Regional Training Workshop on Pacific Tsunami Warning Center
Enhanced Tsunami Products for ICG/CARIBE EWS
Oct. 31 – Nov. 2, 2017
Cartagena, Colombia

TWC Operations –
Wave Amplitude Forecasting

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PTWC Forecast Models

- **RIFT (Real-time Inundation Forecasting for Tsunamis), linear shallow water**
  - Numerics: staggered differencing in space and leap-frog in time, mass conserving.
  - Coastal forecast is based on Green's Law
  - Simplest of models.
- **SIFT (Short-term Inundation Forecasting for Tsunamis), developed at PMEL**
  - Numerics: MOST (Method Of Splitting Tsunamis), Nonlinear shallow-water equations
  - 1700 pre-computed 1700 thrust and outer-rise unit sources covering major world subduction zones
  - Real-time component: Standby Inundation Models (SIMs) (about 75 with 55 in Pacific, only for U.S.

2. Description of the PTWC RIFT Model

- **RIFT: "Real-time Inundation Forecasting for Tsunamis".**
  It is a propagation model.
  Currently, no inundation component
- **Run in real-time using real-time EQ parameters to drive Okada computation for seafloor deformation**
- **Physics: Linear shallow water equations**
- **Numerics: Arakawa C-grid in space and leap-frog in time.**
- **Bathymetry: GEBCO 30-arc-sec. grid,**
- **Typically 4-arc-min resolution for basin-wide forecast or for a large EQ (mag > 7.8).**
- **Up to 30-arc-sec for smaller EQs for regional domains.**

Why is there a need for real-time forecasting?

- Pre-computed database does not cover all possible earthquakes (locations, focal mechanisms). Many recent earthquakes not been thrust faults, as assumed.
- Smaller earthquakes not well represented by current database models used at PTWC (usually unit sources are too large for smaller EQs)
- Labor / Resource intensive to create and maintain large database, especially global (current database models at PTWC only for specific basins).
- If model physics are changed (e.g., improved or modified), the entire database needs to be recomputed.

Non-thrust Earthquakes causing tsunamis

Many large earthquakes (including ones that caused destructive tsunamis) are not of shallow thrusts. Here is a list of large non-thrust earthquakes since 2006:

- Kuril 2007, M8.1, normal
- Samoa 2009, M8.0, normal
- Sumatra 2012, M8.6, Strike-slip
- Philippines 2012, M7.6, Normal
- Okhotsk 2013, M8.3, Normal
- Scotia Sea 2013, M7.7, Strike-slip
- Aleutians 2014, M7.9 Normal/Strike-slip

Default focal mechanisms:

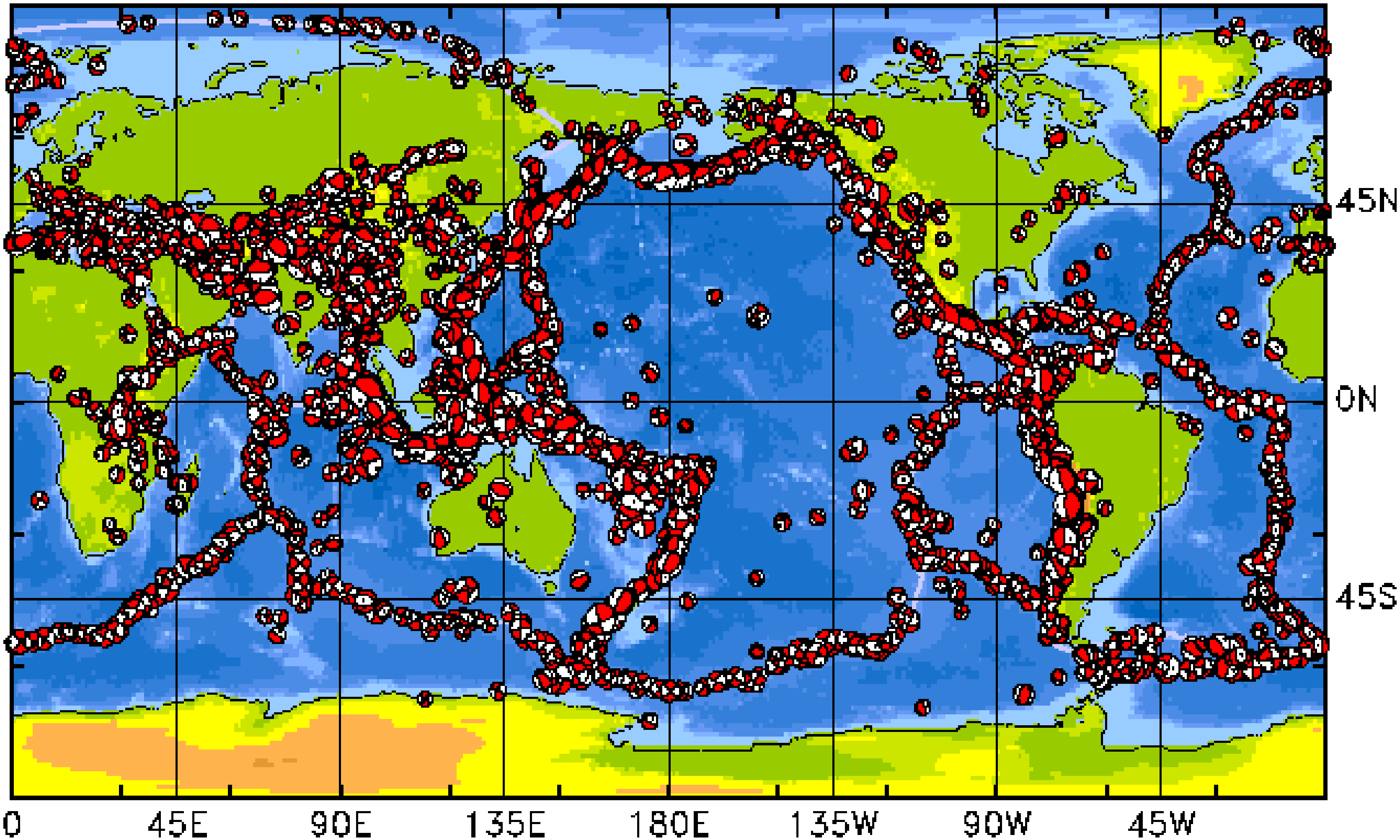
- Historical centroid moment tensors (~40,000 CMT solutions since 1976).
- Default focal mechanism based on EQ epicenter proximity to the type of fault line (USGS)
- Real-time focal mechanisms:
  - W-phase Centroid Moment Tensors
  - Global Centroid Moment Tensors (when available)
  - Other Centroid Moment Tensor solutions (when available
- Seafloor deformation:
  Okada (1985) static dislocation model

Focal mechanisms:

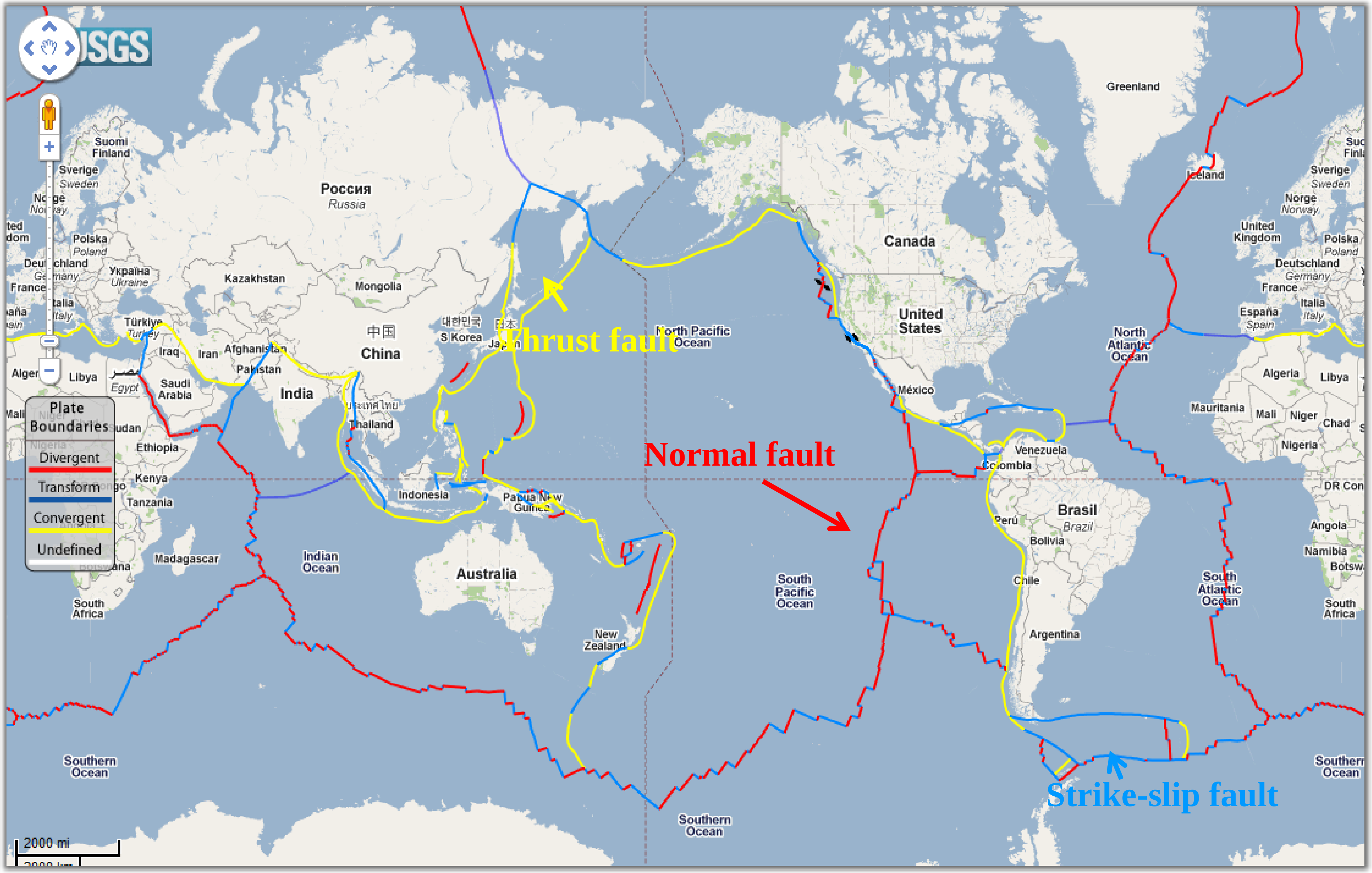
Global (formerly Harvard) CMT catalog

Map as of Dec. 2008

Credit: http://www.globalcmt.org/



Default focal mechanisms based on earthquake's proximity to the type of plate boundaries (credit: USGS)



Green’s Law Coastal Forecast (Green, 1837)

$$A_c = A_o \left(\frac{H_o}{H_c} \right)^{\frac{1}{4}}$$

- **Ho: water depth of an offshore point**
  Hc: water depth of a coastal point (assumed to be at 1 m).
  Ao: offshore wave amplitude = 0.5*(max-min) or half of the waveheight
  Ac: Green’s law coastal wave amplitude

- **Offshore point: closest model grid point in deep water. The offshore water depth is chosen such that the waves with 10-min. period can be resolved by the model grid (eight grid points within one wavelength).**

- **For example,**
  - At 4-arc-min. resolution, Ho = 1000 m
  - At 30-arc-sec resolution, Ho = 16 m

- **If an offshore point is not found within a 300 km radius from a coastal point, there will be no forecast at that point. This essentially excludes wide continental shelves at 4-arc-min. resolution. Higher resolution is needed to have a Green’s law forecast in those regions.**

Underlying Assumptions of Green's Law

- **The coastline is linear and exposed to the open ocean. Therefore, it is assumed that tsunami waves near the coast behave like one-dimensional plane waves.**

- **There is no significant wave reflection and there is no turbulence dissipation. In the real world, dissipation is important in shallow water. The seafloor composition has an influence on tsunami runup (e.g., coral reefs tends to dampen the tsunami runup).**

- **The bathymetry is assumed to be slowly varying compared to the wavelength of the tsunamis. Thus, for locations with steep bathymetry (such as small islands and atolls), the Green's Law forecast tends to overestimate the wave amplitudes, everything else being equal.**

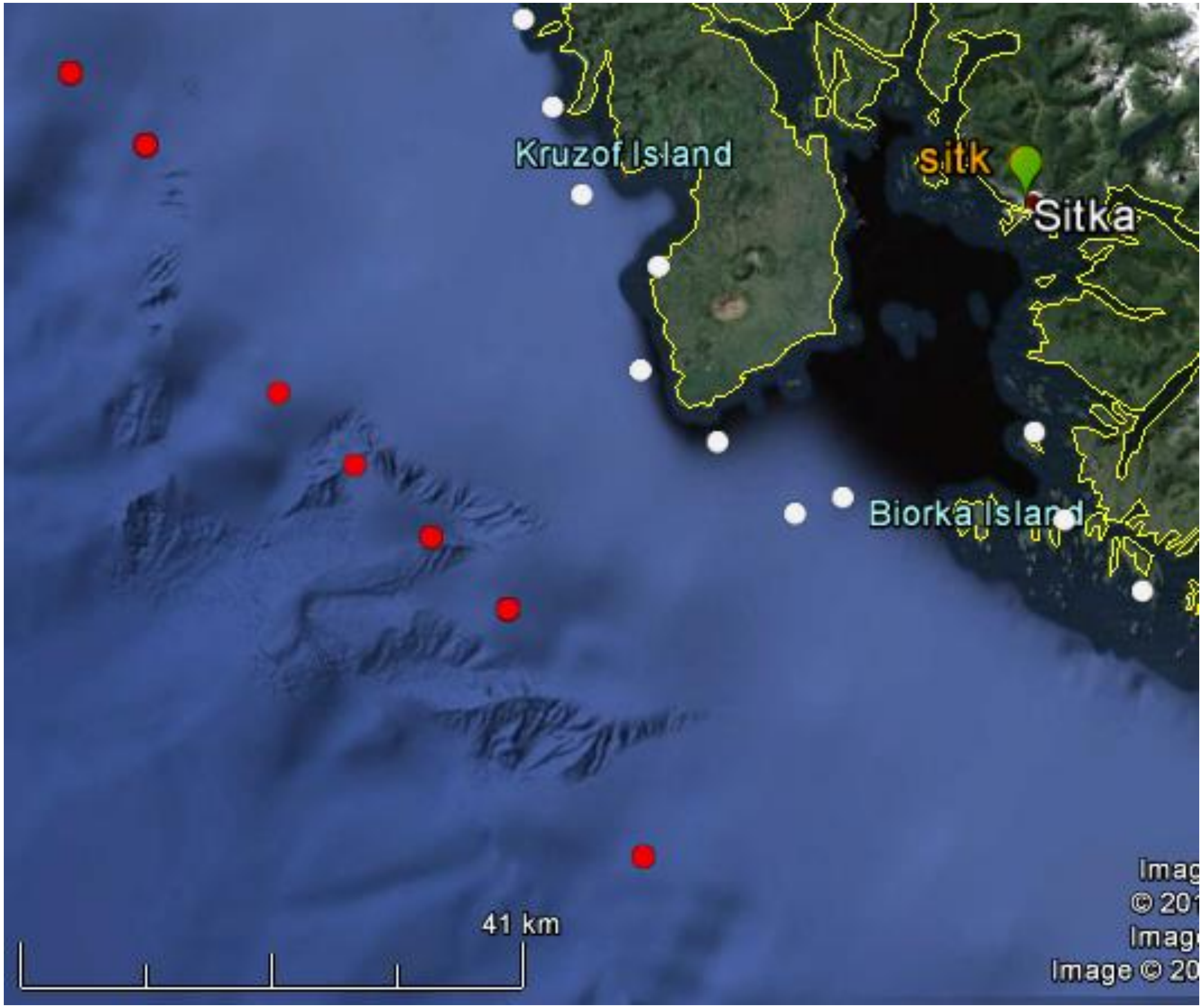
Caveats of Green's Law

- **Meant for coastal points exposed to the open ocean. E.g., forecast for complex geometry coastlines (Fjords, estuaries, river mouths, etc.) easily in error.** Results for these regions should use forecast for the part of coast that is more exposed to open ocean.

- **Cannot use Green's law forecast at "hidden" tide stations (e.g., too far from open ocean, usually over predict) and at tide stations in resonant harbors (usually under predict).** In fact, the model at 4-arc-min. resolution cannot resolve the tide gauge location.

- **For small islands and regions with steep bathymetry, tends to over-predict.** True wave amplitude might lie between Green's law amplitude (upper bound) and resolved amplitude at nearest model ocean/offshore point (lower bound), without Green's law being applied

Comparison of Green's law coastal forecast with tide stations that are hidden or too far from the open ocean is not meaningful, as is shown below (white dots are model coastal points, red dots are offshore points used in the Green's law).



Note the Sitka tide station is many kilometers away from the model coastal wet points (white dots).

Forecast at the model coastal wet points should be interpreted as forecast for the adjacent coastline exposed to the open ocean, not necessarily at the tide station location.

Green’s law forecast tends to overestimate for tide stations on Atolls or on islands with fringing/barrier reefs with steep bathymetry (e.g., Wake Island is such a location).

RIFT’s offshore wave amplitude (without Green’s law applied) or twice the offshore wave amplitude, tends to agree better with tide station observations at these locations. Twice the offshore wave amplitude is equivalent to runup on a vertical wall, assuming the ocean bottom is flat from the offshore point to the coast. Note the offshore point here is the closest model ocean point to the coast/tide station, not necessarily the offshore point used in the Green’s law computation, which has to be at a water depth of 1000 m or deeper for a 4-arc-min. resolution.

Sensitivity & Uncertainty of RIFT Results

- There are many uncertainties in the RIFT forecast due to uncertainties in earthquake magnitude, location, depth, and focal mechanism. Any of these uncertainties can easily result in a factor of two or more difference in forecast.

- For very large earthquakes, the uniform slip assumption on a rectangular fault might be unrealistic, resulting in erroneous propagation forecast and thus erroneous coastal forecast. Detailed distribution of slips, which might be unknown during the event can be important, especially for the near field.

- The Green's law coastal forecast is crude. Even if the propagation forecast is correct, the coastal forecast might still be in error, especially for regions of complex bathymetry (e.g., the tendency to under-predict for resonant harbors and over-predict for coastlines hidden from the open ocean).

Sensitivities of RIFT model solution to earthquake location, magnitude, depth, using hypothetical Luzon trench scenarios

- **Sensitivity to location --** Time is essence for tsunami warning operations. The gain in speed can result in errors in earthquake parameters. **The initial location can be easily off by 50 km, resulting in different tsunami forecast.**

- **Sensitivity to earthquake depth -- The smaller the earthquake magnitude, the more sensitive the model result is to earthquake depth.** For example, a hypocentral depth of 50 km is a ‘deep’ event for a magnitude 6.5 earthquake but it is not a deep event for a magnitude 8.5 earthquake.

- **Sensitivity to earthquake magnitude --** For tsunami warning operations, the initial earthquake magnitude can be easily off by 0.2. **A 0.2 difference in earthquake magnitude generally means a factor of two change in tsunami wave amplitude.**

