IERS Rapid Service/Prediction Center Use of Atmospheric and Ocean Angular Momentum for Earth Orientation

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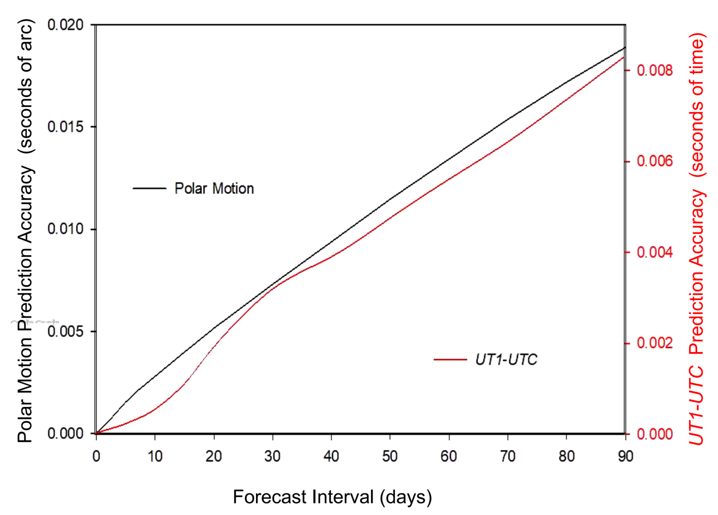
Background

- Earth Orientation Parameters (EOP), describing the transformation between the International Celestial Reference System (ICRS) and the International Terrestrial Reference System (ITRS), are generally expressed in terms of the Earth rotation angle (described by UT1-UTC), polar motion (described by x, the motion of the pole along 0º longitude and y, the motion along 90º W longitude), together with the nutation and precession of the Earth's spin axis.
- EOP are required for spacecraft navigation and pointing systems, and accurate real-time GPS positioning.
- International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center at U. S. Naval Observatory provides daily forecasts in IERS Bulletin A (McCarthy, 1988; Stamatakos, *et al.*, 2012).
- Part of the forecasting method is based on McCarthy and Luzum (1991), with additional methods suggested by Kosek (1997).
- Many attempts at improved forecasting, including the addition of AAM dynamical forecasts, were highlighted in a special campaign: Kalarus (2010).

Current Prediction Capability



- Improvements in near-term prediction accuracy may be possible using estimates of the Earth's atmospheric angular momentum (AAM) and ocean angular momentum (OAM).
- The relation of Earth orientation data and AAM data is facilitated through the use of the dimensionless "effective" angular momentum functions (Barnes *et al.*, 1983).
  - χ_1 along the meridian of 0° longitude
  - χ_2 along the meridian of 90° east longitude
  - χ_3 axial component

$$\chi_1 = x(t) + \frac{1}{\sigma}\frac{d}{dt}y(t), \quad \chi_2 = -y(t) + \frac{1}{\sigma}\frac{d}{dt}x(t), \quad \chi_3 = LOD(t)\big/\mathrm{T}.$$

σ is frequency of the free Chandler wobble, 2π/435 day^{-1}, *LOD(t)* is excess length of day, and T is the length of day, 86,400s.

- AAM data from various operational weather forecasting centers agree well (Rosen *et al.*, 1987), and χ_3 AAM predictions from these models have shown positive skill (Rosen *et al.*, 1987; Rosen *et al.*, 1990; Rosen *et al.*, 1991).
- The relationship of χ_3 and *LOD* is well documented. This poster presents results of a continuing investigation into the possibility of using $\chi_1(t)$, $\chi_2(t)$, and $\chi_3(t)$ to improve operational EOP predictions.

Goals

- Quantify potential contribution of U. S. Navy ESPC data to operational predictions of Earth orientation parameters.
- Compare recent analysis and prediction of ocean and atmospheric angular momentum data with geodetic observation.

Data

***$\chi_1(t)$, $\chi_2(t)$:* Navy Earth System Prediction Capability (ESPC)** Ensemble Resolution (Navy-ESPC$_{ENS}$)

- ATMOSPHERE: NAVY Global Environmental Model (NAVGEM 1.2)
- OCEAN: HYbrid Coordinate Ocean Model (HYCOM)
  - 1/12° resolution, no tides

ANALYSIS and FORECAST (with occasional gaps)

***$\chi_3(t)$:* NAVGEM 1.4.3 currently used operationally at USNO**

- Daily spacing -- 1 January 2019 – 20 February 2020
- $\chi_1(t)$, $\chi_2(t)$, and $\chi_3(t)$ available from NAVOCEANO Stennis Space Center.

