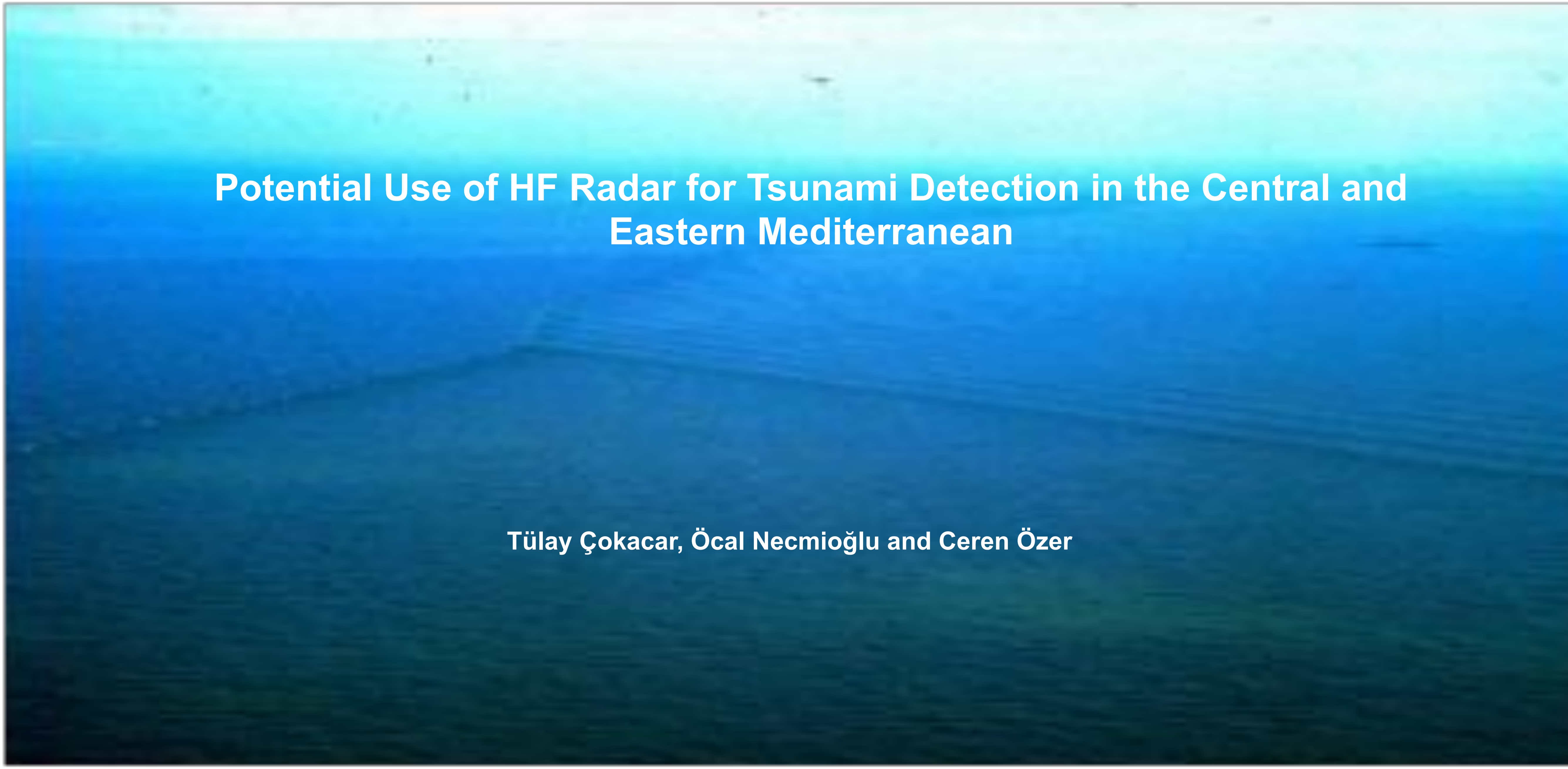

Potential Use of HF Radar for Tsunami Detection in the Central and Eastern Mediterranean

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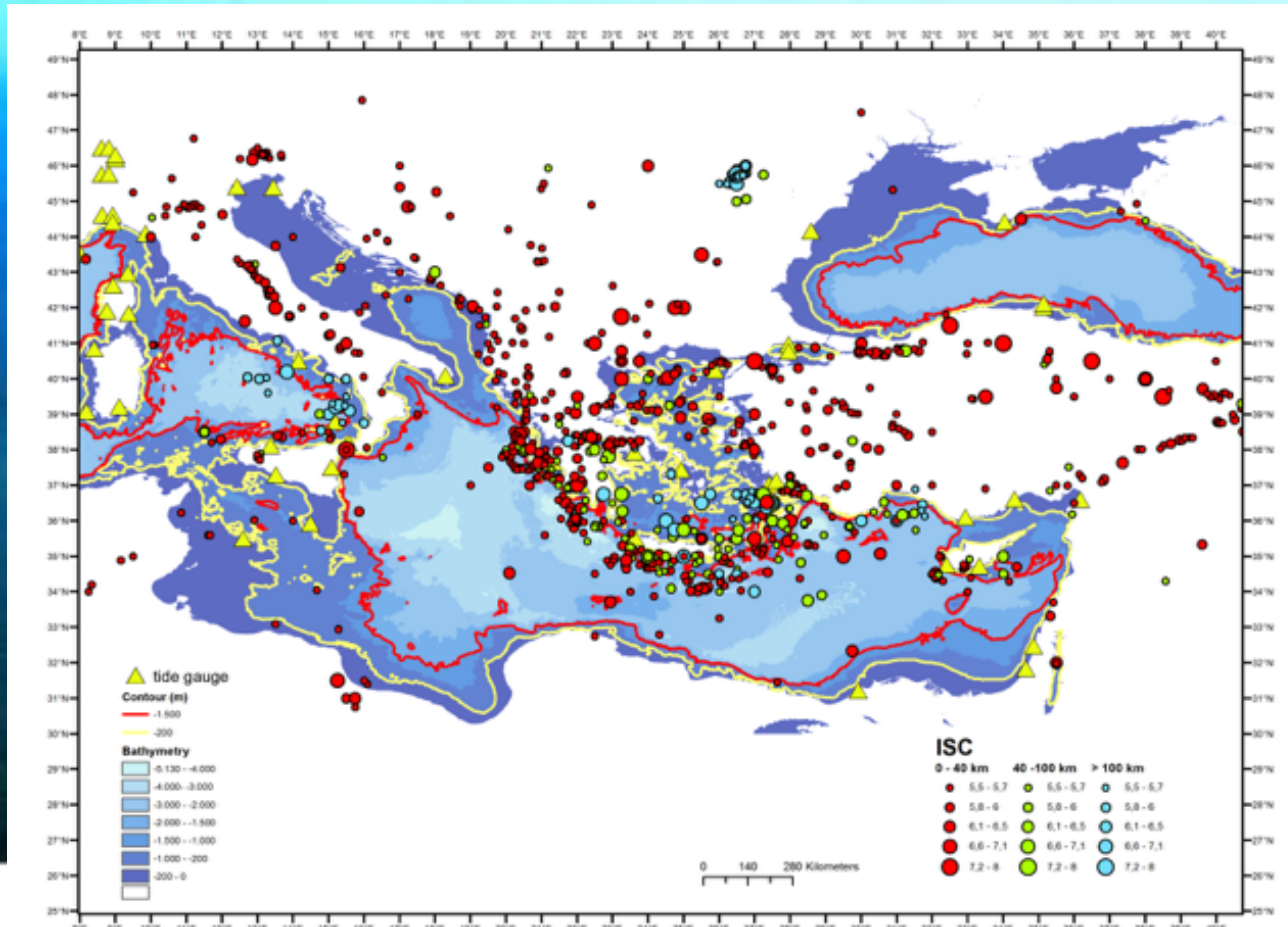


