Calibrating and Validating the CYGNSS signal from *ideal* inland bodies of water

Cinzia Zuffada, Rashmi Shah

Jet Propulsion Laboratory/Caltech

Eric Loria, Andrew O'Brien

Ohio State University

Valery Zavorotny

NOAA, ESRL

Maurizio di Bisceglie, Lilli Galdi

Universita' del Sannio

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Context

- The problem of mapping and monitoring the dynamics of tropical wetlands/inundations has received attention by some in the CYGNSS community thanks to some of the features of the reflected signals
  - Coherent-looking, strong forward scattering off calm in-land bodies of water
  - Modest attenuation by water-standing vegetation

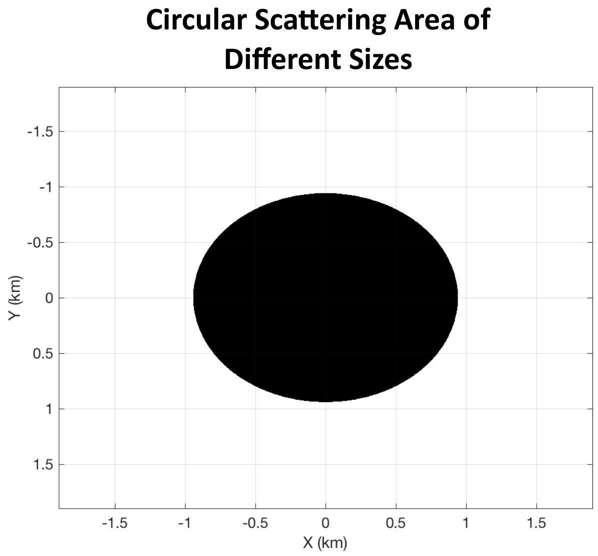
- This has led to assume that
  - Contribution to Peak SNR is from the first Fresnel zone (FFZ) only
  - Spatial resolution (footprint size) is dictated by FFZ
  - Retrieval algorithms have been formulated on a) link between percentage of water in the footprint and Peak SNR or) threshold of detectability based on mapping a) into a binary water/no-water classification with use of additional information

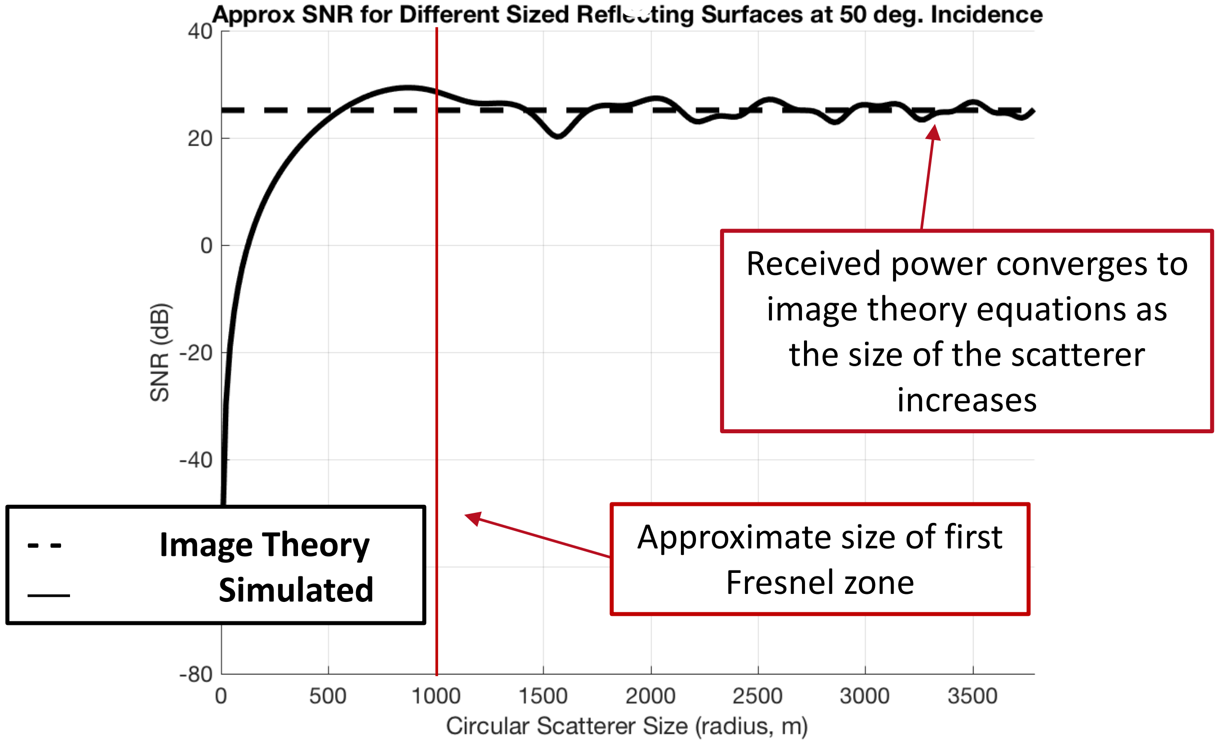
Relevant Modeling Work

- Loria et al. have modeled simplified wetlands and found that
  - Contribution to coherent scattering from areas outside FFZ not insignificant, causing oscillation in Peak SNR
  - Link between Peak SNR ~ Reflectivity ~ % water in the footprint is not straightforward and leads to errors in retrievals of wetlands extent
  - Peak SNR varies considerably with water-scene topology, hence other SNR metrics (such as sd) might be preferable as detectors of water
  - Detection algorithm (based on Peak SNR ~ % water in FFZ) for simplified wetland with vegetation finds 75% probability of detection and false alarm rate of 3%

From Presentation at Jan. 19 ST by E. Loria 1/4

- Consider circular scatterer to examine how the amount of water in the first Fresnel zone affects the received power SNR for a circle with increasing radius
- As the size of the scatterer exceeds the first Fresnel zone, there is significant ripple as contributions from higher Fresnel zones add constructively or destructively
- The complementary problem of circular hole in planar scatterer shows similar ripple, indicating contributions to first Fresnel zone from outside





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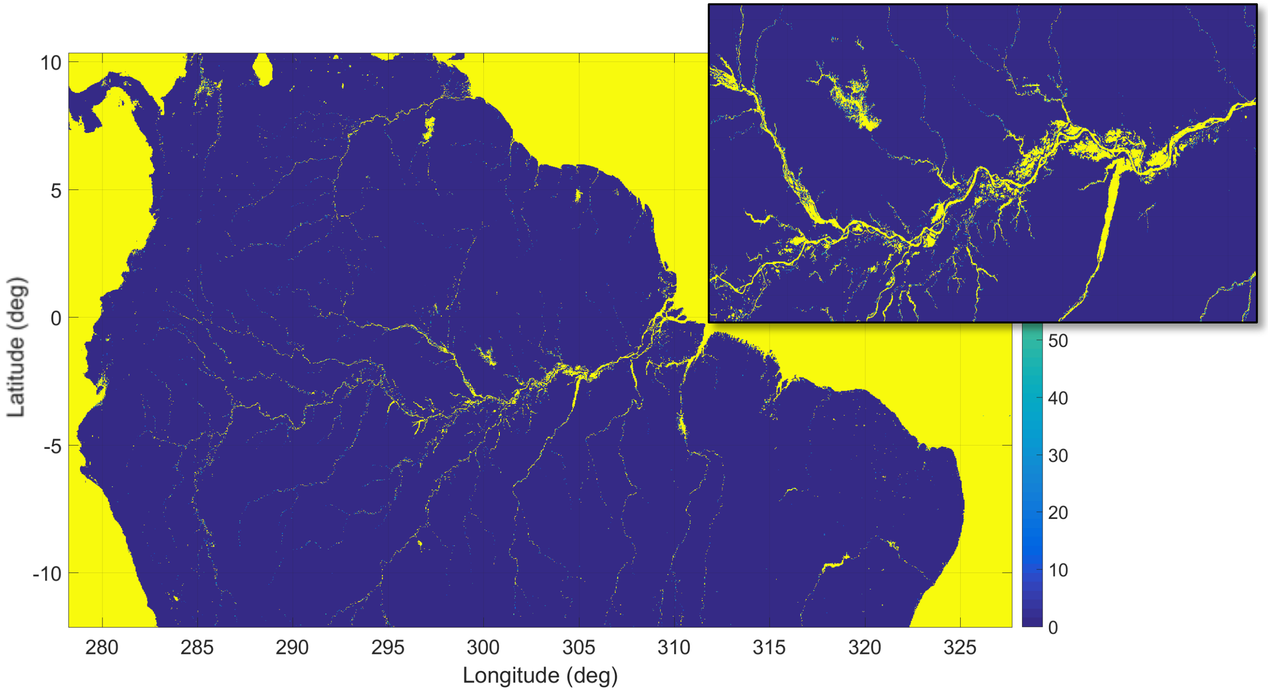
- Simulating CYGNSS DDMs over large area
  - Figure below shows example of MOD44W watermask data used as input to our simulation
  - MODIS allows us to get realistic, complex scenarios that CYGNSS measurements encounter in wetlands
  - We’re interested in looking at how scattering from multiple Fresnel zones and complex scenes affect the SNR



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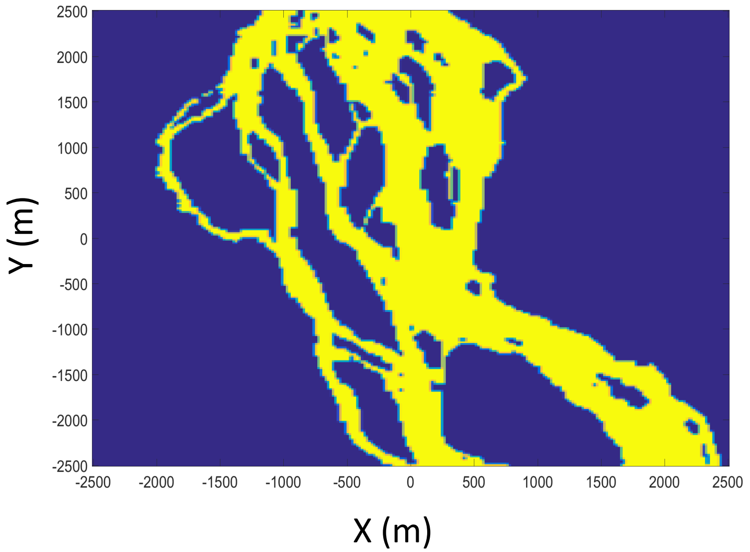
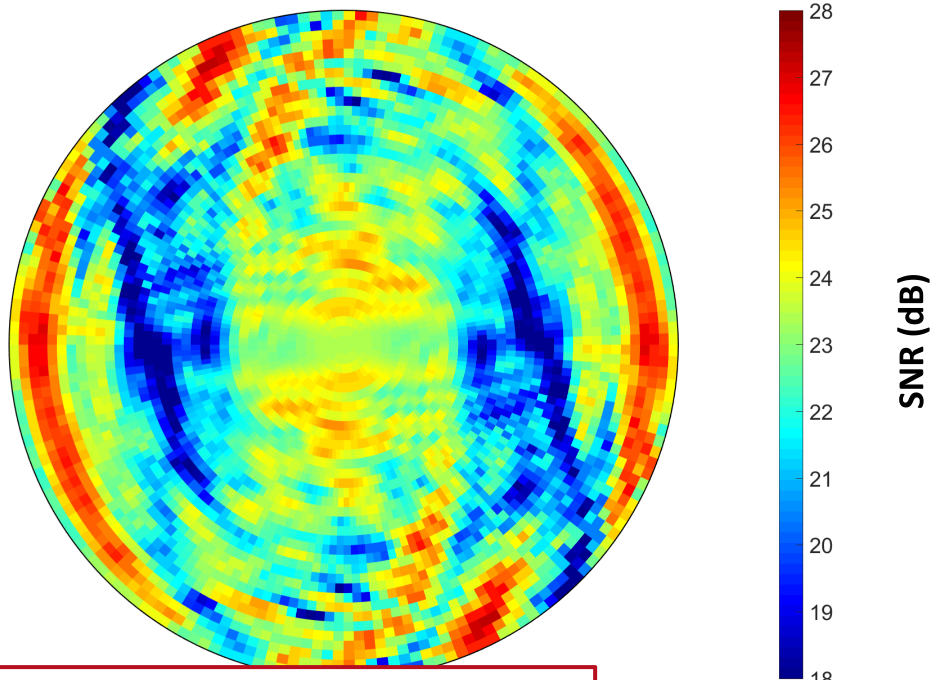
- For a complex river system with multiple branches, we first simulated DDMs as a function of the geometry of reflection (incidence & elevation angles
- No simple relationship between these complex geometries and the received power

