Workshop SAR and Cryosphere

Multi-temporal and multi-sensor quantification of surface flow velocity of mountain glaciers to understand changes in glaciers dynamics and improve glacier thickness

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IGE

Introduction

- Regional and long-term observation of glaciers is necessary to estimate:
  - The contribution of glaciers to sea level rise
  - Freshwater resources
  - Natural hazards (lake outburst floods)

- Ice dynamics is a key parameter
  - It is a good indicator of climate change
  - Essential parameter to model accurately ice thicknesses
  - The volume of mountain glaciers and spatial repartition of the ice masses is poorly documented

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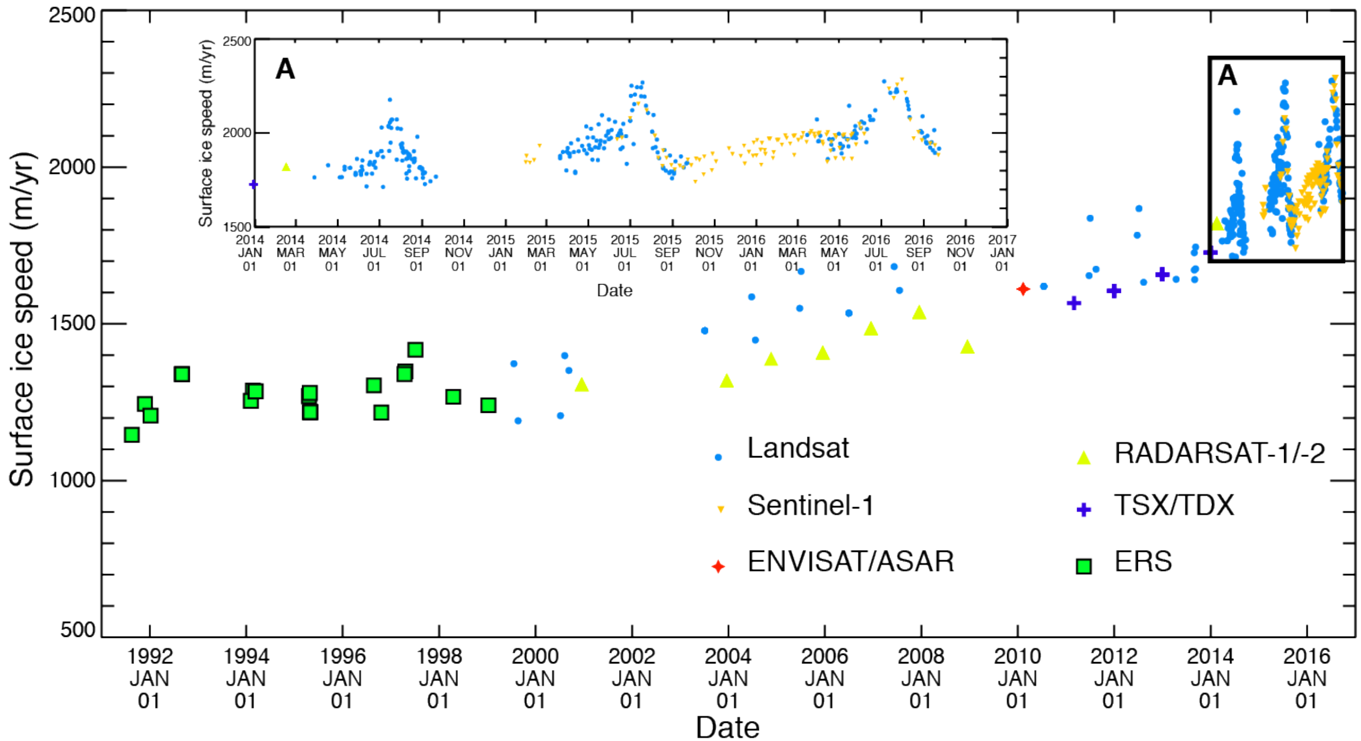
Introduction

- 2013 – Present: new era of satellite imagery that allows
  - Observation of the ice dynamics on seasonal scales
  - Major advance to understand changes in mass and dynamics



Ref: *Mouginot et al.*, 2017

Science questions

- What is the variability of ice dynamics on multi-temporal scales?

Ice velocity

- How can we determine ice thicknesses more accurately on regional scales?

Objectives

- Assemble an automated processing chain that allows to map ice velocity regionally using a wide variety of sensors

- Evaluate the capacity of Sentinel-2 to derive surface ice flow velocity on regional and multi-temporal scales

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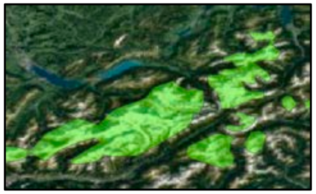
Automated workflow to derive large scale ice velocities

GitLab python

Image preparation

QGIS SQL

Sensor dependent



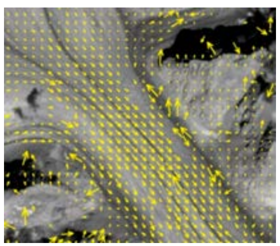
- Delineation of the region of interest
- Local database creation with existing satellite data
- Image pair creation (with identical geometry)
-Sobel Filter

Google USGS Kalideos Alpes peps amazon.fr esa

Ice displacement calculation

.f90

Time consuming



New image correlation software based on AMPCOR/JPL:

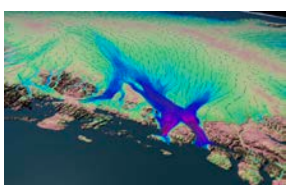
- Python interface + Fortran core code (flexible and efficient)
- Possibility to restart a killed job, use a mask, initial offset map => adaptive system

SQL

Monitoring system of the processing states. Works in parallel with the workflow.

