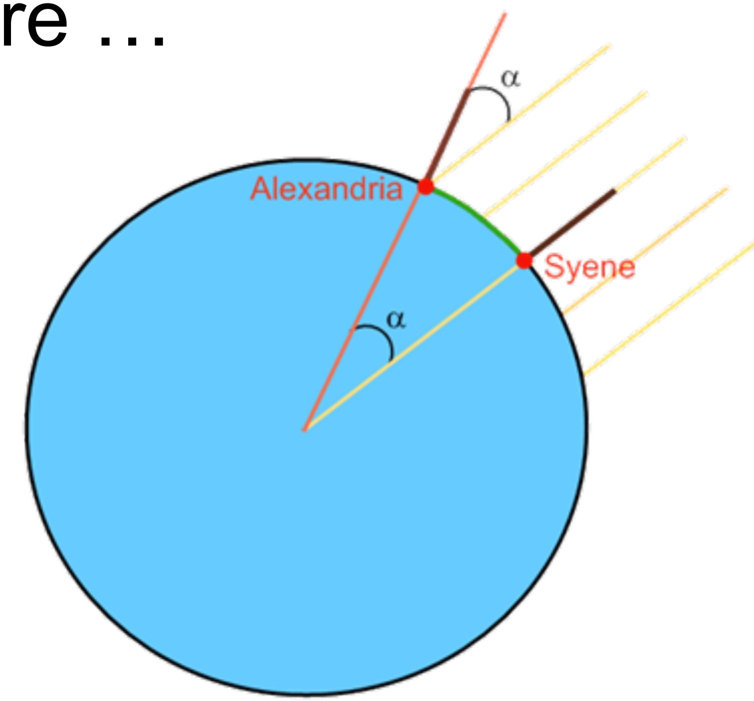
Lecture 17: Direct measurements of plate motion: Tectonic geodesy

Read KK&V chapter 5.8

What is geodesy?

Geodesy is the science of determining the size and shape of the Earth and the precise location of points on its surface.

History of thought about the shape of the Earth: Once upon a time … the world was flat! Then it was a sphere …



- Eratosthenes (276 BC - 194 BC) measured the shade angle in wells in Alexandria & Syene (Egypt)
- Earth's circumference = 252,000 strades (roughly 46,000 km, 15% > current measurement).

History of thought about the shape of the Earth:

First we thought the world was flat …

Then it was a sphere …

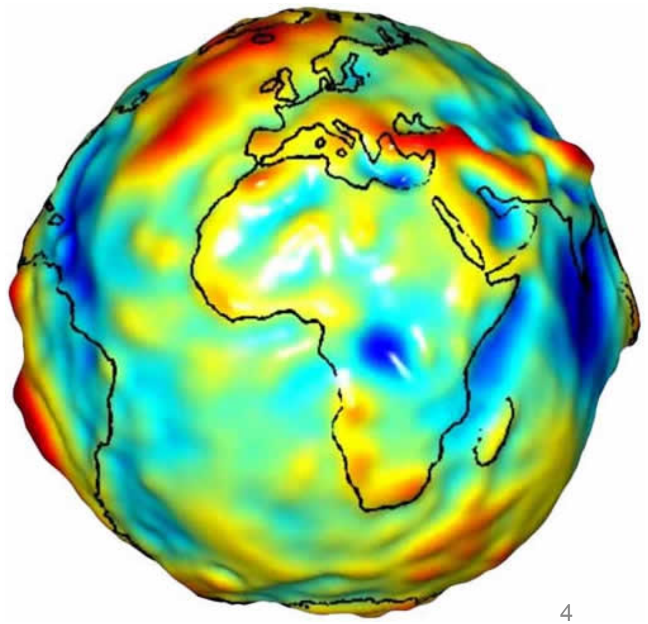
… then it was a squished sphere … (the Earth is spinning)

… then it had bumps!

… And its shape changes with time

-> active tectonics

Variations in the gravitational potential measured by the NASA GRACE satellite mission (red is higher gravity / blue is low gravity).

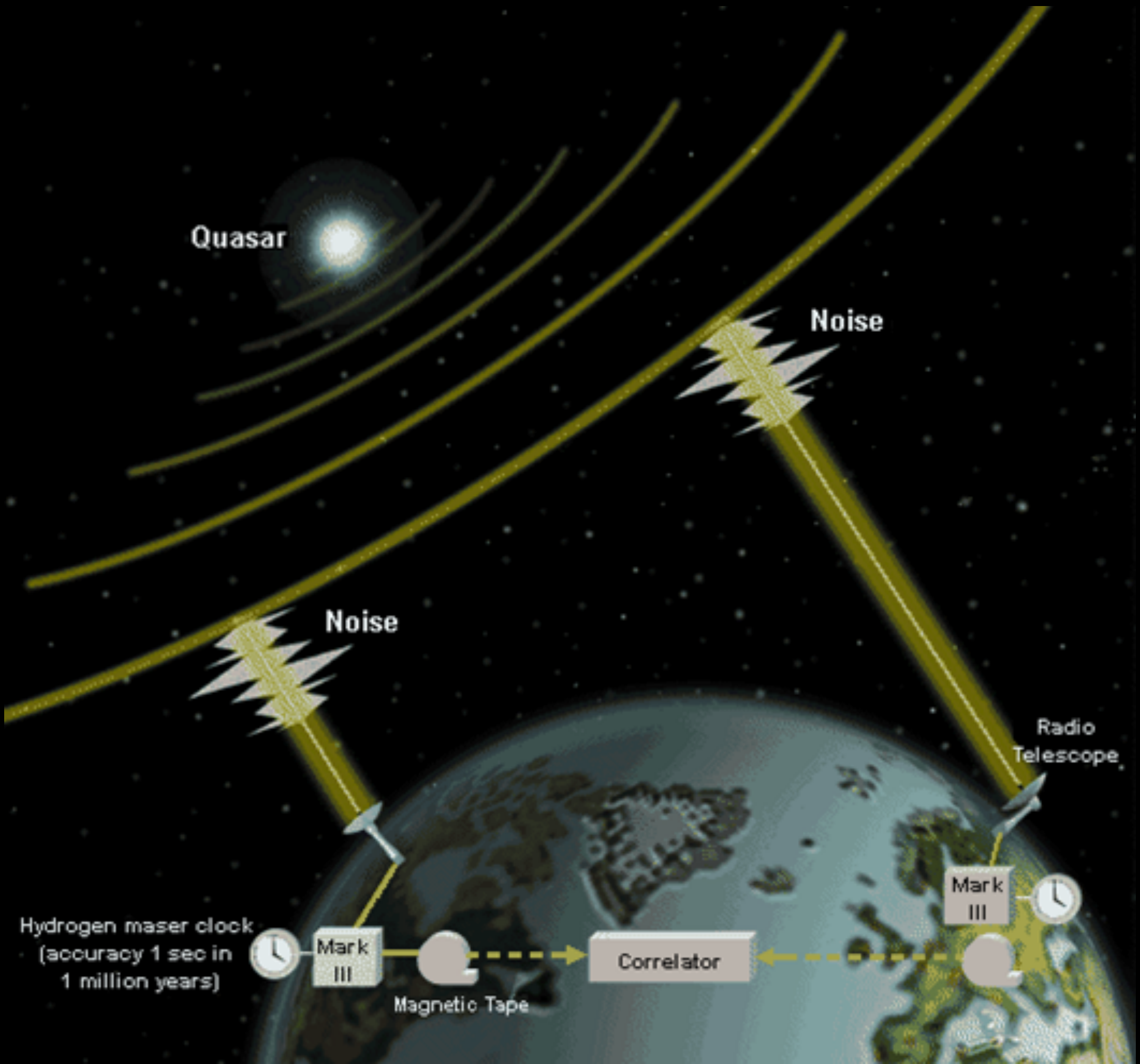


Alfred Wegener

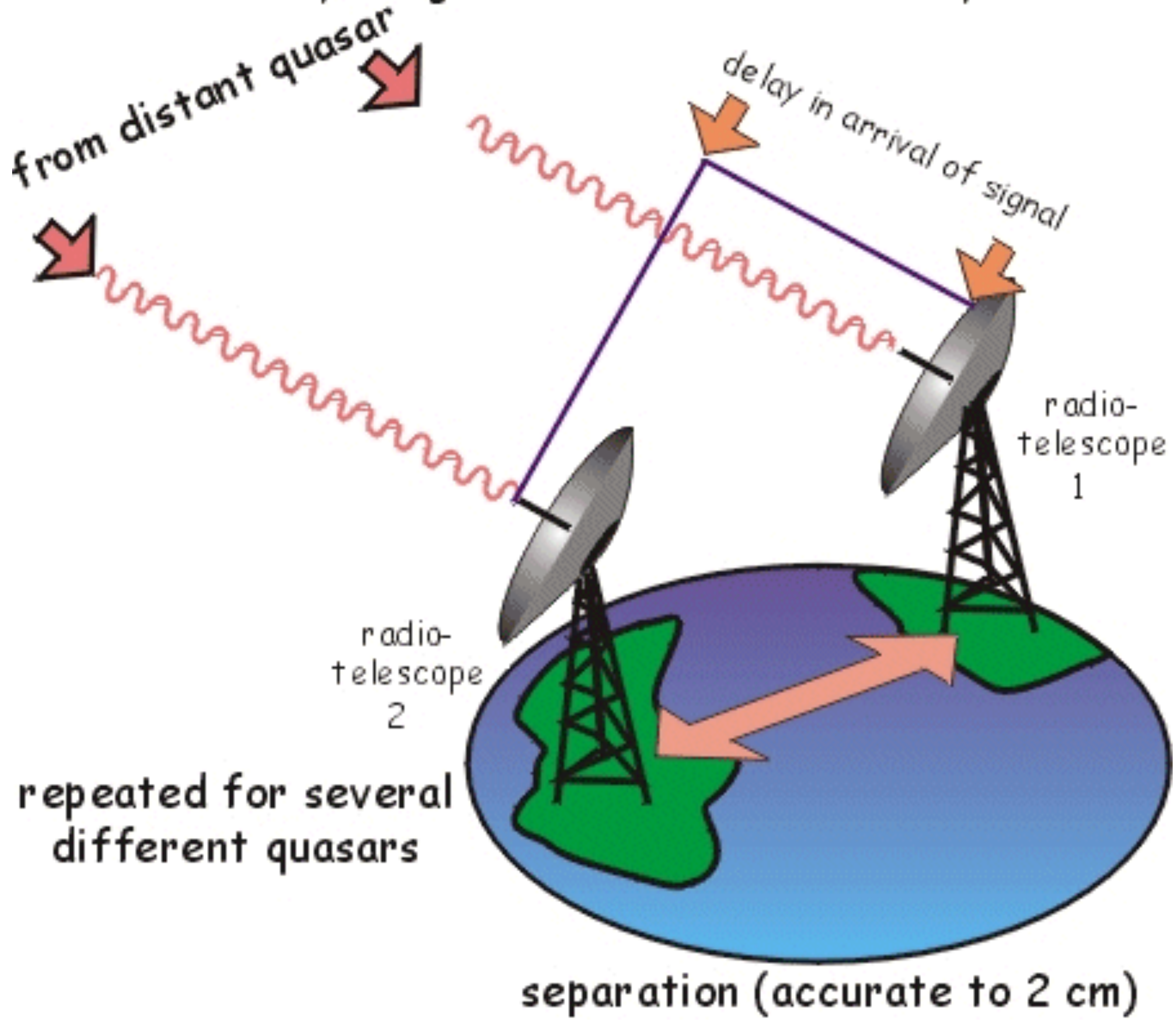
Continental Drift

"This must be left to the geodesists. I have no doubt that in the not too distant future we will be successful in making a precise measurement of the drift of North America relative to Europe."– A. Wegener, 1929

