Operational Aspects of Tsunami Modeling and Detection

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Operational Tsunami Modeling

1-Long-term Forecasting:

Hazzard Assessment

Evacuations Maps

Can be probabilistic or deterministic

2- Short-term Forecasting

Real-time modeling of an occurring tsunami event

Operational Tsunami Modeling

1- Source Design/Detection

2- Modeling Propagation (Linear Regime)

3-Modeling Inundation (Non-Linear Regime)

4- Inundation Calculations.

Long Term Modeling

Advantages:

1-Computation time is not a major concern.

2- Very high resolution DEMs can be used (1-1/3 arcsec).

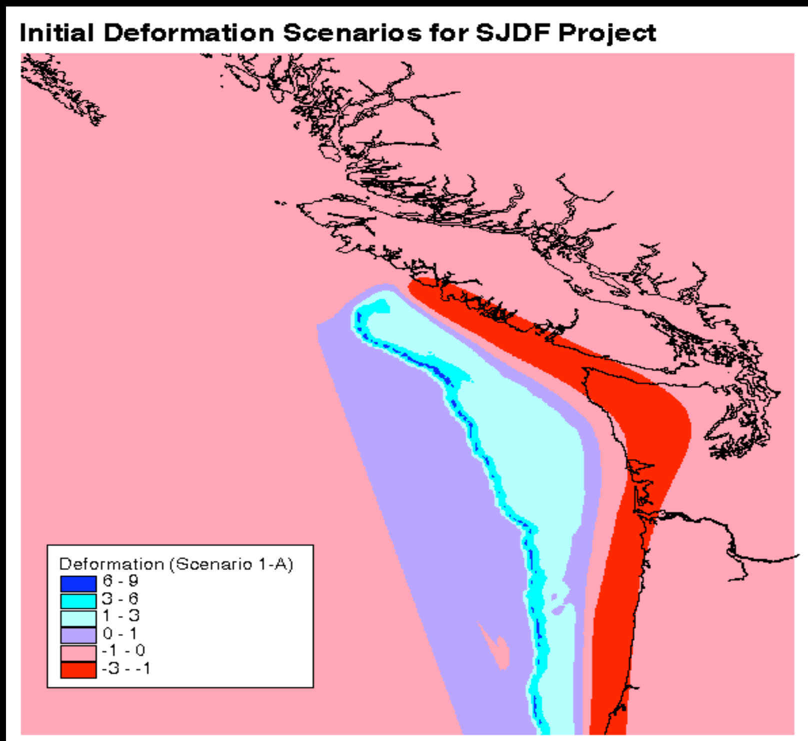
3-Solution is available long before the event occurs.

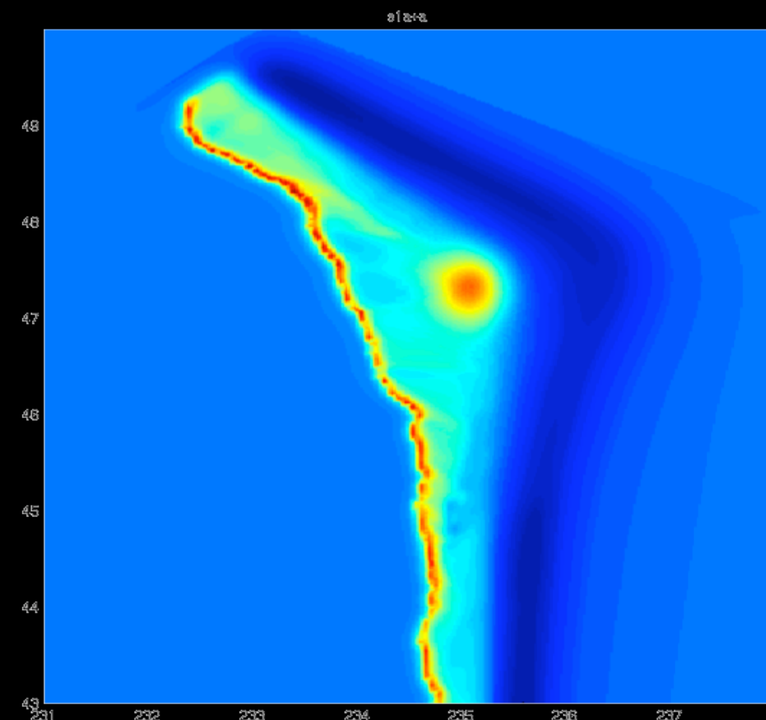
4- Emergency planning can be done based on a long term forecast

Disadvantages:

1-Modeled events are always hypothetical whether deterministic or probabilistic.

Long Term Modeling: Source Design





Central Longitude: 235.06 deg.

Central latitude: 47.324 N deg.

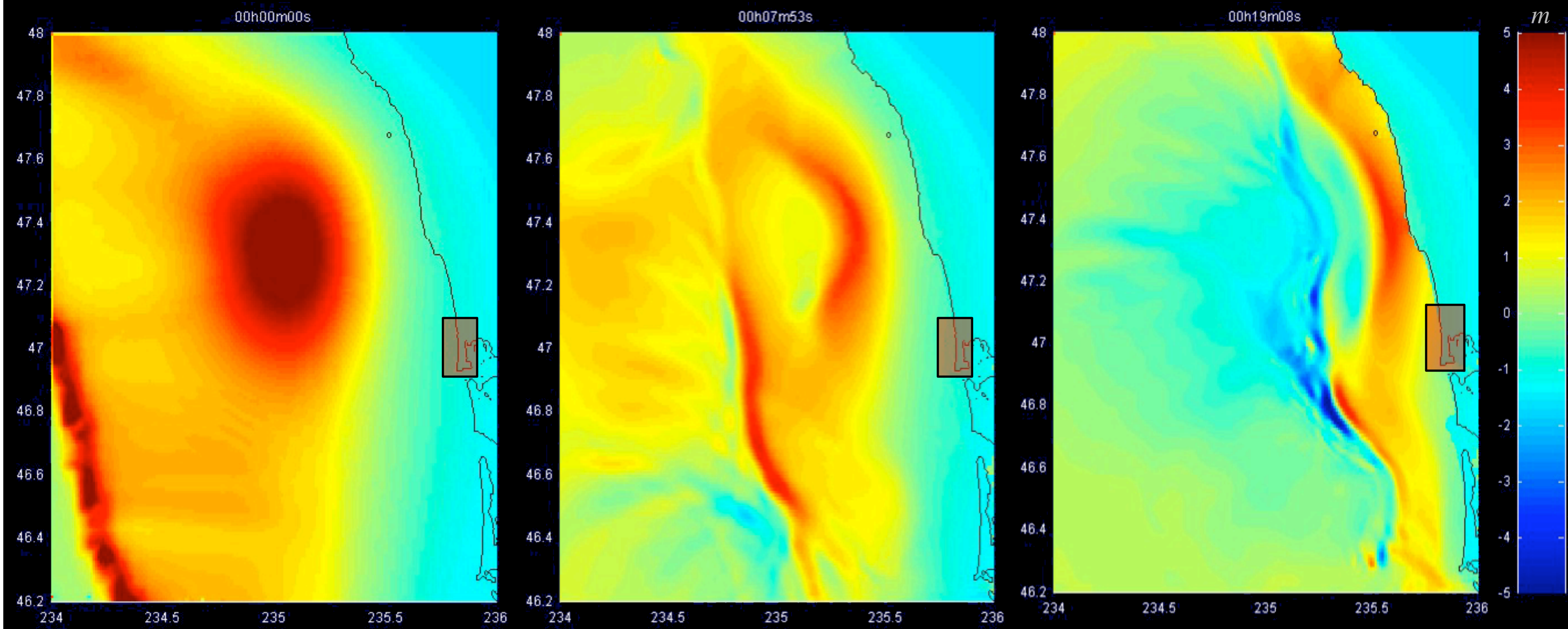
<u>Elliptical Gaussian Asperity Parameters:</u>

Orientation of main axis: 0 deg. (Clockwise with respect to North)

Maximun height: 4.5 meters

Main axis: 38.455 Km /Minor axis: 25.635 Km

Long Term Modeling: Propagation



Time from EQ= 00:00:00 *Time from EQ= 00:07:53* *Time from EQ= 00:19:08*

Long Term Modeling: Inundation for TsunamiReady Program

Operational Short Term Modeling: Forecasting

Advantages:

1-Modeled events are NOT hypothetical. They are always deterministic. Less chance of over or underestimation.

Disadvantages:

1-Computation time IS a major concern.

2- Very high resolution DEMs CANNOT be used (1-3 arcsec).

3-Solution is NOT available before the tsunami is generated but should be available before it makes landfall.

4- Event-dependent emergency planning is not possible.

Operational Short Term Modeling: Forecasting

Implications:

From and emergency management standpoint: We need to forecast: Arrival time, Max/Min wave amplitude, Decay. (Approximate solution)

2- Sources of error:

a-Inaccurate topo/bathy data.

b-Insufficient knowledge about the IC's (Sea surface elevation can be reported by instruments, but there is no data on IC's for the velociy components.

c-Errors in the assumptions of the mathematical model: Shallow Water Wave, Boussinesq, N-S.

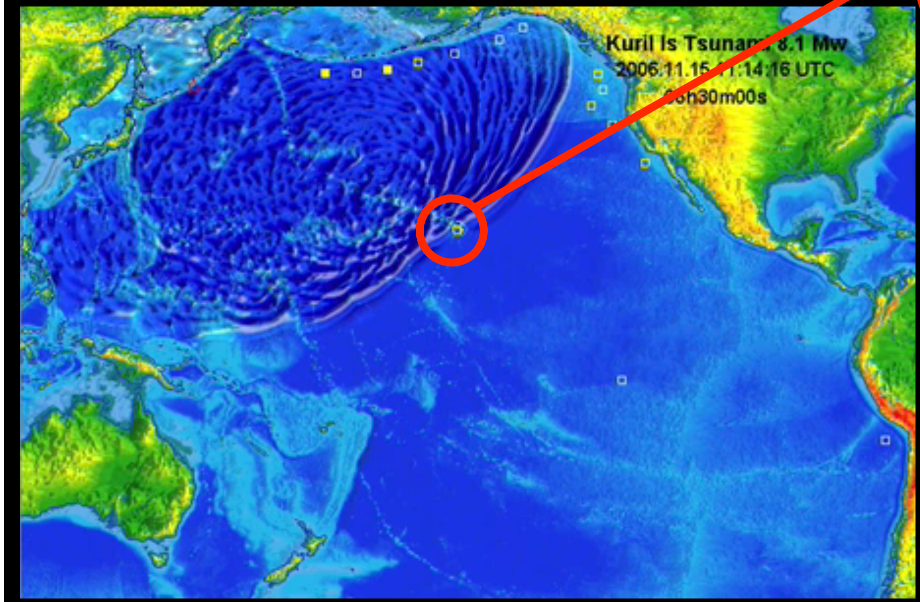
d-Errors in the numerical algorithm: Dispersion/Dissipation

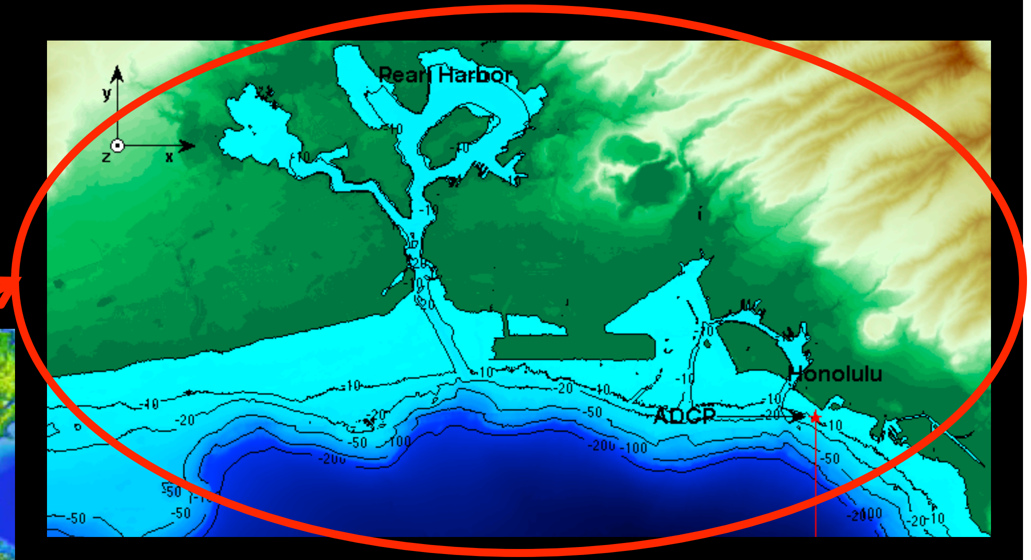
e-Errors in the forecast methodology: Unit sources, Inversion,…

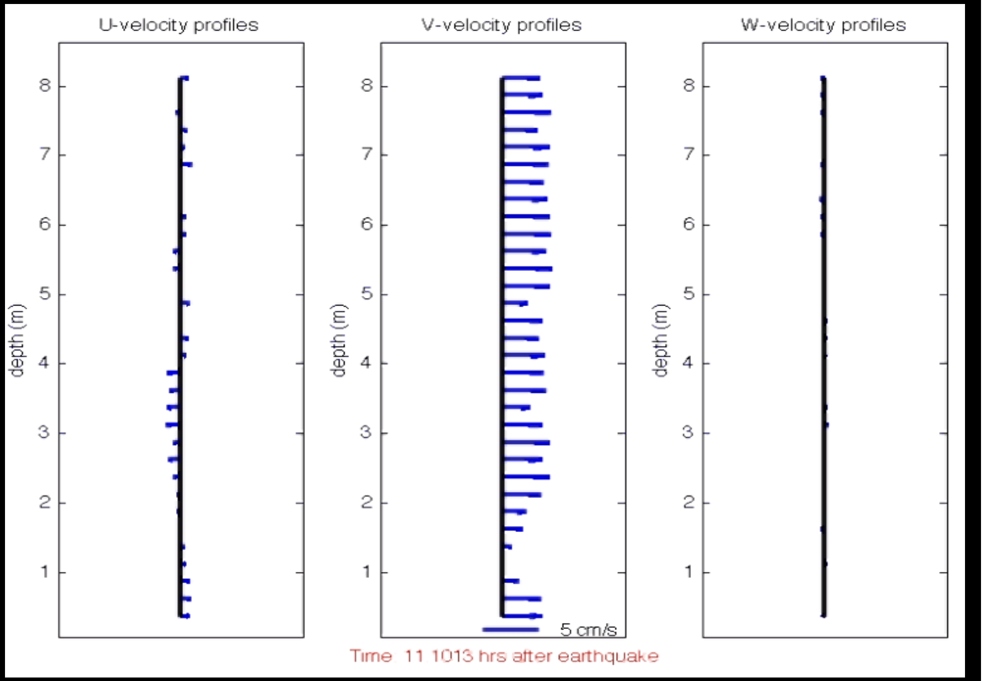
Sources of error: Uniformity of velocity profiles

