Generic Atmospheric Correction Online Service for InSAR (GACOS)

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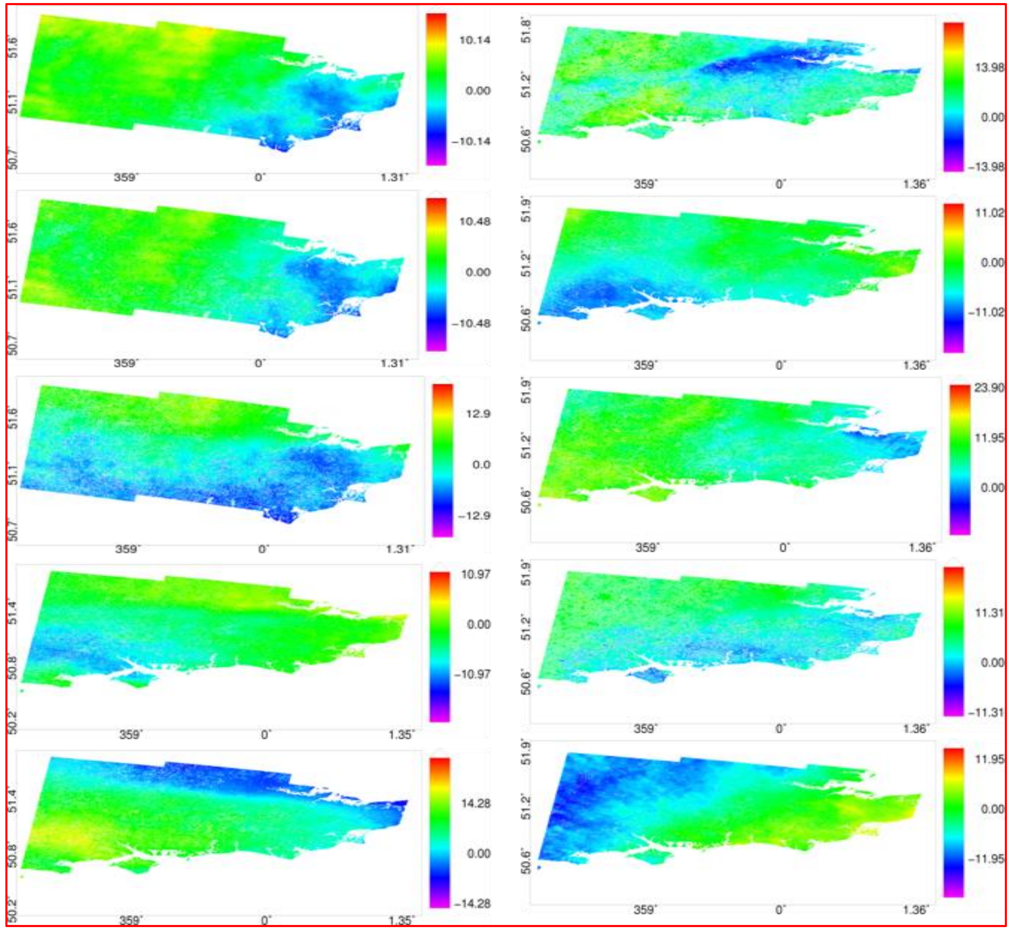
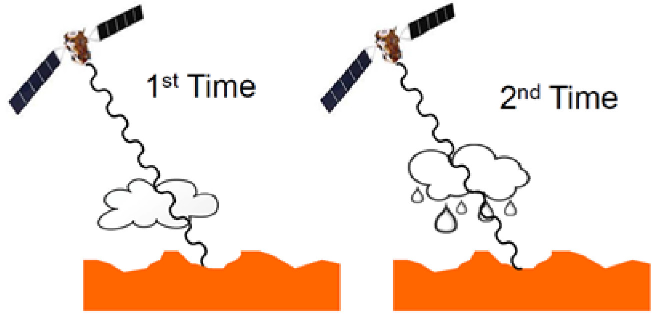
Motivation – Why atmospheric correction ?





- Spatio-temporal variations in T, P and water vapour result in tropospheric effects on InSAR observations.
- Surface displacements caused by tectonic/volcanic activities can be masked by tropospheric effects!
- Impacts on time series analysis

$$\phi_{ifg} = [\phi_{defo} + \boxed{\phi_{tropo}} + \phi_{iono} + \phi_{dem} + \phi_{base} + \phi_{noise}]_{2\pi}$$

Quantifying and mitigating **tropospheric effects** is vital for InSAR!

Motivation - Data

	GNSS	HRES-ECMWF analysis	ERA-Interim reanalysis	ERA-5 reanalysis*	MODIS
Horizontal	10 - 200 km, discrete	9~12 km, regular grid	~75 km, regular grid	~31 km	~ 1 km
Vertical	1	137 levels	61 levels	137 levels	1
Temporal	5 Minutes	00,06,12,18 UTC	00,06,12,18 UTC	Hourly (2010-2016, other data to be released soon)	Daily
availability	Near real-time	Near real-time	latency 3-4 months	Near real-time	latency 1-2 months
Limitation	Coverage	Temporal resolution	• Temporal resolution • Spatial resolution • Latency	N/A	• Clouds • Temporal resolution

Key Questions & Objective

- ❑ **How do we best use of data?**
  - Assessment, Integration, Interpolation
- ❑ **How to evaluate the model performance?**
  - Main factors affecting atmospheric correction
  - Performance indicator
- ❑ **How do we best implement the model?**
  - Availability, efficiency

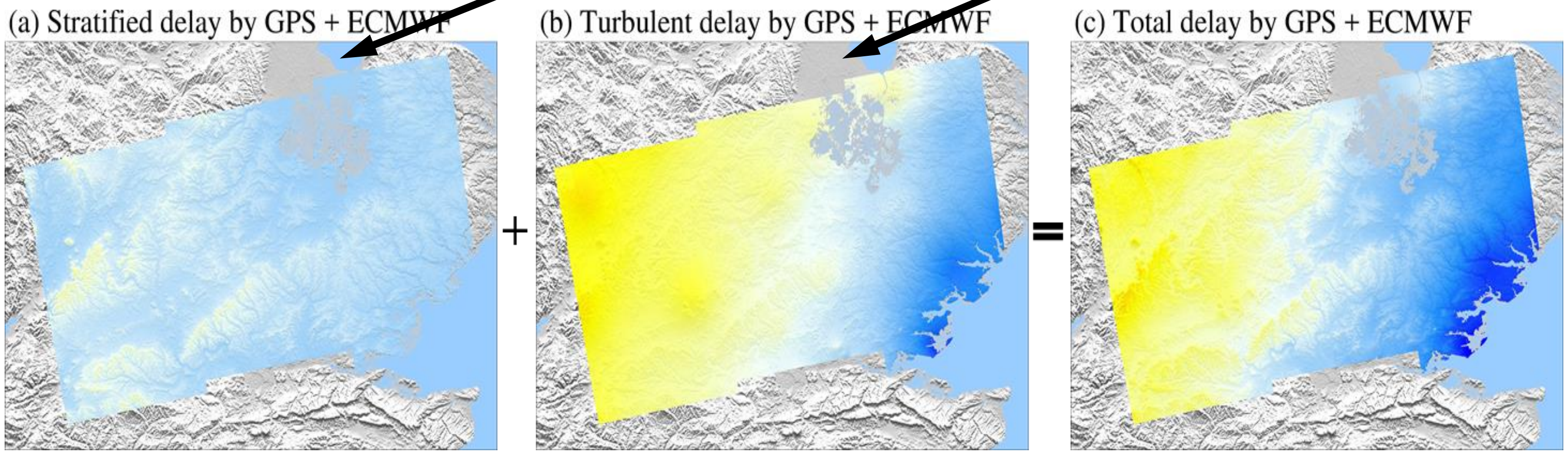
Objective：Generic Atmospheric Correction Model