Case Study Scenario



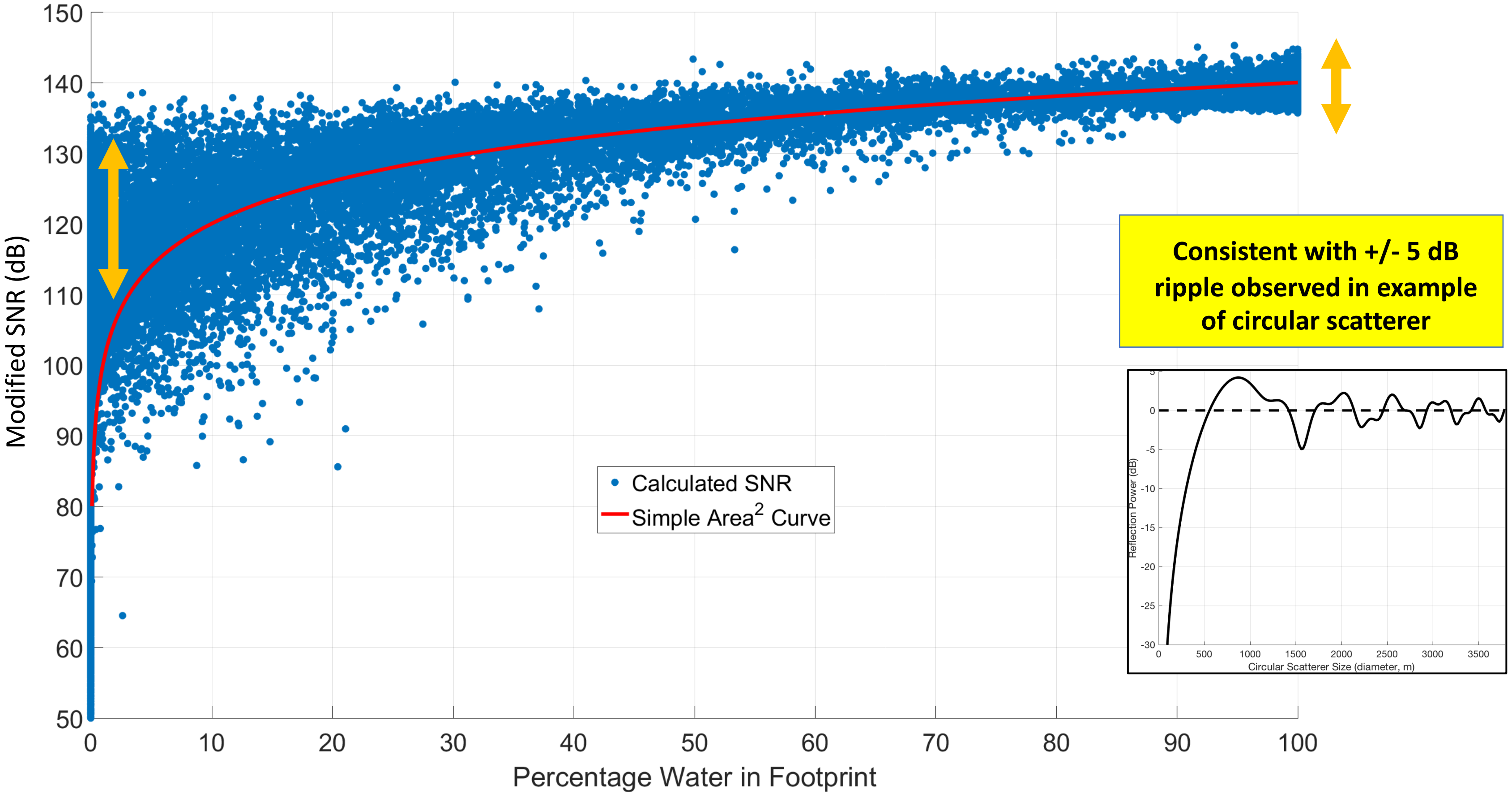


The significant variability in the received power from a scene may be an indicator of the presence of water

- SNR variability for cases with high and low percentages of water in the first Fresnel zone is consistent with argument we showed in earlier slides

Consistent with contribution coming from area outside the first Fresnel zone

Consistent with +/- 5 dB ripple observed in example of circular scatterer



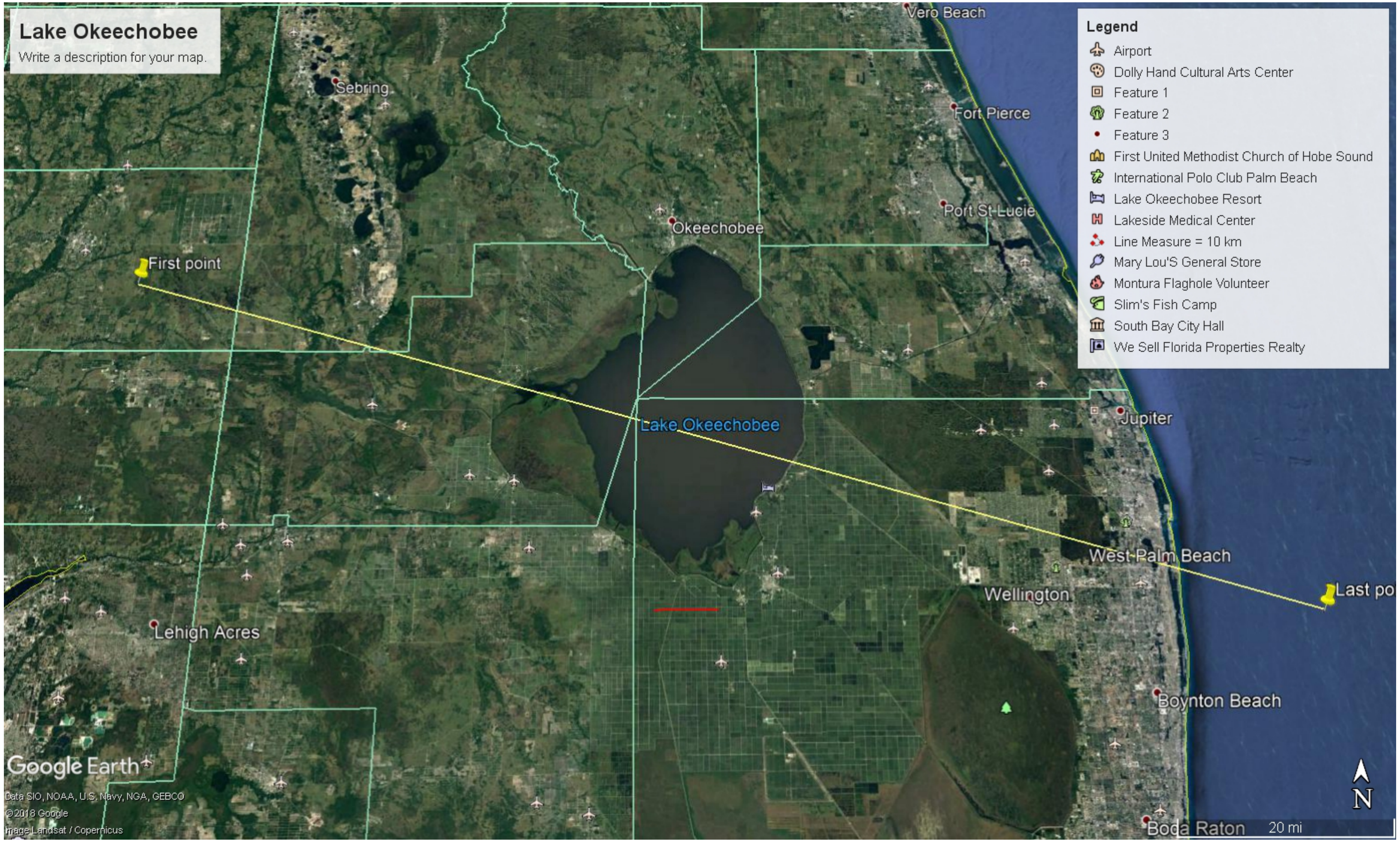
Validating Modeling Results with CYGNSS data

- Objectives
  - Analyze DDMs from a range of targets to understand SNR variability
  - Analyze Raw IF from a range of targets to understand role of coherent integration versus Fresnel zones contribution
  - Choose canonical targets (as close as possible to perfect localized scatterers) to minimize confounding effects from vegetation, roughness, heterogeneity
    - Lakes at high elevation, surrounded by steep walls, such as crater lakes

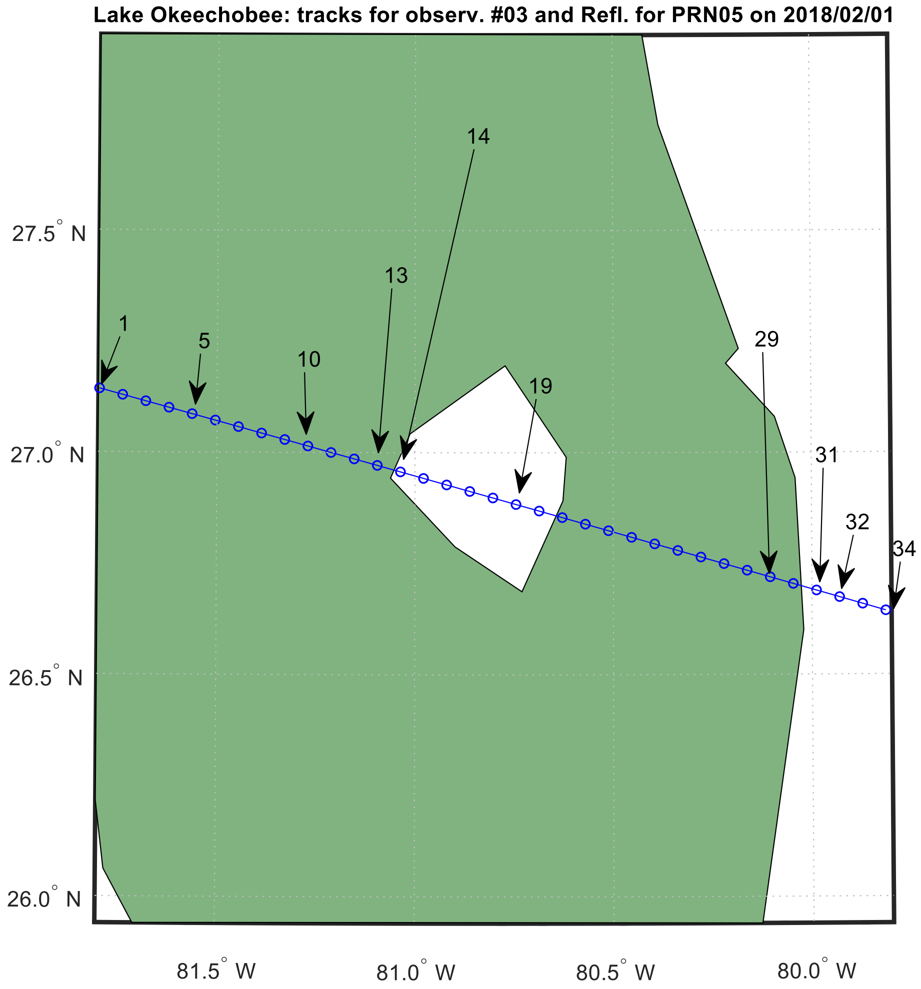
Analysis of Lake Okeechobee, Florida

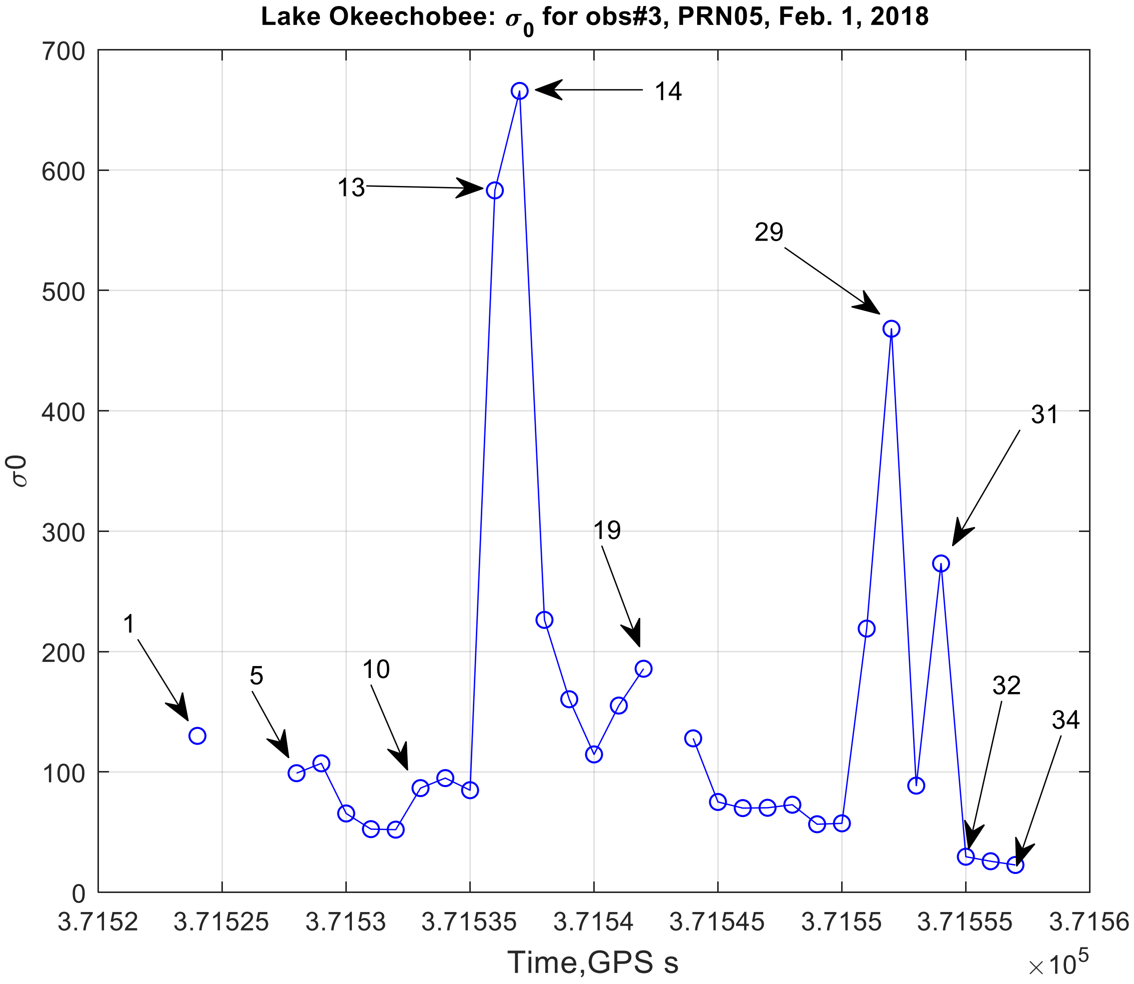
- CYGNSS L1 DDM/σ° data from Observatory #3 (PRN#5) for Feb. 1, 2018, at ~ 6 hours UTC is used.
- The reflection point track is passing over midsection of Lake Okeechobee, FL (~ 60 x 40 km in size)
- The meteorological data for that time indicated a north wind, U_{10} = 3 m/s for Feb.1, 2018
- This example shows the transition from incoherent weak diffuse scattering from land to coherent specular reflection from a small (western) portion of the lake, to incoherent weak diffuse scattering from the rest of the lake, to incoherent strong diffuse scattering from the near-coastal area of the Atlantic ocean.
- It demonstrates a negative impact of even very low surface roughness on the coherence of the reflected GNSS signal.
- Modeling of the decorrelation of the coherently reflected signal from the lake supports this conclusion.

