An Ambient Noise Imaging sonar to detect non-vocalising Sperm Whales

Eric Delory[(1)], Michel André[(1)] & John R. Potter[(2)]

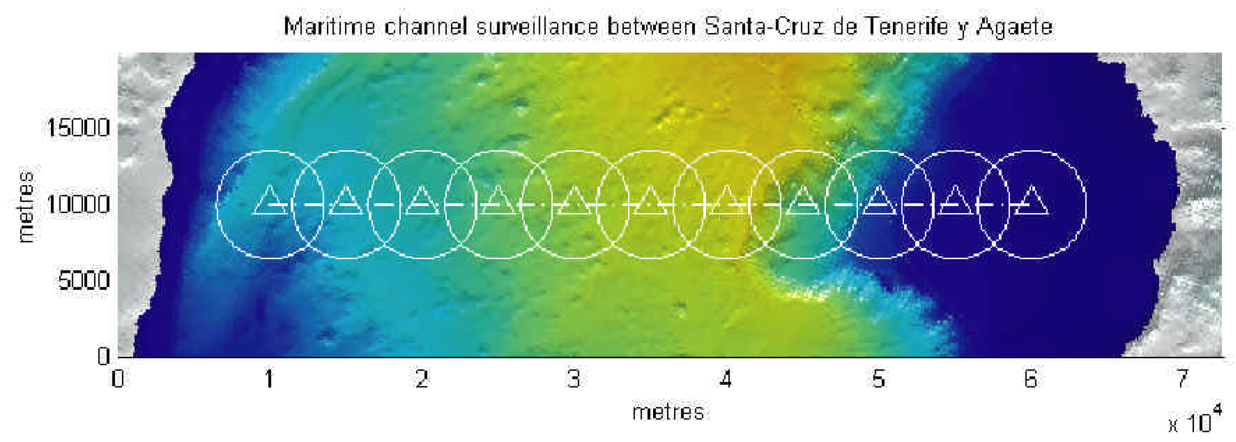
[(1)] **UICMM**, Unidad de investigación para la conservación de los mamíferos marinos
Facultad de Veterinaria, Universidad de Las Palmas de Gran Canaria

[(2)] **ARL**, Acoustic Research Laboratory
Tropical Marine Science Institute, National University of Singapore