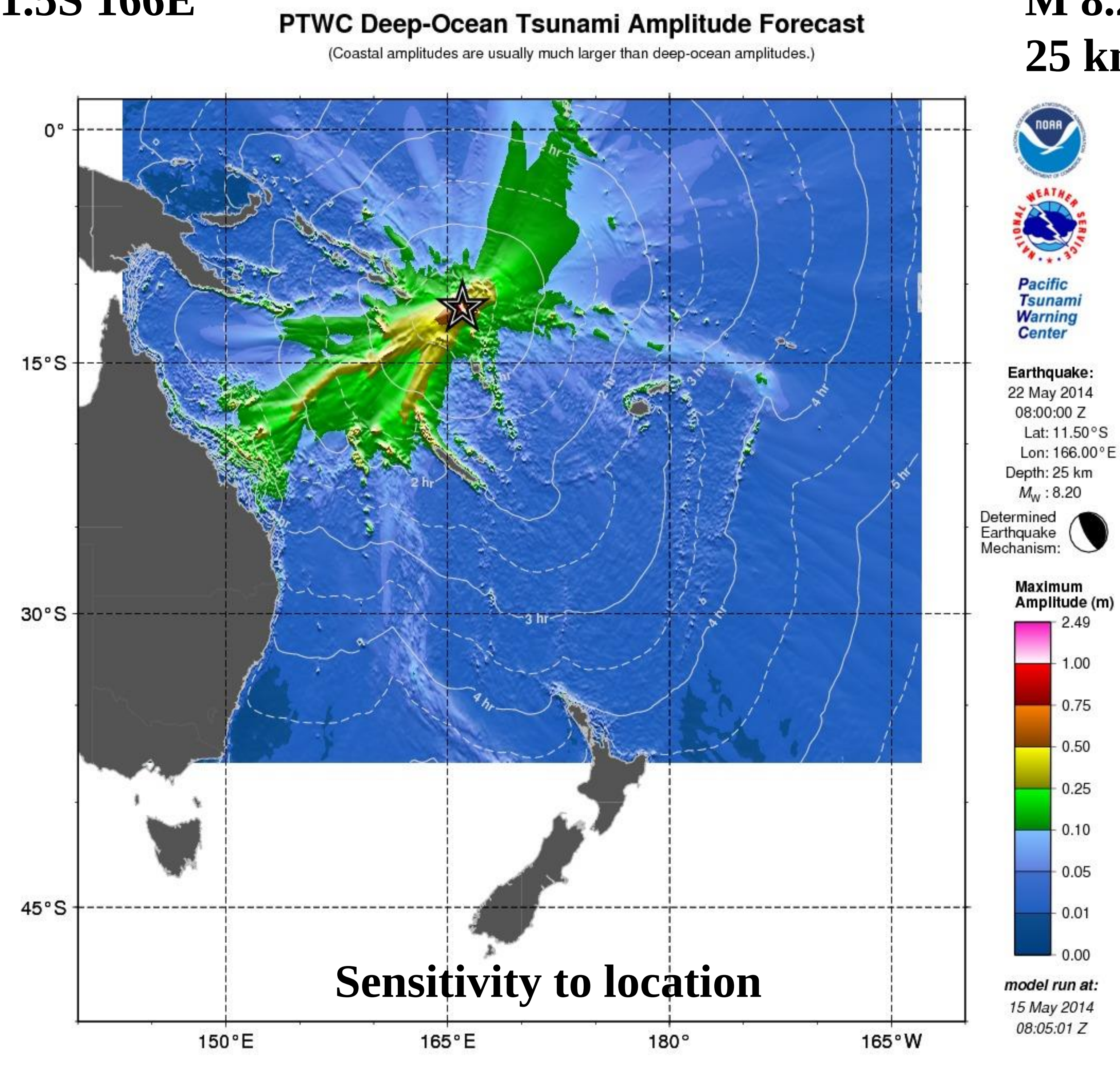
Sensitivity to location

- **Location, location, location**
  - Local
  - Regional
  - Ocean wide

Variance with location with magnitude (M 8.2) and depth (25 km) held constant

Loc: 11.5S 166E

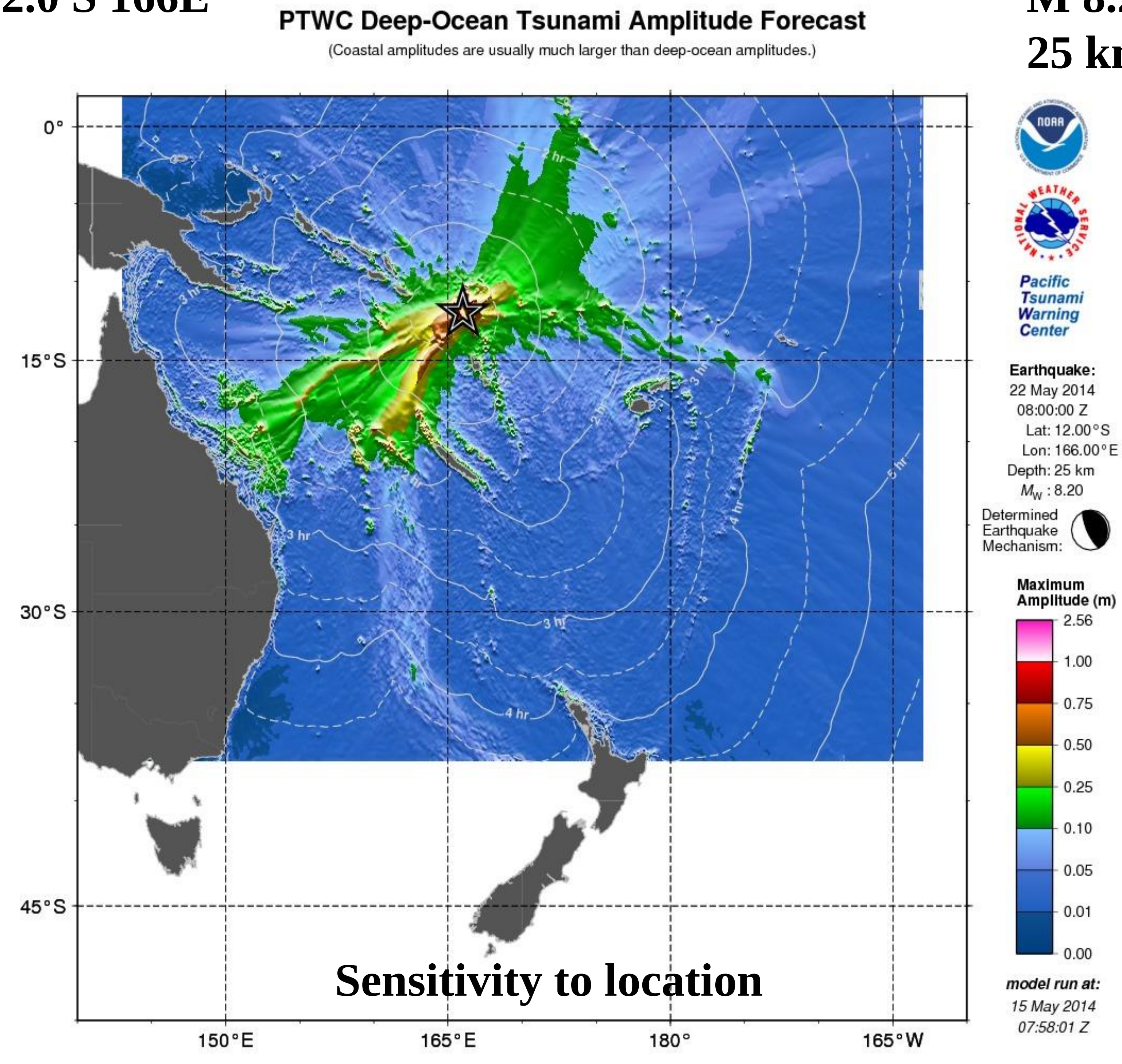
M 8.2
25 km deep



Sensitivity to location

Loc: 12.0 S 166E

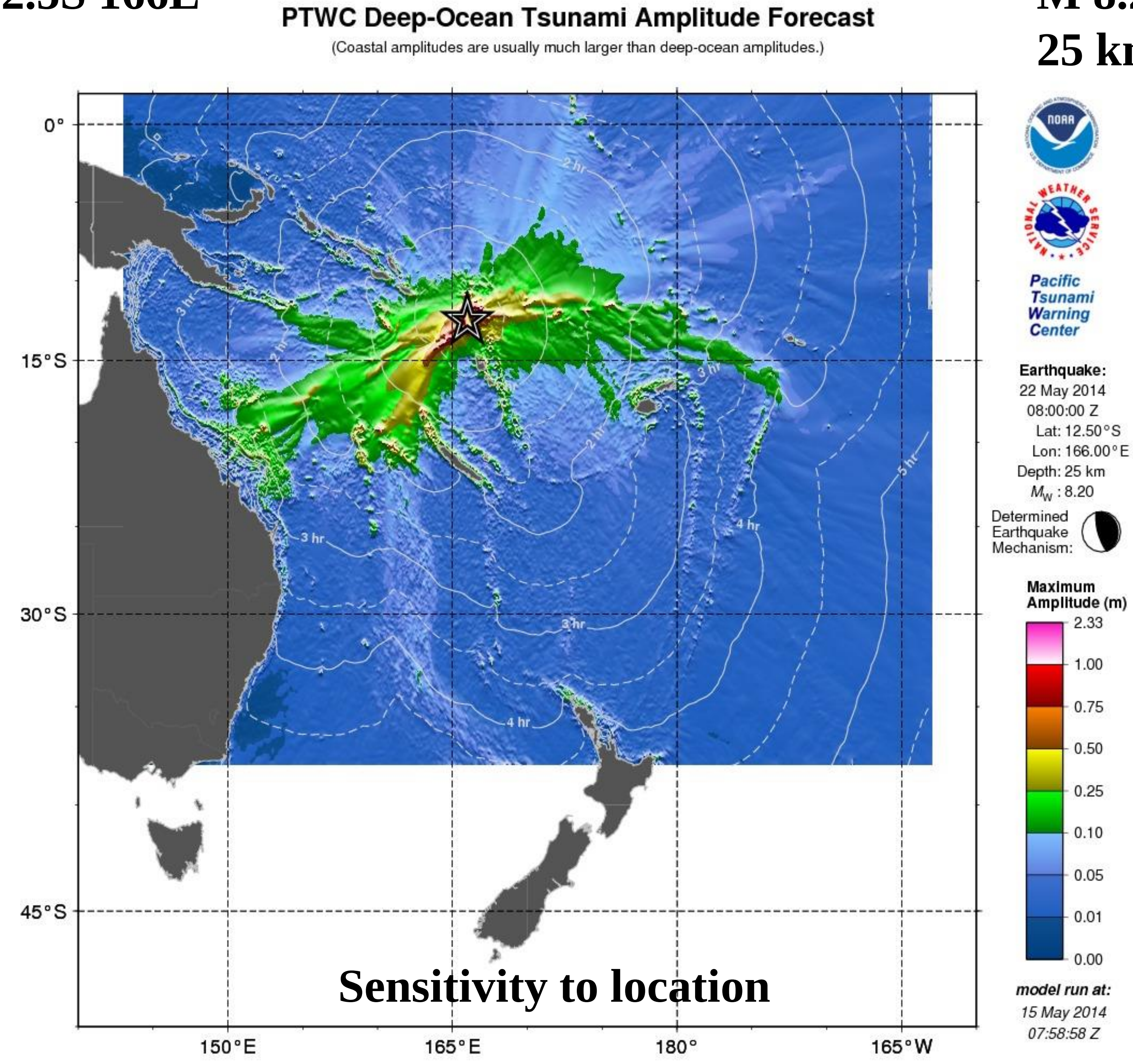
M 8.2
25 km deep



Sensitivity to location

Loc: 12.5S 166E

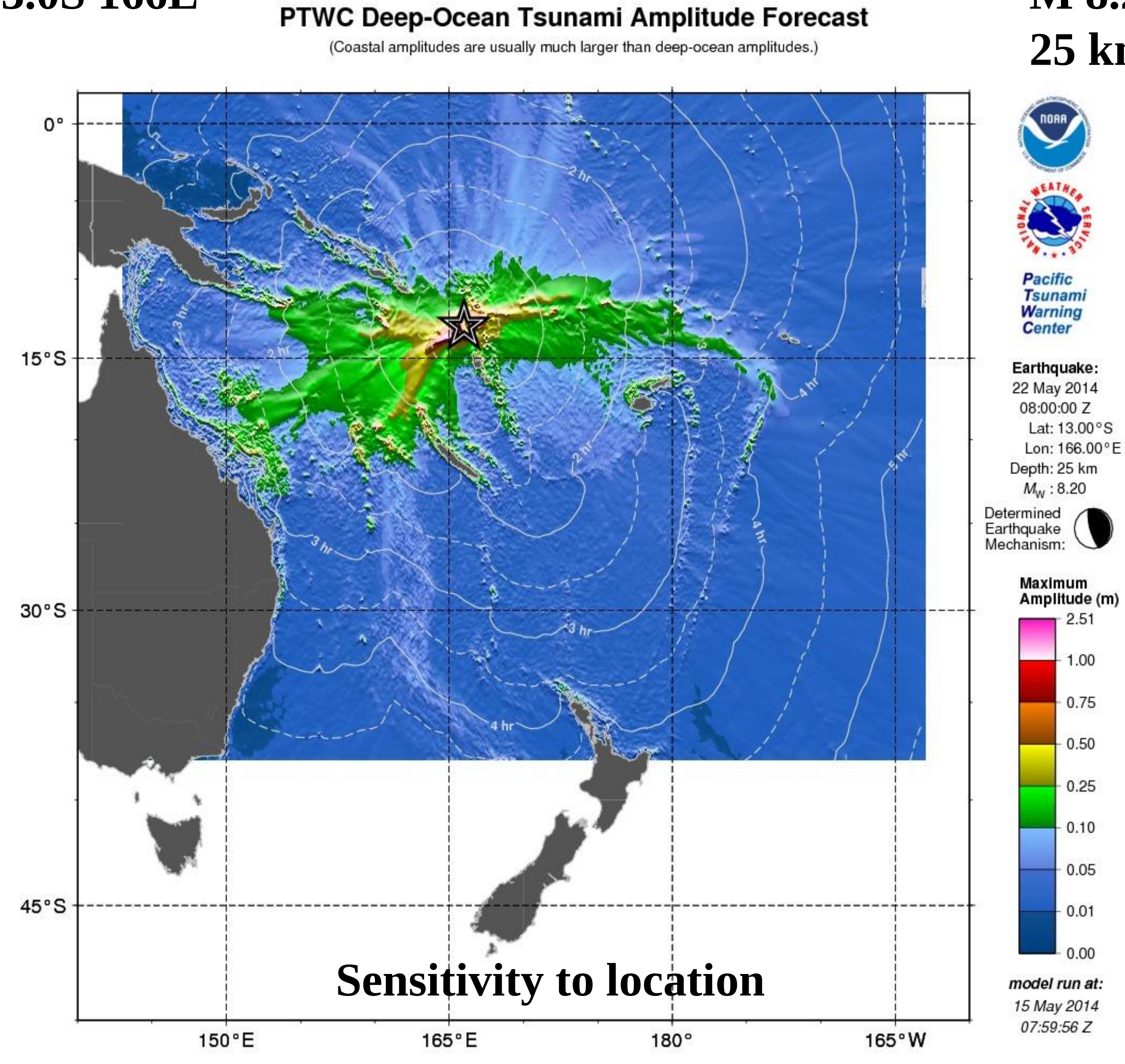
M 8.2
25 km deep



Sensitivity to location

Loc: 13.0S 166E

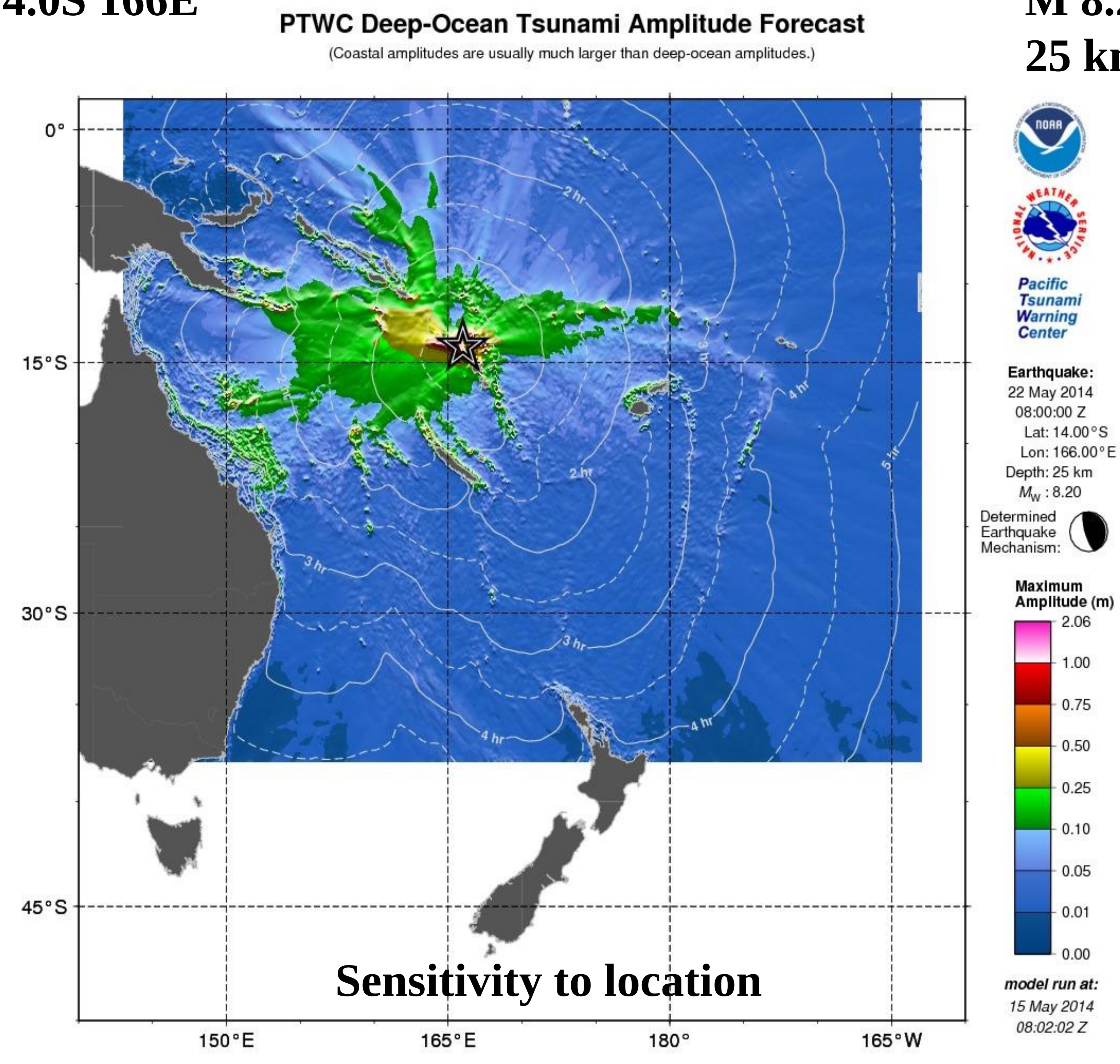
M 8.2
25 km deep



Sensitivity to location

Loc: 14.0S 166E

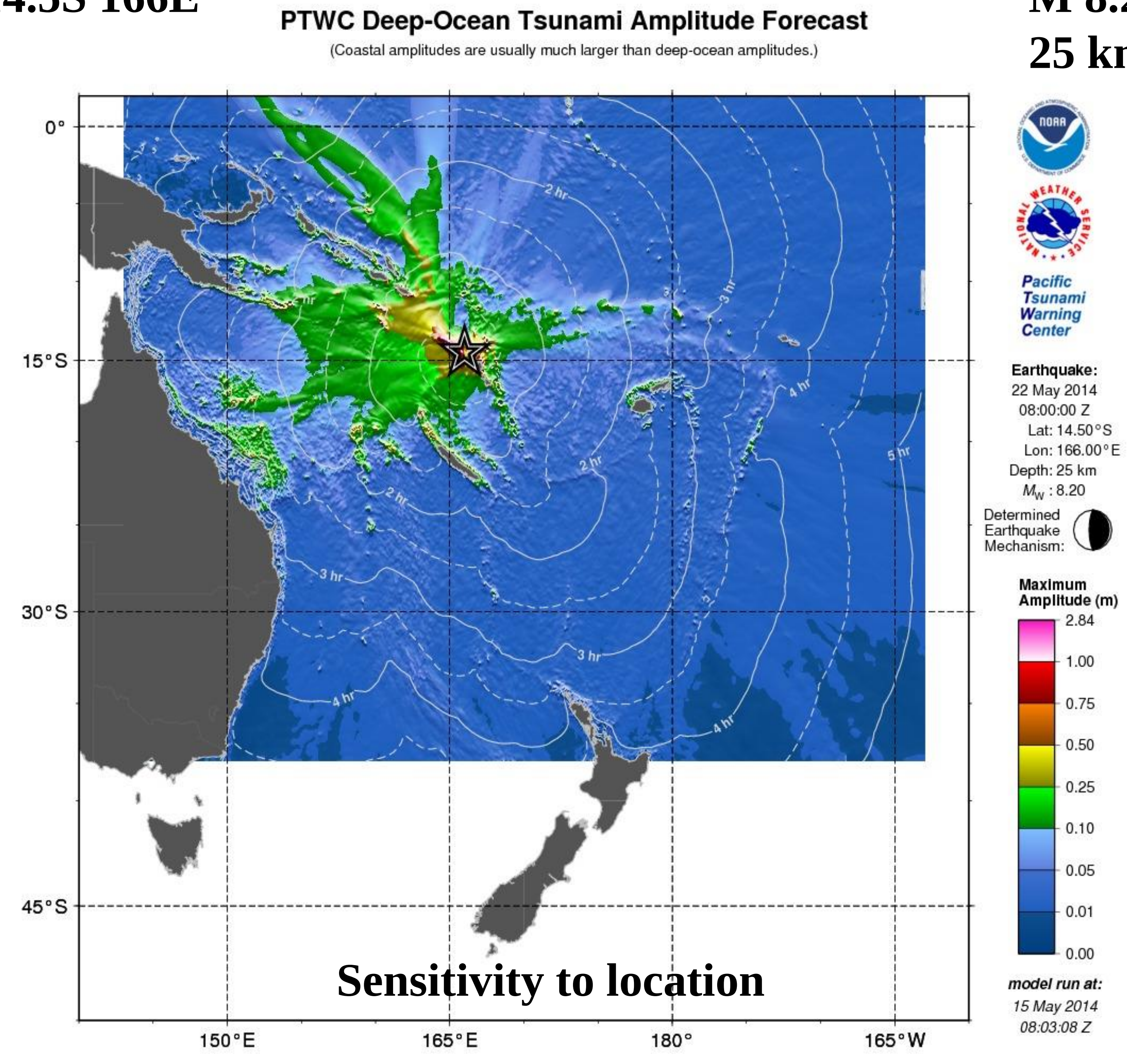
M 8.2
25 km deep



Sensitivity to location

Loc: 14.5S 166E

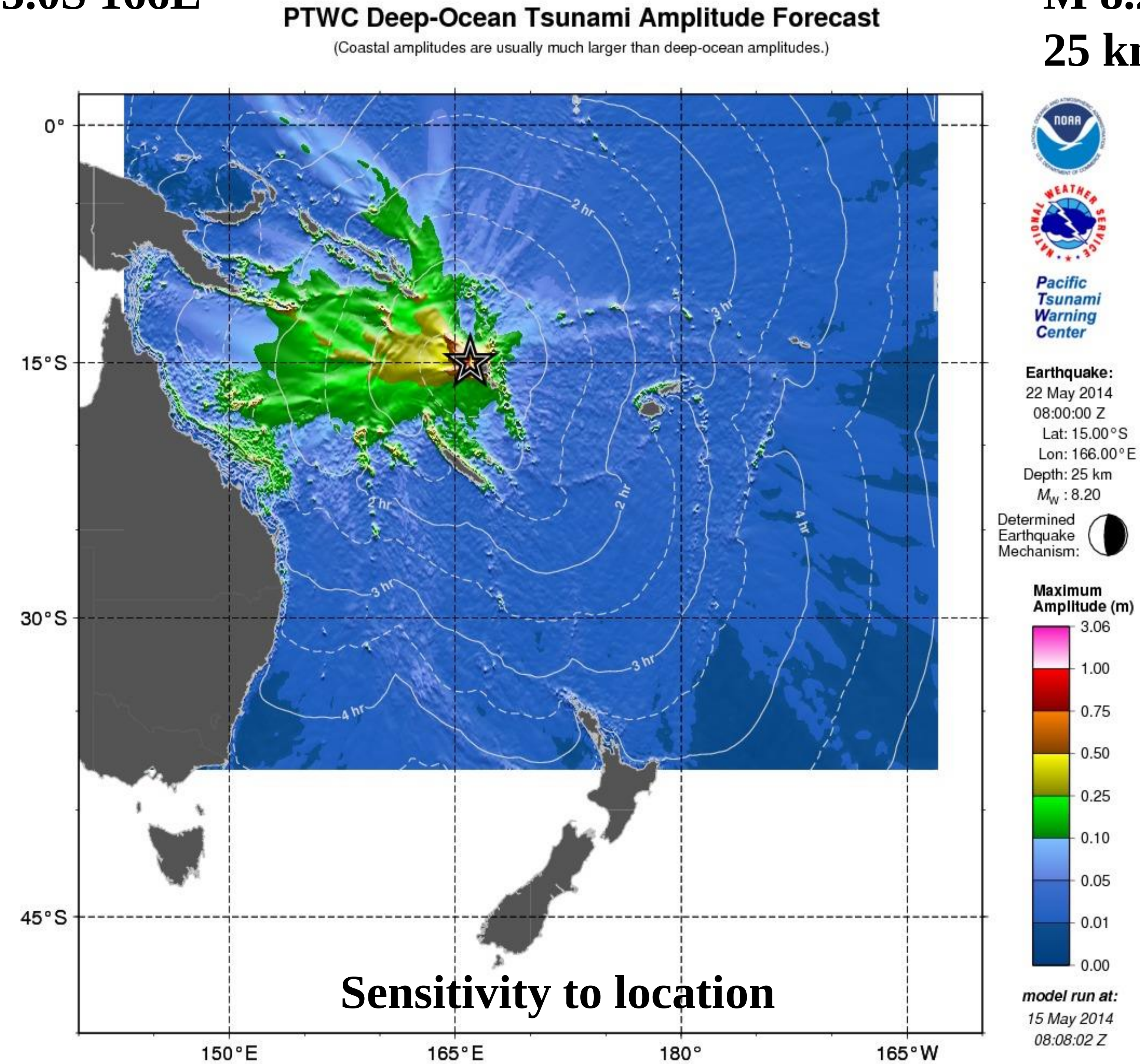
M 8.2
25 km deep



Sensitivity to location

Loc: 15.0S 166E

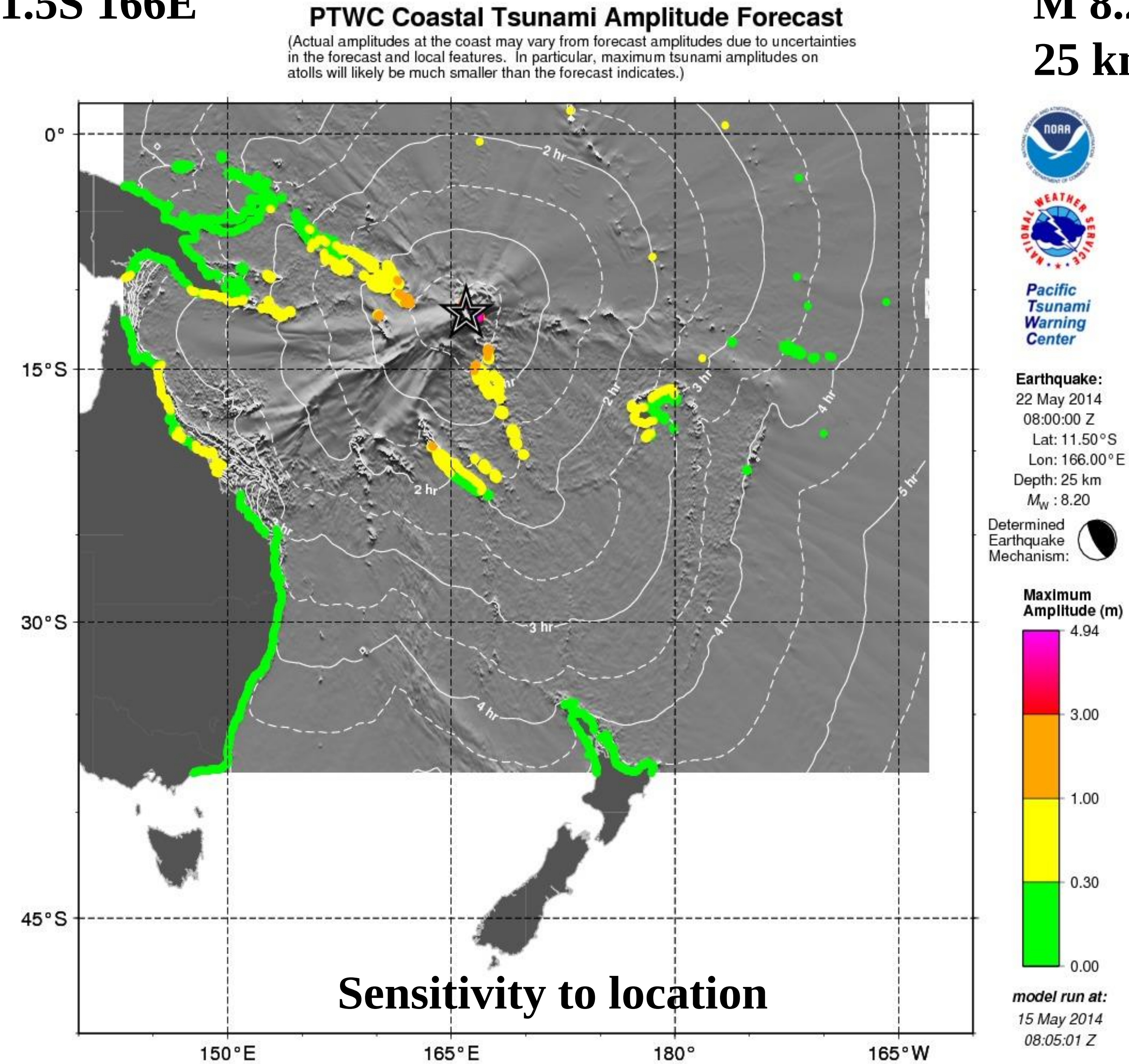
M 8.2
25 km deep



Sensitivity to location

Loc: 11.5S 166E

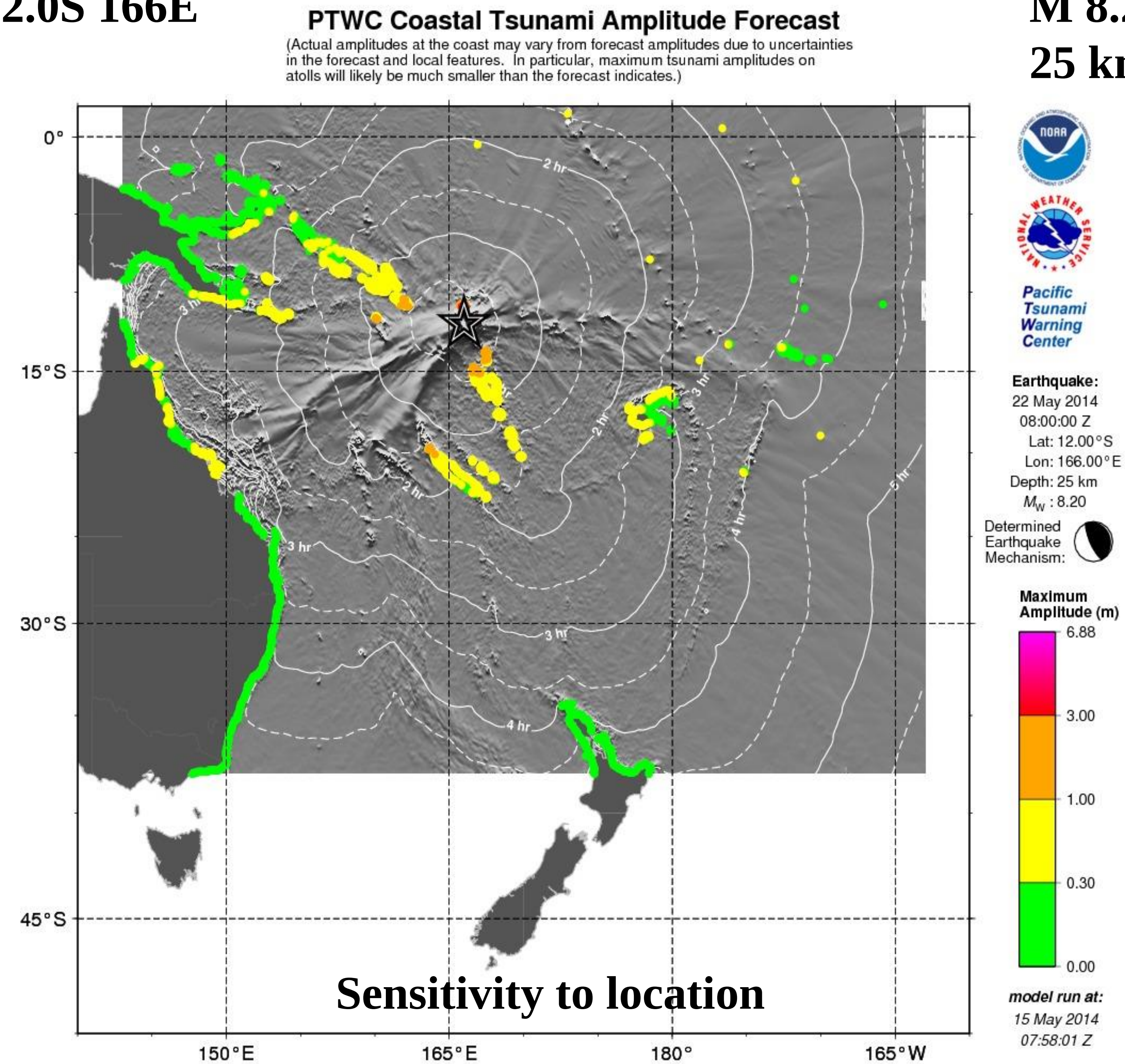
M 8.2
25 km deep



Sensitivity to location

Loc: 12.0S 166E

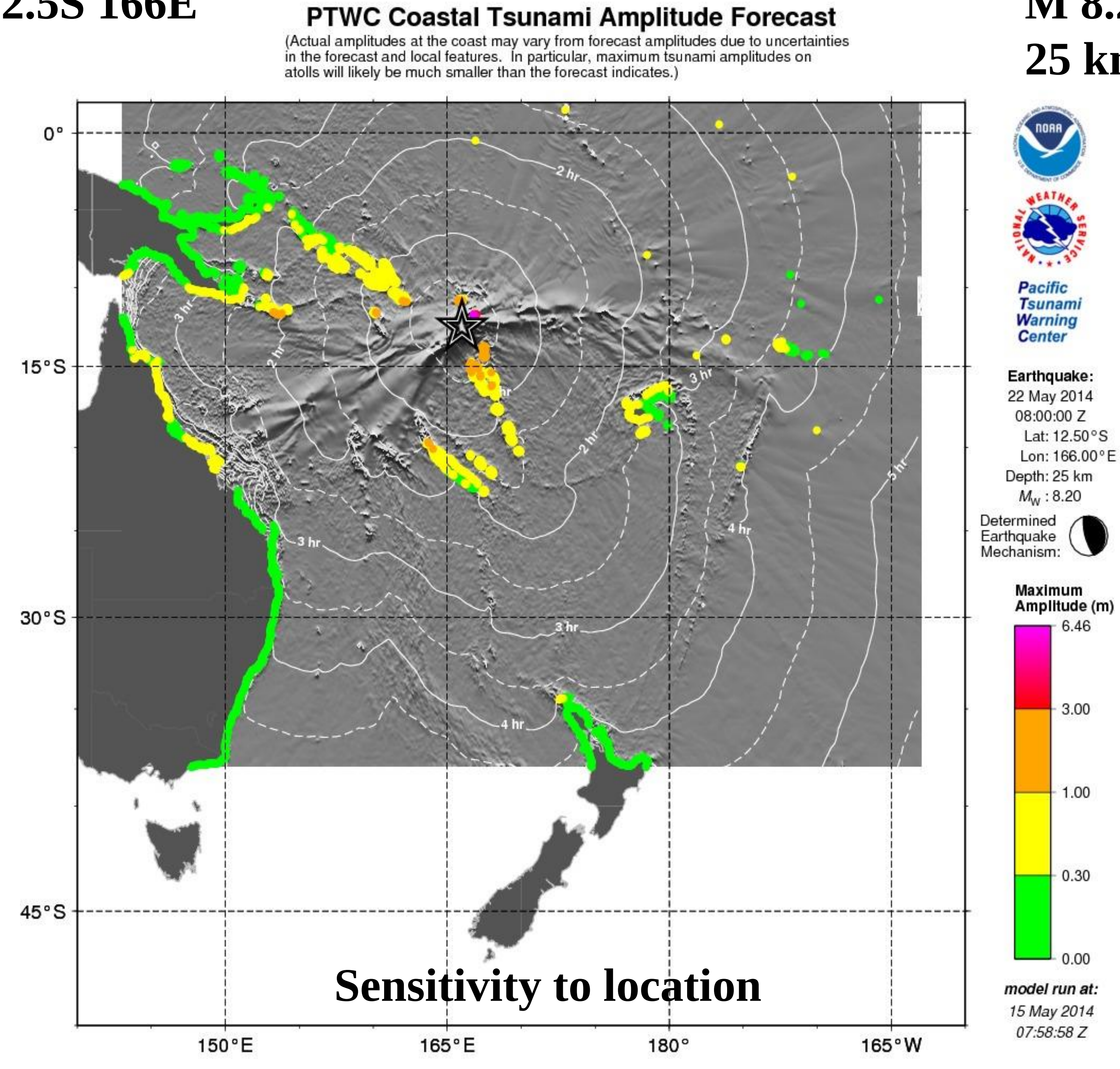
M 8.2
25 km deep



Sensitivity to location

Loc: 12.5S 166E

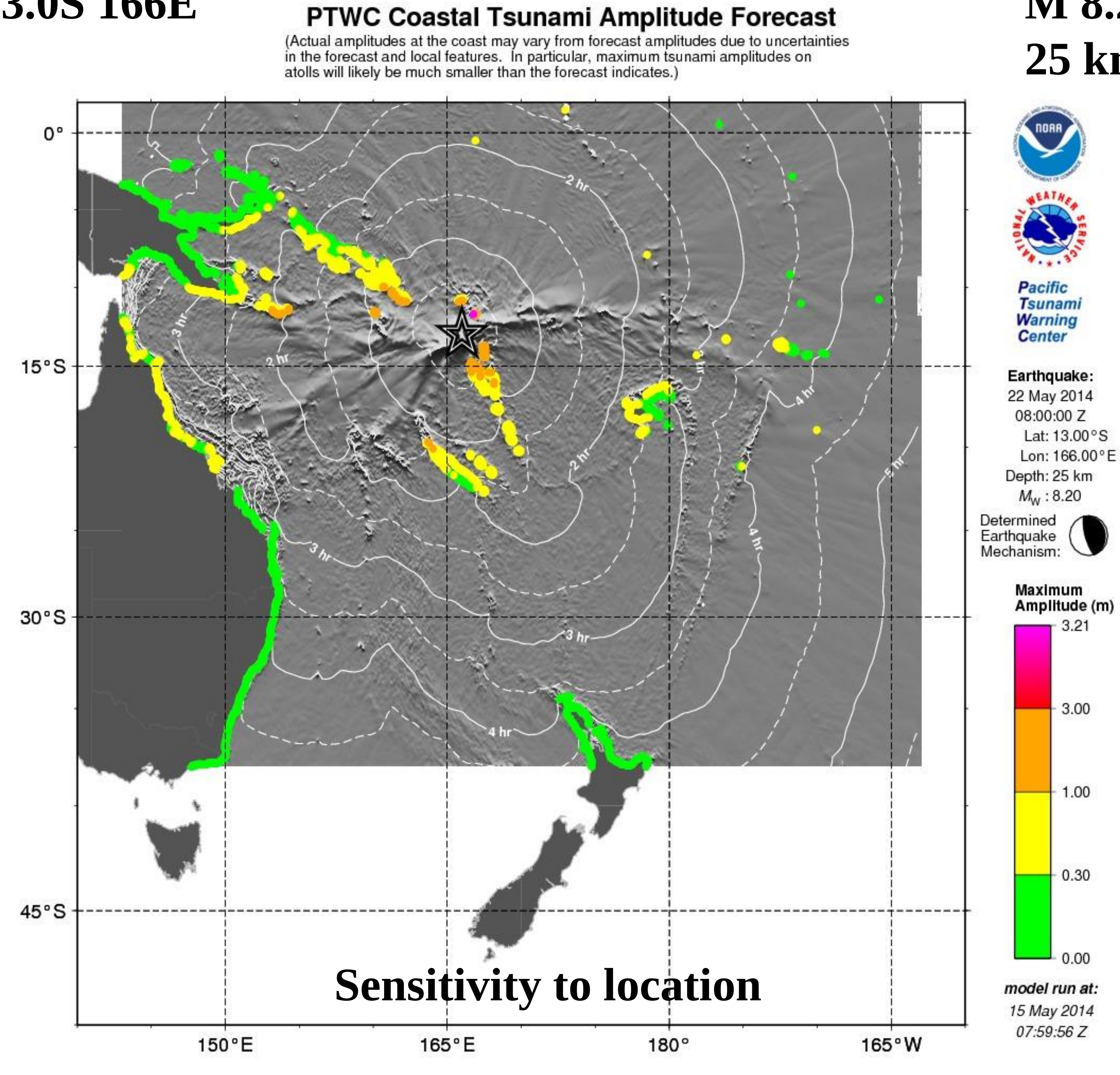
M 8.2
25 km deep



Sensitivity to location

Loc: 13.0S 166E

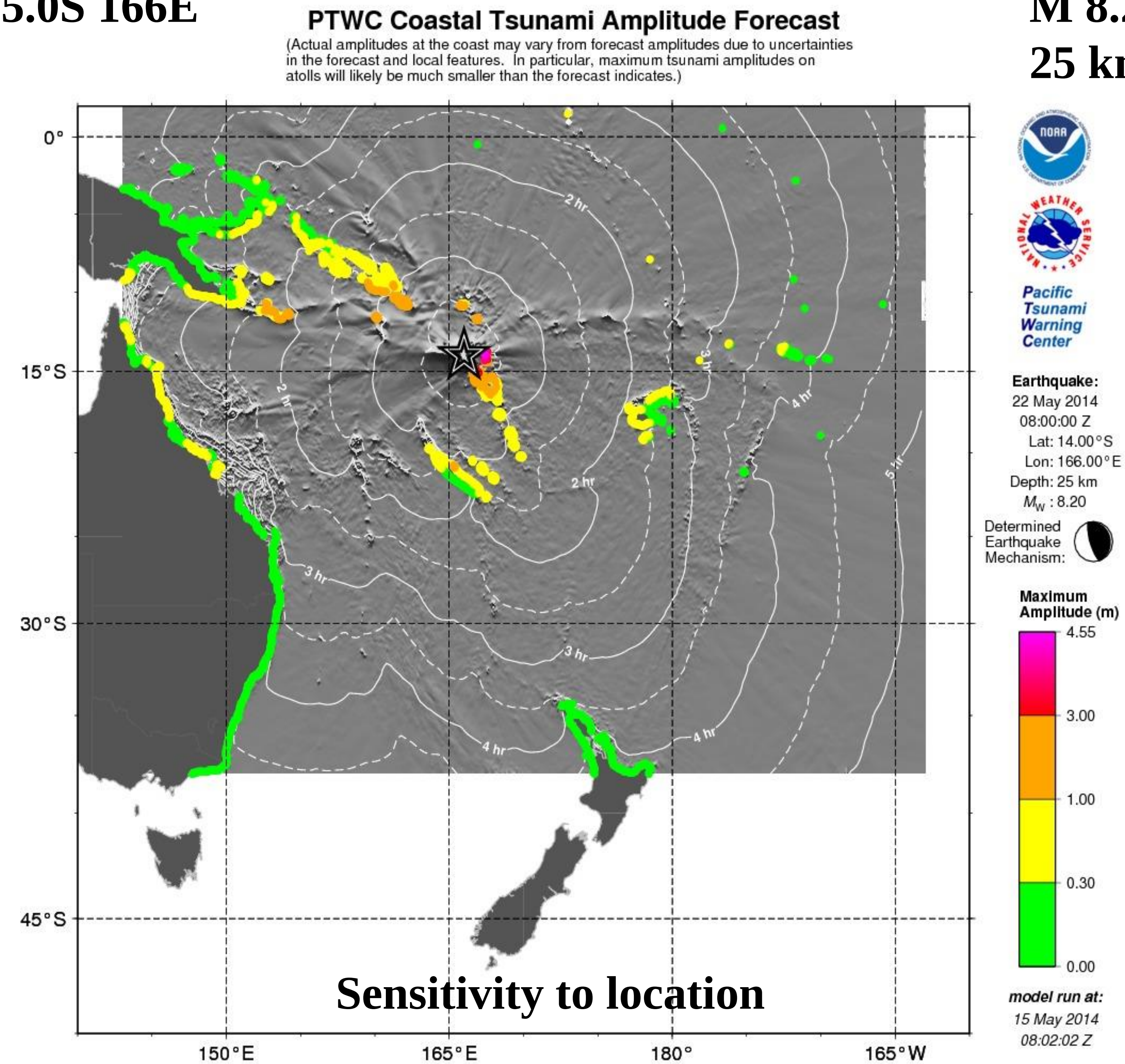
M 8.2
25 km deep



Sensitivity to location

Loc: 15.0S 166E

M 8.2
25 km deep

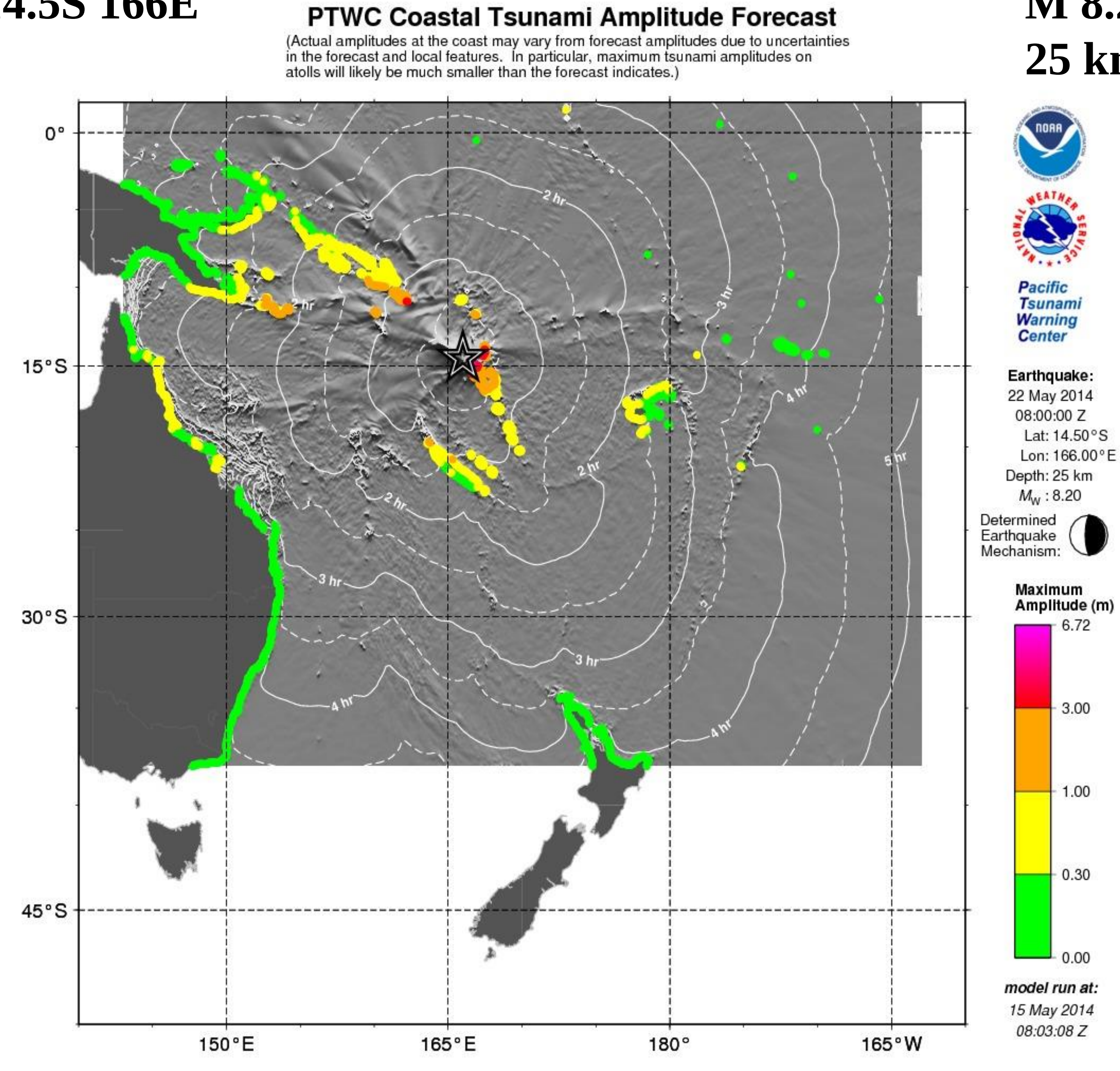


Sensitivity to location

Loc: 14.5S 166E

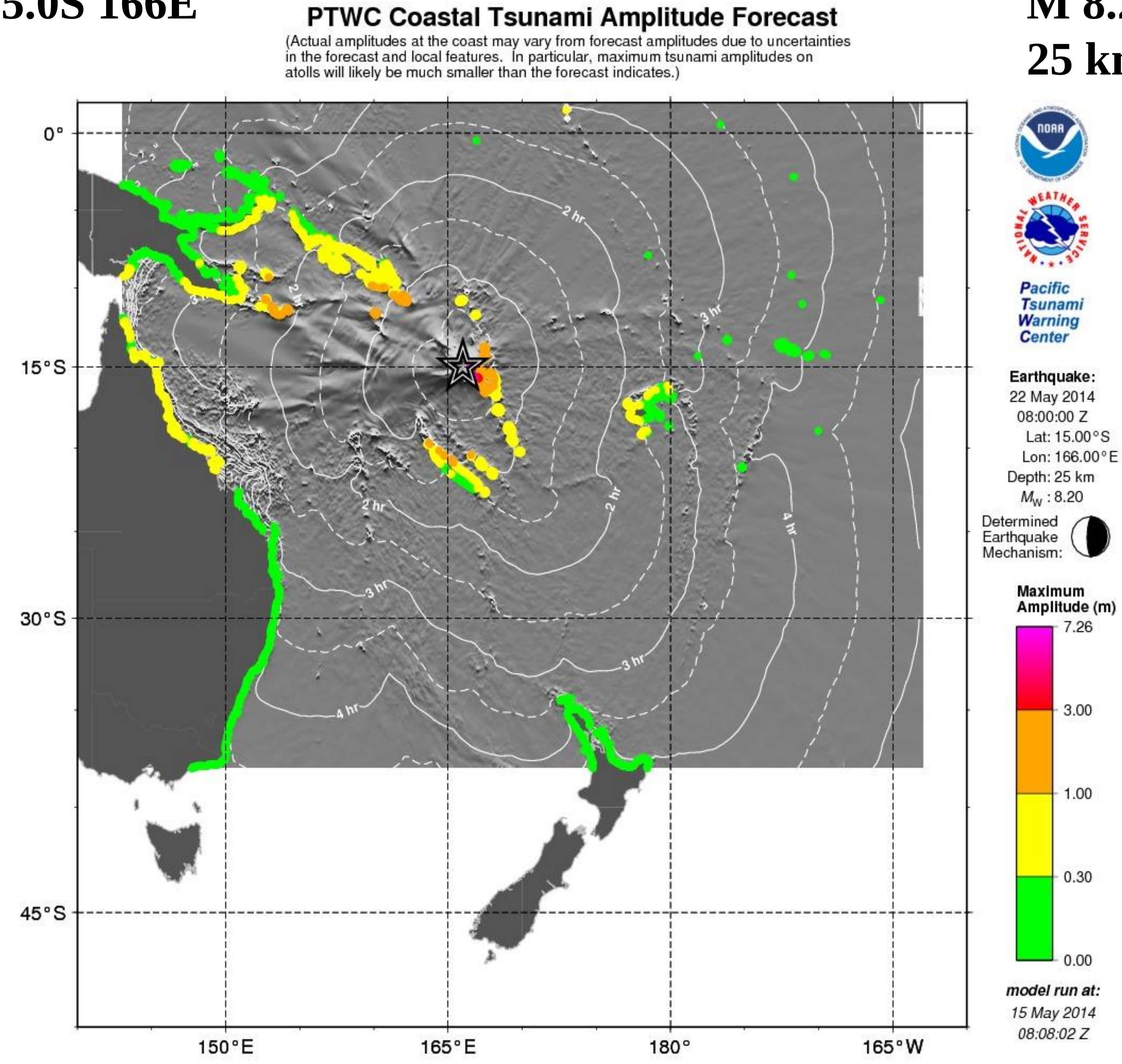
M 8.2

25 km deep



Loc: 15.0S 166E

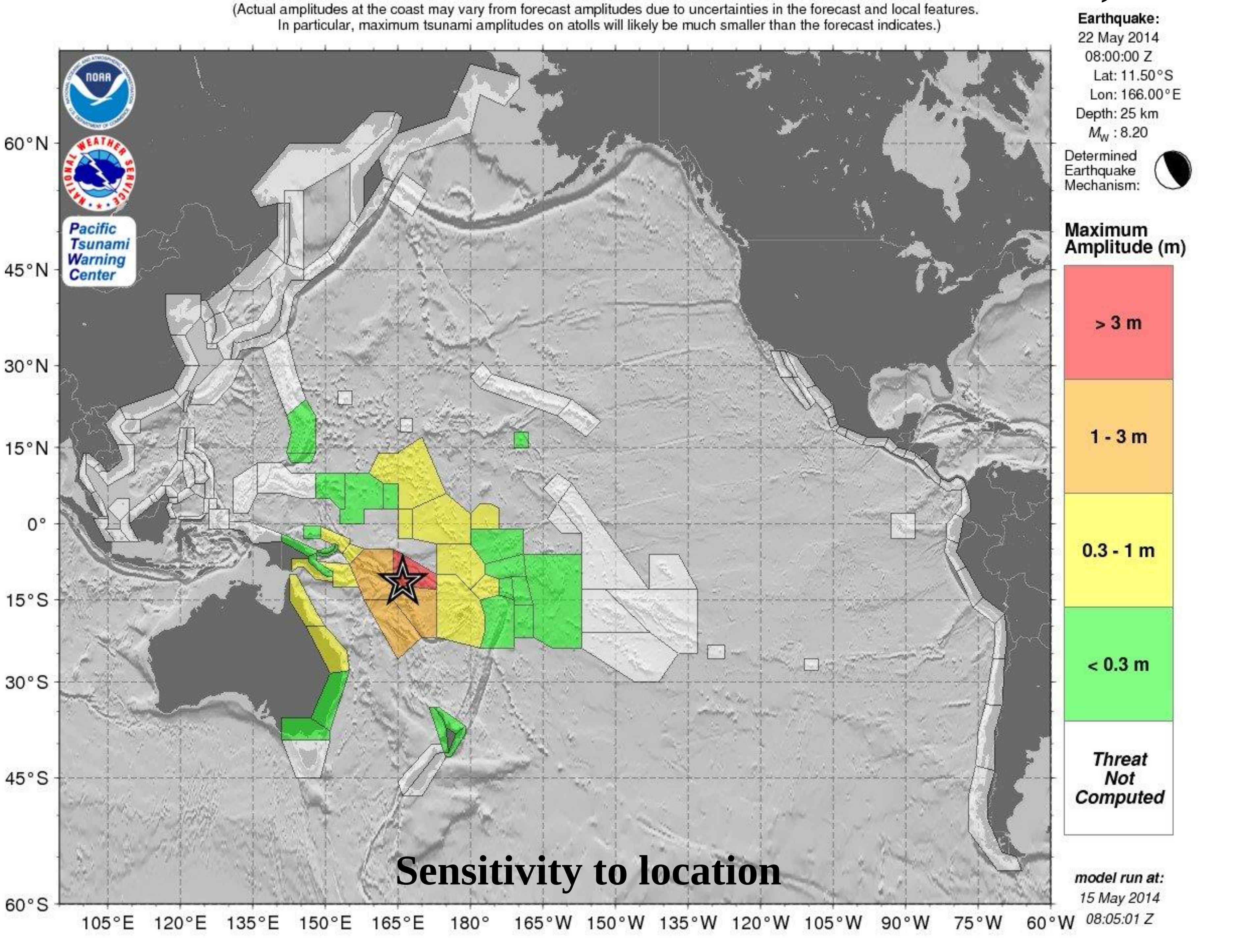
M 8.2
25 km deep



Loc: 11.5S 166E

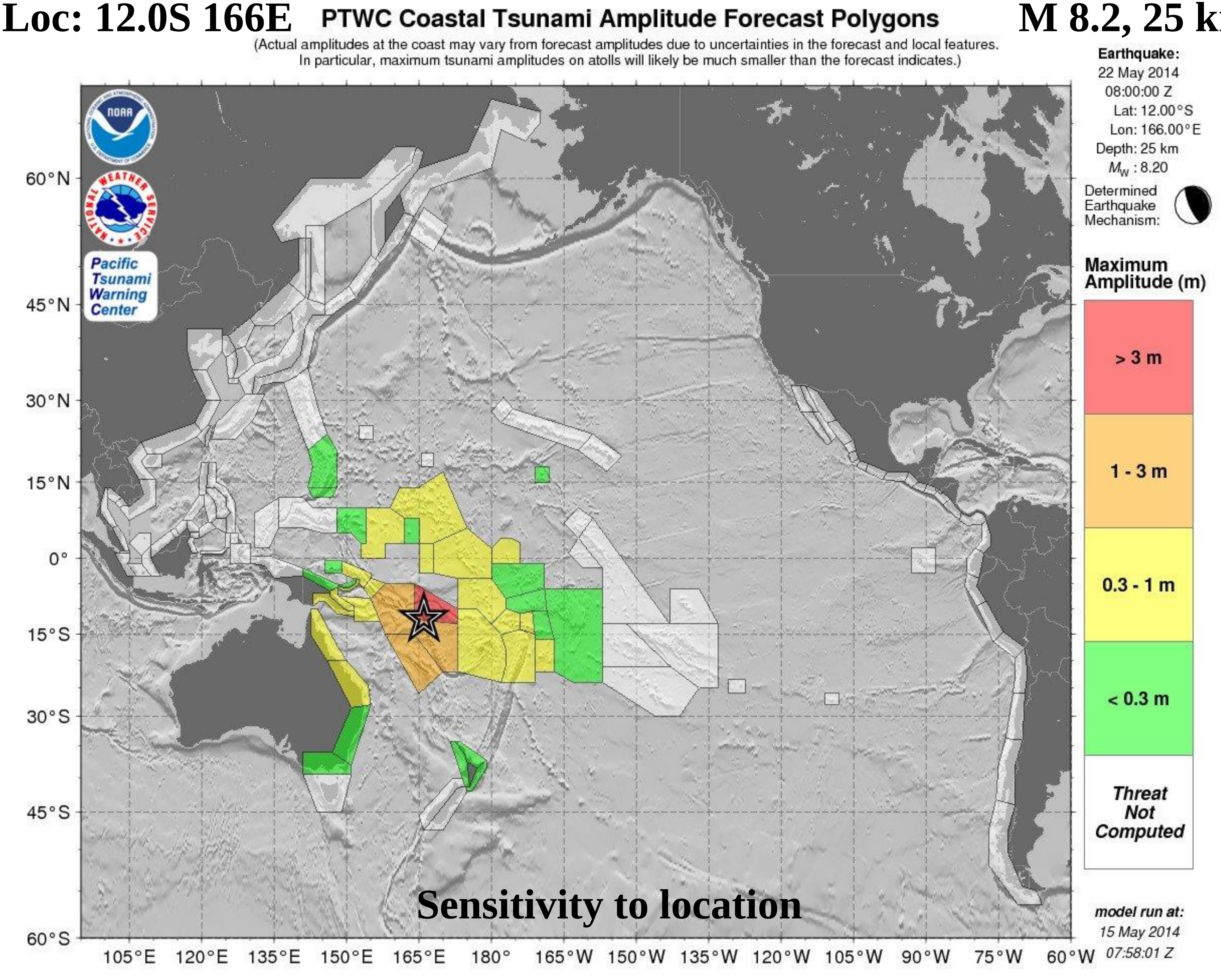
PTWC Coastal Tsunami Amplitude Forecast Polygons

M 8.2, 25km



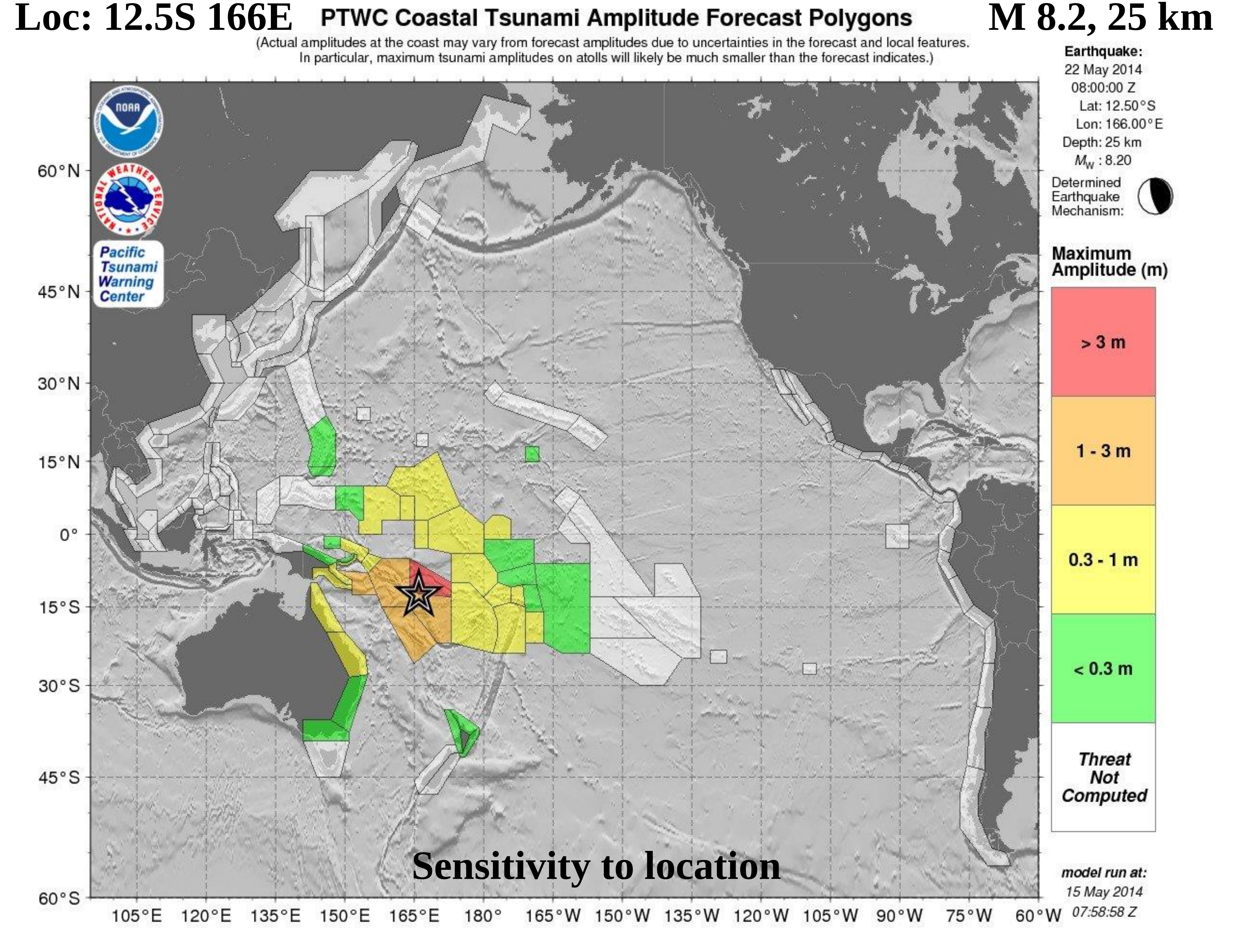
Sensitivity to location

Loc: 12.0S 166E — PTWC Coastal Tsunami Amplitude Forecast Polygons — M 8.2, 25 km



