TEMPORAL EVOLUTION OF S2 ATMOSPHERIC TIDE AS REPRESENTED IN REANALYSIS DATABASES

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RESUMEN

Se ha evaluado la evolución temporal de la componente semidiurna de la marea solar atmosférica (S2) usando seis diferentes reanálisis. La motivación de este trabajo es, en primer lugar la validación del método de interpolación comúnmente usado (los datos de reanálisis se dan normalmente cada 6 horas, justamente en la frecuencia de Nyquist de la marea semidiurna). En segundo lugar, puesto que el principal forzamiento de la marea semidiurna es la absorción de UV en la capa de ozono y en menor medida la absorción de IR por el vapor de agua troposférico, su amplitud podría eventualmente usarse como un *proxy* para estas magnitudes. Los principales resultados de este estudio son i) el método de interpolación usado proporciona resultados medios zonales correctos en latitudes próximas al ecuador; ii) el cálculo estático de la marea (*i.e*. usando la totalidad de los datos, como suele hacerse normalmente) puede ser engañoso, porque existen datos espúreos en alguno de los reanálisis; iii) la evolución de la amplitud de la marea S2 presenta dos frecuencias en periodos de 1 año y 6 meses; iv) los resultados de diferentes reanálisis presentan una gran variabilidad, sin ningún patrón común e identificable en su variación temporal.

Palabras clave: Marea Atmosférica, Marea Semidiurna, Interpolación Temporal, Reanálisis.

ABSTRACT

Temporal evolution of the semidiurnal component of the solar atmospheric tide (S2) has been assessed using six reanalysis databases. The motivation for this work is twofold: first, to validate the interpolation method commonly used (reanalysis data are generally available every 6 hours, just in S2 Nyquist frequency). And second, as the main forcing of the atmospheric tide is the UV absorption in the ozone layer and, to a lesser extent, the IR absorption by water in the troposphere, its amplitude could eventually be used as a proxy for these magnitudes. The main results of this study are: i) the usual interpolation method is basically correct to evaluate mean zonal near-equatorial semidiurnal tide; ii) the static calculation of the tide (*i.e*. using the whole time span as it is usually done) can be misleading, as a number of spurious years are present in some reanalysis; iii) S2 tide variation presents two frequencies at 1 year and 6 months periods; iv) the results from different reanalysis show a great variability and no clear, common pattern in their temporal evolution has been found.

Key words: Atmospheric Tide, Semidiurnal Tide, Temporal Interpolation, Reanalysis.

1. INTRODUCTION

It is known that solar barometric atmospheric tides, and specially the semidiurnal component (S2 from here on), are mainly forced by UV absorption in the ozone layer and, to a lesser extent, by IR absorption by tropospheric water vapor (*e.g.* Chapman and Lindzen, 1970). Several studies have depicted the spatial distribution of the amplitude and phase of these tides (Haurwitz and Cowley, 1973; Hamilton, 1980; Dai and Wang, 1999) and even their relationship with geographic features, such as coastal lines or mountain ranges (Mass *et al.*, 1991; Frei and Davis, 1993; Díaz de Argandoña *et al.* 2010). In these studies, however, the tide calculation is performed using all the available data, obtaining an unique tidal value, implicitly considered as non-variant.

Nevertheless, as the forcing factors are subject to temporal change, atmospheric tides are eventually linked to the temporal variations of ozone concentration, solar activity or humidity concentration in the troposphere. Accordingly the temporal evolution of tides could be used as a proxy to infer the temporal variation of these forcings. Little effort has been made, however, to assess the temporal evolution of atmospheric tides. The main reason seems to be the intrinsic difficulty of obtaining long series of homogeneous pressure data, as the available registers are generally composed from different (albeit nearby) locations, and different pressure sensors, factors that invalidate the eventual tide calculation (Cooper, 1984).

Following this line, Cooper (1982) tried to find a trend in the S2 amplitude using 10 to 14 years data from several stations to deduce a possible solar UV variability. Gavrilov and Kaidalov (1996) found a drop in the semidiurnal tide amplitude at high latitudes of the lower termosphere related to the anomalous decrease in the october ozone concentration. Bartzokas *et al.* (1995) showed a clear trend in the phase of S2 tide over Athens, with a 0.5 h shift during the 20^{th} century and a deep amplitude minimum in 1914.

An alternative way which has been followed in this work, consist in using reanalysis databases as a source of long, homogeneous pressure series, to obtain the temporal evolution of the semidiurnal tide.

