Mitigating Atmospheric Errors in SAR Interferometry Data

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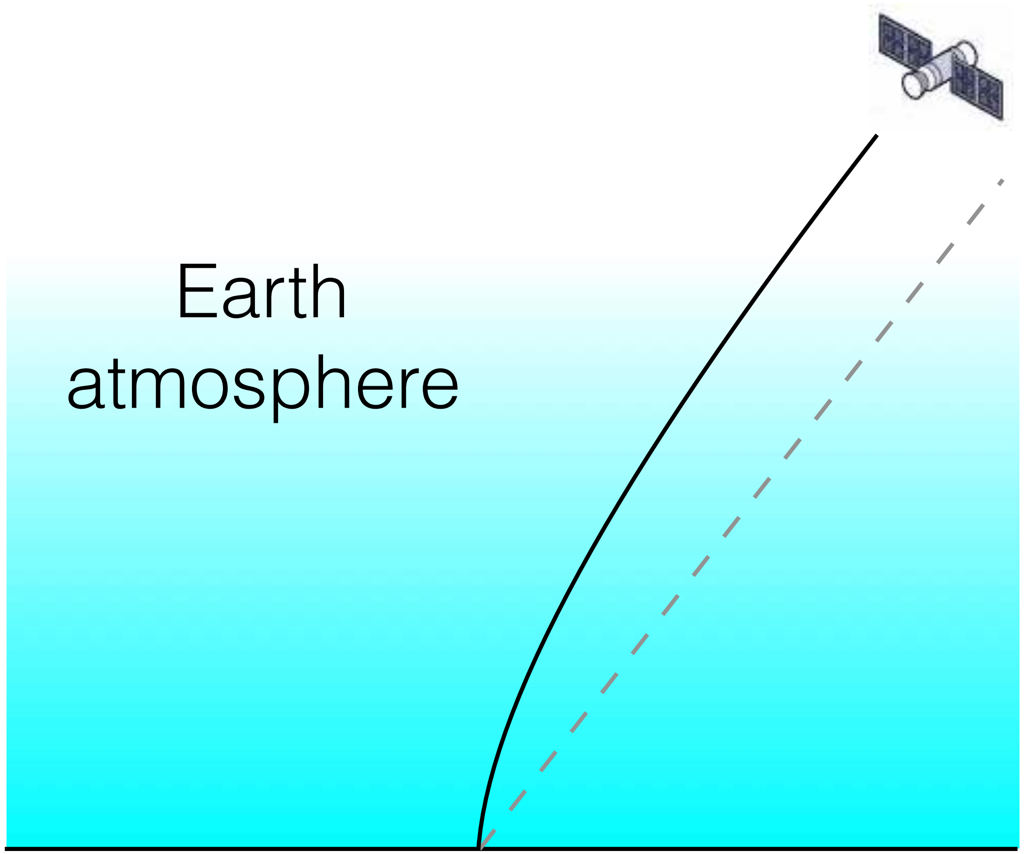
Image: http://www.ualberta.ca/~bsuther/imagelinks/earth.html

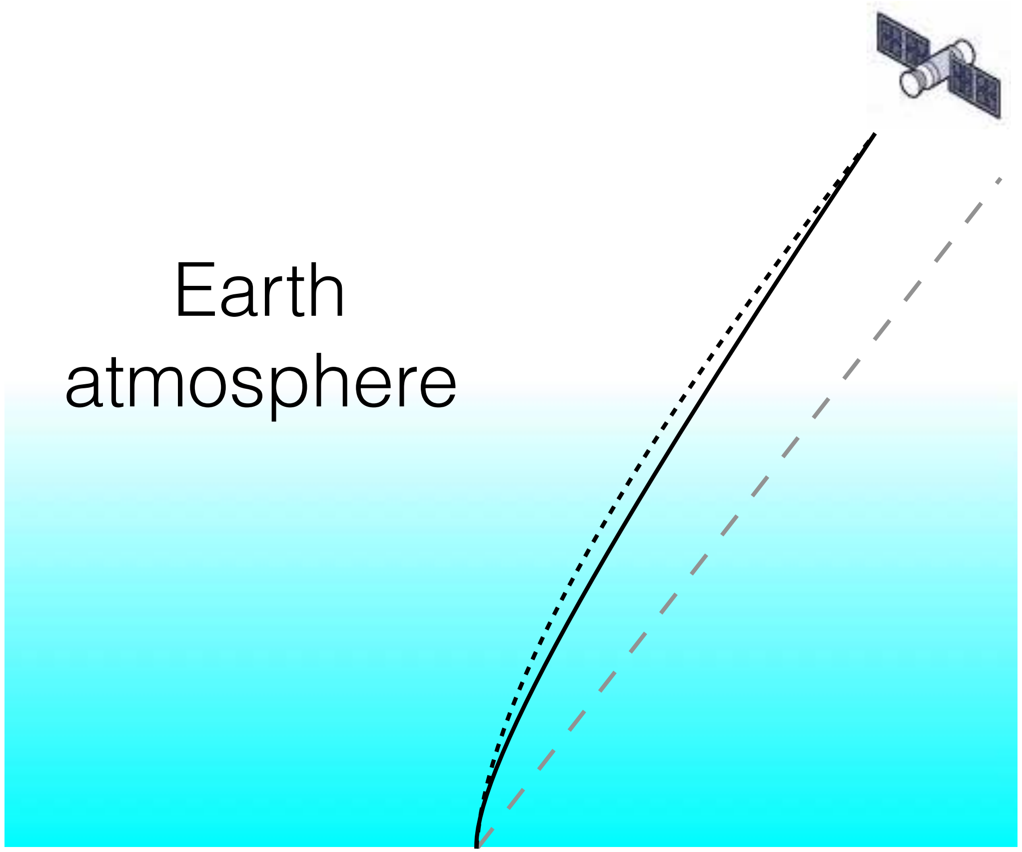
Refraction of radar wave path in atmosphere



Wave path is bent and propagation velocity is reduced as a function of refractive index

$$Path\ length = \int_{z}^{z_{top}} N ds$$

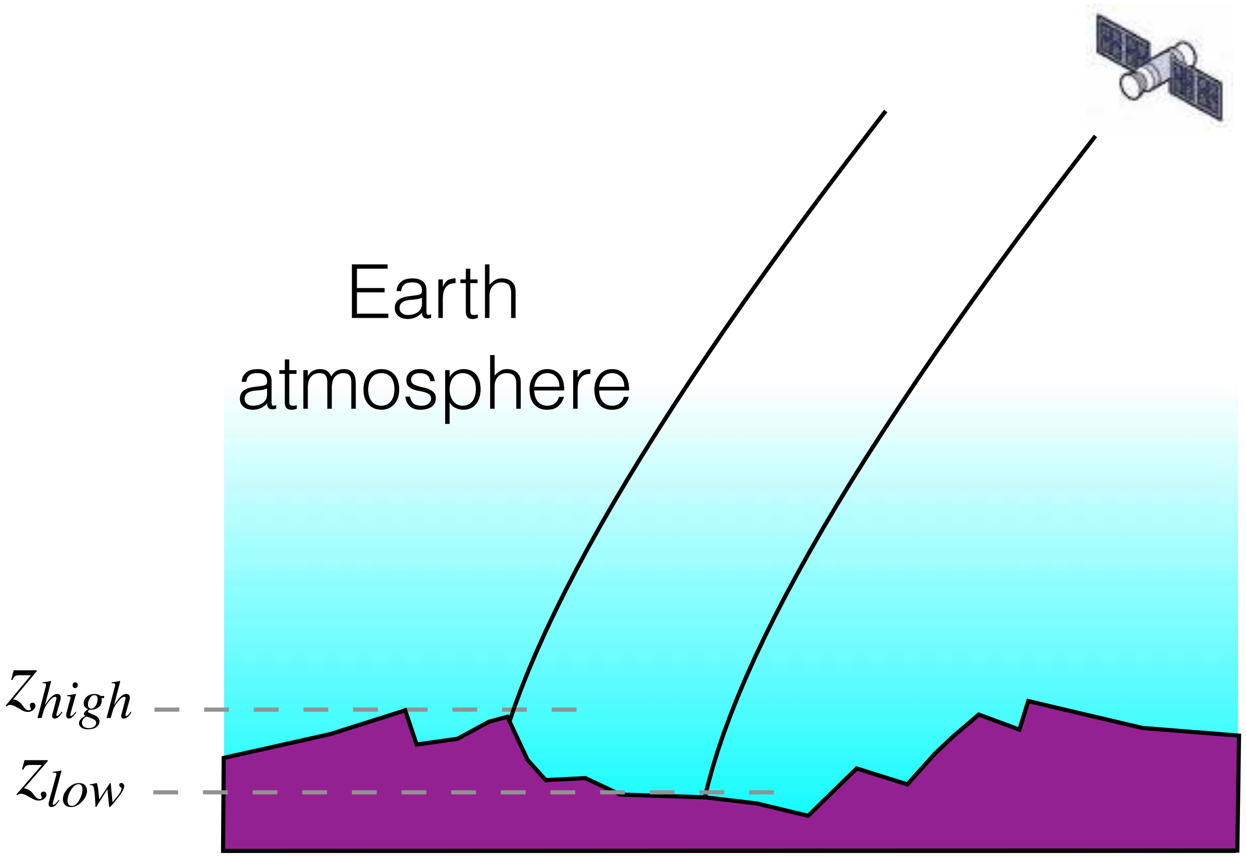
Refraction of radar wave path in atmosphere



If atmospheric conditions change between 2 passes of satellite, it produces a signal in differential phase field.

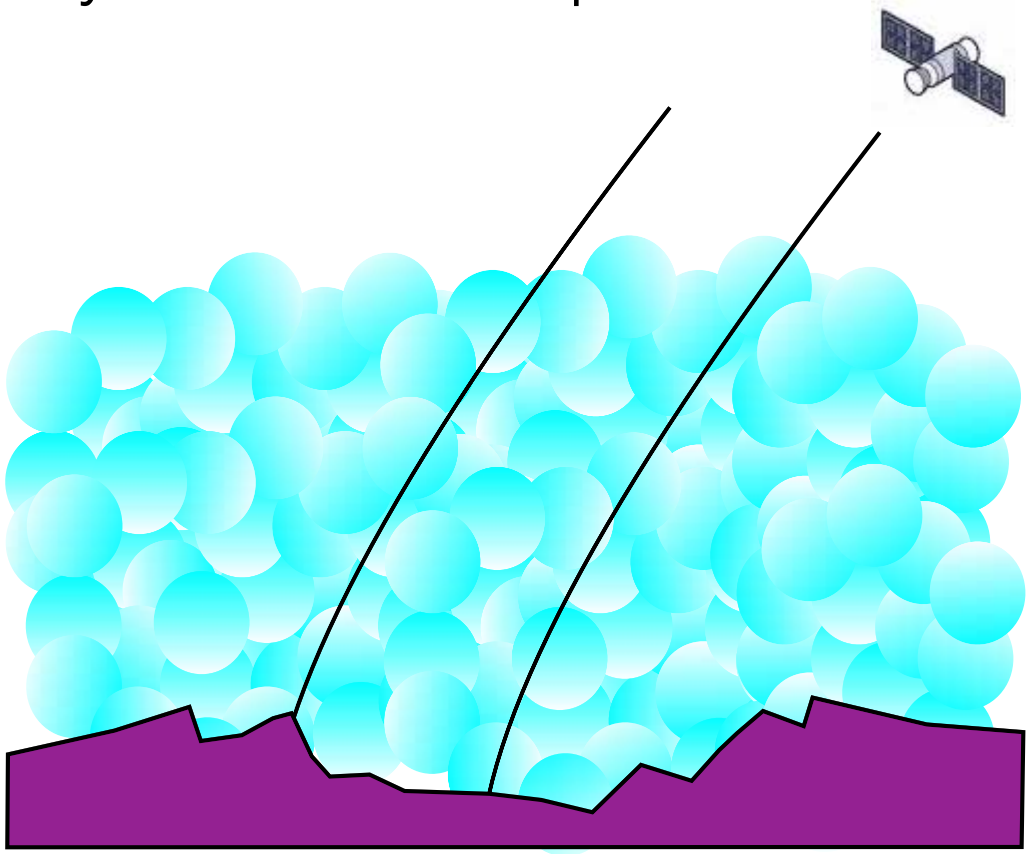
$$Path\ length\ difference = \int_{z}^{z_{top}} (N_2 - N_1)\,ds$$