Sensitivity to location

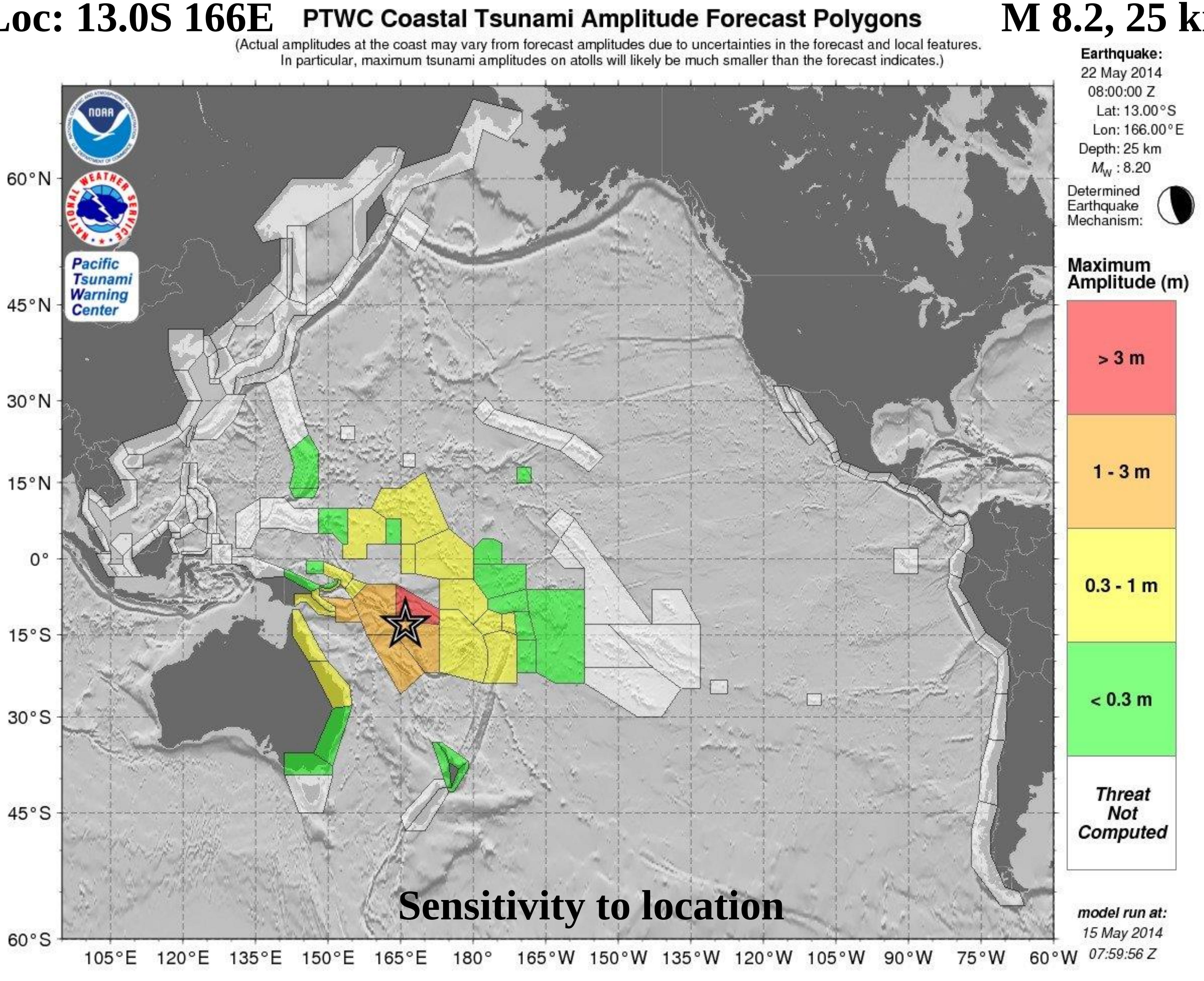
Loc: 12.5S 166E | **M 8.2, 25 km**



Sensitivity to location

Loc: 13.0S 166E

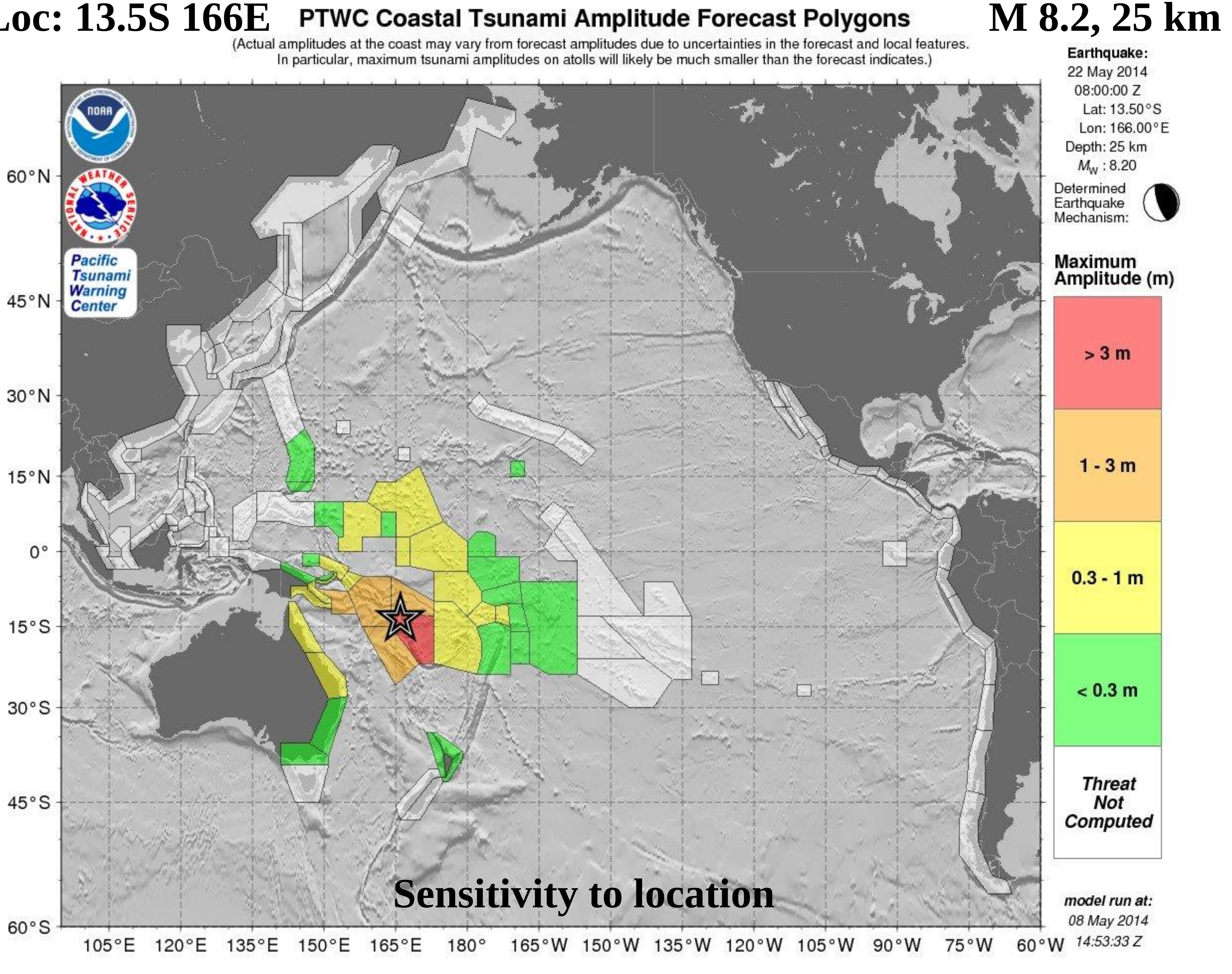
M 8.2, 25 km



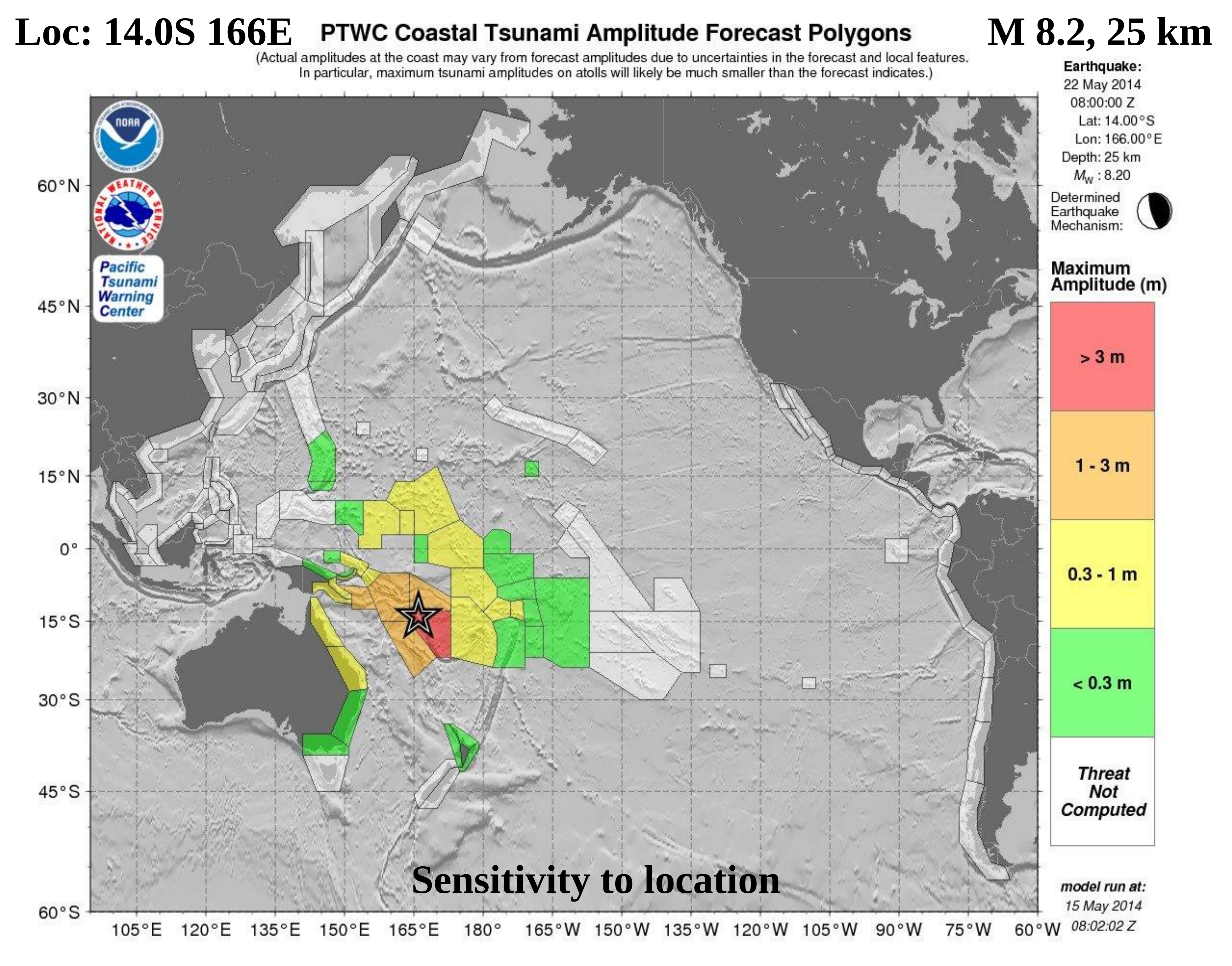
Sensitivity to location

Loc: 13.5S 166E

M 8.2, 25 km



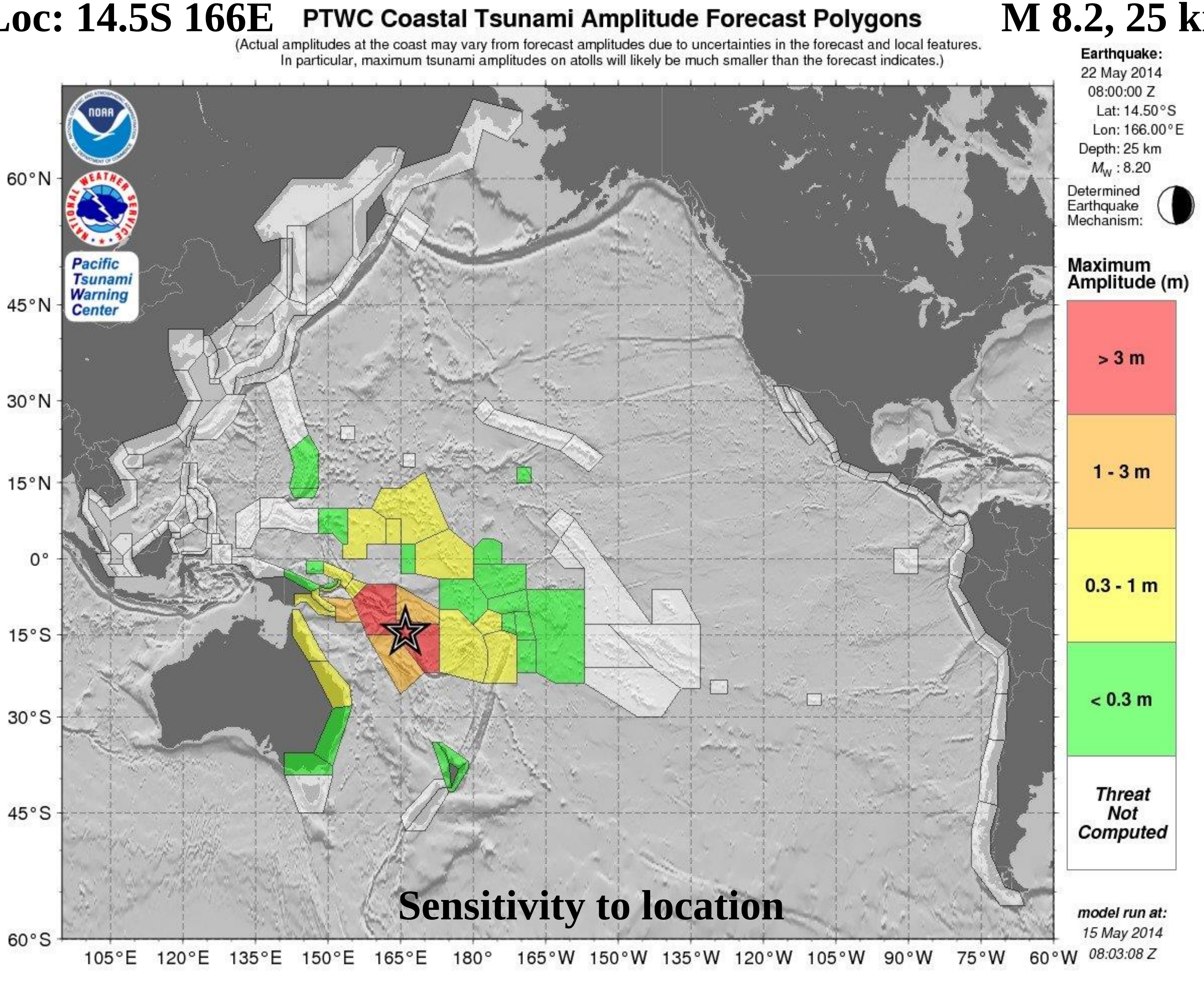
Sensitivity to location



Loc: 14.0S 166E
PTWC Coastal Tsunami Amplitude Forecast Polygons
M 8.2, 25 km
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features.
In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)
Earthquake:
22 May 2014
08:00:00 Z
Lat: 14.00°S
Lon: 166.00°E
Depth: 25 km
M_W : 8.20
Determined Earthquake Mechanism:
Maximum Amplitude (m)
> 3 m
1 - 3 m
0.3 - 1 m
< 0.3 m
Threat Not Computed
Pacific Tsunami Warning Center
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
105°E
120°E
135°E
150°E
165°E
180°
165°W
150°W
135°W
120°W
105°W
90°W
75°W
60°W
Sensitivity to location
model run at:
15 May 2014
08:02:02 Z

Loc: 14.5S 166E

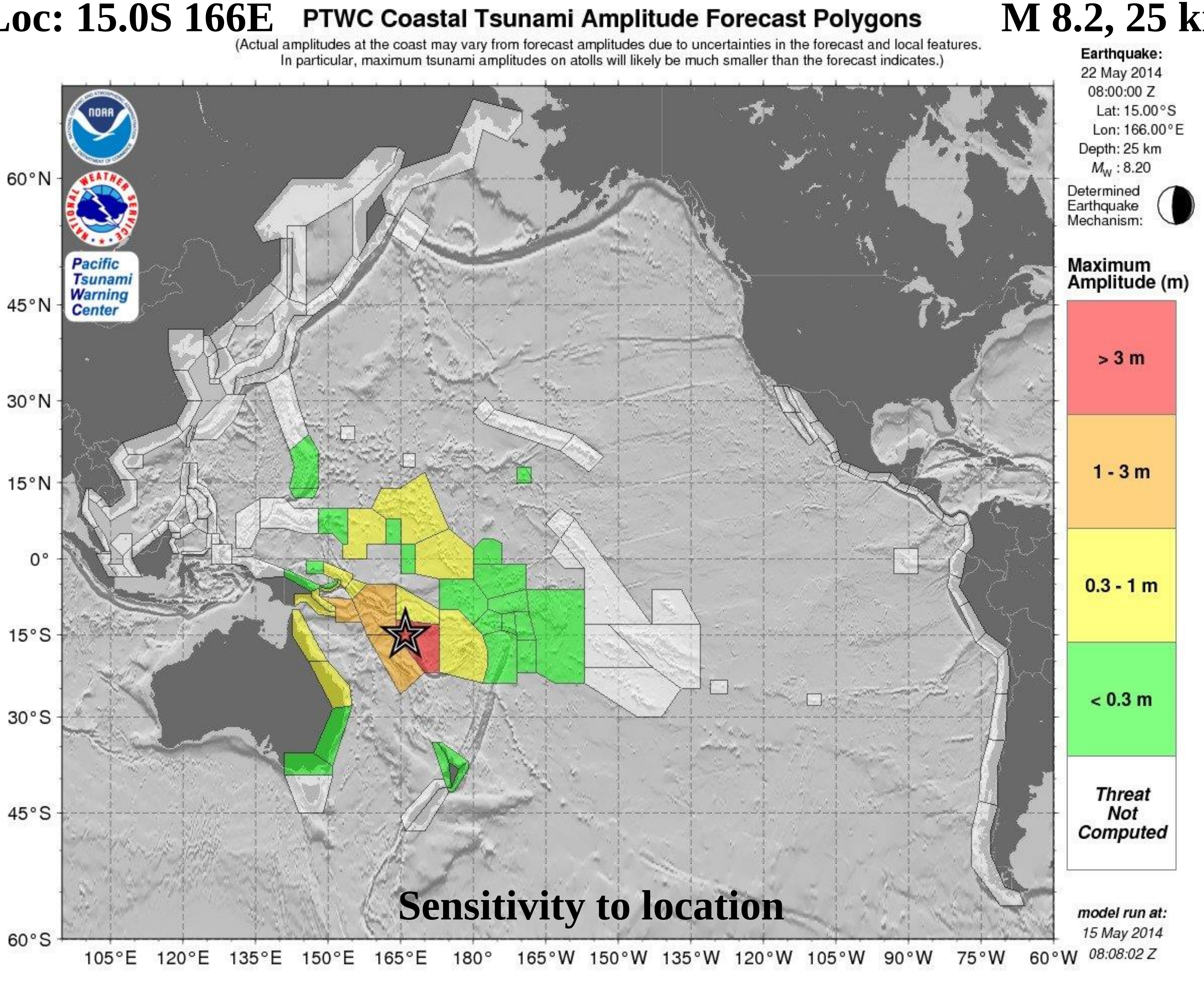
M 8.2, 25 km



Sensitivity to location

Loc: 15.0S 166E

M 8.2, 25 km



Sensitivity to location

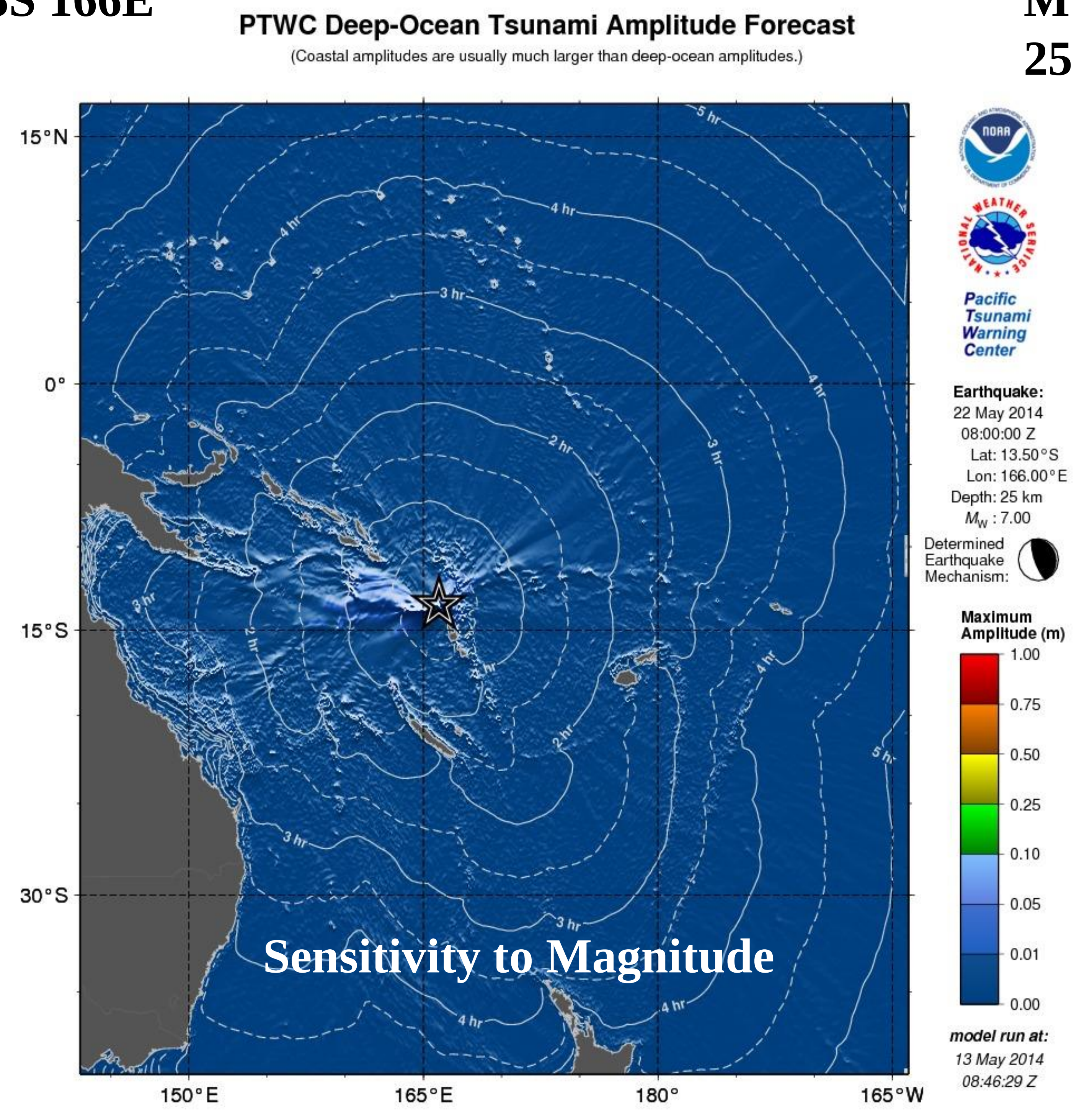
Sensitivity to Magnitude

- Size is everything!

- Variance with magnitude holding location (13.5S, 166E) and depth (25 km) held constant

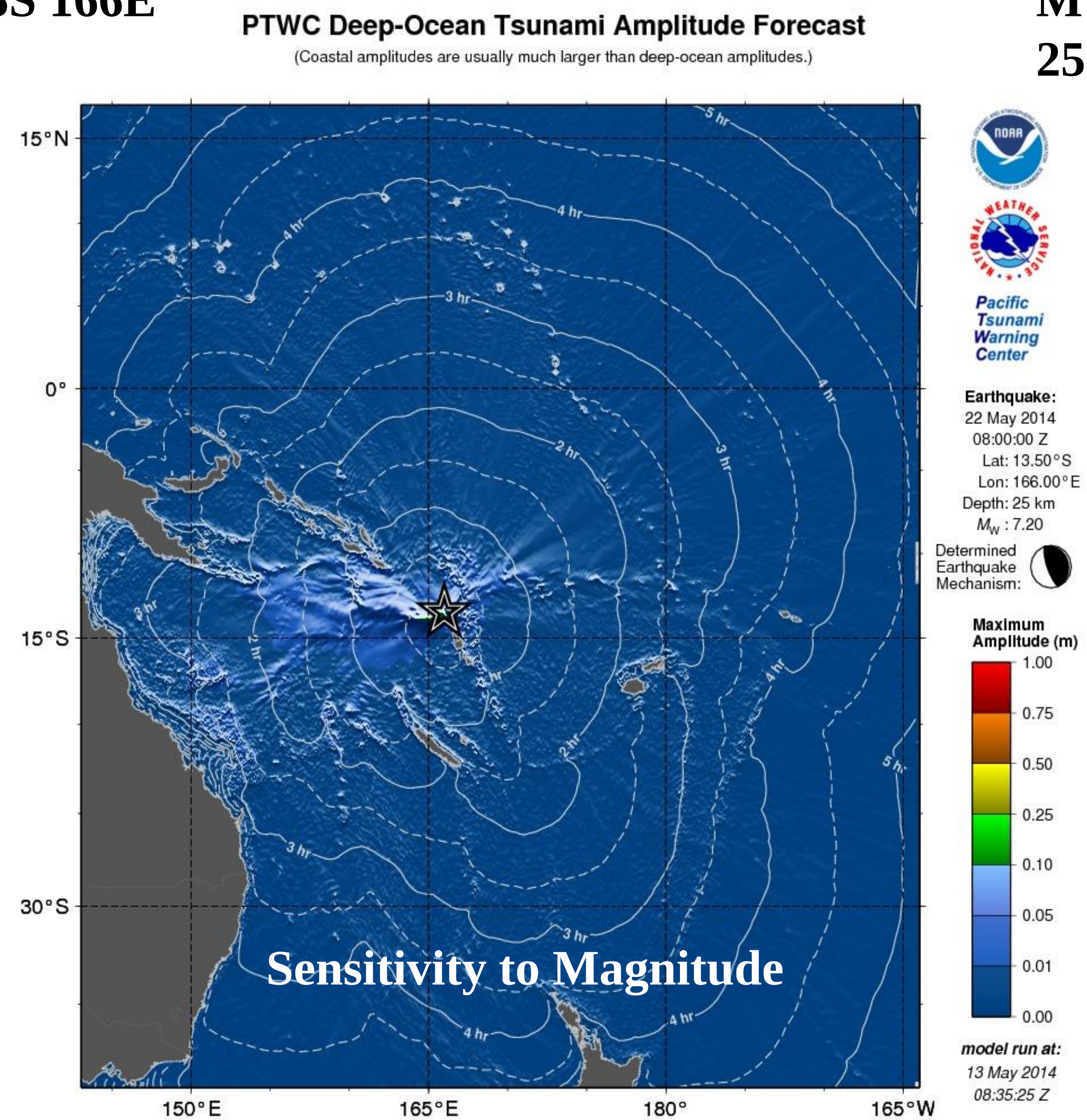
Loc: 13.5S 166E

M 7.0
25 km deep



Loc: 13.5S 166E

M 7.2
25 km deep

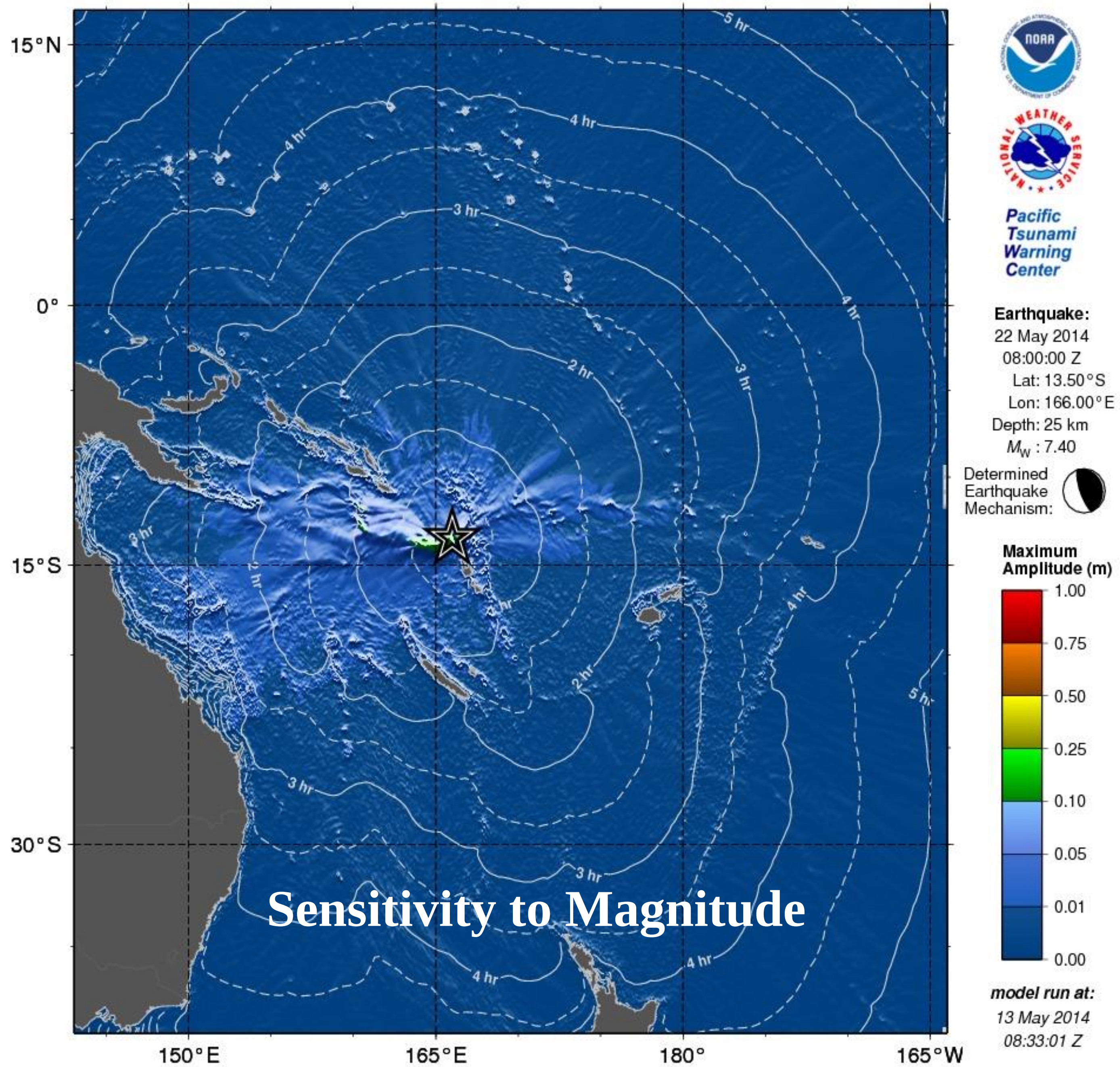


Loc: 13.5S 166E

M 7.4
25 km deep

PTWC Deep-Ocean Tsunami Amplitude Forecast

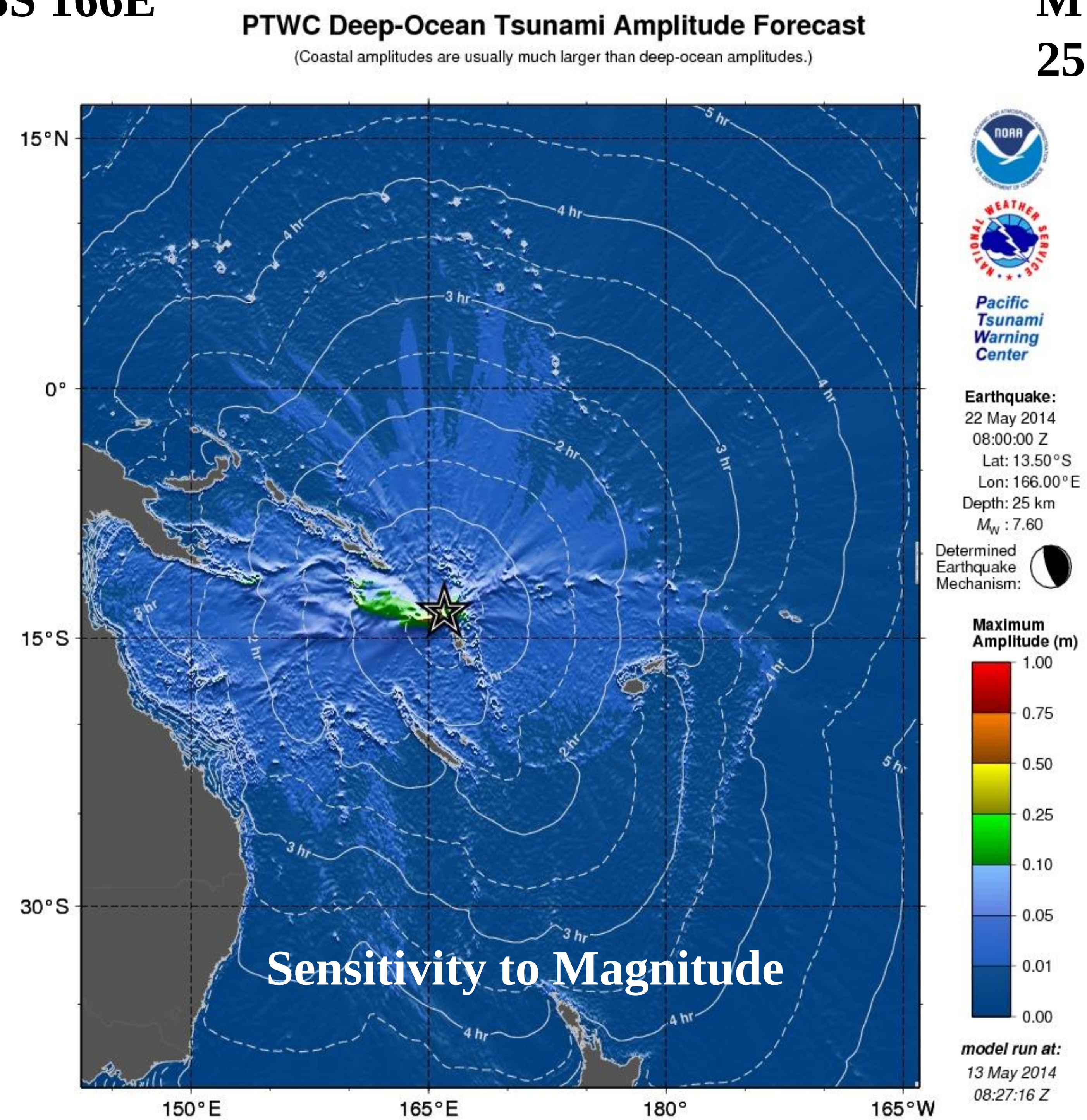
(Coastal amplitudes are usually much larger than deep-ocean amplitudes.)



