2012年電波航法研究会

津波に対するレーダ観測活動の調査(その2)

平成24年9月7日

元日本工業大学
渡辺康夫

調査（その2）の構成

１．　はじめに

２．　衛星搭載マイクロ波電波高度計の津波観測

　　東北太平洋沖地震津波：**merging tsunami**

３．　**HF**レーダの津波観測

　　東北太平洋沖津波: **tsunami signal**

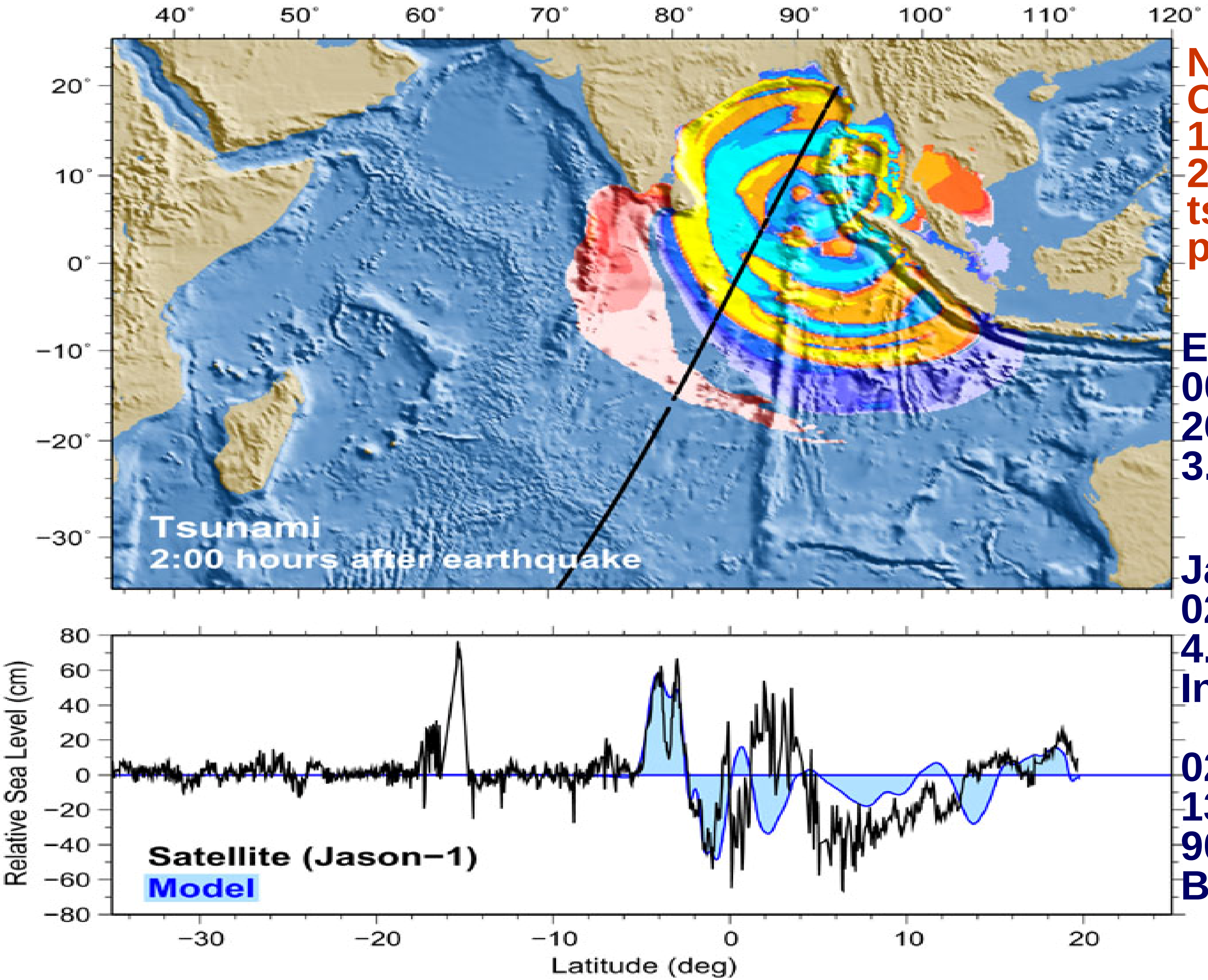
４．　津波探知のためのスペースセンサ

　　GNSS-Rを応用した津波探知技術等

５．　おわりに

論文等資料

Fig. 1 2004 Indian Ocean Tsunami



NOAA News Online 10 Jan 2005: 2004 tsunami propagation

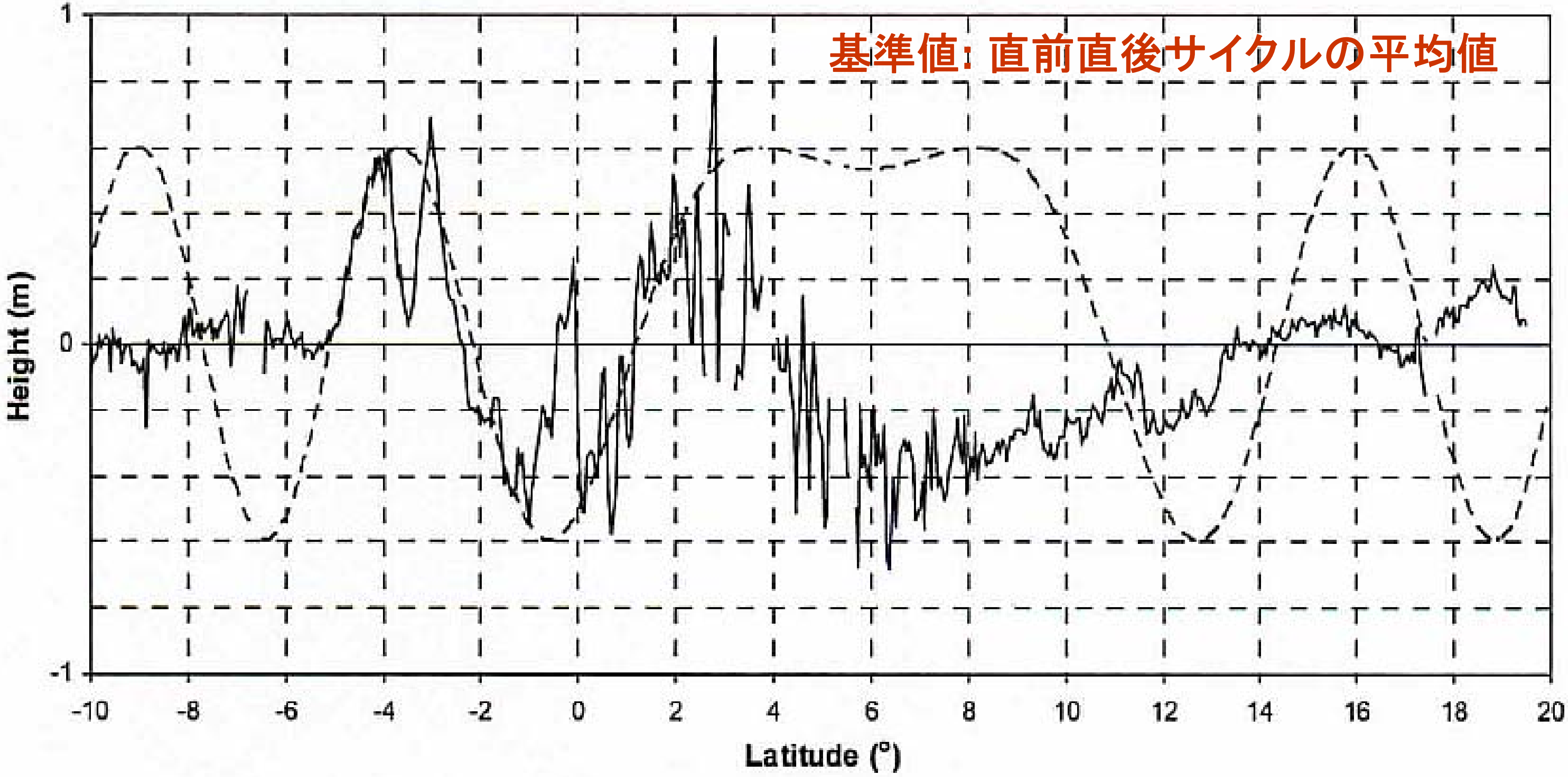
Epicenter:
00.58:53UT, 26 Dec. 2004. 3.2N, 94.2E.

Jason-1:
02:53:51UT, 4.56S, 84.12E. Ind. Ocean.

02:59:53UT, 13.15N, 90.56E. Bay of Bengal

Fig. 2 Sea Surface Height Anomalies: Data by Jason-1 and Model

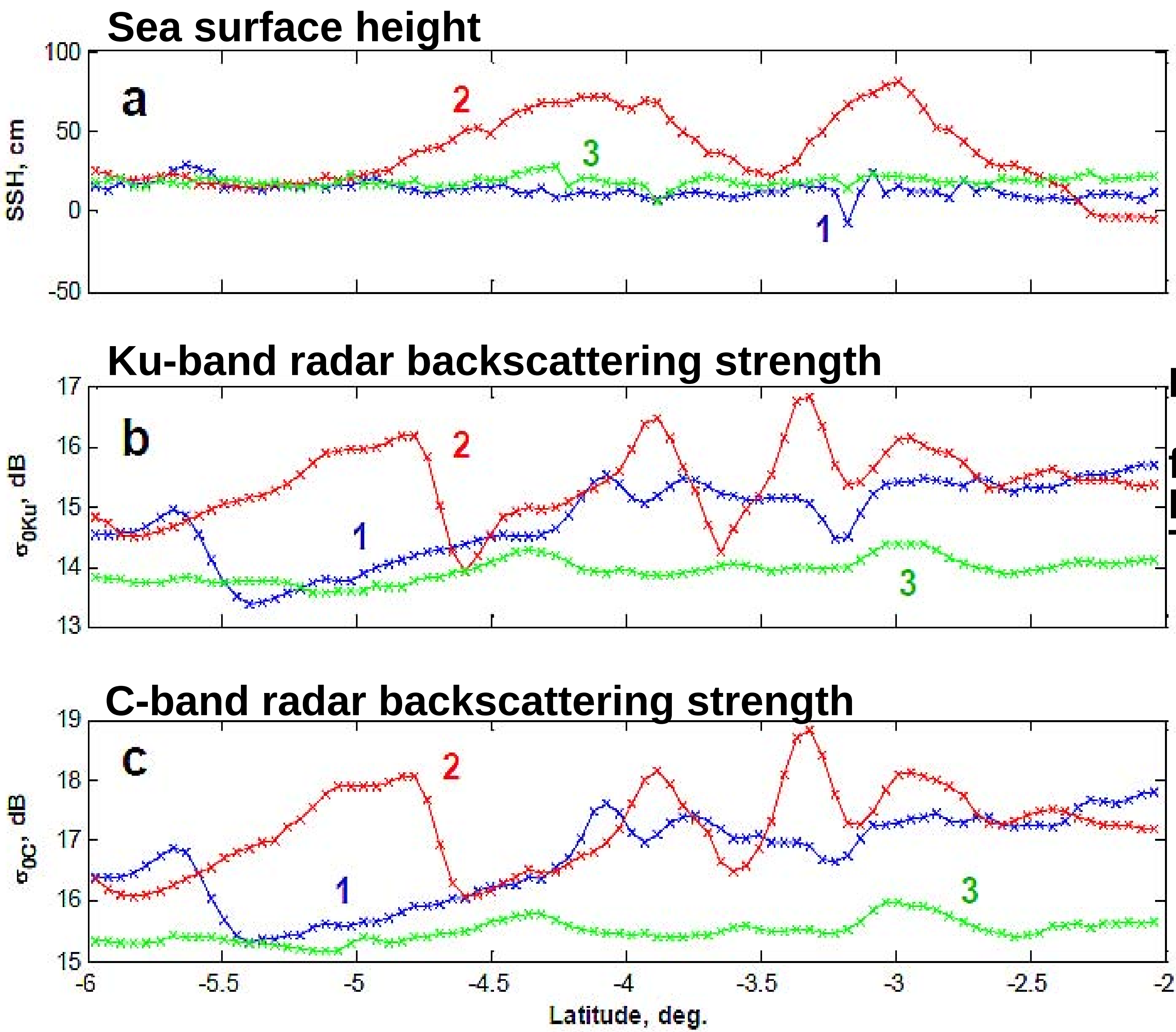
Gower, Int. J. Remo Sens, 2007



Solid: corrected sea surface height: (1) 4.56S: h=70cm-(30-40)cm, peak-to-peak 1m. (2)13.15N: h=-20cm. (3) v=739km/h for av. depth=4300m.

Dotted: sine wave model with λ =580km, v=739km/h, h=0.6m.