2. DATA AND METHODS

The reanalysis used are shown in Table 1. The tidal calculation has been carried out by first averaging the hourly pressure values during a given time gap creating a sort of composite day. The difference between each hourly average pressure and the total average, gives the mean pressure perturbation at each hour of the day during the period considered. Once obtained the diurnal pressure cycle, the diurnal and semidiurnal components have been worked out by Fourier fitting. In this study only the semidiurnal component has been considered, as it is less affected than the diurnal one by local conditions. The chosen time gaps are 1 year, to get the general trend of the tide, and 3 months to resolve sub-annual variations. The tide has been calculated every month.

Unfortunately, with the exception of CSFR, reanalysis temporal resolution is just in the Nyquist frequency for S2 tide (6 hours). If there were only data from one location, it could be not feasible to obtain the semidiurnal tide. But, as it is well established, S2 tide mainly consist in a migrating planetary wave, so the redundant information from adjacent places allows to rebuild the missing pressure information. The interpolation method was designed by Van den Dool *et al*. (1997) and has been used by Ray (2001) and Ray and Ponte (2003) among others to obtain static values for both S1 and S2 using several reanalysis.

We have used this very method to obtain interpolated pressure series each hour. As the CFSR reanalysis provides one pressure value per hour, this can be used to validate the interpolation method by comparing the direct result against the interpolated one.

Name	Institution	Time span (years)	Data Frequency	Resolution lat x lon(deg)
The Climate Forecast System Reanalysis (CFSR)	NCEP	1979-2010	1 h	2,5 x 2,5
ERA-40	ECMWF	1957-2002	6 h	2,5 x 2,5
ERA-Interim	ECMWF	1989-2011	6 h	1,5 x 1,5
NCEP-XX Century	NCEP/NCAR	1948-2011	6 h	2,5 x 2,5
Twentieth Century Reanalysis (REA-XX)	NOAA	1871-2009	6 h	2 x 2
JRA-25	JMA/CRIEPI	1979-2011	6 h	2,5 x 2,5

TABLE 1: *Reanalysis databases used in the present study.*

3. RESULTS

3.1. Interpolation validation

Figure 1 compares the S2 tide amplitude calculated for the CFSR whole time span using one hourly pressure value as provided by the database, and using only 00h, 06h, 12h and 18h values and interpolating from these to obtain the rest of the pressure perturbation diurnal cycle. As can be seen in this figure, the interpolation does not catch many local features of the tide, especially maxima around America and Africa.

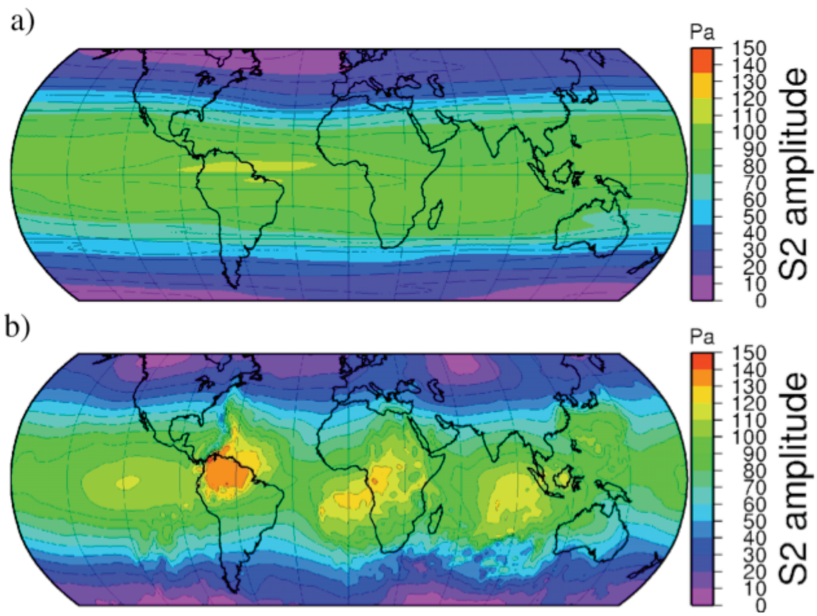

FIG.1: *Comparison between the S2 amplitude tide obtained by a) interpolation, b) direct calculation, using the CFSR whole time span.*

Nevertheless, we are only interested in the global climatological features, mainly related to the migrating component, so in Figure 2 we have compared the mean zonal values, removing the local, non migrating components. This figure shows the degradation of the interpolation accuracy at higher latitudes, probably related to the lower tidal intensity far away from the equator. According to this plot, the interpolated method slightly underestimates the equatorial tide amplitude (probably due to the maxima mentioned above) and gives a fairly good agreement with the non interpolated one to about 50º latitude.

