

# Ocean Bottom Seismometers for Passive Acoustic Monitoring of Baleen Whales

Léa Bouffaut<sup>1</sup>, Richard Dréo<sup>2</sup>, Abdel Boudraa<sup>3</sup>, Martin Landrø<sup>4</sup>, and Guilhem Barruol<sup>5</sup>

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<sup>2</sup>Center for Maritime Research and Experimentation

<sup>3</sup>Ecole Navale IRENav

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November 22, 2022

## Abstract

Over the last decade, the opportunistic use of broadband Ocean Bottom Seismometer (OBS) recordings has been extremely beneficial for baleen whales studies as they regularly record their stereotyped calls ([10-40] Hz). Often deployed in remote areas, OBSs offer additional and often unprecedented locations for acoustic data collection. The long-term, widespread networks are then ideal for passive acoustic monitoring. Therefore OBS-recorded data are crucial to conservation purposes from monitoring their post-exploitation recovery to improving our understanding of these endangered species and threats. As an example of the potential of OBSs for baleen whale studies, this work exploits data collected by the RHUM-RUM (Réunion Hotspot and Upper Mantle - Réunions Unterer Mantel) seismic network. It aimed initially at imaging the mantle structure beneath the Western Indian Ocean and the dynamics of La Réunion volcanic hotspot. To that extent, 57 OBSs were deployed on the ocean floor, covering an area of 2000x2000 km<sup>2</sup> (Lat. 16-34°S, Long. 048-070°E), from October 2012 to November 2013. The RHUM-RUM data provides the second opportunity to record species-specific or regionally-distinct signals of Blue Whales (BW; Antarctic and Madagascar Pygmy BW) within the Western Indian Ocean Sanctuary. BW calls can propagate from tens to hundreds of kilometers. Consequently, results show that recordings from a single OBS are sufficient to determine the acoustic presence of a species and estimate the range of a calling individual. However, the data analysis benefits from the use of automatic and reliable detection processes. Additional information arises from increasing the number of sensors: a small array of the RHUM-RUM network (20km inter-sensor distance) is used for localization and tracking, essential for animal counting. Besides, the broader configuration showed repartition and migration patterns of the studied species. These recordings from the bottom of the ocean shed new light on the study of BWs and, more generally, low-frequency sounds in this area.



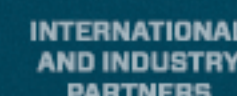
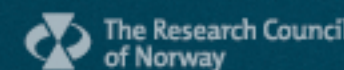
ARCEx

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December 15th, 2020

[lea.bouffaut@ntnu.no](mailto:lea.bouffaut@ntnu.no)

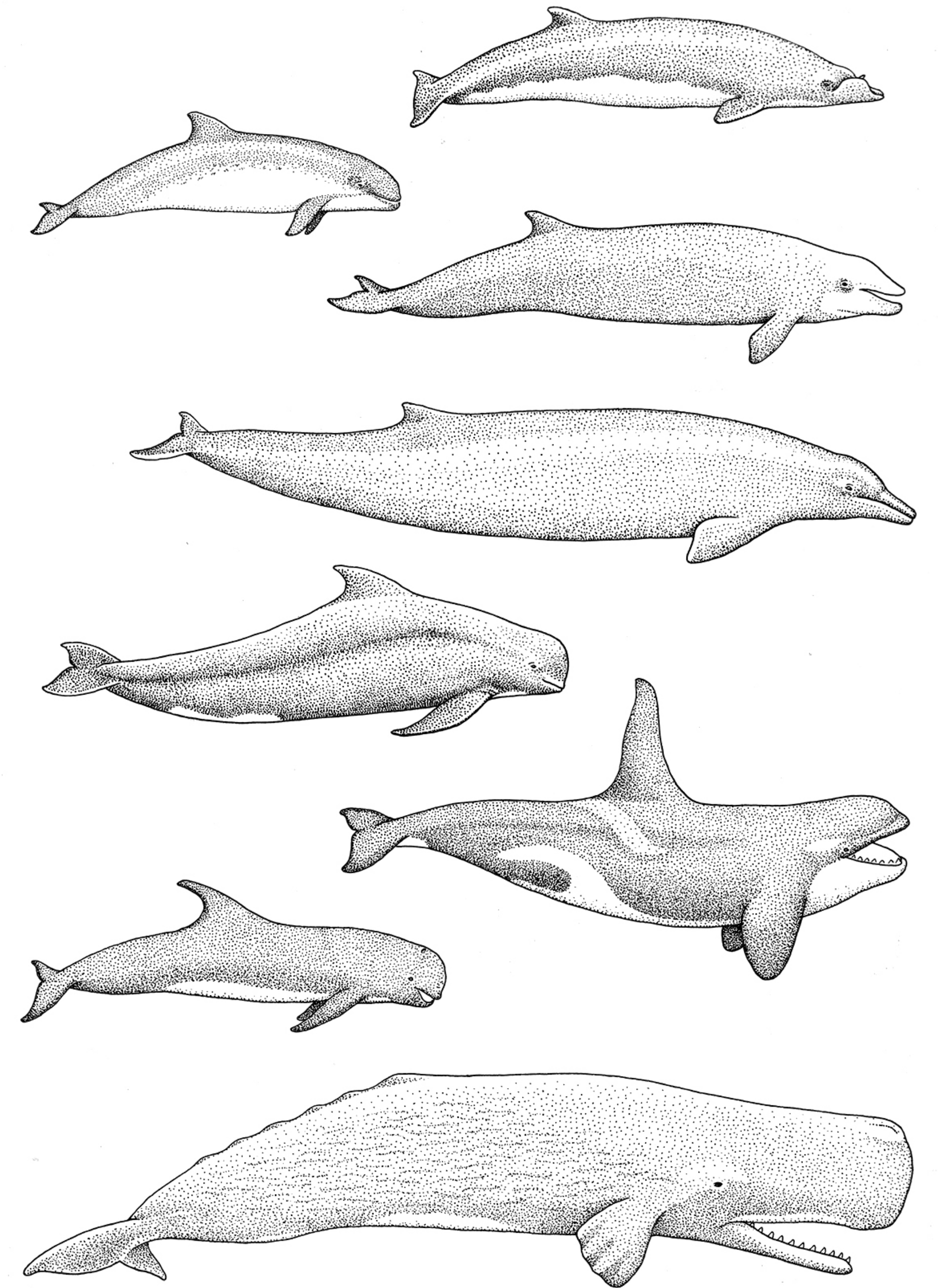




**How can OBSs  
contribute to  
understanding baleen  
whales ?**



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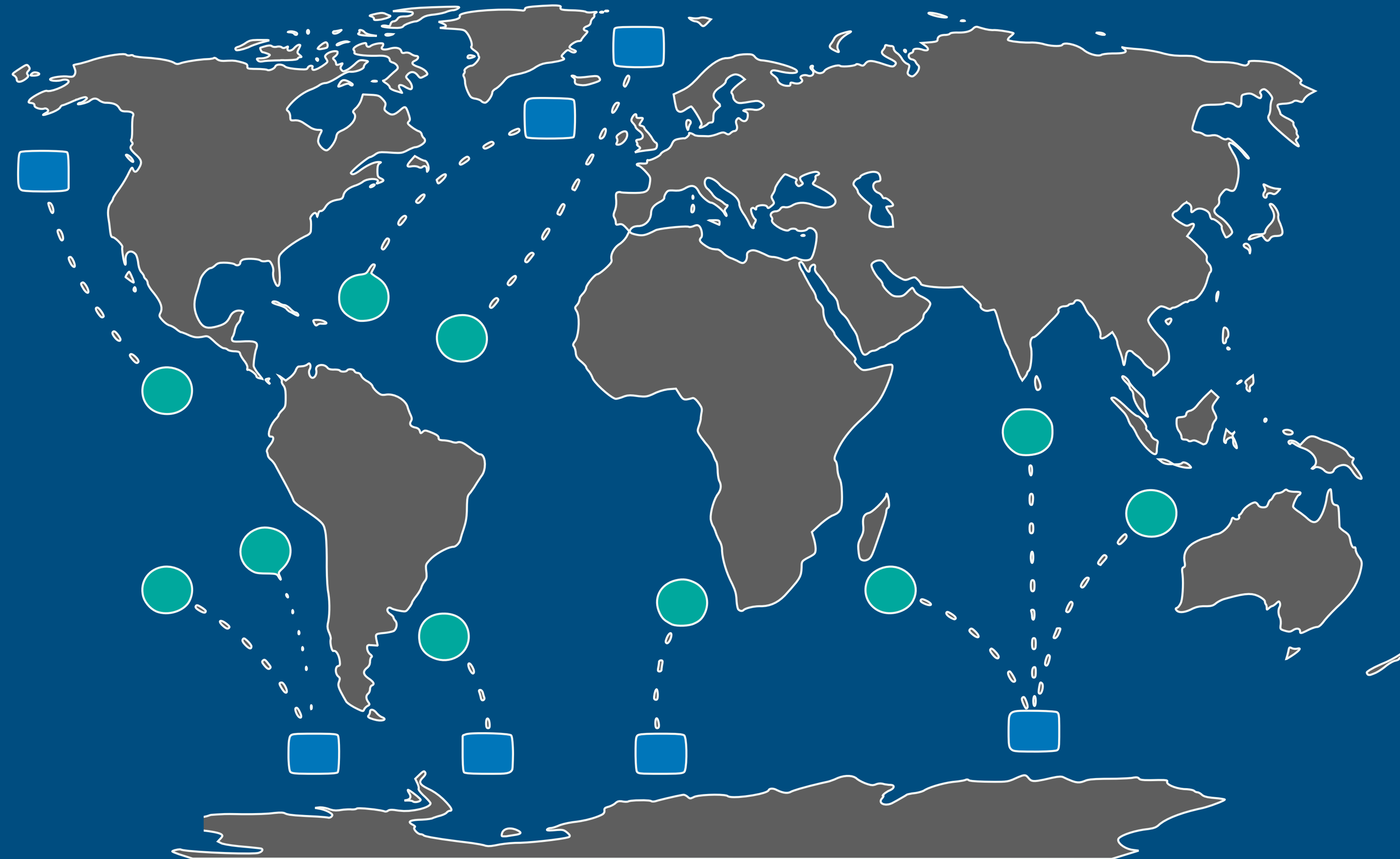




# Blue whales

Feeding grounds

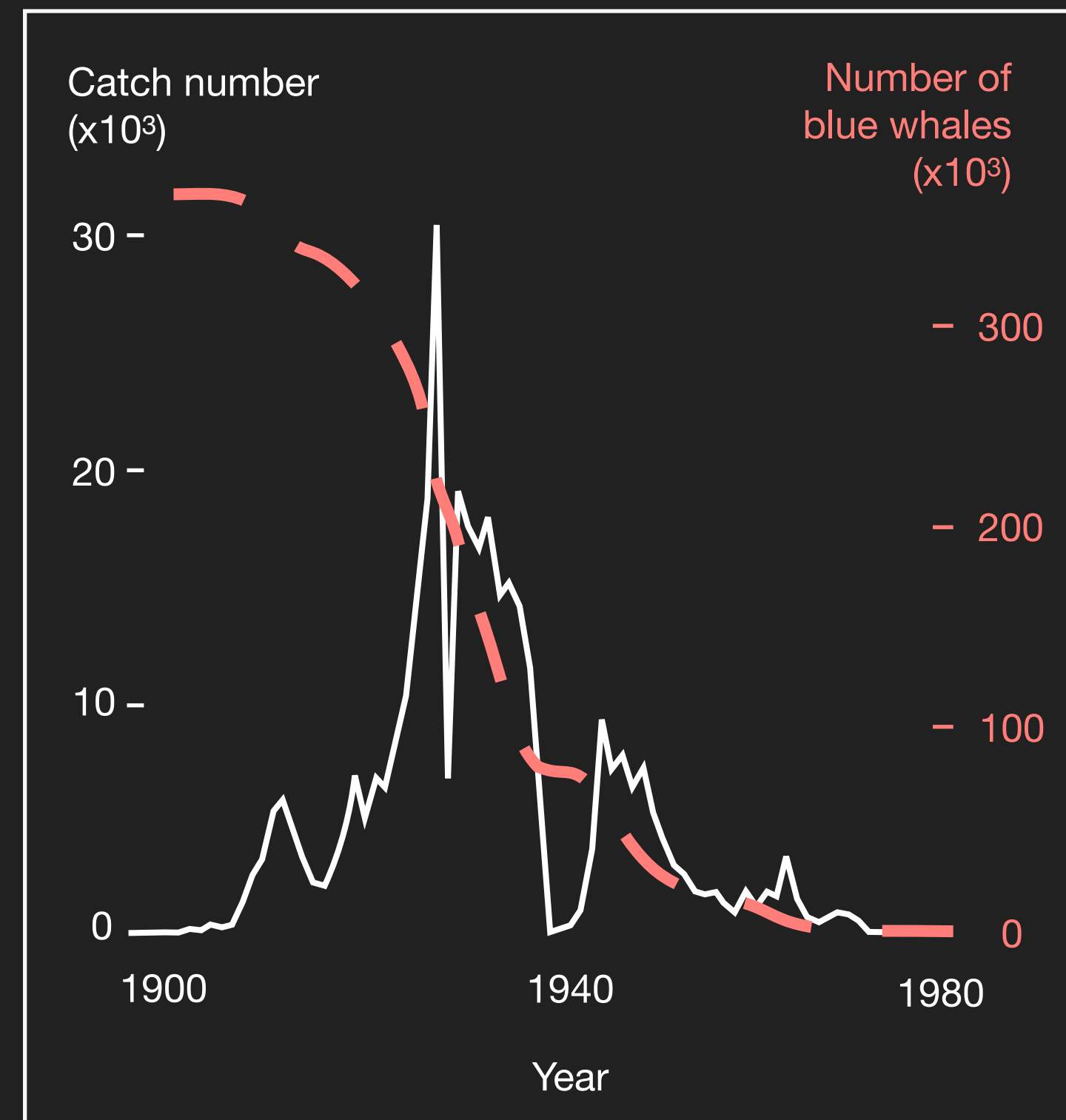
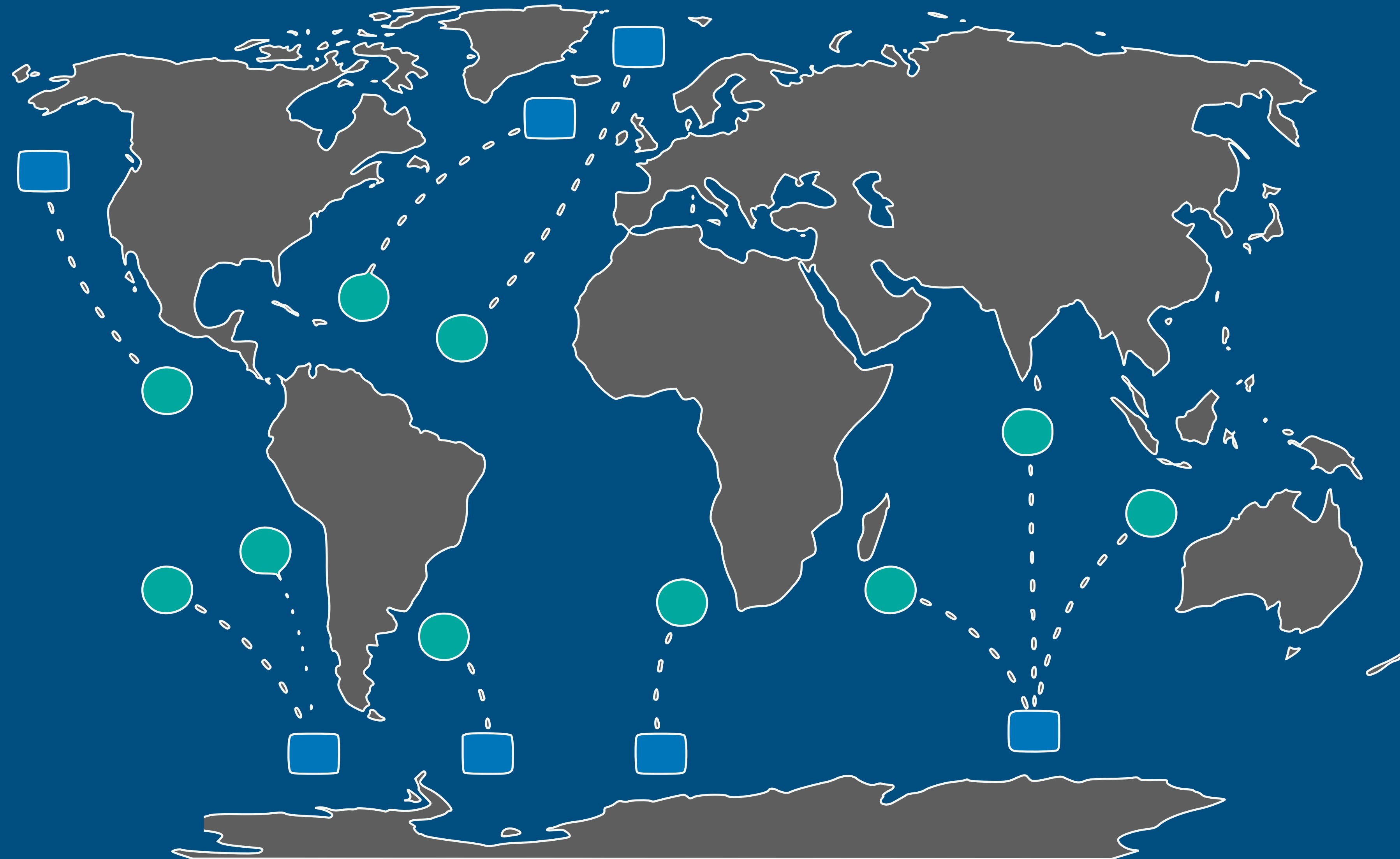
Breeding grounds





# Blue whales

- Feeding grounds
- Breeding grounds

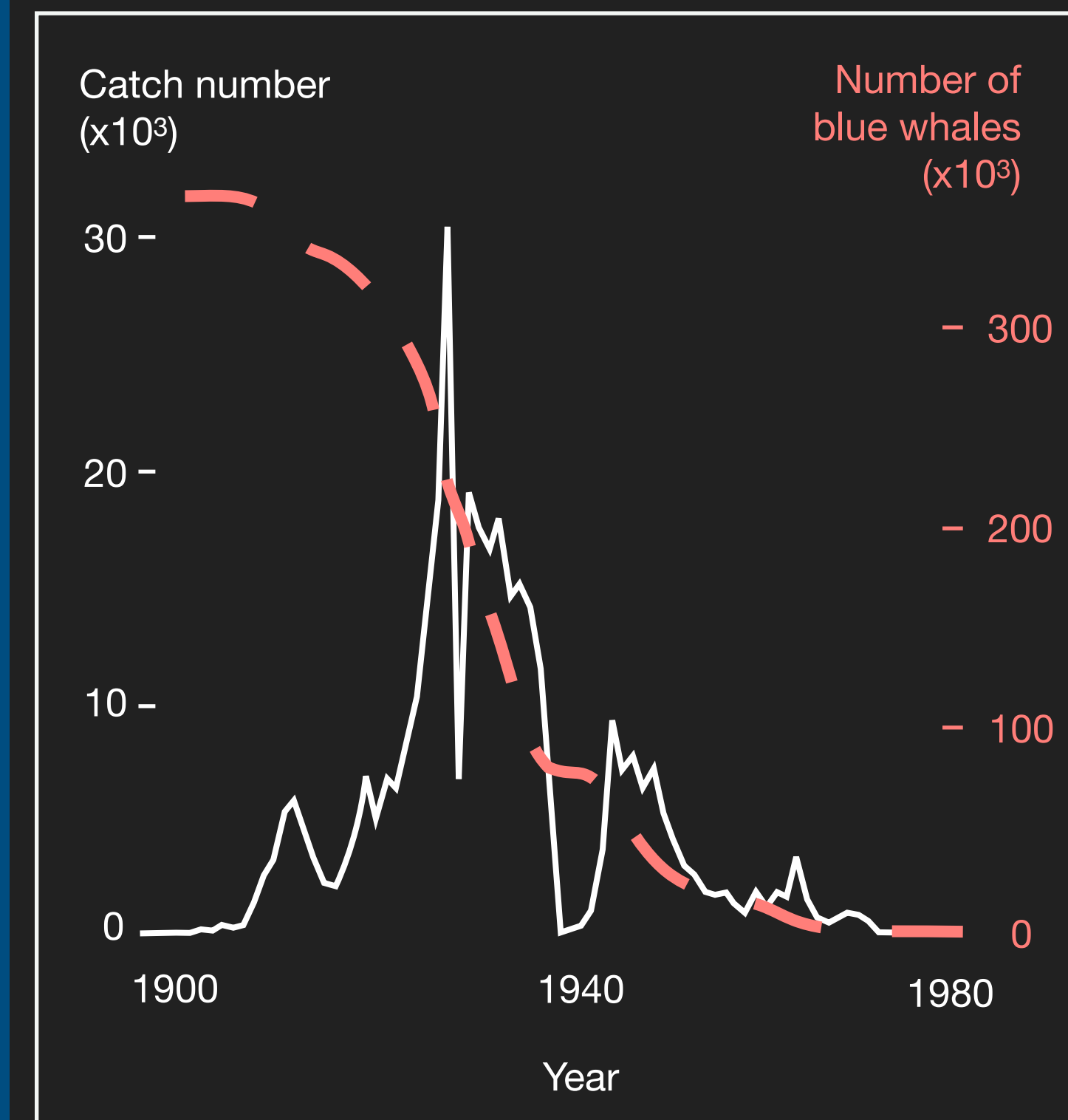
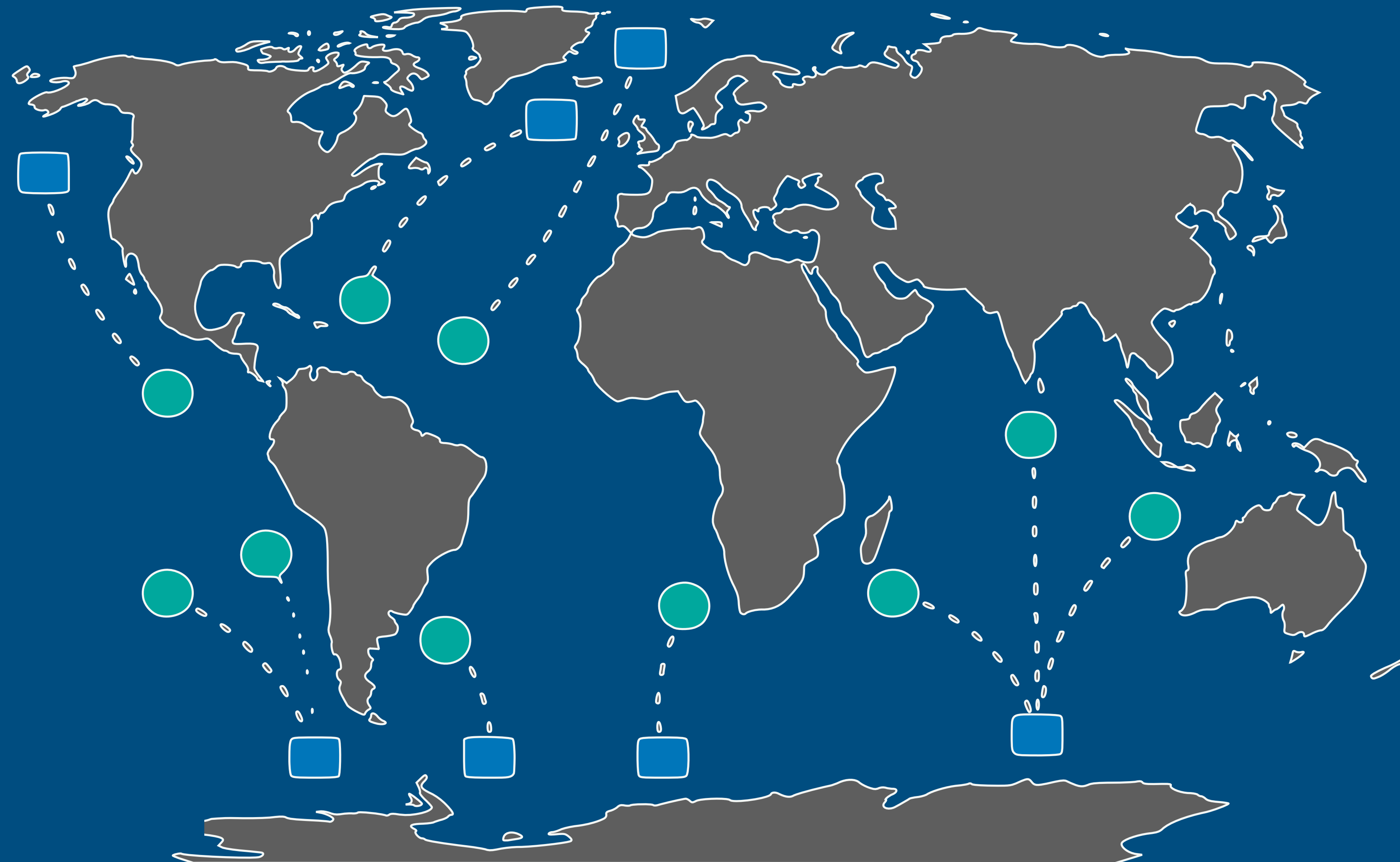


Adapted from Leroy (2017),  
based on IWC data



# Blue whales

- Feeding grounds
- Breeding grounds



Adapted from Leroy (2017),  
based on IWC data

**A small number of  
individuals scattered  
across wide areas:**

**Visual monitoring is  
limited**



# Passive acoustic monitoring of baleen whales

Blue whale produce  
loud, low-frequency  
sounds!



# Passive acoustic monitoring of baleen whales

**Blue whale produce  
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Passive acoustic monitoring

- Autonomous
- Continuous
- Long-term
- Large scale

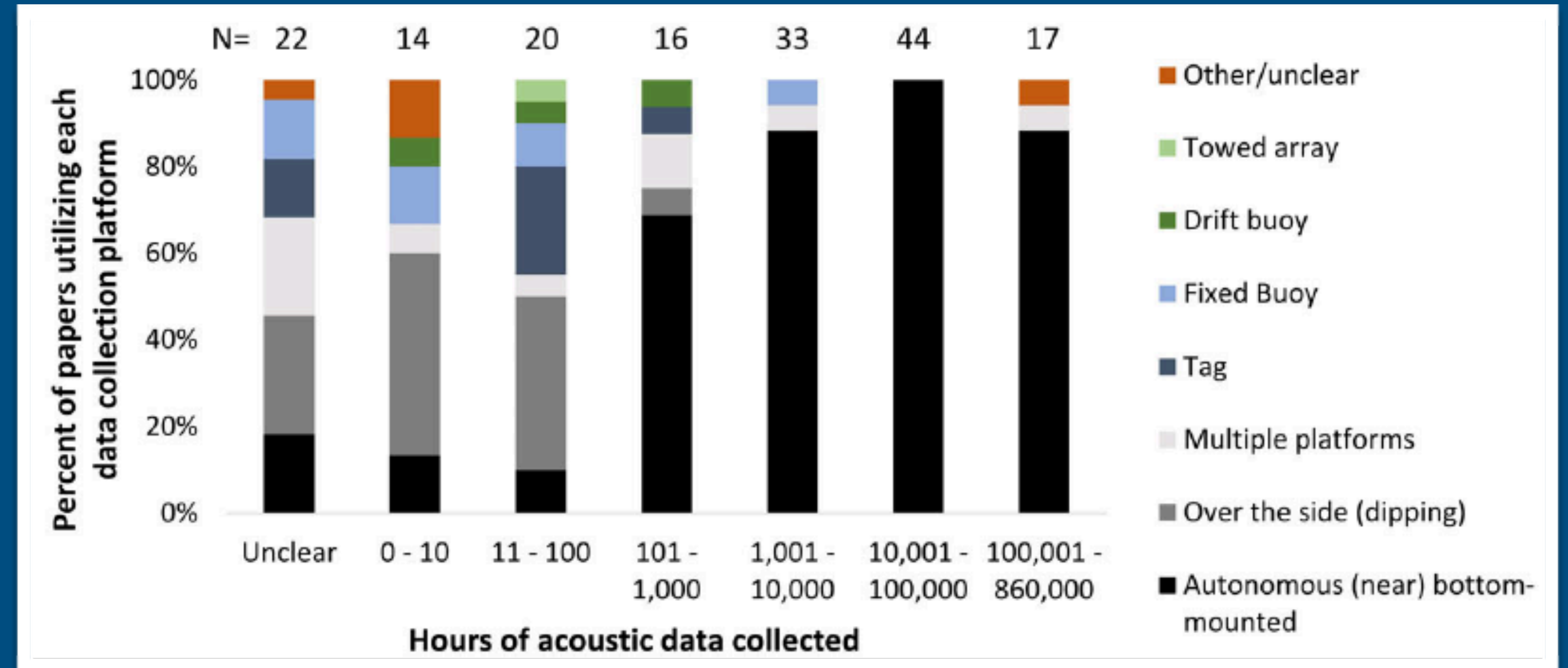


# Passive acoustic monitoring of baleen whales

Blue whale produce loud, low-frequency sounds!