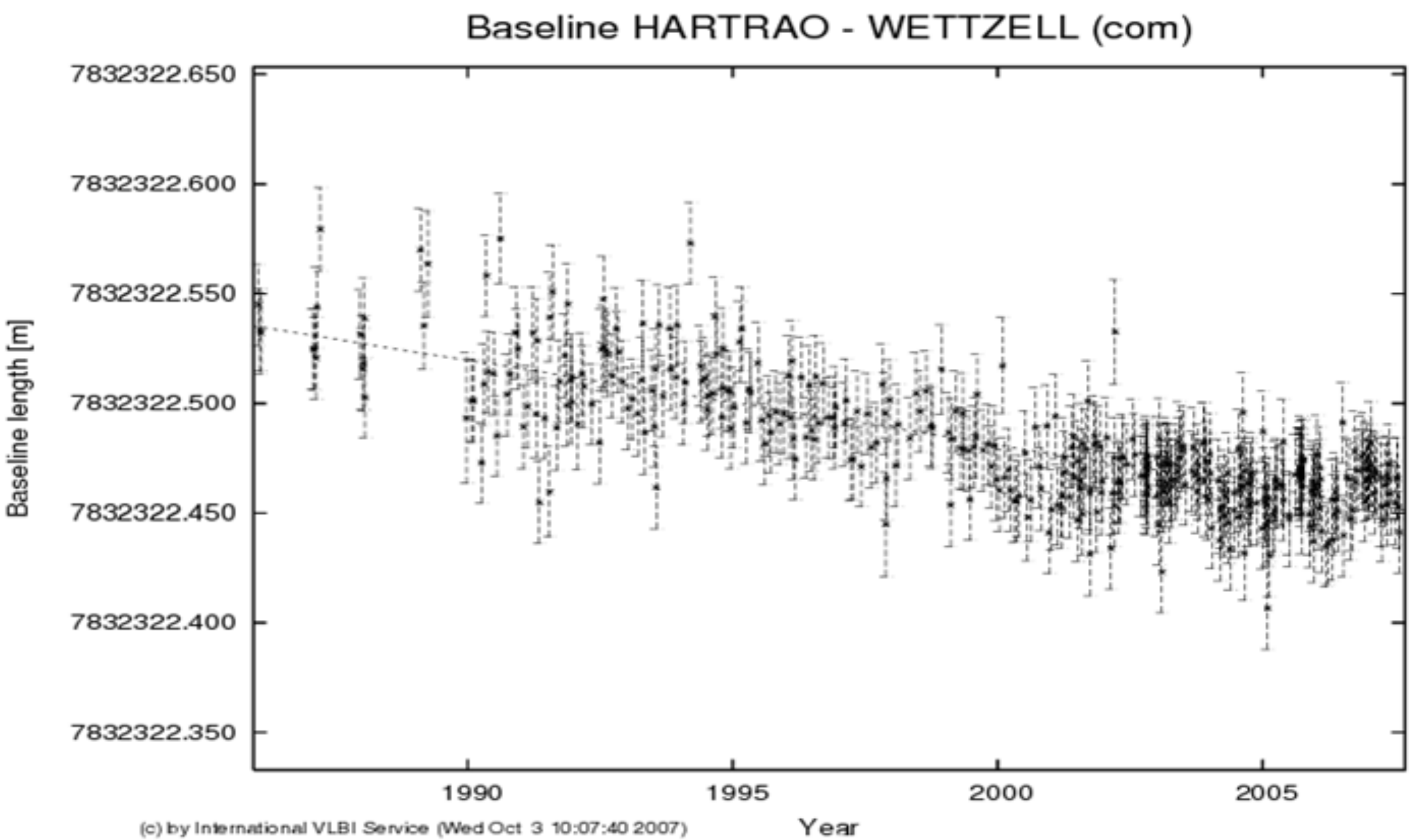
Very Long Baseline Interferometry (VLBI)

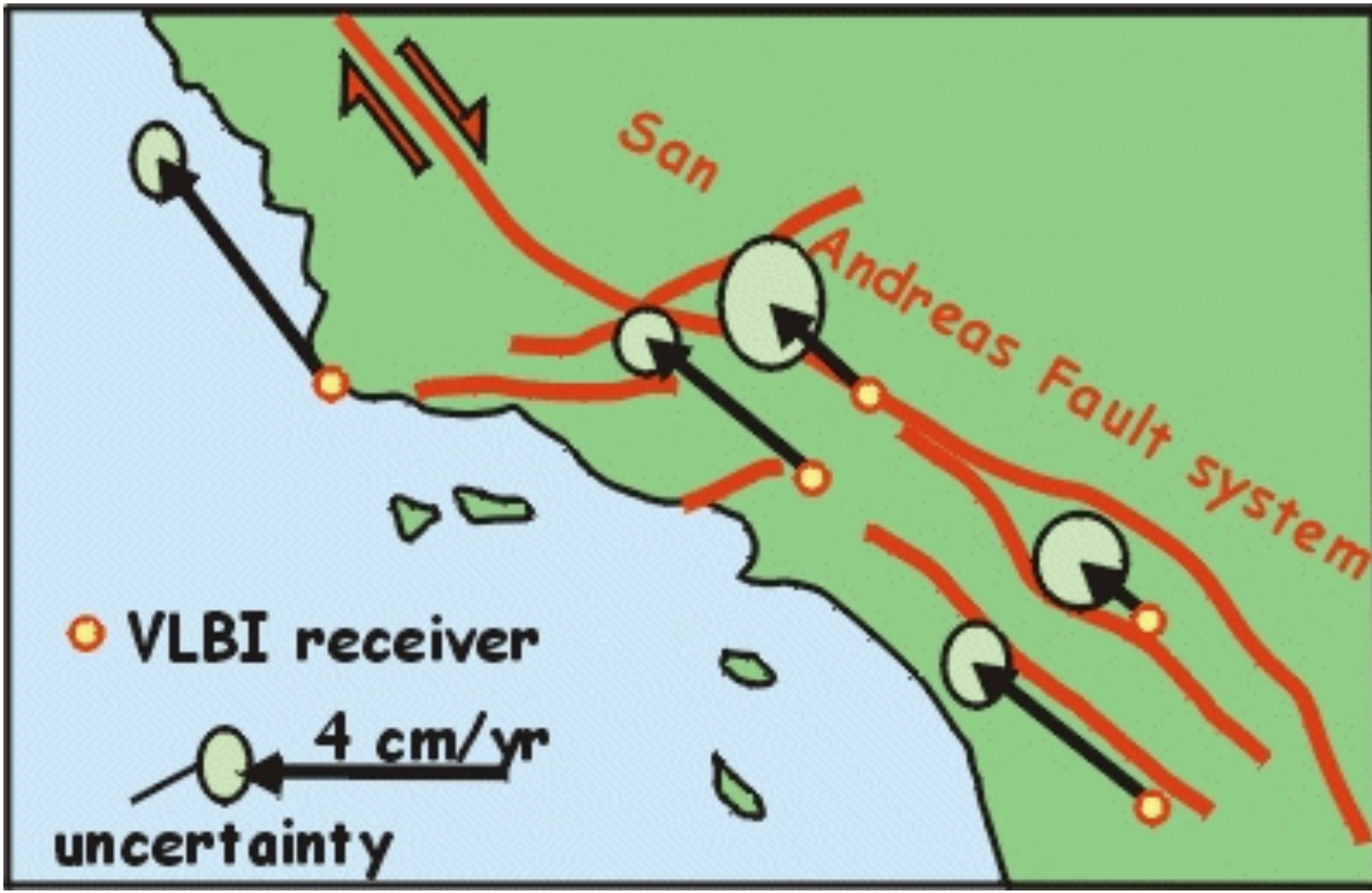


Very Long Baseline Interferometry

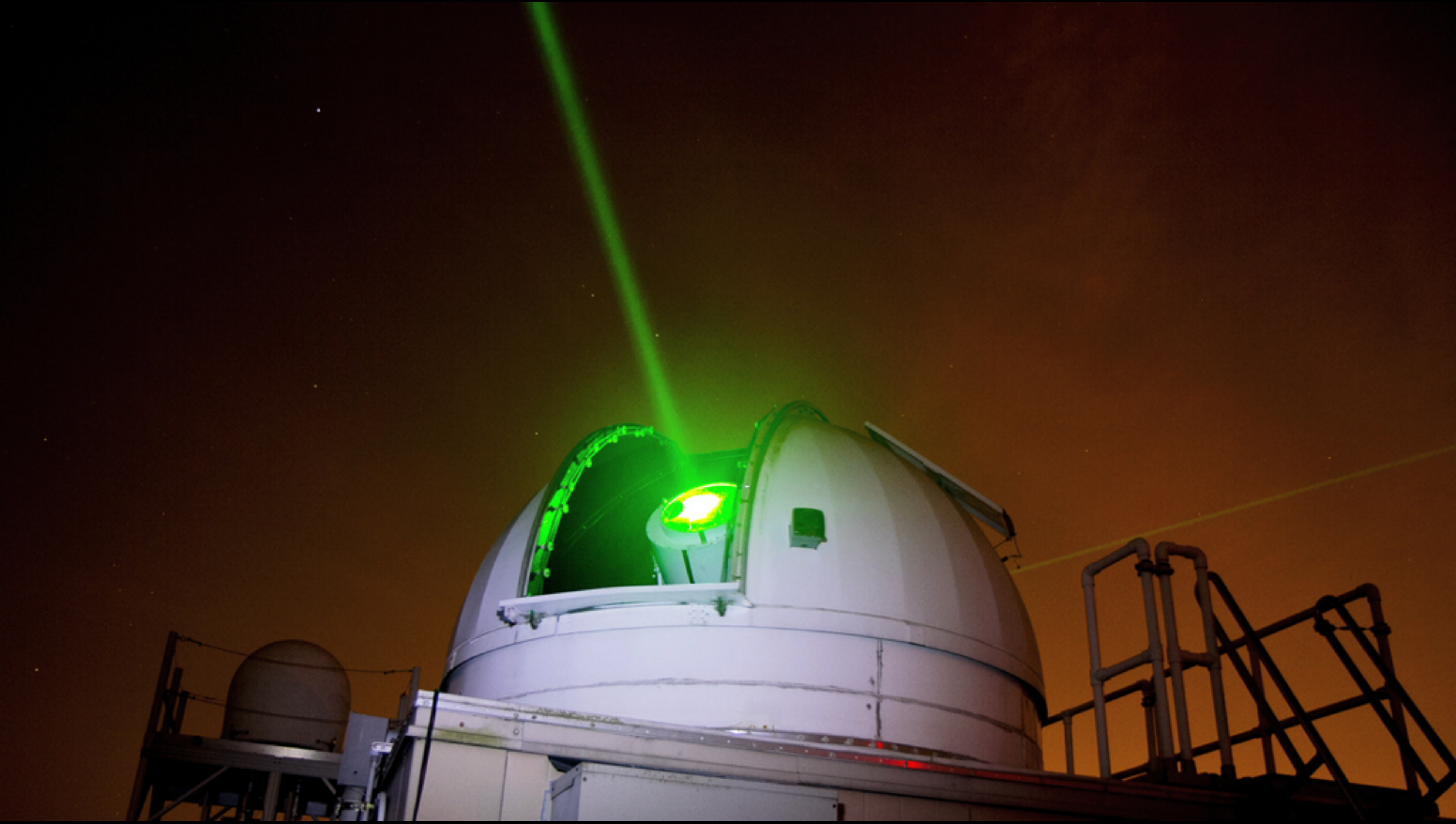


The Global VLBI - Array
Brewster
North Liberty
Hancock
Green Bank
Jodrell Lovell
Jodrell Mk2
Cambridge
Onsala 25m and 20m
Metsähovi
Los Alamos
Owens Valley
Pie Town
Mauna Kea
Kitt Peak
Urumqi
Shanghai
Westerbork
Medicina
Noto
EVN
VLBA
European VLBI Network (EVN)
Very Long Baseline Array (VLBA)
High Sensitivity Array (HSA)
Ft. Davis
St. Croix
V L A
Arecibo
Effelsberg
Yebes
Wettzell
Torun
Hartebeesthoek


Baseline HARTRAO - WETTZELL (com)
7832322.650
7832322.600
7832322.550
7832322.500
7832322.450
7832322.400
7832322.350
Baseline length [m]
1990
1995
2000
2005
Year
(c) by International VLBI Service (Wed Oct 3 10:07:40 2007)


San
Andreas Fault system
VLBI receiver
4 cm/yr
uncertainty

Satellite Laser Ranging (SLR)

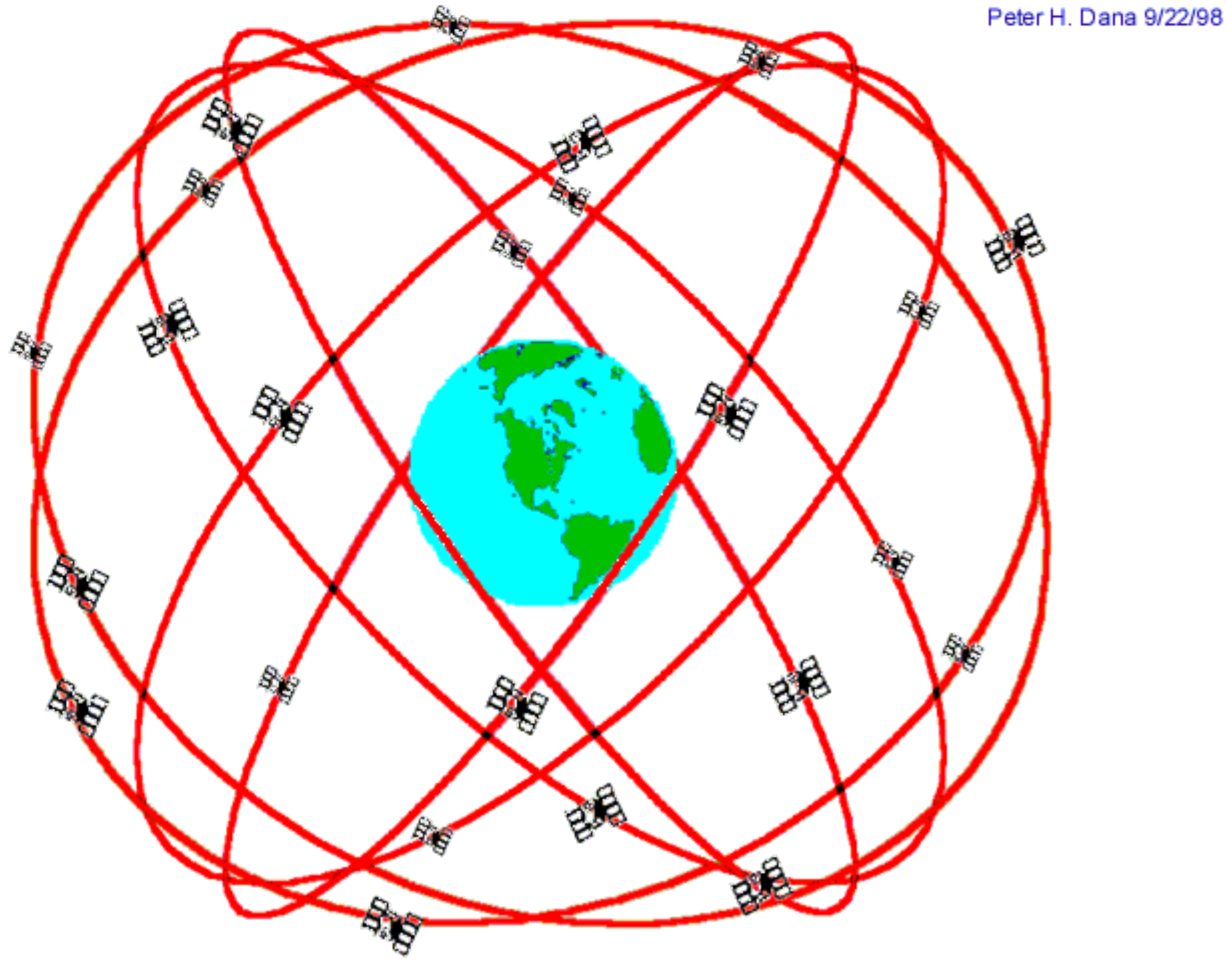



Metsahovi
Riga
Mendeleevo
Potsdam
Borowiec
Herstmonceux
Kiev
Wettzell
Lviv
Simeiz
Zimmerwald
Graz
Grasse
Katzively
Ajaccio
Matera
Cagliari
Chania
San Fernando
Helwan
Riyadh
Maidanak
Urumqi
Komsomolsk
Changchun
Beijing
Shanghai
Wuhan
Lhasa
Kunming
Tokyo
Simosato
Tanegashima
Keystone: Kashima
Koganei
Miura
Tateyama
Greenbelt
Stafford
Monument Peak
McDonald
Haleakala
Arequipa
Tahiti
San Juan
Concepción
Hartebeesthoek
Yarragadee
Mt. Stromlo
Operational ILRS System
Prospective Laser System
Historic Laser System Occupation
Mobile Systems: FTLRS (France)
TROS (China)
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-165°
-150°
-135°
-120°
-105°
-90°
-75°
-60°
-45°
-30°
-15°
0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°

