UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Chile)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
19-30 August 2024, Valparaiso, Chile

Real-Time Earthquake detection and Fast Source Characterization

Stuart Weinstein
NOAA/NWS/PTWC

Types of Magnitude

	Name	Data used	Period range
Ml	Local magnitude	regional S and surface waves	0.1-1 sec
mb	(short period) body wave magnitude	teleseismic P waves	1-5 sec
Ms	Surface wave magnitude	teleseismic surface waves	(20 sec)

Traditional magnitudes based on amplitudes of recorded data.

$$M = \log(A_d/T)_{max} + \sigma(\Delta,h) + Cr + Cs$$

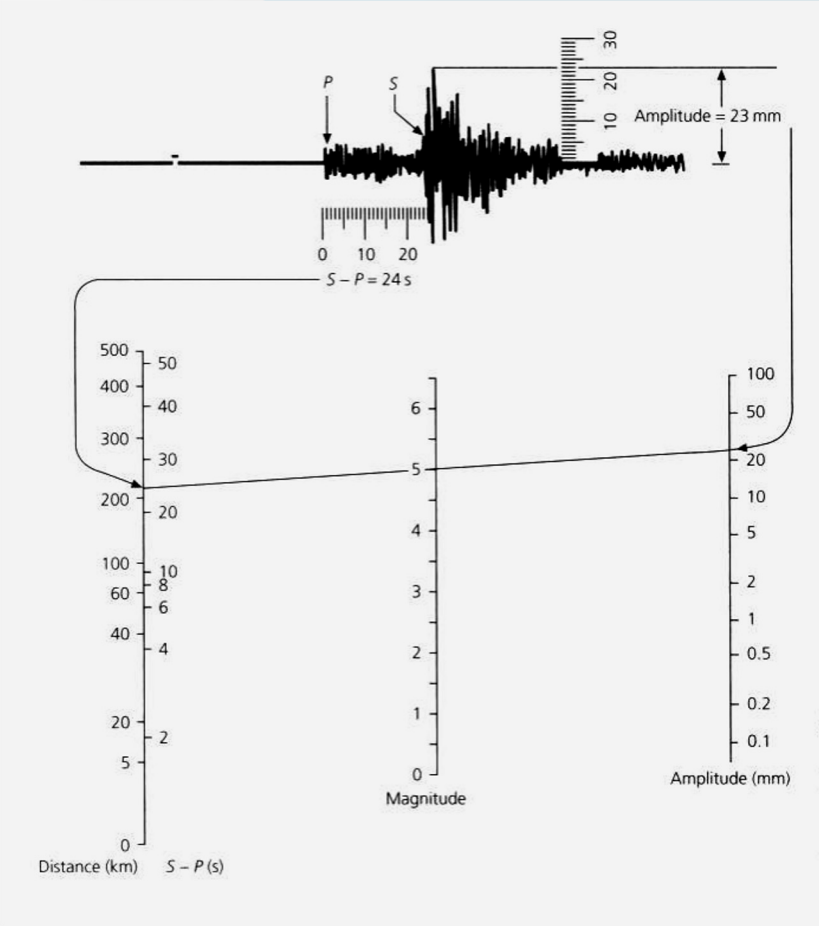
Based on velocity therefore proportional to energy

Distance correction

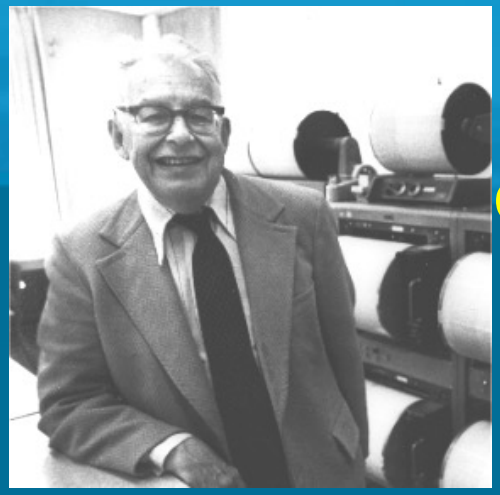
Regional correction for source directionality

Optional station correction

Local magnitude



Bruce Bolt. Earthquakes.
WH Freeman and Company



Charles Richter
1900-1985

USGS, NEIC

$Ml = \log A_{max} - \log A_0$

Defined using horizontal, short period seismometer. Therefore no period consideration.

Log A_0 correction taken from published tables and related to distance (< 600km)

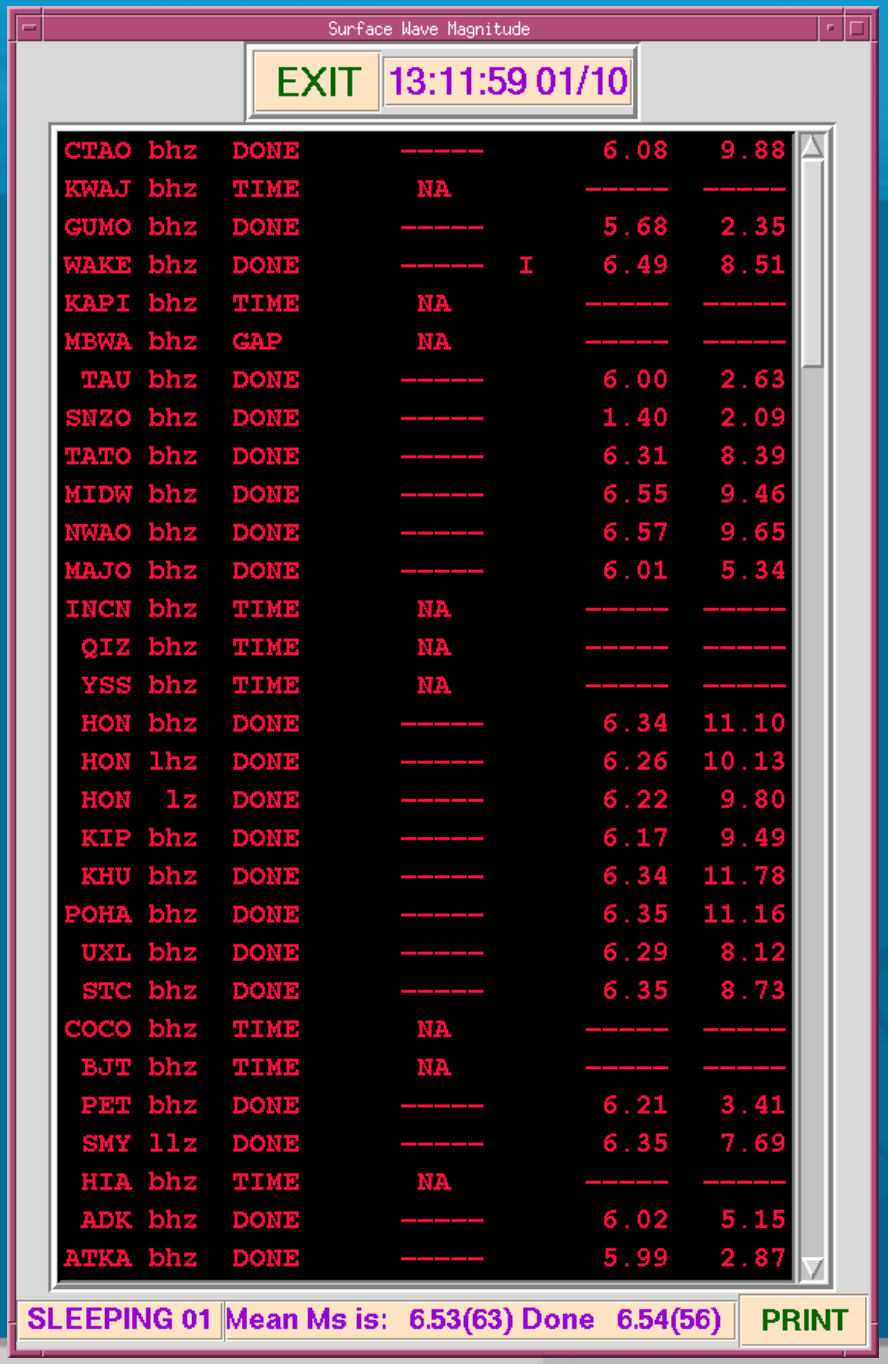
The ~1 sec period response of the seismometer is similar to many small buildings, therefore still useful for engineers.

