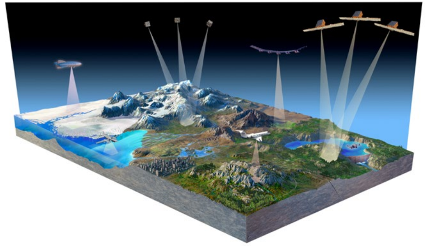
Jet Propulsion Laboratory
California Institute of Technology



STV volcano science and applications observation needs

Paul Lundgren[1], Alberto Roman[1], Grace Bato[1], Brett Carr[2], Hannah Dietterich[3], Raphaël Grandin[4], Tara Shreve[5], Michael Poland[6], Kyle Anderson[7], Francisco Delgado[8],

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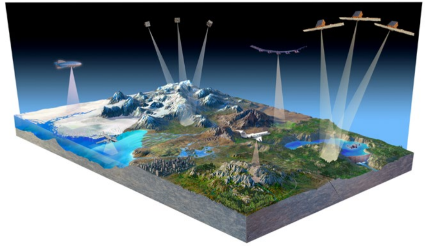
[7]USGS, California Volcano Observatory, [8]Universidad de Chile

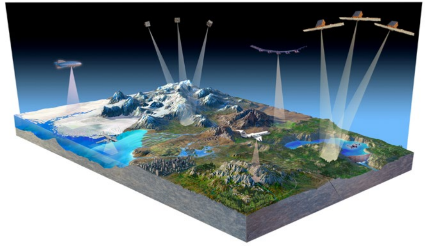
STV background

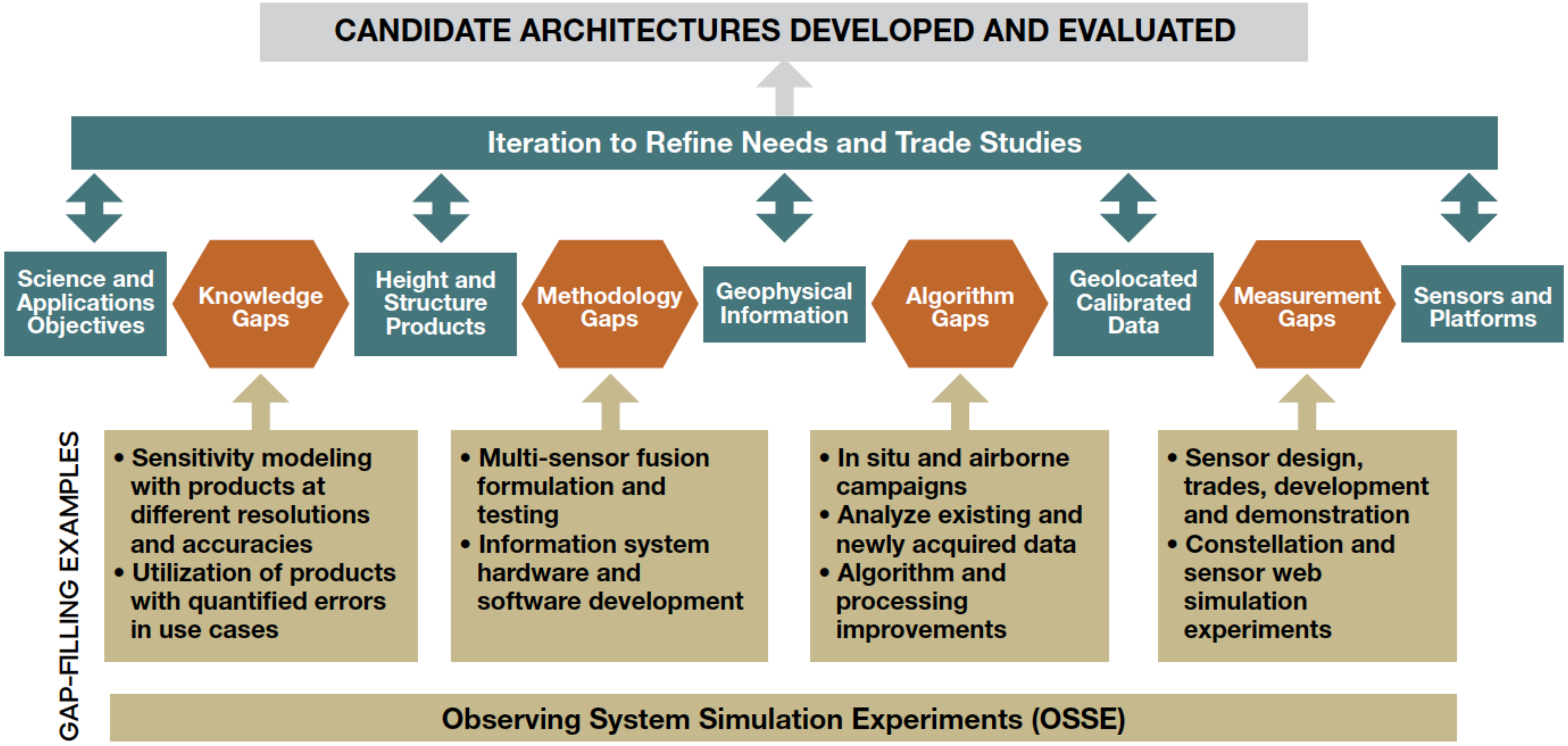


STV: a 2017 Decadal Survey Incubation observable

NASA selected a **Surface Topography Vegetation** study team during 2020-2021 to make recommendations for investments over the next decade to enable an STV mission in the late 2030's

