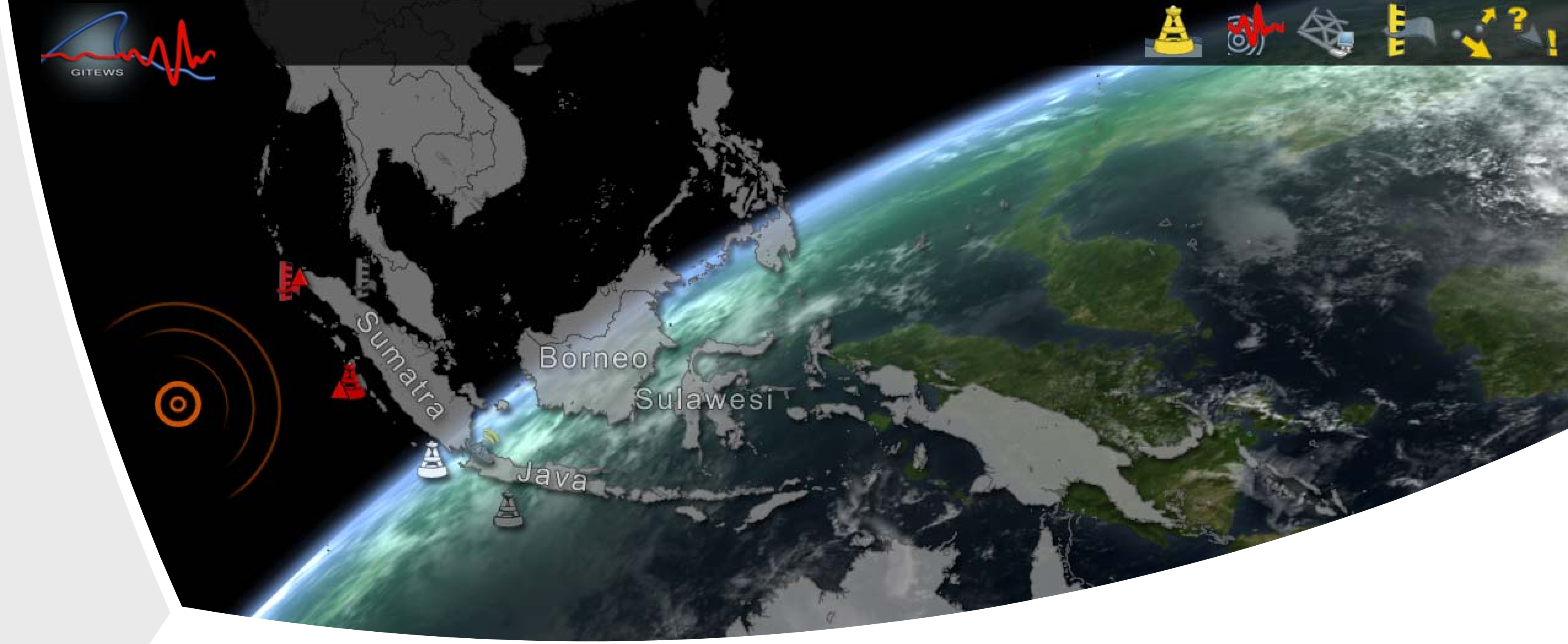


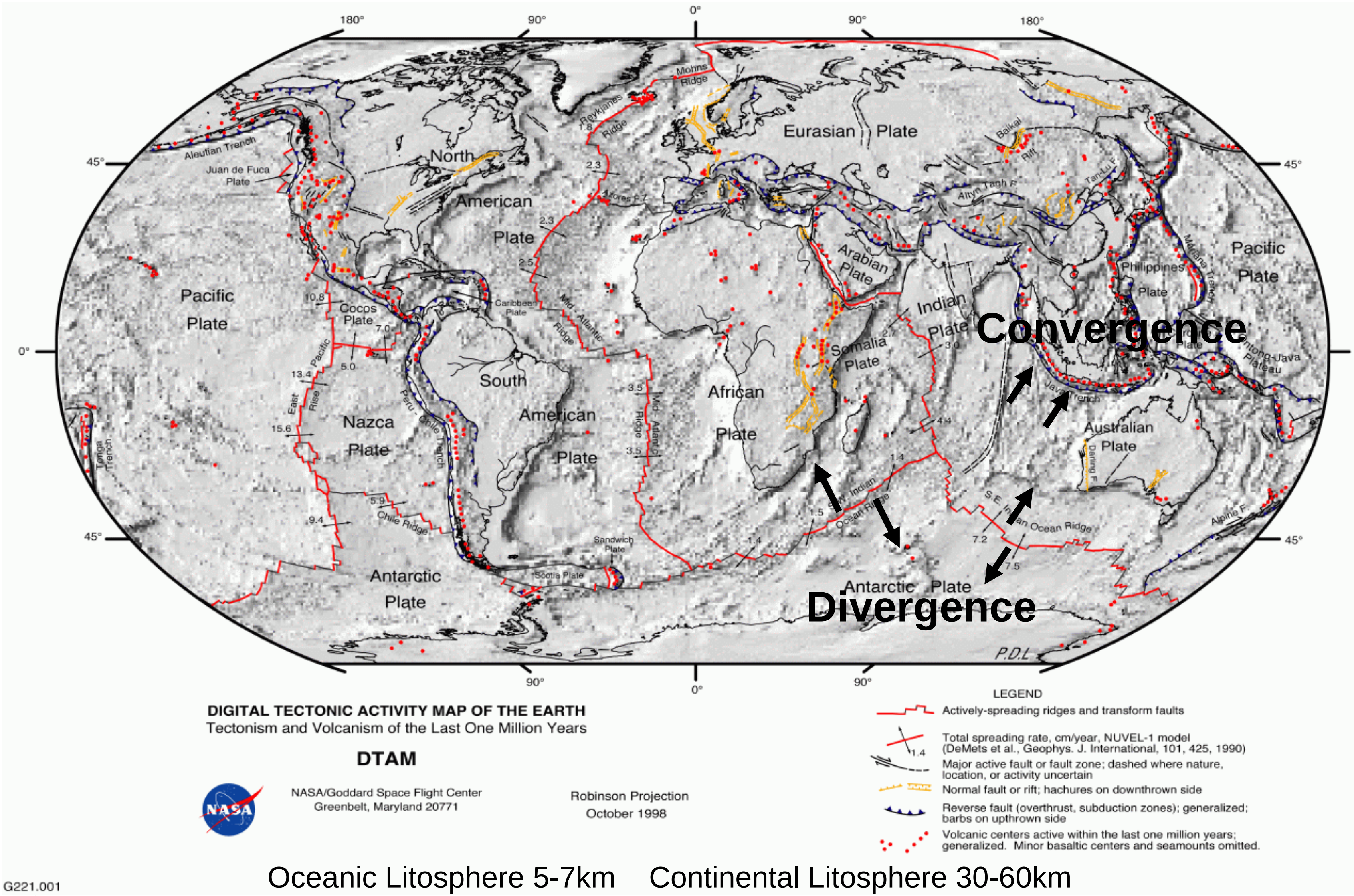
GITEWS

WP 4430 Ground Based HF-Radar System

Dr. Nicolas Marquart
Microwave and Radar Institute (HR)
German Aerospace Center (DLR)

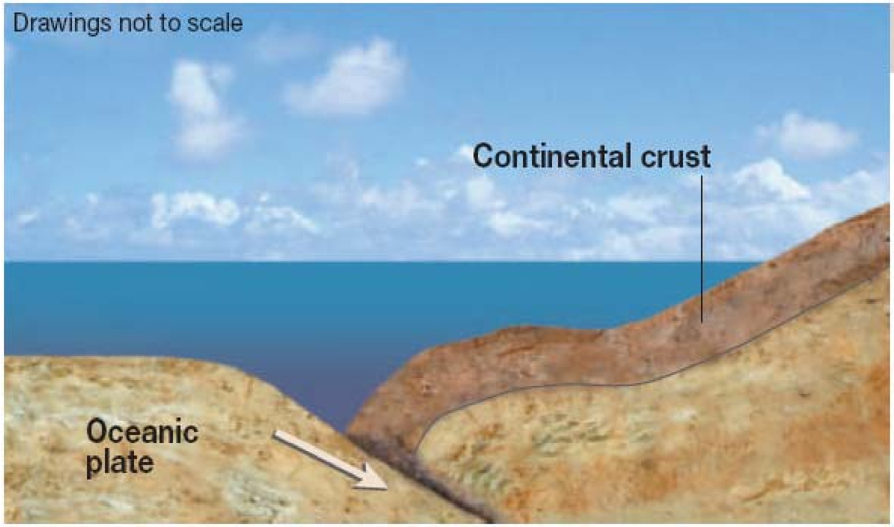
- **Introduction**
  - **Background – HF Radar Observables - Motivation**
- **Surface Model**
  - **Ocean Wave Spectra (2D)**
  - **Calculation-PO-Bragg Lines-Doppler Shift**
  - **Principle of HF Surface Waves**
- **Numerical Results**
  - **Tsunami induced currents: V_c=18cm/s and 5.1cm**
- **Commercial Ground Based System**
  - **Ocean Remote Sensing System WERA-Configuration**
- **HF-OTHR Radar**
- **Conclusions**

Tectonic Activity



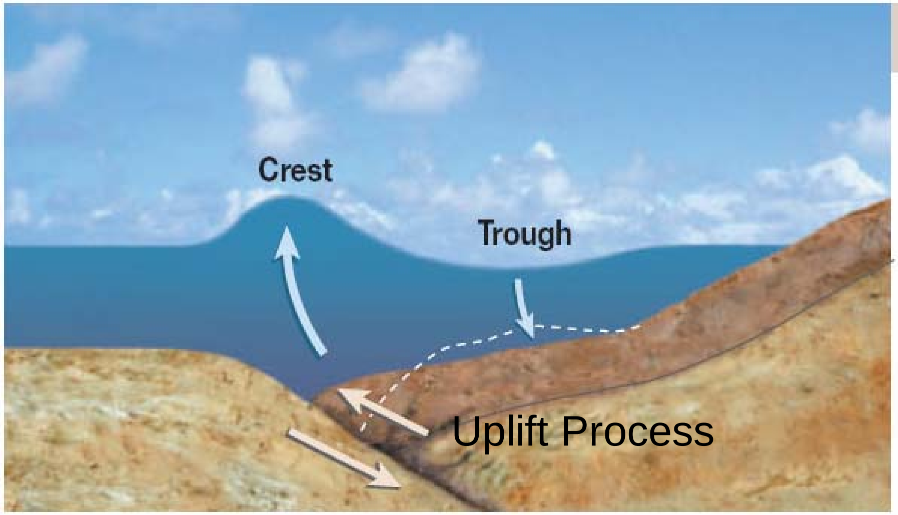
Oceanic Litosphere 5-7km   Continental Litosphere 30-60km

Boxing Day 2004
(Sunda Trench)



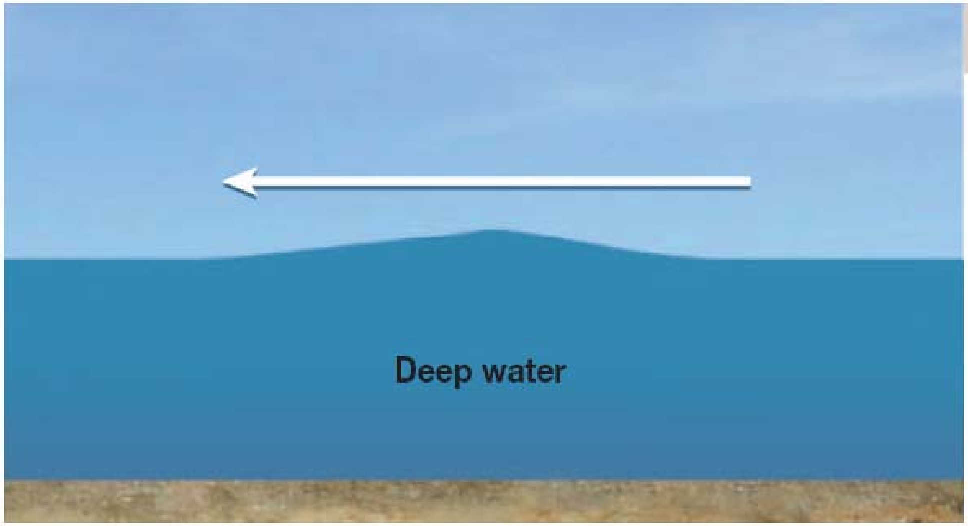
1 Before the earthquake

The plate holding the Indian Ocean was sliding under the continental plate (holding Indonesia and much of Asia) at about 6 cm per year. The continental crust was bent thanks to the constant pressure of collision.



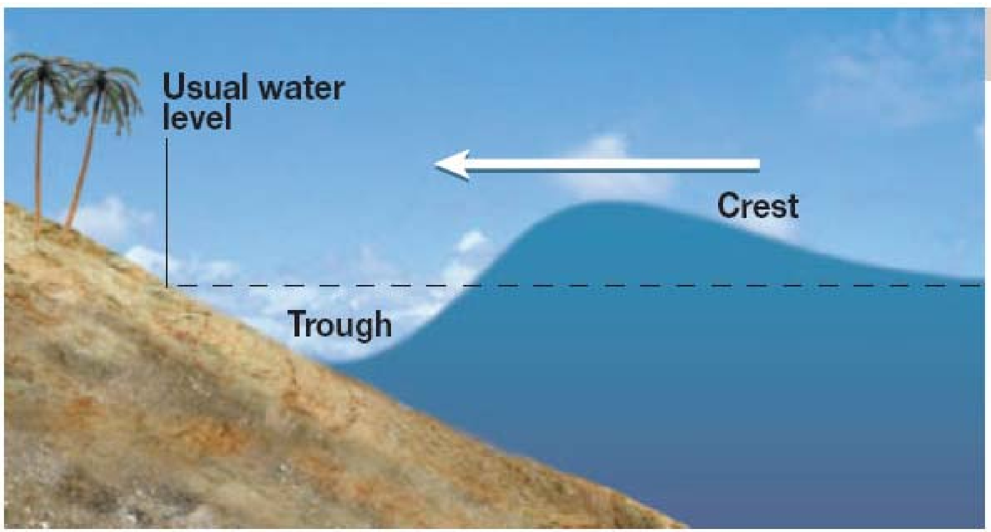
2 During the quake

The fault ruptured violently, allowing the continental crust to unbend and causing portions of the sea floor to move up or down by several metres. The water above the fault responded in kind, creating a wave crest and trough.



