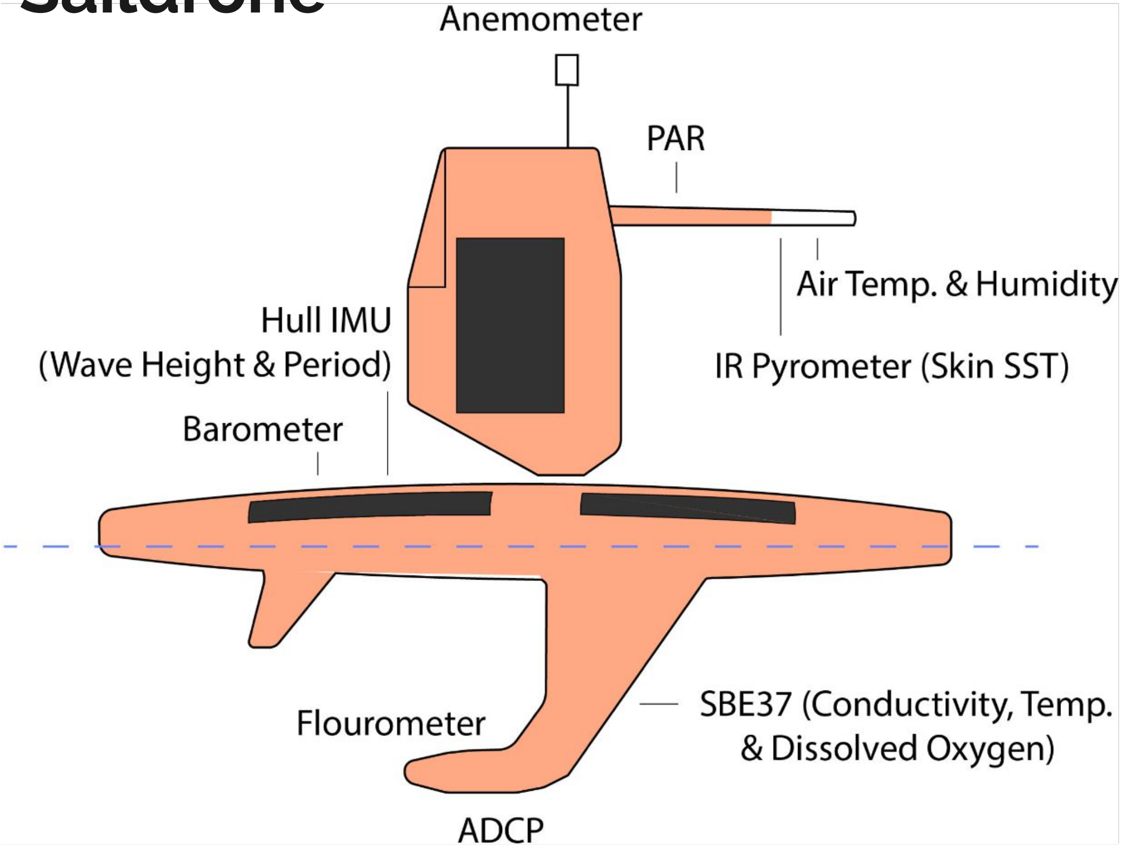
Storm-Generated Near-Inertial Internal Waves in Eastern Chukchi Sea

A Case Study by Observation and HYCOM

Nan-Hsun Chi[1], Dongxiao Zhang[1], Chidong Zhang[2]

1 University of Washington, CICOES
2 NOAA PMEL

Saildrone


Anemometer
PAR
Air Temp. & Humidity
Hull IMU
(Wave Height & Period)
IR Pyrometer (Skin SST)
Barometer
Flourometer
SBE37 (Conductivity, Temp.
& Dissolved Oxygen)
ADCP


