

# Slope deformations in high-mountain regions as observed by InSAR: Examples from the Cordillera Blanca, Peru

H. Frey<sup>1</sup>, T. Strozzi<sup>2</sup>, R. Caduff<sup>2</sup>, C. Huggel<sup>1</sup>, J. Klimeš<sup>3</sup>, V. Vilímek<sup>4</sup>, A. Wiesmann<sup>2</sup>, A. Kääb<sup>5</sup>, A. Cochachin<sup>6</sup> & S. Plummer<sup>7</sup>

<sup>1</sup>Department of Geography, University of Zurich, Switzerland; <sup>2</sup>Gamma Remote Sensing AG, Gümligen, Switzerland; <sup>3</sup>Institute of Rock Structure and Mechanics, Czech Academy of Sciences, Prague, Czech Republic;

<sup>4</sup>Department of Physical Geography and Geoecology, Charles University Prague, Czech Republic; <sup>5</sup>Department of Geosciences, University of Oslo, Norway; <sup>6</sup>Unidad de Glaciología y Recursos Hídricos, Autoridad Nacional del Agua, Huaraz, Peru; <sup>7</sup>ESA Climate Office, ECSAT, Didcot, Oxfordshire, UK

## InSAR & SLOPE STABILITY

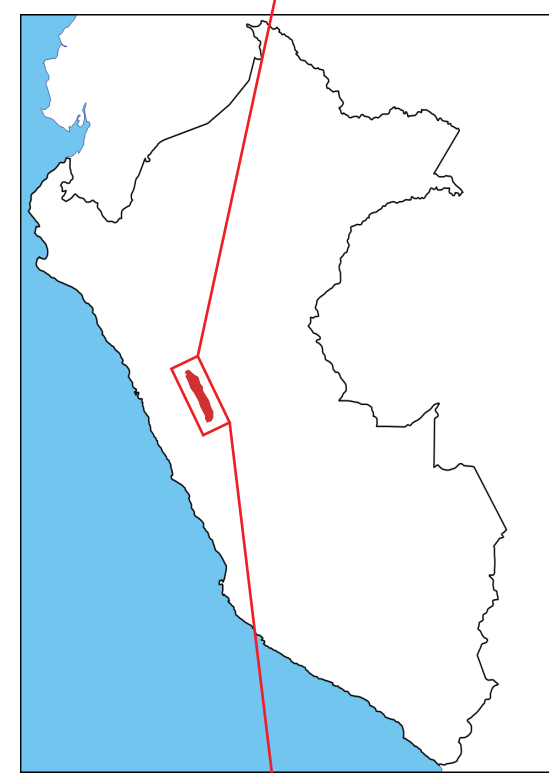
Information on surface displacements is very valuable for early detection of emerging hazard potentials and their assessment. Interferometric processing of SAR data (InSAR) provides the possibility to remotely detect different types of surface displacement processes, also in remote locations where no other monitoring data are available.

## DATA

Data archives of spaceborne SAR sensors such as ERS-1/2, ENVISAT, ALOS PALSAR-1/2, TerraSAR-X, Radarsat-2 and Sentinel-1 provide information reaching back to the 1990s allowing for detection and analysis of both current and past processes.

## STUDY REGION & CONDITIONS

The Cordillera Blanca in Peru (see small map to the right) is characterized by steep topography, the World's highest concentration of tropical glaciers, numerous glacial lakes, strong seismic activity and a densely populated valley bottom. Environmental conditions, with an extended period of mostly cloud-free conditions during austral winter (dry season), sparse vegetation cover and only very limited snow coverage are particularly favorable for InSAR analyses.



## CONTEXT & INVESTIGATED PROCESSES

In the ESA-funded S:GLA:MO project (sglamo.gamma-rs.ch), the potential of InSAR products for hazard assessment of glacial lakes was investigated. In this framework, a number of slope deformation processes (not only related to glacial lake hazards) were detected in the Cordillera Blanca. A selection of such surface displacements as detected by InSAR data is presented here.