3 The wave travels

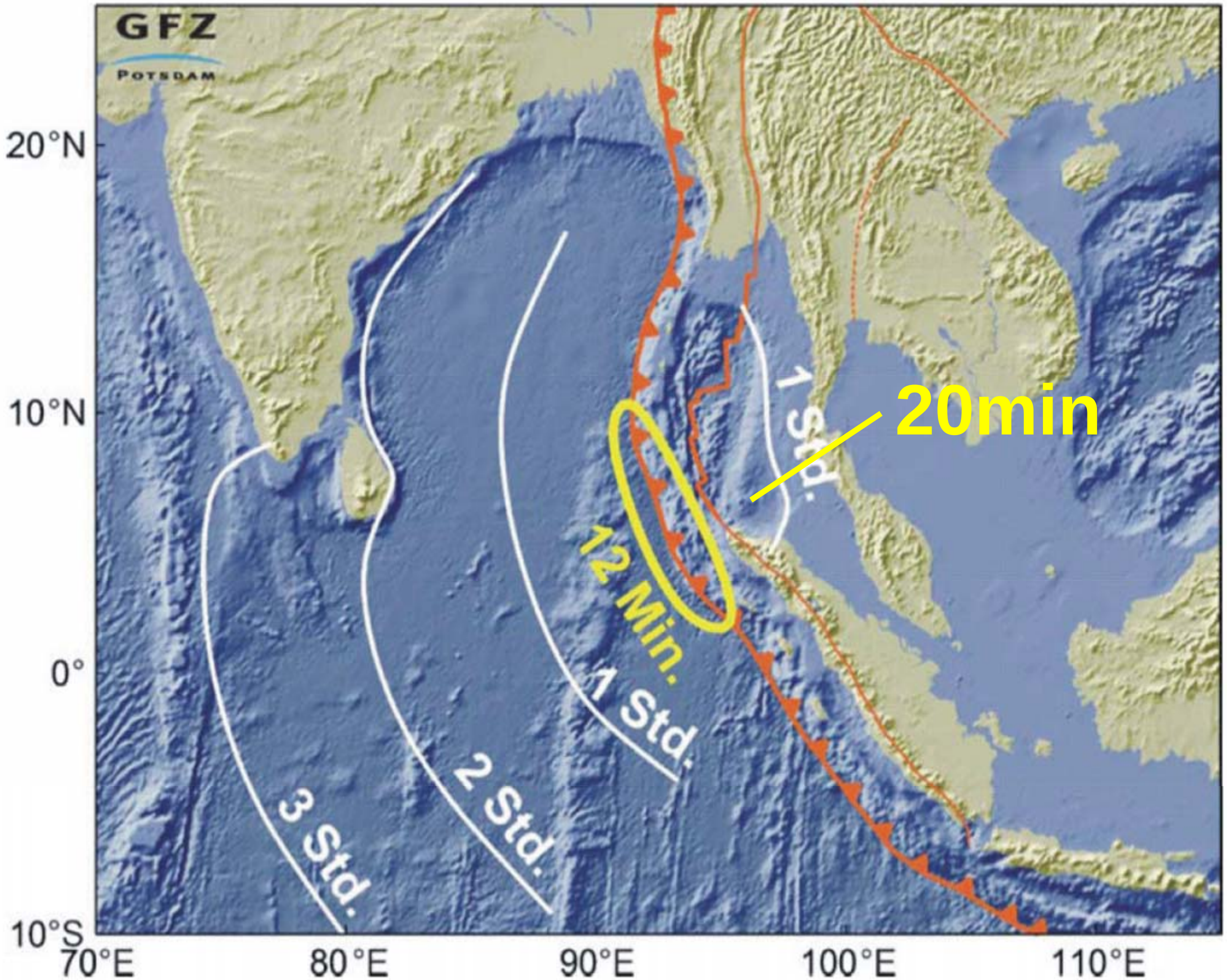
One wave crashed towards the nearby shore of Indonesia. Another barrelled westwards at about 800 km per hour in deep water, with a wavelength of 100 km and an average wave height of just tens of centimetres.



4 Collision

When the wave entered shallow waters, it slowed to tens of kilometres per hour, its wavelength shortened to about 5 km, and its height is thought to have soared to more than ten metres. The trough of the wave often hits before the crest (as shown).

Warning
(26.12.2004)



Causes for Tsunami

- Earth/Seequakes M >7 (90%)

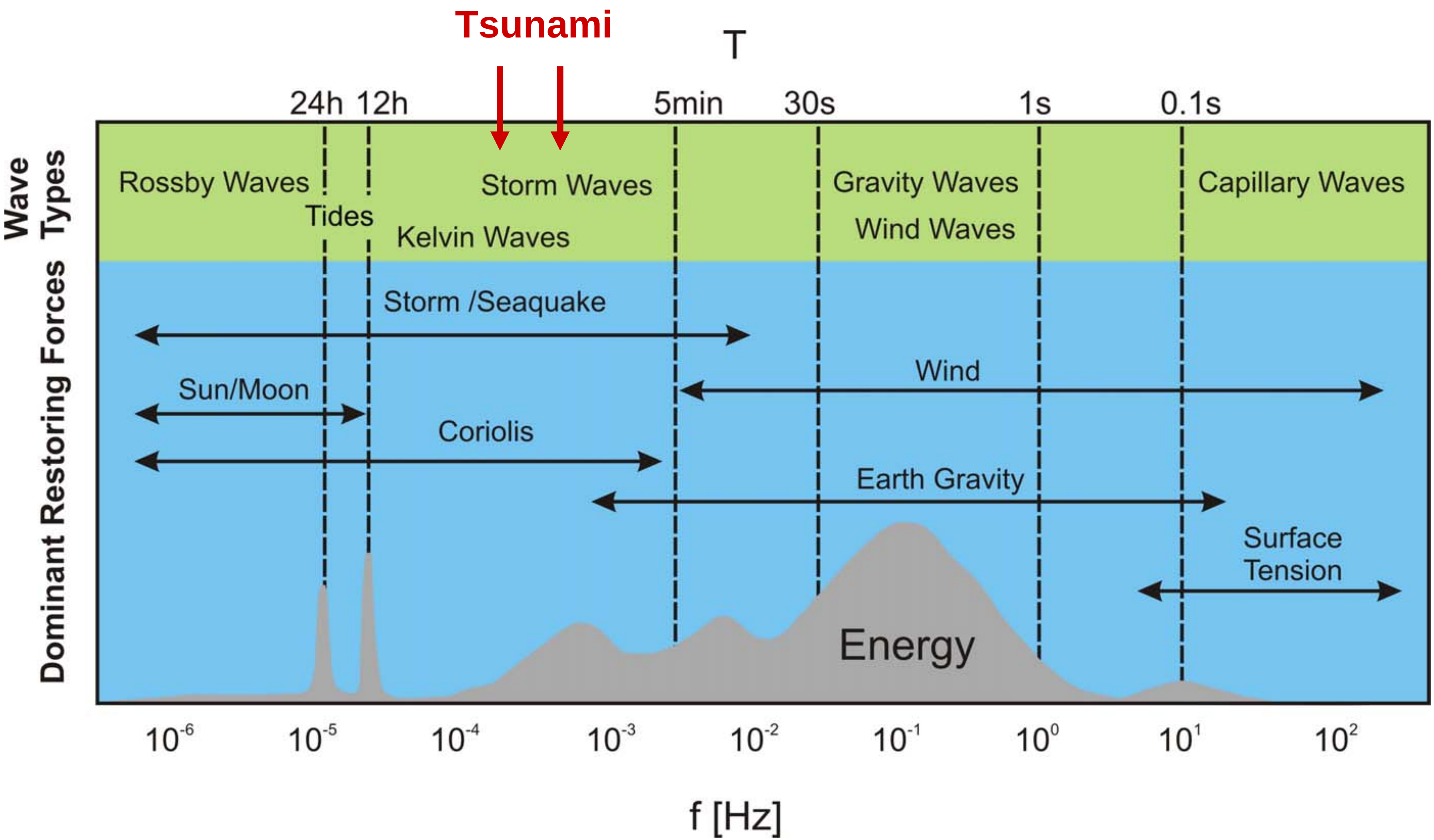
Date	Cause	Height (m)	Site	Deaths
12. December 1992	Earthquake	26	Indonesia	<1000
02. June 1994	Earthquake	14	Indonesia	238
26. December 2004	Earthquake	5	Indonesia	>230.000

- Vulcanic Eruption and/or Landslide

Date	Cause	Height (m)	Site	Deaths
27. August 1883	Krakatau Eruption	35	Indonesia	3600

- Meteorit Impact

Ocean Wave Types



Shallow water: Friction force!

Dispersion Relation

$$c_p = \pm\sqrt{\frac{2\pi g}{\lambda} \tanh\left(\frac{2\pi\lambda}{H}\right)}$$

J.R. Apel, *Principles of Ocean Physics*
Academic Press, 1987

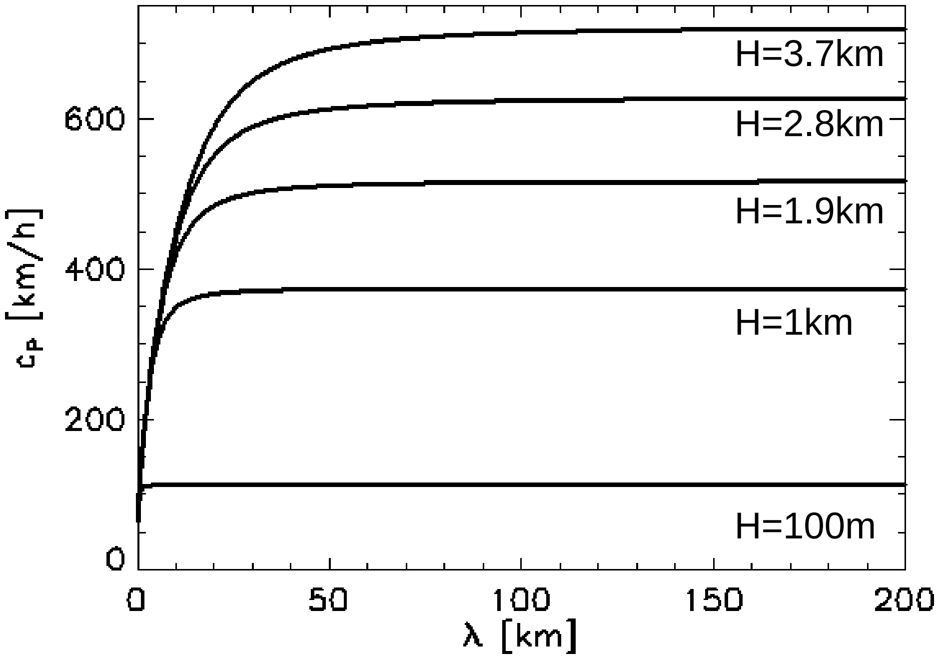
Case 1: Deep Water (H >>λ)

$$k_h H \gg 1 \rightarrow \tanh(k_h H) \approx 1$$

$$c_p = \pm\sqrt{\frac{g k_h}{2\pi}} = \pm 1.25\sqrt{\lambda}$$

Dispersion !

$$c_g = \frac{\partial\omega}{\partial k_h} = \frac{c_p}{2}$$

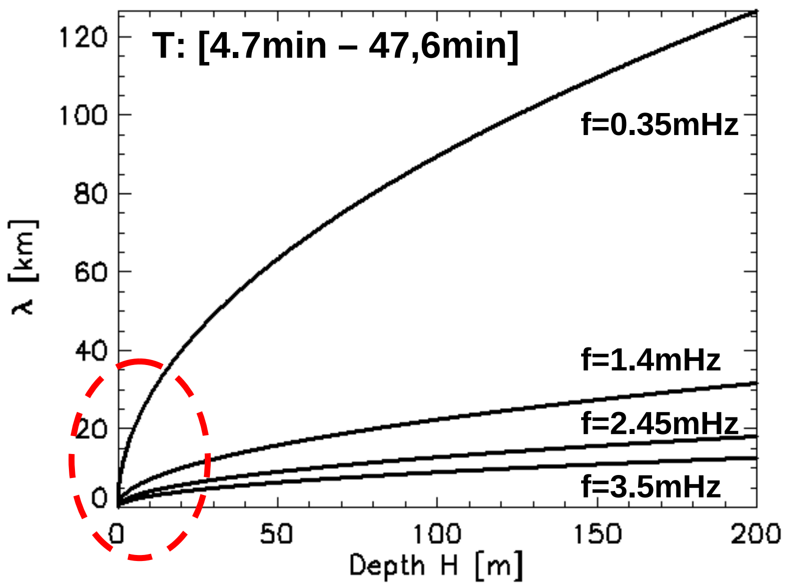


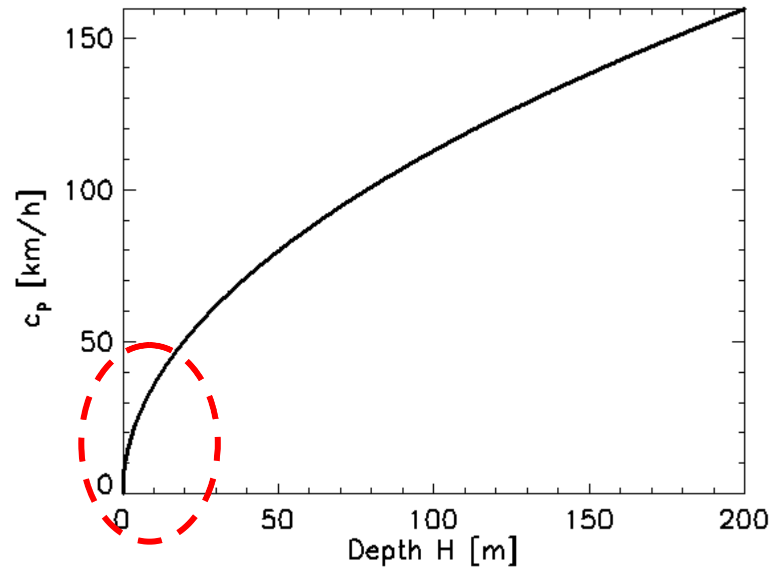
Case 2: Shallow Water (H << λ)

$$k_h\, H \ll 1 \rightarrow \tanh(k_h\, H) \approx k_h\, H$$

$$c_p \;=\; \pm\sqrt{g\,H} \rightarrow c_g$$

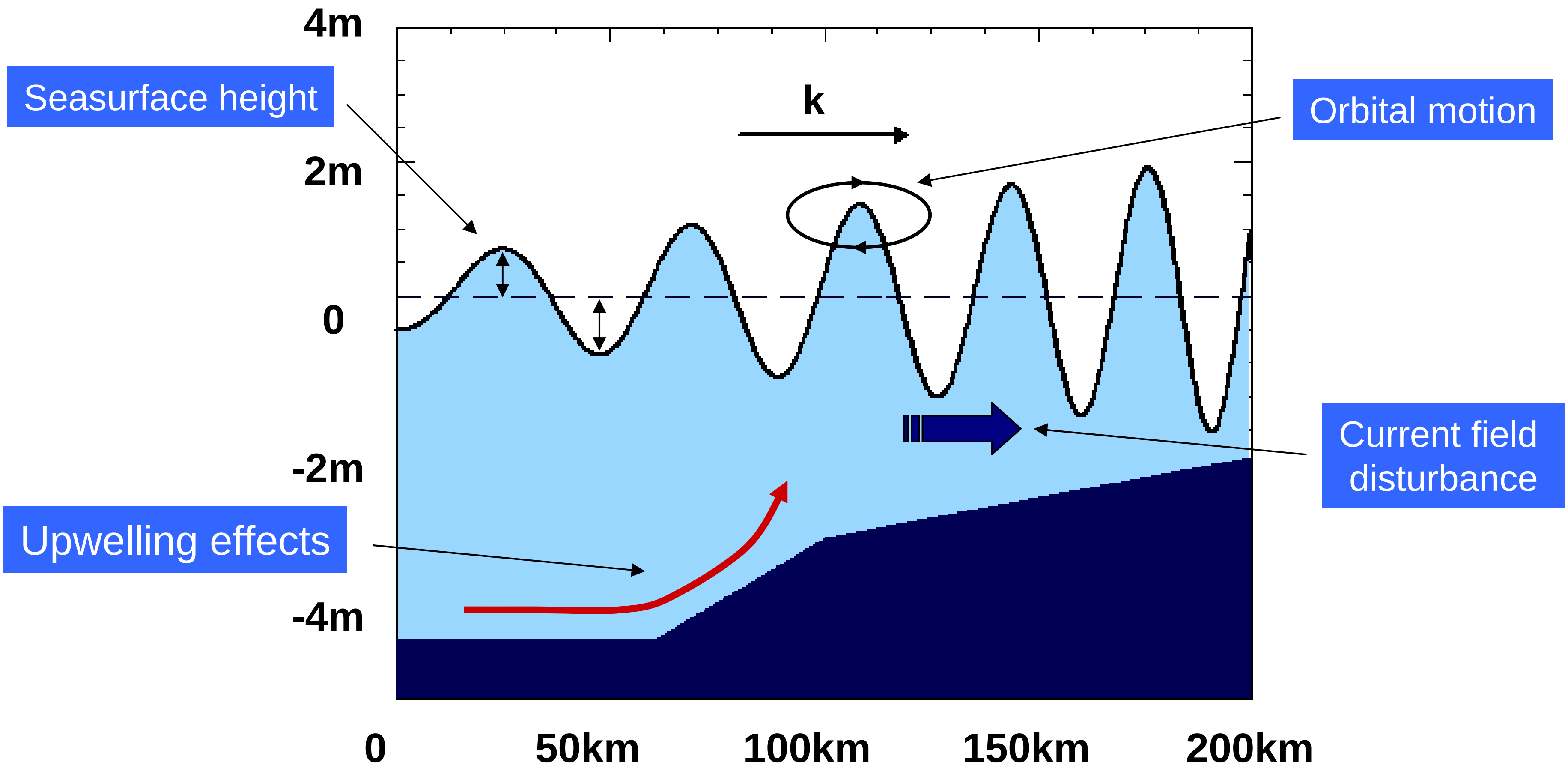
No Dispersion !