Kuril 2006: Honolulu Velocity Profiles

(depth=10 m)







Sources of error: Error in the bathy/topo data

Ocean Shores, WA

Ocean Shores, WA

Forecasting Method

Characteristic Form of the Non-linear Shallow Water Equations.

$$h_t + (uh)_x = 0$$
$$u_t + uu_x + gh_x = gd_x$$
$$v_t + uv_x = 0$$

$$p_t + \lambda_1 p_x = gd_x$$
$$q_t + \lambda_2 q_x = gd_x$$
$$v'_t + \lambda_3 v'_x = 0$$

Riemann invariants

$$p = u + 2\sqrt{gh}$$
$$q = u - 2\sqrt{gh}$$
$$v' = v$$

Eigenvalues

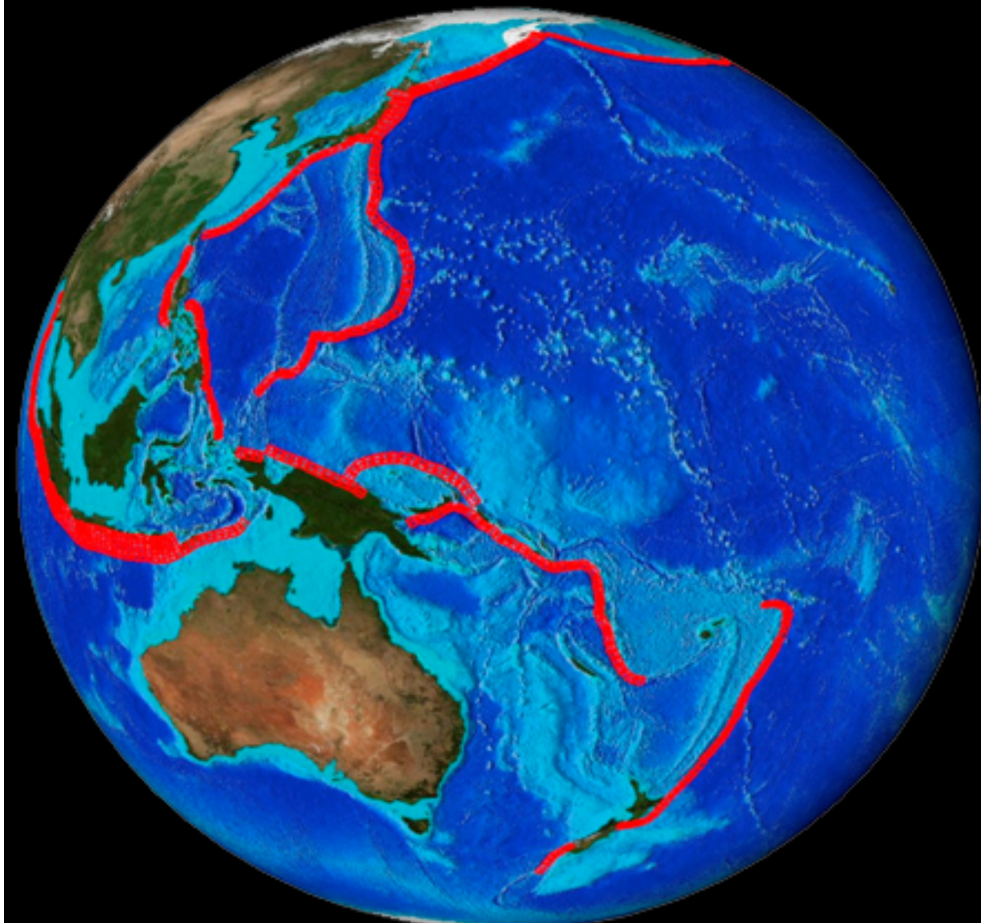
$$\lambda_1 = u + \sqrt{gh}$$
$$\lambda_2 = u - \sqrt{gh}$$
$$\lambda_3 = u$$

In deep water the equations are linear!!

We can do propagation database!!

Forecasting Method

Locations of the unit sources for pre-computed tsunami events.

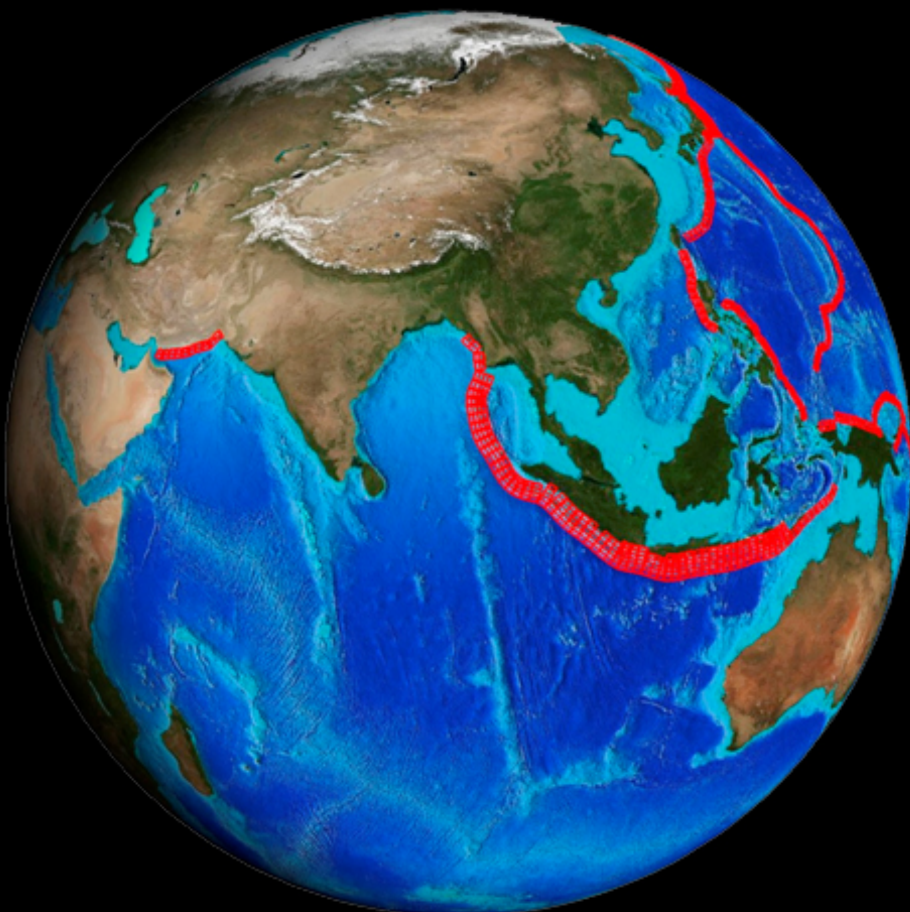


West Pacific

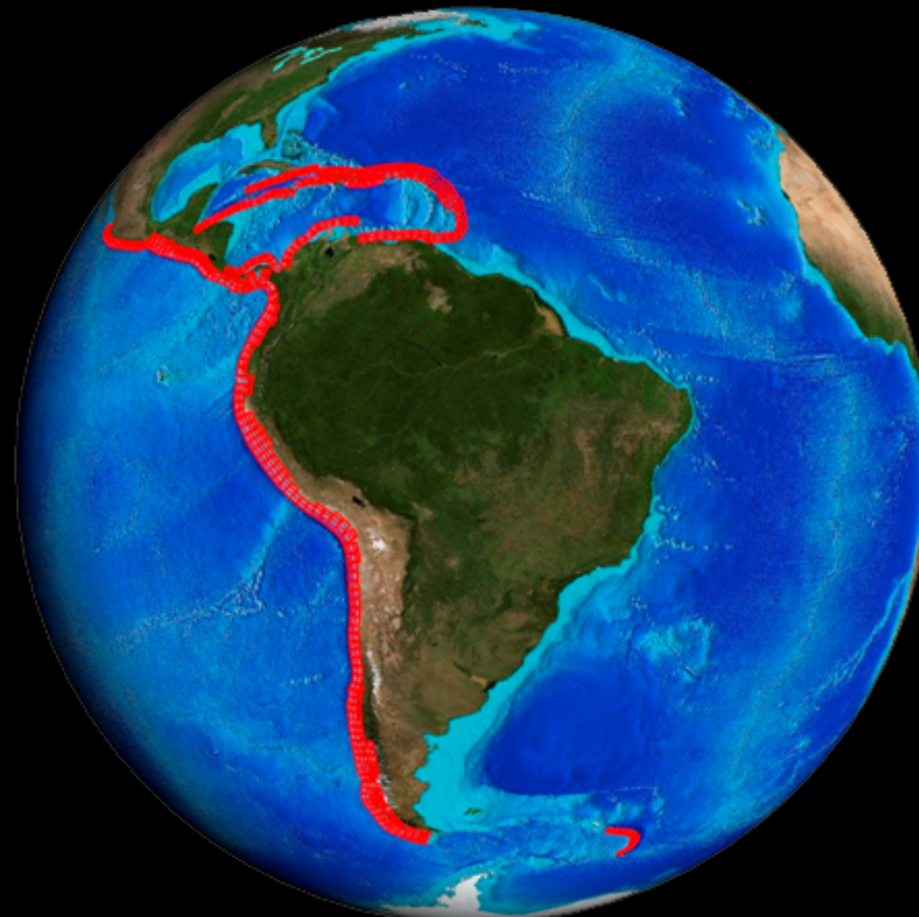
East Pacific

Forecasting Method

Locations of the unit sources for pre-computed tsunami events.