Problem 1: The interferometric phase delay shows terrain elevation



$$\int_{z_{high}}^{z_{top}} (N_2 - N_1)ds \neq \int_{z_{low}}^{z_{top}} (N_2 - N_1)ds$$

Problem 2: The interferometric phase phase delay shows atmospheric turbulence



$$N(x,z) = \bar{N}(z) + \delta N(x,z)$$

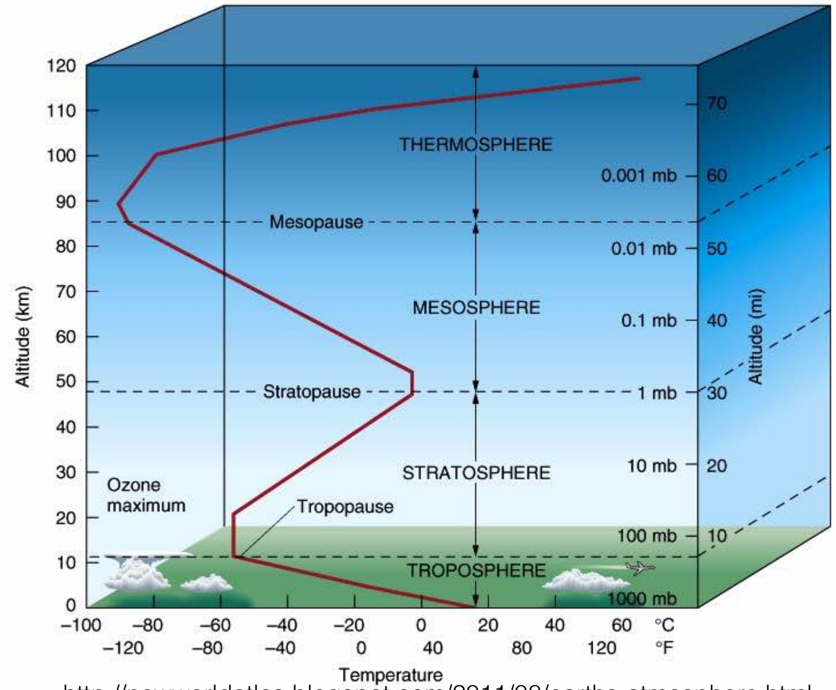
Stratified

Turbulent

Structure of the Earth atmosphere

Troposphere:

- 12 km thick (9-16 km)
- 80% of air mass
- 99% of water vapor
- T, P decrease with altitude



http://newworldatlas.blogspot.com/2011/08/earths-atmosphere.html

Index of refraction:

P_d dry air partial pressure

e water vapor partial pressure

T temperature

W_{cl} condensed water

ne electronic content

f wave frequency

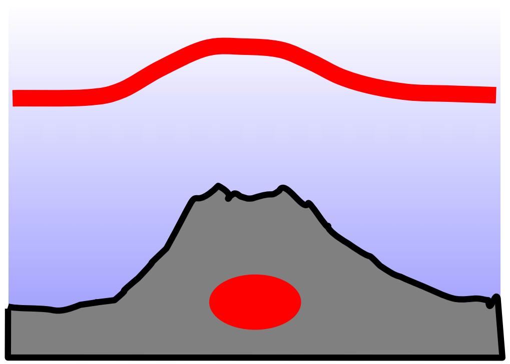
Dry — Wet — Clouds — Ionosphere

$$N = k_1 \frac{P_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2} + k_4 W_{cl} + k_5 \frac{ne}{f^2}$$

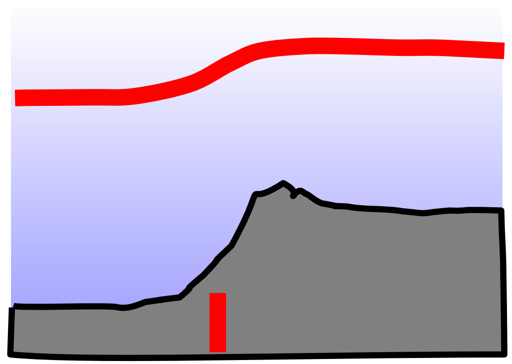
Troposphere signal introduces a bias in geodetic measurements

Deformation signal correlate with topography -> phase delay can be confused with deformation

Volcano inflation

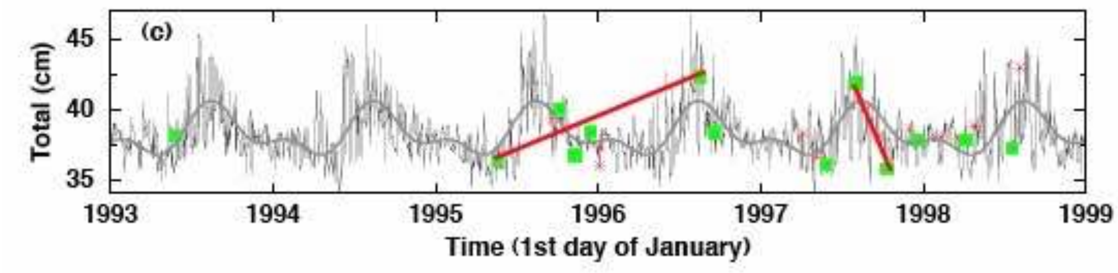


Edge of Tibet



Seasonal delay can be aliased into the estimated velocity due to irregular temporal sampling

Total phase delay computed from ERA-40 model
Gansu, China (z=1400 m)



Doin et al. 2008

Troposphere signal mitigation options

- Empirical models: exploits topography dependence
- Global Climate Models (GCM)
- Model wet delay using IR bands of MODIS/MERIS
  - JPL OSCAR project
- Ground-based GPS zenith delay estimates
- InSAR time series with temporal filter (next presentation)

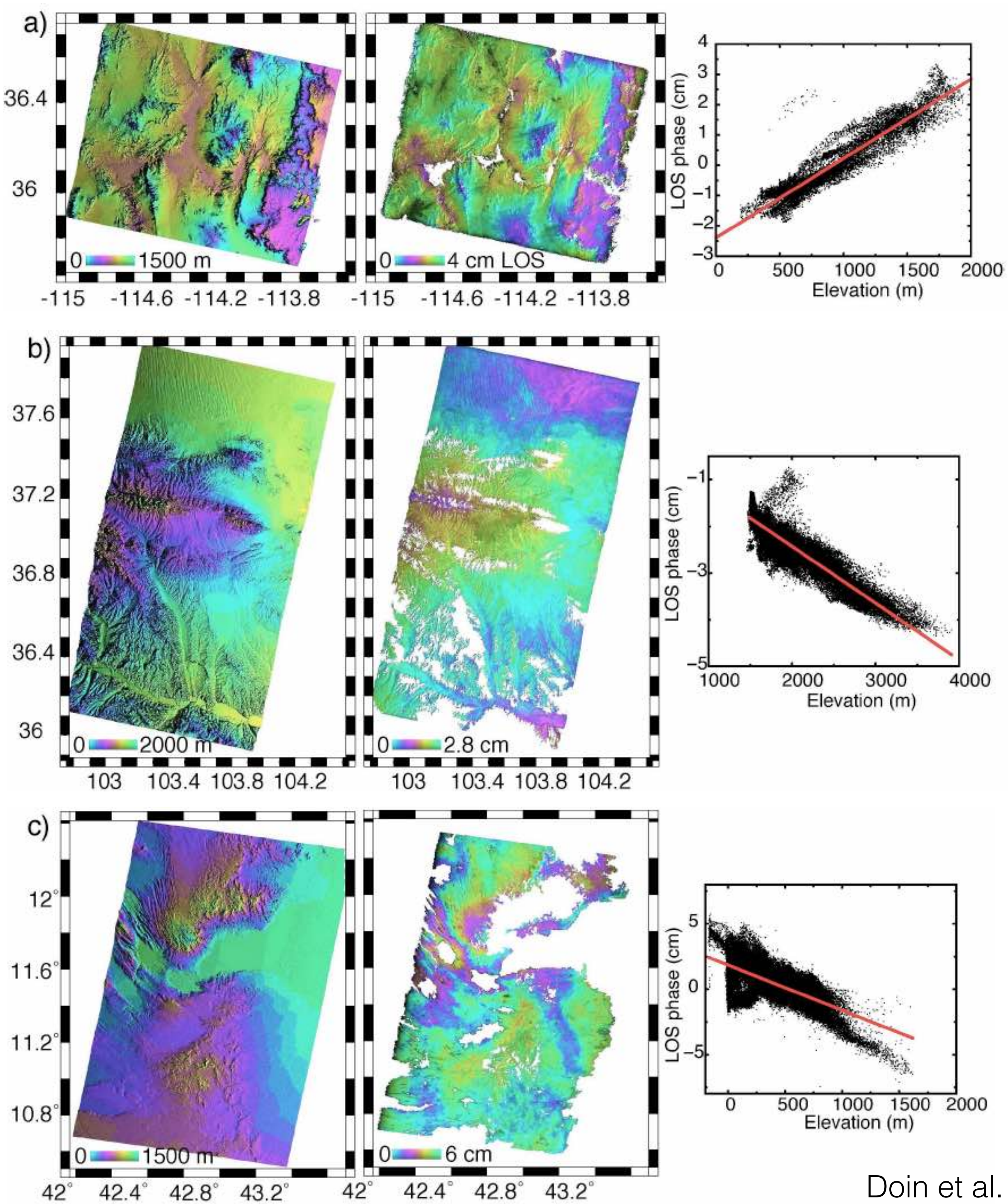
InSAR phase/ topography

Elevation InSAR

Nevada (USA)

Gansu (China)