1035

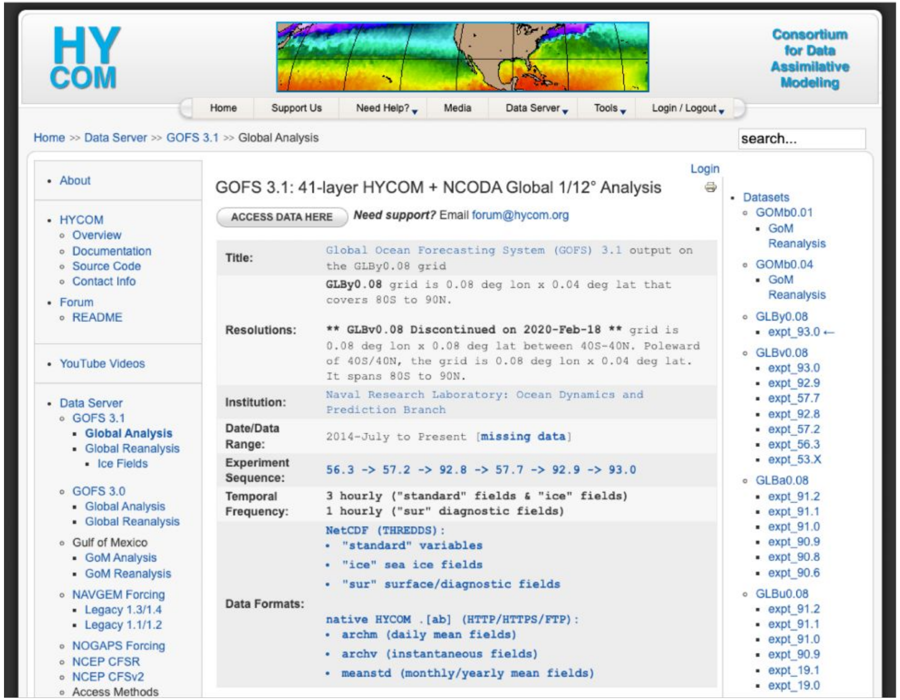

EXPLORER
SPIRIT
SAILDRONE
1037

Introduction

- NIWs are a major contributor to upper ocean mixing[1]. Less documented esp the Pan-Arctic shelves
- The center of Arctic storm shifted towards the Chukchi Sea in the warm season[2] + seasonal increased opening[3] → direct air-sea interactions ↑
- Wind-driven NIWs could affect the local and remote thermohaline properties of the Pacific inflow exiting the Chukchi Sea.
- This study based on obs aims to provide an estimate of NIW characteristics and energy powered by an Arctic storm on the seasonal ice-free Chukchi shelf.

1. Jochum et al. 2013
2. Valkonen et al. 2021
3. Zhang et al. 2023

HYCOM Hindcast data



ALAMO Floats

RBRargo CTD for profiling floats

Ultra low power, salinity to the surface

The RBRargo CTD is designed specifically for the Argo program. The ultra-low power design results in a 5x CTD energy budget savings, while the CFD-optimized flow makes a pump completely unnecessary. Salinity to the surface is default behaviour — the conductivity cell is unaffected by surfactants and is not damaged by drying out. Atmospheric measurements provide helpful drift references.