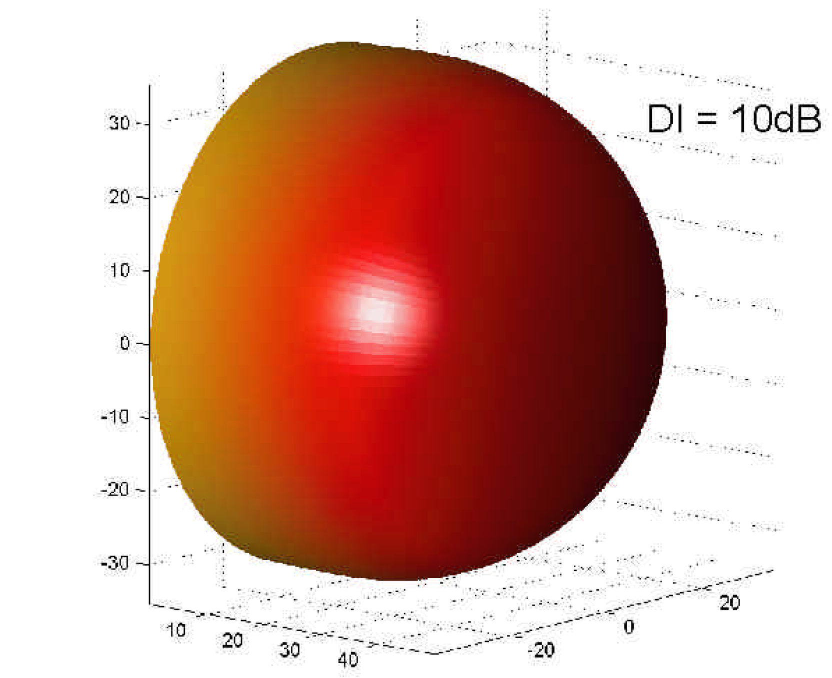
Gobierno de Canarias

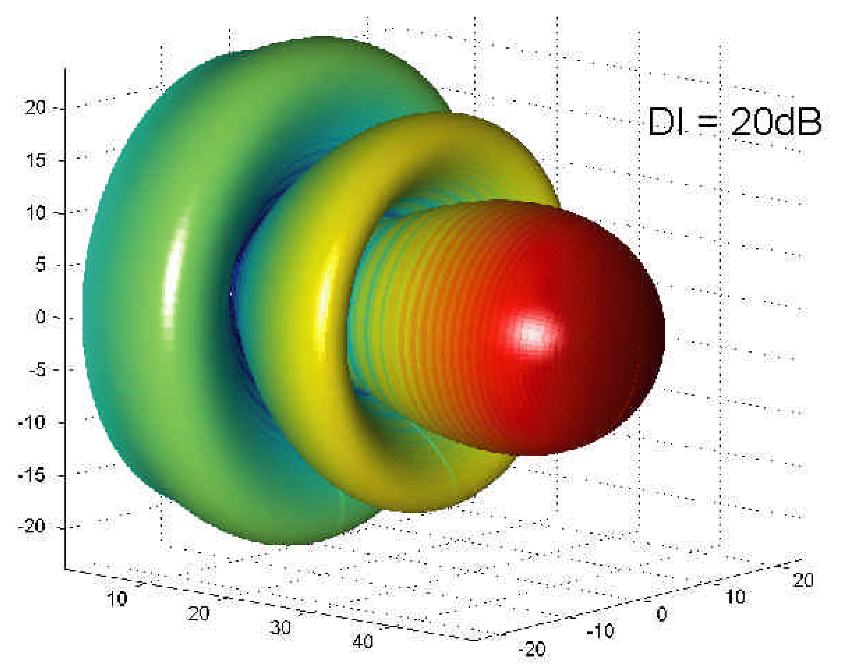
Abstract

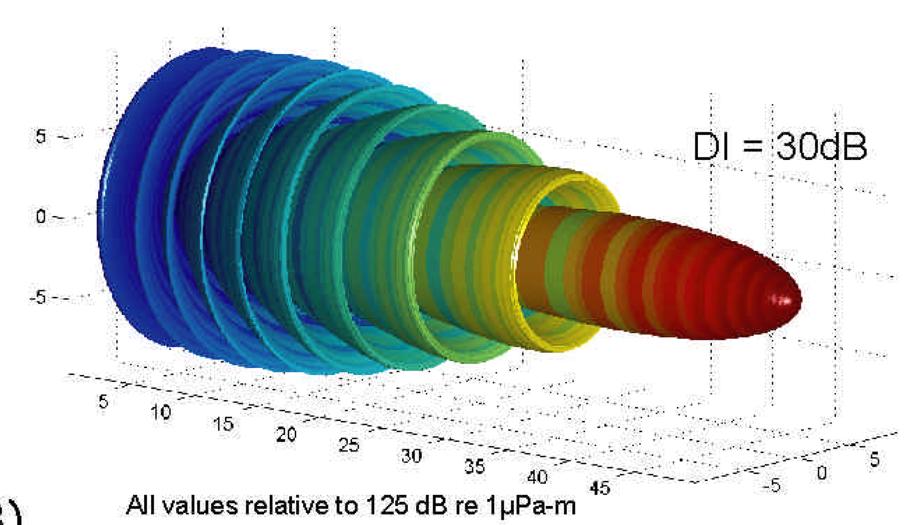
Sperm Whales (*Physeter macrocephalus*) near the sea surface are in danger from collisions with maritime traffic. Unfortunately, they are also known to remain silent when near the surface. There is consequently no conventional passive acoustic way to detect them at their most vulnerable location. The active sonar solution is both fraught with difficulties (due to reverberation from the sea surface and disturbances associated with the vessel's forward motion) and in any case undesirable since the appropriate bandwidth overlaps those used by many marine mammals. Finally, visual detection is very limited in range, particularly at night and in bad weather. These factors currently preclude timely action by fast vessels to avoid collision. We propose a non-intrusive solution; an Ambient Noise Imaging (ANI) method that consists of using natural sources of opportunity in a bistatic sonar mode. We demonstrate that it is feasible to detect a silent sperm whale near the sea surface from the backscatter of known natural acoustic sources. This method differs appreciably from prior ANI techniques in that it treats the opportunistic sources as deterministic, rather than statistical. This requires the additional step of first localising the opportunistic sources, then searching for backscattered signals from silent targets. It appears that vocalising sperm-whale clicks emitted at depth may be suitable sources to perform such a task. We highlight the constraints on this method for the design of a permanent monitoring system such as the proposed Whale Anti-Collision System (WACS) between the islands of Gran-Canaria and Tenerife in the Canaries.



