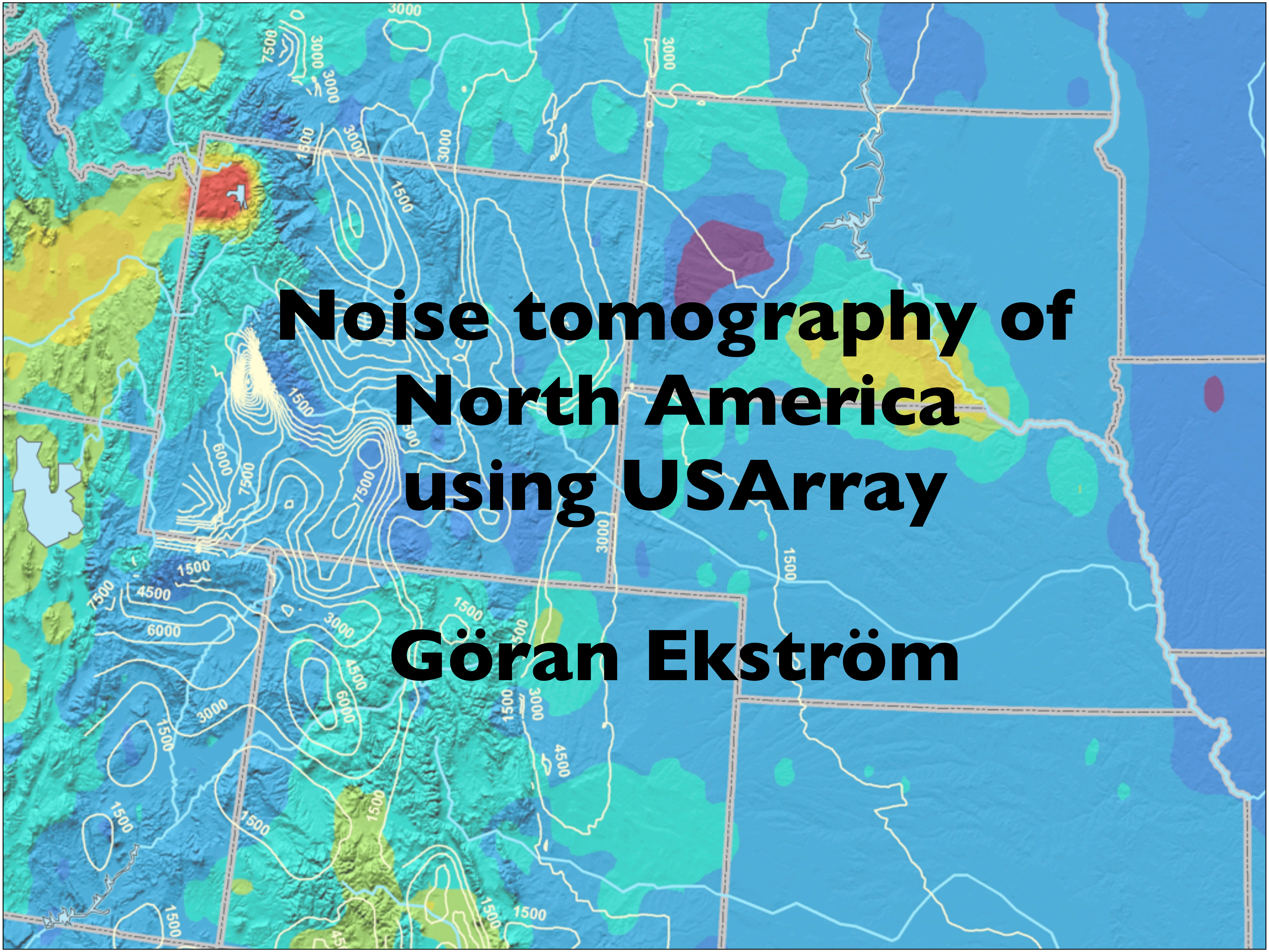
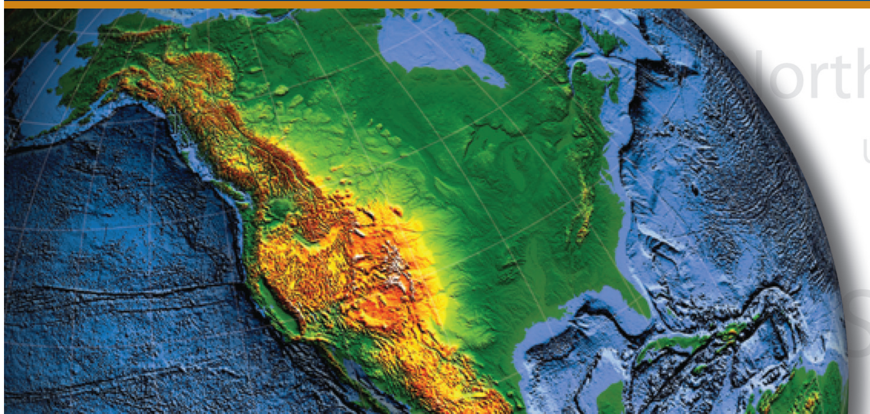


Noise tomography of North America using USArray

Göran Ekström

1. A few words about EarthScope and USArray
2. Surface-wave studies of the crust and mantle
3. Tomography using noise and Aki's method
4. Remarkable images of US crust (and basins)!

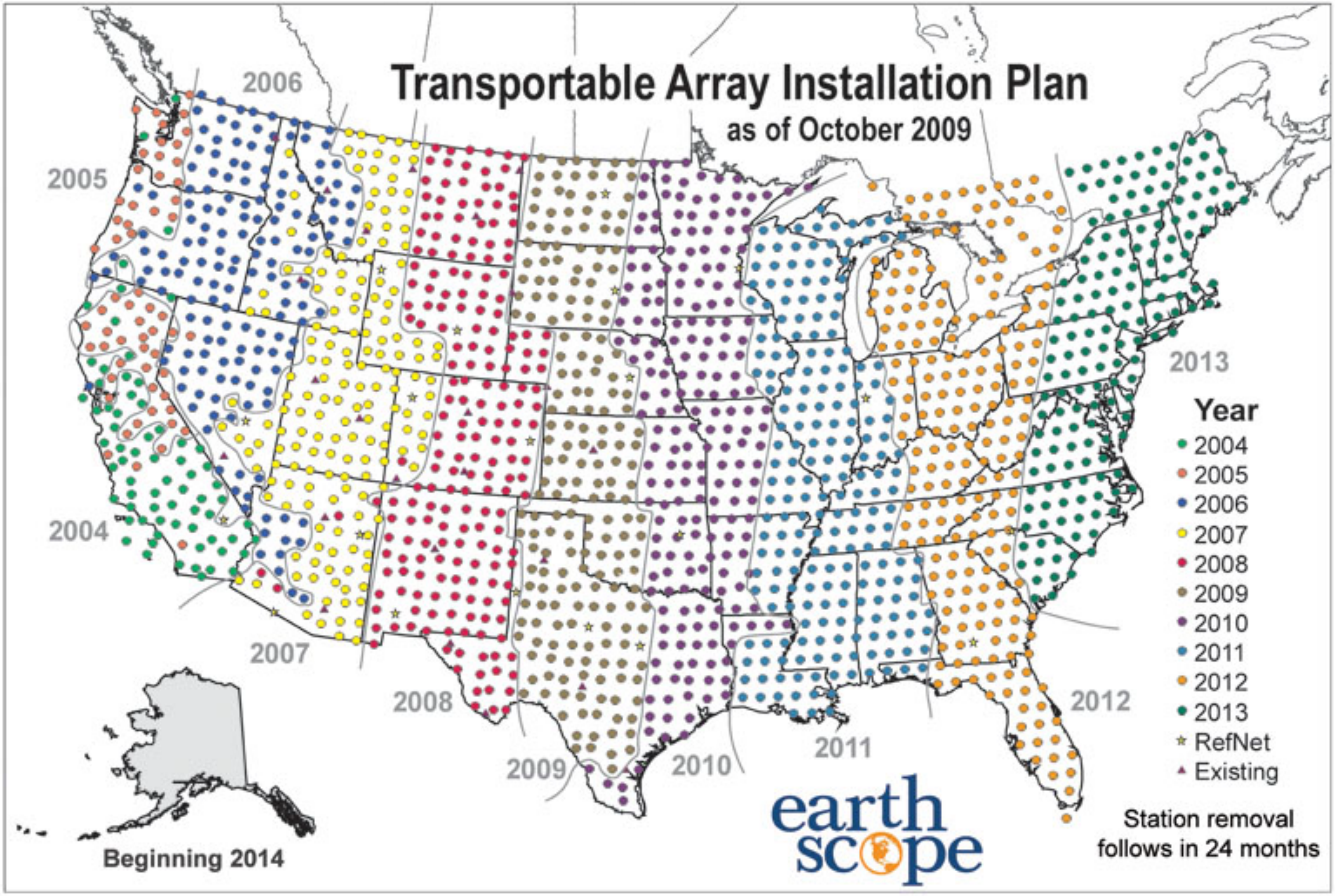
earthscope



orth American Continent
Unlocking the Secrets of the North Americar
Secrets of the Nc

Unlocking the Secrets of the North American Continent

An EarthScope Science Plan for 2010–2020



Transportable Array Installation Plan
as of October 2009
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
RefNet
Existing
Beginning 2014
earthscope
Station removal follows in 24 months

2-year deployments - 2000 sites
uniform instrumentation
systematic quality control

The speed of surface waves (Love and Rayleigh) depend on the shallow structure of the Earth

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 70, PP. 229–244, 11 FIGS. MARCH 1959

DETERMINATION OF CRUSTAL STRUCTURE FROM PHASE VELOCITY OF RAYLEIGH WAVES
PART III: THE UNITED STATES

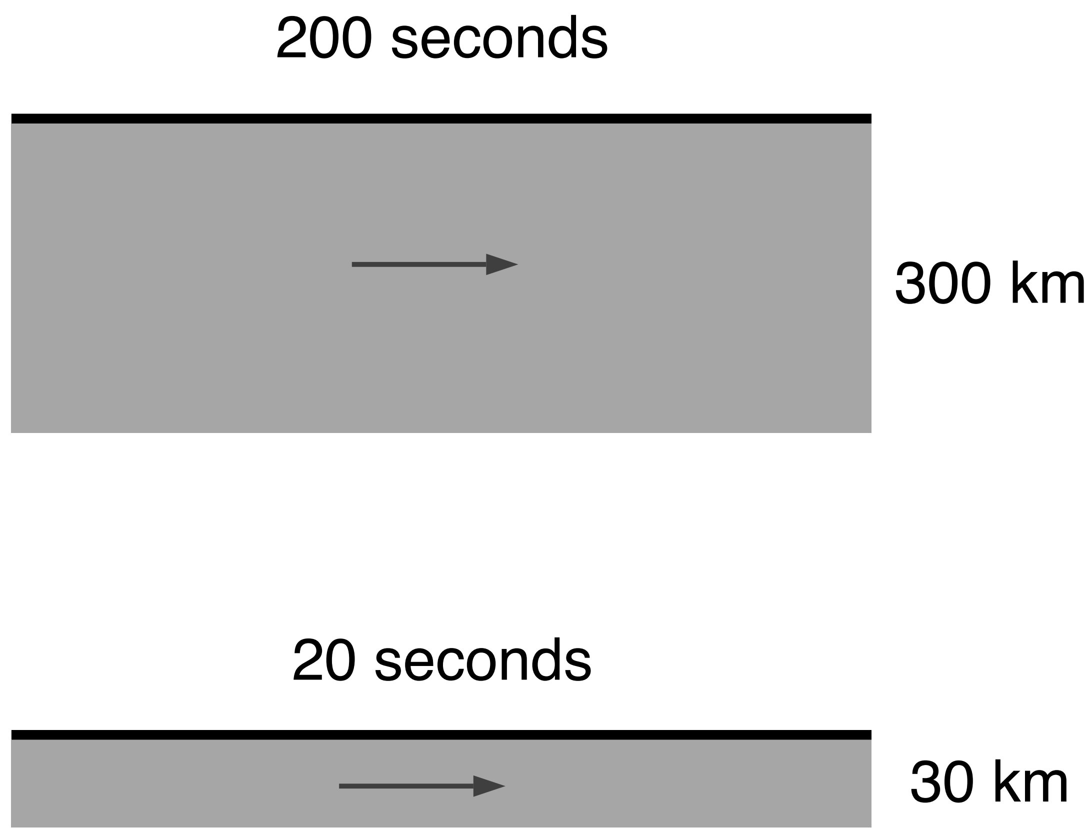
BY MAURICE EWING AND FRANK PRESS

ABSTRACT

Variations in phase velocity of Rayleigh waves from the Samoa earthquake of April 14, 1957 are reported for the United States. These variations are correlated with topography and Bouguer gravity anomaly on a continental scale, demonstrating regional isostatic compensation. The correlation of phase-velocity variations with crustal-thickness changes is justified, and permits specification of the mechanism of compensation as the regional Airy system.

