SLATE
Submarine Landslides and their impact on European continental margins

Funded by the Horizon 2020 Framework Programme of the European Union

Modelling 2018 Anak Krakatoa Flank Collapse and Tsunami

Effect of Landslide Failure Mechanisms and Dynamics on Tsunami Generation

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Published Article in Pure and Applied Geophysics: https://doi.org/10.1007/s00024-020-02489-x
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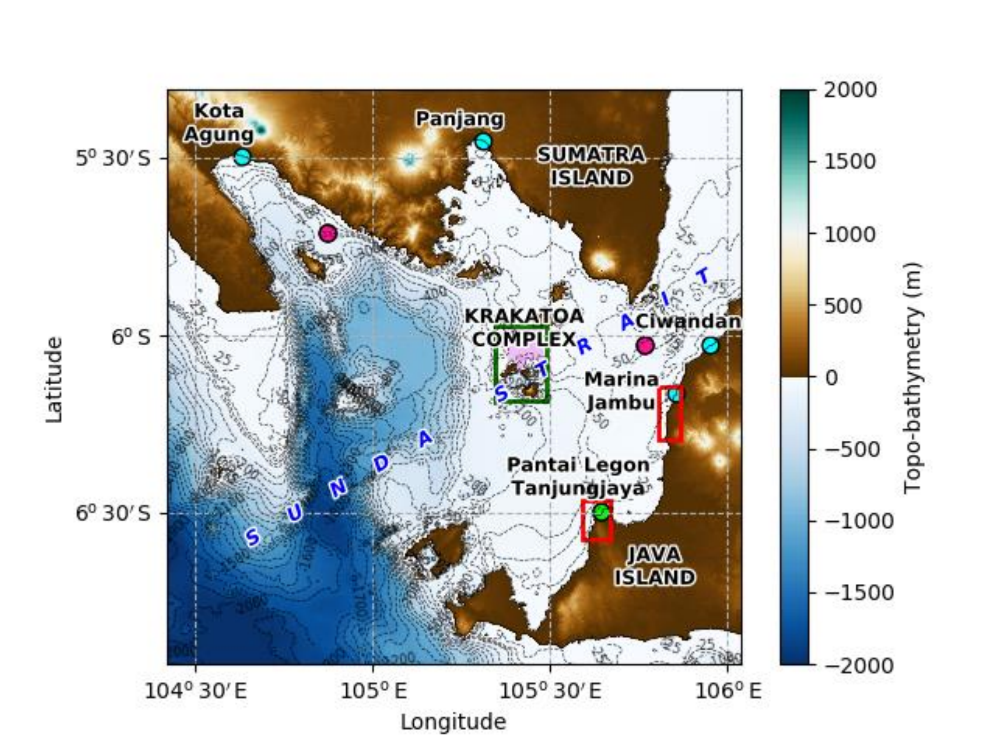
Location and motivation of the volcano Anak Krakatoa



- Landslides and volcano flank collapses are an important tsunami source.
- 2018 Anak Krakatoa event --> several hundred fatalities (Muhari et al. 2019, Putra et al. 2020)
- We study the sea surface elevation at four coastal measurement stations based on various input parameters through numerical modelling.

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Landslide model BingClaw

- Deformable mass flow
- Viscoplastic Herschel-Bulkley rheology

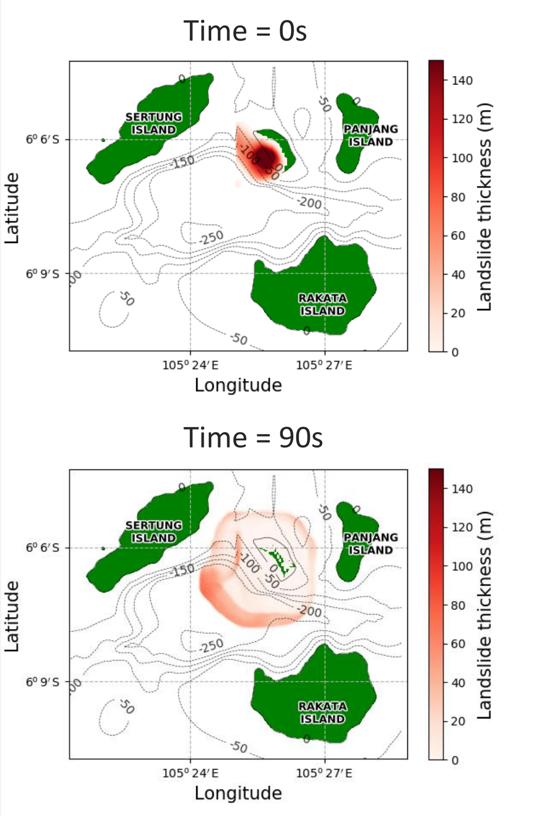
$$\dot{\gamma}_r = \left(\tau_y/\mu\right)^{1/n}$$

$$|\tau| \leq \tau_y \rightarrow \text{no deformation}$$
$$|\tau| > \tau_y \rightarrow \text{deformation}$$

