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Application of stochastic fractal surface rupture on non-planar faults in tsunami simulation

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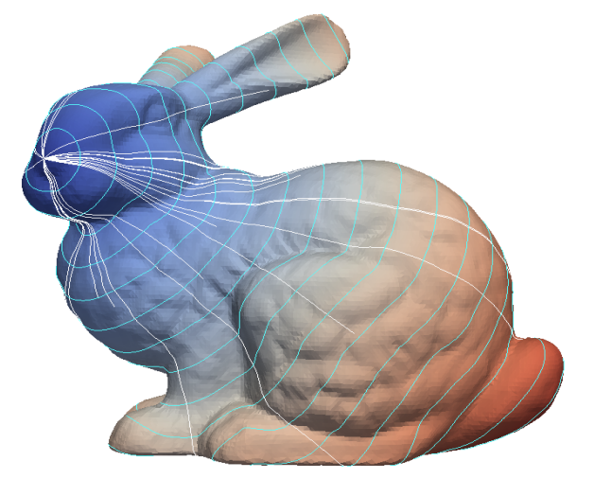

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1. Introduction

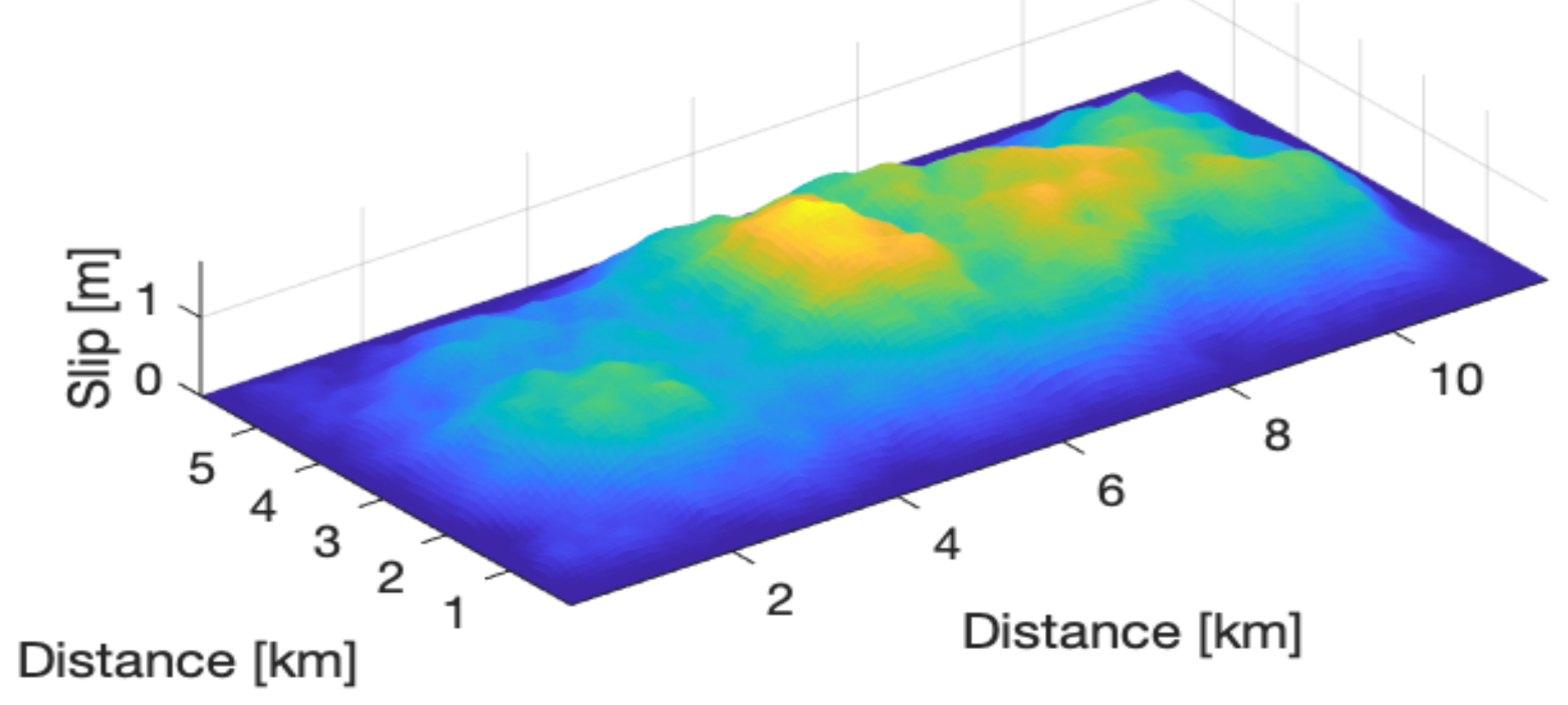
Non-planar faults and surface reached rupture are seldom considered in the source modelling of subduction zone earthquakes. Additionally, in tsunami simulation, earthquakes are often treated as events that occur instantaneously.

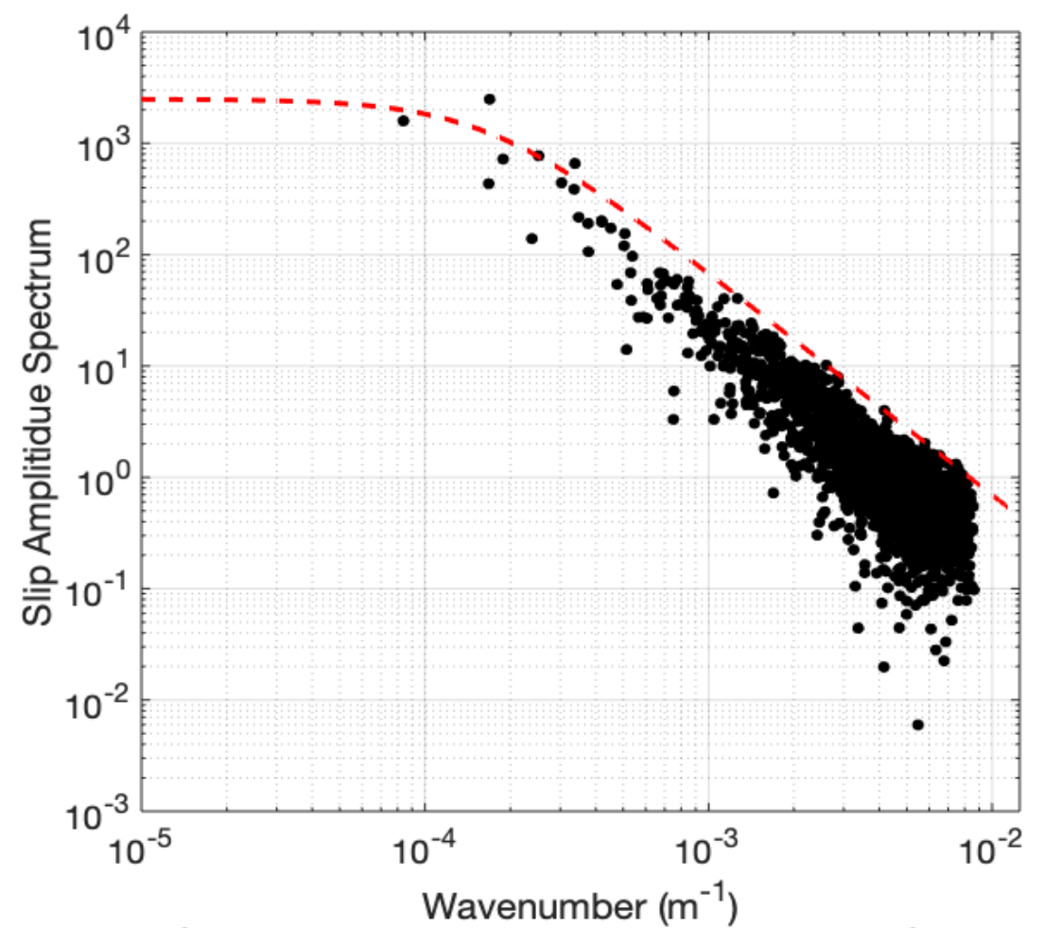
Here we present a preliminary investigation of the effect that surface rupture and rupture velocity have on tsunami waves. To do this generate stochastic slip distributions and look at the tsunami wave generated at a radial distance away from the fault.

