Shelf and Slope Observations & Coastal Dynamics off NC

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Background

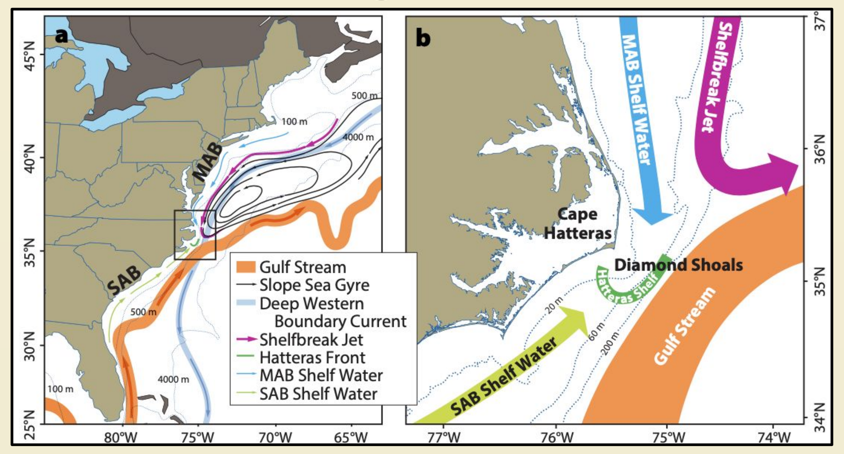


Fig. 1: Schematic of mean circulation off the US east coast & regionally off NC created by Anna Boyette & Dana Savidge after Schmitz (1996) & Csanady & Hamilton (1988).

- South Atlantic (SAB) & Mid-Atlantic Bight (MAB) **shelf waters** converge at the Hatteras Front (HF; Fig. 1).
- Near the shelf break, **GS meanders** propagate downstream (Andres 2021, Muglia et al. 2022) and are asymmetric, extend down to the near bottom, & upwell nutrients onto the shelf (Muglia et al. 2022).
- On synoptic timescales, cascade events are associated with **cross-shore flows** (Han et al. 2021) & at lower frequencies Ekman dynamics drive **cross-shore exchange** (Andres 2023).
- NC's proximity to the GS and exposure to swell generated from atmospheric systems in the south & north Atlantic make this area of interest for **marine energy (ME) development**.

Observations

Multiple observational campaigns off NC have supported several oceanographic & ME research projects. Arrays like the Processes driving Exchange At Cape Hatteras (PEACH) consisted of high-frequency radar (HFR), acoustic doppler current profilers (ADCPs), conductivity, temperature, and depth measurements (CTDs), current & pressure sensing inverted echo sounders (CPIES), & gliders (Fig. 2). Ongoing observations include HFR (SECOORA), ADCPs & CTDs (NC Renewable Ocean Energy Program), & Waverider buoys (CDIP).

