Fusion and mining of glacier surface flow velocity time series

L. Charrier [1,2], Y. Yan [1], E. Koeniguer [2] , E. Trouvé [1], R. Millan [3], J. Mouginot [3], A.Derkacheva [3]

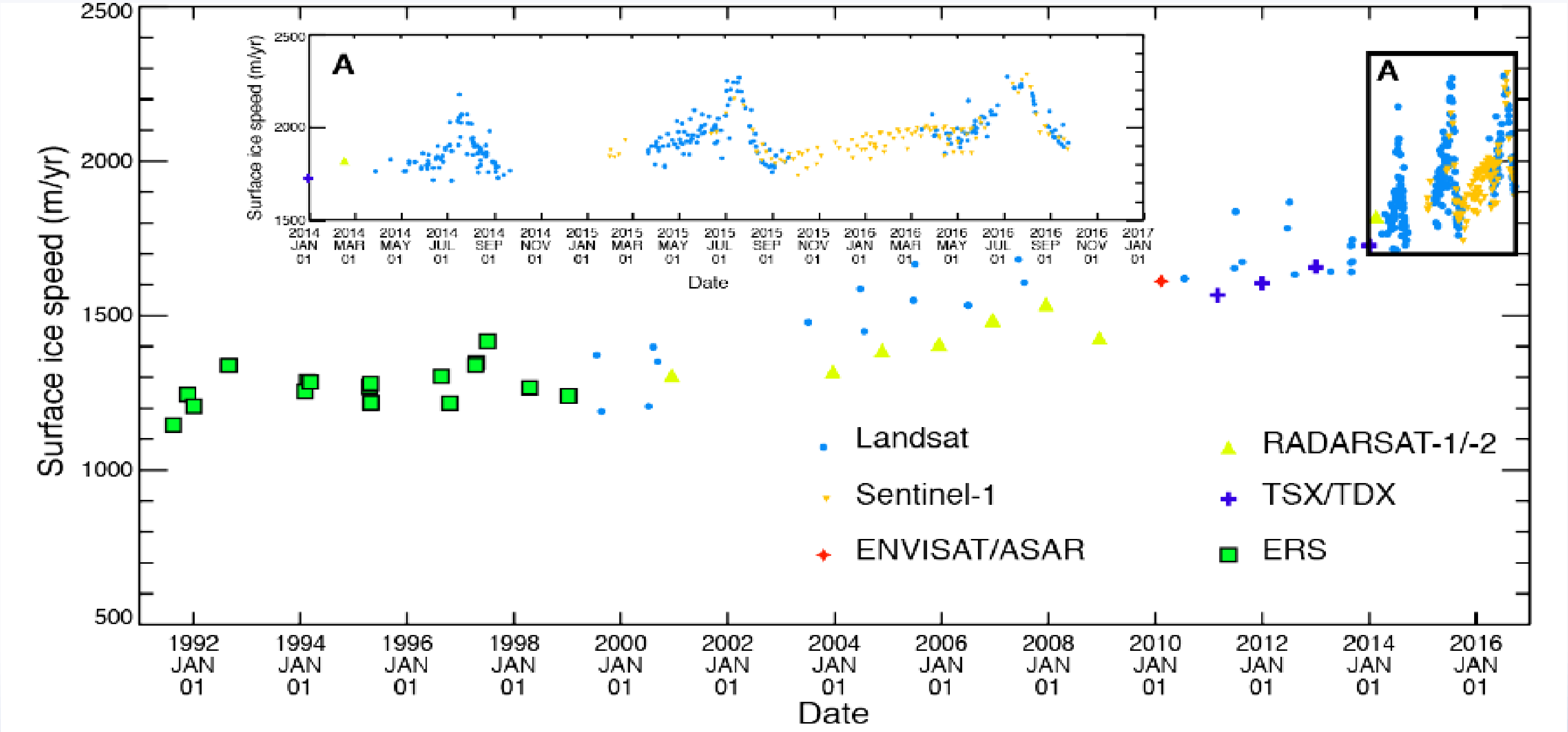
[1]LISTIC, Université Savoie Mont Blanc, Annecy, France
[2]ONERA, Paris, France
[3]IGE, Université Grenoble Alpes, Grenoble, France

Contact: laurane.charrier@univ-smb.fr

Challenge: Post-process displacements time series

- The amount of **displacement fields** online or on-demand ↗
- Spatial, temporal and radiometric **resolution** ↗
- Time series contain **gaps, uncertainty ,** and **redundancy**
- Authors used to **select or average information** in time and space

⇒ Needs of **post-processing**:
- ✓ to reduce uncertainty
- ✓ to manage gaps
- ✓ to extract easily interpretable displacement information



Ice speed of Zachariae Isstrøm between 1992 and 2017 (A) and between 2014 and 2017 from multiple sensors (Mouginot et al.,2017)