Regional average crustal thicknesses are: Peninsular Ranges and Southwestern Desert, 40 km; Basin and Range Province, 48 km; Rocky Mountains, 47 km; Interior Plains, 35–41 km; Appalachian Mountains, 40 km.

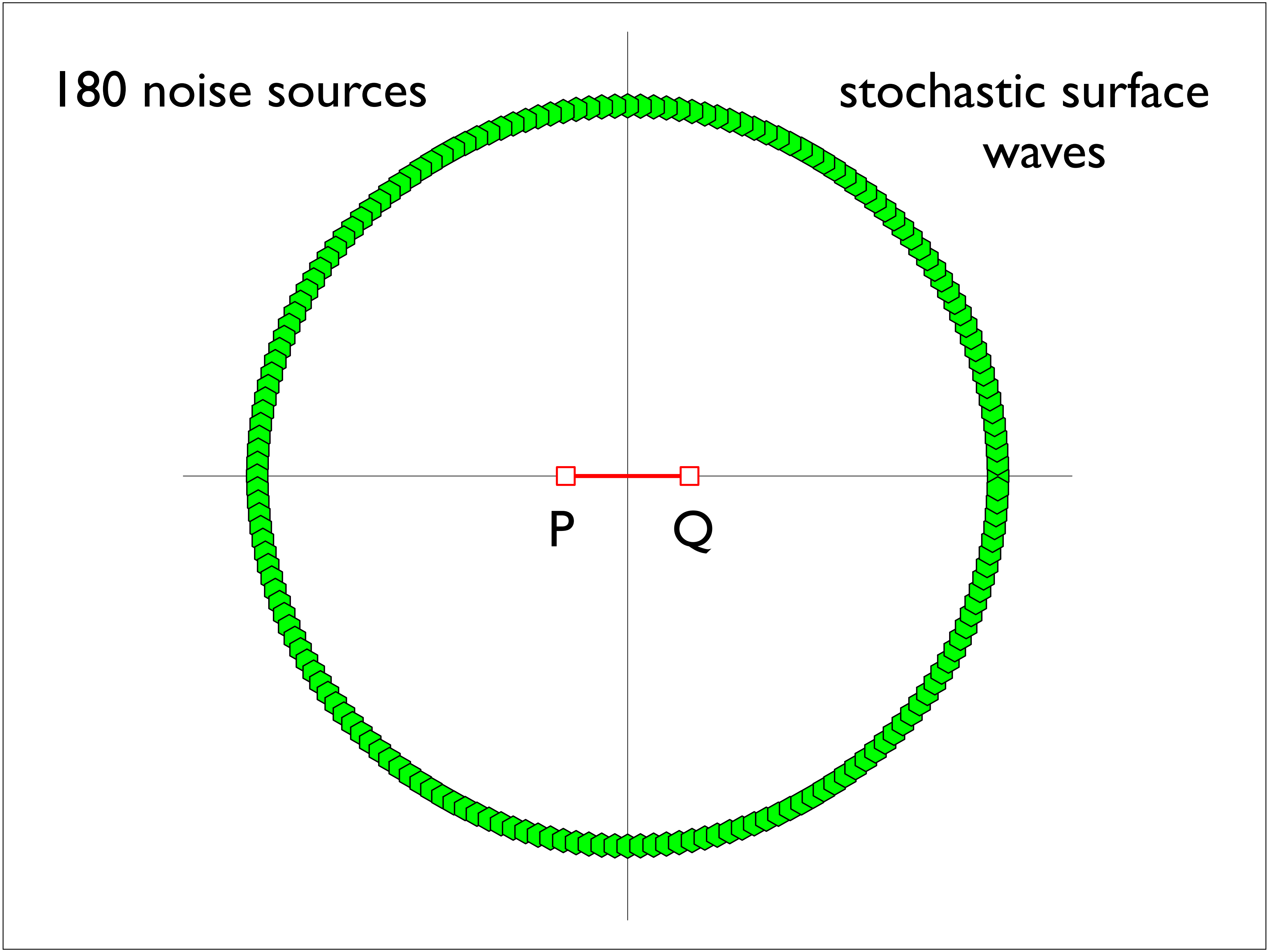
Sensitivity of surface wave velocities to elastic stucture at depth



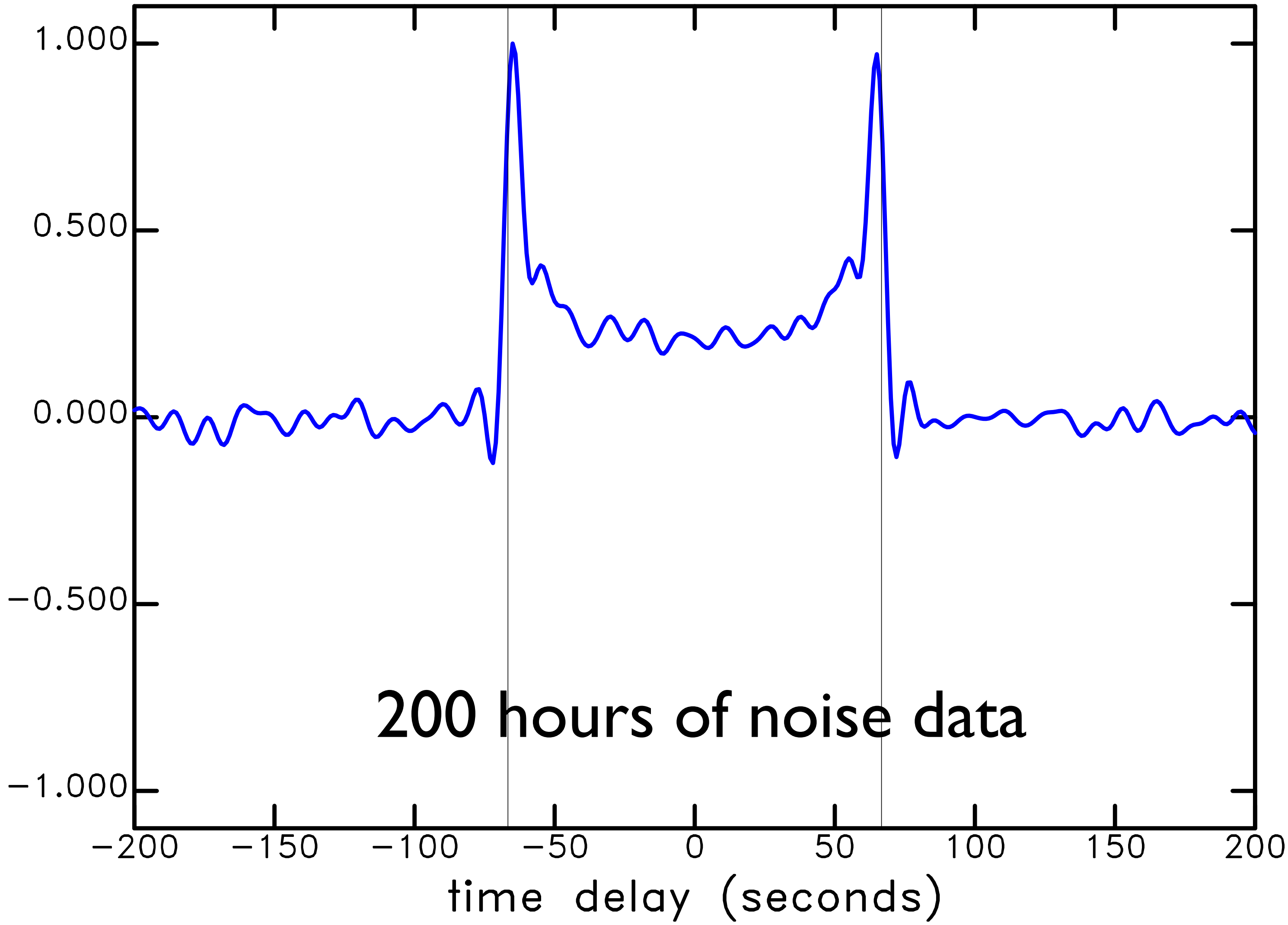
Noise cross correlations - two approaches:

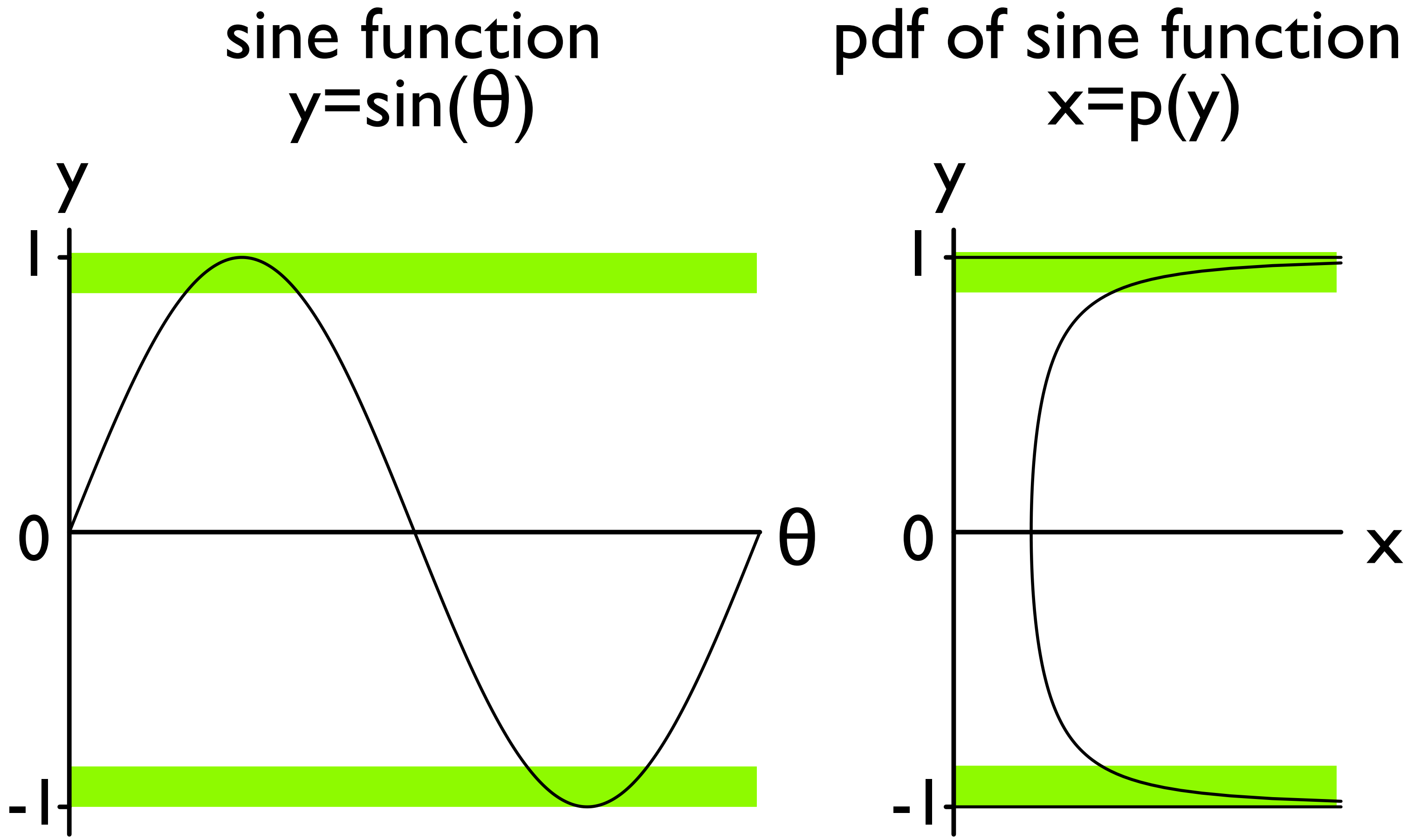
Diffuse and equipartitioned 3-D wavefield:
- leads to Green function (Campillo, ...)