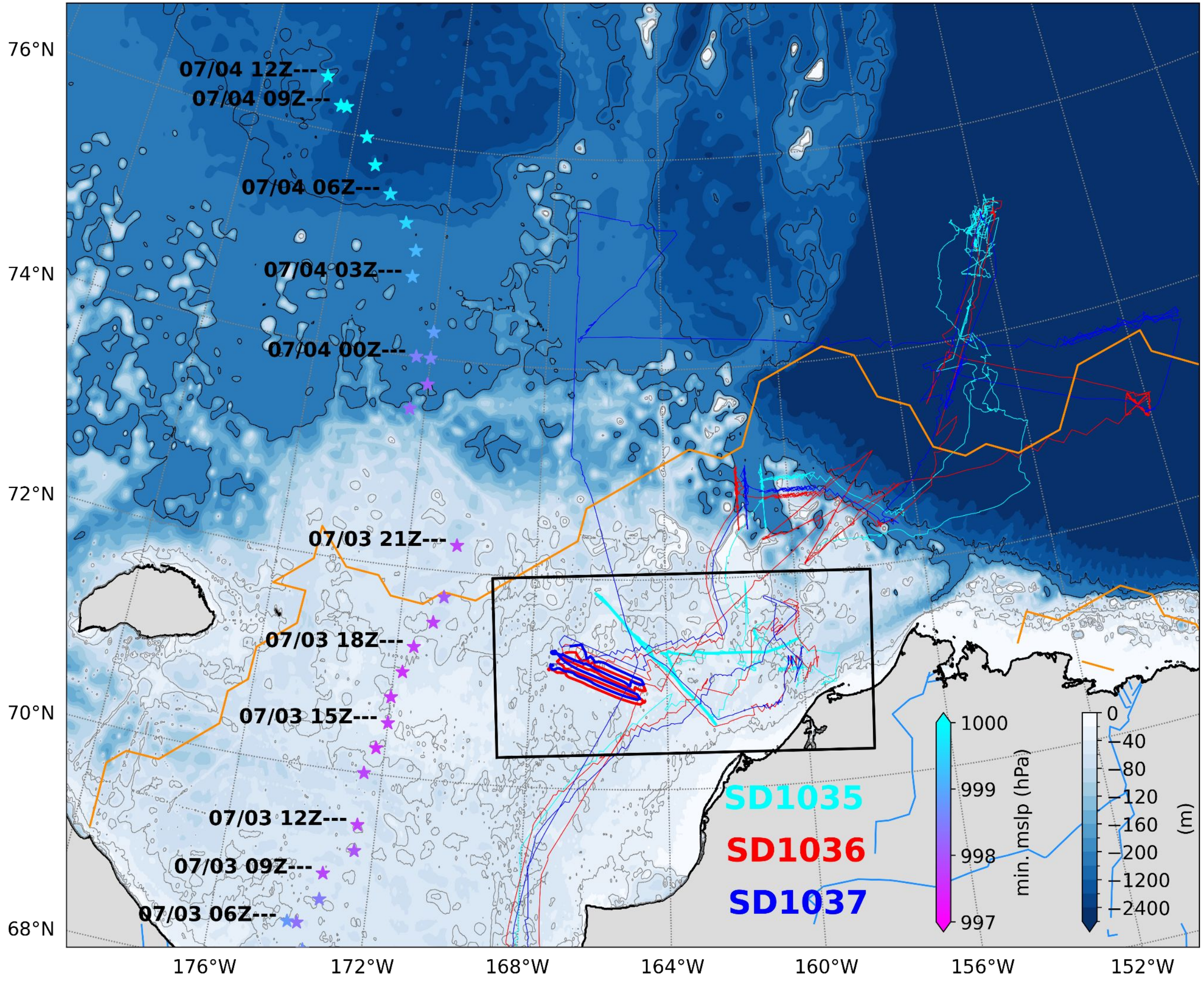
Impeccable power management and a direct engineer-to-engineer support channel, coupled with a design that focuses on ease of use makes integration straightforward. Capable of up to 12Hz sampling, massive storage capacity, and compact electronics, the RBRargo fits in both standard Argo and NATO A-class float hulls, and withstands air deployments.

A full range of BGC sensors are available, including optical DO, pH, PAR, fluorometers, and others.

