GEOS-5 NWP experience with changes in parameterized drag

Andrea Molod[1] , Larry Takacs[2,]

Nathan Arnold[3]

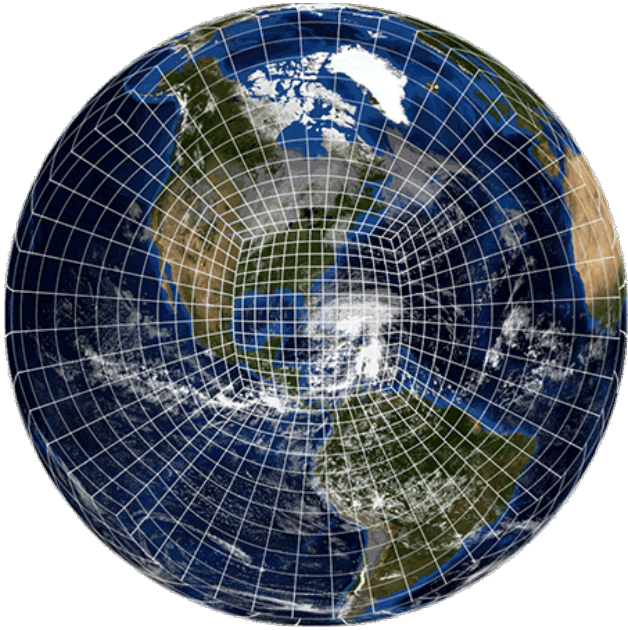
[1] ESSIC / NASA GMAO
[2] SSAI / NASA GMAO
[3] USRA GESTAR / NASA GMAO

NASA Goddard Space Flight Center
Global Modeling and Assimilation Office

Outline

- GEOS-5 background
  - Model physics
  - Applications
- Forecast experiments with varying:
  - Surface drag
  - Gravity wave drag
  - Changes to PBL height
- Conclusions

NASA Goddard Earth Observing System (GEOS-5)



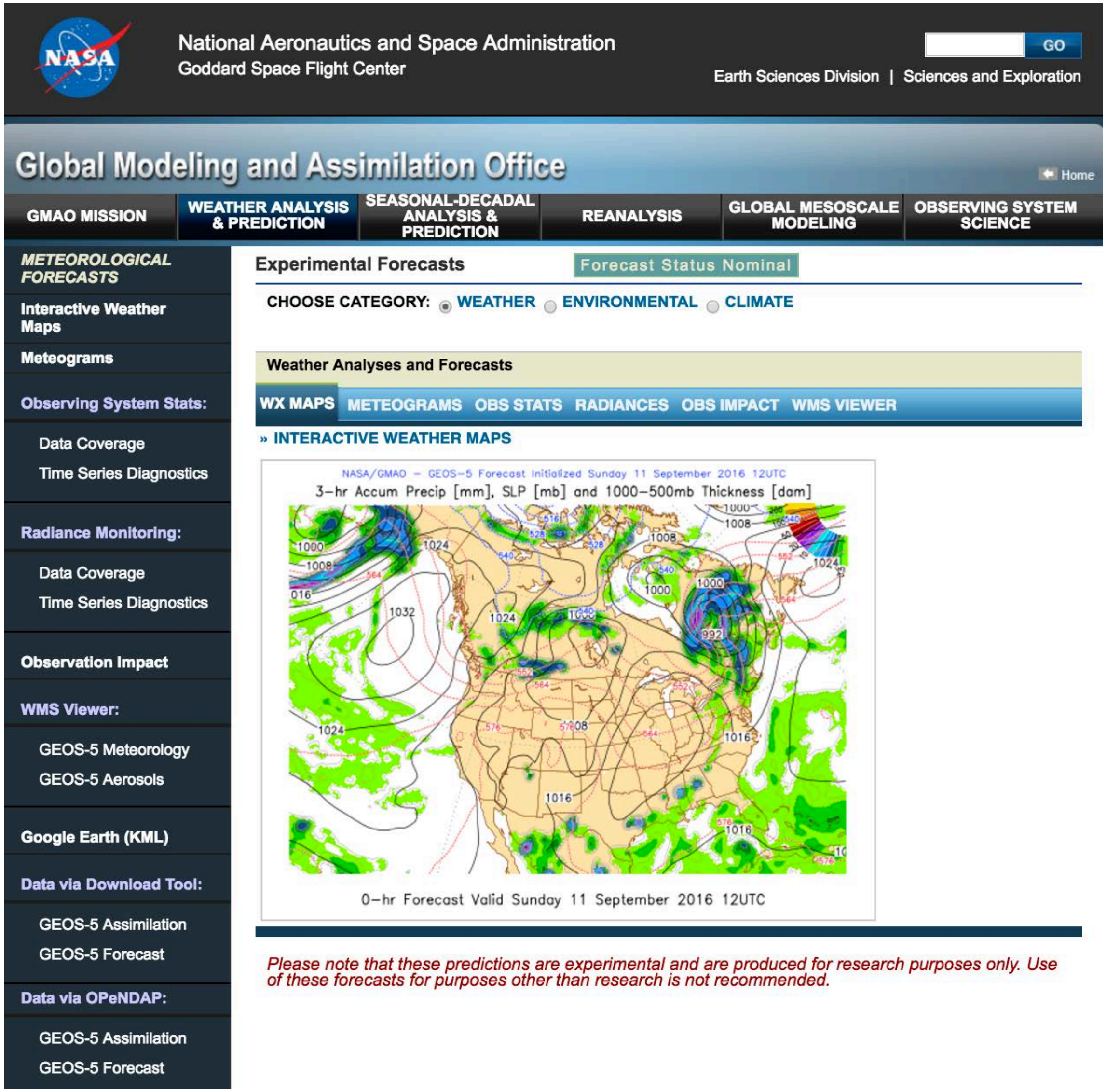
- Cubed sphere FV3 dycore (Putman and Lin, 2009)
- 72 vertical layers, ~8 in PBL. (**Soon: 132 layers)**
- RAS convection (Moorthi and Suarez, 1992)
- Cloud macro/microphysics (Bacmeister et al., 2006; Molod, 2012) (Soon: Barahona et al., 2014, 2-moment)
- Boundary layer turbulence (Lock, 2000; Louis and Geleyn, 1992)
- Surface layer turbulence (Helfand and Schubert, 1995 with ocean roughness of Garfinkel et al., 2011 and Molod et al., 2013)
- Shortwave radiation (Chou and Suarez, 1999)
- Longwave radiation (Chou and Suarez, 1994) (Soon: RRTMG of Iacono et al., 2008)
- Gravity wave drag (McFarlane, 1987 and Garcia and Boville, 1994)
- Catchment land model (Koster et al., 2000) (Soon: Oleson et al., 2010, Interactive Vegetation)
- Snow and glacier models (Steiglitz et al., 2001; Cullather et al., 2014)

Applications of GEOS-5 AGCM

- GEOS-5 Atmospheric Data Assimilation System (ADAS)
  - Assimilation, forecasts at ~25 (12) km, Ensembles at ~100 (50) km
  - Reanalysis at ~50 km – MERRA-2
- Seasonal Prediction (Coupled Atmosphere-Ocean + ODAS)
  - Atmosphere at ~100 (50) km, Ocean at 50 (25) km
- Atmosphere-only Climate (AMIP): ~200 km to ~25 km
- Coupled Ocean climate, decadal (CMIP): ~200 km, moving to ~100 km
- Coupled Chemistry: ~100 km for climate, up to ~25 km targeted
- Global Mesoscale: ~12 km to ~1.5 km
- Chemistry Transport, Single Column, Various offline applications