Fig. 3 Tsunami Shadows

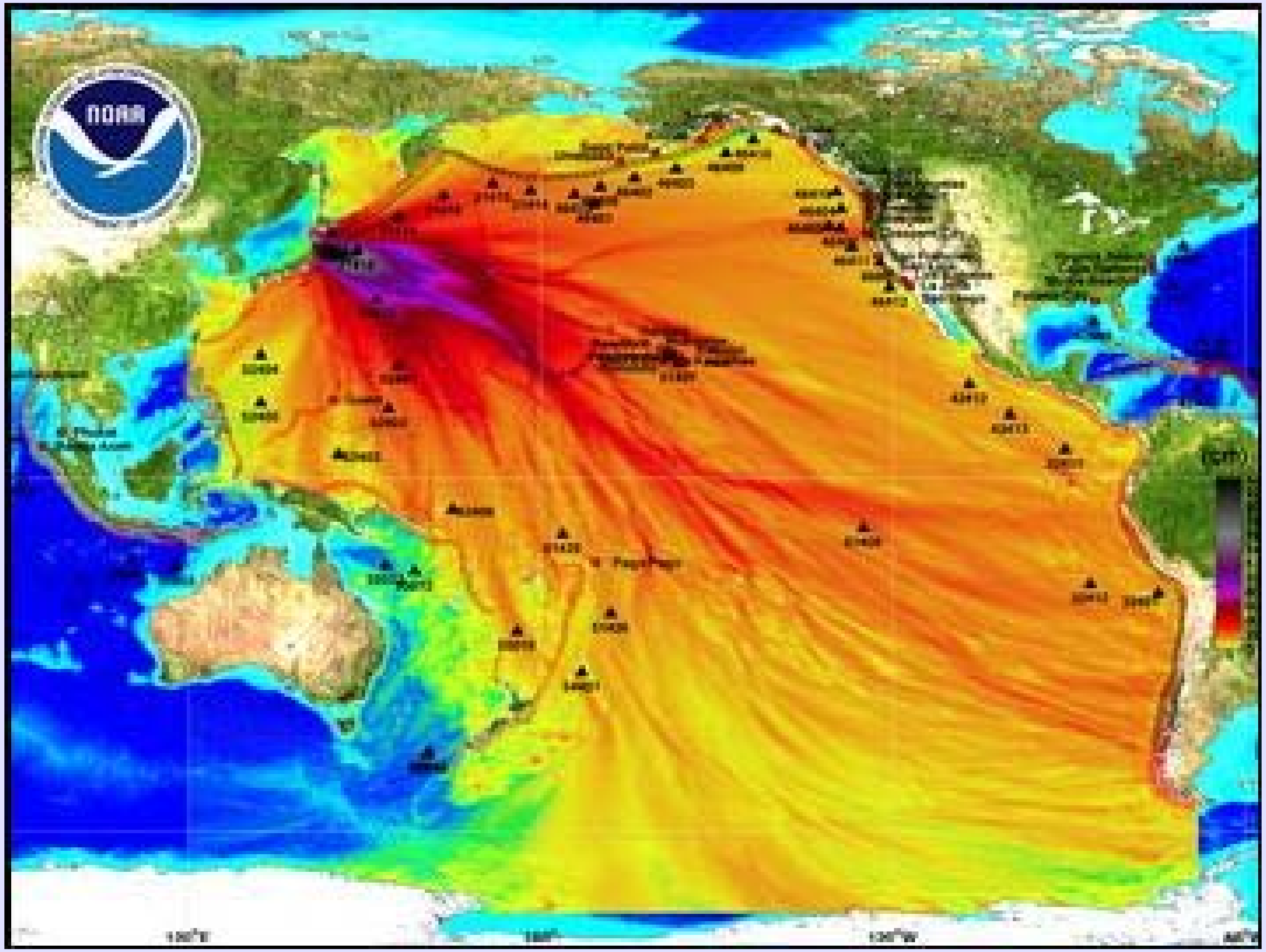


(1) Data days before
(2) Data: cycle 109
(3) Data 10days aft

Estimated σ^o $\pm$ 1dB for wind at H10m: 2-4m/s, Tsunami period 35-45min, SSH: (0.6-0.7m)~ -(0.4-0.5m).

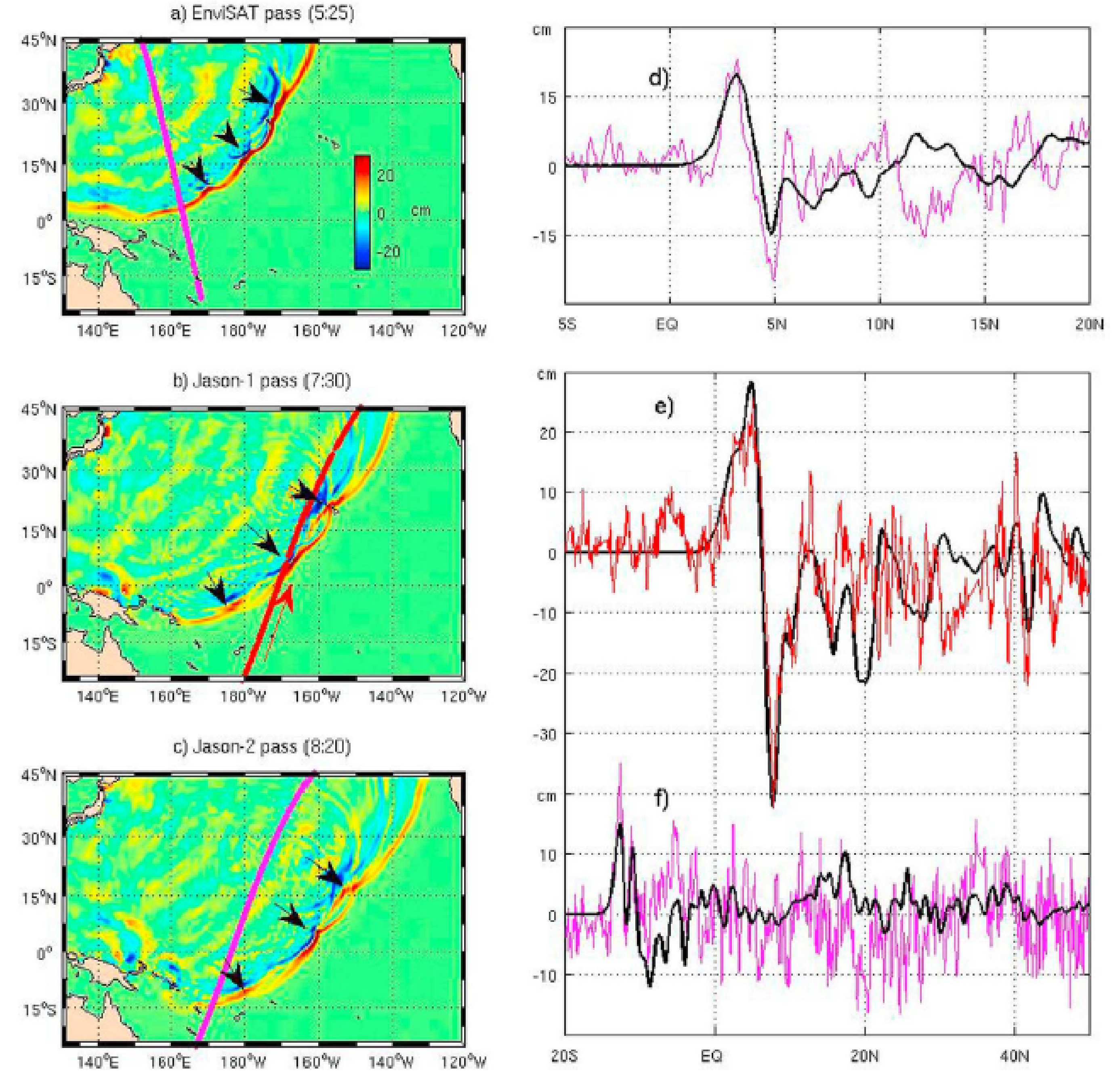
Godin, Nat Haz Earth Sys Sci, 2009

Fig. 4 Japan Tsunami, 11 March 2011



http://nctr.pmel.noaa.gov/

Fig. 5 Merging Tsunami, March 11, 2011



a) ENVISAT at 5:25 after quake
b) Jason-1 at 7:30 after
c) Jason-2 at 8:20 after
d) Tsunami model (black) and ENVISAT data
e) Jason-1 over Mid-Pacific Mt. Merging tsunami (red arrow)
f) Jason-2 data

Black arrows: locations of merging tsunamis

Song, Geo Res Lett, 2012

Fig. 6 Tsunami Model. (a) Amplitude (b) Amplitude (blue lines), Bathymetry (color bar)

Song, Geo Res Let, 2012

Crosses:DART

Black arrows: tsunami jets fr.
ES:Emperor Seamounts
nwHR:N-west Hawaiian Ridge
HR:Hawaiian R
Mid-Pacific Mt
MI:Martial Is
ME:Mendocino Escarpments

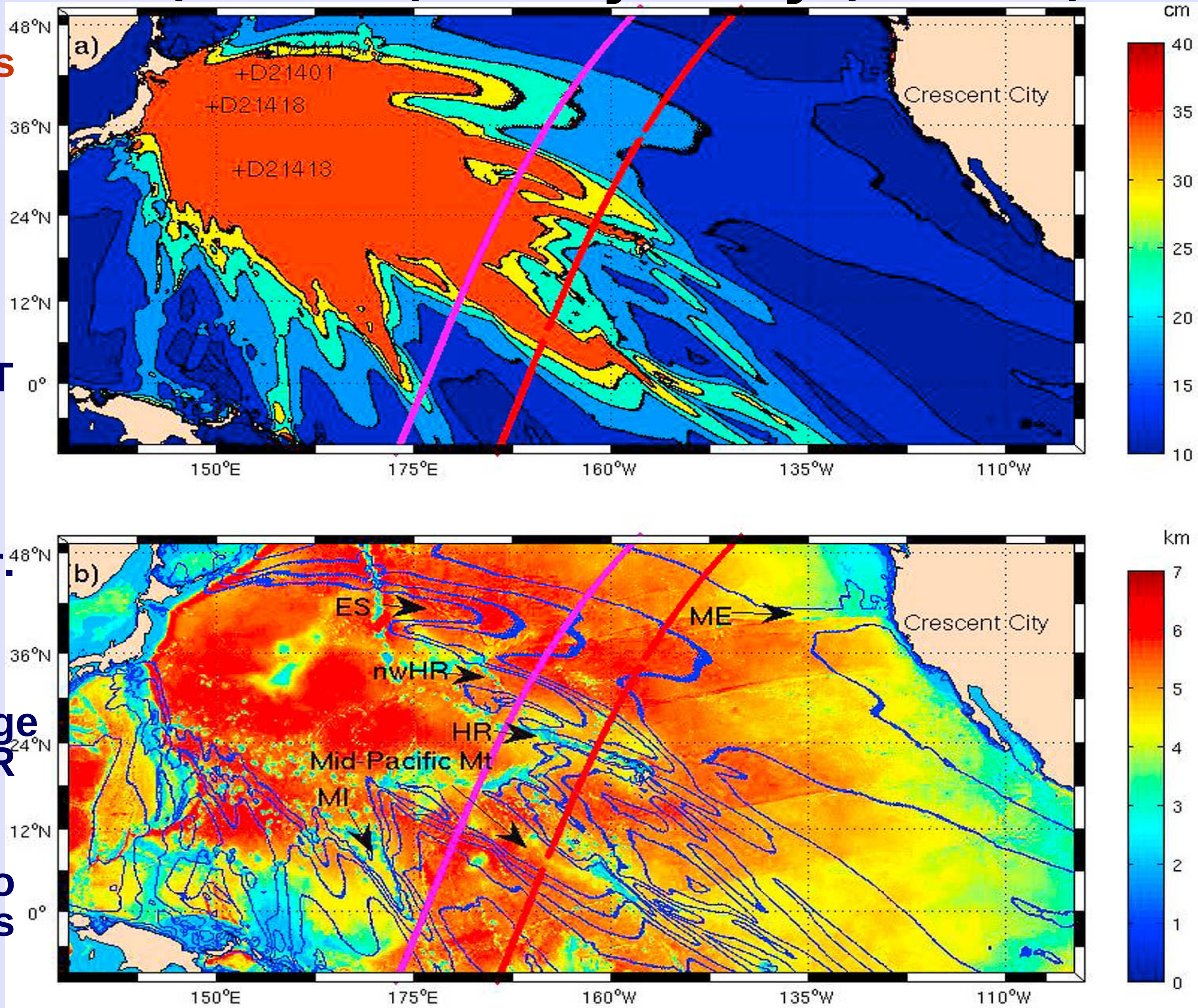
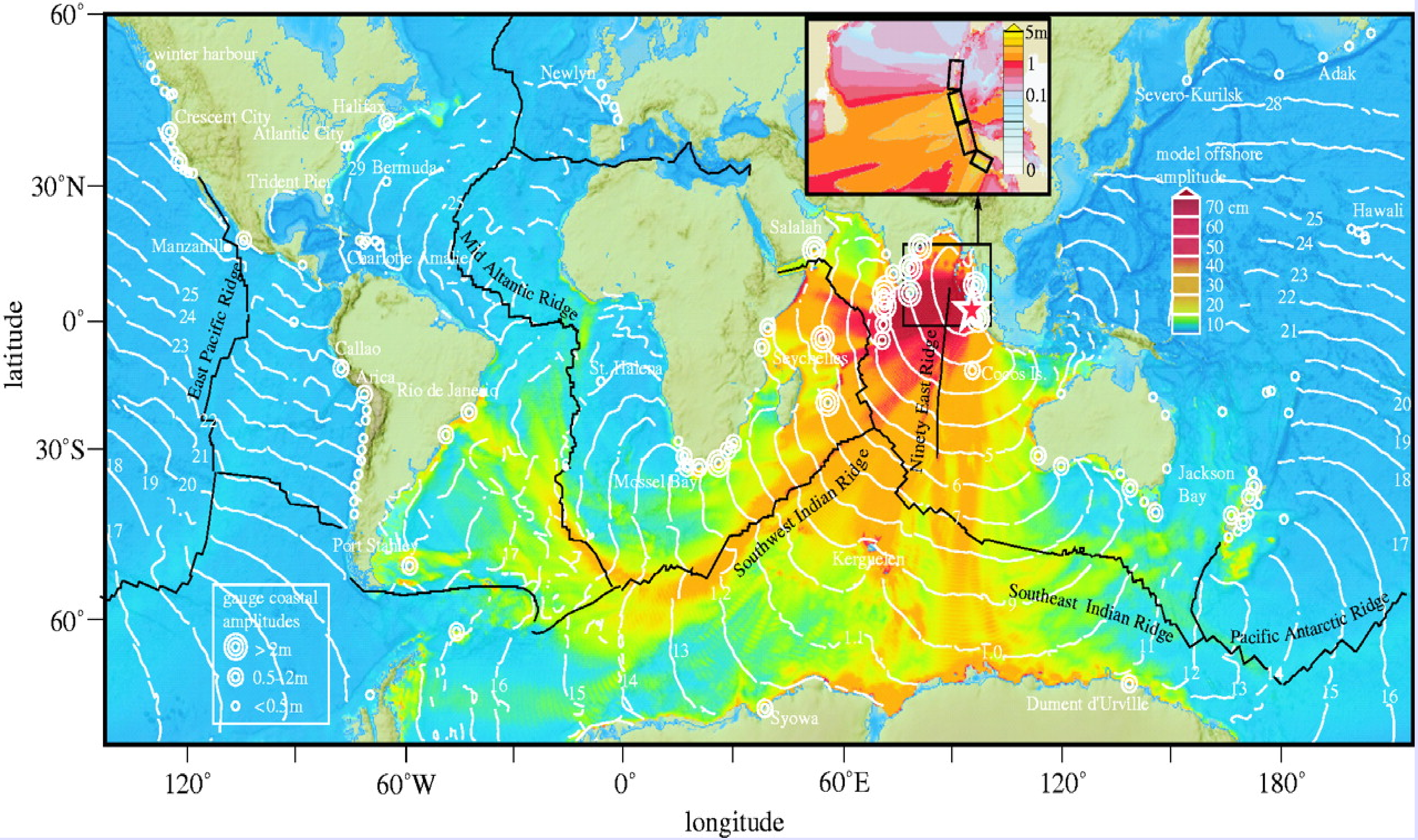


