Surface change based estimation of slow-moving landslide thicknesses

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Motivation:

The bases of most geophysical flows (landslides, glaciers, lava, etc.) are generally inaccessible.

Flow thickness, and how it varies spatially, is essential for estimating flow volumes and fluxes.

Landslide volumes are particularly poorly constrained by limited borehole data, but are nonetheless commonly used to determine erosion rates at the mountain range scale.

We propose an inverse method to accurately **predict thicknesses of slow moving landslides using remotely-sensed surface change data**.

Method:

Continuity equates changes in flow thickness, h, to the divergence of the flux, $\bar{u}h$, at each location (x,y) on a landslide:

$$\frac{\partial h}{\partial t} = -\nabla \cdot (\bar{u}h) \quad (1)$$

Equation (1) can be re-written in terms of the flow's vertically averaged velocity, thickness, and the gradients of these two variables:

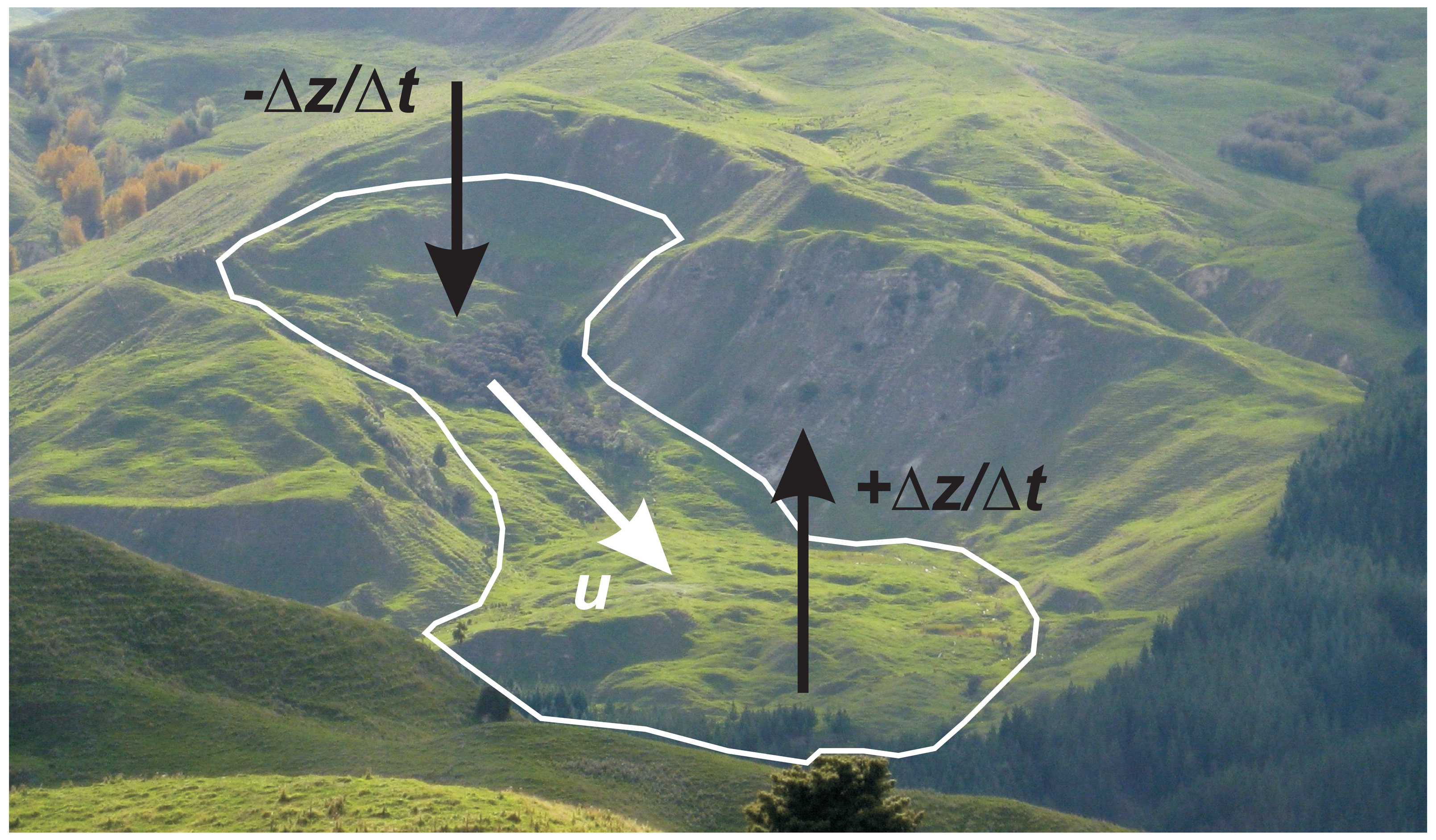
$$-\frac{\partial h}{\partial t} = u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) \quad (2)$$

