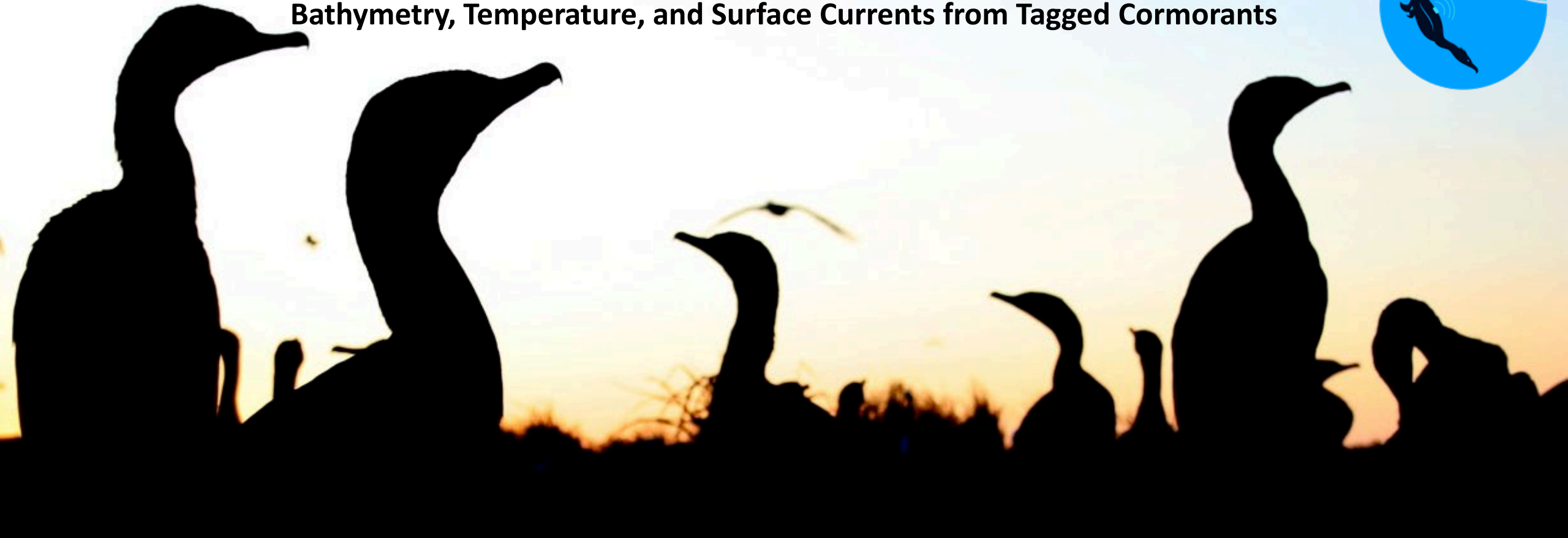
# A Novel Method for Columbia River Estuary Environmental Measurements:

## Bathymetry, Temperature, and Surface Currents from Tagged Cormorants



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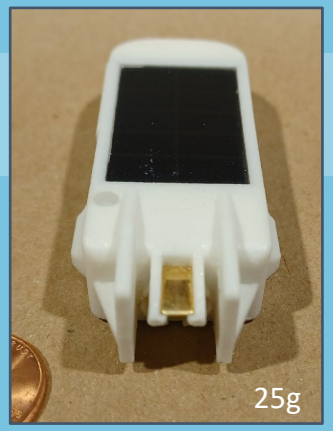
Office of Naval Research Science & Technology

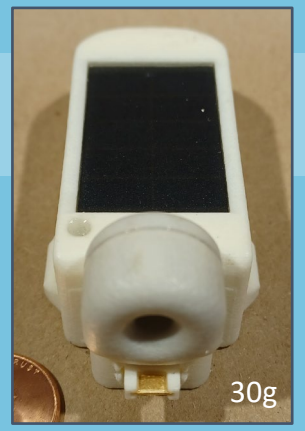
# Cormorant Oceanography Project Objectives

- Develop small biologging devices (<40g) with oceanographic sensors to deploy on diving marine birds
    - Sensors include pressure, temperature, conductivity, inertial measurement unit (IMU) and GPS
    - GSM communications and solar cell battery charging; long deployment periods, 1 month to > 1 year
- Low-latency oceanographic data processing and access
    - Temperature/salinity profiles, bottom soundings, surface currents, surface wave statistics
    - Data to be shared publicly through the Animal Telemetry Network (https://ioos.noaa.gov/project/atn/)
- Utilize biologging measurements in operational data assimilative coastal ocean models [Ardag and Wilson (2021); Ardag et al., (2023)]

# The Tags

***Combining Sensors, Smart Programming, & Bird Behavior***




- ***Bottom soundings*** are measured by 1Hz pressure from benthic dives. These are geo-referenced by GPS fixes on surfacing.
- Fast response temperature sensor and conductivity sensor for *water column temperature and salinity* at 1Hz when bird is diving.
- Post dive GPS burst for measuring *surface currents* at 1Hz for 10sec.
- *Surface waves* measured by a 3-axis accelerometer and magnetometer at 5Hz resolution.