Previously

- Concluded that short-term predictions of polar motion could be improved by using AAM forecasts;
- Concluded that there are significant non-AAM excitations in polar motion;
- Concluded that combination of NAVGEM analysis and forecast data can provide improved polar motion predictions;
- Found good self-consistency between HYCOM analysis and forecast results;
- Found systematic differences between predictions of HYCOM and ocean models used by GFZ;
- NAVGEM 1.4.3 AAM χ_3 shows improved random error and small systematic difference with respect to previous NAVGEM releases;
- Angular momentum data might be used for predictions in combination with more accurate geodetic data or if geodetic data were not available.
- Past posters:
  - Salstein, D., Stamatakos, N., "New Atmospheric and Oceanic Angular Momentum Datasets for Predictions of Earth Rotation/Polar Motion", G13A-0521 poster at the *American Geophysical Union Meeting*, San Francisco, California, December 2014.
  - Stamatakos, N., McCarthy, D., Eubanks, T. M., Salstein, D., "Further Analysis of Atmospheric and Oceanic Angular Momentum Datasets for Predictions of Earth Orientation", G11A-0968 poster, *American Geophysical Union Meeting*, San Francisco, California, 2015.
  - Stamatakos, N., Eubanks, T. M., McCarthy, D., Salstein, D., "Using Atmospheric and Oceanic Angular Momentum to Improve Earth Orientation Products," EGU2016-8556 poster *European Geosciences Union Meeting,* Vienna, 2016.
  - Stamatakos, N., Eubanks T. M., McCarthy, D., Salstein, D.,"Using Atmospheric and Oceanic Angular Momentum to improve Earth Orientation Products", poster *American Geophysical Union Meeting*, San Francisco, California, 2017.
  - Stamatakos, N., McCarthy, D., Salstein, D., "Earth Orientation from the IERS Rapid Service / Prediction Center: Improvements with the Use of Atmospheric and Ocean Angular Momentum Data ", poster *European Geosciences Union Meeting*, Vienna, 2018.
  - Stamatakos, N., McCarthy, D., Salstein, D., "Earth Orientation from the IERS Rapid Service / Prediction Center: Improvements with the Use of Atmospheric and Ocean Angular Momentum Data ", poster *European Geosciences Union Meeting*, Vienna, 2018.
  - Stamatakos, N., Salstein, D., McCarthy, D., "Updates on the use of Earth Atmospheric and Ocean Angular Momentum for Earth Orientation within the IERS Rapid Service/Prediction Center", poster *American Geophysical Union Meeting,* 2018.
- Stamatakos, N., Salstein, D., McCarthy, D., "Investigating Possible Combinations of Atmospheric, Ocean, and other Geophysical Angular Momentum Data to Improve Operational Earth Orientation Information", poster *European Geosciences Union Meeting,* 2019.

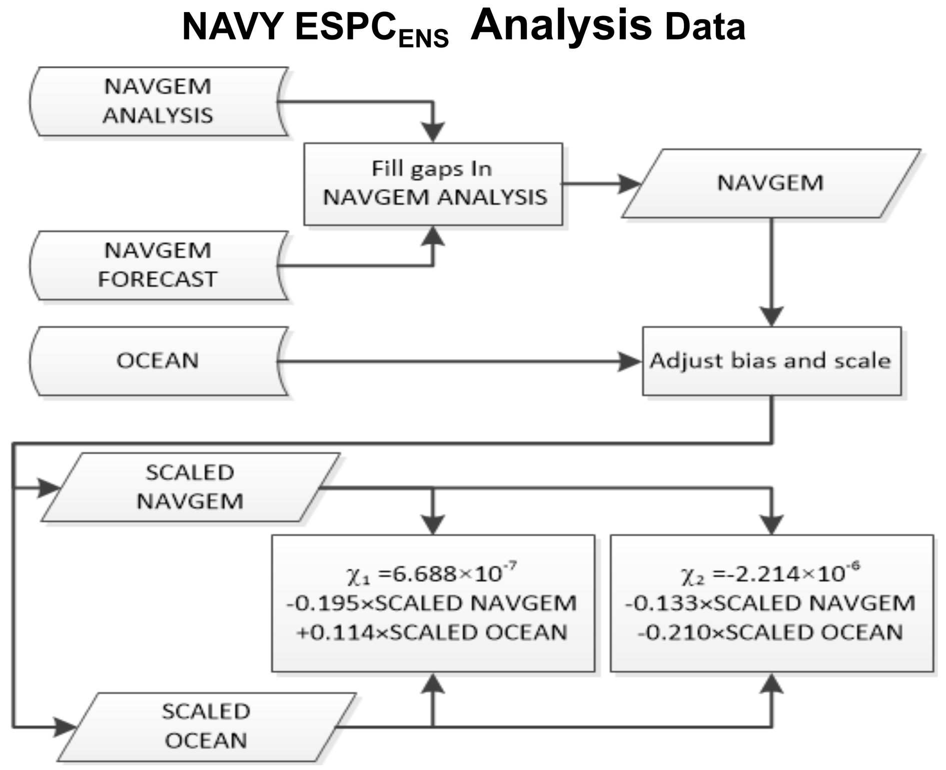
Comparison of Effective Angular Momentum Functions