Satellite Laser Ranging (SLR)

- fairly precise (~mm/yr accuracy)
- limited coverage
- costly to operate

Global Positioning System (GPS)



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

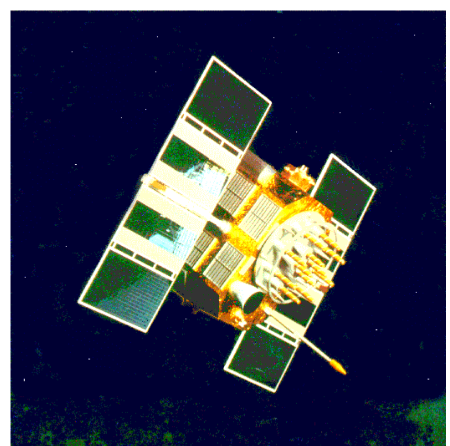
orbit ~ 12 hours

Global Positioning System (GPS)

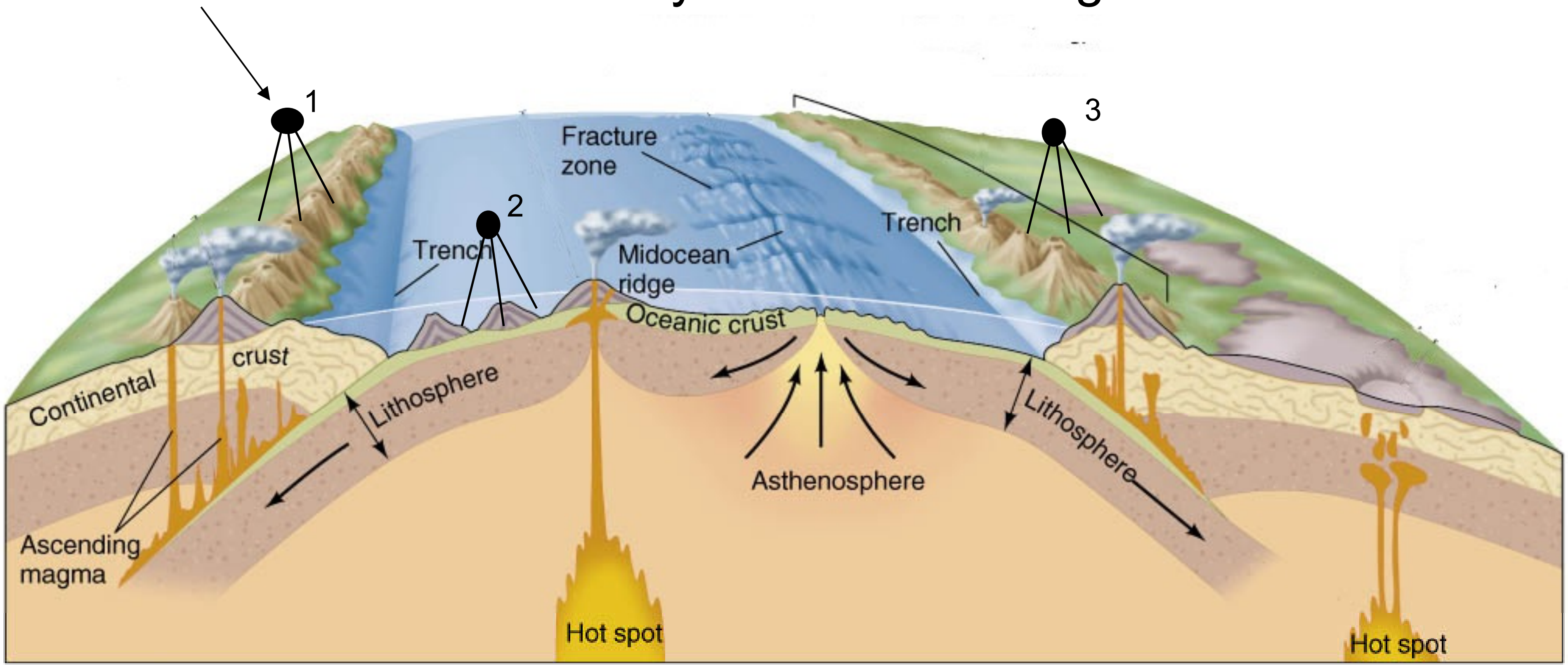
Funded and operated by the US Department of Defense

- constellation of 24 satellites in high altitude orbits
  (cost ~ $12 billion)
- coded satellite signals that can be processed in a GPS receiver to compute position, velocity, and time
- parts of system include:
  - space (GPS satellite vehicles, or SVs)
  - control (tracking stations)
  - users

first one launched in 1978
….June 26, 1993
Air Force launched 24th SV



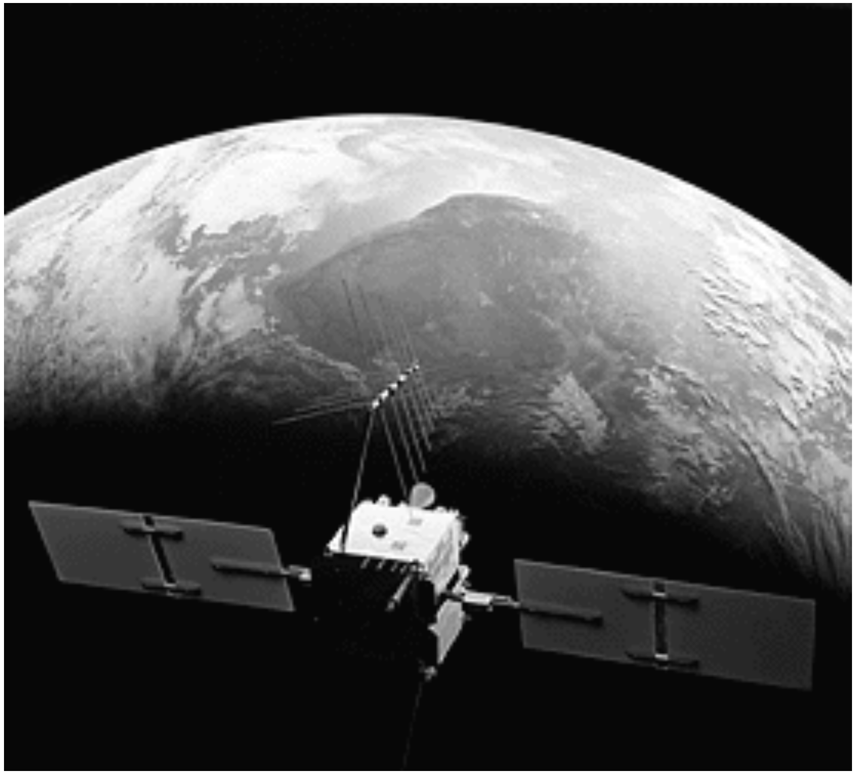
GPS stations are solidly attached to the ground.



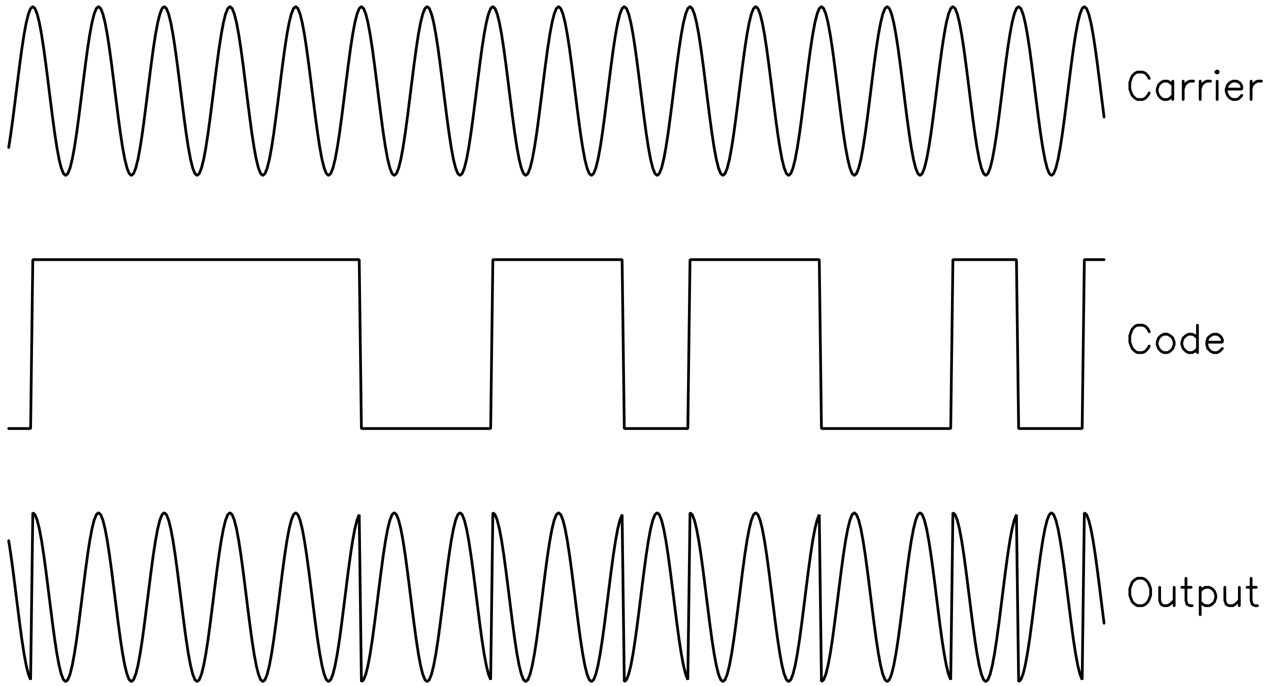
As the plates move, the position of these GPS stations change relative to one another

To understand how GPS works, we can break system into five conceptual pieces

step 1: using satellite ranging
step 2: measuring distance from satellite
step 3: getting perfect timing
step 4: knowing where a satellite is in space
step 5: identifying errors



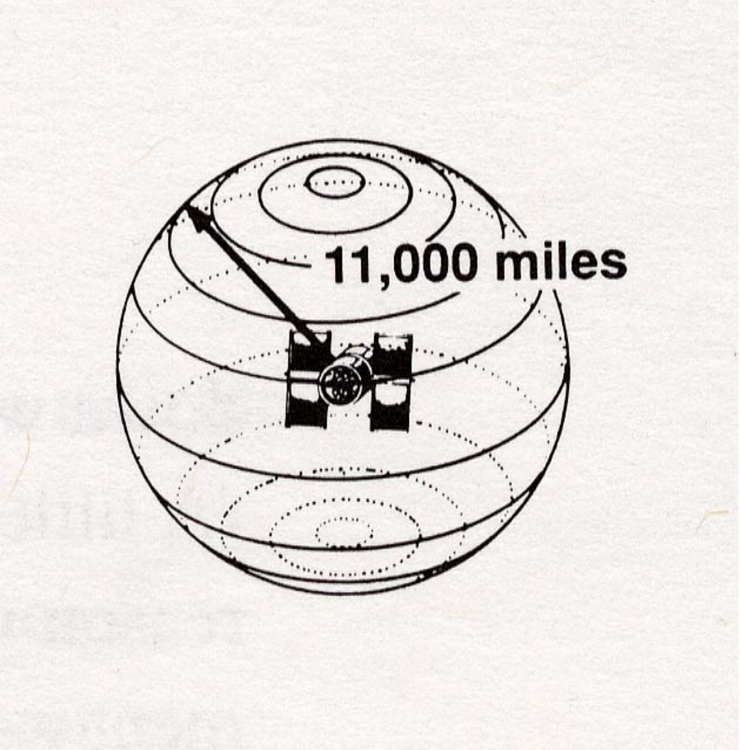
How the GPS Signal is Modulated



step 1: using satellite ranging

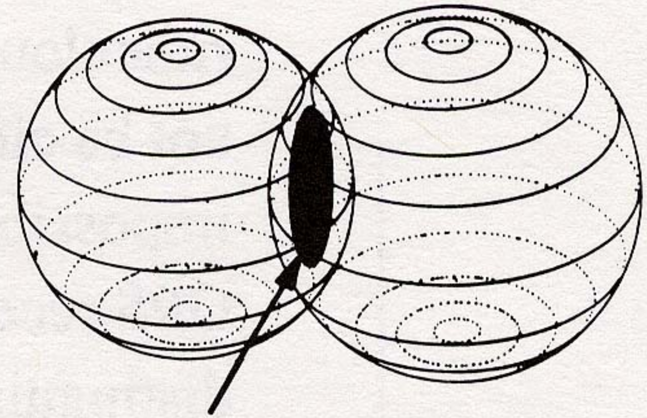
GPS is based on satellite ranging, i.e. distance from satellites
…satellites are precise reference points
…we determine our distance from them

we will assume for now that we know exactly where satellite is and how far away from it we are…



