Using Atmosphere and Ocean Angular Momentum for Earth Orientation

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Introduction

- 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

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

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

Objective and Data

- **Objectives**:
  - Compare geophysical fluids results from US Navy and from German Research Centre for Geosciences with excitation functions derived from Geodetic data.
  - Investigate accuracy and robustness of EOP derived from angular momentum of geophysical fluids using a coupled combination process.
- **Data**:

  $\chi_1(t)$, $\chi_2(t)$, $\chi_3(t)$ from:

  1. **Operational Navy Earth System Prediction (ESPC)**
     - Combines AAM and OAM, 16 independent model runs, with daily spacing 1 December 2021 – 31 March 2022.
       - AAM: Navy Global Environmental Model (NAVGEM)
       - OAM: HYbrid Coordinate Ocean Model (HYCOM)
         - 1/12° resolution, no tides

  2. **German Research Centre for Geosciences (GFZ)**
     - Daily spacing -- 2 January 2021 – 10 April 2022
     - Combines AAM and OAM.

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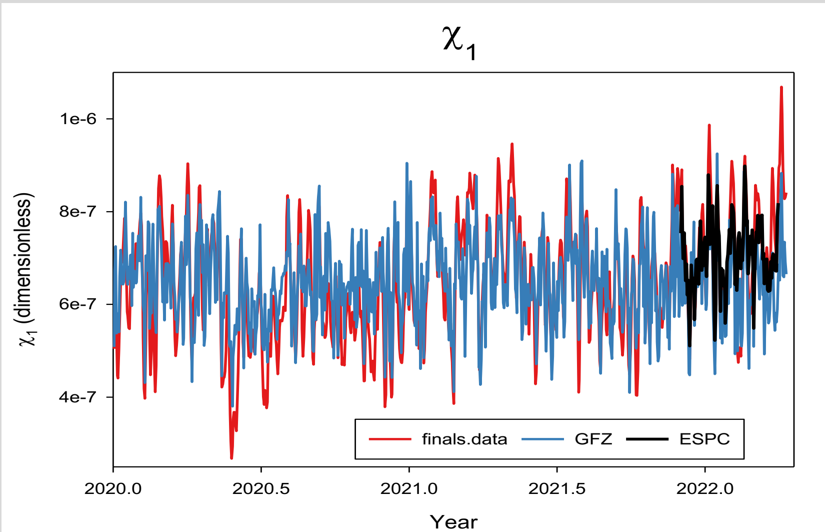
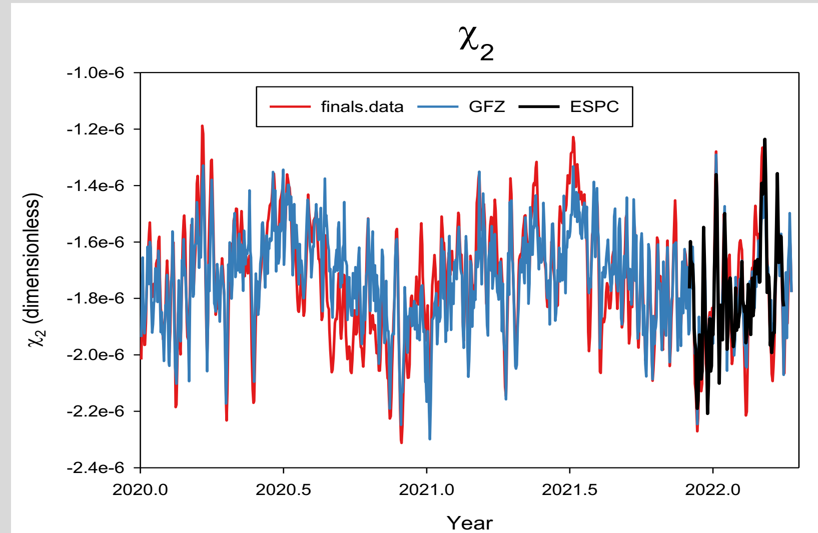
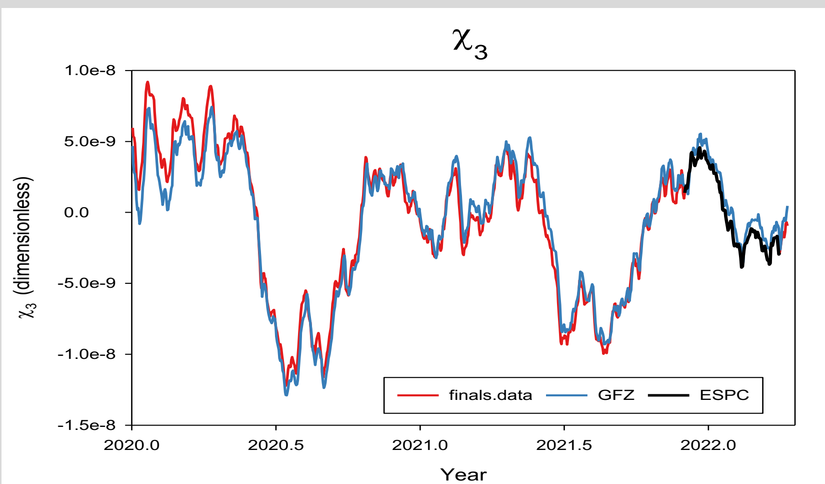
Excitation Functions Derived from Geodetic, ESPC, and GFZ Data







