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Drivers and surface signal of inter-annual variability of boreal stratospheric final warmings

Blanca Ayarzagüena (1,2), Rémi Thiéblemont (3), Katja Matthes (4), and Slimane Bekki (3)

(1) Universidad Complutense de Madrid, Madrid, Spain (bayarzag@ucm.es), (2) Instituto de Geociencias, CSIC-UCM, Madrid, Spain, (3) Laboratoire Atmospheres, Milieux, Observations Spatiales (LATMOS-IPSL), Université Pierre et Marie Curie, Paris, France, (4) GEOMAR Helmholtz Centre for Ocean Research Kiel, Ocean Circulation and Climate Dynamics, Kiel, Germany

Stratospheric final warmings (SFWs) mark the final transition from the typical wintertime westerlies to summertime easterlies at high latitudes in the stratosphere. They occur in both hemispheres, but, due to the enhanced planetary wave activity, these events present a high inter-annual variability in the Northern Hemisphere. In particular, SFWs onset dates oscillate in a range of about two months and SFWs show different vertical temporal developments, i.e. events may occur first in the mid-stratosphere (10-hPa first SFWs) or in the upper stratosphere (1-hPa first SFWs). This variability has been shown to impact the polar ozone depletion, but also the tropospheric circulation, particularly over the North Atlantic sector. Thus, it is important to identify factors that influence SFW variability. However, most of the previous studies were essentially based on reanalysis data and so, the length of observations is relatively short to derive robust conclusions.

In this study, we aim to improve the understanding of drivers, trends and surface impact of dynamical variability of boreal SFWs. To do this, we use multi-decadal integrations (145 years) of a fully coupled chemistry-climate model (CESM1(WACCM)) that ensure a large statistical sampling. Four sensitivity experiments are also analyzed to assess the impact of external factors such as quasi-biennial oscillation (QBO), sea surface temperature (SST) variability and anthropogenic emissions. Our results confirm previous reanalysis results regarding the differences in the time evolution of stratospheric conditions and surface impact between 10-hPa and 1-hPa first SFWs. Additionally, a tripolar SST pattern is, for the first time, identified over the North Atlantic in spring months related to the SFW variability. The analysis of the influence of remote modulators on SFWs revealed that the occurrence of stratospheric sudden warmings in the previous winter prioritizes the development of 10-hPa first SFWs later on. We further found that QBO and interannual SST variability significantly affect the ratio between 1-hPa first and 10-hPa first SFWs. Finally, the long term evolution of ozone depleting substances concentration seems to impact the timing of the occurrence of 1-hPa first SFWs. The results of this study might be useful for improving springtime seasonal forecast in the Euro-Atlantic sector.