

1-6

PALSAR データを用いた微小地殻変動検出

Detection of small crustal deformation using PALSAR data

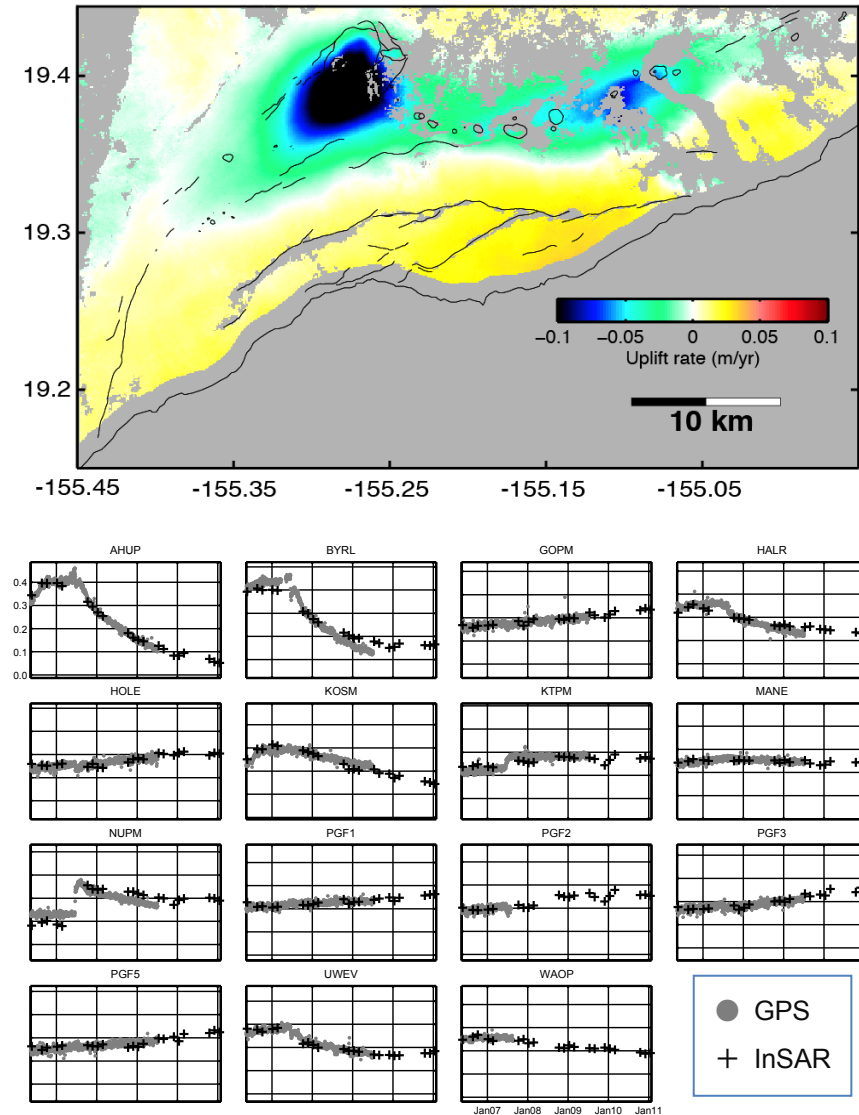
福島 洋(京都大学防災研究所)

Yo Fukushima (DPRI, Kyoto University)

地震・火山噴火・地すべりのメカニズムを探り、それらの発生・推移を予測するためには、微小な変形を時空間的に詳細に捉えることが重要である。合成開口レーダ干渉法(InSAR)を用いると、違う時期に撮像された二枚の SAR 画像から期間内に生じた地表面の変形を面的に捉えることができるが、定期的に撮像された多数の SAR 画像を用いることにより、さらに変形を時間的に追跡することができる。

発表者は、2006～2011 年の間に活躍した ALOS 衛星の PALSAR データを主に用い、この InSAR 時系列解析に関連する手法開発および地震火山プロセスの解明のための実データへの適用を行ってきた。InSAR 時系列解析には、1) 高品質データの安定的供給、2) ロバストな自動干渉処理システム、3) 変動時系列について解くための解析処理が必要である。さらに、その精度向上のためには、4) ノイズ軽減処理も重要である。PALSAR は比較的低頻度な撮像回数(年5回程度)と軌道制御方針が InSAR 時系列解析にとって理想的ではなかったが、高品質なデータを安定的に供給した。自動干渉処理は、シーンの広範囲を海が占める等の場合にも自動処理が可能となるよう条件分岐等を工夫し実現した。変動時系列を解くための解析処理については、主要なノイズ源となる大気遅延や軌道決定誤差の影響も同時に推定することにより時系列解析の精度向上を図った。

InSAR 時系列解析におけるシグナル検出能力のボトルネックは、解析対象シグナルの場所や空間的広がりによって異なるが、運用側(ハード対応)とユーザ側(ソフト対応)および両者の協働(意見交換を通じた観測方針決定等)が大切だろうと思う。この観点から、PALSAR 時代は、関係者の尽力により、一定の成功を収めたと考えられる。



(上) InSAR 時系列解析によって得られたハワイ島キラウエア火山における 2007/10/9-2009/8/29 の平均上下速度。(下)GPSとInSARの変位時系列の比較。

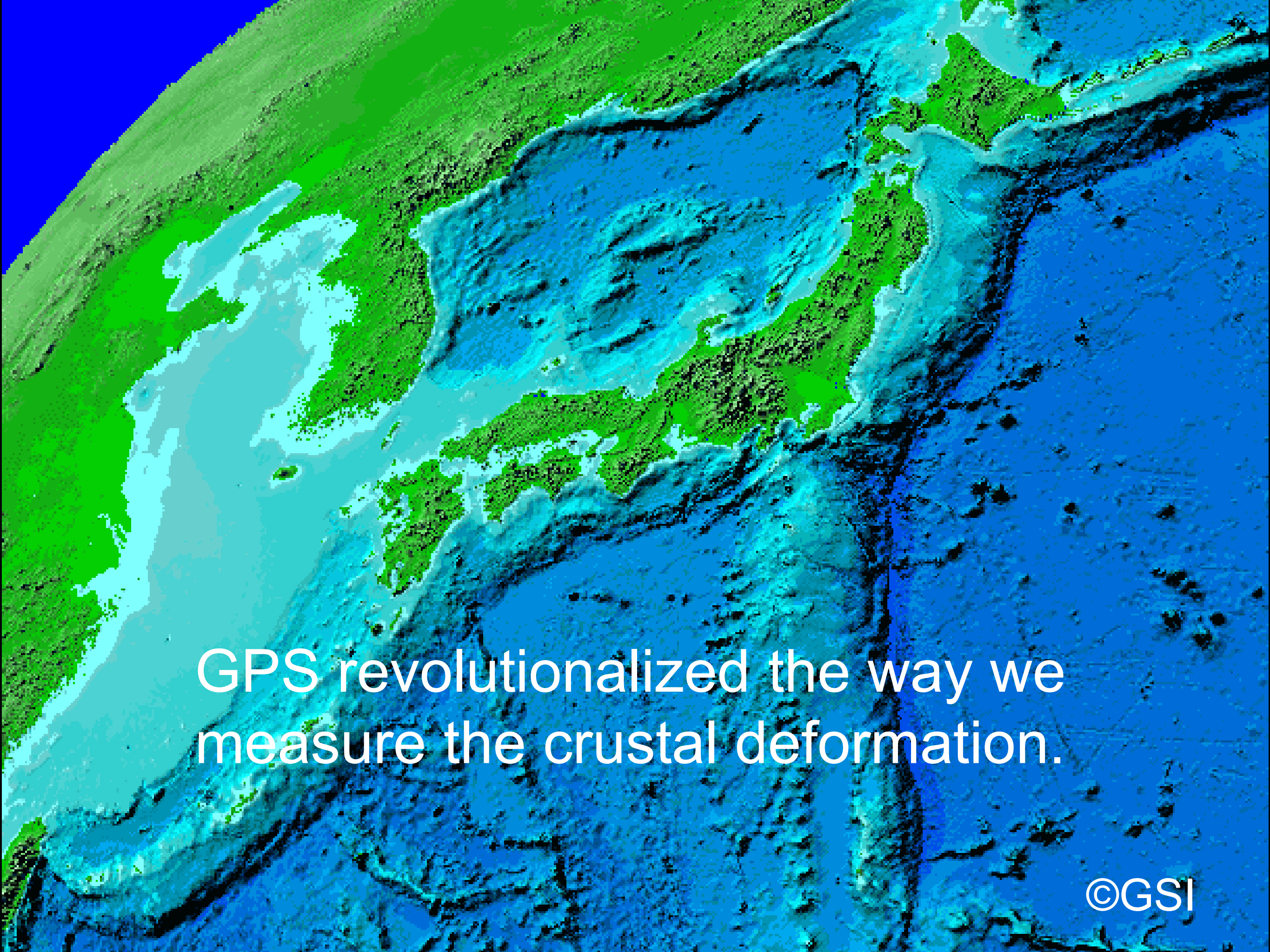
PALSARを用いた微小地殻変動検出

Measurement of small crustal deformation using PALSAR data

- My “activity report” for the past 6 years on InSAR TS studies -

福島 洋（京都大学防災研究所）
Yo Fukushima (DPRI, Kyoto University)

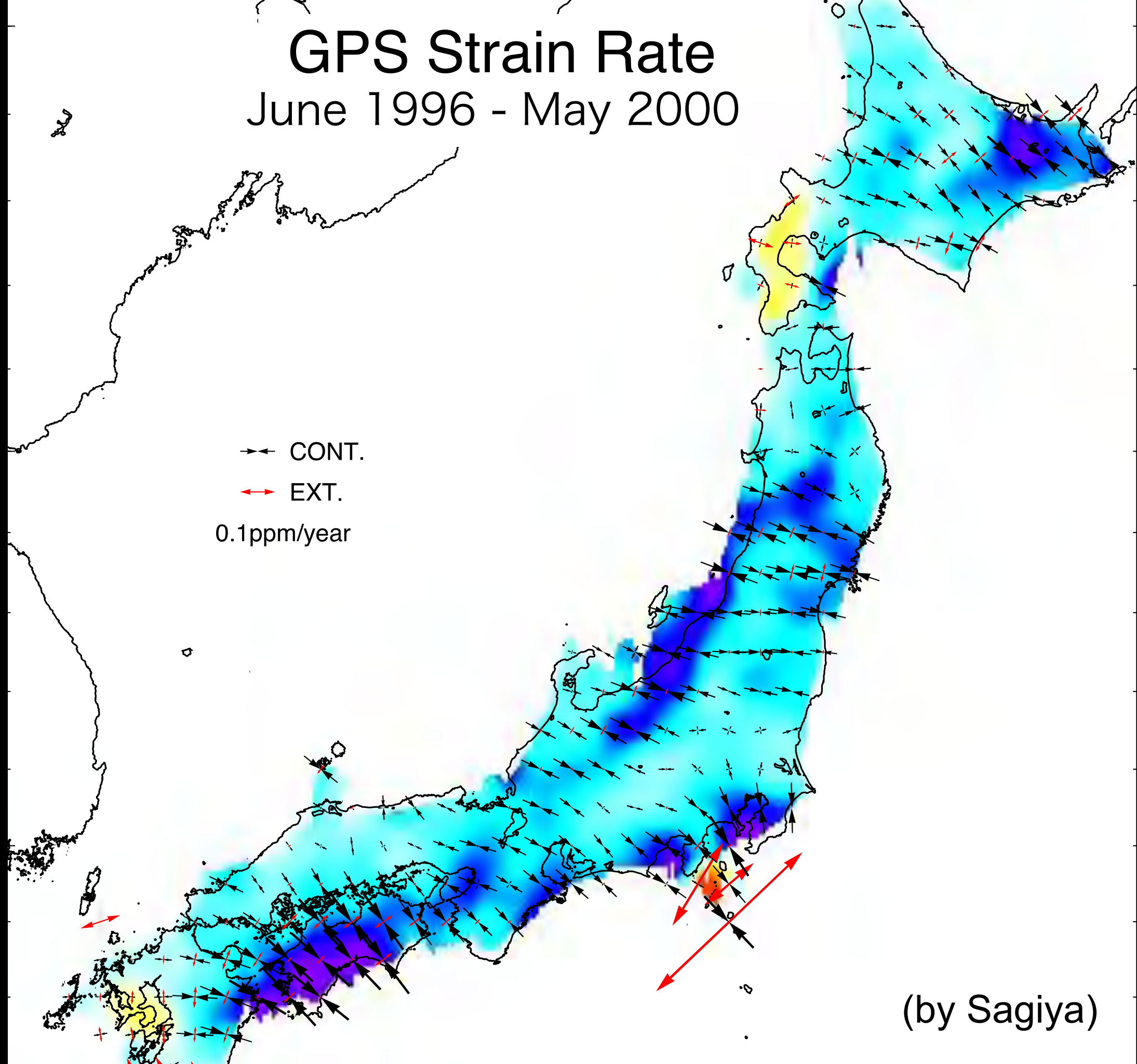


An aerial photograph showing a tectonic plate boundary. A large, green, mountainous island is situated on the left side of the frame. To its right, a deep blue ocean trench runs parallel to the island's coast. Further right, a series of smaller, green, mountainous islands are visible, separated by shallow blue waters. The background is a vast expanse of deep blue ocean. The text "GPS revolutionized the way we measure the crustal deformation." is overlaid in white on the lower right portion of the image.

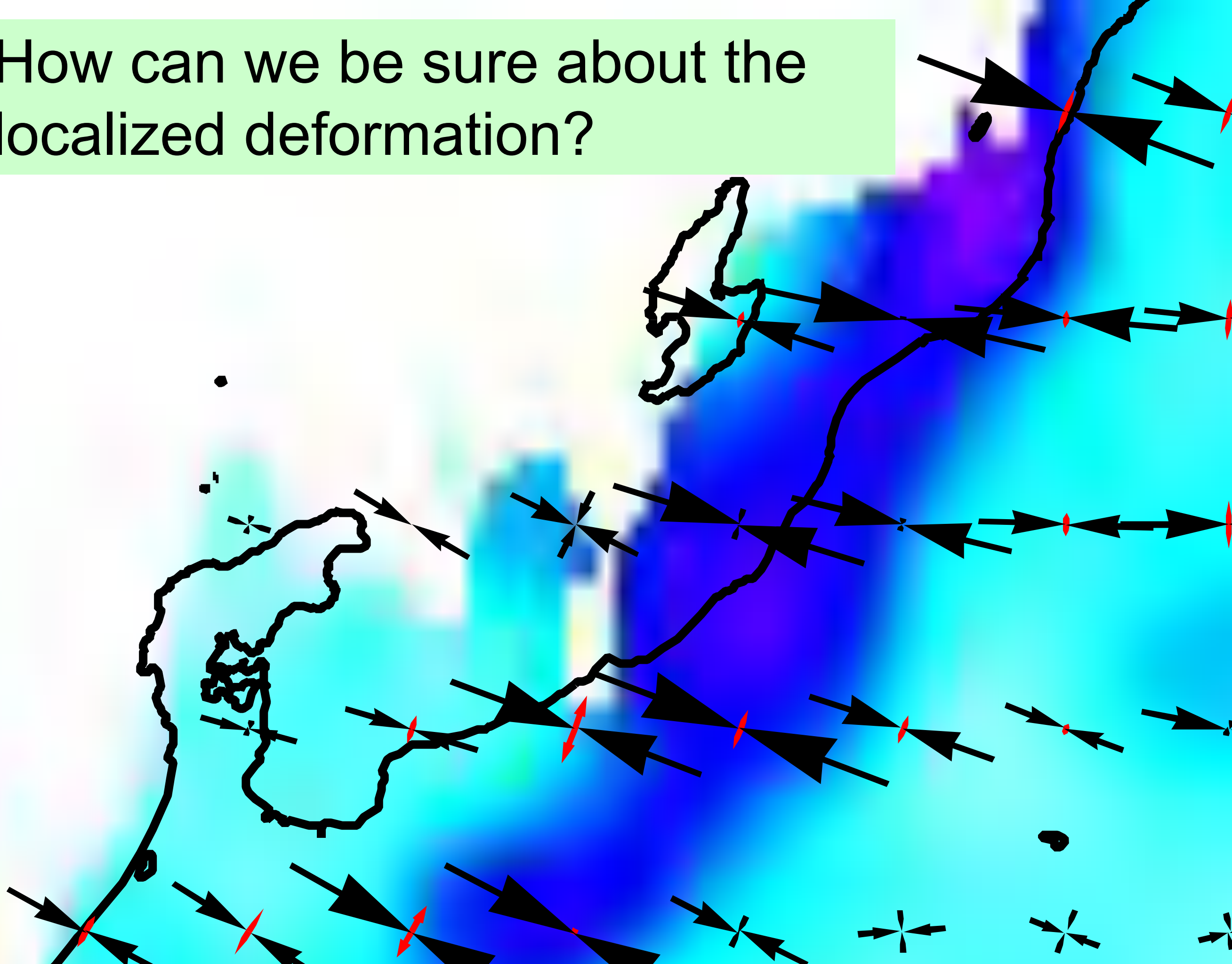
GPS revolutionized the way we
measure the crustal deformation.

GPS Strain Rate

June 1996 - May 2000

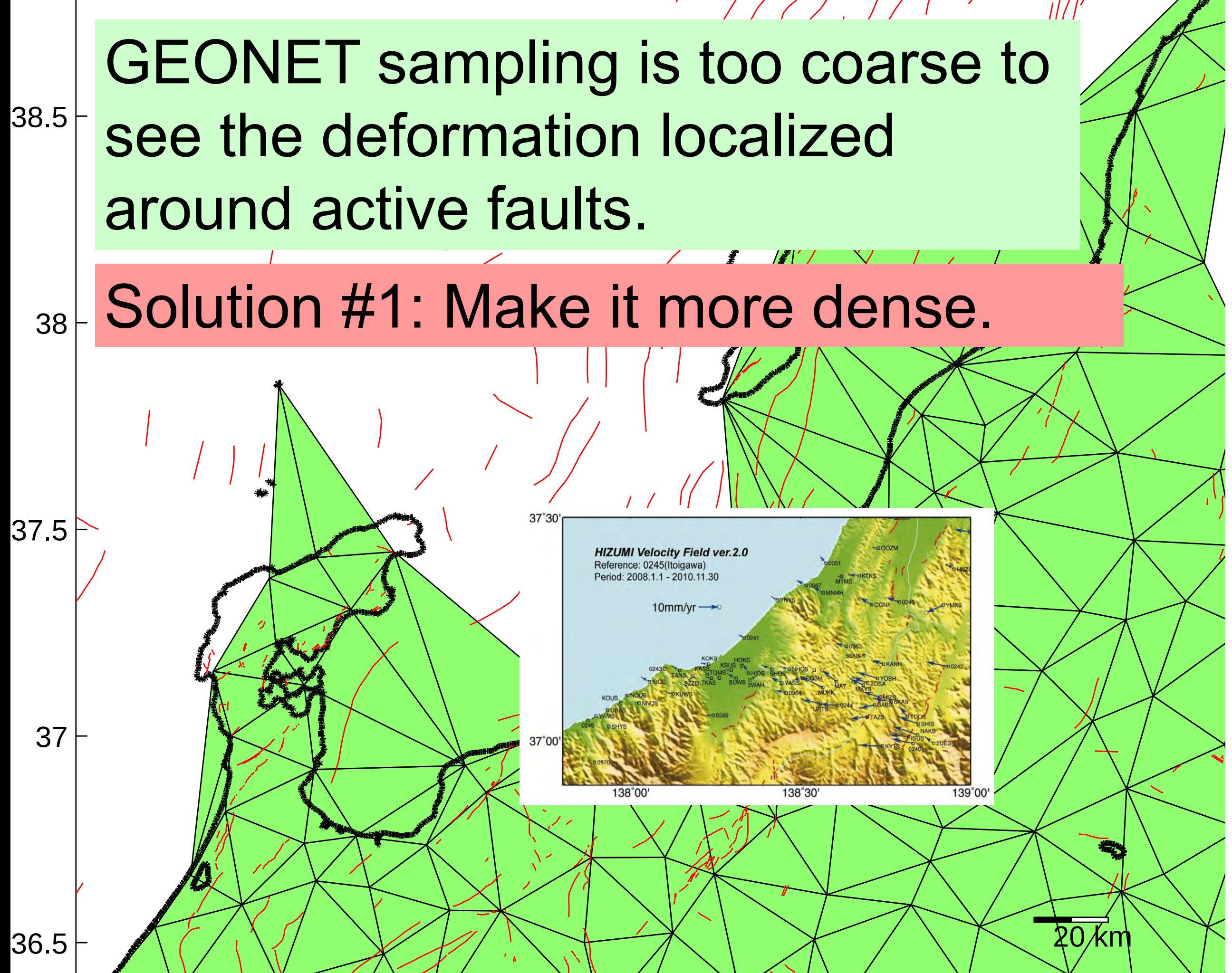


How can we be sure about the localized deformation?

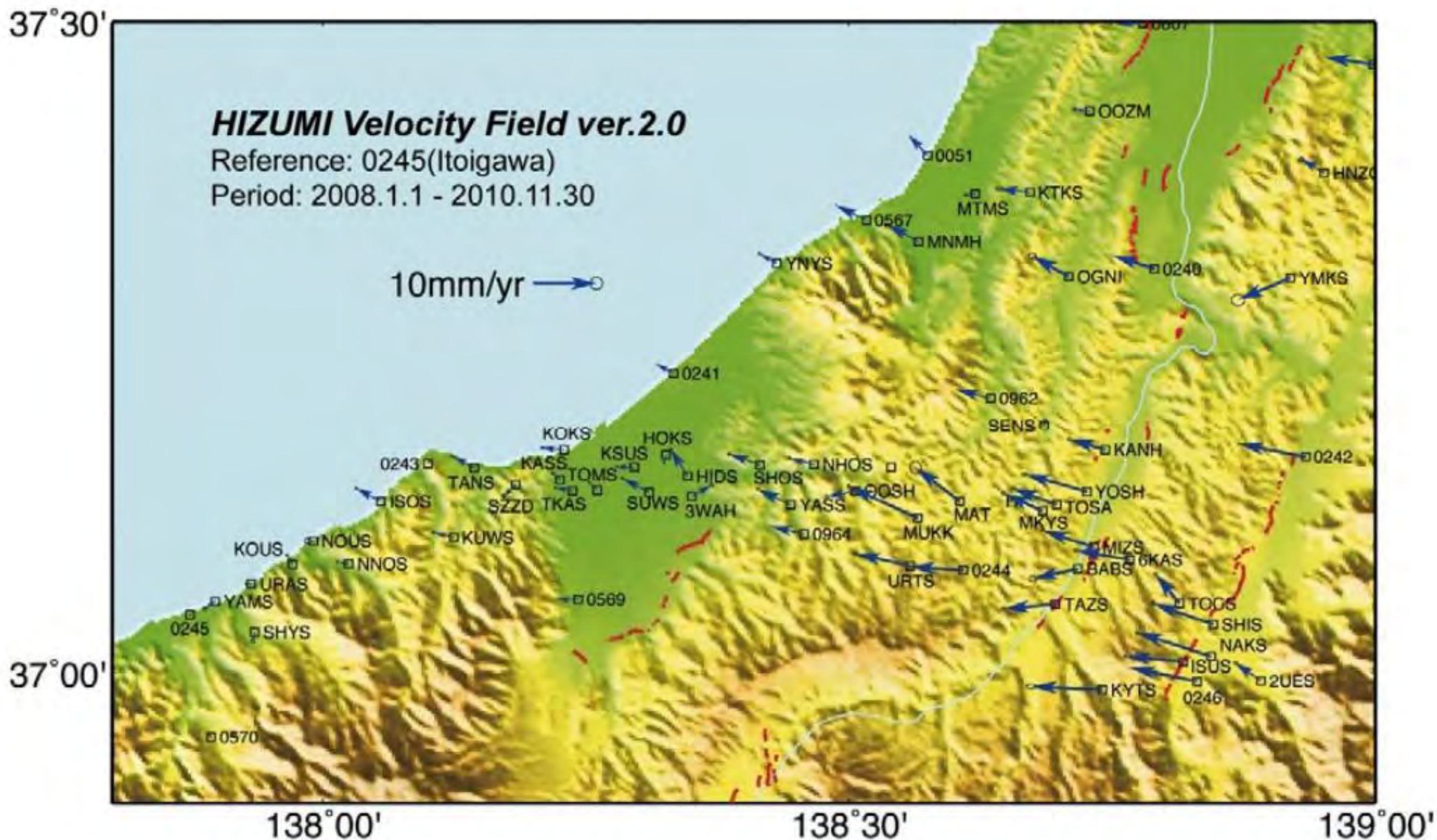


GEONET sampling is too coarse to see the deformation localized around active faults.

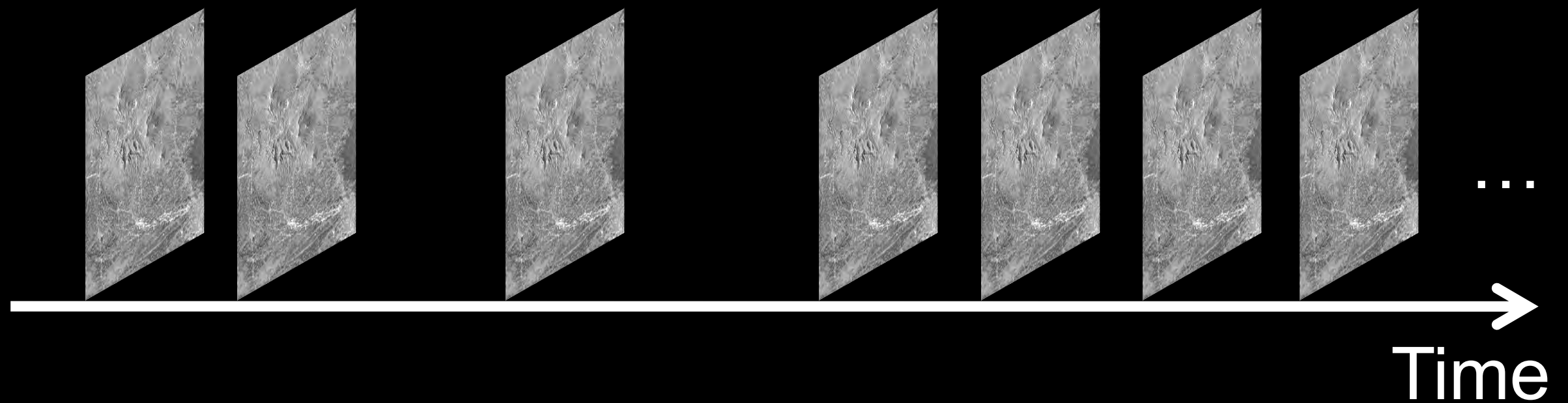
Solution #1: Make it more dense.



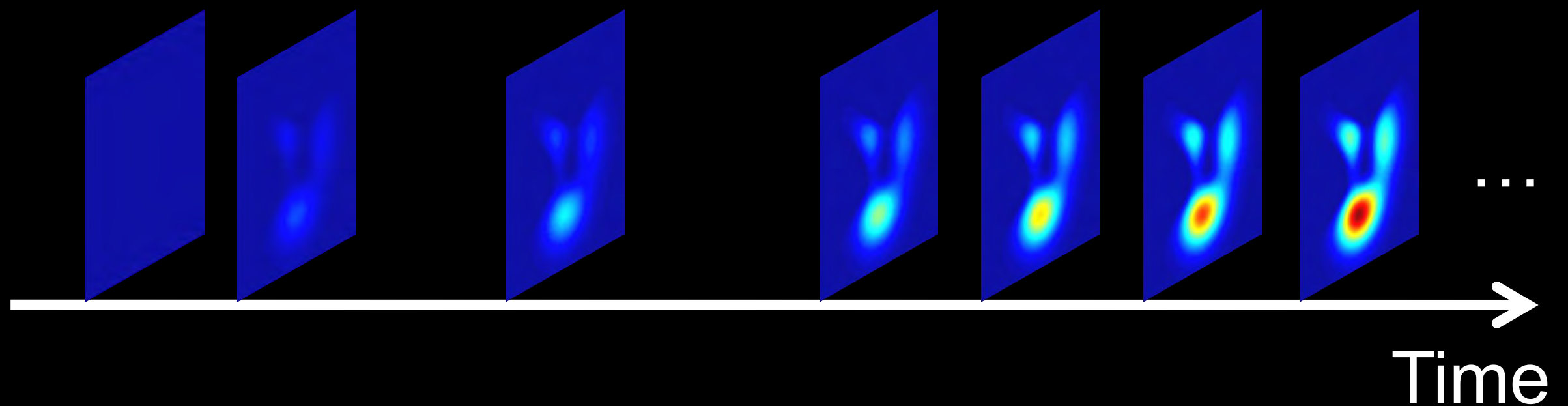
Spatial sampling at a few km



Solution #2: InSAR TS analysis!



InSAR TS analysis

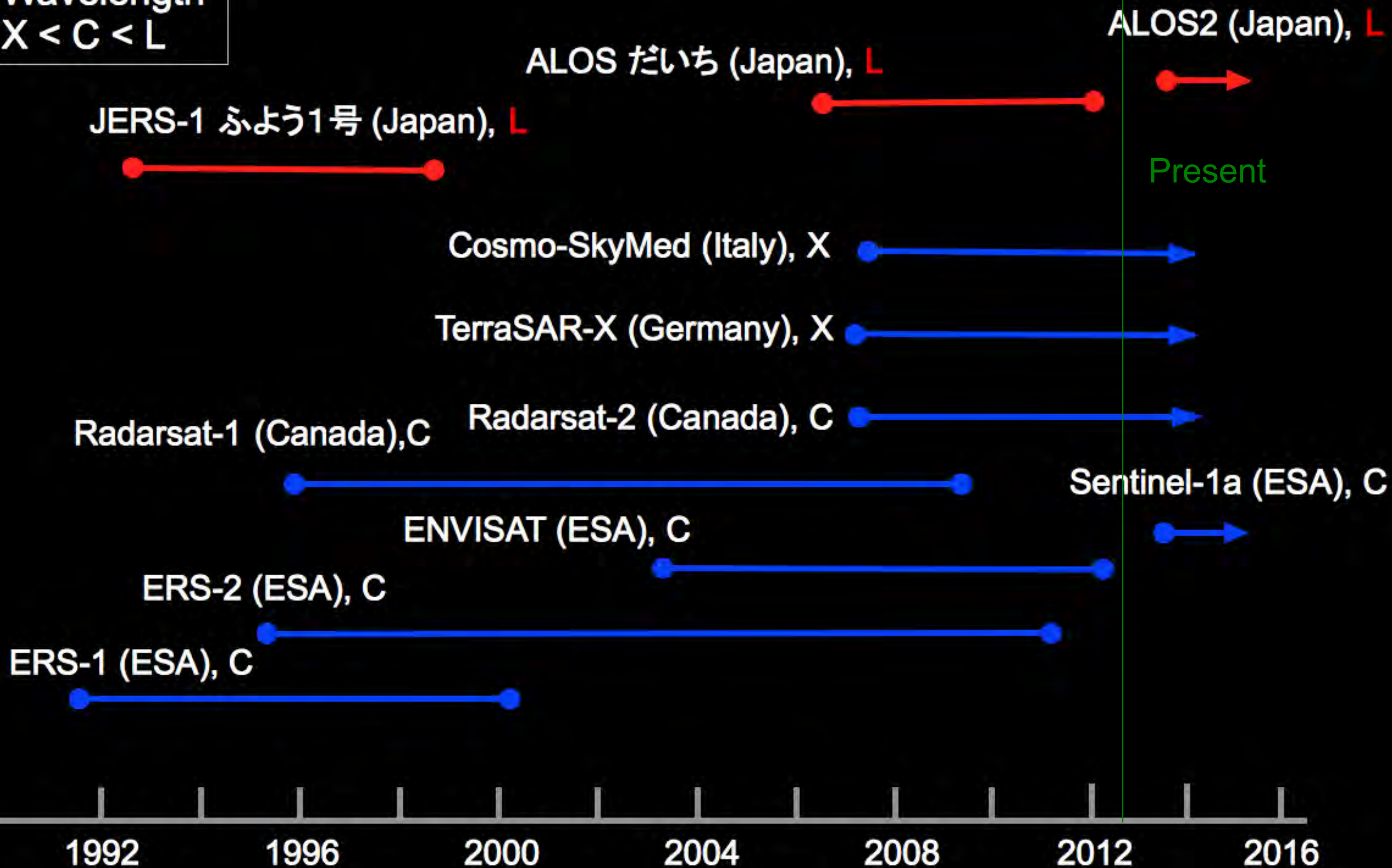


Necessary conditions for the detection of small displacements using InSAR time-series analysis

- Continuity of the satellite missions
- Regular and frequent acquisitions
- Data quality and acquisition stability
- Bulk InSAR processing with a robust, automated and reliable system
- Method to solve for the time-series
- Reduction of noise in each interferogram

Principal EO satellite missions

Wavelength
 $X < C < L$



How have I/we done (with ALOS data)?

