Autonomous Recorder Based Monitoring of Marine Mammal Acoustic Behaviors in Relation to Mid-Frequency Active Sonar

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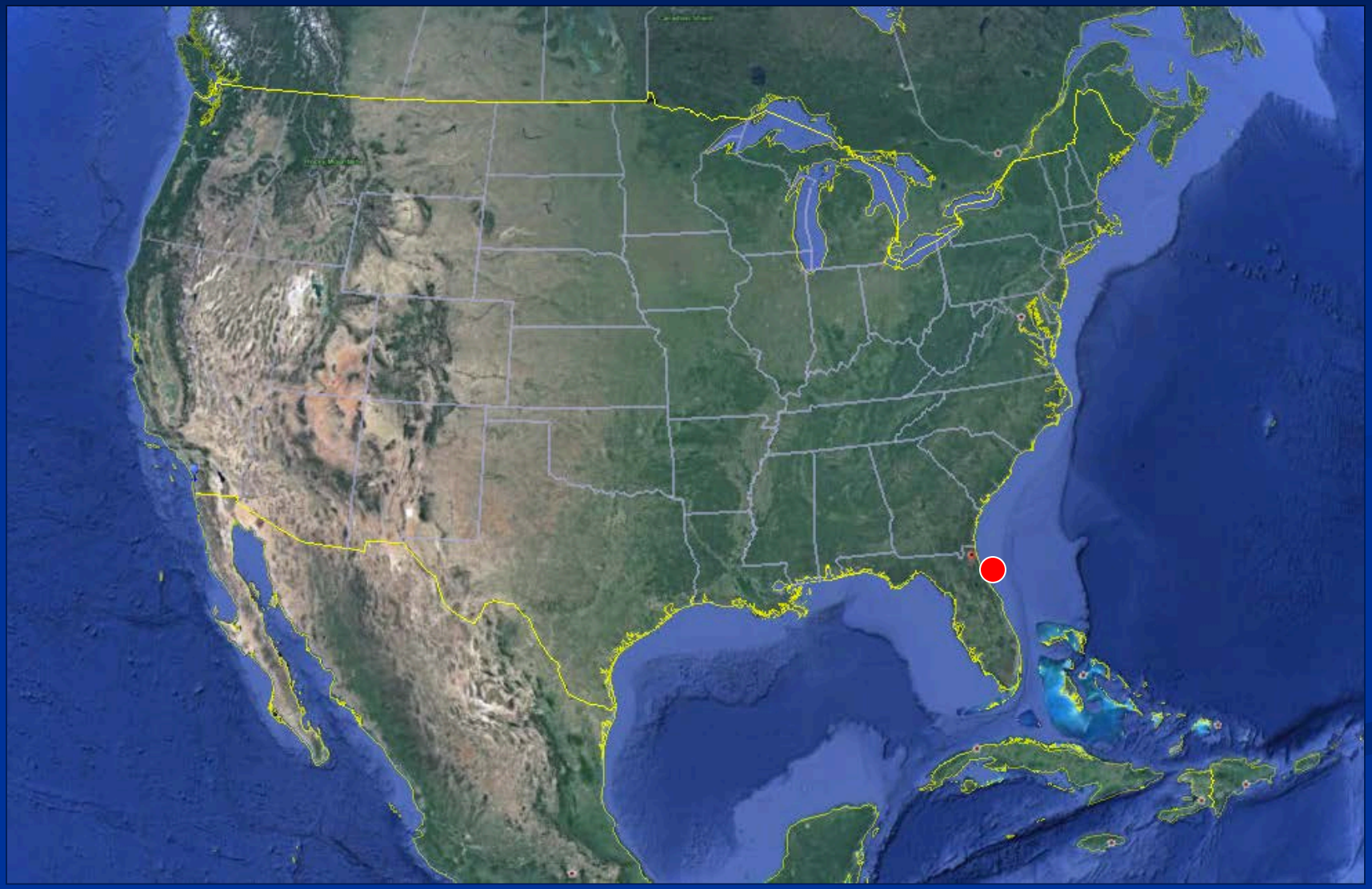
Background

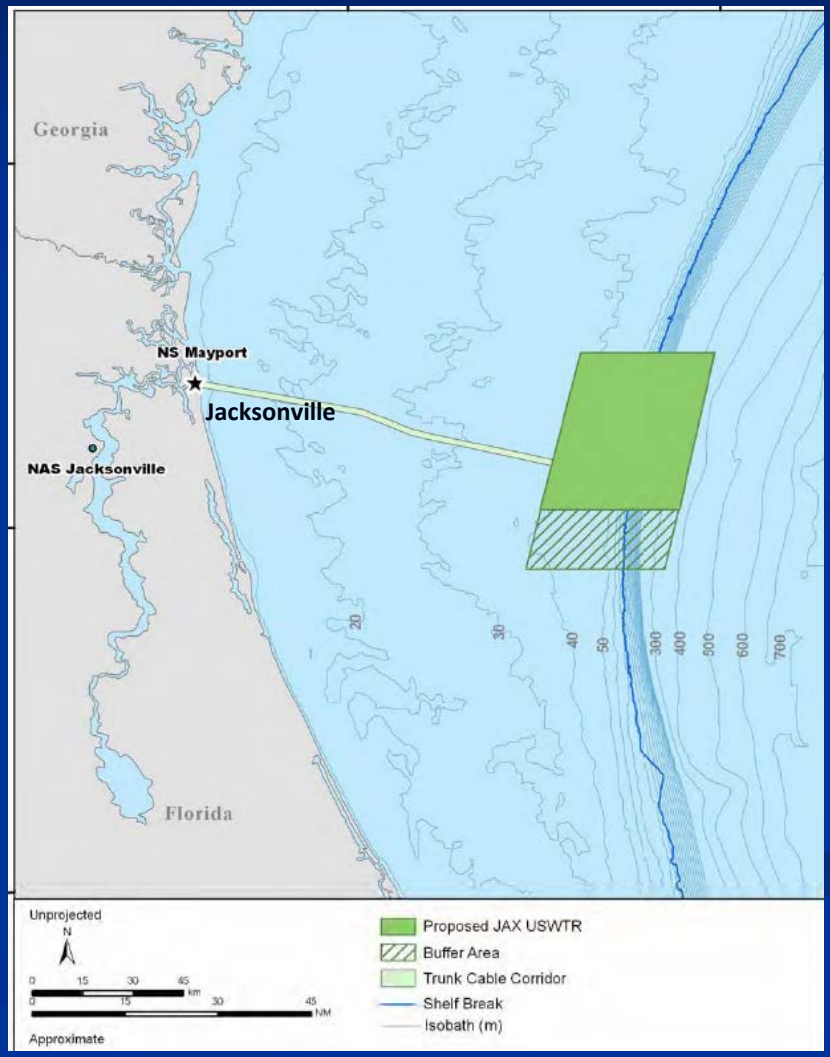
- The US Navy is developing an Undersea Warfare Training Range (USWTR) off Jacksonville, Florida.
- Navy deployed Marine Autonomous Recording Units (MARU's) in 2009 and 2010.
- Recordings made before, during, and after Navy training exercises which included sonar activity.

Study Area



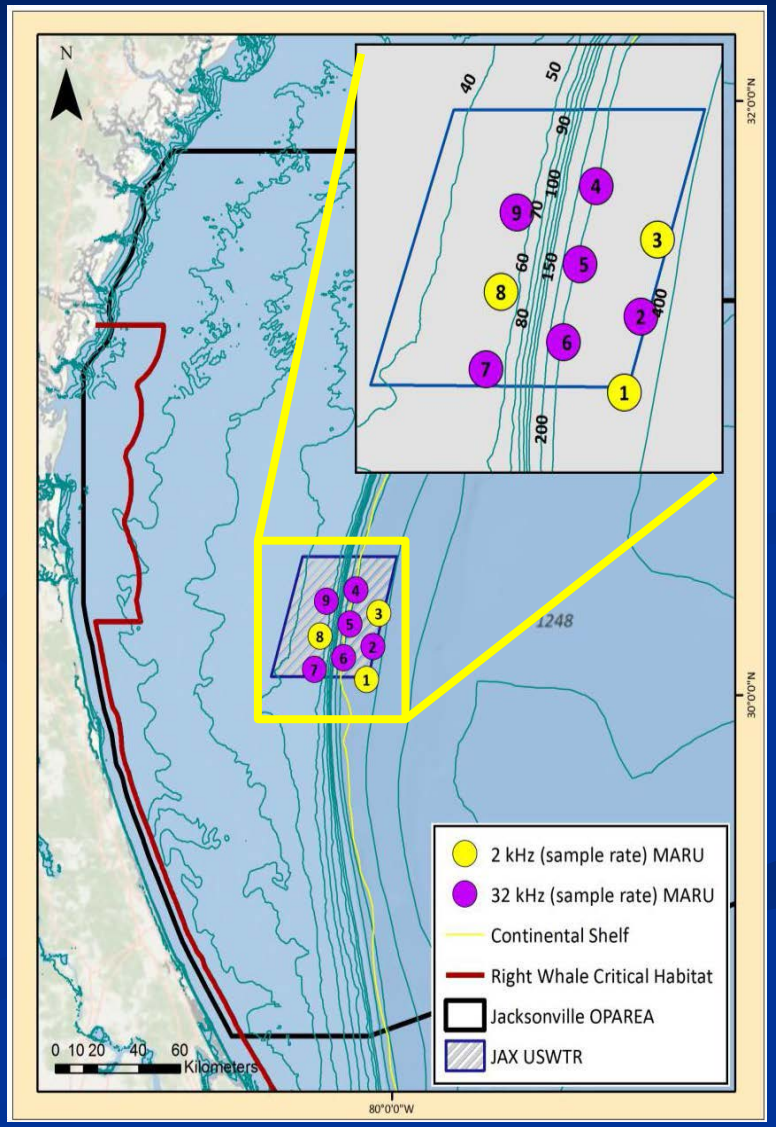
Study Area

- 80 to 150 km off northern FL (Jacksonville to St. Augustine)
- USTWR area is 1,717-km^2
- Area includes the shelf break
- Located well offshore of Right whale critical habitat.



Deployment Details

- An array of 9 MARUs deployed (not synchronized)
- Fall deployment
  - 26 days (13 Sept. - 8 Oct., 2009)
- Winter deployment
  - 37 days (3 Dec. 2009 - 8 Jan. 2010)
- Depths
  - 3 shallow sites (45 m)
  - 3 mid-depth (180 m)
  - 3 deep sites (300 m)
- Sample rates
  - 2khz ( ) and 32khz ( )



GOALS

- To document the presence of marine mammals.
- To characterize seasonal patterns of occurrence.
- To characterize diel patterns of vocalizations.
- To characterize occurrence in relation to depth.
- To assess effects of sonar activity on vocalizations.

Methods

Data Review & Logging

- Data were reviewed and events logged using Triton (Wiggins, 2007).
- Event logs created for every site.
  - Event defined as period of activity with no more than 10 min gap between calls.
  - Start & end time of ***events*** *(not individual calls)*
    - Marine mammal vocalizations (by species)
    - Mid-frequency sonar & ship noise
- Daily event graphs used to characterize patterns.

Methods

Probability Analysis

Custom-written MATLAB scripts used to calculate:

- The probability of vocalizations with sonar.

$$\frac{\#\ bins\ with\ vocalization\ events\ and\ sonar}{(\#bins\ with\ vocalization\ events\ and\ sonar) + (\#\ bins\ with\ only\ sonar)}$$

- The probability of vocalizations in the absence of sonar.

$$\frac{\#\ \text{bins with only vocalization events}}{(\#\ \text{bins with only vocalization events}) + (\#\ \text{of bins with no vocalization events or sonar})}$$

- 10 minute bin (resolution) used

RESULTS
Hours Recorded

Fall deployment:
~7,500 hrs

Winter deployment:
~8,500 hrs
(~ 1 year total)

~ 13% more hrs. in Winter

RESULTS

Species detected

Fall deployment

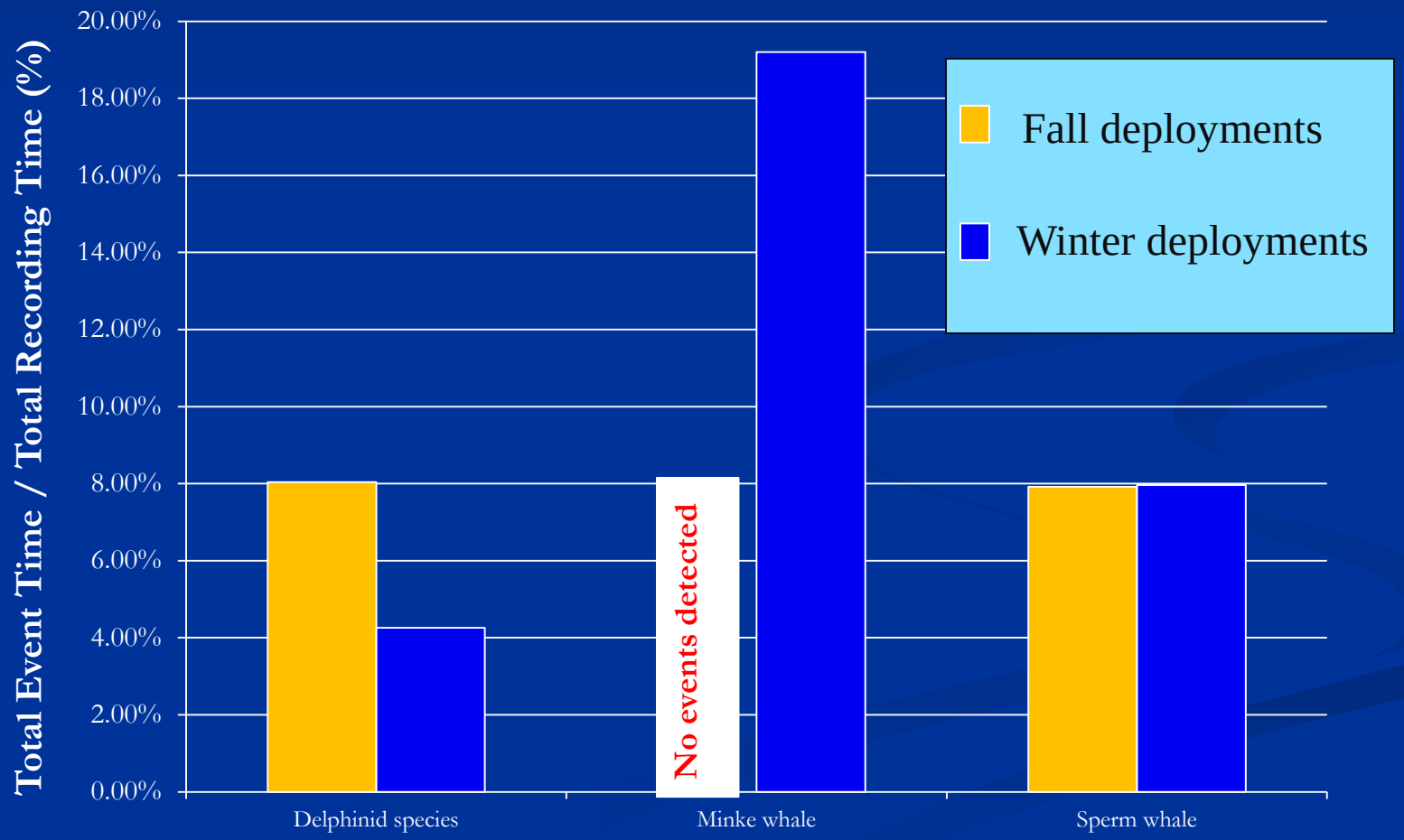
sperm whales
right whales
delphinids
blackfish

Winter deployment

\+ minke whales
\+ sei whales

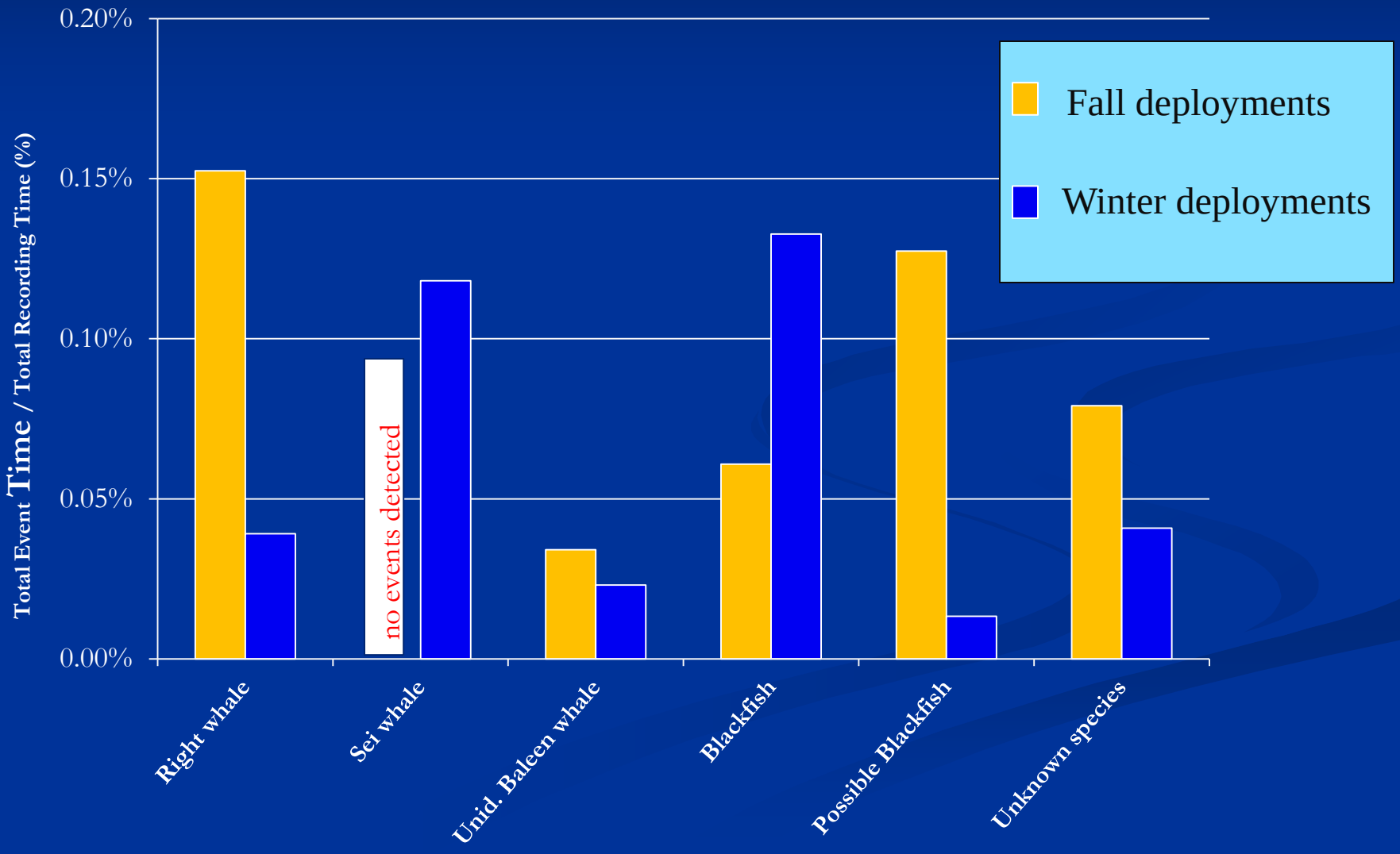
RESULTS

% event totals by season

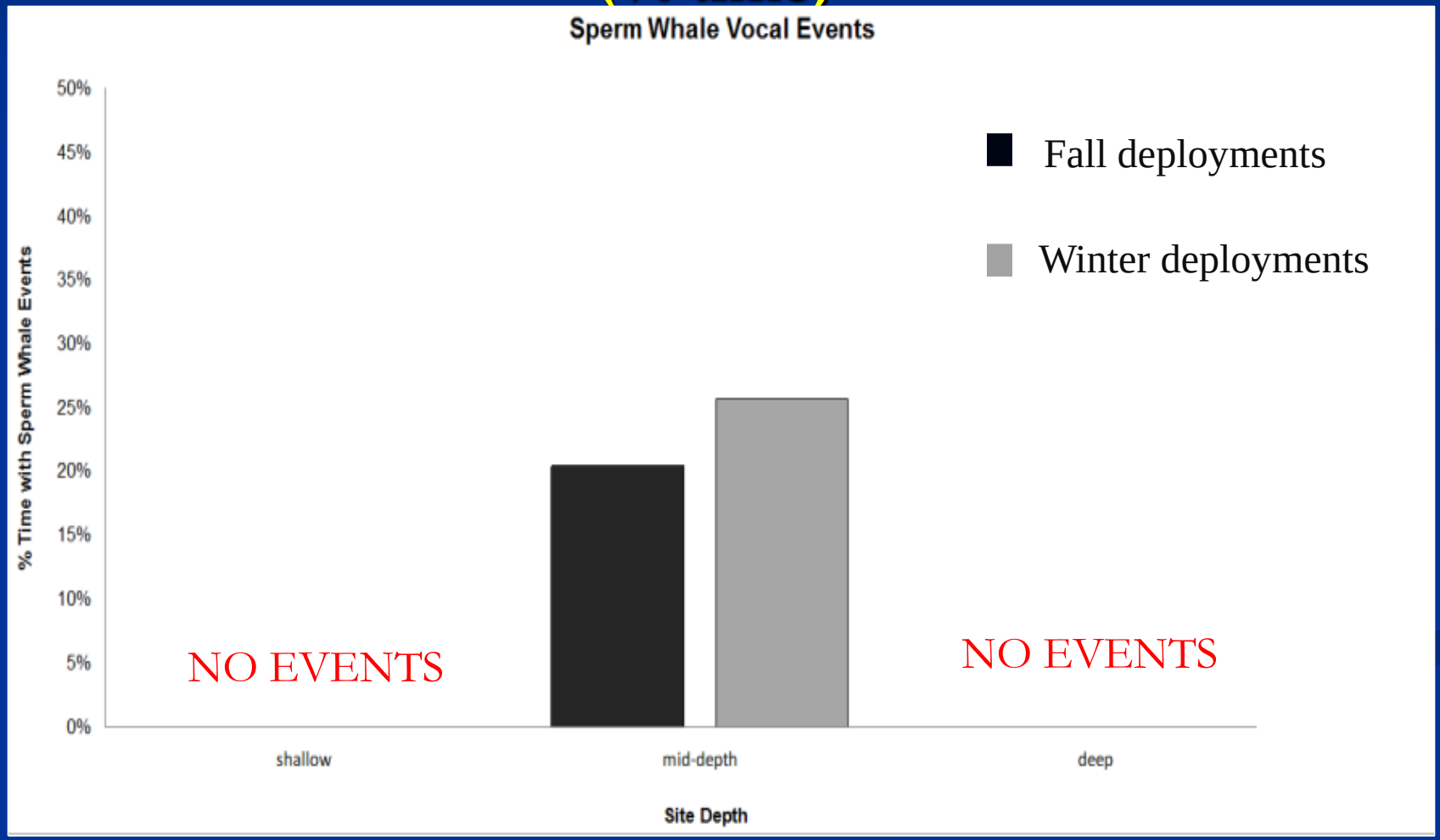


RESULTS

% event totals by season

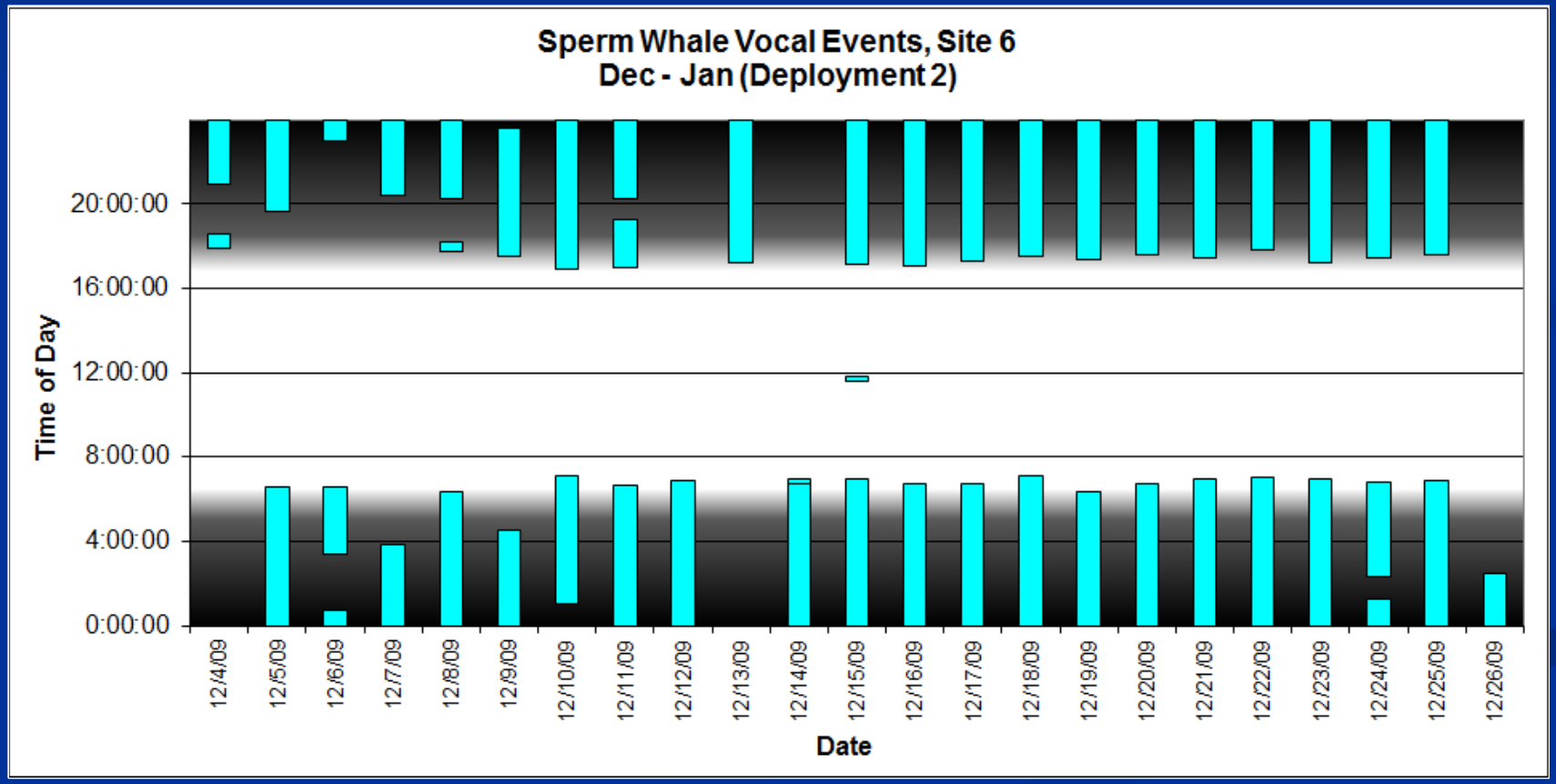


RESULTS
sperm whale events by depth
(% time)

