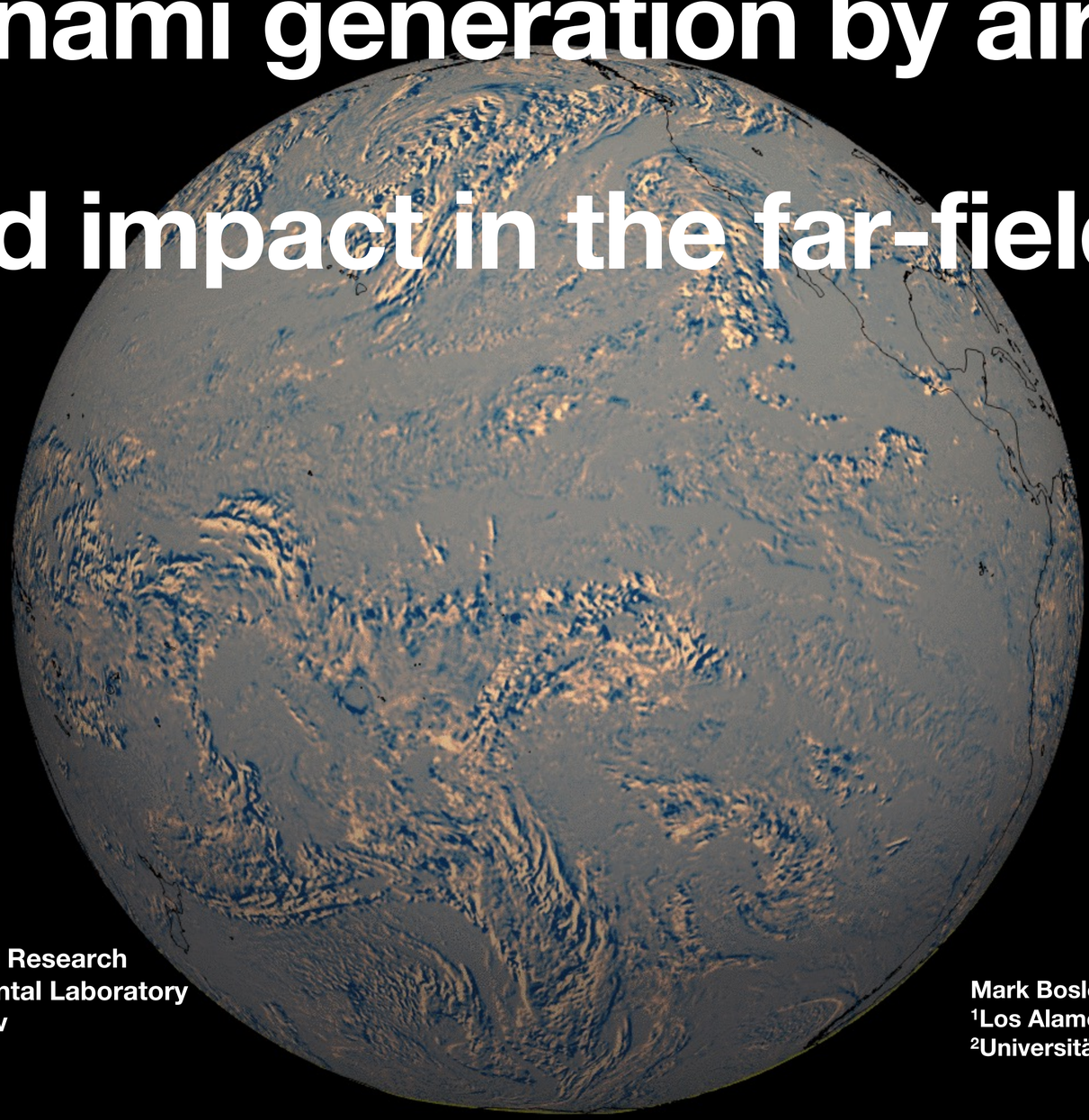
Tonga tsunami generation by air pressure waves and impact in the far-field

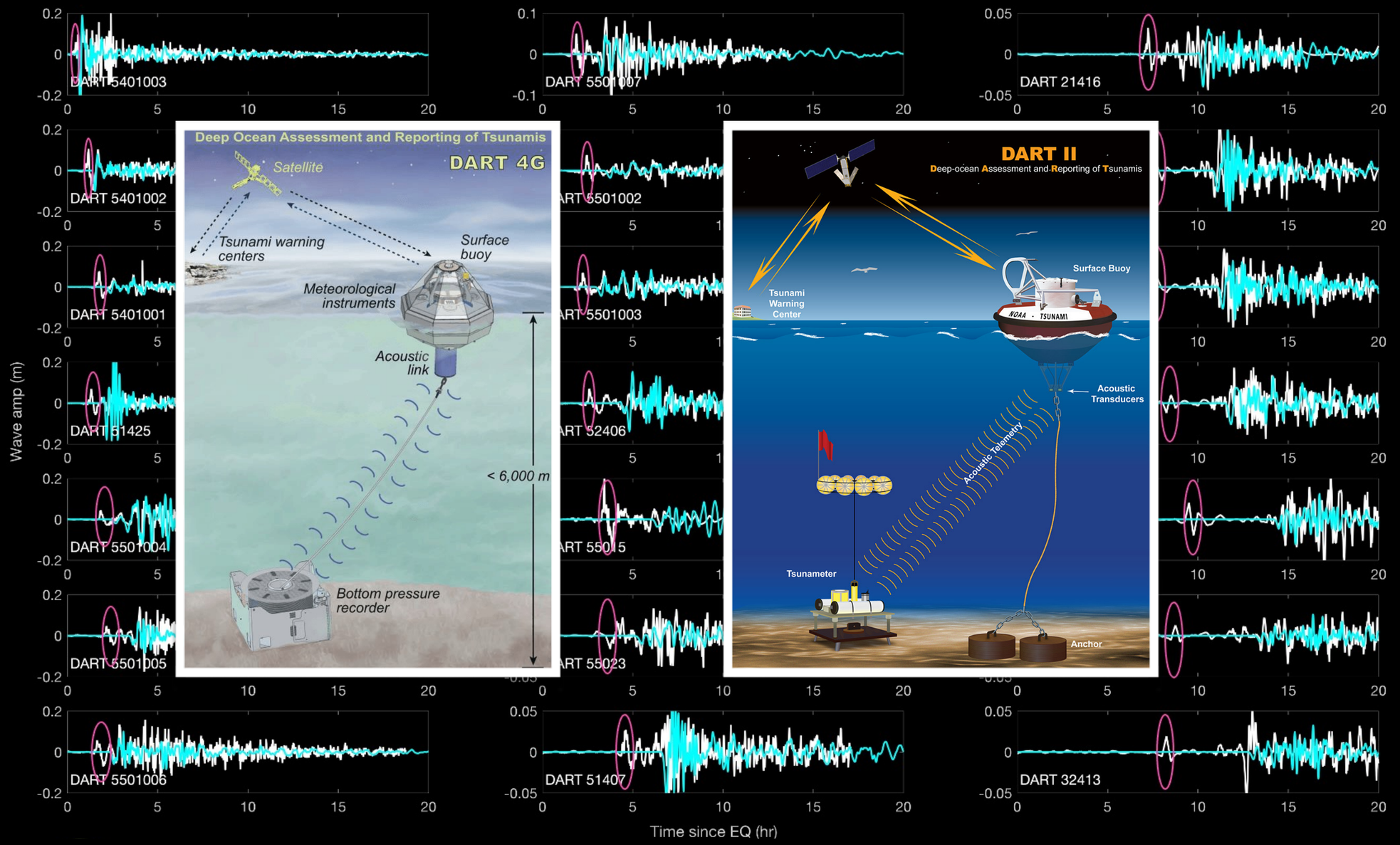


Vasily Titov
NOAA Center for Tsunami Research
Pacific Marine Environmental Laboratory
https://nctr.pmel.noaa.gov

Mark Boslough[1], Sergiy Vasylkevych[2], Nedjeljka Žagar[2]
[1]Los Alamos National Laboratory, New Mexico,USA
[2]Universität Hamburg, Germany

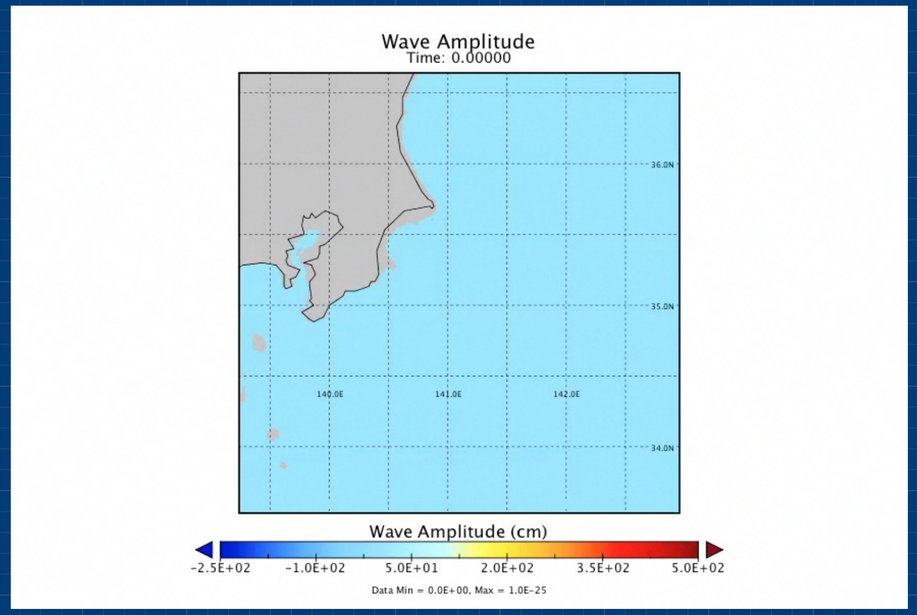
The initial atmospheric response to the eruption was captured by Mathew Barlow using NOAA's GOES-West satellite infrared radiance data (band 13). This sequence is based on images taken 10 minutes apart, and colors show the difference in infrared radiance between each time step.
Credit: Mathew Barlow/University of Massachusetts Lowell.
@MathewABarlow - Environmental, Earth, and Atmospheric Sciences - University of Massachusetts Lowell

DART records tsunami across the Pacific

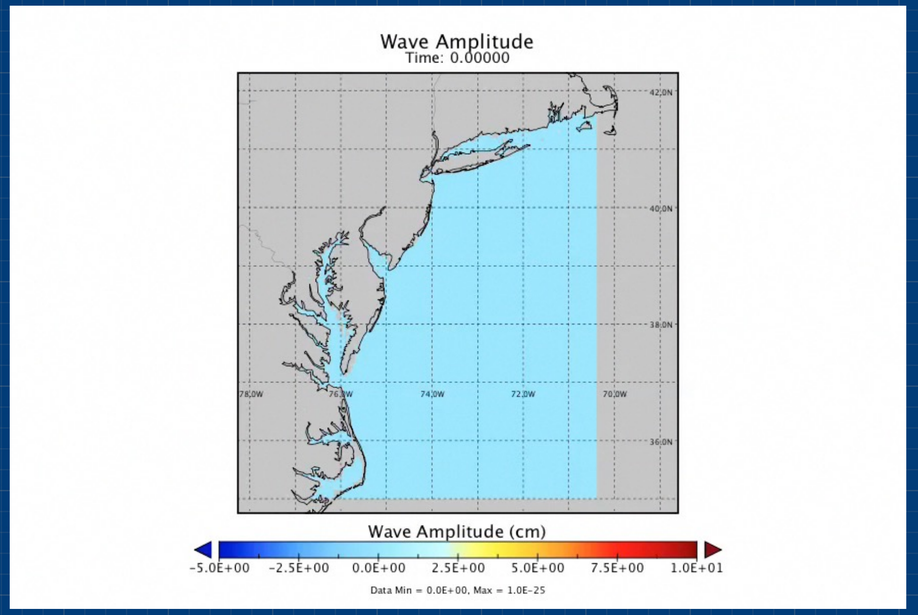


Comparing Two Types of Tsunamis Generated by Pressure-forcing

Proudman Amplification $\eta = \frac{c^2 \eta_s}{c^2 - U^2} = \frac{\eta_s}{1 - F^2}$