- Continuity of the satellite missions

OK (5 yrs). More long-term missions like ERS-1 to 2 would be ideal.

- Regular and frequent acquisitions

OK. More frequent acquisitions is favorable but prioritizing the background mission was nice.

- Data quality and acquisition stability

Excellent!

- Bulk InSAR processing with a robust, automated and reliable system

This became possible thanks to the quality of the products.

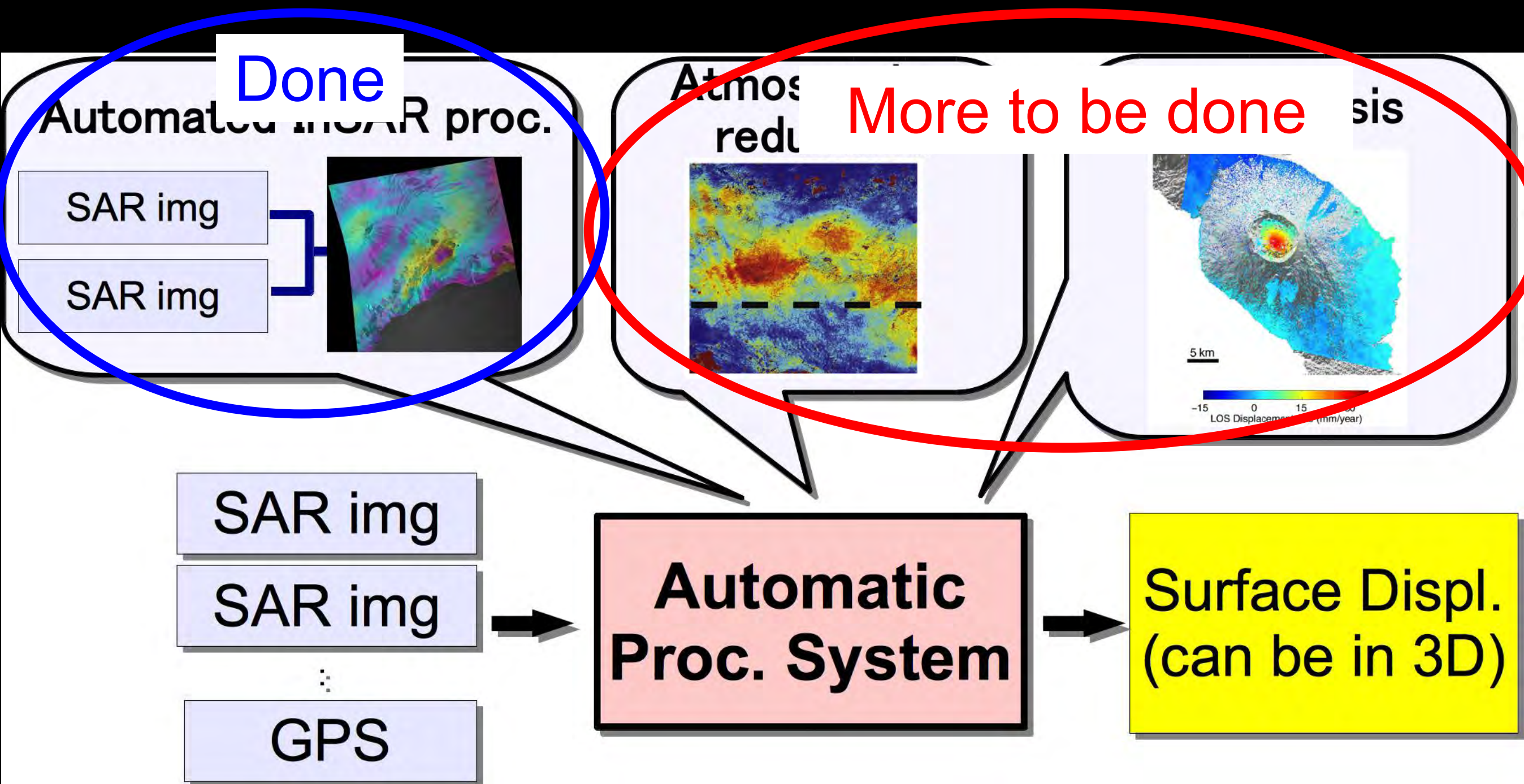
- Method to solve for the time-series

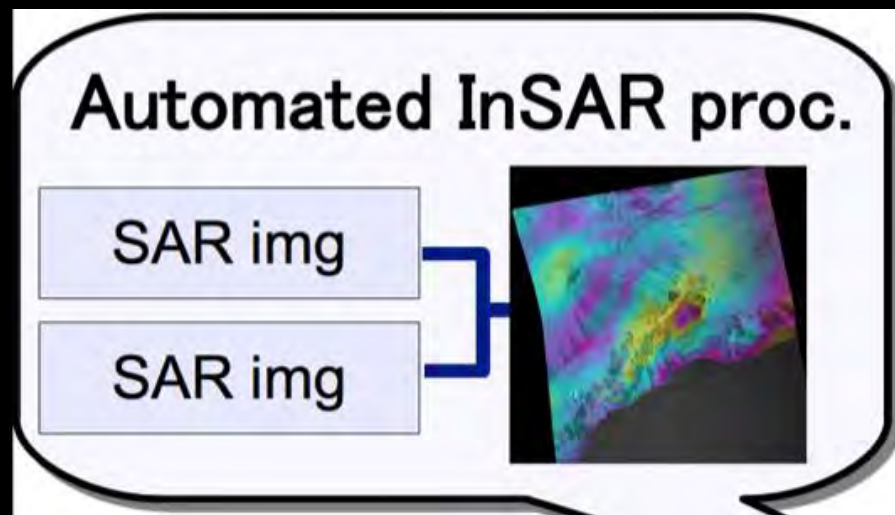
Basic part of the algorithms are now mature. Improvements being developed.

- Reduction of noise in each interferogram

There is room for improvements.

Automated processing chain





Automated InSAR processing (w/Gamma)

- No need to worry about different sensors
- Automatic DL of raw data for PALSAR
- Automatic preparation of DEM (DL, mosaic, crop)
- Robustness was emphasized especially in focusing and coregistration (trials w/different params and patches -> the best one is chosen)
- Bulk ifg processing for PALSAR (just specify the path, frames, dates, the threshold baselines -> stack of ifgs will be obtained)

A study on the atmos. noise reduction

General Observation Equation: (Fukushima, FRINGE, 2011)

$$\mathbf{d} = \mathbf{A}\mathbf{x}$$

where $\mathbf{x}^T = [a_1, a_2, \dots, a_N, u_1, u_2, \dots, u_{N-1}]$

$\mathbf{d}^T = [d_1, d_2, \dots]$: Unwrapped InSAR

$a_n (n = 1, 2, \dots, N)$: Atmospheric and orbital noise in n-th SAR image

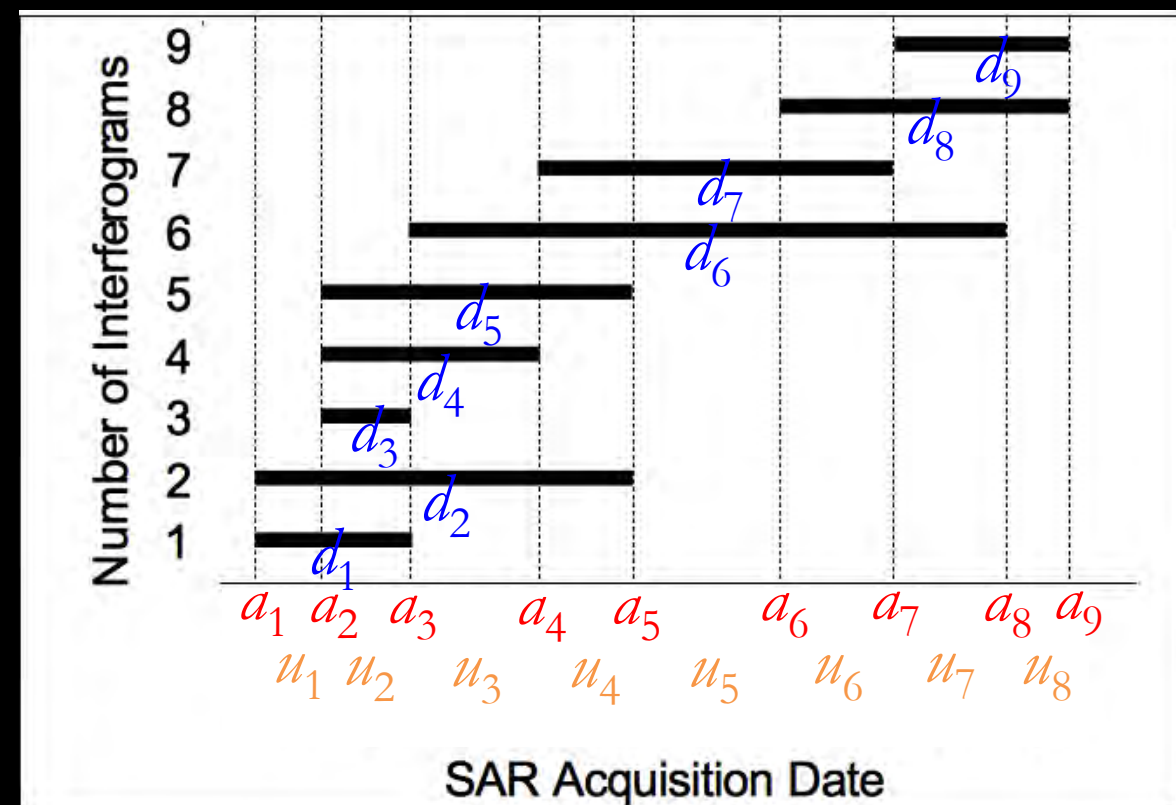
$u_n (n = 1, 2, \dots, N - 1)$: Incremental LOS displ. in n-th time interval

2N-1 unknowns

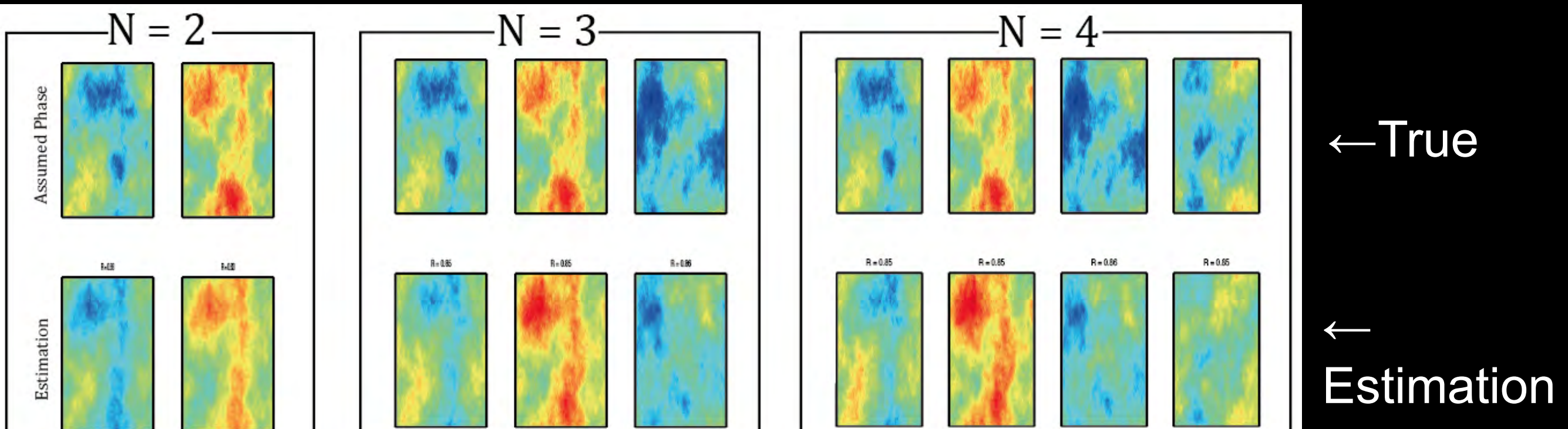
($\leftrightarrow \text{rank}(\mathbf{A}) = N-1$)

→ for the time being, solve by assuming no deformation

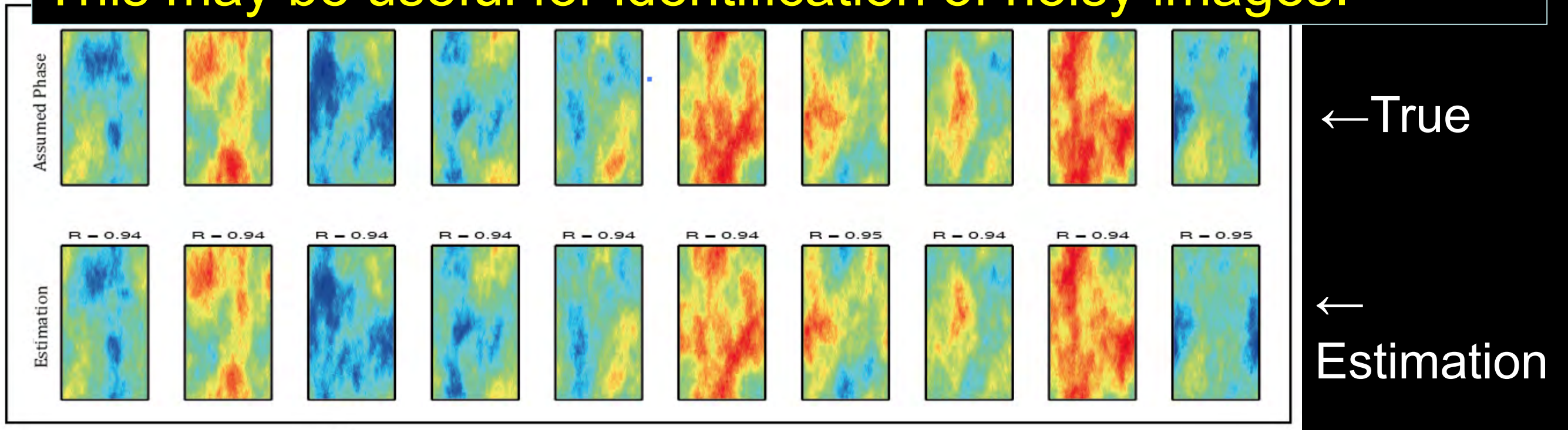
→ N unknowns: solve with a minimum norm condition



Synth. tests on atmos. noise reduction

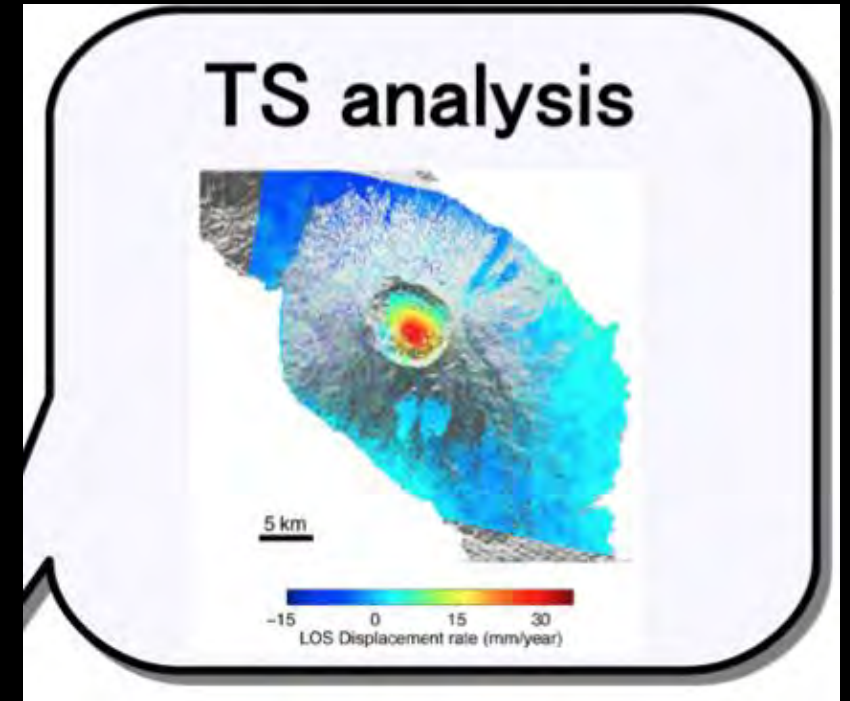


This may be useful for identification of noisy images.



Time-series analysis

- Small-baseline approach: coded with matlab, simultaneous estimation of the phase ramps & altitude-dependent phase
- StaMPS/MTI + post-processing: Combination with GPS to obtain spatiotemporal displacement field reliable also in broad signals



My version of SB approach

Atmospheric noise
correlated with
altitude

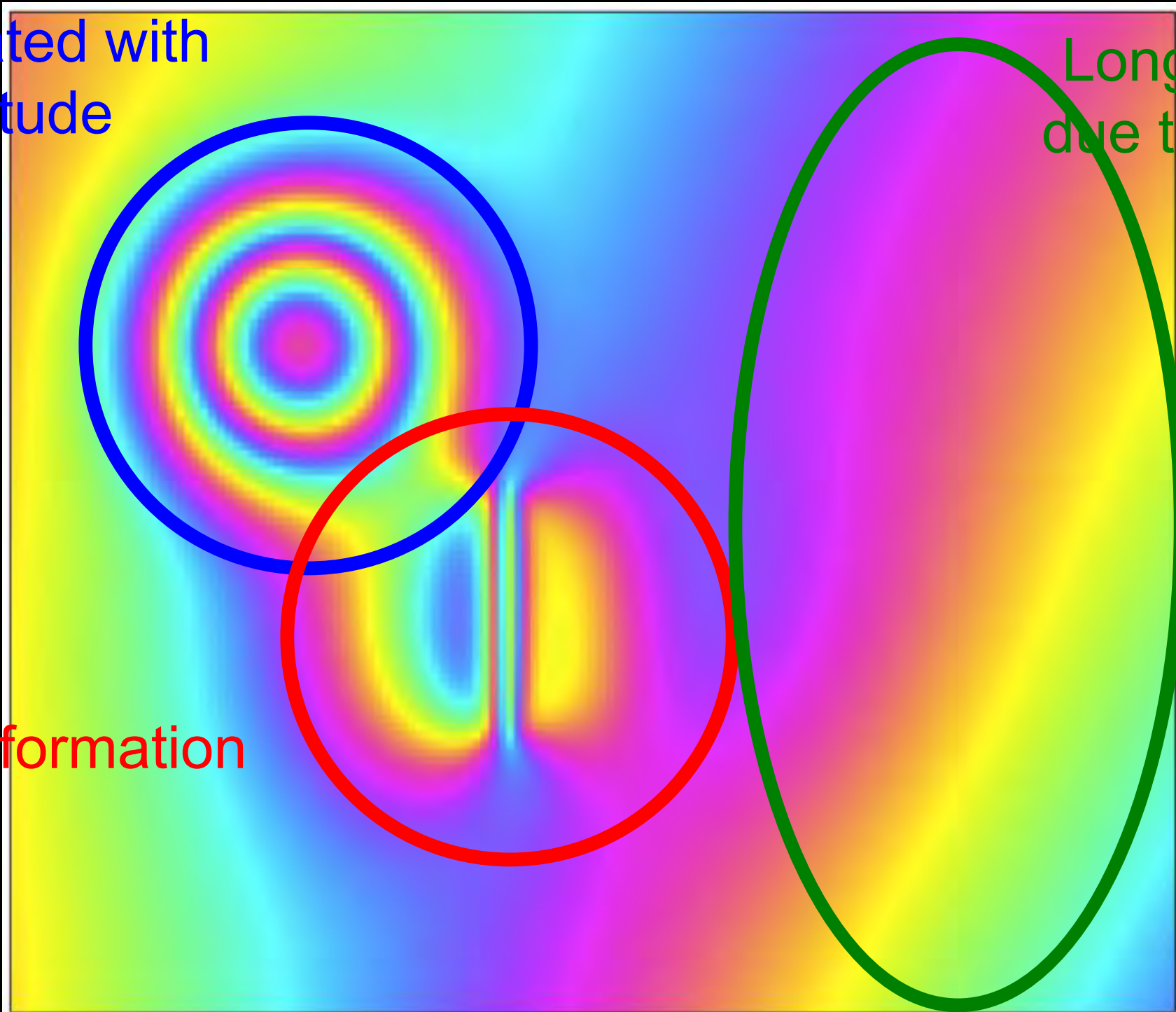
Long-wavelength ramp
due to orbital inaccuracy
etc.

