Case-study on minor tides – modeling, computation or estimation?

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Introduction

In general, global ocean tide models provide tabulated amplitudes and phases for a few most dominant tidal constituents only, e.g. M2, S2, N2, K2, and K1,O1,P1,Q1. The impact of minor tides are accounted for by applying admittance theory, assuming a smooth relationship between the tidal height and the amplitude of the tide generated potential within the same species (frequency band). The hydrodynamic finite-element tidal solution FES2012 (Carrére et al. 2012) provides – beside the major tides – quite a number of minor astronomical and compound tides in the diurnal, semi-diurnal and high frequency band. Satellite altimetry now completed more than two decades with precise monitoring the sea level by two or more contemporaneous missions allowing to estimate and resolve empirically those minor tides with amplitudes above the altimeter noise level.

Thus, there are three alternatives to derive minor tides: hydrodynamic modeling, the theory of admittance or empirical estimation. In this study a few shallow water areas are selected to compare some minor tides derived by the three different approaches. We will discuss the differences and address the question if and to what extent modeling and/or estimation contradicts the usual assumption of a linear or quadratic admittance function.

Motivation is twofold

- The minor tides provided by FES2012 partly differ significantly from the common approach of applying admittance theory e.g. to FES2004.
- Altimetry data records are long enough to estimate empirically some minor tides.

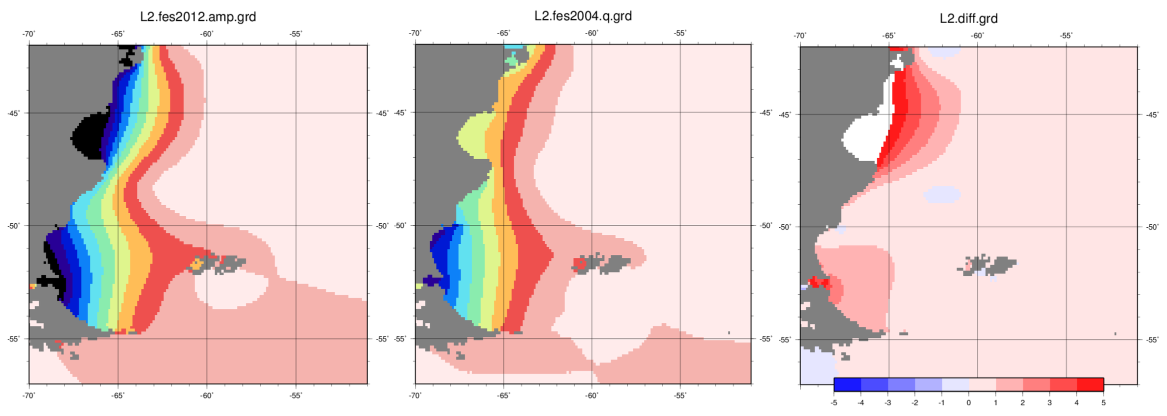


Fig. 1: Example of L2 tide @ Patagonia. Left: amplitude of FES2012. Middle: amplitudes derived by quadratic admittance of FES2004 major tides. Right: differences of both exceeding +5 cm (white area).

Strategy for the empirical tide analysis

The empirical estimate of minor tides (with small amplitudes) has to scope with a poor signal-to-noise ratio. An utmost robust estimate is based on following strategy

- For two test areas (Yellow Sea & Patagonia) we use only the concatenated data from the CNES/NASA missions Topex, Jason-1 and Jason2 on their common repeat ground track.
- Data is taken from the BIN structure of the OpenADB system (Schwatke et al. 2012)
- Tidal analysis is performed for small along-track cells (BINs) extended by about 6 km such that there is at least one observation per repeat cycle.
- The sea surface height data of OpenADB is fully corrected and already de-tided using FES2004 (Lyard et al. 2006) with admittances applied as realized in the FES prediction code. Outliers of the BIN time series are then removed by a 3-σ criteria.
- Along with the minor tides of interest (J1, M1, T2, L2, μ2, ν2) we estimate a local drift term and mission specific offsets to account for systematic biases.
- An iterative variance-component estimate is used to obtain objective relative weightings between the three missions.

Treatment of admittances – linear or quadratic?

The theory of admittance (Munk & Cartwright 1966) assumes that the relationship between tidal heights and the tide generating potential is a smooth, slowly varying function of frequency (within the same species). The 'credo of smoothness' may be realized either by linear or by quadratic interpolation coefficients.