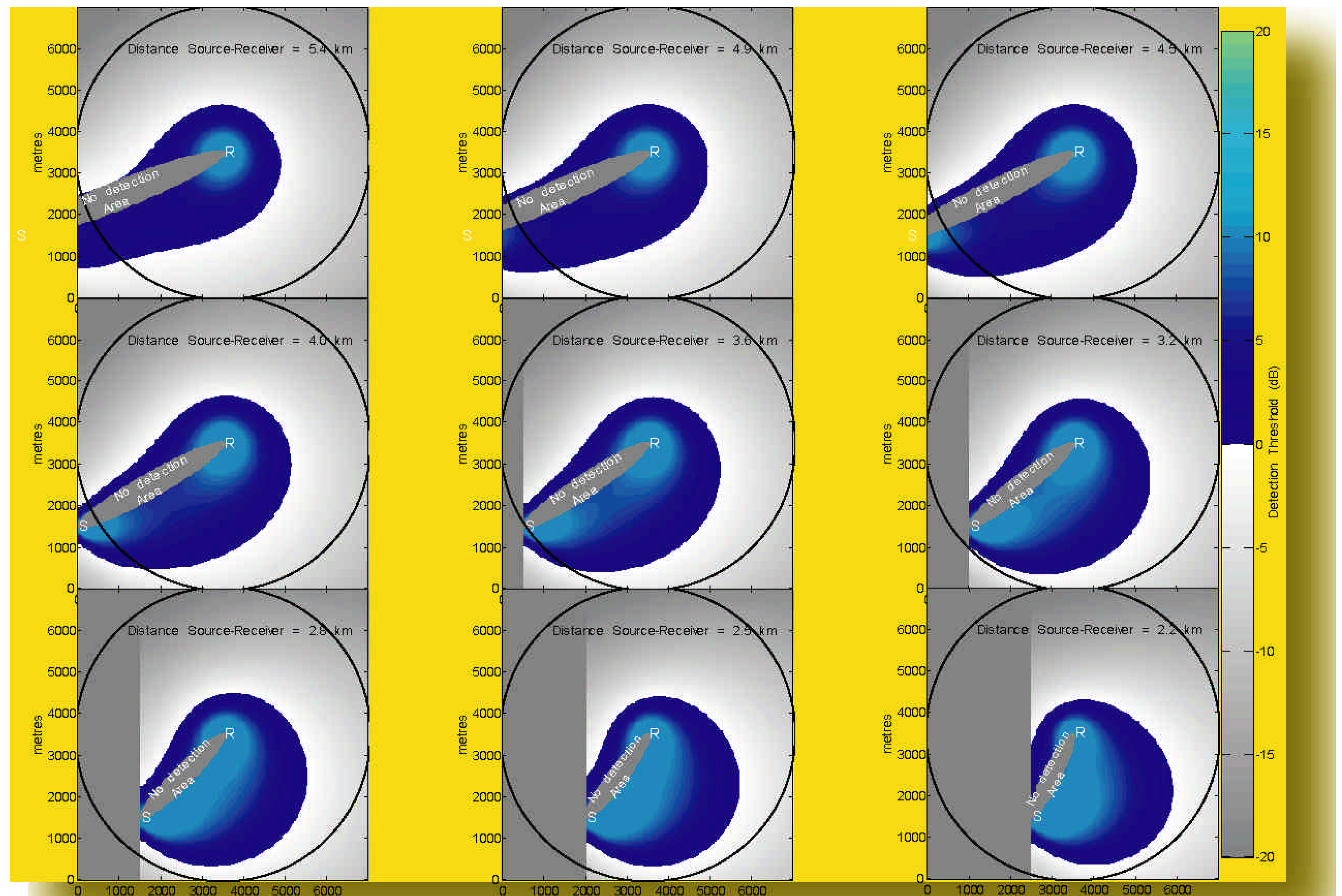
Display of one maritime channel of interest, between Santa-Cruz de Tenerife (left) and Agaete (Gran Canaria, right) where surveillance is a necessity. Each triangle represents the location of a sonobuoy that must scan a 7km diameter disk. Simulations results are presented on the right for one of the eleven disks.

