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Supplement of

Evaluation of CESM1 (WACCM) free-running and specified dynamics atmospheric composition simulations using global multispecies satellite data records

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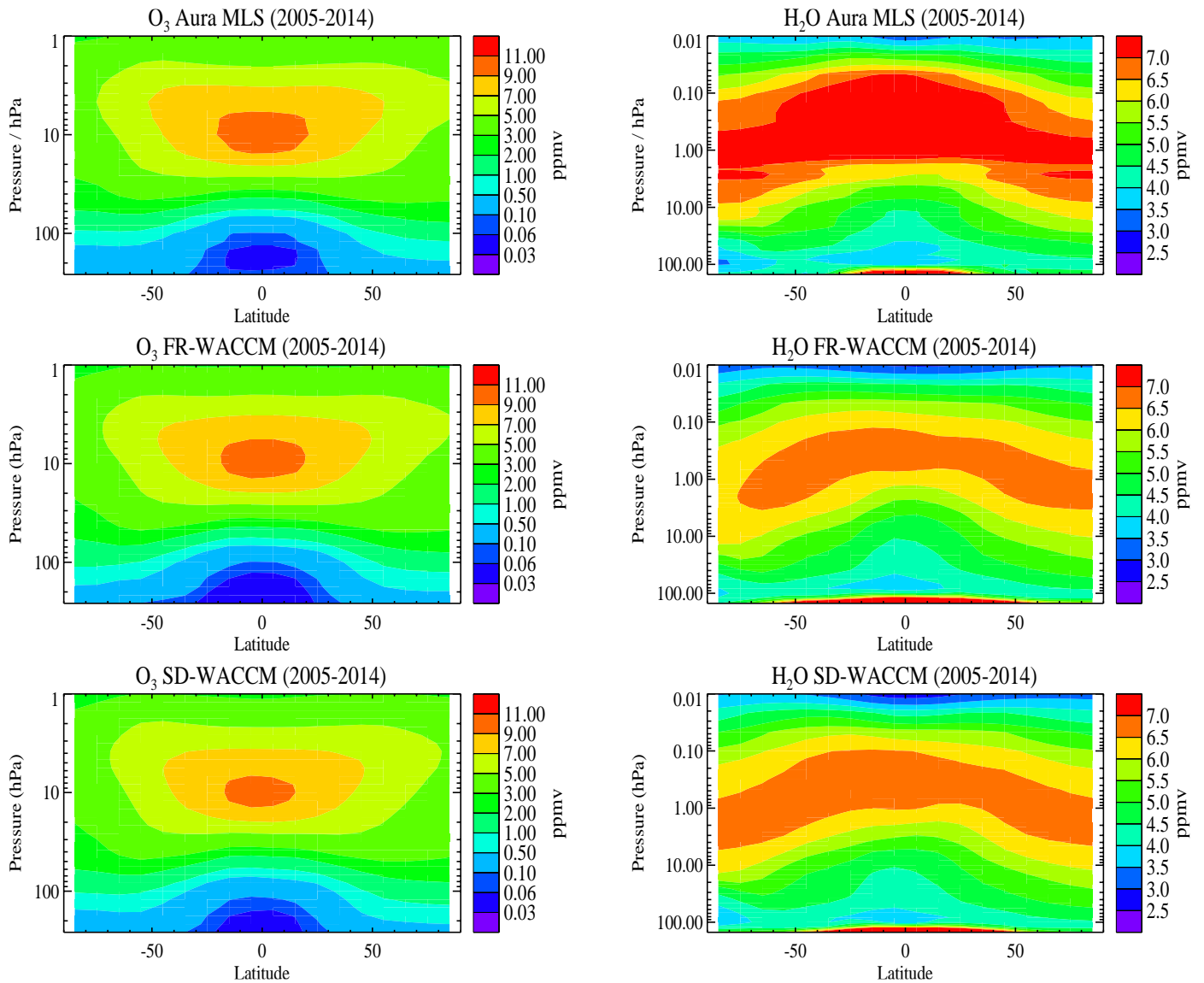


Figure S1. Latitude/pressure contour plots of the average climatological abundances of O₃ (left panels) and H₂O (right panels) for 2005 through 2014. Results are shown for Aura MLS data (top panels), the WACCM free running model (FR-WACCM), and the WACCM specified dynamics version (SD-WACCM).

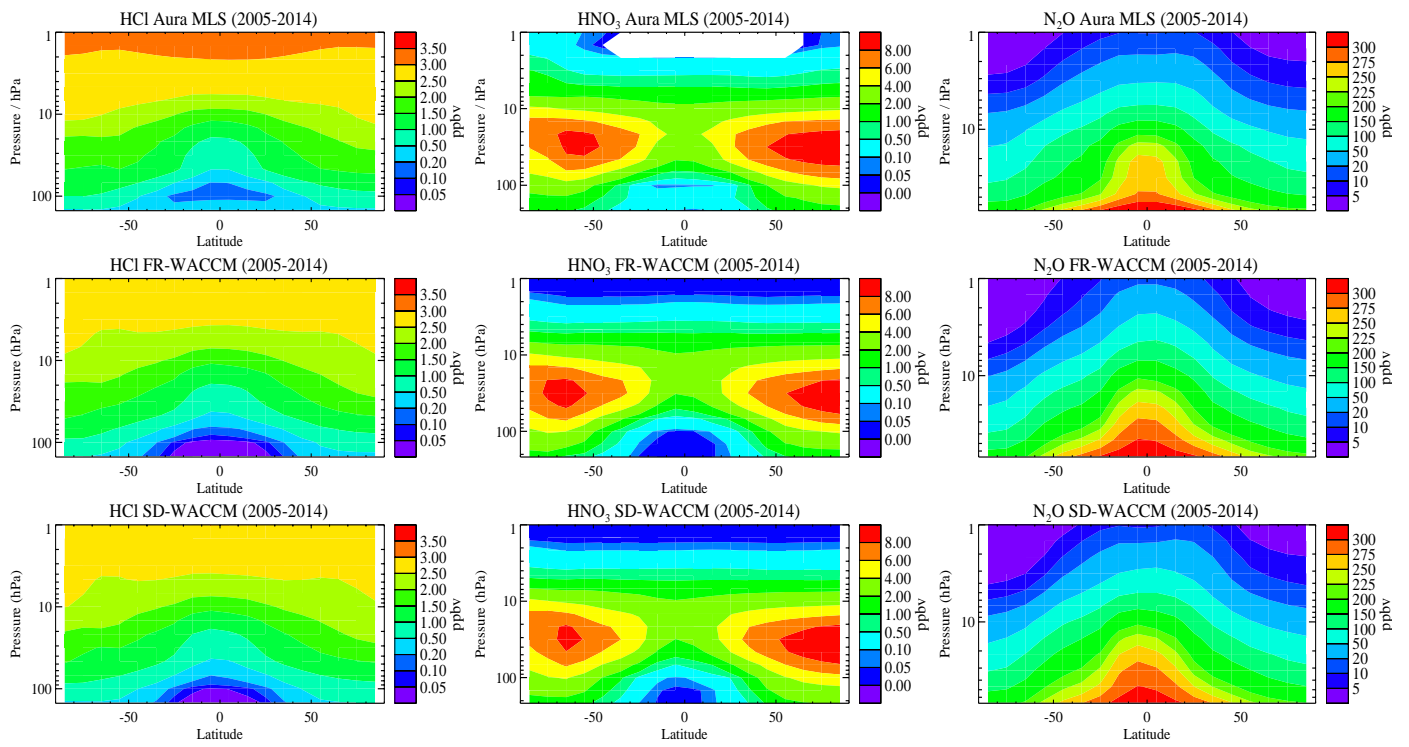


Figure S2. Same as Fig. S1, but for the 2005-2014 climatologies (from Aura MLS, FR-WACCM and SD-WACCM) of three other species: HCl (left panels), HNO₃ (center panels), and N₂O (right panels).