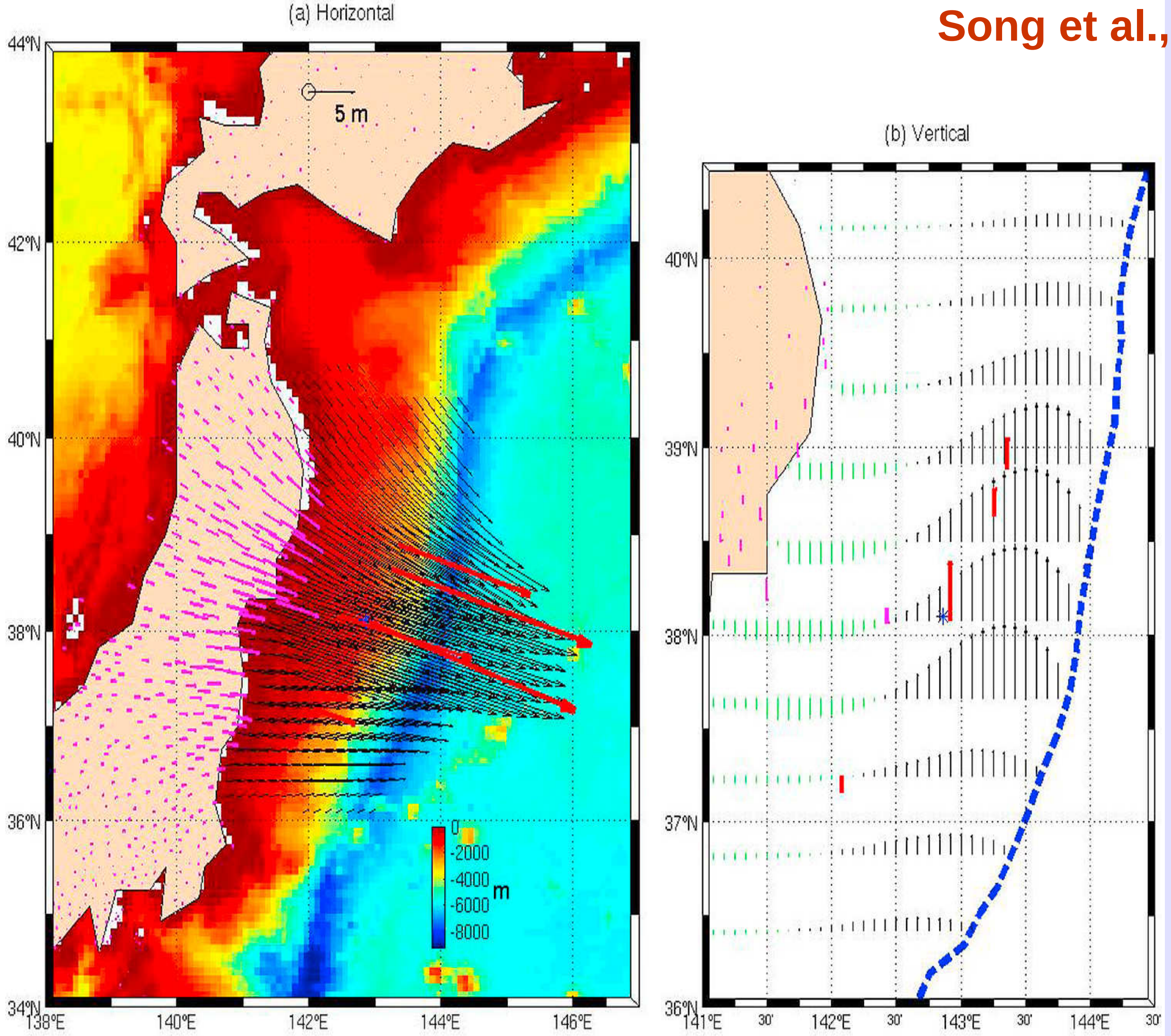
Fig. 7 Max. Amplitude of the 26 Dec. 2004 Tsunami Modelled by Titov et al.



Titov et al., Science, 309, 23 Sept. 2005

Fig. 8 GPS-measured Land Displacement and the Derived Seafloor Displacement

Song et al., Geo Res lett, 2012

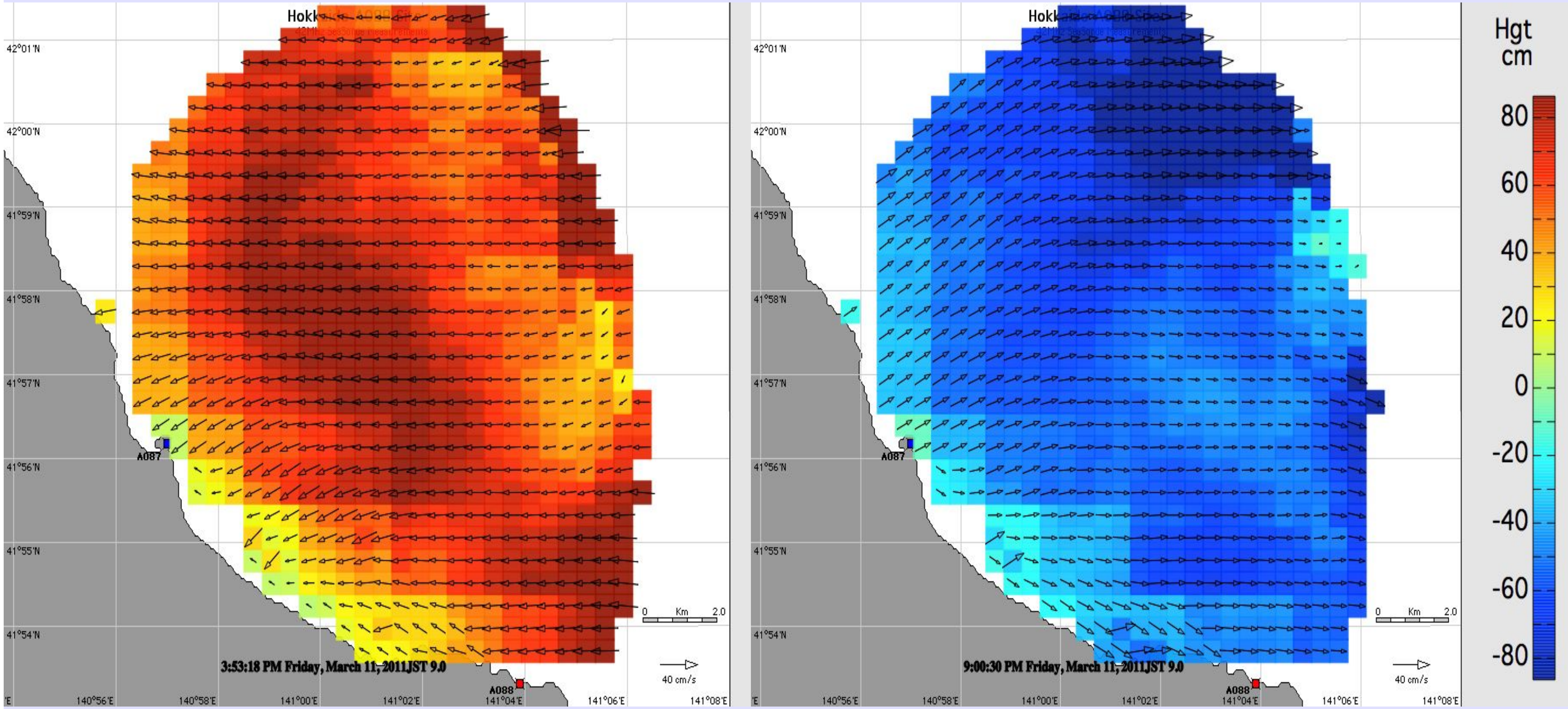


Movements arrows: 5m/div

(L)
pink: GPS data
black: derived seafloor move
heavy red: Sato's model
color: bathymetry

(R)
blue: trench
green: subsidence
black: uplift
heavy red: Sato's model
star: hypocenter

Fig. 9 Tsunami Height Superimposed on Total Current Velocity Field Measured by Radars at Usujiri and Kinaoshi



(L) Tsunami sweeping in, 15:53 JST. (R) sweeping out, 21:00 JST.
Blue dot: Usujiri, Red dot: Kinaoshi. v_0/div: 40cm/s. h: color code.