2. Methodology

We construct stochastic slip distributions using composite source model technique (Frankel, 1991; Zeng et al., 1994), this involves:

1. The placement of circular subevents on a fault plane where subevents have a power size-frequency scaling. Each subevent has a slip distribution. The summation of the subevents generates a fractal slip distribution





2. Surface rupture is accounted for by reflecting the slip from subevents that cross the surface back onto the fault plane (Murphy and Herrero, 2020).

3. The same technique used to calculate distance across the fault can be used to calculate the rupture time from a nucleation location (Herrero and Murphy, 2018).

The earthquake dimensions are defined below. 'Classic' refers to earthquakes that follow standard scaling laws (e.g. Strasser et al, 2010). 'Tsunami refers to shallow subduction zone events such as the Java 2006 tsunami earthquake.

Earthquake Type	M_w	μ (GPa)	Length (km)	Width (km)	Rupture Velocity (km/s)	Dip (º)
Classic	8.0	30	160	85	N/A	20
Classic	7.8	30	120	60	3	20
Tsunami	7.8	10	250	60	1	20

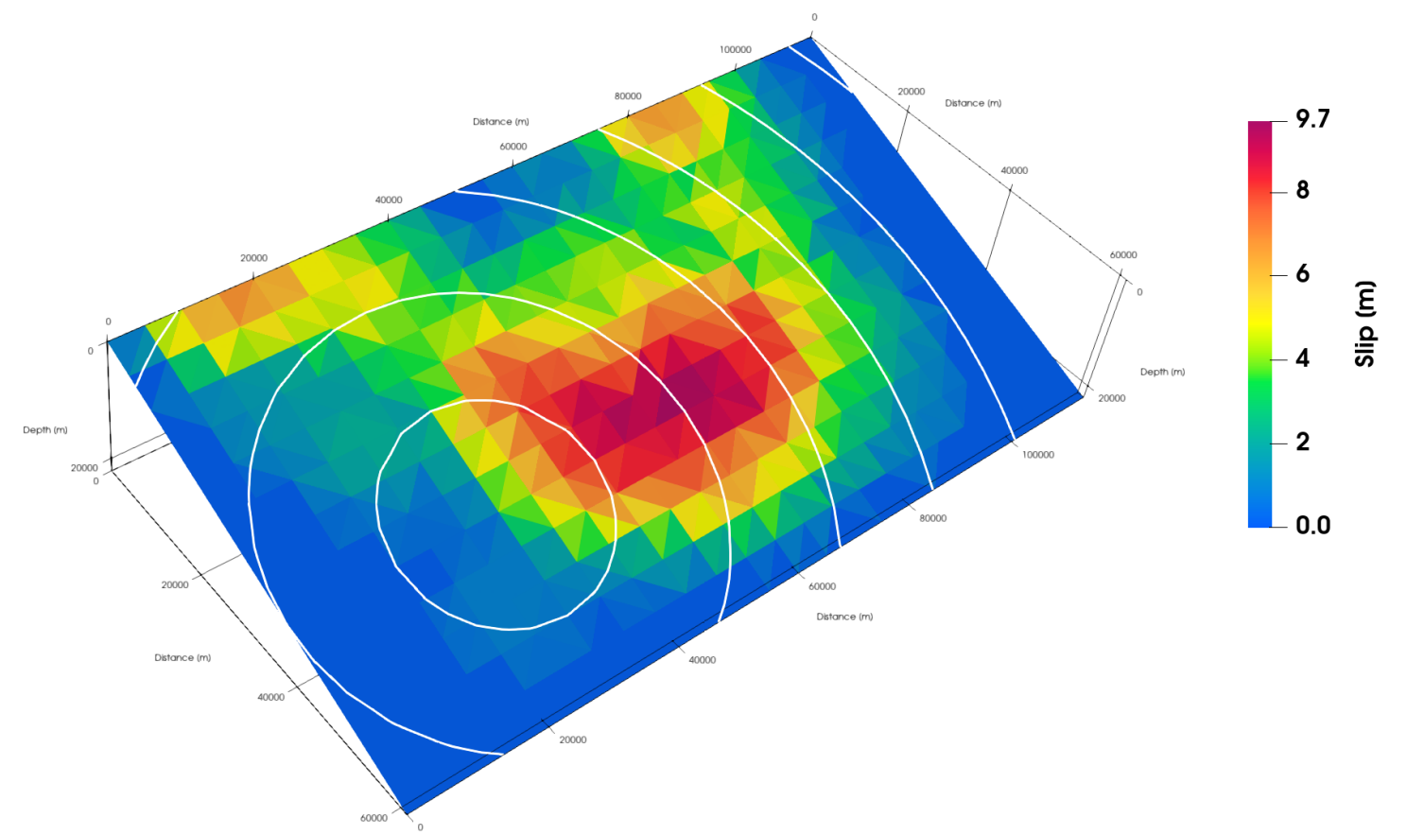
Seafloor displacement caused by the slip is calculated using a dislocation model (Meade, 2007). The tsunami is then simulated in 4km of water using the shallow water code HySea (de la Asunción et al., 2013).

