IMPROVING UT1 PREDICTIONS USING SHORT-TERM FORECASTS OF ATMOSPHERIC, OCEANIC, AND HYDROLOGIC ANGULAR MOMENTUM

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ABSTRACT. Predictions of UT1 are greatly improved when dynamical model-based forecasts of the axial component of AAM are used as proxy length-of-day forecasts. Here, the impact on short-term UT1 predictions of additionally incorporating forecasts of oceanic and hydrologic angular momentum is evaluated.

1. INTRODUCTION

Accurate, short-term predictions of the variations in the Earth's rotation are needed for a number of reasons including precise tracking and navigation of interplanetary spacecraft. Short-term Universal Time (UT1) variations are particularly difficult to predict because, apart from largely predictable tidal variations, they are caused mainly by torques associated with changes in atmospheric circulation, making their prediction as challenging as predicting the weather.

Atmospheric effects on the Earth's rotation are generally studied by examining changes in atmospheric angular momentum (AAM). In the absence of external torques, and neglecting other effects like those due to the oceans and hydrology, the angular momentum of the Earth-atmosphere system is conserved. So when the angular momentum of the atmosphere changes, the angular momentum of the solid Earth must change by an equal but opposite amount, leading to changes in the Earth's rotation.

The angular momentum of the atmosphere, computed from the wind and pressure fields of numerical weather forecast models such as those operated by the US National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF), is available from the International Earth Rotation and Reference Systems Service (IERS) Global Geophysical Fluids Center (GGFC) Special Bureau for the Atmosphere (SBA; http://www.aer.com/scienceResearch/diag/sb.html) and the IERS Associated Product Center at the GFZ German Research Centre for Geosciences in Potsdam (http://www.gfz-potsdam.de/portal/gfz/Struktur/Departments/Department+1/sec13/services). In addition to computing the angular momentum of the atmosphere at regularized epochs of the observations, forecasts of the AAM are also computed from these numerical weather forecast models.

A number of studies have shown that predictions of UT1 are greatly improved when forecasts of the axial component of AAM from numerical weather prediction models are used as proxy length-of-day (LOD) forecasts (Freedman et al. 1994; Johnson et al. 2005). For example, and as shown below, the accuracy of JPL's 7-day predictions of UT1 are improved by about a factor of 1.7 when AAM forecasts from NCEP are used. Here, AAM forecasts from both the NCEP and the ECMWF numerical weather prediction models are used to predict UT1 and the results compared and contrasted. The impact of additionally incorporating forecasts of oceanic angular momentum (OAM) and hydrologic angular momentum (HAM) on short-term UT1 predictions is also evaluated.

2. APPROACH

The impact of AAM, OAM, and HAM forecasts on the accuracy of short-term UT1 predictions is evaluated using JPL's Kalman filter-based approach to combining and predicting Earth orientation

