Comments on "The Life Cycle of the Northern Hemisphere Sudden Stratospheric Warmings"

JUDAH COHEN

Atmospheric and Environmental Research, Inc., Lexington, Massachusetts

DARA ENTEKHABI

Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

KAZUYUKI SAITO

Frontier Research System for Global Change, Yokohama, Kanagawa, Japan

GAVIN GONG

Department of Earth and Environmental Engineering, Columbia University, New York, New York

DAVID SALSTEIN

Atmospheric and Environmental Research, Inc., Lexington, Massachusetts

(Manuscript received 13 August 2004, in final form 17 December 2004)

Limpasuvan et al. (2004, hereafter LTH) consider the life cycle of sudden stratospheric warmings (SSWs) from onset to maturity and eventually decay by compositing multiple events over the course of 80 days. Their main emphasis is on the mature phases of the life cycle when there is a clear chain of downward stratosphere-to-troposphere propagation of anomalies. In this comment, we aim to focus on the onset results reported in LTH by placing the results in the context of more regional phenomena reported in earlier studies and providing a more comprehensive framework for understanding wintertime Northern Hemisphere climate variability and improved predictability.

Among the results presented, LTH show that SSWs are associated with antecedent Eliassen–Palm (EP) flux convergence from the troposphere. These upward-propagating EP flux anomalies precede the large-scale anomalies in the stratosphere, and subsequent downward-propagating anomalies yield an Arctic Oscillation (AO) signal in the lower troposphere. A number of previous studies provide evidence that the forcing for the real or apparent downward propagation of zonally symmetric, large-scale height and wind anomalies from the stratosphere to the troposphere has its origins regionally in the lower troposphere (Kuroda and Kodera 1999; Cohen et al. 2002). Furthermore, these lower-tropospheric precursors have also been linked to anomalies in Eurasian snow cover (Saito et al. 2001; Gong et al. 2003), which antecede even the atmospheric precursors. The EP flux anomalies shown in LTH are similar to the wave fluxes presented in Kuroda and Kodera (1999), Saito et al. (2001), and Gong et al. (2003), which were shown to perturb the stratosphere and originate over Eurasia, but were not considered by LTH, who limit their analysis to zonal means. Kuroda and Kodera (1999) also show wave fluxes over the Atlantic sector, but these are observed only during the mature phase of an AO event and their influence is confined to the troposphere.

Also, LTH show statistically significant height anomalies in the both the stratosphere and the tropo-

Corresponding author address: Judah Cohen, Atmospheric and Environmental Research, Inc., 131 Hartwell Avenue, Lexington, MA 02421.
E-mail: cohen@aer.com

sphere at least 40 days prior to the mature phase of the SSW event in the stratosphere and the strong negative AO in the troposphere. The analysis presented by LTH to demonstrate common precursors in both the troposphere and the stratosphere during the onset stage of negative AO events is shown in their Fig. 9. In the uppermost right panel, a statistically significant wavenumber-1 anomaly in the 1000-hPa height is observed with a positive center over northern Eurasia and a weaker negative center over North America. The remainder of the right-hand panels depicts the evolution of the lower-tropospheric height anomalies through maturity and decay of the negative AO event. This set of panels is similar to the sea level pressure anomalies depicted charting the inception growth and decay of negative AO events in Cohen et al. (2001, 2002) and Cohen (2003) and is suggestive of a predominantly tropospheric pathway for the ultimate surface winter AO signal. However LTH do not suggest that the troposphere leads the stratosphere in producing SSW or negative AO events, but rather that the troposphere and the stratosphere are both preconditioned leading up to common SSW and negative AO events and do not consider precursive tropospheric anomalies.

