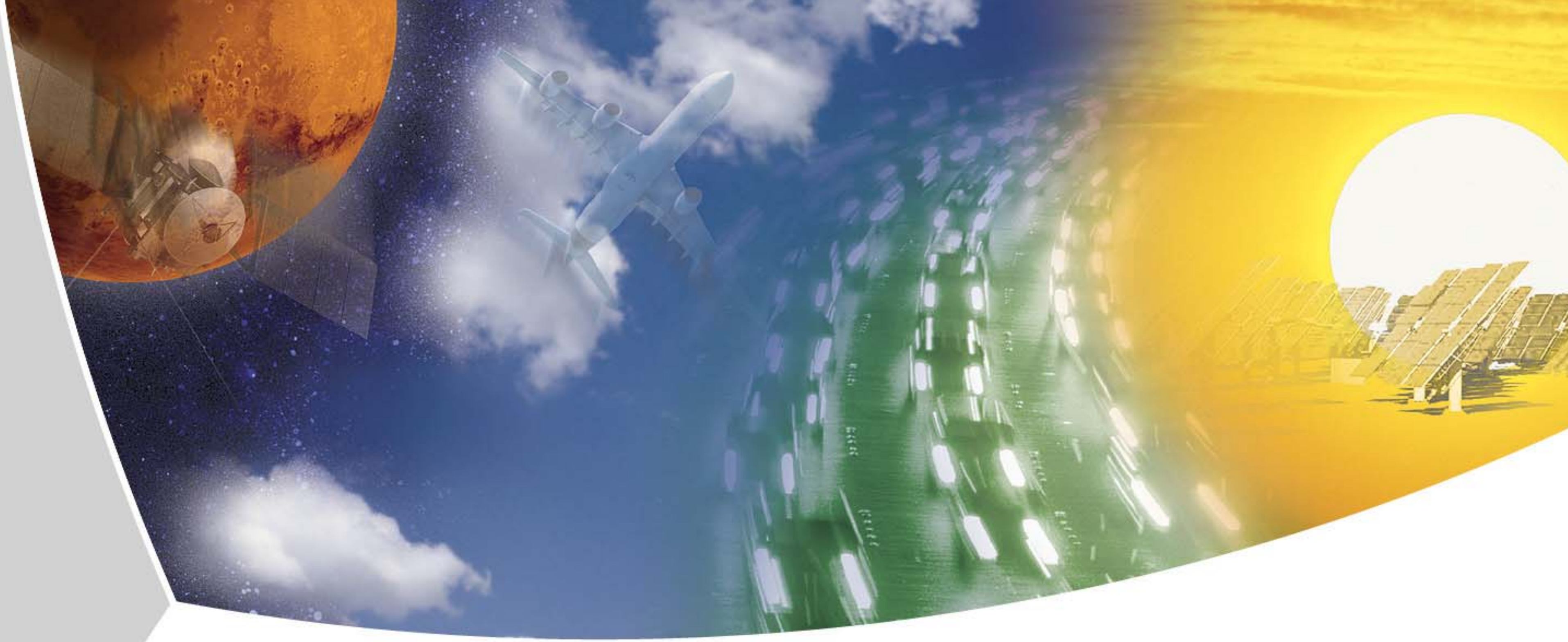

Concept Design of Space-Borne Radars for Tsunami Detection

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***Remote Sensing Institute**