The reflection point track is passing over midsection of Lake Okeechobee, FL



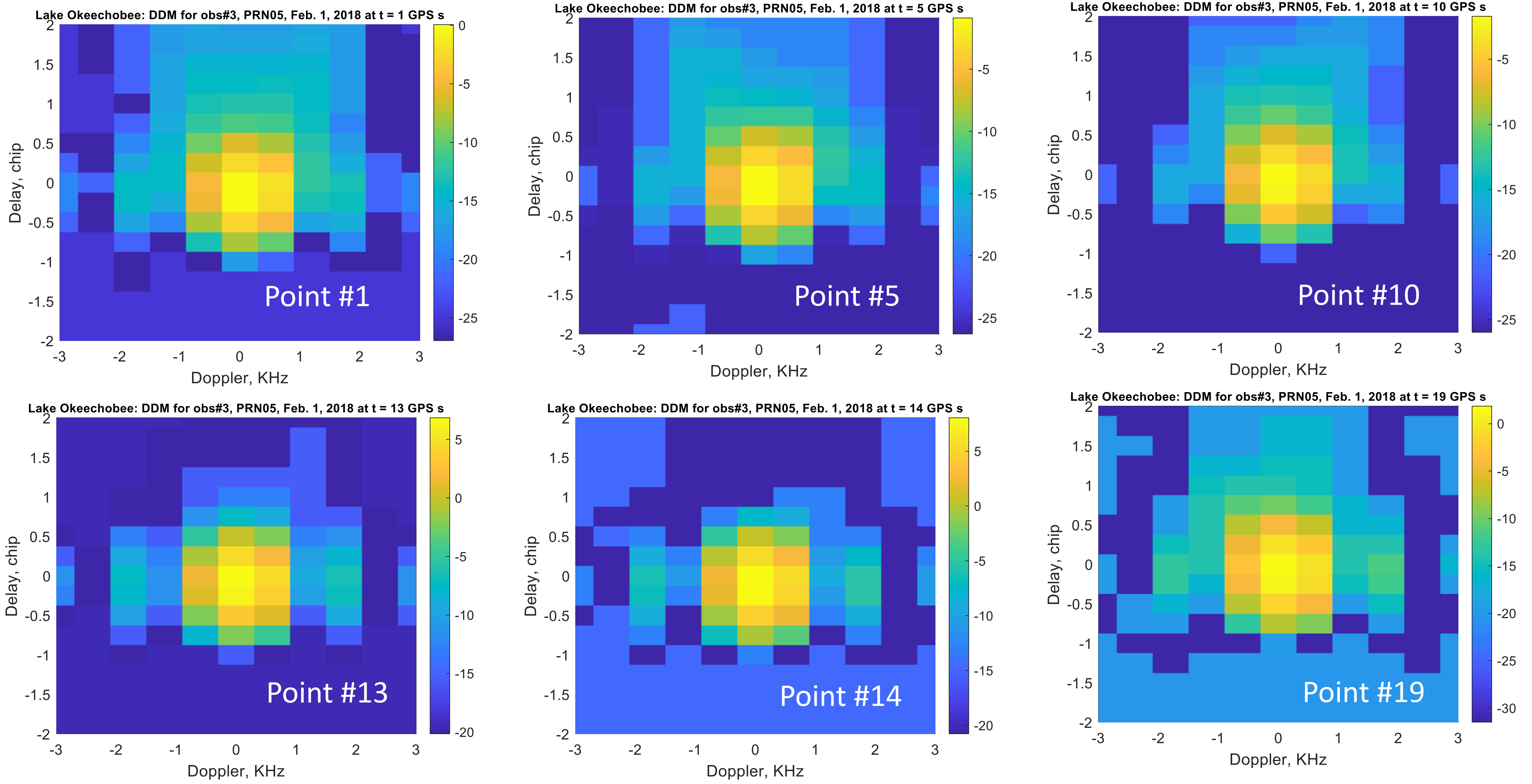
The points of the reflection track for PRN#5 over the lake and corresponding bistatic radar cross section σ° measured by CYGNSS observatory #3



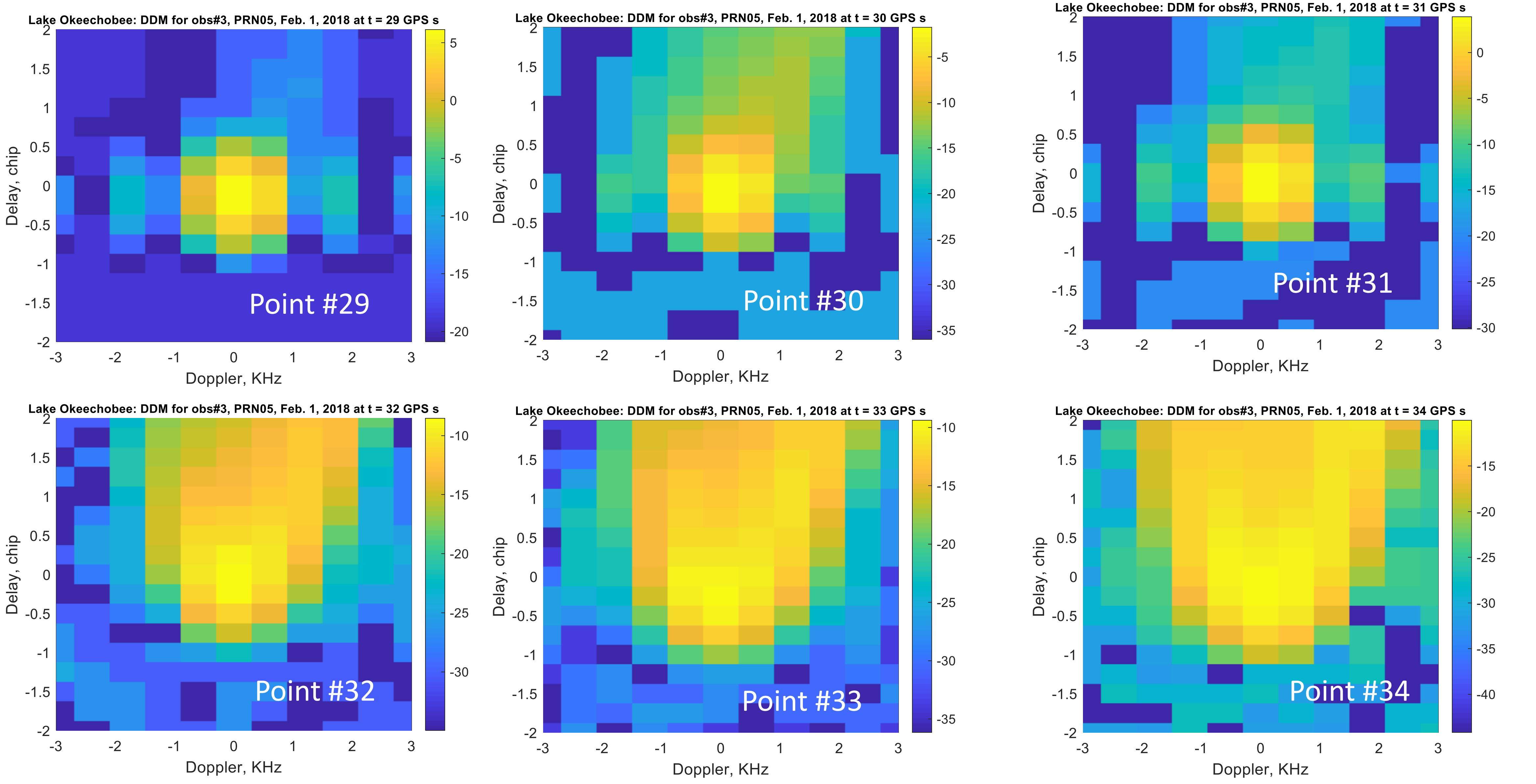


A strong reflected signal is found for points 13, 14 and 29, presumably a coherently reflected by the calm surface of the lake not significantly affected by the wind.

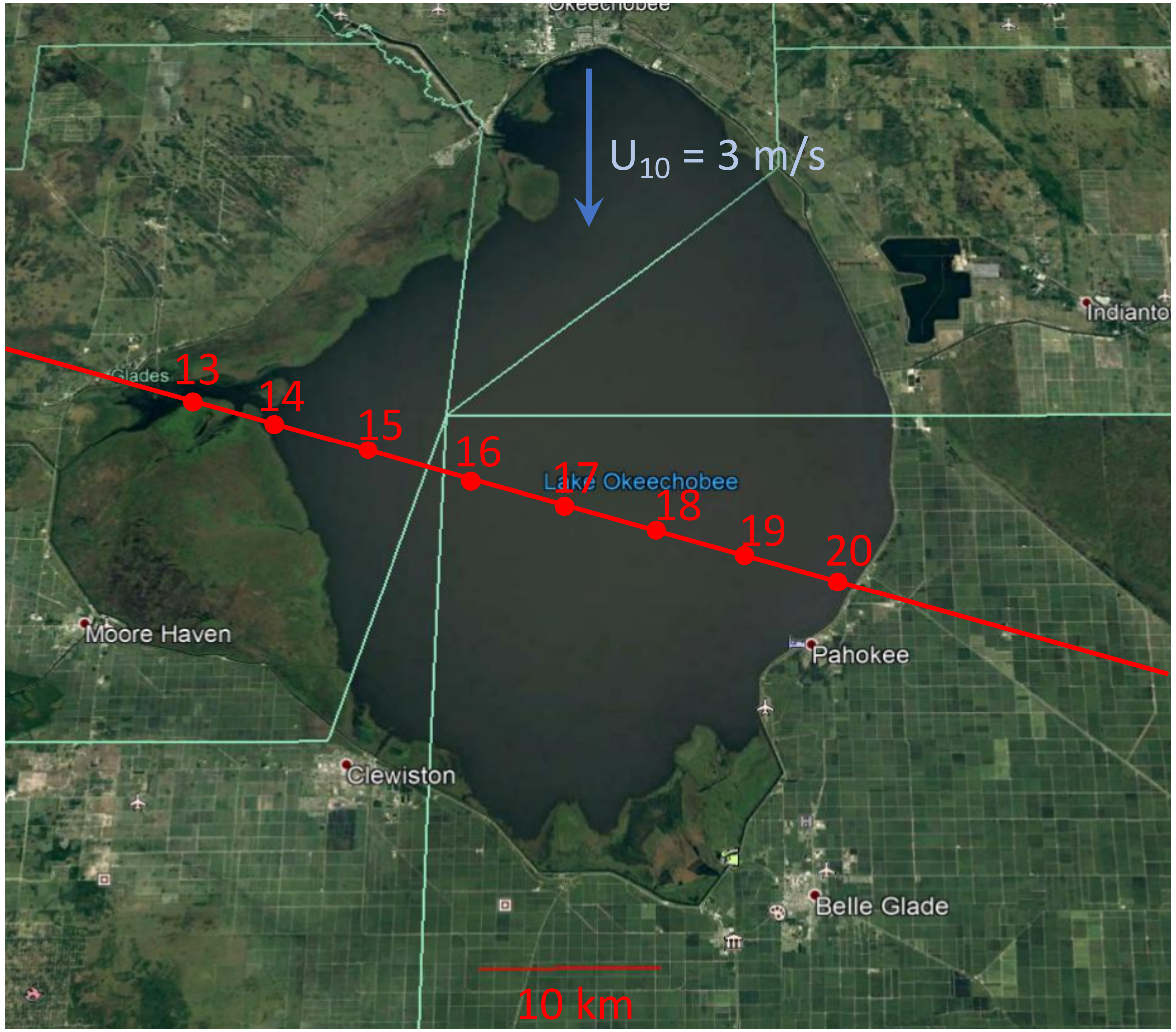
CYGNSS DDMs (in dBs) for several reflection points: incoherent weak diffuse scattering for points 1, 5, 10 and 19, and coherent specular reflection for points 13 and 14