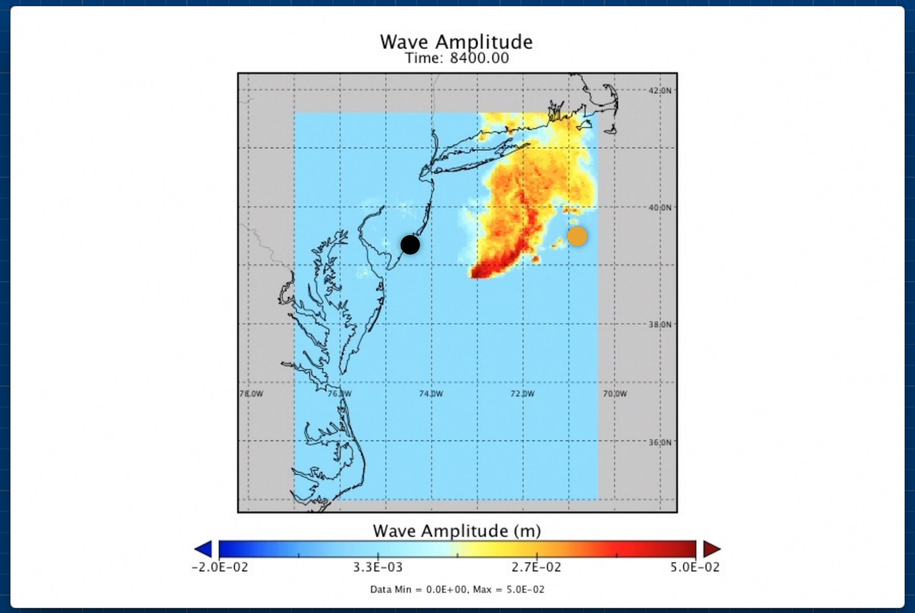
Air blast
over deep water

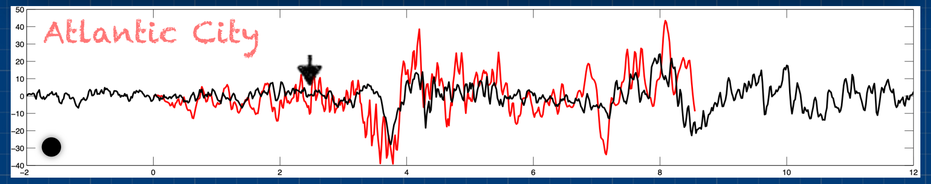


Meteo tsunami
over shallow water

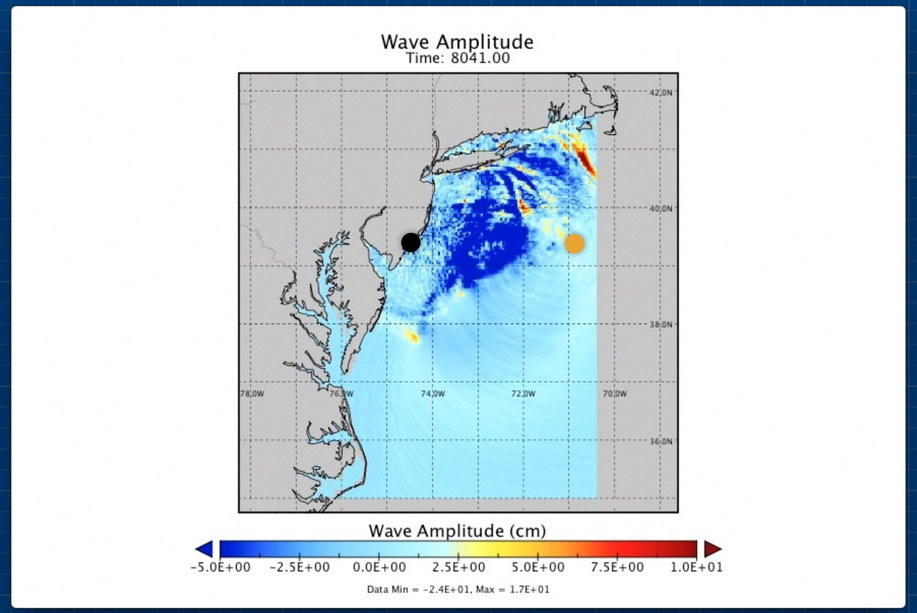
13 June 2013 meteotsunami event

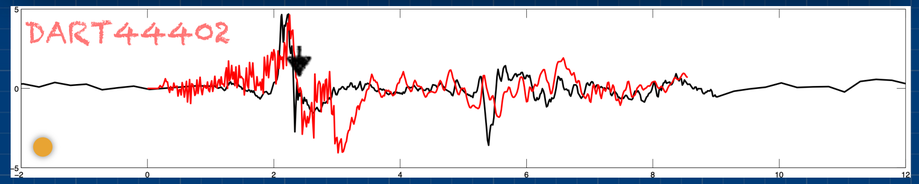
Pressure Forcing

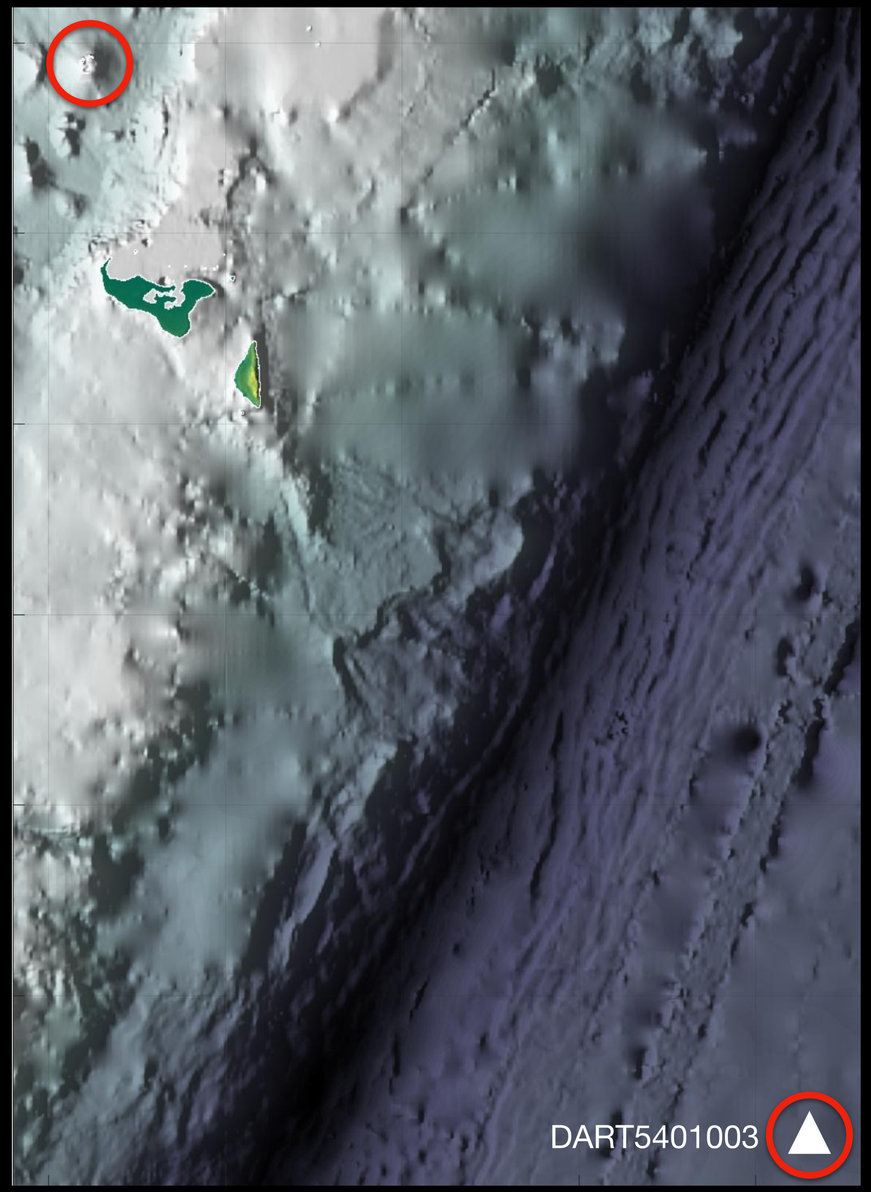




Generated Tsunami





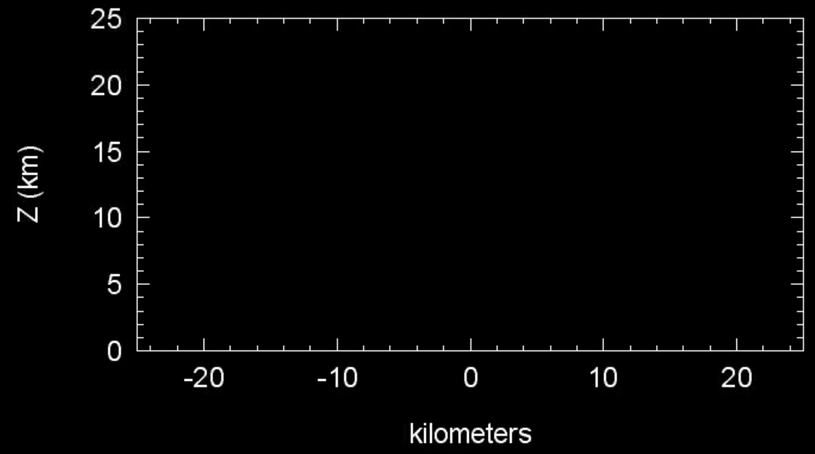


Yield = 250 Mt

Entry angle = 75°

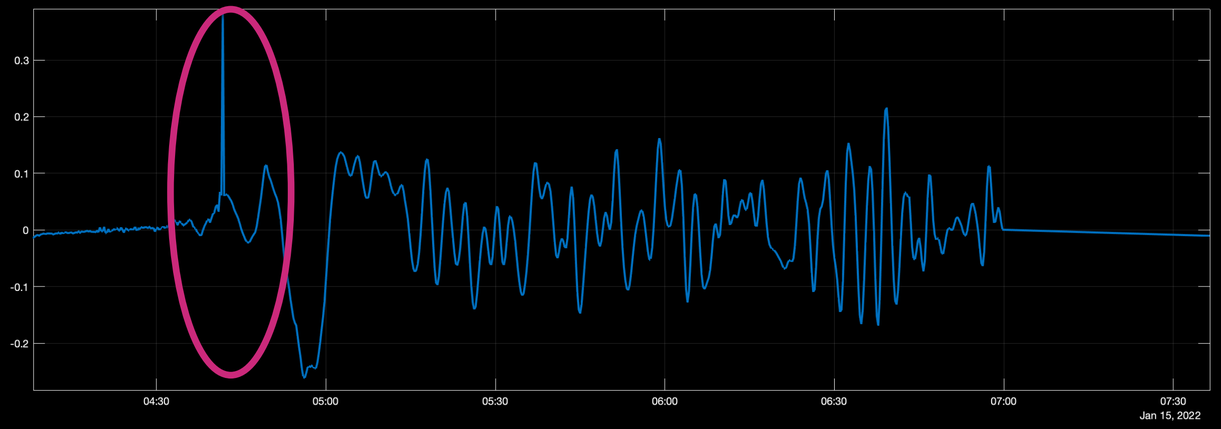
Temperature (K)

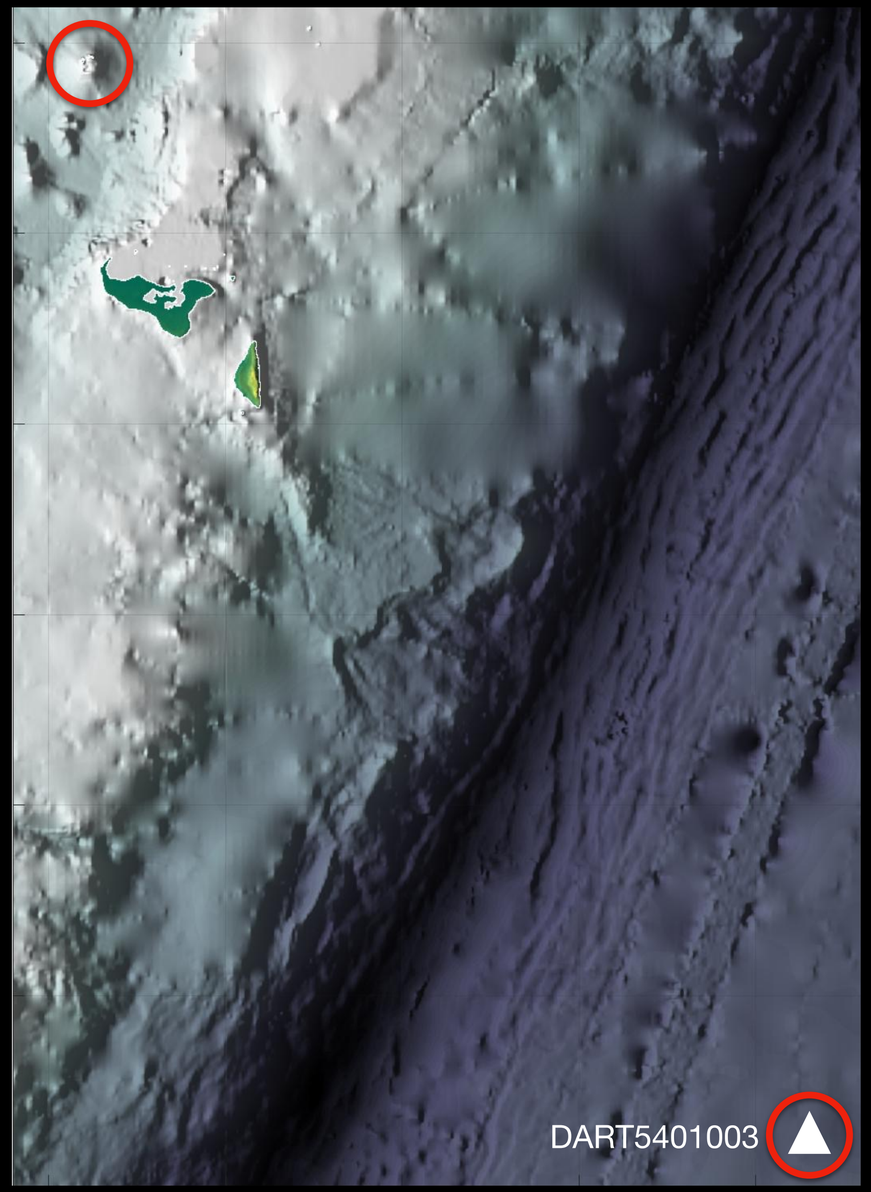
400 500 600 700 800 900 1000 1100 1200 1300