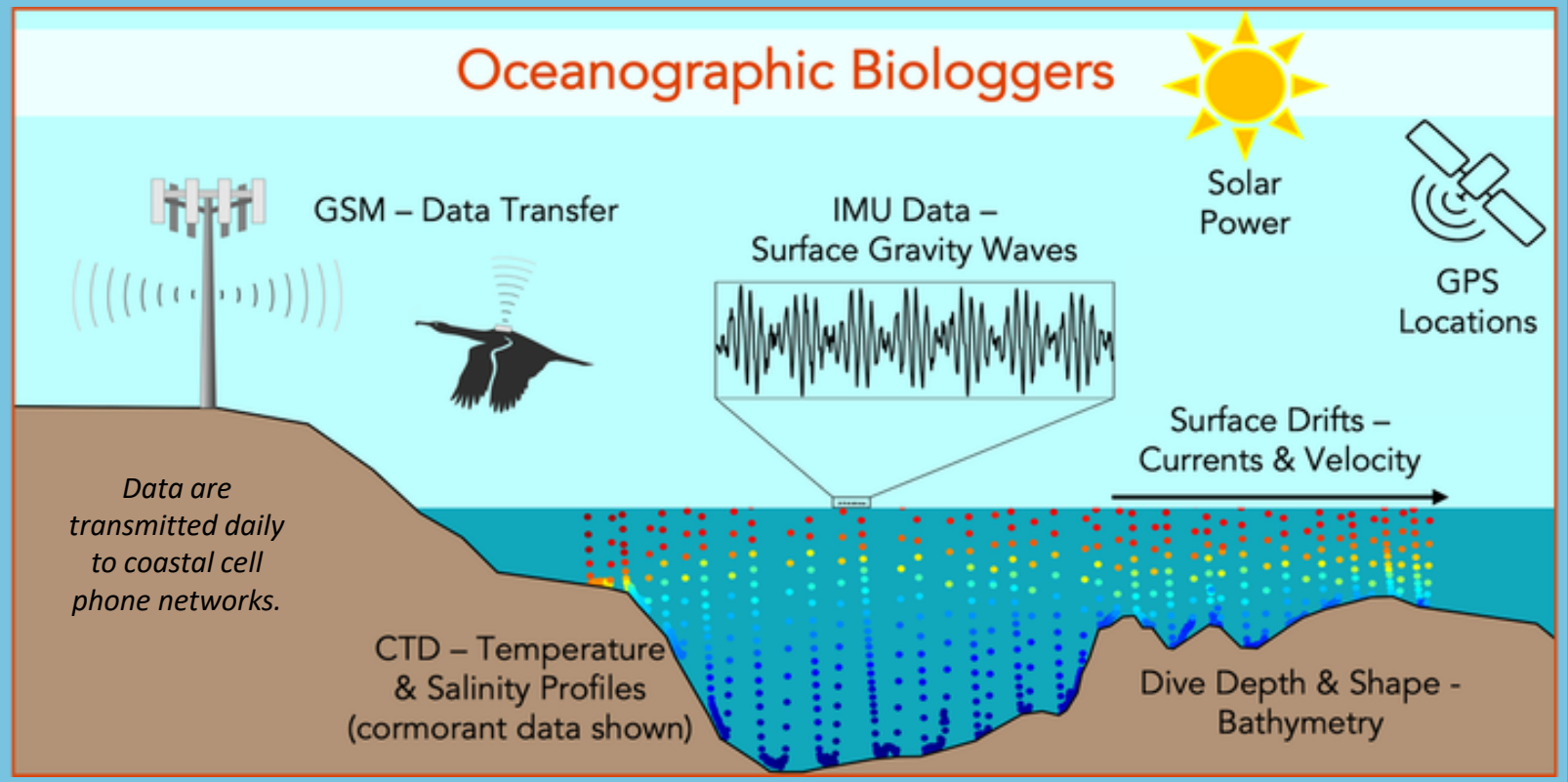
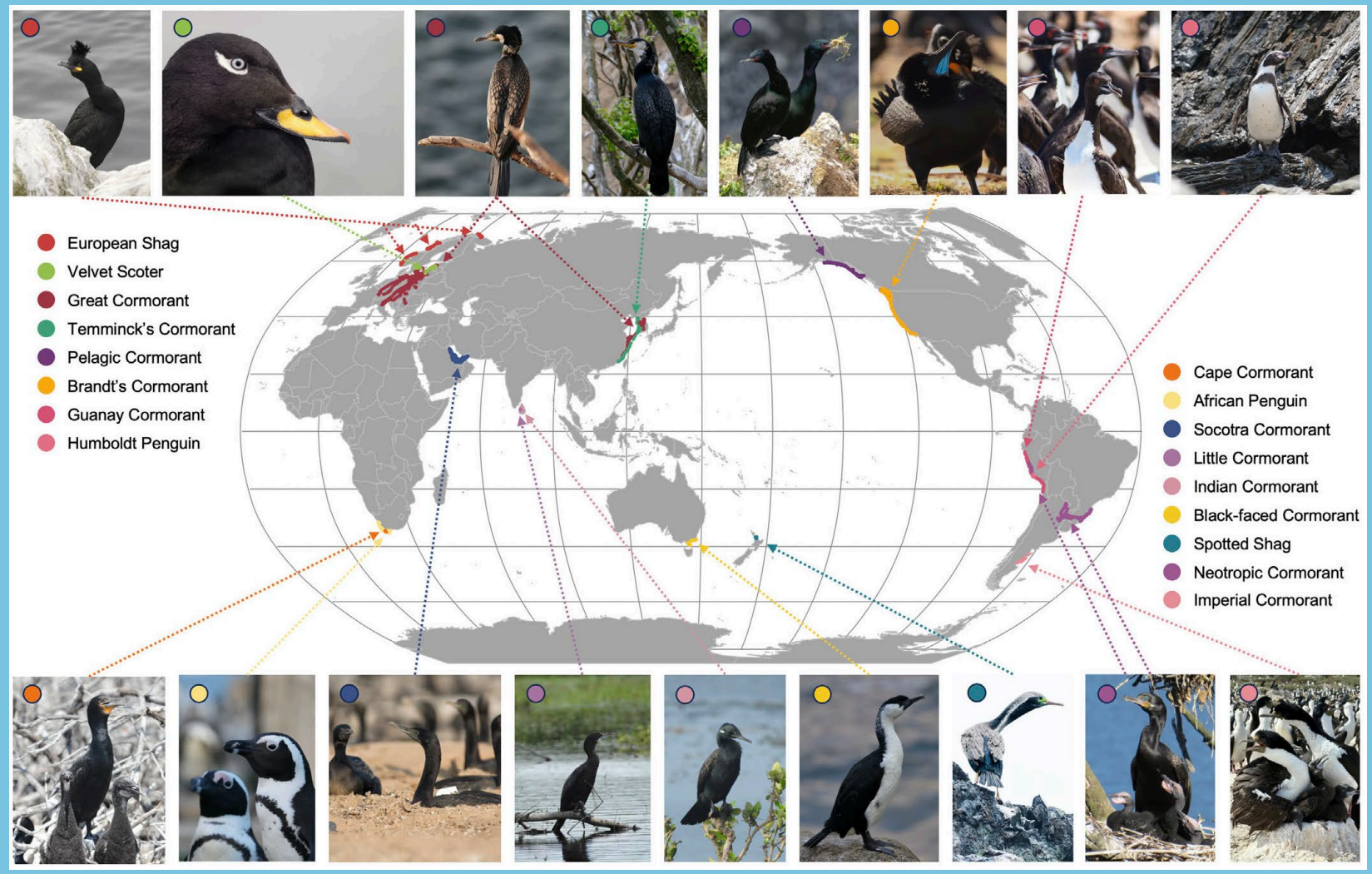



Figure adapted from Orben et al., 2021, *Eos, 102*, https://doi.org/10.1029/2021EO163427.