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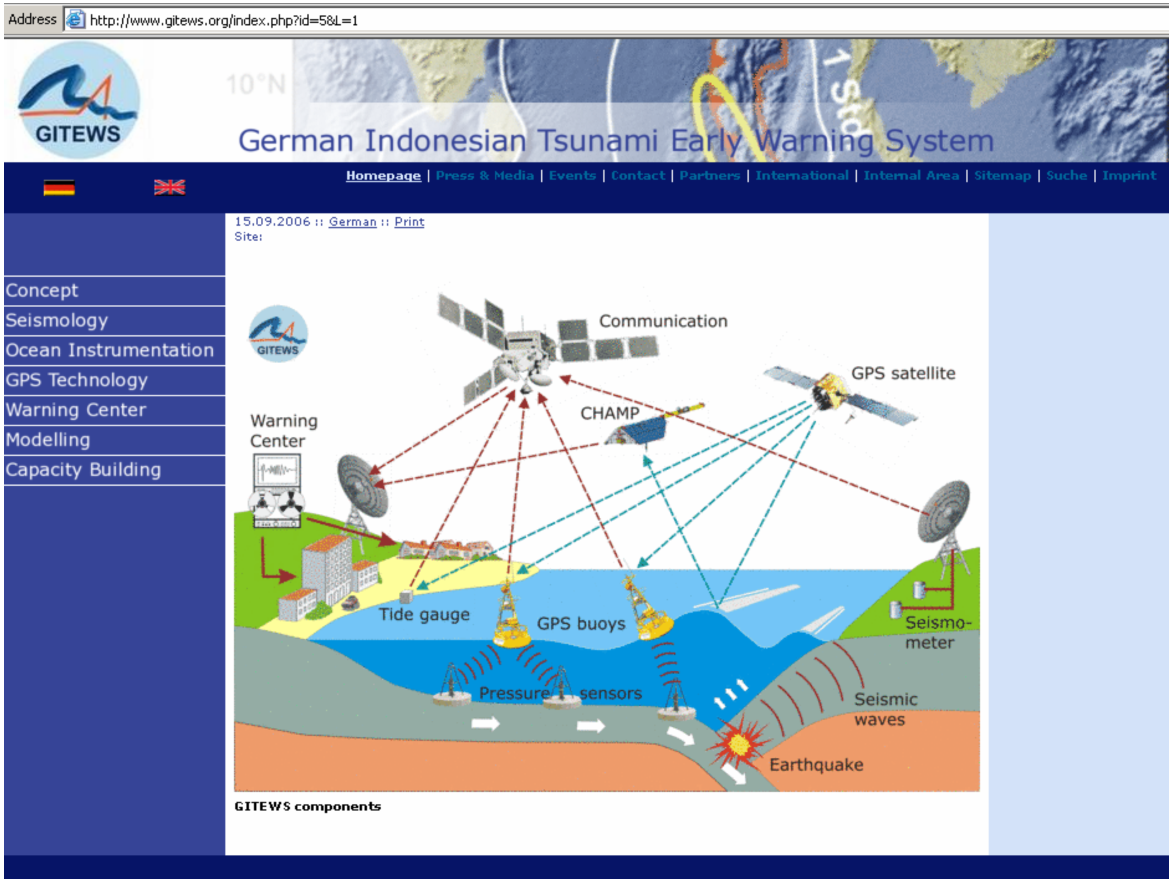
GITEWS: German-Indonesian Tsunami Early-Warning System



www.gitews.org

- Seismic component
- GPS technologies
- Tsunami models
- Ocean Instrumentation

- WP 4400
  New earth-observing technologies

GOAL: Development of new, radar-based concepts for future Tsunami Warning Systems

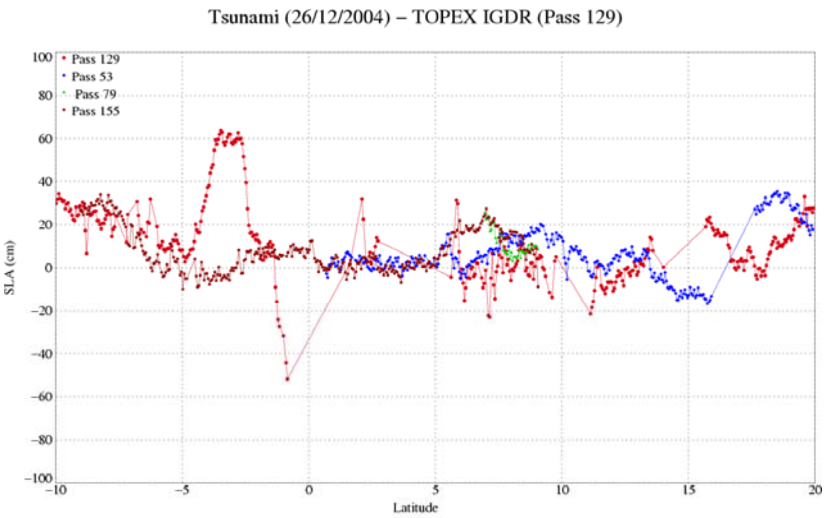
Overview

Principles of Detection for Space-Borne Radars:

What can we 'see' ?

ALTIMETER MODE
(measuring tsunami wave height)

Radar Altimeters measured tsunami wave height !



Cautionary Notes:

Data not immediately available
-Geophysical Noise
-Motion Compensation

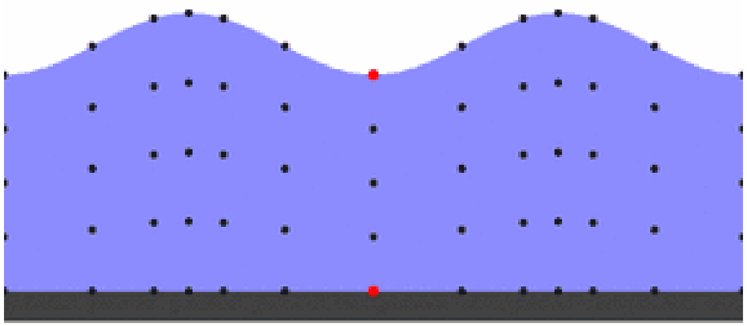
Okal, E. A., A. Piatanesi, and P. Heinrich, Tsunami detection by satellite altimetry, J. Geophys. Res., 104, 599-615, 1999.

Smith, W.H.F., R. Scharroo, V.V. Titov, D. Arcas, and B.K. Arbic, Satellite altimeters measure tsunami. *Oceanography, 18(2)*, 11-13, 2005.