Aura MLS O3: Systematic Uncertainty Estimate

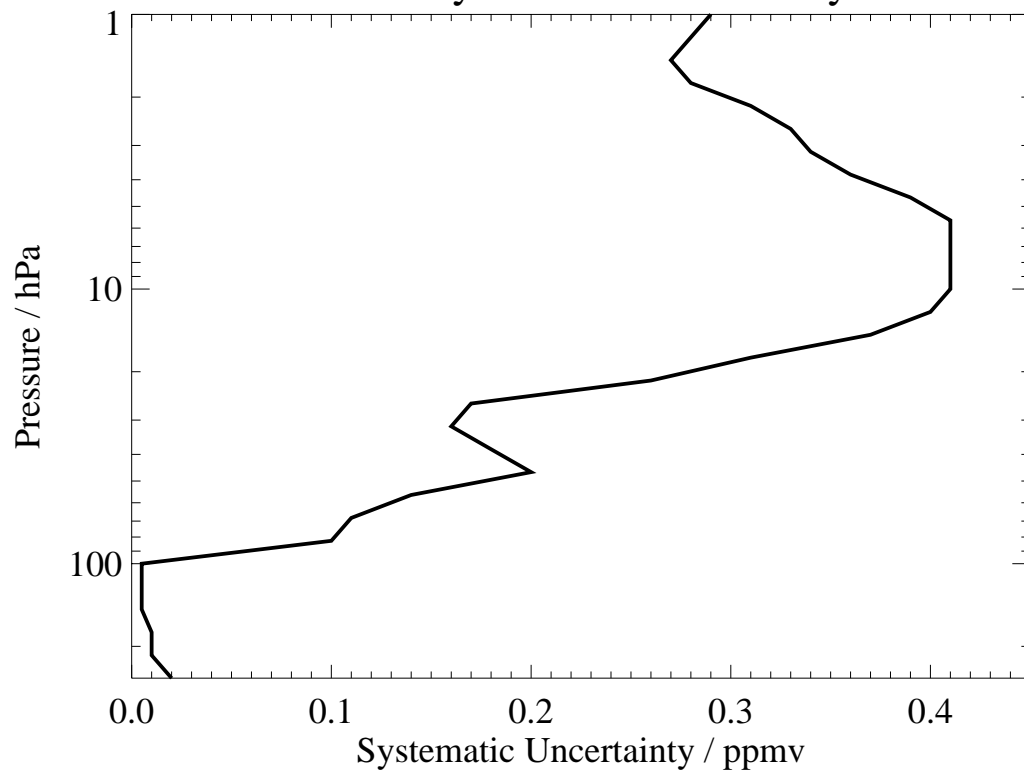


Figure S3. Profile of globally-averaged systematic uncertainties (2σ estimates) in Aura MLS ozone, based on the MLS team's characterization of the likely (known) error sources and their calculated impact on Level 2 retrievals, coupled with validation results (see text).

Time Series (2005-2014) for 70S-80S at 46 hPa: Aura MLS **FR-WACCM** **SD-WACCM**

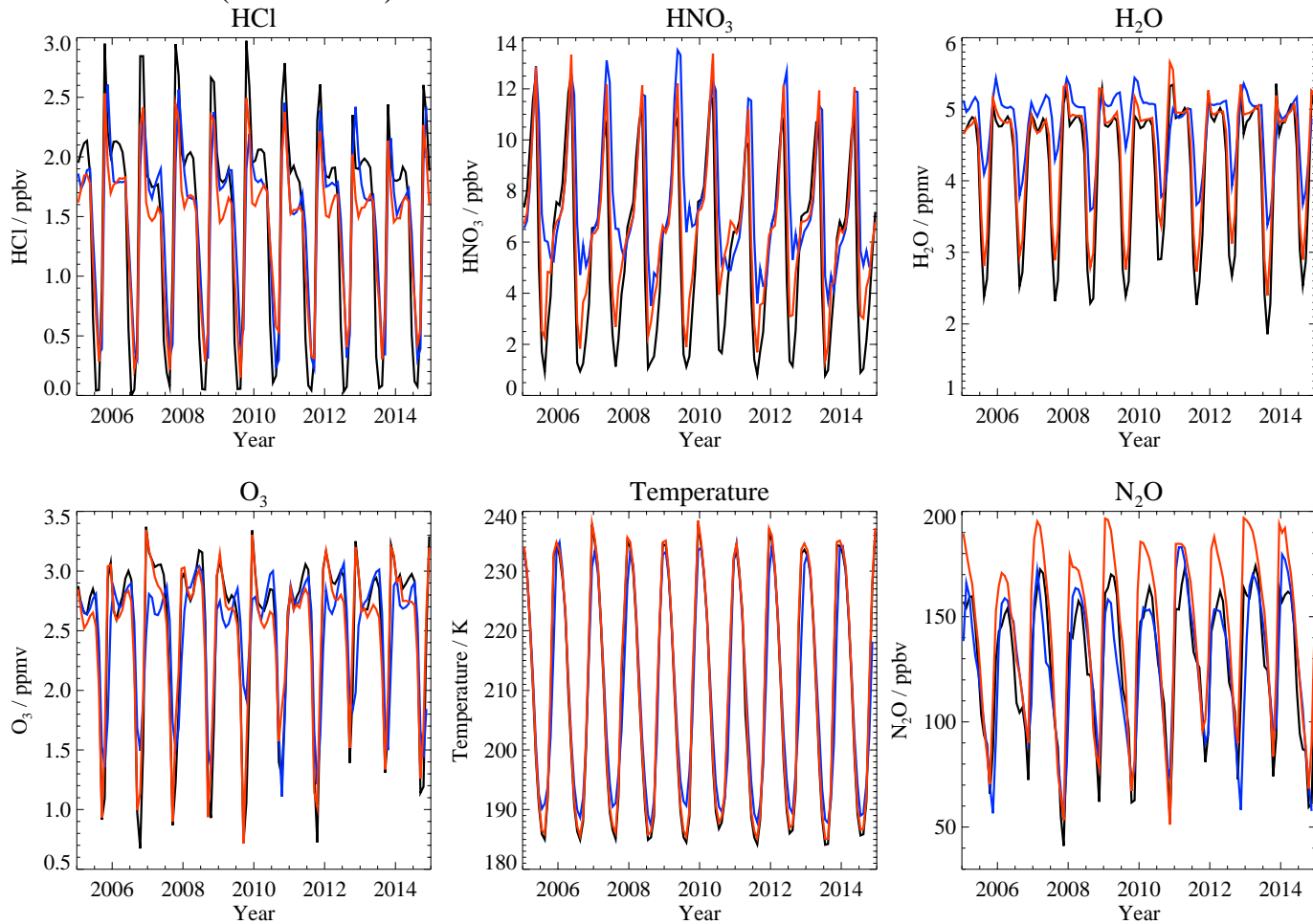


Figure S4. These plots provide the time series for all years (2005 through 2014) from both data (MLS) and models (FR-WACCM in blue, SD-WACCM in red) in the 70°S-80°S latitude range at 46 hPa. The averaged values of these time series are provided in the main text, with emphasis on the slope of the early winter decline in HCl over the Antarctic region, where we see consistently that the model HCl values do not decline as fast as indicated in the data, even though SD-WACCM tracks the interannual variability better, overall, than FR-WACCM.

