Ocean and atmospheric tides standards (used for EIGEN gravity field modeling)

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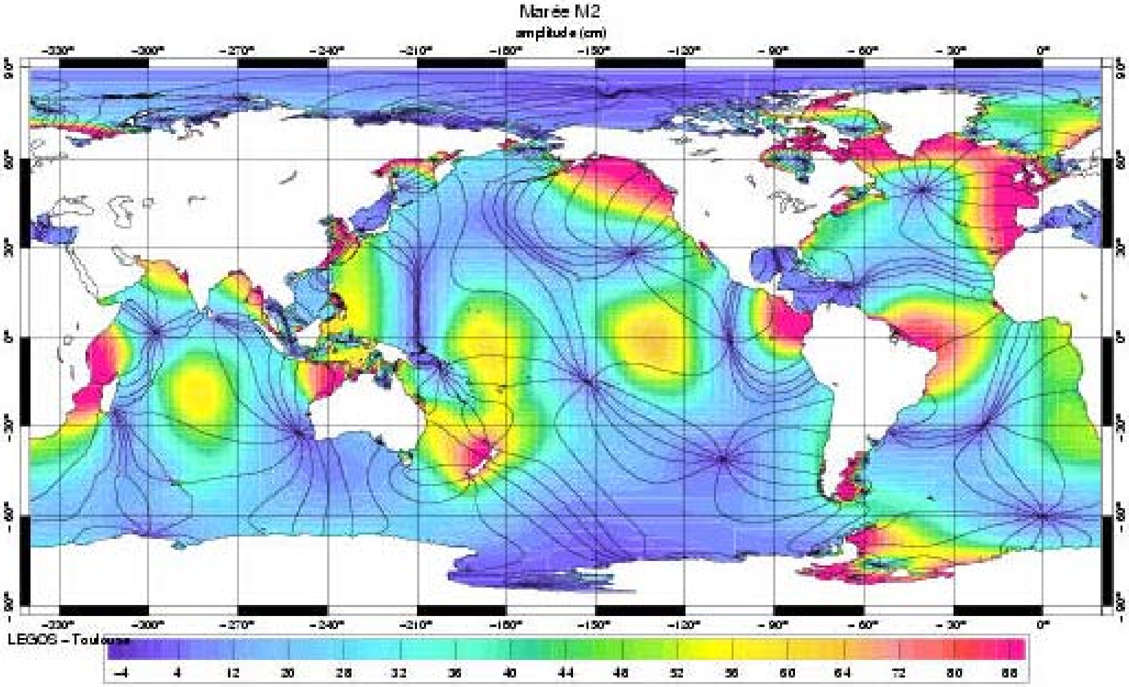


Ocean tides modeling

The height of ocean tides is expressed by a sum over n waves :

$$\boxed{\xi(\varphi\lambda t)=\sum_n Z_n(\varphi\lambda)\cos\left(\theta_n(t)-\psi_n(\varphi\lambda)\right)}$$

Z_n is the amplitude of the wave n,

ψ_n is the phase

θ_n is the Doodson argument which is expressed in linear combination of 6 variables :

$$\theta_n(t) = n_1\tau + (n_2 - 5)s + (n_3 - 5)h + (n_4 - 5)p + (n_5 - 5)N' + (n_6 - 5)p_s$$

These 6 variables with decreasing frequencies represent the fundamental arguments according to the Sun and Moon motions :

τ : *angle of the mean lunar day (1.03505 d)*
s : *angle of the mean tropic month (27.32158 d)*
h : *angle of the mean tropic year (365.2422 d)*
p : *angle of the mean lunar perigee (8.8473 y)*
N' : *angle of the mean lunar node (18.6129 y)*
p_s : *angle of the perihelion (20940.28 y)*

n_1 (= 0, 1, 2, 3...) defines the specie (long period, diurnal, semi-diurnal, ter-diurnal...), n_2 the group (in general :$1 \leq n_2 \leq 9$) and n_3 the constituent ($1 \leq n_3 \leq 9$).

The amplitude (Z_n) and phase (ψ_n) of the different waves of tides represented by **cotidal maps** can be expanded in spherical harmonic functions of $Z_n \cos\psi_n$ and $Z_n \sin\psi_n$:

$$\begin{cases} Z_n \cos\psi_n = \sum_l \sum_m \left(a_{n,lm} \cos m\lambda + b_{n,lm} \sin m\lambda\right) P_{lm}(\sin\varphi) \\ Z_n \sin\psi_n = \sum_l \sum_m \left(c_{n,lm} \cos m\lambda + d_{n,lm} \sin m\lambda\right) P_{lm}(\sin\varphi) \end{cases}$$

Then we have : $\xi(\varphi,\lambda,t) = \sum_n \left(Z_n \cos\psi_n \cos\theta_n + Z_n \sin\psi_n \sin\theta_n\right)$

$$= \sum_n \sum_l \sum_m \left[\begin{array}{l} \dfrac{a_{n,lm} - d_{n,lm}}{2}\left(cos\, m\lambda\, cos\,\theta_n - sin\, m\lambda\, sin\,\theta_n\right) \\ + \dfrac{a_{n,lm} + d_{n,lm}}{2}\left(cos\, m\lambda\, cos\,\theta_n + sin\, m\lambda\, sin\,\theta_n\right) \\ + \dfrac{c_{n,lm} + b_{n,lm}}{2}\left(cos\, m\lambda\, sin\,\theta_n + sin\, m\lambda\, cos\,\theta_n\right) \\ + \dfrac{c_{n,lm} - b_{n,lm}}{2}\left(cos\, m\lambda\, sin\,\theta_n - sin\, m\lambda\, cos\,\theta_n\right) \end{array} \right] P_{lm}(sin\,\varphi)$$

Writing :

$$C^+_{n,lm} = \frac{a_{n,lm} - d_{n,lm}}{2} \quad , \quad C^-_{n,lm} = \frac{a_{n,lm} + d_{n,lm}}{2} \qquad and \qquad S^+_{n,lm} = \frac{c_{n,lm} + b_{n,lm}}{2} \quad , \quad S^-_{n,lm} = \frac{c_{n,lm} - b_{n,lm}}{2} \quad ,$$

the **height of tide** becomes : $\boxed{\xi(\varphi,\lambda,t) = \sum_n \sum_l \sum_m P_{lm}(sin\,\varphi) \sum_{+}^{-} \left[C^{\pm}_{n,lm}\, cos(\theta_n + \chi_n \pm m\lambda) + S^{\pm}_{n,lm}\, sin(\theta + \chi_n \pm m\lambda)\right]}$

