Dynamic initialization for whole-atmospheric global modeling

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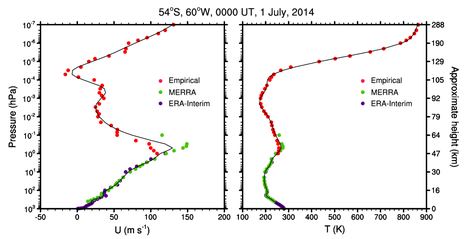
Introduction and motivation

- Appropriate initialization of numerical models is crucial for accurate simulation of the evolution of atmospheric flows.
- Winds and thermodynamic state variables to be used to initialize models should be consistent with the dynamics of slowly-varying large-scale flows. Mass-wind balance is imposed in atmospheric analyses.
- **Issue:** Whole-atmospheric analyses are rare, and their spatiotemporal coverage is limited. For forecast runs using whole atmosphere global models, a dynamic initialization method of initializing the models at specific date and time is presented.

Ground-to-space (G2S) atmospheric profiles

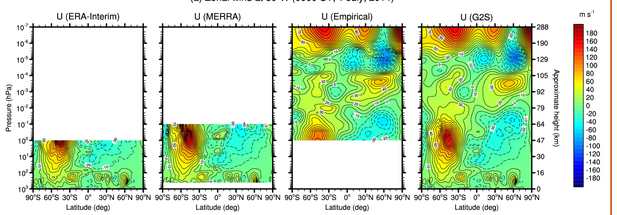
- Vertically contiguous wind and temperature profiles are generated using the meteorological reanalyses (ECMWF-Interim, and MERRA) and empirical model results (HWM14, DWM07, and NRLMSISE-00) at specific date and time.
- 3rd-order B-spline fitting to the reanalyses and empirical model results



Smooth b-spline curves fit to ERA-Interim, MERRA, and empirical model results

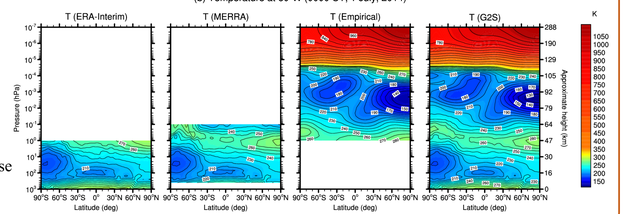
ERA-Interim: 1000-1 hPa
MERRA: 400-0.1 hPa
Empirical: above 1 hPa

(a) Zonal wind at 60°W (0000 UT, 1 July, 2014)



- Subtropical tropospheric jets
- Equatorward tilt of polar jet
- Easterly QBO phase in the lower stratosphere
- Wind reversal at the mesopause
- Higher mesopause height in winter

(b) Temperature at 60°W (0000 UT, 1 July, 2014)



- Coldest temperature near the mesopause
- Cold winter stratosphere
- High temperature near the stratopause

Iterative dynamic initialization

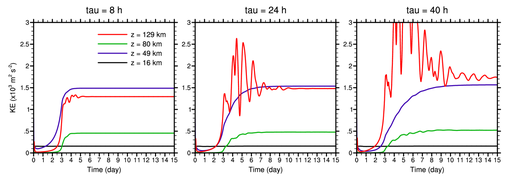
- Iterative nudging of dynamical model (based on CAM-SE) forced by climatological physics forcing towards the G2S profiles at specific time
  - Physics forcing is obtained from SC-WACCM climate runs

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\zeta + f)\,\boldsymbol{k}\times\boldsymbol{u} + \nabla\left(\frac{|\boldsymbol{u}|^2}{2} + \Phi\right) + \dot{\eta}\frac{\partial \boldsymbol{u}}{\partial \eta} + \frac{RT_v}{p}\nabla p = \boldsymbol{P_u} + \boldsymbol{A_u},$$

$$\frac{\partial T}{\partial t} + \boldsymbol{u}\cdot\nabla T + \dot{\eta}\frac{\partial T}{\partial \eta} - \frac{RT_v}{c_p^* p}\omega = P_T + A_T, \qquad \boldsymbol{A_u} = -\frac{\boldsymbol{u} - \boldsymbol{u}_{\mathrm{G2S}}}{\tau} - \frac{\partial \boldsymbol{u}_{\mathrm{G2S}}}{\partial t},$$

$$\frac{\partial}{\partial t}\left(\frac{\partial p}{\partial \eta}\right) + \nabla\cdot\left(\frac{\partial p}{\partial \eta}\boldsymbol{u}\right) + \frac{\partial}{\partial \eta}\left(\frac{\partial p}{\partial \eta}\dot{\eta}\right) = 0, \qquad A_T = -\frac{T - T_{\mathrm{G2S}}}{\tau} - \frac{\partial T_{\mathrm{G2S}}}{\partial t},$$

$$\text{and}\quad \frac{\partial}{\partial t}\left(\frac{\partial p}{\partial \eta}q\right) + \nabla\cdot\left(\frac{\partial p}{\partial \eta}q\boldsymbol{u}\right) + \frac{\partial}{\partial \eta}\left(\frac{\partial p}{\partial \eta}q\dot{\eta}\right) = 0.$$