Features

- WOCE accuracy
- Streamlined design minimizes salinity spiking
- Flushing by design — no pump required
- Classical 2000dbar profile consumes only 700J
- Up to 12Hz sampling
- Conductivity to within 10cm of air-ocean interface
- Integrations with Teledyne Webb APEX, MRV ALAMO, and MetOcean NAMI floats already available, in water, and data observed by ARGO scientists

Fig. S3. ALAMO PT

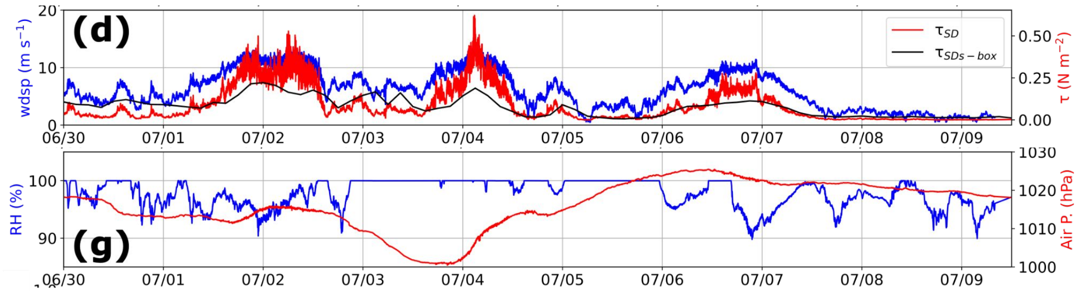


07/04 12Z---
07/04 09Z---
07/04 06Z---
07/04 03Z---
07/04 00Z---
07/03 21Z---
07/03 18Z---
07/03 15Z---
07/03 12Z---
07/03 09Z---
07/03 06Z---
76°N
74°N
72°N
70°N
68°N
176°W
172°W
168°W
164°W
160°W
156°W
152°W
SD1035
SD1036
SD1037
min. mslp (hPa)
1000
999
998
997
(m)
0
−40
−80
−120
−160
−200
−1200
−2400

Saildrone obs.

Wind

RH & Pres



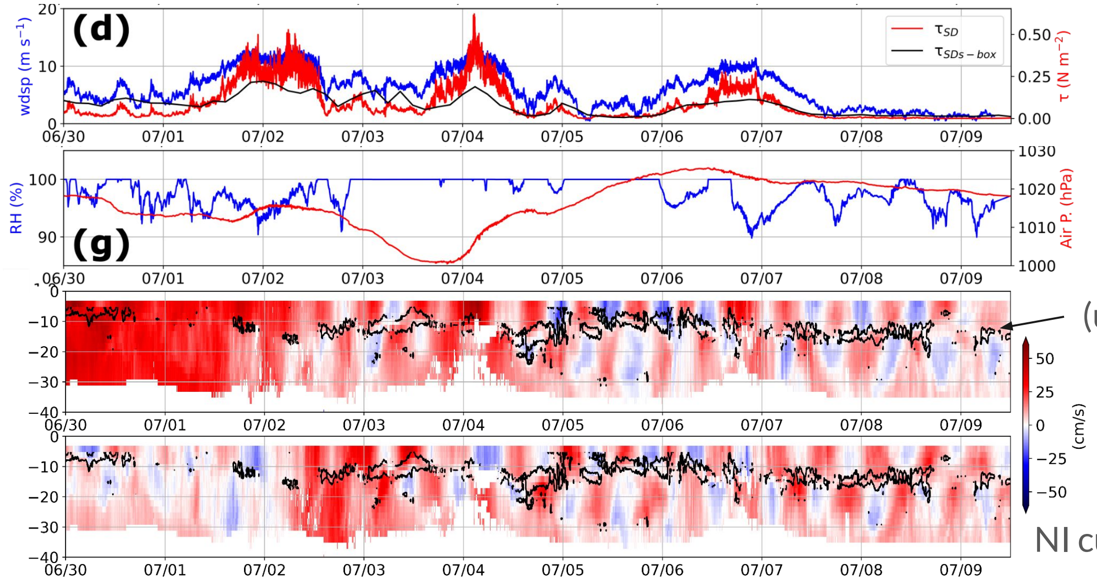
Saildrone obs.

