TIDE TOOL: SOFTWARE TO ANALYZE GTS SEA-LEVEL DATA

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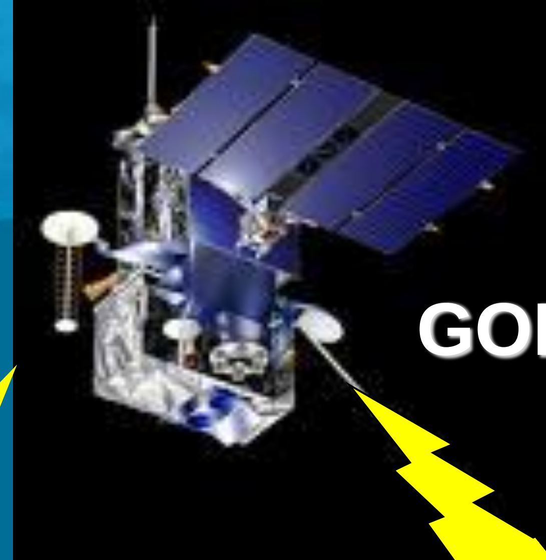
GTS – Global Telecommunications Service:

Maintained by the WMO and is comprised of a network of surface and satellite based telecommunications links and centers. It is a system for the global exchange of meteorological, climatic, seismic and other data to support multipurpose early warning and forecast systems*.

The TWCs (Tsunami Warning Centers) rely heavily on the GTS to supply sea-level data in near real time from ~550 sea-level stations world wide and to transmit Tsunami Bulletins.

*Source: http://www.wmo.ch/pages/prog/drr/events/humanitarian/Documents/HumanitarianBackground%20document.pdf



GOESW

CHANNEL 32

Downloaded at Wallops Island VA/USA and forwarded to the US TWCs and Met. Offices.

Primary Functions of the Global Sea-Level Network

1. Confirm the existence or non-existence of destructive tsunami waves. Measure period and amplitude of tsunami waves.

2. Revise forecasts. Sea-level observations can be used to scale forecasts and/or adjust the source model.

3. Validate forecast models.

4. Hazard Mitigation.

5. Meteorological/Climate (storm surges, sea-level rise etc.)

6. Coastal management.

Requirements for Sea-Level Stations (For Tsunami monitoring)

1. Sample Interval
2. Transmission interval
3. Placement
4. Multiple Instruments
5. Data must be made available to the TWCs

Requirements for Sea-Level Stations

1. Sample interval

Destructive tsunamis have periods from 5 to 60 minutes or more. Therefore the sample interval should be small enough to adequately characterize shorter period tsunamis. “Local” tsunamis usually have short periods and they are the most frequent type of tsunami. Today, most sea-level stations provide sea-level readings at one minute intervals.

Why are High Frequency Sea-Level Data Transmissions needed?

More frequent transmissions allow the TWC's to confirm the existence or non-existence of a destructive tsunami more quickly. This is important because with each moment a tsunami watch/warning remains in effect, more coastline is potentially placed within a watch/warning.

=> We want to reduce the amount of coastline that is unnecessarily evacuated.

Requirements for Sea-Level Stations

2. Transmission interval

Frequent vs. Triggered transmissions

Frequent transmissions are preferred:

1. Tsunamis can happen at any time.

2. Cuts down on latency for detection.

3. Sea-level station may be destroyed before it can transmit evidence of tsunami. warning.

Requirements for Sea-Level Stations

2. Transmission interval

Frequent transmissions are preferred:

4. Trigger algorithm may turn on trigger mode, but what about turning it off? Observations of decay of tsunami wave amplitudes may be used to forecast when it is safe to cancel warning.

5. Small tsunamis might not trigger.

Requirements for Sea-Level Stations

Trade-off with Sample Interval and Transmission window

Short sample intervals require more data to be transmitted. If you have too short a transmission window there may not be room for redundant or other data.

Requirements for Sea-Level Stations

Trade-off with Sample Interval and Transmission window

There is also a trade off with GTS. GOES has 5s transmission slots. If transmitters Only transmit once an hour, a single GOES Channel can service 720 transmitters. If the Transmissions occur every 5 minutes, than A GOES channel can service only 72 transmitters

Requirements for Sea-Level Stations

3. Placement

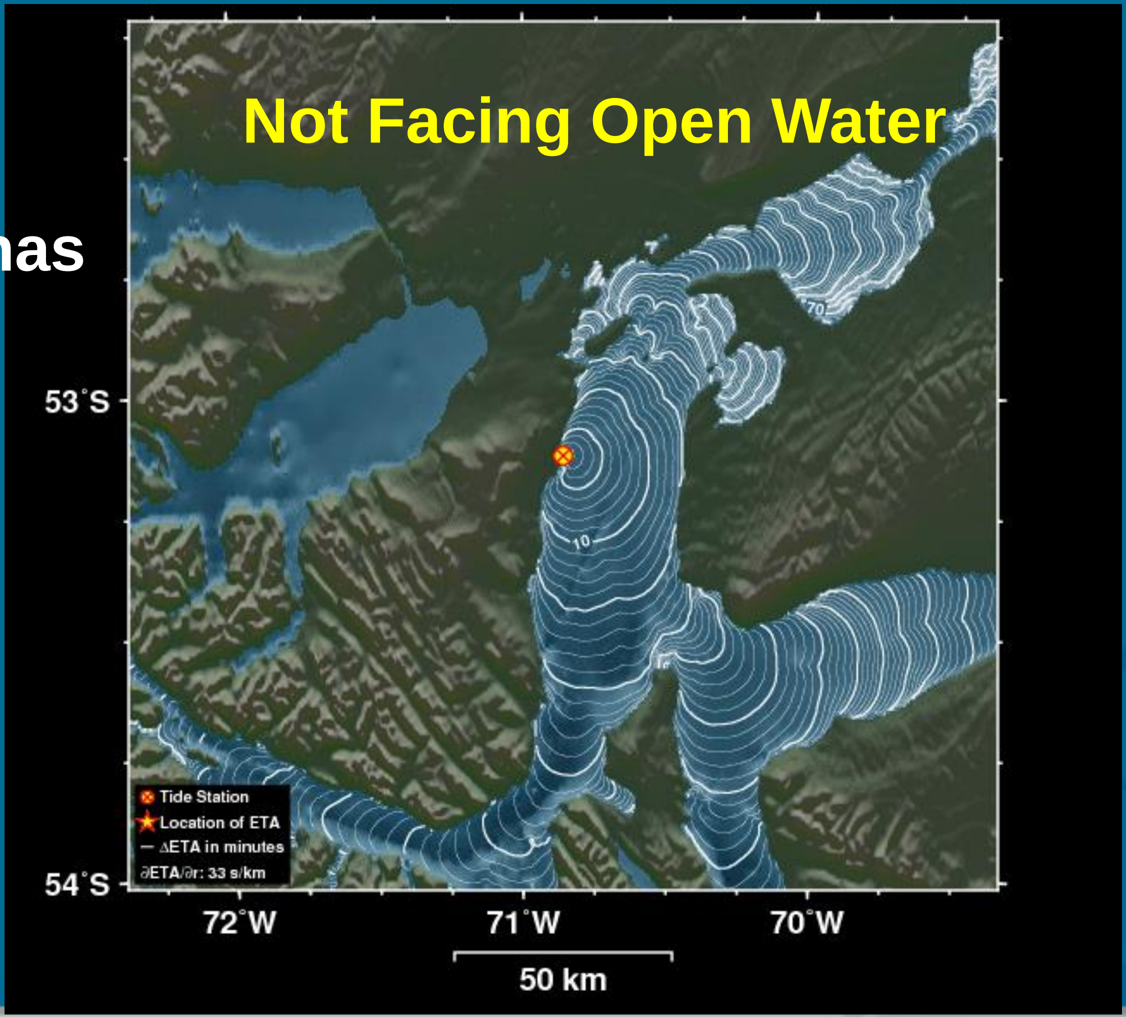
Network Density should be highest in areas with Greatest likelihood have generating tsunamigenic earthquakes. Sea-Level stations should ideally be no more than 50km apart. This will provide for quick overall detection and not miss detection of local tsunamis.

For non-seismically active areas spacing at 100km is sufficient.

Requirements for Sea-Level Stations

3. Placement

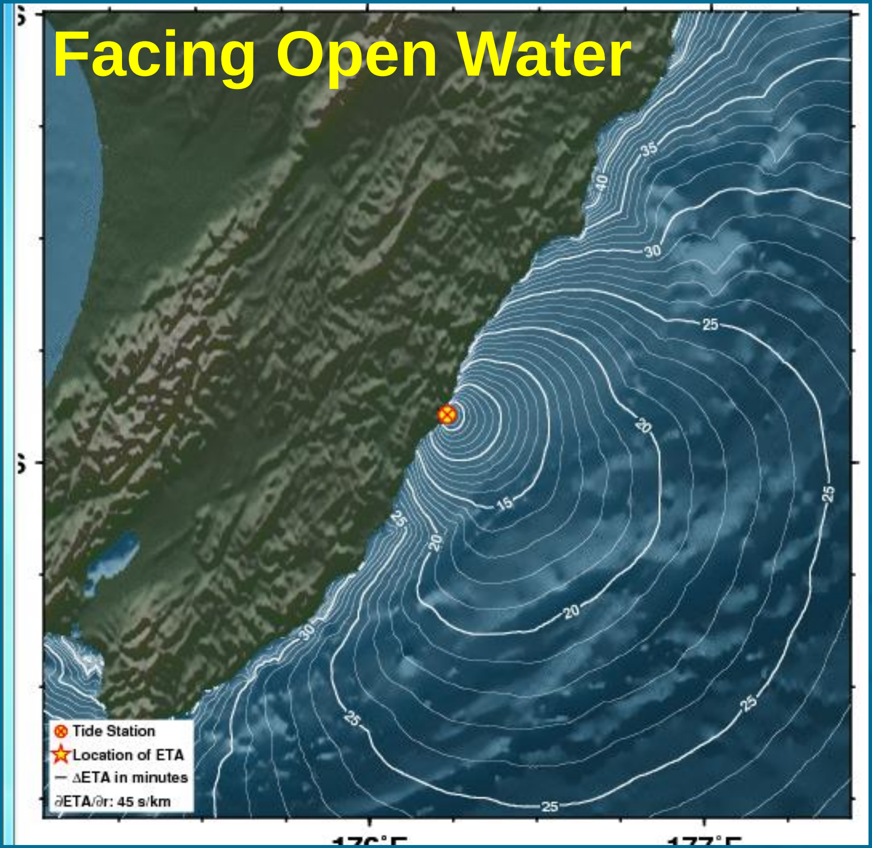
Punta Arenas
Chile



Requirements for Sea-Level Stations

3. Placement

Castle Point
New Zealand



Requirements for Sea-Level Stations

3. Placement

In the Pacific, for every hour a tsunami threat remains in affect 500km-1000km of additional coastline are placed in a warning.

Requirements for Sea-Level Stations

3. Multiple sensors

Best to have multiple sensors for purposes of redundancy.

$\Rightarrow$ Should be different types of instruments

Basic Types of Sea-Level Stations

- Coastal Sea-Level Stations
- DARTs
- Cabled sensors

Function

Coastal Stations (situated in shallow water)

1. Detection. The first recording of a tsunami will normally come from a coastal tide gauge (Safety in numbers). Primary means of detecting local tsunami.

2. Provide Impact information on the shore.

3. Once a tsunami is declared destructive it is the tide gauge readings that are used as a basis for cancelling the warning.

4. Failsafe in case our predictions based on DARTs are in error.

Function

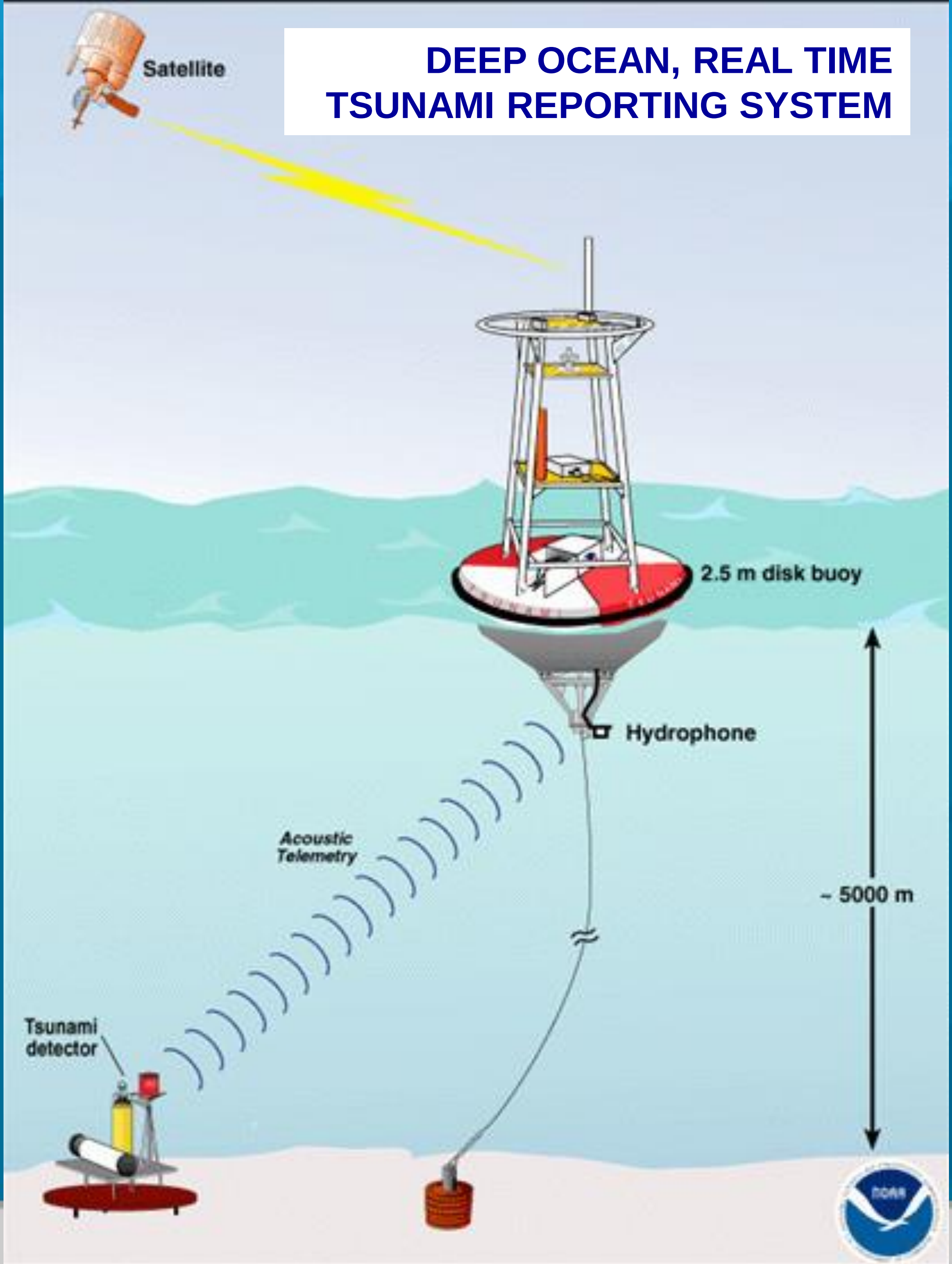
DART Stations (situated in very deep water)

1. Their primary function is to help the TWCs to distinguish between tsunamis that will propagate across an ocean basin with destructive power from those that would just be measurable on tide gauges.
   => Unnecessary evacuation would cost Hawaii ~75M US$

2. Cancellation following an initial Warning/Watch bulletin.

3. Detection.

The tsunami signal is detected by a pressure sensor on the ocean floor. That signal is relayed by acoustic telemetry to the buoy. The buoy in turn transmits the signal via satellite back to the warning centers.



