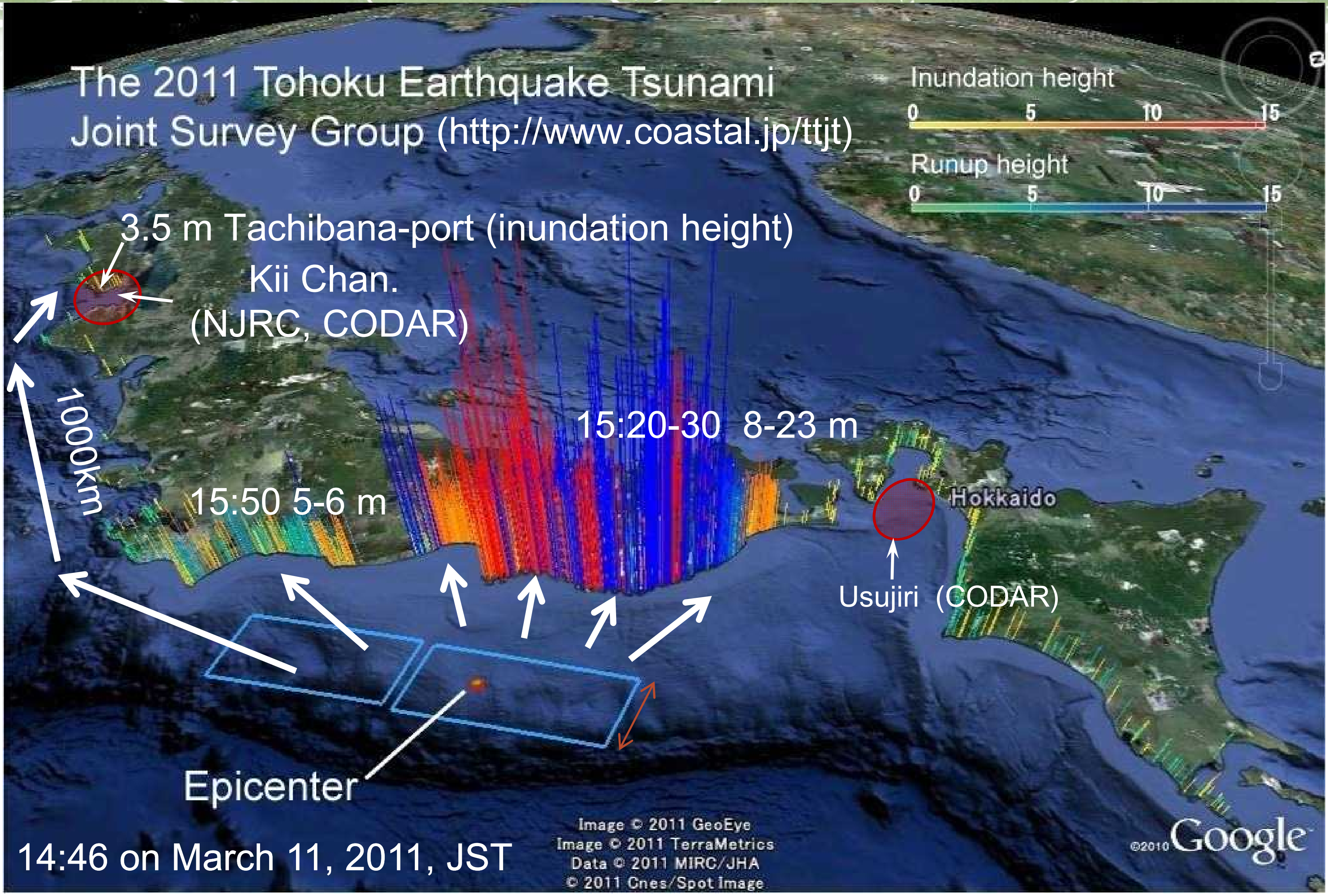
RIAM Workshop of Oceanographic Radar
December12 –13, 2012, RIAM, Kasuga, Fukuoka.

Velocity Fields of Propagating Tsunami Wave and Subsequent Resonant Oscillation Revealed by Oceanographic Radars in the Kii Channel, Japan

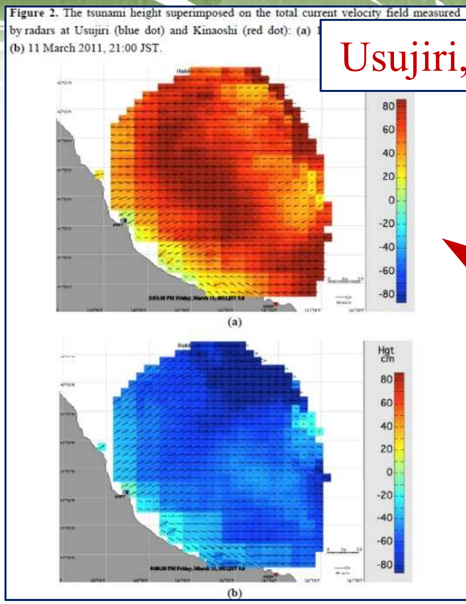
Hinata H., Fuji R., Fujii S., Kataoka T., Kokai K., Kanatsu N., and Takahashi T.

Tohoku-Oki Earthquake (M_w 9.0)



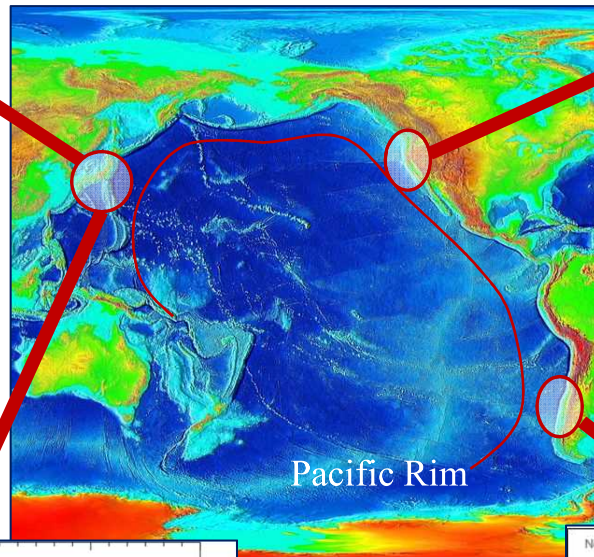
3.11 Tohoku-Oki earthquake induced Tsunami signals detected by Radars