Wind

RH & Pres

U current

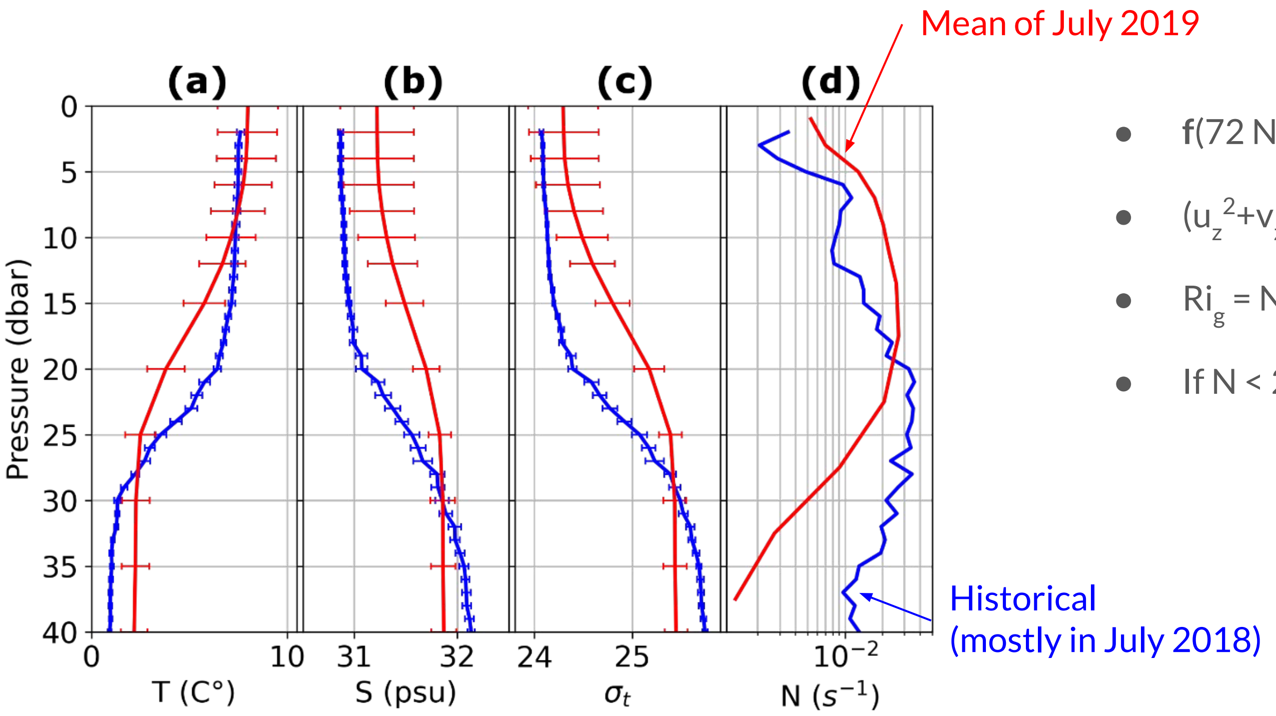
V current



$(u_z^2+v_z^2)^{½} = 0.04\ s^{-1}$

NI current ~ O(15 cm s^{-1})