3. Rupture Velocity

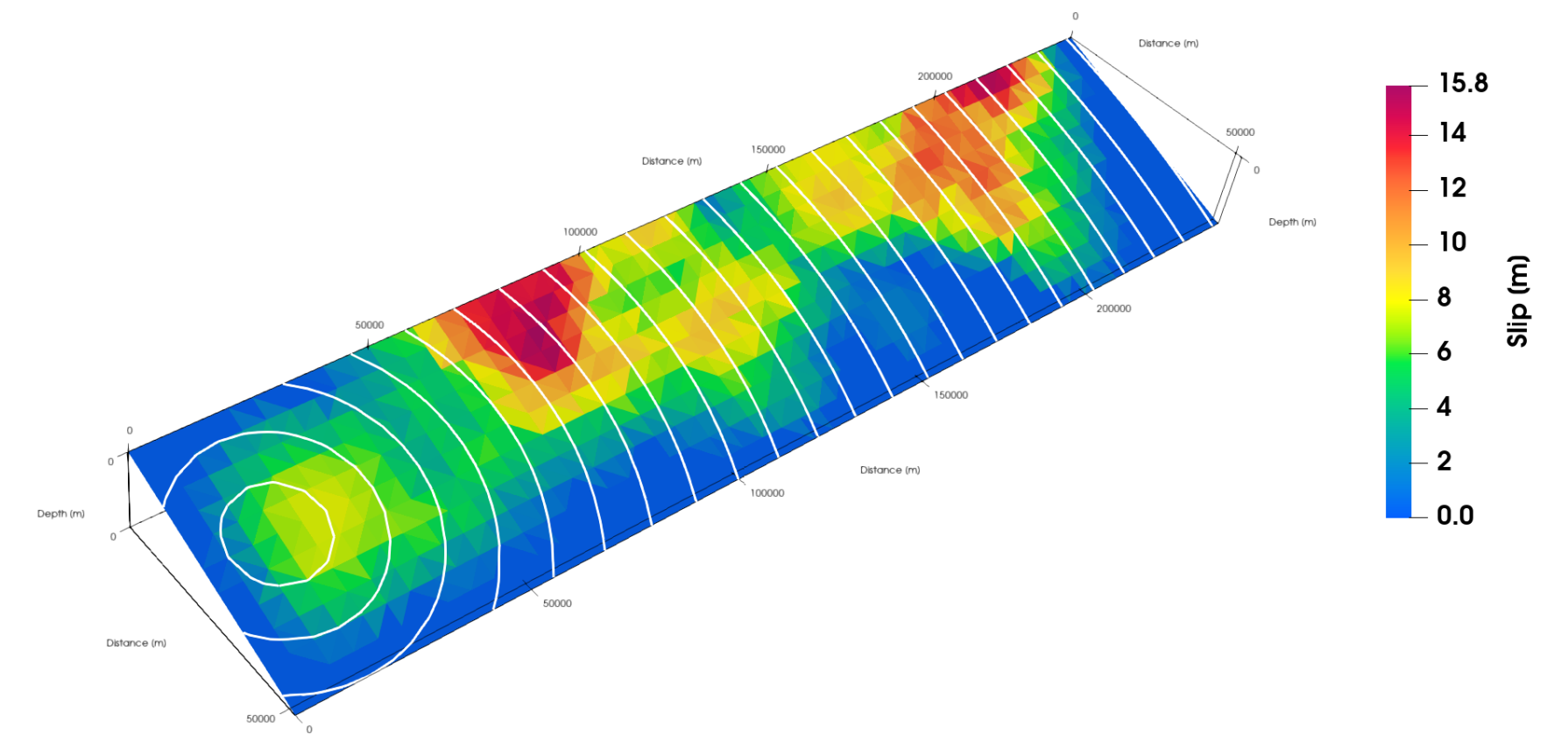
We take 2 types of earthquakes – a 'classic' earthquake and tsunami earthquake. For both types, two tsunami simulations were performed:

1) the static case: the slip is instantaneous across the whole fault
2) the rupture case : cells on the fault start to slip according to a rupture velocity.