- Comparison with excitation function derived from geodetic polar motion observations from IERS finals.data.
- Solid Earth tidal effects removed from *LOD(t)*

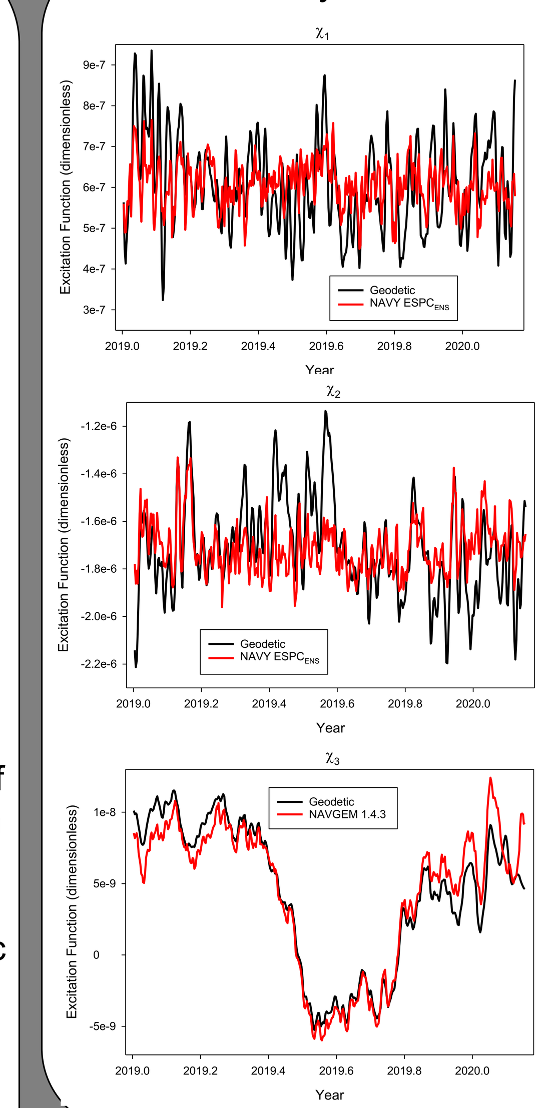
$$\chi_1^{geodetic}(t) = x(t) + \dot{y}(t)/\sigma,$$
$$\chi_2^{geodetic}(t) = -y(t) + \dot{x}(t)/\sigma$$
$$\chi_3^{geodetic}(t) = LOD(t)/\mathrm{T}$$

- Ocean and meteorological data adjusted by bias and scale to match excitation functions derived from geodetic observations of EOP.

