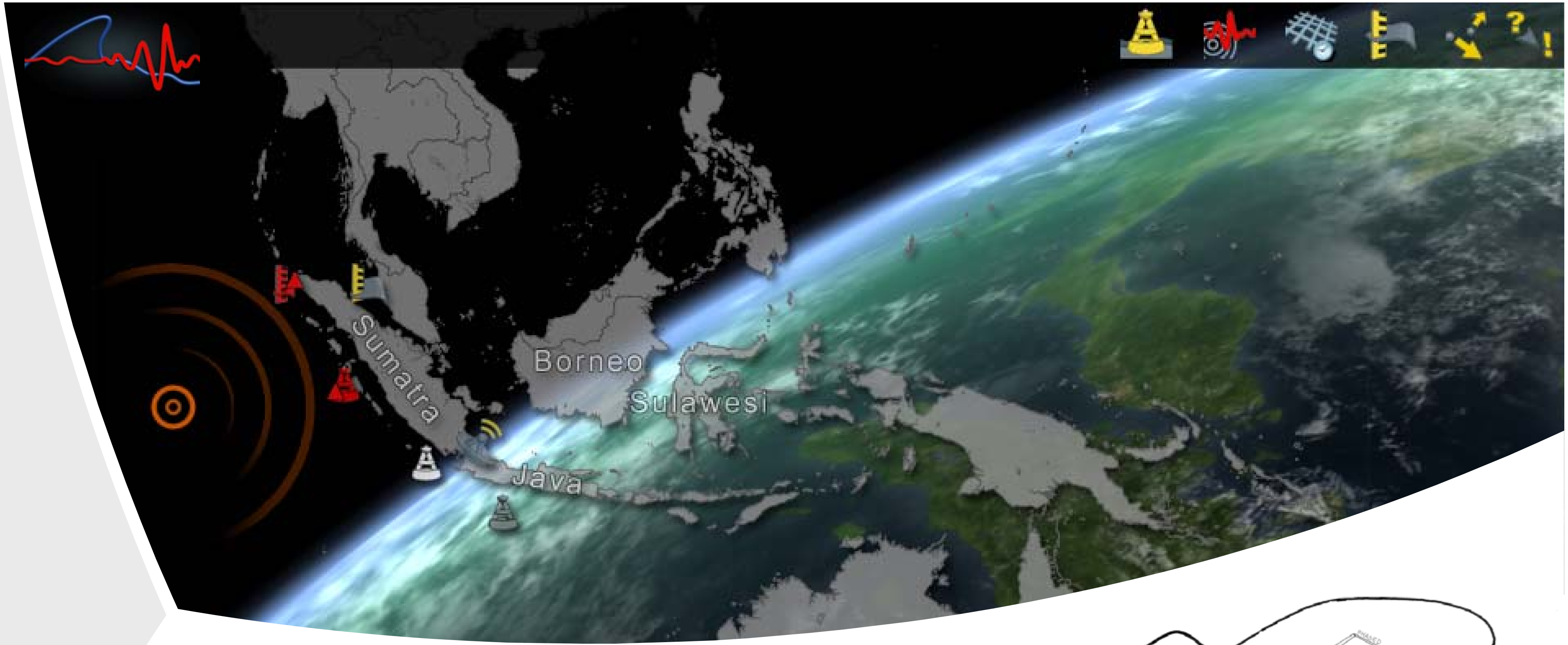

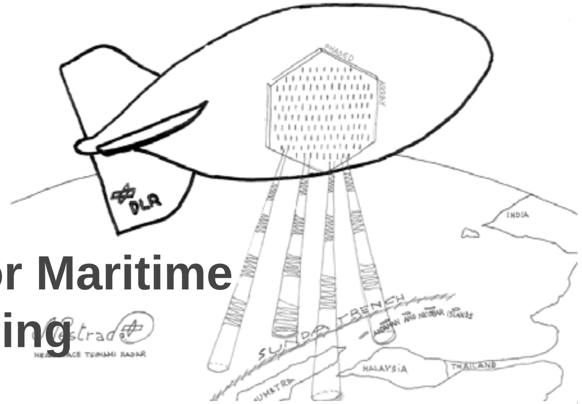

GITEWS

Concept Study and Designs of Radar Sensors for Maritime Surveillance and Near-Field Tsunami Early Warning

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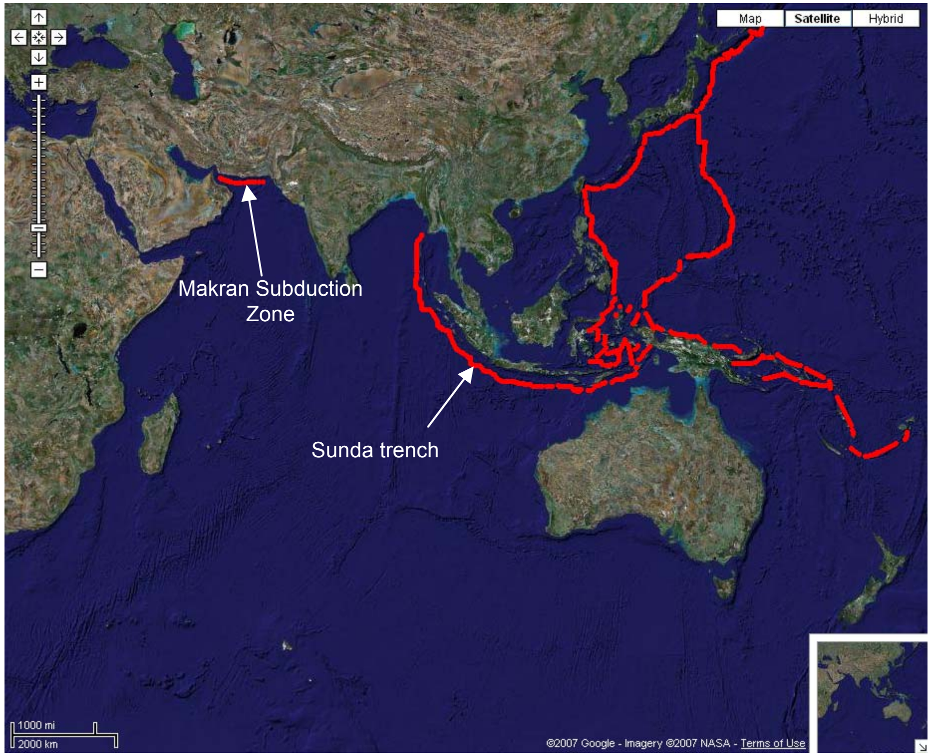
Microwaves and Radar Institute (HR)
German Aerospace Center (DLR)