## CONCLUSIONS & OUTLOOK

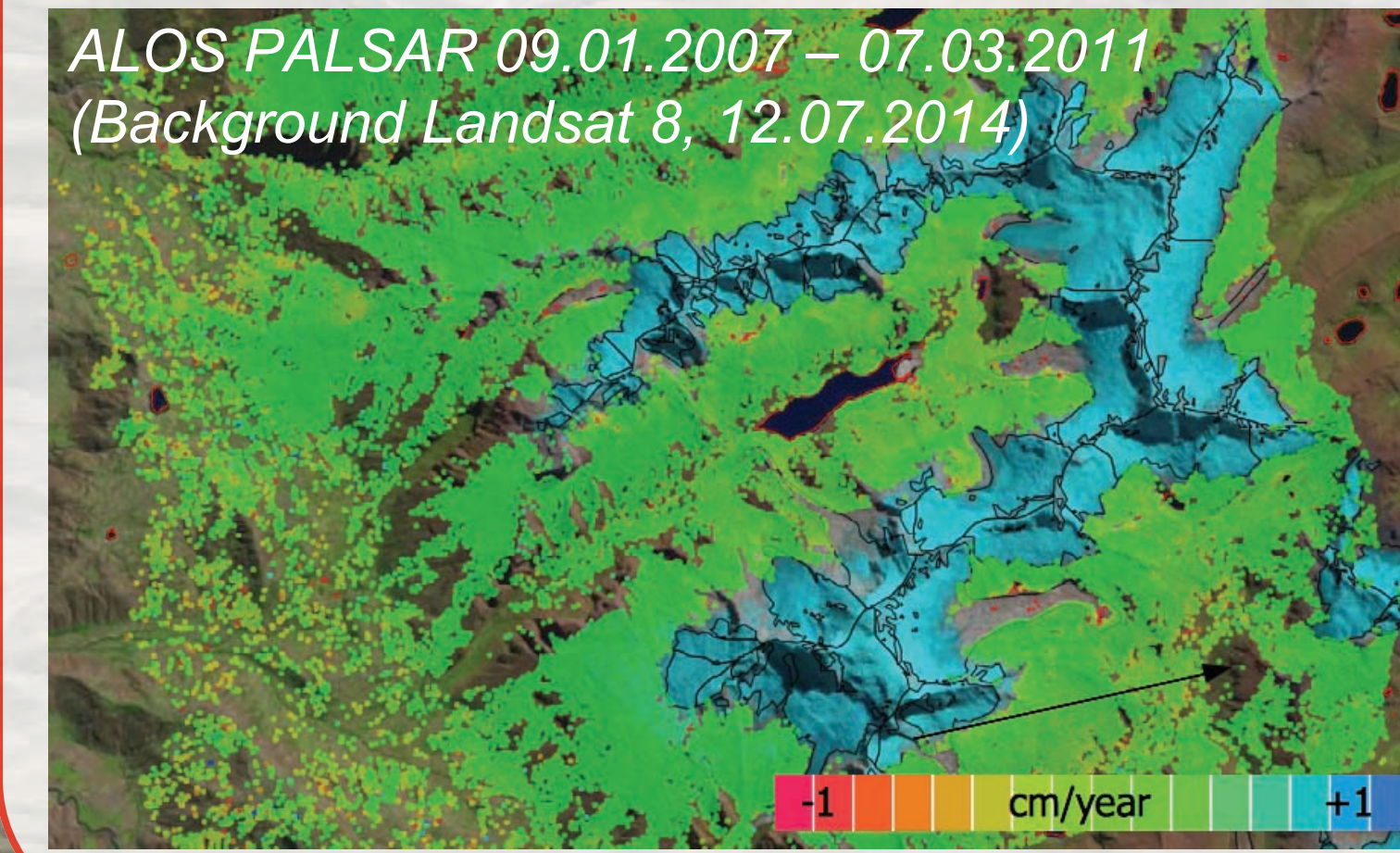
The presented examples demonstrate the potential of different InSAR products on slope deformations and surface displacements. Such information can be used for both integrative hazard assessments and glaciological investigations, but can hardly be obtained by other means. In regions like the Cordillera Blanca where a variety of potentially hazardous and interacting processes are present and coincide with a high exposure and vulnerability, such data products provide invaluable information for early detection of hazard potentials and may serve as a basis for prioritization and decision-making by the authorities. Future work will assess the potential of InSAR data and products for hazard mapping as well as for an operational integration in monitoring and early warning systems, complementing ground-based information.

