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Anomalous transport in the Northern Hemisphere in the stratosphere as diagnosed by nitrous oxide in meteorological and chemical reanalyses

In early 2019, anomalously large concentrations of nitrous oxide (N2O) developed in the Northern Hemisphere (NH) with a very particular pattern. Specifically, a "tripole"structure can be distinguished: positive N2O anomalies over the tropical upper stratosphere (above 10 hPa), large negative anomalies in the mid-upper stratosphere (between 10 and 20 hPa) over the subtropics and equally large positive anomalies in the mid-stratosphere (around 50 hPa) over the whole NH. Given the long chemical lifetime of N2O in the stratosphere, these anomalies are caused by anomalies in the stratospheric transport. We use the Dynamical Linear Model (DLM) tool to separate the impact of different physical processes: the QBO with a lag of 4 months, the de-seasonalized Eliassen Palm Flux divergence (as a measure of the anomaly in the wave activity), the solar cycle, the seasonal variations, and the autoregressive term. We consider several datasets: the merged satellite dataset SWOOSH, the reanalysis of Aura MLS driven by the MERRA2 meteorology (M2-SCREAM), together with several CTM simulations: the GMI model driven by MERRA2 (M2-GMI), and the BASCOE model driven by ERA5 (BASCOE-ERA5), by JRA3Q (BASCOE-JRA3Q) and by MERRA2 (BASCOE-MERRA2). These datasets compare remarkably well in terms of the patterns and magnitudes of the N2O anomalies. The results with the DLM also show very good agreement between the datasets, with a considerable impact of the QBO with a lag of 4 months. In particular, the tripole structure in the N2O anomalies is well reproduced by the 4-months lag QBO regressor across most of the stratosphere. These patterns indicate that the N2O anomalies are generated by the QBO-induced secondary circulation developed 4 months before and were transported and stretched towards the higher latitudes by the transport due to the Brewer Dobson Circulation (BDC). Over the polar region, the positive impact of the de-seasonalized Eliassen-Palm flux divergence suggests the effect of a sudden stratospheric warming that allowed transport of N2O above the Arctic. The contribution of the seasonal cycle reflects the climatological seasonality of the BDC. In order to better understand the role of the transport via the BDC, we also investigated the N2O TEM budget. In particular, we considered the impact of the residual advection on the N2O concentrations. We show that the anomalies of the residual advection term correspond in magnitude and sign to the N2O anomalies. This suggests that the anomalous residual advection generates the N2O anomalies. We applied the DLM to the residual advection term and the DLM confirms that the lagged QBO is the main process generating the residual advection anomalies. This implies that the lagged impact of the QBO generated an anomalous residual advection in the NH that ultimately created the N2O anomalies. We highlight how valuable is N2O to study extreme events of transport and that diagnostics like the DLM and the TEM budget help to better understanding these processes.

Topic

Atmospheric composition (Earth and planets), chemistry and transport

Author: MINGANTI, Daniele (BIRA-IASB)

Co-authors: WARGAN, Krzysztof (NASA); OP DE BEECK, Marc (BIRA-IASB); ERRERA, Quentin (BIRA-IASB); VERVALCKE, Sarah (BIRA-IASB); DAVIS, Sean (NOAA); CHABRILLAT, Simon (BIRA-IASB)

Presenter: MINGANTI, Daniele (BIRA-IASB)