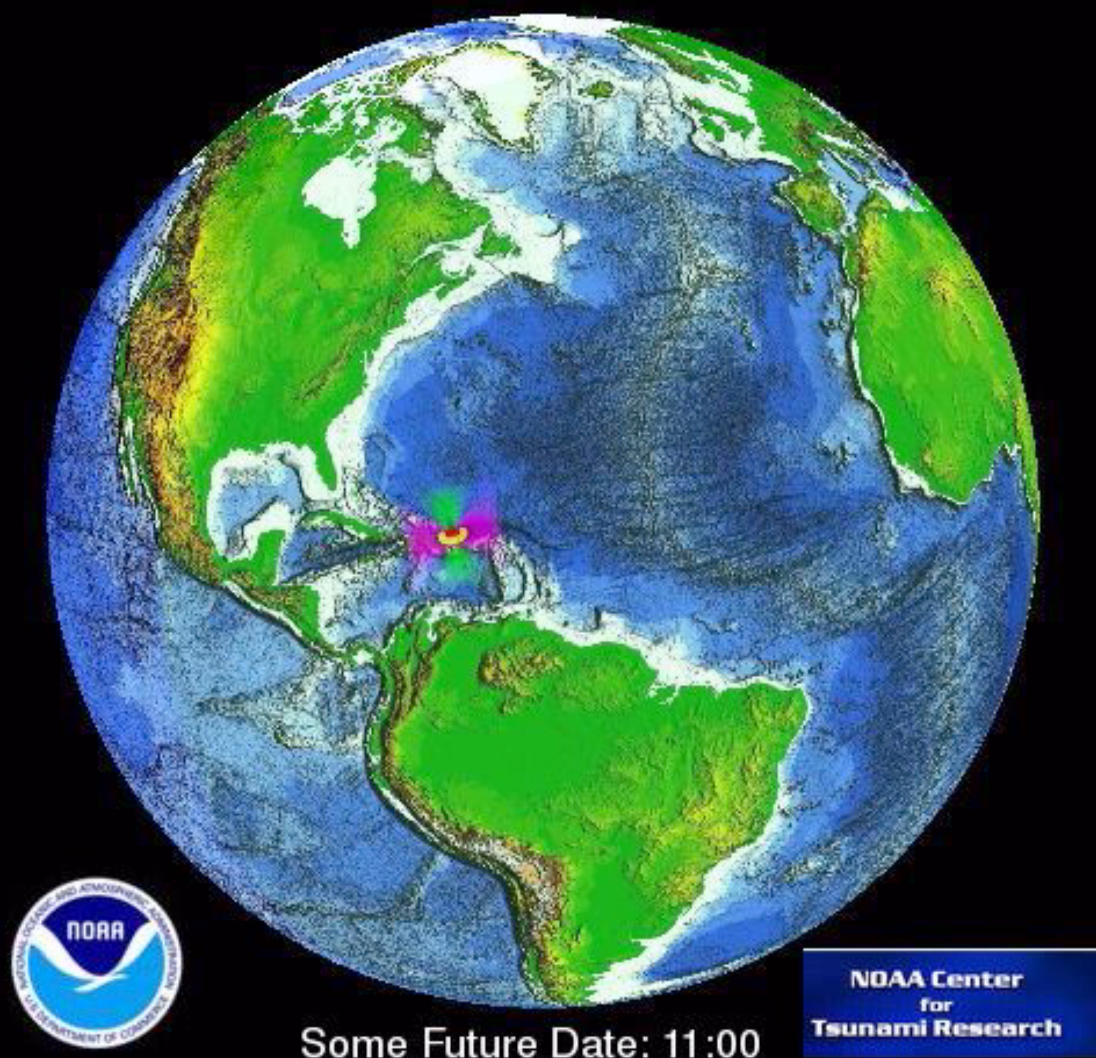
Indian Ocean



Atlantic Ocean

Forecasting Method

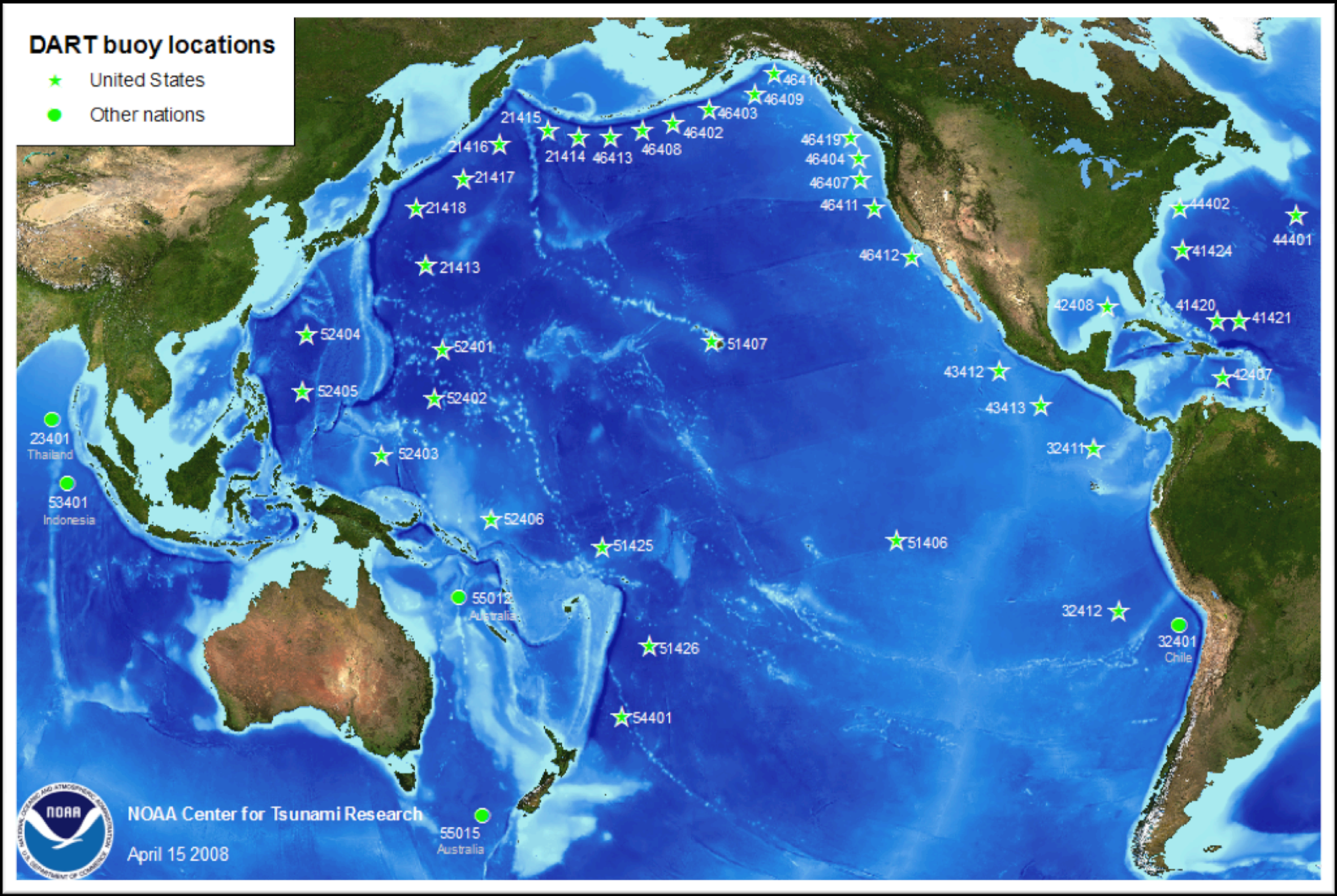
Unit source propagation of a tsunami event in the Caribbean