Tsunami Early-Warning: Far-field and Near-field

Tsunamigenic areas of the Indian Ocean



Under near-field tsunami threat in the world ocean: Indonesia, Makran Subduction zone (Iran, Pakistan), Japan, Mediterranean countries, Cascadia, Caribbean, etc.

FAR-FIELD TSUNAMI > 30 min

- Tsunami can happen anytime but trans-oceanic propagation can take hours!
- Far-field Tsunami Early-Warning is operational and effective.

NEAR-FIELD TSUNAMI < 30 min

- **First warning to be issued within 5 min from the quake!**
  → Temporal Coverage: 24/7, for immediate response.
- **Spatial Coverage: dictated by plate tectonics.**

Tsunami Scale

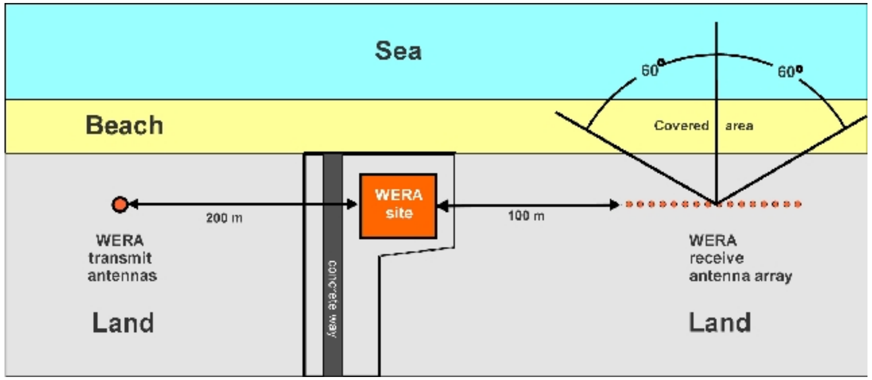
Deep Ocean	d = 4000 m	λ = 150 km	a = 0.7 m	U = 0.08 m/s
Coastal Area	d = 40 m	λ = 15 km	a = 5 m	U = 2.5 m/s

Tsunamis are easier to detect in **coastal areas**

too late !?

WERA Remote Ocean Sensing

Helzel GmbH



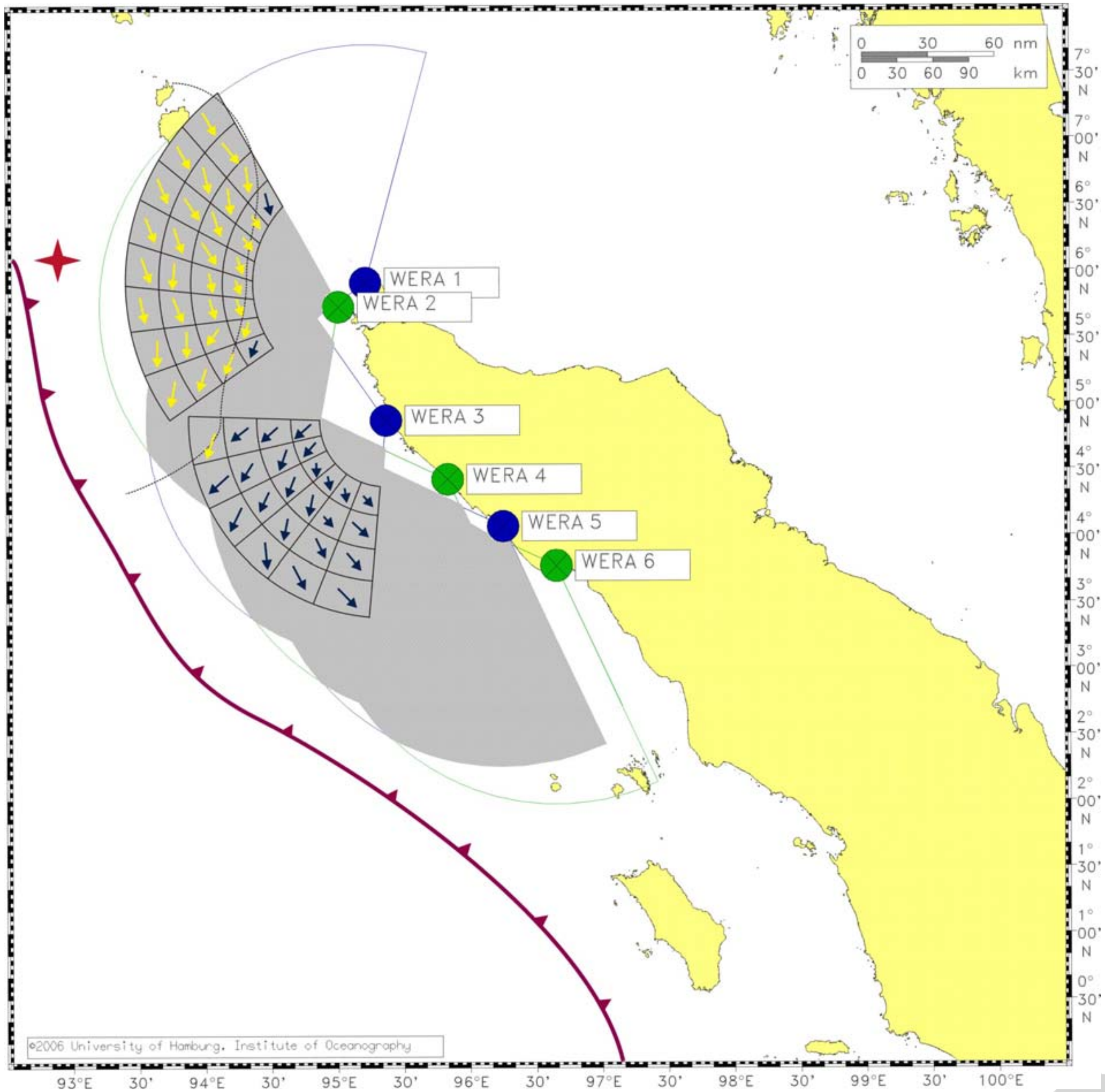
The WERA system (*WavE RAdar*) is a shore-based HF radar to monitor ocean surface currents, waves and wind direction. The system is manufactured by Helzel GmbH. The vertically polarised radiated wave couples to the conductive ocean surface and propagates as a surface wave with a maximum range of about 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.**