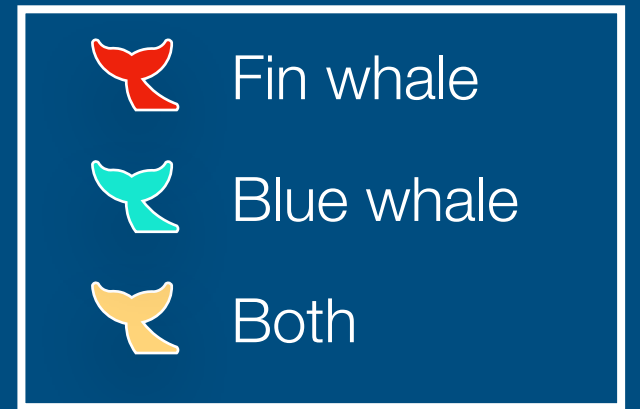
Passive acoustic monitoring

- Autonomous
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Kowarski & Moors-Murphy (2020)

# OBSs and whales in the literature



Weirathmueller  
(2011, 2014, 2017)  
Wilcock (2012)  
Soule (2013)



Rebull  
(2006)



Harris (2013)  
Pereira (2020)



Dunn & Hernandez  
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Franck & Ferris  
(2011)



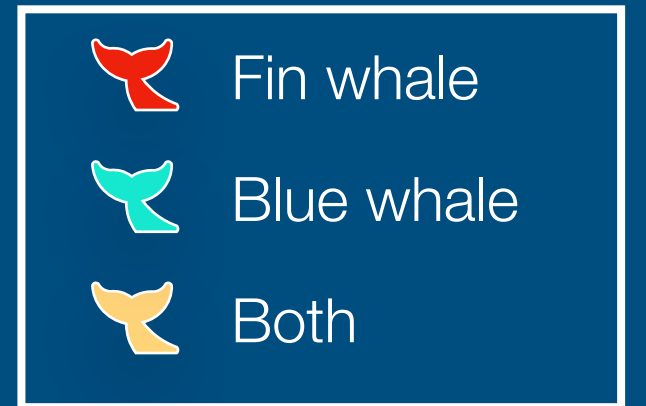
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Brodie & Dunn  
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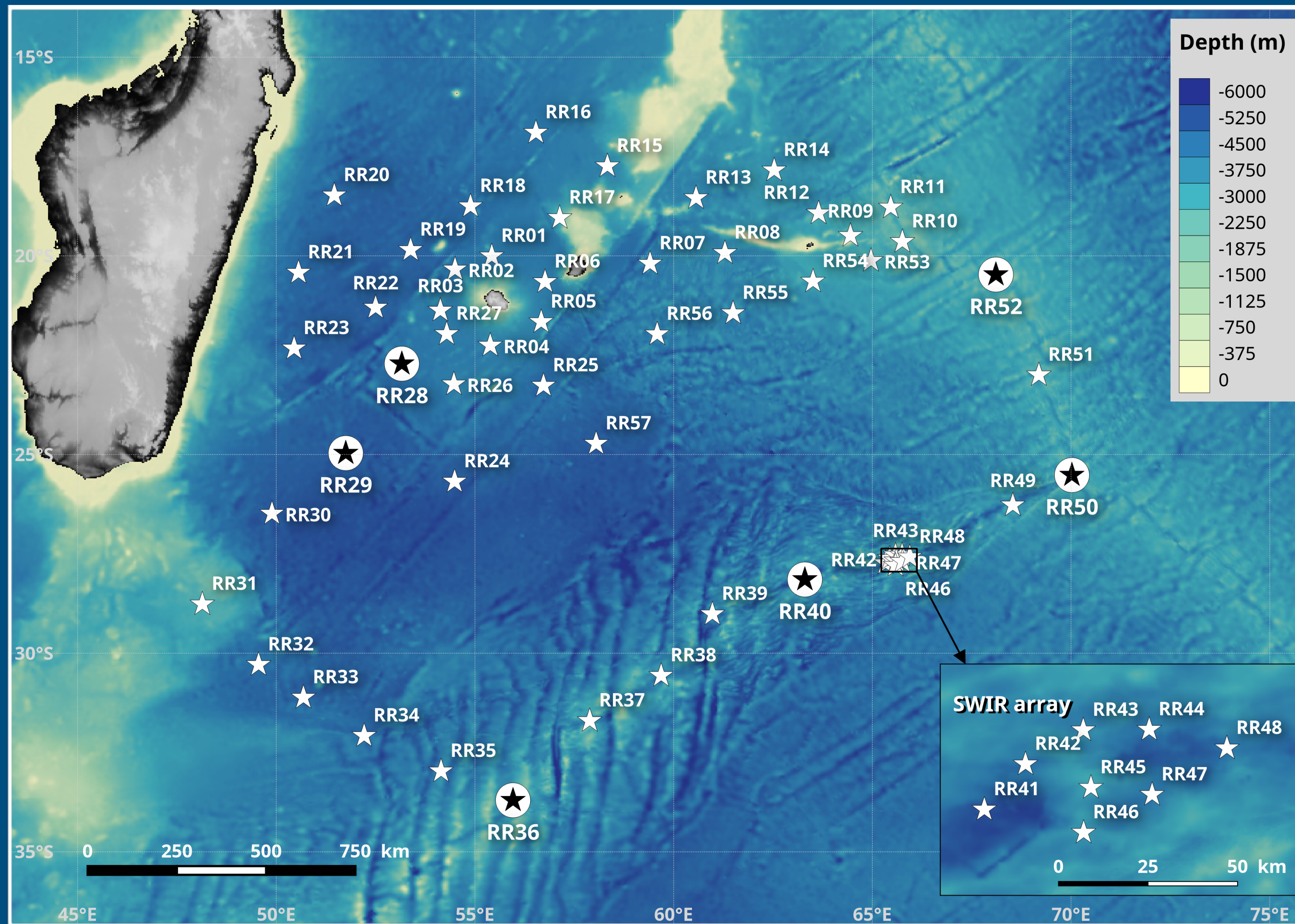
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# The RHUM-RUM experiment



RHUM-RUM data is open source!

- RESIF data center, under the code name YV

<https://doi.org/10.15778/RESIF.YV2011>

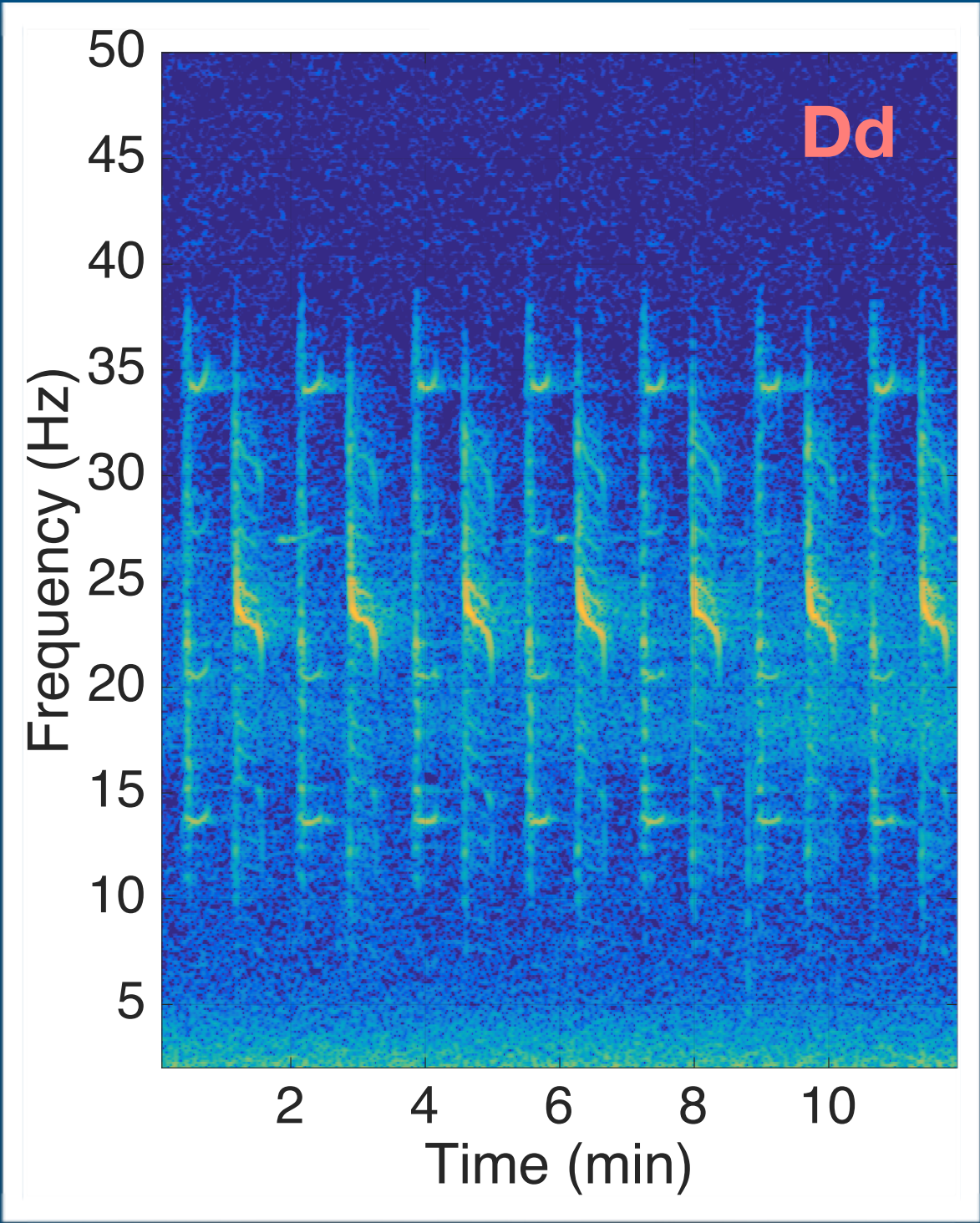
- Find more information on RHUM-RUM on Researchgate

<https://www.researchgate.net/project/RHUM-RUM>

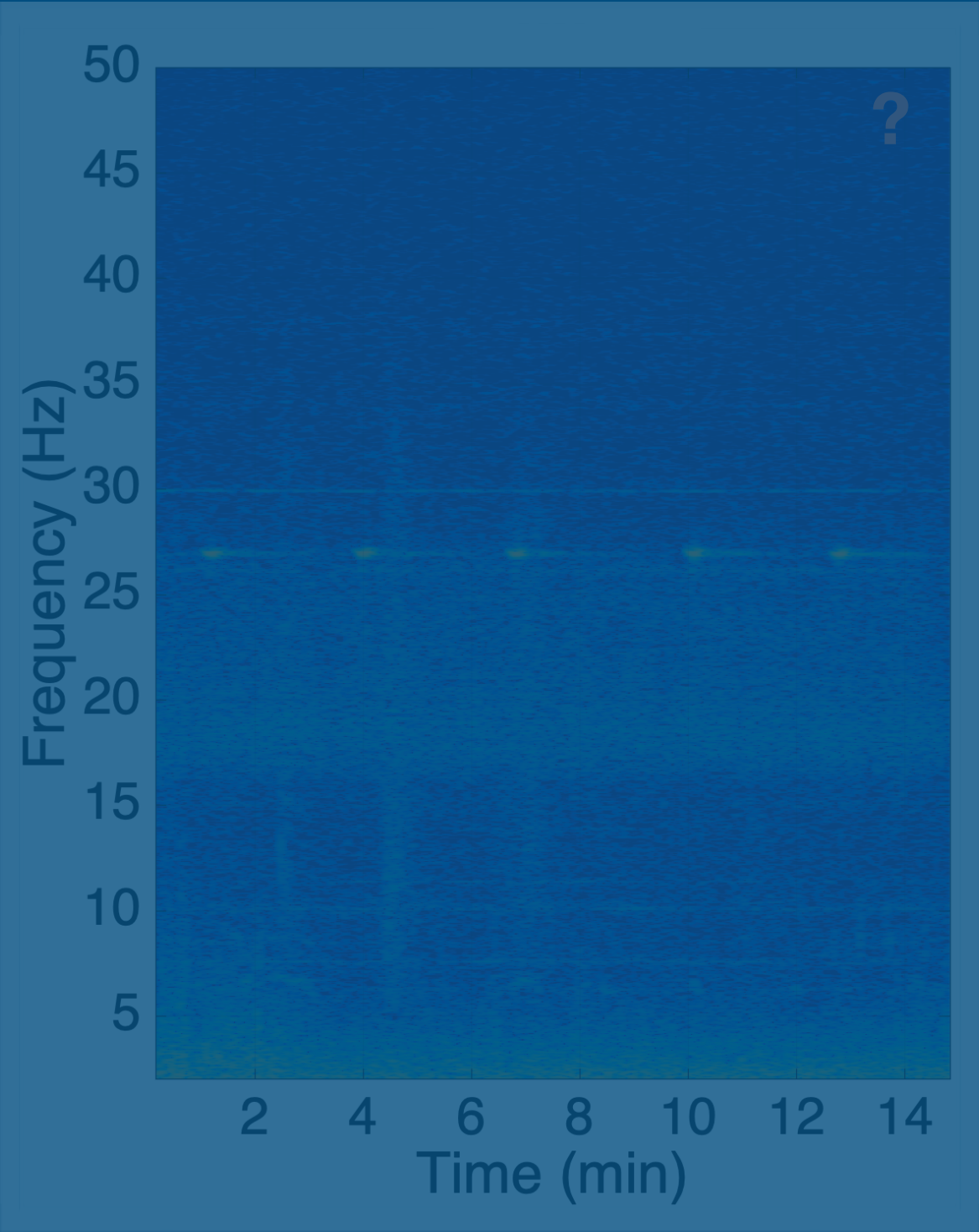


# Recorded baleen whale sounds

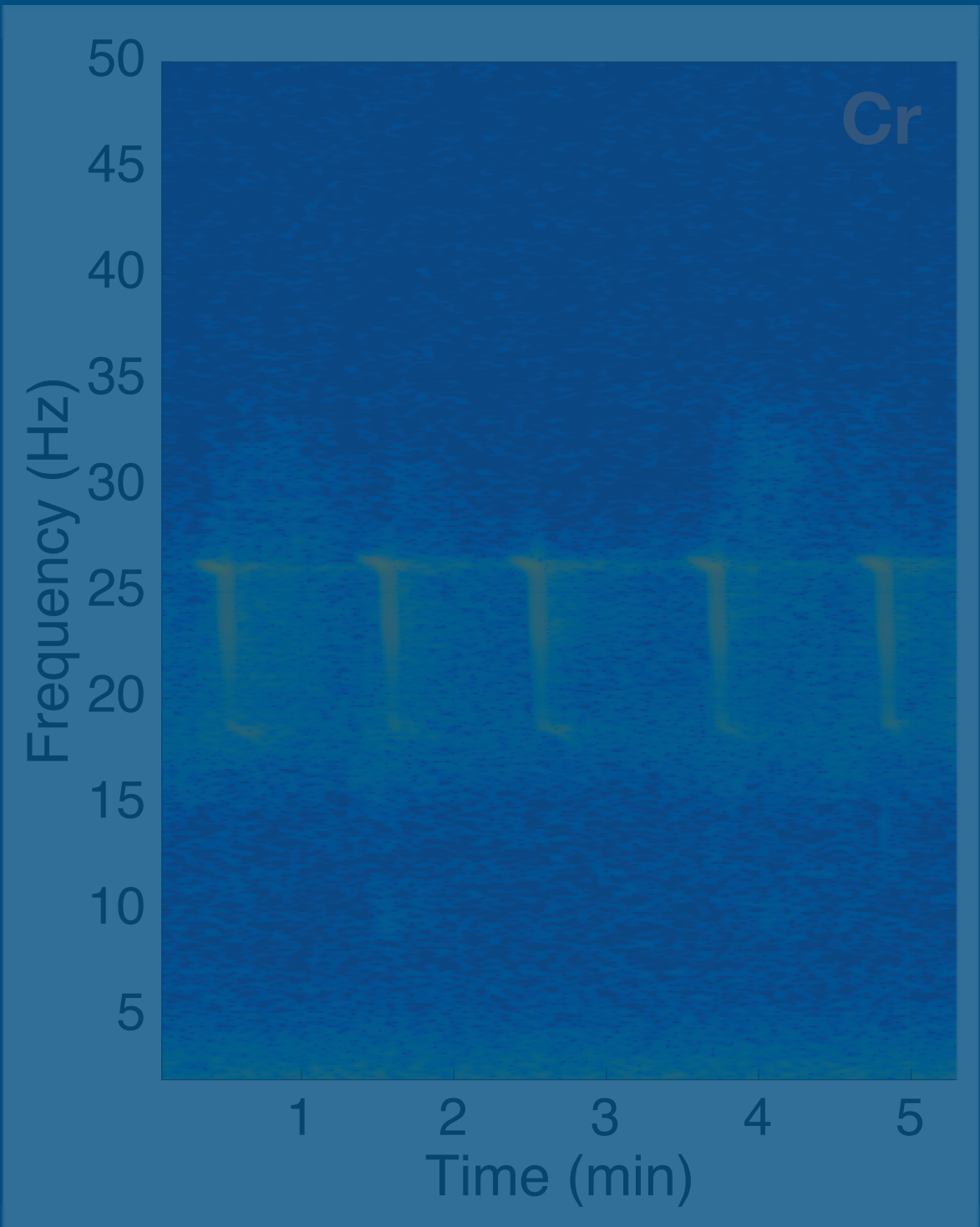
Very local Not so local



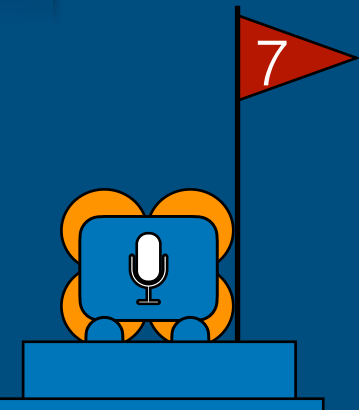
Madagascar Pygmy blue whale  
*Balaenoptera musculus brevicauda*



P-call or spot call  
*unknown*



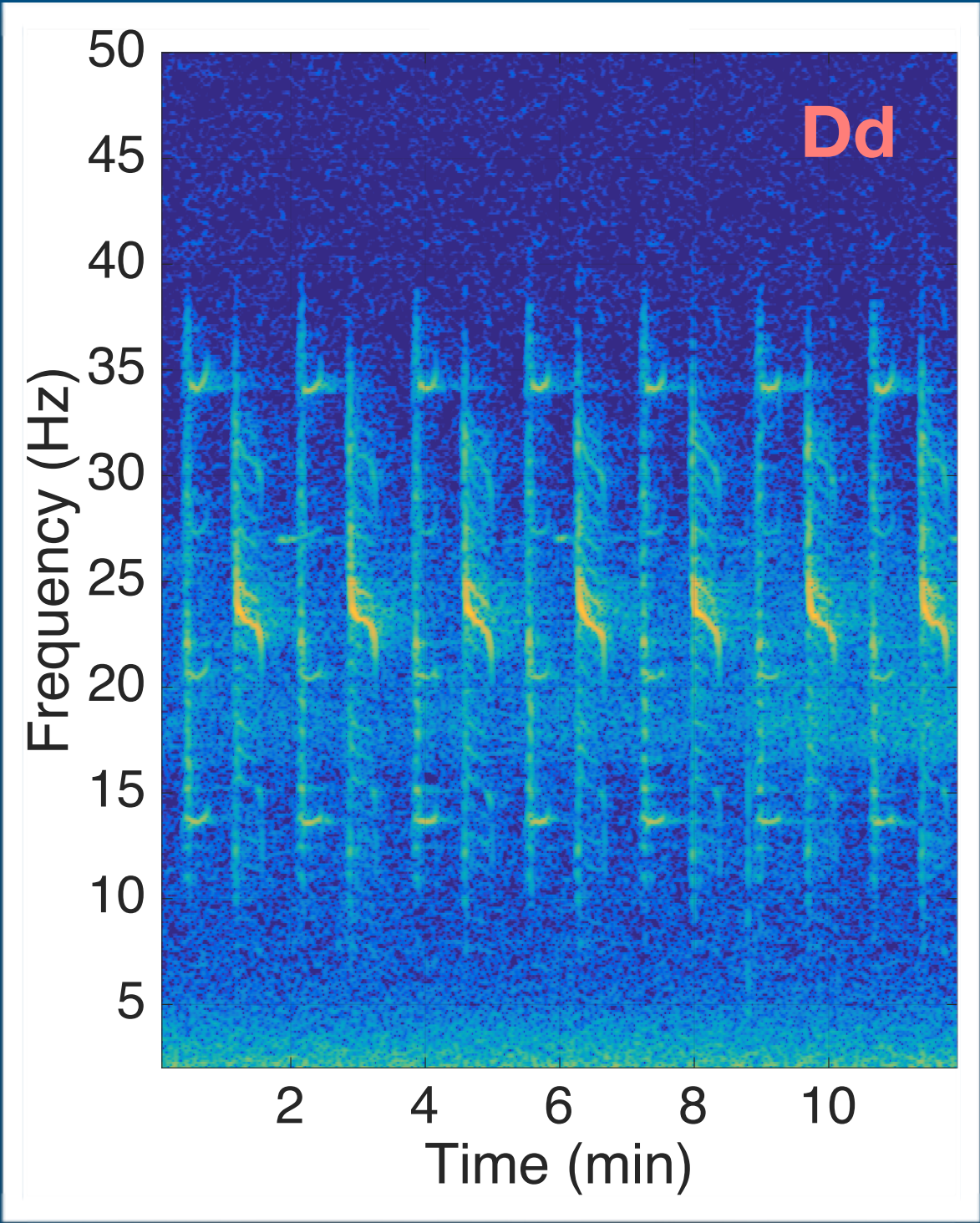
Antarctic blue whale  
*Balaenoptera m. intermedia*