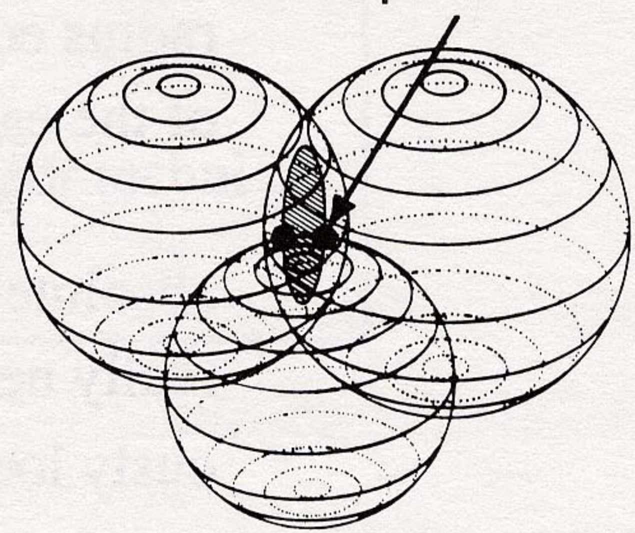
if we are lost and we know that we are 11,000 miles from satellite A…
we are somewhere on a sphere whose middle is satellite A and diameter is 11,000 miles

if we also know that we are
12,000 miles from satellite B
…we can narrow down where
we must be…
only place in universe is on
circle where two spheres intersect



two measurements puts
us somewhere on this circle

three measurements puts us
at one of two points



if we also know that we are
13,000 miles from satellite C
…our situation improves
immensely…
only place in universe is at
either of two points where
three spheres intersect

three can be enough to determine position…

one of the two points generally is not possible (far off in space)

two can be enough if you know your elevation

…why?

one of the spheres can be replaced with Earth…

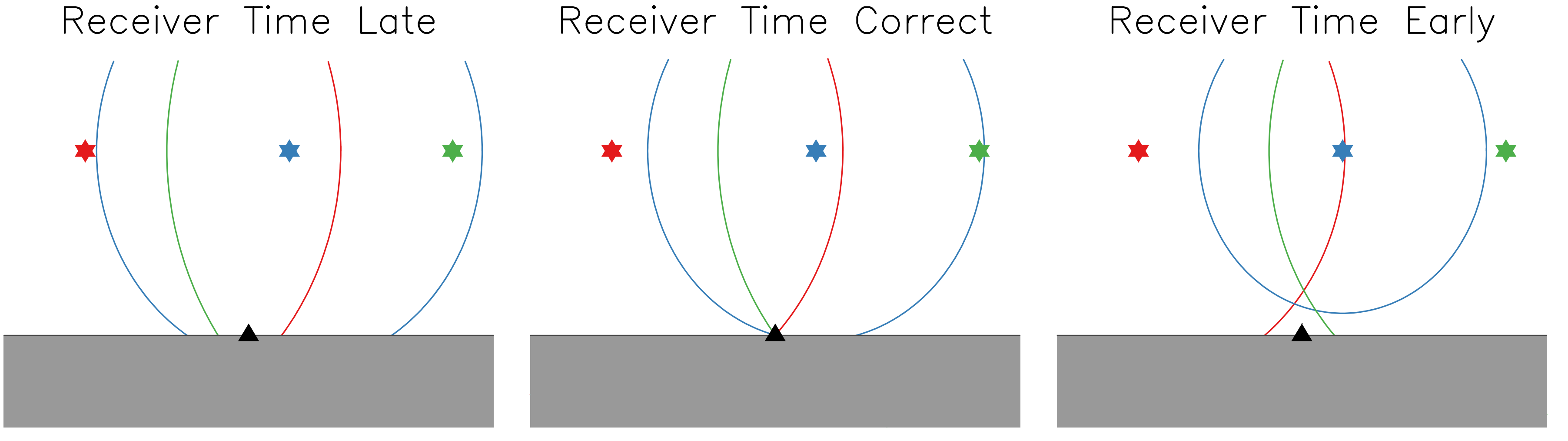
…center of Earth is “satellite position”

generally four are best and necessary…. (why is this?)

this is basic principle behind GPS…

…using satellites for triangulation

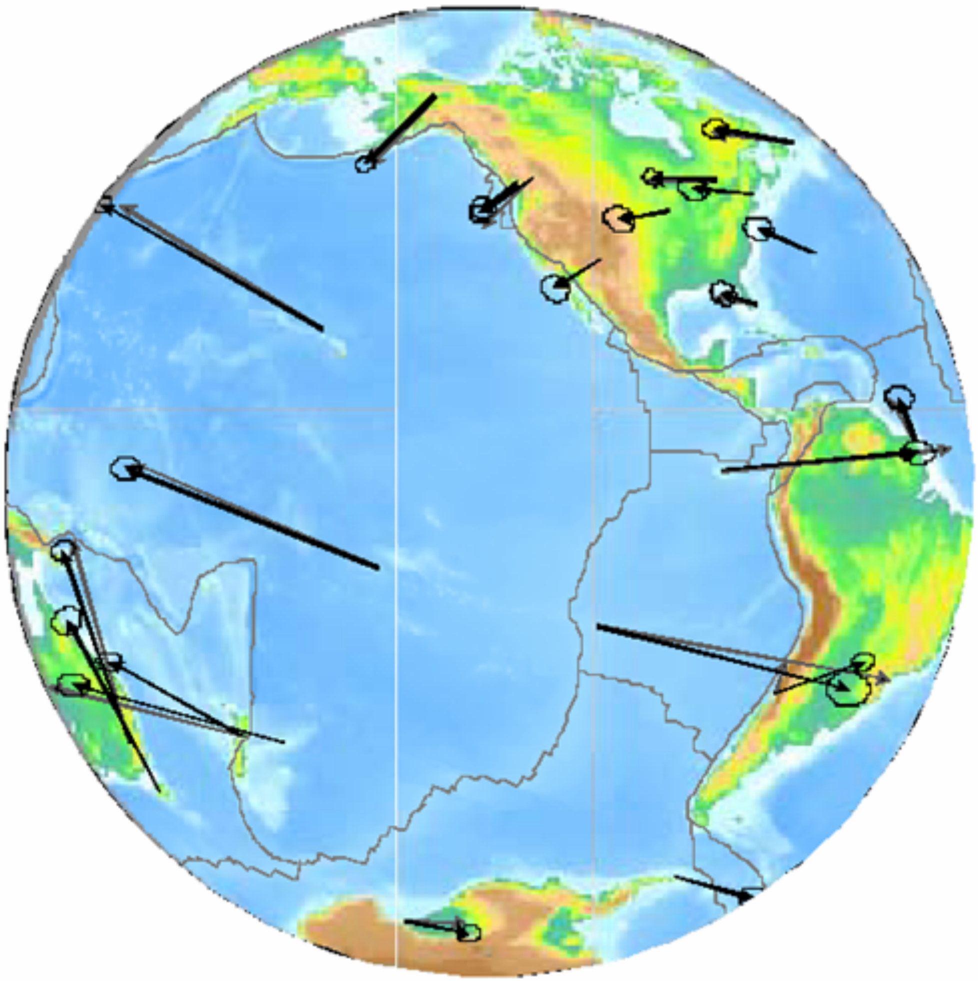
Solving the Clock Problem



- Measure motions over a few years (vectors in black)

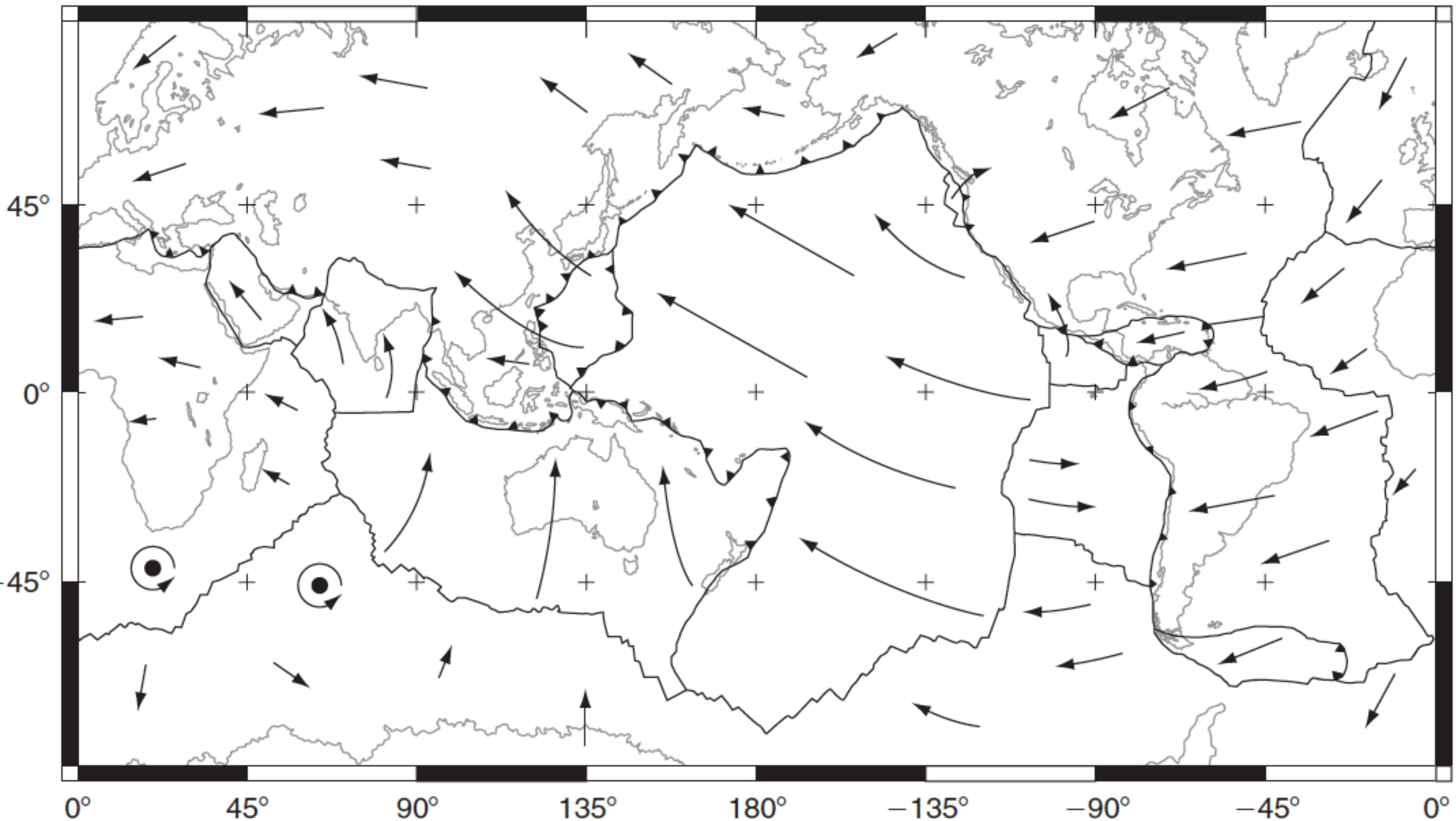
- Compare to those over millions of years (vectors in grey)

