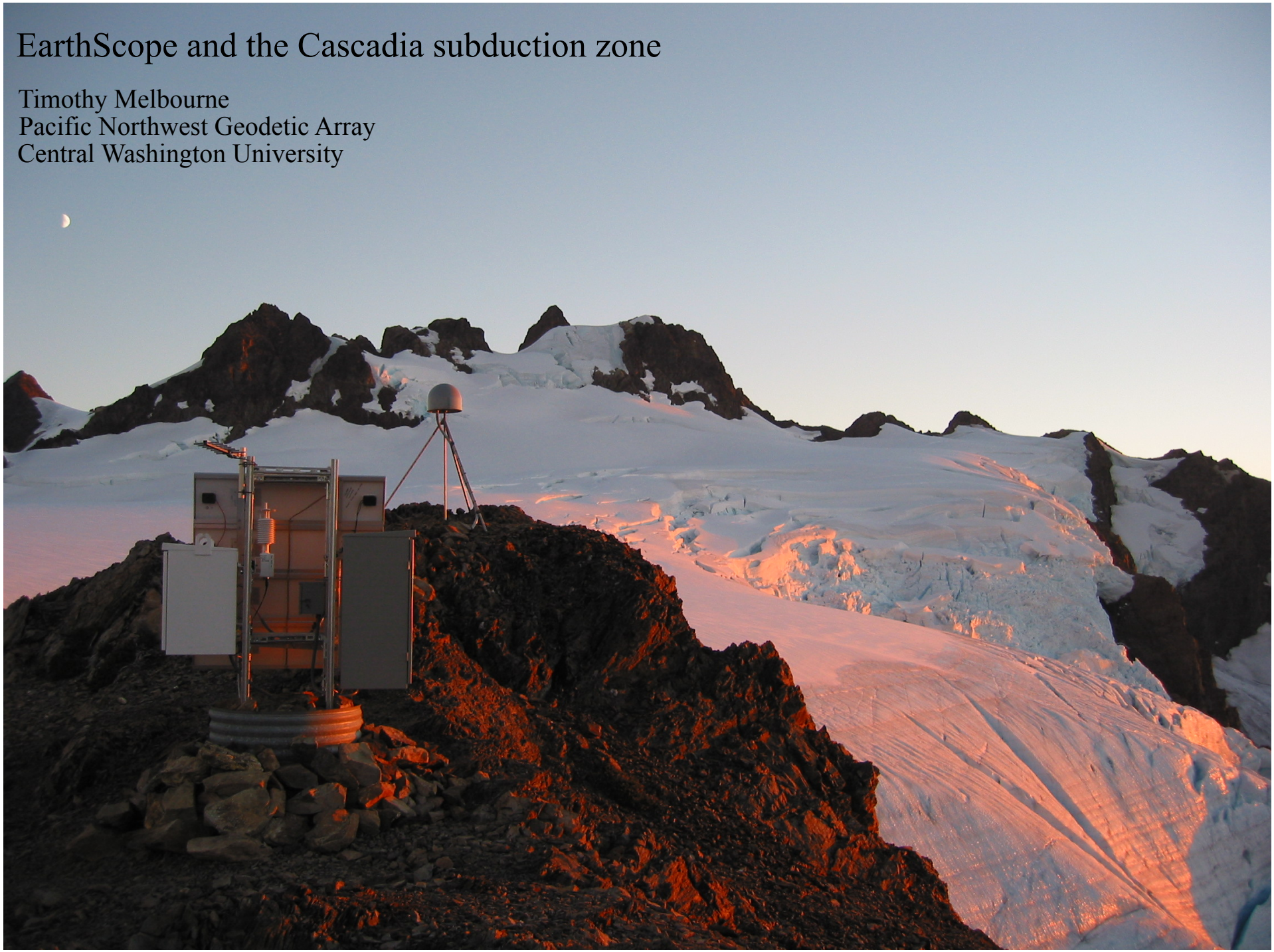
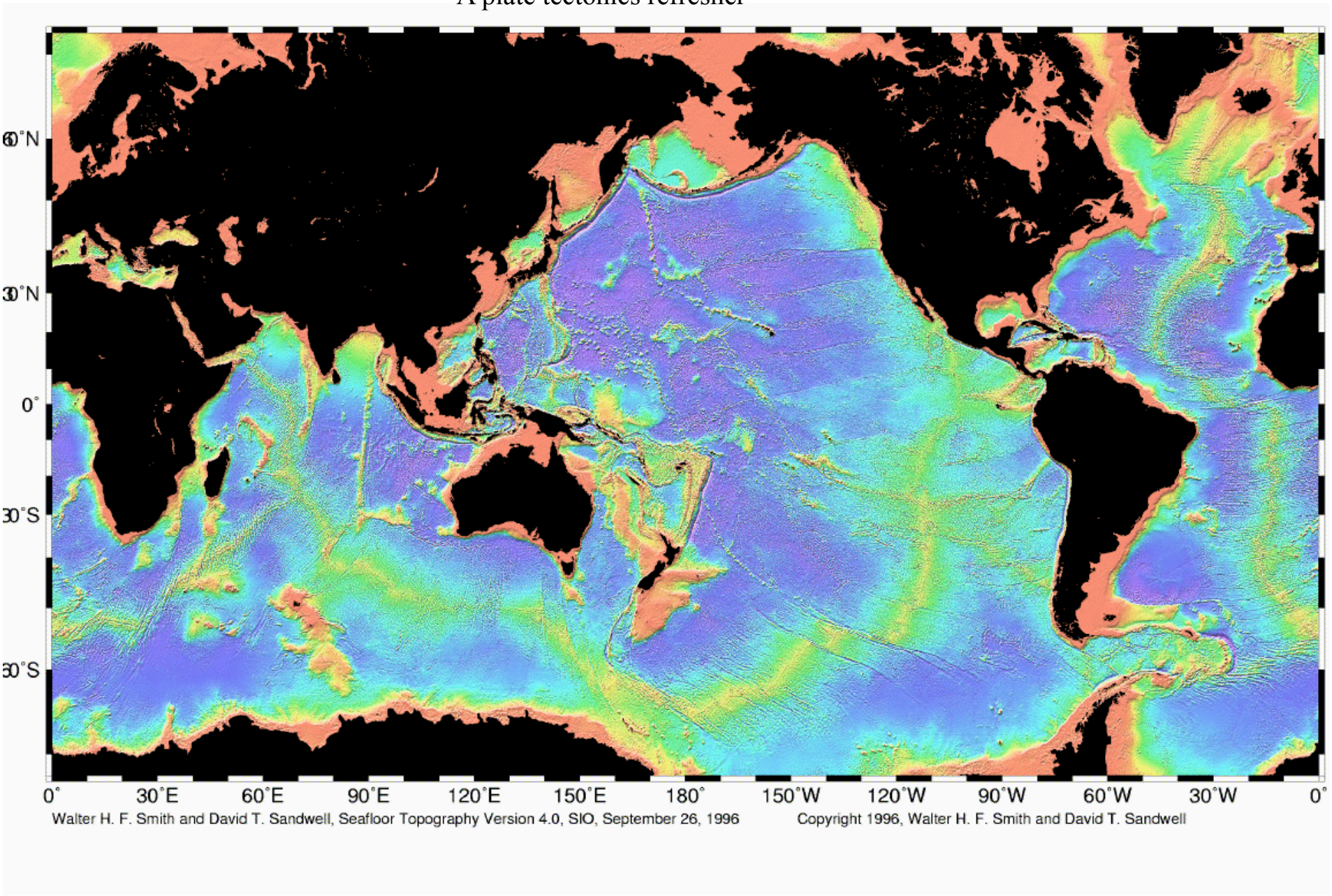
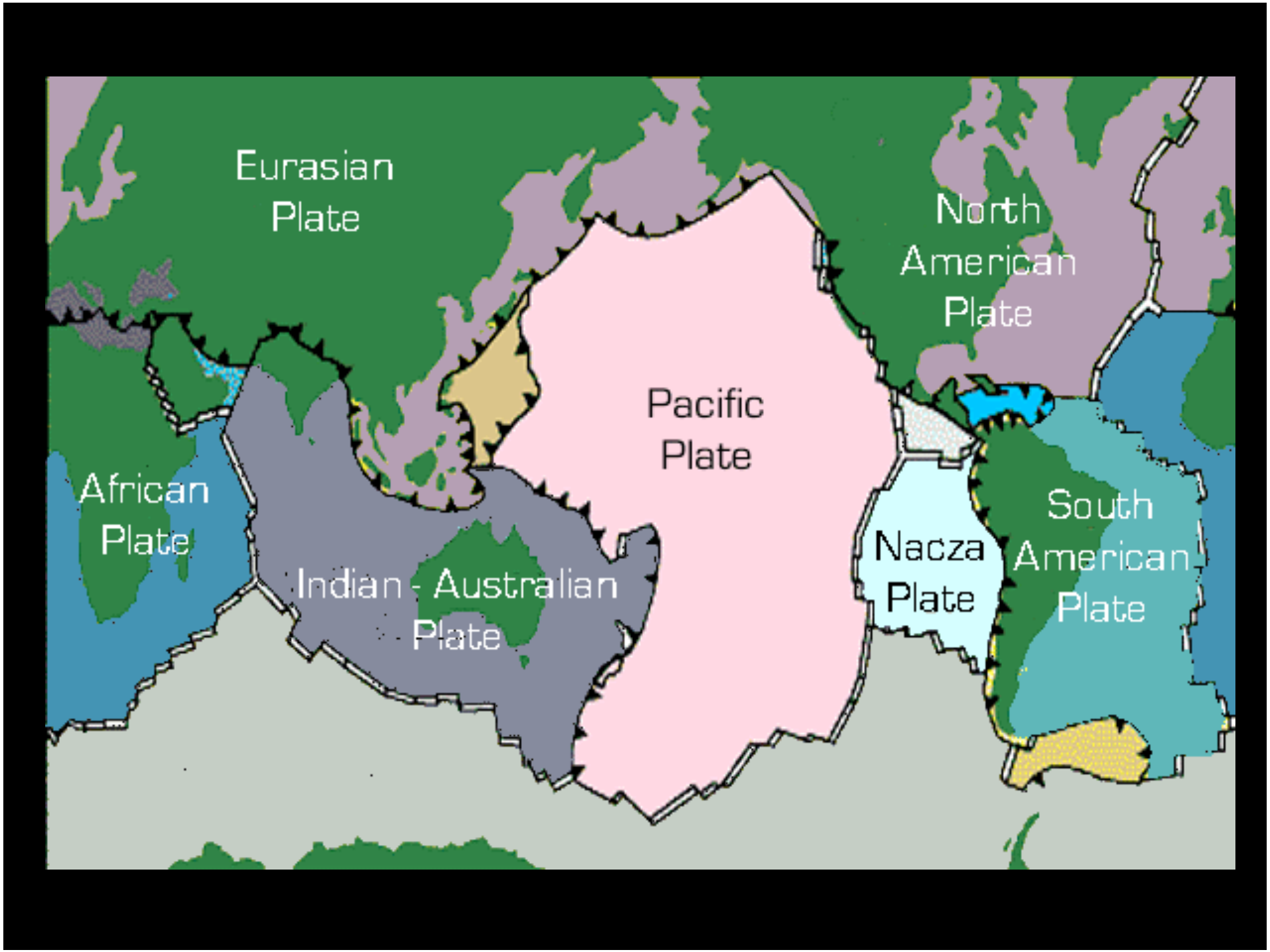
EarthScope and the Cascadia subduction zone

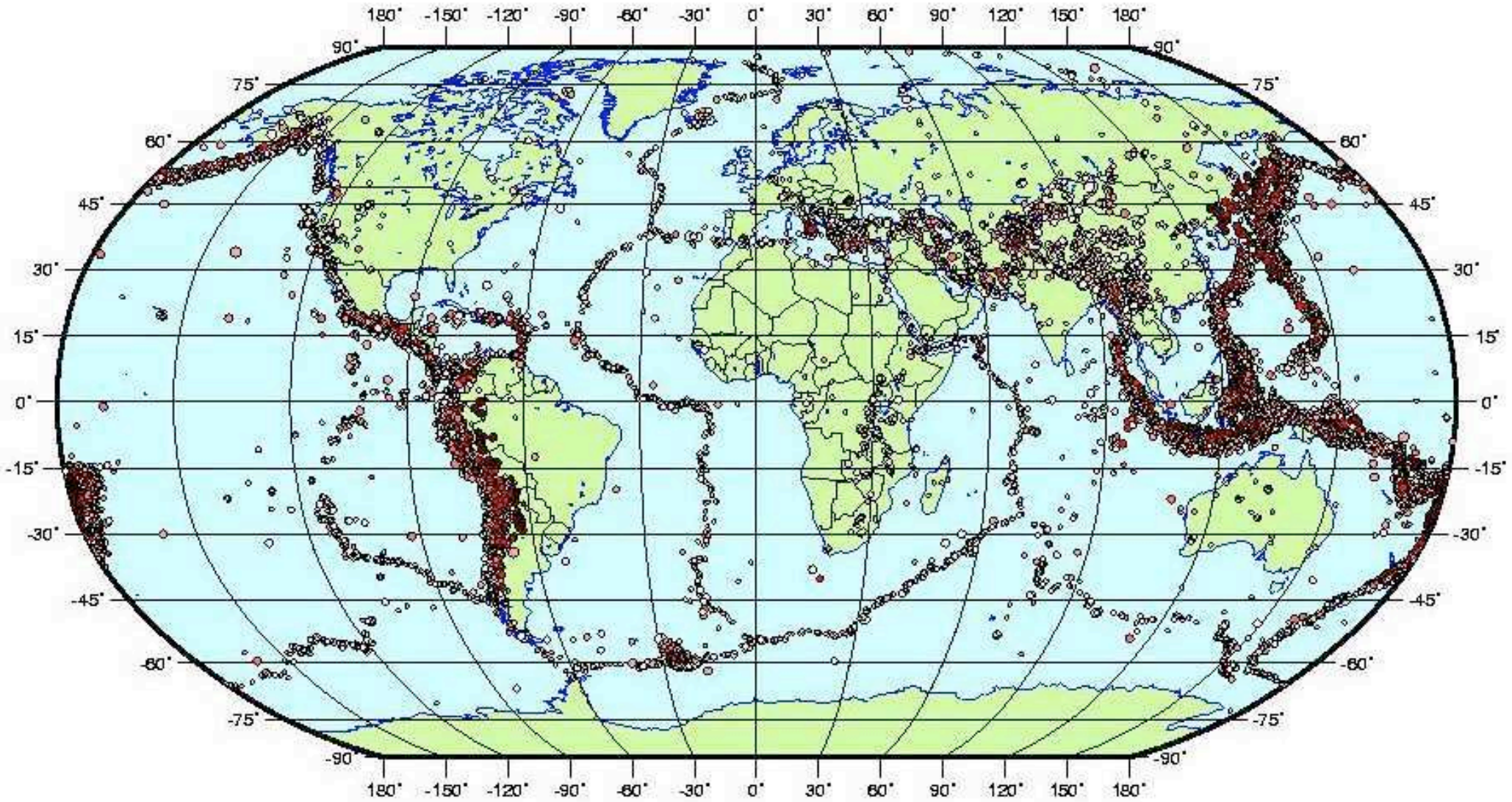
Timothy Melbourne
Pacific Northwest Geodetic Array
Central Washington University

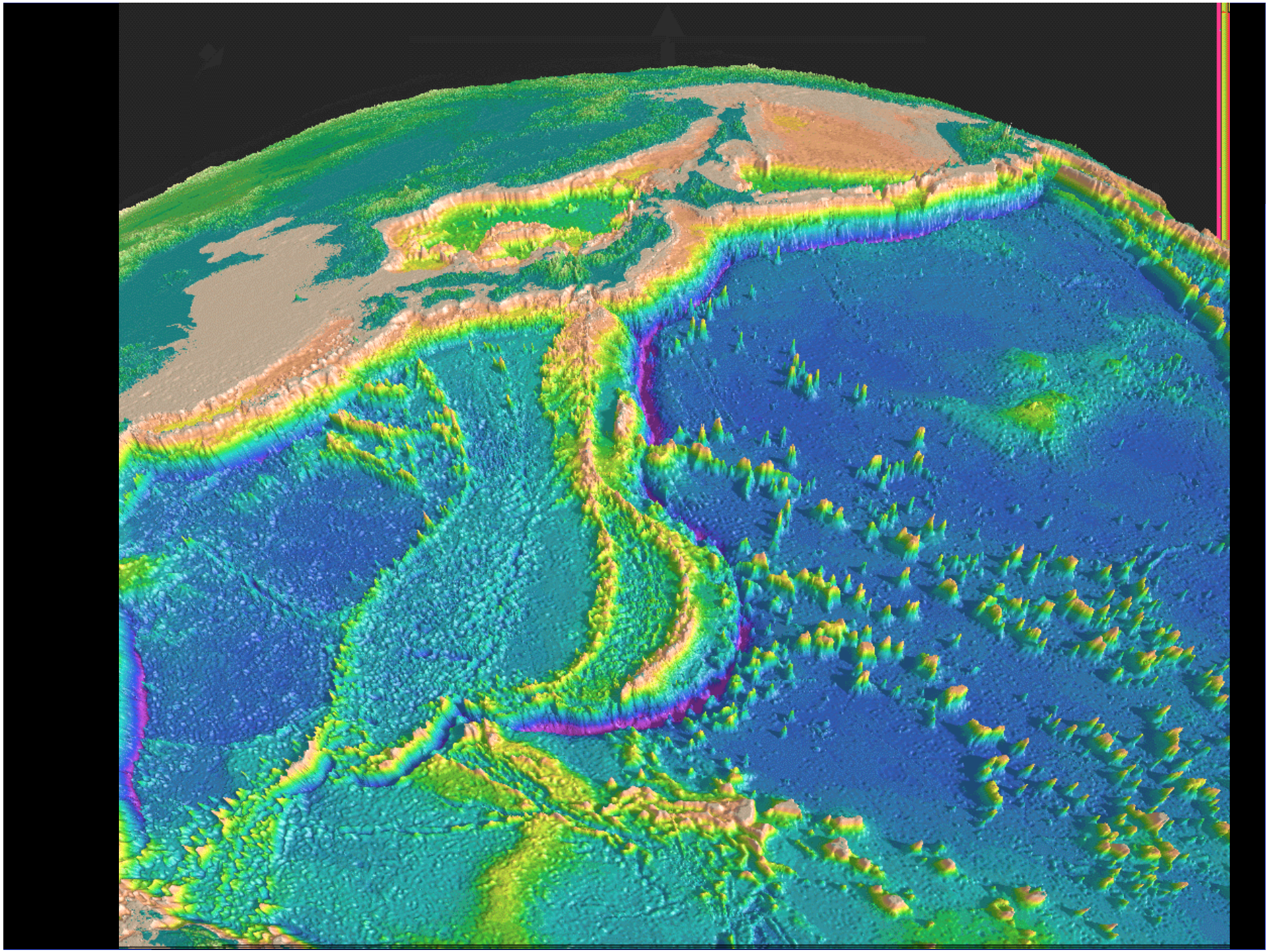


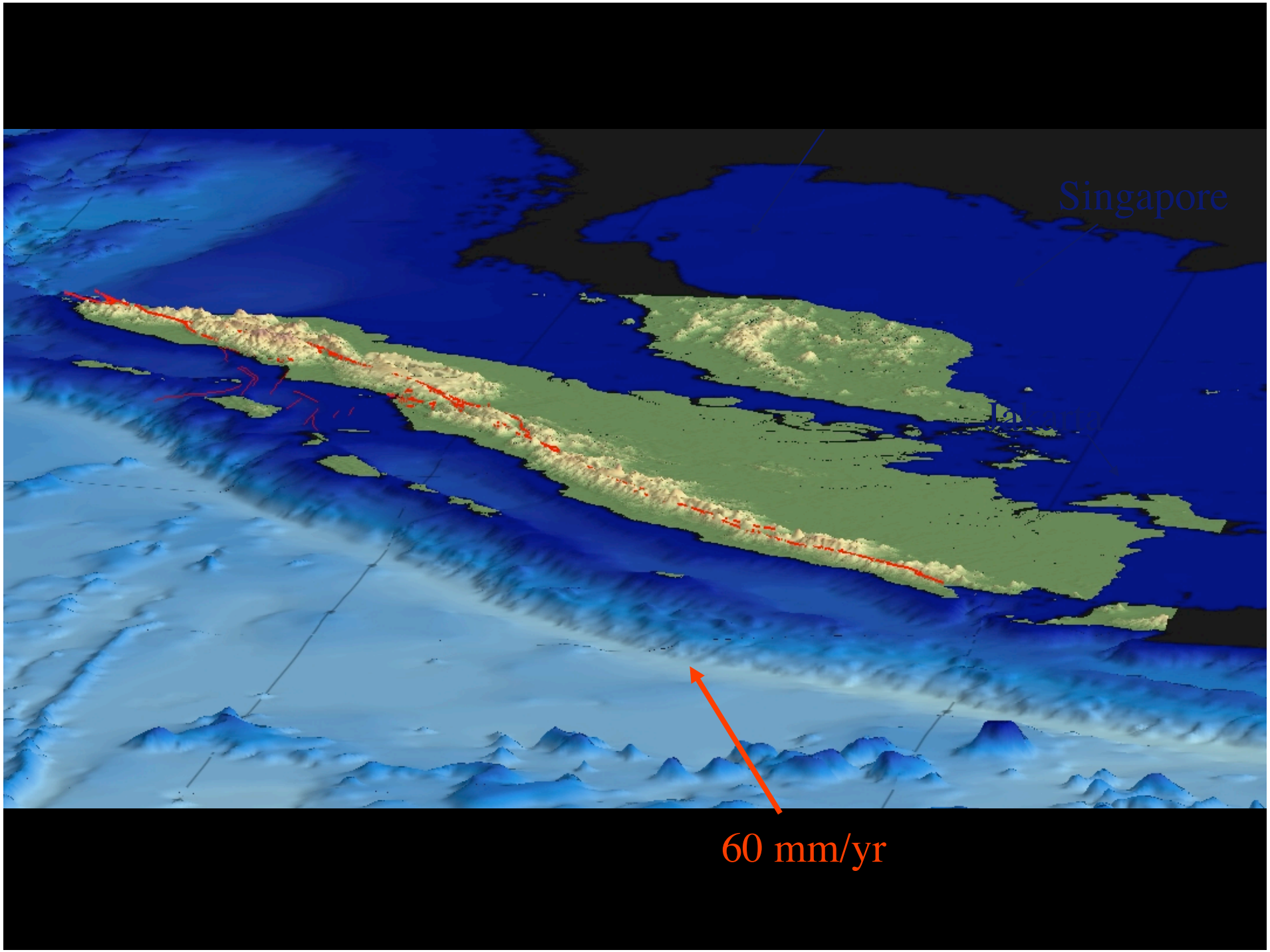
A plate tectonics refresher



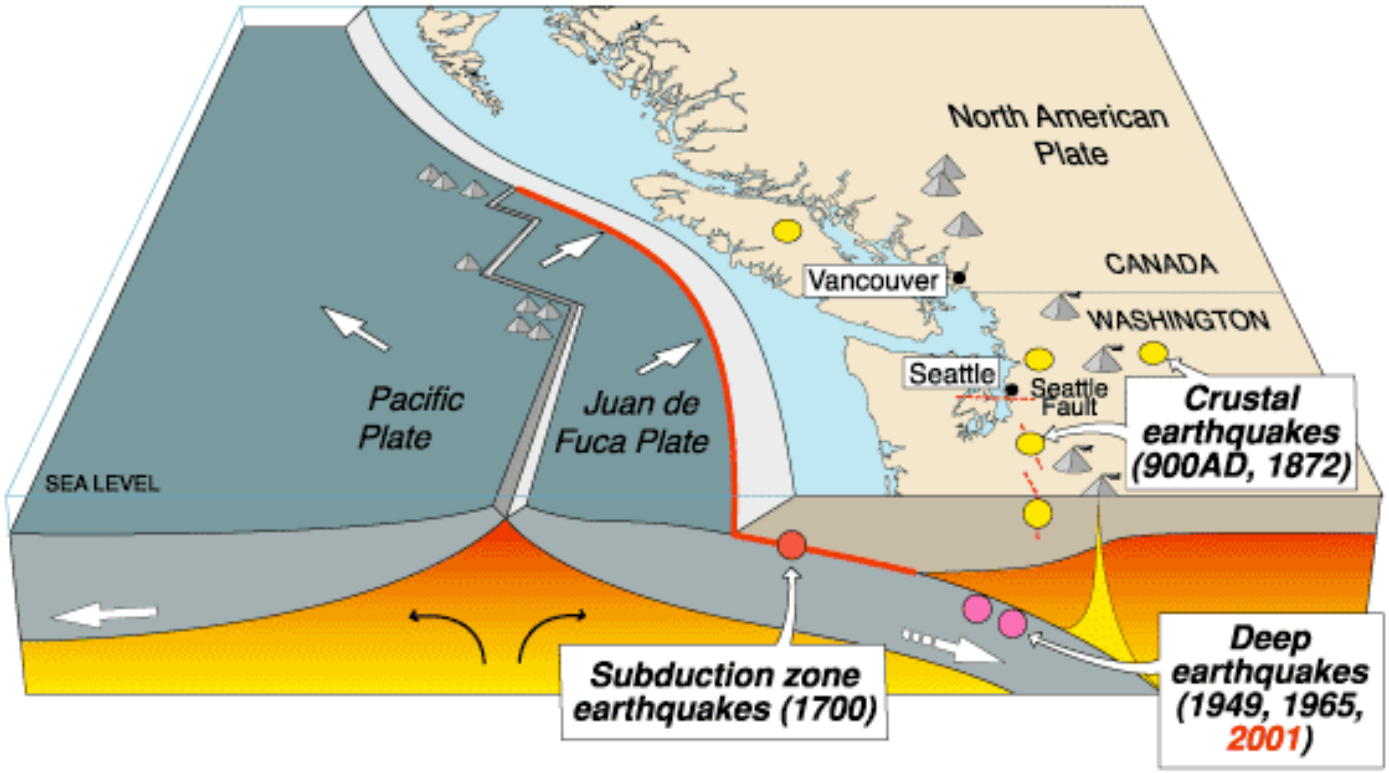

Eurasian Plate
North American Plate
Pacific Plate
African Plate
Indian - Australian Plate
Nacza Plate
South American Plate


180° -150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150° 180°
90°
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-90°