Single AGCM for all applications

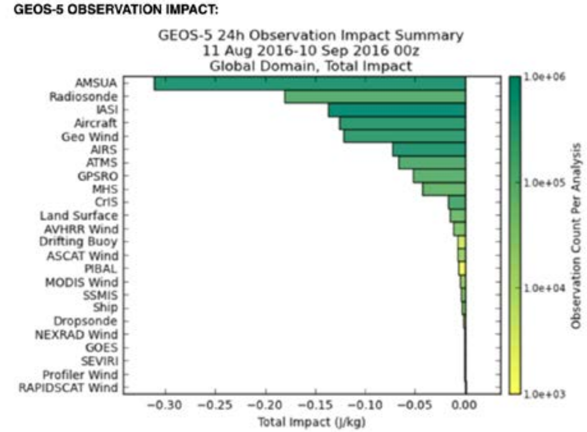
Applications of GEOS-5 AGCM



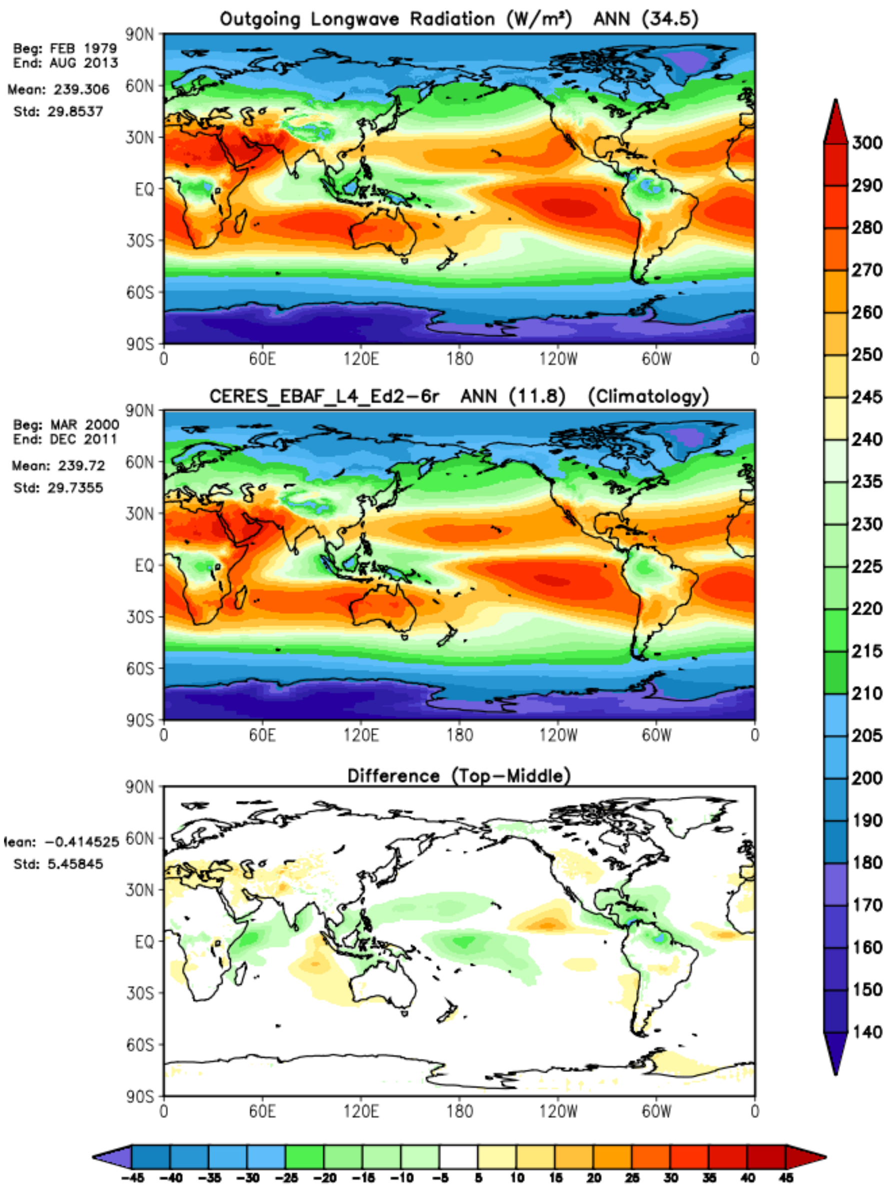
Real time forecasts at ~25 km resolution with the GEOS-5 AGCM, initialized from the GEOS-5 Atmospheric Data Assimilation System.

Forecasts evaluated using anomaly correlation and root mean square error.

GEOS-5 OBSERVATION IMPACT:



Applications of GEOS-5 AGCM

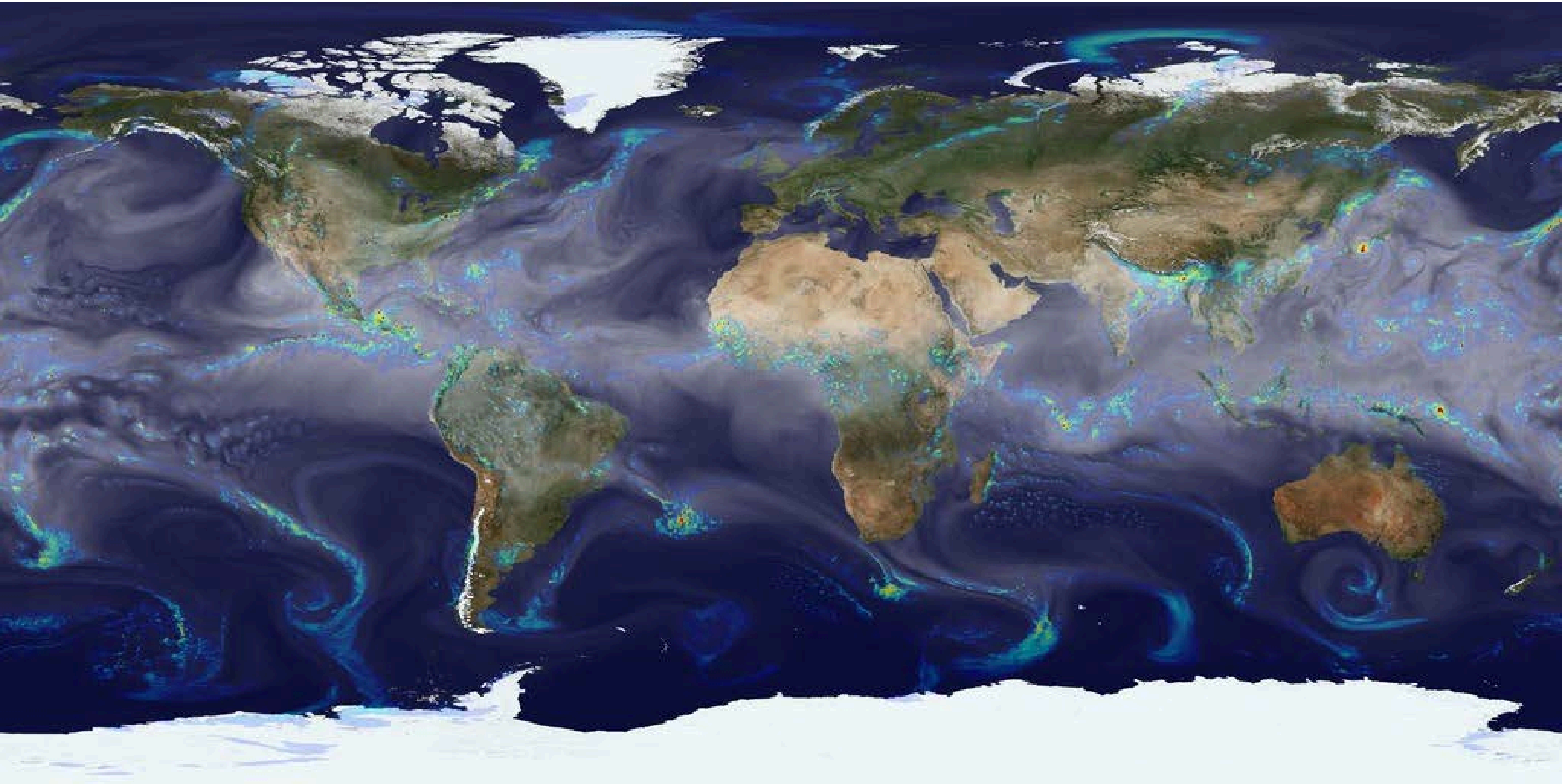


Climate simulations using AGCM at resolutions ranging from ~25 km to ~200 km.

Automated Simulation Evaluation:

- MERRA, MERRA-2, ERA Interim, CFSR
- GSSTF, WHOI ocean surface energy budget, stress, winds
- SRB
- GPCP Precipitation
- CERES-EBAF
- ISCCP Cloud
- Ganachaud & Wunsch implied ocean heat transport,
- CRU land skin temperature)
- Many others

Applications of GEOS-5 AGCM



- 7 km global mesoscale simulation
- Complete model output available through gmao.gsfc.nasa.gov

Surface drag in GEOS-5

1) Vegetation drag - Monin-Obukhov scheme of Helfand and Schubert (1995) with land surface roughness specified as a multiple of the vegetation height. In "control" - multiple is 0.1.

2) Ocean drag - Monin-Obukhov scheme of Helfand and Schubert, with functional relationship between ocean roughness and stress given by a blend of the algorithms of Large and Pond (1981) and Kondo (1975).

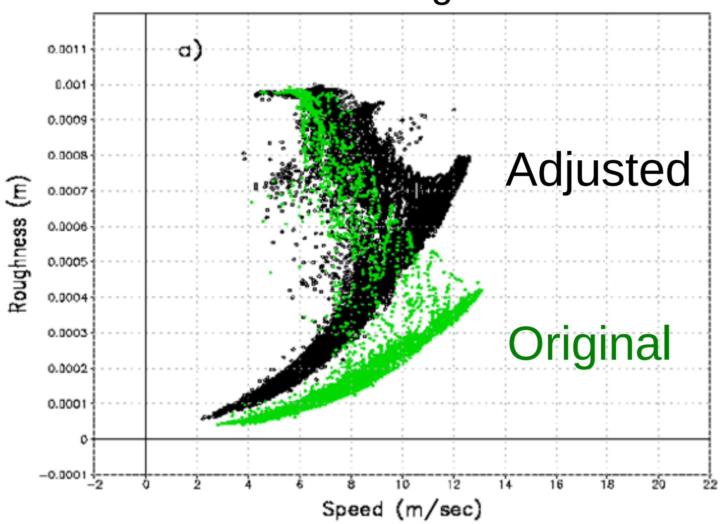
$$[\tau_x, \tau_y] = \rho_a v_s C_D \Delta[u, v] \qquad C_D = \kappa^2 [\Psi_{MO}(\zeta z_0)]^{-2} \qquad z_0 = \frac{A_1}{u*} + A_2 + A_3 u* + A_4 u*^2 + A_5 u*^3$$

3) Form Drag - From Beljaars et al. (2004), scale drag based on sub grid scale variance of topography at scales less than 5 km.

