Seasonality of Lower Tropospheric Stability in the Community Earth System Model Large Ensemble

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Abstract

Arctic amplification is a near-universal feature of climate change in simulations. However, climate models disagree in its magnitude and in its spatial and seasonal expression. Lower tropospheric stability ($\text{LTS} = T_{850hpa} - T_{2m}$) has been linked to Arctic amplification through its influence on radiative cooling efficiency and vertical propagation of surface fluxes. Using monthly mean output from the Community Earth System Model Large Ensemble (CESM LE) we find that internal variability in CESM LE is insufficient to explain the differences in LTS distributions over the Arctic Ocean found in CMIP3 and CMIP5 multi-model ensembles. To facilitate comparison with prior work we compare the CESM LE output to the ECMWF interim reanalysis (ERA-I) for the period 1979-2005. Over the ocean surfaces north of 60°, LTS exhibits a bimodal distribution. Dividing model and reanalysis output into open water and sea ice domains based on a sea ice concentration (SIC) threshold of 15% confirms LTS bimodality is the result of summing distinct distributions. Over sea ice, median NDJF LTS is 3.6 K in ERA-I and ranges from 5.7 K to 6.9 K in the CESM LE. Interquartile range of NDJF LTS is 4.7 K in ERA-I and varies from 9.6 K and 10.5 K across the ensemble. Spatial and seasonal patterns of LTS are qualitatively similar in the model and reanalysis; over ice LTS is positive through most of the year and slightly negative in the summer, and interannual variability is highest near the ice edge. However, the seasonal cycle of stability is stronger in CESM LE. We find that stability during early spring is consistently higher in CESM LE than in ERA-I. The enhanced variability over the central Arctic in CESM LE appears to be the result of variation in sea ice thickness.
Seasonality of lower tropospheric stability in the Community Earth System Model

Daniel Watkins and Jennifer Hutchings

Introduction

Lower tropospheric stability (LTS), defined here as \( T_{500} - T_{2} \), has been linked to Arctic amplification through its influence on radiative cooling efficiency and vertical propagation of surface fluxes. Climate models show high disagreement in the Arctic, which indicates either (or both) high internal climate variability or uncertainty in climate physics. Bias in Arctic LTS in climate models is a persistent problem, both high internal climate variability or uncertainty in climate physics models show high disagreement in the Arctic, which indicates either (or both) high internal climate variability or uncertainty in climate physics. Bias in Arctic LTS in climate models is a persistent problem.4,5,6 Biases in Arctic LTS in climate models is a persistent problem.4,5,6 Biases in Arctic LTS in climate models is a persistent problem.4,5,6

Investigation of the annual cycles of \( T_{500} \), \( T_{2} \), and LTS reveals winter LTS peaking in Dec-Jan in ERA-I and in Mar-Apr in CESM LE (Figure 3). Compared with ERA-I, CESM LE is biased both at the surface and at altitude; however, it is at the surface that the seasonal cycle shows the strongest offset. Total cloud cover is biased high in late summer, while low cloud cover is biased high Feb-Oct. Low clouds typically reflect longwave radiation toward the surface, increasing surface temperatures. Absence of winter liquid clouds in CESM may be to blame for the winter cold 7,8 bias.

Key Results

- Despite strong internal climate variability among CESM LE ensemble members, spread of lower tropospheric stability (LTS) within CESM LE is much smaller than spread within the CMIP5 or CMIP3 model ensembles.
- The annual cycles of lower tropospheric stability in CESM LE and ERA-I differ both in phase and in amplitude.
- Key Results - Despite strong internal climate variability among CESM LE ensemble members, spread of lower tropospheric stability (LTS) within CESM LE is much smaller than spread within the CMIP5 or CMIP3 model ensembles.
- The annual cycles of lower tropospheric stability in CESM LE and ERA-I differ both in phase and in amplitude.

Results

November-February LTS distributions over the Arctic Ocean have a bimodal distribution, as described in earlier studies.4,6,8 Binning with the 15% SIC threshold reveals unimodal distributions over sea ice and open water domains, confirming that the stable (unstable) mode of LTS is the mode of the LTS distribution over sea ice (open water) as shown in Figure 1. The mode of 40-year binned NDJF LTS distribution is 4.5 K in ERA-I and ranges from 5 to 11 K in CESM LE, with an average value of 8 K. Figure 2 compares the distribution of stable modes in ERA-I and CESM LE to values for CMIP5 and CMIP3 from the literature.4,5 The distributions over the 1990-1999 interval and the 1980-2008 intervals are remarkably similar. In both cases, the spread within CESM LE is not large enough to explain the spread in the CMIP5 and CMIP3 ensembles.

Strong biases in LTS persist from mid-winter to the beginning of fall. Satellite observations show a linear relationship relationship between monthly annual sea ice concentration and Dec-Feb LTS4,8. Figure 4 shows that LTS/SIC relationship is tighter and steeper in CESM LE compared with ERA-I. The largest difference is the region with >90% mean annual sea ice concentration. In Figure 5, LTS gradients for Jan-Apr over sea ice mirror gradients of sea ice thickness (not shown).

Next Steps

- Decomposing relationship of sea ice and LTS in NCEP CFSR
- Regional climate model (RASM): effect of higher grid resolution and usage of WRF instead of CAM
- AIRS-derived satellite LTS annual cycle
- Comparison with CESM2

References


Data and computational acknowledgements

Monthly mean output from the Community Earth System Model Large Ensemble (CESM LE) and the ECMWF Interim Reanalysis (ERA-I) for the time period 1979-2018 were obtained from the NCAR Research Data Archive. Analysis was performed on NCAR’s Casper computer. Model-level data was interpolated to the EC-Earth pressure levels using PyTIGO. Area-weighted means and histograms were computed using xarray and cartopy, with plots made using matplotlib and seaborn. Linear regression coefficients were computed with scipy.stats.

Figure 1. The binned LTS distribution over Arctic Ocean divided nearly into two unimodal distributions when split using a 15% sea-ice concentration threshold. Differences in the distributions line indicate differences between the 40 ensemble members of CESM LE. The form of the distribution is dependent on the averaging interval, here, we have binned individual monthly averages then split them rather than only a seasonal mean. Gatter averaging intervals generally result in a wider distribution.

Figure 2. Comparison between DJF LTS and sea ice concentration for CESM LE (top) and ERA-I (bottom). Linear regression coefficients are significantly higher in CESM LE compared with ERA-I. Based on analysis in Figure 5, the winter SIC/LTS relationship in CESM LE is more linear than in ERA-I, which indicates a larger role for internal variability in the climate system.

Figure 3. Annual cycle for (a) 2-meter temperature, (b) temperature at 850 hPa, (c) lower tropospheric stability, (d) low cloud cover. Each time represents a year’s winter season and is centered on 1 January. Red lines are from the ERA-Interim reanalysis, while black lines are from the CESM-LE ensemble average.

Figure 4. Lower Tropospheric Stability vs Sea Ice Concentration

Figure 5. Average LTS in CESM LE (top) and ERA-I (bottom) for Jan-Apr. The dashed black line indicates the 15% SIC contour, while the solid black line indicates 90% SIC.