Lipa et al., Remote Sensing, 3 Aug. 2011

Fig. 10 Radial Current Velocities from Usujiri Radar

Lipa et al., Remote Sensing, 2012

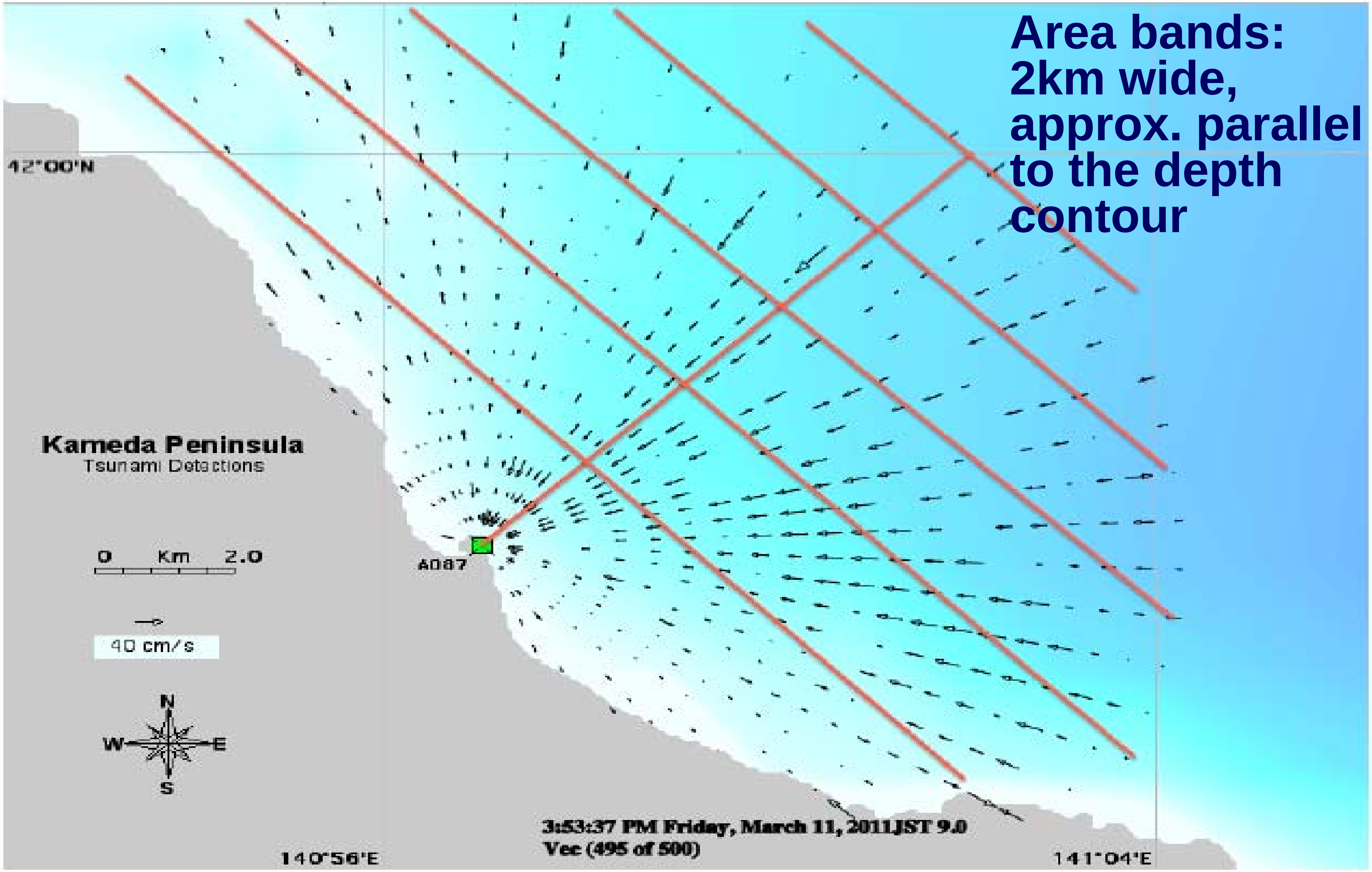
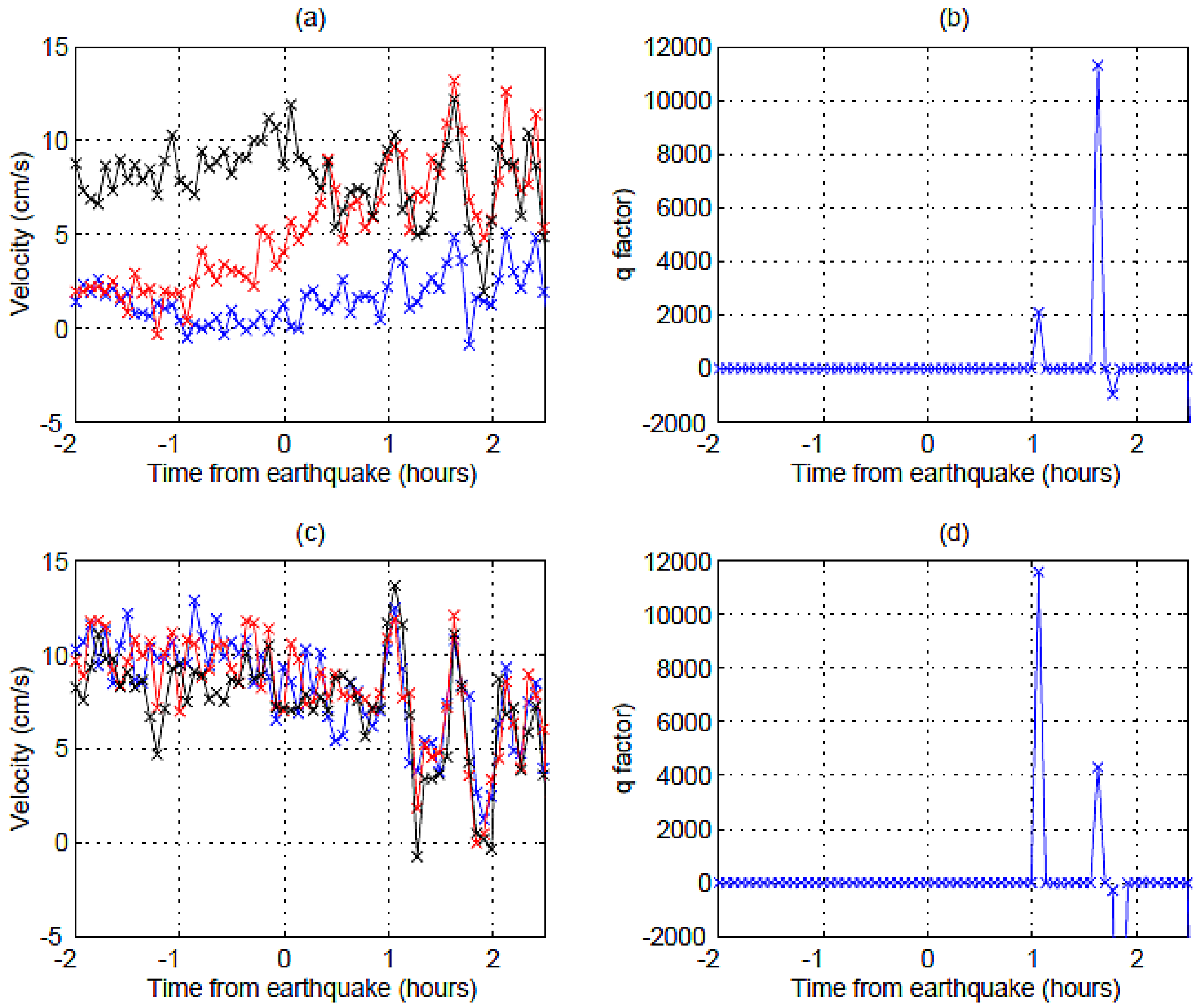