178 Broadband
97 strong motion
6 short period sensors
8 tide gauge stations

+

77 GFZ
16 bilateral agreements

HF Radar technology for the purpose of tsunami detection

Capabilities

Limitations

Maturity

Performance

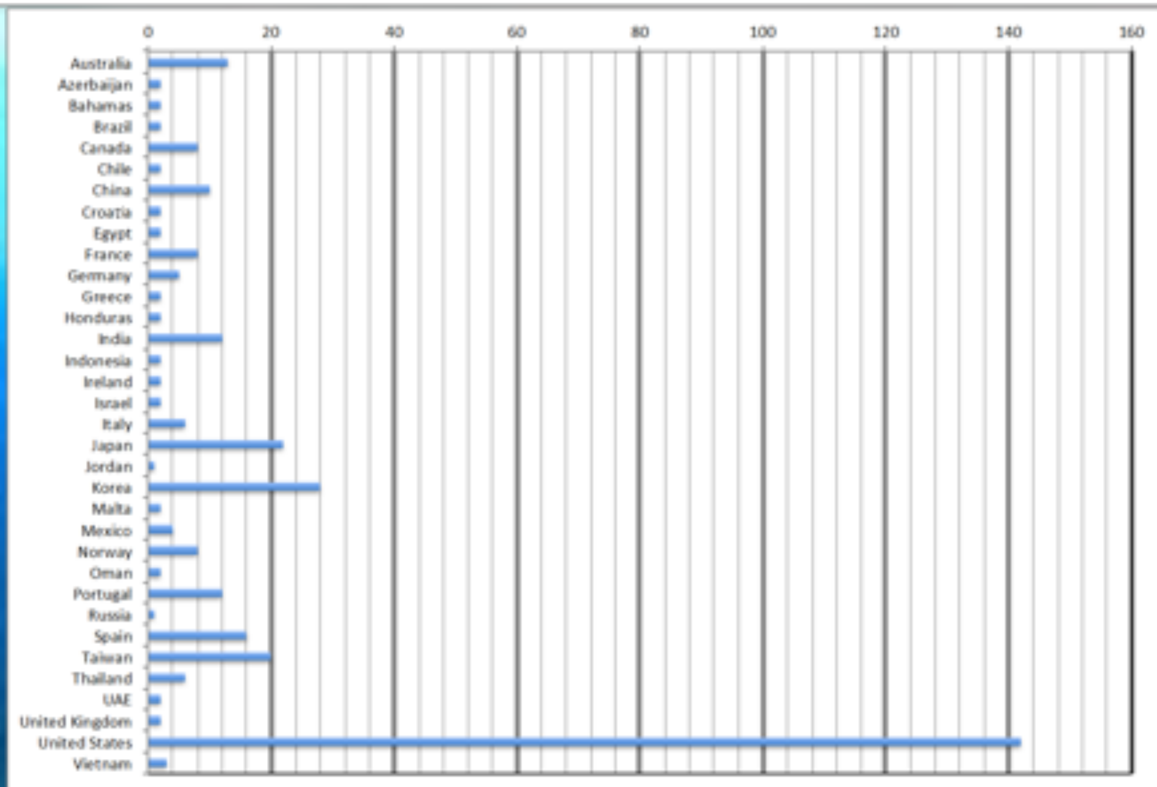
Applicability

HF Radar Applications

Applications around the world, including ship detection, tracking, and guidance, as well as search and rescue, distribution of pollutants, fishery, research in oceanography and tsunami in recent years.