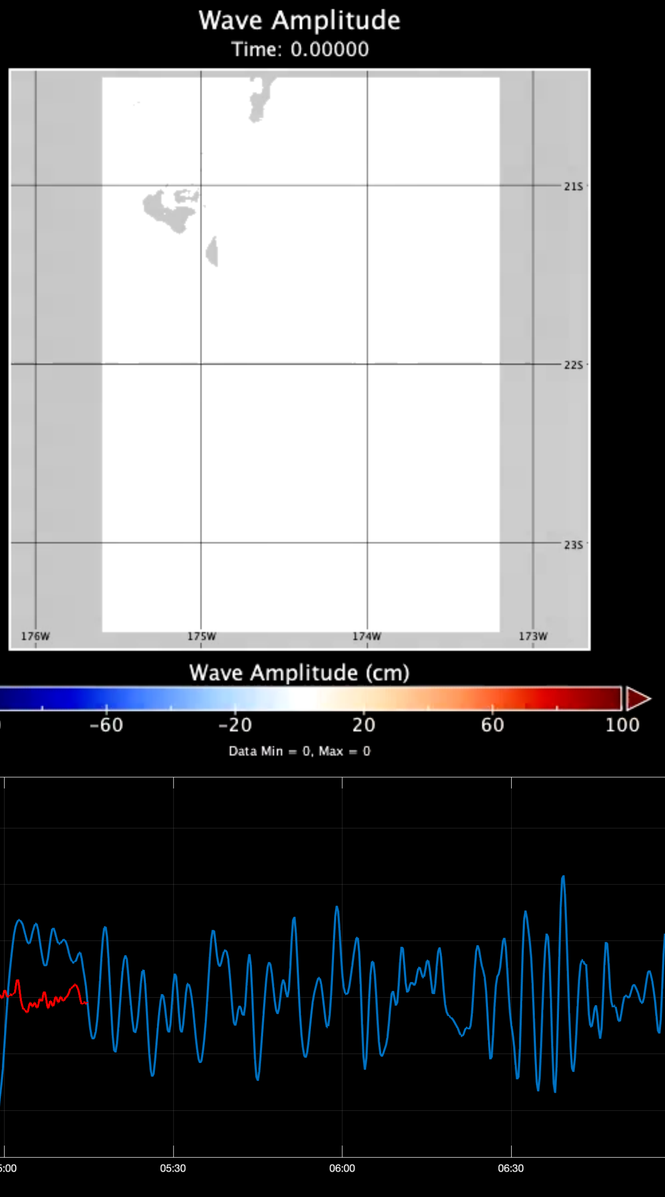


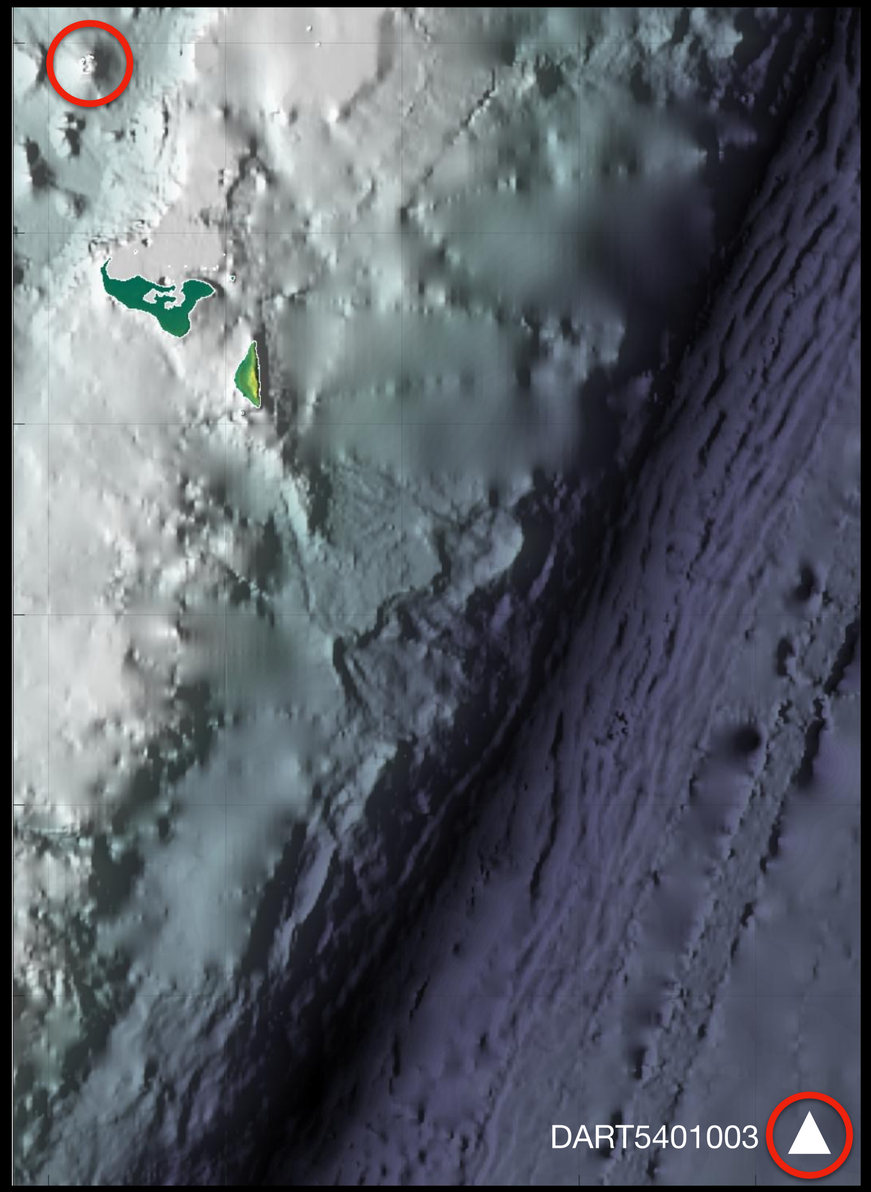
Time = 4.0 s

Line source 250mt_i




DART5401003


Wave Amplitude
Time: 0.00000
21S
22S
23S
176W
175W
174W
173W
Wave Amplitude (cm)
-100
-60
-20
20
60
100
Data Min = 0, Max = 0
0.3
0.2
0.1
0
-0.1
-0.2
04:30
05:00
05:30
06:00
06:30
07:00
07:30
Jan 15, 2022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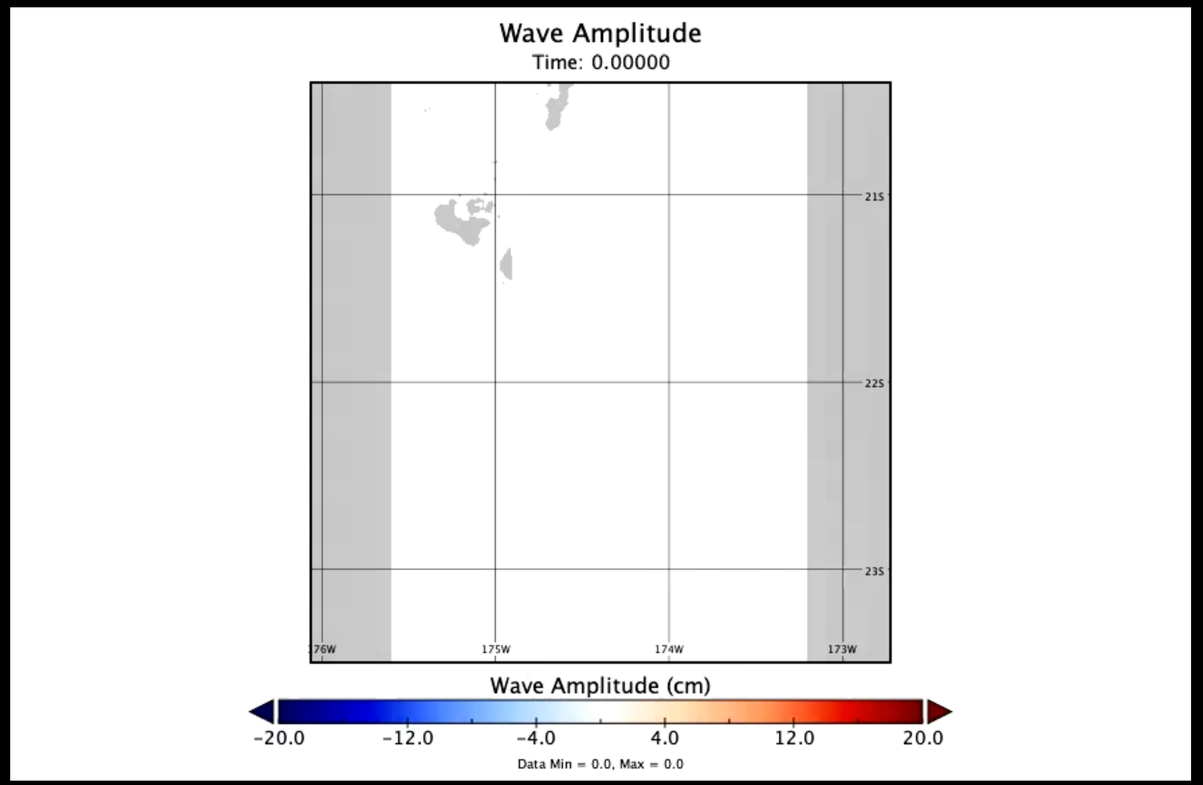
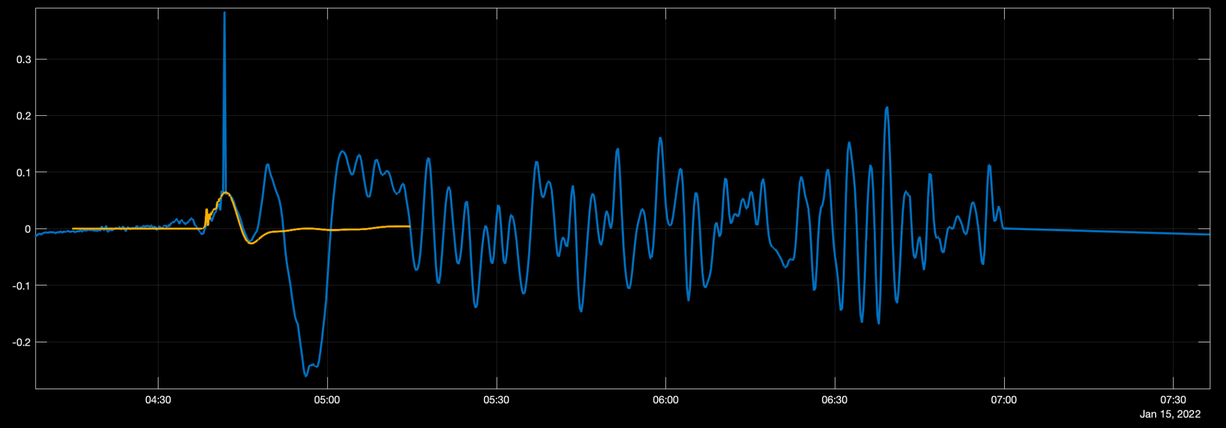
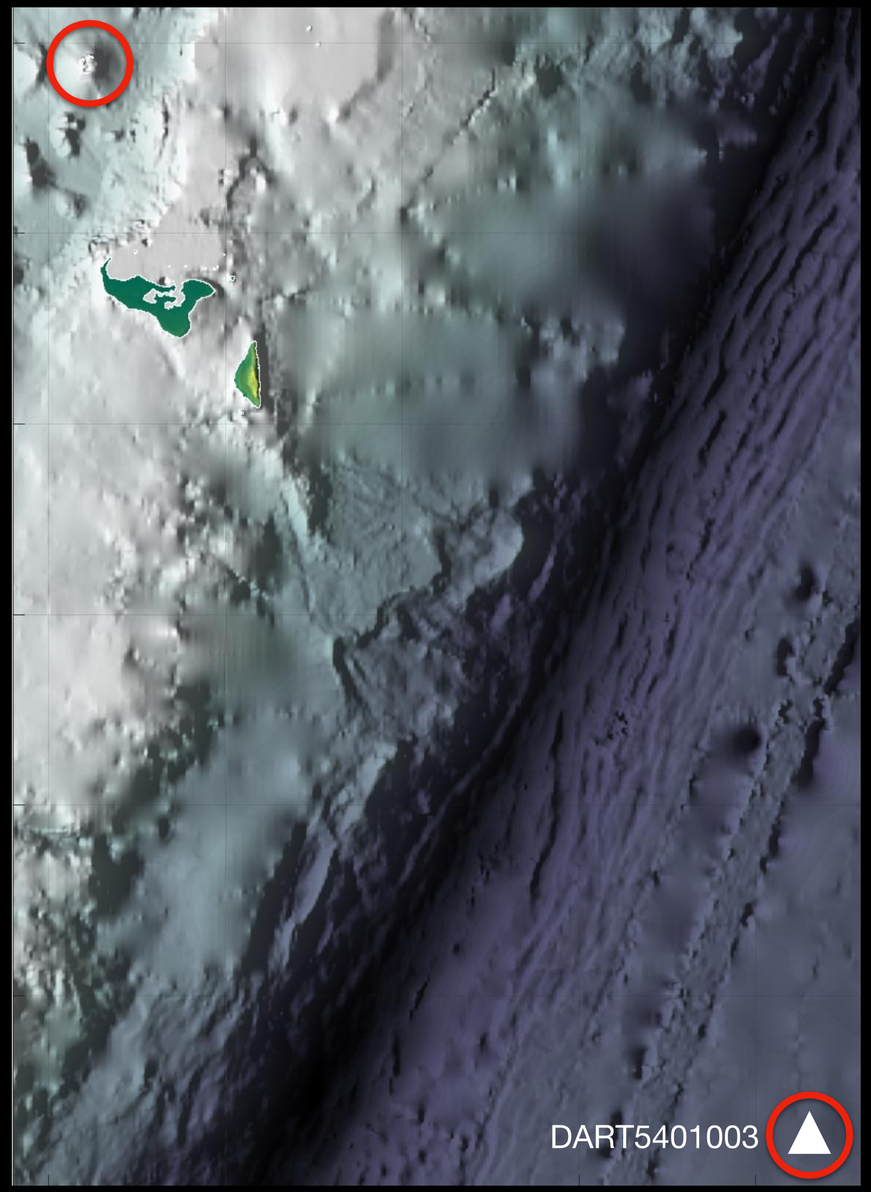
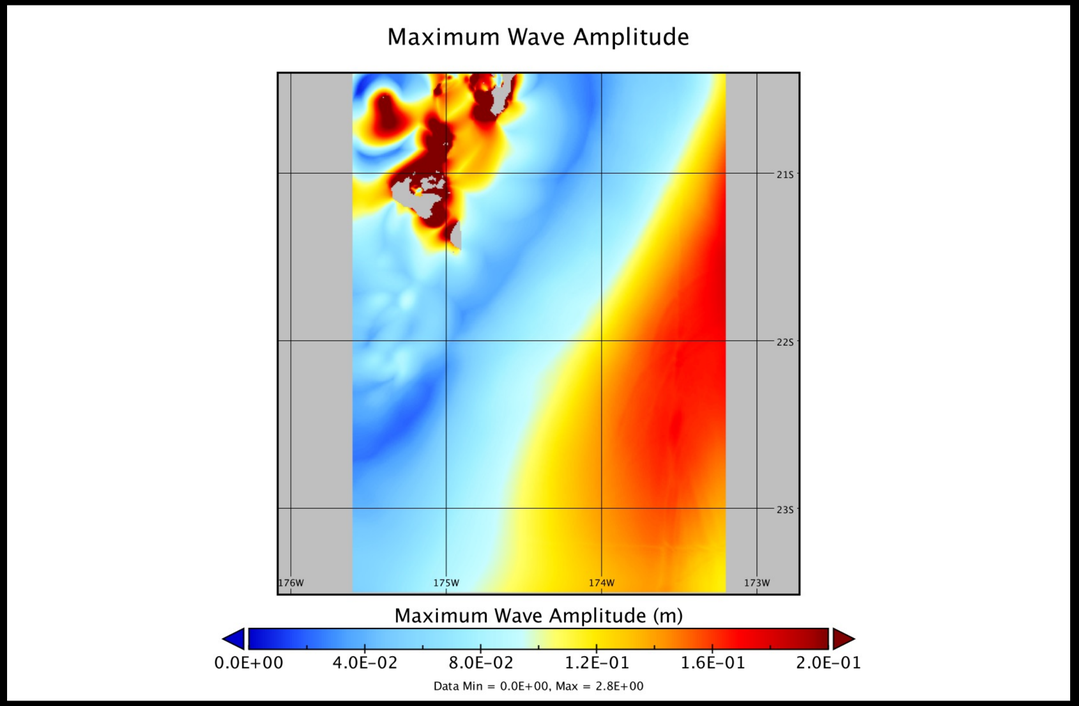
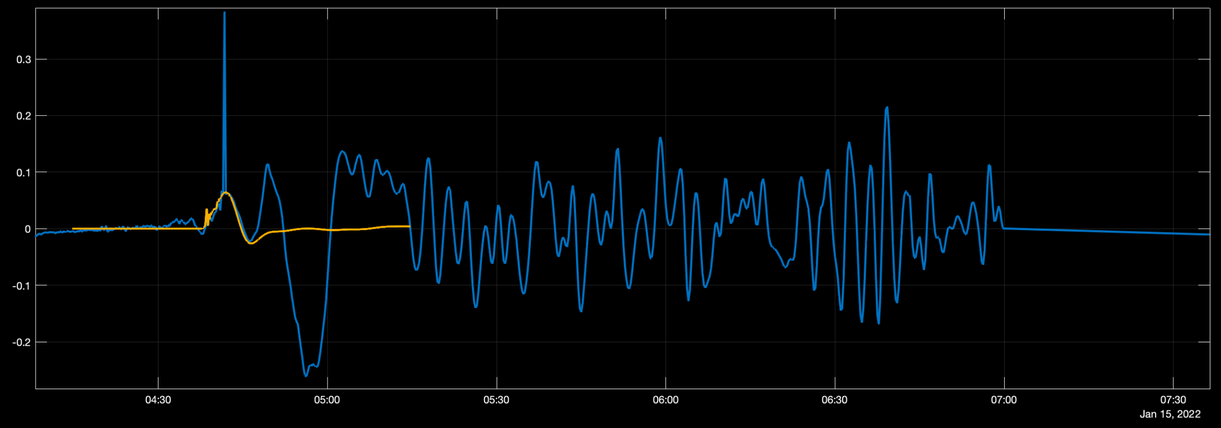