DOPPLER MODE
(measuring tsunami orbital velocities)

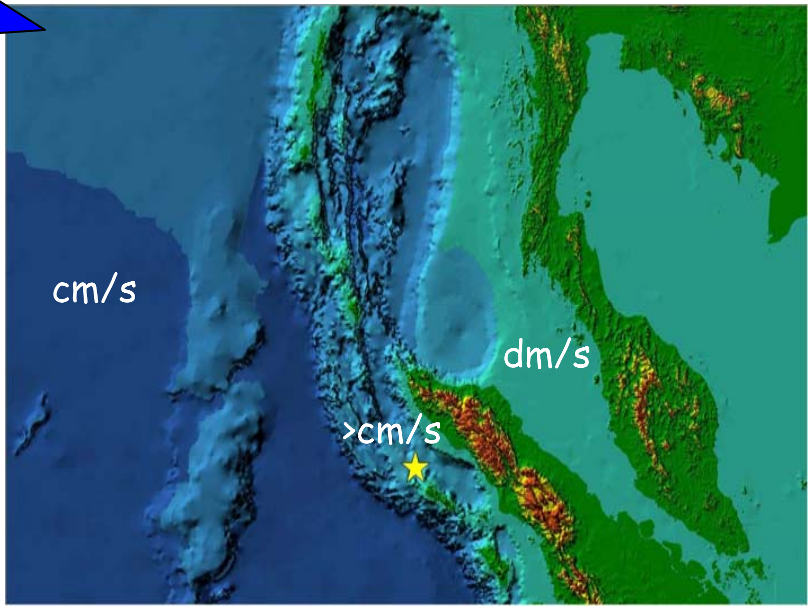
Tsunami horizontal orbital velocities
are in the order of

Units of cm/s (high seas)
Tens of cm/s (continental shelf)



Wikipedia

ATI-SAR has the potential to detect a tsunami !
Doppler Precision in the order of cm/s
(after multi-looking)



Cautionary Notes:

Flight track must be parallel to the wave-front !!

TSUNAMI SHADOWS (measuring Radar Cross Section)

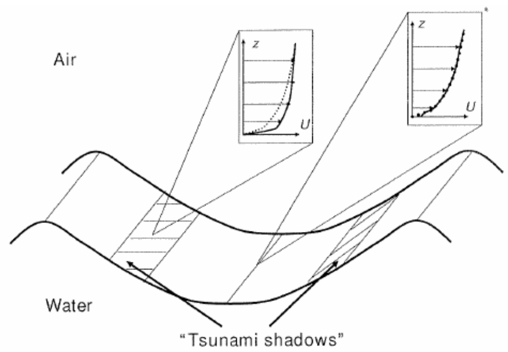


Figure 1. A conceptual representation of "tsunami shadows" and their theoretically predicted relation to the tsunami-induced wind velocity perturbations. "Tsunami shadows" (hatched) are parallel to the tsunami wave front and occur in between the tsunami troughs and crests where the wind perturbation is maximal. Perturbed (solid lines) and unperturbed (dotted lines) wind velocity is shown as a function of height above the ocean surface.

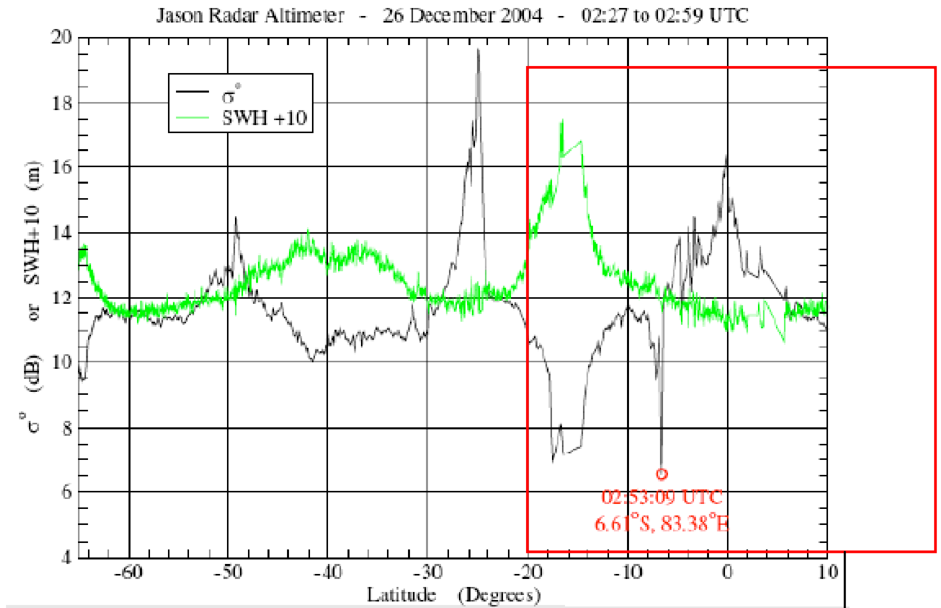
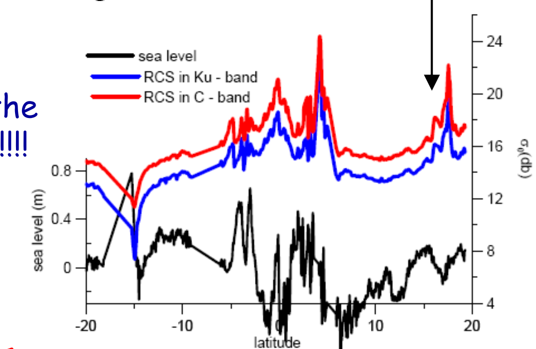


Figure 12. Along-track Jason significant save height and radar back scatter σ_0.

