HF RADAR

HF RADAR DETECTS AN APPROACHING TSUNAMI WAVE ALREADY IN DEEP WATERS

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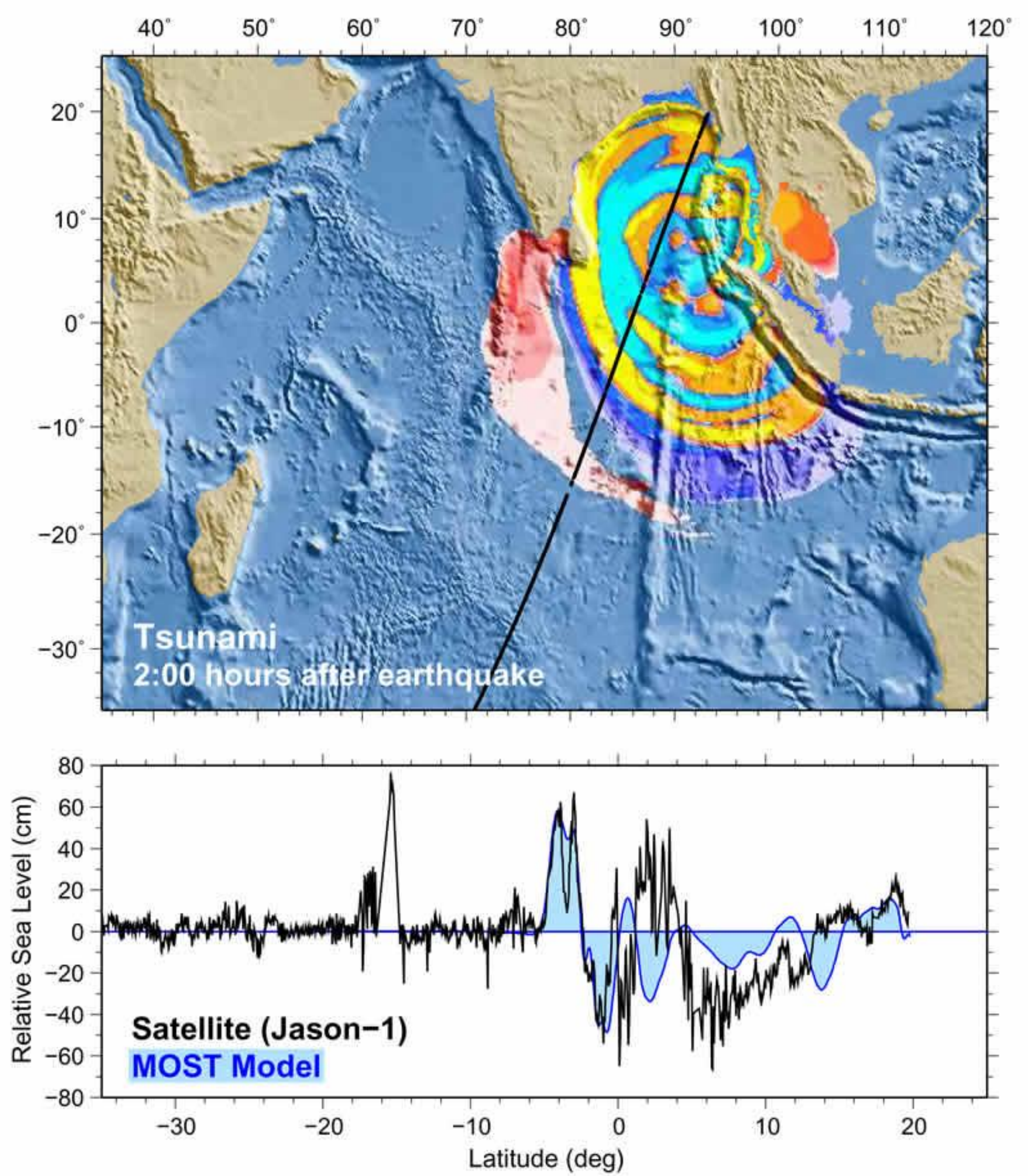
Andaman Island Earthquake 26 Dec 2004



TSUNAMI

Upper Panel: MOST Model Output

Lower Panel: JASON-1 Altimetry

Typically, in deep water:
Wavelength = 10-100 km
Period = 20-40 min
Celerity = ~170 m/s

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LINEAR THEORY

Linear wave theory to transform a wave on the deep ocean into shallow water:

D = reference deep water (3000 m)

d = water depth

$a(D)$ = reference wave height in deep water (0.5 m)

$a(d)$ = wave amplitude

v_m = maximum wave surge velocity at the surface

$$a(d) = a(D)\left(\frac{D}{d}\right)^{1/4} \qquad (1)$$

$$v_m = a(d)\left(\frac{g}{d}\right)^{1/2} \qquad (2)$$

Andaman earthquake:

a(3000) = 0.5 m (Jason data)

v_m(3000) = 0.029 m/s eqn(2)

a(100) = 1.17 m eqn(1)

v_m (100)= 0.37 m/s eqn(2)

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HF RADARS HAVE SEEN TSUNAMIS

Results from SeaSonde crossed loop radars show that tsunamis can be detected when they are on the shelf – in shallow water and at short ranges (0.2 to 12 km from the shore).

Results from a WERA phased array radar show that tsunamis can be detected in medium depth water (880m) at long ranges (>30 km).

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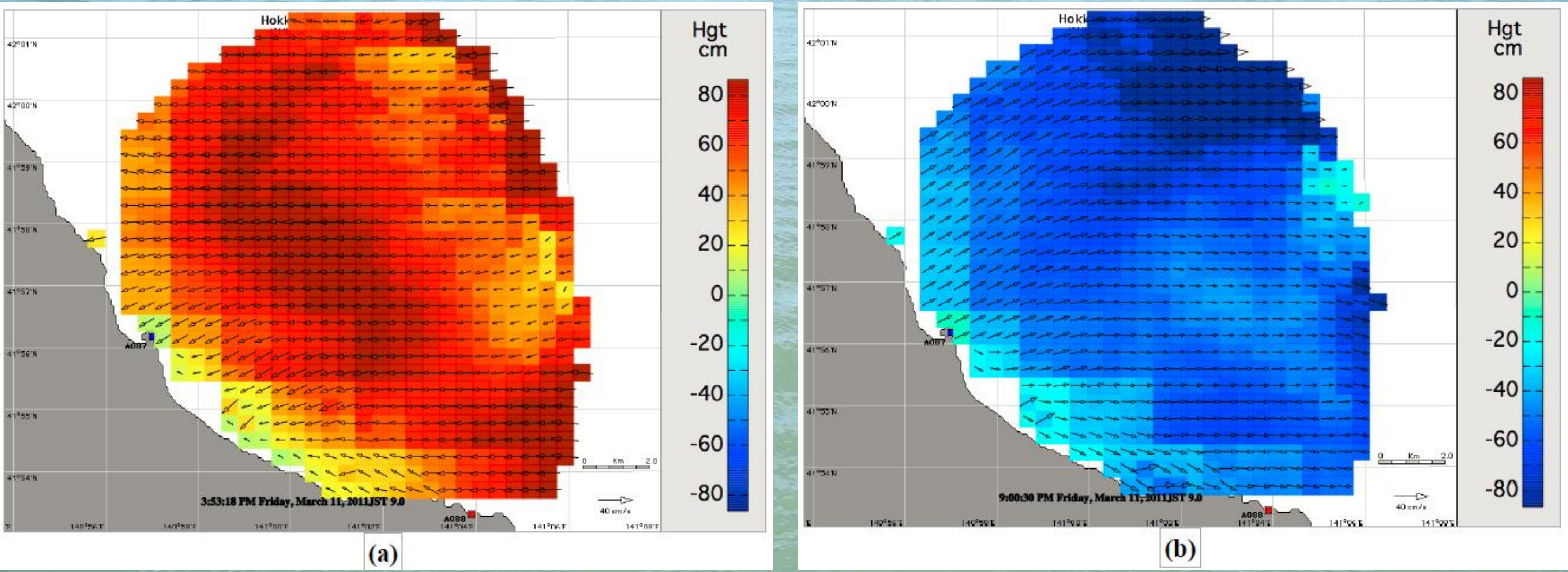
SEASONDE DATA