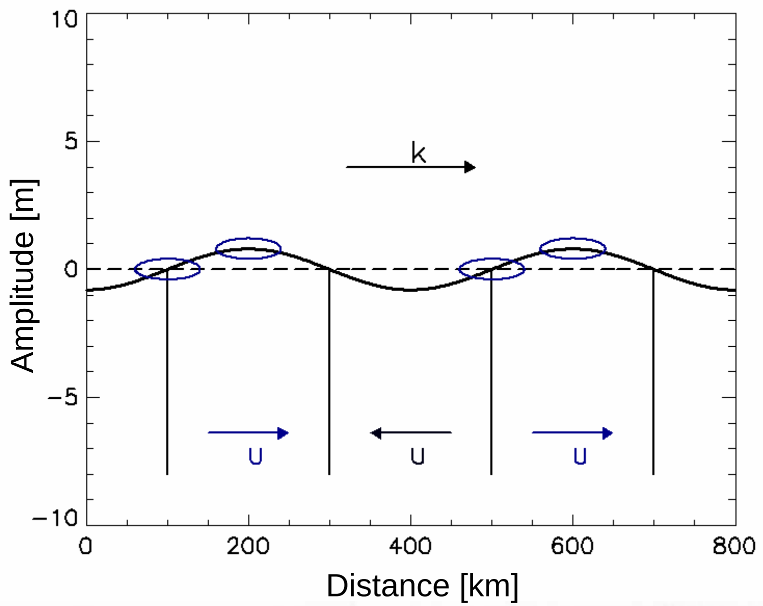


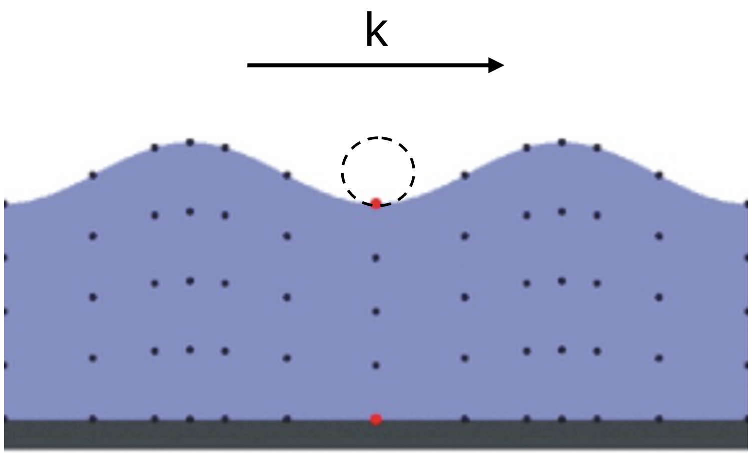
„Waterberg“ Phenomenon

Geophysical Observabels

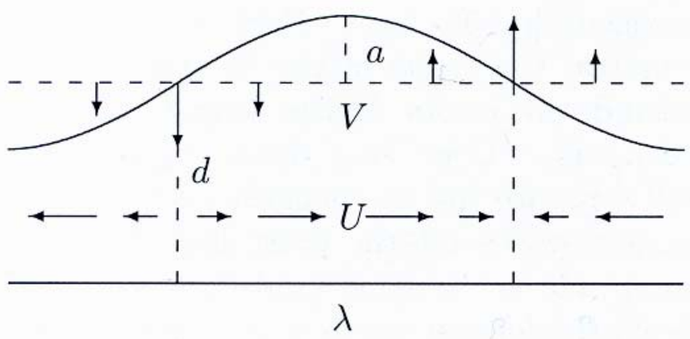


Tsunami Parameters





http://de.wikipedia.org/wiki/Tsunami



A: amplitude
d: water depth
U: horizontal velocity
V: vertical velocity
λ: wave length

Tsunami Scale

Benny Lautrup, *Tsunami Physics*
Kvant, Jan 2005

Deep Ocean	d=4000 m	λ=150 km	a=0.7 m	U=0.08 m/s
Coastal Area	d=40 m	λ=15 km	a=5 m	U=2.5 m/s

Tsunamis are more easily detectable in coastal areas

The spatial propagation of a tsunami is done in such a way that all the water particles of the water column undergo an elliptical orbital motion. The tsunami-induced horizontal water column motion and upwelling effects in the coastal area offshore Indonesia will give an additional horizontal water flow superimposed to the actual surface current field. The WP 4430 investigates the requirements of a possible ground based tsunami early warning radar system as required for a continuous observation over a large ocean area. Here, the observable interaction of a High Frequency field HF (3–30 MHz) with ocean waves is of particular interest.

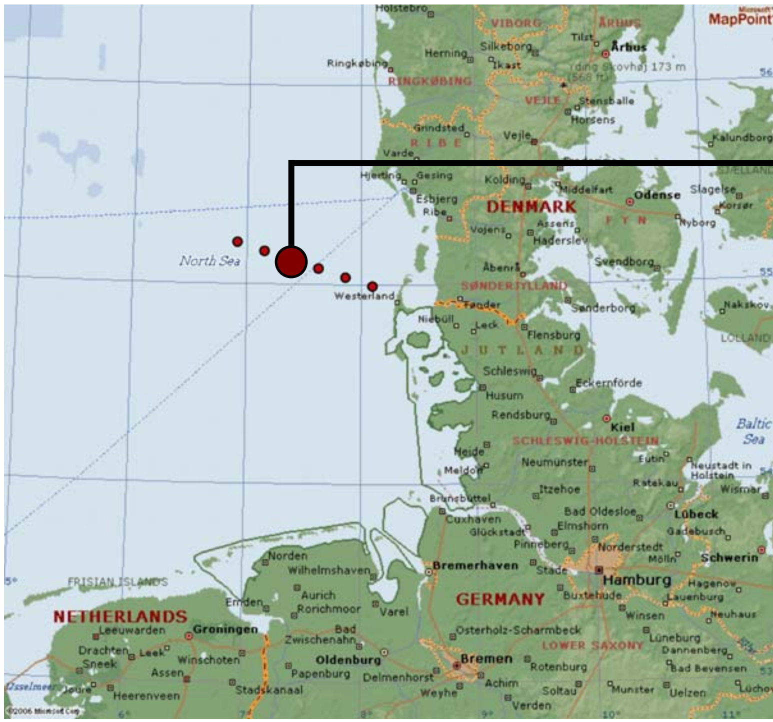
Can we seperate the current pertubations due to an approaching Tsunami from the effective surface current field?

Ocean Surface Model HF-Radar → **Scattered HF Field** → **Doppler Spectrum (V_B)**

Ocean Surface Model HF-Radar + Tsunami → **Scattered HF Field** → **Doppler Spectrum ($V_B + V_T$)**

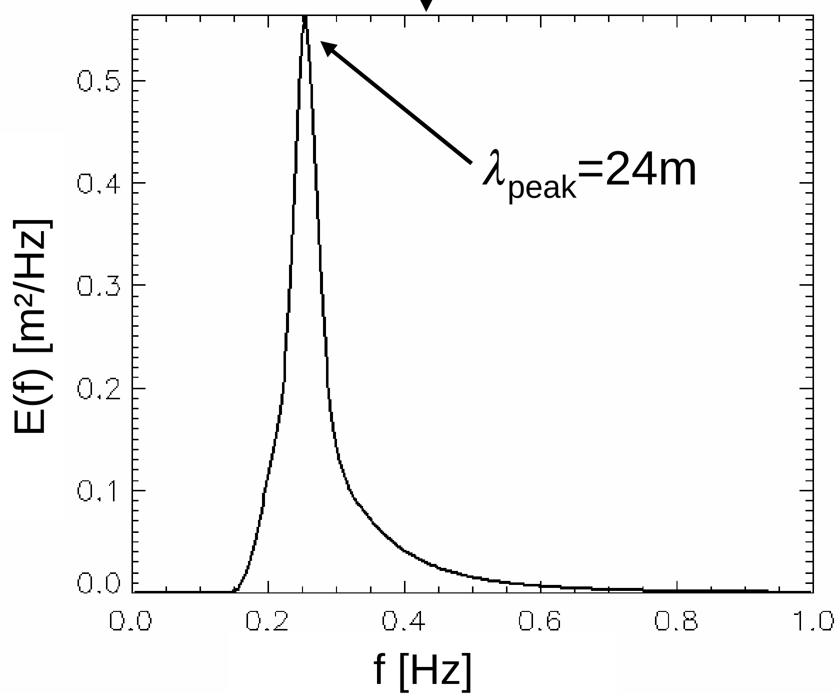
- Introduction
  - Background – HF Radar Observables - Motivation
- **Surface Model**
  - Ocean Wave Spectra (2D)
  - Calculation-PO-Bragg Lines-Doppler Shift
  - Principle of HF Surface Waves
- Numerical Results
  - Tsunami induced currents: V_c=18cm/s and 5.1cm
- Commercial Ground Based System
  - Ocean Remote Sensing System WERA-Configuration
- HF-OTHR Radar
- Conclusions

Joint North Sea Wave Project (1968-69) (JONSWAP)

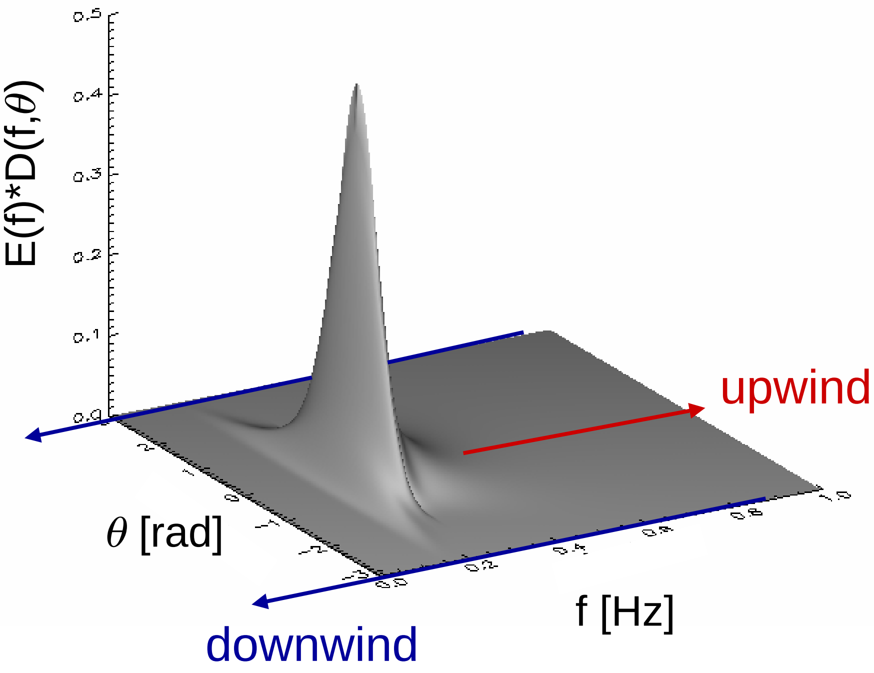


(K. Hasselmann et al)

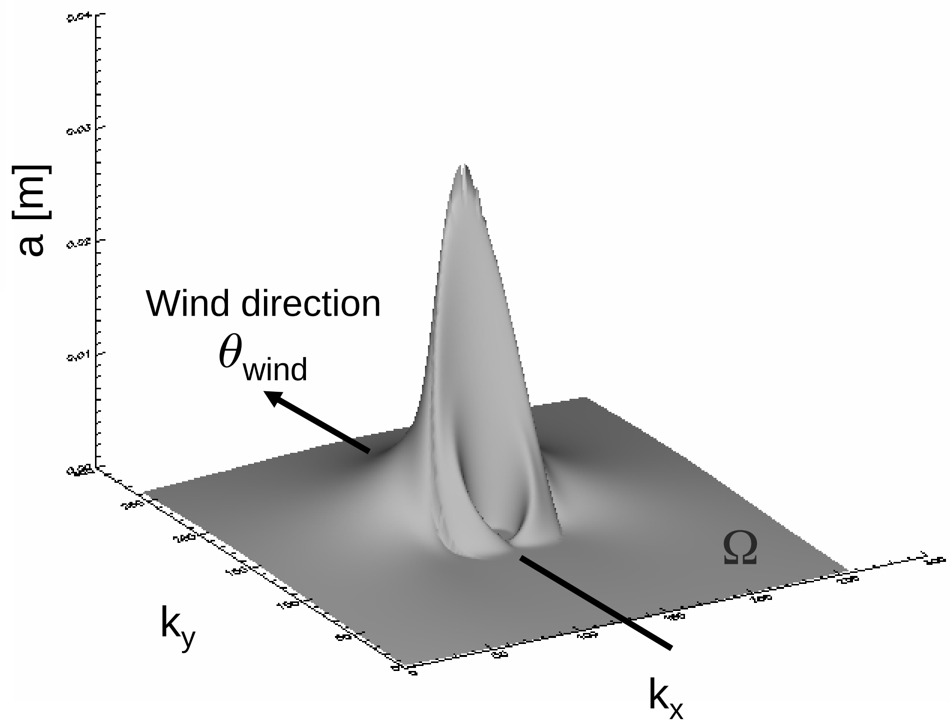
1D ocean surface spectrum for a single bouy at wind/wave equilibrium [U_{10}=5m/s]