Increasing surface drag (~2x)

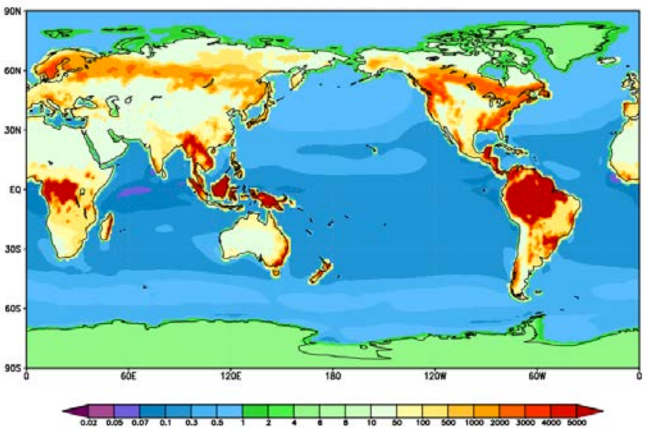
- Ocean roughness modified in mid-regime following Garfinkel et al. (2011).
- Vegetation surface roughness factor increased from 0.1 to 0.2.
- Beljaars (2004) form drag is doubled.

Ocean Roughness

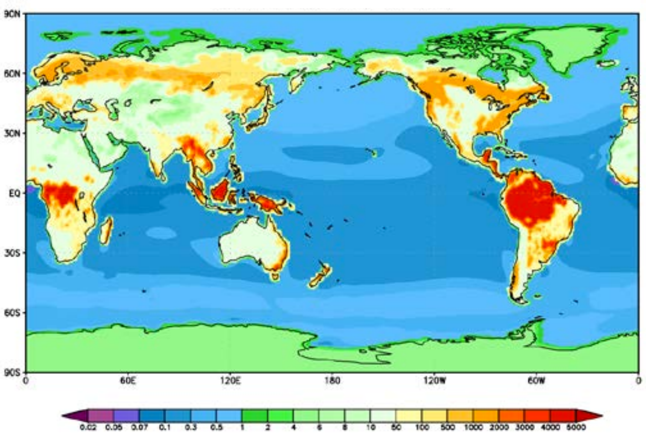


Garfinkel et al., 2011

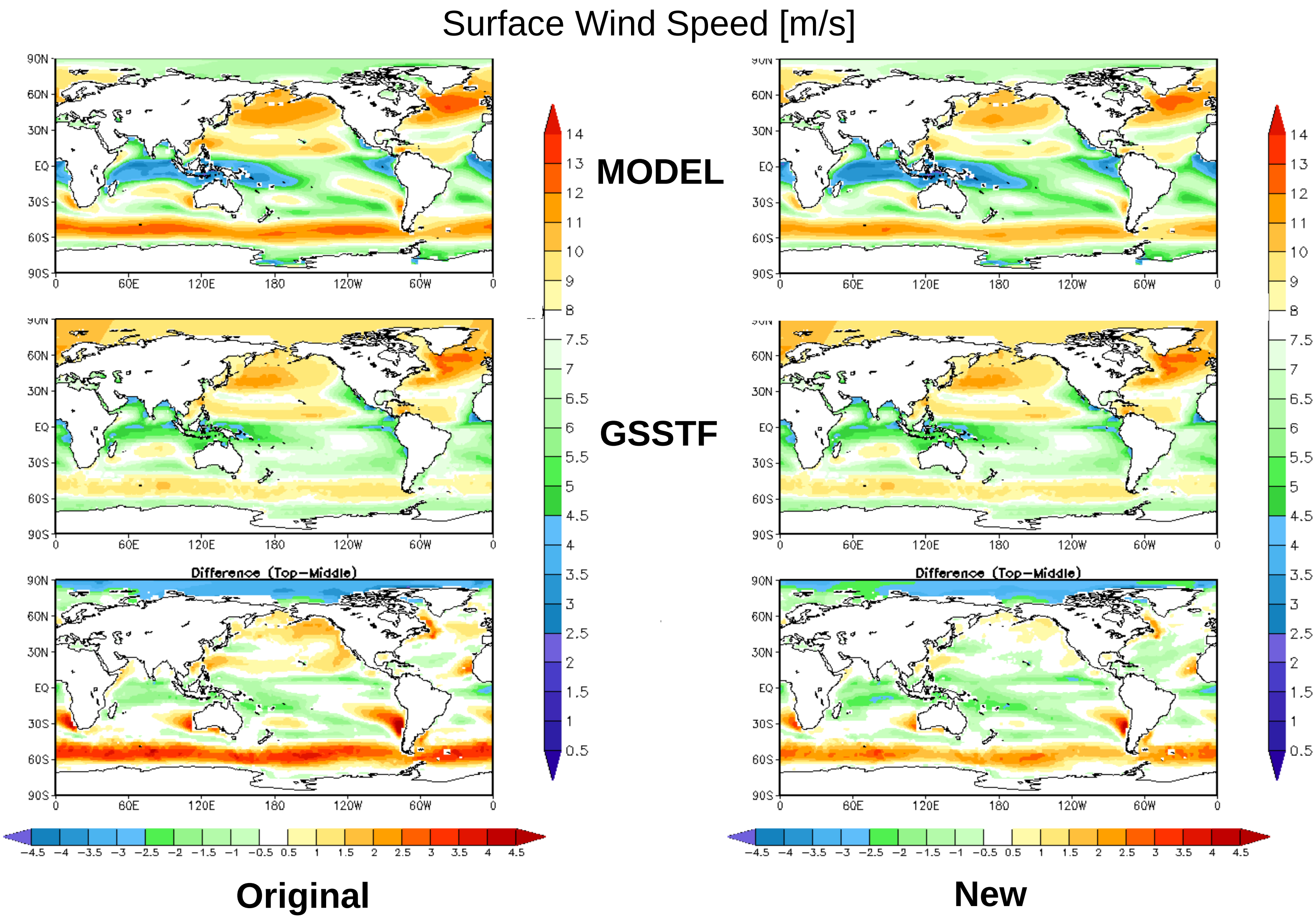
Vegetation roughness - New



Vegetation roughness - Original



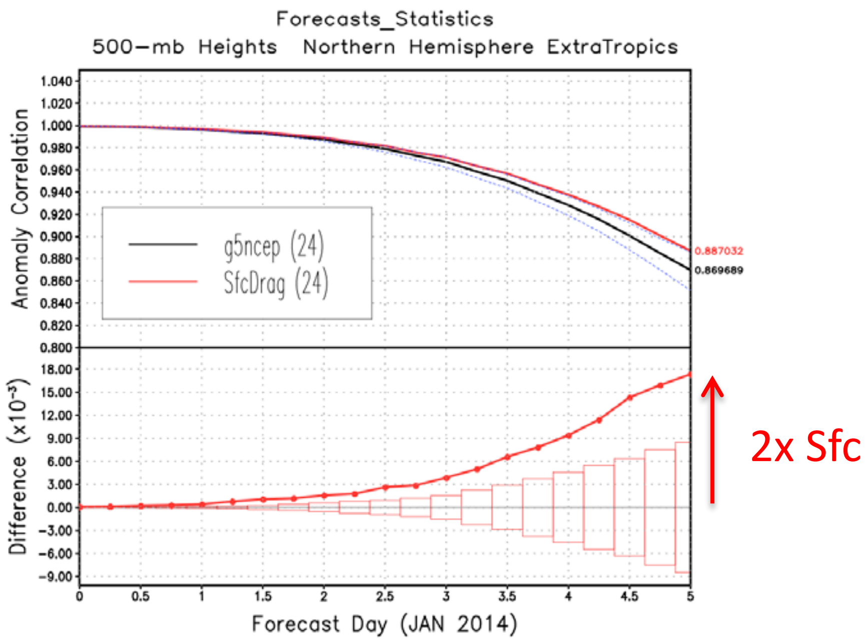
Surface wind bias reduced



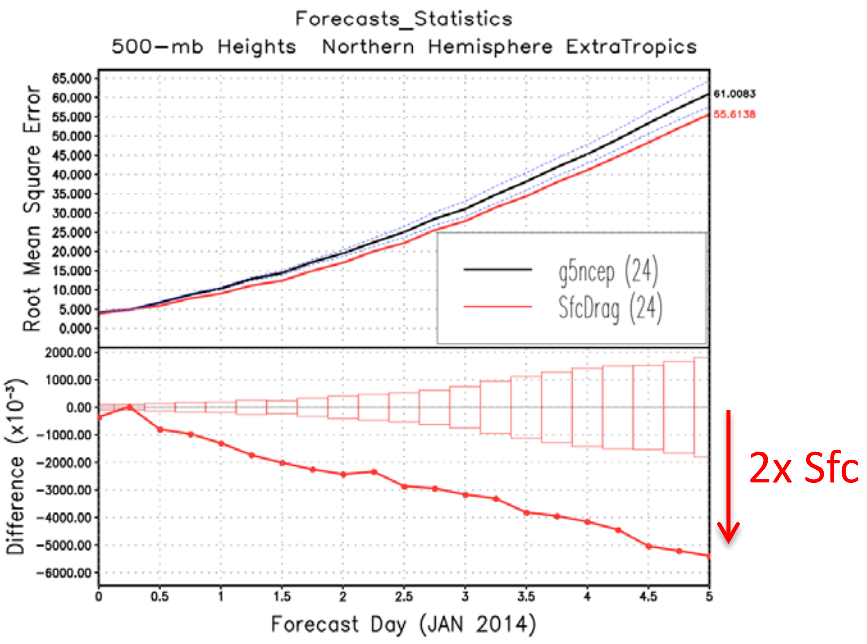
Effect of increased surface drag on forecast skill

Series of forecasts for Jan. 2014

N. H. Anomaly Correlation



N. H. RMS Error

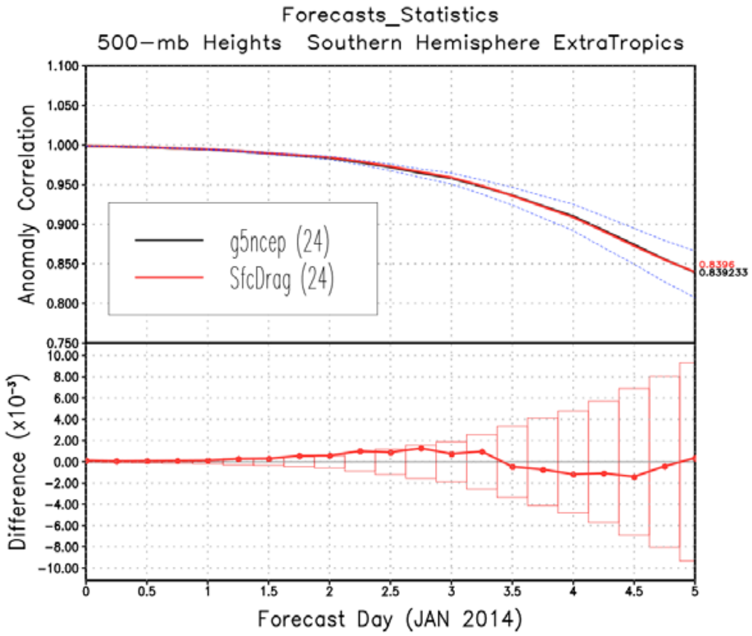