# Tagging in Estuaries and Coastal Regions Across the Globe




Orben et al. (2025)

# Tagging in Estuaries and Coastal Regions Across the Globe

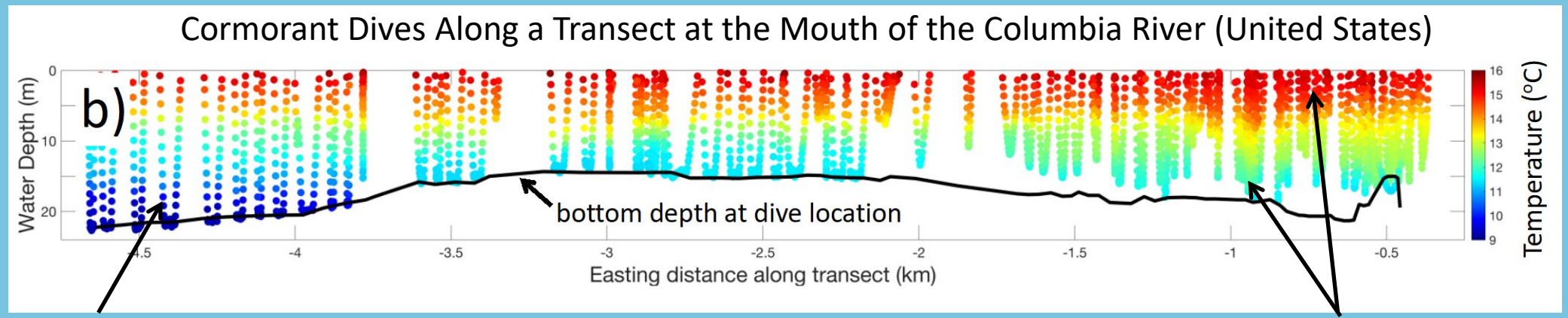
## Global Deployments

- 20 countries
- 17 marine bird species (14 cormorants, 2 penguin, 1 sea duck)
- ~300 tags deployed
- **~5,000,000 dives to date**

## Columbia River Tag Deployments

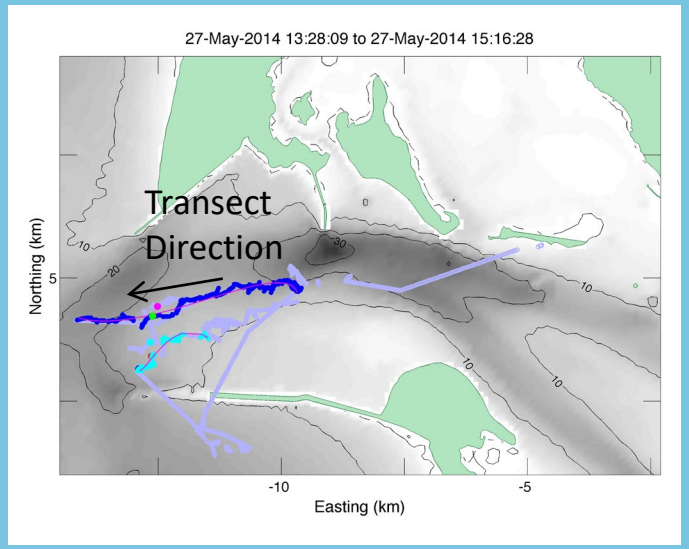
- Three deployments (2013/2014, 2019, 2022)
- Total number of dives:  382,000

# Temperature/Salinity Profiles




Cold N. Pacific Ocean Water.

Highly Stratified Estuarine Water.