The tsunami height superimposed on the total current velocity field measured by radars at Usujiri (blue dot) and Kinaoshi (red dot): (a) 11 March 2011, 15:53 JST; (b) 11 March 2011, 21:00 JST.

TOHOKU Earthquake, 2011
CODAR SeaSonde Data
Lipa et al., Remote Sens. 2011, 3, 1663-1679; doi:10.3390/rs3081663

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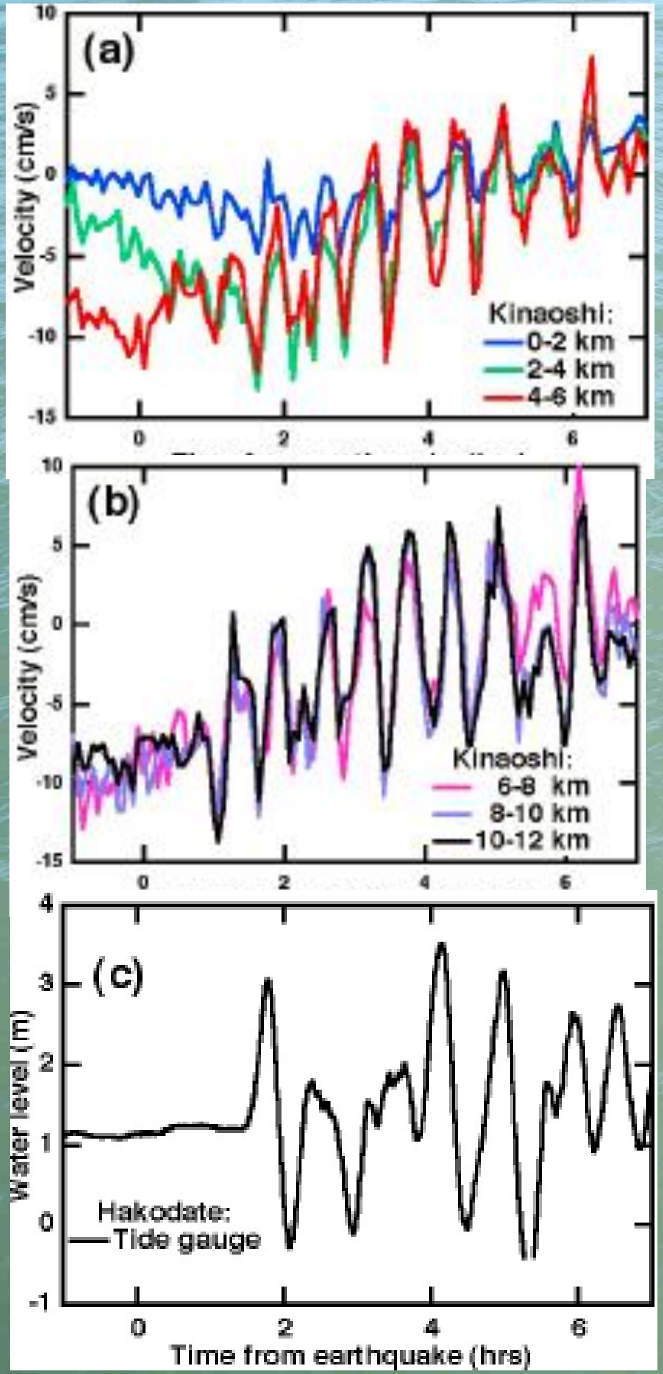
SEASONDE DATA



Time series of velocity components from the Kinaoshi radar (42 MHz transmitter frequency) and simultaneous water level observations from the Hakodate tide gauge. Radial velocity was resolved perpendicular to the shore, and averaged over bands 2 km wide parallel to the depth contours.

TOHOKU Earthquake, 2011
CODAR SeaSonde Data
Lipa et al., Remote Sens. 2011, 3, 1663-1679;
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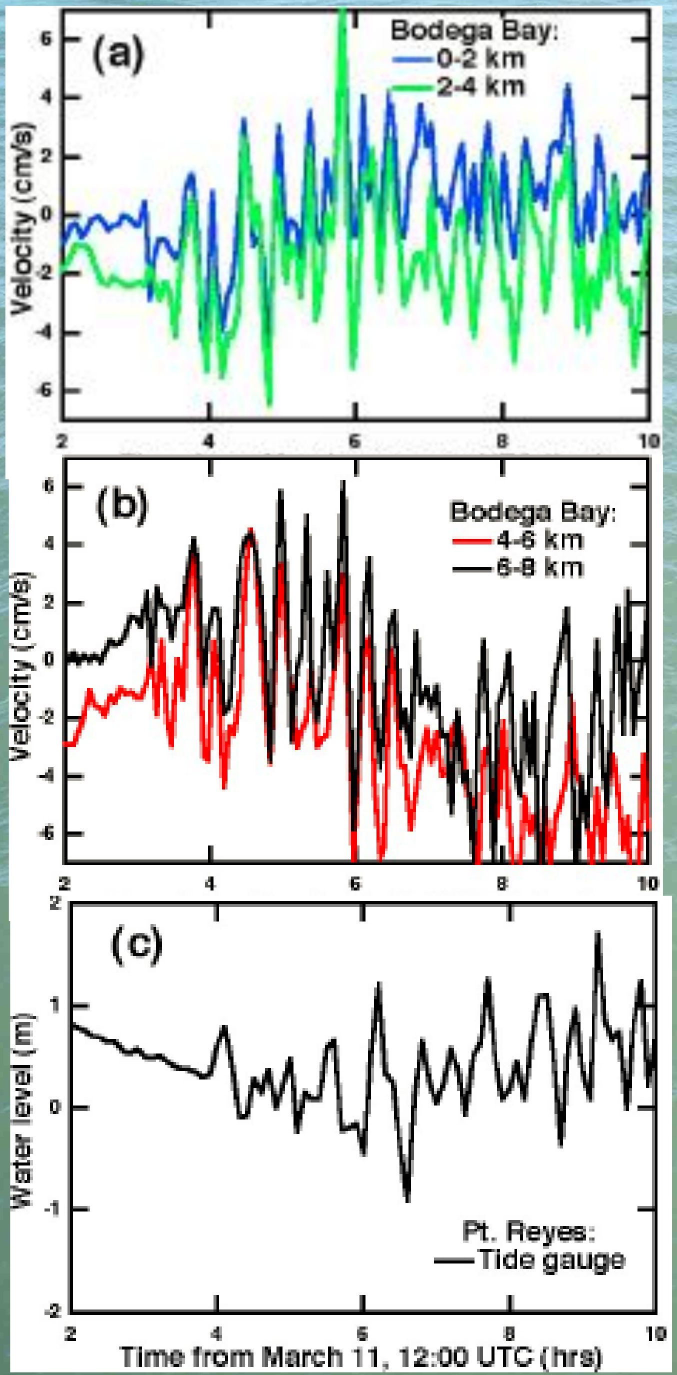
SEASONDE DATA