Significant skill increase for northern hemisphere winter.

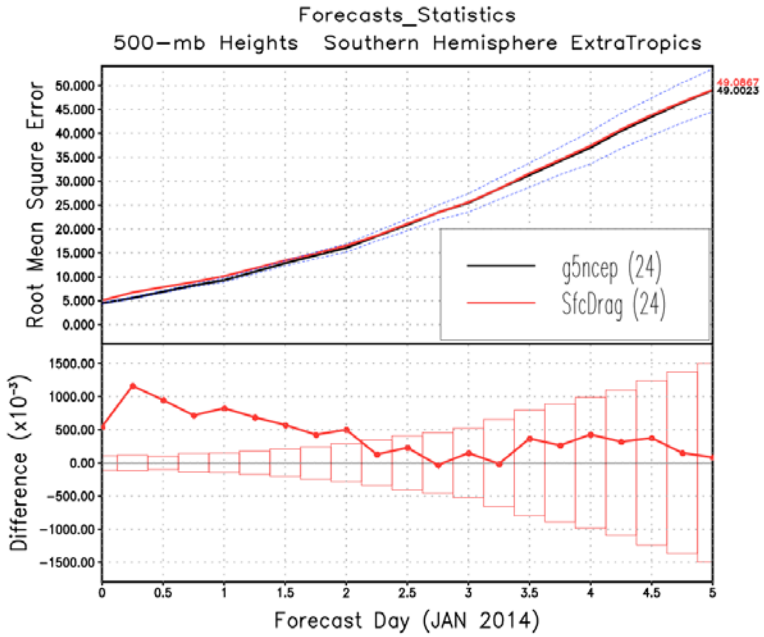
Effect of increased roughness on forecast skill

Series of forecasts for Jan. 2014

S. H. Anomaly Correlation



S. H. RMS Error



Little effect in southern hemisphere.

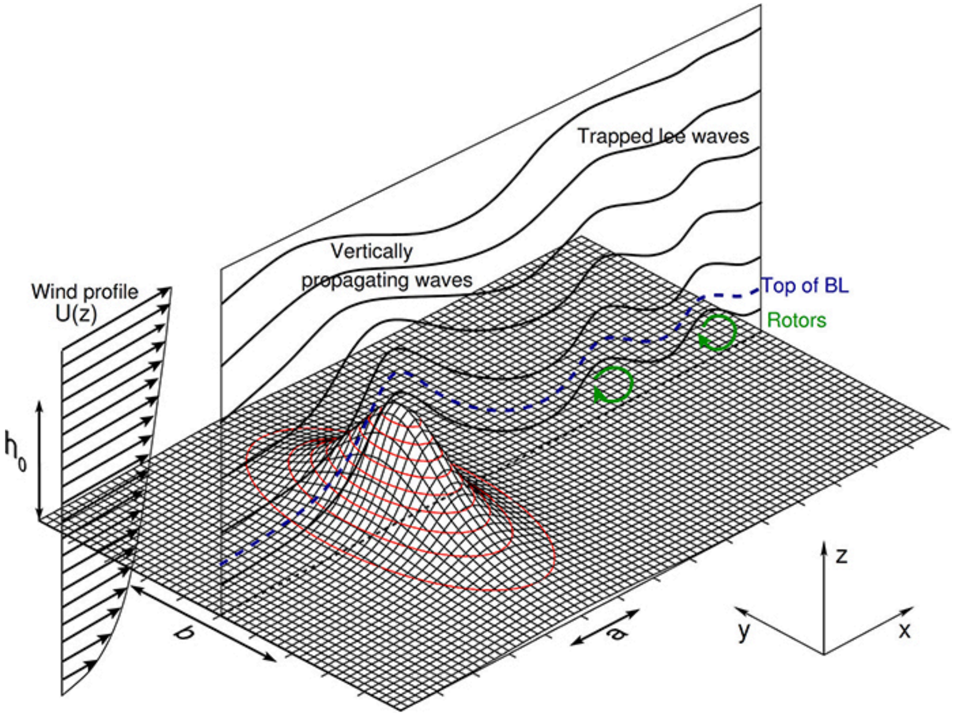
Gravity wave drag in GEOS-5

- Orographic waves parameterized following McFarlane (1987)
  - Proportional to variance of elevation from high resolution topography data. (<3km horizontal wavelengths)

$$\tau_0 = -\left(E\frac{\mu_e}{2}h_e^2\right)\rho_0 N_0 \mathbf{V}_0$$

- Non-orographic GWD follows Garcia and Boville (1994)

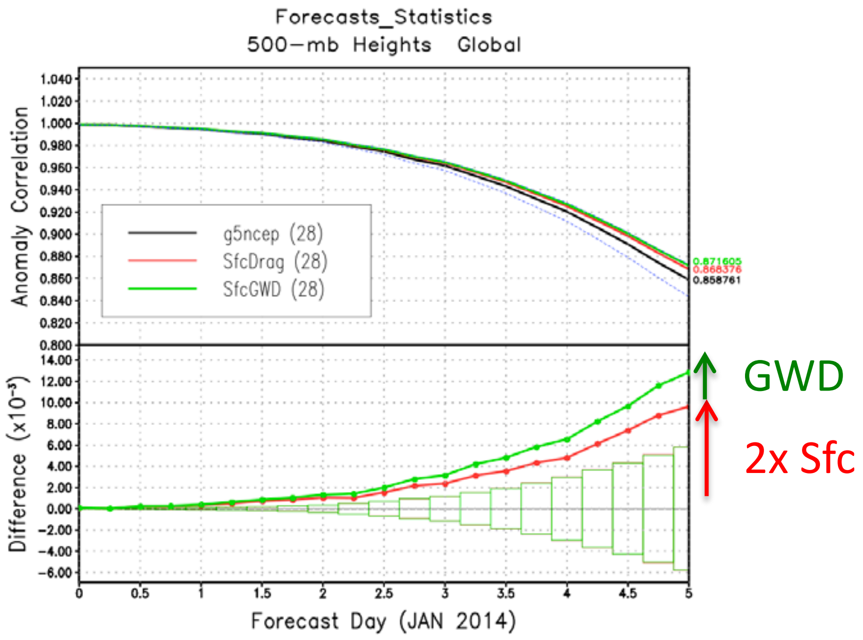
- In experimental run, GWD was doubled for each scheme.