Amplitude Distribution



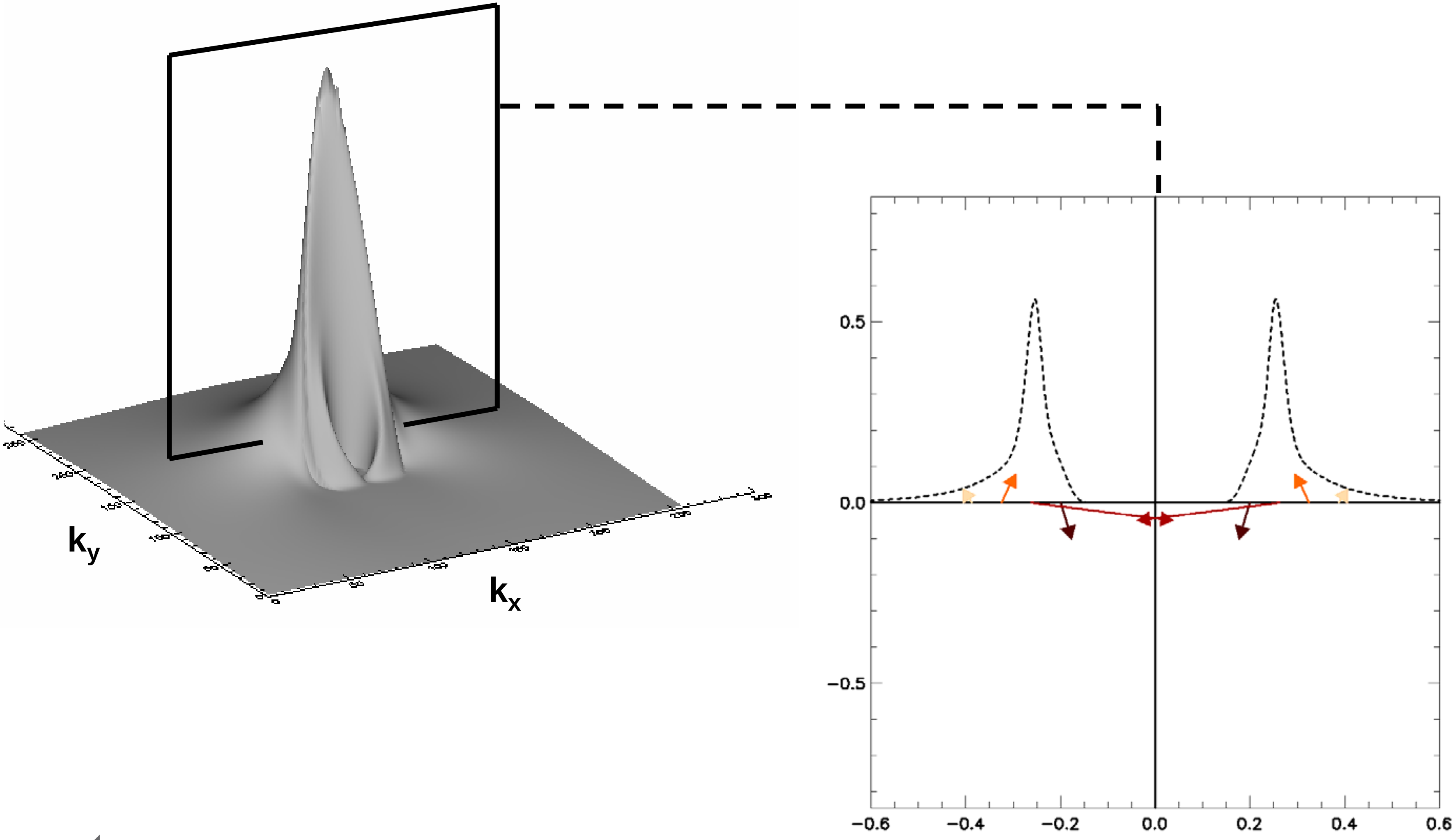
$$|\,a\,| = \sqrt{\frac{E(f)\,D(f,\theta)\,g}{k\,f} * \frac{\pi^2}{\Omega}}$$



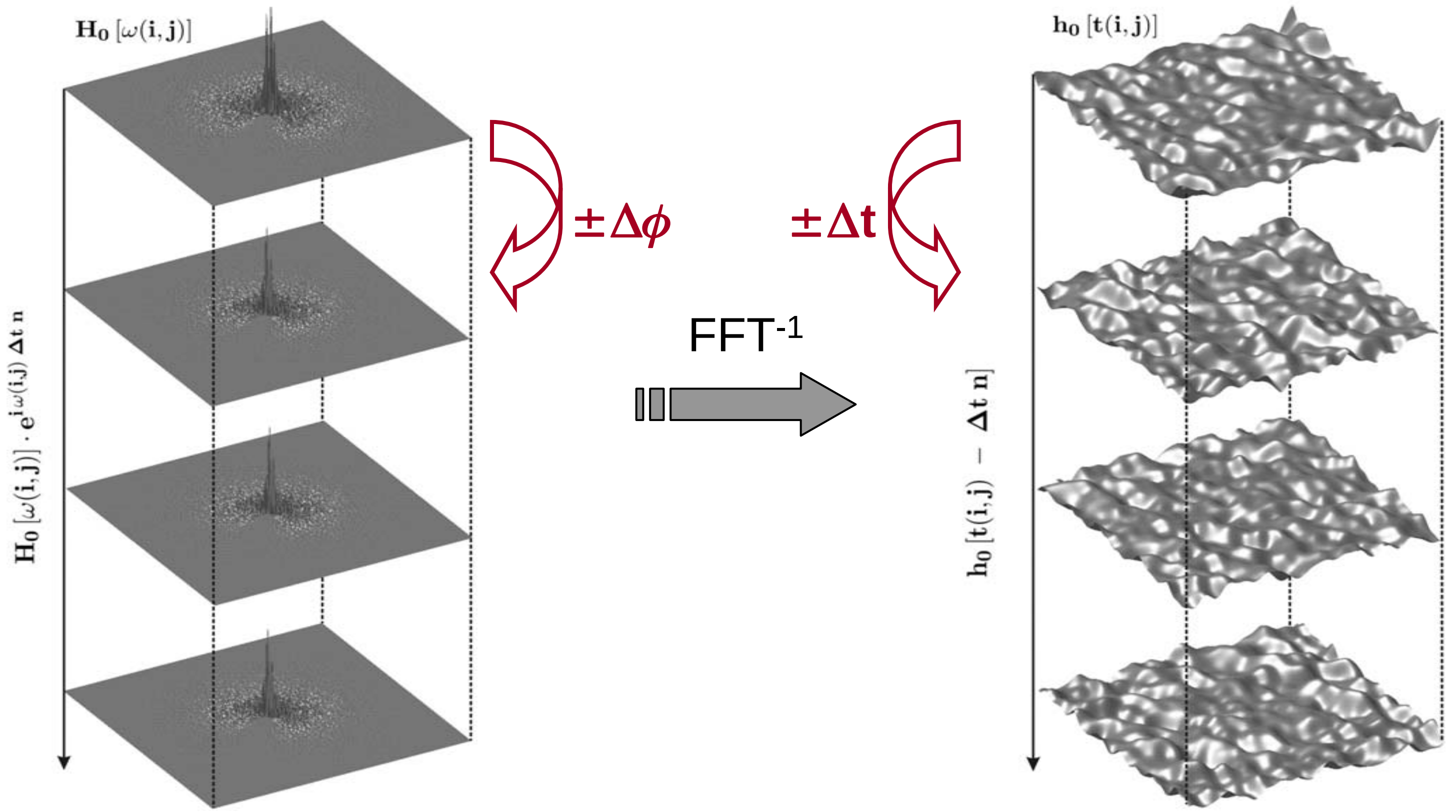
Wind direction dependence of the JONSWAP spectrum E(f) according to Mitsuyasu *D(f,θ)*

$\theta = \theta_{wind} - \theta_{k\text{-}wave}$

Spectrum Dispersion



$H(k_x,k_y,\omega_{i,j}) \Leftrightarrow h(x,y,t)$



Fourier Cube

Snapshots Cube

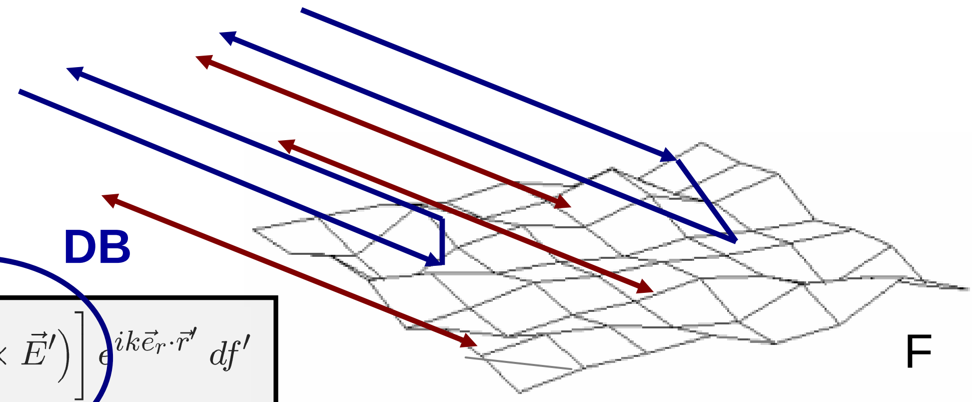
The temporal variation of the sea surface is calculated by a direct phase modulation in the wave number space instead of sequential computed time steps in the time domain.

EM-Scattering

$$\vec{E}_T(\vec{r}) = \vec{E}_S(\vec{r}) + \vec{E}_I(\vec{r})$$

PO **DB**

$$\vec{E}_S(\vec{r}) = \frac{i\omega\mu}{4\pi}\frac{e^{-ikr}}{r}\,\vec{e}_r\times\int_F\left[\vec{e}_r\times\left(\vec{n}'\times\vec{H}'\right) - \frac{1}{Z_0}\left(\vec{n}'\times\vec{E}'\right)\right]e^{ik\vec{e}_r\cdot\vec{r}'}\,df'$$

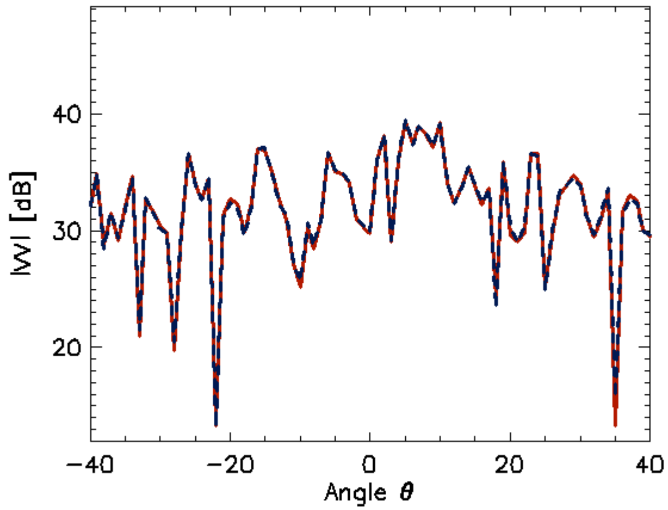


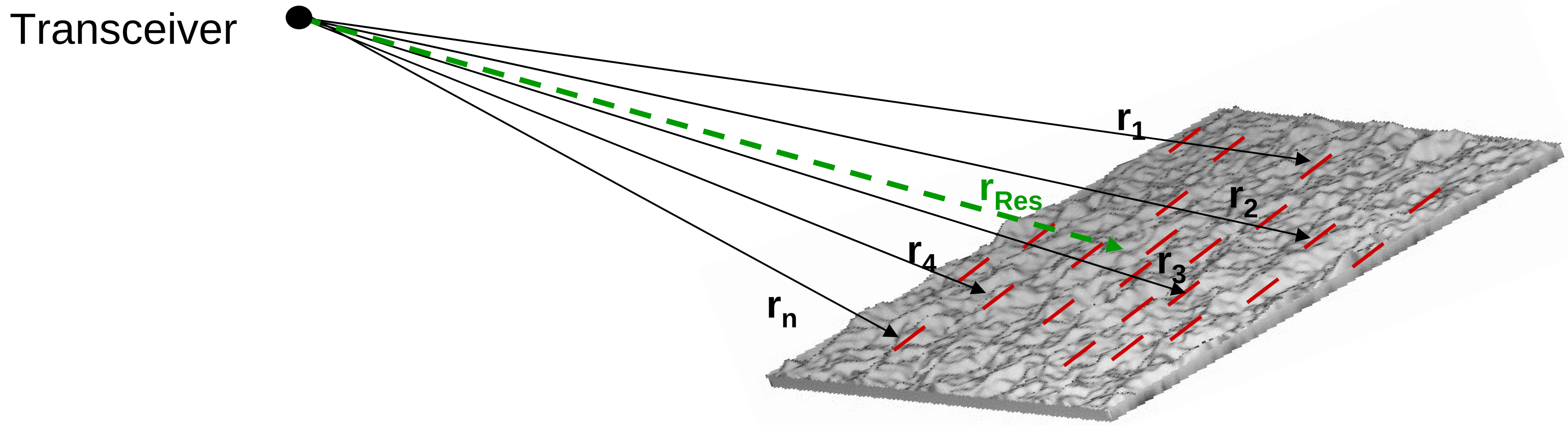
The total field is given by the Physical Optic field (PO) and the double bounced waves (DB) for a monostatic transmitter-receiver alignment.

f =10MHz; U_{10} = 8.0m/s; λ_{min} = 8.1m

λ_{peak}= 61.4m; λ_{max}= 164.2m; Grid: 402;

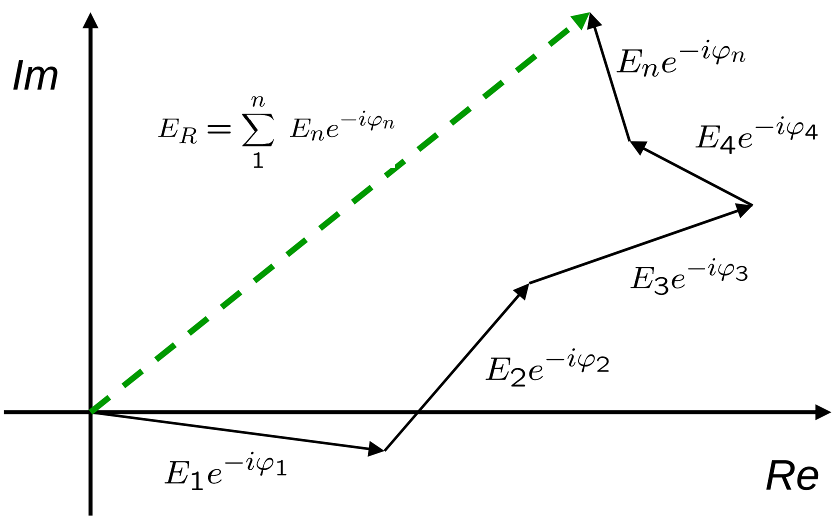
Width: 1.0m; Triangles: 321 602





Bragg Resonance

(Constructive superposition)



$$E_R = |E_R| e^{-i\varphi_R} \quad \text{where} \quad \varphi_R = 2k_i r_R - w_i \cdot t + \delta$$

Bragg-Wave:

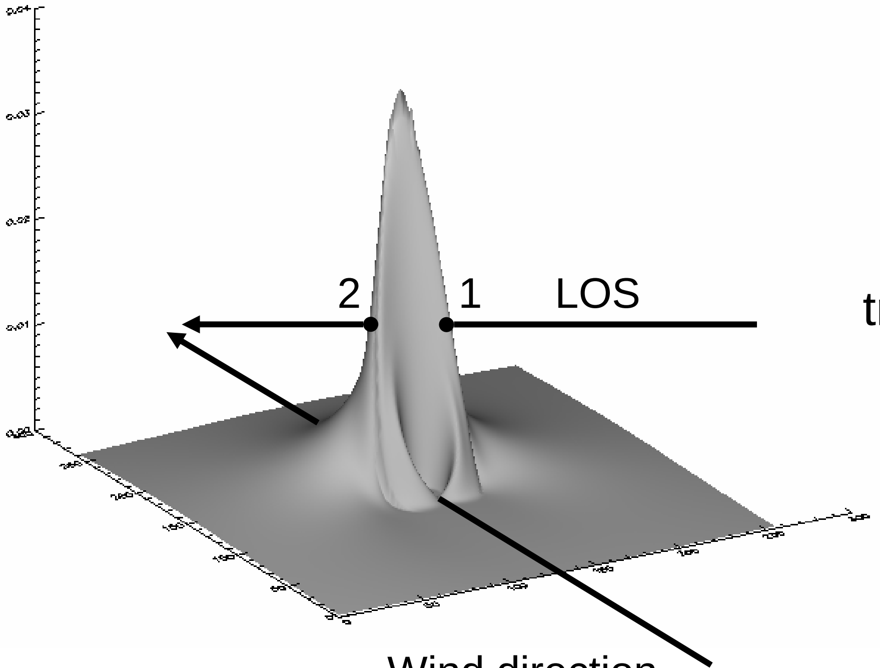
$$\varphi_R = 2k_i \left(r_R \pm v_B \cdot t \right) - w_i \cdot t + \delta$$

$$\varphi_R = 2k_i r_R - \left(w_i \pm \frac{4\pi v_B}{\lambda_B} \right) \cdot t + \delta$$