Surface wave magnitude - Ms

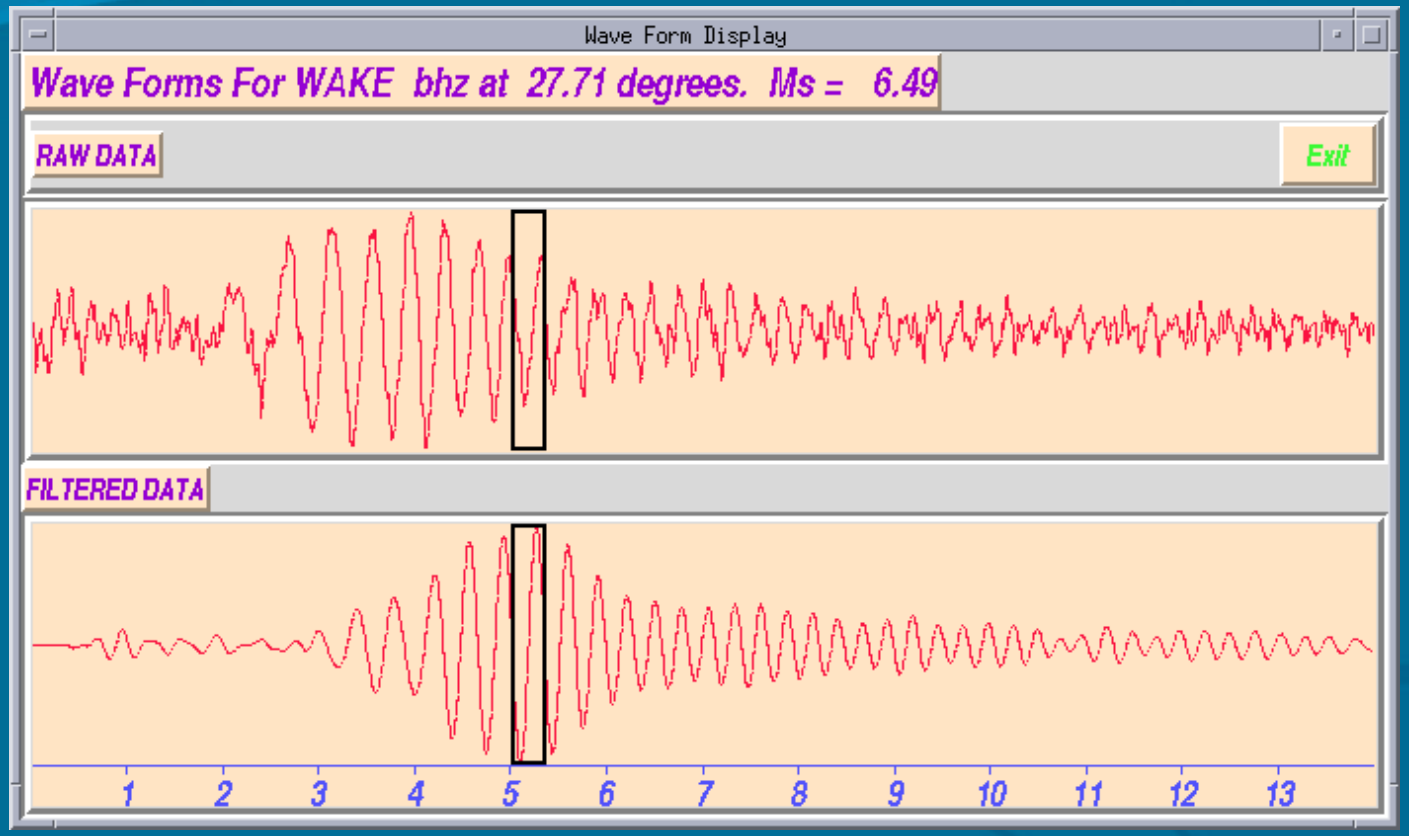
$$Ms = \log (A/T)_{max} + \sigma_S(\Delta) = \log (A/T)_{max} + 1.66 \log \Delta + 3.3$$

- First defined by Gutenberg 1945.
- IASPEI Standard:
  Distances 2 degrees < Δ < 160 degrees.
  Depth h < 50 km.
  Any surface wave period measured on horizontal and vertical components
- NEIC:
  Limit periods to 18 < T < 22 sec and only use vertical component.
  Distances from 20 degrees < Δ < 160 degrees