Recent works give an analytical description of tsunami-induced RCS modulations present in the open ocean as well as in coastal areas: Tsunami Shadows.

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

Tsunami Shadows were observed in the Geophysical Data Record of Jason-1 !!!!



Troitskaya, Yuliya I.; Ermakov, Stanislav A., Manifestations of the Indian Ocean tsunami of 2004 in satellite nadir-viewing radar backscatter variations, Geophys. Res. Lett., Vol. 33, No. 4, 24 February 2006

Size of tsunami shadows: Tens × Thousands of km

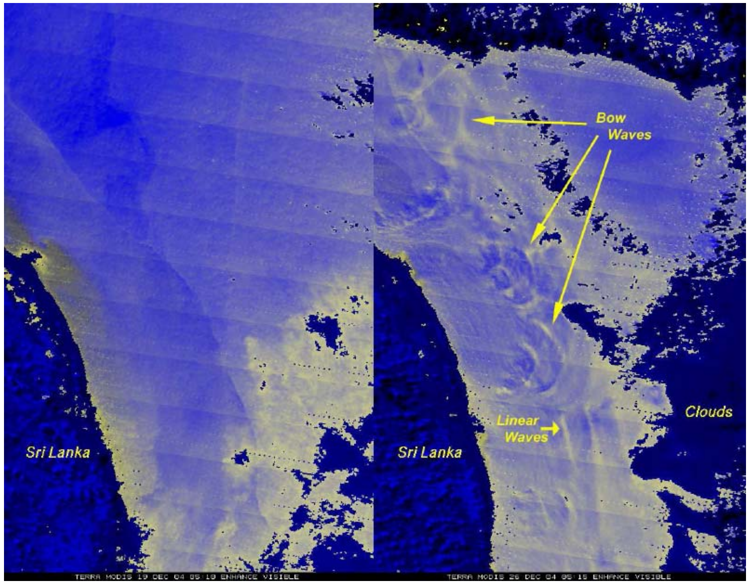
Cautionary Notes about Tsunami Shadows
Robust against sea-state ?
Robust against atmosphere state ?
Robust against Tsunami magnitude ?
Can we timely filter geophysical noise ?
Can we use the effect for early-warning ?

TSUNAMI-INDUCED INTERNAL WAVES
(measuring Radar Cross Section)

MODIS

Tsunamis are long gravity waves.
As well as tides, tsunamis can trigger internal waves.

Tsunami-induced internal waves were observed by MODIS for the 2004 Boxing Day tsunami.



D. A. Santek; Winguth A.,
A satellite view of internal waves induced by the Indian Ocean tsunami,
International Journal of Remote sensing,

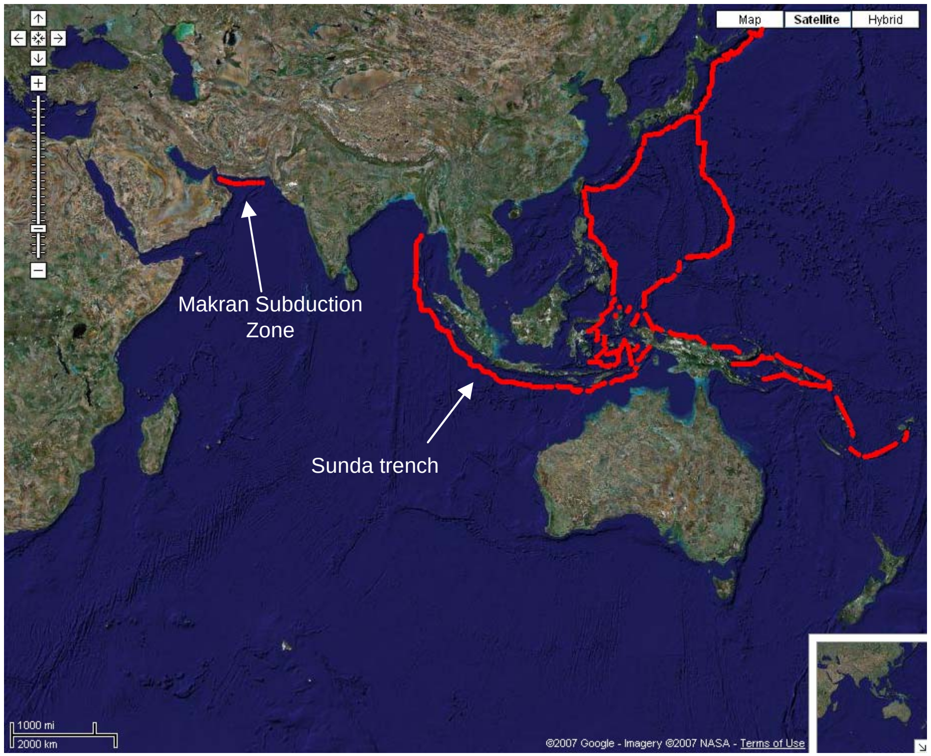
Single channel SAR systems and Optical passive sensors can image tsunami-related features !