Lots of traveling surface waves:
- leads to Bessel function (Aki, 1957)

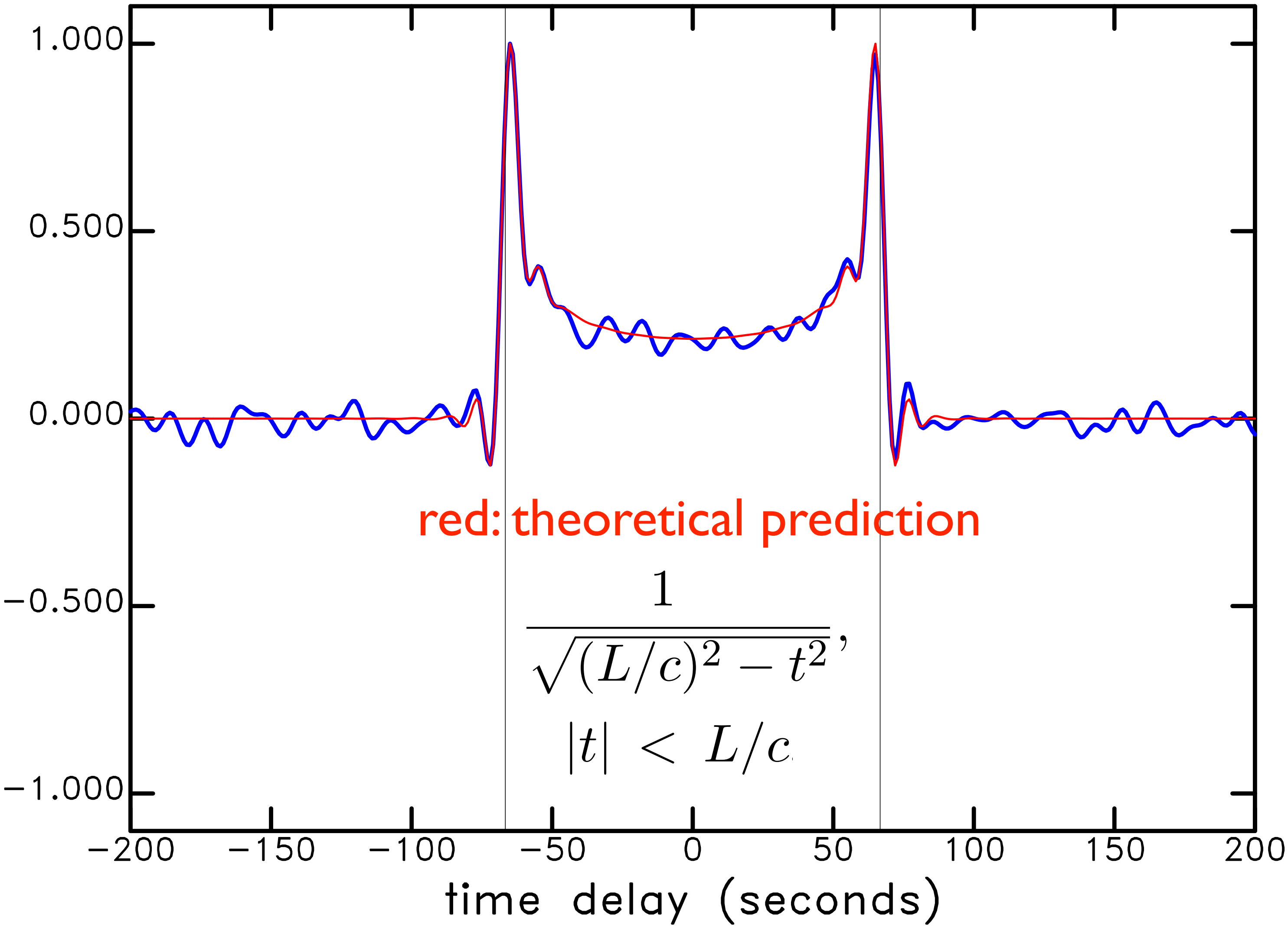

180 noise sources
stochastic surface waves
P
Q

Cross-correlation function, P and Q




sine function
y=sin(θ)
pdf of sine function
x=p(y)
y
1
0
-1
θ
y
1
0
-1
x

Cross-correlation function, P and Q



What about the Fourier transform?

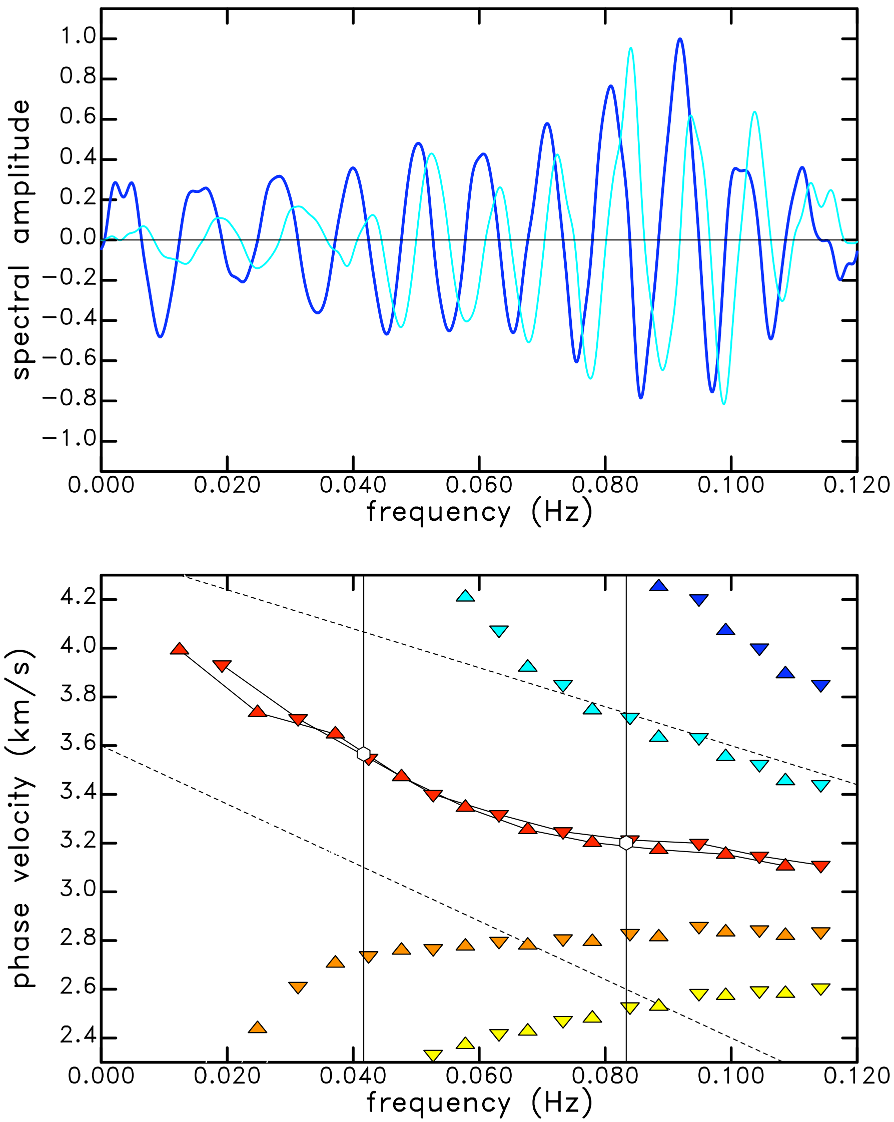
$$\frac{1}{\sqrt{(L/c)^2 - t^2}} \quad \longrightarrow \quad J_0(\frac{\omega L}{c})$$

$$\overline{\rho}(r, \omega_0) = J_0\left(\frac{\omega_0}{c(\omega_0)} r\right)$$

"This formula clearly indicates that if one measures $\overline{\rho}(r, \omega_0)$ for a certain r and for various ω_0's, he can obtain the function $c(\omega_0)$, i.e., the dispersion curve of the wave for the corresponding range of frequency ω_0".