DISPLAY FOR AUTOMATIC SURFACE WAVE MAGNITUDES



DISPLAY TO REVIEW SURFACE WAVE MAGNITUDE

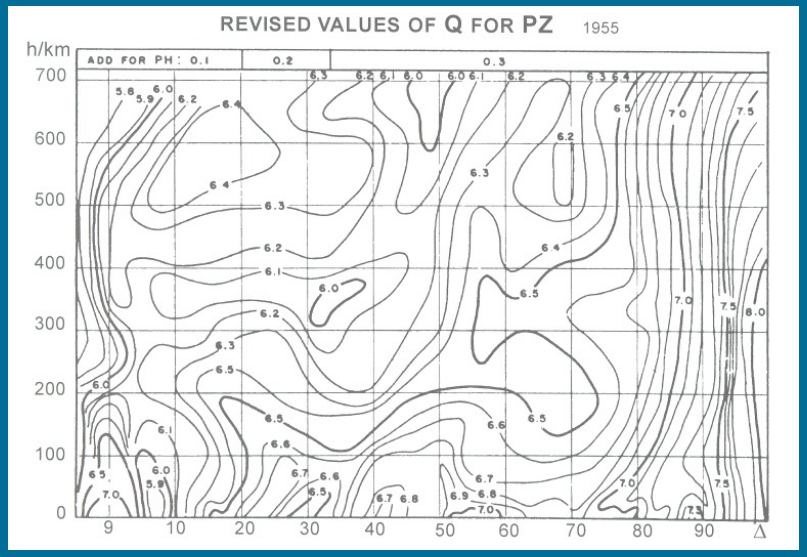


Body wave magnitude - mb

$$mb = \log (A/T)_{max} + Q(\Delta,h)$$

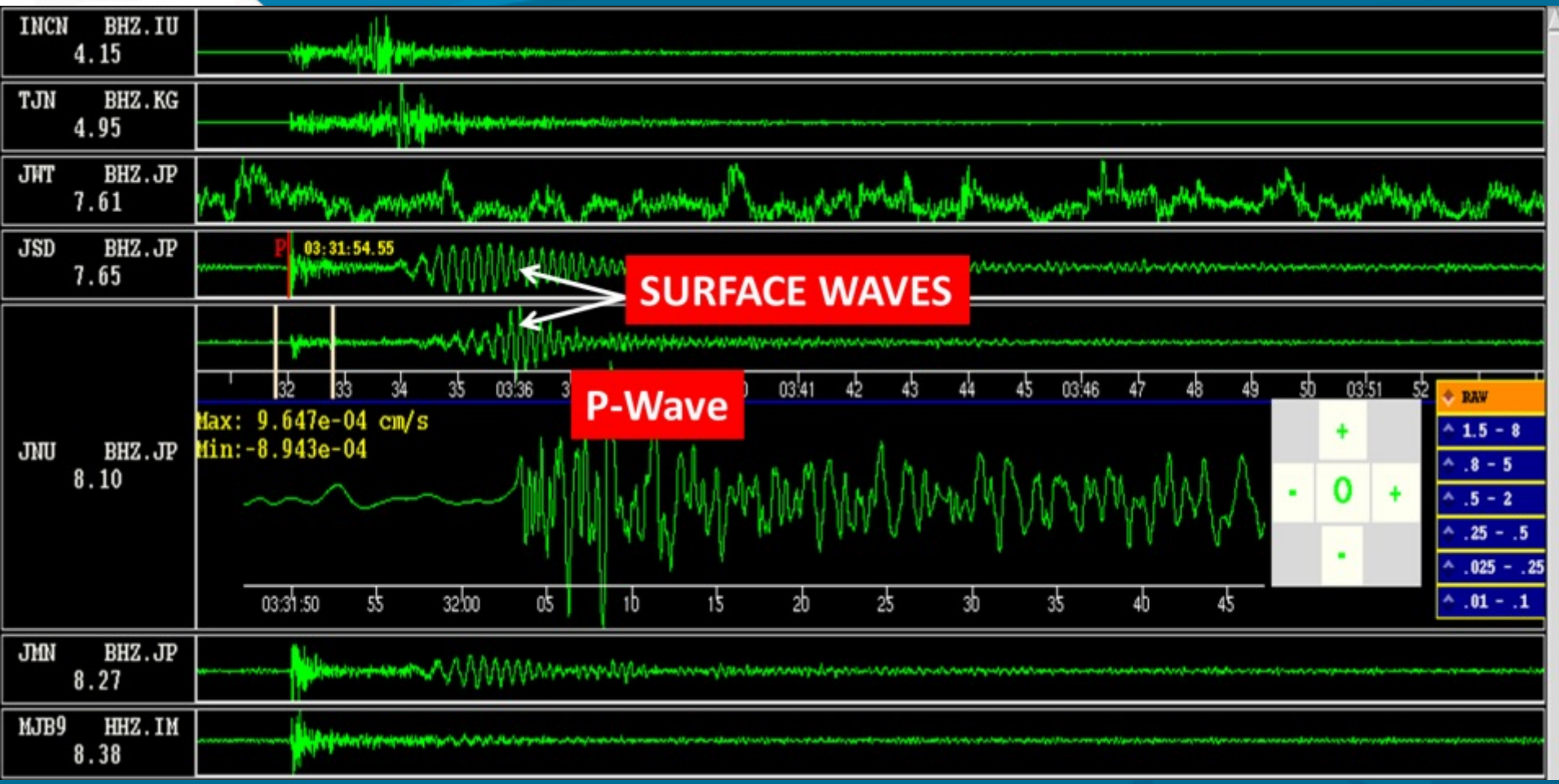
correction from Gutenberg 1945

- Calculated from P wave displacement amplitude. Commonly reported but very variable calculation methods:
- Fairly standard features of measurement:
  distance 20 deg < Δ < 100 deg,
  period T < 3 sec.



- ***IASPEI Standard*: measure A_{max} from whole recorded P wave; vertical or horizontal max.**
- ***NEIC*: vertical P only, measure max amp in first 10 cycles (~10-20 sec), or manually extended to 60 sec for large earthquakes.**
- ***China and the CTBTO*: measure only first 5-6 seconds.**

N. Korea Nuclear Explosion



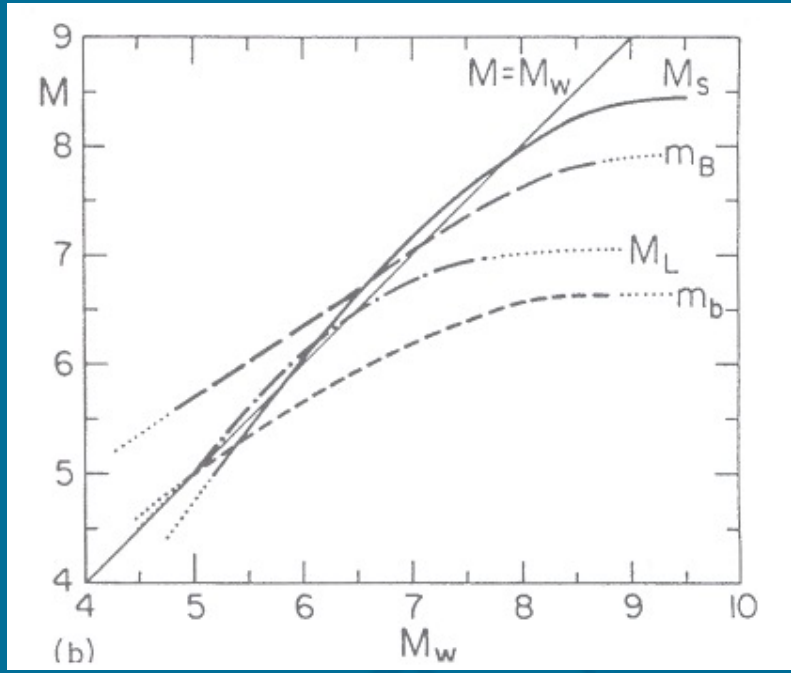
Mb = 6.3, Ms = 4.9

Saturation

- Ml, Ms and mb all suffer from saturation.
- Occurs for 2 reasons:

Time window saturation:
The magnitude is calculated for a time window that is less than the duration of the rupture (particularly effects mb)

Spectral saturation:
The wavelength of the wave is too short to sample the entire rupture (effects mb, Ml, and Ms)