Strengths and Weaknesses

Coastal Station Strengths (DART Weakness)

1. Lots of them (400+).

2. Costs (Inexpensive).

3. Easy to maintain.

4. Primary means of detecting locally destructive Tsunami.

Strengths and Weaknesses

DART Strengths (Coastal Station Weakness)

1. Situated in deep water, far from the effects of harbor resonances and other coastal effects.

2. DART marigrams are smooth and easy to de-tide (makes them very useful for calibrating tsunami wave-height forecast models)

3. Will survive a destructive Tsunami.

DARTs vs. Coastal Stations

DARTs and Coastal Sea-Level stations are complimentary, not competing, Technologies.

GTS Sea-Level Data is structured in a rich variety of formats. There are approximately 12 or so basic formats, with a number of variations.

UHSLC format (Manzanillo, MX) Readable ASCII (XMT 5min)

SEPA40 KWAL 050000 (WMO HEADER Origin Mdhhmm)

^^3541502E (Platform ID#) 186000003 :PRS 0 #1 9140 9139 ……

9139 9068 8284 8446 (Readings in mm):RAD 1 #1 6494 6483 6483 …..

:BAT 4 #5 13.3 :NAME 3541502E 38+0NN 216W (GOESW Chan 216)

NOS "Tsunami Expert" Station (Nawiliwili, Hawaii USA)

SXXX03 KWAL 050000 Base 64 Encoding (XMT 6min)

^^336015FC 186000041"P16114001@|]~[@@v0KwW1@iI@WADWDM

@ij5DY<U`2@Rs@T@"@Rt kTWyJBQBeBcB^BqBo 41+0NN 148W

(one minute data)

SOMX10 KWAL 061135 **OTT Format (Zihuatanejo, Mexico)**

0102D23E 310113501 OTA@Ica{[D@@K@`@@J@`B@h@@J@`B@h

@@J@`B@h@@J@`A@pB@DcCCyp@Nl`CRxPGN|cCvx@CN`^CUxl

As you can see, GTS Sea-Level Data does not come gift wrapped and easy to use.

GTS Sea-Level Data is structured in a rich variety of formats. There are approximately 12 or so basic formats, with a number of variations.

SEHA10 KWAL 051738 **Port Au Prince**
49A00782 309173801 OT12 ID:HT-PTPR-01 DT:2014 11 05 17 36
:RD 1973 1971 1972 1970 1972 1967 1967 1965 1964 1956
:PR 2012 2006 1995 2010 2010 2003 1989 2003 1987 1979
:B 13.6V **Data in chronological order, first 5 samples redundant**

SWPA41 RJTD 051928 **Yap**
:PRS 1 #1 1854 1848 1844 1841 1837 1832 1827 1823 1819 1815 1811 1807
:RAD 1 #1 6666 6661 6657 6653 6649 6644 6639 6635 6631 6627 6622 6619
:ENC 1 #6 5106 5080 5056 5027 :SW1 28 #60 59 :SW2 58 #60 30 :BAT 5 #6
12.4 :NAME 065012F8 **Data in reverse chronological order, last 5 samples redundant**

Redundant data good to have!

For a TWC to use GTS Sea-Level Data, the TWC needs (at minimum):

1. **Access to GTS Data!**
   (Easier said than done in many cases)
2. **A Decoder to translate Sea-Level messages into sea-level data.**
3. **A MetaData Database (used by the decoder).**

Tide Tool

Was originally developed to give BMG (Jakarta) a nascent capability to decode GTS sea-level messages from Indian Ocean and nearby Pacific Ocean sea-level stations back in Nov. 2005.

Tide Tool has grown in sophistication and is now used as an operational sea-level processing system at PTWC and a number of other centers (Chile, Peru, Colombia etc.)

Tide Tool

Tide Tool continuously decodes sea-level messages in real-time and displays the time series using the open source, platform independent, graphical scripting language Tcl/Tk.

Tide Tool consists of three main parts:

1. Data retriever called get_data that acquires data from NOAA and the IOC webservice.
2. Decoder which reads log files of GTS sea-level messages and a sea-level station metadata base.
3. Dynamic map based clients that allow the user to select a single station or a group of stations to display and analyze.

Tide Tool Requirements

In order to decode GTS messages, run the dynamic map clients and display the time series, the following are required*:

- Computer running Tcl/Tk software with BLT extension.
- GTS Sea level messages that are continuously archived into a log file.
- Tide.tcl , get_data.tcl, client Tcl/Tk scripts.
  (contains decoder and creates marigram displays)
- Sea-level Station metadata.
- A link to GTS data via the country's Met Service if possible.

Tide Tool

COMP_META metadata database*

PTWC actively maintains a database (COMP_META) of all sea-level stations that transmit sea-level messages via the GTS. Tide Tool reads a *dump* of this database to understand how sea-level messages are structured for the various sea-level stations.

manz Manzanillo_MX 3541502E SEPA40 prs 1 10 M 3 -1 1.0000
005 0000 19.0558 -104.3176 1 UHSLC 163 PARSE_GLOSS
manz Manzanillo_MX 3541502E SEPA40 rad 1 10 M 3 -1 1.0000
005 0000 19.0558 -104.3176 1 UHSLC 163 PARSE_GLOSS

The COMP_META database has ~1650 entries

get_data.tcl Script

The get_data.tcl script retrieves sea-level data from the IOC using the IOC webservice and sea-level data in the form of GTS messages via ftp from a NOAA website.

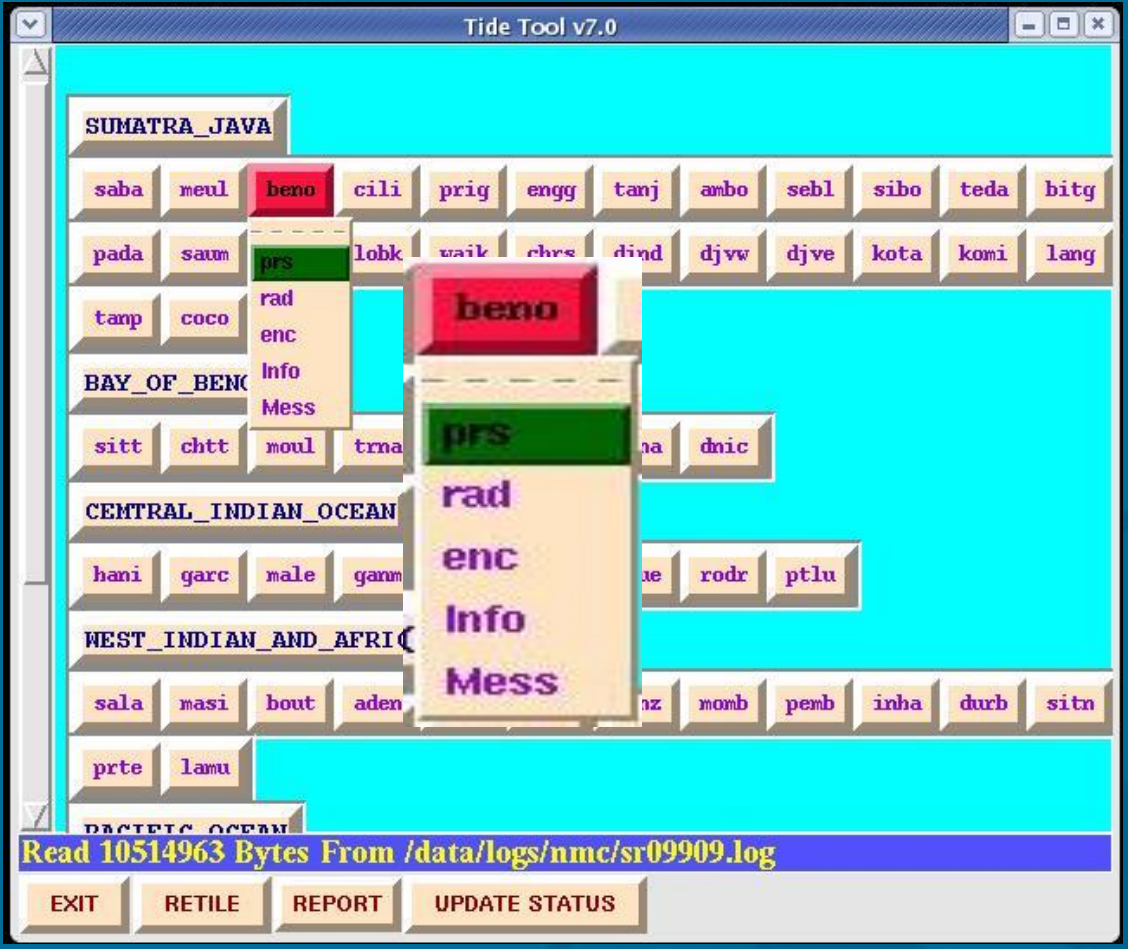
C:\Tcl\bin\wize.exe

```
Start downloading data.
Time 1414527374 seconds
:-rw-rw-r--    1 gfs      mtrim       307344 Oct 28 20:15 sn.0475.txt: :START:
exec C:/Tcl/bin/wget -rq --tries=5  ftp://tgftp.nws.noaa.gov/SL.us008001/DF.an/DC.sfmar/DS.tideg/sn.0475.txt -O tmpfile2 -U anonymous
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=acya&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=alge&timestart=2014-10-28 20:
▲1234AABE  10/28/2014 20:12:00 rad 3 0.674 0.672 0.671:
New Beg_time  2014-10-28 20:14:01
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=busa&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=CA02&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=CT03&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=chenn&timestart=2014-10-28 20
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=clst&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=coch&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=fer1&timestart=2014-10-28 20:
▲1234AABC  10/28/2014 20:12:00 rad 3 2.934 2.924 2.912:
New Beg_time  2014-10-28 20:14:01
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=frtr&timestart=2014-10-28 20:
New Beg_time  2014-10-28 20:11:14
wget  -q --tries=5 --output-document=web_dump  "http://www.ioc-sealevelmonitoring.org/service.php?query=data&format=ascii&code=GE25&timestart=2014-10-28 20:
```

get_data will start the data retrieval process every 200s. Once started it will run continuously, and will not be affected by network outages..

Tide Tool Decoder
(Tide.tcl script)

- Reads and decodes GTS sea-level messages from the logfile.
- Constructs the main GUI which responds to mouse clicks.
- Sends and services Instructions to and from clients respectively.
- Supports multiple clients via sockets.
- Creates transmission report and determines status of stations.
- Scrollable.

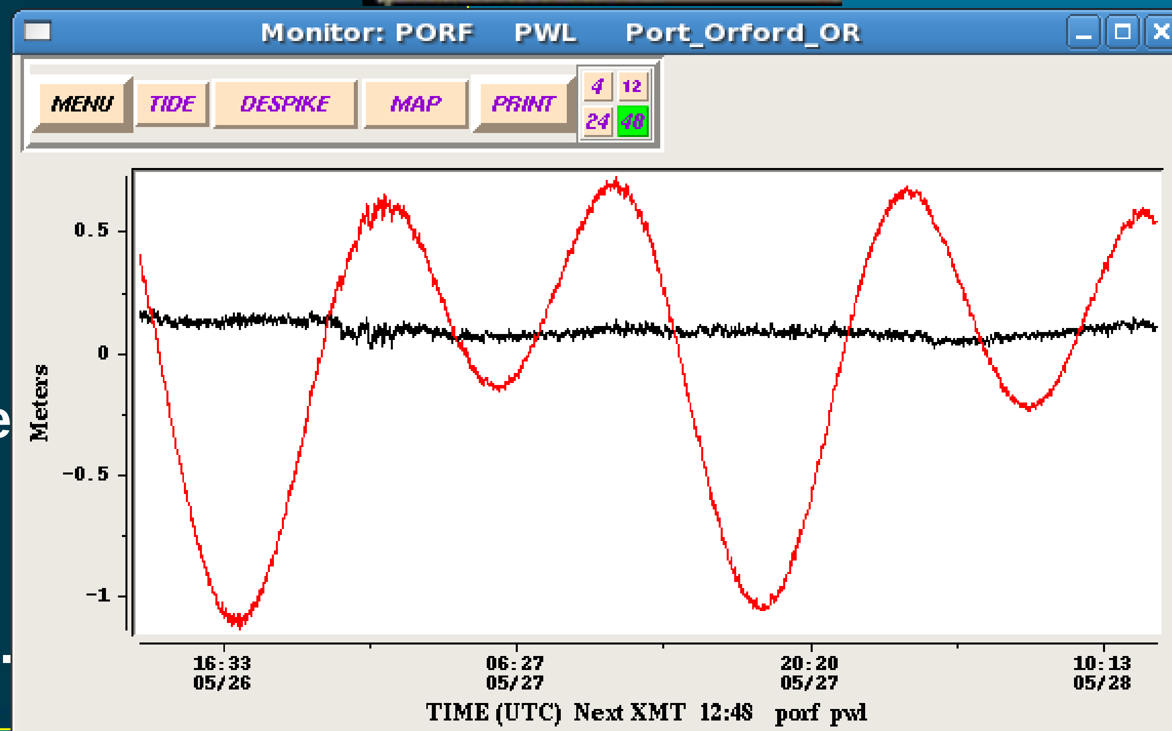


Tide Tool Monitor Widget

- Can display up to three different time series:

Red – Actual time series
Black – De-tided time series
Blue – Predicted time series

- Two de-tiding options: permanent or on-the-fly coefficients.
- Automatically Updates
- Despike option based on three point median.
- Station location map option showing reverse travel-time contours.
- Rubber banding zoom option to expand time series.