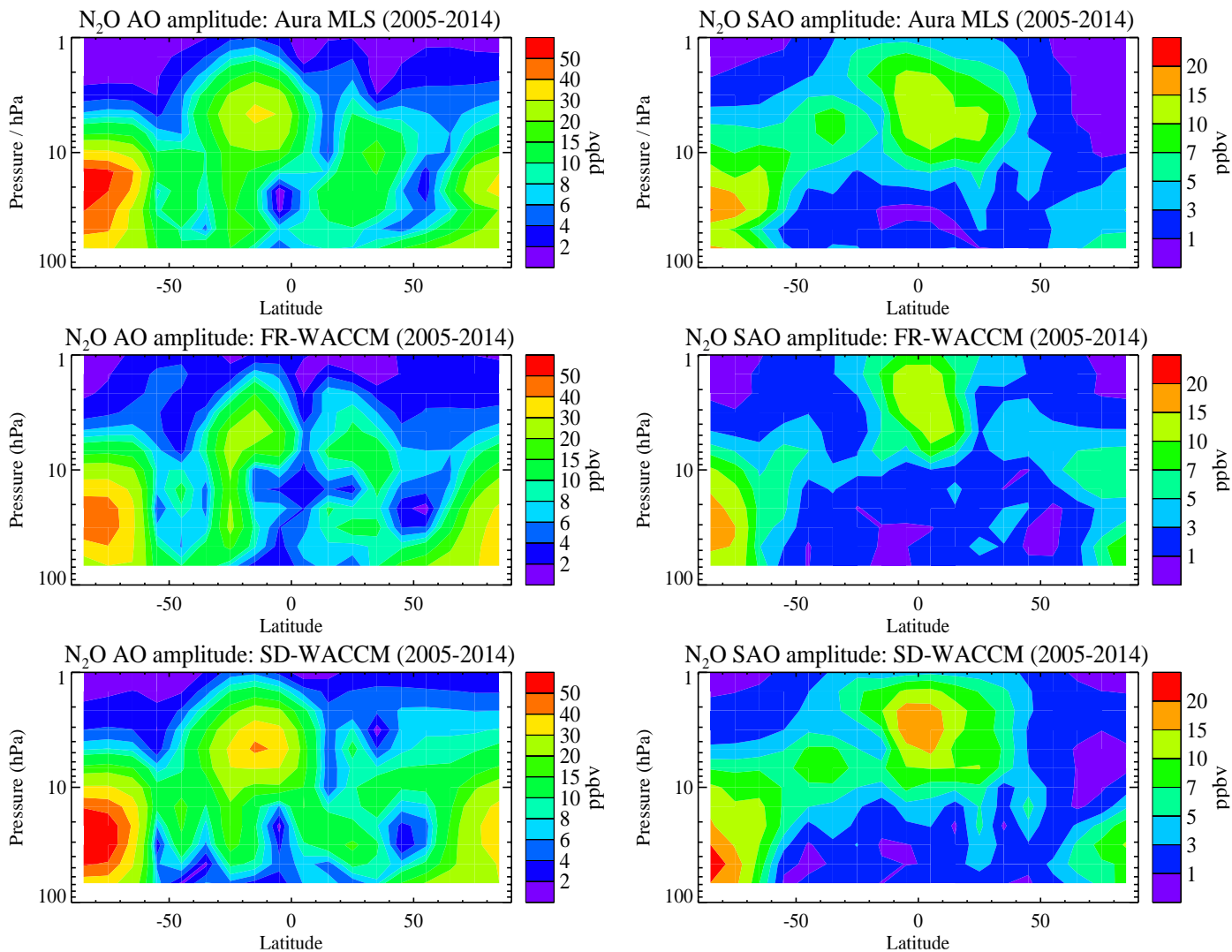


Figure S5. Amplitudes of the annual oscillation (AO, left panels) and semi-annual oscillation (SAO, right panels) for N₂O, based on fits to the 2005-2014 time series from Aura MLS (top panels), FR-WACCM (middle panels), and SD-WACCM (bottom panels). The product used here is N₂O-190 (from the 190 GHz MLS retrievals), since the N₂O-640 retrievals had to be discontinued in 2013, as a result of an instrument degradation issue affecting that band.

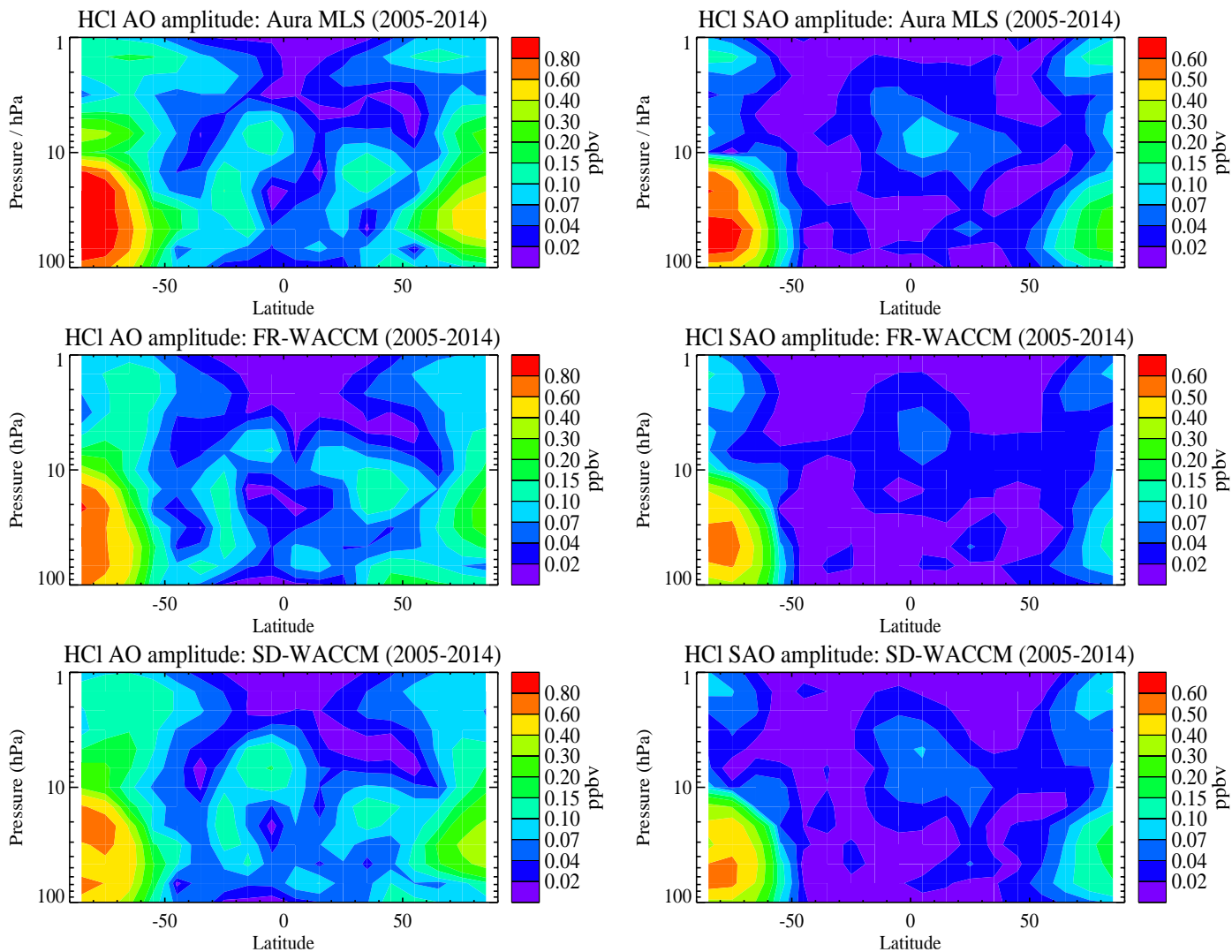


Figure S6. Amplitudes of the annual oscillation (AO, left panels) and semi-annual oscillation (SAO, right panels) for HCl, based on fits to the 2005-2014 time series from Aura MLS (top panels), FR-WACCM (middle panels), and SD-WACCM (bottom panels).

