A Robust Tropical Bottom-up Control of the Lower Stratospheric Circulation

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Introduction

The Brewer-Dobson circulation is the slow overturning of the stratosphere with ascent in the tropics and descent in the extratropics. Its strength plays a central role in determining the concentrations and the spatial distributions of stratospheric species such as water vapor, ozone and aerosols, all of which are radiatively active and can potentially perturb the Earth's climate. We analyzed the Brewer-Dobson circulation in a suite of experiments simulated with the GFDL global climate models, and examined the variations of the simulated stratospheric circulation from interannual to multi-decadal timescales.

Experiments

- CM3: PI Control, Historical (AllForc, Natural, Anthro, Aerosol, WMGGO3).
- CM2.1: Historical (Natural, Aerosol, WMGGO3)

Method

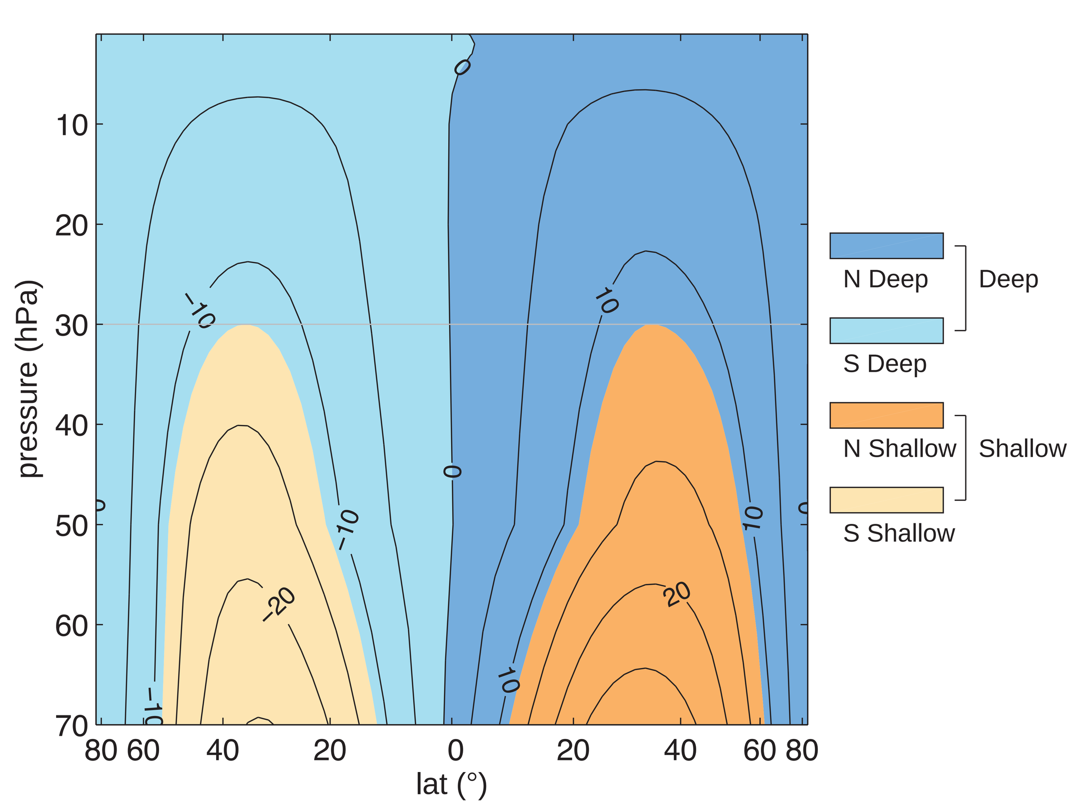

Fig.1 Climatology of the annual mean Transformed Eulerian Mean stream function.

