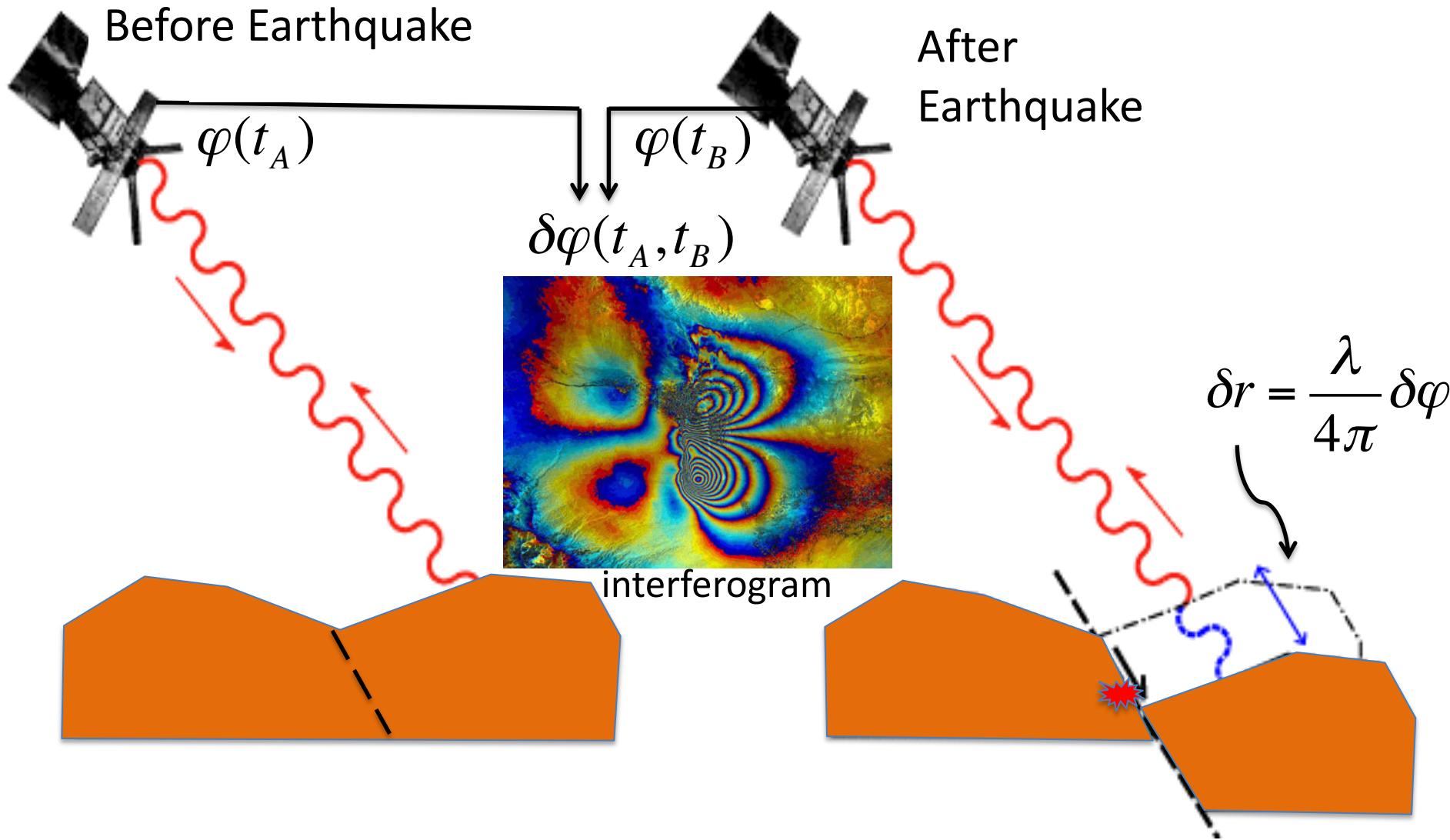

Tropospheric delay in InSAR data

Heresh Fattahi
Updated by **Eric Fielding**

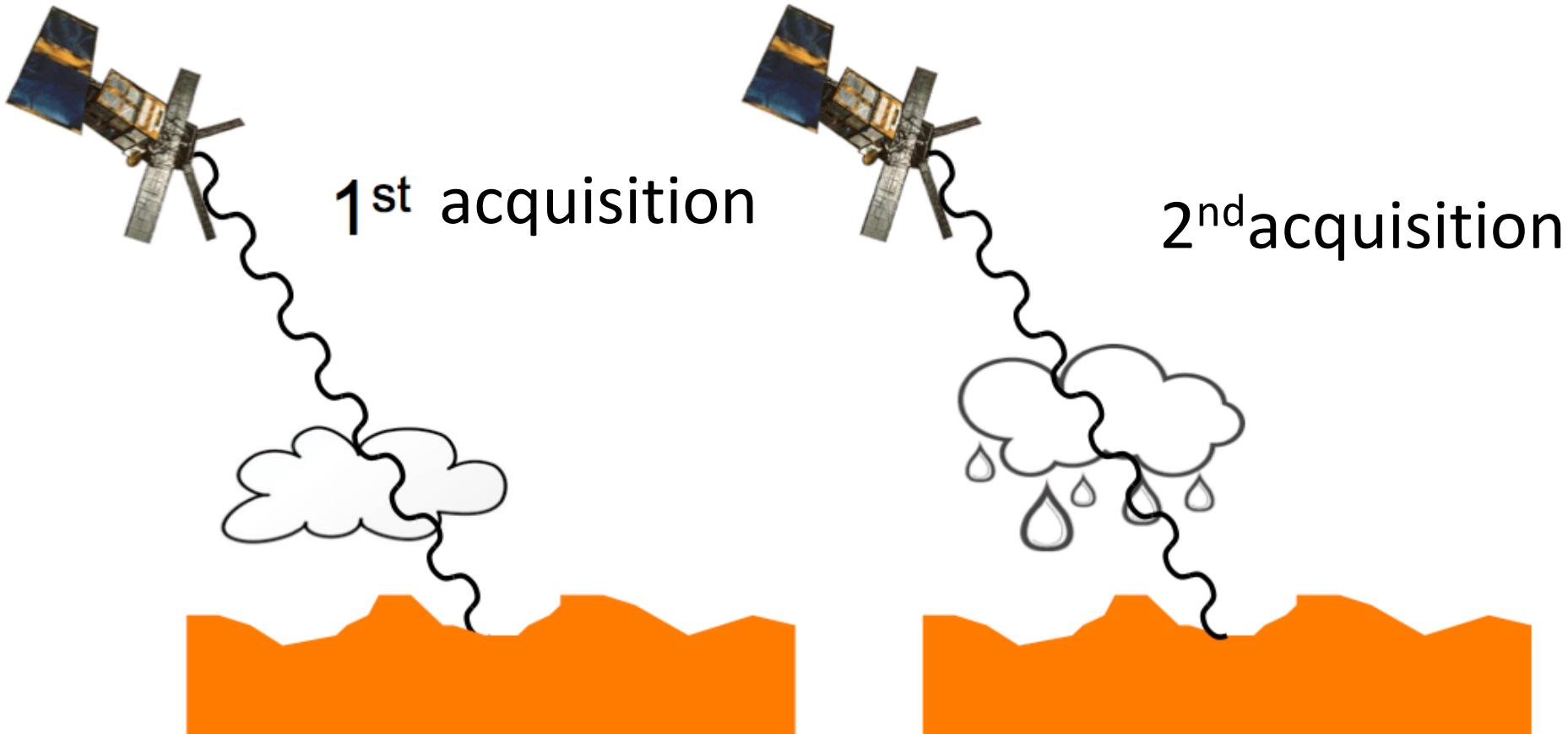
(Jet Propulsion Laboratory, Caltech)
Aug 2023