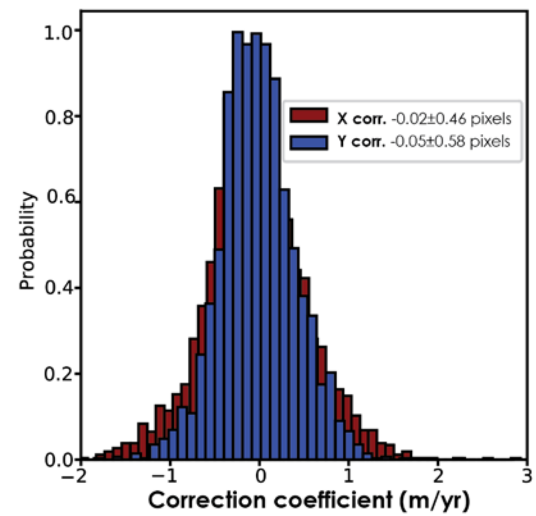
Post-processing

GDAL



- Calculation and calibration of the ice speed maps (Fig. 1)
- Median filter to remove outliers
- Geotiff creations
- Memory cleaning

Ice velocity



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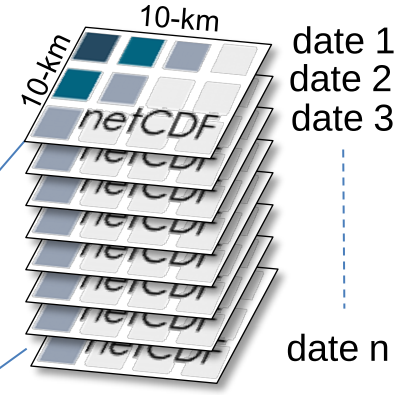
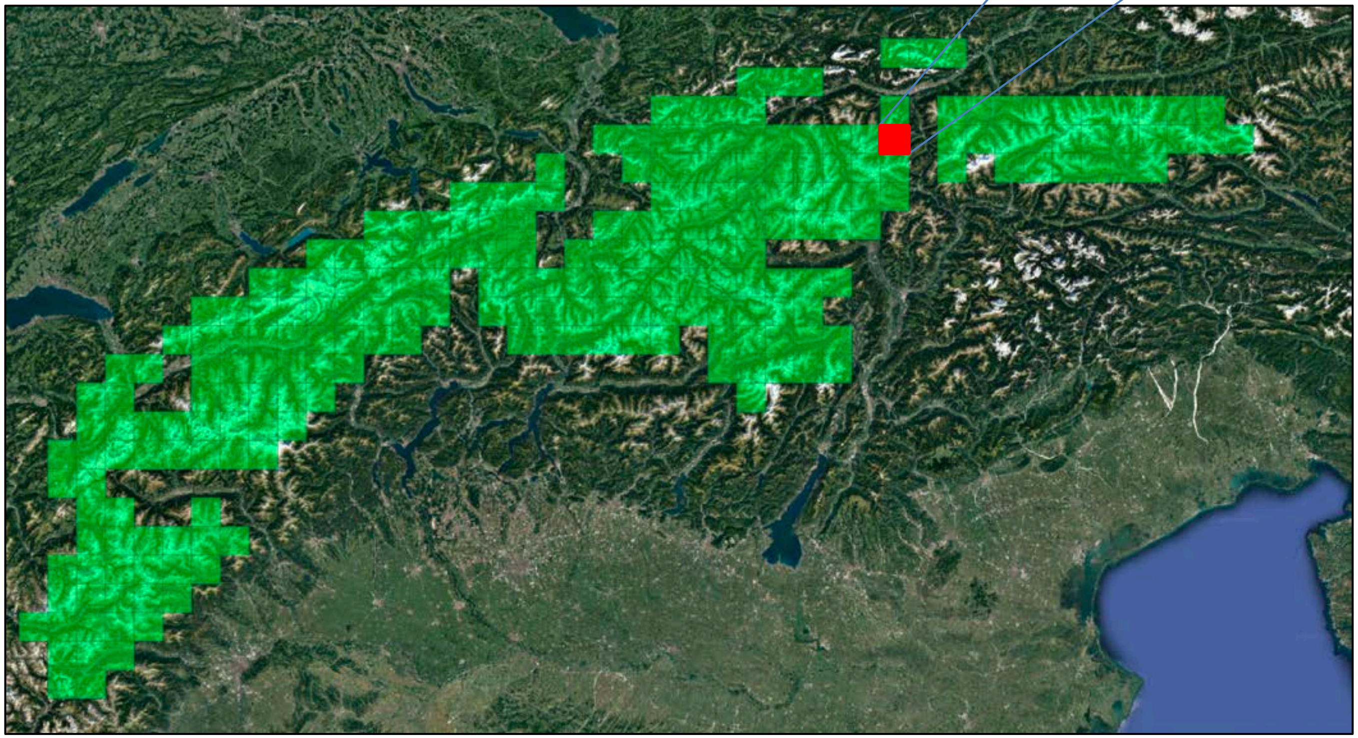
Data analysis - average velocity field calculation