Procedure

reading the point grid by *lec_grille(_quart)_degre*

converting by *gpgm2*; point grid C → mean grid C

converting by *analhs*; mean grid C → a_{lm},b_{lm} harmonics

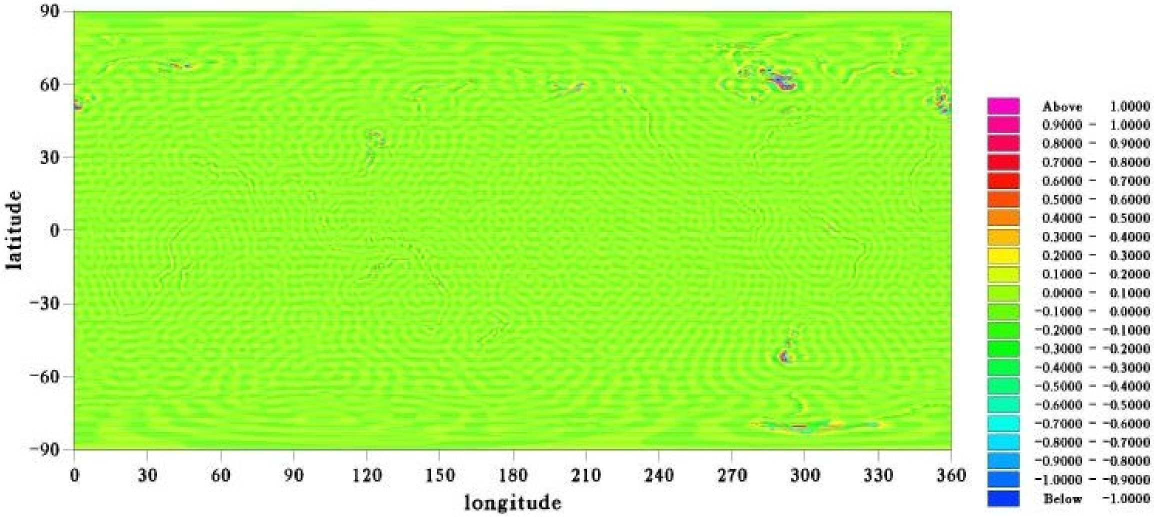
converting by *gpgm2*; point grid S → mean grid S

converting by *analhs*; mean grid S → c_{lm},d_{lm} harmonics

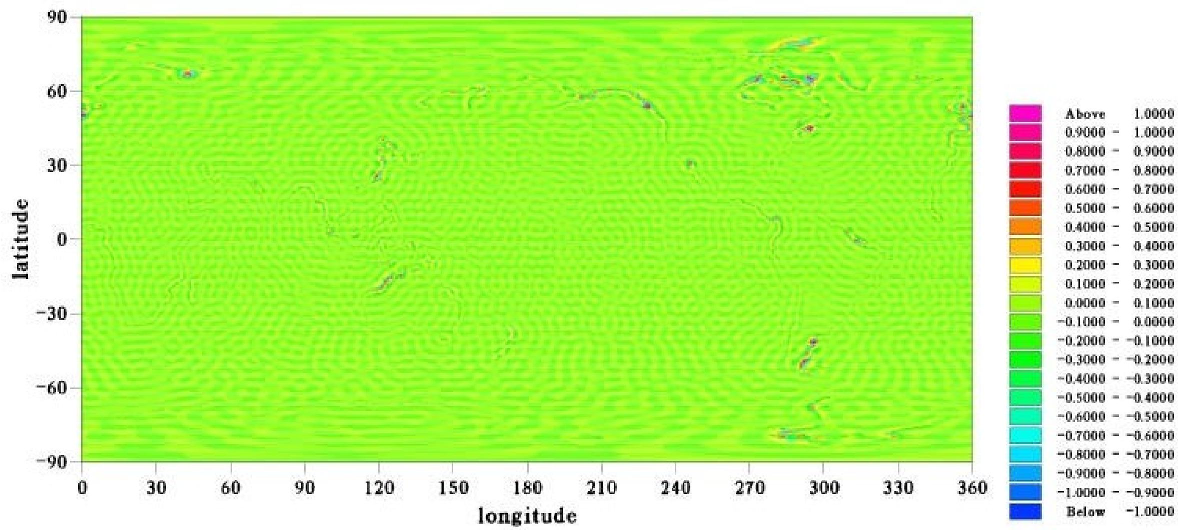
converting by *convers_hs*; $(a_{lm},d_{lm})/(b_{lm},c_{lm})$ harmonics → $C_{lm}^{\pm}$ / $S_{lm}^{\pm}$ ocean tides harmonics

applying by *cor_ellips* the ellipsoidal correction

M2 - FES2004 model
h * cos(phase) in metre
discrepancies
(rms : 0.0537 / moy : 0.0000 / min : -2.4076 / max : 2.8301)



M2 - FES2004 model
h * sin(phase) in metre
discrepancies
(rms : 0.0555 / moy : 0.0000 / min : -3.3586 / max : 1.8381)



FES2004

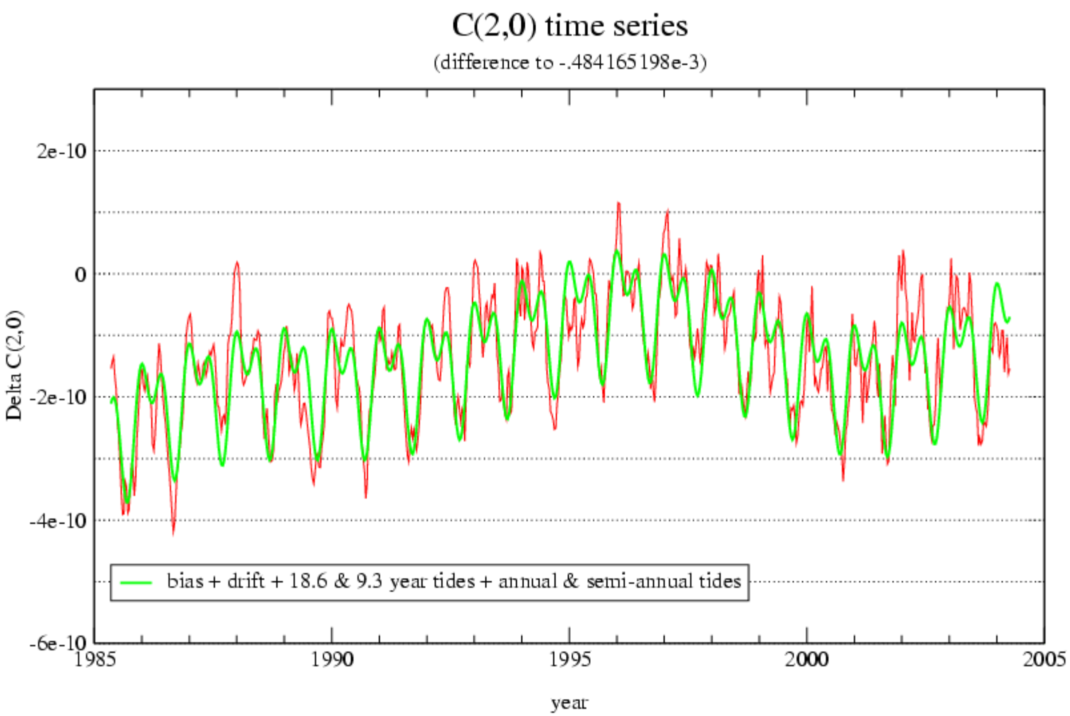
Ocean tide model: FES2004 normalized model (fev. 2004) up to (100,100) in cm
(long period from FES2002 up to (50,50) + equilibrium Om1/Om2, atmospheric tide NOT included)