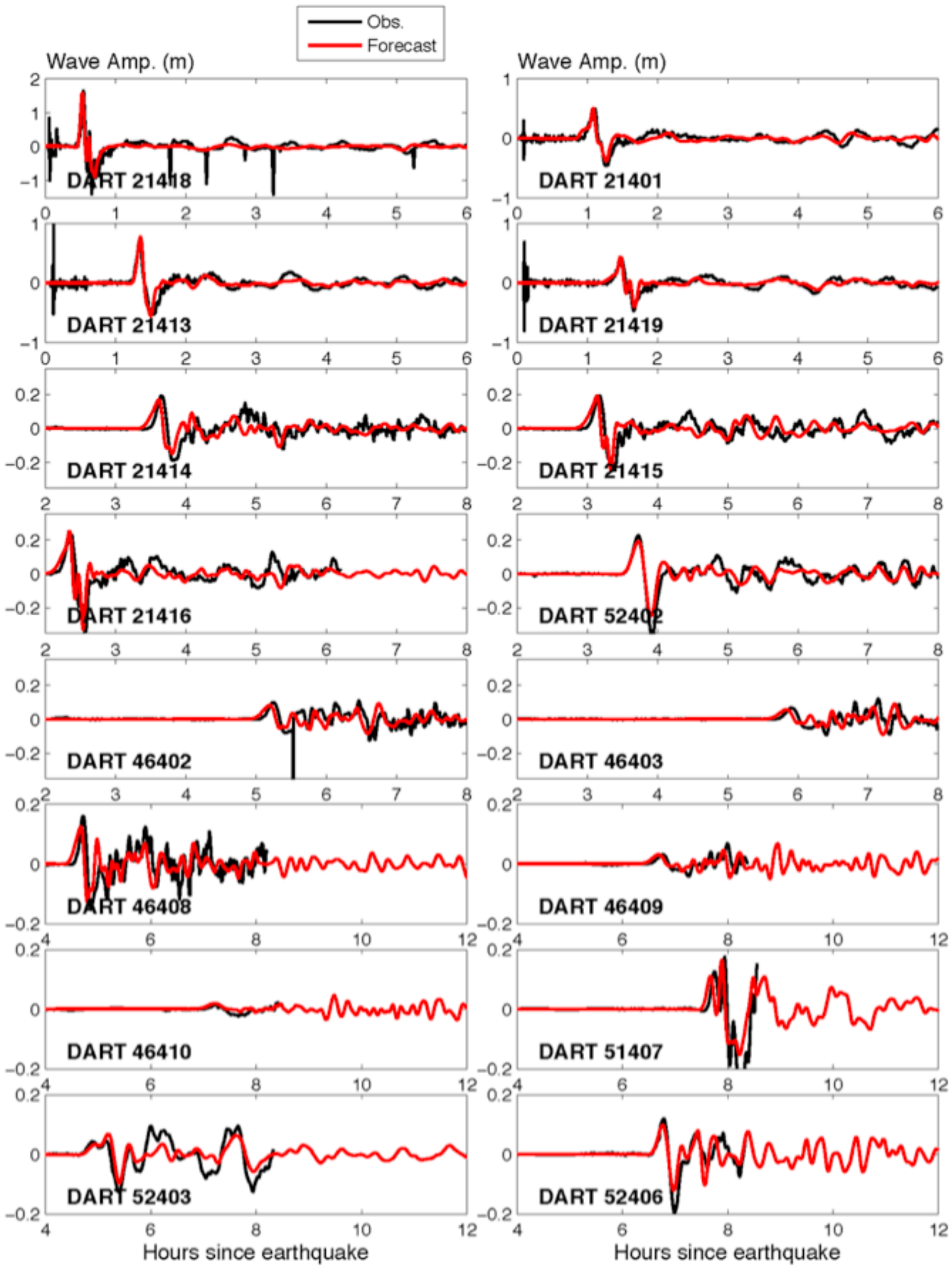


Forecasting Method: Detection

Tsunami Warning: DART Systems

Forecasting Method: DART Positions



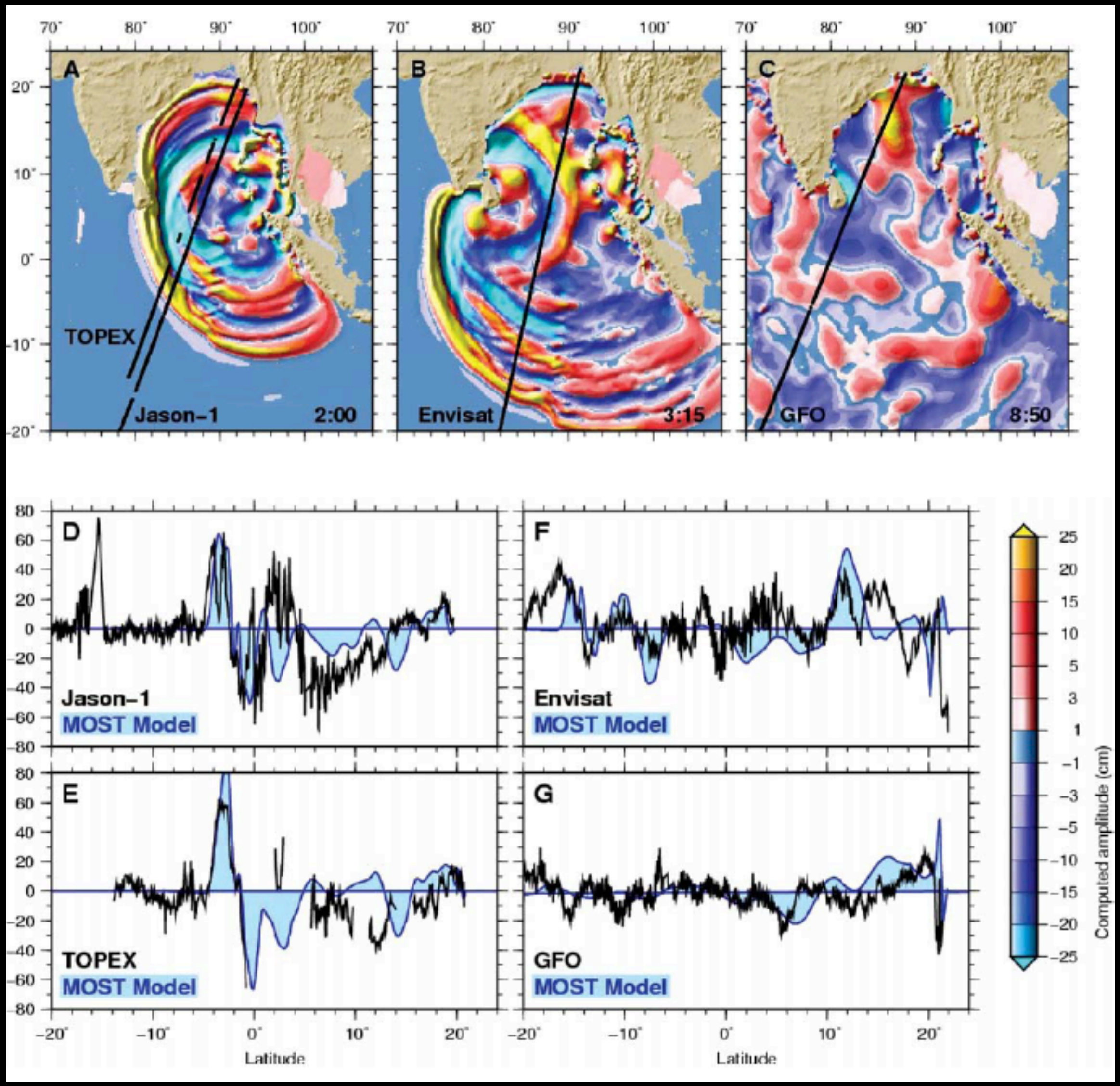


DART model-data comparison plots

NOAA Center for Tsunami Research

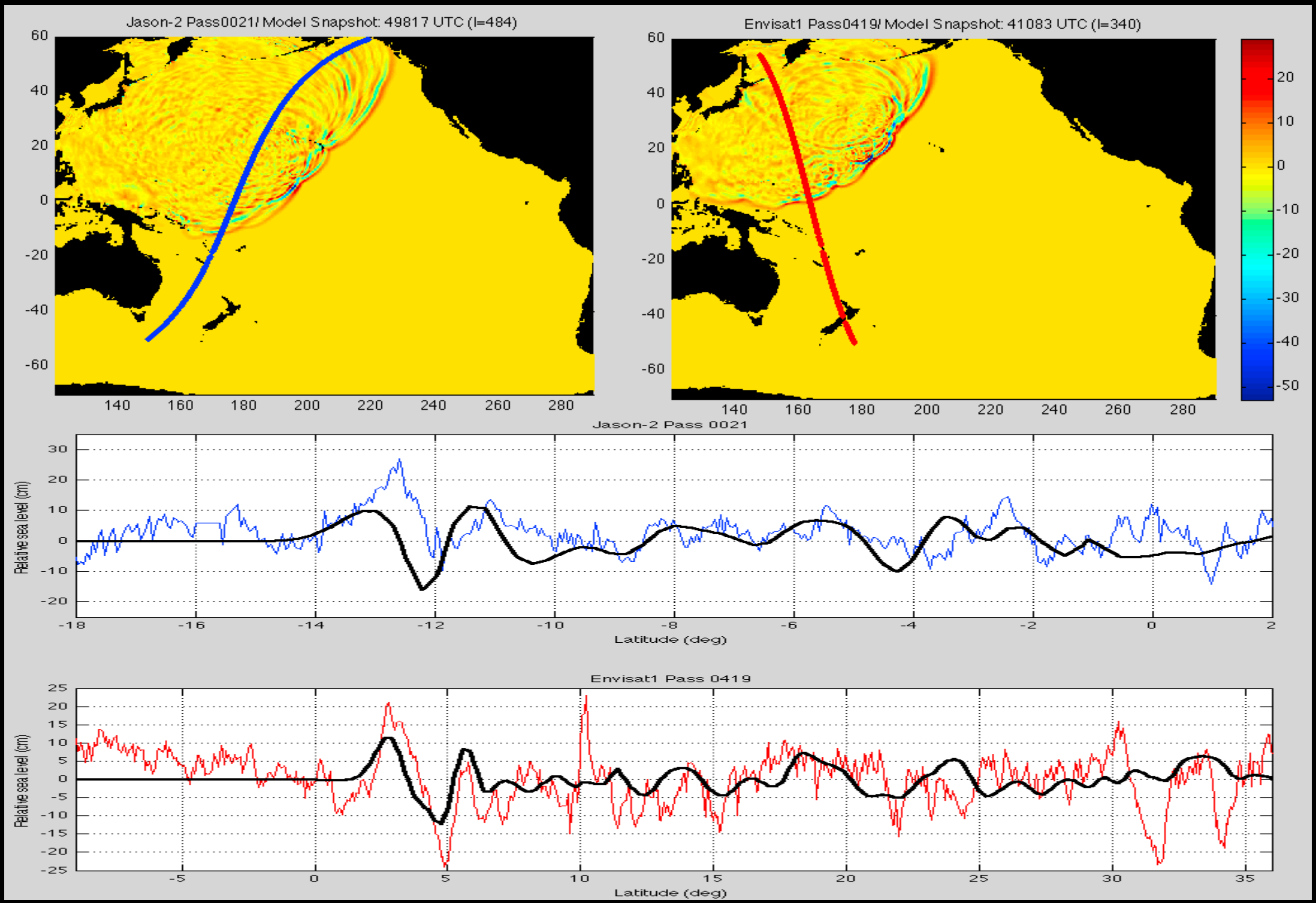
Forecasting Method: Detection

Tsunami Inversion based on satellite altimetry . Sumatra 2004 tsunami



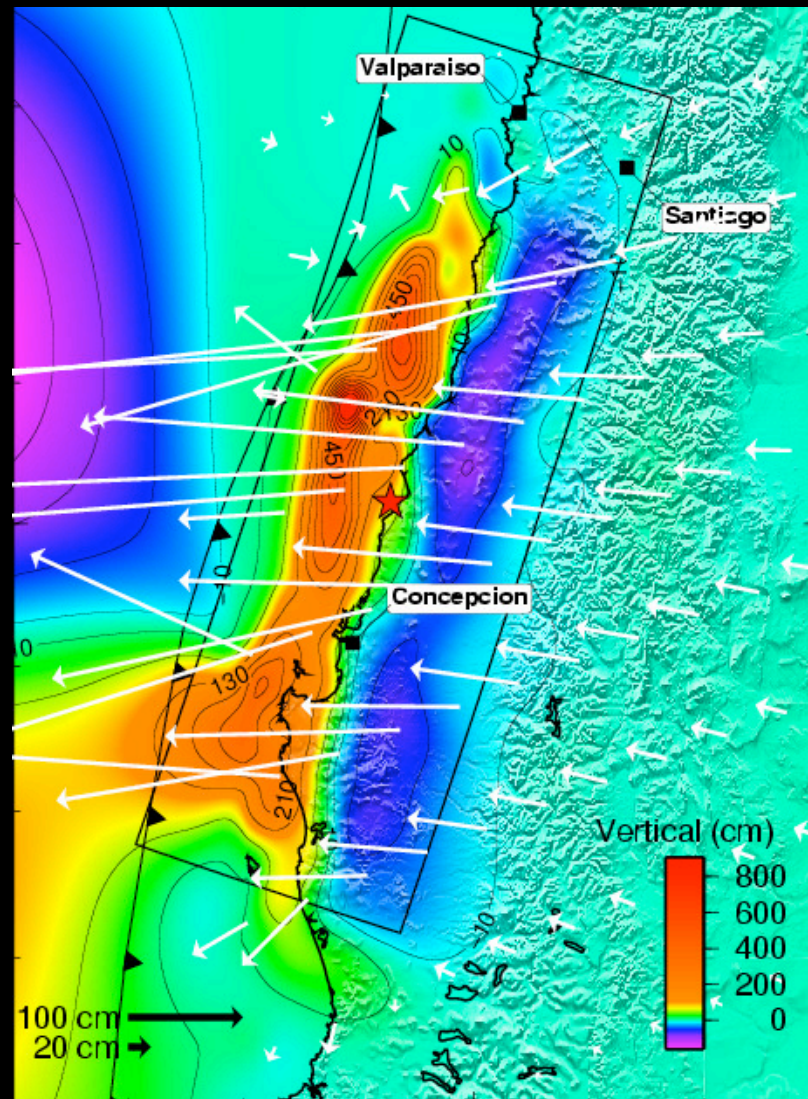
Forecasting Method: Detection

Tsunami Inversion based on satellite altimetry . Japan 2010 tsunami



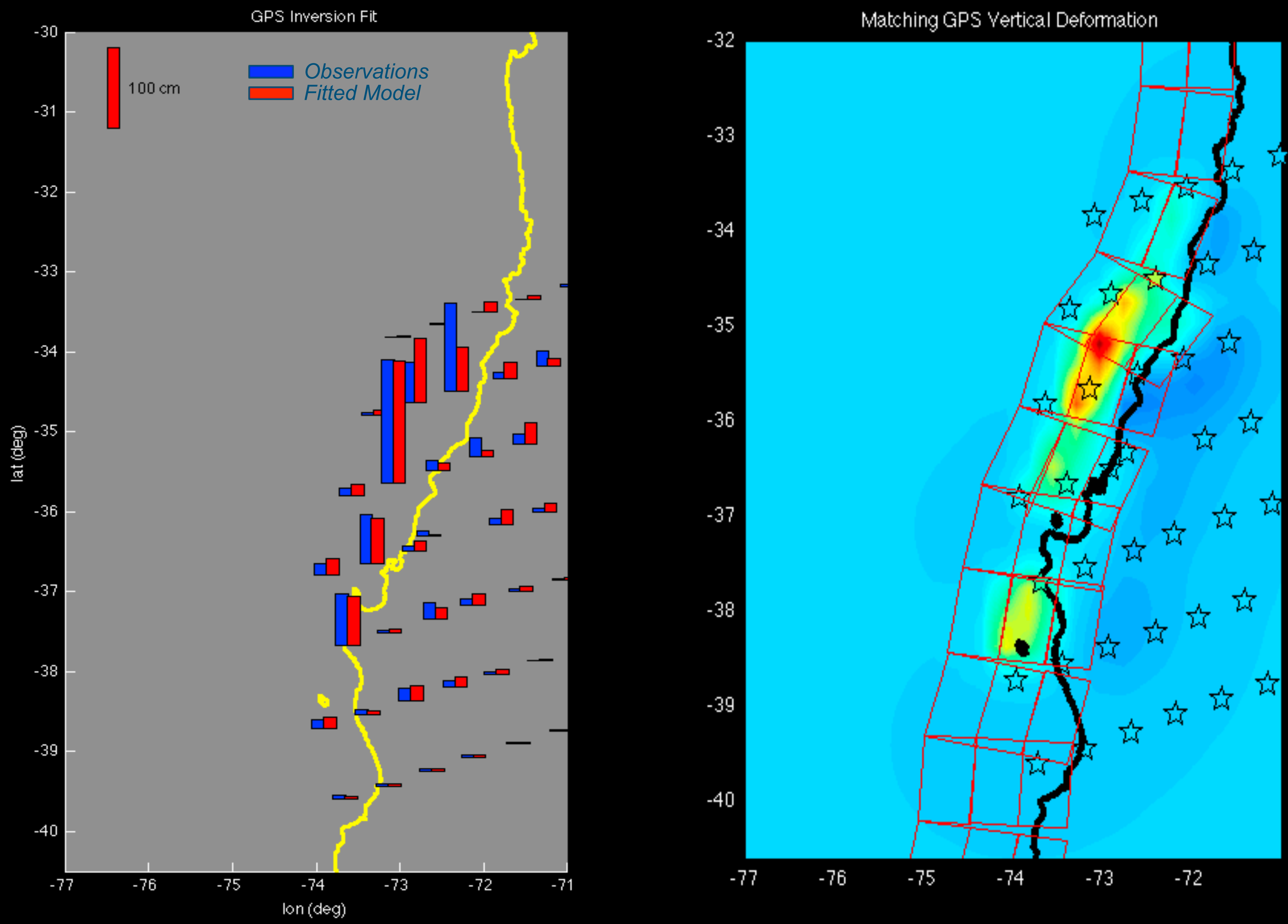
Ground Motion Vectors and Modeled Displacement for the 2010 Chile Earthquake

(detection from GPS and InSAR imagery).