Shown in the leftmost panels of Fig. 9 of LTH are the height anomalies in the stratosphere during the onset, growth, maturity, and decay of negative AO events, which occur simultaneously with the tropospheric height anomalies. The analysis is meant to demonstrate that the height anomalies are occurring in tandem both in the troposphere and in the stratosphere, and therefore it is ambiguous whether one is leading the other through the life cycle of the negative AO event. We would like to highlight several observations from the analysis presented in LTH, which we find difficult to reconcile with their interpretations: during the onset stage the stratospheric anomalies are much weaker and are of opposite sign than the concurrent tropospheric anomalies, and more importantly they are of opposite sign to those of the subsequent mature stage stratospheric AO event. In the onset stage at 50 hPa, a dominant positive height anomaly is observed over the North Pacific with a weak negative height anomaly over northern Eurasia and the region surrounding the North Pole. This is in contrast to the onset stage at 1000 hPa where the main positive height anomaly is located over northern Eurasia and also in contrast to the dominant positive height anomaly centered over the North Pole and negative height anomaly over the North Pacific (and North Atlantic) associated with the mature stage at 50 hPa. LTH could argue that the AO event is being driven or derives from the regional North Pacific center height anomaly in the stratosphere, but they do not demonstrate this. LTH limit their analysis of energy flux to the zonal mean statistics, which precludes demonstrating more regional forcing of the subsequent AO event.

We suggest that the chain of downward stratosphere-to-troposphere anomalies reported by LTH does not originate in the stratosphere, but rather is preceded by upward troposphere-to-stratosphere anomalies originating very near the surface and in the region of northern Eurasia. Saito et al. (2001) and Gong et al. (2003) present a comprehensive troposphere–stratosphere–troposphere sequence of anomalies that originates over northern Eurasia. Their analysis utilized a three-dimensional variation of the EP flux for the stationary eddies [first derived by Plumb (1985) and referred to as wave activity flux (WAF)], which allows for regional isolation of wave energy flow. The results of Saito et al. (2001) and Gong et al. (2003) suggest northern Eurasia as the source region of the upward propagation driving the negative AO event. Plumb (1985) shows that Eurasia is a major center of action in WAF climatology and that Siberia is the major source region of anomalous upward WAF, which impacts the stratosphere. Factors, such as snow cover, that affect the strength of WAF across this region can have effects that extend to hemispheric scales.

Similar to the analysis in Cohen et al. (2001) linking fall snow cover anomalies with tropospheric winter climate variability, in Fig. 1c we correlate October Eurasian snow cover time series (1972–2003) with December, January, and February 50-hPa heights. The pattern in the figure closely resembles the AO or annular mode pattern at 50 hPa, with a high degree of statistical significance. As a possible indication of the stratospheric evolution in the onset and growth of the AO event, we also correlate October Eurasian snow cover time series with October and November 50-hPa heights in Figs. 1a and 1b, respectively. This suggests a more passive role for the stratosphere, where a weakened polar vortex in the stratosphere is more conducive to the absorption of tropospheric wave energy, the ensuing SSW, and downward propagation of anomalies into the troposphere. However, it does not suggest the existence of a stratospheric wave structure contributing to the energy flux driving the life cycle of events, as demonstrated for the troposphere. Also the existence of a positive height anomaly extending from northern Eurasia to the Pole is more consistent with the regional tropospheric height anomalies during the onset as shown in Cohen et al. (2001, 2002) and Cohen (2003) and in LTH.

LTH focused more on the largest-scale variability, that is, the mature stratospheric event and the subsequent downward propagation, and they concluded that

