Leibniz Institute for Baltic Sea Research Warnemünde

Increase of extreme sea levels due to non-linear tide-surge-sea-level interactions in shallow coastal lagoons

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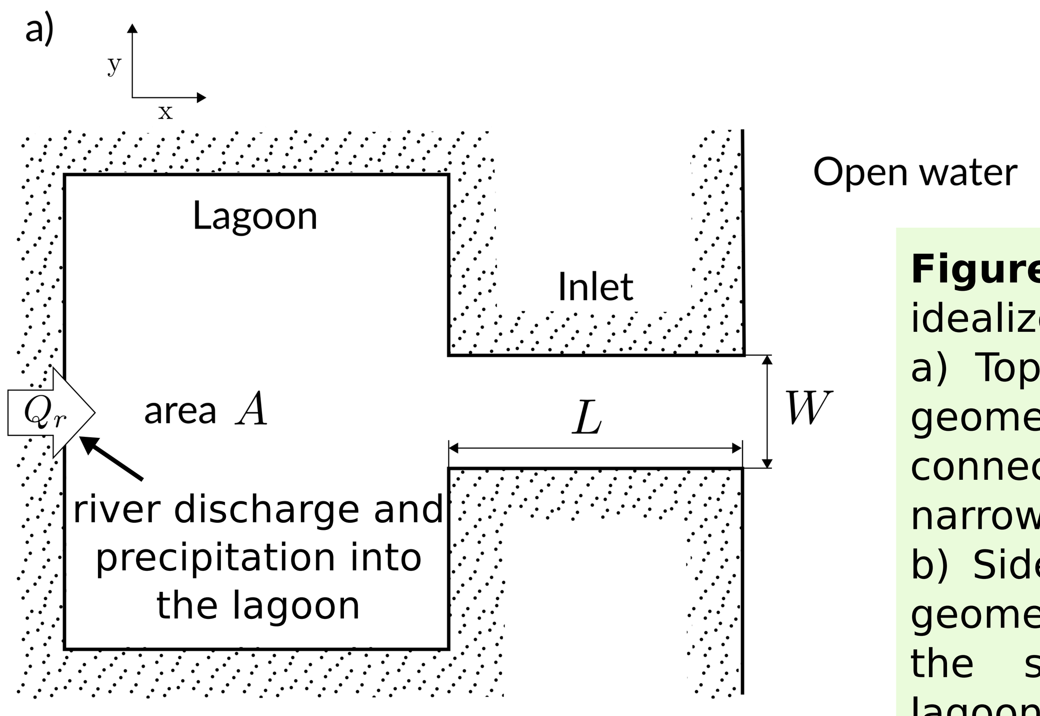
Approach: Studying many lagoons using a non-dim. parameter space with an idealized box model