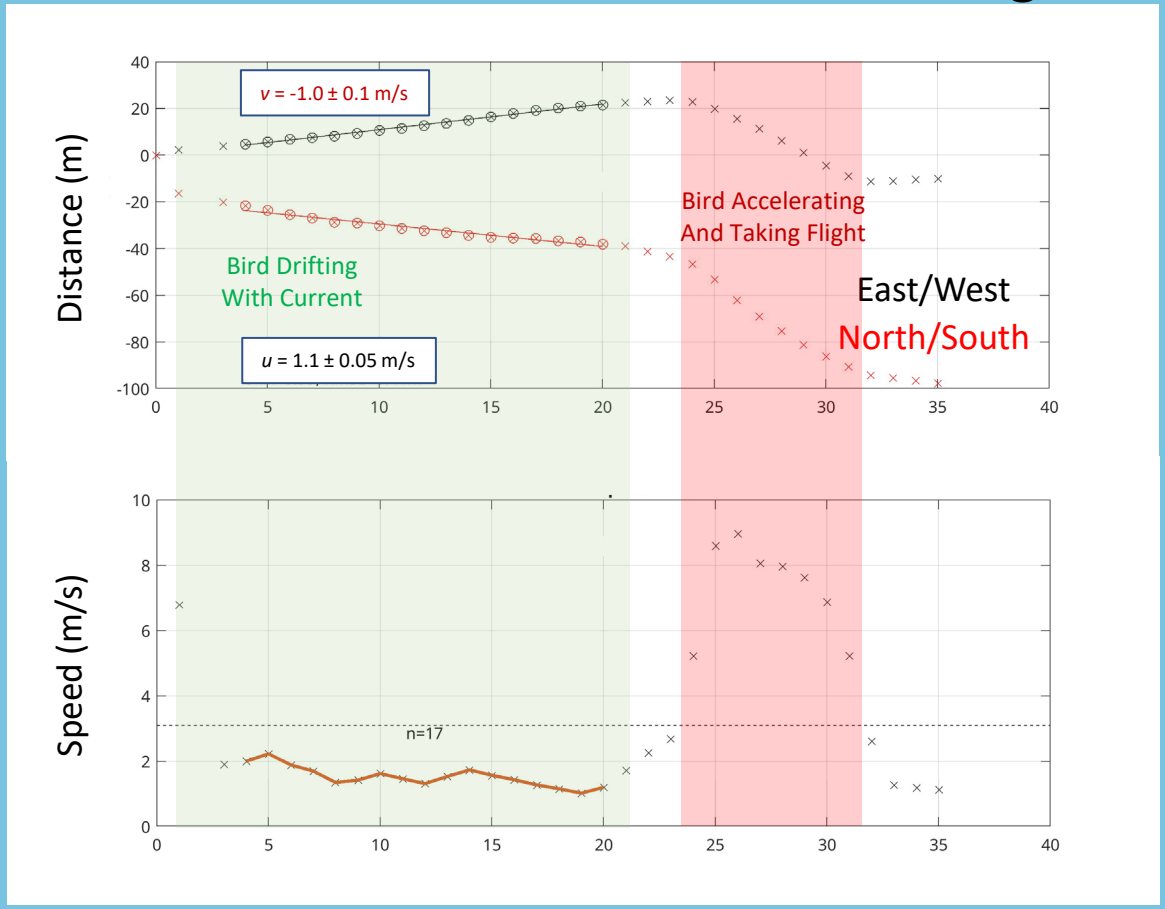



- Detailed vertical temperature profiles from a series of dives from a single tagged Brandt's cormorant within the Columbia River estuary (United States)
- Many dives are benthic dives (left half of figure), providing accurate bottom soundings
- Surface currents are calculated between dives, when tagged birds drift at the surface

Brandt's Cormorant
Columbia River Estuary

# Surface Currents

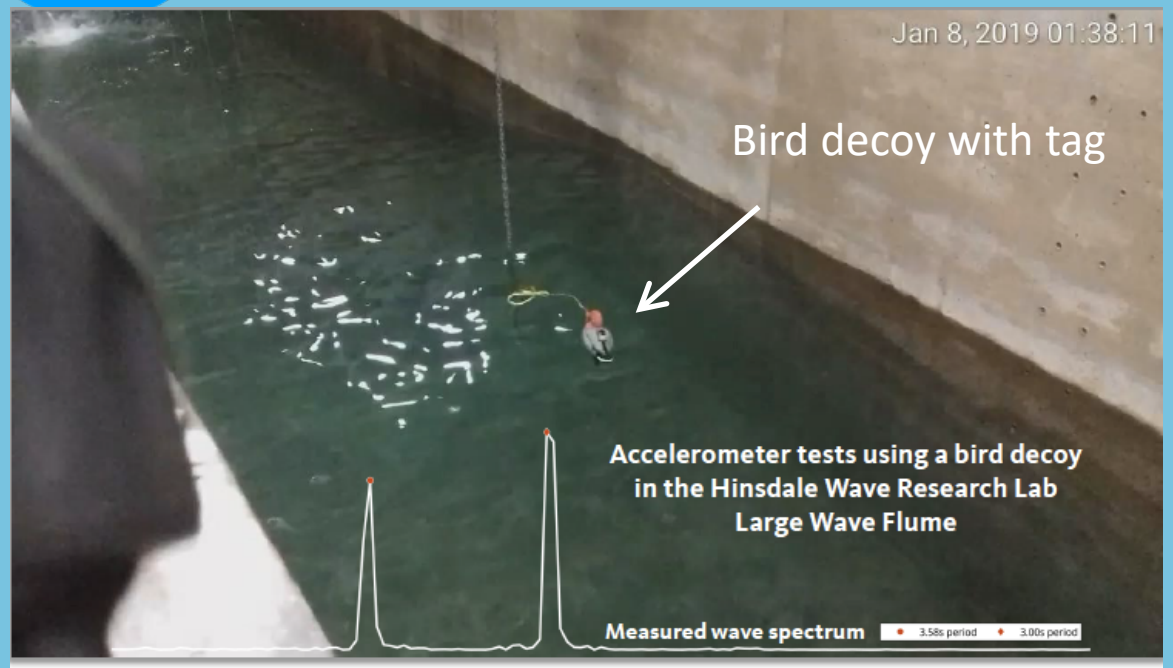
## Horizontal Motions Since Surfacing

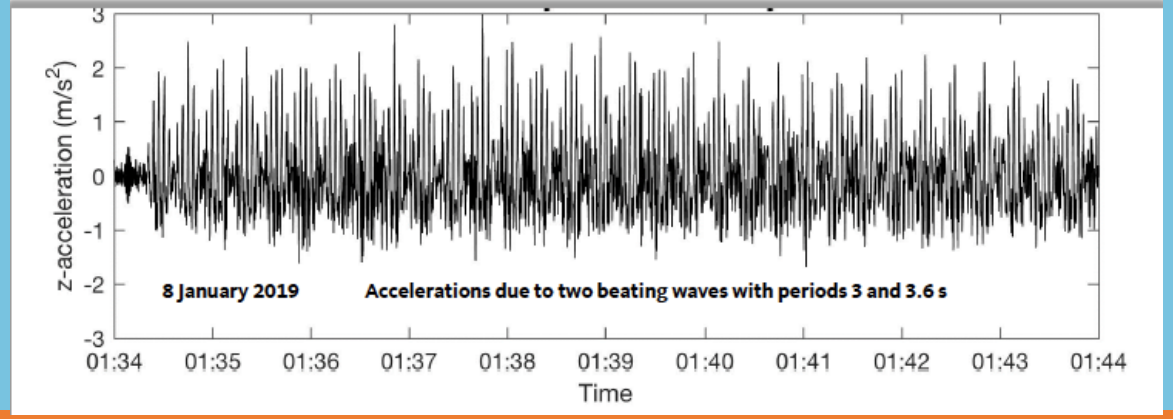



Socotra Cormorant
Persian Gulf

- Surface currents calculated using GPS fixes while bird drifts at the surface following a dive.
- Calculated speed and acceleration amplitude distinguish drifting with the current and bird behavior such as taking flight.