- Surface Wind Direction
- Surface Current Speed
- Significant Wave Height
- Dominant Wave Period
- Dominant Wave Direction
- Surface Wind Speed
- Non-Directional Wave Spectrum
- Directional Wave Spectrum

HF radar Stations

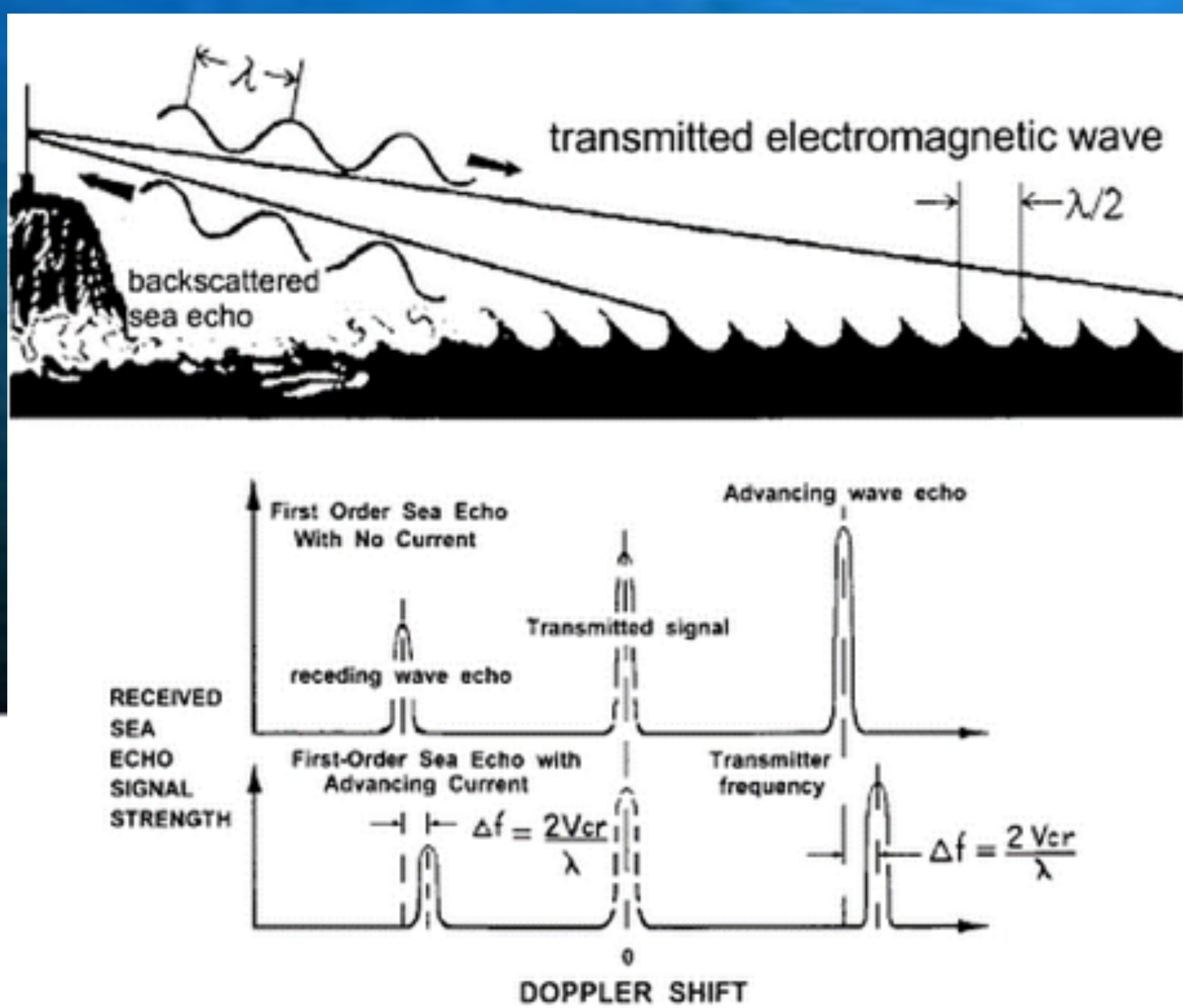


Number of HF radar stations in each country

Locations of HF radar stations

Technical background

The surface current measurement using high frequency (HF) radar is well accepted technology and allows observation of the surface current within the range from tens of kilometres to hundreds of kilometres offshore.



Bragg scattering from the sea wave whose wavelength one half of the radar wavelength, results in two discrete first order Doppler peaks in the sea-echo

The figure at the bottom shows the resulting Doppler spectrum without and with the underlying current.

Technical background - Capabilities

- HF Radar has proved its capacity for measuring currents in wide ranges. The maximum observation range is approximately 200 km for current commercially available HF radars(3-30MHz). Future technical advances are ongoing for increasing the range keeping the fine resolution. For example, a new HFR, STRADIVARIUS covers the Golfe du Lion in the Western Mediterranean Sea. This radar allows detection up to 300 km

External noises have strong influence on radar performance. They appear in the Doppler spectrum. In some cases, making the ocean current calculations misleading. Therefore adequate identification of complex signatures is required.

Application for Tsunami Detection

Application of the HF radar system as a Tsunami warning system was originally reported by Barrick in 1979

A posteriori analysis of the direct HF radar measurements (real data) confirmed the ability of HF radar to detect an approaching tsunami.

How observation of the tsunami is possible by HF radar ?

Tsunami is characterized with a period between 25 and 50 minutes corresponding to 400-800km open ocean wavelengths.

On the other hand, HF radars observes the echo of the ocean surface waves with the wavelengths that are half of the radar wavelength. These waves have typical periods between 1.5 and 4.5 seconds.

Since the tsunami induced orbital velocities add additional velocities to the short Bragg waves that are seen by the radar, the tsunami becomes observable to HF radars.

Tsunami detection by HF radar

- The speed of the tsunami wave is controlled by the water depth and can be calculated from the dispersion relationship of gravity waves for shallow water. When the tsunami travels into shallow water of depth 200 m and less, the wave is dramatically slowed down and becomes shorter and higher. This process induces ocean surface currents of up to 1.5 m/s in the water column

- In deep water, these tsunami-induced velocities fall below a detectable threshold for HF radars. The velocity resolution of HF radars is the important technical parameter to distinguish small increases. As the depth of the ocean decreases, the water particle velocity increases, so tsunami currents are best detected by HF radars

Algorithms

Barrick (1979) discussed the possibility of using HF radar systems to detect current patterns produced by the orbital velocity of tsunami waves

Lipa et al (2006,2011) analysed the limits of the tsunami detection by HF radar. Lipa et al. (2012) algorithm as an empirical method uses reduced time averages of current velocities (4 min) for the automatic detection of a tsunami (~ 0.10 − 0.15 m/s).