Aki, 1957

Matching zero crossings for dispersion



D07A-B04A

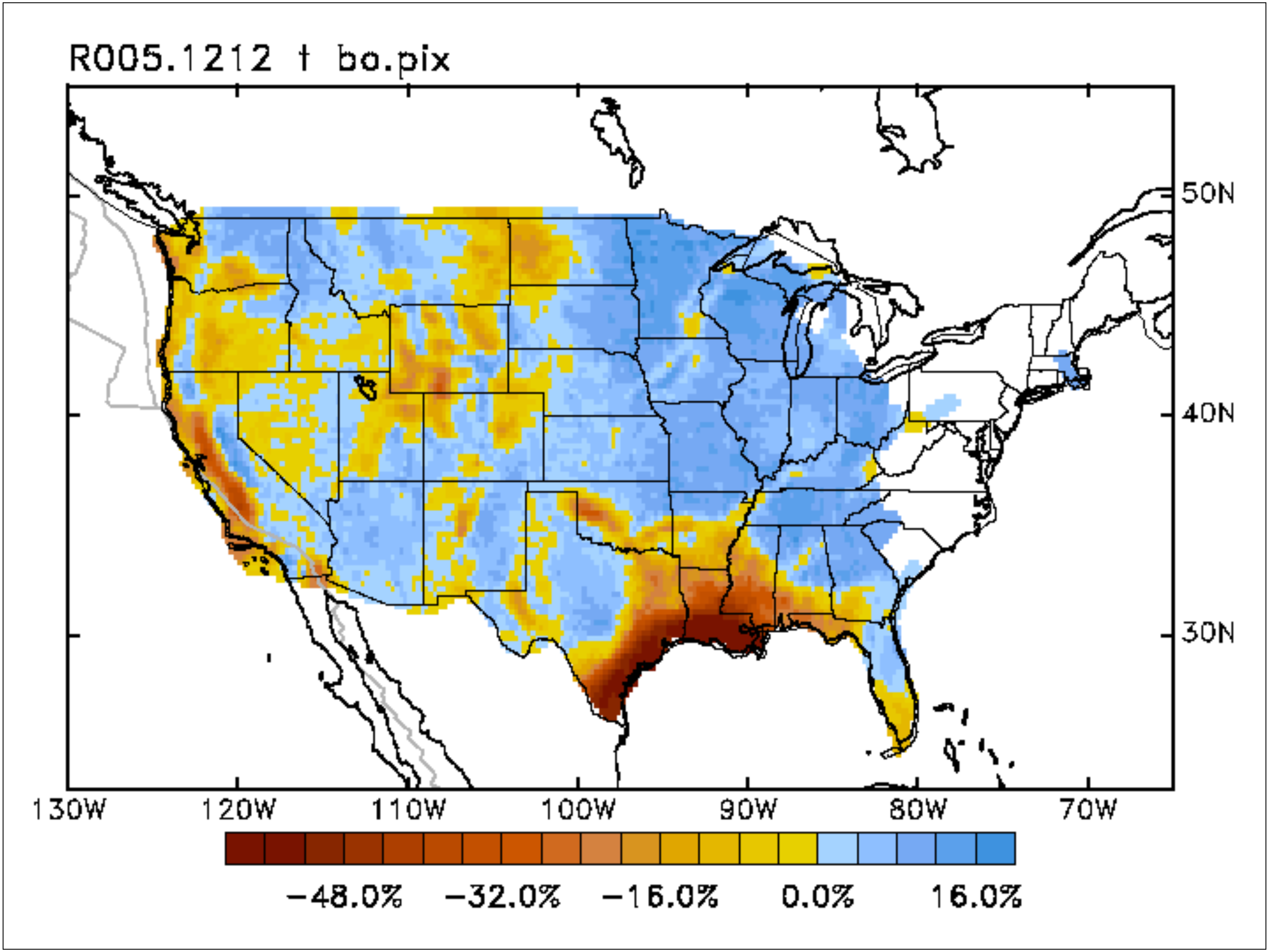
282 km

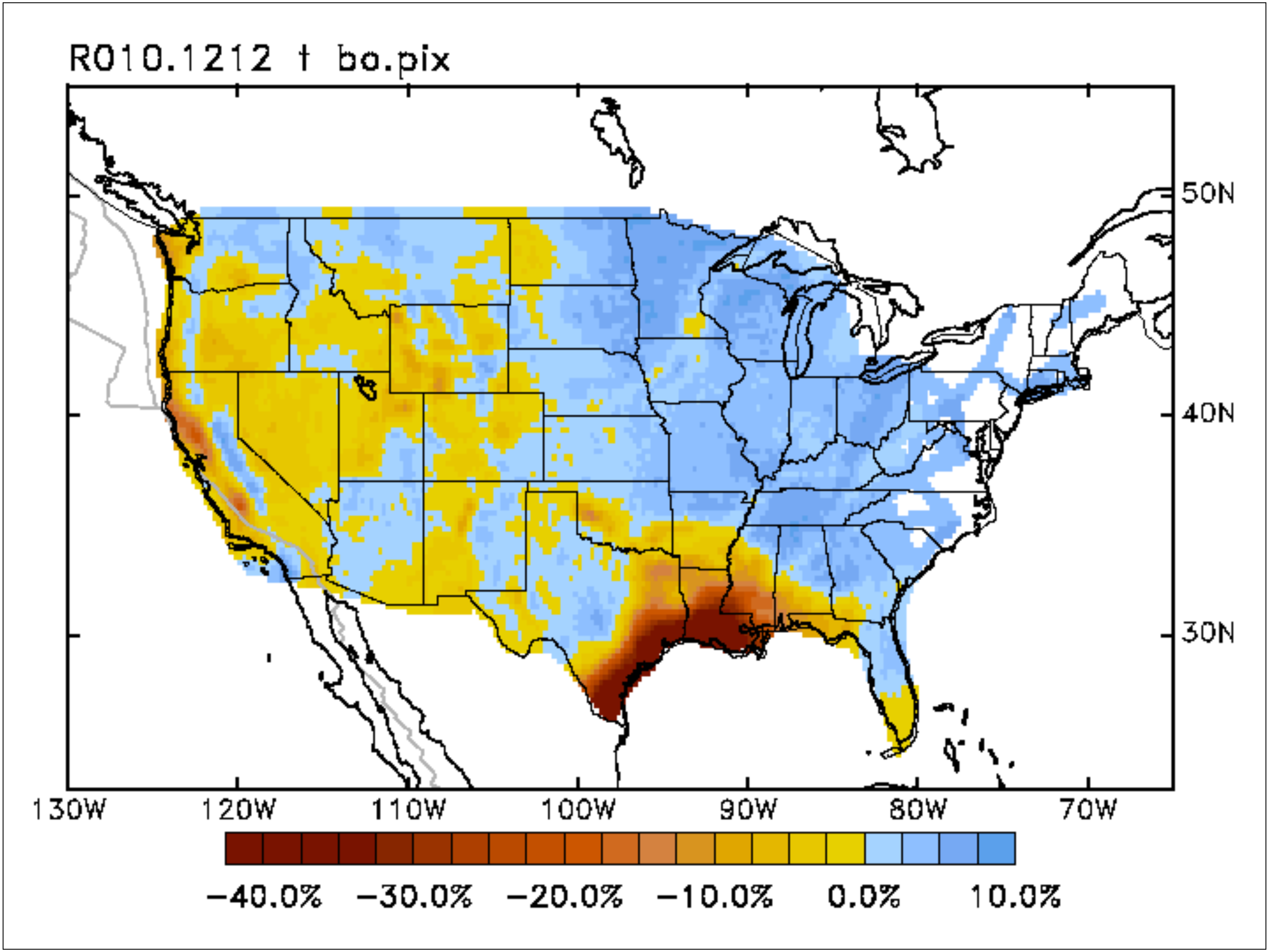
$$c(\omega_n) = \frac{\omega_n r}{z_n}$$

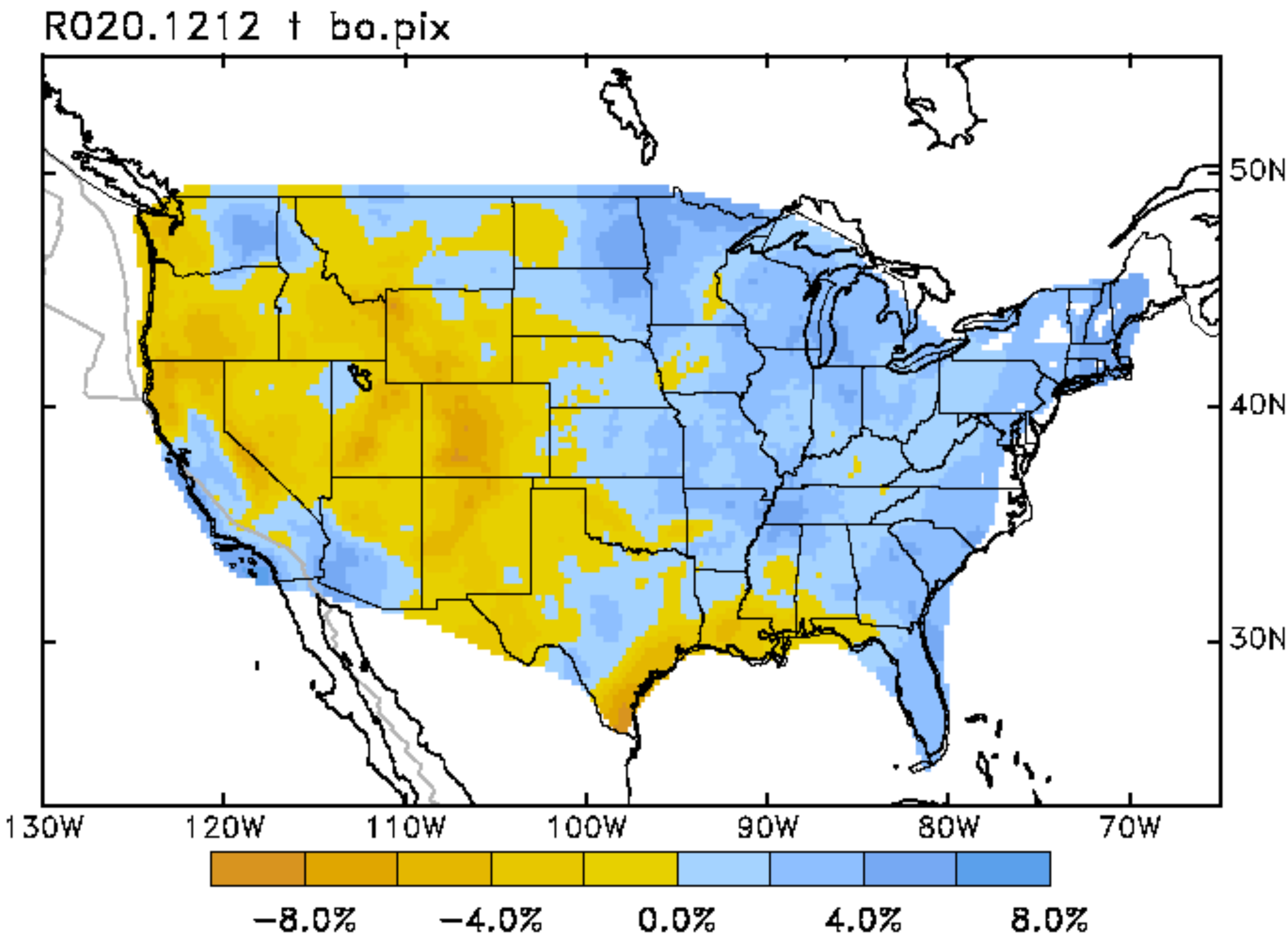
Recipe for tomographic success:

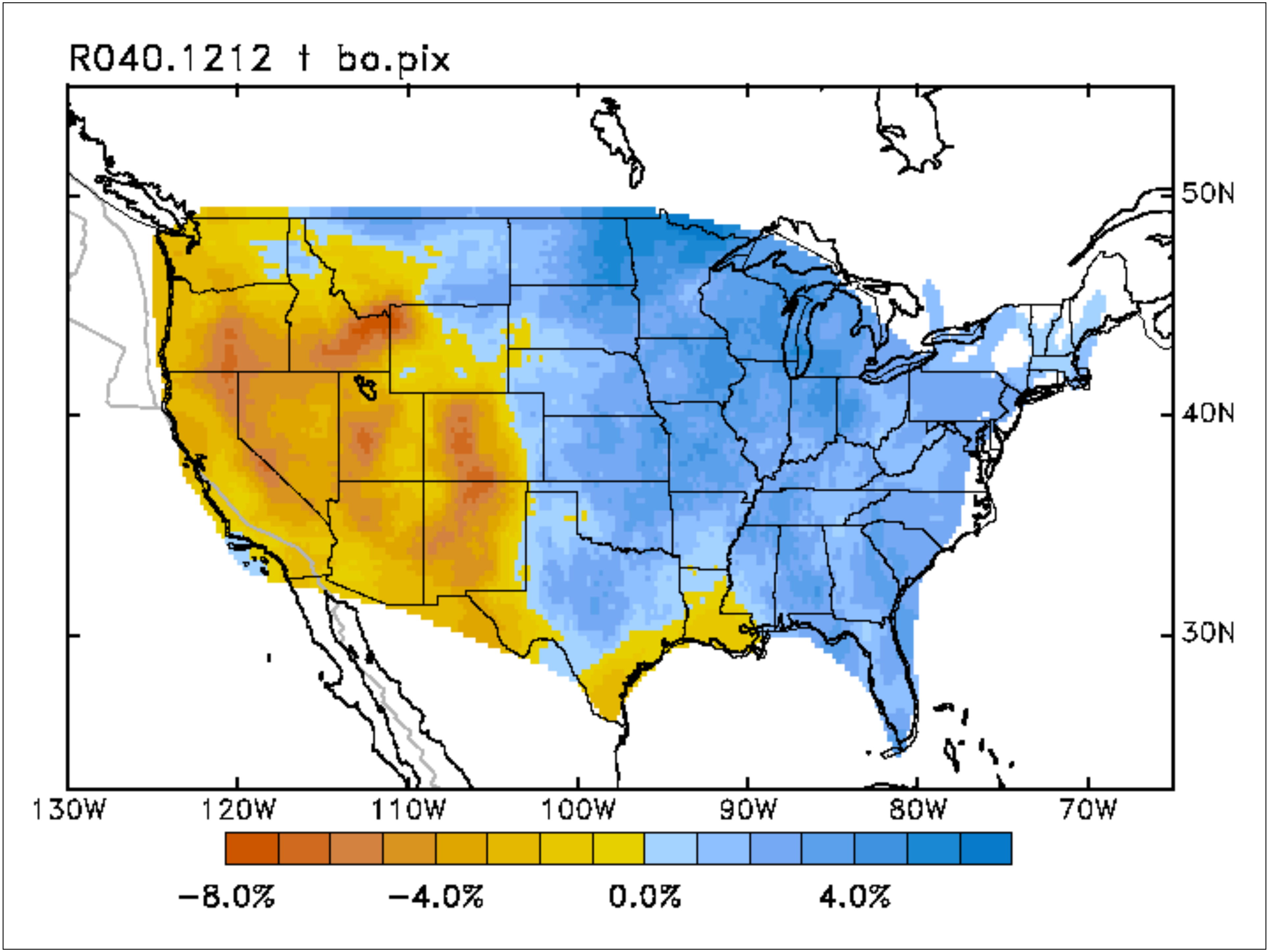
1. Correlate continuous recorded signals at all pairs of USArray stations in 4-h windows (note - this is a big calculation)
2. Stack all correlation functions for each pair
3. Determine zero crossings of stacked cross-correlation spectra
4. Determine phase velocities using Aki's formula
5. Invert phase-velocity observations to determine phase-velocity maps

(no one-bit, no whitening, no nuthin')