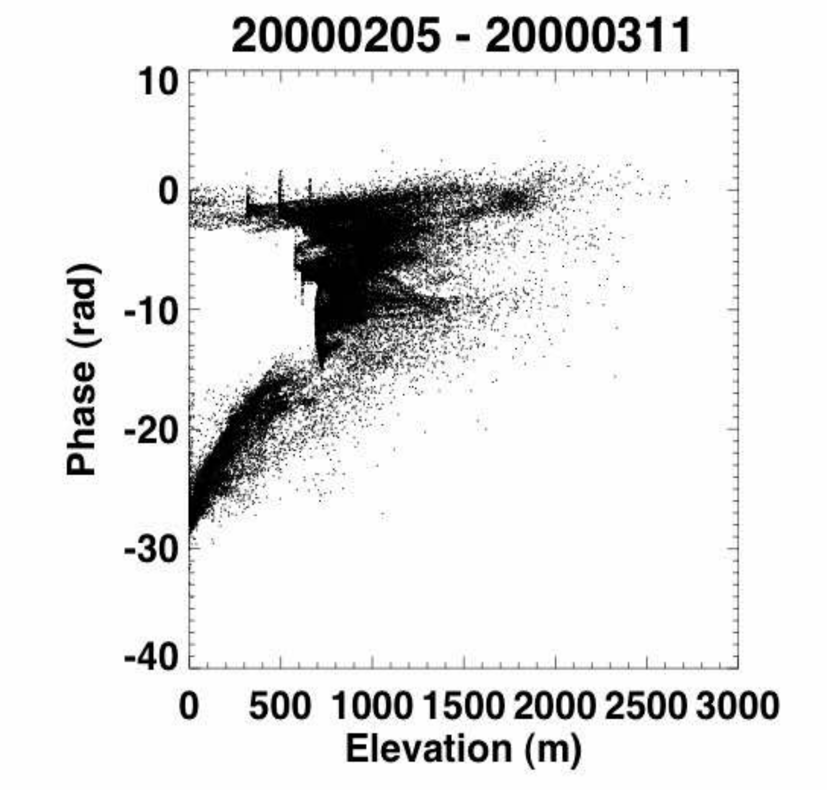
Afar (Ethiopia)



Doin et al. 2009

InSAR phase/ topography

Phase not simply related to topography



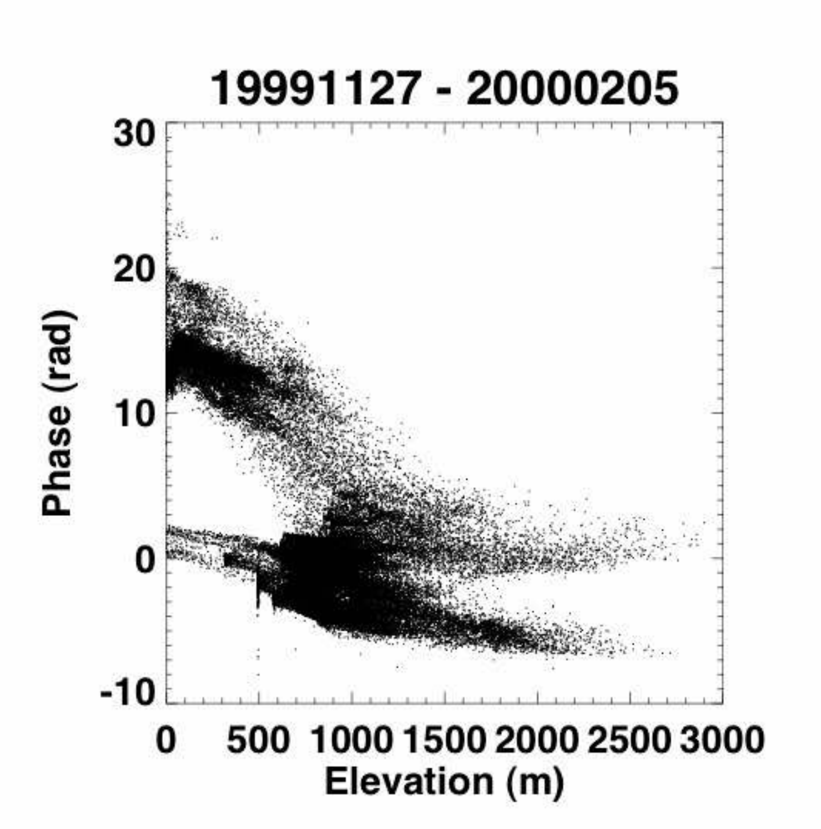
Los Angeles, Mojave area Observed phase

ERS: 2000.02.05 – 2000.03.11

Peltzer et al., ESA workshop, 2010

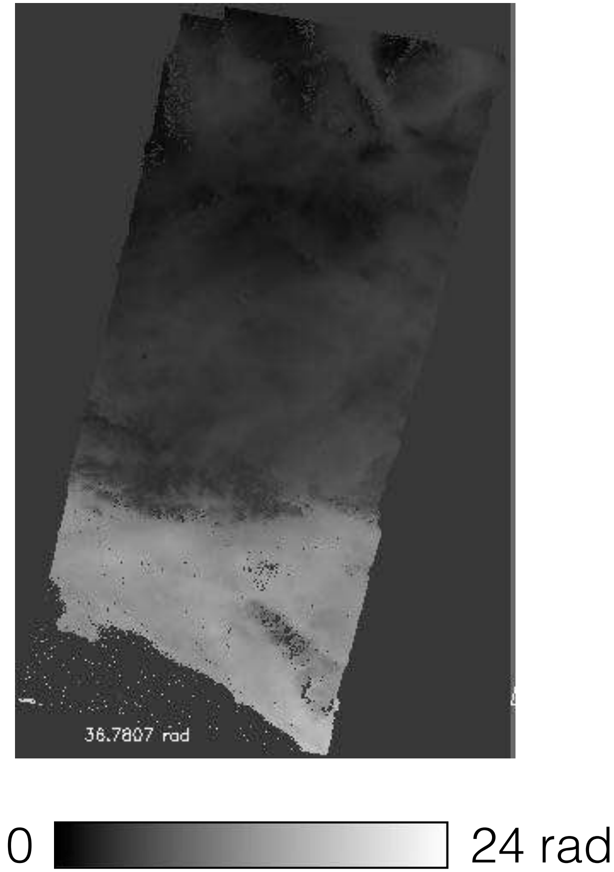
InSAR phase/ topography

Phase not simply related to topography



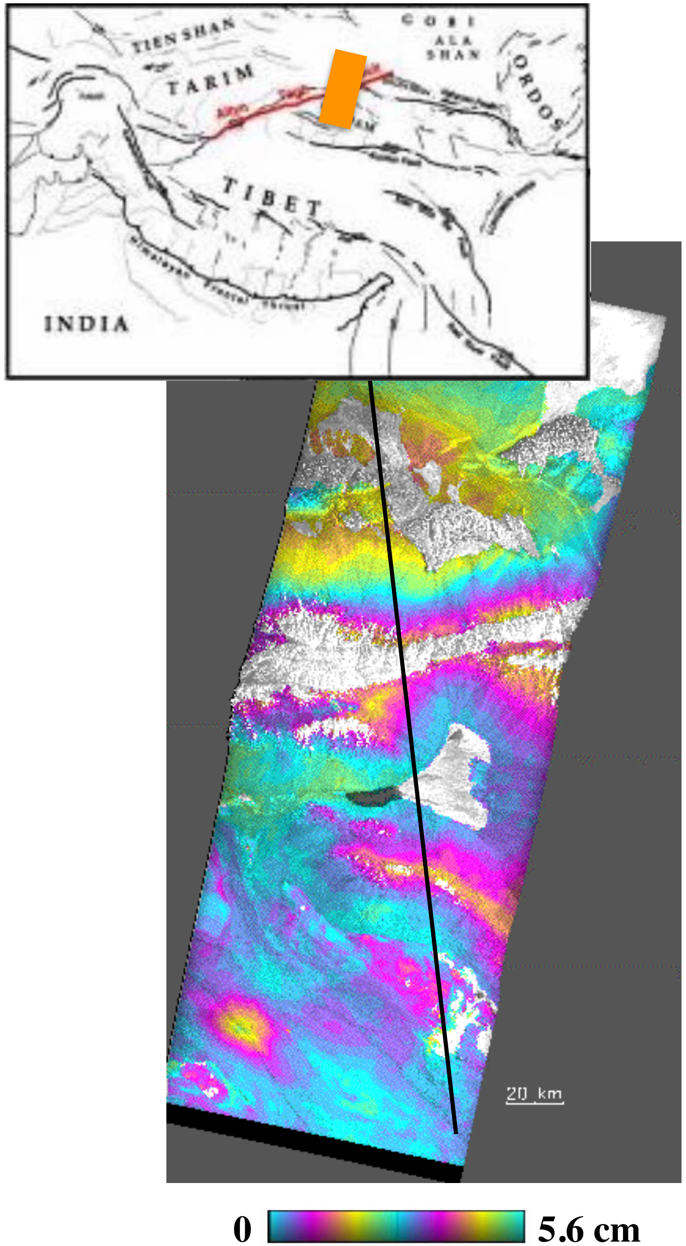
Los Angeles, Mojave area
Observed phase

ERS: 1999.11.27 – 2000.02.25

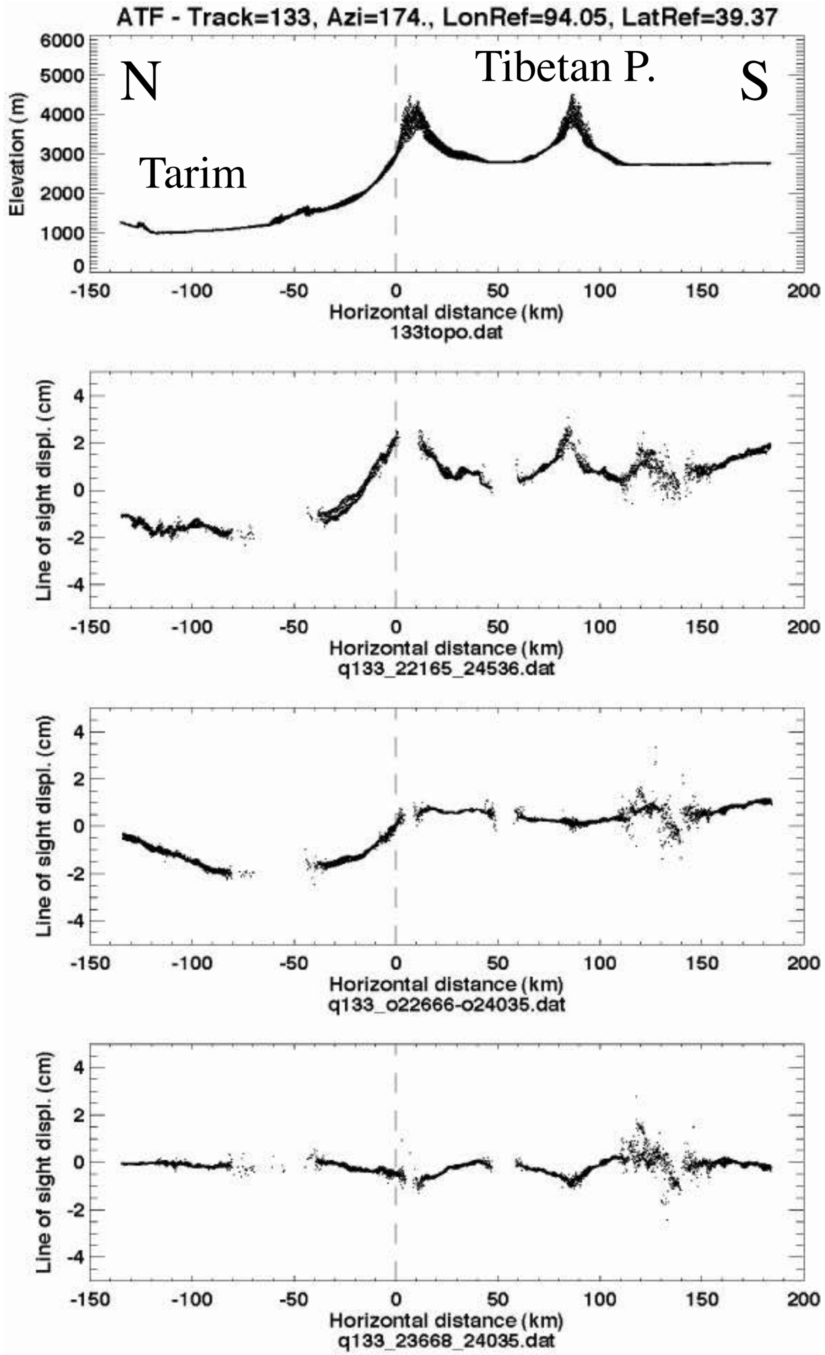


Peltzer et al., ESA workshop, 2010

North Tibet problem



Interferogram Oct.. 1995/ Dec. 1999



Topography

4.2 years
Oct95-Dec99

4.0 years
Nov95-Nov99

3.8 years
Jan96-Nov99

Lasserre et al. EGU, 2007

Global Atmospheric Models to estimate vertical profiles of *Pd*, *e*, and *T* and predict the InSAR stratified delay