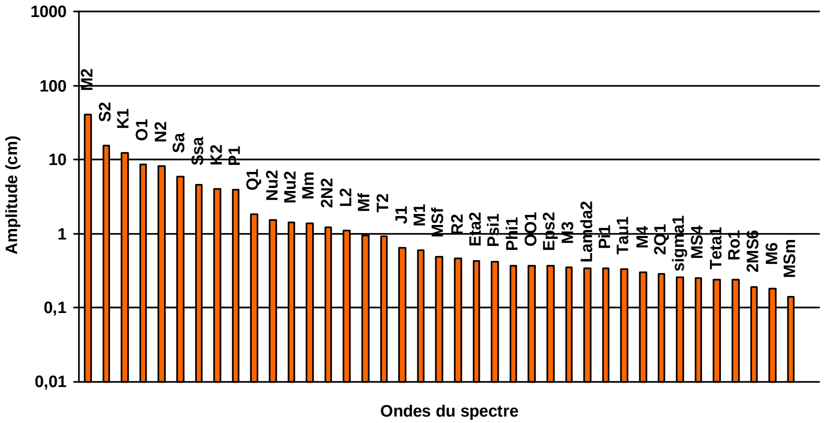
Doodson		l	m	Csin+	Ccos+	Csin-	Ccos-	C+	eps+	C-	eps-
55.565	Om1	2	0	-0.540594	0.000000	0.000000	0.000000	0.5406	270.000	0.0000	0.000
55.575	Om2	2	0	-0.005218	0.000000	0.000000	0.000000	0.0052	270.000	0.0000	0.000
56.554	Sa	2	0	-0.046604	-0.000903	0.000000	0.000000	0.0466	268.890	0.0000	0.000
57.555	Ssa	2	0	-0.296385	-0.010794	0.000000	0.000000	0.2966	267.914	0.0000	0.000
65.455	Mm	2	0	-0.479140	-0.084083	0.000000	0.000000	0.4865	260.047	0.0000	0.000
75.555	Mf	2	0	-0.805539	-0.236132	0.000000	0.000000	0.8394	253.662	0.0000	0.000
85.455	Mtm	2	0	-0.139082	-0.049418	0.000000	0.000000	0.1476	250.439	0.0000	0.000
93.555	Msq	2	0	-0.019391	-0.006674	0.000000	0.000000	0.0205	251.008	0.0000	0.000
135.655	Q1	2	1	-0.291290	0.308134	0.049563	-0.203915	0.4240	316.610	0.2099	166.339
145.555	O1	2	1	-1.480706	1.383072	0.455121	-0.792480	2.0262	313.047	0.9139	150.131
163.555	P1	2	1	-0.505544	0.551083	0.279251	-0.259244	0.7478	317.468	0.3810	132.872
165.555	K1	2	1	-1.530097	1.660923	0.845110	-0.785011	2.2583	317.348	1.1535	132.889
235.755	2N2	2	2	-0.044241	0.134832	0.020987	-0.001671	0.1419	341.834	0.0211	94.552
245.655	N2	2	2	-0.577967	0.958489	0.162389	0.009450	1.1193	328.910	0.1627	86.670
255.555	M2	2	2	-3.233275	3.840723	0.786314	0.430793	5.0205	319.908	0.8966	61.283
273.555	S2	2	2	-1.288610	1.293664	0.040901	0.419782	1.8259	315.112	0.4218	5.565
275.555	K2	2	2	-0.337696	0.358821	-0.000662	0.114679	0.4927	316.737	0.1147	359.669
455.555	M4	4	4	-0.000551	-0.003144	0.001155	-0.002202	0.0032	189.949	0.0025	152.313

LAGEOS ocean tides fit over 19 y (normalized coefficients) :

				LAGEOS		FES-2004		difference	
doodson	darw	l	m	C^+(cm)	ε^+(deg)	C^+(cm)	ε^+(deg)	ΔC^+(%)	$\Delta\varepsilon^+$(%)
55.565	**Ω_1**	**2**	**0**	**0.4387**	**223.72**	**0.5406**	**270.00**	**19.**	**26.**
55.575	Ω_2	2	0	0.3206	125.05	0.0052	270.00	6044.	80.
56.554	Sa	2	0	0.5800	26.61	0.0466	268.89	1144.	65.
57.555	Ssa	2	0	0.7390	277.17	0.2966	267.91	149.	5.

Ω_2, Sa and Ssa results are not to be considered in terms of tides but more probably in terms of mass displacement





Décomposition harmonique du spectre de marée (pour la base de données pélagiques ST95)

Onde	Pourcentage d'importance
M_2	33,5%
S_2	12,6%
K_1	10,1%
O_1	7,0%
N_2	6,8%
K_2	3,3%
Q_1	1,5%
$2N_2$	1,0%
Total	75,9%

Pourcentage d'importance des principales ondes du spectre (source : thèse F. Lefèvre)