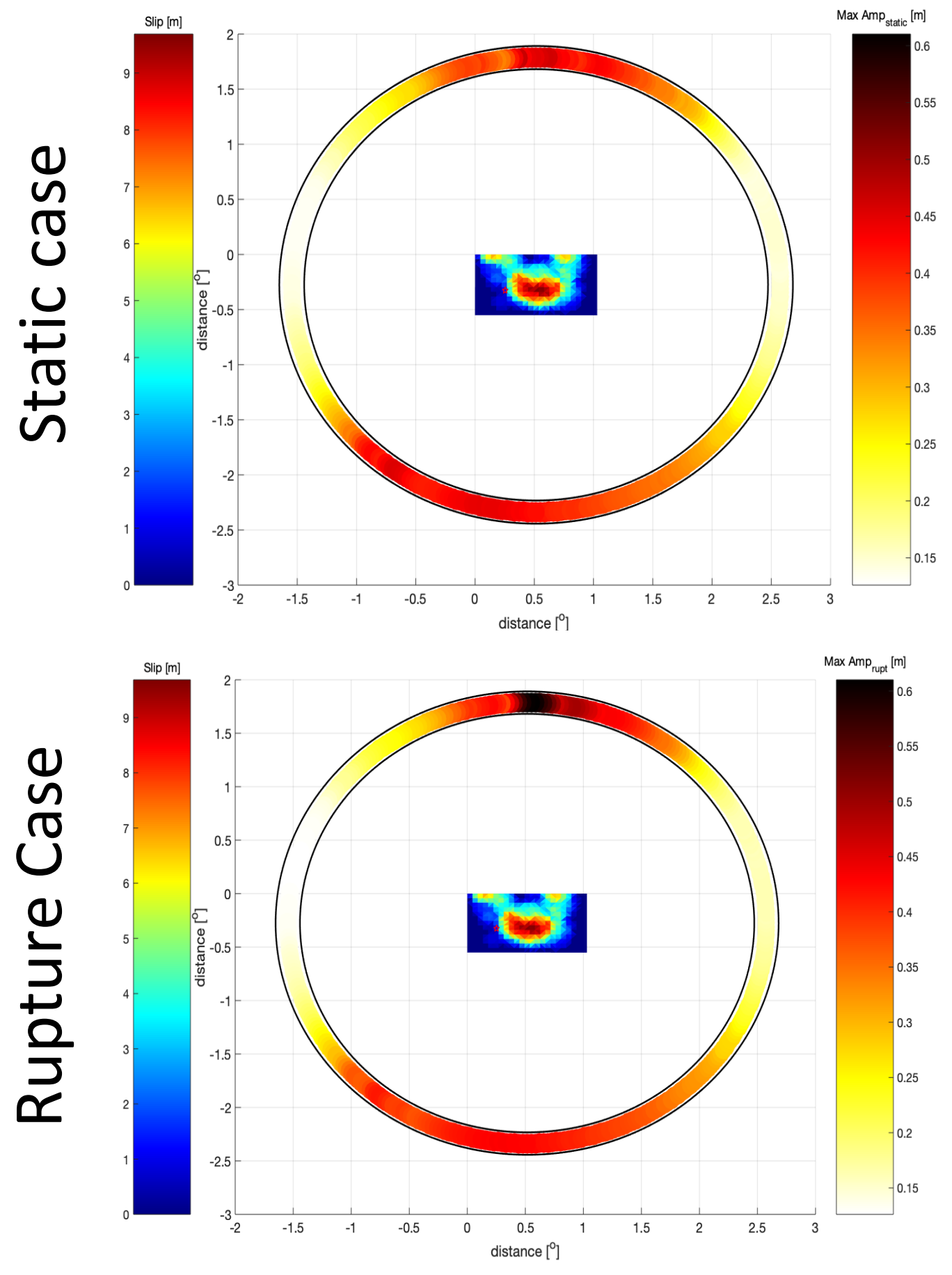
"Classic" M7.8 Earthquake



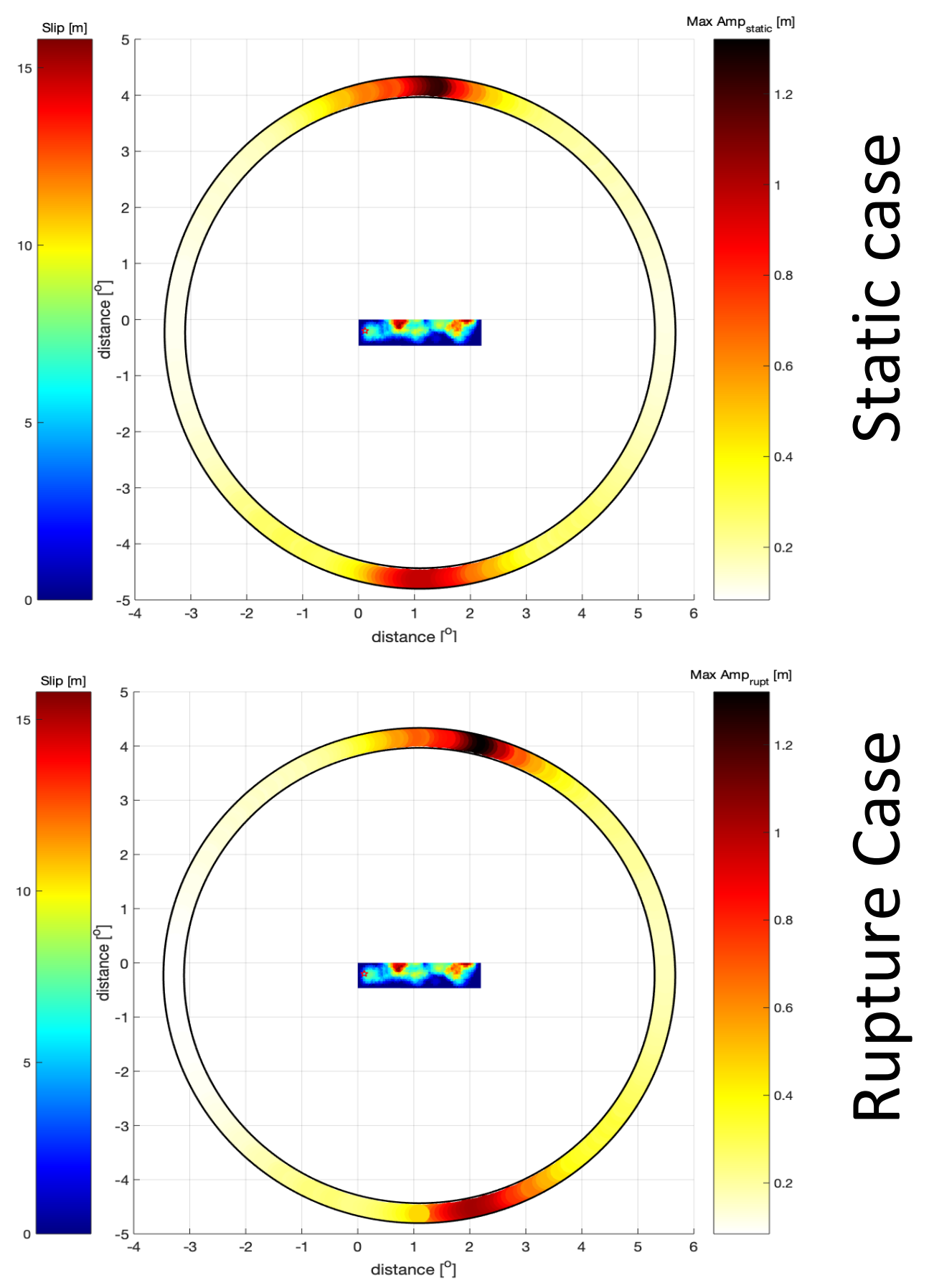
M 7.8 Tsunami Earthquake



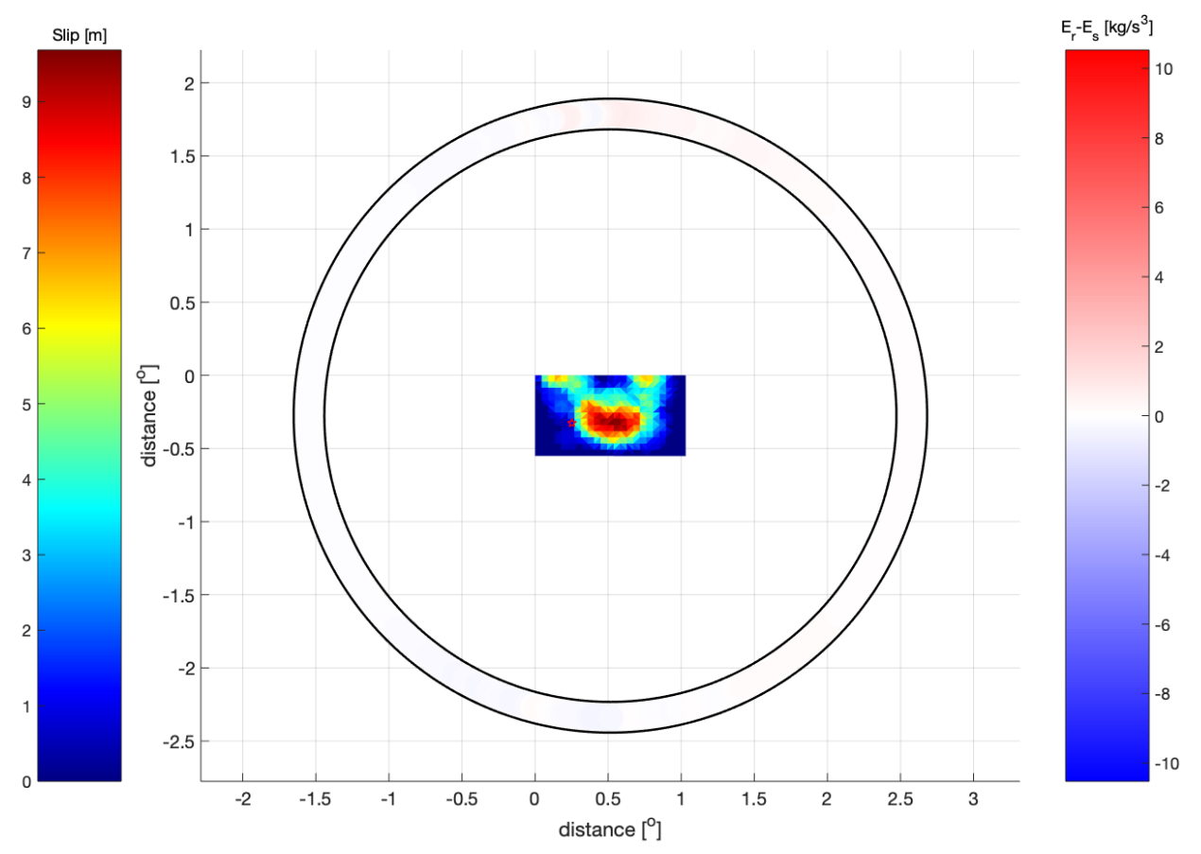
Max. Wave Amplitude for each simulation



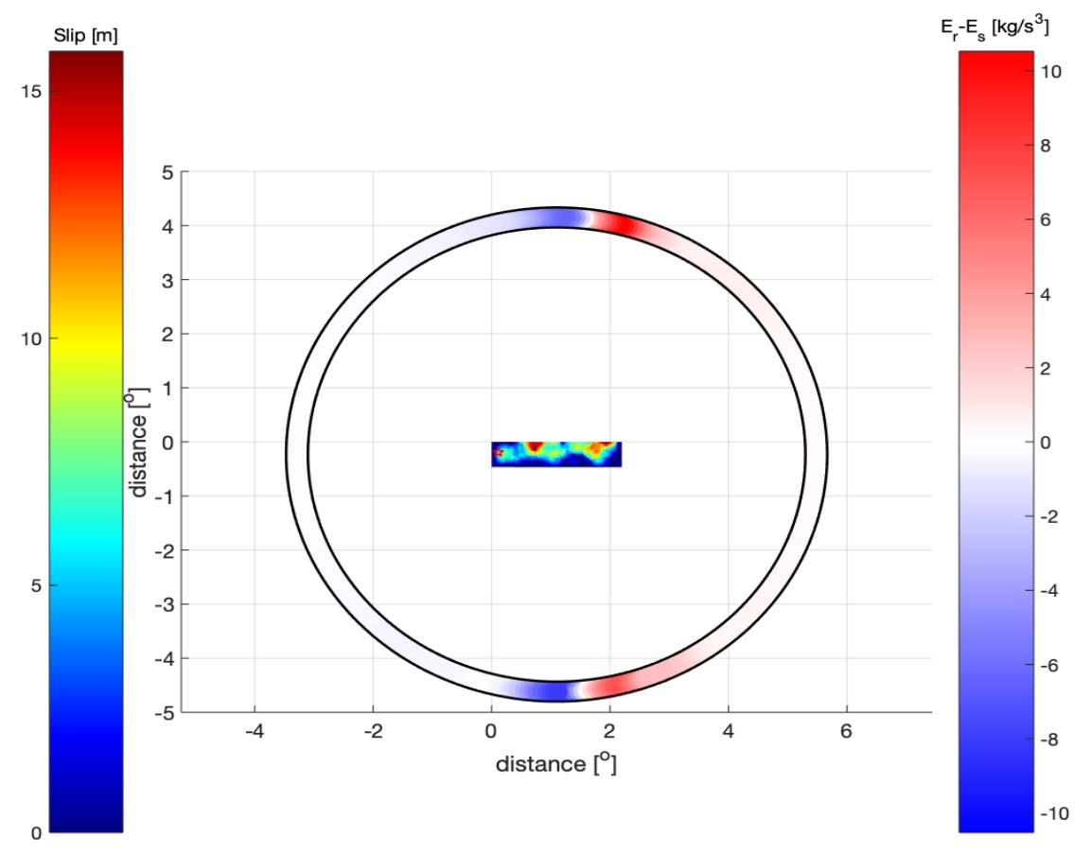
- The wave height is more focused for tsunami earthquakes compared with a more classic earthquake.
