

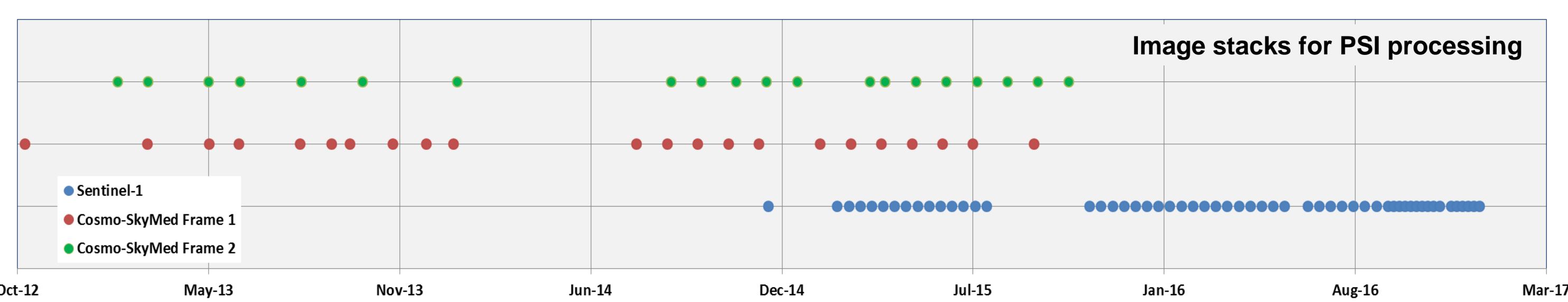
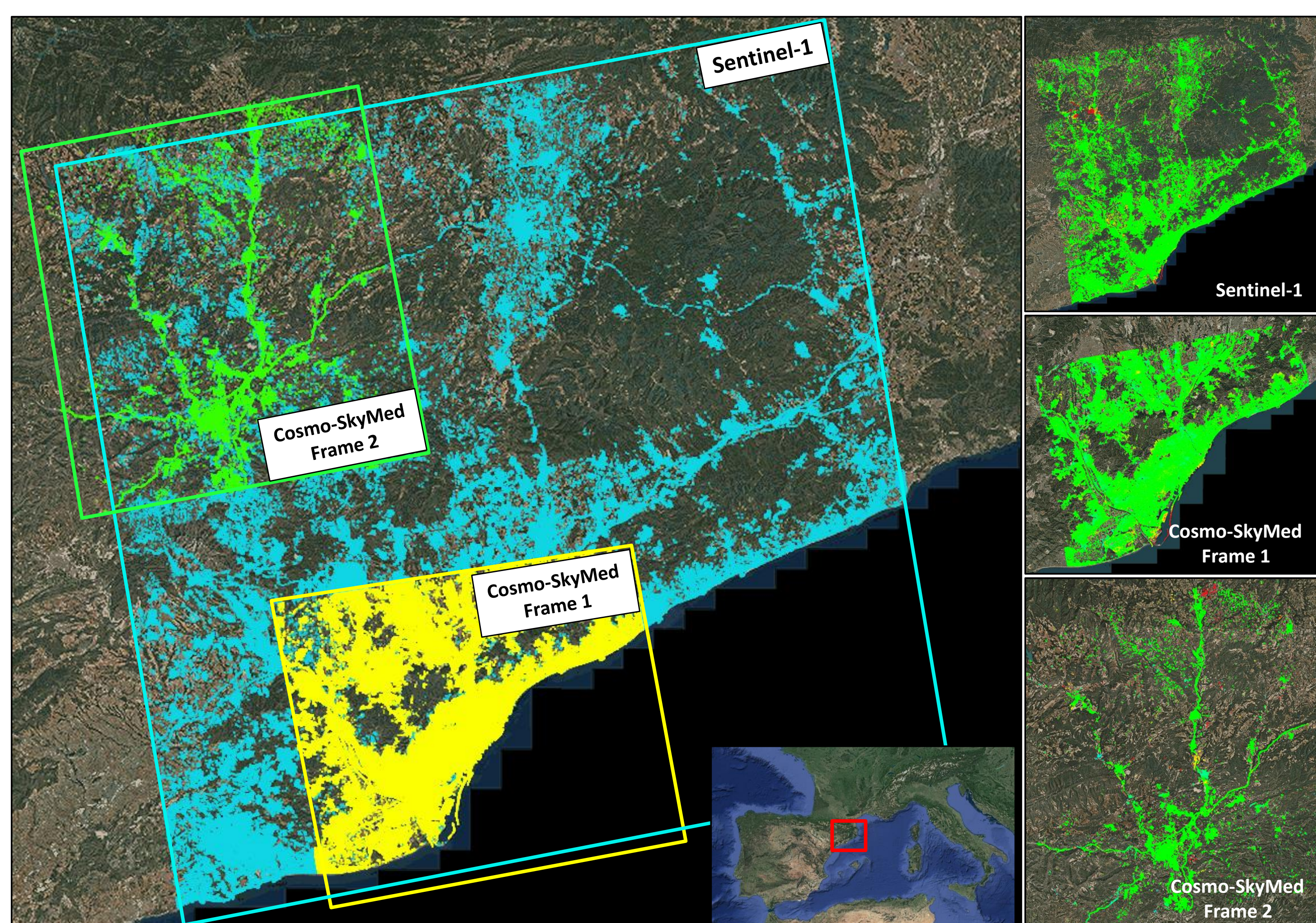
## Introduction