- Region is decomposed in a grid of equally sized cube of 10x10 km with a pixel spacing of 50-m
- All calculated ice velocity for each grid cell is stored in a netCDF data format
- A weighted average is calculated pixel by pixel



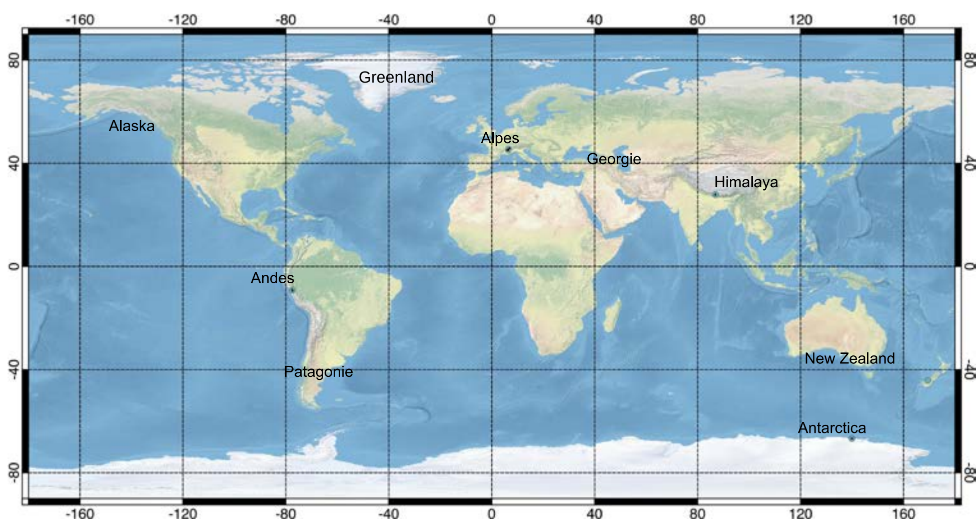


Resources

- Use of calculation structure at UGA: Ciment/GRICAD
- Communautary structure adapted for big data calculation and data storage

Some numbers

- 1 million hours of calculation since early October **(on DIAS[1] or between 30000 and 40000 eur/an).**
- Number of image pairs: ~**600 000**
- Amount of data downloaded: ~ **30-100 To / regions**



[1]Data and Information Access Services

Error analysis

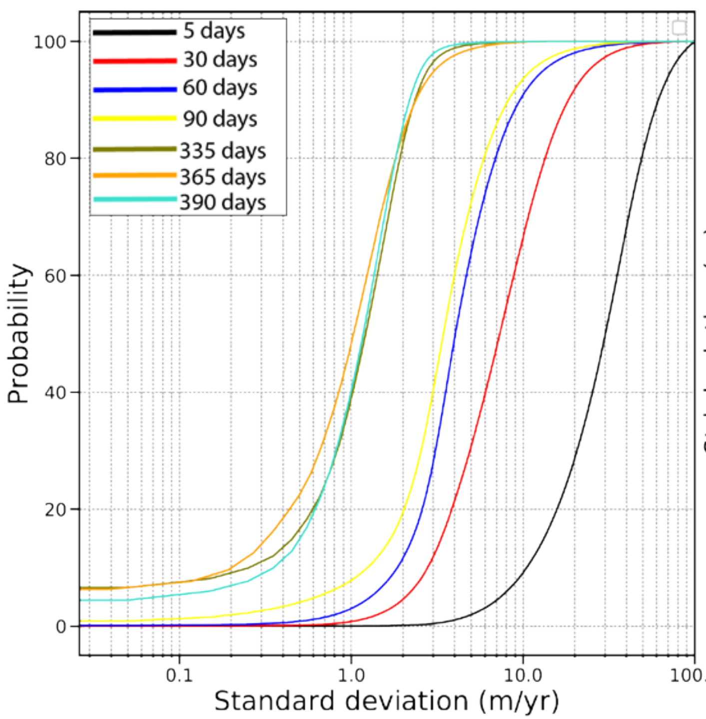
Error on repeat cycles

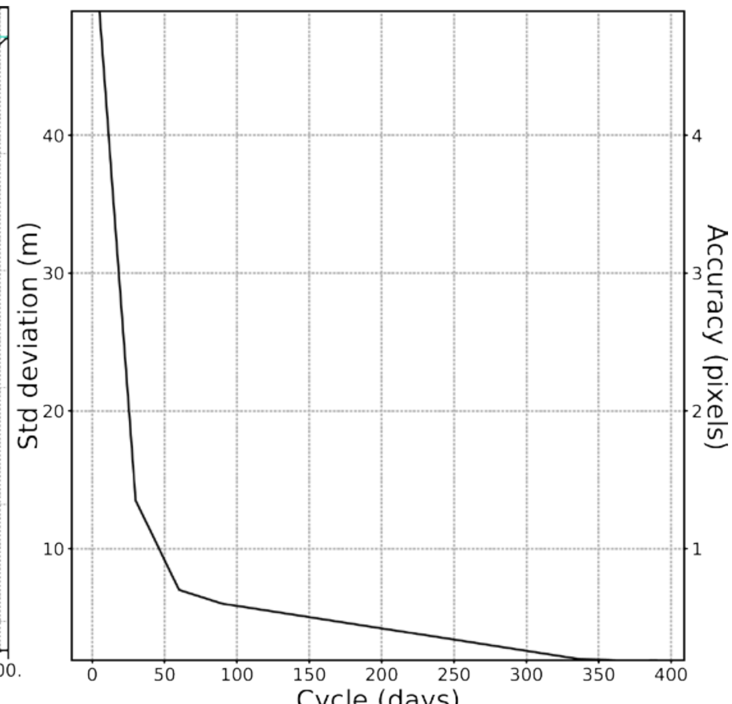
The uncertainty is estimated using:

- The pixel by pixel standard deviation on stable ground, quantifying the variance by pixels
- We then calculate the error on the mean by doing the ratio between the standard deviation and the number of acquisitions at each pixel:

$$Err = \frac{\sigma}{\sqrt{N_{meas}}}$$

σ is the standard deviation
Nmeas is the number of measurements





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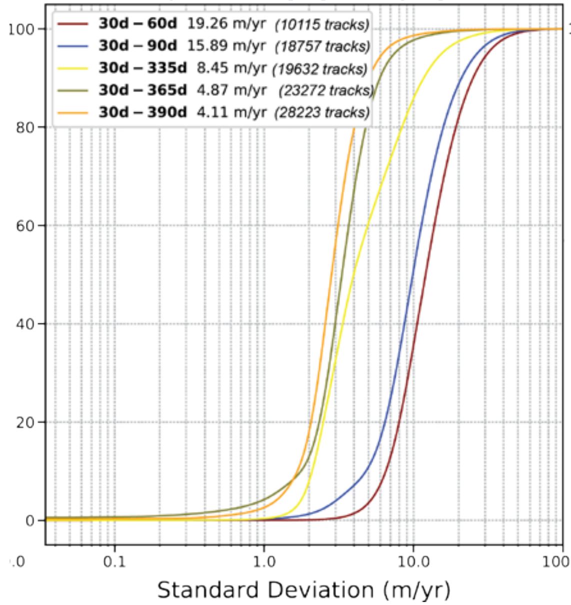
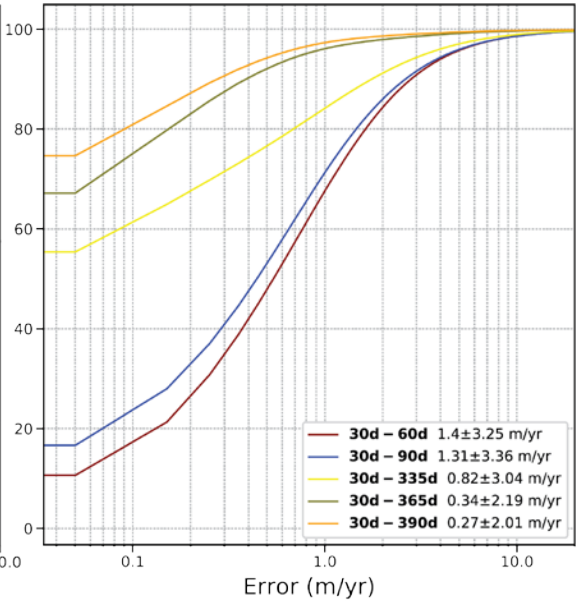
Error analysis