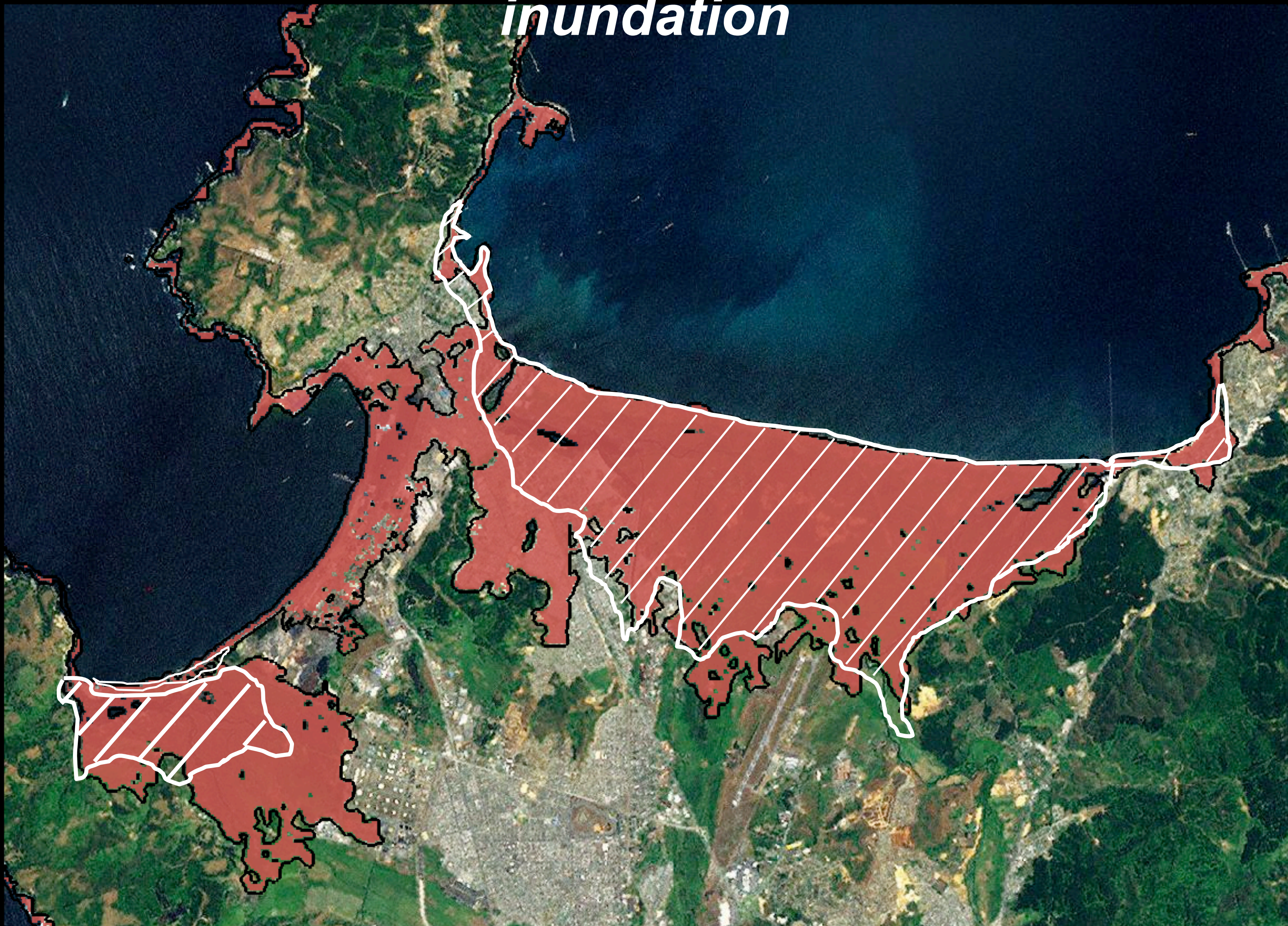


Courtesy of Anthony Sladen

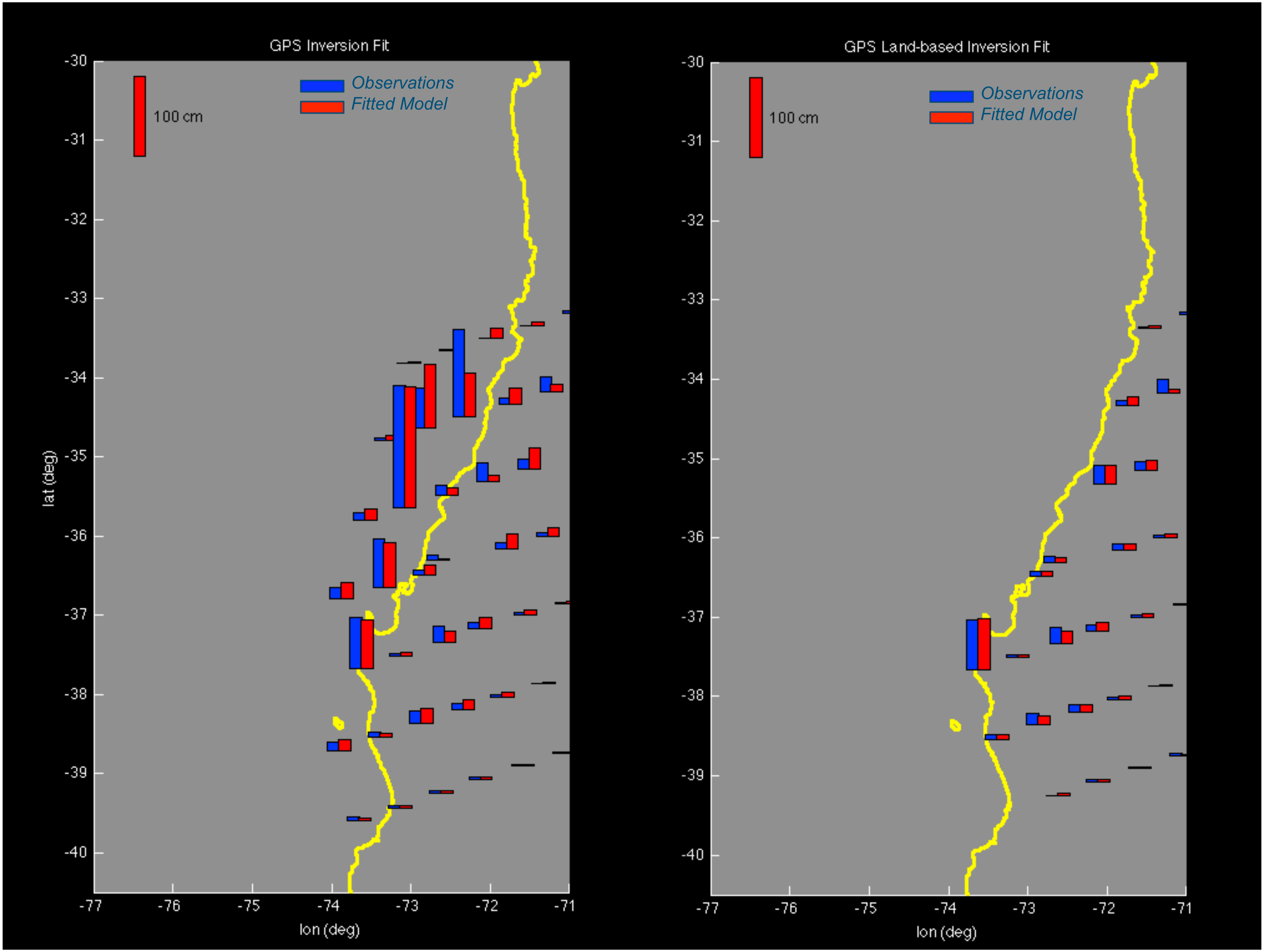
Forecasting Method: Detection



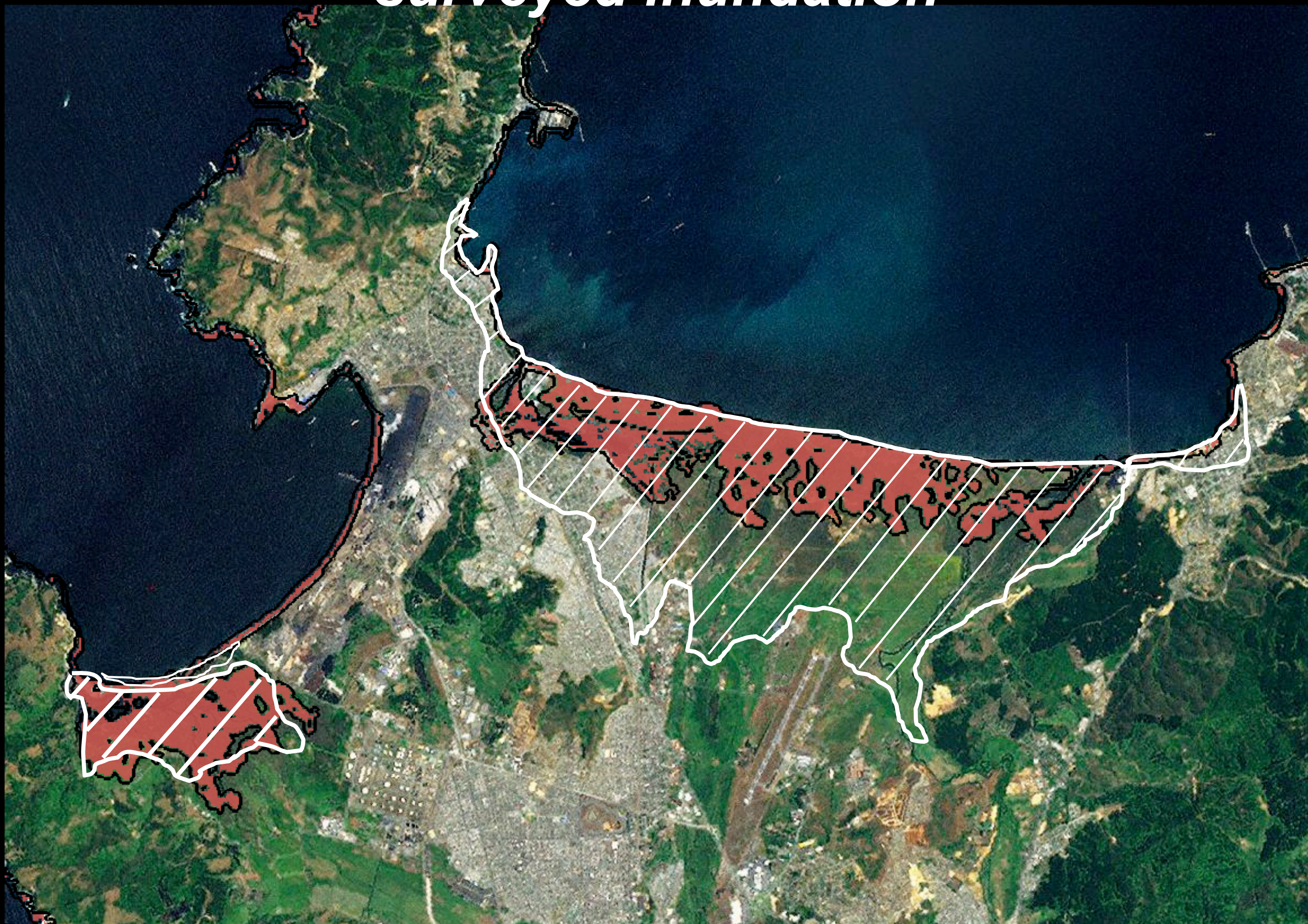
Comparison of GPS forecasted with surveyed inundation



Comparison of DART forecasted with surveyed inundation

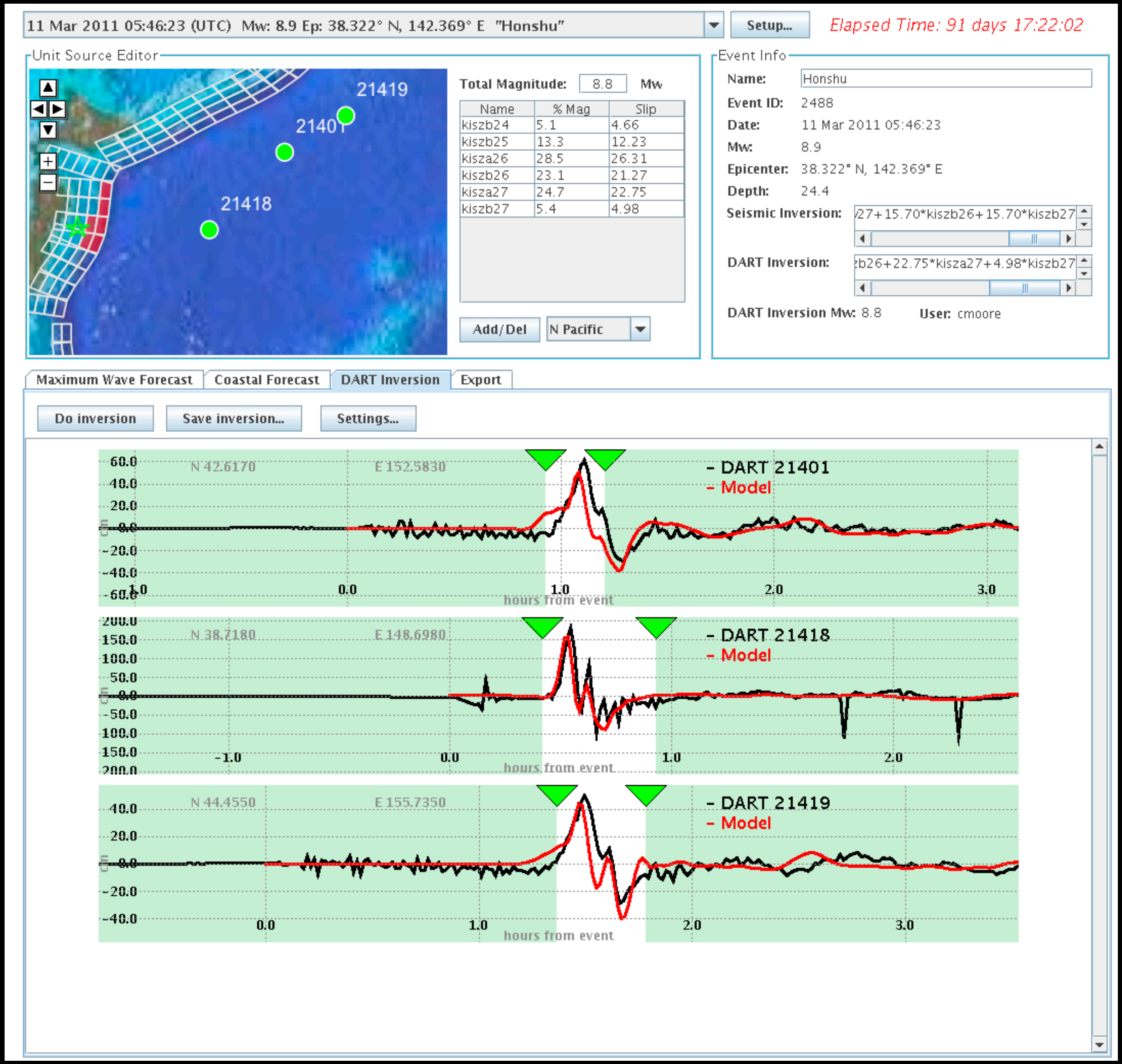

GPS Inversion Fit
Observations
Fitted Model
100 cm
lat (deg)
lon (deg)
-30
-31
-32
-33
-34
-35
-36
-37
-38
-39
-40
-77
-76
-75
-74
-73
-72
-71
GPS Land-based Inversion Fit
Observations
Fitted Model
100 cm
lon (deg)

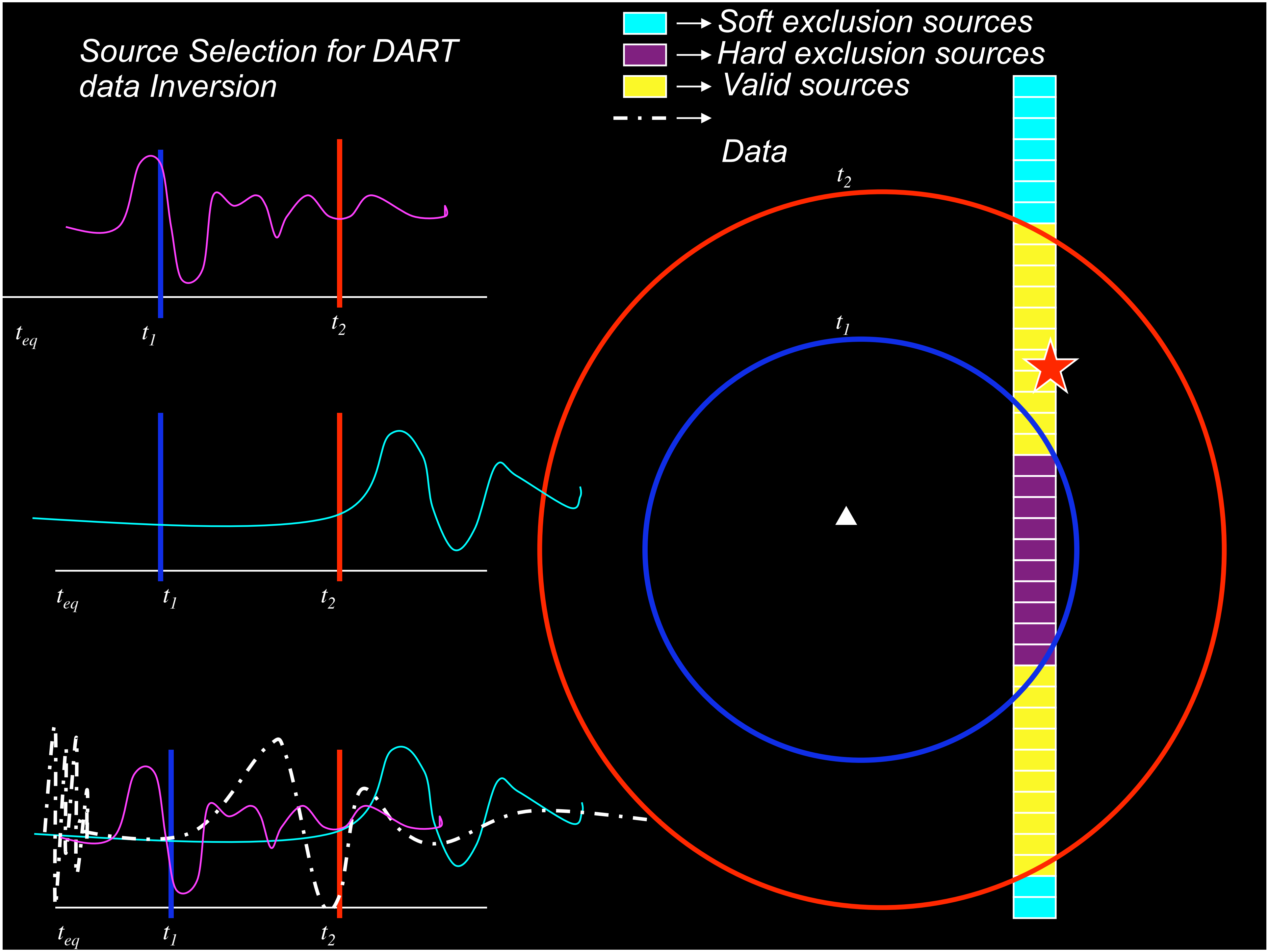
Comparison of land based GPS forecasted with surveyed inundation