If we examine the temporal evolution in the mean zonal amplitude obtained by the two methods, we find a nearly constant difference around the equator, but at mid latitudes the difference is far from being constant. We have represented in Figure 3 this difference in percentage as a function of time. From this figure is evident that the interpolated values away from the equator could be greatly misleading if used to find trends. Comparing Figures 2 and 3, it may looks odd that the temporal average in the amplitude difference (Figure 3) does not approximate zero for medium latitudes as in Figure 2.

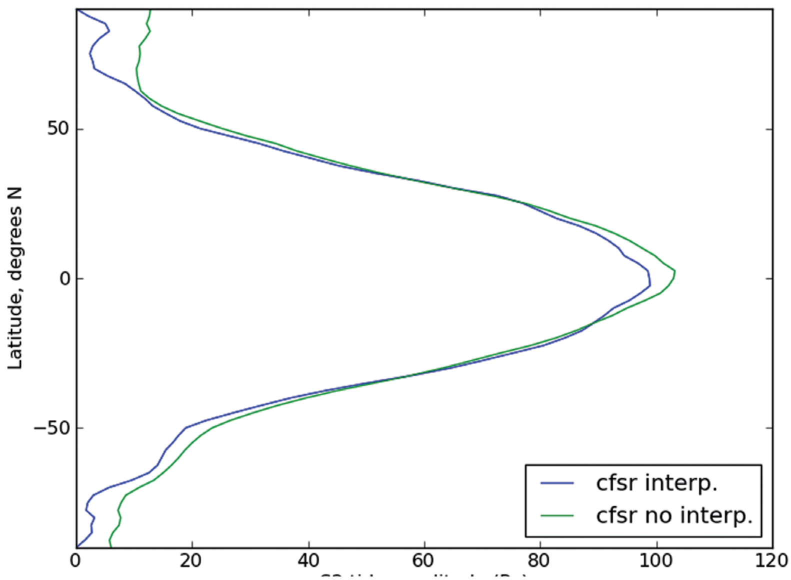

FIG. 2: *Comparison between the S2 zonal mean amplitude tide obtained by interpolation and direct calculation, using the CFSR whole time span.*

We have to notice that averaging tides is a vector-like operation because the phase is also involved, so the amplitude of the average tide is not necessarily equal to the average of the amplitudes.

We can conclude that the interpolation method by Van den Dool *et al.* (1997) is mainly suitable to obtain the migrating component of the static tide at equatorial and mid latitudes to about 50º, as shown in Figures 1 and 2. It should be used with care to assess local tide, especially at continental sites, tide at higher than about 50º latitude, and to evaluate the temporal evolution of the tide away from the equator. It is difficult to say if this result about the interpolation, obtained for the CFSR reanalysis, can be directly apply to other reanalysis, where there is no way to check its feasibility.

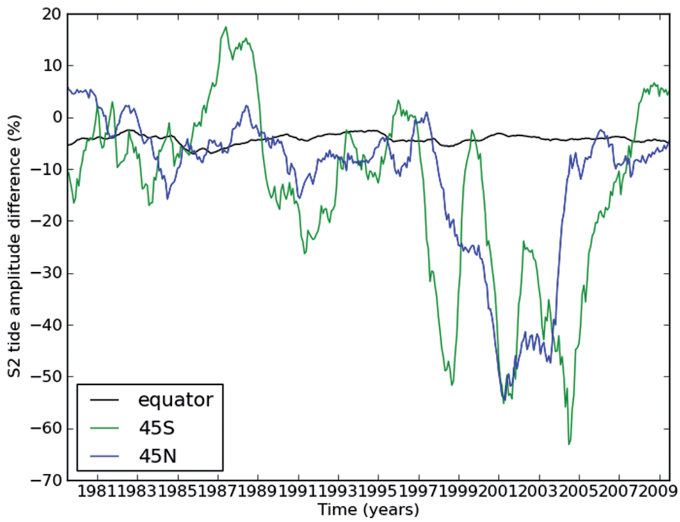

FIG. 3: *Temporal variation of the difference between tidal amplitudes calculated from the raw and interpolated CFSR reanalysis data.*

3.2. Temporal evolution of S2 amplitude and phase

S2 tide amplitude and phase (measured by first maximum local time) have been plotted against time in Figure 4. We can observe some spurious values in NCEP reanalysis from 1948 to 1957, and to a lesser extent around 1997. The static tide amplitude calculated from the whole period will obviously lead to a greater than expected value in the amplitude, due to these outliers. The abnormally high values in the S2 amplitude reported by Ray (2001) and Ray and Ponte (2003) from NCEP reanalysis are probably related to this fact.