Tide Tool Zoom Widget

- Used to measure tsunami wave arrival time, amplitude, and period with mouse clicks and record measurements in a file. Can zoom recursively.

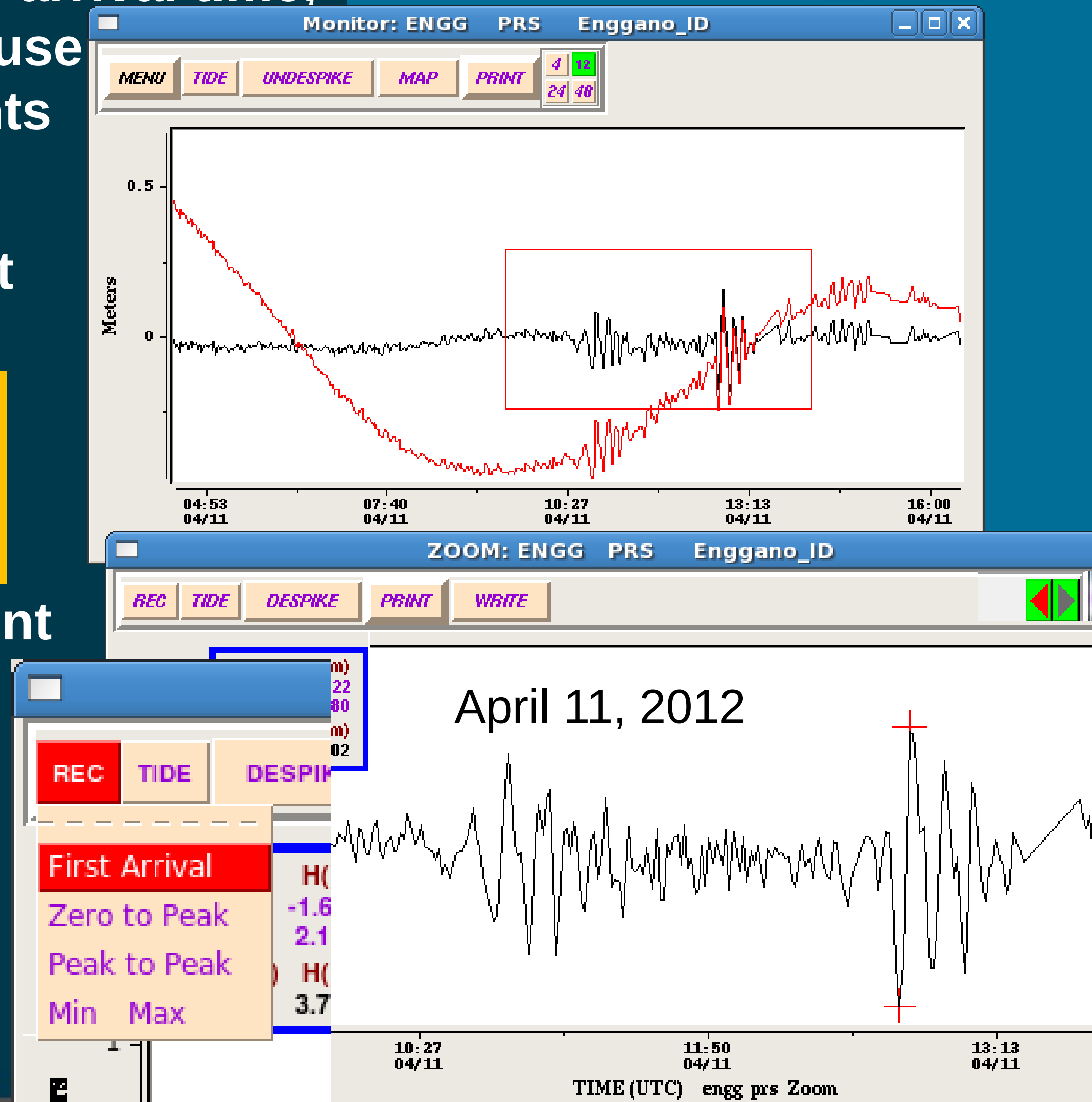
- Can display up to three different time series:

Red – Actual time series
Black – De-tided time series
Blue – Predicted time series

- Two de-tiding options: permanent or on-the-fly coefficients.

- De-spike option based on three point median.

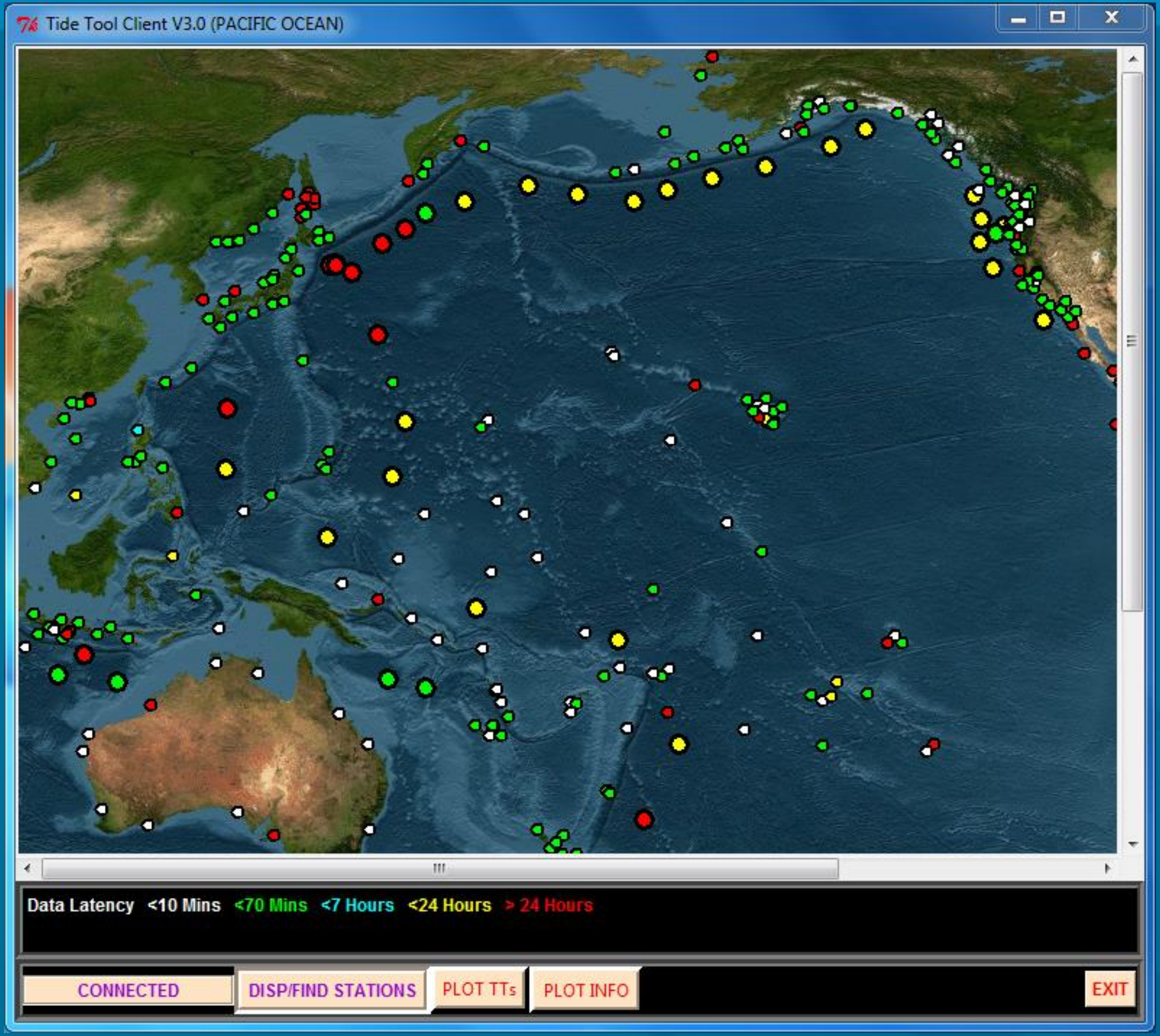
- Zoom History




Tide Tool Clients
Tide Tool Client V3.0 (PACIFIC OCEAN)
Pacific Client
Data Latency <10 Mins <70 Mins <7 Hours <24 Hours > 24 Hours
CONNECTED
DISP/FIND STATIONS
PLOT TTs
PLOT INFO
EXIT
Tide Tool Client V3.0 (CARIBBEAN)
Caribbean Client
Data Latency <10 Mins <70 Mins <7 Hours <24 Hours > 24 Hours
CONNECTED
DISP/FIND STATIONS
PLOT TTs
PLOT INFO
EXIT
Tide Tool Client V3.0 (INDIAN OCEAN)
Indian Client
Data Latency <10 Mins <70 Mins <7 Hours <24 Hours > 24 Hours
CONNECTED
DISP/FIND STATIONS
PLOT TTs
PLOT INFO
EXIT
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Pacific Client

- Send instructions to Decoder to display time series or other information.
- Responds to mouse operations to display a single station or zoom in on a region and display multiple stations.
- Scrollable.
- Indicates station status (color).



New: Client has other layers for display of sea-level observations

Tide Tool Clients

- You can choose to hide DARTs/BPRs or hide coastal Stations.

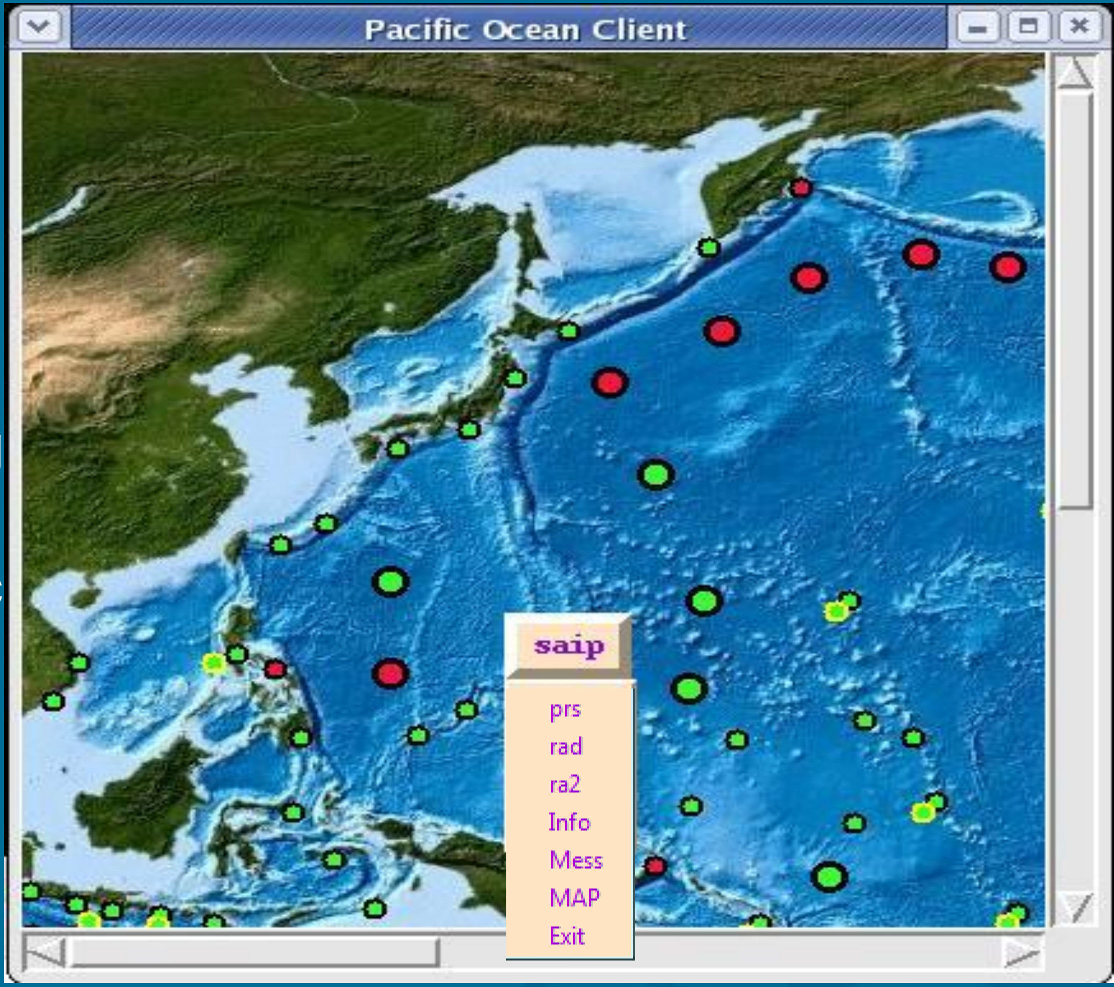
- Locates stations by code or NDBC number (DARTS).

Tide Tool Clients

• Double click on a station Creates a button with a drop-down menu.

• Menu has selections to display time series for each sensor and widgets showing station info, recent GTS messages, and a geographic map of the nearby area with tsunami travel-times.