NAVY ESPC$_{ENS}$ Analysis Data



Analysis Data with missing data filled in by Forecast Data



χ_1

STANDARD DEVIATION

Geodetic	1.13×10^{-7}
ESPC$_{ENS}$ residuals	9.61×10^{-8}

27 % of geodetic variability explained

χ_2

STANDARD DEVIATION

Geodetic	1.99×10^{-7}
ESPC$_{ENS}$ residuals	1.66×10^{-7}

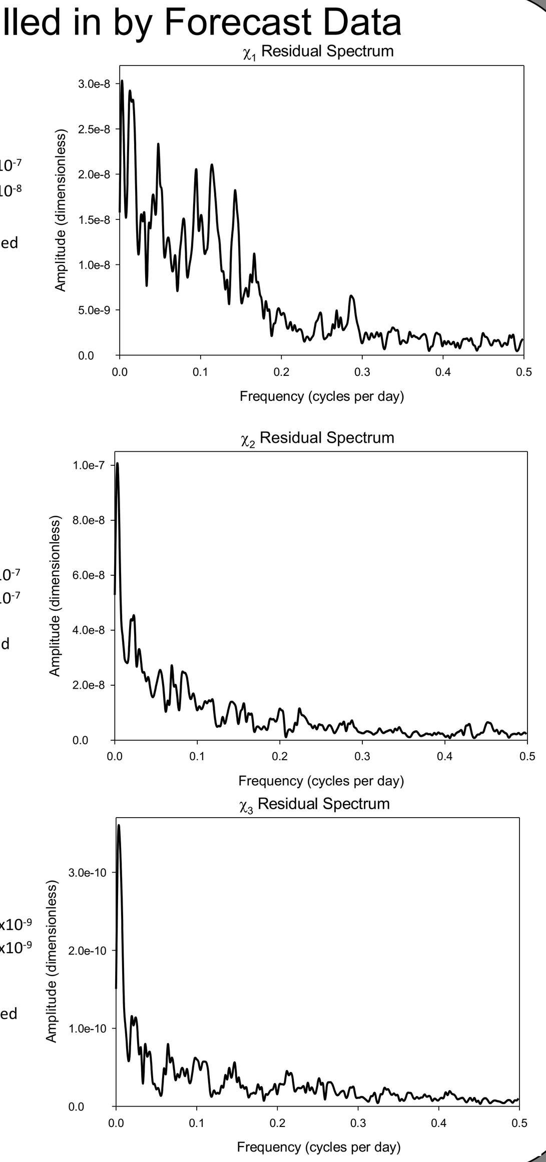
30 % of geodetic variability explained

χ_3

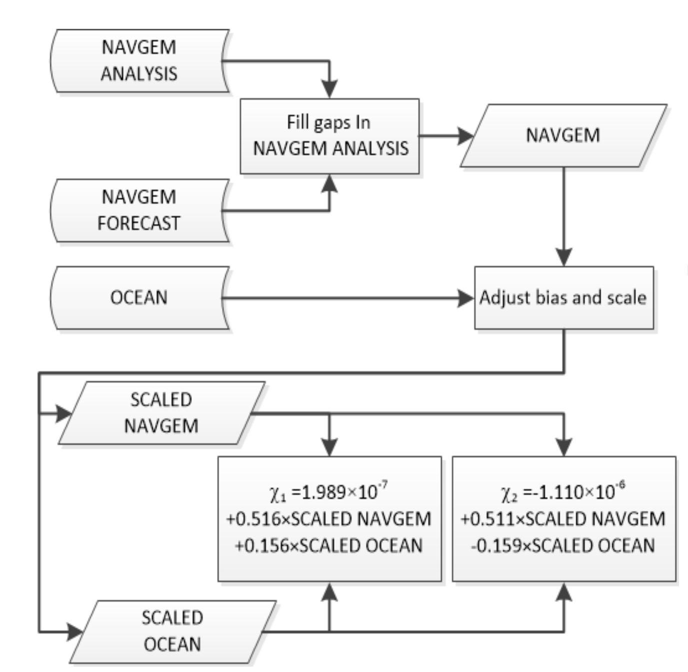
STANDARD DEVIATION

Geodetic	5.44×10^{-9}
ESPC$_{ENS}$ residuals	1.40×10^{-9}

92% of geodetic variability explained



NAVY ESPC$_{ENS}$ Forecast Data



Forecast Interval (days)	χ_1 Standard Deviation		% of geodetic variability explained	χ_2 Standard Deviation		% of geodetic variability explained
	Geodetic	Prediction		Geodetic	Prediction	
1	1.13E-07	1.13E-07	0.0%	1.85E-07	1.78E-07	7.5%
2	1.13E-07	1.11E-07	3.1%	1.84E-07	1.75E-07	9.1%
3	1.13E-07	1.09E-07	6.5%	1.84E-07	1.75E-07	9.2%
4	1.13E-07	1.11E-07	4.8%	1.85E-07	1.77E-07	8.0%

Conclusions

- Navy-ESPC$_{ENS}$ Analysis data explains significant portion of polar motion excitation function variability.
- Navy-NAVGEM 1.4.3 Analysis data explains nearly all of short-term axial excitation function variability.
- Navy-ESPC$_{ENS}$ Forecast data is of limited utility for polar motion forecast
- Navy-NAVGEM 1.4.3 Forecast data might provide an important contribution to predictions of UT1-UTC

Future

- Longer time series of data required for more robust analysis
- Elimination of gaps in Navy-ESPC$_{ENS}$ data might improve their potential contribution to polar motion excitation functions.
- Navy-ESPC$_{DET}$ data combining NAVGEM 1.4 with higher resolution HYCOM including the effects of ocean tides might provide further improvement in the correlation with geodetic polar motion excitation functions.
- Hydrological angular momentum in combination with atmospheric and ocean angular momentum might provide further improvement in the correlation with all components

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