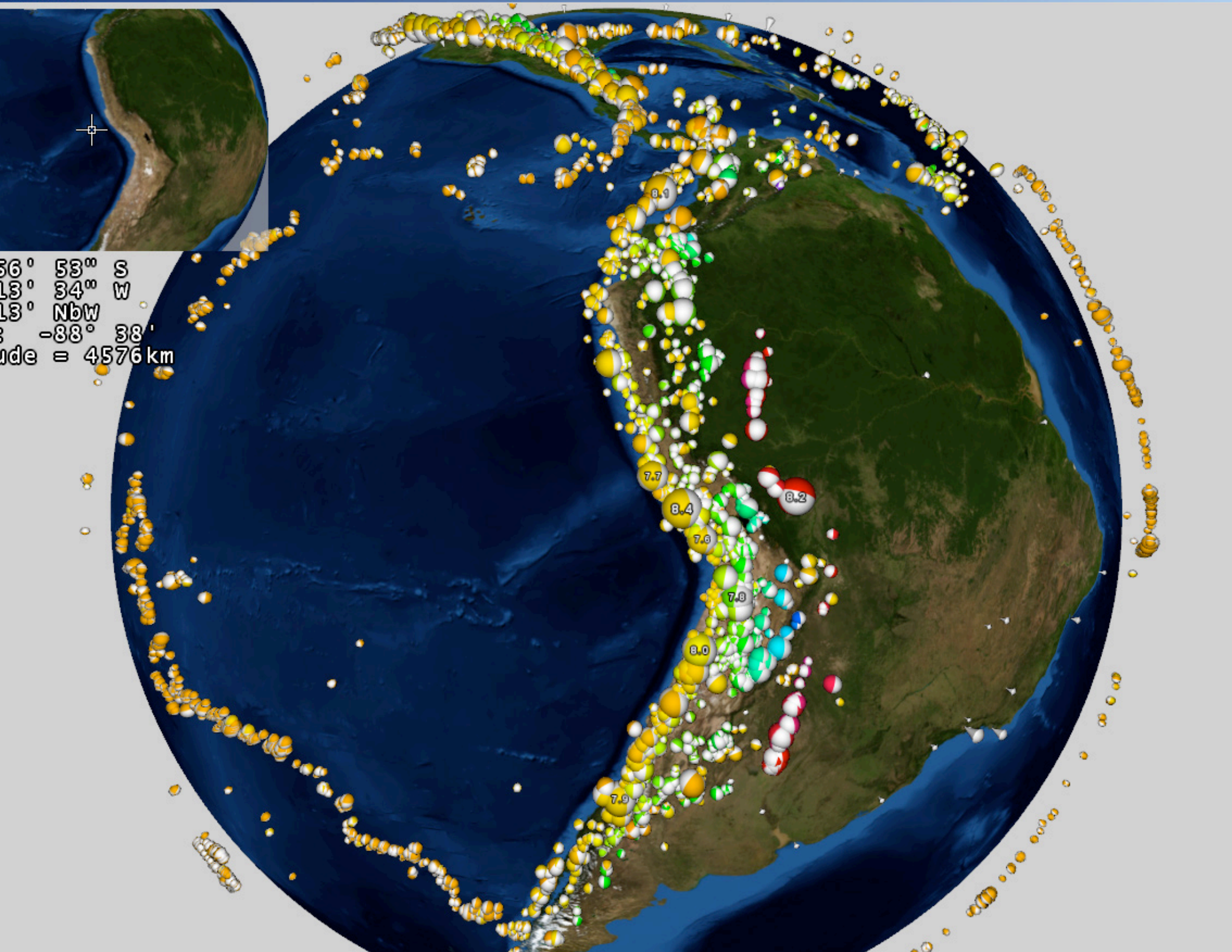


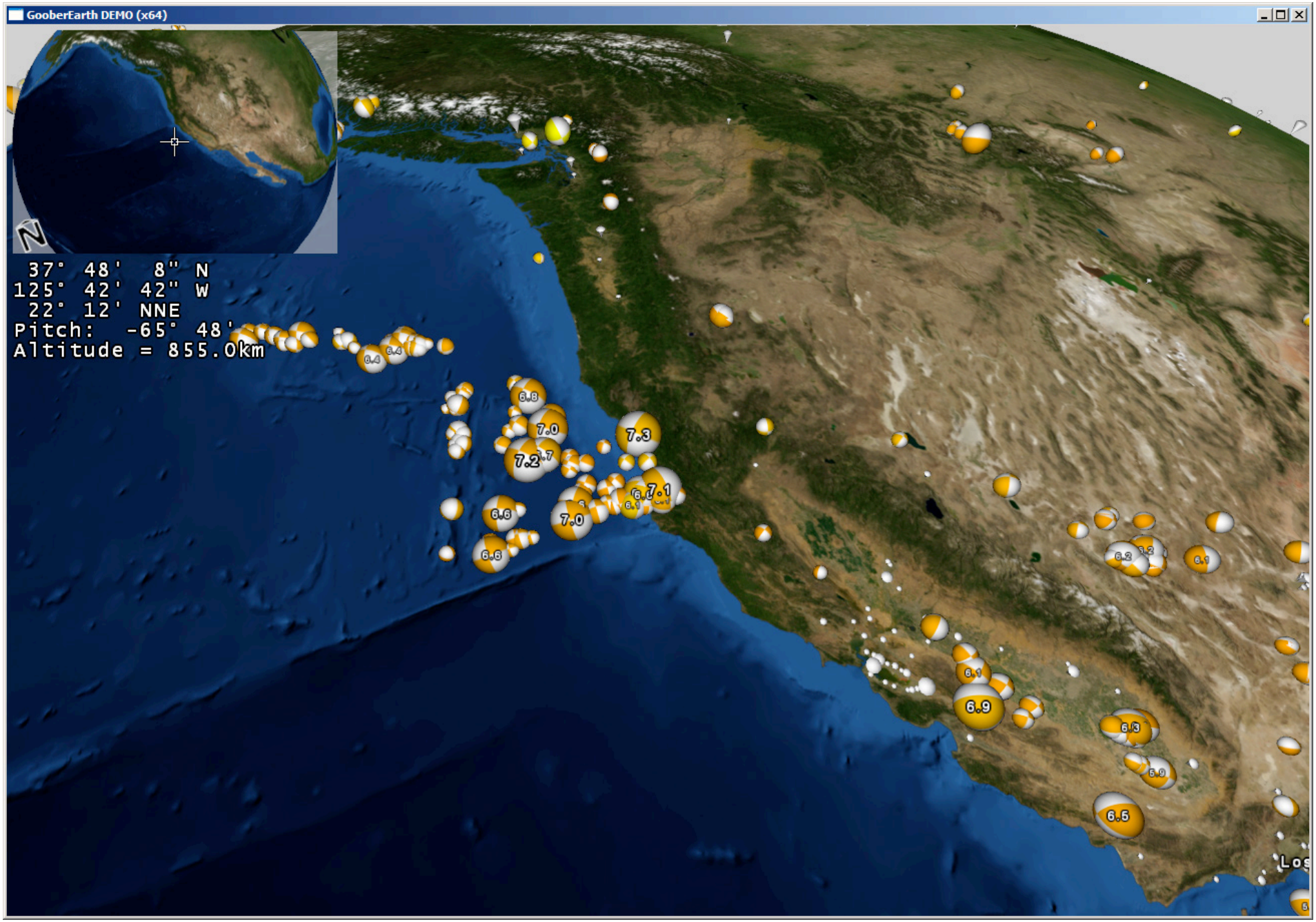

Singapore
60 mm/yr

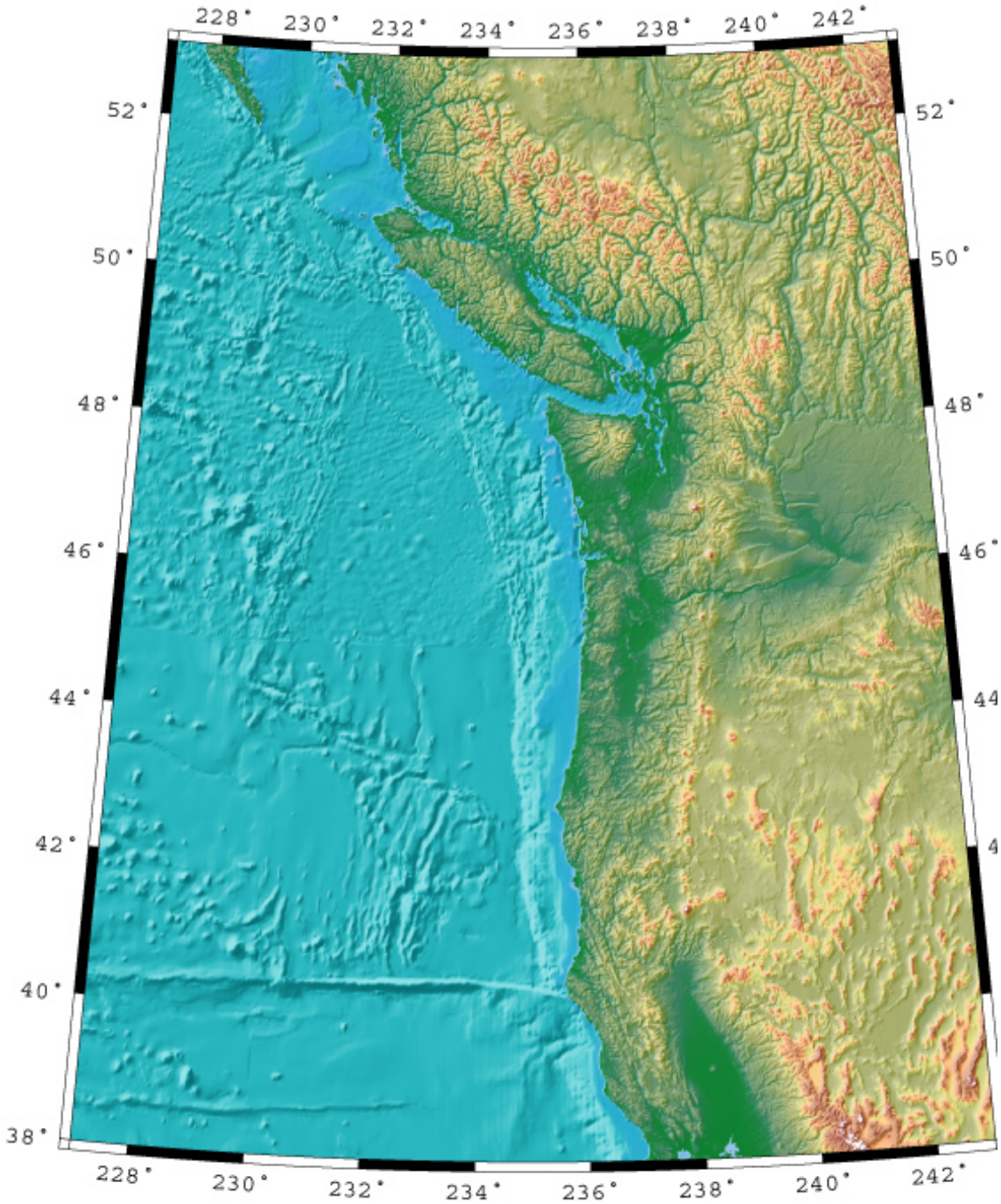
Cascadia earthquake sources



	Source	Affected area	Max. Size	Recurrence
●	Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
●	Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
●	Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?


56° 53‴ S
13° 34‴ W
13° Nbw
-88° 38'
ude = 4576 km
8.1
7.7
8.2
8.4
7.6
7.8
8.0
7.9

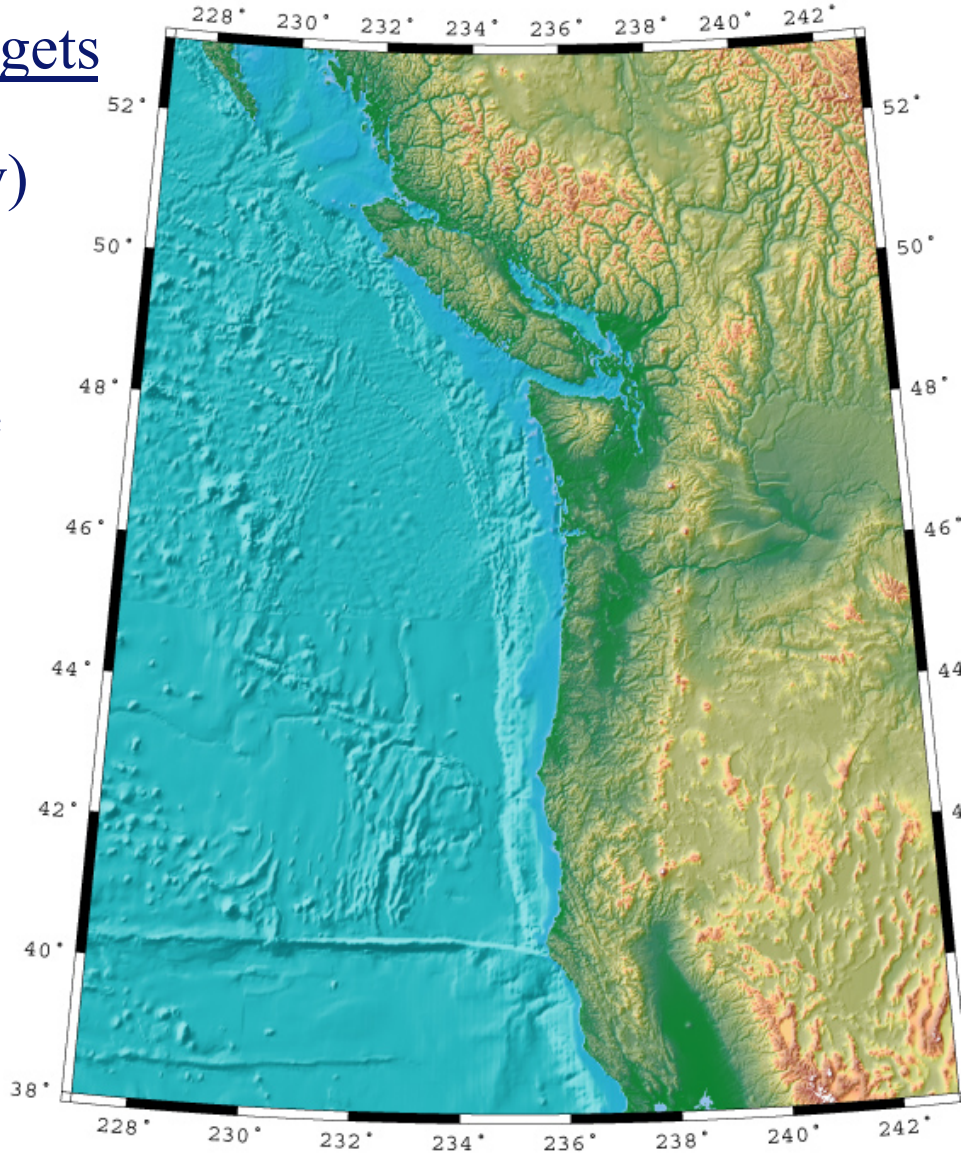

GooberEarth DEMO (x64)
37° 48' 8" N
125° 42' 42" W
22° 12' NNE
Pitch: -65° 48'
Altitude = 855.0km
N
6.4
6.8
7.0
7.3
7.2
7.1
6.6
7.0
6.6
6.1
6.9
6.3
6.5


228°
230°
232°
234°
236°
238°
240°
242°
52°
50°
48°
46°
44°
42°
40°
38°

Some early PANGA Science Targets

- Measure deformation (if any)
- Quantify seismic risks
- Understand subduction zone dynamics

Step 1: install some GPS

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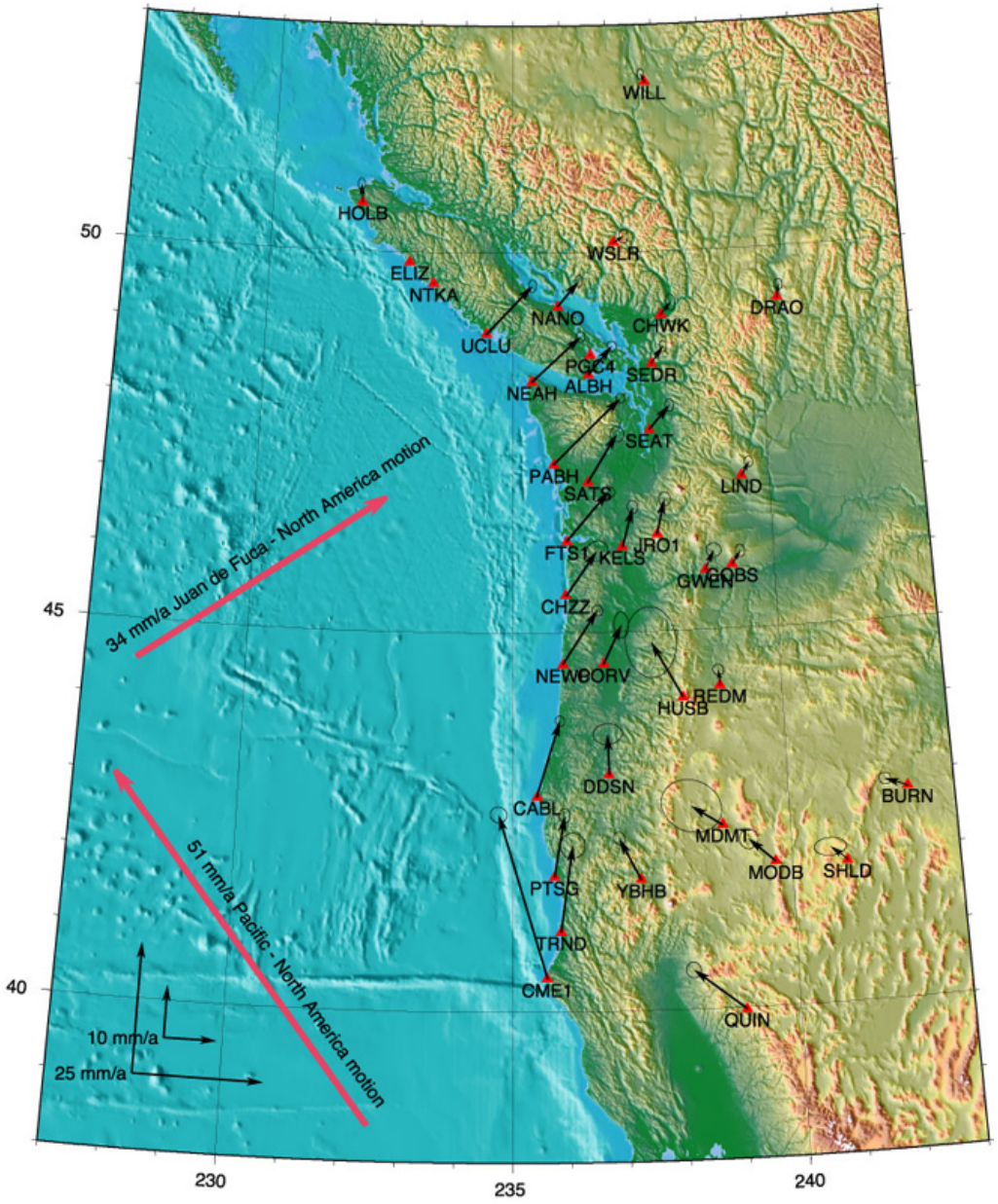
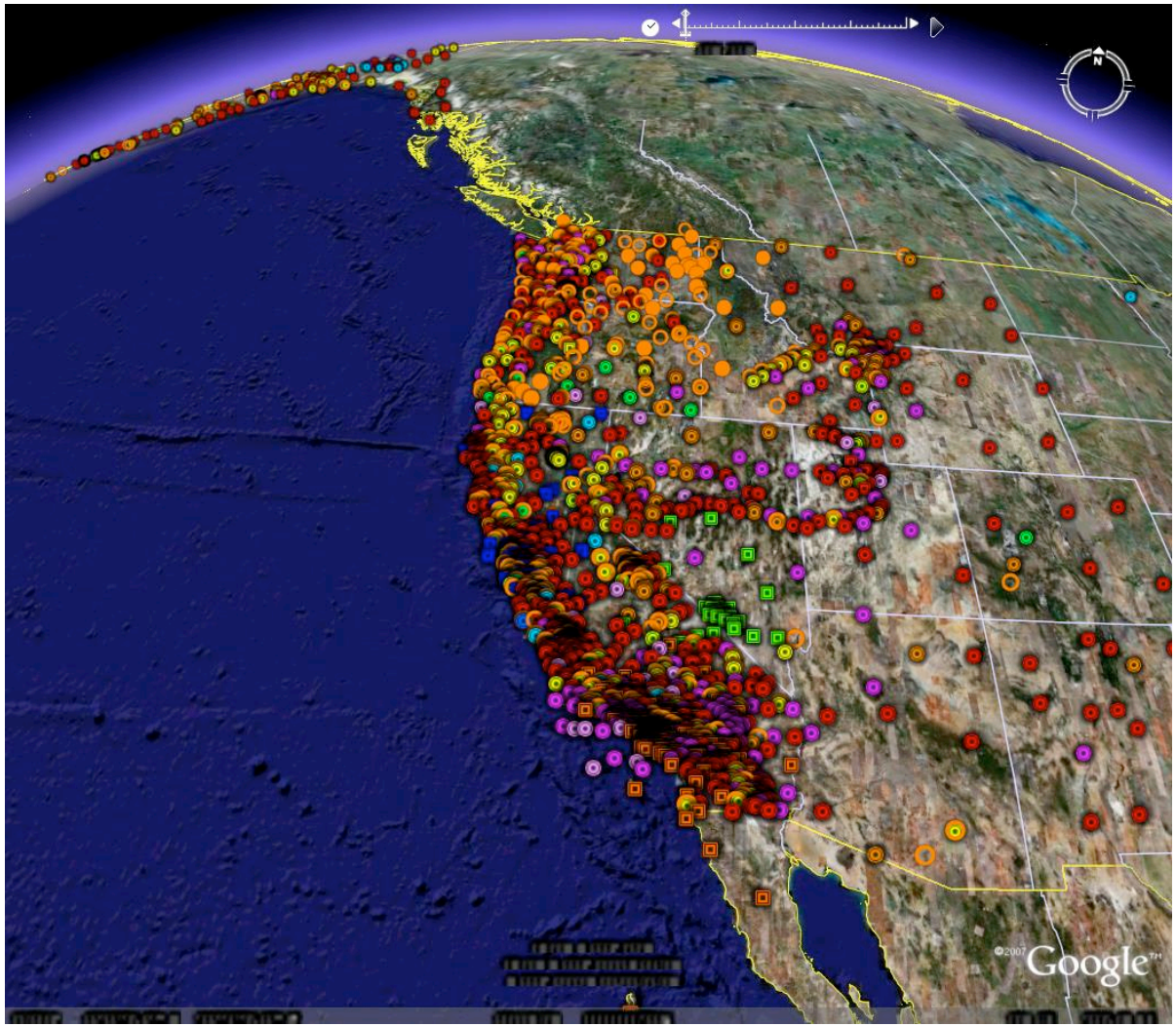
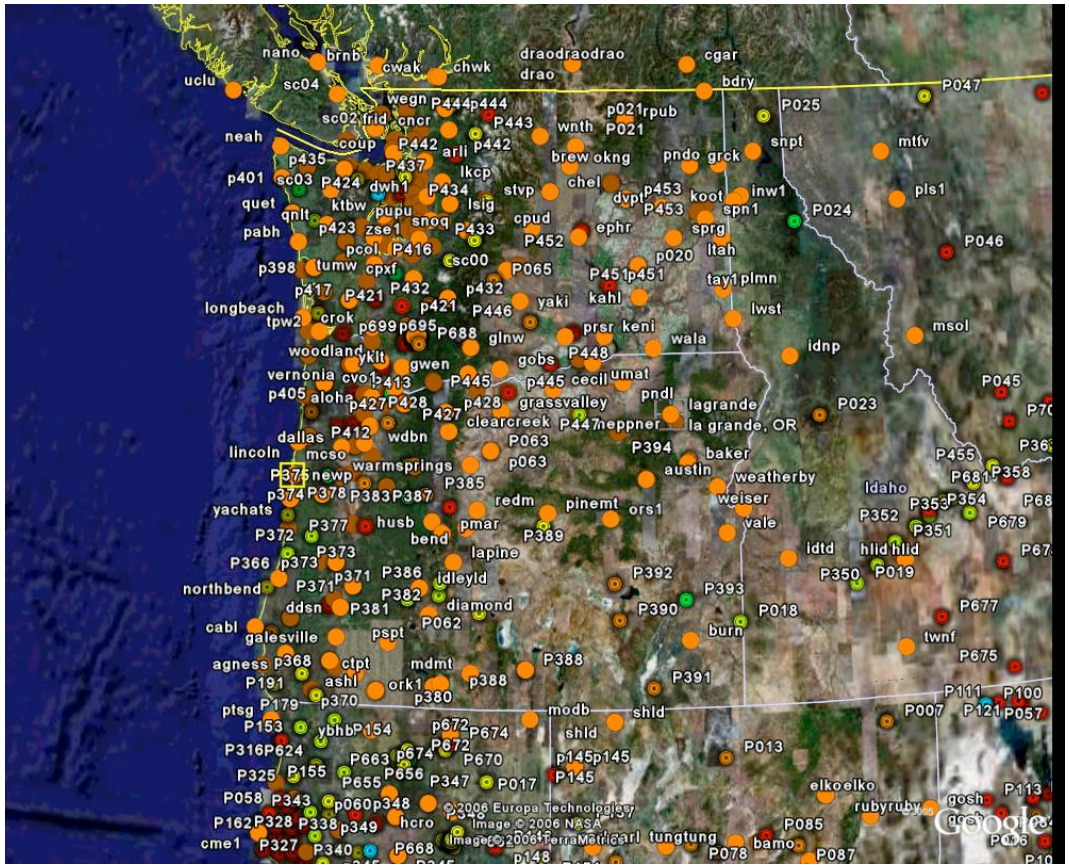
Cascadia forearc interseismic deformation (2002)

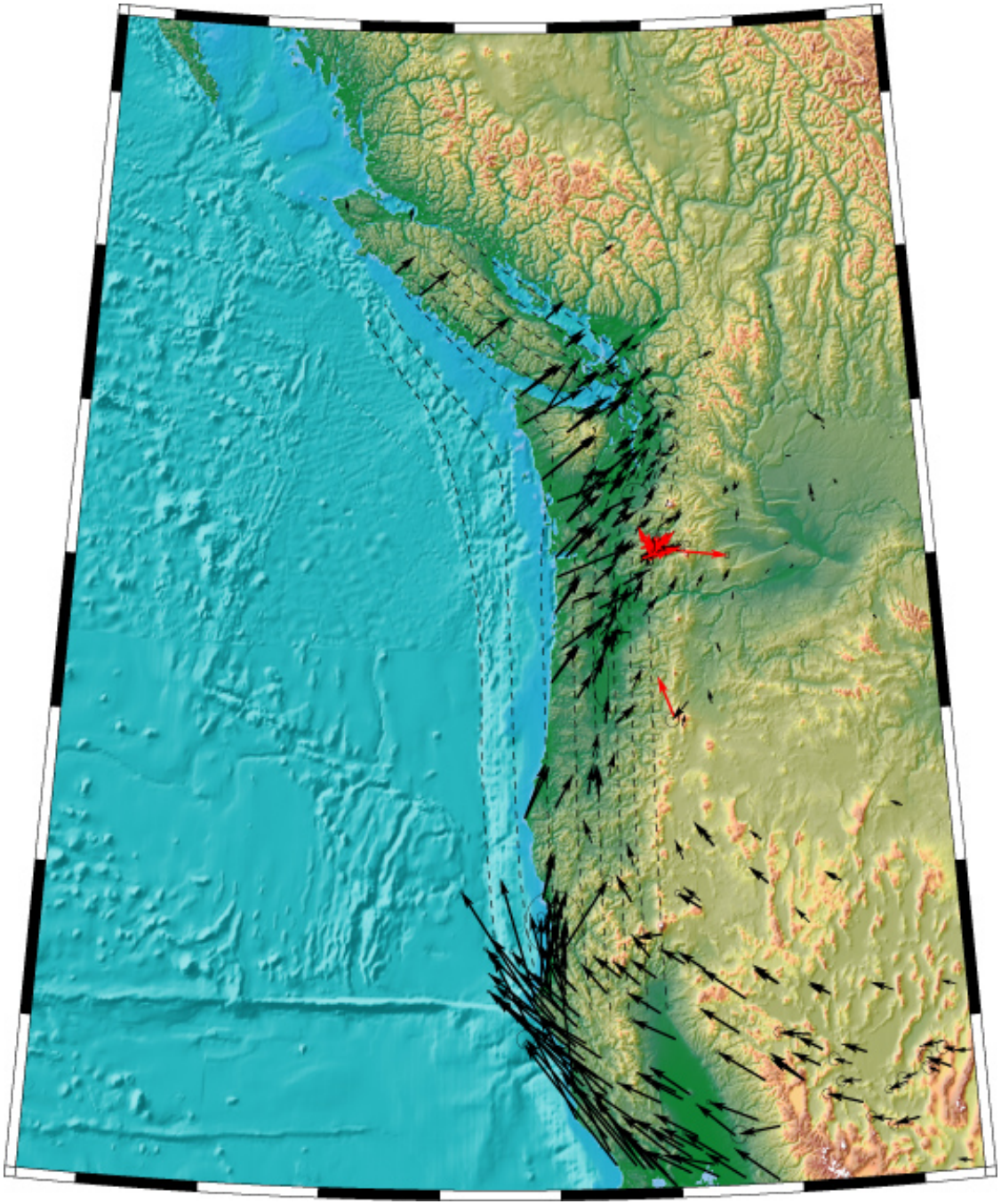


Cascadia forearc interseismic deformation (2002)