European Center for Medium-range Weather Forecast (ECMWF), Reading, UK

ERA-40 reanalysis :
1957-2002
time step: 6h
spatial grid: 1.125°
23 pressure levels

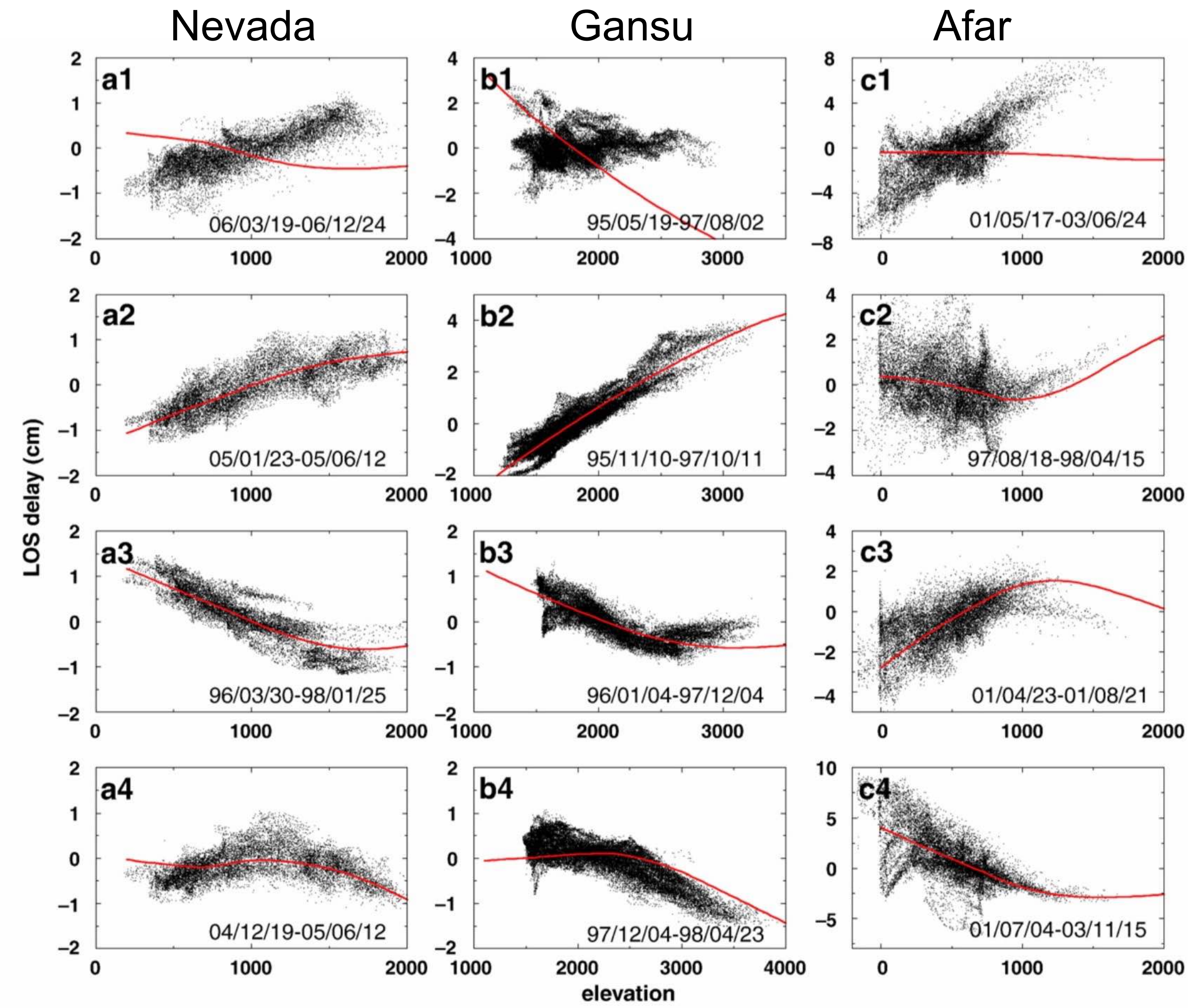
ERA-Interim reanalysis :
1979-present
time step: 12h
spatial grid: 0.75°
60 pressure levels >0.1 hPa

National Center for Atmospheric Research (NCAR), Boulder CO

NARR:
since 1979
time step: 4h
spatial grid: ~32 km
45 pressure levels

More info: https://reanalyses.org/atmosphere/overview-current-reanalyses#ERAINT

Comparison between observed and modeled delays vs elevation



No apparent correlation <10%

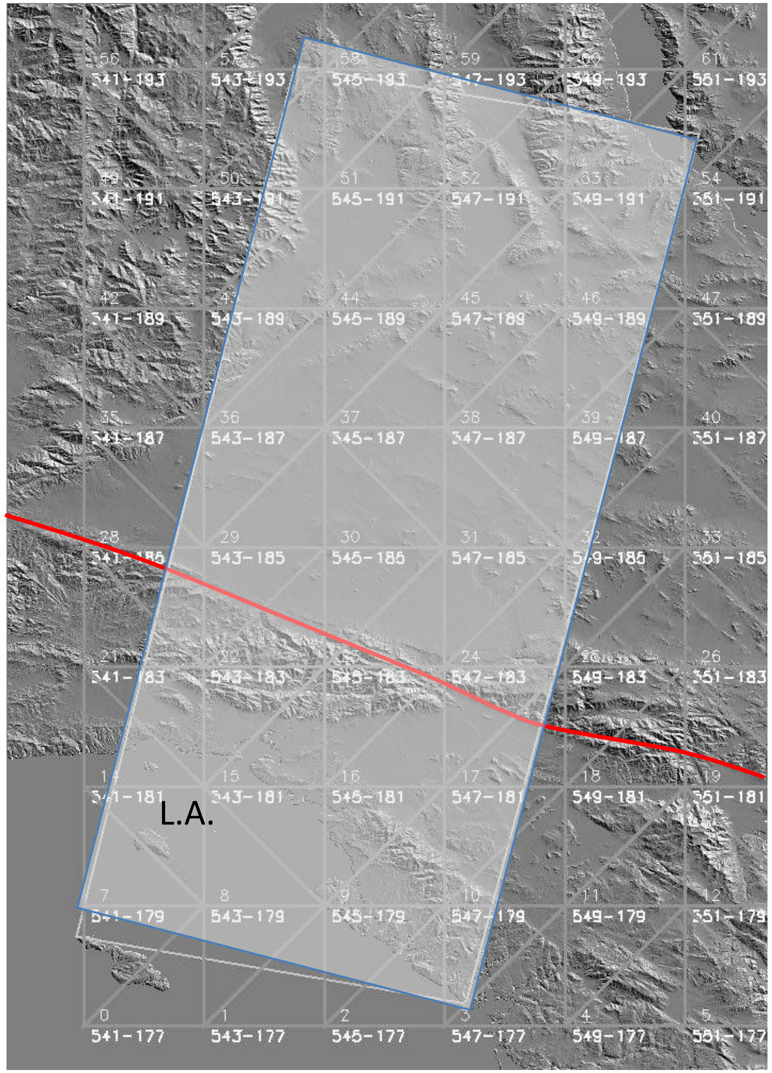
Non-linear dependence is consistent between InSAR and models

Doin et al. 2009

North American Regional Reanalysis (NARR)

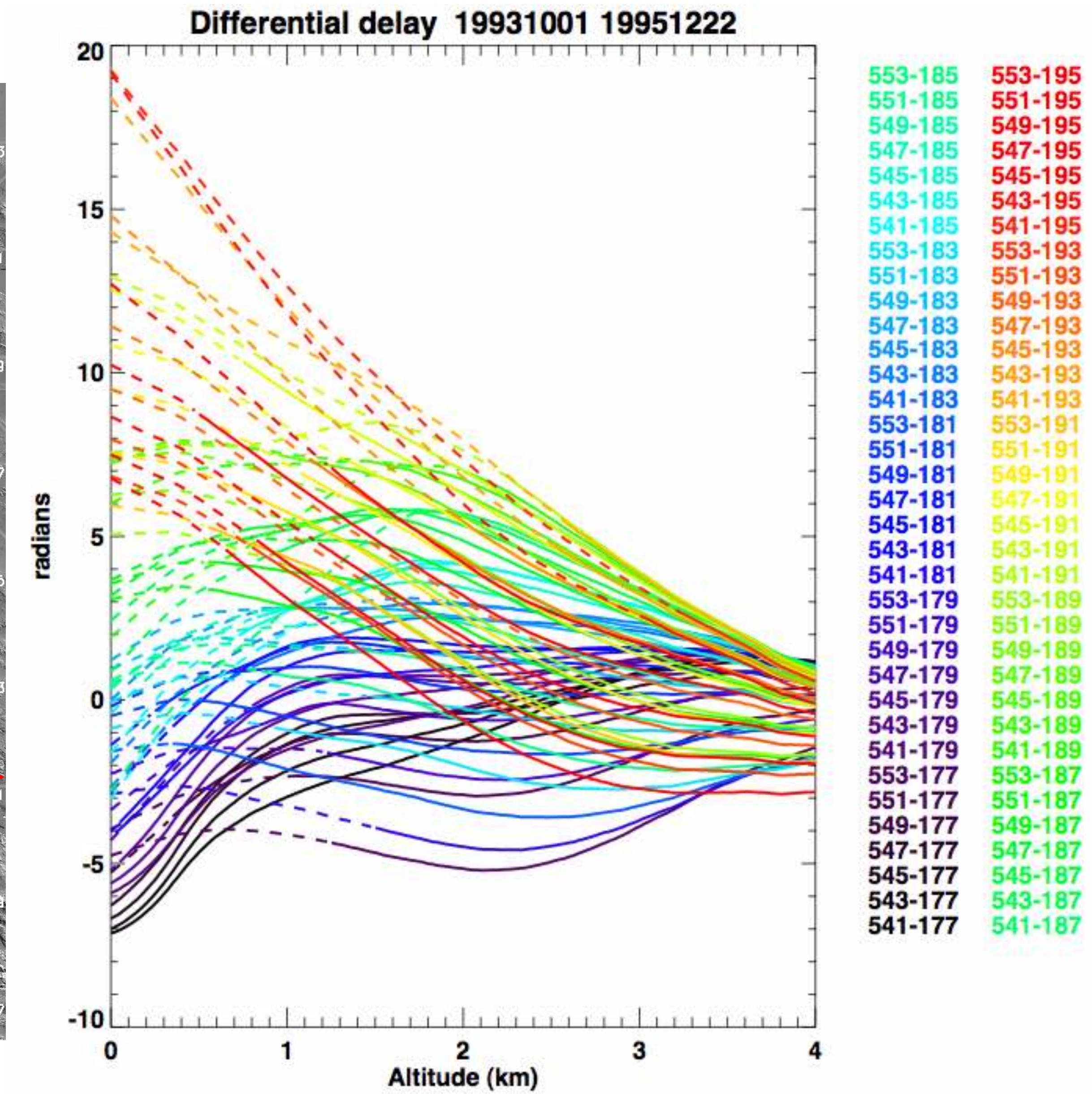
Data available at: http://www.emc.ncep.noaa.gov/mmb/rreanl/

