (troposphere-stratosphere) coupling in the light of QBO-Solar signal interactions and corresponding changes in the wave propagation conditions. The role of UTLS (upper-troposphere-lower stratosphere) region in this coupling will be discussed as well as the potential consequences for the main tropospheric and stratospheric circulations. We will show also that a strong weakening of the polar vortex is closely related to the equatorial lower stratospheric easterly winds. The role of QBO westerlies possibly depends on the latitude of wave dissipation in the middle and upper stratosphere, i.e. – waves breaking near the equator unlock trans-equatorial heat transport from the summer hemisphere, strengthening the polar vortex, while those breaking northward of subtropics decrease the speed of polar jet. The contribution of solar variability is to reduce efficiency of QBO easterly winds in weakening the polar vortex (as solar activity increases), and to enhance the ability of equatorial westerlies to influence the polar atmosphere. This rule can be violated in periods of very high solar activity, due to the better wave propagation conditions, allowing waves' penetration and dissipation into the mesosphere and making the polar vortex more susceptible to the influence of the stronger Brewer-Dobson circulation.

Transport Across the Tropical Tropopause Layer (TTL) and its Role for the Troposphere-Stratosphere Coupling in a Changing Climate

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The tropical tropopause layer (TTL) is the source region for stratospheric air and has been identified as a key region for the interaction of stratospheric chemistry and climate. The composition of the air entering the stratosphere is mainly determined by the transport processes within the TTL coupling the Hadley circulation in the tropical troposphere with the much slower, Brewer-Dobson circulation in the stratosphere. During recent tropical campaigns which took place in Brazil (Troccinox 2005), Australia (Scout 2005) and Africa (Amma 2006), chemical species were measured on-board of the high flying research aircraft Geophysica (ozone, N2O, CH4, CO2, CO, water vapor) in the altitude range up to 20 km (or up to 450 K pot. Temp), i.e.~well-covering the TTL region roughly extending between 350 and 420 K. This unique data set, together with the multi-annual (2001-2006) model simulations with the Chemical Lagrangian Model of the Stratosphere (CLaMS) allows to check our understanding of the dynamical processes occurring in the TTL. In addition to the convection and radiation-dominated parts of transport, the composition of air above 350K is strongly influenced by mixing on a time scale of weeks or even months. Based on CLaMS transport studies where mixing can be completely switched off, we deduce that vertical mixing, mainly driven by the vertical shear in the tropical flanks of the subtropical jets and, to some extent, in the outflow regions of the large-scale convection offers an explanation for the upward transport from the main convective outflow around 350 K up to the tropical tropopause around 380 K. Thus, the seasonal dependence of the composition of the TTL is controlled by the permeability of the subtropical jets with a strong influence of the Asian monsoon during the boreal summer. We discuss the impact of these effects on the formation of the stratospheric tape-recorder.

Combined Effects of Volcanic Eruptions and ENSO in IPCC AR4 Experiments

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Major volcanic eruptions have a significant impact on stratospheric and tropospheric climate, chemical composition and the atmospheric circulation. The effects are global if the volcanoes are located in the tropics and subtropics, where, besides Indonesia and the Philippines , Central America is a major source region. In this paper the effects of the major volcanic eruptions since 1860 are analysed in more detail using the coupled atmosphere ocean model ECHAM5/MPI-OM with a top layer of the model lid at 10 hPa (approx. 30 km altitude). This model was run in an IPCC AR4 experiment from 1860 to 1999 including major volcanic eruptions. To derive a statistical analysis three ensemble runs have been carried out. The model simulates the atmospheric feedbacks with an interactive ocean, taking care of the long-term memory of the ocean for climate change scenarios, but with a limited representation of the Brewer-Dobson Circulation (BDC). The ocean is coupled in a free running mode, which enables us to investigate the impact of volcanic eruptions taking care of different ENSO phases. The climate impact of volcanic eruptions on the atmosphere is investigated by analysing global temperature anomalies, the Arctic oscillation patterns and the impact on sea level rise in more detail.

Stratosphere-Troposphere Coupling and Links with Eurasian Land-Surface Variability

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A diagnostic of Northern-Hemisphere winter extratropical stratosphere-troposphere interactions is presented to facilitate the study of stratosphere-troposphere coupling and to examine what might influence these interactions. The diagnostic is a multivariate EOF combining lower-stratospheric planetary wave activity flux in December with sea-level pressure in January. This EOF analysis captures a strong linkage between the vertical component of lower stratospheric wave activity over Eurasia and subsequent development of hemispheric-wide surface circulation anomalies, which are strongly related to the Arctic Oscillation. Wintertime stratosphere-troposphere events picked out by this diagnostic often have a precursor in autumn: years with large October snow extent over Eurasia feature strong wintertime upward-propagating planetary wave pulses, a weaker wintertime polar vortex, and high geopotential heights in the wintertime polar troposphere. This provides further evidence for predictability of wintertime circulation based on autumnal snow extent over Eurasia.