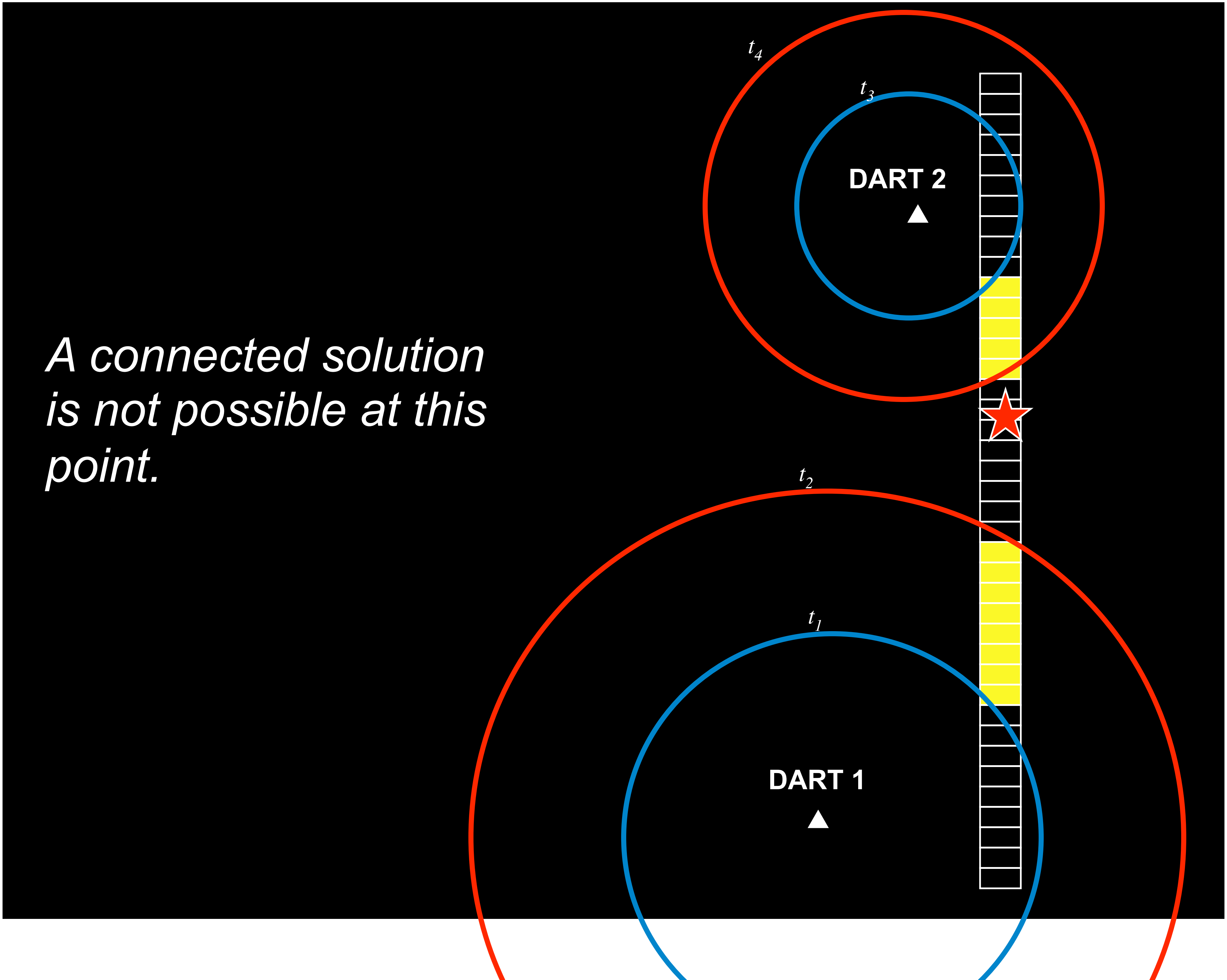
Comparison of DART forecasted with surveyed inundation

Forecasting Method: Inversion from DART



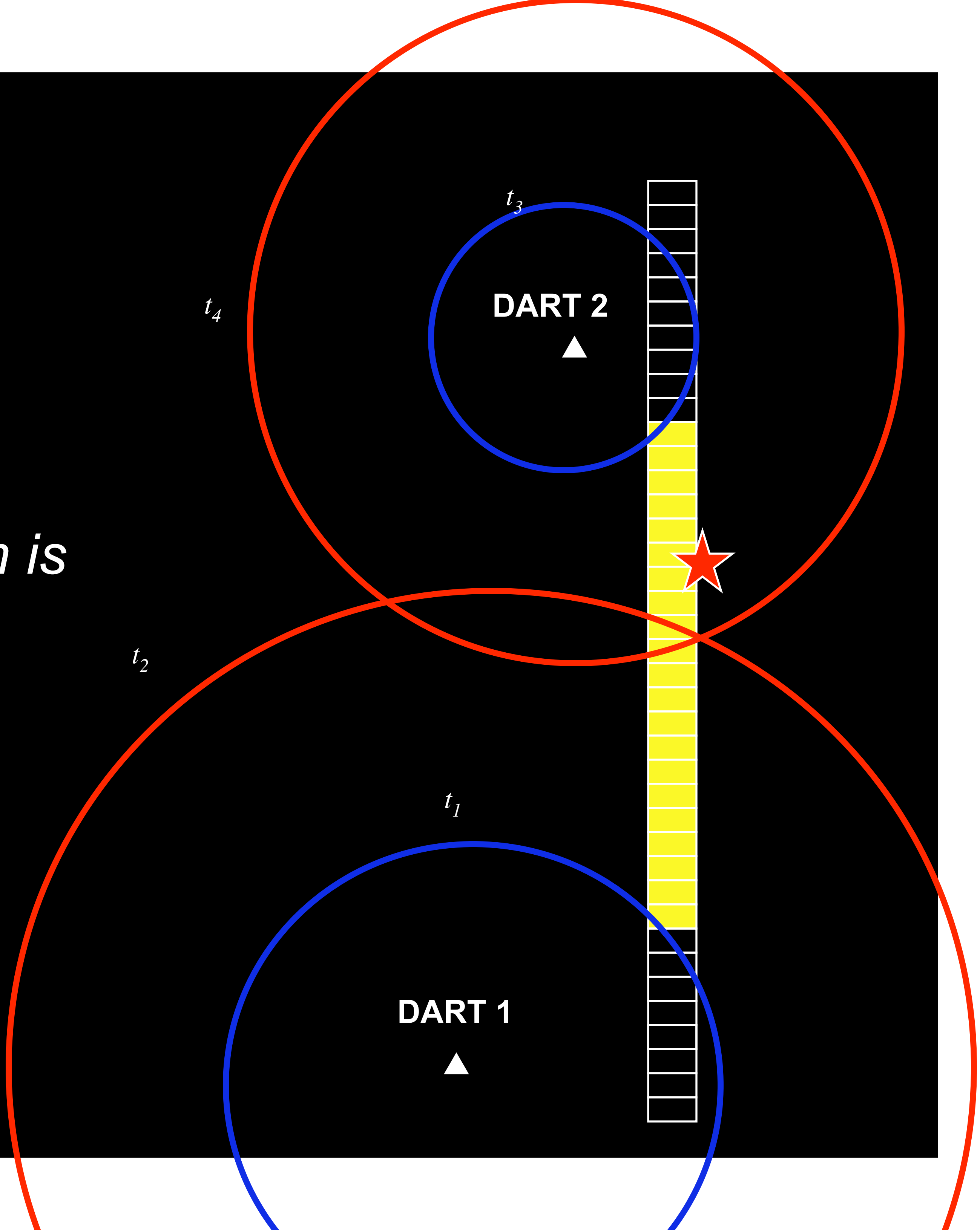


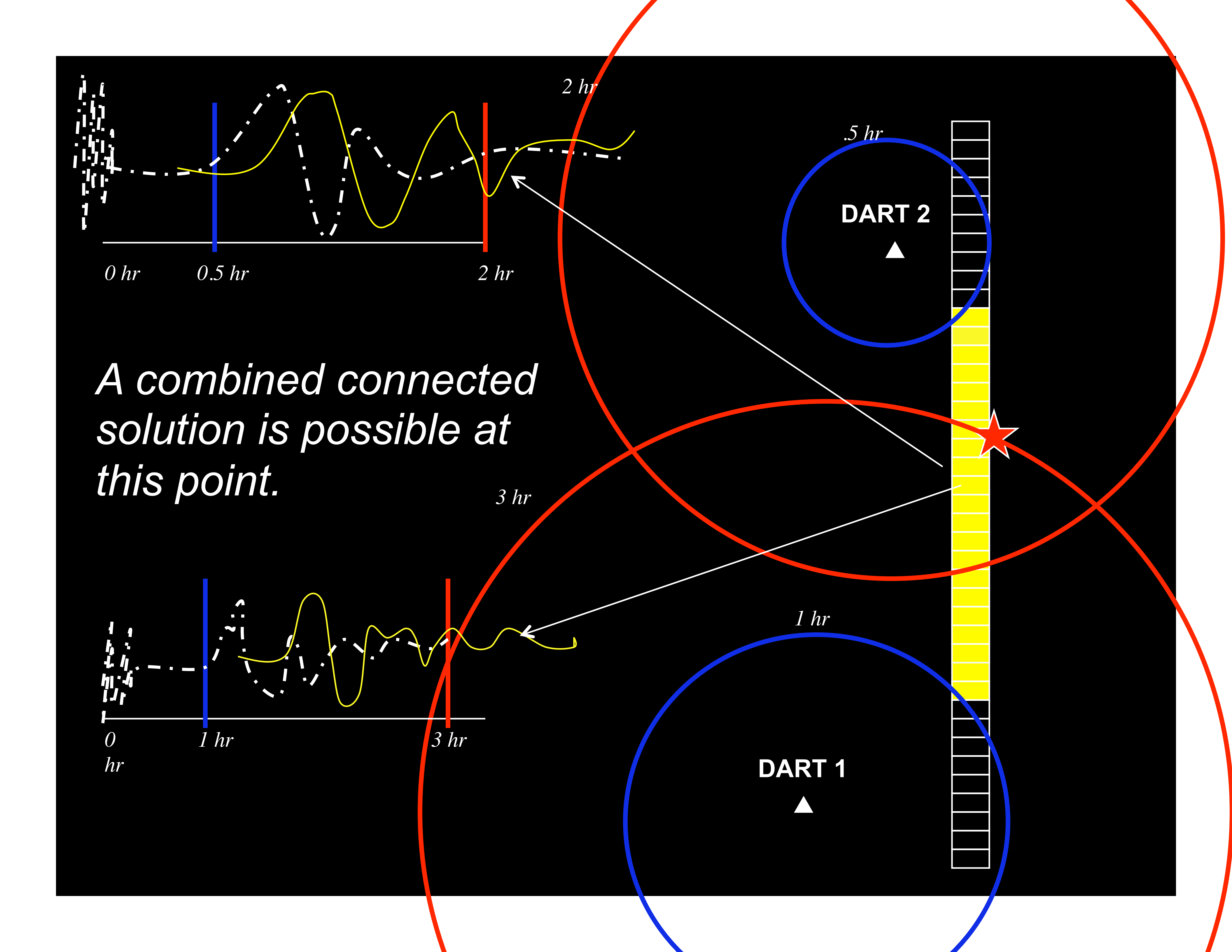
Source Selection for DART data Inversion
Soft exclusion sources
Hard exclusion sources
Valid sources
Data
t_{eq}
t_1
t_2
t_{eq}
t_1
t_2
t_{eq}
t_1
t_2
t_2
t_1



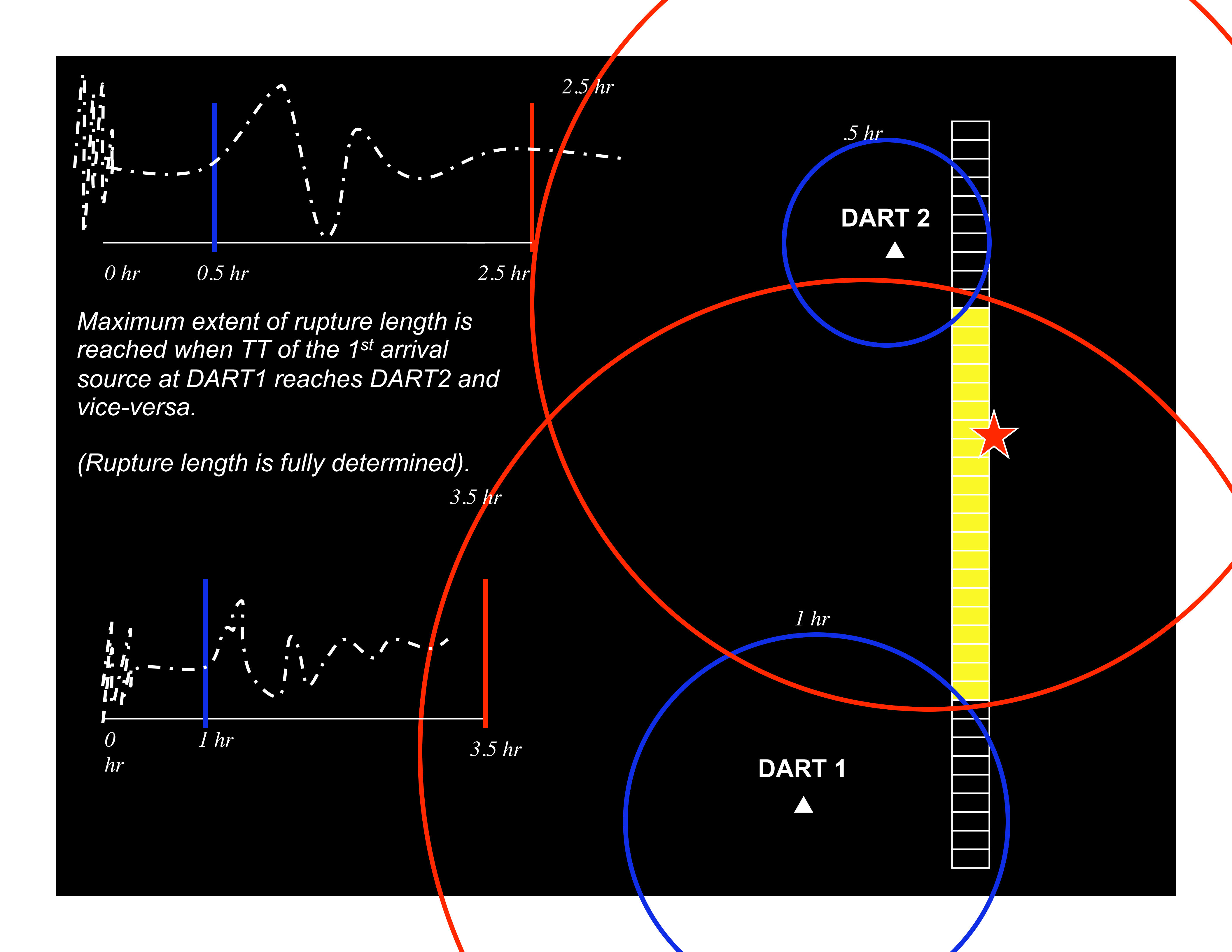
A connected solution is not possible at this point.
t_4
t_3
DART 2
t_2
t_1
DART 1

An uncombined connected solution is possible now.