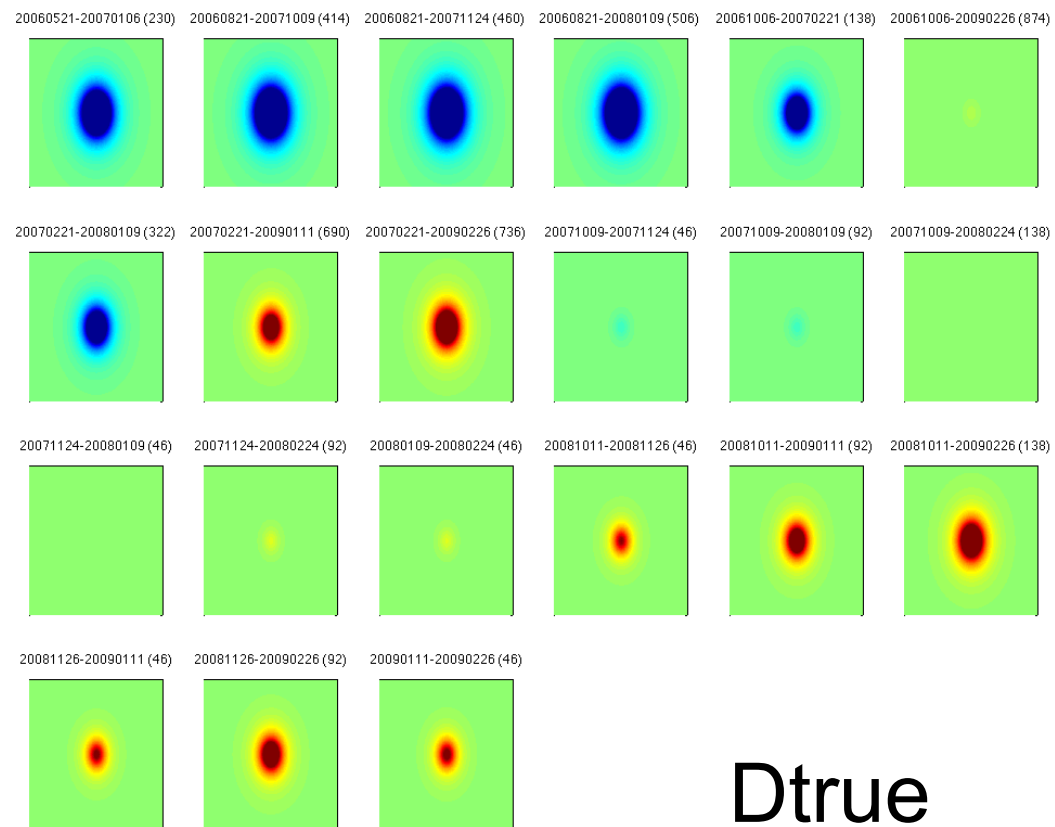
+ Offset

+ artifact due to
DEM error

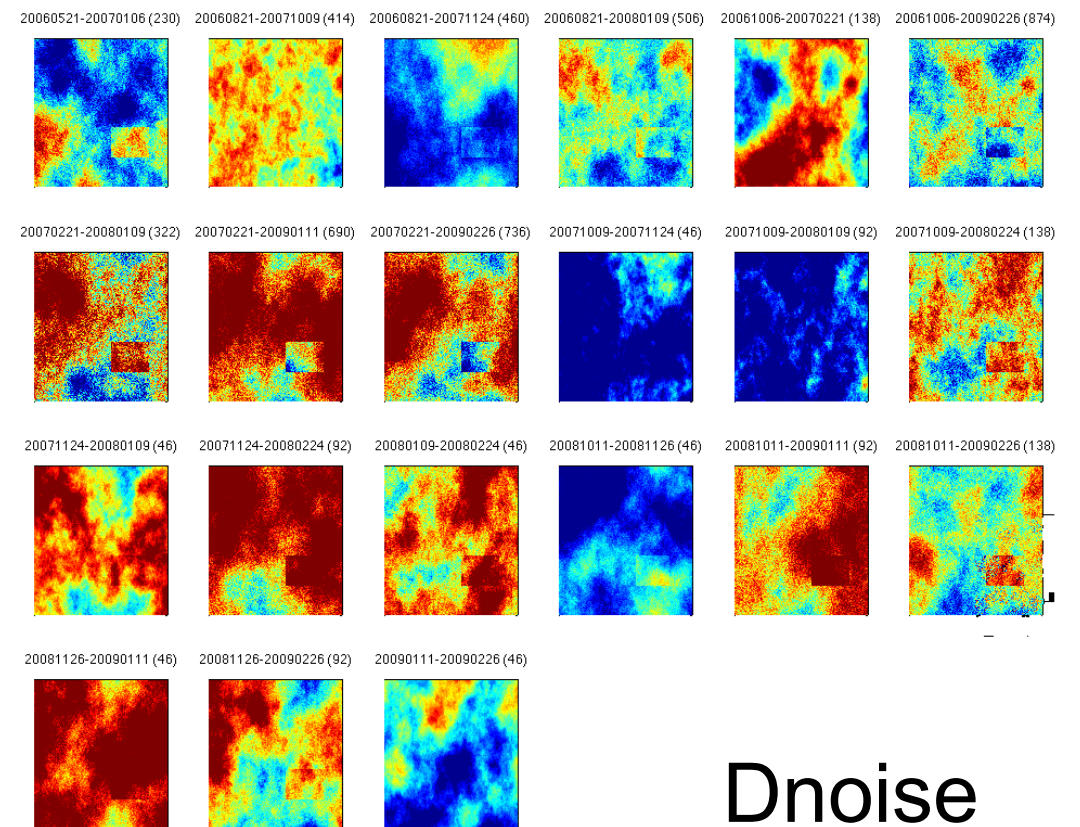
Deformation

Solve for all of these simultaneously

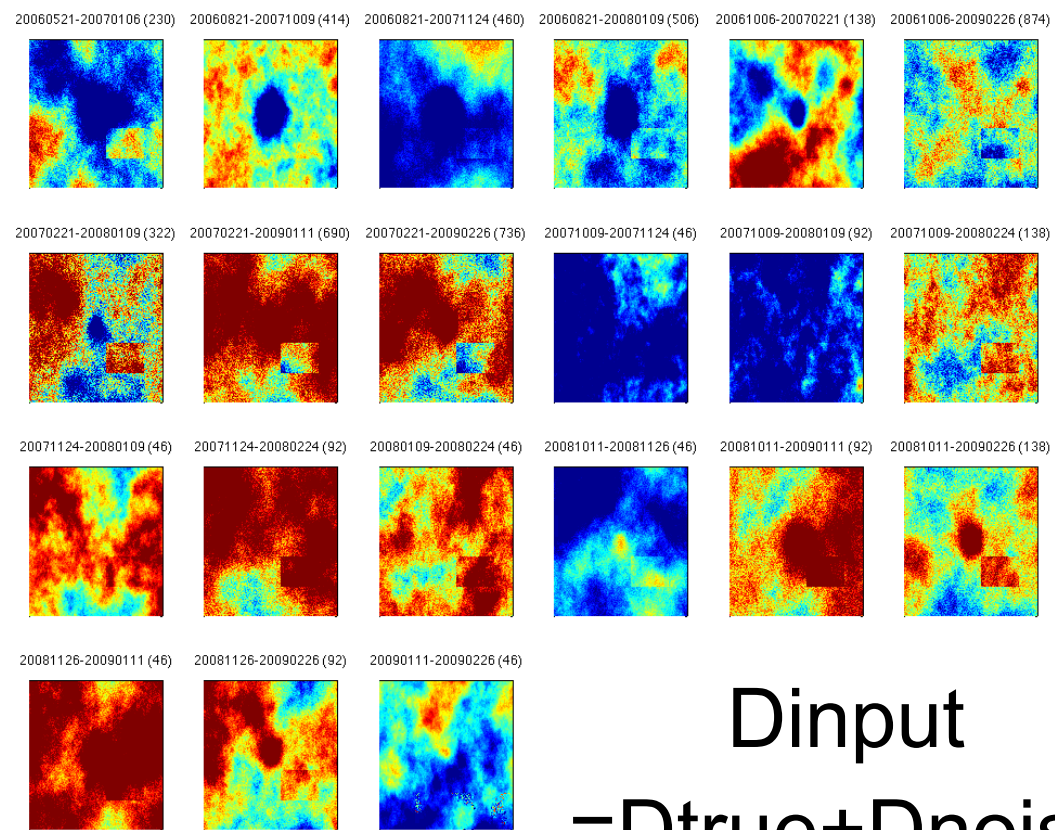




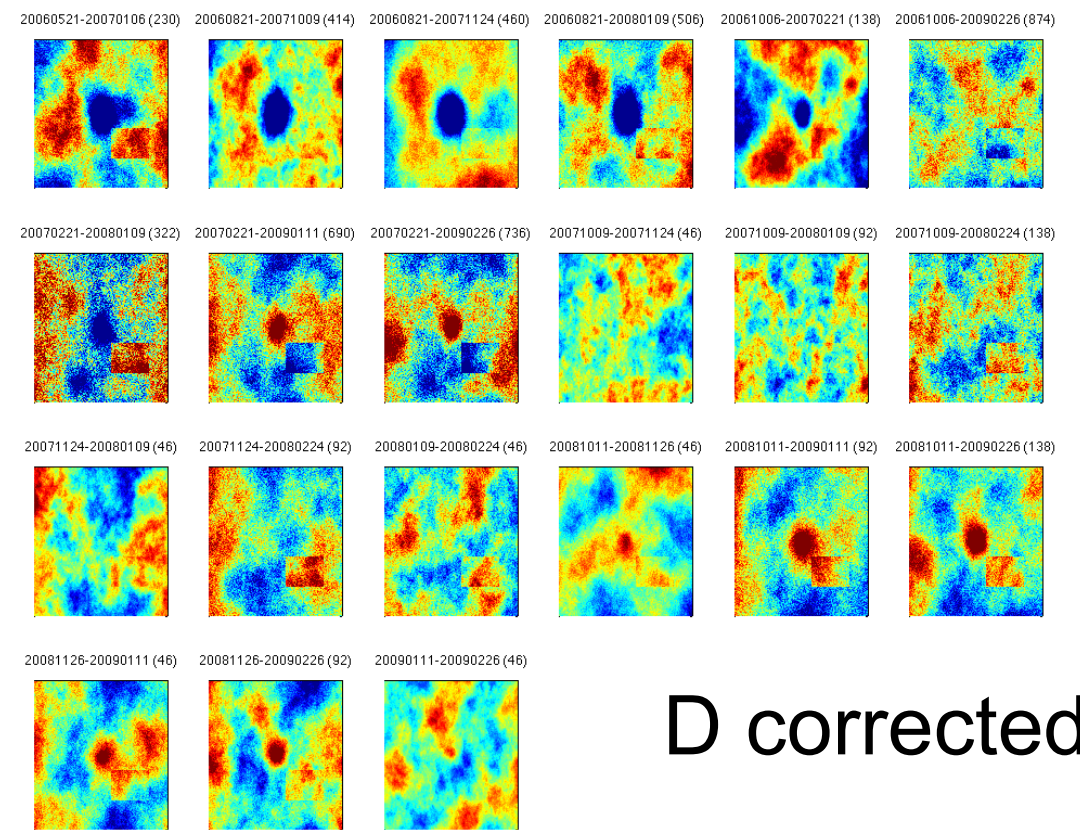
Dtrue



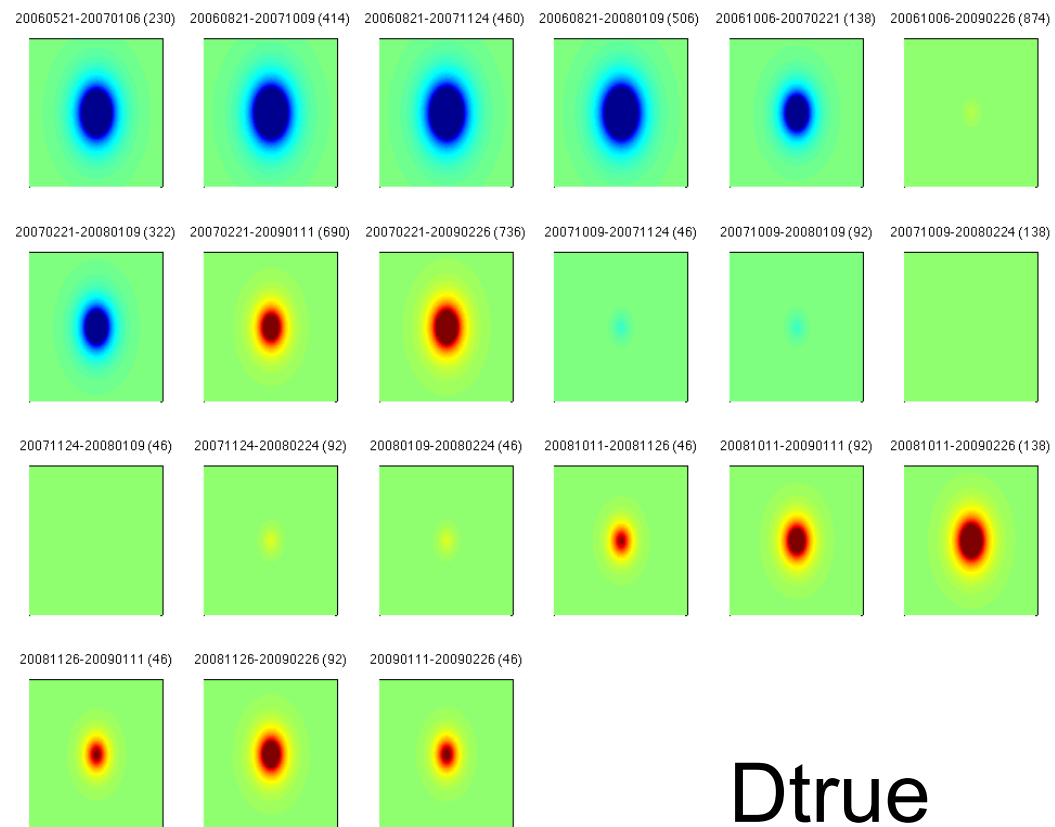
Dnoise



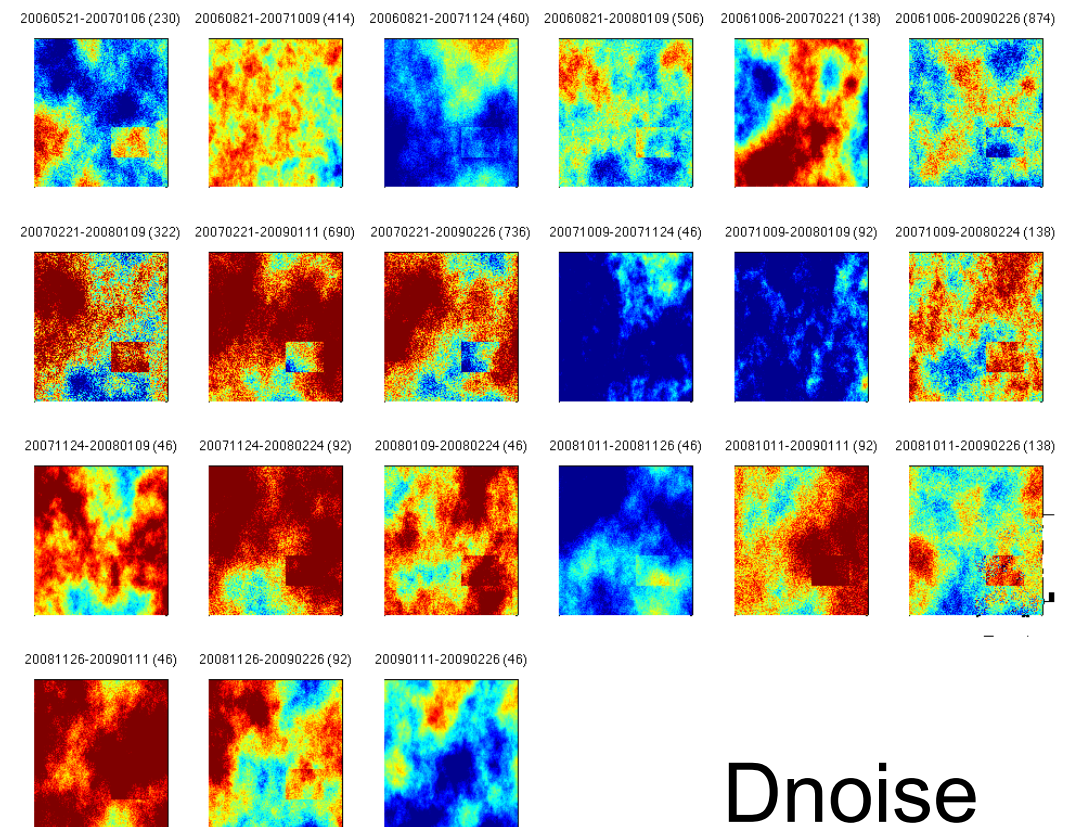
Dinput
=Dtrue+Dnoise



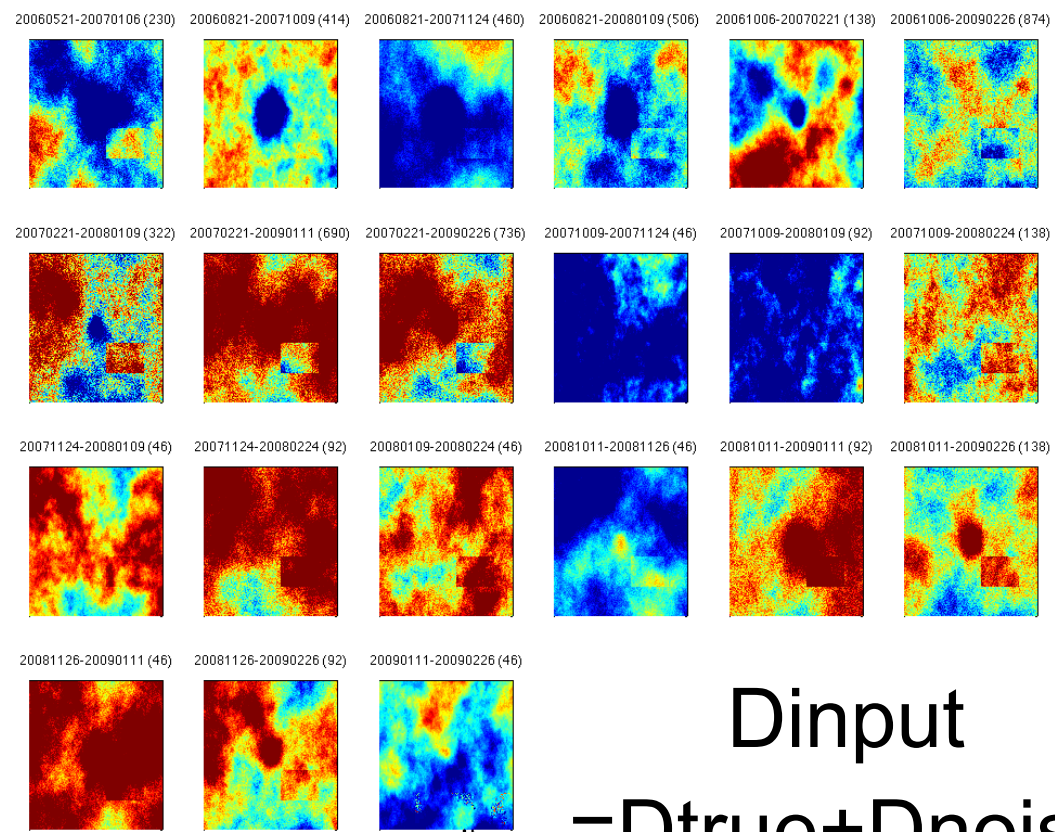
D corrected



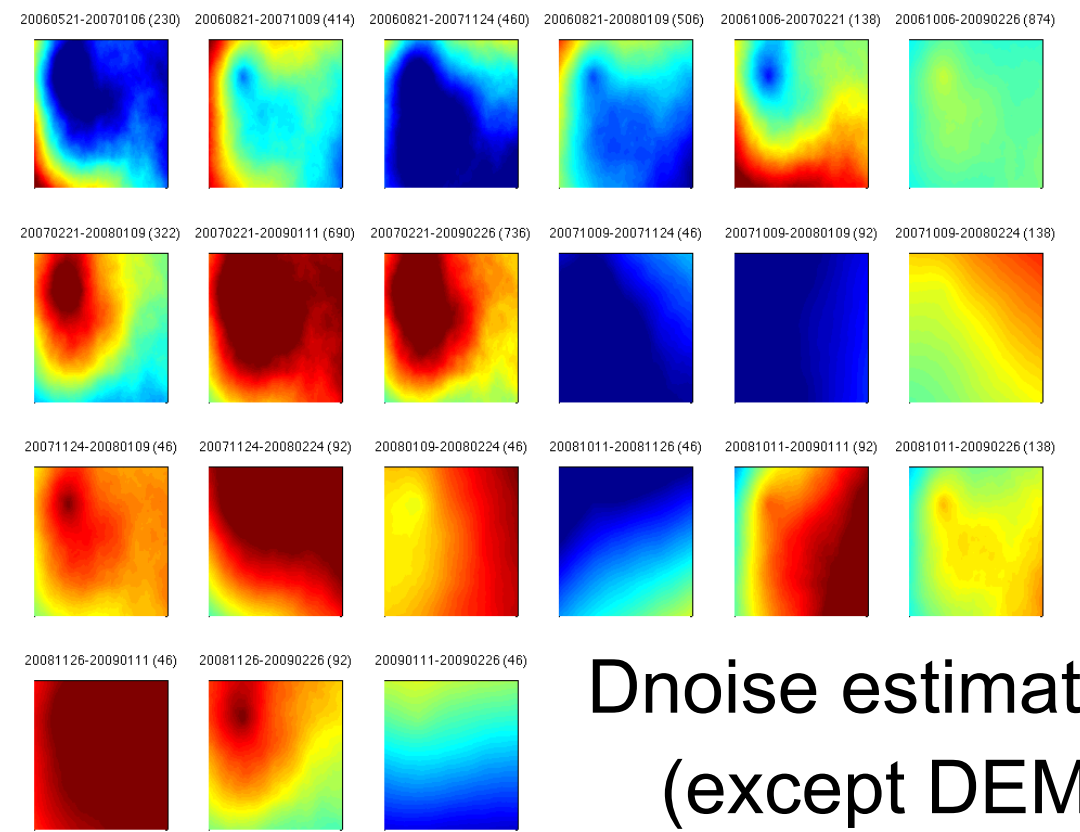
Dtrue



Dnoise

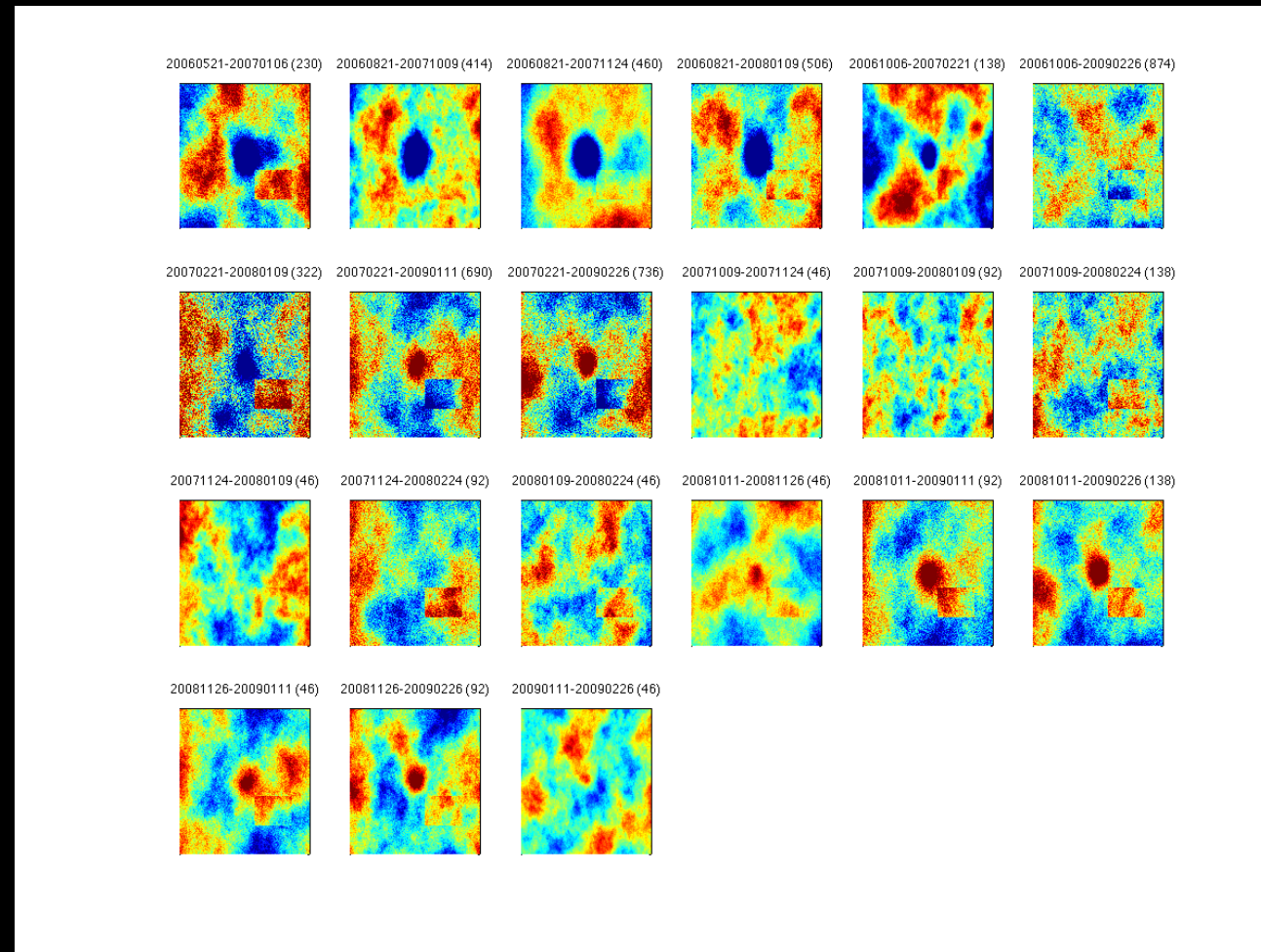


Dinput
=Dtrue+Dnoise

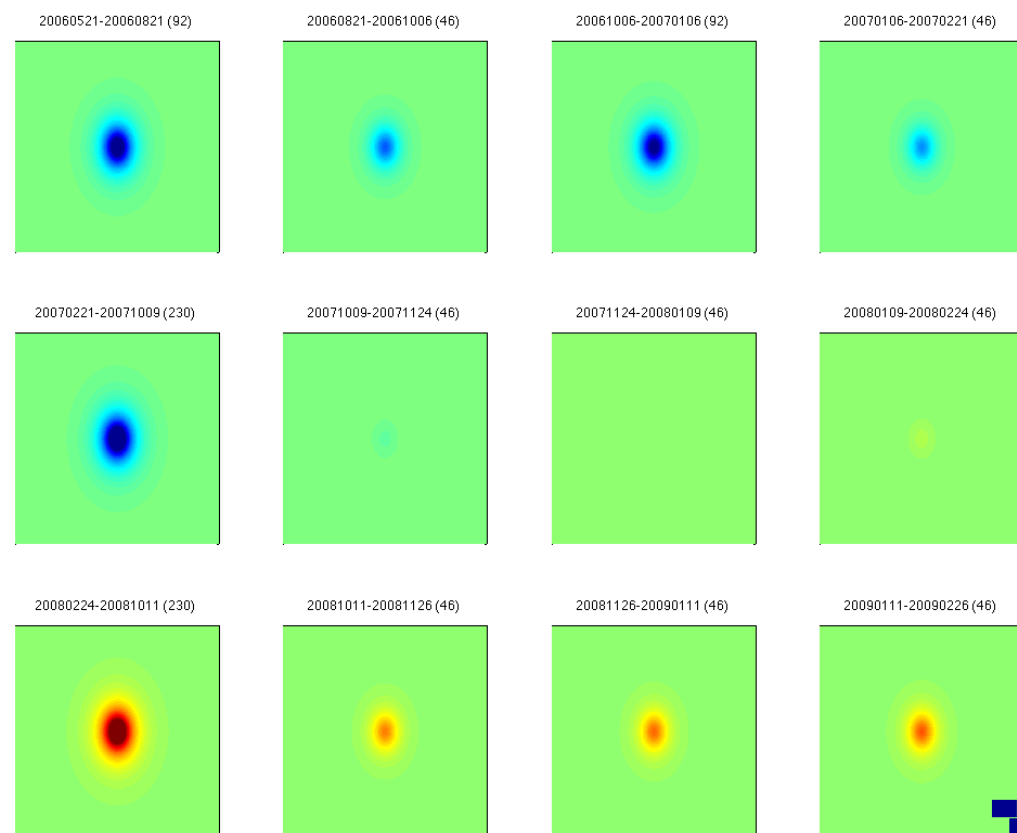


Dnoise estimated
(except DEM
correction)

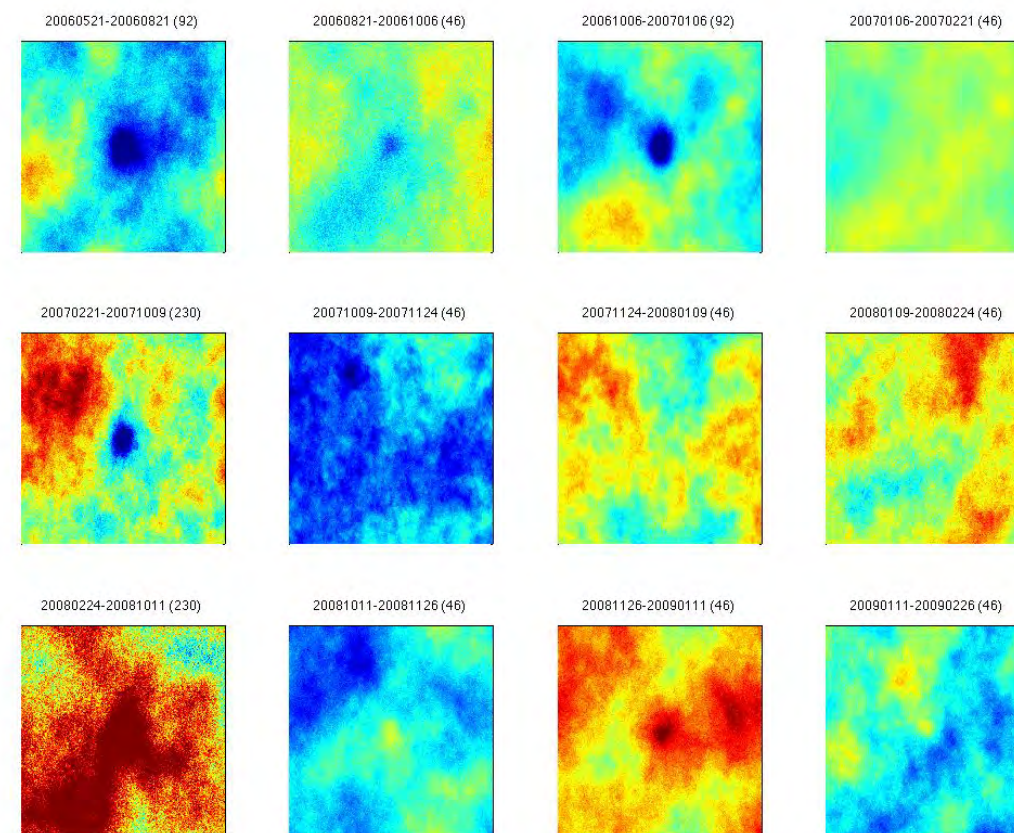
2nd step: invert the corrected ifgs pixel-by-pixel



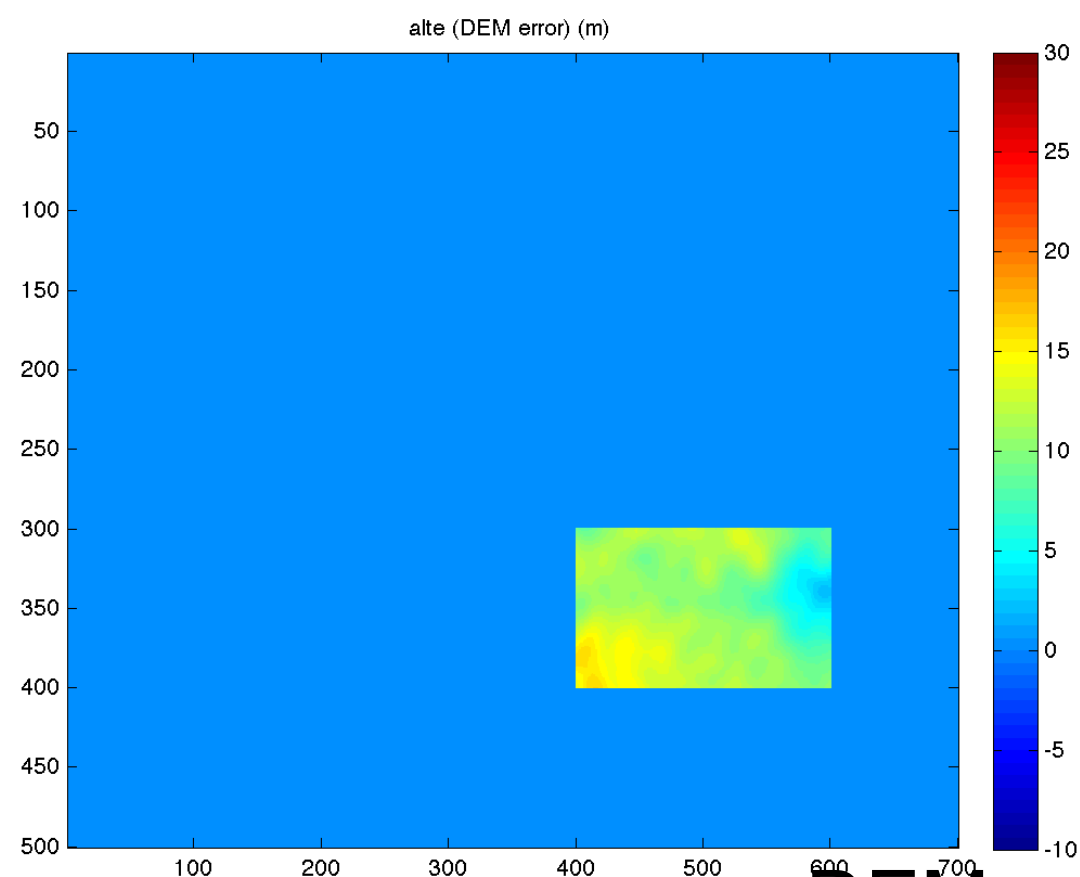
$$\begin{aligned} \phi_k^c &\equiv \begin{bmatrix} \phi_{1,k}^c \\ \phi_{2,k}^c \\ \vdots \\ \phi_{N,k}^c \end{bmatrix} = \begin{bmatrix} \frac{4\pi}{\lambda} \mathbf{g}_1 & q_{1,k} \\ \frac{4\pi}{\lambda} \mathbf{g}_2 & q_{2,k} \\ \vdots & \vdots \\ \frac{4\pi}{\lambda} \mathbf{g}_N & q_{N,k} \end{bmatrix} \begin{bmatrix} \mathbf{v}_k \\ \delta h_k \end{bmatrix} + \epsilon_k \\ &= \mathbf{G}_k \mathbf{m}_k + \epsilon_k, \end{aligned}$$