Sensitivity to Magnitude

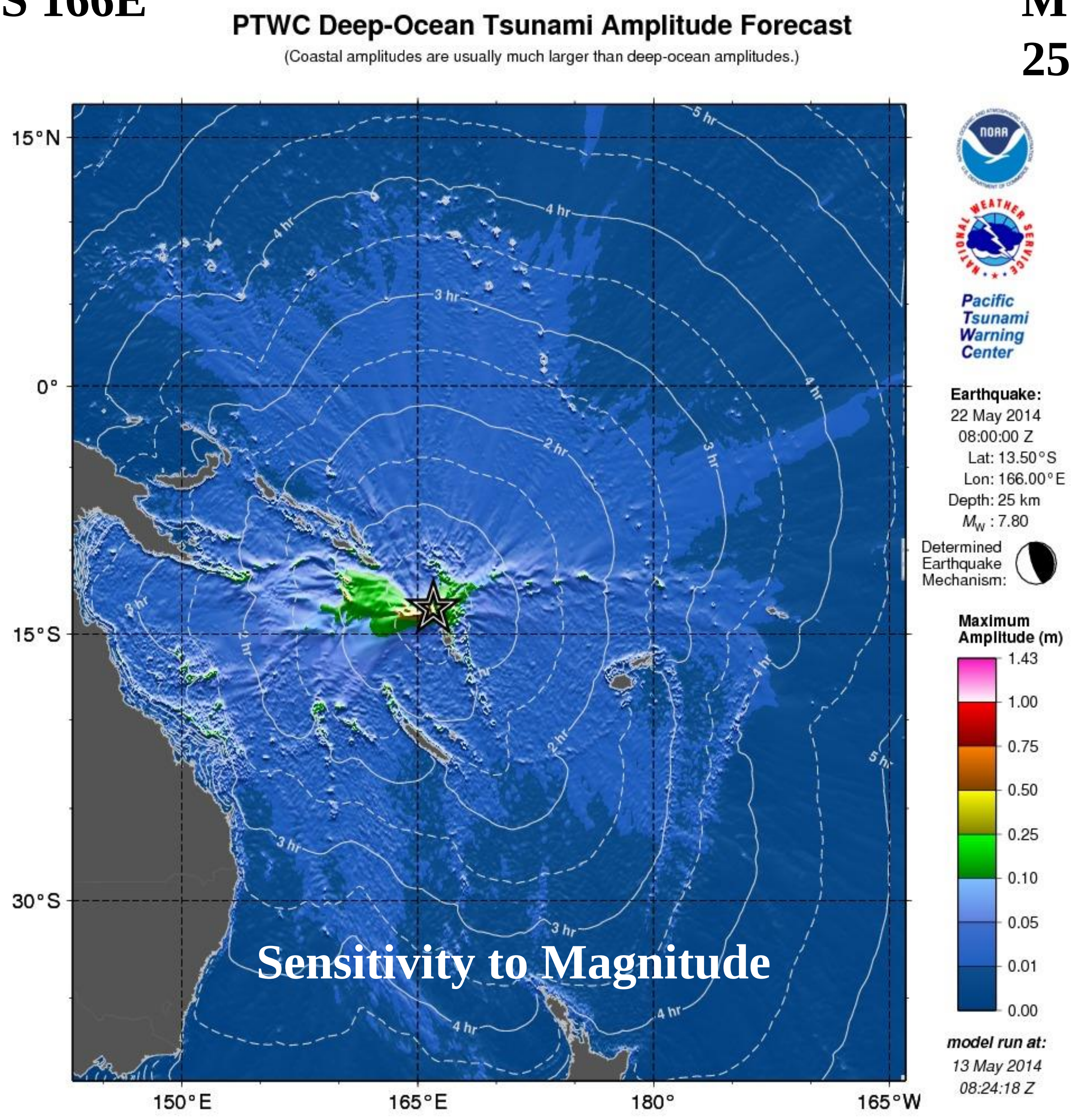
Loc: 13.5S 166E

M 7.6
25 km deep



Loc: 13.5S 166E

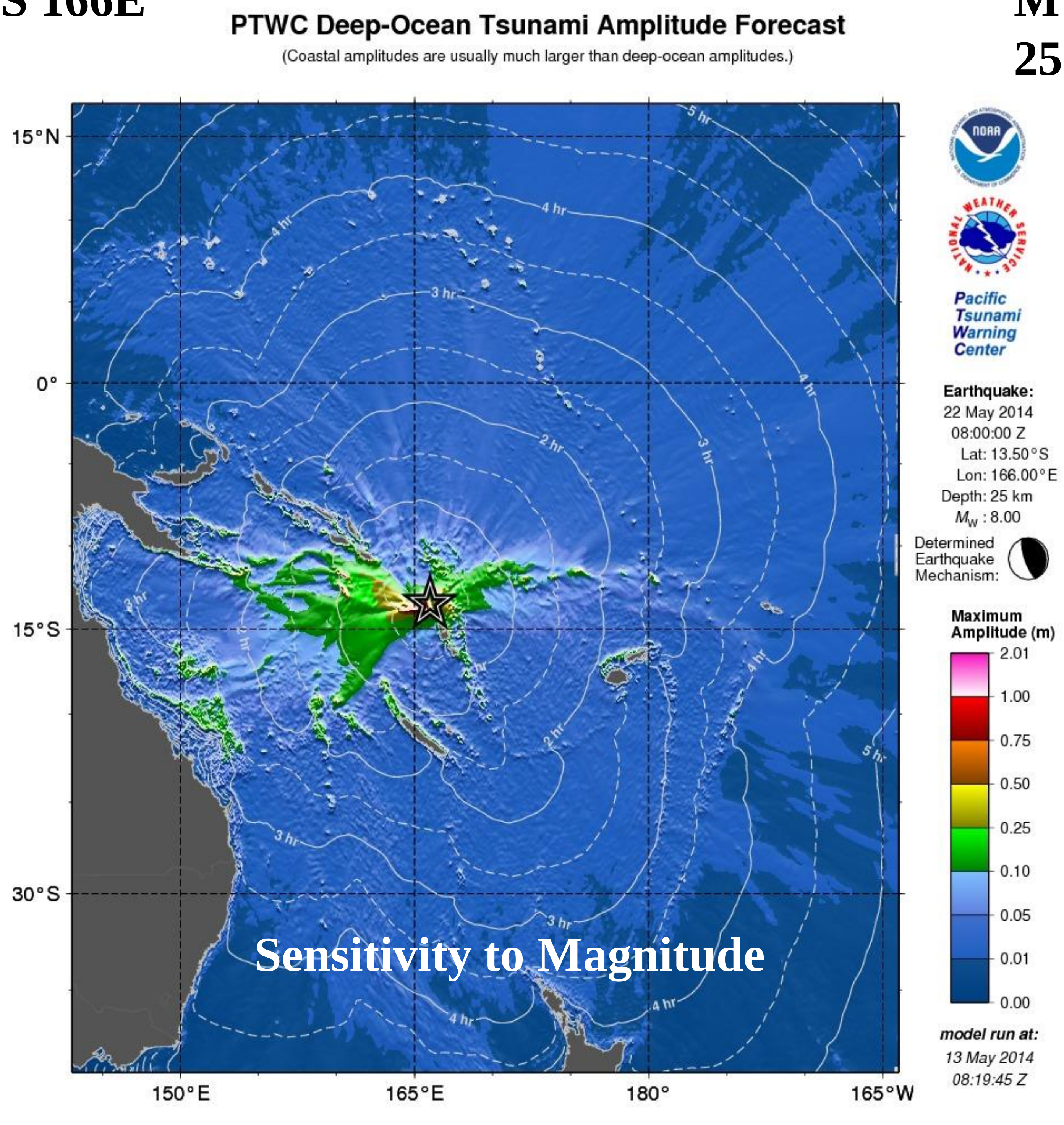
M 7.8
25 km deep



Sensitivity to Magnitude

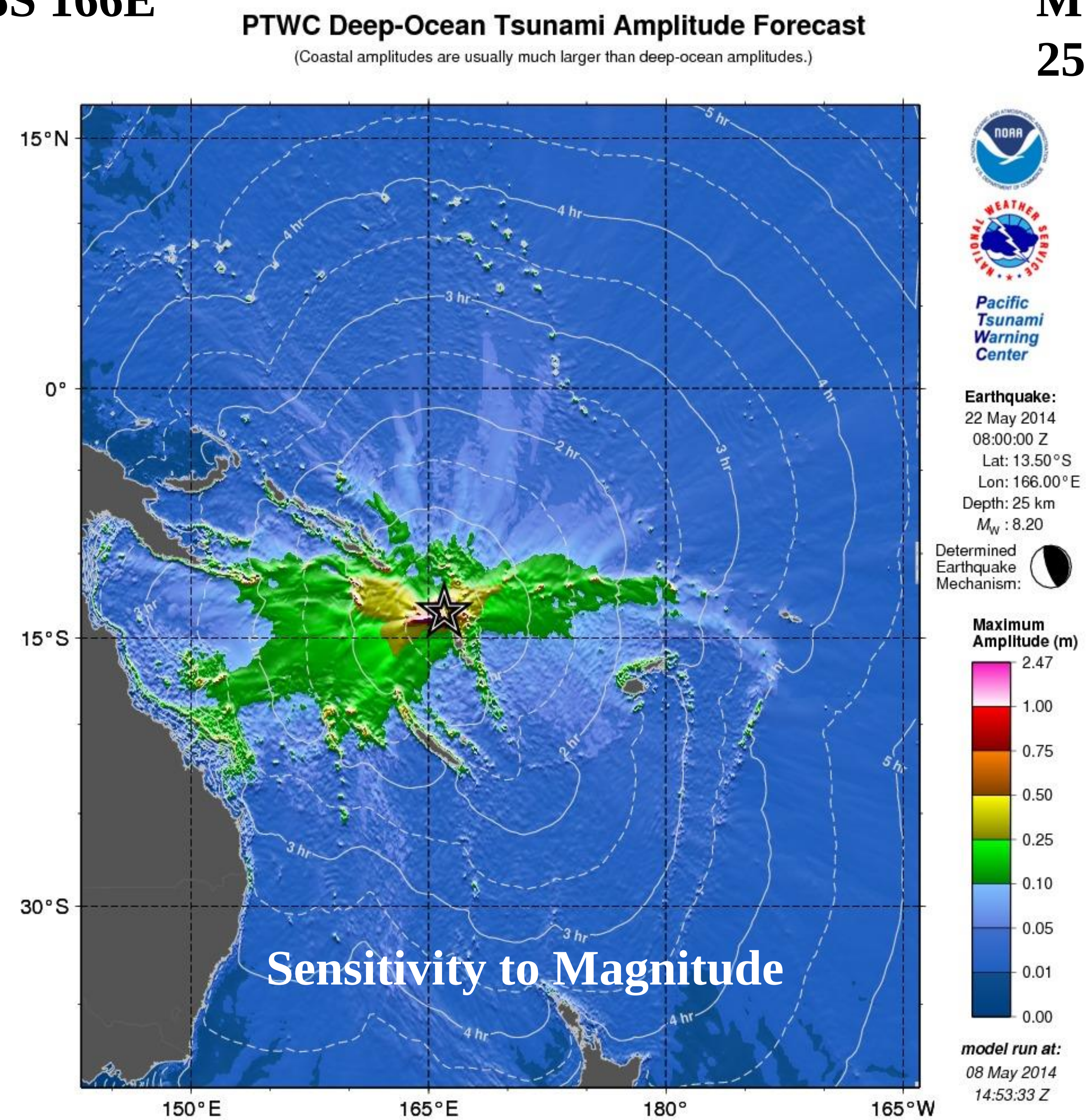
Loc: 13.5S 166E

M 8.0
25 km deep



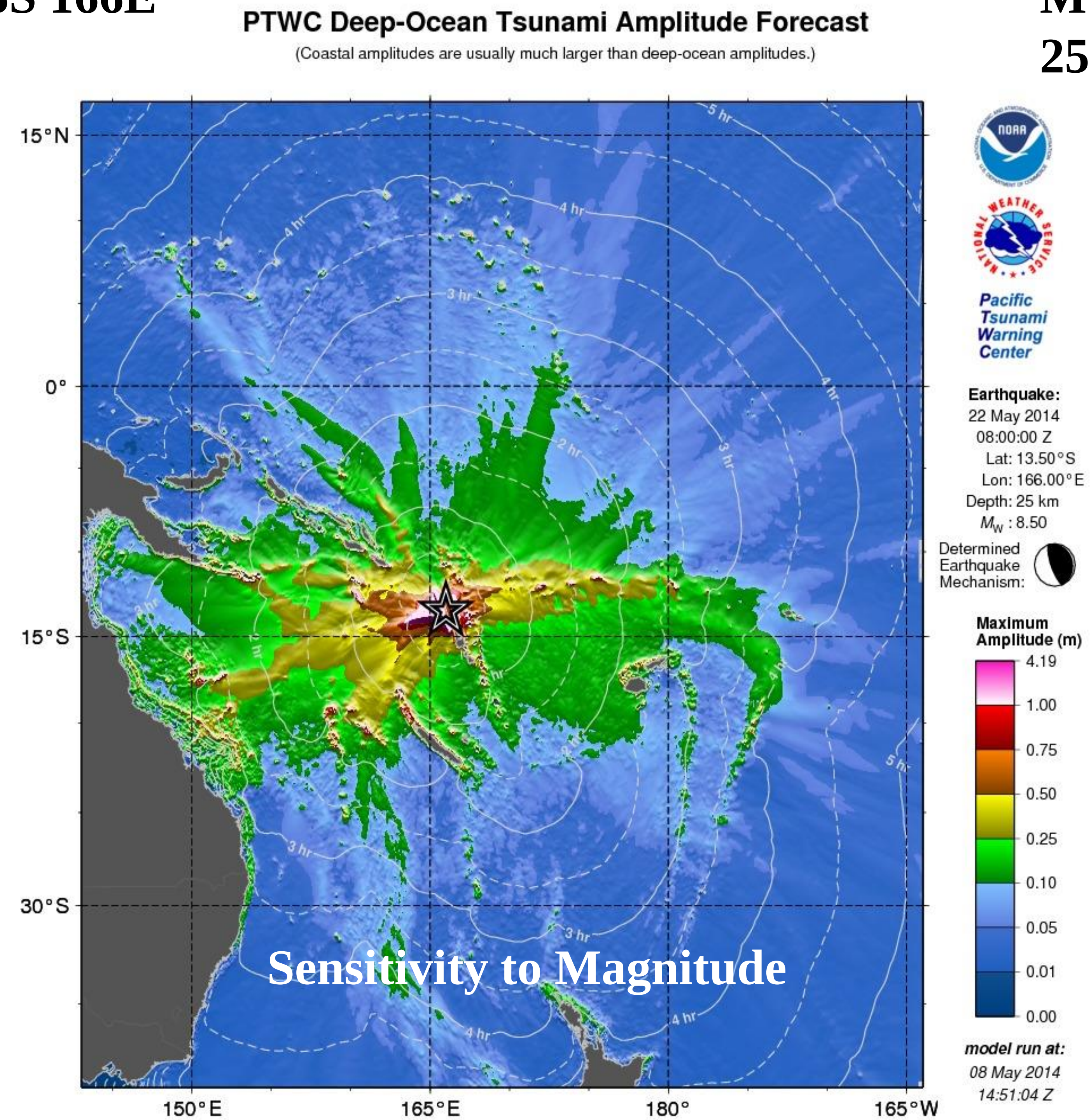
Loc: 13.5S 166E

M 8.2
25 km deep



Loc: 13.5S 166E

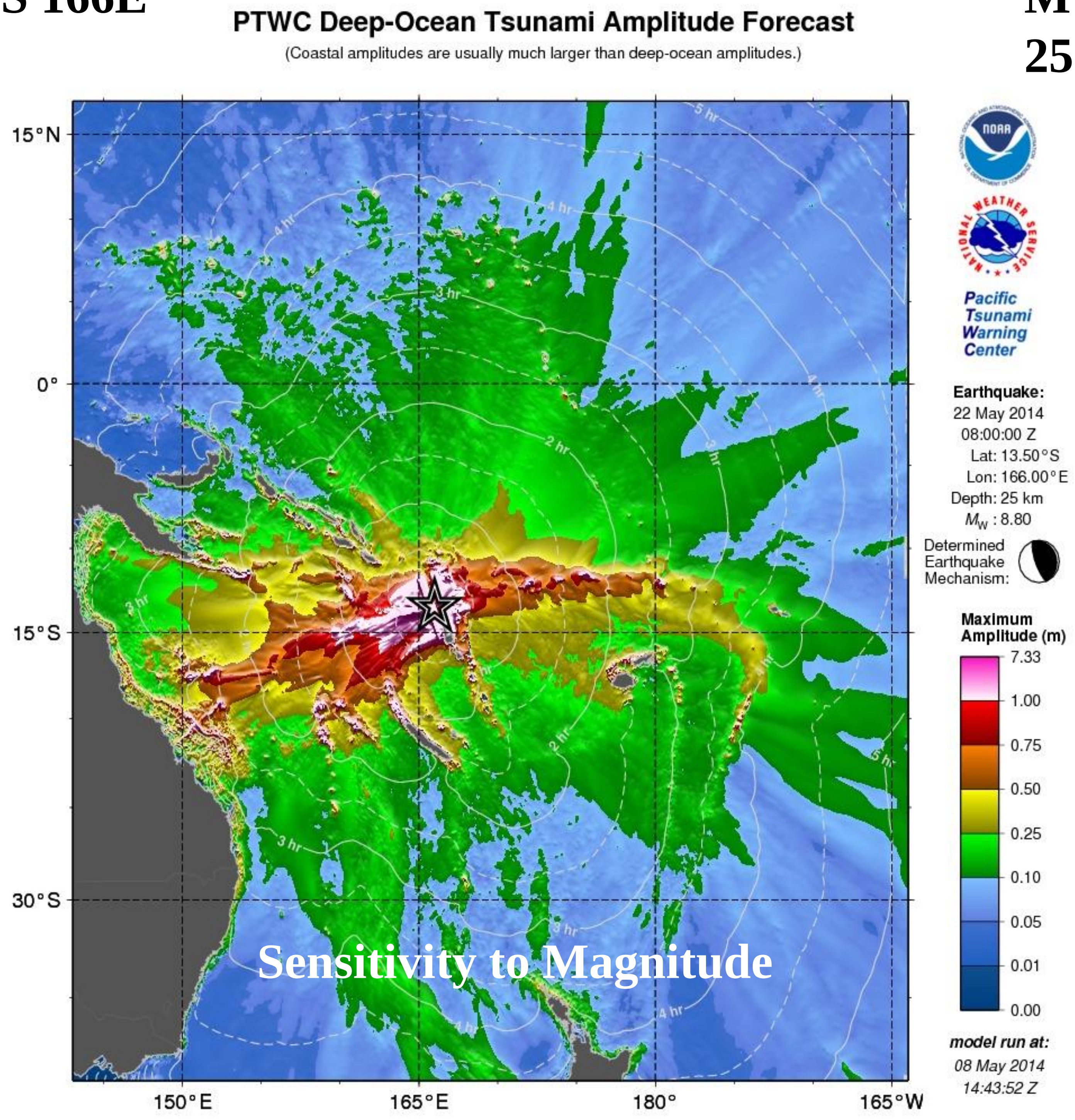
M 8.5
25 km deep



Sensitivity to Magnitude

Loc: 13.5S 166E

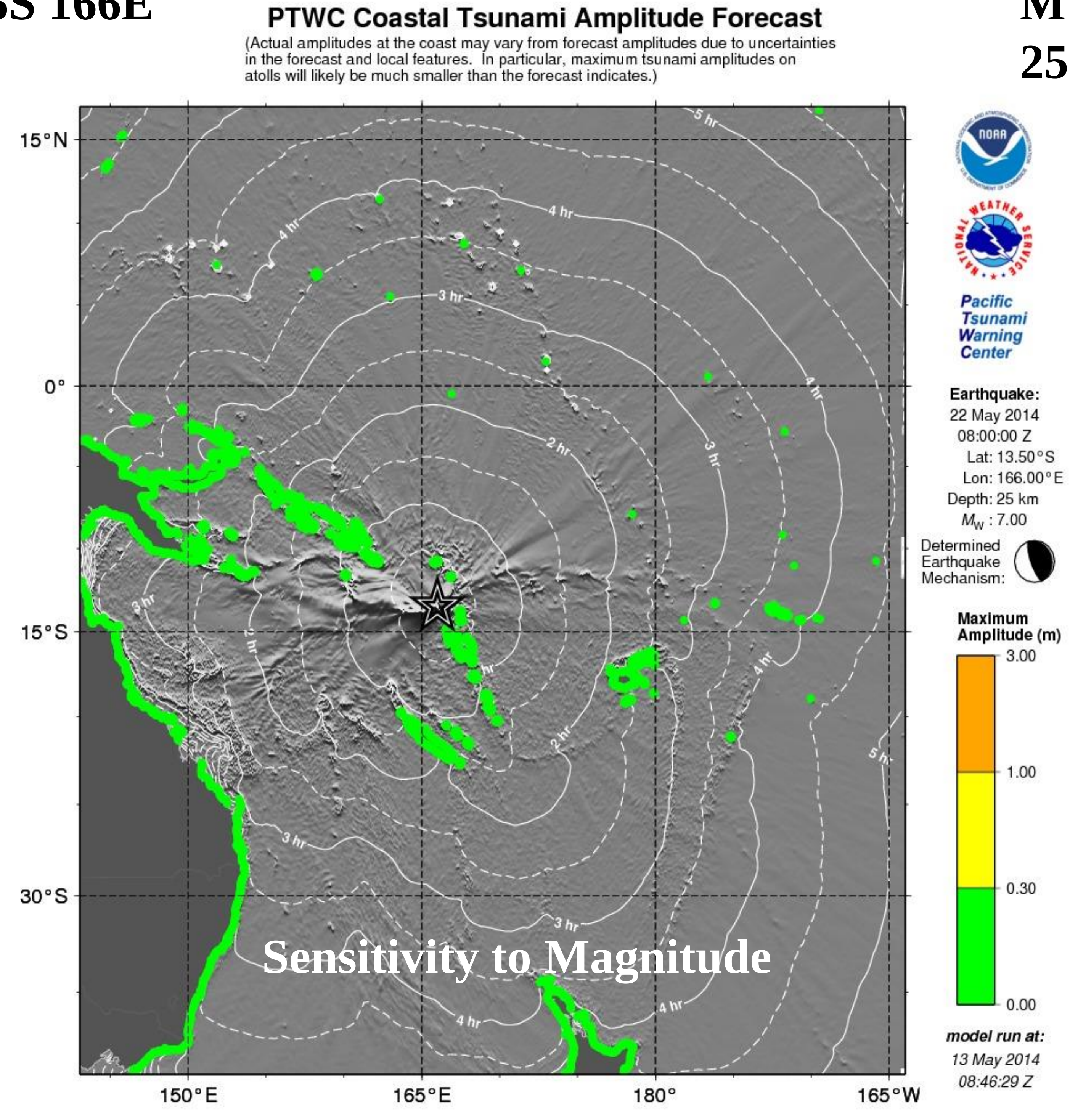
M 8.8
25 km deep



Sensitivity to Magnitude

Loc: 13.5S 166E

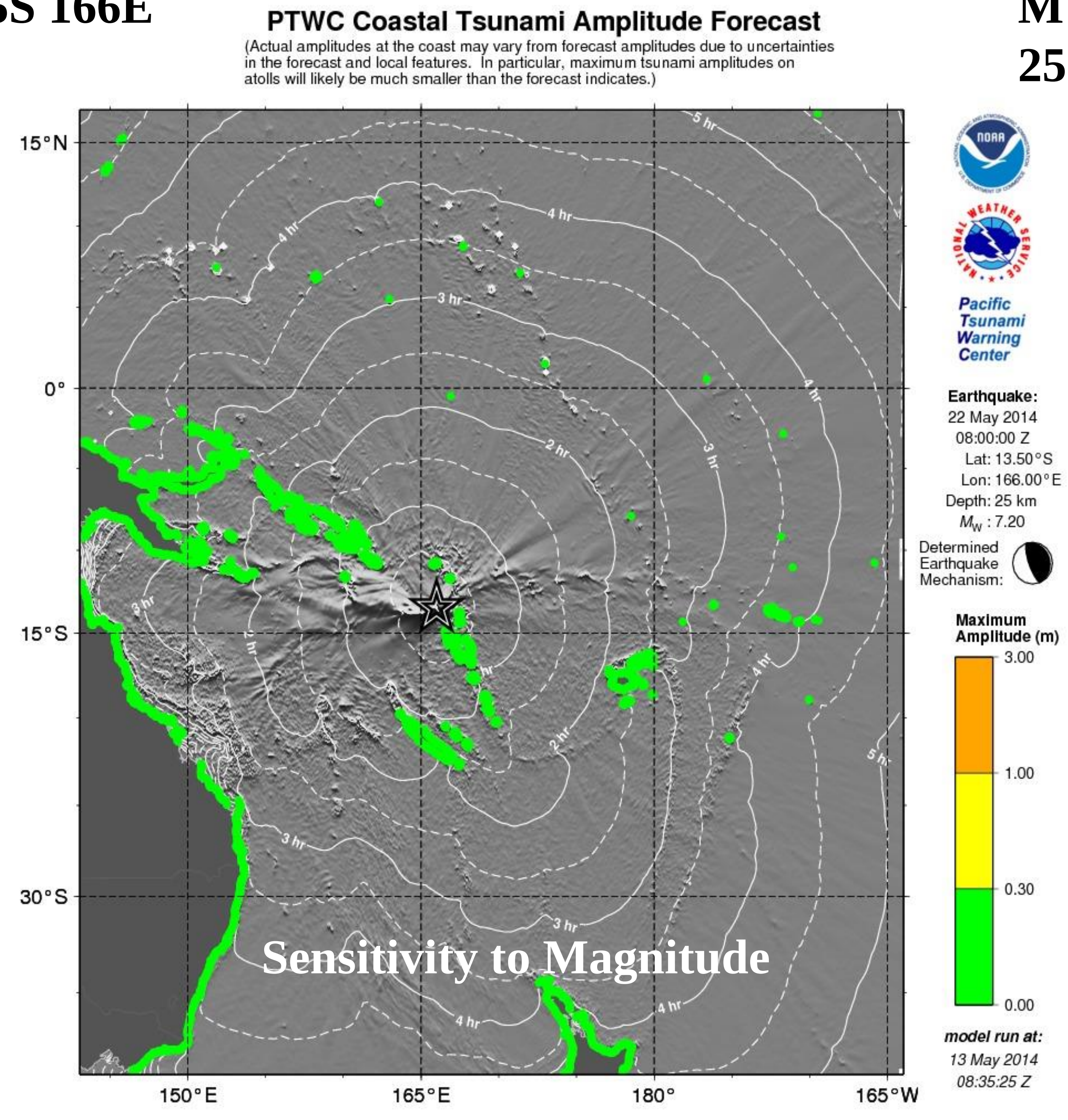
M 7.0
25 km deep



Sensitivity to Magnitude

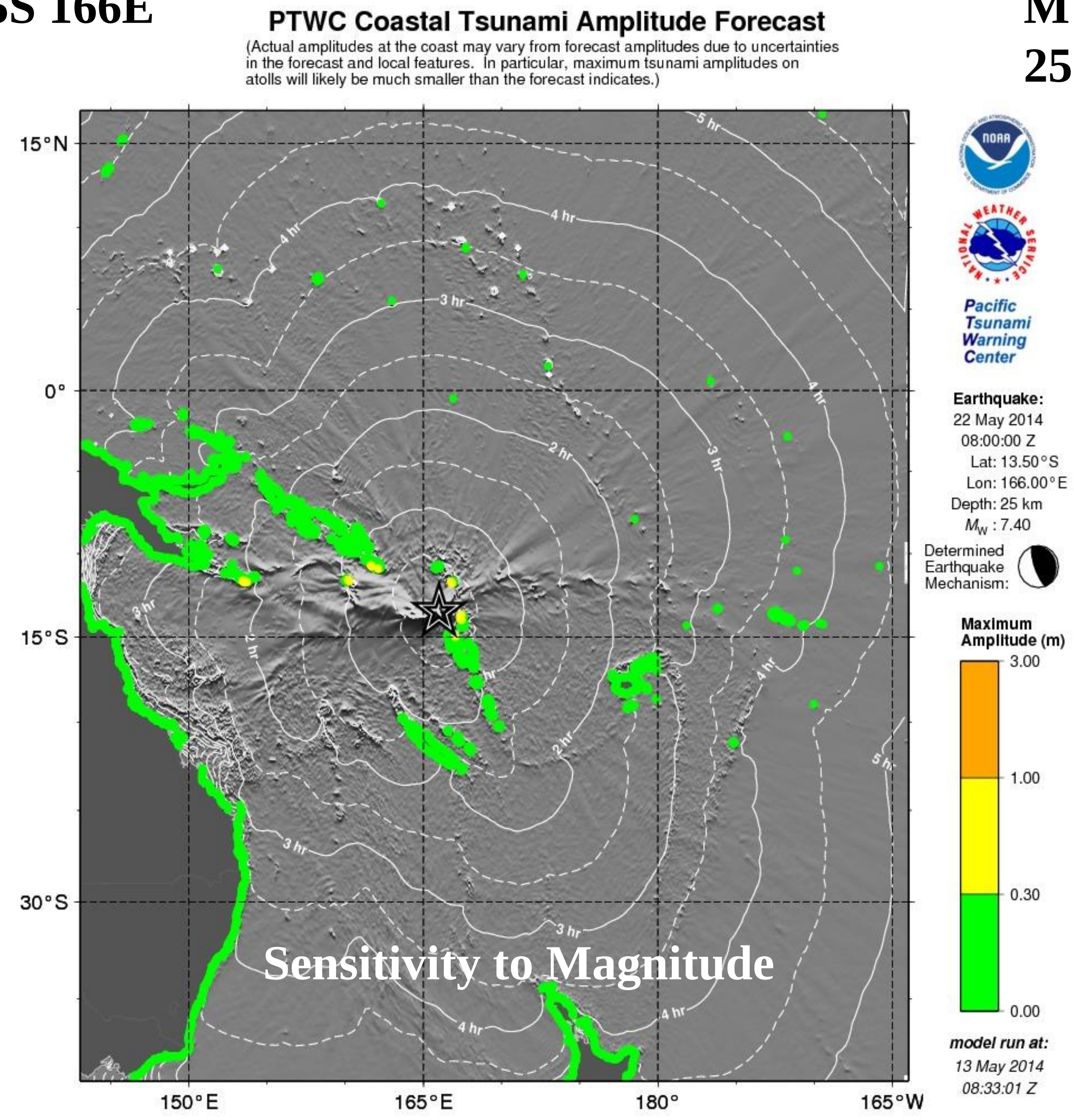
Loc: 13.5S 166E

M 7.2
25 km deep



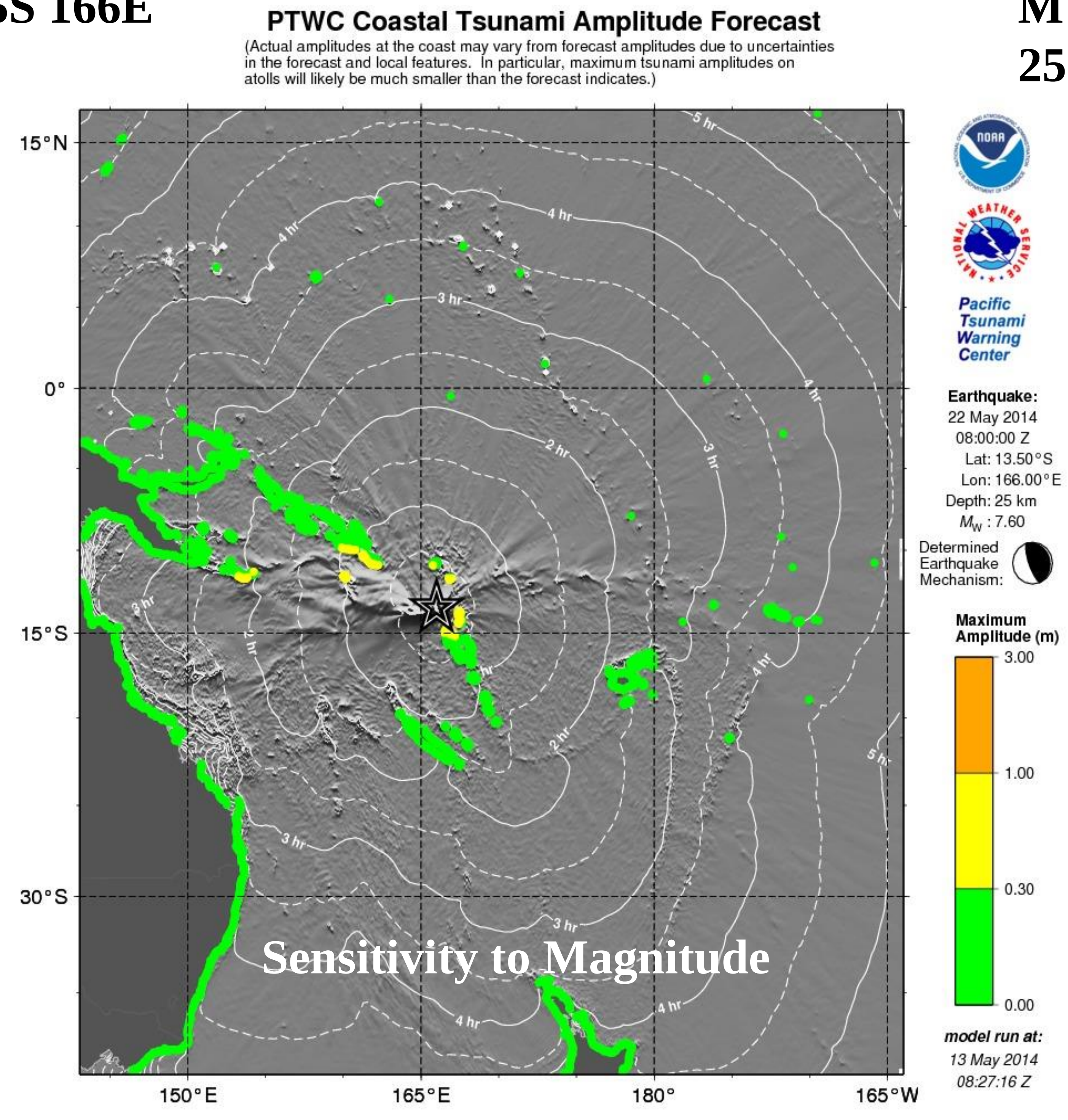
Loc: 13.5S 166E

M 7.4
25 km deep



Loc: 13.5S 166E

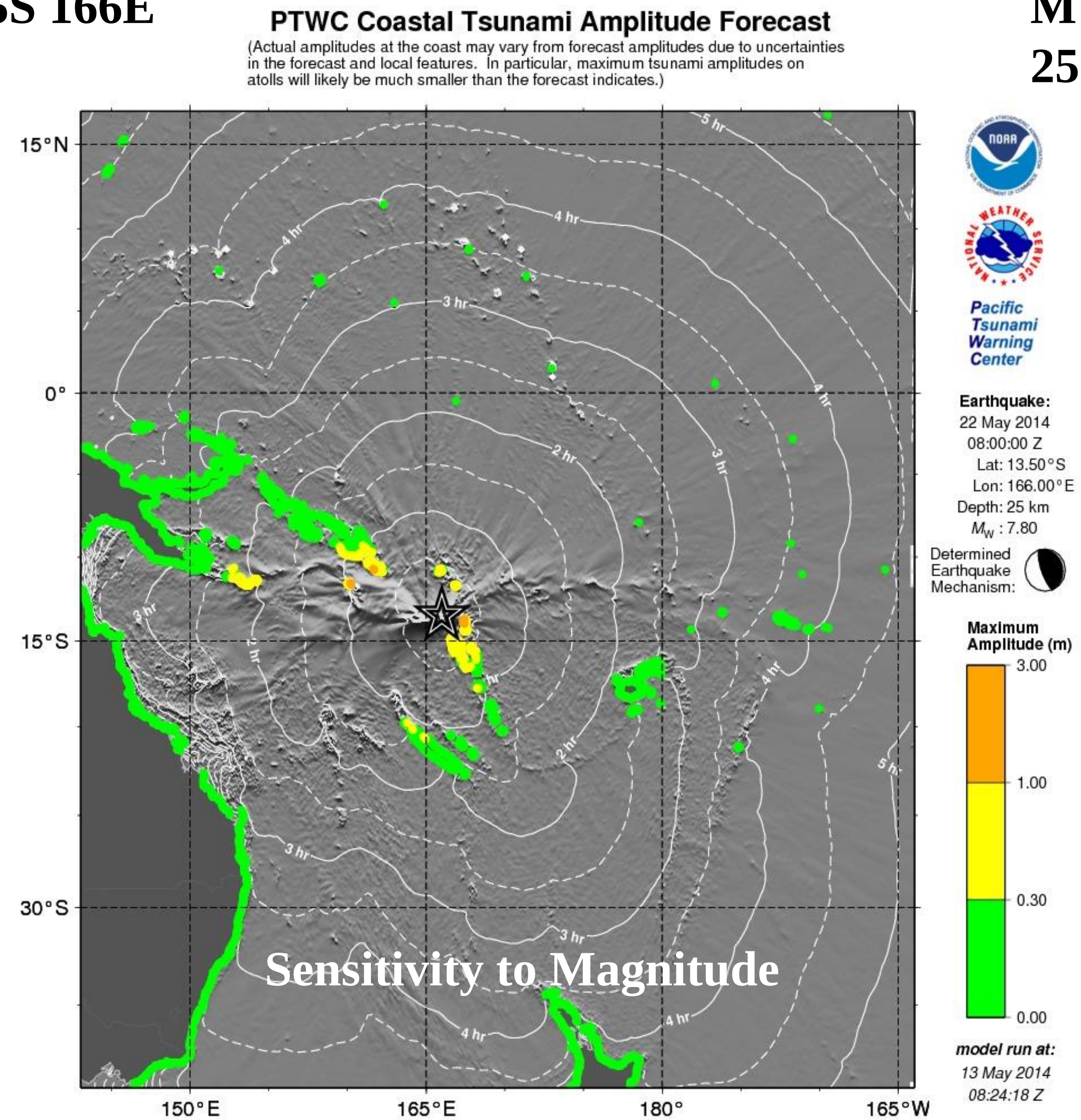
M 7.6
25 km deep



Sensitivity to Magnitude

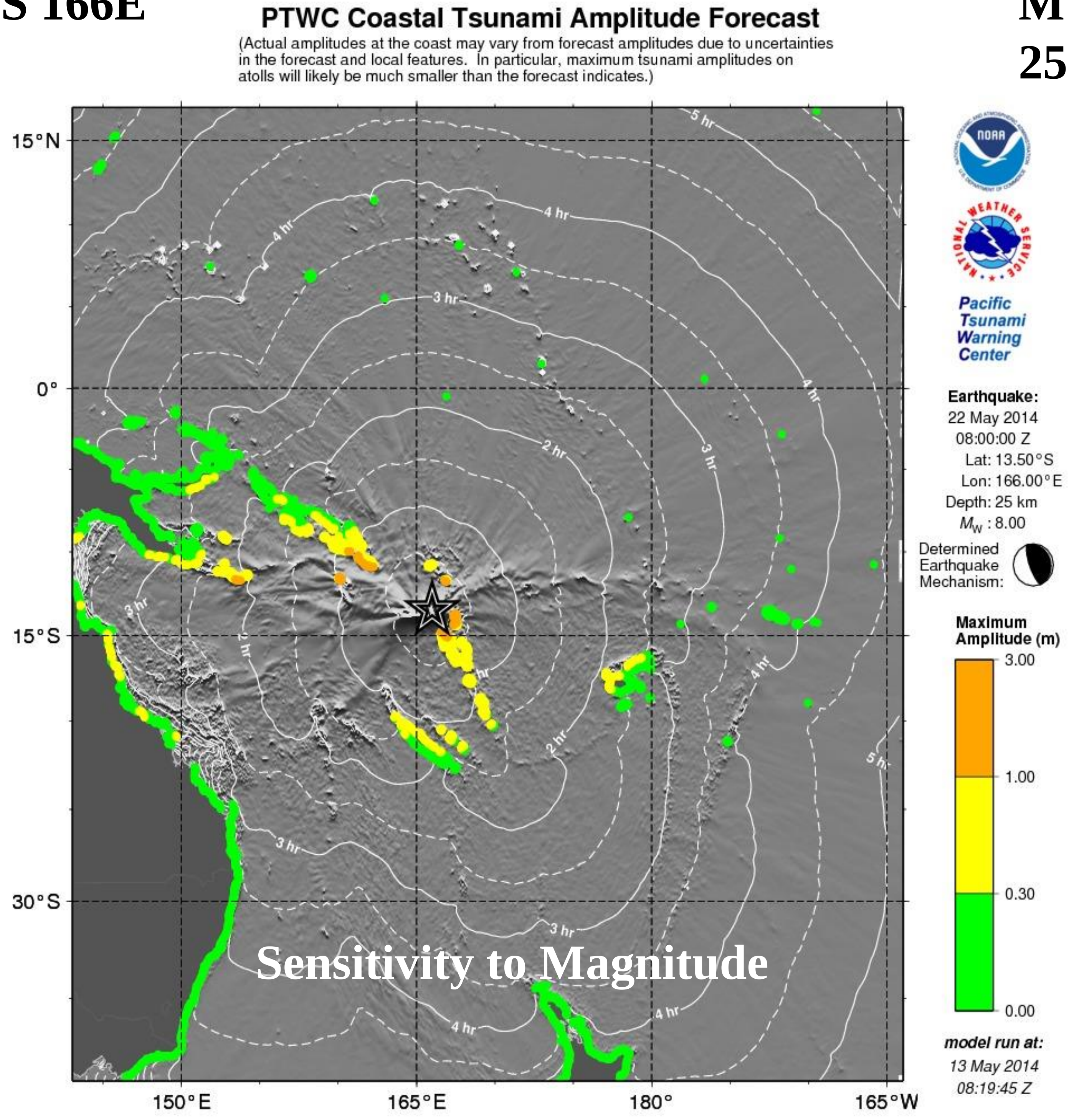
Loc: 13.5S 166E

M 7.6
25 km deep



Loc: 13.5S 166E

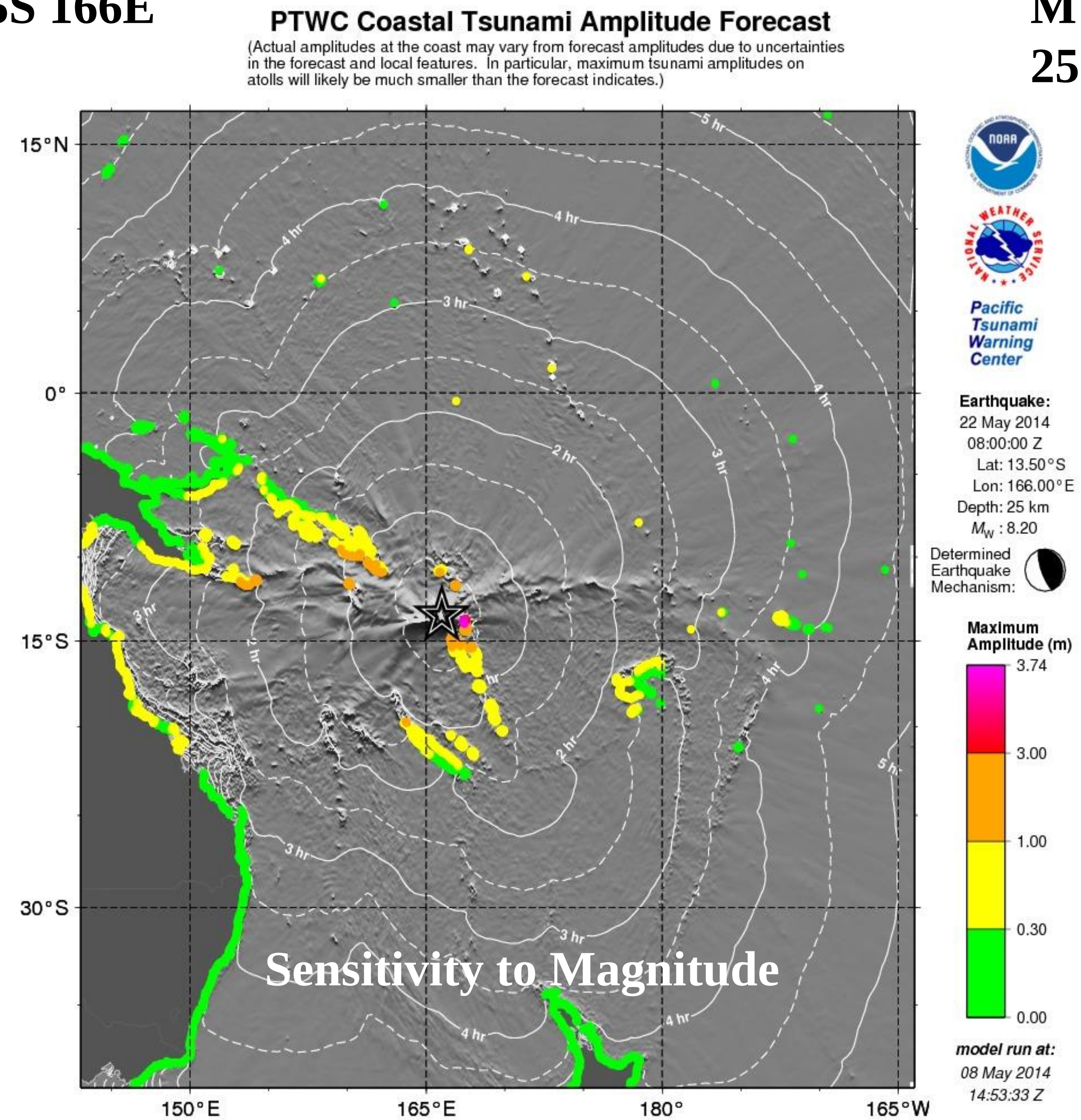
M 8.0
25 km deep



Sensitivity to Magnitude

Loc: 13.5S 166E

M 8.2
25 km deep

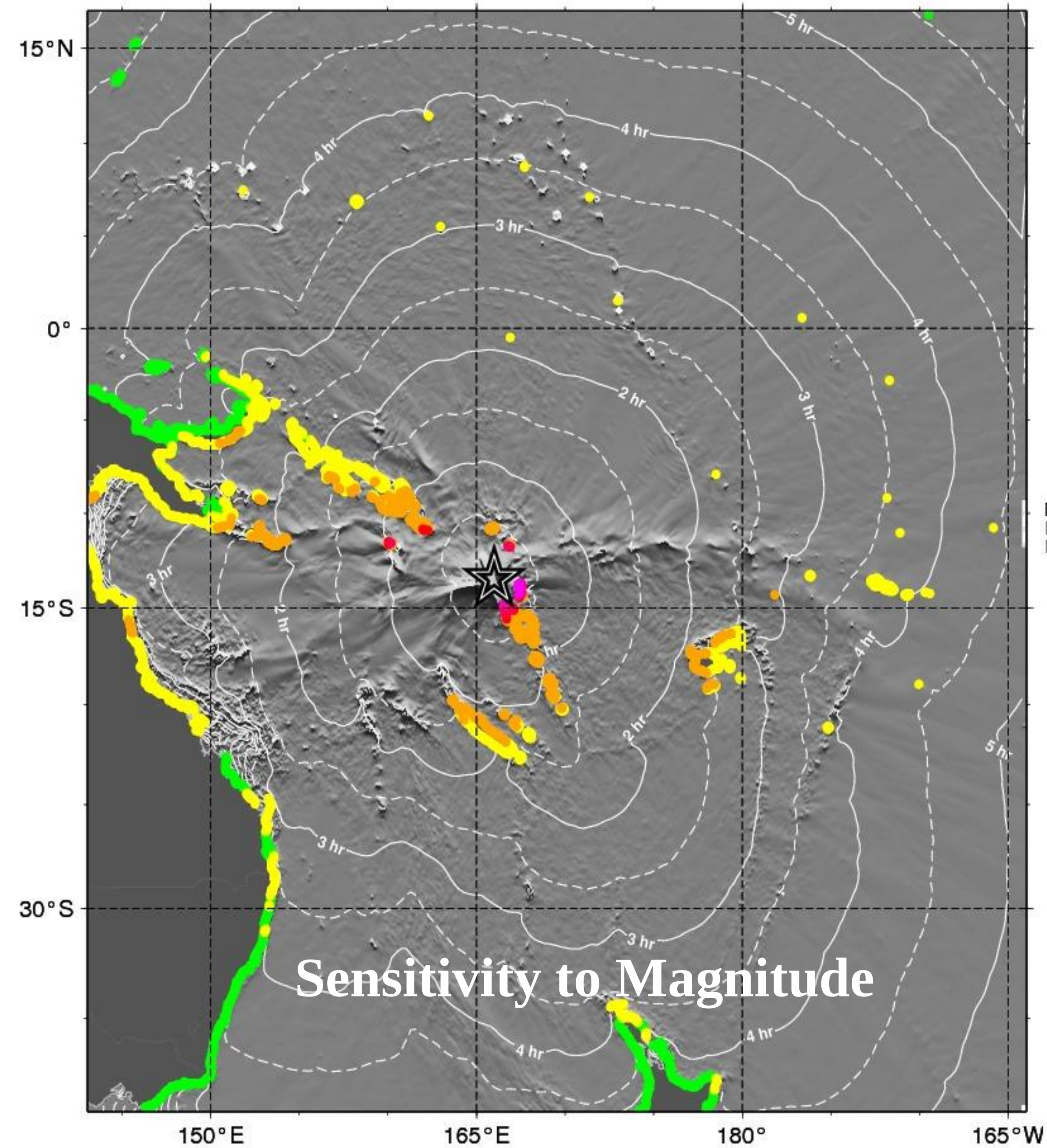


Loc: 13.5S 166E

M 8.5
25 km deep

PTWC Coastal Tsunami Amplitude Forecast

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Pacific Tsunami Warning Center

Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 25 km
M_W : 8.50

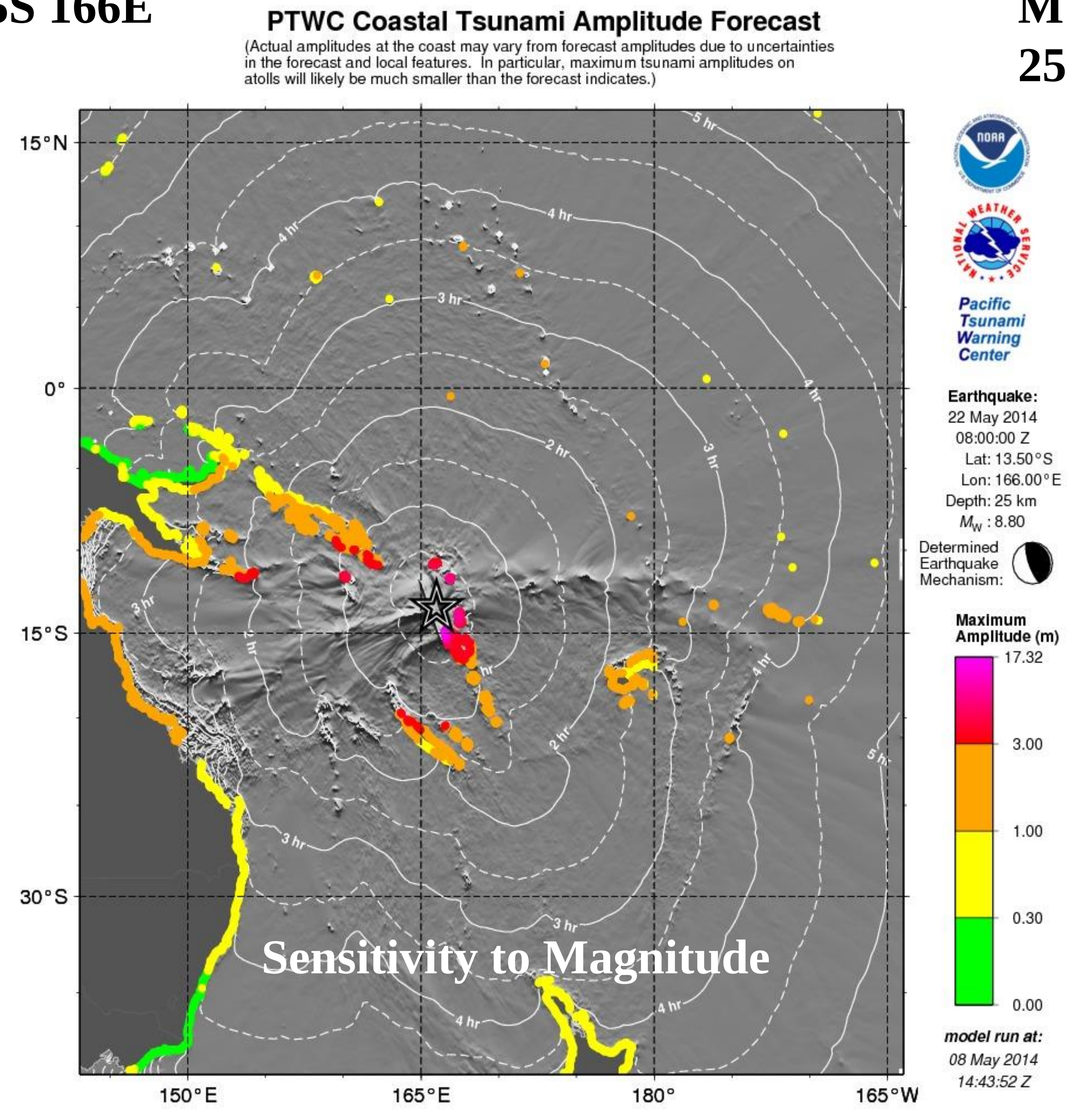
Determined Earthquake Mechanism:

Maximum Amplitude (m)
7.31
3.00
1.00
0.30
0.00

model run at:
08 May 2014
14:51:04 Z

Loc: 13.5S 166E

M 8.8
25 km deep



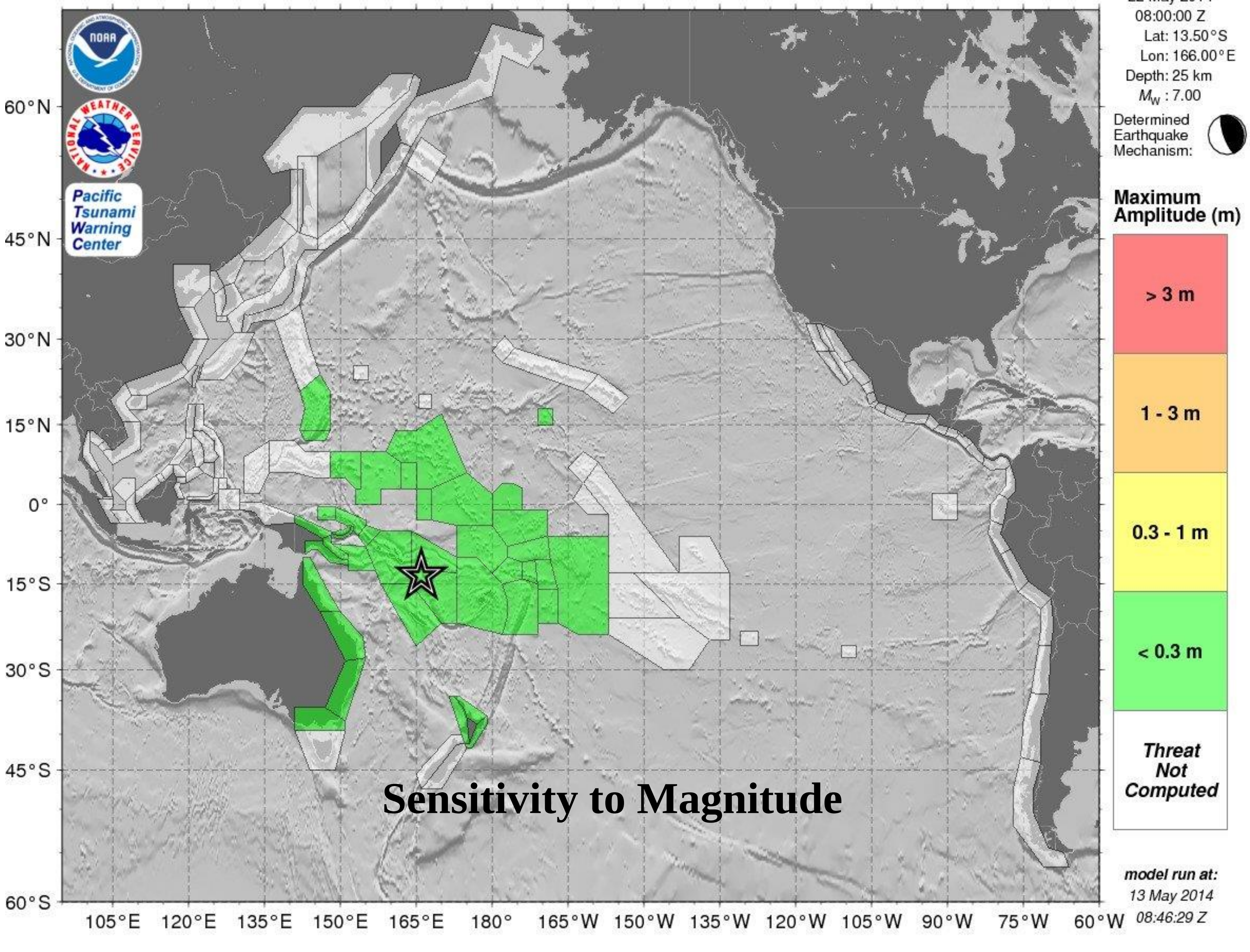
Sensitivity to Magnitude

Loc: 13.5S 166E

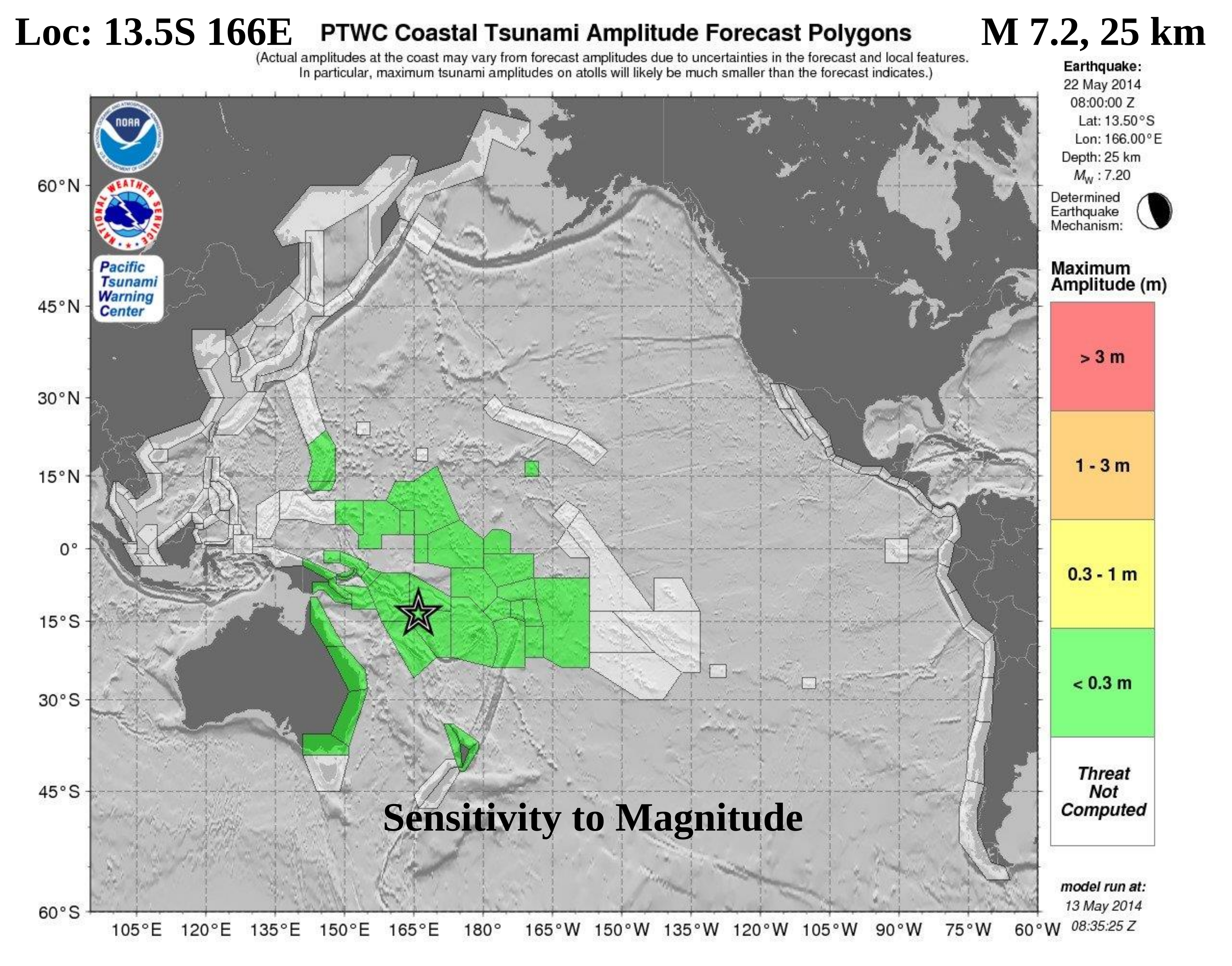
PTWC Coastal Tsunami Amplitude Forecast Polygons

M 7.0, 25 km

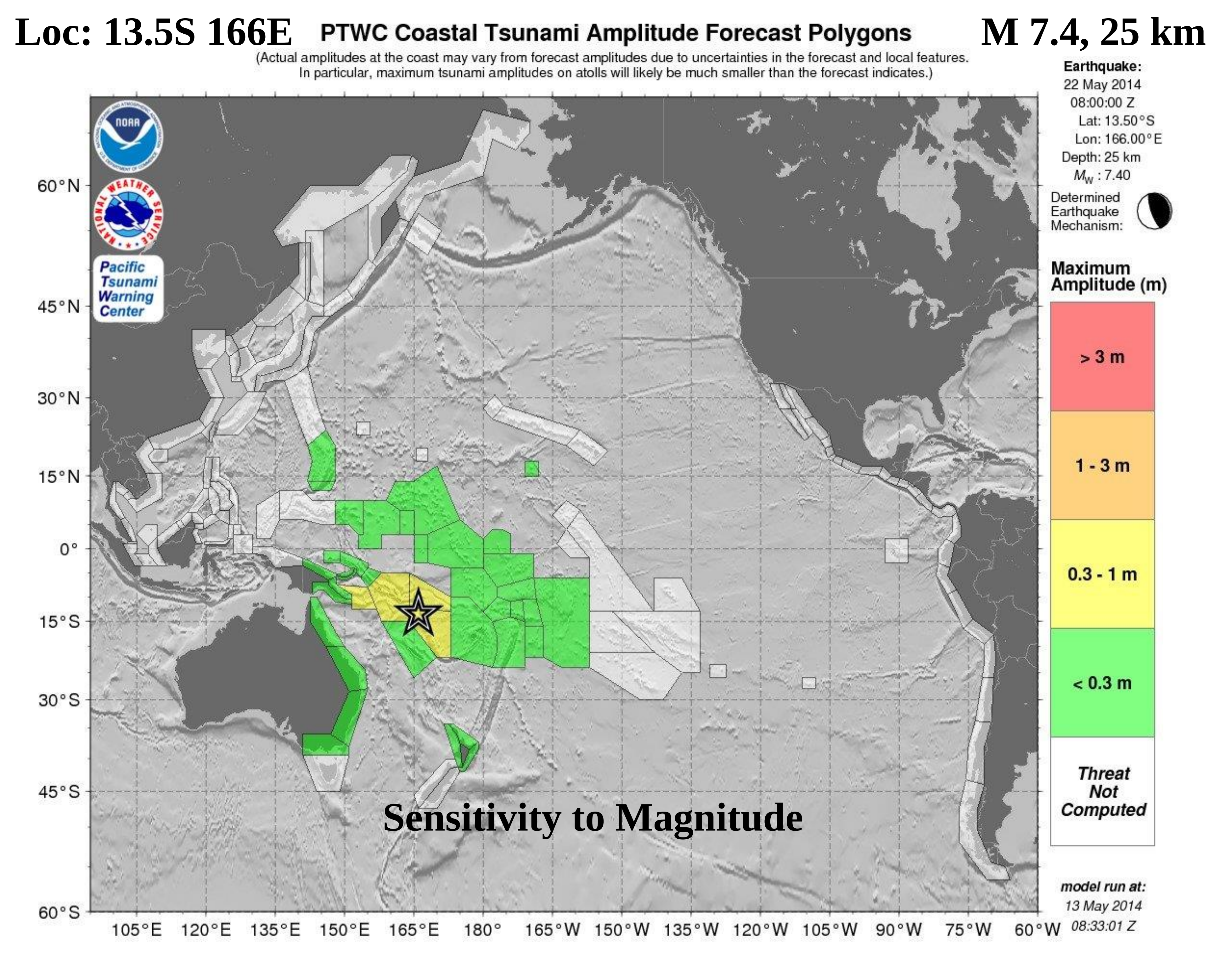
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Sensitivity to Magnitude

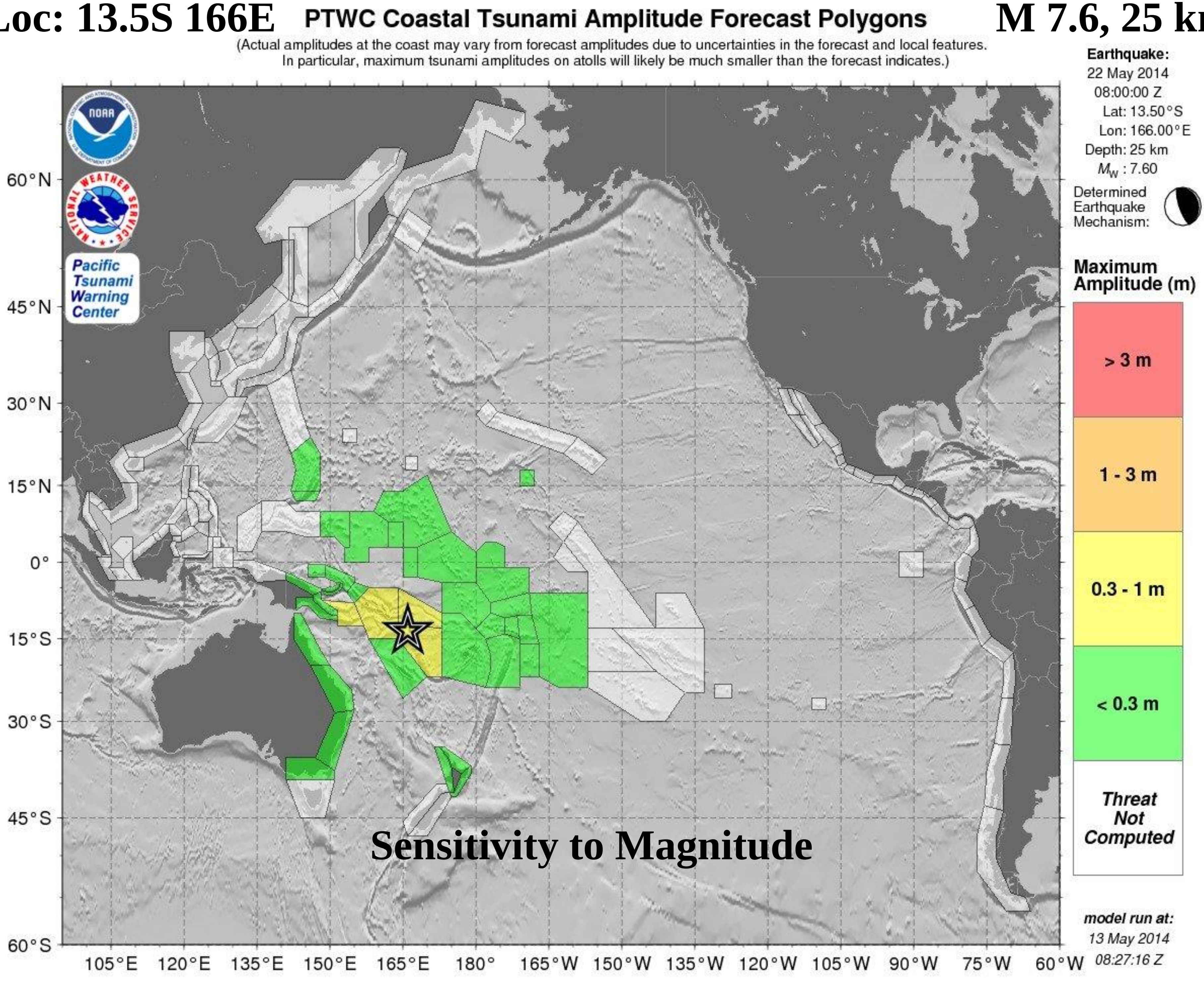


Loc: 13.5S 166E
PTWC Coastal Tsunami Amplitude Forecast Polygons
M 7.2, 25 km
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features.
In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)
Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 25 km
M_W : 7.20
Determined Earthquake Mechanism:
Maximum Amplitude (m)
> 3 m
1 - 3 m
0.3 - 1 m
< 0.3 m
Threat Not Computed
model run at:
13 May 2014
08:35:25 Z
Pacific Tsunami Warning Center
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
105°E
120°E
135°E
150°E
165°E
180°
165°W
150°W
135°W
120°W
105°W
90°W
75°W
60°W
Sensitivity to Magnitude

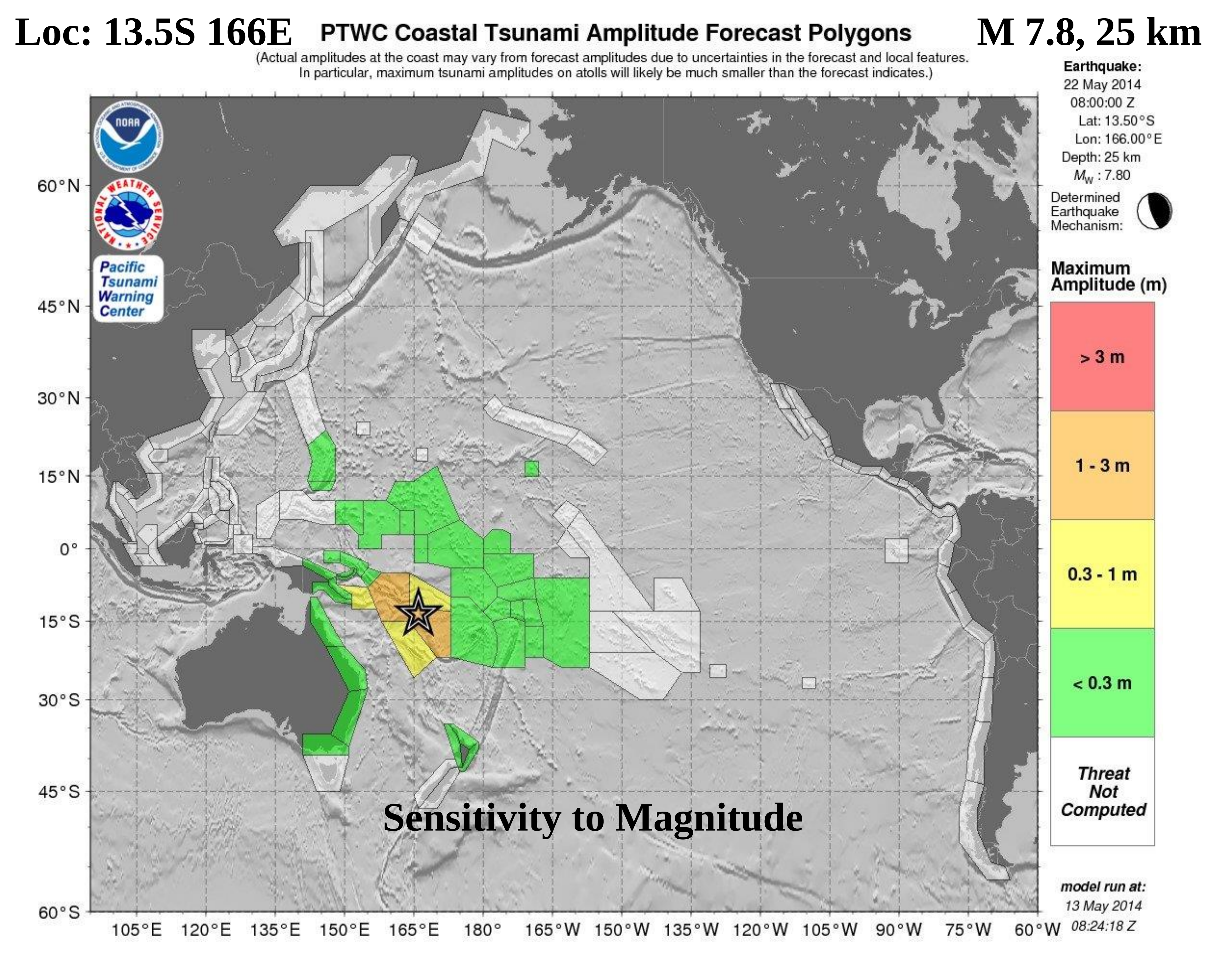

Loc: 13.5S 166E
PTWC Coastal Tsunami Amplitude Forecast Polygons
M 7.4, 25 km
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features.
In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)
Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 25 km
M_W : 7.40
Determined Earthquake Mechanism:
Maximum Amplitude (m)
> 3 m
1 - 3 m
0.3 - 1 m
< 0.3 m
Threat Not Computed
Pacific Tsunami Warning Center
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
105°E
120°E
135°E
150°E
165°E
180°
165°W
150°W
135°W
120°W
105°W
90°W
75°W
60°W
Sensitivity to Magnitude
model run at:
13 May 2014
08:33:01 Z

Loc: 13.5S 166E

M 7.6, 25 km

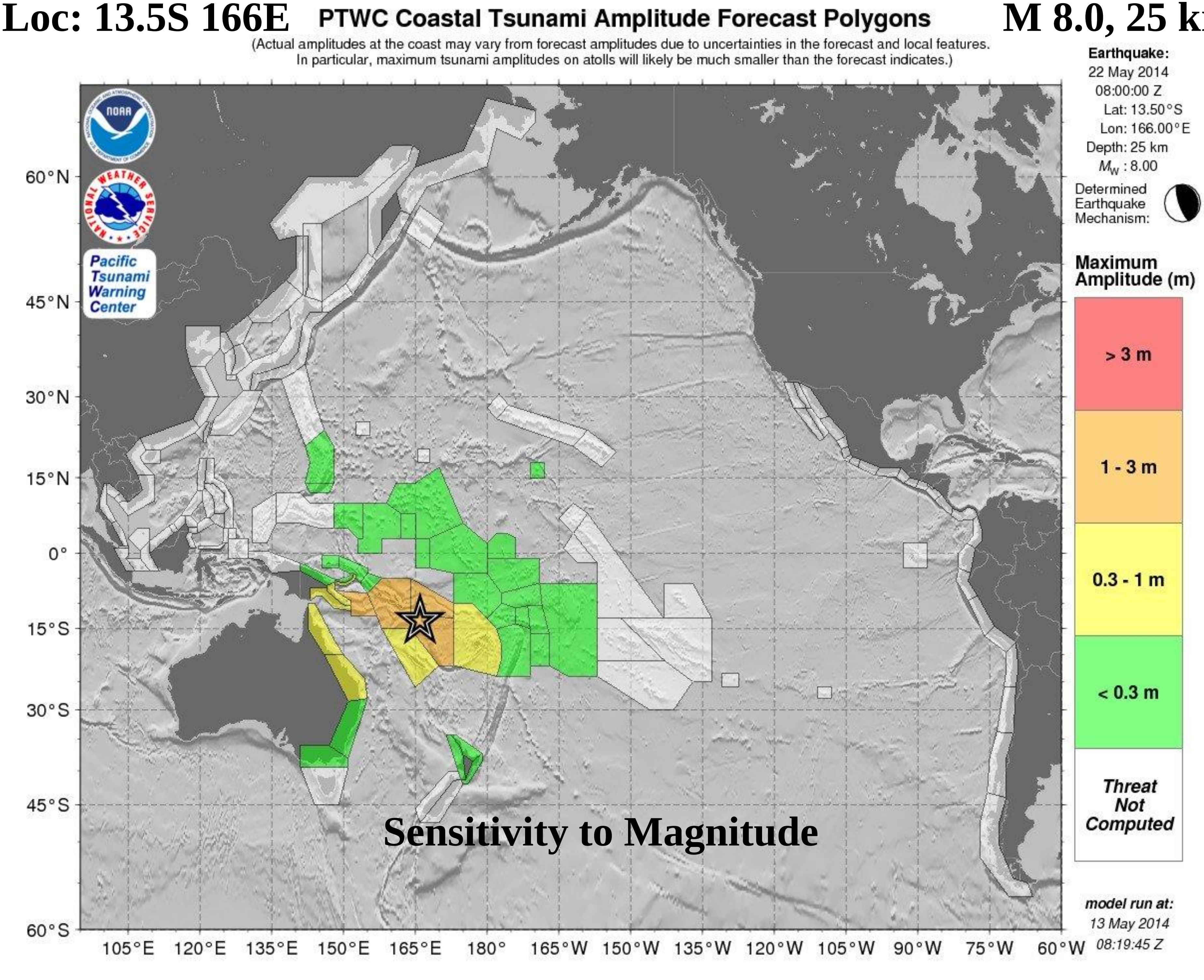


Sensitivity to Magnitude



Loc: 13.5S 166E
PTWC Coastal Tsunami Amplitude Forecast Polygons
M 7.8, 25 km
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features.
In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)
Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 25 km
M_W : 7.80
Determined Earthquake Mechanism:
Maximum Amplitude (m)
> 3 m
1 - 3 m
0.3 - 1 m
< 0.3 m
Threat Not Computed
model run at:
13 May 2014
08:24:18 Z
Pacific Tsunami Warning Center
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
105°E
120°E
135°E
150°E
165°E
180°
165°W
150°W
135°W
120°W
105°W
90°W
75°W
60°W
Sensitivity to Magnitude

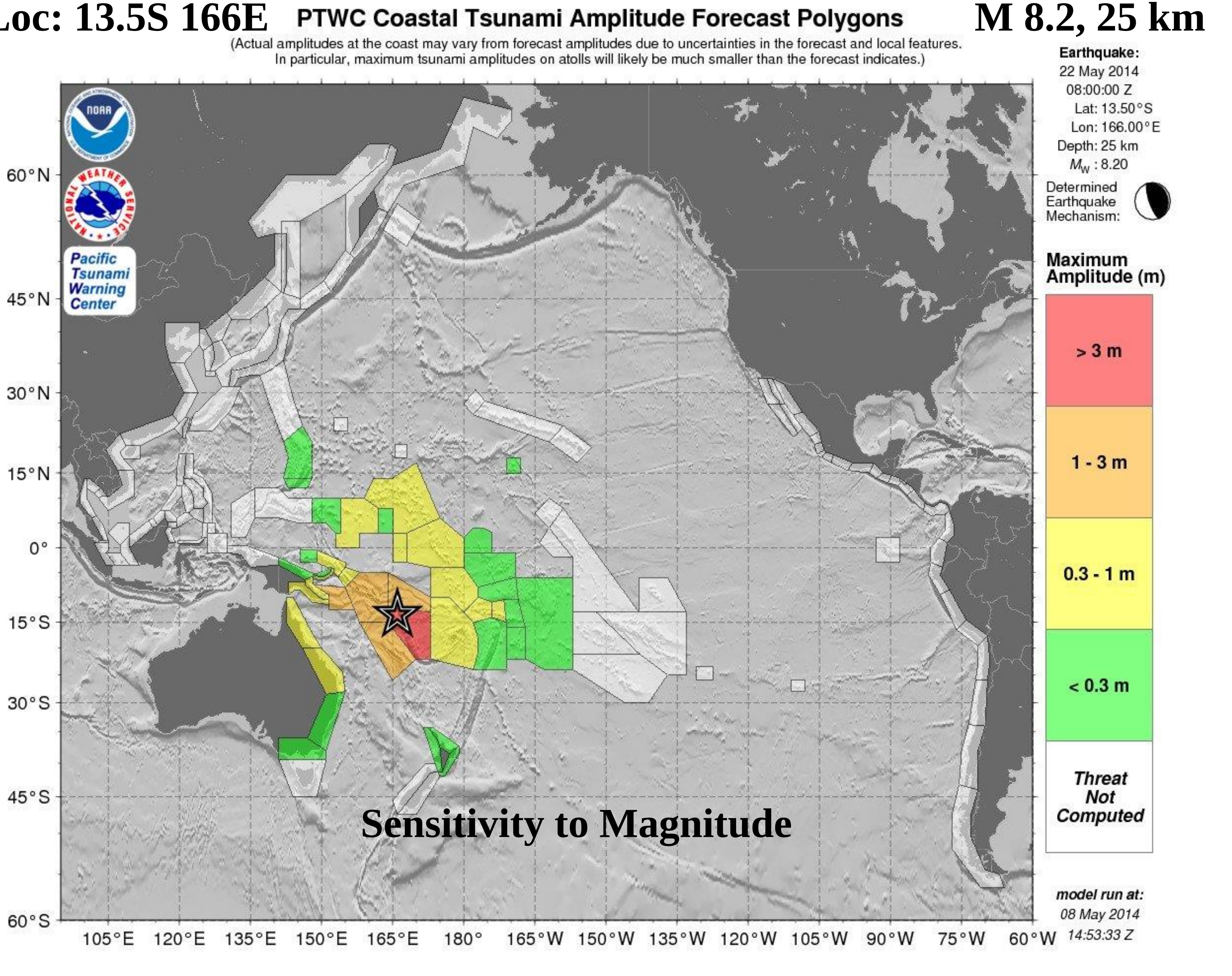
Loc: 13.5S 166E **M 8.0, 25 km**



Sensitivity to Magnitude

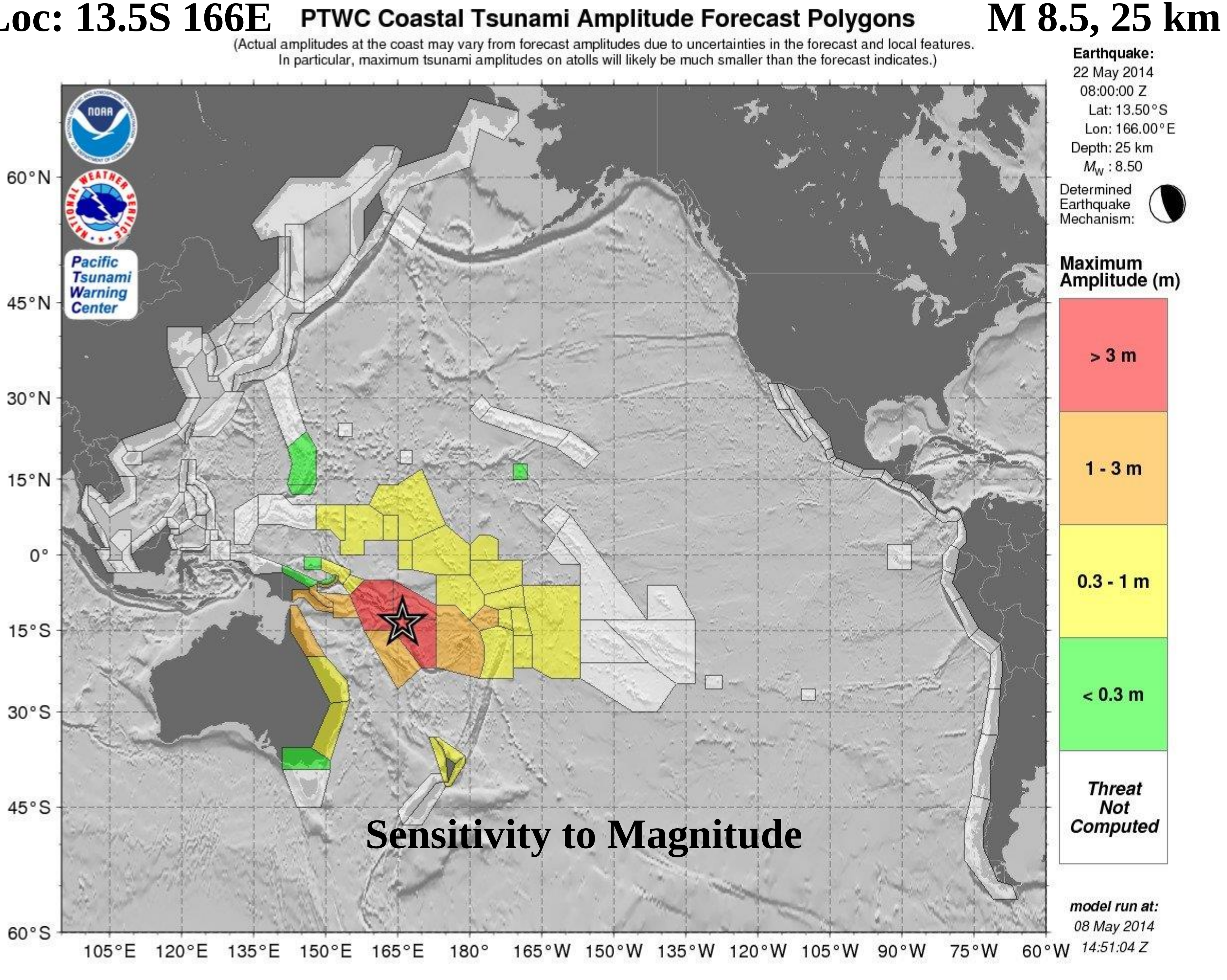
Loc: 13.5S 166E

M 8.2, 25 km



Loc: 13.5S 166E

M 8.5, 25 km



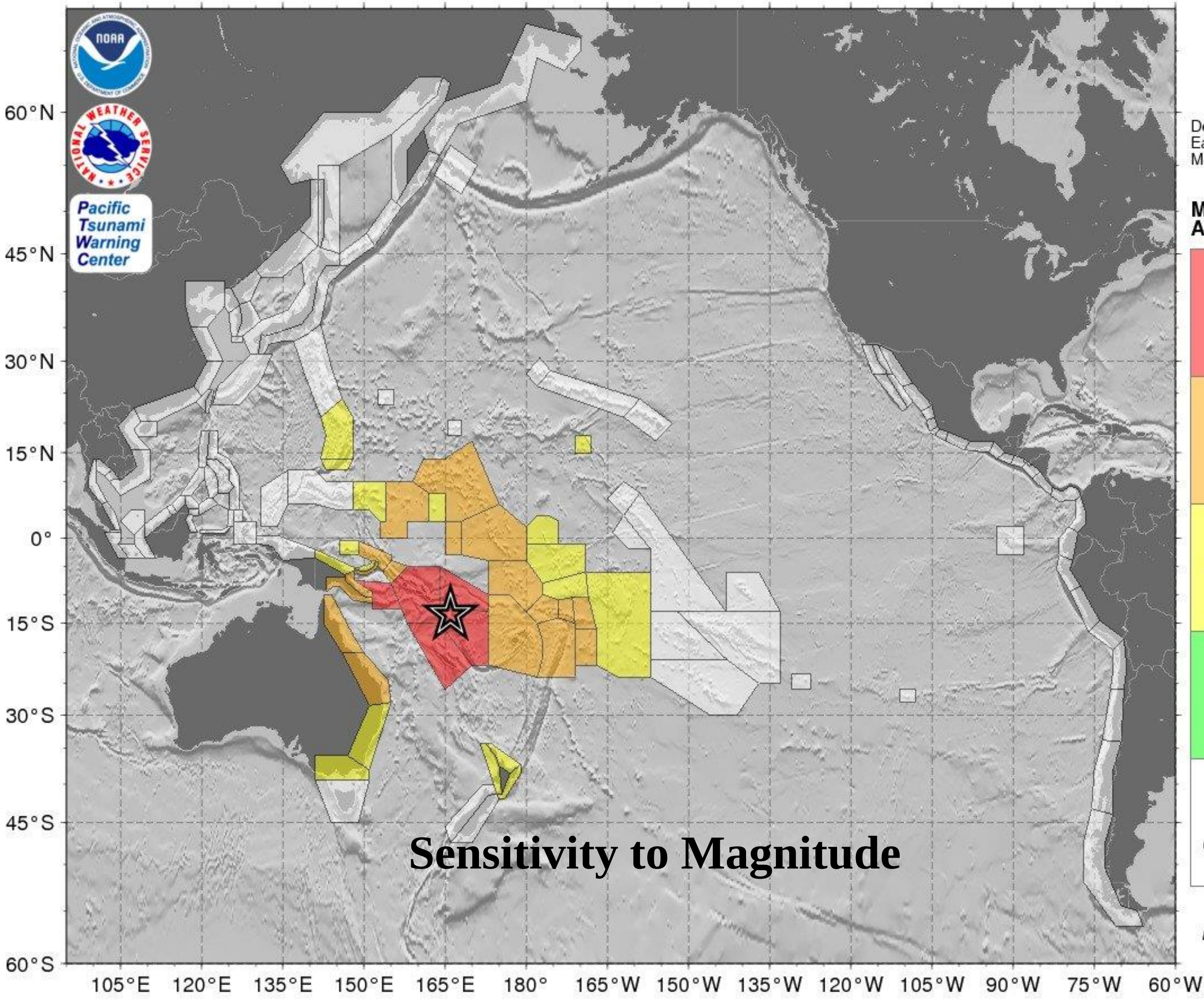
Sensitivity to Magnitude

Loc: 13.5S 166E

PTWC Coastal Tsunami Amplitude Forecast Polygons

M 8.8, 25 km

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 25 km
M_W : 8.80

Determined Earthquake Mechanism:

Maximum Amplitude (m)

- > 3 m
- 1 - 3 m
- 0.3 - 1 m
- < 0.3 m
- *Threat Not Computed*

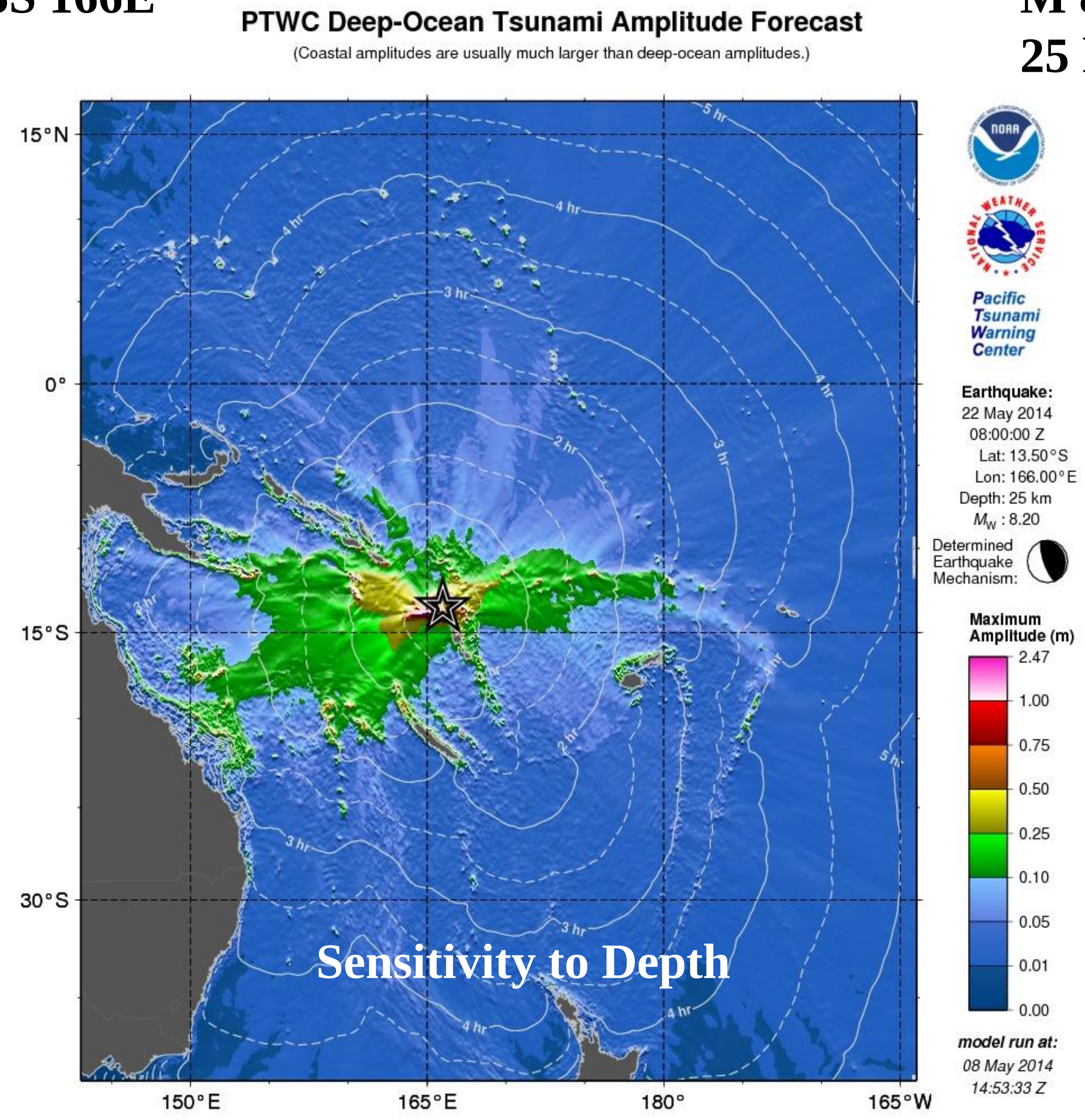
model run at:
08 May 2014
14:43:52 Z

Sensitivity to Depth

- Depth is important because:
- Tsunami size depends of ocean floor disturbance
- Variance with depth with magnitude (M 8.2) and location (13.5S, 166E) held constant