Time series of velocity components from the radar at Bodega Bay and simultaneous water level observations from the Point Reyes tide gauge in California, USA. Radial velocities were resolved perpendicular to the shore, and averaged over bands 2-km wide parallel to the shore. The radar has 13 MHz transmit frequency and 2 km range increments.

TOHOKU Earthquake
CODAR SeaSonde Data
Lipa et al., Remote Sens. 2011, 3, 1663-1679; doi:10.3390/rs3081663

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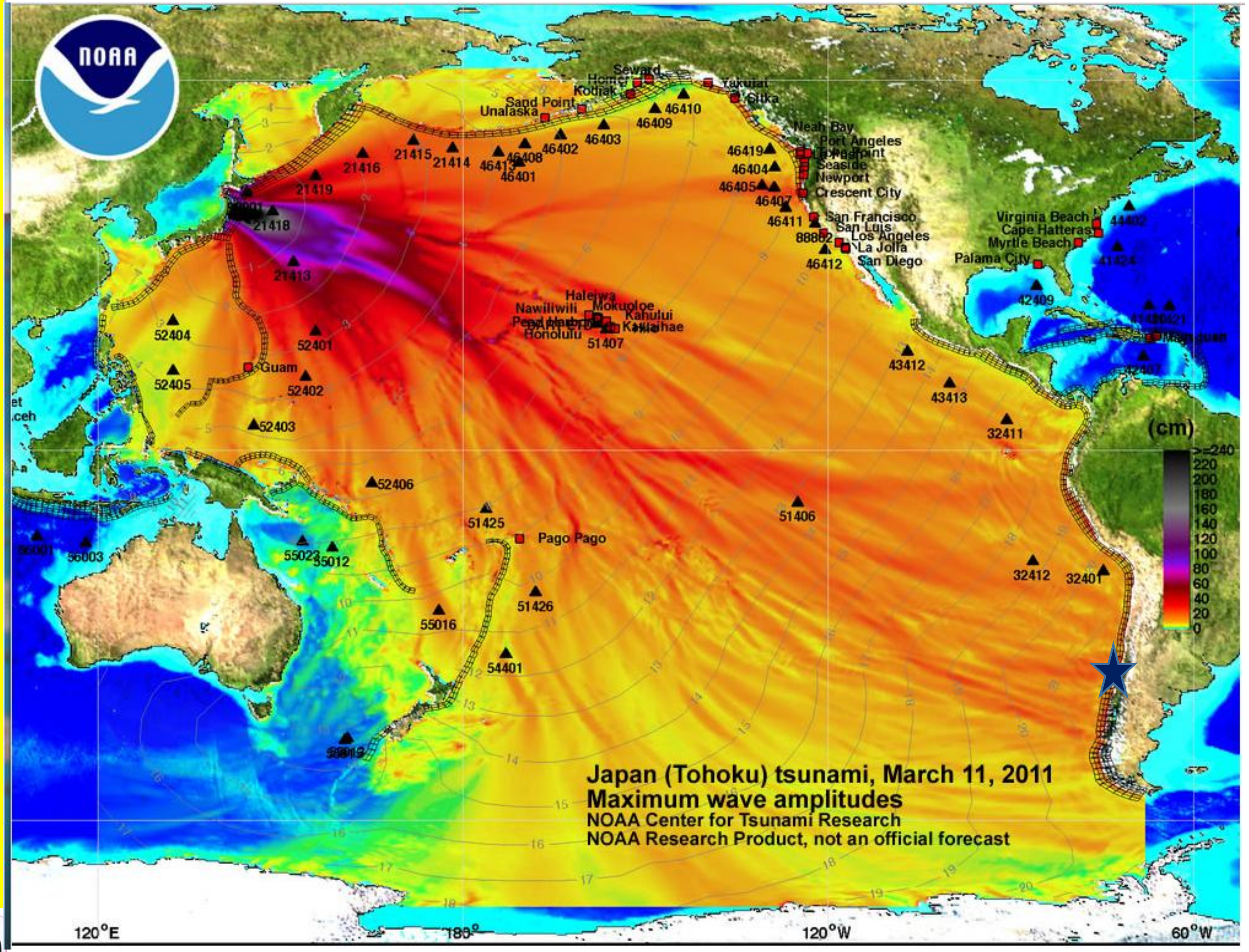
WERA DATA



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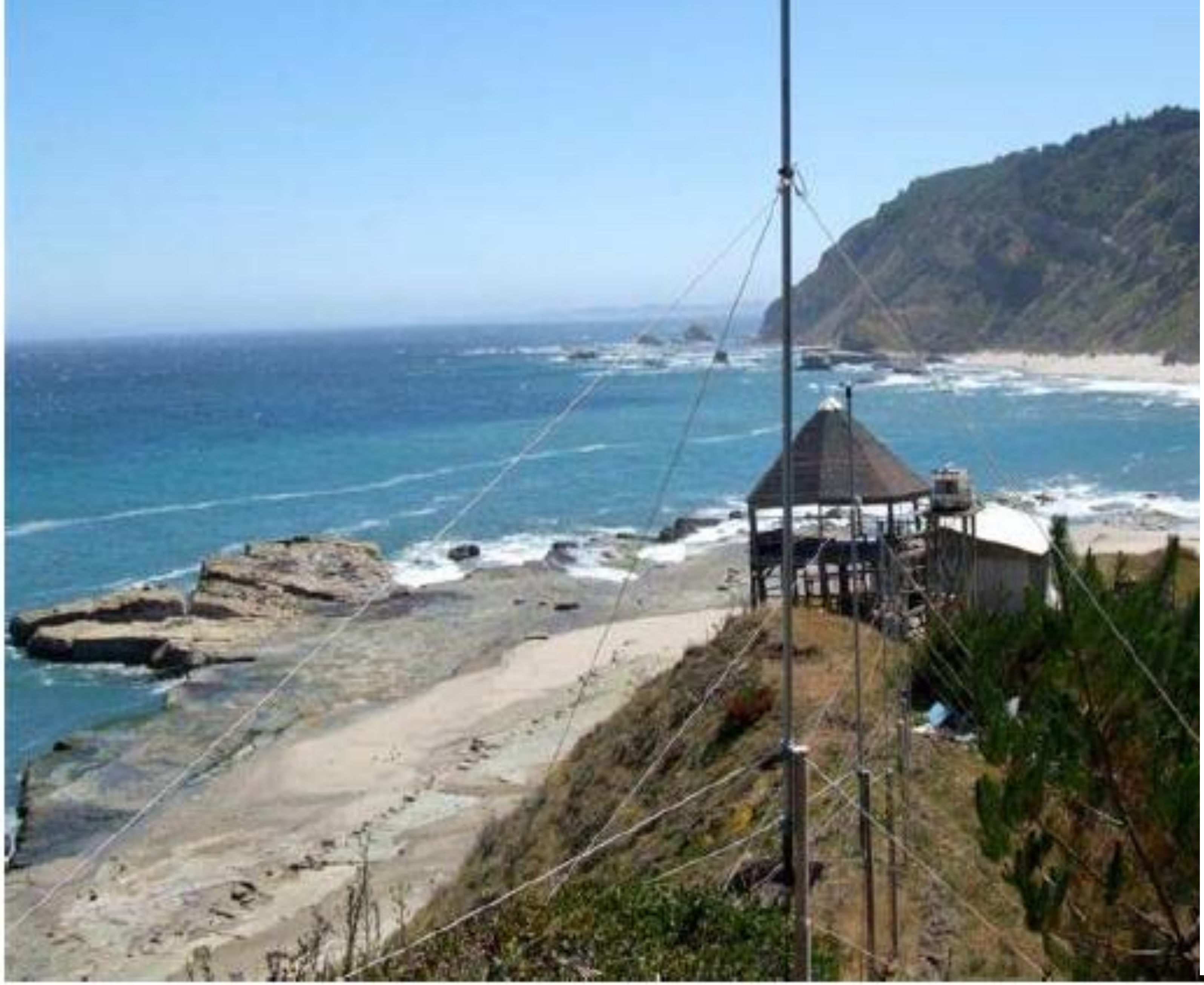
http://nctr.pmel.noaa.gov