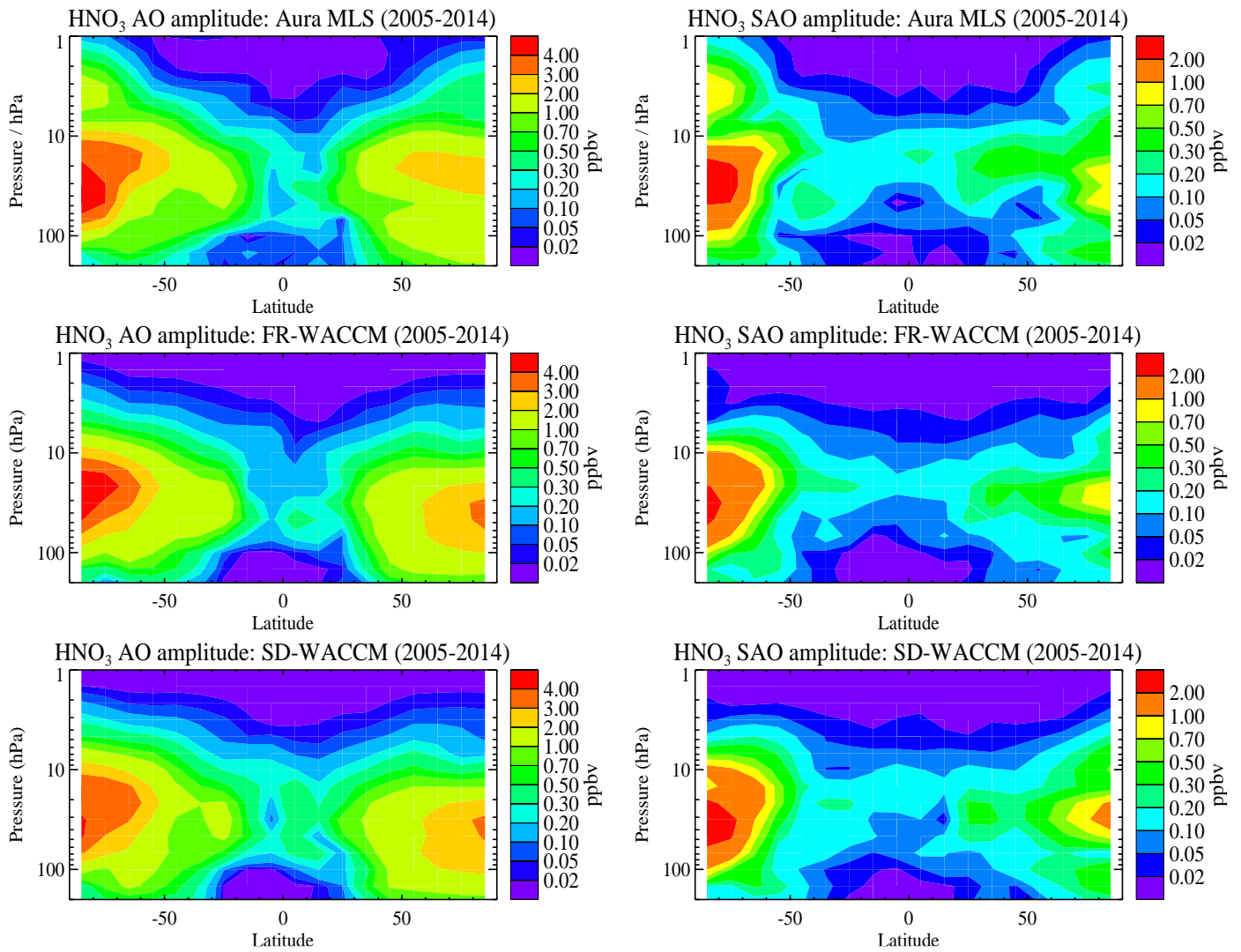


Figure S7. Amplitudes of the annual oscillation (AO, left panels) and semi-annual oscillation (SAO, right panels) for HNO_3 , based on fits to the 2005-2014 time series from Aura MLS (top panels), FR-WACCM (middle panels), and SD-WACCM (bottom panels).

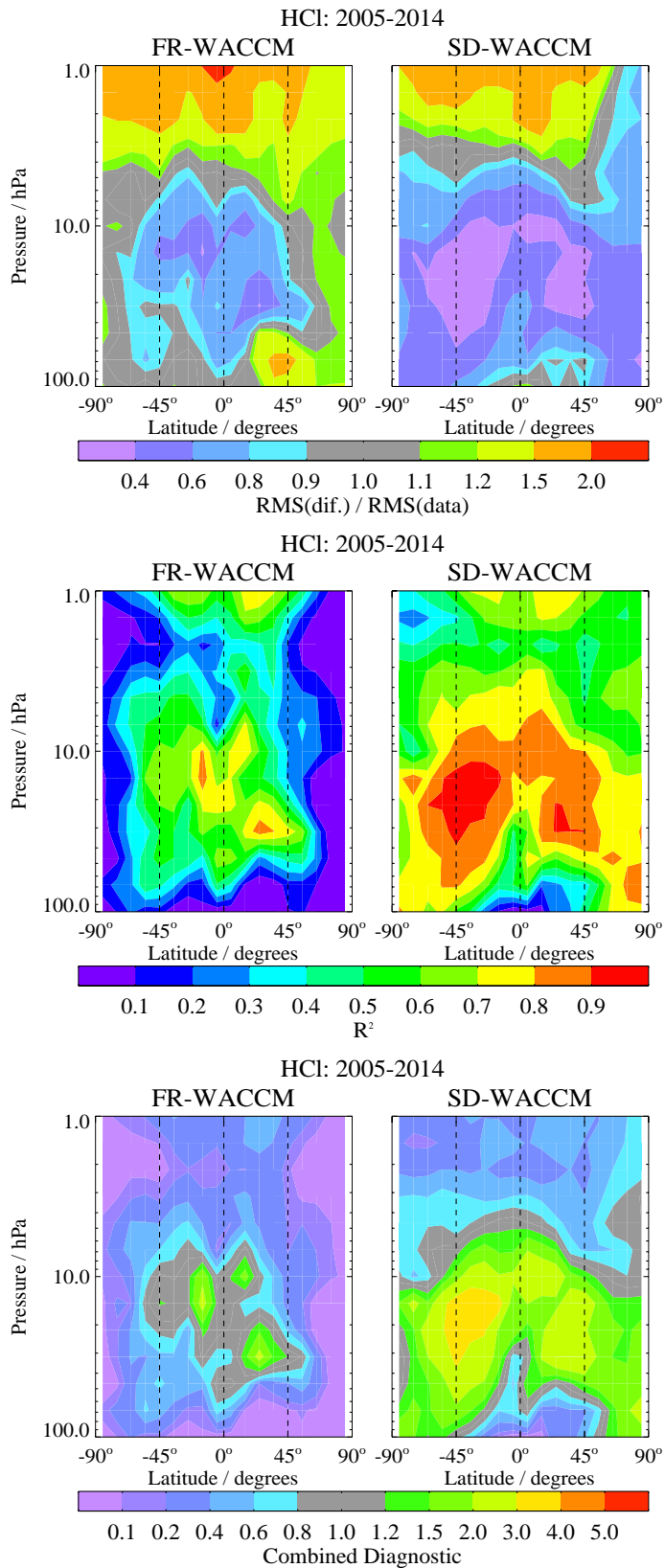


Figure S8. Same as the Fig. 10 diagnostics, but for stratospheric HCl.

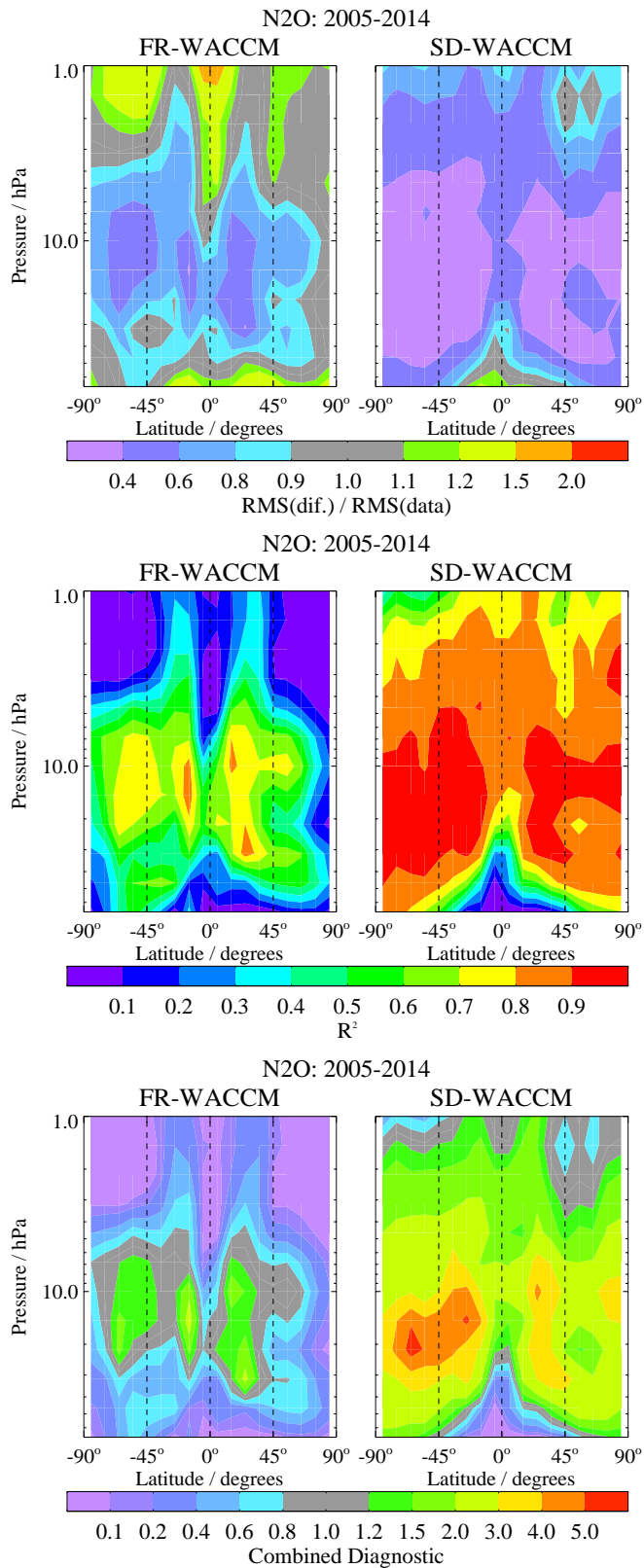


Figure S9. Same as the Fig. 10 diagnostics, but for N₂O (from 68 to 1 hPa).