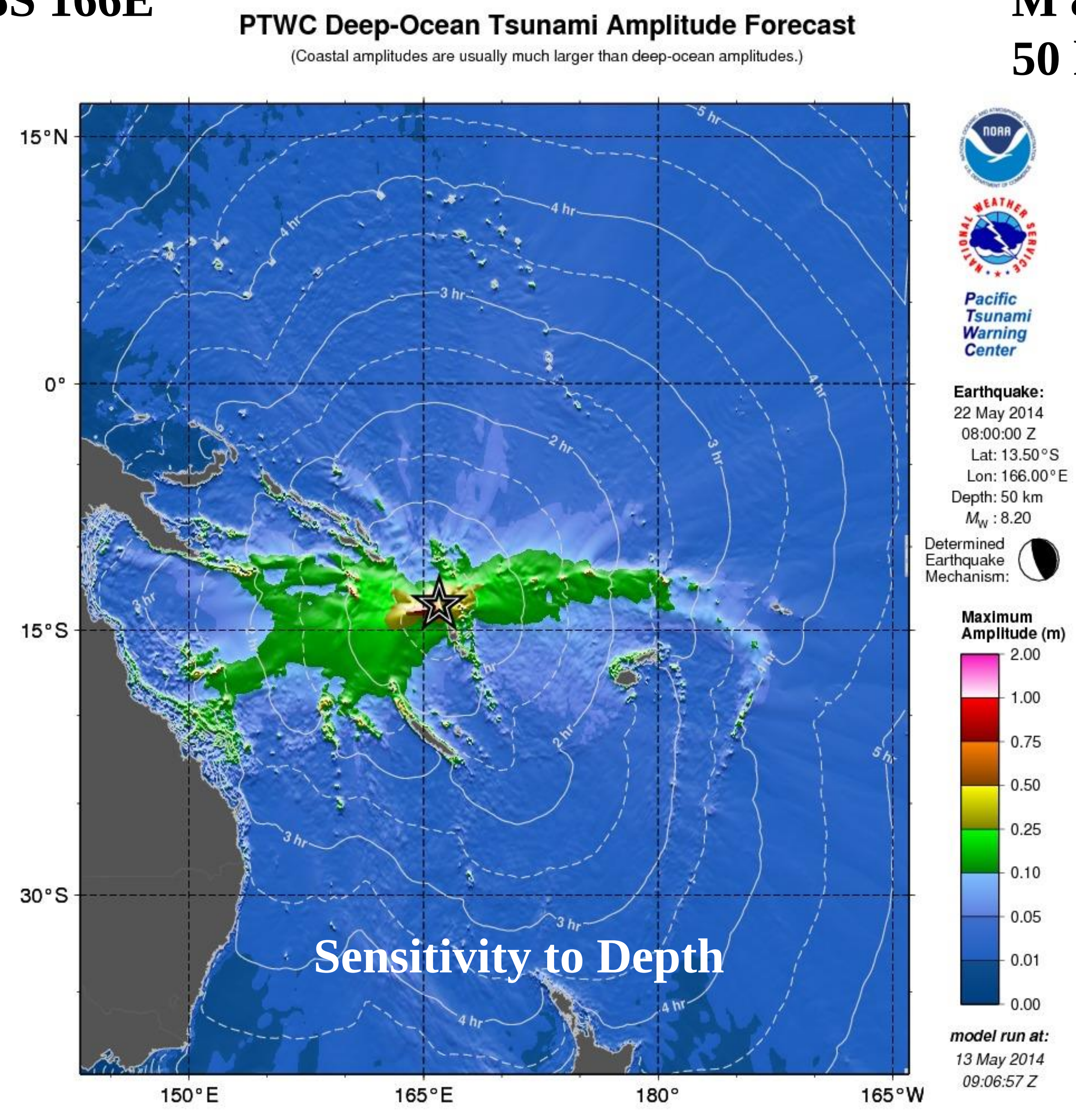
Loc: 13.5S 166E

M 8.2
25 km Deep



Loc: 13.5S 166E

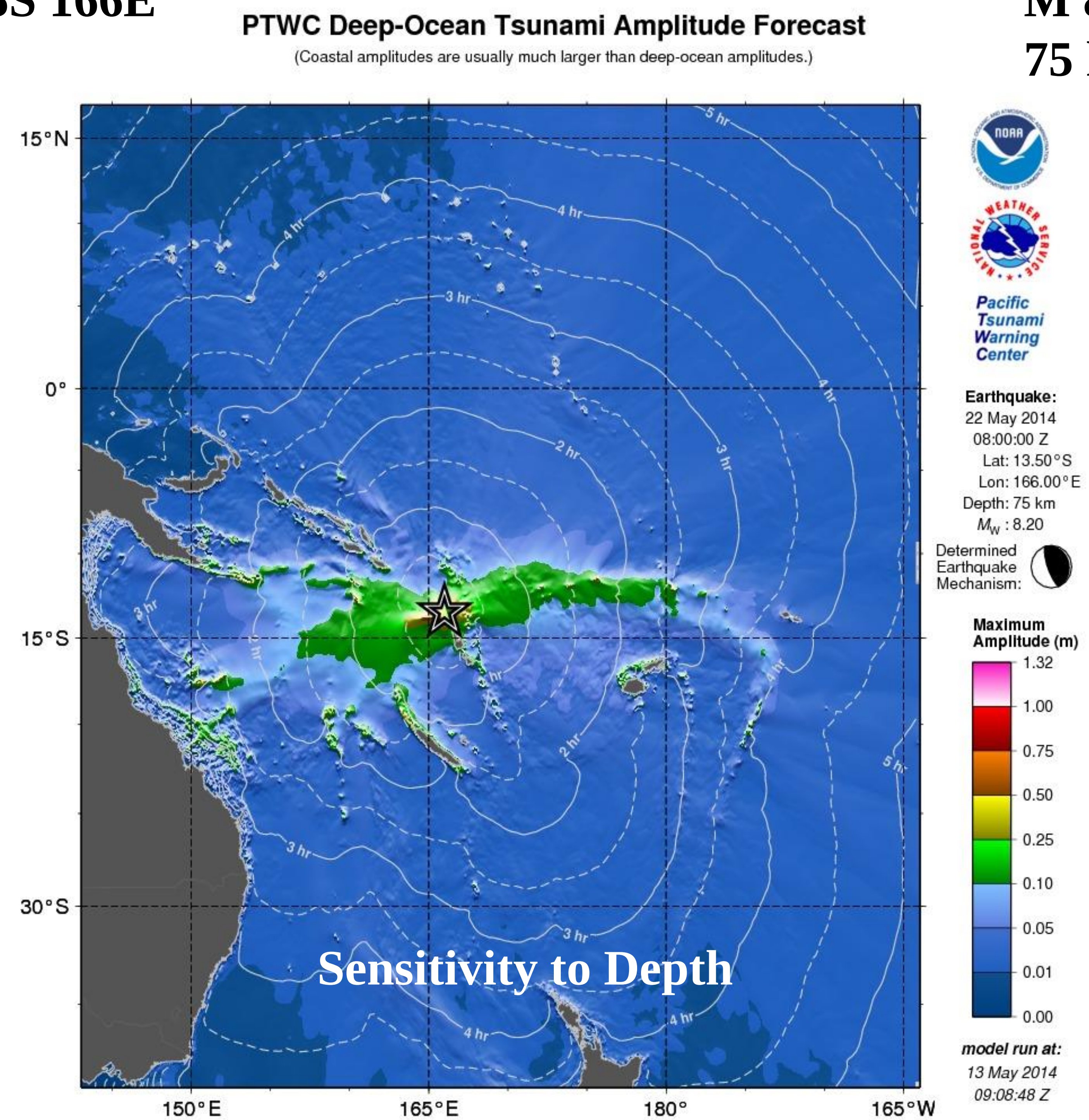
M 8.2
50 km Deep



Loc: 13.5S 166E

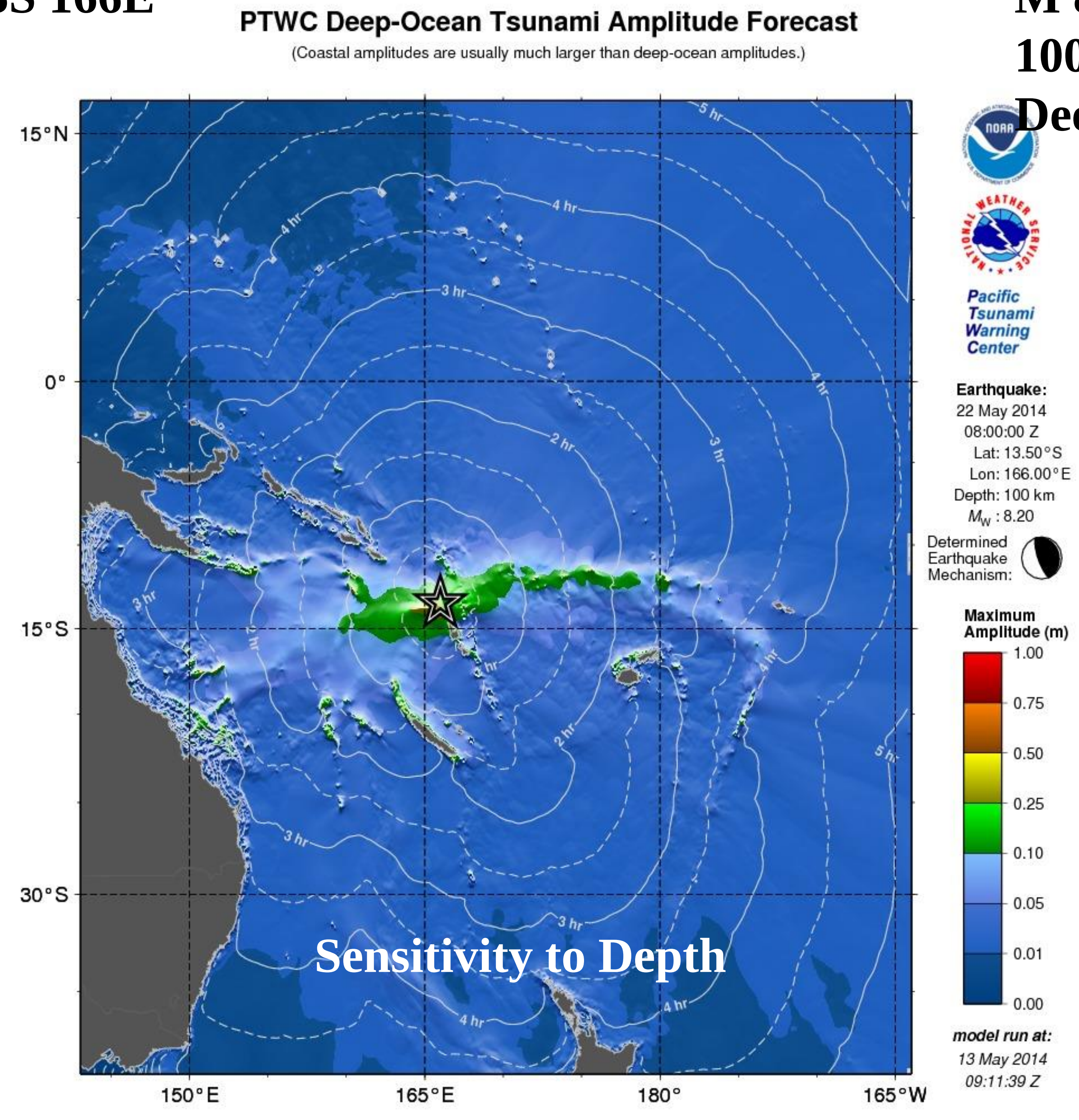
M 8.2

75 km Deep



Loc: 13.5S 166E

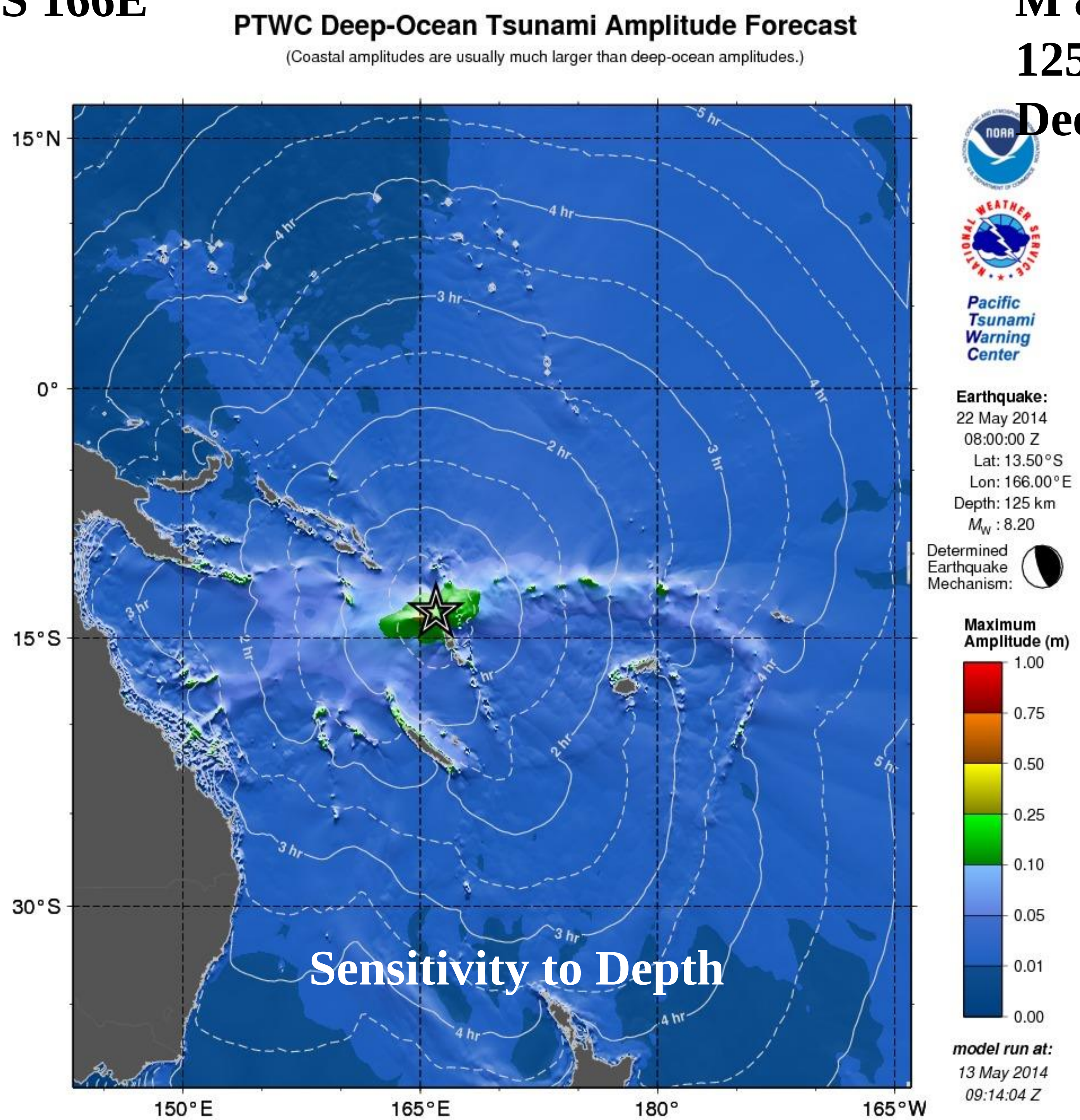
M 8.2
100 km
Deep



Sensitivity to Depth

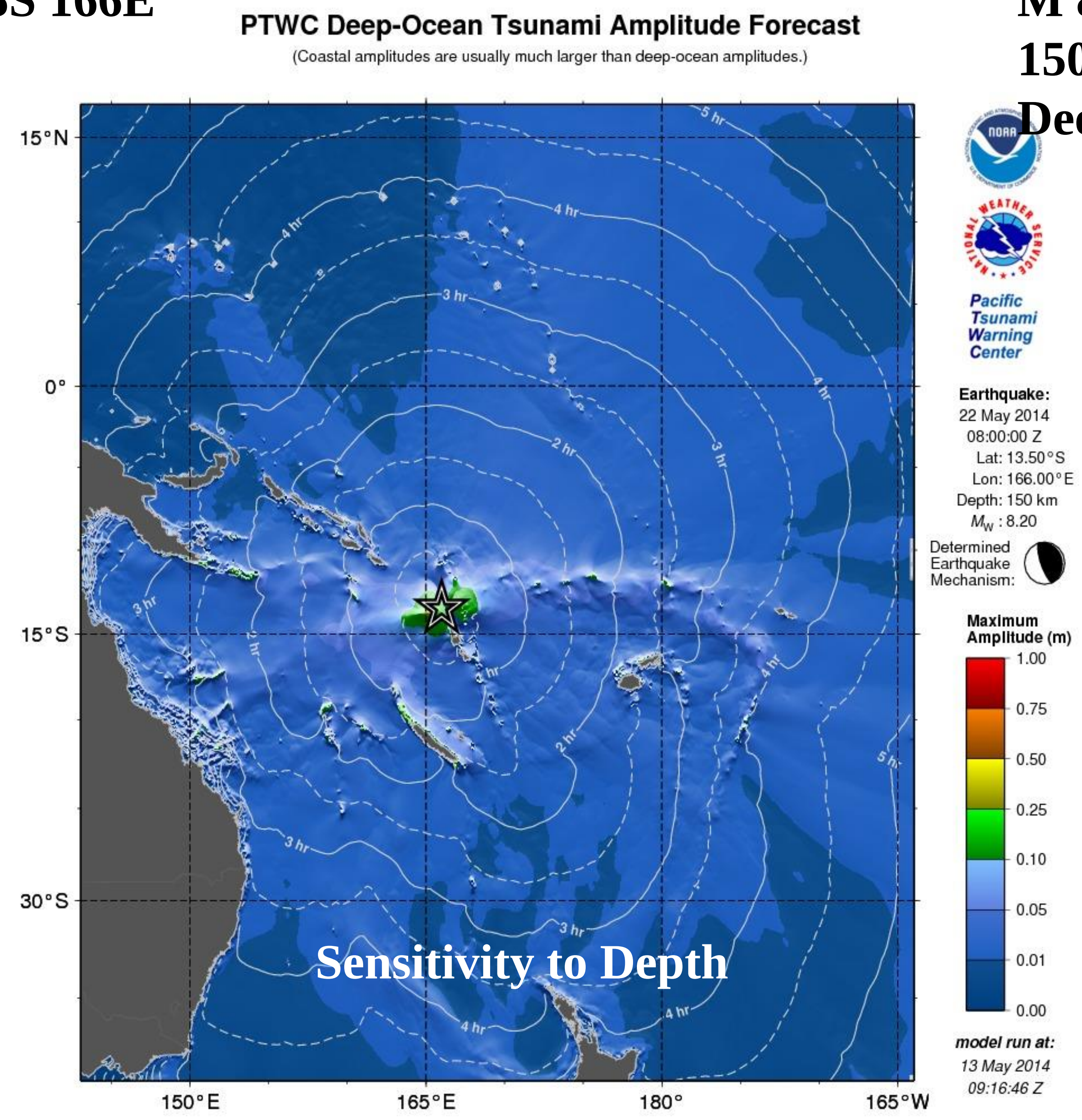
Loc: 13.5S 166E

M 8.2
125 km
Deep



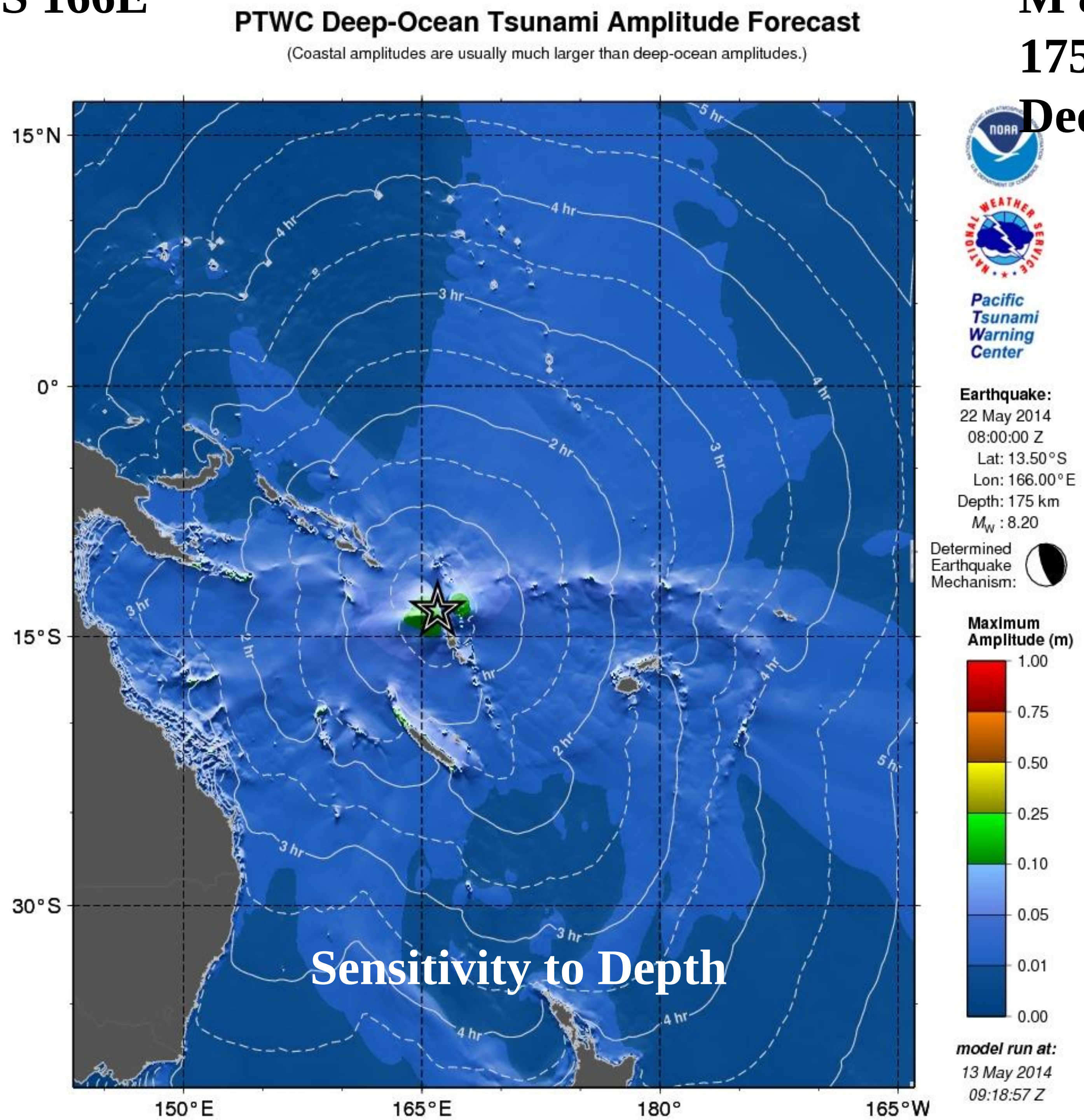
Loc: 13.5S 166E

M 8.2
150 km
Deep



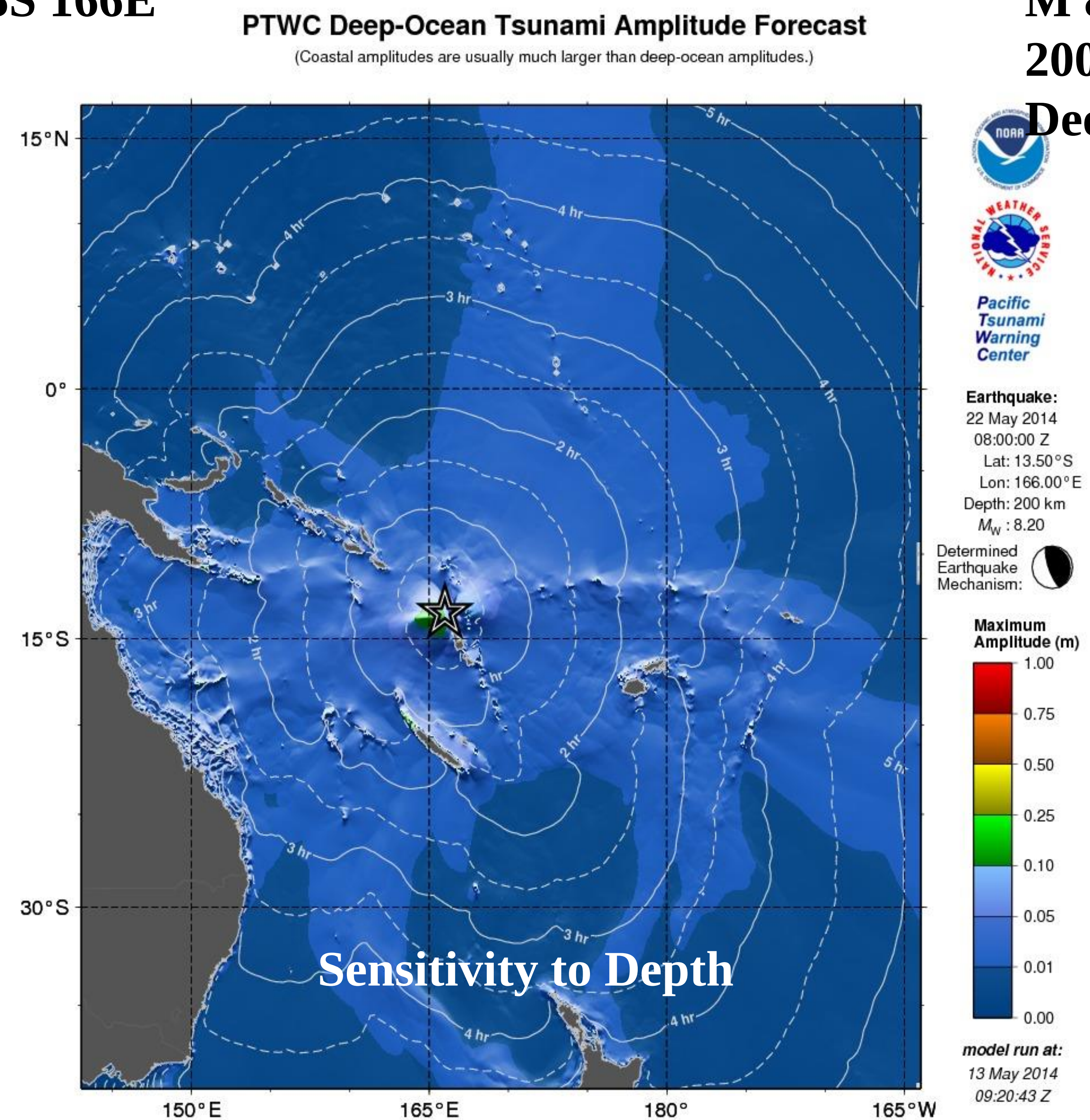
Loc: 13.5S 166E

M 8.2
175 km
Deep



Loc: 13.5S 166E

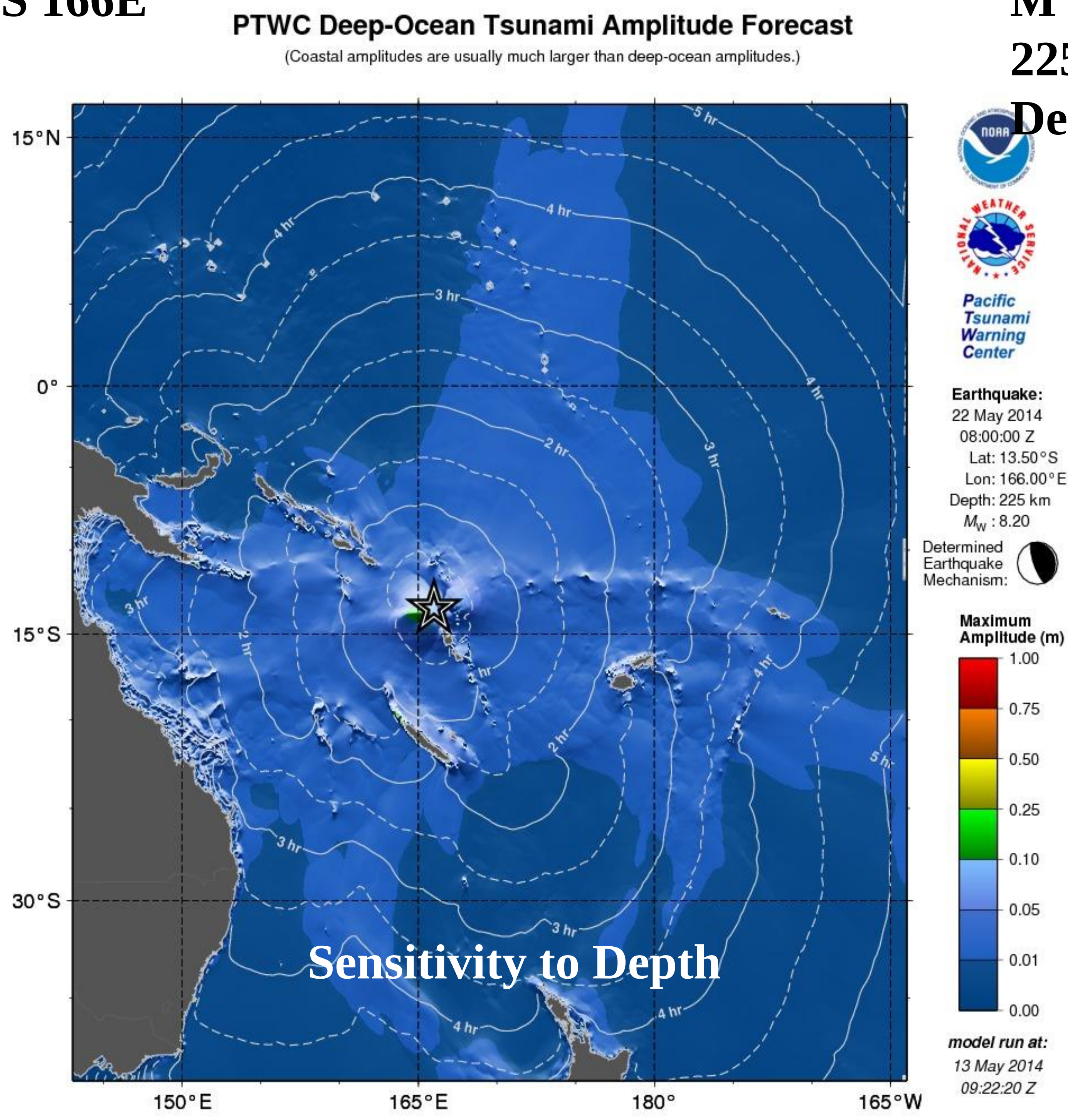
M 8.2
200 km
Deep



Sensitivity to Depth

Loc: 13.5S 166E

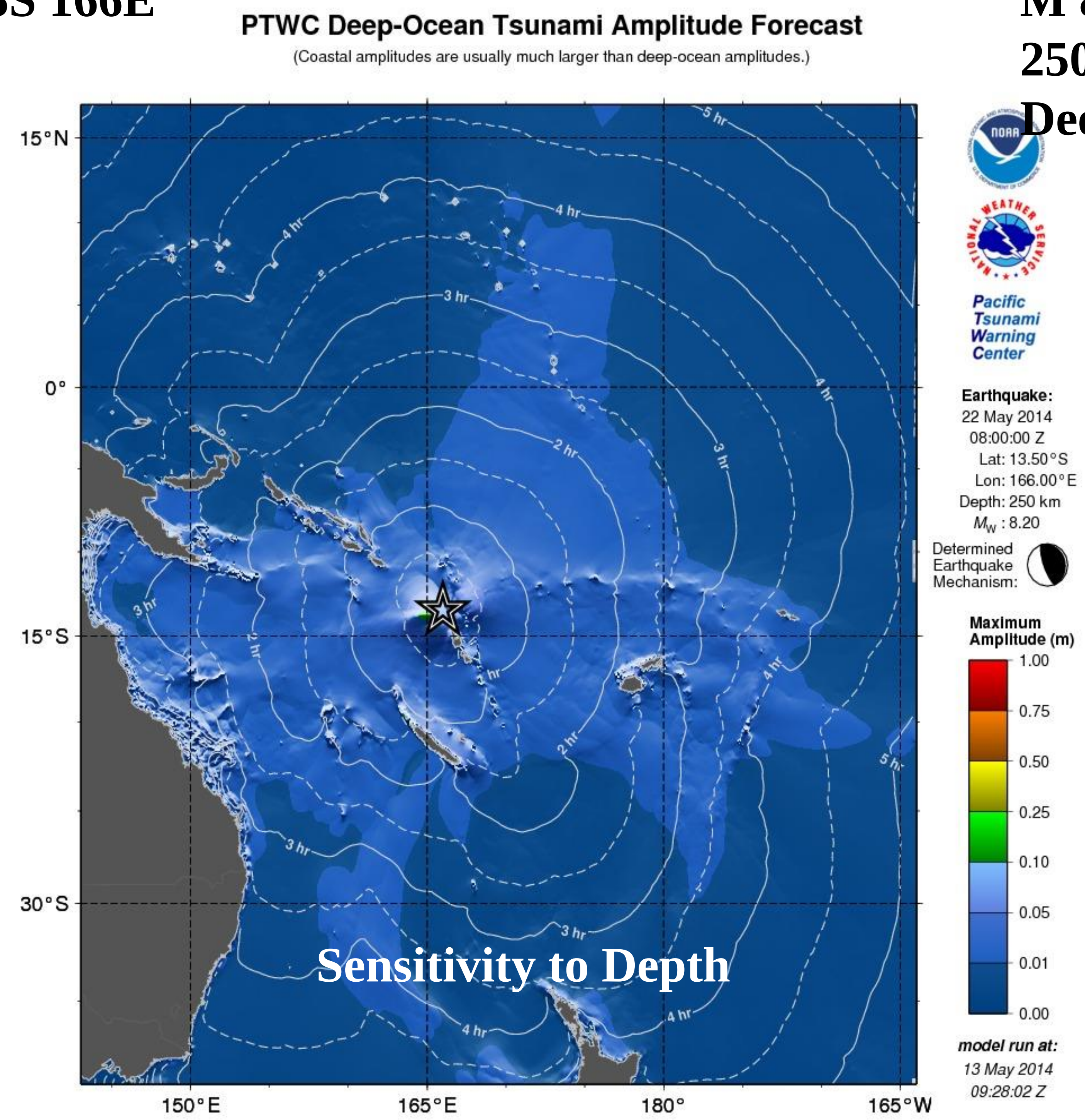
M 8.2
225 km
Deep



Sensitivity to Depth

Loc: 13.5S 166E

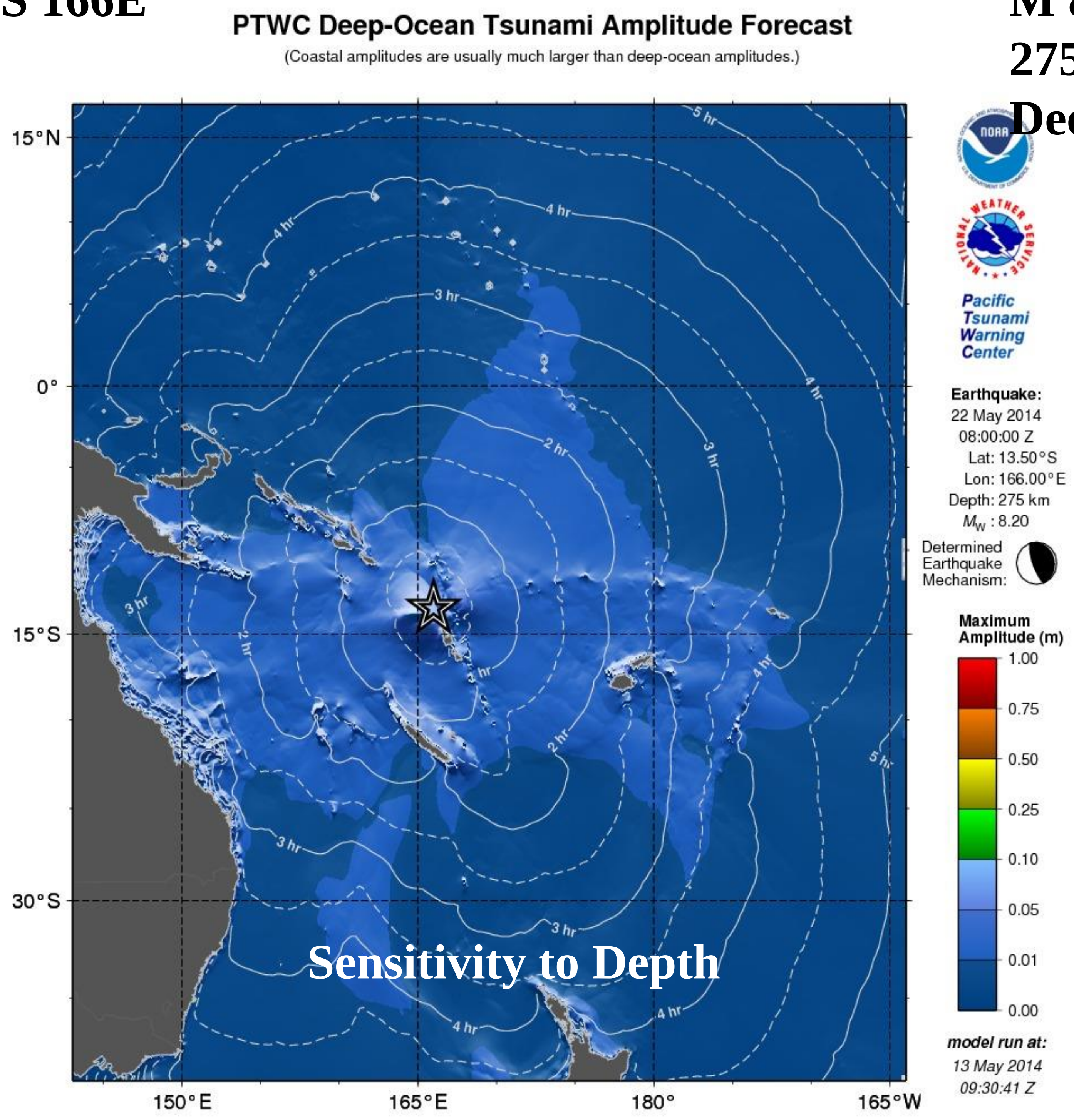
M 8.2
250 km
Deep



Sensitivity to Depth

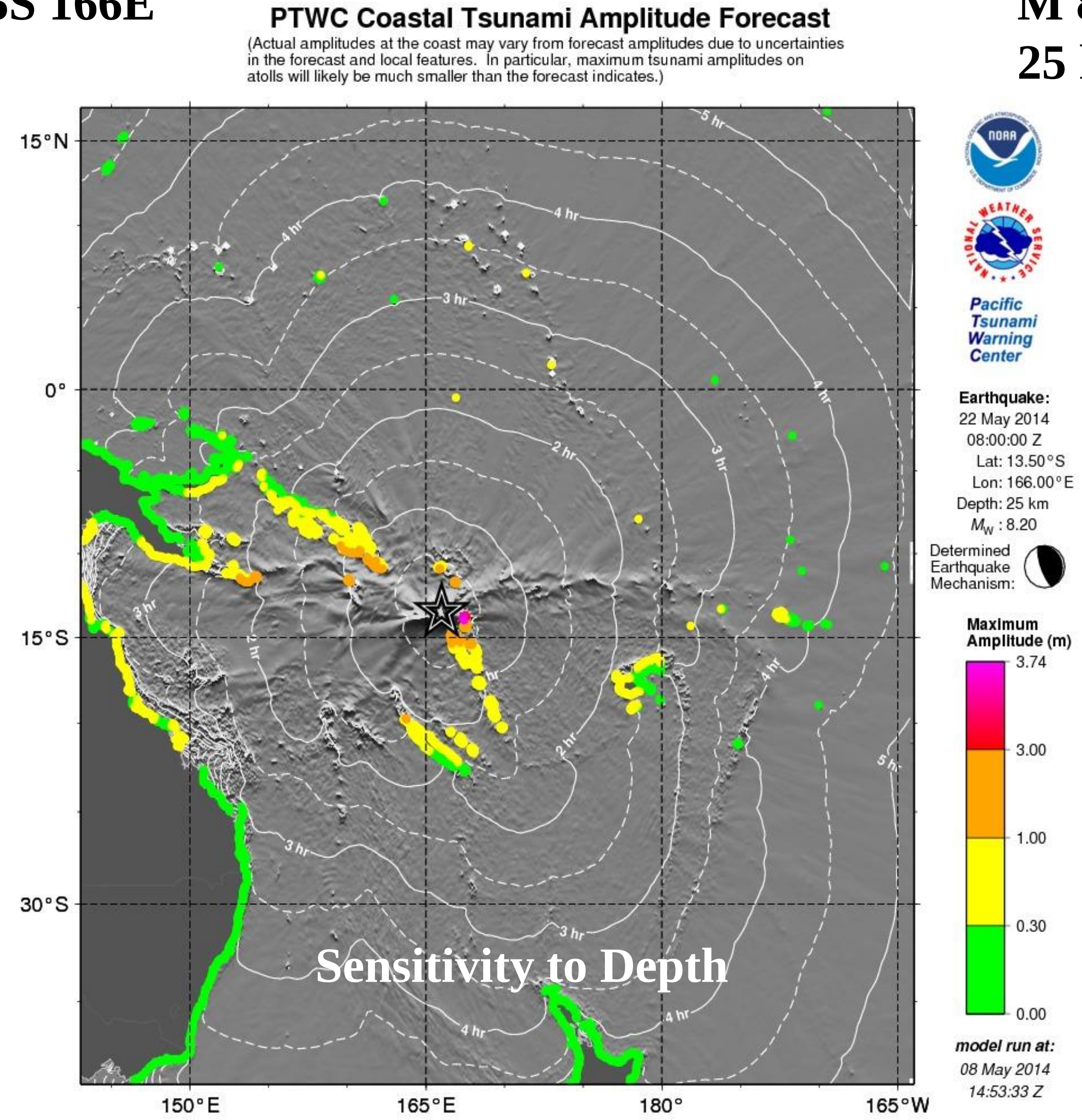
Loc: 13.5S 166E

M 8.2
275 km
Deep



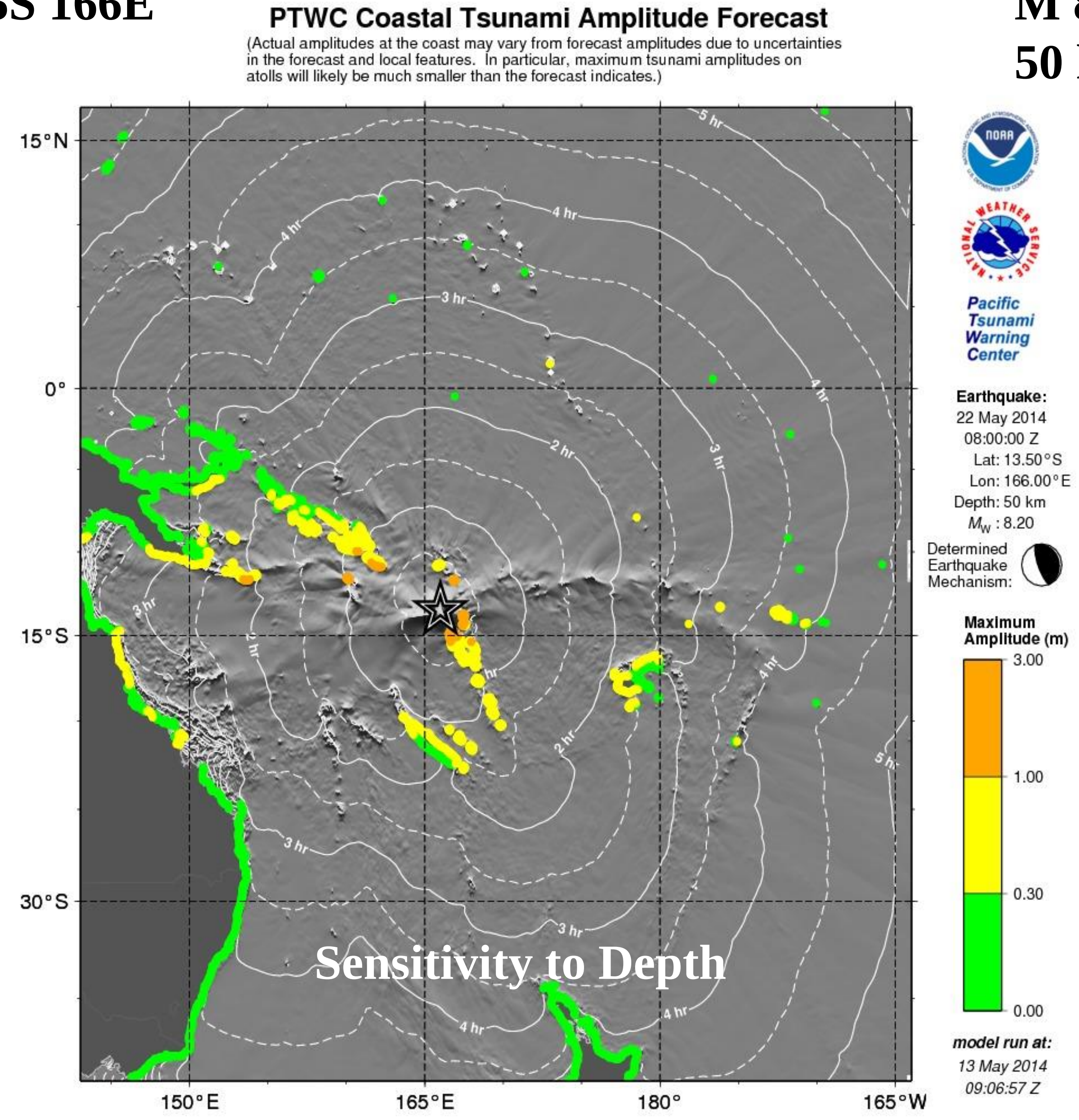
Loc: 13.5S 166E

M 8.2
25 km Deep



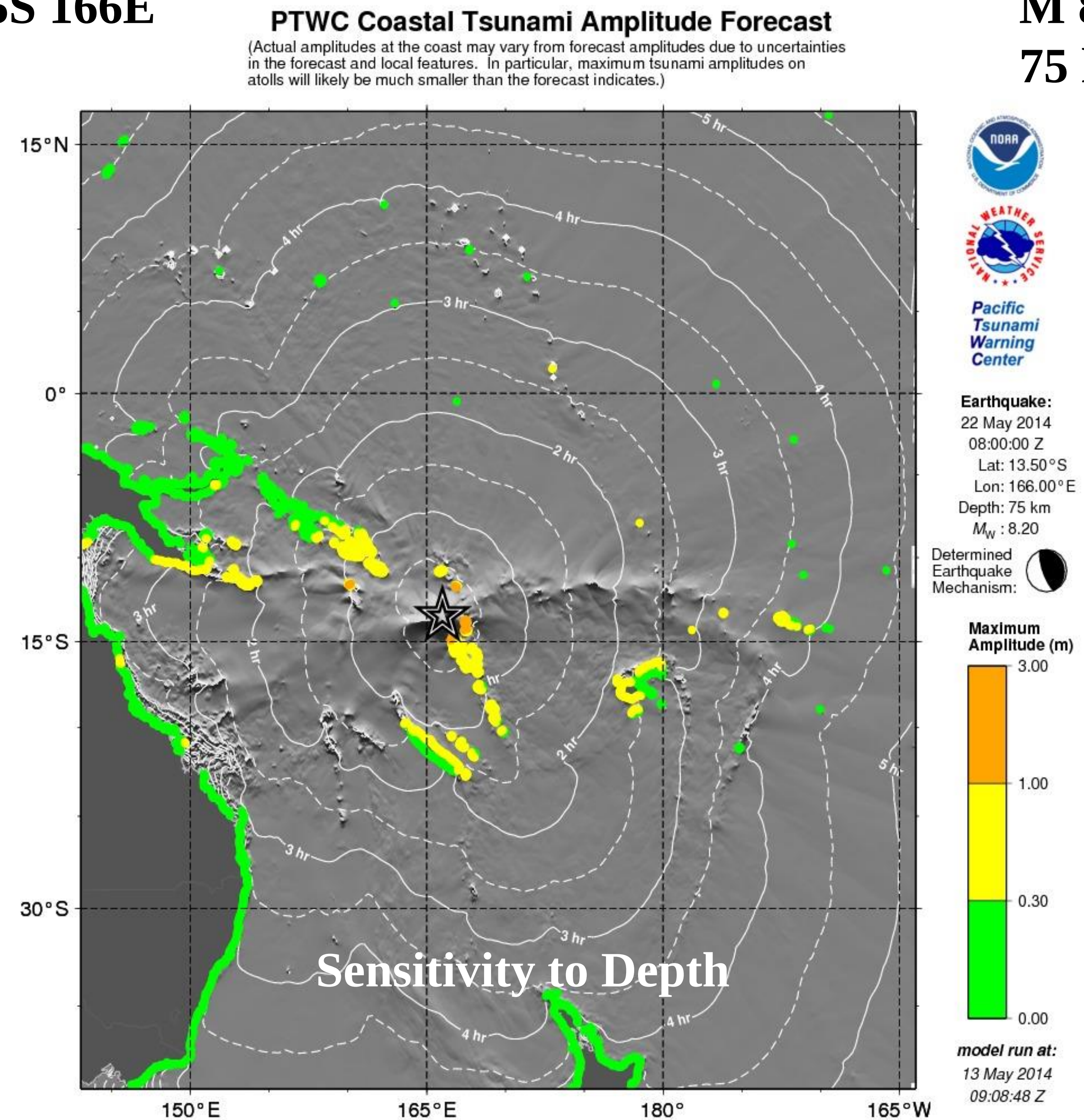
Loc: 13.5S 166E

M 8.2
50 km Deep



Loc: 13.5S 166E

M 8.2
75 km Deep

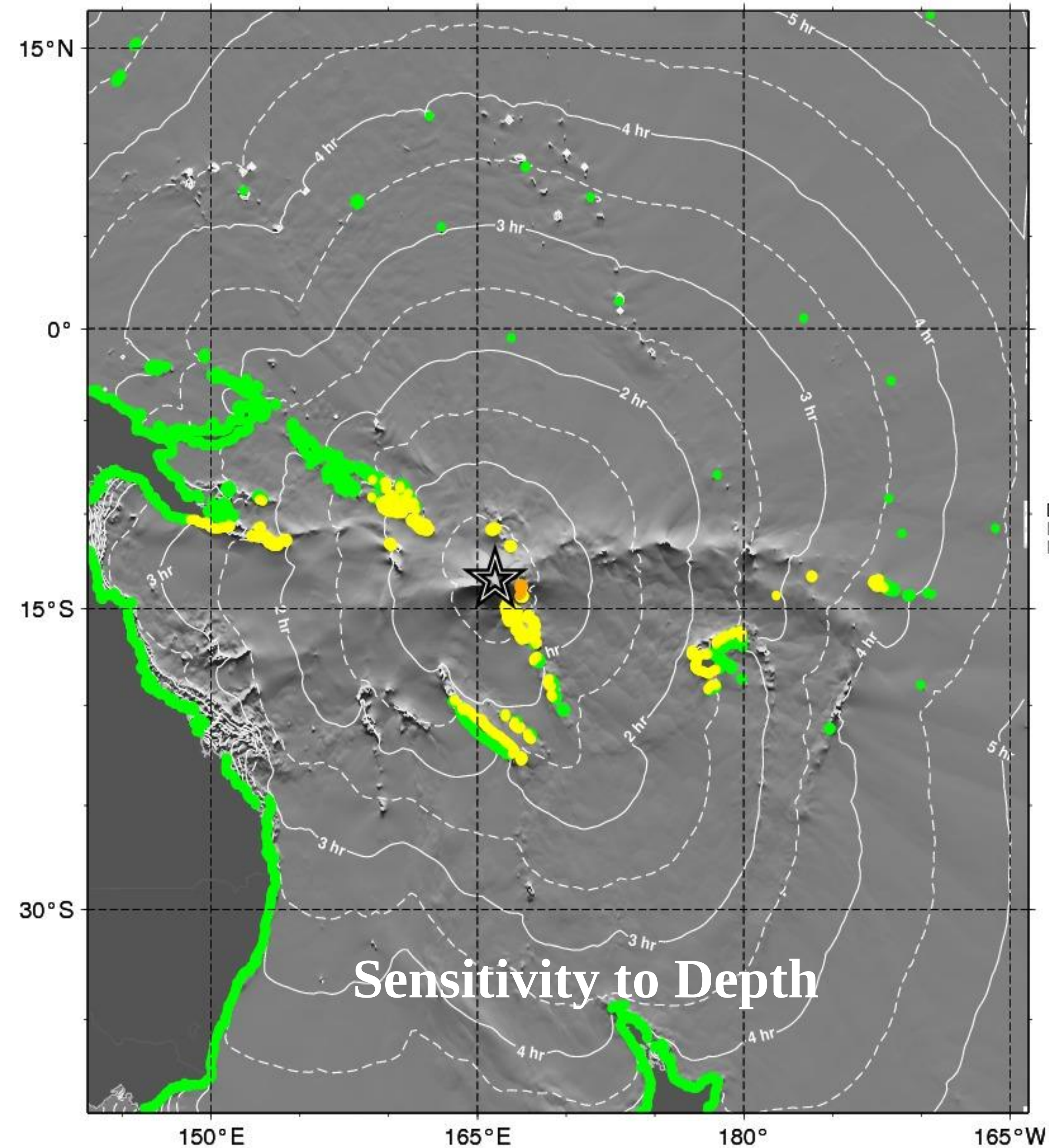


Loc: 13.5S 166E

M 8.2
100 km Deep

PTWC Coastal Tsunami Amplitude Forecast

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Pacific Tsunami Warning Center

Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 100 km
M_W : 8.20

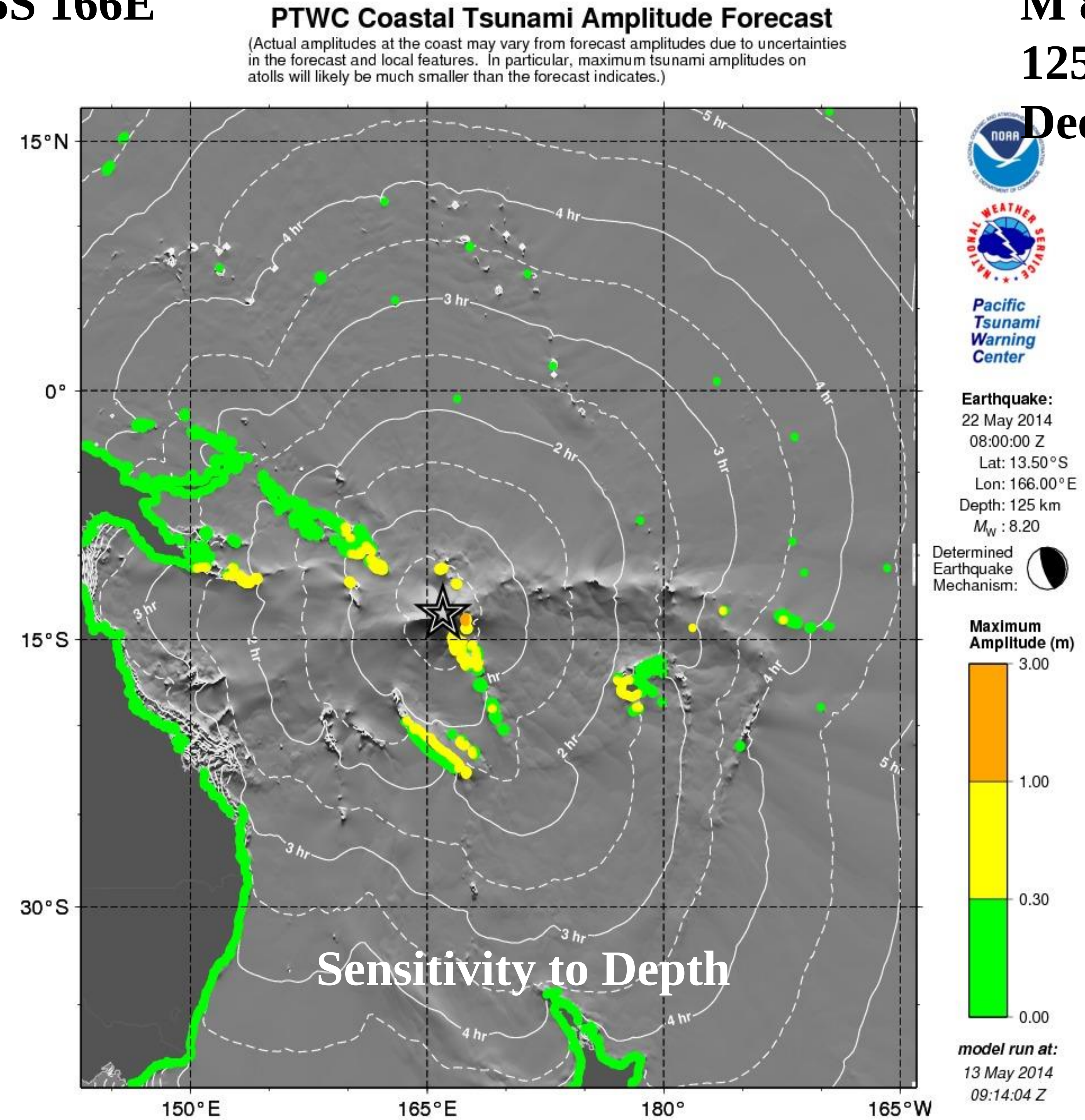
Determined Earthquake Mechanism:

Maximum Amplitude (m)
3.00
1.00
0.30
0.00

model run at:
13 May 2014
09:11:39 Z

Loc: 13.5S 166E

M 8.2
125 km
Deep

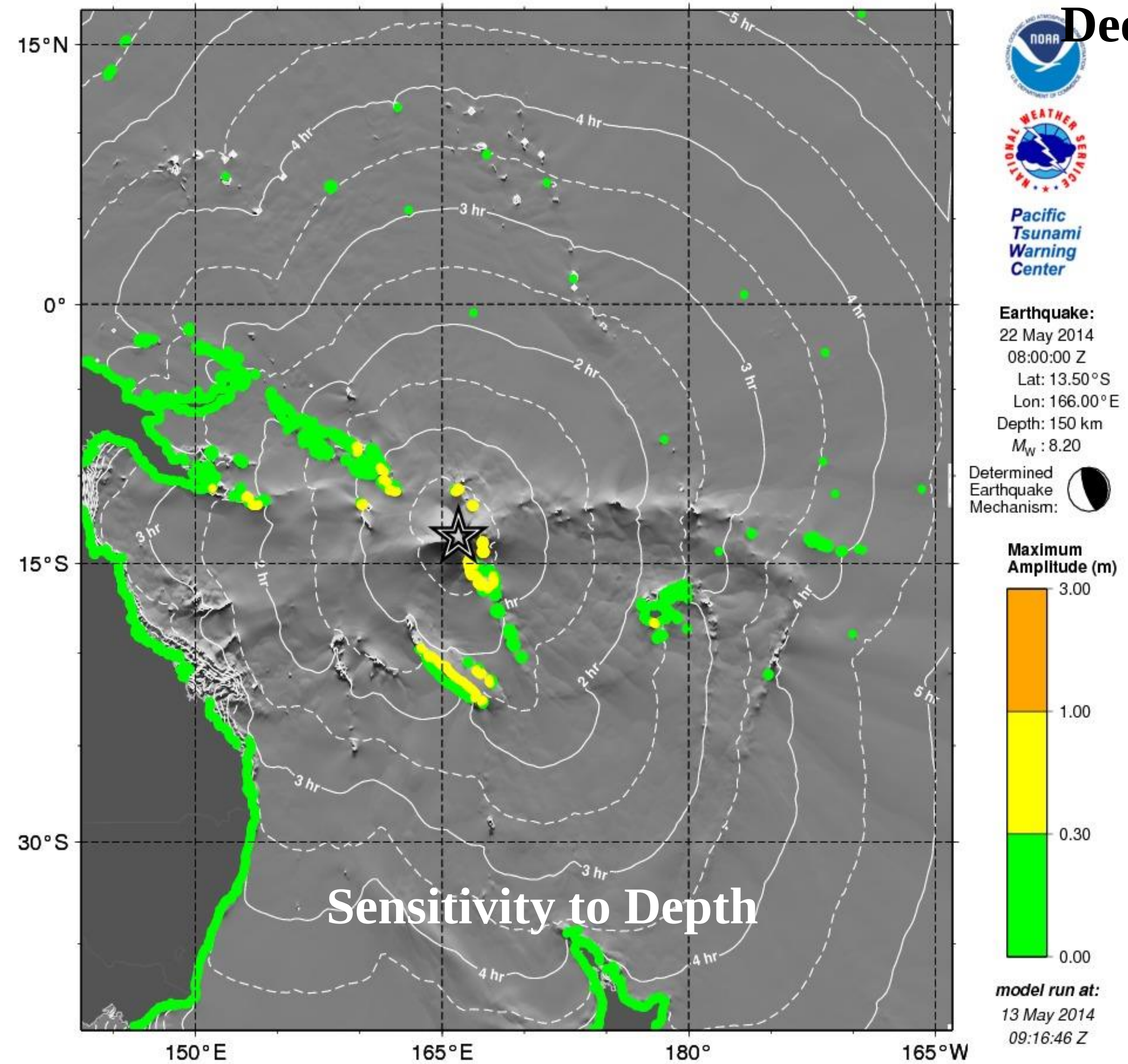


Loc: 13.5S 166E

M 8.2
150 km
Deep

PTWC Coastal Tsunami Amplitude Forecast

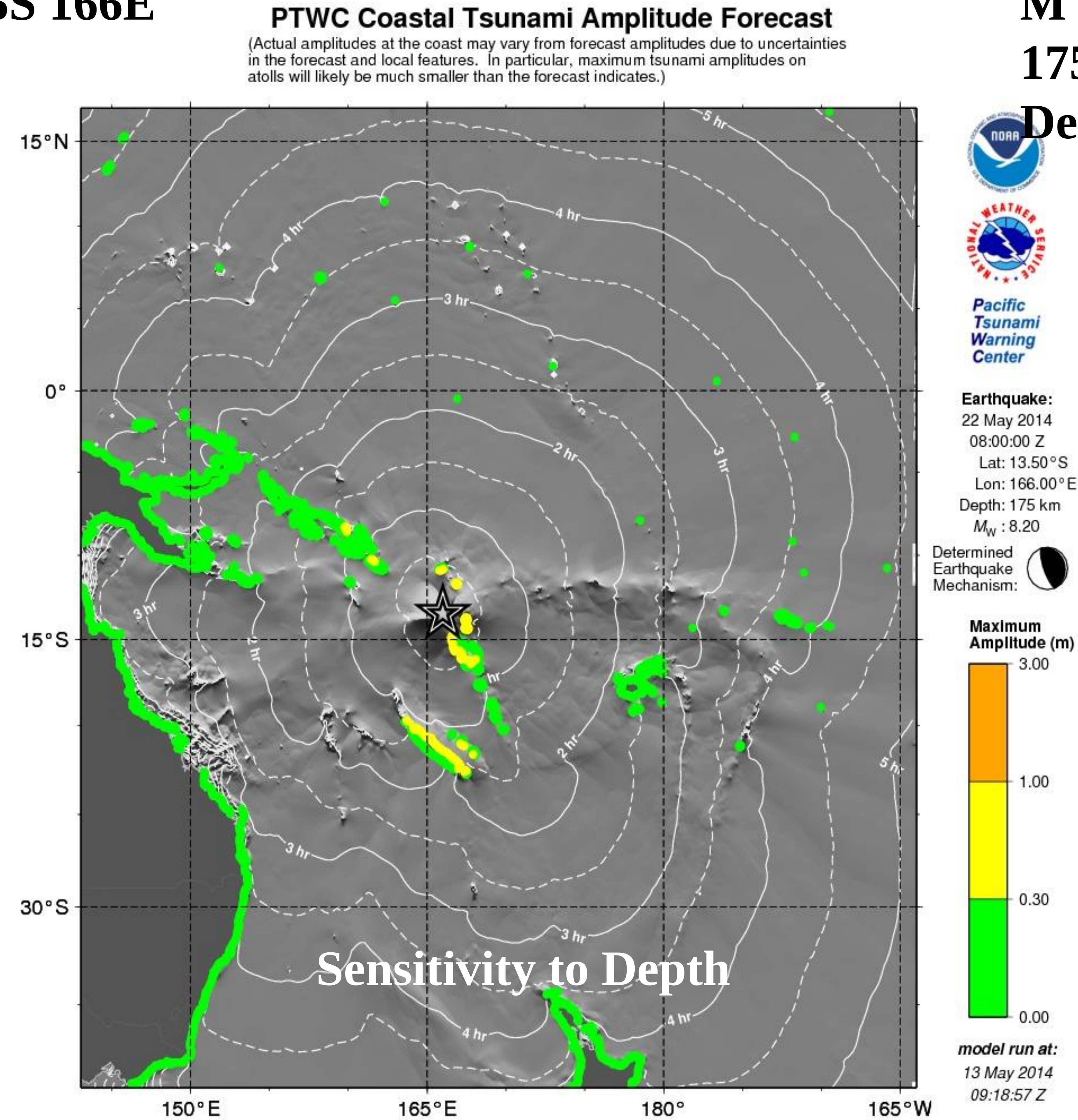
(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Sensitivity to Depth

Loc: 13.5S 166E

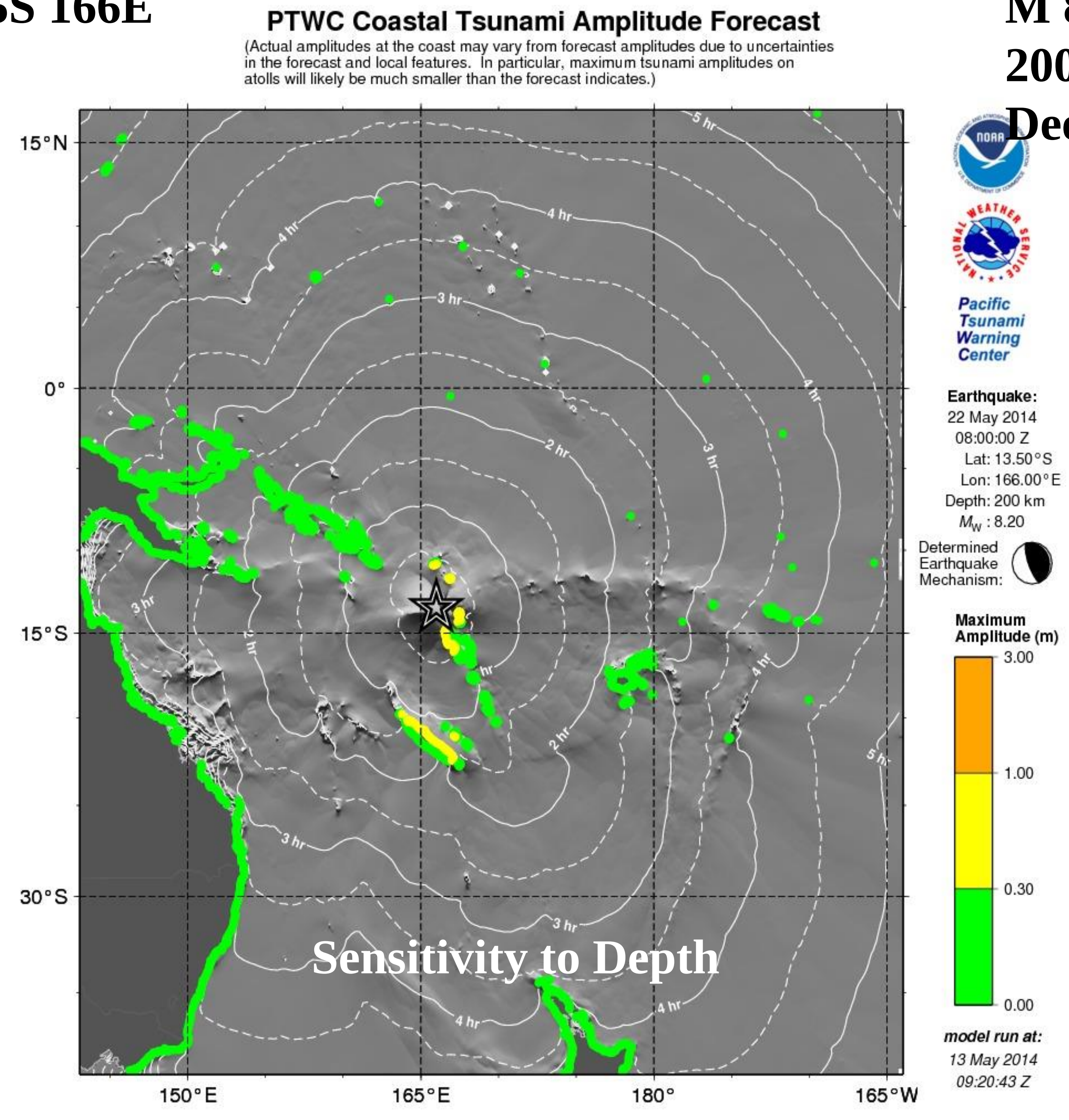
M 8.2
175 km Deep



Sensitivity to Depth

Loc: 13.5S 166E

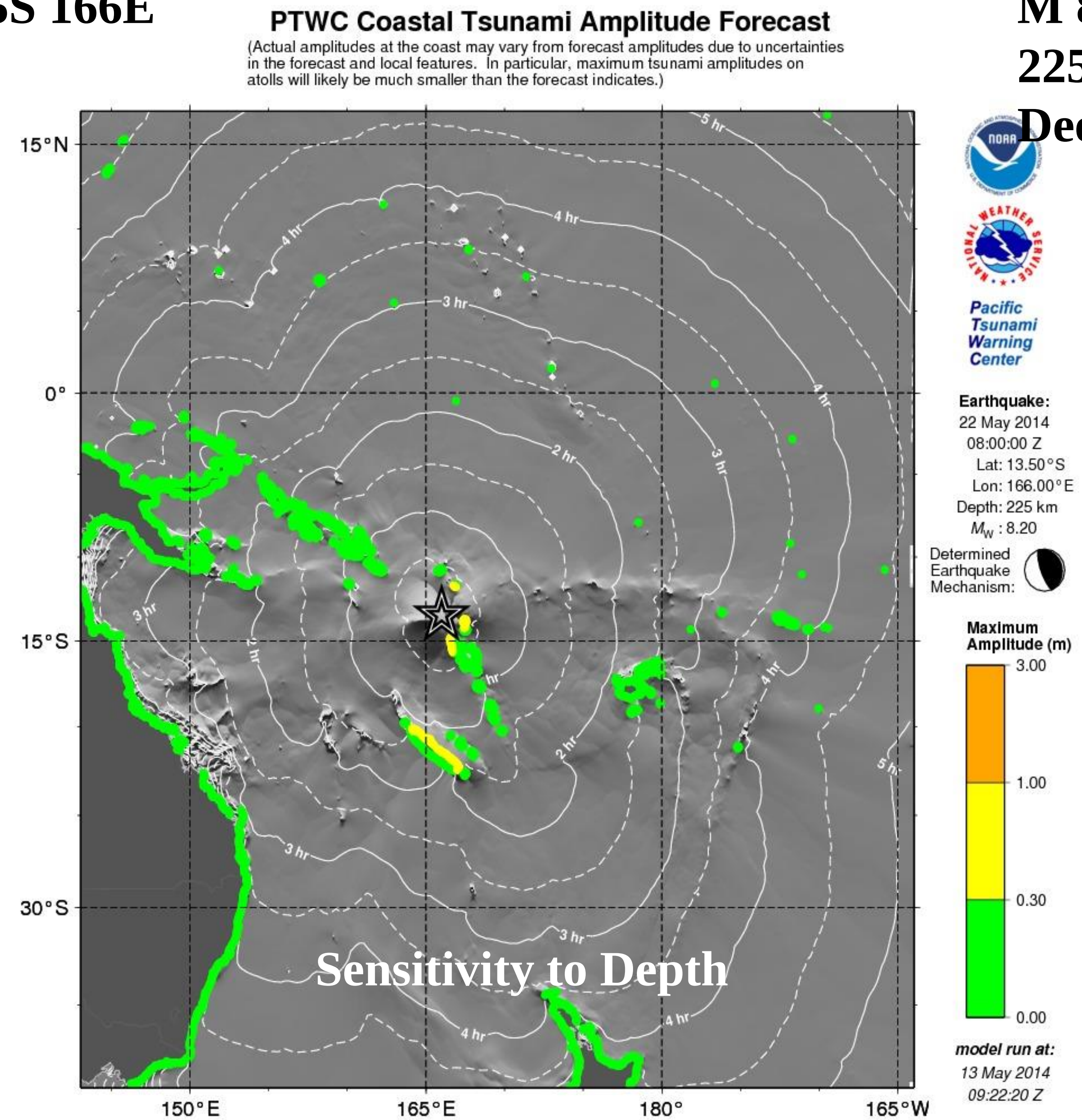
M 8.2
200 km
Deep



Sensitivity to Depth

Loc: 13.5S 166E

M 8.2
225 km
Deep

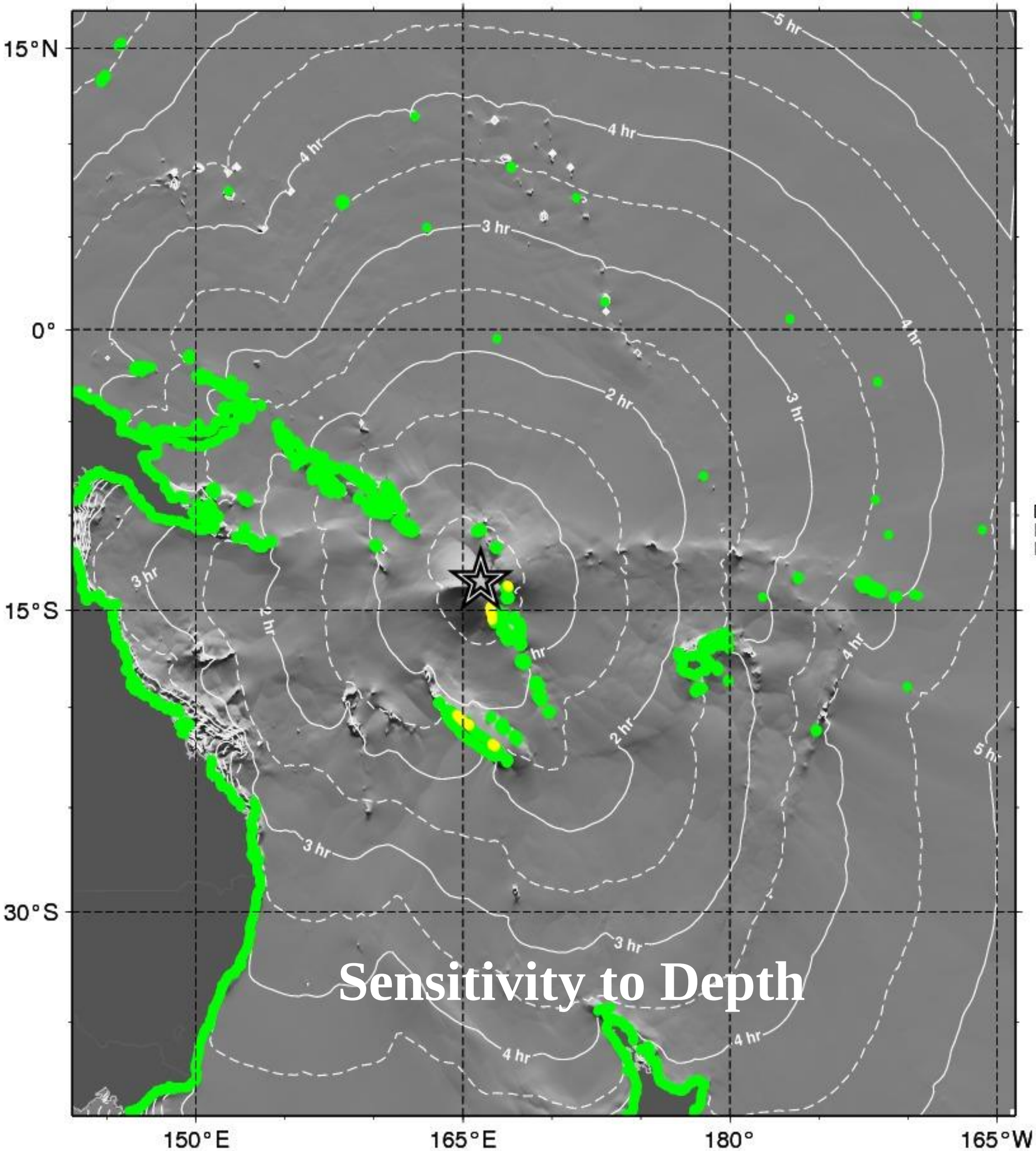


Loc: 13.5S 166E

M 8.2
250 km Deep

PTWC Coastal Tsunami Amplitude Forecast

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Pacific Tsunami Warning Center

Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 250 km
M_W : 8.20

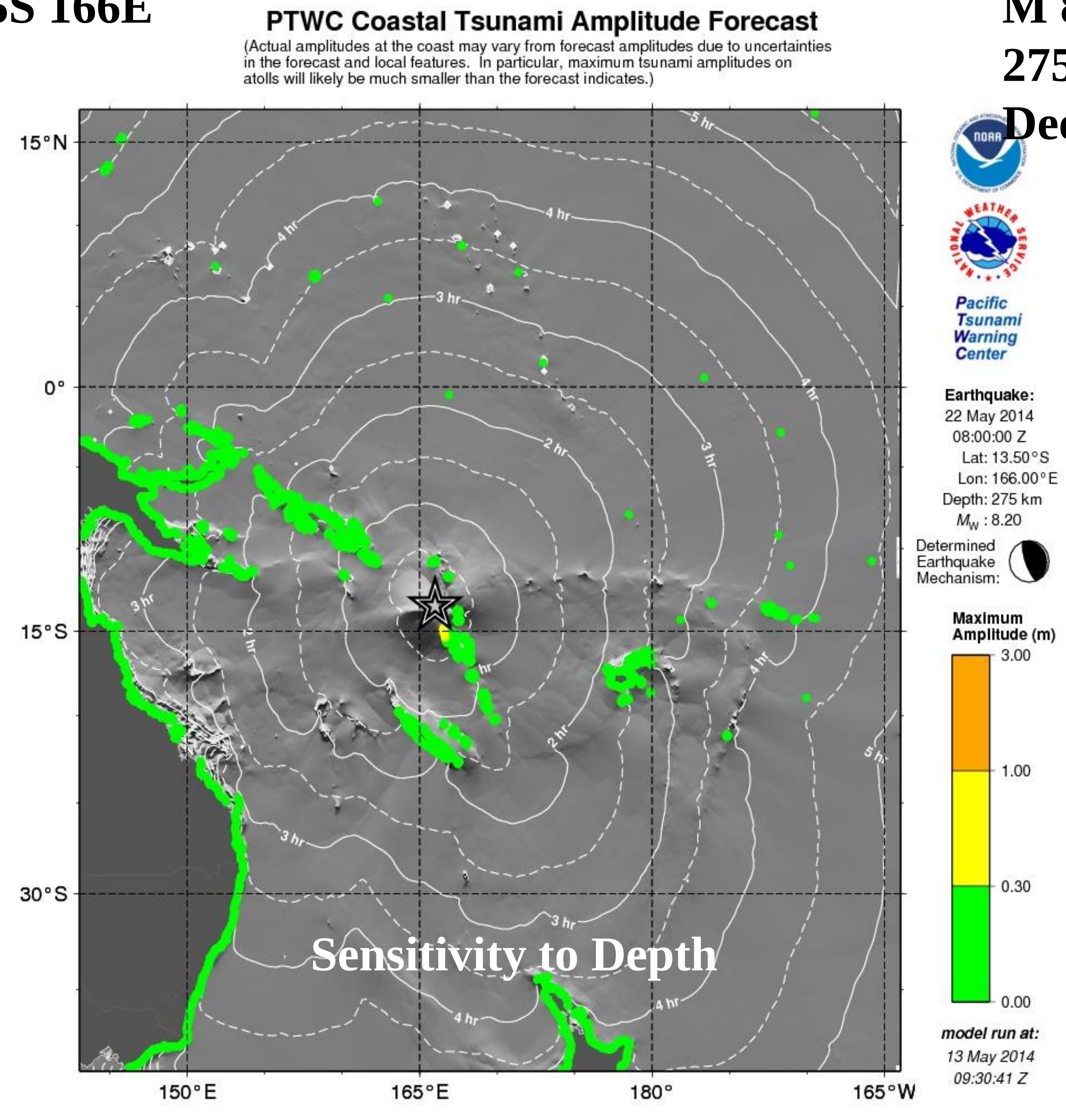
Determined Earthquake Mechanism:

Maximum Amplitude (m)
3.00
1.00
0.30
0.00

model run at:
13 May 2014
09:28:02 Z

Loc: 13.5S 166E

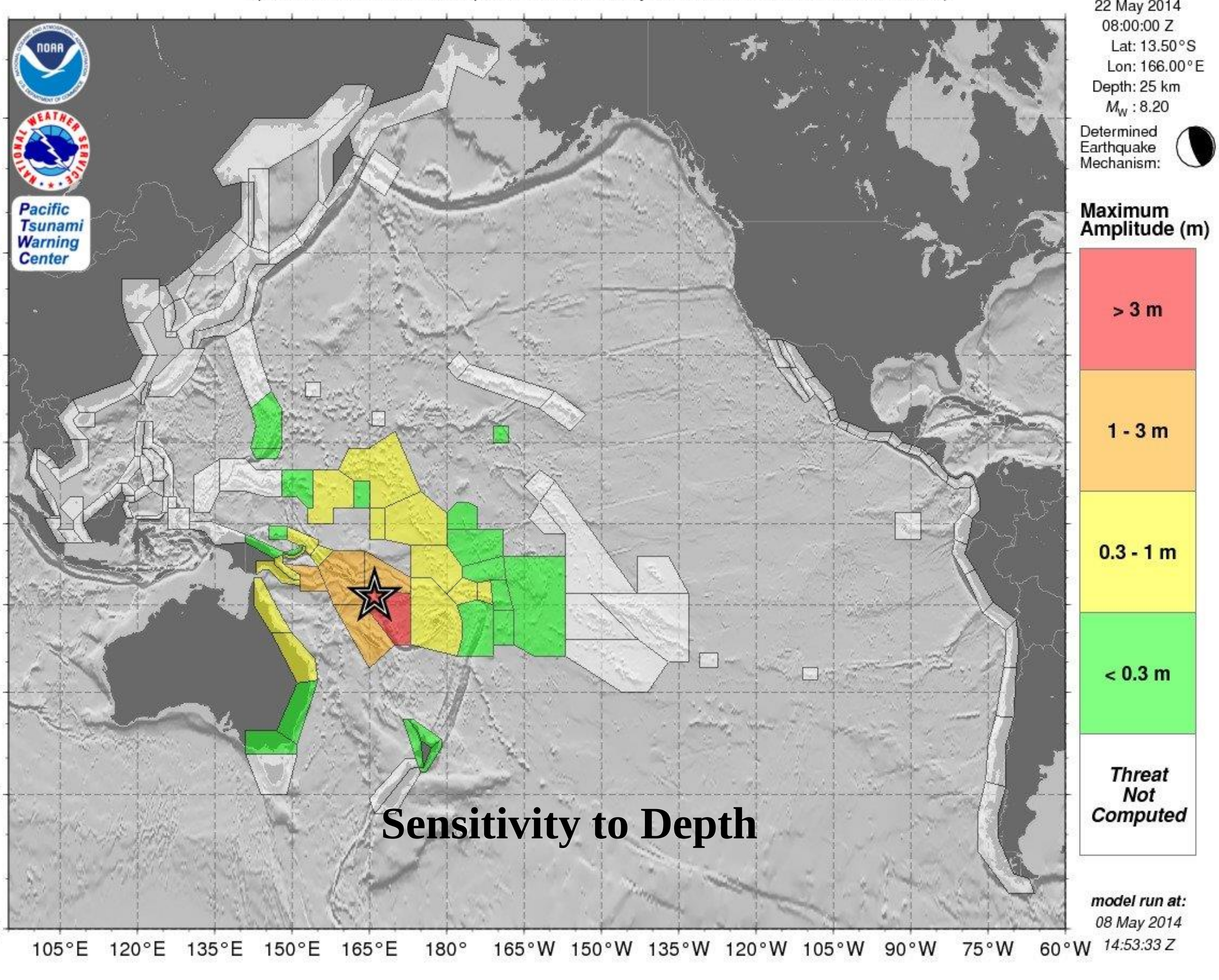
M 8.2
275 km Deep



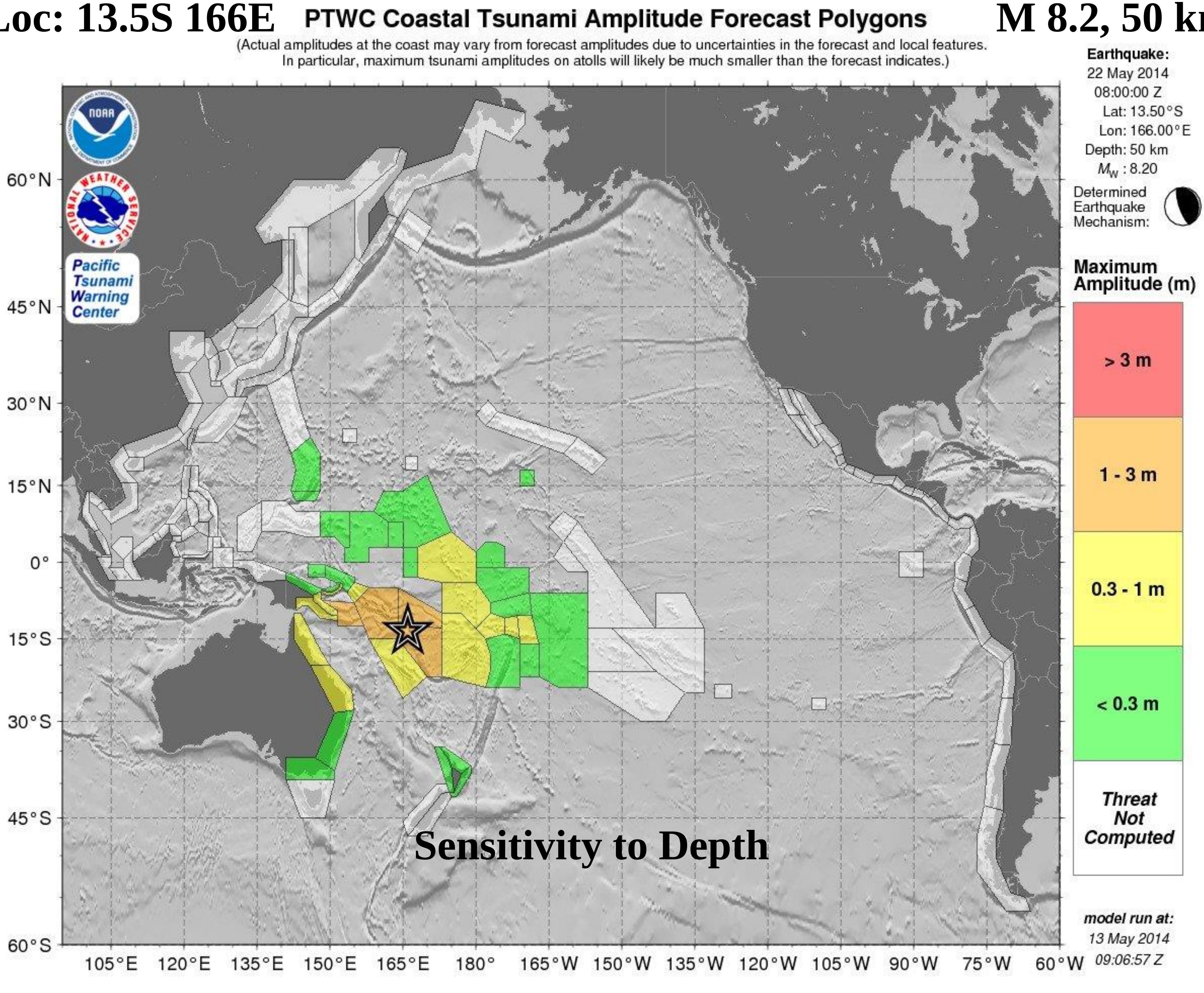
Sensitivity to Depth

Loc: 13.5S 166E **PTWC Coastal Tsunami Amplitude Forecast Polygons** M 8.2, 25 km

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features.
In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



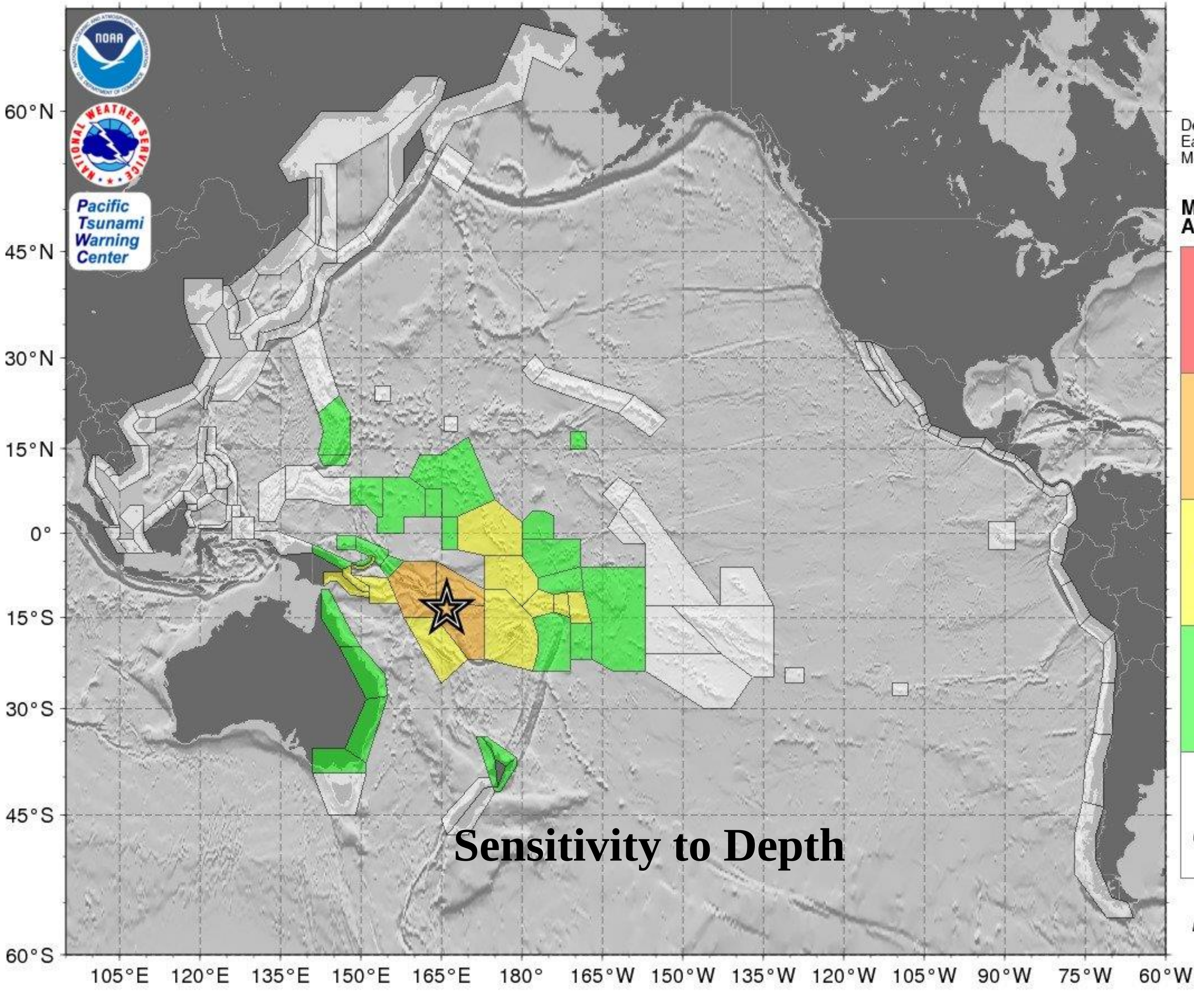
Loc: 13.5S 166E **M 8.2, 50 km**



Sensitivity to Depth

Loc: 13.5S 166E PTWC Coastal Tsunami Amplitude Forecast Polygons M 8.2, 75 km

(Actual amplitudes at the coast may vary from forecast amplitudes due to uncertainties in the forecast and local features. In particular, maximum tsunami amplitudes on atolls will likely be much smaller than the forecast indicates.)