- Strain dependent remoulding

$$\tau_y = \tau_{y,r} + \left(\tau_{y,0} - \tau_{y,r}\right)e^{-\Gamma\gamma}$$

- Two-layer model with depth-integrated velocities



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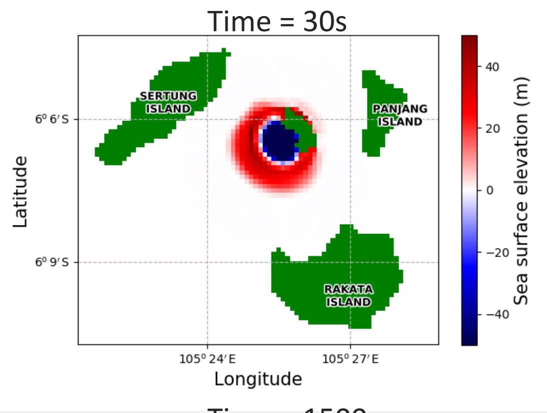
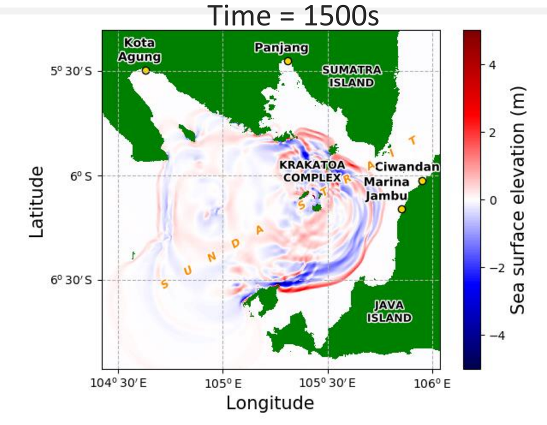
Tsunami model GeoClaw

LeVeque et al. (2011), Berger et al. (2011)

- Depth-averaged shallow water model
- Hydrostatic pressure
- Capture of propagating breaking waves
- Dry-land inundation with moving shoreline