NARR Grid over Track 170
(Odd node numbers only shown)



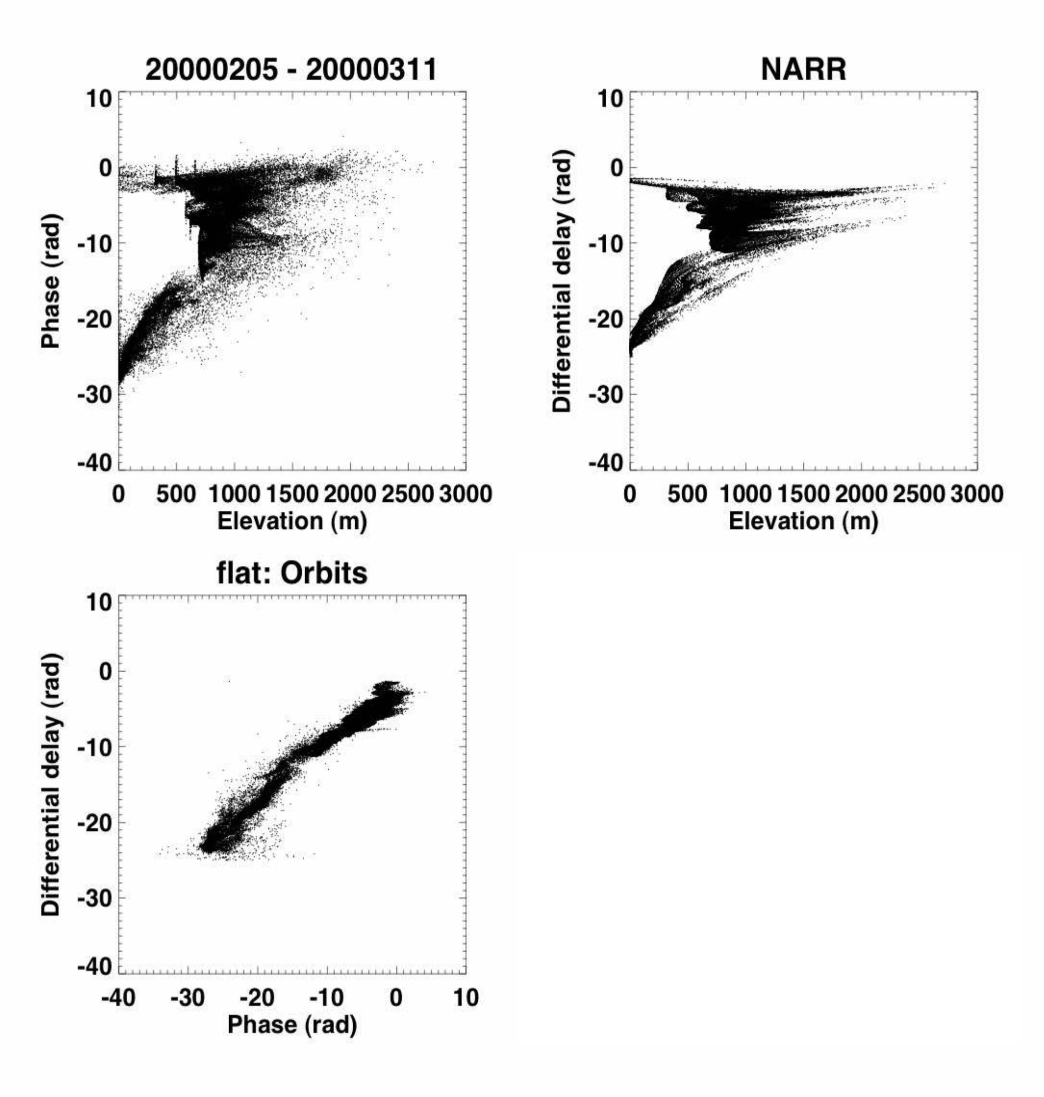
Full grid spacing: 0.18 degree
29 pressure levels