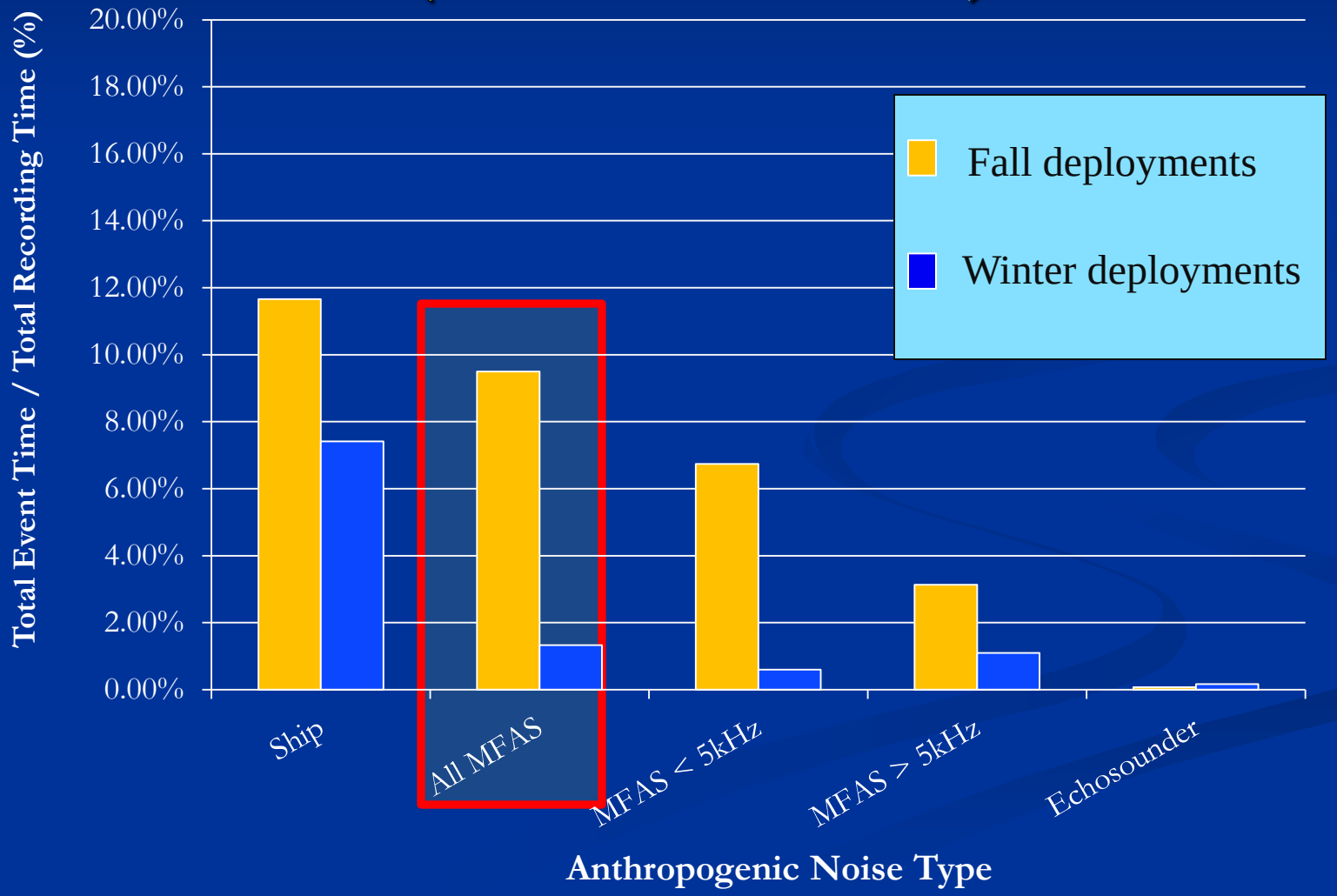


RESULTS

Diel Patterns – Sperm Whales



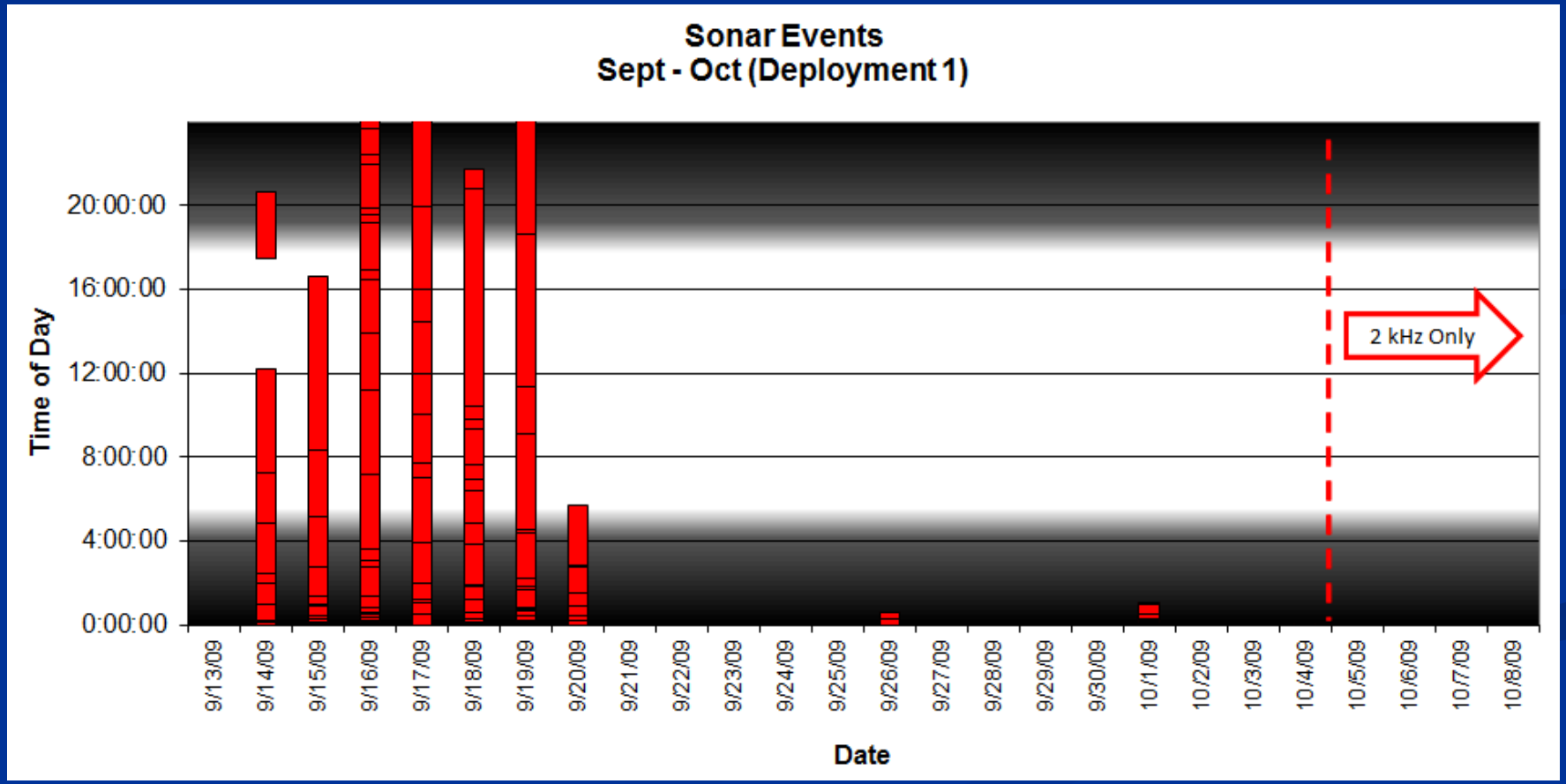
RESULTS
Anthropogenic Noise
(% event totals)



RESULTS

Sonar Events

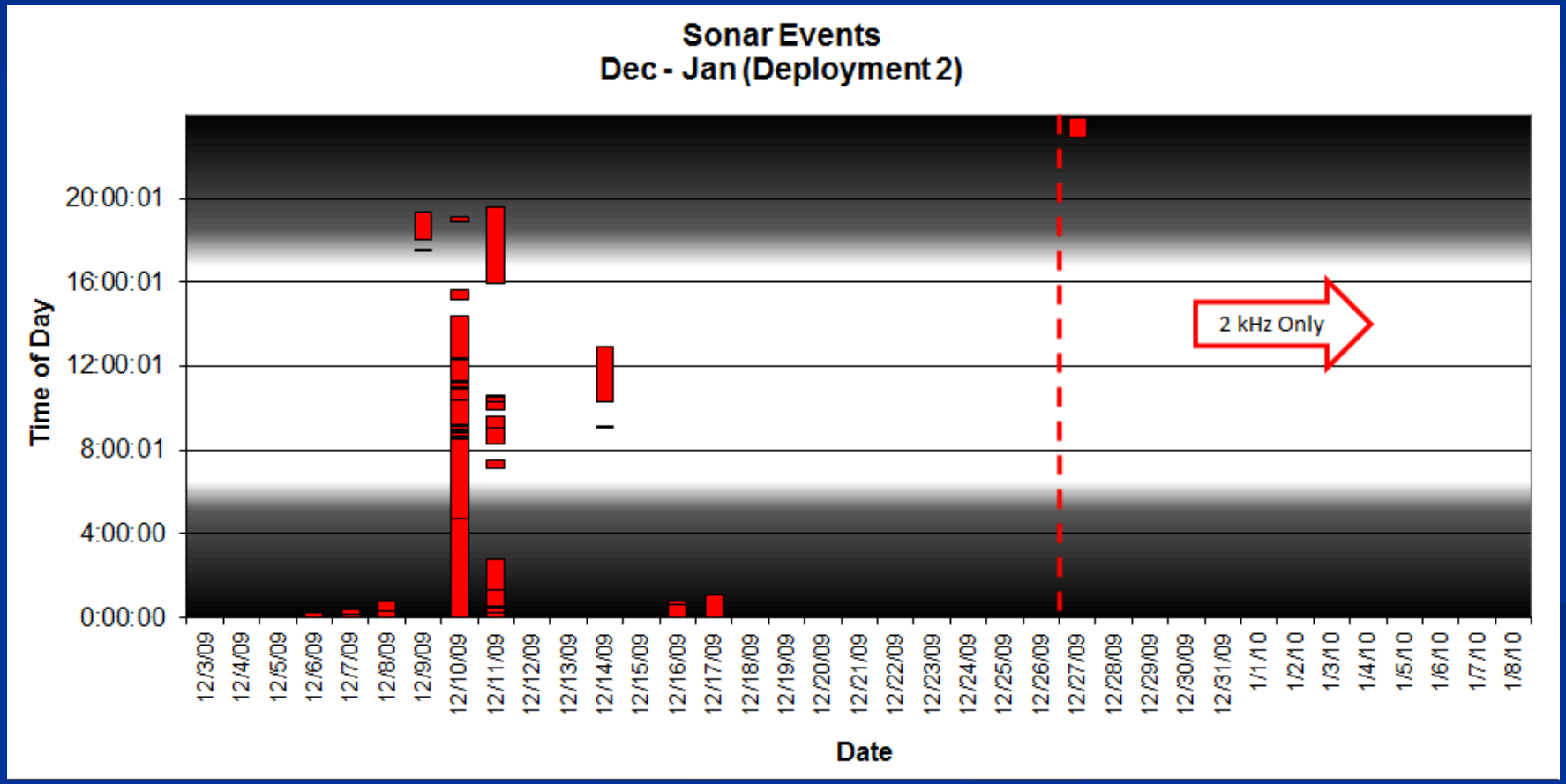
(fall deployment)



RESULTS

Sonar Events

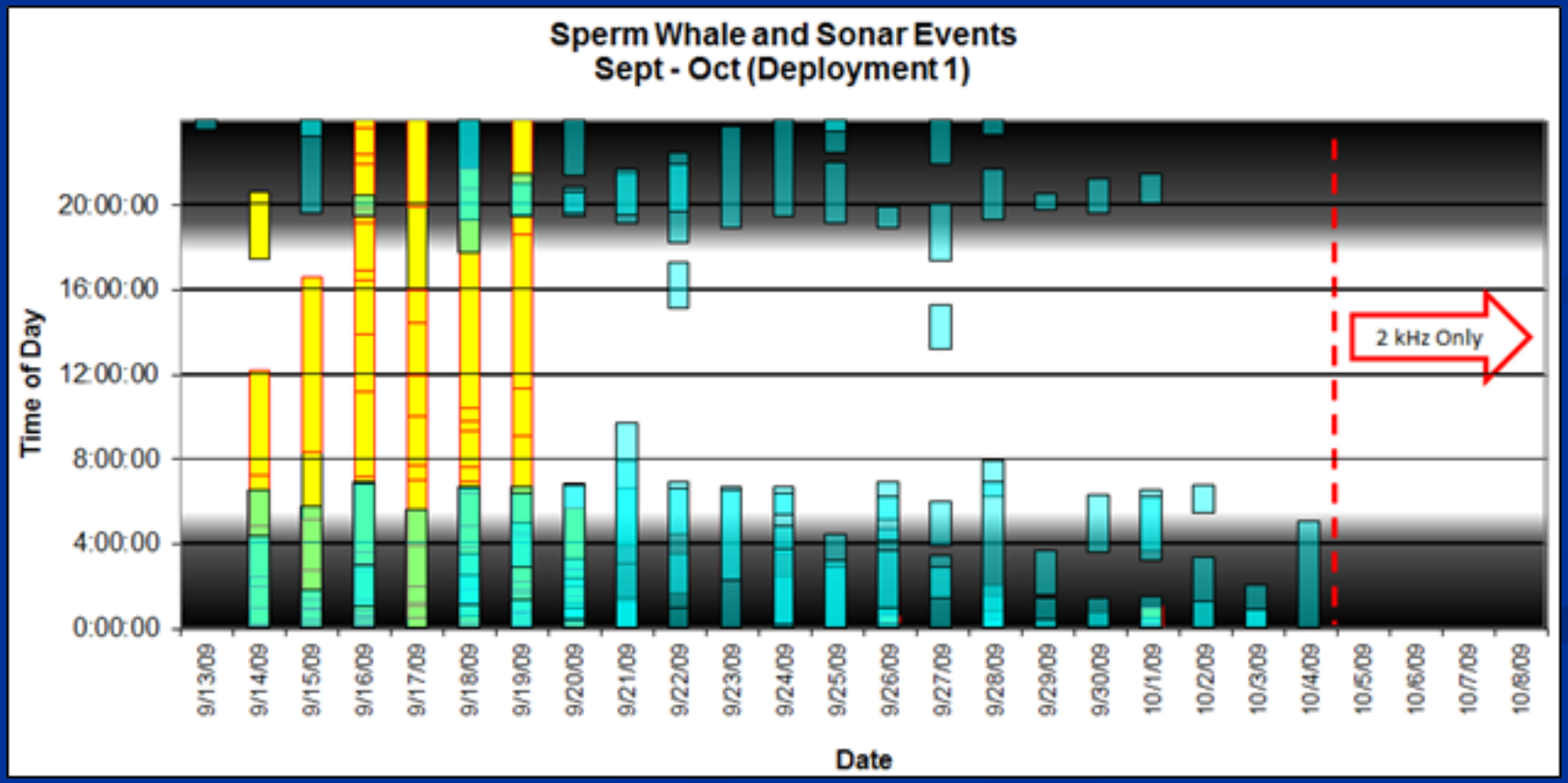
(winter deployment)



RESULTS

Sperm Whale + Sonar Events

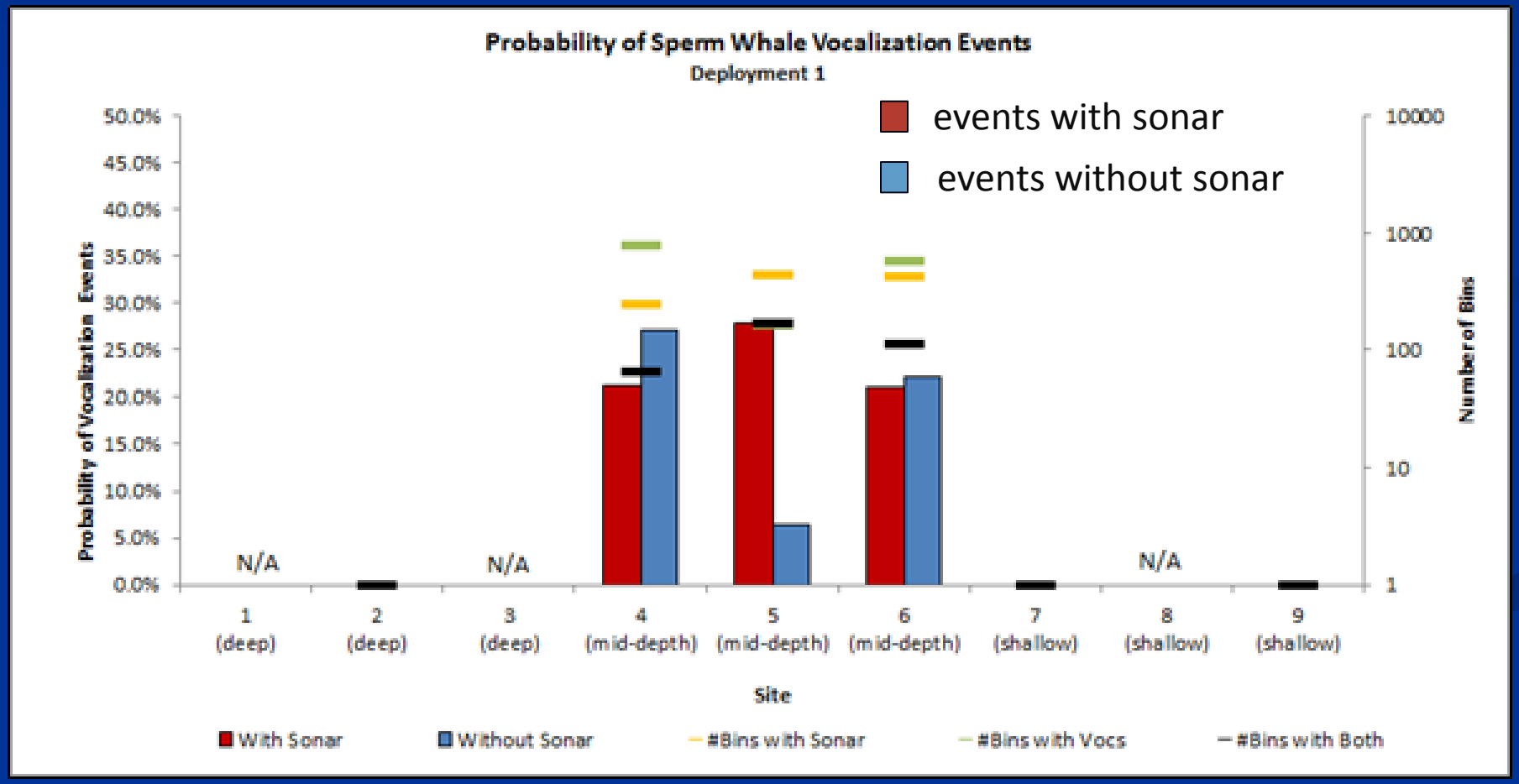
(Fall deployment)