# Surface Wave Statistics (Ongoing)



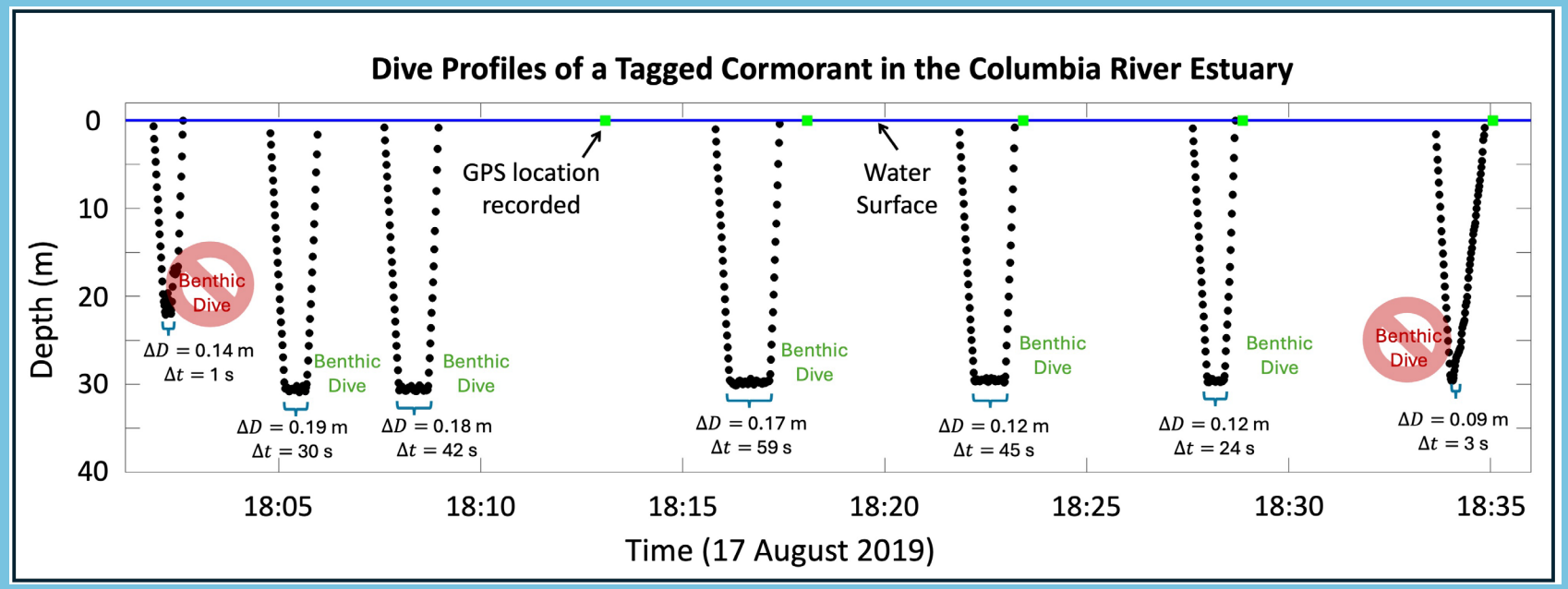

- Target quantities: Significant wave height, dominant wave period, dominant wave direction.

- Tests at the Hinsdale Wave Research Laboratory, Oregon State University, Corvallis, Oregon (2019).
- Surface gravity waves with two periods (3 and 3.6 s) and roughly equal amplitudes were generated.
- Wave accelerations are accurately measured by IMU from tag on bird decoy.
- Note the beating in vertical accelerations (lower panel) due to constructive and destructive interference of the two generated waves.

- More challenging with tagged birds ‘behaving’ in the wild.

# Benthic Soundings – Identifying Bottom (Benthic) Dives

- Bird remains at the deepest depth, $D$, to within a standard deviation, $\Delta D$, and
- For at least a time period, $\Delta t$.
- We set $\Delta D = 0.5$ m and $\Delta t$ = 15 s