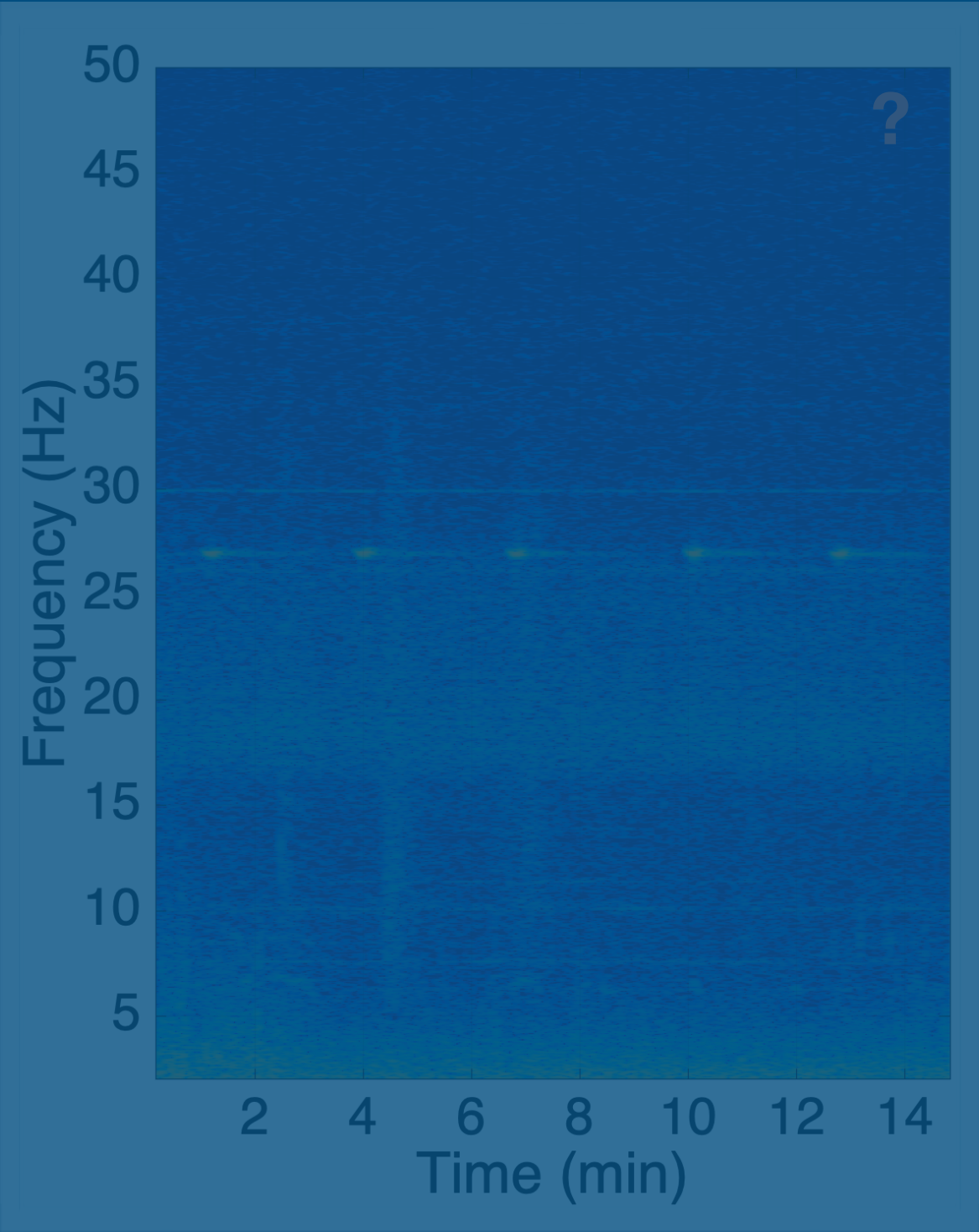


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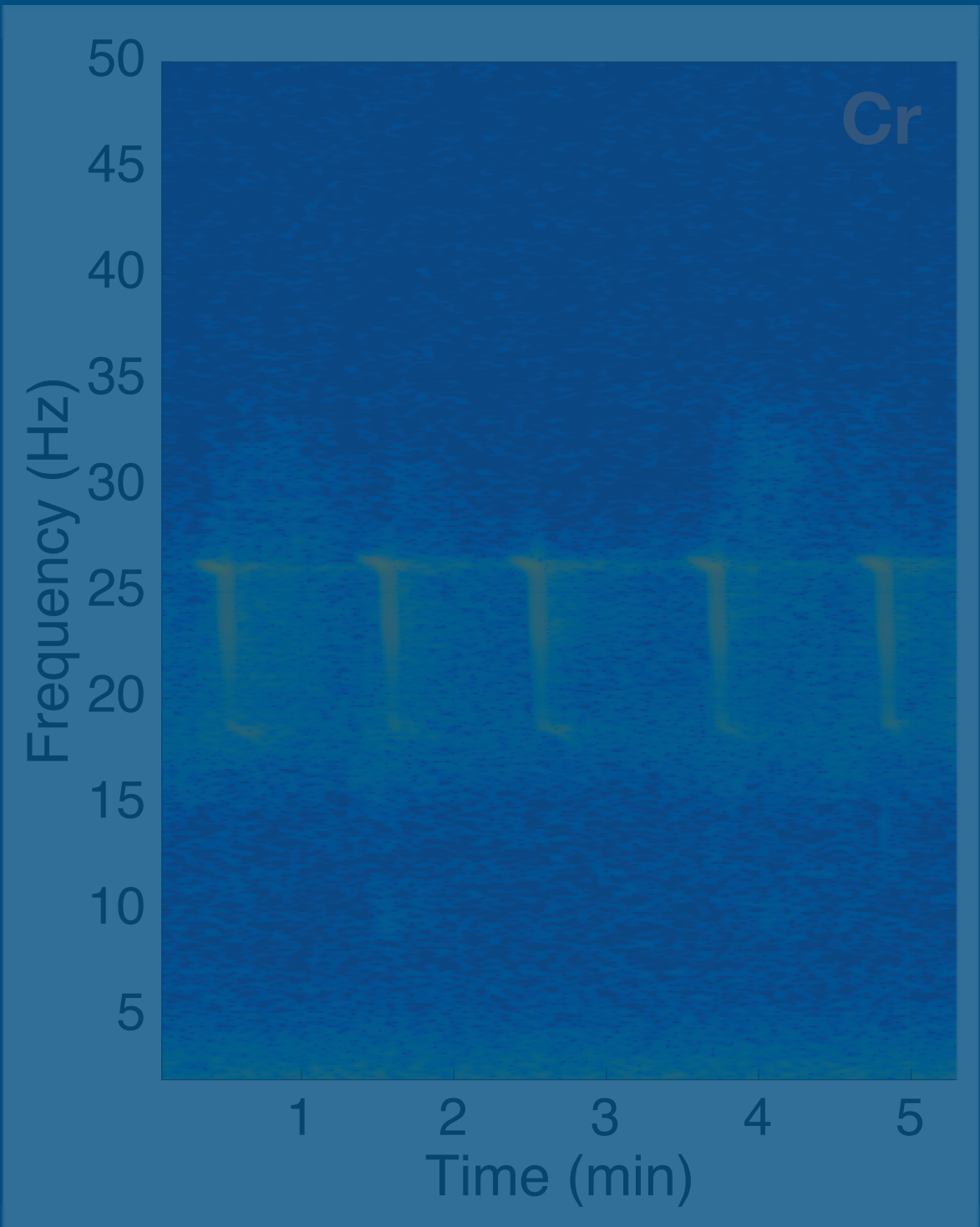
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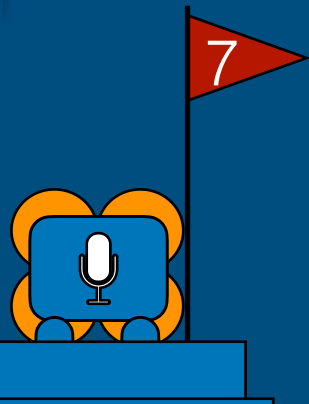
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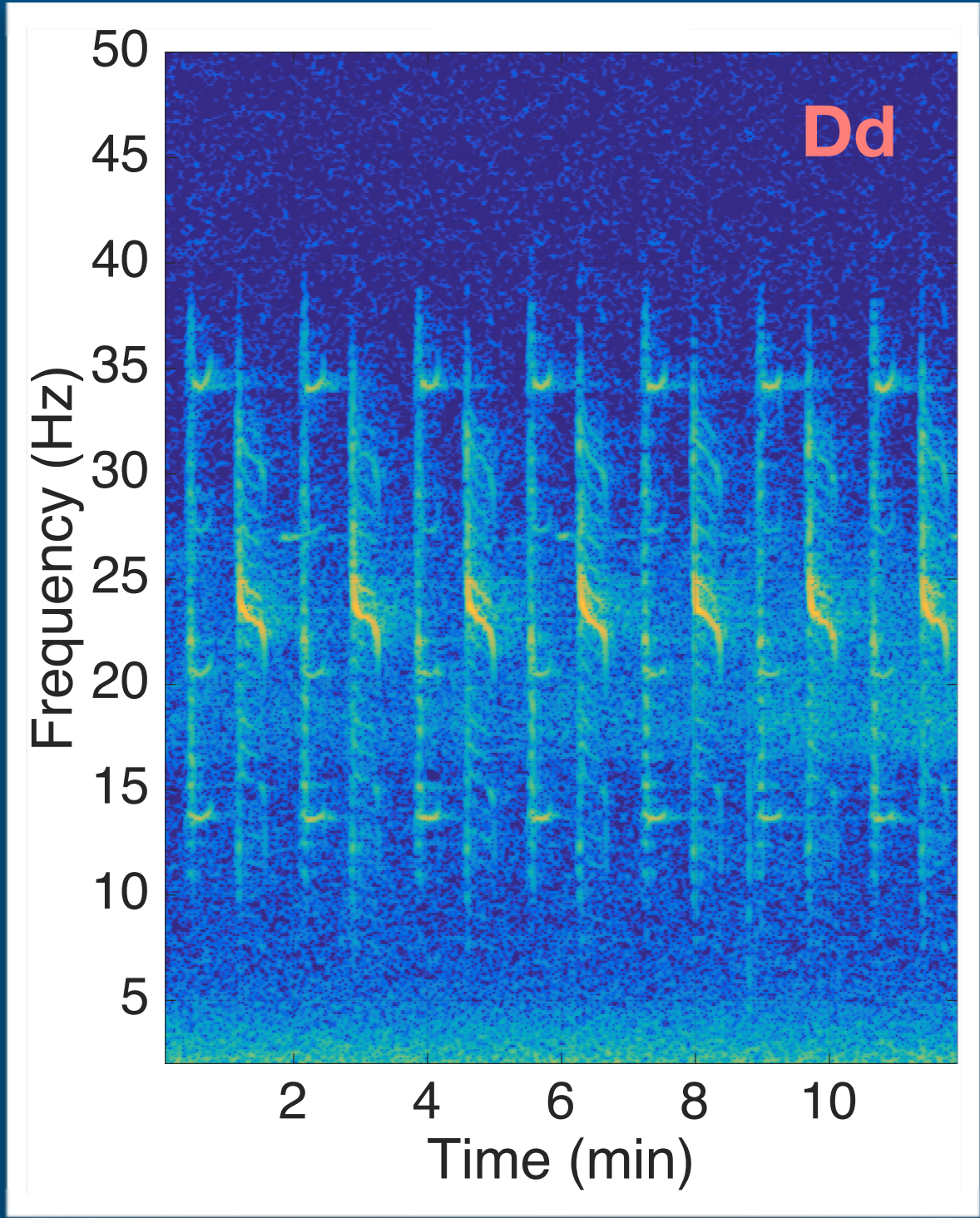
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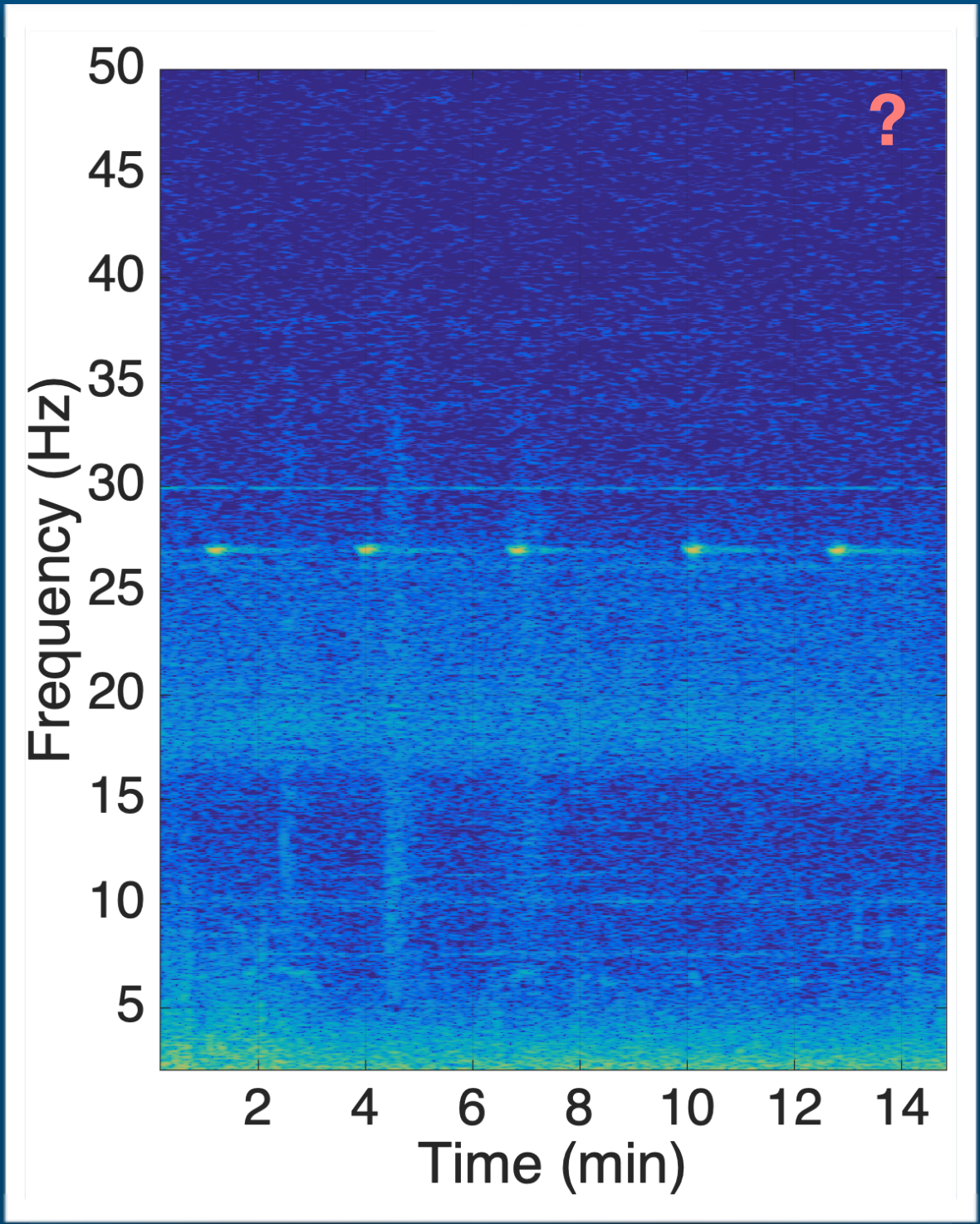


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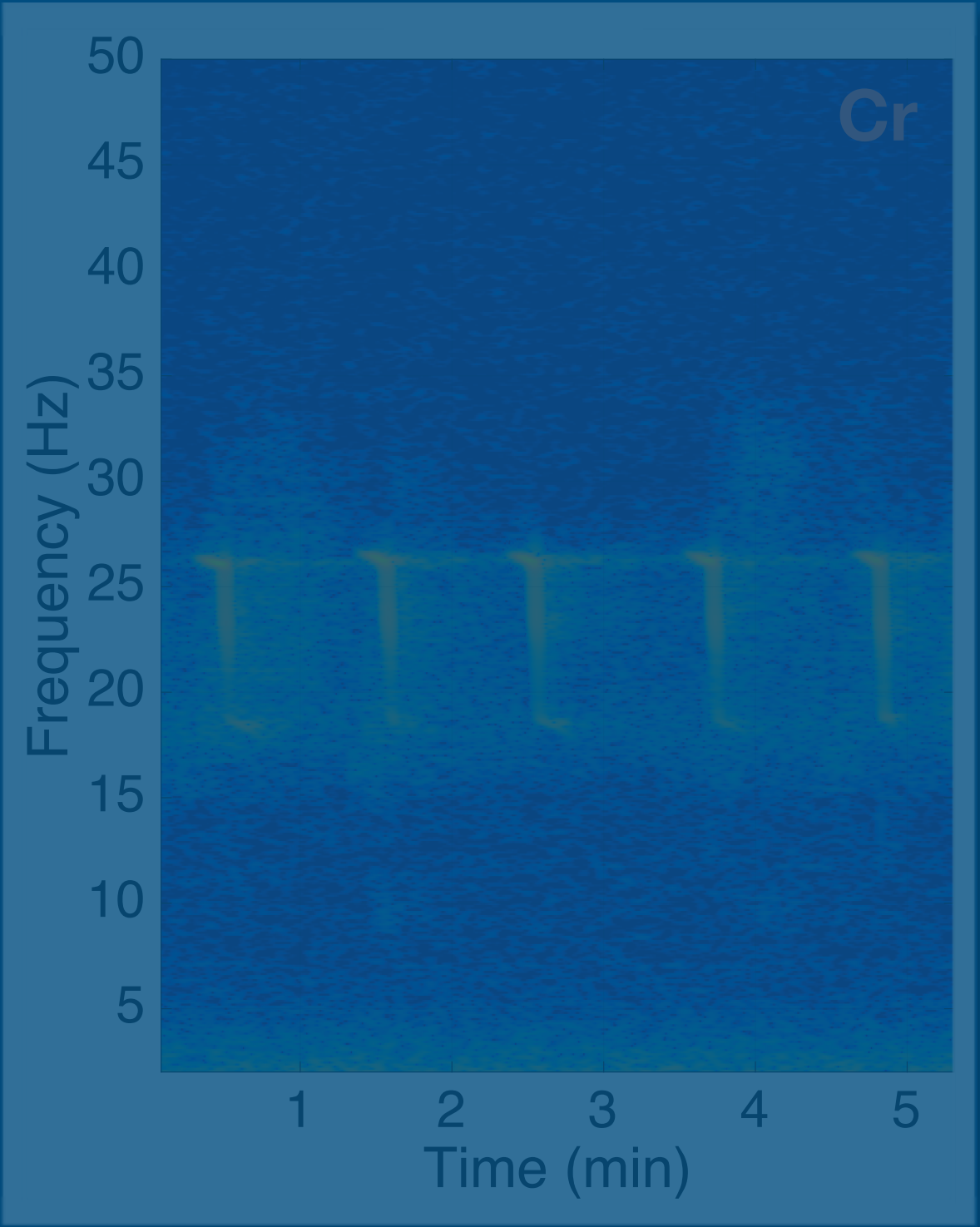
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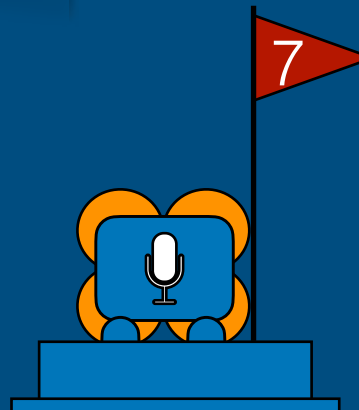
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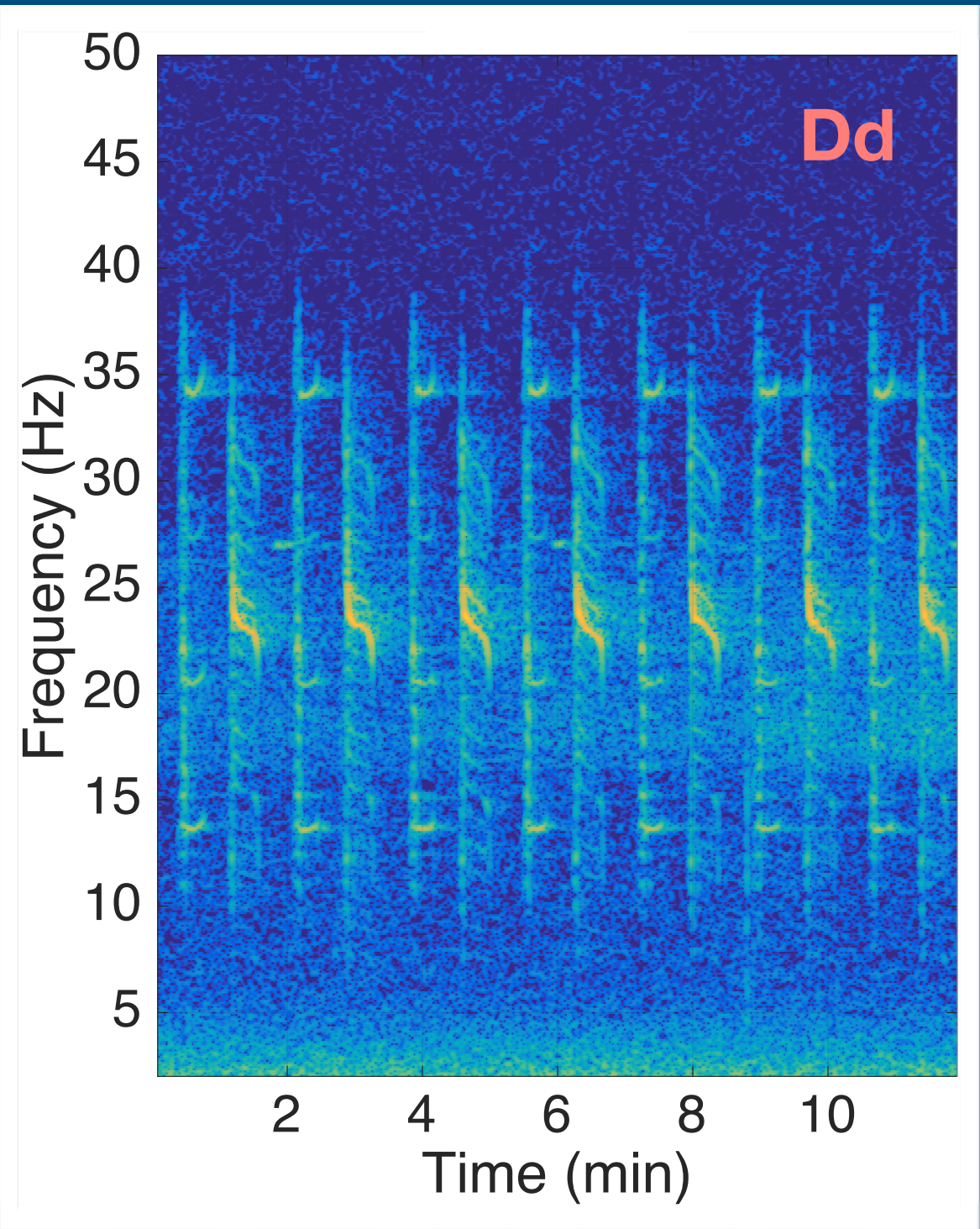




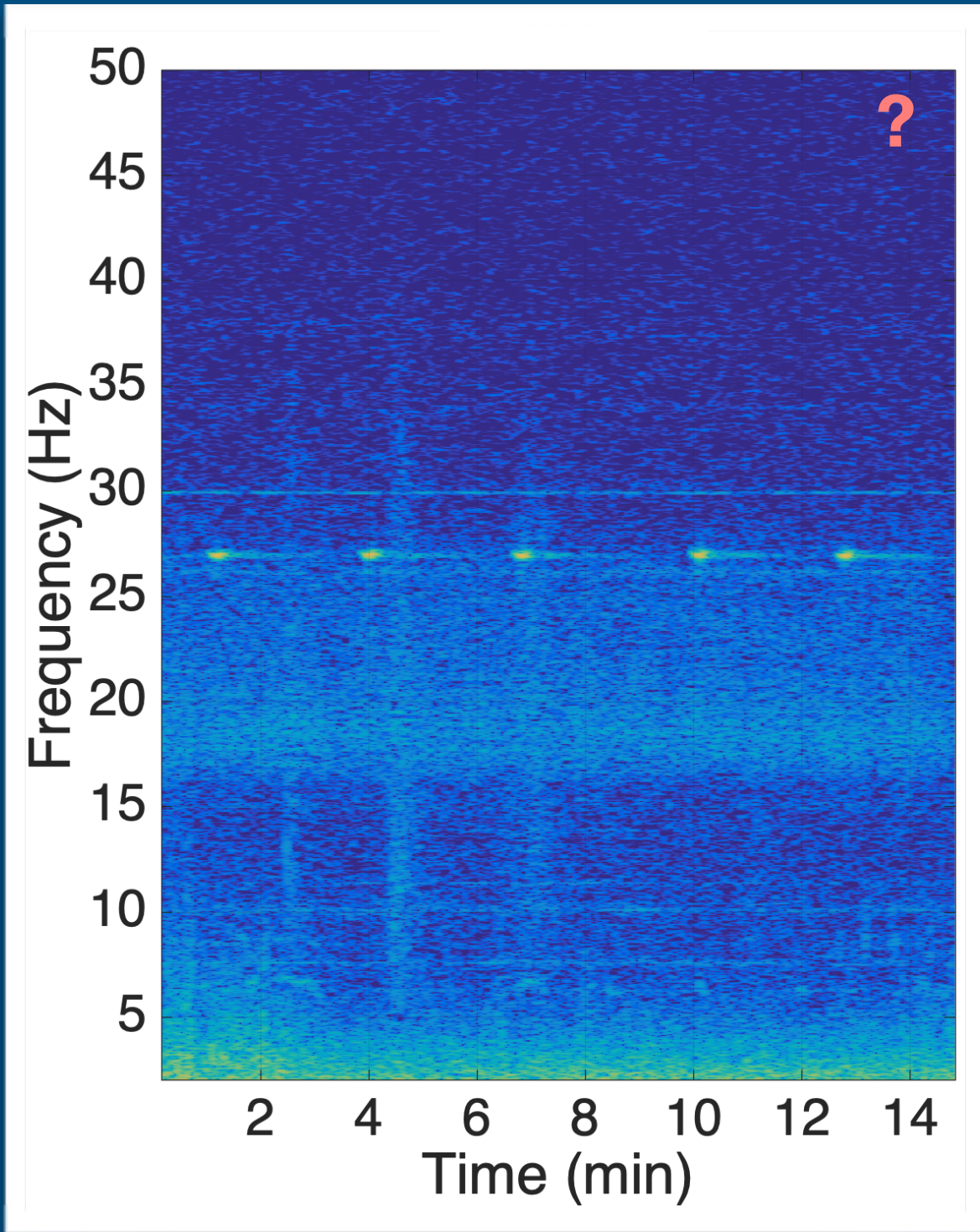
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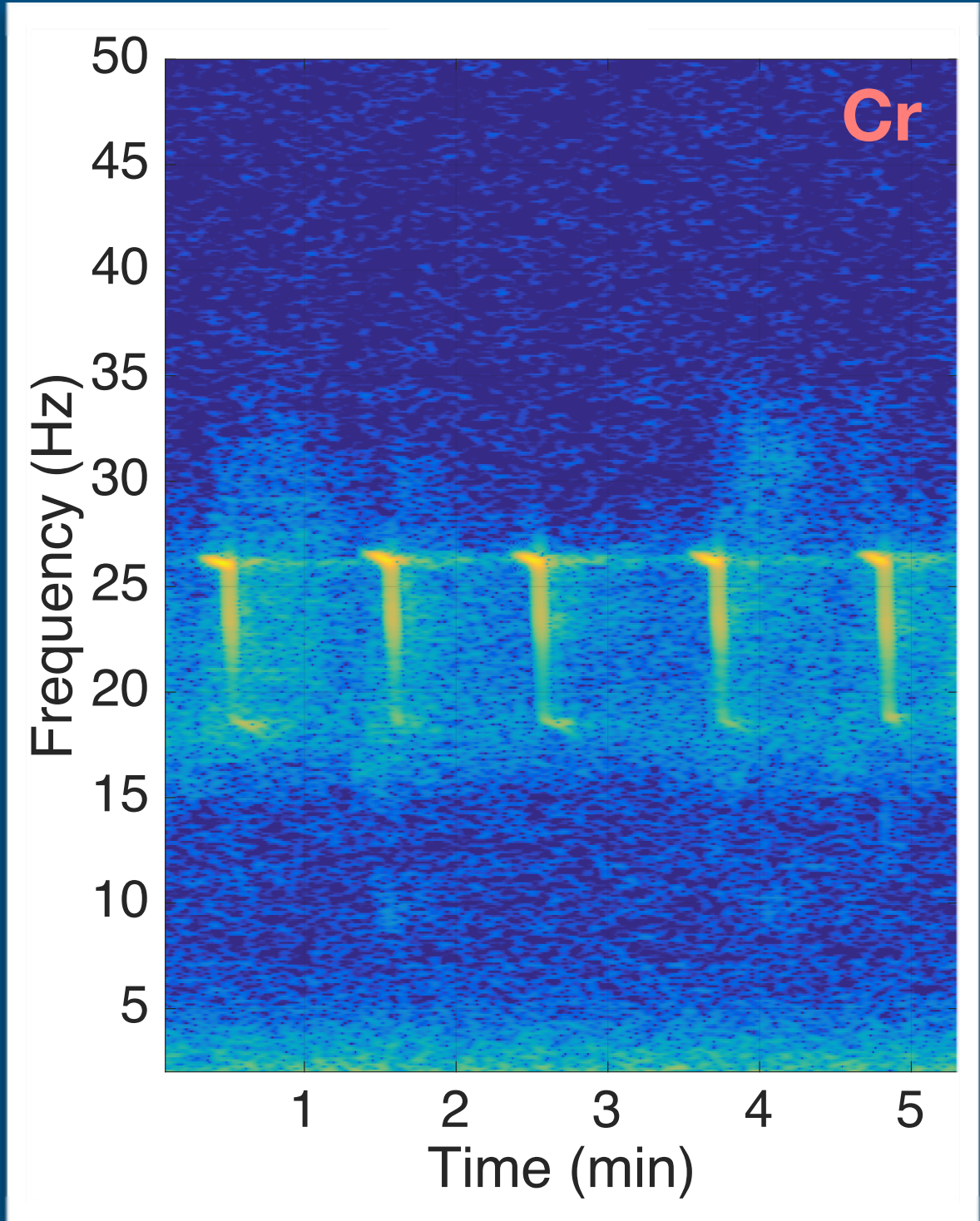
Not so local



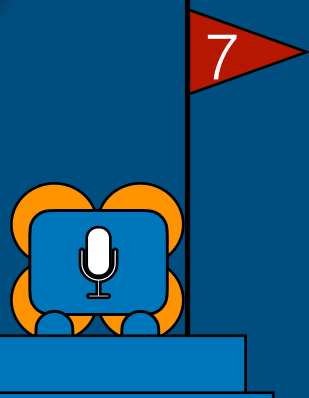
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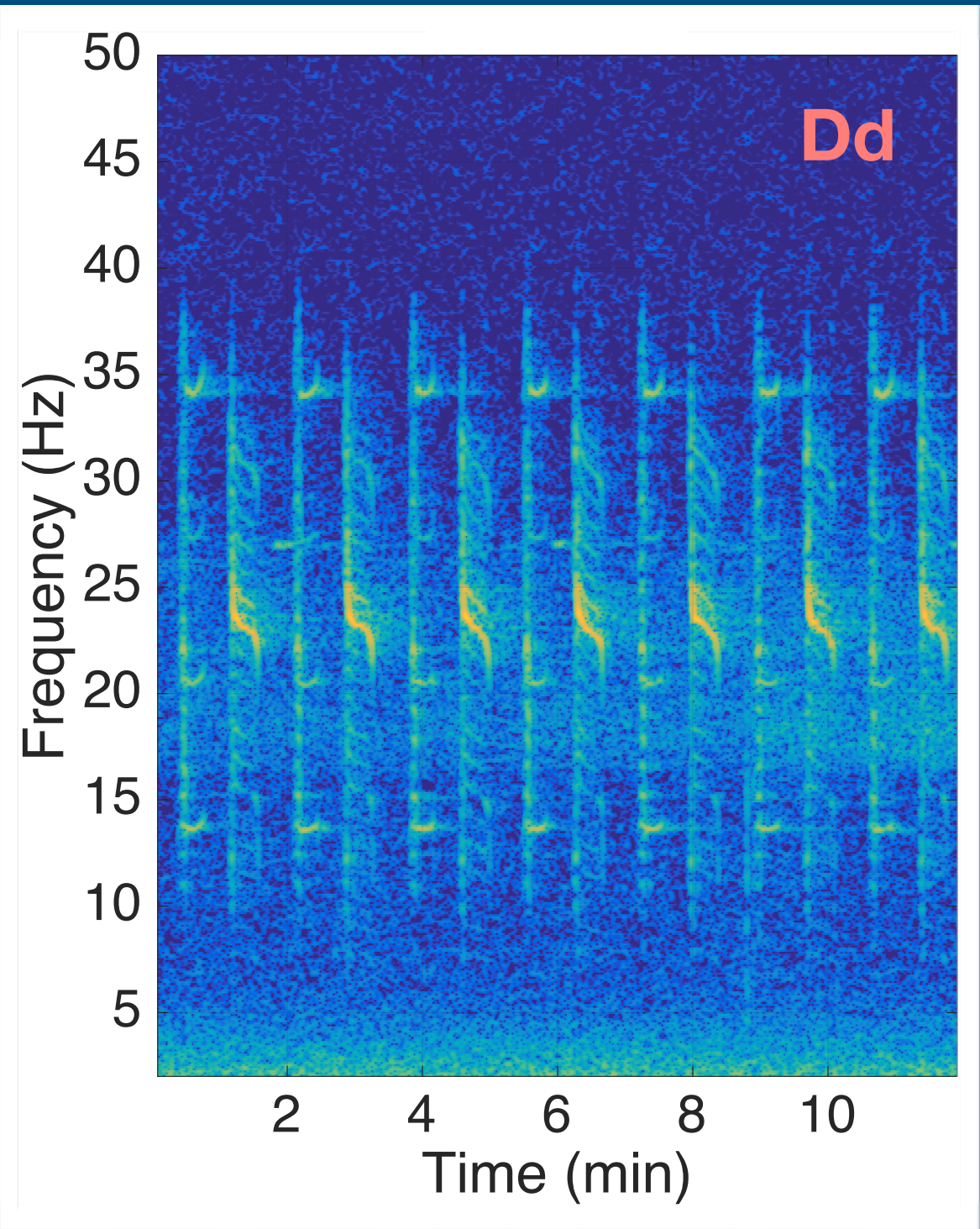