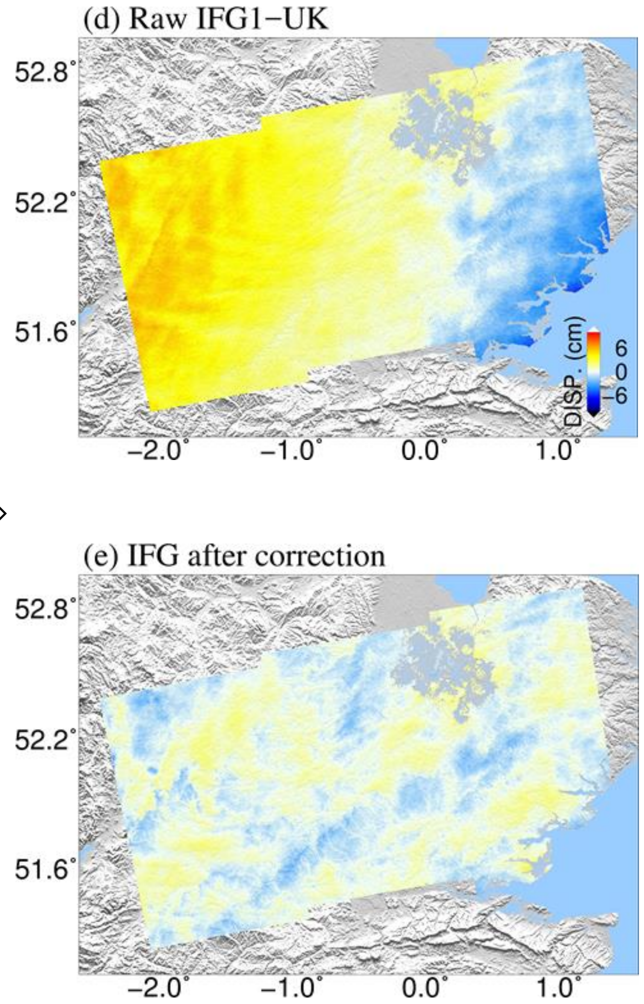
- Globally and at all times available
- In near real time
- Aimed for ~1 cm accuracy (250 by 250 km)
- With reliable quality control indicators

Methodology

~~*Tropospheric delay = Hydrostatic delay + wet delay*~~

*Tropospheric delay = **Stratified delay** + **turbulence delay***





Methodology

- Stratified: Topography-dependent component
- Turbulent: Topography-independent component resulting from turbulent processes

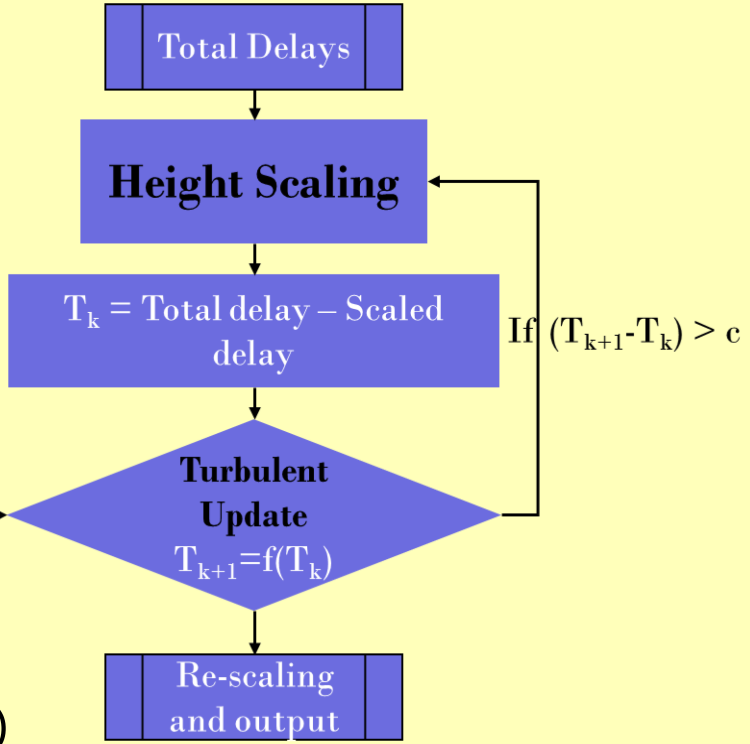
$$\triangle L_{ij}^{k} = T(\mathbf{x}^{k}) + L_0 e^{-\beta h^{k}} + \varepsilon$$

Iterative tropospheric decomposition

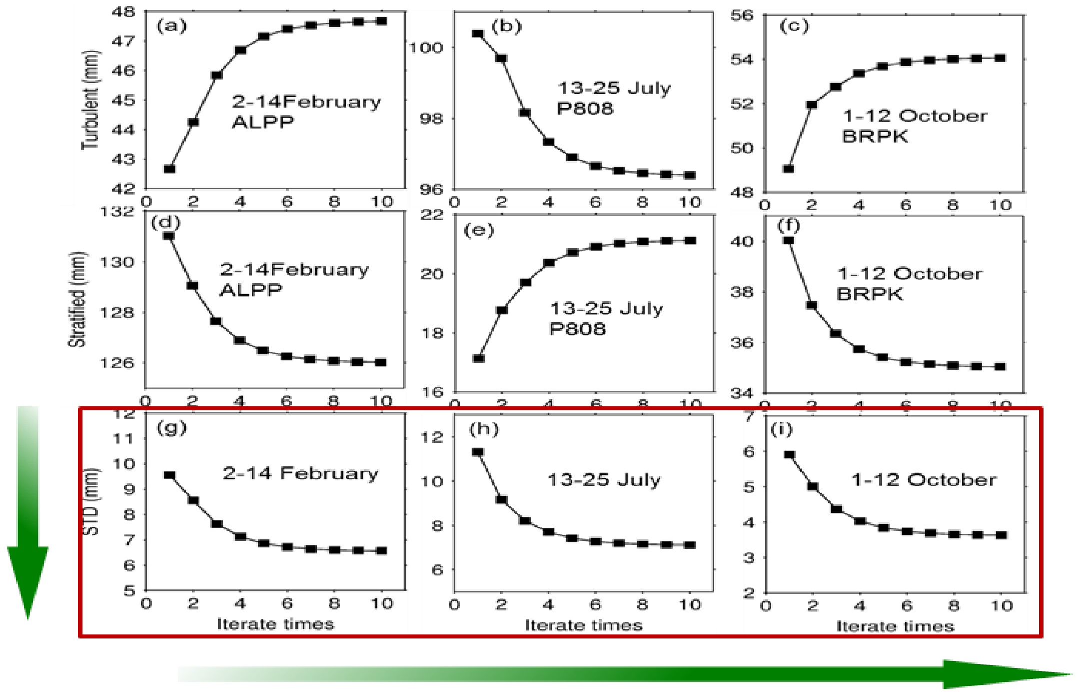
$$\triangle L_{ij}^{k} = T(\mathbf{x}^{k}) + L_0 e^{-\beta h^{k}} + \varepsilon$$

$$\begin{cases} T_u = \sum_{i=1}^{n} w_{ui} T_i(\mathbf{x}_i) \\ w_{ui} = d_{ui}^{-2} \Big/ \sum_{k=1}^{n} d_{uk}^{-2} \end{cases}$$

$$\overrightarrow{T_{k+1}} = \begin{pmatrix} 0 & w_{12} & \cdots & w_{1n} \\ w_{21} & 0 & \cdots & w_{2n} \\ \vdots & \vdots & 0 & \vdots \\ w_{n1} & \cdots & w_{n,n-1} & 0 \end{pmatrix} \overrightarrow{T_k}$$



(Yu et al., 2017, JGR)



Significant improvement after separating stratified and turbulence component

Methodology

- **Stratified:** Topography-dependent component
- **Turbulent:** Topography-independent component resulting from turbulent processes

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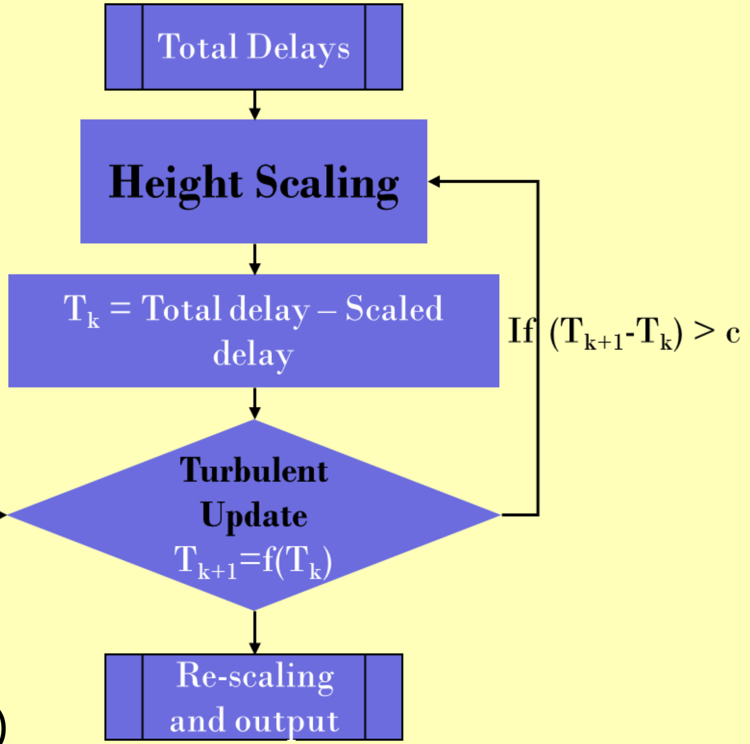