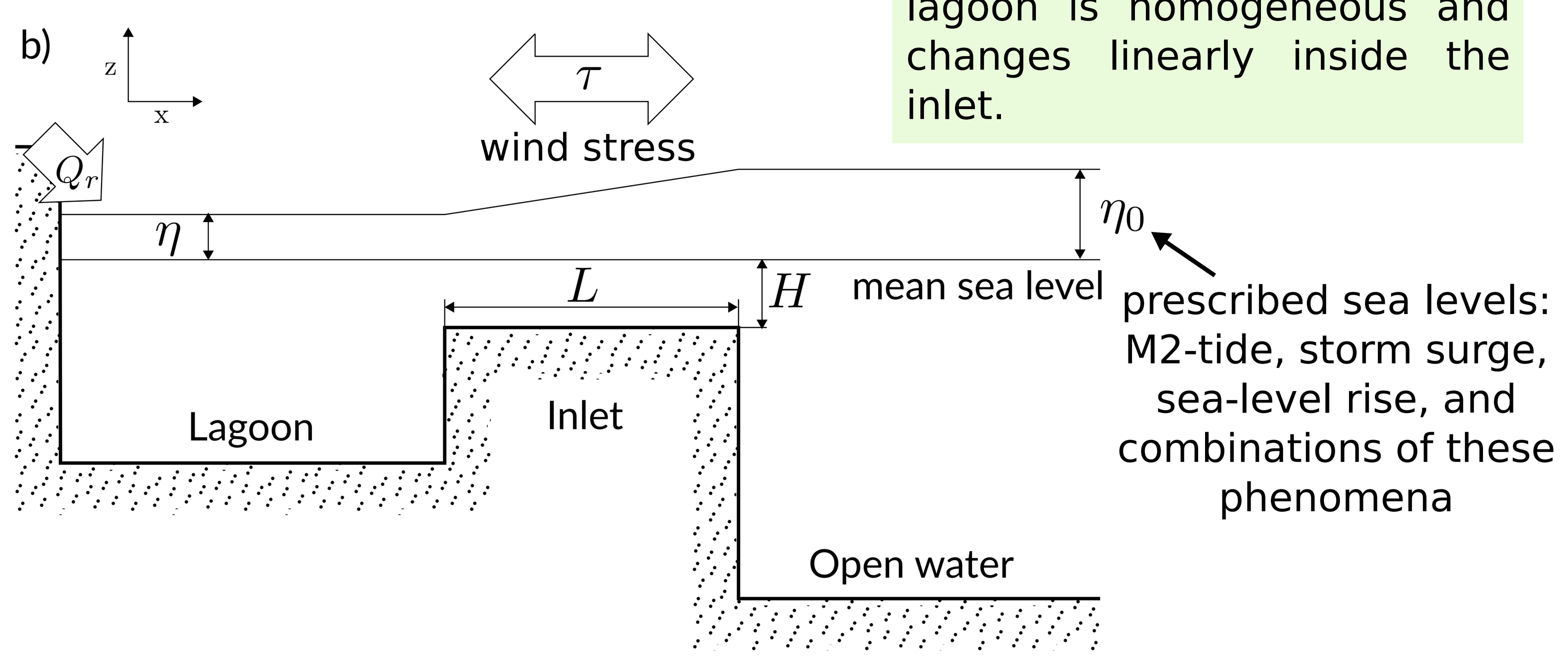


Figure 1: Sketch of the idealized lagoon model.
a) Top view of the idealized geometry. The lagoon is connected to the ocean by a narrow and shallow inlet.
b) Side view of the idealized geometry. It is assumed that the sea level inside the lagoon is homogeneous and changes linearly inside the inlet.

The box model (Stigebrandt, 1980; Hill, 1994) considers the balance between the forcing terms and the friction within the inlet for the **momentum** equation,

$$g\frac{\eta_0-\eta}{L} = -\frac{ku|u|}{D} + \frac{\tau}{\rho_0 D}, \qquad (1)$$

and the **continuity** equation inside the lagoon:

$$A\frac{d\eta}{dt} = -WDu + Q_r. \qquad (2)$$

Combining eqs. (1) and (2), the **evolution of the sea level inside the lagoon** can be calculated as a function of the open water sea level and the geometry of the system:

$$\frac{d\eta}{dt} = -\left(\left|\underbrace{\frac{gW^2D^3}{LkA^2}(\eta-\eta_0) + \frac{W^2D^2\tau}{\rho_0 kA^2}}_{X}\right|\right)^{1/2} \cdot \underset{\text{sign function}}{sgn(X)} + \frac{Q_r}{A}. \qquad (3)$$

For *no discharge and no wind*, eq. (3) can be made **dimensionless**,

$$\frac{d\tilde{\eta}}{d\tilde{t}} = P\left(1+\frac{a}{H}\frac{(\tilde{\eta}_0+\tilde{\eta})}{2}\right)^{3/2}\sqrt{\tilde{\eta}_0-\tilde{\eta}}\, sgn(\tilde{\eta}_0-\tilde{\eta}), \qquad (4)$$

where the non-dimensional parameters are the **ratio of the vertical length scale "a" to the water depth "H"**, and the **choking parameter**:

$$P = \left(\frac{gW^2T^2H^3}{A^2kLa}\right)^{1/2}. \qquad (5)$$

Preliminary results: attenuation inside lagoons

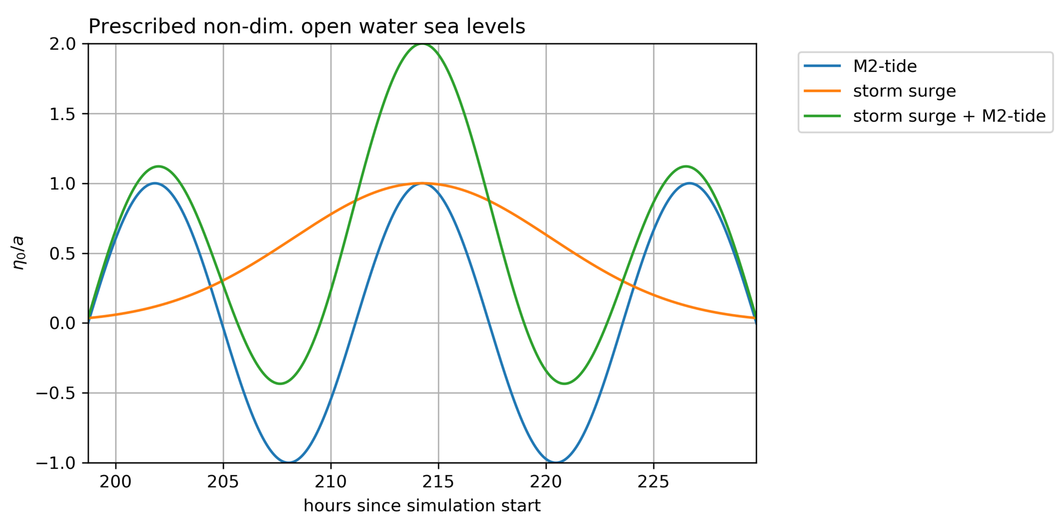


Figure 2: Prescribed open water sea levels used to explore the parameter space. For all simulations, the vertical length scale is a = 1.5m. Both the amplitude of the sinusoidal M2 tide and the height of a Gaussian shaped surge (width parameter 6h) are equal to this length scale.