- For tsunami earthquakes the directivity of the waves shifts when a rupture velocity is applied.
- The rupture cases produces slightly larger amplitudes compared to the static cases



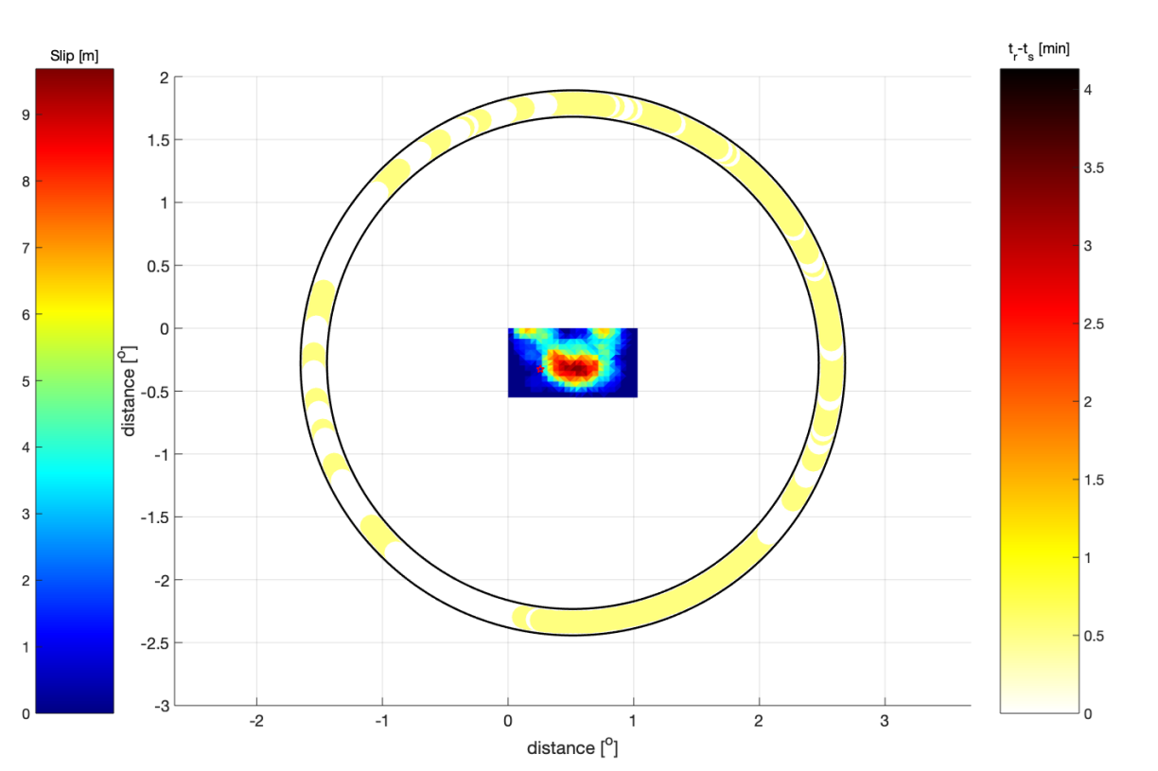
Difference in Tsunami Energy Flux between Static and Rupture Cases