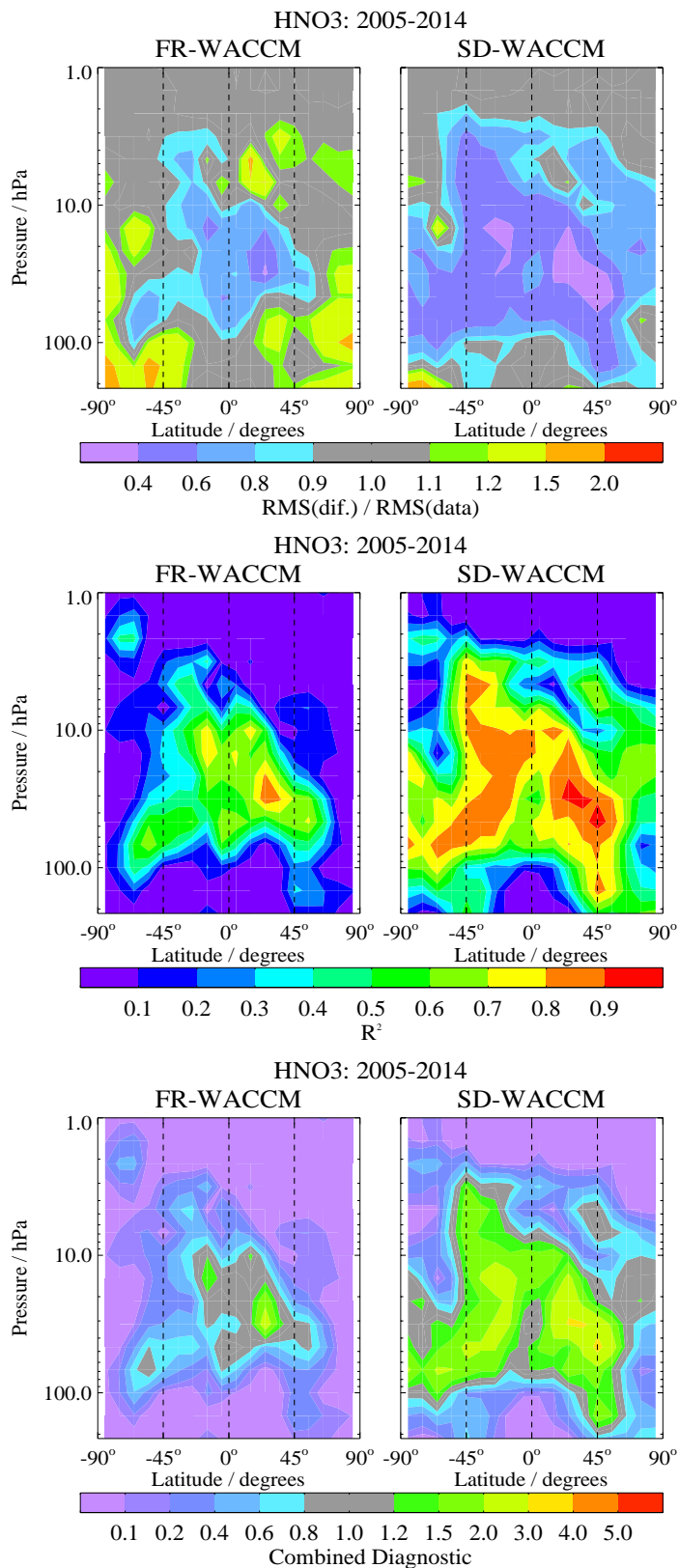


Figure S10. Same as the Fig. 10 diagnostics, but for HNO₃ (from 215 to 1 hPa).

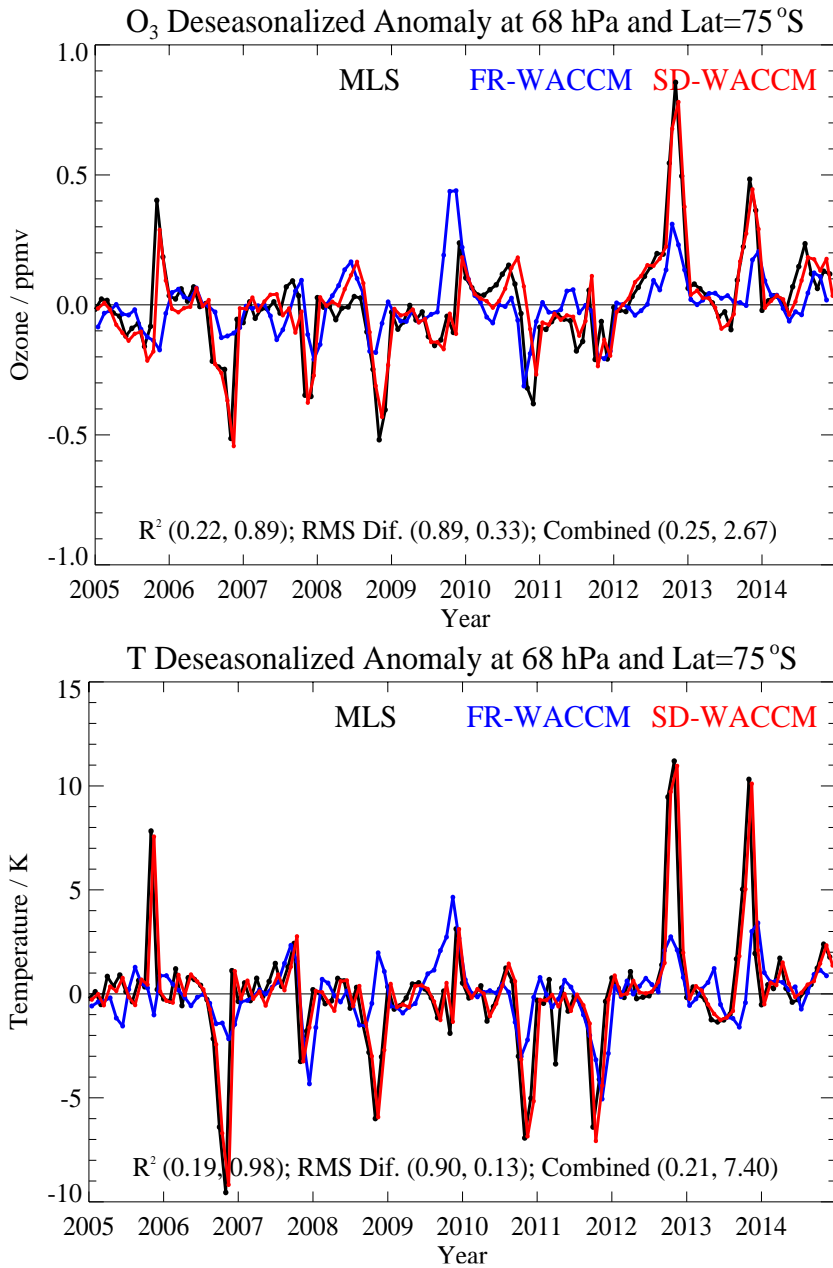


Figure S11. Deseasonalized anomaly time series (2005-2014) at 68 hPa and 70°S-80°S from Aura MLS, FR-WACCM, and SD-WACCM for ozone (top panel) and temperature (bottom panel); calculated values are provided in parentheses for the R^2 , RMS fit, and combined diagnostics used in this work (the 1st number refers to FR-WACCM and the 2nd number to SD-WACCM).