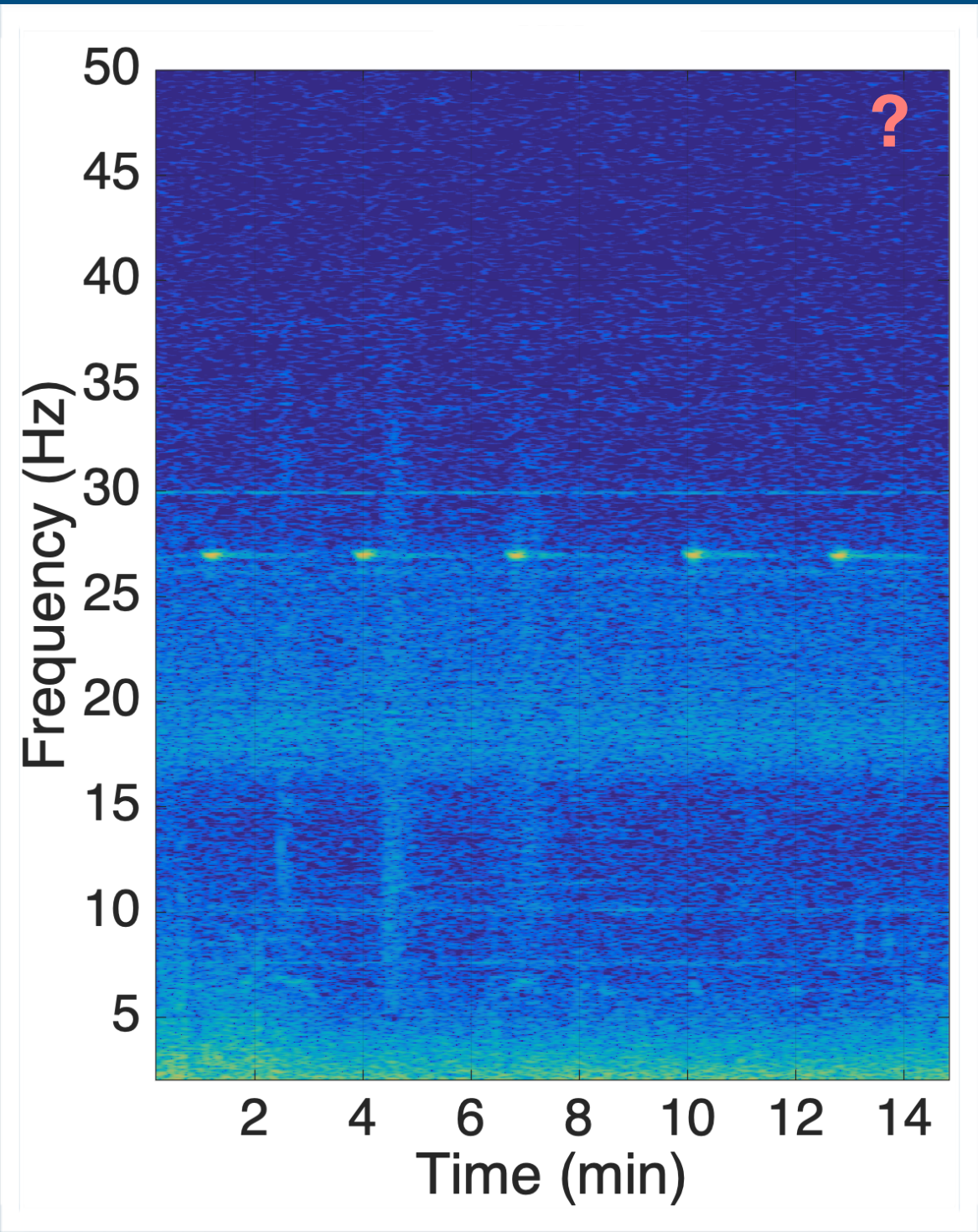
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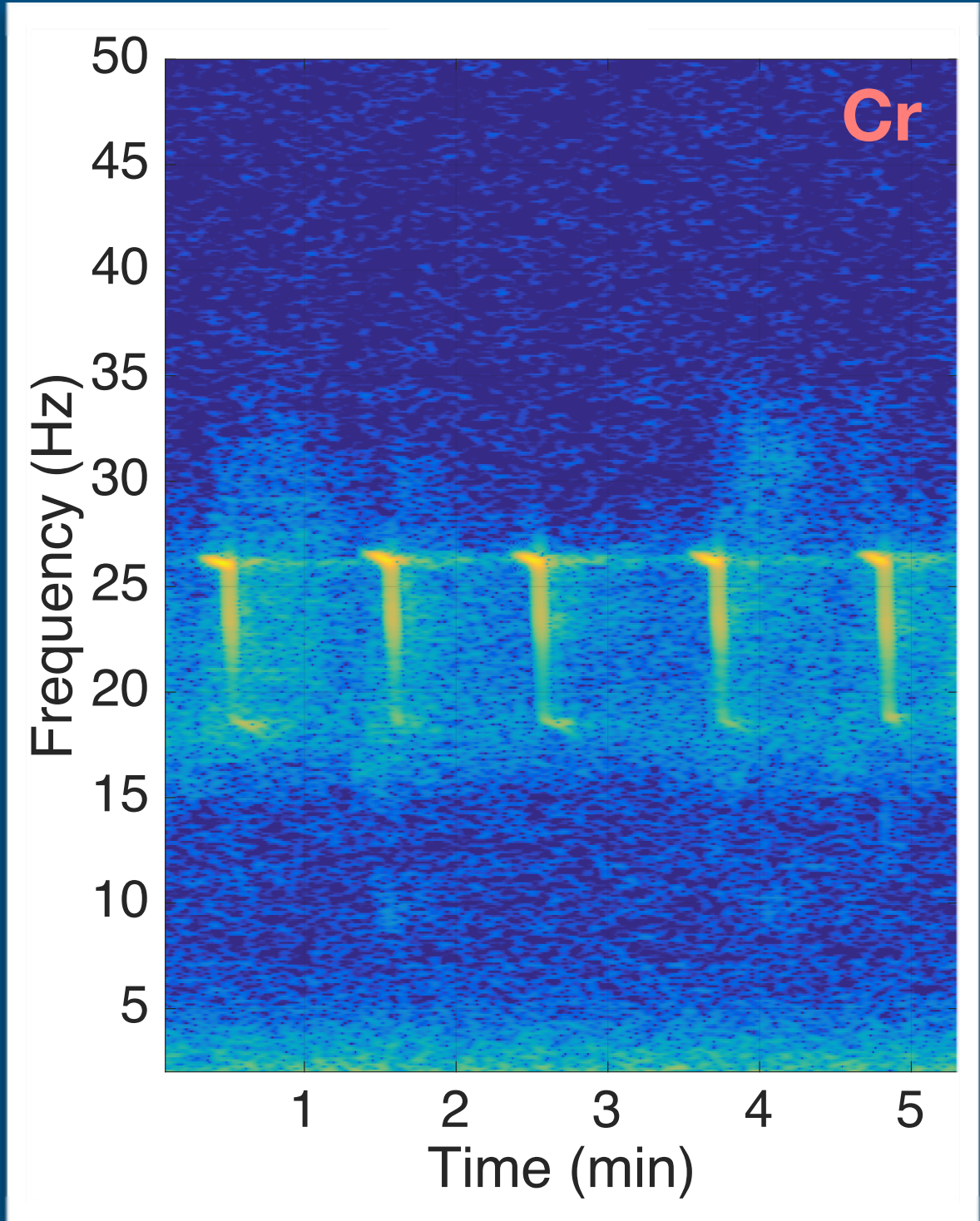
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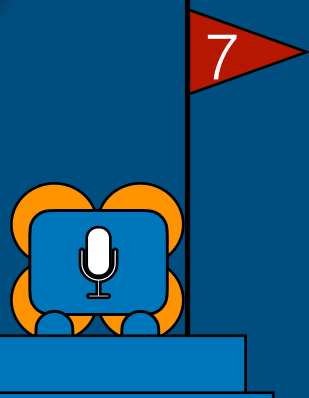
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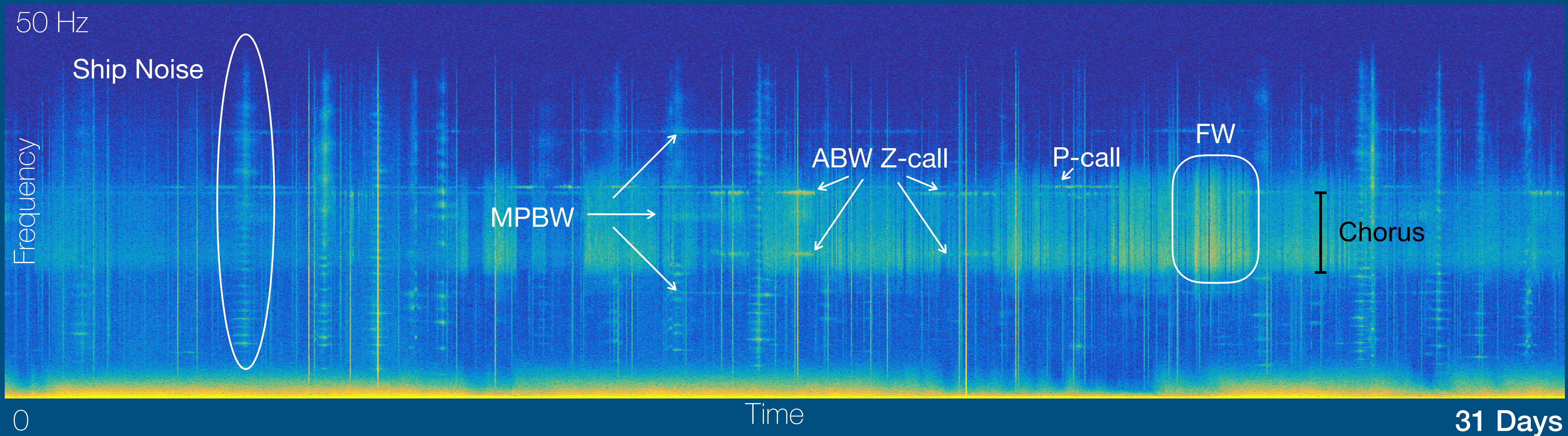


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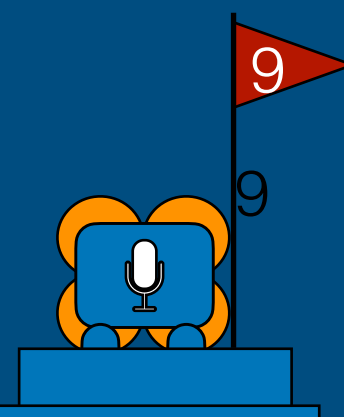


# From large temporal and spatial scales...





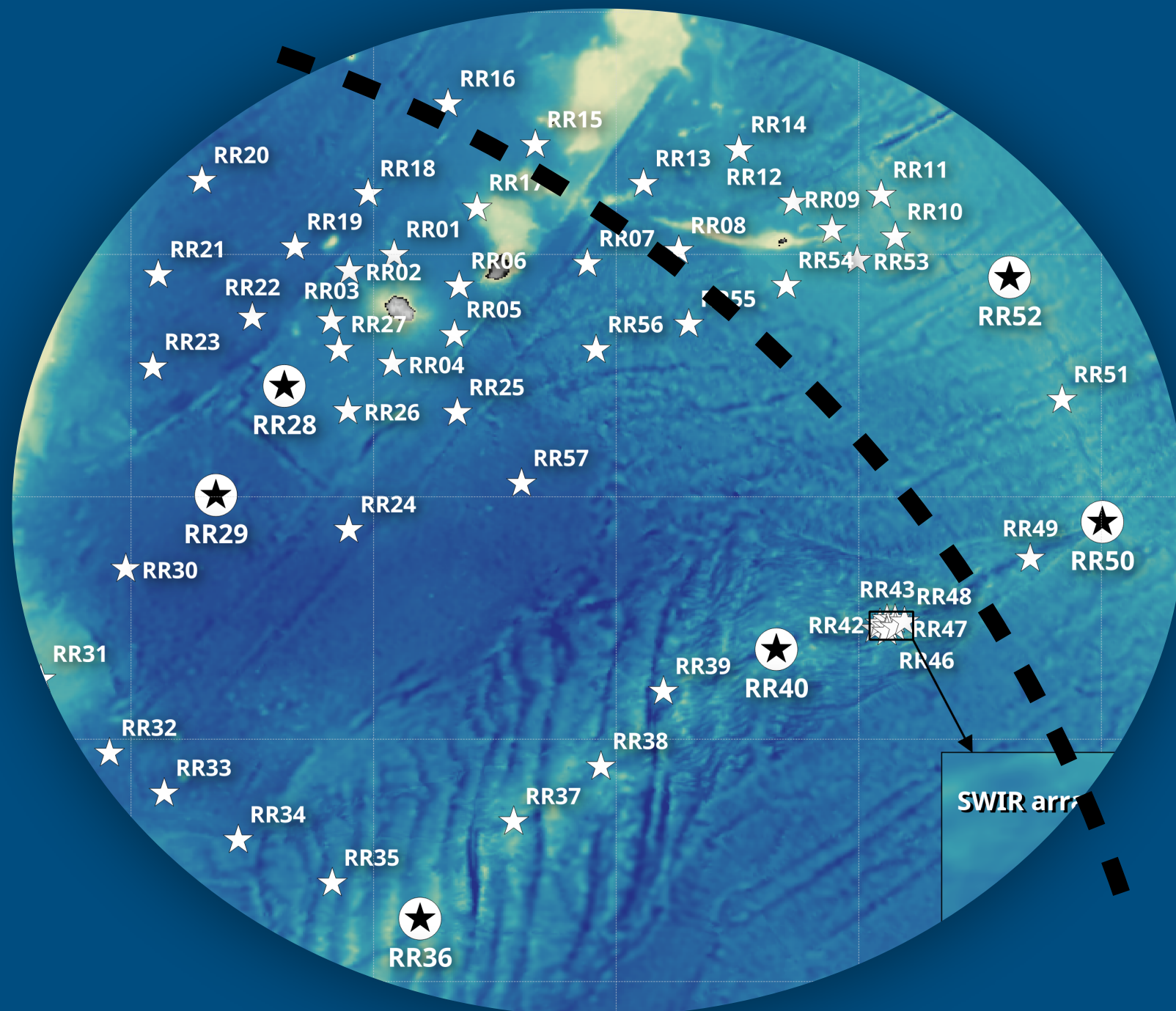
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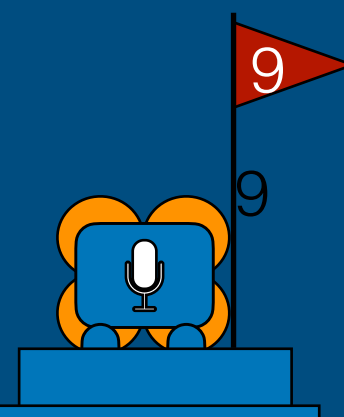


# From large temporal and spatial scales...

## Madagascar pygmy blue whale



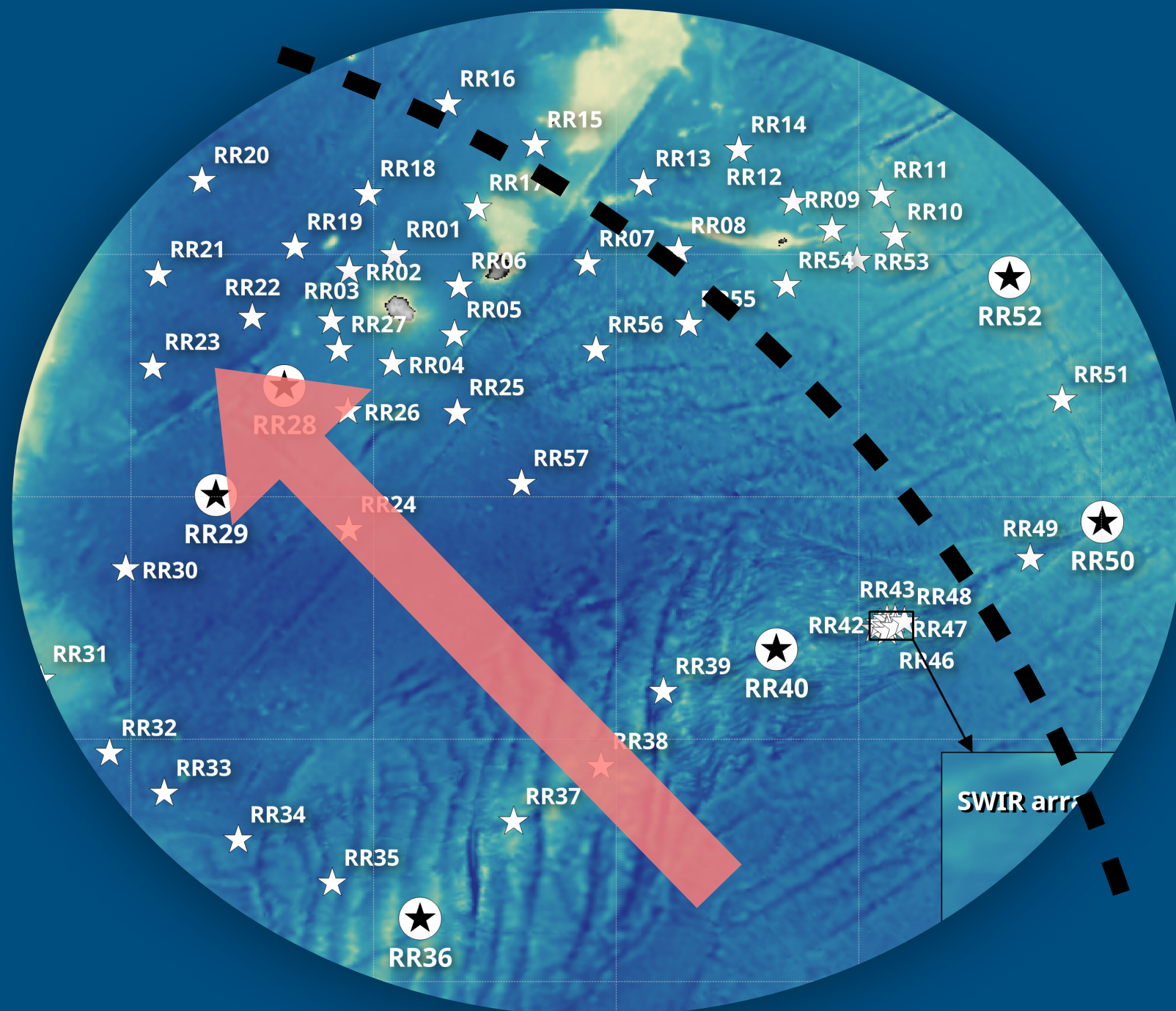
March -> June



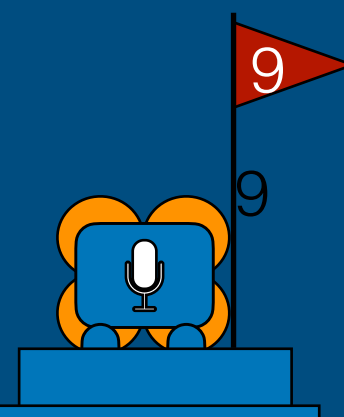


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## Madagascar pygmy blue whale



March -> June

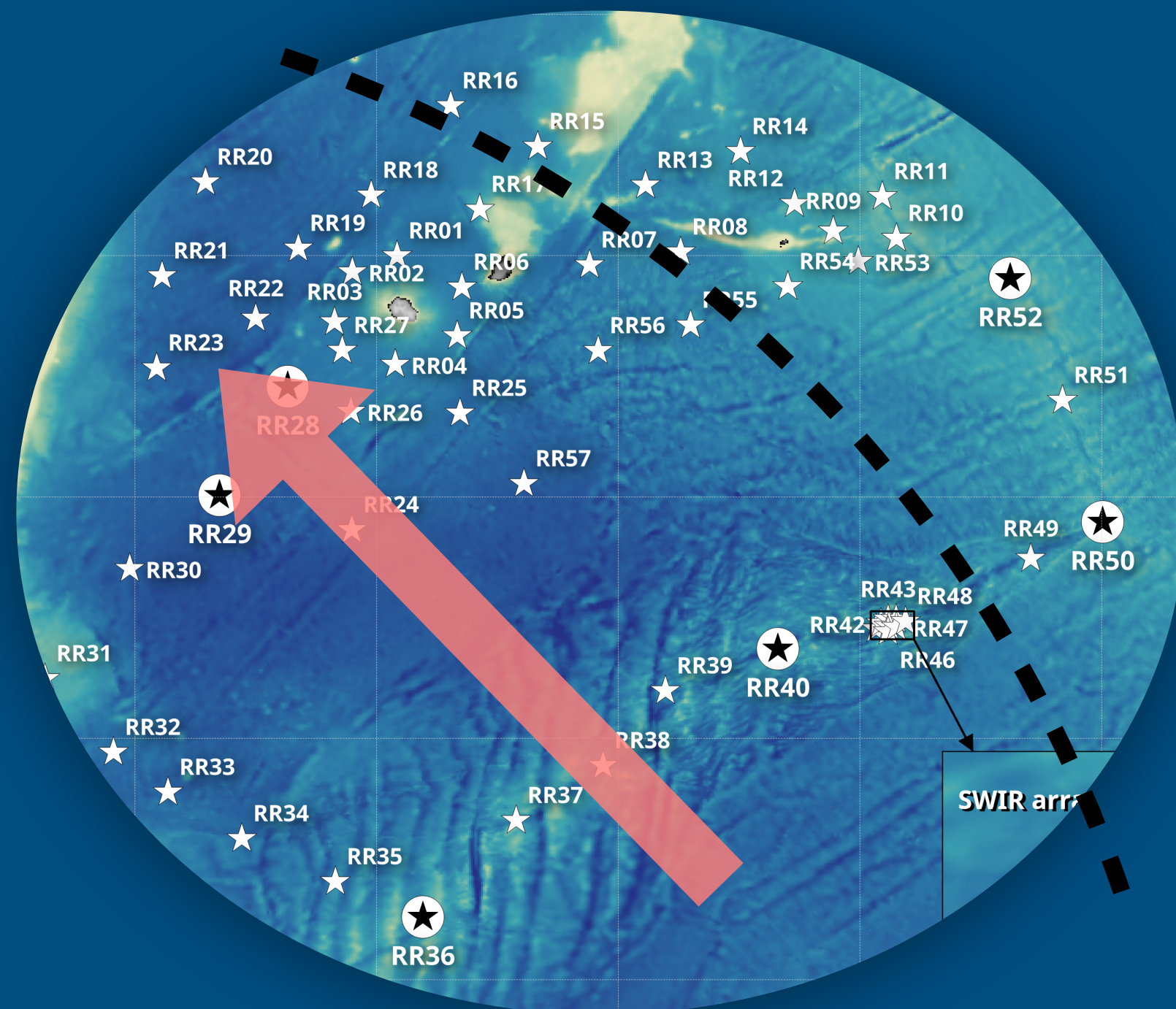




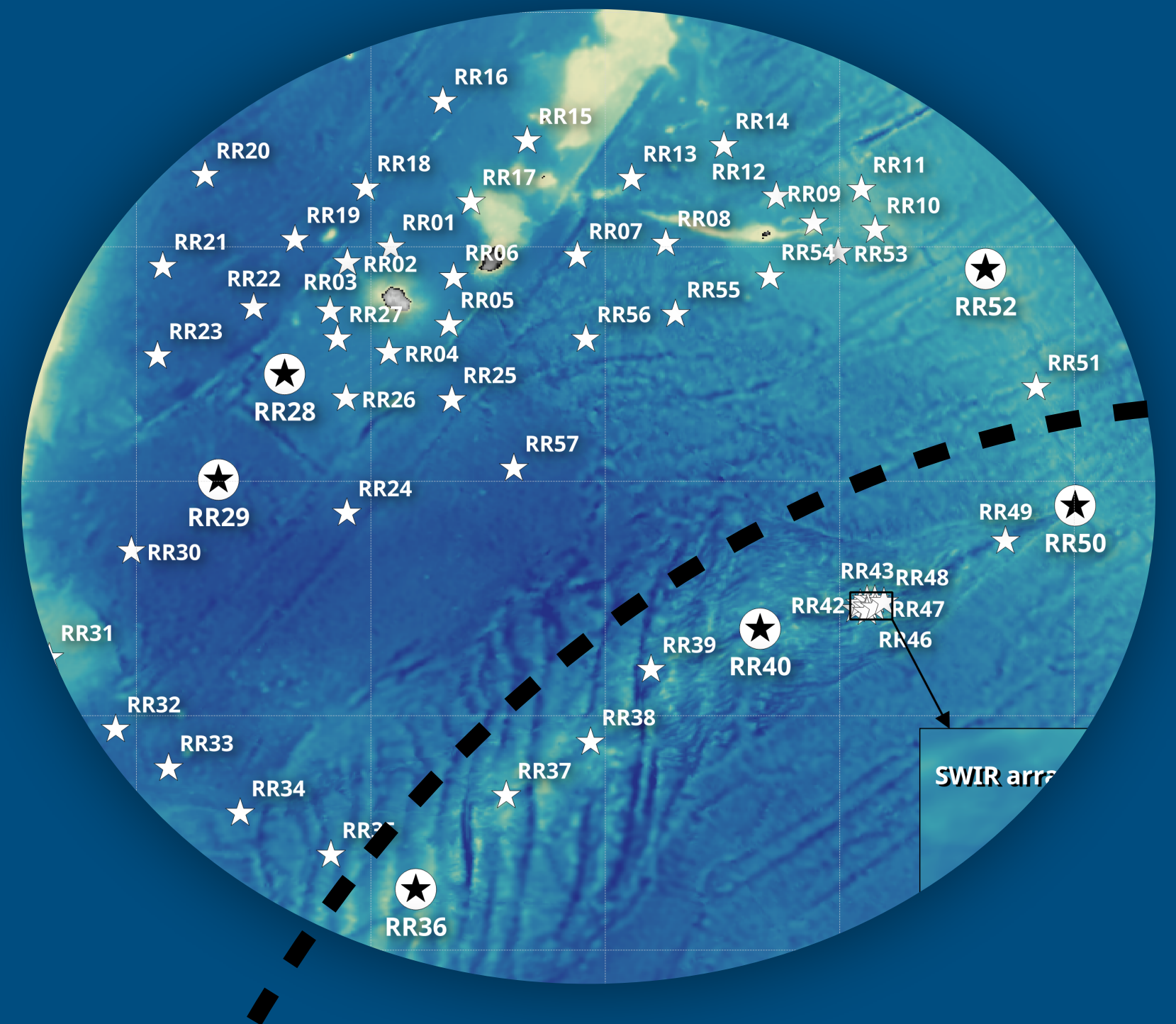
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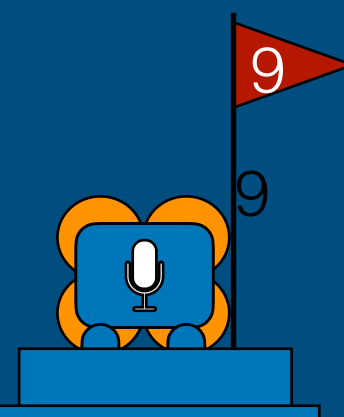
P-call or spot call



March -> June



April -> December



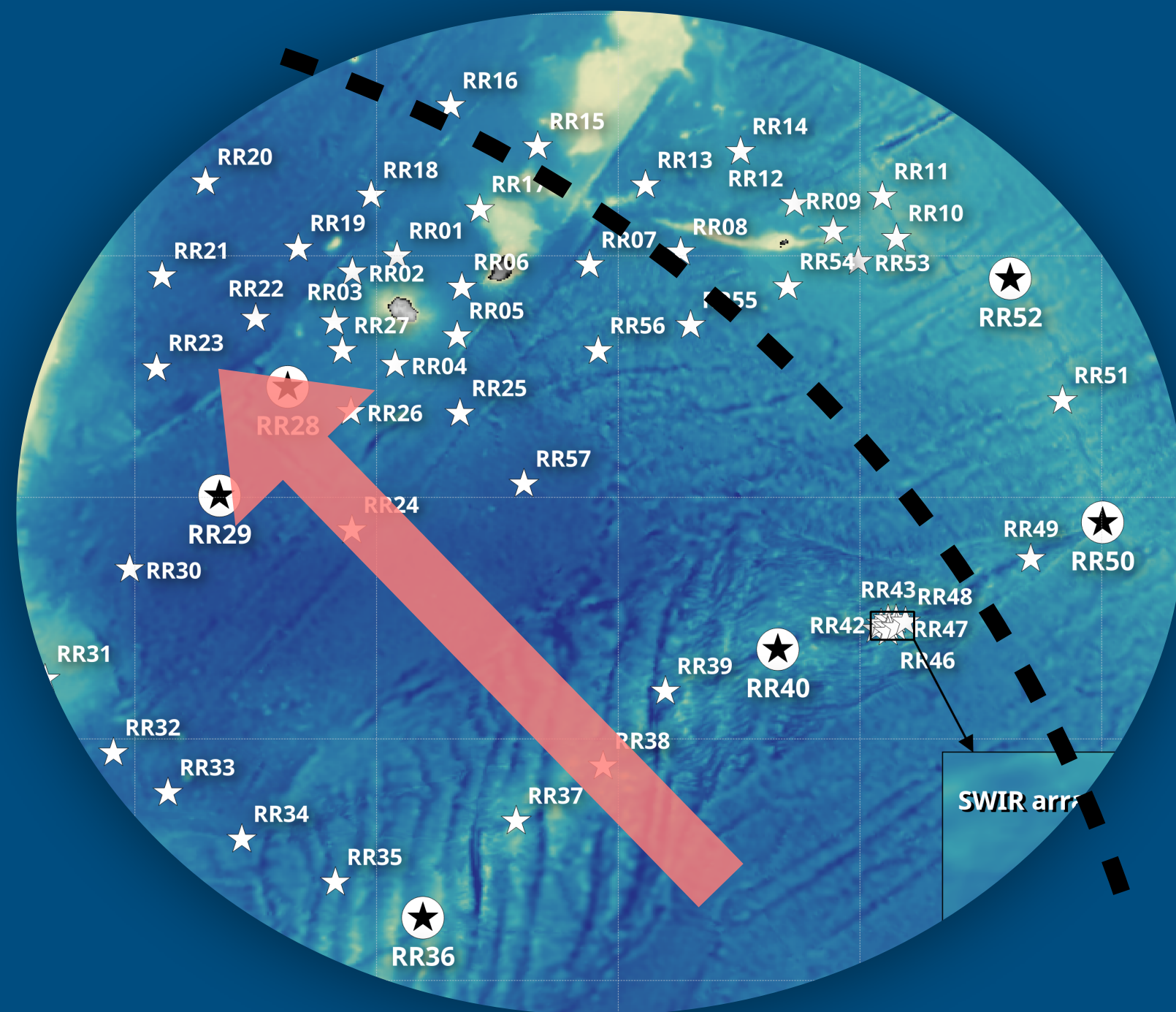


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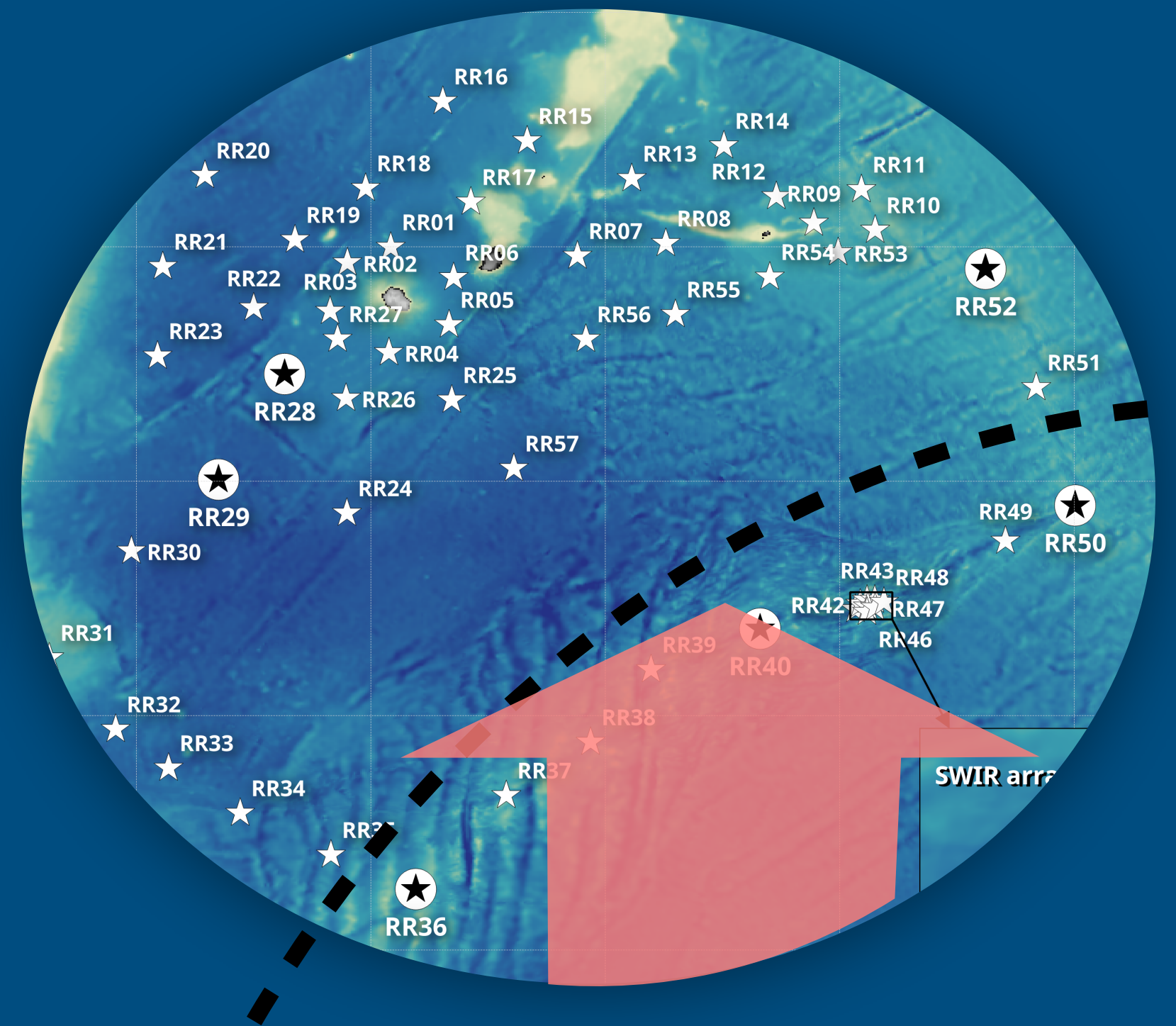