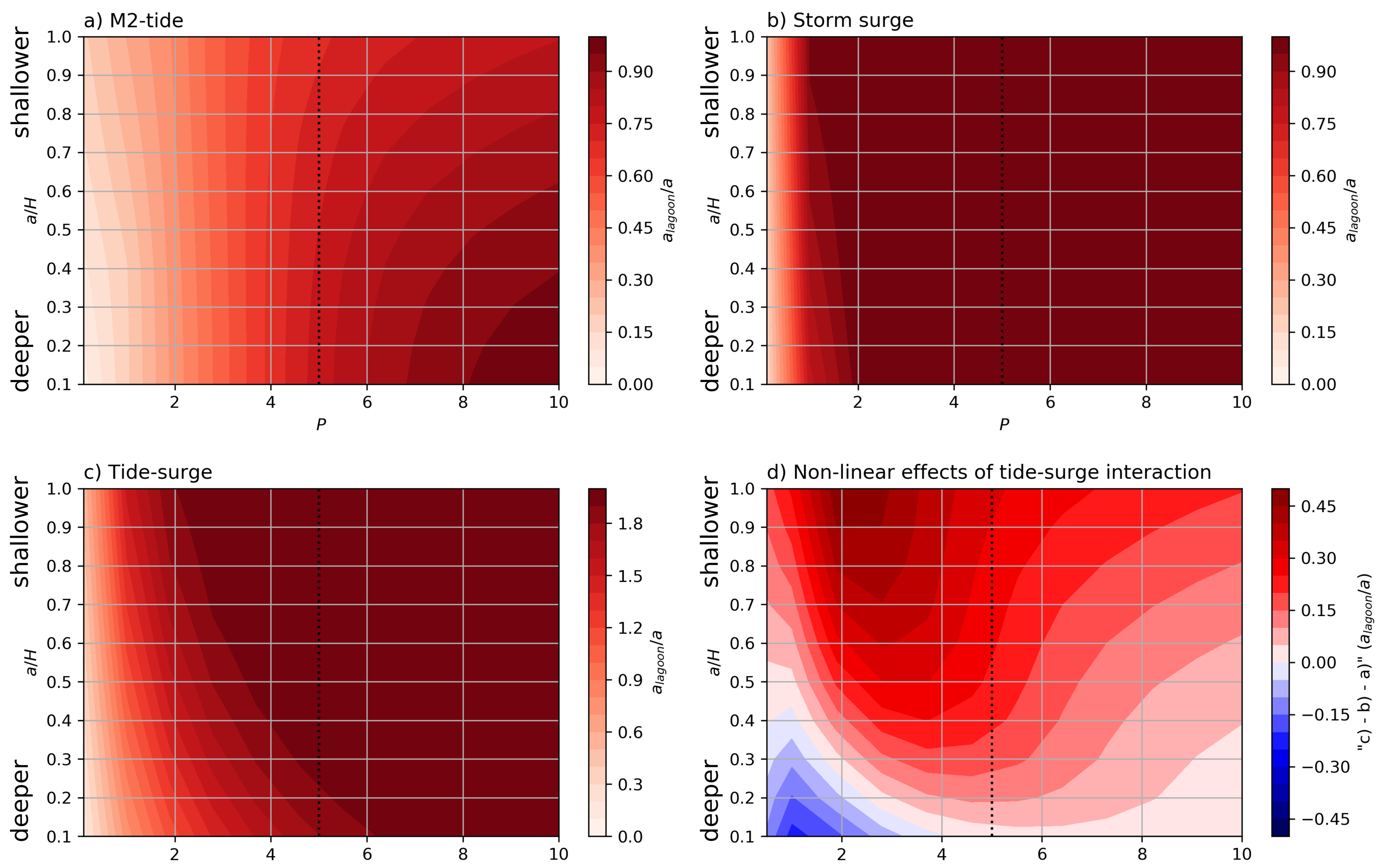


Figure 3: Sea levels inside the lagoon for the different prescribed open water sea levels:
a) The M2 amplitude inside the lagoon in dependence of the two non-dimensional parameters. For small P, the amplitude inside the lagoon is significantly damped.
b) Same as a) but for the surge height inside the lagoon. Only for small choking numbers P the surge height is damped.
c) The maximum sea level inside the lagoon for a tide-surge. Again, the smaller the choking parameter, the lower the maximum sea level inside the lagoon. However, non-intuitively, for constant P and decreasing water depth, the maximum sea level increases due to the non-independence of the two non-dimensional parameters, see eq. (5).
d) The effect of the nonlinearity on the maximum sea level for a storm surge at high tide. The effect is most pronounced for shallow inlets and choking numbers from 2 to 3.

References
Bilskie, M. V., et al. "Dynamics of sea level rise and coastal flooding on a changing landscape." Geophysical Research Letters 41.3 (2014): 927-934.
Hill, A. E. "Fortnightly tides in a lagoon with variable choking." Estuarine, Coastal and Shelf Science 38.4 (1994): 423-434.
Stigebrandt, Anders. "Some aspects of tidal interaction with fjord constrictions." Estuarine and Coastal Marine Science 11.2 (1980): 151-166.