Usujiri, Hokkaido, JP

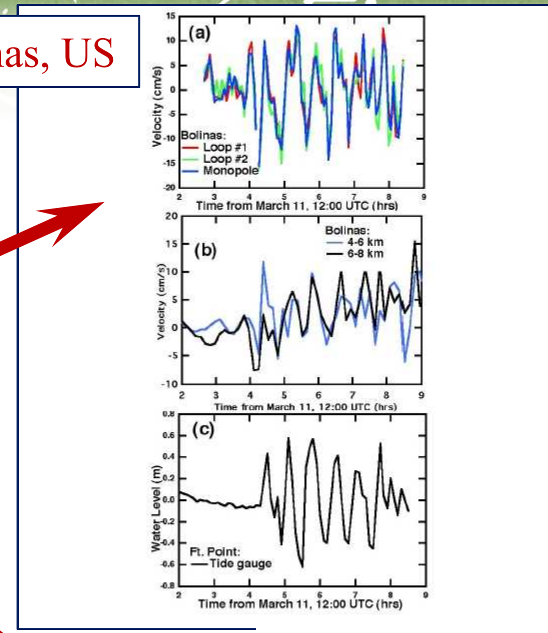


Lipa et al., *RS*, 2011

Tohoku-Oki earthquake (M_w: 9.0)
11-March-2011 14:46

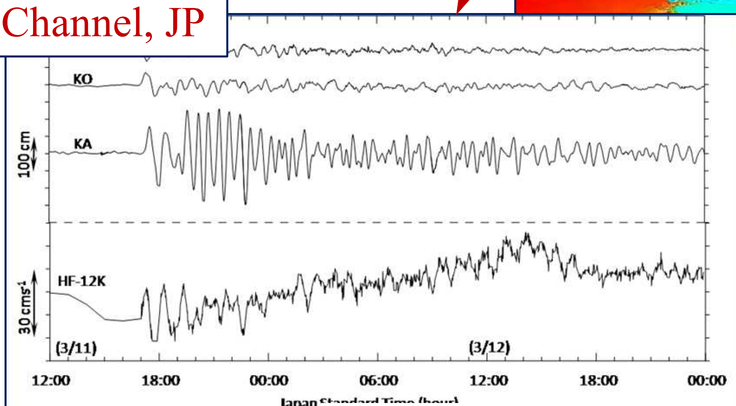


Bodega Bay, Bolinas, US



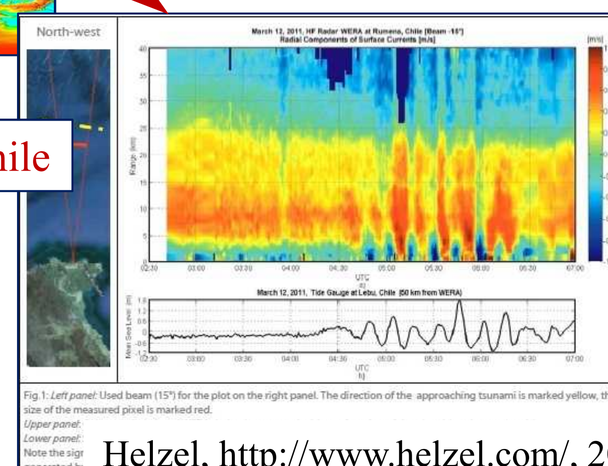
Lipa et al., *RS*, 2011

Kii Channel, JP



Hinata et al., *ECSS*, 2011

Rumena , Chile



Helzel, http://www.helzel.com/, 2011

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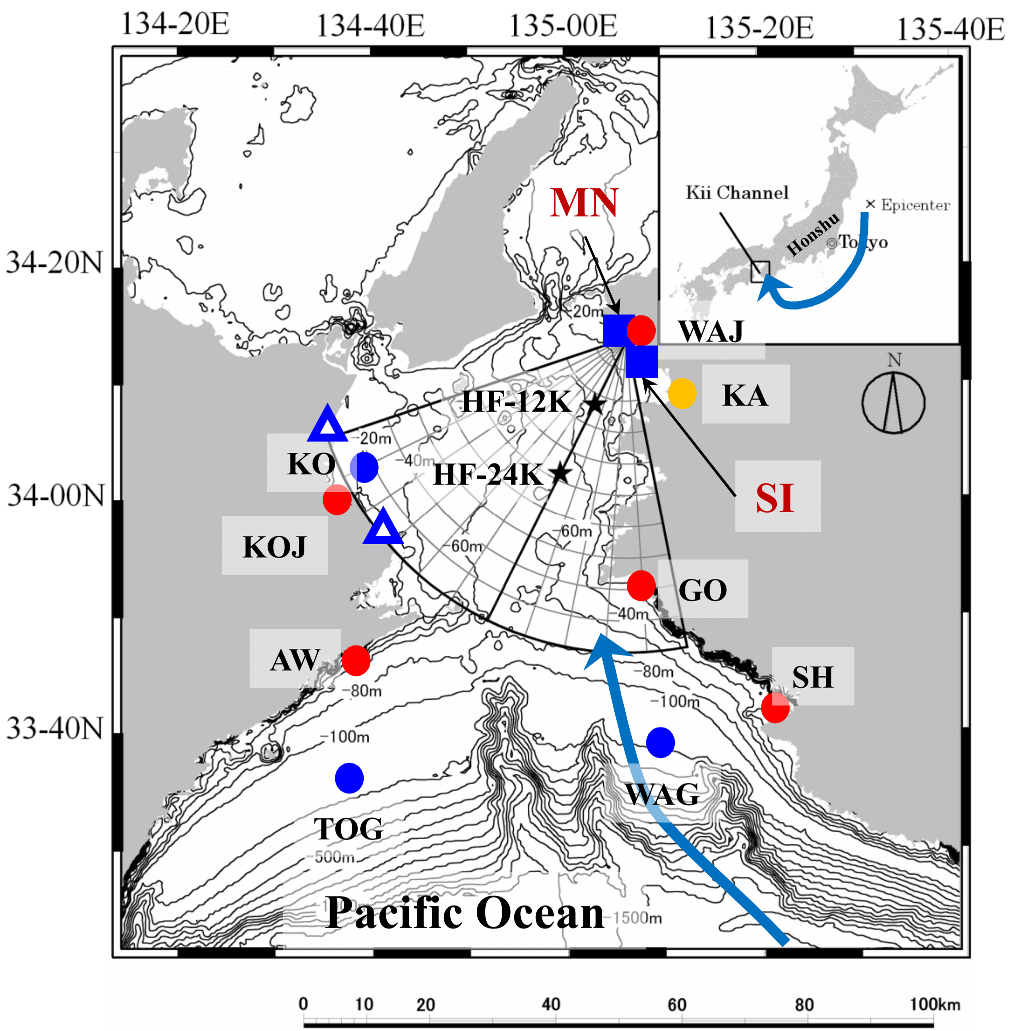
1. Oceanographic Radar (OR) -Derived Tsunami and Resonant Oscillation (RO) Velocity Vector Fields in the Kii Channel

2. Ideas of OR Application to Tsunami Disaster Mitigation

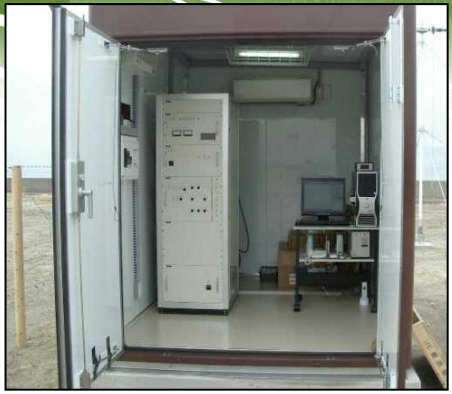
Radars and Tide/Wave Gages in the Kii Channel



■ : NJRC Radars (MLIT) @1min
△ : Codar Radars (MLIT)
● : Tide Gage (JMA) @5sec
● : Tide Gage (GIA) @5sec
● : Wave Gage (MLIT) @5sec

MLIT: Ministry of Land Infrastructure Transport and Tourism
JMA: Japan Meteorological Agency
GIA: Geospatial Information Authority

NJRC Radar (MN)