Regarding the S2 phase, REA-XX reanalysis shows a 0.5 h earlier phase shift along the century. However, this trend is just in the opposite direction than the one found by Bartzokas *et al.* (1995). In contrast, the S2 phase from the NCEP reanalysis changes around 0.6 h in the last 60 years. This latter result is suspicious because of the anomalous amplitudes pointed out above.

Finally the phase from CFSR, ERA-interim and JRA reanalysis shifts 15-20 minutes earlier in the last 20 years, following a more or less common path.

3.3. S2 tide frequencies

Apart from the annual cycle, S2 tide shows also a 6 months cycle, clearly present in all the reanalysis. This cycle can also be found in some station data (Díaz de Argandoña *et al.*, 2011), so it is probably not an artifact. The cause of this cycle can be explained because the tidal forcing is not strictly harmonic, so some high order response is to be expected. It is not clear, however, why the second order harmonic is so prevalent. As an example, the power spectra from ERA40 and REA-XX have been plotted in Figure 5. Finally, we have considered the temporal evolution of the annual and semiannual amplitude modulation, shown in Figure 6. This evolution in turn could be related to the evolution of the annual modulation of the forcing factors. As can be seen, there are a great difference between reanalysis, both in the values and their temporal variation. For example, NCEP provides much lower values that the others, and ERA40 shows the greater variability.

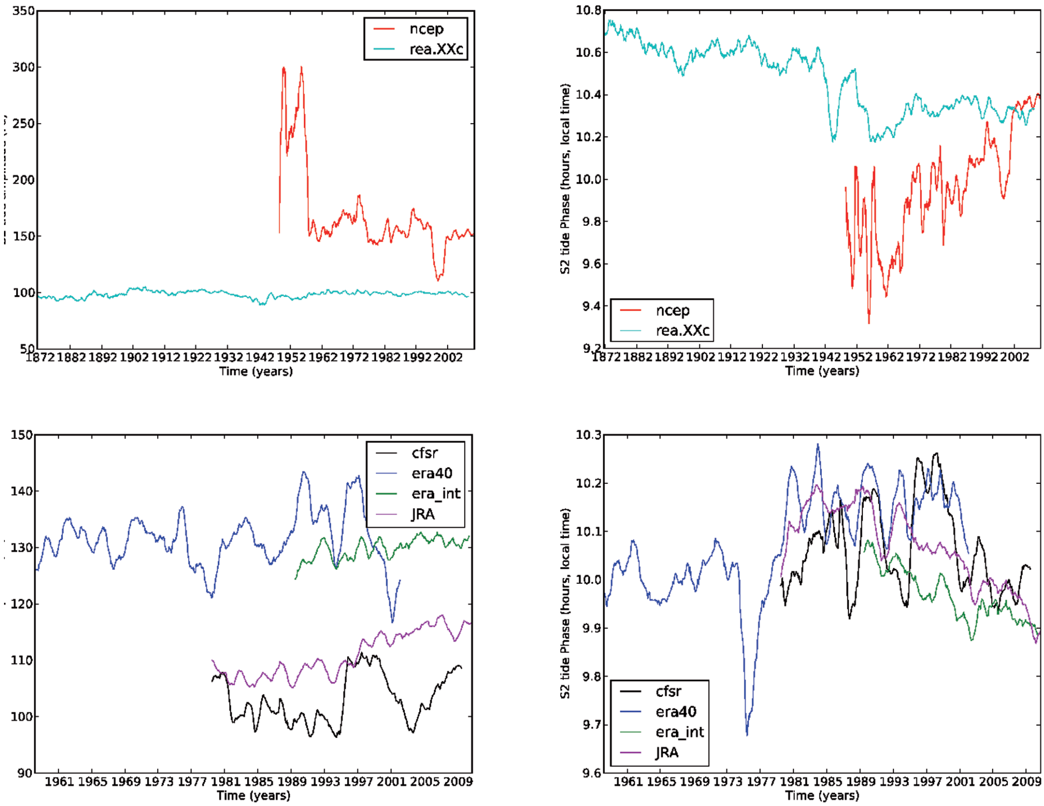

FIG. 4: *S2 mean equatorial amplitude (left) and phase (right). The phase is expressed as the local time occurrence of the first maximum.*

Further study will be necessary to validate and get some insight into these data. For example, comparing these values to ozone concentration or tropospheric humidity, some positive correlation is to be expected, either in the tidal values or in their modulation. This correlation could be probably clearer at high souther latitude than at the equator (Gavrilov and Kaidalov (1996).

