Considering thermal expansion component in IPTA

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1. INTRODUCTION

In this document we describe the IPTA functionality to consider the thermal expansion component in PSI processing. The IPTA was upraded to support the estimation and compensation of the phase term related to thermal expansion of buildings.

We added related functionality through the programs *temp_mod_pt,* used to estimate thermal expansion phase and *temp_mod_sim_pt* used to calculate thermal expansion phase based on the sensitivity map and the temperature difference.

As a result a clear improvements was achieved through (1) the reduction of the residual phase (phase noise) which corresponds to a higher quality of the result and (2) the increase of the spatial coverage, especially for high buildings, and (3) through a physical interpretation of an addition phase component that is relevant in urban areas with high buildings.

In the following the use of the new functionality and the improvement achieved is described.

2. APPROACH

2.1. Thermal expansion

To a first approximation, the change in length measurements of an object due to thermal expansion is related to temperature change by a "linear expansion coefficient”, α:

$$\Delta length = \alpha \bullet L \bullet \Delta temp$$

With L, the length of the object.

2.2. Thermal expansion InSAR phase model

The InSAR phase difference caused by the temperature change is proportional to the thermal displacement in the line-of-sight direction:

$$\Delta\theta \propto \alpha \bullet L \bullet \Delta temp$$

Considering the linear dependence of $\Delta\theta$ on $\Delta temp$ we can write

$$\Delta\theta = a + b \bullet \Delta temp$$

With b including both the length of the object and the linear expansion coefficient, furthermore it includes a direction scaling factor for the projection to the LOS.

In IPTA programs we call *b* the derivative of phase w.r.t. temperature for each point (pdph_dtemp). The unit of pdph_dtemp is [radians/degree C].

2.3. Methodology and assumptions used

We make the following assumptions:

- pdph_dtemp differs from point to point
- the temperature is the same for entire scene (this is clearly a simplification)
- other phase components have been estimated and subtracted (except phase noise)

Based on the stack of residual phases that are unwrapped and that only includes the thermal expansion phase and phase noise we estimate the slope (pdph_dtemp) and offset (pph_offset) in a point-wise linear regression. This is done using the program *temp_mod_pt*.

In addition to the regression parameters we also determine for each layer the thermal expansion phase model. This step can also be done independently using the program *temp_mod_sim_pt*. After this we subtract the thermal expansion phase model from the residual phases and find that the residual phase is significantly reduced over high buildings for pairs with high temperature differences (Figure 1).

Applying this procedure showed, that for some layers the thermal expansion phases calculated based on the temperature different of the available temperatures (we used for example daily averages that we found on the internet) was not ideal. Modifying the temperature difference permited to model more of the residual phase. To automate this refinement of the temperature differences the program *temp_mod_pt* includes the functionality for one iterative improvement of the temperature differences applied. This refinement is done layer.

The phase to temperature sensitivity (pdph_dtemp) determined for the TX stack over Barcelona is shown in Figure 2. The sensitivity depends clearly on the building height and therefore allignes with the building blocs and high buildings locations.