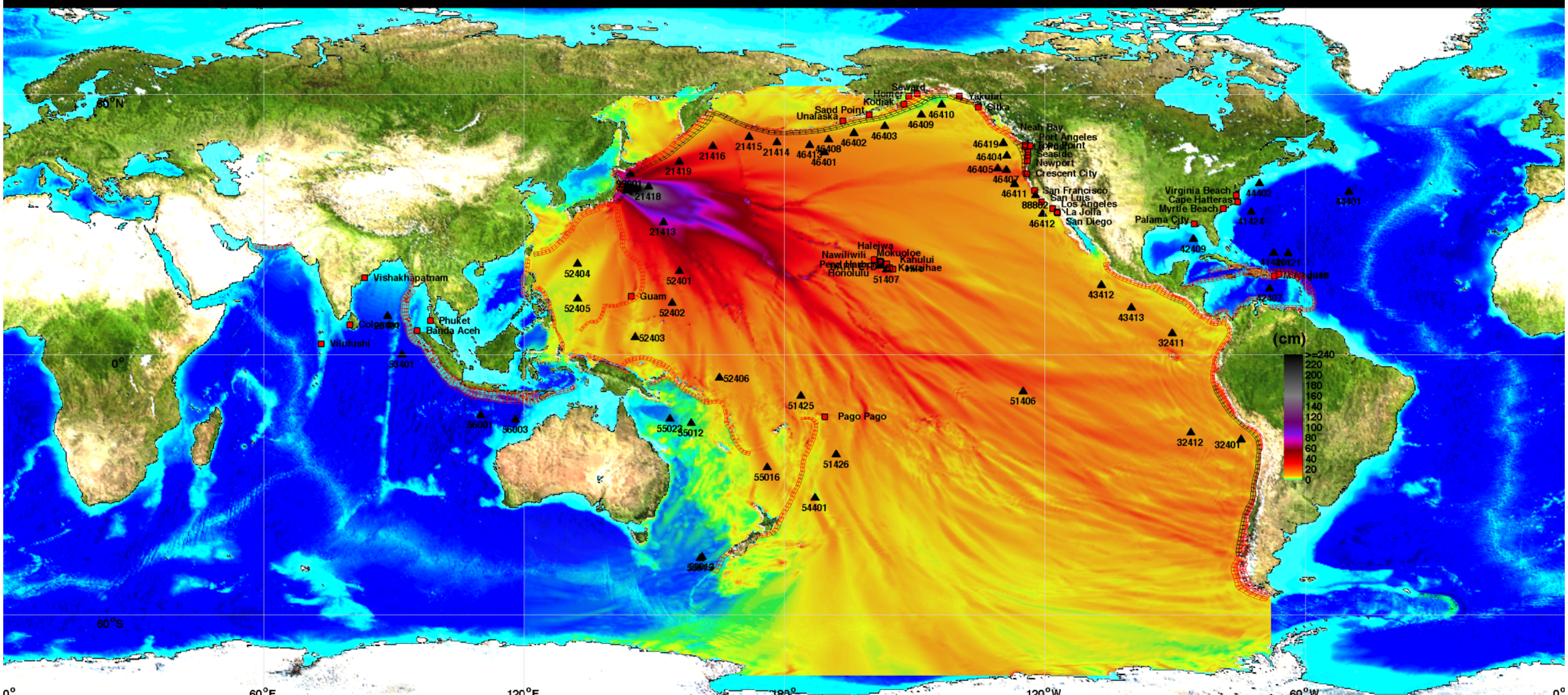


2 hr
.5 hr
DART 2
0 hr
0.5 hr
2 hr
A combined connected solution is possible at this point.
3 hr
1 hr
0 hr
1 hr
3 hr
DART 1



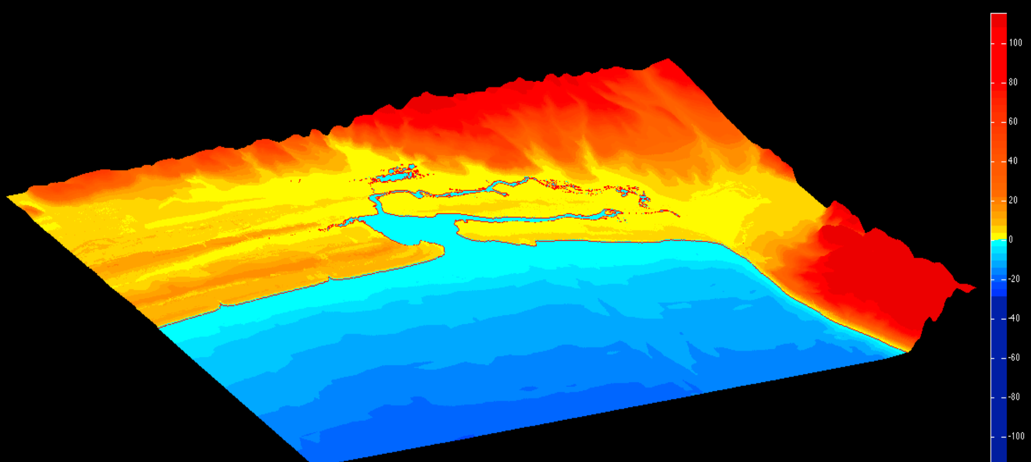
2.5 hr
0 hr
0.5 hr
2.5 hr
.5 hr
DART 2
Maximum extent of rupture length is reached when TT of the 1st arrival source at DART1 reaches DART2 and vice-versa.
(Rupture length is fully determined).
3.5 hr
1 hr
0
hr
1 hr
3.5 hr
DART 1

Example :Forecasted Max Amplitude Distribution (Japan 2010)



Forecasting Method: Inundation Forecast Model Development

-1/3 arc sec resolution is necessary for high quality simulations.

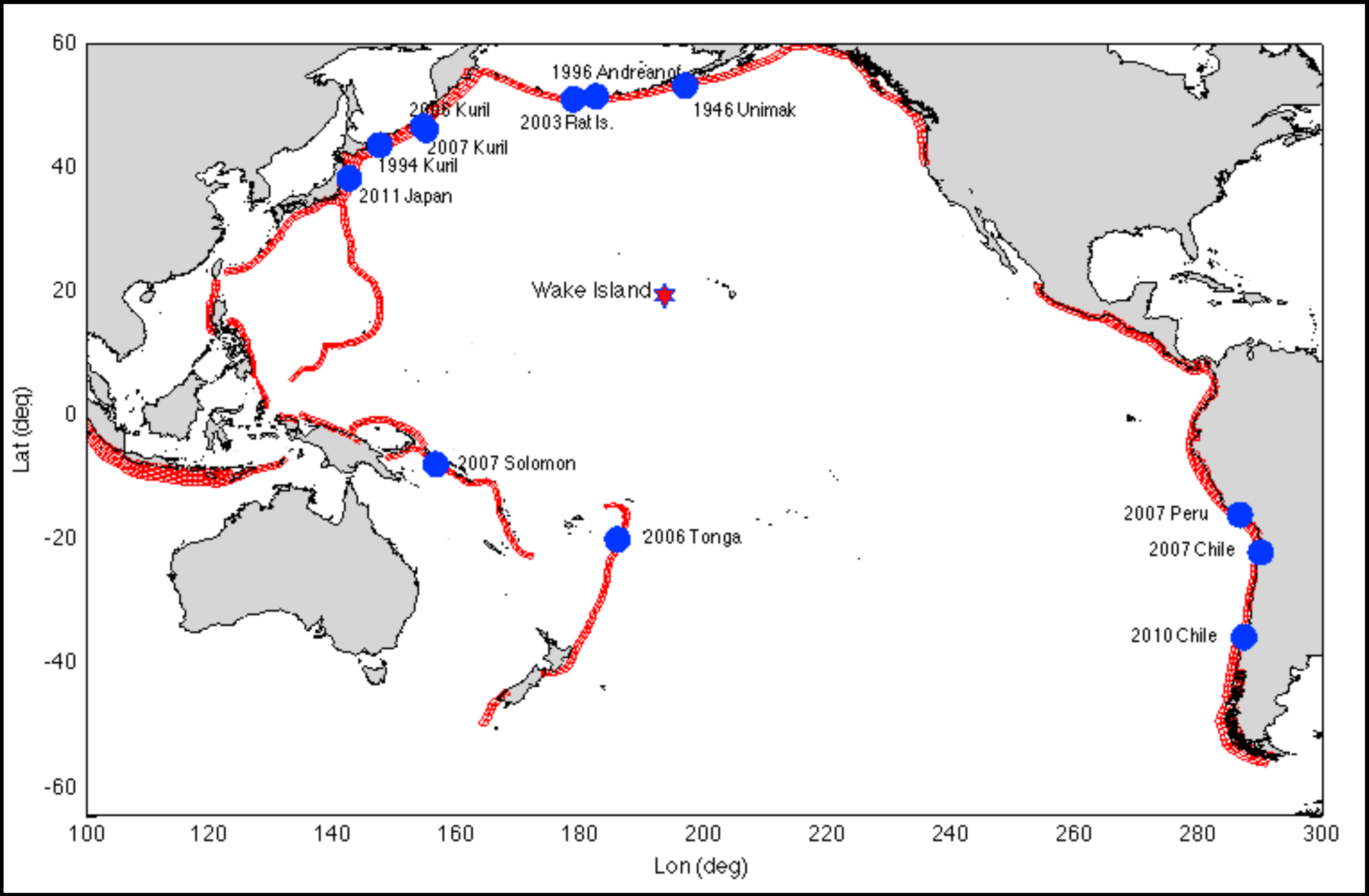


-Grids should cover deep (1000 m) and shallow areas.

-DEM is generated in partnership with NGDC, USGS…

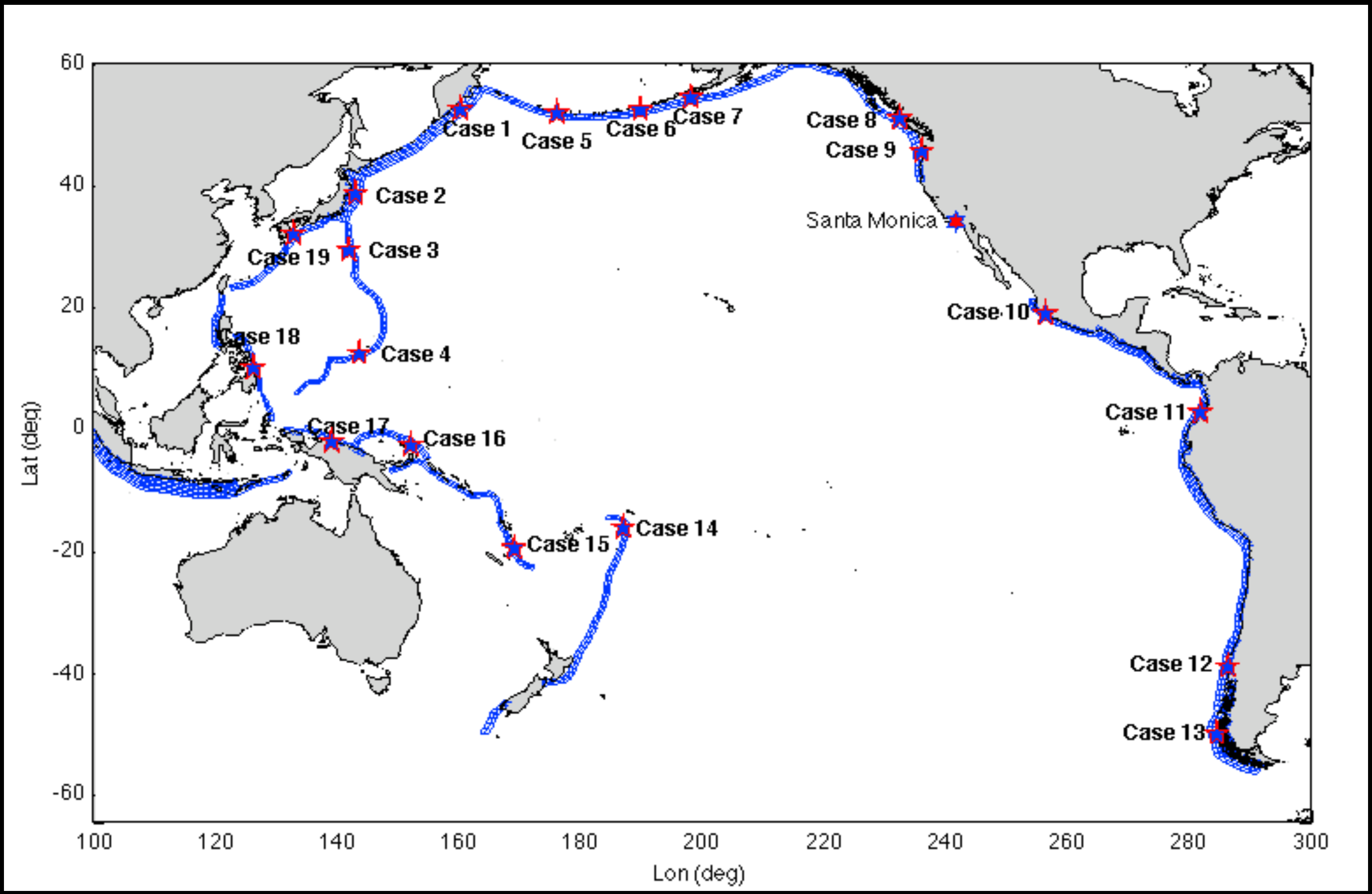
Forecasting Method: Inundation Forecast Model Development