Preliminary results: changes due to sea-level rise

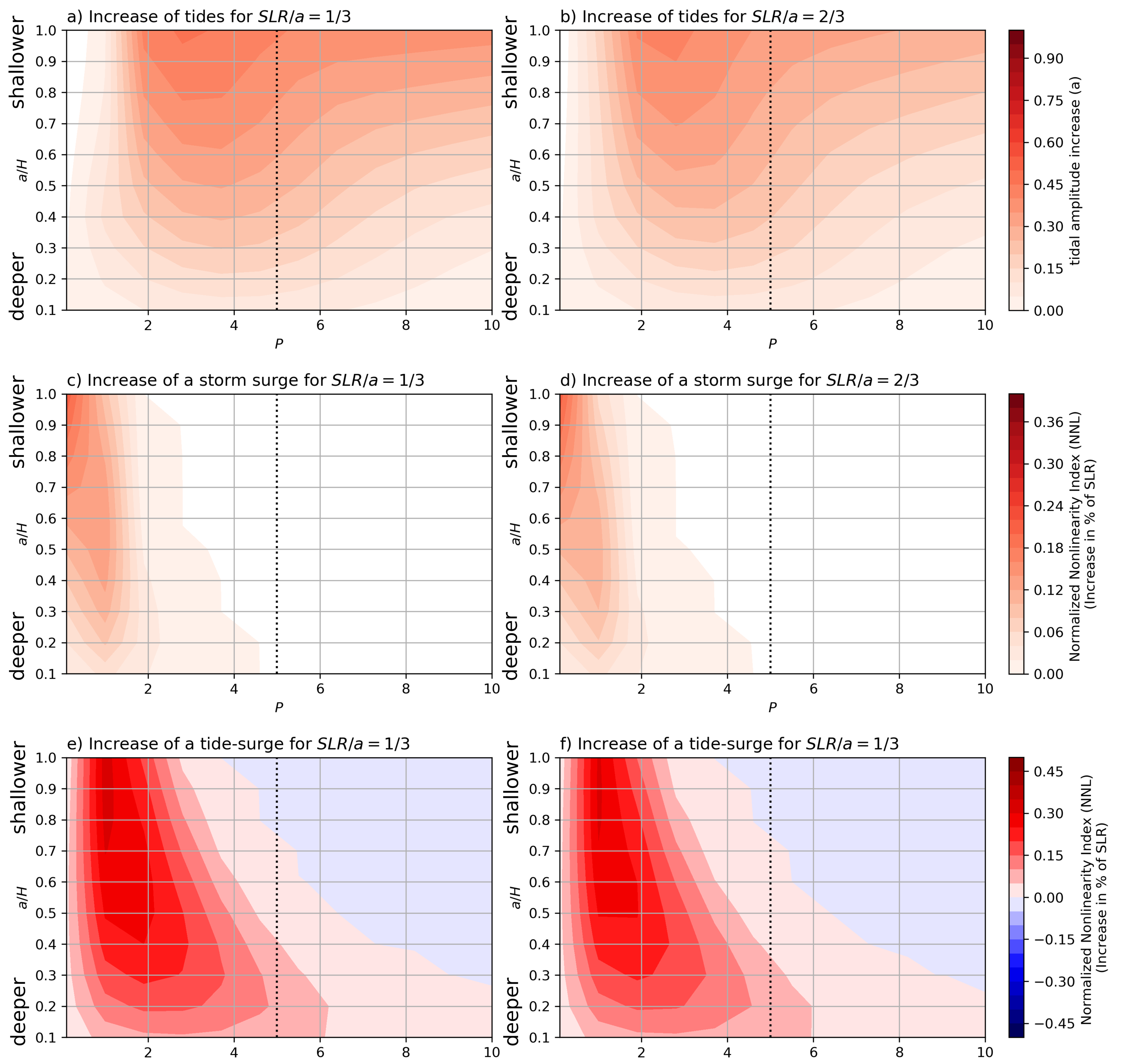


Figure 4: Impact of sea-level rise on the lagoon water level. Left column SLR = 1/3 a = 50cm; right column SLR = 2/3 a = 1 m.
a) and b) Increases in M2 amplitude inside the lagoon for the respective SLR scenarios. The amplitude can increase up to 40% of the vertical length scale a, depending on the lagoon geometry.
c) and d) Normalized Nonlinearity Indexes (NNL, Bilskie et al., 2014),

$$\mathrm{NNL} = \frac{\eta_2-\eta_1-\mathrm{SLR}}{\mathrm{SLR}} = \frac{\eta_2-\eta_1}{\mathrm{SLR}} - 1,$$

of a storm surge with the respective SLR scenarios. The NNL describes the change of the maximum sea level relative to the SLR, i.e. by how many percent of the SLR the maximum sea level changes. Only for choking parameters P<2 the surge height increases up to ~20% of SLR inside the lagoon.
e) and f) Same as c) and d) but for the tide-surge scenario. Again, for P<2 significant increases up to 30% SLR can be expected, depending on the lagoon geometry.