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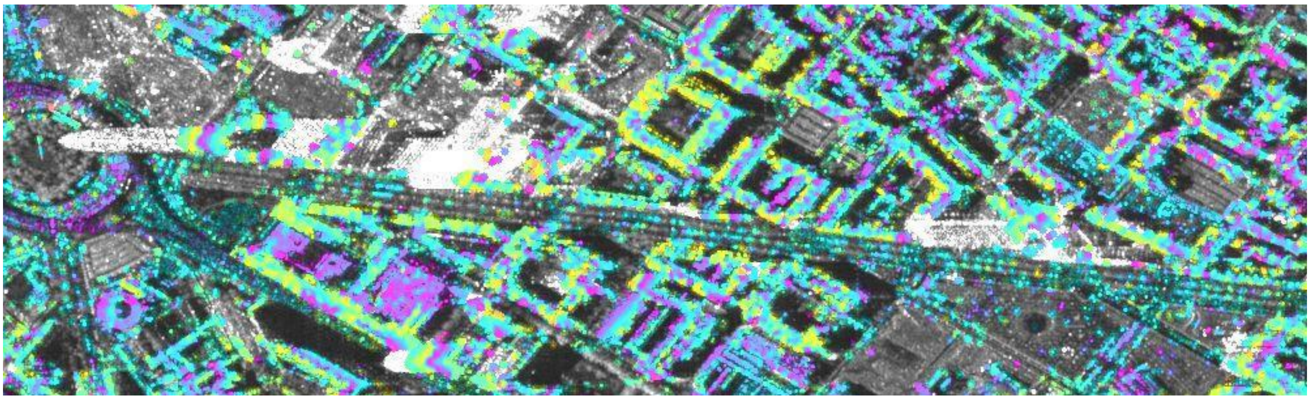
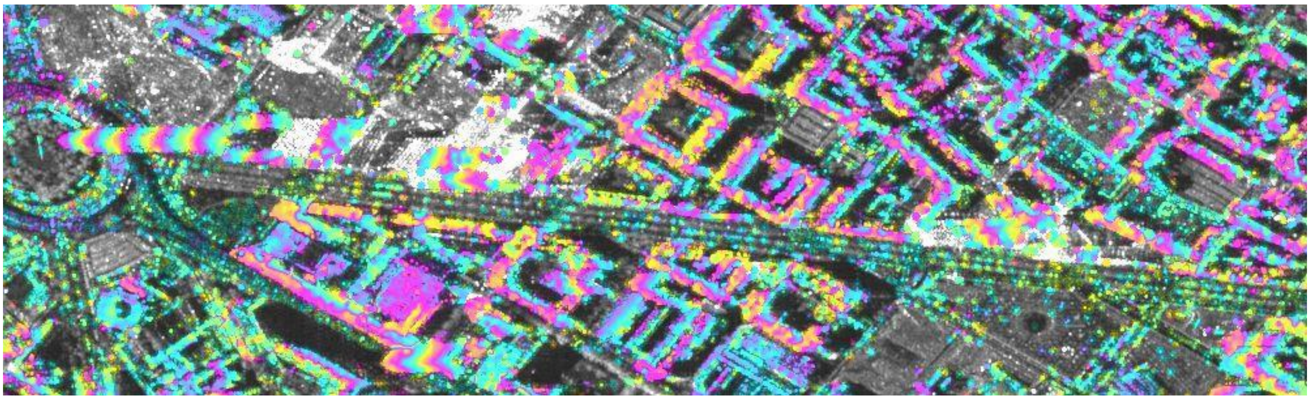
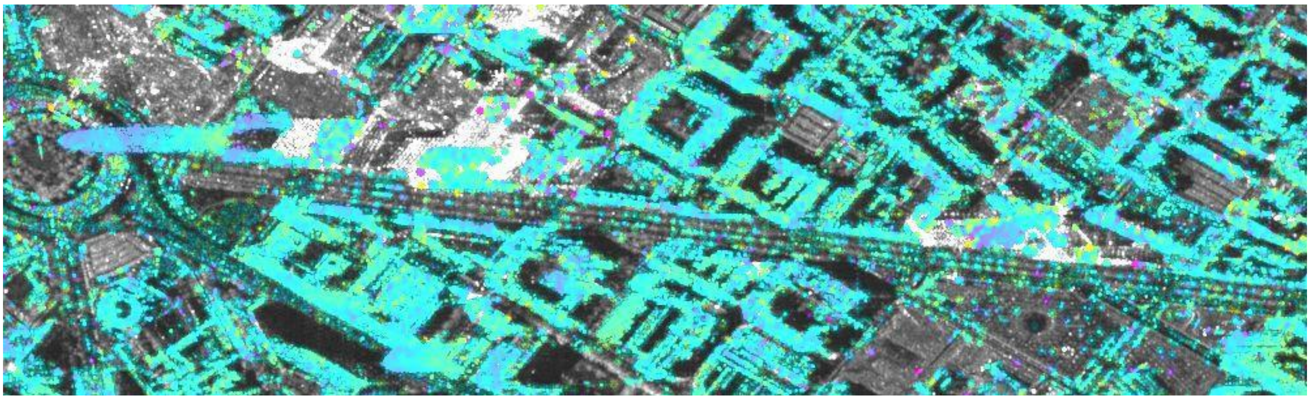


(a) residual phase (at start)



(b) estimated thermal expansion phase



(c) residual phase after subtraction of estimated thermal expansion phase

Figure 1 Example of improvement for one layer of a TX data stack over a secion of Barcelona. One color cycle corresponds to one phase cycle.