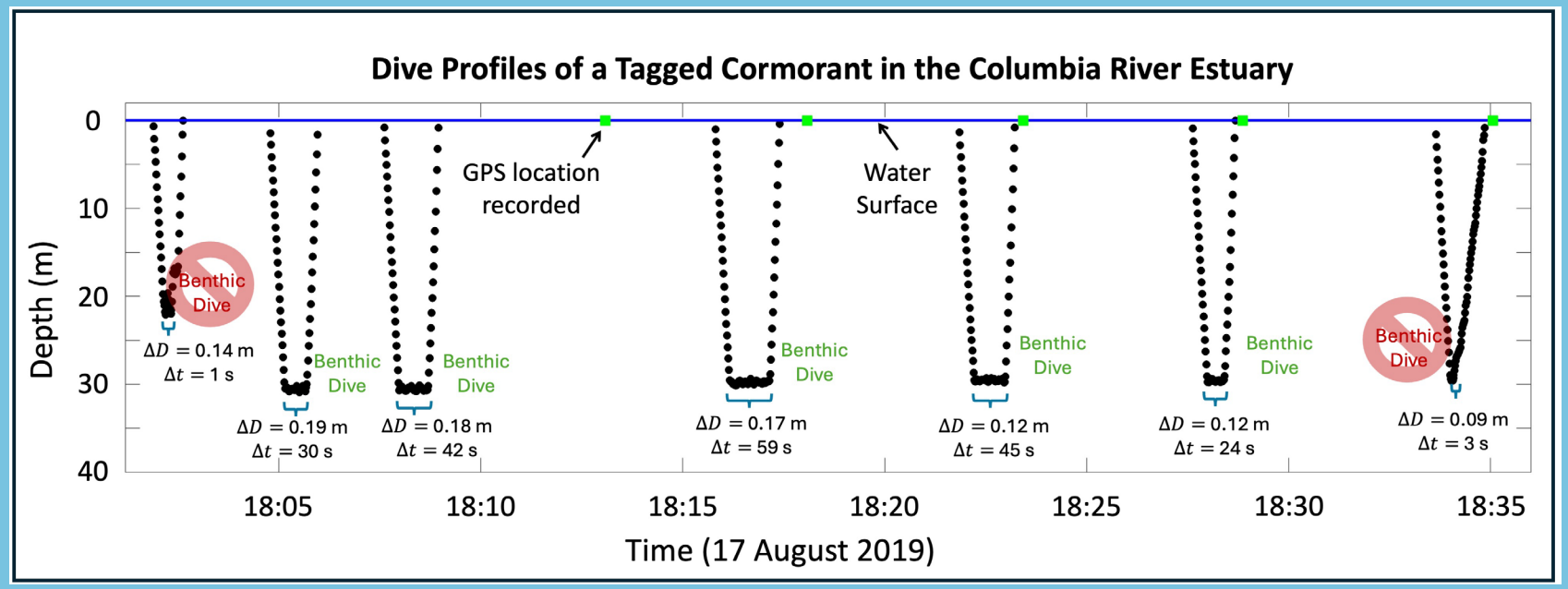




## Methods

- **Identifying bottom (benthic) dives**
- Georeferencing
- Corrections for tides
- Gridding

# Benthic Soundings – Georeferencing

- GPS fix before and after dive (or just after or just before).
- Challenging due to timing of GPS fixes and bird behavior (flying).

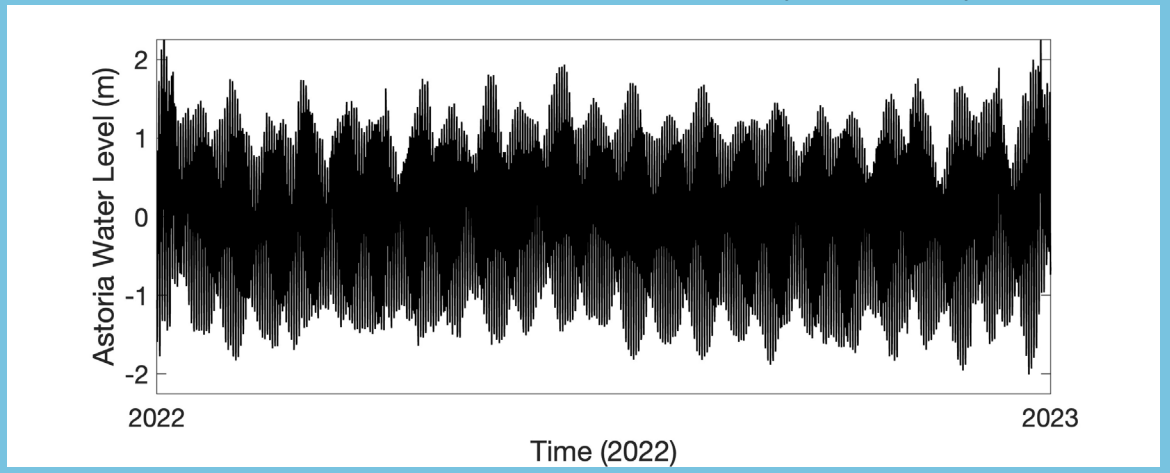

## Methods

- Identifying bottom (benthic) dives
- **Georeferencing**
- Corrections for tides
- Gridding

# Benthic Soundings – Tides and Gridding

- Correct sea level variations from data (Astoria water level data) or model
- Gridding
  - Grid size based on data density
  - Require multiple soundings with grid cell
  - Remove outliers (e.g., due to poor georeferencing)


NOAA PORTS Data – Astoria (9439040)