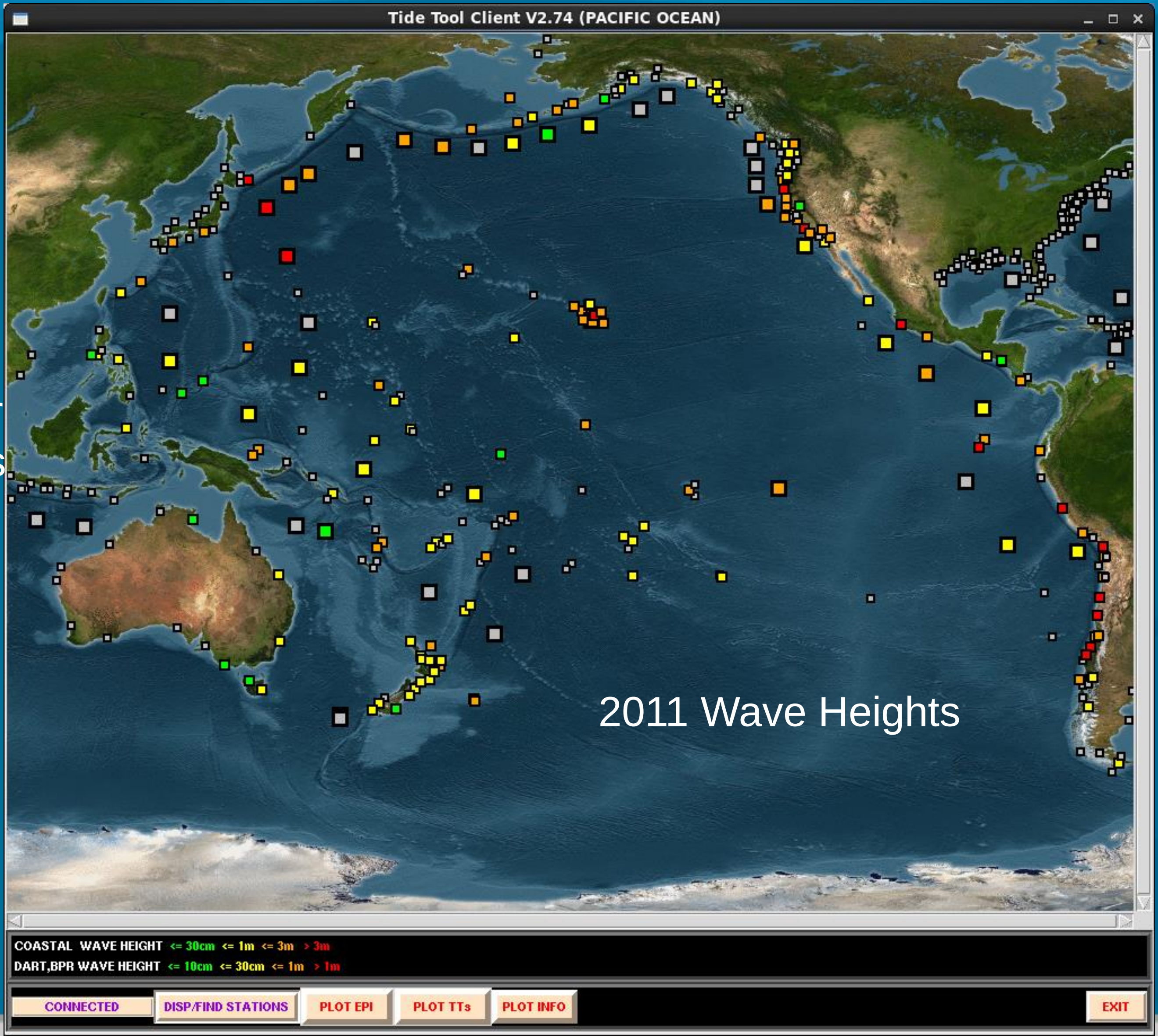
(Settlement Pt., Bahamas in this example.)



Tide Tool Clients

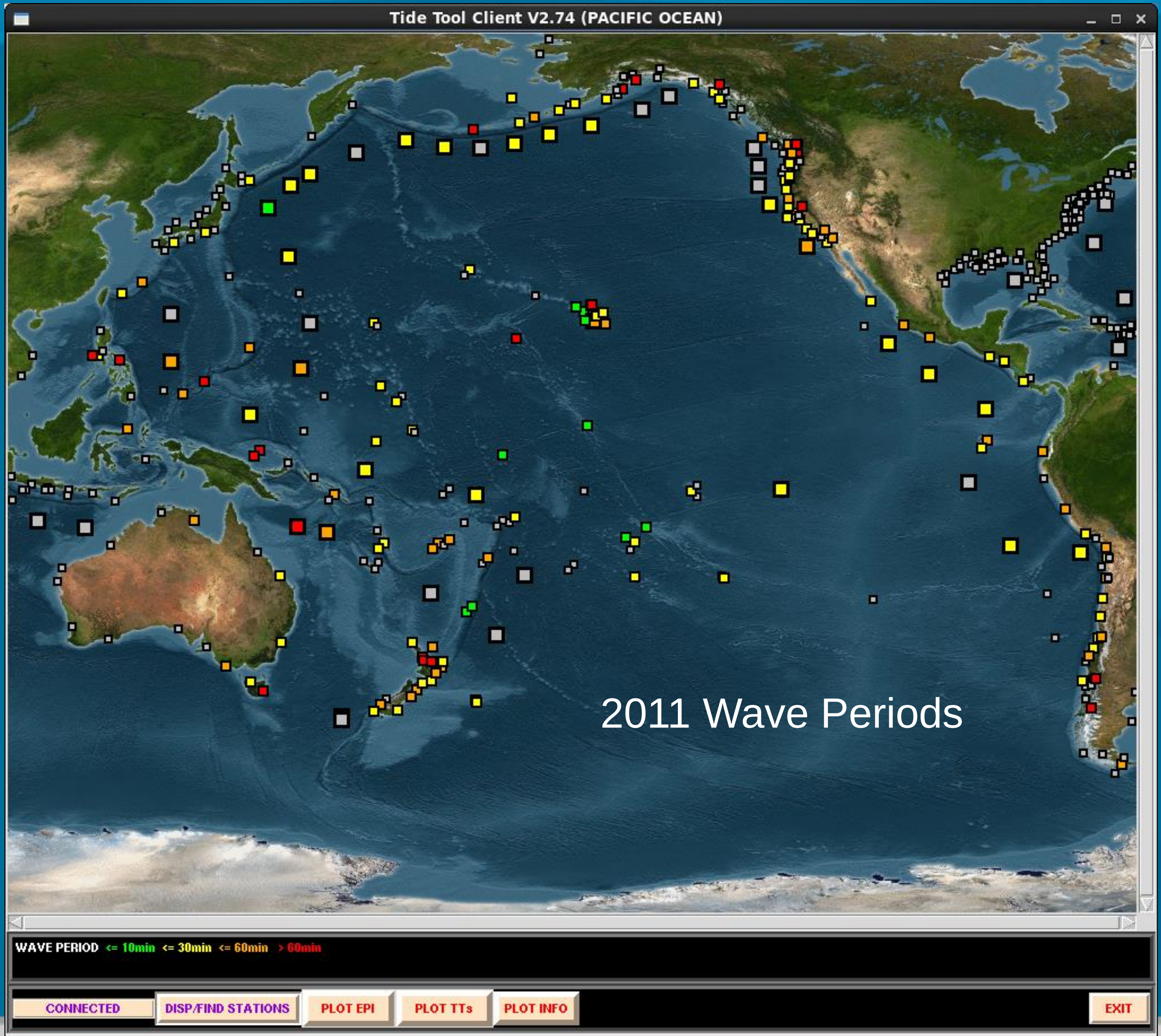
Tide Tool clients now have layers for showing Observations

Wave Height/Amp uses different color scales for BPRs & coastal stations



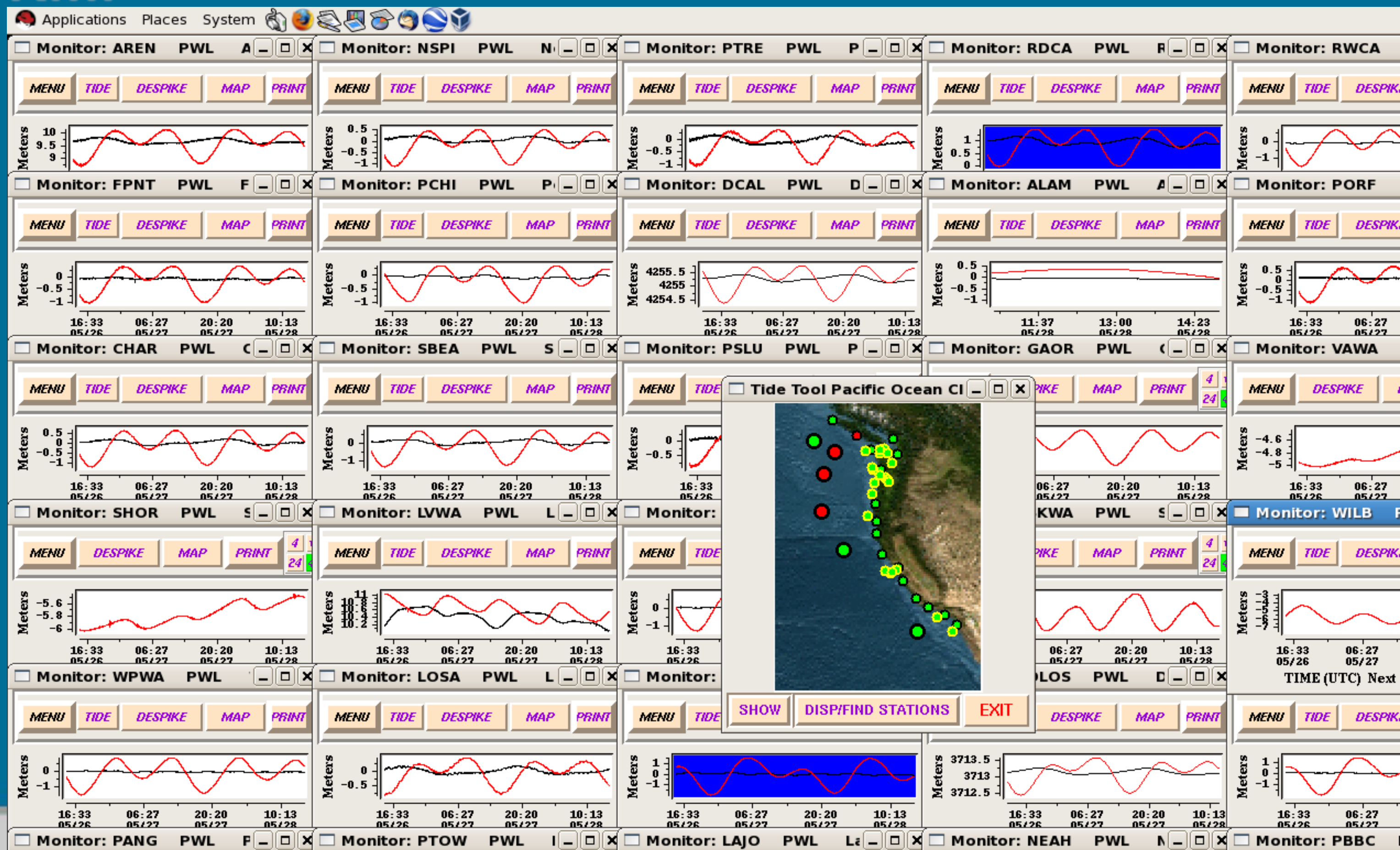
Tide Tool Clients

Tide Tool clients now have layers for showing Observations



Tide Tool Clients

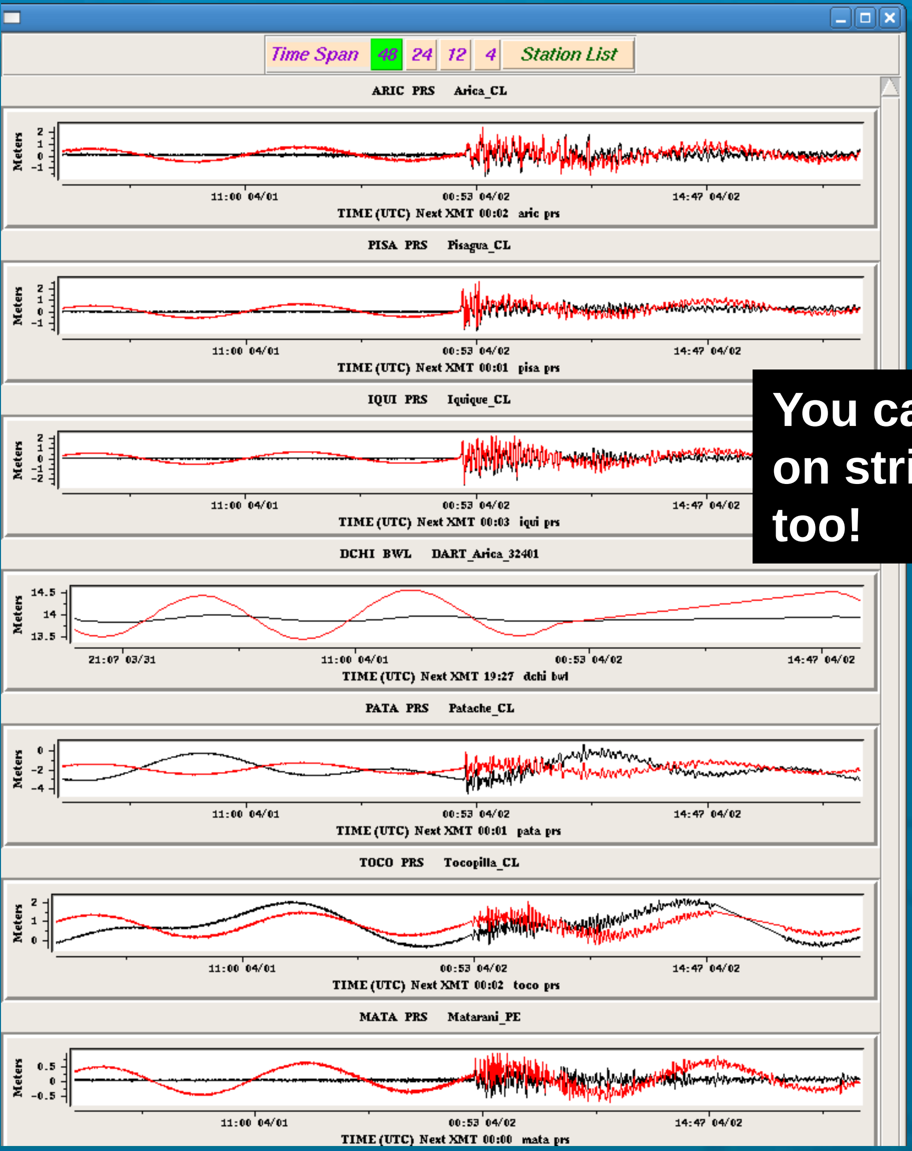
- Draw a rectangle (rubber banding) to zoom in on a region and tile the screen OR….



