FES98 and FES99
two new versions of the FES' global tide finite element solutions

Fabien Lefèvre (*Fabien.Lefevre@cls.fr*)*
Christian Le Provost
Florent Lyard
Laboratoire d'Etude en Géophysique et Océanographie Spatiales, Toulouse, France
*(*now in CLS, Ramonville Saint-Agne, France)*

E.J.O. Schrama
Faculty of Geodesy, Delft University of Technology, Delft, The Netherlands

1.FES98

An improved version of the global hydrodynamic tide solutions FES94 has been developed, implemented and validated at the LEGOS. This new version is based on the resolution of the tidal barotropic equations on a global finite element grid (Figure 1) without any open boundary condition, which leads to solutions independent of in situ data (no open boundary conditions and no data assimilation). The accuracy of the 'free' solutions was improved by assimilating tide gauge (FES98) through a revised representer assimilation method. A careful selection of in situ tide gauge data from different data banks allowed us to build a collection of about 700 data values for each of the eight computed waves M_2, S_2, N_2, K_2, $2N_2$, K_1, O_1 and Q_1. These data were assimilated to produce the FES98 version of our model, which is independent of altimetry. However, despite of the quality of this new solution along the world coastlines, the quality of FES98 is worse than the altimetric FES95 solution in deep ocean.

2. FES99

To improve FES98, TOPEX/Poseidon (T/P) altimeter data were also assimilated to produce the FES99 version of our model. For the eight main constituents of the tidal spectrum (M_2, S_2, N_2, K_2, $2N_2$, K_1, O_1 and Q_1), approximately 700 tide gauges (Figure 3) and 687 T/P altimetric crossover data sets harmonically analysed (Figure 4), were assimilated. An original algorithm was developed to calculate the tidal harmonic constituents at crossover points of the T/P altimeter database. Additional work was performed for the S_2 wave by reconsidering the inverted barometer correction. For the two new versions of our model, 19 minor constituents have been added by admittance as well as 3 long period constituents to complete the spectrum. They are both distributed on a 0.25°x0.25° grid interpolated from the full finite element solutions.

3. ASSIMILATION SCHEME

The main purpose to compute FES99 was to overcome the uncertainties which occur in our free global tide model (i.e. without introducing any kind of in situ or remote sensing measurements) by using an assimilation procedure as described in [*Egbert et al.,* 1994; *Egbert and Bennett,* 1996]. As a result FES99 is mainly improved thanks to the assimilation of tide gauge and altimetric information. The aim of an assimilation scheme is to combine the information provided by the available data (in our case the tide gauge measurements and the T/P altimetric analyses) with the information derived from a numerical model (i.e. the hydrodynamic equations solved with the finite element model). These different information are rationally used to best fit the data and the dynamics in a least squares sense. The representer method is used to compute FES99 from the former 'free' hydrodynamic solution (the a priori solution) which lacks of accuracy. A representer is a field that gives the error correlation that our hydrodynamic finite element model propagates from one interpolated position of the mesh to all the other ones. So, one representer is associated to one assimilated data point. It gets the dimensions of the tidal elevation field (Figures 5 and 6). It leads to the classical result of the representer method, that the global solution is the sum of the a priori solution plus a weighted linear combination of the representers: $_{prior}+ \; b_k r_k$, where is the assimilated sea surface elevation, $_{prior}$ is the a priori solution, b_k (respectively r_k) is the computed vector (representer) associated to the k^{th} assimilated data (cf. [*Le Provost et al.,* 1998; *Lyard,* 1999] for further details). A strong correlation between a given assimilated position and another position yields to an undamaged tide computation if the assimilated data is accurate. On the opposite, if the assimilated data is not so accurate, the solution on all the correlated positions (not only on the position associated to the representer) will lack of accuracy too. Then, it is essential to assimilate very accurate data. As the origins of the data which can be assimilated are various, there associated accuracies are too different to be considered as homogeneous. The types of information data provided cannot influence the computation of a solution with the same weights. So as to take into account these differences, confidences (inverse of error) are set on each of the data used in the assimilation. In practice, these confidences are the weights to apply to each representer to compute the final solution. It is the reason why the selection of these confidences is the key-element of the assimilation scheme. Moreover, we cannot consider our model free of any problem. Thus, we must take into account dynamics error which are included in our case in the tidal forcing.

4.ACCURACY OF FES98 AND FES99

The accuracy of FES98 and FES99 is evaluated against the former FESs. They are compared in a first step to two tide gauge data sets: ST95 with 95 open-ocean measurements and ST739 with 739 coastal measurements (Figure 2). For ST95, the root sum square (RSS) of the differences between observations and solutions is reduced from ~2.8 cm (FES95) to ~2.4 cm (FES99), which represents a gain of ~17% in overall accuracy. For ST739, the FES99 overall accuracy compared to FES94 is ~32%.