## Methods

- Identifying bottom (benthic) dives
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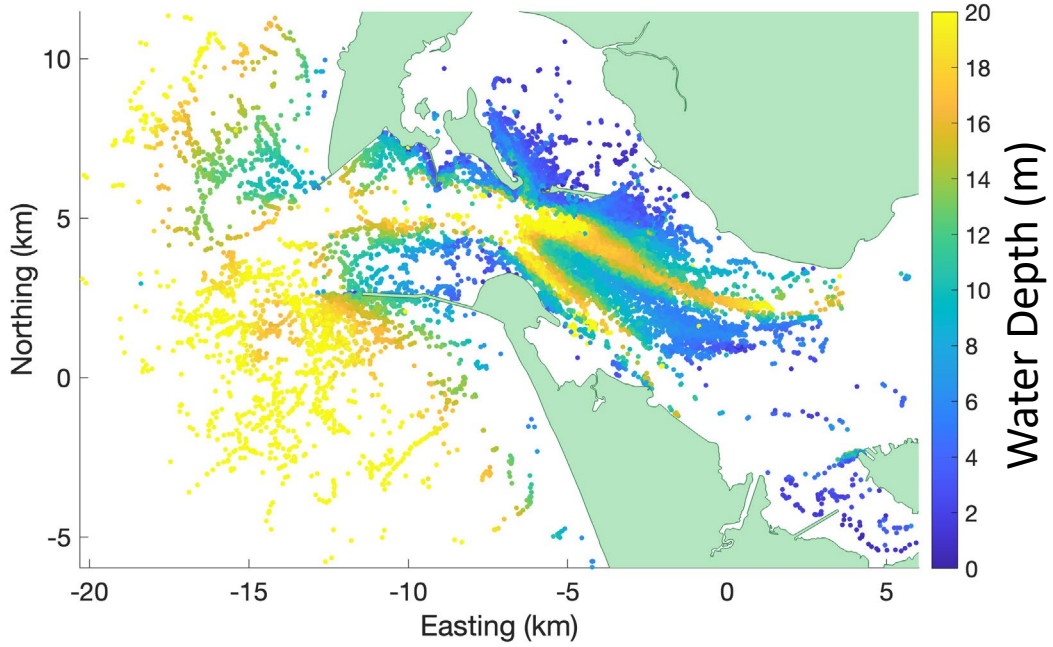
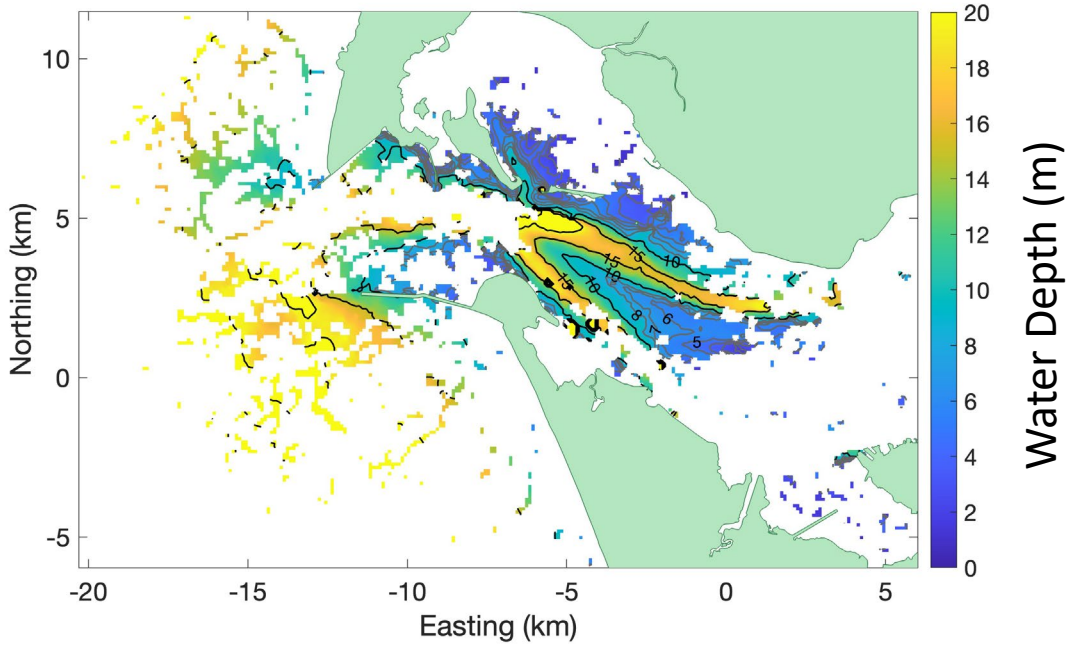
- **Corrections for tides**
- **Gridding**