InSAR (Interferometric Synthetic Aperture Radar)



$$\delta\varphi = \delta\varphi_{dis} + \delta\varphi_{atm} + \delta\varphi_{geometry} + \delta\varphi_{decor}$$

Atmospheric delay



$$d = vt \quad v = \frac{c}{n}$$

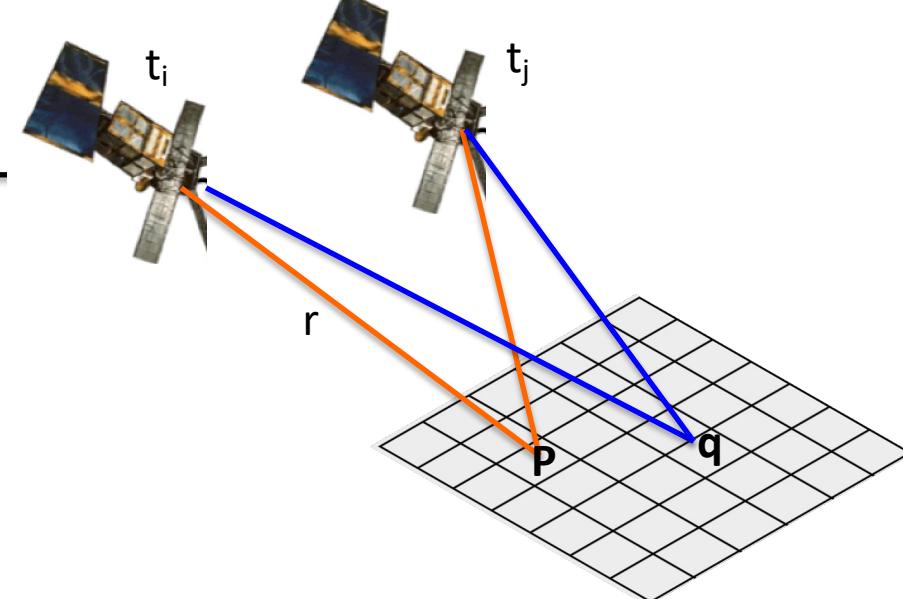
Index of refraction

$$\left\{ \begin{array}{ll} n = 1 & \text{vacuum} \\ n > 1 & \text{atmosphere} \end{array} \right.$$

[Modified from Z. Li]

Atmospheric delay

Atmospheric delay for double difference InSAR measurements between two pixels (p and q) and between acquisition times t_i and t_j :



$$\delta L_{pq}^{t_i, t_j} = \left[\int_0^{r_p} N(r, t_j) dr - \int_0^{r_p} N(r, t_i) dr \right] - \left[\int_0^{r_q} N(r, t_j) dr - \int_0^{r_q} N(r, t_i) dr \right]$$

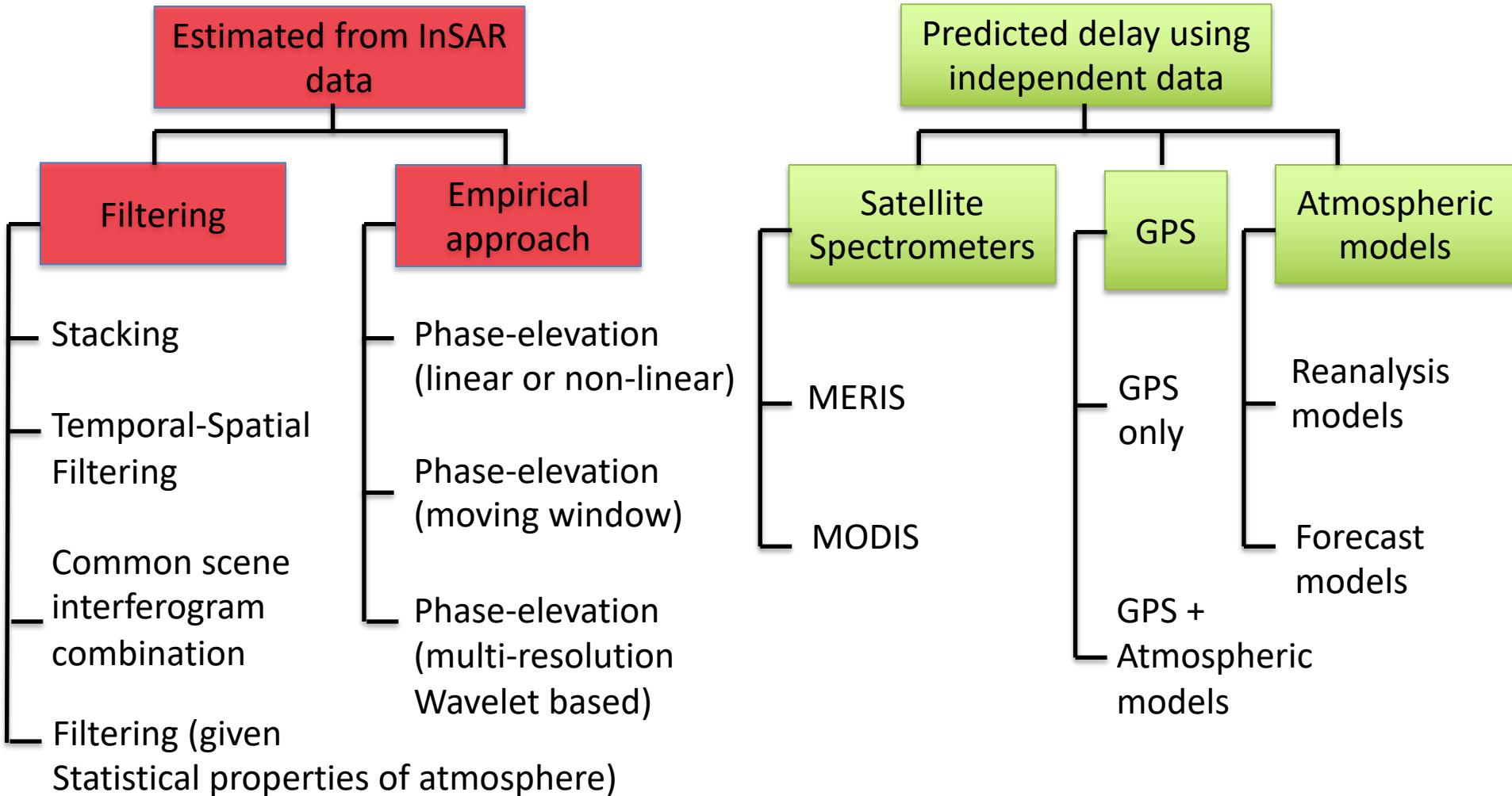
With r the range from the radar to the target and N the refractivity

$$N = K_1 \frac{P_d}{T} + K_2 \frac{e}{T} + K_3 \frac{e}{T^2} + K_4 W_{cl} + K_5 \frac{ne}{f^2}$$