## REFERENCE

Klimeš, J. & Vilímek, V. (2011). A catastrophic landslide near Rampac Grande in the Cordillera Negra, northern Peru. *Landslides* 8 : 309–320. DOI: 10.1007/s10346-010-0249-1  
Klimeš, J., Novotný, J., Jordán de Urries, B., Vilímek, V., Emmer, A., Strozzi, T., Kusak, M., Rapre, A.C., Hartvich, F. & Frey, H. (in review). Landslides in moraines as triggers of glacial lake outburst floods: example of the Palcacocha Lake (Cordillera Blanca, Peru). *Landslides*.

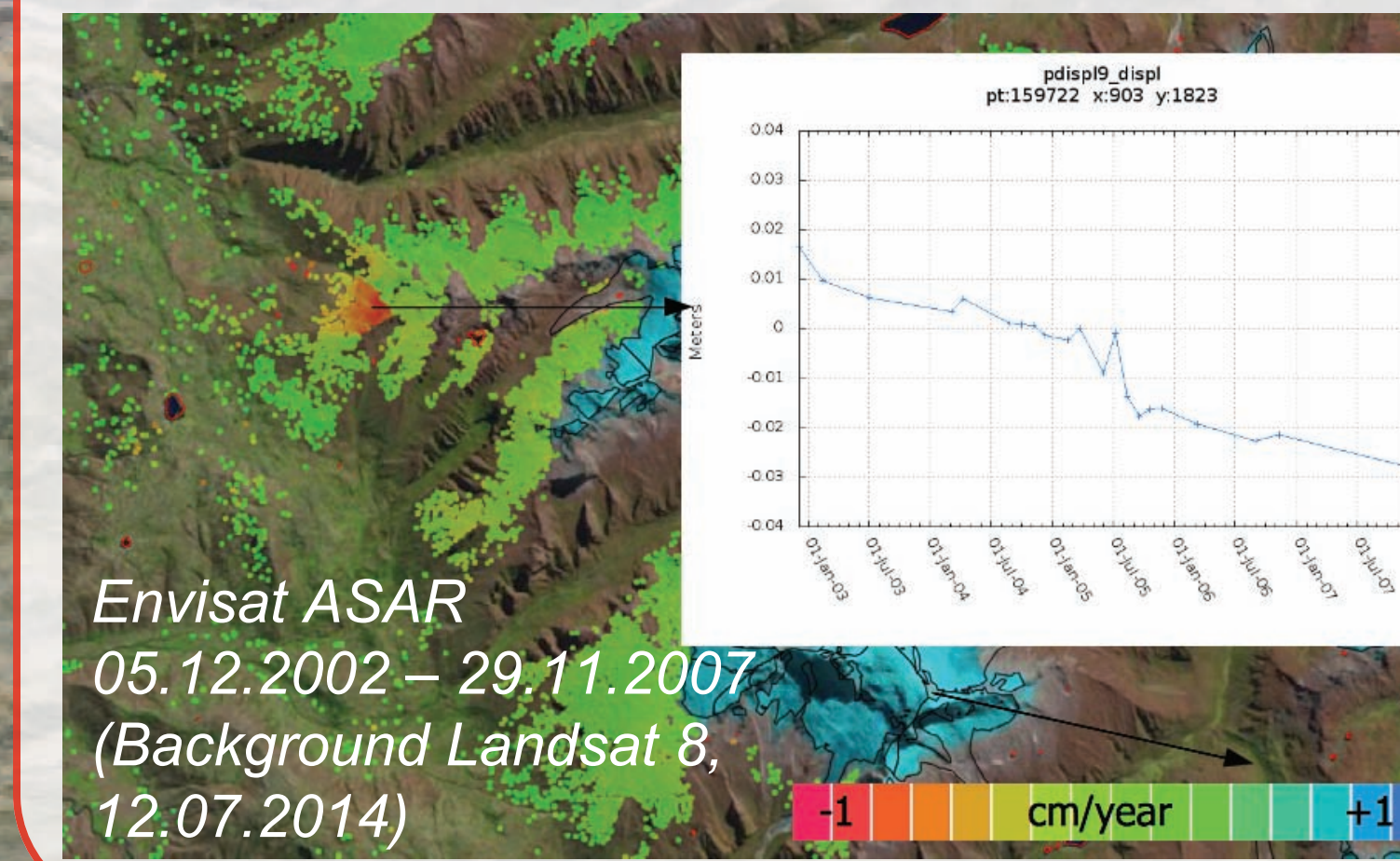
## SLOPE STABILITY OF STEEP VALLEY FLANKS

The image below shows the result of a Persistent Scatterer Interferometry (PSI) for the Santa Cruz Valley (north) and around Laguna Paron (center), based on a stack of 19 ALOS scenes. Valley flanks show no displacements between 2007 and 2011. This information so far has not been available.