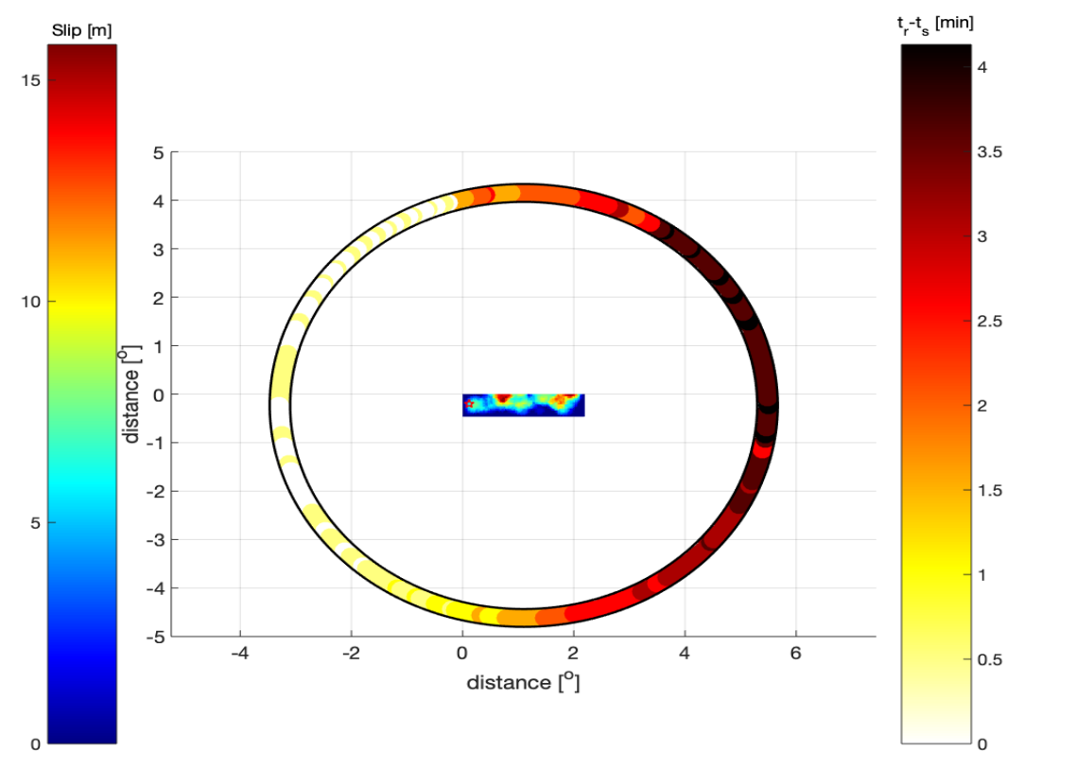
- There is a change in directivity of the energy flux in the case of the tsuami earthquake
- The flux it is a factor of 10 stronger for the tsunami earthquake compared to the classic earthquake



Difference in Arrival time between Static and Rupture Cases



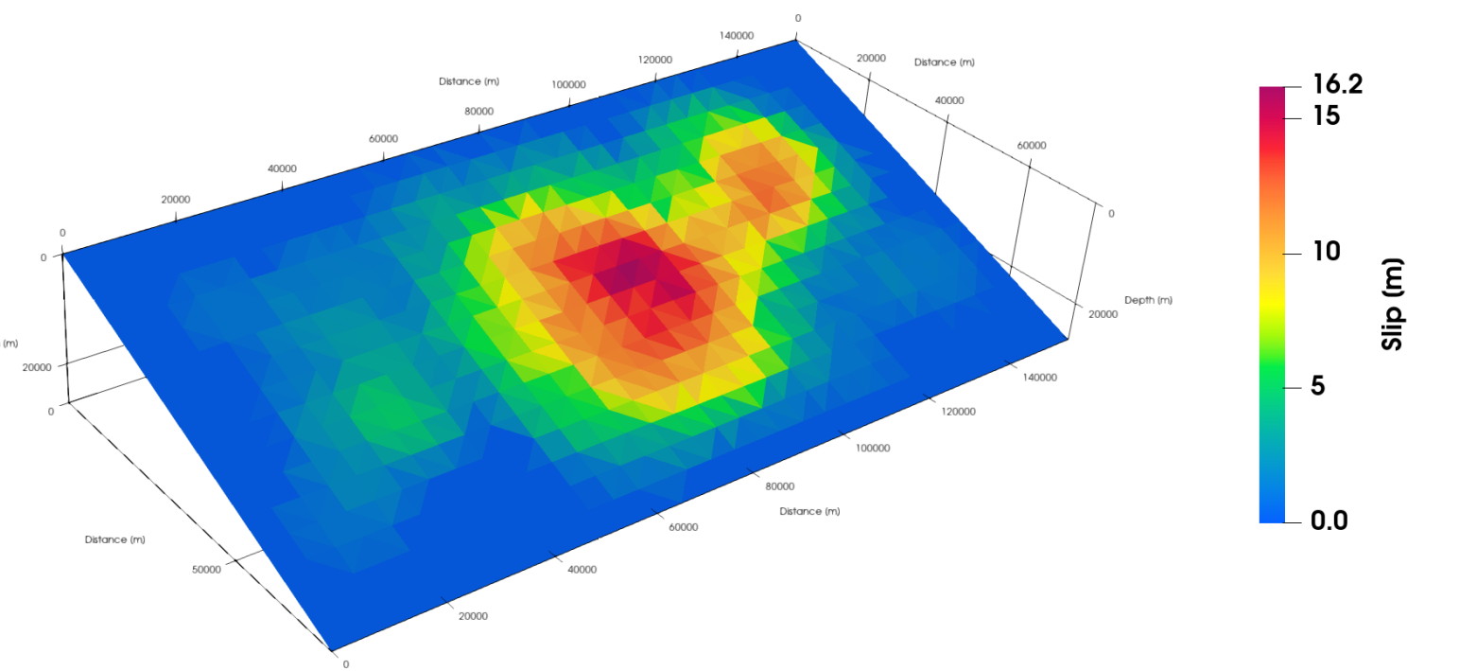
- Tsunami arrival times consistently slower for rupture case with tsunami earthquake
- No difference in arrival times for classic earthquake (differences are at same value as the temporal discretisation of the tsunami model).