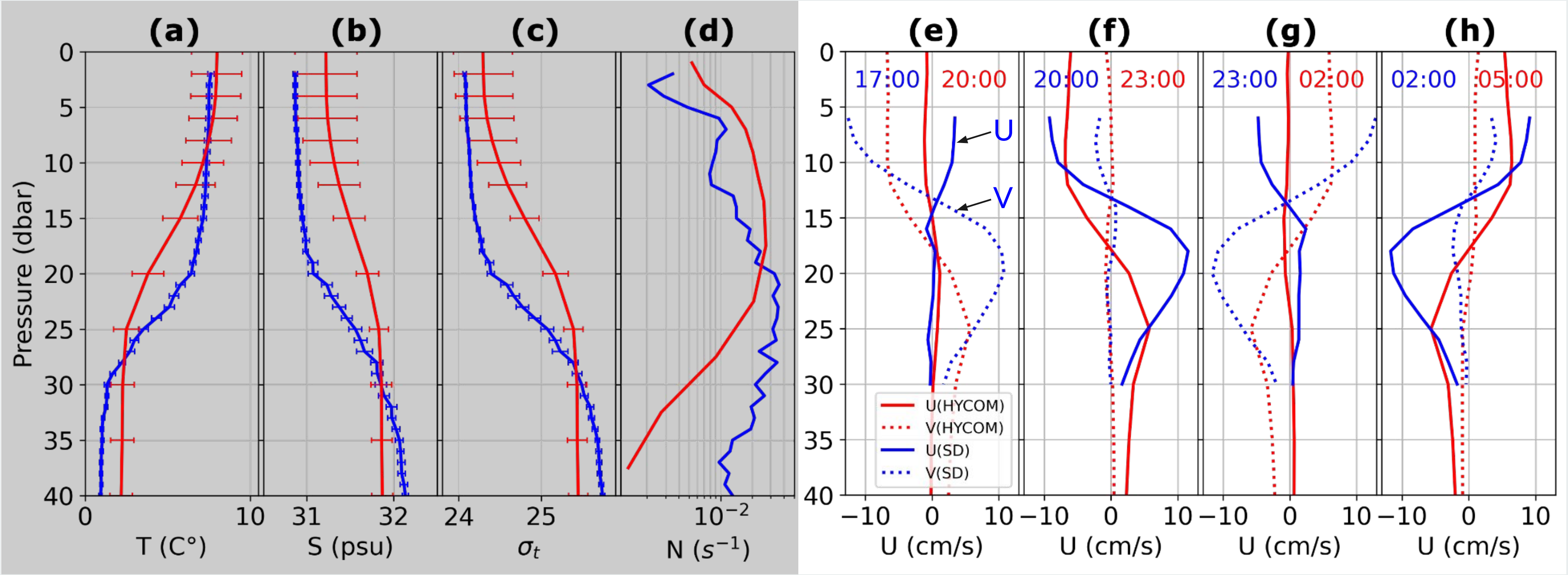
Alamo floats vs. HYCOM



- **f**(72 N) = 1.38 x 10^{-4} s^{-1} **<<N**
- $(u_z^2+v_z^2)^{½}_{max\text{-}on\text{-}SD}$ ~ **4x10^{-2} s^{-1}**
- $Ri_g = N^2/S^2$
- If N < 2x10^{-2} s^{-1}, Ri_g < ¼.

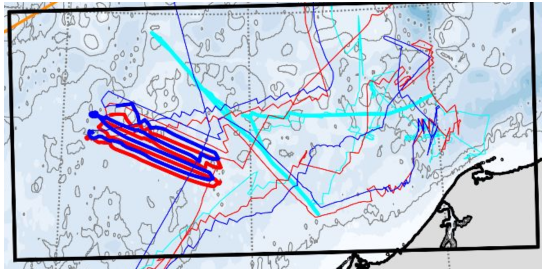
Saildrone current profiles

SD-1036 July 3 & 4



Use mean $N_{\text{ALAMO floats}}$ in July: first mode ~70%

Estimate NIW phase distribution

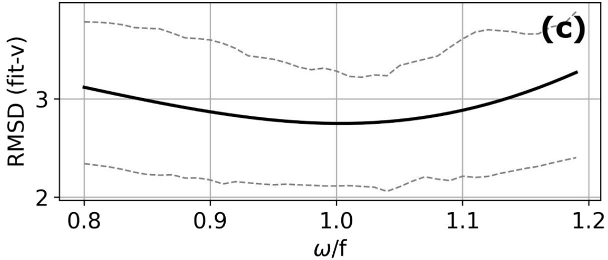


- At every 4 hr, the 12-hr windows of “Quasi-Eulerian” tide-removed and 18-hr high-pass filtered Saildrone current velocities are fitted to:

$$u(t) = A_u \cos\left(\omega\left(t - t_0\right) + \phi_{fit-u}\right) + B_u \quad (1)$$

$$v(t) = A_v\, sin\left(\omega\left(t - t_0\right) + \phi_{fit-v}\right) + B_v \quad (2)$$