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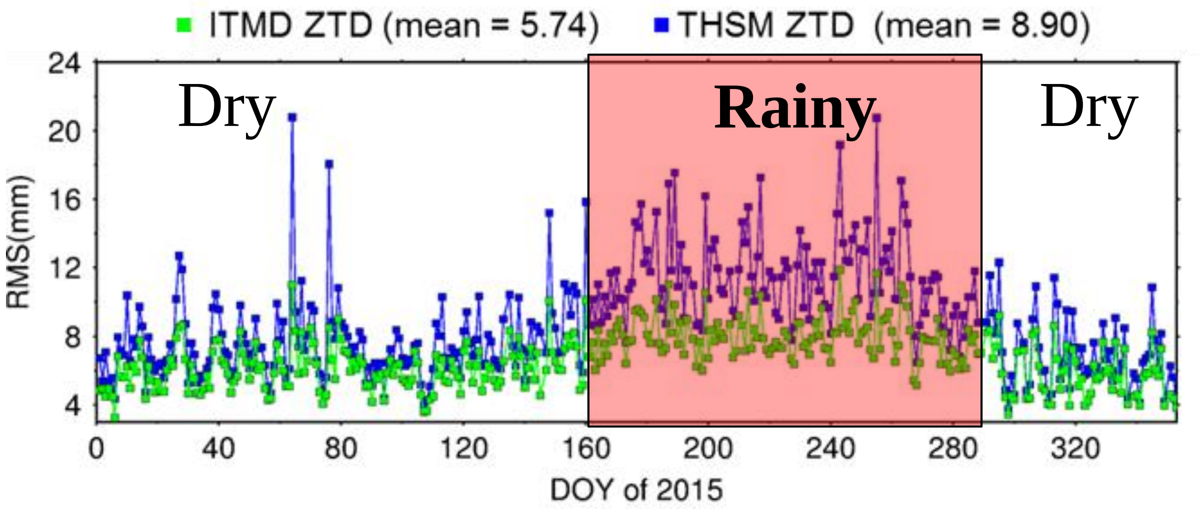
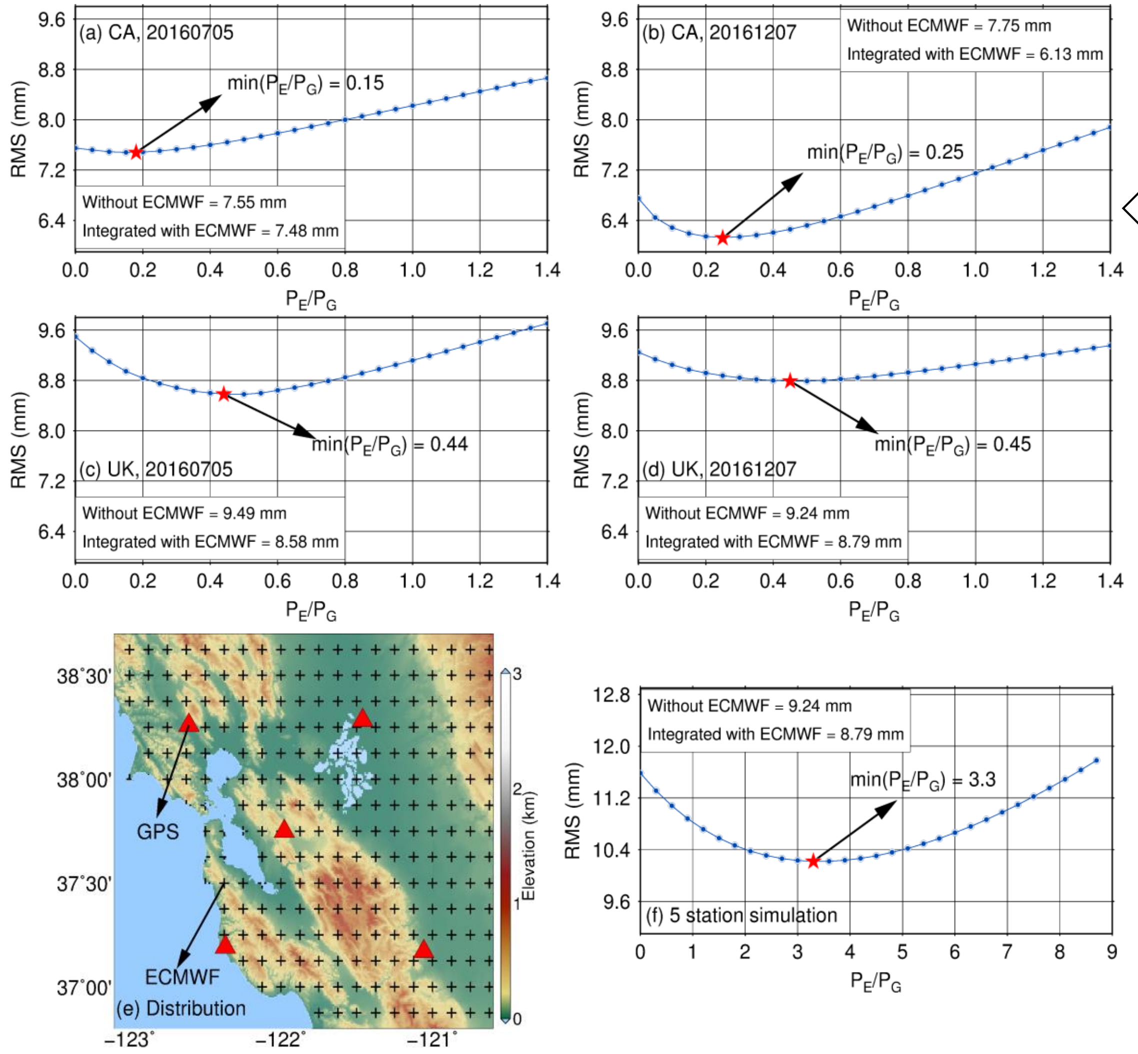