Fig. 11 Velocity Components from Kinaoshi Radar and q-factor



(a)
blue: 0-2km
red: 2-4km
black: 4-6km

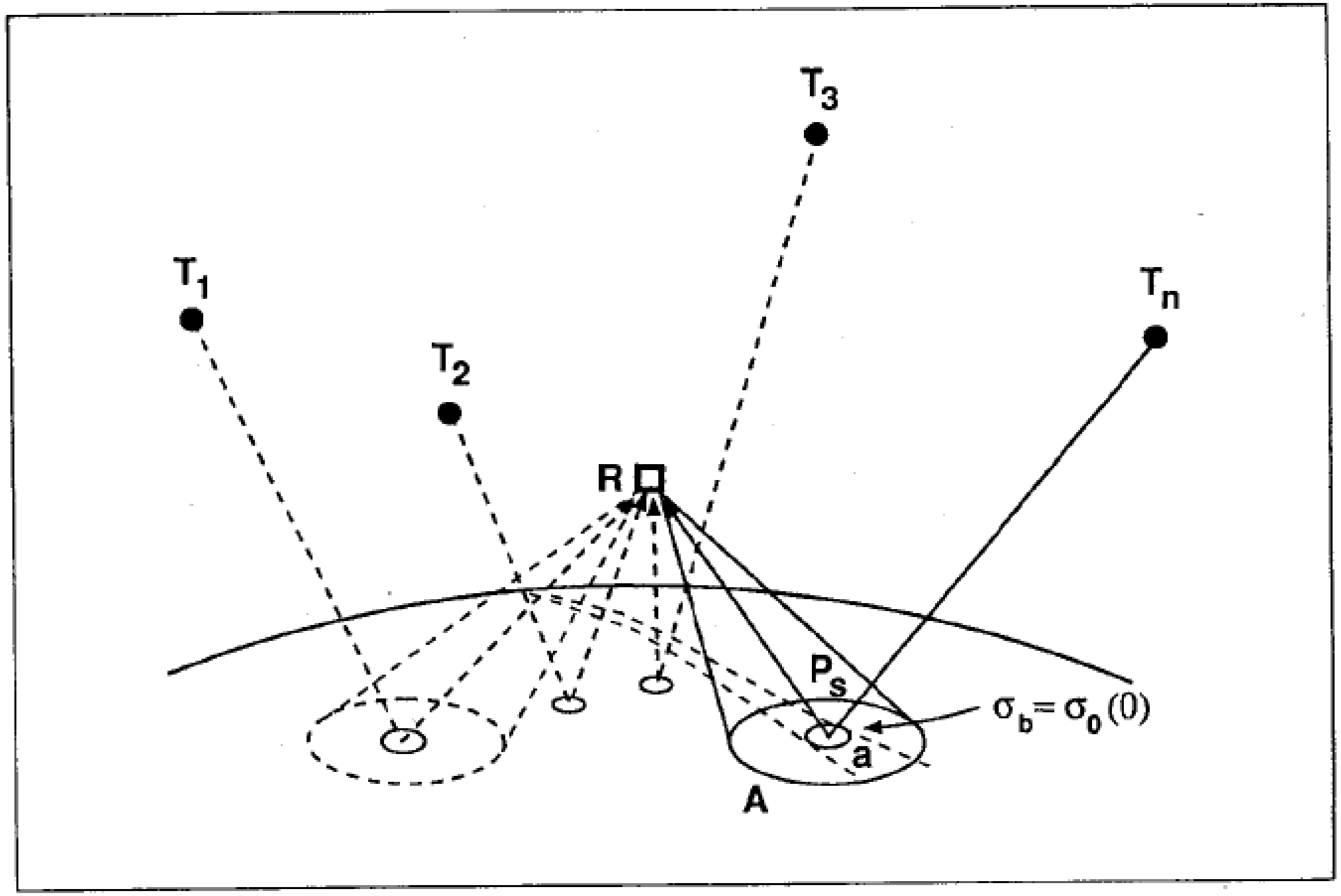
(b)
Q-factor for 0-6km

(c)
blue:6-8km
red: 8-10km
black:10-12km
(d) q-factor for 6-12km

Lipa, Remote Sensing, 2012

Fig. 12 Overall System with PARIS Concept

PARIS: Passive Reflectometry and Interferometry System

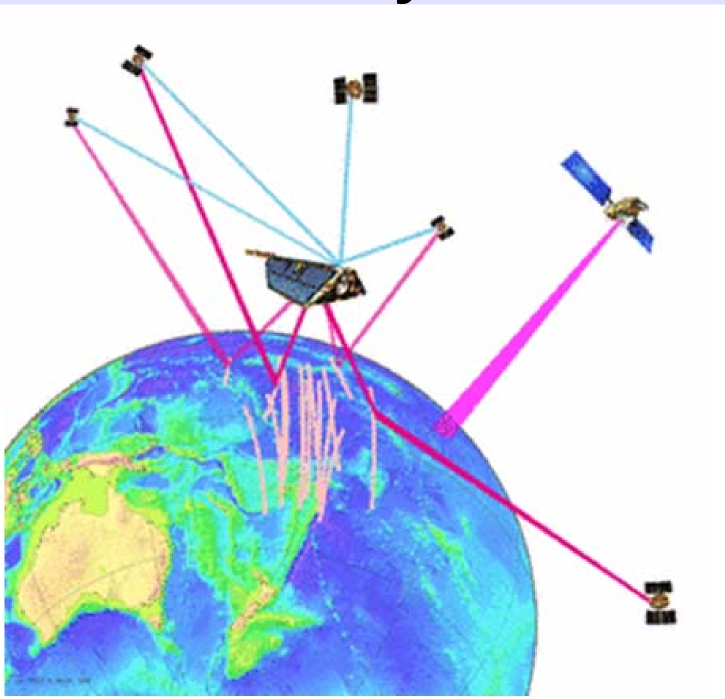


R: receiver
T: source
Number of reflections = Number of sources

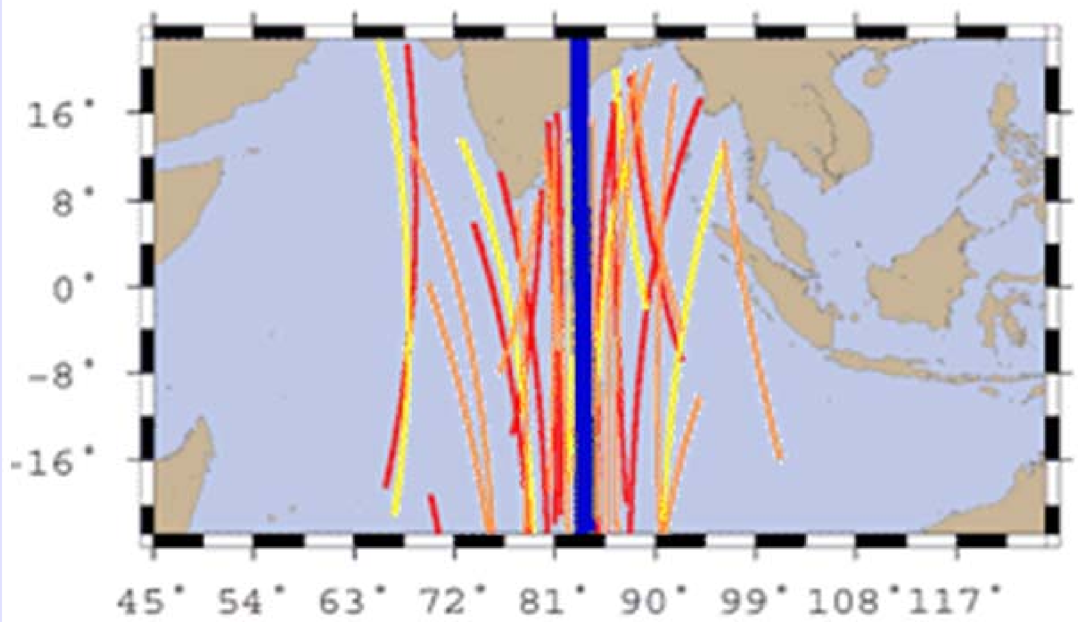
Martin-Neira, ESA Journal, 17, 1993

Fig. 13 Tsunami Warning Study based on GNSS-R LEO Constellation

GPS Occultation, Reflectometry and Scatterometry Receiver



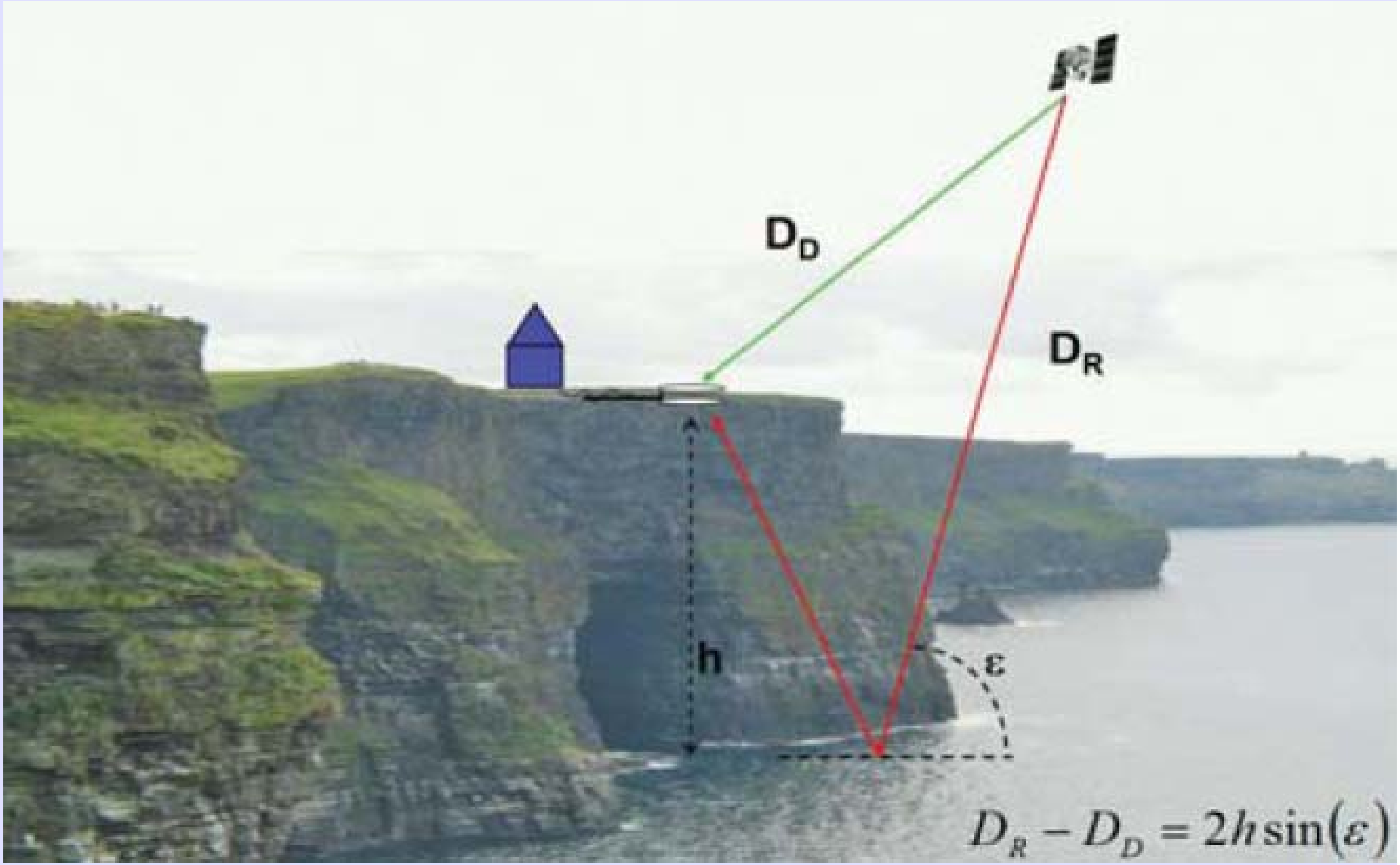
GNSS-R Reflection Points Track (blue) at CHAMP-like LEO orbit



GPS (red), GLONASS (yellow), Galileo (ora)

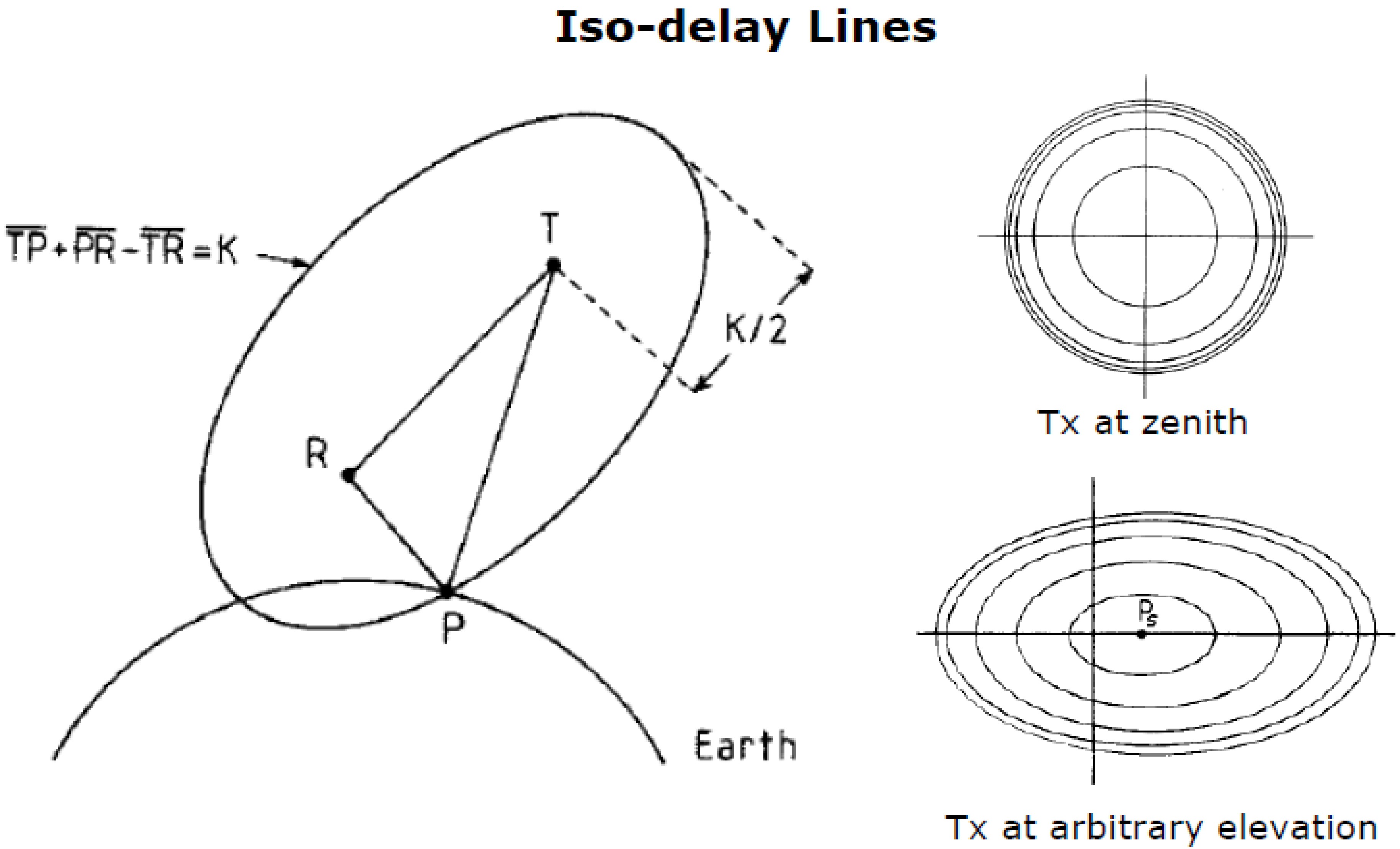
GNSS-R: Global Navigation Satellite System Reflectometry
LEO: Low Earth Orbit
GITEWS GPS Technology, March 2012
GITEWS: German Indonesia Tsunami Early Warning System