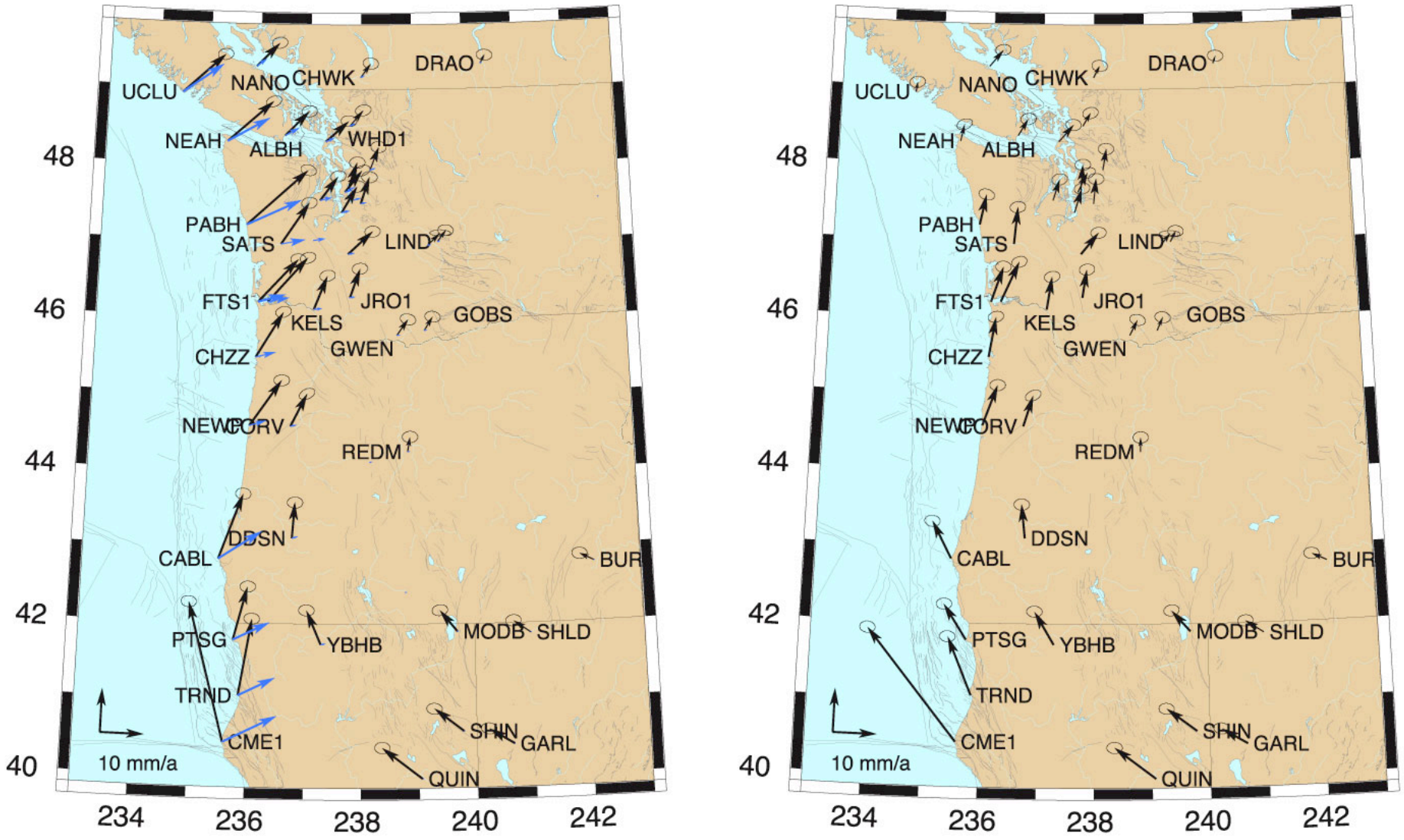


Cascadia forearc interseismic deformation (2002)

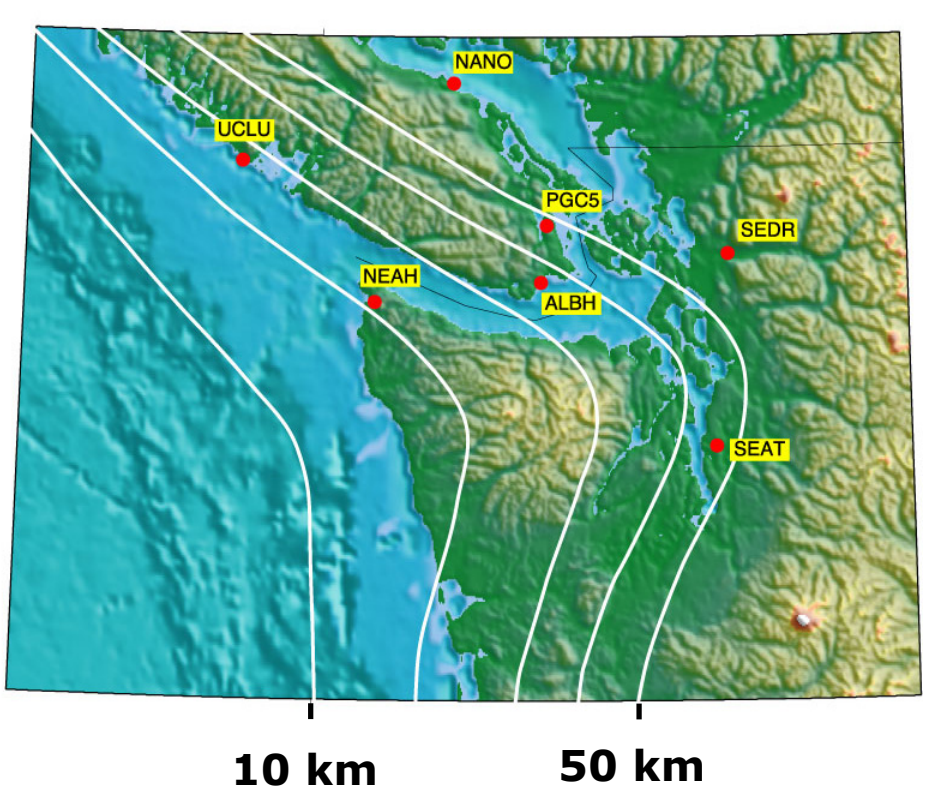


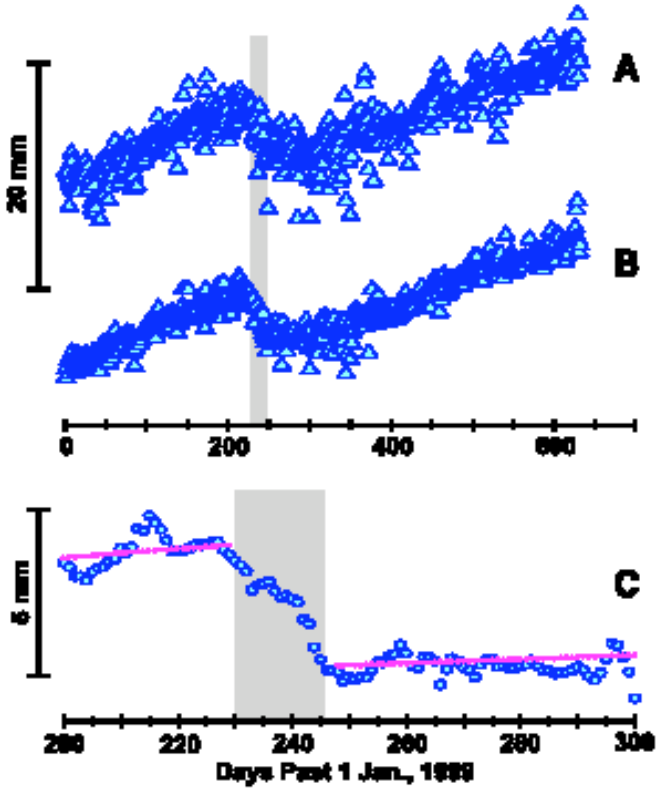


Szeliga, Melbourne, Santillan & Miller, JGR, (in press) 2008

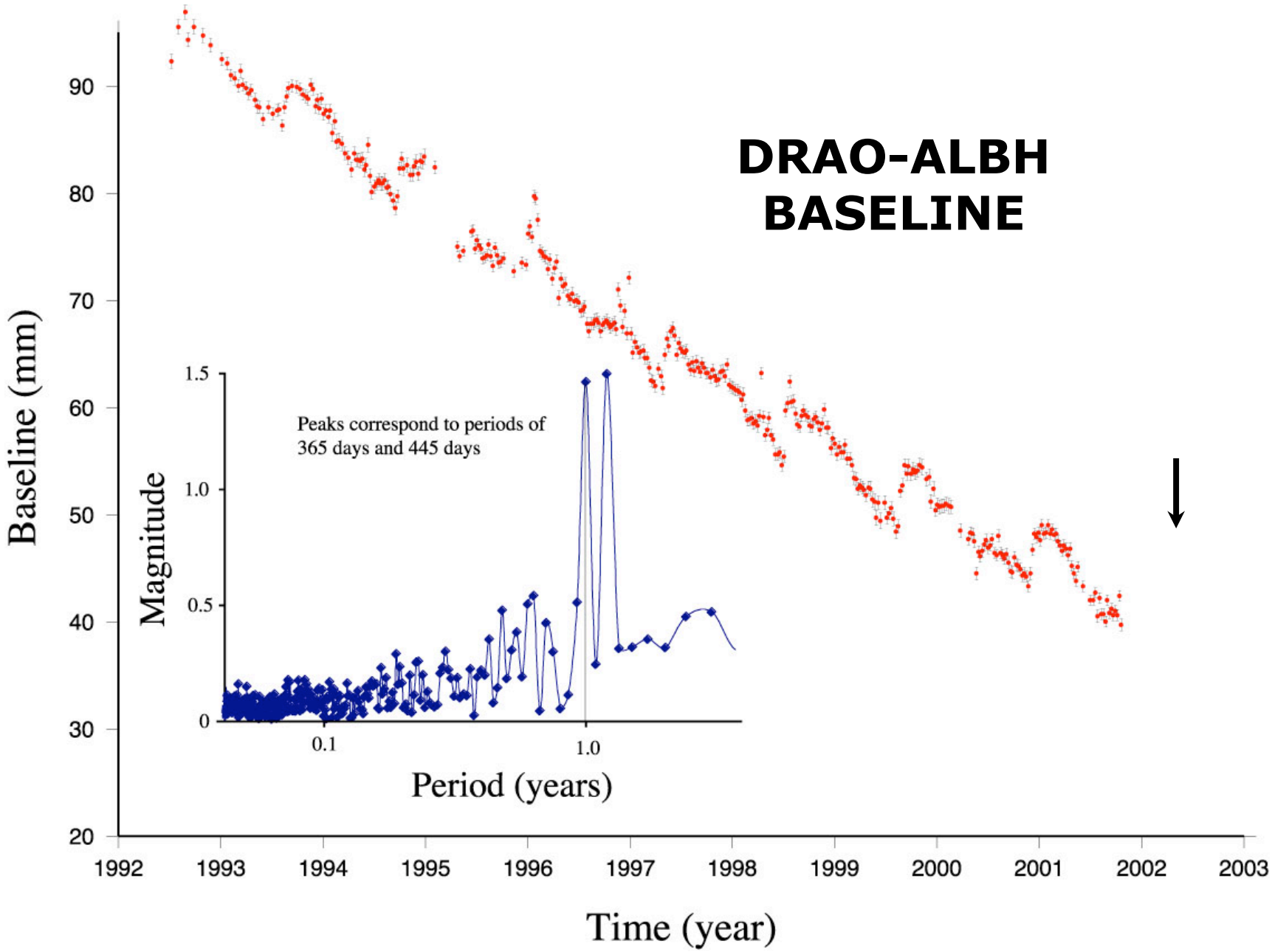


Updated from Miller, Johnson, Rubin, Dragert, Wang, Qamar, & Goldfinger, 2001

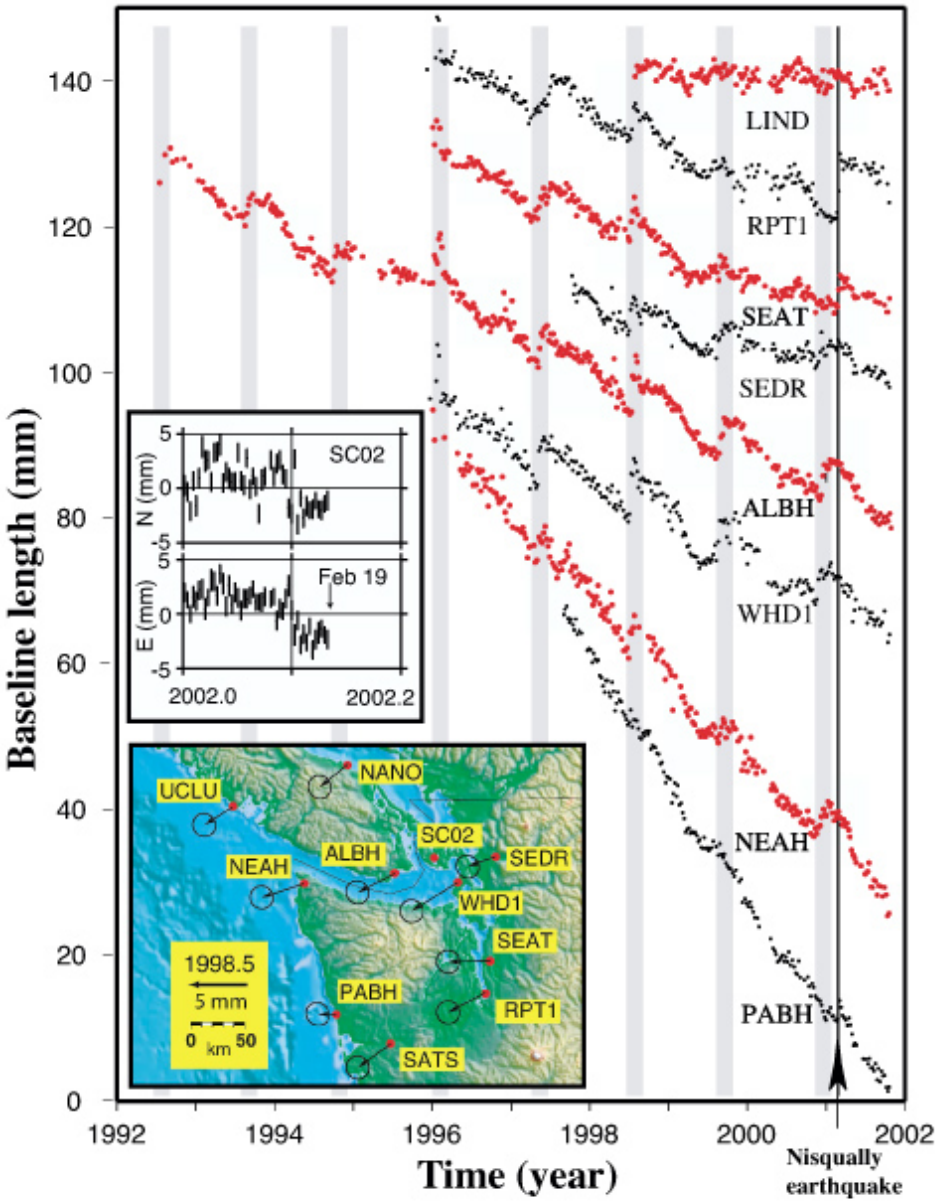




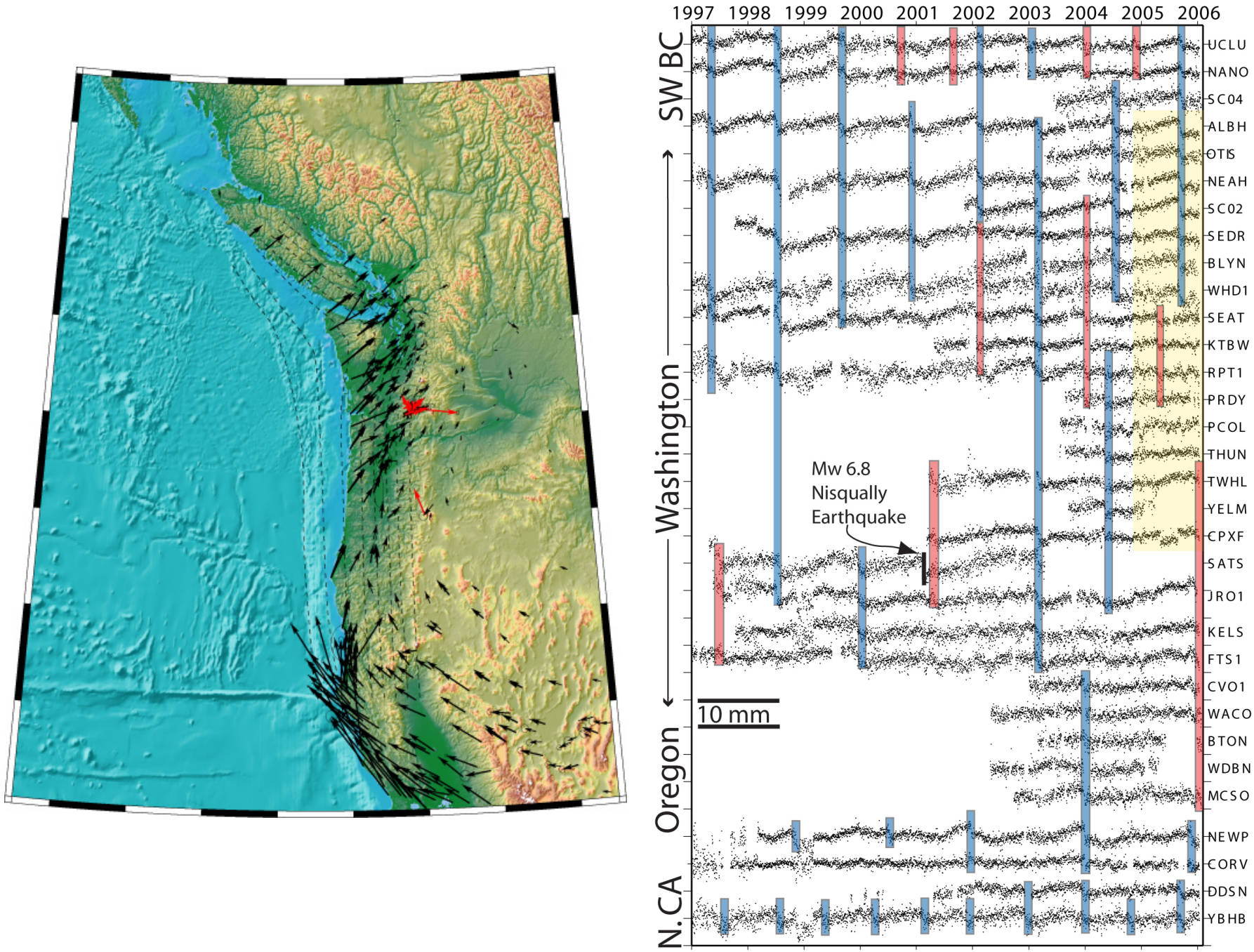
Dragert, Wang and James, 2001


DRAO-ALBH
BASELINE
Baseline (mm)
90
80
70
60
50
40
30
20
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time (year)
Peaks correspond to periods of
365 days and 445 days
Magnitude
1.5
1.0
0.5
0
0.1
1.0
Period (years)

Periodic Cascadia slow earthquakes



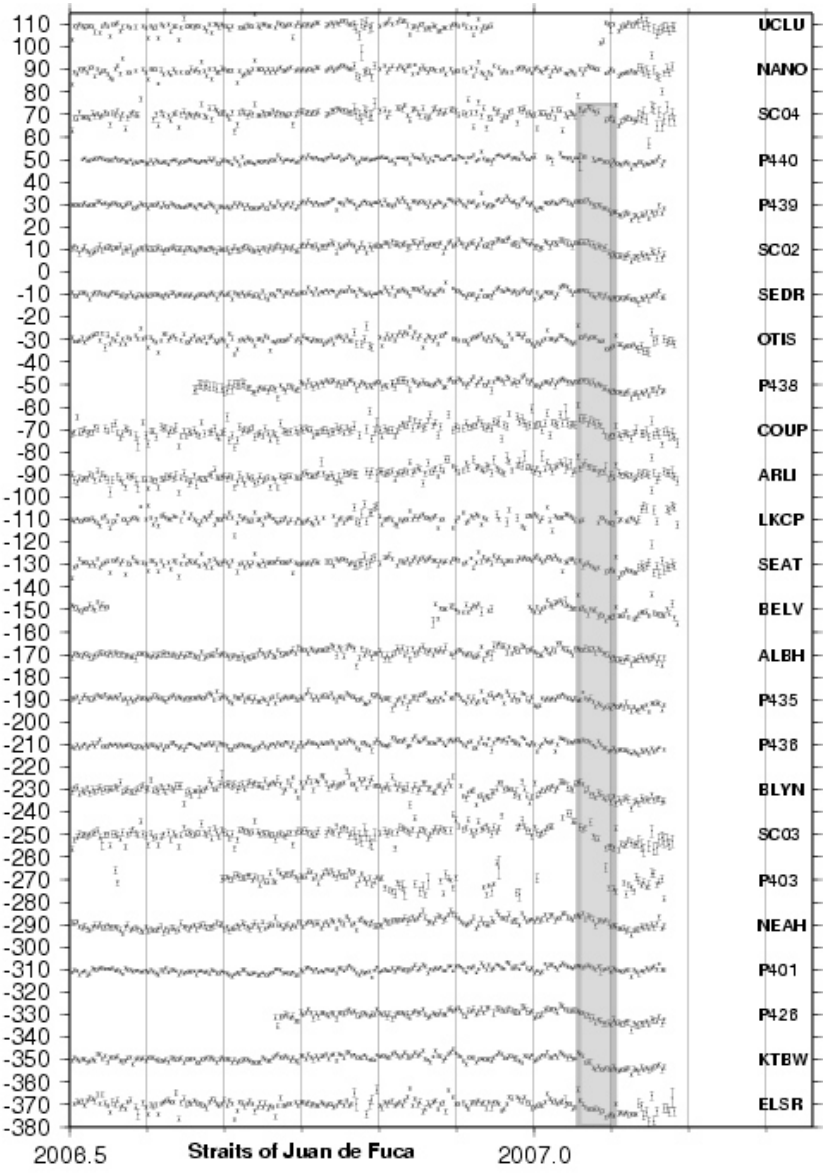
Miller, Melbourne, Johnson and Sumner, 2002



Szeliga, Melbourne, Santillan & Miller, JGR, (in press) 2007

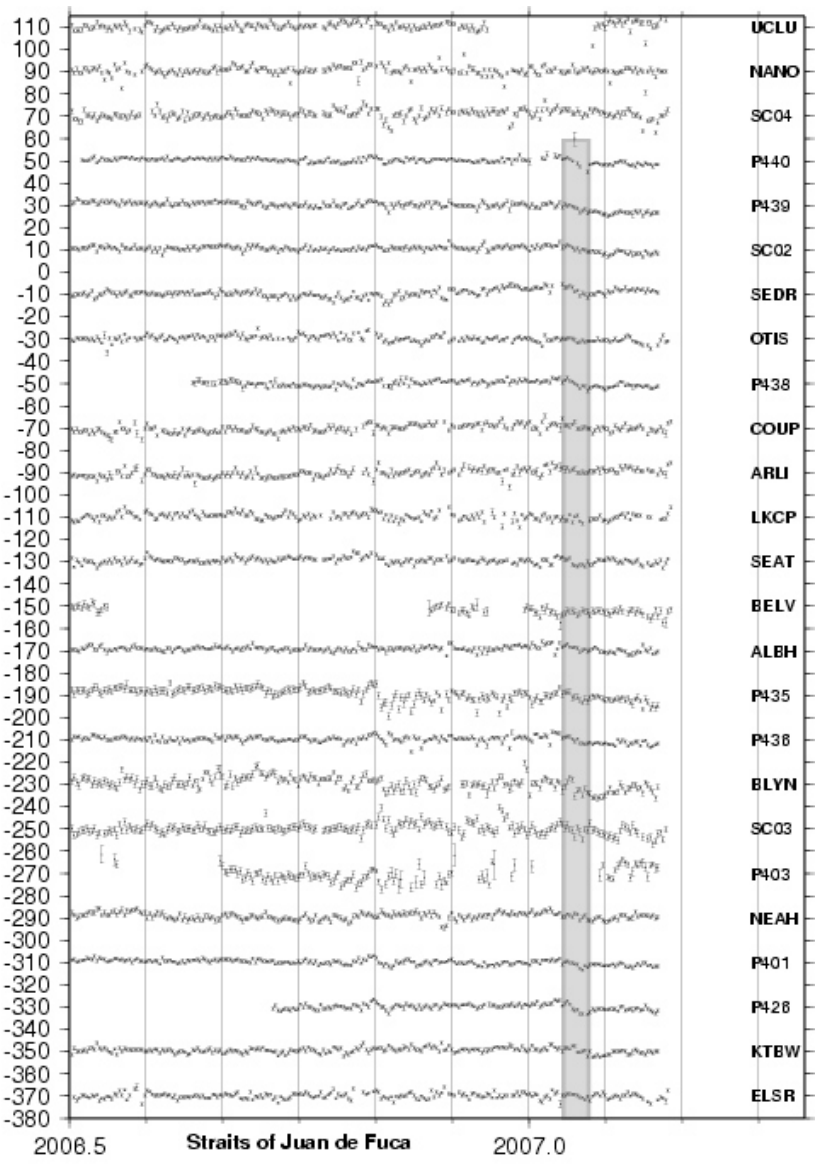
2007.08 ETS

Longitude



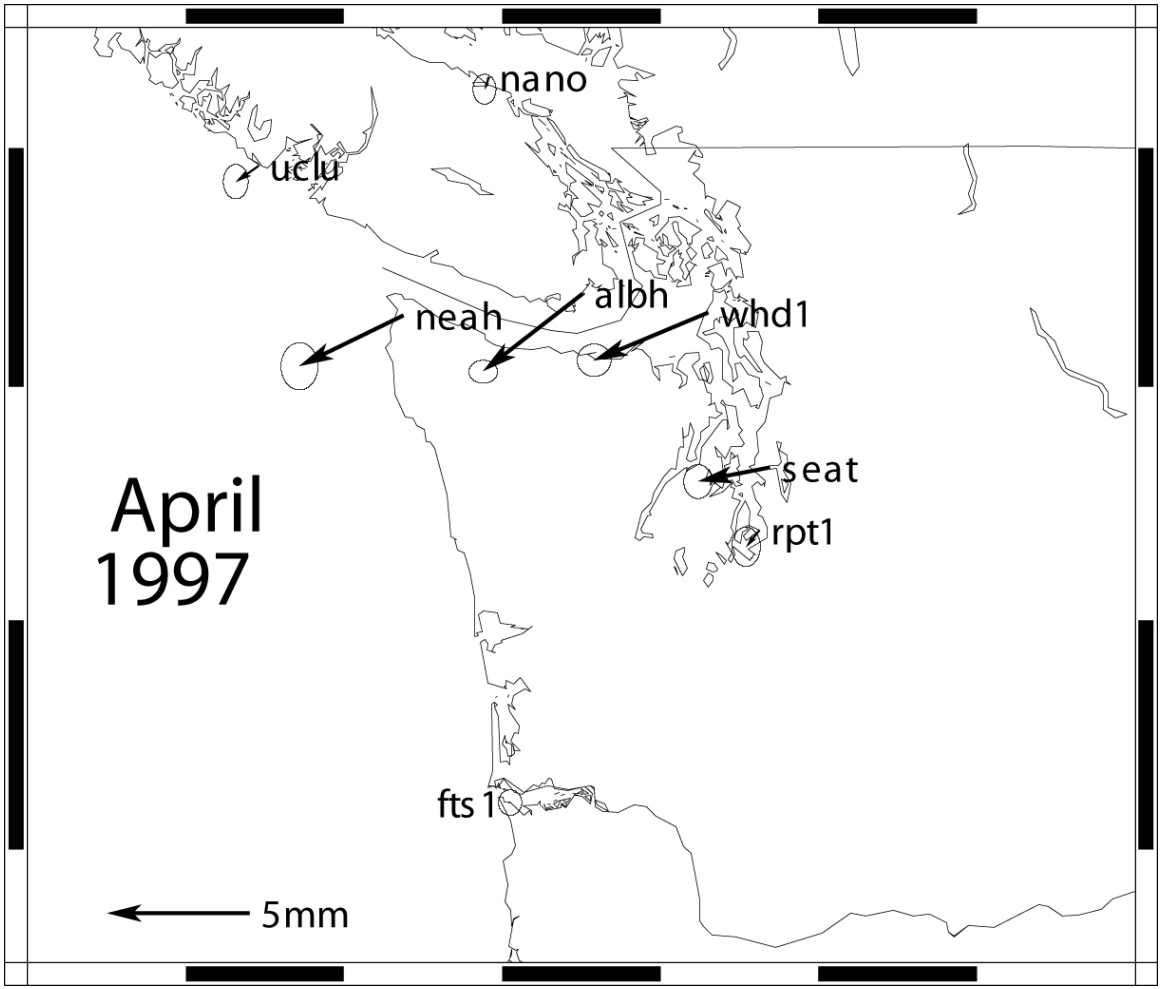
GMT 2007 Feb 28 12:11:05 Central Washington University Geodesy Lab