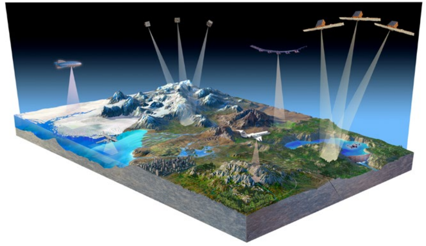
STV identified gap-filling activities

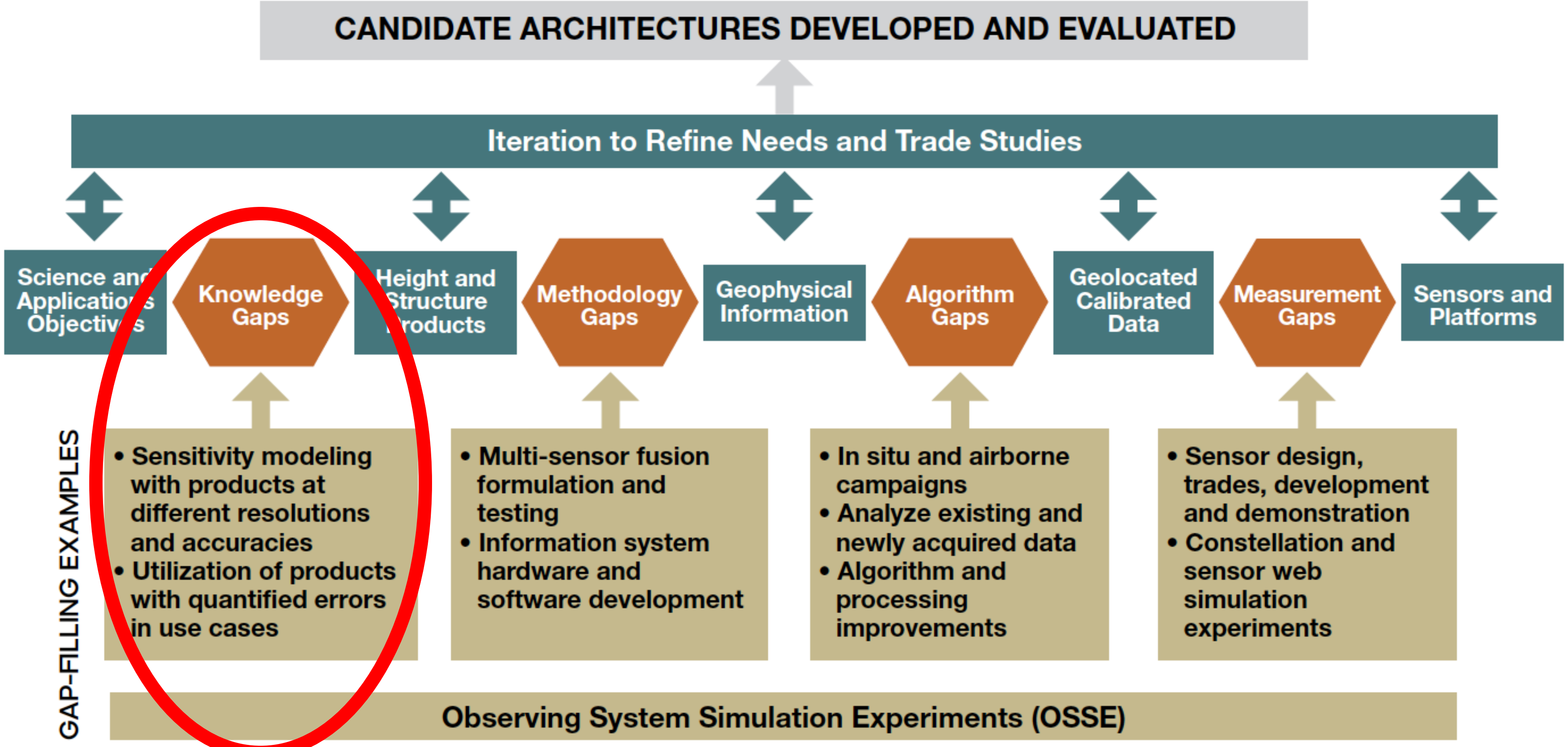




Knowledge gaps:	the understanding of product quality needed to accomplish science and applications objectives is inadequate
Methodology gaps:	the approaches to derive height products from geophysical information are inadequate
Algorithm gaps:	the solutions to derive geophysical information from data are inadequate
Measurement gaps:	the sensor and platform assets to acquire needed data are inadequate

STV identified gap-filling activities





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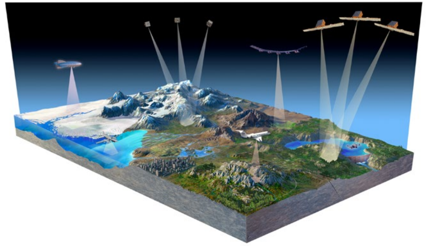
Volcanoes Project Background Information



Volcano topography and topography change needs

Our primary objectives are:

1. Quantify the topography change product needs for **dynamic volcano models**
2. Quantify the product needs for volcanic **hazards forecasting**: lava flow pathways and thicknesses, lava domes, avalanches, pyroclastic flows and deposits
3. Understand the impacts of measurement **type** and **architecture** on Objectives 1-2

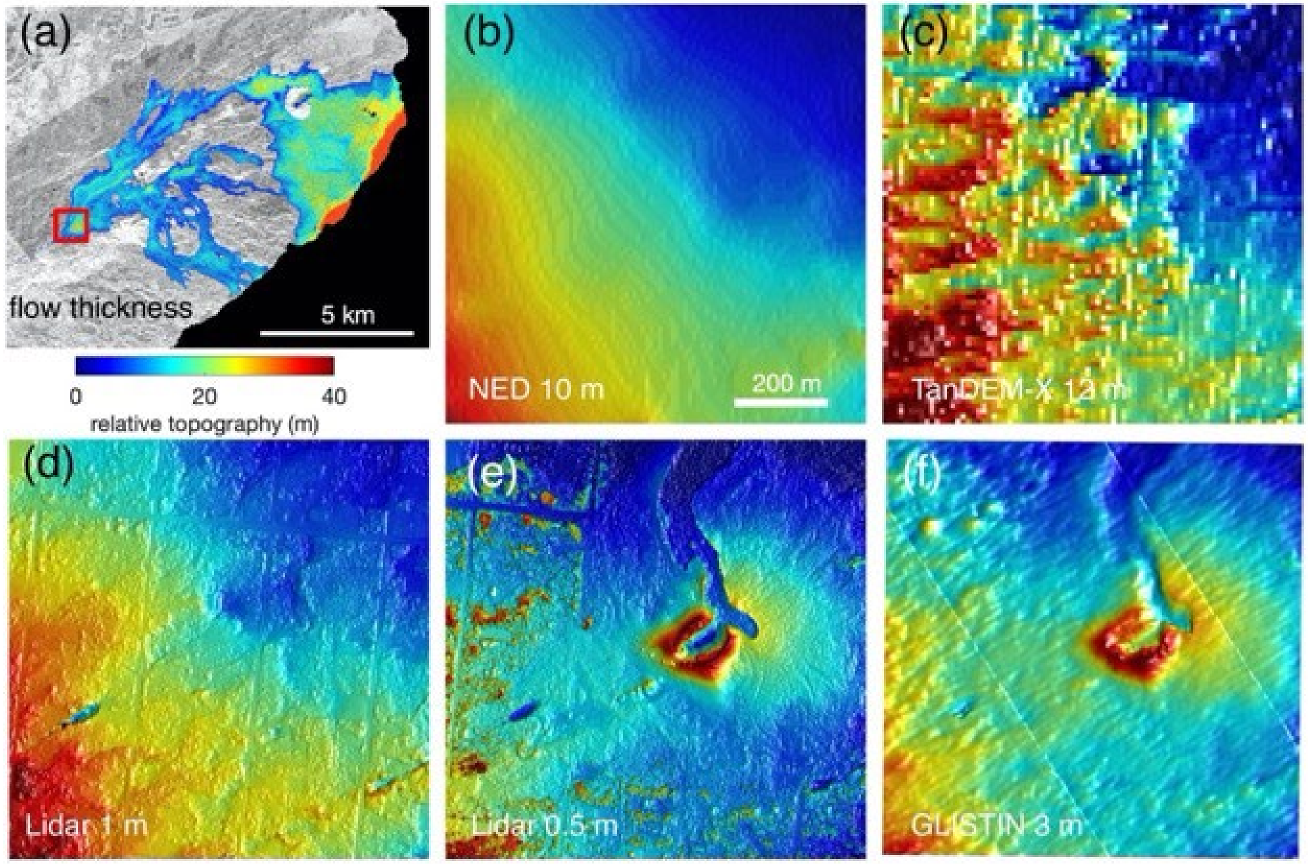
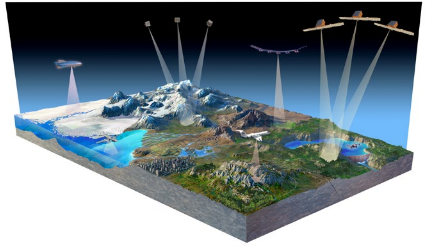
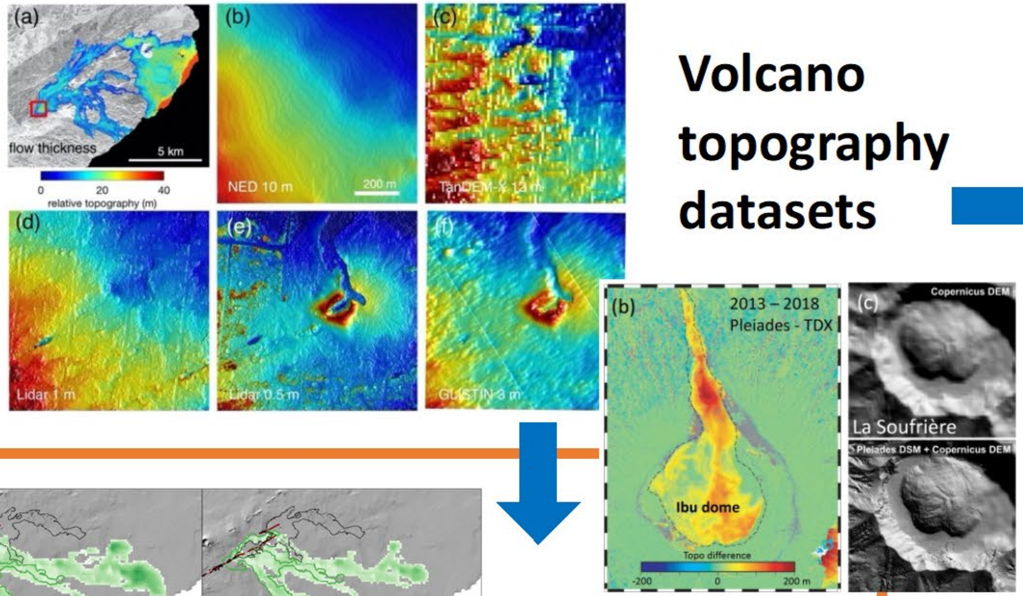