Equatorial Waves in the Stratospheric Version of LMDz Model and in the NCEP Reanalysis

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Equatorial waves play a significant role in the dynamics of the tropical stratosphere. The waves have been used to describe some of the basic phenomena of the climate of low latitudes like, Semi Annual Oscillation, El-Nino Southern Oscillation, Madden Julian Oscillation and Quasi Biennial Oscillation (QBO) through wave mean flow interaction. In addition, they also contribute to the dehydration at the tropical tropopause. At present limited knowledge of the waves and their structure are available to the scientific community; especially representation of the waves in the chemistry climate models. A reasonable representation of these tropical waves is essential for a good calculation of the stratospheric dynamics. In order to extract equatorial waves in the LMDz model, a new method is developed. The waves in the LMDz stratospheric model are extracted using the novel method that mixes spectral analyses techniques with the equatorial waves theory. In this work, the equatorial waves are analysed in a 20 year simulation with the LMDz model, which are compared to those extracted from the NCEP reanalyses data during the time period of 1981-2000. The analysis is focussed on the Kelvin wave with zonal wave number (s) =1, Rossby wave with s=1, and Rossby Gravity (Yanai) wave with s=4. Descrepancies between the waves in the simulations and reanalyses data are crtitically discussed in terms of the limitations of the model calculations in a dynamical perspective.

Different Roles of Stationary and Transient Planetary Wave in Maintaining Stratospheric Polar Vortex Regimes in Northern Hemisphere Winter

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The different roles of the stationary and transient planetary waves in the Stratosphere-Troposphere interaction in Northern Hemisphere (NH) winter are shown through the climatology of the Eliassen-

Palm flux and its divergence by analyzing the NCEP/NCAR reanalysis data. It is found that both the stationary waves and transient waves contribute to maintaining the stratospheric polar vortex regimes in NH winter, but in different ways. In strong (weak) polar vortex regimes, the transient waves propagate more (less) at mid and high latitudes (around 60N) while the stationary waves propagate less (more) in polar area (around 75N) from the troposphere to the stratosphere. Moreover, the low frequency transient waves dominate the propagation of transient waves.

The Three Dimensional Structure and Evolution of the Decadal Variability in the ECMWF Reanalyses

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By investigating the correlation/covariance structure of the ECMWF variables, properly time filtered by using wavelet analysis, correlated/regressed with a key time series of the 1000 hPa southerly winds at a grid point (0, 30 W), we were able to identify the comprehensive structure and evolution of the decadal oscillation globally. Horizontally the decadal oscillation is basically confined to tropical regions with very weak signature in the extratropics for the meteorological parameters such as relative humidity, specific humidity, temperature, winds in their means and variances and correlation and covariance statistics. While vertically the decadal signatures clearly manifest themselves up to the upper limit of the ECMWF analyses for the ozone density, zonal winds, and relative humidity near the tropopause level. The maximum variability of ozone mass mixing ratio appeared near 20 hPa level approximately. The evolution of the decadal components in each atmospheric variables such as winds, ozone, and relative humidity are very consistent with each other. Strong and consistent signatures in the structure and its evolution of the decadal oscillations clearly outrun the restrictions in data record length and some defects of too much strong convections over the tropics, which are the inherent propensity of the ECMWF reanalysis for studying oscillations with periods of about 10 years or more.

Stratospheric Temperature in the North Pole and Iberian Peninsula Rainfall in March

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The recent negative significant trend of precipitation over most of the Iberian Peninsula is an obvious fact. This study seeks a possible cause of polar vortex behaviour in late winter. A reduction of northern polar stratospheric temperatures in March since the end of the seventies might lead to a strengthening of the west winds at high levels (northern annular mode –NAM– high index), and consequently at surface level (Arctic oscillation index –AOI– increase), by means of a stratosphere-troposphere coupling. During the last two decades, the number of March months with warm stratospheric anomalous temperatures has decreased, but those with a cold and undisturbed vortex have increased. In order to validate the hypothesis, a T-mode Principal Component Analysis was applied to a daily data grid (NCEP/NCAR reanalysis) at sea level pressure (SLP) over Western Europe for those March months with a positive anomalous temperature in the North Pole (30h-Pa) and for those March months with a negative anomalous one. The circulation patterns obtained are compared with the rainfall anomalies over the Iberian Peninsula. The results validate the hypothesis, as they show that those March months with a very cold middle to low North Pole stratosphere have a strengthening of the westerlies in comparison with those with a warm one. It currently implies a more frequent anticyclone weather type in March over the Iberian Peninsula, which significantly reduces precipitation.