Troposphere Cloud Ionosphere

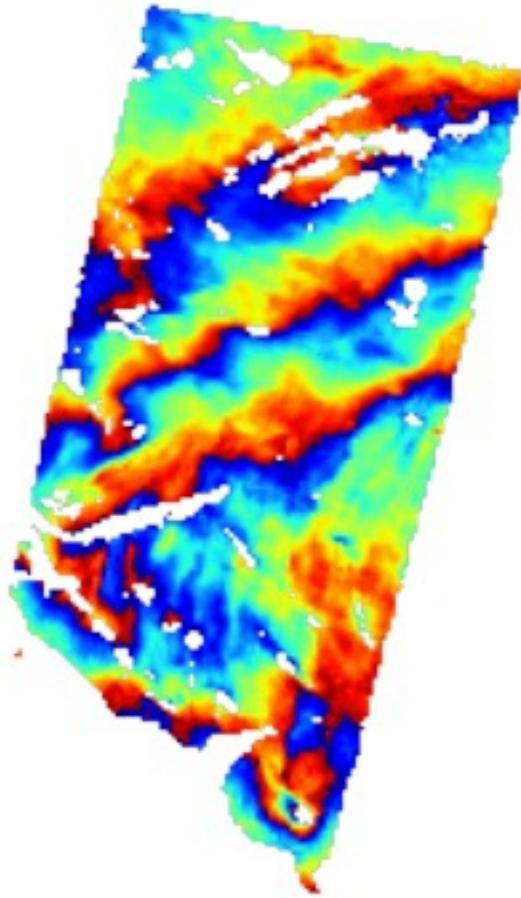
P_d : dry air partial pressure, e : water vapor partial pressure, T : atmospheric temperature,
 W_{cl} : liquid water content [kg/m³], ne : electron number density/m³, f : radar frequency

Methods to correct the Tropospheric delay in InSAR data

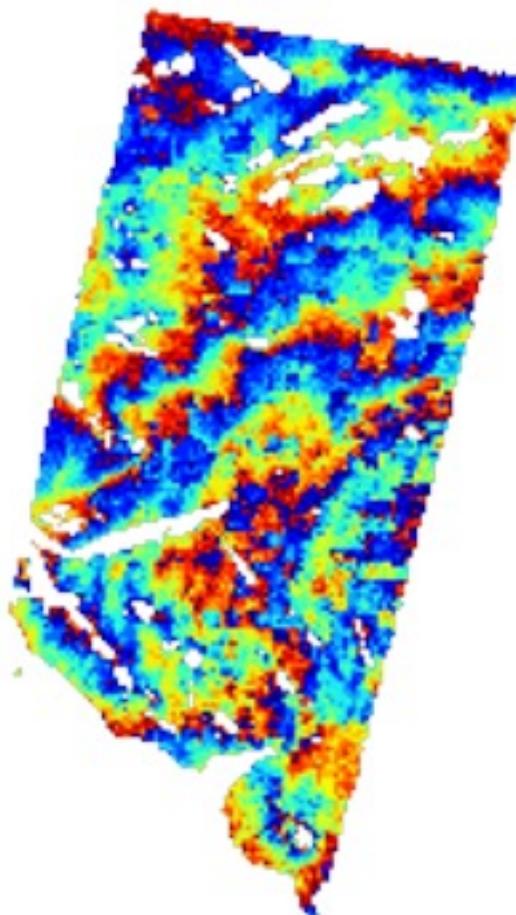


Correction using MERIS

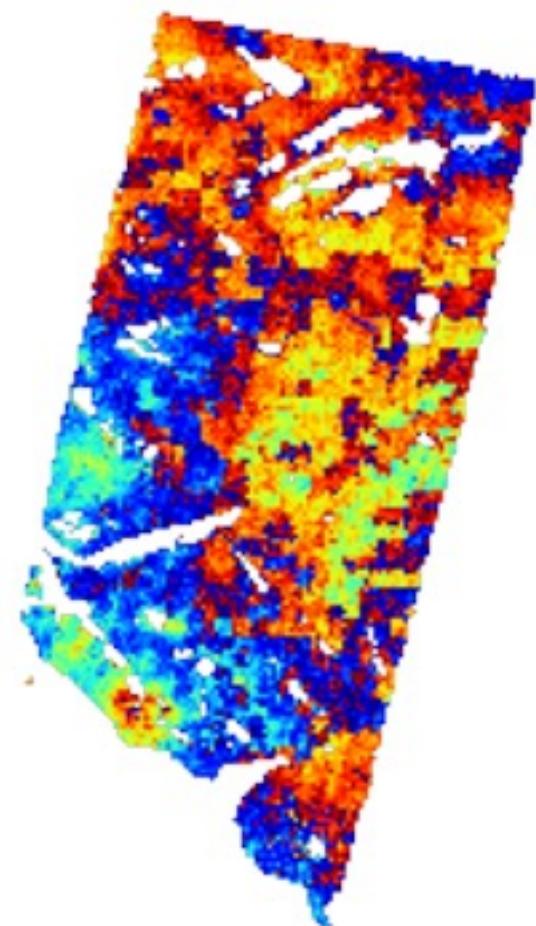
InSAR



MERIS (wet delay)