The advent of the Sentinel-1 constellation poses an opportunity for terrain deformation surveillance at unprecedented coverage and temporal resolution. Availability of free imagery over a study zone every 6 days facilitates subsidence monitoring at regional scale, generally unaffordable with existing X-band, high resolution sensors because of cost constraints. However, the issue of sensitivity still remains. Is Sentinel-1 IWS spatial resolution enough for detecting and quantifying small-scale subsidence phenomena? Is C-band sensitivity to deformation good enough when averaged over this pixel size?

This work proposes a study of the subsidence phenomenon over two different areas in Catalonia, based on the application of PSI interferometric techniques (Persistent Scatterer Interferometry) [1] [2]. The first area covers the city of Barcelona and its surroundings, where several subsidence phenomena have been detected associated to public works, aquifer depletion, etc. The second area centers in the middle Llobregat river basin, where salt mining activity yields -direct or indirectly- important subsidence processes. To compare results from both satellites, the time-overlapping part of Sentinel-1 and Cosmo-SkyMed stacks in these areas of interest are analyzed. It covers an observation time window of approximately 9 months, from February to October 2015, even though additional images outside this window are also being selected and processed in order to obtain accurate deformation results. For their processing, the Differential Interferometric Software developed at the Institut Cartogràfic i Geològic de Catalunya (ICGC) has been used [3]. The results of the processing of both satellites stacks will be compared, paying special attention to known subsidence phenomena already studied and quantified.

## AOIs & Stack Processing

This study is framed within the Catalonia government project for global monitoring of its territory using PSI techniques. For this project, Sentinel-1 data have been selected, since frame coverage and C-band frequency are optimal for large scale studies, as well as the high temporal revisit time. On the other hand, two previous small scale studies performed with Cosmo-SkyMed images are suitable to analyze the temporal continuity and detection capabilities of both X-band and C-band platforms. This study is necessary to plan future global monitoring of ground motion, using for example Sentinel-1 satellites as background system and X-band SAR systems as high-resolution products in case of detection of areas affected by motion patterns.