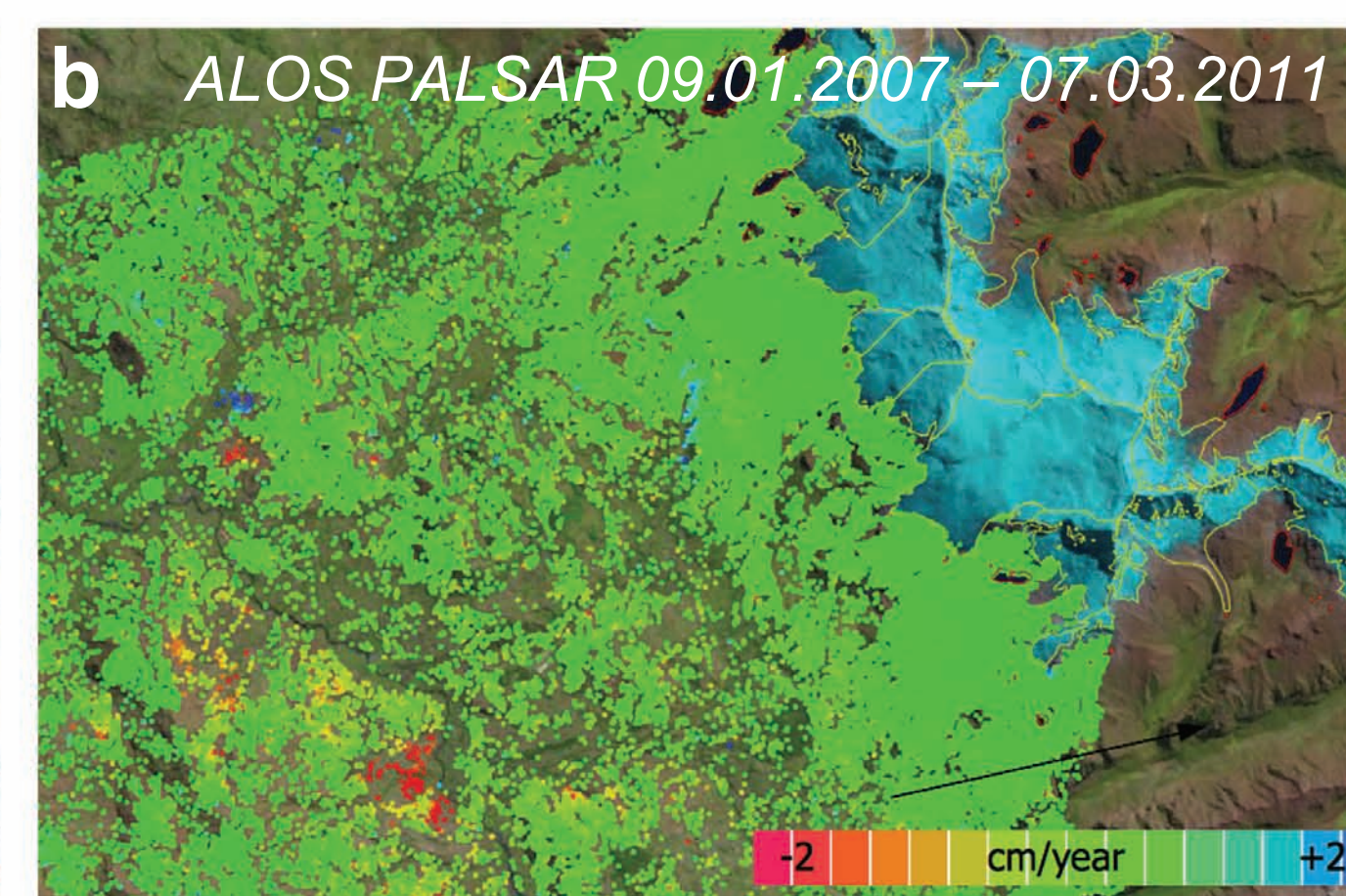
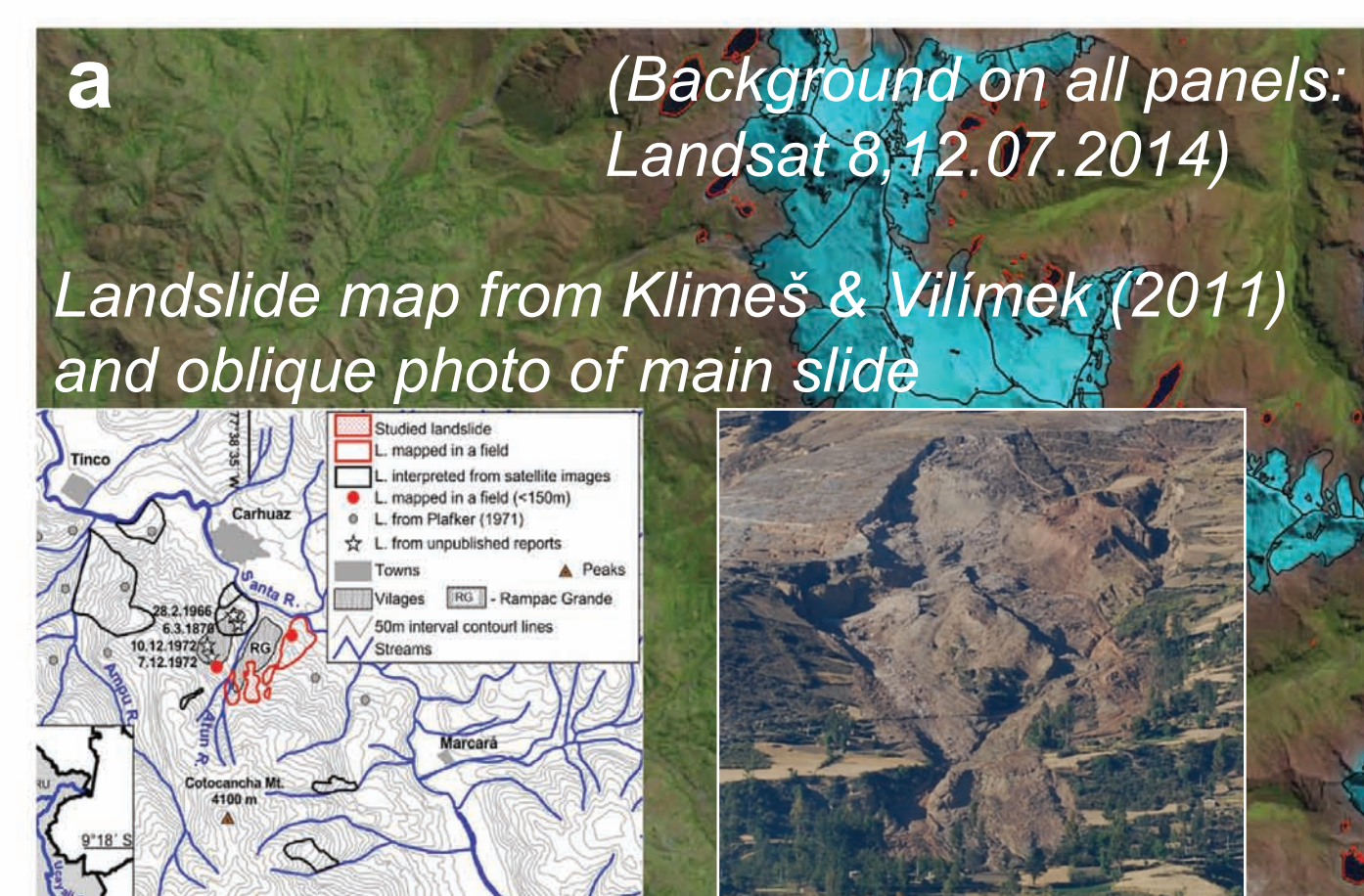