Fig. 14 Coastal Altimetry with GNSS-R



Ruffini, IEEE Geo Remo Sens Soc Newsletter, 2006

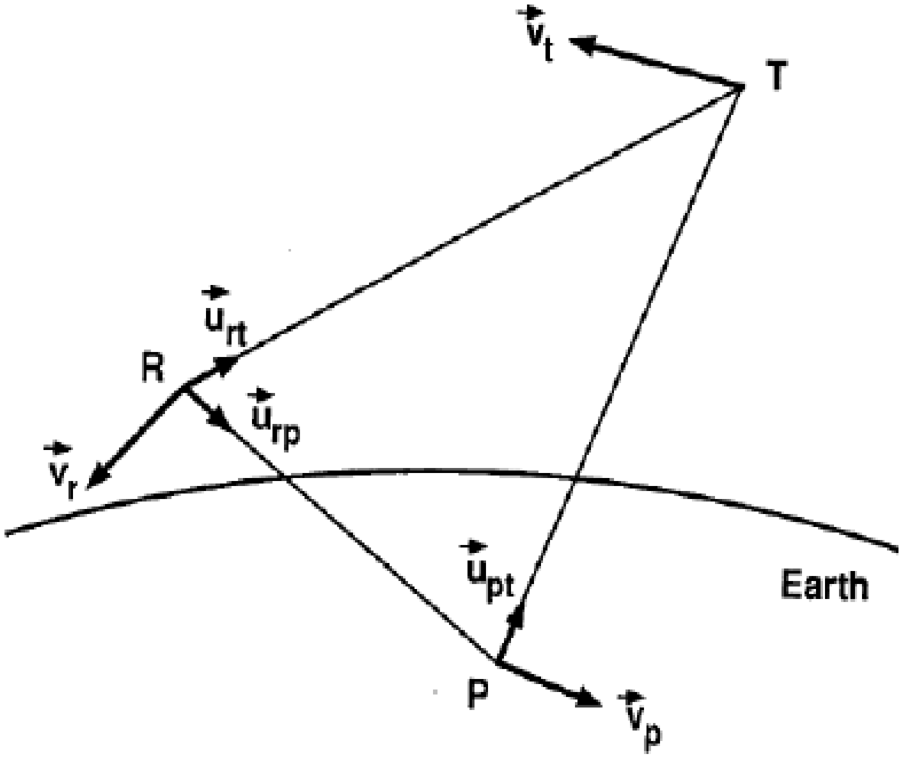
Fig. 15 PARIS: Iso-delay lines



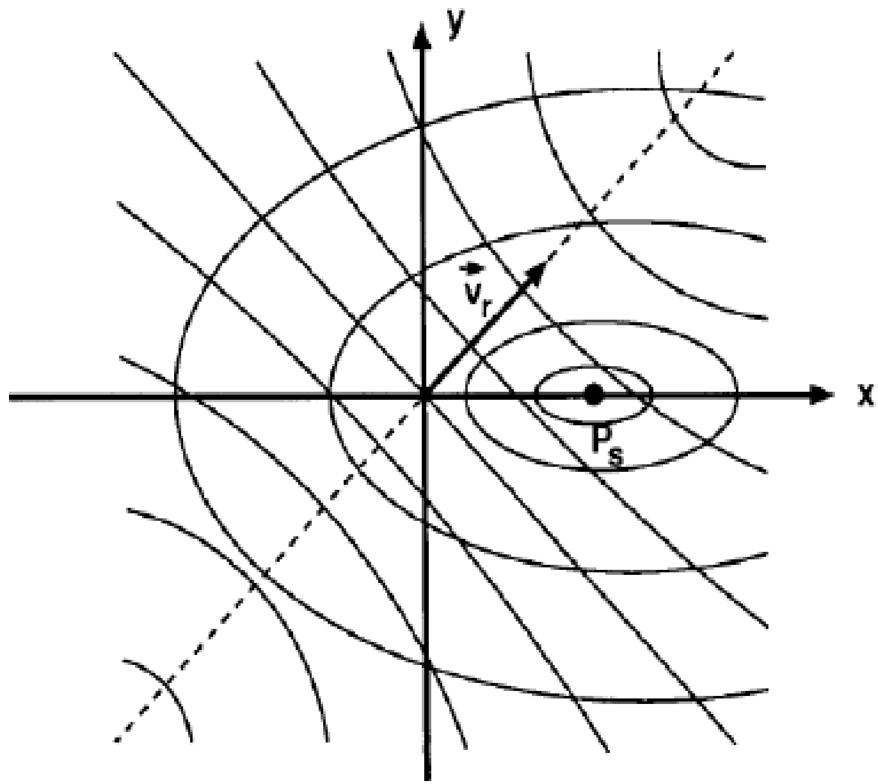
Martin-Neira, ESA Journal, 17, 1993

Fig. 16 PARIS: Iso-Doppler Lines

Iso-Doppler Lines

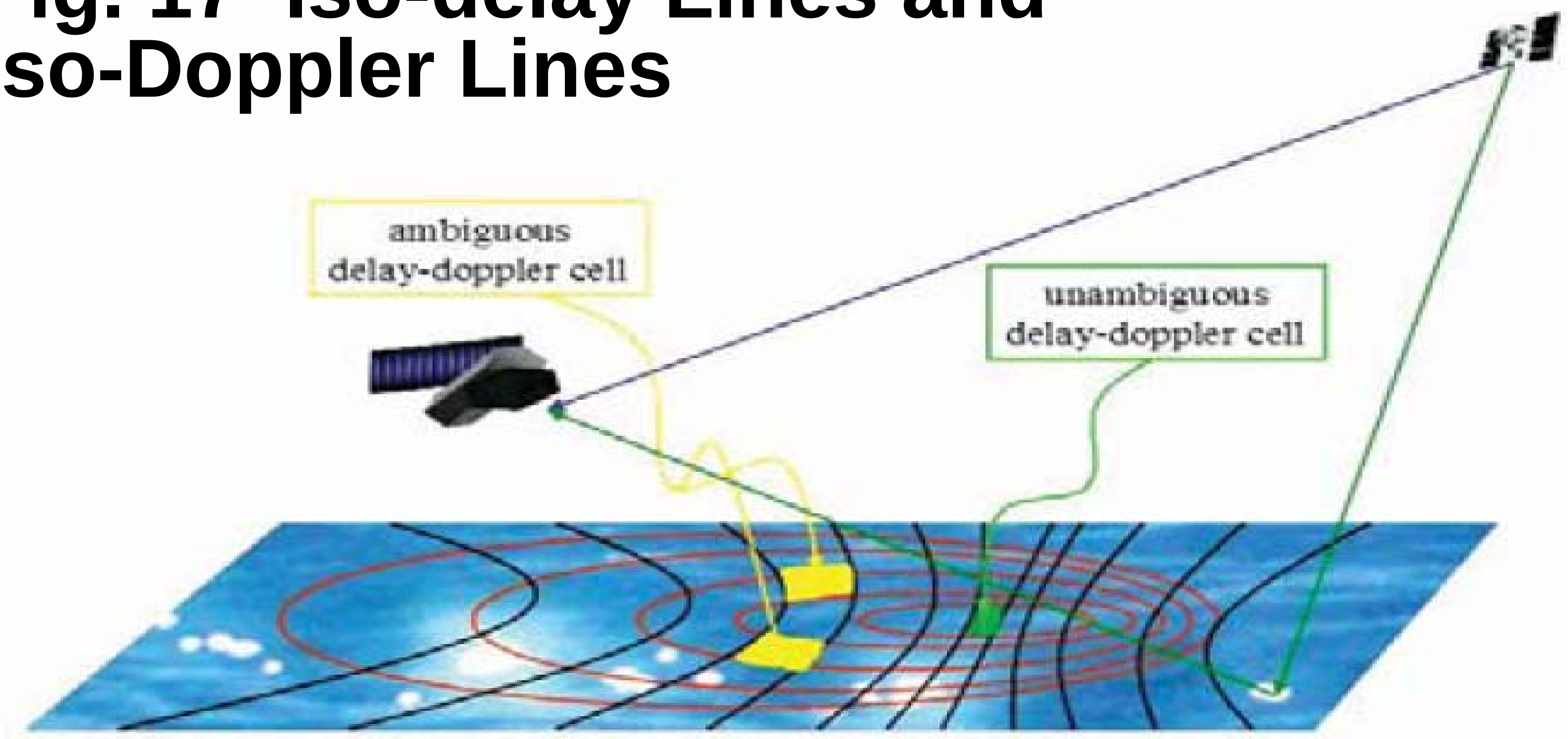


$$\vec{v}_r \bullet \vec{u}_{rp} = k_D$$



Martin-Neira, ESA Journal, 17, 1993

Fig. 17 Iso-delay Lines and Iso-Doppler Lines



Direct and reflected waveform produced by cross-correlation with clean replica

Ruffini, IEEE Geo Remo Sens Soc Newsletter, 2006

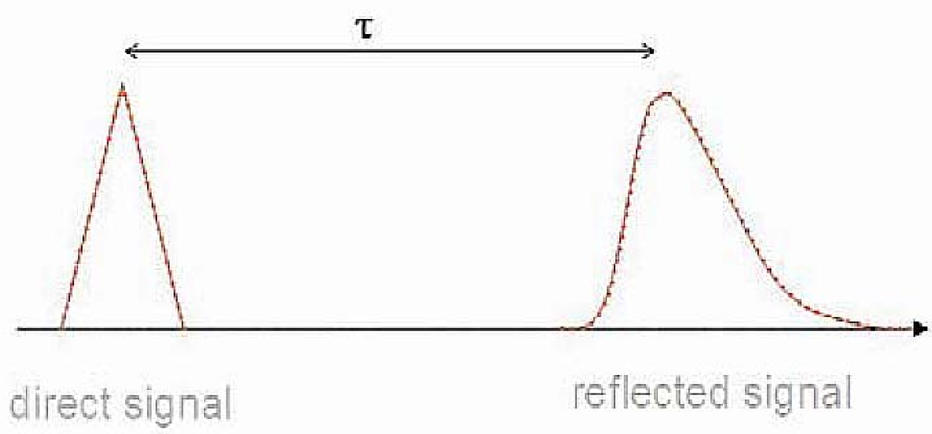
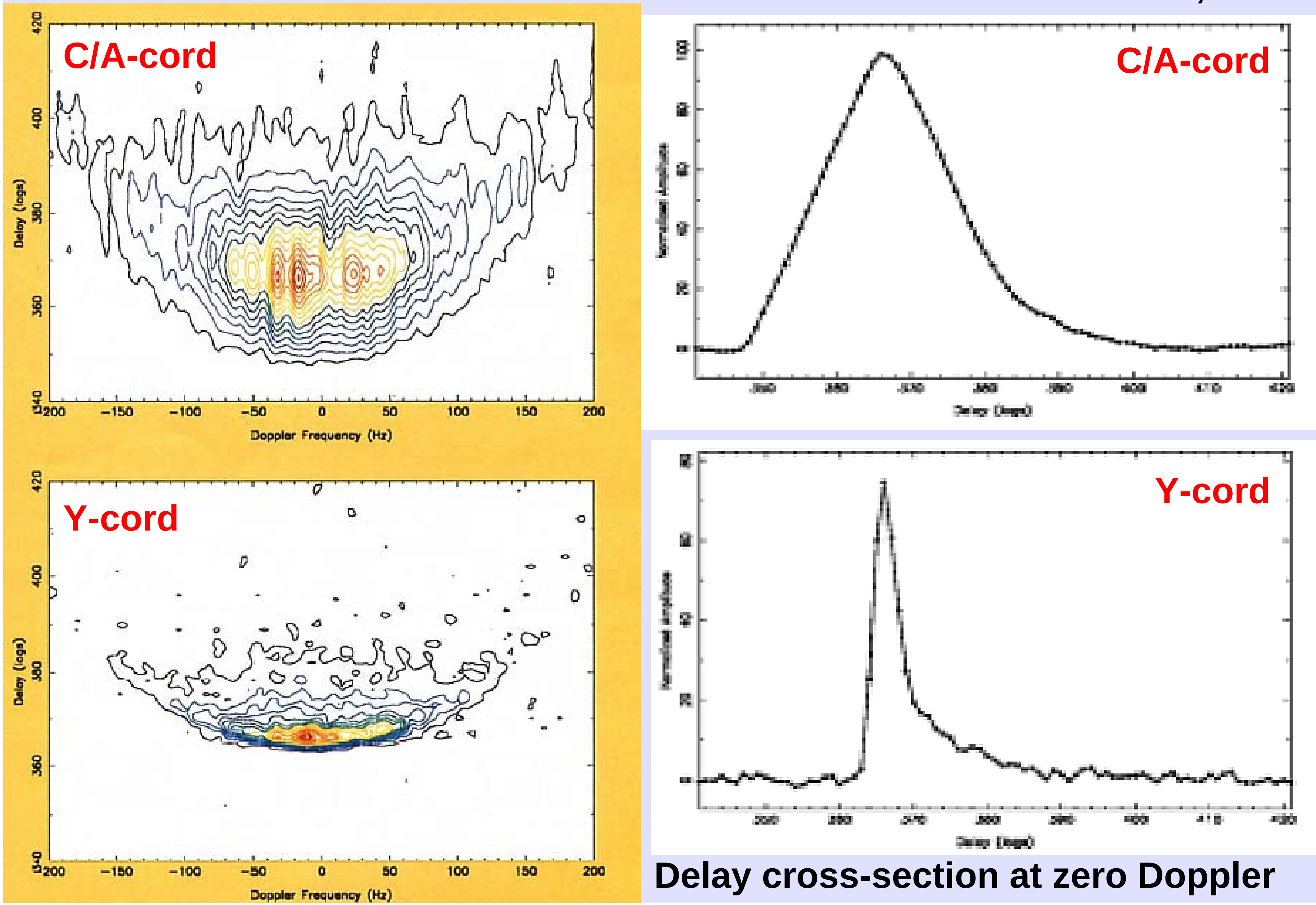


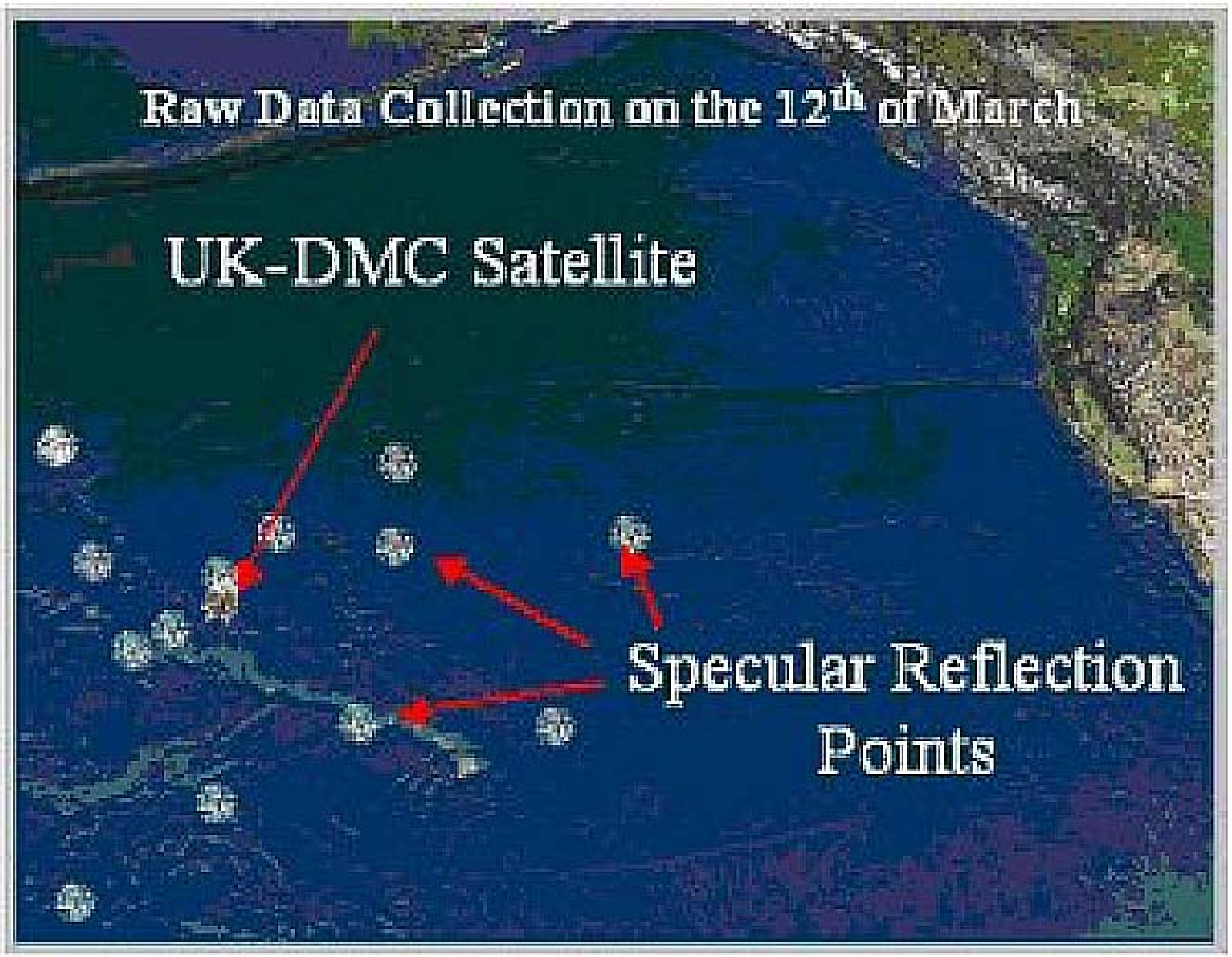
Fig. 18 Delay/Doppler Waveform

Lowe, IEEE Geo. Remo Sens, 2002



Delay cross-section at zero Doppler

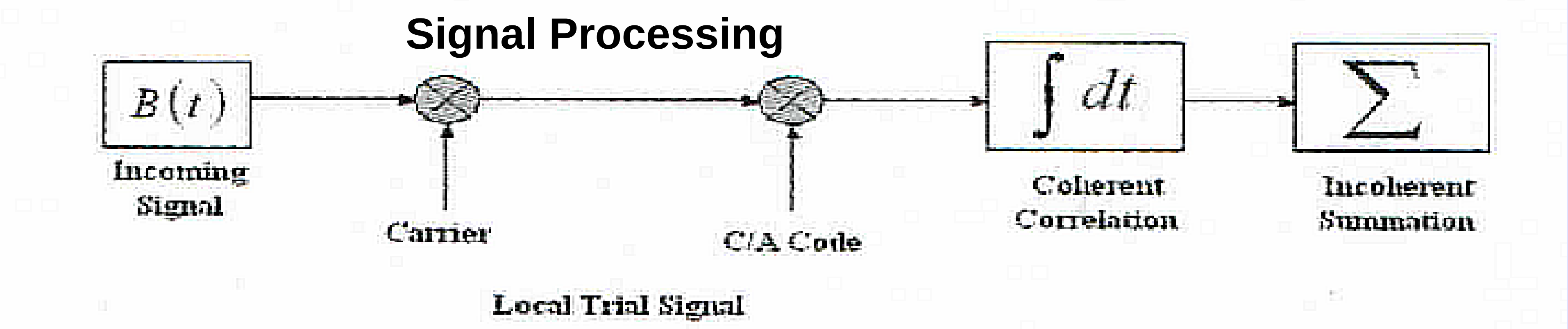
Fig. 19 Data Collection with UK-DMC Satellite March 12, 2004