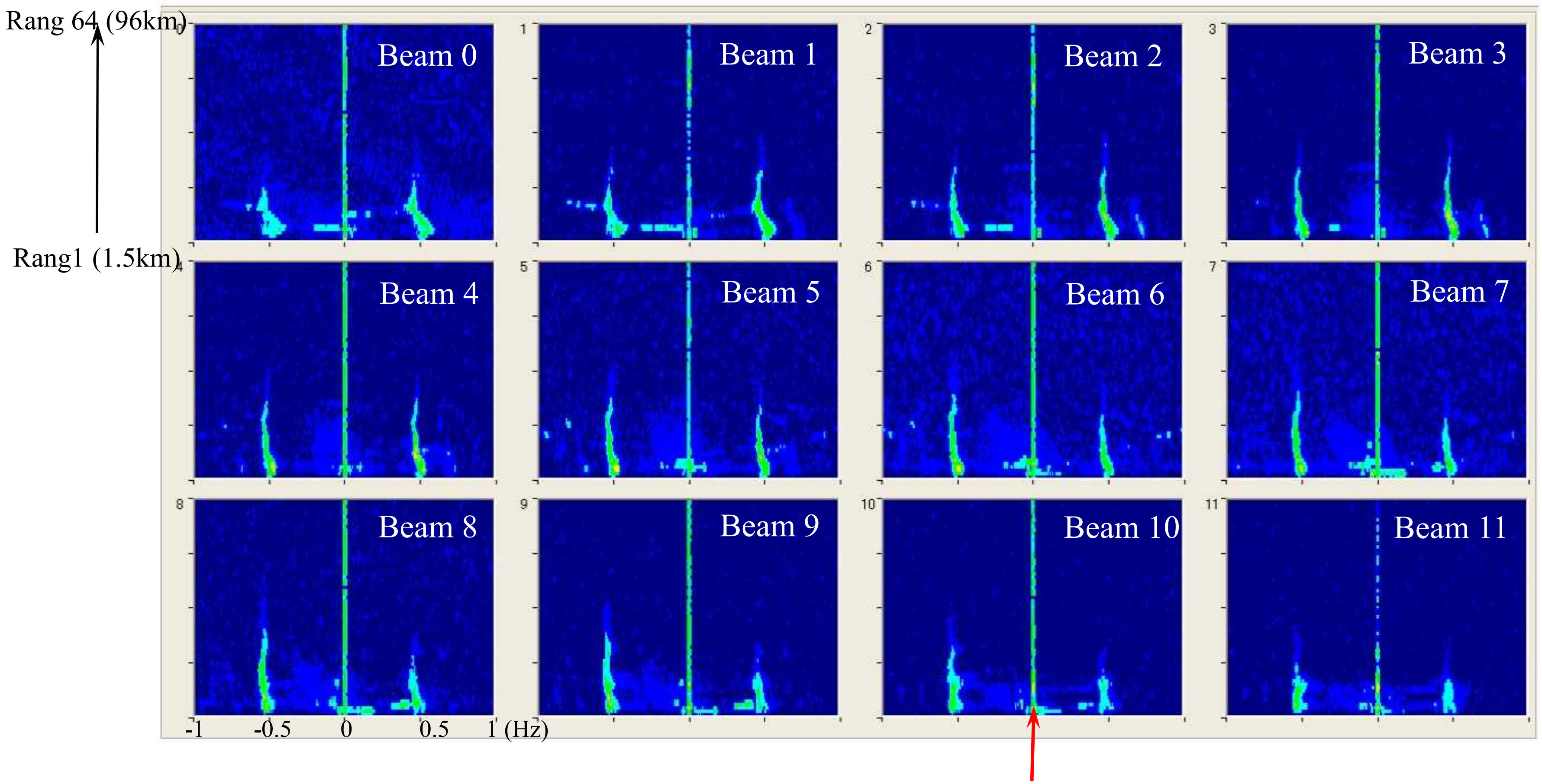


Radar type	FMICW (Frequency Modulated Interrupted Continuous Wave)
Center Frequency	24.515 MHz
Sweep Bandwidth	100 kHz (24.465 – 24.565 MHz)
Frequency Sweep Interval	0.5 s
Maximum Transmission Power	200 W (peak)
Range Resolution	1.5 km
Velocity Resolution	> 4.78cms^{-1} (2min measurement)
Antenna Type	1 transmission and 8 receive antennas of 3-elemnt Yagi
Beamforming Method	Multi-beam DBF in broadside array
Beam Width	12º (3dB beam width)
Bearing Resolution	±45º in steps of 7.5º

Backscatter Range-Doppler Spectrum (MN)

11-March-2011 18:15 JST

Sampling time ≈8.5min (1024 samples)



Internal noise emitting from the inside of the radar

Doppler Spectra ➔ Radial Velocity

Ordinary observation mode: turned on every hour for 15min.

➔Integration time: 8.5min (1024data samples)

➔ Just before 5PM on March 11: Continuous Mode

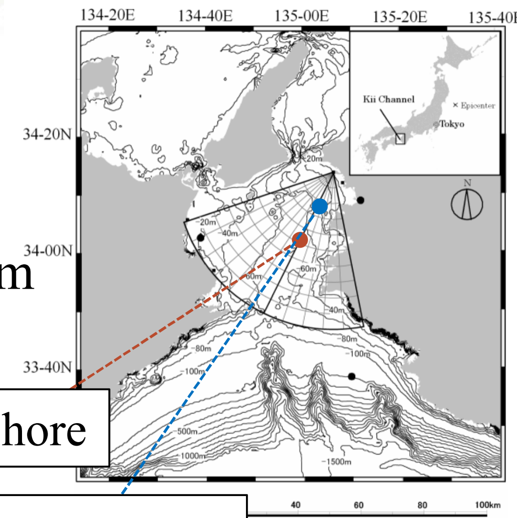
➔Range-Doppler Spectra: 256 data samples

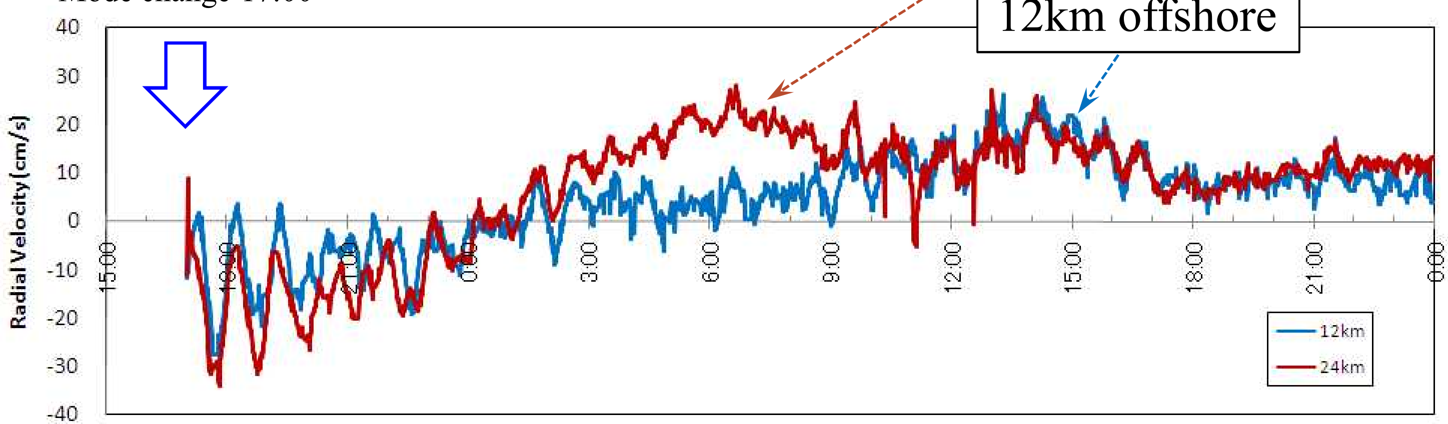
➔ Integration time: 128s with an overlap of 50 %