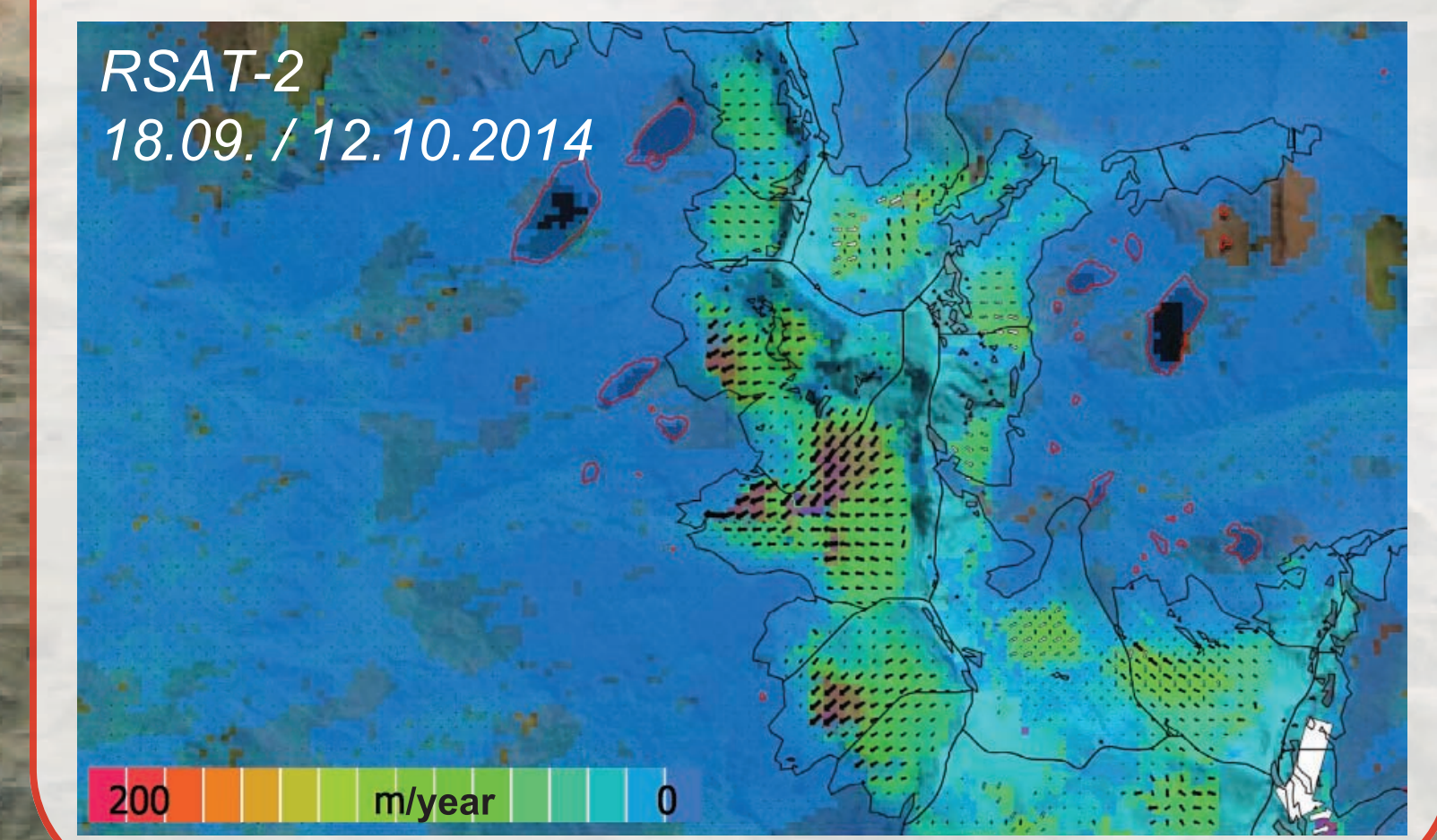
## EVOLUTION OF SLOPE STABILITY