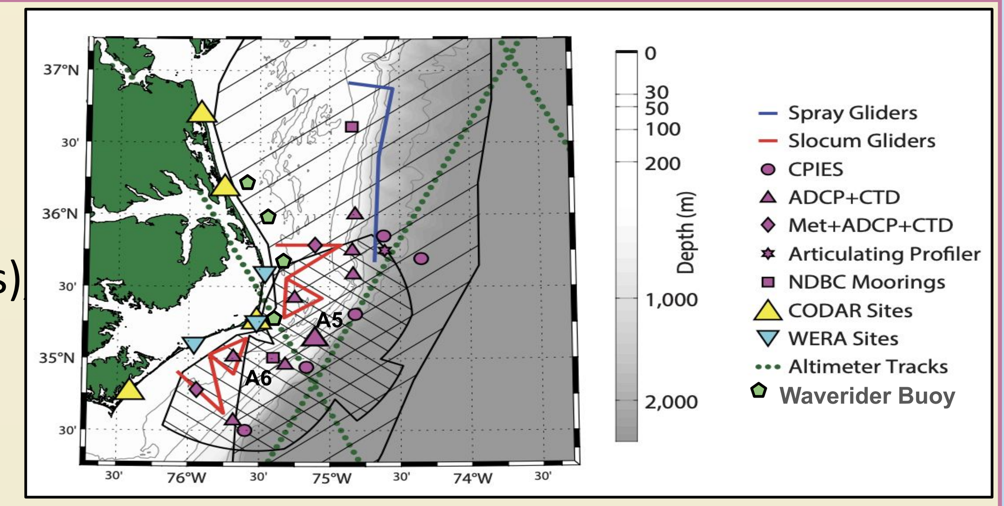


Fig. 2: Map of observational assets during PEACH campaign from Seim et al. (2022) with the addition of Waverider buoys.

Mean Circulation

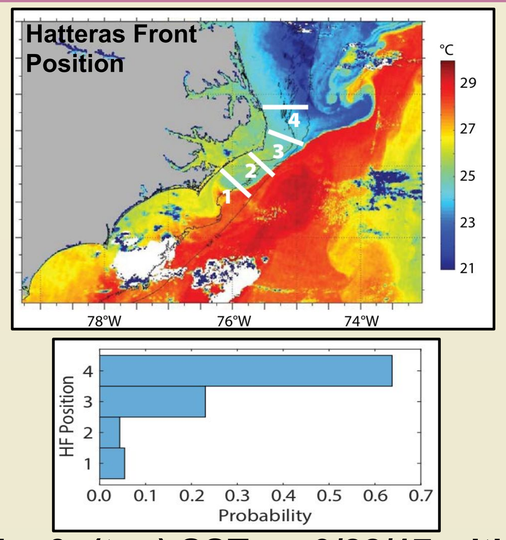


Fig. 3: (top) SST on 9/22/17 with HF positions. (bottom) HF position distribution from Seim et al. (2022).

- The location of the HF is most often found north of Cape Hatteras & south of Nags Head (Seim et al. 2022; Fig. 3)
- Mean GS transport off NC is ~57 Sv & mostly composed of 18° Water (EDW) & GS Thermocline Water (TW; Heiderich & Todd 2020; Fig. 4)

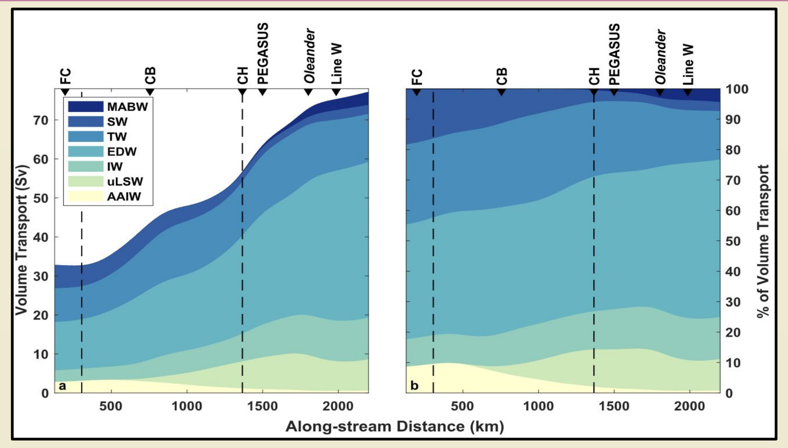


Fig. 4: Glider-estimated mean GS transport & water mass composition from Heiderich & Todd (2020). CH=Cape Hatteras, SW=GS surface water, IW=intermediate water, uLSW=upper Labrador Sea water, AAIW=Antarctic IW.