RESULTS

Probability Analysis - Sonar

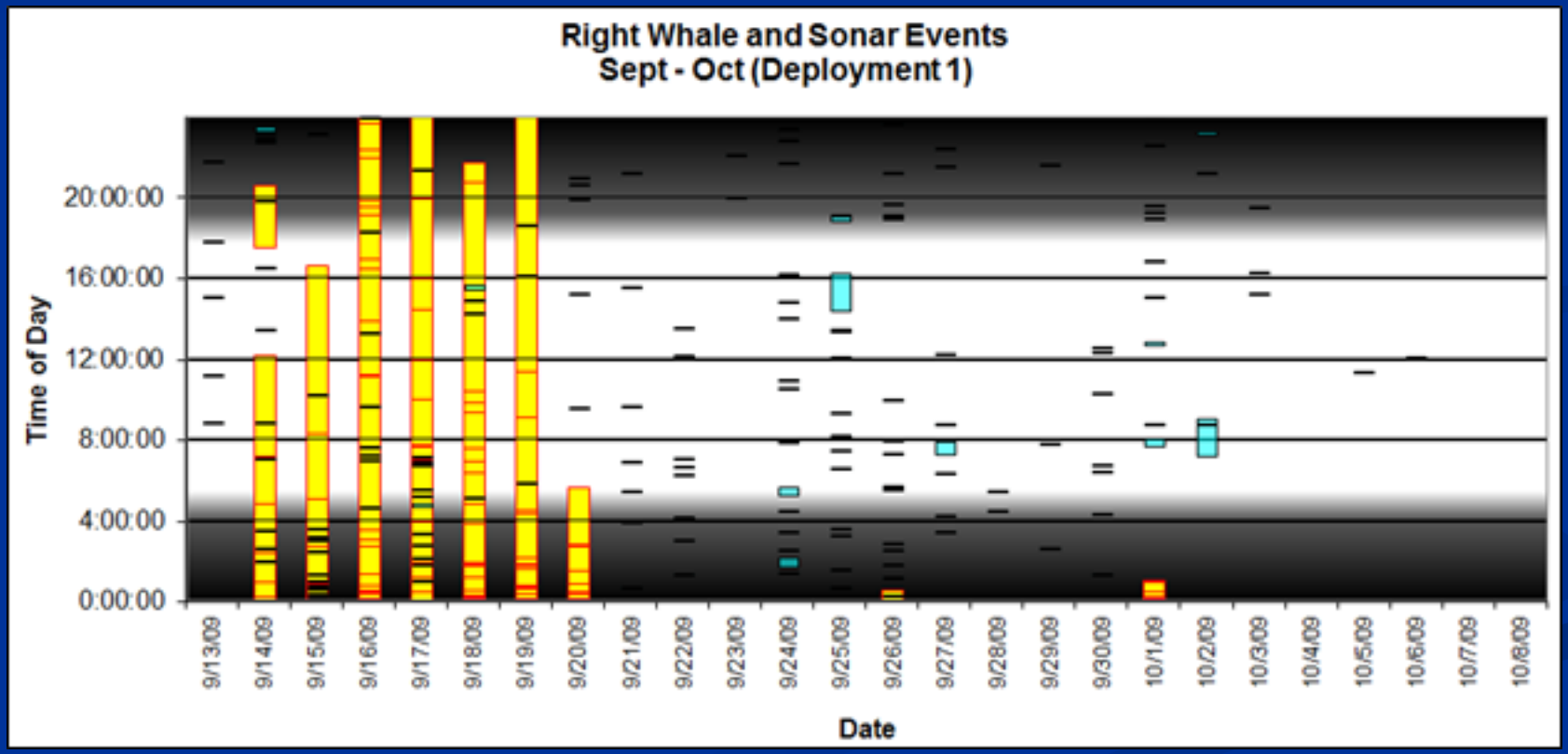
(sperm whales - fall deployment)



RESULTS

Right Whale + Sonar Events

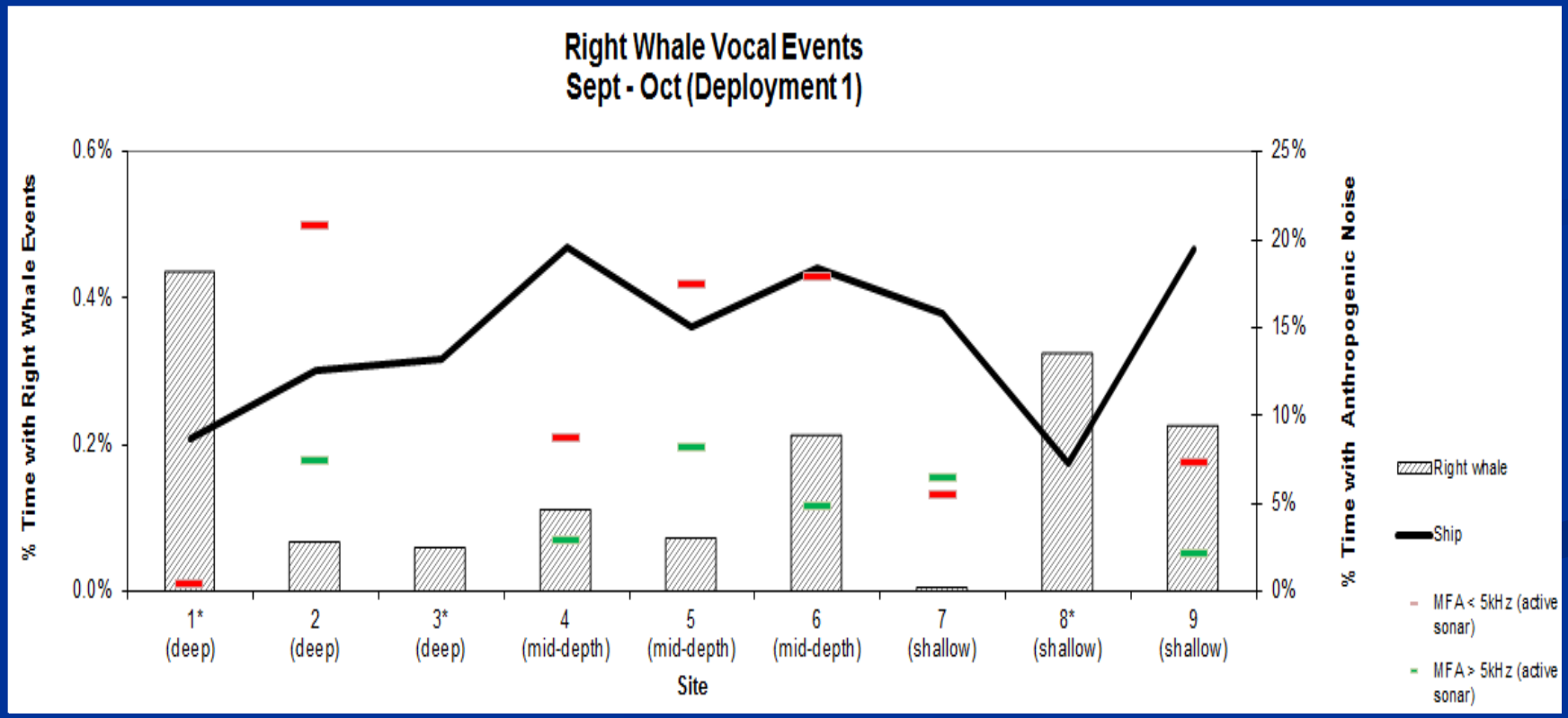
(fall deployment)



RESULTS

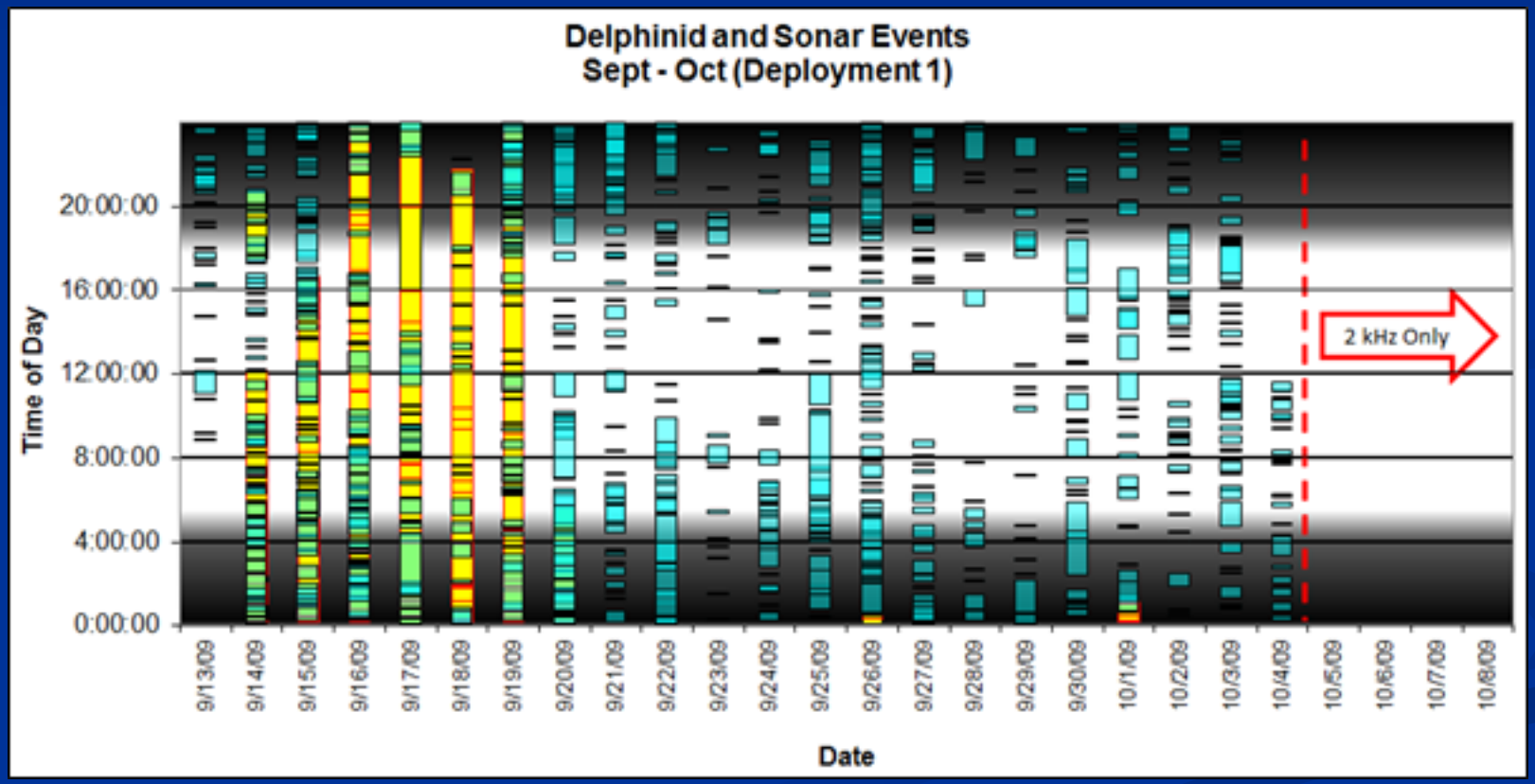
% Time with Events

(right whales - fall deployment)



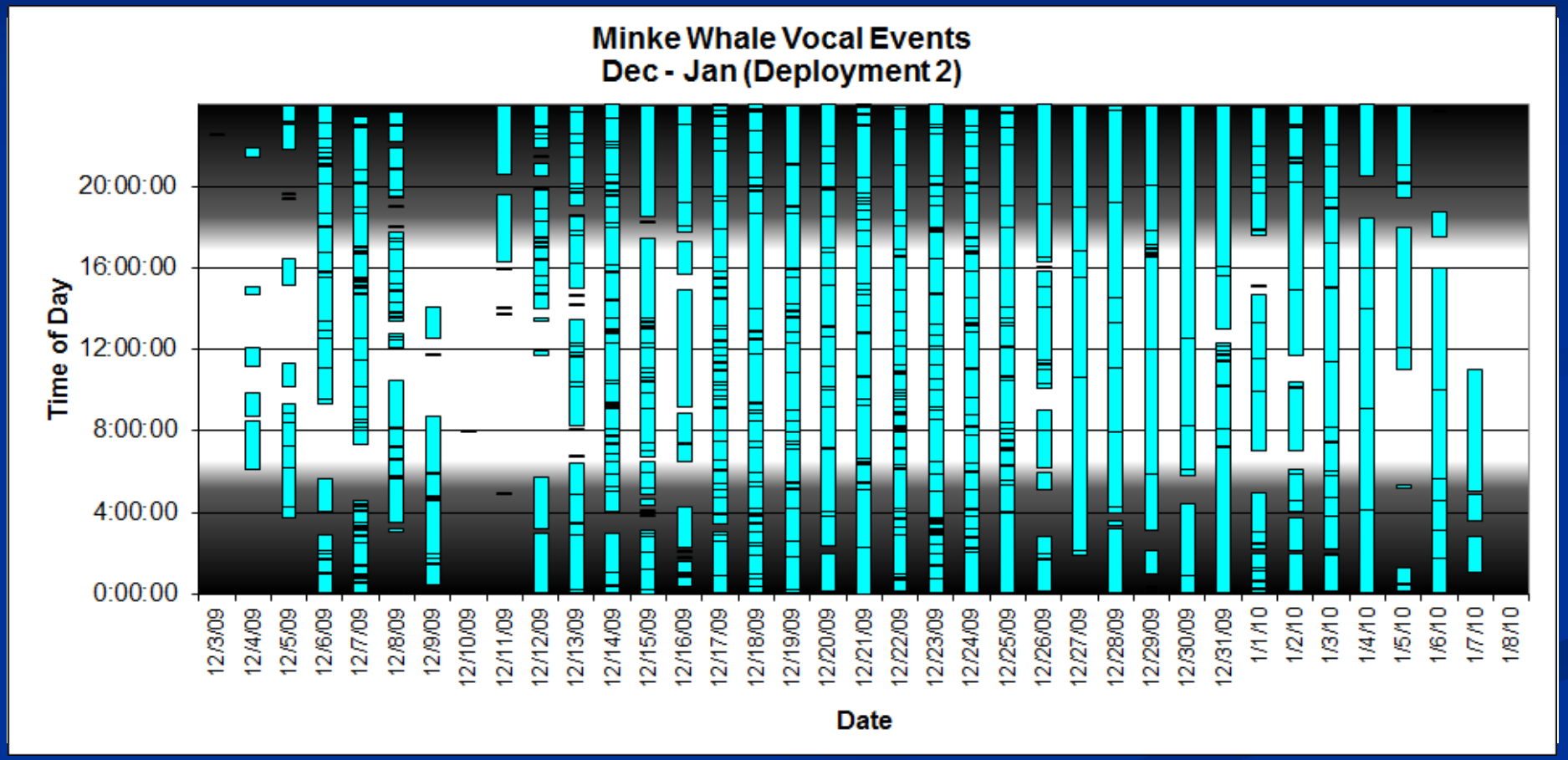
RESULTS

Delphinds



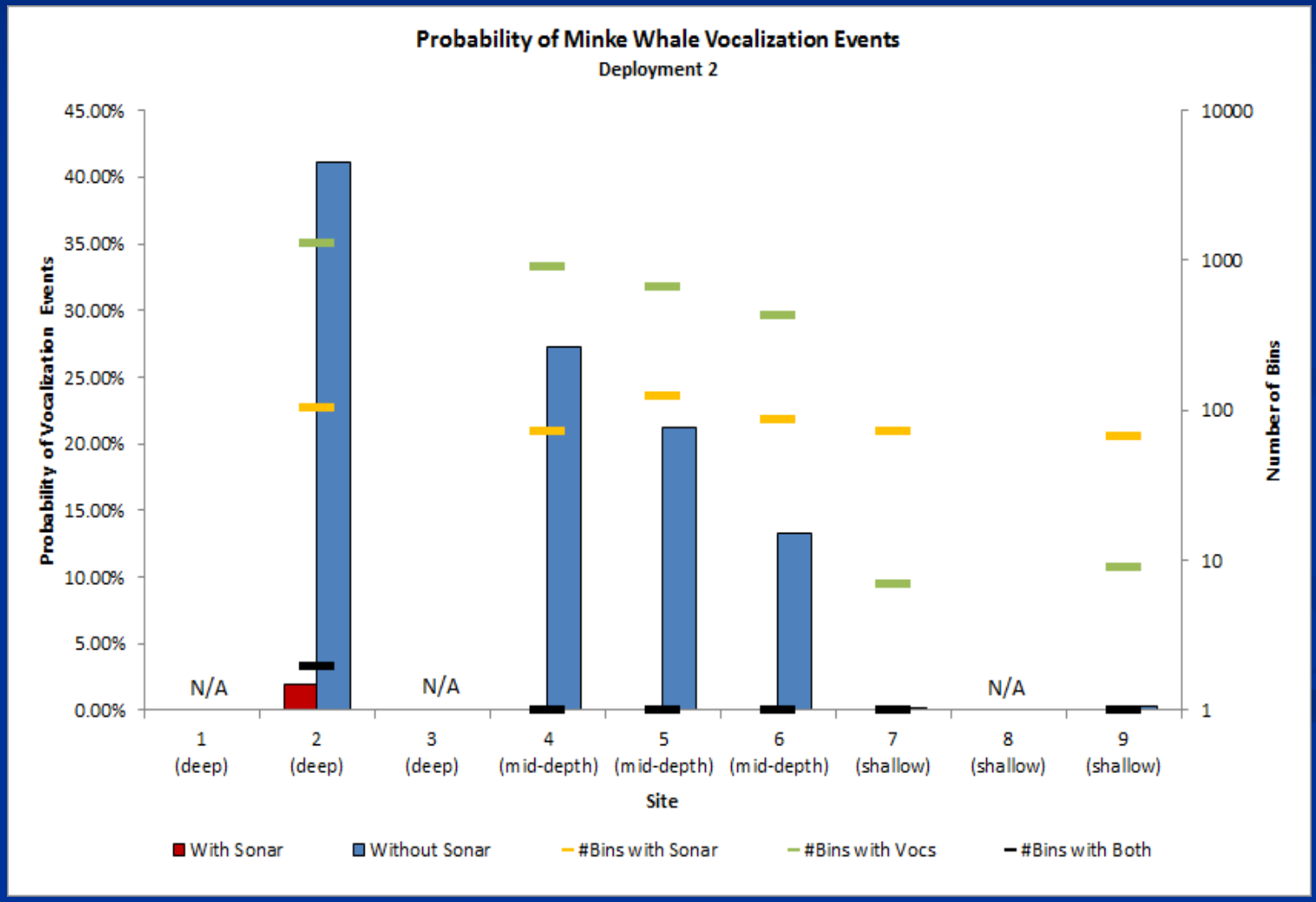
RESULTS

Minke Whale Sonar



See Poster # 168 by Talia Dominello for more info!!

RESULTS
Probability Analysis - Sonar



Summary

- Sperm whales, delphinids & ‘blackfish’ detected in both fall and winter.
- Minke and sei whales were detected *only* in winter mostly @ mid-deep sites.
- Sperm whale detected *only* along shelf break with a strong diel patt**ern**.
- Right whales detected at all site depths (with high event totals at 1 deep site)

Summary

- No *obvious* relationship in the probability of vocalization events in relation to sonar *for most species*,

However,

- Only events recorded (not every call)
- Delphinids events not classified to species
- Minke whales were an exception

Recommendations

Deployments of multiple recorders (arrays) can provide a more complete picture of patterns of occurrence by grouping or combining data.

(Low- cost recorders under development)

Ongoing Work

- More detailed (statistical) analysis of vocalizations in relation to mid-frequency sonar
  - delphinids
    - ROCCA
    - CREEM/St. Andrews (Len Thomas) developing statistical framework
  - Cornell BRP analyzing baleen whales calls

Future Work

- High-density deployments of recorders needed:
  - Spatial/temporal patterns
  - Abundance estimation
- Validation/observational studies needed
  - Vessel based (with towed arrays)
  - Aerial based (behavioral monitoring)

Acknowledgements

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Under a Contract to: HDR

NAVFAC Atlantic provided the funding and the data.

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- Cornell University BRP for providing the MARU's.
- **Numerous** expert reviewers (too many to list!)
- Report reviewers : Melissa Soldevilla (NMFS-SEFSC)/HDR
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- Bio-Waves data analysts:
  - Shannon Coates and Kerry Dunleavy Talia D.
- Bio-Waves Programmer
  Michael Oswald for writing MATLAB scripts for analysis.

More Information

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An Analysis of Marine Acoustic Recording Unit (MARU) Data Collected off Jacksonville, Florida in Fall 2009 and Winter 2009-2010

Suggested Citation:

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Photo: Sperm whale surfacing taken by Cornelia Oedekoven, courtesy of U.S. Navy.

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Subproject #164744, Task #003

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21 November 2012

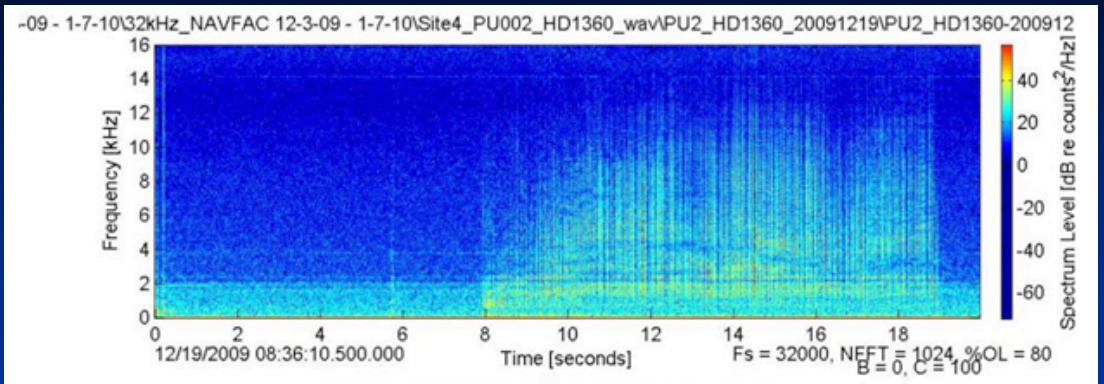


Figure 68. Example #1 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval, and occurred in a large repertoire of patterns, such as creaks, rapid clicks, etc.