Tide Tool Clients

…. make a
"Strip Chart Widget"

ancu	Ancud_CL
bmsa	Bahia_Mansa_CL
buca	Bucalemu_CL
cons	Constitucion_CL
coqu	Coquimbo_CL
corr	Corral_CL
crnl	Coronel_CL
cstr	Castro_CL
juan	Juan_Fernandez
lebu	Lebu_CL
pcha	Puerto_Chacabuco_CL
pich	Pichidangui_CL
pmel	Puerto_Melinka_CL
pmon	Puerto_Montt_CL
qtro	Quintero_CL
quel	Queule_CL
quir	Quiriquina_CL
sano	San_Antonio_CL
talc	Talcahuano_CL
valp	Valparaiso_CL

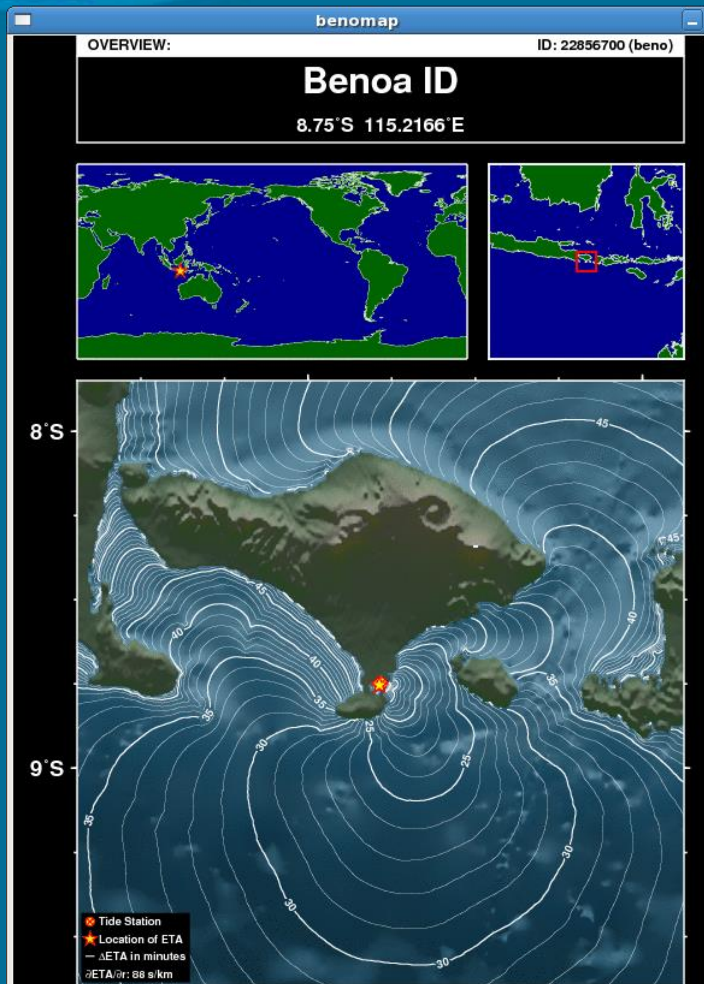


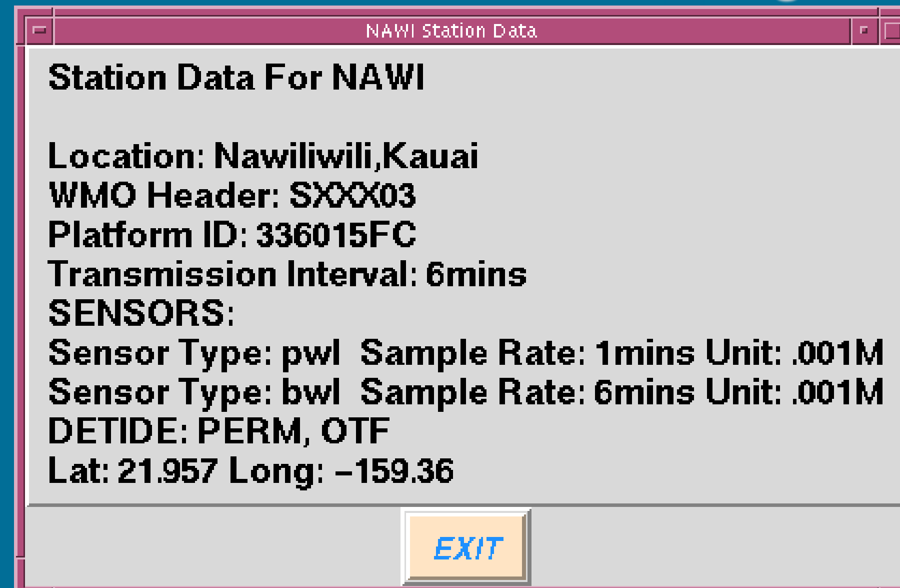
You can zoom on stripchart widget too!

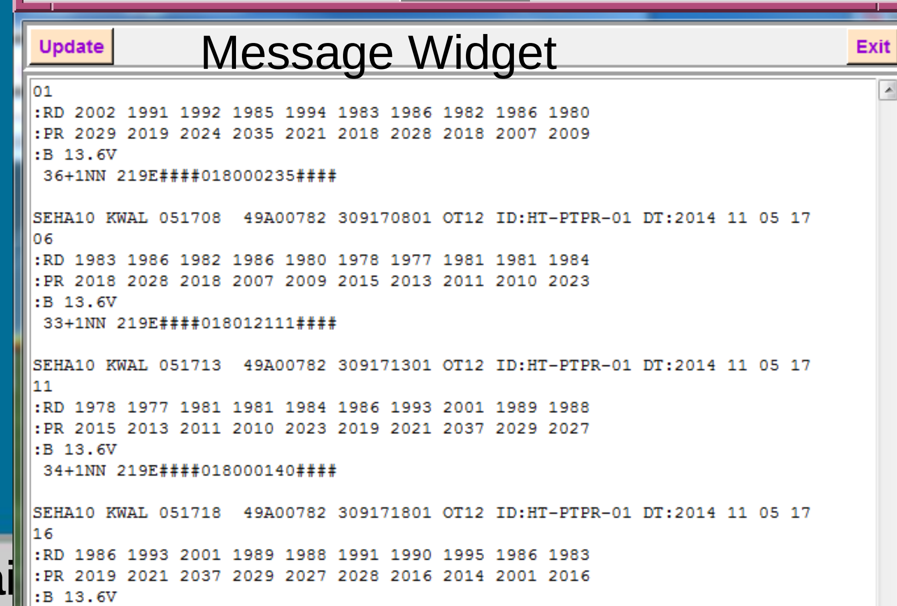
Other Features

Station Information Widget

Station MAP







Other Features

Tide Tool will decode historical GTS logfiles provided the correct Metadata is available.

Tide Tool will write files containing decoded data in a simple two column format:

102.48542 0001.300
102.48611 0001.324
102.48681 0001.333
102.48750 0001.290

Tide Tool records wave measurements:

engg prs Peak to Peak 102/12 12:45 H -0.222 102/12 12:48 H 00.180 Per 00:03 Amp 00.402 2012149 15:13

Tide Tool De-Tiding

For the purpose of accurate tsunami measurement it is important to remove the tide signal. Tsunamis have long enough periods that variations in sea-level can significantly affect the measurement of Tsunamis from marigrams. On the marigram, the tsunami will "ride the tide" affecting the precision of measurement.

Tide Tool uses two methods for de-tiding. One method is based on *permanent* coefficients* (long term prediction) determined (Foreman's method) from long time series (years). The other method, "on-the-fly" (short term prediction), uses non-static coefficients determined using recent (previous few days) data (Wang, 2009).

*PTWC maintains a set of permanent coefficients and these are available for distribution with Tide Tool

Tide Tool De-Tiding

Long Term Prediction (Permanent Coefficients)*

- Interactive (matlab) harmonic analysis of tide records of one year or longer (raw 3-6 min. or processed hourly data).
- Built-in de-spiking algorithm and quality control, and visual inspection.
- 67 of the Foreman's astronomical constituents are used in the analysis.

Short Term or On-The-Fly Prediction

- Using latest data (as short 2-3 hours and up to 5 days of data).
- Same method as above except fewer constituents are used: Depending on the length of records, 1 to 10 constituents (with increasing periods) can be used.
- Limited de-spiking but without interactive quality control
- Detiding one station takes about one sec of cpu or less.

*PTWC maintains a set of permanent coefficients and these are available for distribution with Tide Tool

Tide Tool De-Tiding

Long Term Prediction

Harmonic analysis: Least-square fit of 67 of Foreman's astronomical constituents to tide record of one year or longer (hourly means, or 3-6min data). If sampling interval is < 3min, it is resampled at 3-min or 4-6-min. In cases where quality of raw data is really poor, hourly mean data (NOS and UHSLC) are used.

Time series are despiked and smoothed if they appear noisy under visual inspection. After this formal harmonic analysis can be applied:

Least-square fit: minimization of L:

$$L = \Sigma_k \{ (\Sigma_i (A_i * \cos(\omega_i * T_k) + B_i * \sin(\omega_i * T_k)) - tide\_obs(T_k))^2 \}$$

where, T_k=time(k), A_i and B_i are harmonic coefficients, ω_i are frequencies of constituents.

Tide Tool De-Tiding

Short Term Prediction

1. Use the latest data (up to 5 days). If there are multiple sensors at a given station, the sensor with the most data is used for de-tiding (unless that data is of poor quality, in which case another sensor is used.

2. De-spiking based on the distribution of data

3. Harmonic analysis of de-spiked data: depending on the length of data, one or more constituents with periods typically less or comparable to the length of data are used.

4. Number of harmonics considered depends on length of time series. The number of harmonics that gives the best fit in a least-squares sense is used.

Tide Tool De-Tiding

Both de-tiding methods have strengths and weaknesses:

Short Term Prediction

Strengths: Does not require long time series and can therefore be used for new stations.

Will eliminate non-gravitational effects.

Weakness: Will not work well if data contains gaps or other defects.

Coefficients need to be computed every few hours.

Tide Tool De-Tiding

Both de-tiding methods have strengths and weaknesses:

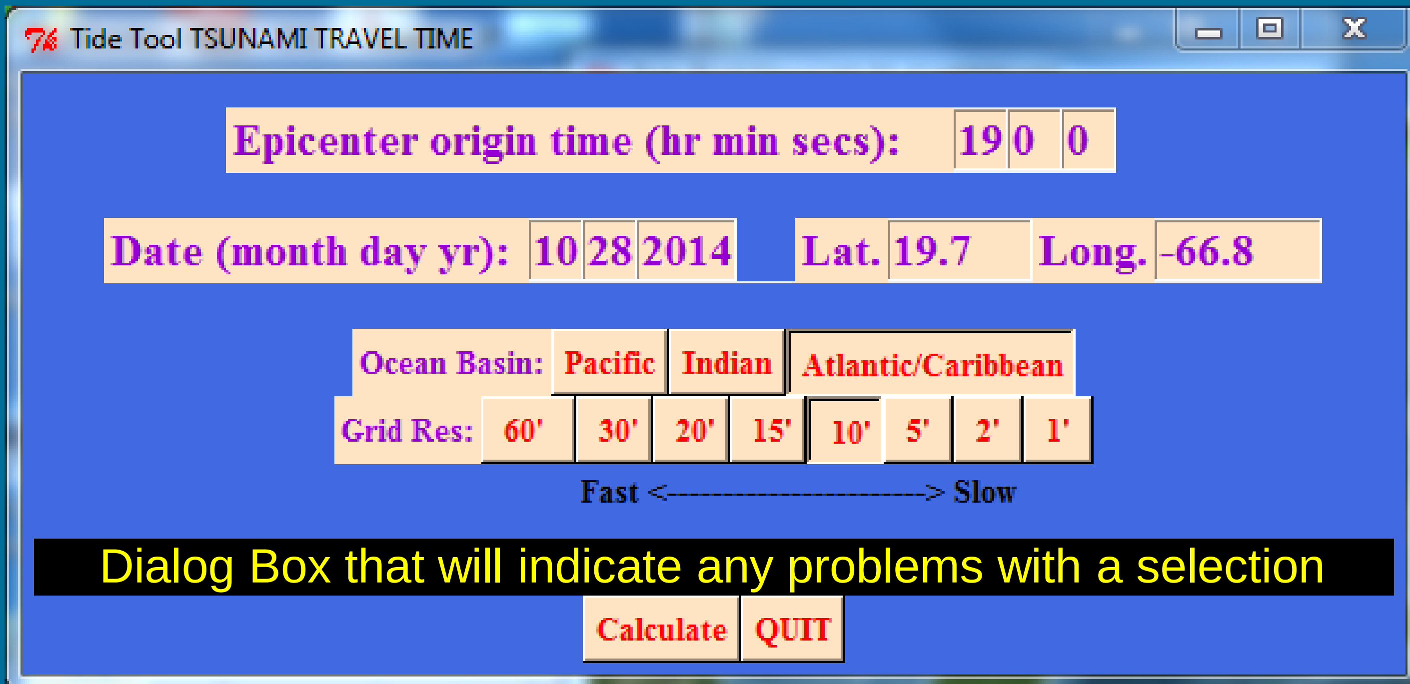
Long Term Prediction

Strengths: De-tiding not affected by spikes or other defects in the data.

Weaknesses: Susceptible to non-gravitational effects.