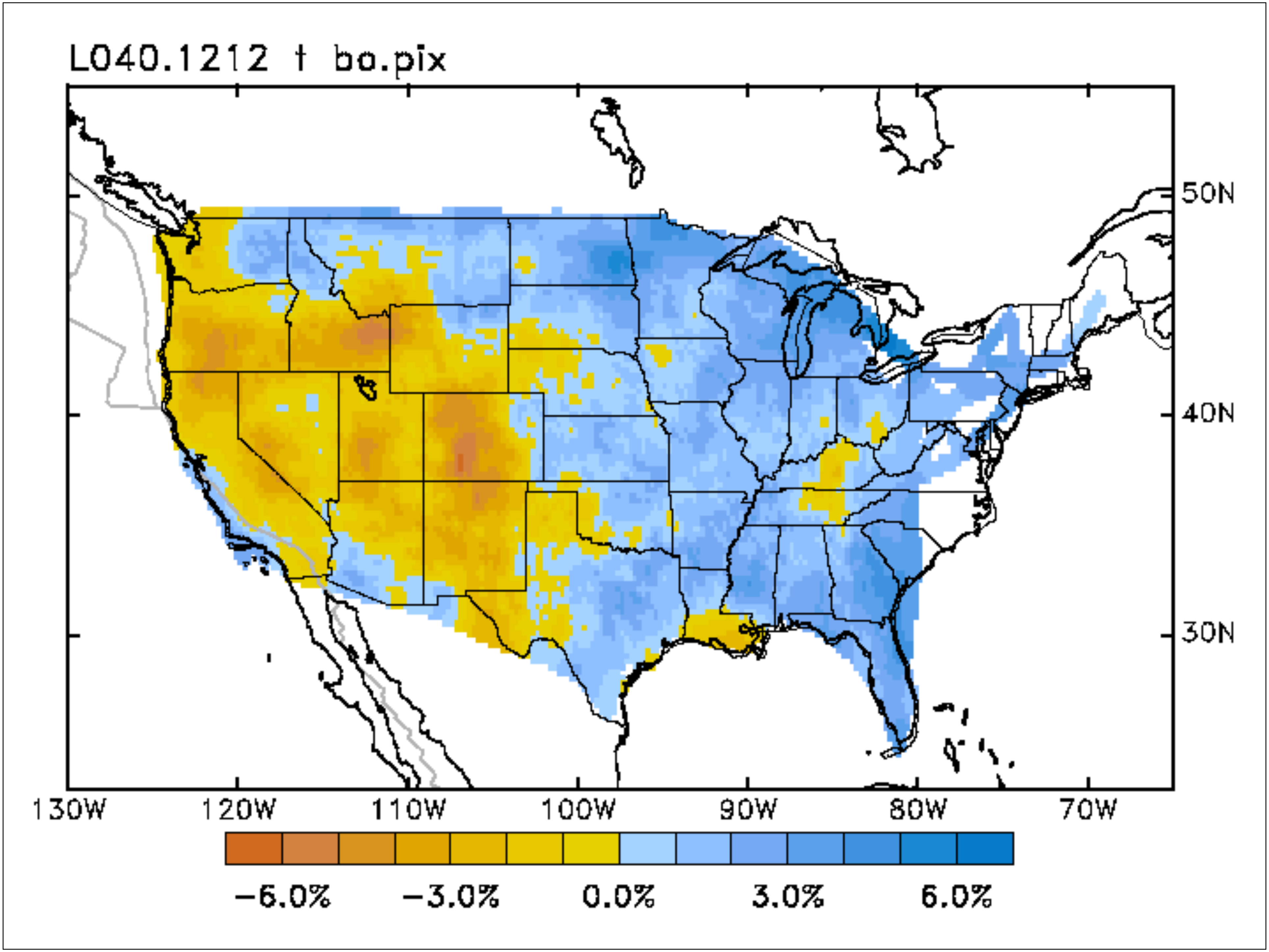

R005.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
-48.0%
-32.0%
-16.0%
0.0%
16.0%


R010.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−40.0%
−30.0%
−20.0%
−10.0%
0.0%
10.0%

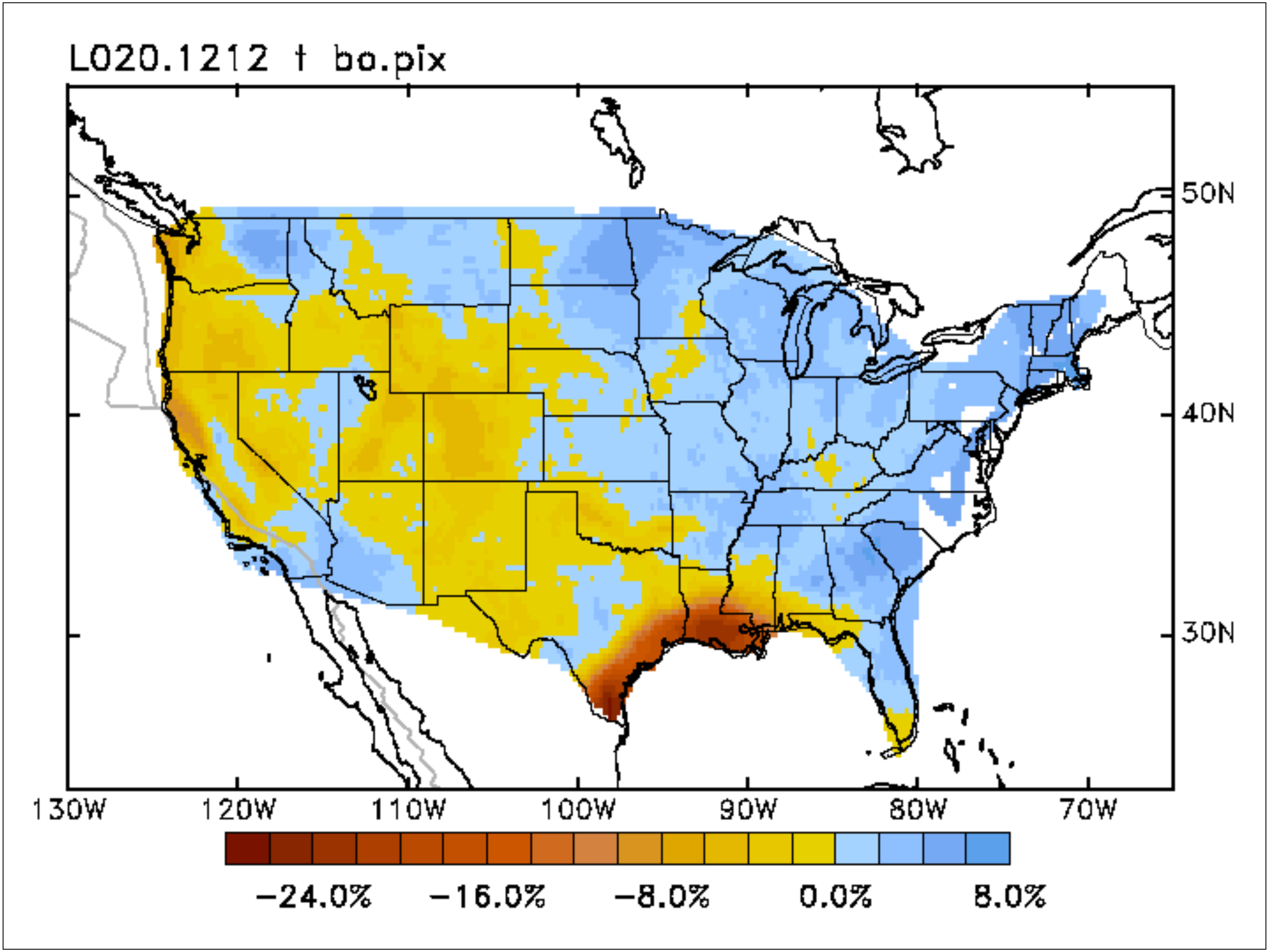

R020.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−8.0%
−4.0%
0.0%
4.0%
8.0%

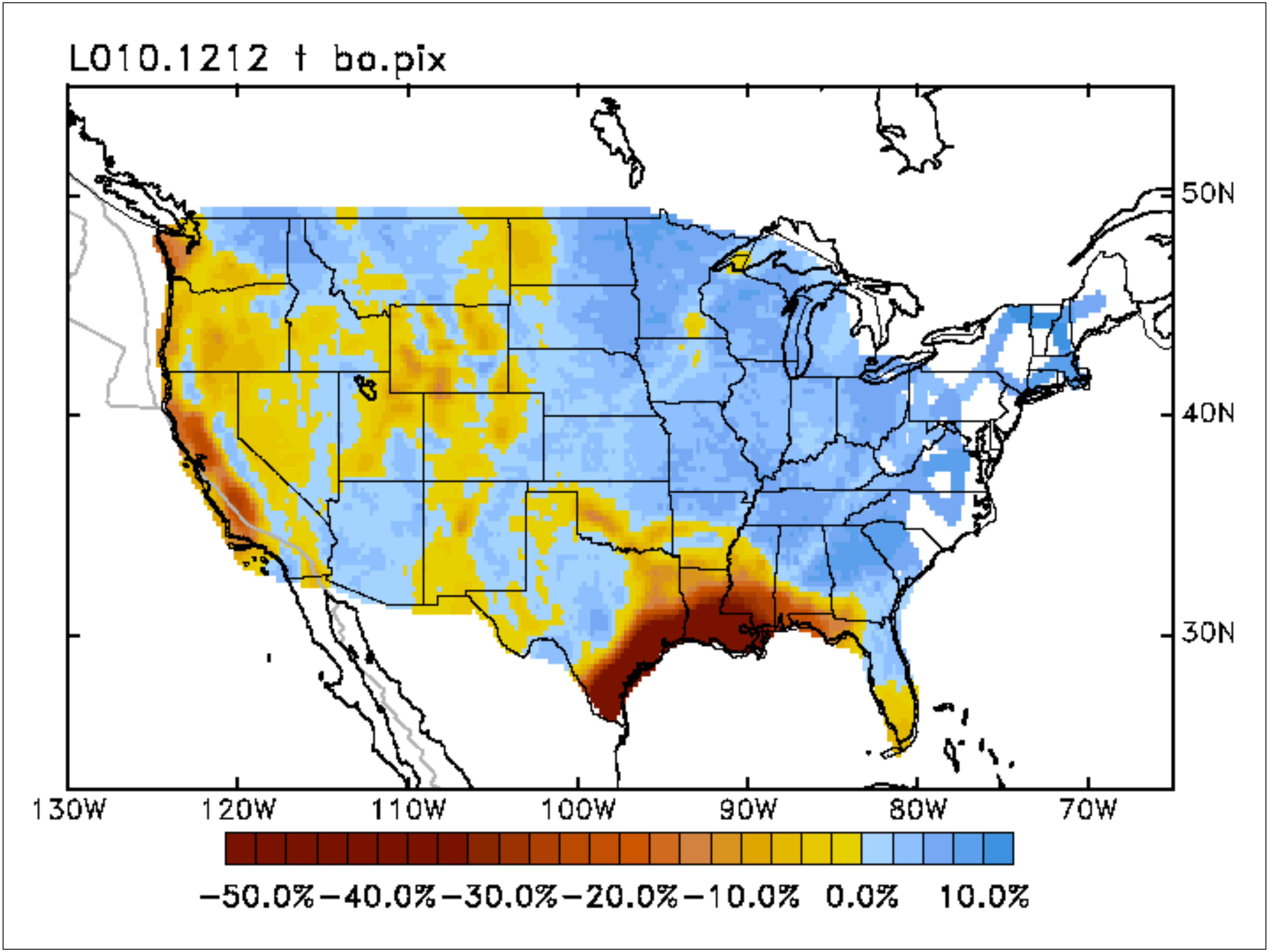


R040.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−8.0%
−4.0%
0.0%
4.0%

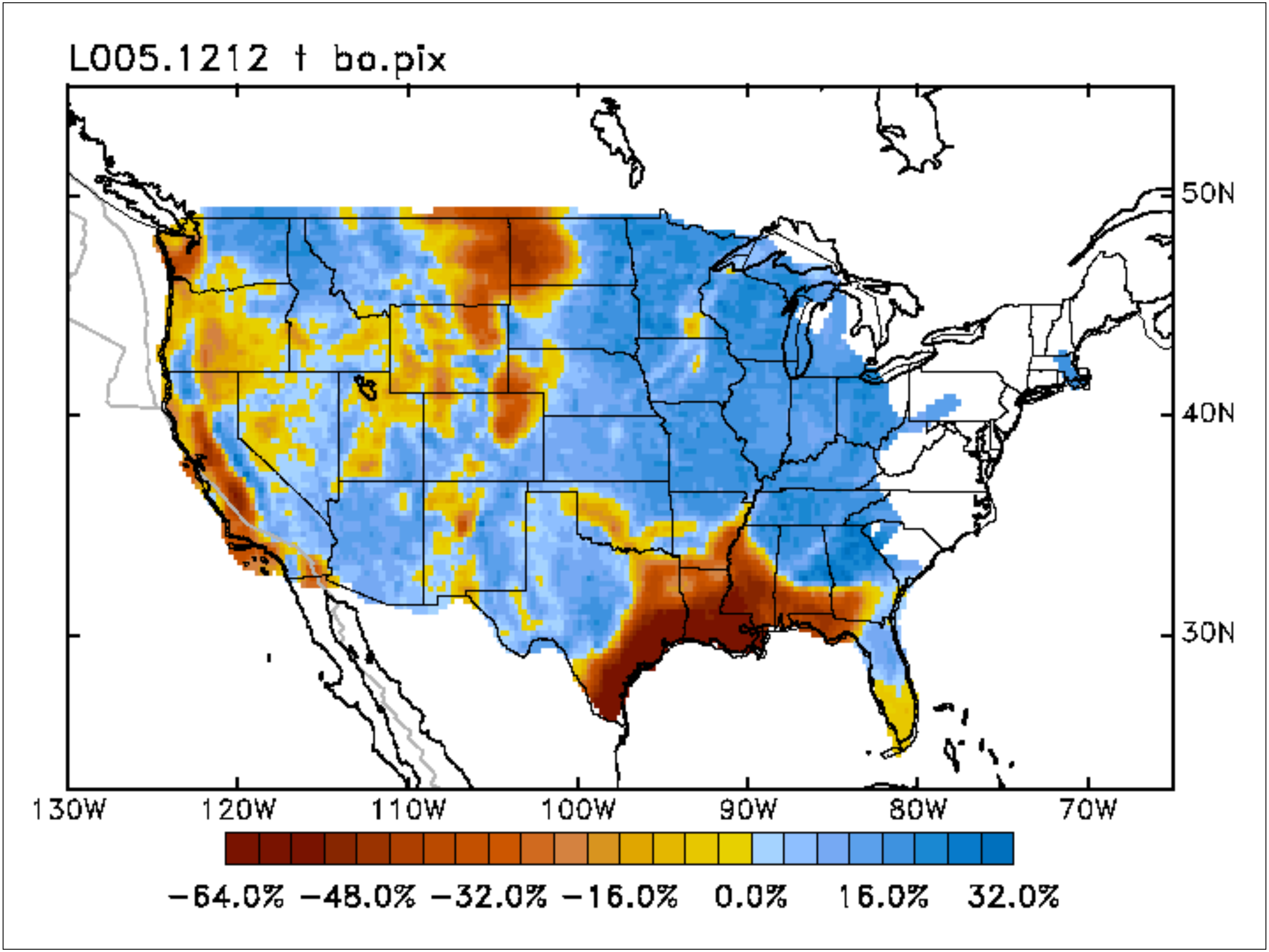


L040.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−6.0%
−3.0%
0.0%
3.0%
6.0%