HF Radar Range and Integration Times

Frequency [MHz]	Range [km]
8	200
15	100
30	60

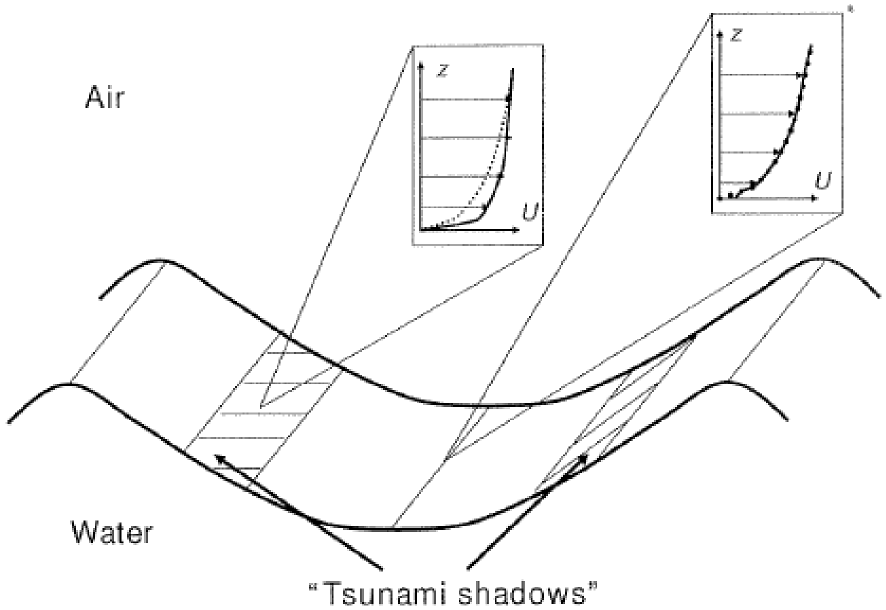
V_{radial}	T_{min}
5 cm/s	10min (@ 5 MHz) 5min (@ 10 MHz)
10 cm/s	5min (@ 5 MHz) 2min 30s (@ 10 MHz)
20 cm/s	2min30s (@ 5 MHz) 1min 15s (@ 10 MHz)
50 cm/s	1min (@ 5 MHz) 30s (@ 10 MHz)
100 cm/s	30s (@ 5 MHz) 15s (@ 10 MHz)

Possible Configuration (Banda Aceh)

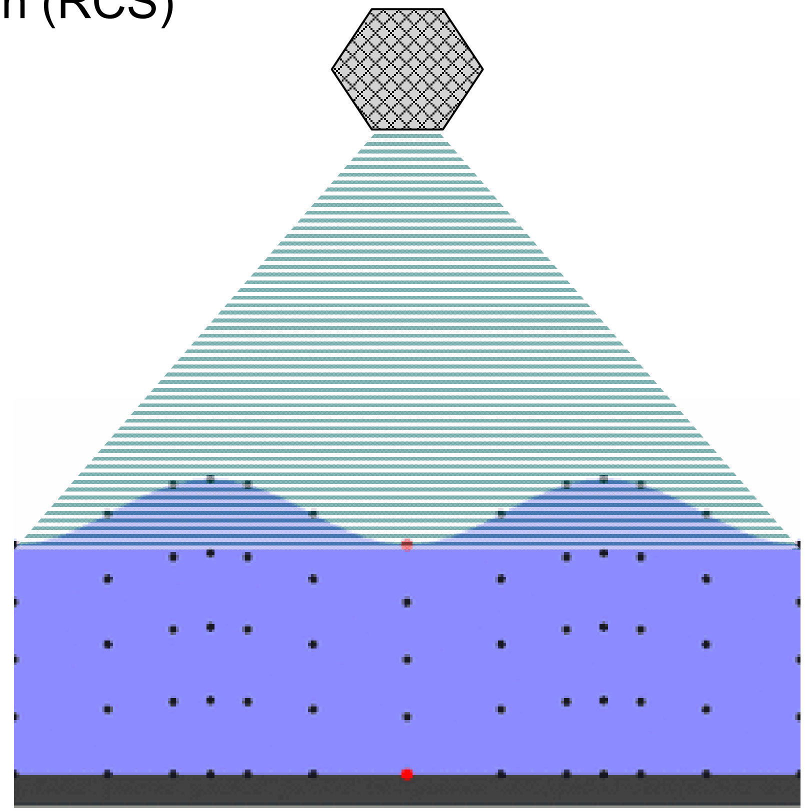


Tsunami Signatures for Air-/Spaceborne Radar

- Wave height → altimetry
- Orbital velocities → Doppler
- Internal waves → radar cross section (RCS)
- Tsunami shadows → RCS