Kanamori 1983

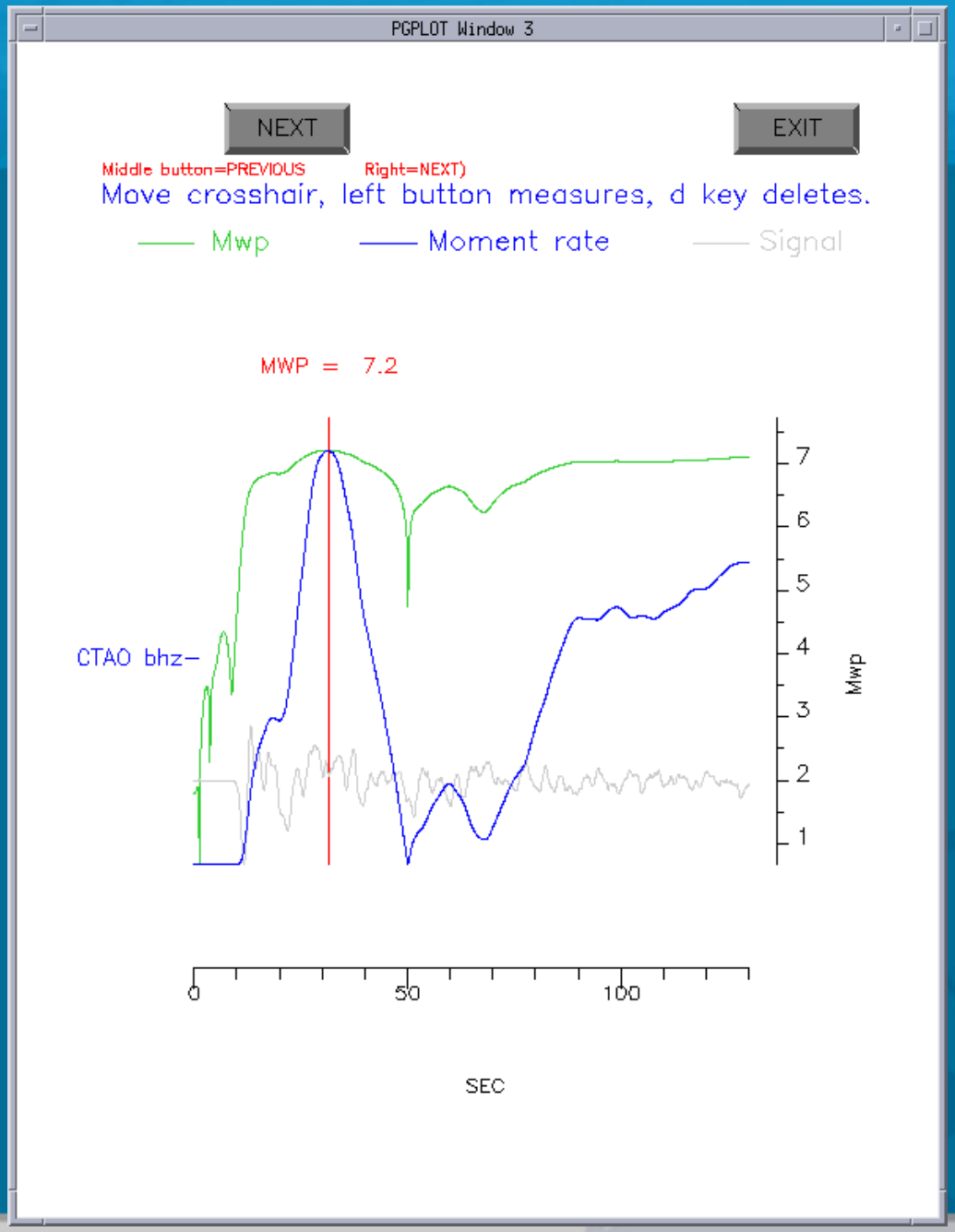
Saturation

How do we overcome saturation?

=> Examine Longer Period Waves!