Middle to Late Winter Atmospheric Wind and Temperature Responses to Solar Irradiance and Geomagnetic Activity in the Northern Hemisphere

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By using Era40 reanalysis and ECWMF operational data from 1958 to 2006, this study demonstrates that changes in both solar irradiance and solar wind can influence atmospheric circulation. It is shown that, in the northern hemisphere and during middle to late winter, statistically significant solar F10.7-cm radio flux (Fs) signals in both the wind and temperature anomalies can be found when January geomagnetic Ap index is high. Such geomagnetic activity modulated Fs signals appear mostly in the sub-tropical to mid-latitude stratosphere. The signals construct a vertical descending pattern from February to April and become more or less stationary during May to August. Similar enhanced Fs signals are found when the stratospheric quasi-biennial oscillation (QBO) at 50 hPa is westerly. Alternatively, stronger Ap signals in wind and temperature anomalies can only be found when Fs is high. The solar irradiance modulated geomagnetic activity signals are distinct from those of geomagnetic activity modulated solar irradiance signals. When November to January averaged Fs is high, the Ap signature in the wind anomalies is evident as a dipole pattern with the negative correlations centred at 30°N, 50 hPa, and positive correlations centred at 60°N, 50 hPa, similar to that of northern annular mode (NAM). For those affected regions, up to 50% of the variances of the wind and temperature anomalies can be explained by those solar related indices. These results strongly suggest that the solar influences on the atmospheric circulation are of multiple sources and the signals of solar irradiance and geomagnetic activity tend to enhance each other. These results help to identify the responsible mechanisms for the apparent solar signal amplification in the atmospheric variables.

Network for the Detection of Atmospheric Composition Change (NDACC)

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The international Network for the Detection of Stratospheric Change (NDSC) was formed to provide a consistent standardized set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed research stations. Officially operational since 1991, the NDSC was conceived and formalized during the late 1980s in response to the need to document and understand worldwide stratospheric perturbations resulting from increased anthropogenic emissions into the atmosphere of long-lived halogenated source gases with strong ozone-depleting and global-warming potentials. Recognizing the increased scope of the network and to better reflect the free tropospheric and stratospheric coverage of Network measurement, analysis, and modeling activities, as well as to convey the linkage to climate change, the Steering Committee voted in 2005 to change the name of the network to the Network for the Detection of Atmospheric Composition Change (NDACC): Monitoring Changes in Atmospheric Composition and Their Links to Ozone Depletion and Climate. Accordingly, the network web site has been changed to http://www.ndacc.org. In this presentation we will give a brief overview of the operation, goals, and achievements of the NDACC.

Transport Across the Extratropical Tropopause in an AGCM with the Horizontal Grid Size of 20 km

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Transport process across the extratropical tropopause is investigated using an atmospheric global climate model with the horizontal grid size of about 20km, which can depict filamental structures near the tropopause. The model is TL959L60 version of the JMA/MRI global atmospheric general circulation model, which is used both for operational numerical weather prediction and climate researches. Time integrations over 20 years were performed making use of the Earth Simulator, one of the fastest computers available for meteorological applications, and the model's ability of simulating the present-day climate has been confirmed from global scale through small scale, including storm tracks and tropical cyclones. Idealized passive tracer which is initialized to 1 above 2 PVU surface and 0 below that (following Gray,2006) is advected for 24 hours. Transport across the tropopause is evaluated by comparing the tracer and 2 PVU surface at the final time. Calculation is 3D online with semi-Lagrangian, same as the model dynamics. The tracer is initialized each day of one particular month in the 20-year simulation and the monthly mean transport is estimated. The horizontal resolution dependence is also examined using the coarse-resolution (200km) model. Both stratosphere to troposphere transport and troposphere to stratosphere transport have their maximum amounts at 300hPa in January and at 200-250hPa in July. Above 400hPa, about a half of the transport amount in each direction is simulated in the 20-km model compared with the 200-km model. However, net transport from the lowermost stratosphere to the troposphere does not depend on the horizontal resolution and total amount of the net transport is consistent with the residual mean circulation estimation of the transport from the polar stratosphere to the lowermost stratosphere. Net troposphere to stratosphere transport is seen above 300hPa and is large near the subtropical jet over Eurasia. Large part of this transport is attributed to the temporal change of PV estimeted from vertical difference of longwave radiation. Net stratosphere to troposphere transport is seen below 400hPa and is large over the Pacific and Atlantic storm track. The spatial distribution of the transport is similar to that estimeted from the effect of latent heat, but the estimation is not quantitatively enough to explain the transport.

Recent Stratospheric Temperature Trends in NCEP-DOE and NCEP-NCAR Reanalysis, with Dynamical Implications

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The NCEP-DOE reanalysis (R-2), covering 1979-present from the Earth's surface to the middle stratosphere (10 hPa), is an improved version of the well-known NCEP-NCAR reanalysis (R-1). The usefulness of these global datasets in detecting climate change is assessed in this study with an analysis of the recent temperature trends in the lower stratosphere. In general, both R-1 and R-2 capture the substantial cooling trend of the global and annual-mean temperature in the stratosphere, with the cooling rates in R-2 somewhat larger than their R-1 counterparts. Embedded in the cooling trend are two noticeable transient warming bites after the El Chichon (1982) and Pinatubo (1991) volcanic eruptions. The meridional structure of annual-mean trends has a tropical cooling center near the tropopause (100 hPa), two subtropical cooling centers in the middle (or upper) stratosphere, and a cooling center in the lower stratosphere over the South Pole with strong implication of the Antarctic ozone hole. Significant seasonal variations occur within both polar caps. In the Northern Hemisphere, temperatures in the polar stratosphere experience large interannual oscillations with noticeably large warming trends in the winter season and persistent cooling trends in the other seasons. Within the Southern Hemisphere polar cap, a warming center at 20 hPa occurs above a cooling center at 70 hPa in the spring season.