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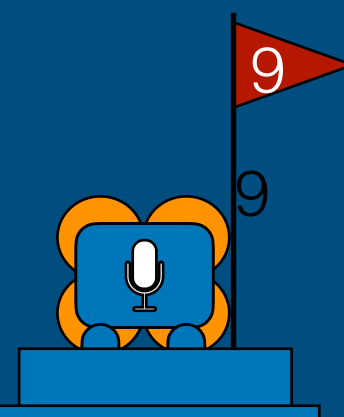
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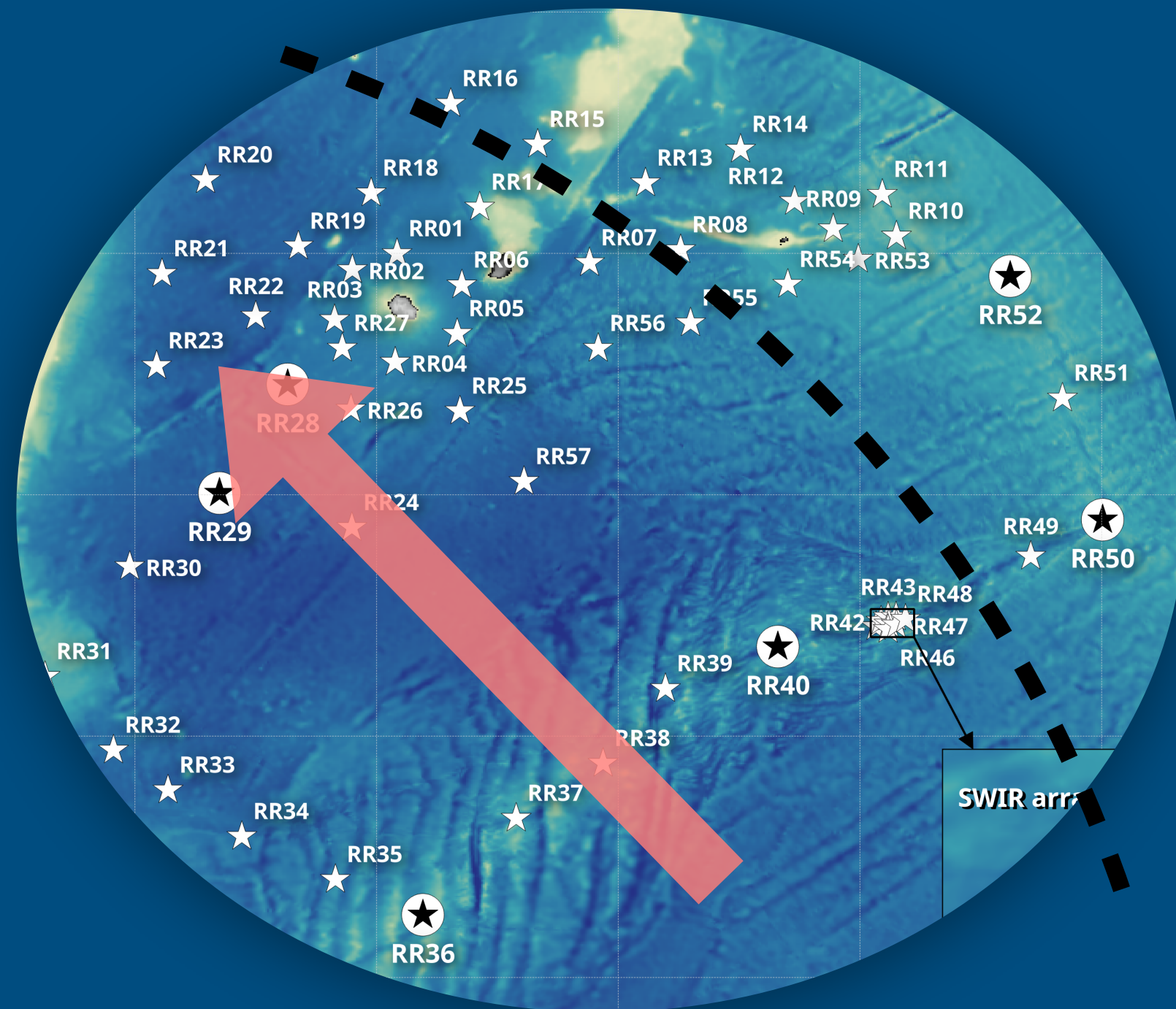
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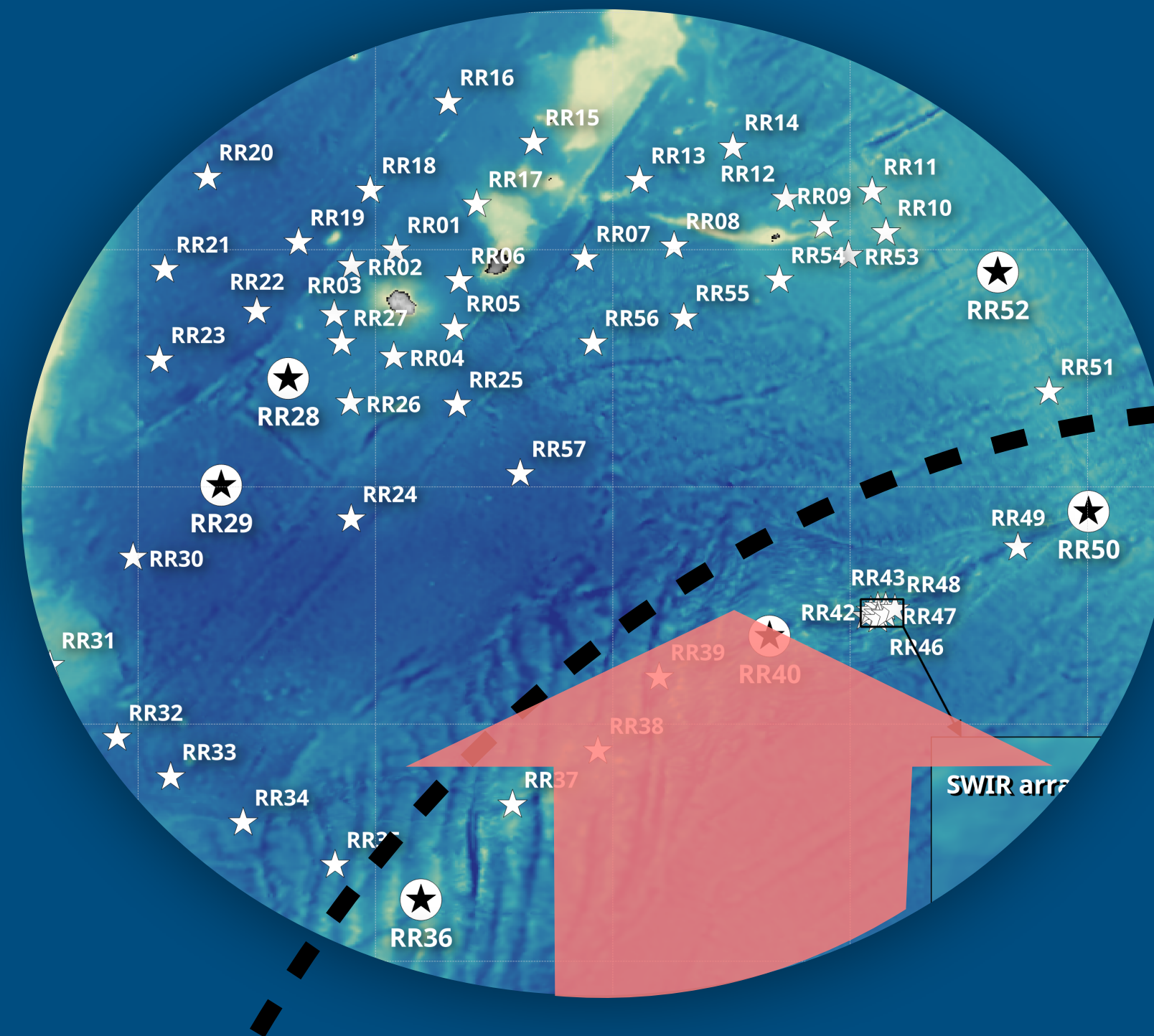
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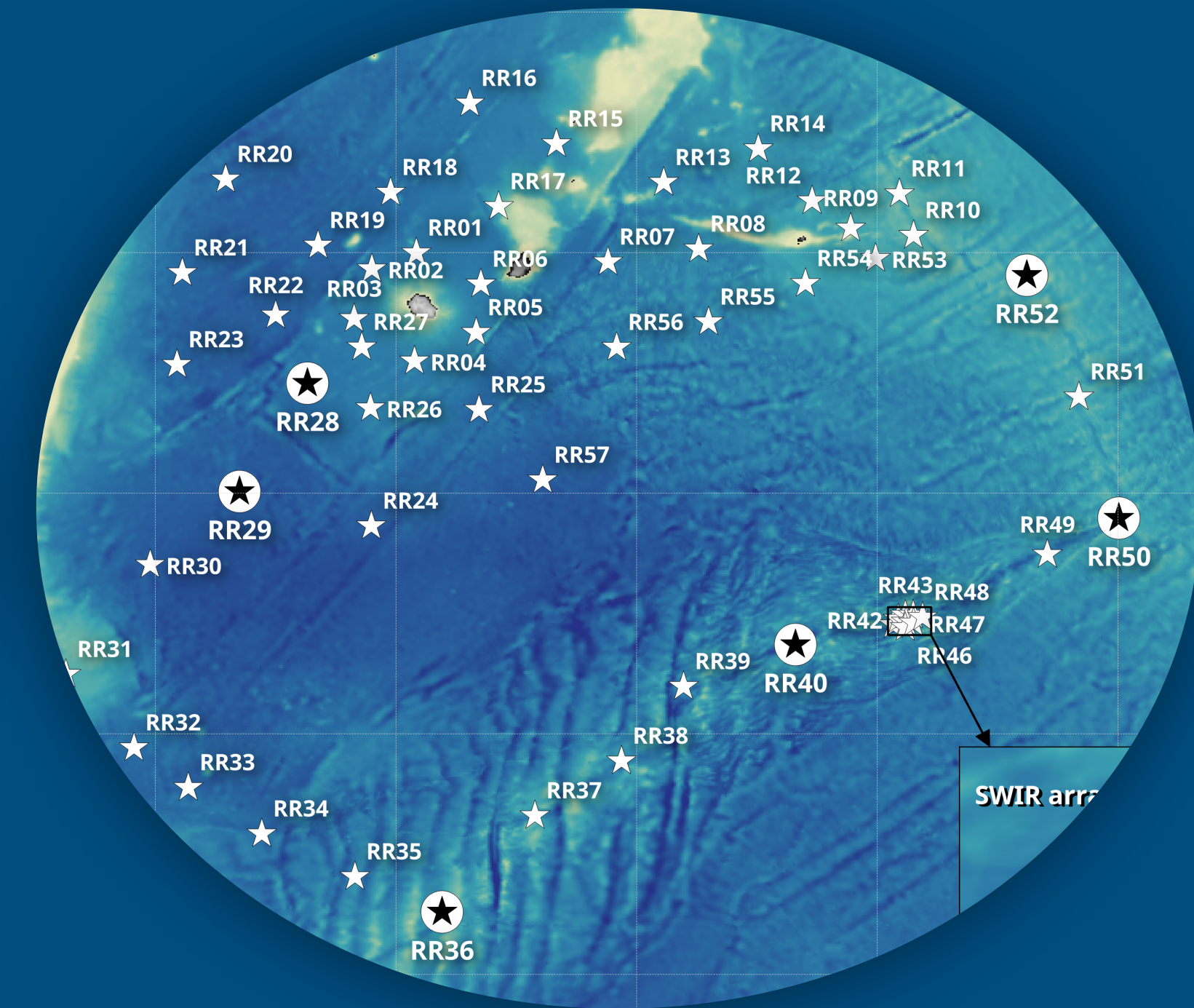
Antarctic blue whale



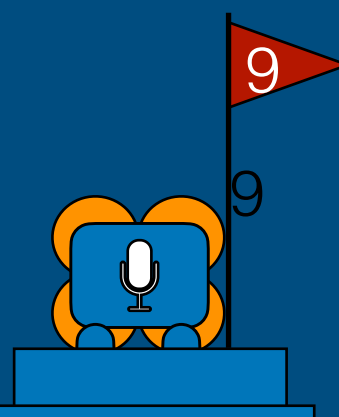
March -> June



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February -> October





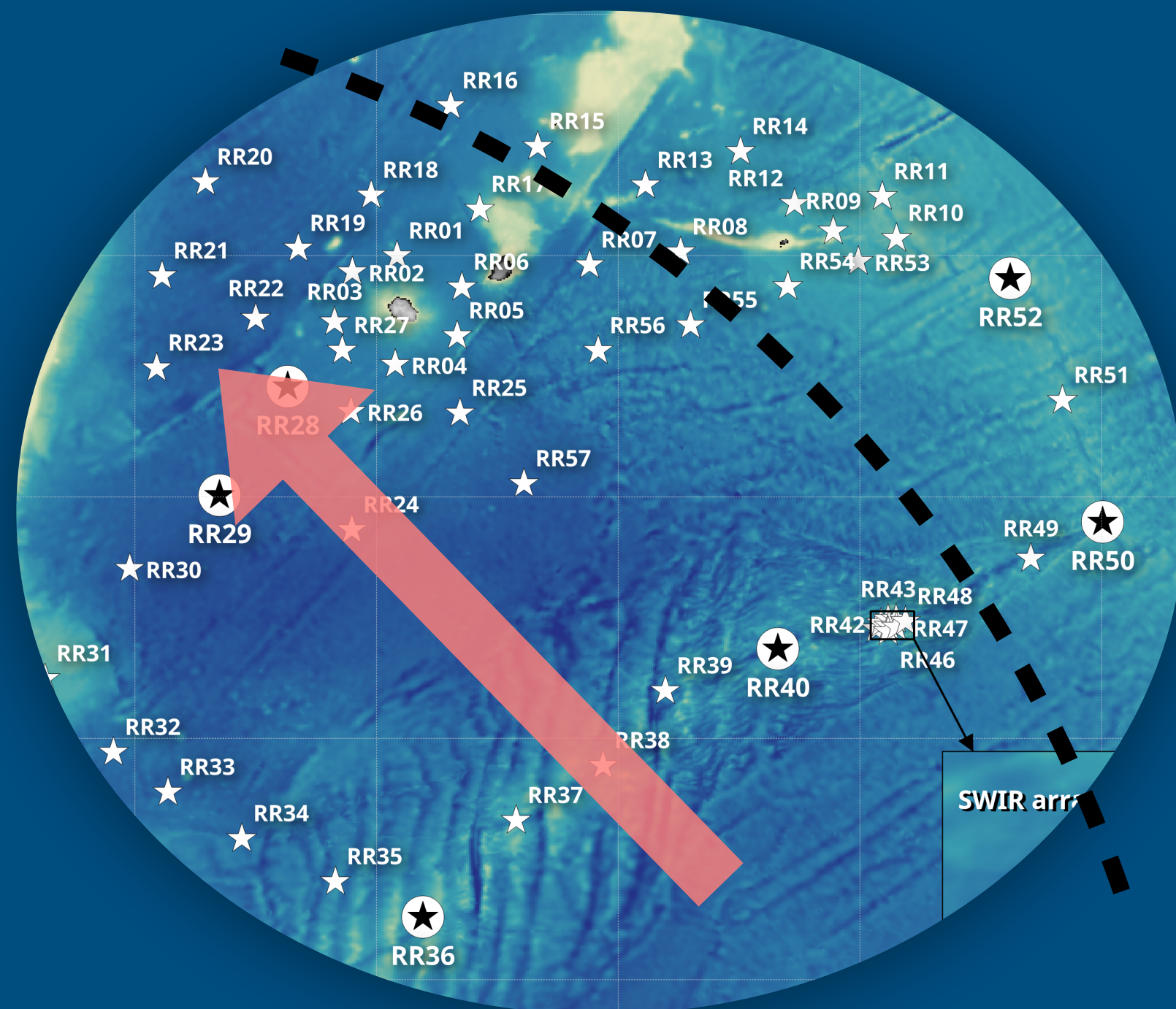
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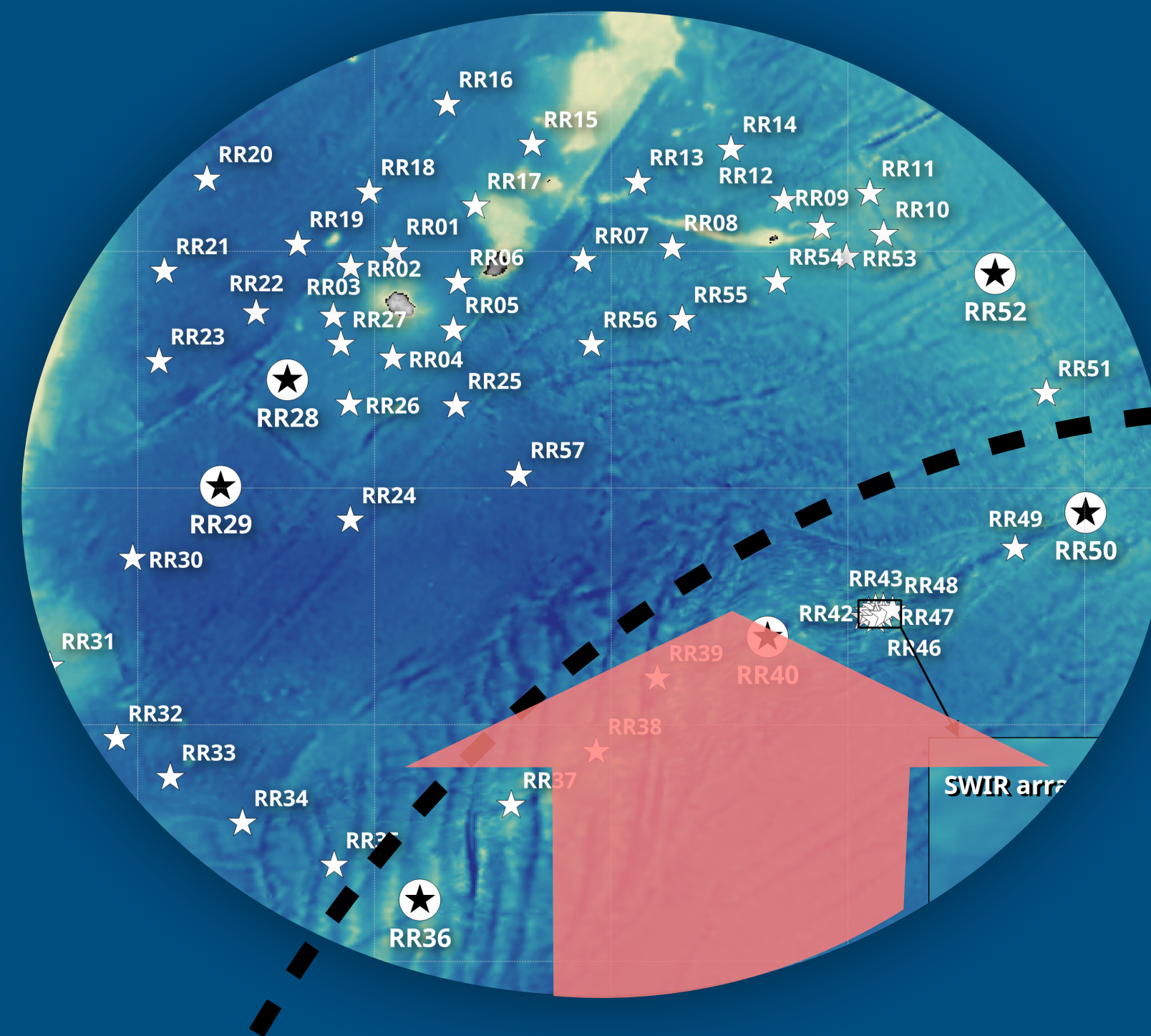
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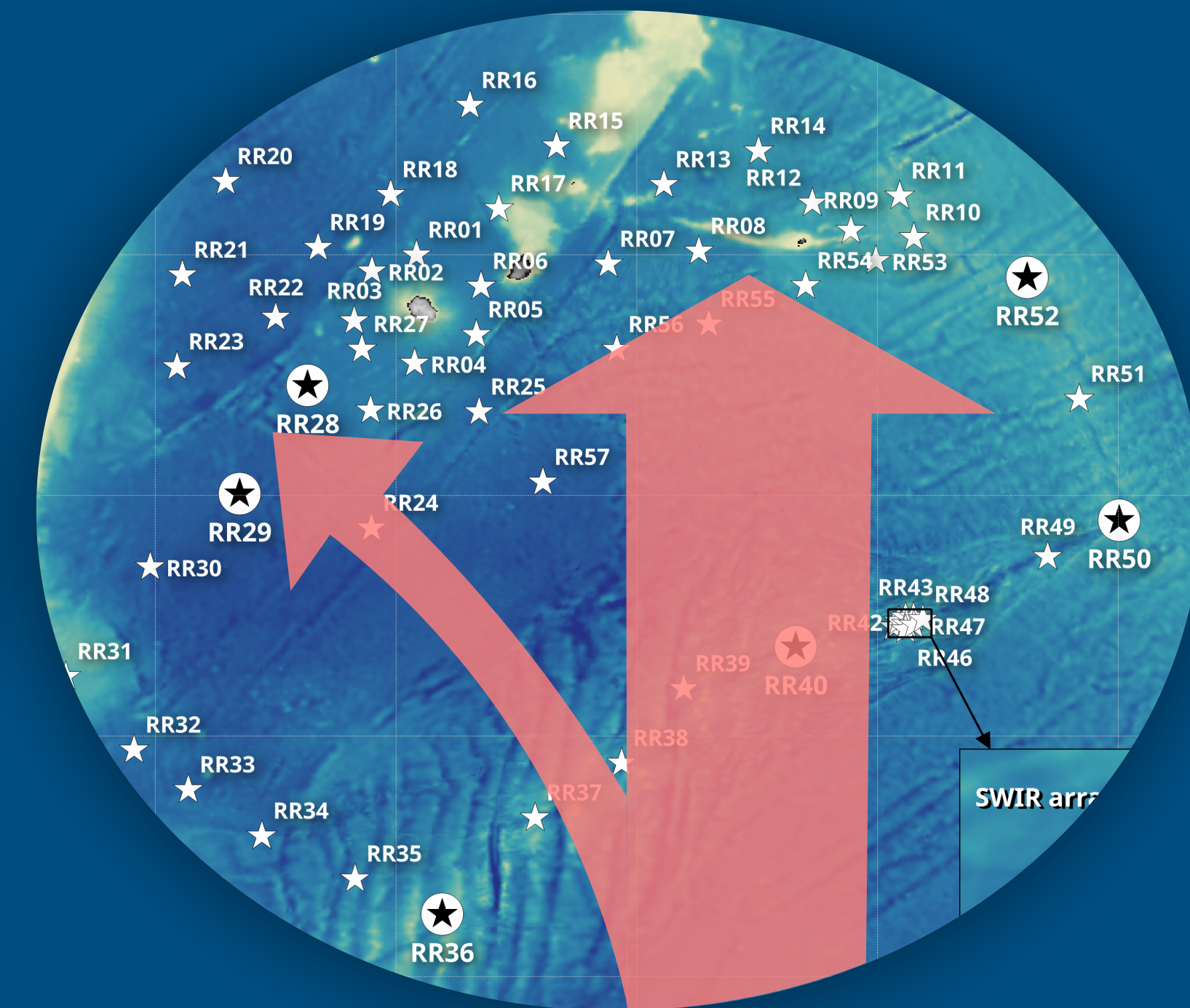
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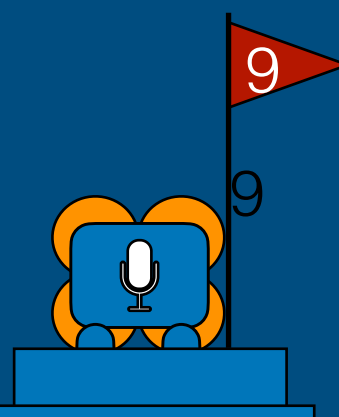
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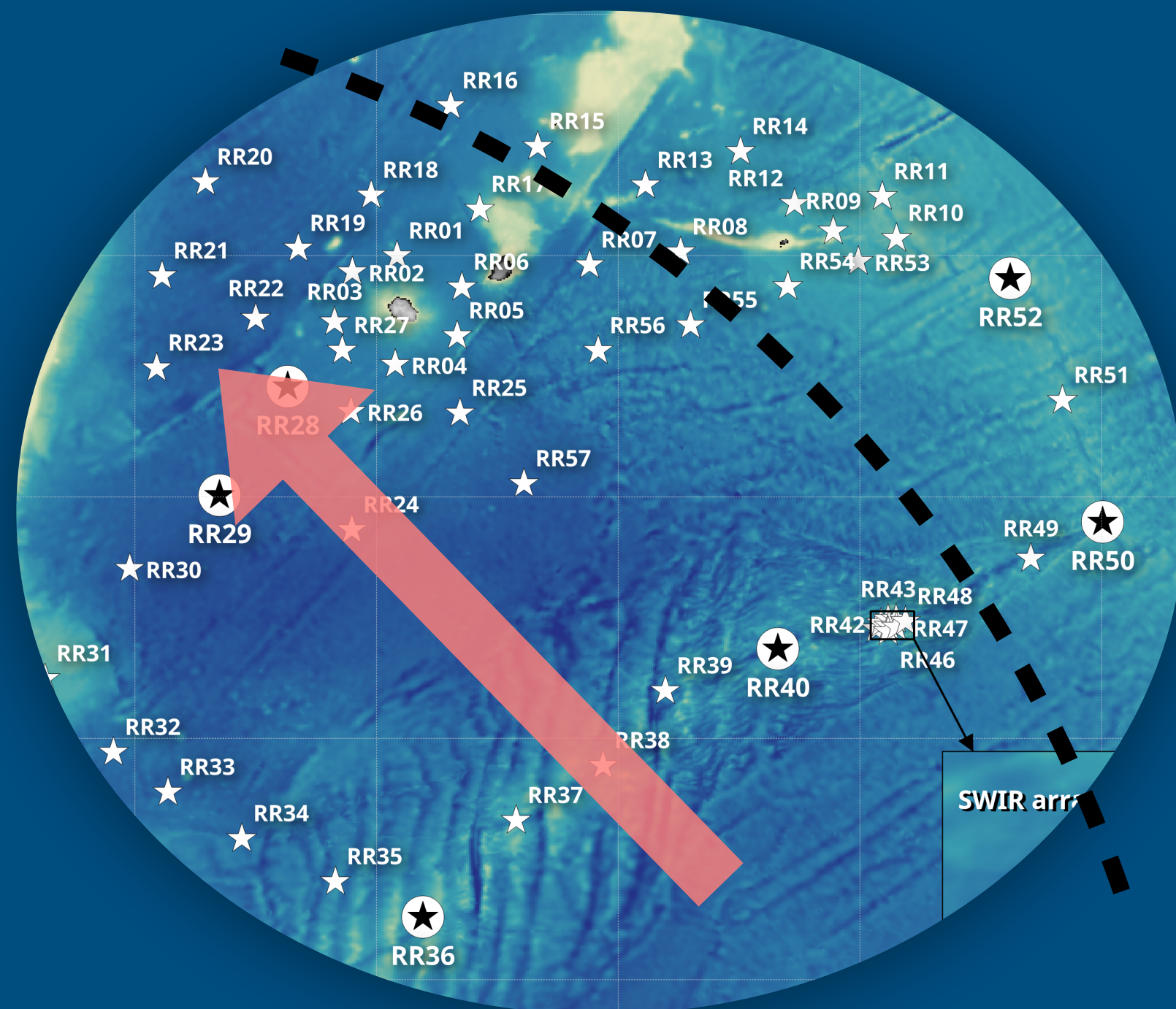
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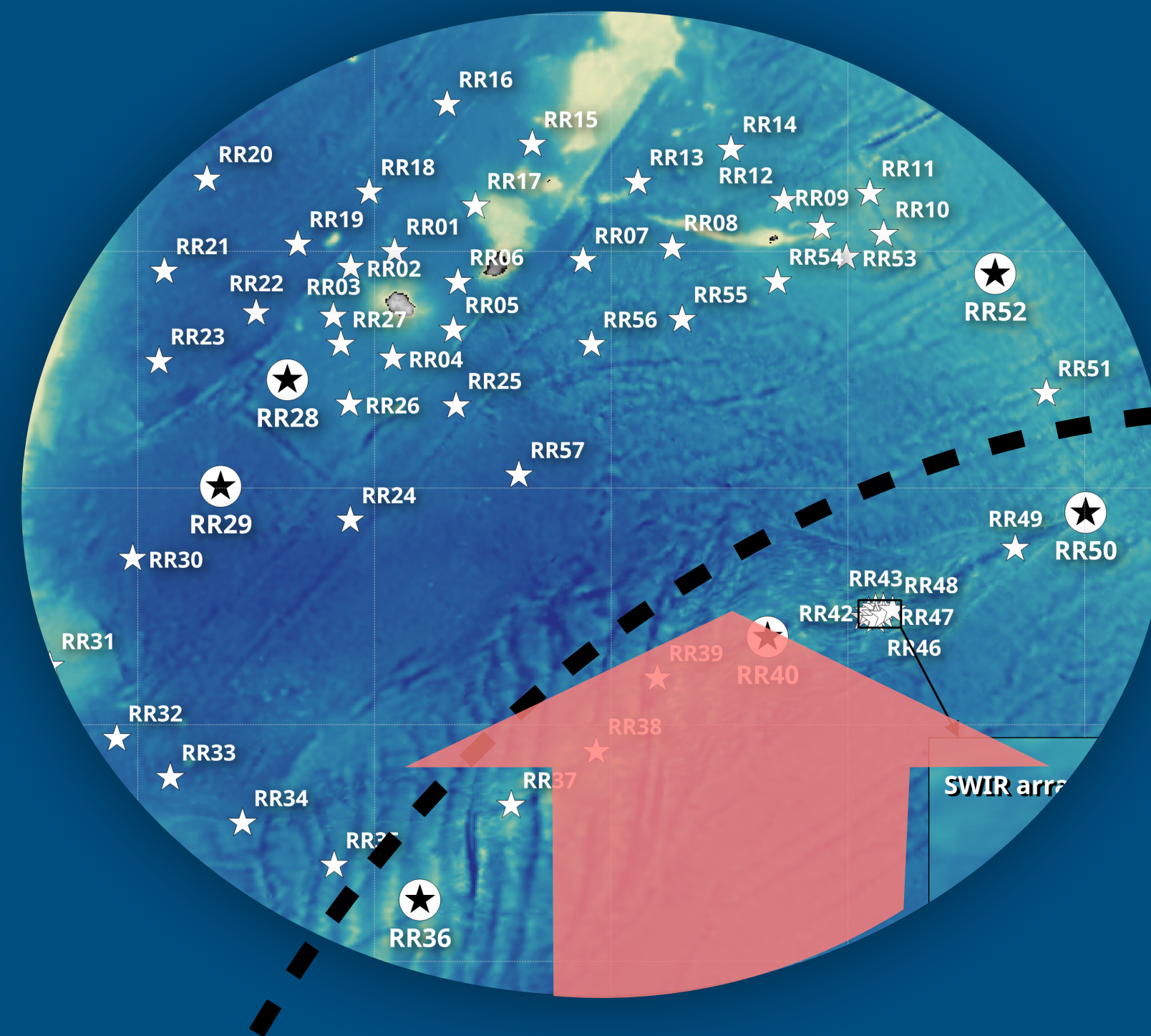
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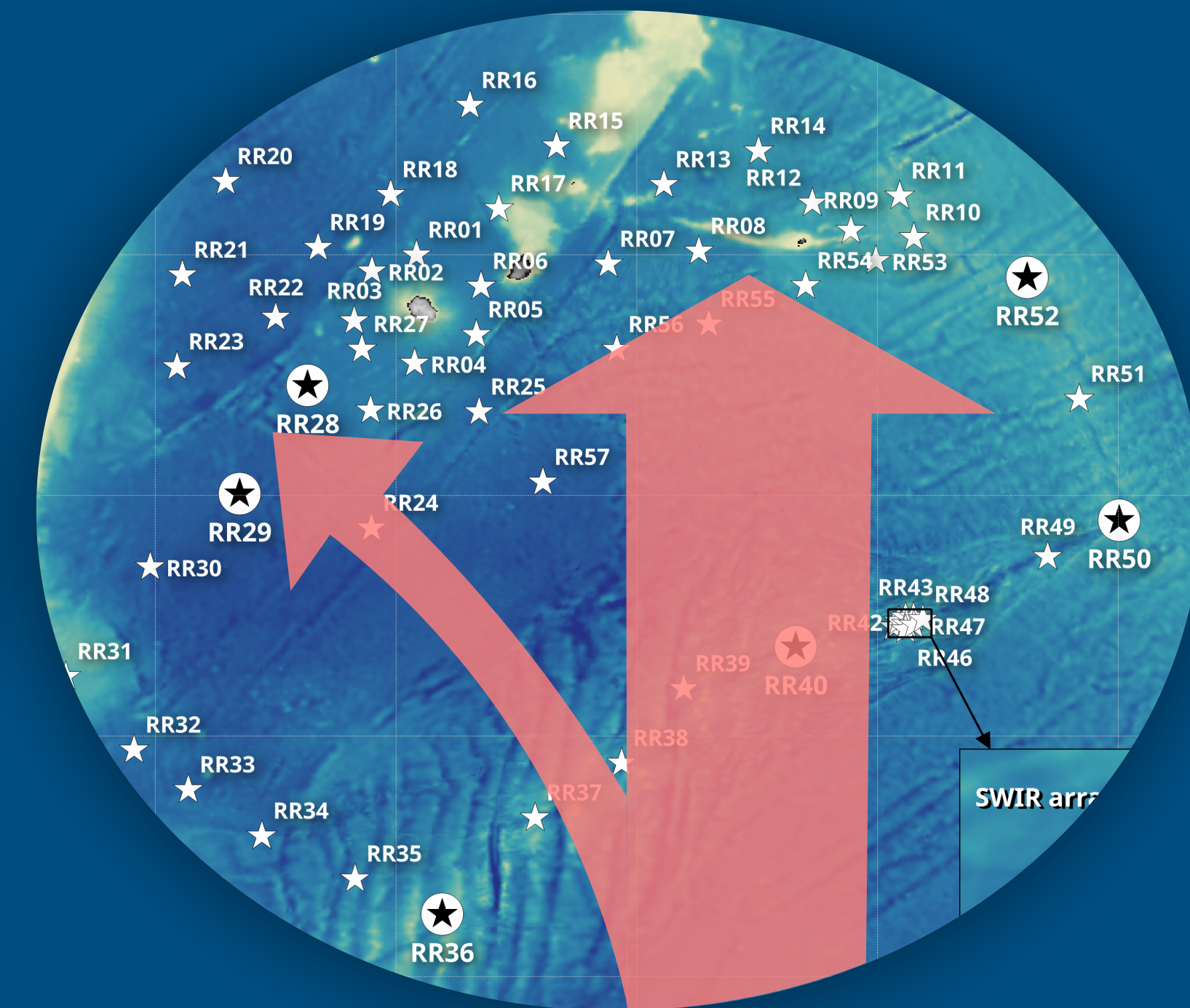
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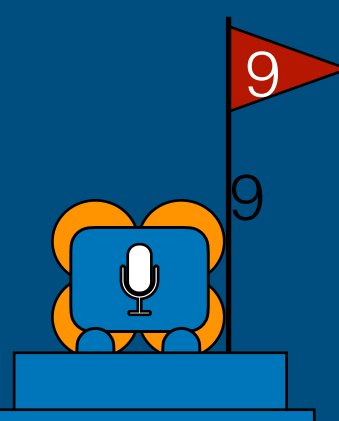
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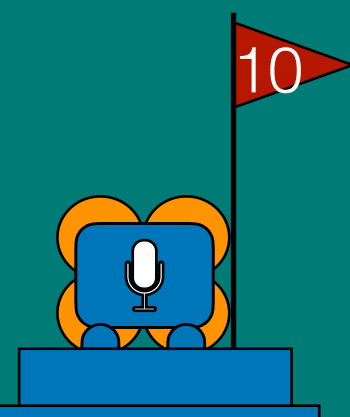
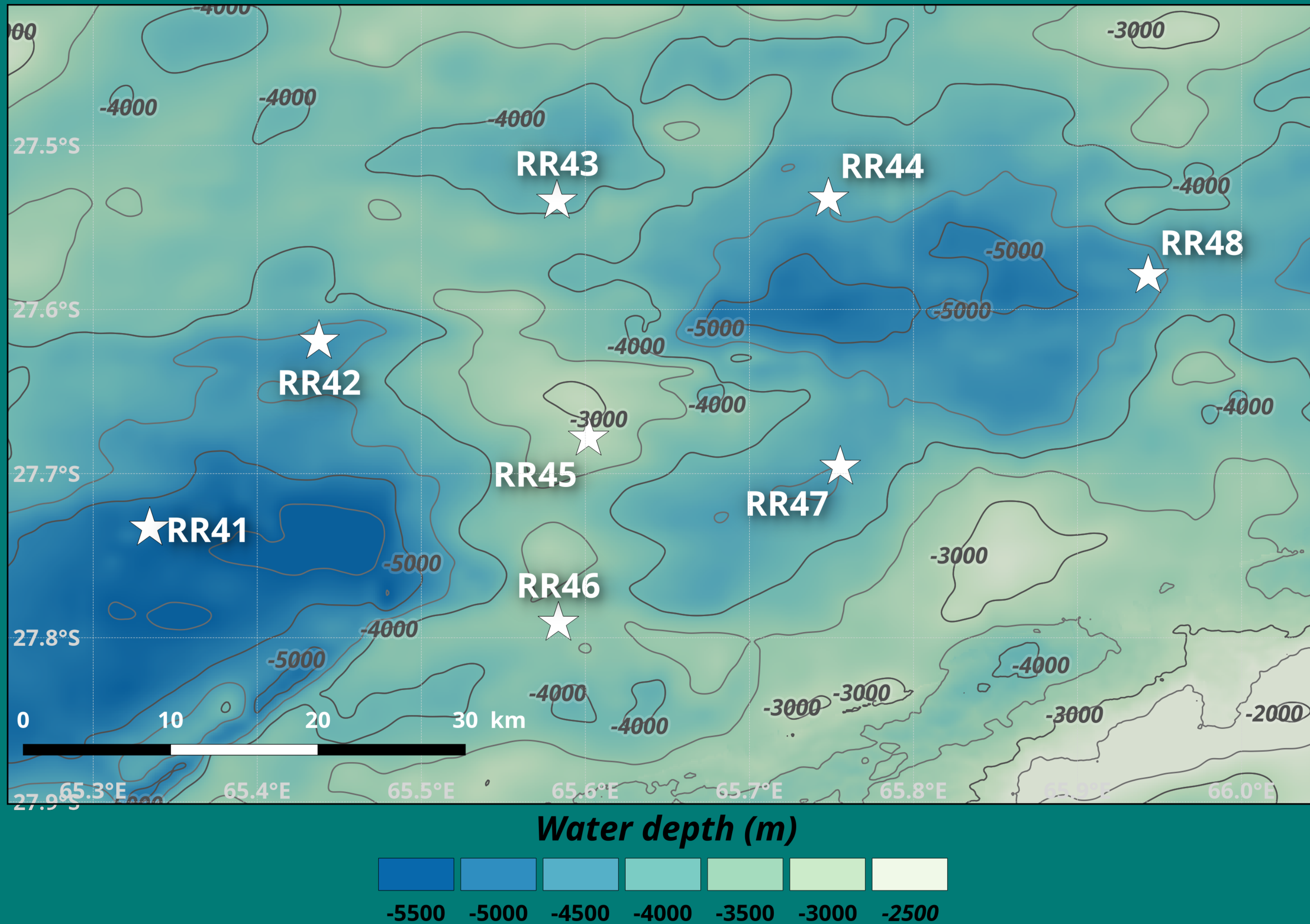