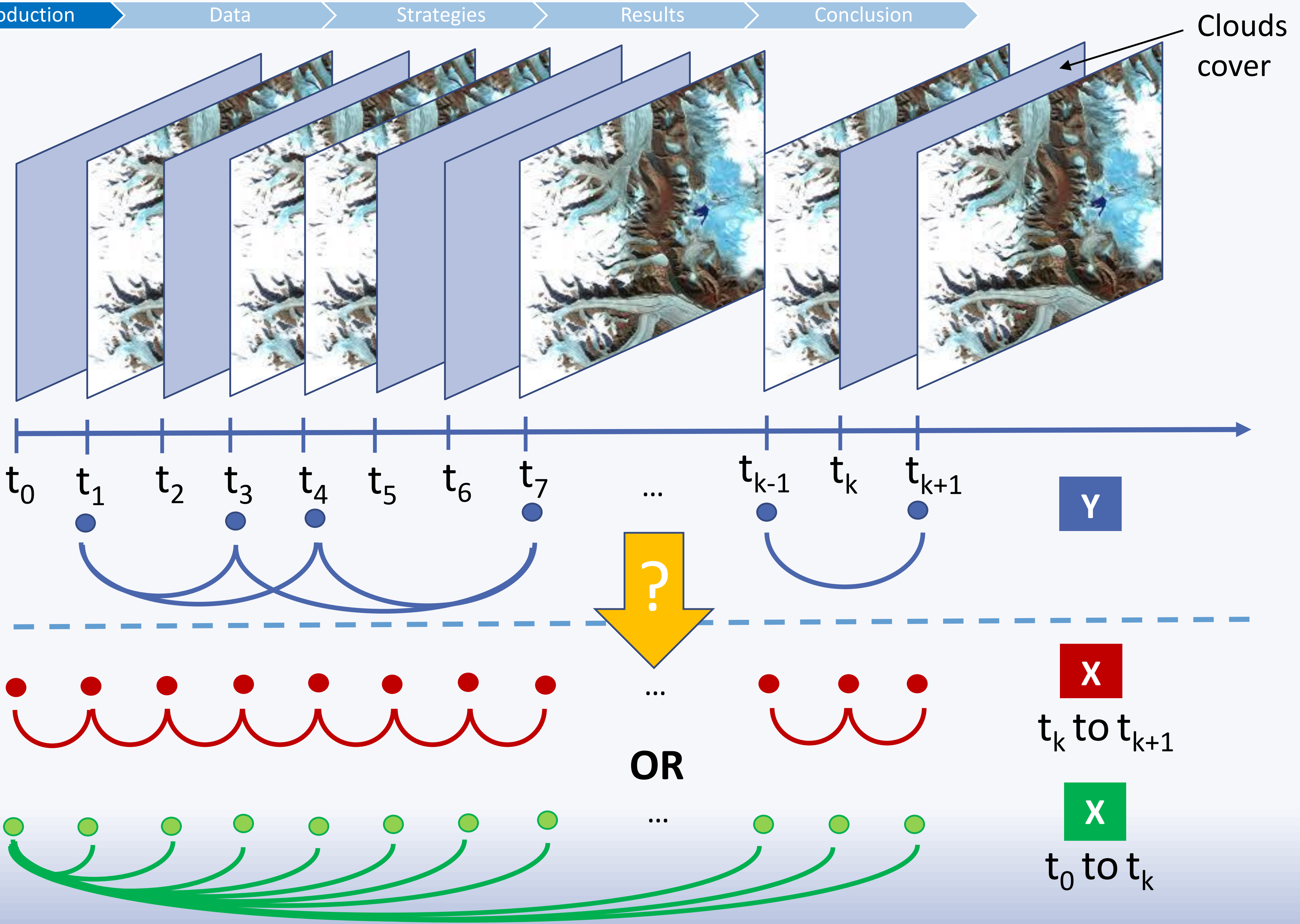
Redundancy
- ✓ Mono sensor: Different temporal baselines
- ✓ Multi sensors

Data Gaps
- ✓ Outliers rejected
- ✓ Clouds cover
- ✓ Limitation of displacement computation techniques

L. Charrier, Y. Yan, E. Koeniguer, E. Trouvé, R. Millan, J. Mouginot, and A. Derkacheva

Goal:

Use all available displaments **(Y)** To build an easily interpretable time series **(X)** with reduced uncertainty and improved data completeness



Input: Displacements Y

Ouput: Displacements X

Between all consecutive dates (Leap Frog)

OR

From a common date (Common Master)

L. Charrier, Y. Yan, E. Koeniguer, E. Trouvé, R. Millan, J. Mouginot, and A. Derkacheva

Data of interest: Ice flow time series

Ice flow time series computed in Millan et al., 2019
-> **Studied area :** Fox Glacier (the Southern Alps of New Zealand)

-> **Method to compute surface ice flow velocity:**
Cross-correlation using a modified version of ampcor (NASA)

Sensor	Spatial resolution	Temporal resolution	Temporal baselines
Landsat-8	15 m	16 days	[16:100] U [330:400] days
Sentinel-2	10 m	5 days	[5:100] U [330:400] days
Venus	5 m	5 days	[5:100] U [330:400] days

Several sensors
+ Several temporal baselines
= redundancy

-> **Post-processing**
Outliers removal: pixel offsets which deviate more than 3 units from offsets filtered by a 9 pixel x 9 pixel median filter are rejected

Less outliers but more data gaps

-> **Final product**
Pixel spacing = 50 m
Precision depends on the sensor: Sentinel-2 precision = 2 x Landsat-8 precision (Millan et al., 2019)
Precision depends on the temporal baselines