L020.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−24.0%
−16.0%
−8.0%
0.0%
8.0%



L010.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−50.0% −40.0% −30.0% −20.0% −10.0% 0.0% 10.0%

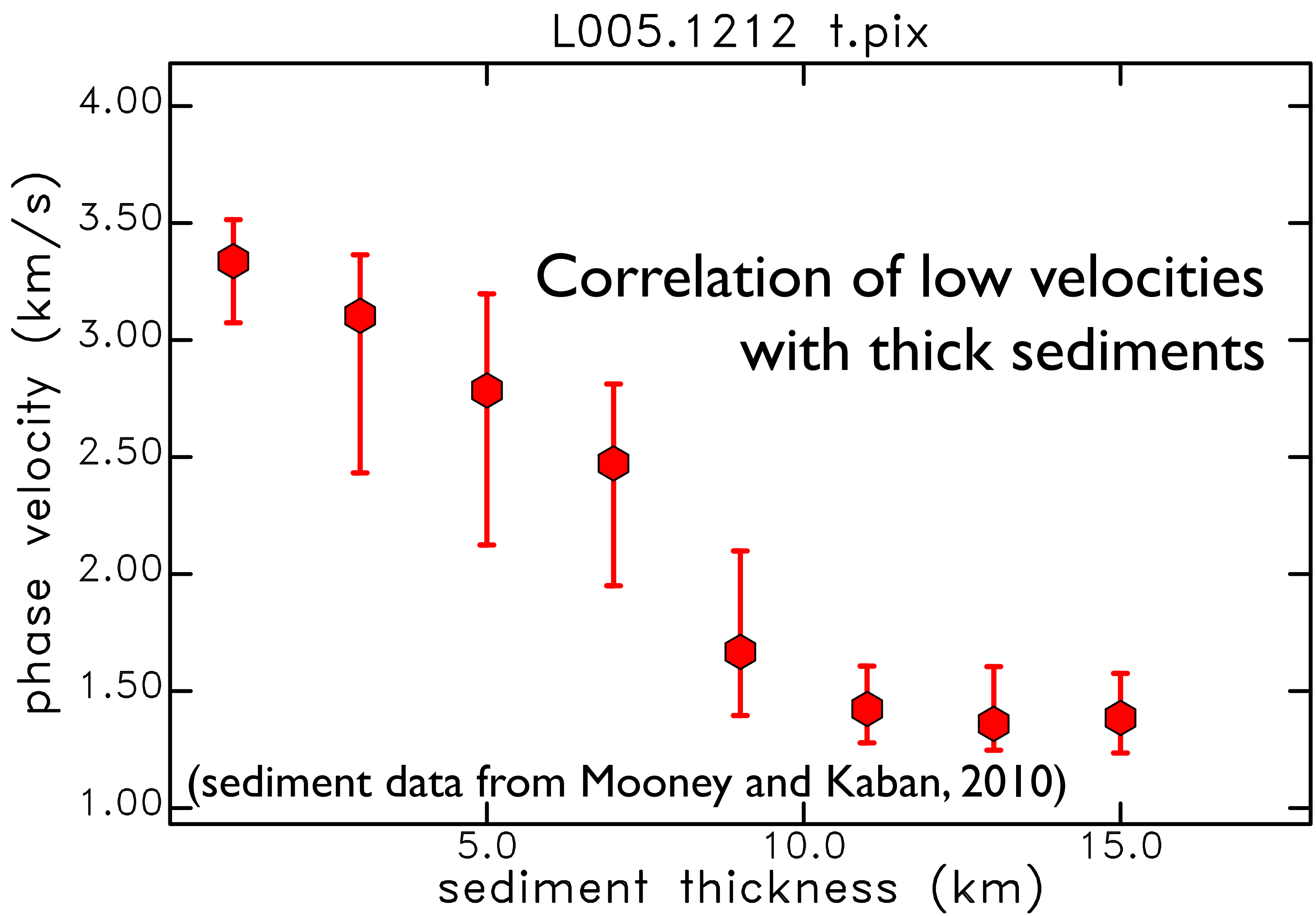


L005.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−64.0% −48.0% −32.0% −16.0% 0.0% 16.0% 32.0%

What are we looking at?

Mainly elastic effects of the crust

Including strong signals of slow sediments



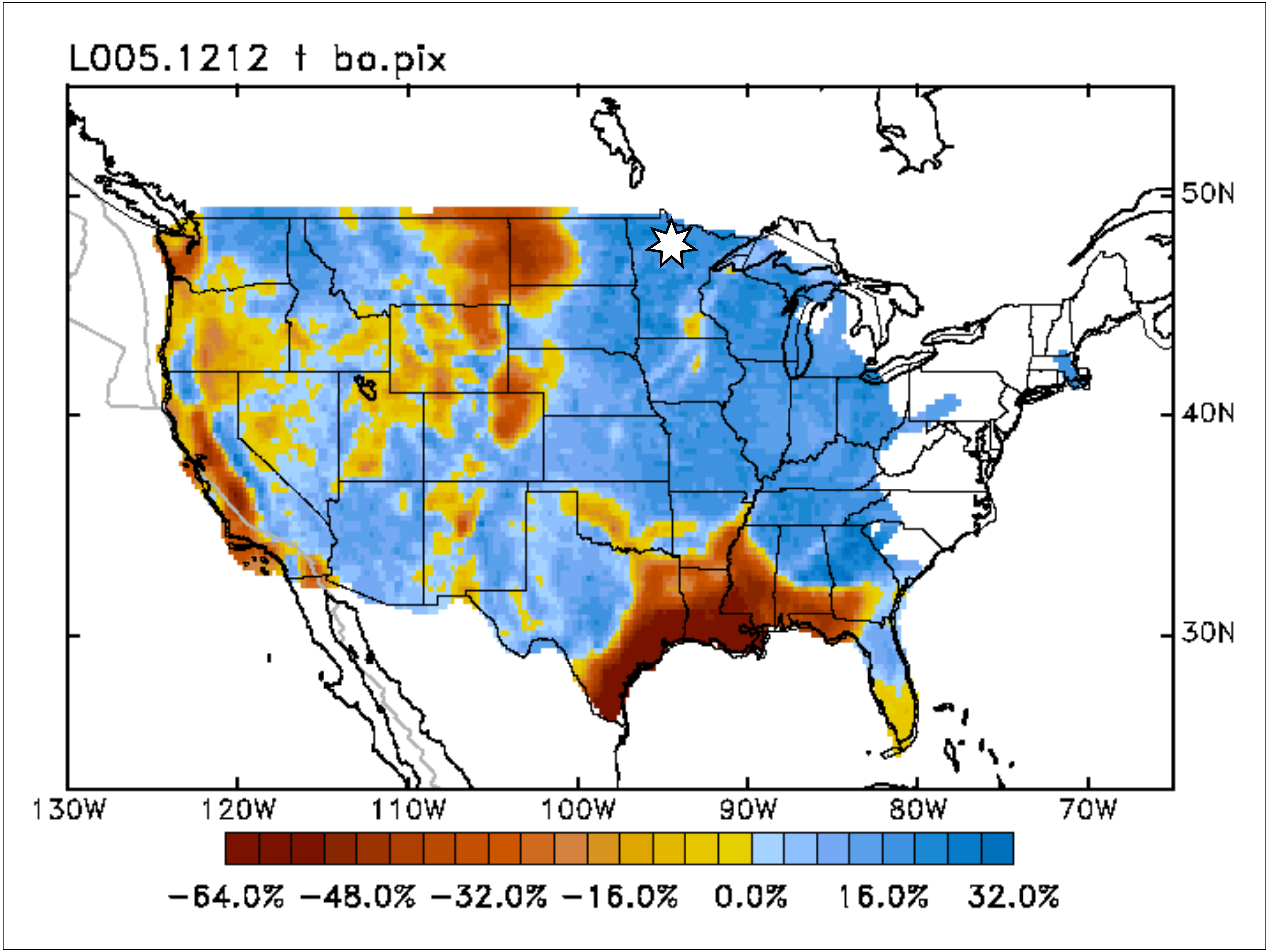
L005.1212 t.pix
Correlation of low velocities
with thick sediments
(sediment data from Mooney and Kaban, 2010)
phase velocity (km/s)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
5.0
10.0
15.0
sediment thickness (km)

What are we looking at?

