Chemistry Simulations using MERRA-2 Reanalysis with the GMI CTM and Replay in Support of the Atmospheric Composition Community

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Summary

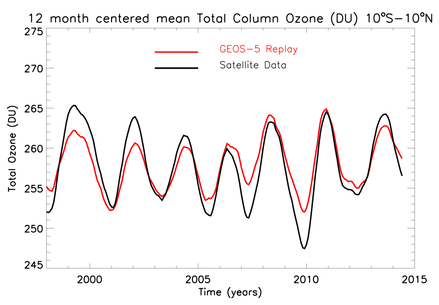
Simulations using reanalysis meteorological fields have been long used to understand the causes of atmospheric composition change in the recent past. Using the new MERRA-2 reanalysis, chemistry simulations are being conducted to create products covering 1980-2016 for the atmospheric composition community.

These simulations use the Global Modeling Initiative (GMI) chemical mechanism in two different models: the GMI Chemical Transport Model (CTM) and the GEOS-5 model in Replay mode. Replay mode means an integration of the GEOS-5 general circulation model that is incrementally adjusted each time step toward the MERRA-2 reanalysis. The GMI CTM is a 1° x 1.25° simulation and the MERRA-2 GMI Replay simulation uses the native MERRA-2 approximately 1/2° horizontal resolution on the cubed sphere.

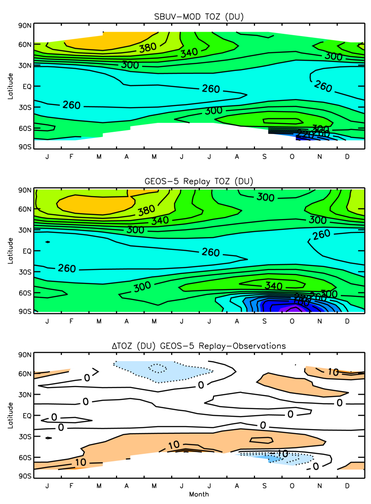
A specialized set of transport diagnostics is included in both runs to better understand trace gas transport and its variability in the recent past.

Driven by MERRA-2 Meteorology

Both the CTM and Replay are driven by the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) meteorology. MERRA-2 is a global reanalysis of 1980 to the present using modern hyperspectral radiance and microwave observations, along with GPS-Radio Occultation datasets. The inclusion of an internally generated QBO in the general circulation model improves the representation of transport in the tropics and subtropics.



The figure above shows the tropical total column ozone interannual variability, which is dominated by the QBO and is largely reproduced in a GEOS-5 Replay scout simulation.



The figure to the left shows an example of total column ozone from the SBUV-MOD data set (top) compared to a GEOS-5 Replay scout simulation (middle) for 1998-2000 and the difference between the two (bottom panel). The agreement is very good and generally within a few percent of observations.

Specialized Diagnostics and Output Collections

In addition to chemical constituents, the GMI CTM and Replay simulations will include a suite of tracers sensitive to tropospheric and stratospheric transport processes on a range of time and spatial scales. Some of the tracers are:

CH_3I - Marine convection tracer. Emitted over oceans with a 5-day e-fold.

Rn/Pb - Land-based convection tracer (Rn) with a 5.5 day e-fold, decaying to Pb, which is lost through washout.

e90 - Tropospheric transport tracer emitted at the surface with a 90-day e-fold. It is used to identify the tropopause.

Mean Age – a pulsed and a clock tracer – For transport pathways and timescales.

SF_6 – Emitted at the surface with a large interhemispheric gradient. No losses.

Simulations will include specialized output collections including high frequency 3-hrly (replay) to daily (CTM) output for a number of important constituents, satellite overpass output, and station data. Please contact Luke Oman and Susan Strahan for more information on available outputs.

CTM Overview

A simulation using the GMI chemistry transport model (CTM) driven by MERRA-2 meteorological fields is currently underway and will be completed by late 2016. MERRA-2 met fields driving the CTM are 3-hr averages (e.g., u,v,T, etc.) with no interpolation between the 3-hr updates. This differs from Replay (see below). The native MERRA-2 vertical coordinate is used (72 levels) and horizontal resolution is 1° x 1.25°. The updated GMI chemical mechanism (JPL 2015) contains 124 species, 322 kinetic and 81 photolytic reactions. MERRA-2 aerosols are used in the troposphere and IGAC sulfate aerosols are used in the stratosphere.

GMI-MERRA-2 results are not yet available, but below we present an example of science that can be done with the GMI CTM integrated with MERRA fields.