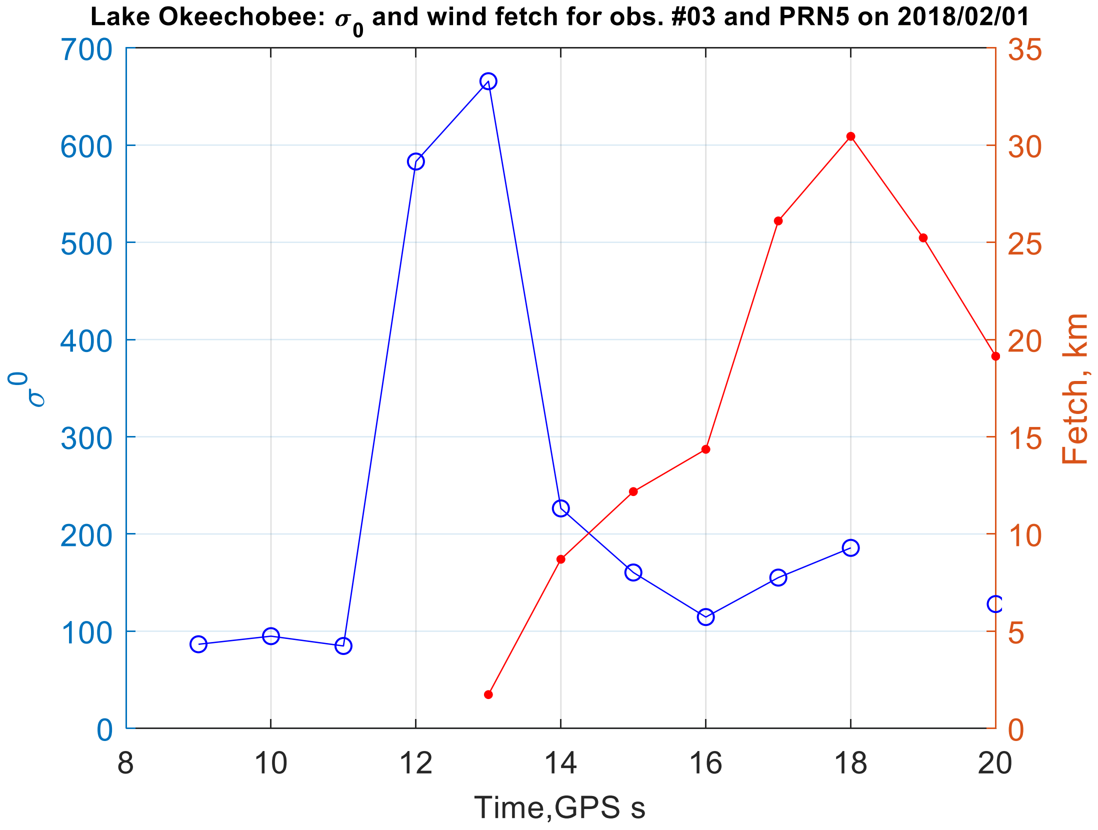


Examples of coherent specular reflection for point 29 (from a lake near West Palm Beach), and incoherent strong diffuse scattering for points 32-34 from the ocean



A more detailed picture of the scattering from the lake: increased decorrelation of the coherently reflected signal due to surface roughness in a presence of increased wind fetch



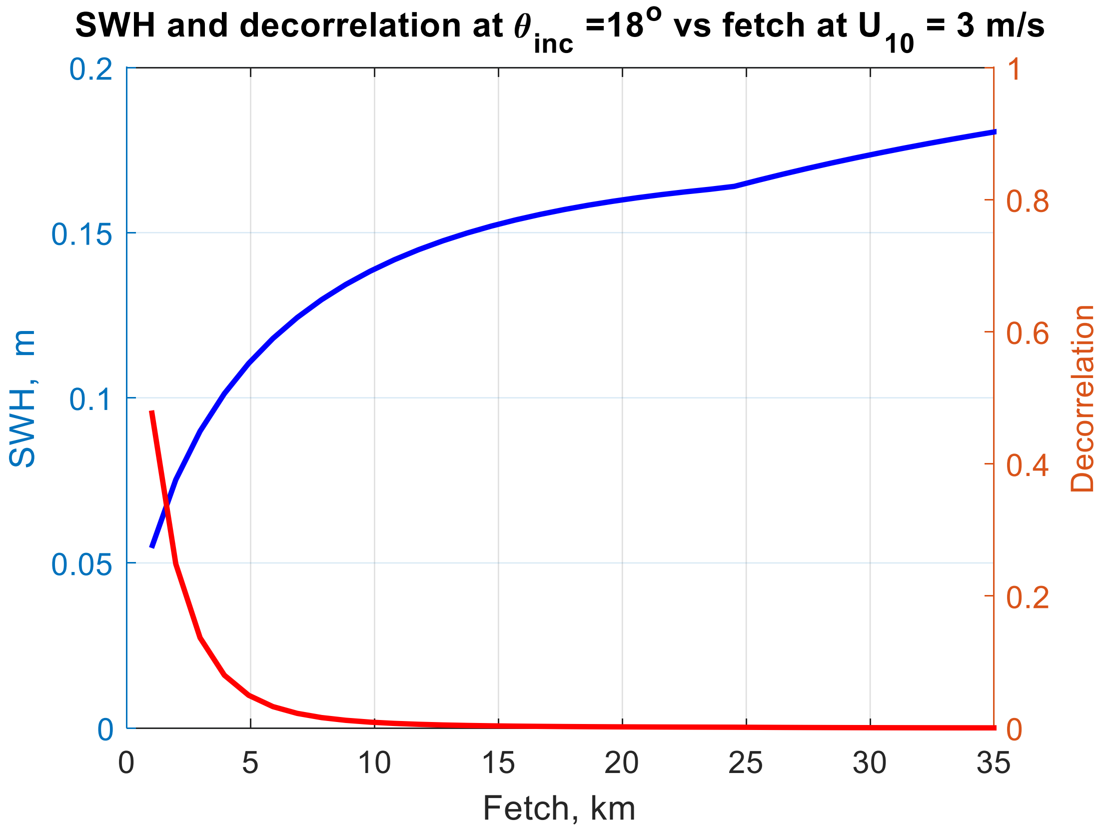


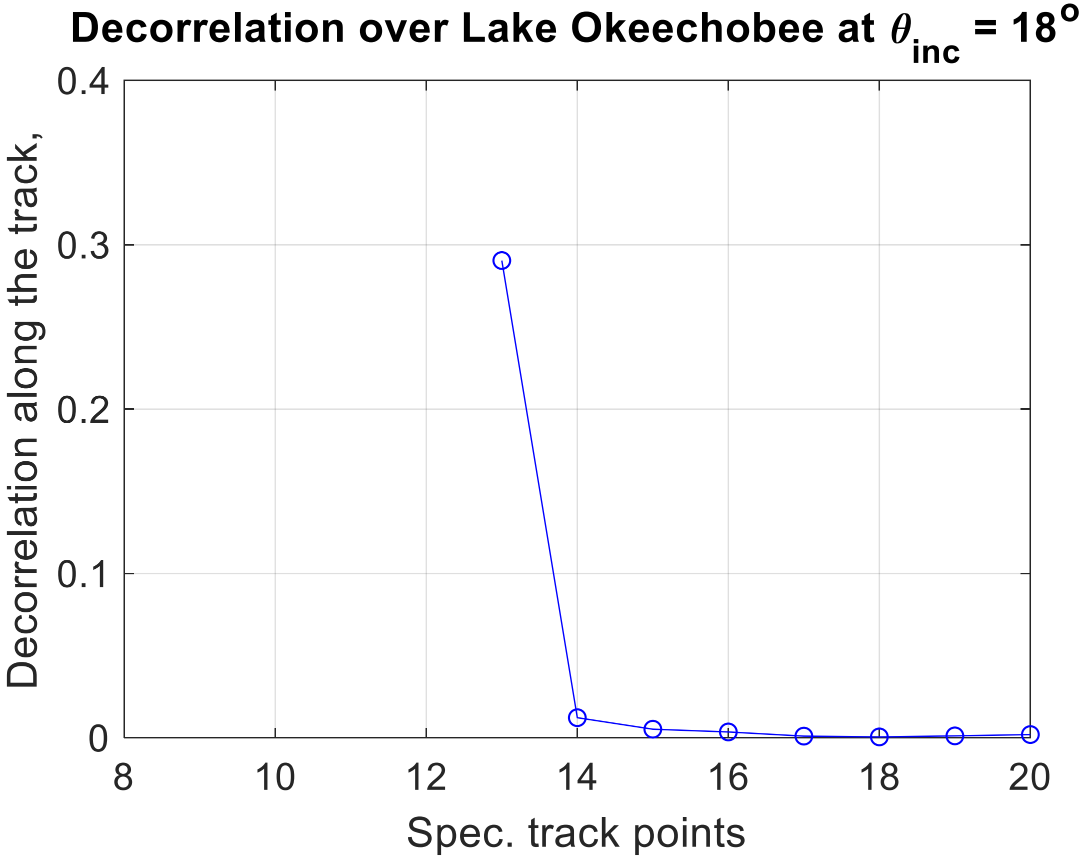
Results of modeling of the significant wave height (SWH) and the decorrelation as a function of fetch

$$\mathrm{SWH(fetch)} = 4*\langle h^2\rangle \equiv 4 * \iint \Psi(\kappa, fetch)\, d^2\kappa$$

Rayleigh parameter: $R_a = 0.5*\pi*\mathrm{SWH}*\cos\theta_{inc}/\lambda;$

Decorrelation: $\Gamma = \exp(-4* R_a^2)$





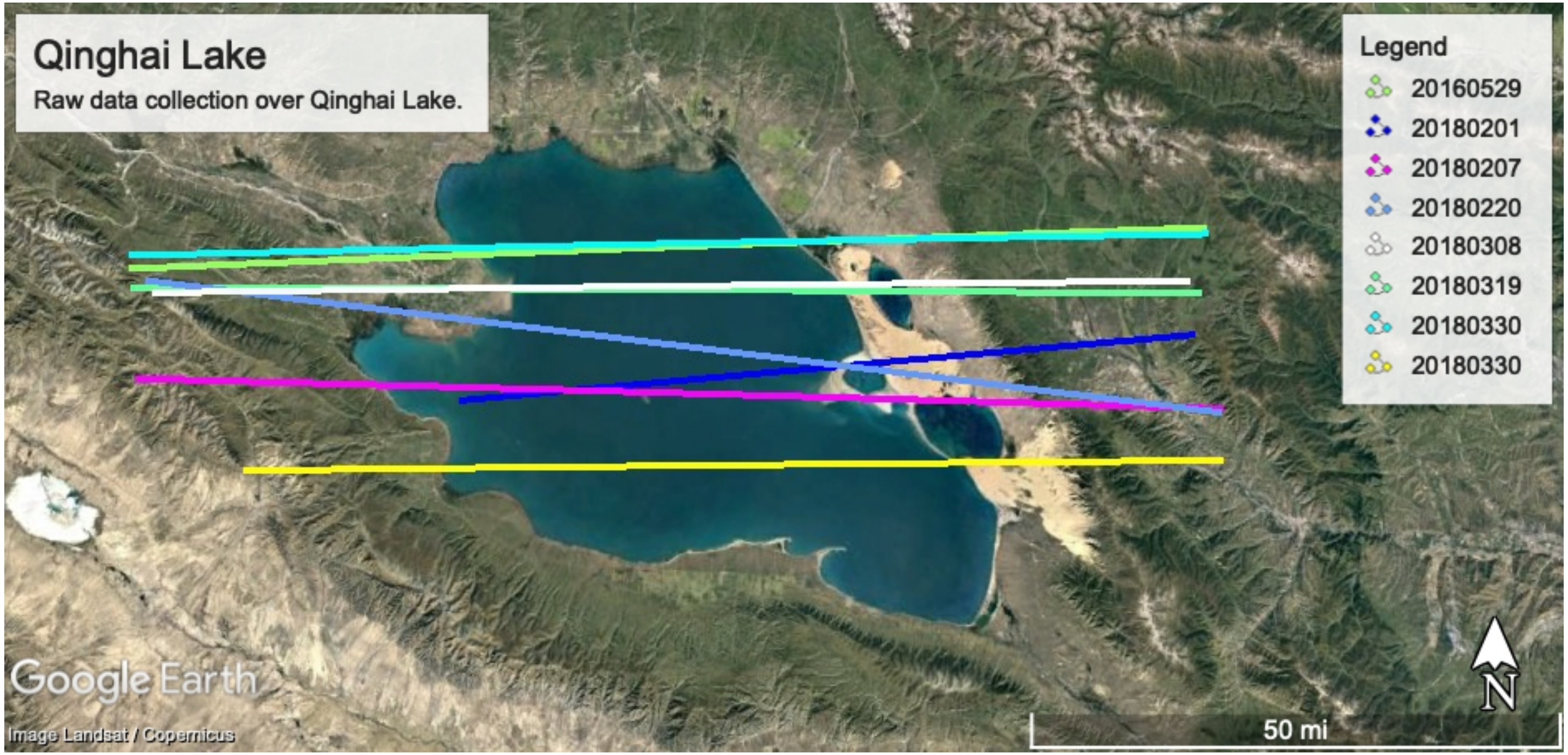
Analysis of Lake Qinghai Dataset

- Lake Qinghai is a saline-alkaline lake located in the northeast hollow of the Tibet Plateau, China.
- Extends from $36^{\circ}32'$ to $37^{\circ}15'$N ($\sim$70 km) and $99^{\circ}36'$ to $100\circ47'$E ($\sim$100 km), with an altitude of $\sim$3,200m above sea level.
- 8 tracks from 7 sets of L0 data collected near the Lake Qinghai from 1 February to 29 May 2018 is being analyzed (*similar to Li et al., 2018*)
  - Raw IF data are processed to produce 1 sec DDMs

Summary of Dataset Analyzed

Start Time	CYGNSS SC	GPS PRN	Incidence Angle	Surface Condition
2018-02-01T16:33:13	03	17	25.9–26.0^o	Ice
2018-02-07T14:35:02	05	28	22.1–22.2^o	Ice
2018-02-20T08:56:44	06	16	31.9-31.6^o	Ice
2018-03-08T00:43:41	05	10	27.3-27.6^o	Ice
2018-03-19T19:02:30	06	05	27.6-27.3^o	Ice
2018-03-30T13:42:57	04	17	27.7-27.1^o	Broken Ice
2018-03-30T13:42:57	04	19	25.0-25.1^o	Ice
2018-05-29T08:51:46	07	17	25.1–25.2^o	Open Water