- Geodetic excitation is derived from observed polar motion and LOD.
- AAM and OAM χ's were scaled independently to fit the geodetic results.
- After scaling there is apparent reasonable correlation of GFZ and ESPC χ's with geodetic.

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Description of Kalman-Filter/Smoother to Generate Polar Results using AAM and OAM inputs

Kalman Filter System Dynamic Model including Chandler Wobble Coupling with Constant, Annual, & Gauss-Markov AAM/OAM Terms:

$$\dot{x} = \sigma[y + \chi_2] = \sigma[y + (b_2 + c_2 + s_2 + r_{gm2})]$$

$$\dot{y} = \sigma[-x + \chi_1] = \sigma[-x + (b_1 + c_1 + s_1 + r_{gm1})]$$

$$\dot{b}_i = 0, \quad \dot{c}_i = (2\pi/365.25)s_i, \quad \dot{s}_i = -(2\pi/365.25)c_i \qquad \text{(for } i = 1,2\text{)}$$

$$\dot{r}_{gmi} = v_{gmi}, \ \dot{v}_{gmi} = -(2\pi/10)^2 r_{gmi} - \sqrt{2}(2\pi/10)v_{gmi} + w_{gmi} \qquad \text{(for } i = 1,2\text{)}$$

Kalman Filter Measurement Model (with measurement noise terms ν):

$$x_{VLBIk} = x(t_k) + \nu_{xVLBIk}$$

$$y_{VLBIk} = y(t_k) + \nu_{yVLBIk}$$

$$x_{GPSk} = x(t_k) + \nu_{xGPSk}$$

$$y_{GPSk} = y(t_k) + \nu_{xGPSk}$$

$$\chi_{1AAM/OAMk} = b_1 + c_1(t_k) + s_1(t_k) + r_{gm1}(t_k) + \nu_{1AAM/OAMk}$$

$$\chi_{2AAM/OAMk} = b_2 + c_2(t_k) + s_2(t_k) + r_{gm2}(t_k) + \nu_{2AAM/OAMk}$$

Kalman-Filter/Smoother Calculations: Optimally fit a span of data by adjusting filter state initial conditions & process-noise time histories $w_{gm1}(t)$ & $w_{gm2}(t)$.