Nom de Darwin	Nombre de Doodson	Argument de Doodson	Coef. harm. α_i	Fréquence (°/h)	Fréquence (rad/s)	Période (jours)	Origine
M_0	055.555	-	0,50458	0		-	L
S_0	055.555	-	0,23411	0		-	S
S_a	056.554	$h - p_1$	0,01176	0,0410667	0,0000001991	365,2594	S
S_{sa}	057.555	$2h$	0,07287	0,0821373	0,0000003982	182,6211	S
S_{ta}	058.554	$3h - p_1$	0,00427	0,1232040	0,0000005973	121,7493	S
M_{sm}	063.655	$s - 2h + p$	0,01578	0,4715211	0,0000022860	31,8119	L
M_m	065.455	$s - p$	0,08254	0,5443747	0,0000026392	27,5546	L
M_{sf}	073.555	$2s - 2h$	0,01370	1,0158958	0,0000049252	14,7653	L
M_f	075.555	$2s$	0,15642	1,0980331	0,0000053234	13,6608	L
M_{stm}	083.655	$3s - 2h + p$	0,00569	1,5695548	0,0000076094	9,5569	L
M_{tm}	085.455	$3s - p$	0,02995	1,6424078	0,0000079626	9,1329	L
M_{sqm}	093.555	$4s - 2h$	0,00478	2,1139288	0,0000102486	7,0958	L
$2Q_1$	125.755	$\tau - 3s + 2p$	0,00955	12,8442862	0,0000622709	1,1678	S
σ_1	127.555	$\tau - 3s + 2h$	0,01153	12,9271398	0,0000626725	1,1603	L
Q_1	135.655	$\tau - 2s + p$	0,07216	13,3986609	0,0000649585	1,1195	S
ρ_1	137.455	$\tau - 2s + 2h + p$	0,01371	13,4715145	0,0000653117	1,1135	L
O_1	145.555	$\tau - s$	0,37689	13,9430356	0,0000675977	1,0758	L
τ_1	147.555	$\tau - s + 2h$	0,00491	14,0251729	0,0000679960	1,0695	
M_{11}	155.655	$\tau + p$	0,02964	14,4966939	0,0000702820	1,0347	L
M_{12}	155.655	$\tau + p$	0,01040	14,4874103	0,0000702369	1,0295	L
χ_1	157.455	$\tau + 2h - p$	0,00566	14,5695476	0,0000706352	1,0295	L
π_1	162.556	$\tau + s - 3h + p_1$	0,01029	14,9178647	0,0000723238	1,0055	S
P_1	163.555	$\tau + s - 2h$	0,17554	14,9589314	0,0000725229	1,0027	S
K_1^L	165.555	$\tau + s$	0,36233	15,0410686	0,0000729212	0,9973	L
K_1^S	165.555	$\tau + s$	0,16817	15,0410686	0,0000729212	0,9973	S
ψ_1	166.554	$\tau + s + h + p_1$	0,00423	15,0821353	0,0000731203	0,9946	S
φ_1	167.555	$\tau + s + 2h$	0,00756	15,1232059	0,0000733194	0,9919	S
θ_1	173.655	$\tau + 2s - 2h + p$	0,00566	15,5125897	0,0000752072	0,9670	L
J_1	175.455	$\tau + 2s - p$	0,02954	15,5854433	0,0000755604	0,9624	L
SO_1	183.455	$\tau + 3s - 2h$	0,00492	16,0569644	0,0000778464	0,9342	L
OO_1	185.655	$\tau + 3s + N'$	0,01623	16,1391017	0,0000782446	0,9294	L
ν_1	195.455	$\tau + 4s - p$	0,00311	16,6834764	0,0000808838	0,8991	L
ε_2	227.655	$2\tau - 2s + 2p + N'$	0,00671	27,3416964	0,0001325563	0,5486	L
$2N_2$	235.755	$2\tau - 2s + 2p$	0,02301	27,8953548	0,0001352405	0,5363	L
μ_2	237.555	$2\tau - 4s + 4h$	0,02777	27,9682084	0,0001355937	0,5363	L
N_2	245.655	$2\tau - s + p$	0,17387	28,4397295	0,0001378797	0,5274	L
ν_2	247.455	$2\tau - s + 2h - p$	0,03303	28,512583	0,0001382329	0,5261	L
M_2	255.555	2τ	0,90812	28,9841042	0,0001405189	0,5175	L
λ_2	263.655	$2\tau - s - 2h + p$	0,00670	29,4556253	0,0001428049	0,5092	L
L_2	265.455	$2\tau + s - p$	0,02567	29,5284700	0,0001431580	0,5078	L
T_2	272.556	$2\tau + 2s - 3h + p_1$	0,02479	29,5589333	0,0001433058	0,5075	S
S_2	273.555	$2\tau + 2s - 2h$	0,42286	30,0000000	0,0001454441	0,5000	S
R_2	274.554	$2\tau + 2s - h - p_1$	0,00354	30,0410667	0,0001456432	0,4993	S
K_2^S	275.555	$2\tau + 2s$	0,03648	30,0821373	0,0001458423	0,4986	S
K_2^L	275.555	$2\tau + 2s$	0,07858	30,0821373	0,0001458423	0,4986	L

Principales composantes extraites du développement de Doodson (source : thèse F. Lefèvre)

Admittance function

The **admittance function** is defined for each wave as the **ratio between the potential generating tides and the ocean response** :

$$G_n(\varphi,\lambda)=\frac{\xi_n(\varphi,\lambda,t)}{U_n(\varphi,\lambda,t)} \quad \text{with} \quad U_n = gH_n Y_2^{n_1}(\varphi,\lambda)\begin{bmatrix} 1 \\ -i \end{bmatrix}_{n_1 odd}^{n_1 even} e^{i\theta_n}$$

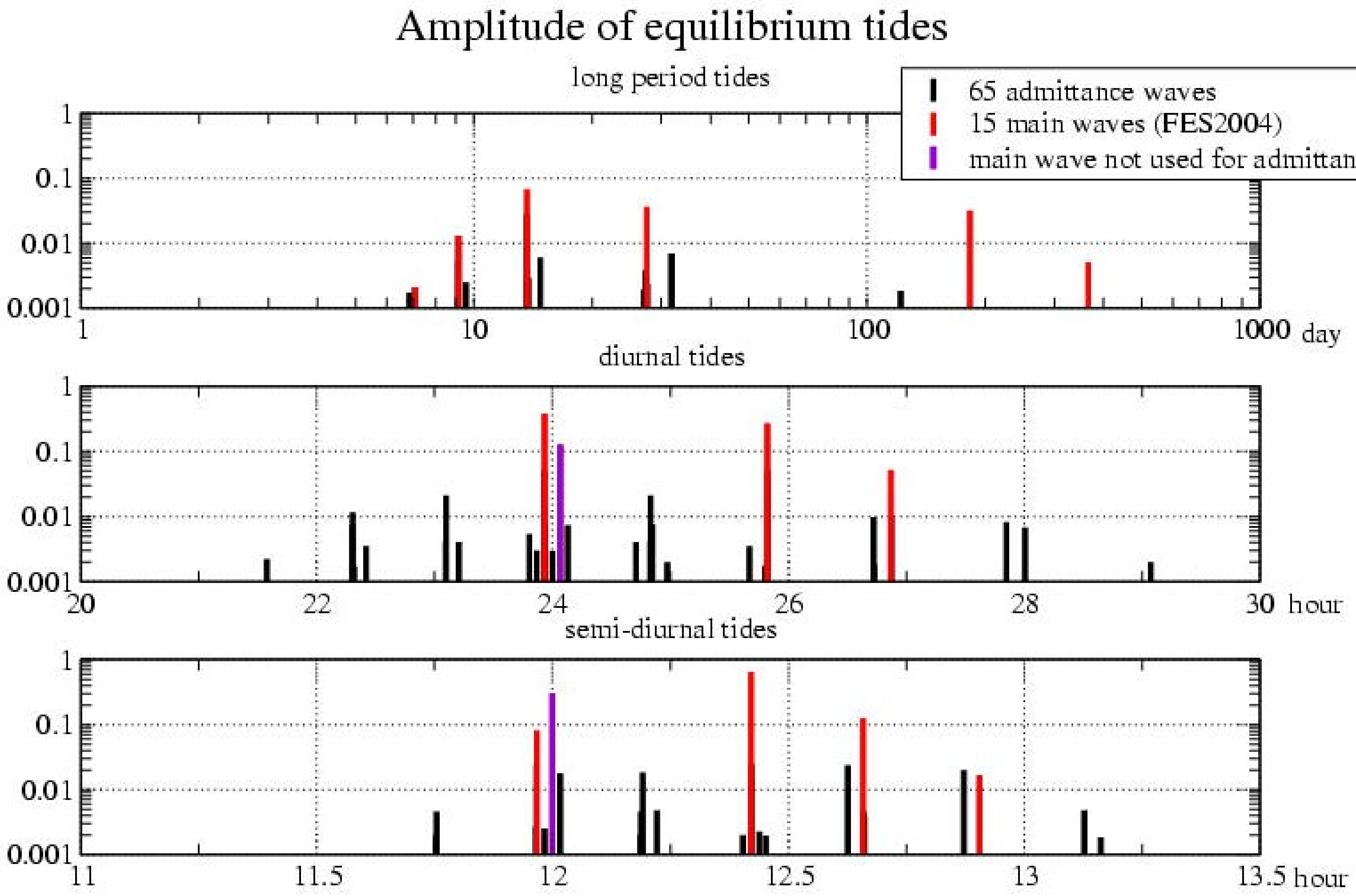
The behavior of the admittance function is smooth in frequency so that it can be interpolated linearly between 2 main waves of close frequencies $(\dot\theta_1 \text{ and } \dot\theta_2)$:

$$G(\dot\theta_n)=\frac{\dot\theta_n-\dot\theta_1}{\dot\theta_2-\dot\theta_1}G(\dot\theta_2)-\frac{\dot\theta_n-\dot\theta_2}{\dot\theta_2-\dot\theta_1}G(\dot\theta_1) \quad \text{with} \quad G(\dot\theta_1)=\frac{\xi_1}{U_1} \quad , \quad G(\dot\theta_2)=\frac{\xi_2}{U_2}$$

$$\xi_n = G(\dot\theta_n)U_n = \frac{\dot\theta_n-\dot\theta_1}{\dot\theta_2-\dot\theta_1}\frac{U_n}{U_2}\xi_2-\frac{\dot\theta_n-\dot\theta_2}{\dot\theta_2-\dot\theta_1}\frac{U_n}{U_1}\xi_1$$

O. Colombo, thesis of S Casotto, (1989)

$$\boxed{\begin{aligned}\xi_n = \frac{\dot\theta_n-\dot\theta_1}{\dot\theta_2-\dot\theta_1}\cdot\frac{H_n}{H_2}\Big\{ & cos(\theta_n-\theta_2)\sum_{\ell,m}P_{lm}(sin\,\varphi)\sum_{+}^{-}\left[C_{\ell m}^{\pm}cos(\theta_2+\chi_2\pm m\lambda)+S_{\ell m}^{\pm}sin(\theta_2+\chi_2\pm m\lambda)\right] \\ & + sin(\theta_n-\theta_2)\sum_{\ell,m}P_{lm}(sin\,\varphi)\sum_{+}^{-}\left[S_{\ell m}^{\pm}cos(\theta_2+\chi_2\pm m\lambda)-C_{\ell m}^{\pm}sin(\theta_2+\chi_2\pm m\lambda)\right]\Big\} \\ + \frac{\dot\theta_2-\dot\theta_n}{\dot\theta_2-\dot\theta_1}\cdot\frac{H_n}{H_1}\Big\{ & cos(\theta_n-\theta_1)\sum_{\ell,m}P_{lm}(sin\,\varphi)\sum_{+}^{-}\left[C_{\ell m}^{\pm}cos(\theta_1+\chi_1\pm m\lambda)+S_{\ell m}^{\pm}sin(\theta_1+\chi_1\pm m\lambda)\right] \\ & + sin(\theta_n-\theta_1)\sum_{\ell,m}P_{lm}(sin\,\varphi)\sum_{+}^{-}\left[S_{\ell m}^{\pm}cos(\theta_1+\chi_1\pm m\lambda)-C_{\ell m}^{\pm}sin(\theta_1+\chi_1\pm m\lambda)\right]\Big\}\end{aligned}}$$



Amplitude of equilibrium tides
long period tides
65 admittance waves
15 main waves (FES2004)
main wave not used for admittance
1
0.1
0.01
0.001
1
10
100
1000
day
diurnal tides
20
22
24
26
28
30
hour
semi-diurnal tides
11
11.5
12
12.5
13
13.5
hour

Comparison of CHAMP orbits over 10 days
with the one computed with P1 from FES2004

Orbit differences (mm)	3D	Radial	Normal	Tangential
without P1	144	10	247	36
P1 with admittance	3	1	4	2
admittance (65 waves)	90	16	74	135

ELLIPSOIDAL CORRECTIONS TO SPHERICAL HARMONICS OF SURFACE PHENOMENA GRAVITATIONAL EFFECTS

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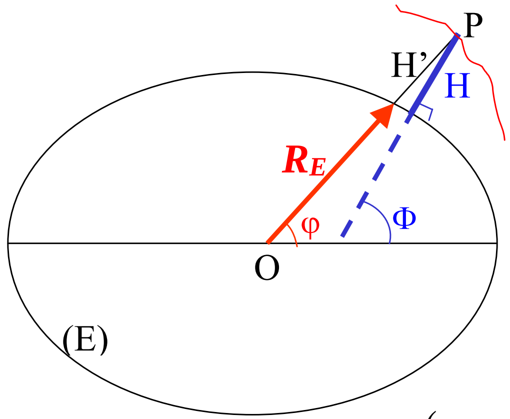

$$H' = H\left(1+\eta^2/2\right) \quad \text{with} \quad \eta = \Phi - \varphi$$

$$\Phi - \varphi = e^2\left(1-\frac{H}{R_0}\right)\sin\Phi\cos\Phi + e^4\left[1-\frac{3}{2}\frac{H}{R_0}+\left(\frac{H}{R_0}\right)^2\right]\sin^3\Phi\cos\Phi$$

$$R_E(\varphi') = R_0(1-\varepsilon_2\sin^2\varphi'+\varepsilon_4\sin^4\varphi'+\ldots)$$

$$(2-\delta_{om})\overline{K}_{lm} = \overline{C}_{lm} - i\,\overline{S}_{lm}$$

$$\delta\overline{K}_{lm} = \alpha_{lm}\rho\iint_{\sigma_1}\left\{\int_{R_E(\varphi')}^{r(\varphi',\lambda')} r'^{\,l+2}dr'\right\}\overline{Y}^*_{lm}(\varphi',\lambda')d\sigma' \quad \text{with} \quad \alpha_{lm} = \left[(2-\delta_{0m})(2l+1)MR^l\right]^{-1}$$