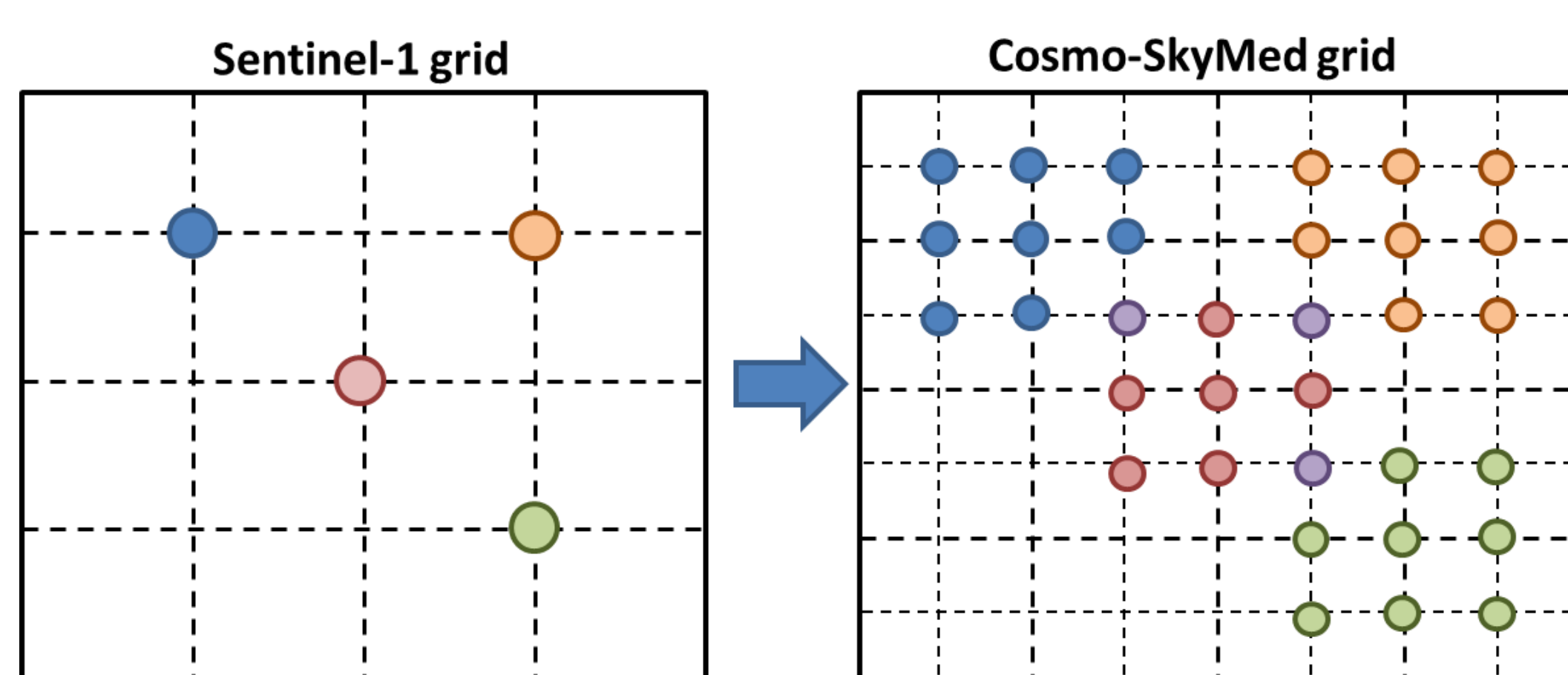


Frame	Orbit	Incidence angle	Number images	Temporal period	Number interferograms	Processed spatial resolution
Sentinel-1A/B	Ascending	38°	56	Dec 2014 Dec 2016	218	30 x 30 m
Cosmo-SkyMed 1	Ascending	36°	22	Oct 2012 Sept 2015	45	10 x 10 m
Cosmo-SkyMed 2	Ascending	36°	20	Jan 2013 Oct 2015	40	10 x 10 m