The two best understood causes of stratospheric cooling are the ozone depletion and the enhanced greenhouse effect due to anthropogenic pollution. It is argued that the cooling peak near the tropical tropopause results from the vertical convergence, induced by the Hadley circulation, of greenhouse gases (GHG) and ozone-depleting substances (ODS). This cooling aloft, in turn, increases the convective instability of the tropical troposphere and thus enhances the Hadley cells, providing a positive feedback effect. It is understood that the GHG and ODS are transported further up and poleward by the Brewer-Dobson circulation

through the stratosphere, leading to the substantial cooling in the upper and extratropical stratosphere. However, there is compelling evidence to suggest that the two subtropical cooling peaks result from the secondary circulation associated with a westerly trend in the quasi-biennial oscillation (QBO). It is conceivable that the enhanced tropical convection could provide the extra source of westerly momentum for the QBO. In addition, the cooling peak near the tropical tropopause also alerts the extratropical thermal winds, and then inserts a dynamical impact on the propagation and absorption of planetary waves in the lower stratosphere. The resulting deceleration of the polar jet provides a plausible explanation of the seasonal warming phenomena within the polar caps.

Climatology and Interannual Variability of Upward and Downward Propagation of Rossby Wave Activity Across the Tropopause

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The climatology and interannual variability of upward and downward propagation of Rossby wave-activity propagation across the tropopause associated with submonthly zonally-confined wave-packet-like fluctuations are studied for the SH late winter based on reanalysis data from 1979 to 2003. The upward and downward wave-activity propagation is prominent over the Southeastern Pacific and South Atlantic, where the axes of the climatological-mean polar-night jet (PNJ) and subpolar jet (SPJ) meridionally overlap to form a vertical waveguide, and submonthly fluctuations are active both in the lower stratosphere and troposphere. Interannual enhancement in local downward wave-activity injection into the troposphere to the south of Australia and over the South Pacific tends to be associated with a poleward shift of the stratospheric PNJ axis upstream and the strengthening of the tropospheric SPJ underneath. The enhanced downward injection also accompanies the enhancement of tropospheric submonthly fluctuations downstream, suggestive of stratospheric influence on tropospheric variability.

Dynamics of the Coupled System Stratosphere/Troposphere at Strong Polar Vortex

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The dynamical coupling between stratosphere, troposphere and lower mesosphere is investigated during strong stratospheric Northern Annular Mode (NAM) using the middle atmospheric version of the ECHAM5 general circulation model (MAECHAM5) coupled to a mixed layer ocean model. A lag composite analysis based on the 50hPa NAM-Index (NAMI) shows that strongly positive stratospheric NAM-phases are associated with strong anomalous westerlies in high latitudes and a temperature quadripole between the troposphere and lower mesosphere. The lower part of this quadripole shows a dipole structure with an anomalous cold (warm) polar (mid-latitude) troposphere and stratosphere and is associated with a positive vertical shear of the anomalous westerlies there. This dipole strengthens (weakens) together with the anomalous westerlies in the NAM-increase (decrease) phase. The upper part of the temperature quadripole shows a coherent dipole with an anomalous warm (cold) polar (mid-latitude) upper stratosphere and lowermost mesosphere and is associated with a negative vertical shear of the anomalous zonal flow there. The warm pole in the mesosphere and upper stratosphere strengthens and propagates downward together with anomalous easterlies, especially in the NAM-decrease phase.

The dynamics during strong vortex is analyzed by computing the wave forcing, residual Coriolis forcing and non resolved (residual) forcing in the Transformed Eulerian Mean formulation (TEM). The NAM temperature, zonal flow and geopotential

height patterns and their downward propagation can be explained by the response of the stretching vorticity to residual Coriolis forcing changes, which in turn are caused by the resolved and non resolved wave forcing. The stretching vorticity approach can be seen as another form of the downward control and potential vorticity inversion mechanisms.

The persistence, increase, and downward propagation of the NAM-patterns is enhanced by two positive feedbacks that accelerate the westerlies within the coupled troposphere/stratosphere system: The stationary wave-vortex feedback, caused by vertical wind shear and curvature, and the residual forcing-vortex feedback, which can be explained by the enhanced baroclinic instability due to the westerly vertical wind shear. The decrease and modulation of the strong NAM-anomalies is enhanced by two negative feedbacks that decelerate the westerlies in the upper and lower boundaries of the coupled troposphere/stratosphere system. The first feedback is a vortex-residual forcing feedback acting in the upper stratosphere and lower mesosphere and can be explained by the filtering of gravity waves by the stratospheric jet. The second feedback acts near the bottom and is driven by both residual and stationary wave forcing.