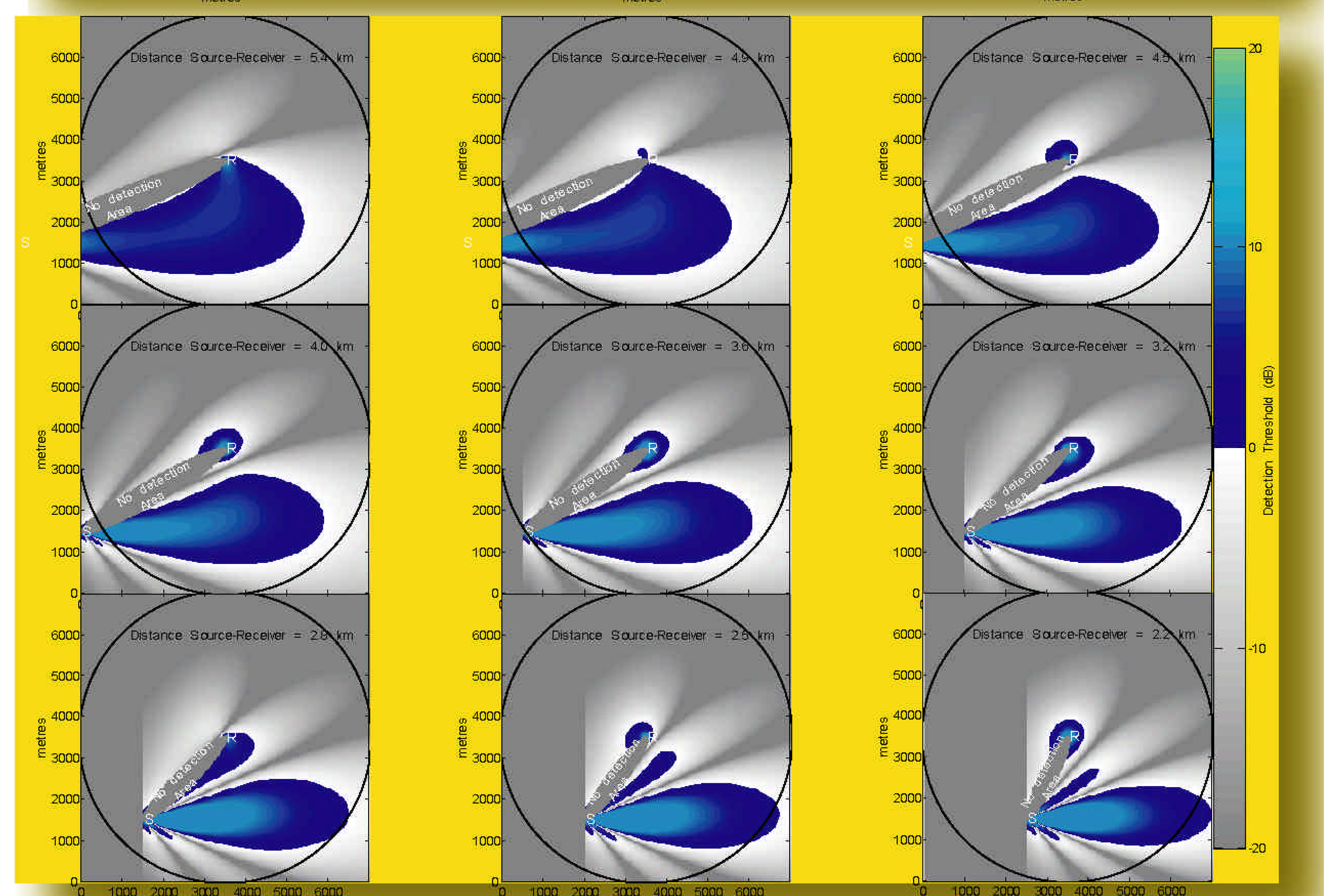


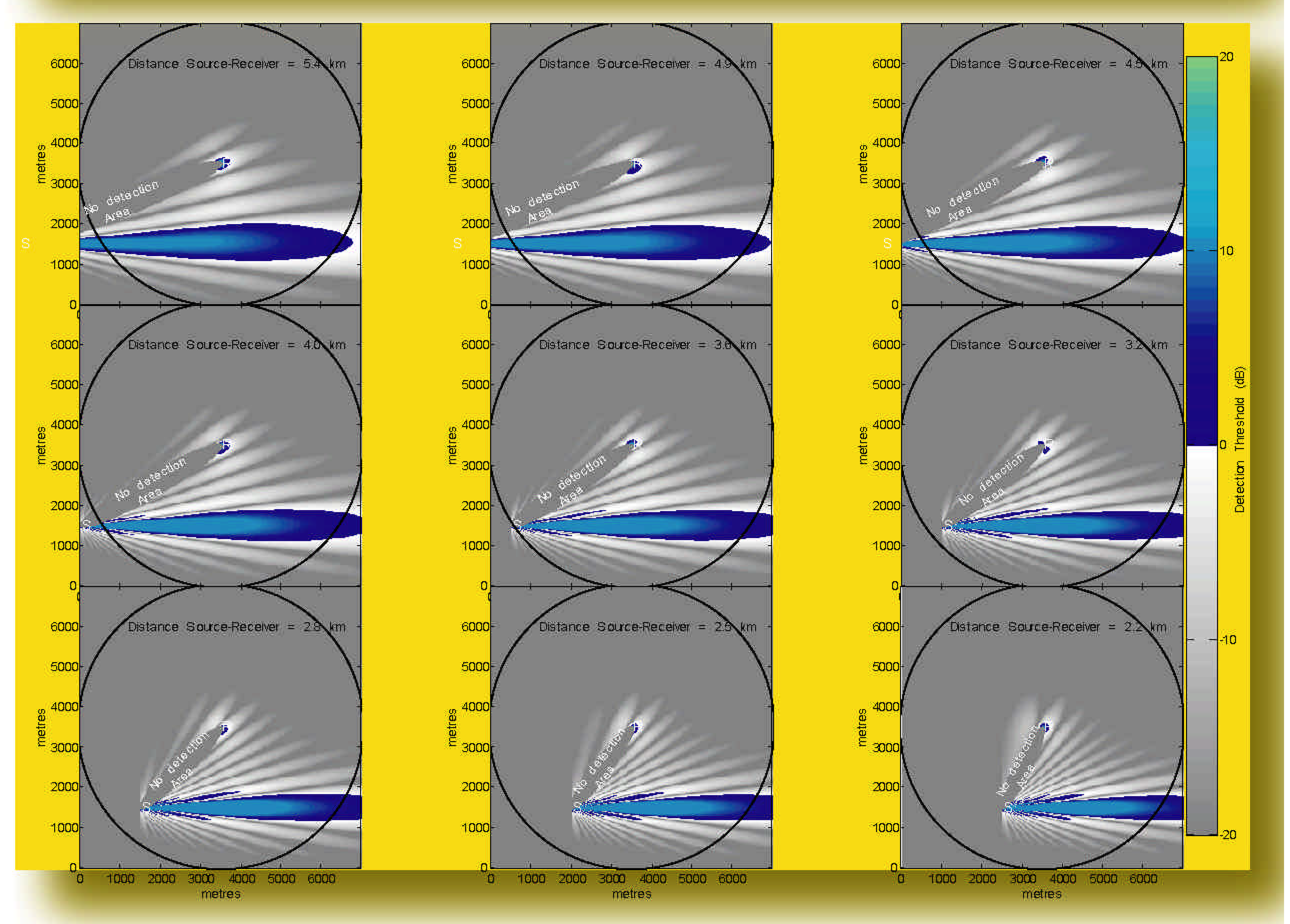




All 6 figures:
Top three: 3D-intensity beampattern of the piston model used for the Sperm-Whale click production system at the respective frequencies of 1kHz, 3kHz, and 10kHz, from top to bottom. See text for details.
Right, from top: Simulation results, where S is the source (a clicking adult Sperm Whale) travelling through the 7km diameter surveillance circle from left to right. The blue area corresponds to the positions where a silent Sperm Whale can be detected by the receiver (R, at the center) thanks to the echo the silent whale produces of the source click. Top figure results are for DI=10dB, middle figure for DI=20dB, and bottom for DI=30dB.







Target Strength (TS) of Sperm Whales:

To our knowledge, very few results are available concerning the target strength of whales. In this study, we referred to measurements performed on Humpback Whales in 1973 (Love 1973) and on one Sperm Whale in 1969 (Dunn 1969). Humpback Whales and Sperm Whales are considered here as acoustically equivalent in terms of TS. Respectively, TS values of 0dB (profile sight) at 10kHz and 0 to 10dB at 1kHz (surprisingly) were estimated. At bow aspect it is likely that TS reduces to -5 dB. Consequently, we decided to run detection simulations for the following TS values: -5, 0, and 10 dB, at the respective central frequencies of 1kHz, 3kHz, and 10 kHz.

Simulation model:

We use the sonar equation for a bi-static system to calculate the detection threshold of a silent Sperm Whale. SL: Source level and time-frequency characteristics are those of a Sperm Whale click (Møhl et al. 2000)

TS: extracted from (Love 1973) and (Dunn 1969); NL: 60dB re 1uPa-m (assumed flat in 1kHz-10kHz BW)

DI: We use an axisymmetric source, 3D beam-pattern extrapolated from (Møhl et al. 2000) which fits a piston model. As controversy still remains regarding the directionality of Sperm Whales sound production, we decided to run simulations for a 1,5m diameter piston at frequencies of 1kHz, 3kHz, and 10kHz, the latter corresponding to a 30dB directivity index, i.e. the same DI suggested for echolocating dolphins in (Au 1993).

TL: Spherical spreading one-way (20logR) and absorption is considered insignificant at the distances and bandwidths of interest (<1dB)

Source - Sperm whale click: We chose a conservative but realistic approach and assessed a 200dB maximum for the source beampattern. This amplitude is calculated as the total power of a 160dB/Hz flat power spectral density (PSD) on a 10kHz bandwidth, broadside. The average 30ms click duration only influences (here) the width of the "No Detection Area". Again, this value is conservative and it is likely that this area be narrower than the one displayed.

No Detection Area:

This area corresponds to the positions where the reflected signal from the silent whale corrupts the source signal at the receiver.

Discussion:

This study is a preliminary approach to a more advanced sonar system. The next step is to include a directional receiver and a discriminant matched filter which will both increase the signal-to-noise ratio and expand the detection area. The matched-filter will also enable and optimize the necessary source identification step. In the face of scenari such as the simulation with DI= 30dB (bottom figure), it is likely that ANI will not be efficient enough and that these add-ons might be a necessary constraint to the sonobuoy design in WACS. To confirm such necessity will remain an issue until a better noise, Sperm Whale sound production and target strength model are known. We conclude that this simple sonar equation model has fulfilled to convince that the bi-static deterministic ANI approach is in principle a rather successful method towards future passive localization of silent Sperm Whales.

Key References: Au, W. W. L. (1993). The Sonar of Dolphins, Springer-Verlag, Inc., New York.
Dunn, J. L. (1969). "Airborne measurements of the acoustic characteristics of a Sperm Whale." Journal of the Acoustical Society of America, 46(4(2)), 1052-1054.
Love, R. H. (1973). "Target strengths of humpback whales Megaptera novaeangliae." Journal of the Acoustical Society of America, 54(5), 1312-1315.
Møhl, B., Wahlberg, M., Madsen, P. T., Miller, L. A., and Surlykke, A. (2000). "Sperm whale clicks: Directionality and source level revisited." Journal of the Acoustical Society of America, 107(1), 638-648.