H₂O % anomalies (deseasonalized) at 83 hPa
 Black=AMLS, Blue=FR-WACCM, Red=SD-WACCM

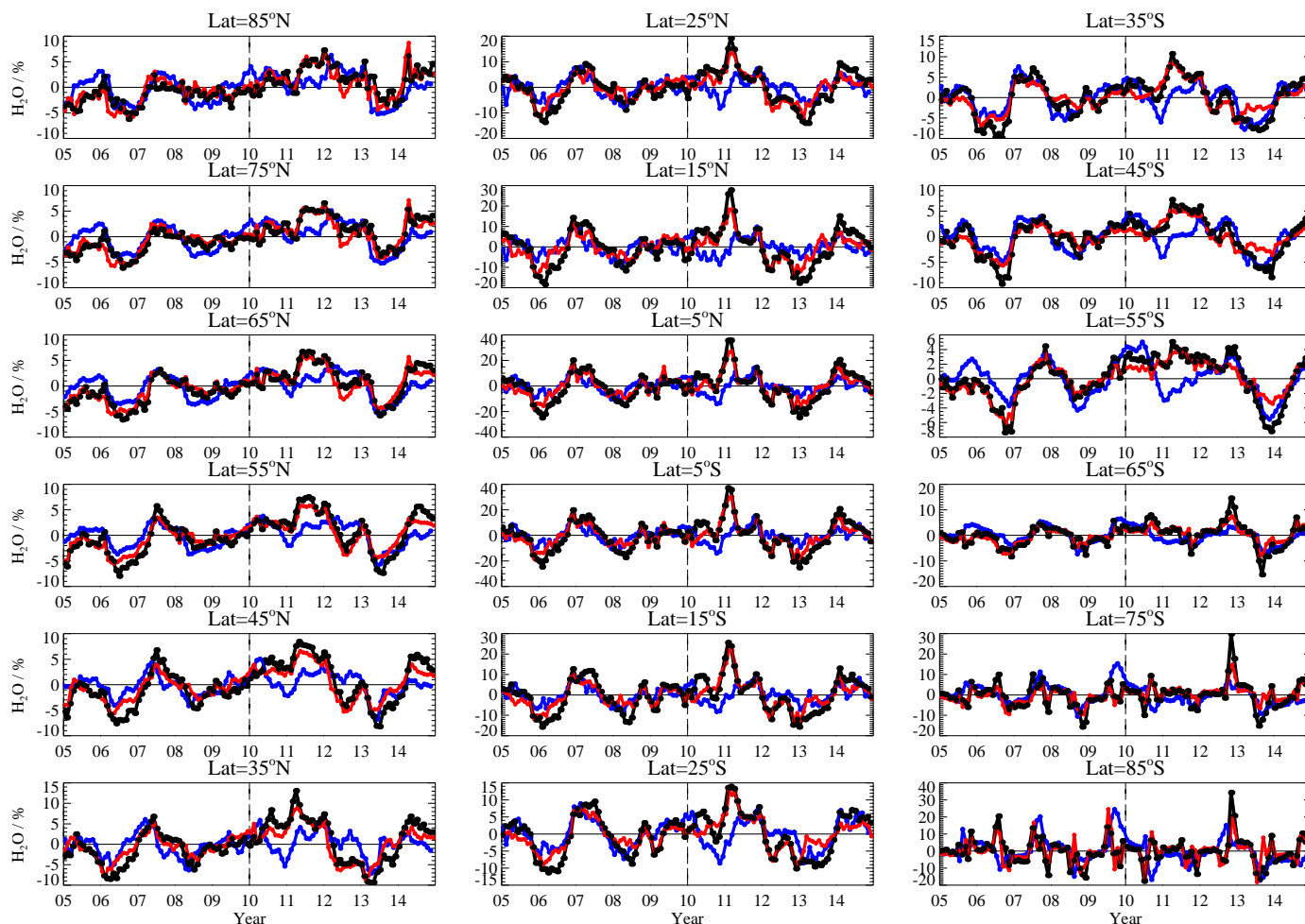


Figure S12. This shows H₂O model and data series comparisons at 83 hPa, as percent deseasonalized anomalies for 2005 through 2014 for all latitude bins from 85°S to 85°N, for Aura MLS data (black), FR-WACCM (blue), and SD-WACCM (red).

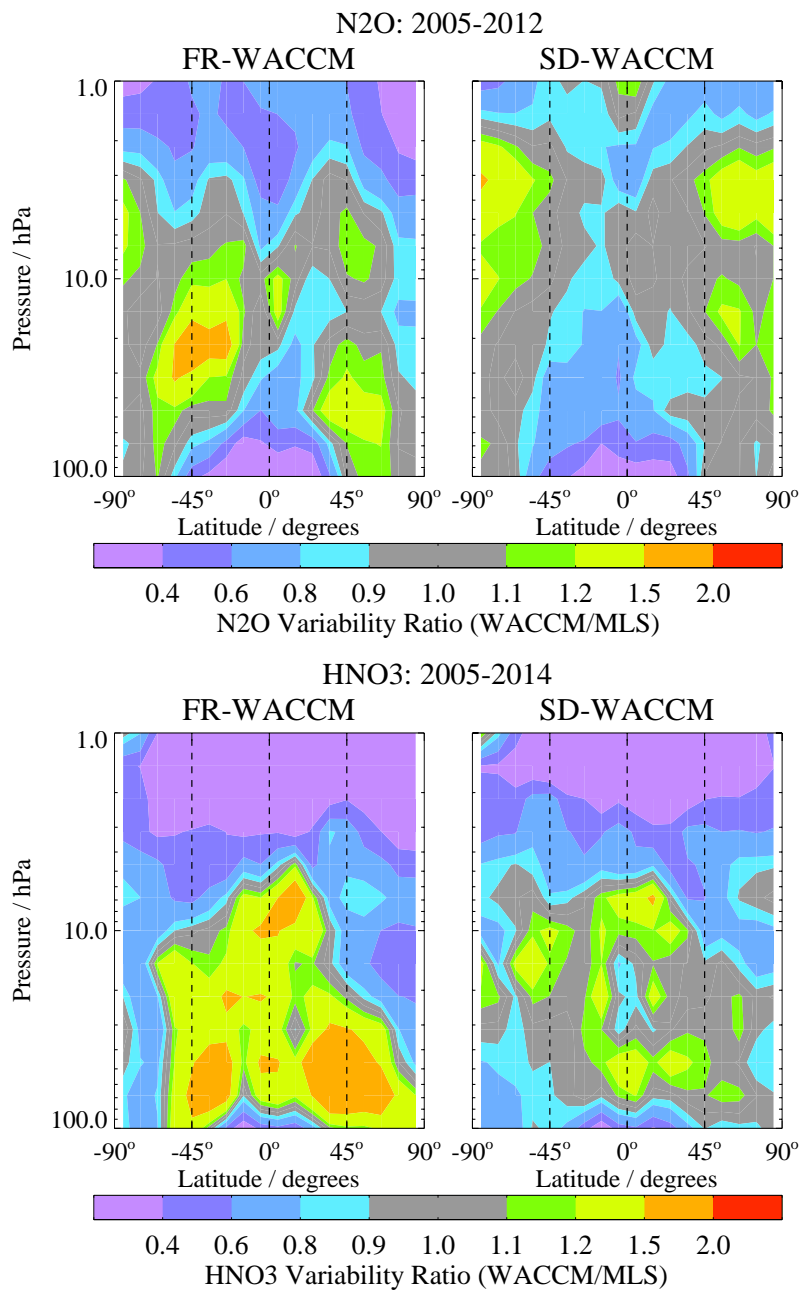


Figure S13. Same as Fig. 14, but for ratios (model/data) of the variability in stratospheric N₂O for 2005-2012 (top panels) and HNO₃ for 2005-2014 (bottom panels). The MLS N₂O-640 product (see text) is used for the comparisons in the top panels.