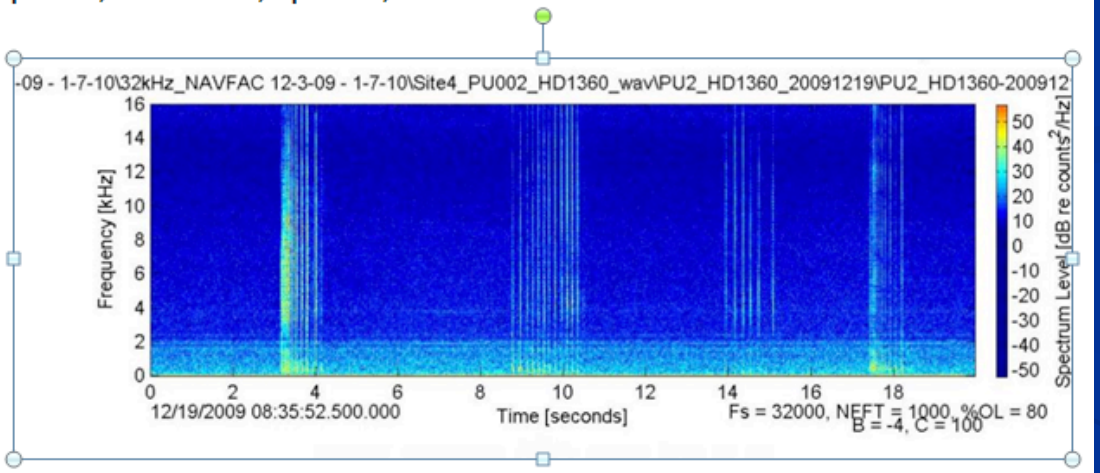
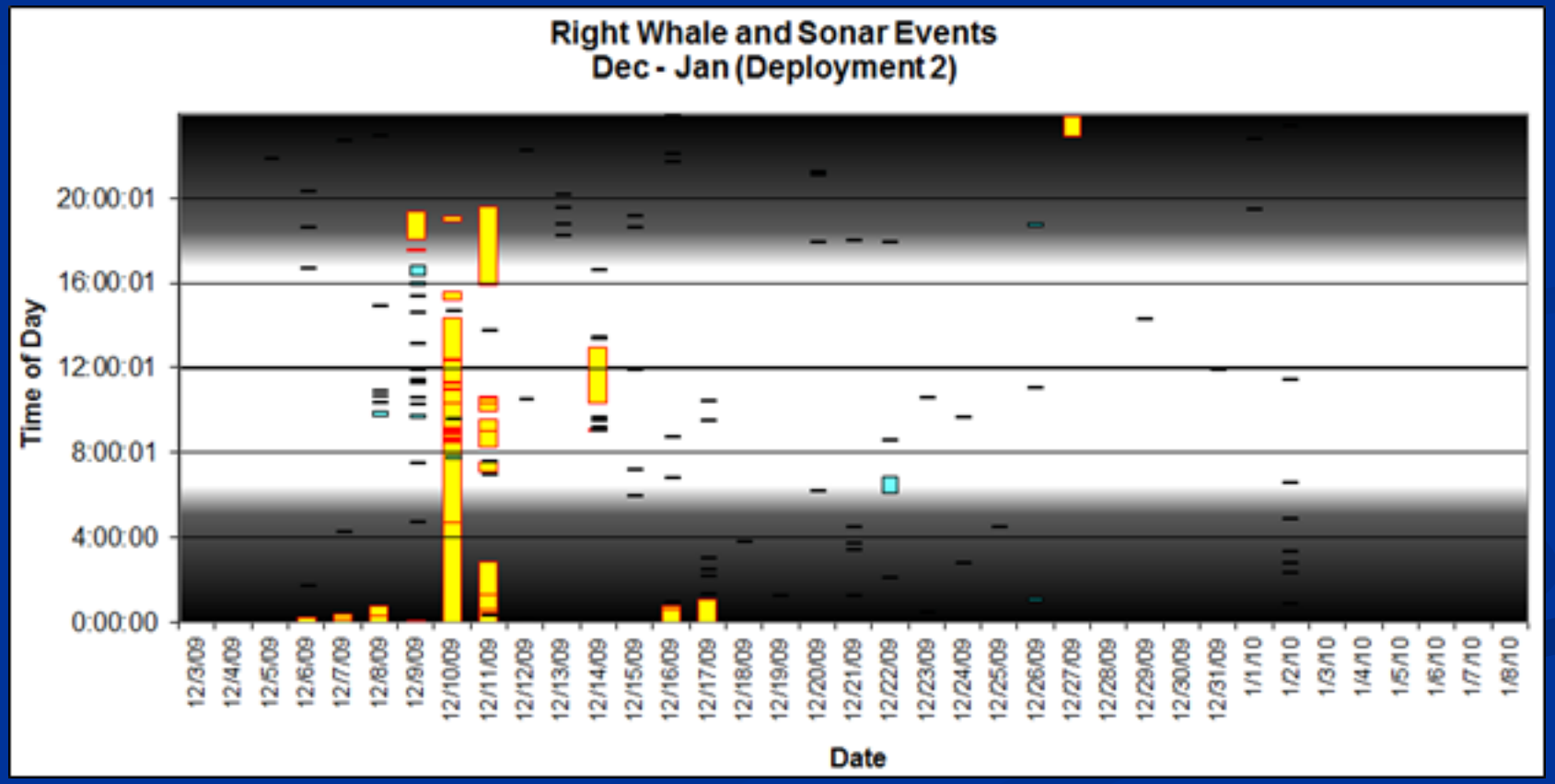


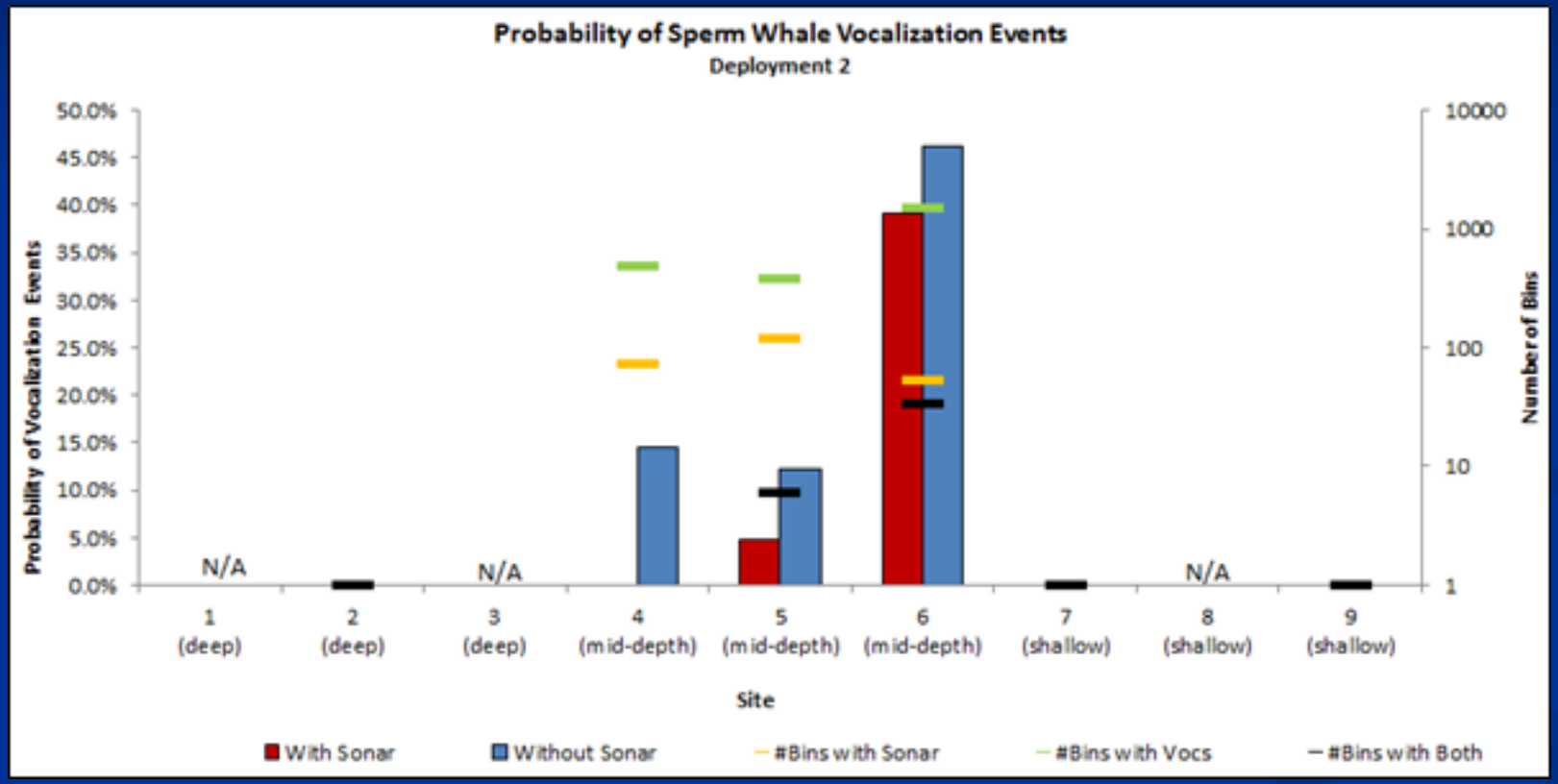
Figure 69. Example #2 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval and contains a large repertoire of patterns, such as creaks, rapid clicks, etc.

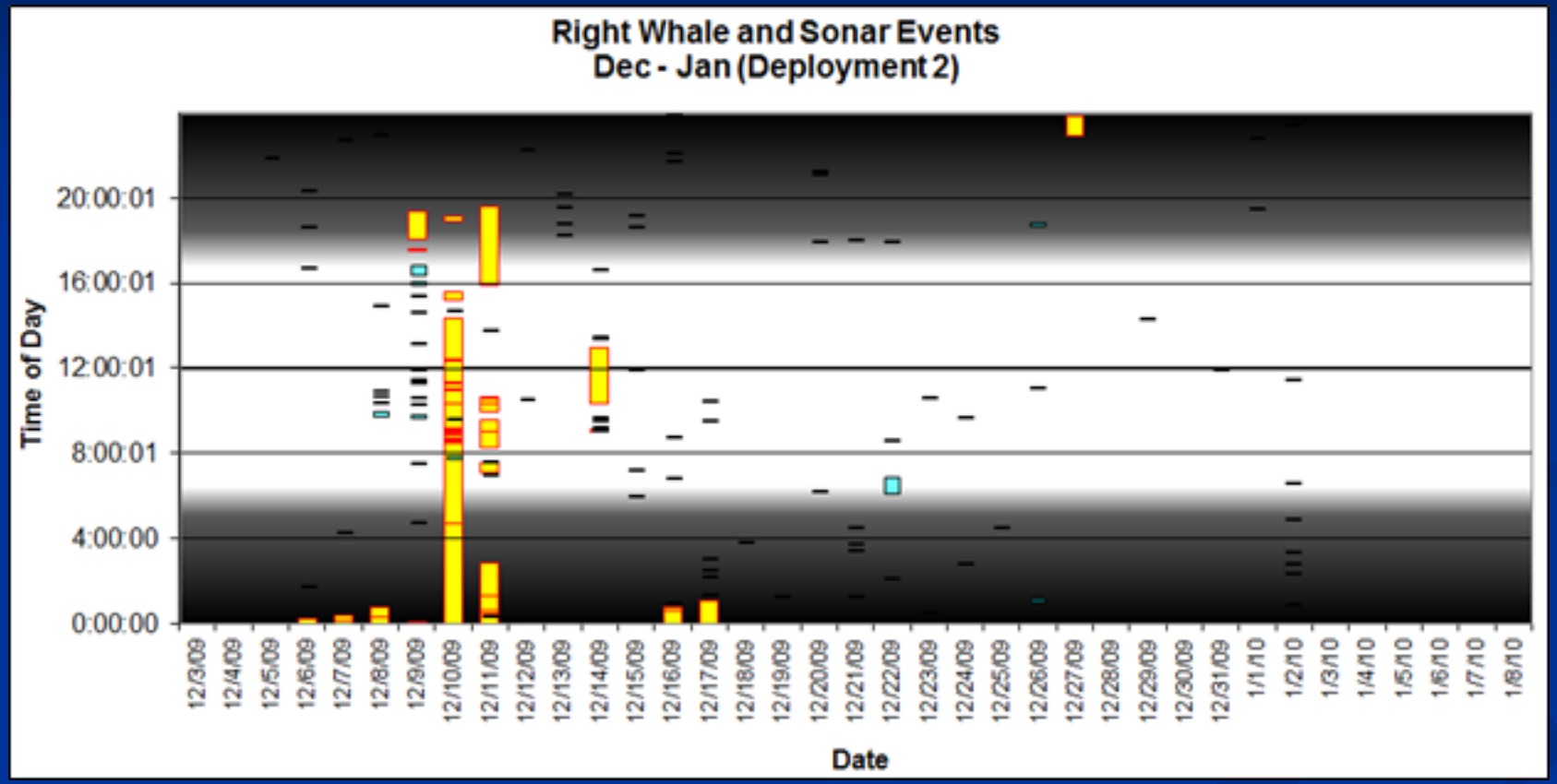
RESULTS

Right Whale + Sonar Events

(Winter deployment)




Probability of Sperm Whale Vocalization Events
Deployment 2
Probability of Vocalization Events
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Number of Bins
10000
1000
100
10
1
N/A
N/A
N/A
1 (deep)
2 (deep)
3 (deep)
4 (mid-depth)
5 (mid-depth)
6 (mid-depth)
7 (shallow)
8 (shallow)
9 (shallow)
Site
With Sonar
Without Sonar
#Bins with Sonar
#Bins with Vocs
#Bins with Both


Right Whale and Sonar Events
Dec - Jan (Deployment 2)
Time of Day
20:00:01
16:00:01
12:00:01
8:00:01
4:00:00
0:00:00
12/3/09
12/4/09
12/5/09
12/6/09
12/7/09
12/8/09
12/9/09
12/10/09
12/11/09
12/12/09
12/13/09
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12/31/09
1/1/10
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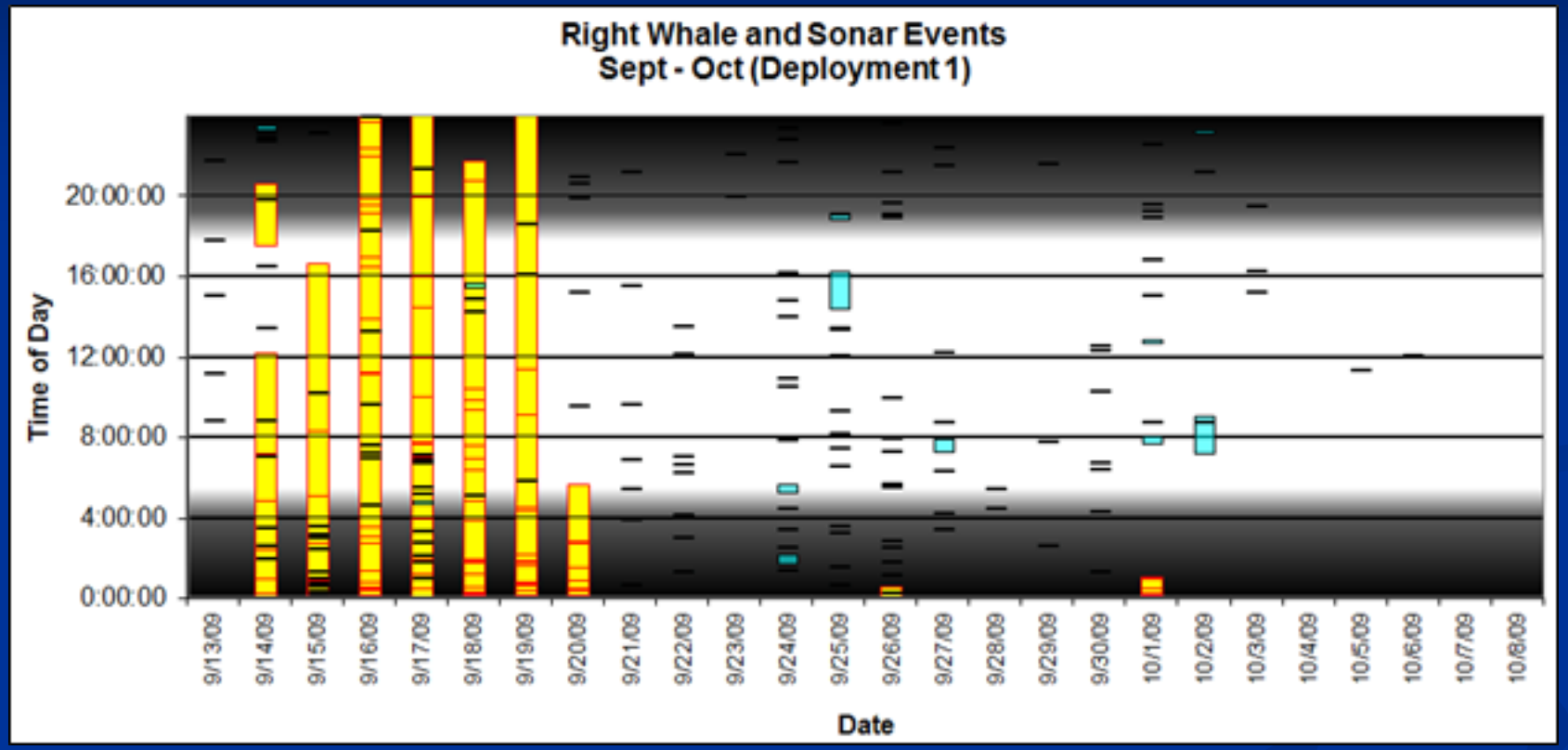
1/8/10
Date


Right Whale and Sonar Events
Sept - Oct (Deployment 1)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
9/13/09
9/14/09
9/15/09
9/16/09
9/17/09
9/18/09
9/19/09
9/20/09
9/21/09
9/22/09
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9/26/09
9/27/09
9/28/09
9/29/09
9/30/09
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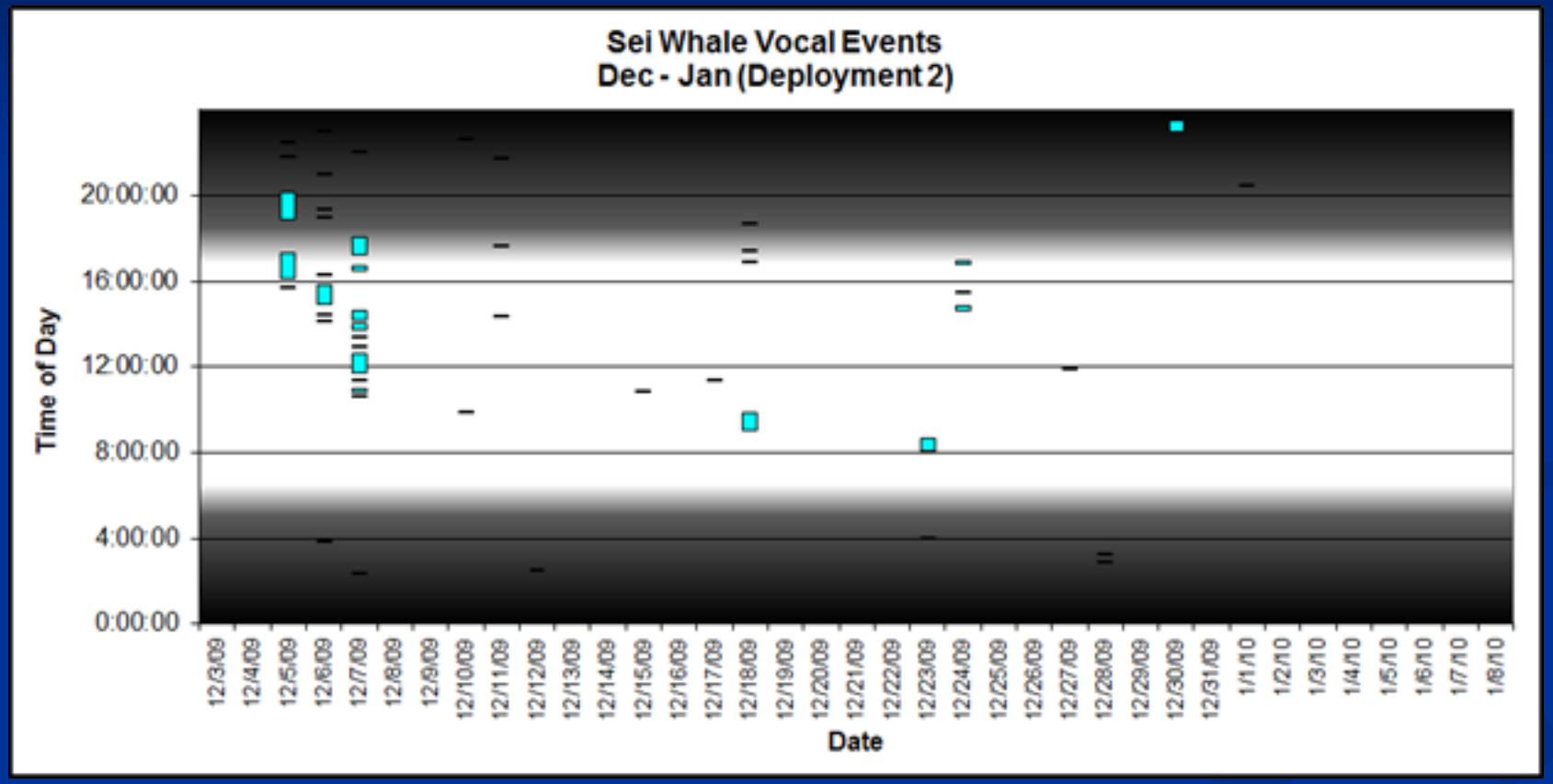
10/4/09
10/5/09
10/6/09
10/7/09
10/8/09
Date


Sei Whale Vocal Events
Dec - Jan (Deployment 2)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
12/3/09
12/4/09
12/5/09
12/6/09
12/7/09
12/8/09
12/9/09
12/10/09
12/11/09
12/12/09
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12/30/09
12/31/09
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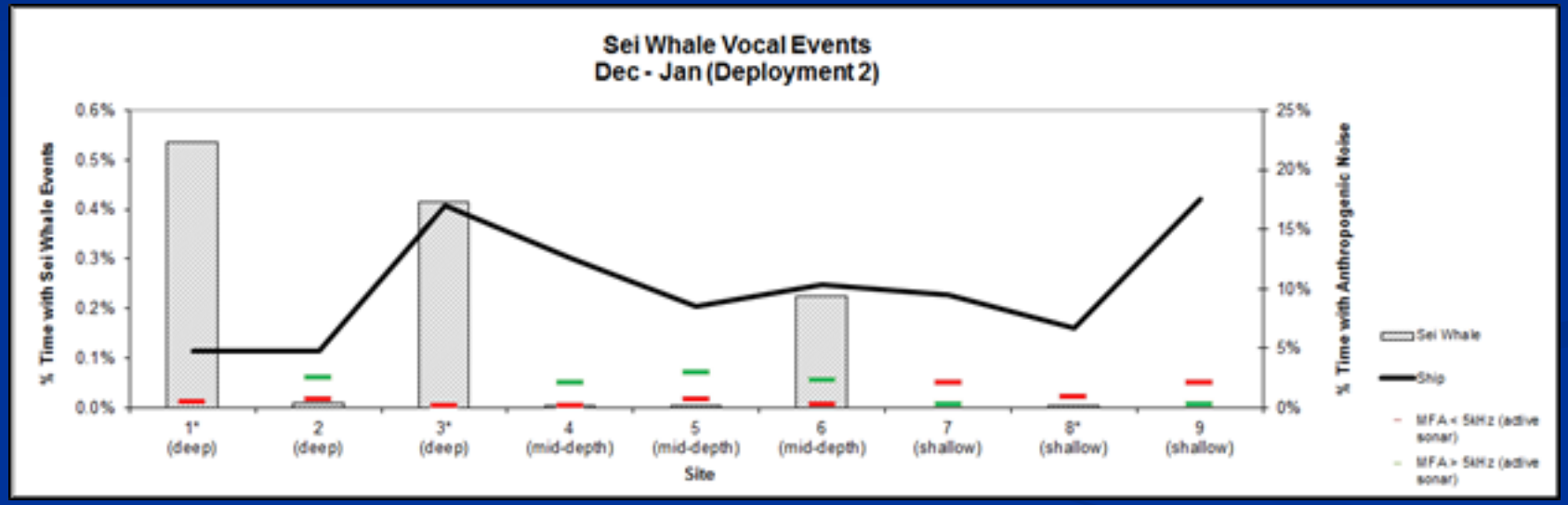
1/4/10
1/5/10
1/6/10
1/7/10
1/8/10
Date


Sei Whale Vocal Events
Dec - Jan (Deployment 2)
% Time with Sei Whale Events
0.6%
0.5%
0.4%
0.3%
0.2%
0.1%
0.0%
25%
20%
15%
10%
5%
0%
% Time with Anthropogenic Noise
1*
(deep)
2
(deep)
3*
(deep)
4
(mid-depth)
5
(mid-depth)
6
(mid-depth)
7
(shallow)
8*
(shallow)
9
(shallow)
Site
Sei Whale
Ship
MFA < 5kHz (active sonar)
MFA > 5kHz (active sonar)

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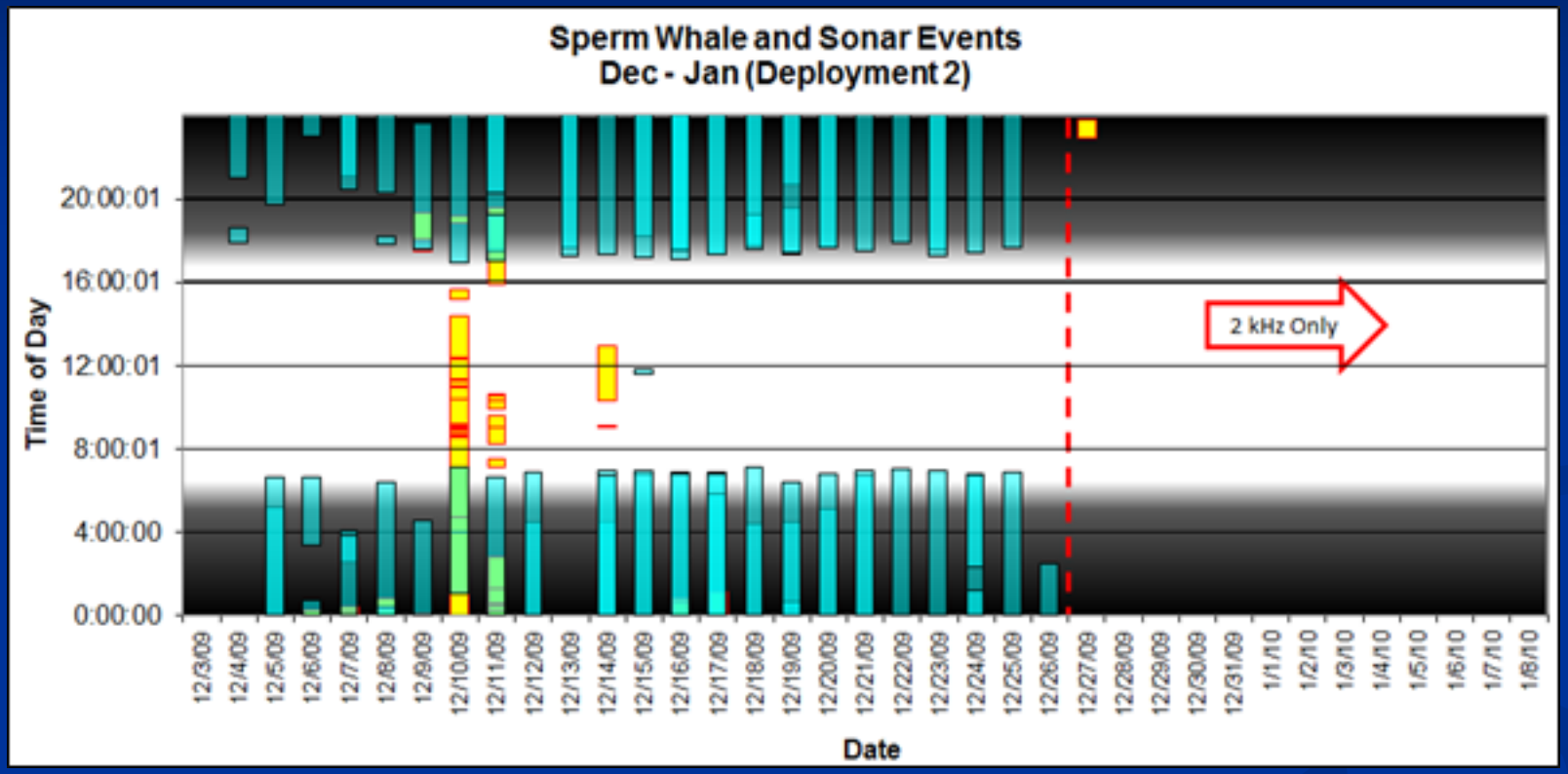