More improvements in strong turbulence seasons

Methodology

Integration of GNSS and HRES-ECMWF

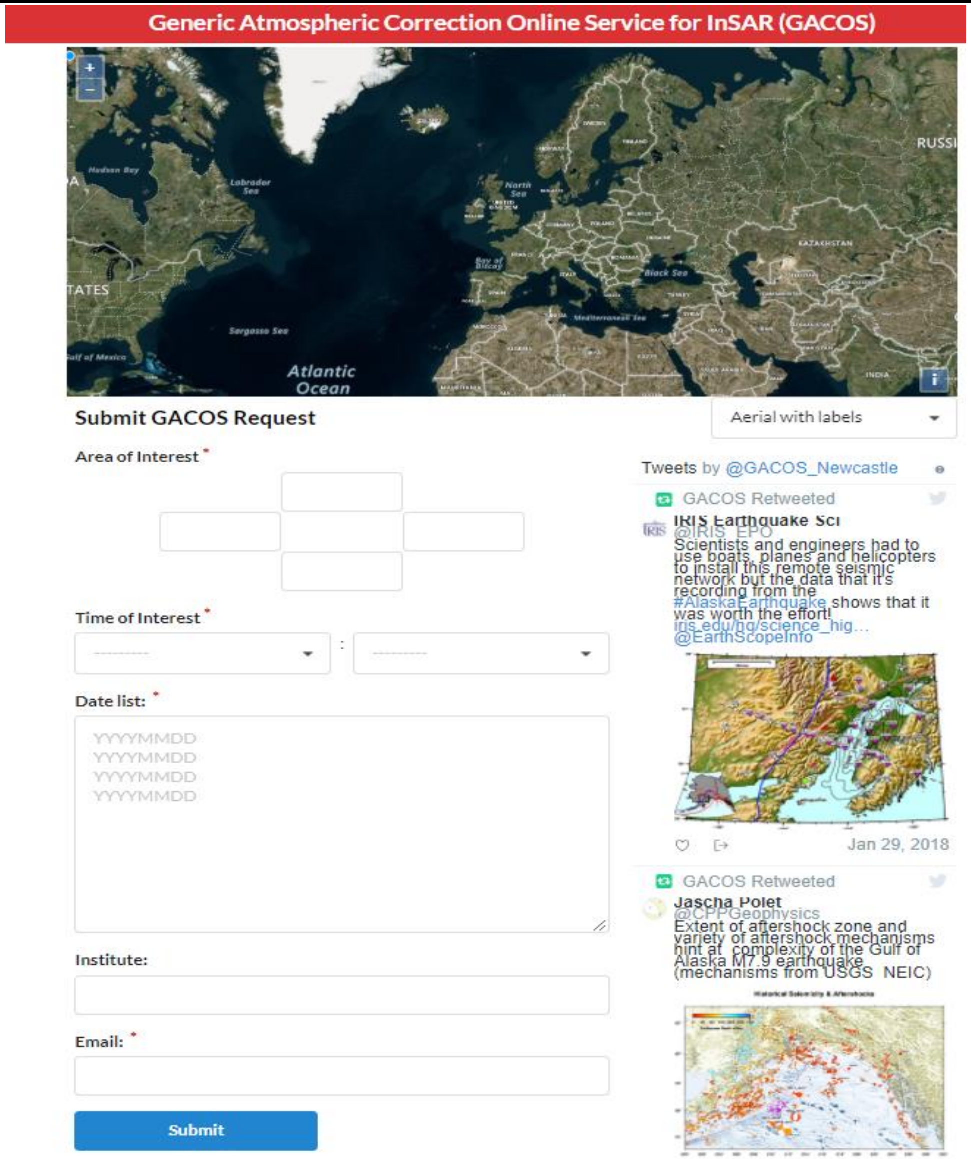


$$S = L_0 e^{-\beta h} \Rightarrow \begin{cases} S_m^G = L_0 e^{-\beta h_m} \\ S_n^E = L_0 e^{-\beta h_n} \end{cases}, \quad \boxed{P_S = \begin{bmatrix} P_G & 0 \\ 0 & P_E \end{bmatrix}}$$

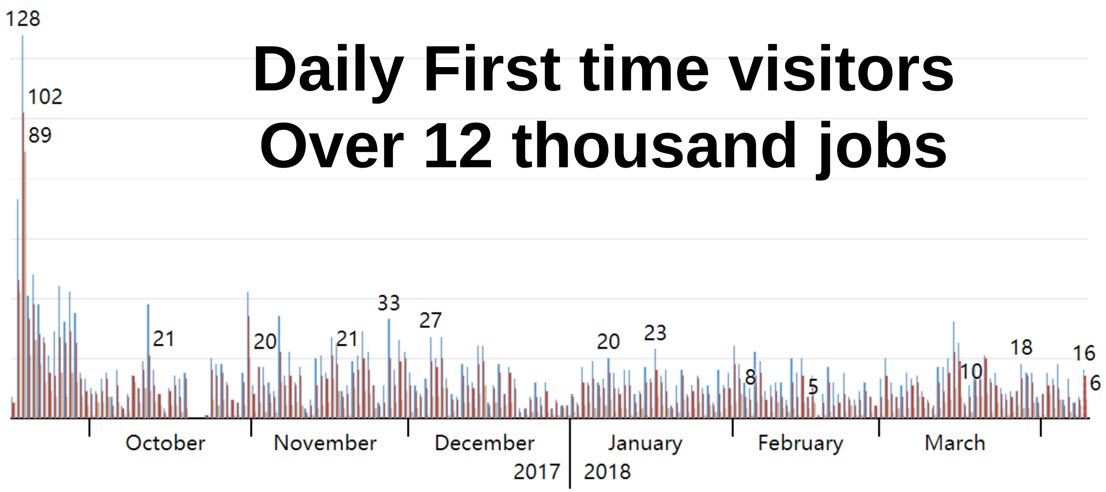
$$T_u = \sum_{i=1}^{n} w_{ui} T(\mathbf{x}_i), \quad w_{ui} = p_i d_{ui}^{-2} \Big/ \sum_{i=1}^{n} p_i d_{ui}^{-2}$$

- ❖ Cross Interpolation weight determination.
- ❖ Automatic weighting strategy.
- ❖ The relative weighting between GNSS and HRES-ECMWF are controlled by the precision and station distribution of the GNSS network.

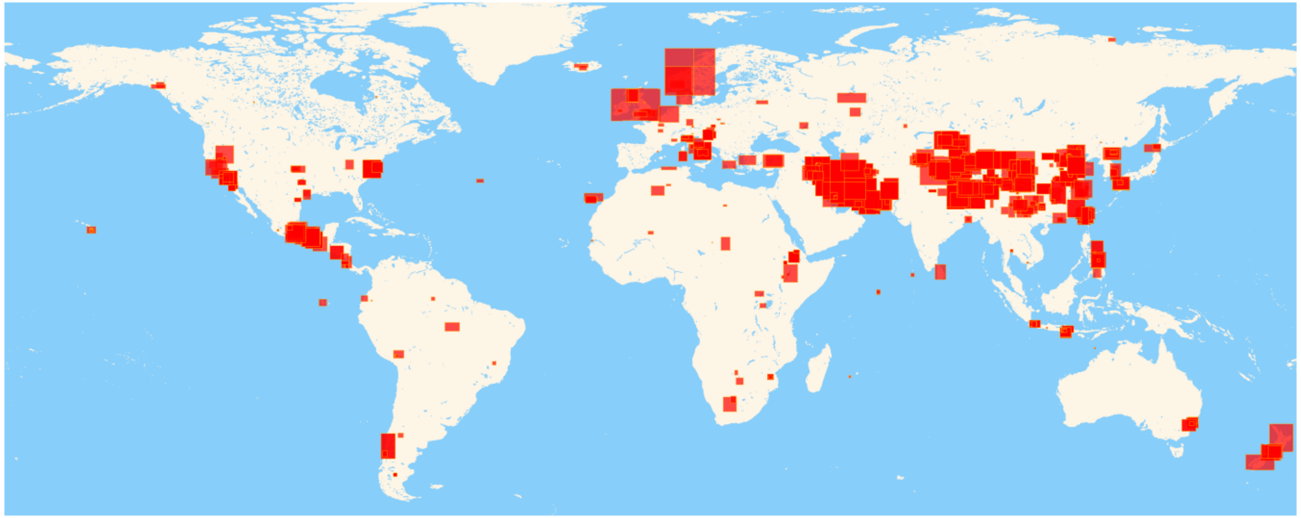
GACOS (Version 1.5)