with $r' = R_E(\varphi') + H'(\varphi',\lambda')$ and $R_E(\varphi') = R_0(1-\varepsilon_2\sin^2\varphi'+\varepsilon_4\sin^4\varphi'+\ldots)$

$$\left\{r'^{\,l+3}/(l+3)\right\}_{R_E}^{r'} = R_E^{\,l+3}(\varphi')\{1+[H'/R_E(\varphi')]$$
$$+(l+2)/2\,[H'/R_E(\varphi')]^2+\ldots - R_E^{\,l+3}(\varphi')\}$$

$$\delta^1\overline{K}_{lm} = \alpha_{lm}\rho\iint_{\sigma_1}\left[R_o^{\,l+2}\left(1-\varepsilon_2\sin^2\varphi'+\varepsilon_4\sin^4\varphi'\right)^{l+2}\sum_{n,k}\overline{h}_{nk}\overline{Y}_{nk}(\varphi',\lambda')\right].\,\overline{Y}^*_{lm}(\varphi',\lambda')d\sigma'$$

$$\boxed{\delta^1\overline{K}^1_{lm} = -\beta_l(l+2)\varepsilon_2\left[a_{l-2,m}\frac{\overline{h}_{l-2,m}}{R_o}+b_{lm}\frac{\overline{h}_{lm}}{R_0}+\overline{c}_{l+2,m}\frac{\overline{h}_{l+2,m}}{R_0}\right]}$$

Ellipsoidal correction

Model 1: Ocean tide model: **FES2004** normalized model (in cm)
Model 2: Ocean tide model: **FES2004** normalized model **with ellipsoidal correction** (in cm)

				model 1		**model 2**		**2 - 1**			
doodson	darw	l	m	c+(cm)	eps+(deg)	c+(cm)	eps+(deg.)	difference		/ relative(%)	
255.555	M2	1	0	0.5888	40.8014	0.5885	39.9910	-0.0003	-0.8104	0.0	-0.5
255.555	M2	2	0	1.2812	180.4369	1.2766	180.0110	-0.0046	-0.4259	-0.4	-0.2
255.555	M2	3	0	1.4460	152.1206	1.4422	152.1420	-0.0038	0.0214	-0.3	0.0
255.555	M2	4	0	1.6966	295.4730	1.6952	295.3580	-0.0014	-0.1150	-0.1	-0.1
255.555	M2	5	0	1.2362	328.6181	1.2222	328.0520	-0.0140	-0.5661	-1.1	-0.3
255.555	M2	1	1	0.3929	140.8622	0.3979	141.2420	0.0050	0.3798	1.3	0.2
255.555	M2	2	1	1.0510	250.4822	1.0551	250.0190	0.0041	-0.4632	0.4	-0.3
255.555	M2	3	1	1.2578	345.4651	1.2555	346.4350	-0.0023	0.9699	-0.2	0.5
255.555	M2	4	1	2.3442	30.4333	2.3297	30.3530	-0.0145	-0.0803	-0.6	0.0
255.555	M2	5	1	3.5506	237.7274	3.5192	237.7810	-0.0314	0.0536	-0.9	0.0
255.555	**M2**	**2**	**2**	**5.0115**	**319.9495**	**5.0205**	**319.9080**	**0.0090**	**-0.0415**	**0.2**	**0.0**
255.555	M2	3	2	0.8508	171.8101	0.8549	172.0060	0.0041	0.1959	0.5	0.1
255.555	M2	4	2	4.7345	128.8852	4.7241	129.0010	-0.0104	0.1158	-0.2	0.1
255.555	M2	5	2	1.7639	9.9130	1.7569	9.9690	-0.0070	0.0560	-0.4	0.0
255.555	M2	3	3	3.2388	36.5296	3.2347	36.7060	-0.0041	0.1764	-0.1	0.1
255.555	M2	4	3	3.7611	178.5463	3.7461	178.4950	-0.0150	-0.0513	-0.4	0.0
255.555	M2	5	3	2.8611	295.8639	2.8309	295.7940	-0.0302	-0.0699	-1.1	0.0
255.555	M2	4	4	3.7494	302.6906	3.7439	302.6140	-0.0055	-0.0766	-0.1	0.0
255.555	M2	5	4	4.0702	49.1312	4.0430	49.1210	-0.0272	-0.0102	-0.7	0.0
255.555	M2	5	5	0.8065	70.9801	0.8011	70.6670	-0.0054	-0.3131	-0.7	-0.2

GRGS-GRACE tide model

Model 1 : Ocean tide model: **FES2004** normalized model (fev. 2004) up to (100,100) in cm
(long period from FES2002 up to (50,50) + equilibrium Om1/Om2, atmospheric tide

Model 2 : OCEAN TIDES – from **GRACE** solution

			model 1		model 2		2 - 1			
doodson	l	m	c+(cm)	eps+(deg)	c+(cm)	eps+(deg.)	difference		/ relative(%)	
135.655 Q1	2	1	0.4240	316.6096	0.4603	313.7090	0.0363	-2.9006	8.6	-1.6
145.555 O1	2	1	2.0262	313.0474	1.9586	315.2550	-0.0676	2.2076	-3.3	1.2
163.555 P1	2	1	0.7478	317.4678	0.6771	316.2990	-0.0707	-1.1688	-9.5	-0.6
165.555 K1	2	1	2.2583	317.3477	2.4783	323.8800	0.2200	6.5323	9.7	3.6
235.755 2N2	2	2	0.1419	341.8343	0.1484	338.2020	0.0065	-3.6323	4.6	-2.0
245.655 N2	2	2	1.1193	328.9101	1.1100	330.6140	-0.0093	1.7039	-0.8	0.9
255.555 M2	2	2	5.0205	319.9080	4.8235	321.1620	-0.1970	1.2540	-3.9	0.7
273.555 S2	2	2	1.8259	315.1121	1.8941	309.9170	0.0682	-5.1951	3.7	-2.9
275.555 K2	2	2	0.4927	316.7372	0.2573	311.0220	-0.2354	-5.7152	-47.8	-3.2

Mean Annual and Seasonal Atmospheric Tide Models based on 3-hourly and 6-hourly ECMWF Surface Pressure Data