Over an interval of time, we can measure a flow's change in thickness and its velocity, allowing $h(x,y)$ to be determined by inverse methods. We solve the matrix equation

$$Ah = -2\Delta x \frac{\Delta h}{\Delta t} \quad (3)$$

for h, where the matrix A is sparse with ($u_{i+1,j}$ - $u_{i-1,j}$ + $v_{i,j+1}$ - $v_{i,j-1}$) on the main diagonal, and +/- $u_{i,j}$ and $v_{i,j}$ on the off diagonals, subject to non-negative constraints, to **predict landslide thickness** at each location in a given study area.

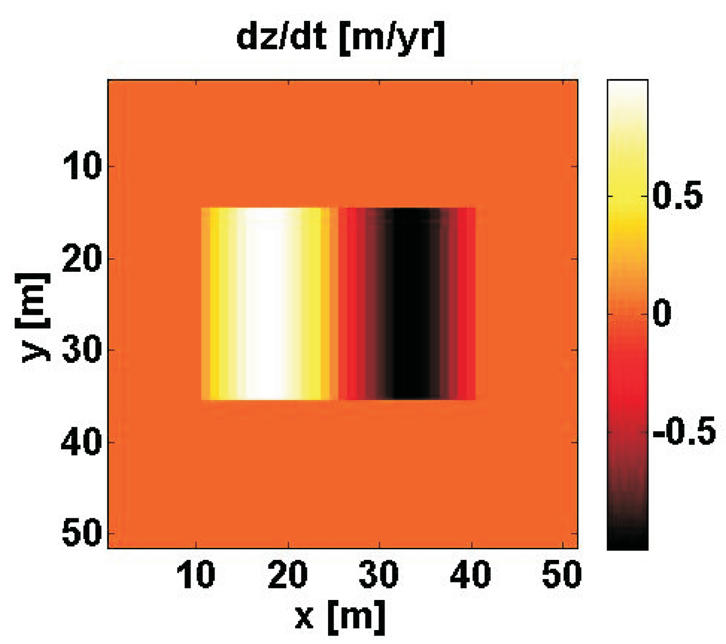
Landslide measurements:



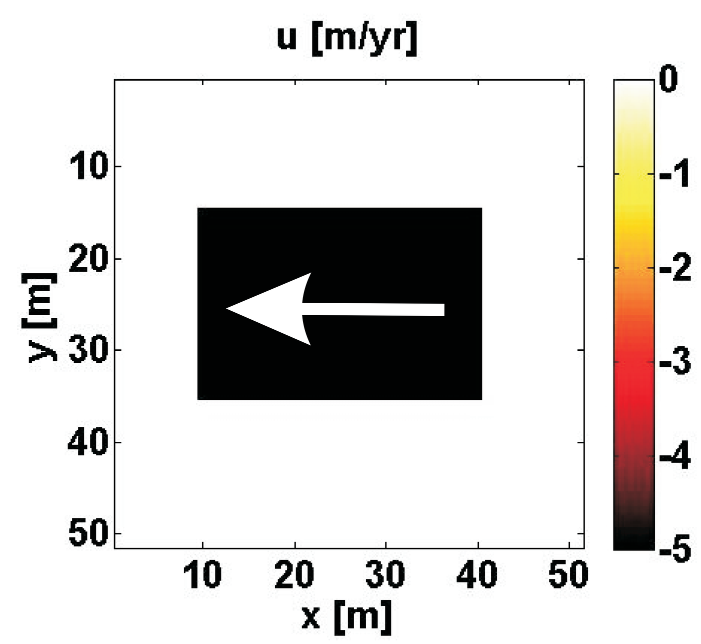
Synthetic test:

A **rotational slump** landslide:

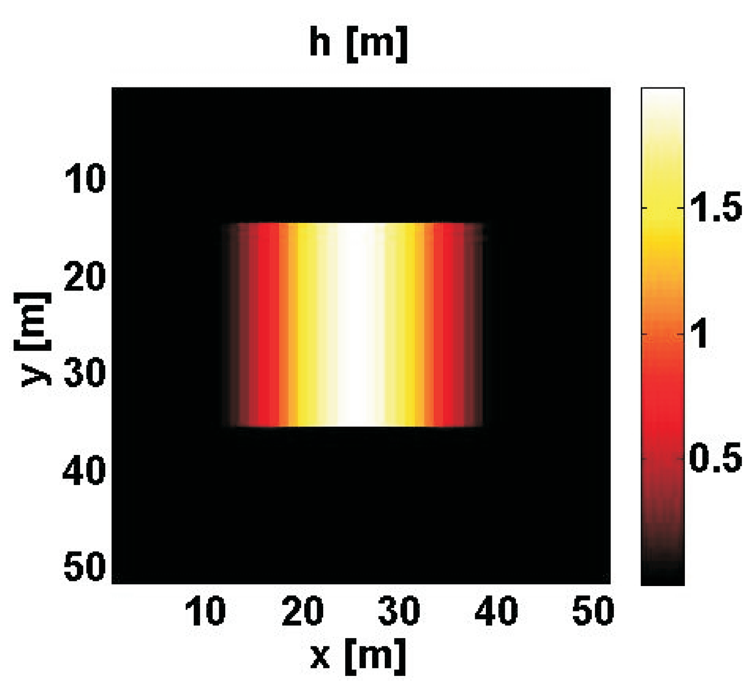
Δh/Δt



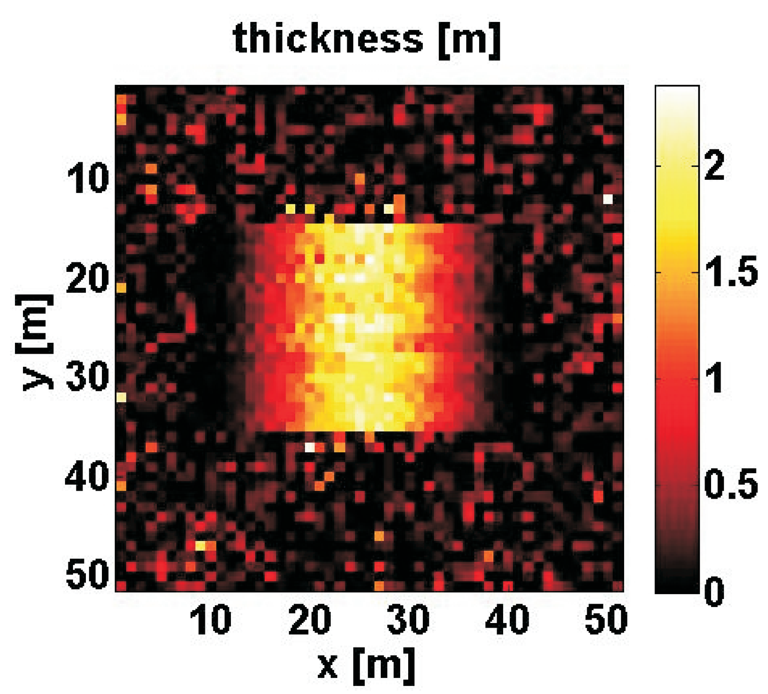
velocity



Known thickness



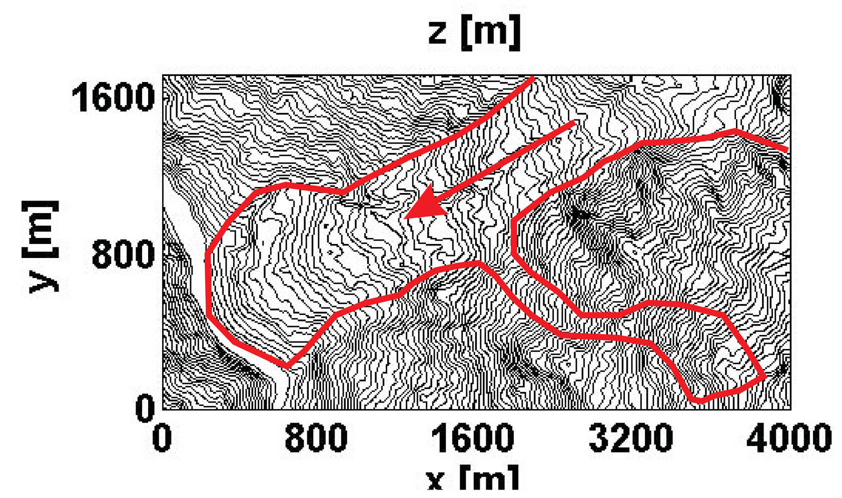
Predicted w/ 10% measurement errors