Gurgel et al. (2011) described detection of tsunami signal by using a statistical approach. They map the current velocity values into an entropy field by using Shannon’s filtering with a coherent integration time.

Grilli et al. (2015) proposed and validated a new type of tsunami detection algorithm for STRADIVARIUS radar (200-300 km range) using proprietary phase coding technology. This algorithm can detect tsunami signature for the presence of tsunami currents as low as 0.05-0.1 m/s and thus tsunami detection is able to be done in deeper water, beyond the continental shelf.

Algorithms

Doppler spectrum includes noise and hence the current velocities obtained from this spectrum are affected from this condition. Therefore sufficiently large interval of the data is necessary to get reduce the noise from the spectrum data. For example to extract velocity maps at specific time, over 10 minutes time slot of data required.

On the other hand, tsunamis travel quickly. So there is no time to perform analysis in long time slots. Hence methods must be based on data over short time scales. Therefore the algorithms for the detection of tsunami signals use an approach different than that used for normal current mapping.

Current velocity measured by HF radar includes background flow due to tides and wind driven surface currents, in addition to current velocity changes due to tsunami velocities. Hence, fluctuations due to other than tsunamis must be eliminated from current velocity values for extracting the tsunami induced orbital velocities.

Tsunami-generated current velocities can be determined based on pattern-recognition in time series.

Performance of HF Radar & Algorithms

Lipa *et al*. analysed the performance of tsunami detection method against the tide gauges using data measured during the Japan tsunami

- it is possible to announce the arrival of the tsunami approximately 8 min after its first appearance.

- the arrival times measured by the radars preceded those at neighbouring tide gauges by an average of 19 min in Japan and 15 min in USA. Larger tsunamis could obviously be detected further from the coast.

Pros and Cons of using HF radars in Tsunami Detection

Advantages

HF radar provides a technology for local detection of an actual arriving tsunami with a significant warning capability. Ranges are up to 300 km. On the other hand tide gauges or DART buoys which require forecasting to determine where/when tsunami wave is going to reach to the coast. Then HF radars are particularly useful compared to traditional buoy measurements which needs extra time for modelling to compute tsunami arrival time and place.

It is just a software package to be added for the tsunami detection if the HF radar system has already been installed at the coast.

Installation and maintenance of HF radar on land are easy.

Pros and Cons of using HF radars in Tsunami Detection

Limitations

Water depth <200m is area to detect tsunami signature for commercially available HF radars. The distance offshore at which the tsunami can be detected, depends on the bathymetry. On the other hand, there are many vulnerable coastal sites where the sensitivity of conventional HF radars would not permit detection at ranges sufficient to provide a meaningful warning time.

Use of HF Radar technology for detecting Tsunami signature is based on empirical algorithms. False alarms are to be expected when any empirical signal detection algorithm is applied to noisy data.

Test of the detection algorithms are based on either simulations or existing HF radar records (2011 Japan tsunami was the first event observed using HF radar). Since tsunami is a rare event, there is limited real observation data for testing the algorithms.

Maturity

- The development of the HF Radar and its applications for tsunami detection are relatively new and its use is not extended. The system has shown its potential for automatic detection of arriving tsunami.
- The early warning is possible if the tsunami is still far offshore. If the continental shelf is narrow then there is no time to detect the tsunami early enough to provide much advanced warning.

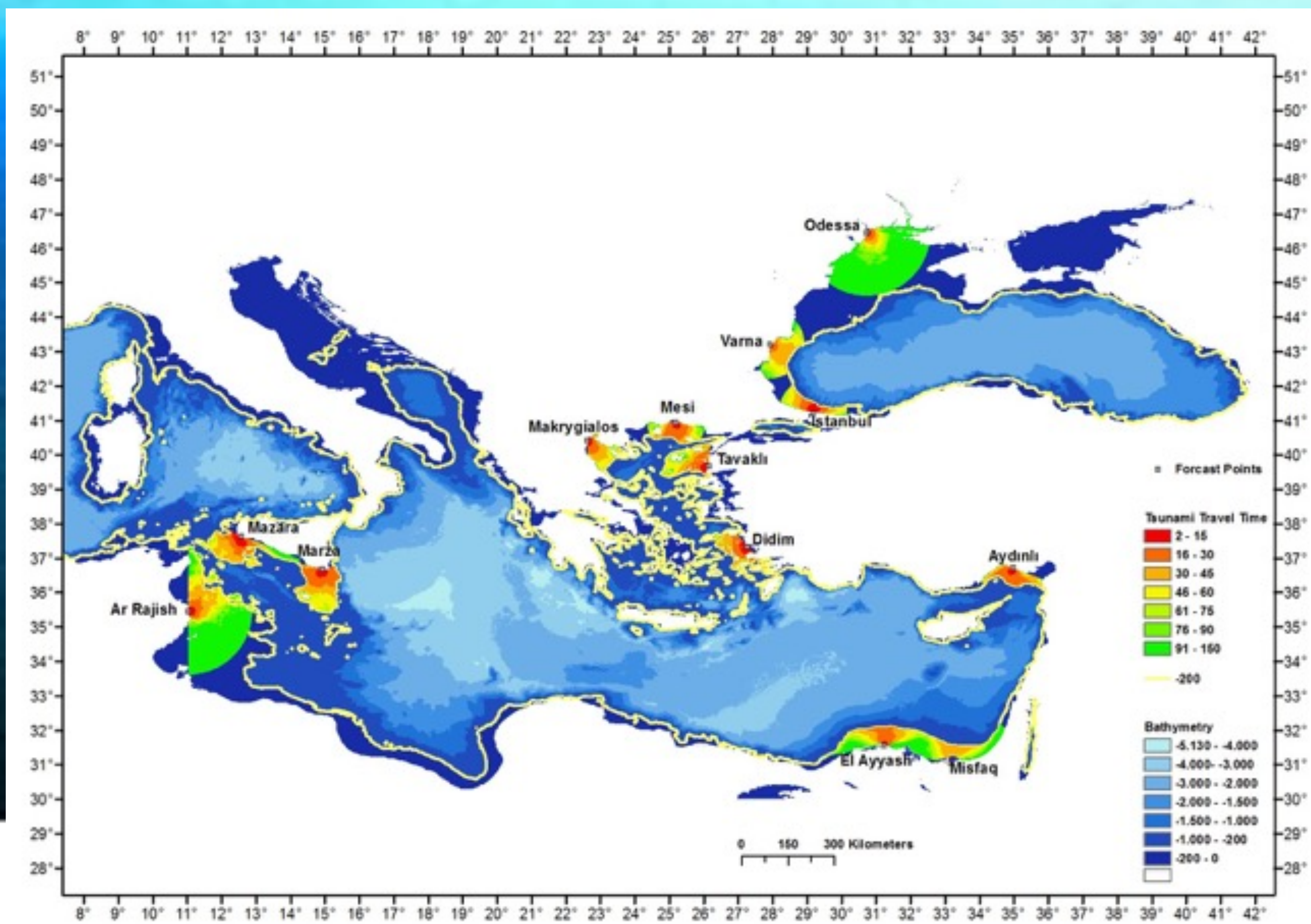
Potential use in Central and Eastern Mediterranean