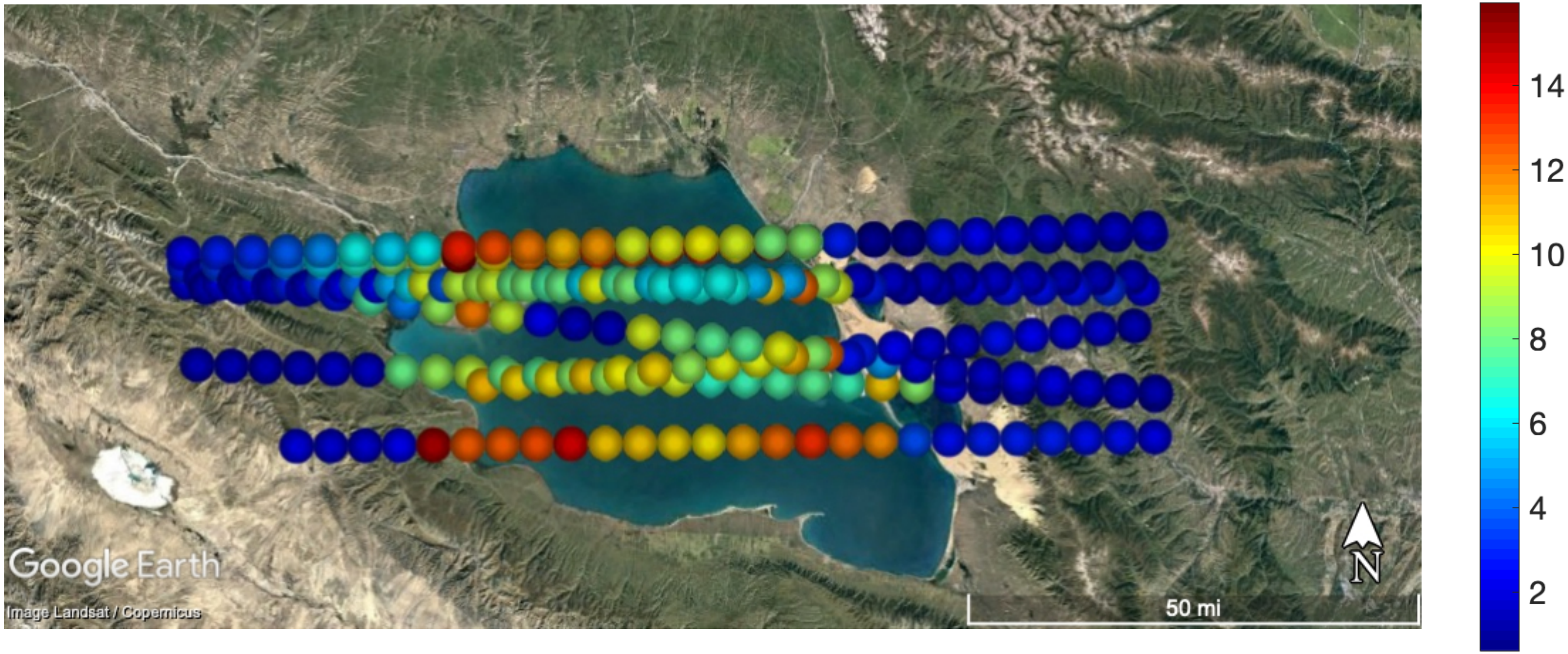
Tracks of Data Analyzed



Overlaps:

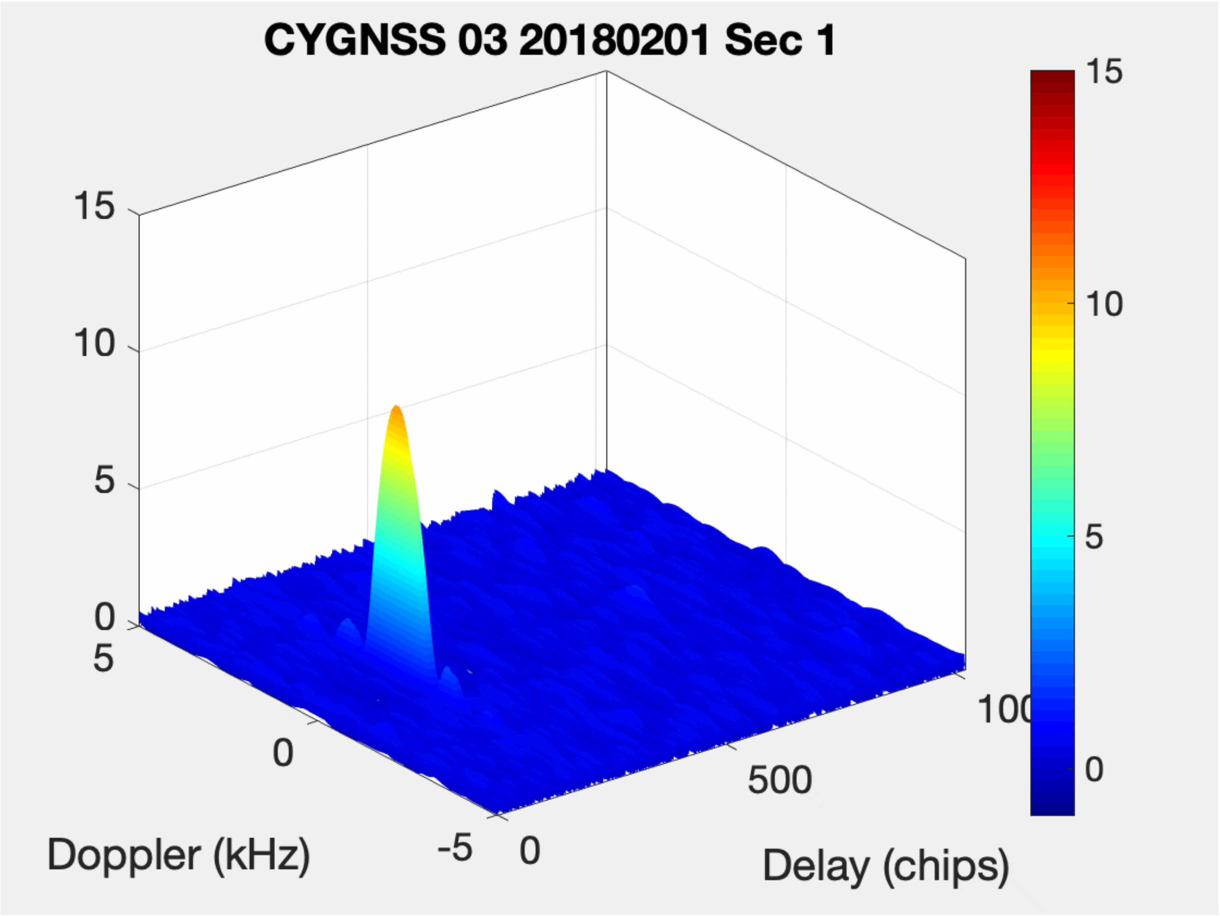
- 03/30 PRN 19 (Ice) and 05/29 PRN 17 (Open Water)
- 03/08 PRN 10 (Ice) and 0319 PRN 5 (Ice)