In Memory of Peter Schwintzer †

Richard Biancale

Groupe de Recherches de Géodésie Spatiale (GRGS), CNES Toulouse, France
Sabbatical at GeoForschungsZentrum Potsdam (GFZ)
September 2001 – December 2002

and

Albert Bode

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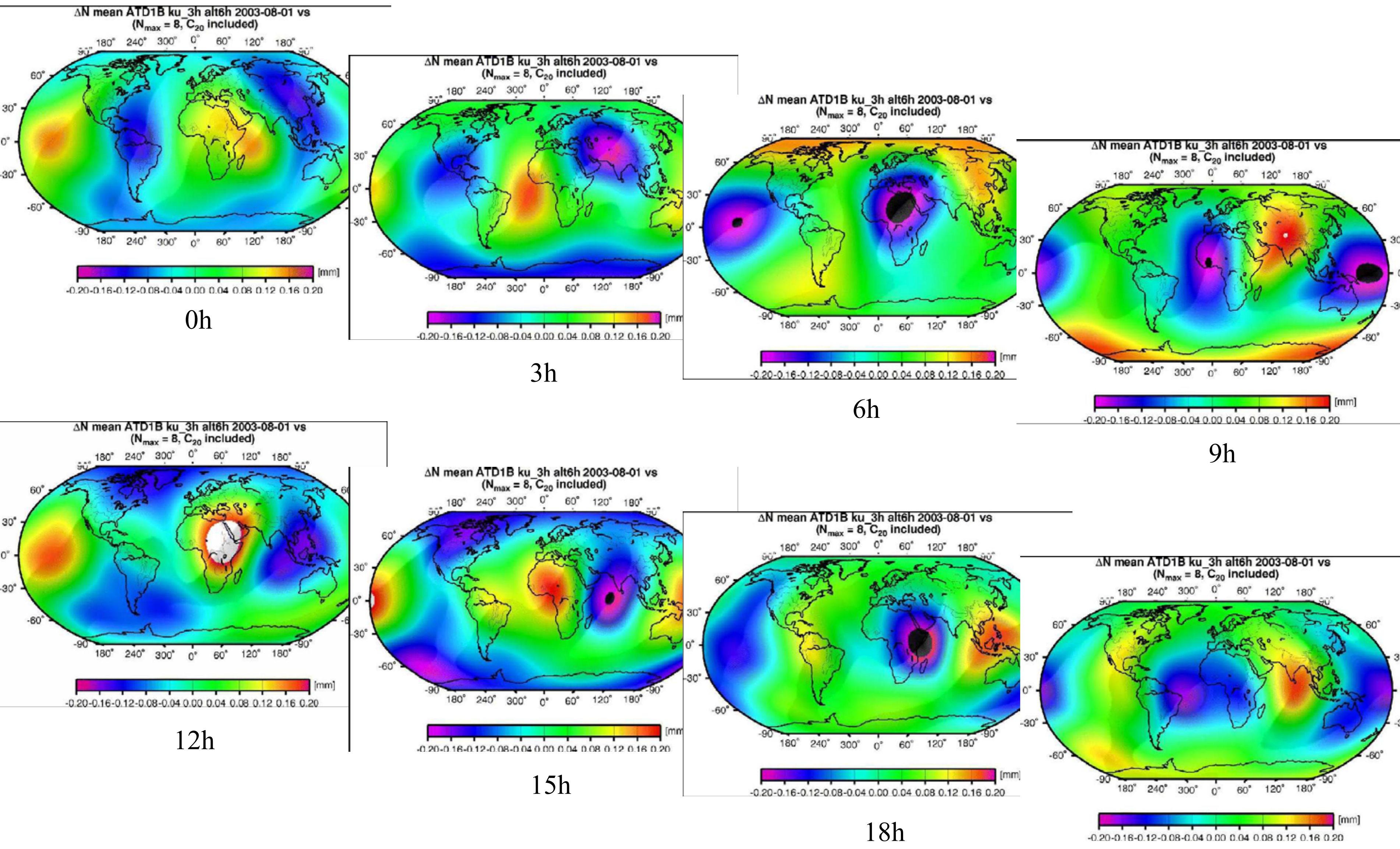
(retired since May 1, 2002)

Temporal evolution of the geoid differences derived from the mean atmospheric tide models

based on 6h ECMWF pressure field data (1985-2002) for August 2, each 3h.



S1

ECMWF derived atmospheric tides (Bode & Biancale,2003)
normalized model (in mbar)

Doodson	Darw	l	m	Csin+	Ccos+	C+	eps+
164.556	S1	0	0	-0.010427	0.004887	0.0115	295.112
164.556	S1	1	0	-0.011572	0.007151	0.0136	301.714
164.556	S1	2	0	-0.021999	-0.019367	0.0293	228.641
164.556	S1	3	0	-0.019447	-0.001090	0.0195	266.792
164.556	**S1**	**1**	**1**	**0.211548**	**0.063876**	**0.2210**	**73.199**
164.556	S1	2	1	0.011431	0.014826	0.0187	37.633
164.556	**S1**	**3**	**1**	**-0.125362**	**-0.011301**	**0.1259**	**264.849**
164.556	S1	4	1	0.006730	-0.015007	0.0164	155.846
164.556	S1	2	2	0.040451	0.052284	0.0661	37.728
164.556	S1	3	2	-0.000839	0.024861	0.0249	358.067
164.556	S1	4	2	-0.027001	-0.014535	0.0307	241.706
164.556	S1	5	2	0.001710	-0.002672	0.0032	147.382
164.556	S1	3	3	-0.016213	-0.011110	0.0197	235.579
164.556	S1	4	3	-0.028287	0.015258	0.0321	298.342
164.556	S1	5	3	-0.018513	-0.003835	0.0189	258.297
164.556	S1	6	3	-0.001229	-0.011130	0.0112	186.301
164.556	S1	4	4	-0.011813	0.026961	0.0294	336.339
164.556	S1	5	4	0.013651	-0.002437	0.0139	100.122
164.556	S1	6	4	0.005458	0.007862	0.0096	34.769
164.556	S1	7	4	-0.002848	0.010407	0.0108	344.695
164.556	S1	5	5	-0.019909	0.031089	0.0369	327.365
164.556	S1	6	5	0.034243	-0.001804	0.0343	93.016
164.556	S1	7	5	0.011923	0.001275	0.0120	83.896
164.556	S1	8	5	-0.006841	-0.000462	0.0069	266.136

S2

ECMWF derived atmospheric tides (Bode & Biancale,2003)
normalized model (in mbar)