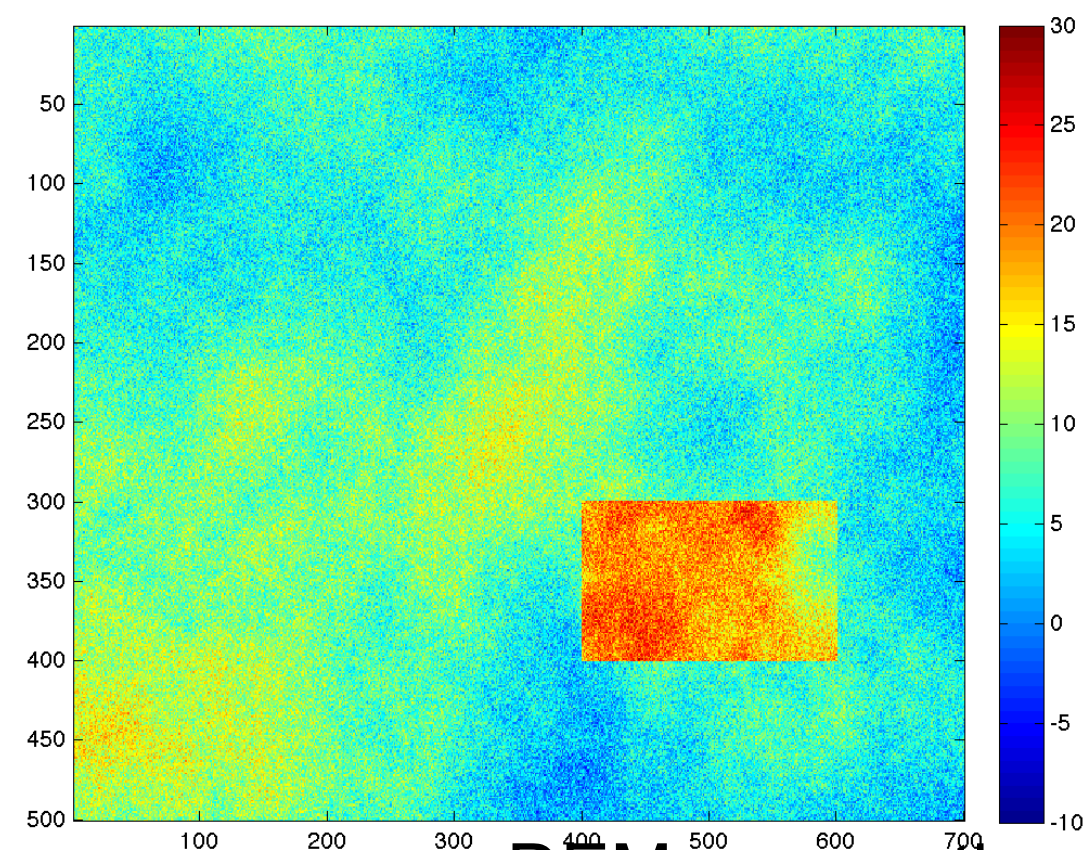
U_{true}



U_{estimated}

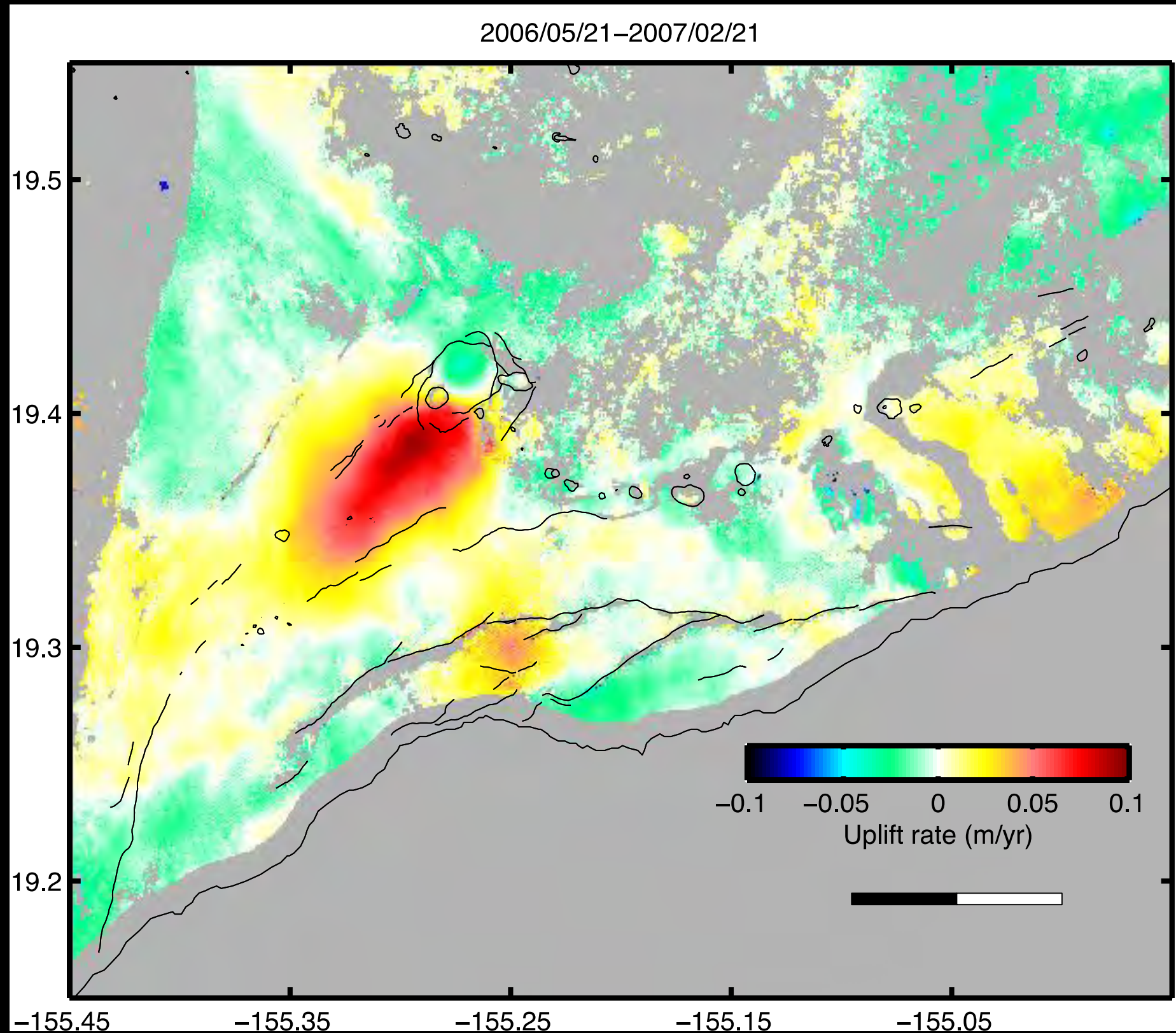


DEM error

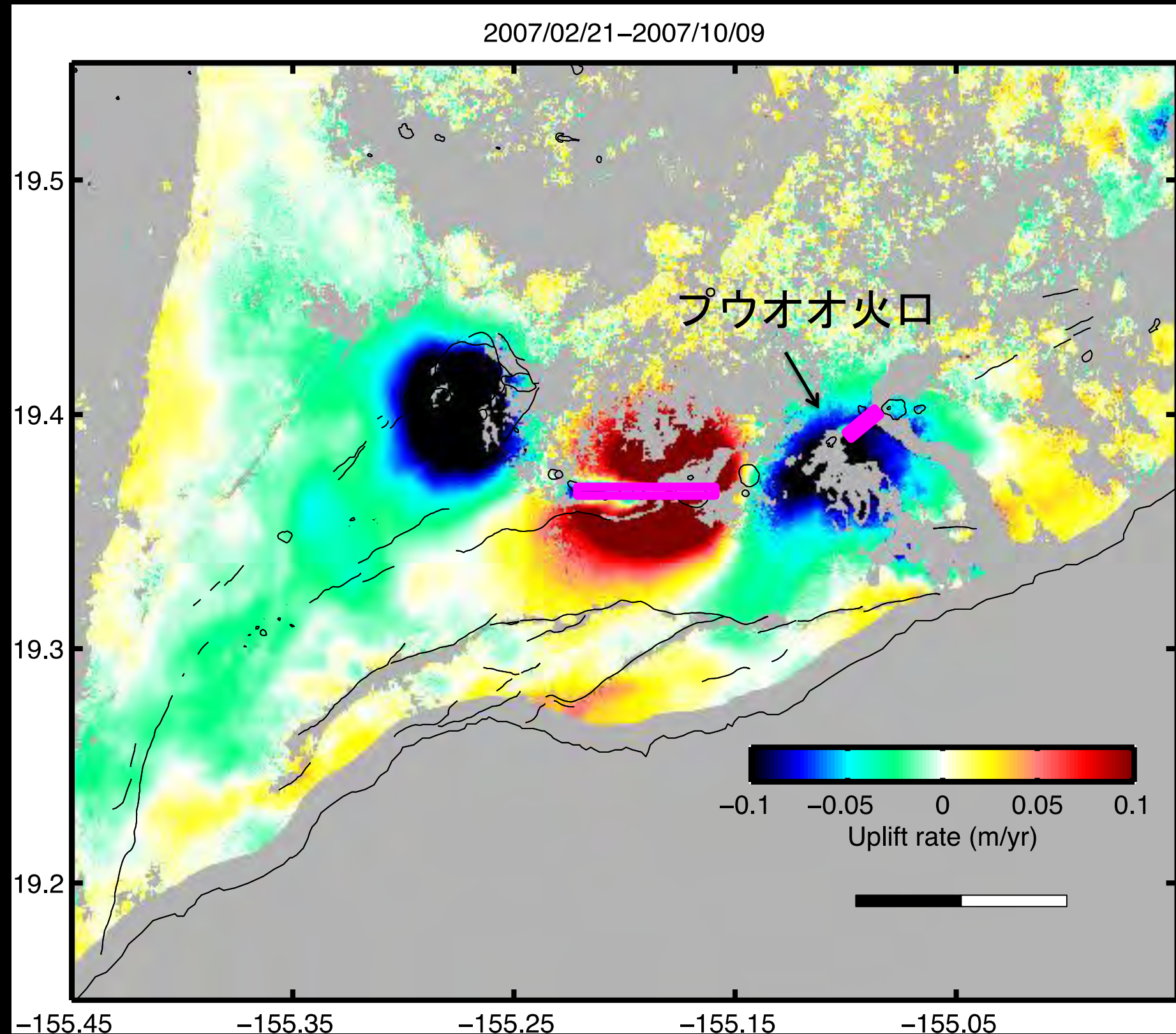


Applications

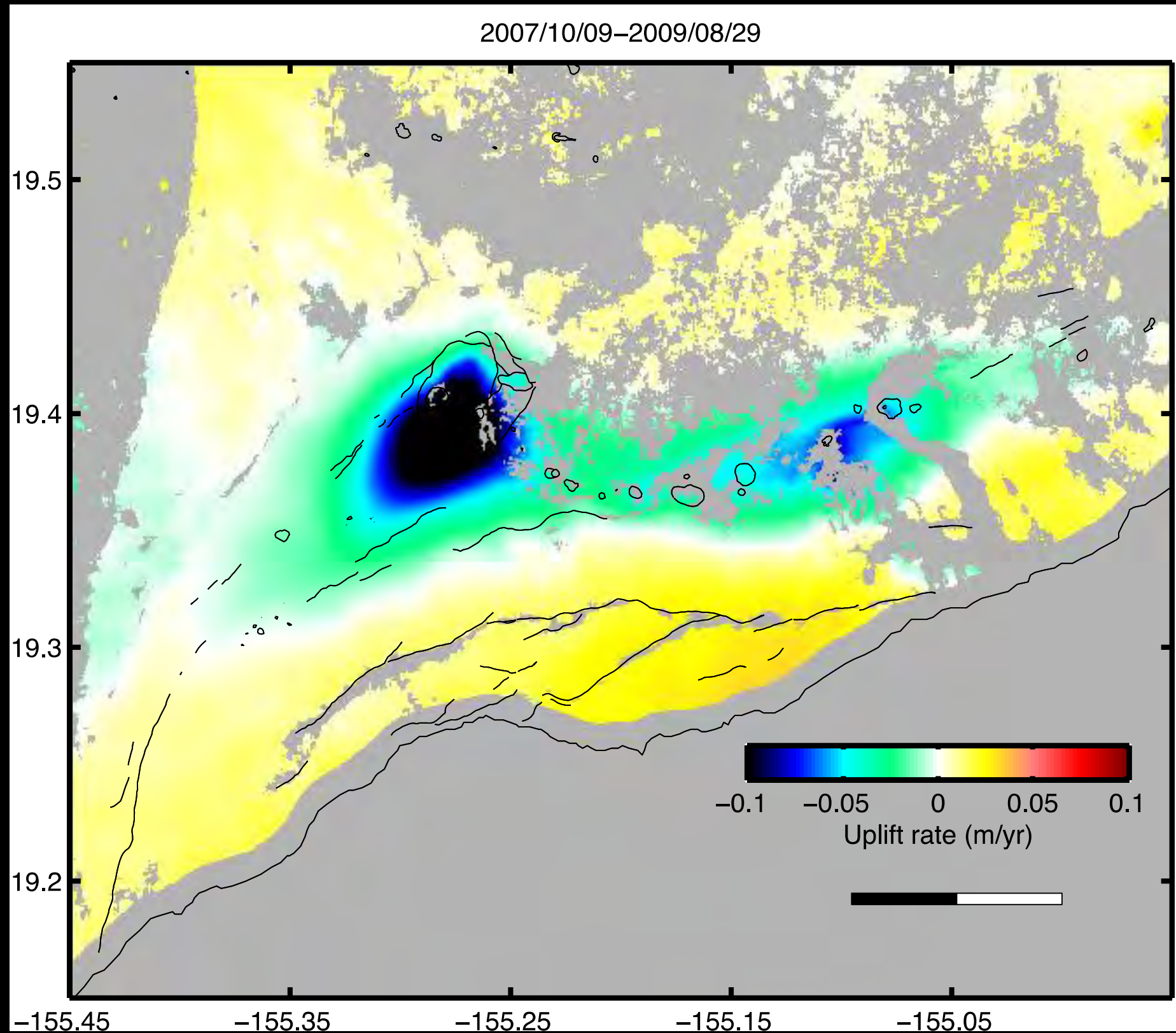
Kilauea, Hawaii



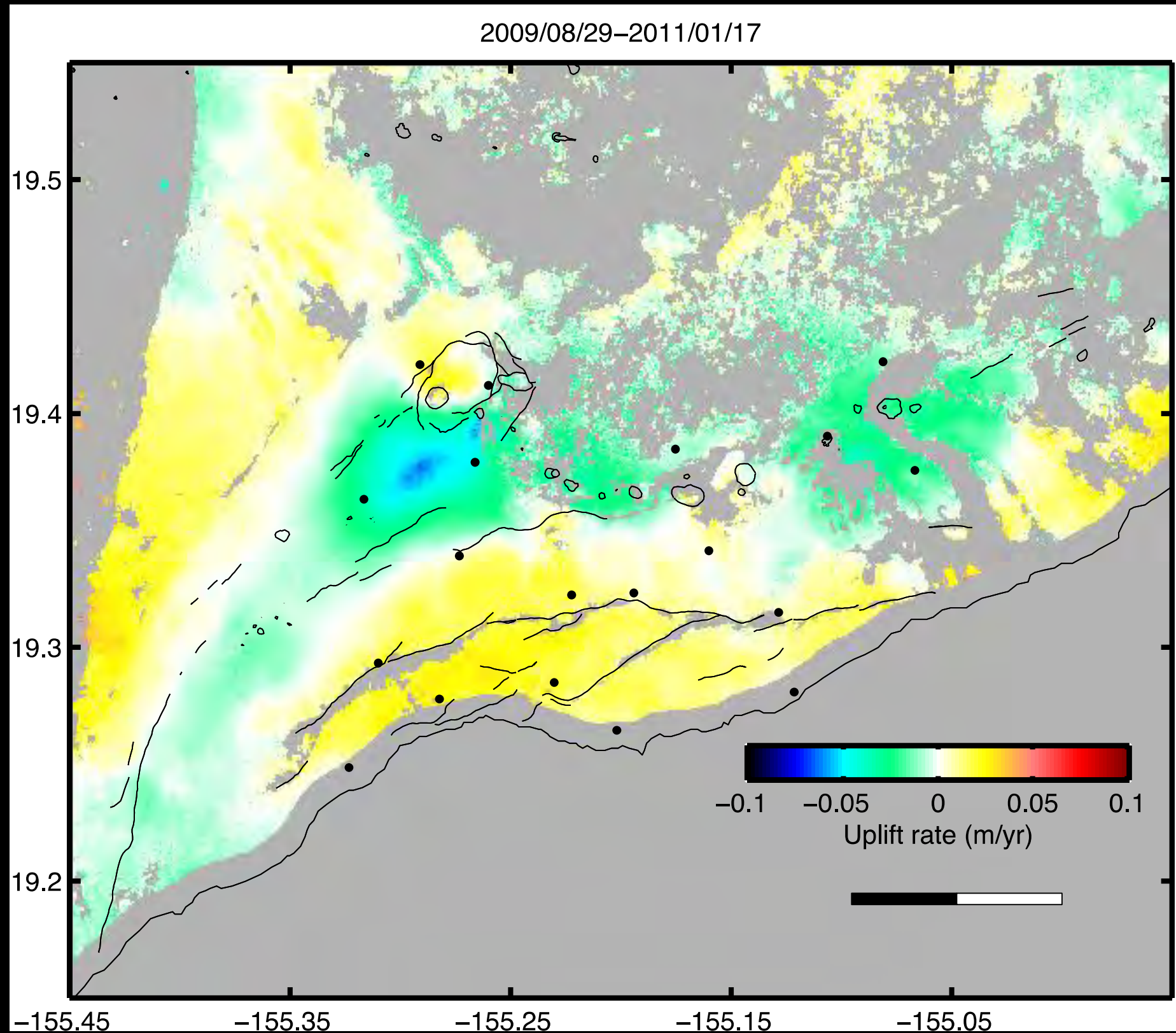
Kilauea, Hawaii



Kilauea, Hawaii

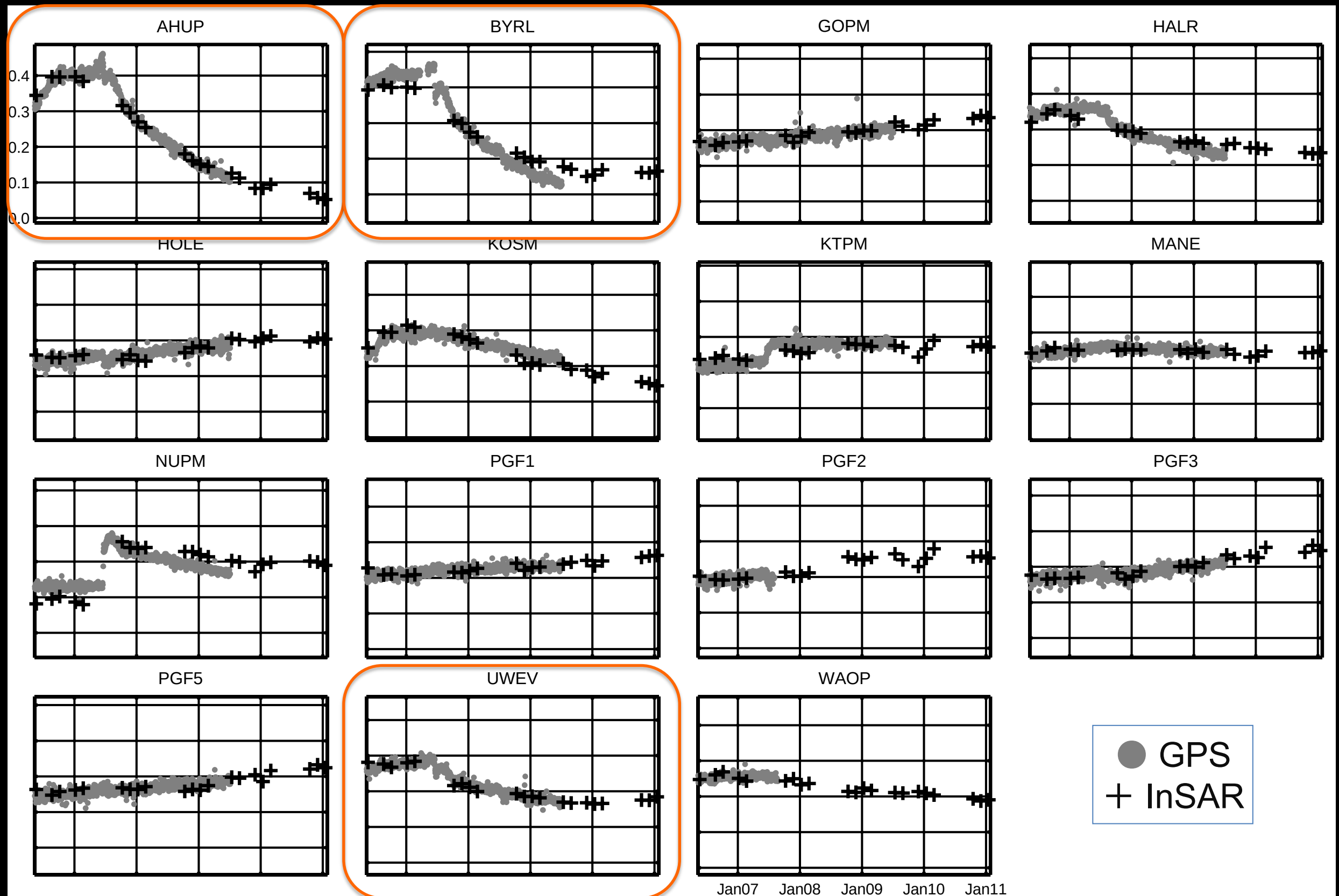


Kilauea, Hawaii

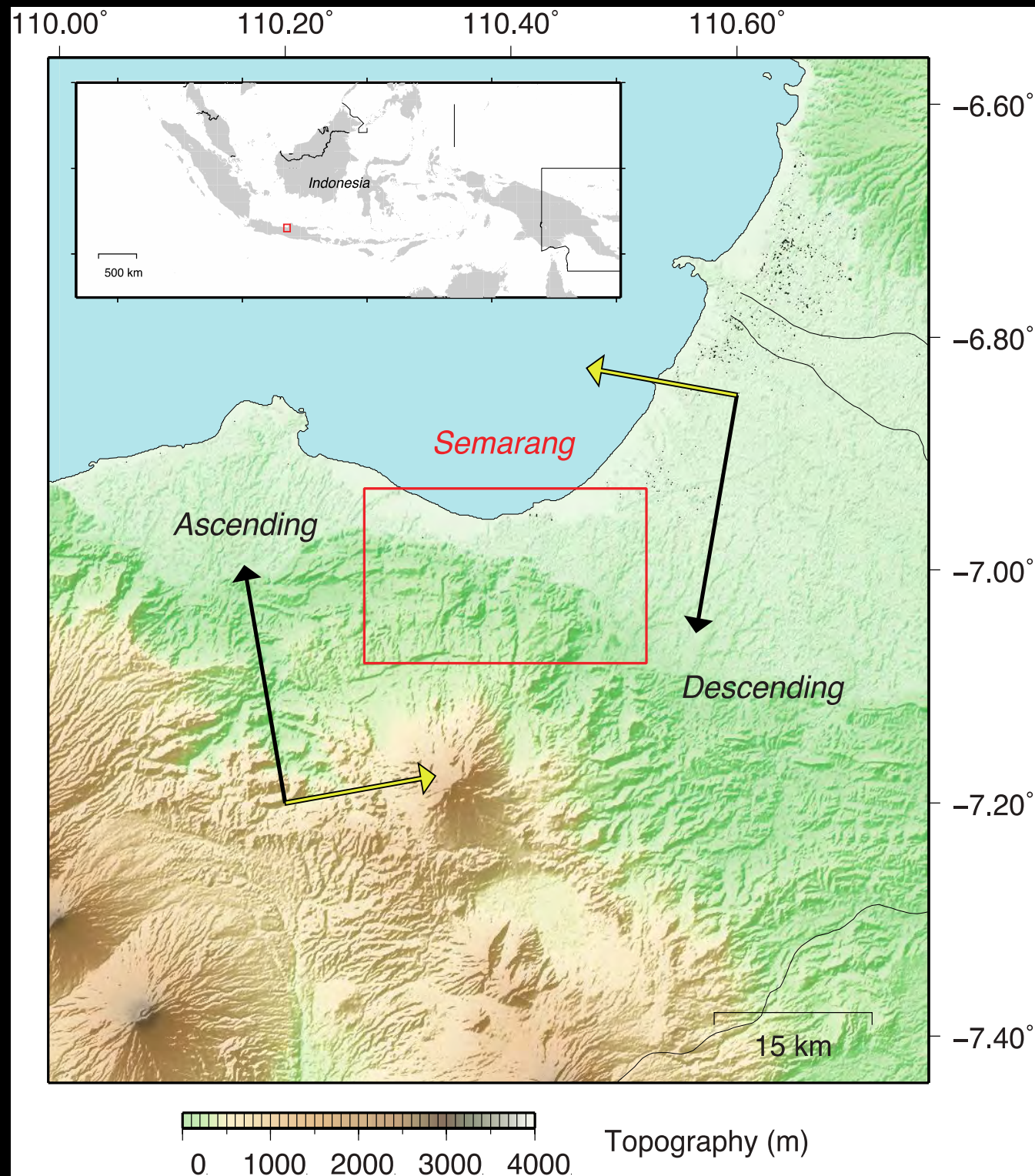


Fairly consistent with GPS vertical (RMS 1.6 cm)

山頂付近

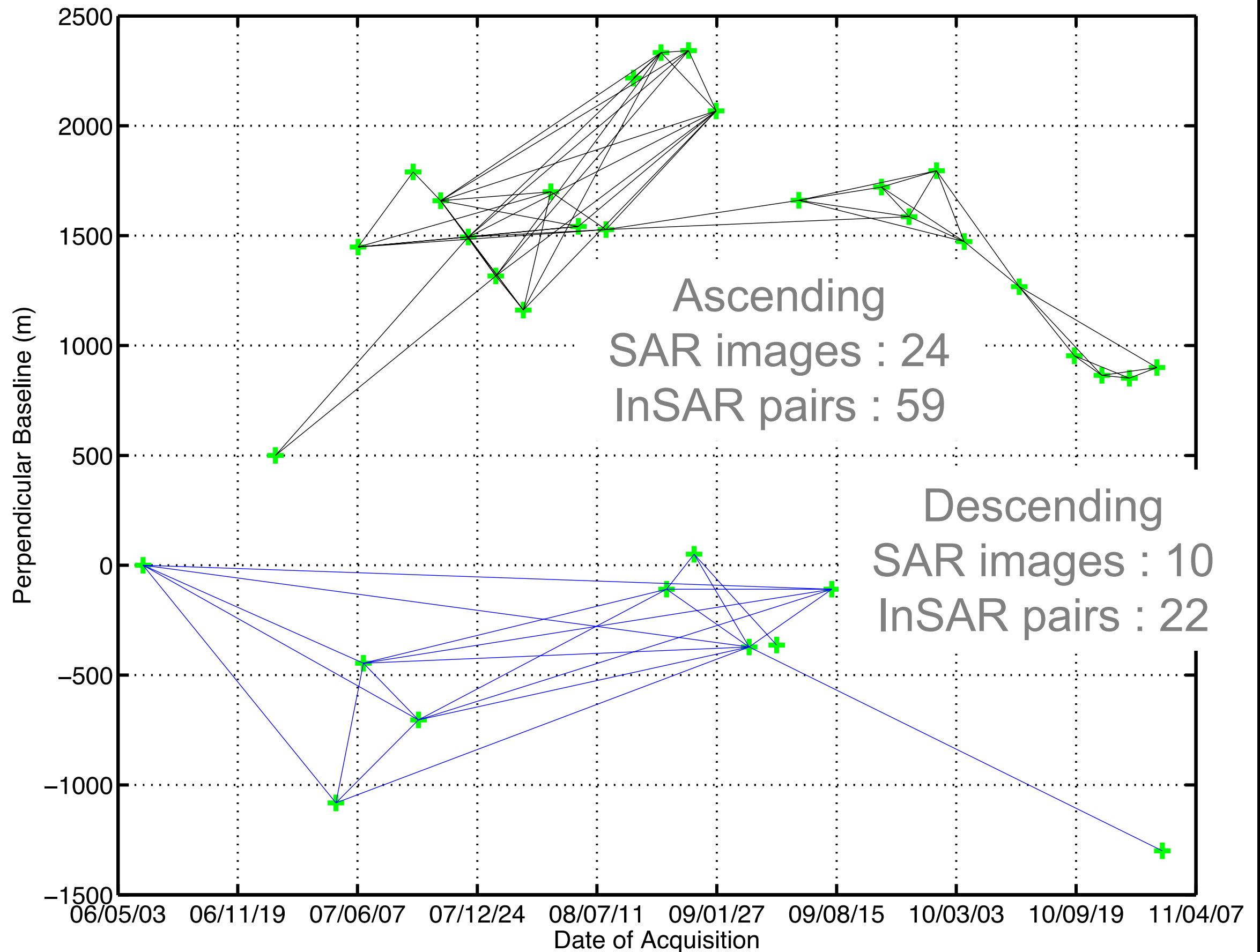


Land subsidence in Semarang, Indonesia (analyzed by M. Arimoto)

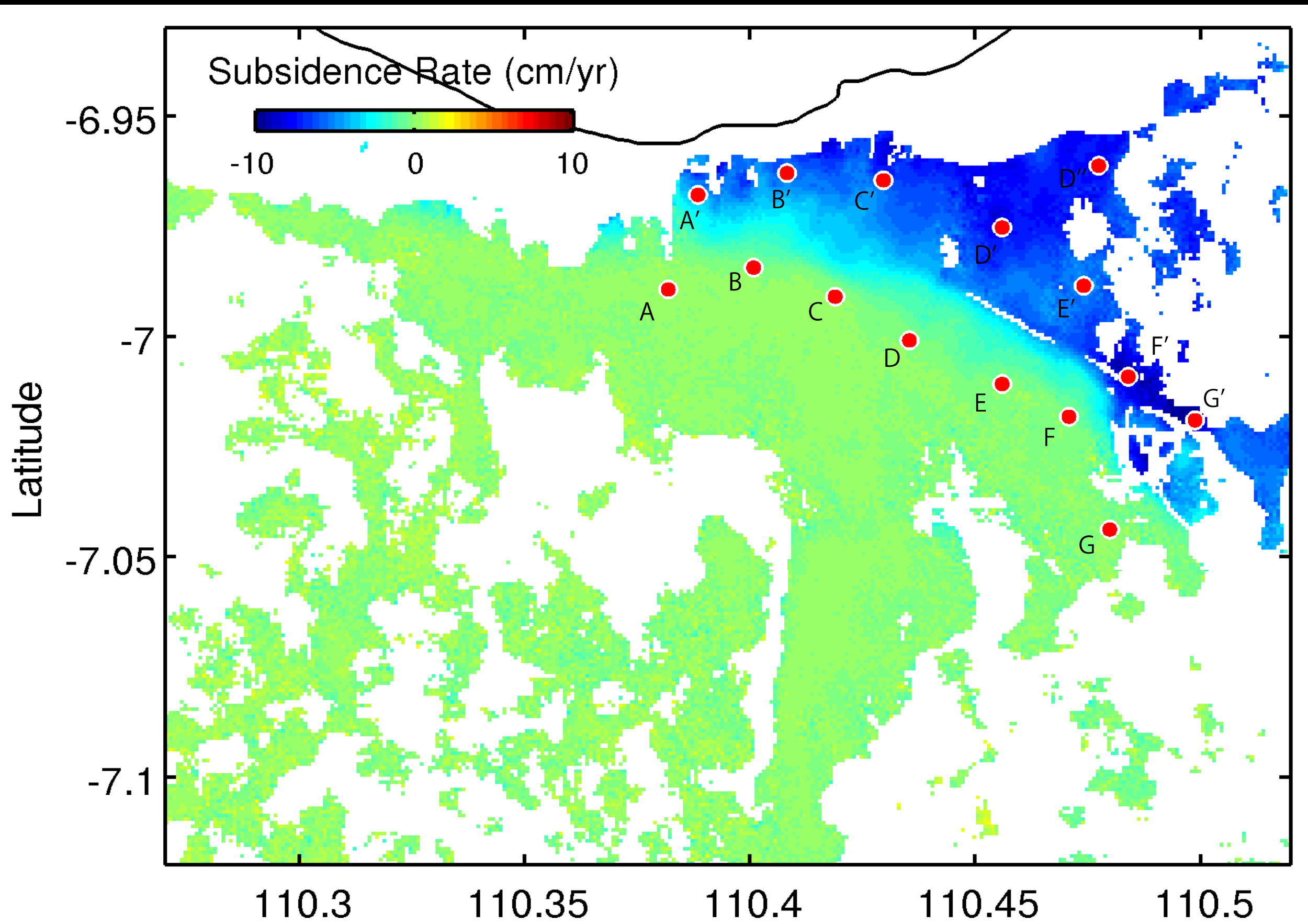


写真提供：橋本学氏

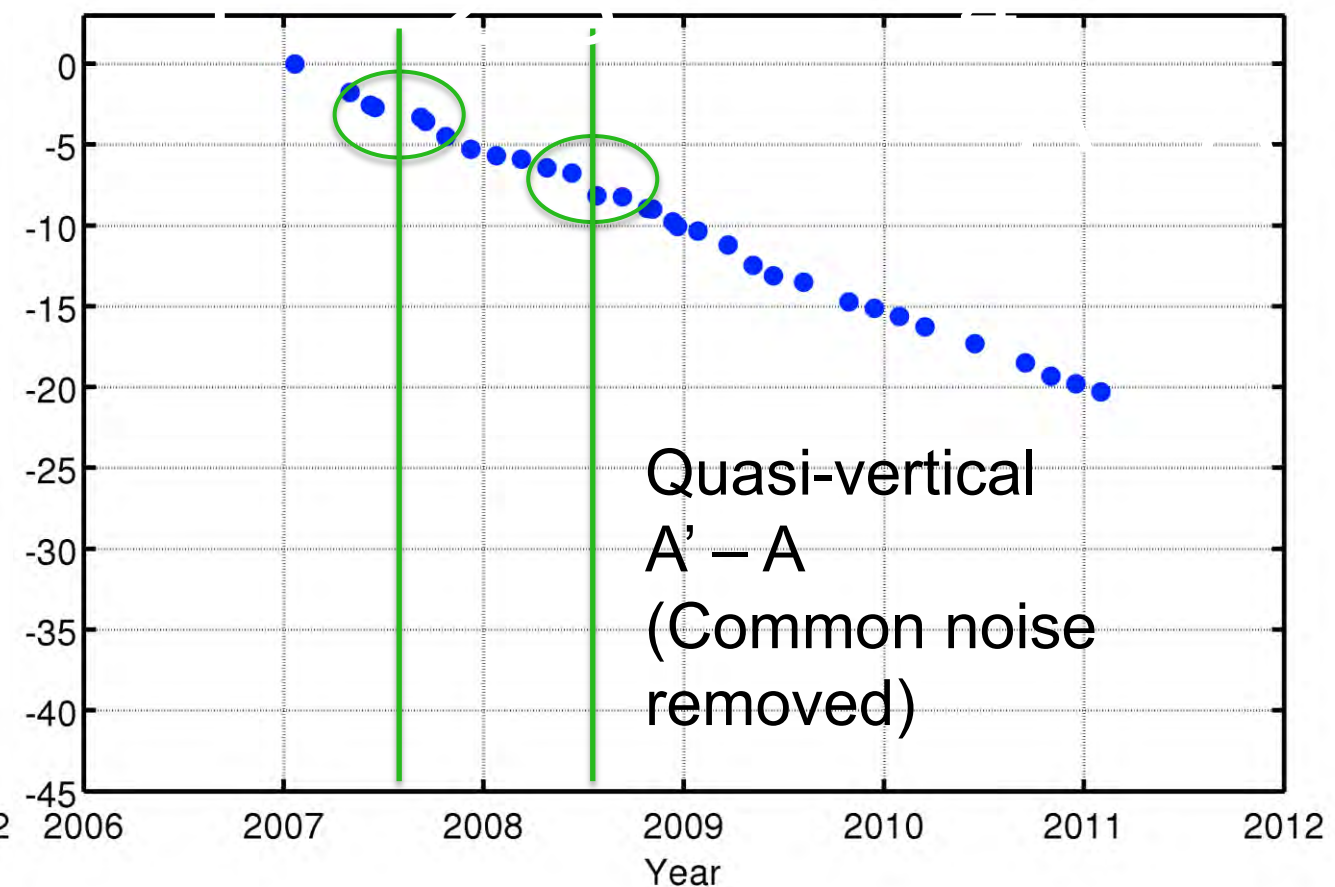
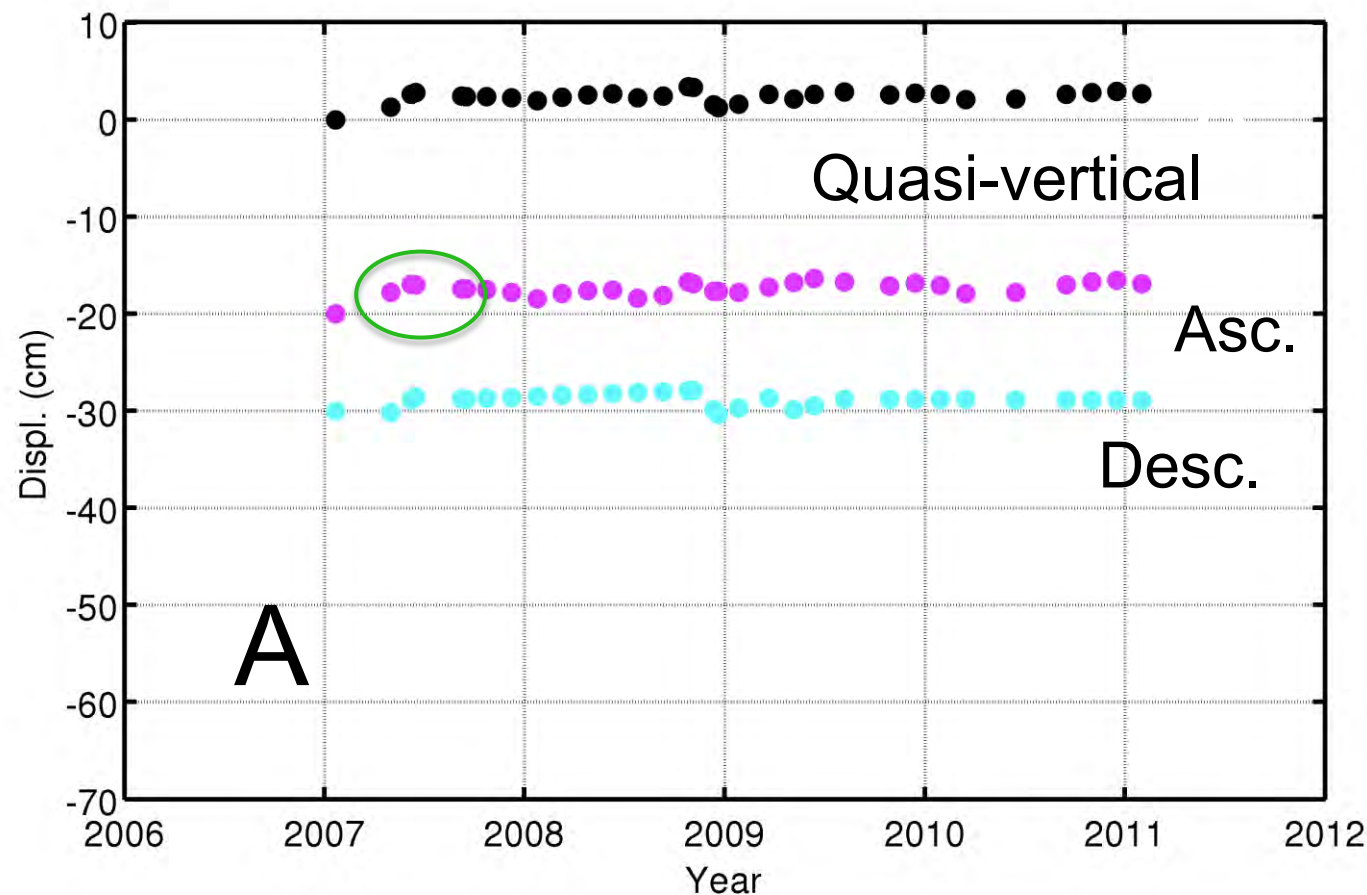
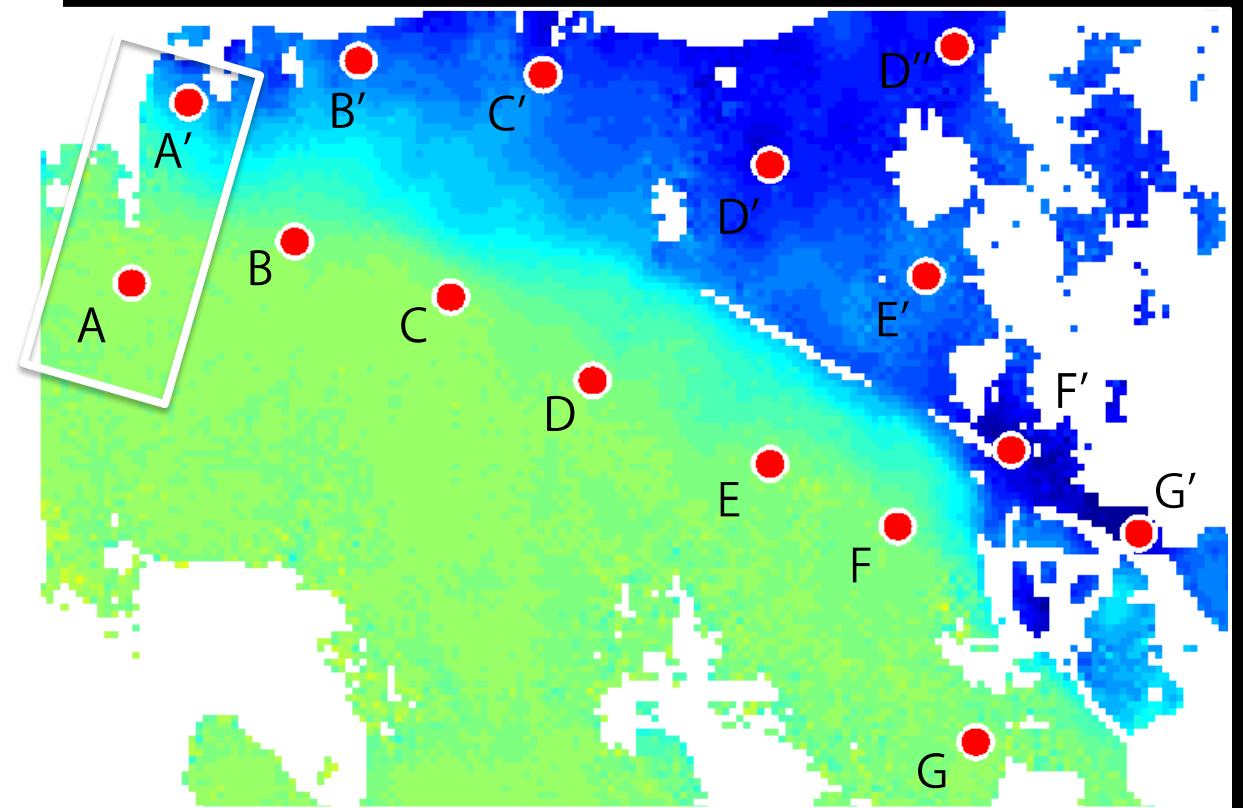
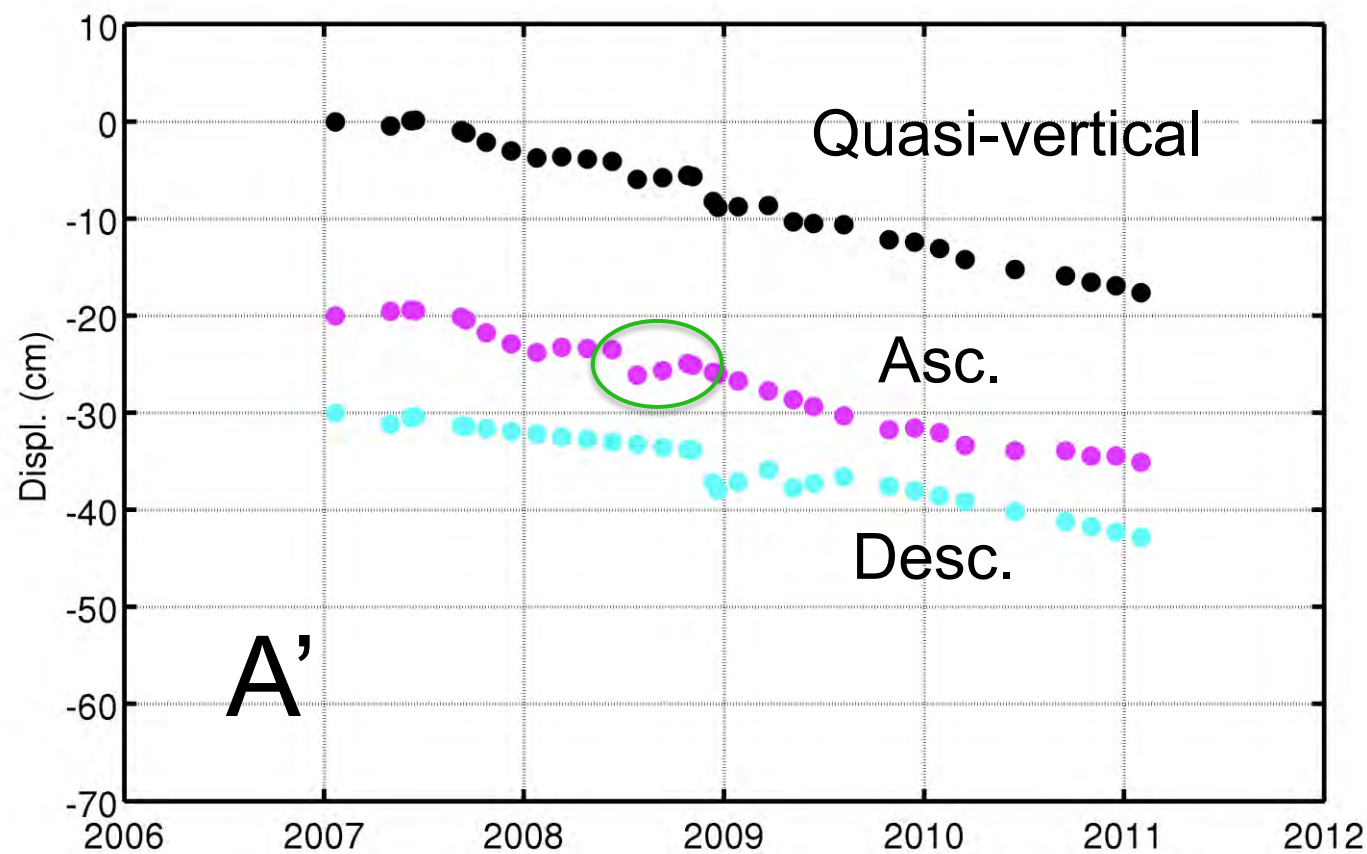
Baselines: Ascending and Descending