Wave Amplitude
Time: 0.00000
21S
22S
23S
176W
175W
174W
173W
Wave Amplitude (cm)
-20.0
-12.0
-4.0
4.0
12.0
20.0
Data Min = 0.0, Max = 0.0

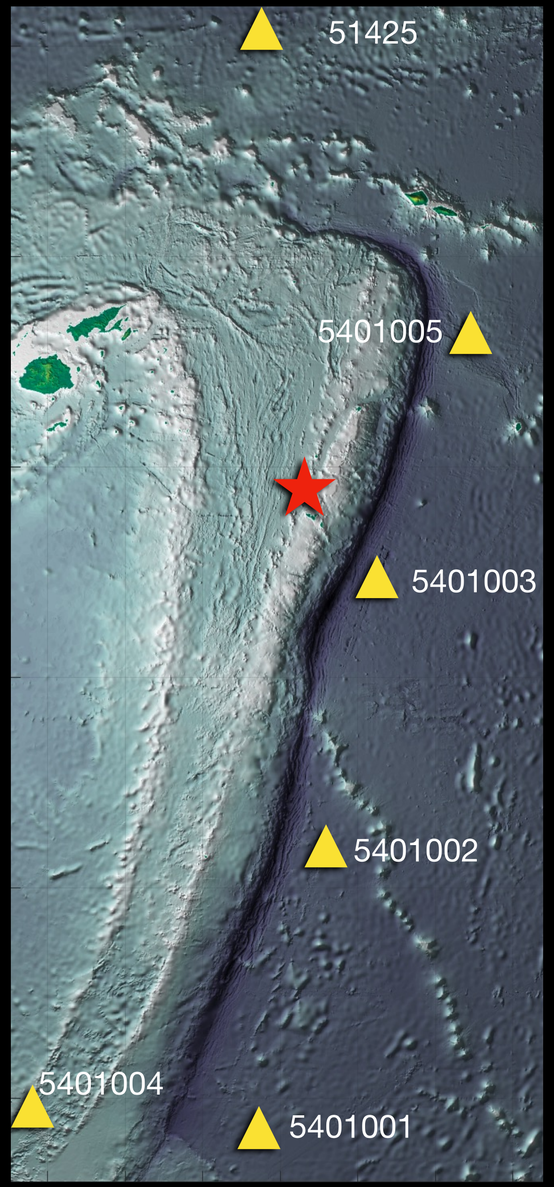

0.3
0.2
0.1
0
-0.1
-0.2
04:30
05:00
05:30
06:00
06:30
07:00
07:30
Jan 15, 2022

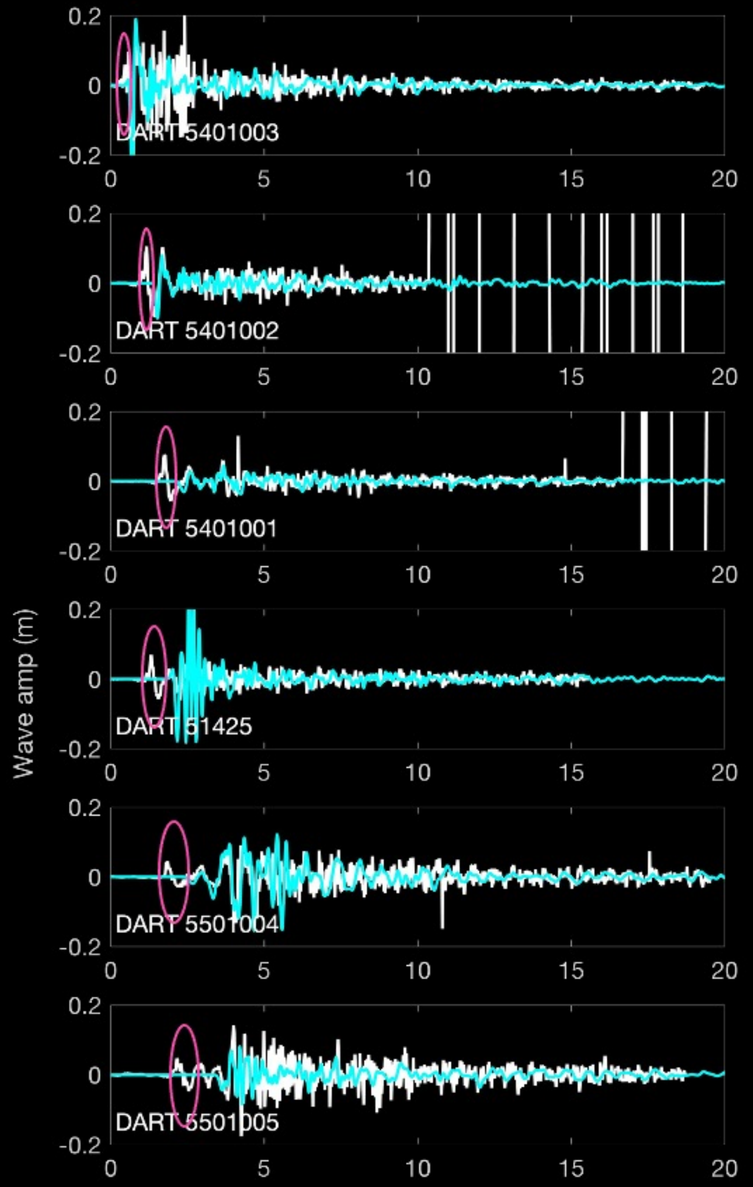

DART5401003

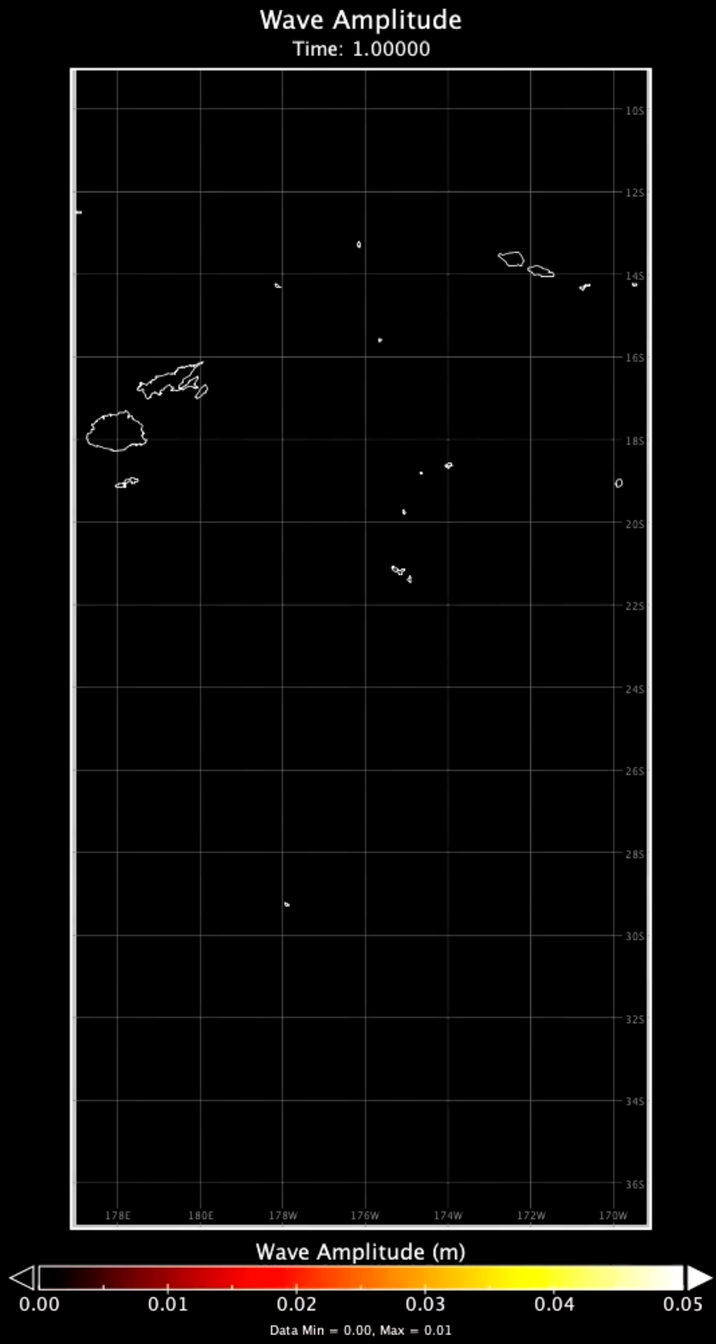

Maximum Wave Amplitude
21S
22S
23S
176W
175W
174W
173W
Maximum Wave Amplitude (m)
0.0E+00
4.0E-02
8.0E-02
1.2E-01
1.6E-01
2.0E-01
Data Min = 0.0E+00, Max = 2.8E+00