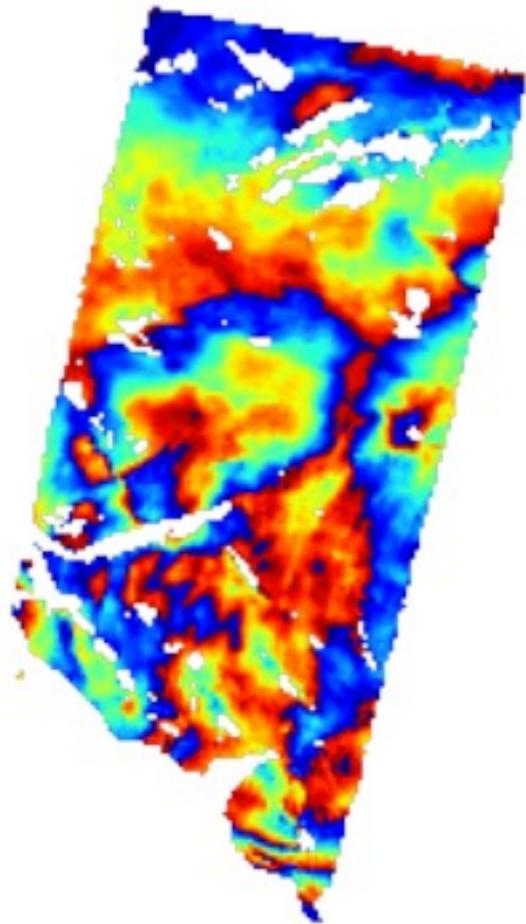
corrected InSAR



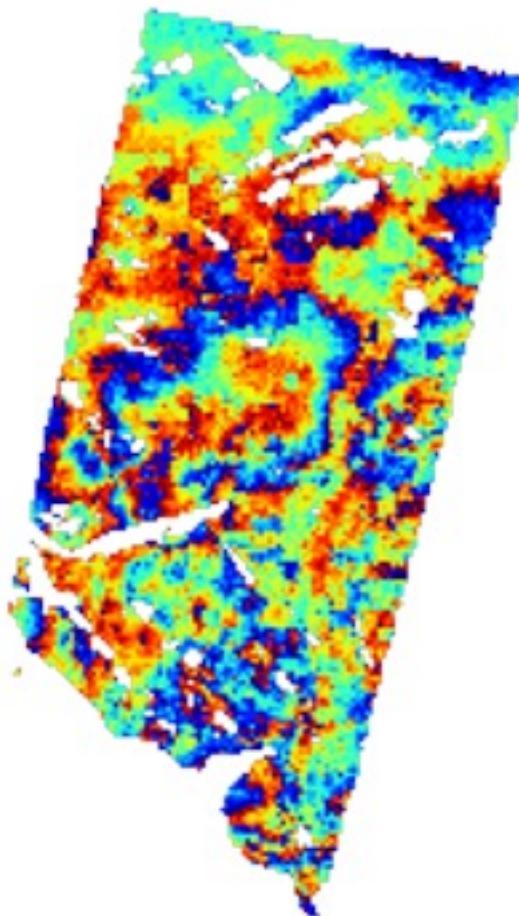
The interferogram is formed from ASAR data onboard Envisat which also was carrying a spectrometer called MERIS

Correction using MERIS

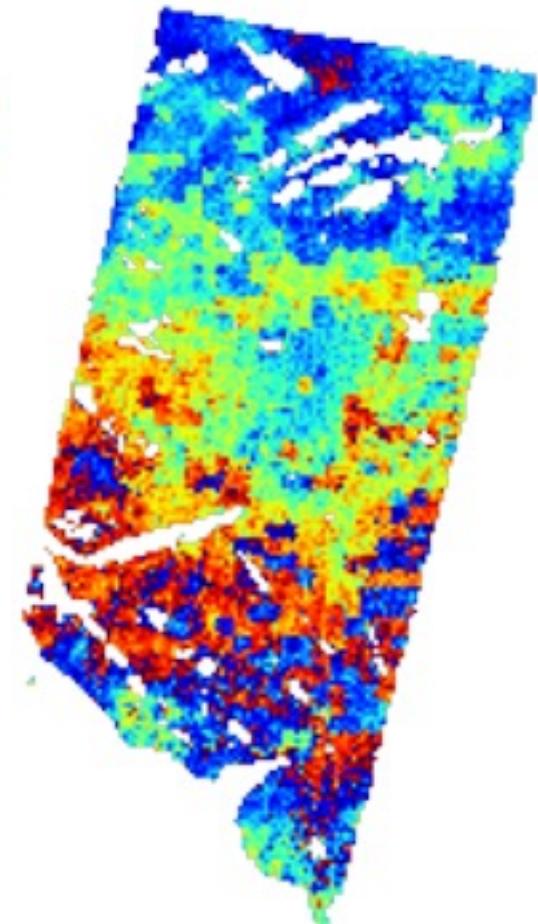
InSAR



MERIS (wet delay)



corrected InSAR

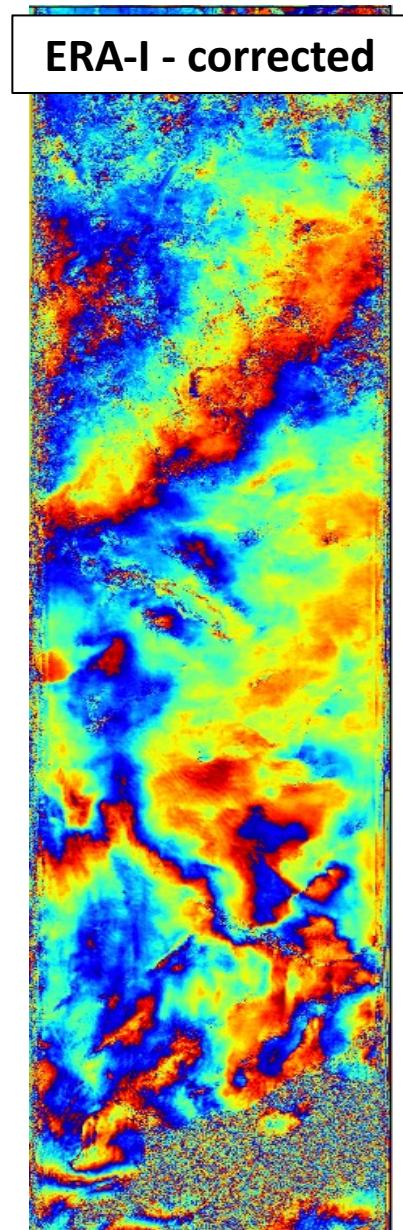
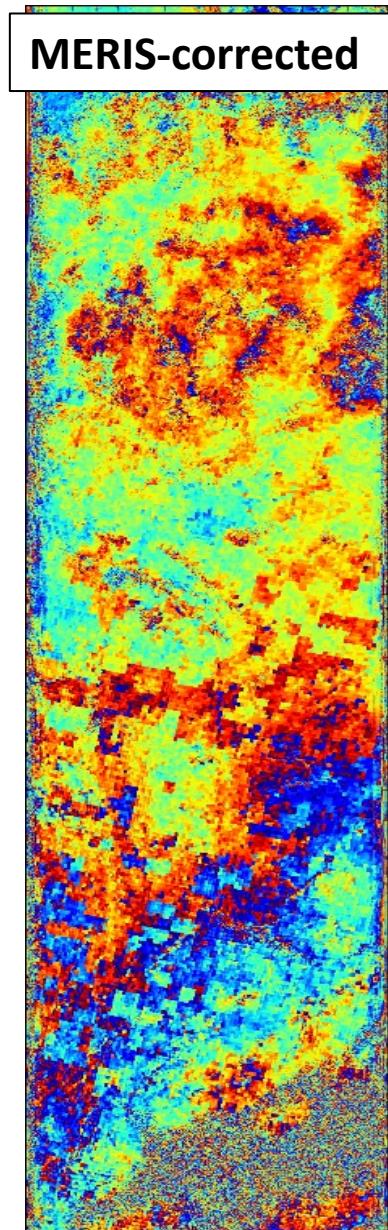
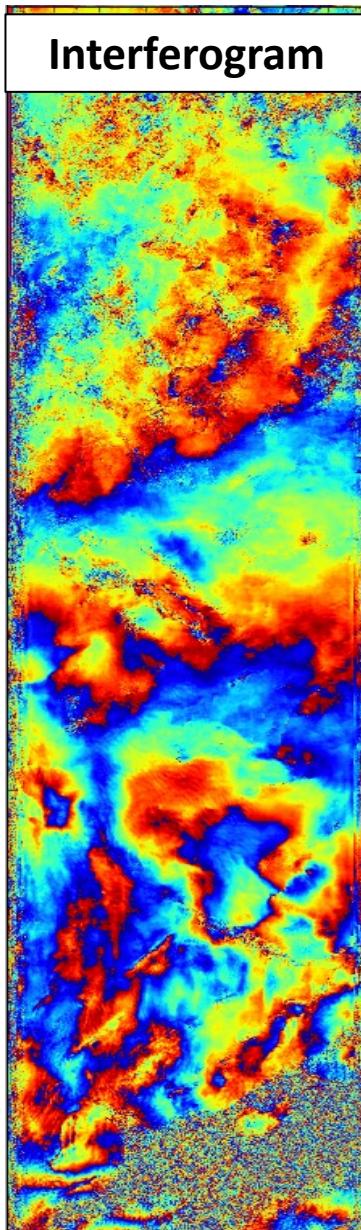