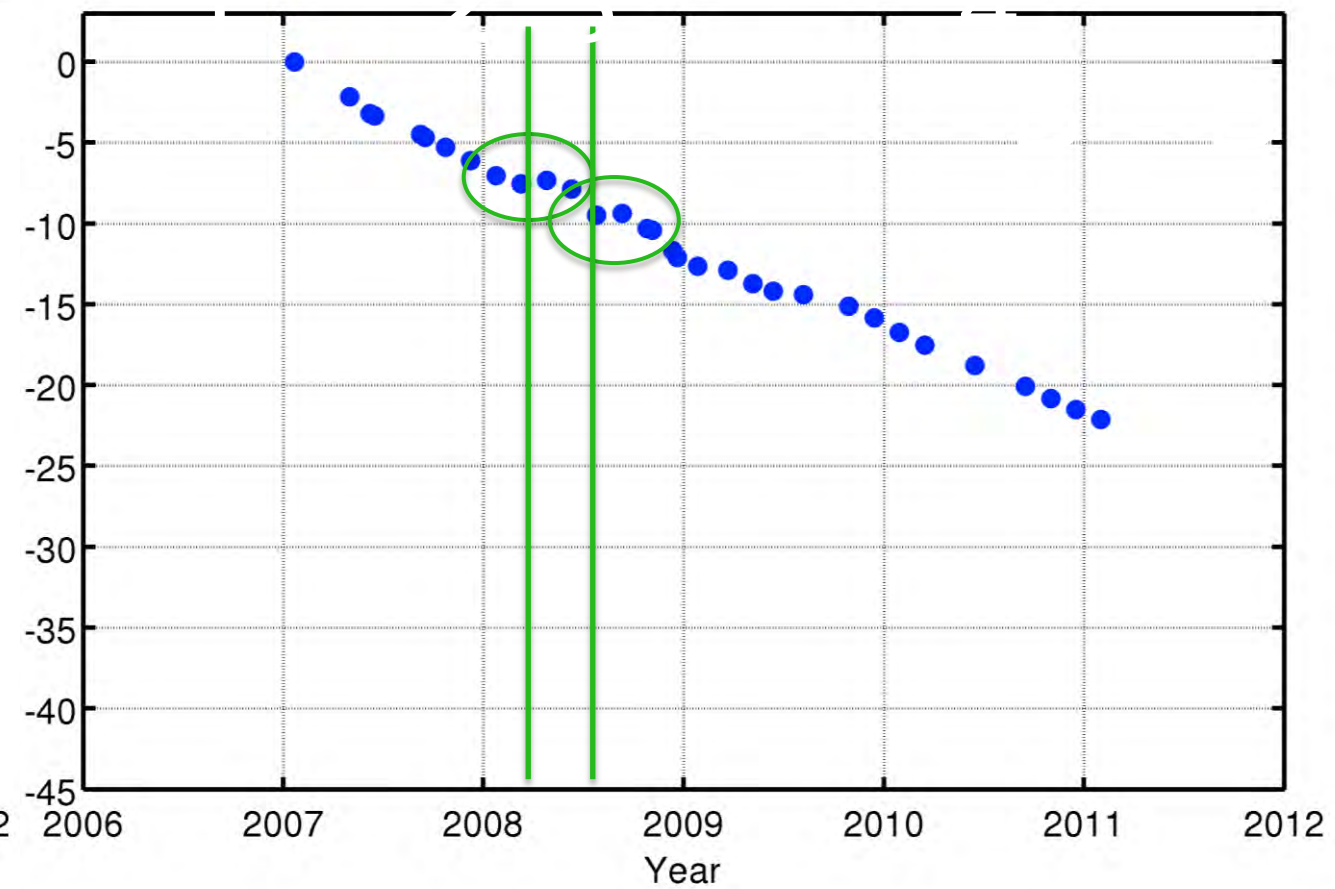
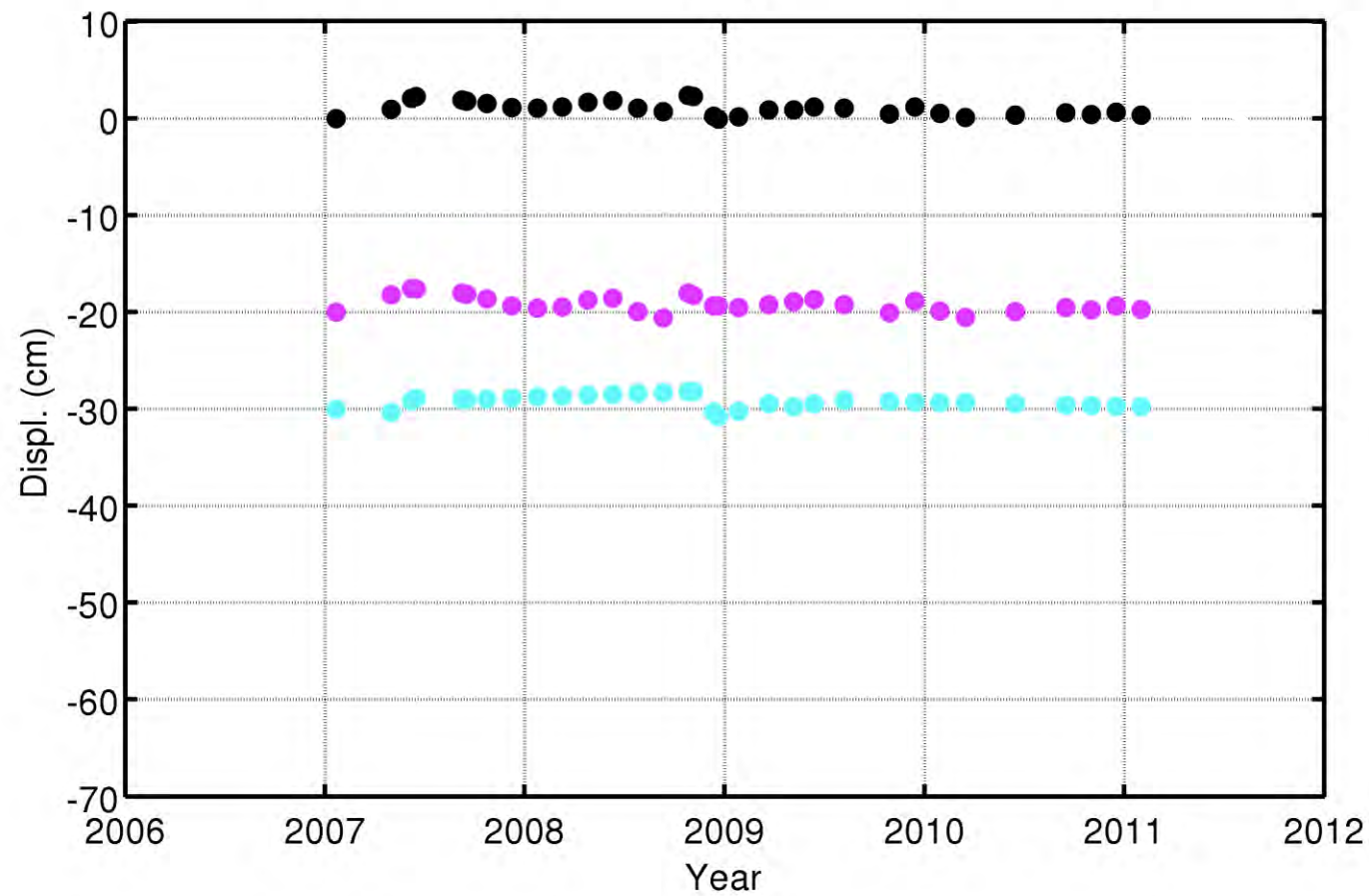
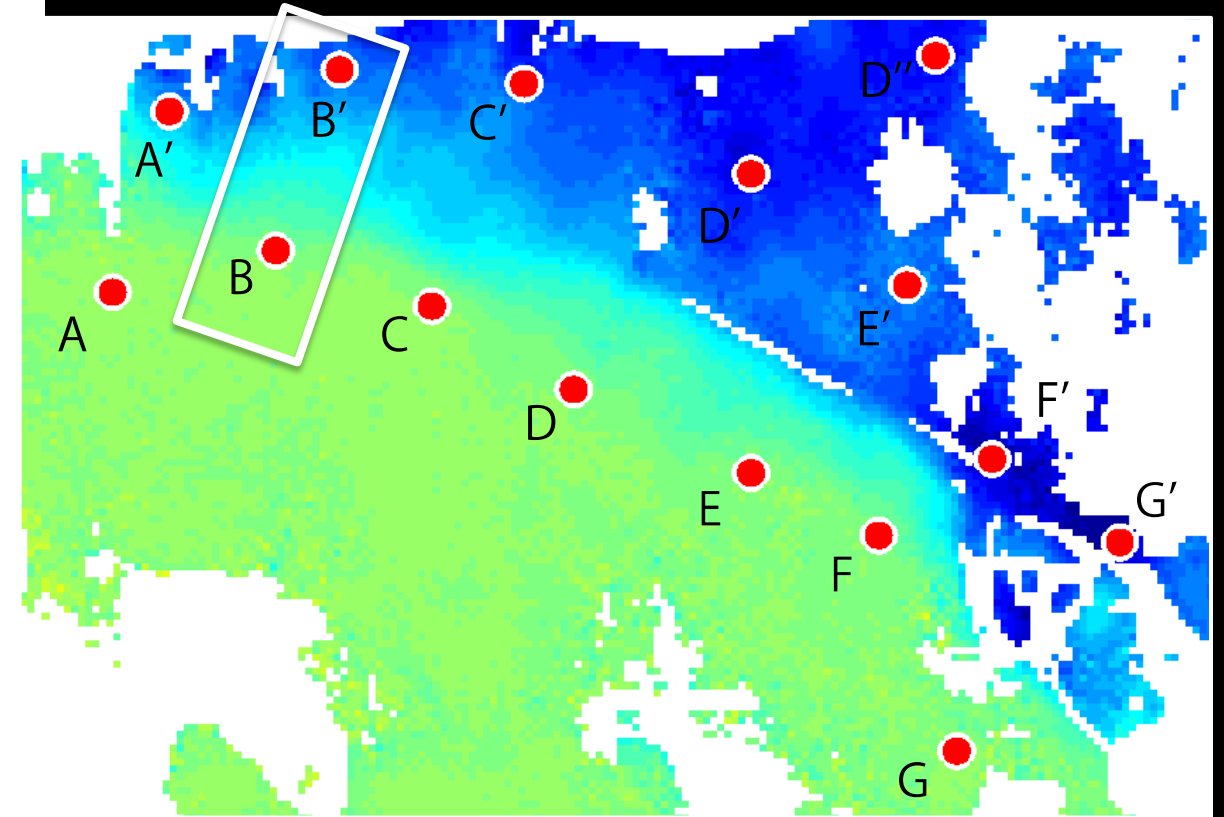
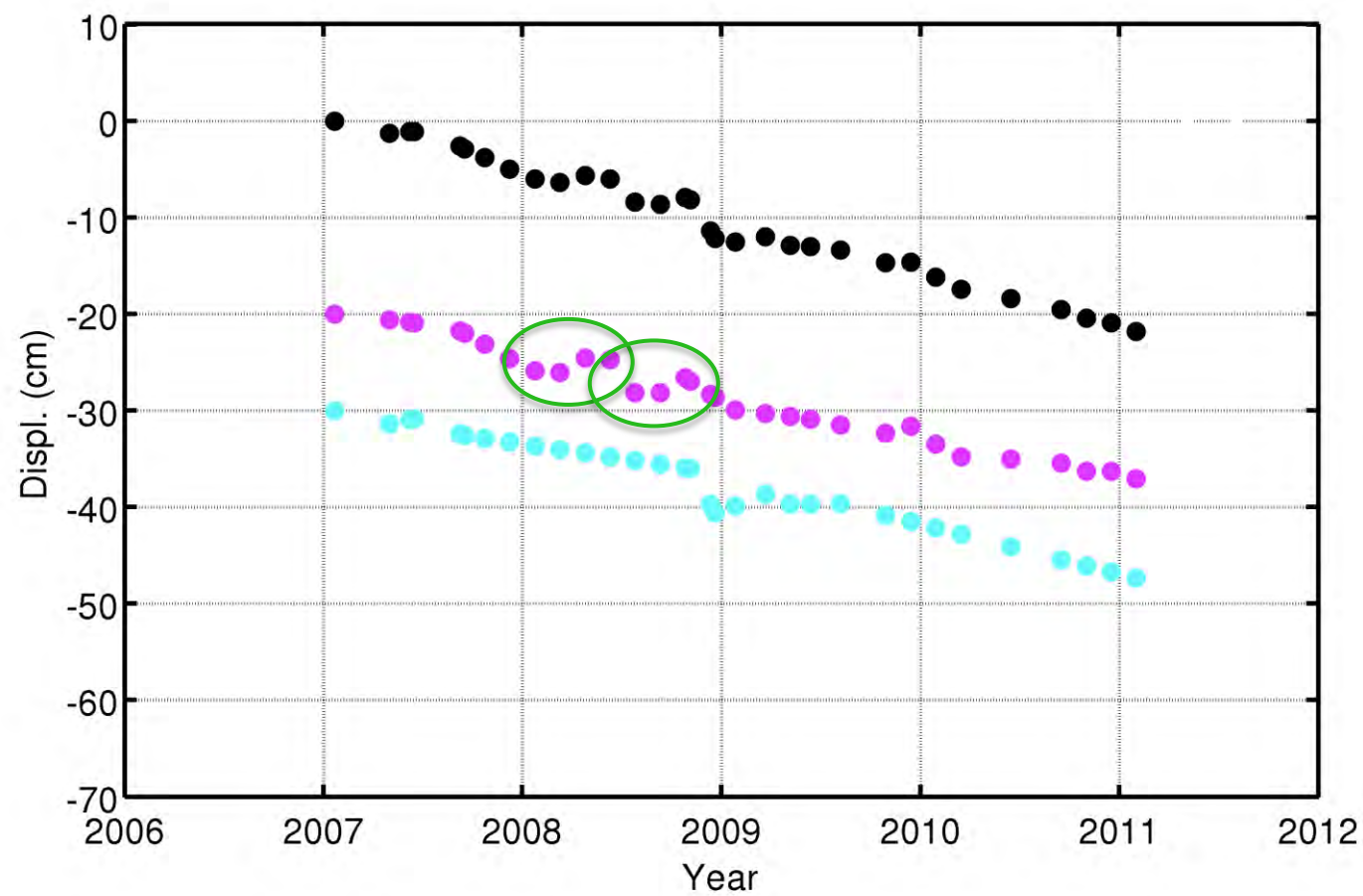
Velocity of quasi-vertical component



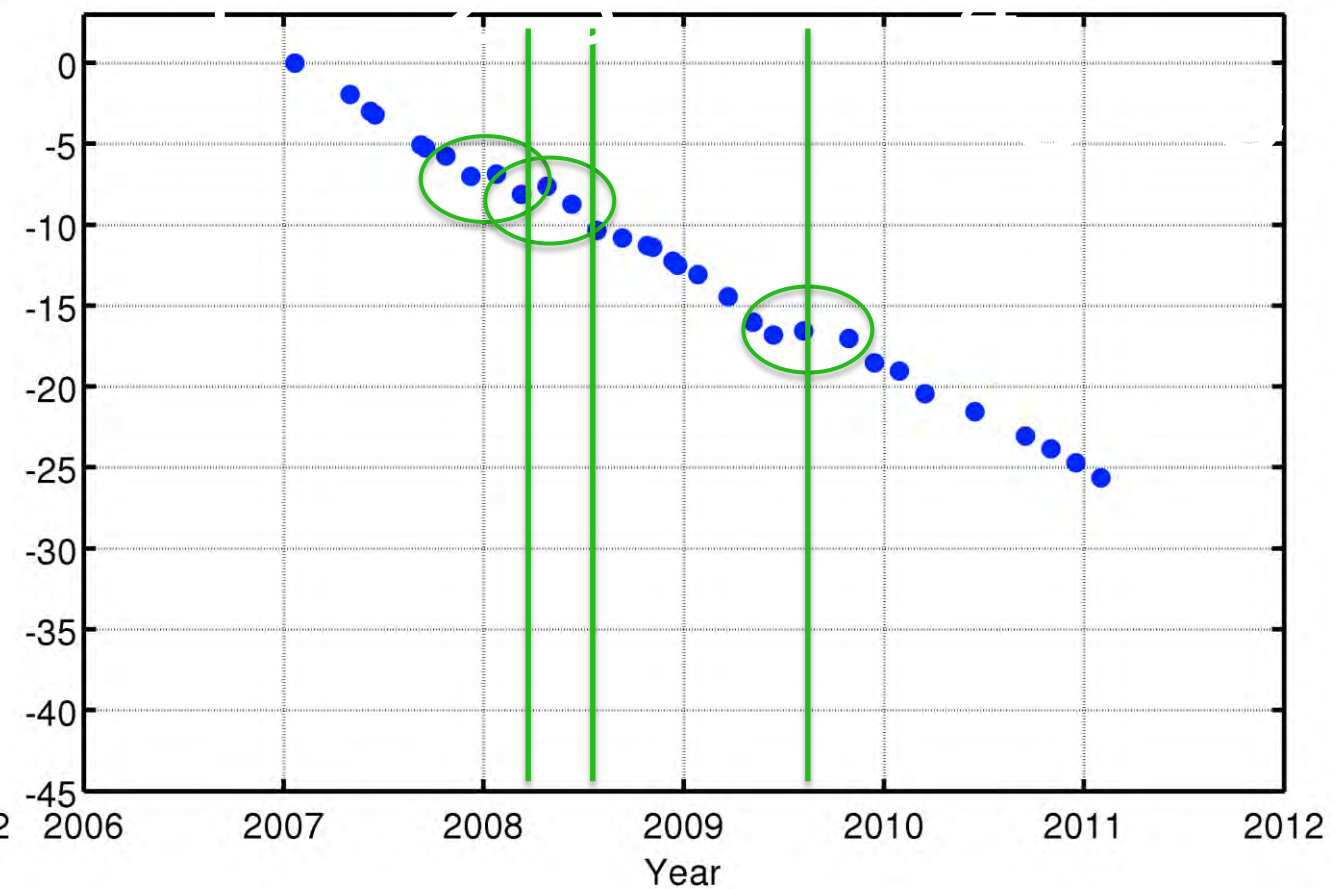
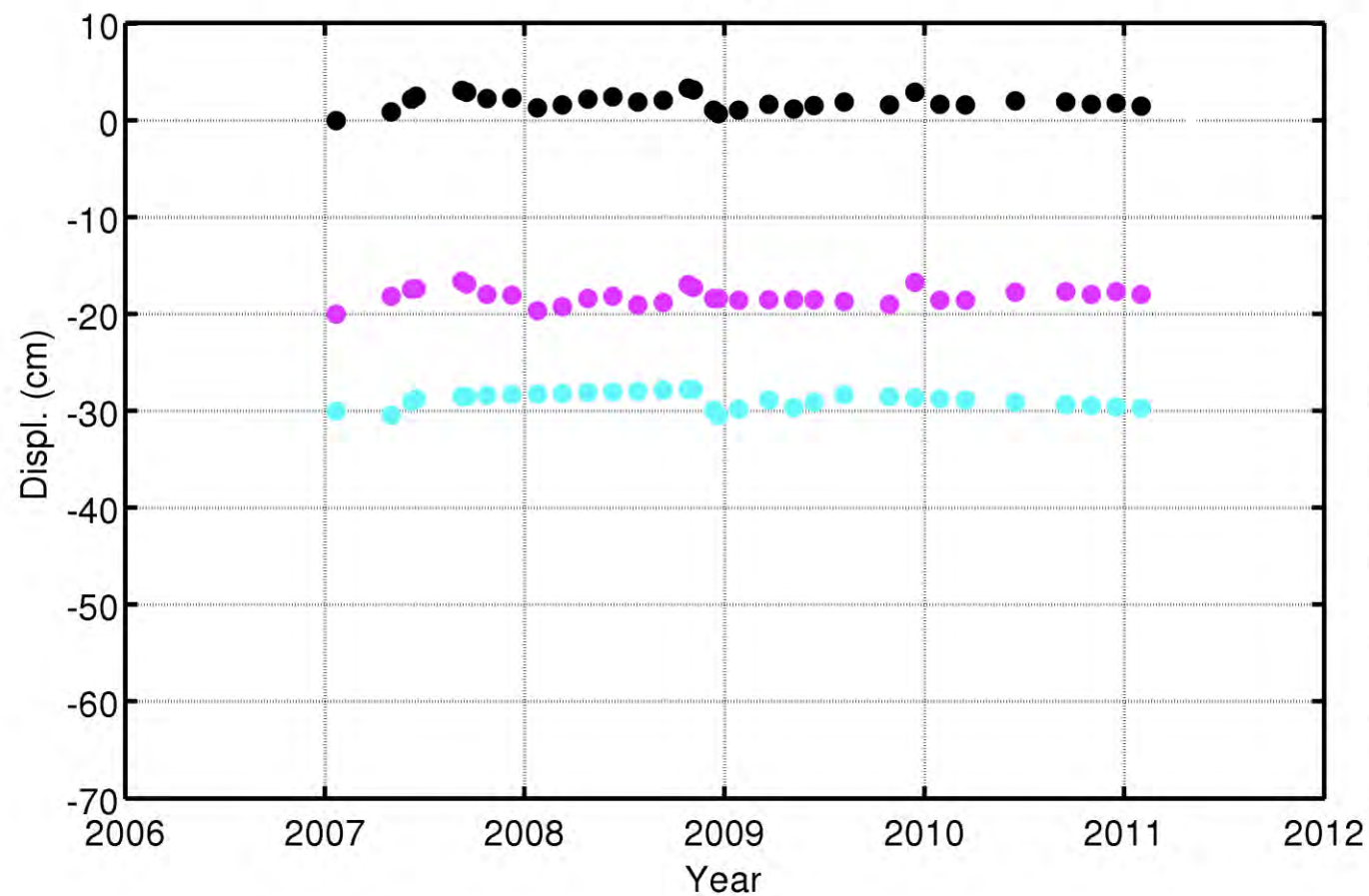
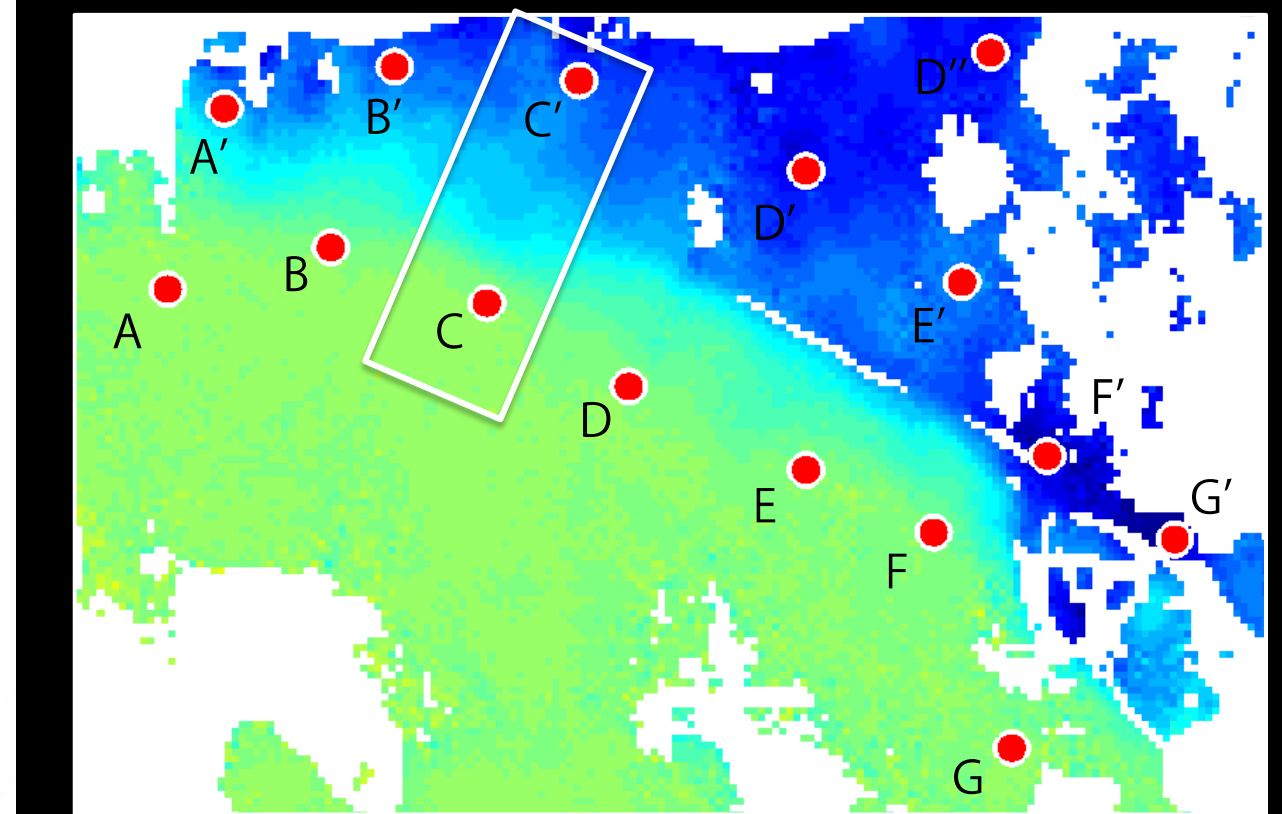
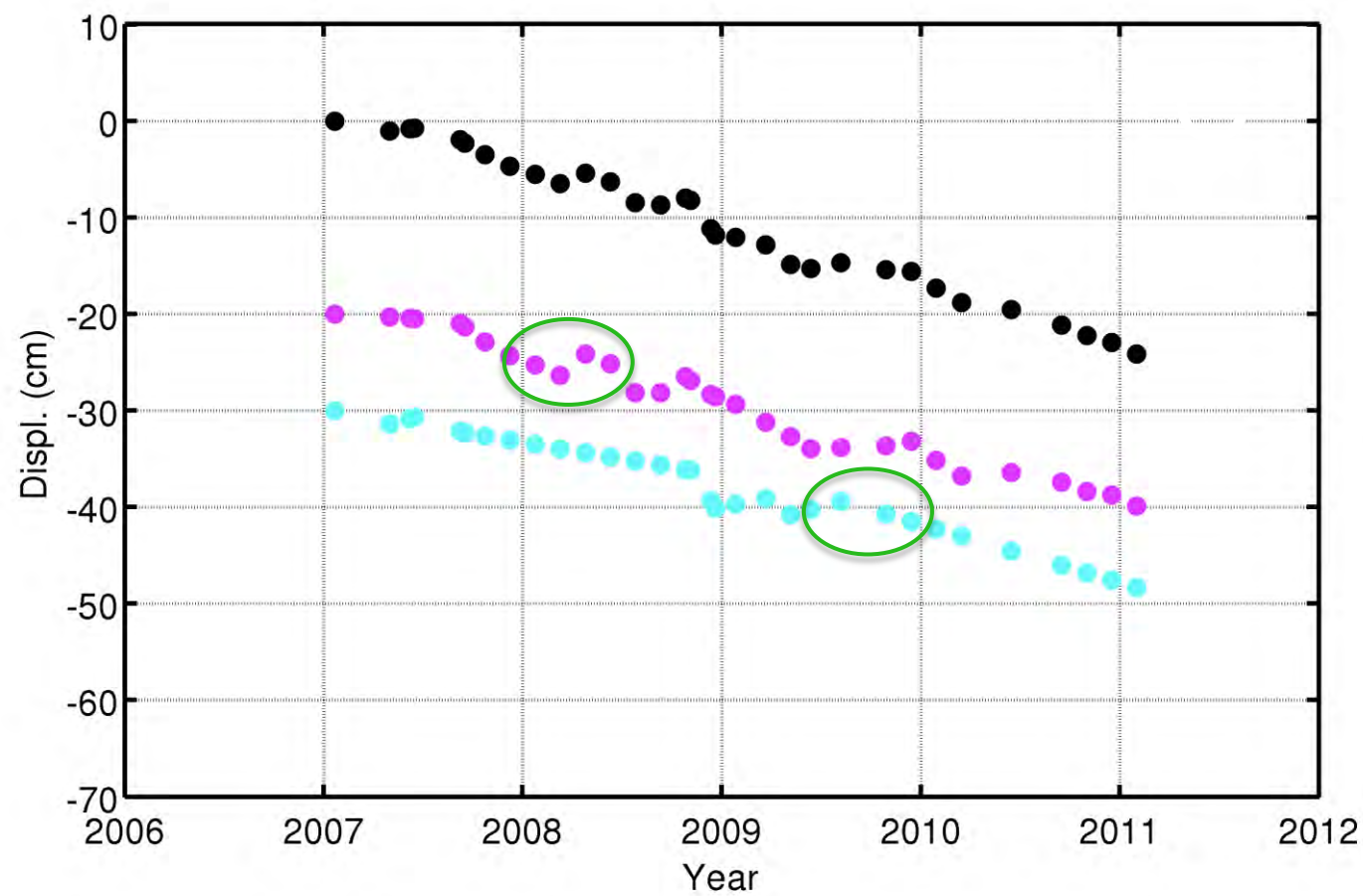
Profiles at Selected Points