CAUTIONARY NOTES:
Even though they both appear as radar cross section modulations, Tsunami Shadows and Tsunami-induced internal waves are generated by different physical mechanisms !!!

Tsunami Early-Warning Systems:
Requirements on temporal and spatial coverage

Requirements for Tsunami Early-Warning

Tsunamigenic areas



NEAR-FIELD TSUNAMI

- Indonesian government requires first warning to be issued within 5 min from the quake……
- Temporal Coverage: 24/7, for immediate response…
- Spatial Coverage dictated by plate tectonics:

we need to cover tsunamigenic areas lying close to densely populated coasts: new problem!!

FAR-FIELD TSUNAMI

- Tsunamis can happen anytime but trans-oceanic propagation can take hours….

we need to track propagation to assess the tsunami hazard in the far-field.

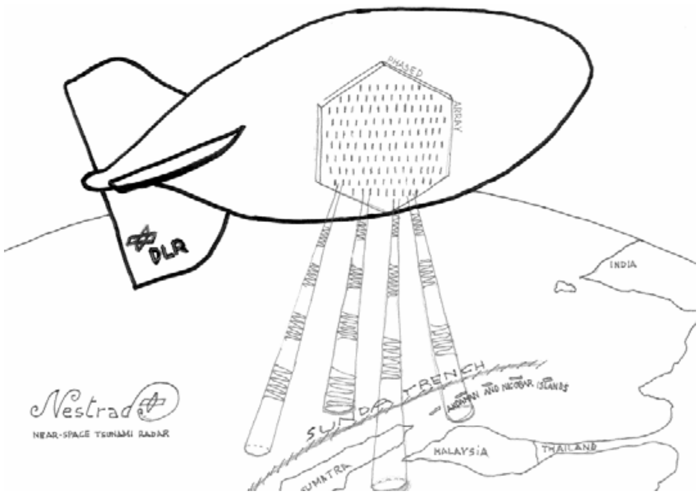
CONCEPT DESIGN OF SPACE-BORNE RADARS FOR TSUNAMI DETECTION

- Implementing one or more of the above-mentioned principles of detection from a platform capable of providing adequate temporal and spatial coverage

1. Stratospheric Airships
2. MEO orbits
3. GEO orbits

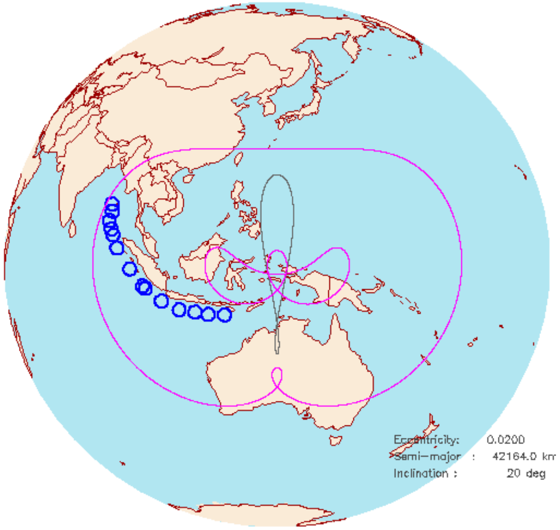
NESTRAD

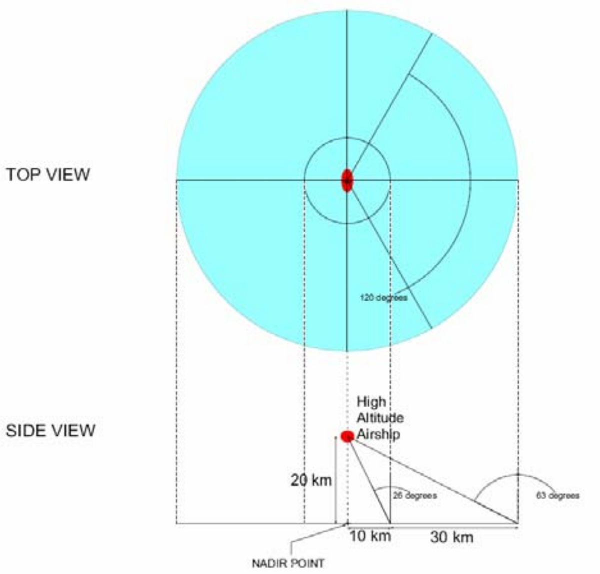
Concept Design of a Near-Space Radar for Tsunami Detection