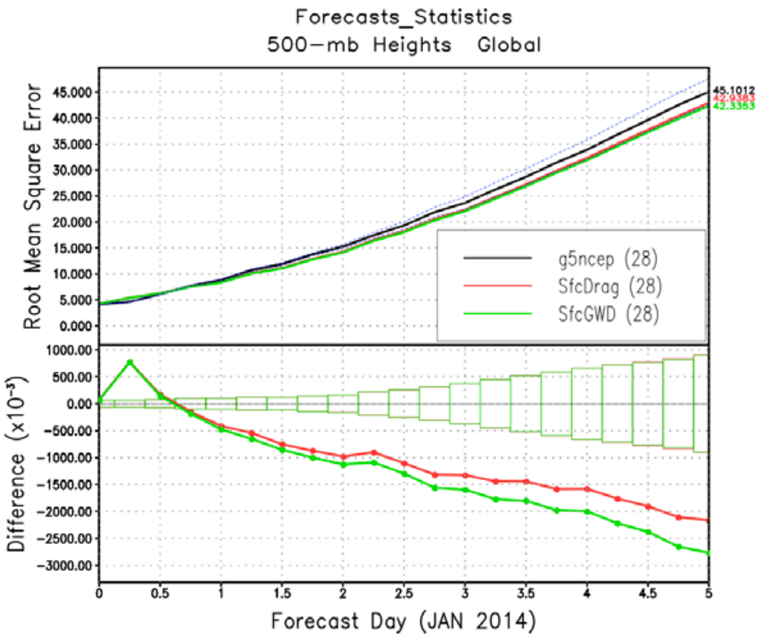
Forecast skill with 2x Sfc + enhanced gravity wave drag

Series of forecasts for Jan. 2014

N. H. Anomaly Correlation



N. H. RMS Error

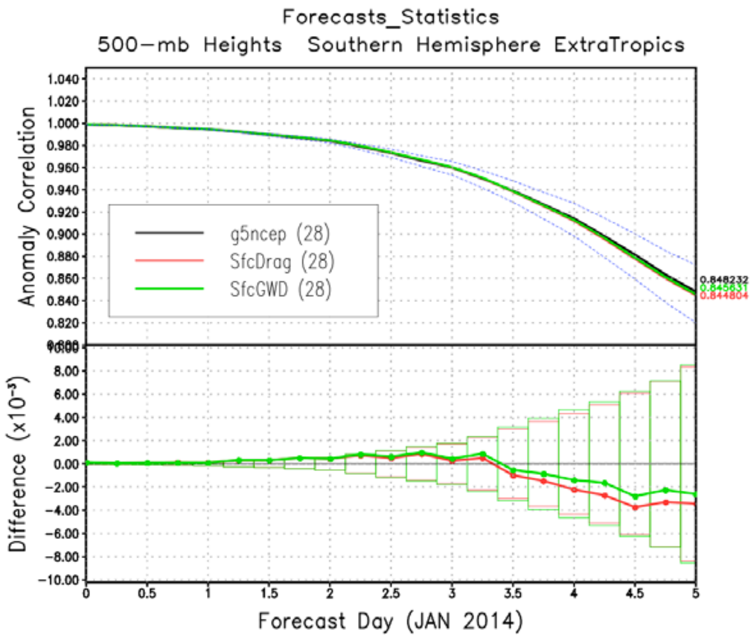


Additional increase in skill for northern hemisphere winter.

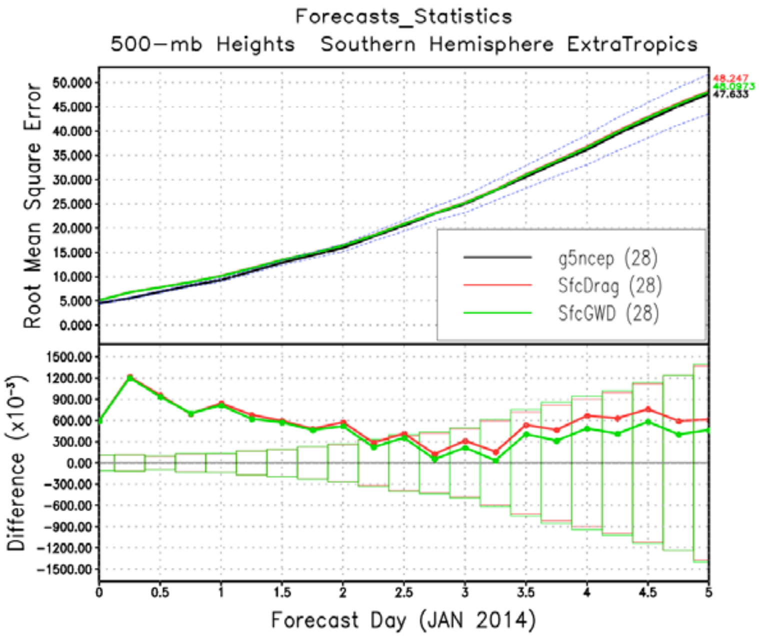
Forecast skill with 2x Sfc + enhanced gravity wave drag

Series of forecasts for Jan. 2014

S. H. Anomaly Correlation



S. H. RMS Error



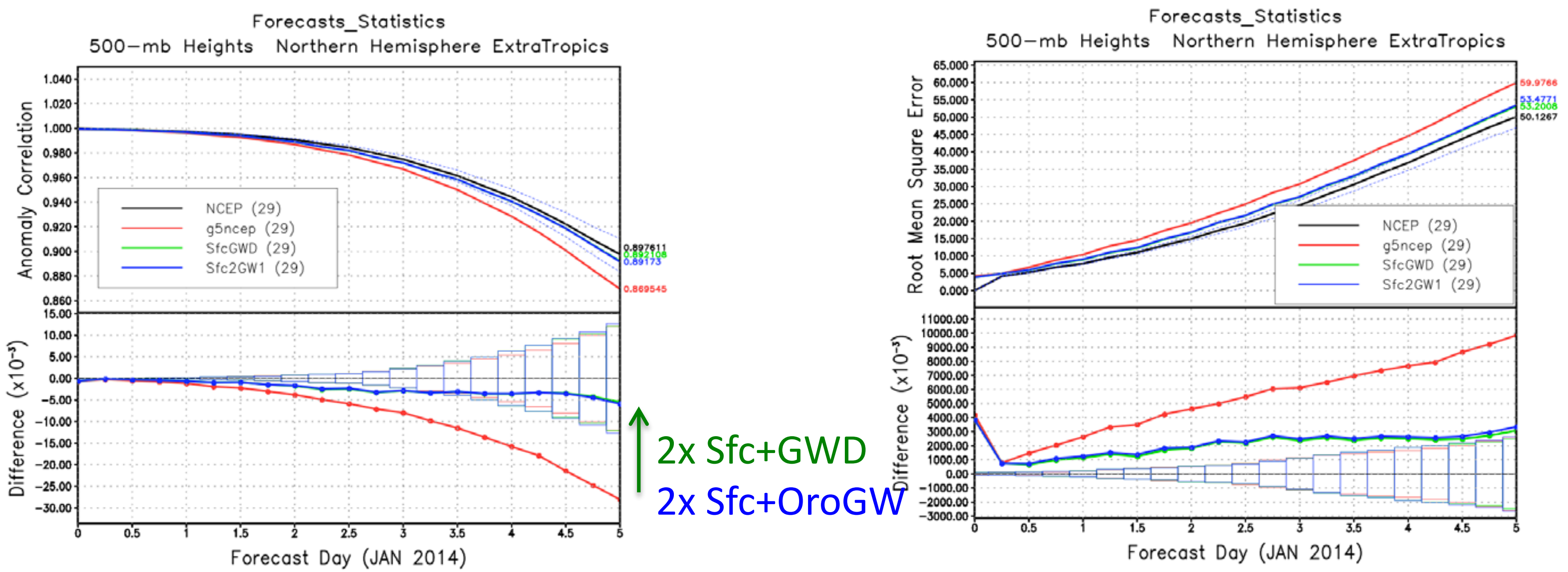
Again, little effect in southern hemisphere.

Forecast skill with 2x Sfc + orographic GWD only

Series of forecasts for Jan. 2014

N. H. Anomaly Correlation

N. H. RMS Error



Forecast skill improvements are due to orographic GWD.
Background GWD is negligible.

Changes to the Planetary Boundary Layer

GEOS-5 turbulence parameterization combines the Lock scheme (for unstable layers and cloud-generated turbulence) and the Louis scheme (for very near surface unstable layers and stable layers). Diagnosed PBL depth is used to estimate the turbulent length scale at the next time step used in the Louis scheme.