The strength of the Brewer-Dobson circulation is diagnosed by the vertical mass flux calculated from the Transformed Eulerian Mean (TEM) velocity. We then correlate the strength of the Brewer-Dobson circulation with the tropical mean (20°N-20°S) surface temperature. We compare:

- BDC Shallow branch: 30-70 hPa
- BDC Deep branch: above 30 hPa

- Interannual: annual mean - 5 year running mean
- Decadal to Multi-Decadal: 5 year mean

Correlation between the Brewer-Dobson circulation and the tropical surface temperature

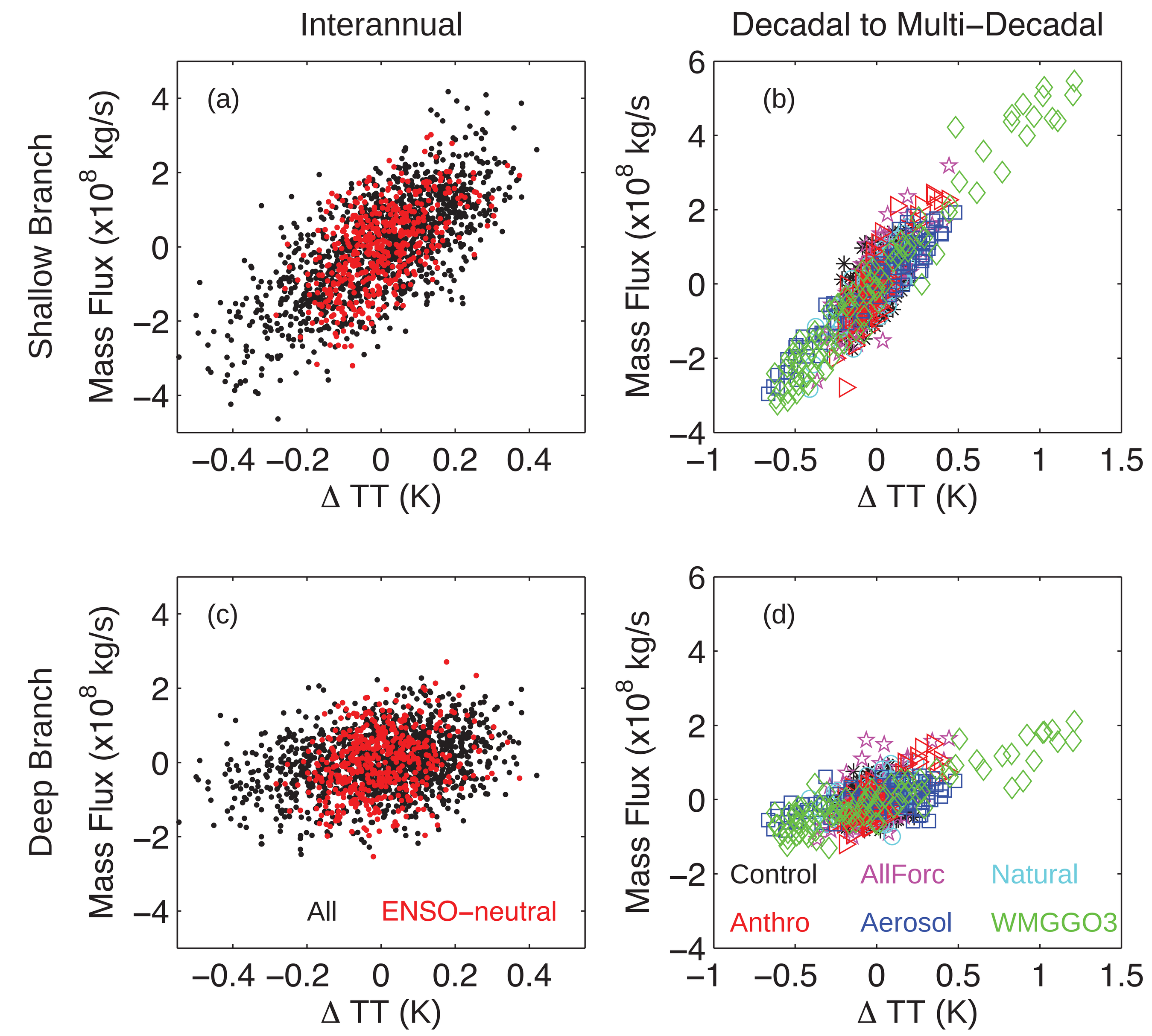

Fig.2 Scatter plot of the strength of the Brewer-Dobson circulation versus the tropical mean surface temperature.