NARR-predicted differential delay at odd nodes

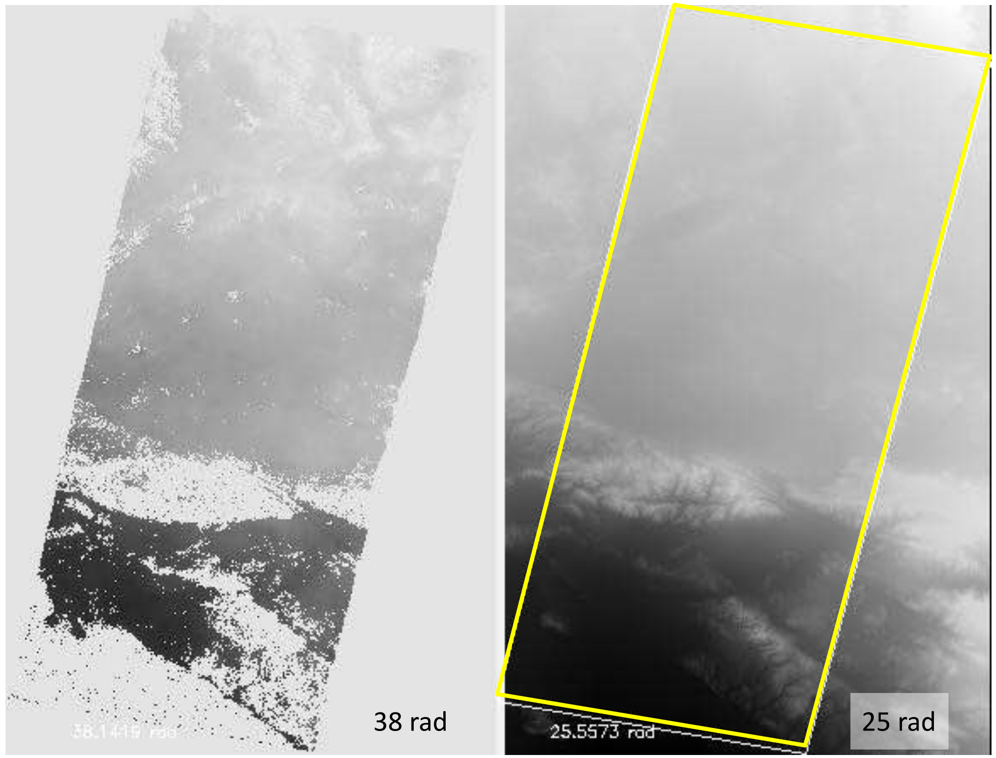


Peltzer et al., ESA workshop, 2010

Comparison of InSAR phase with NARR predicted delay



ERS: 2000-02-05 – 2000-03-11

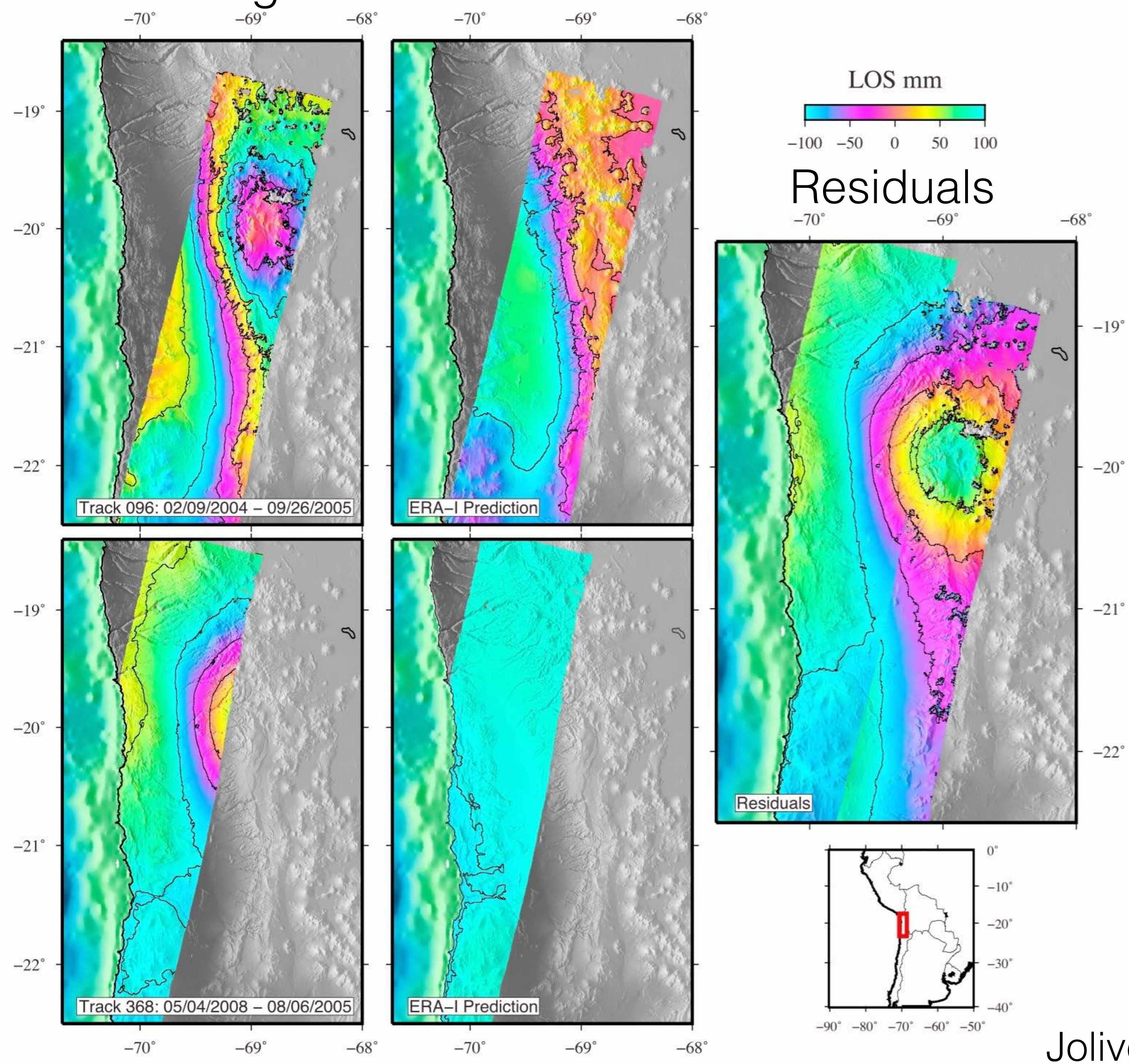


InSAR NARR

Peltzer et al., ESA workshop, 2010

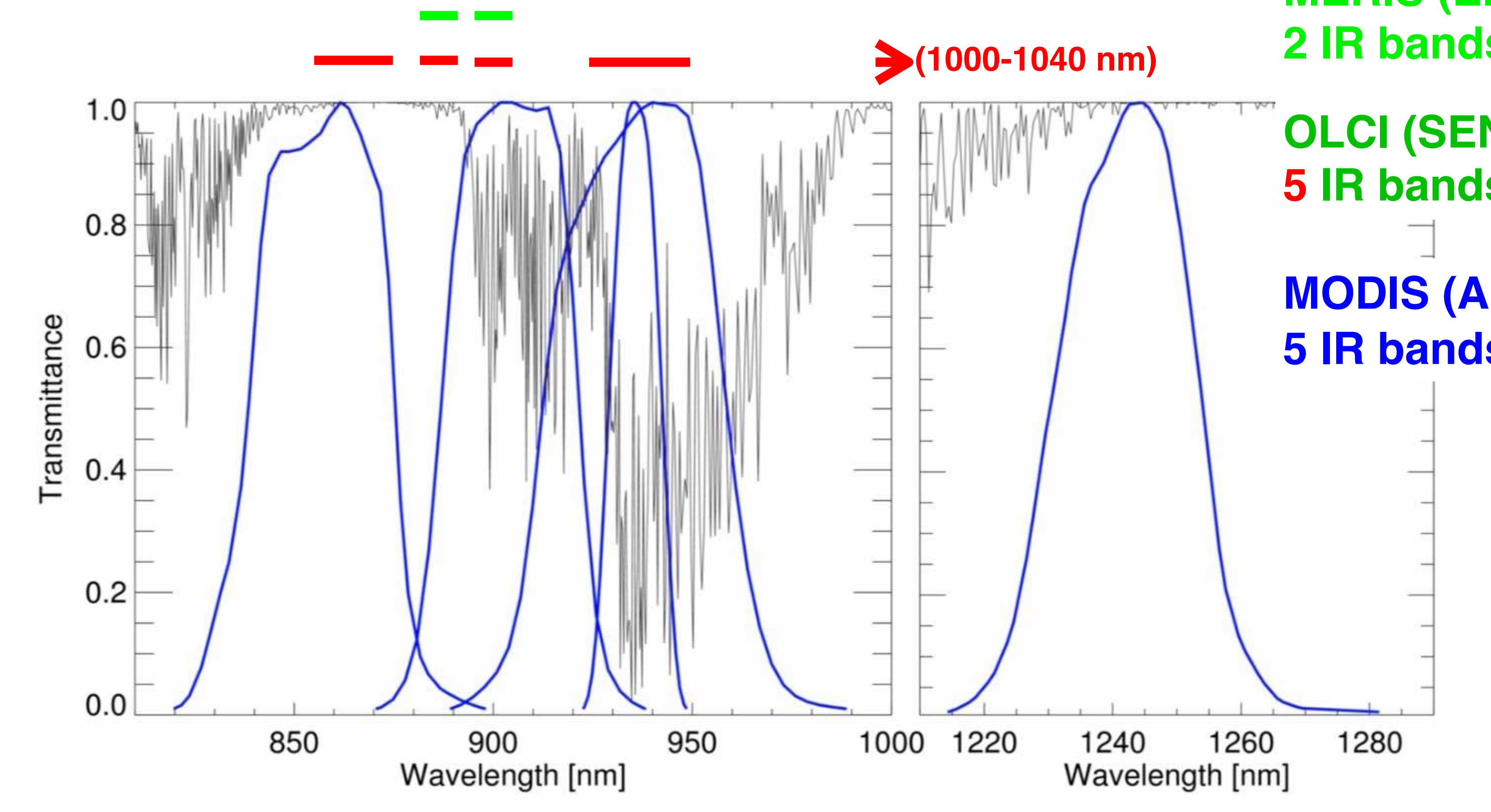
The 2005 Mw 7.7 Tarapacá earthquake.

Interferogram ERA-I model



Jolivet et al., 2014

MODIS, MERIS, and OLCI IR bands and Water Vapor transmission spectrum in near-infrared



MERIS (ENVISAT)
2 IR bands

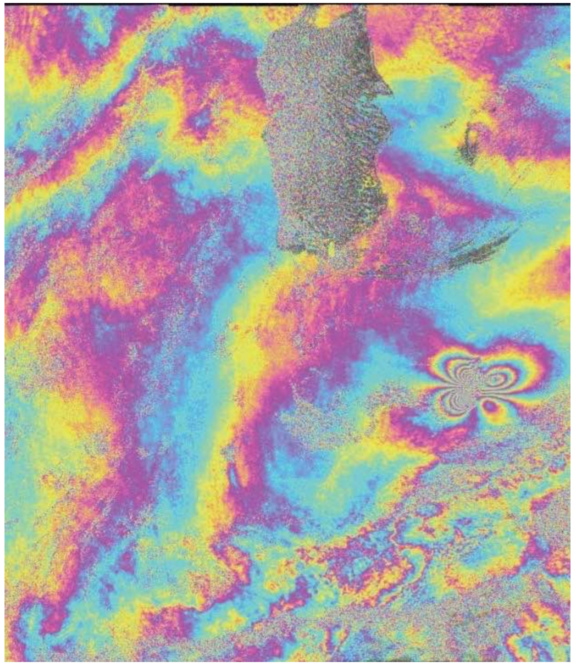
OLCI (SENTINEL-3)
5 IR bands

MODIS (ACQUA)
5 IR bands

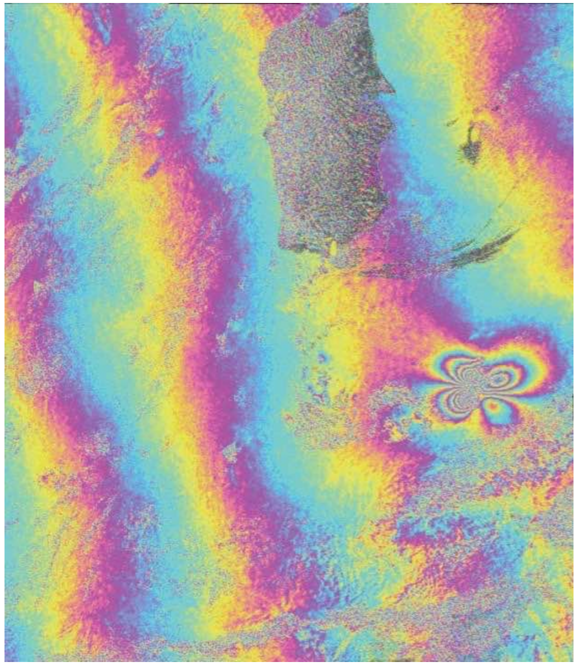
Atmospheric transmittance (WV) and MODIS relative response function of NIR bands (Dietrich et al., 2015)

Precipitable water vapor column can be retrieved using band ratio technique (Li et al., 2012)

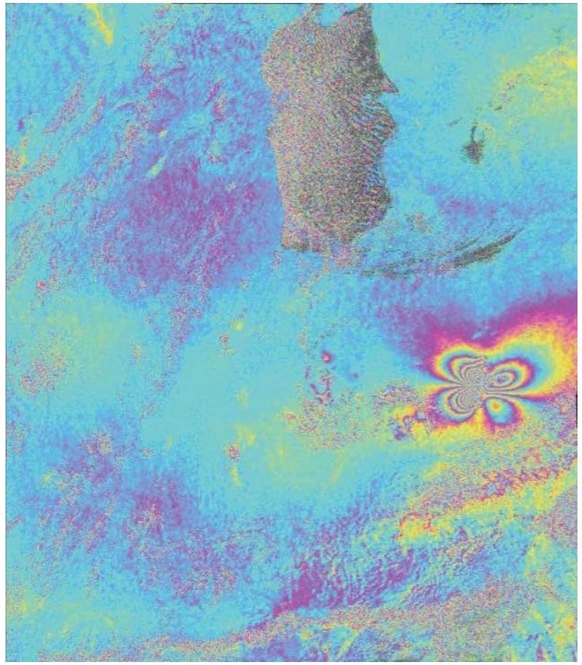
MERIS water vapor corrections of ENVISAT WS interferogram of M6.6 Bam Earthquake (Iran, 2003)