The Extratropical QBO Signature in the Northern Winter Hemisphere

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Typically it has been considered that the winds at the low stratosphere determine the signal induced at high latitudes. However, L. J. Gray et al. (2000) suggested that northern-hemisphere winter circulation is sensitive to equatorial winds through the entire stratosphere and not only to the lower-stratospheric wind direction. Here we examine the extratropical QBO signature in the northern winter stratosphere and troposphere in function of the latitude-height structure of the zonal wind in the tropical region in order to determine how the extratropical response depends on the vertical phase structure of the QBO. In this work the MTM-SVD (Mann and Park, 1999) is used to reconstruct the QBO zonal wind, temperature and mass stream function patterns for 8 different vertical phase distributions of the tropical QBO winds. Data from the ERA-40 reanalysis has been used in this study covering a 21-year period (1979 -1999) and extending from 1000hPa to 0.1hPa. The zonal wind pattern sh ows that the high latitude circulation is stronger (weaker) when westerlies (easterlies) dominate the low equatorial stratosphere with the largest QBO signature in the polar vortex for maximum W/E centred at 40 hPa. However the signature induced at high latitudes in the intermediate phases between the westerly and easterly QBO phases is characterized by a sign reversal at a certain stratospheric level. At these phases, the QBO induces anomalies of the opposite sign at the upper and lower stratosphere. We observed that this might be related with the different effects that the first and second QBO westerly and easterly wind layers have on the upward propagating planetary waves. The extratropical QBO signature in the zonal wind, temperature and mass stream function extends to all tropospheric levels, although the signal is stronger above 500hPa. The interaction mechanism between the tropical and extratropical QBO is also analyzed through the analysis of the QBO signal induced in the Eliassen Palm (EP) flux.

The Influence of Zonal Asymmetry in the Polar Vortex on Upper Tropospheric Rossby Wave Breaking Events

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The decadal and zonal variability of observed stratospheric polar vortex, as seen in temperature or Ertel's potential vorticity (EPV) maps, is assumed to be forced mainly by the decadal variability of upward propagating tropospheric planetary waves. On the other side, decadal changes in stratospheric planetary wave structure may have an influence on upper tropospheric baroclinic wave activity because the wave structure forms the background flow in the upper troposphere / lower stratosphere region. This study examines the coupling between the zonal change of the stratospheric wave structure and planetary waves in the upper troposphere. For the analyses the ECMWF Reanalysis data (ERA-40) and model sensitivity runs with a simplified version of the SGCM ECHAM are used. In details, we have analyzed observed and modeled EPV-fields and stationary wave activity fluxes, showing that the amplitude and the phase of the stratospheric planetary wave one dominate the polar vortex changes, which have an influence on regional occurrence of Rossby wave breaking events, especially in the long-term winter mean. A climatology of Rossby wave breaking events is derived with a diagnostic index that is a function of the large-scale diffluent/confluent flow and the meridional wave flux component for quasi-stationary Rossby waves in a zonally varying basic flow. The index separates Rossby wave breaking events that are evolving poleward upstream (P1) or downstream (P2).We found more breaking events over the Northern Pacific - North America region and over the Northern Atlantic - European region. Also, the results suggest an efficient dynamical feedback-loop between decadal changes in stratospheric planetary wave structure and upper tropospheric Rossby wave breaking events. The relationship between Rossby wave fluxes in a diffluent/confluent flow and Rossby wave breaking indicated by overturning of EPV on isentropic surfaces is discussed.

New 3D-Var Dynamical Constraints at Environment Canada

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New dynamical constraints are investigated in the context of the 3D-Var global data assimilation system used by Environment Canada. Flow dependence in the mass wind balance is introduced by replacing statistical, time-averaged covariances with the Charney and hydrostatic balances, linearized about the background state. The Charney balance performs well in the extra-tropics and has some value in the tropics. A new constraint is also imposed on the velocity potential by employing the quasigeostrophic omega equation and continuity equation. This is done in order to limit spurious mixing caused by the insertion of observations which are not in balance with the background and with each other. The GCM used in the assimilation system is a variant of the operational model at Environment Canada (GEM), which has a relatively high lid (0.1 hPa) and includes a comprehensive online chemistry package (BIRA). The new constraints have been implemented using the hybrid vertical coordinate for consistency with the model. Resulting balanced increments are shown to compare favorably with output from a free-running model. The utility of the new constraints is examined in online 3D-Var experiments, comparing with the previous statistical approach, and focusing in particular on the tropical region. The impact on forecast scores is also discussed.