Calculations of maximum wave amplitude using the MOST model. The braided channel effect across the Pacific Ocean indicates multi-path propagation.

★ marks the WERA site in Chile

WERA DATA

Rumena, Chile.



WERA Radar with an 8-element phased array.
Freq 22 MHz
Max range 50km
Range res:0.6km
Sampling on 133s time series sliding in steps of 33s.

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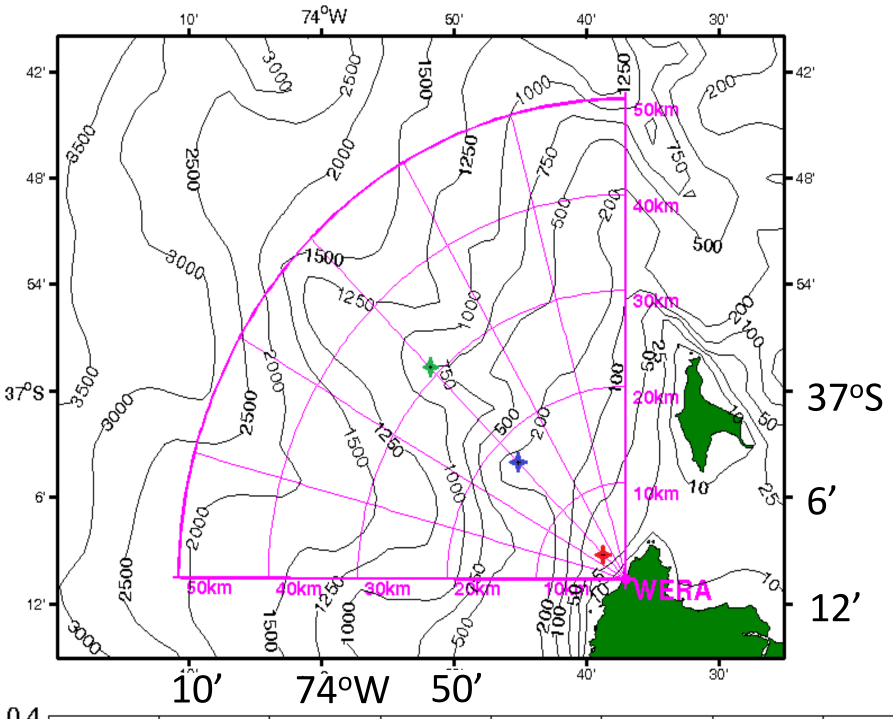
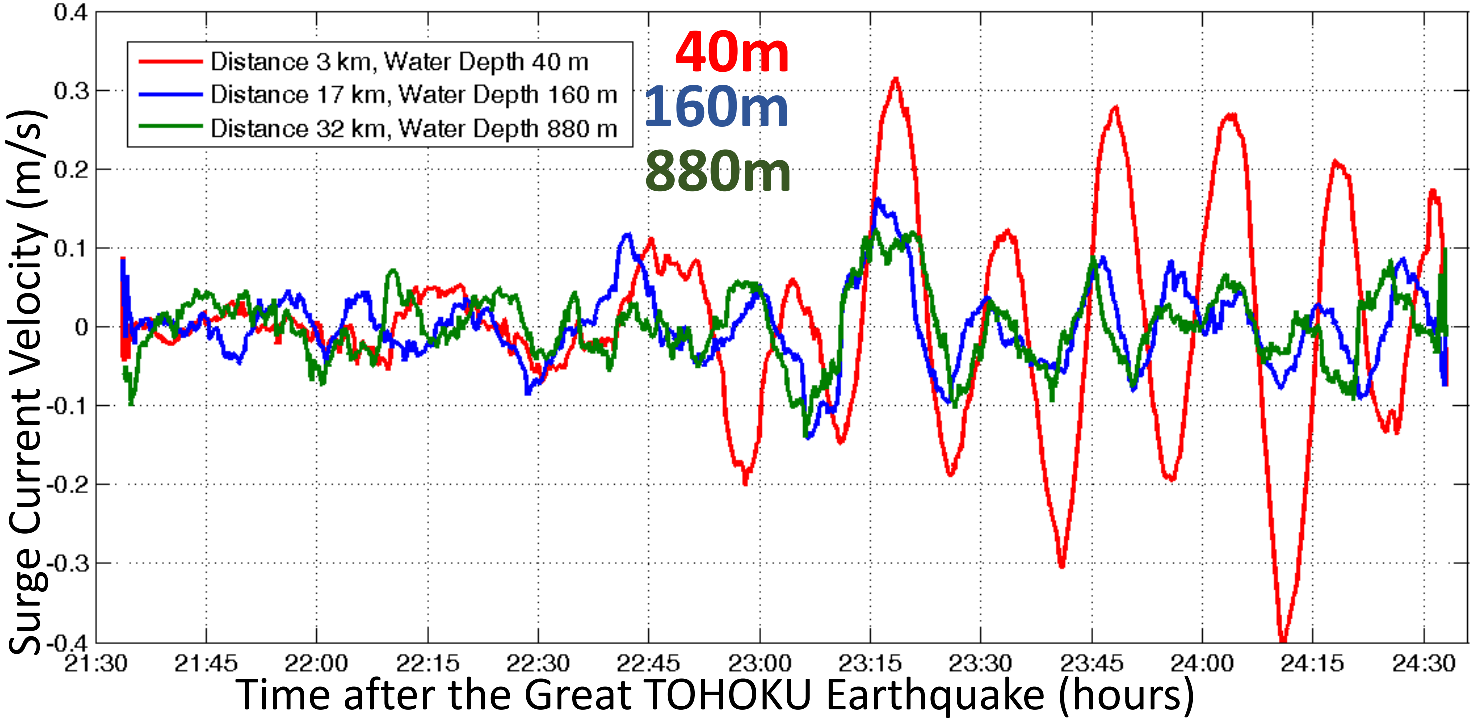
WERA DATA



WERA Phased Array radar at Rumena, Chile made observations at depths 40m, 160m and 880m along the transect 45 degrees west of north.