## Data Homogenization

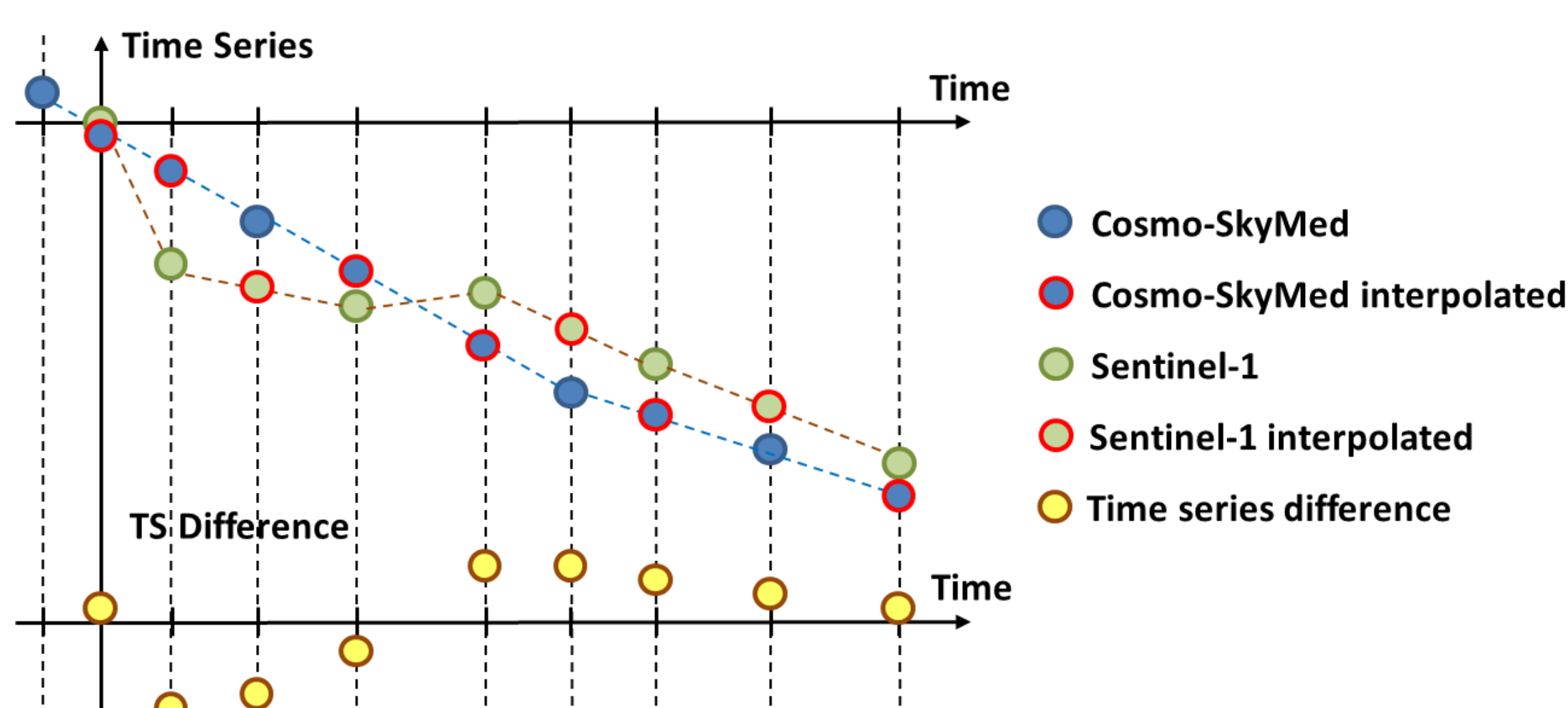
### 1 - Common spatial grid

In order to compare Cosmo-SkyMed and Sentinel-1 frames, a synthetic UTM grid is defined for the entire area of interest. In this case, the 10 x 10 m grid of Cosmo-SkyMed has been selected as master. For each point of the grid, velocity and time series of all the pixels from C-Band Sentinel-1 stack are interpolated and stored in the new grid if measurement data is available. When common locations are found for different points measurements, an averaging processing is performed to obtain a single value in the Cosmo-SkyMed grid.



### 2 - Temporal selection and interpolation

Once step 1 has been performed, spatial homogenization is ready, while temporal periods of both studies are still different. Accordingly, time series must be trimmed to the common temporal period and velocity re-calculated. This processing is carried out by using a linear interpolation in time, generating overlapping time series for both Cosmo-SkyMed and Sentinel-1 products. Subtraction of time series provides information about the measurement statistics of both platforms. These differences should be mainly caused by the X-band and C-band different wavelengths and spatial resolutions.