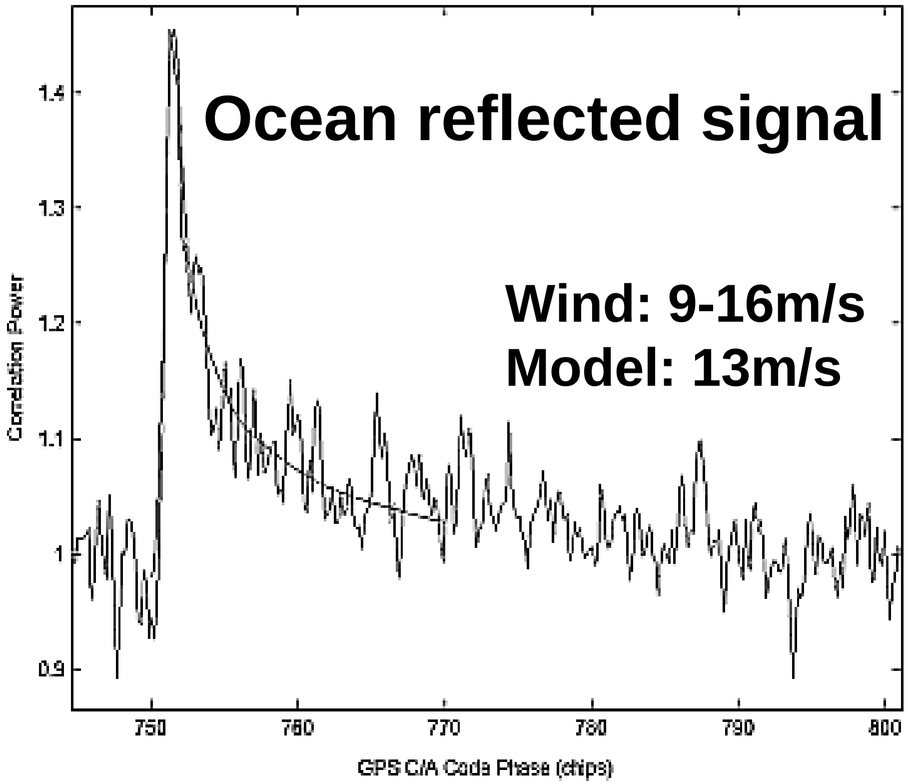


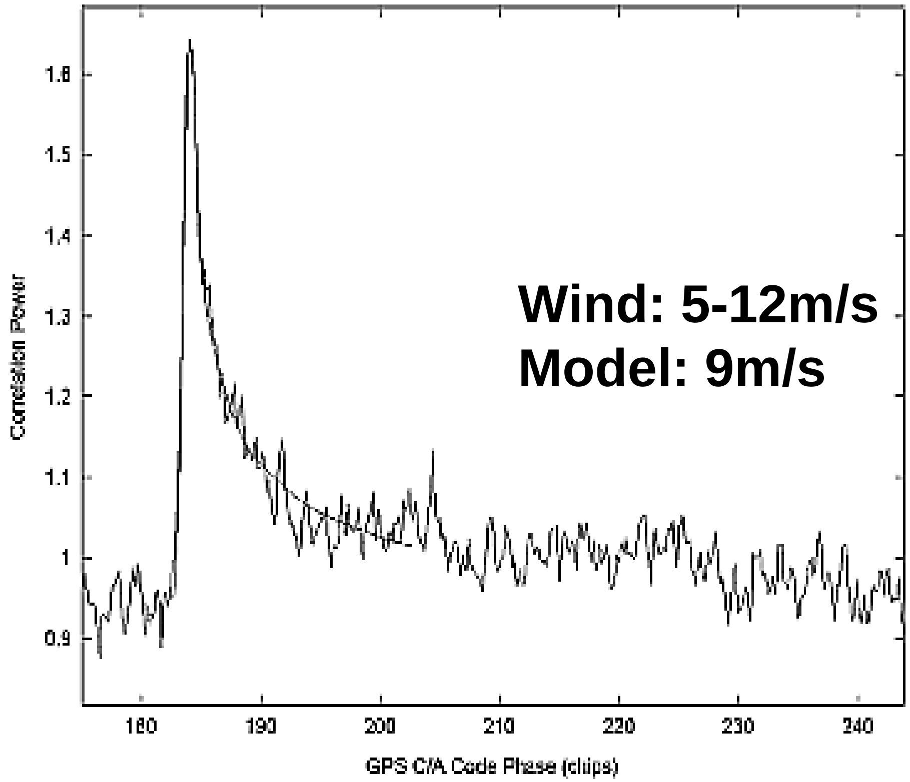
UK-DMC:United Kingdom's Disaster Monitoring Constellation

Gleason, et al., IEEE Geo Rem Sens, 2005

Fig. 20 Signal Processing

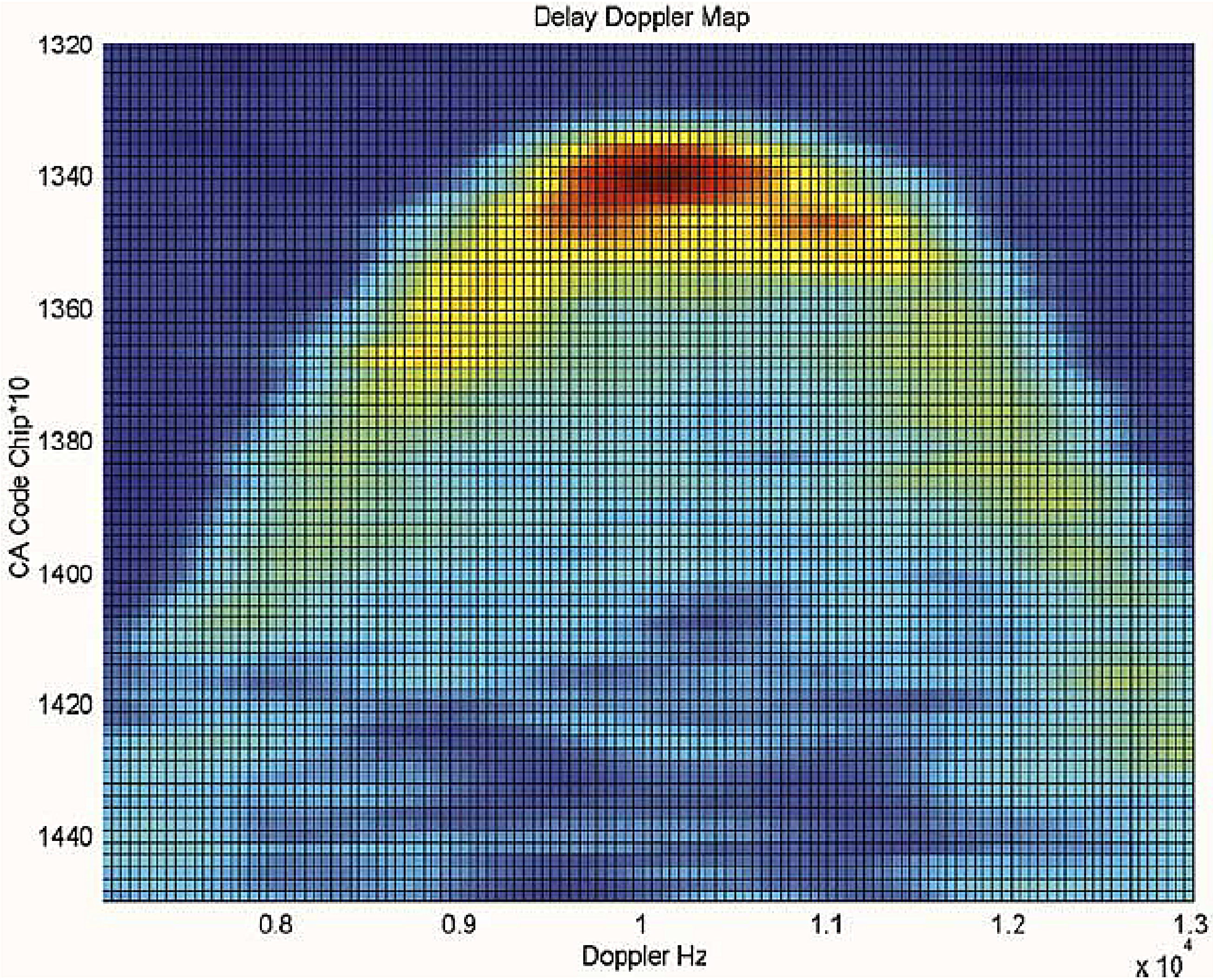






Gleason, et al., IEEE Trans. Geo Remo Sens, 2005

Fig. 21 Delay-Doppler Map of Ocean Reflected Signal of GPS



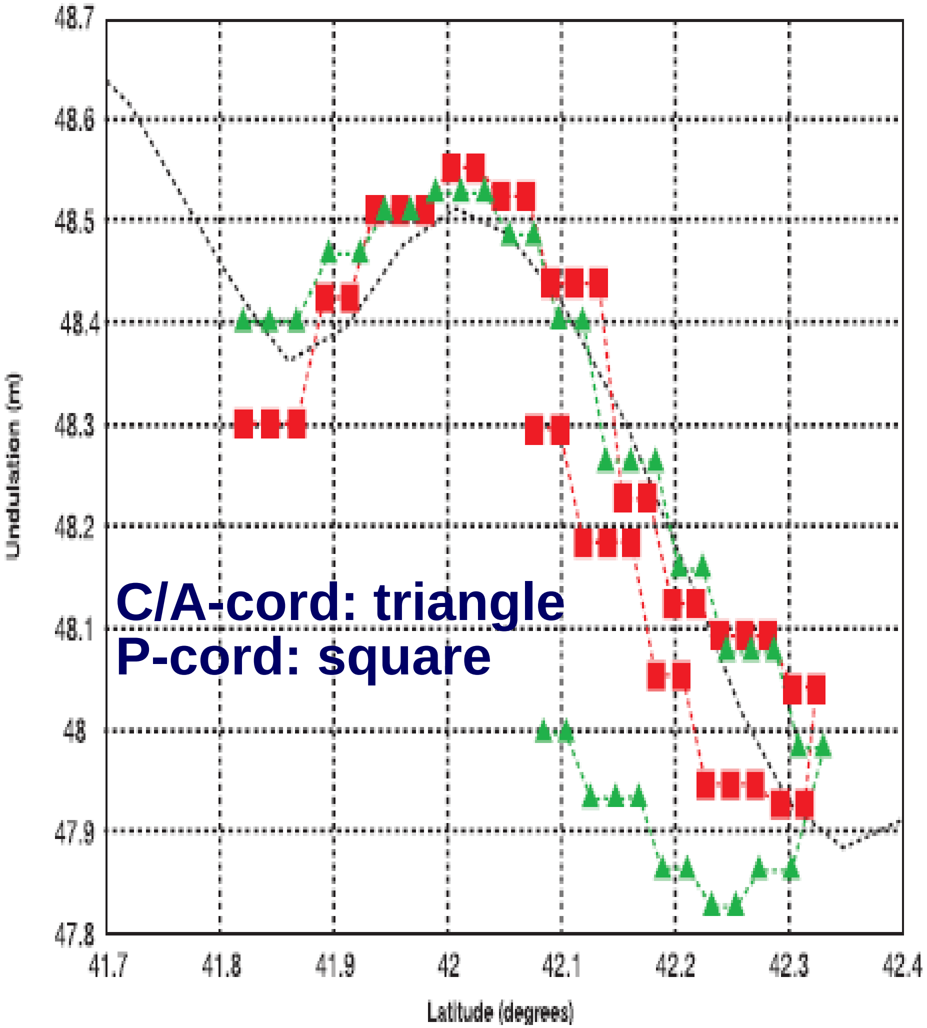
Coherent Integration:1ms

Incoherent Summation:1s

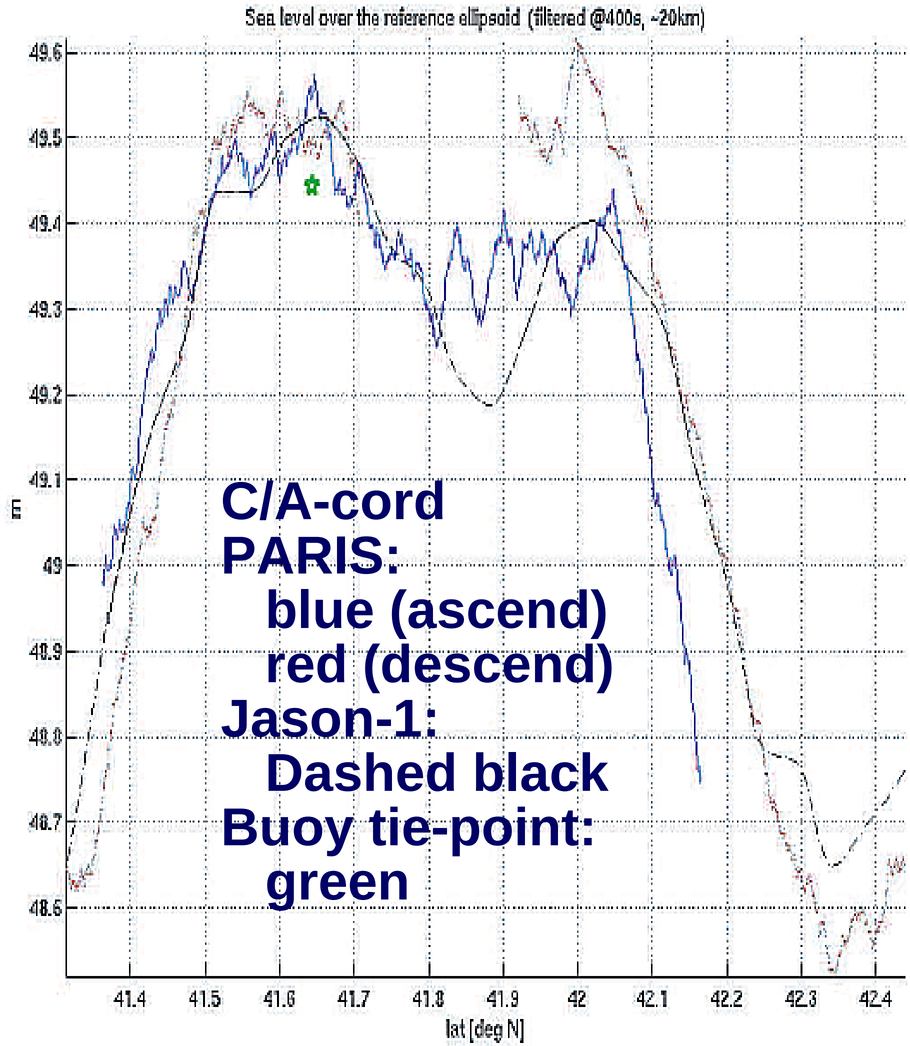
Gleason, et al., IEEE Trans. Geo Remo Sens, 2005