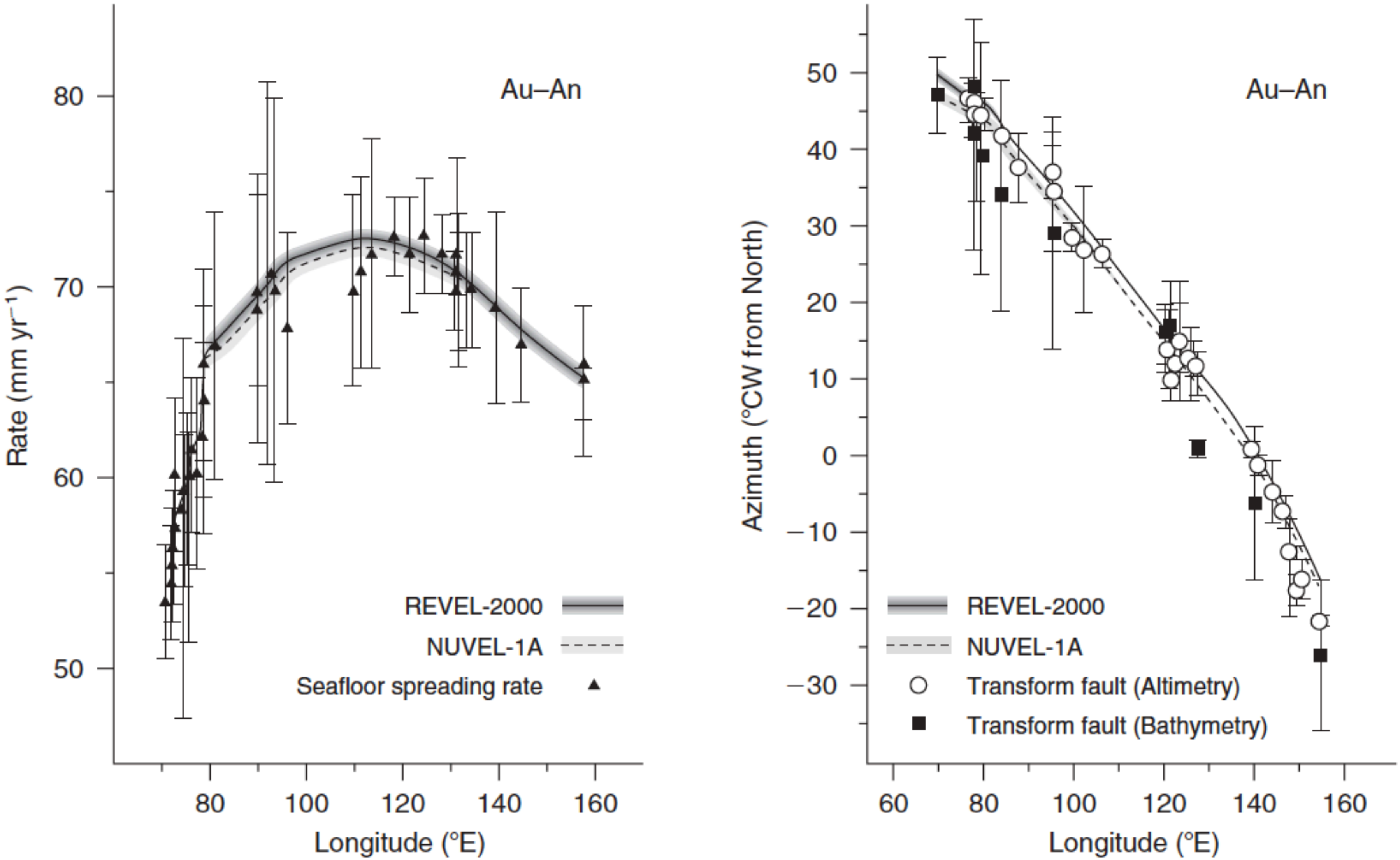
(the circles show the potential error in measurement)



Larson et al. [1997]

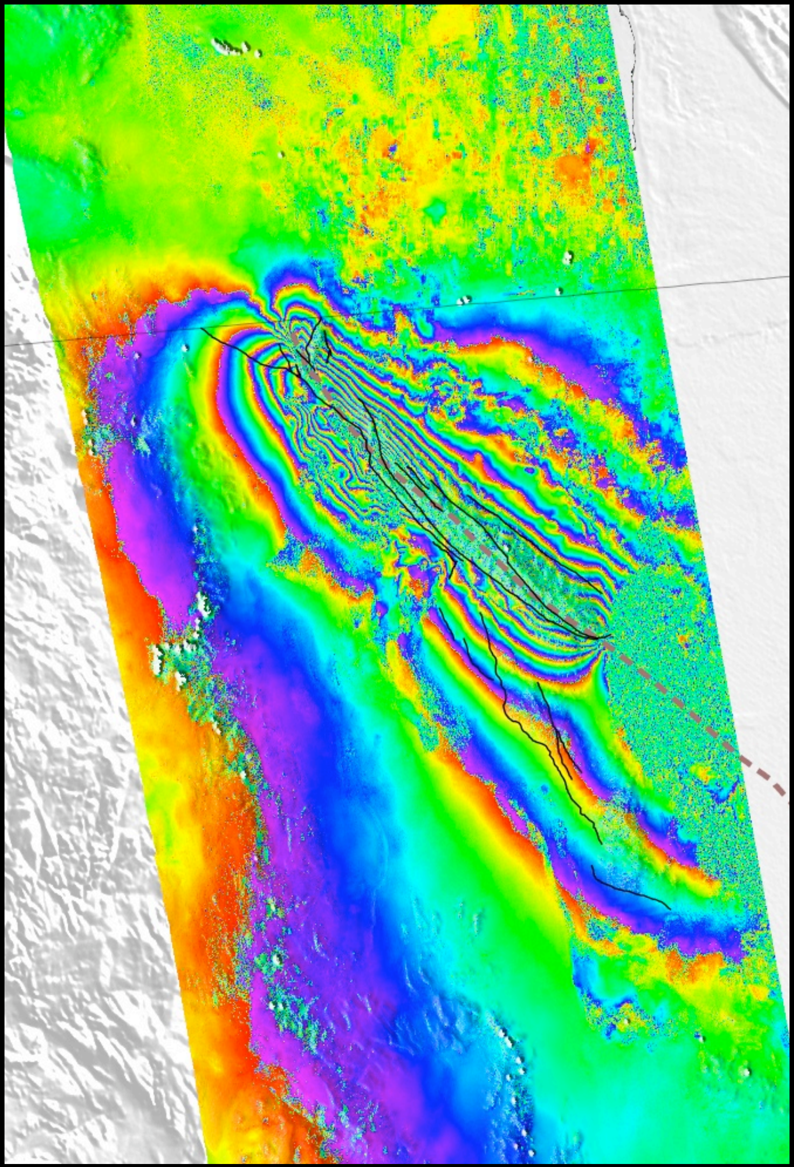
Absolute Plate Velocities



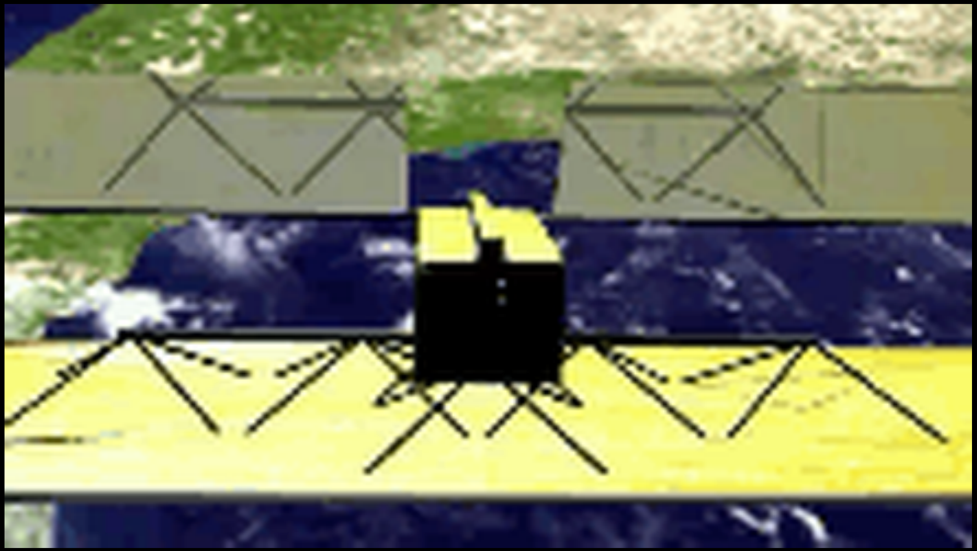


REVEL-2000 – space-geodetic velocity model (Sellla et al., 2000)

Interferometric Synthetic Aperture Radar (InSAR)



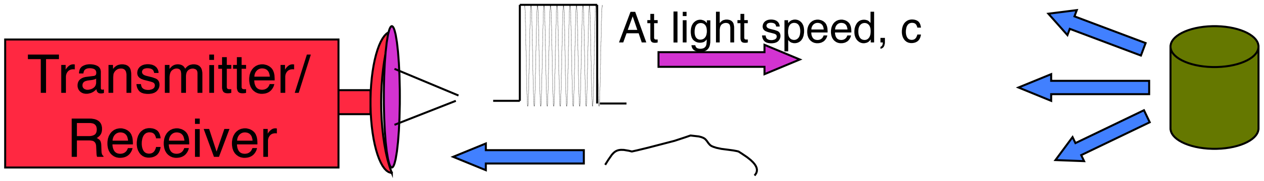
radar inerferogram of the 2010 El Mayor eq

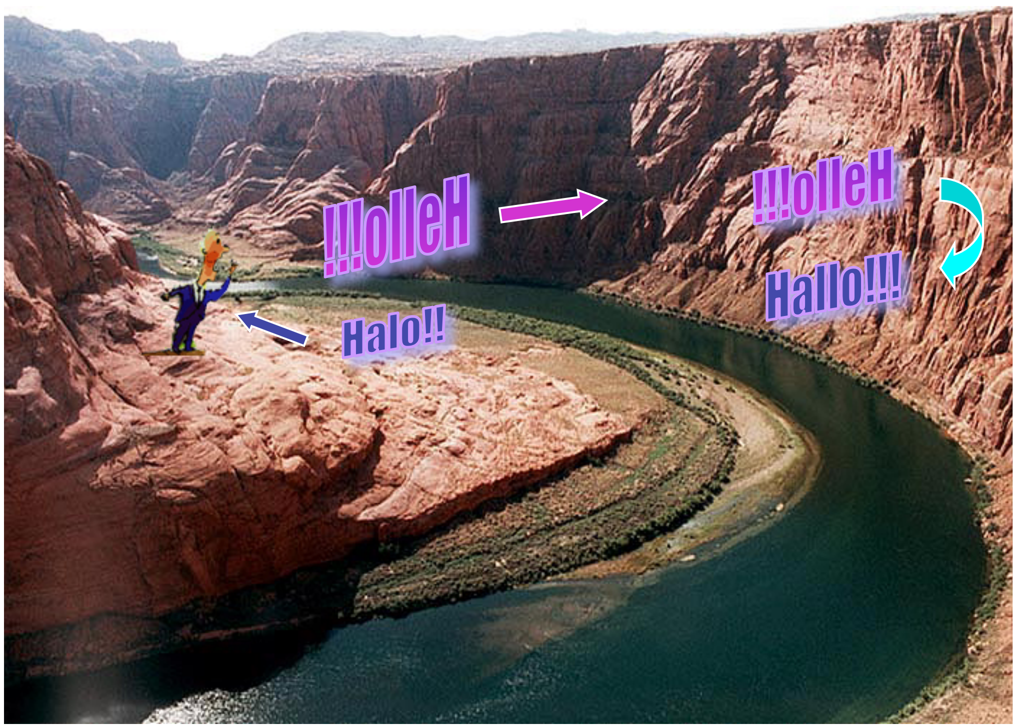


animation: JPL, NASA

- Space- or airborne radar platforms
- Repeat orbits
- Day and night, clouds/no clouds
- Scalar measurement
- Spatially dense, temporally sparse

The Radar Concept





- Much like sound waves, radar waves carry information that echoes from distant objects
- The time delay of the echo measures the distance to the object
- The changes of the message in the echo determines the object characteristics