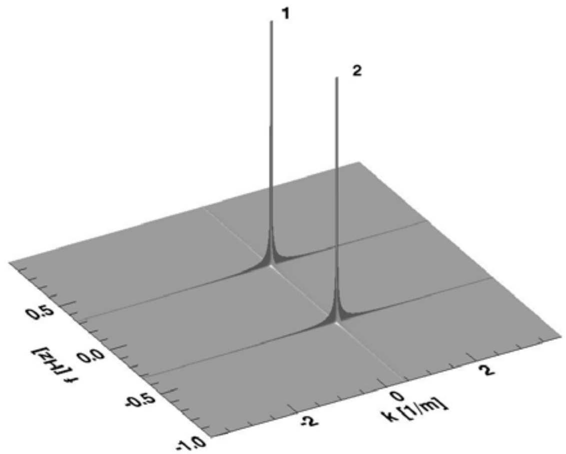
$$f_D = \pm \frac{2v_B}{\lambda_i}$$

Doppler Shifts

Surface Current Measurements

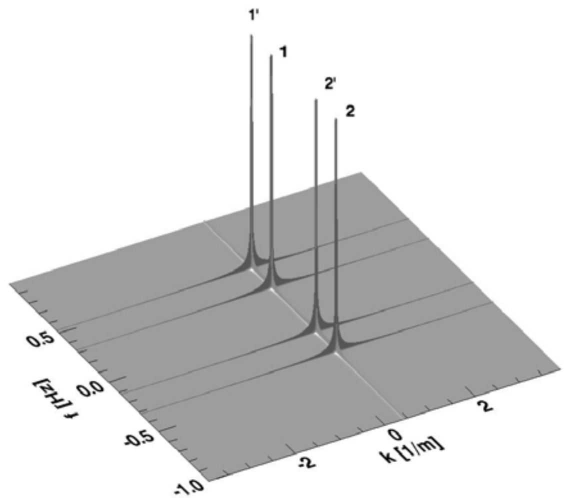


Two opposite travelling waves

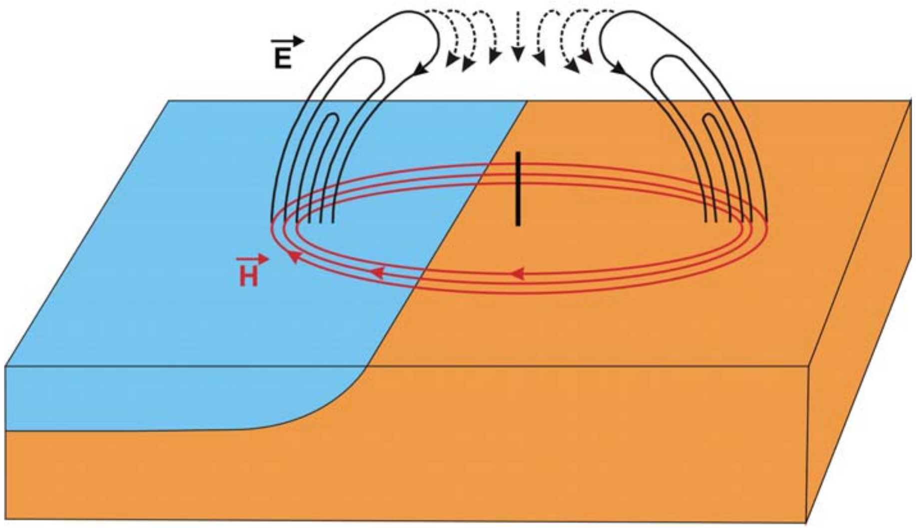


Underlying surface current v_C

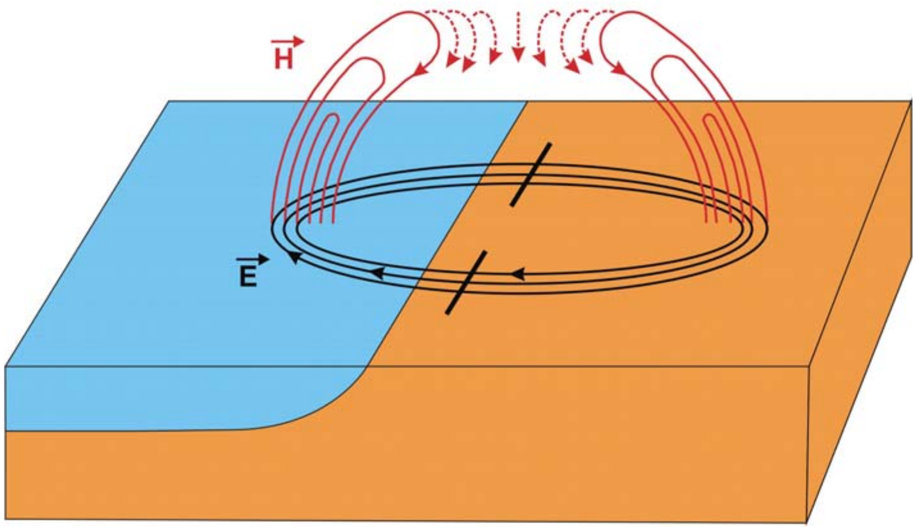
Additional Doppler shift



Surface Waves



Sommerfeld Identity (1909)

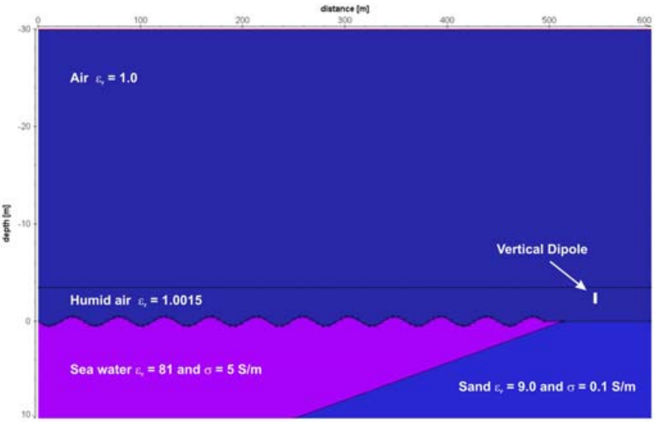


Hörschelmann (1911)

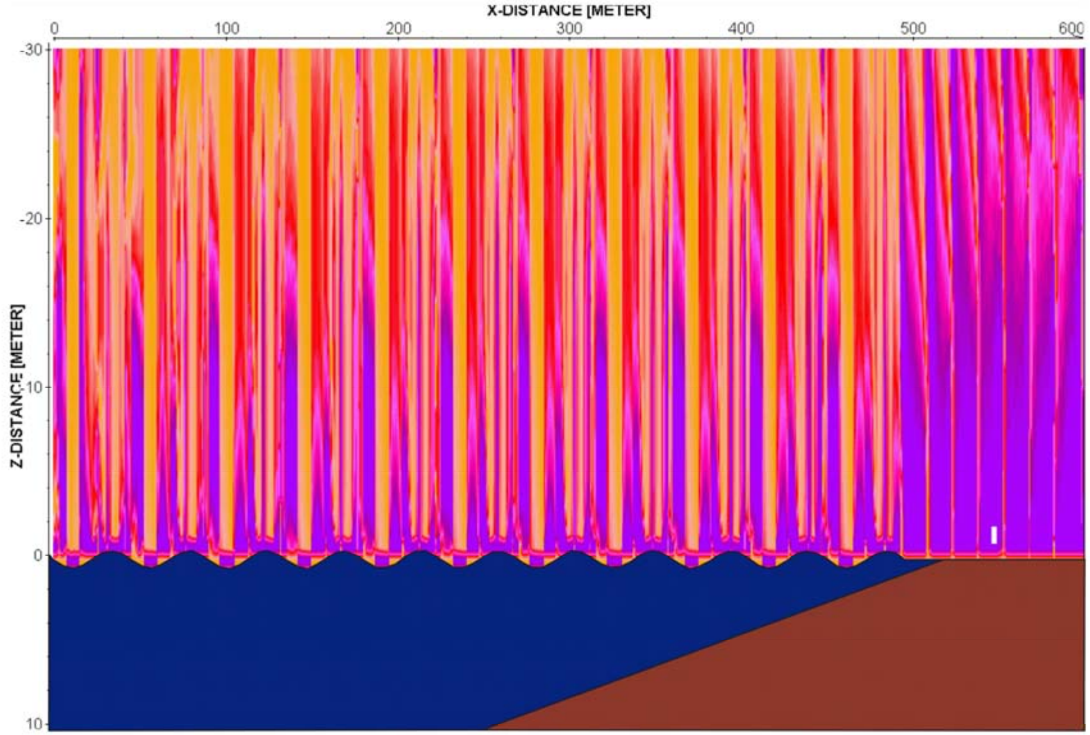
$$\frac{e^{i\,k\,R}}{R} = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{1}{\gamma}\, e^{-\gamma\,|z| + i(k_x \hat{x} + k_y \hat{y})} dk_x dk_y$$

Resonant Bragg Scattering

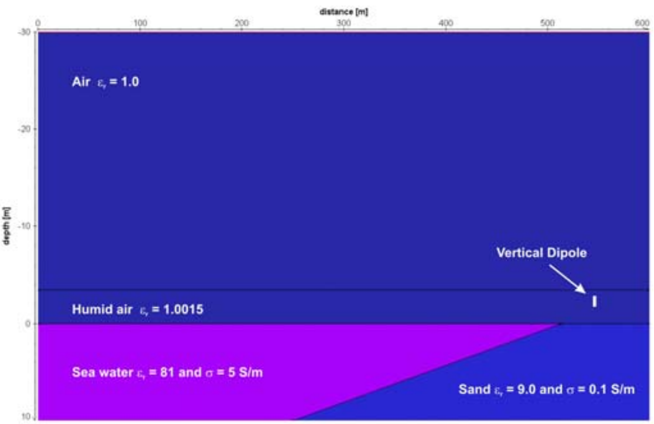
$$E_z^{bragg}(t) = E_z^{rough\_tot}(t) - E_z^{flat\_tot}(t)$$



$E_z^{roug\_tot}$



(1) - (2) = Bragg scattering

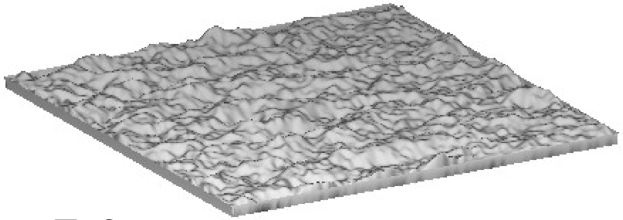


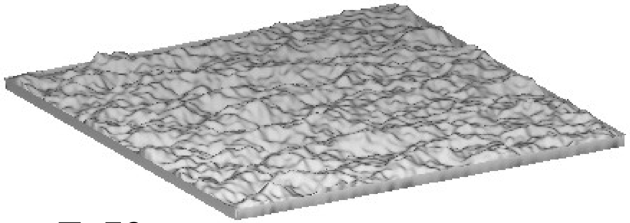
$E_z^{flat\_tot}$

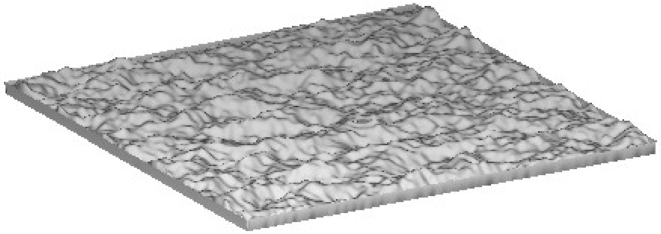
Continuous Wave (CW) Modus f=10MHz Δgrid =0,4m, Δt=0,5ns,Tmax=2000ns

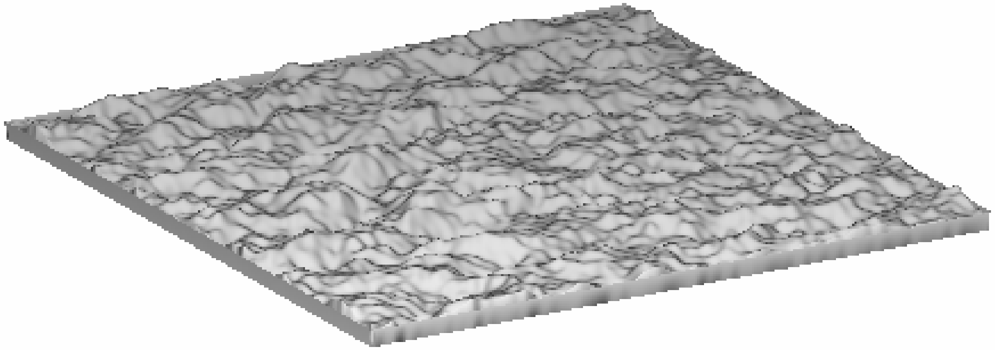
- Introduction
  - Background – HF Radar Observables - Motivation
- Surface Model
  - Ocean Wave Spectra (2D)
  - Calculation-PO-Bragg Lines-Doppler Shift
  - Principle of HF Surface Waves
- **Numerical Results**
  - Tsunami induced currents: V_c=18cm/s and 5.1cm
- Commercial Ground Based System
  - Ocean Remote Sensing System WERA-Configuration
- HF-OTHR Radar
- Conclusions

T_{meas}=90sec; f=10MHz
V_c = 18cm/s (12mHz)

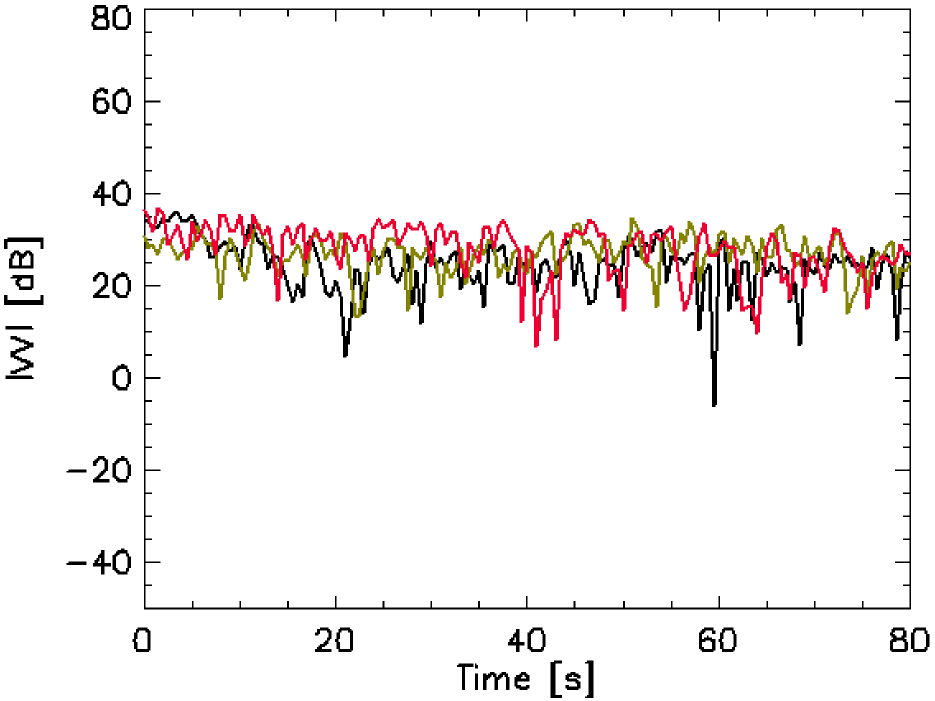

T=0s


T=50s

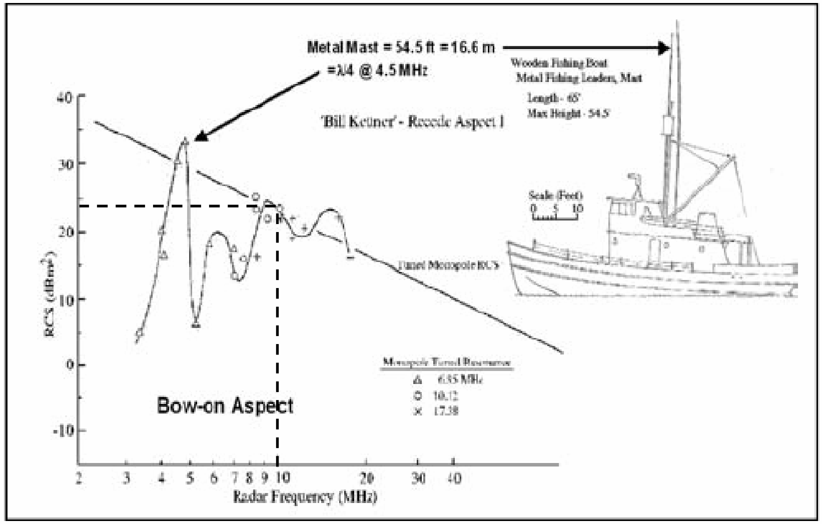

T=90s



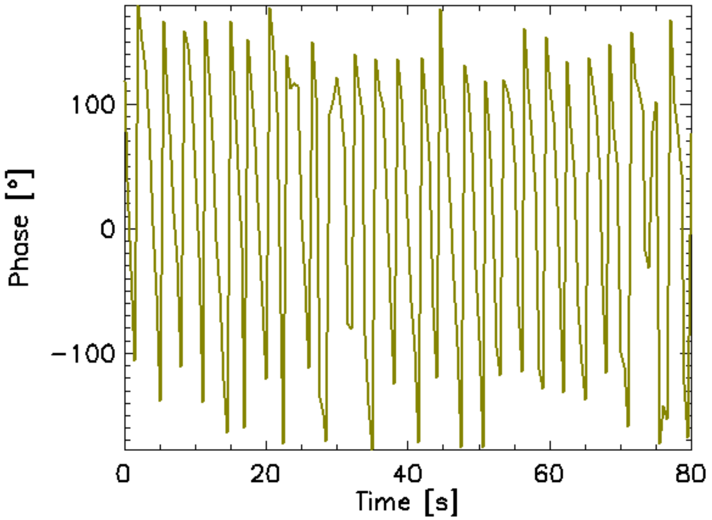
V_c = ±18cm/s (12mHz)
T=90s; f=10MHz; f_B=0.3220Hz; A=25cm