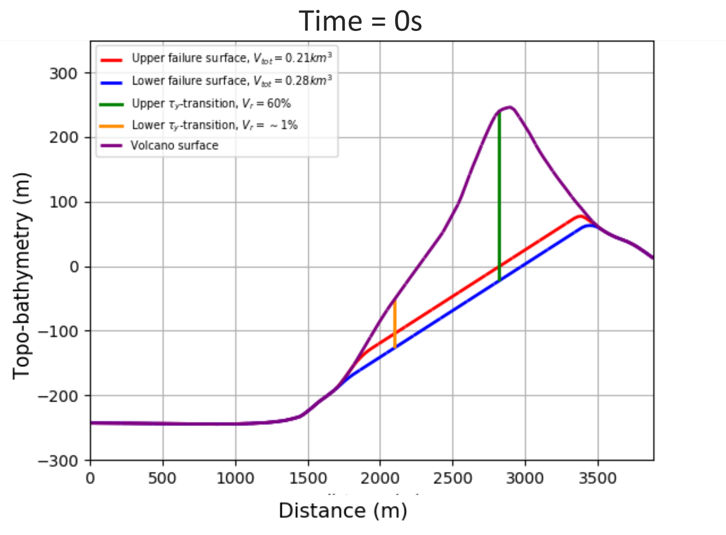


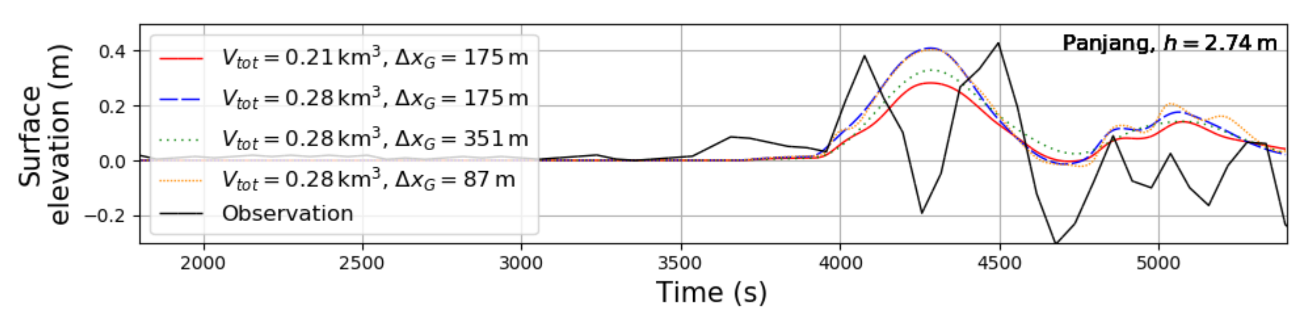


Total release volume V_{tot}

- $V_{tot} = 0.21$ km³ (red failure surface)
  --> generally smaller sea surface elevations at the gauges

- $V_{tot} = 0.28$ km³ (blue failure surface)
  --> generally larger sea surface elevations at the gauges





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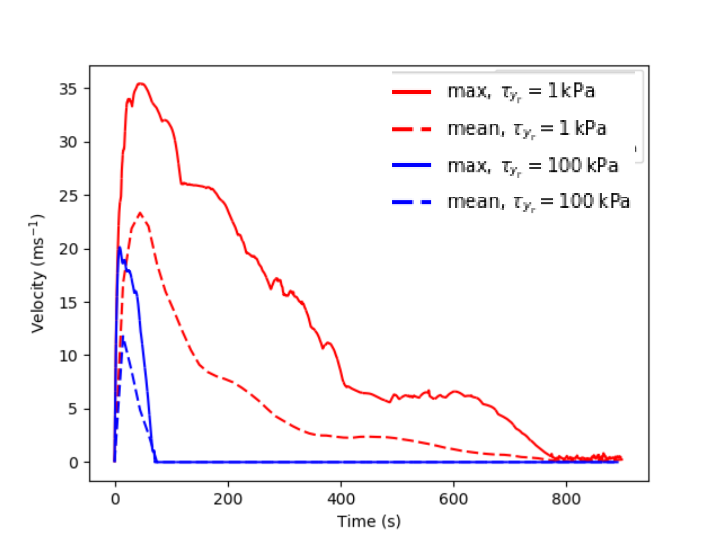
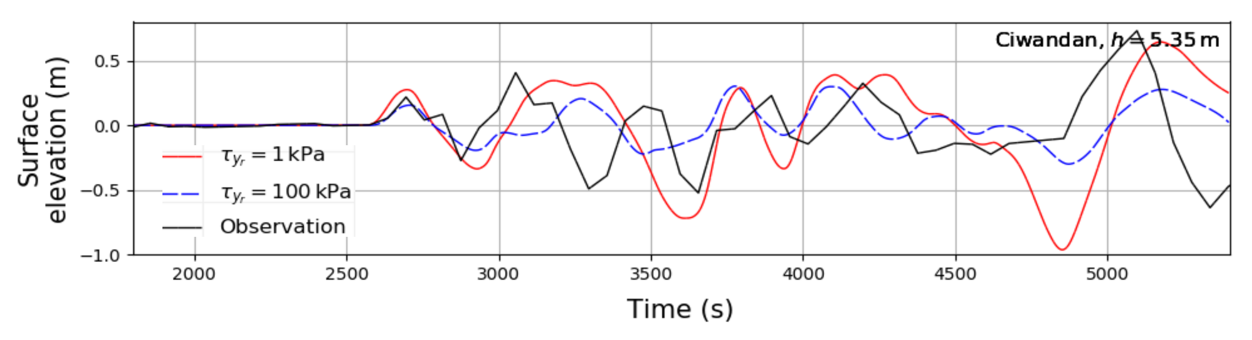
→$V_{tot} = 0.28$m³ is reasonable for simulating the event