<u>In control run:</u>

PBL depth is diagnosed based on the vertical profile of turbulent eddy diffusivity for heat (Kh); PBL depth is set at level where Kh descends below 2 kg/m^2/s

<u>In experiment</u>:

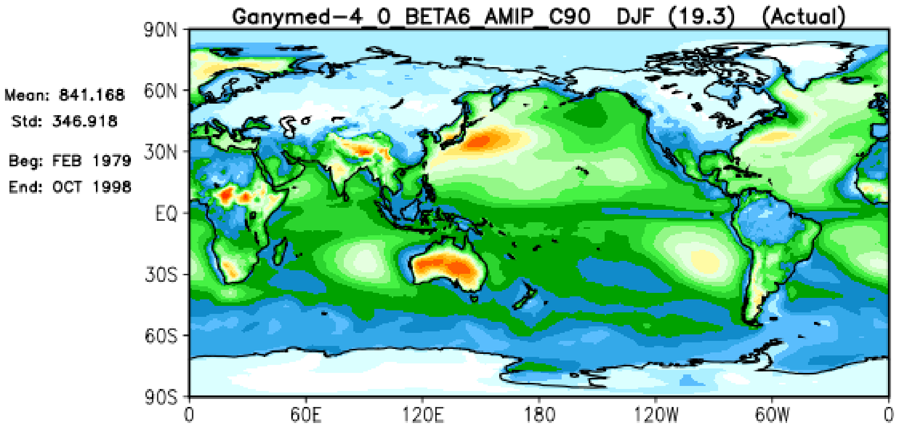
PBL depth over ocean is based on profile of Kh; PBL is set at level where Kh descends below 10% of the column maximum. Over land PBL depth is diagnosed based on vertical profile of bulk Richardson Number (McGrath-Spangler and Molod, 2014). Stable layer PBL depths will be low by definition.

Described in *McGrath-Spangler et al (2015)*

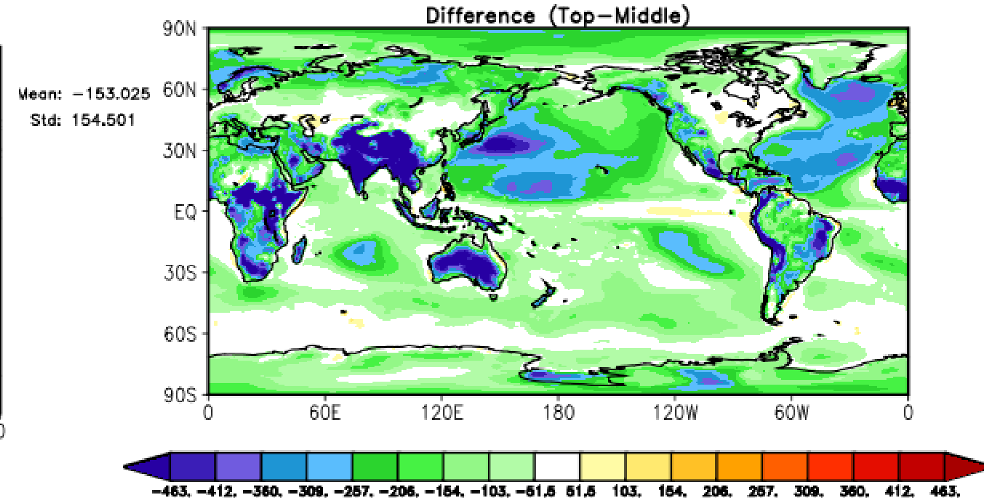
----> Expect reduction in nighttime PBL depth over land, reduction in

Change in PBL height (AMIP run)

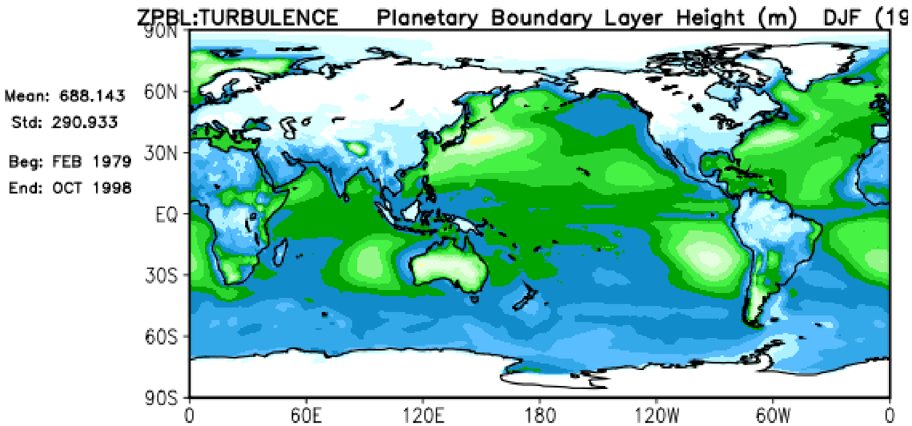
CTRL

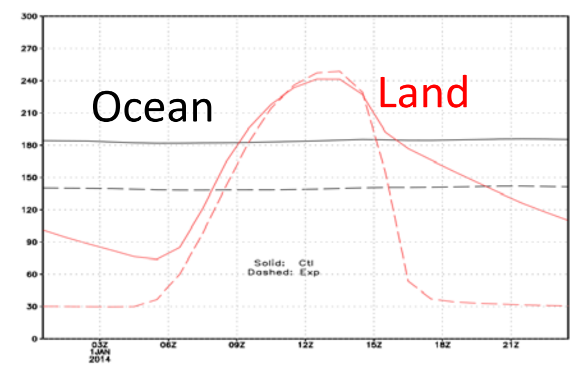


New PBL - CTRL



New PBL



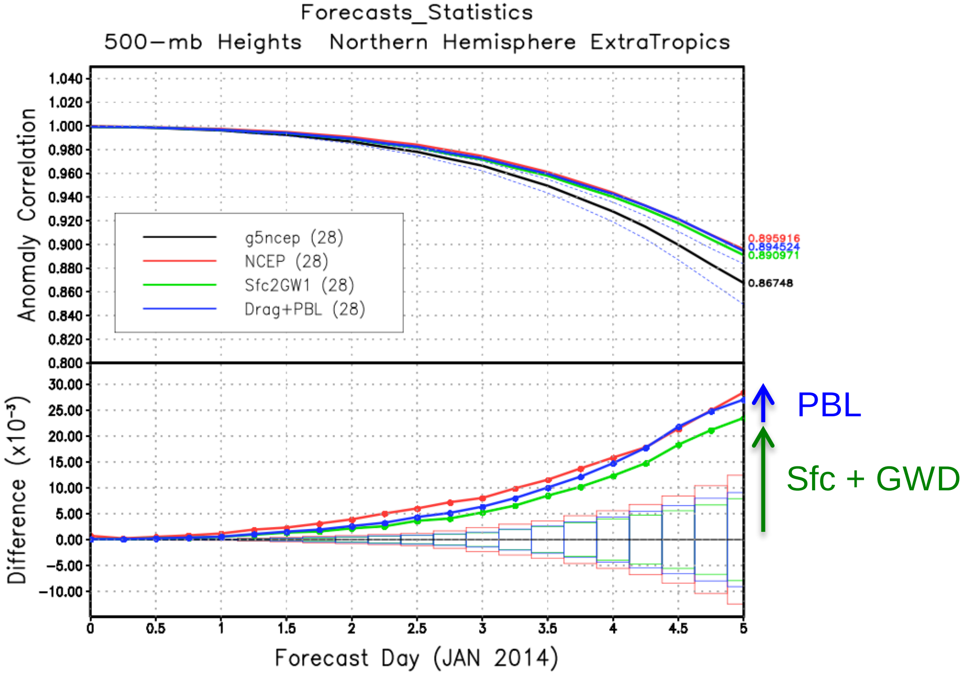


Generally decreased PBL height, and improved diurnal cycle over land.