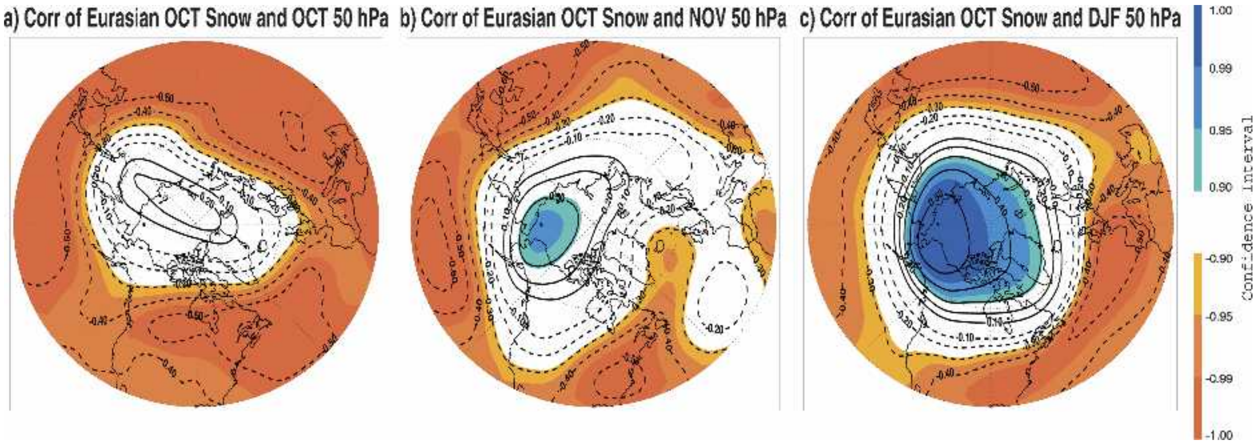

FIG. 1. Correlation of Oct Eurasian snow cover with 50-hPa geopotential heights for (a) Oct, (b) Nov, and (c) Dec, Jan, and Feb. Light, dark, and darkest color shading represents 90%, 95%, and 99% confidence limits, respectively. Every 0.1 interval of the correlation coefficient is contoured.

the onset stage is characterized by preconditioning of the stratosphere and wavenumber-1 forcing in both the stratosphere and the troposphere. However, this interpretation can be modified so that it reconciles the absence of a clear stratospheric precursor. Though we cannot rule out the possibility of a precursor in the stratosphere during the onset stage of the AO event, we find it unlikely to be restricted to the form as presented in LTH. Our earlier troposphere-centric analyses indicate a more focused role of the troposphere in the propagation of very similar events and isolate northern Eurasia as a land surface source region, which initiates the life cycle of the AO signal. This interpretation supports the importance of Eurasia as an anomalous WAF center of action.

Although presented in the context of stratospheric precursors and the subsequent downward propagation of stratospheric anomalies to the troposphere, the work of LTH is consistent with a body of literature that in fact supports the existence of tropospheric precursors. An accurate understanding of the directions and sequencing of troposphere–stratosphere interaction has important implications for climate predictability. We believe that it may be advantageous to investigate tropospheric precursors for winter climate prediction given the potentially longer lead time than stratospheric precursors. Another shortcoming of using stratospheric anomalies to predict future tropospheric anomalies is that they do not always propagate to the lower troposphere and therefore do not impact lower-tropospheric weather (Baldwin and Dunkerton 2001). Use of tropospheric precursors, presented in this comment, has already been reported as demonstrating improved skill over current approaches in forecasting the cold eastern U.S. winter of 2002/03 (Kerr 2003). We are optimistic that a more comprehensive understanding of Northern Hemispheric winter variability is materializing, which shows a life cycle that involves a two-way interaction between the stratosphere and the troposphere. Both models and observational data are needed to spur further improvements in understanding climate variability and improved seasonal predictions.

Acknowledgments. Cohen is supported by National Science Foundation Grant ATM-0443512.

REFERENCES

Baldwin, M. P., and T. J. Dunkerton, 2001: Stratospheric harbingers of anomalous weather regimes. *Science,* **294,** 581–584.

Cohen, J., 2003: Introducing sub-seasonal and temporal resolution to winter climate prediction. *Geophys. Res. Lett.,* **30,** 1018, doi:10.1029/2002GL016066.

——, K. Saito, and D. Entekhabi, 2001: The role of the Siberian high in Northern Hemisphere climate variability. *Geophys. Res. Lett.,* **28,** 299–302.

——, D. Salstein, and K. Saito, 2002: A dynamical framework to understand and predict the major Northern Hemisphere mode. *Geophys. Res. Lett.,* **29,** 1412, doi:10.1029/2001GL014117.

Gong, G., D. Entekhabi, and J. Cohen, 2003: Modeled Northern Hemisphere winter climate response to realistic Siberian snow anomalies. *J. Climate,* **16,** 3917–3931.

Kerr, R., 2003: Can northern snow foretell next winter's weather? *Science,* **300,** 1865–1866.

Kuroda, Y., and K. Kodera, 1999: Role of planetary waves in the stratosphere–troposphere coupled variability in the Northern Hemisphere winter. *Geophys. Res. Lett.,* **26,** 2375–2378.

Limpasuvan, V., D. W. J. Thompson, and D. L. Hartmann, 2004: The life cycle of the Northern Hemisphere sudden stratospheric warmings. *J. Climate,* **17,** 2584–2596.

Plumb, R. A., 1985: On the three-dimensional propagation of stationary waves. *J. Atmos. Sci.,* **42,** 217–229.

Saito, K., J. Cohen, and D. Entekhabi, 2001: Evolution in atmospheric response to early-season Eurasian snow cover anomalies. *Mon. Wea. Rev.,* **129,** 2746–2760.