Average ice velocity mapping precision

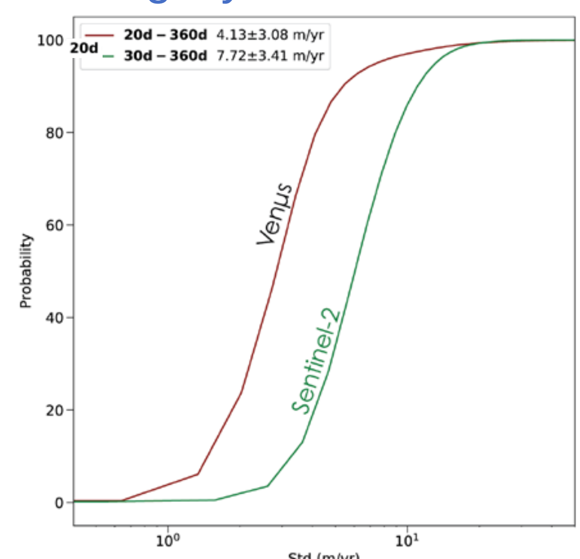




Comparison with higher temporal and spatial resolution imagery

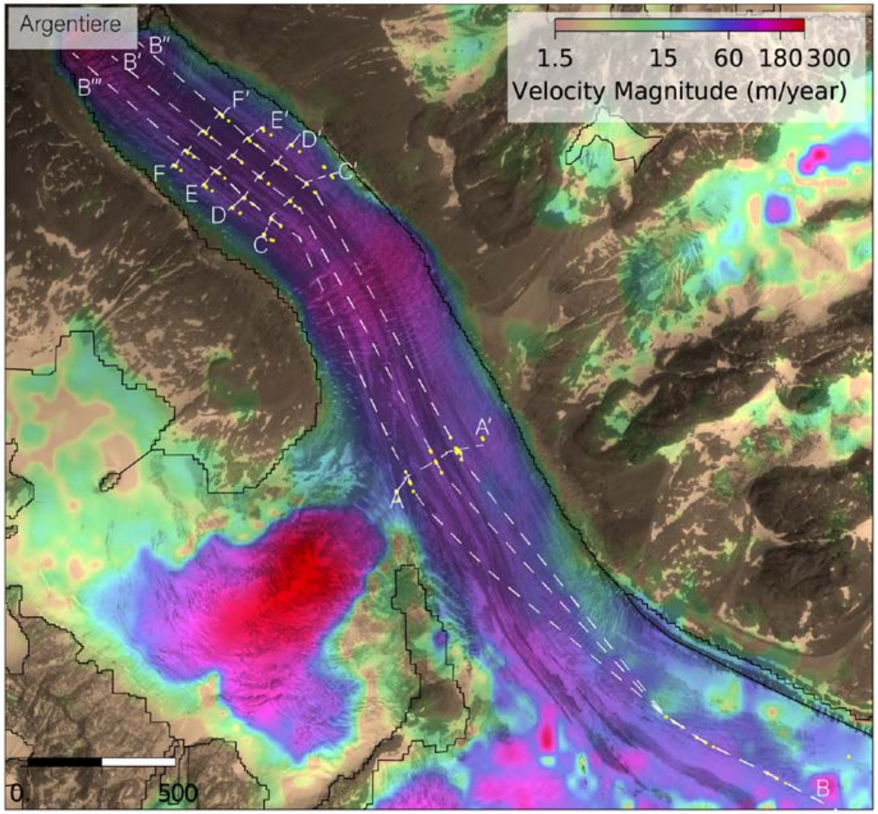
Comparison with CNES's Venus:

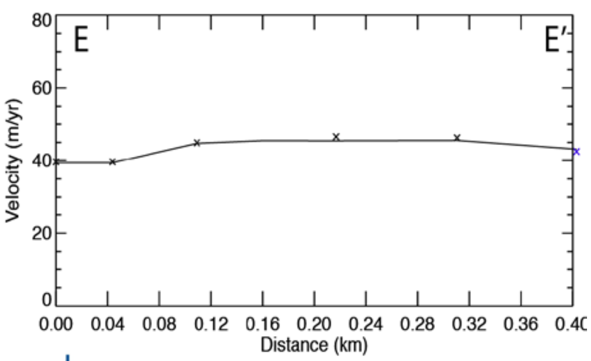
- Venμs: 5-m resolution, 2-days repeat cycle
- Comparison of average mosaics for year 2018
- The highest resolution and shortest repeat cycle shows a standard deviation twice lower than Sentinel-2 on stable ground

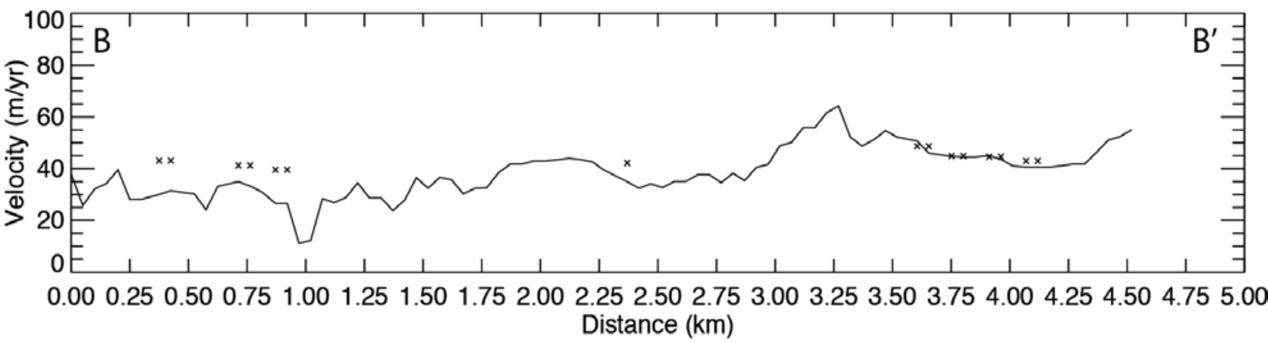


Comparison with GPS measurements

- We underestimate the GPS ice velocity by 5% over the lower part of the ice tongue,
- Underestimation of 15% in the accumulation area
- The difference between these two regions is mainly due to the persistent shade, snow cover and the resulting loss of coherence
- Ablation area: 10 times more track than upper
- Causes: spatial and temporal filtering and smoothing