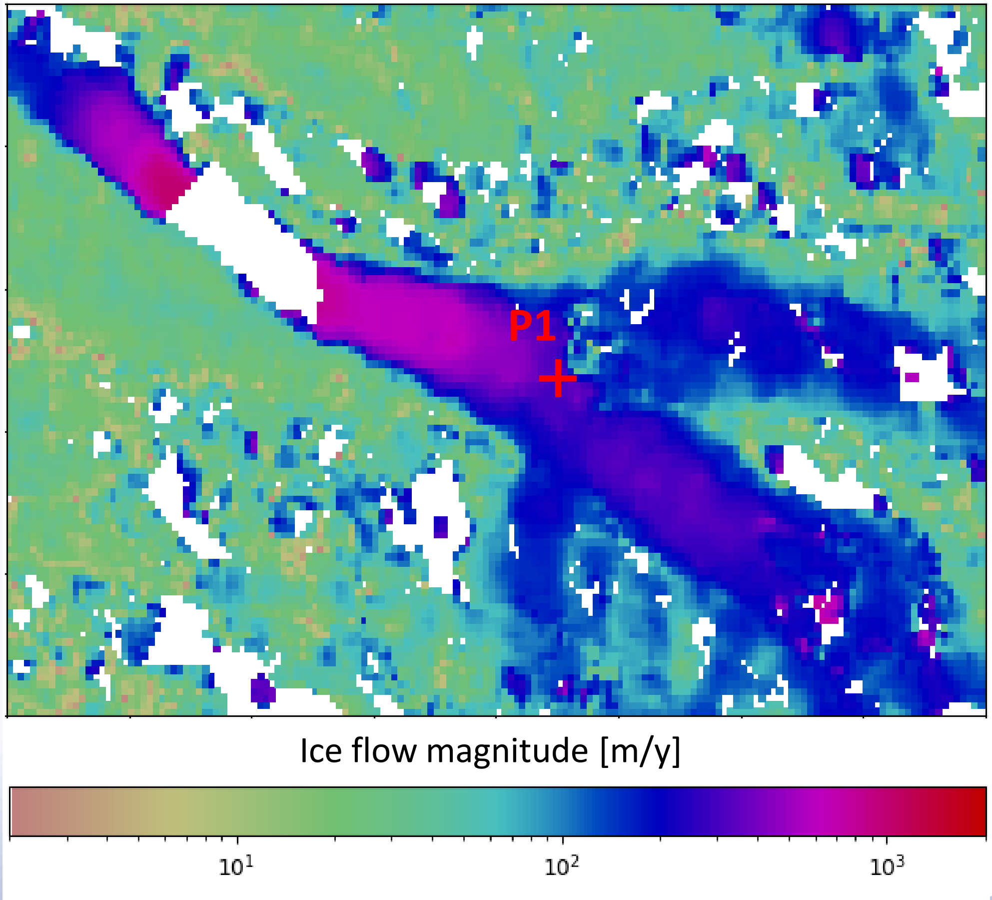
Difference in precisions

Data of interest: Ice flow velocity example

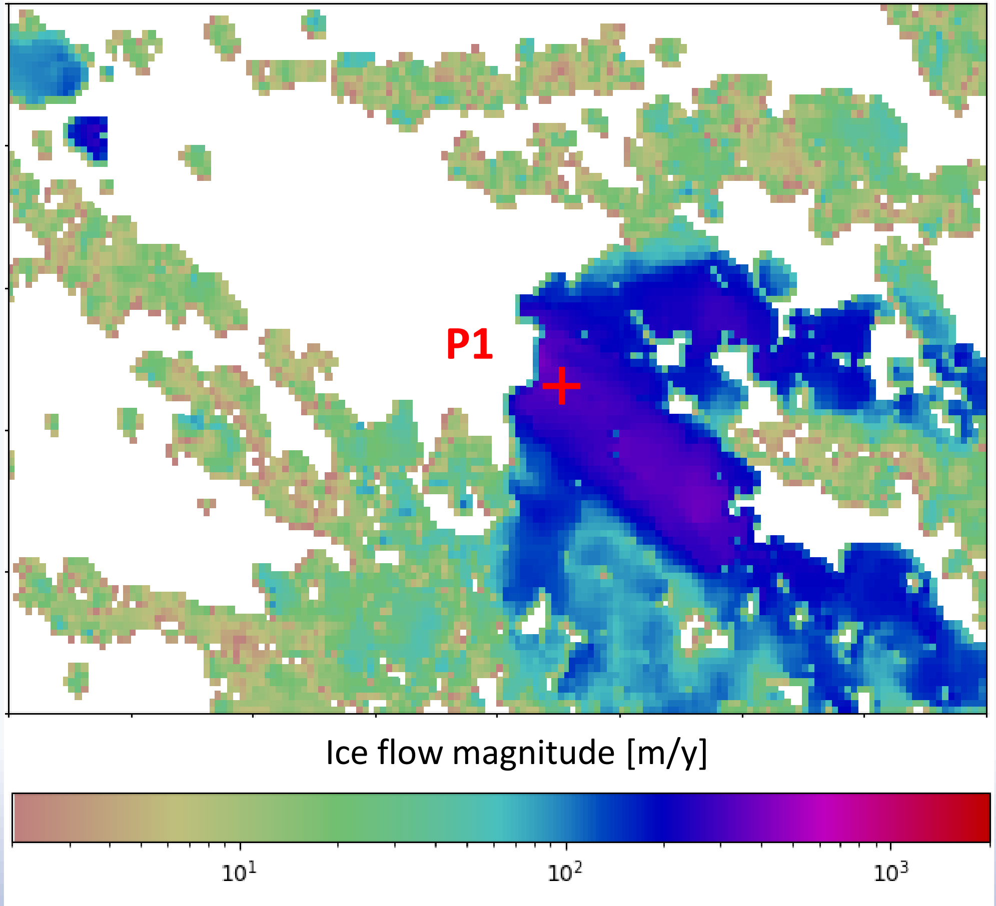
Studied area: Fox Glacier in the Southern Alps of New Zealand