Ray's perth3.f code realizes linear interpolation for all minor tides also suggested by the IERS conventions (Petit & Luzum 2010). Le Provost et al. (1991) and the FES prediction software apply a linear interpolation for minor diurnal tides and a quadratic (spline) interpolation to semi-diurnal tides. Other processing centers (e.g. GFZ) use exclusively quadratic interpolation.

diurnal species, linear

O1	K1	
0.038986	0.028192	M1
-0.038974	0.083605	J1
-0.043062	0.061235	OO1

diunal species, quadratic

Q1	O1	K1	
-0.138460	0.078636	0.018848	M1
0.410611	-0.156559	0.111316	J1
0.606619	-0.216778	0.102173	OO1

Semi-diurnal species, linea

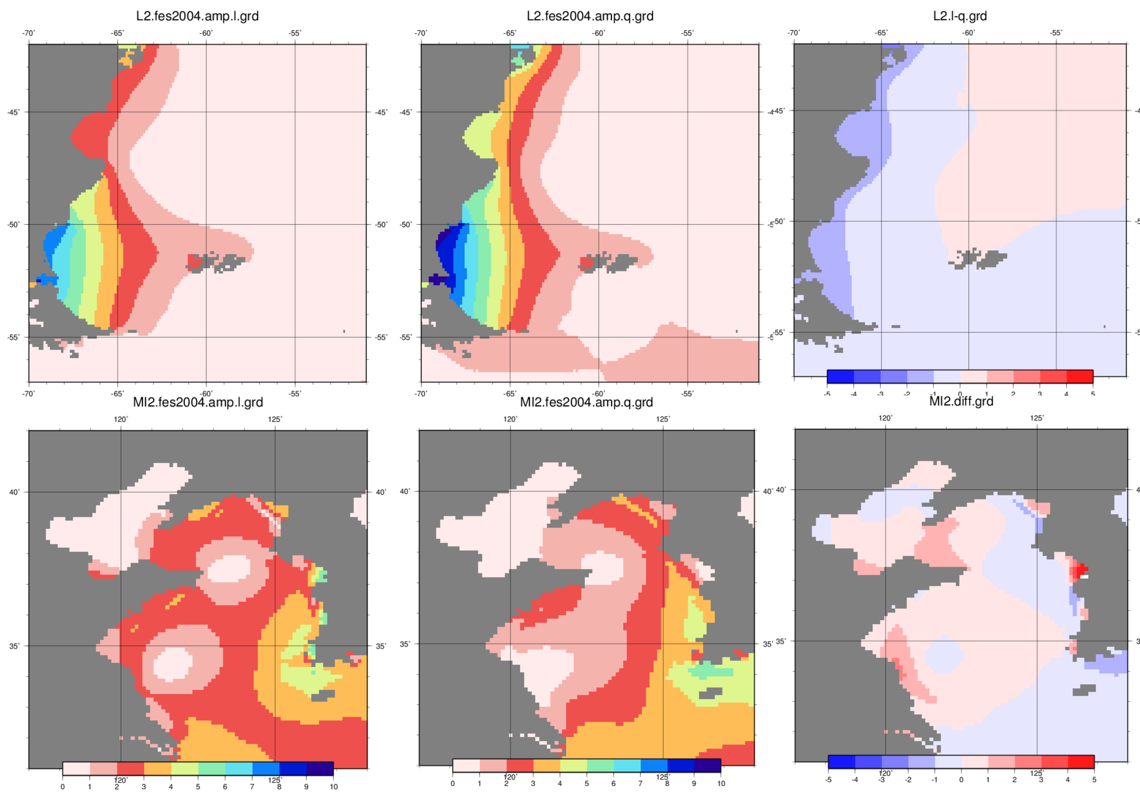
M2	N2	
0.004867	0.164533	NI2
-0.026476	0.297929	MI2
M2	**S2**	
0.013119	0.032556	L2
0.001099	0.056087	T2

Semi-diurnal species, quadratic

M2	N2	K2	
0.006958	0.157235	-0.005477	NI2
0.028504	-0.049766	0.073443	L2
0.008515	-0.019079	0.176551	T2
M2	**N2**	**2N2**	
-0.001772	0.039872	0.975051	MI2

Tab. 1: Coefficient for linear (left) and quadratic (right) interpolation for diurnal (top) and semi-diurnal species (bottom). Based on Cartwright, Tayler, Edden (CTE73)

Fig. 2: Comparison between linear and quadratic admittance for the minor tide L2 at the Patagonia Shelf (top row) and μ2 at Yellow Sea (bottom row). Linear admittance is shown left, quadratic admittance at center plots, differences between linear and quadratic admittance in the right column. Note, differences between linear and quadratic admittances can reach ± 2cm or more.