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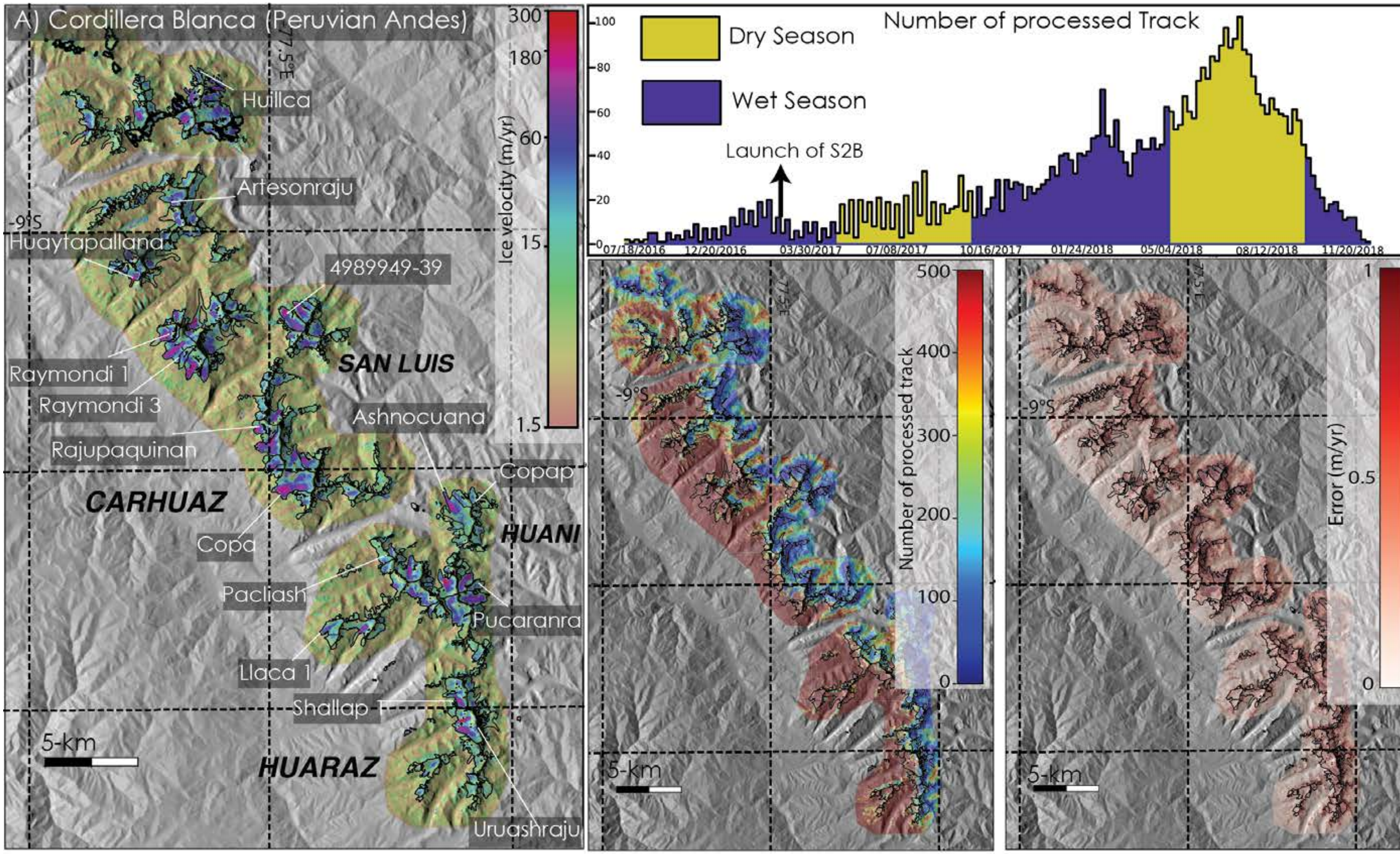
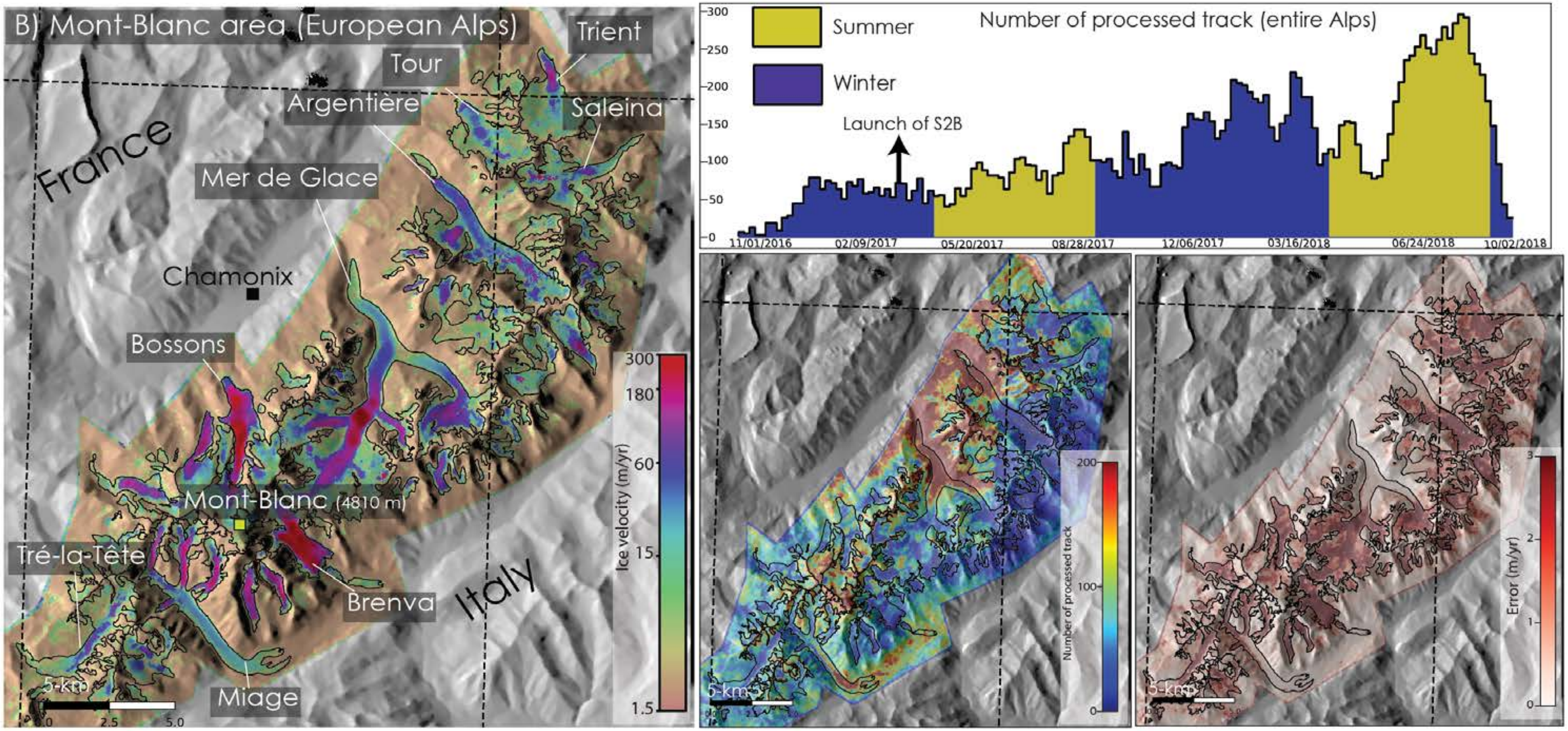
Results: Andes