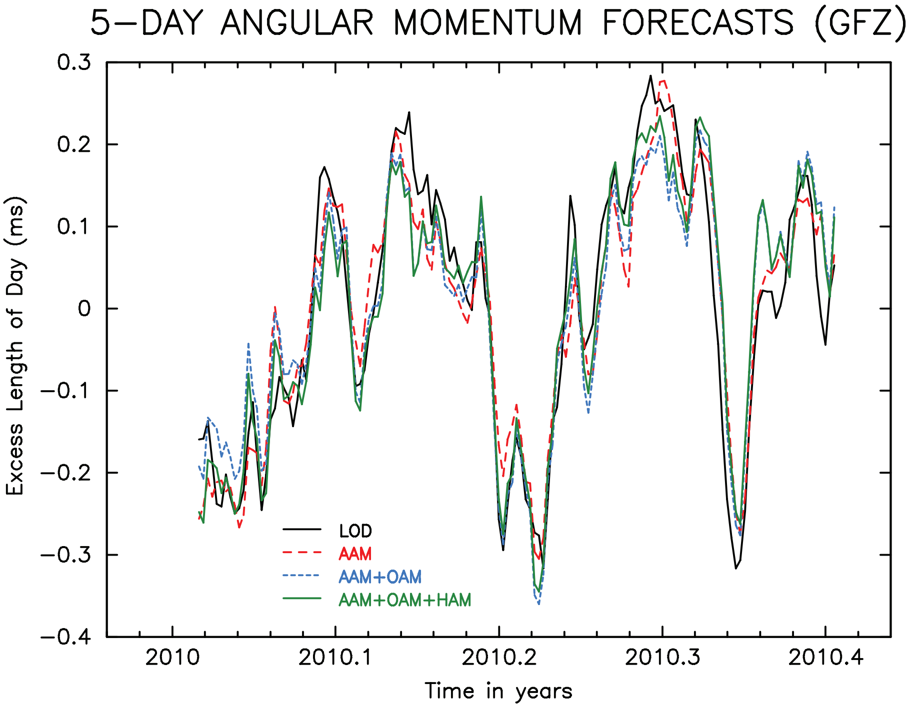

Figure 1: Comparison of observed LOD variations in milliseconds (ms, solid black line) during 06 January 2010 to 02 June 2010 with variations caused by 5-day forecasted ECMWF/GFZ AAM (long dashed red line), sum of 5-day forecasted ECMWF/GFZ AAM and OMCT OAM (short dashed blue line), and sum of 5-day forecasted ECMWF/GFZ AAM, OMCT OAM, and LSDM HAM (solid gray or green line). The AAM is the sum of the wind and inverted barometer pressure terms, the OAM is the sum of the current and bottom pressure terms, and the HAM is the sum of the motion and mass terms, although the motion term is negligibly small. A mean has been removed from each displayed time series. Note that the comparison is being done at the forecasted epoch, not at the epoch 5 days earlier when the forecasts were generated.

parameters (Gross et al. 1998). For nearly three decades, the Kalman Earth Orientation Filter (KEOF) has been used at JPL to combine and predict Earth orientation parameters in support of interplanetary spacecraft tracking and navigation. Kalman filters are commonly used to estimate parameters of some system when a stochastic model of the system is available and when the data contain noise. For the purpose of combining Earth orientation series, the system consists of the usual Universal Time and polar motion (UTPM) parameters, their excitations, and full covariance matrices. The data consist of observed Earth orientation parameters (EOPs) and covariance matrices. KEOF not only estimates all three UTPM parameters along with their excitations but also predicts them out to 78 days in advance. Since the early 1990s, KEOF has included AAM forecasts from NCEP, obtained through the IERS SBA (Salstein et al. 1993), in order to improve the accuracy of the UT1 predictions.

KEOF is run operationally once-a-day to generate the combined and predicted EOP files that are delivered to the spacecraft navigation teams. Here, 143 of the operational runs done between 01 January 2010 and 28 May 2010 have been re-done using AAM forecasts from ECMWF instead of the NCEP forecasts that were used operationally. The ECMWF AAM forecasts were obtained from the GFZ German Research Centre for Geosciences in Potsdam (Dill and Dobslaw 2010). Since the angular momentum of only the 5-day wind forecasts from NCEP are used at JPL to improve the UT1 predictions, only the 5-day wind forecasts from ECMWF/GFZ have been used here. In order to study the impact of forecasted pressure variations on the accuracy of UT1 predictions, the respective 5-day inverted barometer (ib) pressure AAM forecasts have been added to the wind forecasts.

The ECMWF forecast fields are used at GFZ to force the Ocean Model for Circulation and Tides (OMCT; Dobslaw and Thomas 2007) in order to generate forecasted OAM and are also used to force the Land Surface Discharge Model (LSDM; Dill 2008) in order to generate forecasted HAM. These models

Forecast Series	LOD Variance Explained	Correlation with LOD
ECMWF/GFZ 5-day wind forecasts	84.311%	0.9215
ECMWF/GFZ 5-day wind+ib forecasts	88.566%	0.9426
GFZ 5-day AAM+OAM (mass+motion)	86.093%	0.9294
GFZ 5-day AAM+OAM+HAM (mass+motion)	87.625%	0.9361

Table 1: Comparison of 5-day AAM, OAM, and HAM Forecasts with Observed LOD

are run in such a manner that global freshwater mass conservation is enforced (Dobslaw et al. 2010). The resulting 5-day forecasted OAM and HAM (sum of mass and motion terms) have been added to the total 5-day forecasted ECMWF/GFZ AAM (sum of wind and ib pressure terms) in order to study their impact on UT1 predictions.

3. RESULTS

Figure 1 compares the observed LOD variations (solid black line) from the COMB2009 combined EOP series (Ratcliff and Gross 2010) with those caused by the total 5-day forecasted ECMWF/GFZ AAM (long dashed red line), those caused by the sum of the total 5-day forecasted ECMWF/GFZ AAM and OMCT OAM (short dashed blue line), and the sum of the total 5-day forecasted ECMWF/GFZ AAM, OMCT OAM, and LSDM HAM (solid gray or green line). Note that the comparison is done at the epoch of the forecast, not at the epoch 5 days earlier when the forecasts were generated. As can be seen, the 5-day forecasted AAM, AAM+OAM, and AAM+OAM+HAM series are all in good agreement with the LOD observations.