February -> October



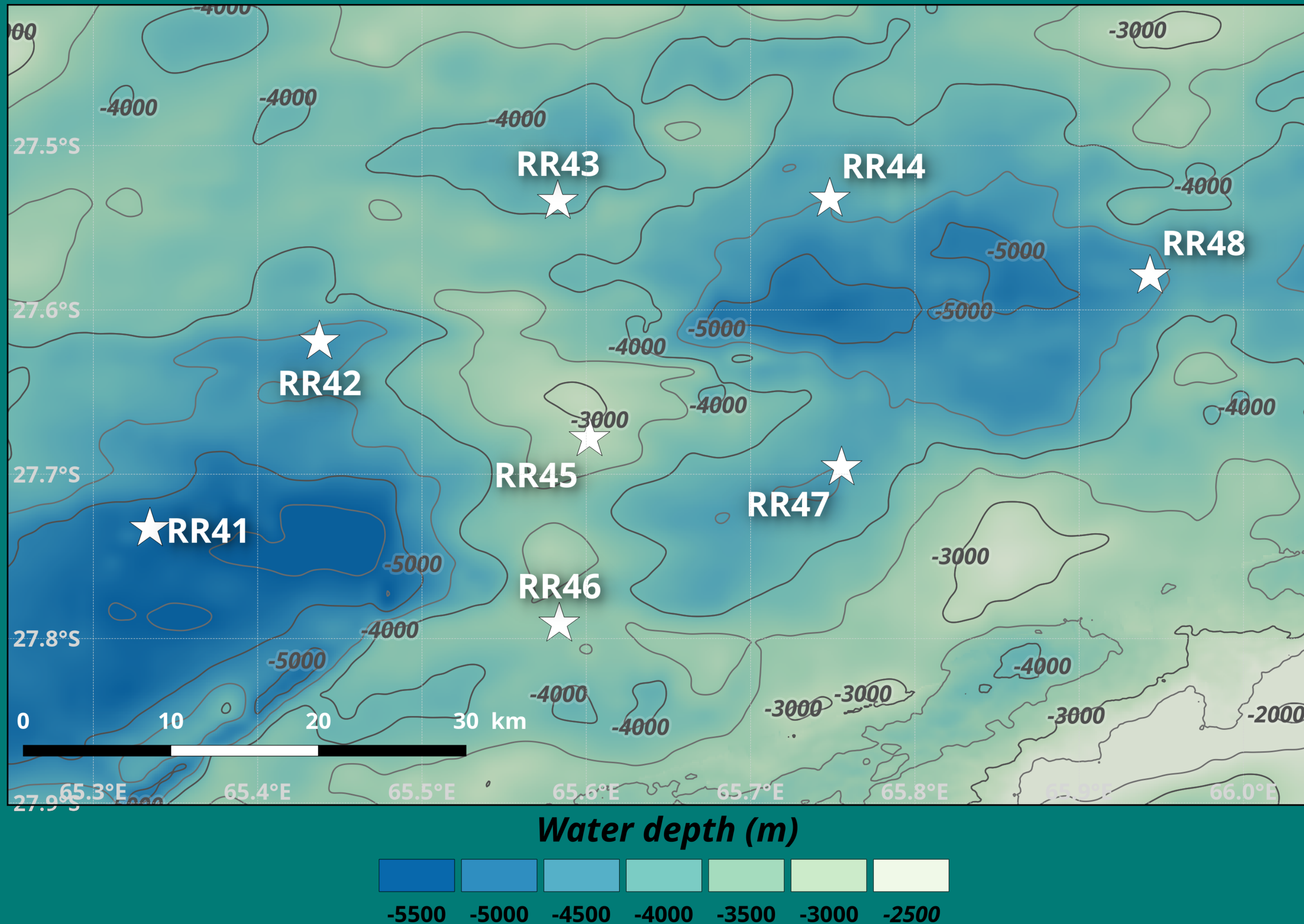


...to smaller scales

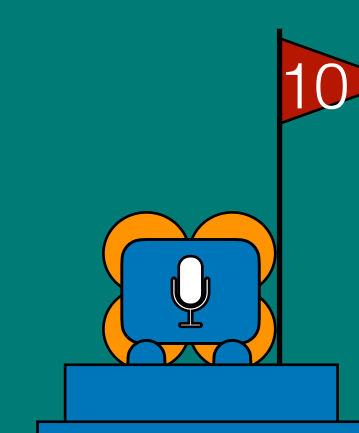
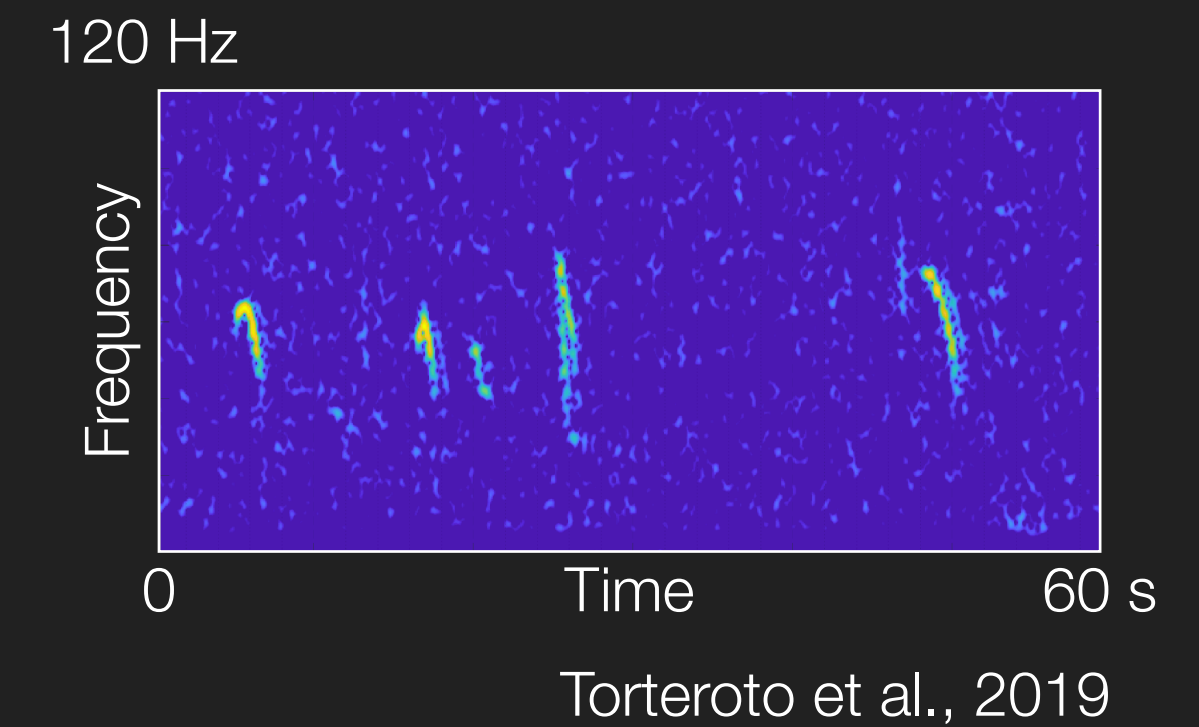
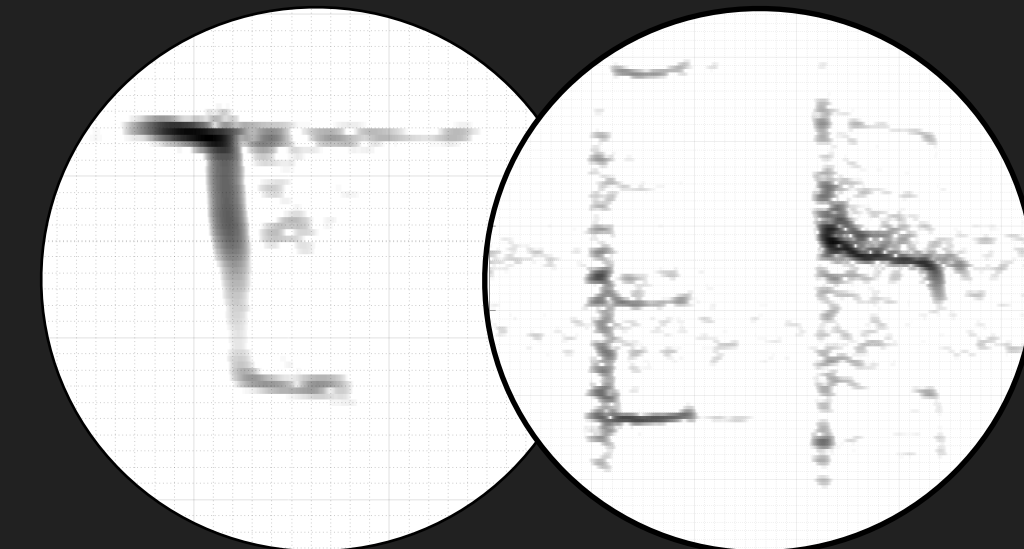