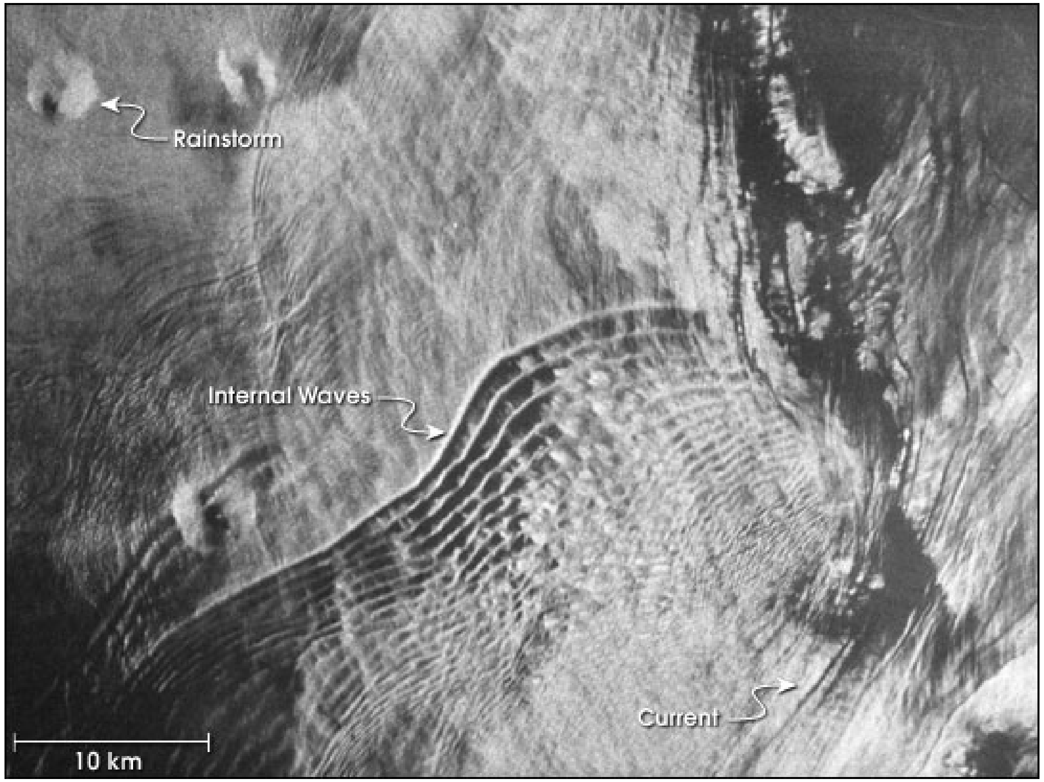
Godin, O. A. (2004), Air-sea interaction and feasibility of tsunami detection in the open ocean, J. Geophys. Res., 109.



First civilian SAR satellite: SEASAT (1978)

Crucial disadvantages:

- → not geostationary
- → poor revisit times (days/weeks)



Launch	June 26, 1978	Wavelength	0,235 m
Altitude	~780 km	Bandwidth	19 MHz
Weight	2300 kg	Antenna Size	10,74 m x 2,16 m
Incident Angle	~ 23°		
Swath Width	100 km	Resolution	25 m x 25 m

Near Space Platforms:
Stationary Stratospheric Airships for 24/7 coverage

- Geosynchronous satellite at ~20 km (500 km to horizon)
- Unmanned, Untethered
- Persistence: 1 year on station
  - Develop long term clutter maps
  - Learn normal patterns
  - 1 min for attitude change
- Stationary
  - Improved Doppler precision
  - Continuous Coverage

- Airship Size: >50m diameter, 150m length
  - Accommodate large aperture
  - Limited payload prime power and weight
  - No stowing, launch or deployment required
  - Easy to maintain

Lockheed-Martin

Zeppelin GmbH

NESTRAD (NEar-Space Tsunami RADar): System Design

System	Antenna	10×3 m^2 phased array
	Frequency	5 GHz
	Polarization	VV
	Path Loss	3 dB
	Noise Figure	3 dB
Antenna	Antenna Aperture	30 m^2
	Antenna Gain	51 dBi
	Side lobe level	-15 dB
	Max. scan angle (elevation)	45°
	Max. scan angle (azimuth)	60°

Response time: ~ 3 min or even better!

NESTRAD: Waveform Design (RCS Mode)

Far range

Waveform Parameters	
Incidence angle	87°
Backscatter cross section	-30 dB
PRF	800 Hz
Pulse Width	1.25 ms
Peak Power	100 W
Bandwidth	150 MHz
Duty Cycle	100% FMCW
SNR	13 dB
Range resolution	1 m
Azimuth resolution	2000 m

Near range

Waveform Parameters	
Incidence angle	20°
Backscatter cross section	-20 dB
PRF	2 kHz
Pulse Width	0.5 ms
Peak Power	1 W
Bandwidth	150 MHz
Duty Cycle	100 % FMCW
SNR	40 dB
Range resolution	3 m
Azimuth resolution	100 m

Far range resolution: 2 × 0.5 km

Near range resolution: 100 × 100 m

→ We can resolve tsunami shadows: tens × thousands of kms !