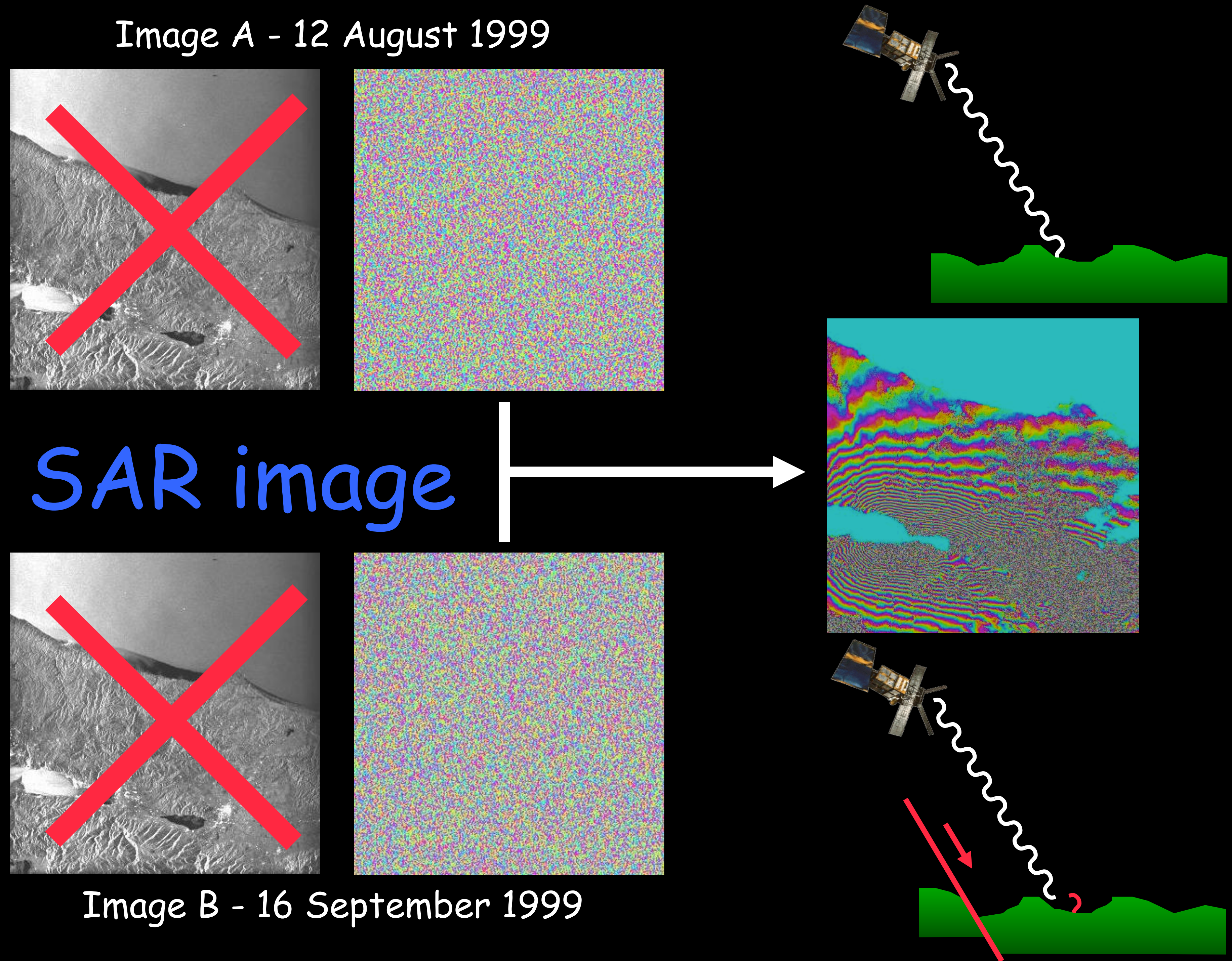
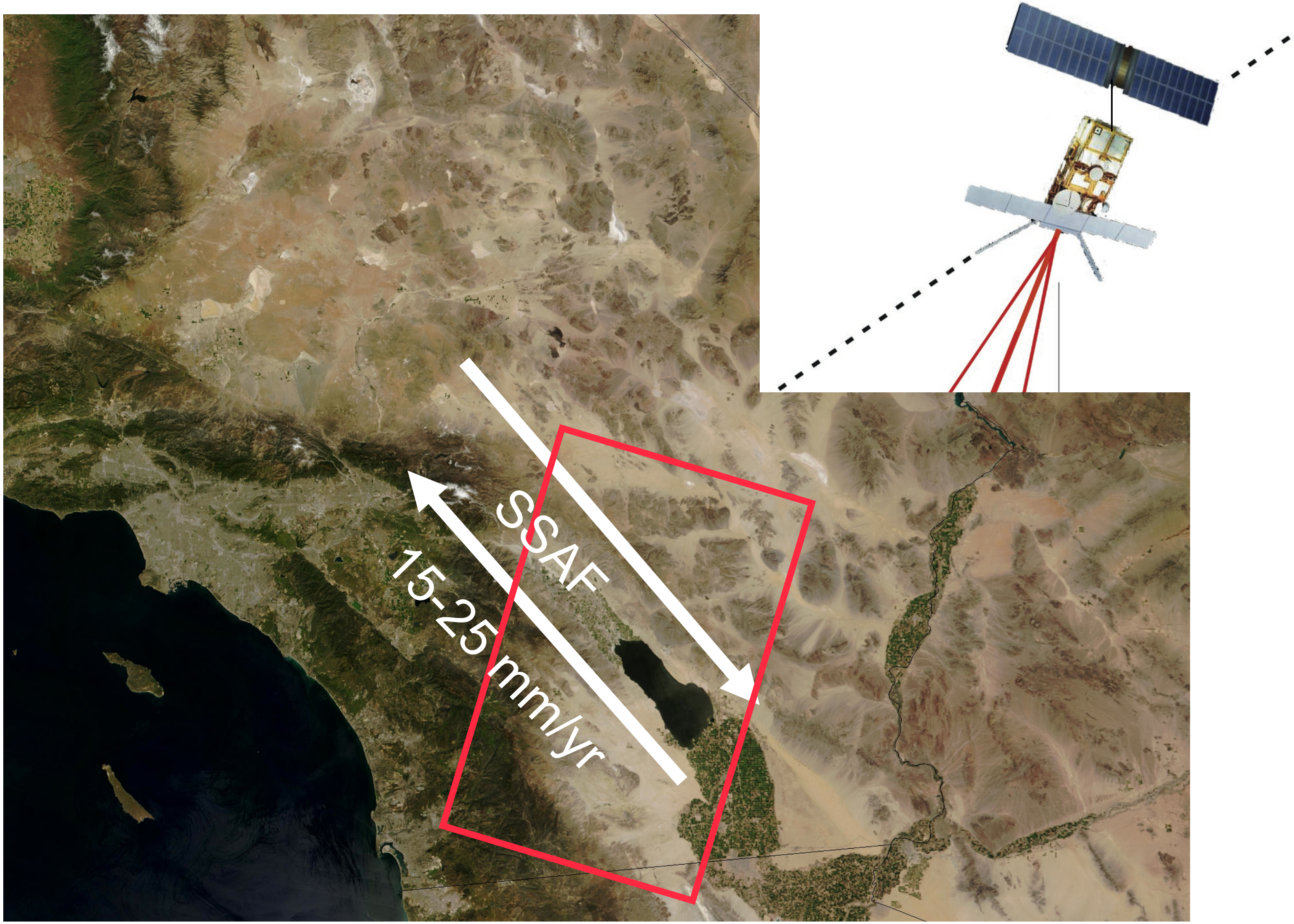


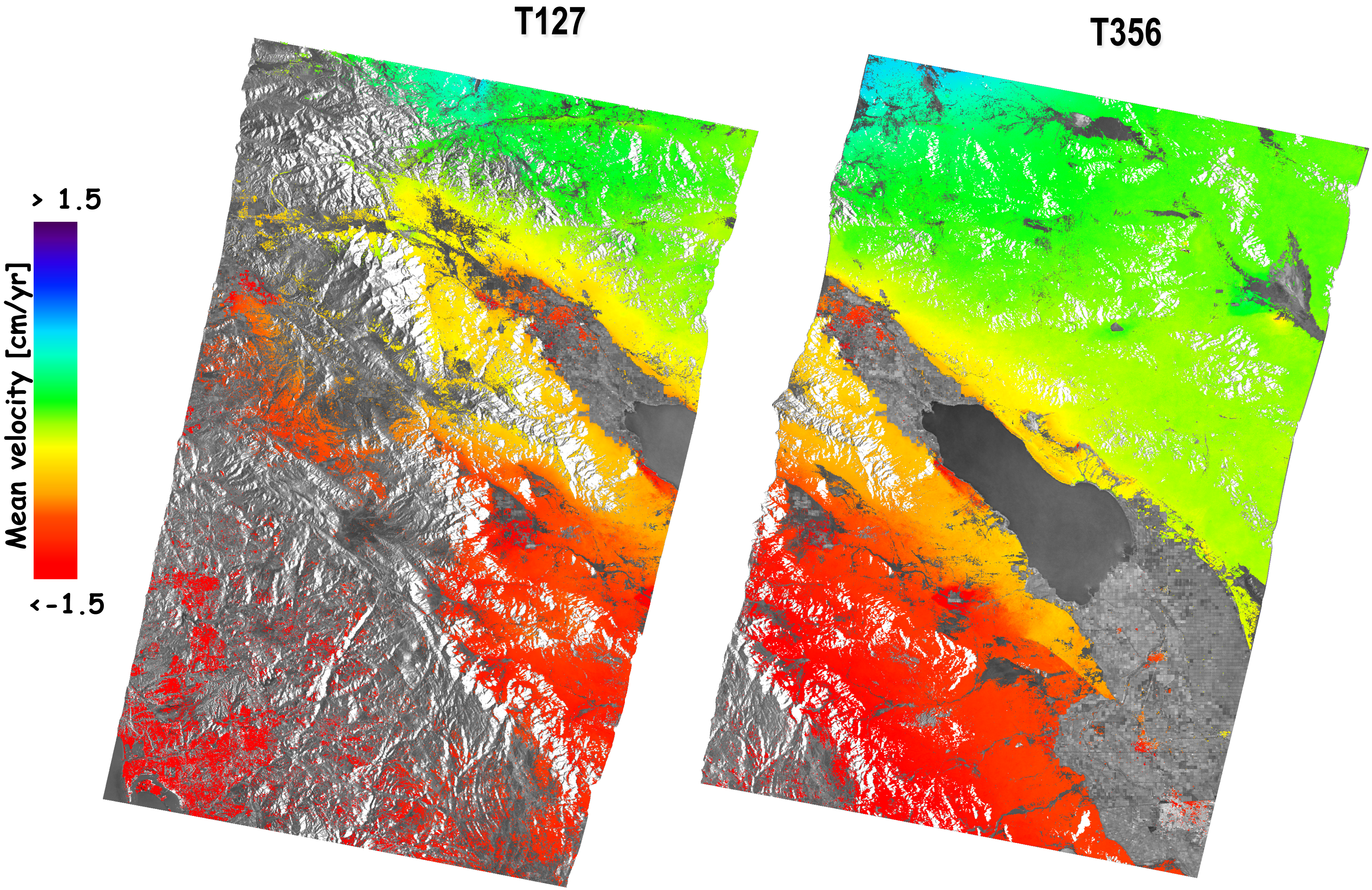
Image A - 12 August 1999
SAR image
Image B - 16 September 1999



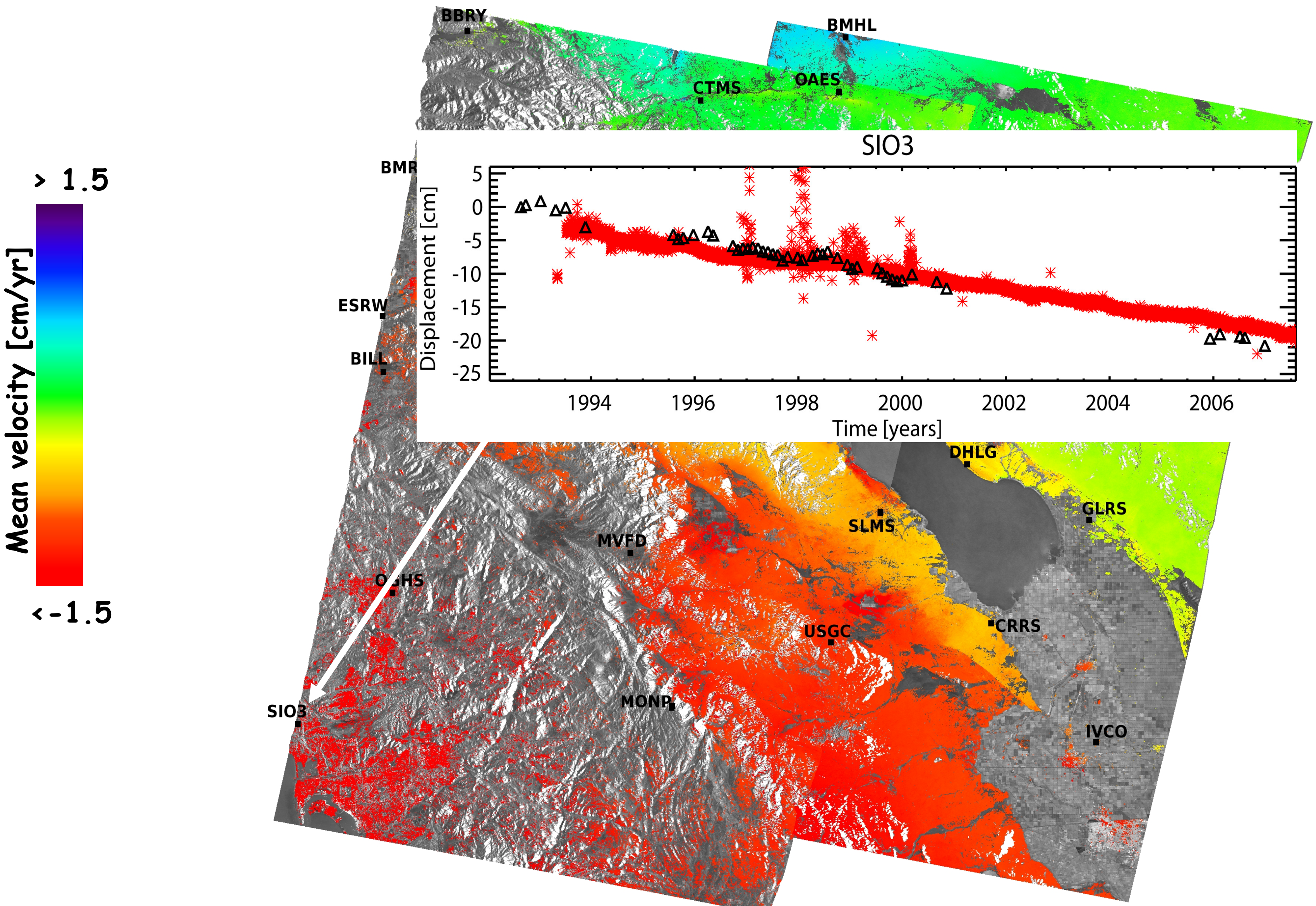
15 years (1992-2007)
InSAR data
campaign and continuous GPS