Southern Ocean Carbon Source or Sink?: The Role of Southern Hemisphere Westerlies

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Coupled model simulations show clearly that the major source of uncertainty in the role of the ocean in future atmospheric carbon dioxide concentrations is the wide range of predictions of heat and carbon uptake in the Southern Ocean. Given that the ocean will be the ultimate repository for about 85% of the anthropogenic carbon, and given the limited long term capacity of the terrestrial carbon sink, it is likely that the Southern Ocean will be the major source of uncertainty for our ability to predict the future evolution of the entire carbon cycle, including the terrestrial carbon sink. Increasing ocean stratification has been posited to serve as a positive feedback on global warming by reducing the storage of anthropogenic carbon dioxide and heat by the ocean. We hypothesize that the projected poleward intensification of the southern hemisphere westerly winds counteracts the stratifying influence of warming and freshening in the Southern Ocean, increasing the oceanic storage of anthropogenic carbon dioxide and heat. We demonstrate the relative impact of global warming, ice melt and the shift in the Westerly Winds on the uptake of anthropogenic carbon dioxide in the Southern Ocean in the best coupled climate model simulation of the Southern Ocean.

On the Lagrangian Dynamics of Atmospheric Zonal Jets and the Permeability of the Stratospheric Polar Vortex

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The Lagrangian dynamics of zonal jets in the atmosphere are considered, with particular attention paid to explaining why, under commonly encountered conditions, zonal jets serve as barriers to meridional transport. The velocity field is assumed to be two-dimensional and incompressible, and composed of a steady zonal flow with an isolated maximum (a zonal jet) on which two or more travelling Rossby waves are superimposed. The associated Lagrangian motion is studied with the aid of KAM (Kolmogorov–Arnold–Moser) theory, including nontrivial extensions of well-known results. These extensions include applicability of the theory when the usual statements of nondegeneracy are violated, and applicability of the theory to multiply periodic systems, including the absence of Arnold diffusion in such systems. These results, together with numerical simulations based on a model system, provide an explanation of the mechanism by which zonal jets serve as barriers to meridional transport of passive tracers under commonly encountered conditions. Causes for the breakdown of such a barrier are discussed. It is argued that a barrier of this type accounts for the sharp boundary of the Antarctic ozone hole at the perimeter of the stratospheric polar vortex in the austral spring.

Spurious Sensitivity of Middle Atmospheric Climate Simulations to Model Lid Height due to Nonconservation of Angular Momentum

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It is well recognized that middle atmosphere models require parameterized wave drag to obtain a reasonable zonal mean climate. If the model domain is truncated and momentum flux is lost to space, there will be missing upwelling or downwelling because of missing torques. Such nonconservation of angular momentum can lead to spurious responses to climate perturbations (e.g. ozone depletion) which are nonnegligible, and which extend to the surface. In the context of two-dimensional model experiments, when momentum

is not conserved the model response to a localized radiative perturbation is sensitive to the height of the model lid. However, when momentum is conserved, through deposition of excess momentum flux in the top few model layers, such strong sensitivity disappears. We find similar behaviour while exploring the sensitivity of the zonal mean climate of the Canadian Middle Atmosphere Model for model lid heights at 10 and 0.001 hPa. With a model lid height at 10 hPa the zonal mean climate is found to be very sensitive to whether or not parameterized momentum flux is conserved. The impact of this sensitivity on the troposphere is found to be particularly large in Antarctic winter. There is much less sensitivity with the model lid height at 0.001 hPa. The sensitivity is quantified via changes in the vertical component of the residual circulation.

Diabatic Processes Associated with Stratosphere-Troposphere Exchange and Their Link

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Air mass and the enclosed pollutants are transported across the tropopause (here defined as the 2 pvu isosurface) in so-called STE (stratosphere-troposphere exchange) events. Several studies focused on the dynamical features associated with these STE events, among them breaking Rossby waves and extra-tropical cyclones. In this study we combine several data sets derived from ERA-40 and ERA-15 reanalysis to shed further light on the physical processes associated with STE. In a first part, we adopt a fluid parcel's perspective, and follow its 3d trajectory from the stratosphere to the troposphere (for STT) and vice versa for the opposite direction (TST). Thereby, the state of the atmosphere is sampled along the trajectory with respect to diabatic processes, for instance turbulence indicators, condensational and radiative heating. This will finally allow to determine which diabatic processes are associated with the crossing of the tropopause, which constitutes a barrier for any adiabatic flow. Special focus will also given to the possibility of STE on isentropic surfaces, so-called isentropic transport. Detailed case studies illustrate that nearly isentropic transport is possible and indeed fairly common. In a second part, consideration is given to the meso- and synoptic-scale features which are associated with STE events, including extratropical cyclones and anticyclones, tropopause folds and atmospheric blockings. Particular focus is given to the link with potential vorticity (PV) streamers, which are defined as extrusions of stratospheric (tropospheric) air towards the south (north). The PV streamers (based upon ERA-15 reanalysis) are identified on isentropic surfaces from 300 to 350 K, and are then used to quantitatively determine their impact on STE. It turns out that most STE events can be found in the vicinity of PV streamers.