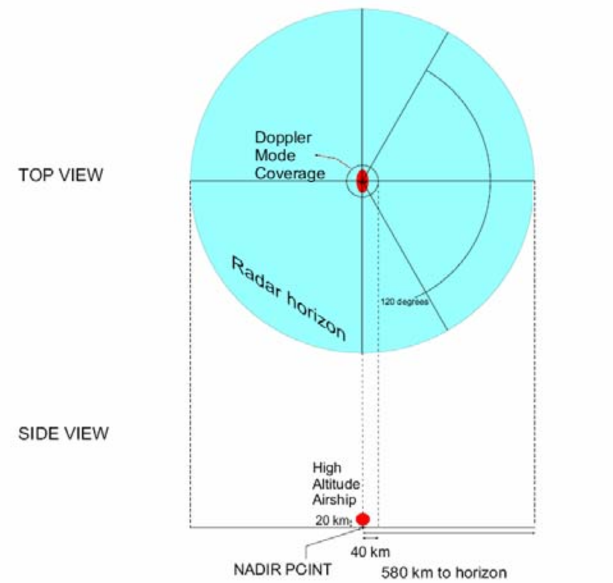


G-SAR

Concept Design of a Geosynchronous SAR for Tsunami Detection







NESTRAD

DOPPLER MODE
ALTIMETER MODE

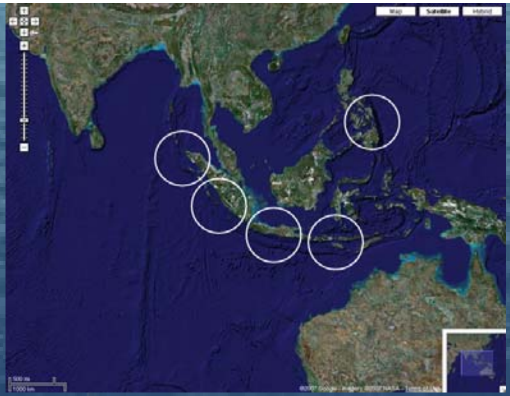
- Wave Height at Nadir
- Orbital Velocities
- Tsunami Shadows
- Tsunami-induced internal waves

RADAR CROSS SECTION

NESTRAD coverage (NEAMTWS)

NESTRAD consists of a real aperture phased array radar accommodated inside a stationary stratospheric airship.
It provides all-weather, day-and-night coverage.

Stratospheric Airships are unmanned, untethered, lighter-than-air vehicles expected to persist 12 months on station providing continuous, real-time coverage.



NESTRAD coverage (IOTEWS)

More on IGARSS 07 Conference Proceedings !!

G-SAR

Concept Design of a Geosynchronous SAR for Tsunami Detection

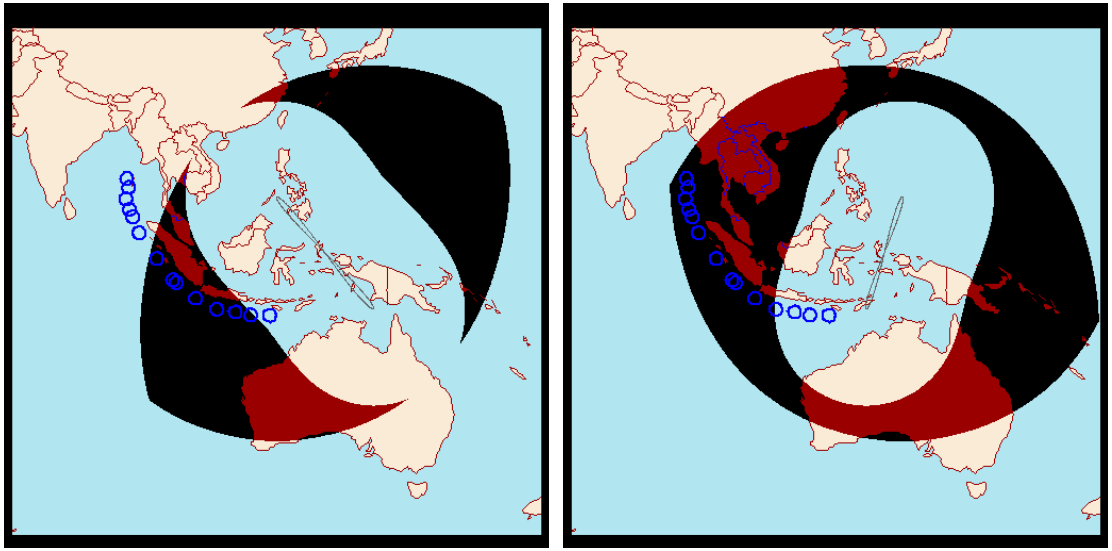
G-SAR: Concept Design of a Geosynchronous SAR for Tsunami Detection

Detected feature: Tsunami Shadows

Spatial Resolution
Δr ~ 10 km Δaz ~ 10 km

Temporal Coverage
24/7 for Near-field tsunami

Spatial Coverage
As large as possible



we can choose eccentricity, inclination and argument of perigee to optimize the coverage….