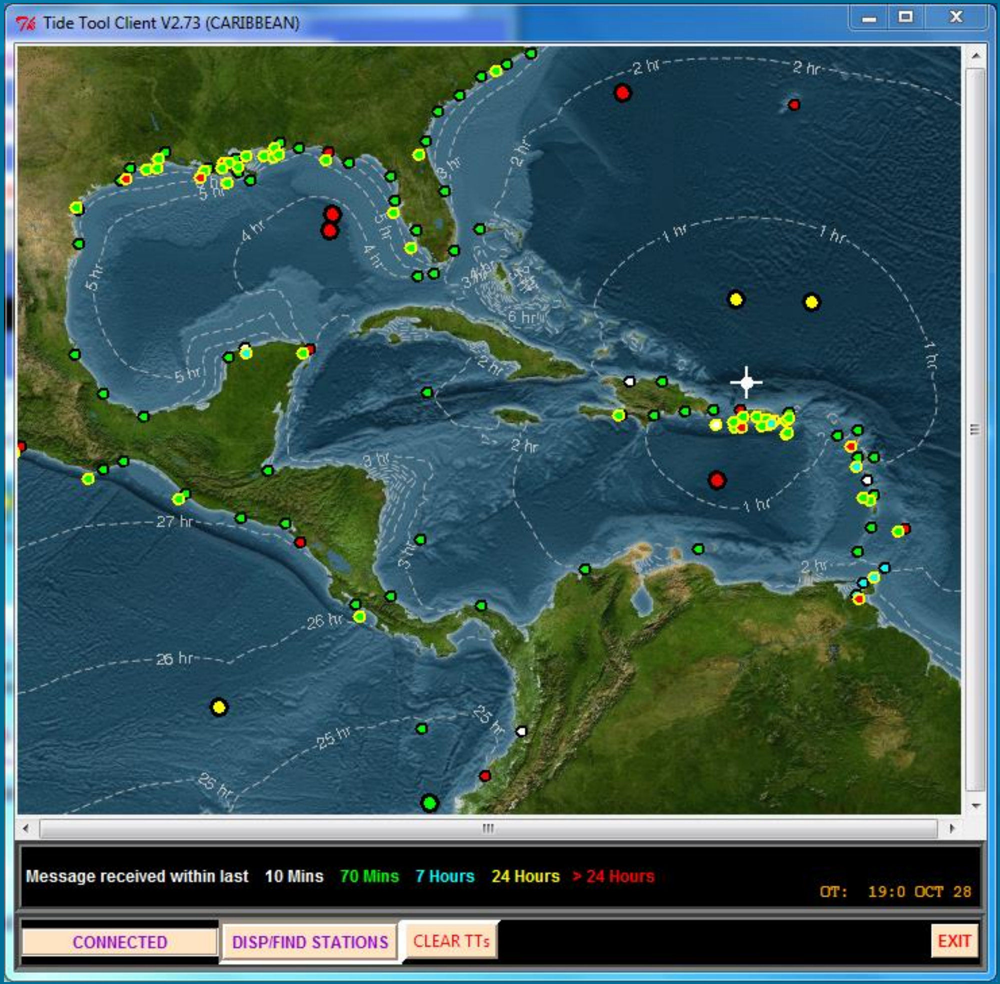
Requires one or more years worth of data to compute coefficients that give correct phase well into the future.
=> Can't be used for new stations

Tide Tool and Tsunami Travel Times



Simple to use GUI that can be invoked by hitting the TTT button on the Main GUI. A WINx cmdtool is created and the ttt_client program is executed. When it is done…

Tide Tool and Tsunami Travel Times

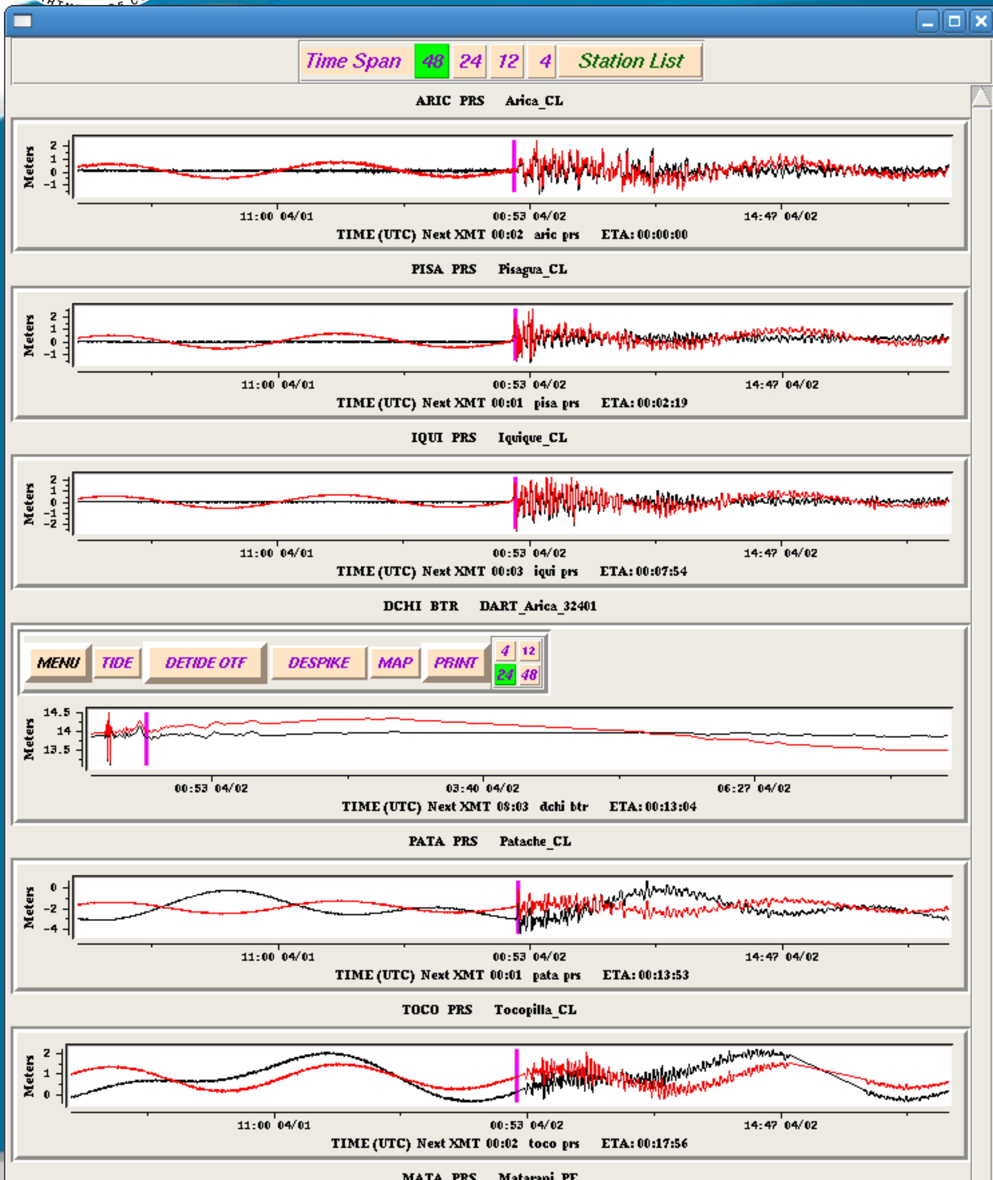


Click the "TTT" button on the base of the Client and the travel-time contours are superimposed. Moving the mouse over the Client will reveal the ETA.

Tide Tool and Tsunami Travel Times

Note that the zoom widgets are larger when travel time contours are displayed. On the Client zoom widgets, the contour interval is 15 minutes. Moving the mouse over the Client zoom widget will reveal the ETA and coordinates under the cursor.

Tide Tool and Tsunami Travel Times



Click the "Get ETAs" button on the main GUI which loads the ETAs into Tide Tool's data structures.

Select the "Strip" option under the "SHOW" button and create the stripchart. Stations are arranged in ETA order.

The magenta line indicates the expected arrival time.

The marigrams in the stripcharts have exactly the same time scale and every 60s the time scale updates.

12 hour time scale

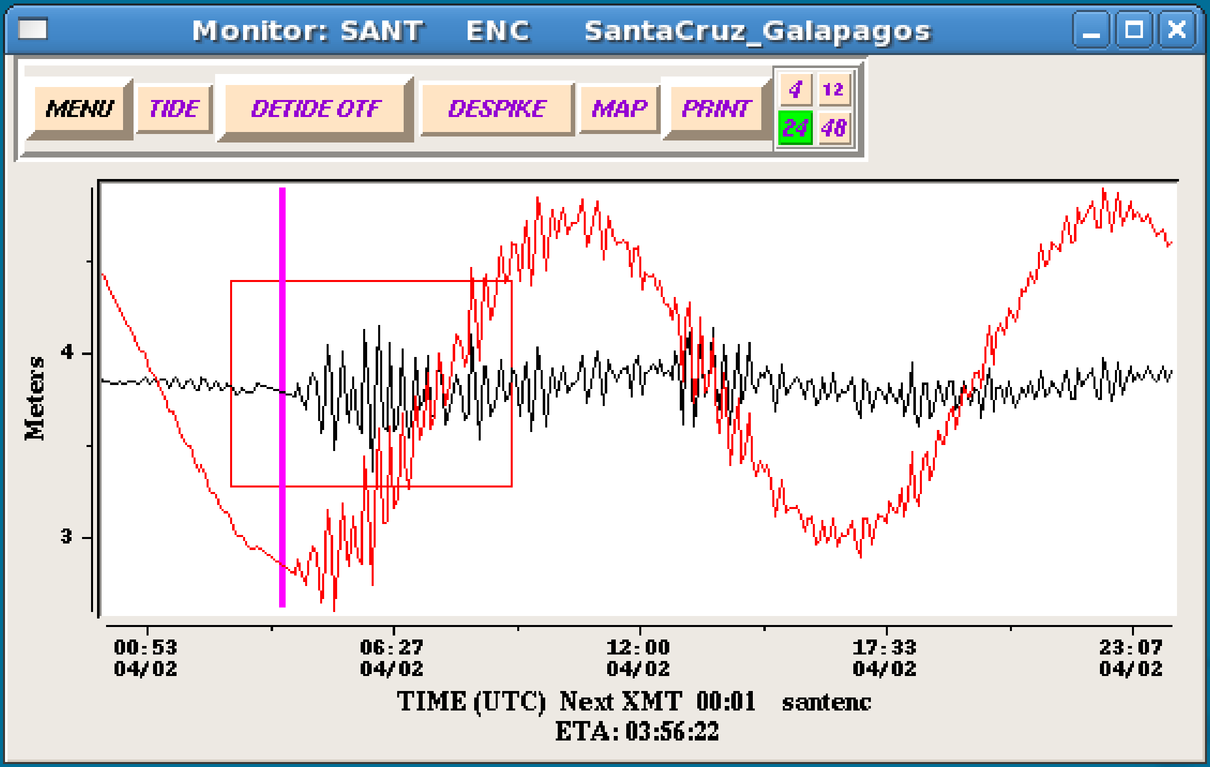
Future Directions

1. “On The Fly” Tide Modeling distributed with Tide Tool

2. FFT

3. Tsunami Detection

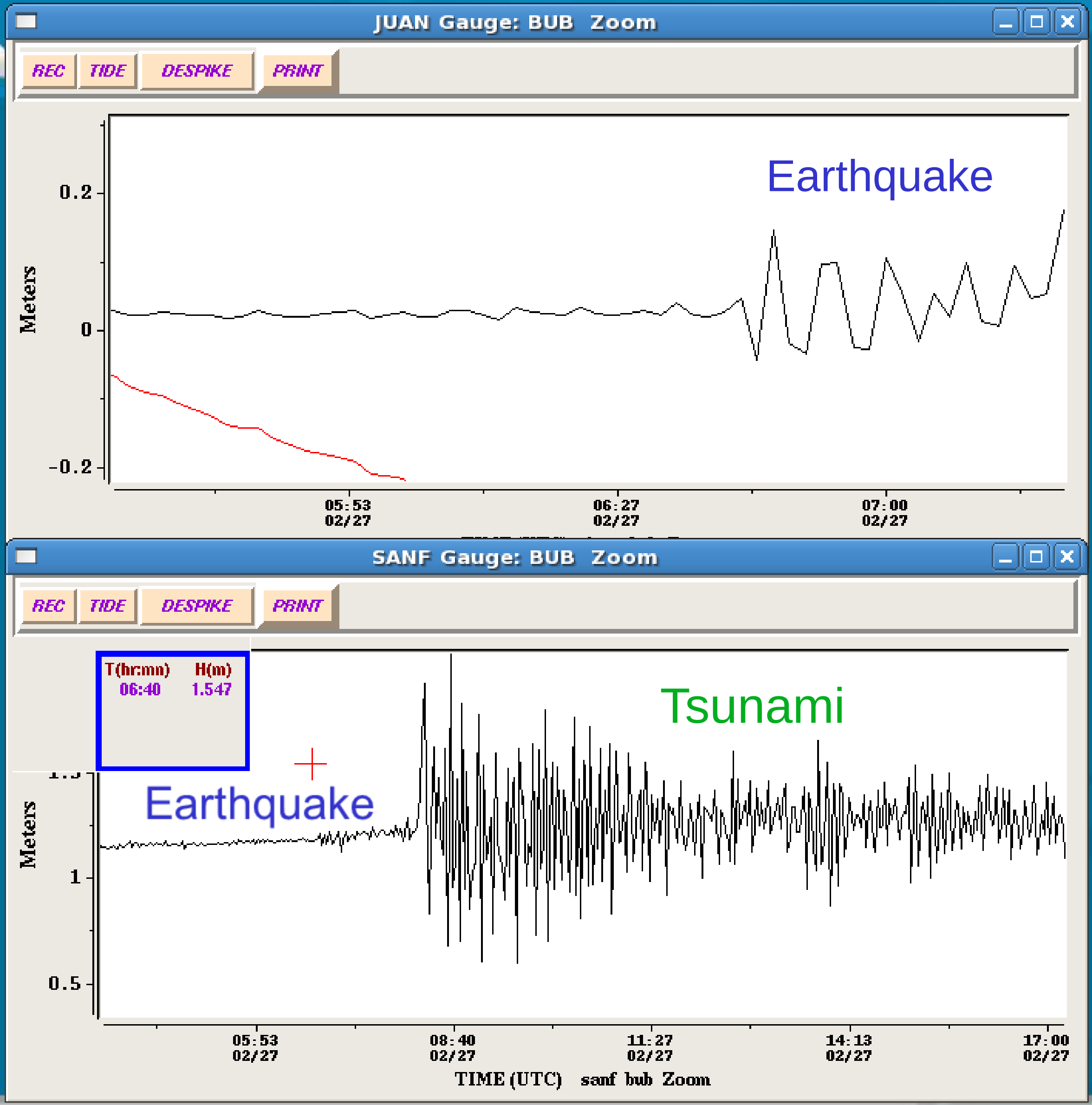
Tide Tool and Tsunami Travel Times



ETA also indicated on the monitor widgets….