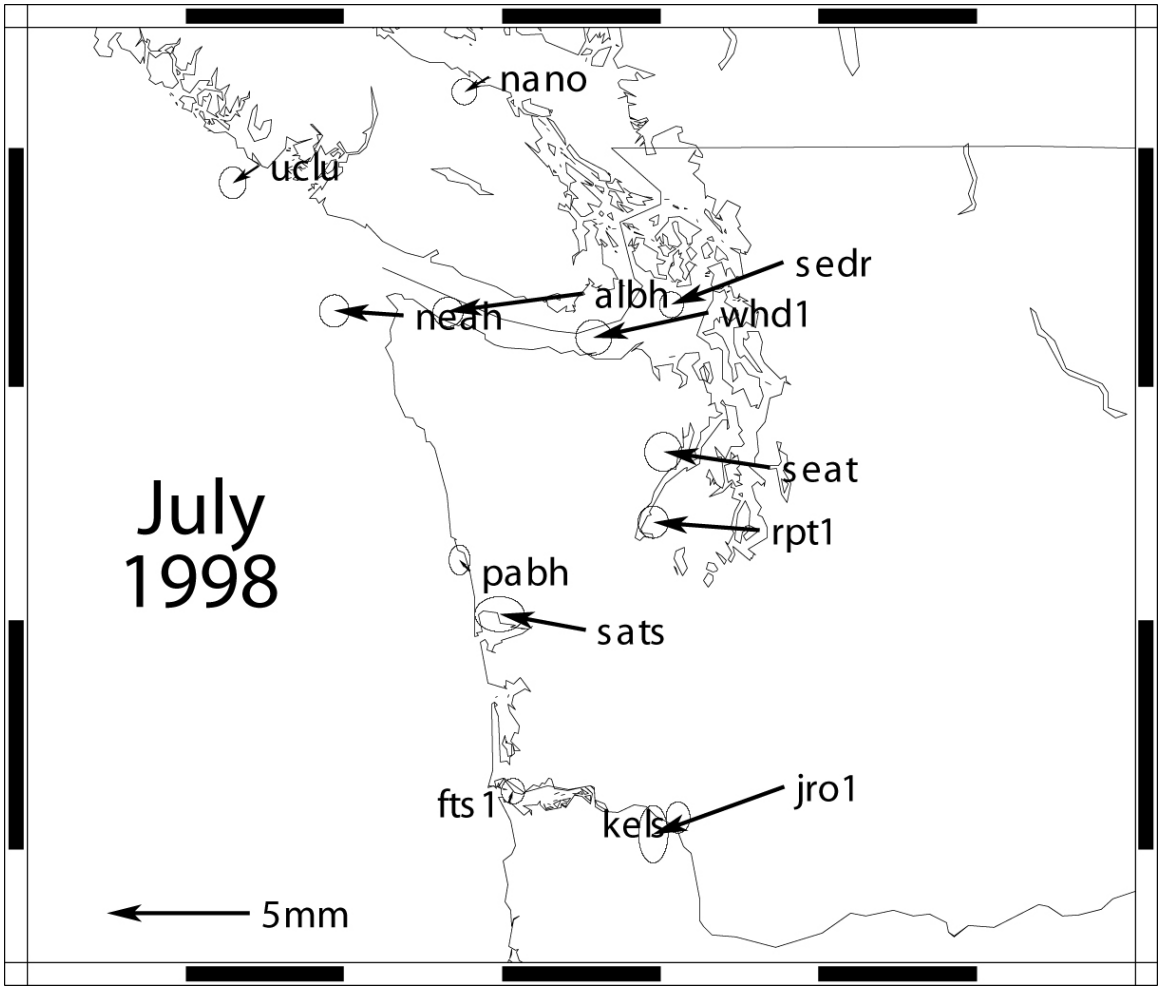
Latitude

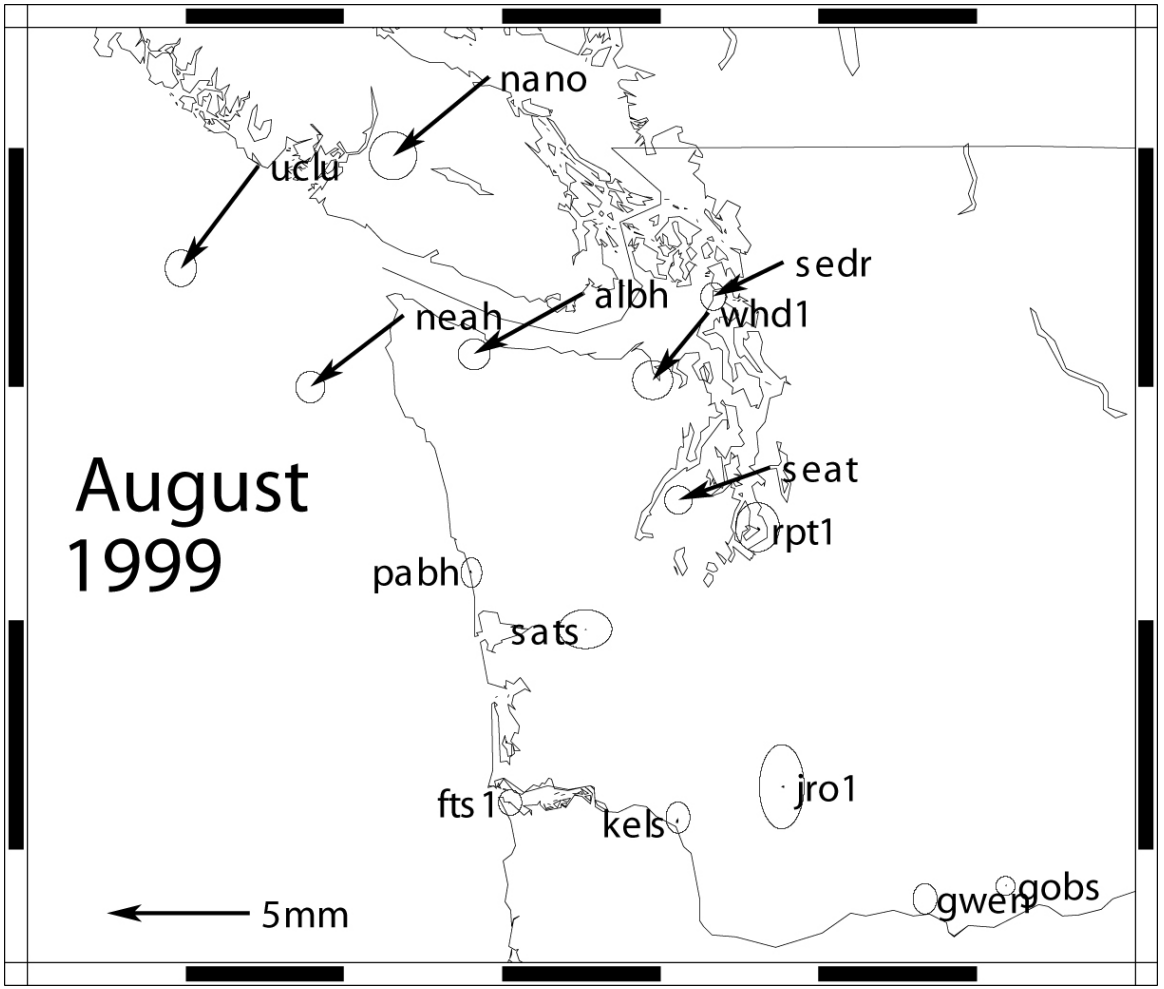


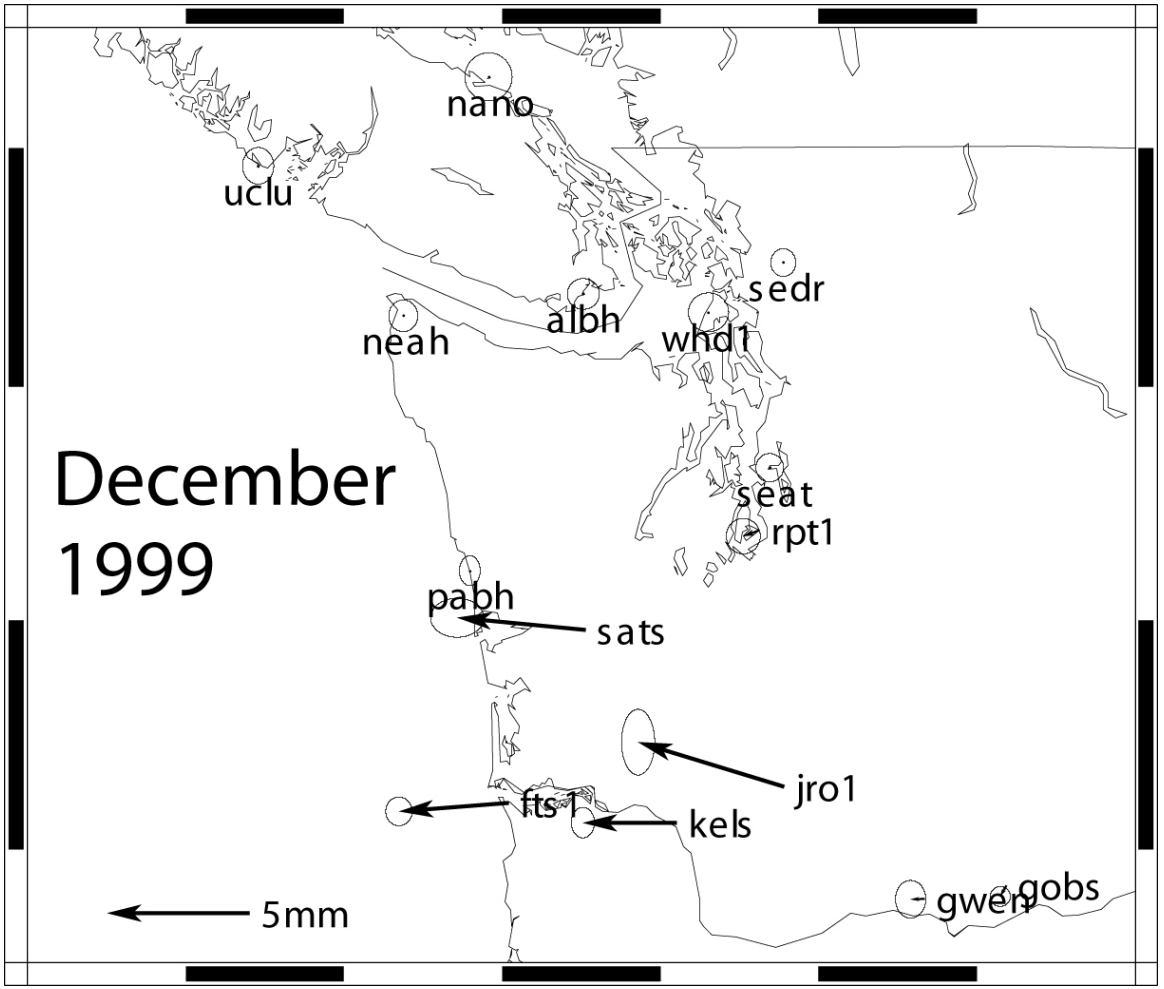
GMT 2007 Feb 28 12:11:01 Central Washington University Geodesy Lab

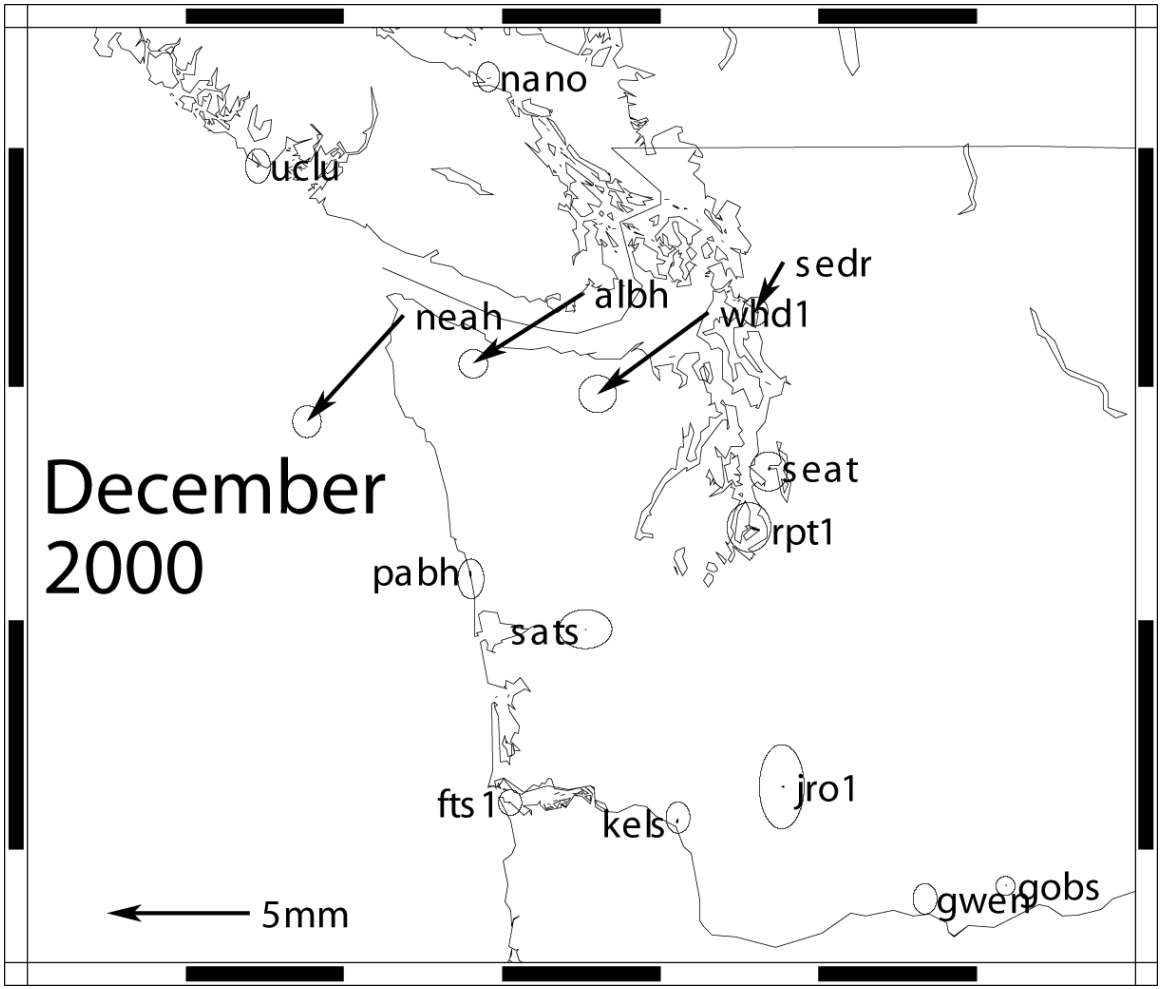
www.geodesy.org/pnwdaily

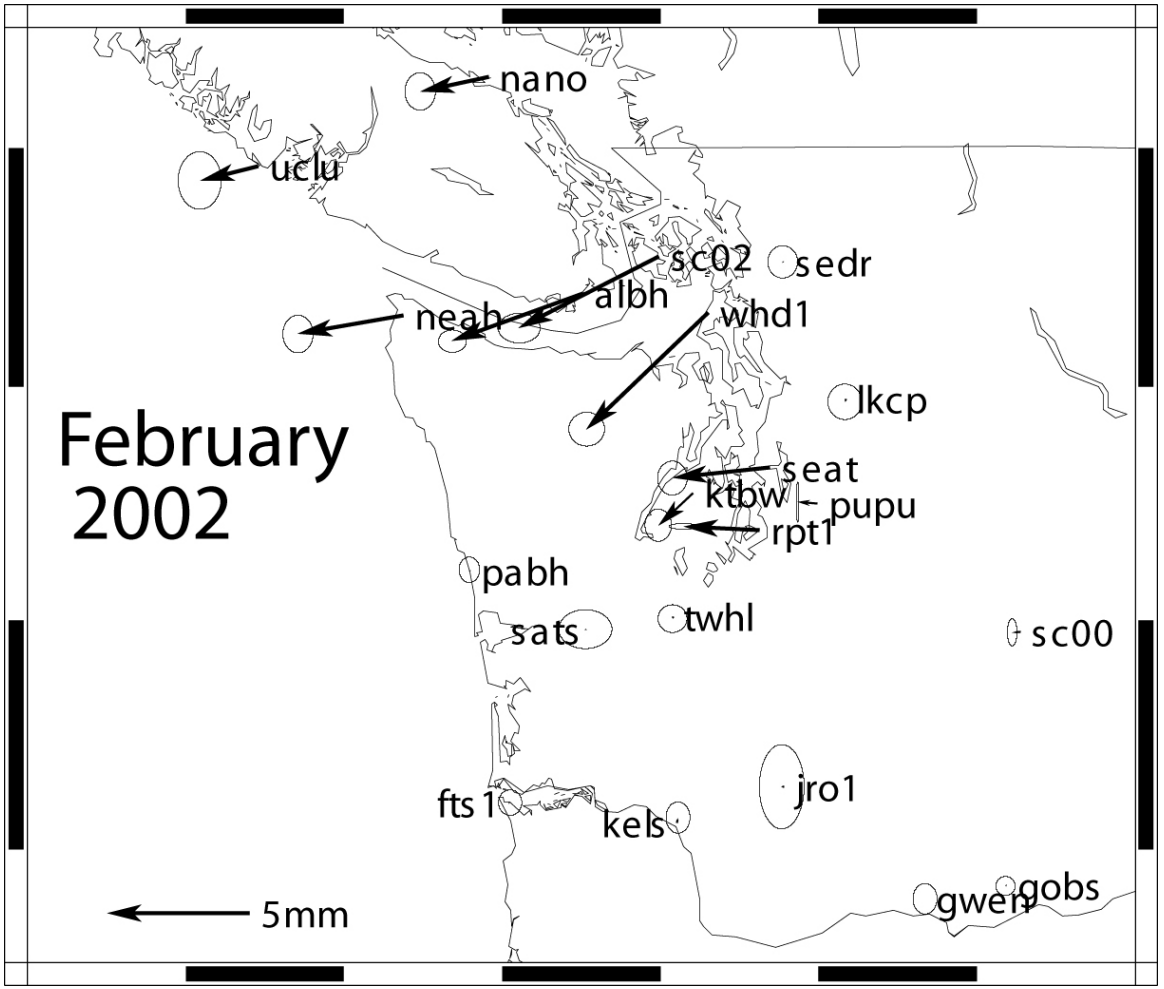

nano
uclu
albh
neah
whd1
seat
rpt1
fts1
April
1997
5mm

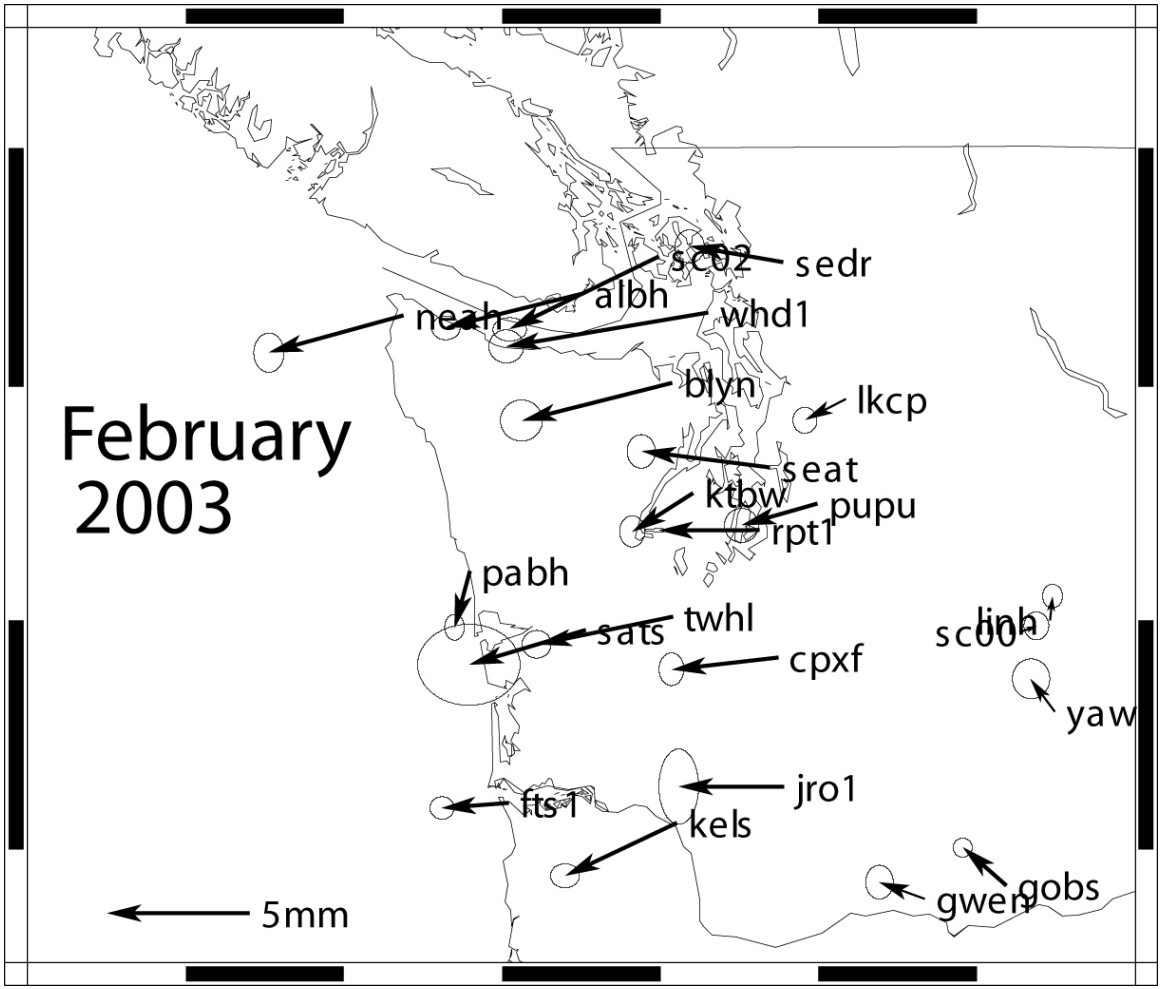

nano
uclu
sedr
albh
neah
whd1
seat
rpt1
July
1998
pabh
sats
fts1
kels
jro1
5mm


nano
uclu
sedr
albh
whd1
neah
seat
rpt1
August
1999
pabh
sats
jro1
fts1
kels
gobs
gwen
5mm


nano
uclu
sedr
albh
neah
whd1
December
1999
seat
rpt1
pabh
sats
jro1
fts1
kels
gobs
gwen
5mm


nano
uclu
sedr
albh
neah
whd1
December
2000
seat
rpt1
pabh
sats
jro1
fts1
kels
gobs
gwen
5mm


nano
uclu
sc02
sedr
albh
neah
whd1
lkcp
February
2002
seat
ktbw
pupu
rpt1
pabh
twhl
sats
sc00
jro1
fts1
kels
gobs
gwen
5mm