➔ Doppler frequency of 1st order Bragg peak: KKC algorism

➔ Radial Velocity @ 1min interval

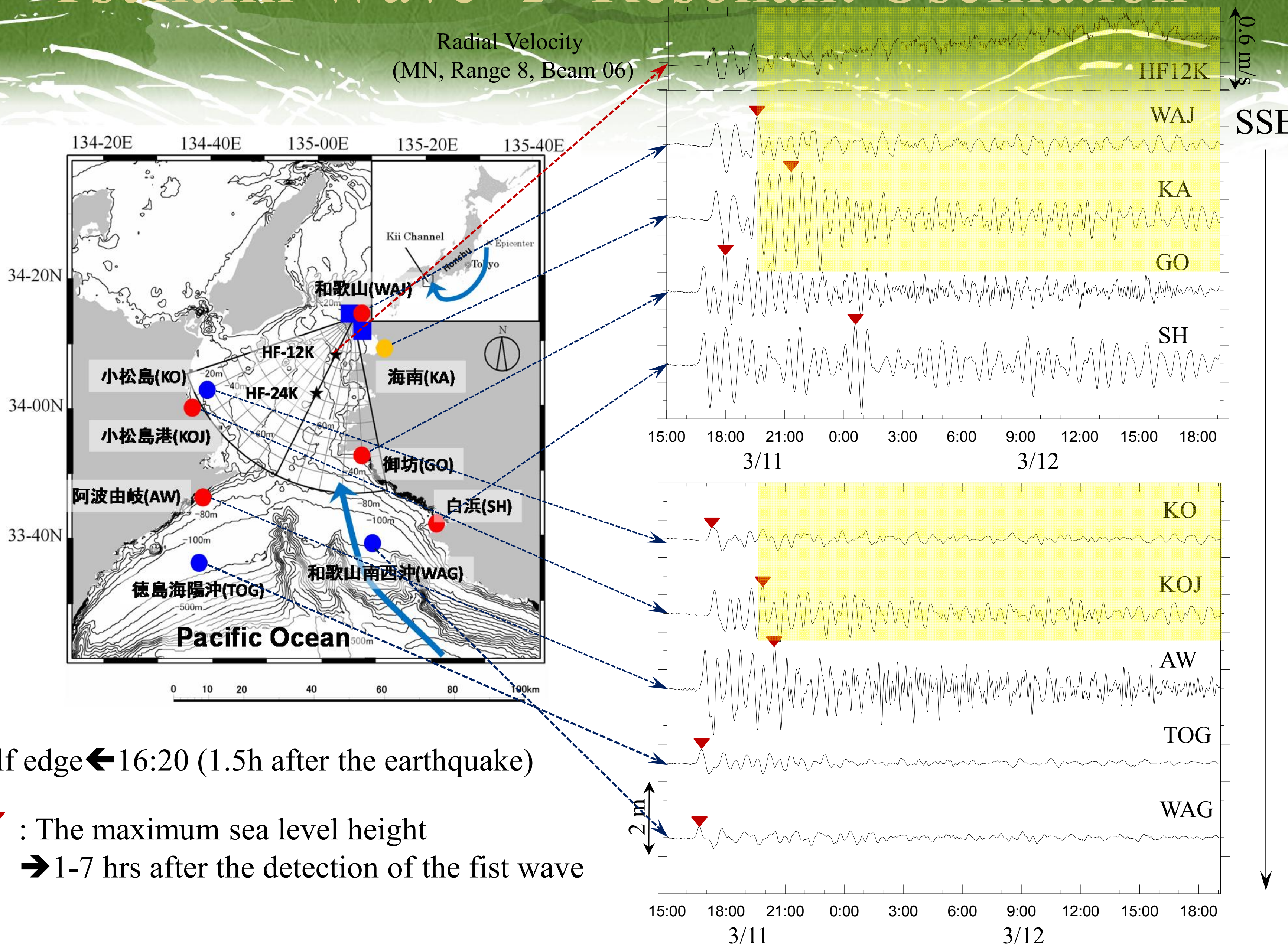
1st tsunami wave coming into the channel





5pm-10pm
2 radars

Tsunami Wave ➔ Resonant Oscillation



Shelf edge ← 16:20 (1.5h after the earthquake)

▼ : The maximum sea level height
➔ 1-7 hrs after the detection of the fist wave

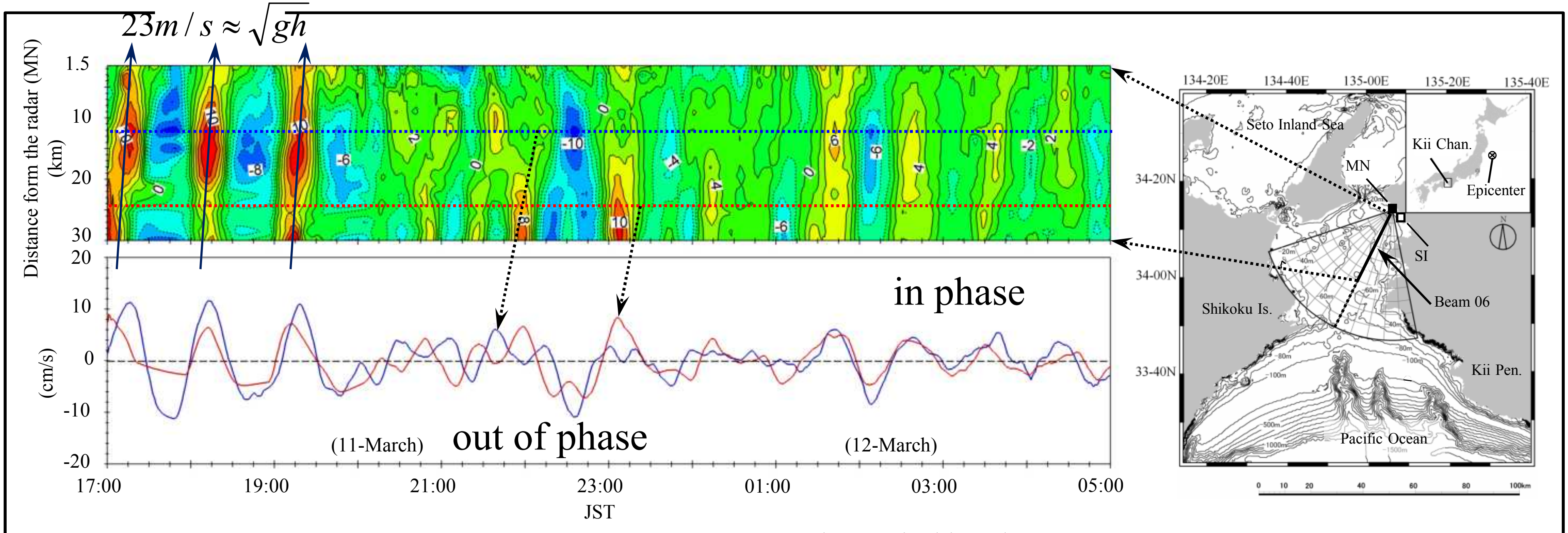
Tsunami Wave ➔ Resonant Oscillation

RO: higher mode (T≈30min) ?