Historical Test Cases



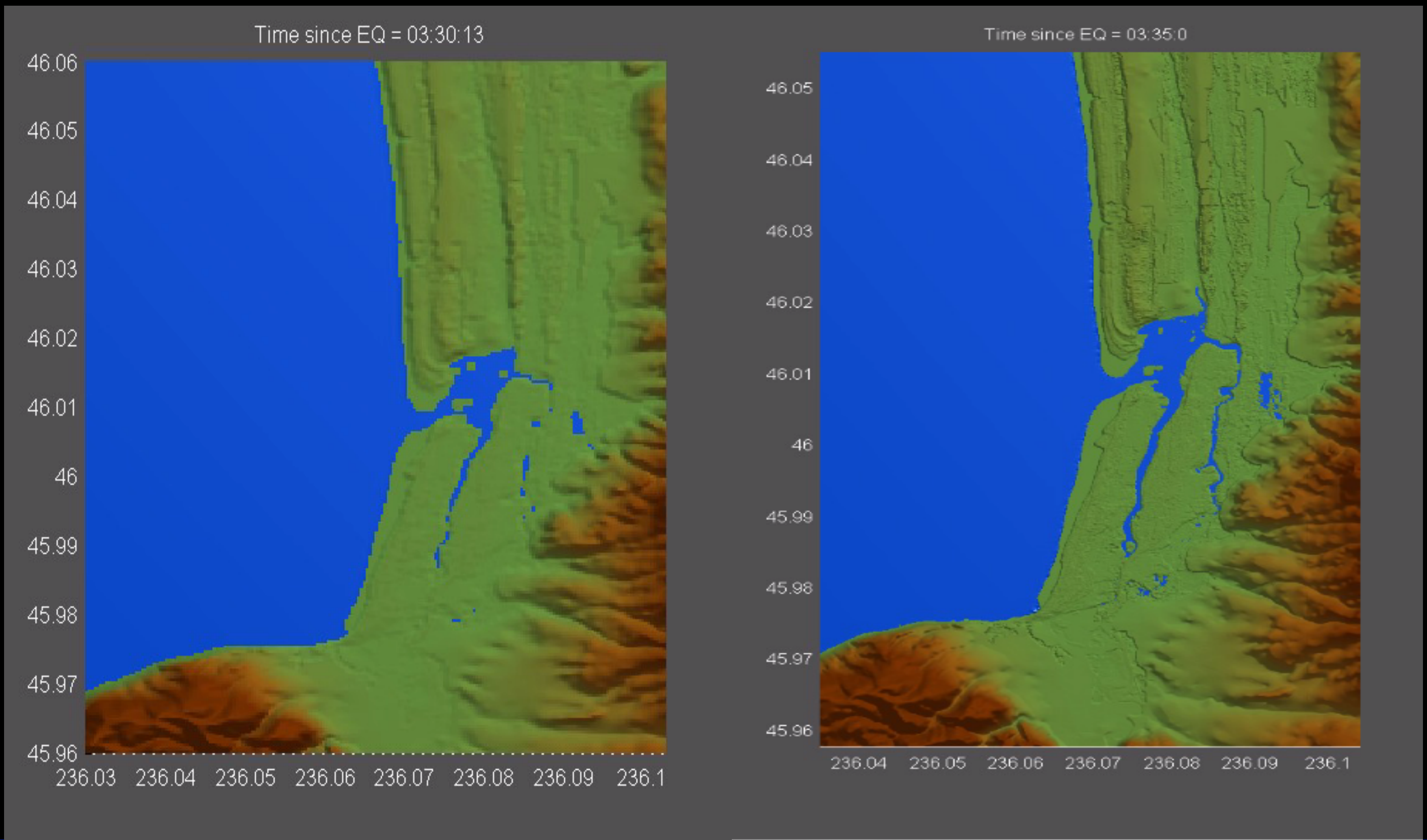
Forecasting Method: Inundation Forecast Model Development

Artificial Test Cases

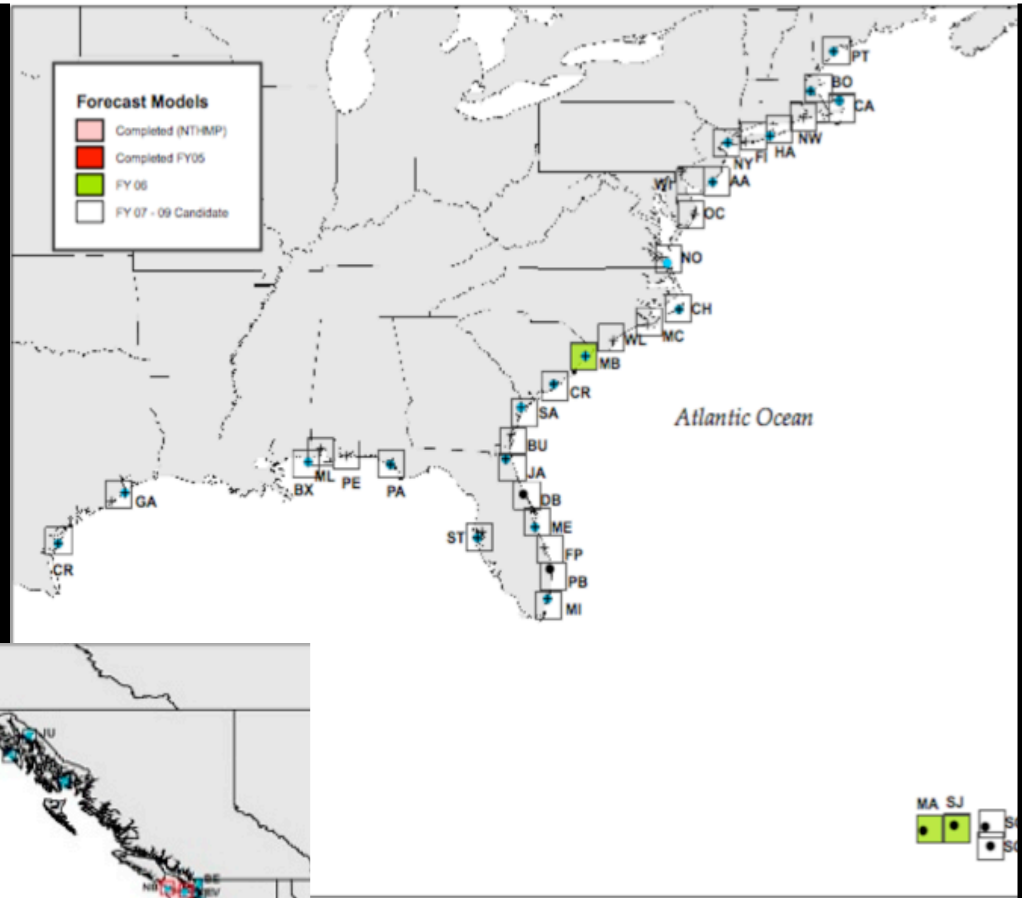


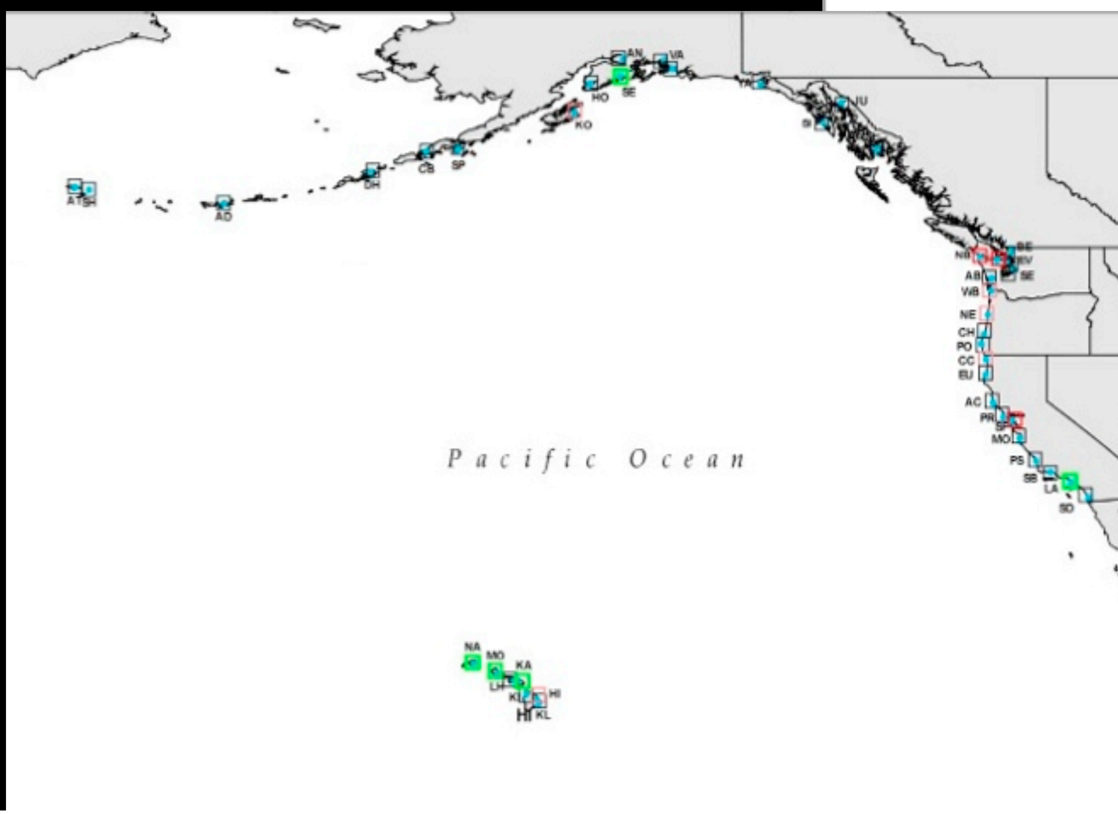
Forecasting Method: Inundation Forecast Model Development

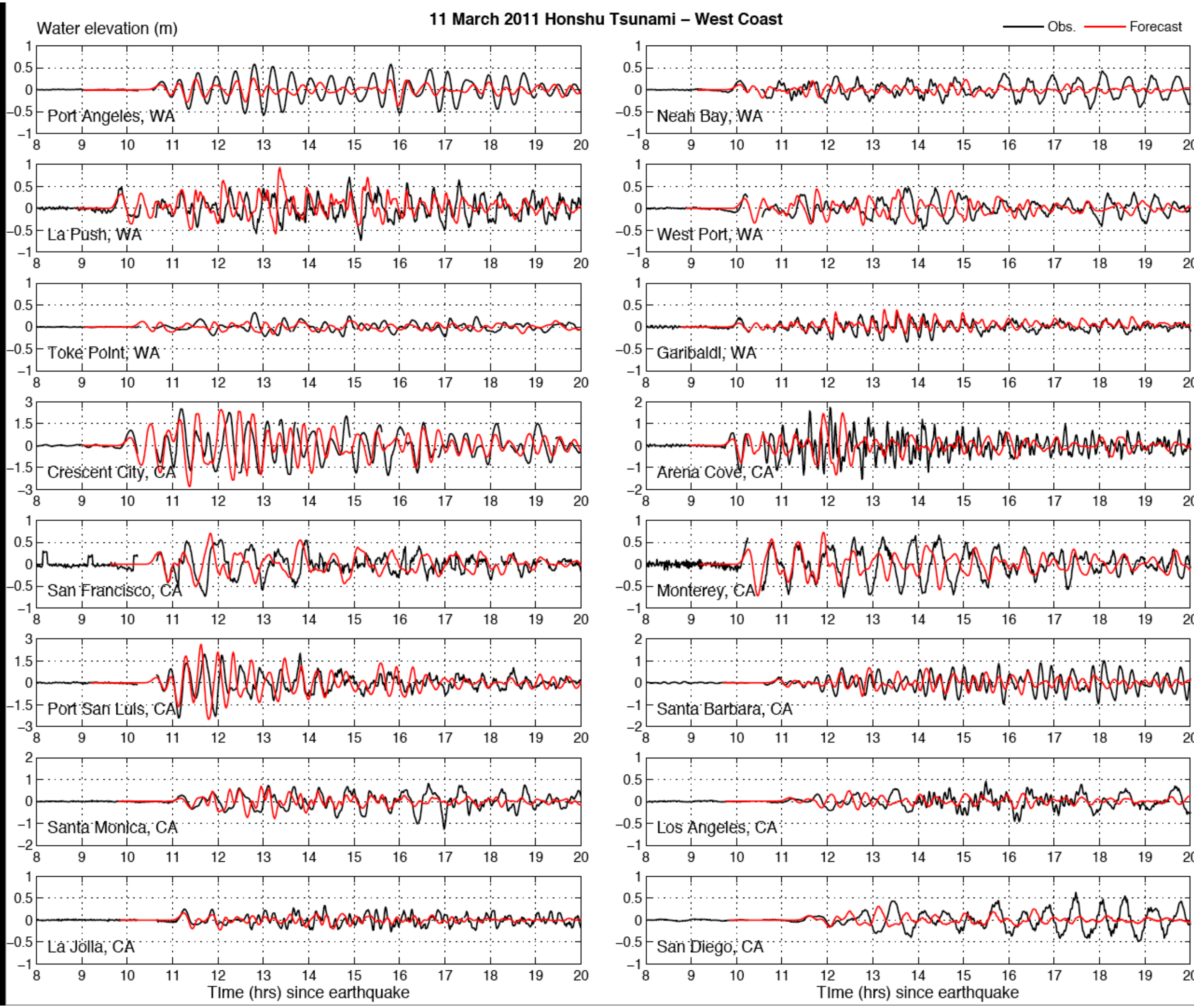
Comparison of the and SIM (10 mins) Reference (5.2 hours)



Forecasting Method:
Inundation Forecast Model Development







11 March 2011 Honshu Tsunami – West Coast
Water elevation (m)
Obs.
Forecast
Port Angeles, WA
Neah Bay, WA
La Push, WA
West Port, WA
Toke Point, WA
Garibaldi, WA
Crescent City, CA
Arena Cove, CA
San Francisco, CA
Monterey, CA
Port San Luis, CA
Santa Barbara, CA
Santa Monica, CA
Los Angeles, CA
La Jolla, CA
San Diego, CA
Time (hrs) since earthquake
Time (hrs) since earthquake