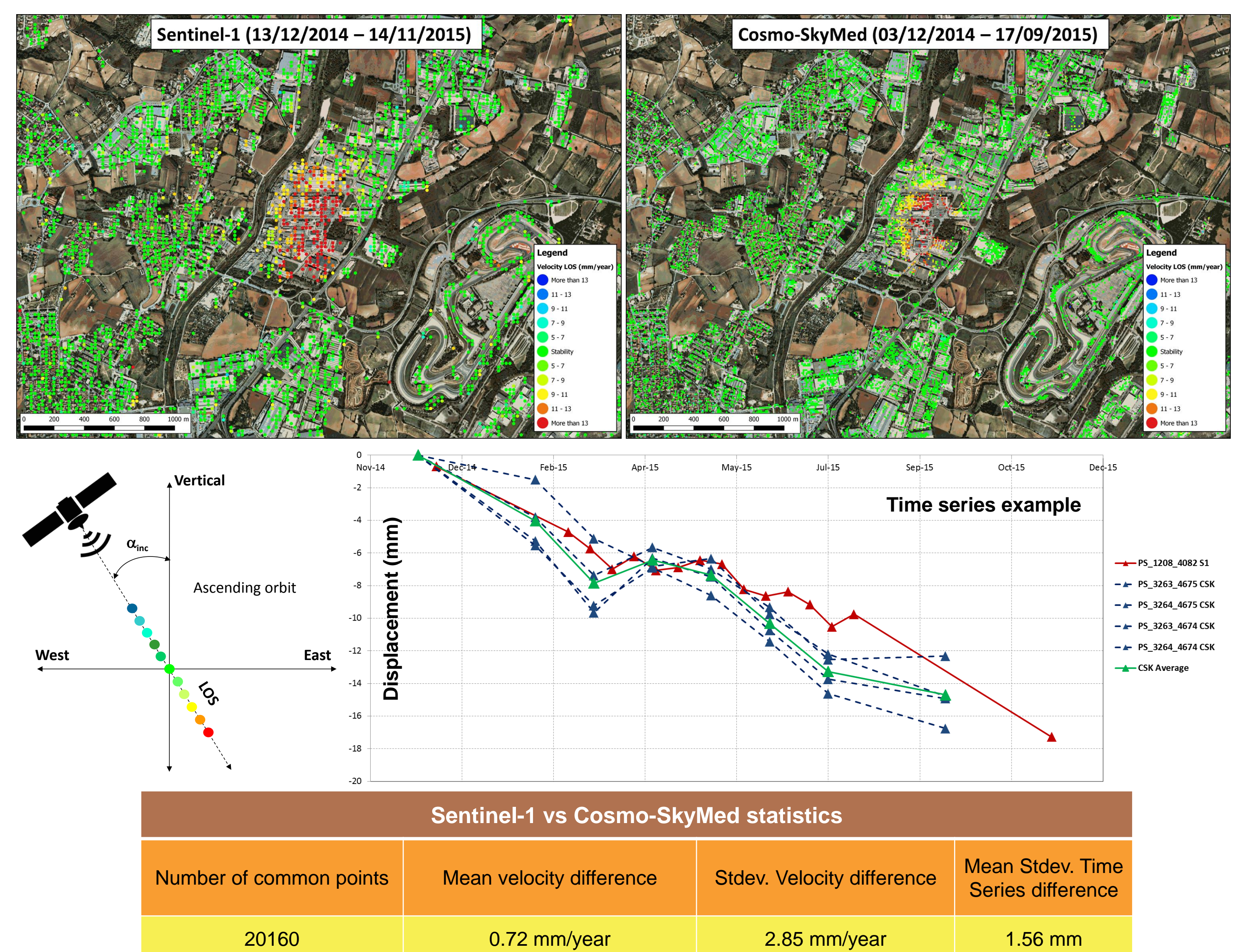


## Results

Full frame processing has been performed for Sentinel-1 (swath 2) and Cosmo-SkyMed data stacks using multilook averaging. This multilook improves phase quality and reduces the computational cost, since a lower number of points must be computed. When enough RAM memory and core processors are available, the single-look processing presented in this work is straightforward and equivalent to the presented results. Once the presented global monitoring project is ready to produce updated ground motion maps of Catalonia, next step will be to generate these products at maximum spatial resolution. Below several specific areas affected by ground motion phenomena are detailed with a sensitivity analysis between X and C-band.