NESTRAD: Waveform Design (Doppler Mode)

PRT = 1ms	T_c = 10 ms	N = 1000 (dwell-time=1s)

$$\gamma_n = \frac{1}{1+SNR^{-1}} \qquad \gamma = \gamma_n \cdot \gamma_t \qquad \gamma_t = \exp\left(-\frac{t^2}{\tau_c^2}\right)$$

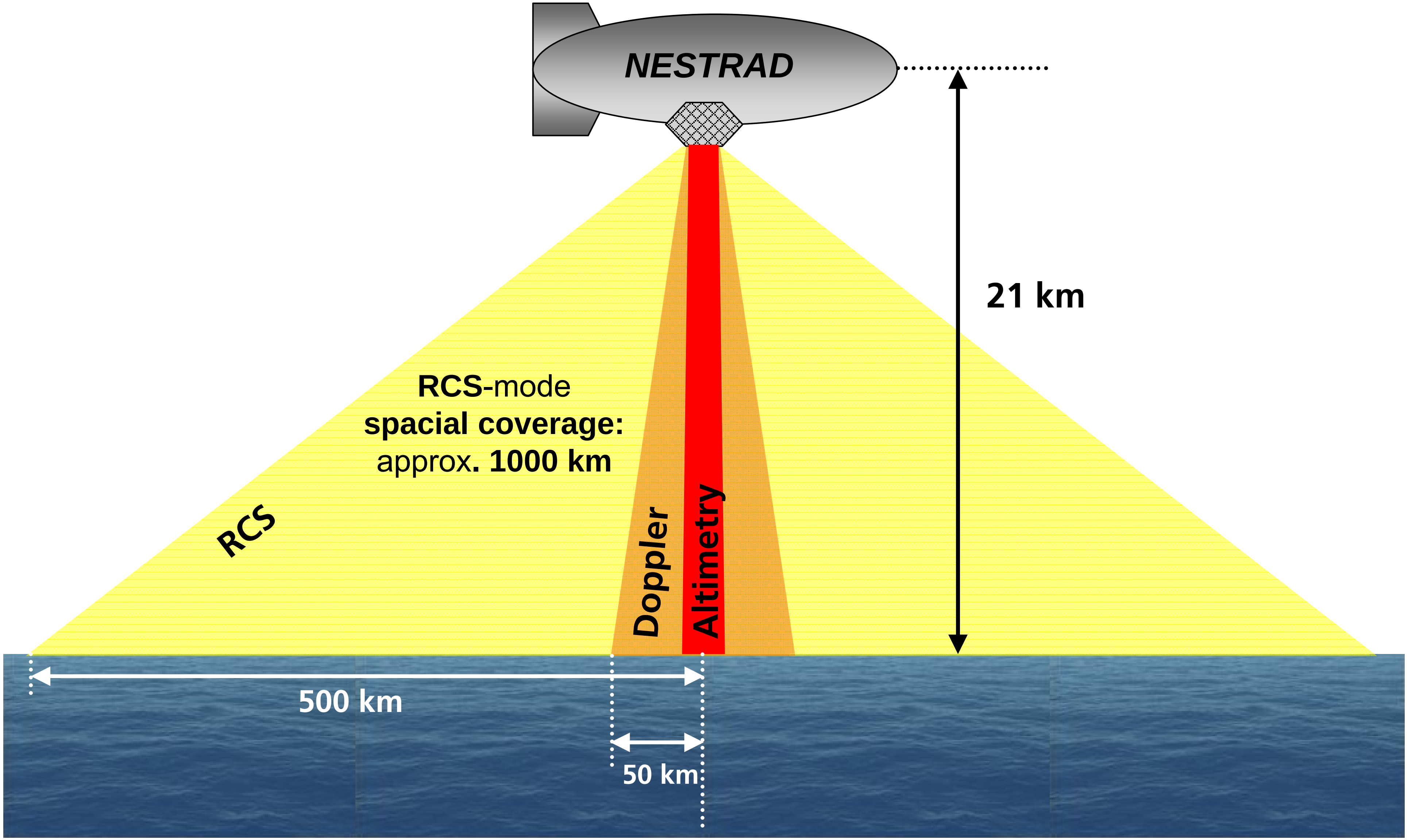
$$\sigma_\varphi = \frac{1}{\sqrt{2N}} \frac{\sqrt{1-\gamma^2}}{\gamma}$$

SNR = 10 dB $$\Delta V = \frac{\lambda}{2\pi} \cdot \frac{1}{2 \cdot PRT} \cdot \sigma_\varphi = 2.5\, cm/s$$

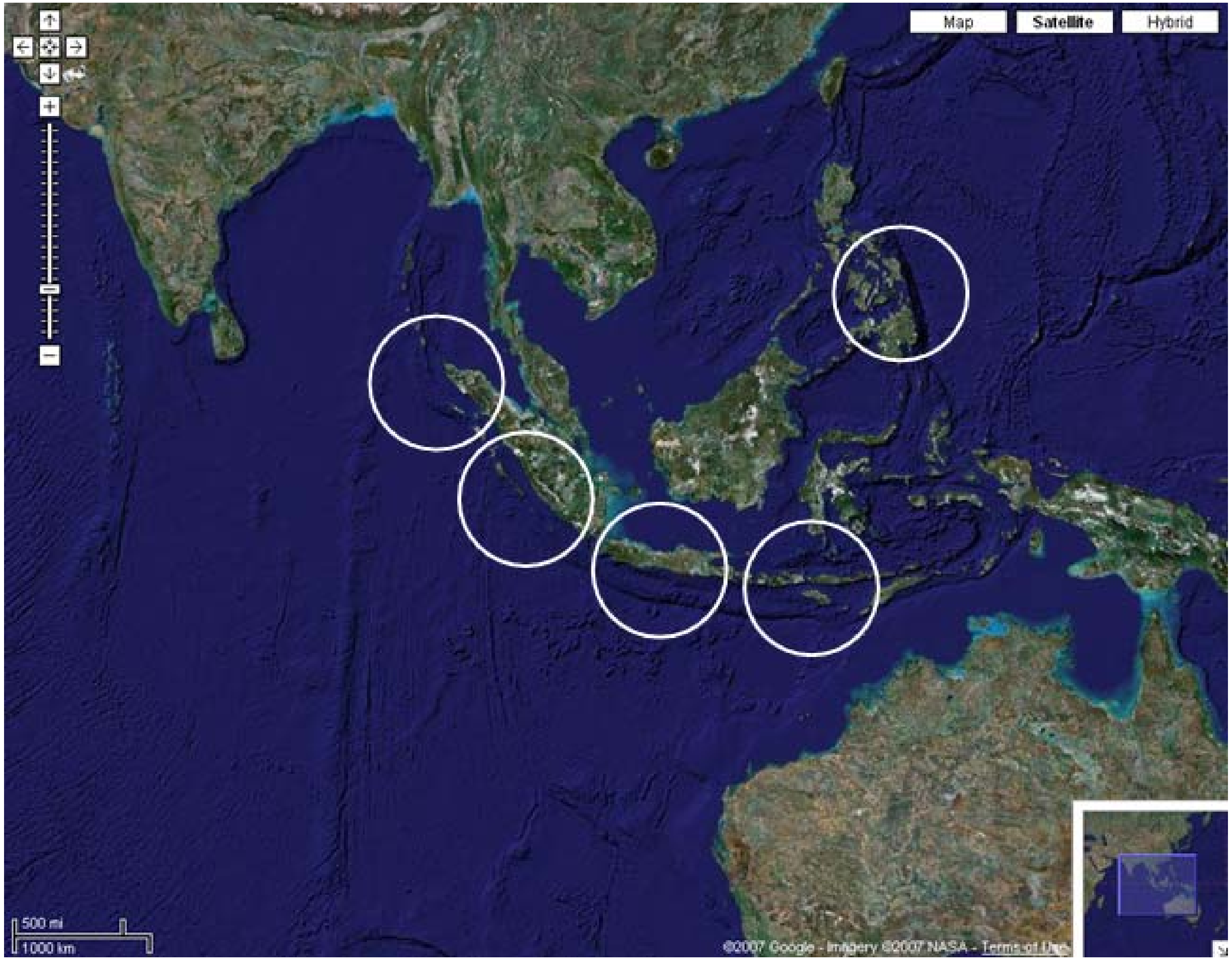
SNR = **20 dB** $$\Delta V = \frac{\lambda}{2\pi} \cdot \frac{1}{2 \cdot PRT} \cdot \sigma_\varphi = 1{,}07\, cm/s$$