...to smaller scales

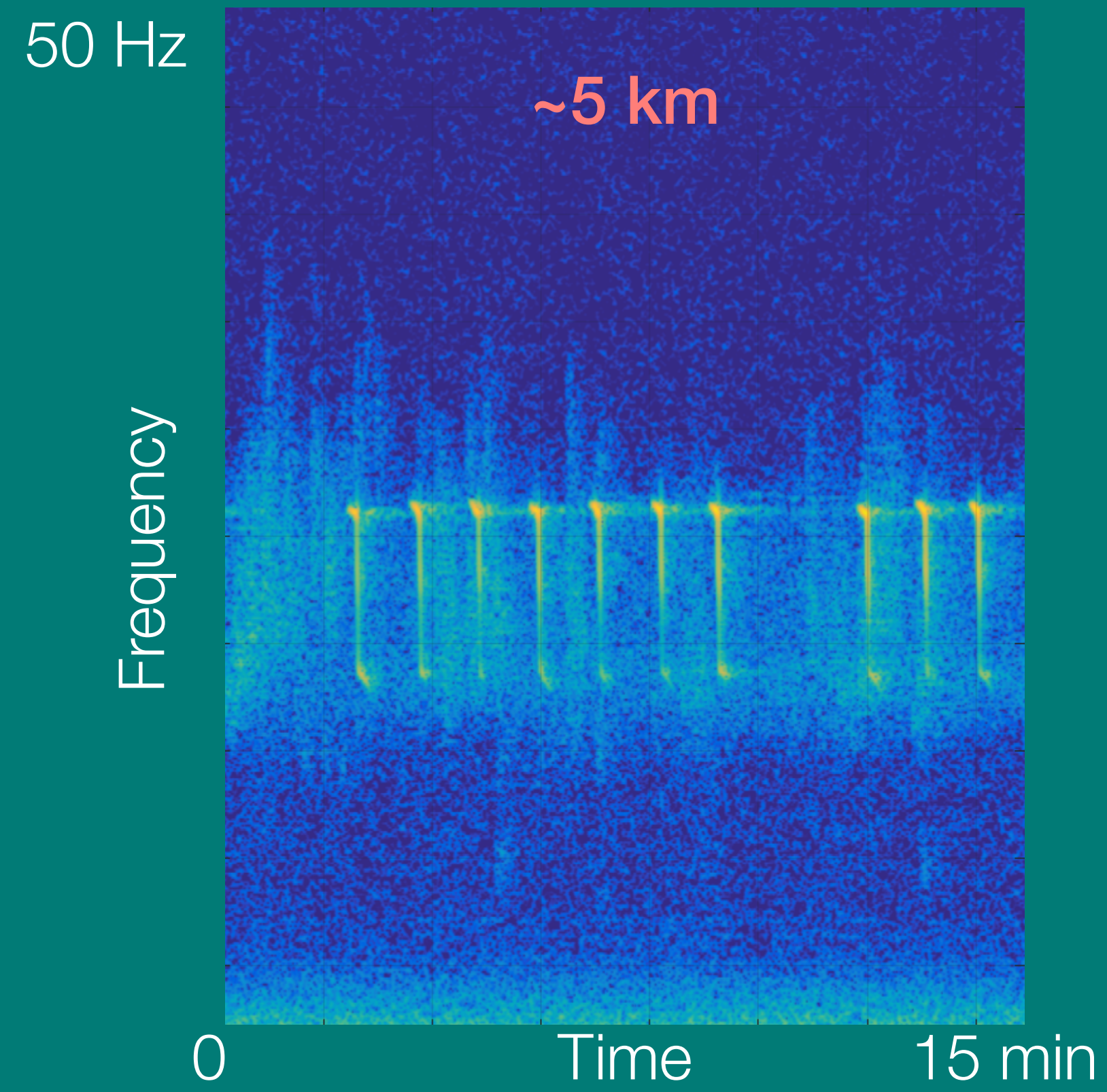


$f_s = 100\text{Hz}$



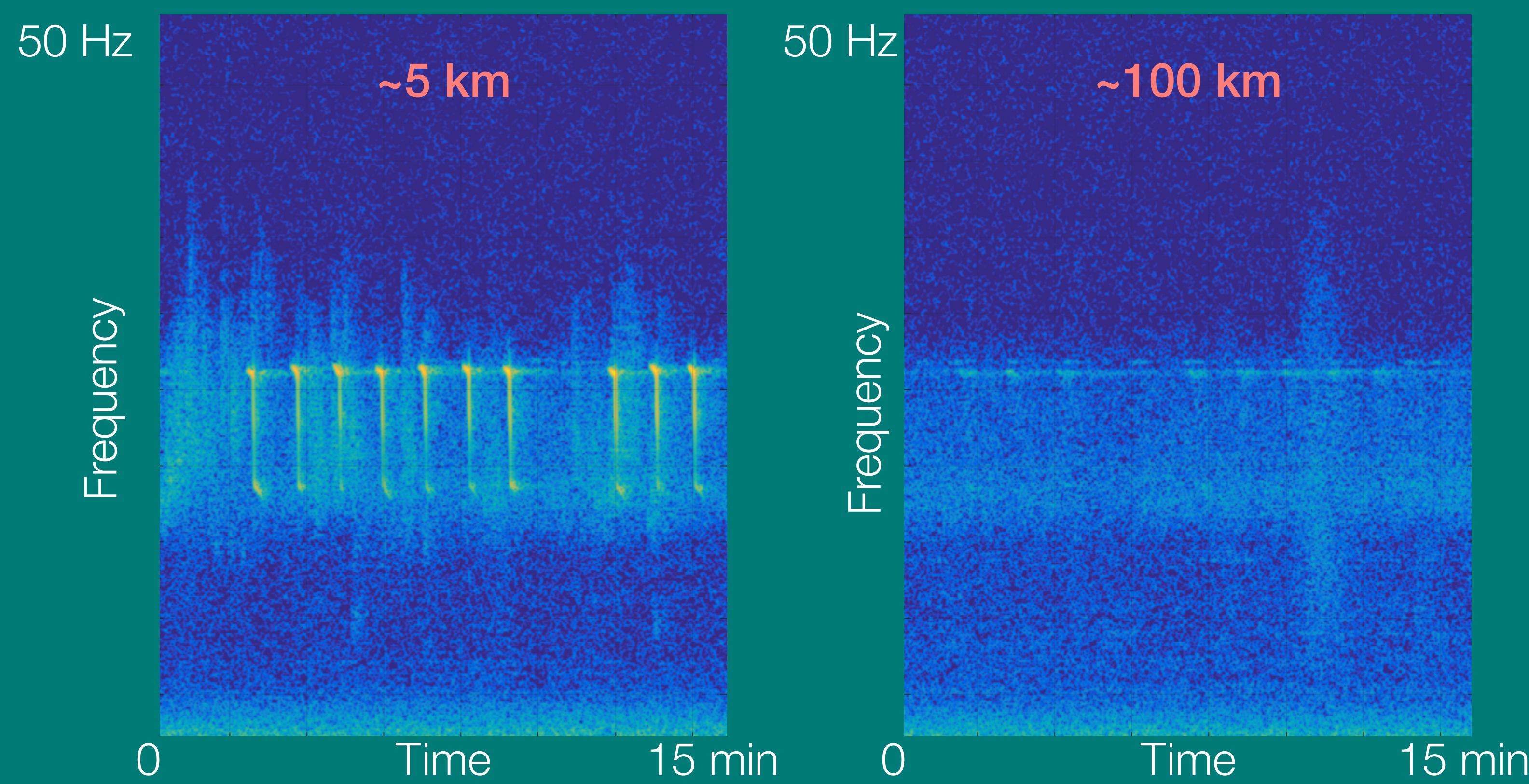


...to smaller scales





...to smaller scales





...to smaller scales

50 Hz

Frequency

0

~5 km

Time

15 min

50 Hz

Frequency

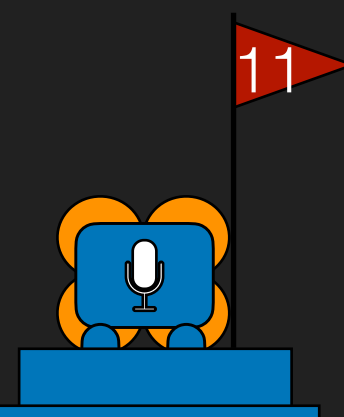
0

~100 km

Time

15 min

Signals modified by  
propagation channel +  
changing background  
noise





...to smaller scales

50 Hz

Frequency

0

~5 km

Time

15 min

50 Hz

Frequency

0

~100 km

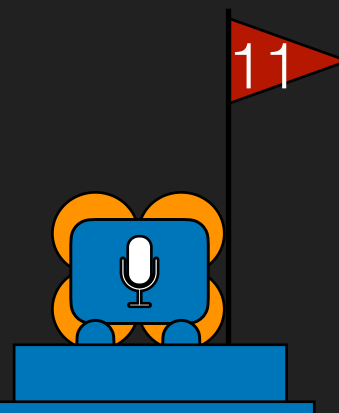
Time

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Signals modified by  
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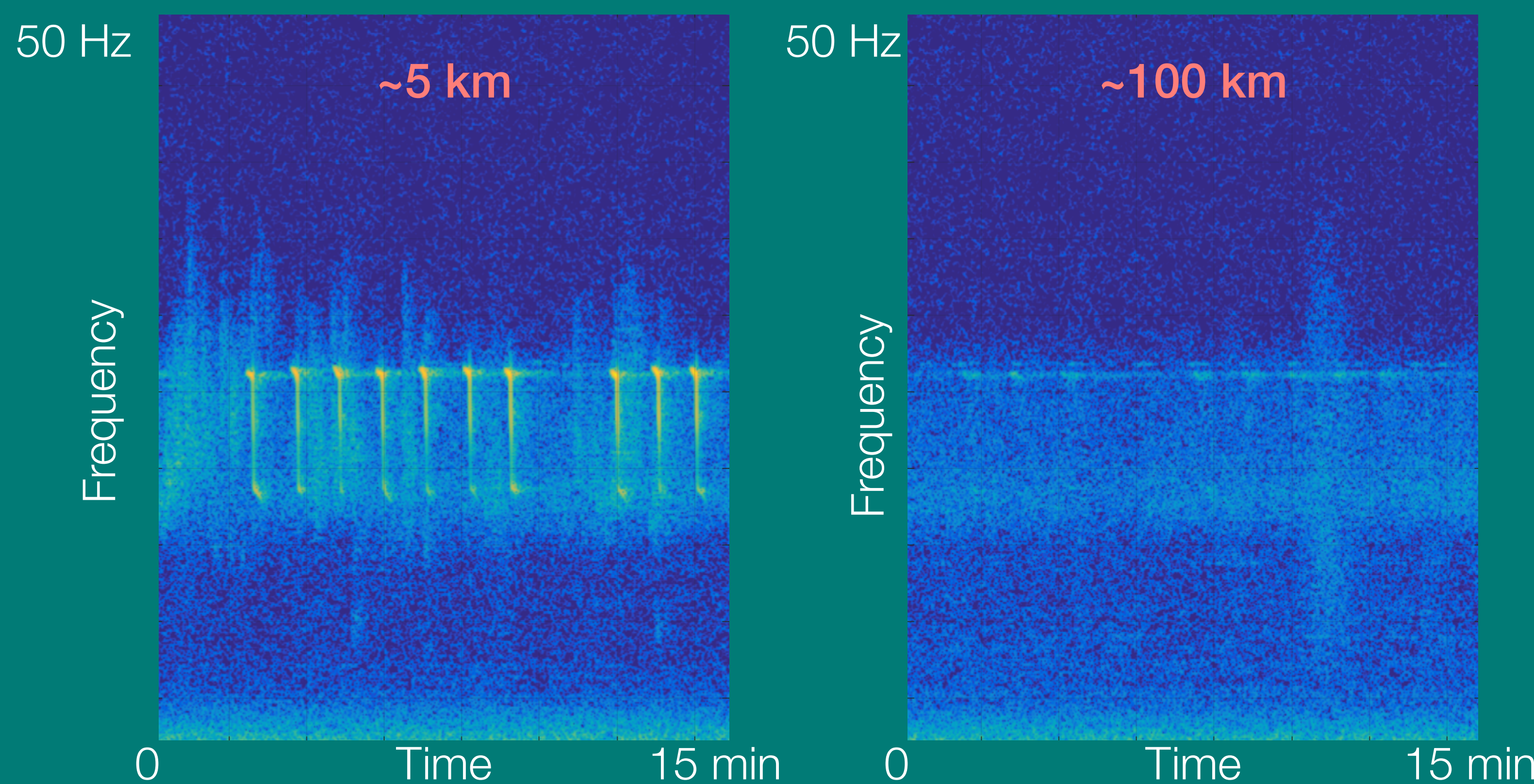


1 month of continuous  
data x 8 OBS  
 $\simeq$  6000h of recording  
(and lots of calls!)





...to smaller scales



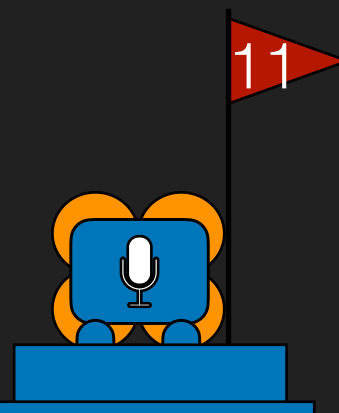
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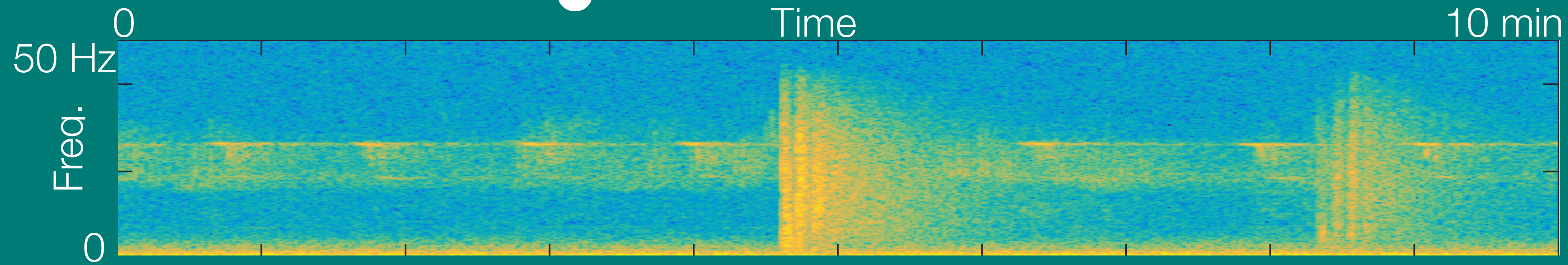


**Robust & controlled  
automatic detection  
methods**



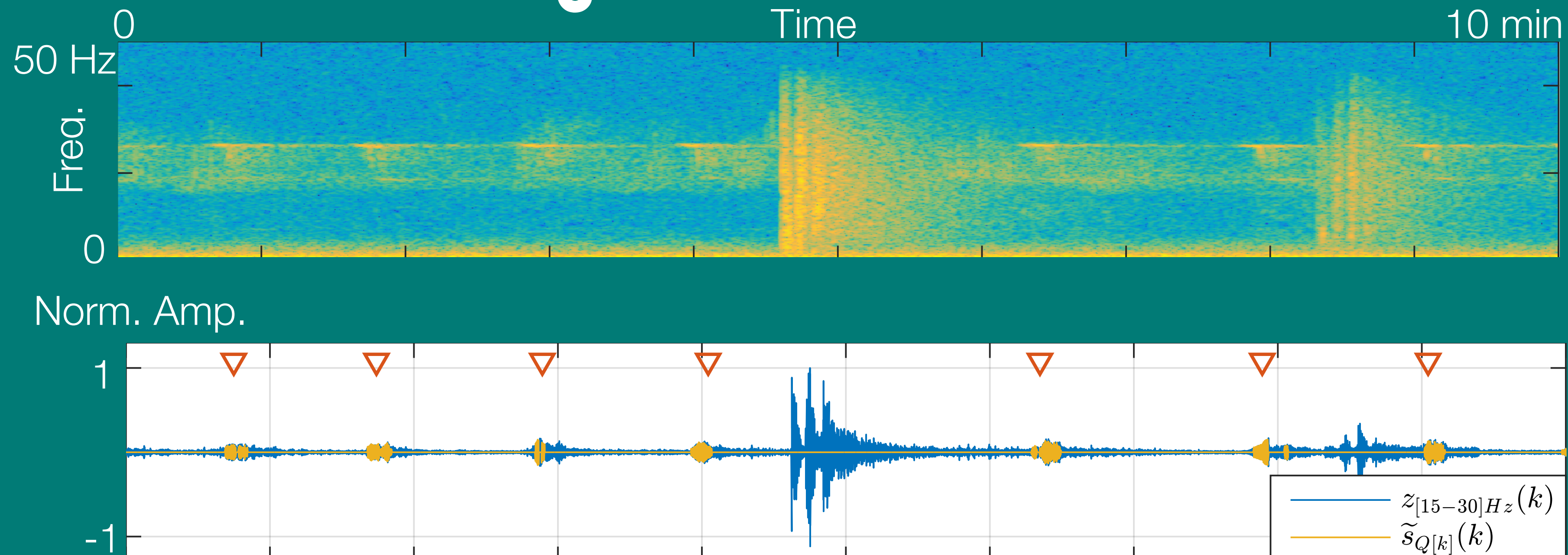


# Stochastic matched filter for the detection of low SNR signals



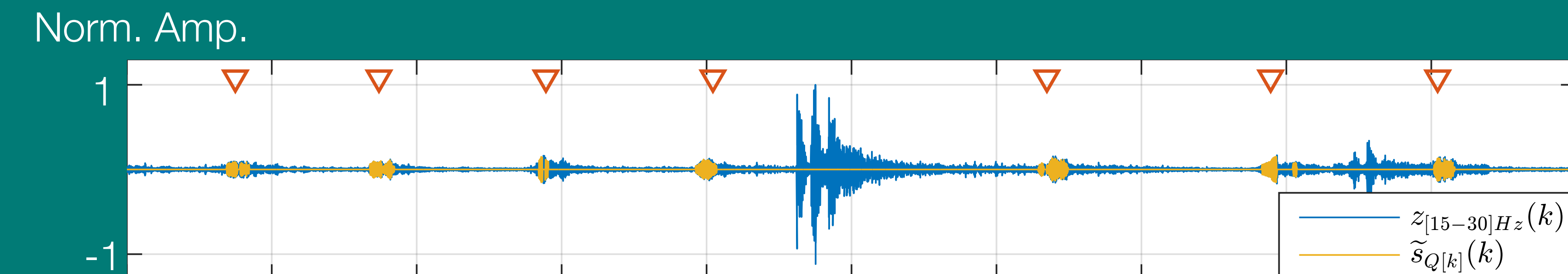
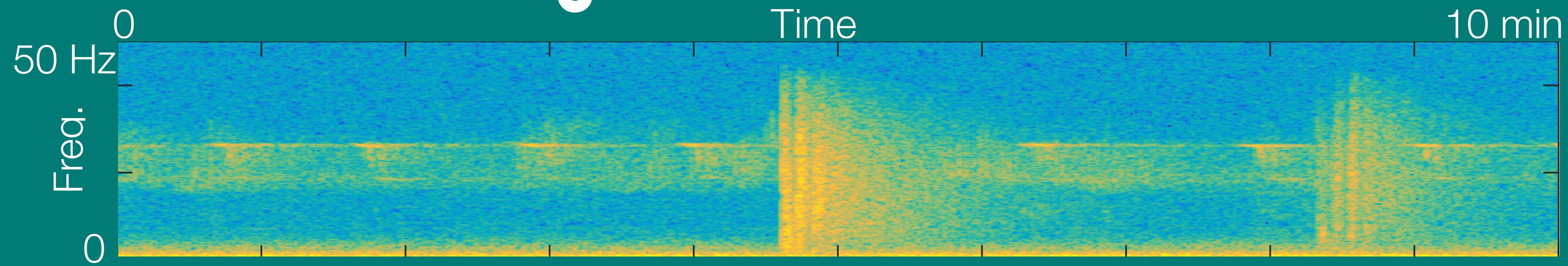


# Stochastic matched filter for the detection of low SNR signals

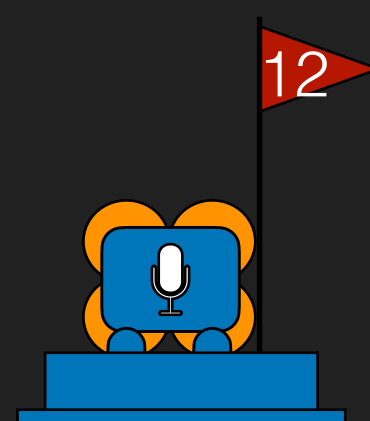
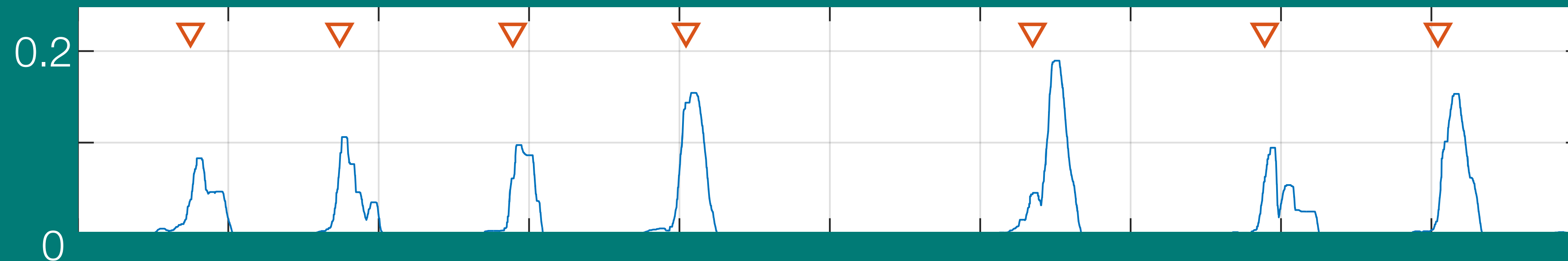




# Stochastic matched filter for the detection of low SNR signals

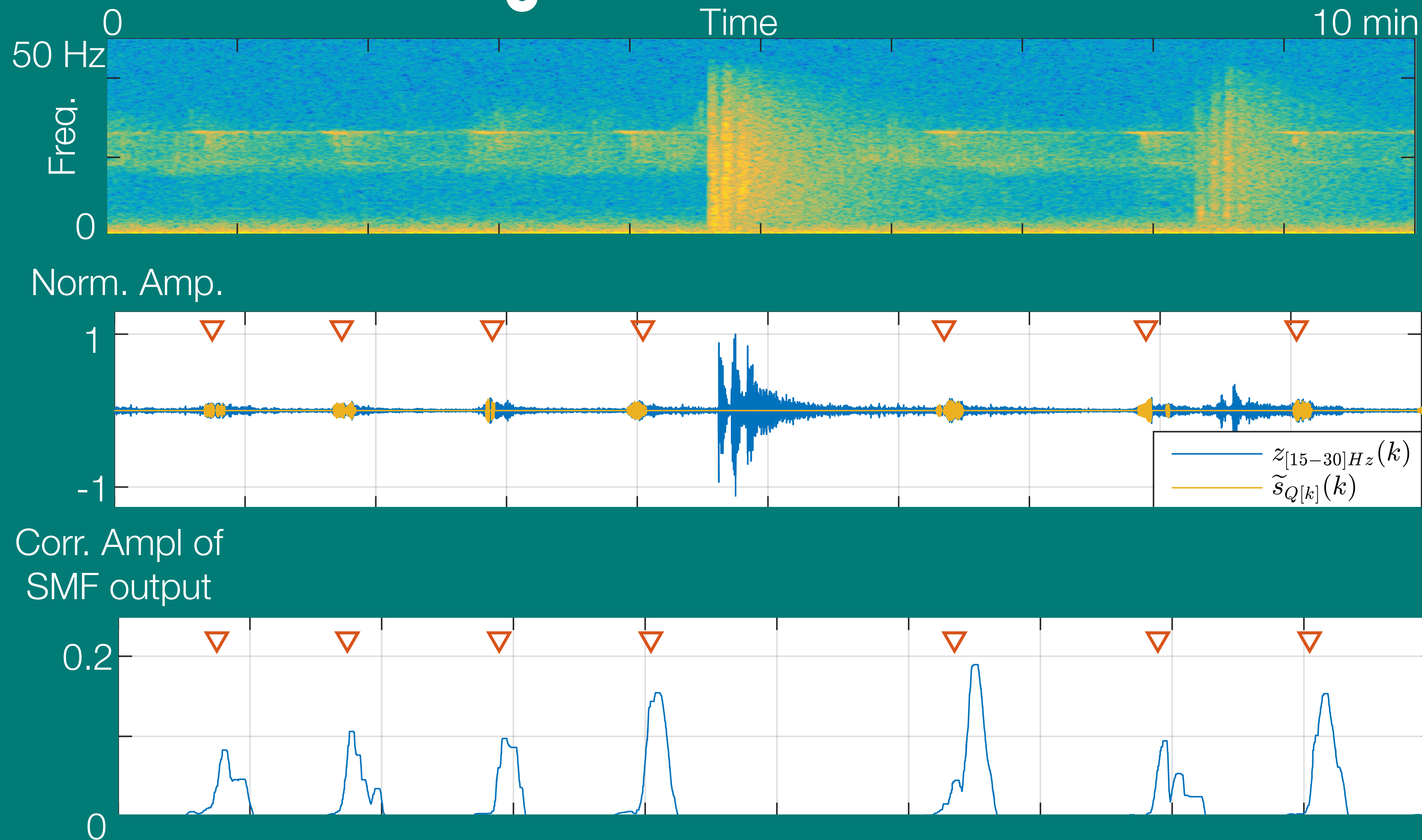


Corr. Ampl of  
SMF output





# Stochastic matched filter for the detection of low SNR signals



## ► Publication

L. Bouffaut, R. Dréo, V. Labat, A. Boudraa and G. Barruol "Passive stochastic matched filter for antarctic blue whale call detection," J. Acoust. Soc. Am, vol. 144, no. 2, pp. 955-965 (2018)

## ► SMF code is available!

[https://leabouffaut.github.io/SMF\\_package/](https://leabouffaut.github.io/SMF_package/)



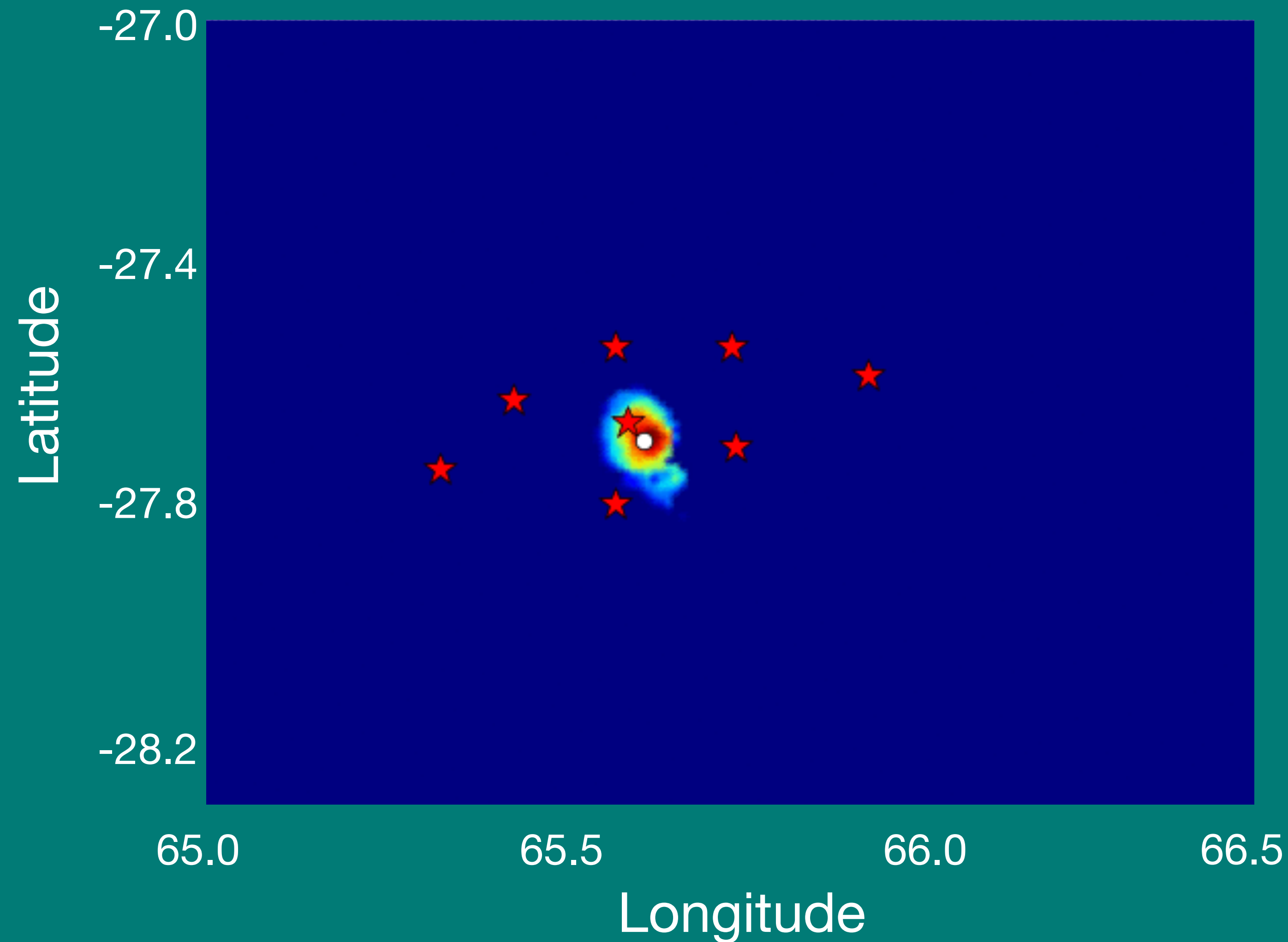
## ► Open source annotated test dataset

<https://doi.org/10.5281/zenodo.3624145>





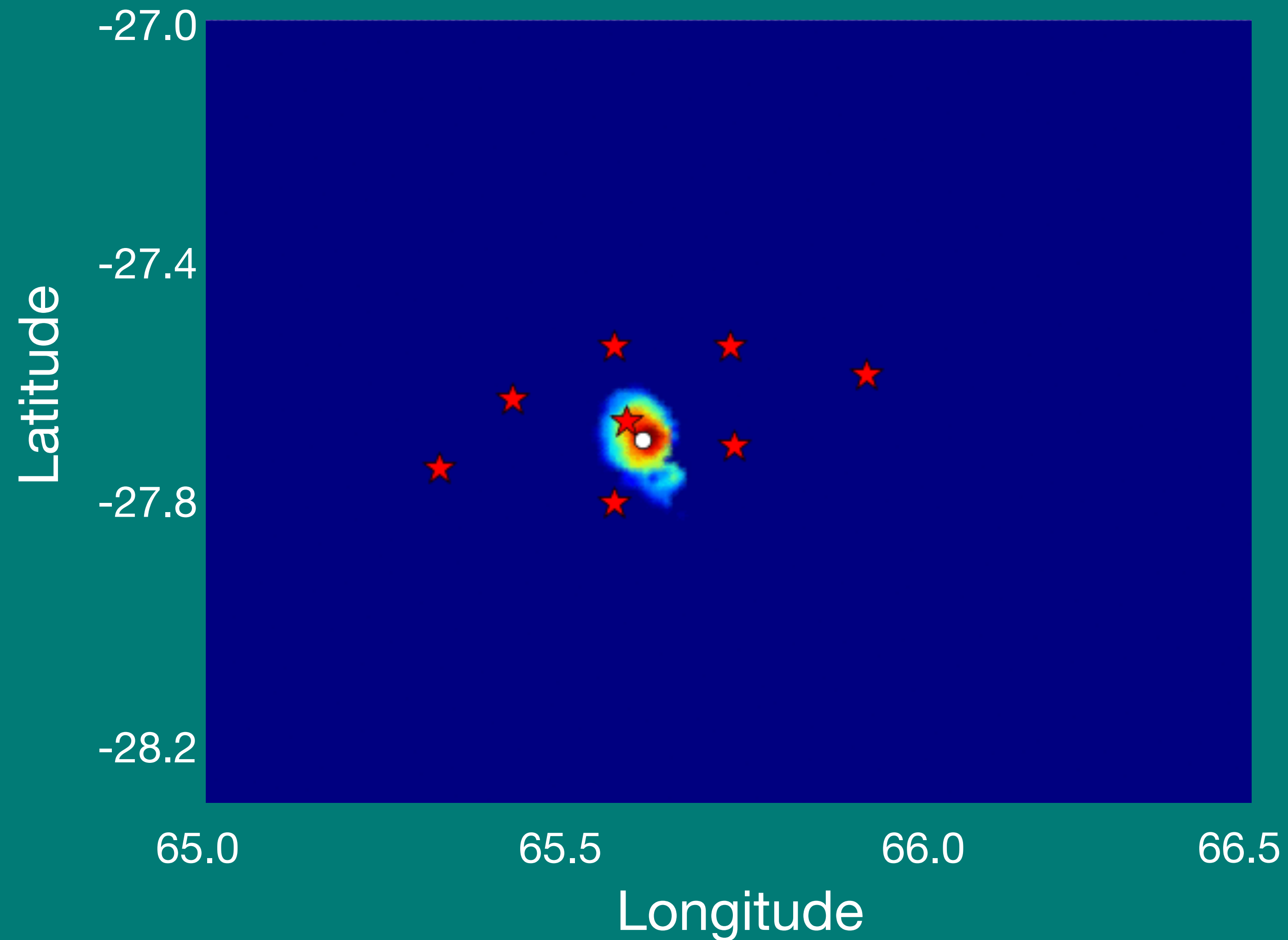
# Tracking of an ABW



R. Dréo, L. Bouffaut, L. Guillon, V. Labat, G. Barruol and A. Boudraa “Antarctic Blue Whale localization with Ocean Bottom Seismometer in Southern Indian Ocean”, *UACE 2017*, Greece, pp. 2-7 (2017).