- We choose representative focal points with wide shallow continental shelf area for the analysis. More test sites are chosen in the areas close to the earthquake faults.

The tsunami travel time (TTT) is derived at each bathymetry grid. The phase speed at which tsunami wave moves is given by the shallow water equation. The bathymetry data is provided from GEBCO. The grid interval of the bathymetry and the topography is 0.5 x 0.5 arc-min.

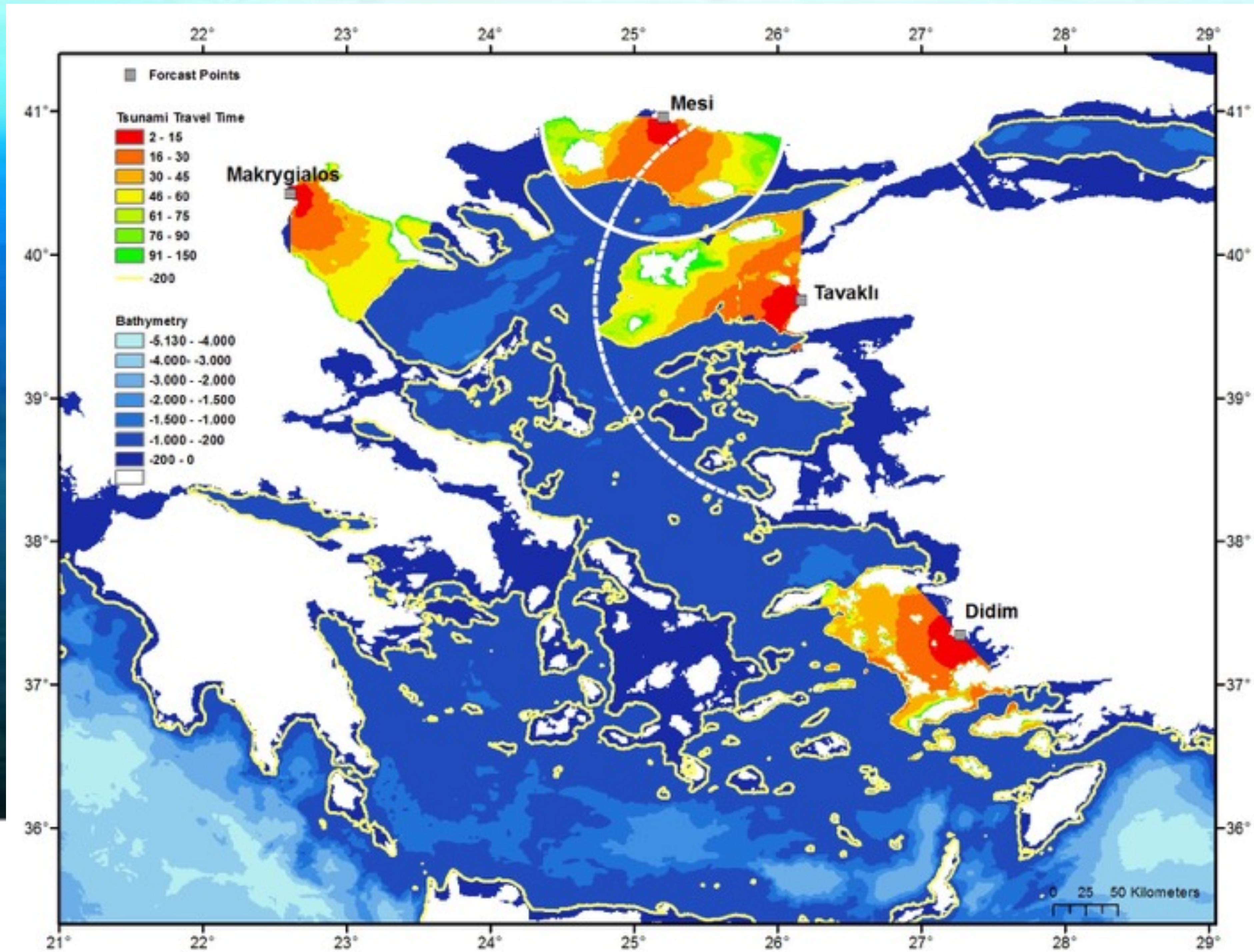
We select optimum range for the HF radar specific to the application/case study sites so that range of radar is sufficiently large to cover the continental shelf area bounded by 200 m bathymetry line. The working ranges of the radars are accepted/set starting from 75 km to maximum 200 km according to the size of continental shelf. Moreover the azimuth angle of radars are accepted to be maximum 180˚ for all sites (changes from site to site depending on the topography).

