Trajectory Model Primer

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Welcome to the wonderful world of trajectory calculations. Modeling of atmospheric dynamical and chemical processes has over the last several years become increasingly reliant upon the output of trajectory models. These models provide a straightforward, simple, and effective way to carry out studies in both the stratosphere and troposphere. There are, however, a few items the user should know before using the trajectory model or interpreting its output.

First, and most importantly, the output of the trajectory model is dependent upon the meteorological data sets employed. The Goddard Trajectory Model offers three different meteorological analyses at present upon which trajectory calculations can be based: the National Meteorological Center (NMC) data, the Goddard Data Assimilation Office (ASM) data, and the United Kingdom Meteorological Office (UKM) data. Each of these data sets has its own set of advantages and disadvantages.

The standard NMC data is available on 18 pressure surfaces between 1000 and 0.4 hPa on a latitude/longitude grid of $2^o \times 5^o$. This data is computed once per day and reported at noon Greenwich Mean Time (GMT). This meteorological data set is the default data set of the Goddard Trajectory Model. The wind fields employed in this data set are derived from balanced wind calculations [1, 7, 5, 4] and suffer from deficiencies in the equatorial regions, where the balanced wind approximation is invalid. Results of trajectory calculations in the tropics using NMC balanced winds, therefore, should be viewed with caution.

Wind fields in the ASM data set [13, 10] are also reported on 18 pressure levels between 1000 and 0.4 hPa on a latitude/longitude grid of $4^o \times 5^o$. This data set is computed four times per day and reported at 00:00, 06:00, 12:00, and 18:00 GMT. Additional data sets with different spatial and/or temporal resolution (e.g. 2×2.5) are available from the Data Assimilation Office.

Finally, wind fields in the UKM data set [12] are available on 18 pressure levels between 1000 and 0.4 hPa on a latitude/longitude grid of $2.75^o \times 3.5^o$. The data is reported once daily at noon GMT.

As of this time, all diabatic calculations must be performed with NMC fields. The heating rates have been computed for the NMC data with a radiative transfer model [8].

Several warnings are in order. Operating near the upper and lower limits of the meteorological data sets (i.e. near 1000 or 0.4 hPa) can result in erroneous trajectories. In particular, in the lower troposphere, trajectory calculations have often resulted in parcels penetrating the surface of the earth, a result which is clearly unphysical. Any trajectory which intersects the surface, therefore, should be disregarded. Furthermore, operating near the surface in the boundary layer, where the magnitude of small-scale eddies become important in trajectory calculations, is discouraged. It is unrealistic to expect the meteorological analyses to reproduce the important small scale features found in the boundary layer.

As of the current time, the trajectory model will also encounter troubles if some of the pressure levels are missing in the meteorological data sets. While this is not a common occurance in the met data, we cannot guarantee that your particular run of the trajectory model will be free from the types of errors such days can generate. In some cases, the model may appear to have run perfectly well, in other cases, it will simply stop functioning when these days are encountered. We are constructing a new version of the trajectory code which will warn you when such days of meteorological data are encountered. But, for now, your best bet is to check over the meteorological data during the period of trajectory analysis desired before running your studies. This might entail contacting staff here in Code 916 at NASA/Goddard for assistance.

Warnings aside, actually running trajectories is very easy! To run a trajectory, the model only REQUIRES an input latitude, longitude, and potential temperature surface. Pressure and temperature are computed from the input potential temperature as based upon the meteorological data set used in the trajectory calculations. A fourth order Runge-Kutta time integration scheme is used. Spatial interpolations are linear in latitude and longitude and can be either linear or cubic spline in the vertical direction. Computational errors from trajectory calculations have been shown to be quite small [[9]].

Trajectory calculations can be quite sensitive to initial conditions [[11, 3, 2, 6]]. Care, therefore, should be exercised when trying to draw conclusions from trajectory calculations, particularly those which involve a small number of trajectories.

For further information on the trajectory model and errors associated with trajectory calculations, see the reference list. Also, see the information contained in the AutoMailer document, available via the automailer by asking for "help."

Bibliography

[1] R. D. McPherson et al. The NMC operational global data assimilation system. *Monthly Weather Rev.*, 107:1445–1461, 1979.

[2] G. A. Morris. *A Demonstration and Evaluation of Trajectory Mapping.* PhD thesis, Rice University, Houston, TX, September 1994.

[3] G. A. Morris et al. Trajectory mapping and application to data from the Upper Atmosphere Research Satellite (UARS). *J. Geophys. Res.*, 1995 in press.

[4] R. N. Nagatani. Tech. Rep. 40, Natl. Oceanic Atmos. Admin. (NOAA), 1988.

[5] P. A. Newman, D. J. Lamich, et al. Meterological atlas of the Southern hemisphere lower stratosphere for August and September 1987. Tech. Mem. 4049, NASA, 1988.

[6] R. B. Pierce and T. D. A. Farlie. Chaotic advection in the stratosphere: implications for the dispersal of chemically perturbed air from the polar vortex. *J. Geophys. Res.*, 98(D10):18589–18595, 1993.

[7] W. J. Randel. The evolution of winds from geopotential height data in the stratosphere. *J. Atmos. Sci.*, 44:3097–3120, 1987.

[8] J. E. Rosenfield. A simple parameterization of ozone infrared absorption for atmospheric heating rate calculations. *J. Geophys. Res.*, 96:9065–9074, 1991.

[9] M. R. Schoeberl and L. Sparling. Trajectory modeling. In G. Fiocco and G. Visconti, editors, *Proceedings of the International School of Physics: Diagnostic Tools in Atmospheric Physics*, New York, 1994. Elsevier Science Publishing Company, Inc.

[10] S. D. Schubert, R. B. Rood, and J. Pfaendtner. An assimilated dataset for Earth science applications. *Bull. Amer. Meteor. Soc.*, 74(12):2331–2342, 1993.

[11] L. Sparling, M. R. Schoeberl, et al. Trajectory modeling of emissions from lower stratospheric aircraft. *J. Geophys. Res.*, 100:1427–1438, 1995.

[12] R. Swinbank and A. O'Neill. A stratosphere-troposphere data assimilation system. *Monthly Weather Rev.*, 122:686–702, 1994.

[13] L. L. Takacs, A. Molod, and T. Wang. Documentation of the Goddard Earth Observing System (GEOS) general circulation model–Vol. I. Tech. Mem. 104606, NASA, 1994.