Table 1 Correlation coefficients between the strength of the Brewer-Dobson circulation and the tropical mean surface temperature. Results from ENSO-neutral years are shown in parentheses.

		Shallow branch		Deep branch	
		Interannual	Decadal to Multi-decadal	Interannual	Decadal to Multi-decadal
ERA-i		0.58	-	-0.16	-
CM3	Control	0.68 (0.56)	0.59	0.27 (0.25)	0.18
	AllForc	0.75 (0.59)	0.80	0.23 (0.29)	0.49
	Natural	0.67 (0.46)	0.83	0.31 (0.24)	0.36
	Anthro	0.66 (0.49)	0.86	0.34 (0.31)	0.73
	Aerosol	0.67 (0.50)	0.96	0.31 (0.25)	0.58
	WMGGO3	0.67 (0.59)	0.98	0.22 (0.18)	0.90
CM2.1	Natural	0.75 (0.66)	0.70	0.48 (0.43)	0.09
	Aerosol	0.71 (0.67)	0.60	0.60 (0.69)	0.31
	WMGGO3	0.78 (0.54)	0.95	0.64 (0.42)	0.91

Variations of the shallow branch can be largely explained by those of the tropical mean surface temperature, which holds from interannual to multi-decadal timescales, and holds for internal, natural and anthropogenic forced variations alike.

Mechanism

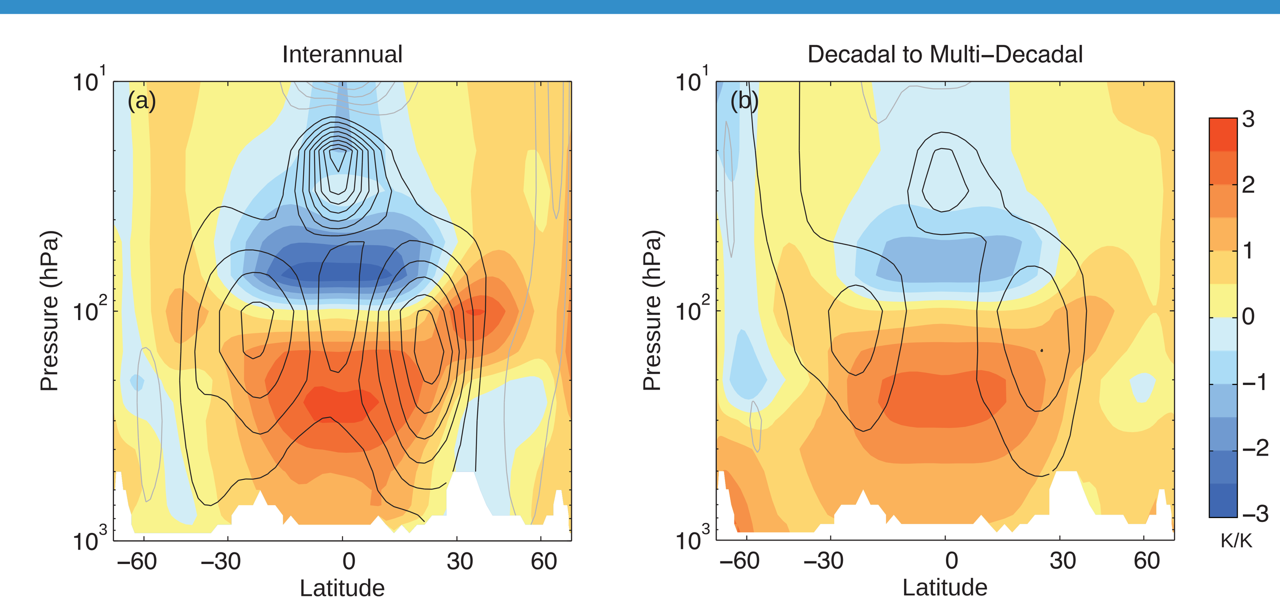

Fig.3 Regression of zonal mean temperature (color shading) and zonal wind (contours) upon tropical mean surface temperature from the control simulation.