Water Masses & Shelf-Slope Exchange

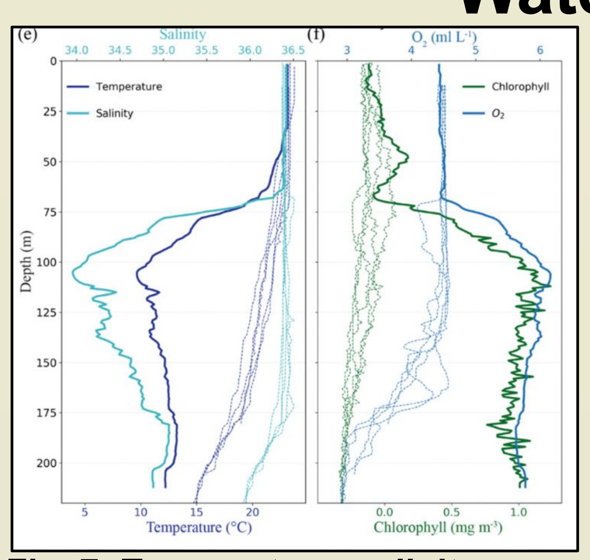


Fig. 7: Temperature, salinity, dissolved oxygen, & chlorophyll fluorescence from shipboard CTD casts on the upper slope between Capes Lookout & Hatteras in 01/2018 from Han et al. (2023).

- Along-slope variability in water mass properties (i.e., temperature, salinity, dissolved oxygen, & chlorophyll fluorescence) indicates a localized phenomena (cascade event) off Cape Hatteras (Fig. 7).
- Cooler, fresher, oxygenated waters with higher chl fl suggest MAB shelf water is exported offshore on the upper slope.
- One mechanism for shelf/deep ocean exchange (high-freq.) is the increased density of cooled MAB shelf water that cascades down the shelf slope below less dense GS water (Fig. 8).

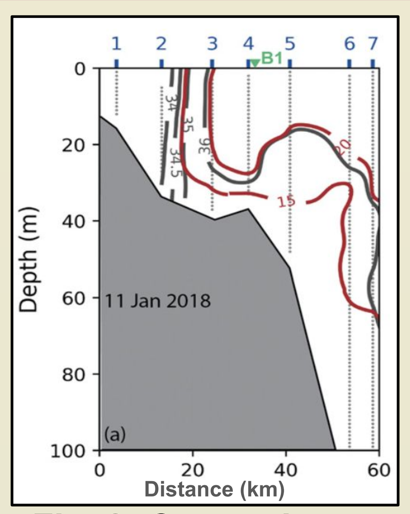


Fig. 8: Cross-shore transect at 35.75°N of temperature (red) and salinity (black) from shipboard CTD casts from Han et al. (2023).

- Other cascade events have been identified with pronounced changes in temperature, salinity, & velocity (Fig. 9).
- Near bottom intensification of cross-shore velocity (Fig. 9).
- Alongshore velocities may decrease as in the 3/2014 event (Fig. 9) or increase as in Han et al. (2023).

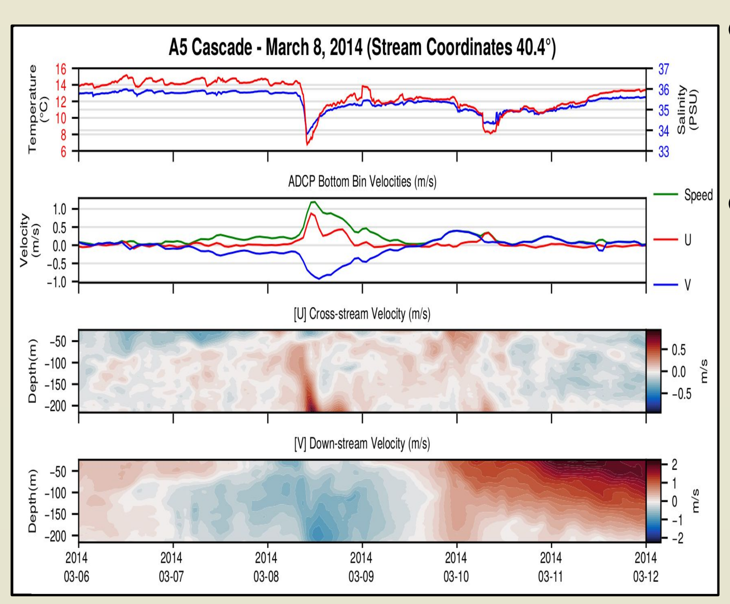


Fig. 9: A5 ADCP bottom temperature, bottom salinity, & horizontal velocities in 03/2014. Note the cascade event on 03/08/14.