February
2003
sc02
sedr
albh
neah
whd1
blyn
lkcp
seat
ktbw
pupu
rpt1
pabh
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sats
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sc00
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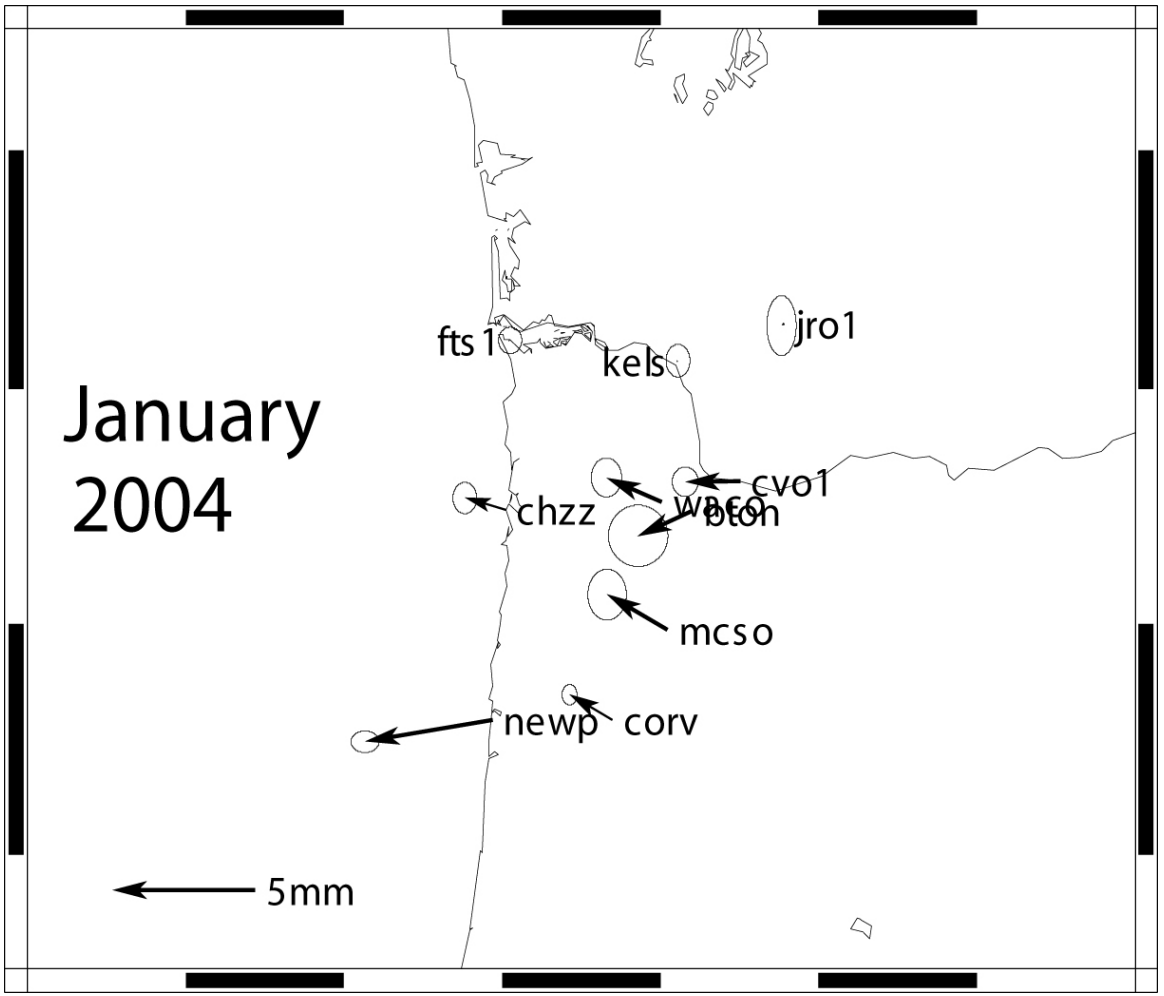
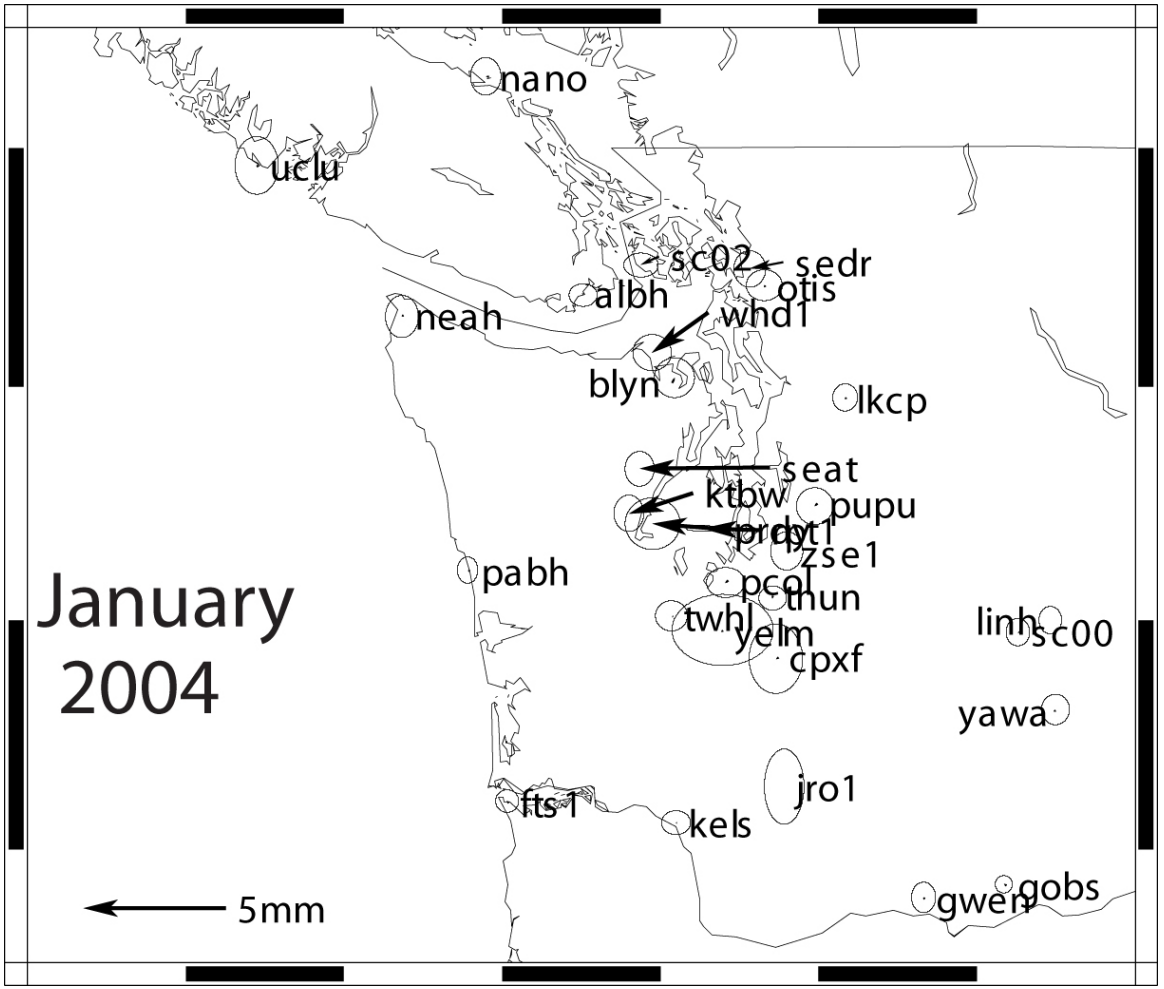
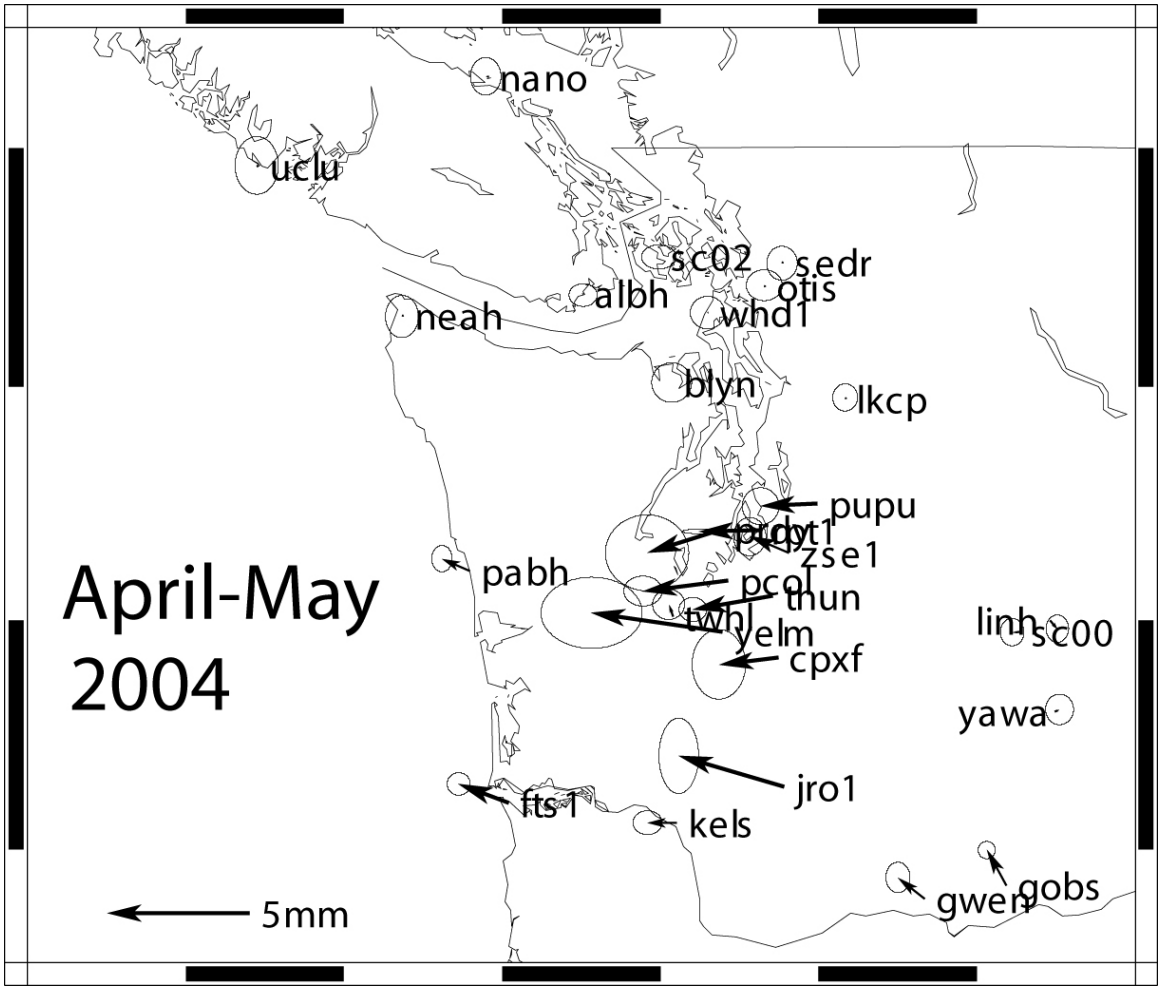
jro1
fts1
kels
gobs
gwen
5mm


January
2004
fts1
kels
jro1
chzz
cvo1
wpeo
bton
mcso
newp
corv
5mm


nano
uclu
sc02
sedr
albh
otis
neah
whd1
blyn
lkcp
seat
ktbw
pupu
pabh
pcol
thun
twhl
yelm
cpxf
linh
sc00
yawa
jro1
fts1
kels
gobs
gwen
January
2004
5mm


nano
uclu
sc02
sedr
albh
otis
neah
whd1
blyn
lkcp
pupu
zse1
pabh
pcol
thun
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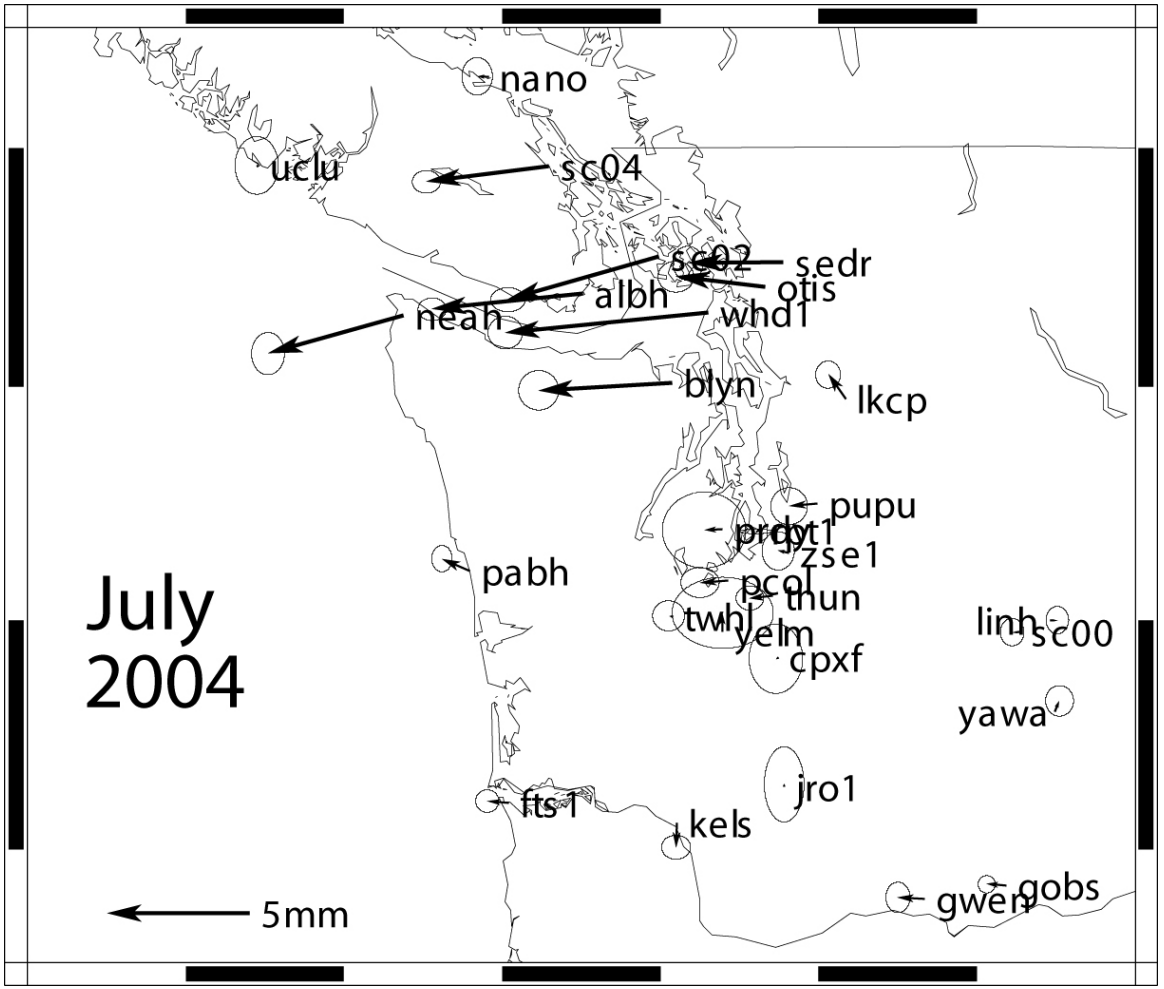
yawa
jro1
fts1
kels
gwen
gobs
5mm
April-May
2004


nano
uclu
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sedr
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albh
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lkcp
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prdy
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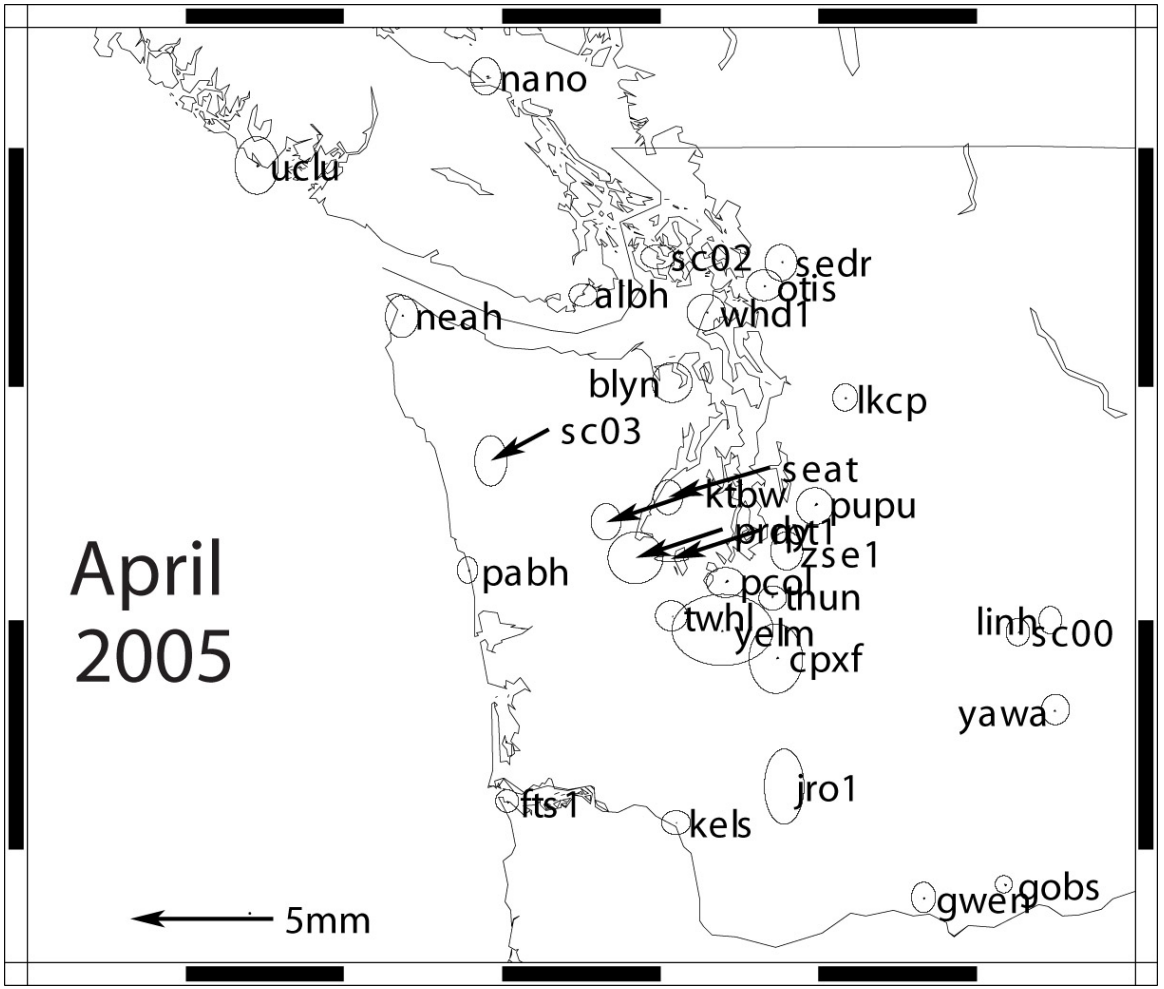
zse1
pabh
pcol
thun
twhl
yelm
linh
sc00
cpxf
yawa
jro1
fts1
kels
gobs
gwen
July
2004
5mm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uclu
sc02
sedr
albh
otis
neah
whd1
blyn
lkcp
sc03
seat
ktbw
pupu
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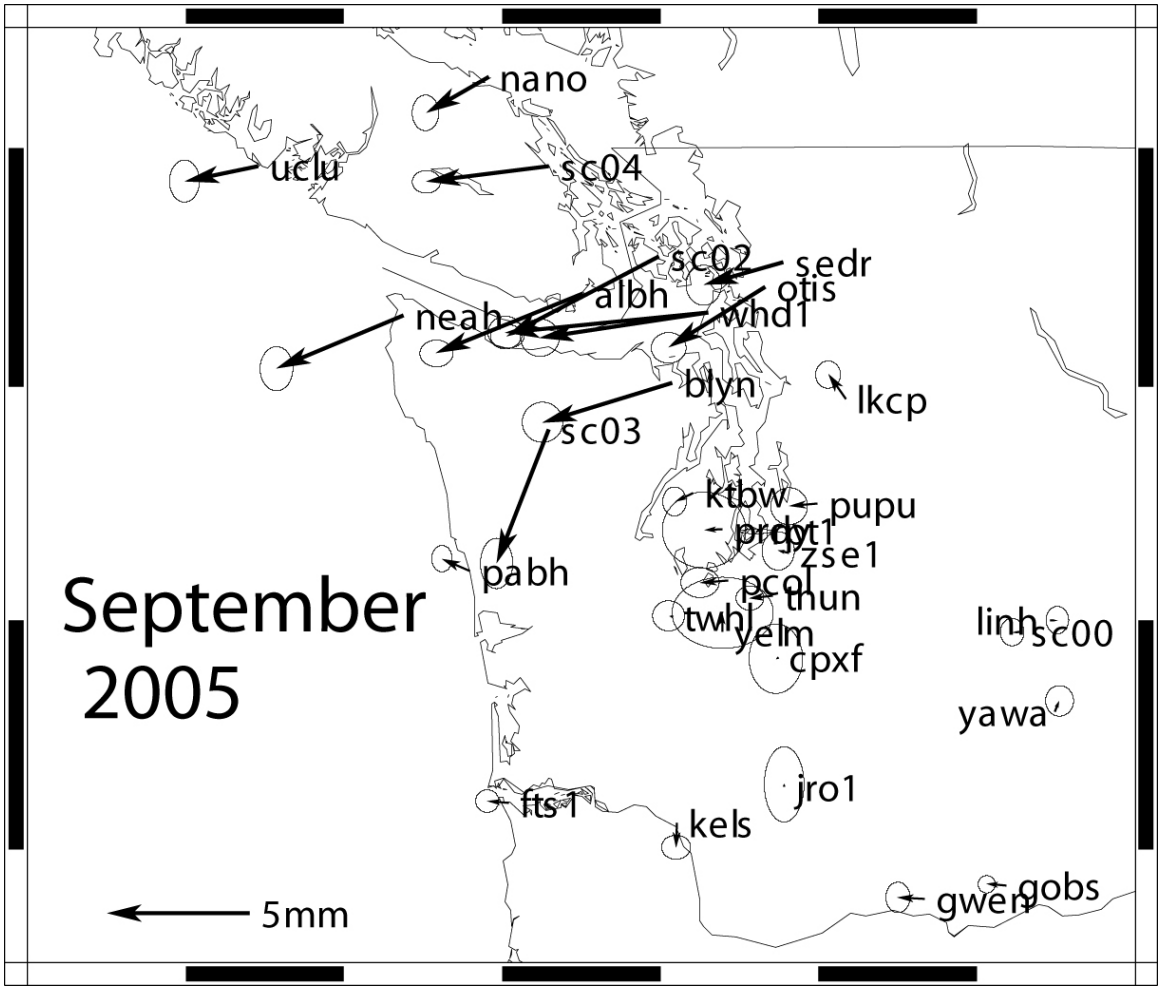
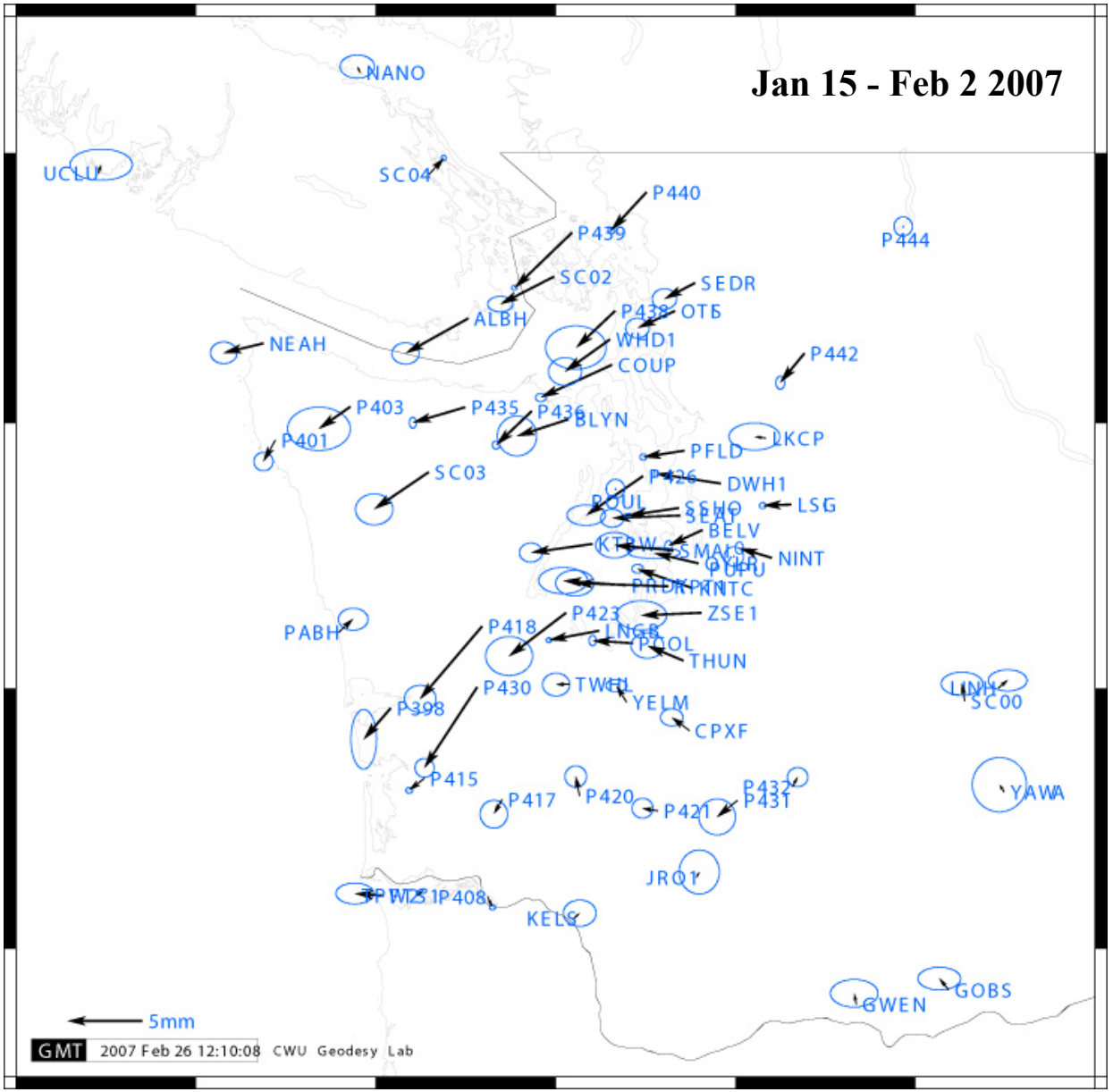
pyt1
zse1
pabh
pcol
thun
twhl
yelm
linh
sc00
cpxf
yawa
jro1
fts1
kels
gobs
gwen
April
2005
5mm


nano
uclu
sc04
sc02
sedr
albh
otis
neah
whd1
blyn
lkcp
sc03
ktbw
pupu
prdy
gyt1
zse1
pabh
pcol
tmun
twhl
yelm
linh
sc00
cpxf
yawa
jro1
fts1
kels
gobs
gwen
5mm
September
2005


Jan 15 - Feb 2 2007
NANO
UCLU
SC04
P440
P439
P444
SC02
SEDR
ALBH
P438
OTB
NEAH
WHD1
COUP
P442
P403
P435
P436
BLYN
P401
LKCP
PFLD
SC03
P426
DWH1
POUL
SCHO
LSG
SEAT
BELV
NINT
PUPU
PABH
P423
ZSE1
P418
THUN
P430
TWEL
P398
YELM
CPXF
SC00
P415
P417
P420
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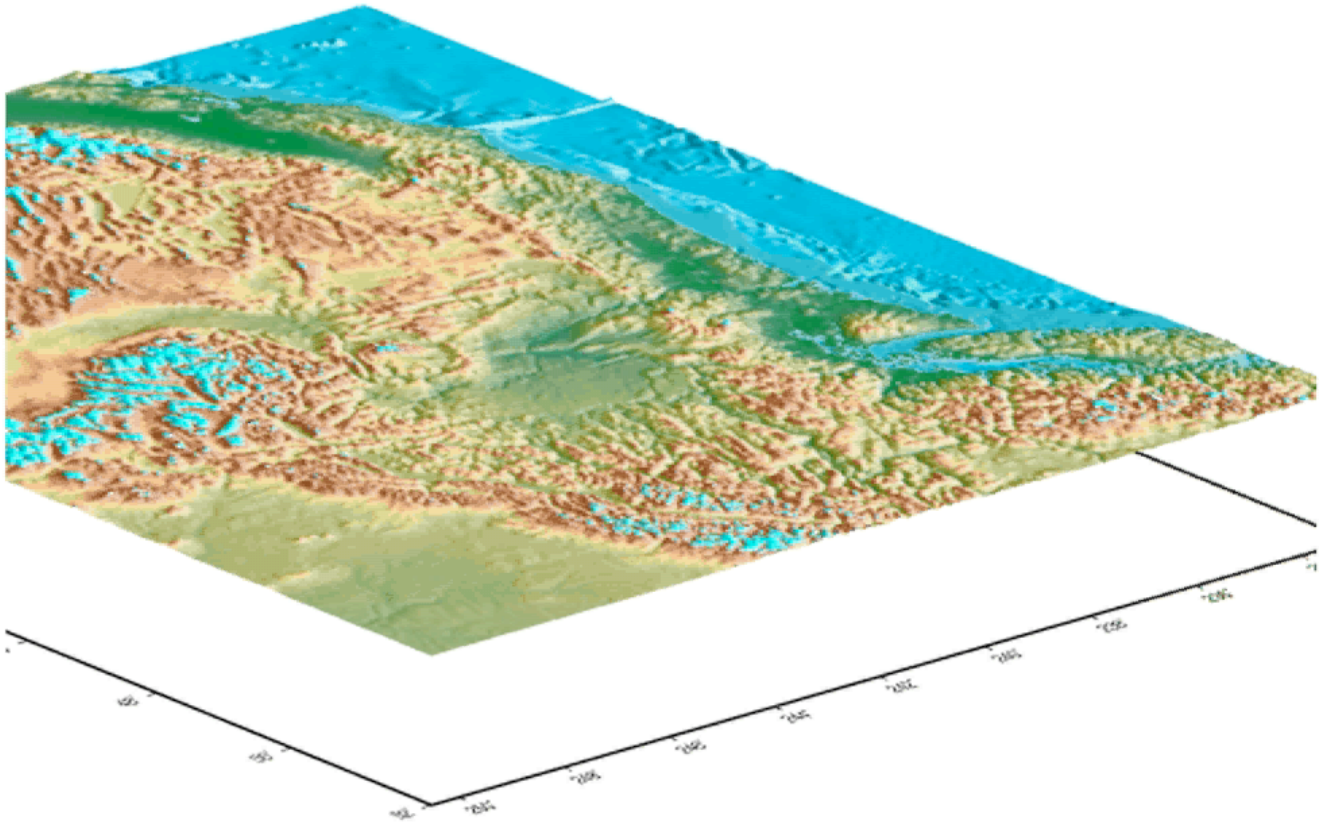
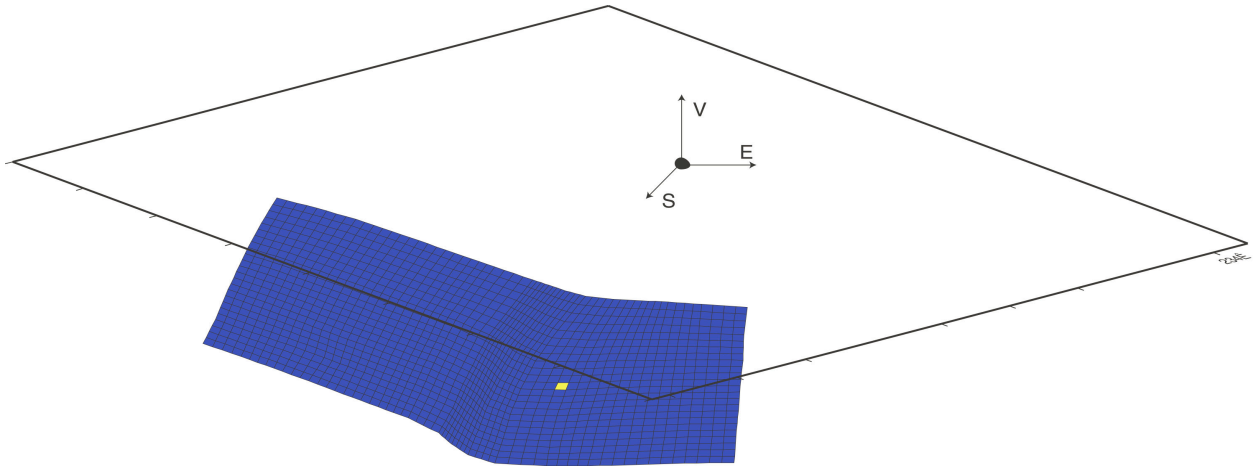
GOBS
5mm
GMT
2007 Feb 26 12:10:08
CWU Geodesy Lab