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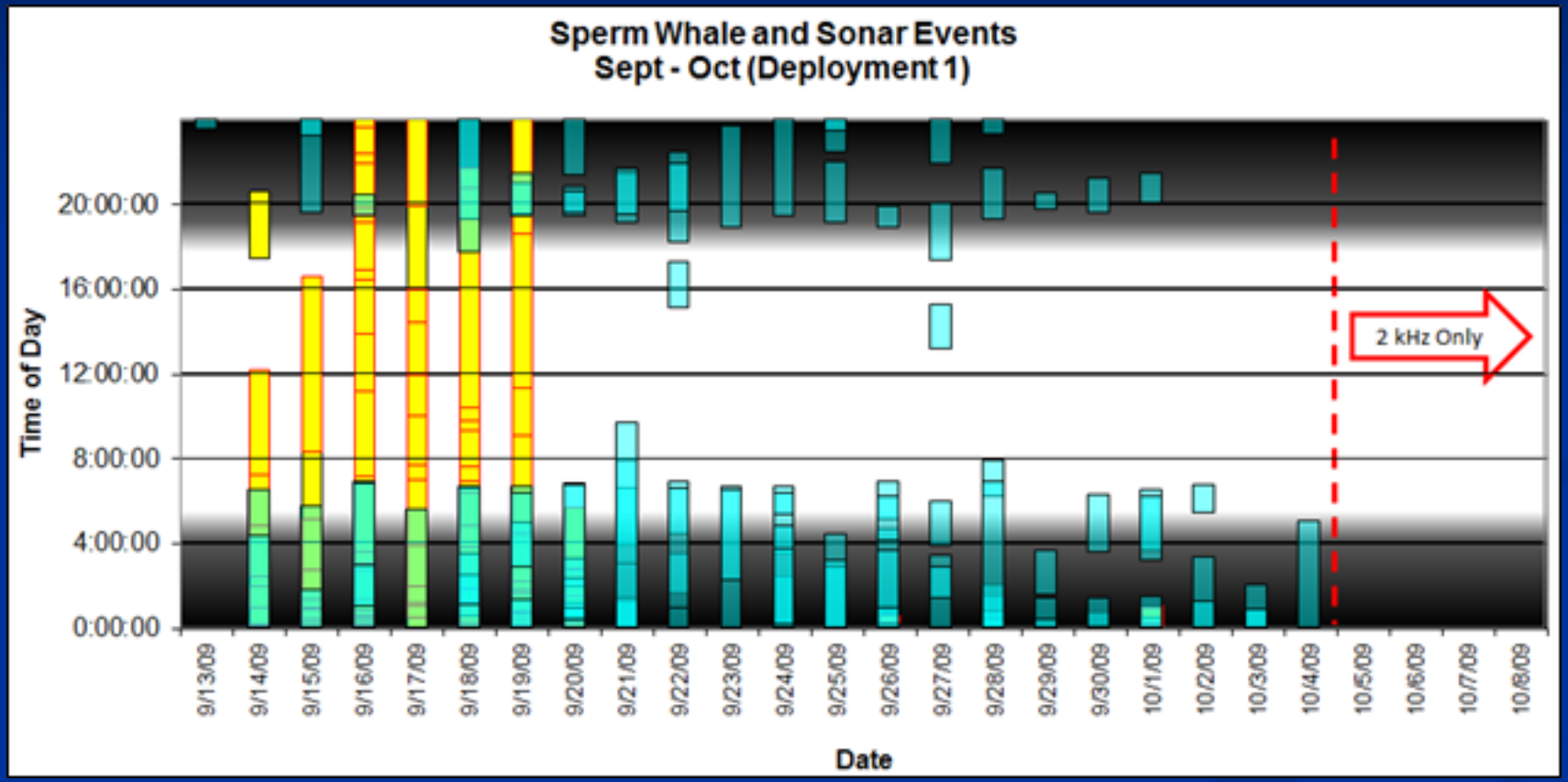

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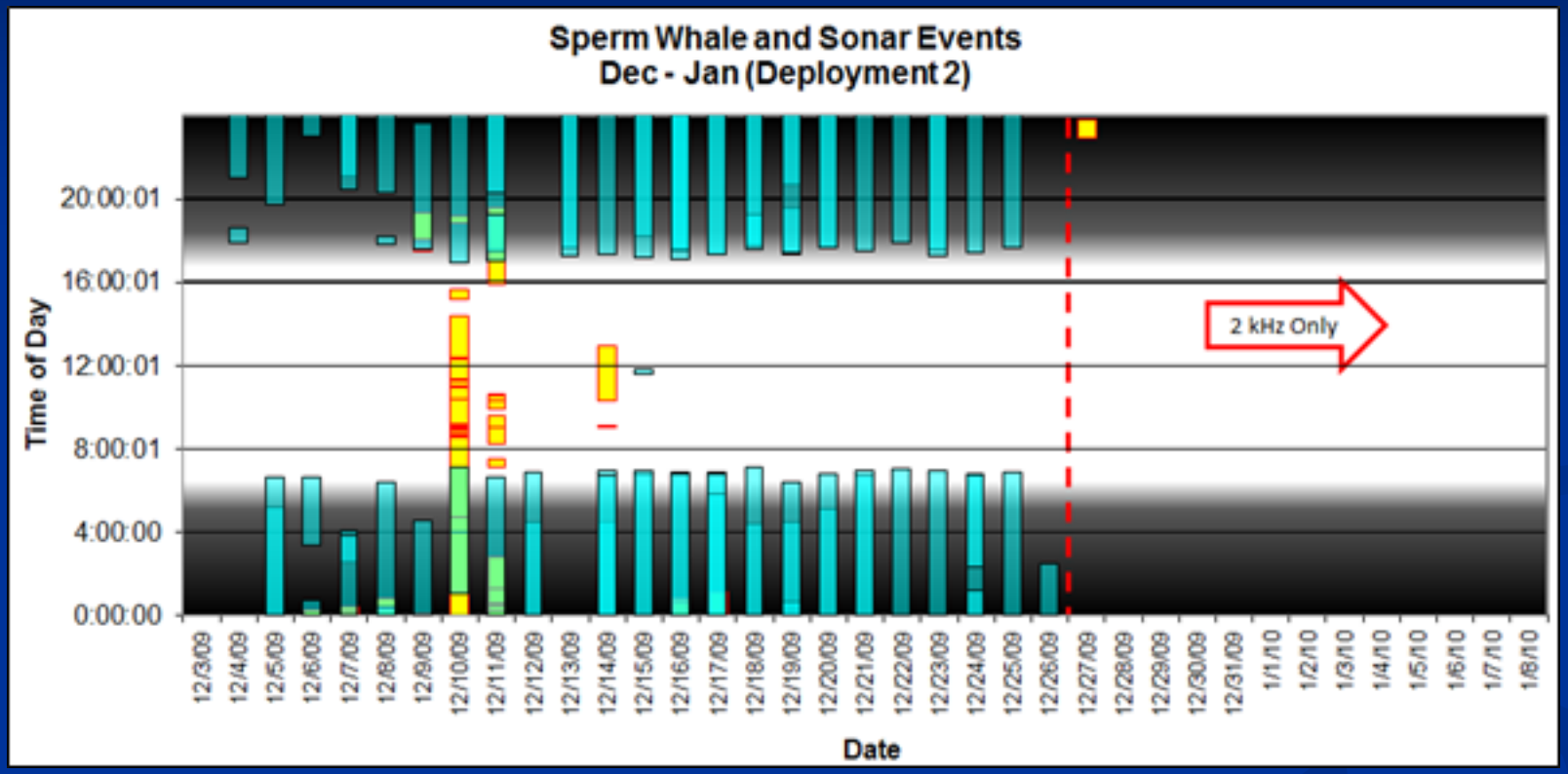

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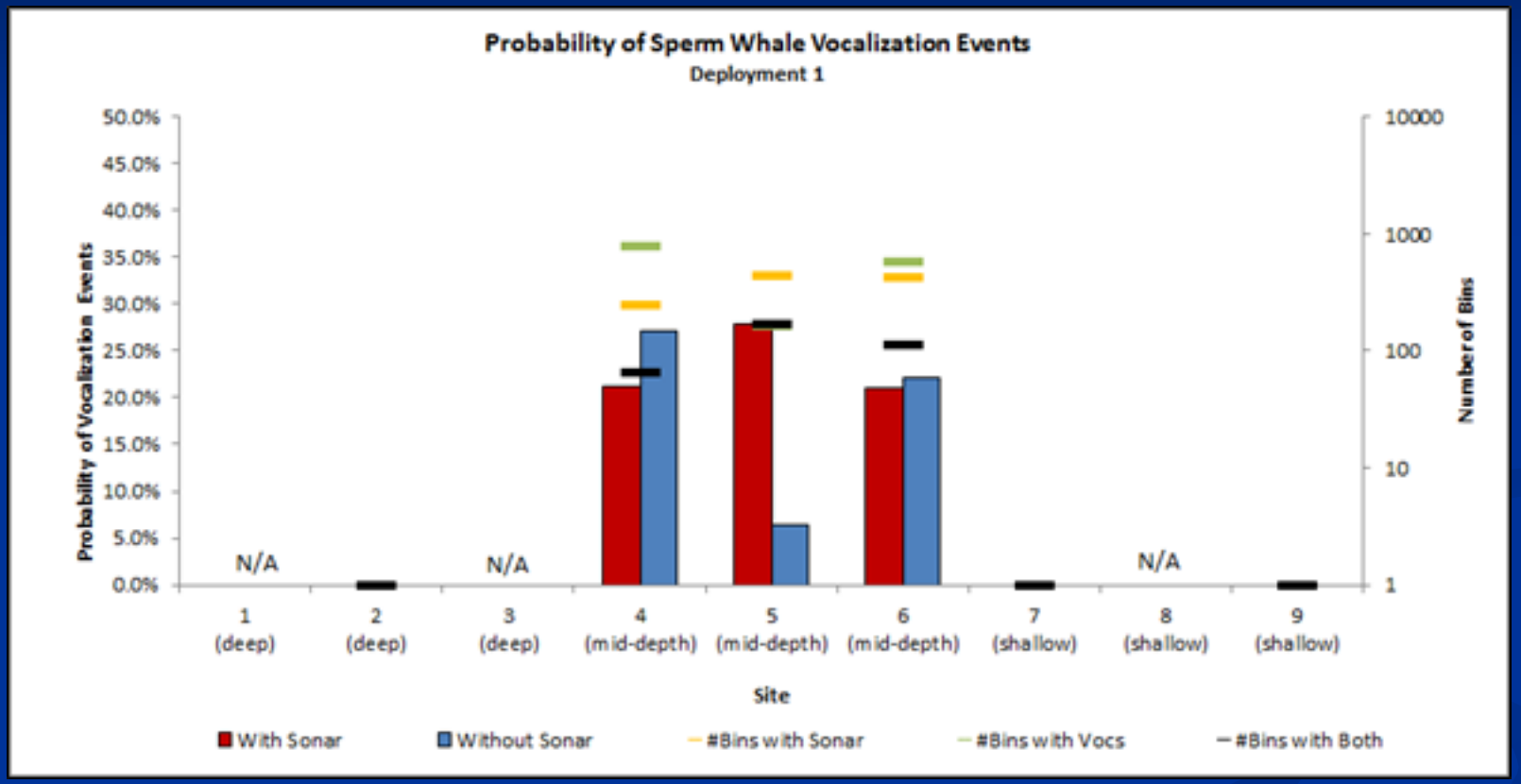
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Probability of Vocalization Events
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40.0%
35.0%
30.0%
25.0%
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15.0%
10.0%
5.0%
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Number of Bins
10000
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100
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N/A
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1 (deep)
2 (deep)
3 (deep)
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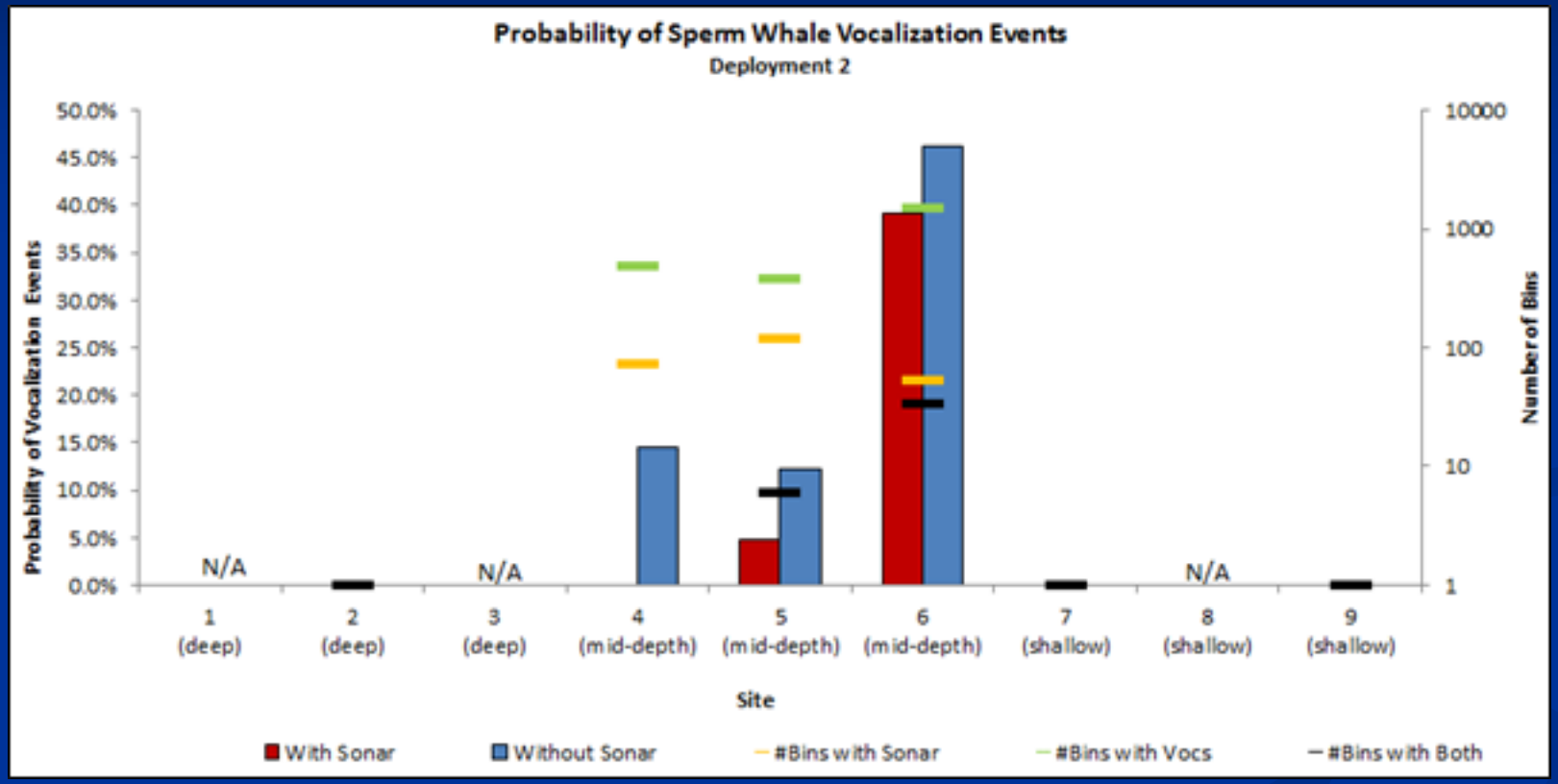
7 (shallow)
8 (shallow)
9 (shallow)
Site
With Sonar
Without Sonar
#Bins with Sonar
#Bins with Vocs
#Bins with Both


Probability of Sperm Whale Vocalization Events
Deployment 2
Probability of Vocalization Events
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Number of Bins
10000
1000
100
10
1
N/A
N/A
N/A
1 (deep)
2 (deep)
3 (deep)
4 (mid-depth)
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6 (mid-depth)
7 (shallow)
8 (shallow)
9 (shallow)
Site
With Sonar
Without Sonar
#Bins with Sonar
#Bins with Vocs
#Bins with Both

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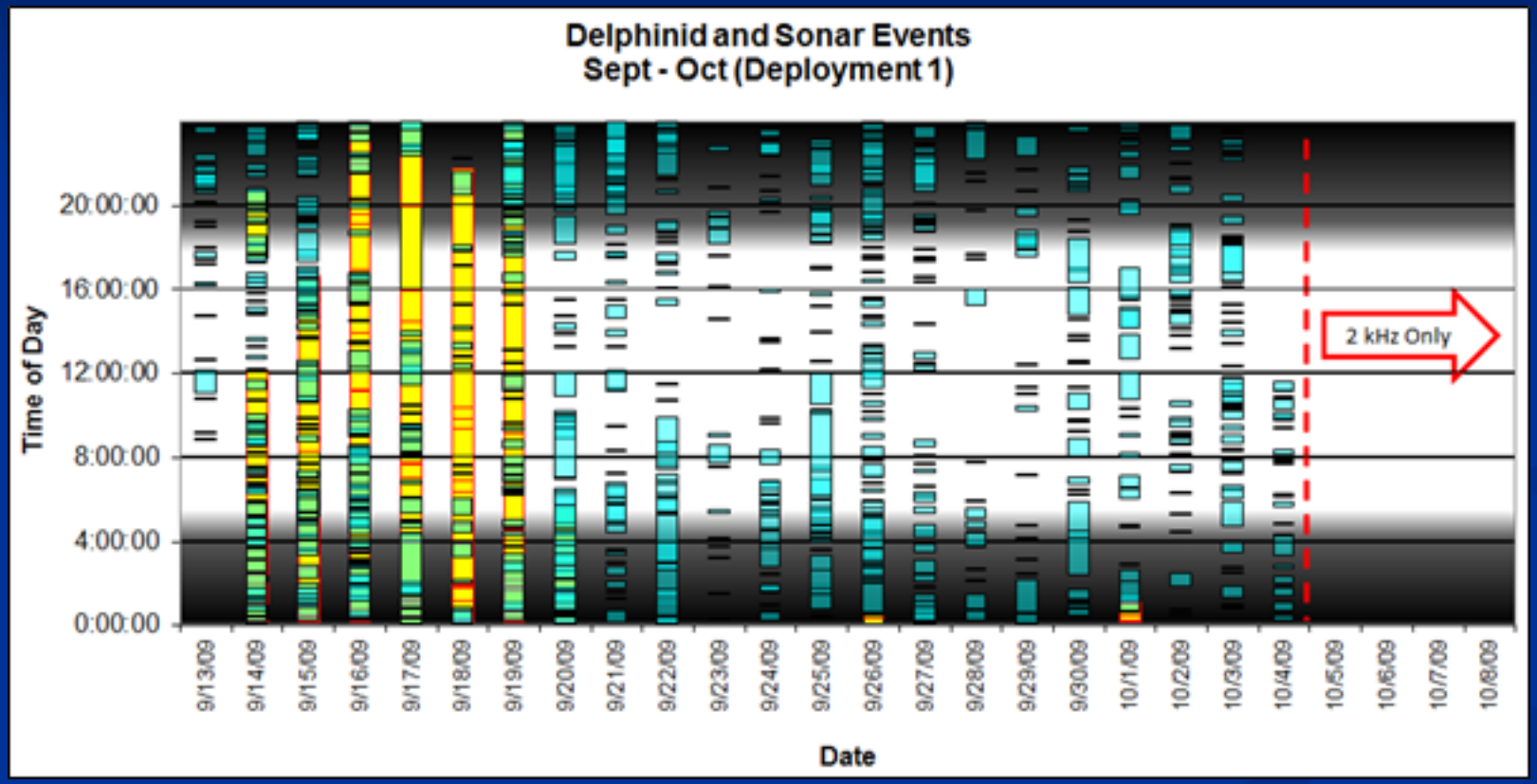