Variability of the Northern Polar Vortex During the Past 100 Years

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The stratospheric polar vortex in the Northern Hemisphere features a large year-to-year variability regarding its shape, persistence and strength. This can be caused by interaction with upward propagating planetary waves, which in turn is modulated by various factors. Tropospheric forcing such as El Niño/Southern Oscillation (ENSO) may play a role, but stratospheric perturbations such as volcanic eruptions, solar variability, and the Quasi-Biennial Oscillation (QBO) could also be important. For instance, the QBO modulates the wave guide and thus influences the interaction with the mean flow, resulting in a strengthening (weakening) of the polar vortex when the QBO at 40 hPa is in its westerly (easterly) phase (referred to as the Holton-Tan effect). The variability of the polar vortex and in particular its breakdown during sudden stratospheric warmings (SSWs) can affect weather and climate at the ground. Studying interannual-to-decadal variability of the polar vortex is therefore important for a better understanding of the effect of stratospheric forcings on climate.

Here we present an analysis of the polar vortex variability during the 20th century using observations (statistical reconstructions based on historical upper-air data, ERA40) and simulations with the transient chemistry-climate model SOCOL. SOCOL is a middle atmosphere version of ECHAM4 (MPI, Hamburg), which is coupled to the chemistry-transport model MEZON (PMOD/WRC, Davos). The simulations were carried out in ensemble-mode (9 members) prescribing the time evolution of sea surface temperature, sea ice distribution, volcanic aerosols, solar variability, greenhouse gases and ozone depleting substances, land surface changes and the QBO. We will provide a statistical analysis on the frequency characteristics, strength and seasonality of SSWs and on the interannual-to-decadal variability of the northern polar vortex. In particular, we address the stationarity of the Holton-Tan effect and the effect of different forcing factors.

The Impact of Stratospheric Ozone Depletion and CO2 on Southern Annular Mode and Regional Climate: Implications for Water Resources in Australia

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During the past decade eastern Australia has experienced significant rainfall decline. In particular, low rainfall during the recent La Niña period (1998-2001), and reduced tropical cyclone activity were unusual. The widespread and persisting drought have resulted in water use restrictions in major population areas such as Adelaide, Melbourne, Sydney and Brisbane. At the same time northwestern Australia with little population, had a significant and unexplained rainfall increase. The observed rainfall decline and trends in simulated soil moisture and runoff are investigated in order to determine whether the emerging trends during the past decade are unusual in historical context. The results of the analysis are used then to compare the observed trends with modelling results. Global warming trends and natural climate variability have been hypothesised to affect regional rainfall in Australia. In addition a positive trend in the Southern Annular Mode (SAM) has been documented in the literature with effects on synoptic systems in the Southern Hemisphere. The cause of this trend has been attributed to stratospheric ozone depletion, increasing concentration of CO2 and natural variability. However, there has been as yet no mechanistic link between the trend in SAM and regional climate changes, including recent trends in Australian rainfall.

The impact of long-term changes in radiative forcing on regional rainfall was investigated using a climate model to conduct an attribution experiments to quantify the effects of solar variability, increasing CO2, and stratospheric ozone depletion. Ensembles of simulations using the CSIRO T63 AGCM forced with observed HadISST for the period 1871-2003 and using the Climate of the 20th Century International Project protocol have been completed. In addition ensemble of model simulations using fully coupled CSIRO T63 climate model for period 1871-2000 has been completed recently and the results will be presented. The analyses of the modelling results show a good agreement between observe and simulated mean sea level pressure (MSLP) trends for period 1971-2003. Both the observed and simulated data show a decline of MSLP at high latitudes and increase in mid-latitudes of Southern Hemisphere. In both cases a characteristic wavenumber-3 pattern is present in trend data at mid-latitudes. The resultant analyses suggest that ozone depletion had the strongest contribution to the trend during all months, except for winter where the CO2 effect was strongest. The results also demonstrated that the ozone depletion had contributed strongly to the positive trend in the SAM. The analyses of simulated rainfall from these experiments indicated an impact of ozone depletion and CO2 increase on the patterns summer rainfall distribution during the past decade in Australia. The impacts of increasing CO2 and ozone depletion on rainfall appear to be of opposite sign across many regions of globe and in particular eastern Australia and South Pacific Convergence Zone, with CO2 forcing resulting in increased summer rainfall, while ozone forcing led to rainfall decrease. The observed drying trends in eastern Australia and positive rainfall anomalies in northwestern Australia over the past decade are best explained by the combination of SST, solar, CO2 and ozone forcing in the ensemble of model simulations. Overall the stratospheric ozone depletion has been the decisive agent in maintaining the persistent drought conditions in eastern Australia. This new findings have far reaching implications for future options for water supply in eastern Australia.

The Climate Impact of Mt. Pinatubo Eruption: Sensitivity to SSTs in a Middle Atmosphere Model

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Volcanic radiative forcing causes significant changes in stratospheric and tropospheric circulation patterns producing global and regional climate effects. One of the major impact triggered by the volcanic aerosols is the so called "winter warming" observed in the mid and high latitudes in the NH and has been observed for two consecutive winters following the tropical eruptions. The observed response is due to direct radiative cooling/heating caused by volcanic aerosols and associated ozone changes, variations of SST and the phase of the Quasi Biennial Oscillation (QBO). Hence, while simulating this impact, one mustconsider all these interactions. The main goal of this study is to assess the response as realisticallyas possible and also to understand the combined and individual responses of volcanic forcing and varying SST boundary conditions on the stratospheric and tropospheric circulation. For this, the middle atmosphere version of the general circulation model (MA)ECHAM5.4 is employed to carry out ensemble simulationsincluding or excluding Pinatubo aerosol loadings or El Nino SST variations. The separate and combined effects of Pinatubo and El Nino are then investigated by comparison of ensemble means. Here, in this study, the model is forced by zonally averaged values of aerosol extinction, single scattering albedo and asymmetry parameter and volcanically induced ozone anomalies. The differences in the volcanic responses toclimatological SST and observed SST as boundary conditions will be discussed. Also, the response to the different QBO phases will be examined.