In a second step, the variance of the sea surface variability is calculated and compared for FES95, FES98 and FES99 at the T/P and ERS-2 crossover data points. FES99 proved to perform the best, with a residual standard deviation for the independent ERS-2 data set of 13.5 cm (15.2 cm for FES95). Finally, the performance of tidal predictions is considered for the FESs, which provides along-track estimations of the sea surface variability for both T/P and ERS-2. Compared to ERS-2, FES99 residuals are 11.8 cm against 12.4 cm for FES95. All the accuracy tests show that FES99 is a significant improvement compared to former FESs both in the deep ocean and along coasts.

To evaluate the performances of our new model, we compared FES99 to the altimetric model GOT99 (Figure 7) and to NAO99 (Figure 8).

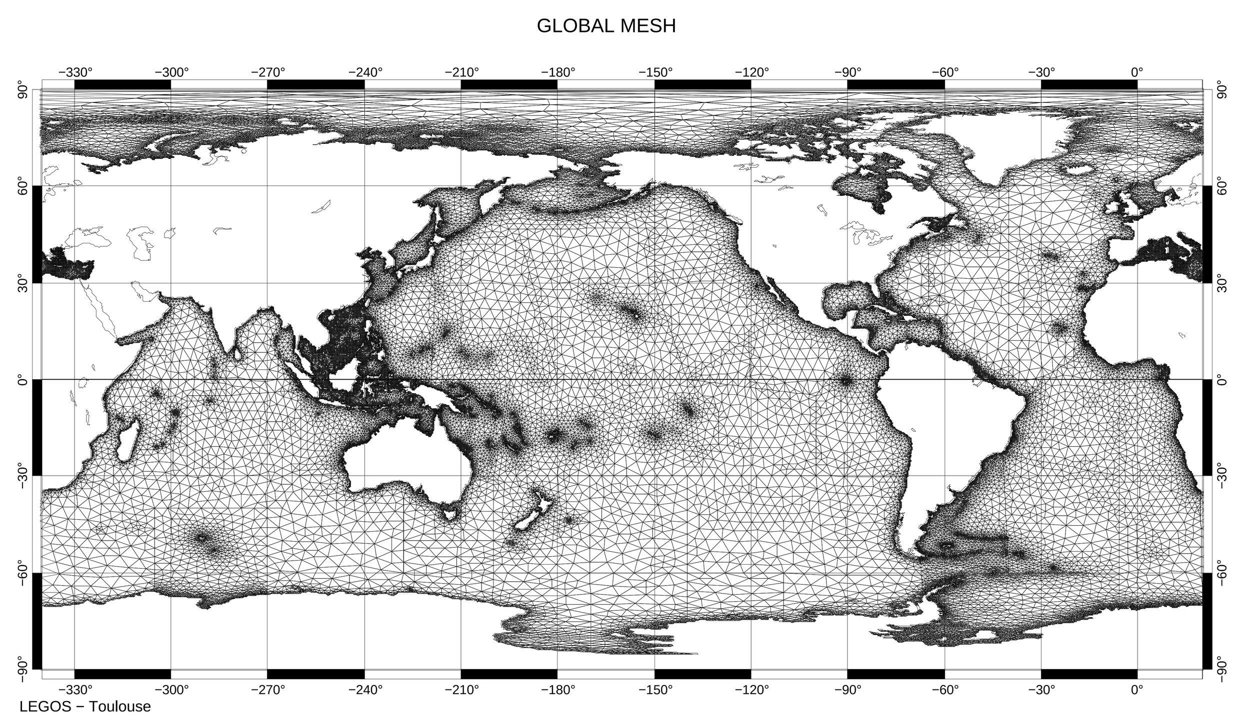

Figure 1 :
Global finite element mesh used to compute FESs

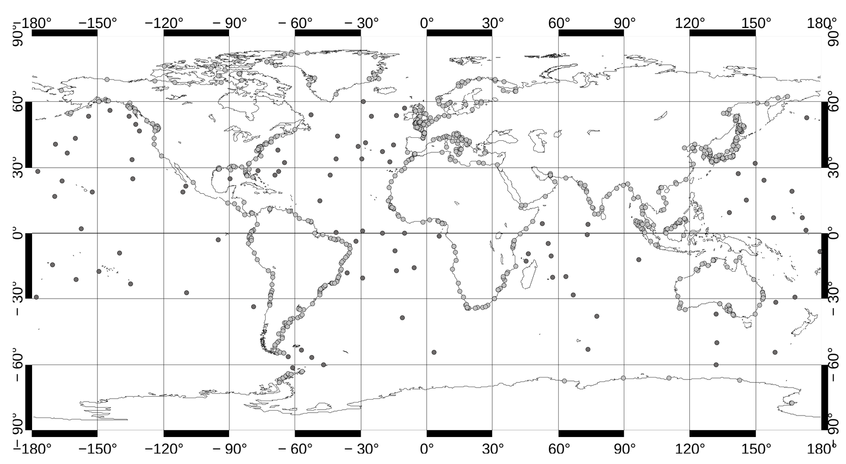

Figure 2 :
Tide gauge data sets used for comparisons
(ST95 : grey ; ST739 : yellow)