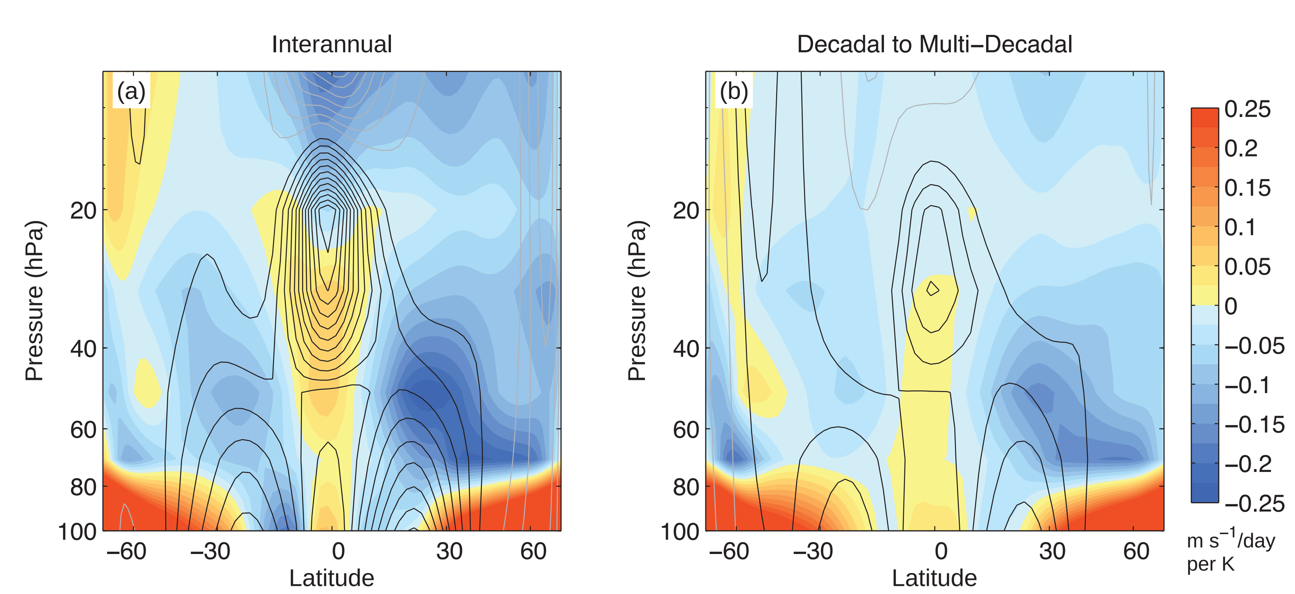

Fig.4 Regression of wave forcing (color shading) and zonal mean zonal wind (contours) upon tropical mean surface temperature from the control simulation.

tropical surface warming
↓ moist adiabatic
stronger warming at tropical upper troposphere (UT)
↓
stronger meridional temperature gradient at subtropical UT
↓ thermal wind
stronger zonal wind at subtropical UT/lower stratosphere (LS)
↓ critical layer
more wave dissipation at subtropical LS
↓
stronger lower stratospheric circulation

Summary and Conclusion

With the high model top and the decent stratospheric chemistry scheme, current GFDL GCM is capable to simulate the dynamical, radiative and chemical processes in the stratosphere, and to simulate the coupling between the stratosphere and the troposphere. A strong and robust correlation between the tropical surface temperature and the shallow branch of the Brewer-Dobson circulation has emerged in the simulations. The deep branch, on the other hand, is less sensitive to changes of the tropical surface temperature. We suggest the robust response of the lower stratospheric circulation arises from the tropical upper tropospheric amplification of the variations of the surface temperature, and the resulting changes in the meridional temperature gradient and subtropical zonal wind structures.

References

1. R. R. Garcia and W. J. Randel, 2008, JAS.
2. T. G. Shepherd and C. McLandress, 2011, JAS.
3. P. Lin and Q. Fu, 2013, JGR
4. P. Lin, Y. Ming and V. Ramaswamy, 2014, to be submitted.