Comparing empirical estimates (on TP/J1/J2 ground tracks) w.r.t FES2004 admittance and w.r.t minor tides from FES2012

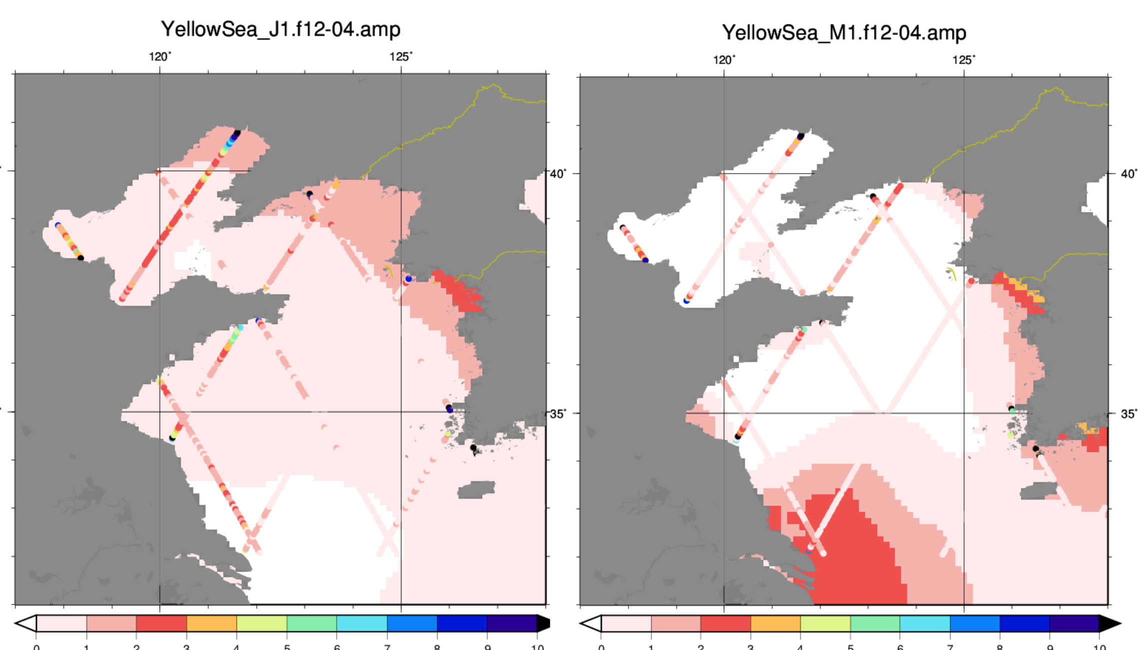


Fig. 3: Empirical amplitude (w.r.t FES2004 admittance) not significant except for J1 in the NW of Yellow Sea. In the West the empirical amplitude differs from FES2012 by some 1 – 2 cm.