Phased Array radars have low noise and high sensitivity for Tsunami Monitoring.

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HFR for TSUNAMIS

HF RADAR FOR TSUNAMI MONITORING

To be useful in Monitoring Tsunamis, HF Radars need to have:

1. Time resolution of a few minutes;
2. Surface current resolution of a few cm/sec;
3. Long range capability.

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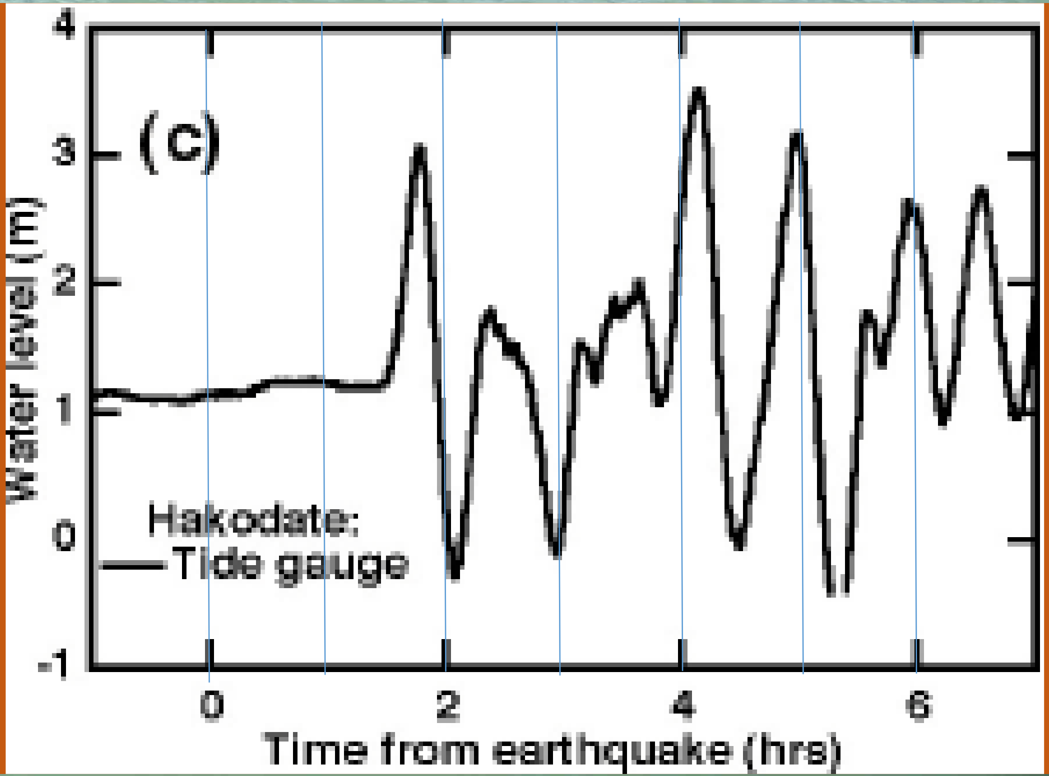
HF RADAR FOR TSUNAMI MONITORING

1. Time resolution of a few minutes:

Tsunami periodicity ranges from about 20 minutes to 1 hour.

Tohoku Earthquake, 2011

A monitoring radar needs to return independent samples about every 3 - 5 minutes.



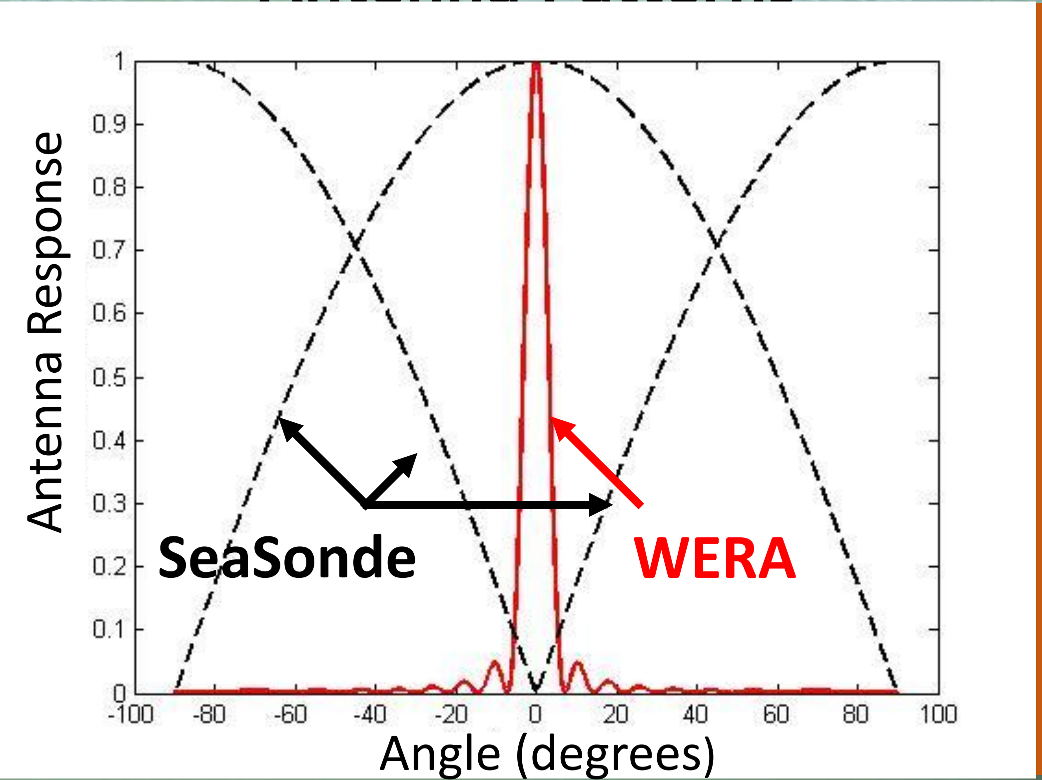
HF RADAR FOR TSUNAMI MONITORING

HFR for TSUNAMIS

Time resolution of a few minutes:
Long range SeaSondes integrate for 1-3 hours;
Long range WERAs integrate for a few minutes.

REASON: The SeaSonde is more exposed to atmospheric noise. Ratio of antenna noise (area under curves) is 1:31. This is overcome by integrating for 3 min: 1.5 hour.