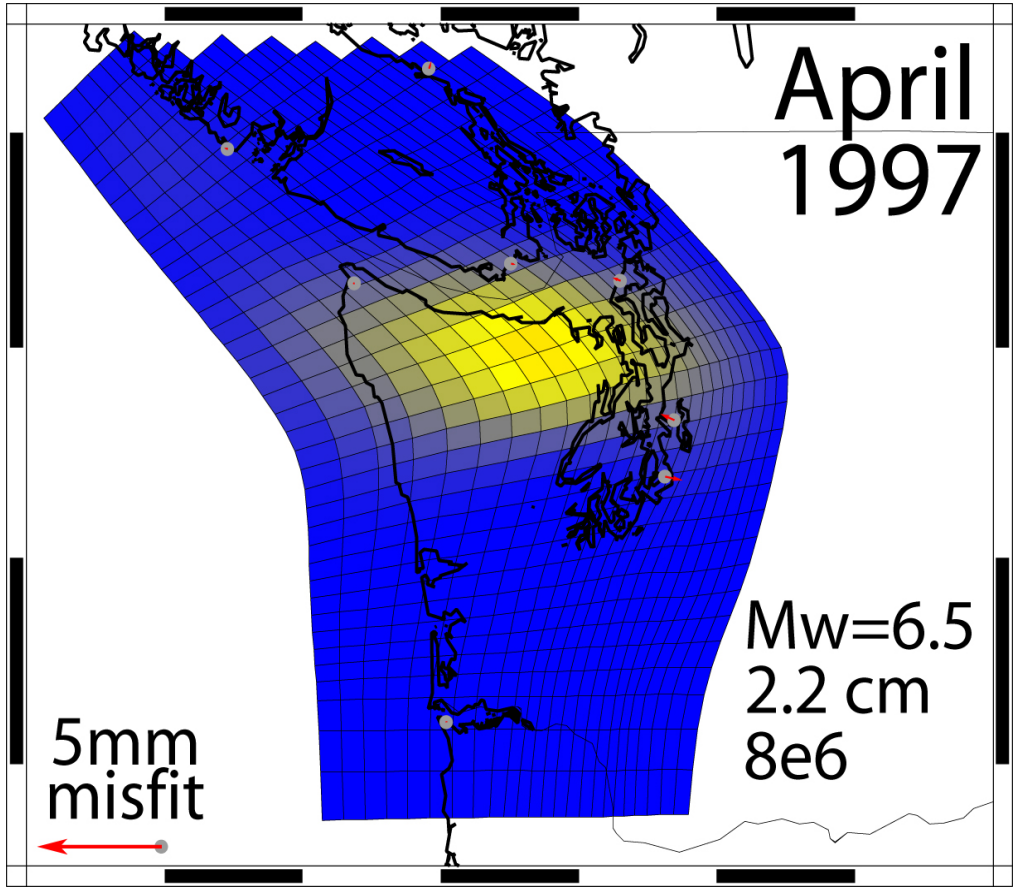


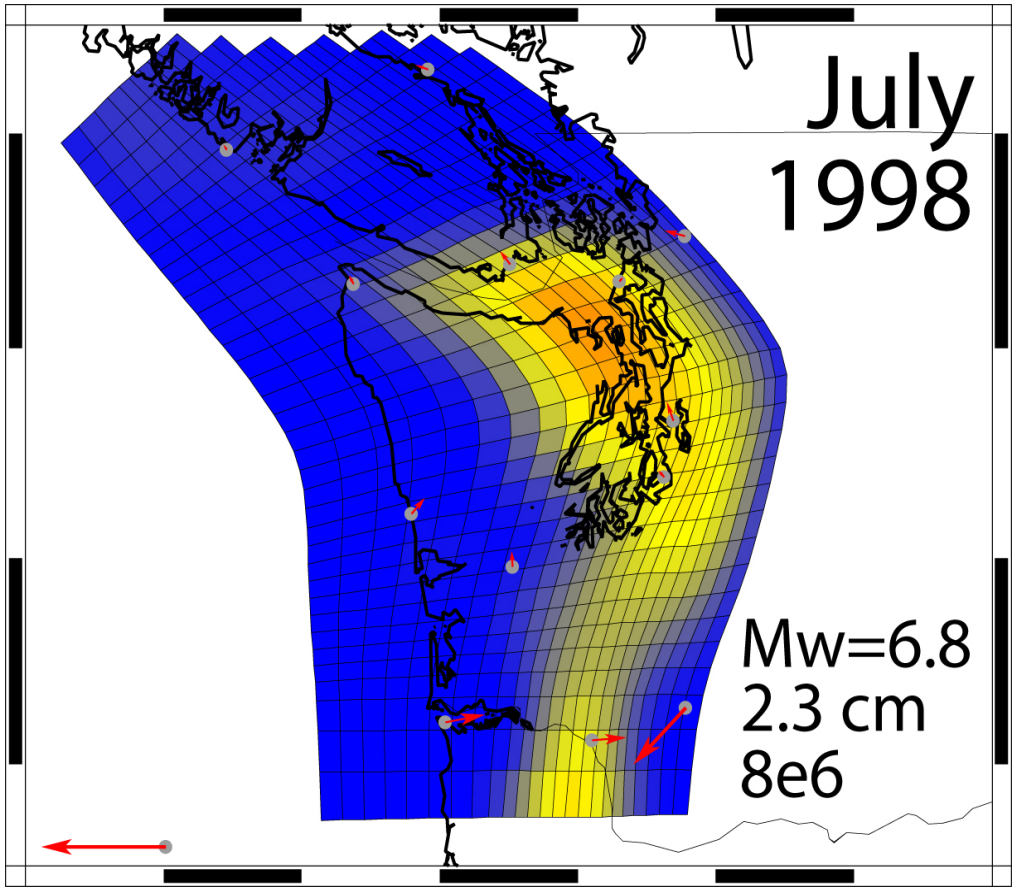
Spatial inversion of geodetic data:

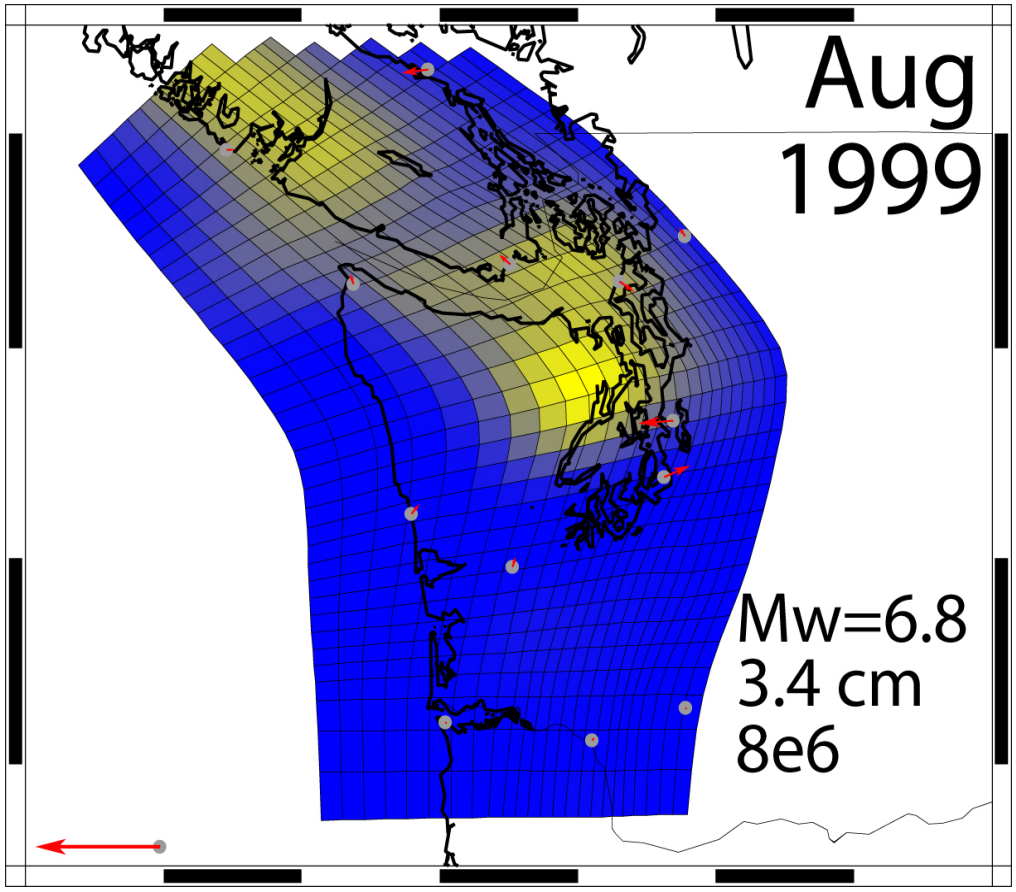


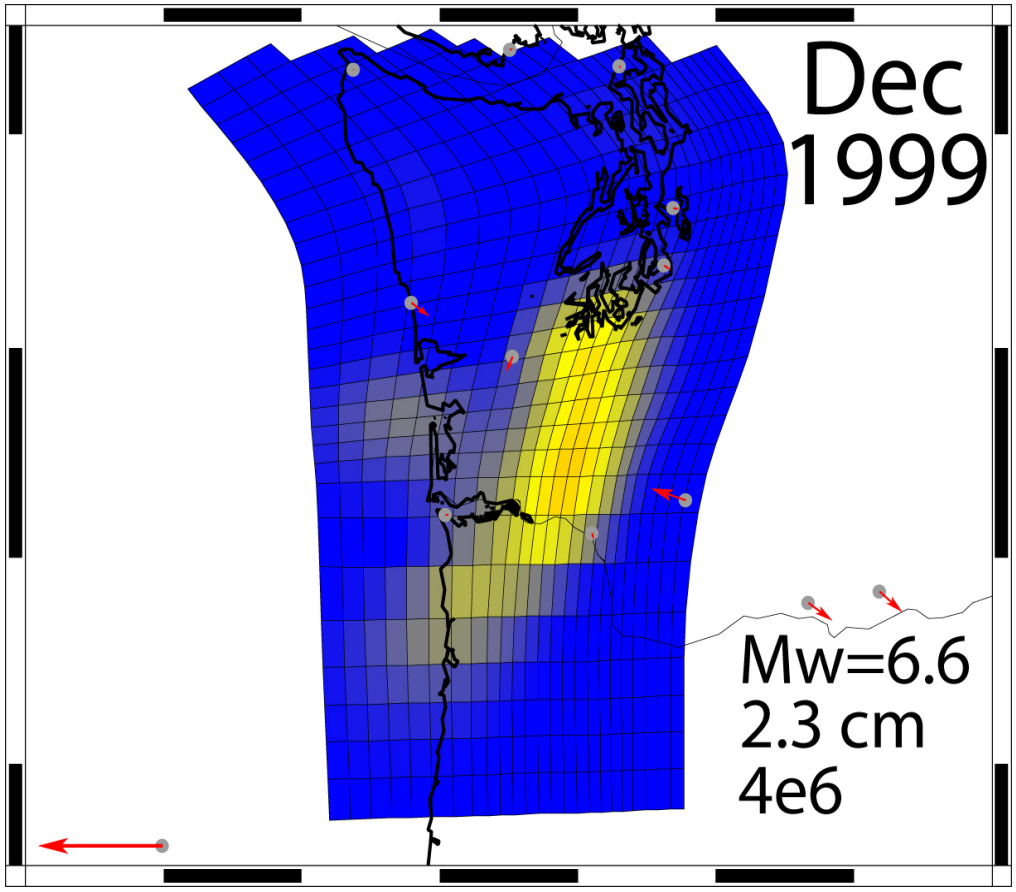
$$R(\mathbf{x},\lambda) = \left\| \sum^{-1/2} (\mathbf{Ax} - \mathbf{b}) \right\|^2 + \lambda^{-2} \left\| \nabla^2 \mathbf{x} \right\|^2$$

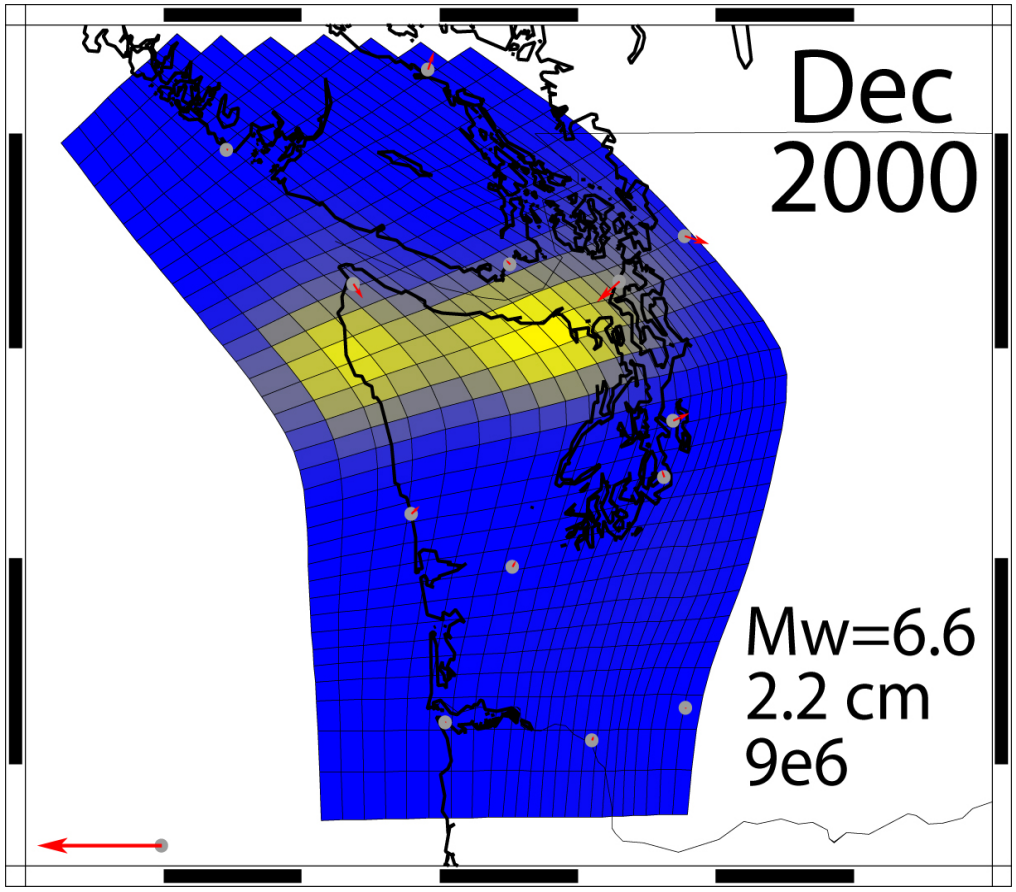
b data
x slip
A Green's fns
λ misfit/roughness
Σ data covariance