A PSI analysis of 21 Envisat ASAR scenes allows for the reconstruction of the landslide evolution between 2003 and 2007 of an active zone at the entry of the Santa Cruz Valley; periods with minor displacement rates are interrupted by a more active phase in 2005.



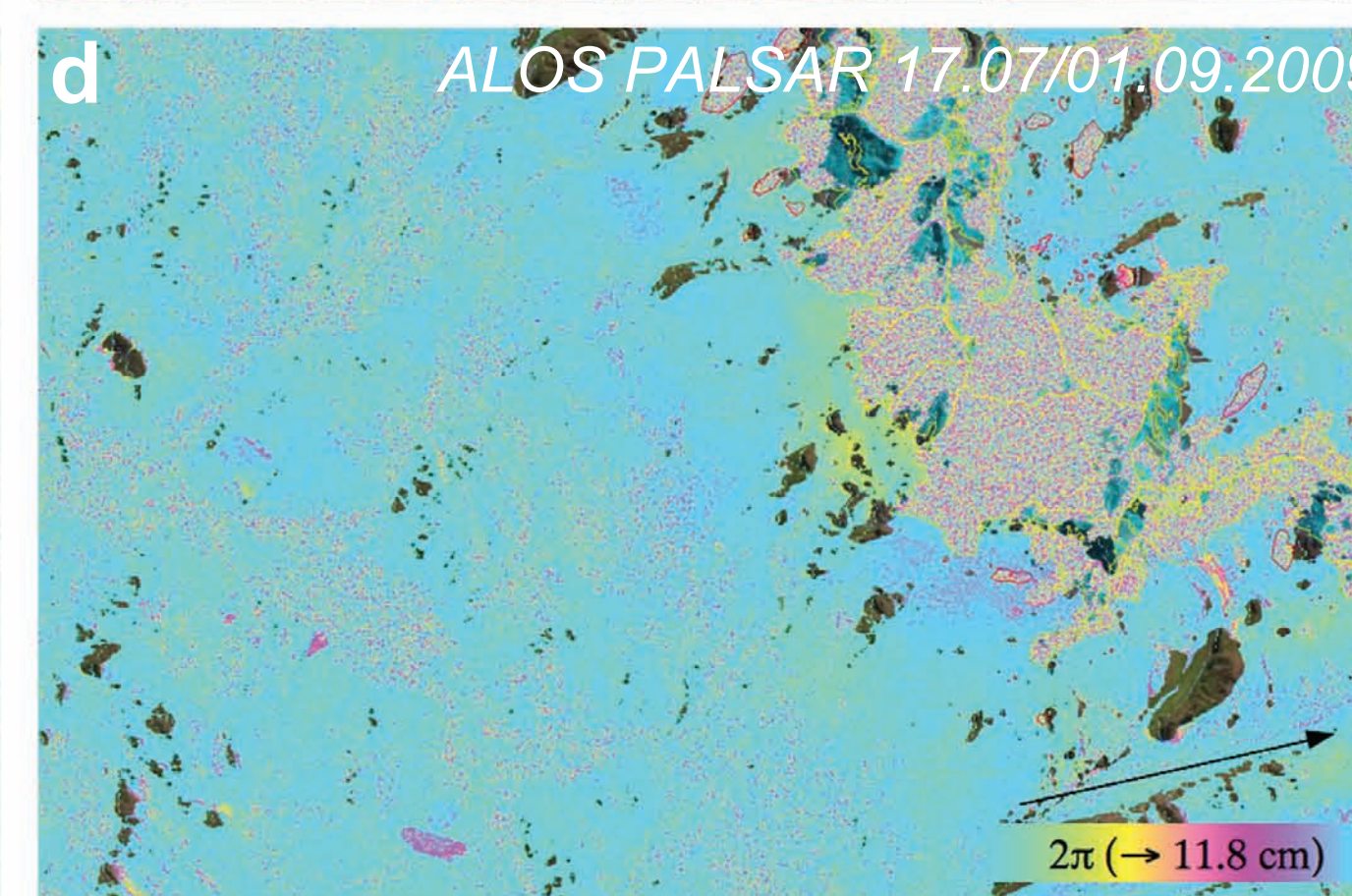
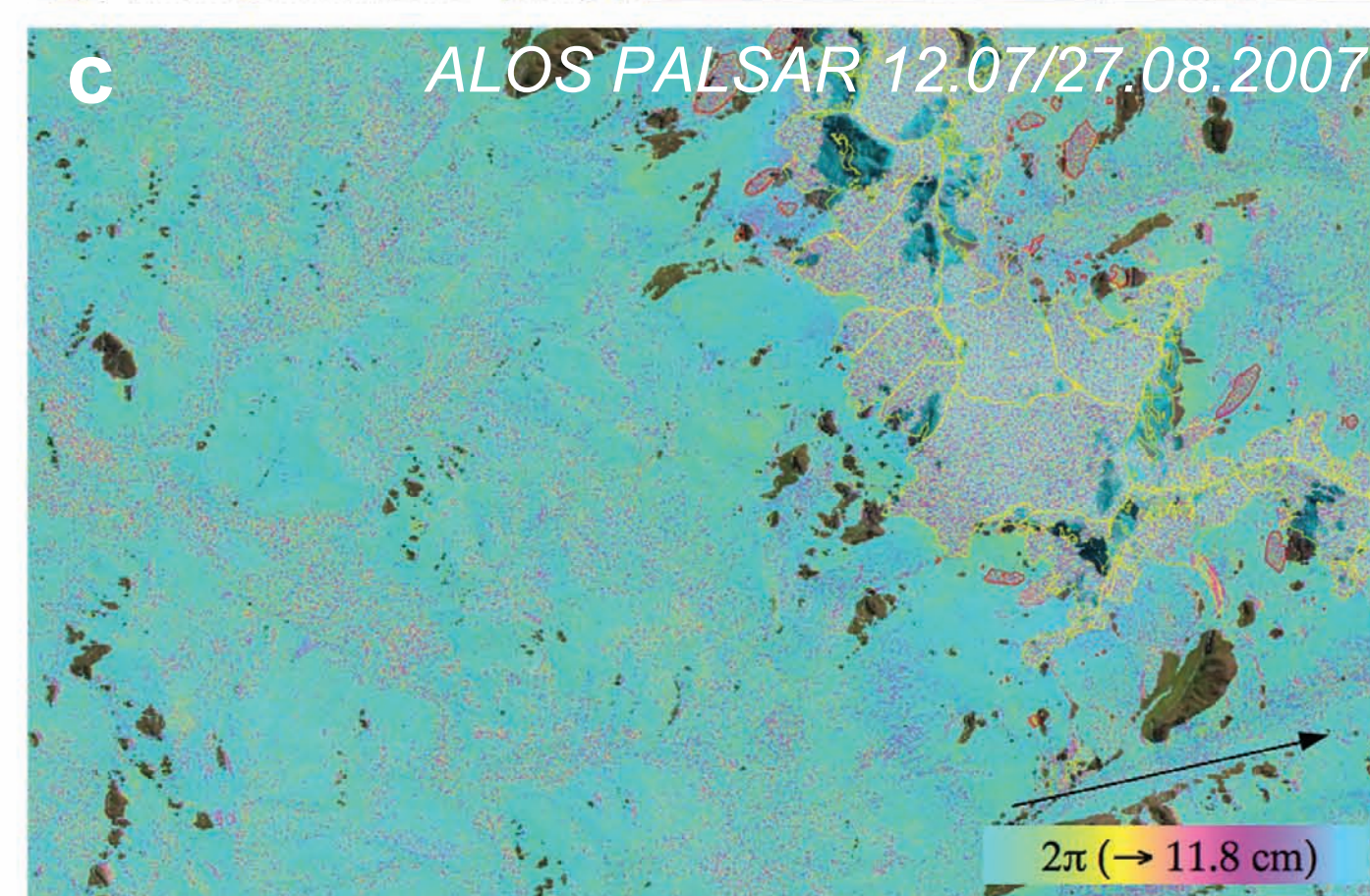
## GLACIER FLOW VELOCITIES