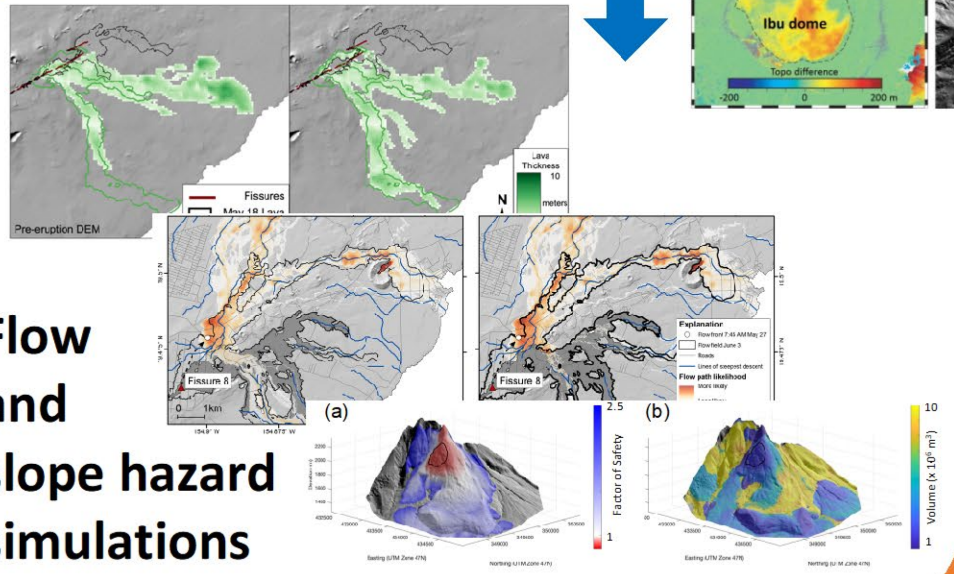
Figure 1. Kīlauea volcano produced significant lava flows over the three-month eruption May – August, 2018. (a) Differential flow thicknesses used a combination of pre-eruption bare earth lidar, near shore bathymetry, and pre-, co-, and post-eruption NASA GLISTIN-A airborne bistatic synthetic aperture radar (SAR) DEMs and flow outlines (Lundgren et al., 2019). The red box in (a) shows the 1 x 1 km area DEMS shown in (b) through (f) (b) NED 10 m. (c) TanDEM-X 12 m. (d) Lidar 1 m bare earth. (e) DEMs from co-eruptive 0.5 m lidar (Dietterich et al., 2021) and (f) post-eruption GLISTIN 3 m data show a new eruptive vent and lava flow field, with a lava channel to the north, within the Leilani Estates residential area.