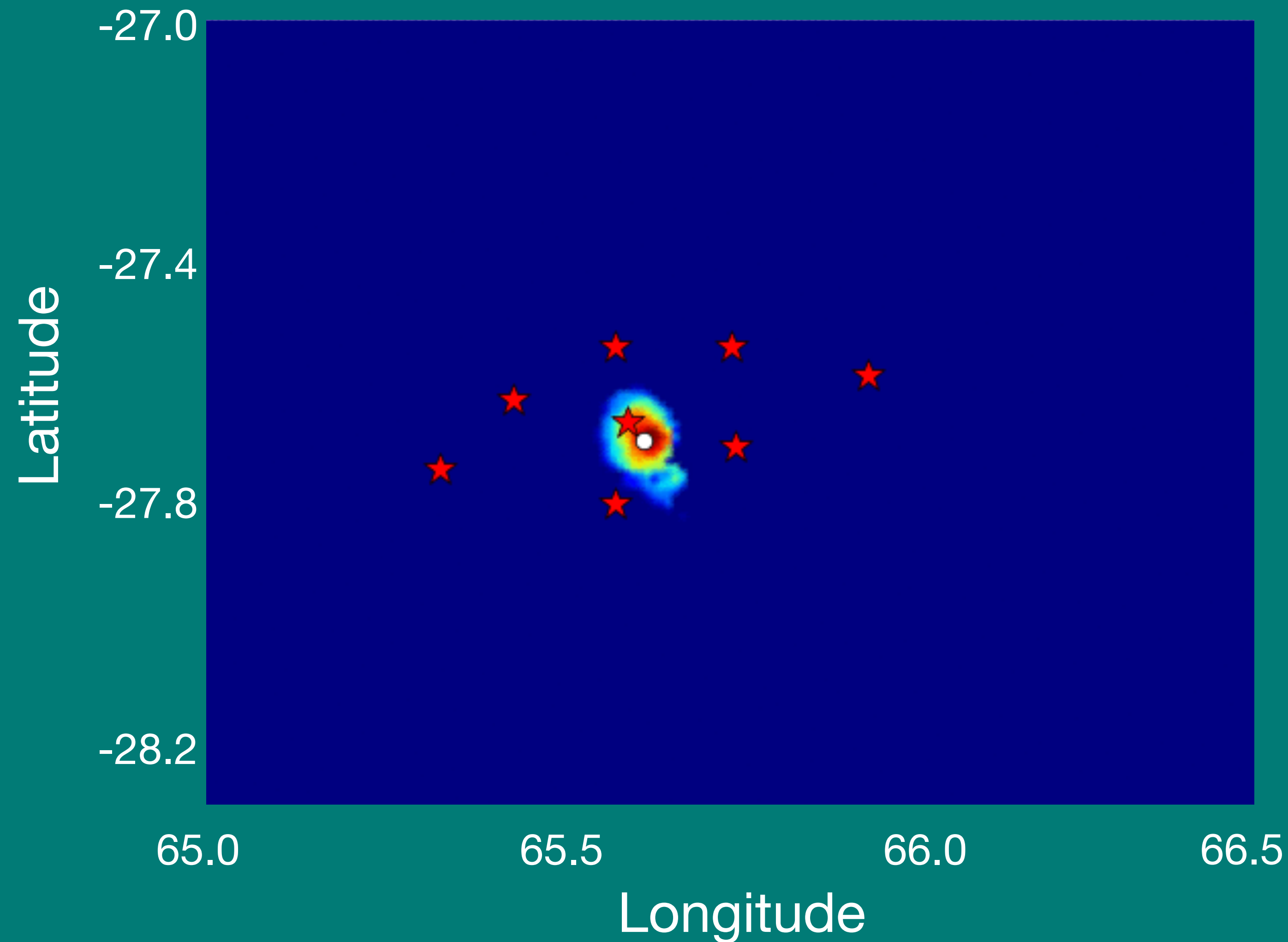
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# Tracking of an ABW

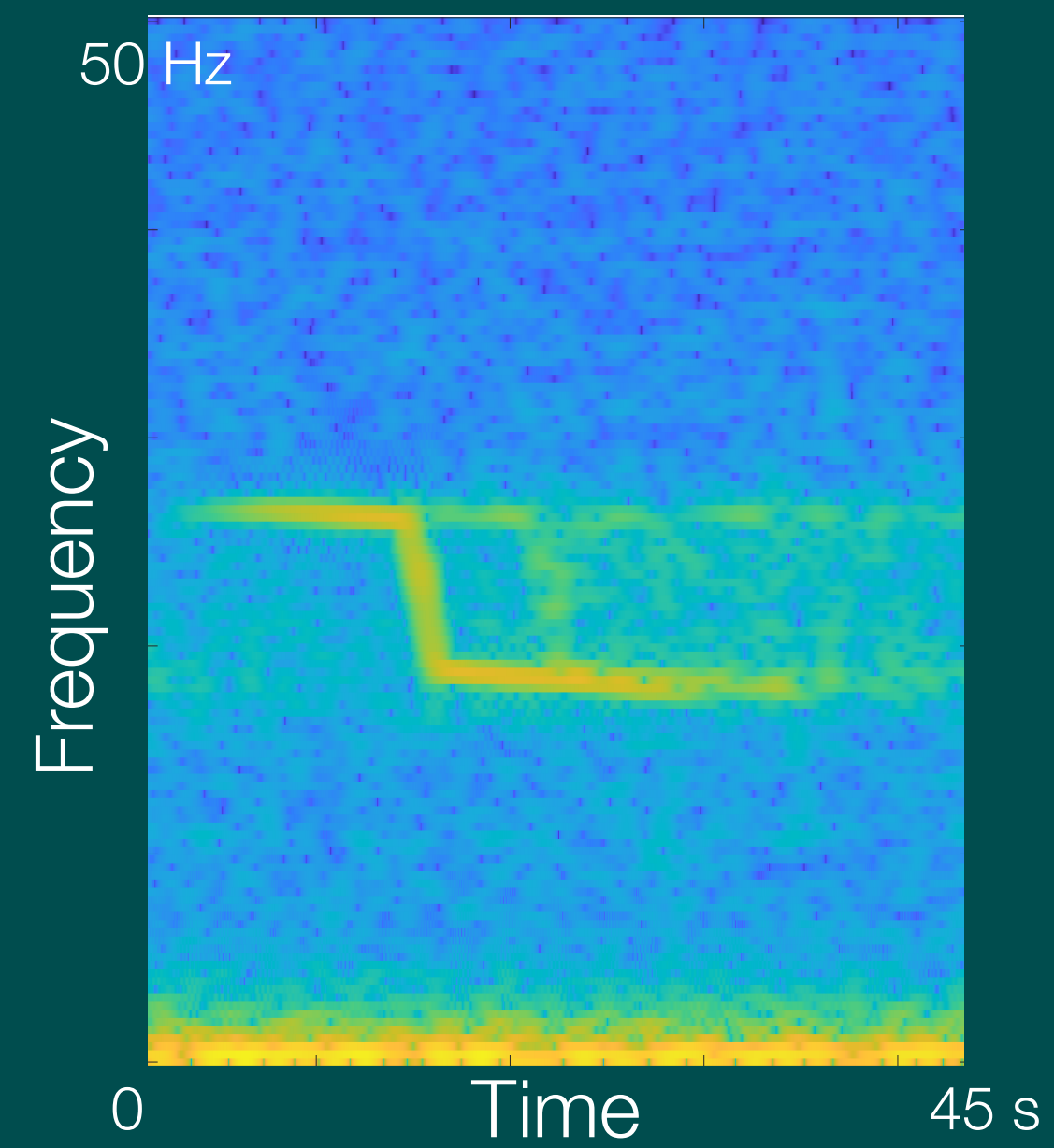


R. Dréo, L. Bouffaut, L. Guillon, V. Labat, G. Barruol and A. Boudraa “Antarctic Blue Whale localization with Ocean Bottom Seismometer in Southern Indian Ocean”, *UACE 2017*, Greece, pp. 2-7 (2017).

**A lot can also be  
done with a  
single  
hydrophone!**

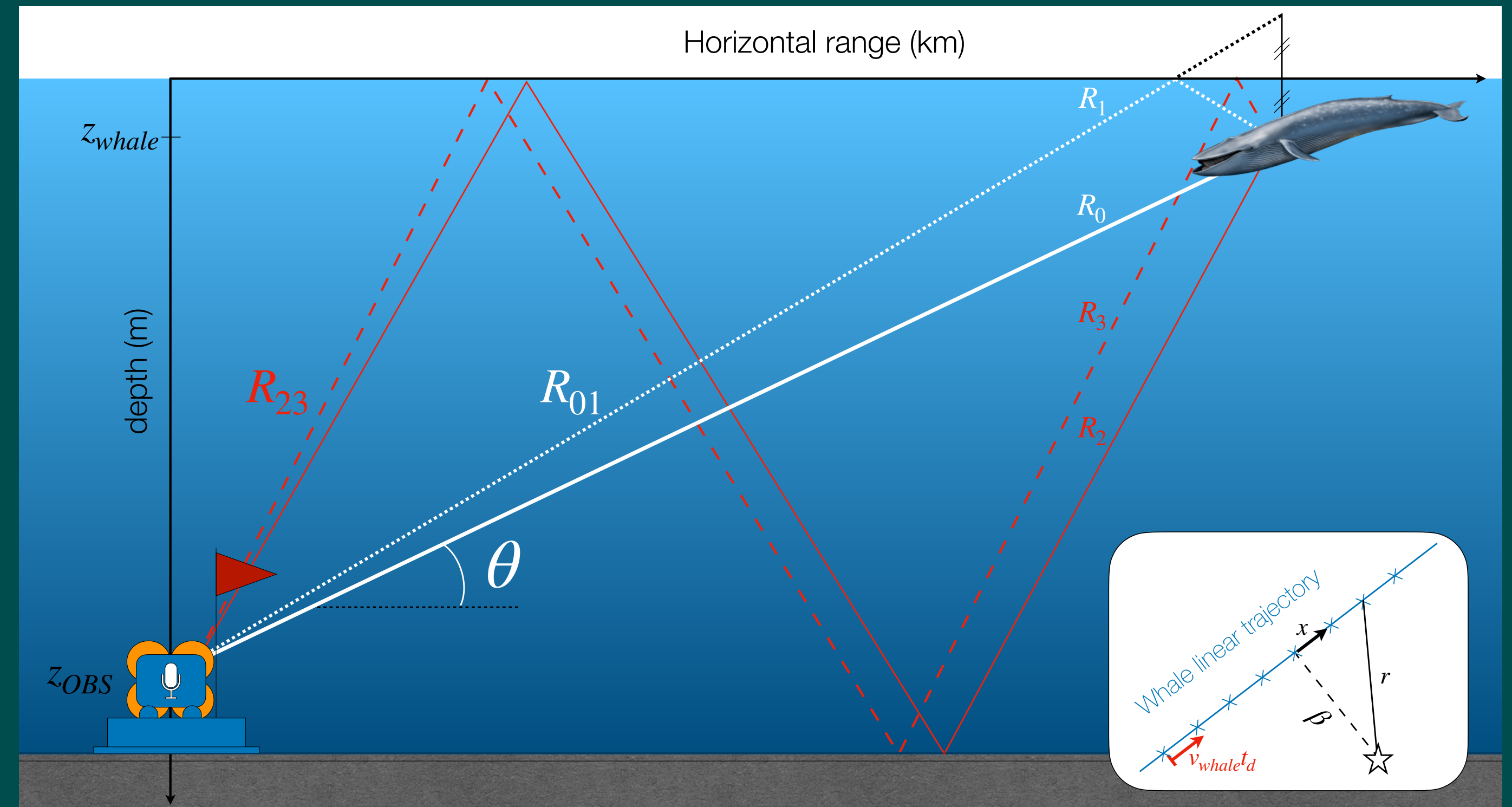
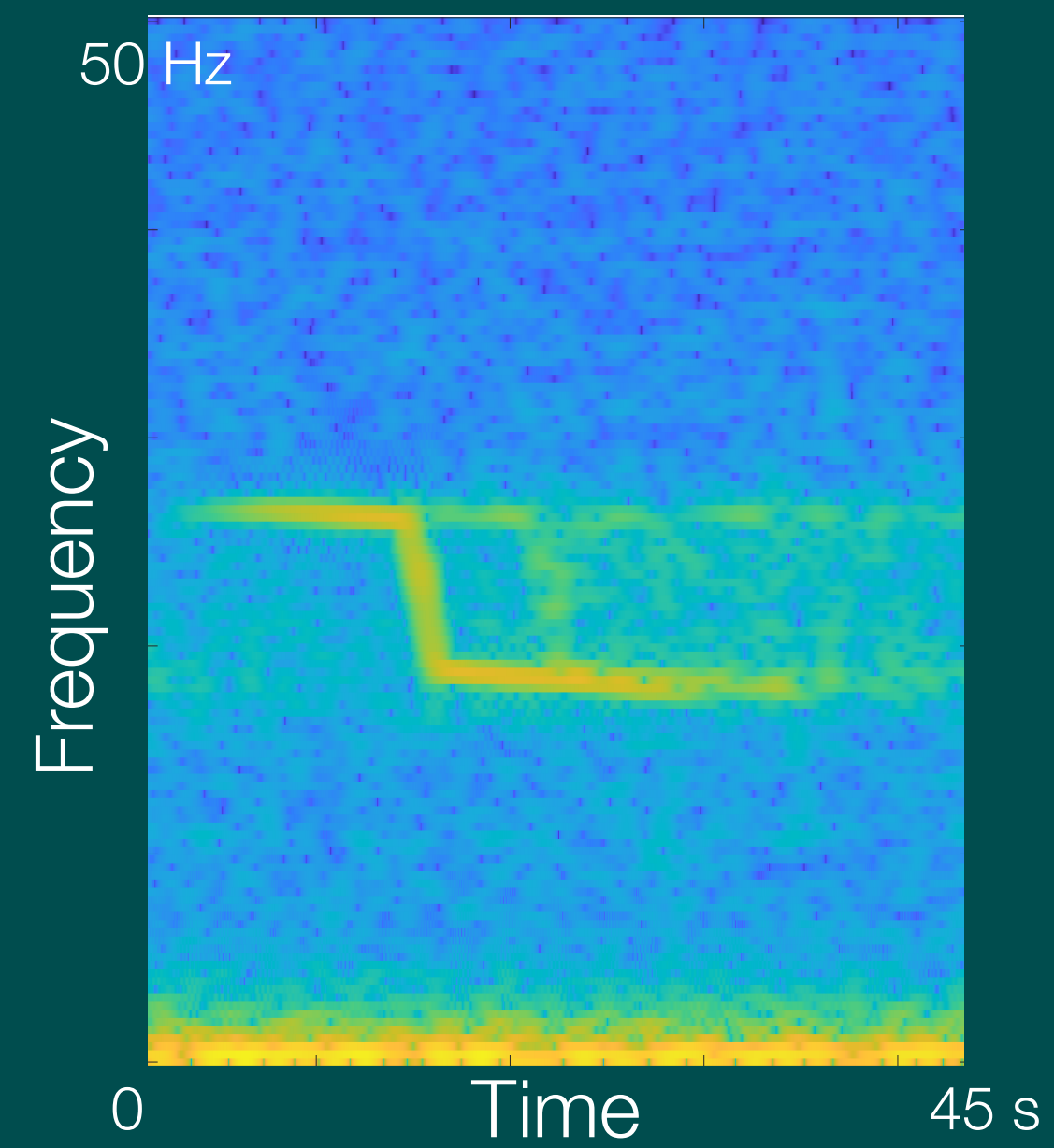


# Blue whale acoustic diving profile



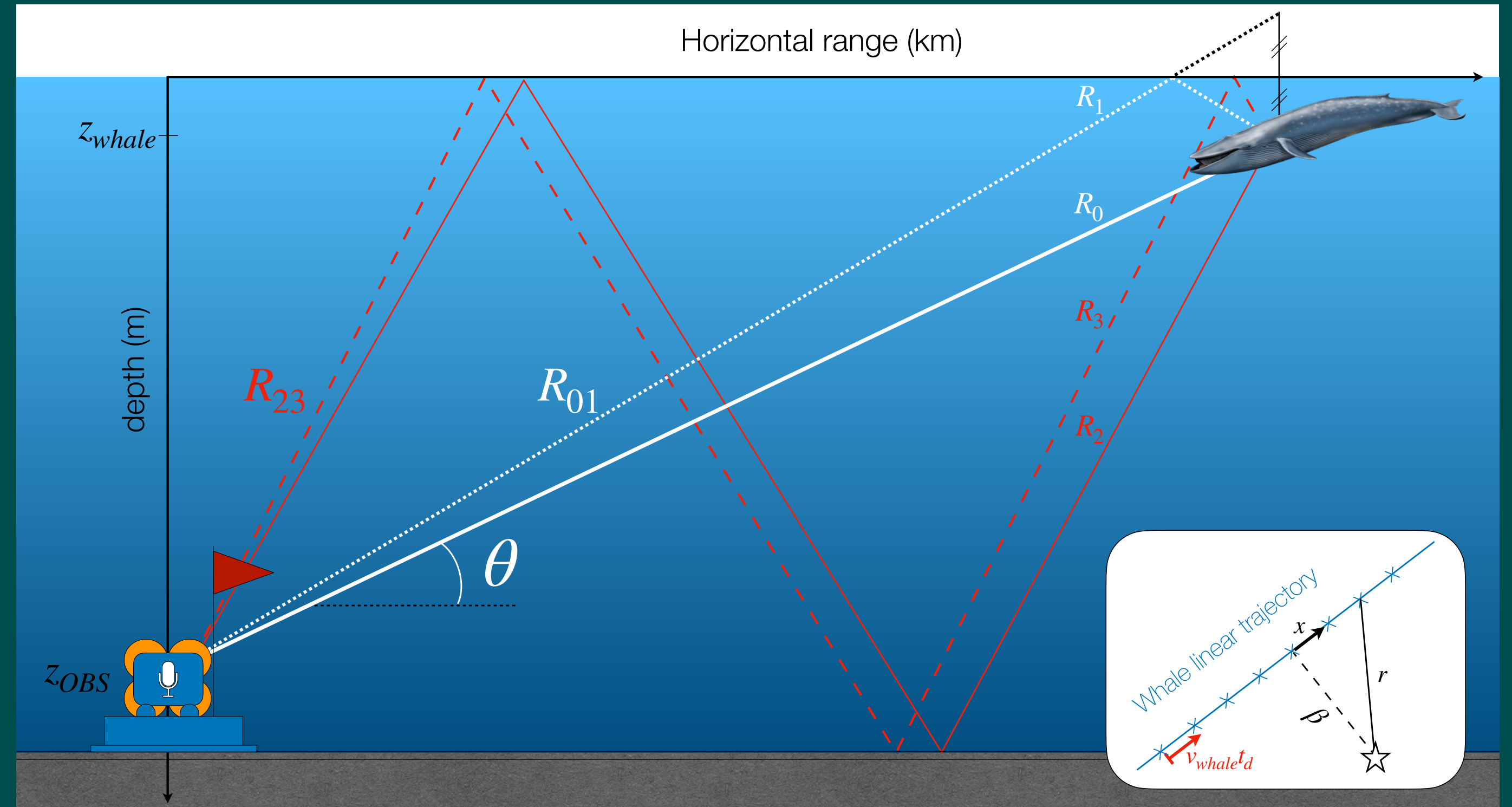
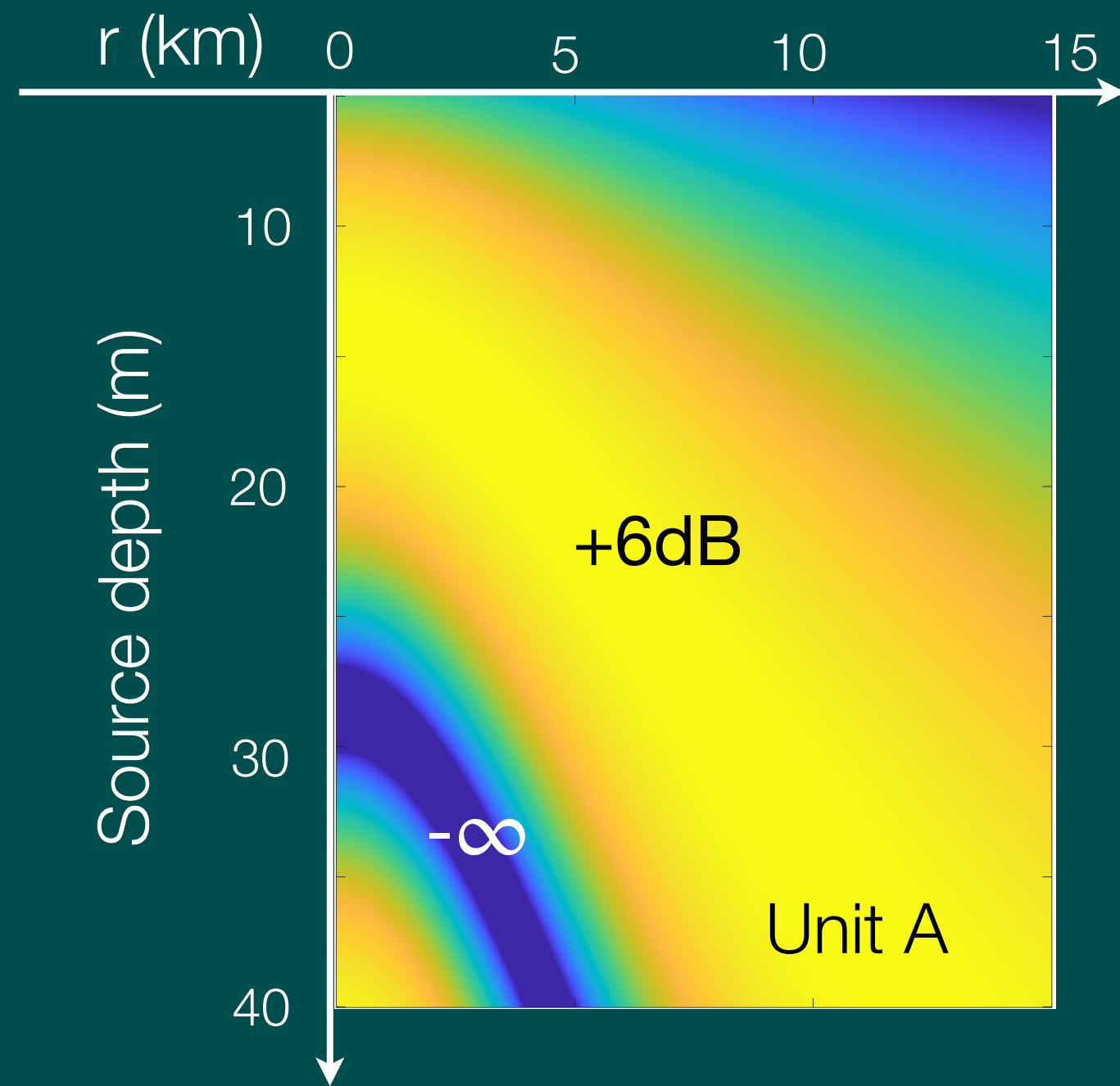


# Blue whale acoustic diving profile



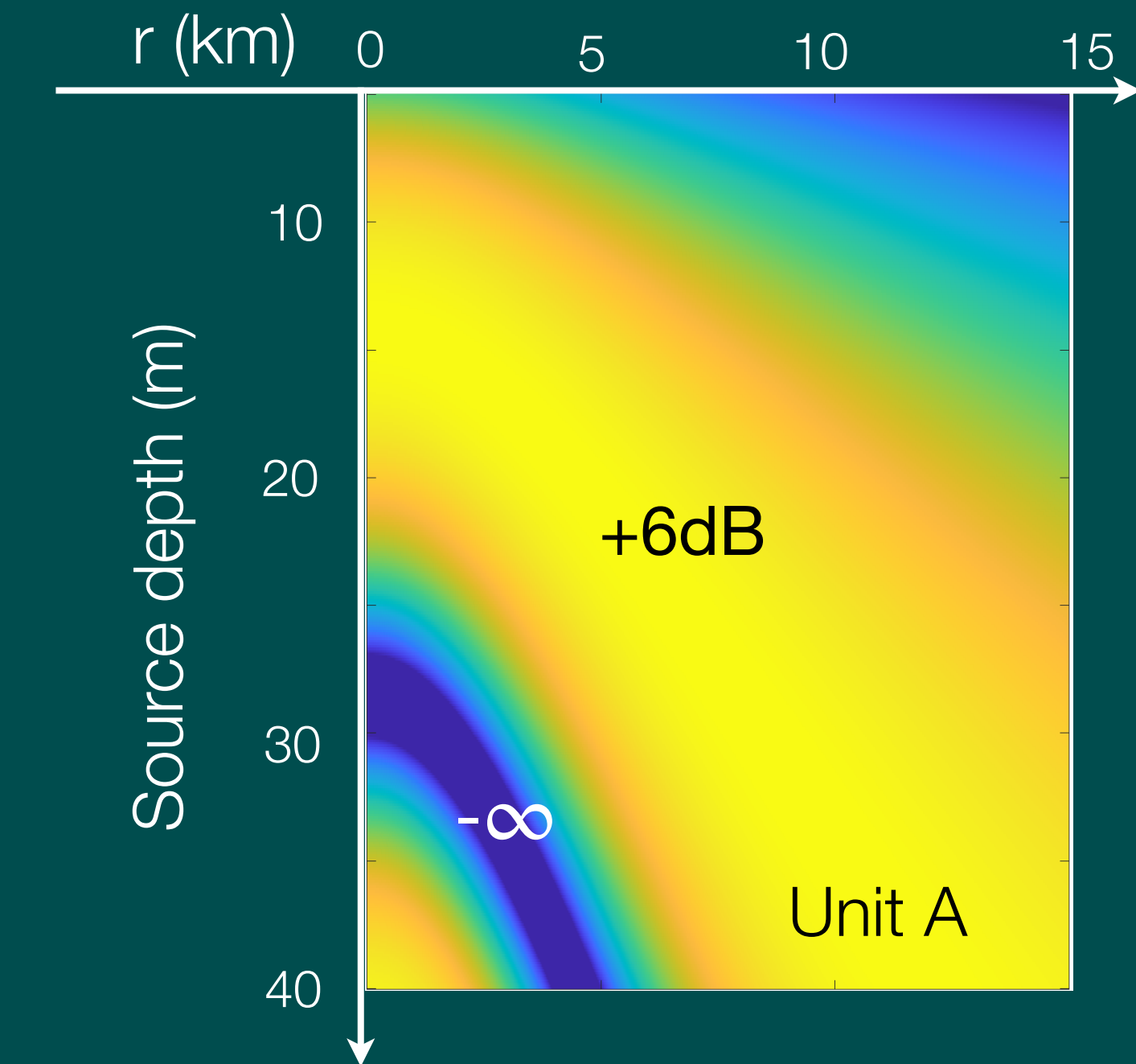


# Blue whale acoustic diving profile

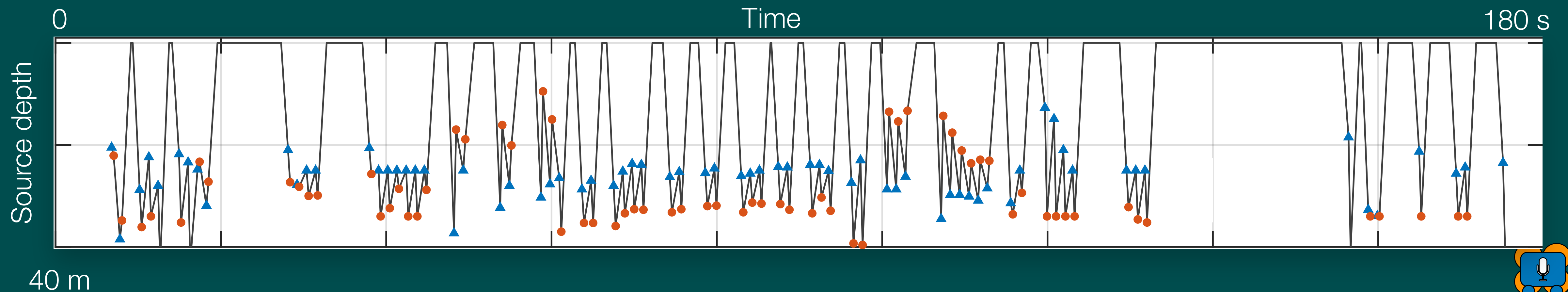




# Blue whale acoustic diving profile

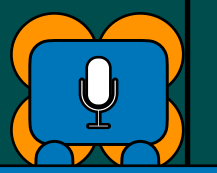
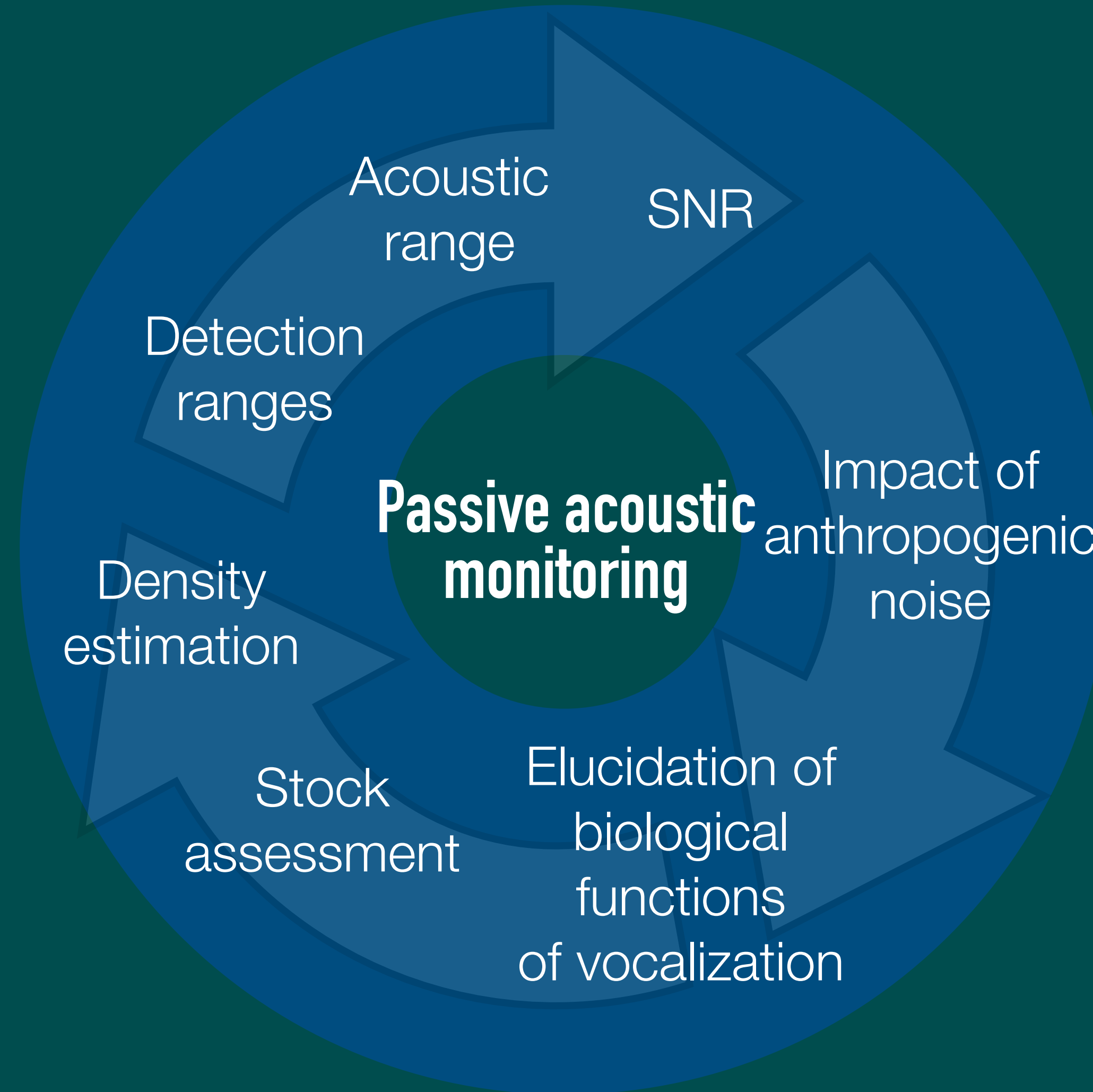


L. Bouffaut, M. Landrø, J. R. Potter  
“Source level and vocalizing depth estimation of two blue whale subspecies in the western Indian Ocean from single sensor observations” J. Acoust. Soc. Am (Under review).





# Conclusions







**Whale, Thank you.**

[lea.bouffaut@ntnu.no](mailto:lea.bouffaut@ntnu.no)



# Question?

**Whale, Thank you.**

lea.bouffaut@ntnu.no