It is possible to design a system with sub-centimetric accuracy!

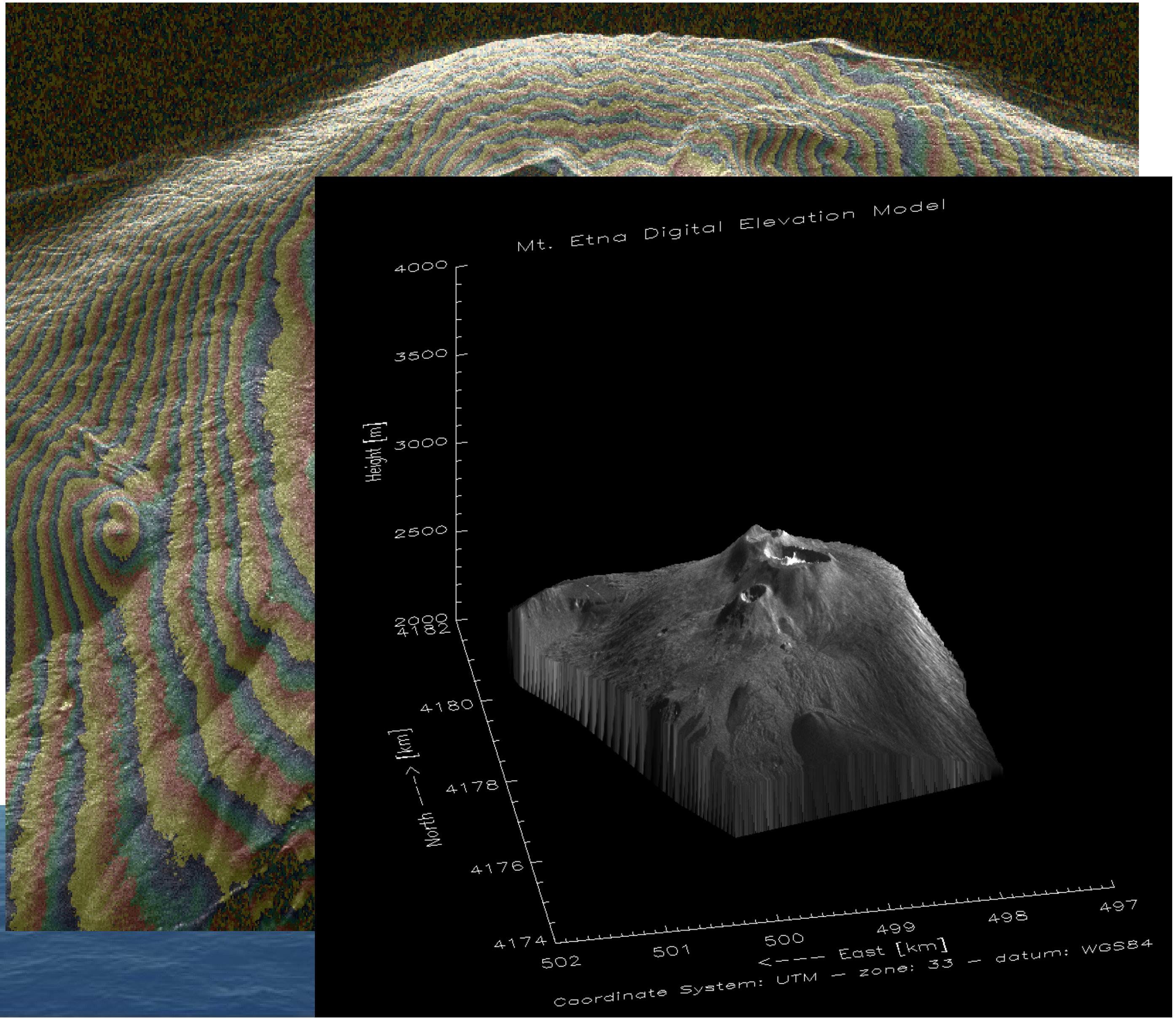
NESTRAD concept



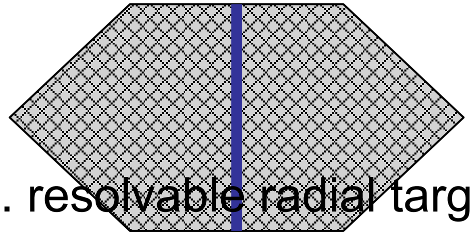
NESTRAD: Spatial Coverage for Indonesia



NESTRAD additional modes: SAR and InSAR



NESTRAD additional modes: ATI (along-track interf.)