Volcano Project Summary

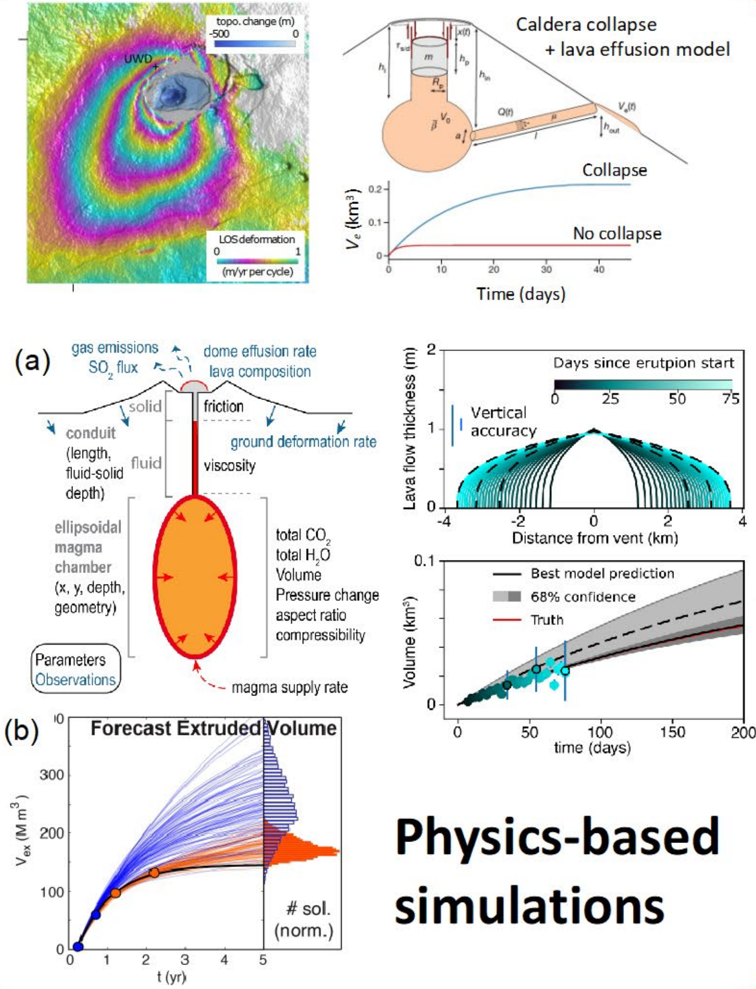




Volcano topography datasets

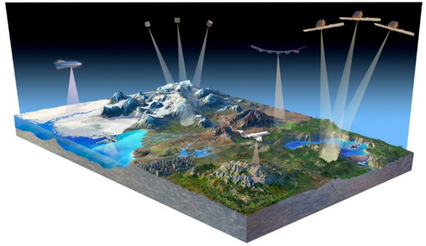


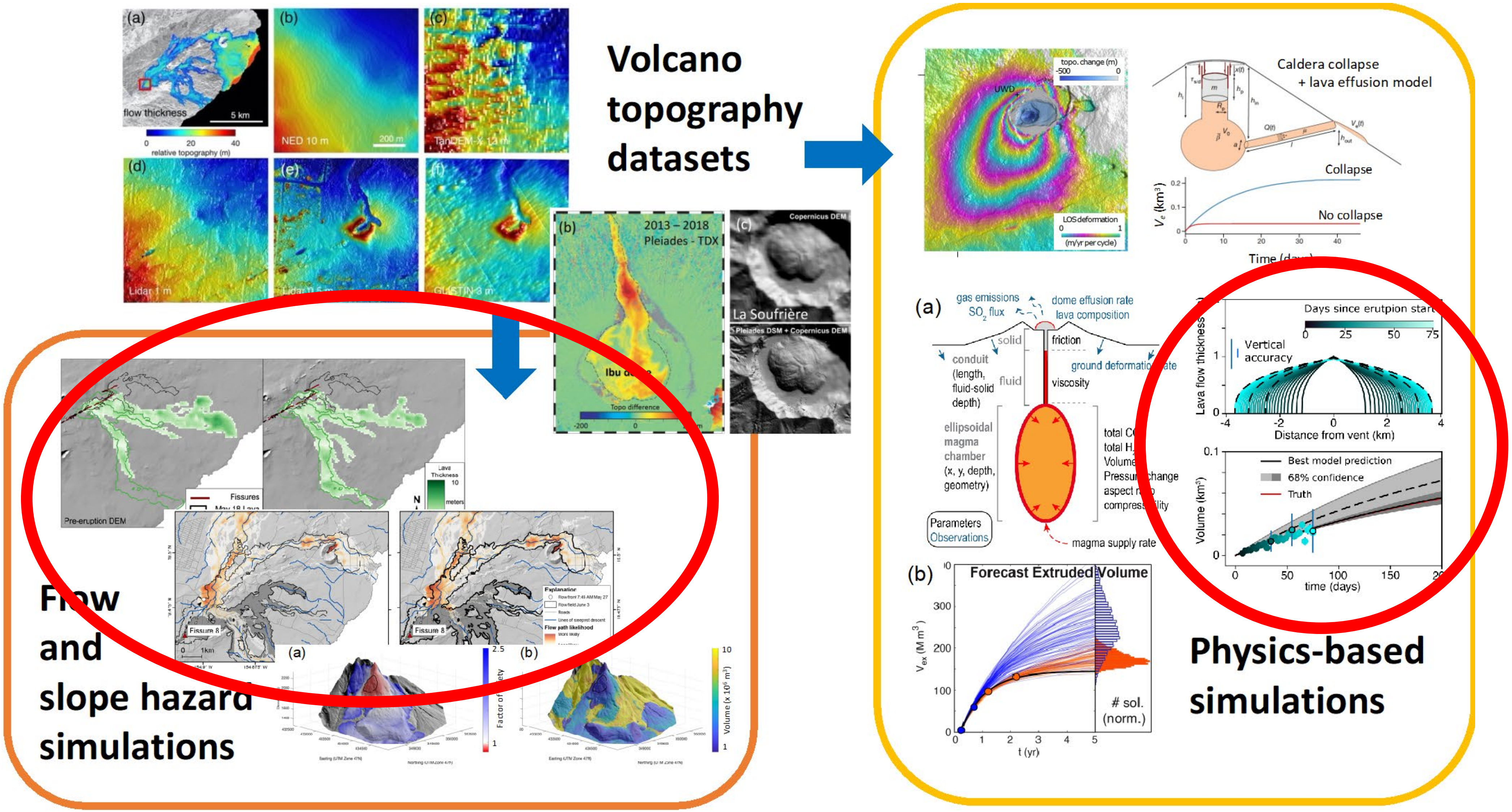
Flow and slope hazard simulations



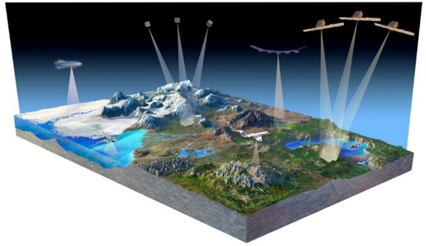
Physics-based simulations

Volcano Project Summary

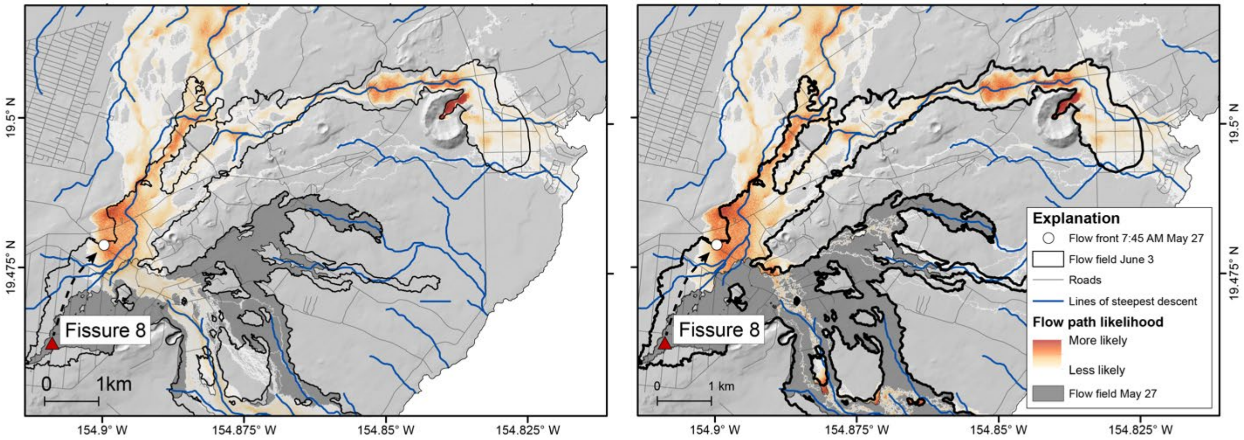




Methods

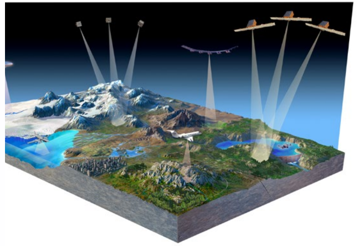


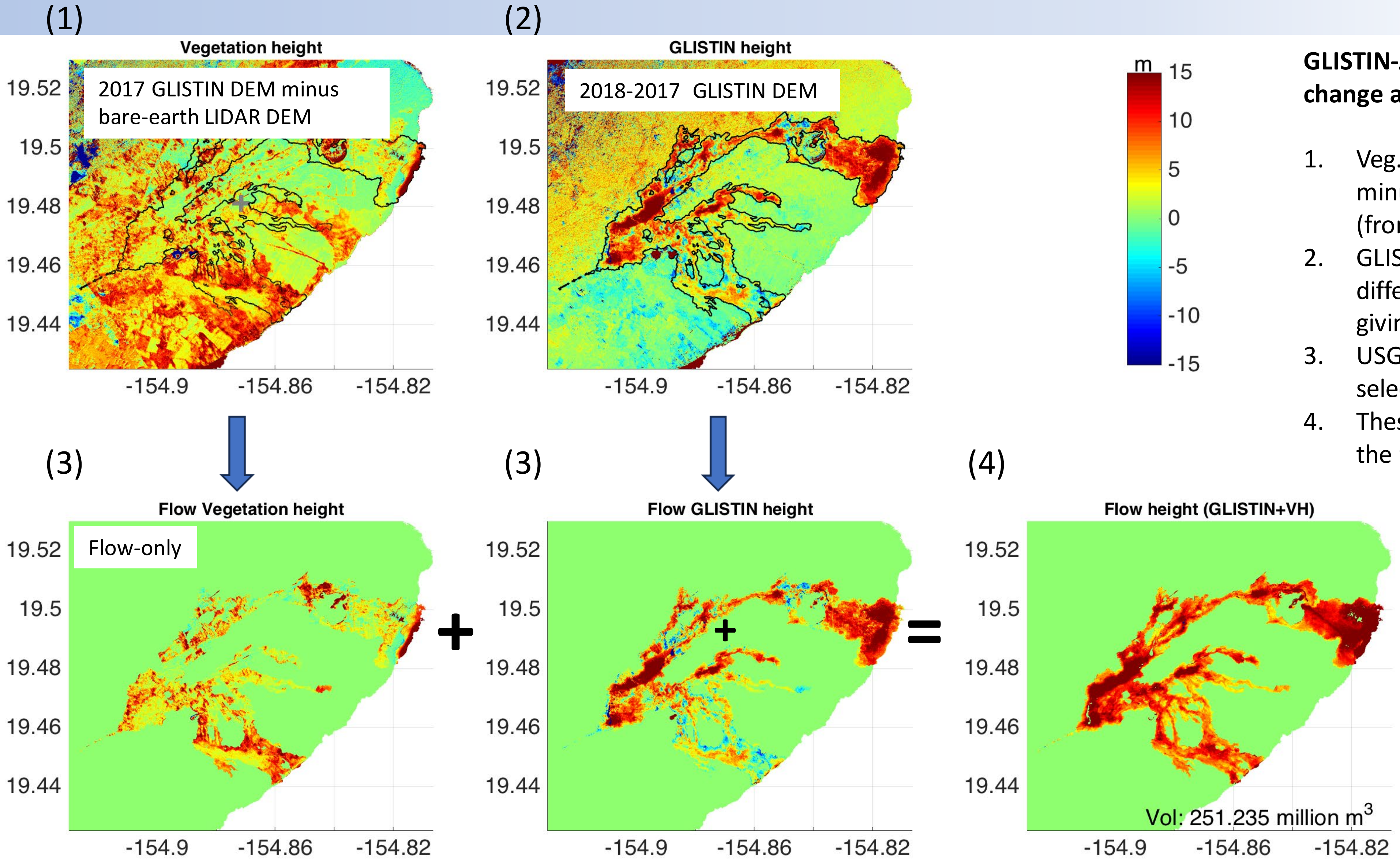
- Surface process forecasting
    - Kīlauea flow forecasting
    - Silicic dome and flow simulations
    - Dome stability analysis
- Physics-based models of volcanic eruptions and lava flows
    - Dynamical models
    - Coupled models of eruption dynamics and flows



DOWNFLOW probabilistic simulations during the 2018 Kilauea LERZ eruption.

