Review of the paper entitled "Trends in high latitude mesosphere temperature and mesopause revealed by SABER," submitted by X. Liu et al.

Overview:

This paper presents a study of trends in temperature at high latitudes using data from the SABER instrument on the TIMED satellite. The trends are determined by a standard linear regression procedure. The paper clearly understands the issue with the 'moving' yaw cycle and presents analyses which attempt to account for that. While mostly in accord with other trend studies involving SABER data, the paper presents some very remarkable trend values (6 K/decade to 10 K/decade) which are well beyond what is expected if the trends are due solely to the radiative response to increasing greenhouse gases. The paper also appears to lack any consideration of measurement uncertainty of the SABER temperature parameter and the impact of these uncertainties on the uncertainty of the derived trends.

Recommendation:

There are a couple of major issues which the authors need to address and that relate to uncertainties/errors in the SABER temperature data. The authors must convincingly address these before the paper can be considered for publication.

Comments:

1. The large trends identified in the polar region (ranging from 6 K/decade to 10 K/decade) are presented without discussion of possible effects of measurement error and without discussion of their physical meaning or likelihood. Mlynczak et al. (2022) noted that the expected global average mesosphere temperature change to a doubling of CO_2 (i.e., the climate sensitivity) was about 6.5 K. The paper is presenting results that imply a climate sensitivity of the polar mesosphere of about 10 times that. What would be the physical mechanism for a solely radiative effect that would make the polar mesosphere 10 times more sensitive to CO_2 increase than the global average? Is there a radiative or dynamical feedback that causes additional cooling besides what might be expected from a purely radiative effect? It is important to understand this point because a 10 K/decade trend would result in non-physical temperatures in a few decades and would also imply a substantially hotter polar upper mesosphere and lower thermosphere at the start of the Industrial Age. We are about halfway to doubled CO_2 now and so addressing this issue is critical to placing the results and their consequences in perspective.

2. In order to believe the large, derived trends, all analyses must consider the uncertainty in the SABER temperature data, particularly in polar regions, and particularly at the lowest pressure levels (highest altitudes). The paper cites papers by Remsberg and Rezac in temperature uncertainties below 100 km. The Rezac paper is for a version of the SABER data that is not used by the authors. The authors are referred to this link for a summary of SABER measurement errors for temperature:

https://saber.gats-inc.com/temp_errors.php

In particular, the paper states there is a trend of 10 K/decade (line 296) at 10^{-4} hPa. However, the uncertainty at this pressure level is 25 K at mid-latitudes and it is likely higher in polar regions. The main drivers of SABER temperature uncertainty are the knowledge of atomic oxygen and carbon dioxide which are provided to the SABER temperature algorithm by the MSIS 2000 model and by the WACCM model, respectively.

The MSIS 2000 model is over 20 years old and has incorrect local time variations in atomic oxygen as has been noted in the literature. In addition, below 100 km, no atmospheric observations of atomic oxygen are incorporated into the MSIS 2000 model. It must be assumed that the atomic oxygen (which influences the uncertainty on temperature from ~ 75 km to 110 km) is uncertain in the polar regions and there are corresponding uncertainties in temperature.

Furthermore, monthly average values of CO_2 used in the derivation of temperature are provided by the WACCM model. There is no local time variation in CO_2 used in the SABER retrieval. SABER temperatures, particularly above 80 km, are very sensitive to the CO_2 abundance.

In essence, for the trends in temperature to be correct, the variability and trends in O and CO_2 provided by MSIS 2000 and WACCM must also be correct. There is no real way to validate if this is true in the polar regions.

As noted above, the uncertainty of SABER data at mid latitudes is 25 K at 10^{-4} hPa. It may be higher in the polar regions during summer due to the low temperatures. The key point is that the uncertainty *at any altitude* does not necessarily cancel out when computing trends because the error in temperature due to O and to CO_2 may not be constant or even the same sign over time. This may be thought of as a mild form of algorithm instability in which the inputs to the temperature algorithm do not represent the actual atmosphere and consequently cause uncertainty on the retrieved temperature. The uncertainty in temperature may not be constant in time.

The recommendation to the authors is to compute the uncertainty in the trend assuming the errors on the temperatures are non-zero and follow standard error analyses for uncertainty calculations when taking differences. At what point do the uncertainties in temperature negate the large trend values?

3. The multiple linear regression equation contains terms involving the QBO. Have these been de-trended? Stratospheric temperature trends could create trends in the winds used in the QBO predictors. Failure to de-trend these predictors could lead to false or incorrect trends in the linear regression where the QBO predictors are significant.