A Synthetic Aperture Radar in a geosynchronous orbit…

incidence angle range:	20° ≤ η ≤ 50°
Max scan angle off nadir:	6.6° -> Nadir looking antenna
Accessible area:	two sectors, right and left of flight track

Ambiguities Constraints

La	antenna length	La	= 5 m	
Wa	antenna width	Wa	= 2 m	(antenna aperture = 10 m^2)
λ	wavelength	λ	= 0.03 (X band)	
c	speed of light	c	= 299792458. m/s	
η	incidence angle	η	= 20° - 50° (SAR)	
PRF	pulse repetition frequency	PRF	= 4000 Hz	
R	slant range	R	= dependent on η	
V	platform velocity	V	= 15 m/s	

Range Ambiguities: $Wa > 2\lambda R\,(PRF)\tan(\eta)/c$

Azimuth Ambiguities: $La > 2V/(PRF)$

Antenna Aperture: $(La \times Wa) > 4\lambda R V \tan(\eta)/c$

Nadir Interference: okay

Transmit Interference: okay

SNR   Signal-to-Noise Ratio

Pt	transmitted power	Pt	= 100 W	
τ	pulse width	τ	= 50 μs	(duty cycle 20%)
N	noise figure	N	= 3 dB	
T	noise temperature	T	= 300 K	
L	loss	L	= 3 dB	(dependent on atmosphere state)
σ^0	normalized RCS	σ^0	= - 20 dB	dependent on η, pol and sea state
SNR	Signal-to-Noise Ratio	Pol	VV	

Signal Power (radar equation) — Noise Power

$$SNR = \underbrace{\left(\frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4}\right)\left(\frac{1}{L}\right)\sigma^0\left(\frac{c\tau}{2\sin(\eta)}\right)\left(\frac{\lambda R}{L_a}\right)}_{\text{Signal Power (radar equation)}}\underbrace{\left(\frac{1}{kNTB}\right)}_{\text{Noise Power}}$$

SNR ≈ 30 dB

Spatial Resolution

B bandwidth
La antenna Length
R slant range
Re Earth radius
h platform height
Ls synthetic aperture length
Ts integration time

B = 200 MHz
La = 5 m
R dependent on η
Re = 6400 km
h = 20 km

	20°	50°
$\Delta r = \frac{c}{2B\sin(\eta)}$	11 km	4.9 km
$\Delta az = \left(\frac{L_a}{2}\right)\left(\frac{R_e}{R_e+h}\right)$	0.53 m	0.53 m
$T_S = \frac{L_S}{v}$	2031 s	2128 s
$L_S = \left(\frac{\lambda R}{L_a}\right)\left(\frac{R_e+h}{R_e}\right)$	1.02e6 m	1.06e6 m

Not needed, and further,

requires very long integration times,

not suitable for tsunami early-warning !!

~ 35 min

Then go for sublooks

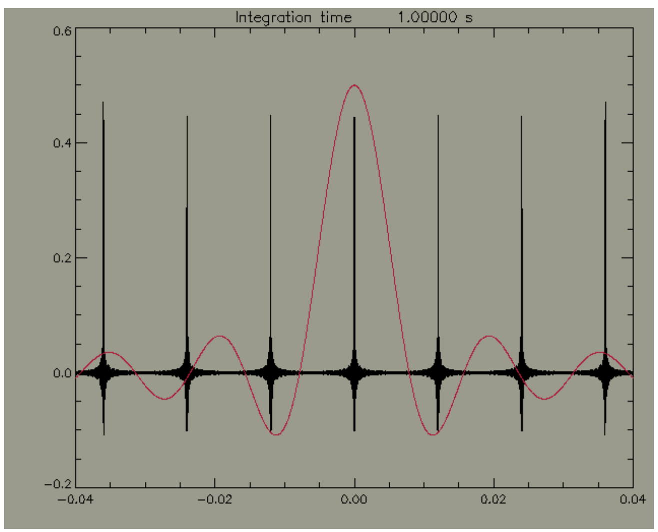
Sublook Azimuth Resolution

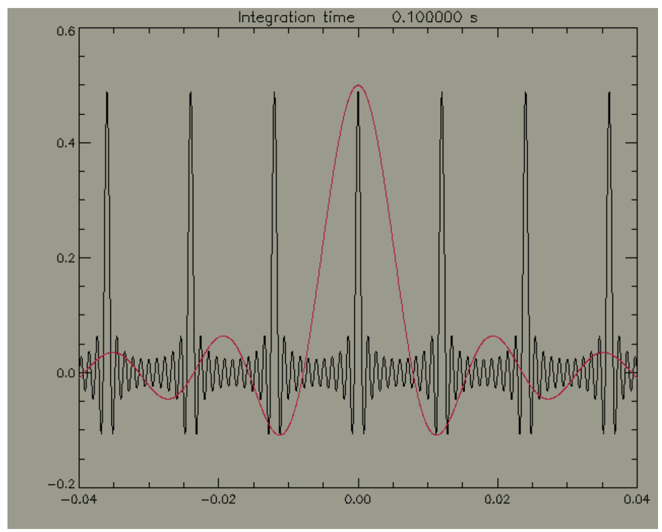
La Antenna Length 7 m
λ wavelength 0.03 m
} SAR antenna radiation pattern