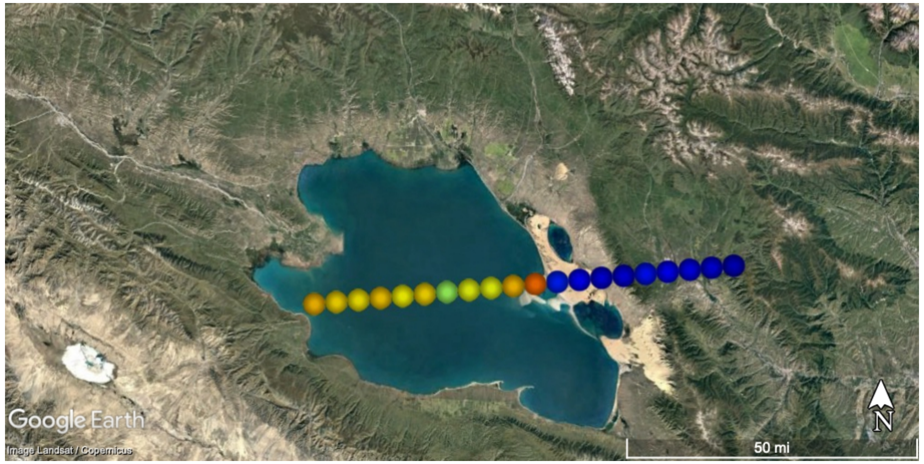
Power levels

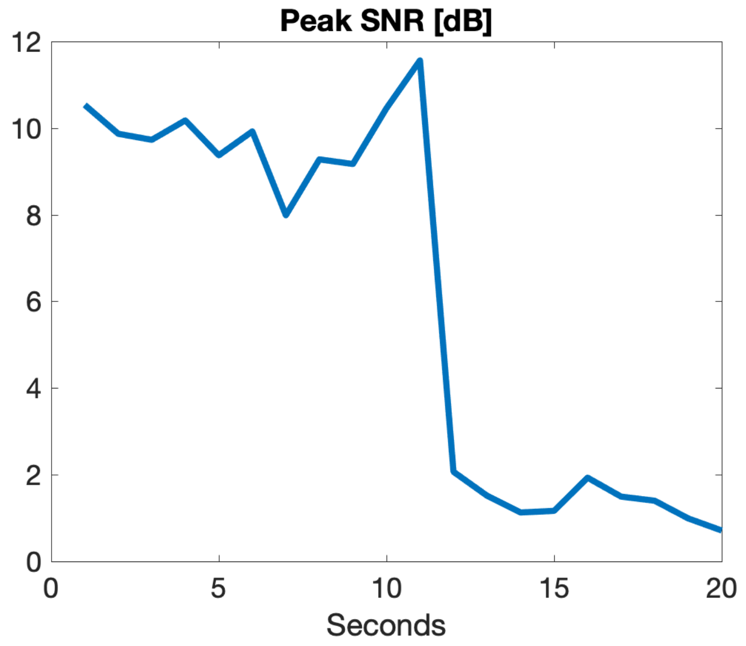


Power levels are generally high over lake but they are not consistent

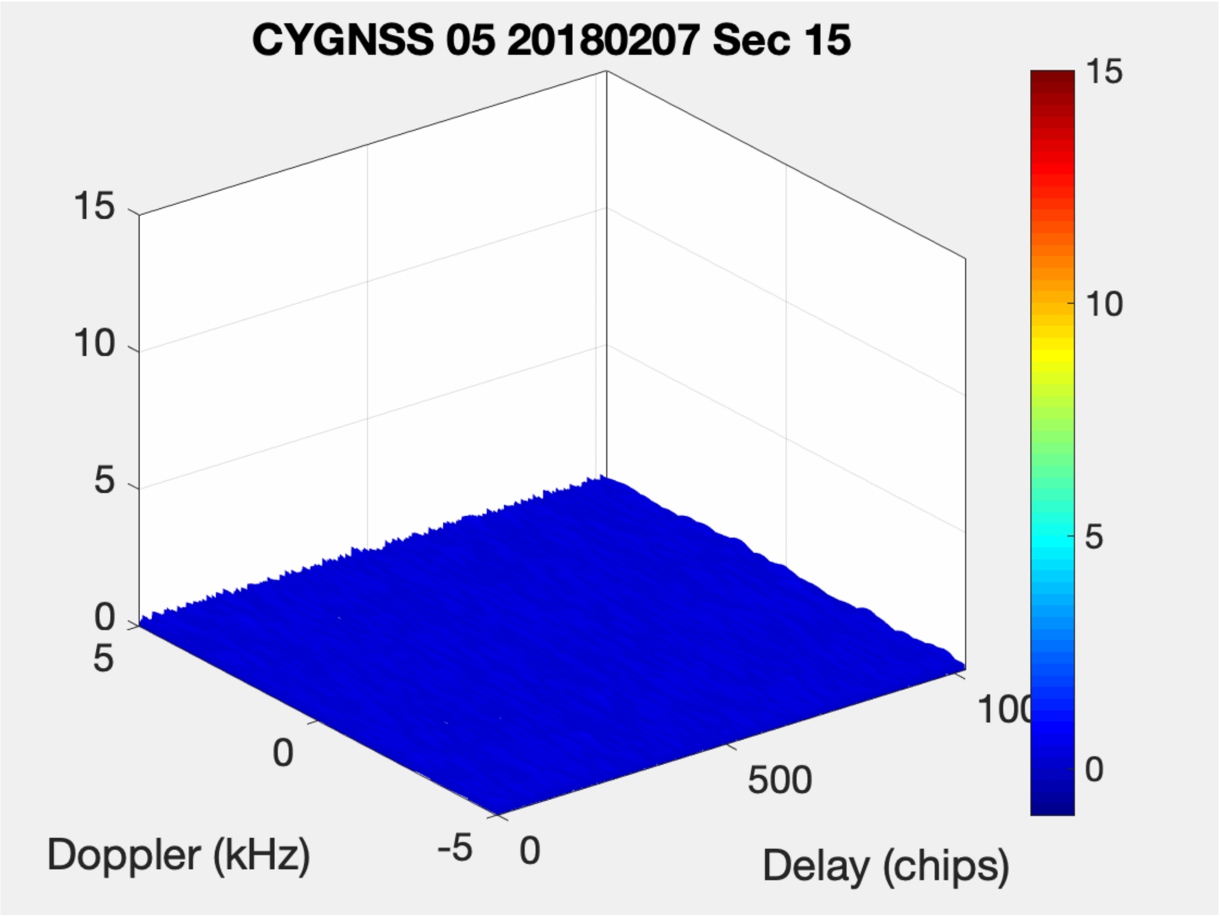
Feb. 01, 2018: Ice

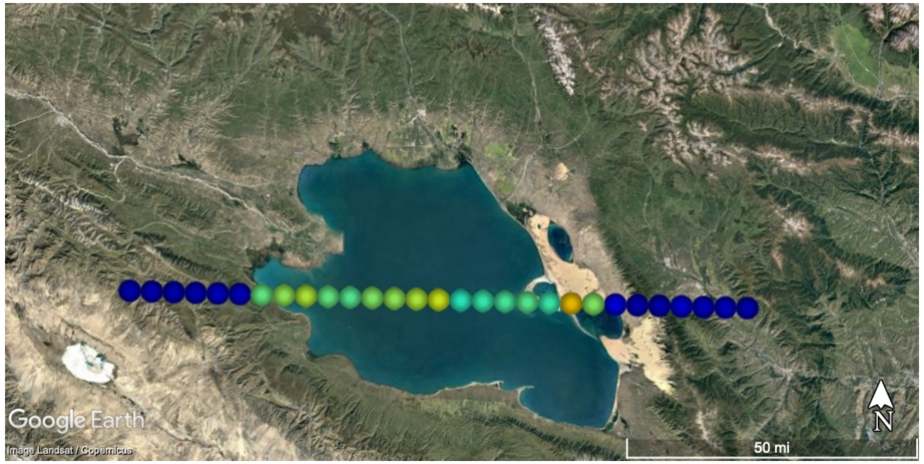


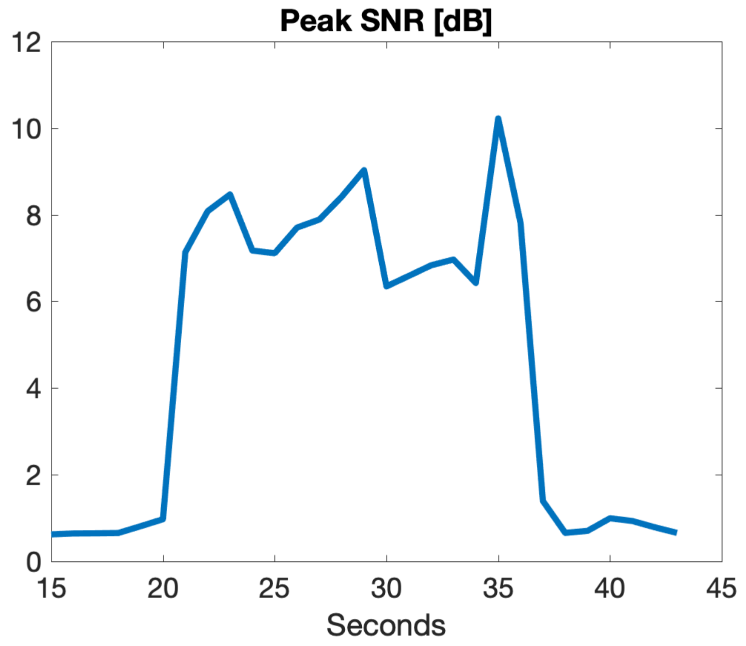




Feb. 07, 2018: Ice

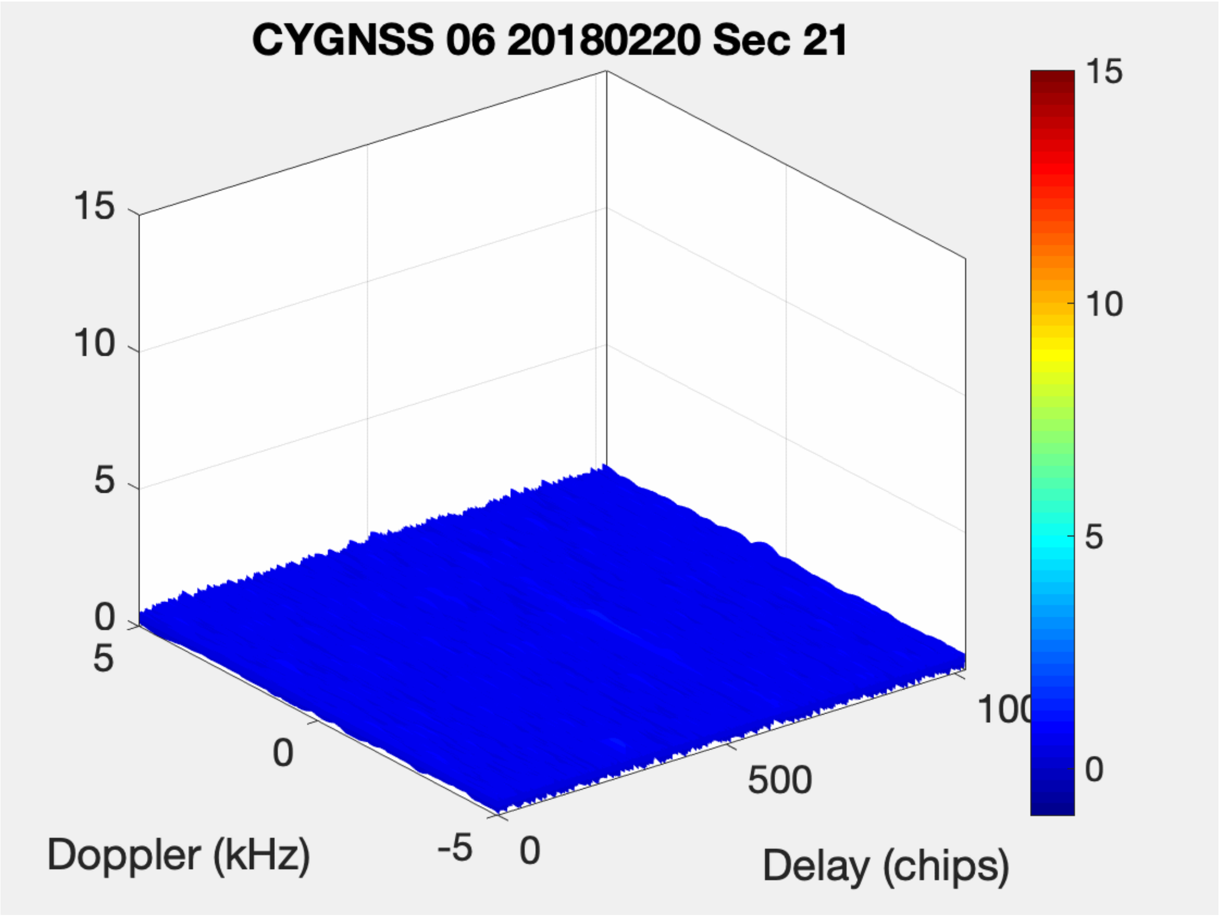


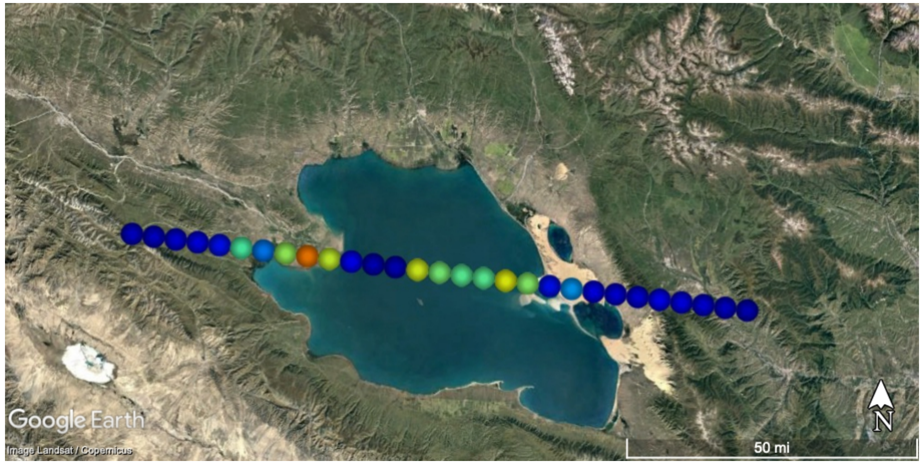


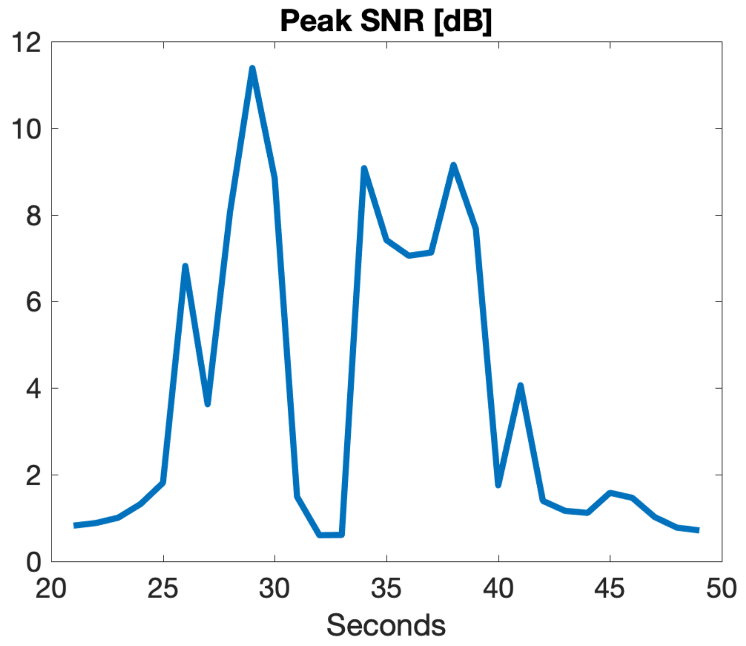


Feb. 20, 2018: Ice

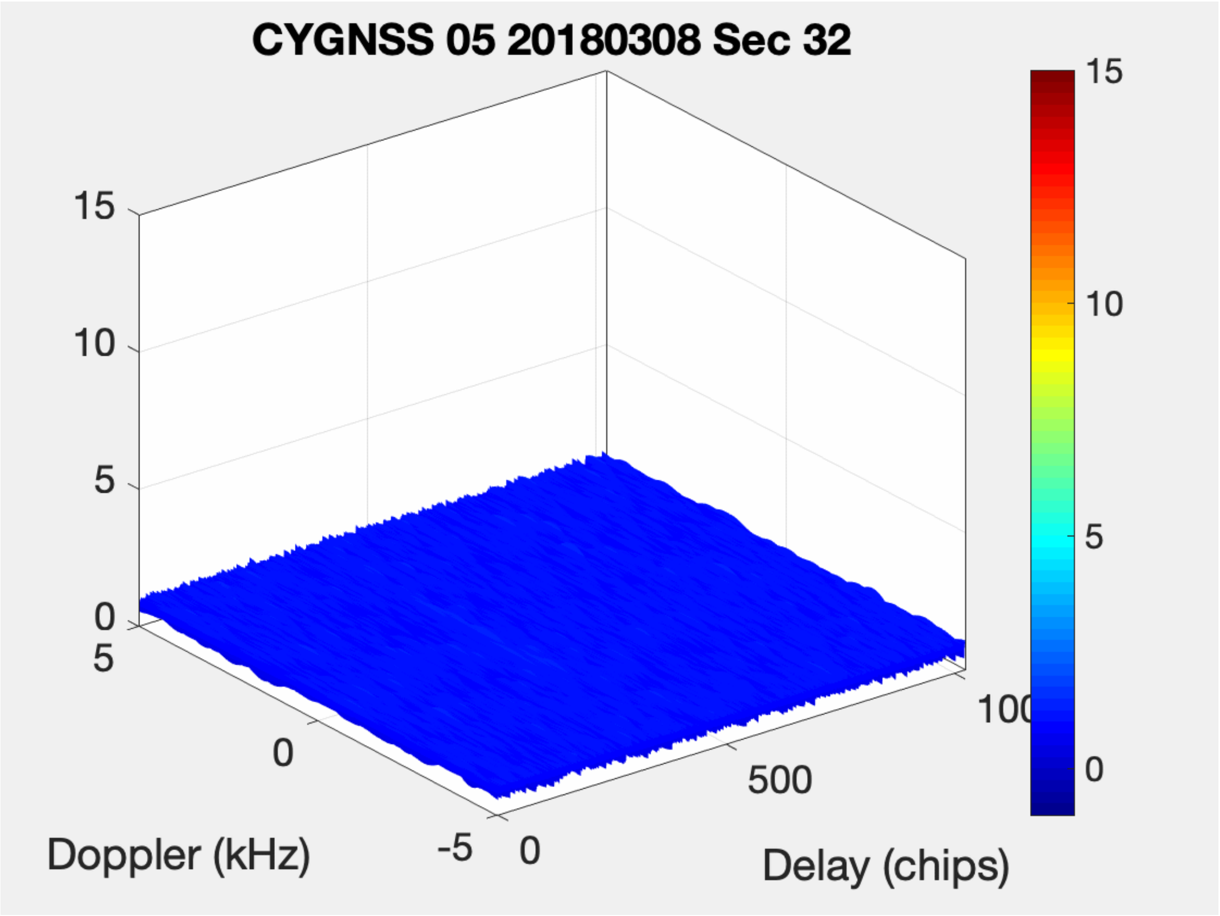
Loss of power in the middle: reason unknown