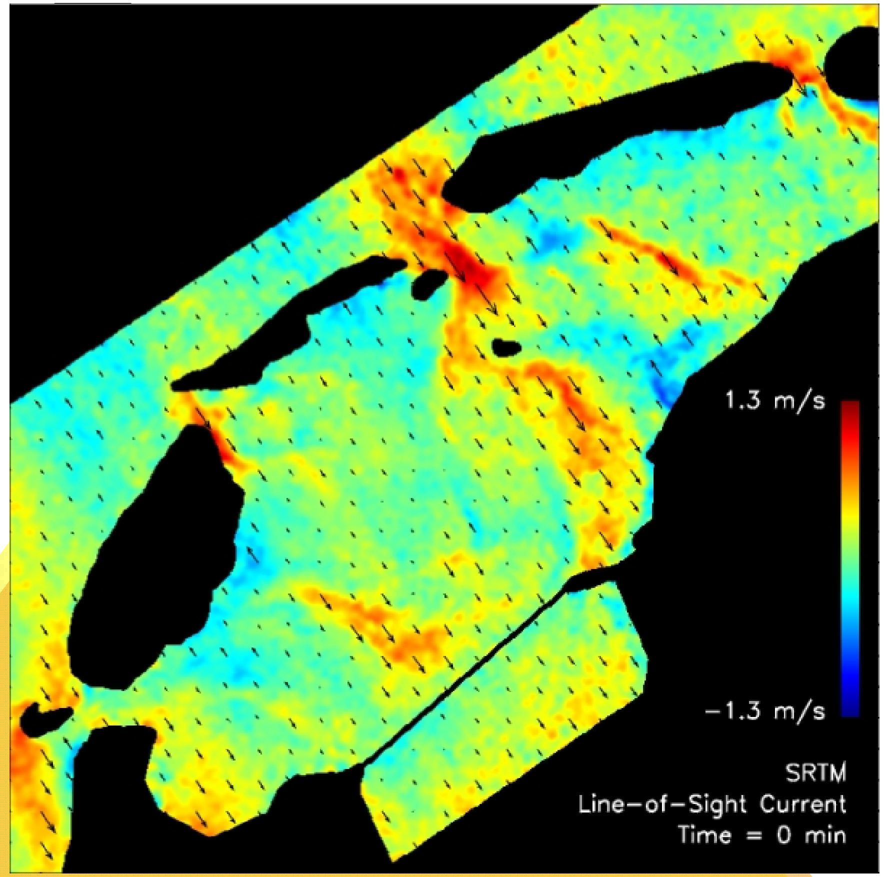


Min. resolvable radial target velocities:

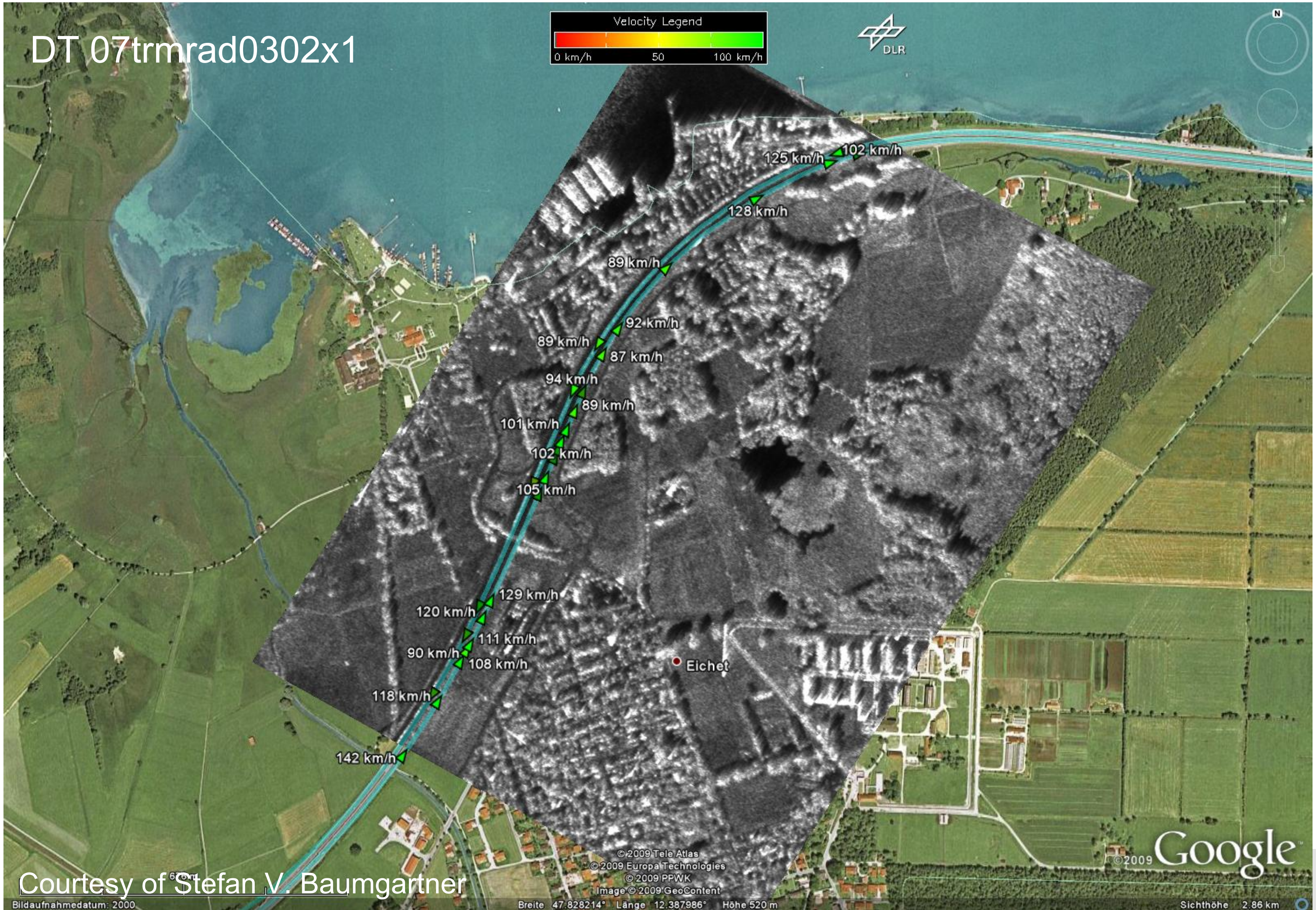
$v_{min} = \lambda v_P/(2L) = 0.025$ m/s = 0.09 km/h