Antenna Patterns



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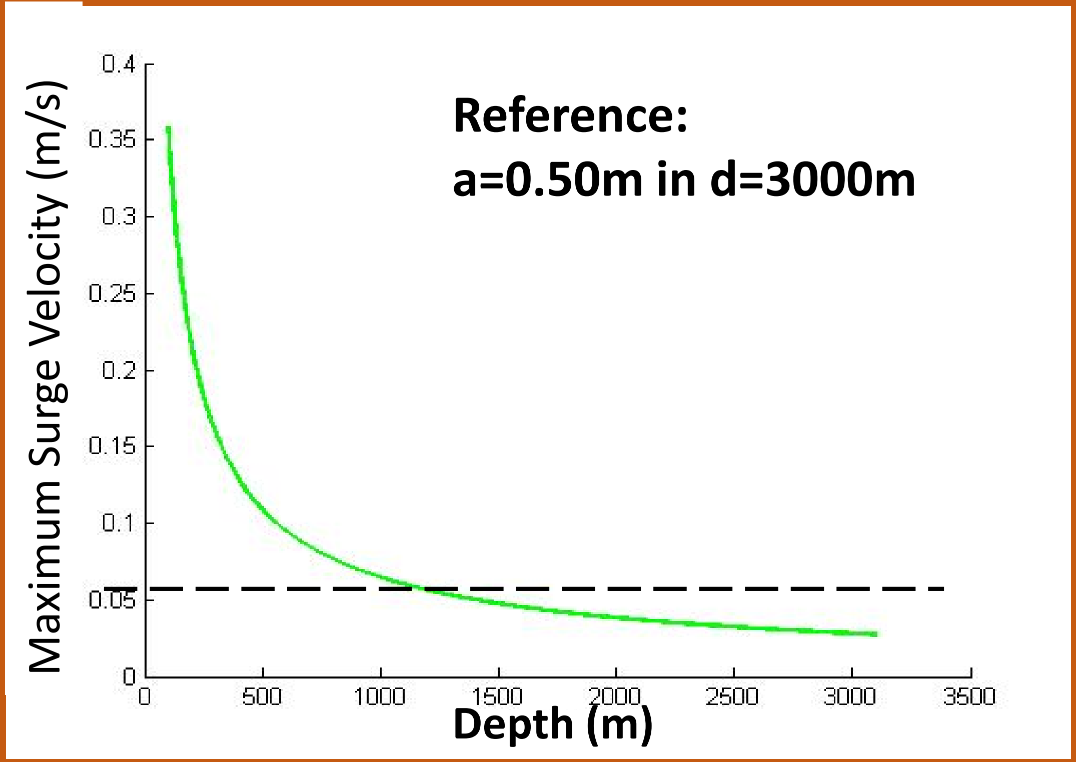
2. Surface current resolution of a few cm/sec.

A tsunami with elevation 0.5m in deep water will have a maximum surge velocity of about 0.1 m/s at a depth of 500m (Linear Theory).

A Monitoring radar needs to have current resolution of at least 5 cm/s.



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HF RADAR FOR TSUNAMI MONITORING

2. Surface current resolution of a few cm/sec.

Long range SeaSondes achieve surface current resolution of better than 10 cm/sec (MUSIC analysis).

Long range WERAs achieve surface current resolution of better than 5 cm/sec (Auto Regression analysis).

Higher operating frequencies give better surface current resolution.

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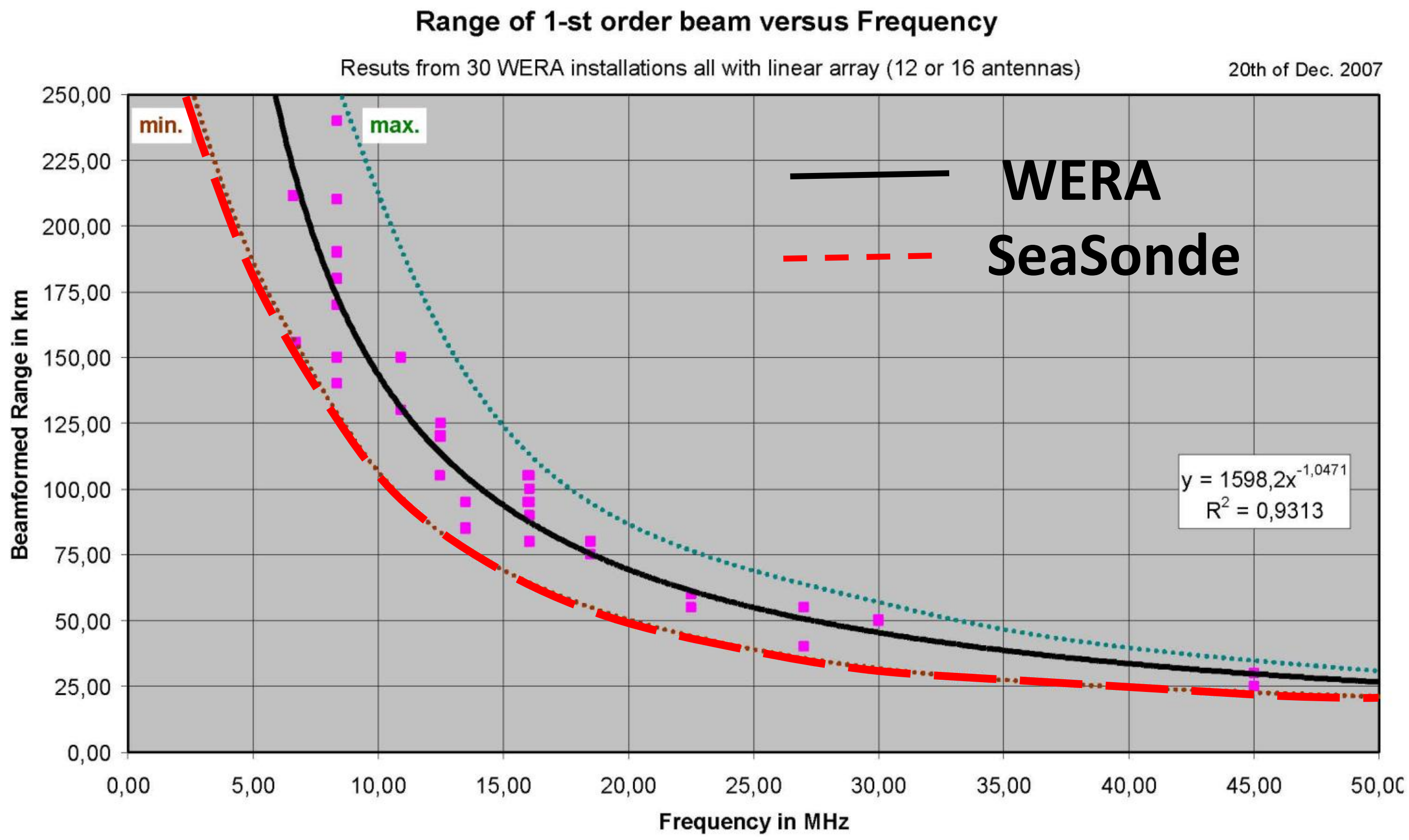
3. Long Range Capability

A monitoring radar needs to achieve maximum range possible without compromising time resolution, or surface current resolution.