The interferogram is formed from ASAR data onboard Envisat satellite which also was carrying a spectrometer called MERIS

Troposphere correction with MERIS and ERA-Interim

MERIS more accurate than atmospheric models.

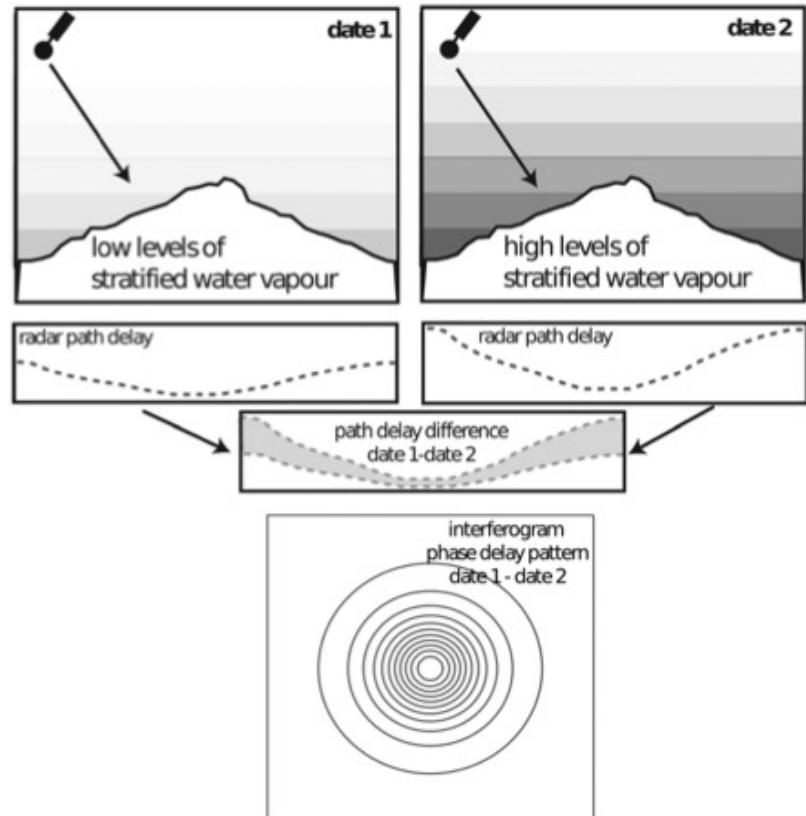
Limitations:
Requires daylight, limited by cloud and not available at SAR acquisition time except for Envisat data.



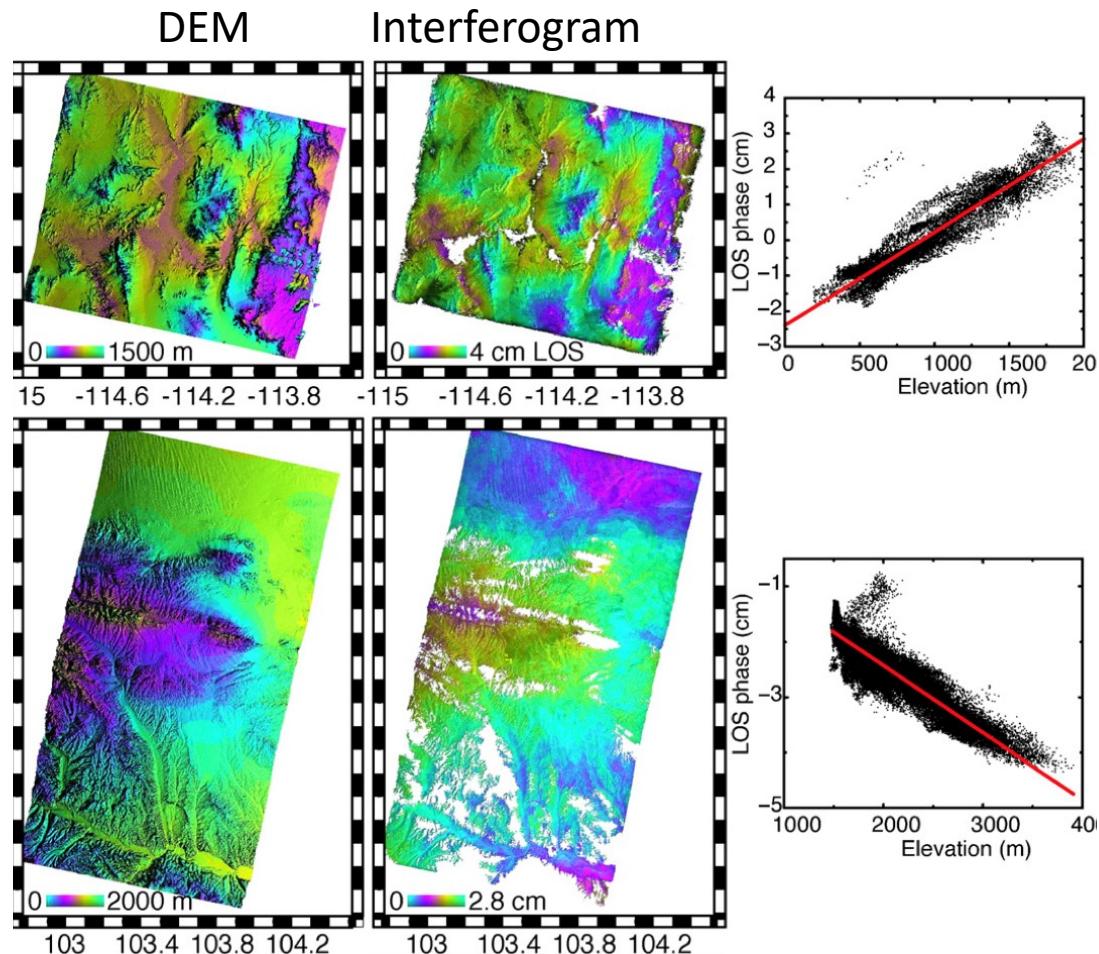
Troposphere correction with Empirical approach