SAR offset tracking allows for estimating glacier flow fields. Based on an Radarsat-2 image pair from 18.09. and 12.10.2014 (24d), flow velocities of up to 200 m y<sup>-1</sup> have been observed at Mount Hualcán for this period.



## LANDSLIDE ACTIVITY

On 25 April 2009 a landslide near the village of Rampac caused casualties and destruction of infrastructure. Klimeš and Vilímek (2011) mapped the landslide zones in the field (a). A PSI analysis of 19 ALOS scenes confirms these zones and indicates another active zone some 5 km upstream the Santa River (b). Comparisons of ALOS interferograms from 12.07. and 27.08.2007 (c) and 17.07. and 01.09.2009 (d) reveal higher activity in two zones in 2009 (d). Such interferograms allow for the identification of movements more rapid than a few cm y<sup>-1</sup> and can be used for the delineation of landslides.



## MORaine STABILITY

There is concern on the stability of the moraine surrounding Lake Palcacocha above the city of Huaraz. In-situ observations (mapping and geophysical investigations, (a) and (b)) have here been compared to zones with different surface displacement rates, identified based on different InSAR products (polygon outlines in c).

A PSI analysis indicates stable conditions over large areas and several locations with velocities close to 1 cm y<sup>-1</sup> (arrows A–E in (c)). One such zone is located on the moraine crest, above the zone where a moraine slip detached in 2003 (A). (B) is on or close to a temporarily inactive landslide as identified in field investigations. At the location of the other movements (C–E) pronounced rills are found, indicating that the observed surface changes might be related to superficial movements. ((a) and (b) from Klimeš et al. (in rev.))