V_c = +18cm/s
V_c = 0cm/s
V_c = -18cm/s

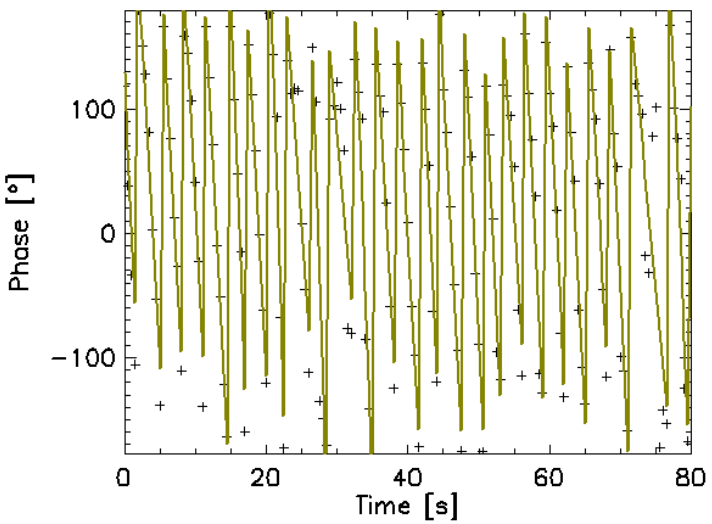


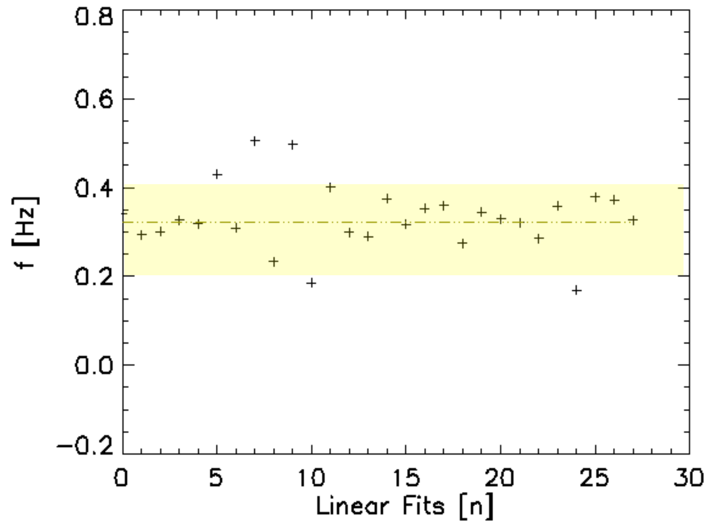
Dennis B. Trizna, *Microwave and HF Multi-Frequency Radars*, **U.R.S.I. Proceedings 2005**

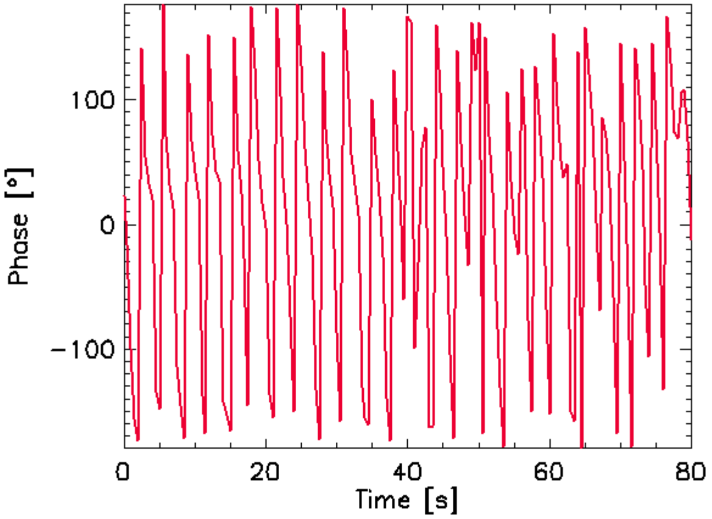


V_c = 18cm/s (12mHz)

T=90s; f=10MHz; f_B=0.3220Hz; A=25cm

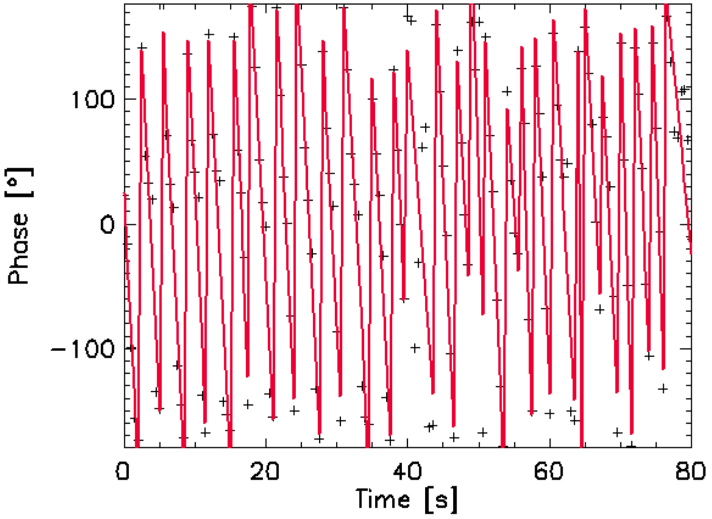


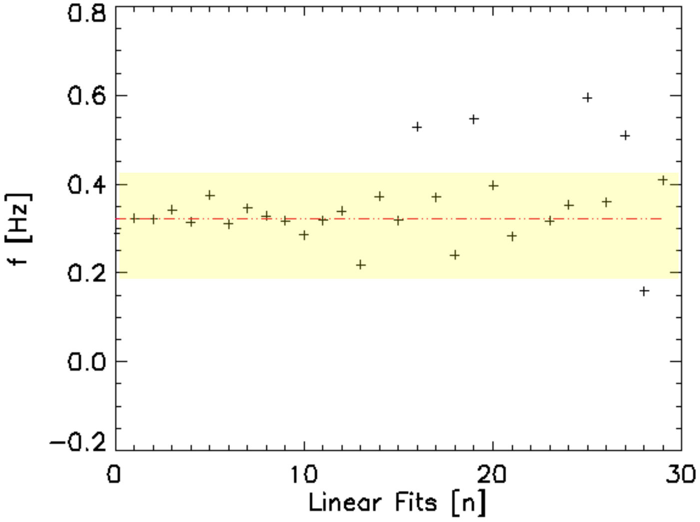




V_c = -18cm/s (-12mHz)

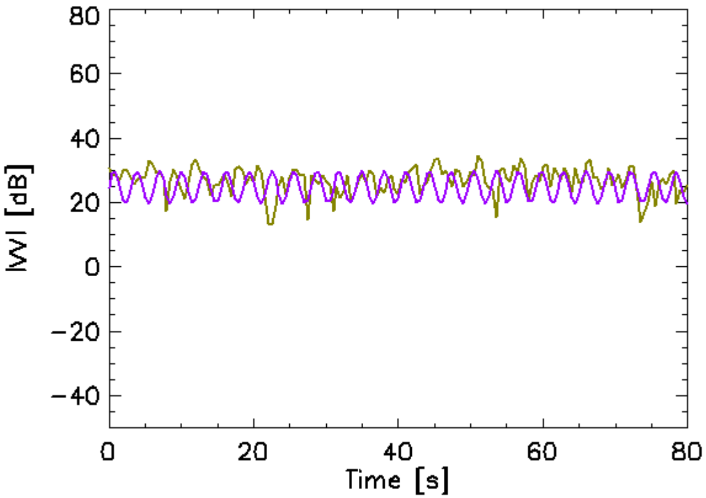
T=90s; f=10MHz; f_B=0.3220Hz; A=25cm



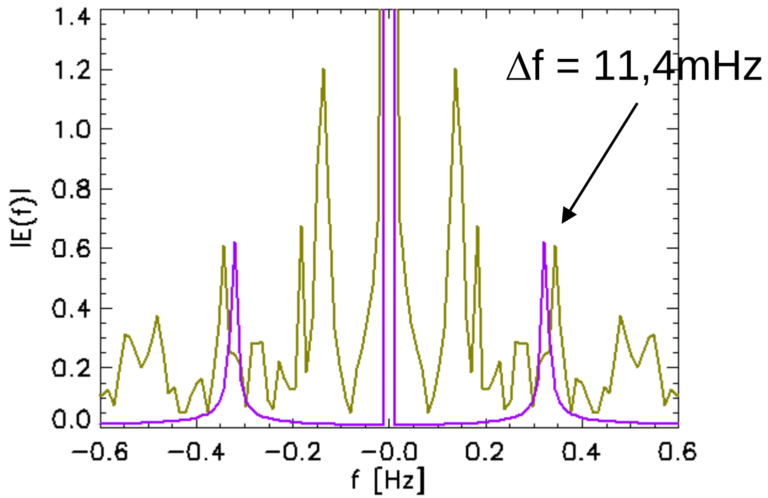


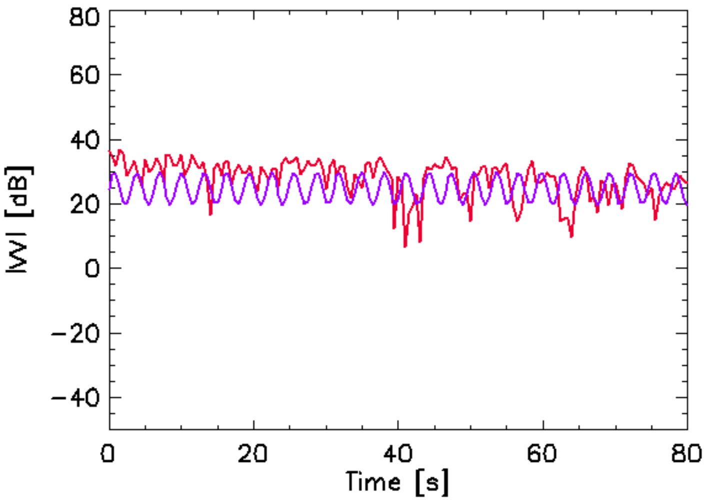
$V_c = \pm 18 cm/s$ (12mHz)

T=90s; f=10MHz; f_B=0.3220Hz; A=25cm

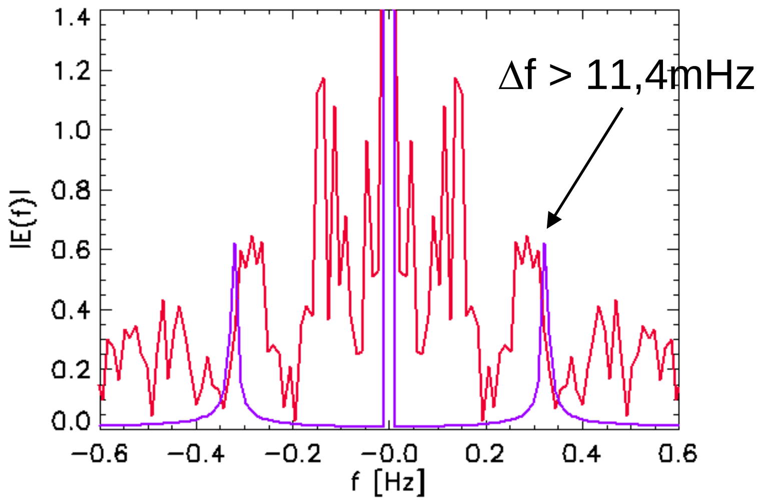


V_c = 18cm/s



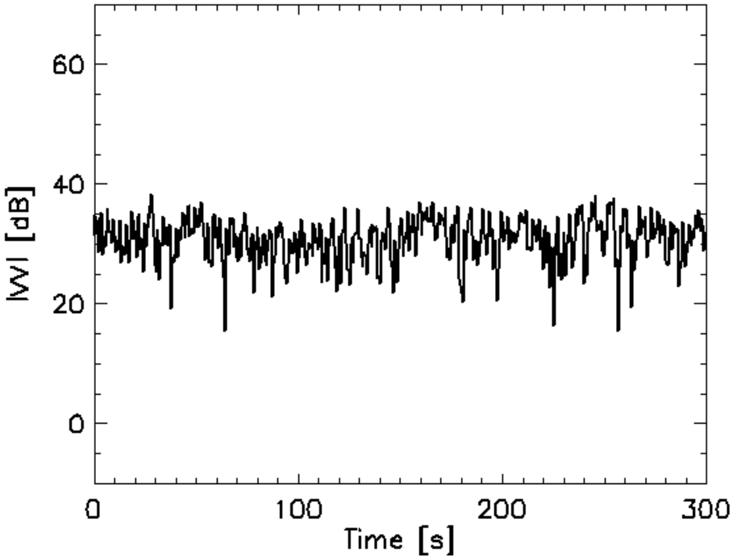


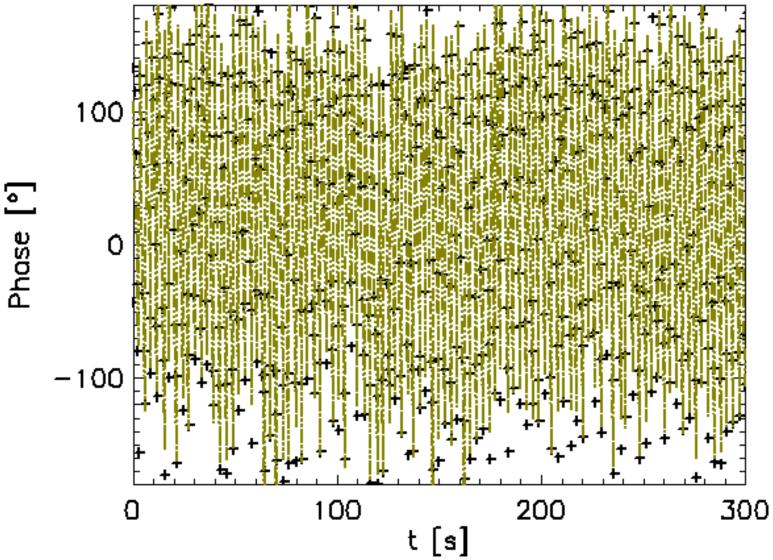
V_c = -18cm/s

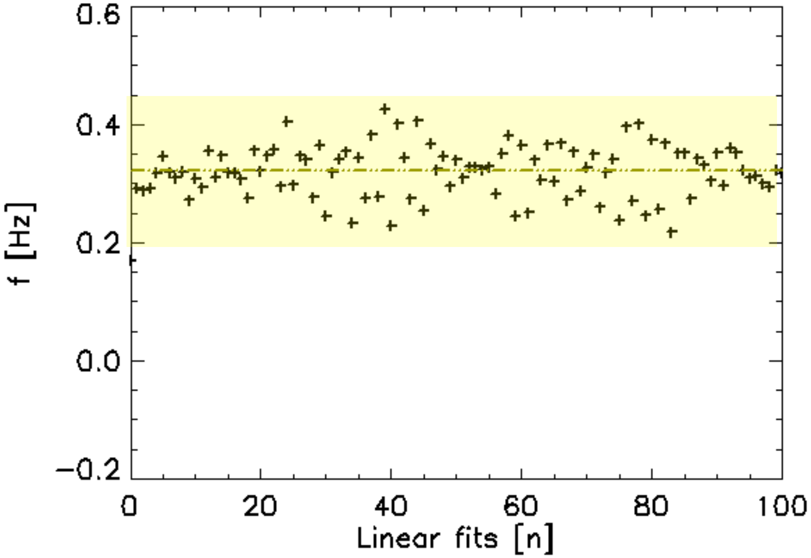


V_c = 5.1cm/s (3.4mHz)