Lava flow thickness computation





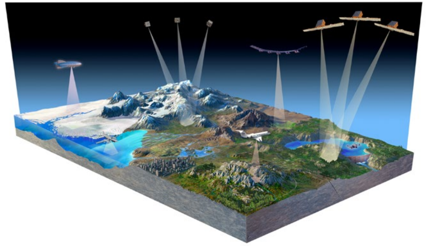
GLISTIN-A lava flow topography change and volume estimation:

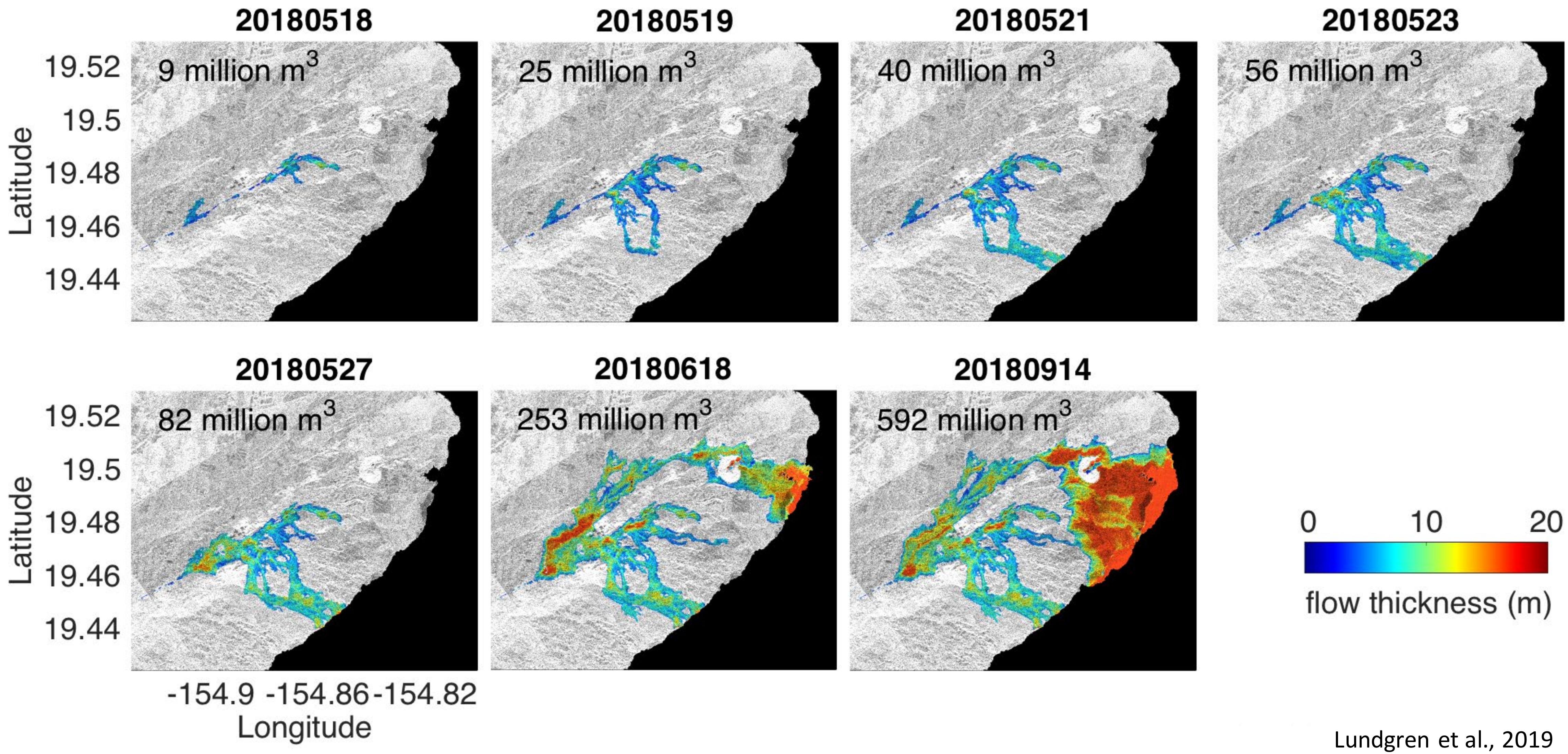
1. Veg. height: 2017 GLISTIN DEM minus bare-earth LIDAR DEM (from PGV via HVO)
2. GLISTIN co-eruption DEMs are differenced relative to Feb. 2017, giving the GLISTIN height change.
3. USGS lava flow shapefiles used to select flow areas.
4. These two (3) are summed to give the flow height (or thickness)

Flow shape files courtesy HVO, USGS

Lundgren et al., 2019

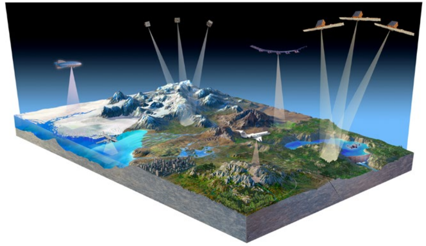
Thicknesses and volumes by date acquired