Daily First time visitors
Over 12 thousand jobs

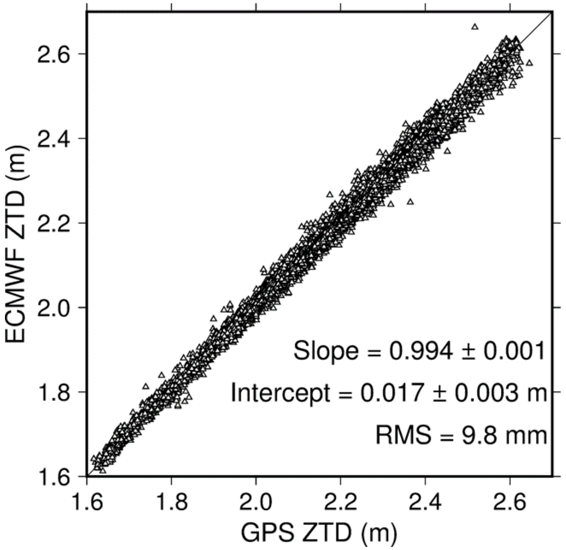


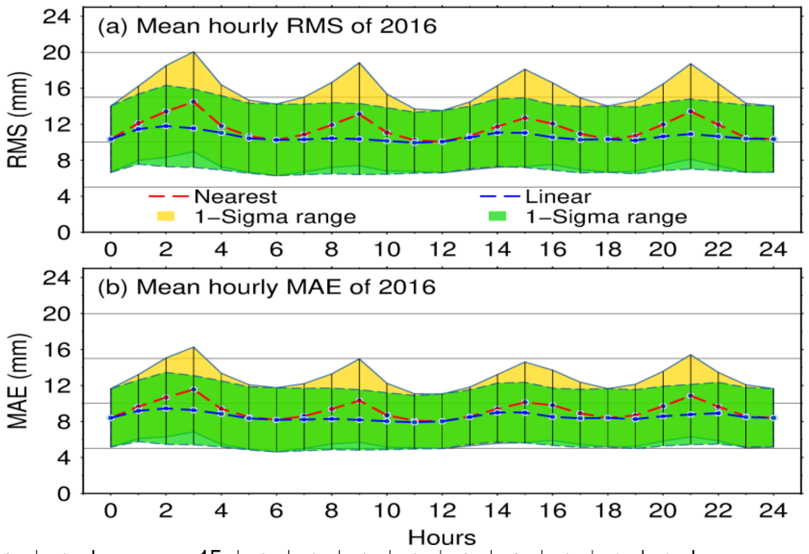
Popular Study Areas



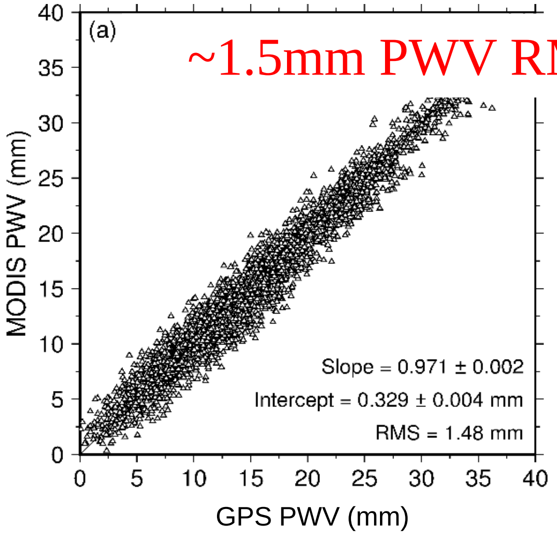
Model Evaluation - Data Quality

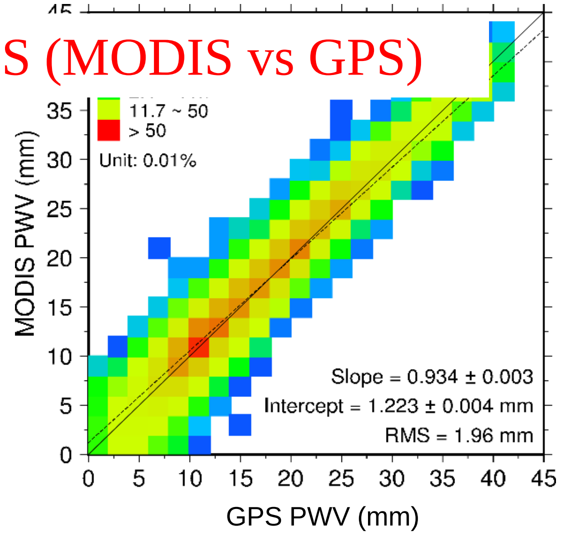
~1cm ZTD RMS (GPS vs HRES ECMWF)



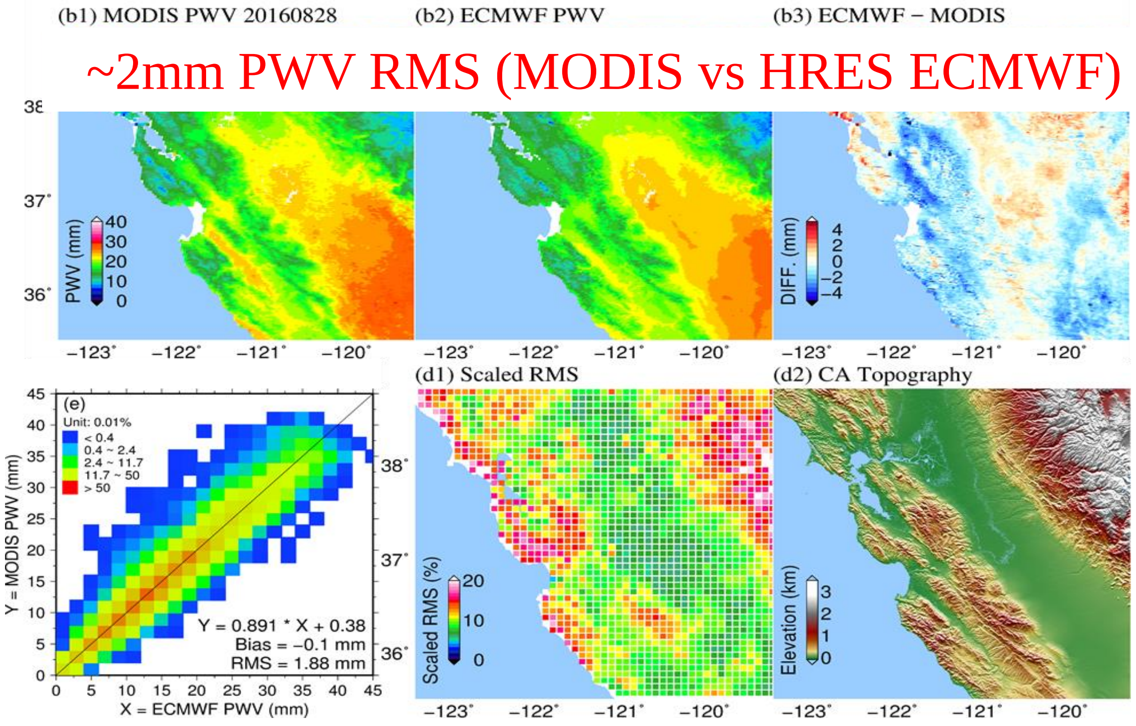


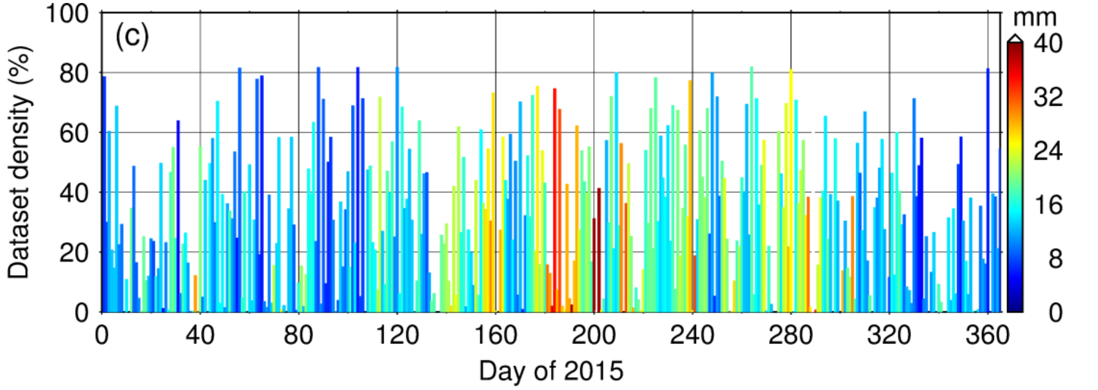
~1.5mm PWV RMS (MODIS vs GPS)