Replay Overview

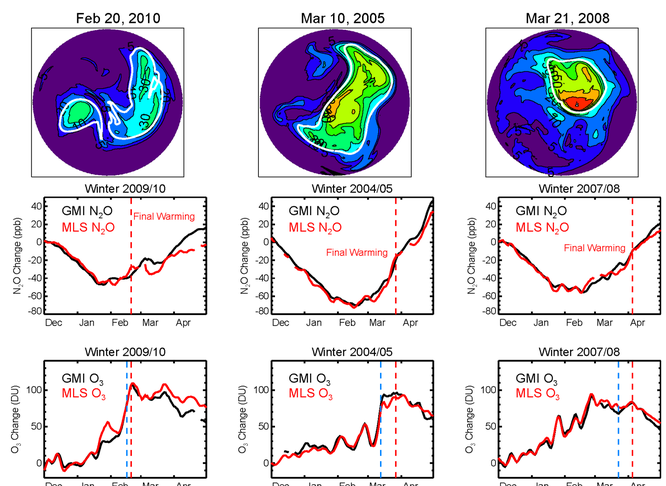
A simulation using the GMI chemical mechanism and the GEOS-5 Replay mode will be done at 1/2° horizontal resolution on the cubed sphere and output onto the same 0.625° x 0.5° grid as MERRA-2 Reanalysis. Replay requires running two forecasts with the GEOS-5 model.

The first forecast calculates the background model predicted state (bkg), which then is compared to the assimilated state (asm) from time averaged MERRA-2 fields (u,v,t,pressure + others which are optional).

Taking the difference and dividing by the number seconds elapsed produces the Increment Analysis Unit (IAU). This is applied to the "replayed" variables at each time time step (IAU * time step) as the model is run forward again.

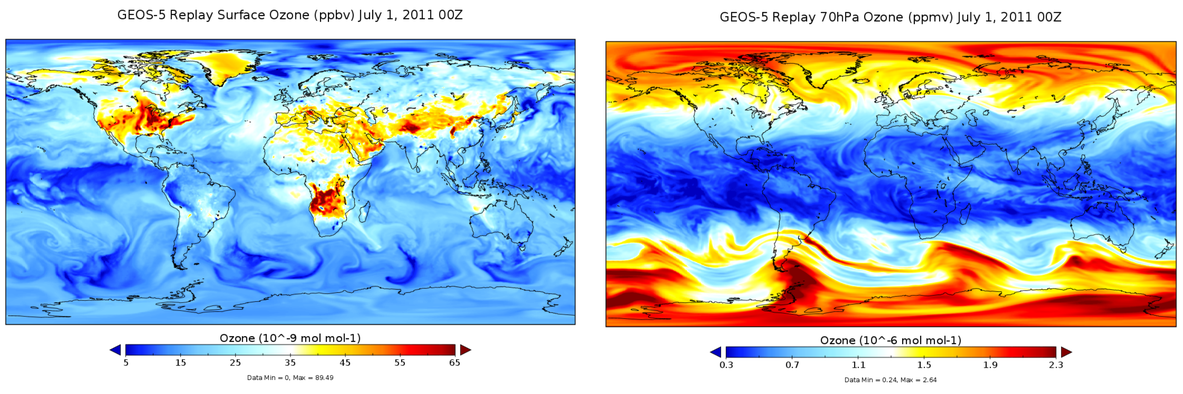
The users chooses the frequency of "replaying" but for the simulation described below we use a 3-hour frequency. This is repeated for the entire simulation.

CTM and Replay Examples



These panels, from Strahan et al. [JGR, submitted], show polar O_3 depletion (DU) in 3 Arctic winters during the Aura period, along with comparisons to MLS N_2O and O_3.

The figure above shows the excellent representation of chemistry and transport in the GMI-MERRA CTM Hindcast simulation. The depletion shown (top) is the difference between 2 GMI simulations, one with and one without heterogeneous halogen reactions. The 6 line plots show the evolution of MLS and GMI N_2O and O_3 during Arctic winter to demonstrate the credibility of vortex descent and isolation (middle) and the O_3 resupply and depletion (bottom). Line plots show the change in 450 K N_2O and column O_3 averaged over the Arctic vortex from December 1. The dashed blue line indicates when lower stratospheric temperatures became too high for halogen activation on cloud particles.



The figures above show examples of surface (left) and 70 hPa (right) ozone from a test GEOS-5 Replay ½° simulation for July 1st, 2011, showing resolved structures in the boundary layer and lower stratosphere.

Availability

These simulations are done in support of the Atmospheric Composition Community and we appreciate feedback on their use.

GMI CTM output will be available in late 2016 via anonymous ftp from dirac.gsfc.nasa.gov. The directory is /pub/gmidata2/users/mrdamon/Hindcast-Family/HindcastMR2.

Contact Susan Strahan (susan.strahan@nasa.gov) for additional information and support.

The Replay simulation will also be available late 2016 using similar downloading mechanisms as MERRA-2 Reanalysis (i.e. OPeNDAP and web-based interfaces)

For more information see: http://acd-ext.gsfc.nasa.gov/Projects/GEOSCCM/MERRA2GMI/ or contact Luke Oman (luke.d.oman@nasa.gov)