Interferogram



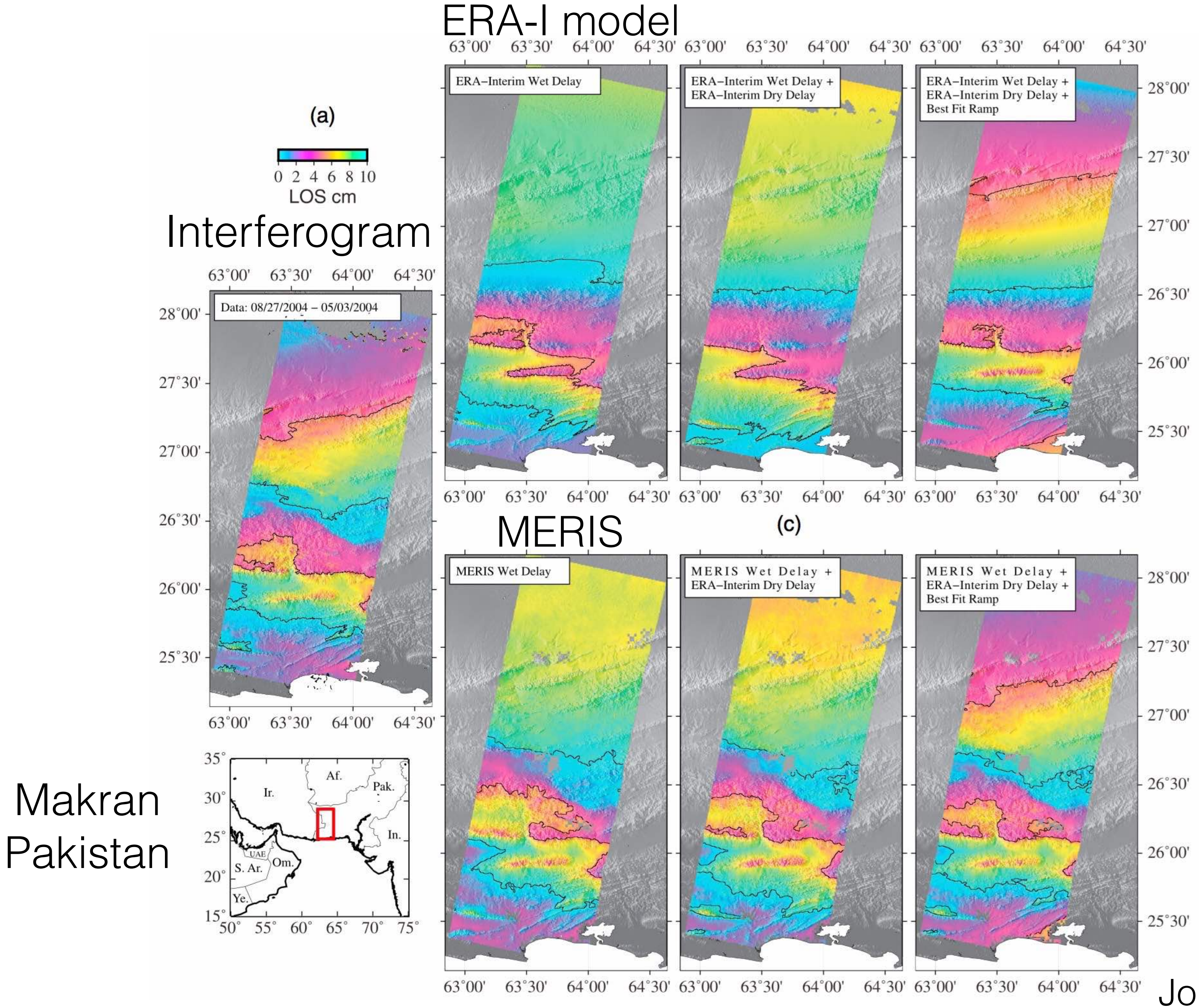
After MERIS corrections



After ramp removal

Li et al., 2011

Comparison of MERIS wet delay with ERA-I prediction



Jolivet et al., 2014

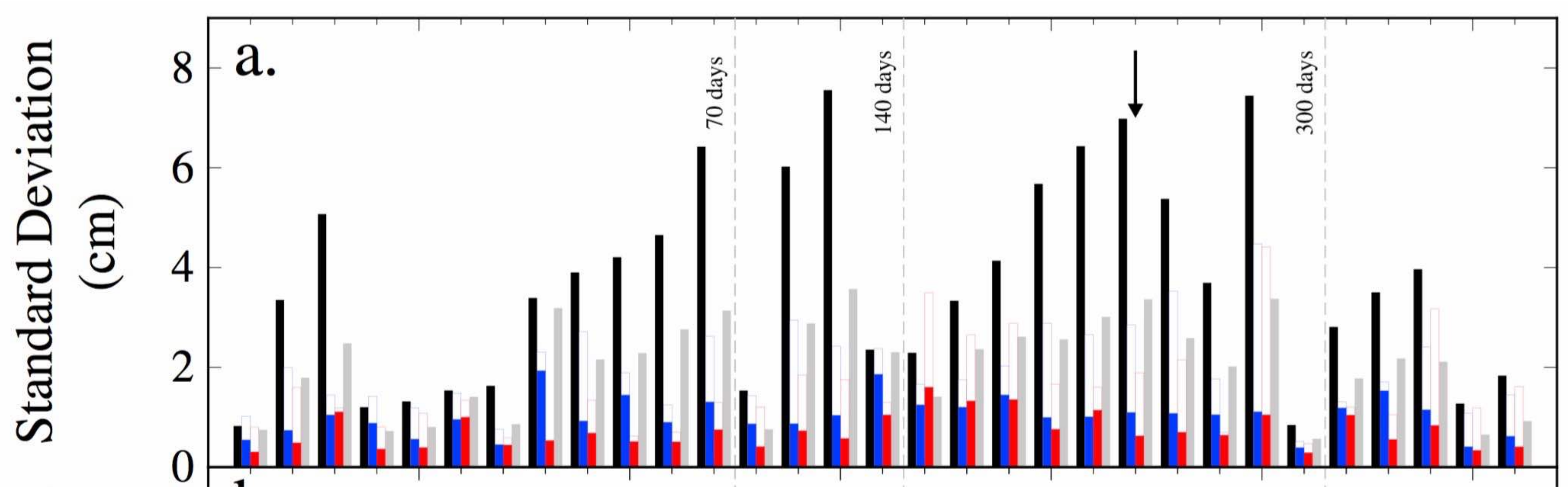
Comparison of phase noise in interferograms before and after atmospheric corrections

Interferograms

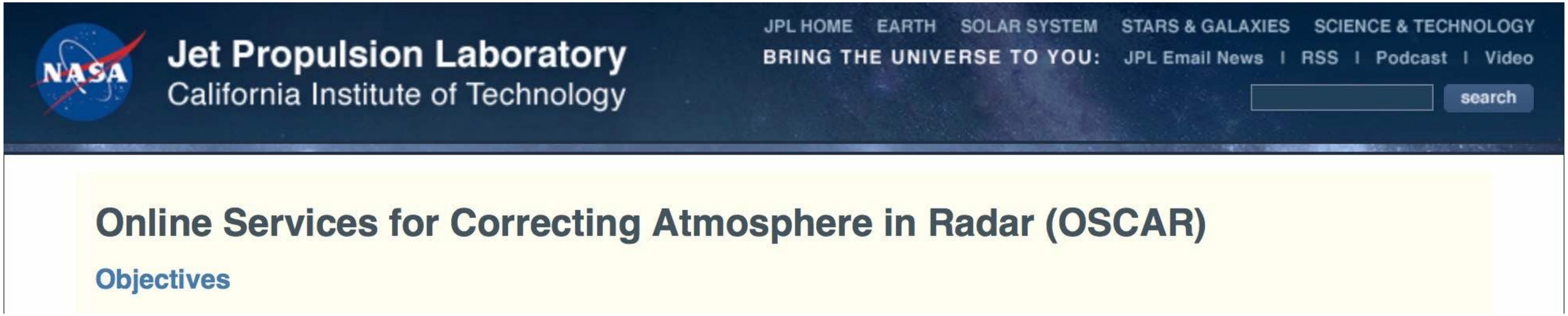
De-ramped interferograms

ERA-I corrections

MERIS corrections



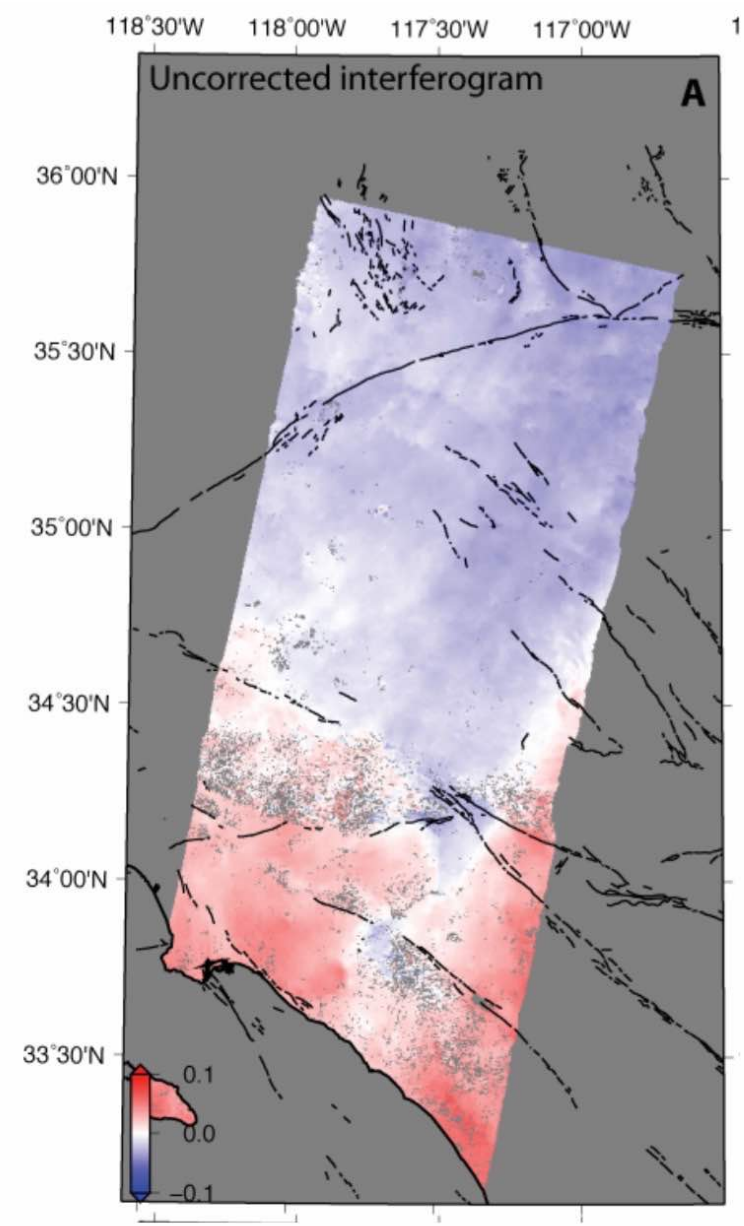
Jolivet et al., 2014



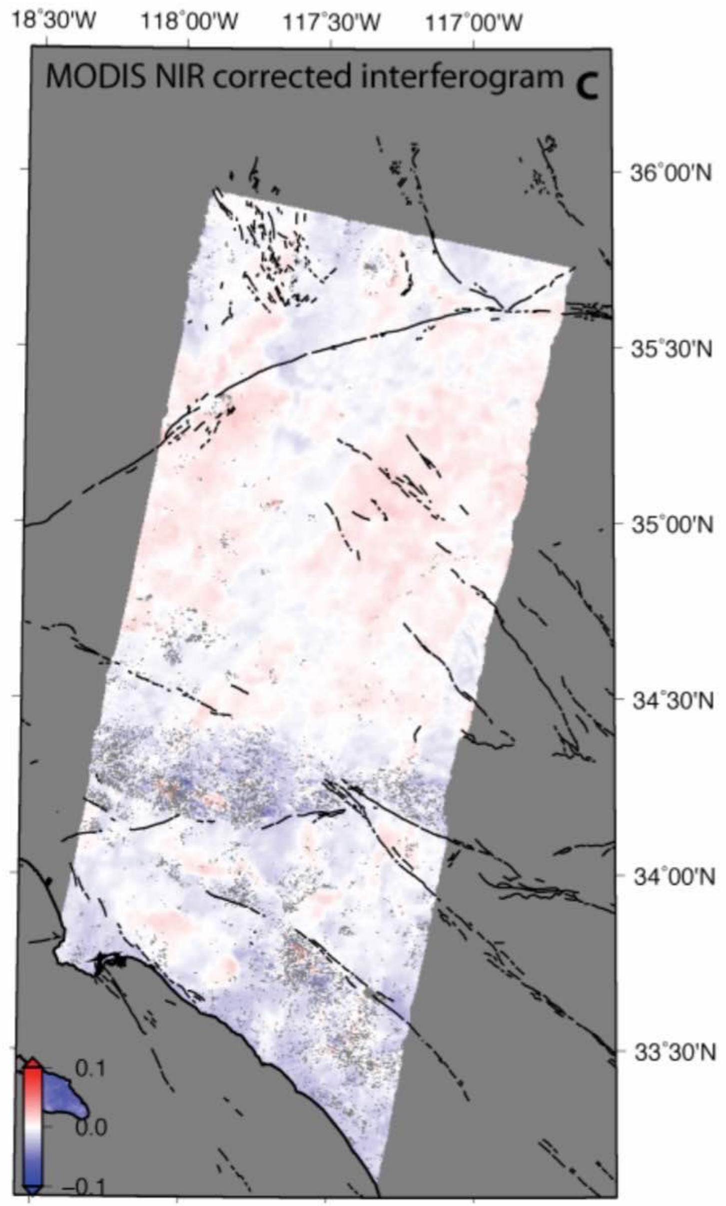
- Time series filtering or estimation (InSAR)
- Correlation of phase with topography
- CGPS (Continuous Global Positioning System) zenith wet delay interpolated spatially and temporally (Ground- Based)
- Total column water vapor from absorption of reflected near IR (MODIS and MERIS) (Remotely- Sensed)
- Water vapor measurements (profiling and total column) from thermal IR and MW (AIRS, MODIS, AMSU) (Remotely- Sensed)
- Numerical Weather Forecast Models
- European Center for Medium Range Weather Forecasting (ECMWF)
- NOAA NCEP North American Mesoscale Model (NAM)

Investigators: Paul von Allmen Eric Fielding, Evan Fishbein, Zhangfan Xing, Lei Pan, and Martin Lo, JPL; Zhenhong Li, University of Glasgow