Caused by changes in tropospheric layering – correlates with topography (wet & dry)

Phase-elevation correlation can be estimated



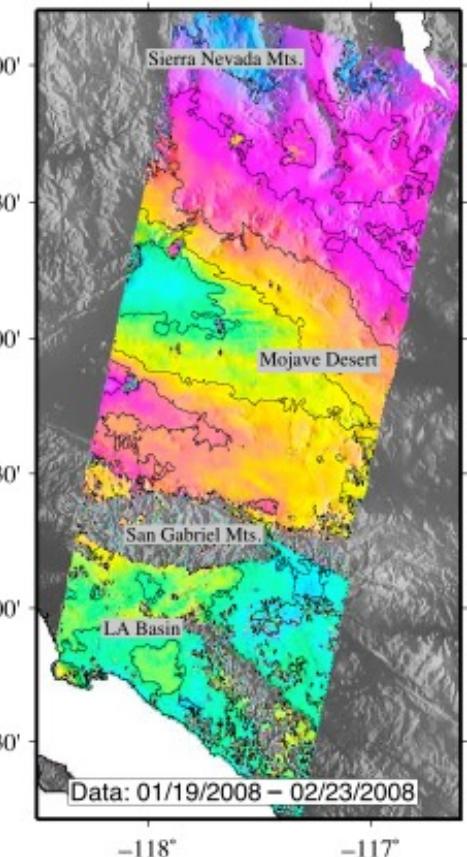
Differences in tropospheric layering cause delays correlating with topography.



Empirical estimation across a portion or the whole scene

Tropospheric delay correction with Atmospheric model (ERA-I)

Interferogram



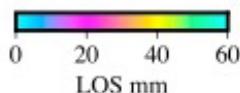
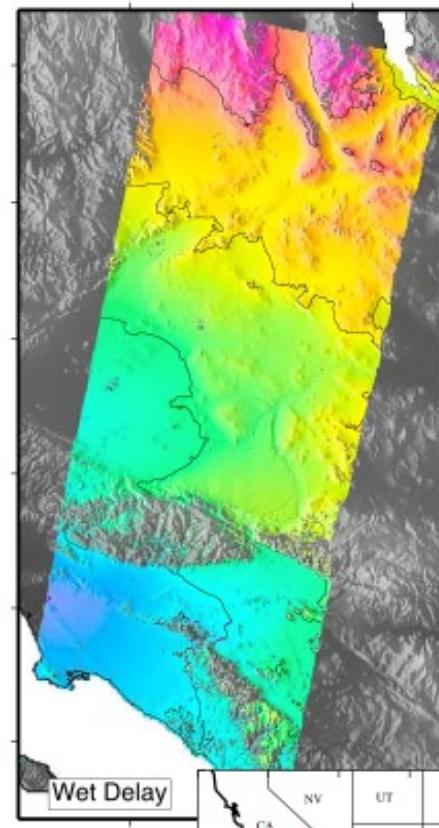
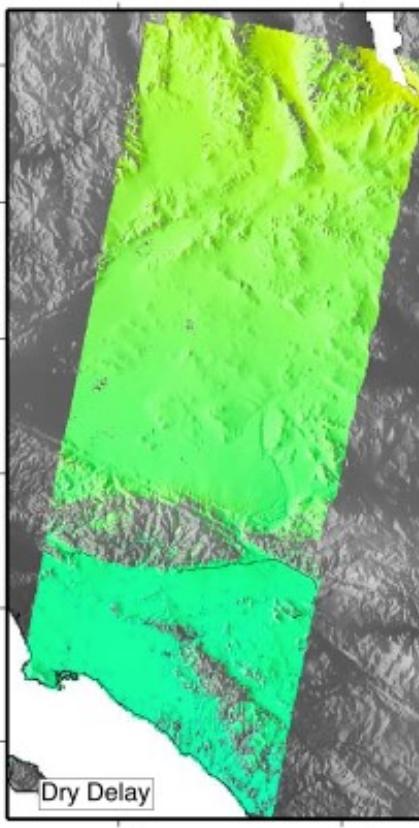
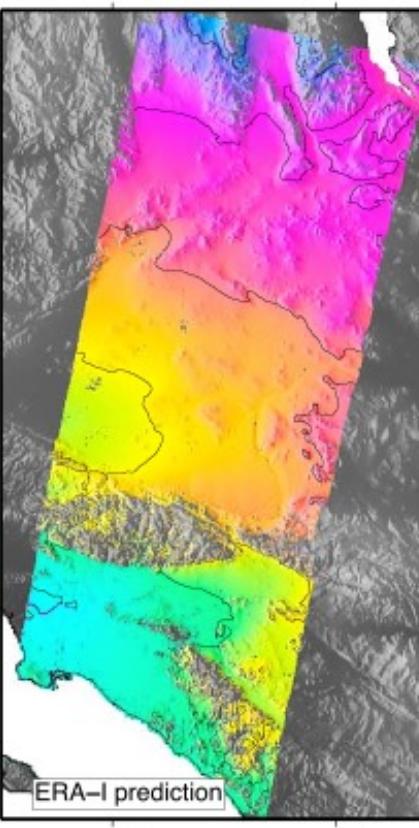
Δd_{tropo}