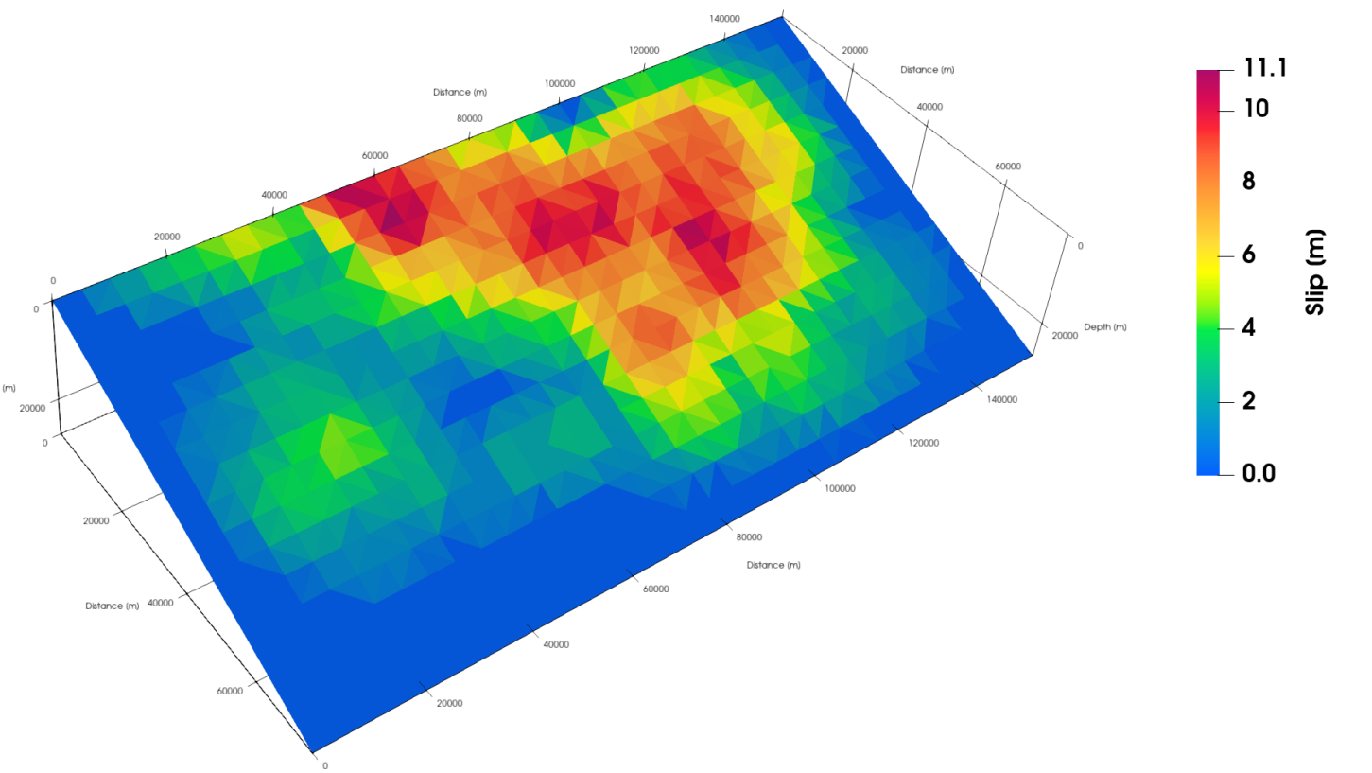
4. Surface Rupture

To examine the effect of surface rupture, two M8 slip distributions were produced one where large slip at the surface could occur and the other where slip taper to zero at the surface. Fault dimensions based on 'classic' scenario.