Fialko, 2006

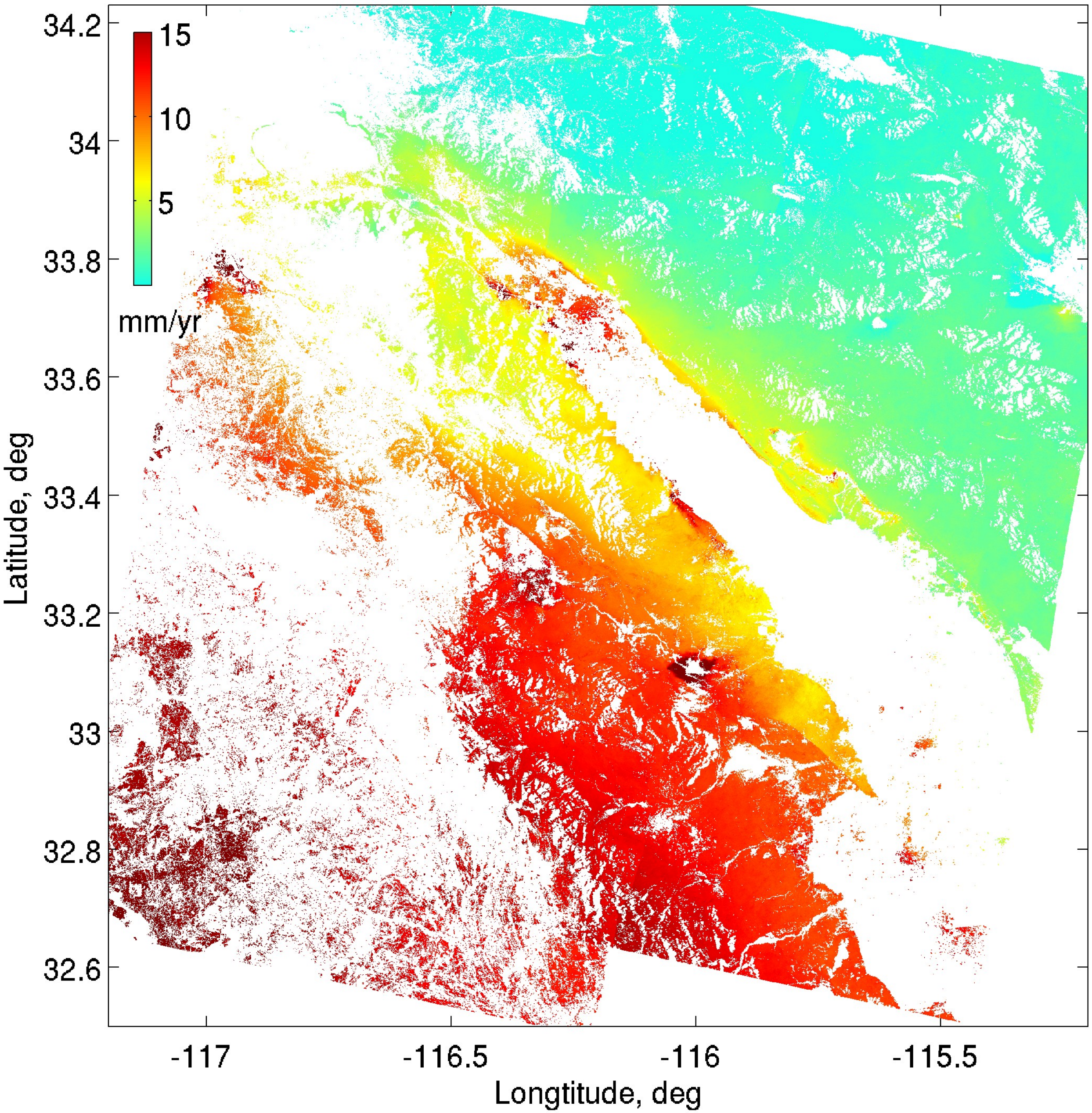
ERS-1/2: 1992-2007



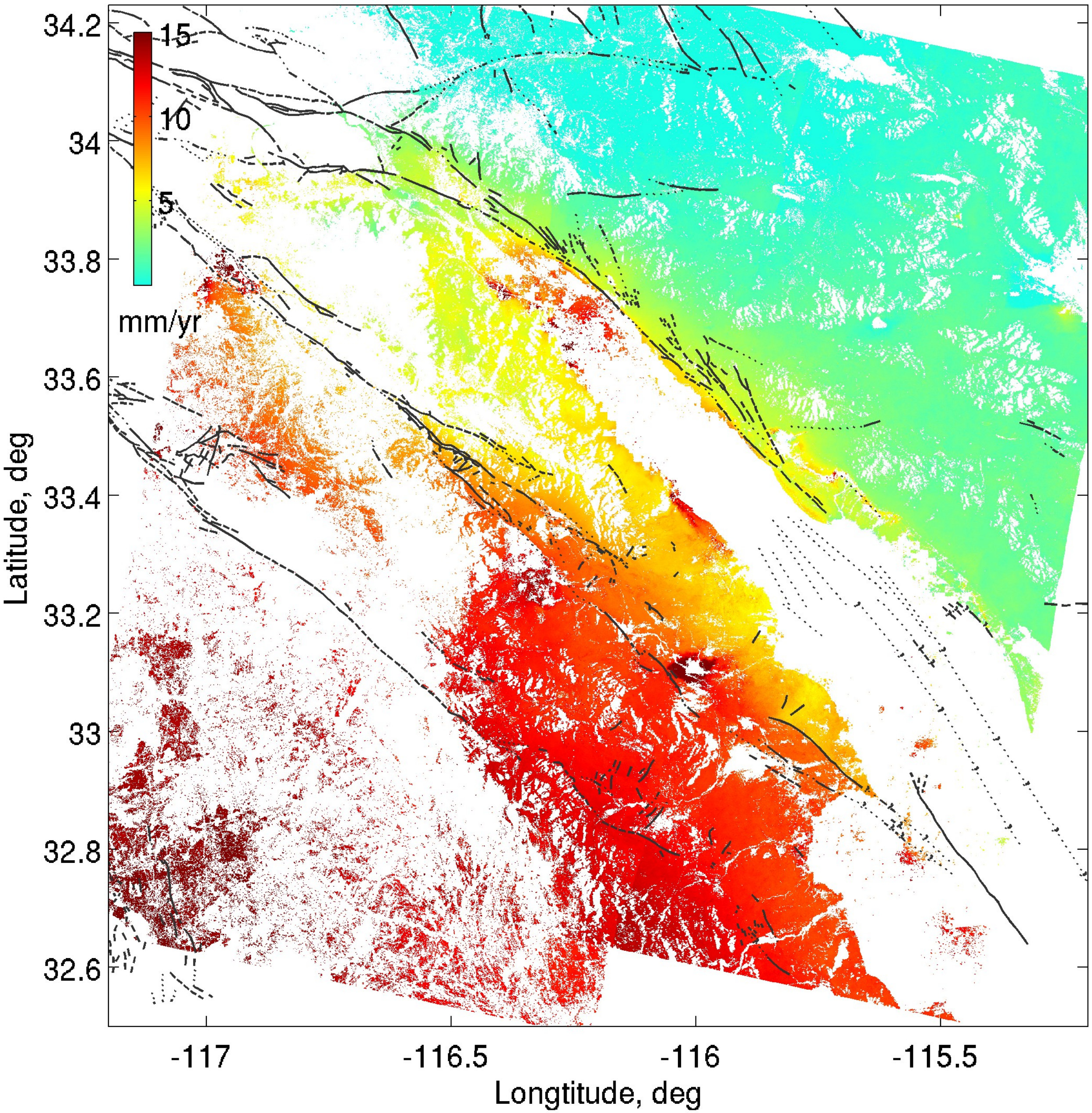
Manzo et al., 2012



Manzo et al., 2012



15
10
5
mm/yr
34.2
34
33.8
33.6
33.4
33.2
33
32.8
32.6
Latitude, deg
-117
-116.5
-116
-115.5
Longtitude, deg



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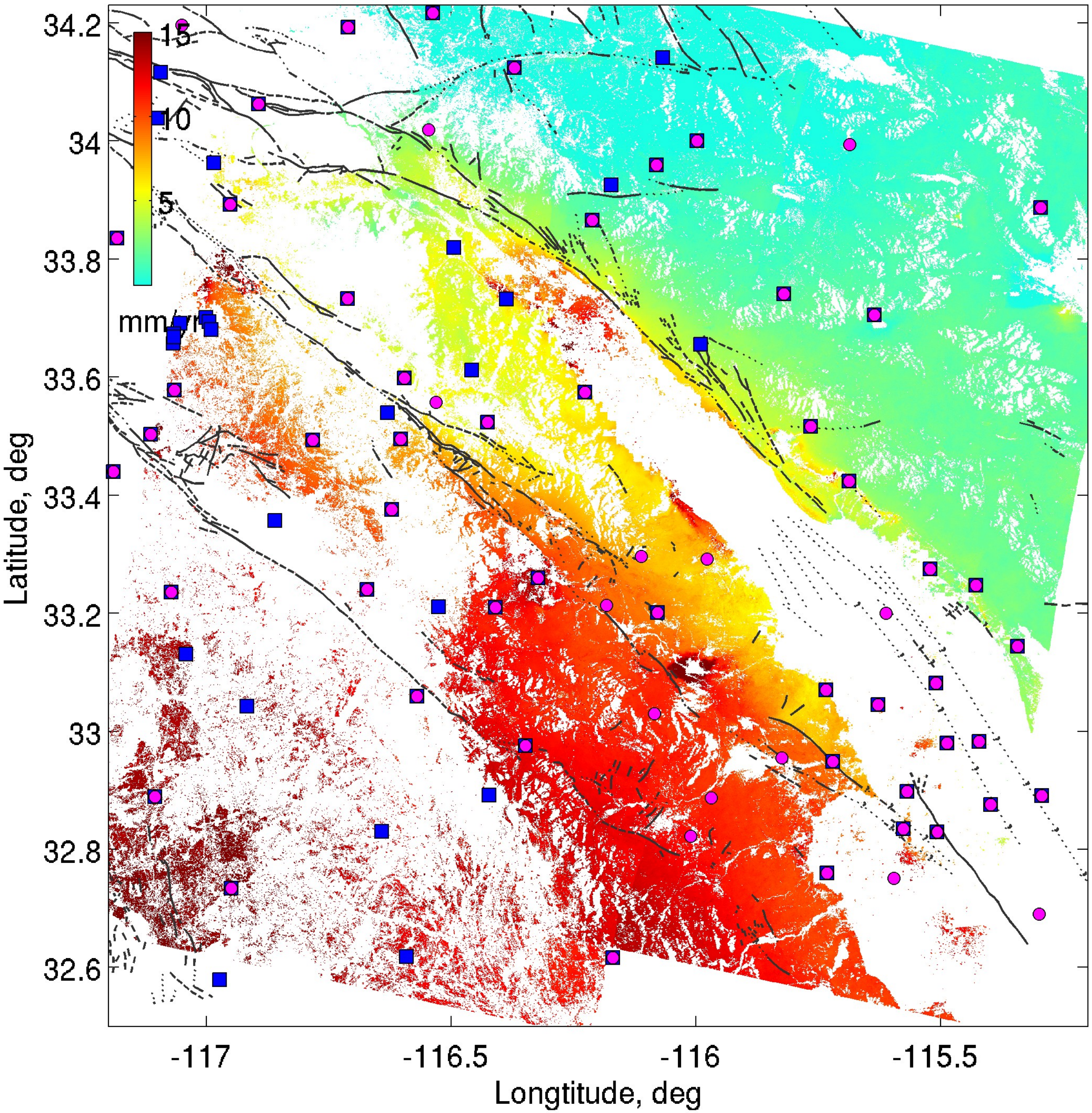

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Latitude, deg
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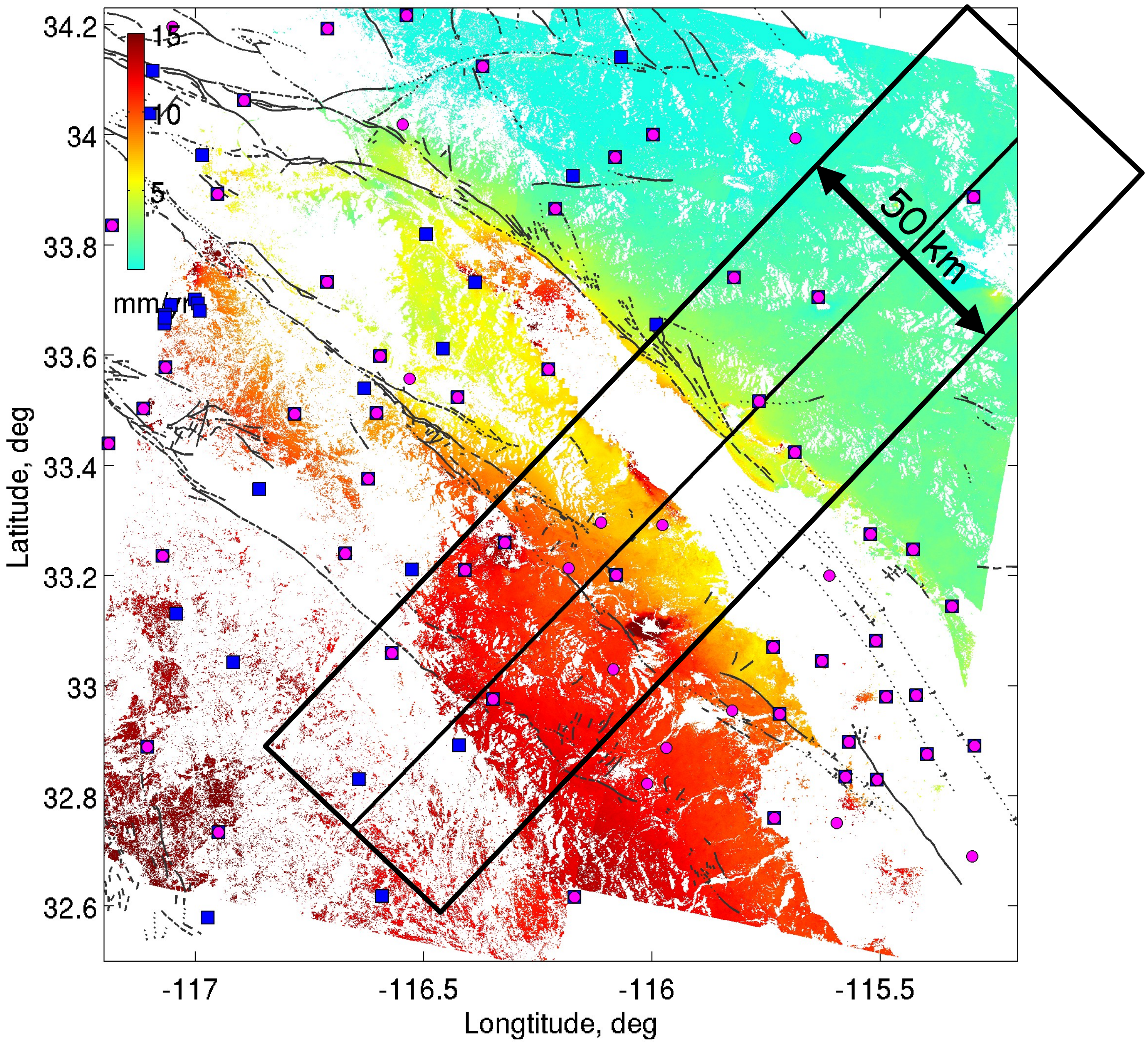