The data points are for WERA radars, and an estimate of the variability is shown. The red dashed line is fitted to data from ACORN.

With ACORN configurations, the WERAs have about 30% greater range than SeaSondes at the same frequency.

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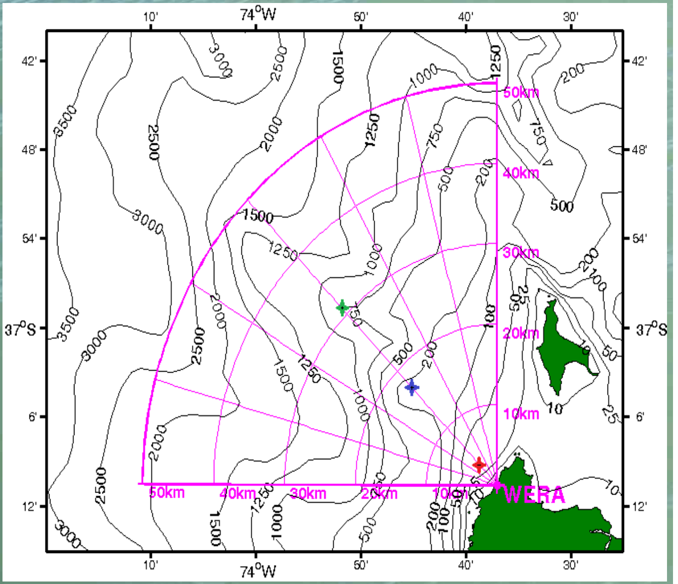
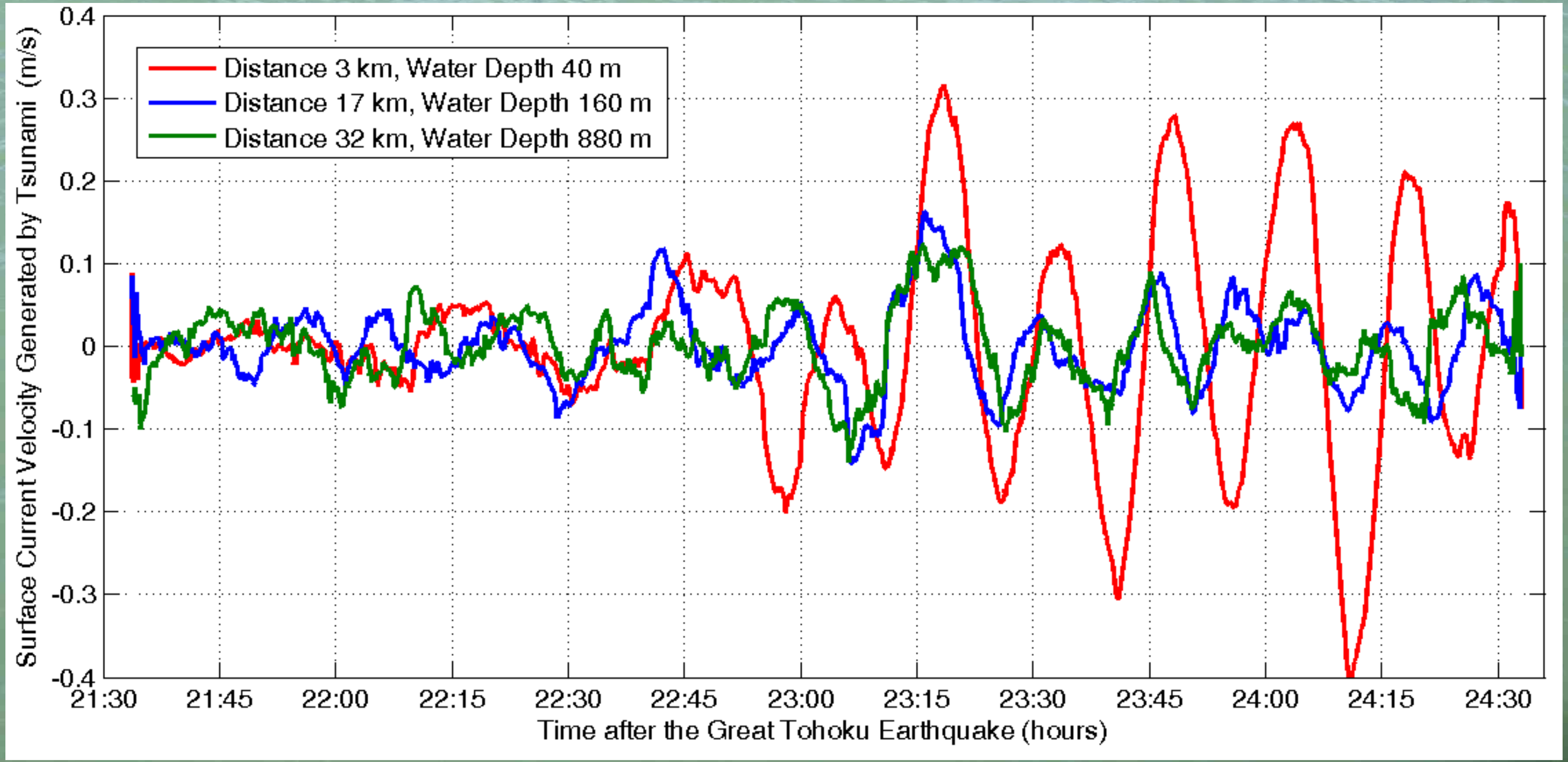
The WERA radar in Chile observed the tsunami in water 880m deep at a range of 32km.