P1: Pixel used in the folling study

S2 Image pair: 2018-02-06 / 2018-02-21

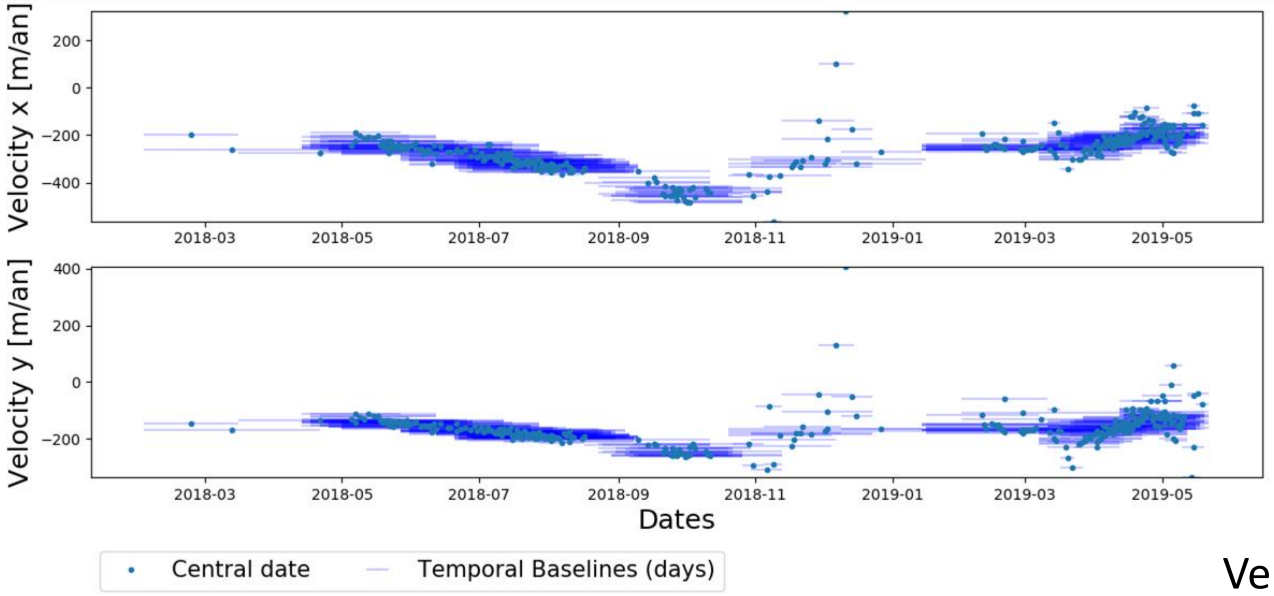


S2 Image pair: 2018-04-22 / 2018-07-11

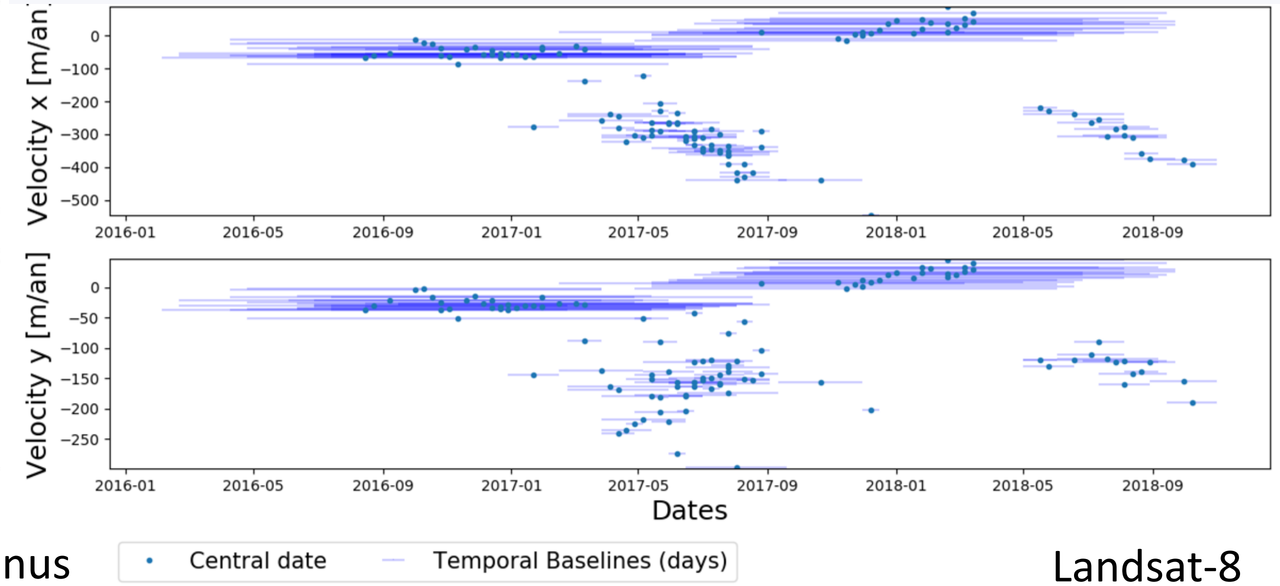


L. Charrier, Y. Yan, E. Koeniguer, E. Trouvé, R. Millan, J. Mouginot, and A. Derkacheva

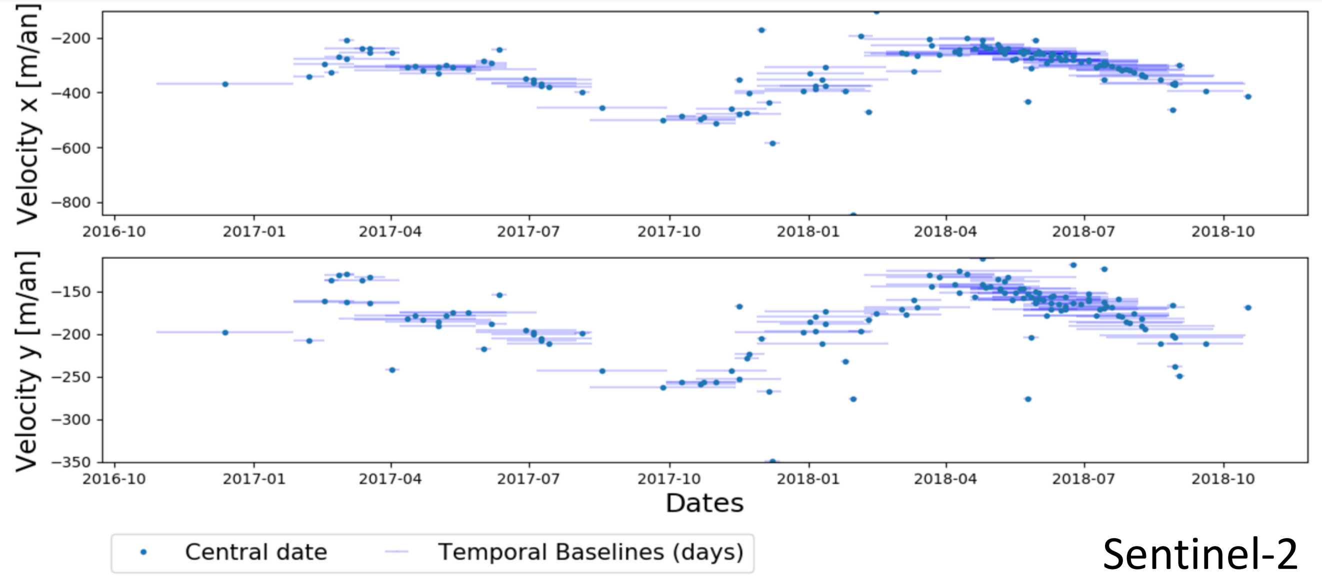
Data of interest: velocity time series at location P1



Venus



Landsat-8



Sentinel-2

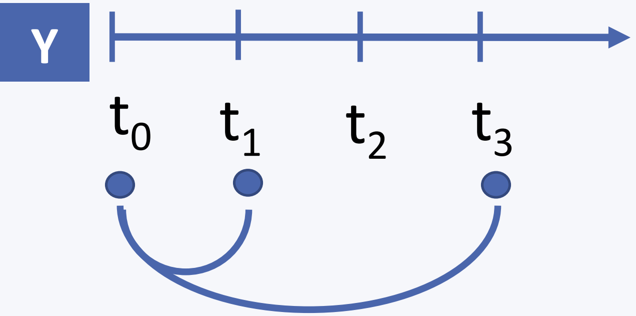
L. Charrier, Y. Yan, E. Koeniguer, E. Trouvé, R. Millan, J. Mouginot, and A. Derkacheva

Strategies

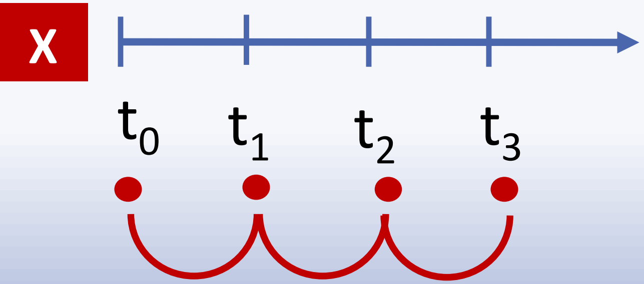
Goal: Build a time serie **(X)** with a given temporal interval (Δt) using all available displacements **(Y)** based on the **temporal closure** of displacements' network

Equation to solve: $Y = AX + \varepsilon$, with $E(\varepsilon) = 0$ and $Var(\varepsilon) = \sigma^2 V$

Example of temporal closure:



$$Y = \begin{bmatrix} Displacement_{t_0-t_1} \\ Displacement_{t_0-t_3} \end{bmatrix}$$



$$X = \begin{bmatrix} Displacement_{t_0-t_1} \\ Displacement_{t_1-t_2} \\ Displacement_{t_2-t_3} \end{bmatrix}$$

1) Construction of A

Y | A | X

$$\begin{bmatrix} Displacement_{t_0-t_1} \\ Displacement_{t_0-t_3} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} Displacement_{t_0-t_1} \\ Displacement_{t_1-t_2} \\ Displacement_{t_2-t_3} \end{bmatrix}$$

2) Invertion to obtain X

Strategies

2) Invertion to obtain X

Equation to solve: $Y = AX + \varepsilon$, with $E(\varepsilon) = 0$ and $Var(\varepsilon) = \sigma^2 V$

Several strategies for the inversion:

1) Ordinary Least Square (OLS):

$$X = (A^T A)^{-1} A^T Y$$

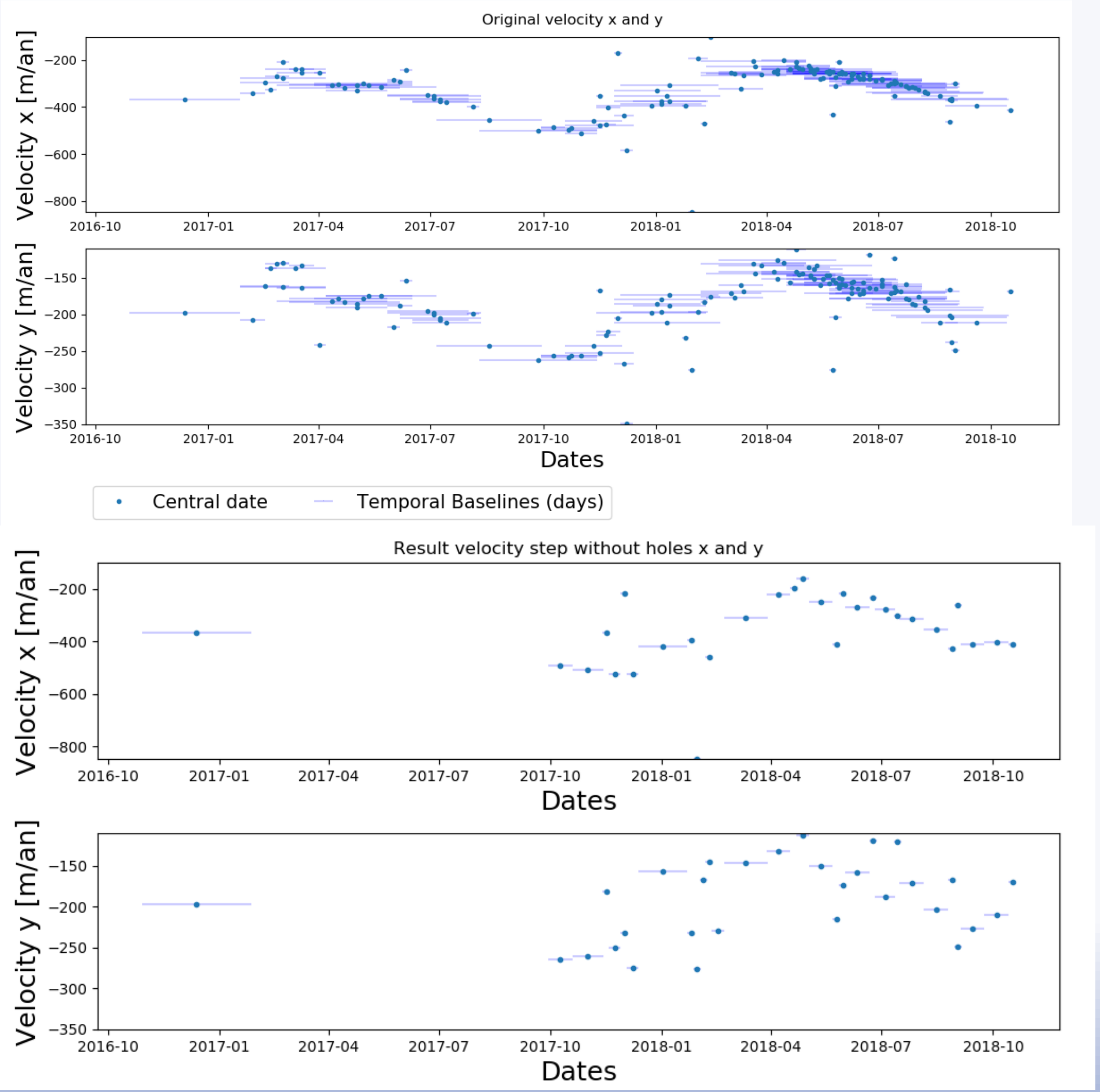
2) Generalized Least Square (GLS)

$$X = (A^T W^{-1} A)^{-1} A^T W^{-1} Y$$

Allow to take velocity **uncertainty** into account

Early results
Mono Sensor – Common Master OLS

Pixel P1
Sentinel-2 in 2017/2018



Results are consistent with the original data in 2018

-> Limit: in 2017 the density of the input data is not sufficient to get consistent output velocities