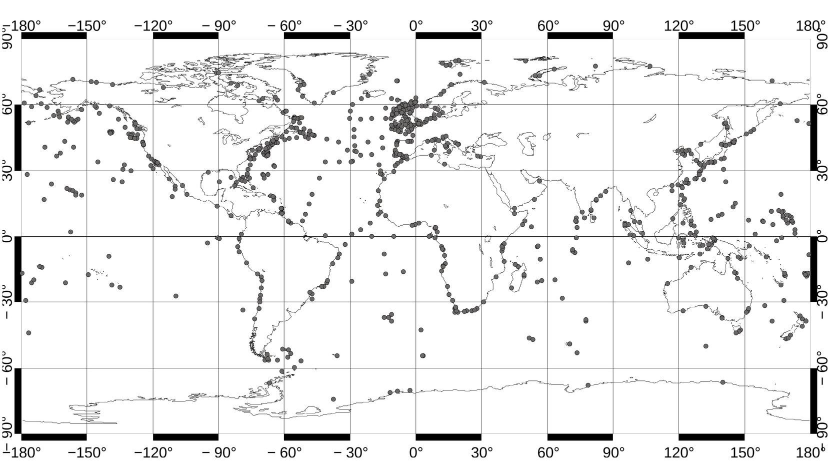

Figure 3 :
Assimilated tide gauges in FES99

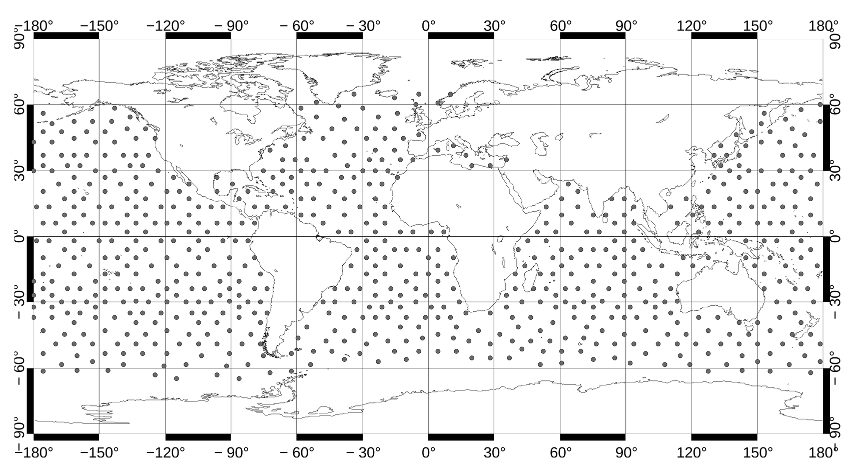

Figure 4 :
Assimilated T/P crossover points in FES99

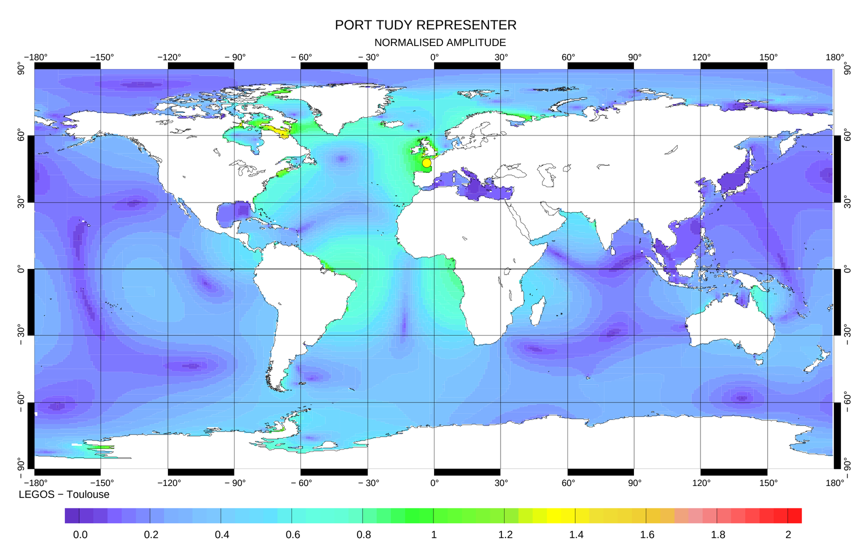

Figure 5 :
Representer associated to a coastal tide gauge
(M_2 normalised amplitude)