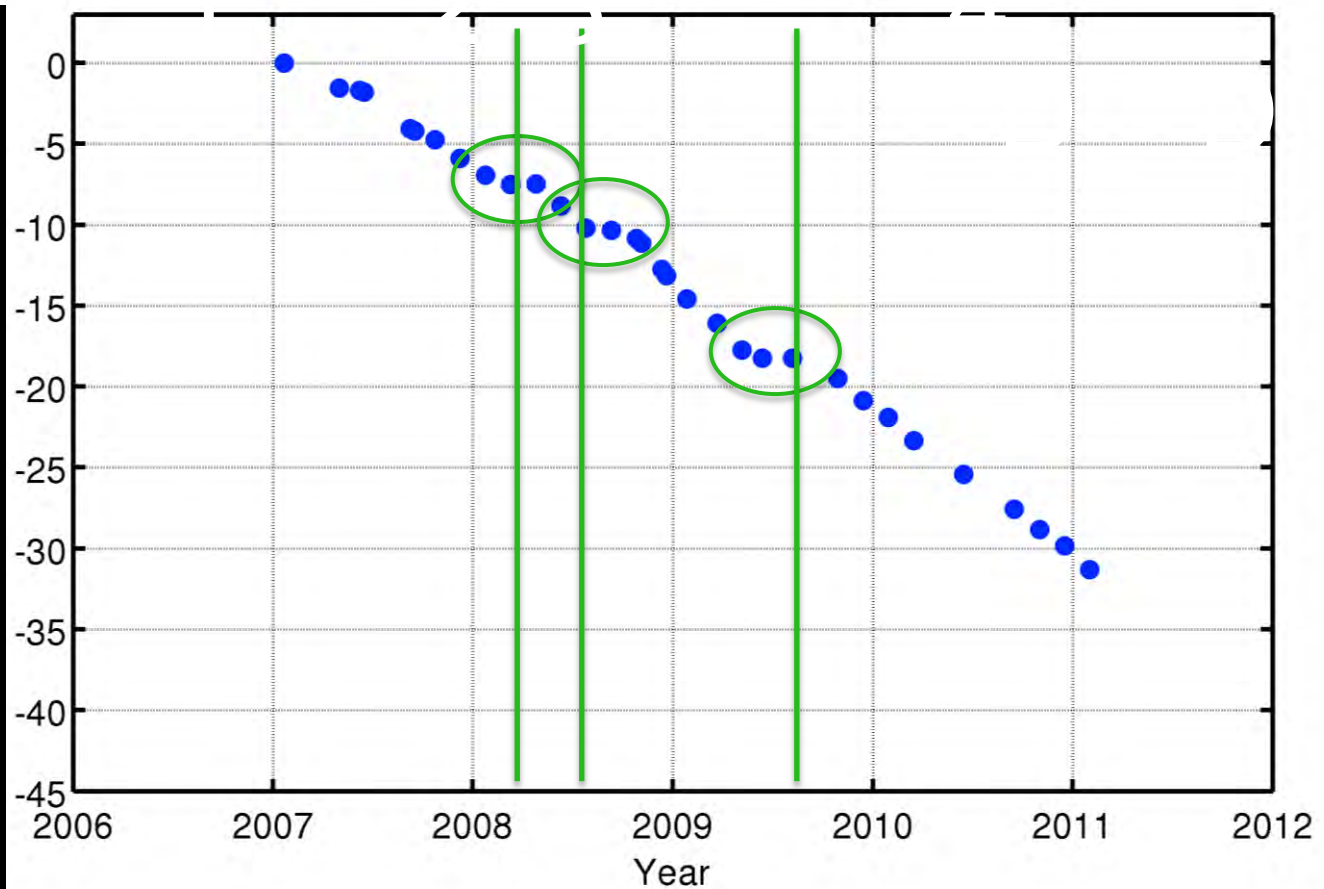
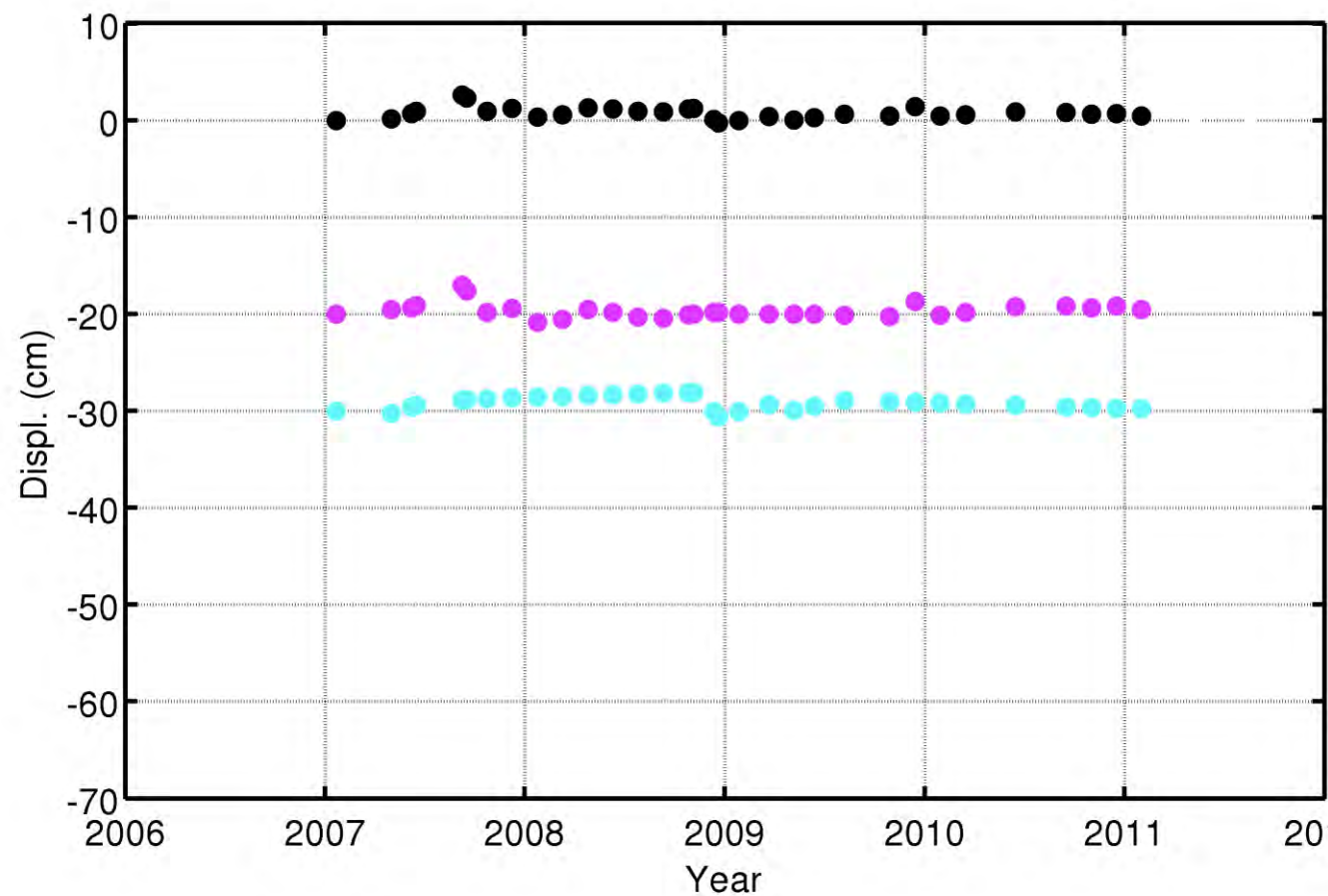
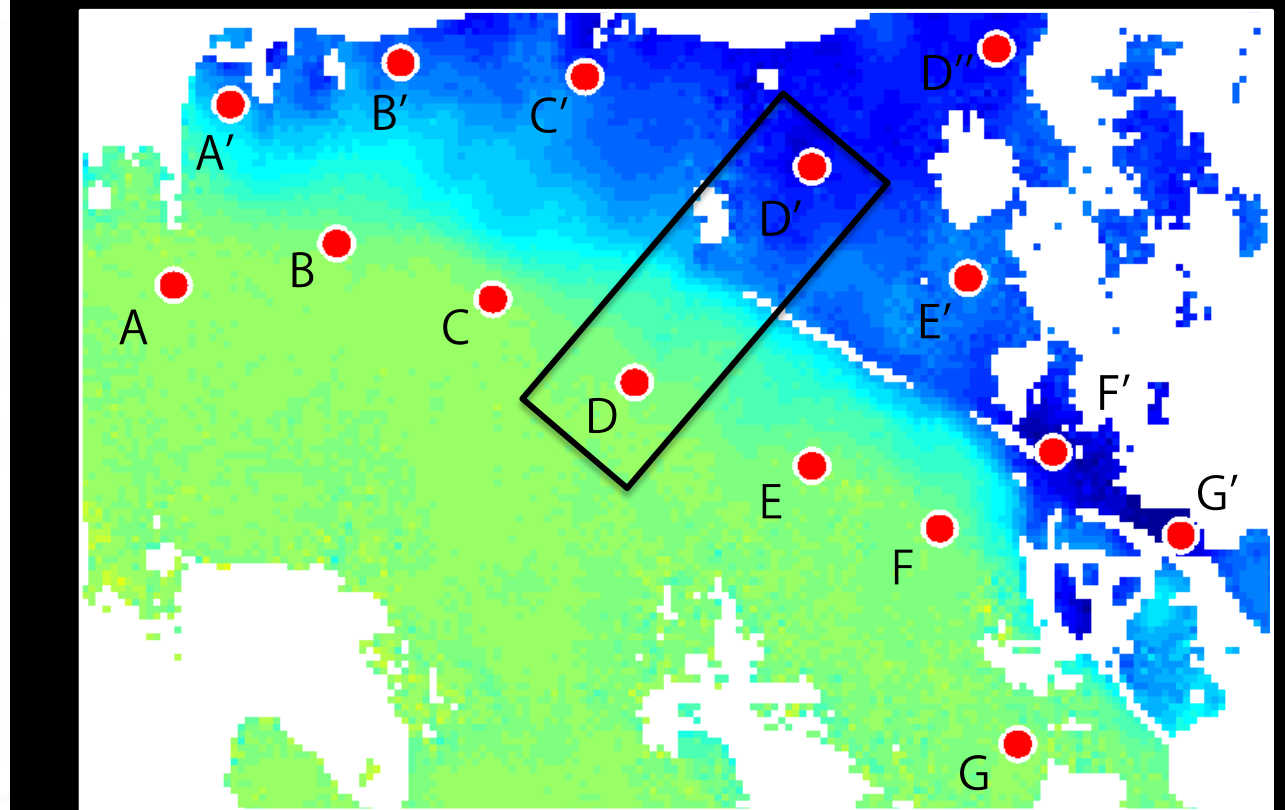
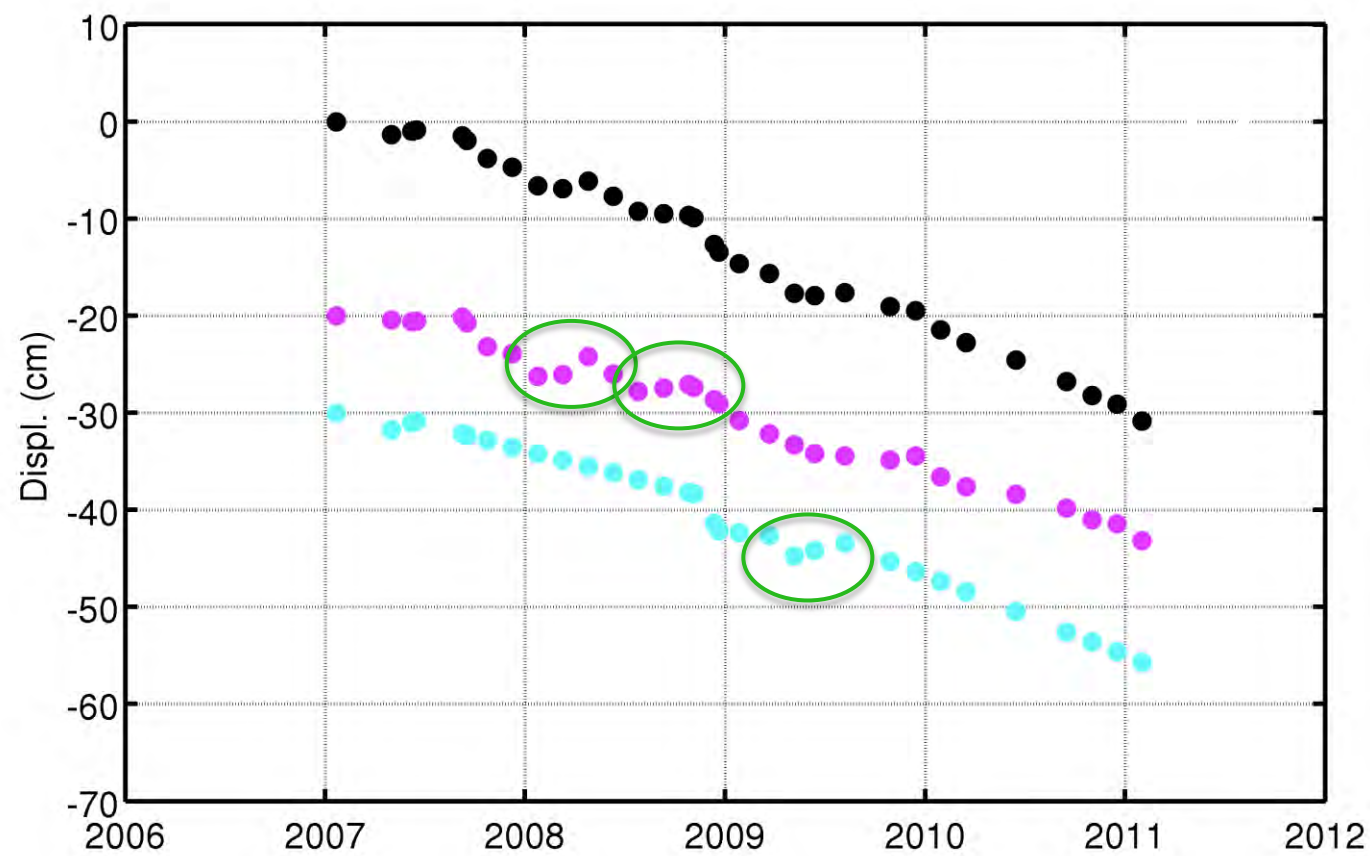
Profiles at Selected Points



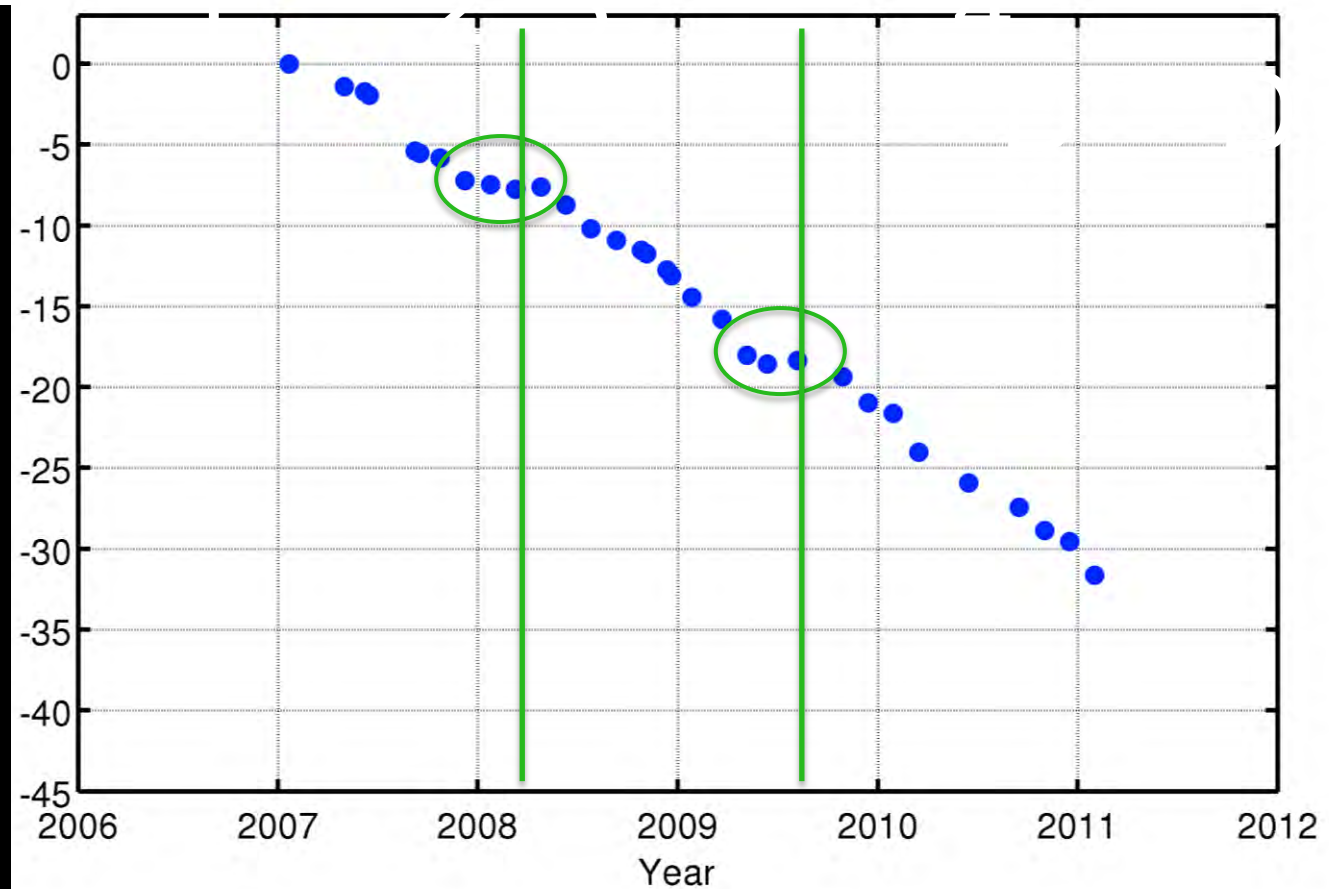
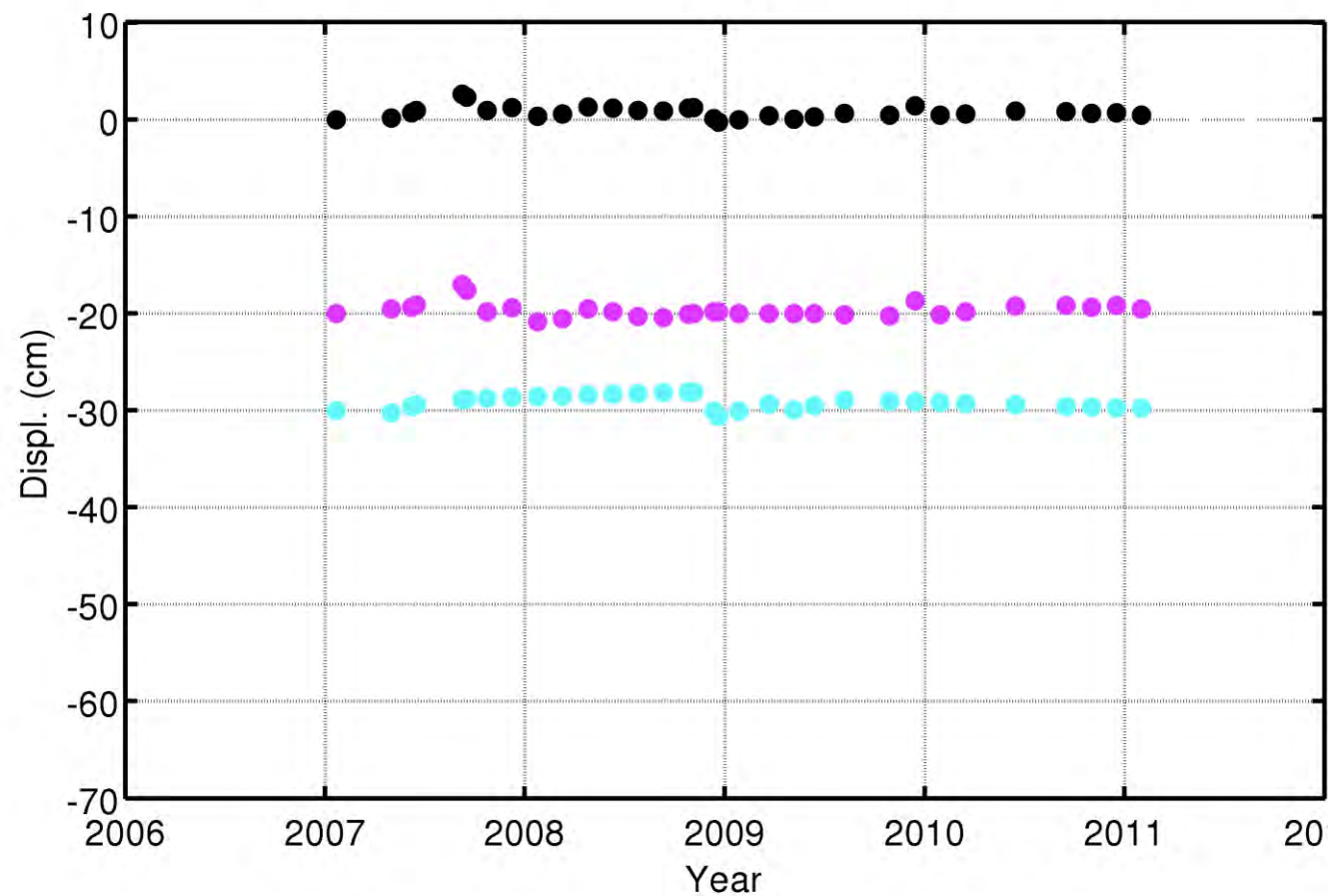
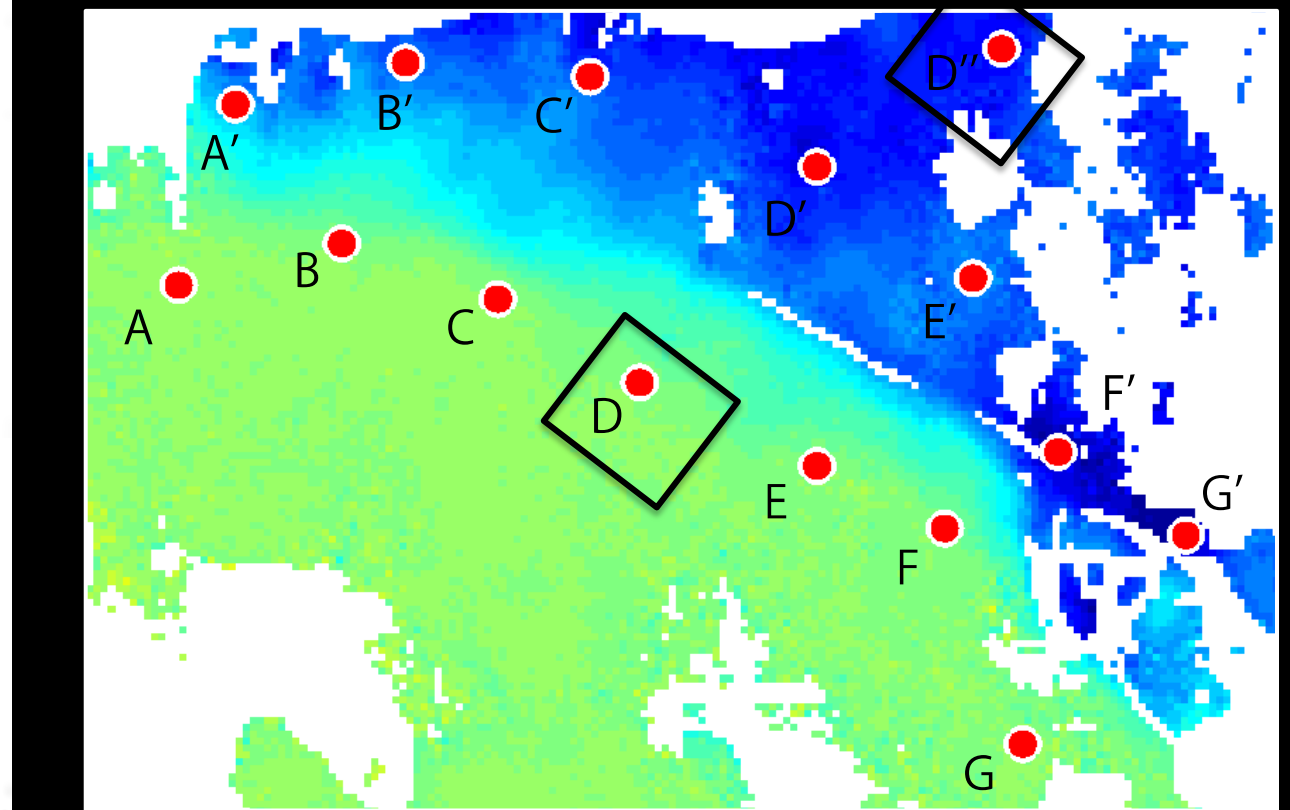
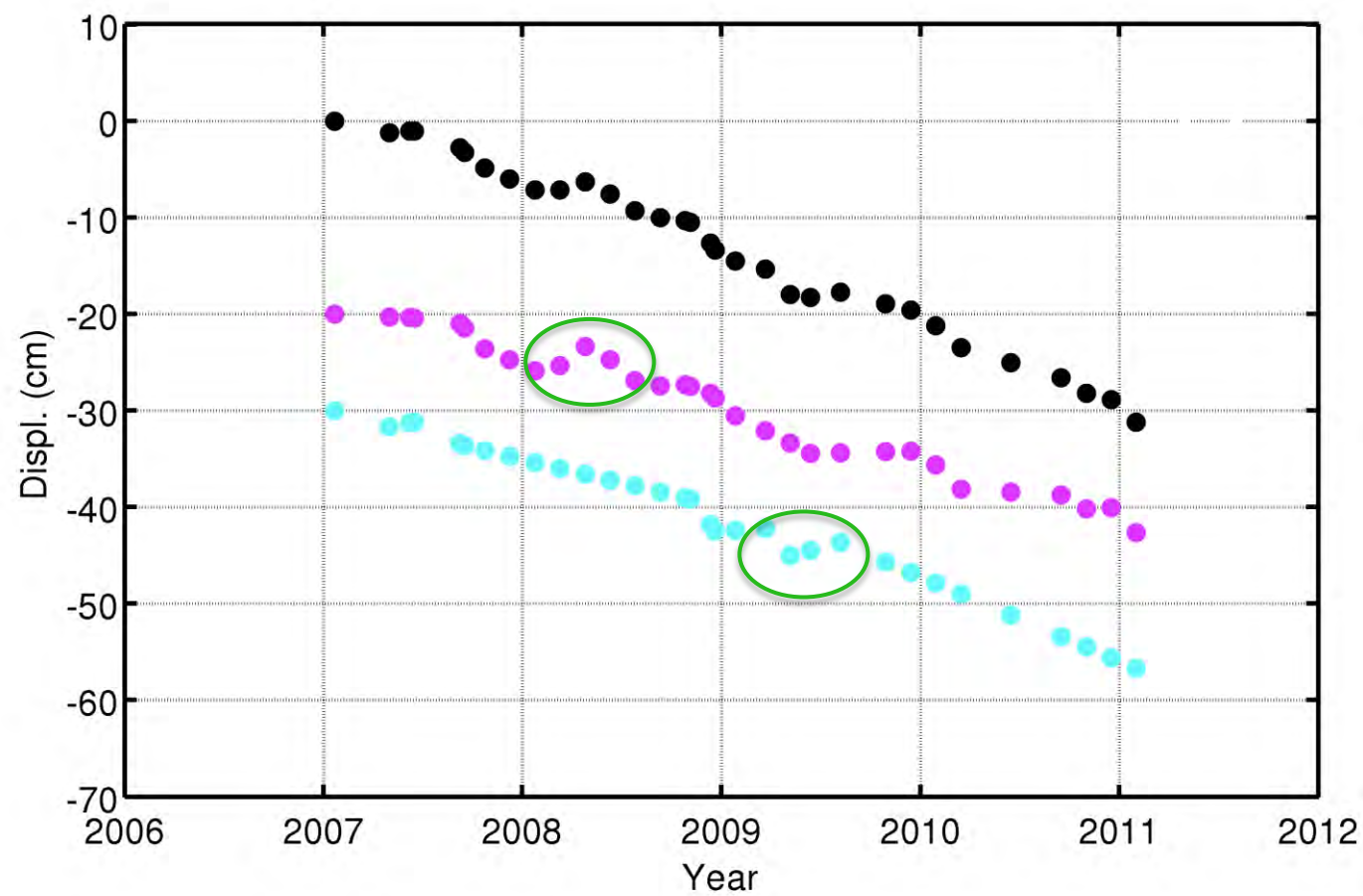
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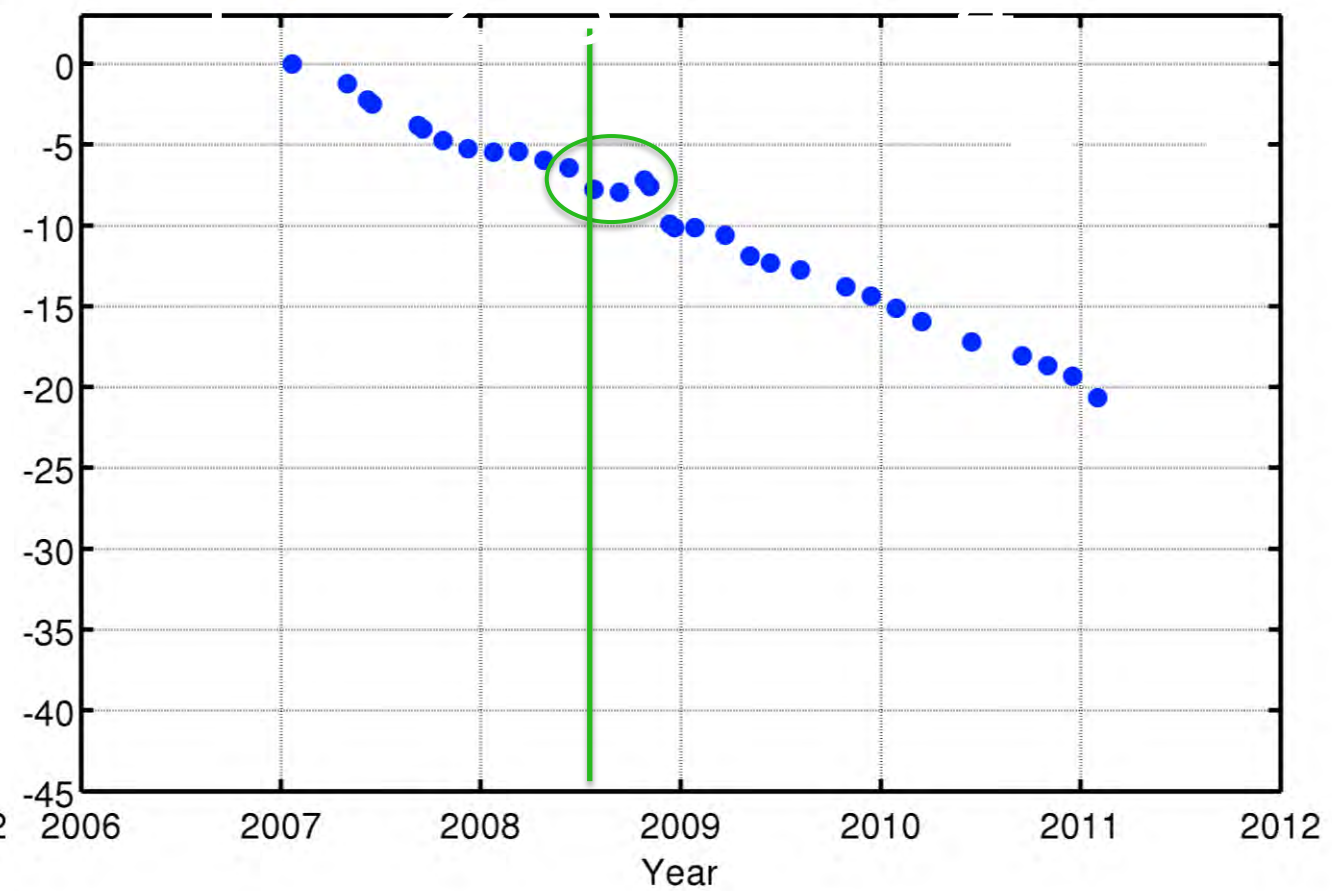
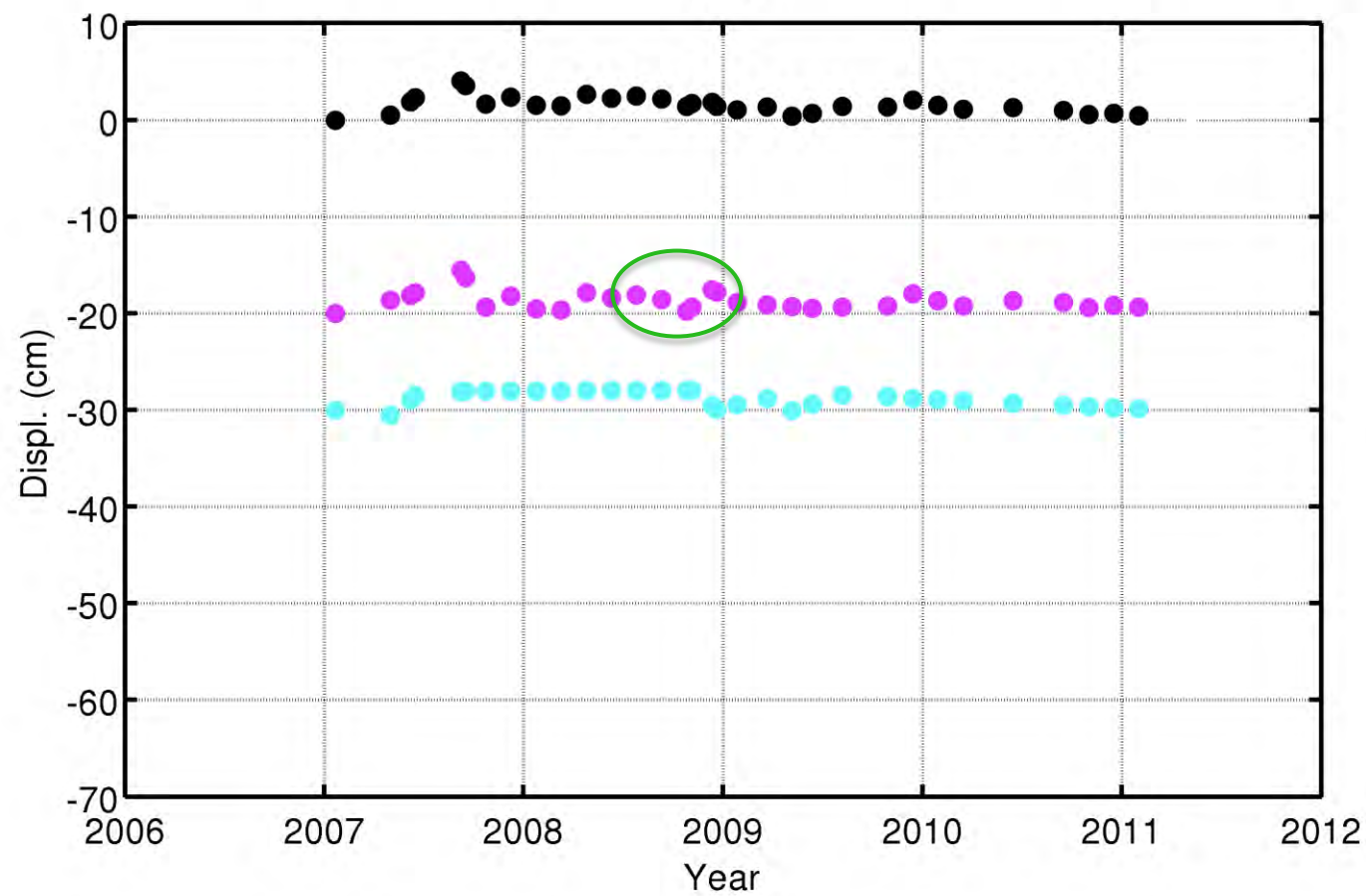
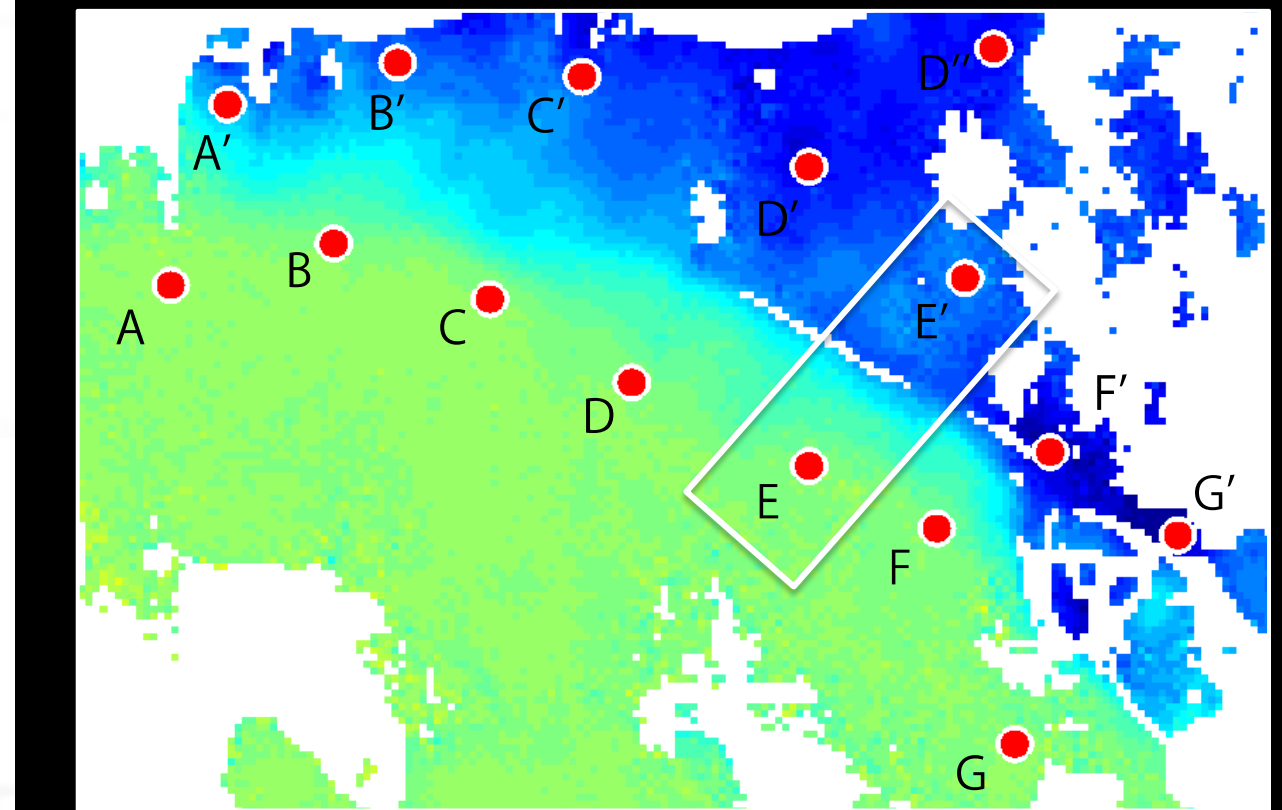
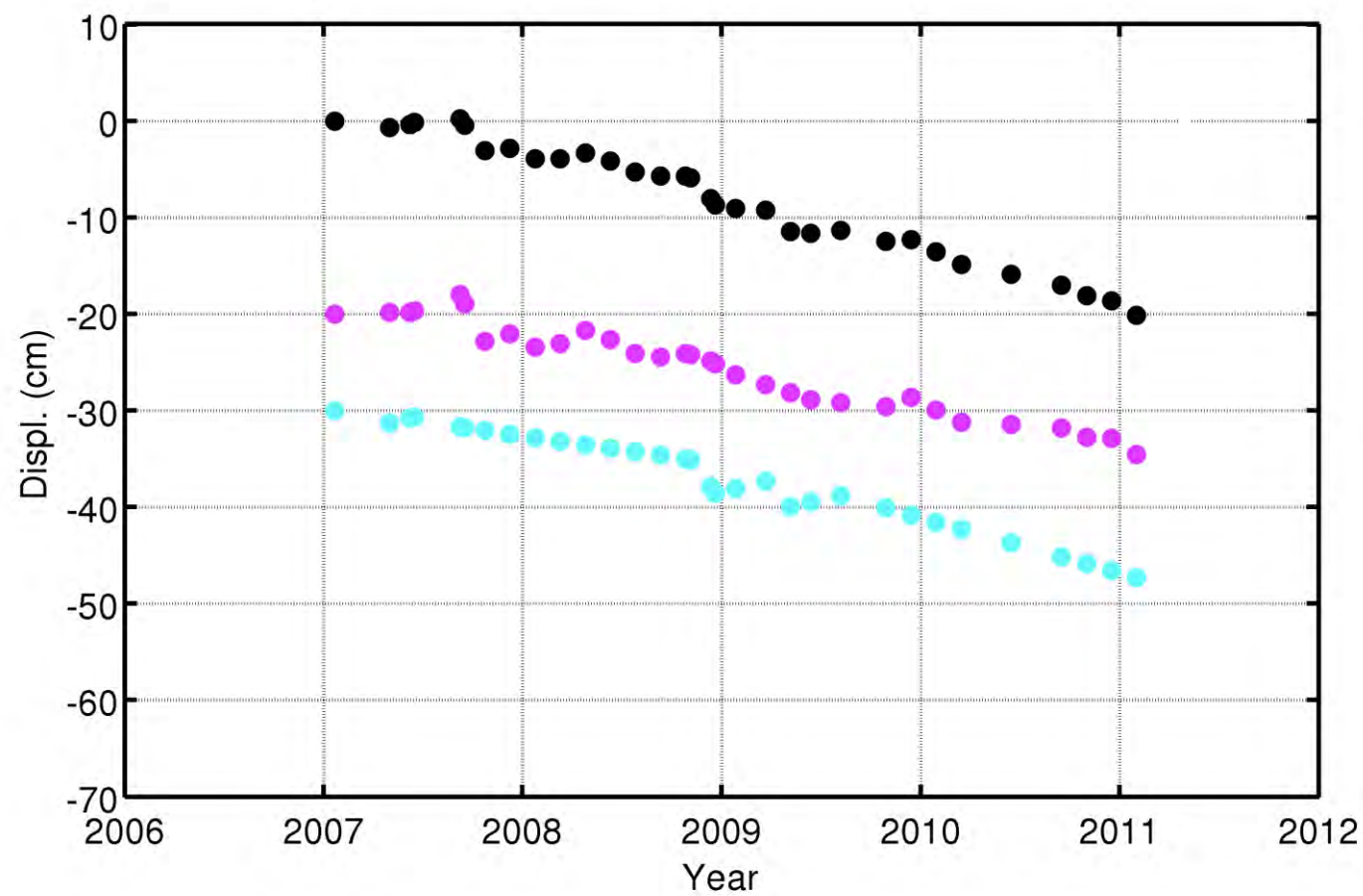
Profiles at Selected Points