0.3
0.2
0.1
0
-0.1
-0.2
04:30
05:00
05:30
06:00
06:30
07:00
07:30
Jan 15, 2022

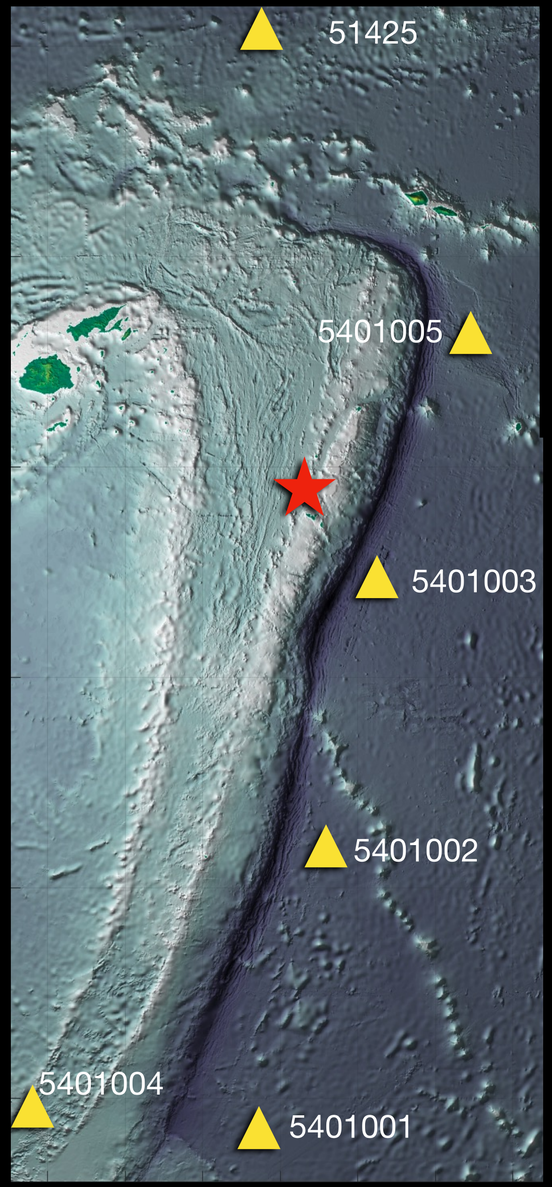
Larger area

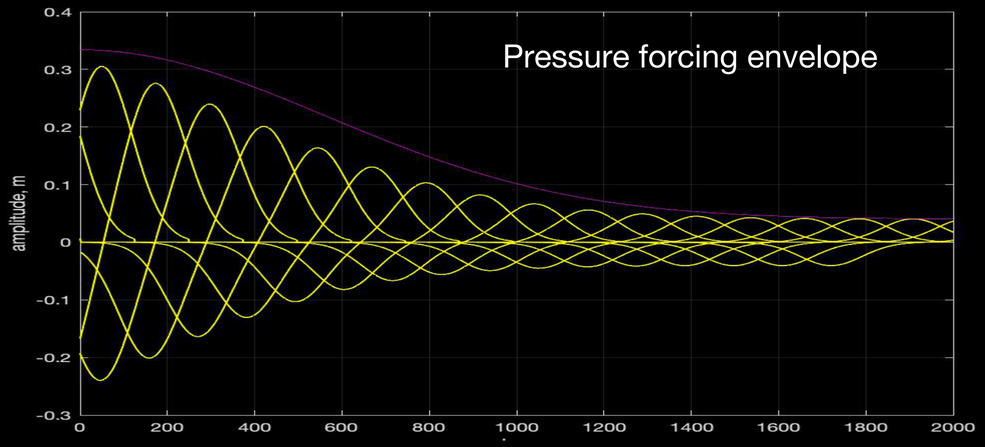

51425
5401005
5401003
5401002
5401004
5401001

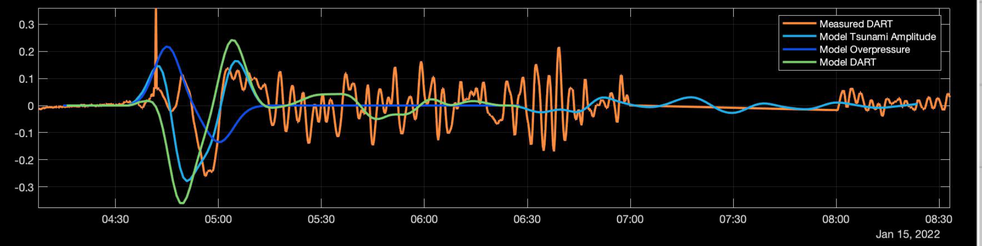

Wave amp (m)
DART 5401003
DART 5401002
DART 5401001
DART 51425
DART 5501004
DART 5501005
0.2
0
-0.2
0
5
10
15
20

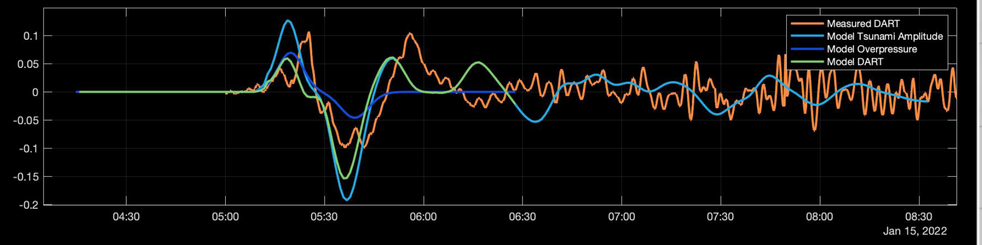

Wave Amplitude
Time: 1.00000
Wave Amplitude (m)
0.00
0.01
0.02
0.03
0.04
0.05
Data Min = 0.00, Max = 0.01

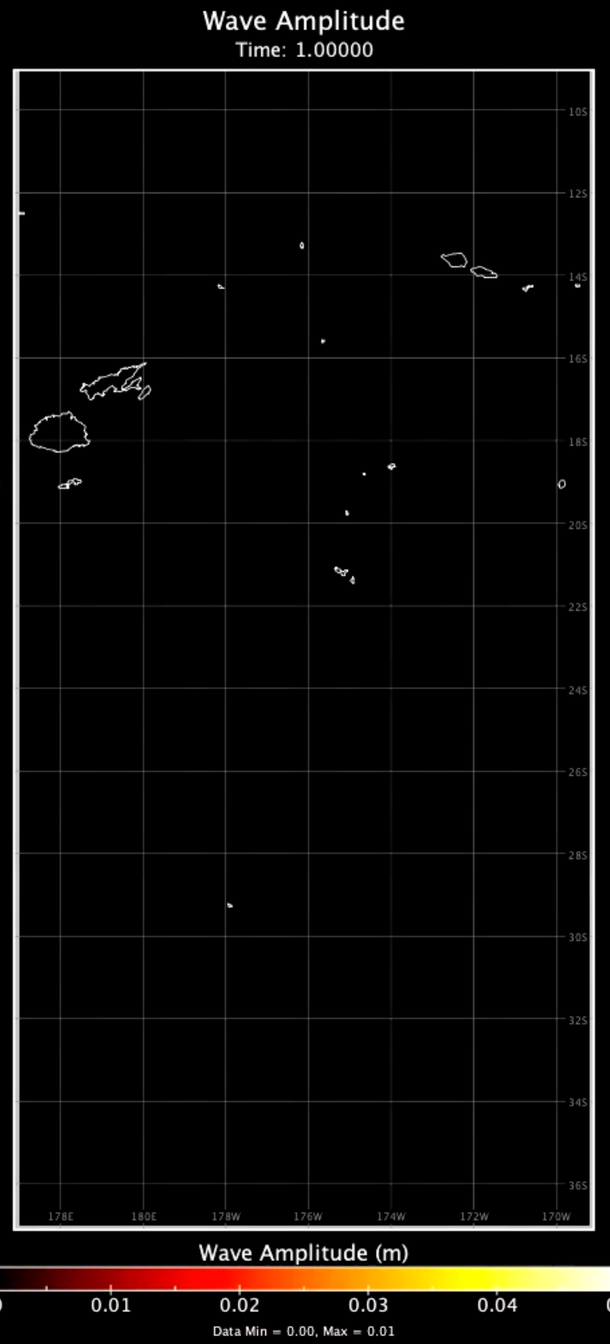
Larger area


51425
5401005
5401003
5401002
5401004
5401001


Pressure forcing envelope
amplitude, m
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
200
400
600
800
1000
1200
1400
1600
1800
2000

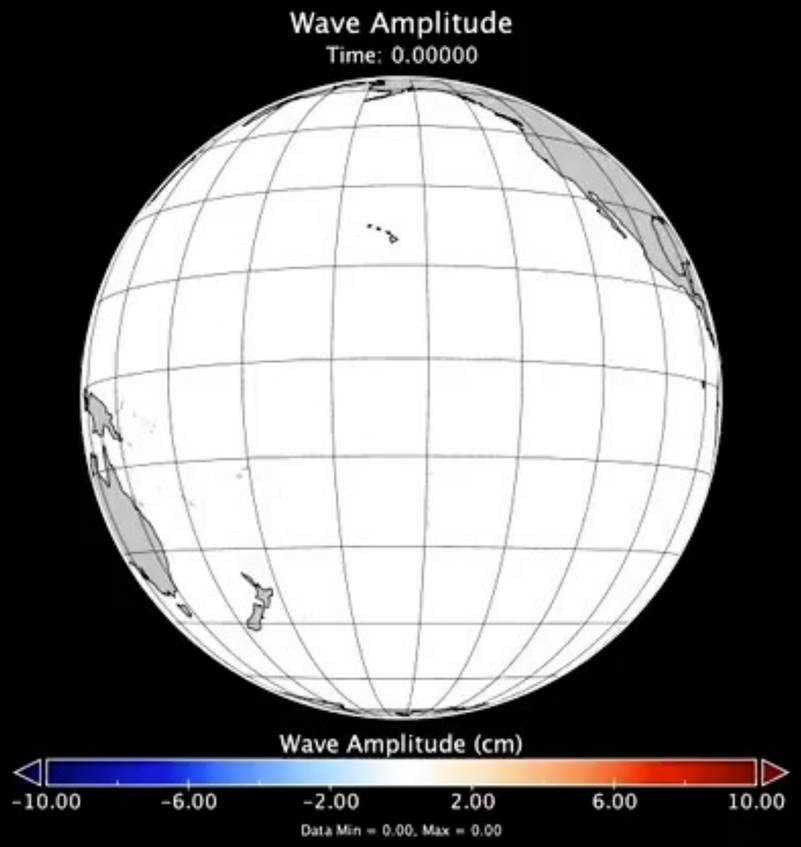

Measured DART
Model Tsunami Amplitude
Model Overpressure
Model DART
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
04:30
05:00
05:30
06:00
06:30
07:00
07:30
08:00
08:30
Jan 15, 2022


Measured DART
Model Tsunami Amplitude
Model Overpressure
Model DART
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
04:30
05:00
05:30
06:00
06:30
07:00
07:30
08:00
08:30
Jan 15, 2022

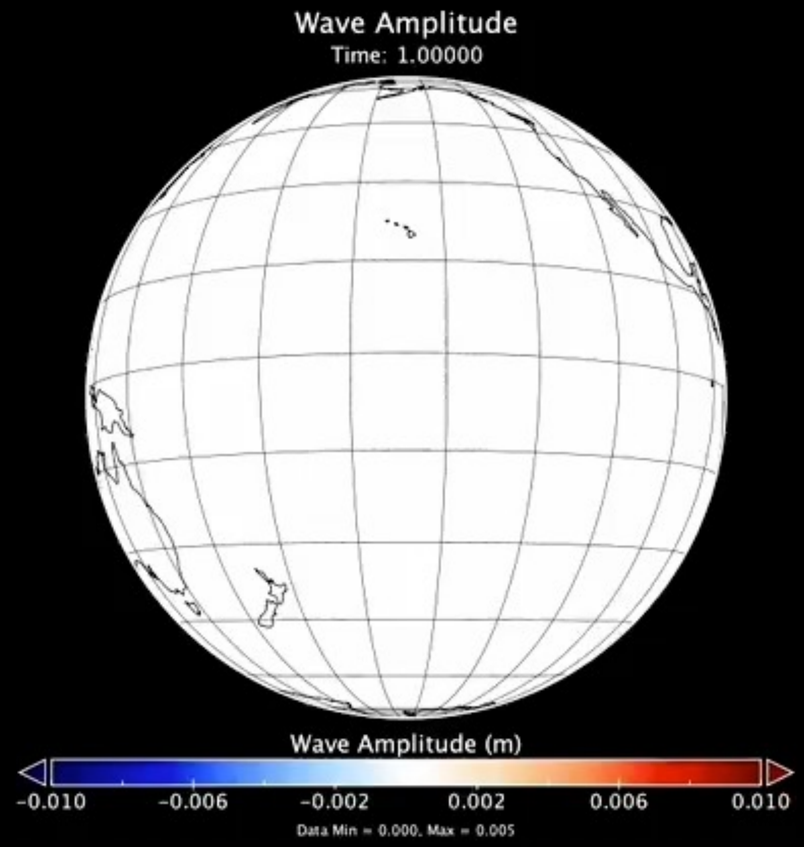

Wave Amplitude
Time: 1.00000
10S
12S
14S
16S
18S
0
20S
22S
24S
26S
28S
30S
32S
34S
36S
178E
180E
178W
176W
174W
172W
170W
Wave Amplitude (m)
0.00
0.01
0.02
0.03
0.04
0.05
Data Min = 0.00, Max = 0.01