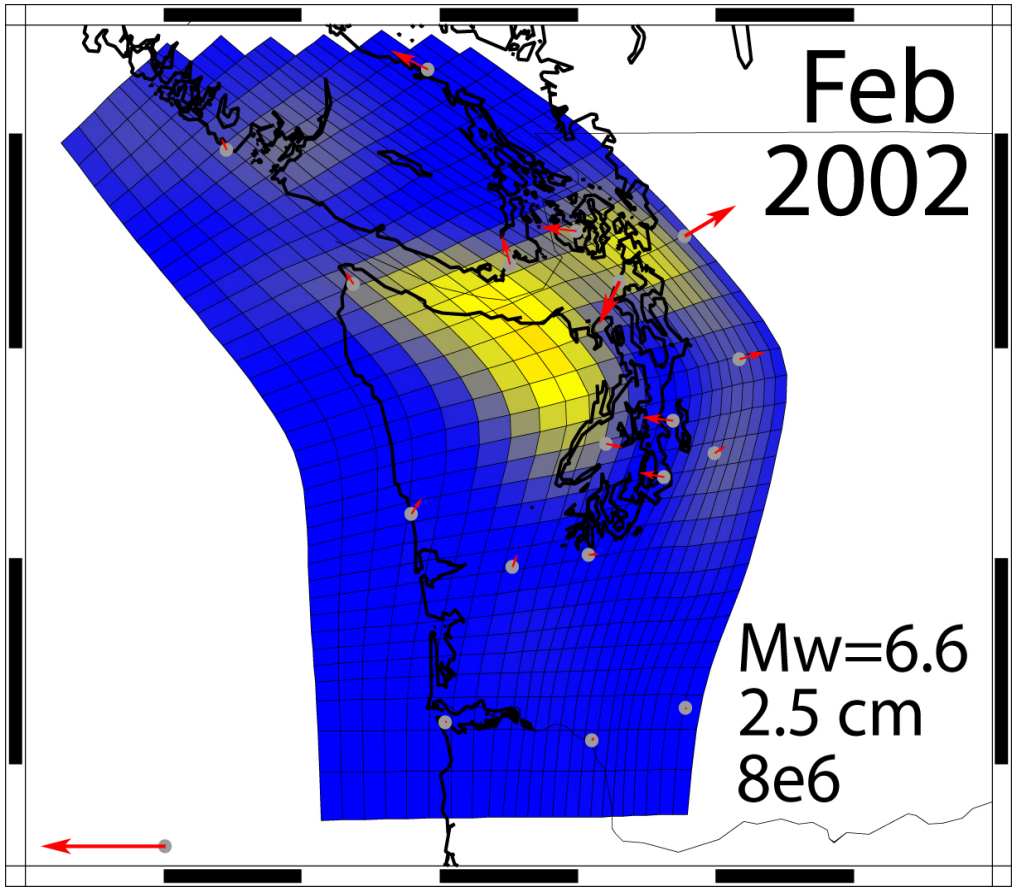

April
1997
Mw=6.5
2.2 cm
8e6
5mm
misfit

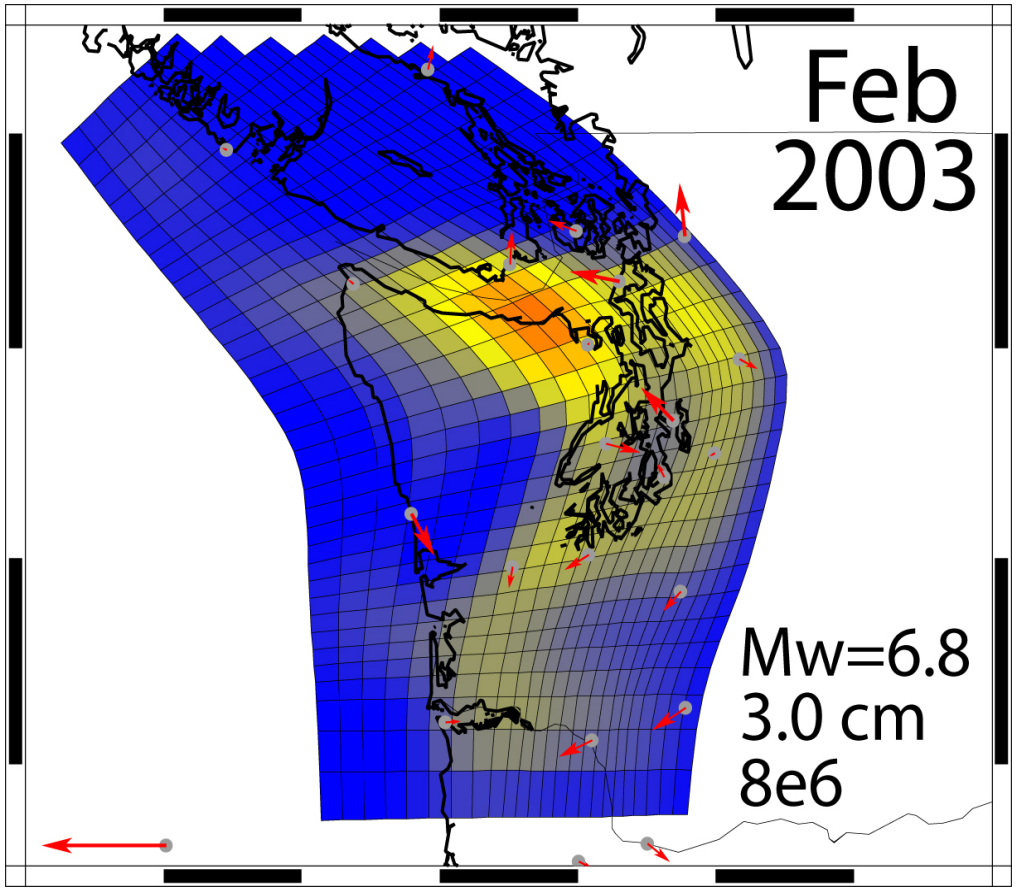

July
1998
Mw=6.8
2.3 cm
8e6

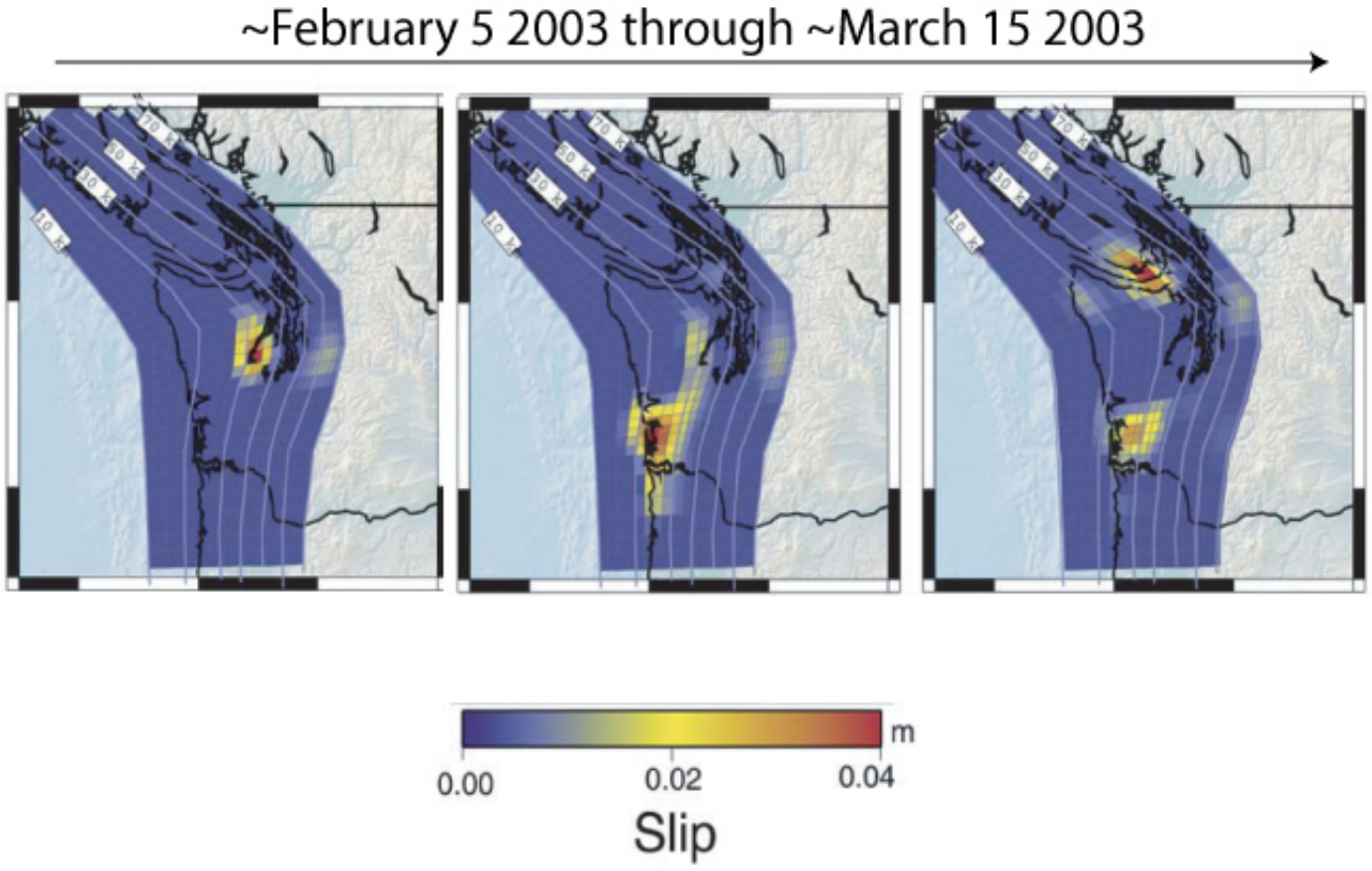

Aug
1999
Mw=6.8
3.4 cm
8e6


Dec
1999
Mw=6.6
2.3 cm
4e6

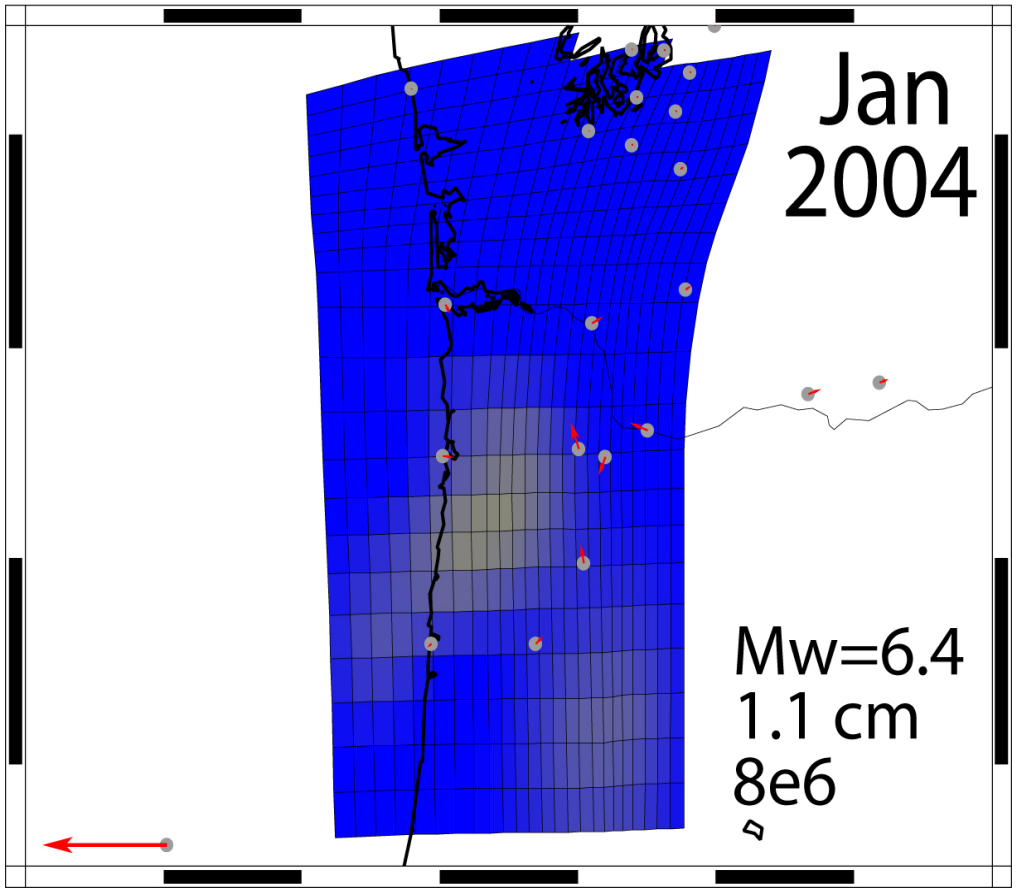

Dec
2000
Mw=6.6
2.2 cm
9e6

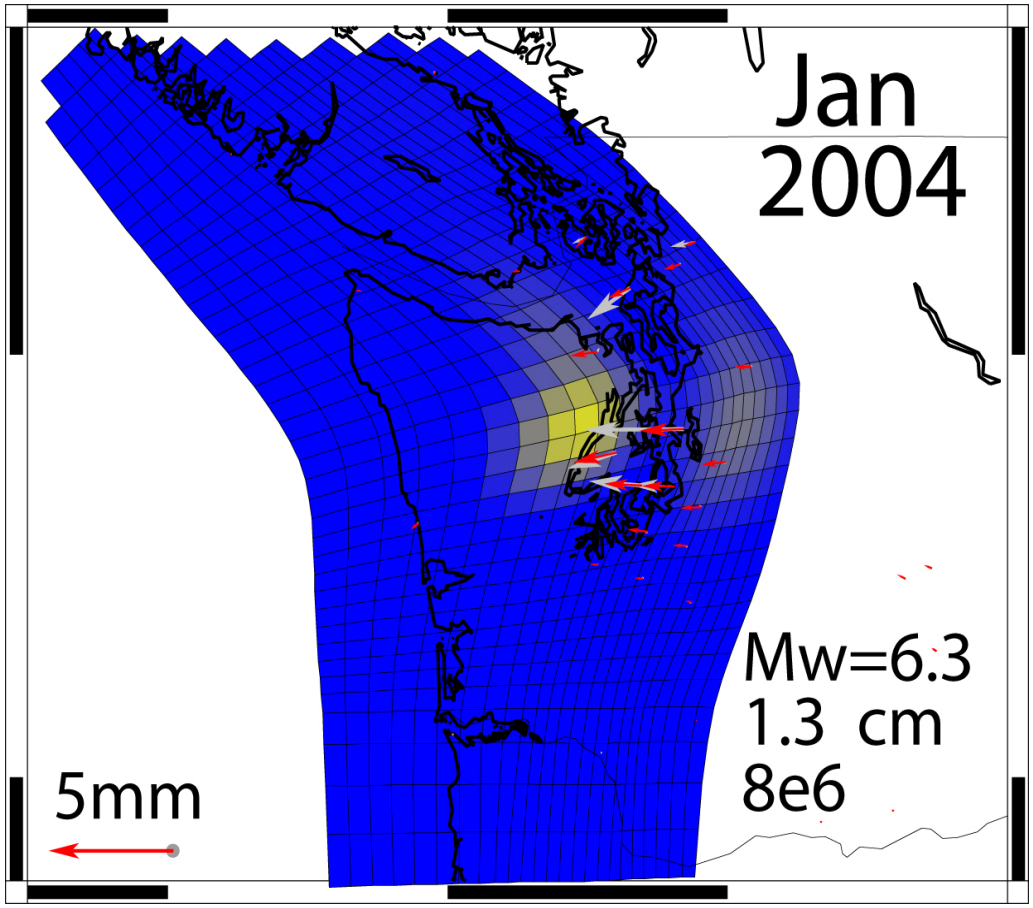

Feb
2002
Mw=6.6
2.5 cm
8e6

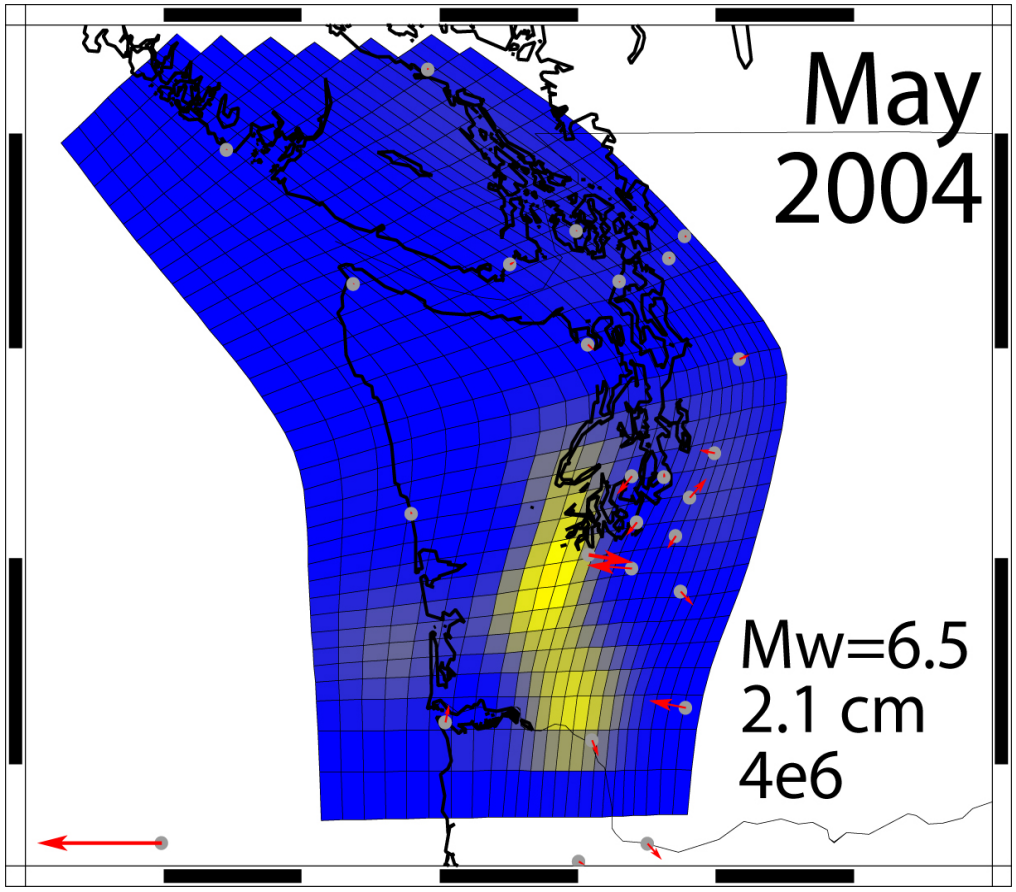

Feb
2003
Mw=6.8
3.0 cm
8e6

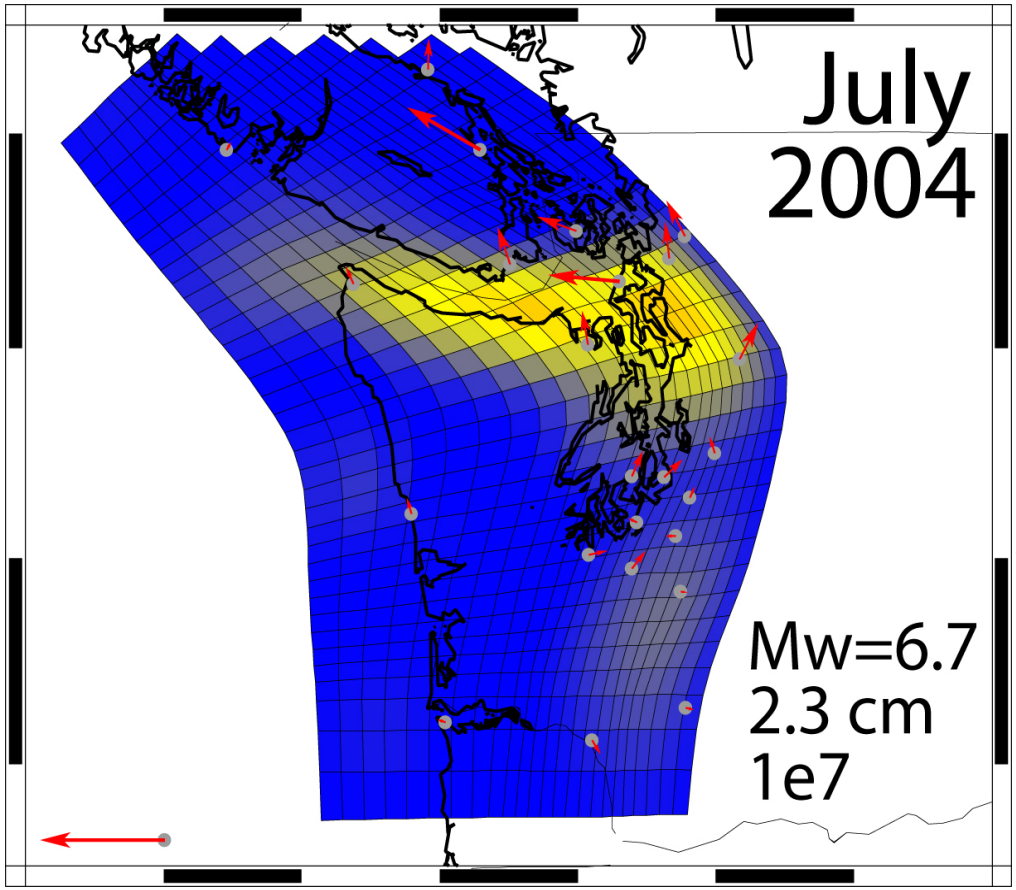


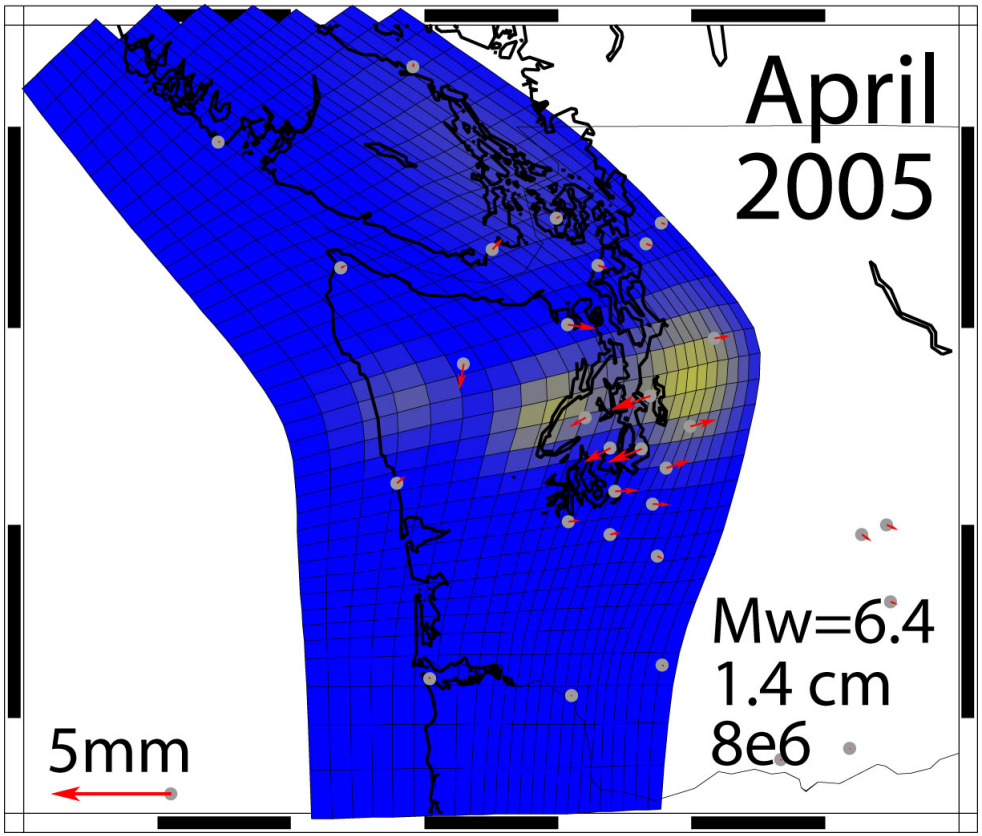
Melbourne et al, 2005

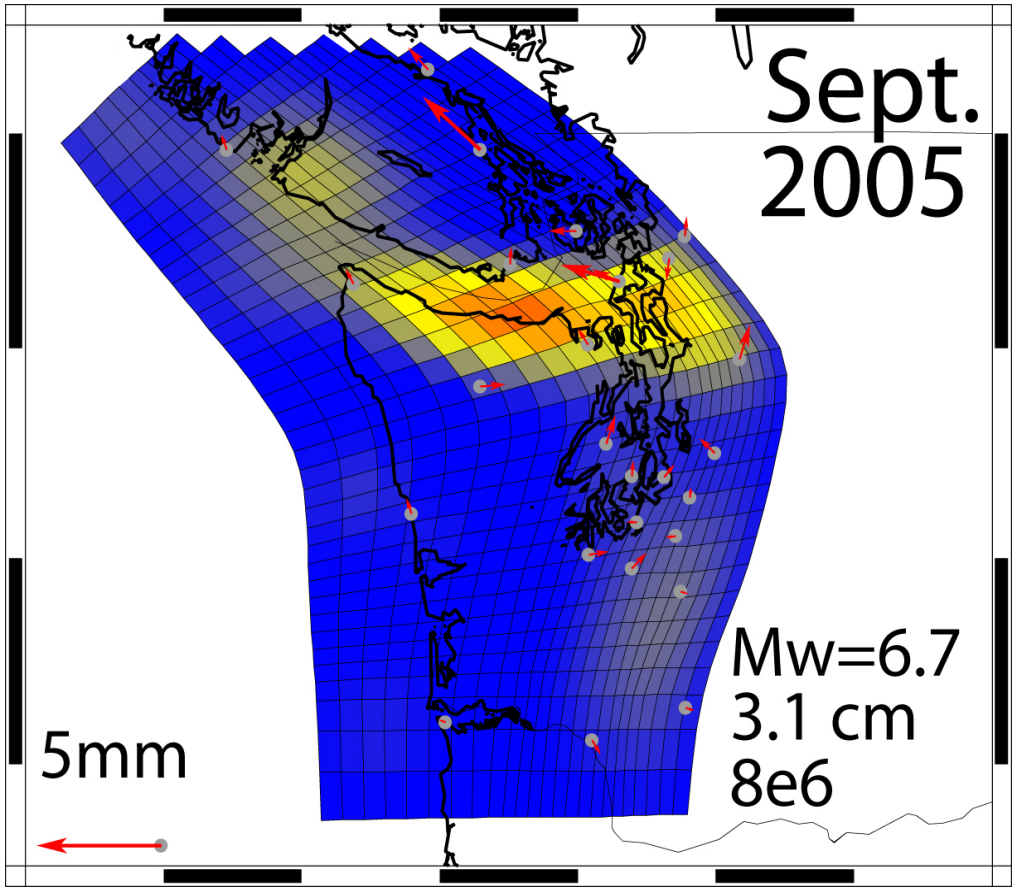

Jan
2004
Mw=6.4
1.1 cm
8e6

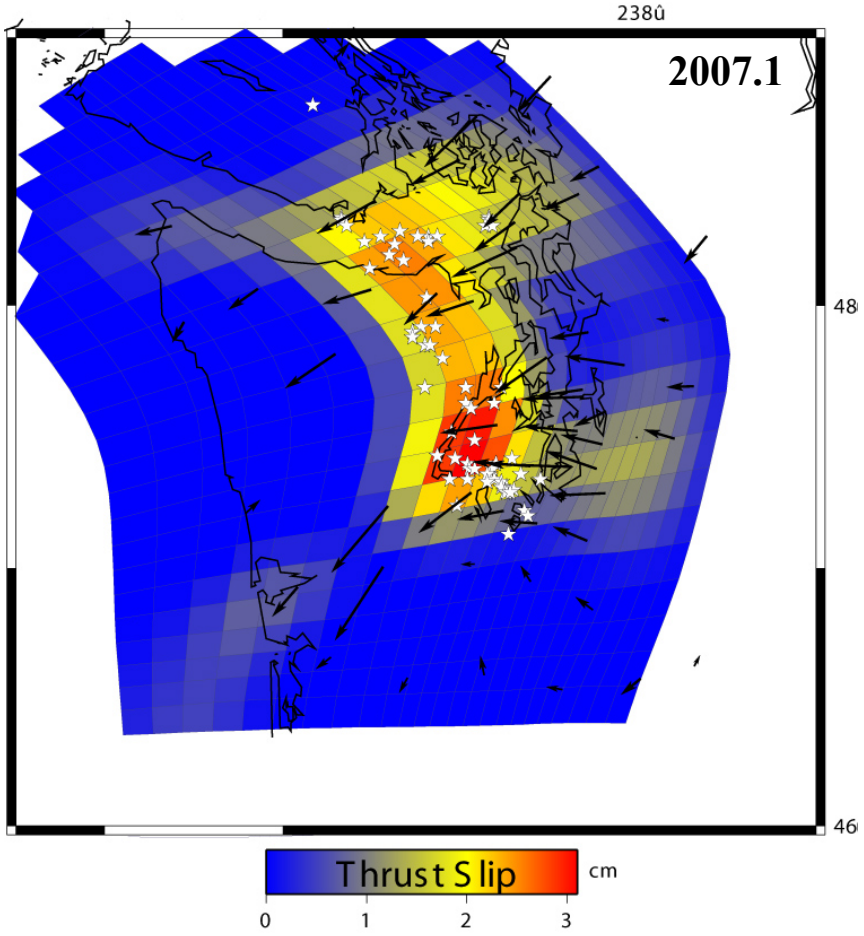

Jan
2004
Mw=6.3
1.3 cm
8e6
5mm


May
2004
Mw=6.5
2.1 cm
4e6


July
2004
Mw=6.7
2.3 cm
1e7


April
2005
Mw=6.4
1.4 cm
8e6
5mm

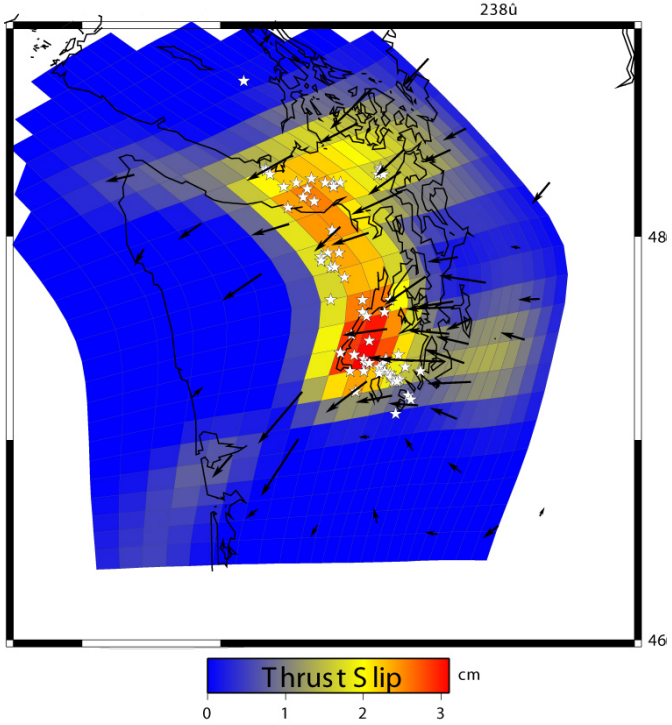

Sept.
2005
Mw=6.7
3.1 cm
8e6
5mm



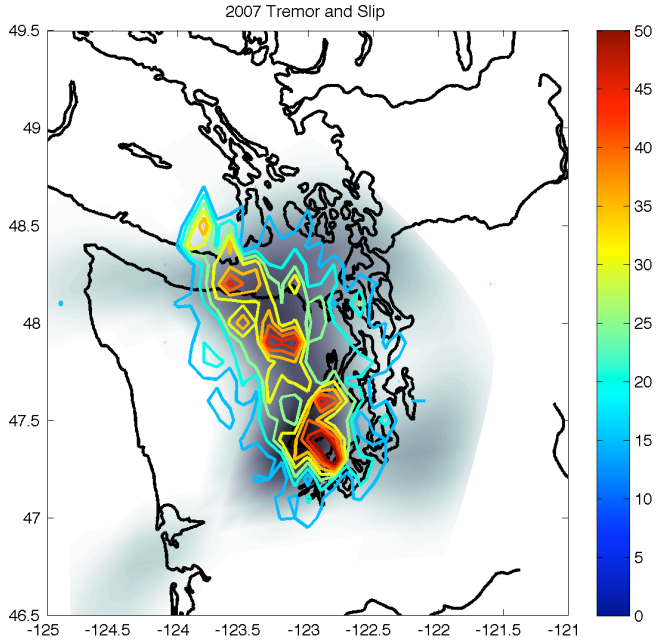
Tremor hypocenters from Wech & Creager, 2007