Antenna devided in along-track direction

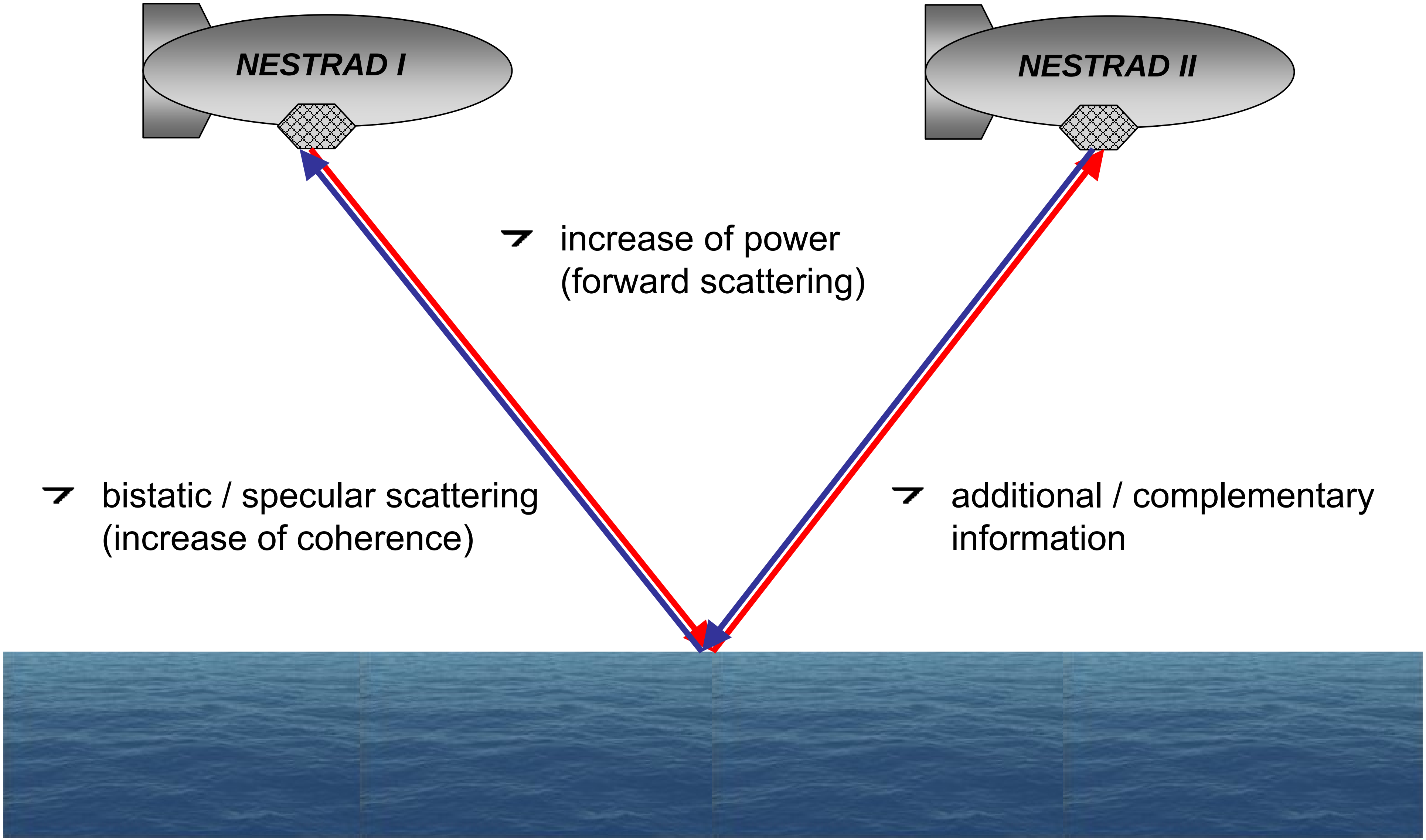
→ moving target identication or motion detection (e.g. ocean currents, ships and traffic monitoring)!



Real Road Traffic near Chiemsee on 16. July 2007



NESTRAD additional modes: bistatic geometries



- increase of power (forward scattering)
- bistatic / specular scattering (increase of coherence)
- additional / complementary information

What could be done …

- Seldom do Tsunami happen!
- → NESTRAD must be conceived as a **multi-purpose sensor** serving e.g.
  - Tsunami detection
  - Sea state monitoring
  - Ship tracking (traffic, piracy, etc.)
  - Reconnaissance and surveillance
  - Weather monitoring
  - Hurricane monitoring
  - Volcano monitoring
  - Flood monitoring
  - Traffic monitoring

- Platform:
  - can carry **multiple sensors** (radar, GNSS, optical, infrared, etc.)
  - can also serve as communication relay station