The resonant oscillation gradually developed
➔Phase relationship changed to become out of phase
➔Phase eventually came to in phase

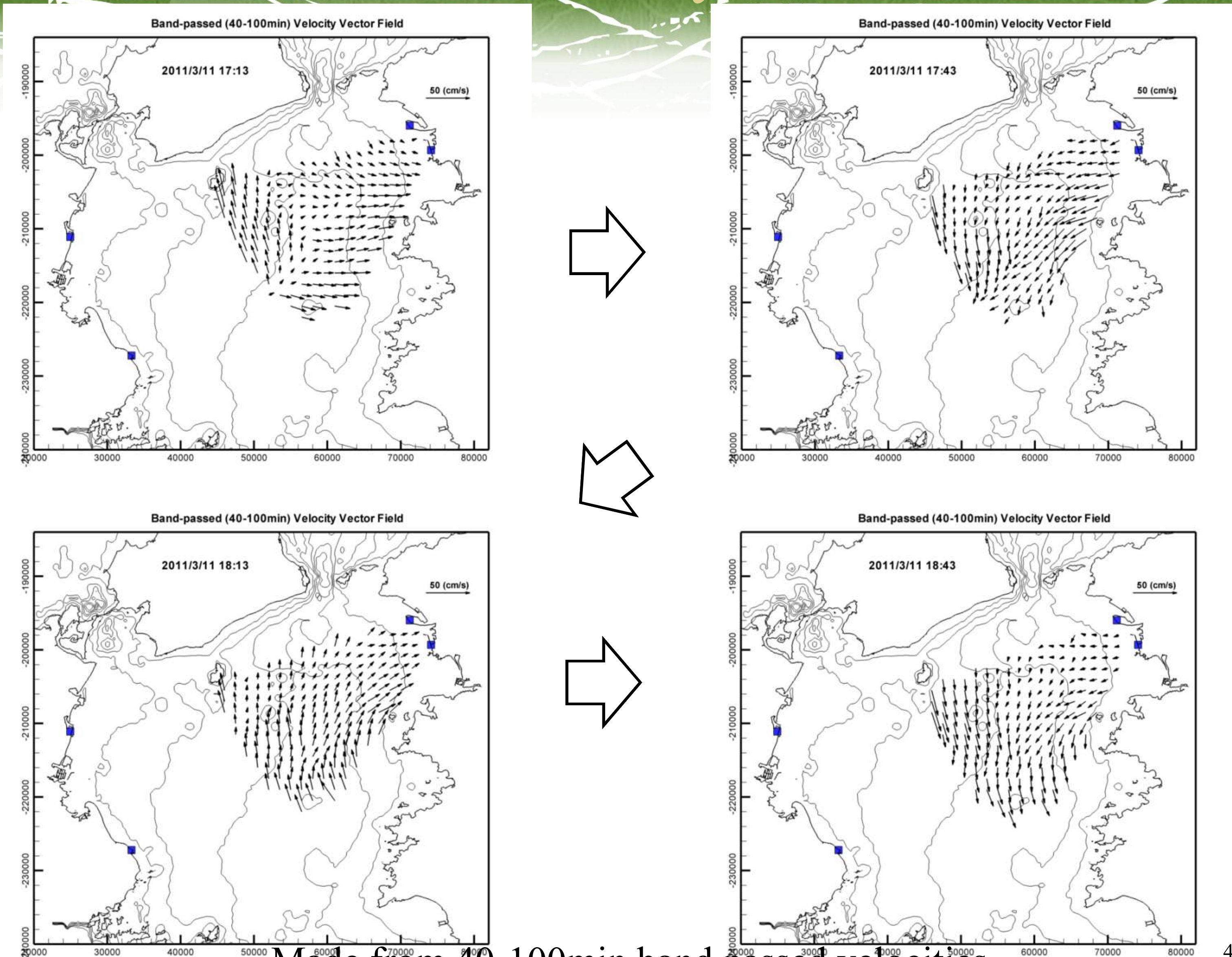
Propagating Wave
T≈60-70 min.

RO: Lower Mode (T≈60min)?



9-200 min. period band comp.

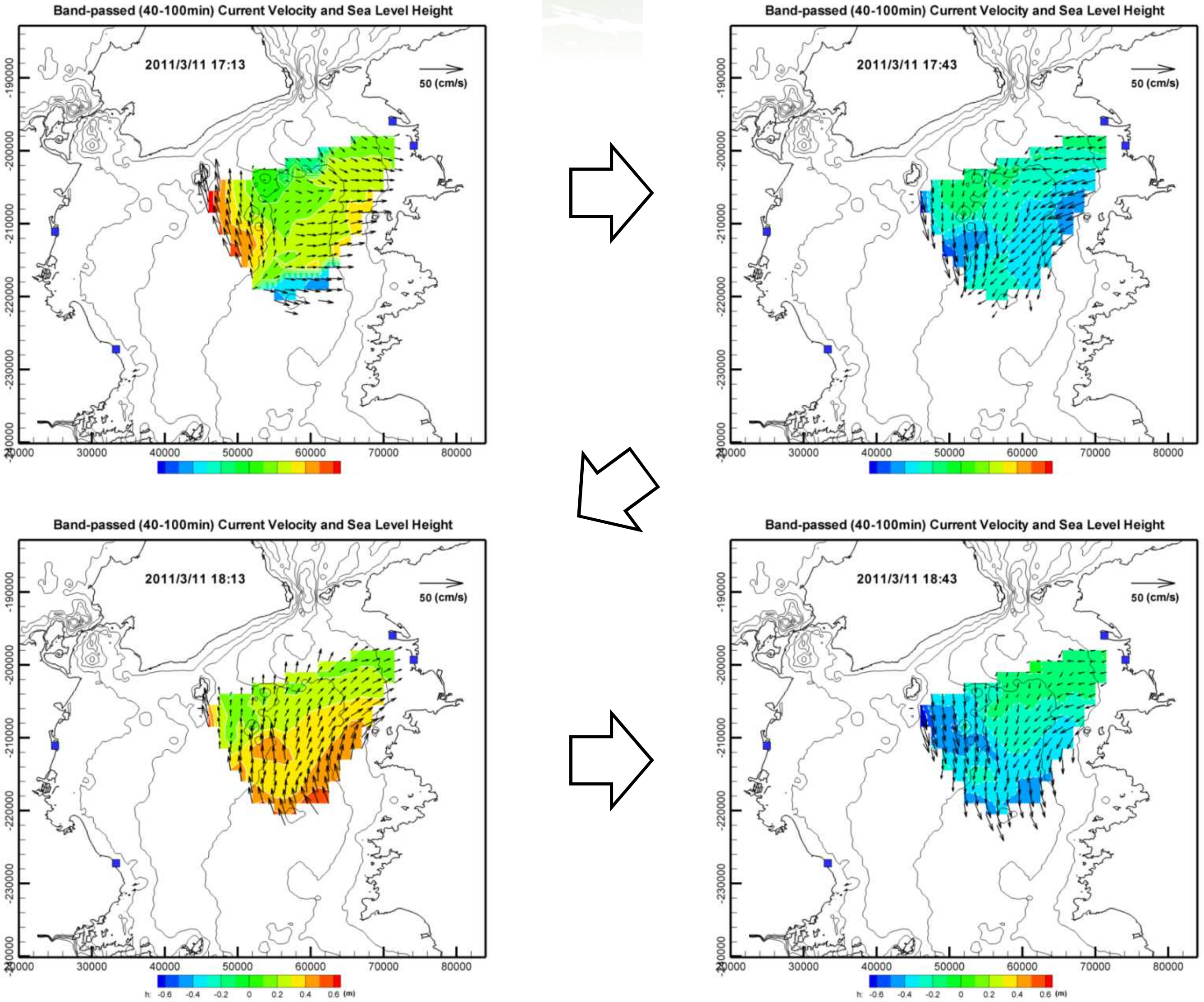
Propagating Tsunami Wave-Induced Velocity Filed



Made from 40-100min band passed velocities.