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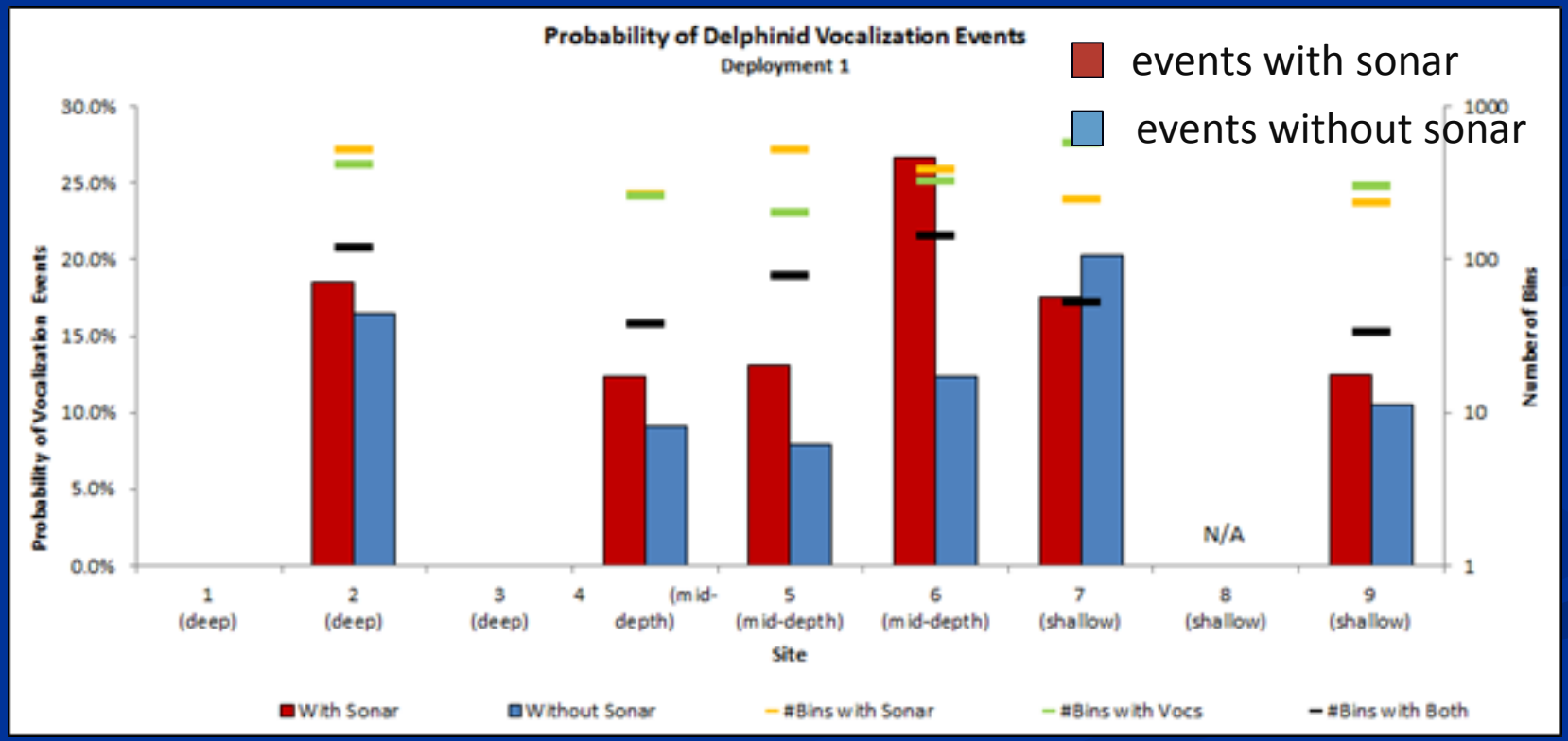
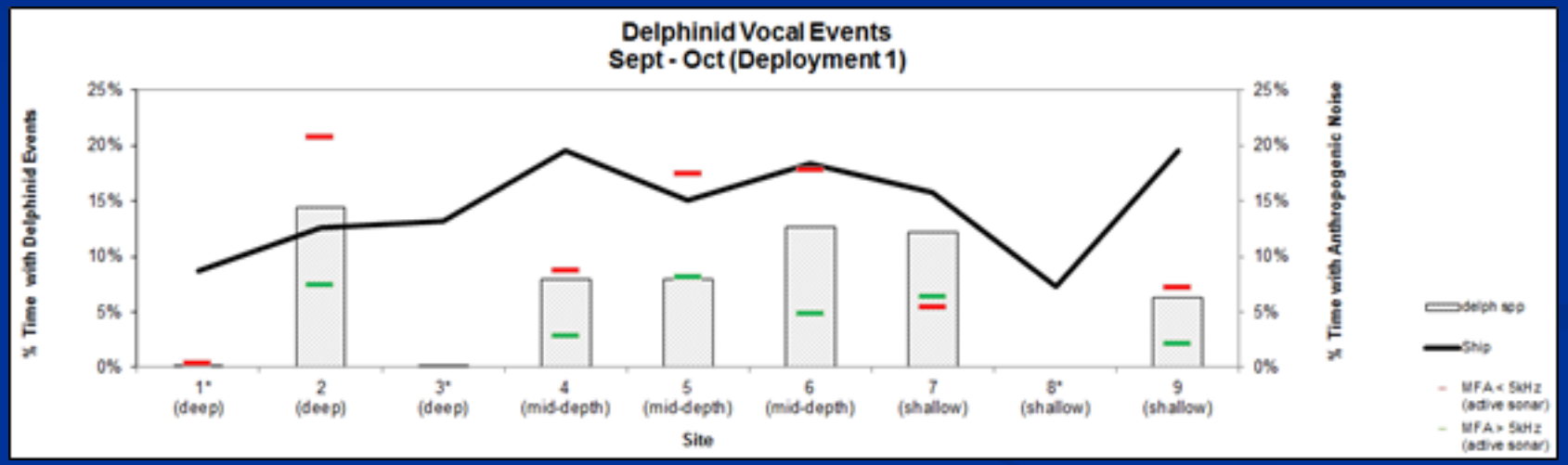
RESULTS

Probability Analysis - Sonar

(delphinids - fall deployment)




Delphinid Vocal Events
Sept - Oct (Deployment 1)
% Time with Delphinid Events
% Time with Anthropogenic Noise
25%
20%
15%
10%
5%
0%
1* (deep)
2 (deep)
3* (deep)
4 (mid-depth)
5 (mid-depth)
6 (mid-depth)
7 (shallow)
8* (shallow)
9 (shallow)
Site
delph app
Ship
MFA< 5kHz (active sonar)
MFA> 5kHz (active sonar)

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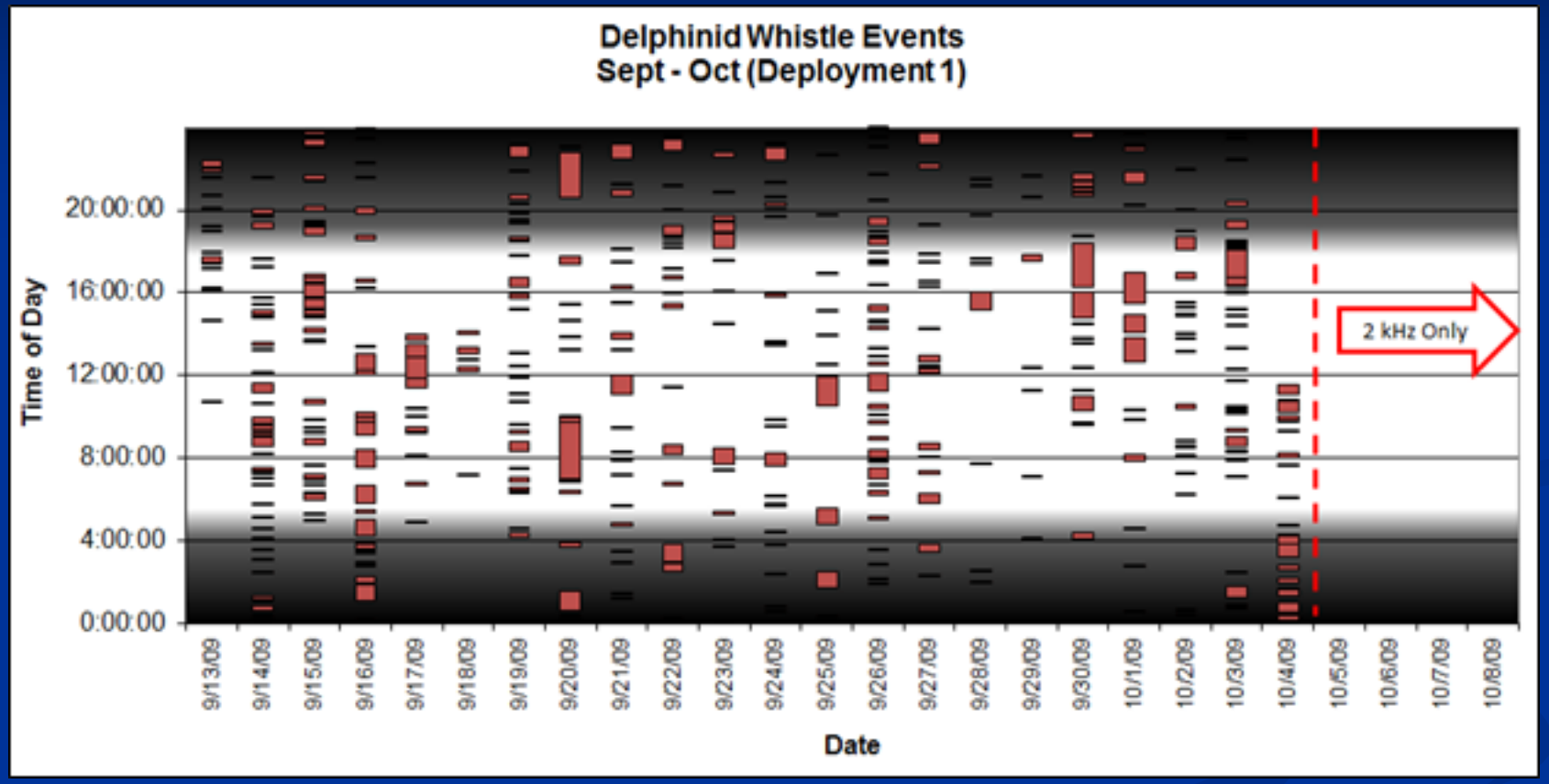

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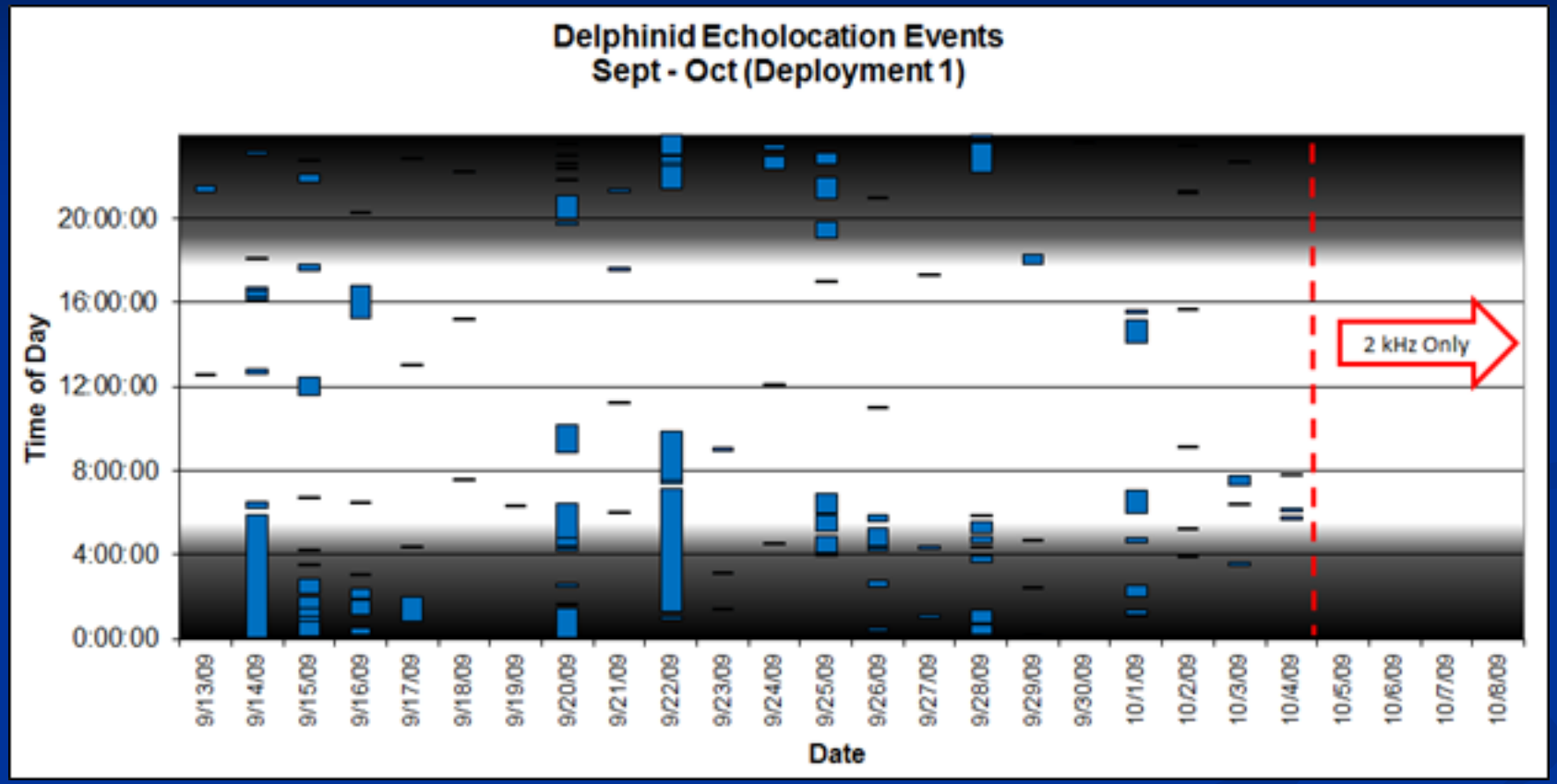
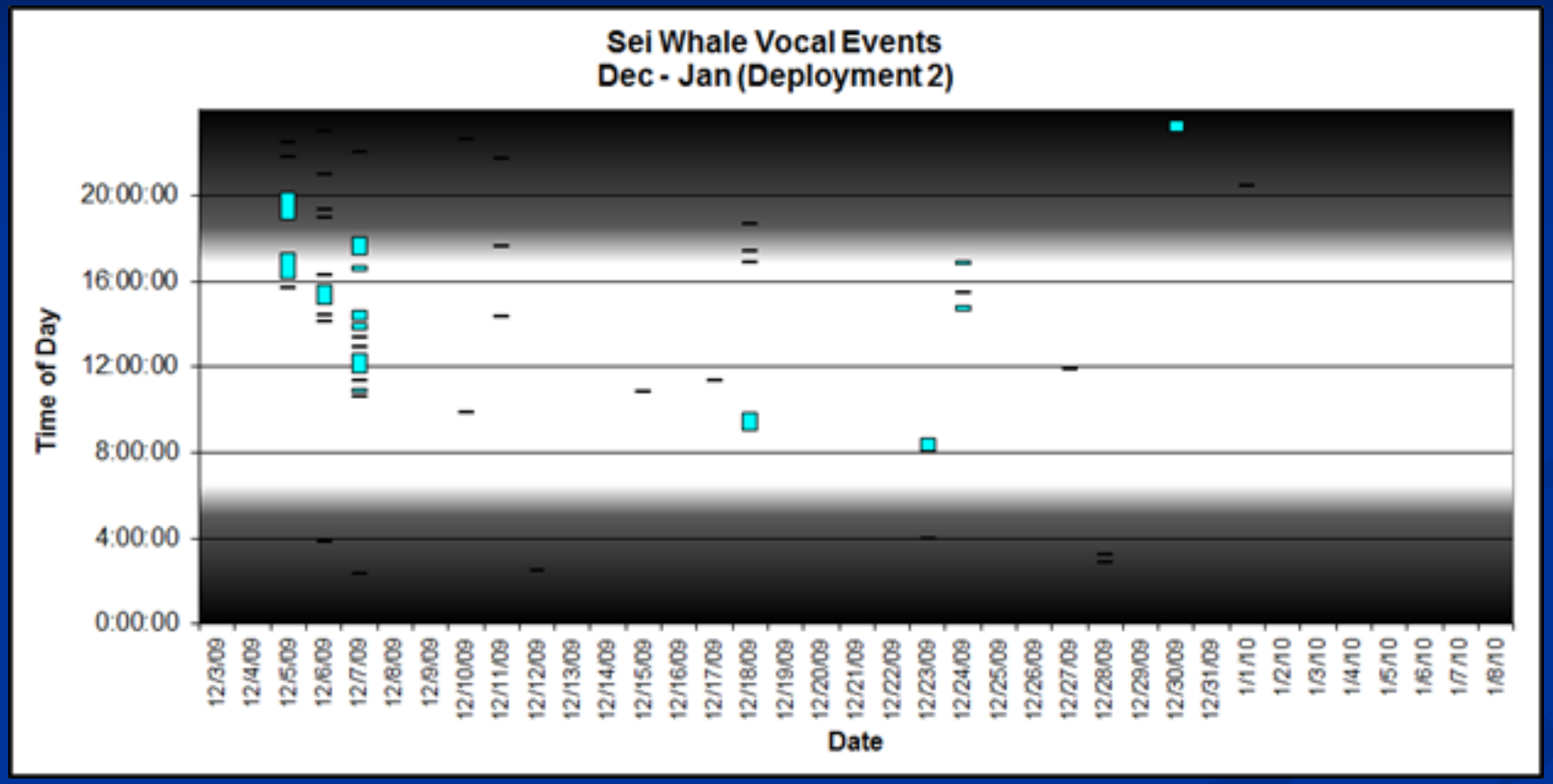
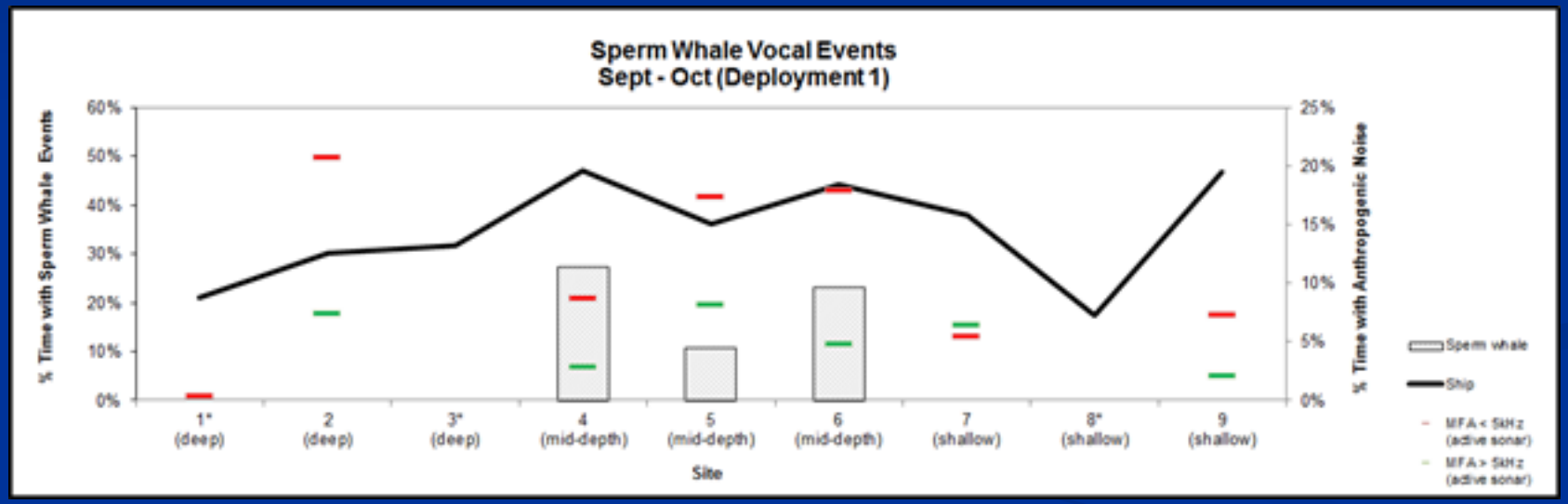

Delphinid Echolocation Events
Sept - Oct (Deployment 1)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
2 kHz Only
9/13/09
9/14/09
9/15/09
9/16/09
9/17/09
9/18/09
9/19/09
9/20/09
9/21/09
9/22/09
9/23/09
9/24/09
9/25/09
9/26/09
9/27/09
9/28/09
9/29/09
9/30/09
10/1/09
10/2/09
10/3/09
10/4/09
10/5/09
10/6/09
10/7/09
10/8/09
Date


Sei Whale Vocal Events
Dec - Jan (Deployment 2)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
12/3/09
12/4/09
12/5/09
12/6/09
12/7/09
12/8/09
12/9/09
12/10/09
12/11/09
12/12/09
12/13/09
12/14/09
12/15/09
12/16/09
12/17/09
12/18/09
12/19/09
12/20/09
12/21/09
12/22/09
12/23/09
12/24/09
12/25/09
12/26/09
12/27/09
12/28/09
12/29/09
12/30/09
12/31/09
1/1/10
1/2/10
1/3/10
1/4/10
1/5/10
1/6/10
1/7/10
1/8/10
Date


Sperm Whale Vocal Events
Sept - Oct (Deployment 1)
% Time with Sperm Whale Events
60%
50%
40%
30%
20%
10%
0%
25%
20%
15%
10%
5%
0%
% Time with Anthropogenic Noise
1*
(deep)
2
(deep)
3*
(deep)
4
(mid-depth)
5
(mid-depth)
6
(mid-depth)
7
(shallow)
8*
(shallow)
9
(shallow)
Site
Sperm whale
Ship
MFA < 5kHz
(active sonar)
MFA > 5kHz
(active sonar)

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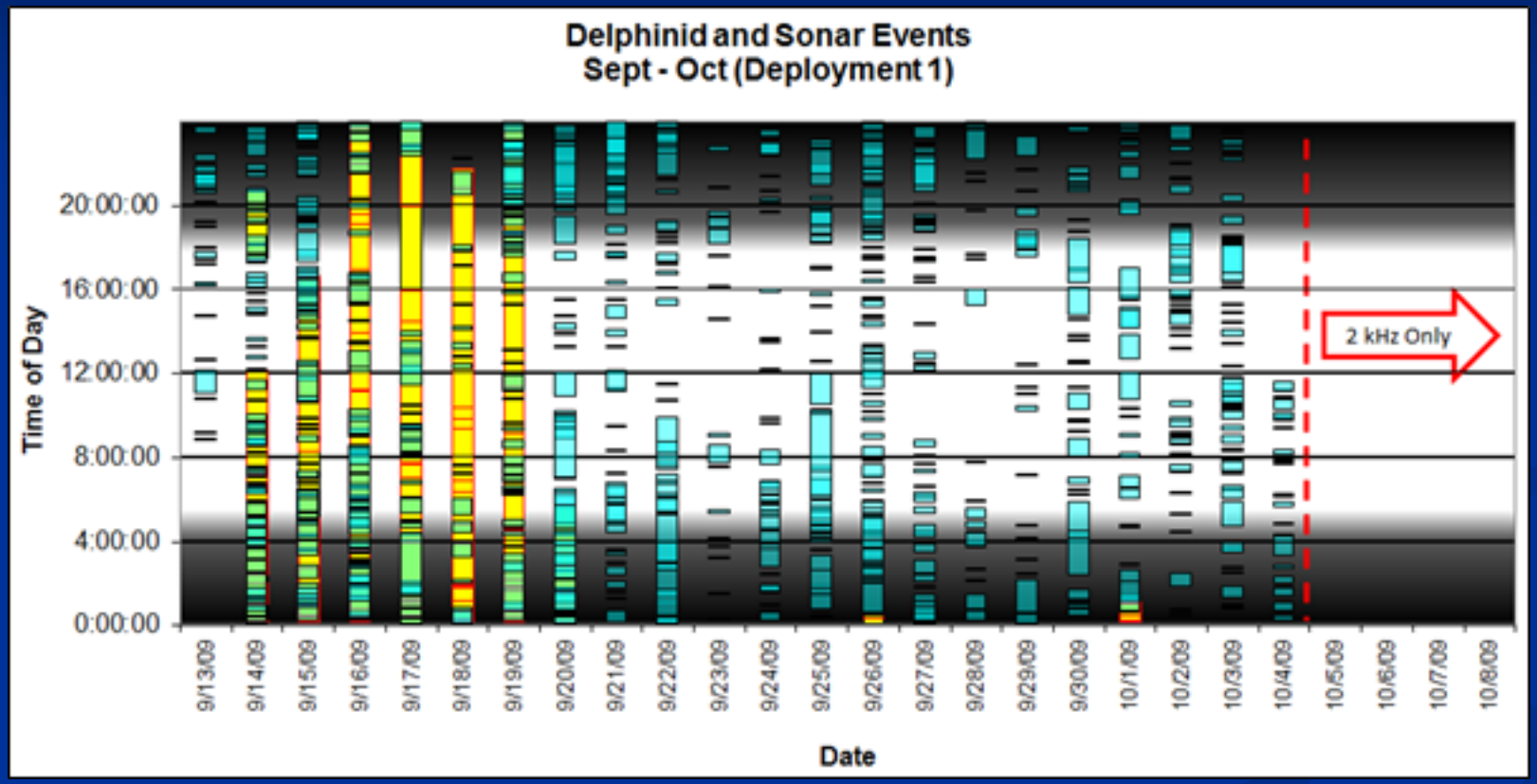