Enter Mwp, Mantle Magnitude
And
The CMT

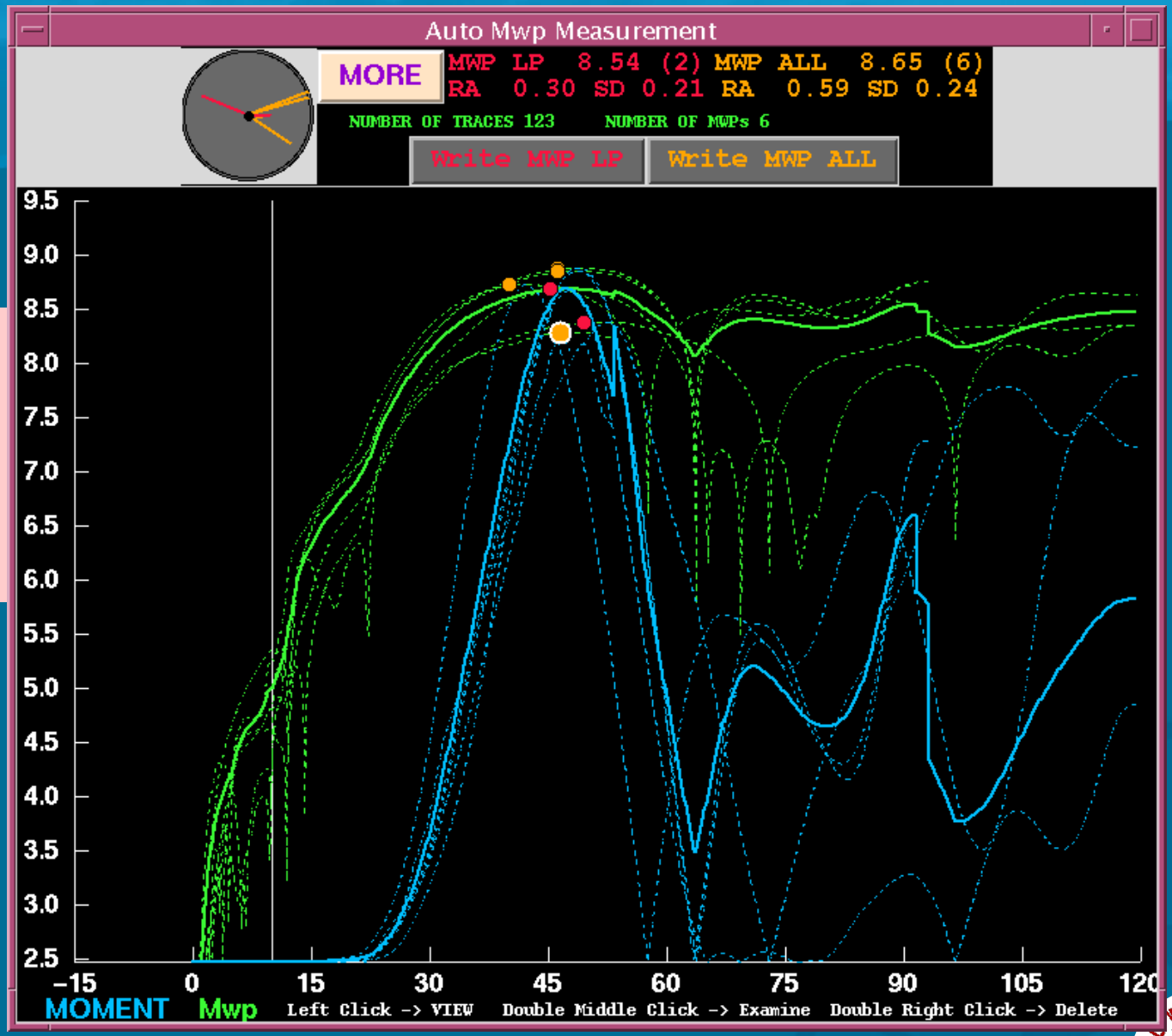
INTERACTIVE TOOL TO DETERMINE MWP MOMENT MAGNITUDE



Compute Mwp

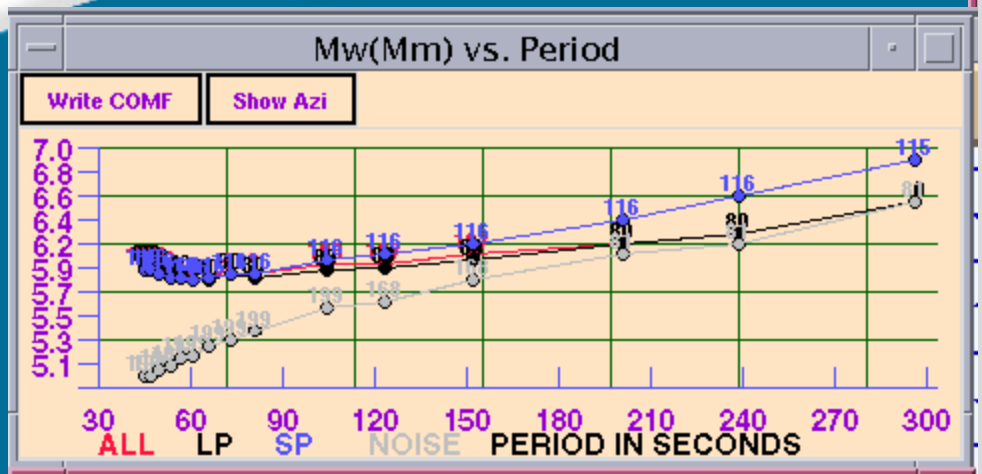
This is the Mwp GUI Interface

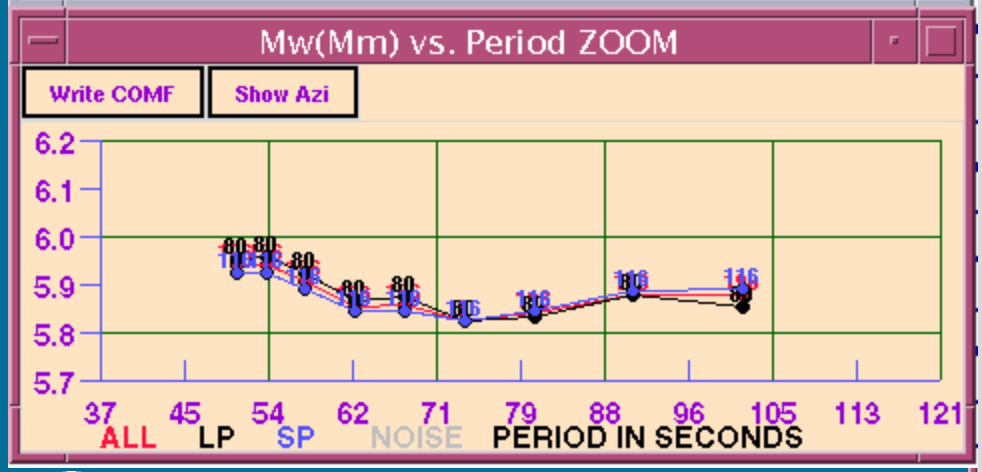
Sumatra 2012

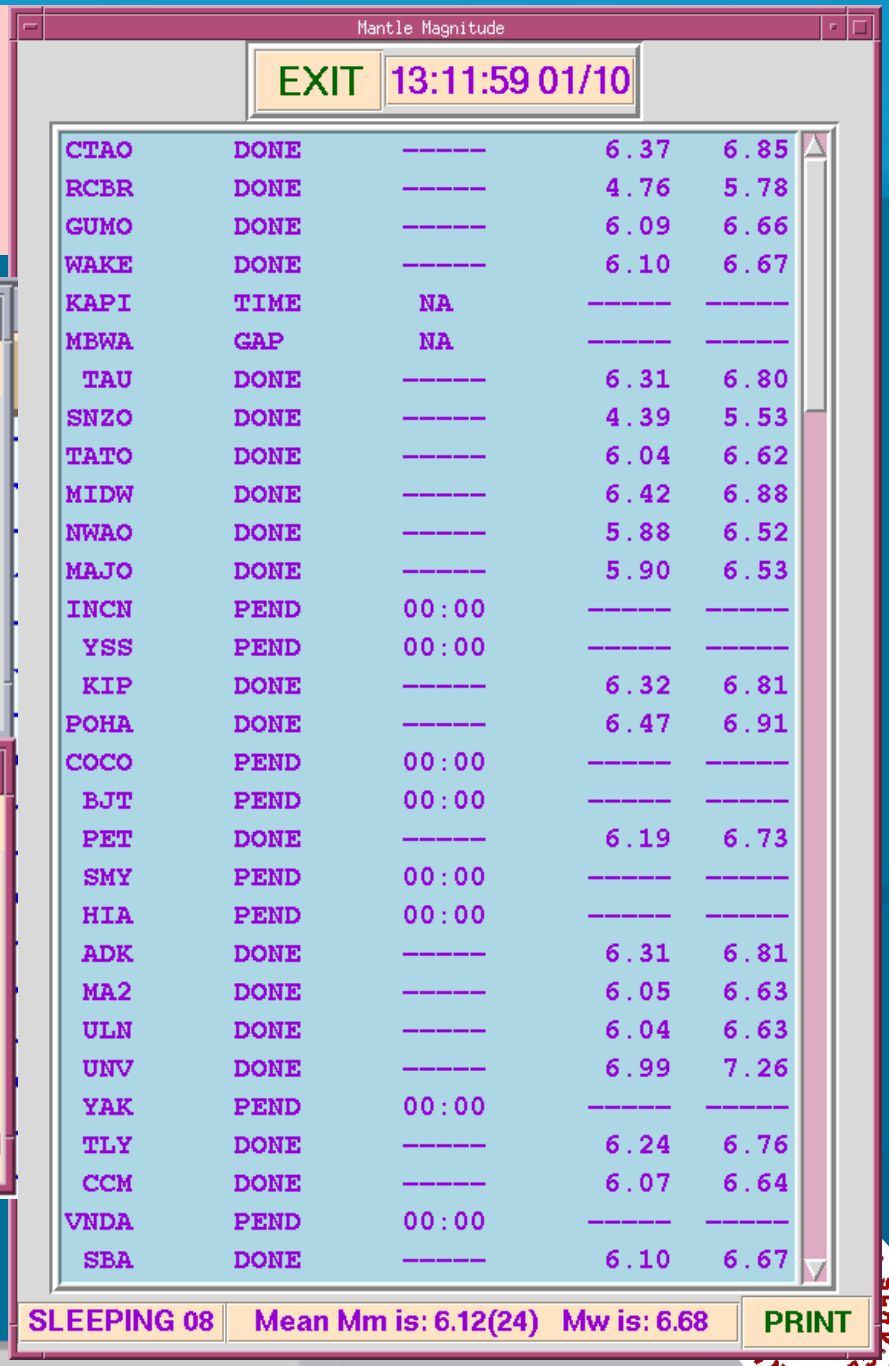


Mwp method developed by Tsuboi et al., 1995