Early results

Mono Sensor – Leap Frog OLS

Pixel P1

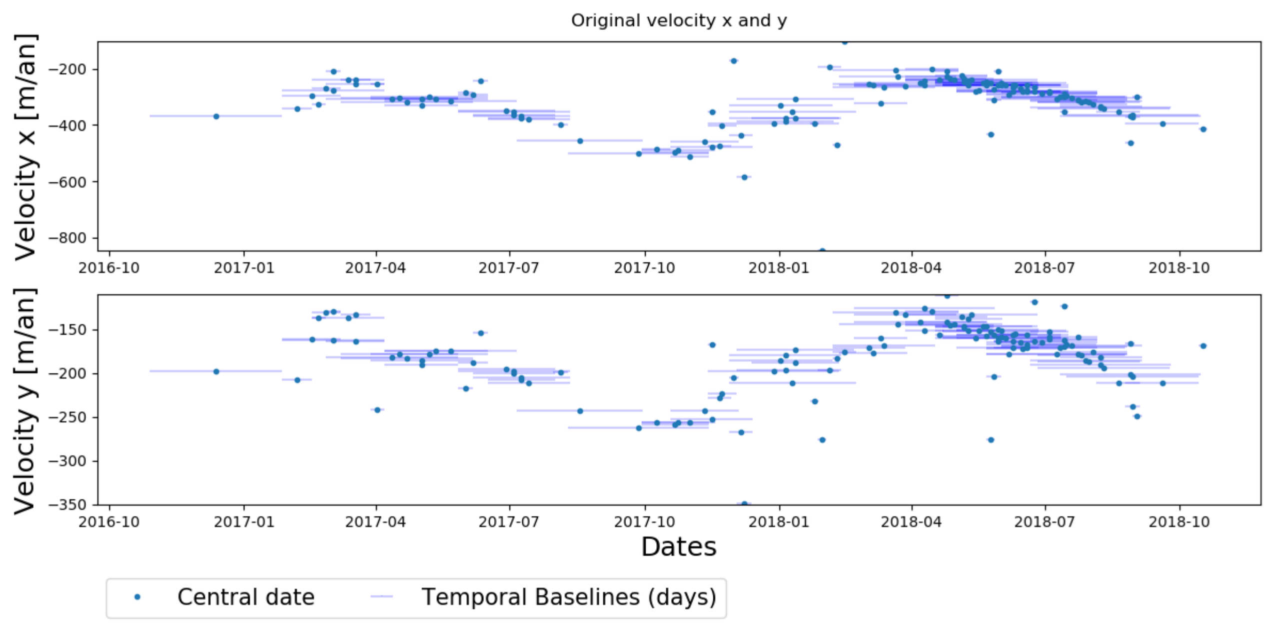
Sentinel-2 in 2017/2018

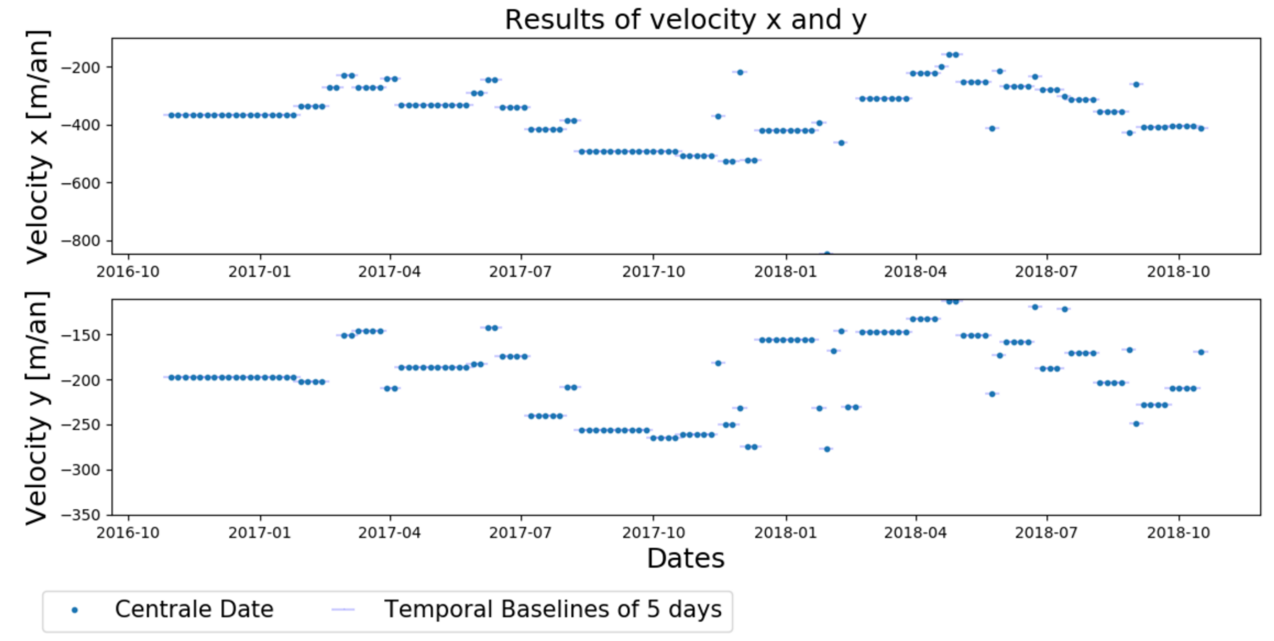
Results are consistent with the original data in 2017 and 2018

The resulted time series seems to be easily interpretable with reduced uncertainty and improved data completeness