=

Δd_{dry}

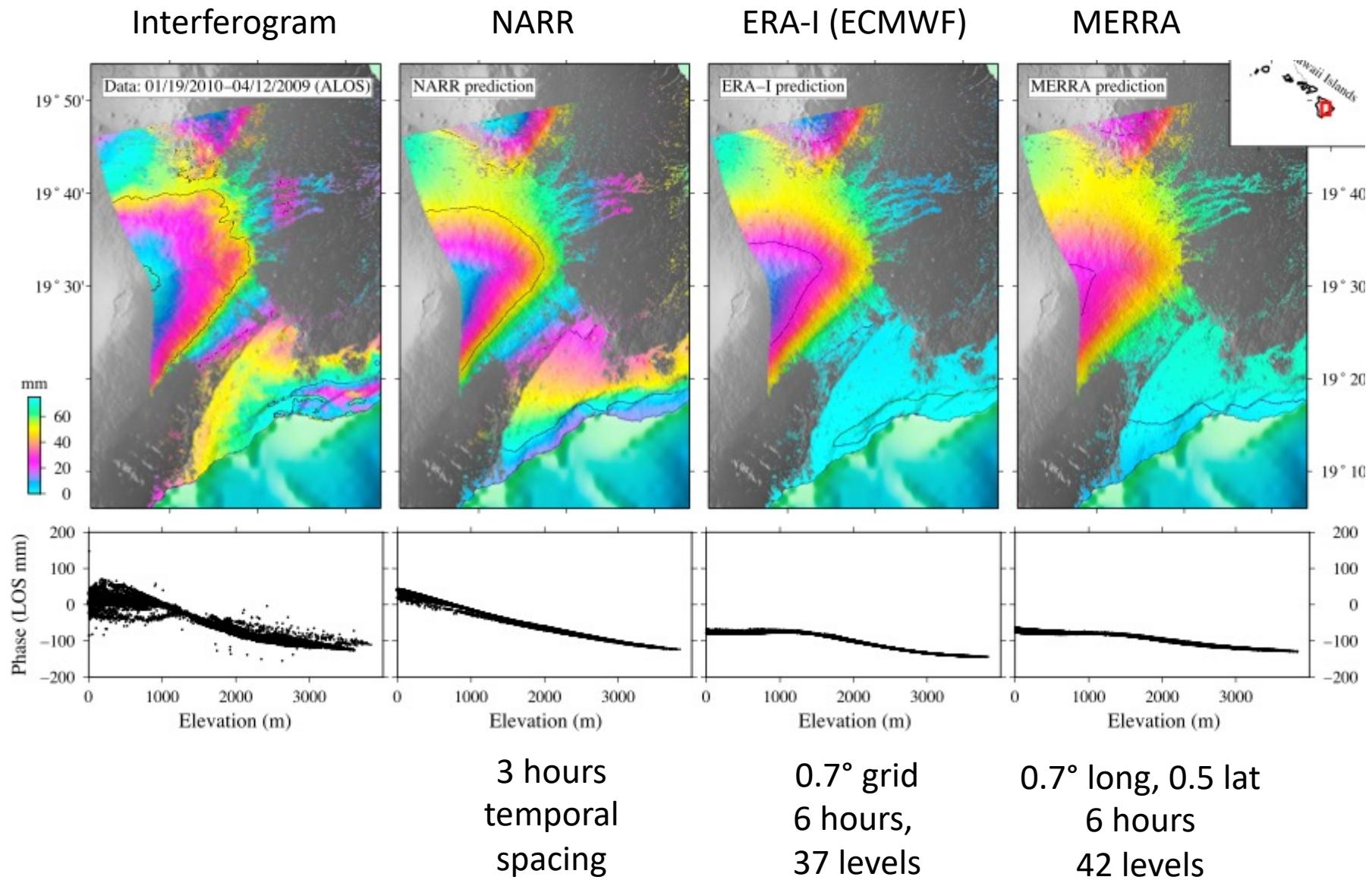
+

Δd_{wet}

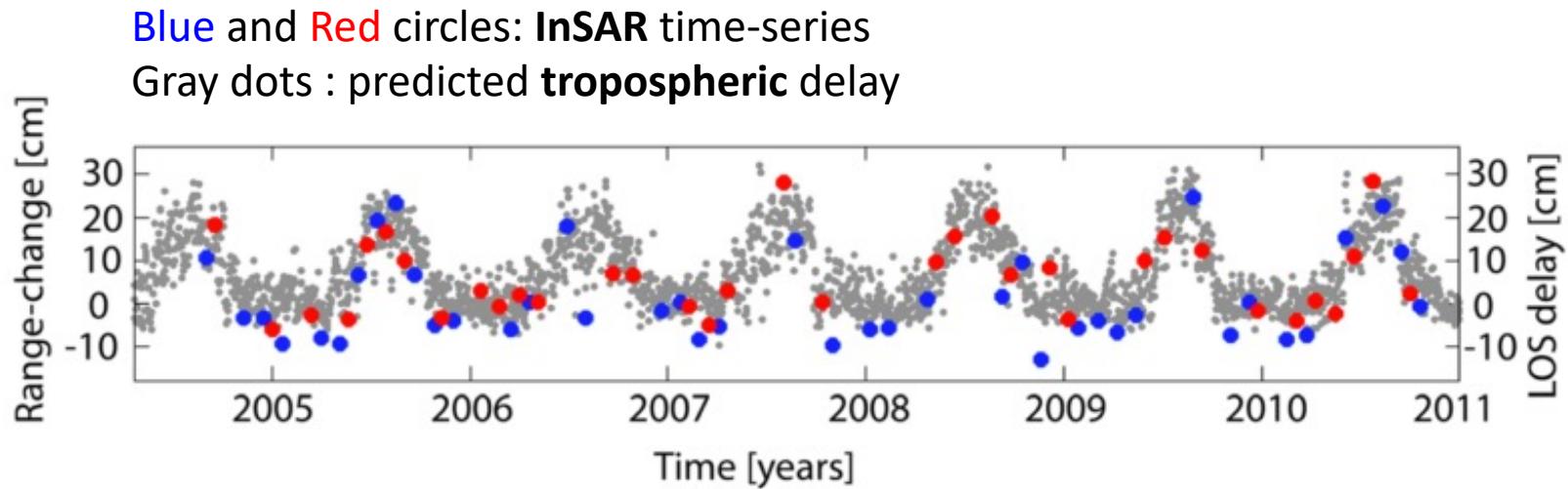


$\Delta d_{dry} \ll \Delta d_{wet}$ as expected

Troposphere correction with Atmospheric model (different models)