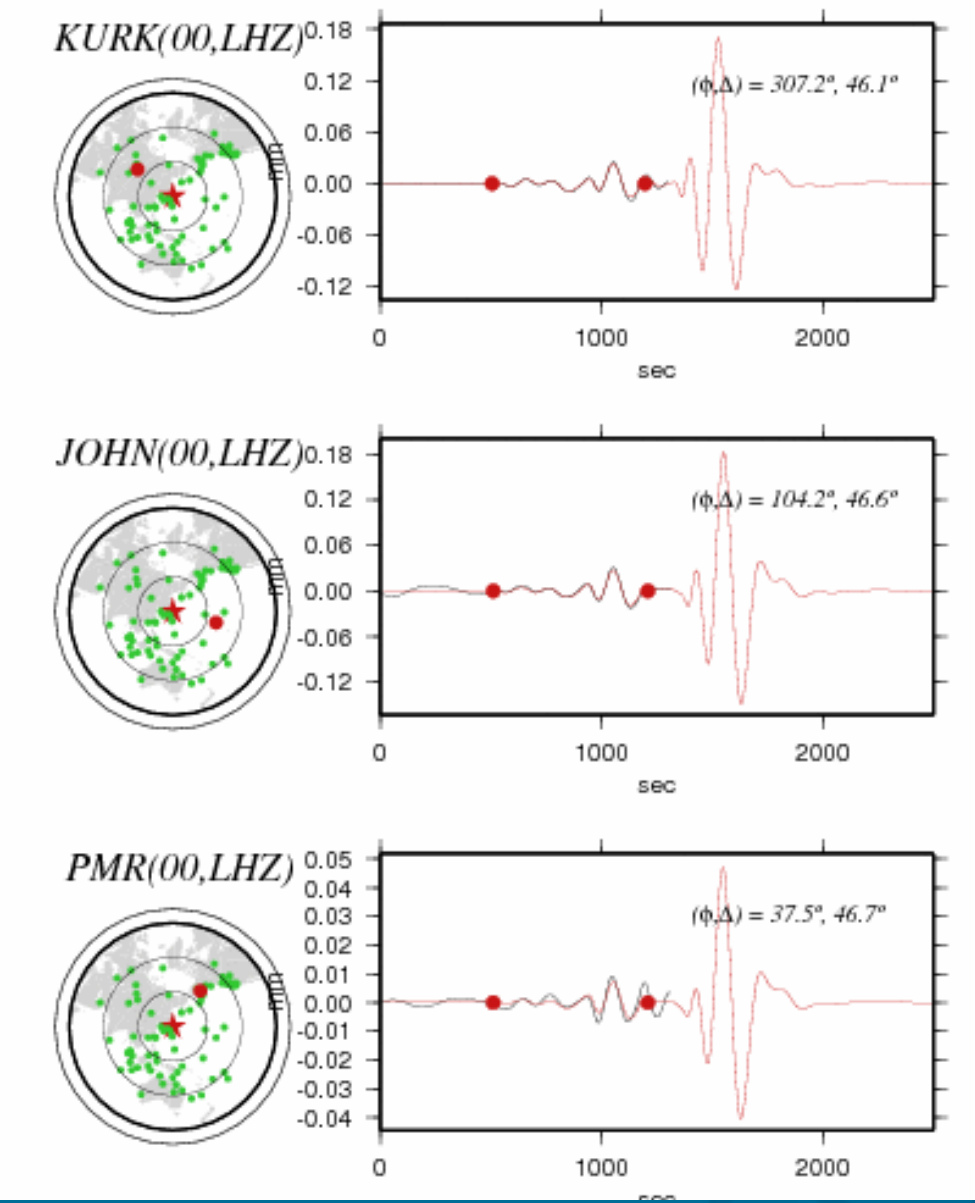
DISPLAY FOR AUTOMATIC MOMENT MAGNITUDE FROM MANTLE MAGNITUDE







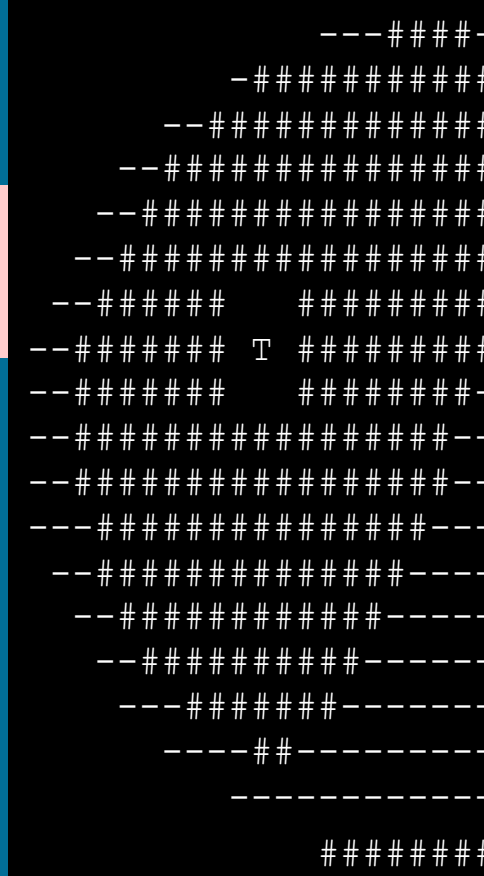
Wphase Inversion



Wphase Inversion

Focal Mechanism

Best Double Couple: M0=1.93E+29 dyn.cm Mw = 8.79
NP1: Strike=165 ; Dip=10 ; Slip= 55
NP2: Strike= 20 ; Dip=82 ; Slip= 96