40_100min_1700_2000.avi

SSE from Radar-Derived Surface Currents



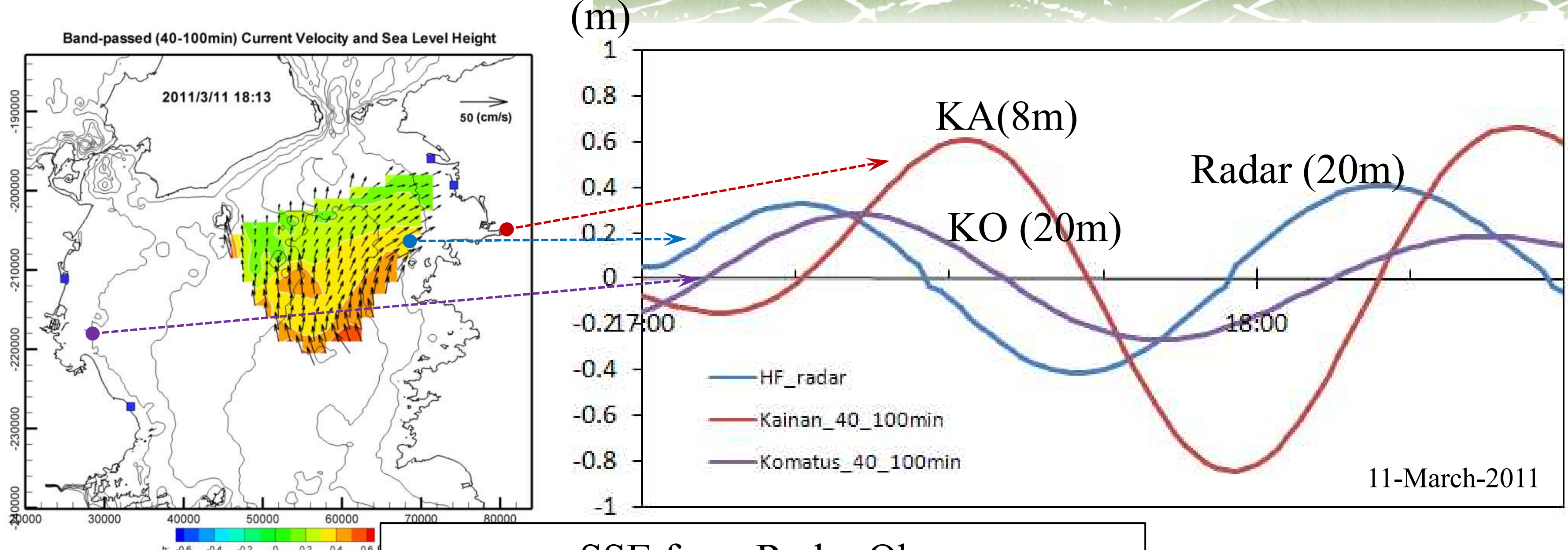
Linear Long Wave Theory

$$u = \frac{C}{h}\eta$$

$$= \sqrt{\frac{g}{h}}\eta$$

40_100min_vec_hgt2.avi

SSE from Radar-Derived Surface Currents



<u>SSE from Radar Obs.</u>

(1) Amplitude: One half KA; Same KM

(2) Phase: Preceding KH by 15 min

↔ Long-wave traveling time ≈ 12-14min

→ Reasonable

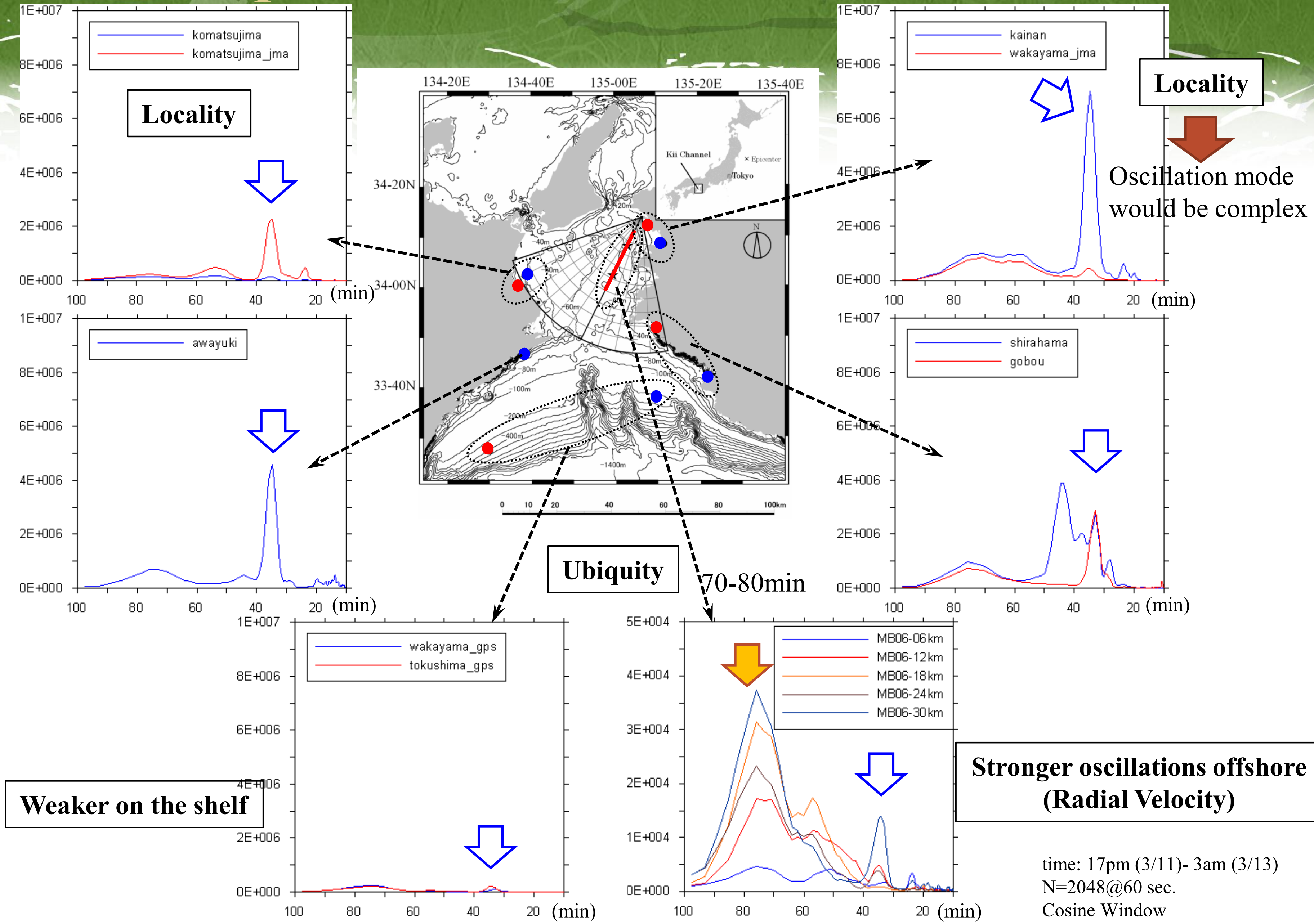
↕

Calculation of Wave direction

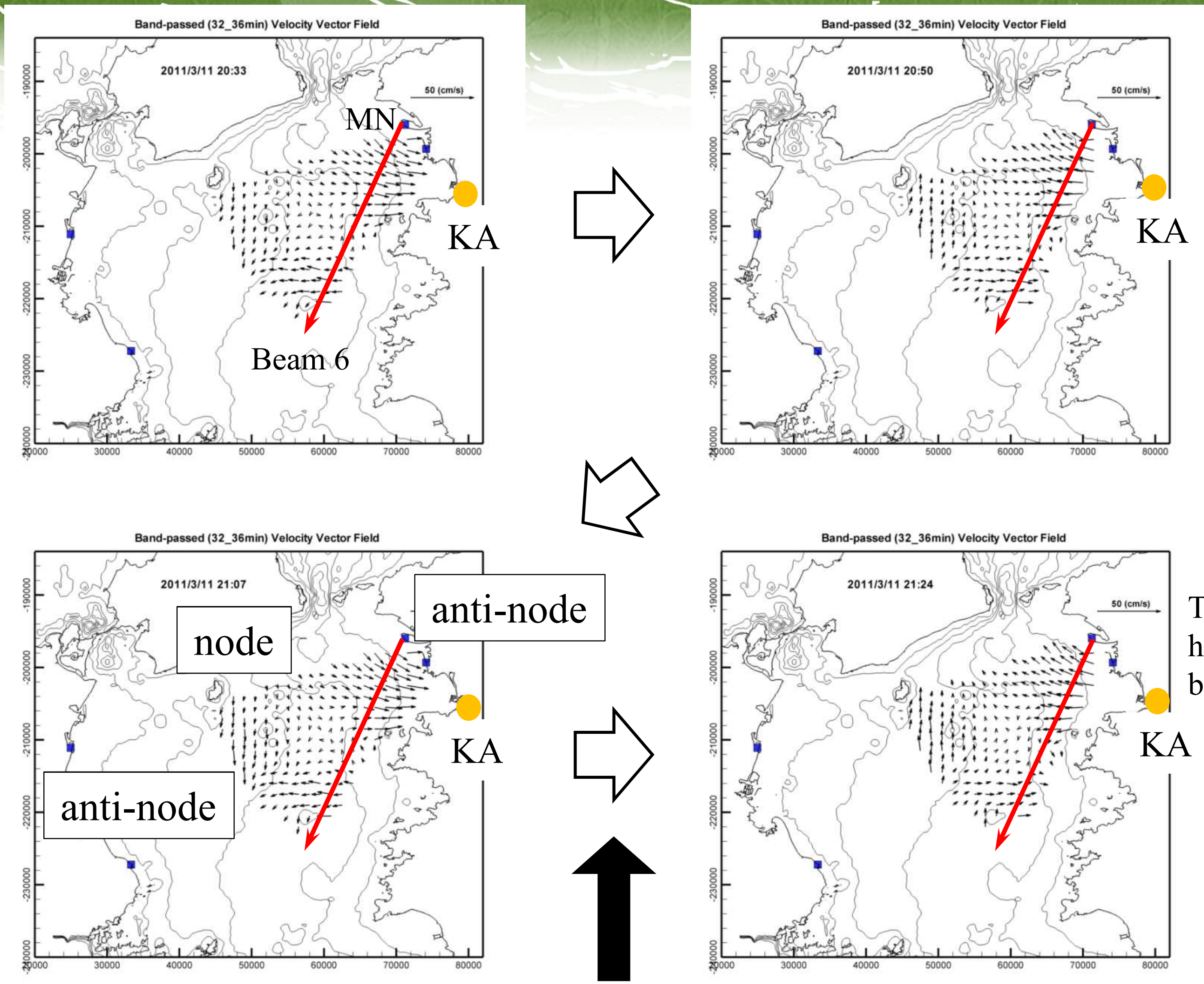
➔ $\eta < 0$? $\eta > 0$?

→ Disadvantage

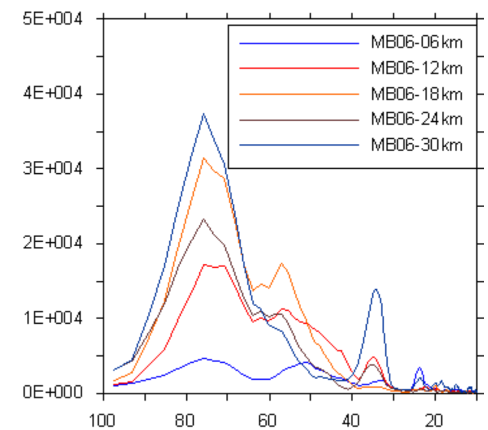
Spectral Characteristics of RO



RO (30-40min)-induced Velocity Field



KA: Maximum Wave Height (130cm) at 21:19



The radial velocities offshore have much power in the 30-40min band

32_36min_03111800_2.avi

Eigenmodes from Radar Obs. and Linear Long Wave Theory

The mode pattern was found to be complex.
+
Beam angle : 10-20 deg. in the offshore region

Liner Long-Wave Eq. ➔ Eigenvalue Problem

$$\begin{cases} \dfrac{\partial^2 \phi}{\partial^2 t} = g\nabla \cdot (h\nabla \phi), \\ \phi = \phi_1(x,y)e^{i\omega t}\ (velocity\ \ potential\,) \end{cases} \Rightarrow \nabla \cdot (h\nabla \phi_1) = -\frac{\omega^2}{g}\phi_1$$