# Columbia River Bathymetry (all years)

**Bottom Soundings (data from all years; N = 60,000)**

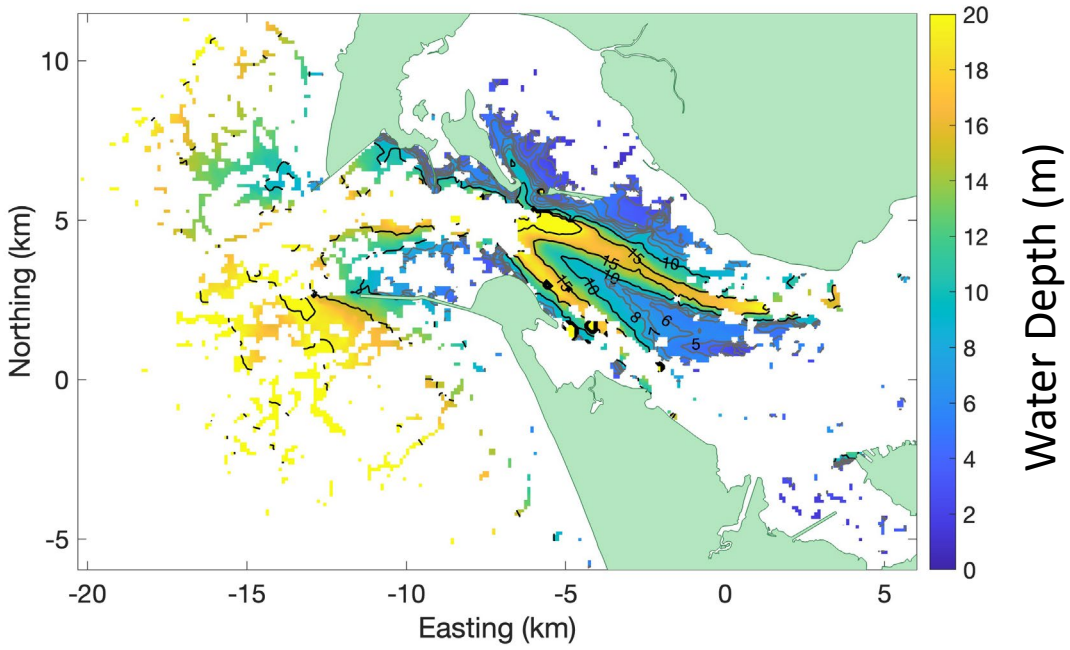



**Gridded Data ($\triangle x$ = 100 m)**

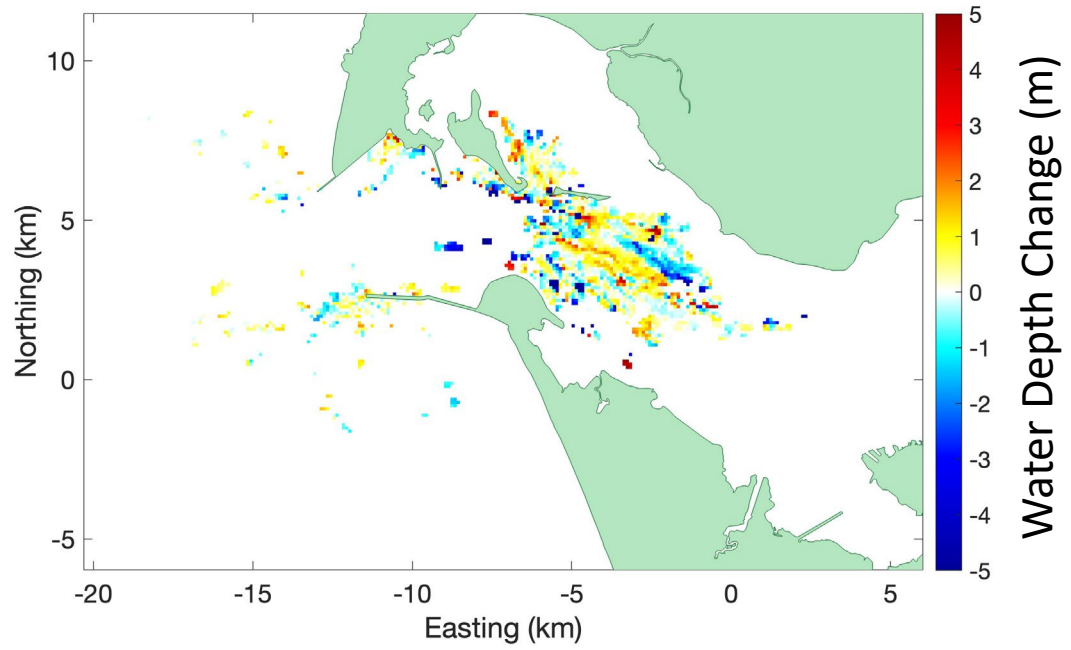


# Columbia River Bathymetric Changes (2022 vs. 2019)

**Gridded Data ($\triangle x$ = 100 m)**




**2022 - 2019**




**Shifting of the North Channel Apparent**

# The Cormorant Oceanography Project

- Method for collecting high volumes of data
  - ~100 dives/day/bird;
  - ~600,000 profiles in the Columbia River estuary.
- High resolution bathymetry in some regions of the estuary.
- Heterogeneous sampling (birds go where they want to go).
- Methods for assimilating data into regional ocean models are promising.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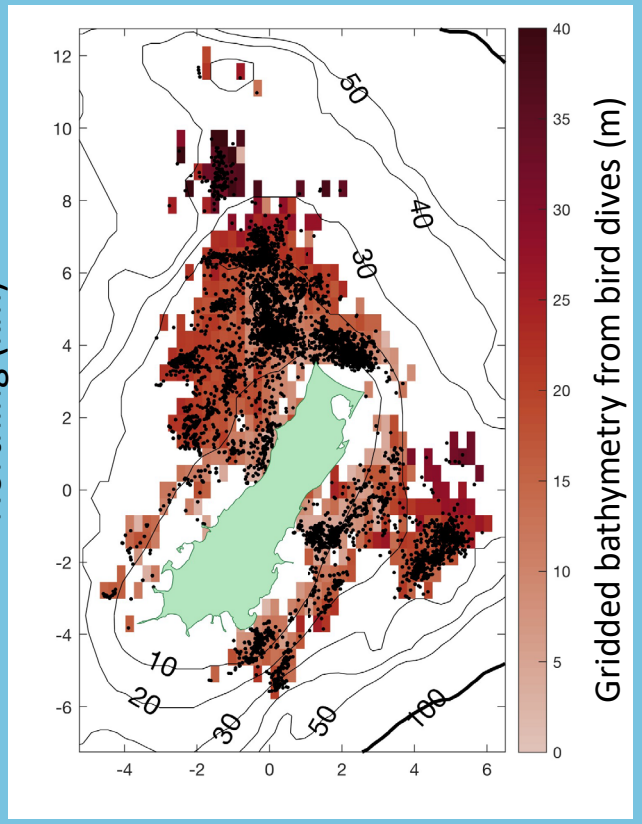
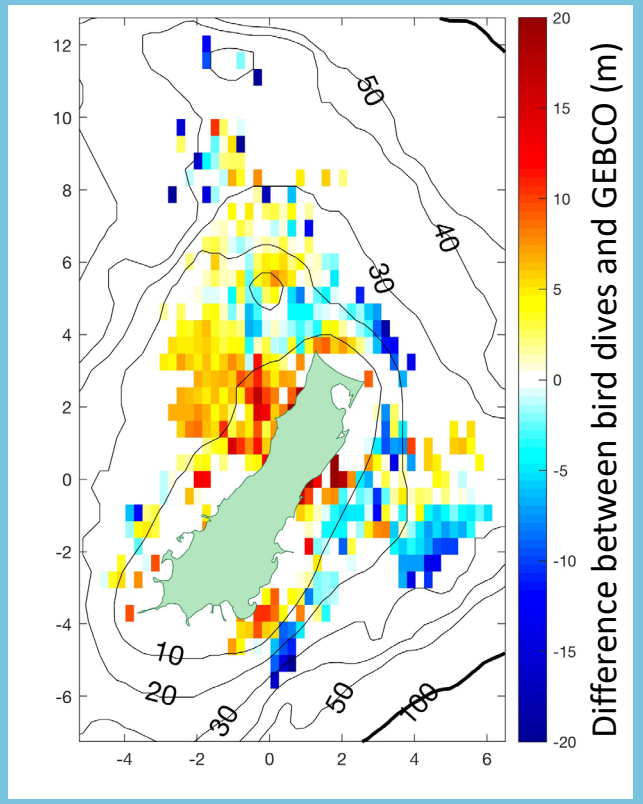
# High Resolution Bottom Soundings

Pelagic Cormorant
Middleton Island Alaska




- Middleton Island, Gulf of Alaska
- Contours: 2021 GEBCO published bathymetry database
- Shading: Gridded bathymetry from cormorant benthic soundings (left panel)
- Color-shaded differences between bird and published (GEBCO) bathymetries (right panel)
- Red shaded = bird bathymetric depths greater than GEBCO.
- Differences as big as 20 m.
- Many soundings in Gulf of Alaska pre-date the Alaska Earthquake of 1964.

# Assimilation of Data in Numerical Models

- Test with Cormorant (black dots: $\mathbf{u_{surf}}$,$\mathbf{v_{surf}}$), SAR (magenta dots: **k**), and SWIFT (red dots: $\mathbf{u_{surf}}$,$\mathbf{v_{surf}}$, $\mathbf{H_s}$) data.
- For transect plots; blue lines show the estimated bathymetry (posterior), black lines are the USACE survey (truth), red lines are the initial guess (prior).