A Mechanism for the Wintertime Temperature Maxima at the Subtropical Stratopause in a T213L256 AGCM

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Temperature and zonal wind structures around the tropical and subtropical stratopause region have been studied using the Center for Climate System Research/National Institute for Environmental Studies/Frontier Research Center for Global Change (CCSR/NIES/FRCGC) AGCM. The AGCM has T213 spectral truncation in the horizontal and 256 layers in the vertical from the surface up to 85 km (i.e., vertical spacing of 300 m). Gravity waves are spontaneously generated by

convection, topography, instability, and so on in the AGCM with no gravity wave drag parameterizations. The AGCM successfully reproduces a quasi-biennial oscillation (QBO)-like oscillation with a period of about 1.3 yr in the tropical stratosphere. The semi-annual oscillation (SAO) reproduced in the AGCM has easterly maxima during the solstices in the lower mesosphere of the summer hemisphere subtropics. An interesting feature is that temperature maxima appear at the subtropical stratopause in the winter hemisphere, simultaneously with the easterly maxima of the stratospheric SAO in the summer hemisphere. In fact, a careful looking at the CIRA-86 climatology shows that the temperature maxima in the winter stratopause are clearly evident. The transformed Eulerian-mean (TEM) analysis has shown that the temperature maxima are brought about by a strong residual-mean meridional circulation composed of a single cell with an ascent in the summer hemisphere tropics (i.e., 0-10 degrees latitude) and a descent in the winter hemisphere extratropics (i.e., around 30 degrees latitude). This meridional circulation is induced by a modest Eliassen-Palm (EP) flux convergence in the winter hemisphere subtropics of the lower mesosphere, which is mainly due to dissipation of extratropical planetary waves. The region of the EP flux convergence has a small absolute vorticity, because of the cancellation between the Coriolis parameter and anticyclonic shear of the zonal wind. Hence, a strong poleward flow is induced in order to cancel a westward acceleration force due to the modest EP flux convergence. However, why the absolute vorticity is small around the wintertime (sub)tropical stratopause region is uncertain. We will discuss contributions of the middle atmosphere Hadley circulation and inertial instability to the formation of small absolute vorticity region.

Development of an Atmospheric General Circulation Model of an Integrated Earth System Model on the Earth Simulator

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We have developed an integrated earth system model, where biological and chemical processes important for the global environment are allowed to interact with climate changes. In order to simulate long-time changes in climate systems and atmospheric chemistry as well as their seasonal and interannual variations, an appropriate representation of the stratosphere is required. The top of an atmospheric general circulation model (AGCM) is extended upto the mesopause height. The sigma-vertical coordinate system of the AGCM is replaced with a hybrid sigma-pressure coordinate, which makes transport processes near the tropopause realistic. A new version of a radiative transfer scheme dramatically decreases cold biases near the tropical tropopause and extratropical lower stratosphere. An incorporation of a non-orographic gravity wave drag parameterization with a source function derived from results of a high-resolution AGCM simulation allows the model to reproduce the realistic general circulation in the stratosphere and mesosphere.

Solar Cycle Modulation of Wave Forcing Over Troposphere Related to the Annular Mode Over Stratosphere

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The energy flux of high energy UV radiation changes by large (>5%) amounts during the 11-year solar cycle. The temperature in the stratosphere is affected by the direct radiation, while the lower atmosphere can be influenced through the interaction with dynamics (Kuroda and Kodera, 2002). The winter (DJF) mean 10.7cm solar radio flux is used for evaluation of solar activity. Based upon the winter solar activity, we divide all years into high solar (HS) and low solar (LS) period. The Empirical Orthogonal Function (EOF) decomposition is applied over stratosphere, and we derive the principal component (PC) time-series of the EOF-1 in December. Data used in the EOF decomposition originate from the NCEP/NCAR reanalysis monthly mean geopotential height fields for 1979 to 2005. The zonal mean zonal wind is regressed to the PC 1 over stratosphere in December. In the HS, the westerly wind anomaly at 60 N extends from the stratosphere to the troposphere. The westerly wind anomaly over the troposphere is maintained largely by wave forcing term, and the wave forcing term over troposphere is strong in HS and weak in LS. The result indicates that the wave forcing term is important factor to the solar cycle modulation of the westerly wind anomaly in the troposphere. The stationary component is large contribution to the wave forcing term, and the transient component is significant contribution.