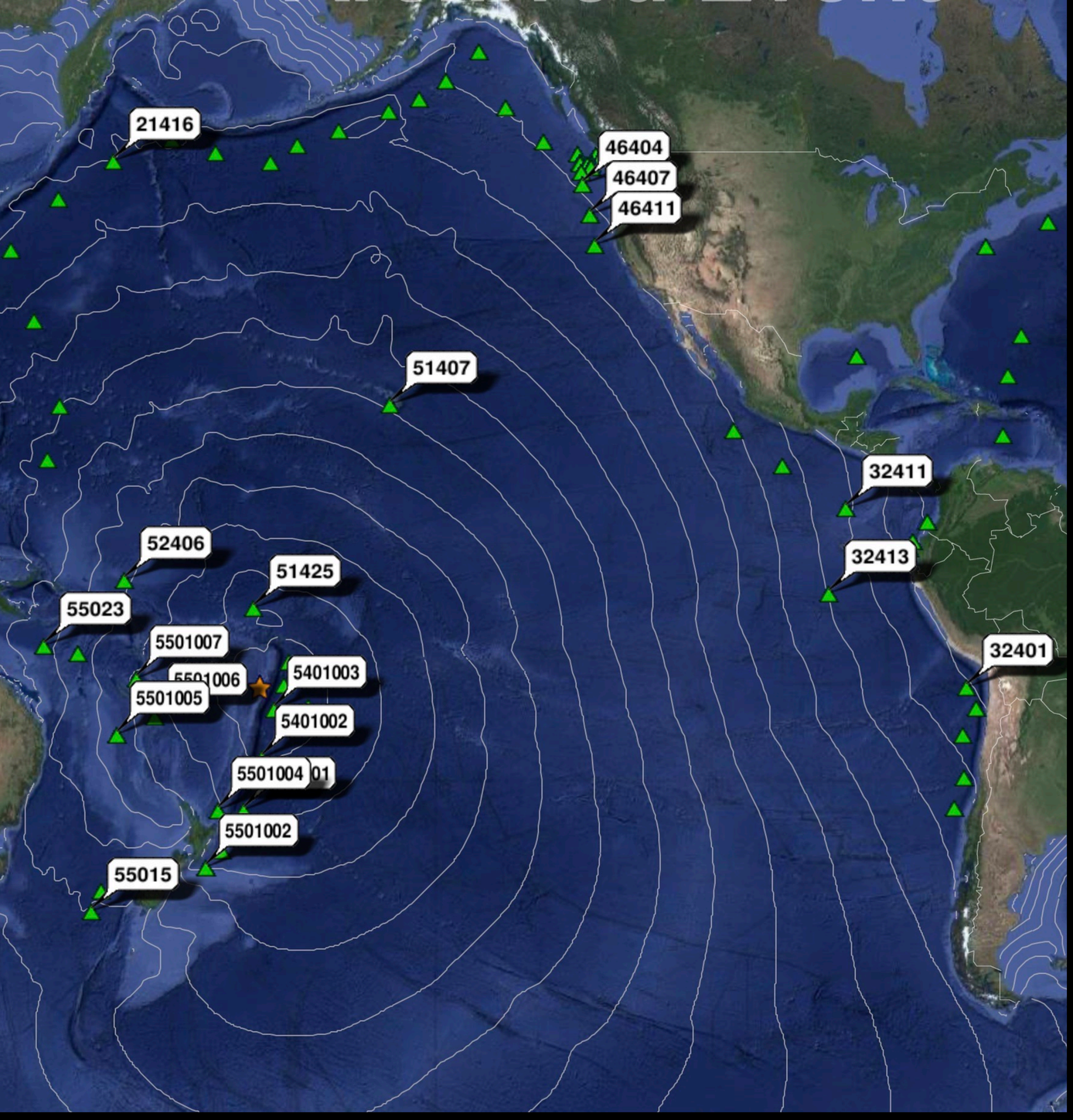
Pacific propagation

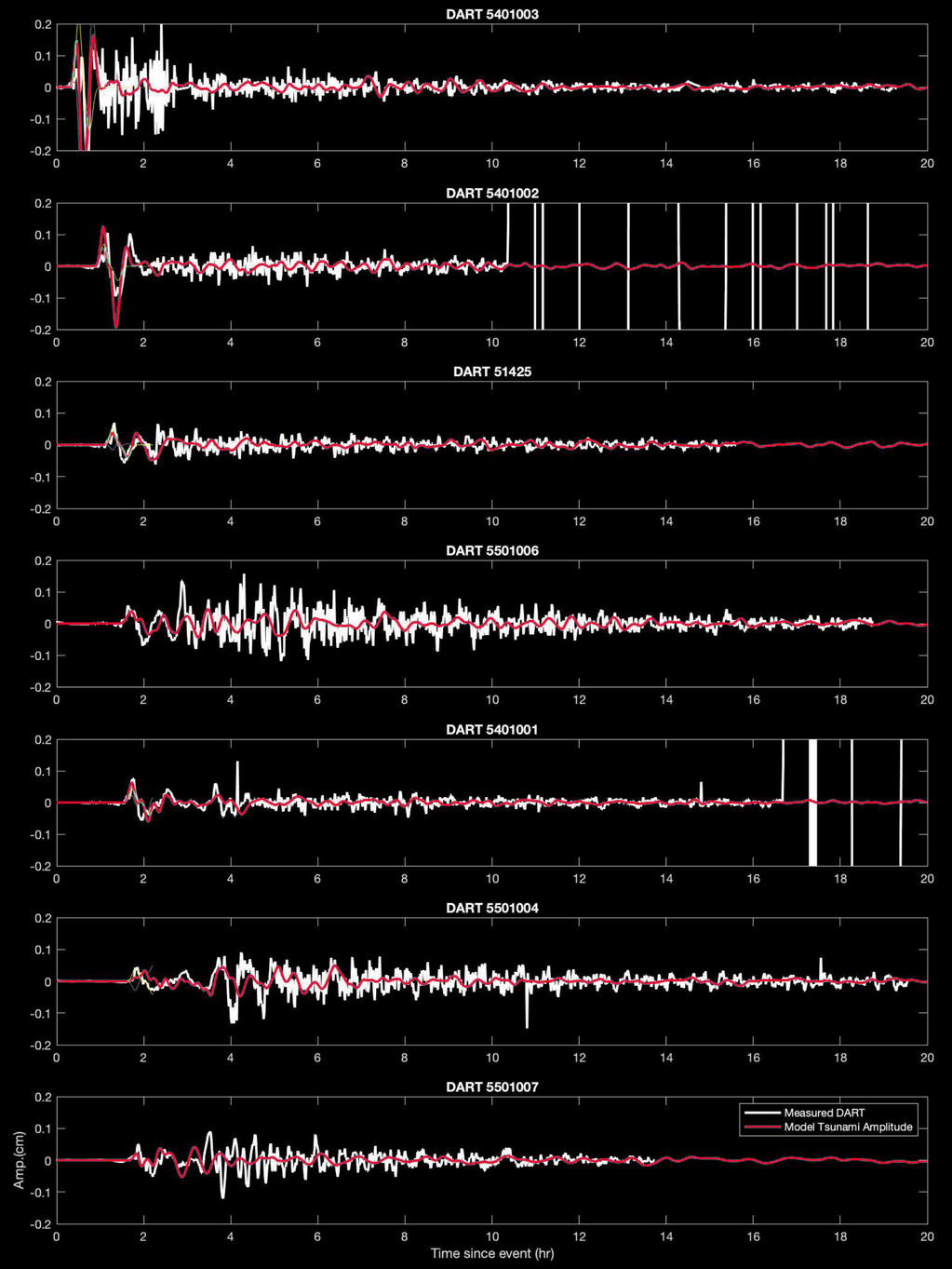
Tsunami Amplitudes

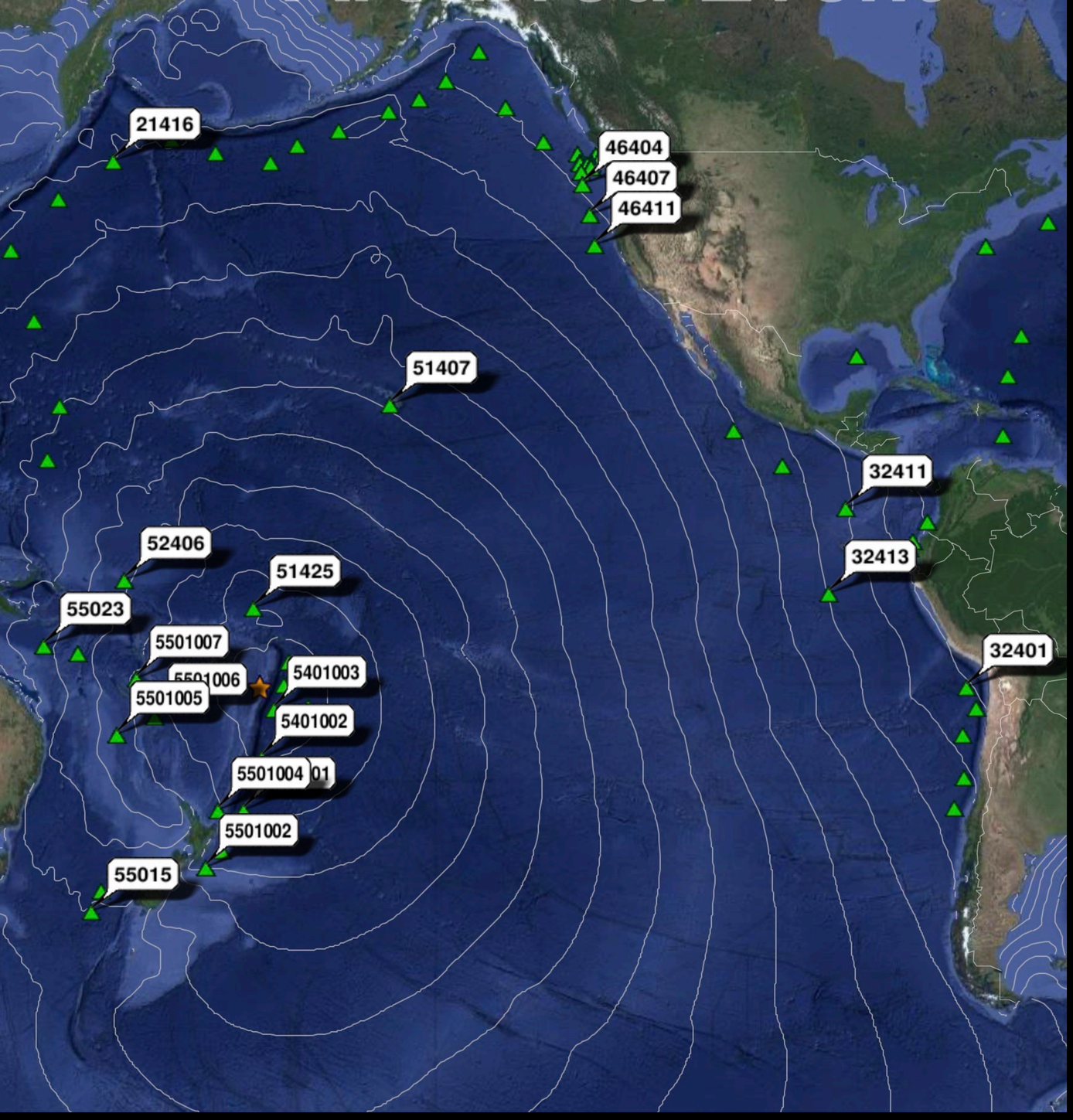


Air Pressure Wave (Gaussian dipole)




21416
46404
46407
46411
51407
32411
52406
51425
32413
55023
5501007
5501006
5401003
5501005
5401002
32401
5501004
5501002
55015


DART 5401003
DART 5401002
DART 51425
DART 5501006
DART 5401001
DART 5501004
DART 5501007
Measured DART
Model Tsunami Amplitude
Amp.(cm)
Time since event (hr)


21416
46404
46407
46411
51407
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32413
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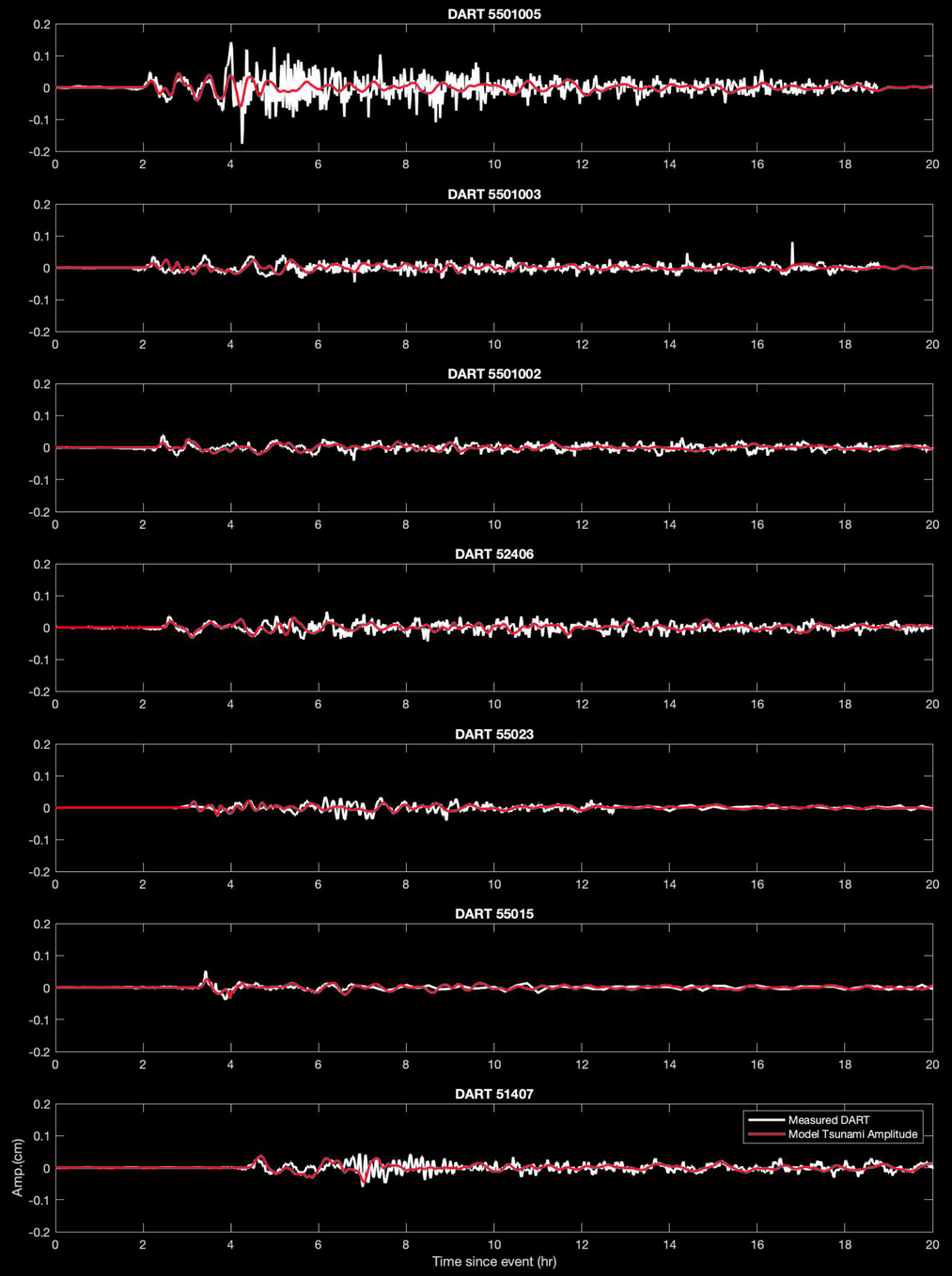
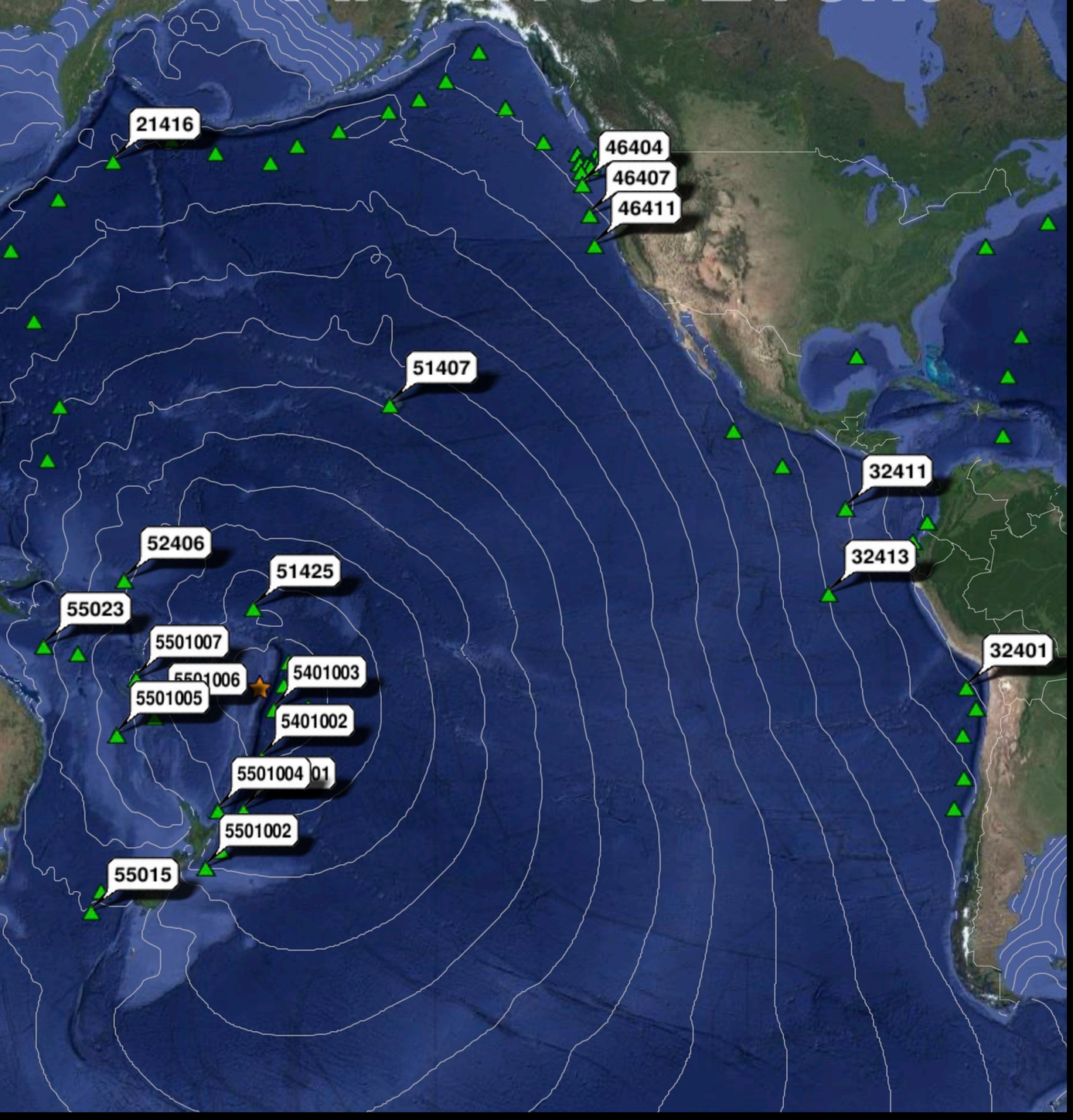
55015