Doodson	Darw	l	m	Csin+	Ccos+	C+	eps+
273.555	S2	0	0	-0.001267	0.004729	0.0049	345.001
273.555	S2	1	0	0.003017	-0.001218	0.0033	111.985
273.555	S2	2	0	0.046910	-0.110495	0.1200	156.997
273.555	S2	3	0	0.011240	0.003652	0.0118	72.000
273.555	S2	1	1	0.025133	-0.003030	0.0253	96.874
273.555	S2	2	1	0.011672	-0.022752	0.0256	152.842
273.555	S2	3	1	-0.019507	0.009509	0.0217	295.988
273.555	S2	4	1	-0.004188	0.001154	0.0043	285.406
273.555	**S2**	**2**	**2**	**0.283369**	**-0.468298**	**0.5474**	**148.822**
273.555	S2	3	2	0.009812	0.026639	0.0284	20.220
273.555	**S2**	**4**	**2**	**-0.036313**	**0.070506**	**0.0793**	**332.750**
273.555	S2	5	2	-0.004402	-0.002872	0.0053	236.878
273.555	S2	3	3	0.016795	0.005516	0.0177	71.818
273.555	S2	4	3	0.003813	-0.000086	0.0038	91.292
273.555	S2	5	3	-0.004878	0.006430	0.0081	322.815
273.555	S2	6	3	0.001879	0.001580	0.0025	49.940
273.555	S2	4	4	-0.015098	0.000828	0.0151	273.139
273.555	S2	5	4	0.002428	0.008129	0.0085	16.630
273.555	S2	6	4	-0.001503	0.000413	0.0016	285.365
273.555	S2	7	4	-0.004306	-0.001009	0.0044	256.812
273.555	S2	5	5	0.009324	-0.000794	0.0094	94.867
273.555	S2	6	5	0.000304	0.000524	0.0006	30.120
273.555	S2	7	5	0.003957	-0.000054	0.0040	90.782
273.555	S2	8	5	0.005283	0.001430	0.0055	74.854

Sa

ECMWF derived atmospheric tides (Bode & Biancale,2003)
normalized model (in mbar)

Doodson	Darw	l	m	Csin+	Ccos+	C+	eps+
56.554	Sa	0	0	-0.168856	-0.049683	0.1760	253.604
56.554	Sa	1	0	0.105071	-0.057879	0.1200	118.848
56.554	Sa	2	0	0.071952	0.653729	0.6577	6.281
56.554	Sa	3	0	-1.225490	-0.371665	1.2806	253.129
56.554	Sa	1	1	0.047282	0.220890	0.2259	12.082
56.554	Sa	2	1	0.306172	0.548859	0.6285	29.154
56.554	Sa	3	1	-0.042330	0.336106	0.3388	352.822
56.554	Sa	4	1	-0.112705	-0.170263	0.2042	213.502
56.554	Sa	2	2	-0.218981	0.158912	0.2706	305.968
56.554	Sa	3	2	-0.256851	-0.042370	0.2603	260.633
56.554	Sa	4	2	-0.264284	0.003188	0.2643	270.691
56.554	Sa	5	2	-0.197183	-0.006217	0.1973	268.194
56.554	Sa	3	3	0.133799	-0.031722	0.1375	103.338
56.554	Sa	4	3	0.096020	0.241783	0.2602	21.660
56.554	Sa	5	3	0.181815	0.111700	0.2134	58.435
56.554	Sa	6	3	0.017368	0.156099	0.1571	6.349
56.554	Sa	4	4	0.013902	-0.131590	0.1323	173.969
56.554	Sa	5	4	-0.103664	-0.034022	0.1091	251.830
56.554	Sa	6	4	0.061234	-0.034274	0.0702	119.237
56.554	Sa	7	4	-0.053530	0.014686	0.0555	285.342
56.554	Sa	5	5	-0.013892	-0.035348	0.0380	201.455
56.554	Sa	6	5	0.093559	-0.112805	0.1466	140.328
56.554	Sa	7	5	0.056152	-0.089431	0.1056	147.876
56.554	Sa	8	5	0.047282	-0.034263	0.0584	125.929

Ssa

ECMWF derived atmospheric tides (Bode & Biancale,2003)
normalized model (in mbar)

Doodson	Darw	l	m	Csin+	Ccos+	C+	eps+
57.555	Ssa	0	0	0.026418	-0.043967	0.0513	149.000
57.555	Ssa	1	0	0.213356	0.369254	0.4265	30.019
57.555	Ssa	2	0	-0.037297	0.093489	0.1007	338.251
57.555	Ssa	3	0	0.440373	0.198389	0.4830	65.748
57.555	Ssa	1	1	-0.187842	-0.054635	0.1956	253.783
57.555	Ssa	2	1	-0.100279	0.028146	0.1042	285.678
57.555	Ssa	3	1	0.022220	0.062821	0.0666	19.479
57.555	Ssa	4	1	0.025233	0.041395	0.0485	31.365
57.555	Ssa	2	2	-0.033028	0.012868	0.0354	291.286
57.555	Ssa	3	2	-0.071309	0.002881	0.0714	272.314
57.555	Ssa	4	2	0.028970	0.007771	0.0300	74.984
57.555	Ssa	5	2	-0.028689	-0.015389	0.0326	241.791
57.555	Ssa	3	3	-0.075016	-0.066689	0.1004	228.363
57.555	Ssa	4	3	0.007825	-0.056142	0.0567	172.065
57.555	Ssa	5	3	-0.111399	-0.068246	0.1306	238.507
57.555	Ssa	6	3	-0.022692	-0.077537	0.0808	196.313
57.555	Ssa	4	4	-0.003236	-0.013119	0.0135	193.856
57.555	Ssa	5	4	0.048517	-0.037387	0.0613	127.618
57.555	Ssa	6	4	-0.013902	0.014806	0.0203	316.804
57.555	Ssa	7	4	0.035921	0.013320	0.0383	69.655
57.555	Ssa	5	5	0.004073	-0.025976	0.0263	171.089
57.555	Ssa	6	5	0.000599	-0.026941	0.0269	178.726
57.555	Ssa	7	5	-0.037086	-0.009590	0.0383	255.502
57.555	Ssa	8	5	-0.028427	-0.007664	0.0294	254.912

Comparison to the Haurwitz and Cowley model

Model 1 : H & W atmospheric tides (Haurwitz & Cowley, 1973)
normalized model up to (8,5) (in mbar)

Model 2 : ECMWF derived atmospheric tides (Bode & Biancale, 2003)
normalized model up to (8,5) (in mbar)

			model 1		**model 2**		**2 - 1**			
doodson	l	m	c+(mb)	eps+(deg)	c+(mb)	eps+(deg.)	difference	/	relative(%)	
164.556 S1	**1**	**1**	**0.2885**	**12.0001**	**0.2210**	**73.1990**	**-0.0675**	**61.1989**	**-23.4**	**34.0**
164.556 S1	2	1	0.0365	330.9997	0.0187	37.6330	-0.0178	66.6333	-48.8	37.0
164.556 S1	**3**	**1**	**0.0860**	**197.0001**	**0.1259**	**264.8490**	**0.0399**	**67.8489**	**46.4**	**37.7**
273.555 S2	**2**	**2**	**0.5510**	**159.0000**	**0.5474**	**148.8220**	**-0.0036**	**-10.1780**	**-0.7**	**-5.7**
273.555 S2	3	2	0.0260	81.0007	0.0284	20.2200	0.0024	-60.7807	9.2	-33.8
273.555 S2	**4**	**2**	**0.0540**	**330.9995**	**0.0793**	**332.7500**	**0.0253**	**1.7505**	**46.9**	**1.0**