Fig. 22 PARIS-Aircraft Test at H1000m over Palamos Canyon

PARIS-Alpha aircraft test



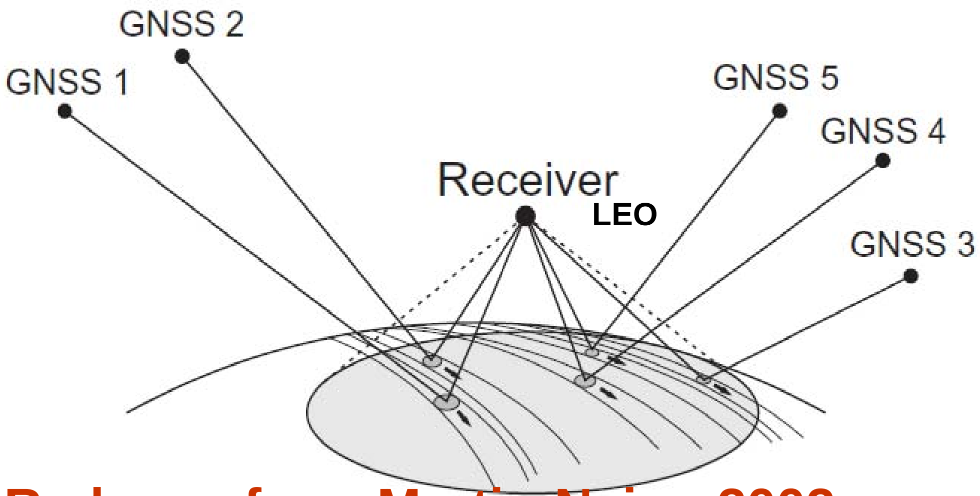
PARIS-Gamma aircraft test



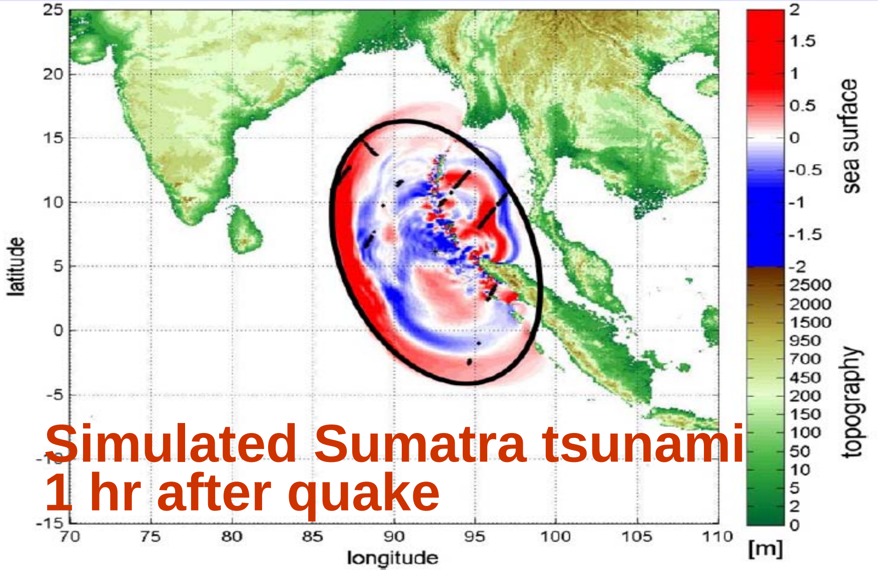
Martin-Neira, URSI-F, 2005

Fig. 23 Tsunami Detection Using GNSS Reflectometry

Stosius, Adv Spa Res, 2011



Redrawn from Martin-Neira, 2002



Detection probability

LEO 18/3:
18-Rx on 3-orbit planes
GPS: as on 26 Dec. 2004

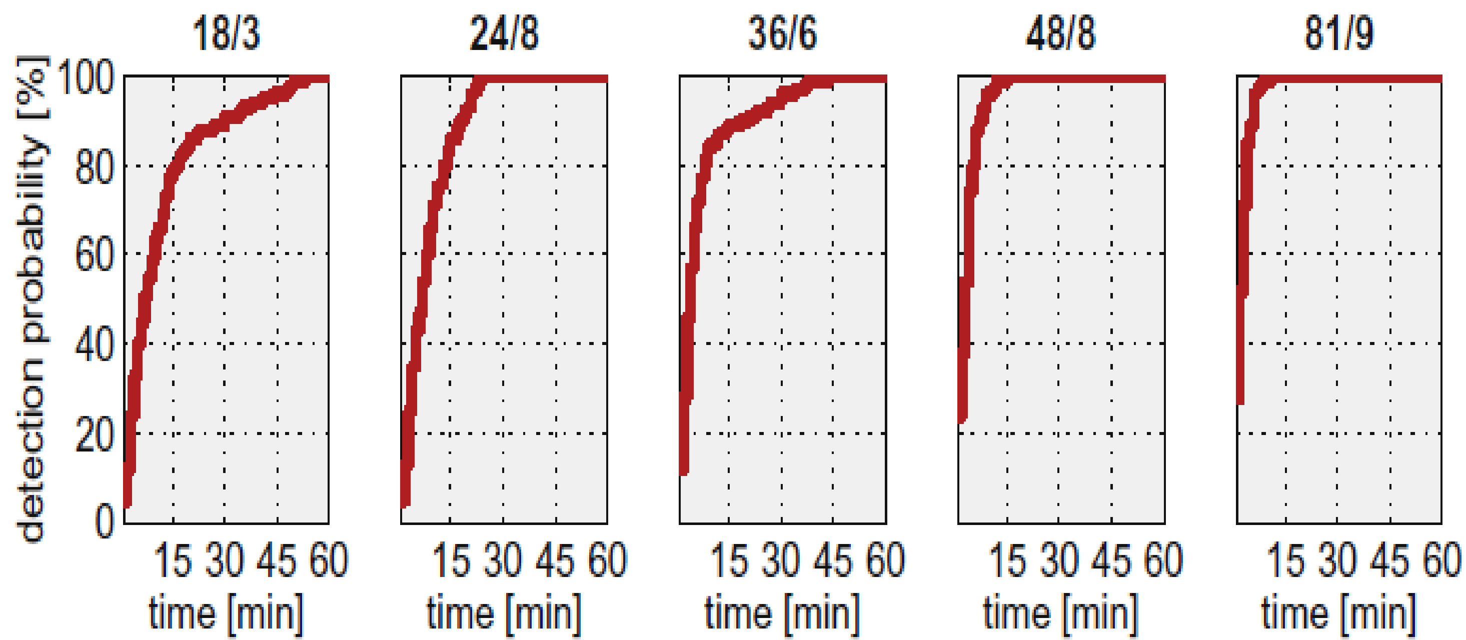
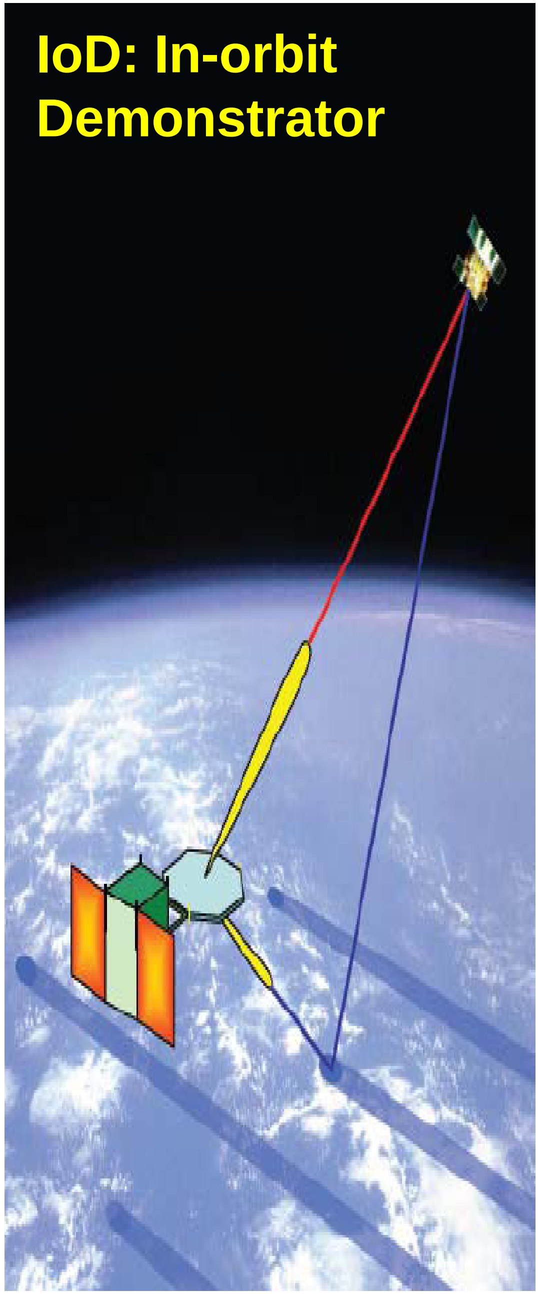


Fig. 24 PARIS-IoD Concept

Martin-Neira, IEEE Geo Rem Sens, 2011



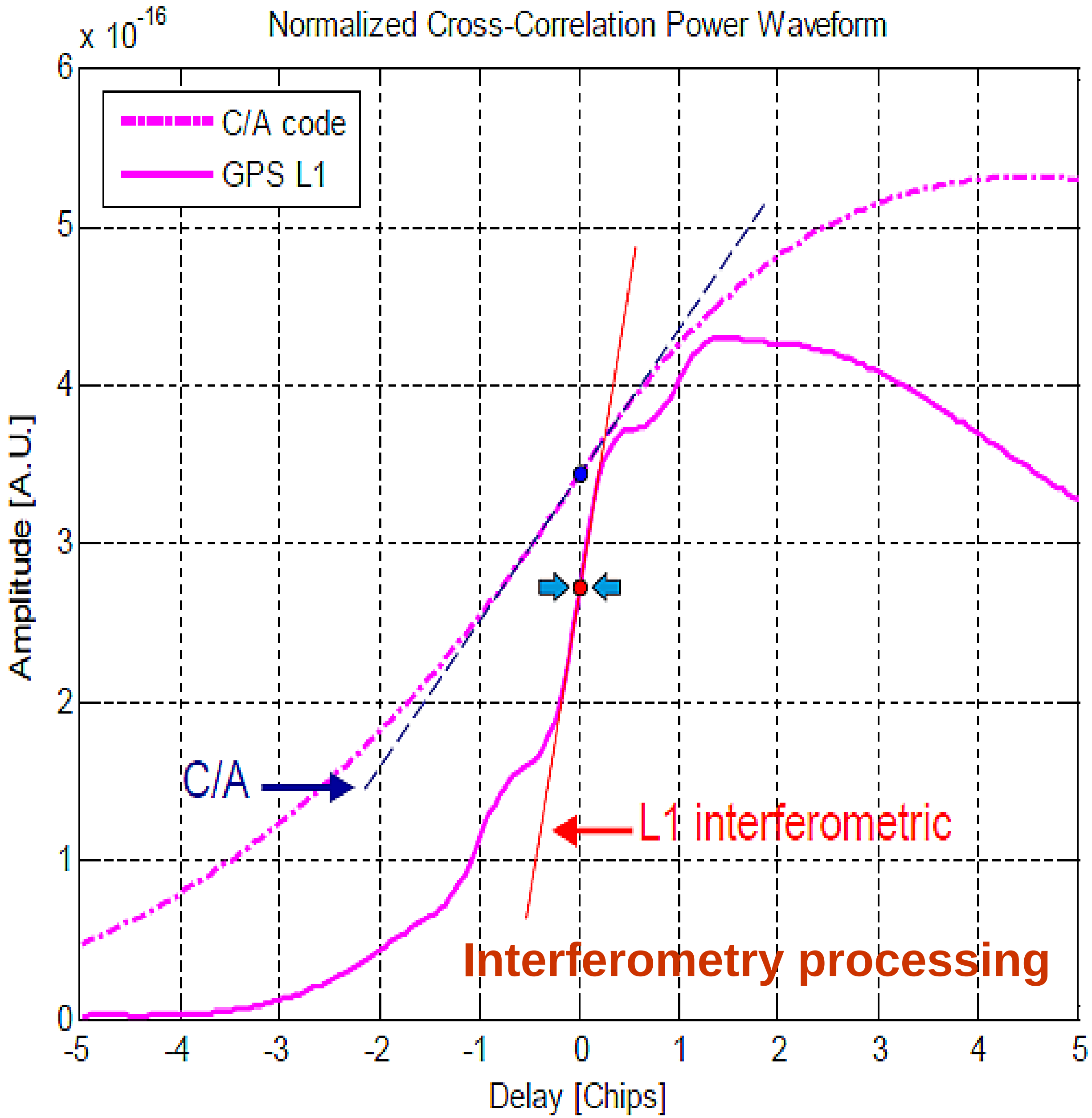


Table 1 Estimated Performance: IoD and Operational Mission

	IOD	Operational
Parameter	Height Accuracy on 100km, G=23dBi, h=800km	Height Accuracy on 100km, G=30dBi, h=1500km
Instrument Noise and Speckle	12.5 cm	4.2 cm
Ionosphere	9.7 cm (2 frequencies)	4.8 cm (3 frequencies)
Troposphere (Wet and Dry)	5 cm	2 cm
Electromagnetic Bias	2 cm	2 cm
Skewness Bias	2 cm	2 cm
Orbit	5 cm	2 cm
Total RMS Height Accuracy	**17 cm (13 cm at nadir)**	**7.5 cm (5 cm at nadir)**

Martin-Neira, IEEE Geo Rem Sens, 2011

おわりに

3/11津波のレーダ観測

- **merging tsunami**
- **tsunami signal**

スペースセンサの研究

- **GNSS-Reflectometry**

今後の調査

- **津波の観測報告**
- **津波レーダの研究動向**
- **津波の早期警戒システムへの取り組み**