DART 5501005
DART 5501003
DART 5501002
DART 52406
DART 55023
DART 55015
DART 51407
Measured DART
Model Tsunami Amplitude
Amp.(cm)
Time since event (hr)


21416
46404
46407
46411
51407
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55023
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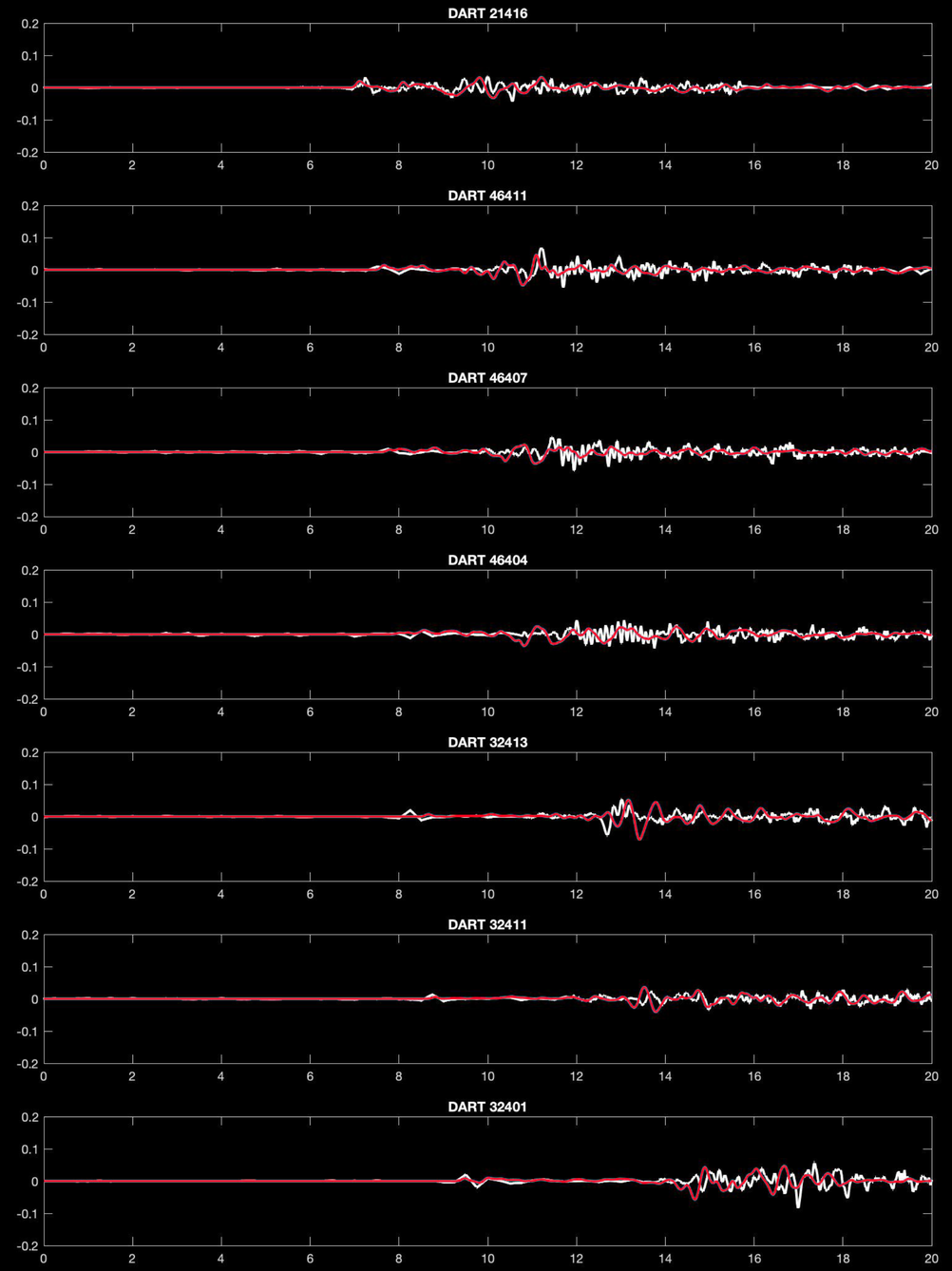
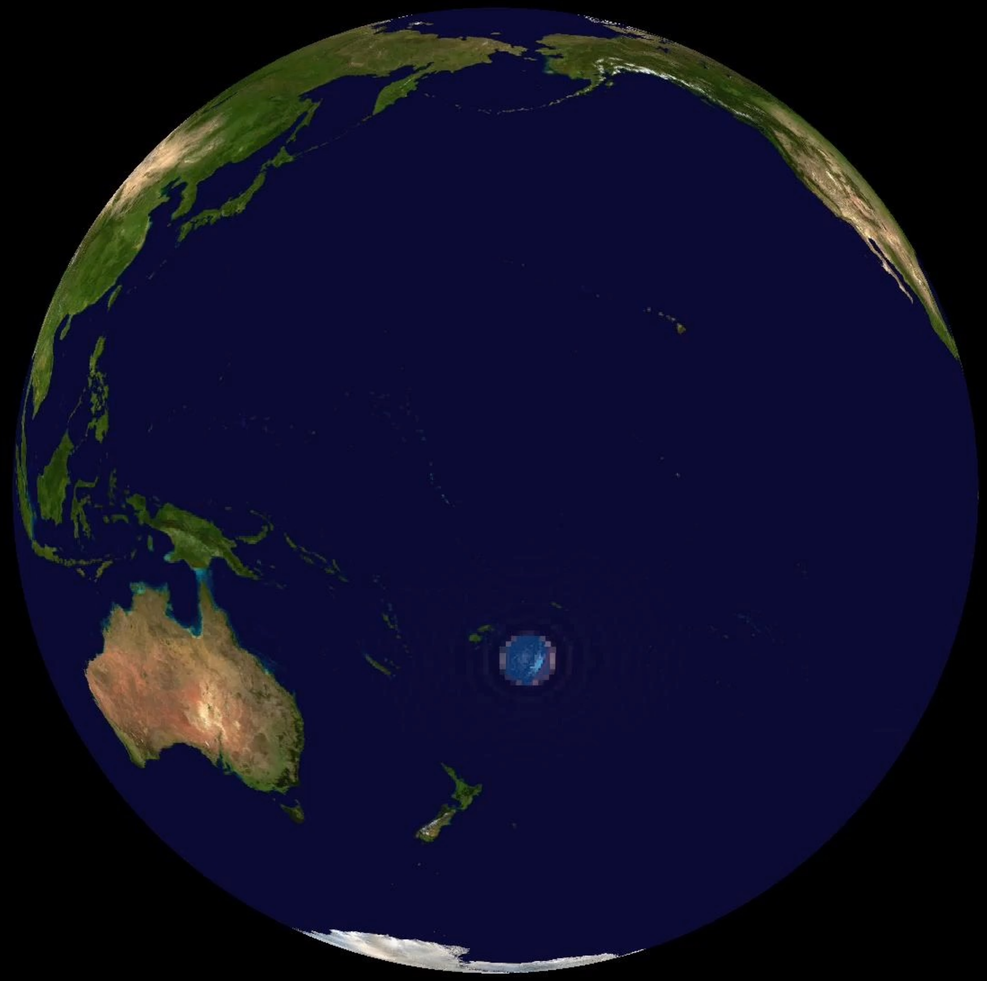
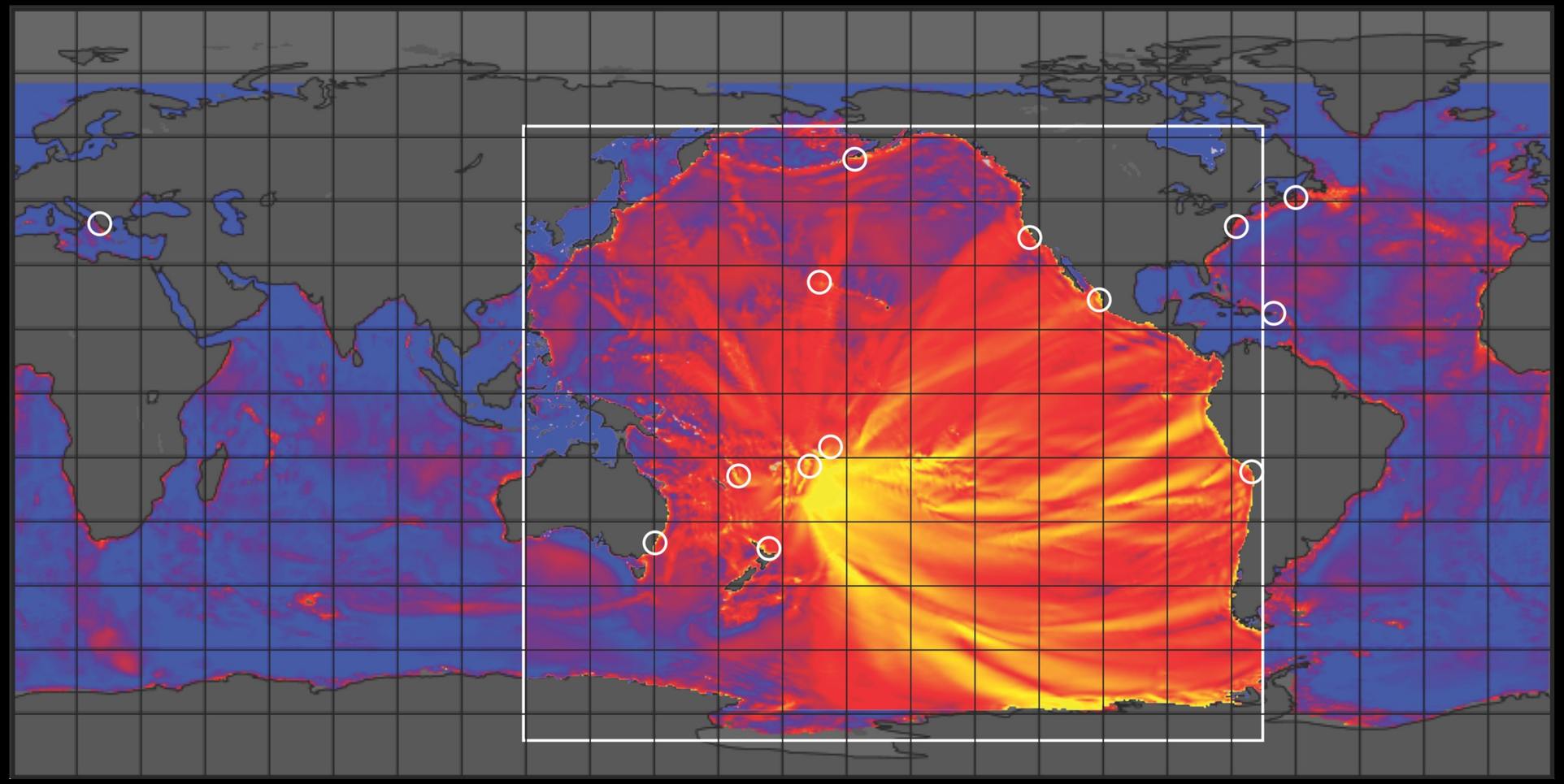
5401002
5501004
5501002
55015


DART 21416
DART 46411
DART 46407
DART 46404
DART 32413
DART 32411
DART 32401
0.2
0.1
0
-0.1
-0.2
0
2
4
6
8
10
12
14
16
18
20