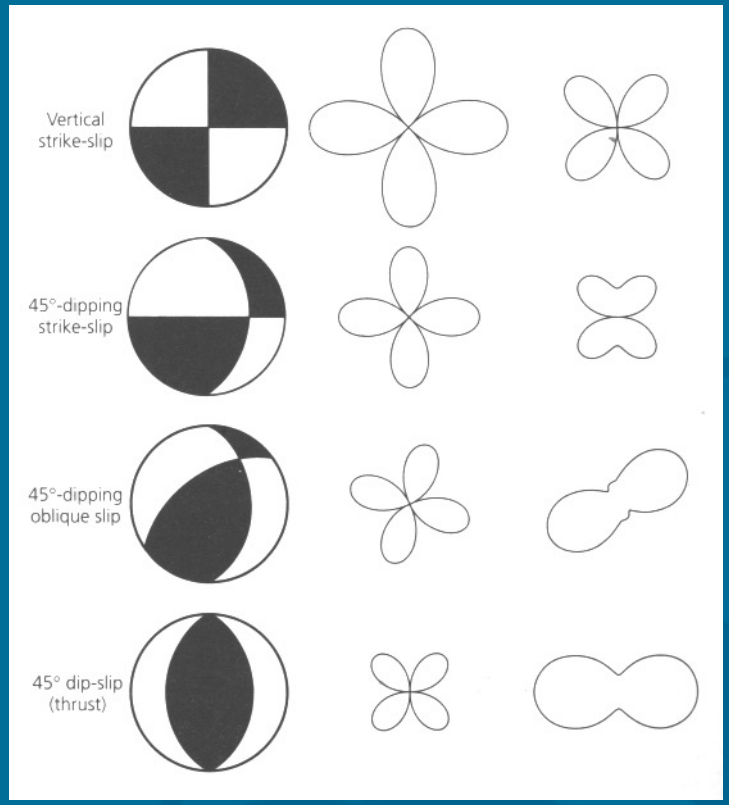


Moment Magnitude - Mw

- Calculated from seismic moment (Mo). Therefore *related to fault slip* not energy released as waves. More relevant for tsunamis, less relevant for damage from ground shaking.

- **Harvard CMT and NEIC calculate Mw from the moment tensor solution.**

- **Fit shape and amplitude of long period surface waves to synthetics to model moment tensor and Mo.**



Stein and Wysession, "An Introduction to seismology, earthquakes and Earth structure"

Theta = $\log_{10}$ (Er / M_o)

E_r is the energy carried by high frequency P-waves and Mo is the seismic Moment. Basically it the ratio of the energy contained by high frequency P-waves to the energy released by the earthquake.

This is a slow, or tsunami earthquake!

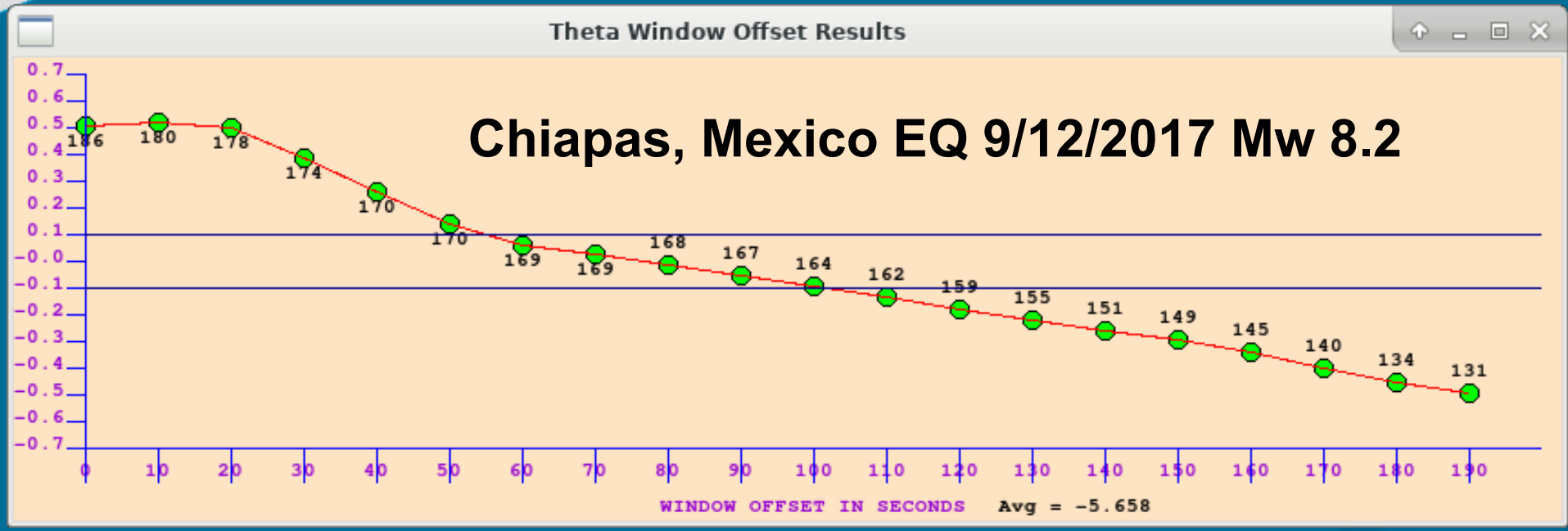
Energy Discriminant

EXIT | 01:05:19 09/02 | Mw: 7.20

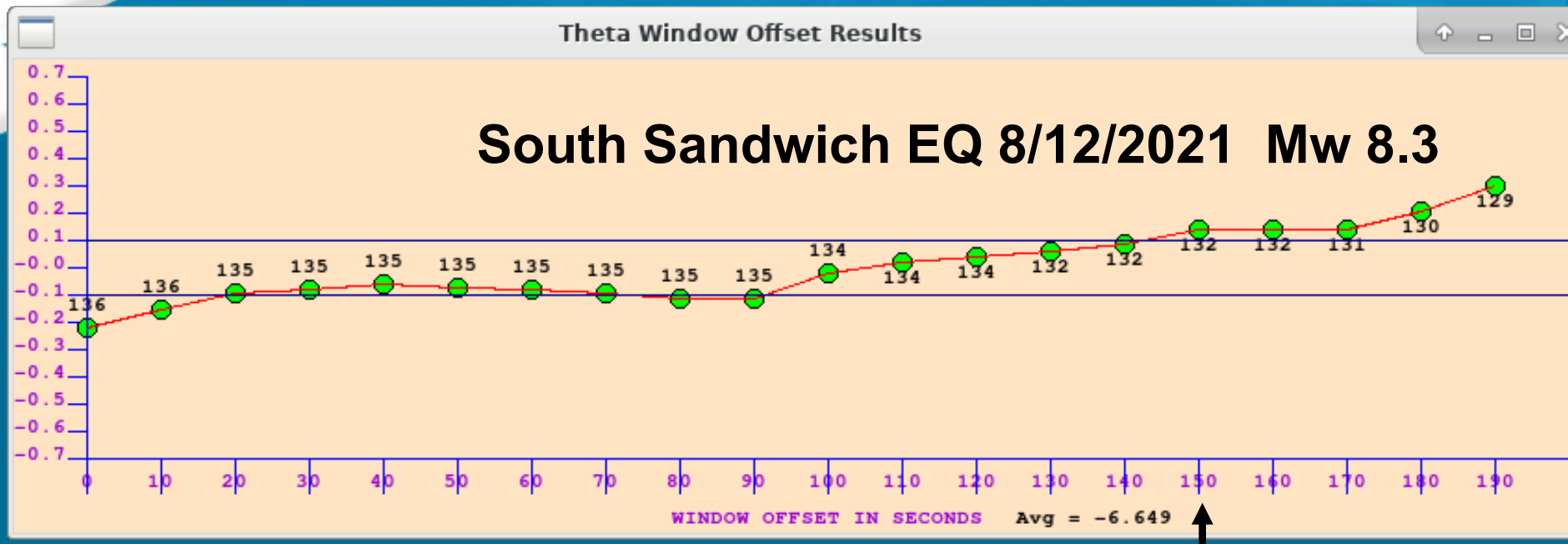
STA	STATUS	ETA	THETA
HIA	PEND	00:00	-----
KDAK	DONE	-----	-6.23
YAK	DONE	-----	-5.32
ULN	DONE	-----	-5.37
TNA	DONE	-----	-6.37
BILL	PEND	00:00	-----
RPN	PEND	00:00	-----
PMR	DONE	-----	-5.81
EYAK	DONE	-----	-5.86
DIV	PEND	00:00	-----
MCK	DONE	-----	-5.86
LSA	PEND	00:00	-----
JCC	DONE	-----	-5.94
SAO	DONE	-----	-6.06
SIT	DONE	-----	-6.14
COLA	DONE	-----	-5.74
SNCC	PEND	00:00	-----
PKD	DONE	-----	-6.03
CRAG	DONE	-----	-6.06
WDC	DONE	-----	-6.00
YBH	DONE	-----	-6.10
ORV	DONE	-----	-6.30
CMB	DONE	-----	-6.18
OSI	PEND	00:00	-----
COR	DONE	-----	-5.94
PAF	GAP	NA	-----
SKAG	DONE	-----	-6.09
PAS	PEND	00:00	-----
KCC	DONE	-----	REM
ISA	PEND	00:00	-----