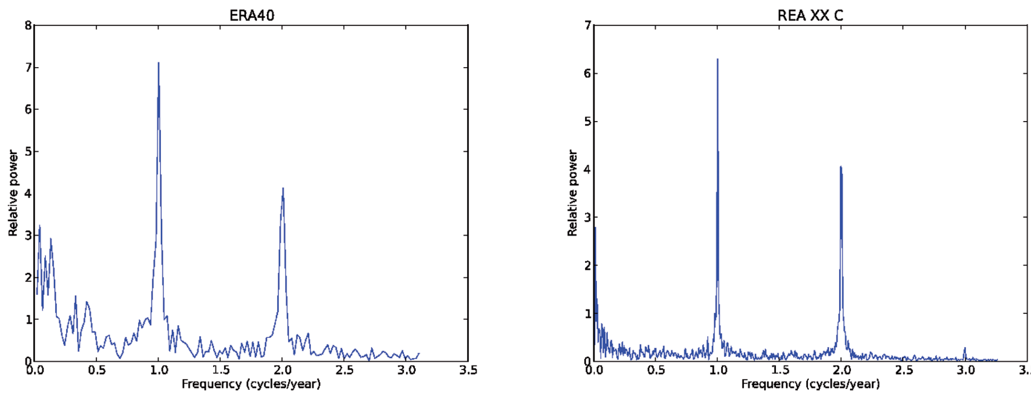

FIG. 5: *Power spectra from the S2 equatorial mean amplitude as calculated from ERA40 (left) and REA-XX reanalysis (right).*

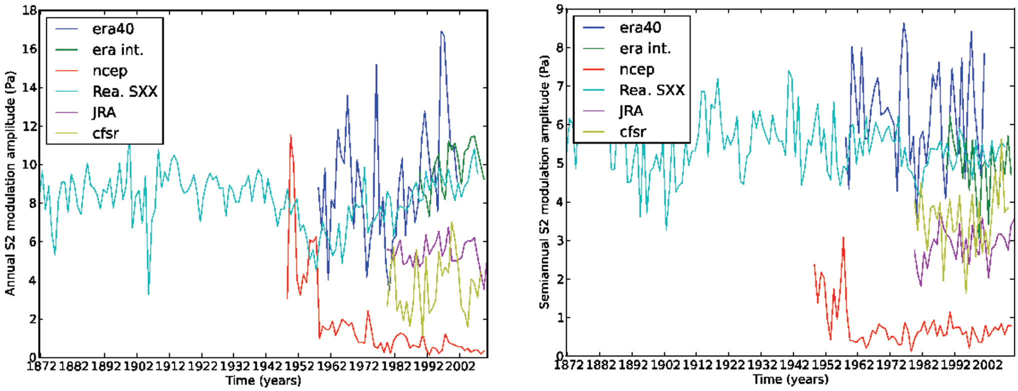

FIG. 6: *Temporal evolution of the equatorial zonal mean S2 tide amplitude modulation: annual (left) and semiannual (right).*

4. CONCLUSIONS

Semidiurnal tide has been computed from several reanalysis using a temporal interpolation method. The validity of this method has been assessed using data from CFSR reanalysis. The interpolation consistently underestimates the equatorial S2 tide amplitude by about 5 Pa. Non migrating components and medium to high latitude tides are not accurately reproduced. We can conclude that this interpolation must be used with care out from the equatorial latitudes, and that some results previously obtained from it could be partially questioned.

The temporal evolution of S2 tide amplitude shows a great dispersion between different reanalysis and no clear, common pattern is apparent in the data. The tidal temporal variability shows two main frequencies, at 1 year (to be expected) and at 6 months. This latter frequency is not easy to interpret, but it is probably a second harmonic due to the not exactly harmonic forcing.

Further research, involving formal assessment of the trends, correlation studies to the forcing factors and the evolution of the tide at other than equatorial latitudes, is necessary to fully interpret the results.

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