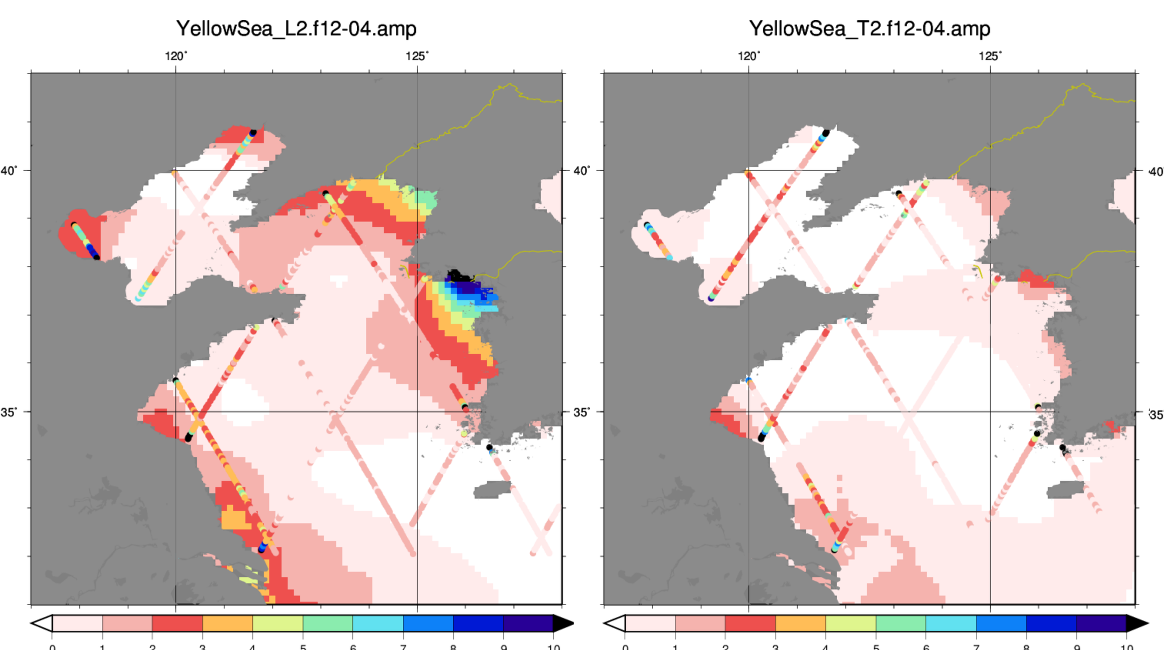


Fig.4: L2 (left): Empirical amplitudes (w.r.t FES2004 admittance) increasing towards the coast. Deviations to FES2012 in the order of 2 cm. T2 (right): In the NW of Yellow Sea there are empirical amplitudes up to 2 – 3 cm. Inconsistent with FES2012.

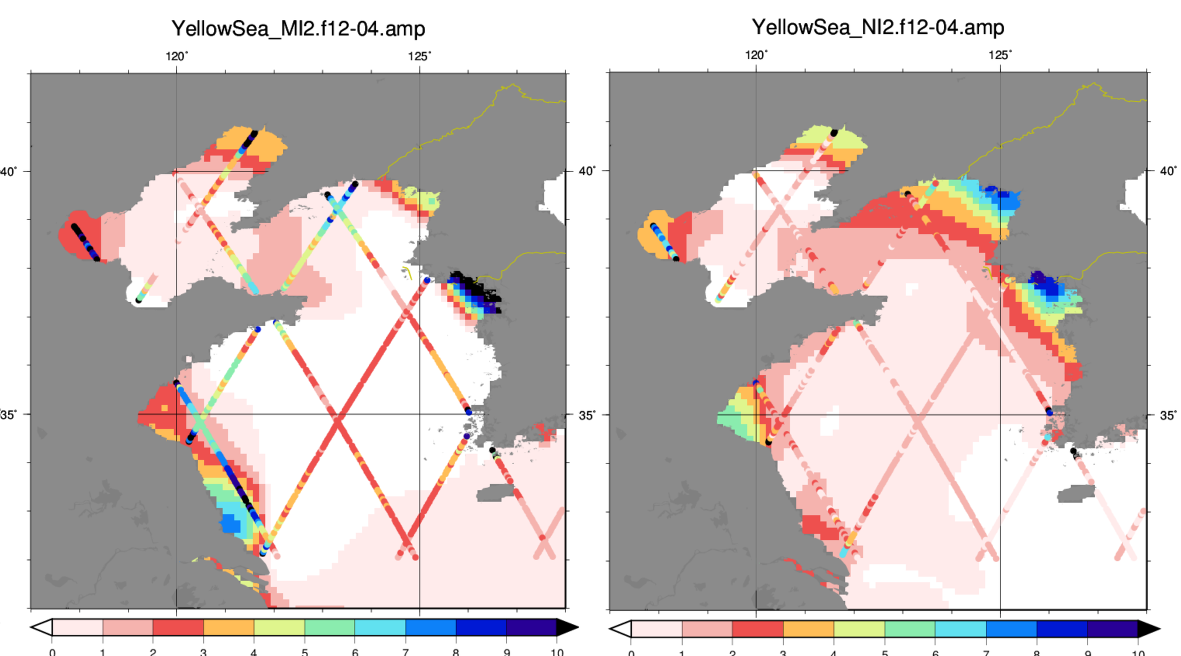


Fig.5: μ2(left): Large empirical amplitude (w.r.t FES2004 admittance) up to 8 cm. Inconsistent with FES2012. ν2(right):Empirical amplitudes between 2 cm (open ocean) and 5 cm (coast). Rather consistent with FES2012.