- ADCP observations suggest a bottom Ekman layer drives cross-shore exchange (low-freq.).
- ~Monthly filtered alongshore velocities are negatively correlated with onshore flow in a bottom layer (Fig. 10).

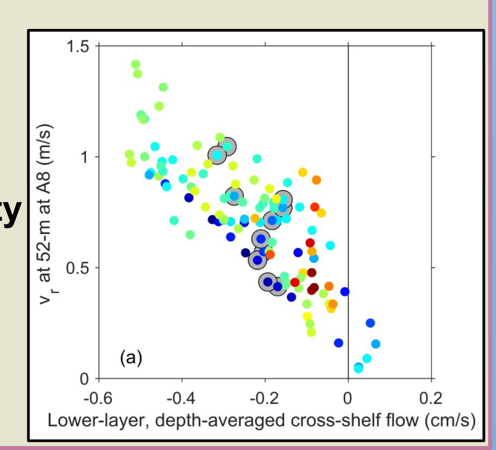


Fig. 10: ADCP upper ocean alongshore velocity vs. layer-averaged cross-shore velocity near the bottom from Andres (2023).

Gulf Stream Meanders

Characterization

- GS meanders have a crest, trough, & warm filaments & frontal eddies may also form (Fig. 5).
- Increased (decreased) & deepening (shoaling) of alongshore velocity in the crest (trough; Fig. 6b).
- Asymmetric velocity structure - transition time from trough to crest is longer than crest to trough.
- Vertical velocities increase throughout most of the water column on the crest's upstream side while near bottom velocities are downward (Fig. 6d).
- Bottom temperature peaks when alongshore current is a max (Fig. 6c).

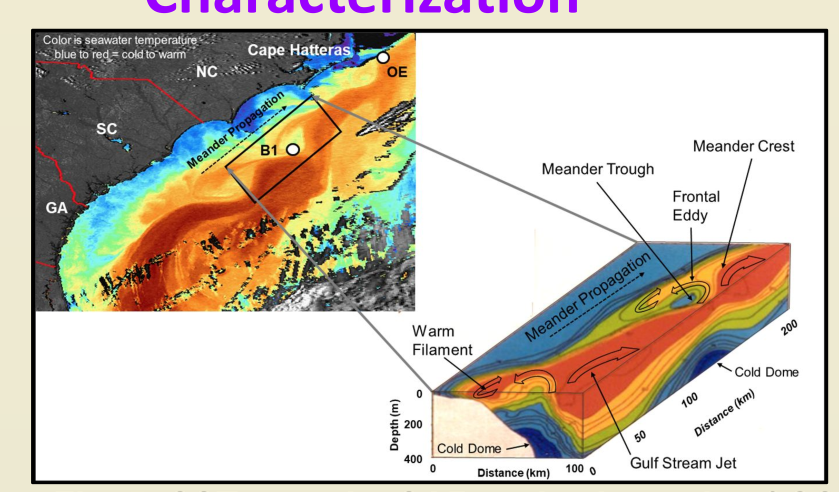


Fig. 5: SST over the SAB and schematic of GS meander from Muglia et al. (2022).