=> Leap Frog seems to be a more suitable method for this case than Common Master

-> Limit: Lack of variability in some part



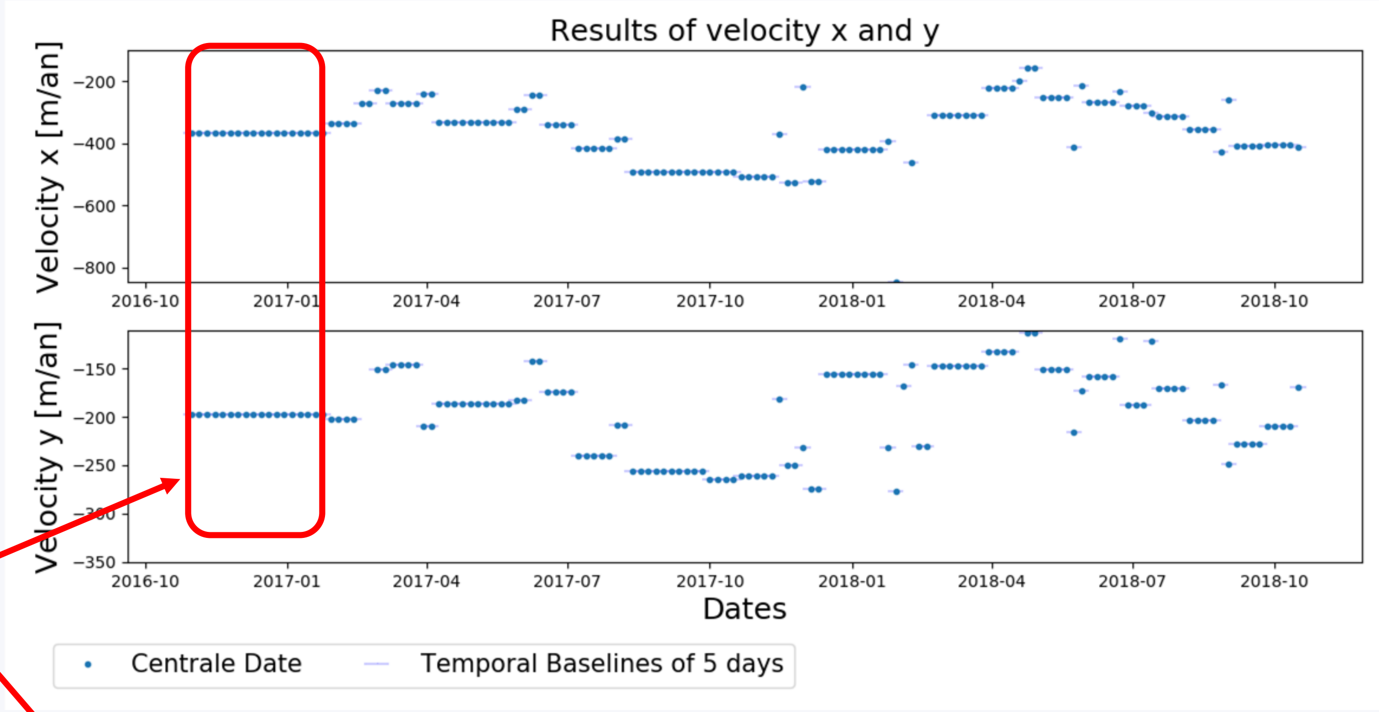


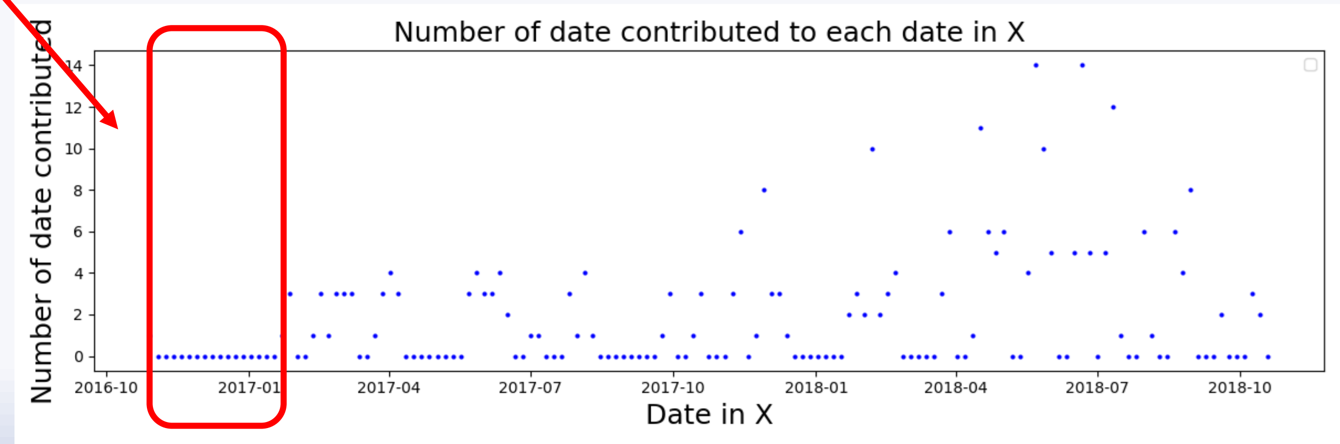
Early results
Mono Sensor – Leap Frog OLS