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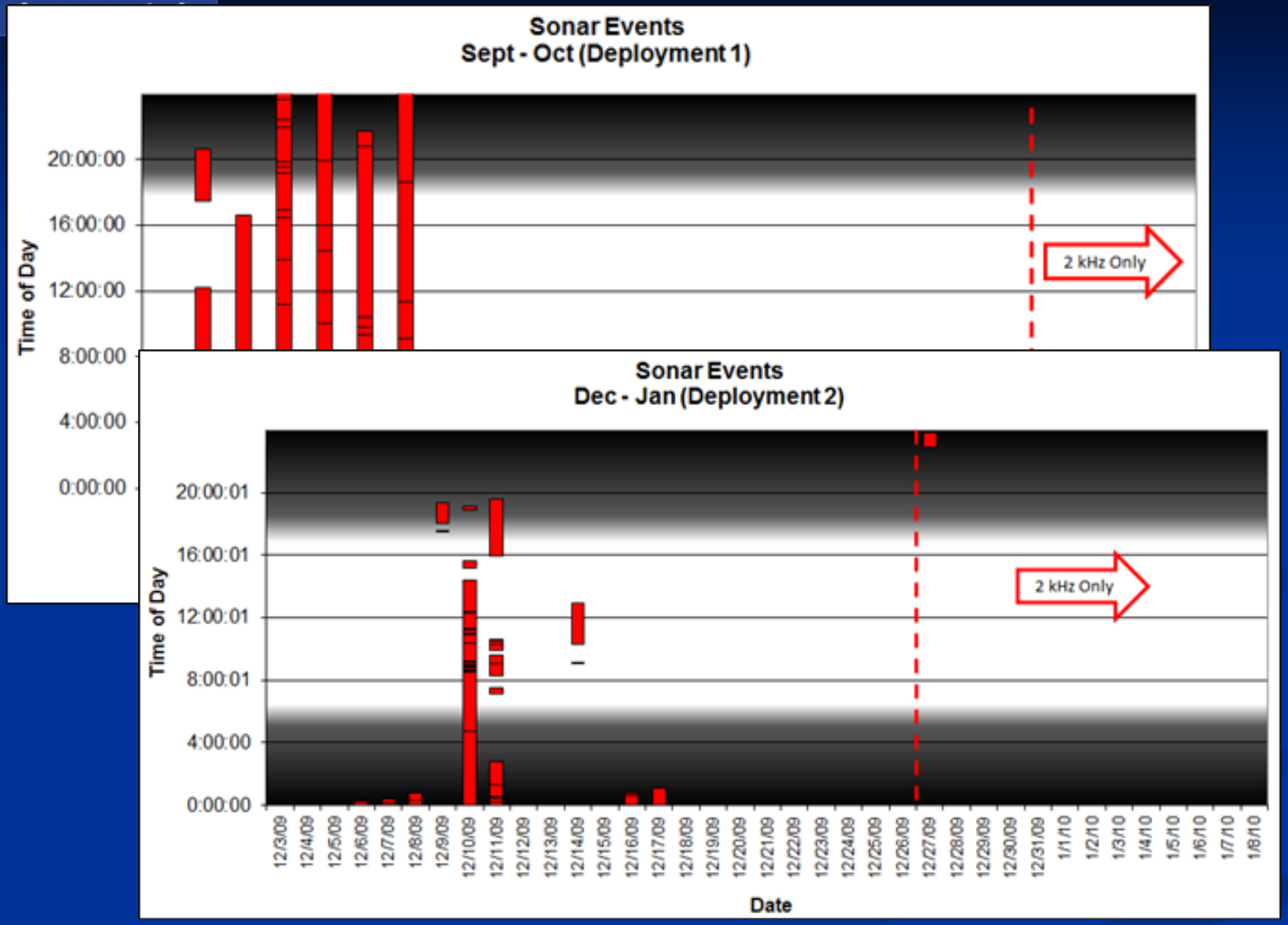
Sonar Events
Sept - Oct (Deployment 1)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
2 kHz Only
Sonar Events
Dec - Jan (Deployment 2)
Time of Day
20:00:01
16:00:01
12:00:01
8:00:01
4:00:00
0:00:00
2 kHz Only
12/3/09
12/4/09
12/5/09
12/6/09
12/7/09
12/8/09
12/9/09
12/10/09
12/11/09
12/12/09
12/13/09
12/14/09
12/15/09
12/16/09
12/17/09
12/18/09
12/19/09
12/20/09
12/21/09
12/22/09
12/23/09
12/24/09
12/25/09
12/26/09
12/27/09
12/28/09
12/29/09
12/30/09
12/31/09
1/1/10
1/2/10
1/3/10
1/4/10
1/5/10
1/6/10
1/7/10
1/8/10
Date

Title Here

Something here:

- More here
- More here
- More here

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THANK YOU

"What is a scientist after all?

It is a curious man looking through a keyhole, the keyhole of nature, trying to know what's going on"

Jacques Yves Cousteau

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Executive Summary

Acoustic data collected from Marine Autonomous Recording Units during 26 days in fall (13 September to 8 October) and 37 days in winter (3 December to 8 January) 2009-2010 were analyzed for acoustic detections of marine mammals and patterns resulting from these detections. The study site coincided with the United States (U.S.) Navy's planned Undersea Warfare Training Range (USWTR) located approximately 60 to 150 kilometers offshore Jacksonville, Florida. Acoustic data consisted of two types of recordings, 2-kilohertz (kHz) and 32-kHz sample rate recordings. All 32-kHz sample rate data were downsampled to 2-kHz in order to make them comparable to the 2-kHz recordings and allow better low-frequency resolution for reviewing. These 2-kHz sample rate files were reviewed primarily for baleen whale calls, which are generally expected to occur below 1 kHz. The 32-kHz files were reviewed for all other species (e.g., sperm whale [*Physeter macrocephalus*]) and species groups (e.g., delphinids and 'blackfish') with vocalizations above 1 kHz. Data were first reviewed using long-term spectral averages (LTSAs), and then reviewed in greater detail from spectrograms using the MATLAB program Triton (Wiggins 2007). Vocalization events (defined as any continuous vocalization or series of vocalizations with no more than a 10-minute gap) were logged and later compiled into spreadsheets for graphing and additional analyses. Summary graphs of daily vocalization events and graphs of percent total time containing vocalizations by site were compiled. Probability of vocalization event occurrence was calculated for each species relative to sonar events. Species and species groups detected included minke whale (*Balaenoptera acutorostrata*), North Atlantic right whale (*Eubalaena glacialis*), sei whale (*Balaenoptera borealis*), (possible) humpback whale (*Megaptera novaeangliae*), sperm whale, 'blackfish,' and unidentified delphinids. Results indicated that minke whales were not present during fall, but occurred almost continuously during the winter deployment period. Right whale vocalization events were much shorter in duration and less frequent than those of the minke whale, and also were most concentrated during winter, as expected, but were also detected frequently at deep sites, which was somewhat unexpected. Sperm whales were detected in both seasons at similar rates, exclusively at mid-depth sites (i.e., near the continental shelf break), and showed a strong diel pattern with almost all vocalization events occurring at night from dusk until dawn. There were less obvious patterns for delphinid vocalization events, possibly because we were not able to identify vocalization events to species, and therefore, multiple species were grouped into one category. Blackfish were detected infrequently, but were most common at the shallow-water sites. There was only one possible vocalization event of a humpback whale, and none identified for fin or blue whales (*Balaenoptera physalus* and *Balaenoptera musculus*, respectively). Minke whales showed the strongest relationship between sonar events and vocalizations, with the probability of minke whale vocalization events occurring simultaneously with sonar events being much less than in the absence of sonar. A preliminary qualitative analysis of two extended periods of delphinid whistles that occurred simultaneously with sonar revealed that call-matching (i.e., mimicry) was likely occurring. Recommendations for future work are provided, and these include a more detailed analysis of vocalizations (instead of vocalization events) for some species in order to reveal important patterns and trends. The results reported here provide an assessment of marine mammal occurrence and distribution within the U.S. Navy's planned USWTR and insights on species specific vocal responses to sonar events.

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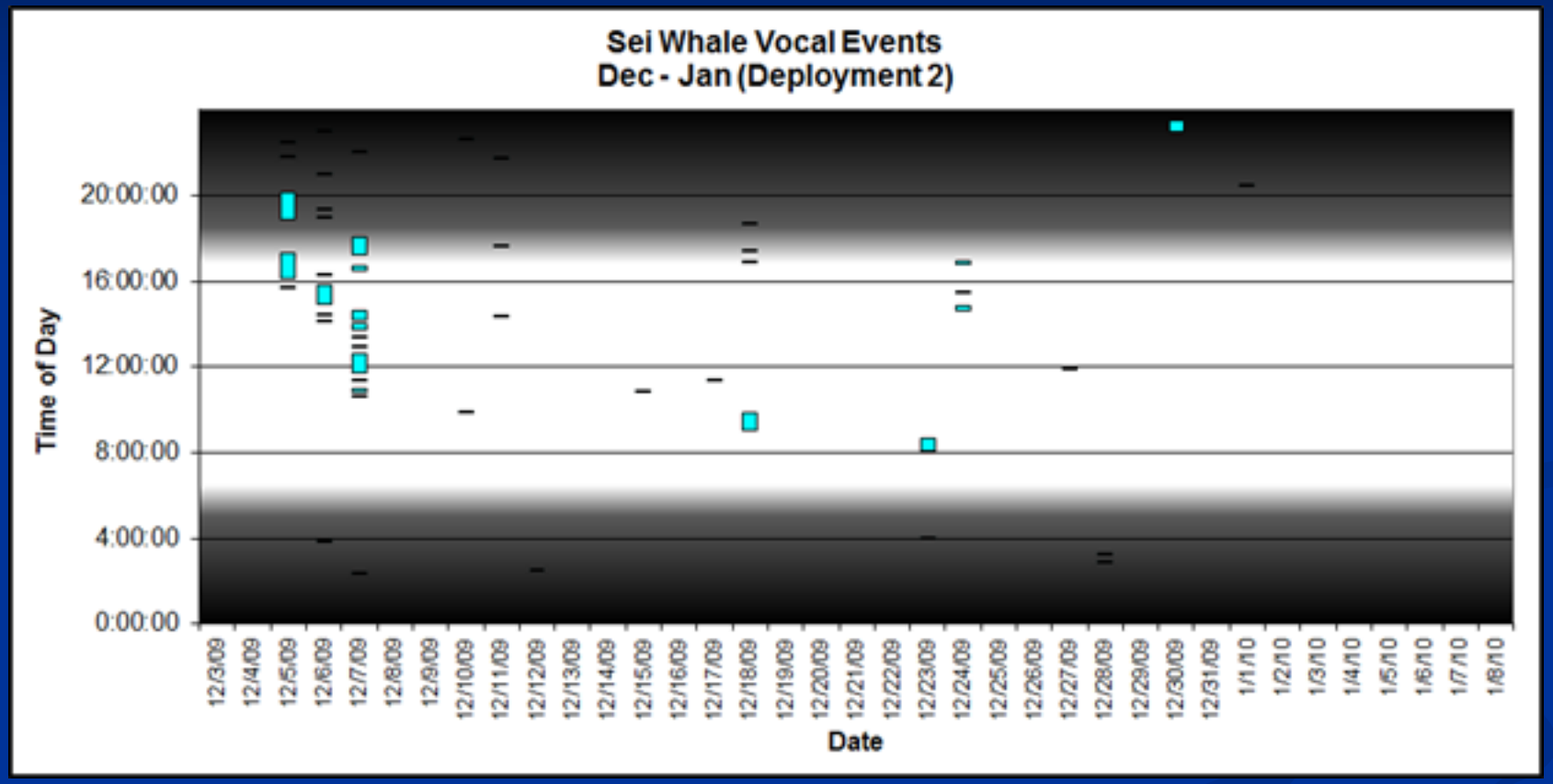
Sei Whale Vocal Events
Dec - Jan (Deployment 2)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
12/3/09
12/4/09
12/5/09
12/6/09
12/7/09
12/8/09
12/9/09
12/10/09
12/11/09
12/12/09
12/13/09
12/14/09
12/15/09
12/16/09
12/17/09
12/18/09
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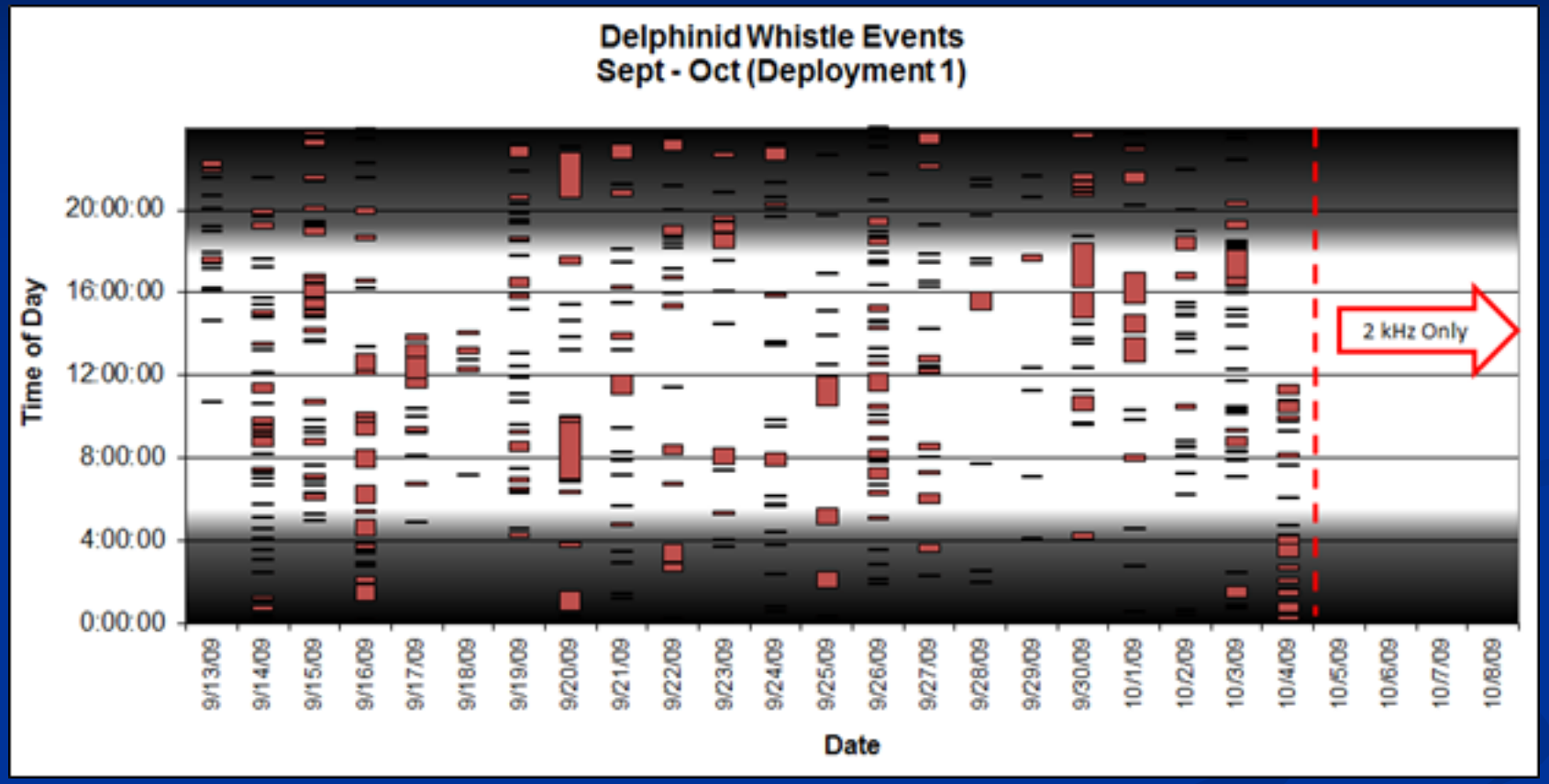
12/23/09
12/24/09
12/25/09
12/26/09
12/27/09
12/28/09
12/29/09
12/30/09
12/31/09
1/1/10
1/2/10
1/3/10
1/4/10
1/5/10
1/6/10
1/7/10
1/8/10
Date

Bio·Waves Incorporated



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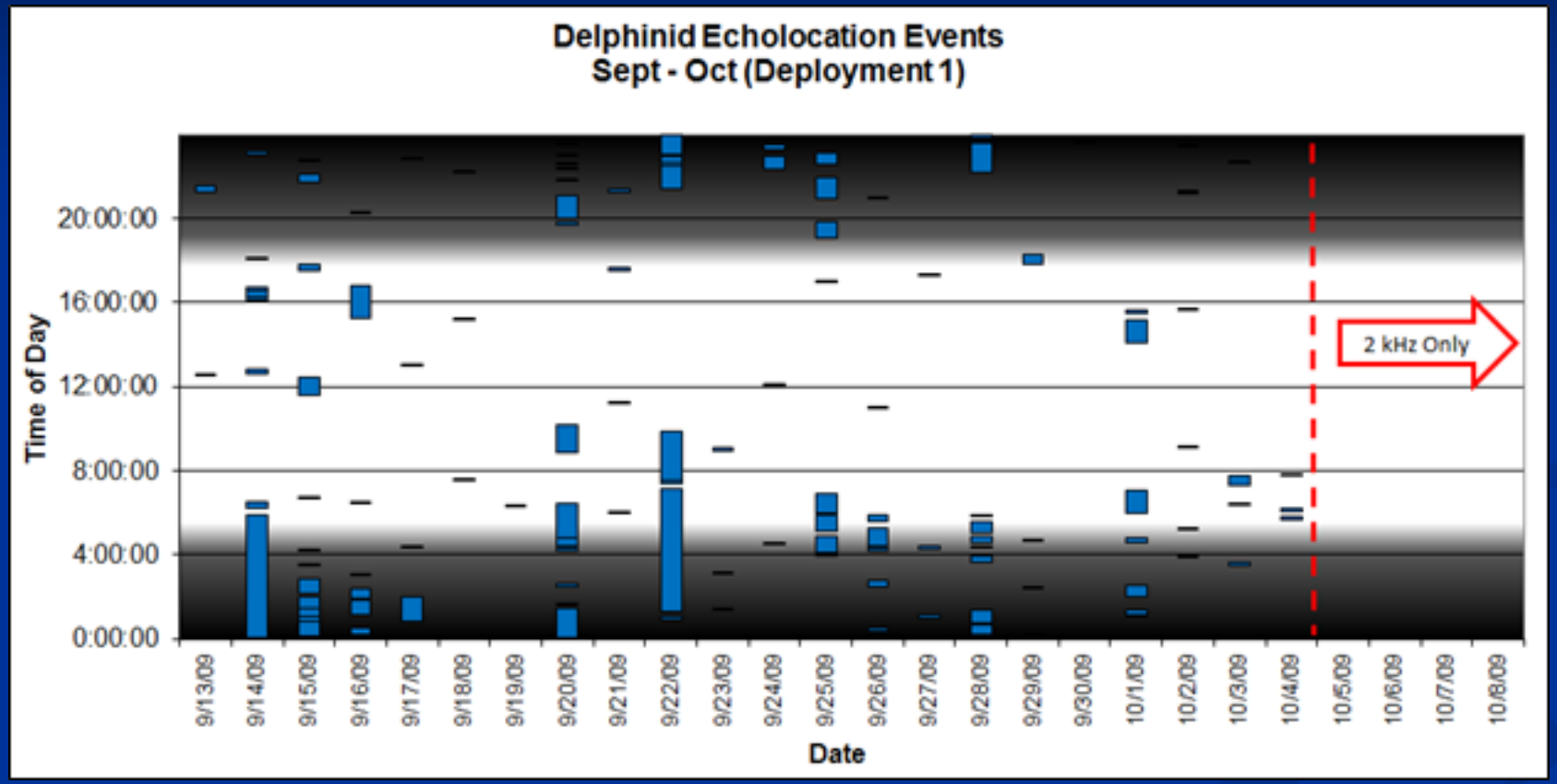
Delphinid Echolocation Events
Sept - Oct (Deployment 1)
Time of Day
20:00:00
16:00:00
12:00:00
8:00:00
4:00:00
0:00:00
2 kHz Only
9/13/09
9/14/09
9/15/09
9/16/09
9/17/09
9/18/09
9/19/09
9/20/09
9/21/09
9/22/09
9/23/09
9/24/09
9/25/09
9/26/09
9/27/09
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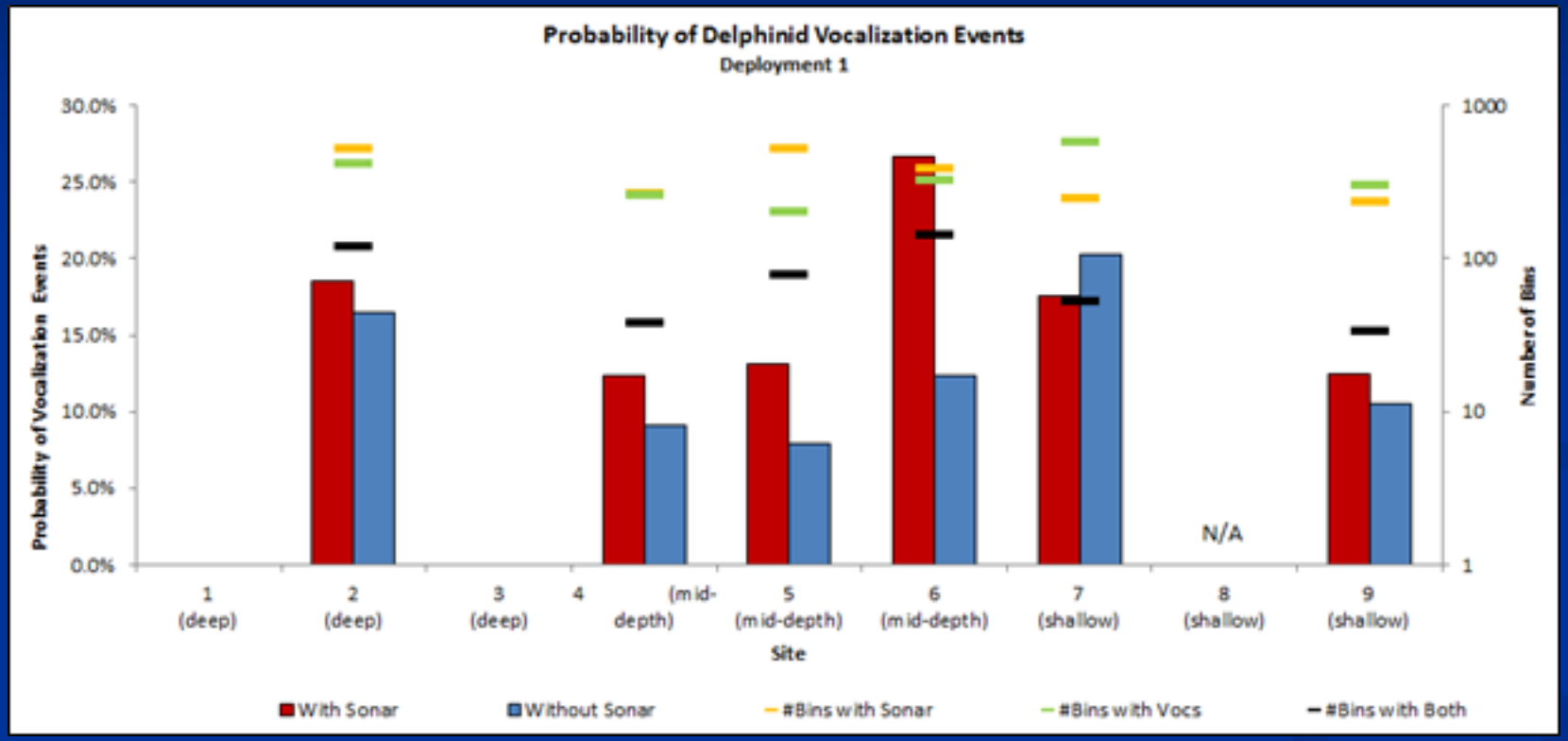
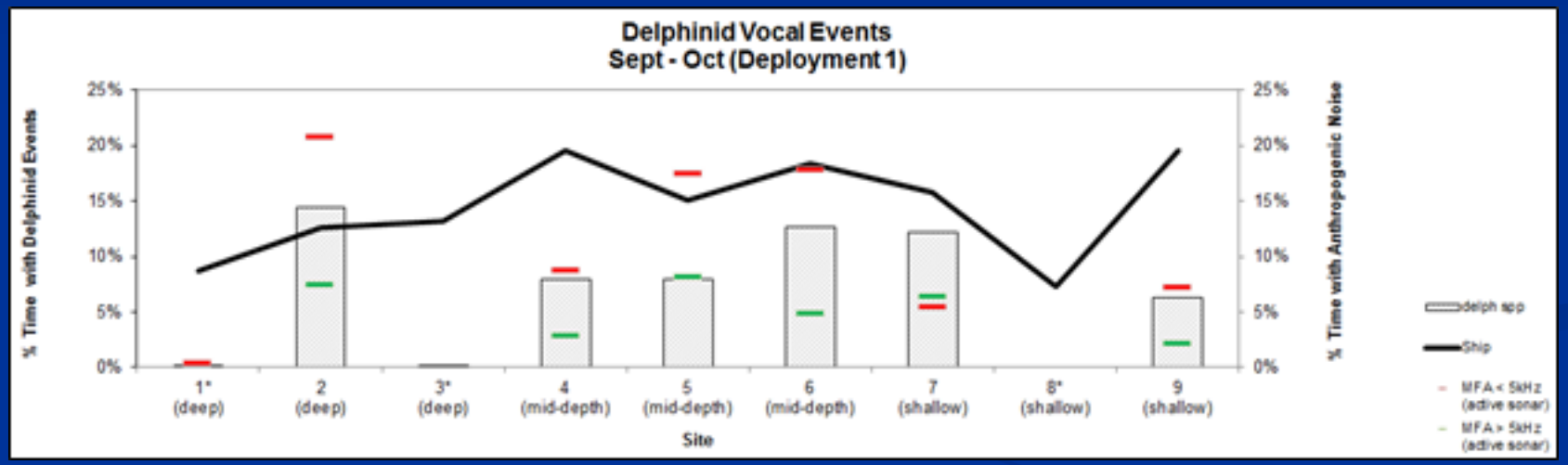
10/5/09
10/6/09
10/7/09
10/8/09
Date