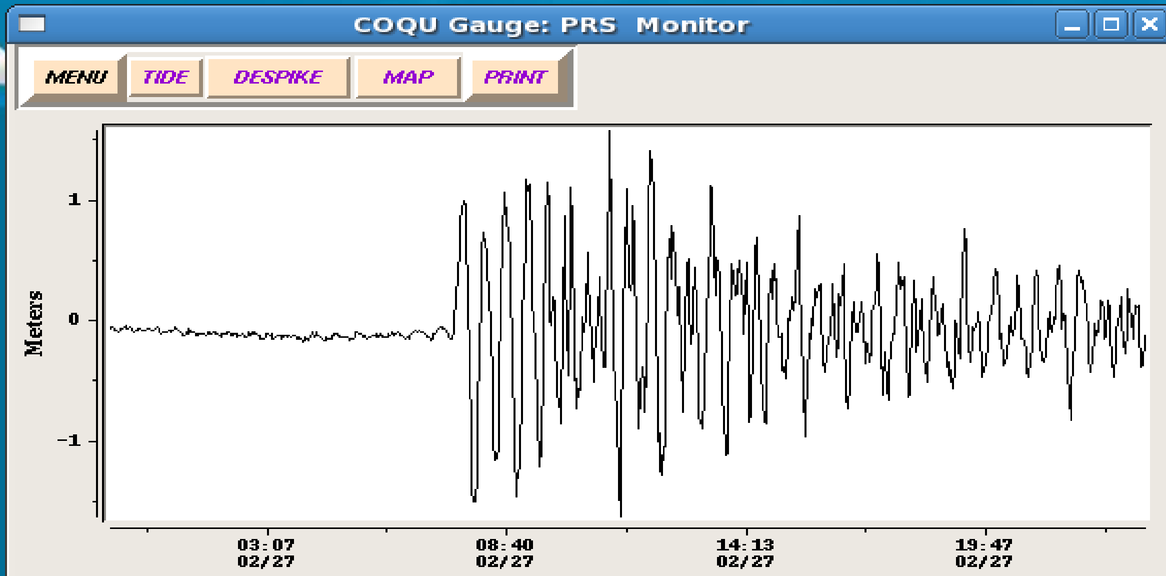
Chile 2010 Tsunami Marigrams

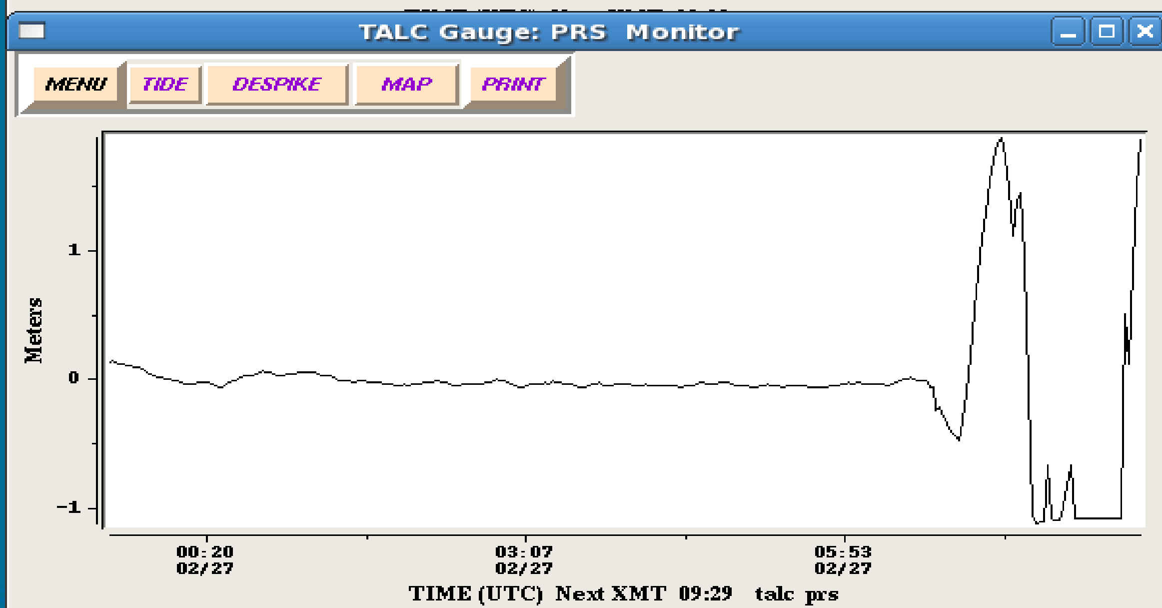
OT 6:34 UTC, Feb 27 2010 Mw = 8.8



Chile 2010 Tsunami Marigrams

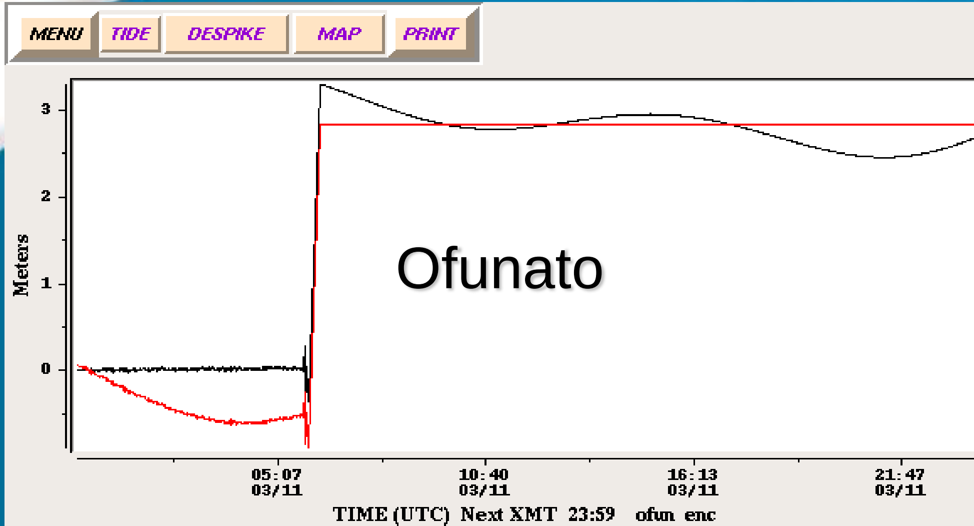
OT 6:34 UTC, Feb 27 2010

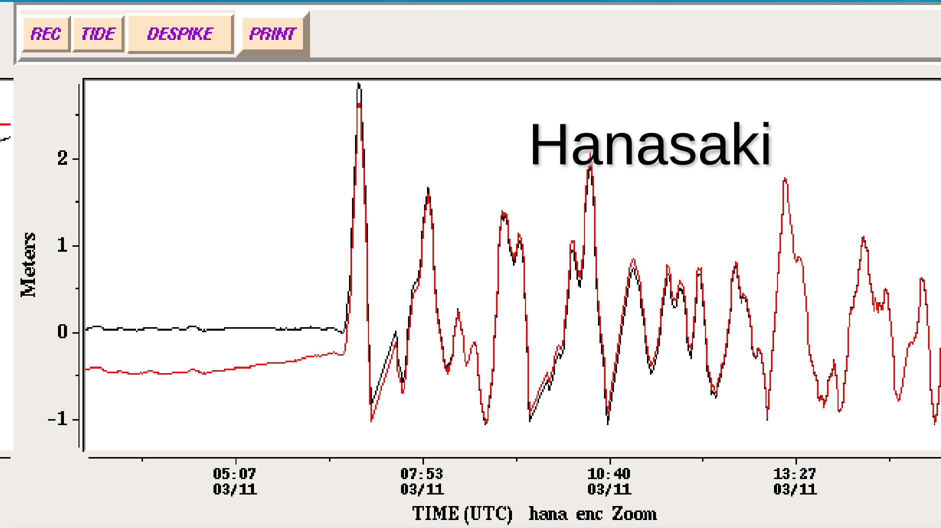


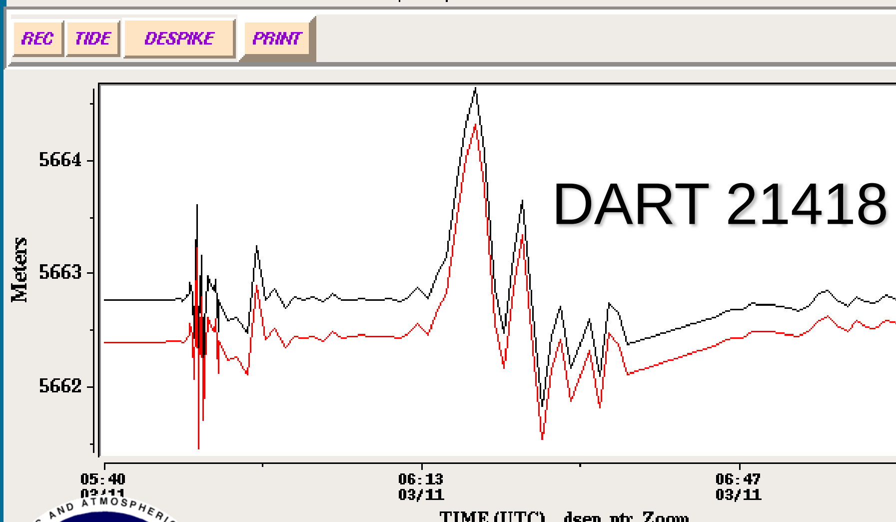


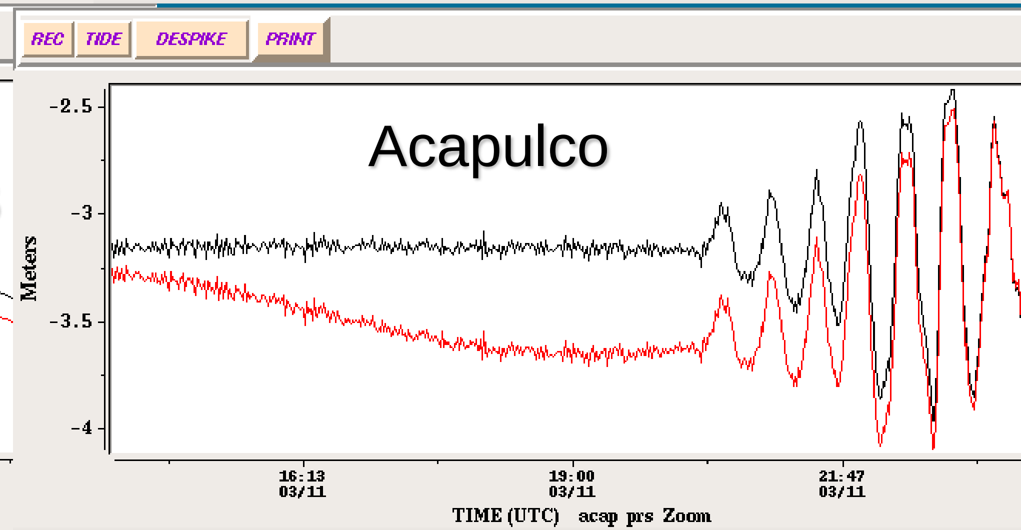
Tohoku Tsunami Marigrams

OT 5:46 UTC, Mar 11 2011 Mw = 9.1



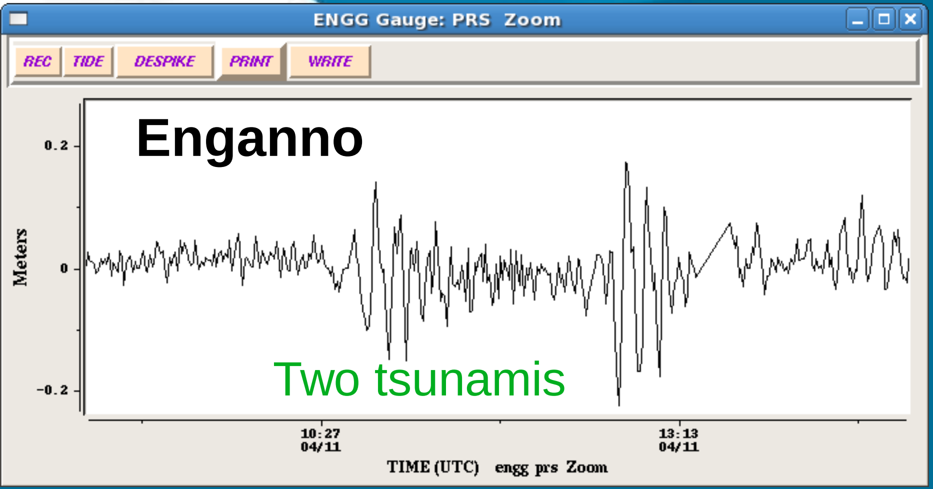


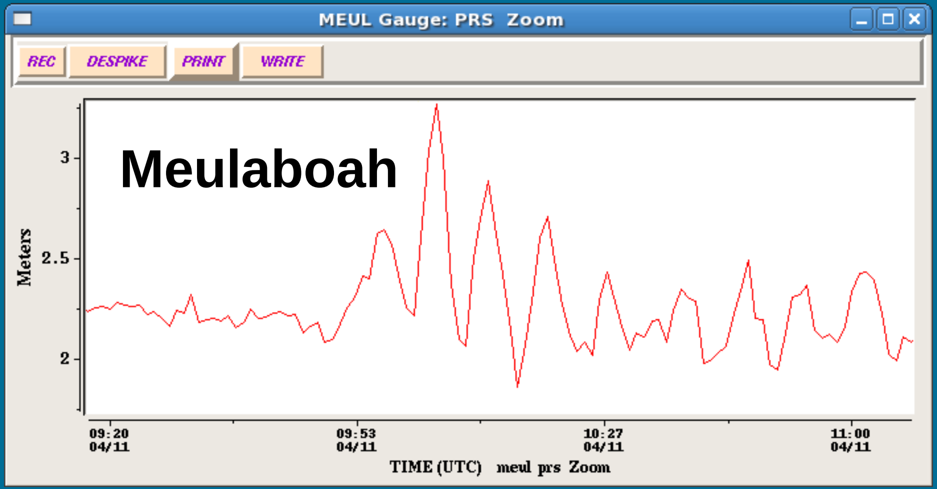


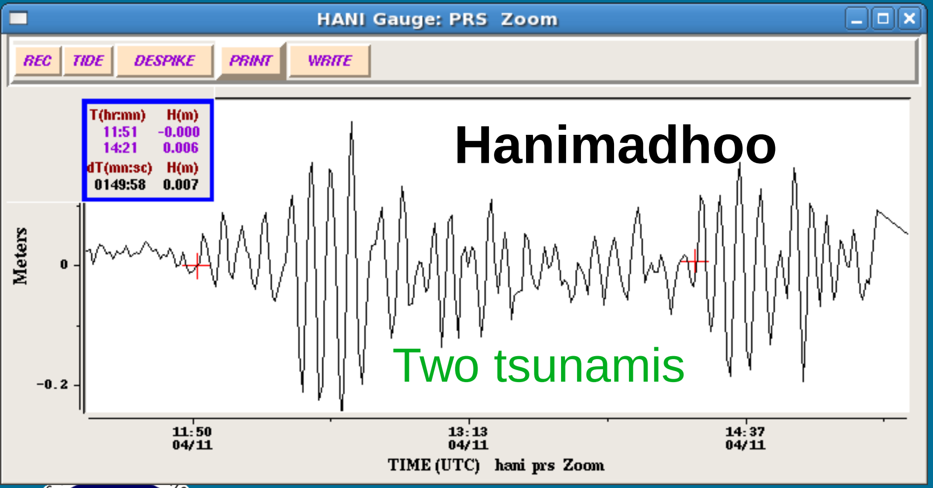


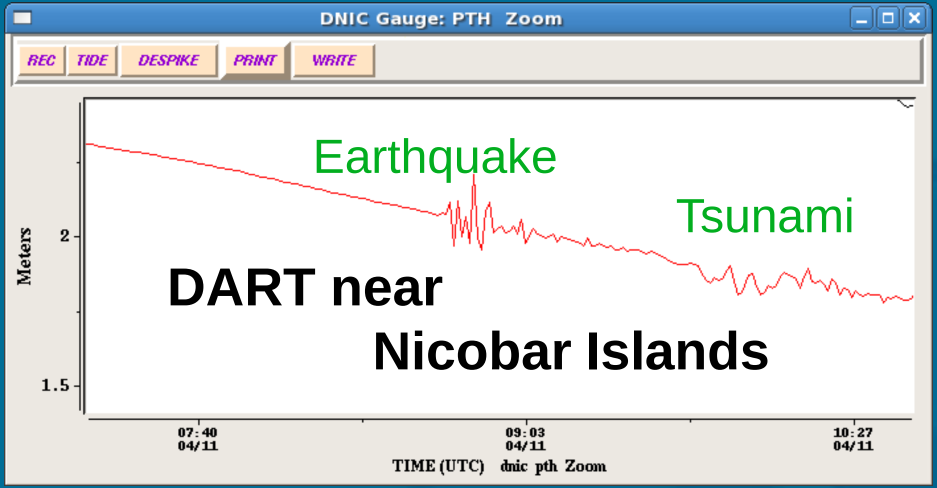