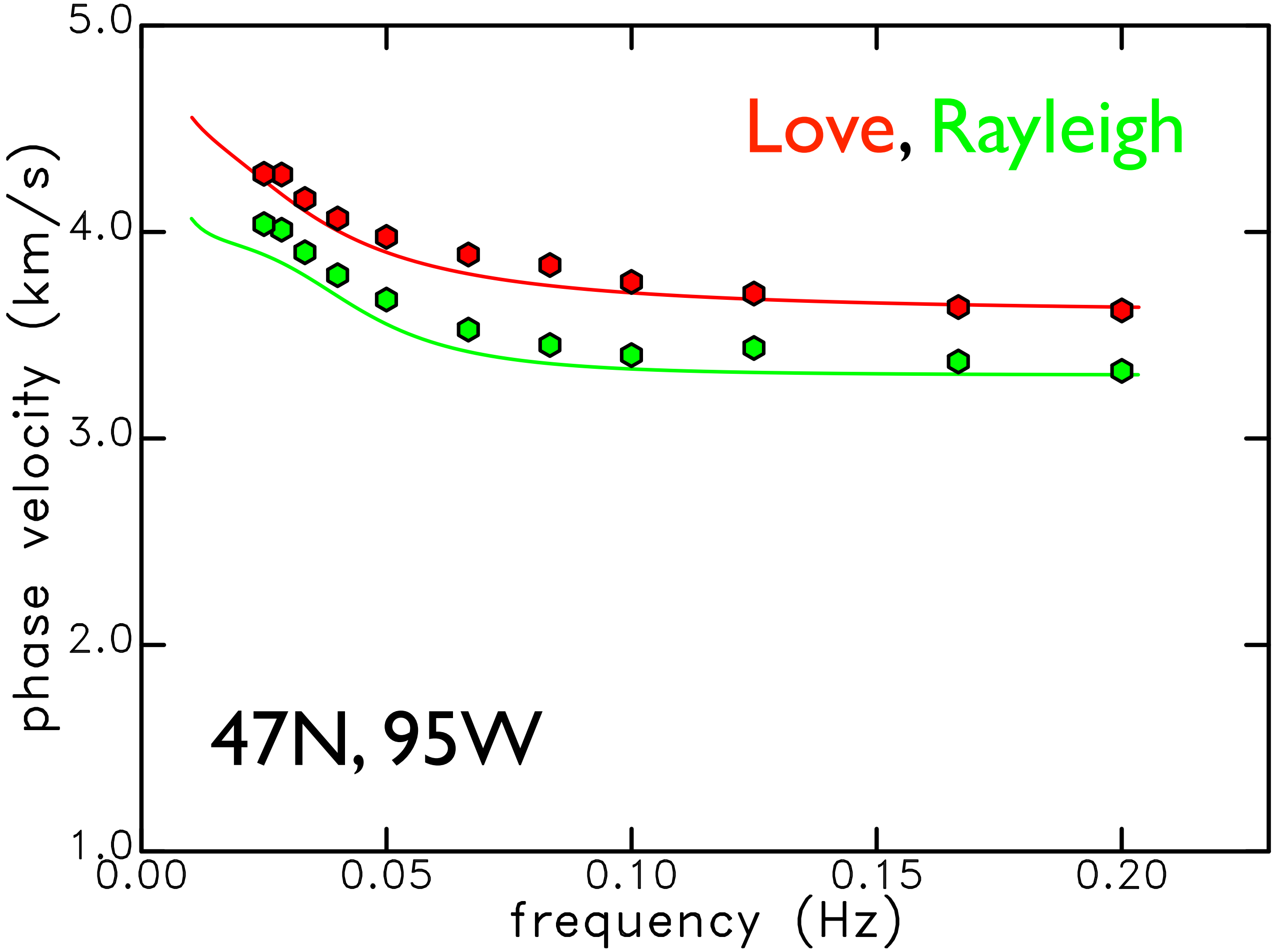
Mainly elastic effects of the crust

Including strong signals of slow sediments

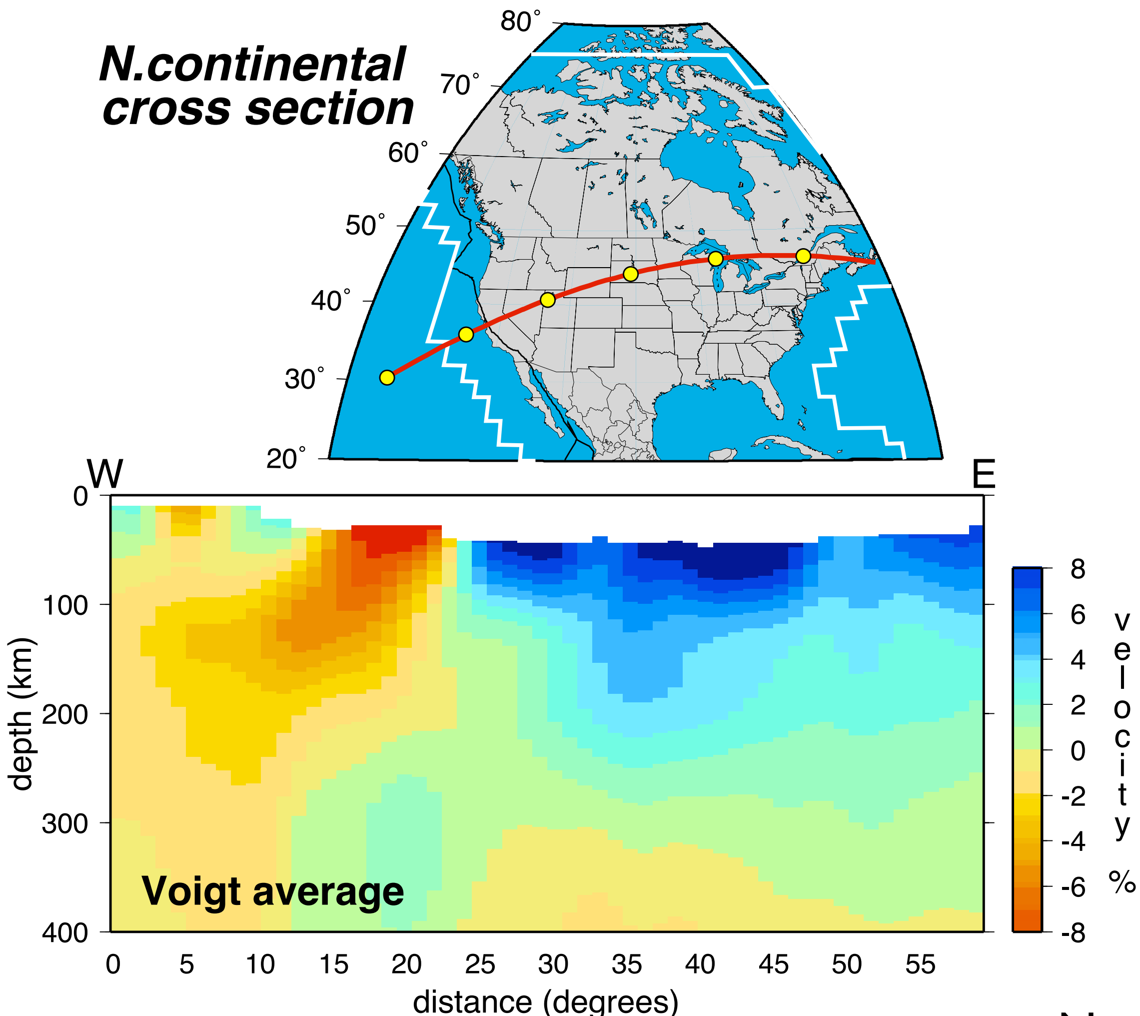
Compare with predictions from CRUST 2.0


L005.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−64.0% −48.0% −32.0% −16.0% 0.0% 16.0% 32.0%