Table 1 gives the percentage of the observed LOD variance explained by different combinations of the angular momentum series. It also gives their correlation with the LOD observations. Adding the 5-day forecasted ib pressure term to the 5-day forecasted wind term increases the agreement with the LOD observations with both the LOD variance explained and the correlation becoming greater. Adding the total 5-day forecasted OAM to the total AAM causes the agreement with LOD to get worse. Adding the total HAM to the total AAM+OAM improves the agreement, although the best agreement with the LOD observations is obtained with just the total AAM.

Table 2 gives the error in the predictions of UT1 out to 7 days in the future when different combinations of the angular momentum series are used. If no AAM forecasts are used to predict UT1 then the error in the predictions grows rapidly, becoming 34.9 centimeters (cm) after just 7 days. But when AAM forecasts are used, the error is dramatically reduced, becoming only 20.3 cm after 7 days when the total NCEP forecasts are used, and 19.9 cm when the total ECMWF forecasts are used. For both the NCEP and ECMWF forecasts, adding the respective 5-day forecasted ib pressure terms to the wind terms improves the UT1 prediction accuracy only slightly. The accuracy of the UT1 predictions is no better when the NCEP and ECMWF forecasts are averaged than it is when just the ECMWF forecasts are used (either wind term alone or the sum of the wind and ib pressure terms).

Adding the total OMCT OAM forecasts to the total ECMWF/GFZ AAM forecasts improves the UT1 predictions, reducing the error of the 7-day prediction from 19.9 cm to 17.6 cm. However, additionally adding the total LSDM HAM forecasts slightly degrades the UT1 prediction error.

4. DISCUSSION AND SUMMARY

All of the 5-day forecasted angular momentum series studied here agree quite well with the observed LOD during 06 January 2010 to 02 June 2010 (see Figure 1 and Table 1). This high degree of agreement allows AAM forecasts to be used as proxy LOD forecasts when predicting UT1. However, the forecasted angular momentum series that agreed best with the LOD observations, the total AAM forecasts, does not lead to the best UT1 predictions. The best UT1 predictions are obtained when the sum of the total ECMWF/GFZ AAM and OMCT OAM forecasts are used.

Adding OAM to AAM forecasts improves the accuracy of the UT1 predictions by about 12%. This relatively small degree of improvement is to be expected given the high degree of agreement that already exists between LOD and AAM. But adding OAM to AAM forecasts should greatly improve polar motion

Forecast	Prediction Interval, days							
Series	0	1	2	3	4	5	6	7
No forecasts	1.2	2.6	5.7	10.1	15.5	21.5	28.0	34.9
NCEP 5-day wind forecasts	1.2	2.2	4.3	7.0	10.1	13.3	16.7	20.7
NCEP 5-day wind+ib forecasts	1.2	2.2	4.1	6.7	9.7	12.8	16.2	20.3
ECMWF/GFZ 5-day wind forecasts	1.2	2.2	4.2	6.8	9.7	12.8	16.2	20.2
ECMWF/GFZ 5-day wind+ib forecasts	1.2	2.1	4.1	6.5	9.4	12.4	15.9	19.9
Average NCEP+ECMWF/GFZ 5-day wind	1.2	2.2	4.2	6.9	9.8	12.9	16.3	20.2
Average NCEP+ECMWF/GFZ 5-day wind+ib	1.2	2.1	4.1	6.6	9.4	12.5	15.9	19.9
ECMWF/GFZ AAM+OAM (mass+motion)	1.2	2.0	3.6	5.7	8.1	10.7	13.8	17.6
ECMWF AAM+OAM+HAM (mass+motion)	1.2	2.0	3.7	5.8	8.2	11.0	14.1	18.0

Table 2: UT1 Prediction Error. Prediction day 0 is the epoch of the last LOD measurement. The epoch of the last UT1 measurement is typically a few days earlier. Units of UT1 prediction error are cm. A change in rotation equivalent to a 1 ms change in UT1 corresponds to a 46.3 cm displacement of the Earth's surface at the equator.

predictions since the oceans are known to be a major source of polar motion excitation.

In summary, it is found that by reprocessing operational runs done during 01 January 2010 to 28 May 2010, the 7-day UT1 prediction accuracy is about 2% better when the 5-day wind AAM forecasts from ECMWF/GFZ are used instead of those from NCEP. Including the respective 5-day ib pressure AAM forecasts with the wind forecasts improves the UT1 predictions by about 2%. Averaging the 5-day NCEP and ECMWF/GFZ AAM forecasts does not improve the UT1 predictions. Finally, we find that adding the total 5-day OMCT OAM forecasts to the total ECMWF/GFZ AAM forecasts improves the accuracy of the UT1 predictions by about 12%, but additionally adding the total 5-day LSDM HAM forecasts is found to slightly degrade the accuracy of the UT1 predictions.

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