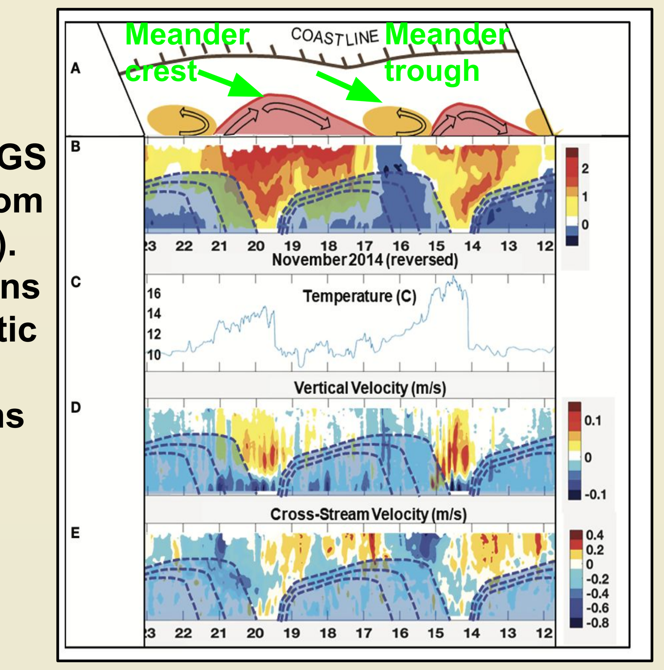


Fig. 6: Physical characteristics of GS meanders at A5 from Muglia et al. (2022). Blue shaded regions represent schematic cold domes with assumed isotherms (dashed lines).

Detection

- GS edge is estimated as location of HFR radial velocity max gradient along each bearing. Edge detection from radial velocities agrees with total velocity field (Fig. 11).
- Meanders are detected from ADCP alongshore flow. Decreased alongshore flow suggests meander trough & increased range to GS edge (Fig. 12).

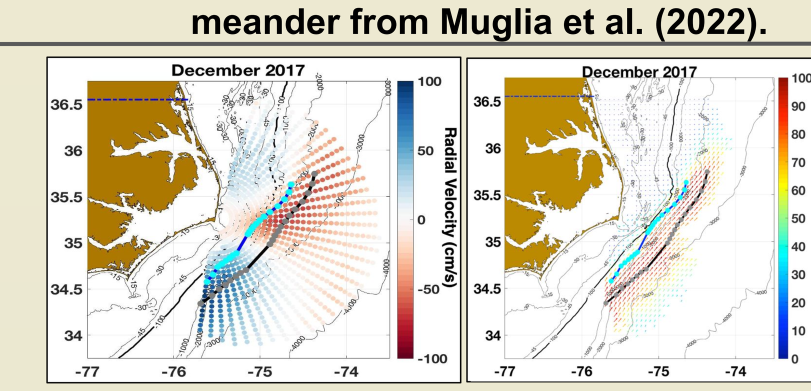


Fig. 11: (left) 12/2017 mean HFR radial velocities (positive/negative = towards/away from site) & (right) 12/2017 mean HFR total velocities. Blue/gray is GS edge/jet detected from HFR data.

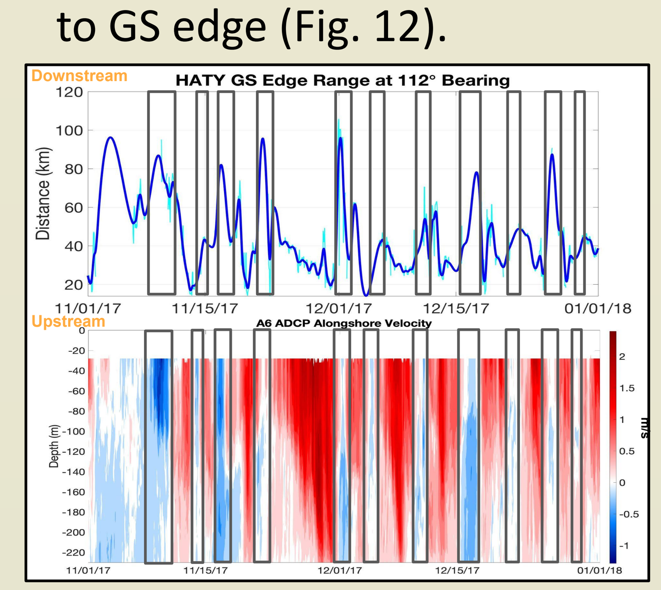


Fig. 12: (bottom) A6 ADCP alongshore velocities, red = poleward flow & blue = equatorward flow. (top) GS edge range ~30 km downstream of A6 from HFR data. Rectangles indicate meander troughs.