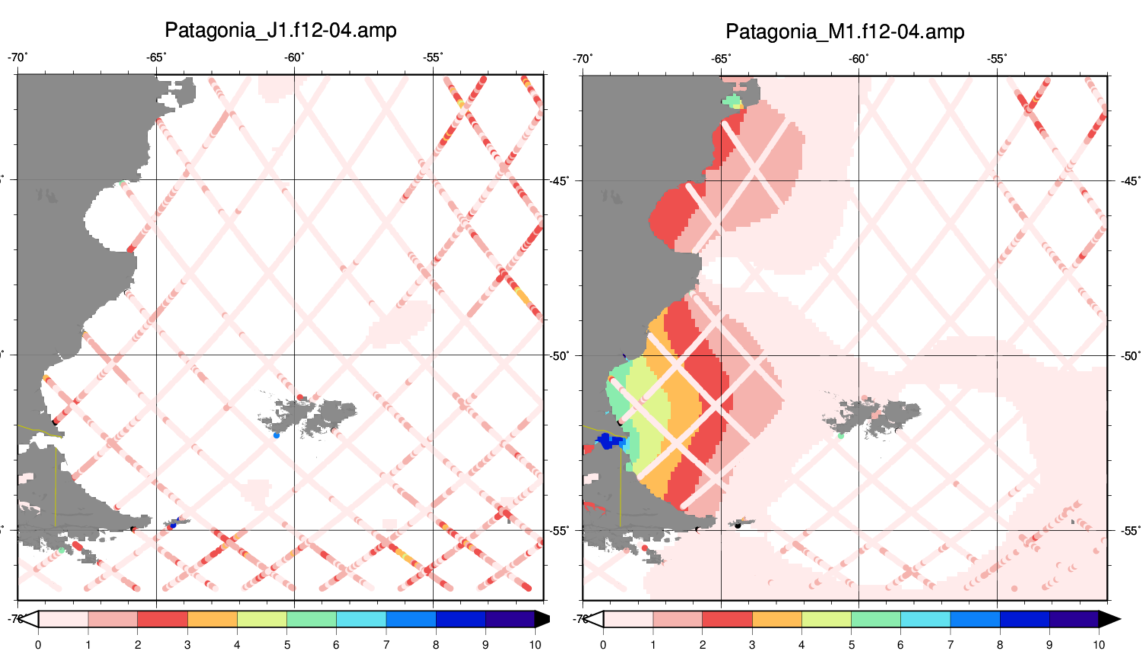


Fig. 6: J1(left): Empirical amplitude (w.r.t FES2004 admittance) in the order of 1 – 2 cm. Small differences to FES2012. M1(right): Small empirical amplitudes, significantly deviating from FES2012 at the Shelf.