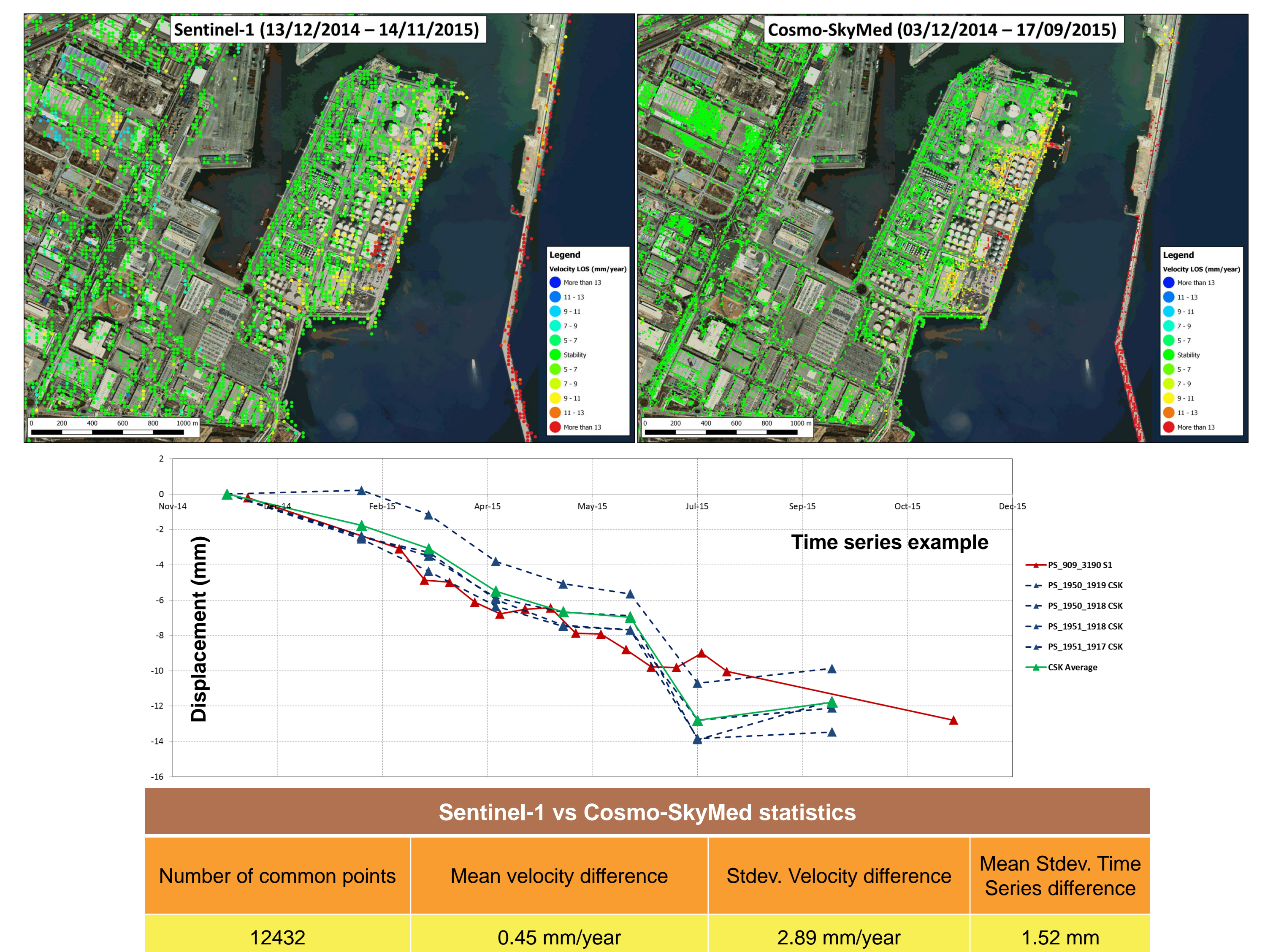
### Area 1 – Industrial park

This area corresponds to an industrial park located near the Barcelona-Catalunya circuit in Montmeló. A strong subsidence pattern has been detected using Cosmo-SkyMed and Sentinel-1, the main cause of the problem being considered aquifer depletion due to well water extraction. If the common temporal period of acquisitions is considered, velocity intensities are very similar, but some differences can be observed in the border areas between stability and motion. These discrepancies are caused by the different pixel size of Cosmo-SkyMed and Sentinel-1. Nevertheless, results confirm the suitability of Sentinel-1 to perform continuous monitoring and a very good continuity with previous and future X-band products. An example of time series for the same pixel area is presented, as well as a table with statistics of the comparison of measured pixels in this zone.