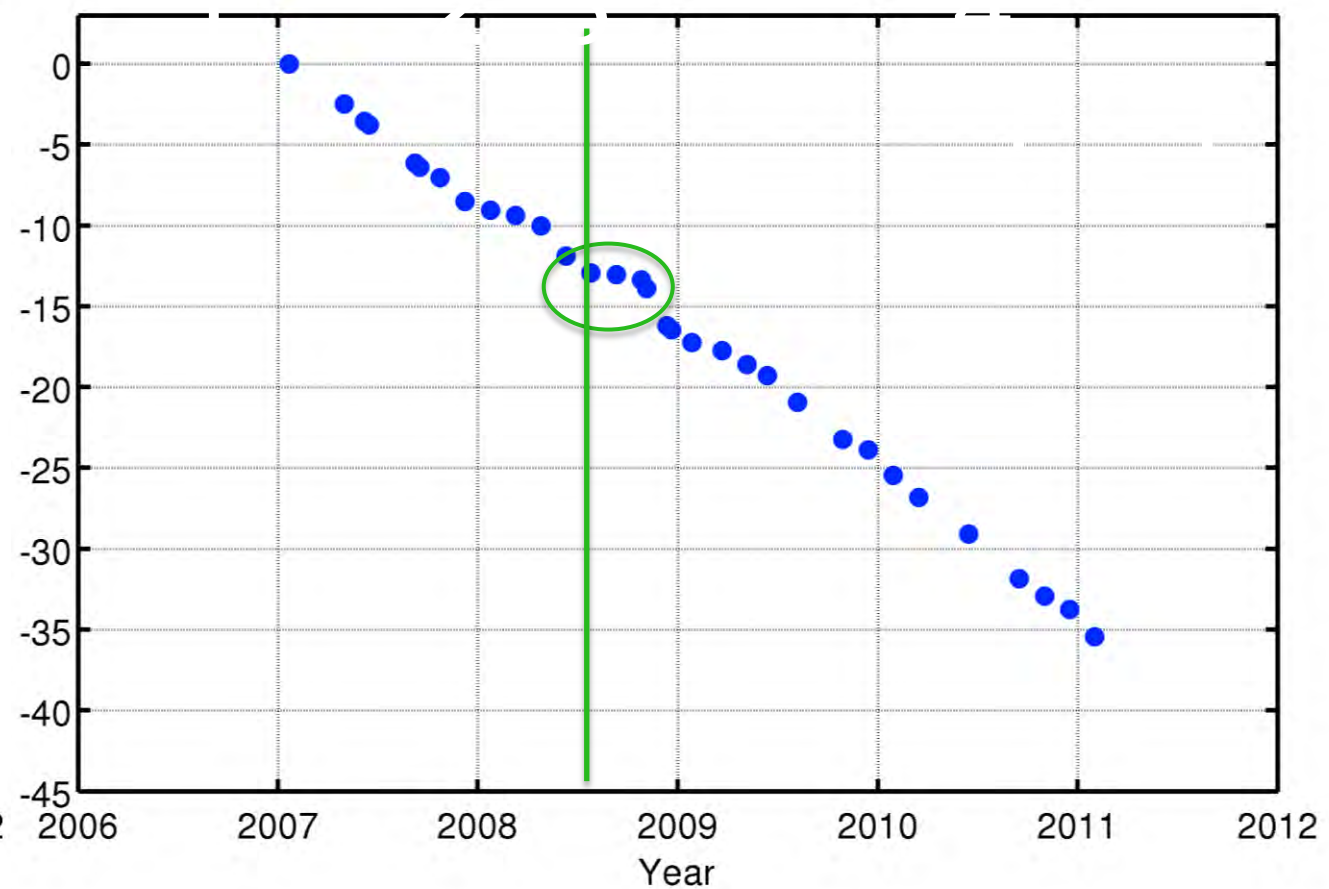
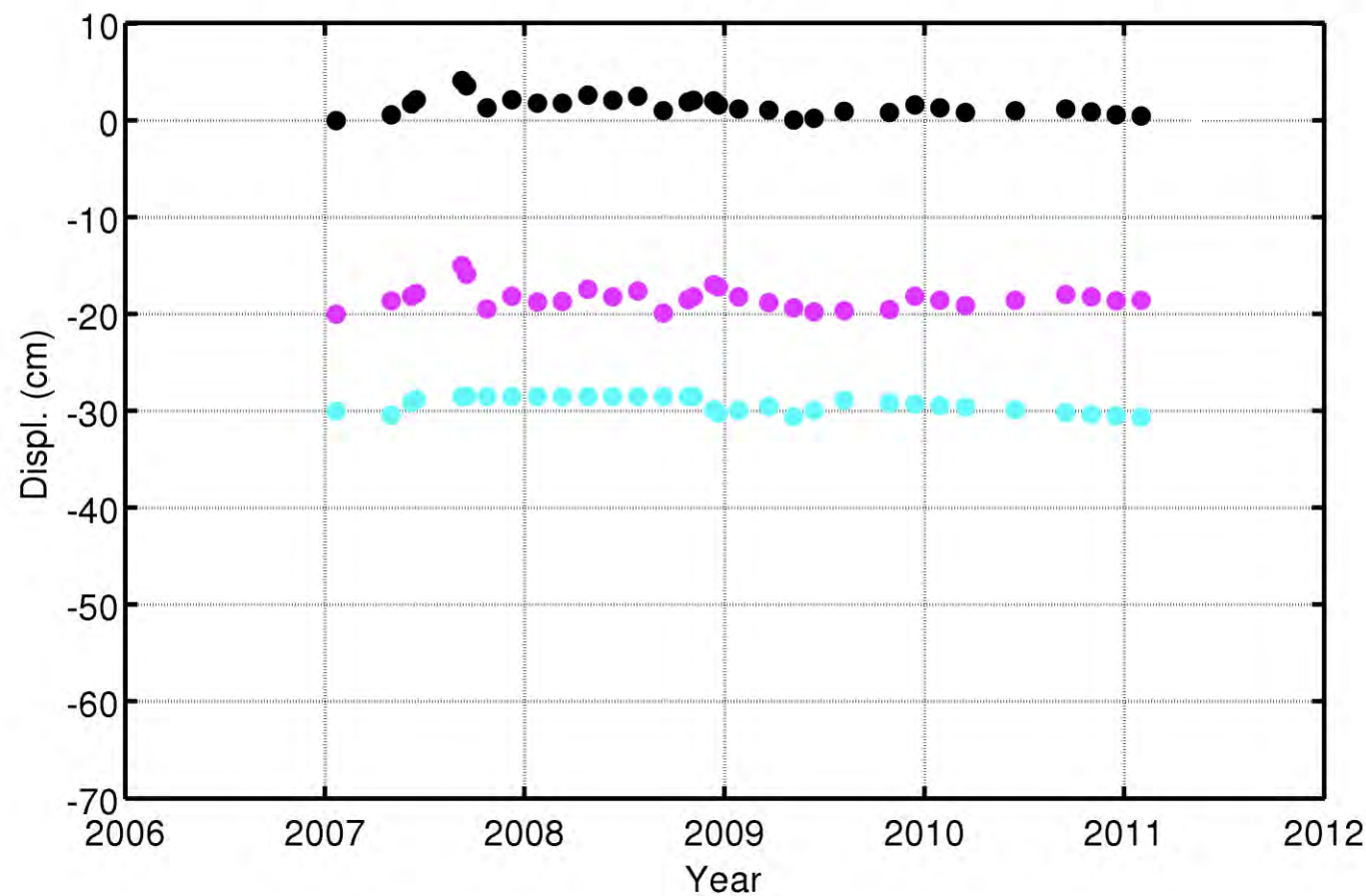
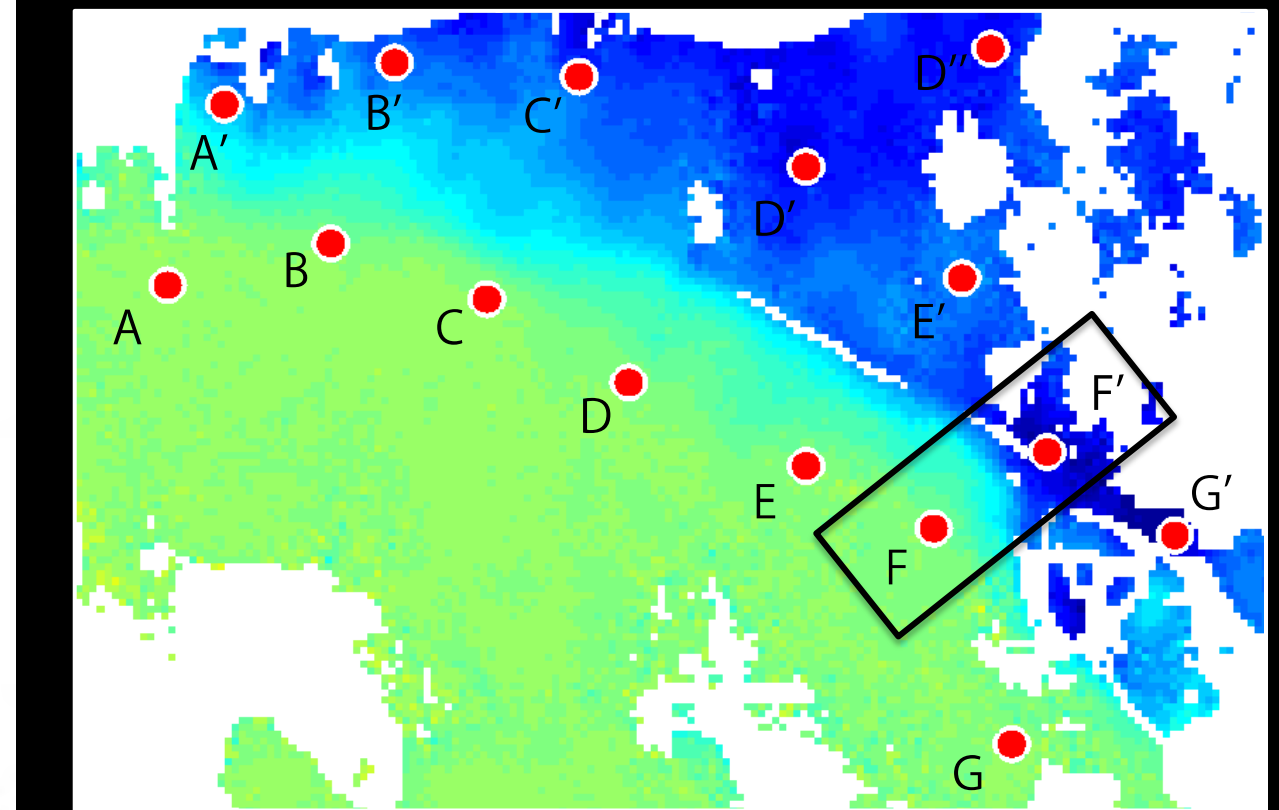
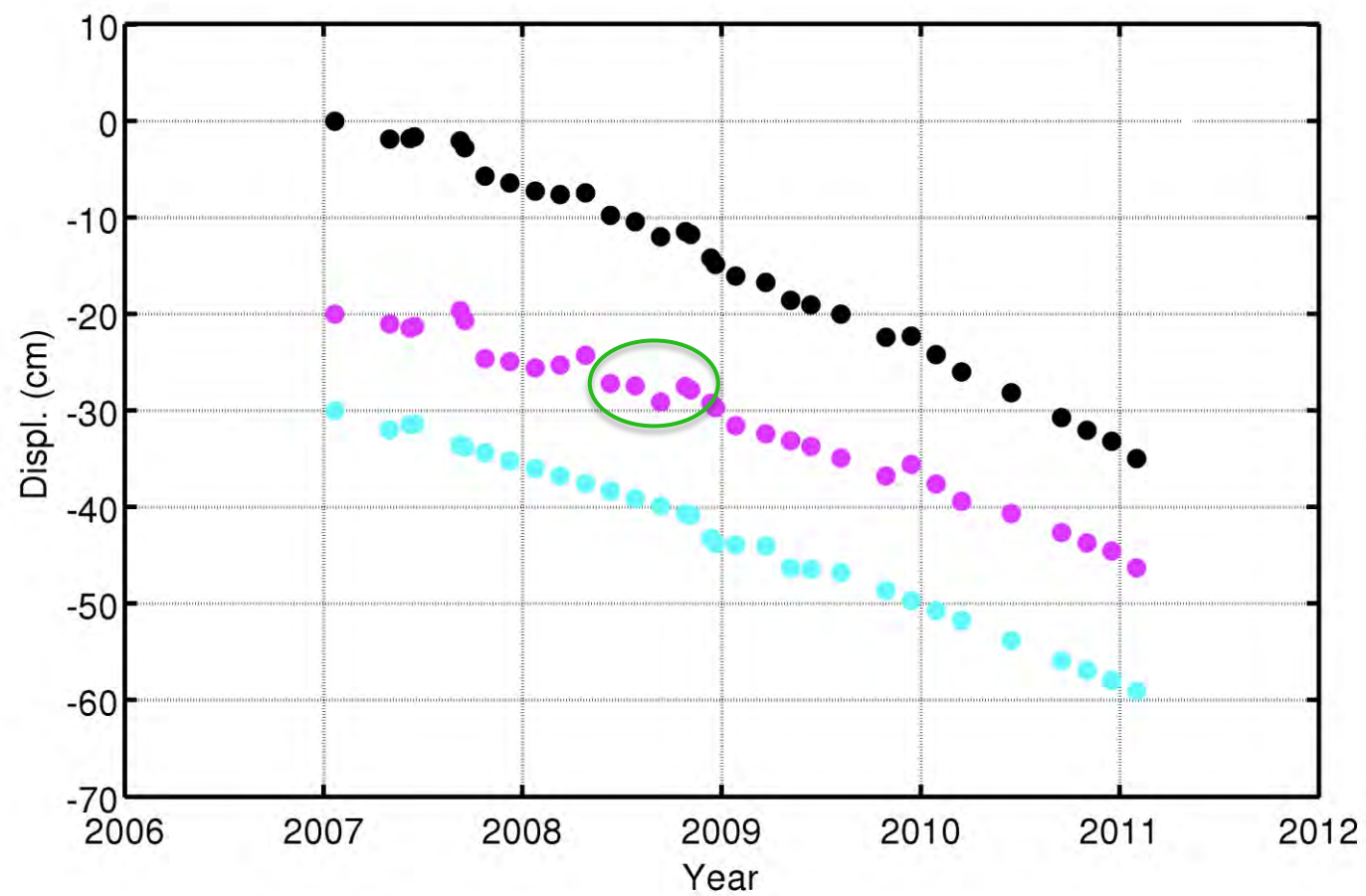
Profiles at Selected Points