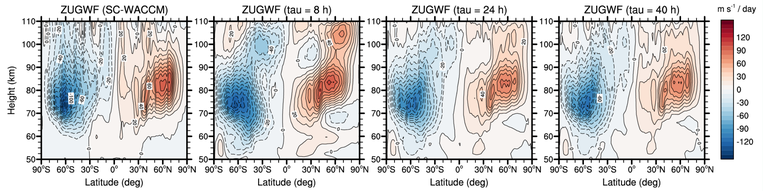


- Time series of globally averaged horizontal kinetic energy for different values of nudging time scale

- Determination of nudging coefficient
  - Estimation of GW momentum forcing in the mesosphere and lower thermosphere (MLT) (Liu et al. 2009)

$$\bar{F}_\lambda^{\mathrm{GW}} = -\left(f + \frac{\bar{u}\tan\phi}{a}\right)\bar{v} + \overline{\frac{v}{a}\frac{\partial u}{\partial \phi}},$$

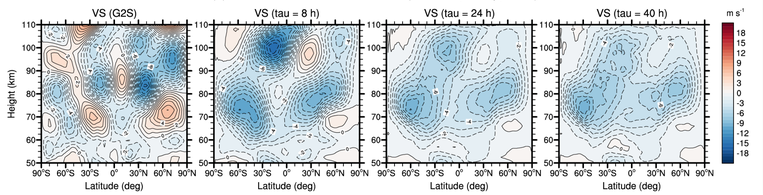
(a) Zonal-mean zonal GWF (0000 UT, 1 July, 2014)



  - Estimation of the residual mean meridional circulations (Andrew et al. 1987)

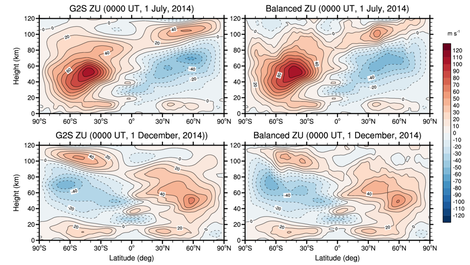
$$\bar{v}^* = \bar{v} - \frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\frac{\rho_0\overline{v'\theta'}}{\partial\bar{\theta}/\partial z}\right) \qquad \bar{w}^* = \bar{w} + \frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}\left(\frac{\overline{v'\theta'}\cos\phi}{\partial\bar{\theta}/\partial z}\right)$$

(a) Residual-mean meridional flow (0000 UT, 1 July, 2014)

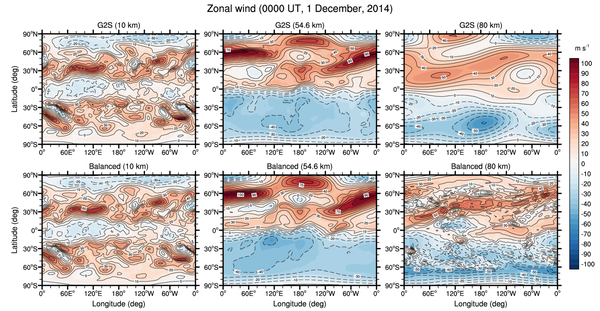


Balanced flow and validation

- Balanced flow vs G2S data

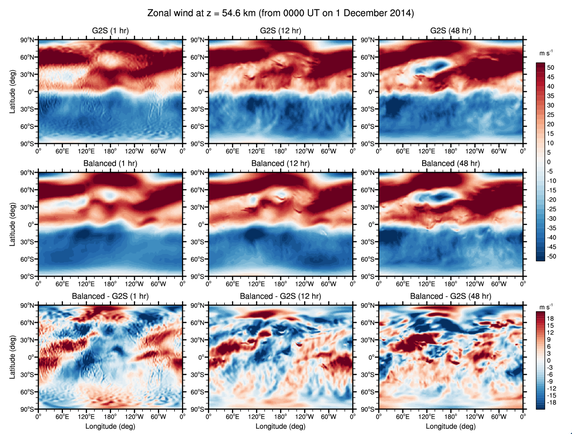


- Balanced flow is similar to the G2S data below the stratopause
- Wind structure is modified in the mesosphere and lower thermosphere
- Difference is related to baroclinic instability in the balanced flow in the MLT region



- Balanced flow is quite similar to the G2S data in the troposphere and stratosphere (i.e., reanalysis data)
- Balanced flow in the mesosphere exhibits the small-scale instabilities as well as the smooth large-scale structure

- Forecasts using SC-WACCM with full physics



- When initialized with the G2S data, initial noises are significant. These noises are diffused, affect the large-scale structure, and nearly dissipated after 2 day
- When initialized with the balanced flow, no initial noises are found. Wind structure becomes different from the G2S case from 12-h forecast

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