Global Impact

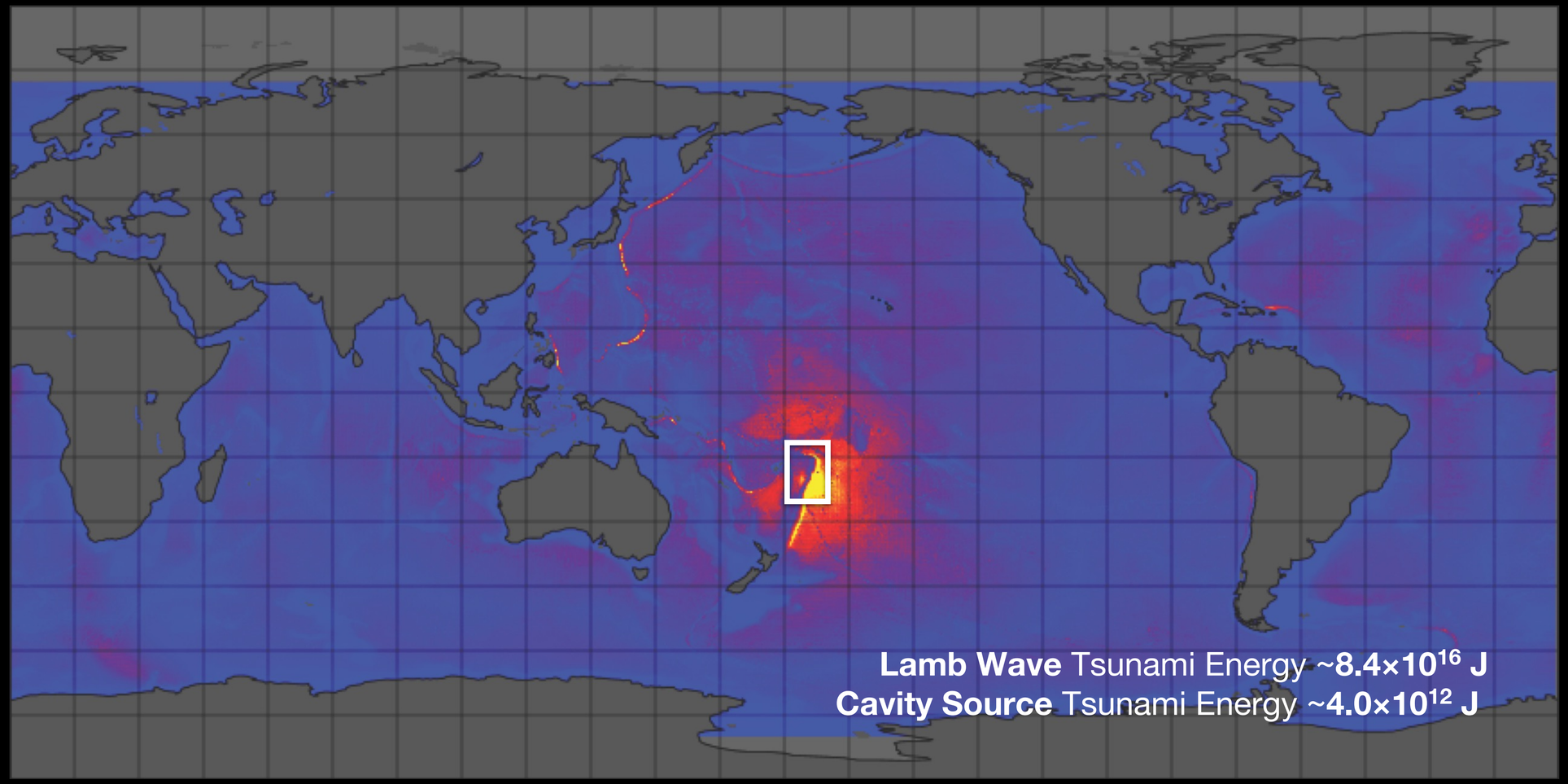


Global Tsunami Amplitudes



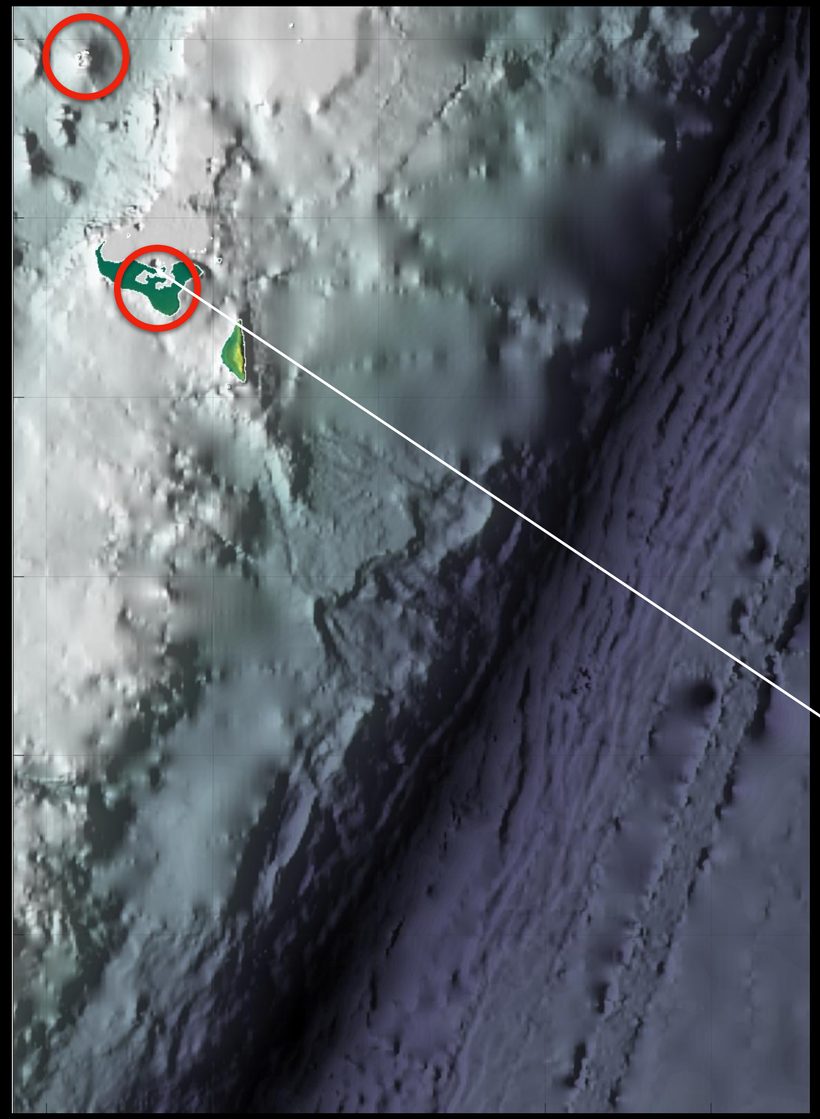
Global Tsunami Amplitudes

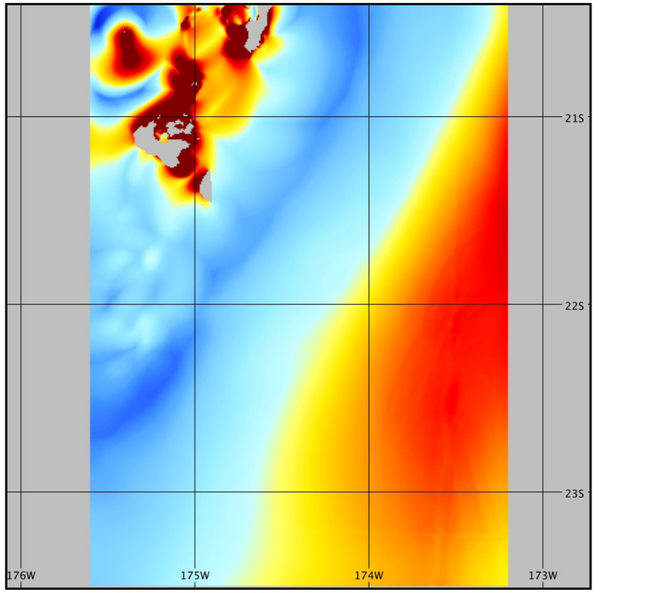
Proudman Amplification for Tonga Explosion

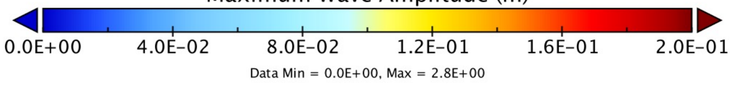


$$\eta = \frac{c^2 \eta_s}{c^2 - U^2} = \frac{\eta_s}{1 - F^2}$$

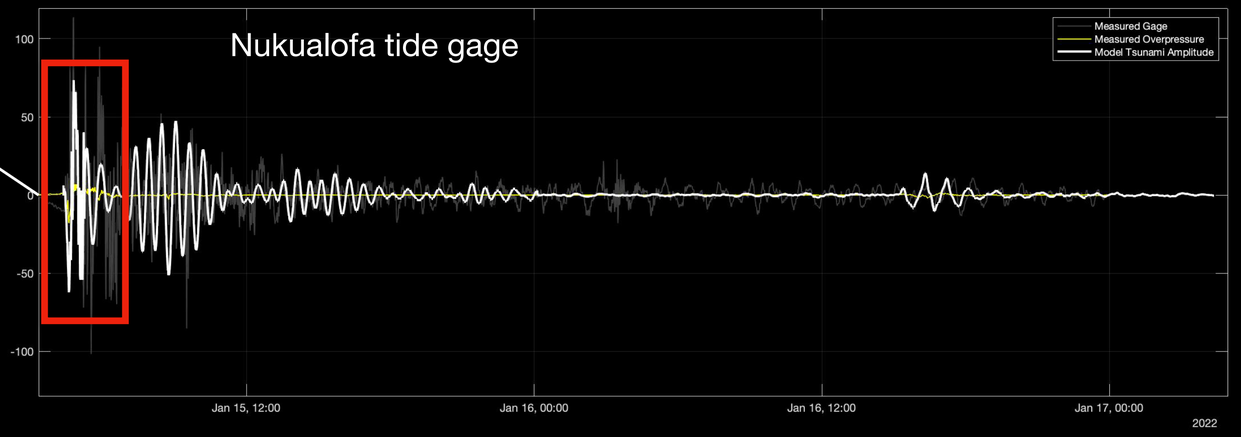
0 0.1 0.2 m







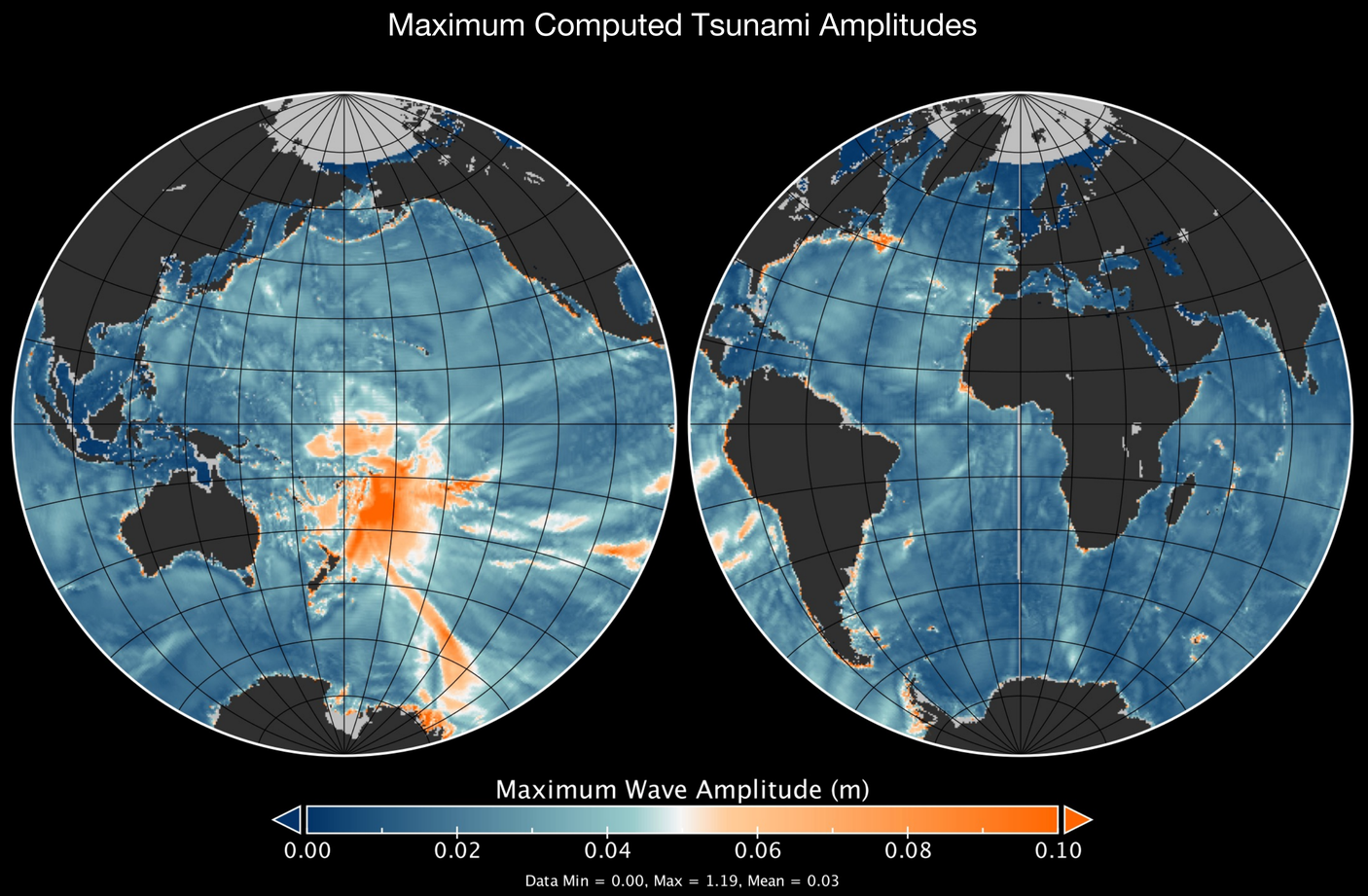
Data Min = 0.0E+00, Max = 2.8E+00



Summary and Issues

- ✓ Forecast of pressure-driven tsunami is quite important
- ✓ Modeling framework exist to simulate pressure-forced tsunamis
- ✓ Real-time data is available for constraining models for forecast

Combining these existing capabilities into functioning forecast is an immediate challenge for TWSs



Science Issues

- What is the mechanism of Lamb wave generation?
- How do Lamb waves scale with magnitude?
- What is the source of the local tsunami impact?
  - cavity formation from the explosion
  - explosion shock waves
  - caldera collaps
  - slope mass failures
  - collapse of eruptive column
  - combination of above