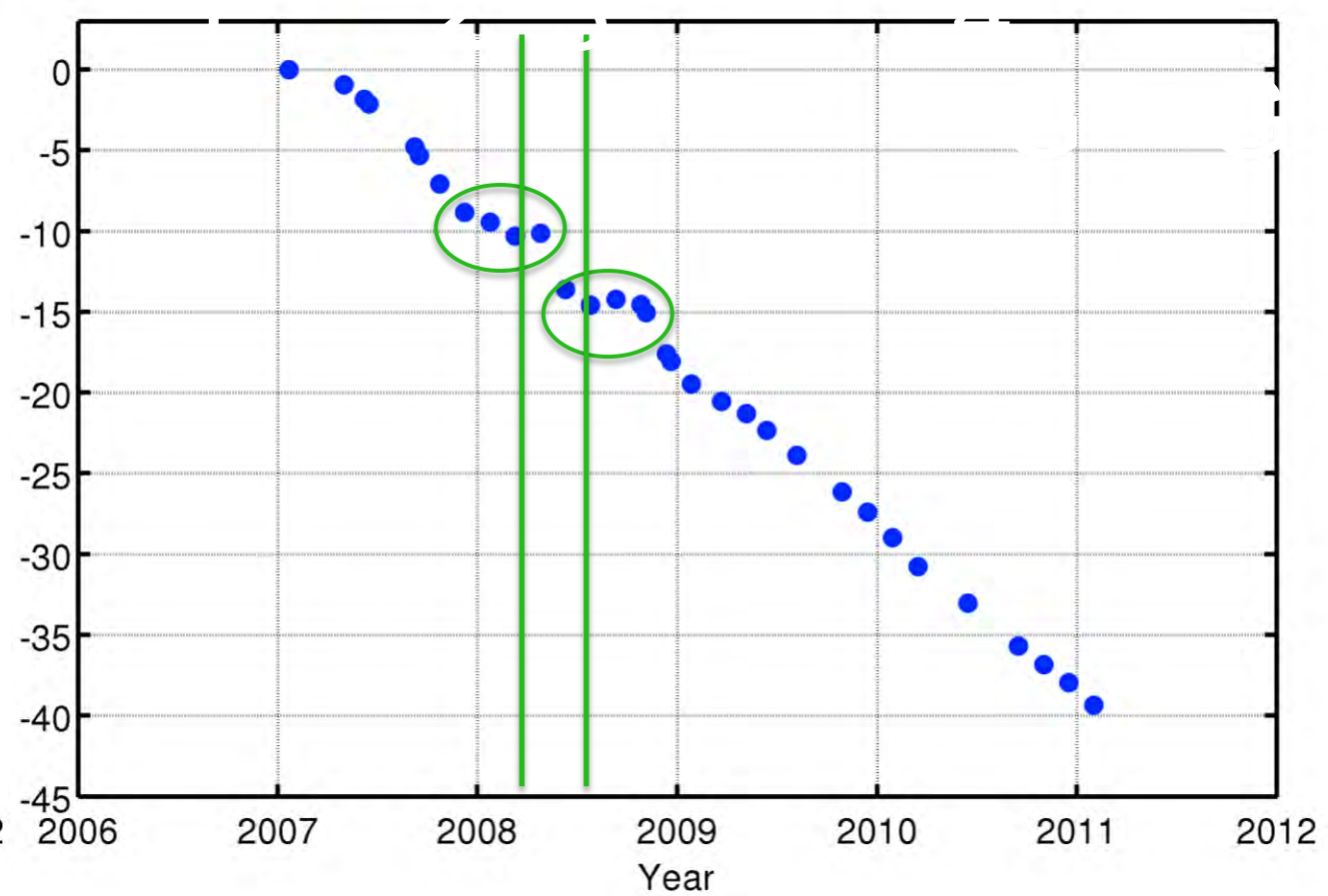
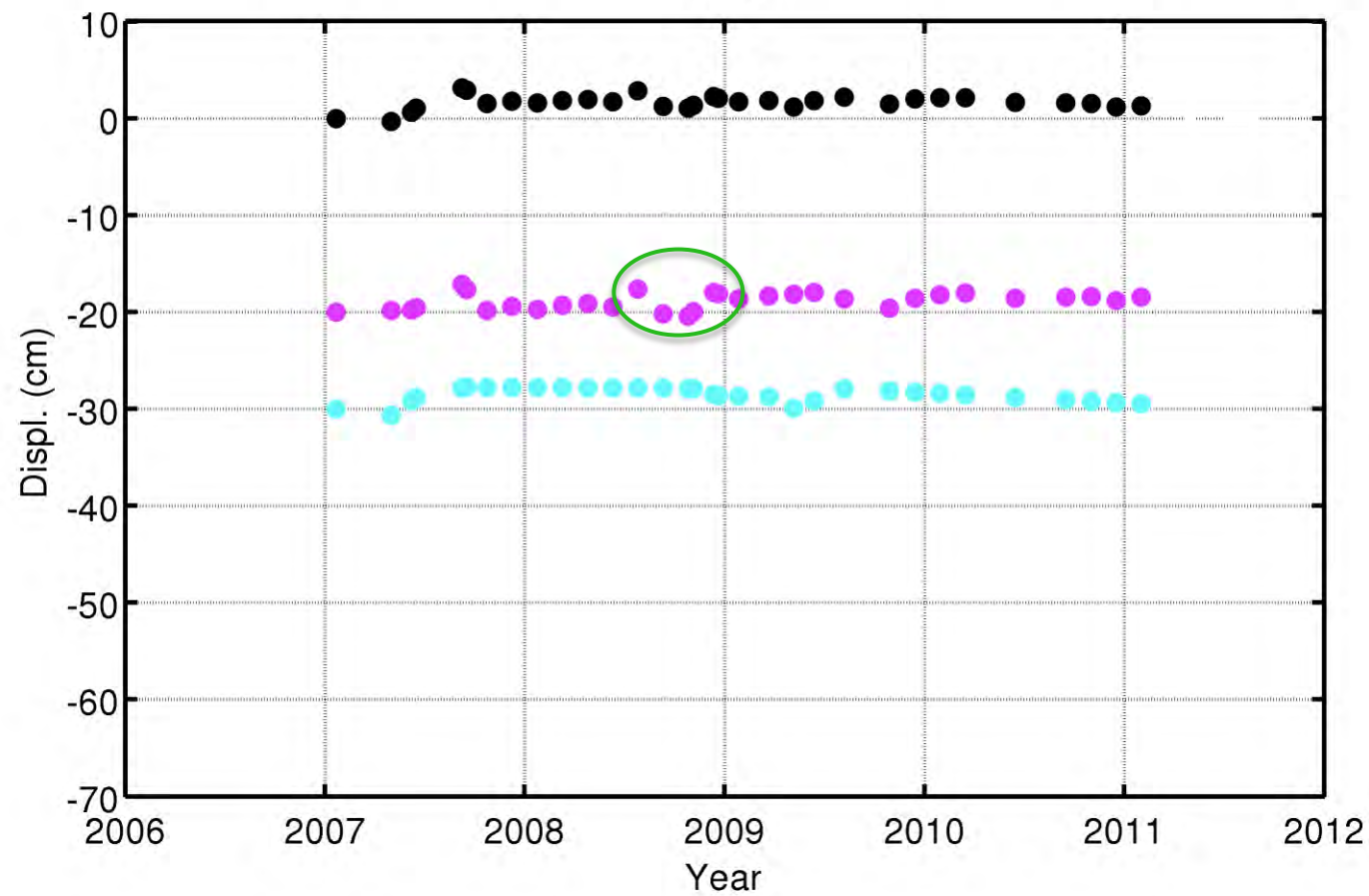
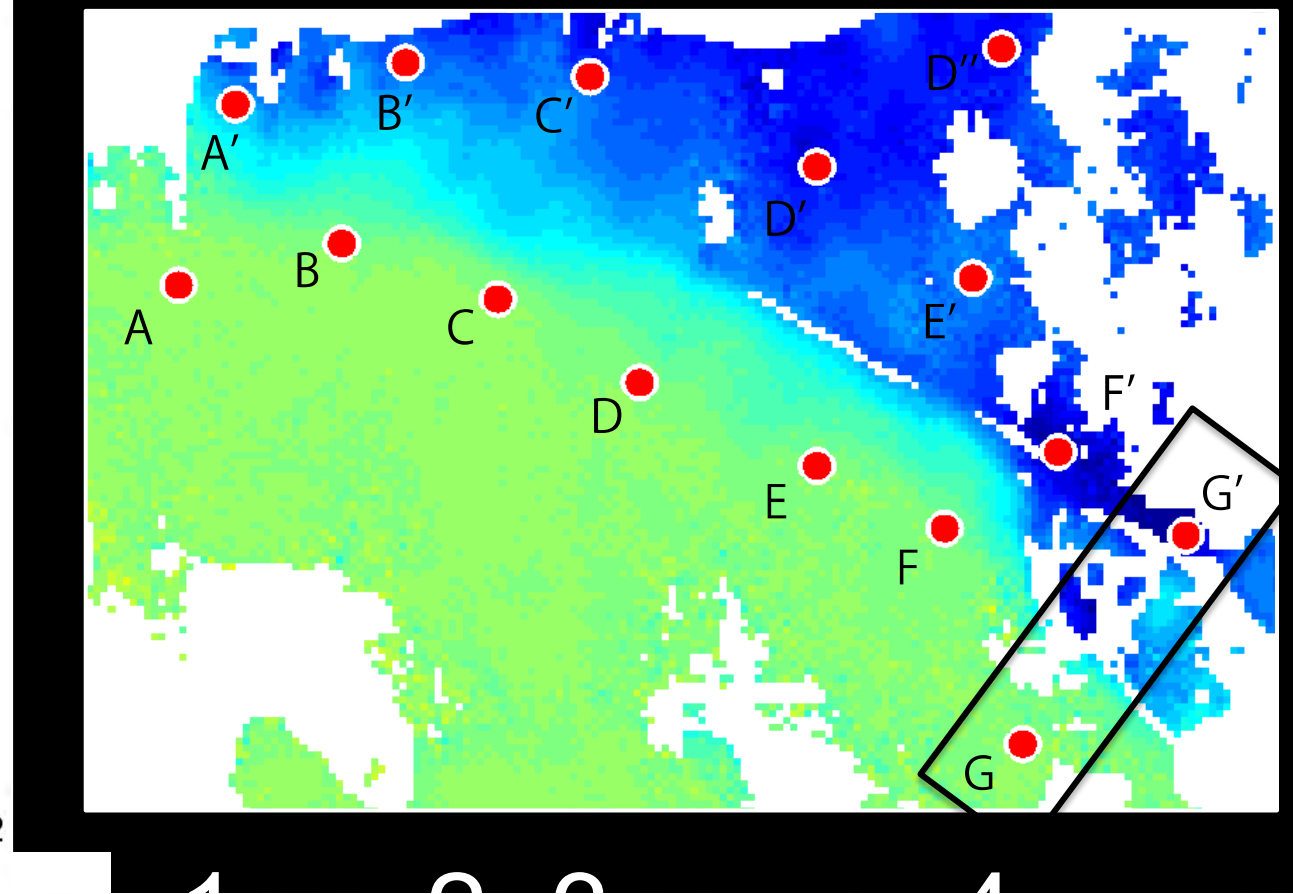
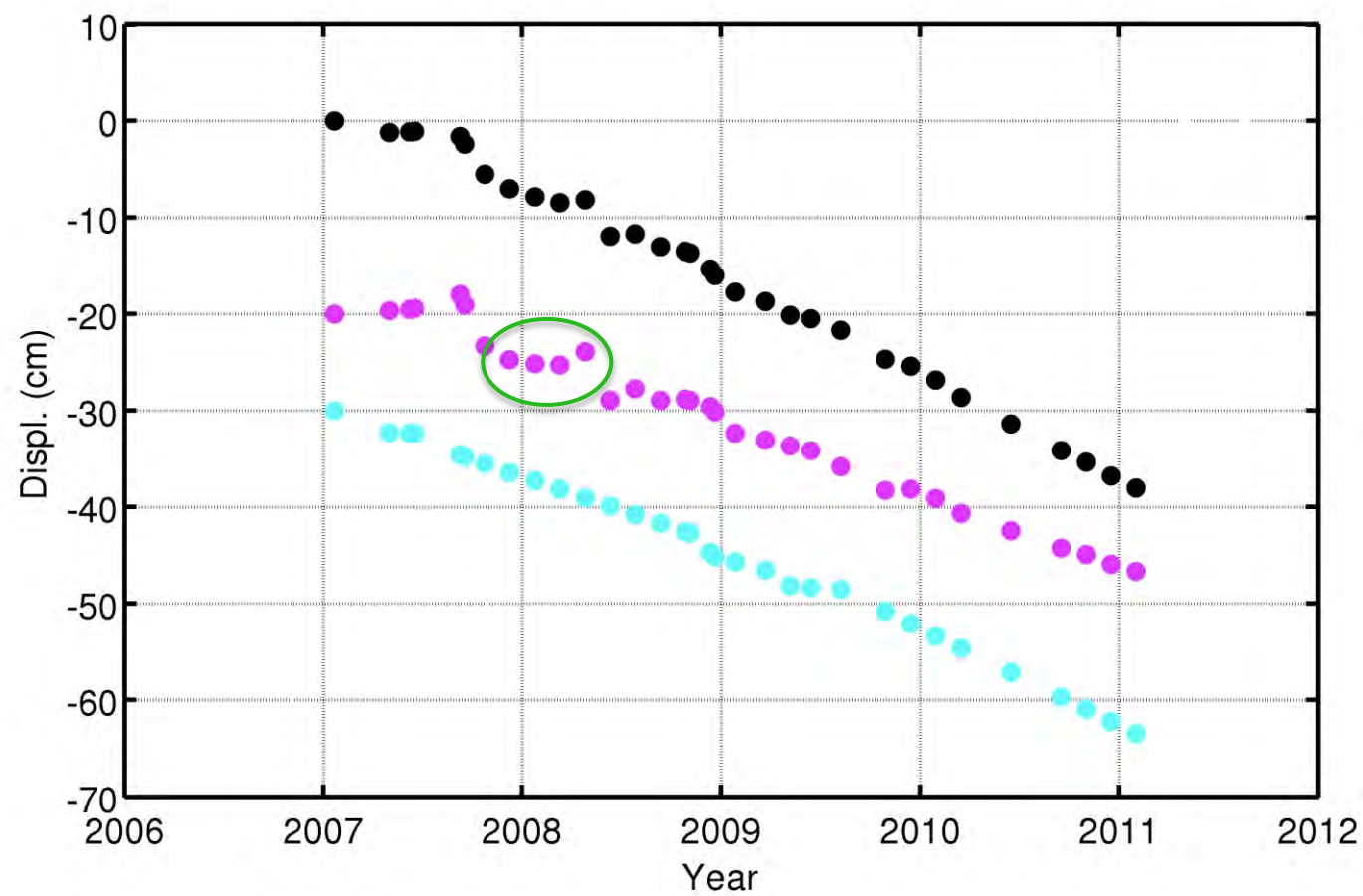
Profiles at Selected Points



Profiles at Selected Points

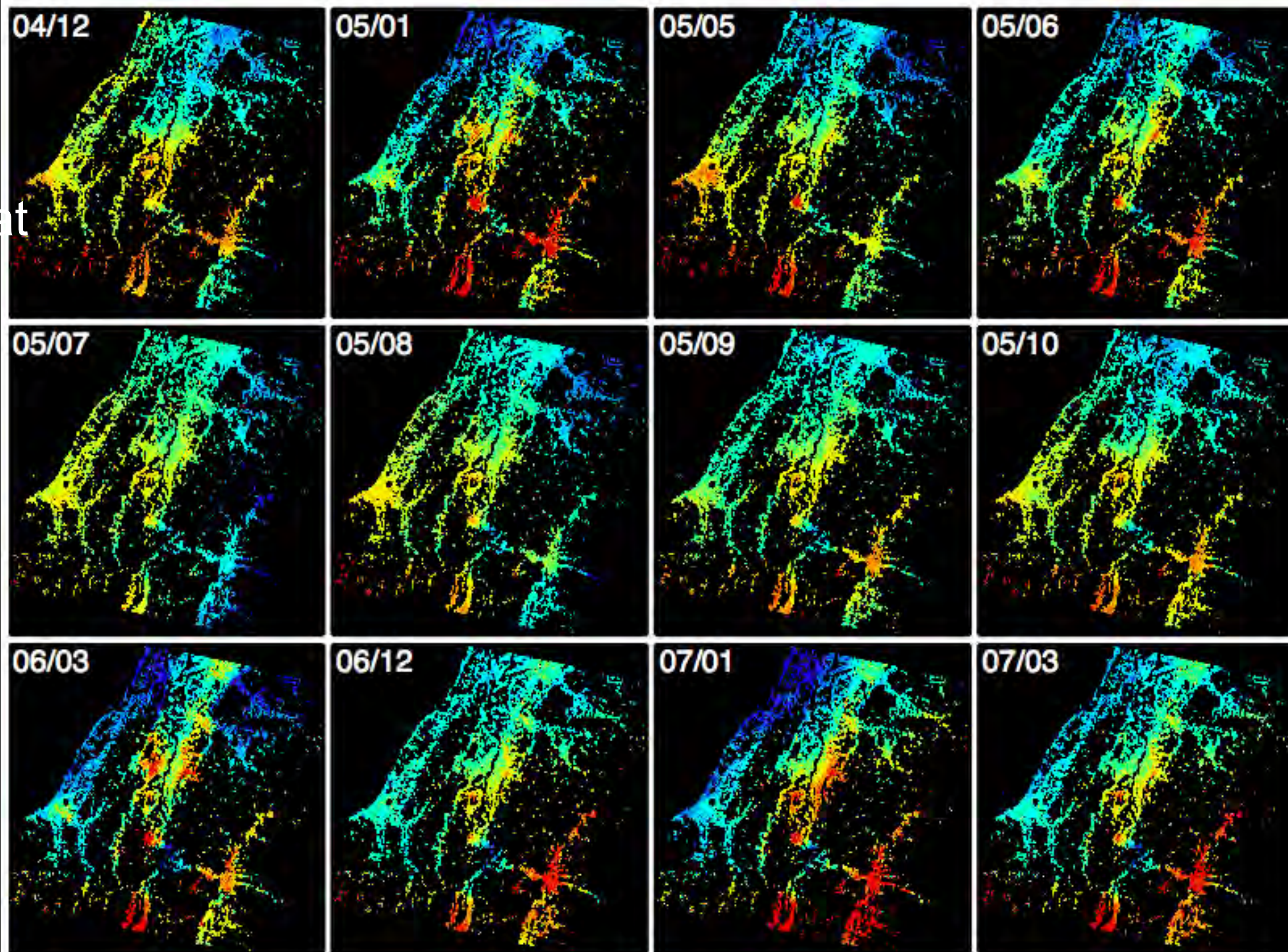


Profiles at Selected Points

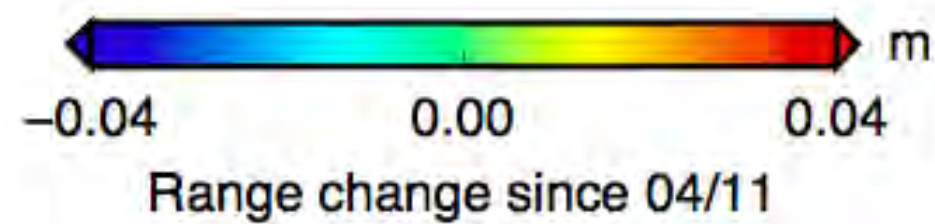


StaMPS
result

data: Envisat

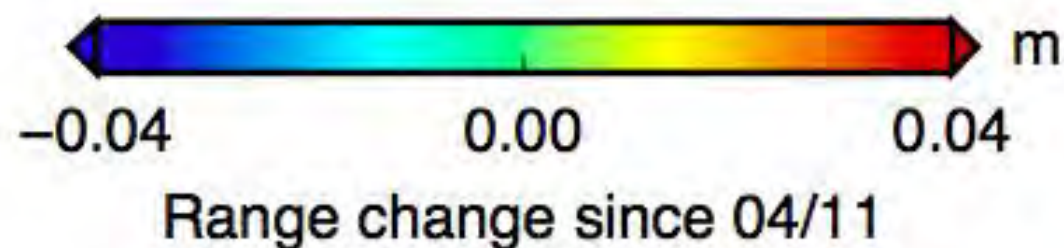
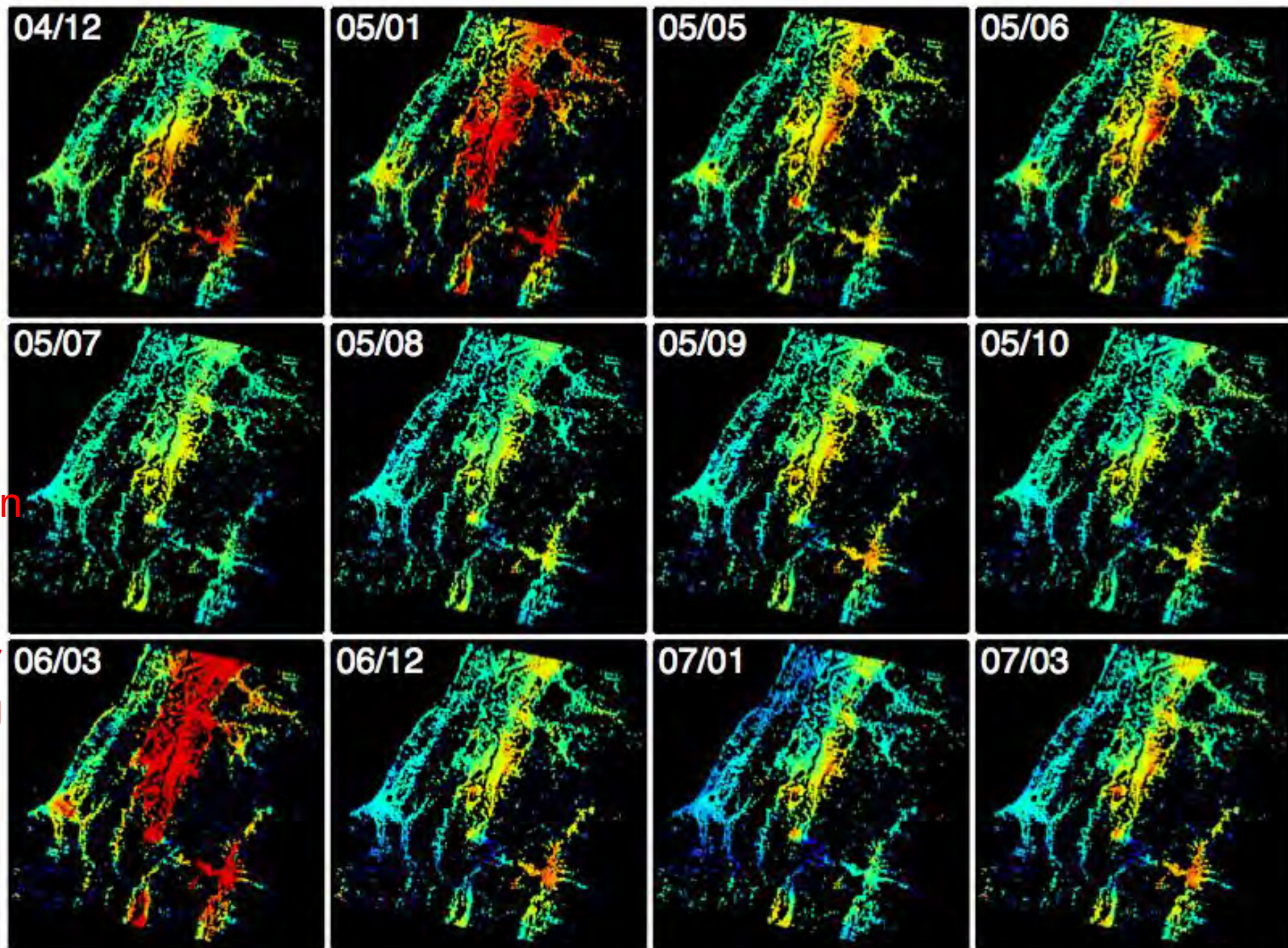


Fukushima and Hooper, 2010

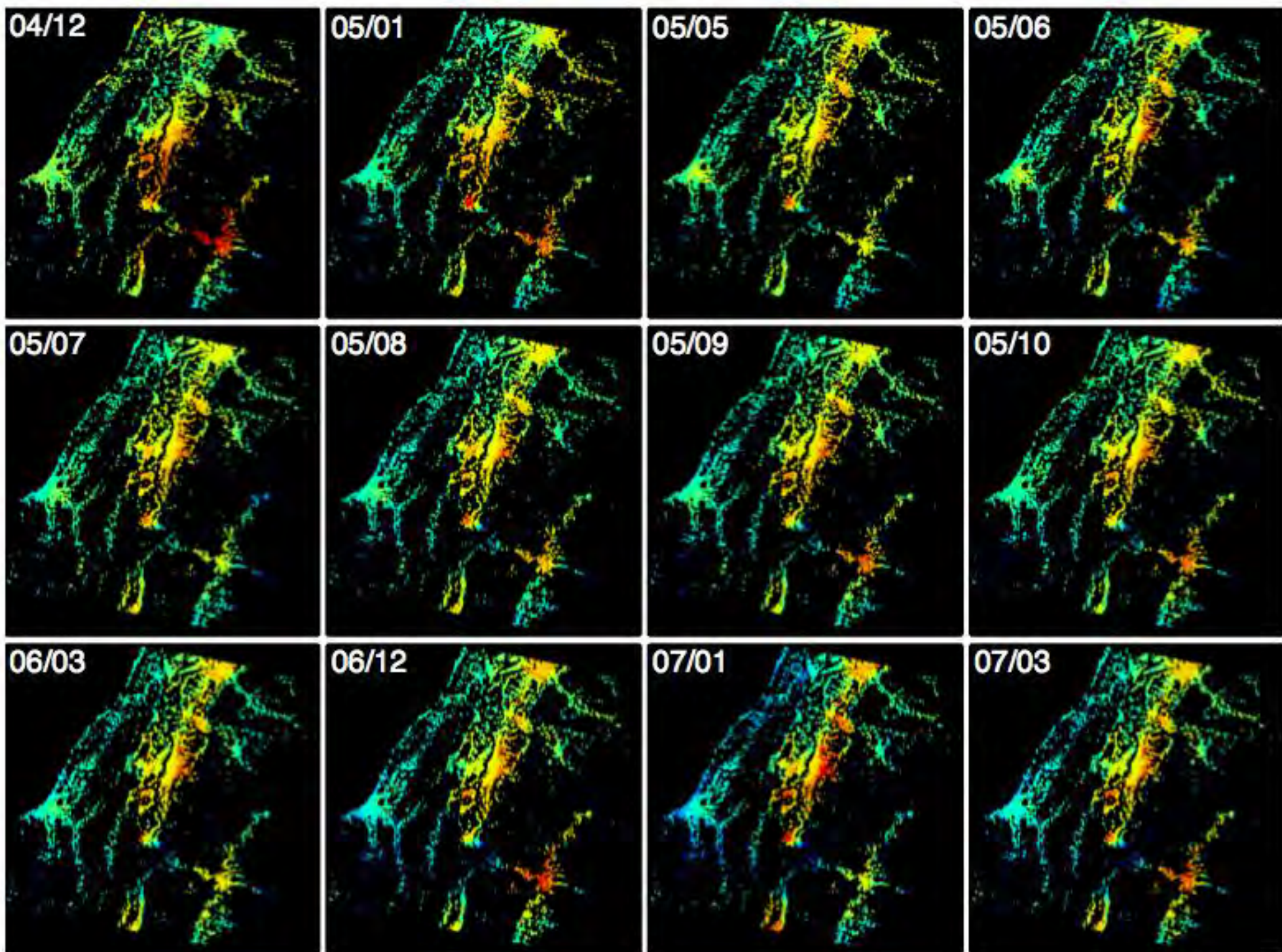


Long-wavelength trend and topo-correlated phase corrected using GPS

Subsidence in winter due to water extraction for snow melting

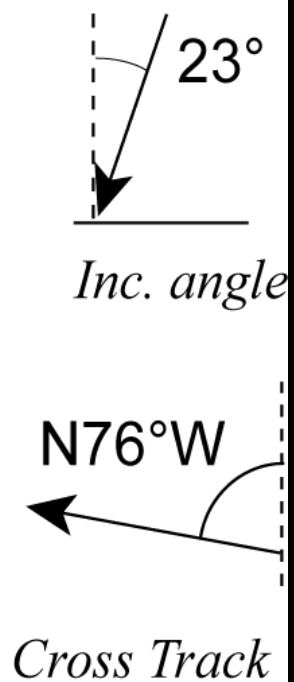
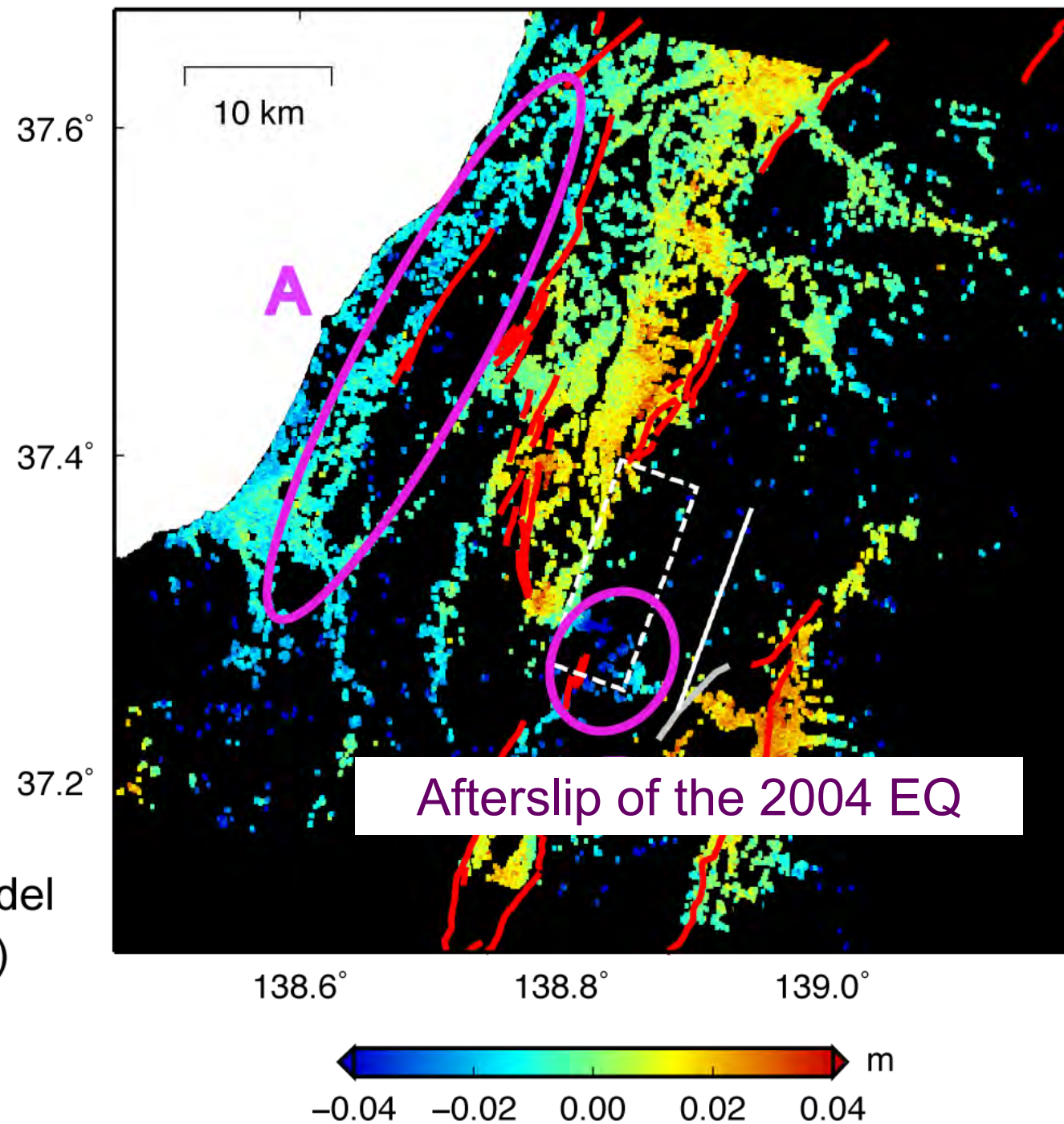
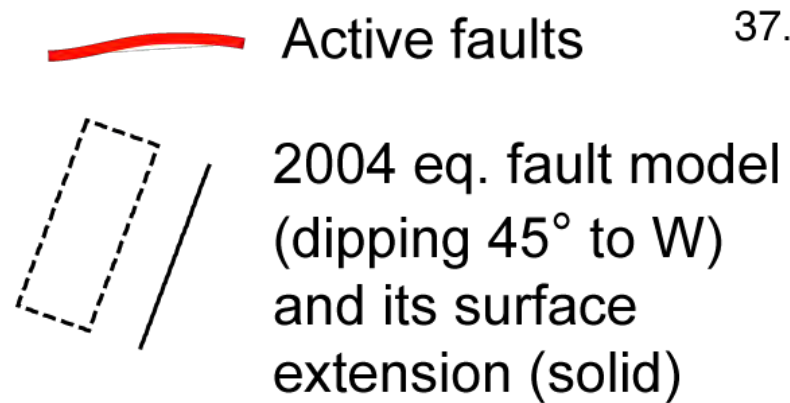
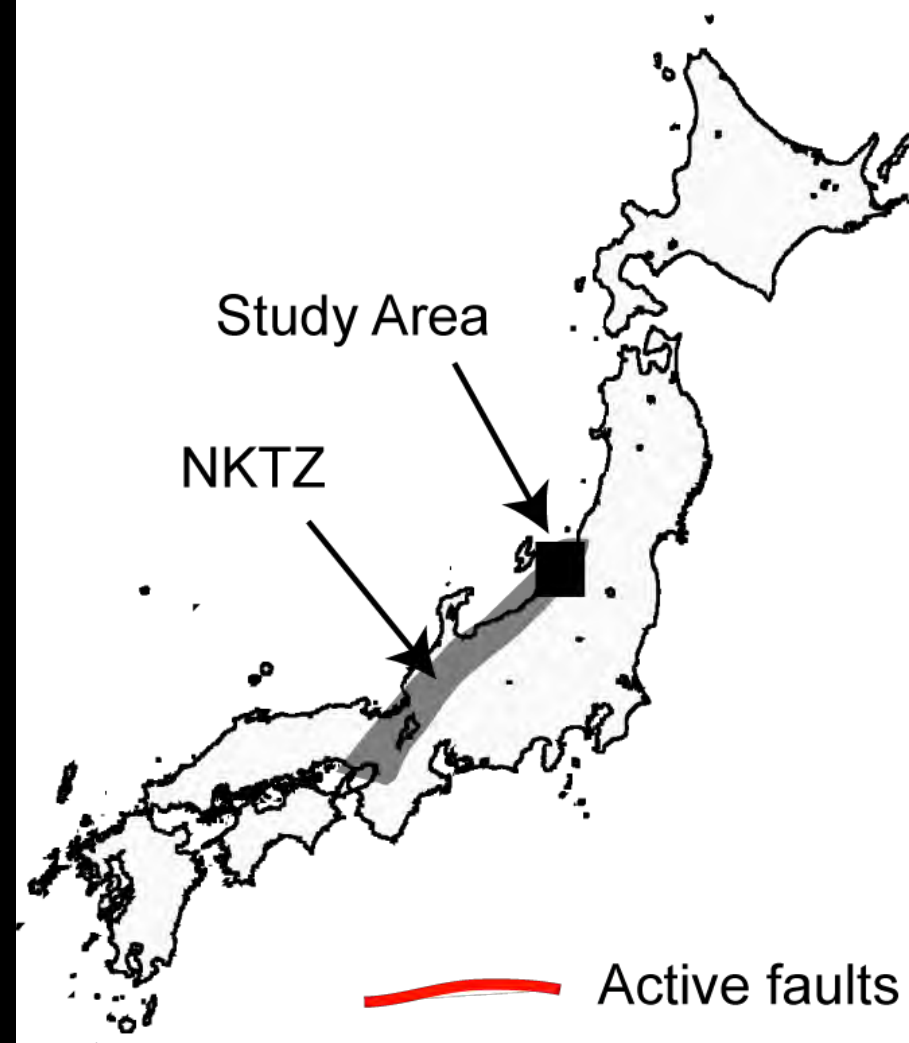


+ PCA to
get rid of
the
seasonal
signals and
see the
tectonic
signals



Fukushima and Hooper, 2010

Range change, 19 days to 859 days after the 2004 eq.



Summary

- Efforts have been made for measurements of small displacements at various scales. This includes
 - Automatic InSAR processing with robustness and accuracy
 - Atmospheric noise reduction
 - Algorithm development to solve for the displacement time-series (including post-processing)