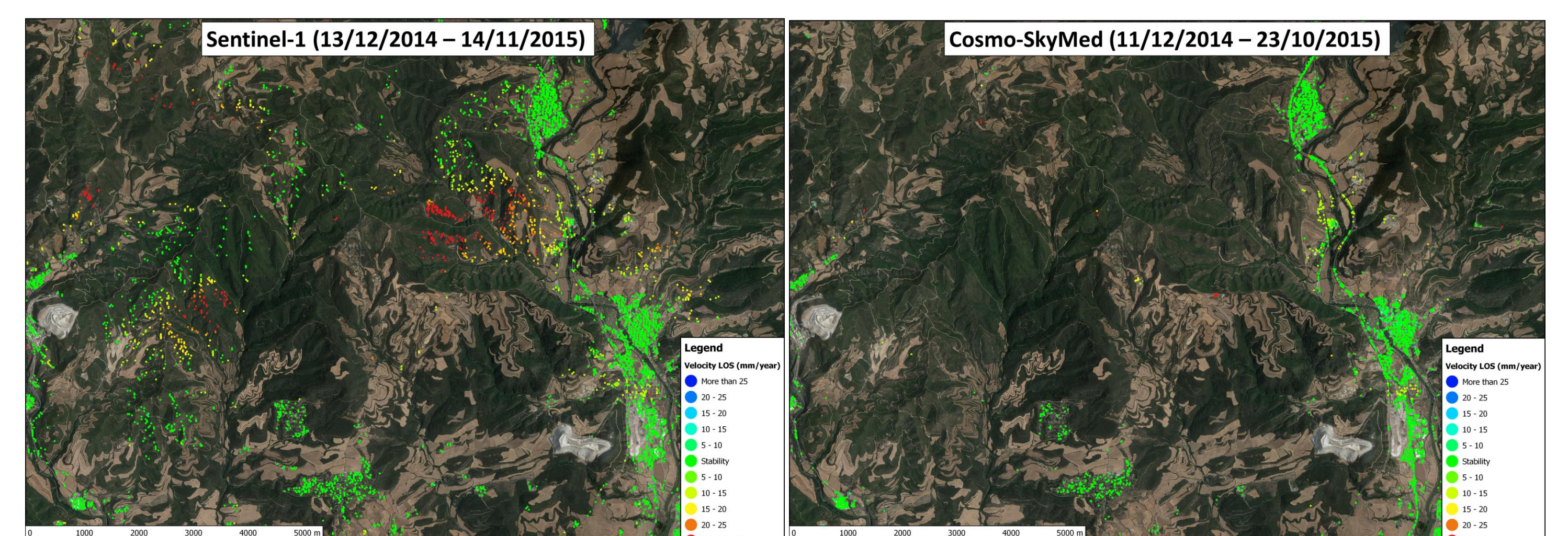
### Area 2 – Barcelona harbour

Subsidence patterns have been identified in areas of land reclaimed from the sea and breakwaters. Results coming from Sentinel-1 and Cosmo-SkyMed data are consistent, showing similar motion velocities and time series in the common temporal period. The areas affected by ground motion are mainly located in the Liquefied Natural Gas (LNG) plant and the breakwaters that protect Barcelona's harbour. More spatial detail is obtained with Cosmo-SkyMed, thanks to its higher spatial resolution, but Sentinel-1 demonstrates its good capabilities to detect small motion patterns.



### Area 3 – Mining area

Mountainous area affected by subsidence caused by salt mining activity. In this example the benefits of using Sentinel-1 C-band data, acquired with high temporal frequency, is evident. Measurement points showing the subsidence patterns can be detected even in moderately vegetated zones. On the contrary, Cosmo-SkyMed product is not able to detect coherent points in these areas, and only non-vegetated and urban zones present a good density of measurements.



## Conclusions

The work here presented demonstrates the good continuity and compatibility of interferometric results with Cosmo-SkyMed and Sentinel-1 data. Although both platforms present different spatial resolution and wavelength, a variety of ground motion patterns can be measured with similar precisions. Sentinel-1 satellites allow the monitoring of large areas at reduced cost, since images are cost-free. Alternatively X-band satellites, such as Cosmo-SkyMed and TerraSAR-X, can be useful for detailed analysis when motion is detected with global analysis performed by Sentinel-1.

## References

- [1] Ferretti A., Prati C., Rocca F., "Permanent scatterers in SAR interferometry", IEEE Transactions on Geoscience and Remote Sensing, Vol 39, No. 1, 2002, pp. 8-20.
- [2] Mora, O., Mallorquí, J., Broquetas, A., "Linear and nonlinear terrain deformation maps from reduced set of interferometric SAR images", IEEE Transactions on Geoscience and Remote Sensing 41(10):2243-2253.
- [3] Pipia, L., Pérez, F., Marturà, J., Corbera, J., Jornet, L., Rovira, A., "Two decades of Multi-Sensor Subsidence Monitoring over Ebro Delta Using Coherence-Based DInSAR Techniques", Living Planet Symposium Proceedings, 9-13 May 2016, Prague, Czech Republic.