Observations and CRUST 2.0

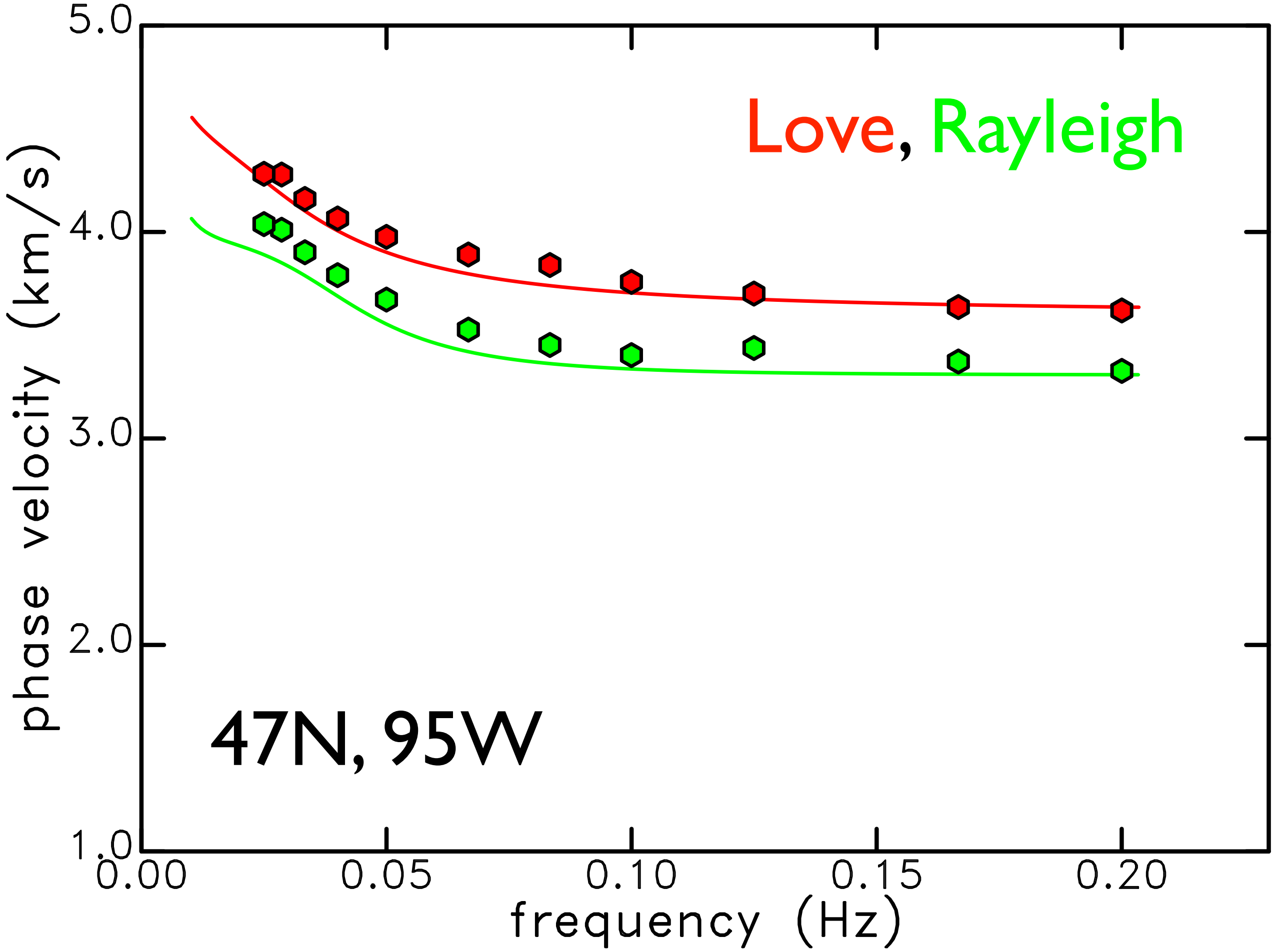


Mantle structure from surface waves

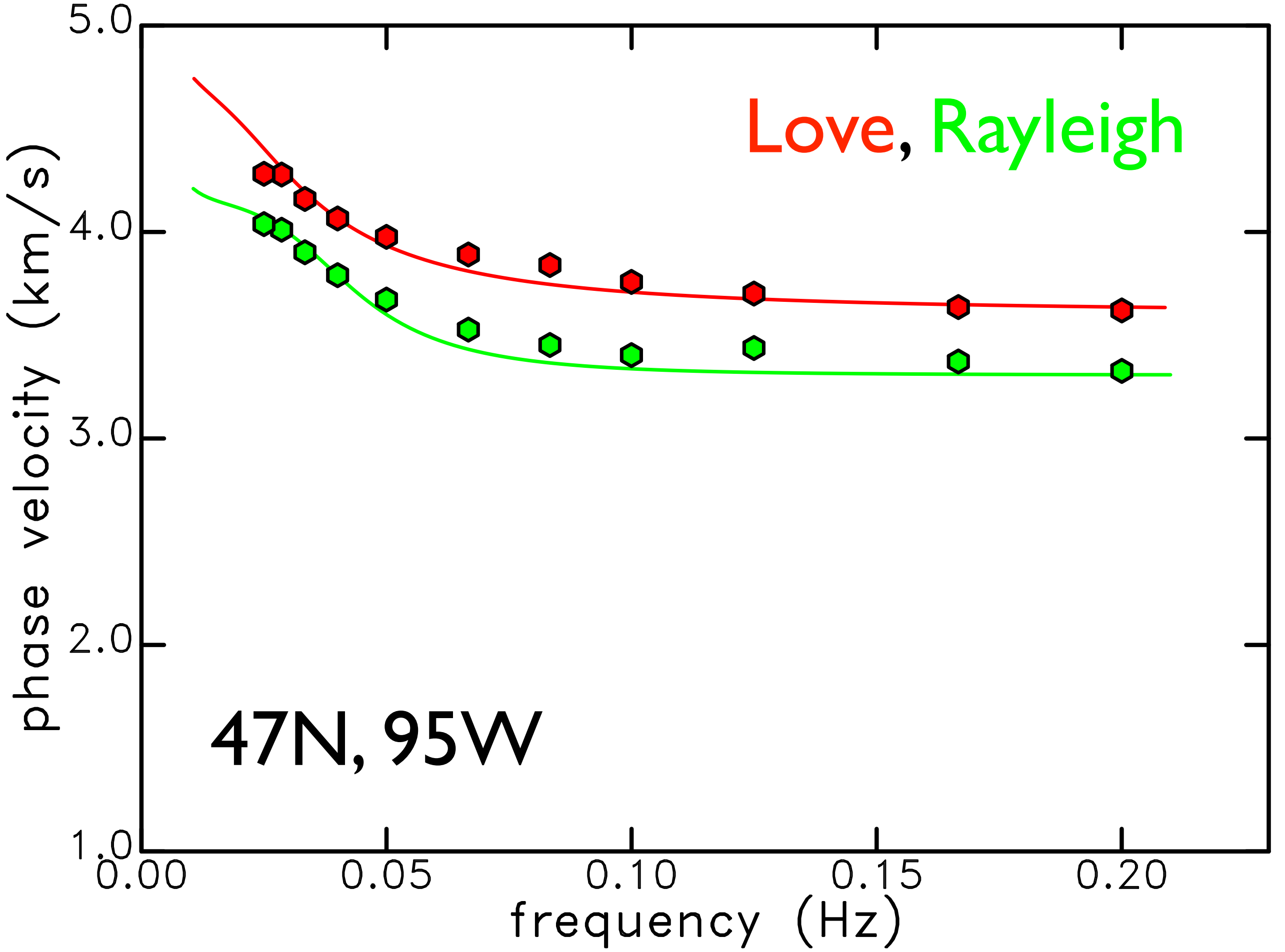


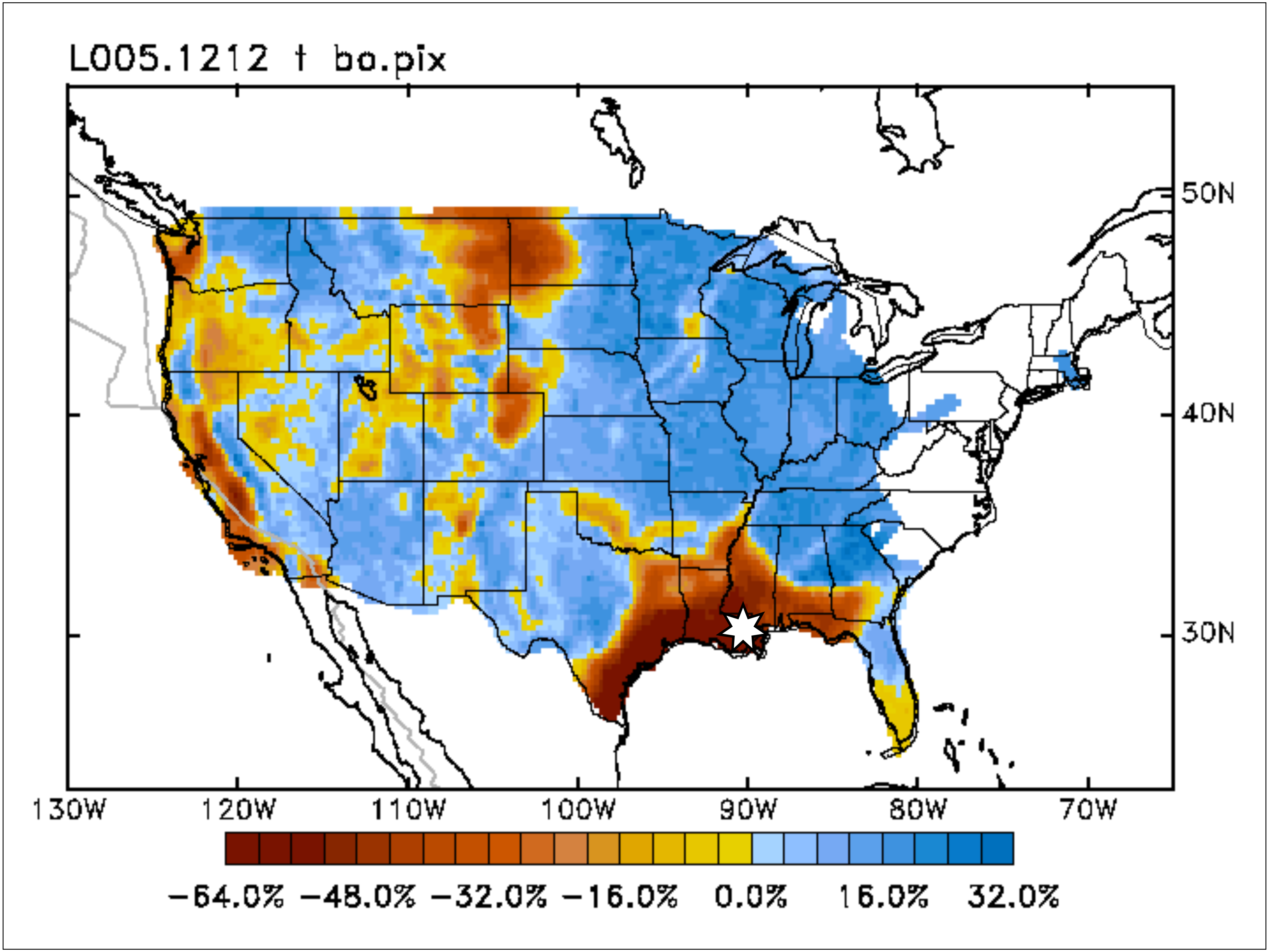
Nettles, 2005

Observations and CRUST 2.0

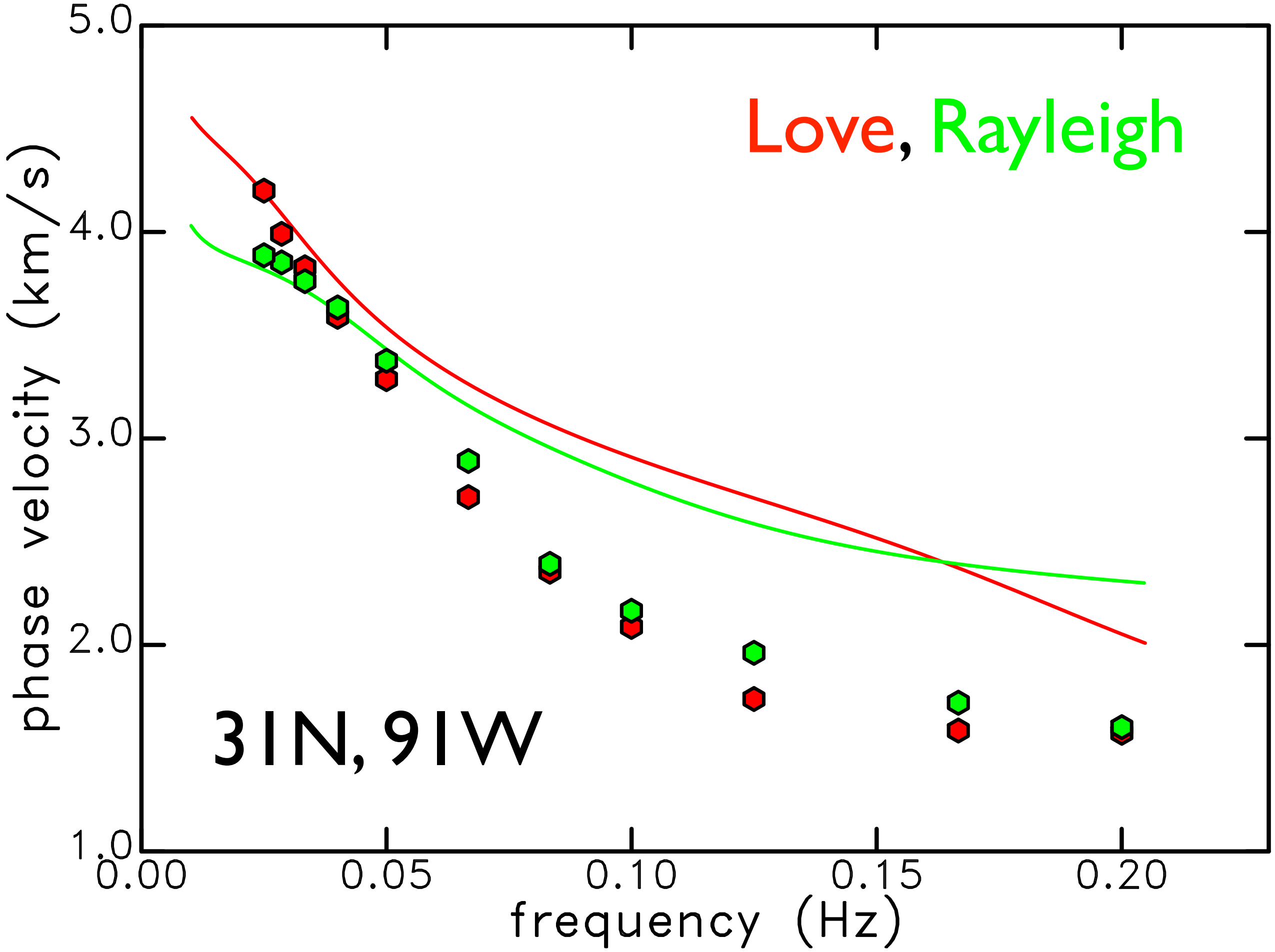


Observations and ND08

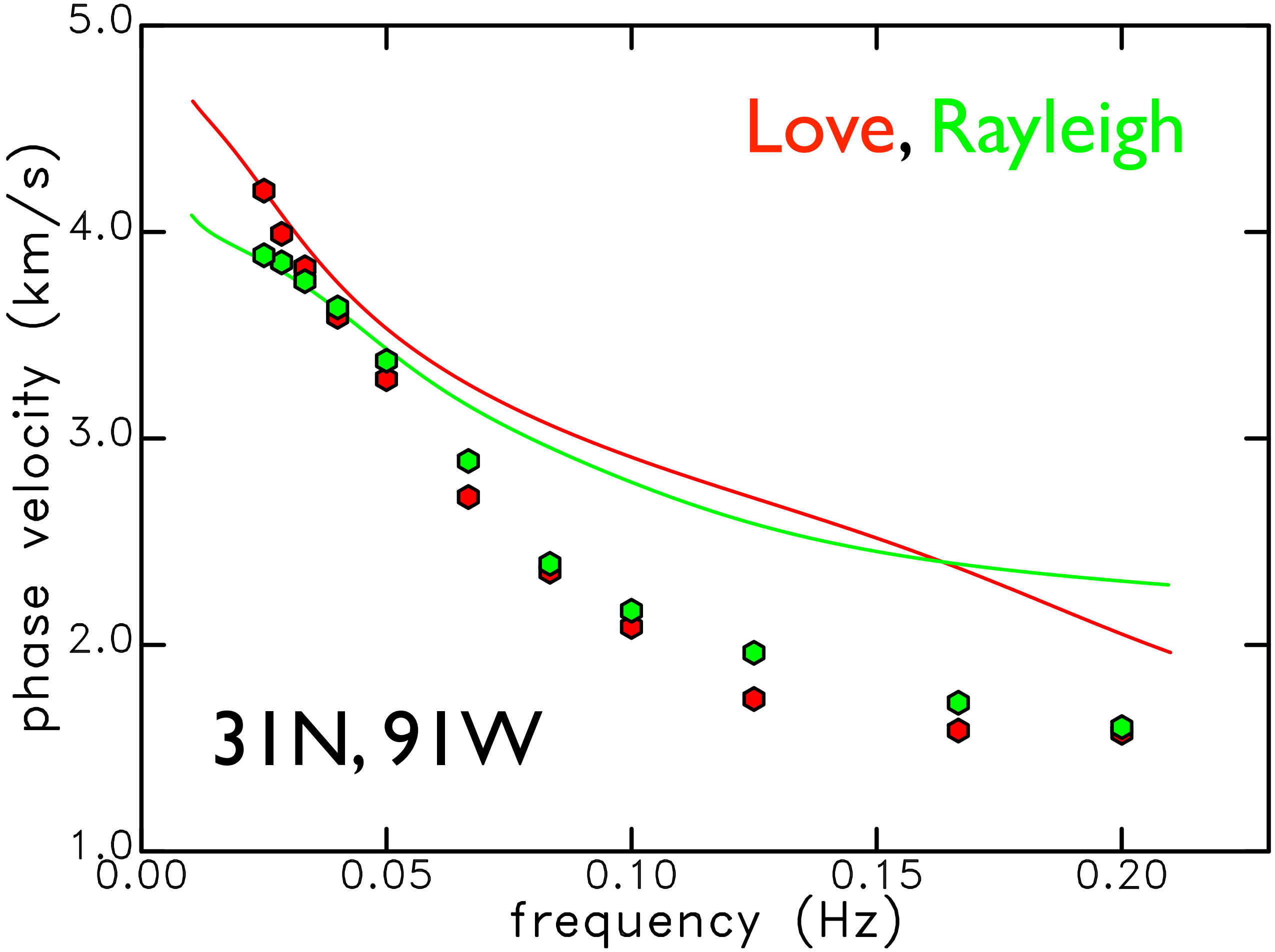



L005.1212 t bo.pix
50N
40N
30N
130W
120W
110W
100W
90W
80W
70W
−64.0%
−48.0%
−32.0%
−16.0%
0.0%
16.0%
32.0%

Observations and CRUST 2.0



Observations and ND08



1. The Transportable Array of USArray allows spatially uniform mapping of surface-wave dispersion across the US using noise tomography

2. Aki's spectral approach works well for automation

3. Extremely slow Love and Rayleigh velocities along the Gulf coast (and in other areas) are not matched by current models of the crust

4. Very low VS is needed (high VP/VS ratio) to explain the signals from the basins