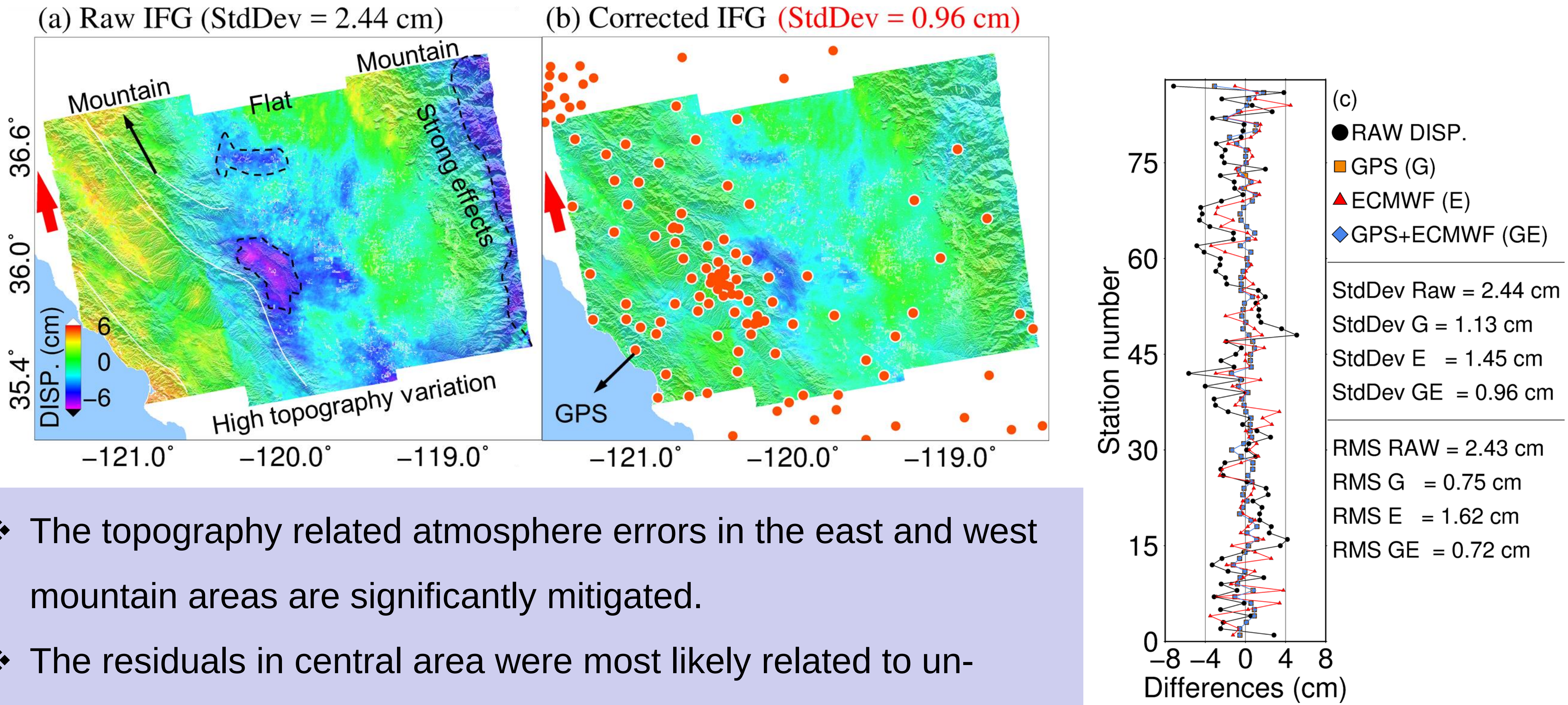


~2mm PWV RMS (MODIS vs HRES ECMWF)