Remoulded yield strength τ_{y_r}



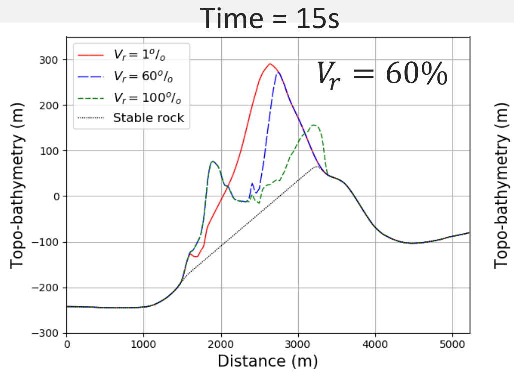
- τ_{y_r} $= 1$ kPa --> smaller landslide velocities and generally smaller sea surface elevations at the gauges
- τ_{y_r} $= 100$ kPa --> larger landslide velocities and generally larger sea surface elevations at the gauges

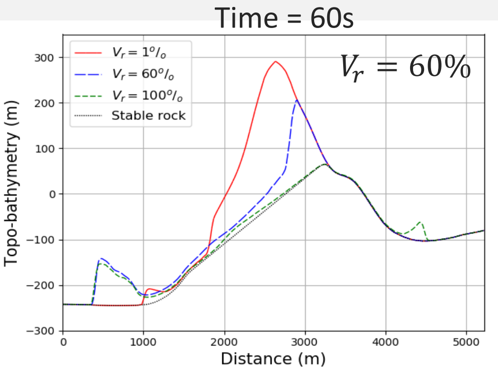


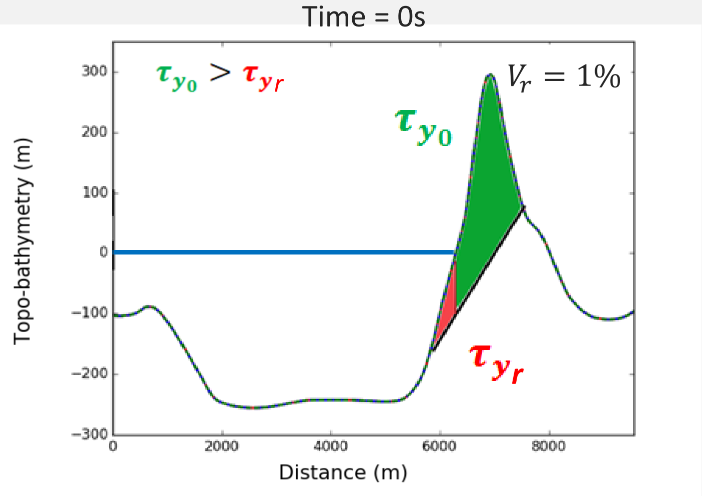
→ τ_{y_r} $= 100$ kPa is reasonable for simulating the event

Gradual volume release V_r

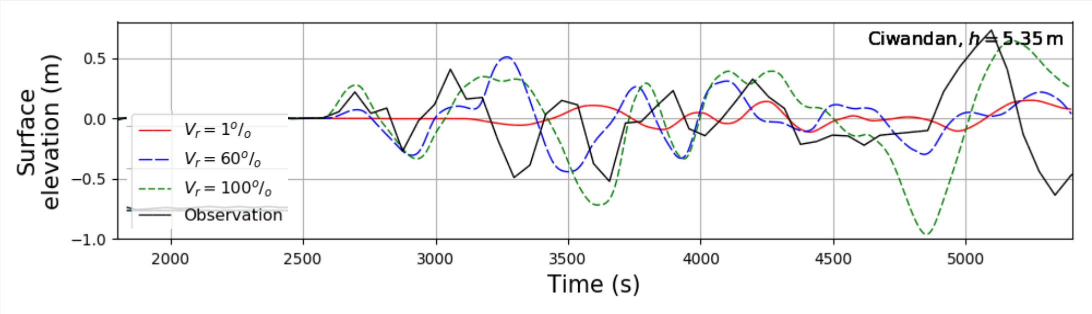
- Setup
  - Lower, initially weak, landslide part with τ_{y_r}
  - Upper, initially stiff, landslide part with τ_{y_0}