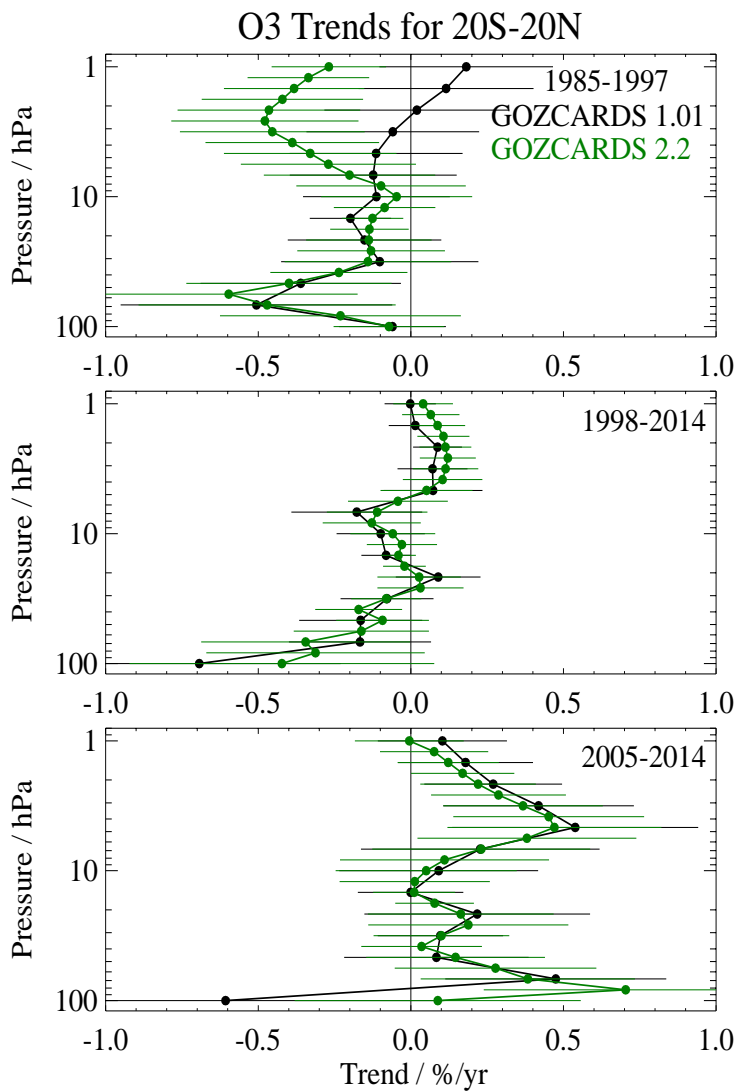


Figure S14. Stratospheric ozone trends in the 20°S-20°N latitude range from two different GOZCARDS data versions (2.20 versus 1.01) for three time periods, as labeled above. The tropical region for the early time period (see top panel) shows the largest differences between the two GOZCARDS merged ozone data sets (as explained in the text).

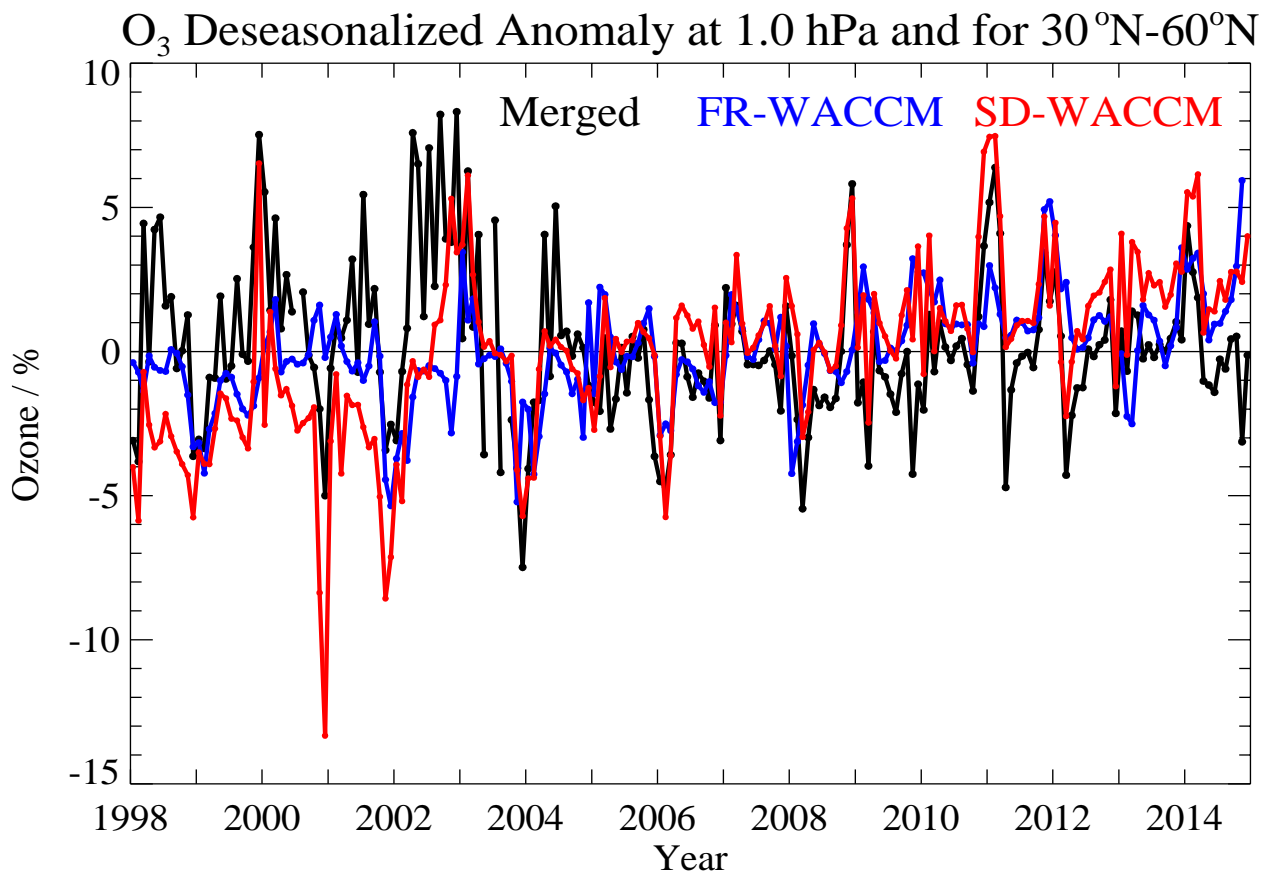


Figure S15. Percent anomalies in deseasonalized time series (1998 through 2014) from GOZCARDS merged O_3 at 1 hPa for 30°N-60°N are compared to the corresponding model anomalies from FR-WACCM and SD-WACCM, as labeled above.

HCl at 1.0 hPa and for 60°S-60°N

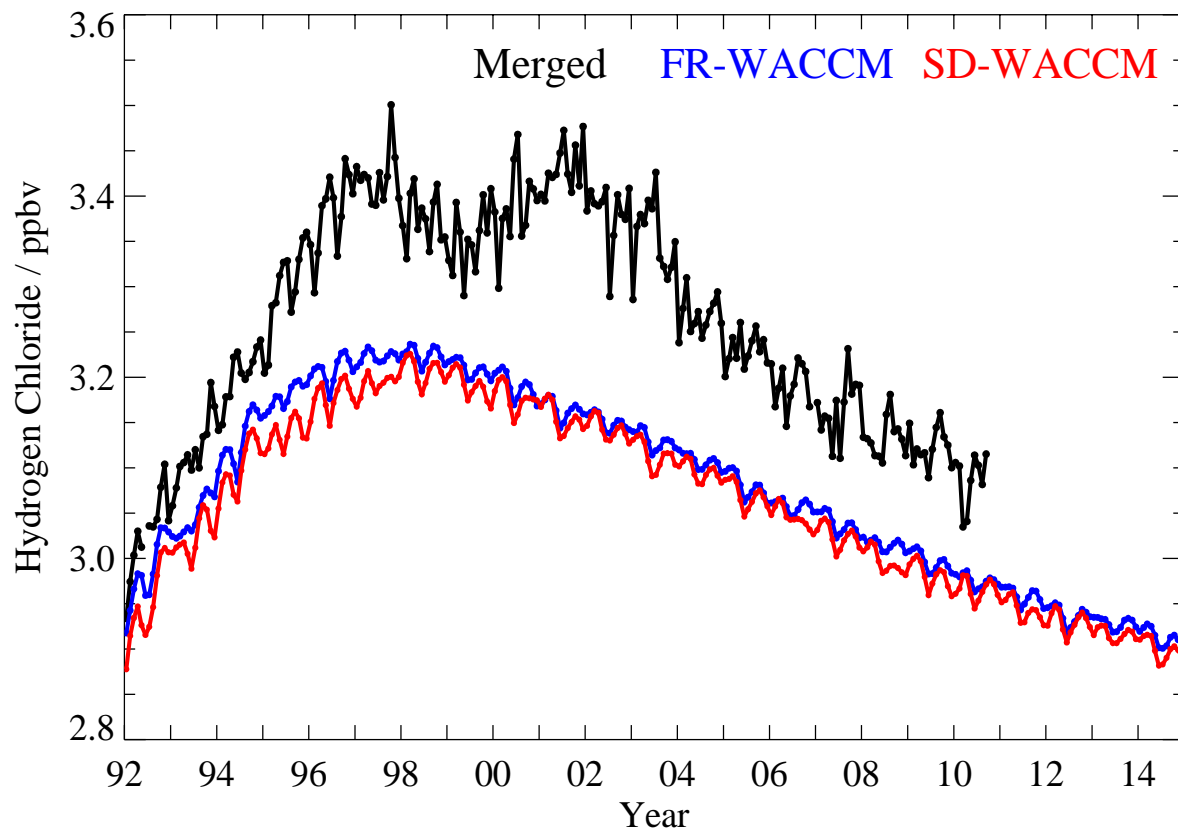


Figure S16. Time series for average near-global (60°S-60°N) HCl from the GOZCARDS merged data record (black), compared to the FR-WACCM (blue) and SD-WACCM (red) model series. The GOZCARDS data (version 1.01) for HCl stopped at the end of 2010, after some issues with ACE-FTS data processing; while a new ACE-FTS data version now exists, this has not yet been replaced into the GOZCARDS merged data record.