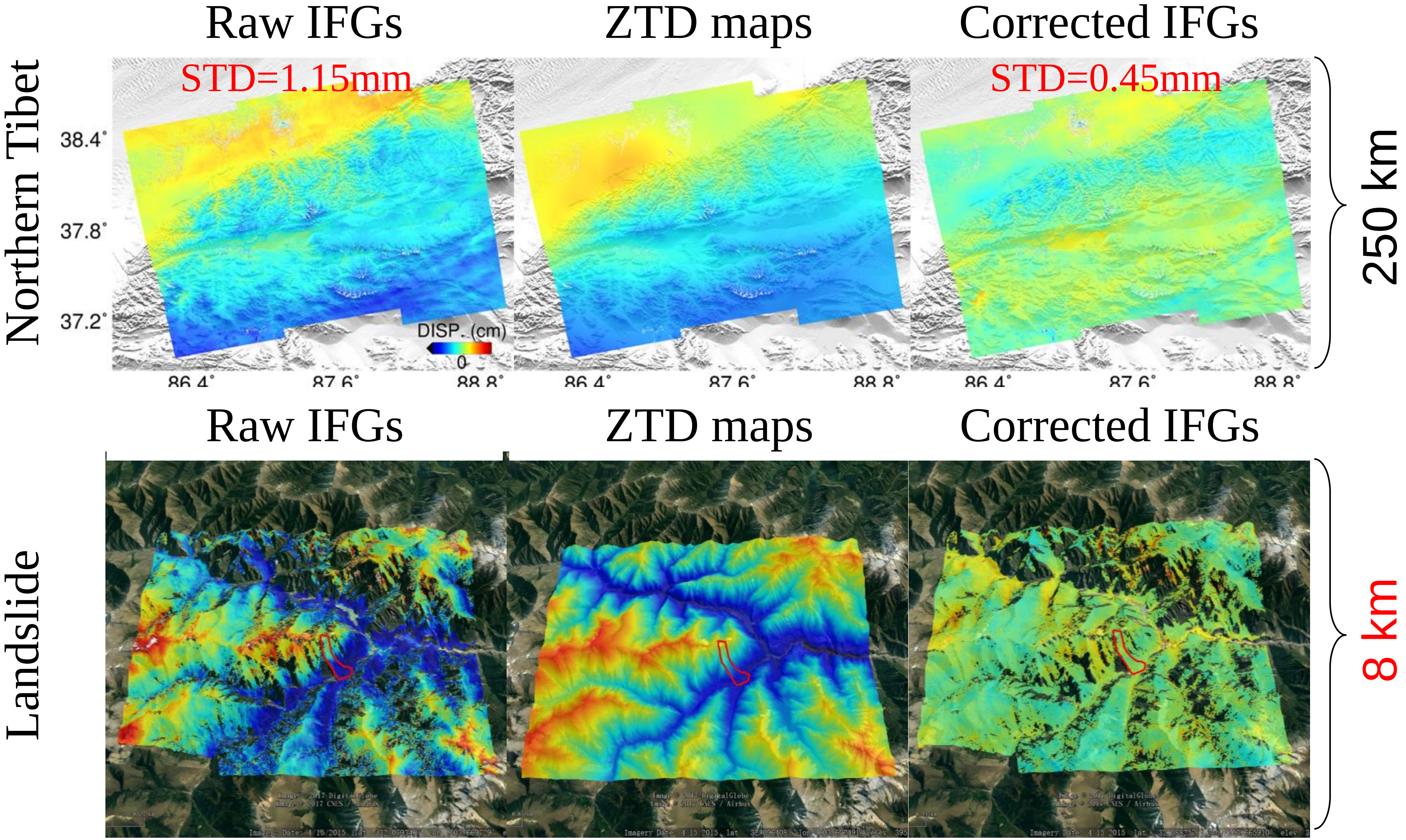


Model Evaluation - California



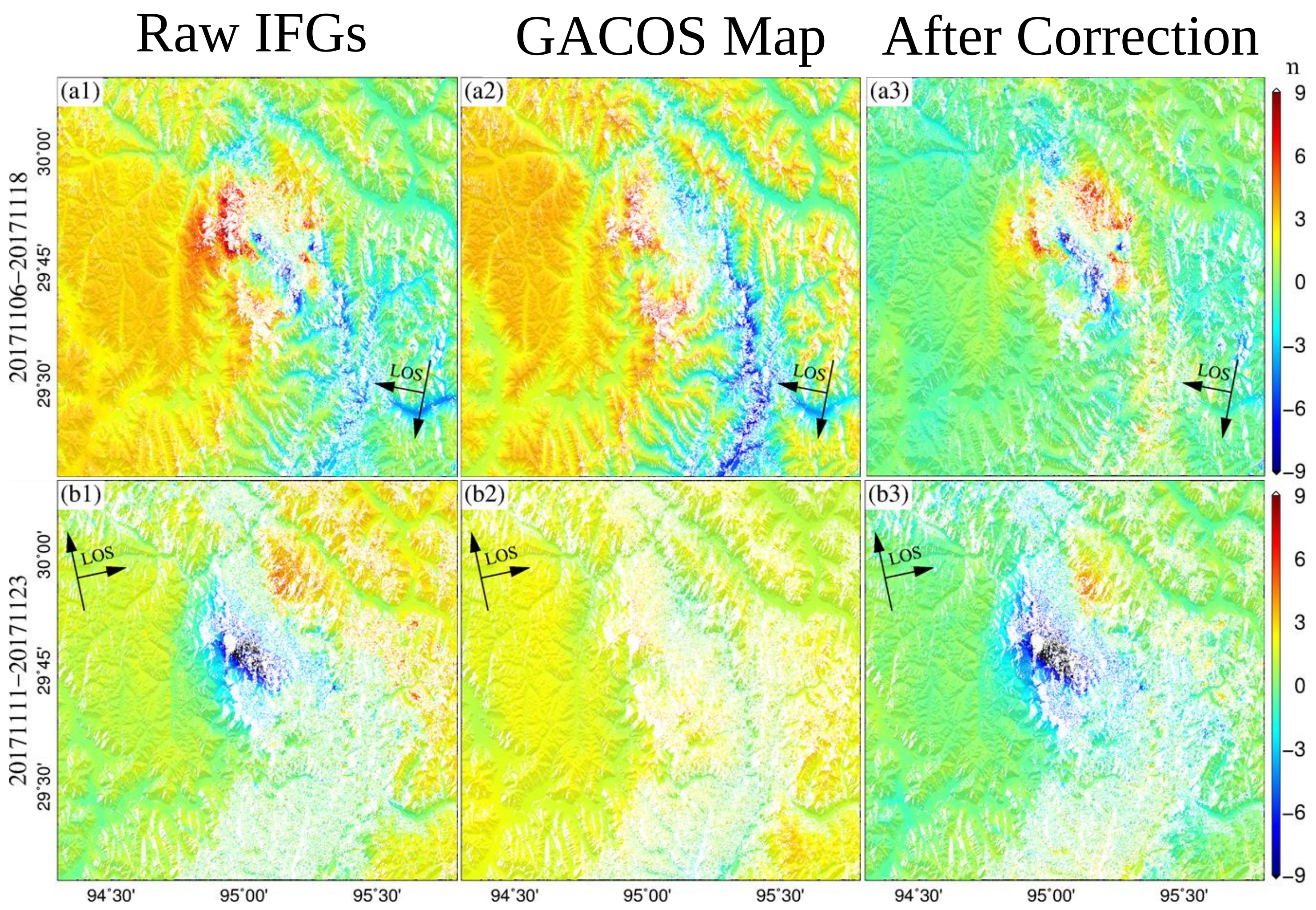
- The topography related atmosphere errors in the east and west mountain areas are significantly mitigated.
- The residuals in central area were most likely related to un-modelled tropospheric turbulence.