Sumatra 2012 Tsunami Marigrams

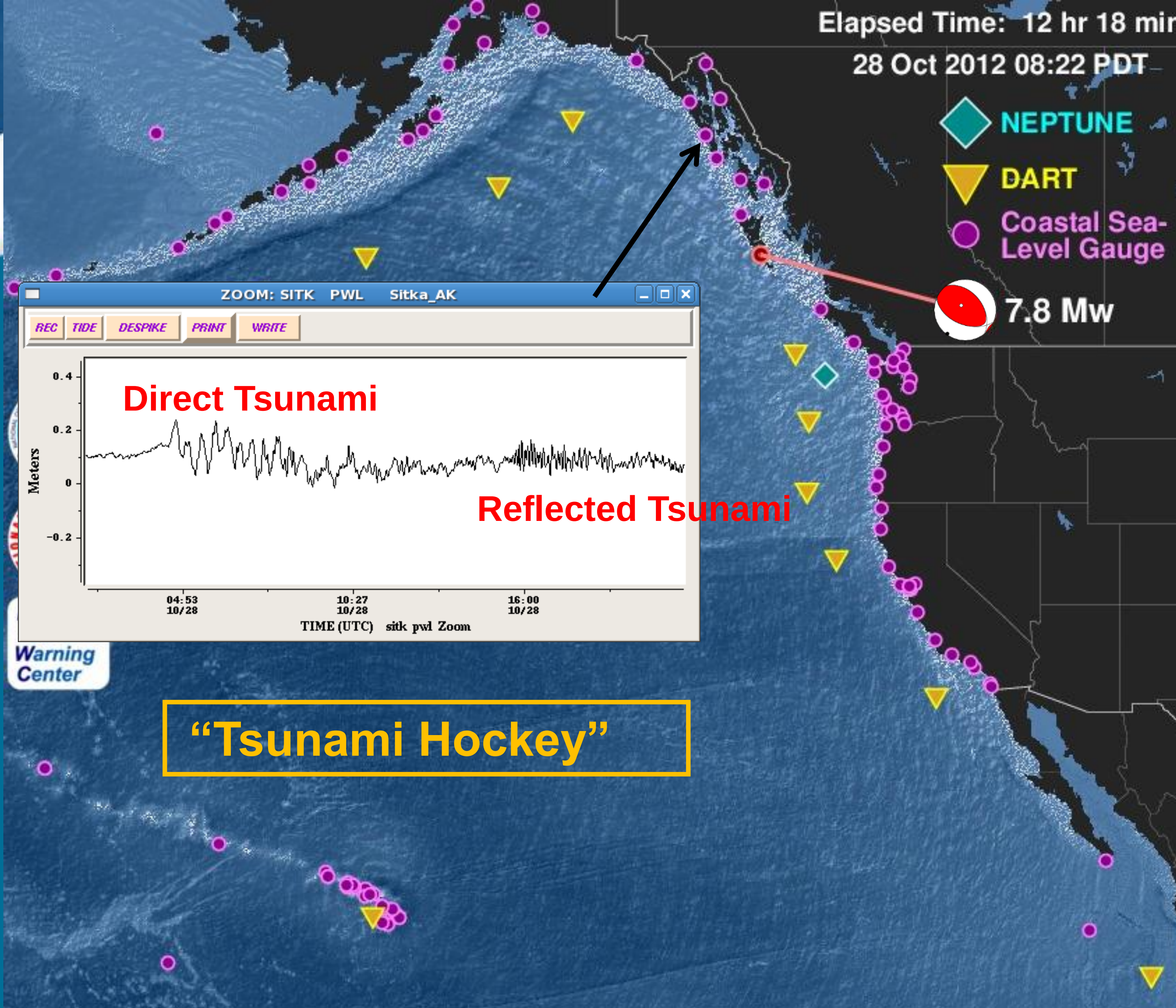
OT 8:39 UTC, Apr 11 2012 Mw = 8.6 (Aftershock 8.2)









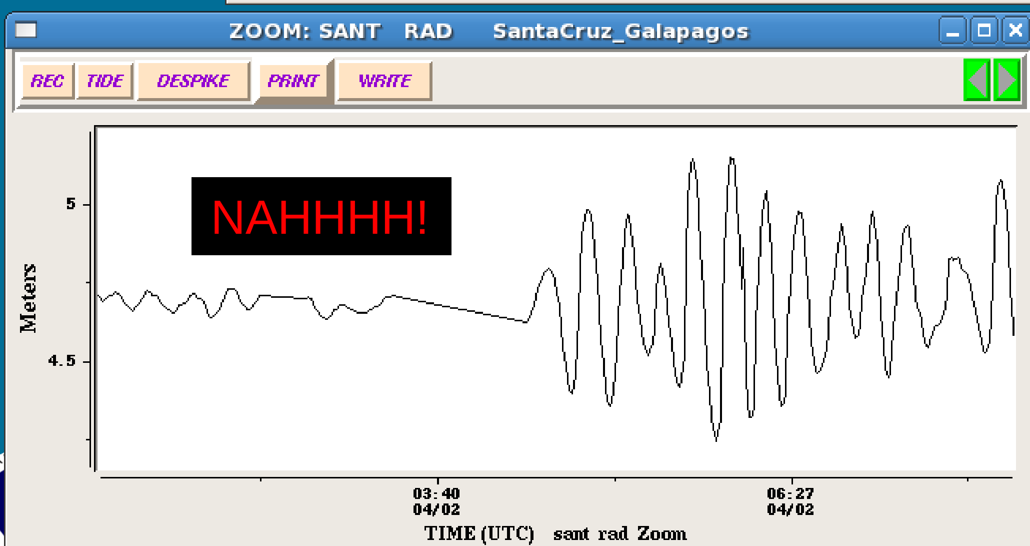


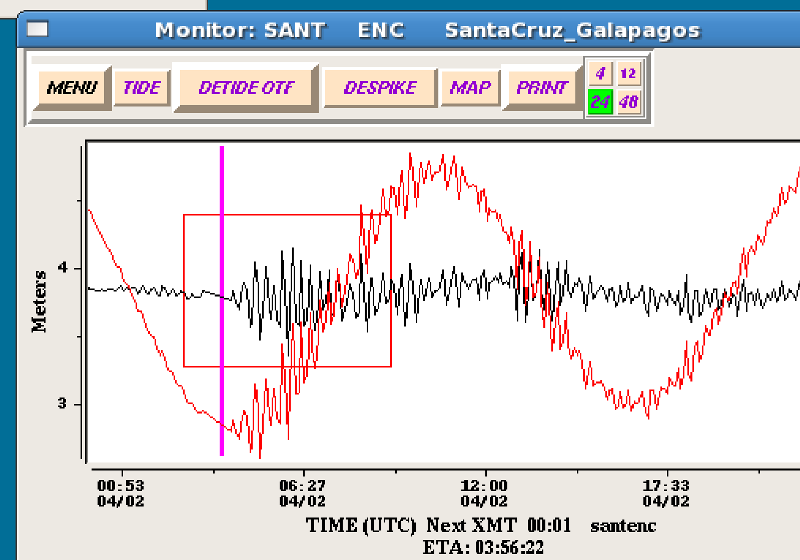
738 MIN

Reflection from Hawaii Recorded at Sitka AK.

Chile 2014Tsunami Marigrams

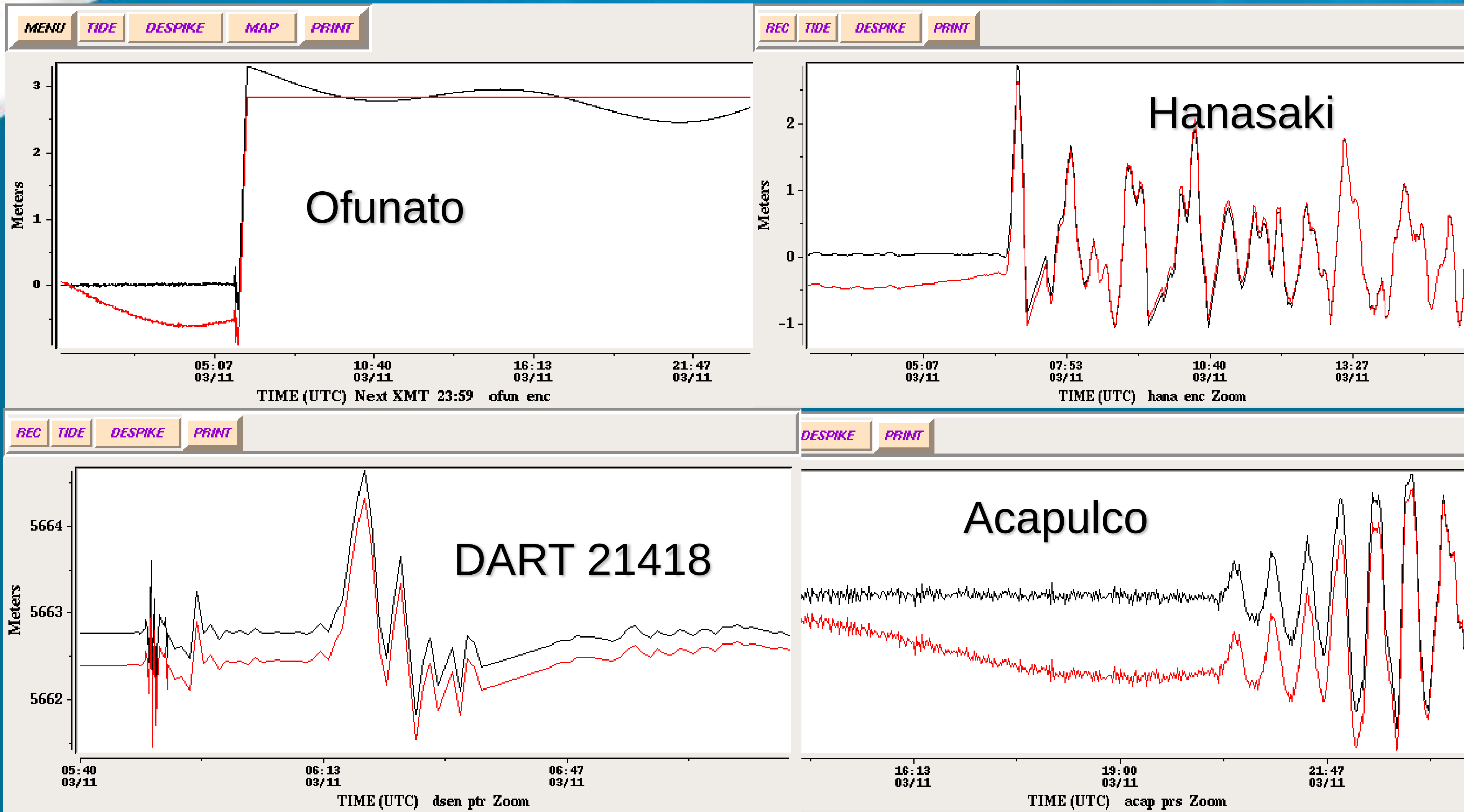
OT 23:47 UTC, Apr 1 2014 Mw = 8.1





Tohoku Tsunami Marigrams

OT 5:46 UTC, Mar 11 2011 Mw = 9.1



Updates (FTP site)

Updates will be posted to the UHSLC anonymous FTP server:

ftp.soest.hawaii.edu

Login with anonymous FTP
cd ptwc

Or via the web:
ftp://ftp.soest.hawaii.edu/ptwc

Gracias!