FINISHED | Mean Theta is: -5.83(43) | PRINT

Integration window 70s



Theta = -5.1
GCMT Source Duration ~65s (Assumed)



Theta = -6.8
GCMT Source Duration ~300s (Assumed)

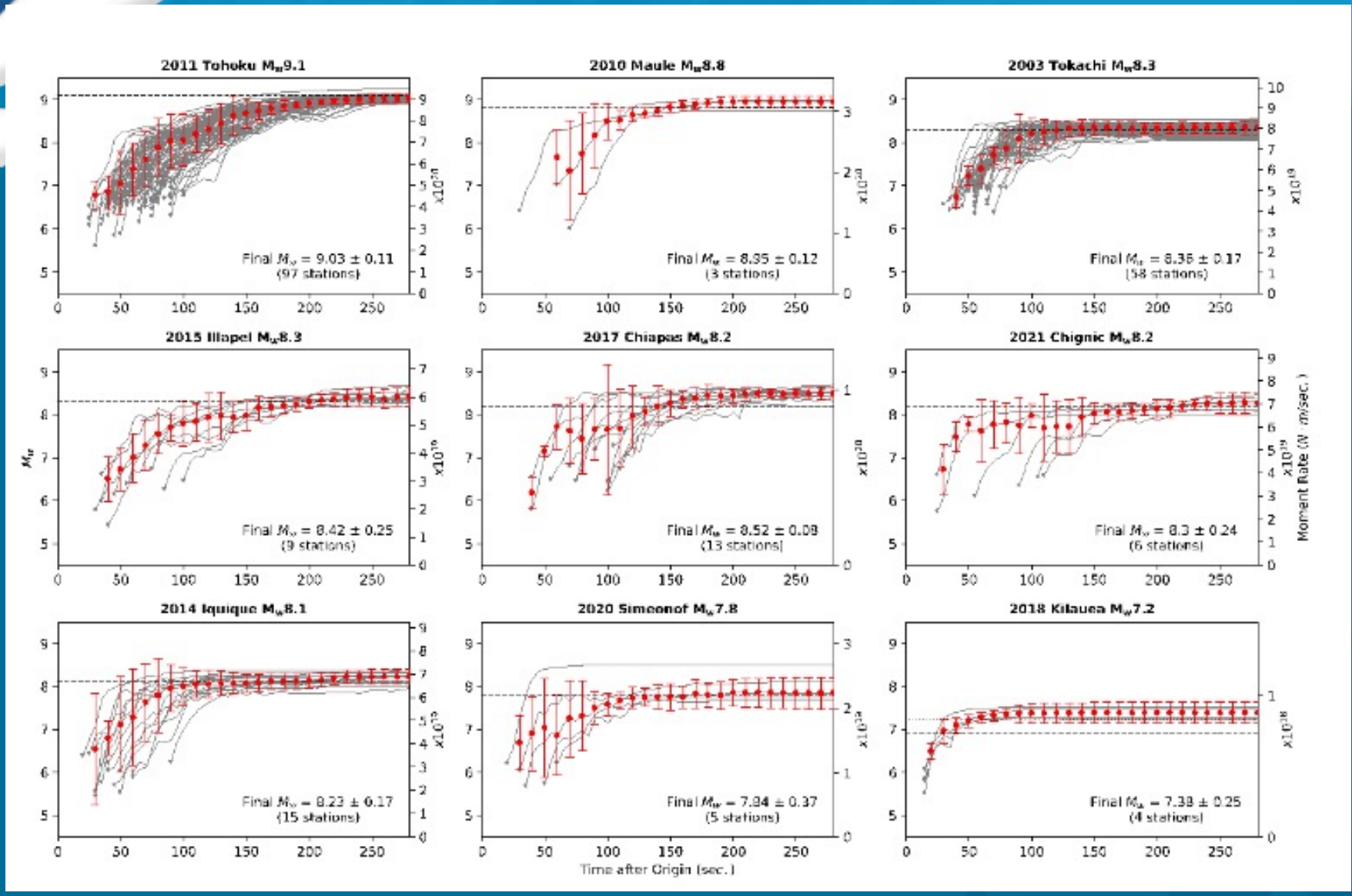
Second Quake

Seismogeodetic Data

⇒ Combine Accelerometer Data with GNSS Data

⇒ Gives the *ultimate seismogram* It never "clips", and therefore can be used to assess earthquake magnitude even in the nearfield of great earthquakes

⇒ Can yield the magnitude of great earthquakes in ~3mins


2011 Tohoku M_w9.1
Final M_w = 9.03 ± 0.11
(97 stations)
2010 Maule M_w8.8
Final M_w = 8.85 ± 0.12
(3 stations)
2003 Tokachi M_w8.3
Final M_w = 8.36 ± 0.17
(58 stations)
2015 Illapel M_w8.3
Final M_w = 8.42 ± 0.25
(9 stations)
2017 Chiapas M_w8.2
Final M_w = 8.52 ± 0.08
(13 stations)
2021 Chignic M_w8.2
Final M_w = 8.3 ± 0.24
(6 stations)
2014 Iquique M_w8.1
Final M_w = 8.23 ± 0.17
(15 stations)
2020 Simeonof M_w7.8
Final M_w = 7.84 ± 0.37
(5 stations)
2018 Kilauea M_w7.2
Final M_w = 7.38 ± 0.25
(4 stations)
M_w
Moment Rate (N m/sec.)
Time after Origin (sec.)

unesco
Intergovernmental Oceanographic Commission

Thank You

Stuart Weinstein
NOAA/NWS/PTWC

USAID FROM THE AMERICAN PEOPLE

SMART CABLES Earth's Pulse