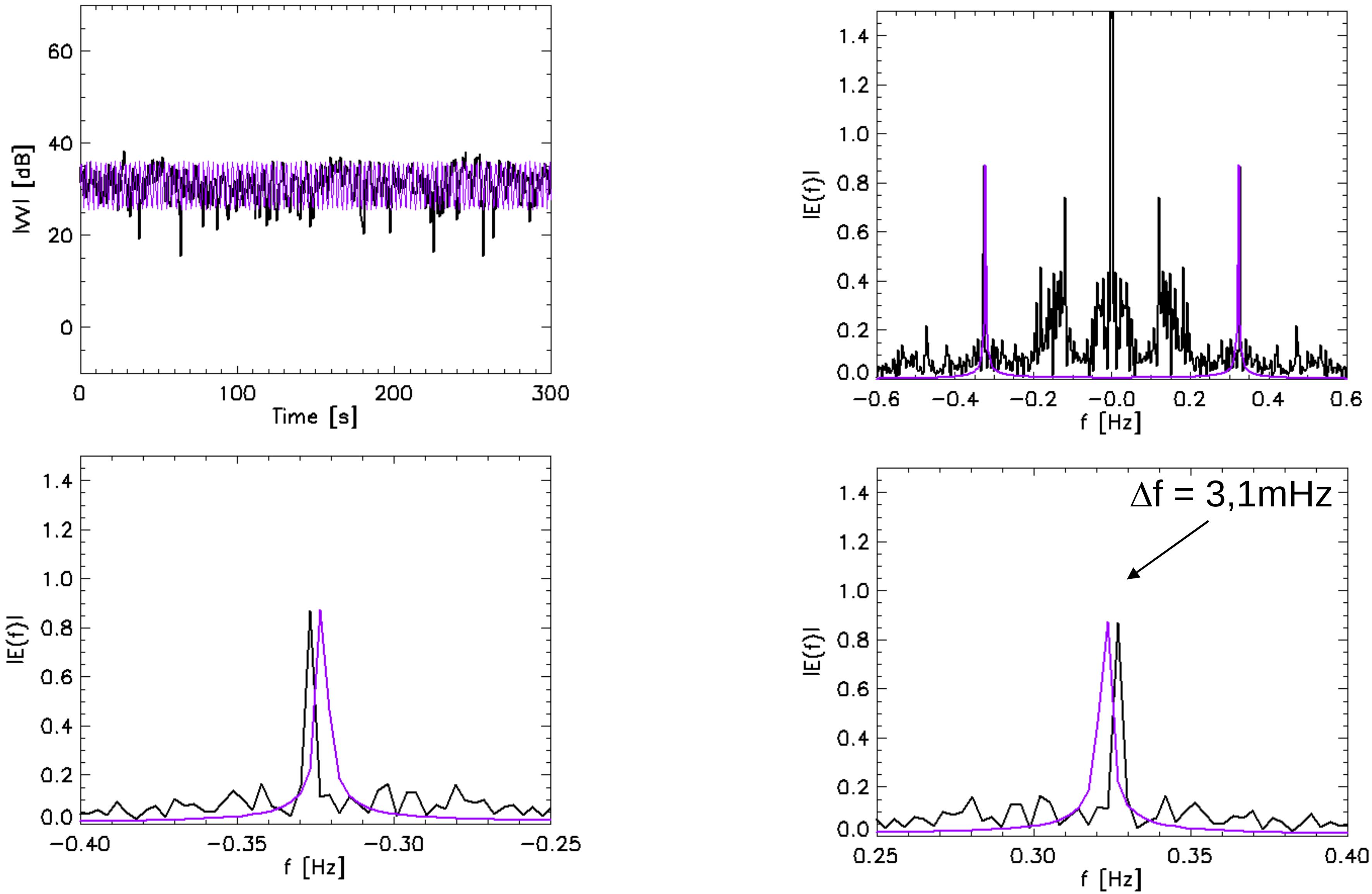
T=300s; f=10MHz; f_B=0.3220Hz; A=10cm







V_c = 5.1cm/s (3.4mHz)



Observation Time

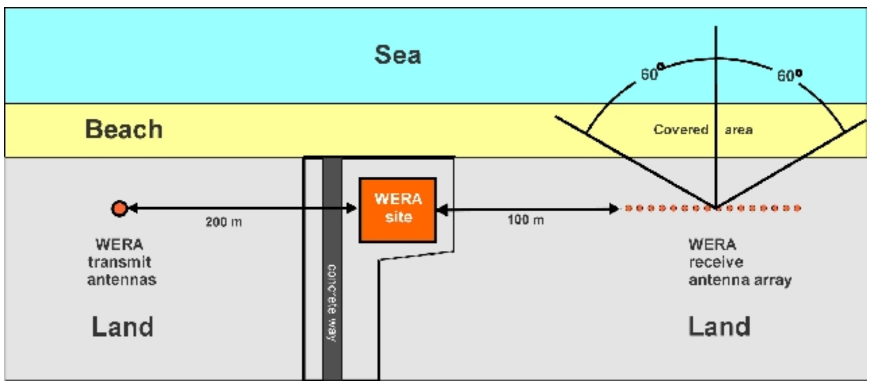
V_{radial}	$f_{Doppler}$ [mHz] f_{Radar}: 5MHz (λ=60m) 10MHz (λ=30m)	$T_{min.}$ [s]	Bathymetry
5 cm/s	1,667 3,333	10min 5min	Indonesia?
10 cm/s	3,333 6,667	5min 2min30s	
20 cm/s	6,667 13,667	2min30s 1min15s	Shelf-edge e.g.Phuket
50 cm/s	16,667 33,333	1min 30s	
100 cm/s	33,333 66,666	30s 15s	

$$\Delta T = \frac{1}{\Delta f}$$

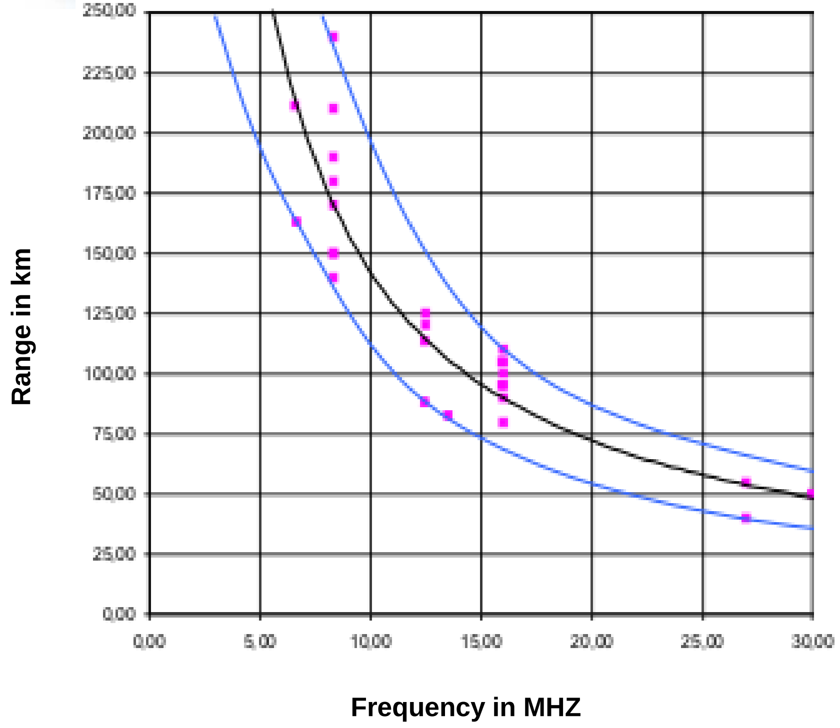
- Introduction
  - Background – HF Radar Observables - Motivation
- Surface Model
  - Ocean Wave Spectra (2D)
  - Calculation-PO-Bragg Lines-Doppler Shift
  - Principle of HF Surface Waves
- Numerical Results
  - Tsunami induced currents: V_c=18cm/s and 5.1cm
- **Commercial Ground Based System**
  - Ocean Remote Sensing System WERA-Configuration
- HF-OTHR Radar
- Conclusions

WERA
Remote Ocean Sensing

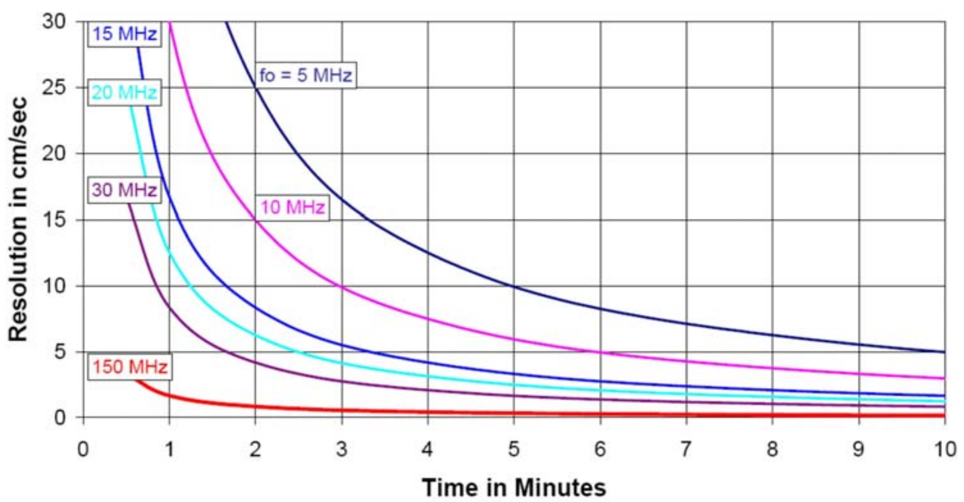
Helzel L.L.C.
Germany



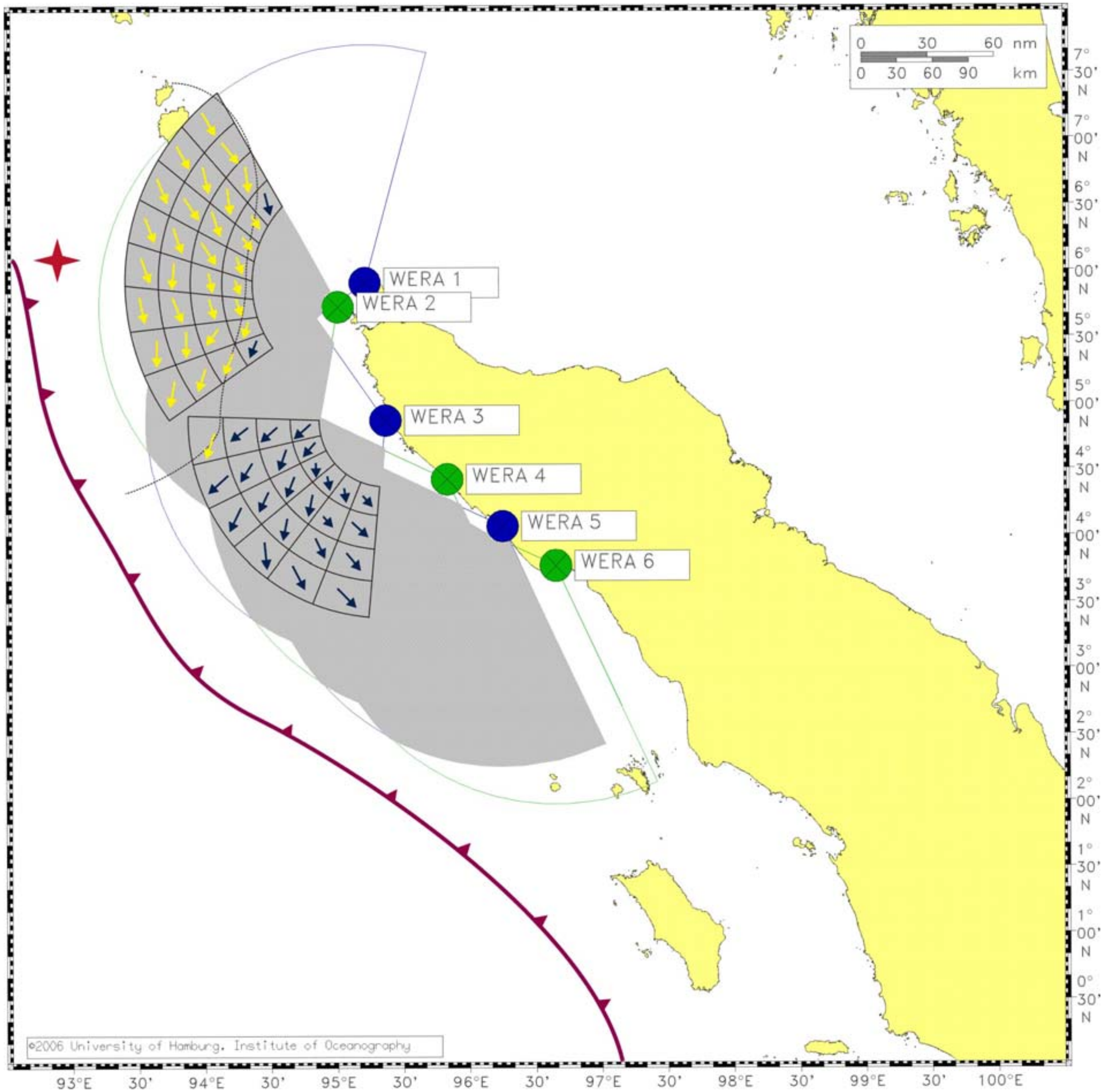
The WERA system (*WavE RAdar*) is a shore-based HF radar to monitor ocean surface currents, waves and wind direction. The system is manufactured by Helzel GmbH. The vertically polarised radiated wave couples to the conductive ocean surface and propagates as a surface wave with a maximum range of about 200 km and a field of view of about 120°. Radar performance depends on site geometry, system configuration and environmental conditions. There is a trade-off between Doppler resolution and Integration time.