Example of OSCAR MODIS correction



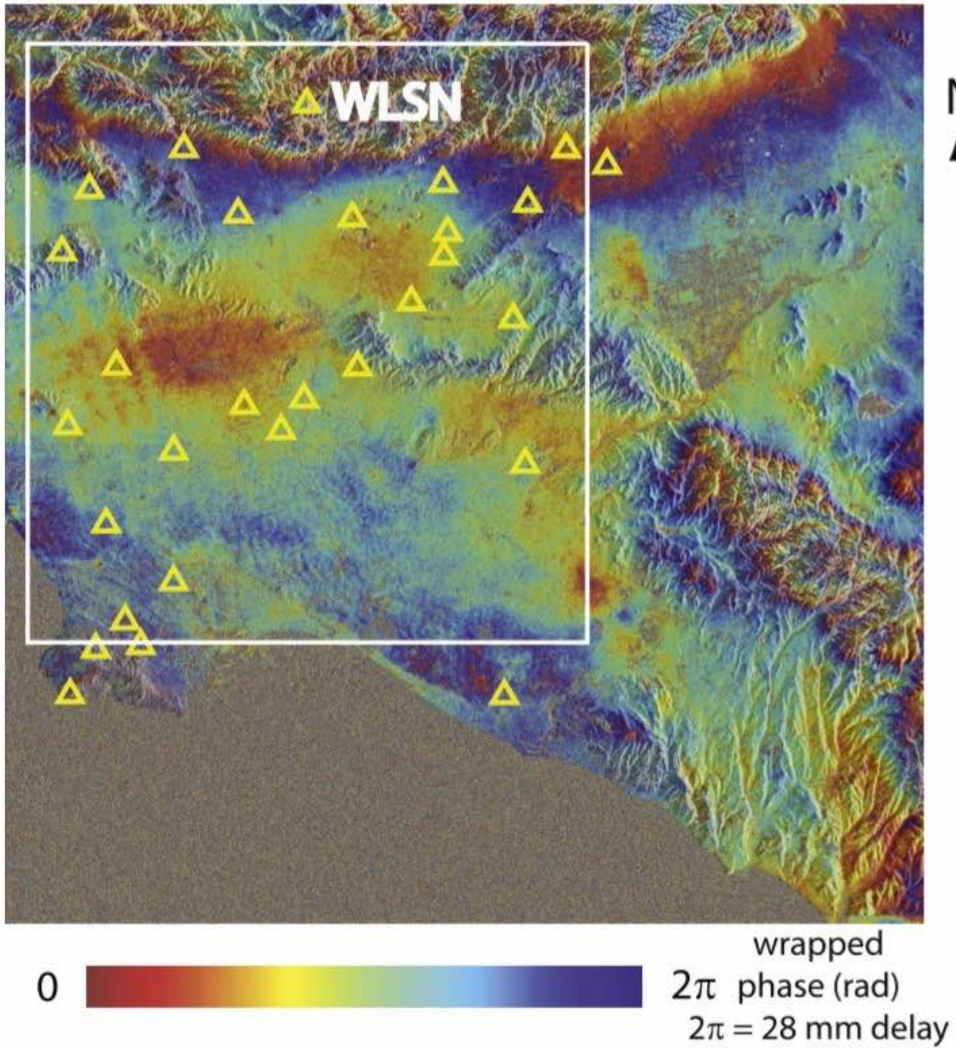
Interferogram

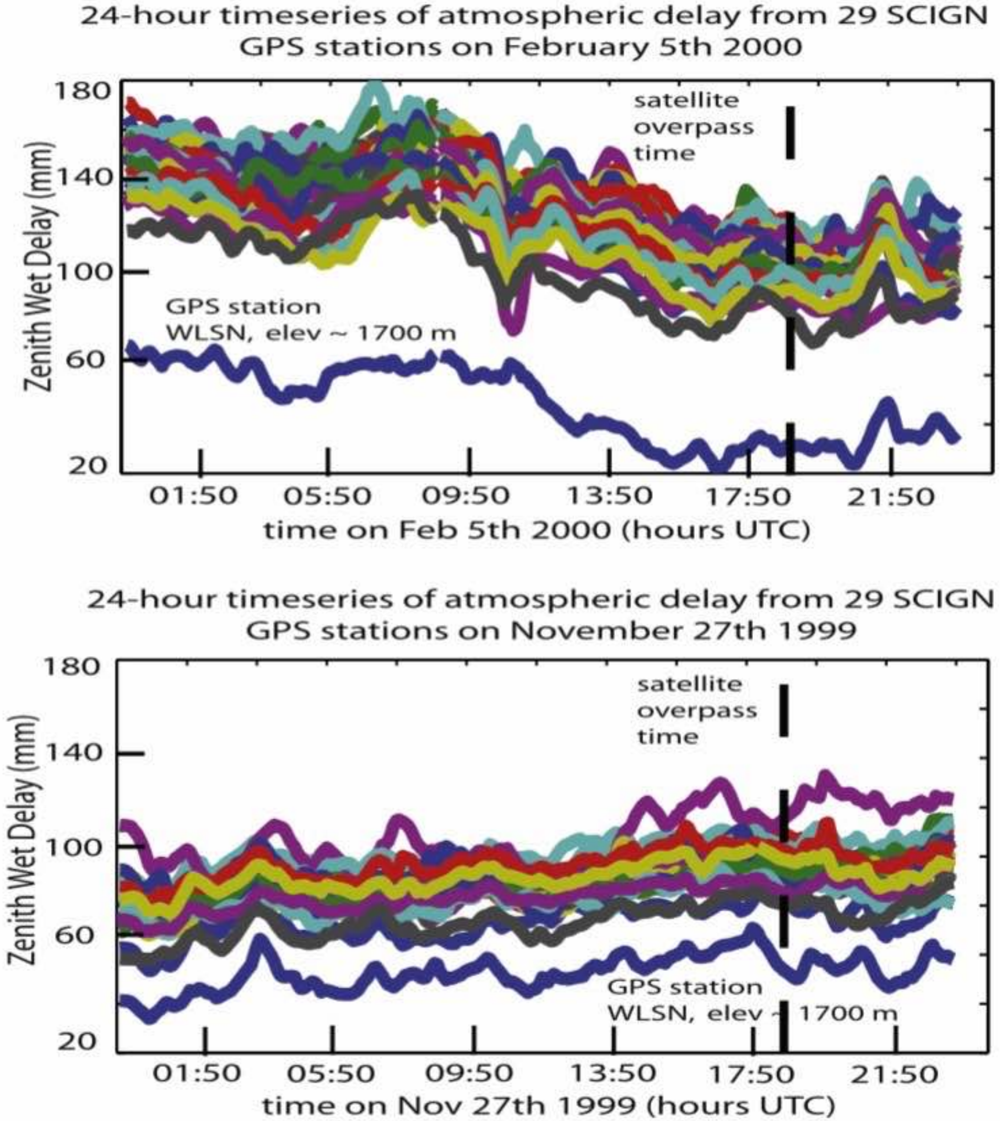


Residual after MODIS correction

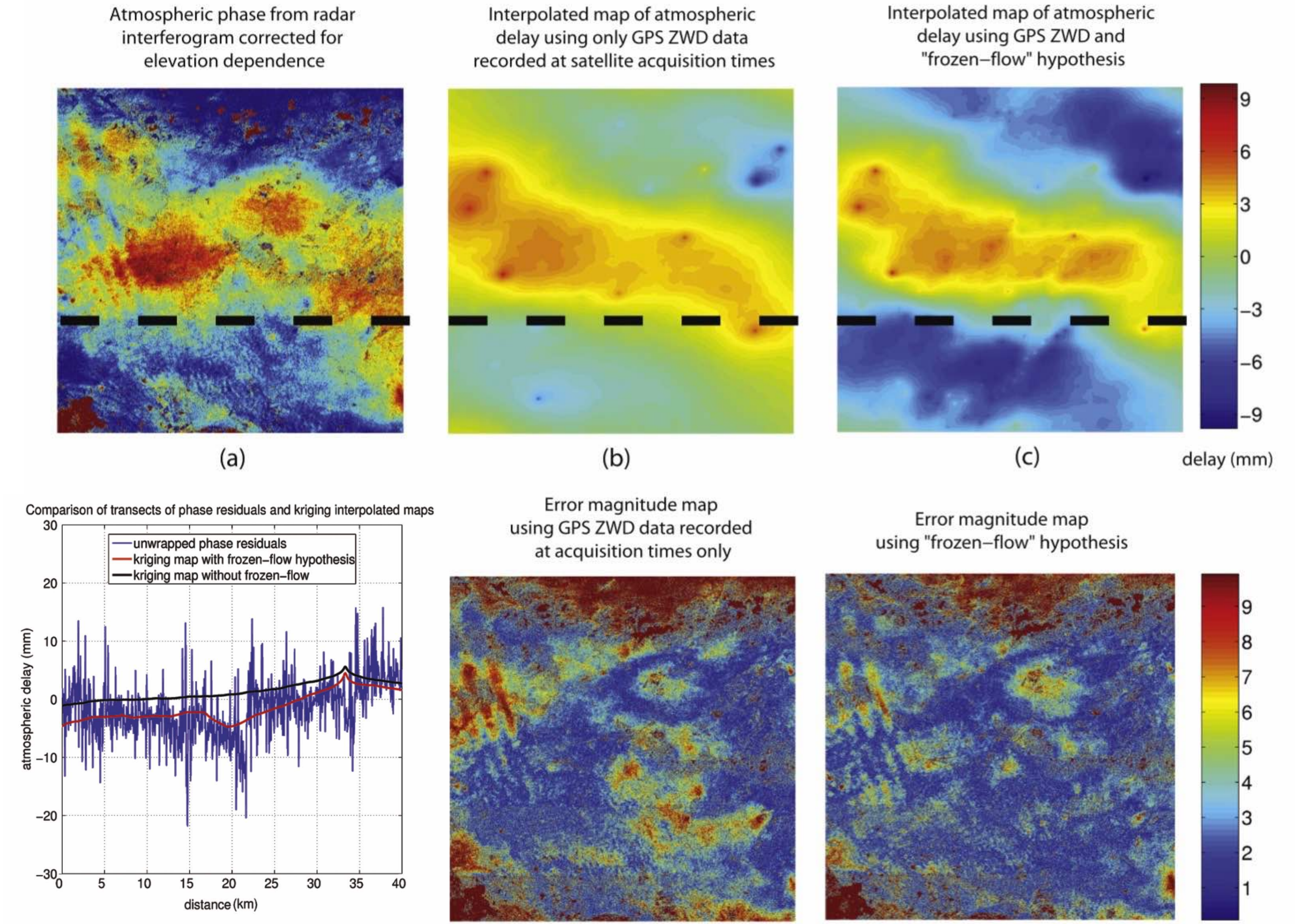
Zenith Wet Delay estimated using ground-based continuous GPS (Onn and Zebker, 2006)

Nov 27, 1999 - Fev 5, 2000





Additional “control points” using frozen flow hypothesis to effectively interpolate between GPS station



(Onn and Zebker, 2006)

Comparison of various methods for mitigating atmospheric signal in InSAR data

	Global/ regional	Spatial sampling	Temporal sampling	All weather	Day/Night	Accuracy
Empirical (Phase/ topo)	global	radar/dem	radar	yes	yes	
GCM	global	0.18-1.0 degree	4-12 hours	yes	yes	
MODIS/ MERIS/ OLCI	global	300-1000 m	day	no	day	
C-GPS ZTD	regional networks	station spacing	continuou s	yes	yes	
Time Series filtering	global	radar image	radar	yes	yes	