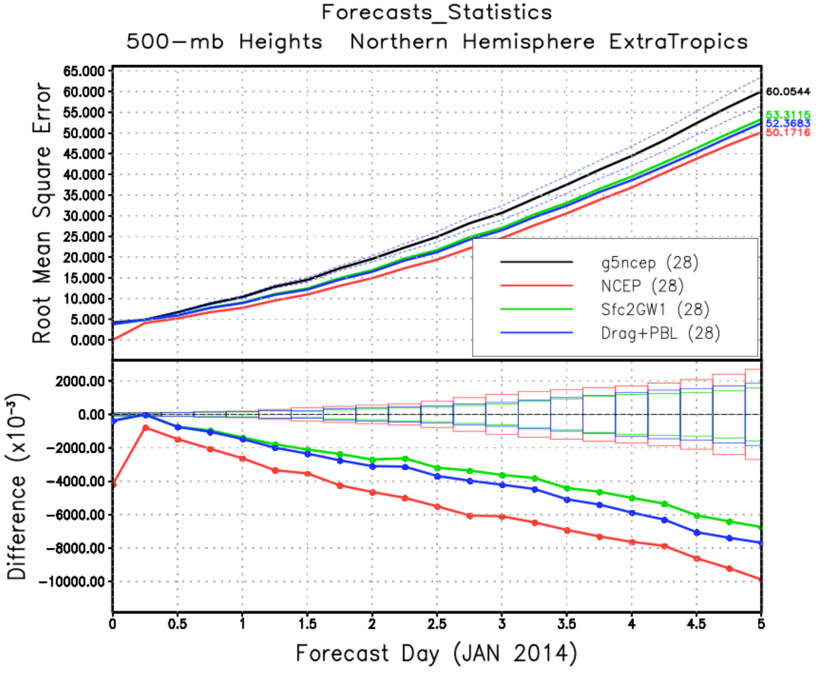
Forecast skill with 2x Sfc + GWD + PBL changes

Series of forecasts for Jan. 2014

N. H. Anomaly Correlation



N. H. RMS Error

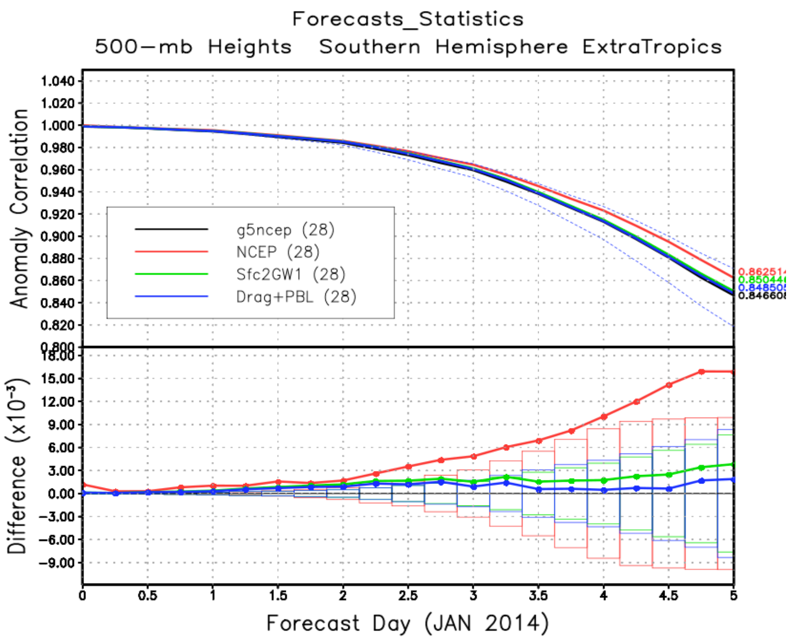


Additional skill increase due to PBL changes.

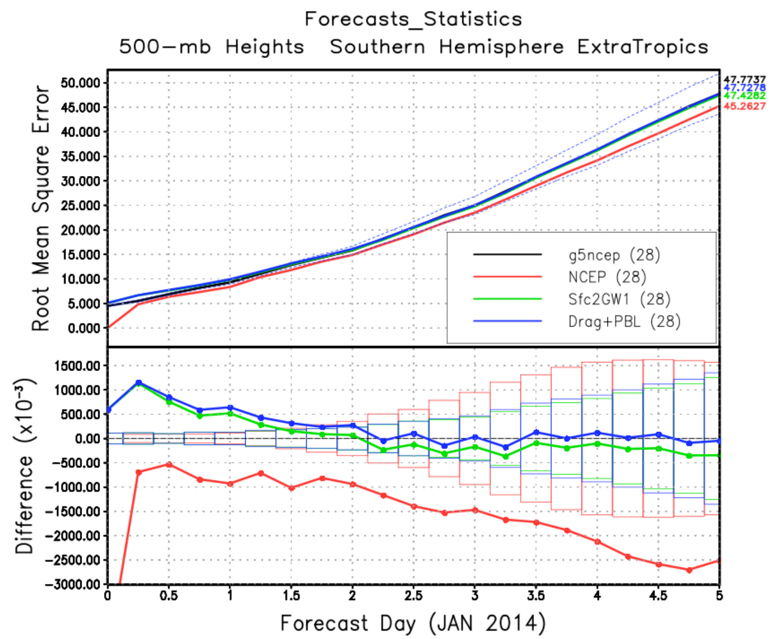
Forecast skill with 2x Sfc + GWD + PBL changes

Series of forecasts for Jan. 2014

S. H. Anomaly Correlation



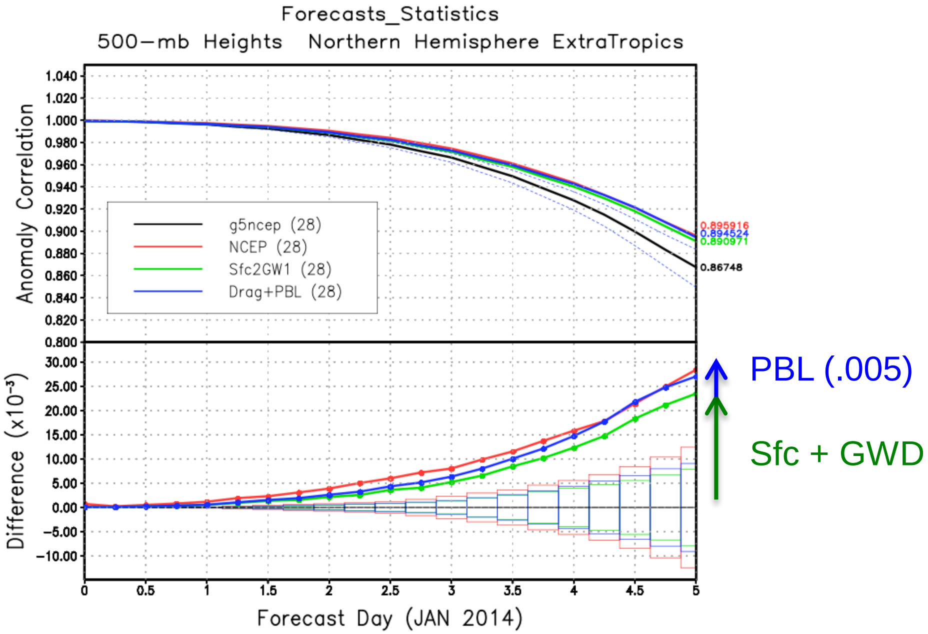
S. H. RMS Error



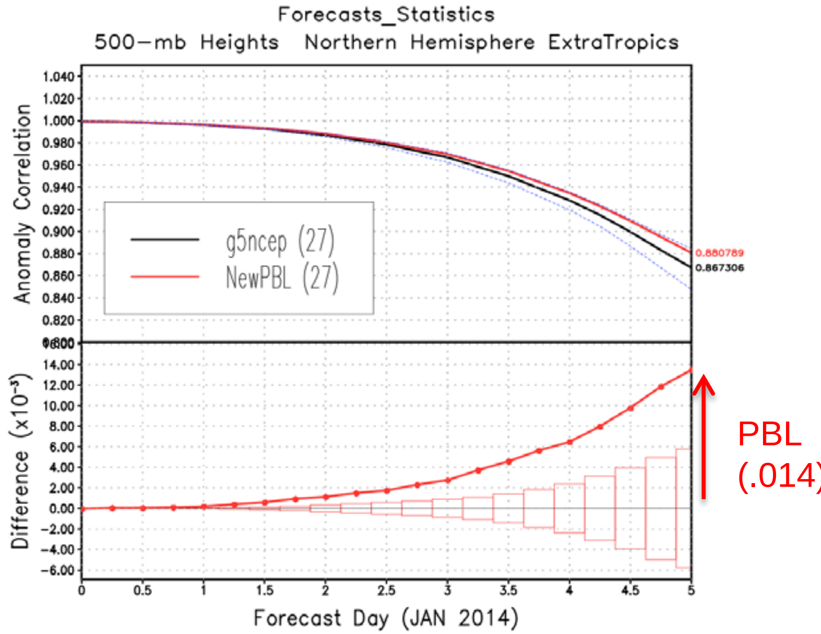
Again, little effect in southern hemisphere.