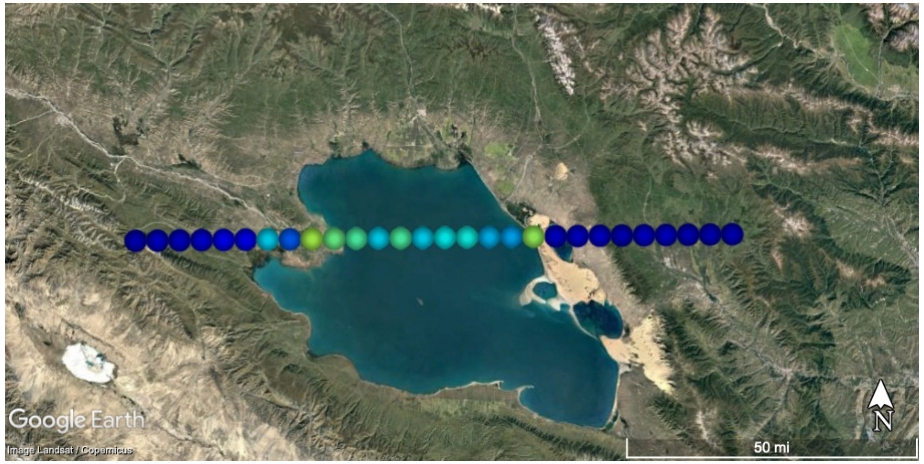


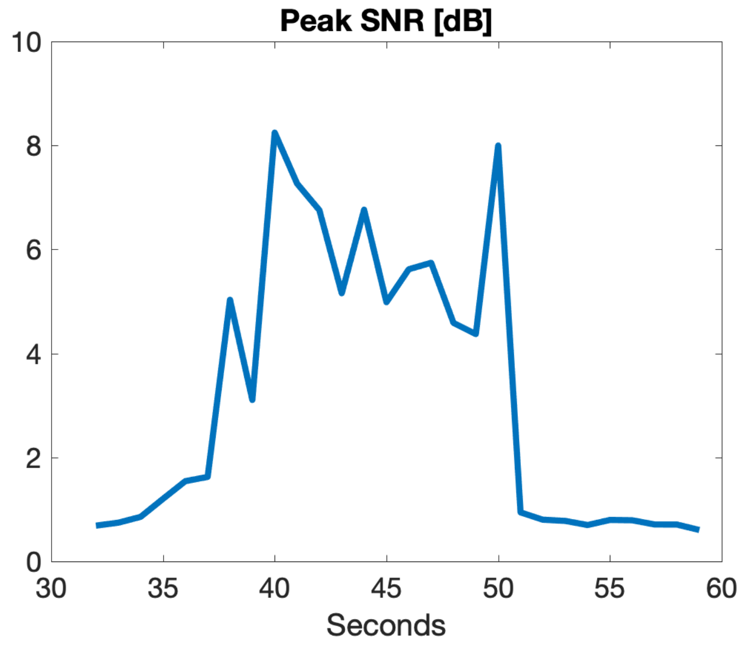




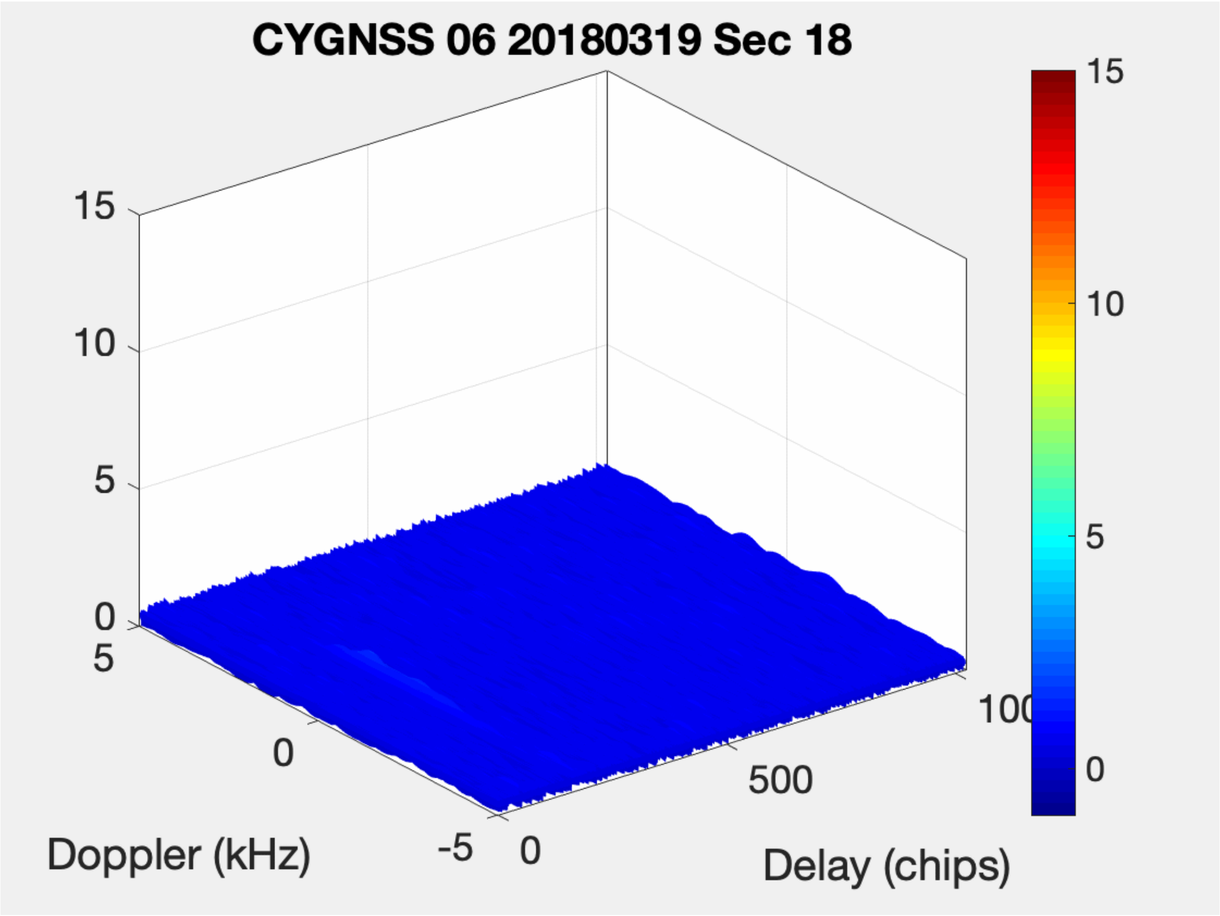
Mar. 08, 2018: Ice

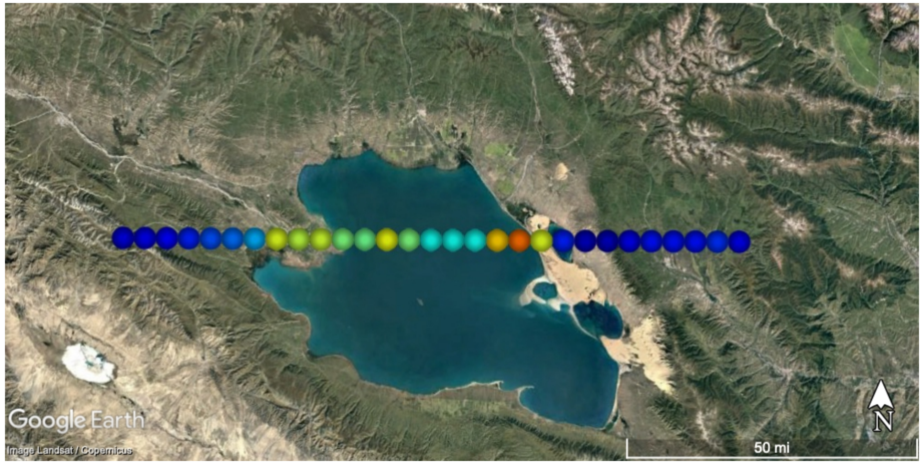


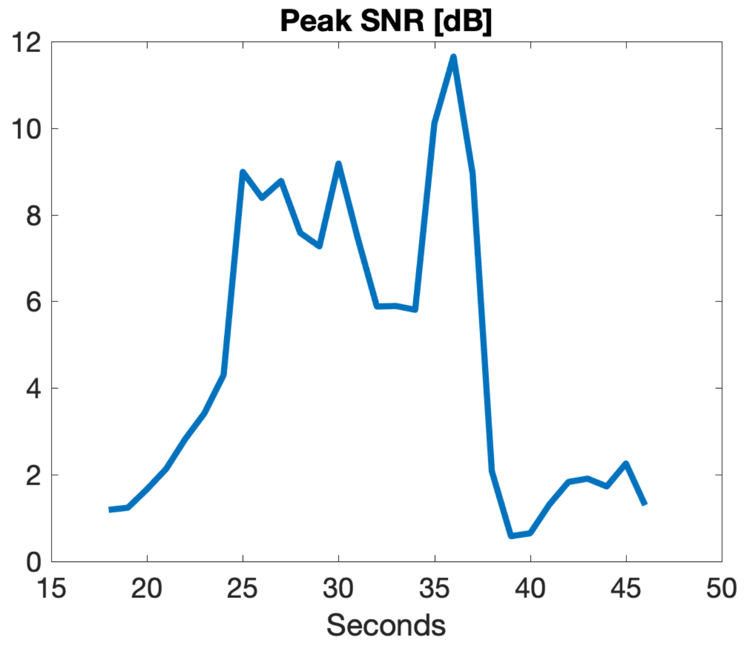




Mar. 19, 2018: Ice

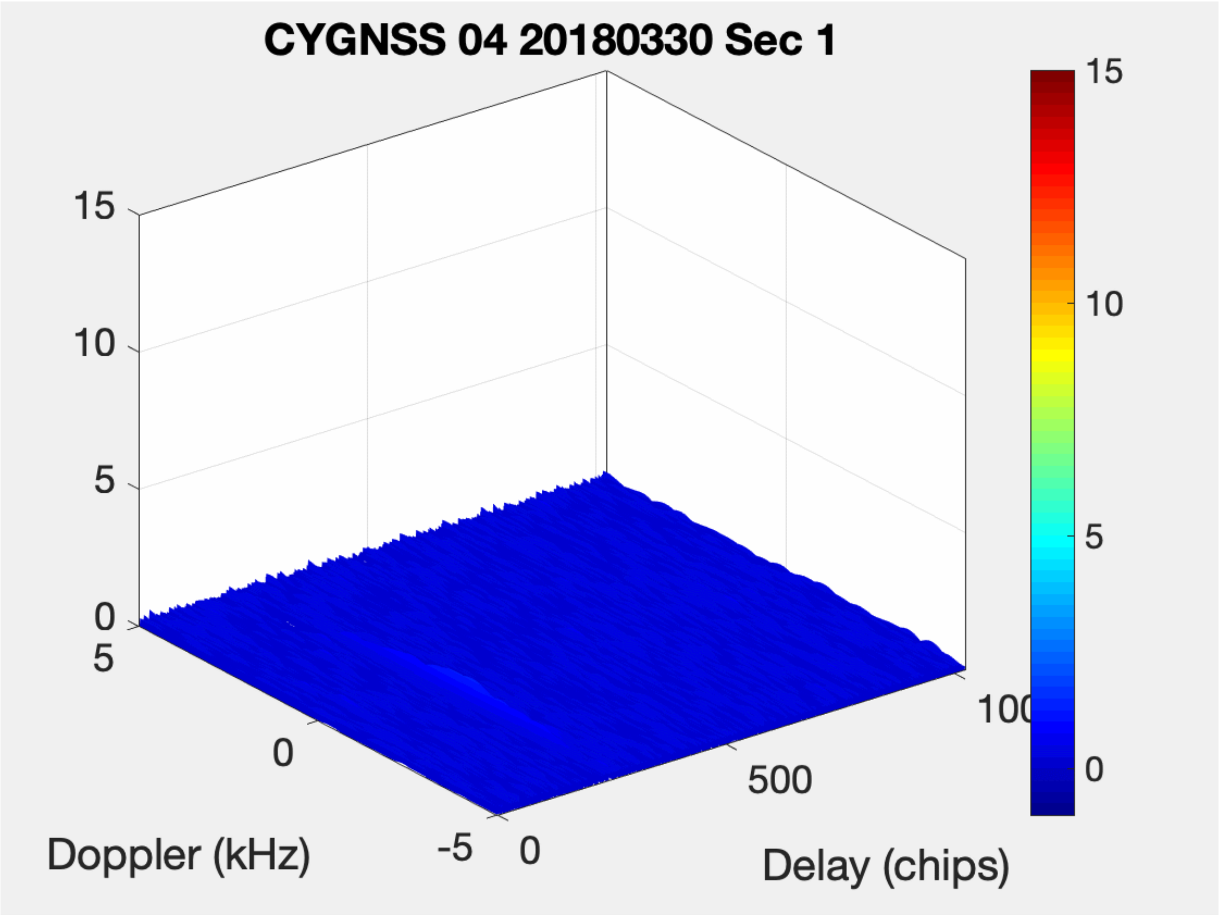


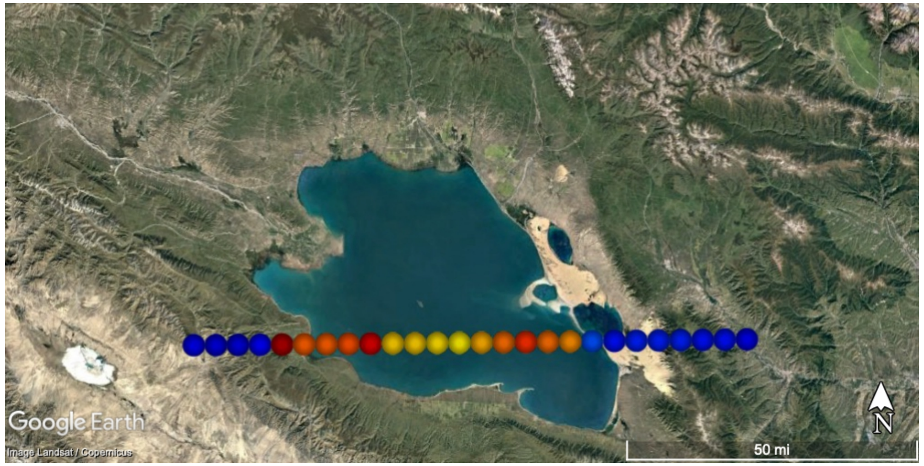


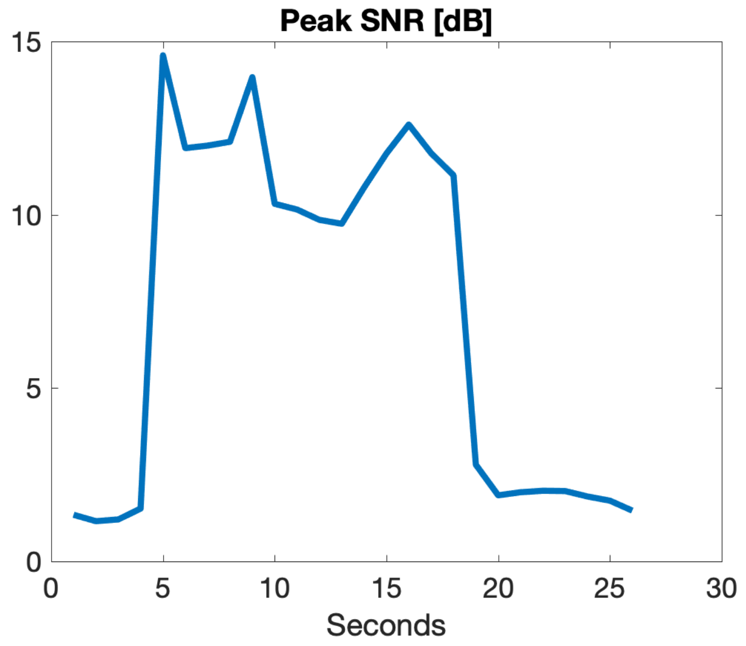


Mar. 30, 2018: Broken Ice

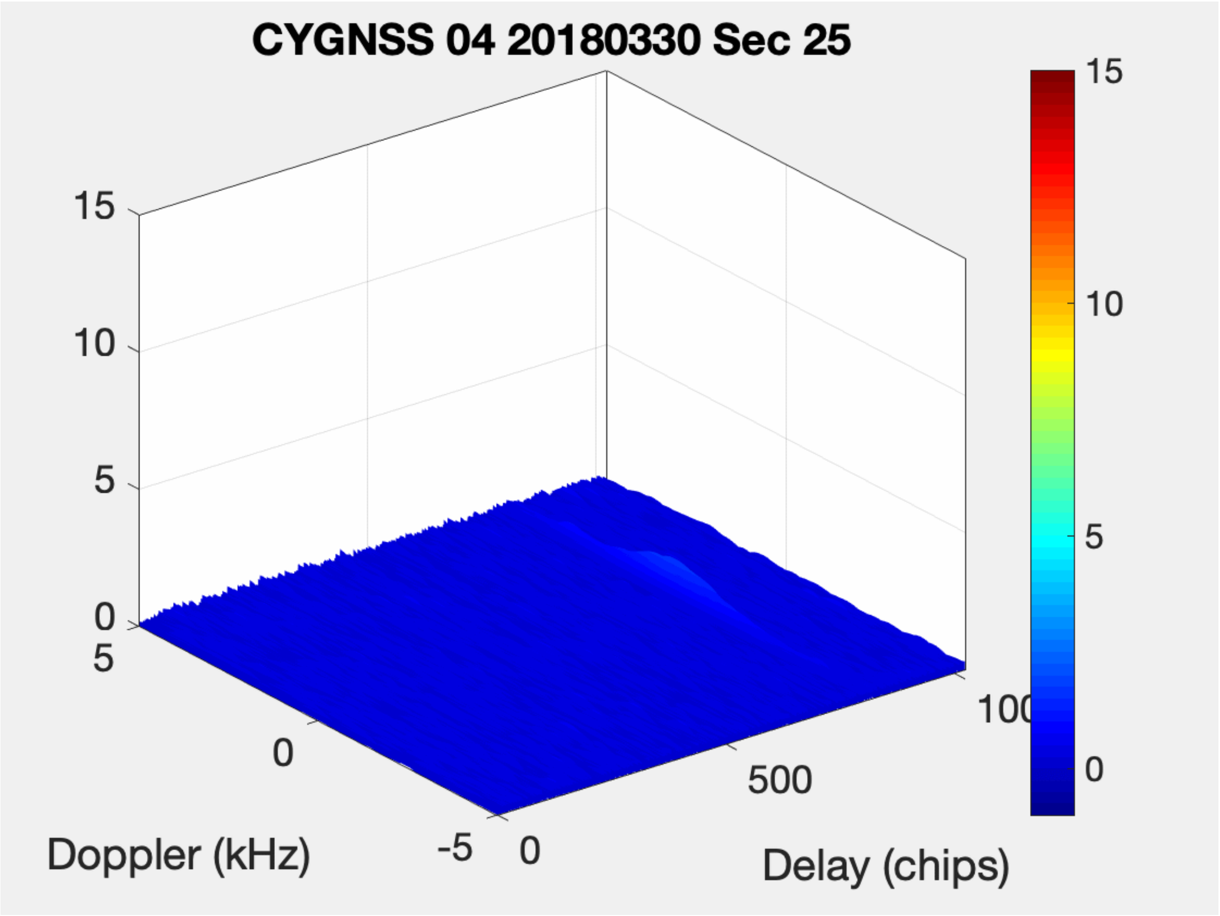
Higher peak in broken ice compared to ice

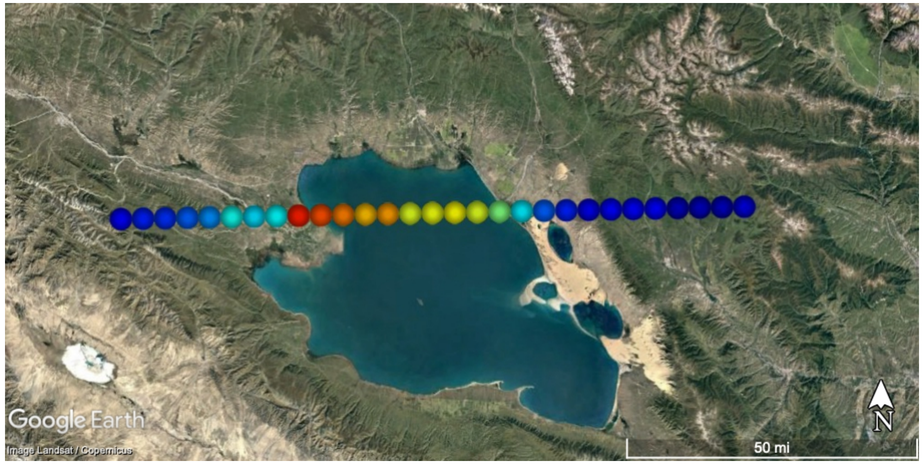


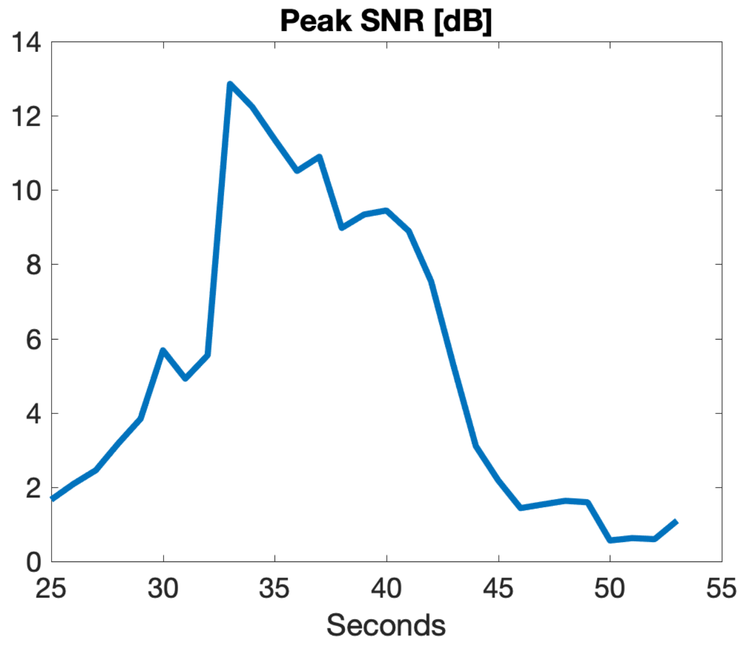




Mar. 30, 2018: Ice