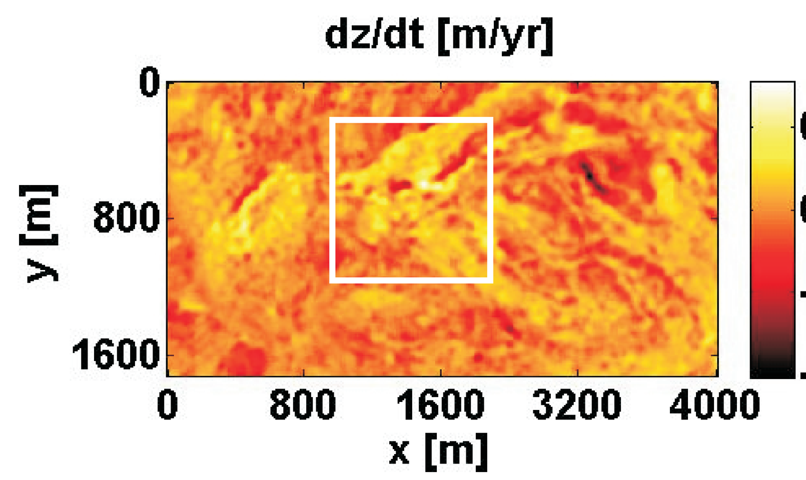
Preliminary real-world example:

Boulder Creek Earthflow, Eel River, northern California

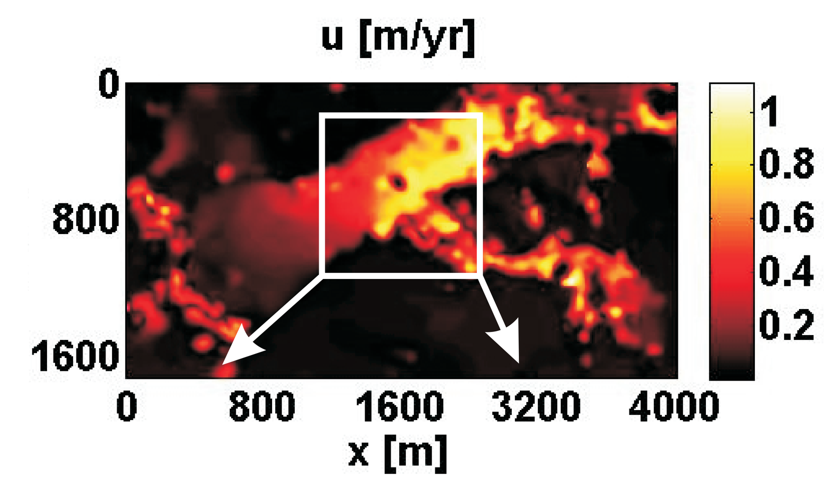
DEMs from 2006 airborne LiDAR and 1944 aerial photo stereo pair