Improvements are not additive

N. H. Anomaly Correlation

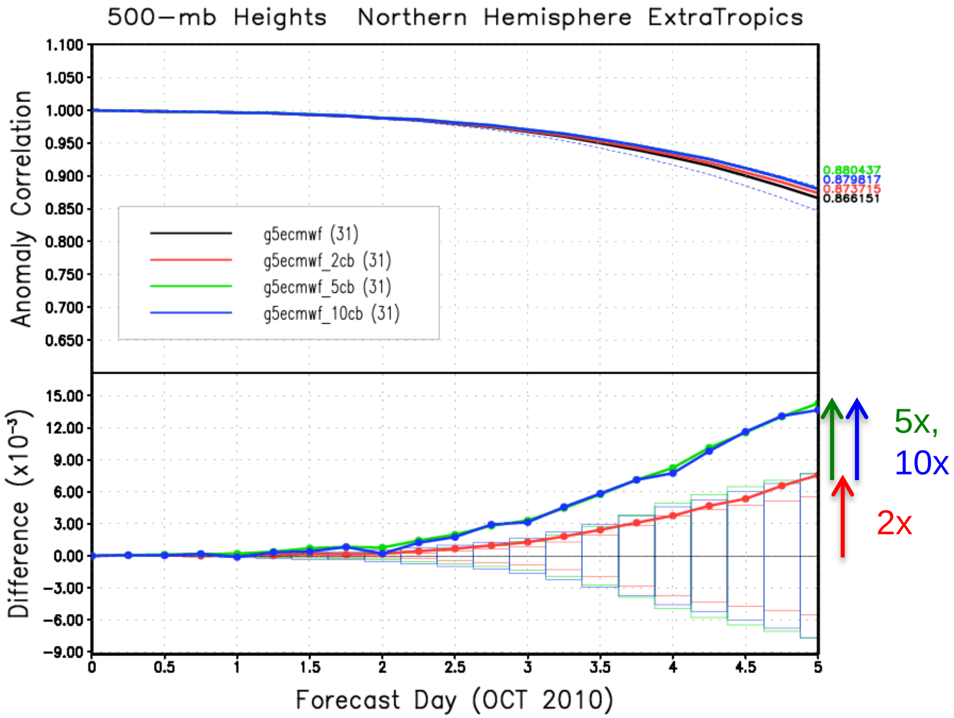


N. H. Anomaly Correlation



Improvement with PBL changes depends on baseline.

Effect saturates for high levels of form drag



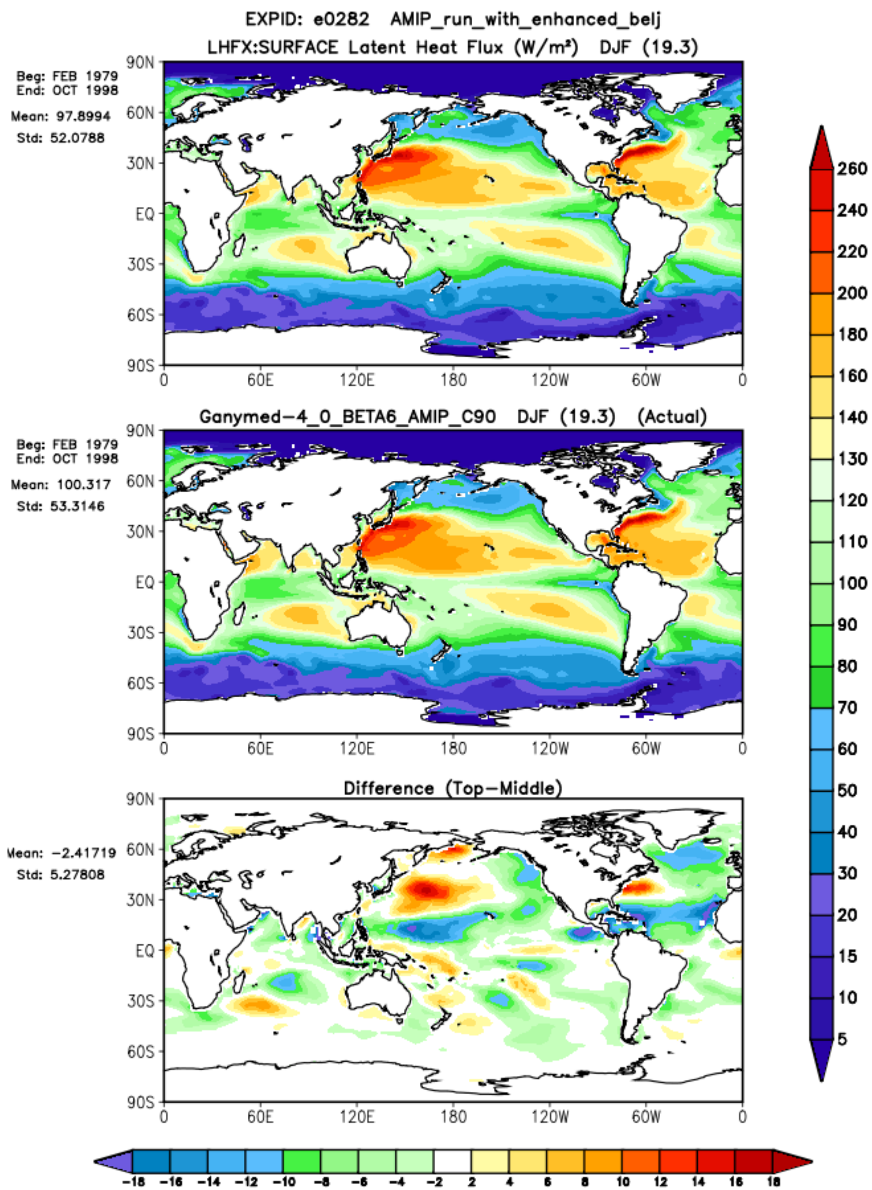
Anomaly correlation increases with 2x and 5x Beljaars drag, but no further improvement with 10x.

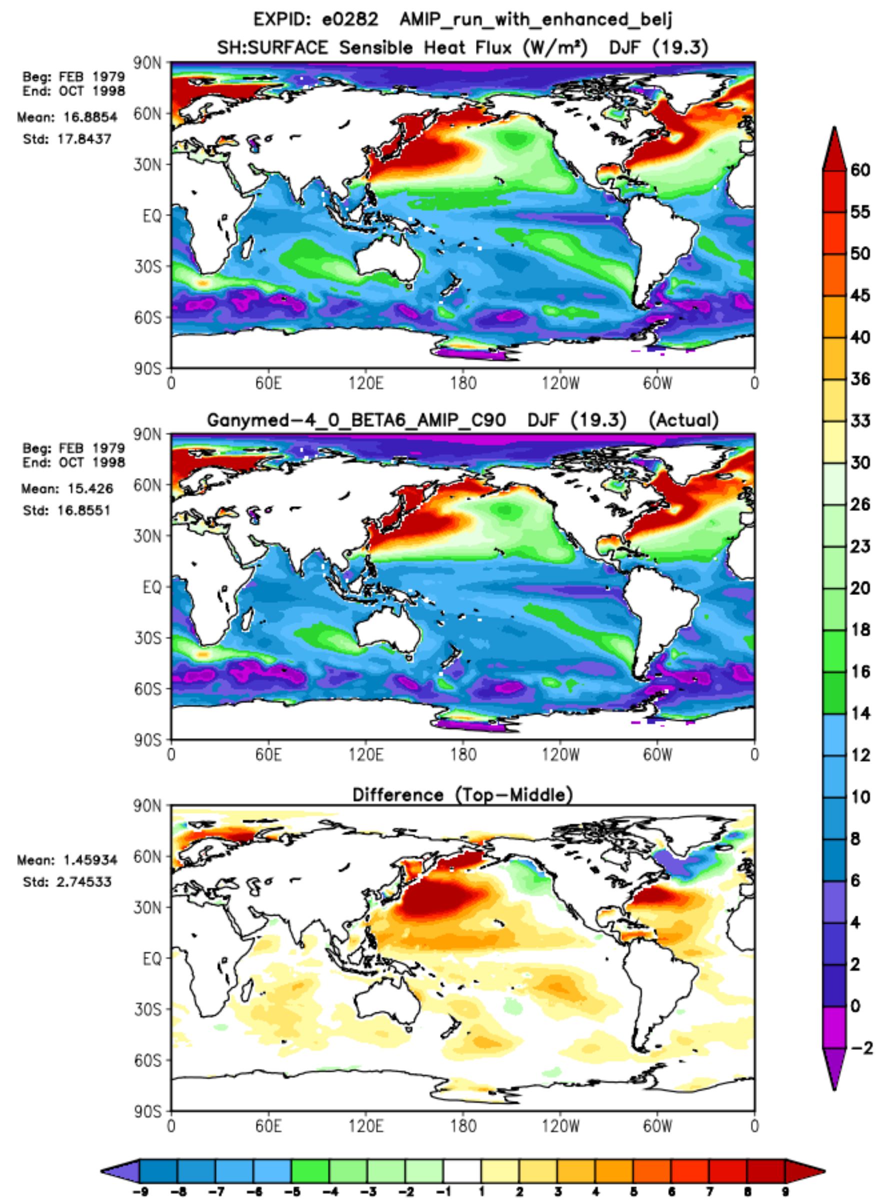
Conclusions

- Increasing three forms of surface drag (ocean, vegetation, topo form) significantly increased GEOS-5 forecast skill in the northern hemisphere.
- Increasing orographic gravity wave drag similarly improved forecast skill. Changes in non-orographic GWD had a negligible effect.
- Changes in diagnostic PBL height, through Louis turbulence scheme, again increased forecast skill.
- All three changes have little effect in the southern hemisphere.
- Precise mechanisms relating drag/PBL changes to forecast skill currently unknown.

Corresponding author: andrea.m.molod@nasa.gov

Change in surface fluxes, AMIP





Change in precip, AMIP