Earthquake:
22 May 2014
08:00:00 Z
Lat: 13.50°S
Lon: 166.00°E
Depth: 75 km
M_W : 8.20
Determined Earthquake Mechanism:

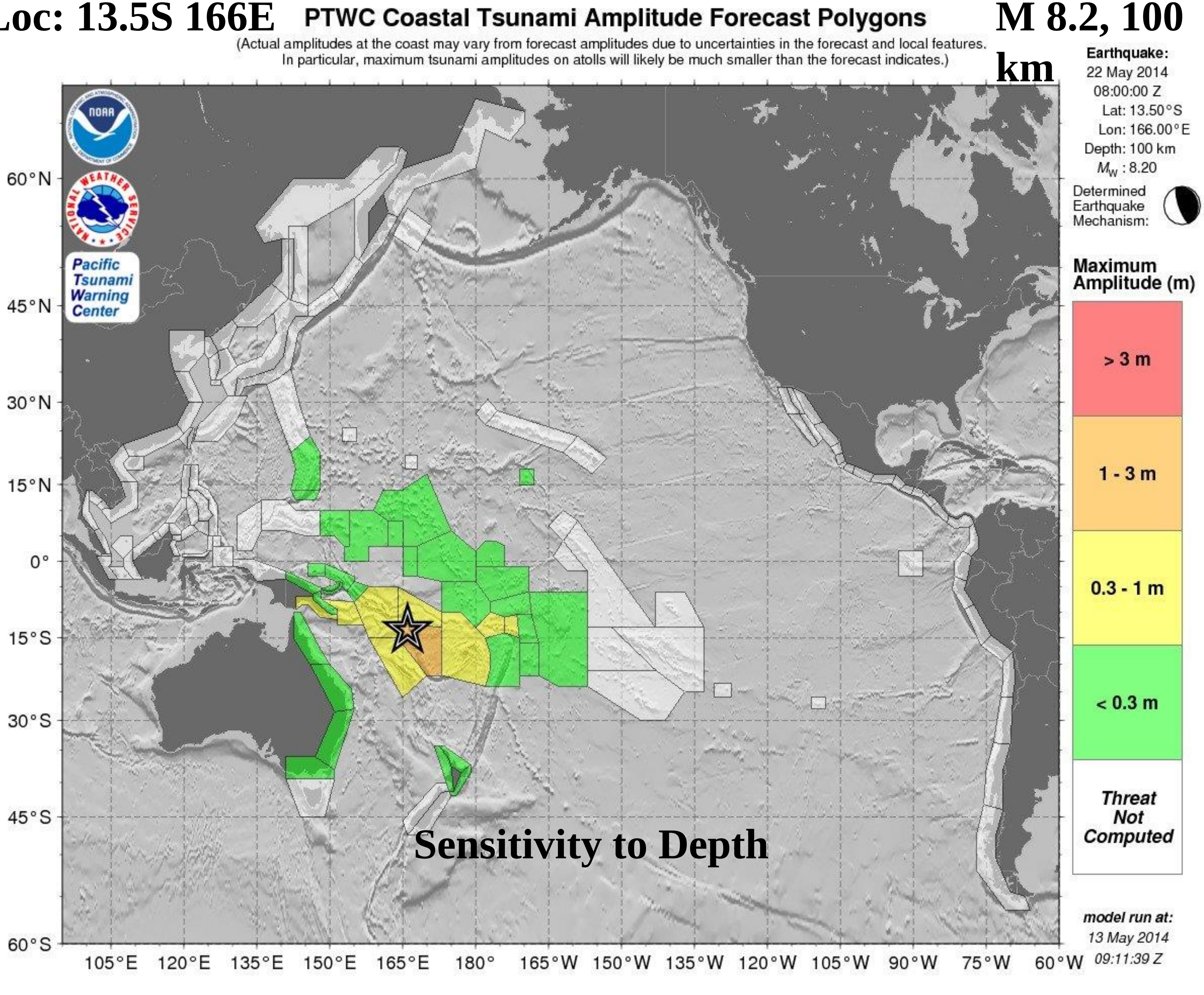
Maximum Amplitude (m)

- > 3 m
- 1 - 3 m
- 0.3 - 1 m
- < 0.3 m
- Threat Not Computed

model run at:
13 May 2014
09:08:48 Z

Loc: 13.5S 166E

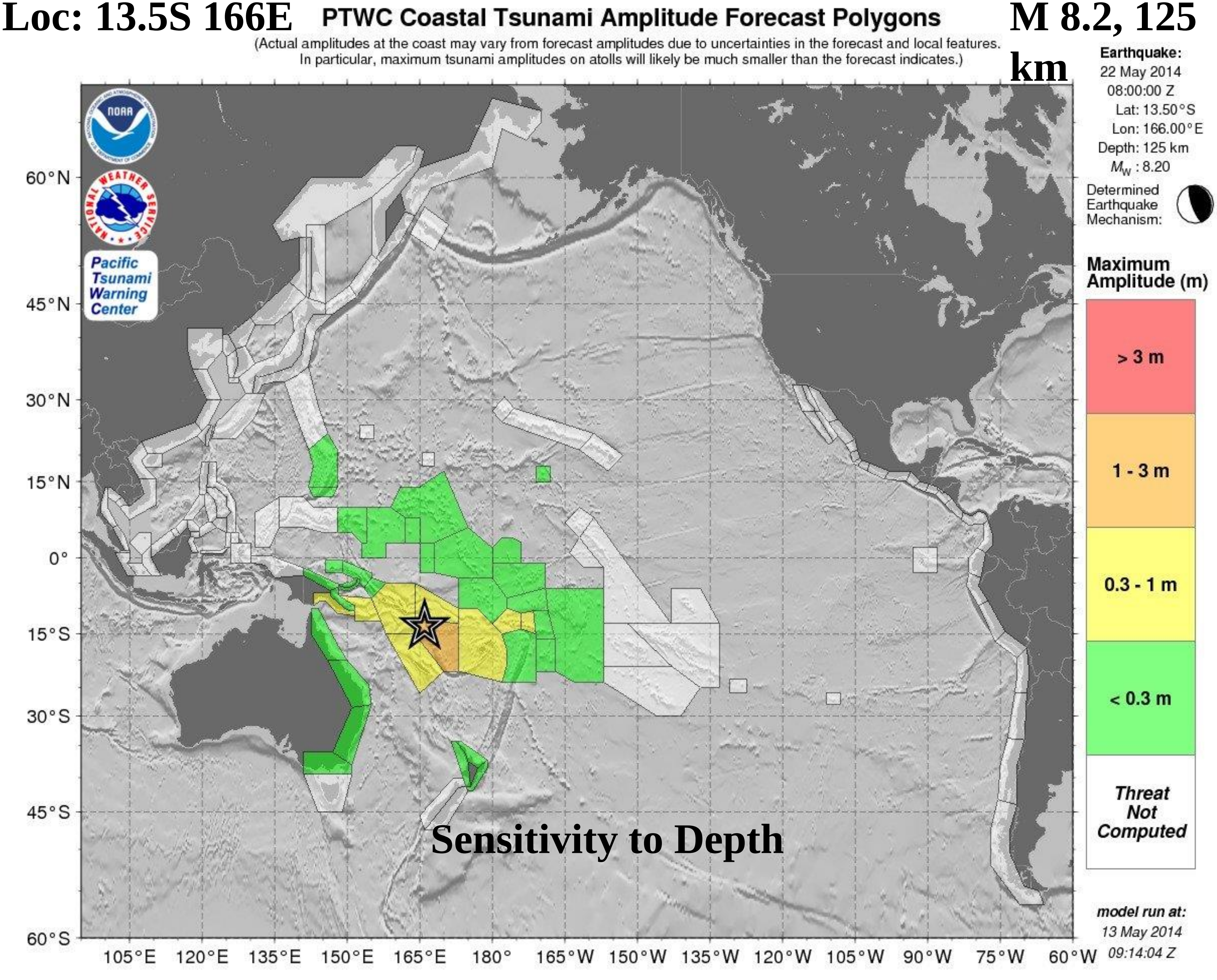
M 8.2, 100 km



Sensitivity to Depth

Loc: 13.5S 166E

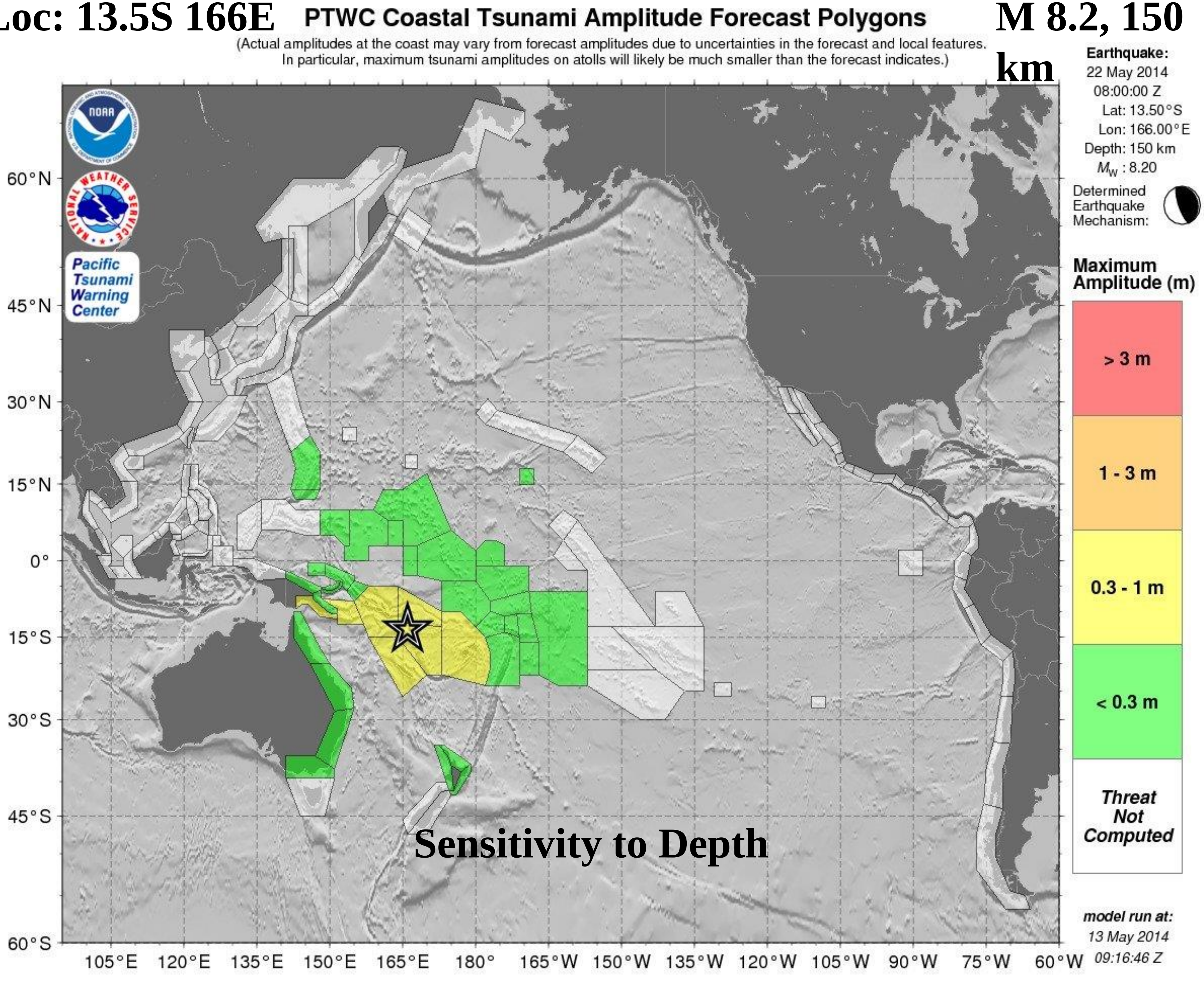
M 8.2, 125 km



Sensitivity to Depth

Loc: 13.5S 166E

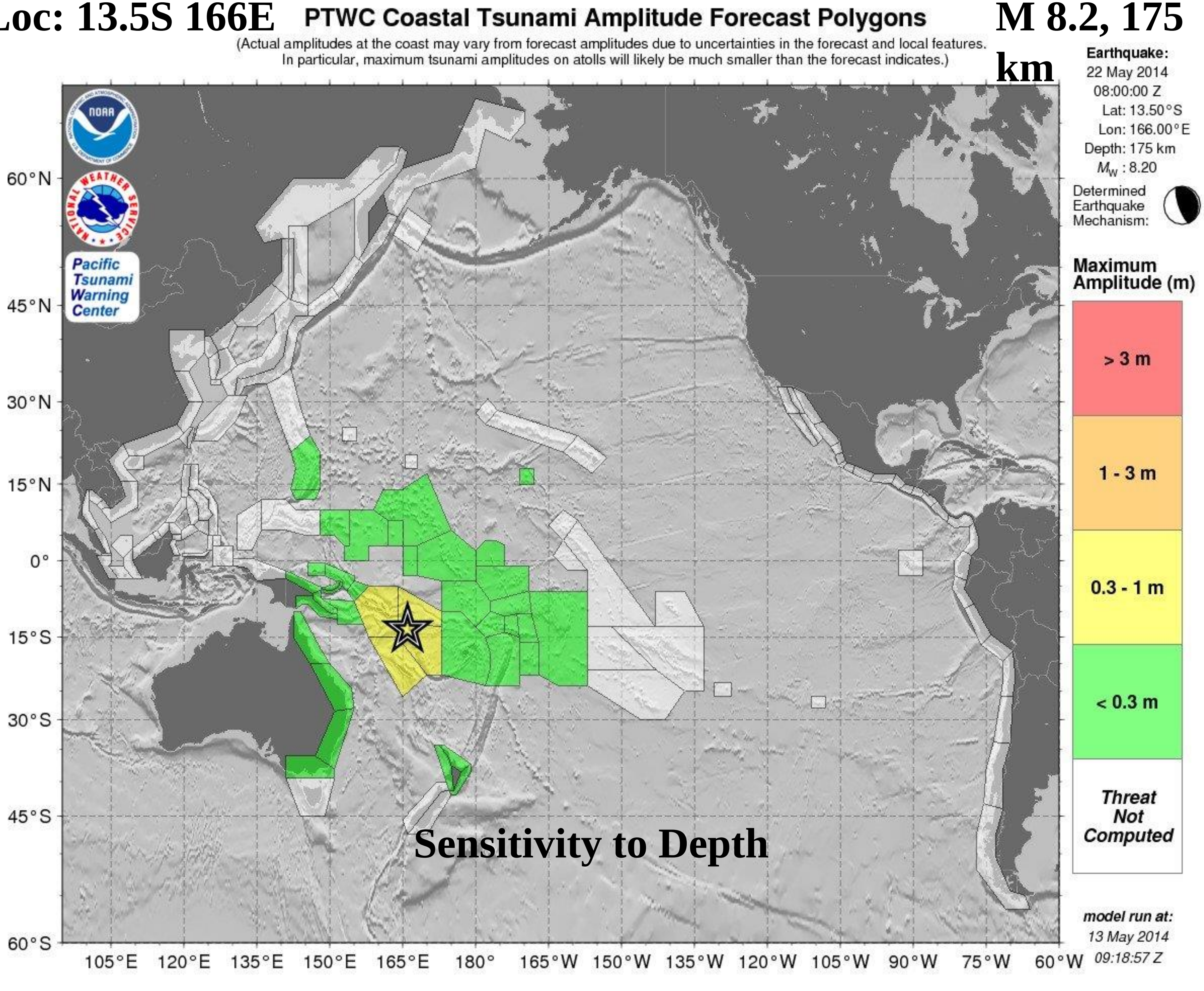
M 8.2, 150 km



Sensitivity to Depth

Loc: 13.5S 166E

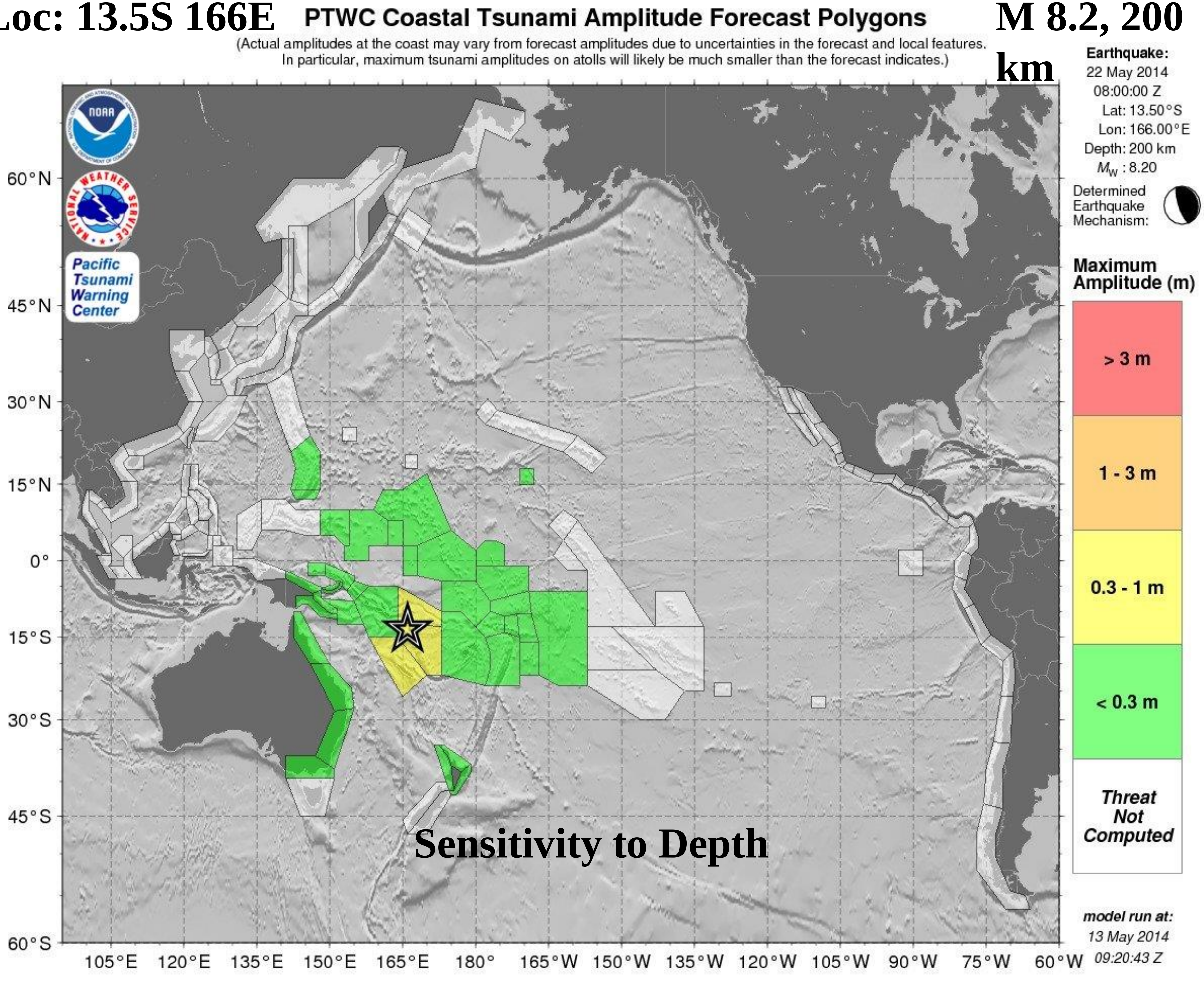
M 8.2, 175 km



Sensitivity to Depth

Loc: 13.5S 166E

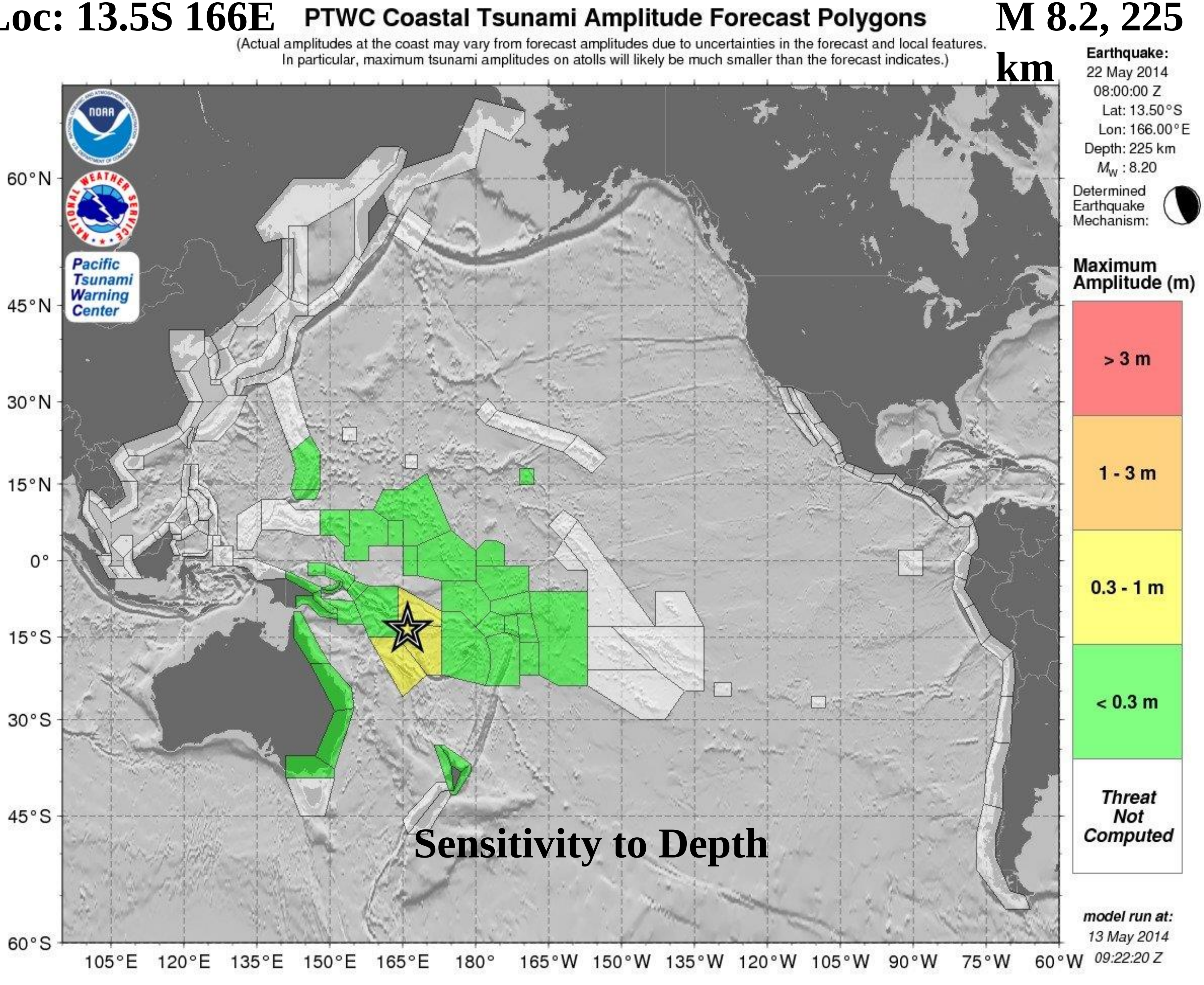
M 8.2, 200 km



Sensitivity to Depth

Loc: 13.5S 166E

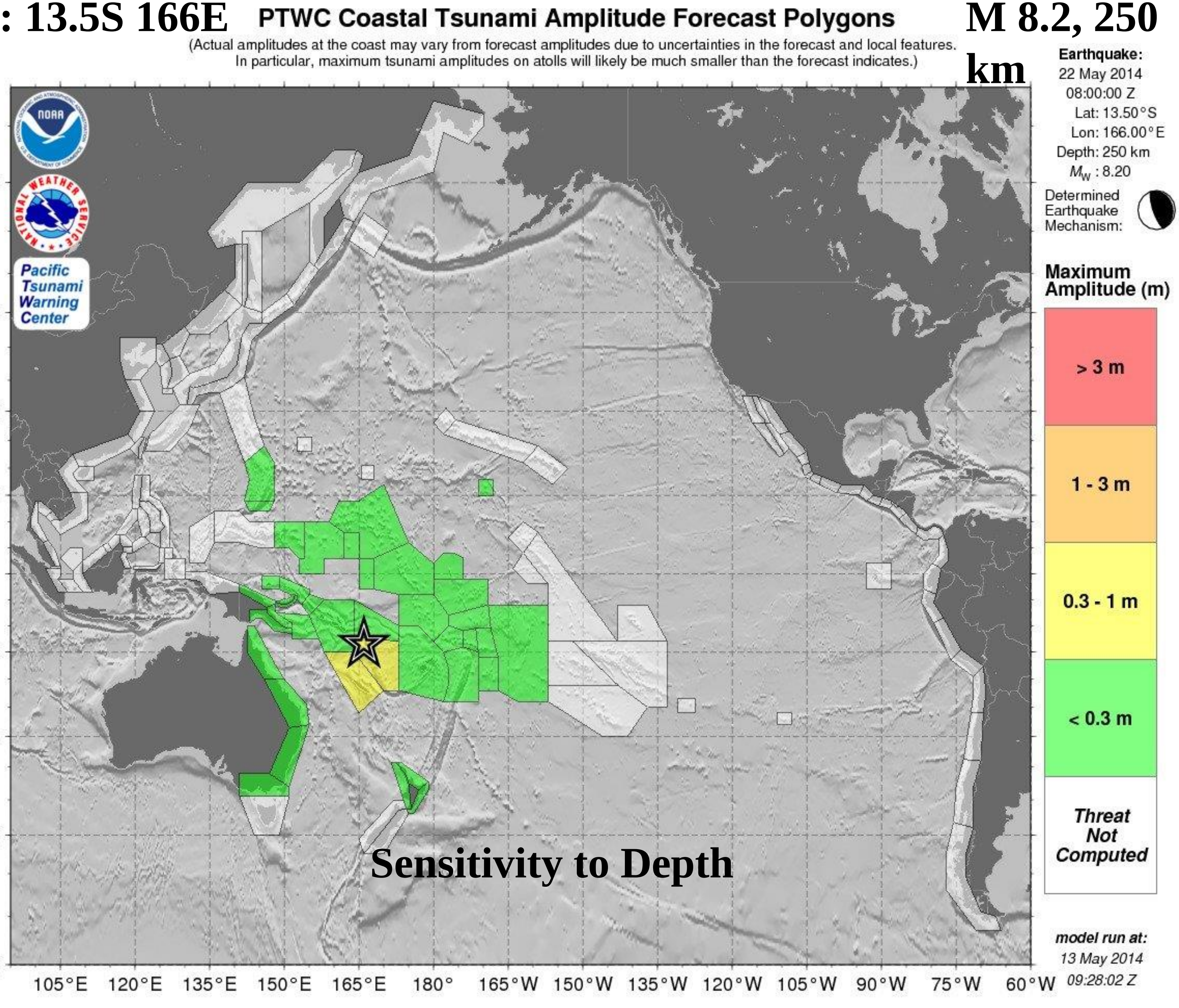
M 8.2, 225 km



Sensitivity to Depth

Loc: 13.5S 166E

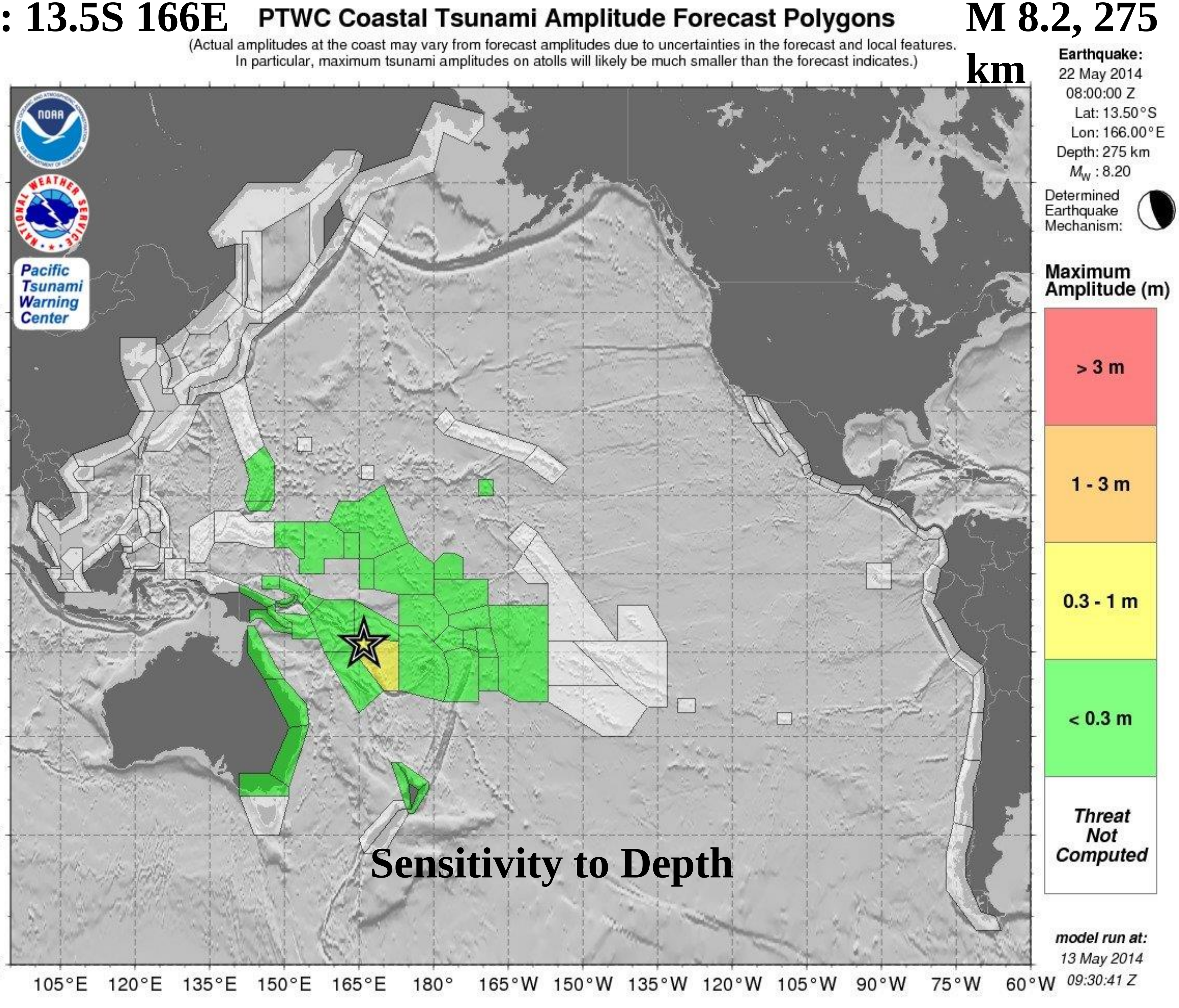
M 8.2, 250 km



Sensitivity to Depth

Loc: 13.5S 166E

M 8.2, 275 km



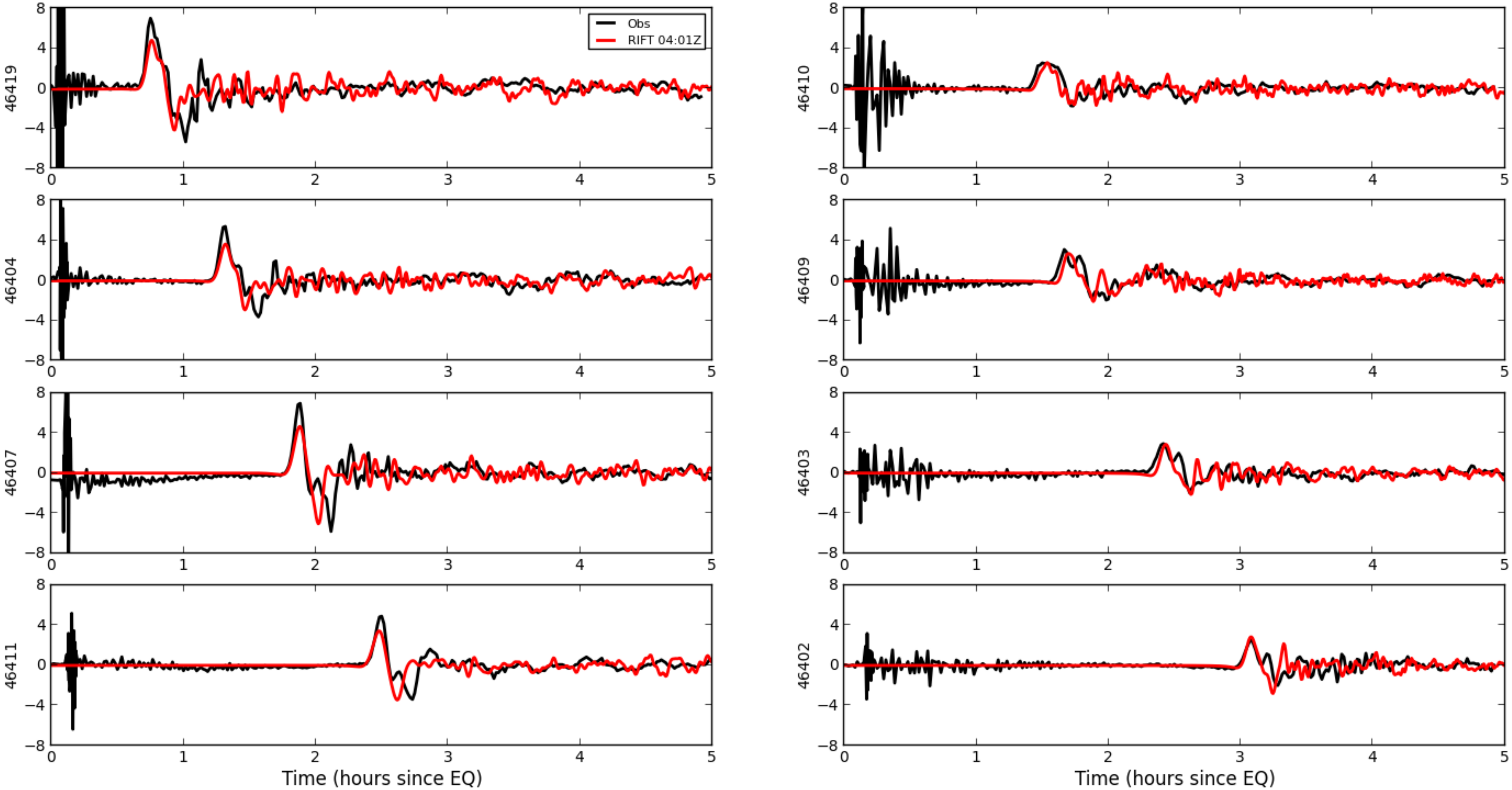
Sensitivity to Depth

4. Comparison of RIFT results with recent events

- In this section, we compare RIFT results with observations at tide stations of eight recent events that generated basin-crossing tsunamis in the Pacific (event, followed by forcing used):
  - Kuril M8.3, Nov. 15, 2006
  - Kuril M8.1, Jan. 13, 2007
  - Samoa M8.0, Sep. 29, 2009
  - Chile M8.8, Feb. 27, 2010
  - Tohoku M9.0, Mar. 11, 2011
  - Haida Gwaii, M7.7, Oct. 28, 2012
  - Solomon Islands, M8.0, Feb. 6, 2013, M8.0
  - Northern Chile M8.2, Apr. 1, 2014
- RIFT runs were made post-event using the current model executable, forced with W-phase CMTs or Global CMTs (when W-phase CMT was not available).

In general, the RIFT model agrees better with DARTs than with tide station observations. For example, below is a comparison of RIFT real-time forecast during the event with DARTs for the 2012 Haida Gwaii tsunami.

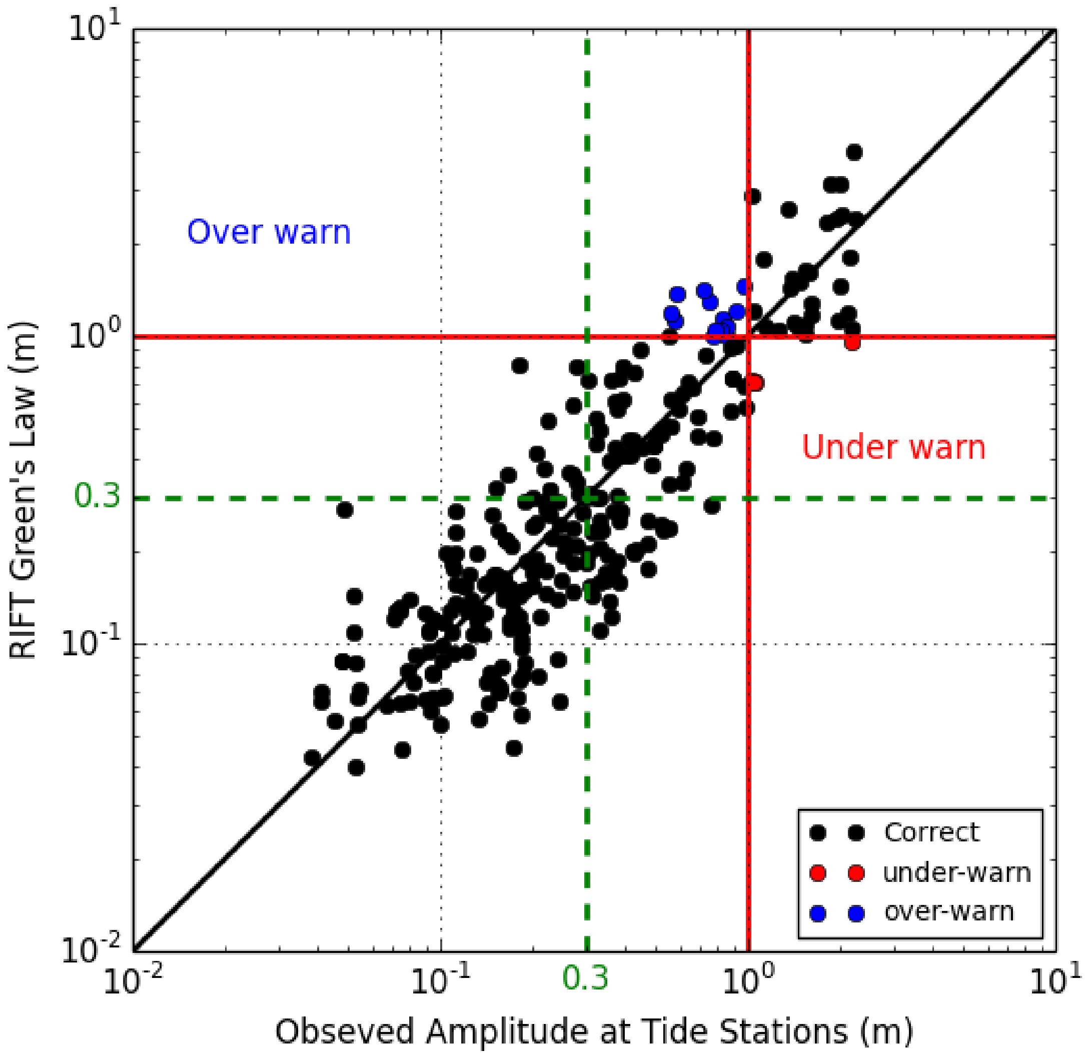
Comparison with DARTs, RIFT model forced with USGS WCMT 03:28Z



- RIFT’s Green’s law forecast is meant for coastlines that are more linear and are exposed to the open ocean.
- Comparing RIFT’s Green’s law with tide stations that are hidden can be misleading.
- The RIFT results satisfy the “factor-of-two” requirement for all eight events tested.

Composite comparison of RIFT's Green's law with tide station observations from eight basin crossing tsunamis.

"Open ocean" tide stations: excluding tide stations on atolls, islands with barrier or fringing reefs, small islands, and tide stations in well protected harbors or are too far from the open ocean.



Mean Error = 41%
Mean Mod/Obs Ratio=1.1

This means the model result is well within a factor of two of the observations on average.

Note that upward bias is greatly reduced when only "open ocean" tide stations are included in the error analysis, which is a more meaningful assessment of the efficacy of the Green's law.

Using 1-m as warning threshold: the model :
under warns: 1% of total
over warns: 5% of total
is correct: 94% of total

Summary

1. Although real-time computation of tsunami travel time (TTT) and the RIFT model is feasible for any earthquake location and any focal mechanism, these methods have their limitations.

2. The Green's law coastal forecast is meant for an open/linear coast. It is not capable of making a forecast for hidden locations. Therefore, forecasts at well-hidden locations should be discarded or the results should be interpreted as forecast for the nearby open coast.

3. Green's law coastal forecast is an order of magnitude forecast (general level of threat) and is not suitable for evacuation mapping.

Summary

4. The RIFT model forecast are generally within a factor of two of the open ocean gauges. Assume RIFT forecasts can be off by a factor of two on average (a forecast of 1 m could easily be 0.5 m or 2 m in reality).

5. For atolls or regions with fringing/barrier reefs and steep bathymetry Green's law will overestimate.

6. For small islands without fringing/barrier reefs, it is prudent to use the Green's law forecast as guidance because it has an upward bias to avoid under-estimation.

7. For locations that historically tend to show resonance and tsunami amplifications, the Green's law might underestimates the threat.

Limitations of Tsunami Forecasting

- **Estimated Arrival Time Forecast**
  - Based on initial seismic analysis
  - Point source or assumed finite fault
- **Initial Threat Level Forecast**
  - Based only on initial seismic analysis and general geophysical/oceanographic contraints
  - Least accurate
- **Sea Level Constrained Forecast**
  - Too late for local tsunami
  - Deep ocean measurements best constraint
  - More accurate

Have a Great Day!

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