- Meander amplitude is the difference in max & min GS edge range on HFR 72° bearing.
- Meander wavelength is the distance between max & min GS edge range over HFR bearings doubled.
- Amplitudes are between ~10–40 km while meander wavelengths are ~25–150 km (Fig. 13).
- Mean amplitude is ~20 km & wavelength is ~90 km.

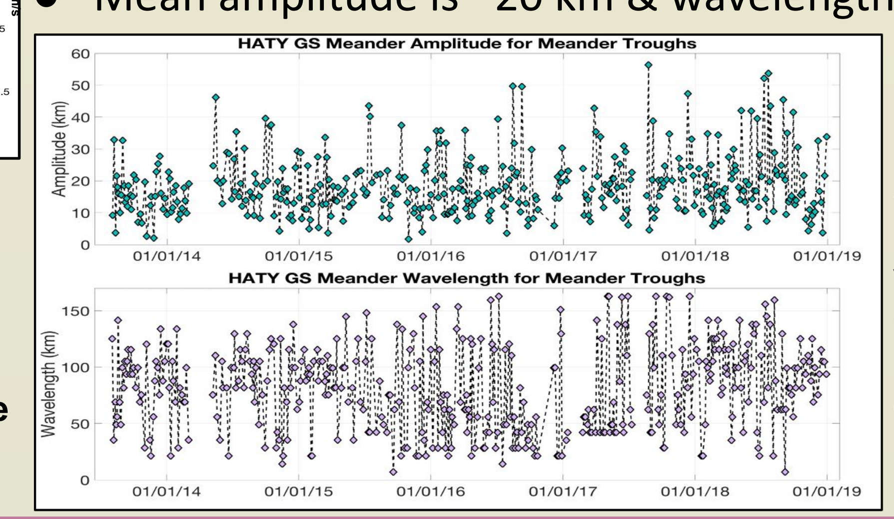


Fig. 13: GS meander (top) amplitudes & (bottom) wavelengths during detected meanders estimated from HFR data.

Statistics

- Meander amplitude & wavelength peak in summer when there are fewer meanders (Fig. 14).
- Meander amplitude & wavelength have relative minima in late winter when meander events are a max (Fig. 14).
- 5 – 8 meander events per month.
- Meander amplitude has overall increasing trend (Fig. 15).
- Meander wavelength & phase speed are lowest in 2016.

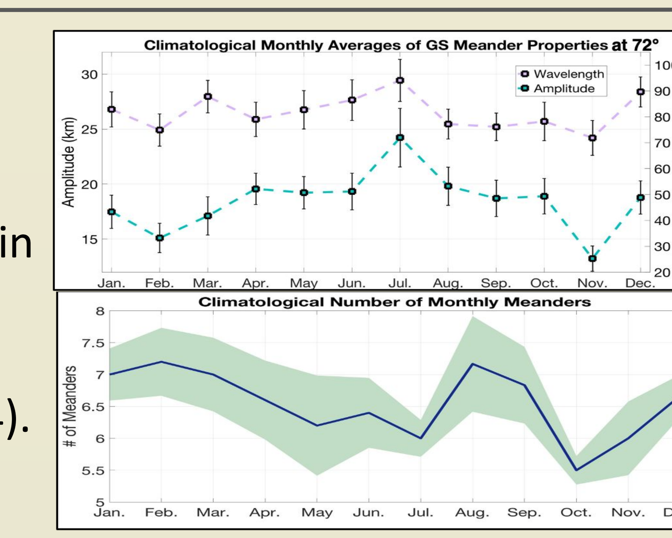


Fig. 14: (top) Monthly climatological values of meander properties over 2013-18 with standard error. (bottom) Mean number of meander events per month over 2013-18 with standard error.