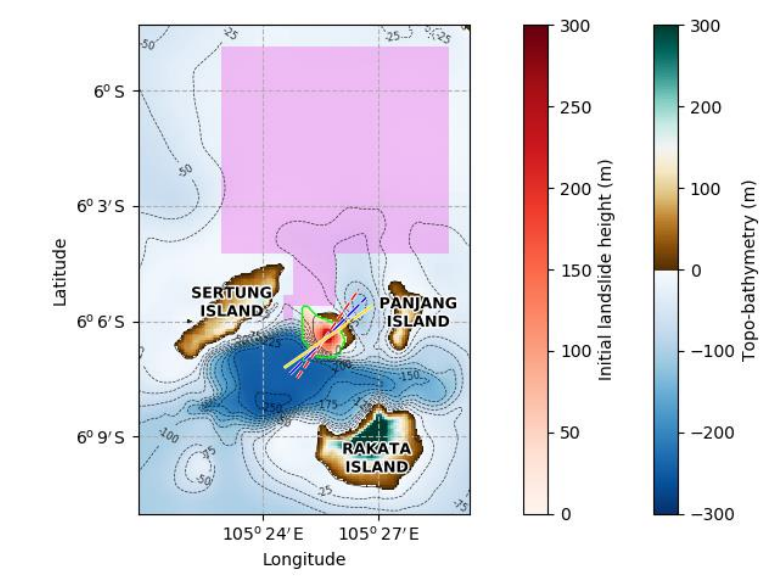


- Gradual volume release is a significant control on tsunami genesis

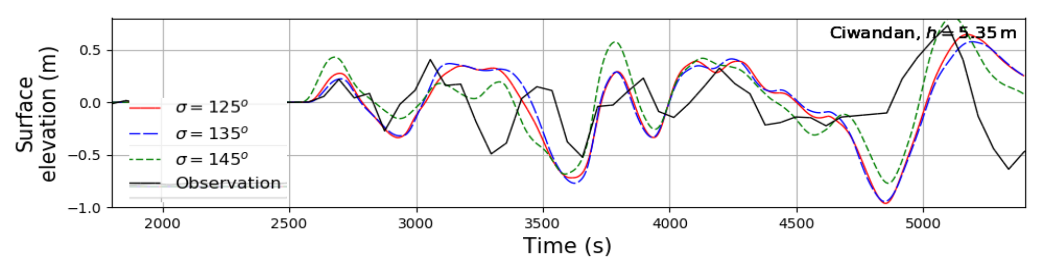


→ Simulated instantaneous collapse fit observation fairly well

Landslide directivity σ



- Satellite images form Babu and Kumar (2019) --> SW failure
- Three failure plane dip directions are indicated in the left figure as lines.
- Simulations with $\sigma = 145^o$ west from the north disagree most with sea surface elevation observation



→ $\sigma = 125^o$ and $\sigma = 135^o$ match simulation with observation best.

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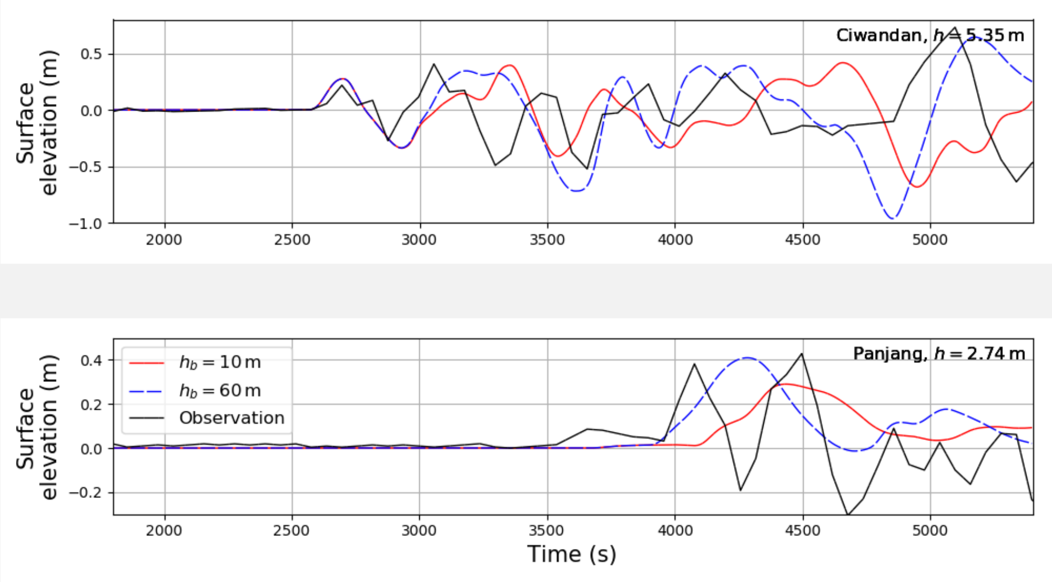
Modification of bathymetric depth



- Water depth increase from 10 m to maximum 60 m (violet zone in left figure previous slide)

  --> Increase in wave speed, earlier arrival in Panjang

  --> Increase in first sea surface elevation in at least Panjang

→ Deeper water north of the source is a possibility to decrease the max. surface elevation mismatch in at least Panjang. Simulated wave period is still too large.