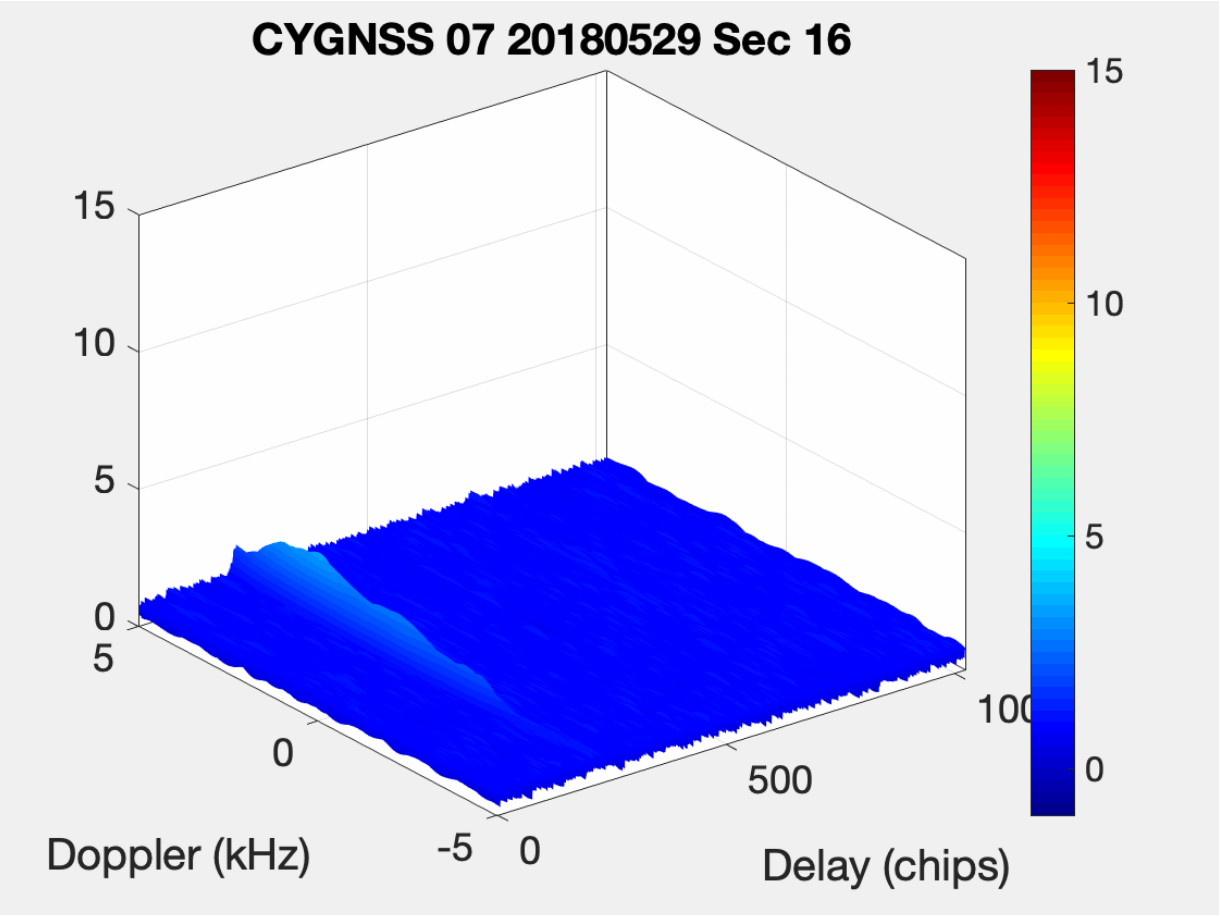


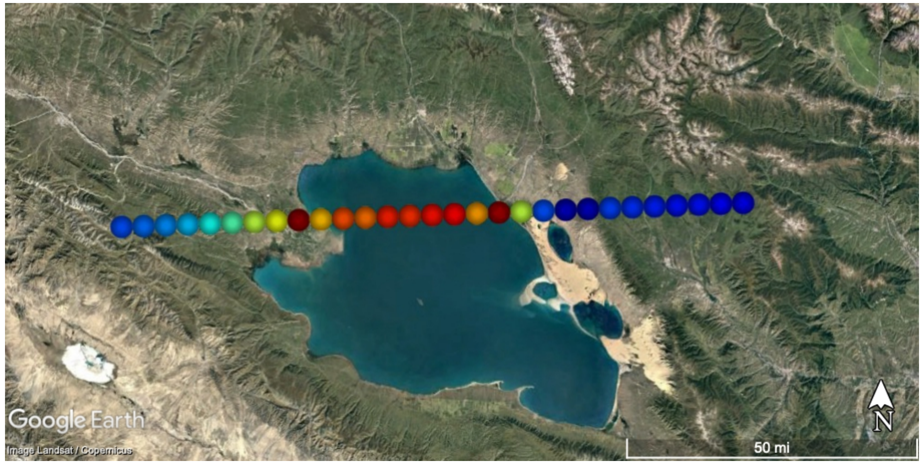


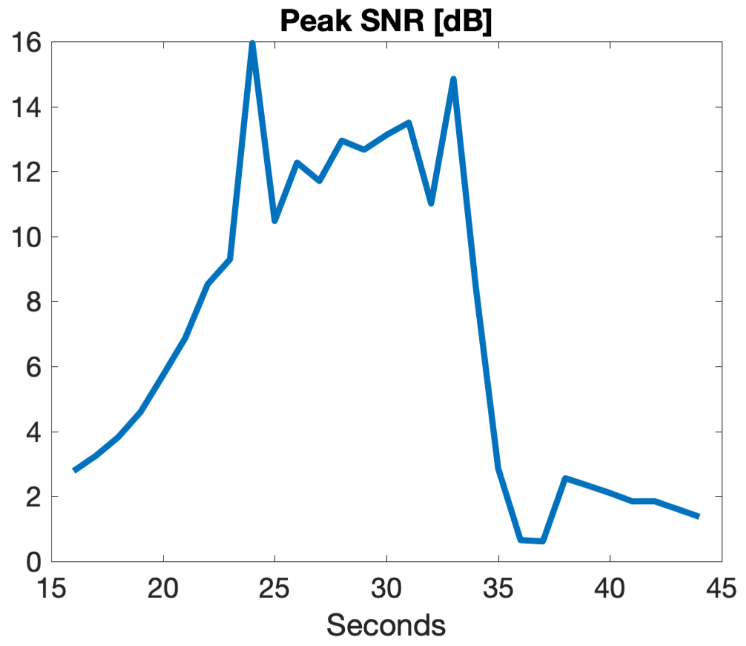


May 29, 2018: Open Water

More spreading in open water







Preliminary Observations

- Peak power levels (SNR) are highest in open water compared to ice, indicating calm water conditions with limited roughness
  - Meteorological data not known
- Lack of uniformity points to effect of contributions from area around specular reflection in the lake outside first Fresnel zone, which varies along the track
- Pond at one edge of the lake seems to create a strong coherent reflection