Potential use in Central and Eastern Mediterranean

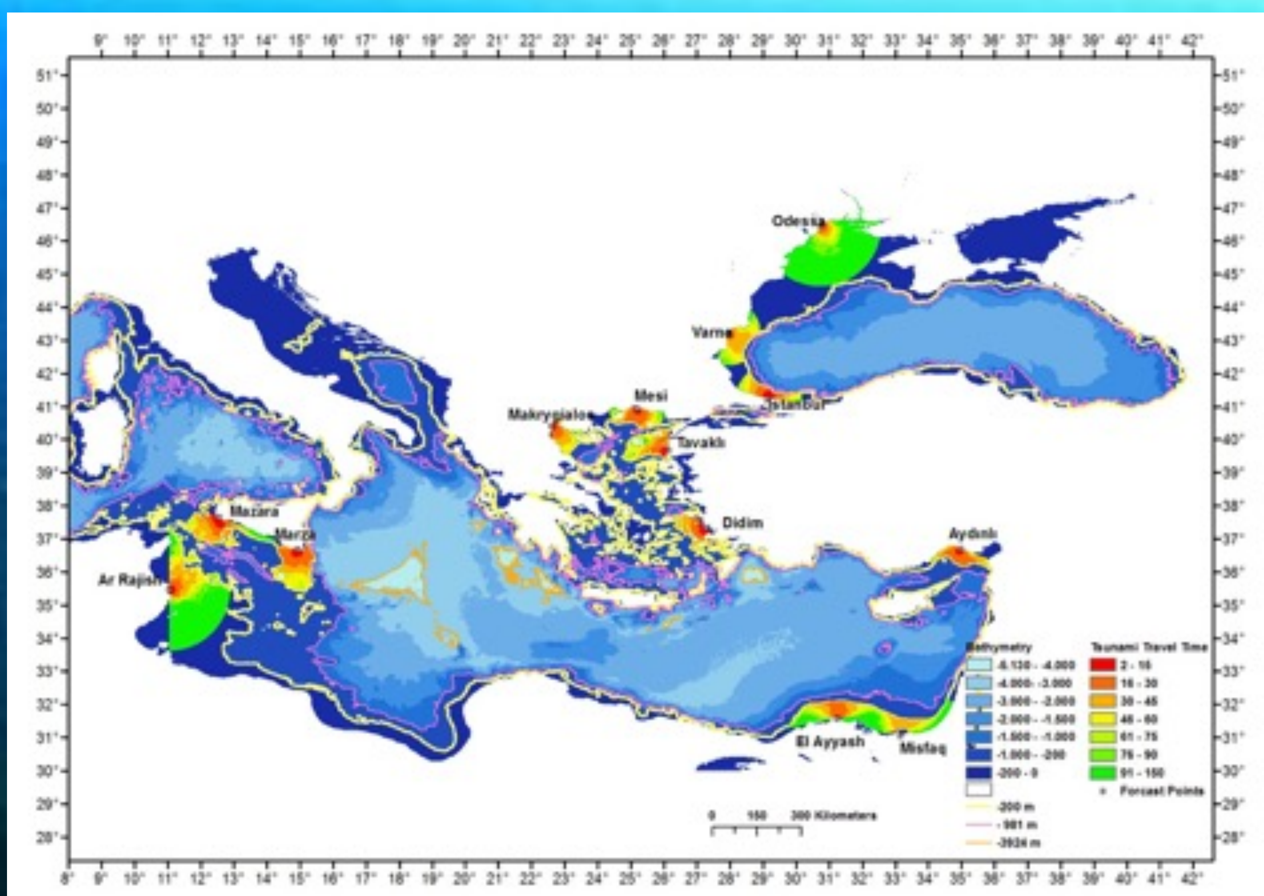


how much time in advance the radar can start to receive the observations so that the detection algorithm can distinguish the tsunami signal from the data

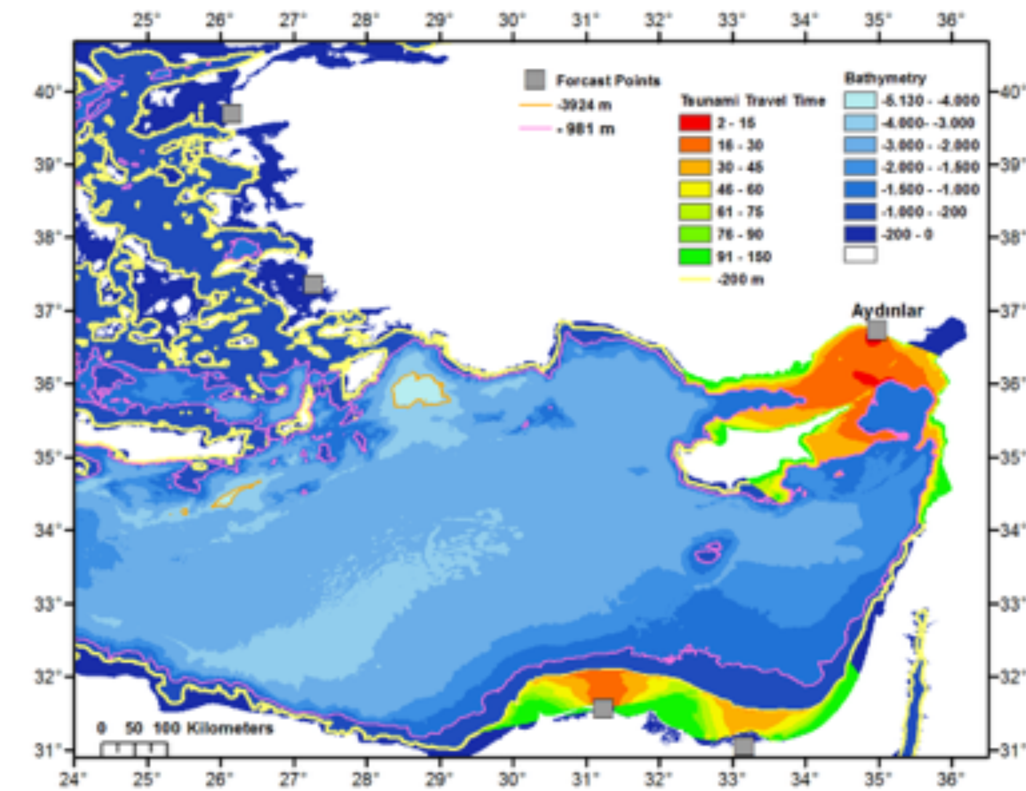
Potential use in Central and Eastern Mediterranean