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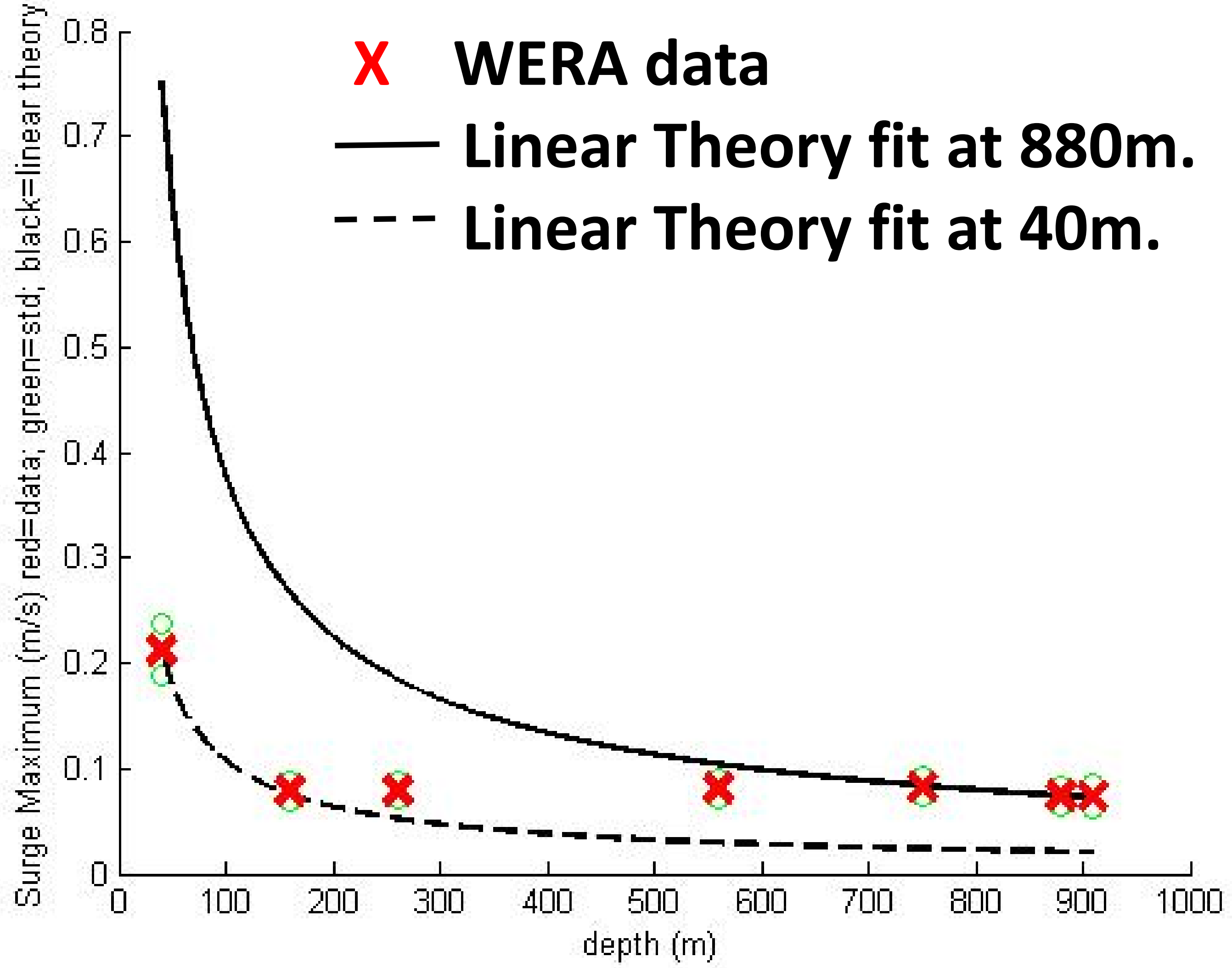
The WERA radar in Chile showed that the tsunami was non-linear between 880 and 160m depths.



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HF RADAR FOR TSUNAMI MONITORING
Technical Summary

PARAMETER	PREFERENCE	COUNTERPOINT	TRADE-OFF
Time Resolution	Short	Increased Noise	Shorter Range
Current Resolution	Short	Increase Frequency	Shorter Range
Current Resolution	Short	Decreased Integration Time	Shorter Time Resolution
Range	Long	Decrease Frequency	Longer Time Resolution Increased Current Resolution

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HF RADAR FOR TSUNAMI MONITORING SUMMARY

The optimal system for monitoring tsunamis is:

1. a narrow-beam phased-array radar (low noise);
2. sampling every 3-5 minutes (time resolution);
3. operating at low frequency (long range).

Note:

The range (operating frequency) is a trade-off against surface current resolution and the choice is site-specific.

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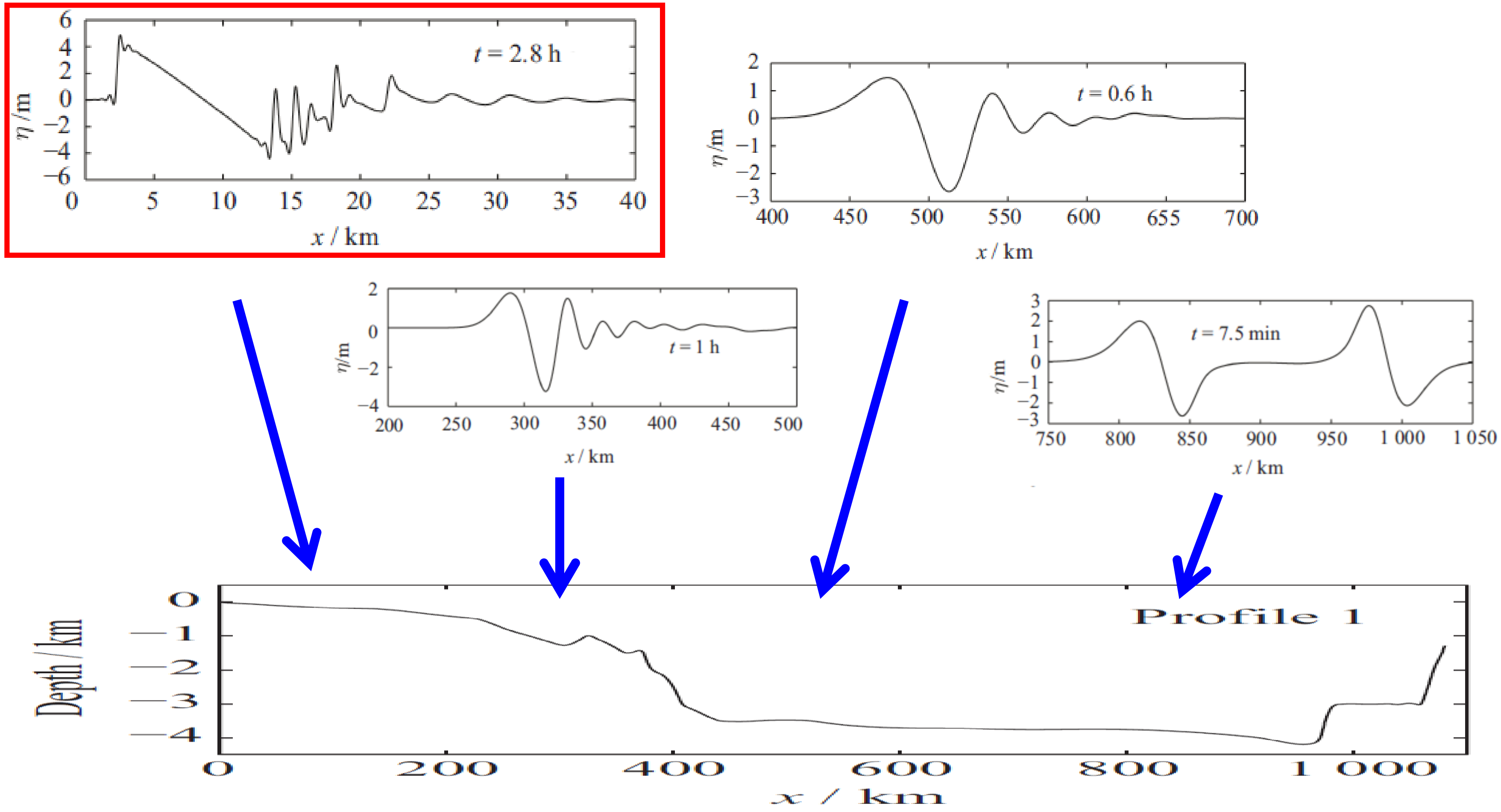
Tsunami wave patterns in SCS



- South China Sea, Profile 1, M9.0

Hua Liu, SCSTW-7, November 2014

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