2007.1 ETS

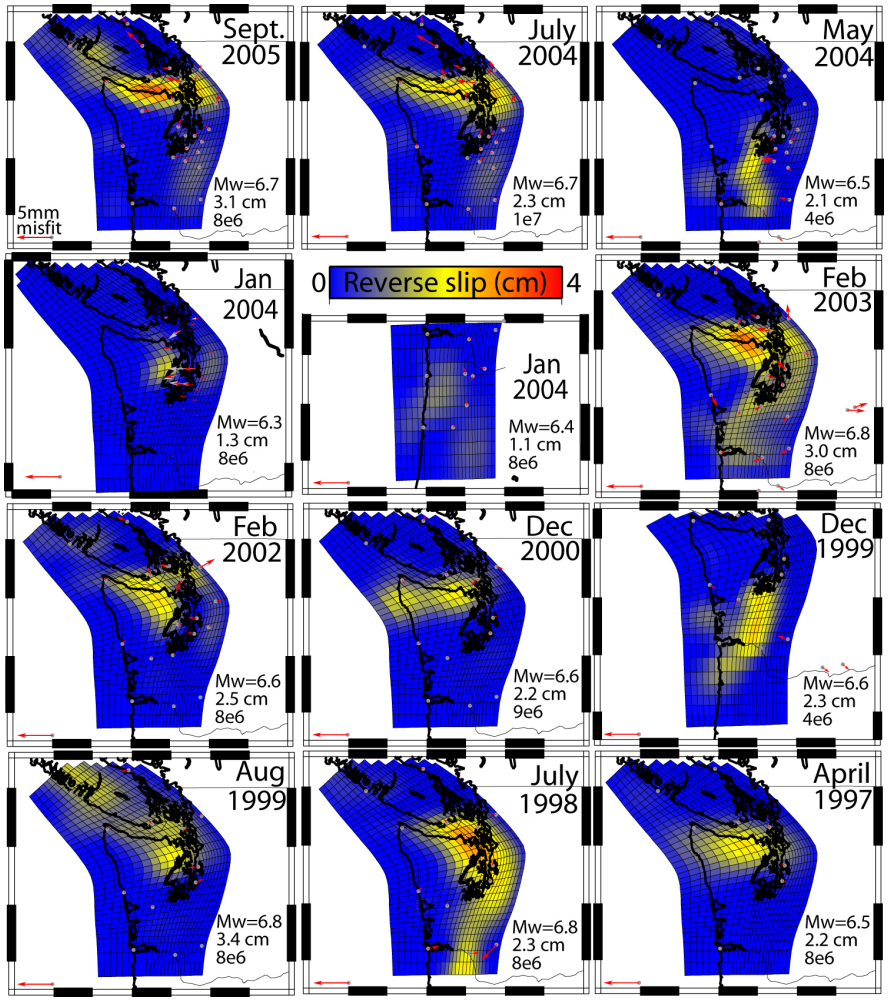
GPS

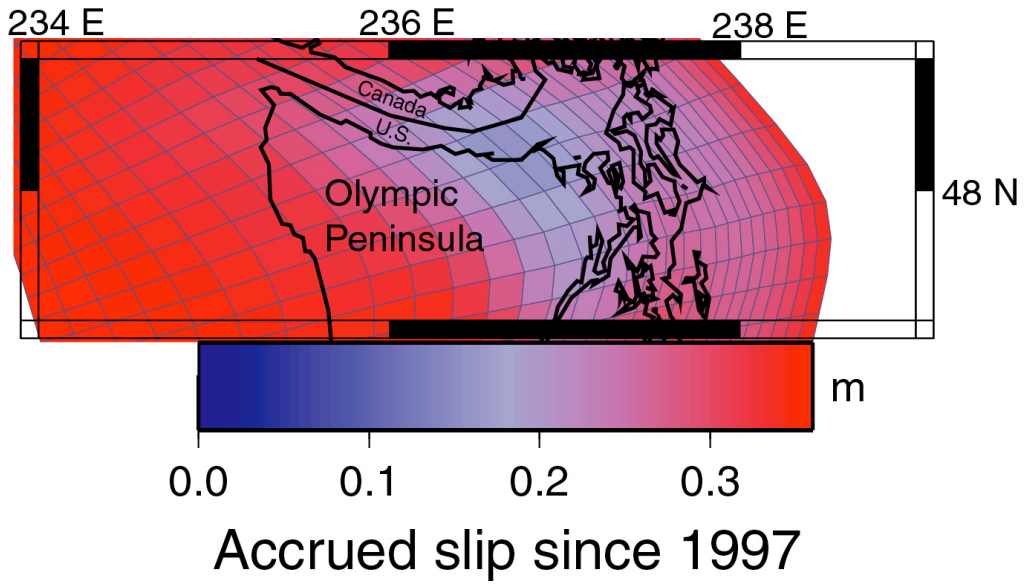


Tremor

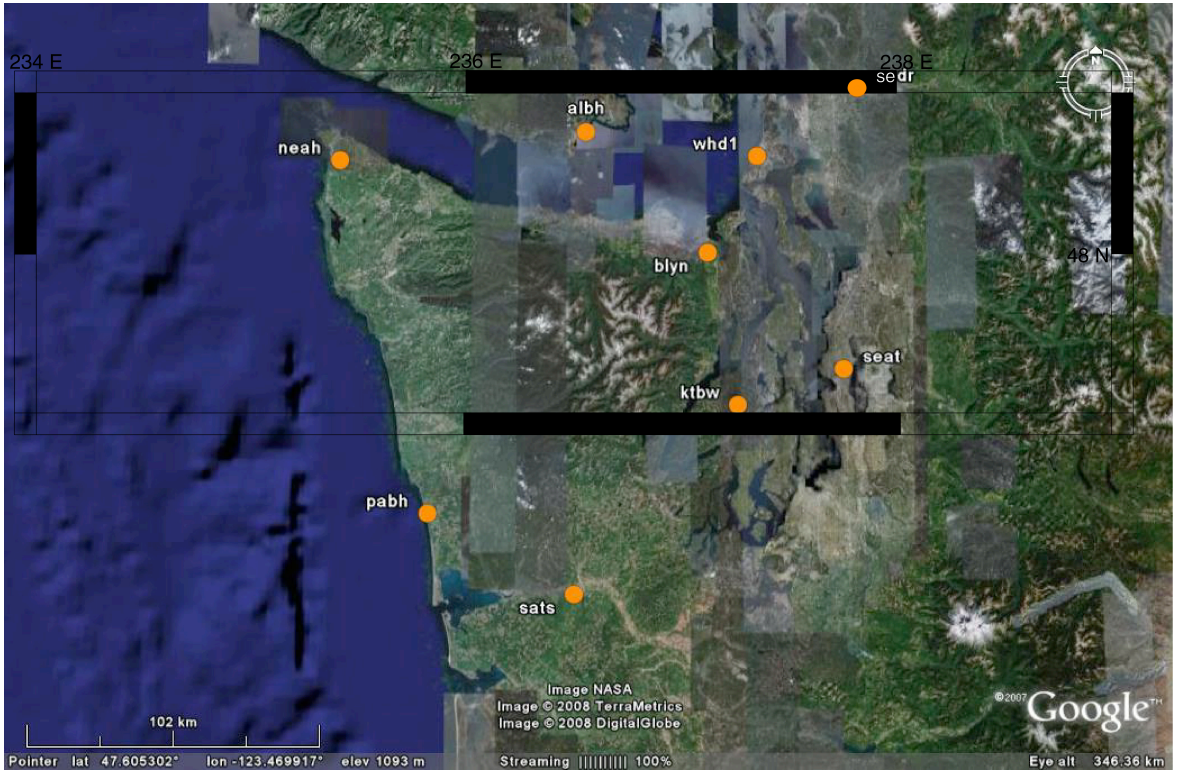


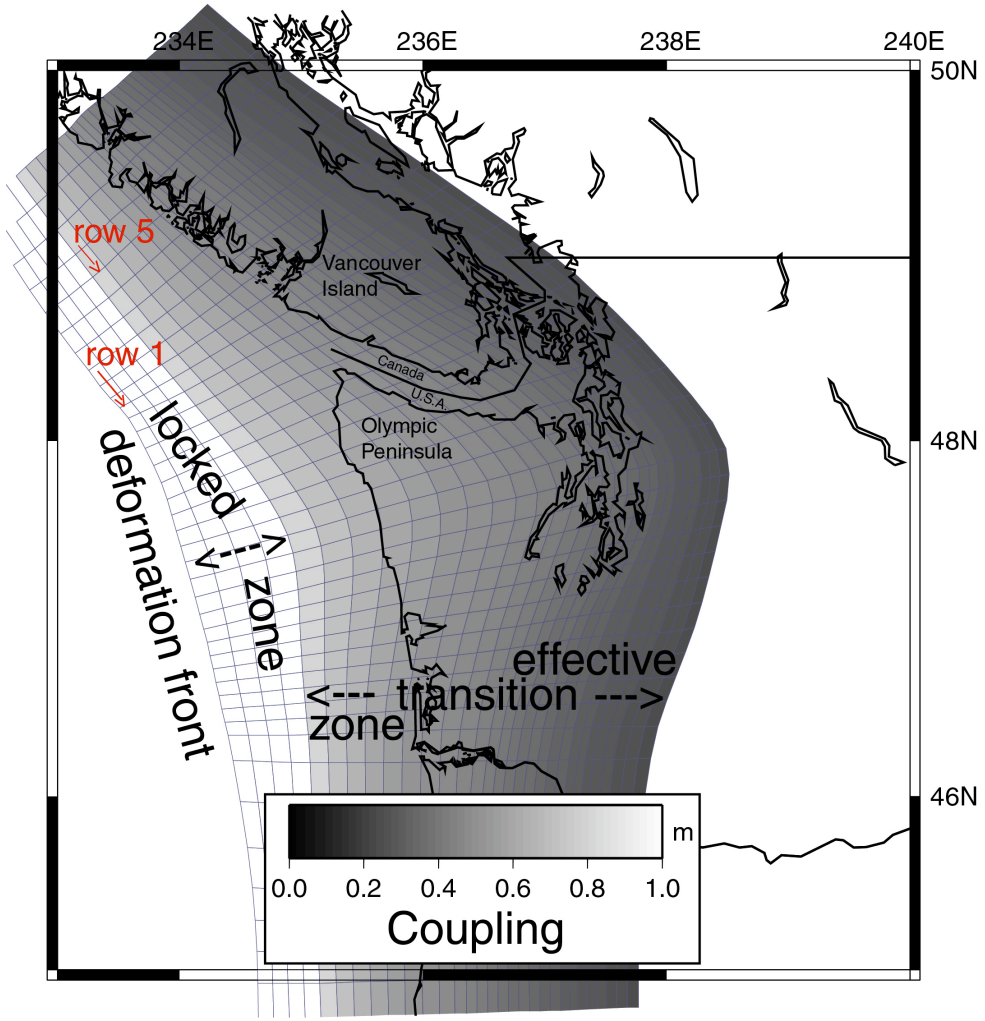
Tremor hypocenters from Wech & Creager, 2007

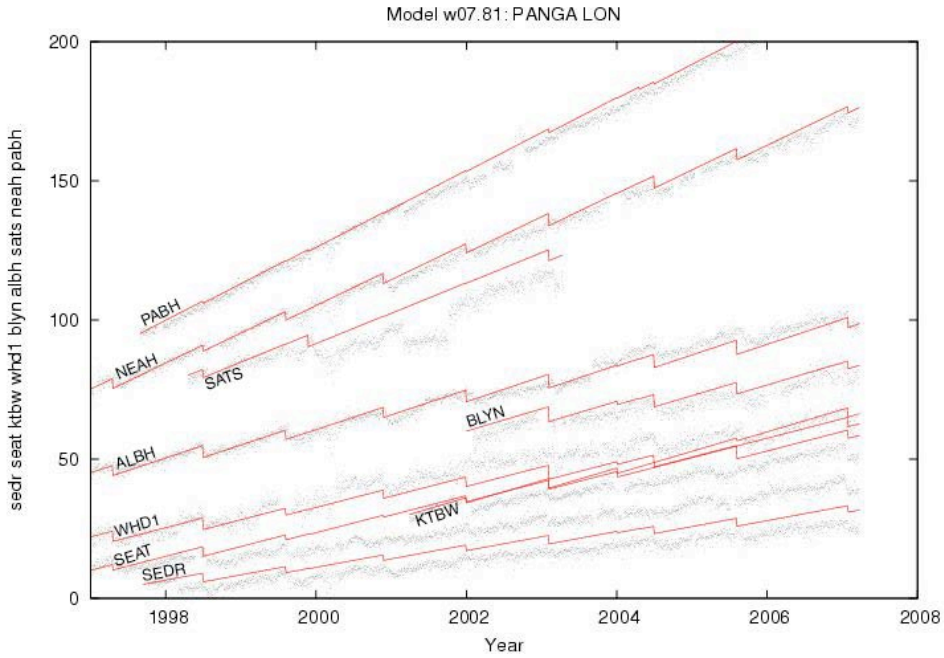

Sept.
2005
Mw=6.7
3.1 cm
8e6
5mm
misfit
July
2004
Mw=6.7
2.3 cm
1e7
May
2004
Mw=6.5
2.1 cm
4e6
Jan
2004
Mw=6.3
1.3 cm
8e6
0
Reverse slip (cm)
4
Jan
2004
Mw=6.4
1.1 cm
8e6
Feb
2003
Mw=6.8
3.0 cm
8e6
Feb
2002
Mw=6.6
2.5 cm
8e6
Dec
2000
Mw=6.6
2.2 cm
9e6
Dec
1999
Mw=6.6
2.3 cm
4e6
Aug
1999
Mw=6.8
3.4 cm
8e6
July
1998
Mw=6.8
2.3 cm
8e6
April
1997
Mw=6.5
2.2 cm
8e6

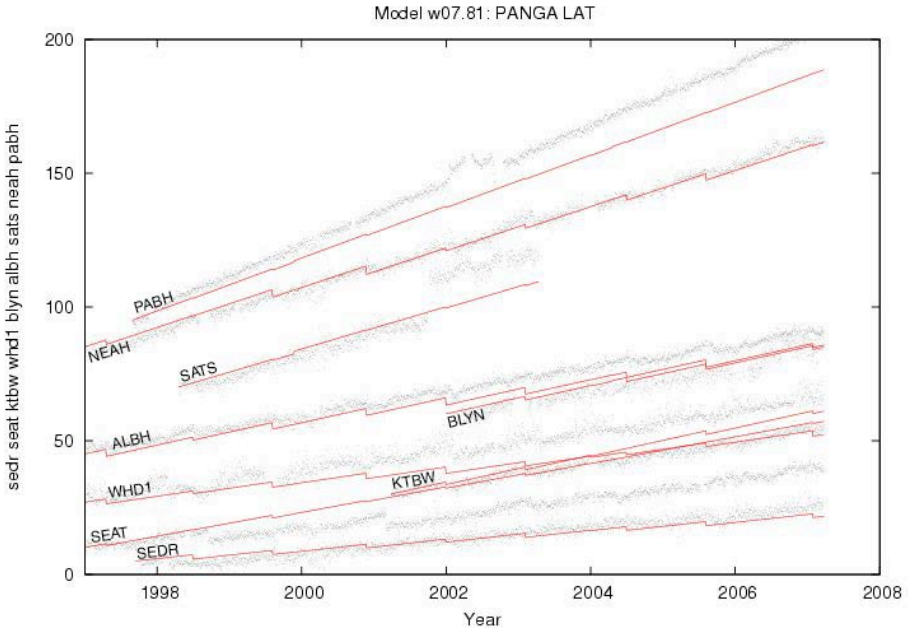


Up-dip limit of ETS lies well east of the coast (and much closer to Seattle)


234 E
236 E
238 E
seadr
albh
neah
whd1
blyn
48 N
seat
ktbw
pabh
sats
Image NASA
Image © 2008 TerraMetrics
Image © 2008 DigitalGlobe
©2007 Google
102 km
Pointer lat 47.605302° lon -123.469917° elev 1093 m
Streaming 100%
Eye alt 346.36 km

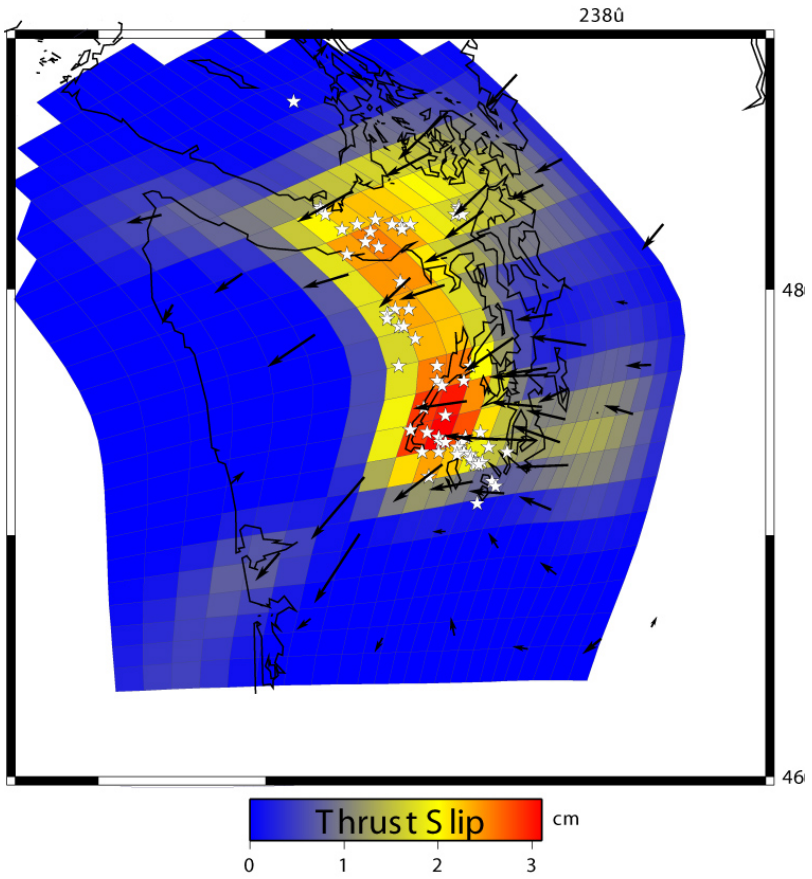

234E
236E
238E
240E
50N
48N
46N
row 5
row 1
Vancouver
Island
Canada
U.S.A.
Olympic
Peninsula
locked
zone
deformation front
effective
<--- transition --->
zone
m
0.0
0.2
0.4
0.6
0.8
1.0
Coupling


Model w07.81: PANGA LON
sedr seat ktbw whd1 blyn albh sats neah pabh
Year
PABH
NEAH
SATS
BLYN
ALBH
WHD1
KTBW
SEAT
SEDR
0
50
100
150
200
1998
2000
2002
2004
2006
2008

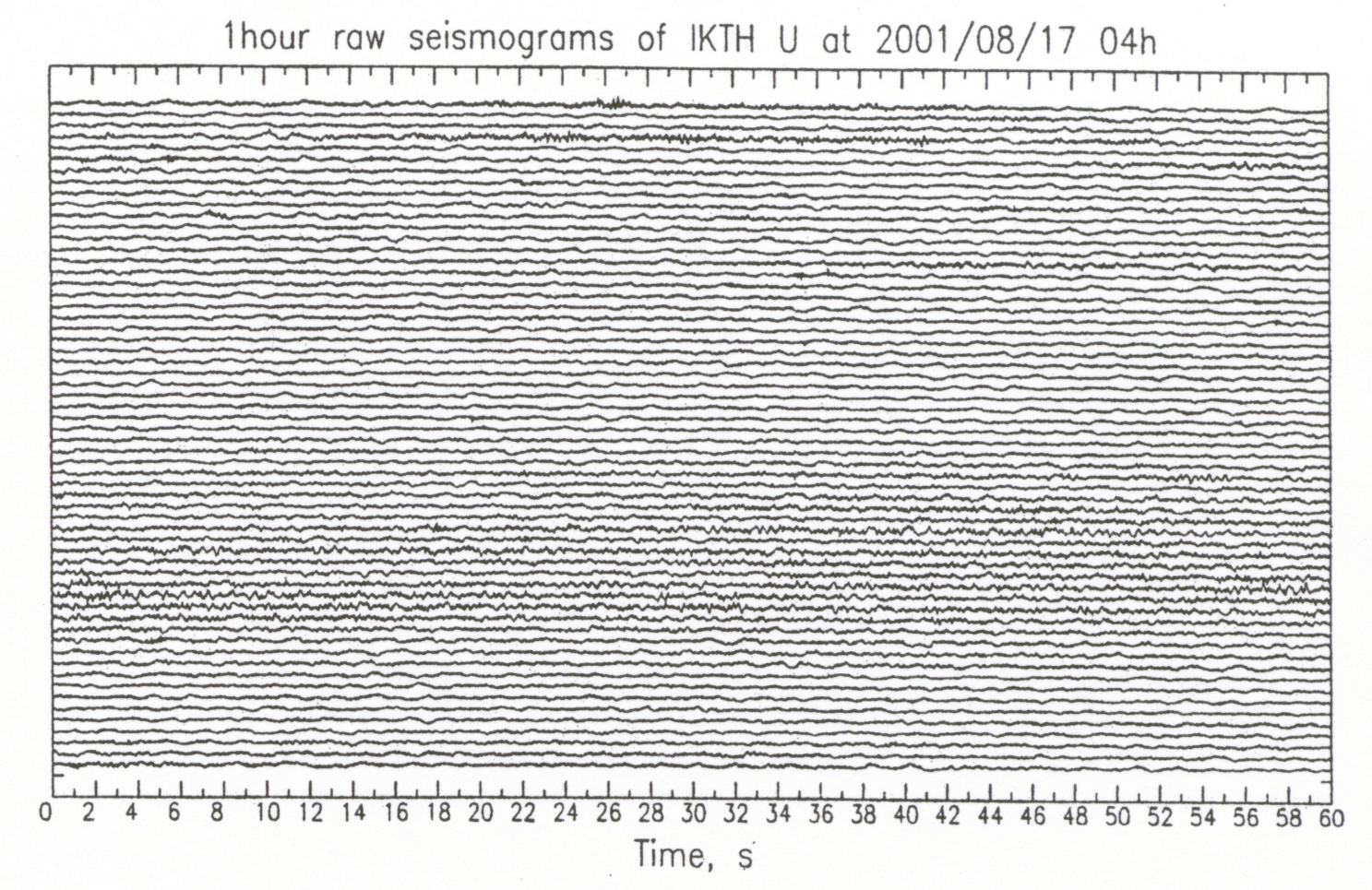

Model w07.81: PANGA LAT
sedr seat ktbw whd1 blyn albh sats neah pabh
Year
PABH
NEAH
SATS
BLYN
ALBH
WHD1
KTBW
SEAT
SEDR
0
50
100
150
200
1998
2000
2002
2004
2006
2008

Noteworthy GPS aspects of Cascadia slow earthquakes:

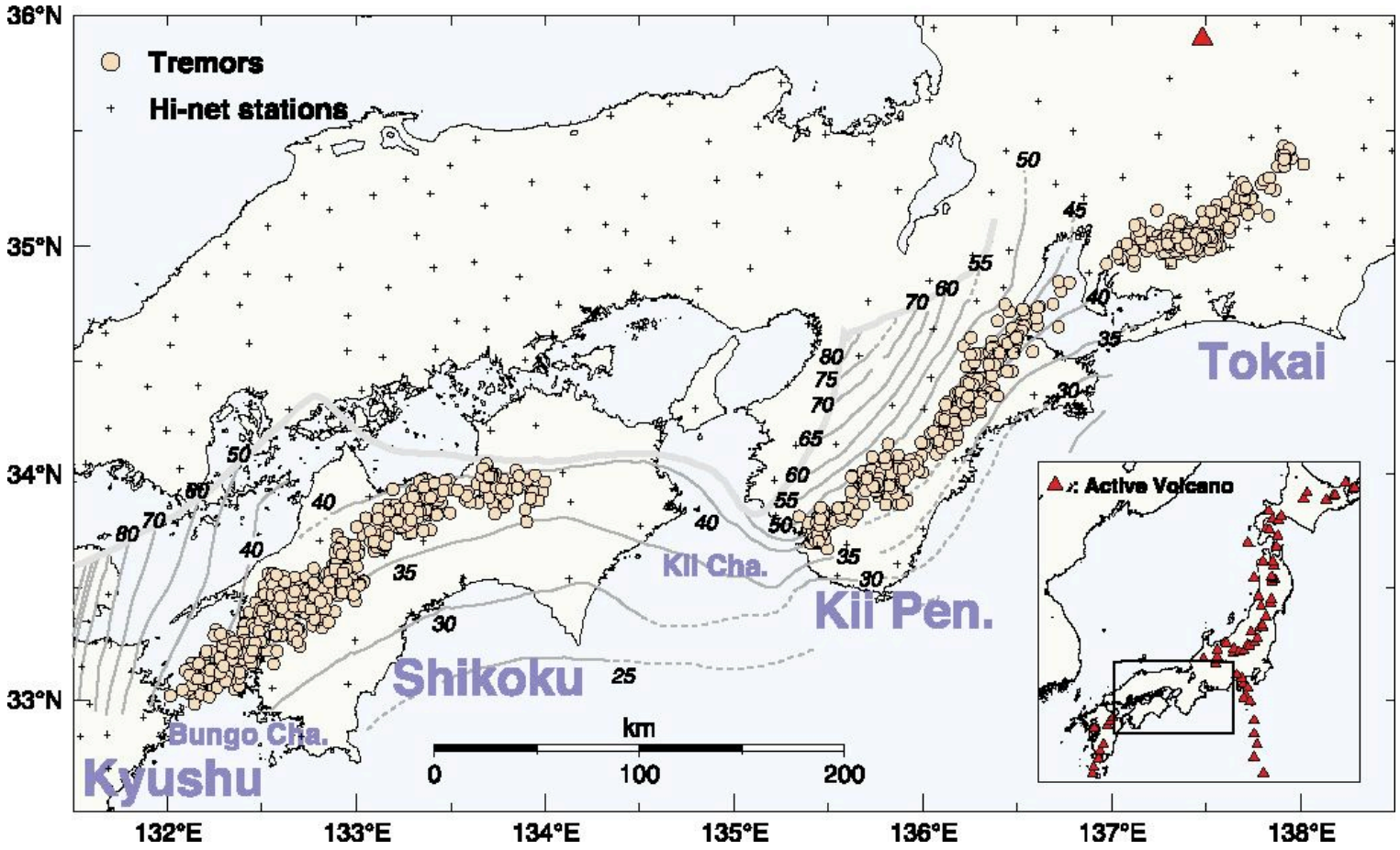
- SSEs occur every few months, 36 since 1997
- Equivalent magnitudes of 6.3-6.8, 2-3cm of slip (lower GPS detection limit)
- Slip may delineate a locked/transition zone
- Inverted slip locations increasingly agree with tremor
- 2007 captured on 70+ GPS stations, many more en route



A New Signal
Non-Volcanic deep tremor associated with subduction in southwest Japan



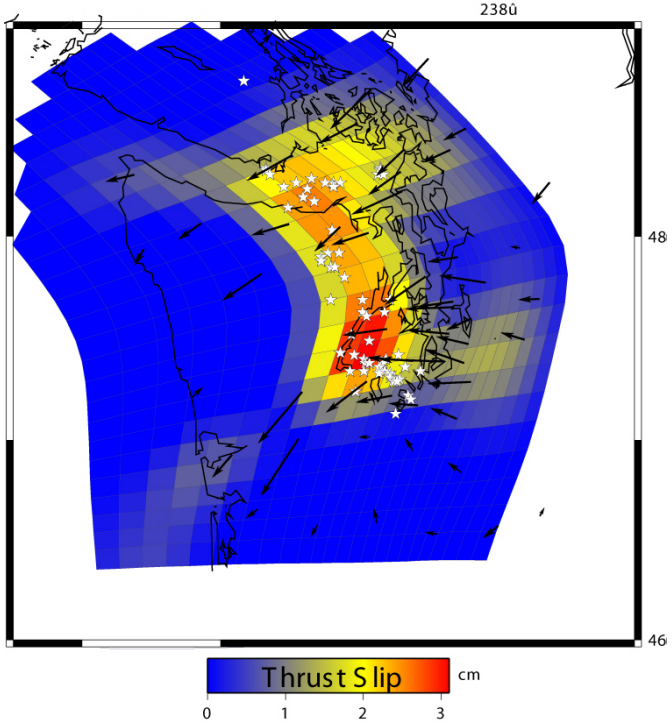
HI-NET recording (*Obara, 2002*)


Tremors
Hi-net stations
Tokai
Kii Pen.
Kii Cha.
Shikoku
Bungo Cha.
Kyushu
km
0
100
200
▲: Active Volcano
36°N
35°N
34°N
33°N
132°E
133°E
134°E
135°E
136°E
137°E
138°E

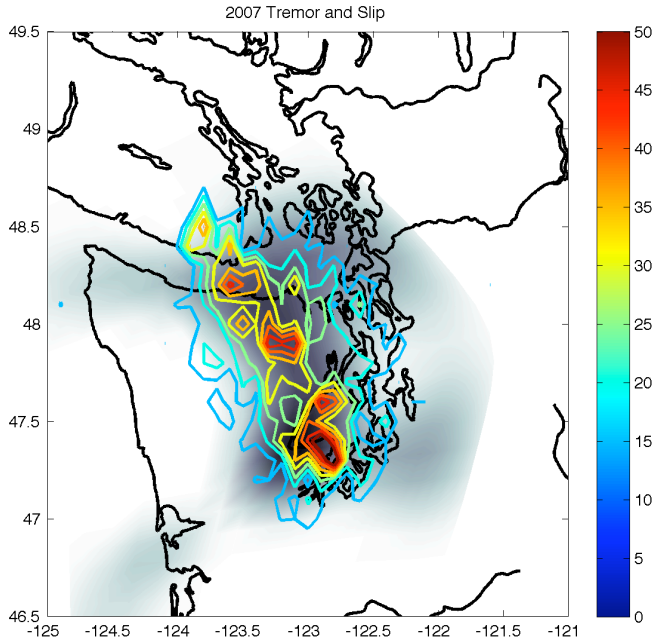
(*K. Obara, 2002*)

2007.1 ETS

GPS

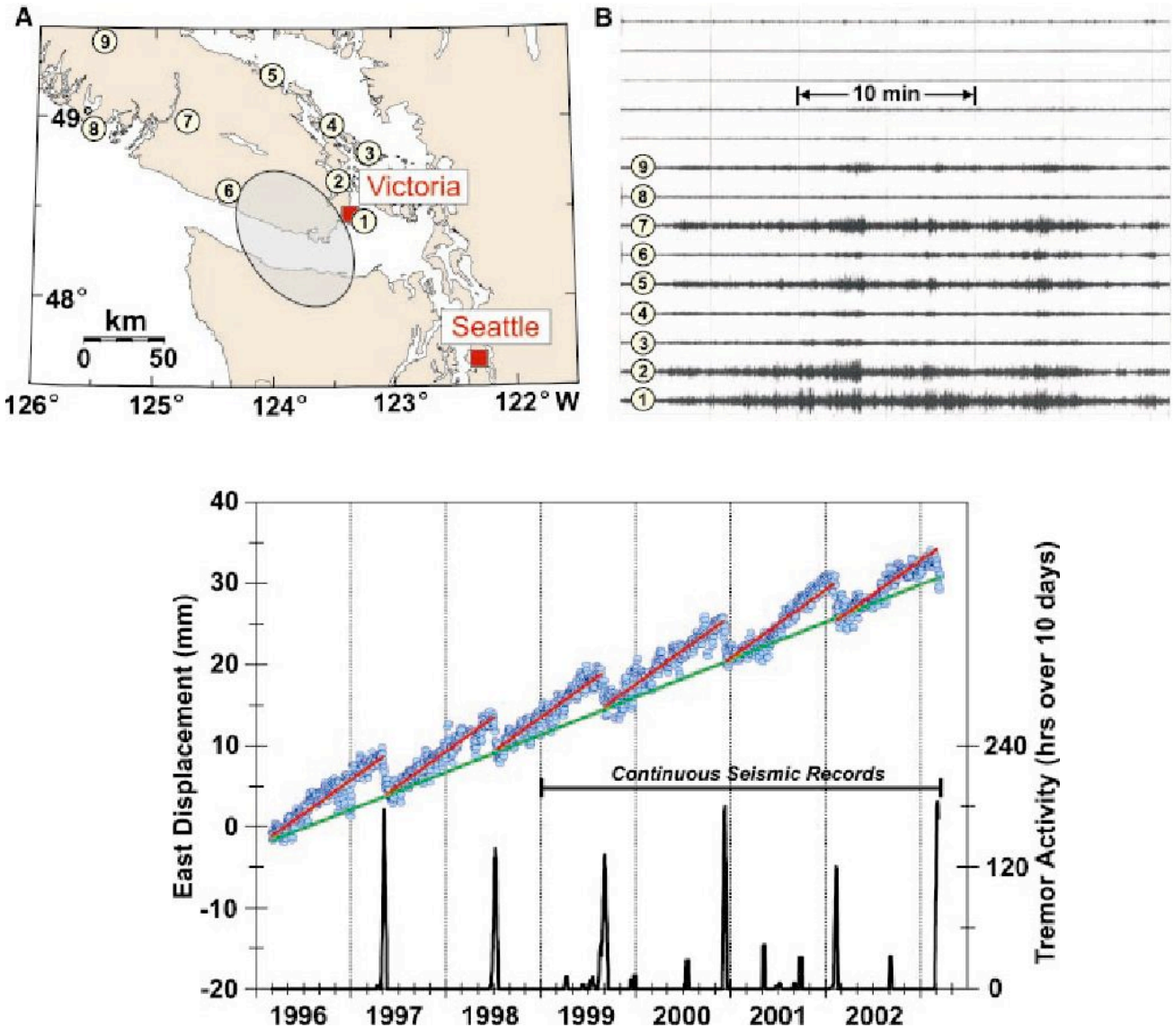


Tremor



Tremor hypocenters from Wech & Creager, 2007

Cascadia NVT



Rogers and Dragert, 2003