PRF 200 Hz
v 500 m/s
} Ambiguity positions

Ts integration time } main lobe 3dB beamwidth

Inc. angles / Int. times (s)	20°	50°
0.1	10.8 km	11.4 km
0.2	5.4 km	5.7 km
0.5	2.2 km	2.3 km
1	1.1 km	1.1 km





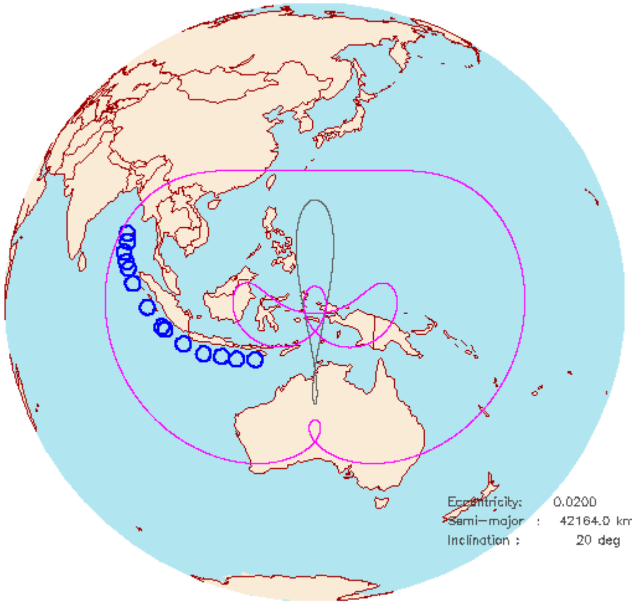
Minimum integration times to match the (10×10) km resolution constraint

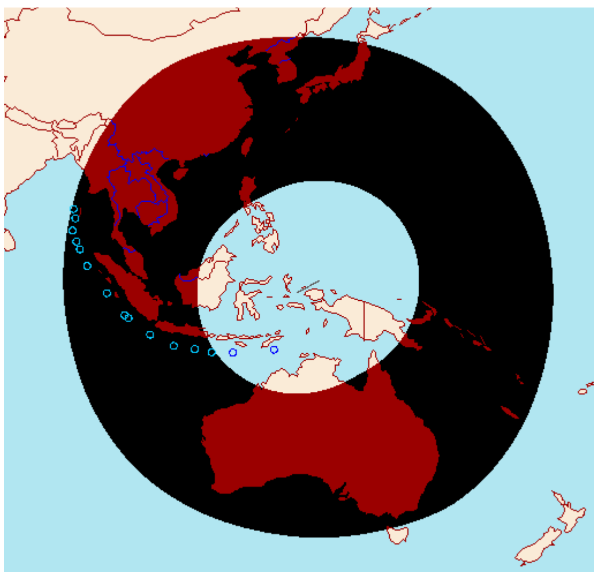
500 m/s -> 0.1 s
50 m/s -> 1 s
5 m/s -> 10 s

range of allowed platform velocities !!

50 m/s < V < 500 m/s

G-SAR: 2 SAR satellites in geosynchronous orbit





v_min:	50.7m/s
v_max:	115.2m/s
Inclination:	1.0°
Semi major:	42164.0km
Eccentricity:	0.0165
Ascend. Node:	132.3°
Arg. of Perigee:	0.0°

System Parameters	
Antenna	(7×2)m phased array
Frequency	10 GHz
Polarization	VV
Path Loss	3 dB
Noise Figure	3 dB
Antenna Parameters	
Antenna Aperture	14 m^2
Antenna Gain	53 dBi
Side lobe level	-13 dB
Max. scan angle	7°
Waveform Parameters	
Range resolution	~ 10 km
Azimuth resolution	<10 km (depending on V)
Peak Power	2 kW
Bandwidth	40 kHz
Pulse width	1 ms
PRF	200 Hz
Power Duty cycle	20 %

CONCLUSIONS

- A number of sensors (passive and active) can provide valuable information about tsunami

RADAR ALTIMETRY	(tsunami shadows and wave height)
GPS REFLECTOMETRY	(tsunami shadows and maybe wave height)
SCATTEROMETERS	(tsunami shadows)
ATI-SAR	(tsunami shadows and orbital velocities)
single channel SAR	(tsunami shadows)
RADIOMETERS	

- It is mandatory to know more about tsunami-related features (especially tsunami shadows !)
    - Airborne SAR campaigns
    - Theoretical modeling

- *A Geosynchronous SAR is proposed as a concept for tsunami early-warning.*

- NESTRAD, another concept for tsunami early-warning is illustrated in the proceedings

- BOTH CONCEPTS ARE DESIGNED AS MULTI-PURPOSE SENSORS

- Always consider the possibility of implementing the same concepts with parasitic signals from communication and navigation !! (GPS signals or TV signals)

THANKS, and go to high ground !!