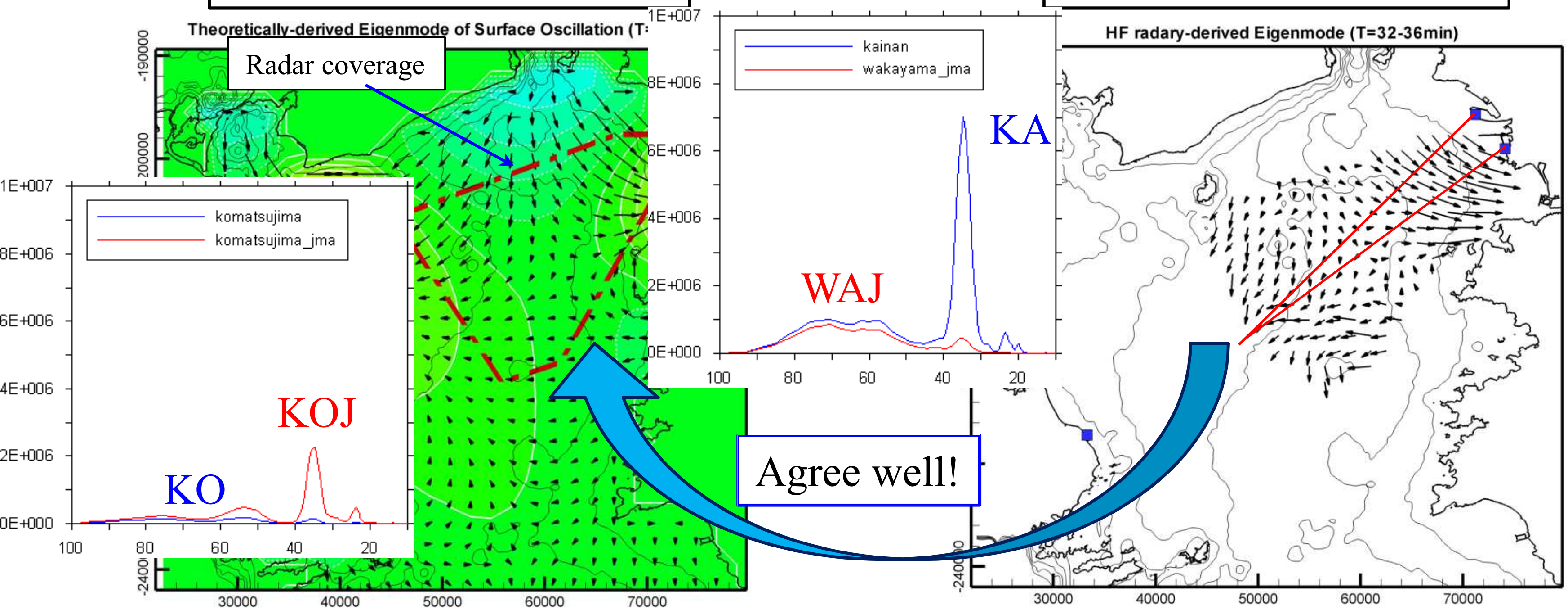
(Loomis, 1973, 1975)

⇓ Finite difference method

Observed oscillation pattern is physically possible?

Numerically-derived Eigenmode (T=33.5 min.)

EOE1 mode from the observed 30-40 min. band comp.



The number of the mode you get from the method equals the number of the grid point.

Future Works
Based on the Kii Channel Observation

We have observed surface current fields of tsunami wave and resonant oscillation by oceanographic radars.

If we can produce these velocity maps in (quasi-) real-time, we can use of these maps for tsunami disaster mitigation.

① We can apply propagating Tsunami Wave Maps for

➔ Tsunami Warning System

➔ Tsunami Waveform Inversion (Fuji et al., Preparing)

➔ Detection of Seriously Damaged Area within a few hours (at least 24h).

② We can apply resonant Oscillation Maps for

➔ Cancellation of Tsunami Warning

➔ Meteotsunami Warning and Its' Cancellation

We have frequently meteotsunamis in the coastal regions.
The damages are not severe compared to those caused by earthquake-induced tsunamis.
These happen frequently

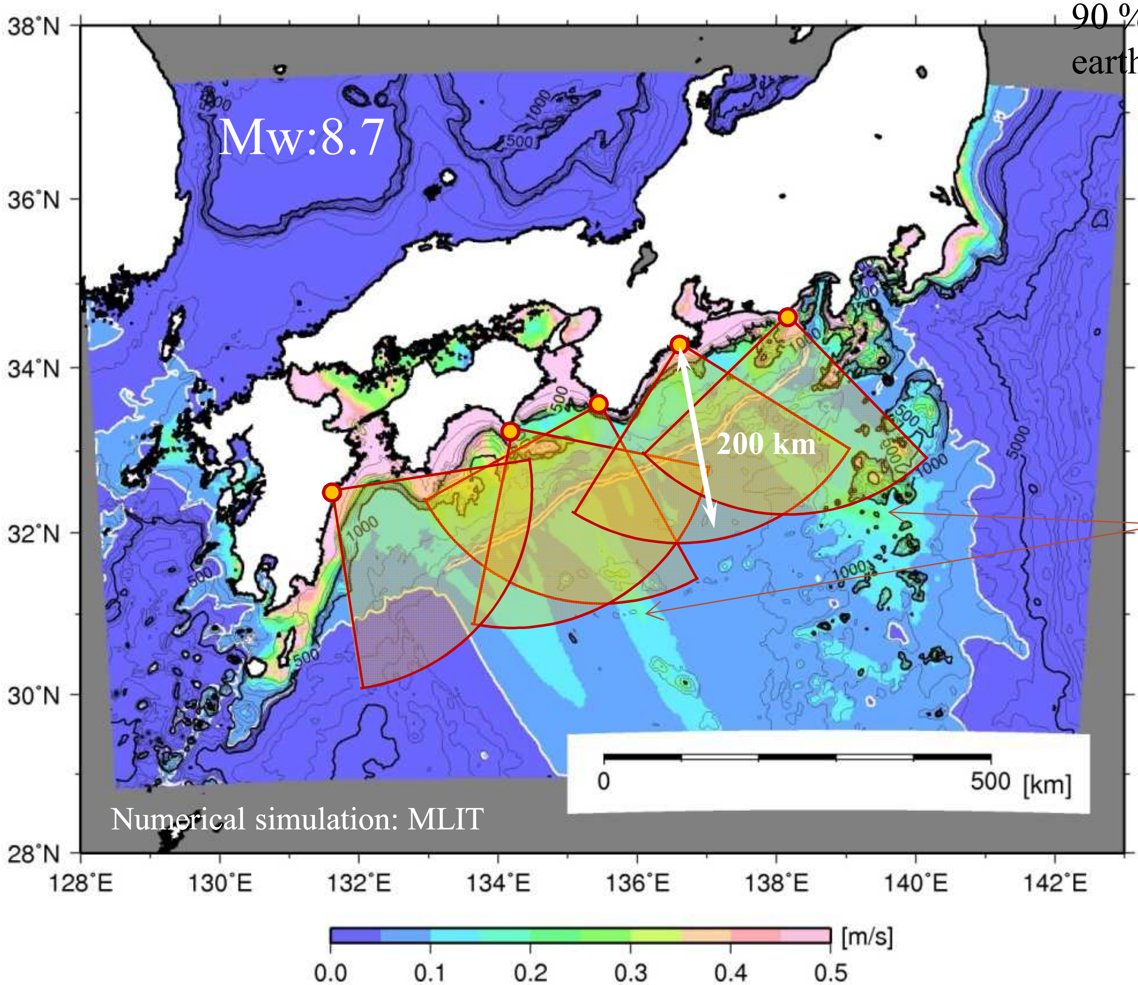
To realize real-time velocity map production, S/N improving is required.

Candidates ➔ Increasing Transmit Power, Enlarging Aperture Size, Using FMCW Type Radar,..

Also, we are estimating Required Radar Specification for Tsunami Detection and Inversion Based on Numerical Simulations.

Tsunami Detection Potential of Radars
A Case of Huge Tsunami Hitting South Coast of Japan

Maximum velocity distribution



The south coast of Japan main island has a 90 % chance of having a 7-8 magnitude earthquake or lager within 50 years.

Expected Sea Level Height: ~ 15m

Strong currents (>10cm/s) are expected and would be detected by high-spec long range radars

If we can simulate range-Doppler spectra for various tsunami scenarios,
we can provide warning times for coastal regions against these scenarios.