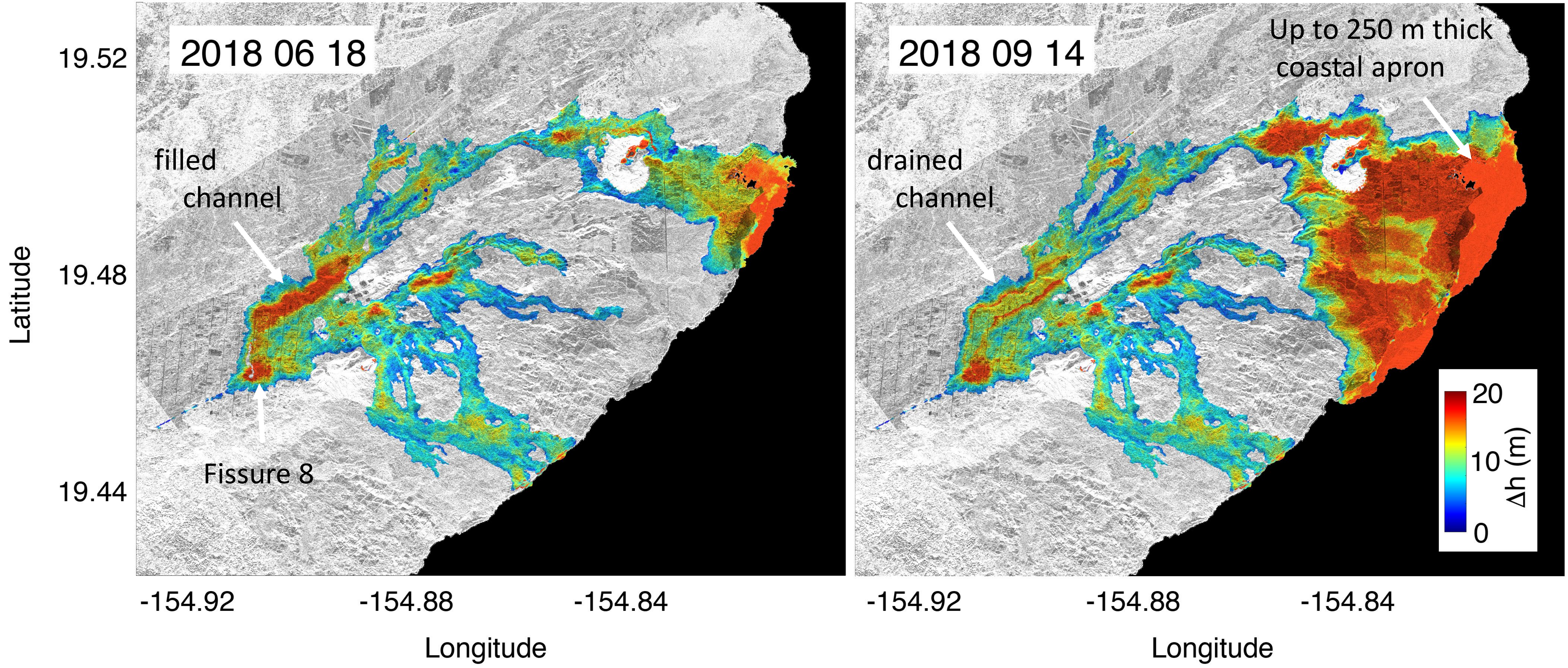




Lundgren et al., 2019

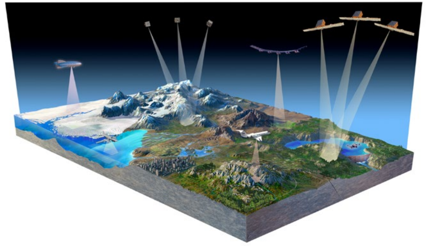
June 18 vs September 14 (post-eruption)





Lundgren et al., 2019

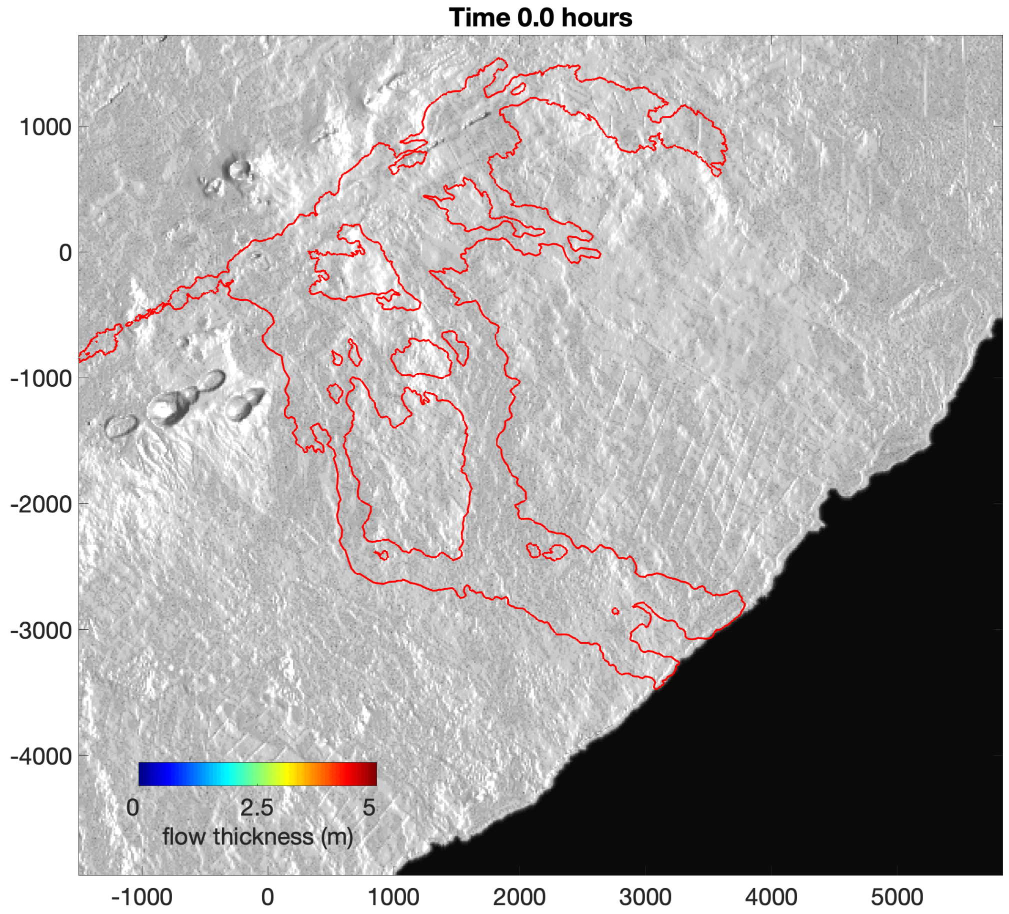
Lava flow modeling



Alberto Roman (JPL) has developed a lava flow modeling code (flowDEM) that is reasonably simple:

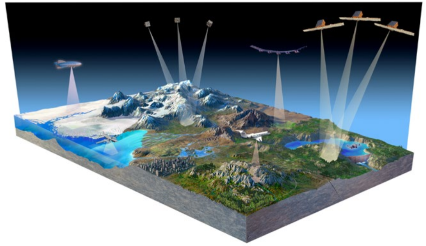
- Newtonian viscous
- isothermal

Yet captures the first-order flow features, and is a suitable starting point for testing lava flow sensitivity to topography resolution and noise



Simulation of Fissure 22, May 21, 2018, Kilauea Lower East Rift Zone (12.5 m sampled LiDAR bare-earth DEM)

Model for lava flows over topography

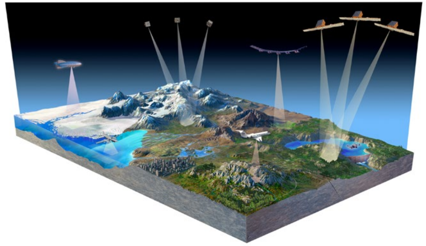


- Non-linear convection-diffusion PDE (e.g. Hinton et al., JFM, 2019)

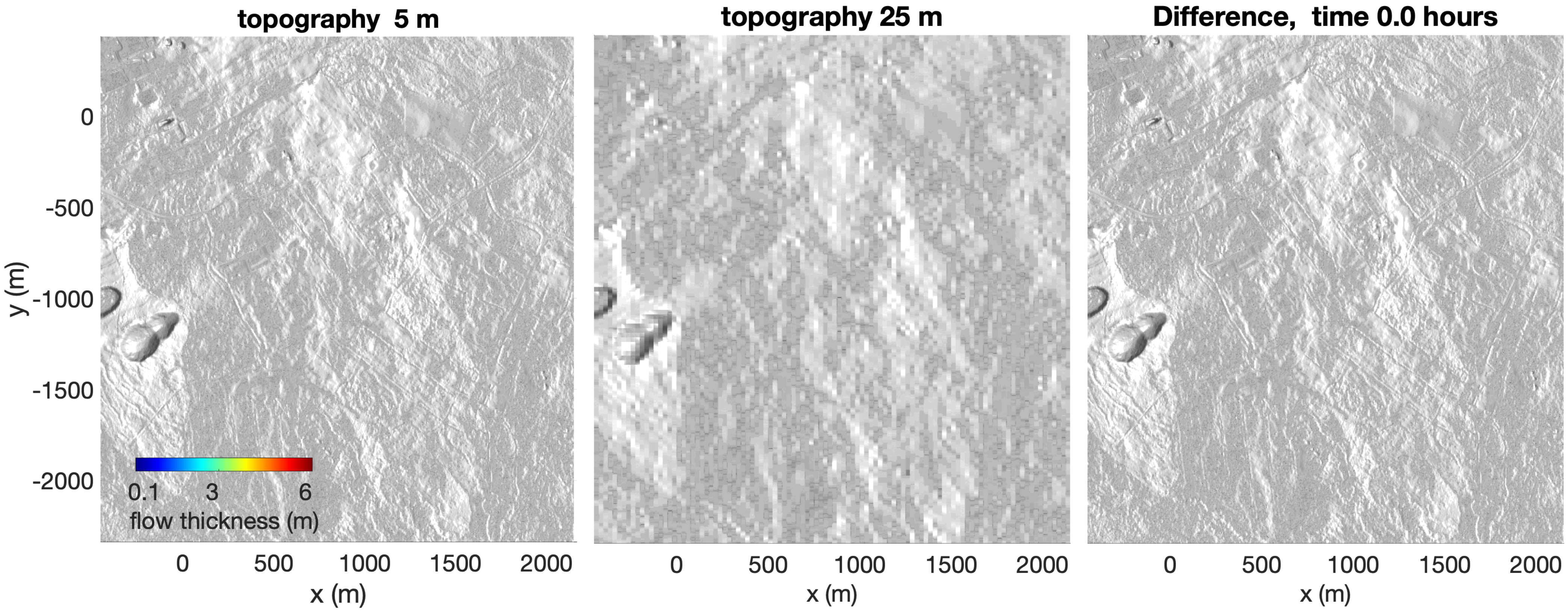
$$\frac{\partial h}{\partial t} = \frac{\rho g}{3\mu} \nabla \cdot [h^3 \nabla (B + h)]$$