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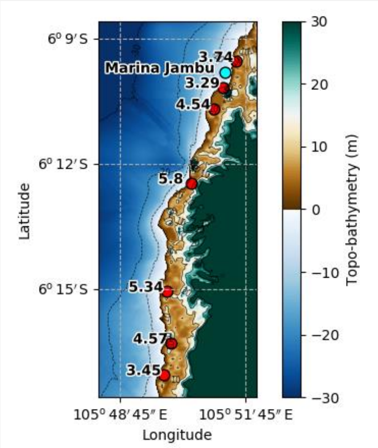
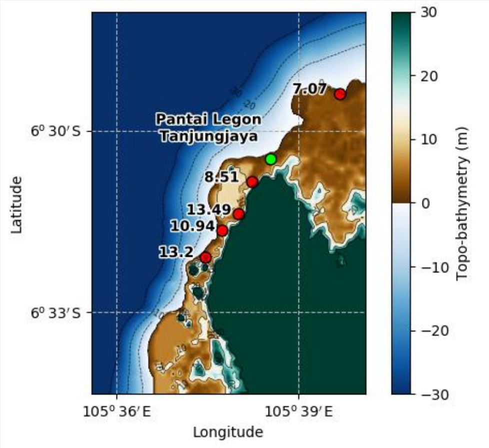
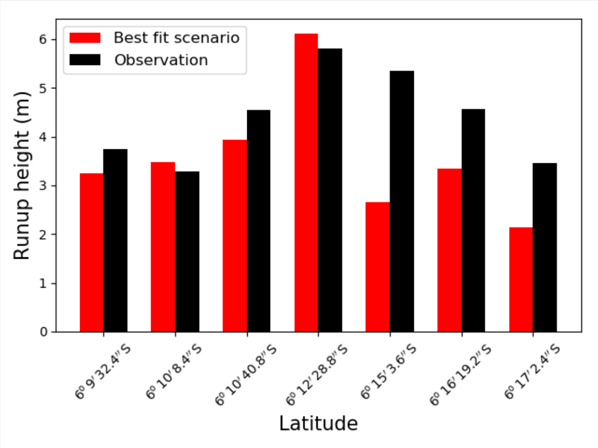
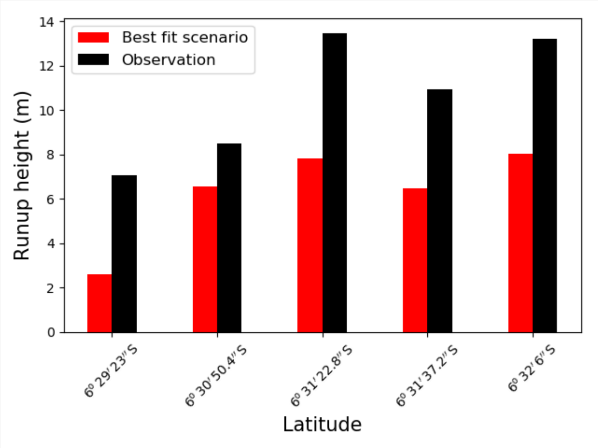
Inundation study of the best fit scenario





- Coarse topo-bathymetric data (100 m) refined to 11 m.
- Northern region (top):
  - Maximum simulated runup height 6.1 m
  - Partly good match and partly underestimation
- Southern region (bottom):
  - Max. in the southern region 7.9 m
  - Underestimation





Summary – what have we learnt

- BingClaw is fairly well suited to model the 2018 Anak Krakatoa flank collapse.

- Flank collapse was most probable
    - a single failure with 0.28 km^3
    - directed towards SW

- On Java we have a good overall wave metrics match, on Sumatra some mismatches concerning wave height and wave period.

- Bathymetric depth modifications reduce maximum wave height mismatches in at least Panjang, however not the wave period mismatch.

- Runup heights in selected regions on Java agree with observations in 50%, otherwise underestimated.

Outlook

- Further validation of the landslide model through detailed pre- and post collapse bathymetric data on and around the volcano

  --> a more accurate volume estimate
  --> a more detailed failure surface
  --> extent of the landslide run-out

- Finer resolved topo-bathymetric data could be have less errors in shallow regions, and thus better agreement with observations.

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