Tropospheric delay has seasonal variations

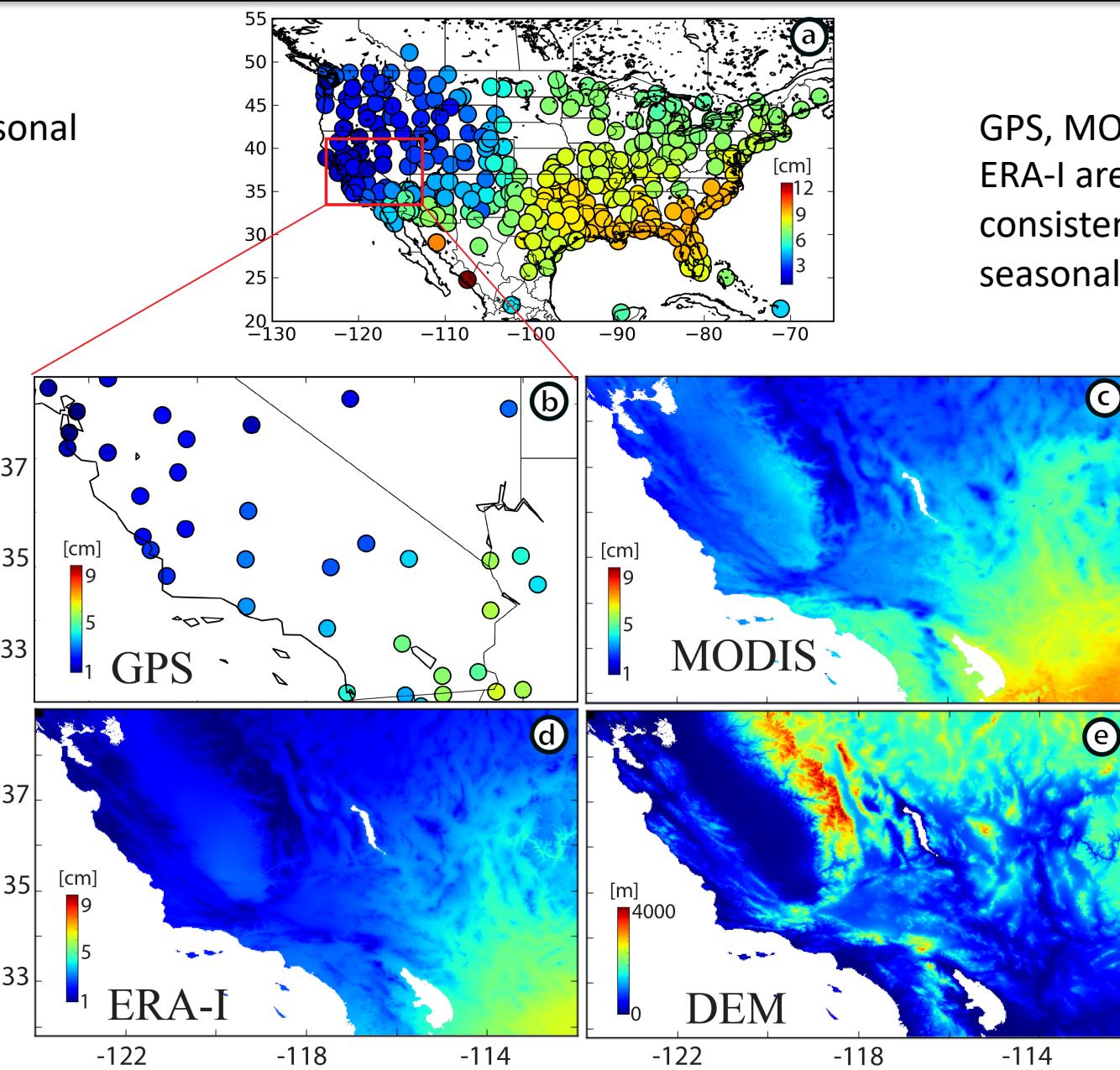


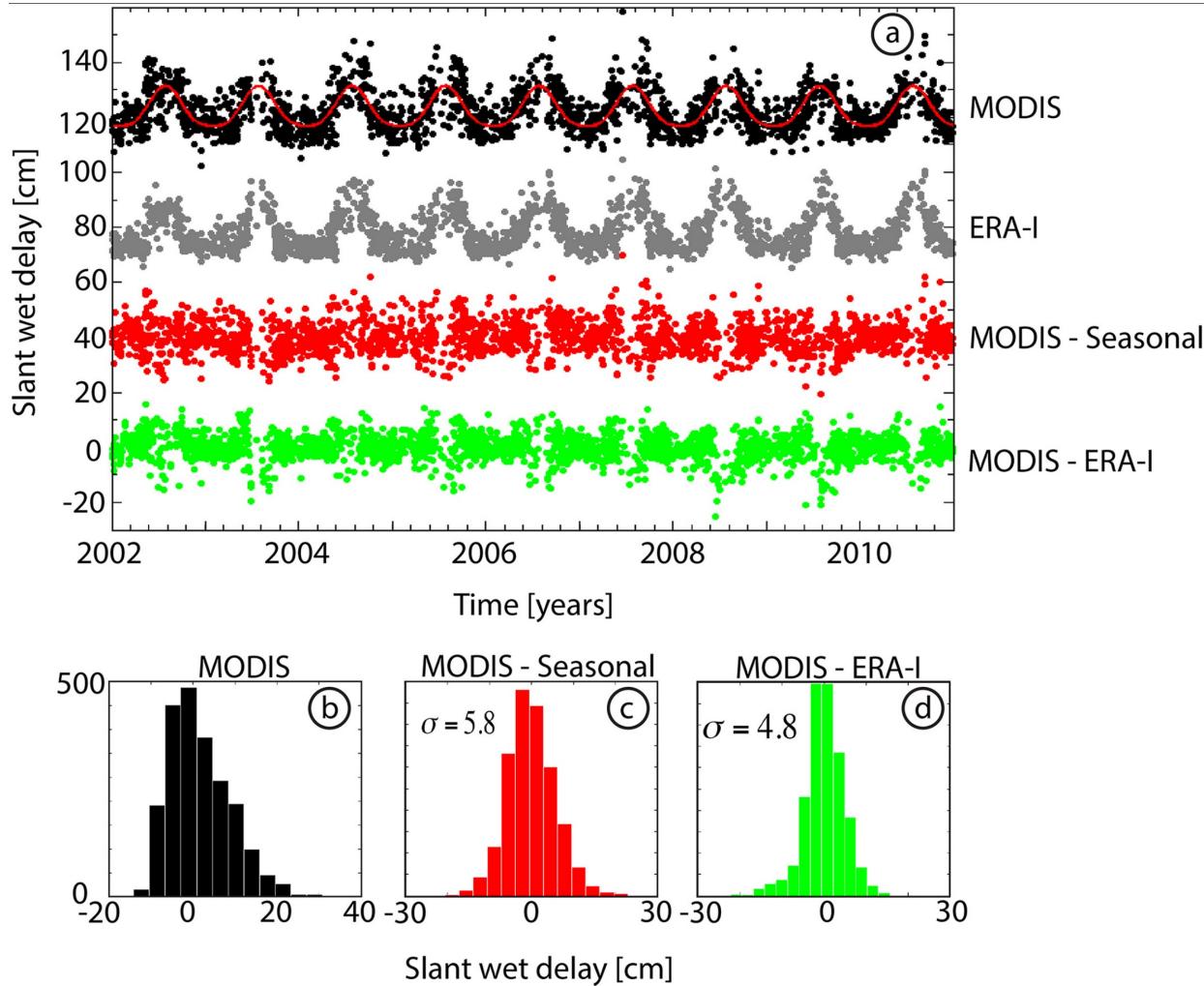
The atmospheric models seem to successfully predict the seasonal delay while the improvement in the stochastic component may be minimal.

Amplitude of the Seasonal delay across US

Smaller seasonal variation in western US

GPS, MODIS and ERA-I are consistent for the seasonal delay





Tropospheric delay correction with atmospheric models accounts for systematic seasonal delay and reduces the standard deviation of the stochastic components by 10-20%.

References:

Fattah & Amelung, InSAR bias and uncertainty due to the systematic and stochastic tropospheric delay, JGR-Solid Earth, 2015.

<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015JB012419>

Jolivet, R., P. S. Agram, N. Y. Lin, M. Simons, M. Doin, G. Peltzer, and Z. Li (2014), Improving InSAR geodesy using Global Atmospheric Models, *J. Geophys. Res. Solid Earth*, 119, 2324– 2341, doi:[10.1002/2013JB010588](https://doi.org/10.1002/2013JB010588).

Tropospheric correction software

- GACOS server can generate tropospheric corrections—see Jupyter notebook for code to post-process the GACOS products
- PyAPS can download and calculate corrections from ECMWF Re-Analysis v5 (ERA5)—see MintPy lectures that can apply PyAPS corrections
- RAiDER under development
<https://github.com/dbekaert/RAiDER>