Pixel P1
Sentinel-2 in 2017/2018

-> Limit: Lack of variability in some part

Because few values in Y contribute to values in X for these dates



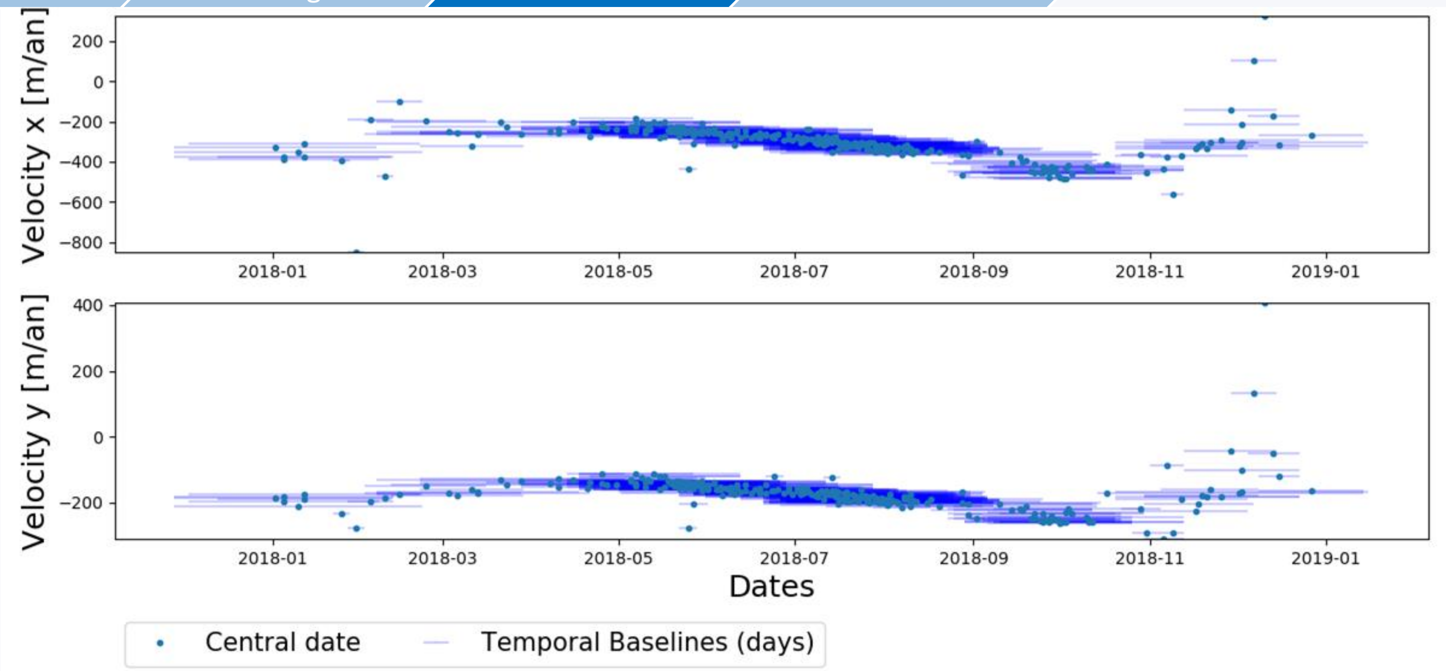


Early results

Multi sensors – Leap Frog OLS

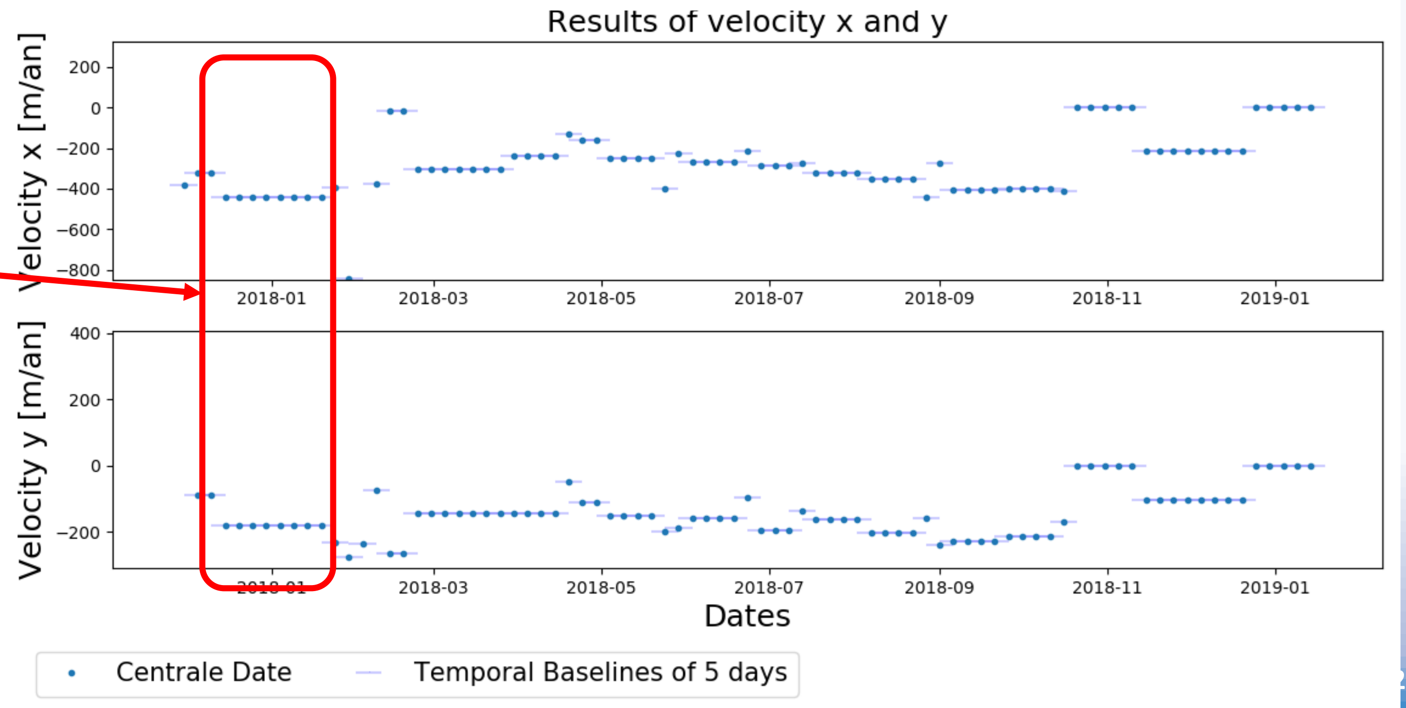
Pixel P1

Sentinel-2 + Venus in 2018



- Results are consistent with the original data
- The resulted time series seems to be easily interpretable with reduced uncertainty and improved data completeness

-> Limit: Even when the number of data is increased, a lack of variability persist in some part



Conclusion and Perspective:

-> Conclusion:

Propose an automatic approach to extract **easily interpretable displacement** fields time series (leap frog and common master) with **improved accuracy and completeness** from a large number of displacement fields of different temporal baselines

-> Actual problem:

Insufficient redundancy => a lack of variability in the output velocy

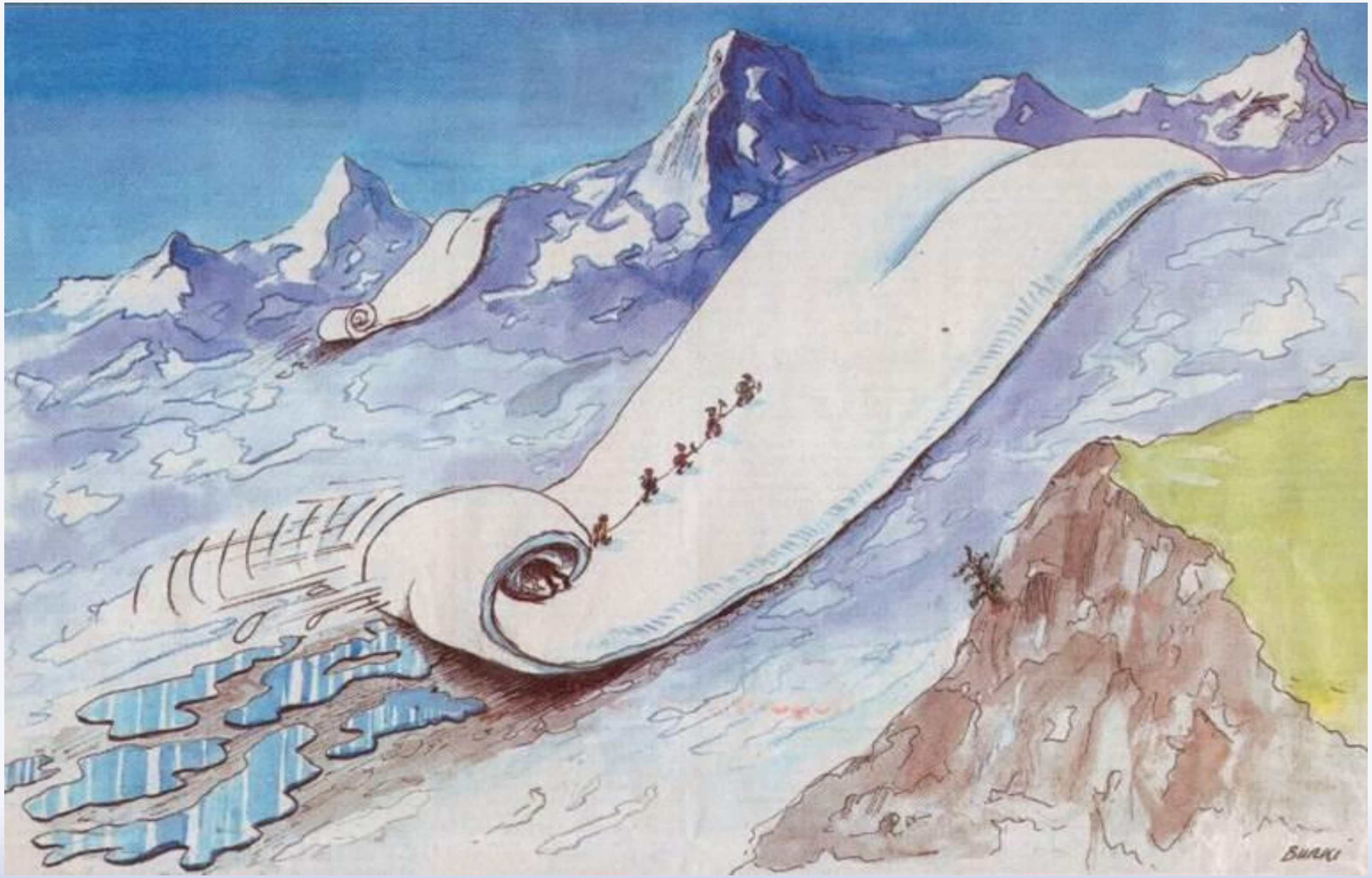
-> Possible solutions:

Add regularisation terms based on spatial, temporal and/or spatio-temporal correlation in the inversion

To start the chat ?

- How to automatically select the input datasets with **optimal temporal baselines**?

Thanks !



Raymond Burki

Reference

Millan, R., Mouginot, J., Rabatel, A., Seongsu, J., Cusicanqui, D., Derkacheva, A., Mondher, C., Mapping Surface Flow Velocity of Glaciers at Regional Scale Using a Multiple Sensors Approach. Remote Sensing 2019 11, 2498

L. Charrier, Y. Yan, E. Koeniguer, E. Trouvé, R. Millan, J. Mouginot, and A. Derkacheva