Since early October:

- Andes Cordillera Blanca (7351 pairs), Royal Cordillera (8838 pairs) – years 2017-2018



Results: Alps



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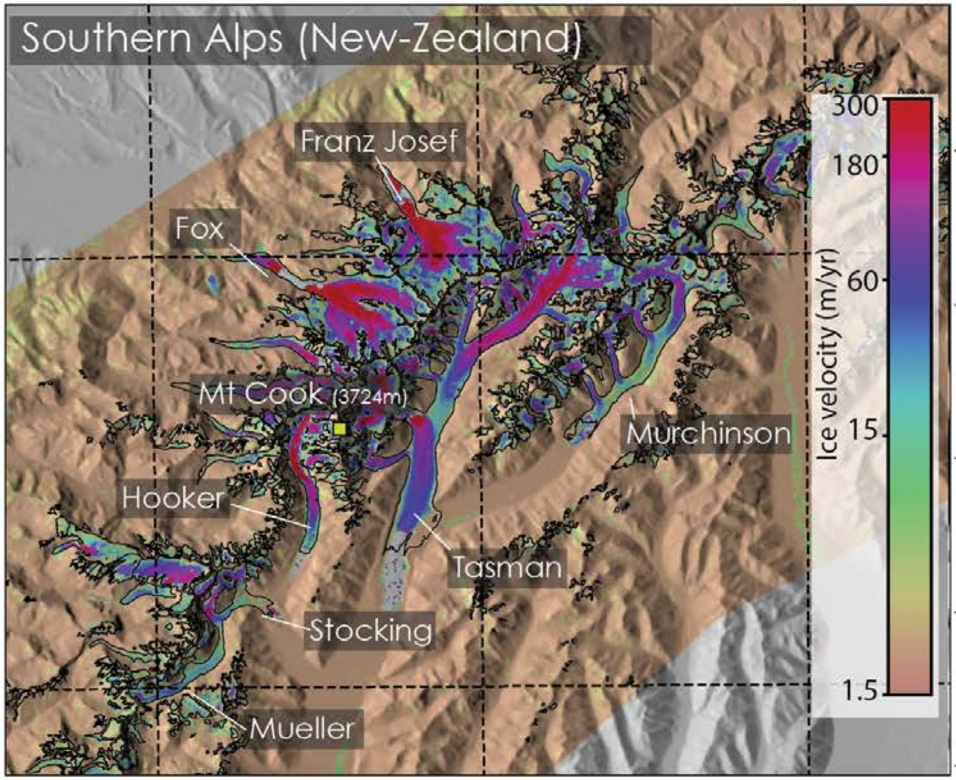
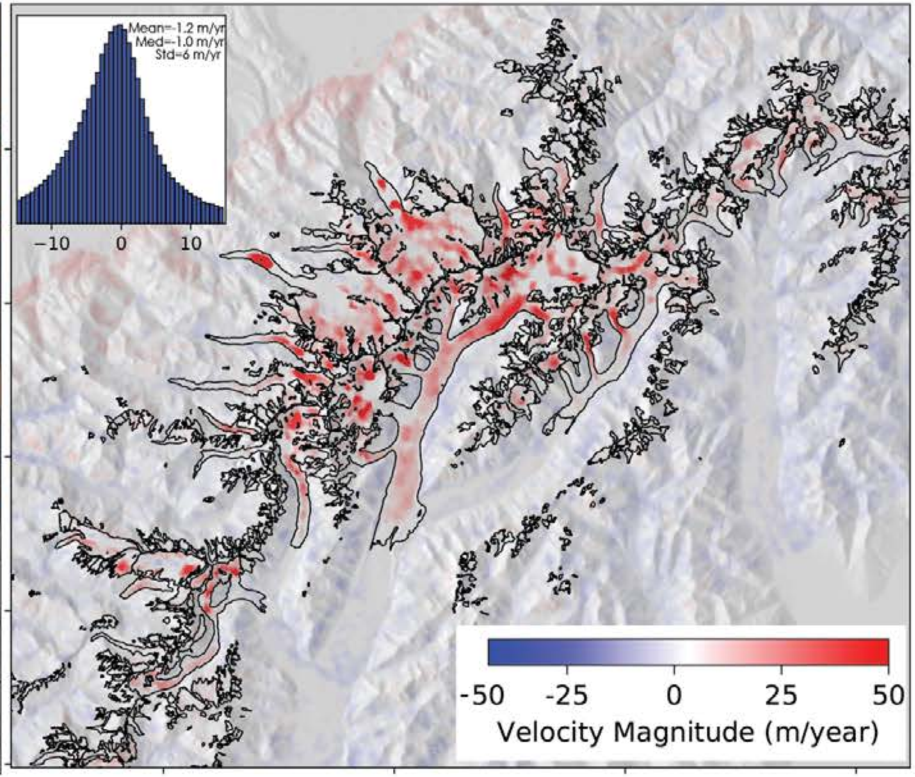
Results: Seasonal variations