WERA
Remote Ocean Sensing



WERA
Remote Ocean Sensing

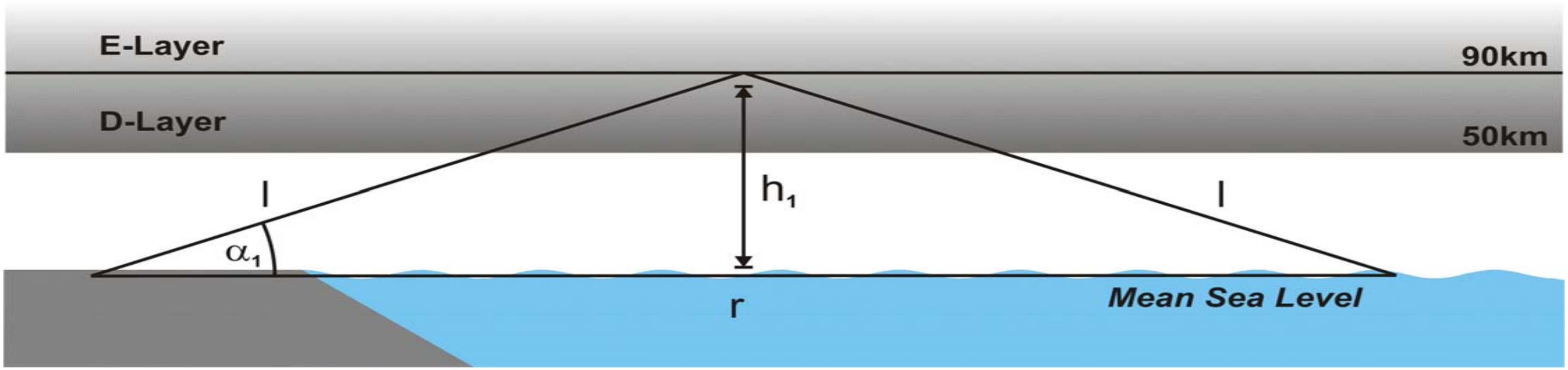


Possible Configuration (Banda Aceh)

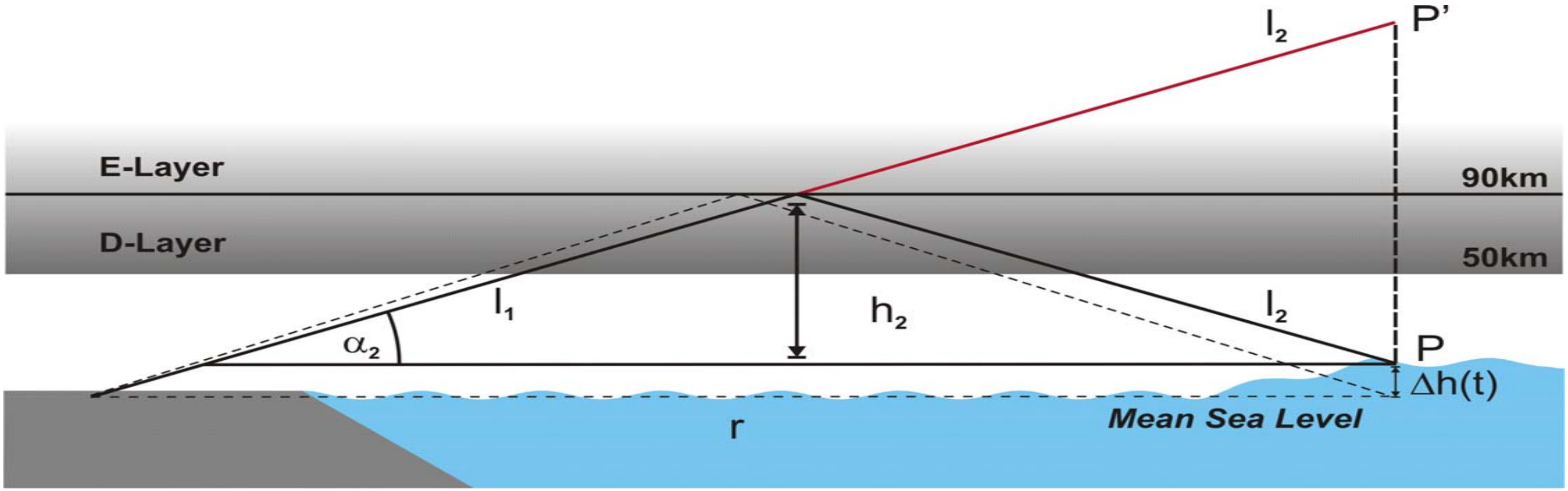
Possible WERA configurations for northern Sumatra. After a hypothetical seaquake (red dot marks the epicenter) the tsunami alters the local surface current field. The tsunami-induced pattern can be observed over time.

- Introduction
  - Background – HF Radar Observables - Motivation
- Surface Model
  - Ocean Wave Spectra (2D)
  - Calculation-PO-Bragg Lines-Doppler Shift
  - Principle of HF Surface Waves
- Numerical Results
  - Tsunami induced currents: V_c=18cm/s and 5.1cm
- Commercial Ground Based System
  - Ocean Remote Sensing System WERA-Configuration
- **HF-OTHR Radar**
- Conclusions

HF-OTH Radar



E-Layer
90km
D-Layer
50km
l
h1
l
α1
r
Mean Sea Level



l2
P'
E-Layer
90km
D-Layer
50km
l1
h2
l2
α2
P
Δh(t)
r
Mean Sea Level

HF-OTH Radar

$$h_1 = \frac{c_0}{4} t_1 \sin\left[\cos^{-1}\left(\frac{2r}{c_0 t_1}\right)\right]$$

$$h_2 = \frac{c_0}{4} t_2 \sin\left[\cos^{-1}\left(\frac{2r}{c_0 t_2}\right)\right]$$

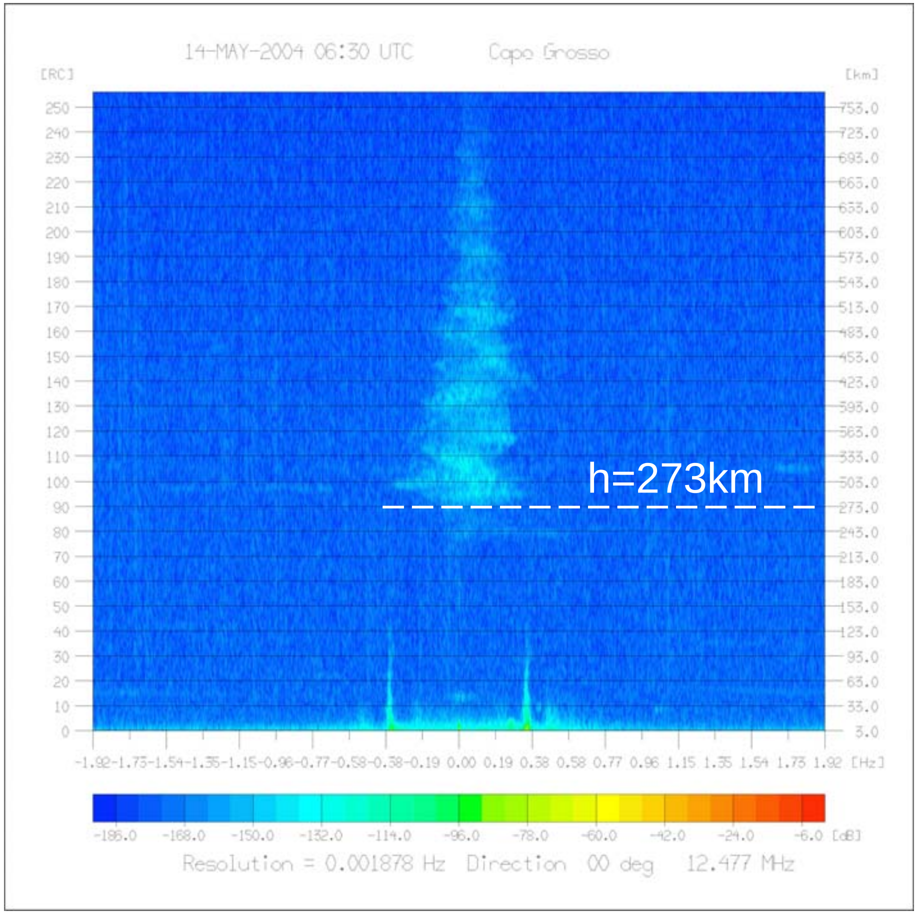
$$\Delta h(t) = h_1 - h_2$$

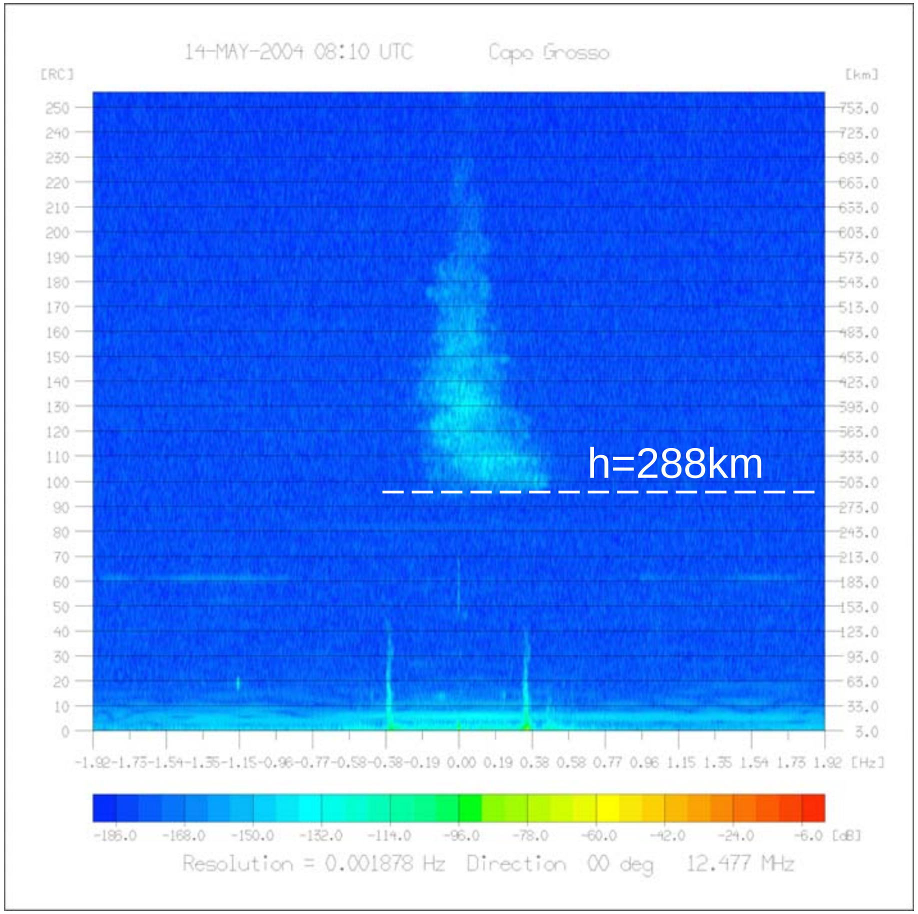
Continuous mapping of the temporal variance of the em mean sea level

Problems:

- Sensitive to frequency
- F_2 layer instability
- Military frequency range
- …

Reflection at the F2-Layer





WERA HF Radar System
(Capo Grosso-Marina di Camerota)

- Introduction
  - Background – HF Radar Observables - Motivation
- Surface Model
  - Ocean Wave Spectra (2D)
  - Calculation-PO-Bragg Lines-Doppler Shift
  - Principle of HF Surface Waves
- Numerical Results
  - Tsunami induced currents: V_c=18cm/s and 5.1cm
- Commercial Ground Based System
  - Ocean Remote Sensing System WERA-Configuration
- HF-OTHR Radar
- **Conclusions**

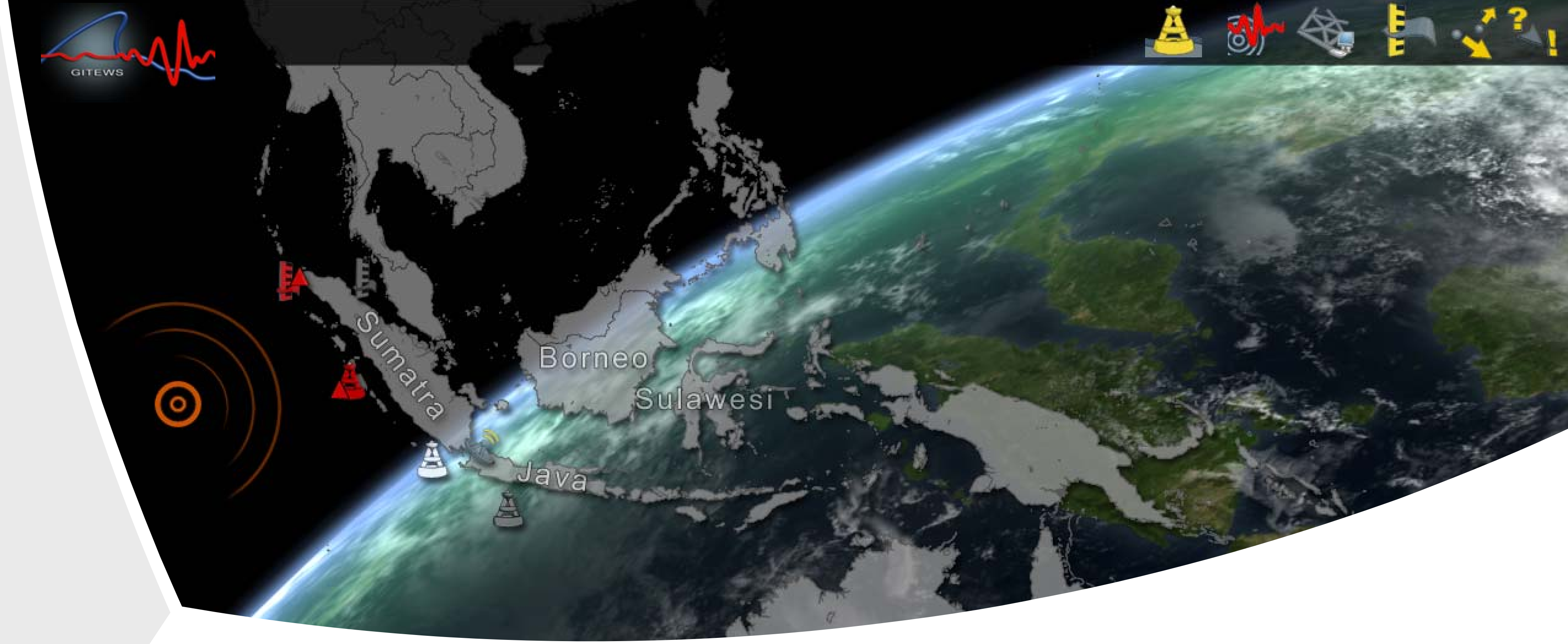
Conlusions

- The used 2D Wave spectra is suitable for HF-Radar signatures according to the PO
- The implemented algorithm computes either approaching or outgoing waves relative to the LOS
- The surface waves couple at the sea water and follow the curvature of the ocean
- The measurement period is reciprocal to the Doppler frequency resolution
- Current field perturbation v_c > 10cm/s, where $T_{tot}=T_{meas} + T_{proc}$, should be accurately timed. What's about v_c < 10cm/s?
- Current field estimations can be integrated with the buoy system

Final Remarks

- Combination with other remote sensing data
- The continuously generated current maps assure the reliability of the hardware
- Multipurpose use of such a ground based system e.g. WERA (ship tracking, current and wave information)
- **Recommendation: Installation of a basic HF-system and performing in situ measurements**

Thanks for your attention!
Questions?



GITEWS

WP 4430 Grond Based Hf-Radar System

Nicolas Marquart
Microwave and Radar Institute
German Aerospace Center (DLR)