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32.8
32.6
Latitude, deg
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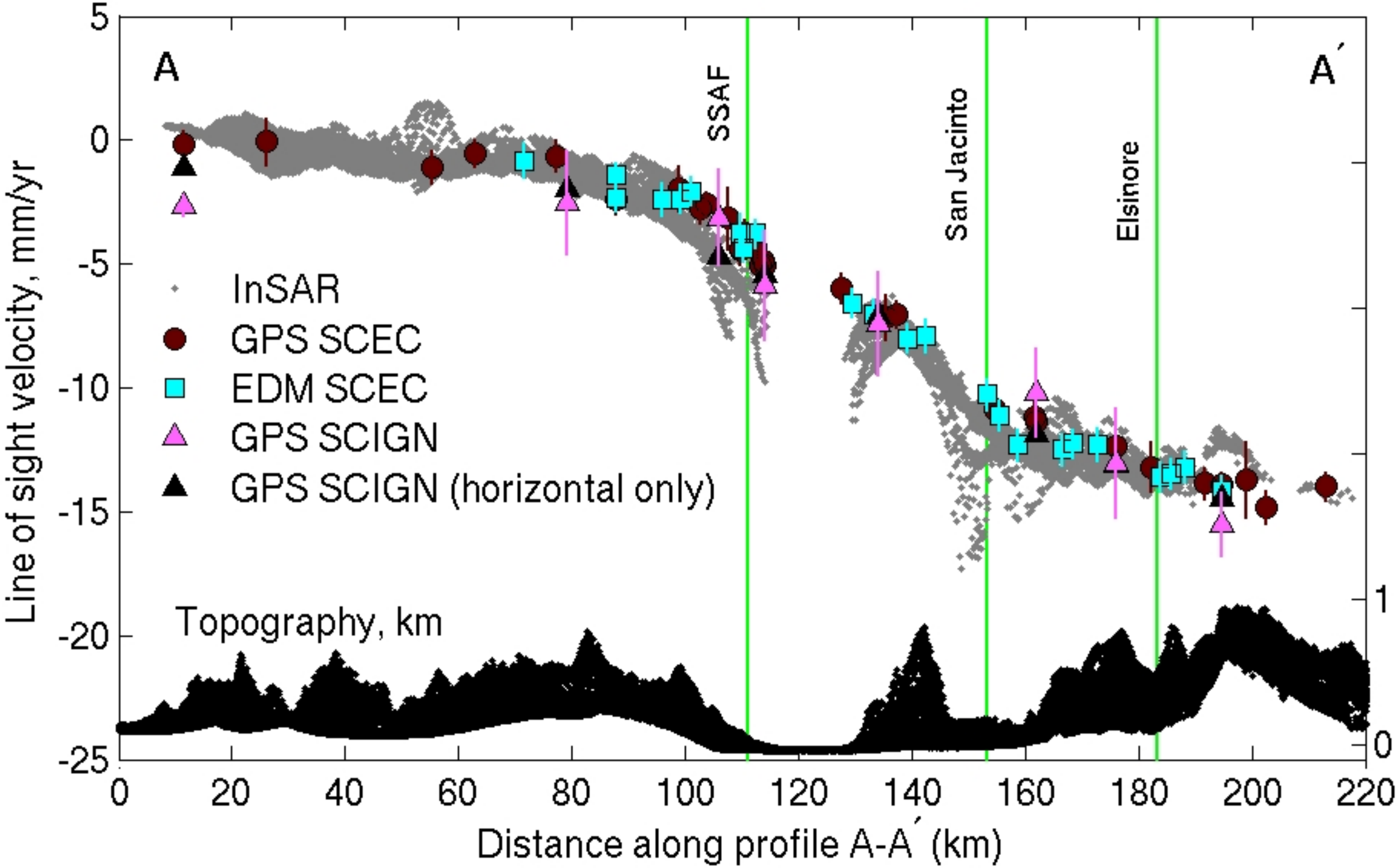
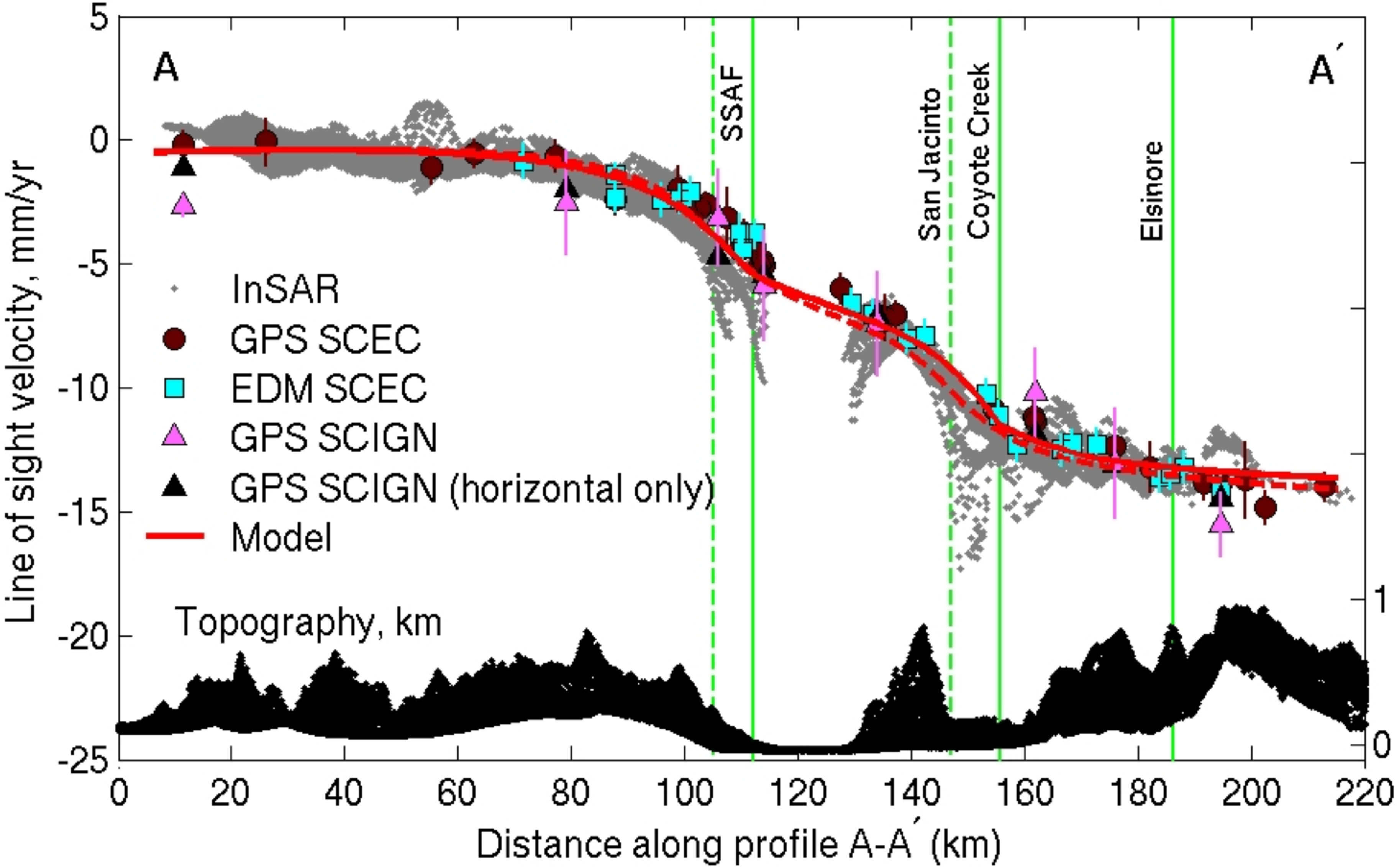
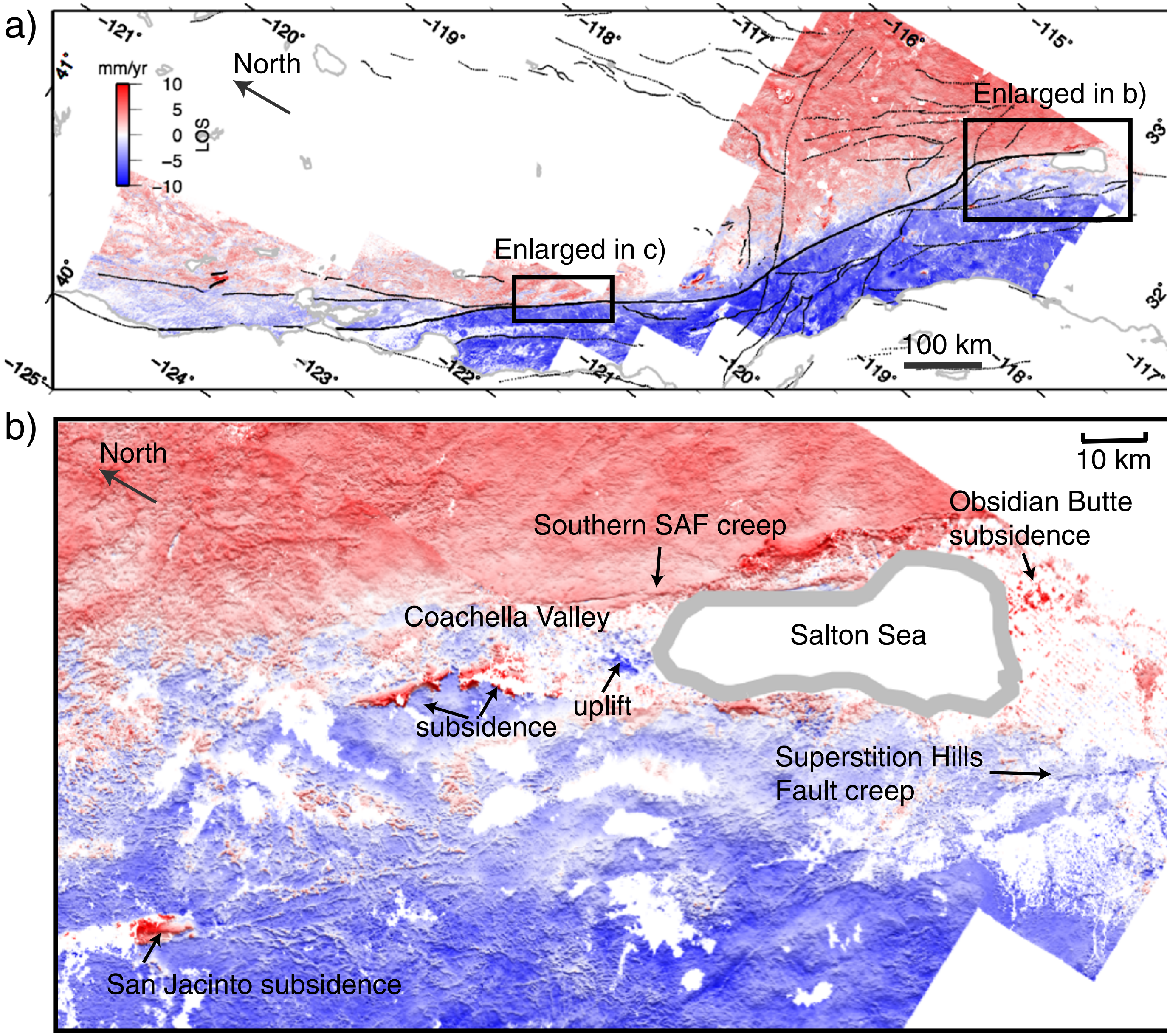
-116.5
-116
-115.5
Longtitude, deg



A
A´
SSAF
San Jacinto
Elsinore
InSAR
GPS SCEC
EDM SCEC
GPS SCIGN
GPS SCIGN (horizontal only)
Topography, km
Line of sight velocity, mm/yr
Distance along profile A-A´ (km)
5
0
-5
-10
-15
-20
-25
0
20
40
60
80
100
120
140
160
180
200
220
1
0

15-20 mm/yr x 300 yrs = 4-6 m !





Tong et al., 2013