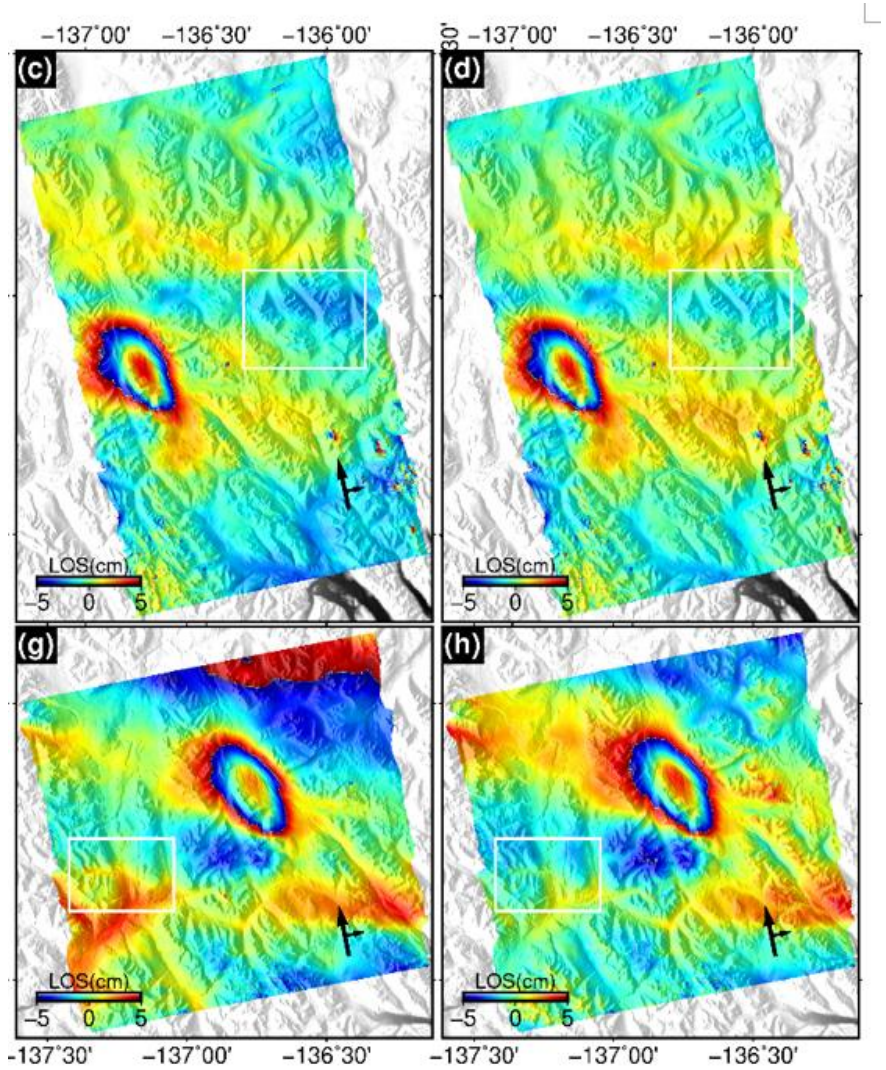
Model Evaluation - China



Model Evaluation - Co-Seismic

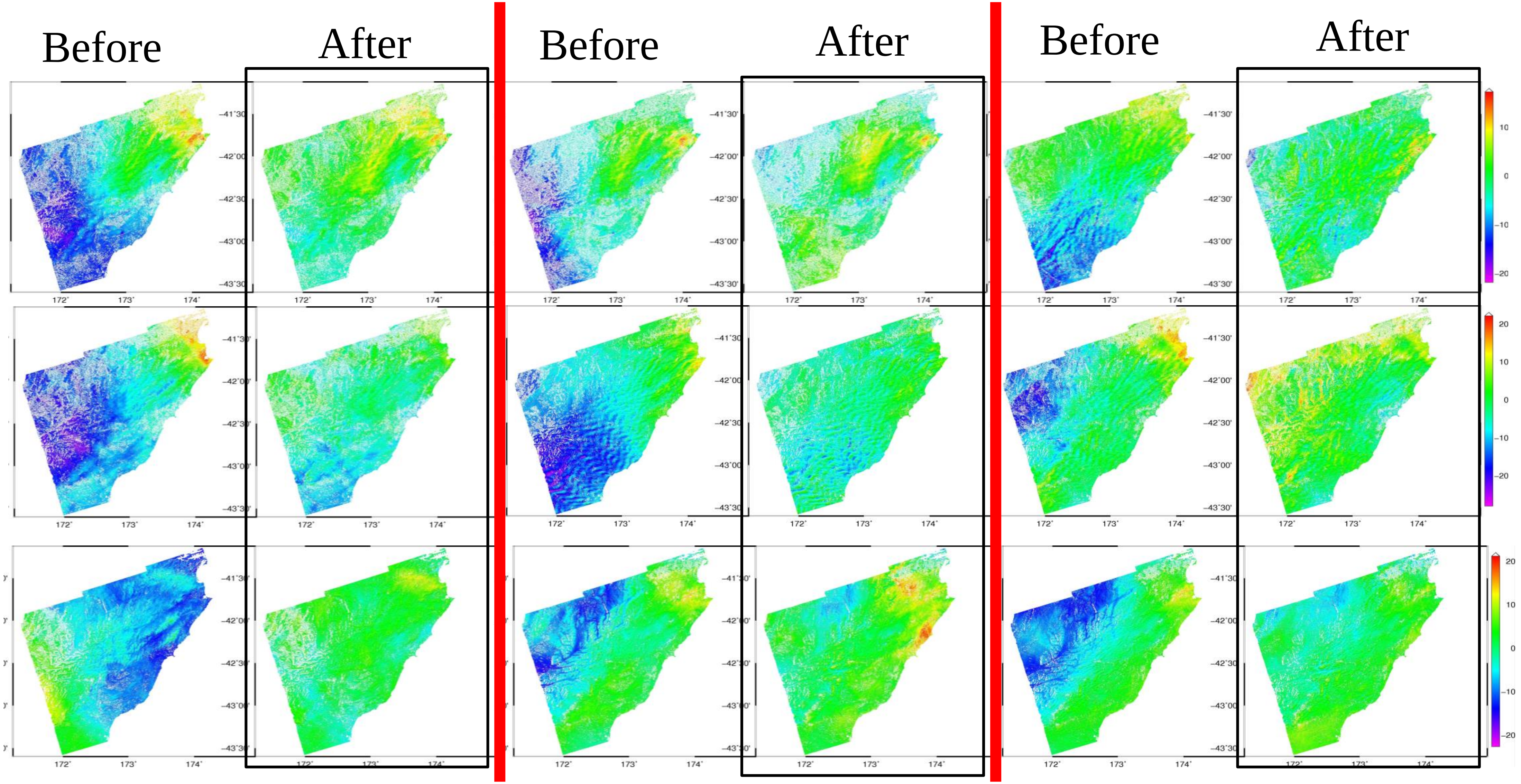
Identify Small Co-Seismic Signal





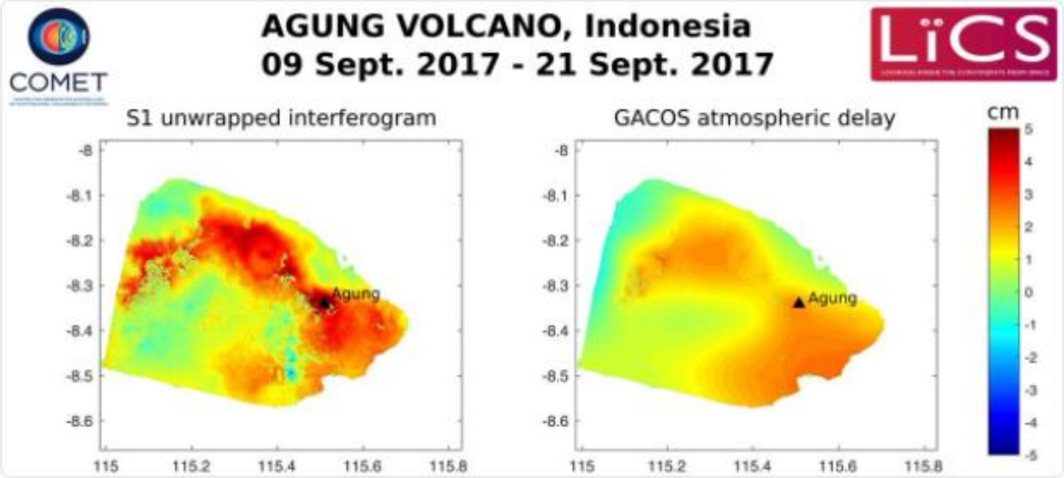
Feng, et al., 2018

Model Evaluation - Post-Seismic



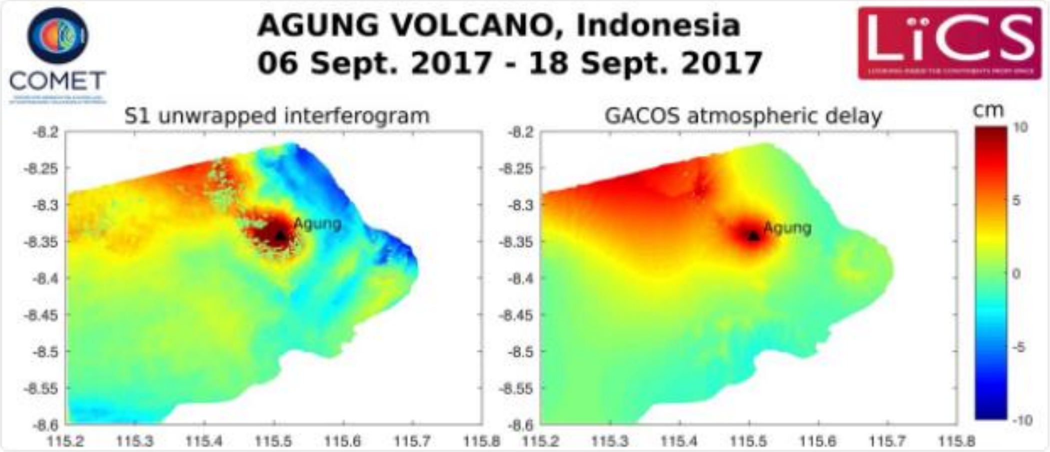
Model Evaluation - Volcano

Weather models show @Agung InSAR fringes are atmospheric NOT deformation. Thanks @falbino @GACOS_Newcastle @USGSVolcanoes @NERC_COMET.



11:08 AM - 26 Sep 2017

Agung example 2. Also mostly atmosphere NOT deformation. We're investigating the slight underestimate.@FabienAlbino @GACOS_Newcastle.

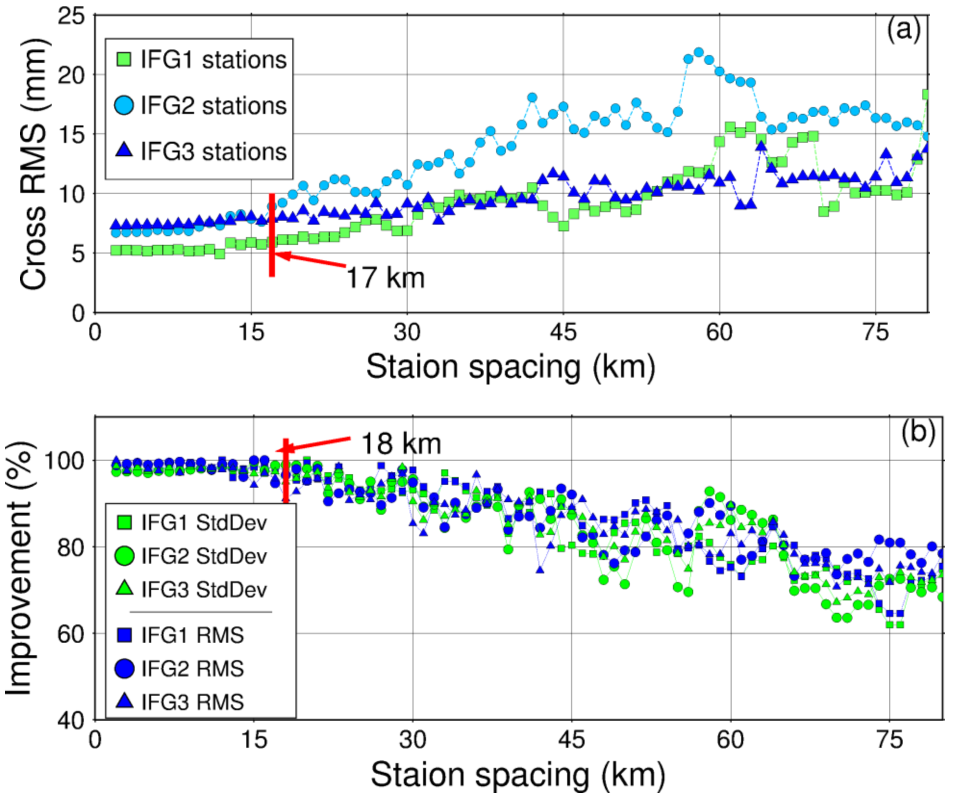


12:35 PM - 26 Sep 2017

Significant elevation dependent signal around volcano.

Performance Matrix (Indicators)

- Cross RMS
- Correlation coefficients
- ECMWF time difference
- Topography variation
- Extreme weather



(Yu et al., 2018, RSE)

❖ Model performance decreases as Cross RMS increases.

Conclusions

- Generic Atmospheric Correction Online Service for InSAR (GACOS) is free for the InSAR research community: (http://ceg-research.ncl.ac.uk/v2/gacos/).
- Our GPS/HRES-ECMWF integrated model can achieve over 50% improvement with RMS < 1 cm for InSAR displacements over a 250x250 km region, which can be applied globally and at all times, in near real time.
- Indicators such as correlation analysis, cross test and time differences have been developed to assess model performances, which can inform users when and where atmospheric correction is feasible.
- For a interferogram extending 250 by 250 km =>

EGU2018-14158, 14:00 Fri, L6

Total delays ⇨ Spatio-temporally differenced ⇨ After GACOS ⇨ Time series constrain/filtering

~2 meter | 5 - 20 cm | ~1 cm | mm level