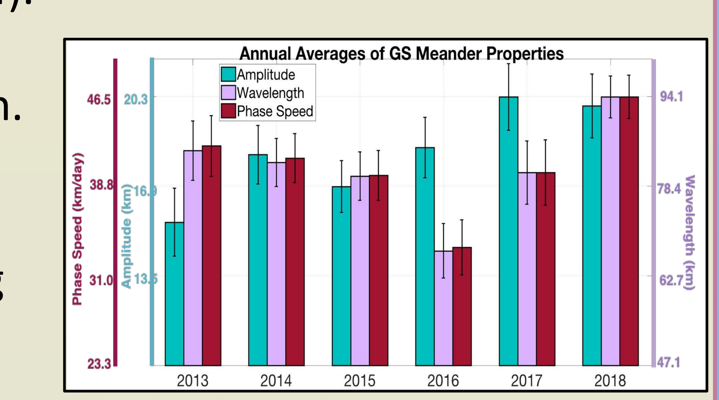
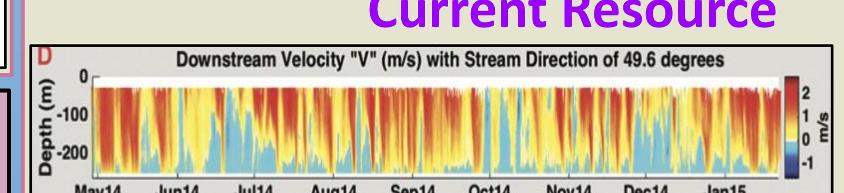


Fig. 15: Annual averages of GS meander properties with standard error.

Marine Energy

Current Resource



E — Table of percentage of good measurements greater than Water Speed (m/s)

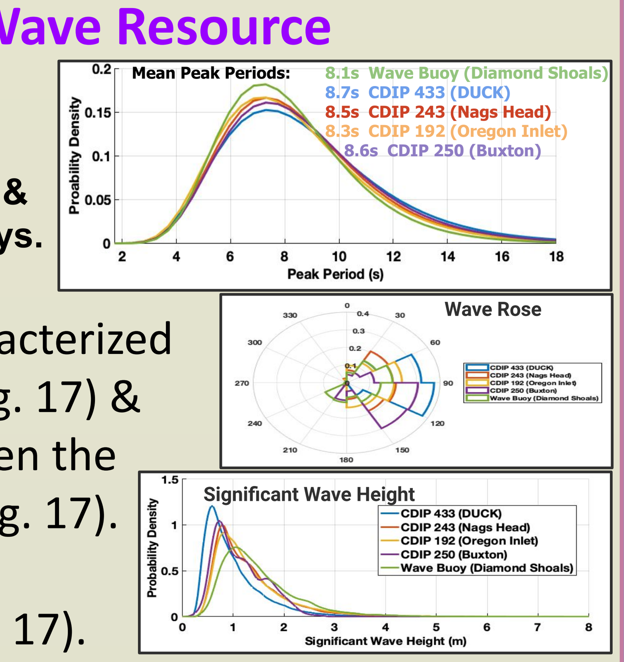
Depth (m)	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
40	98.72	94.41	86.82	76.43	63.96	50.15	35.37	20.62	7.84	1.87	0.26
76	98.22	90.94	79.49	64.44	54.31	38.96	23.57	9.45	2.52	0.42	0

Fig. 16: (top) A5 ADCP alongshore velocity & (bottom) table of percentage of velocity observations in each speed bin from Muglia et al. (2020).

- Off NC, alongshore velocities often exceed 2 m/s near the surface due to the GS (Fig. 16).
- More than 63% of the time, speed in the upper ocean exceeds 1 m/s (Fig. 16).

Wave Resource

Fig. 17: Probability density functions of (top) wave period & (bottom) significant wave height & (middle) wave rose for CDIP buoys.



- Off NC, wind swell is characterized by 6-9 second periods (Fig. 17) & direction is largely between the southeast & northeast (Fig. 17).
- Significant wave height is predominately < 2 m (Fig. 17).

Acknowledgements

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