- Competition of two terms
  - Gradients in the topography: ∇B
  - Gradients in the flow thickness: ∇h
- Solution through second order, shock capturing, finite difference scheme (Kurganov and Tadmor, 2000)

Kilauea F22 DEM resolution example

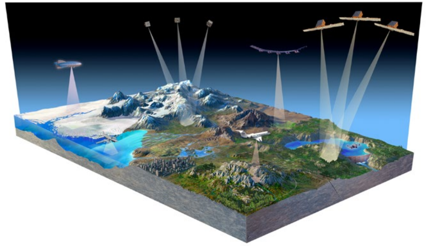


Higher (5 m) vs lower (25 m) resolution DEM

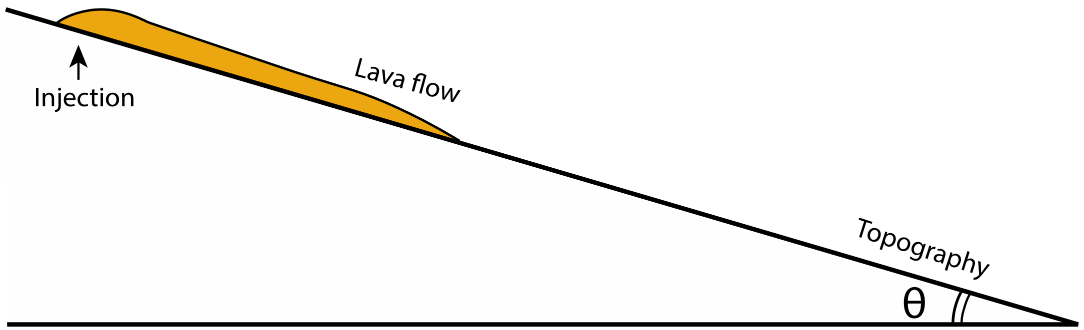


Flow parameters: q = 120 m^3/s, $\mu = 10^4$ Pa-s, solution grid scale = 5 m

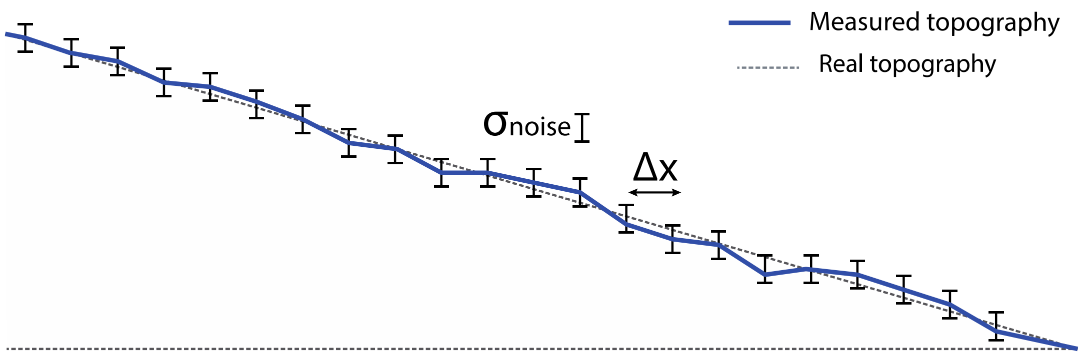
Noise effects: constant slope experiments



Real topography

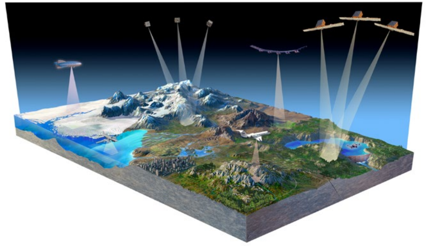


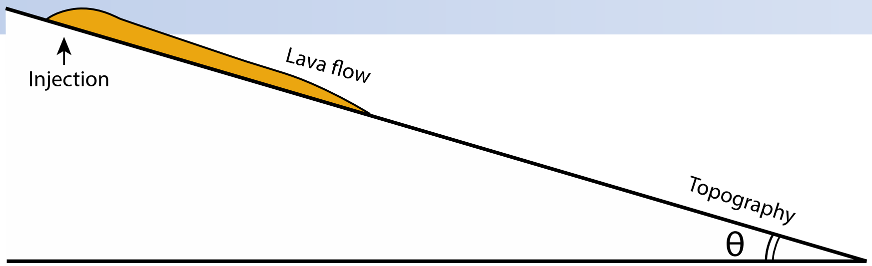
Measured topography

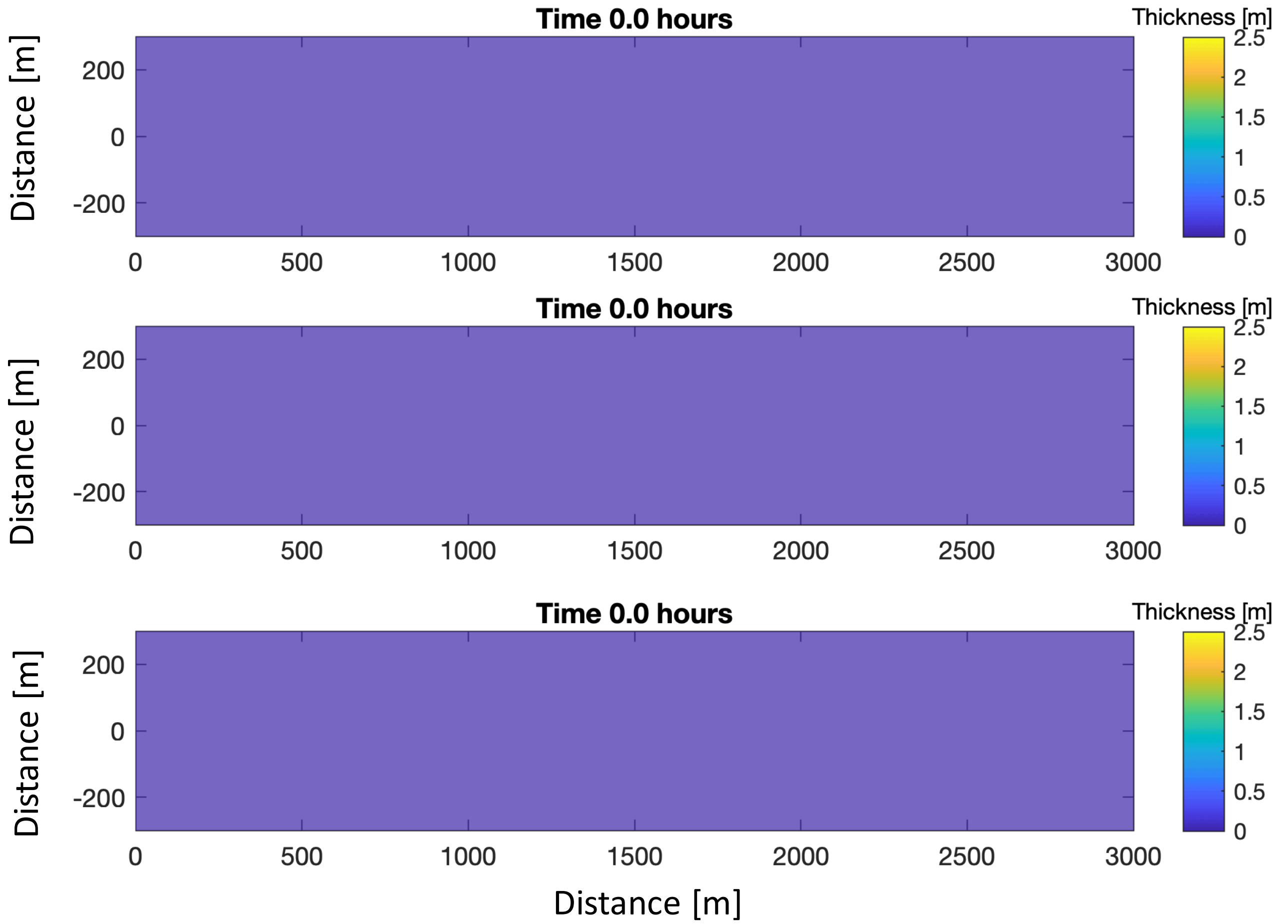


How noise levels and spatial resolution affect lava flow models?
For simplicity, we first assume uncorrelated gaussian noise