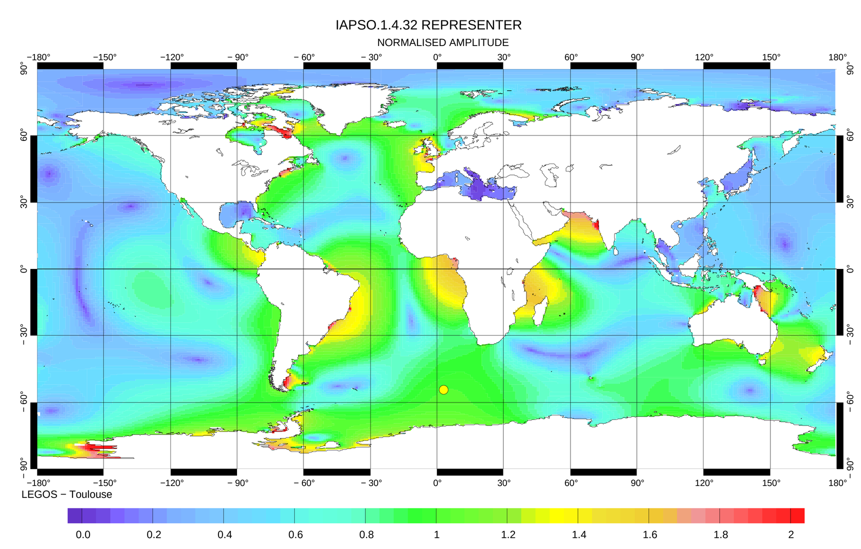

Figure 6 :
Representer associated to a deep ocean tide gauge
(M_2 normalised amplitude)

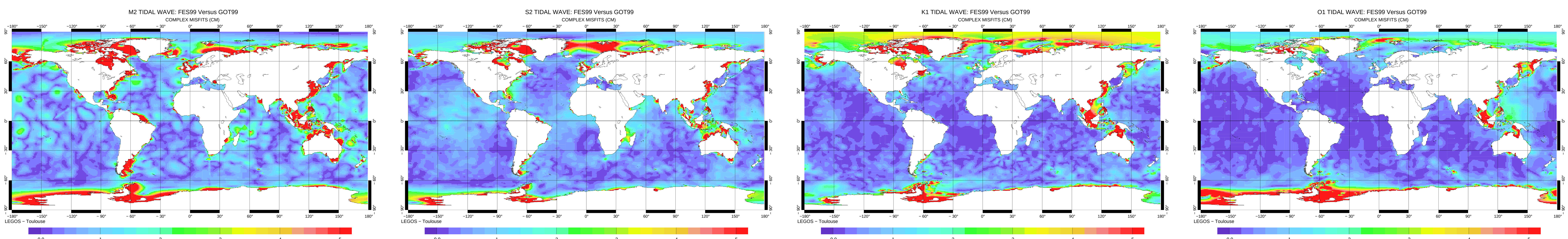

Figure 7 : Complex misfits between FES99 [*Lefèvre et al., 2000*] and GOT99 [*Ray, 1999*] (centimeters)

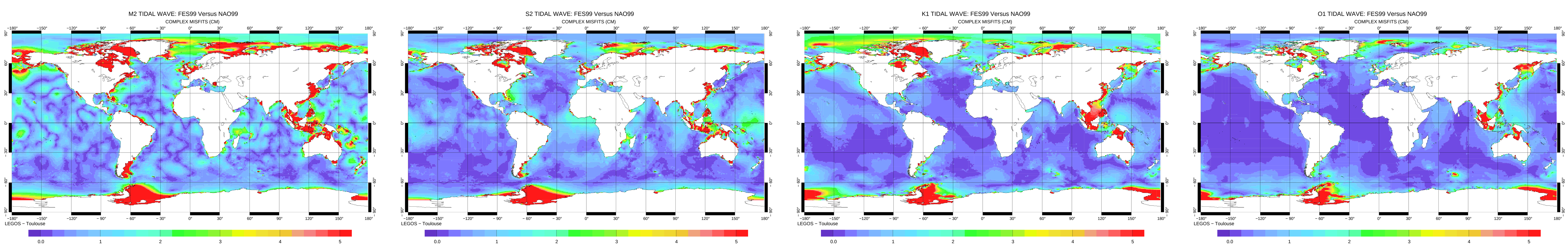

Figure 8 : Complex misfits between FES99 [*Lefèvre et al., 2000*] and NAO99 [*Matsumoto et al., 1999*] (centimeters)

LEGOS / GRGS - UMR 5566 CNES-CNRS-UPS
14, Avenue Edouard Belin
31400 Toulouse - FRANCE

CLS
8-10 rue Hermès - Parc Technologique du canal
31526 Ramonville Saint-Agne - FRANCE