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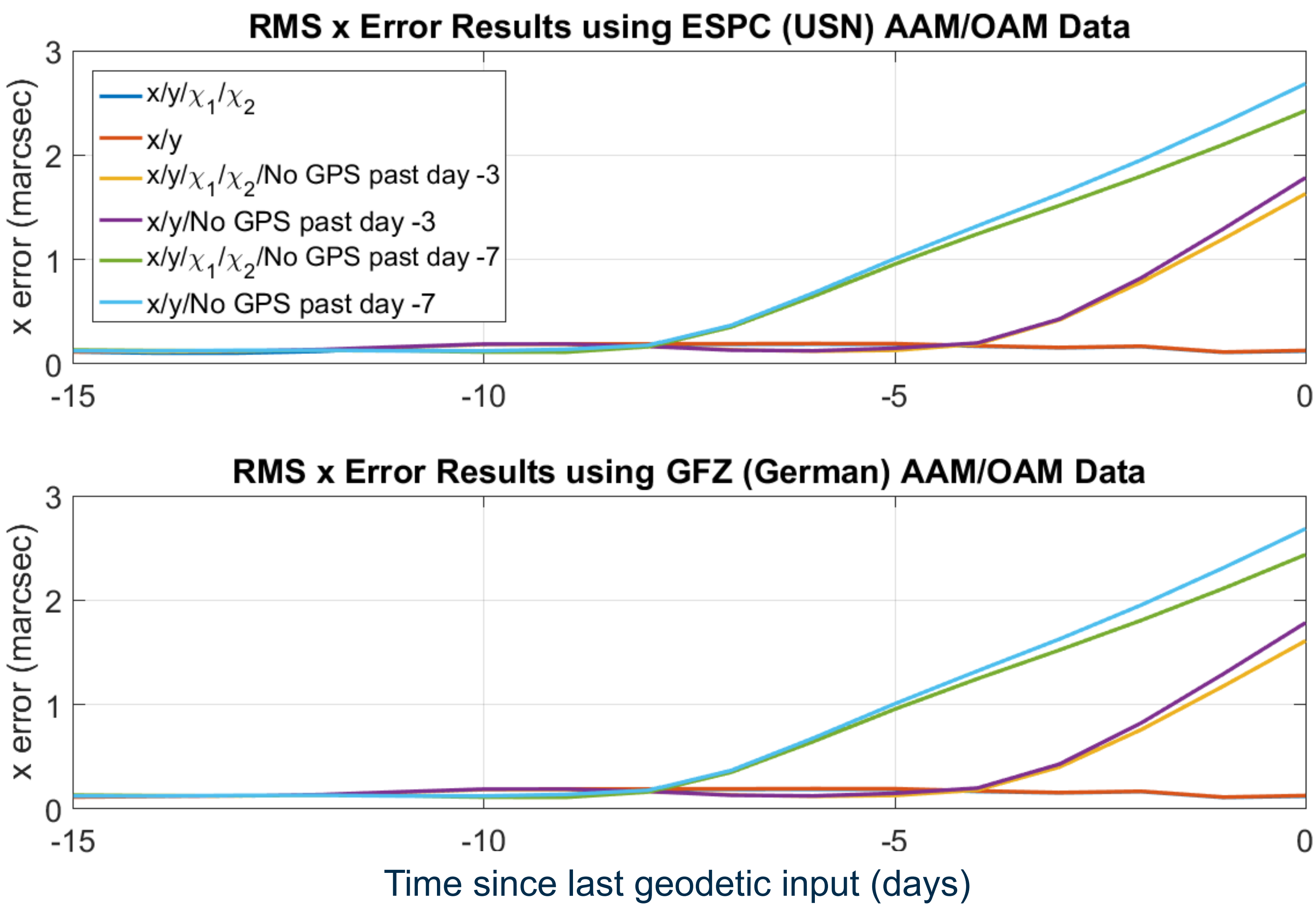
Results: Small Improvements in Polar Motion with AAM/OAM Inputs.



Summary

- **ESPC AAM and OAM revised model results have improved and show good correlation with geodetic excitation functions.**
- **GFZ model results also show good correlation with geodetic excitation functions.**
- **Kalman Filter approach, which makes use of coupled differential equations and models for Chandler and annual terms and AAM/OAM inputs, has potential for improving polar motion determination in the absence of International GNSS Service inputs.**
- **Future effort to fine-tune the Kalman Filter approach (*e.g.*, accounting for colored-noise nature of errors in χ_1 & χ_2 AAM/OAM data) may be undertaken and shown in future posters.**
- **Future investigations would involve not only analysis results but also predictions of polar motion.**

Backup Slides / Appendix

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Abstract:

The accuracy and robustness to input data outages of near real-time estimates and short-term predictions of Earth orientation parameters (EOPs) may be enhanced by using atmosphere and ocean angular momentum data accounting for the global conservation of angular momentum in the Earth system. The US Navy Earth System Prediction Capability (ESPC) data that combines the motion and mass fields of the atmosphere angular momentum information from the NAVY Global Environmental Model (NAVGEM 1.2) with that of the ocean angular momentum information from the HYbrid Coordinate Ocean Model (HYCOM) provides a source that can be used to evaluate the nature of the possible contribution of these physical data to the operational determination of the EOPs. The rates of change of the EOPs derived from the most recent angular momentum data are evaluated in comparison with observed values of polar motion and UT1-UTC rates from the IERS RS/PC EOP data series, and the stability of statistical models accounting for systematic errors in scaling and bias in the ESPC data was investigated. Analyses of these data show good agreement and indicate the viability of the practical integration of the rate data alone as well as in combination with data from other techniques in the operational determination of EOPs. Several months of past ESPC data (from new model runs) were analyzed to provide estimates of the possible precision of the resulting polar motion and UT1-UTC data.