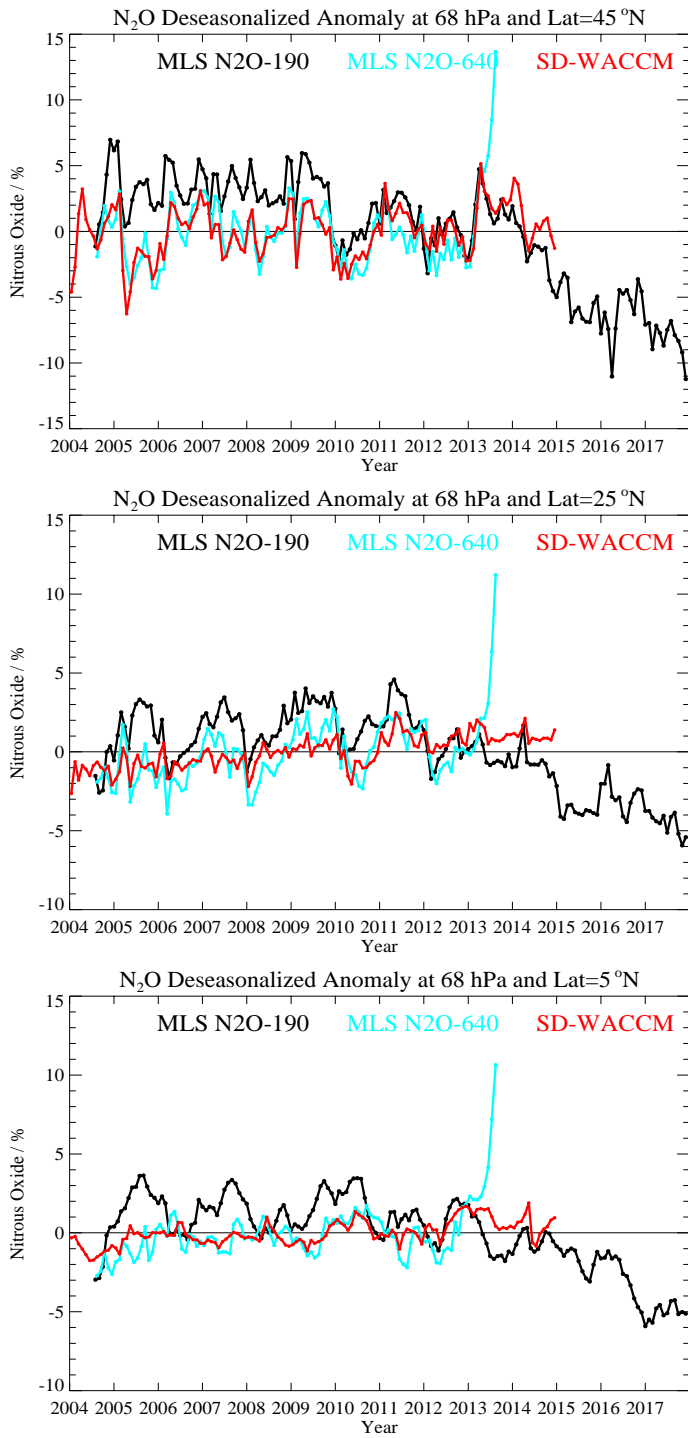


Figure S17. Percent anomalies (deseasonalized) for N₂O from the 2 MLS retrieval bands (N2O-190 and N2O-640) in 3 northern hemisphere latitude bins (labeled above) are compared to SD-WACCM anomalies, which are only through the end of 2014. While results from the standard MLS N₂O product at launch came from the 640 GHz radiometer band, these retrievals had to be discontinued in 2013, as a result of a hardware degradation issue affecting that particular N₂O band as early as April 2013.

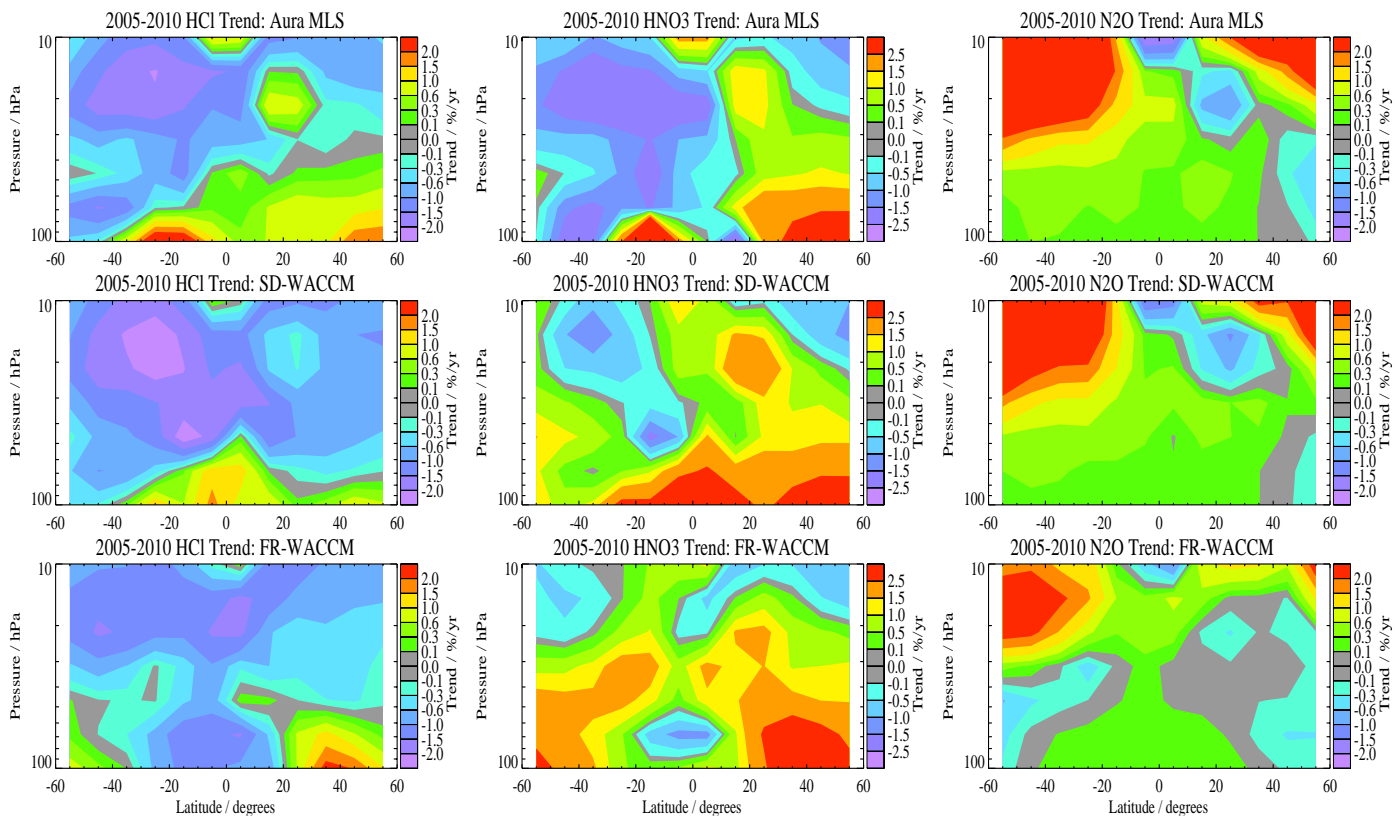


Figure S18. Pressure/latitude contour comparison of short-term (2005-2010) lower stratospheric trends from Aura MLS data (top panels) versus model trends (from SD-WACCM in middle panels and FR-WACCM in bottom panels). The left column is for HCl, the middle column for HNO₃, and the right column is for N₂O (using data from the MLS 640 GHz radiometer band).