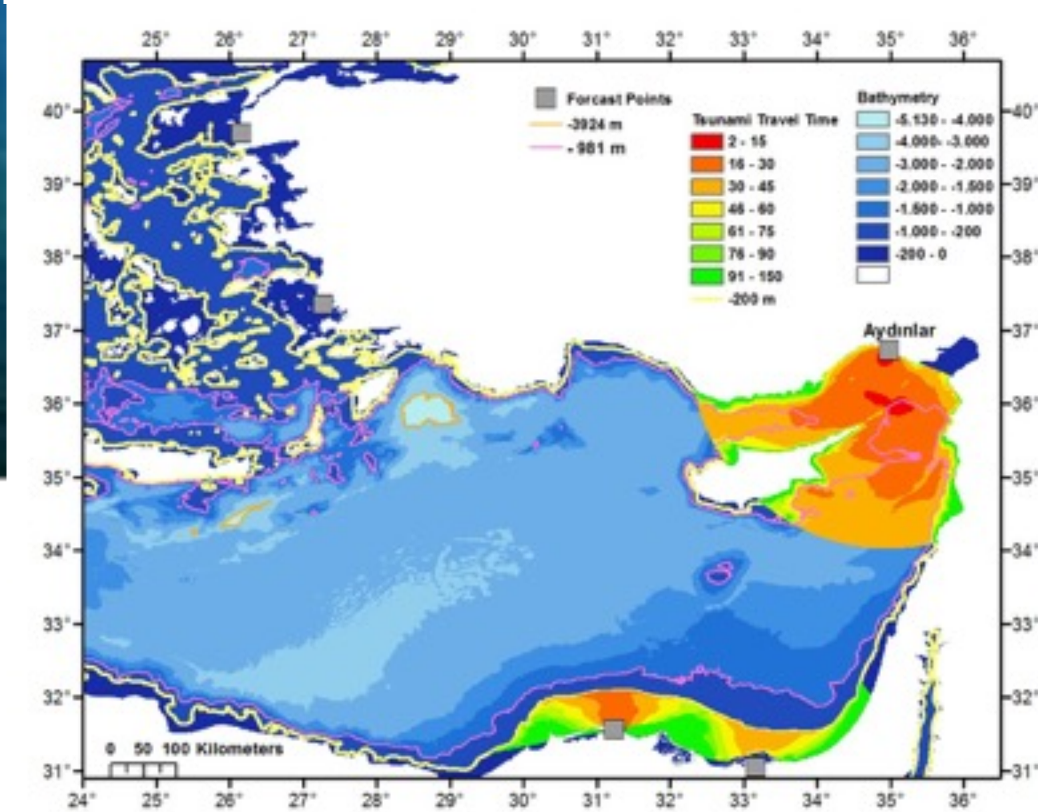


Potential use in Central and Eastern Mediterranean



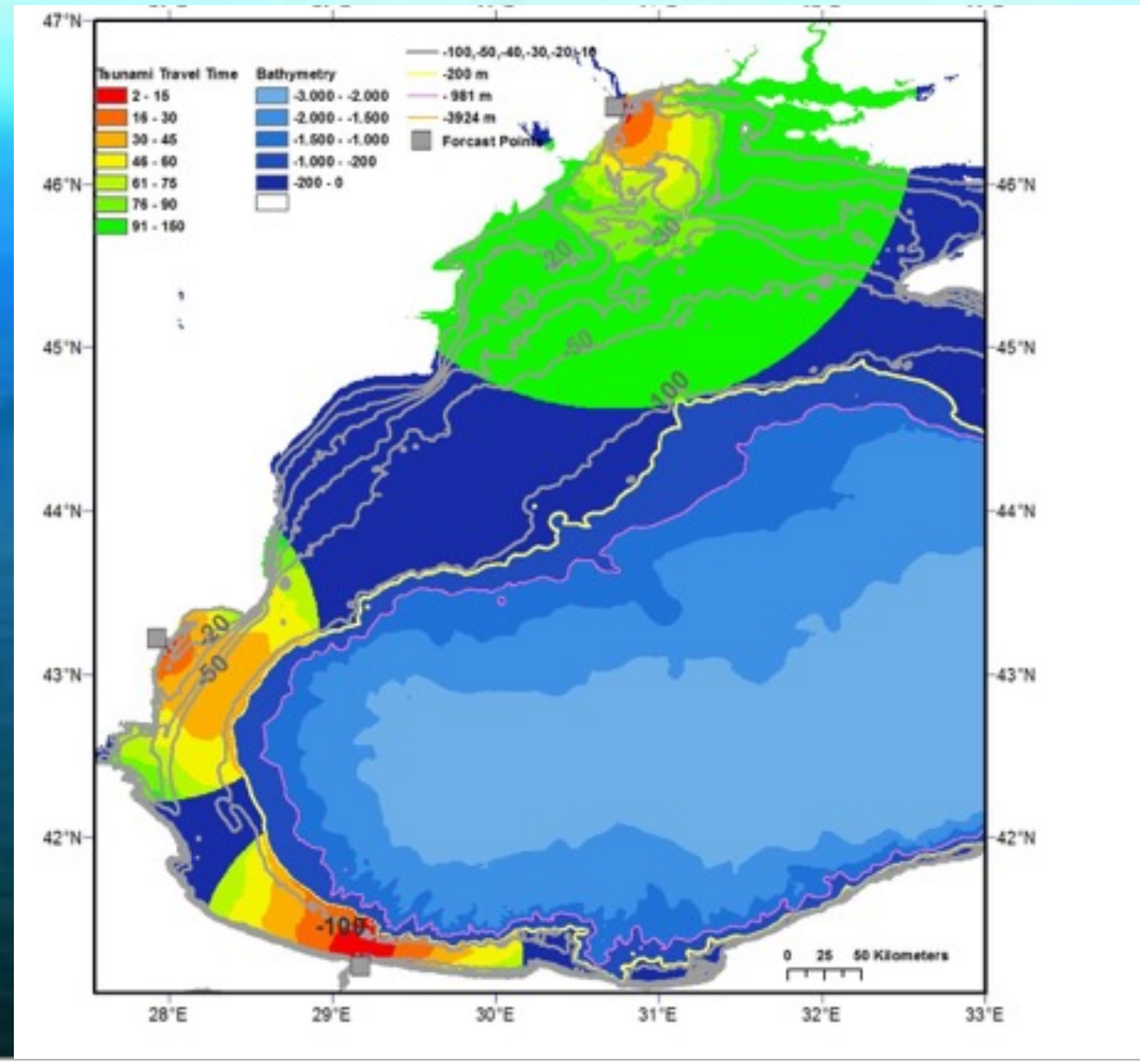
STRADIVARIUS radar





Potential use in Central and Eastern Mediterranean

Bathymetry effect on tsunami travel time



Conclusion

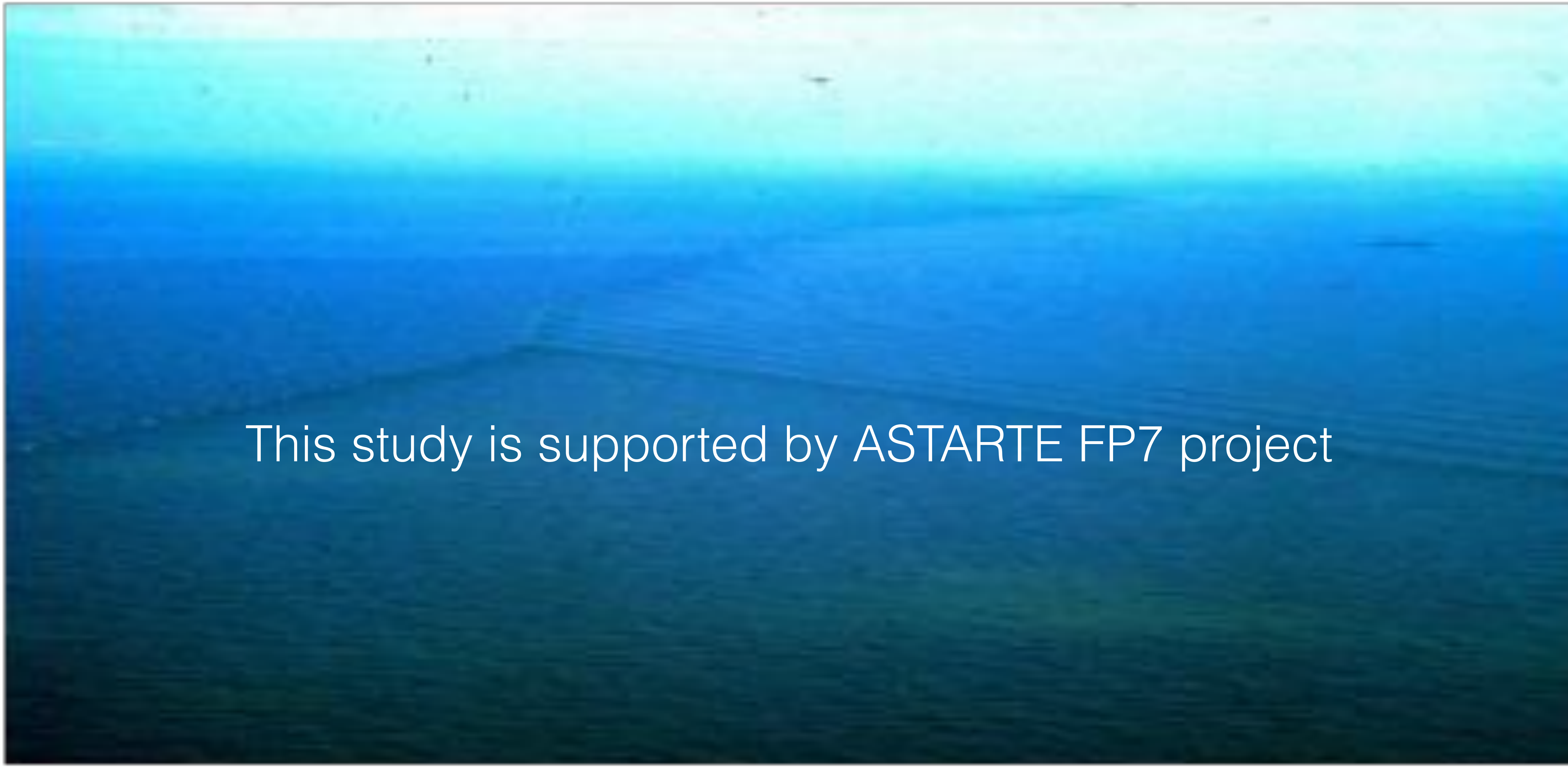
HF radar is recognised as internationally cost-effective and efficient solution to provide near-real time measurements that cover a large area continuously over time for ocean hazards warning and long term ocean monitoring studies

HF radar data used for the tsunami warnings, can also be used for the other purposes. Moreover multi user applications will ensure the system is maintained operationally over the long term.

Since the study area is characterised by narrow continental shelf area, the HF radar observation for the purpose of tsunami detection is possible in restricted areas. While extensive continental shelves in the northeastern Black Sea and along the coast of Tunisia in the central Mediterranean let tsunami detection 2.5 hours before tsunami waves hit the coast, the detection is possible around 1 hr or less in advance for the remaining basins with wide continental shelf areas.

The bathymetric structure is important for deciding the applicability of HF radar systems for the tsunami detection in continental shelf areas, which can be covered by medium range radars (75 - 100km). The steep continental shelf slope areas away from the cost are suitable for providing an advance warning for tsunami. On the other hand, areas deepening sharply close to shoreline would not be suitable for providing advance tsunami warning by using HF radar.


Thank you


This study is supported by ASTARTE FP7 project