Δh/Δt

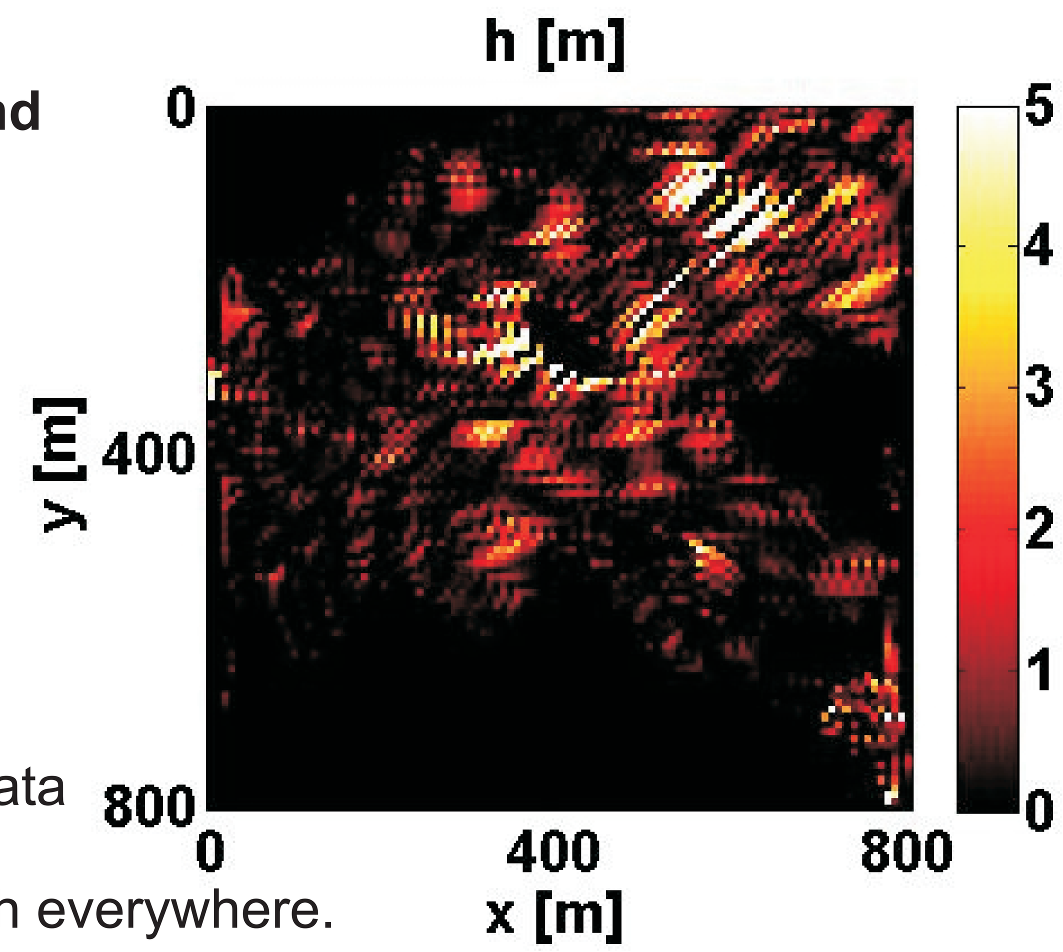


velocity magnitude



Velocity fields derived from co-registration and correlation of repeat aerial photographs using the COSI-Corr software.

Predicted thickness:



Thickness is the right magnitude where predicted, but too little data was retained in this inversion to predict depth everywhere.

Future improvements:

(1) Create more accurate DEMs from stereo aerial and satellite imagery.

(2) Constrain depths using shallow geophysics (GroundPenetrating Radar).

(3) Streamline the inversion to allow more data to be used.