Probability of Delphinid Vocalization Events
Deployment 1
Probability of Vocalization Events
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Number of Bins
1000
100
10
1
N/A
1 (deep)
2 (deep)
3 (deep)
4 (mid-depth)
5 (mid-depth)
6 (mid-depth)
7 (shallow)
8 (shallow)
9 (shallow)
Site
With Sonar
Without Sonar
#Bins with Sonar
#Bins with Vocs
#Bins with Both


Delphinid Vocal Events
Sept - Oct (Deployment 1)
% Time with Delphinid Events
% Time with Anthropogenic Noise
25%
20%
15%
10%
5%
0%
1* (deep)
2 (deep)
3* (deep)
4 (mid-depth)
5 (mid-depth)
6 (mid-depth)
7 (shallow)
8* (shallow)
9 (shallow)
Site
delph app
Ship
MFA< 5kHz (active sonar)
MFA> 5kHz (active sonar)

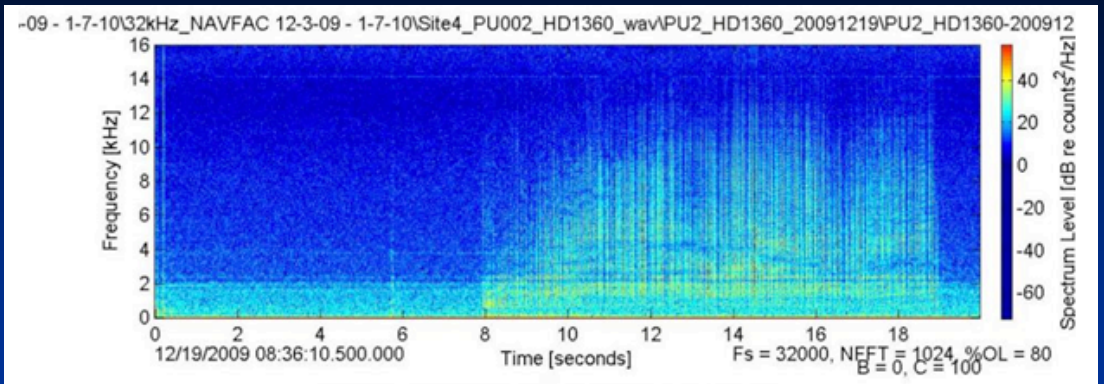


Figure 68. Example #1 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval, and occurred in a large repertoire of patterns, such as creaks, rapid clicks, etc.

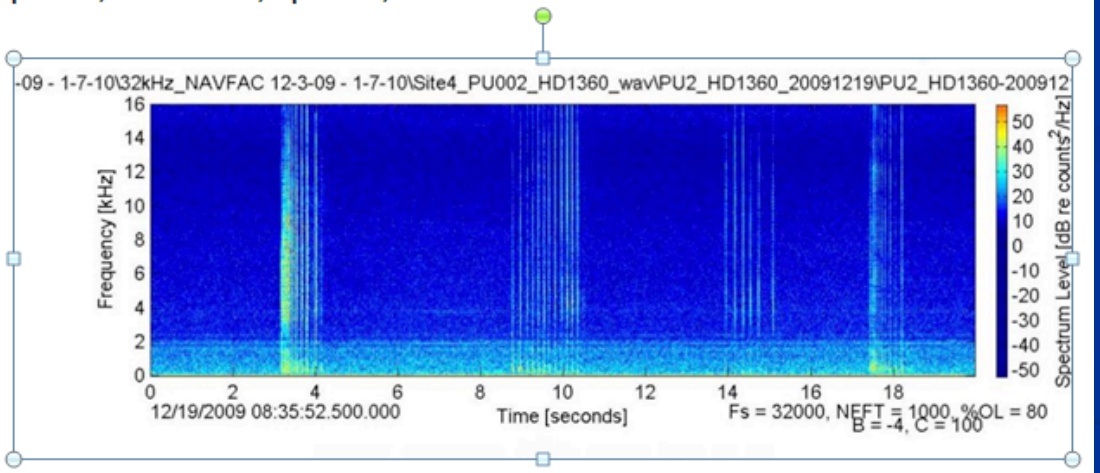
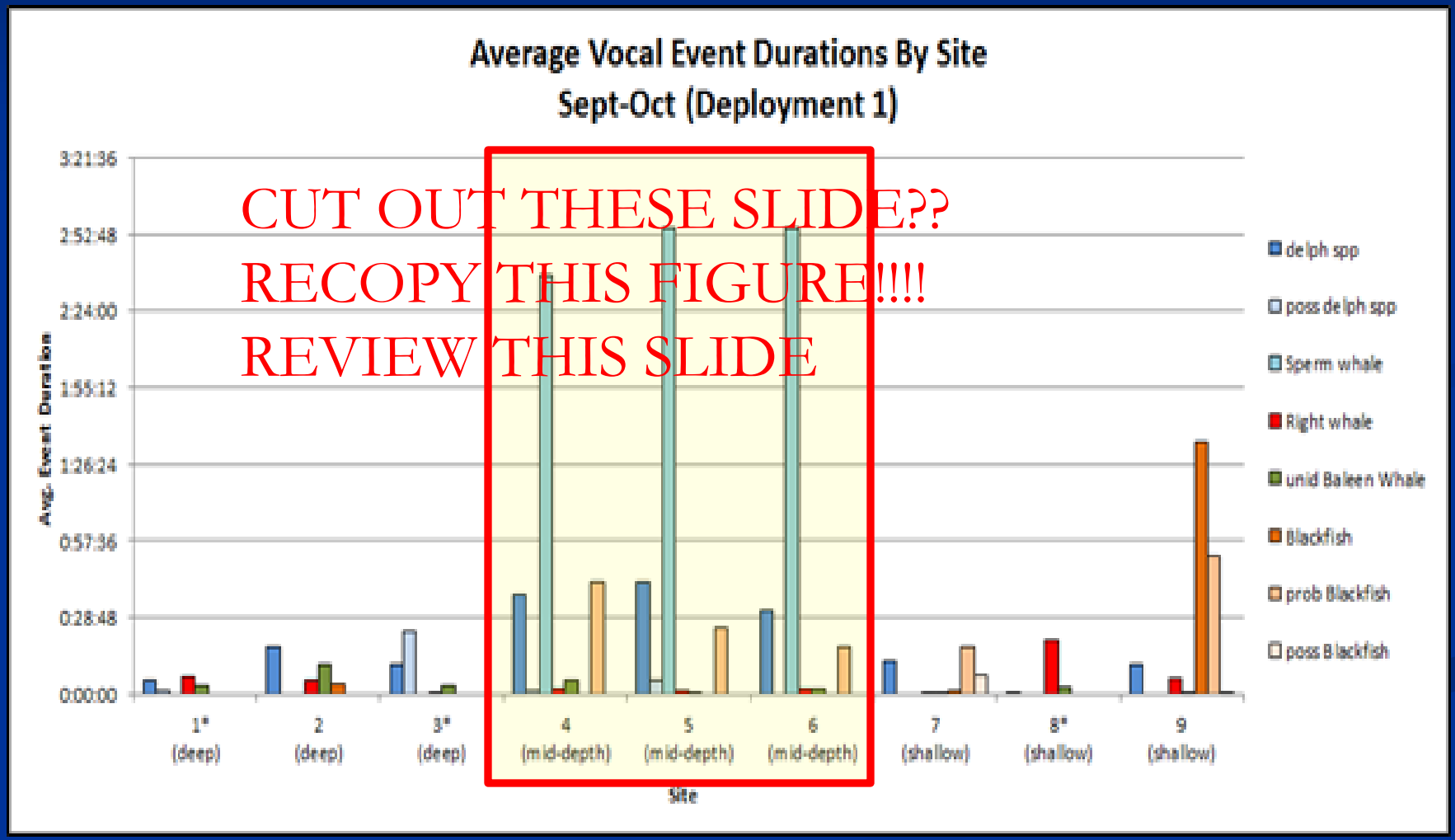


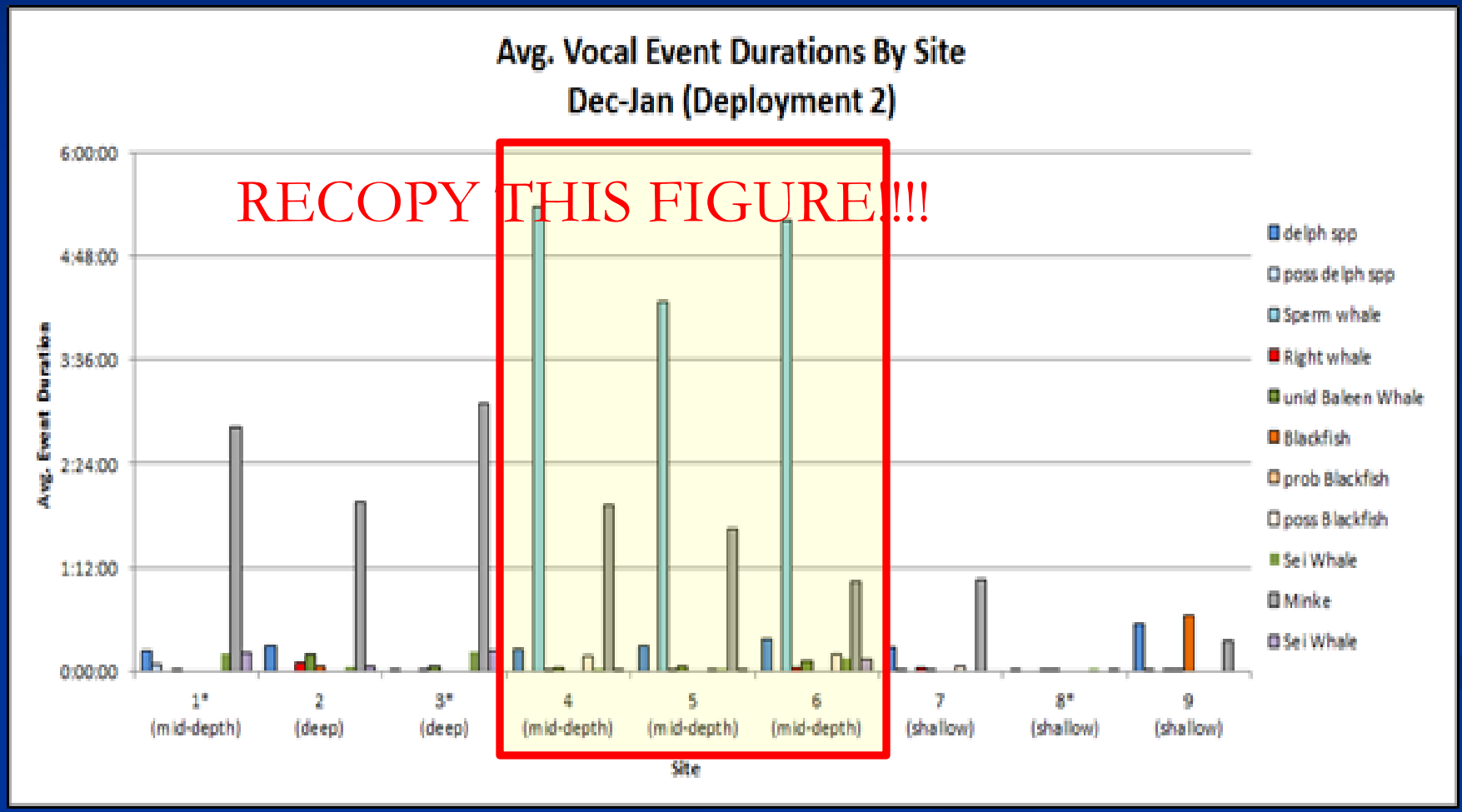
Figure 69. Example #2 of Sperm Whale Feeding Event at Site 4 on 19 December 2009. Echolocation clicks varied dramatically with respect to inter-click interval and contains a large repertoire of patterns, such as creaks, rapid clicks, etc.

WINTER RESULTS
average event durations (hrs)



RESULTS

average event durations (hrs)



Background Info

Executive Summary

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SMM TALK

Subtitle - Here

(topic jere)

SMM TALK

Subtitle - Here

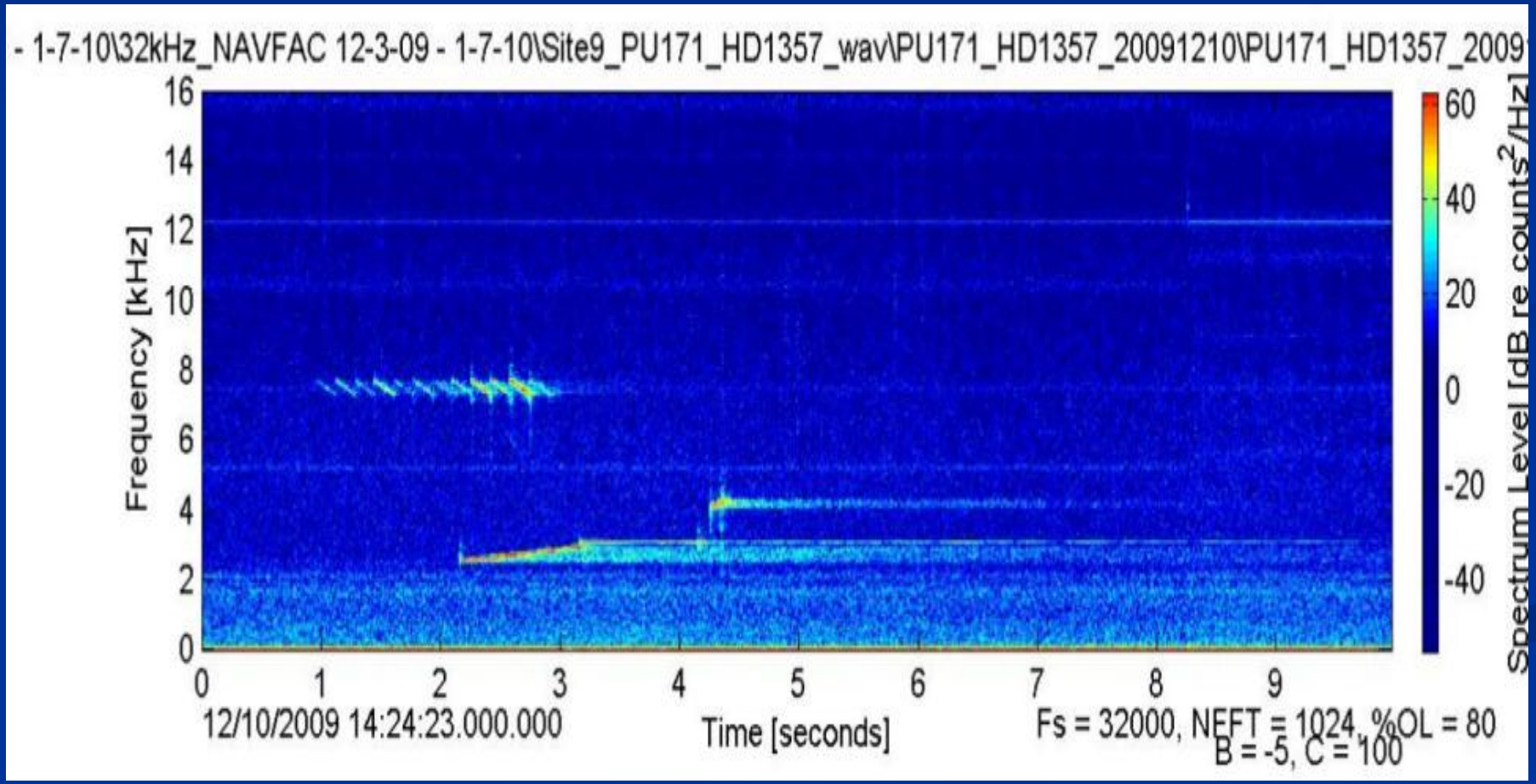
(topic here)

Something here:

- More here
- More here
- More here

RESULTS

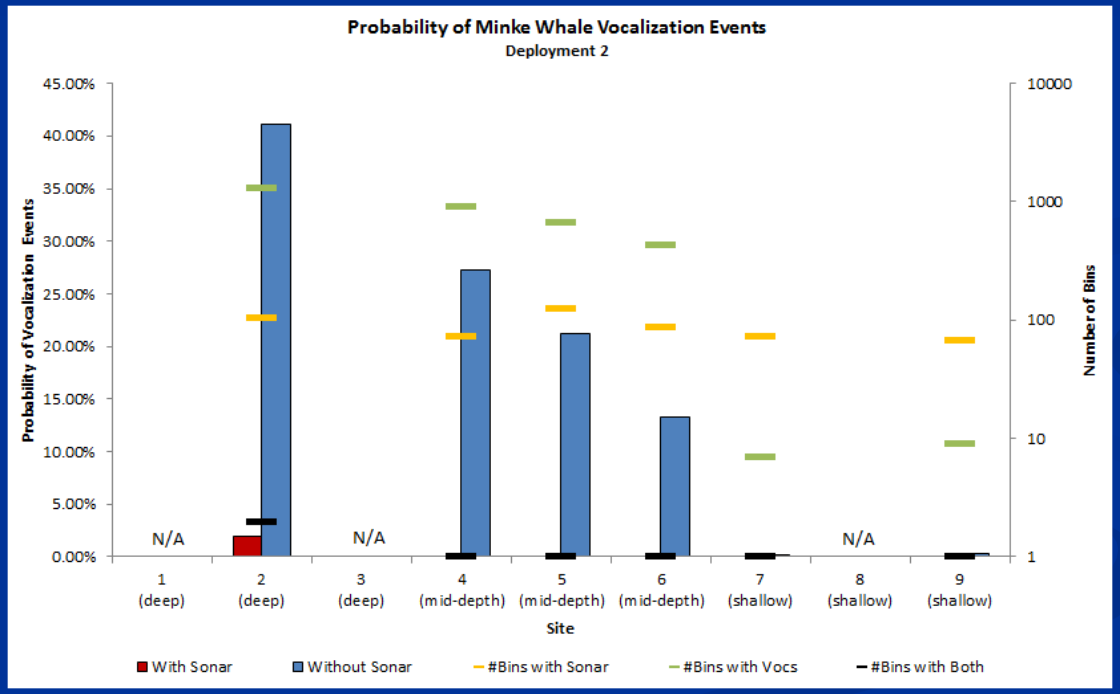
MFA Sonar Example



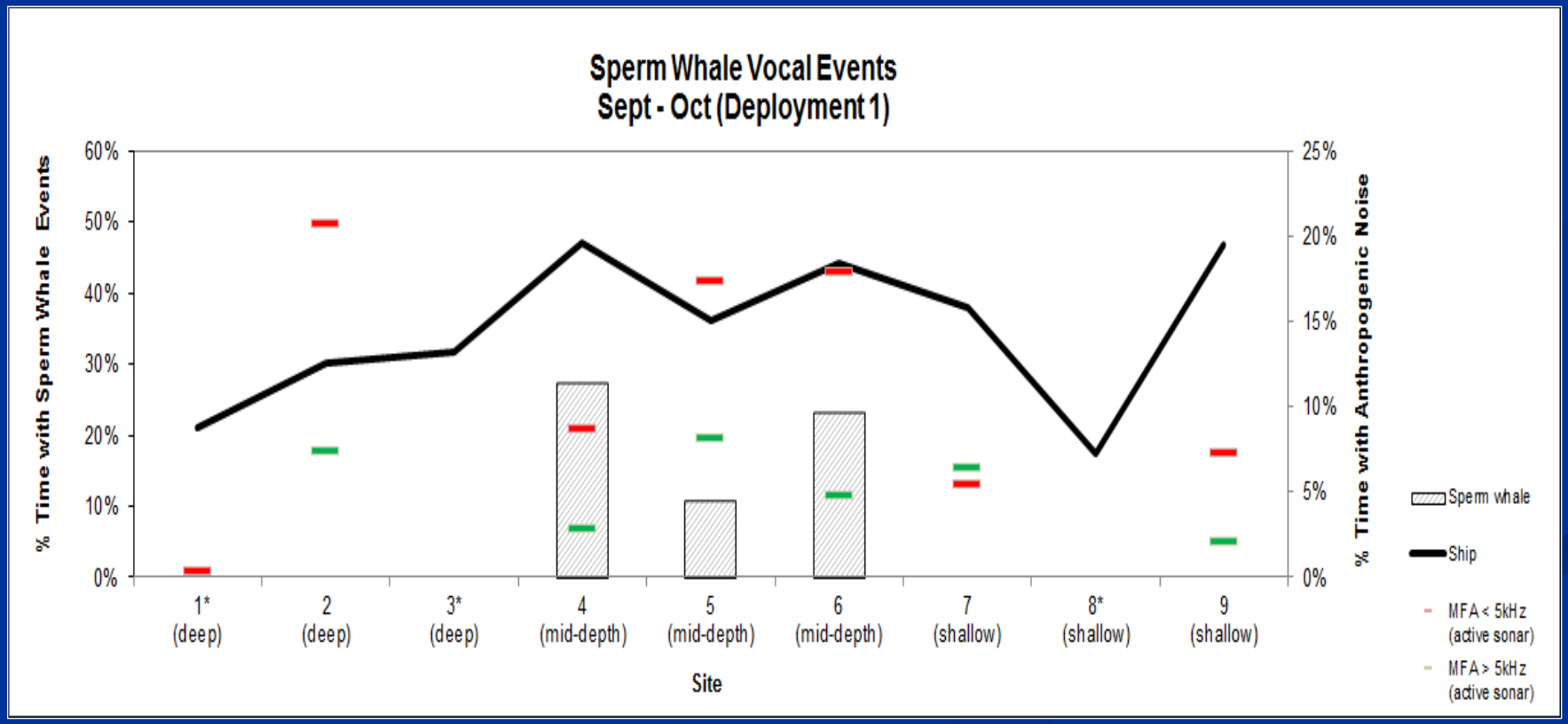
SMM TALK

Subtitle - Here

(topic ere)



RESULTS
% Time of Events
(Sperm whales - Fall deployment)



Slide two - animation go faster
Practice slide with the formulas - don't review the formulas
Review Diel Patterns - Sperm Whales slide
Review "Results Probablity Analysis - Sonar"
Review "Results % Time of Events" % time with black line
Review "Results Minke Whale"
In Summary at "only" before
Get link for report
- Say Tina's last name - when referring to Tina's talk
- Don't say the size of sf "which is considered a small city as far as cities go" leave with saying it is theree times of SF - good point.
- Last (watch next talk) don't need to say Tina again
- Results - overview of what is on each axis before going into results (hard to read from afar)
- Point on arrays - move before results?

RESULTS
Minke Whales