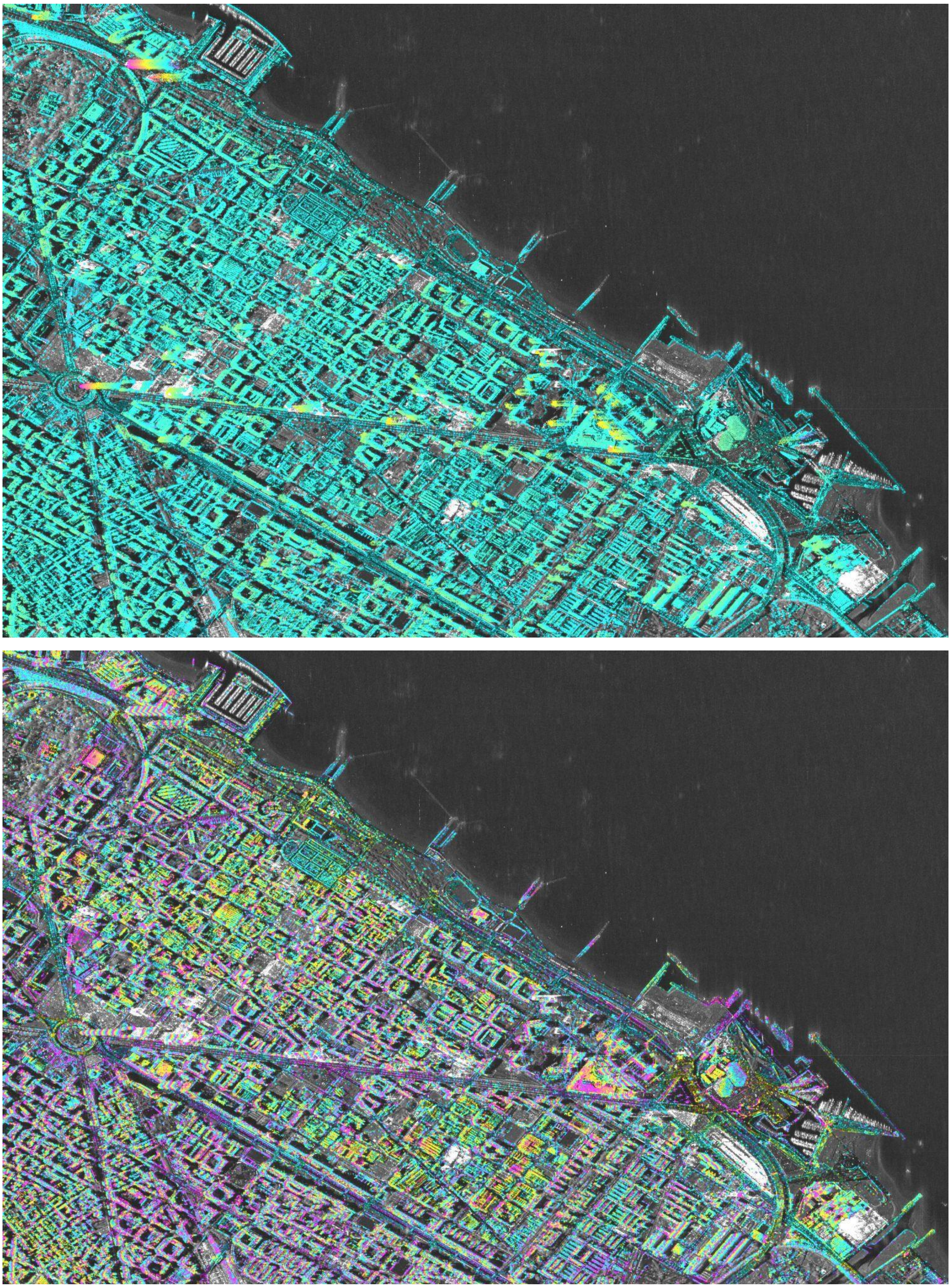


Figure 2 Phase to temperature sensitivity (pdph_dtemp) determined for the TX stack over Barcelona, using two different color scale: 10rad/1deg C (top) and 1rad/1deg C (bottom).

3. DISCUSSION

The residual phase present in the result could clearly be reduced by estimating and subtracting the thermal expansion phase. This has the consequence that the phase noise of the results (e.g. deformation history) is significantly reduced. As we typically use the phase noise (or coherence) as one parameter to characterize the quality of a result this means that a higher quality is achieved.

Working with a given quality thresholds this results in accepting significantly more points into the solution, especially for relatively high buildings (> 20m). For very high buildings the variation of the thermal expansion phase over time is so high, that the solution is often not accepted unless the thermal expansion phase is subtracted.

Deriving a deformation time series for a very high building is not so easy because the solution is initially too noisey because of the thermal expansion phase. As a consequence no result is obtain if regression through the stack are use (multi_def_pt, def_mod_pt). Estimating the thermal expansion phase for the pixels where this was possible and expanding this solution spatially permited us to expand the spatial coverage where we obtained a solution. To get a result for the very high buildings required quite many of these iterations. To get many additional accepted points on the smaller buildings (e.g. 30m high) was more straightforward. The thermal expansion phase on high buildings (130m) was up to several phase cycles!

An iteration on the temperature differences used resulted in an improvement of the results. Getting an optimal “effective temperature” that optimally represents the thermal expansion of the buildings without such an iteration is not easily possible.

The point wise phase to temperature sensitivity map shows spatial characteristics that look reasonable.