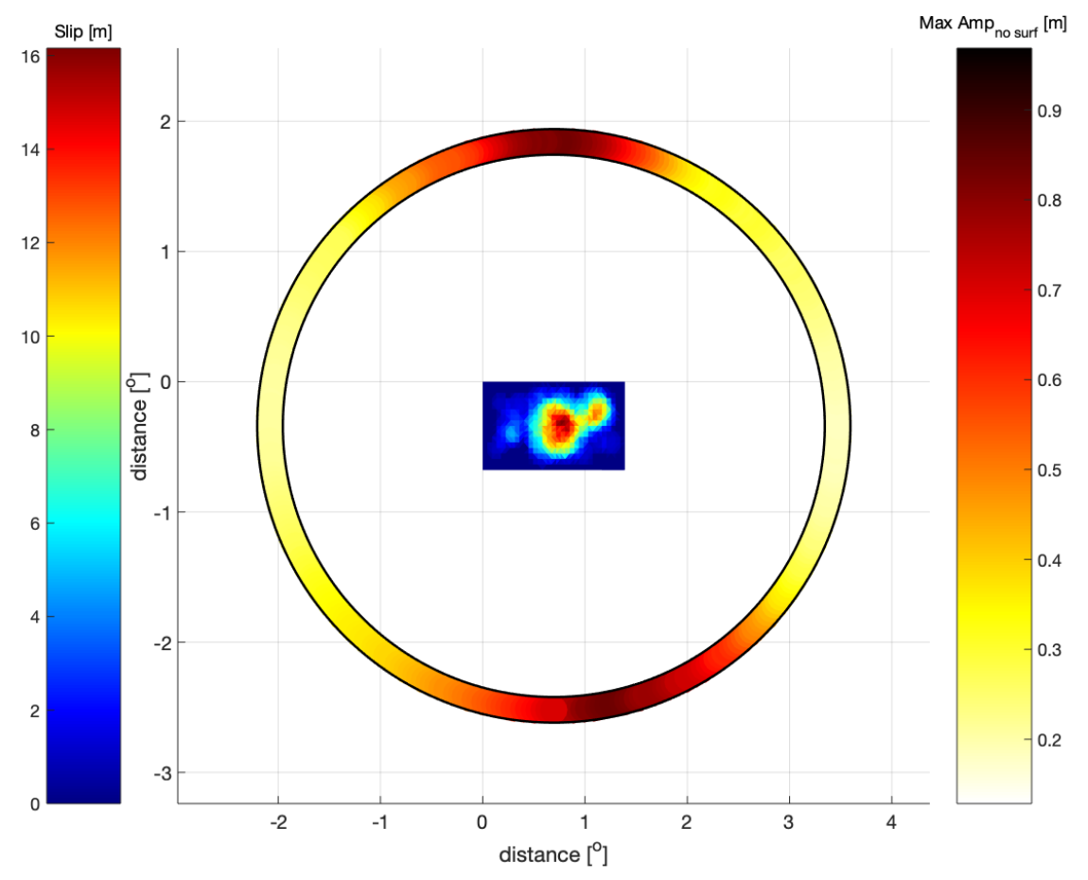
No surface rupture



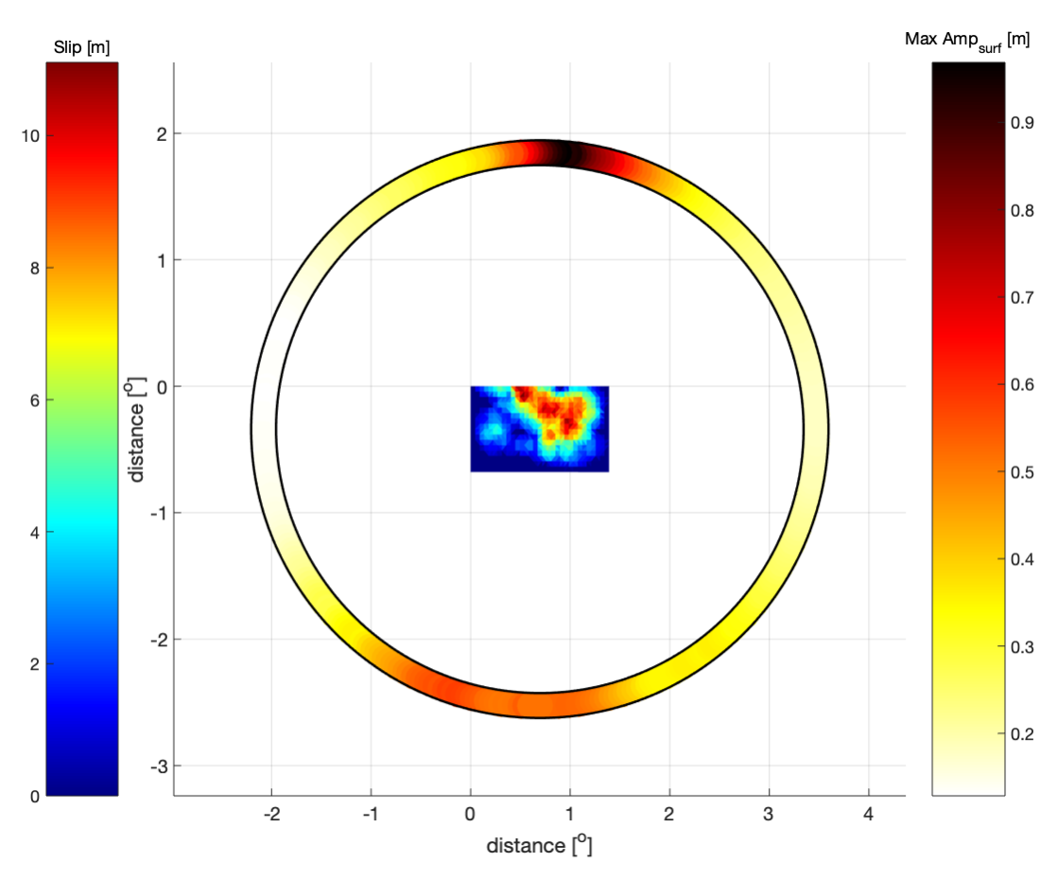
Surface Rupture Case



Max. Wave Amplitude for each simulation



- Tsunami wave is more focused in case where there is surface rupture
- Tsunami wave is higher in case where there is no surface rupture as slip was higher (+5m)

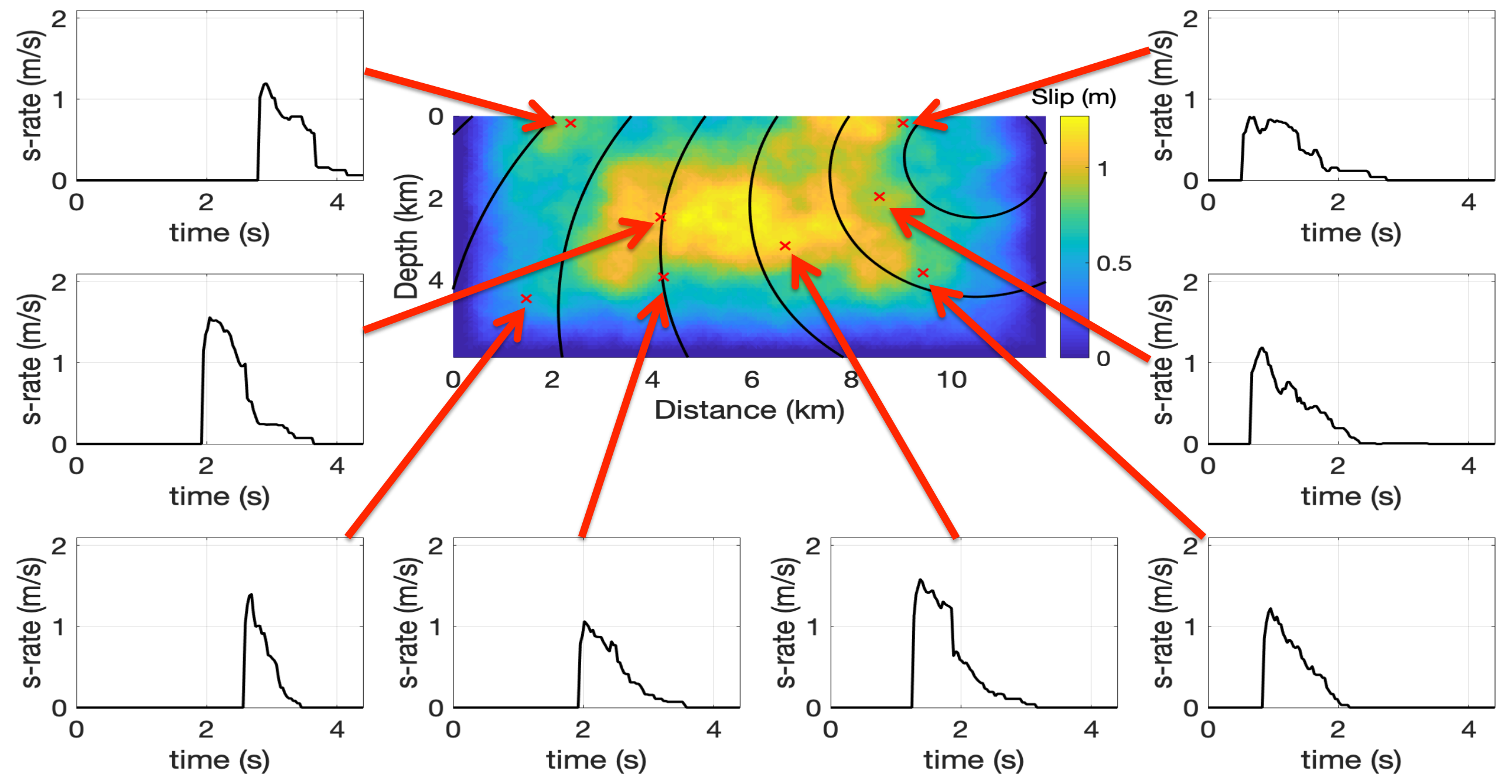


5. Conclusion

The effect of surface rupture:
- Tsunami wave is more focused in case of surface rupture.

The effect of rupture velocity:
- When slip is instantaneous the tsunami waves arrive faster
- The introduction of low rupture velocity changes the directivity of the tsunami wave

Future work will involve:
- Application to non-planar geometries
- The inclusion of rise-time functions on each cell (e.g. Ruiz et al., 2011)



Hypothetical slip distribution for a M 6 variable rupture velocity (black contours represent rupture front at 0.5 sec intervals). The rupture velocity is based on a depth dependent velocity gradient [i.e. v(z) = 2500 + z*0.4 where z is in metres].

References

Frankel, (1991), *JGR*, 96, 6291-6302.**de la Asunción** et al. (2013), *Computers and Fluids*, *80*(C), 441–452, doi:10.1016/j.compfluid.2012.01.012., **Herrero** and Murphy (2018), *GJI,* doi: 10.1093/gji/ggy104. **Meade**, (2007), *Computers & Geosciences*, *33*(8), 1064–1075, doi: 10.1016/j.cageo.2006.12.003. **Murphy** and Herrero (2020), Surface rupture in stochastic slip models, *GJI*, *221*(2), 1081–1089, doi:10.1093/gji/ggaa055., **Ruiz**, et al. (2011), *GJI*, *186*(1), 226–244, doi:10.1111/j.1365-246X.2011.05000.x., **Strasser,** et al. (2010), *SRL*, *81*(6), 941–950, doi:10.1785/gssrl.81.6.941. **Zeng, Y.**; et al. (1994), *GRL*, 21, 725-728