- Summary of the processing: Sentinel 2 (12883 pairs), Venµs (2008 pairs)
- Capacity of Sentinel-2 to monitor seasonal variations:
  - Calculation of winter and summer average mosaics
  - Difference between summer and winter noise on stable ground of 1±6 m/yr
  - Seasonal amplitude >50 m/yr (highest during summer) on the main trunk of the glaciers during summer
  - Strong seasonal signal consistent and observable even over small glaciers





Conclusions

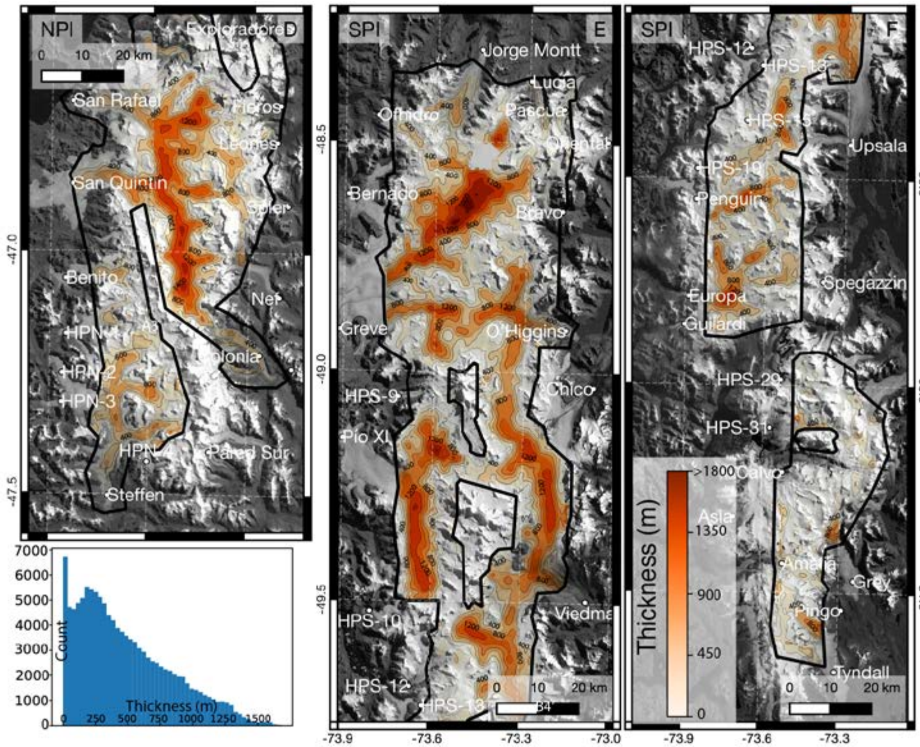
- We have developed a multi-sensor processing chain to process ice velocity on regional scales

- Our study shows the high capacity of Sentinel-2 to map ice velocity of mountain glacier
  - Production of accurate averaged ice velocity mapping for modelers
  - Monitoring of seasonal variations in surface ice flow

- We also show the value of high resolution sensors (Venµs, Pleiades), with capacity to largely enhanced the mapping locally

Next objectives

- Reconstruction of ice thicknesses:
  - Parametrization of the relation between ice velocity and ice thickness over the GlaThiDa database
  - Farinotti et al., 2017; Morlighem et al., 2014; Fürst et al., 2018 (mass conservation)
  - Reconstruction of ice thicknesses in transcient mode
- Monitoring of ice dynamics:
  - Extension of the time serie of ice velocity with Landsat-7/8
  - Processing of the Pleiades, SPOT and Venus data to monitor changes in ice speeds in great details
  - For largest glaciers use of Sentinel-1
  - Rock glacier monitoring (D. Cusicandi)



Ref: *Millan et al.*, 2019