Resolution and noise effects: constant slope







High resolution - no noise

$\Delta x = 2.5$ m, $\sigma_{\text{noise}} = 0$ m

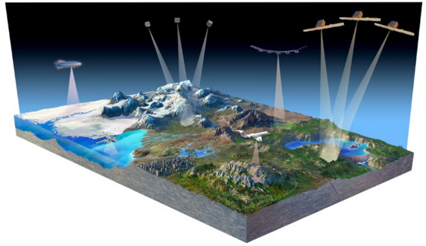
High resolution - noisy

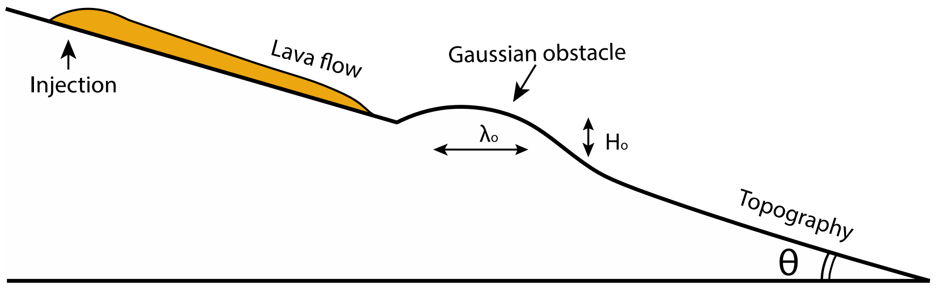
$\Delta x = 2.5$ m, $\sigma_{\text{noise}} = 0.5$ m

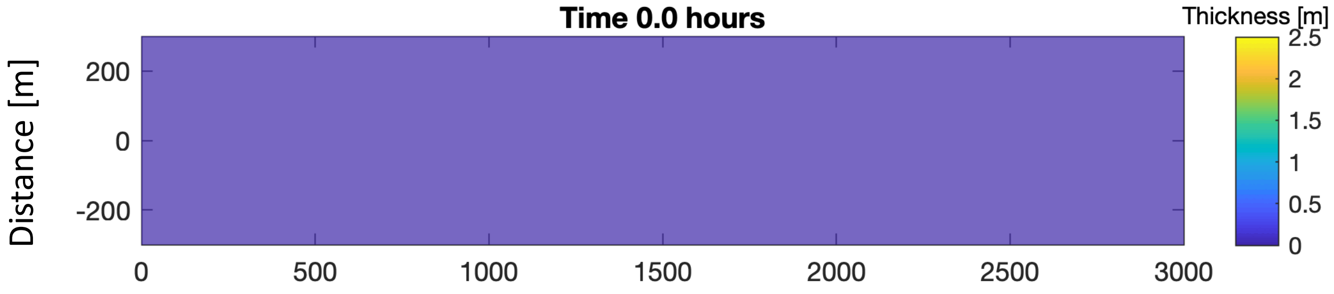
Low resolution - noisy

$\Delta x = 15.0$ m, $\sigma_{\text{noise}} = 1.0$ m

Resolution and noise effects: obstacles

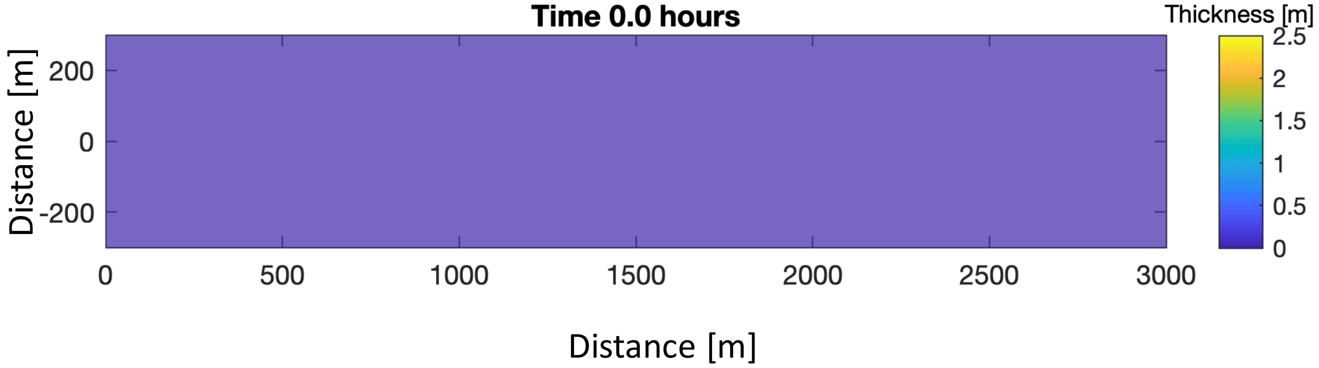






High resolution - no noise

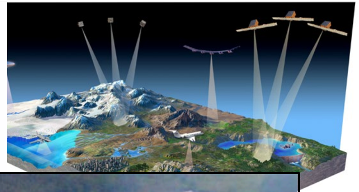
$\Delta x = 2.5$ m, $\sigma_{noise} = 0$ m



Low resolution - noisy

$\Delta x = 15.0$ m, $\sigma_{noise} = 0.5$ m

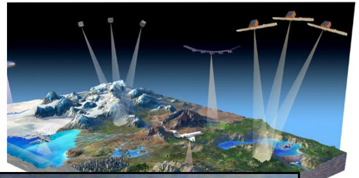
Key Takeaways



- STV science and technology gap filling efforts are underway (see AGU session)
- For volcano science we are investigating lava flow simulation outcomes:
  - Noise levels
  - Thickness and coverage
  - Flow advance rate
  - Effects of updated topography
- Other considerations:
  - Flow boundary detection
  - Increased physical realism (temperature-dependent viscosity, channelized flow)

Fissure 22 on May 22, 2018

Key Takeaways



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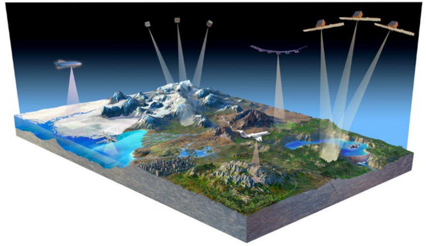
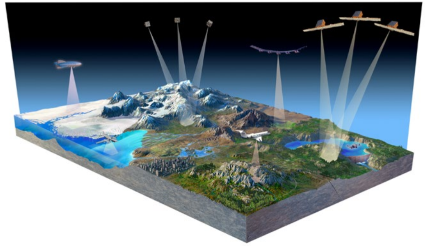
see poster by **Alberto Roman** for more details

Fissure 22 on May 22, 2018



Thank you!

End Goal/Planned Contribution to STV Observing System Architecture



- We will combine modeling tools with existing satellite and airborne topography datasets to investigate the impact of data quality and spatiotemporal sampling on our capability to forecast volcanic systems.
- Our goal is to provide a quantitative framework relating the characteristics of topographic change measurements to the accuracy and uncertainty of model solutions and predictions.
- This will allow us to identify optimal sampling strategies for different volcanic processes, which will serve as guidance for future missions.