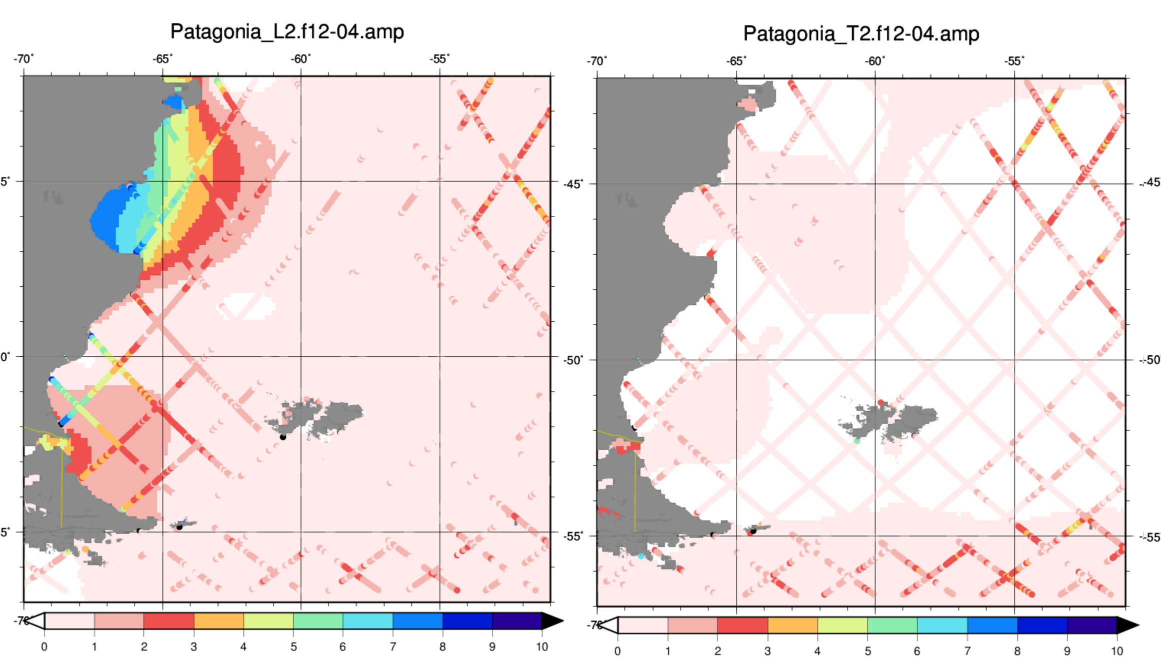


Fig.7: L2(left): empirical amplitudes (w.r.t FES2004 admittance) increasing towards the coast; up to 7 cm. Rather consistent with FES2012. T2(right):.

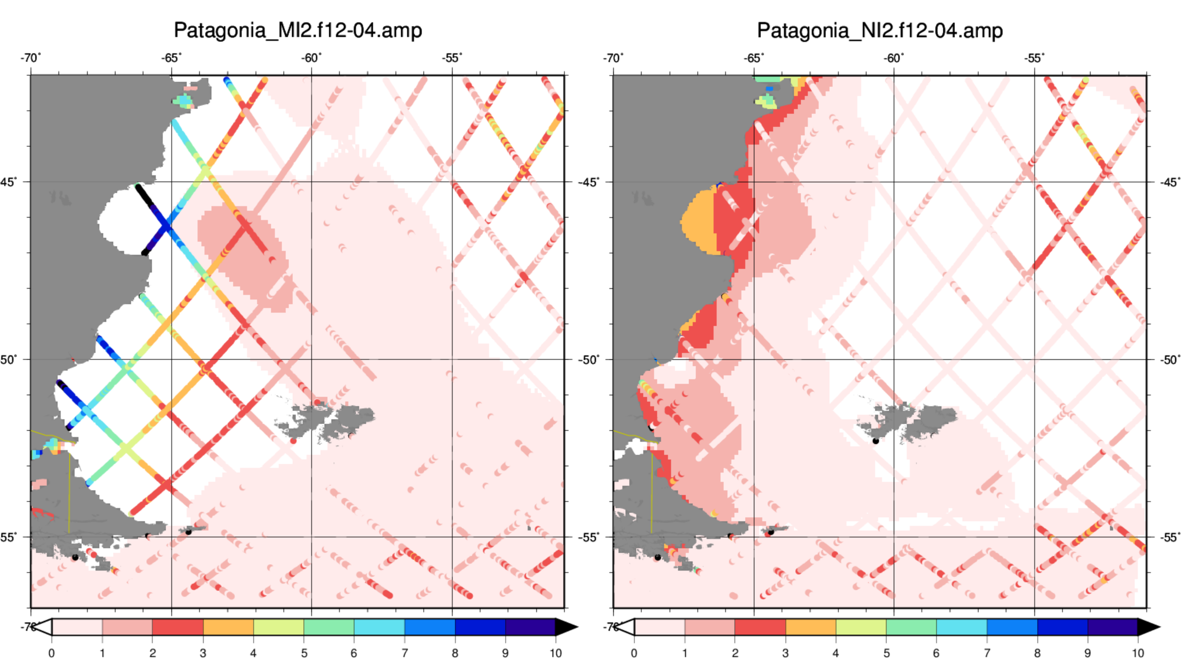


Fig.8: μ2 (left) Large empirical amplitude (w.r.t FES2004 admittance) in particular at the Shelf. Inconsistent also to FES2012. ν2(right): Small empirical amplitudes (w.r.t FES2004 admittance). Inconsistent with FES2012.

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Conclusions

- Empirical modeling of a few tides (μ2 and to a lesser extend L2) neither agree with FES2004 admittances nor with FES2012 hydrodynamic modeling.
- Some tides (J1, M1, and T2) show rather small residual amplitudes w.r.t FES2004 admittance. M1@Patagonia significantly disagrees to FES2012 (J1 & T2 to a lesser extend)
- Investigation were not completed! A validation with tide gauge constants were not (yet) included but is indispensible for a sound decision on wich approach performs best.

OSTST Meeting, 22-31 October 2014, Konstanz, Germany