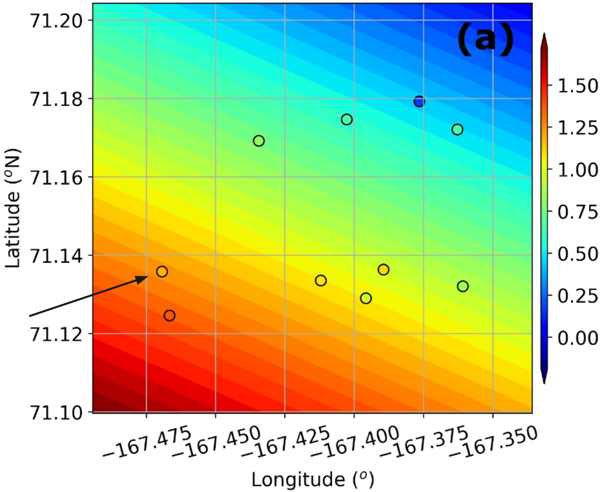
- Fitted ω is 0.8f : 0.01f : 1.2f
  - From 71 to 72N: f increases by only 0.58%



- The choice of depths of current velocity is for the larger velocity magnitude & for the larger stratification — 20-24 m.

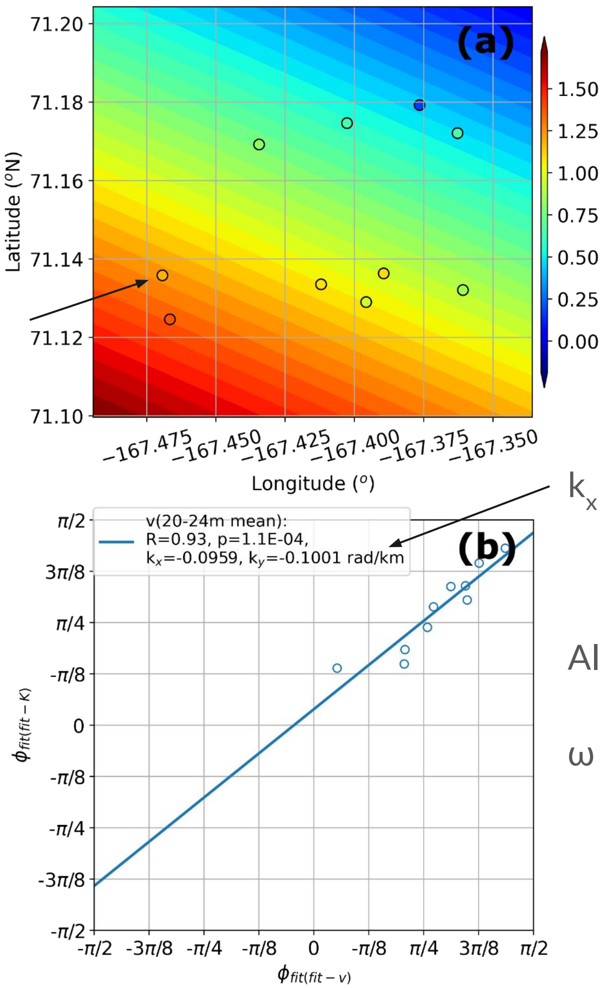
With fixed $\omega = 1.03f$

$\varphi_{fit\text{-}v}$ in eq. (2)



With fixed $\omega = 1.03f$

$\varphi_{fit\text{-}v}$ in eq. (2)



k_x & k_y ~ O(-0.1 rad km^{-1})

Rainbow background:

fit $\varphi_{fit\text{-}v}$ to

$\varphi_{fit\text{-}k} = \mathbf{k_x}(x-x_0)+\mathbf{k_y}(y-y_0)$

All good fits (between $\varphi_{fit\text{-}v}$ & $\varphi_{fit\text{-}k}$):

ω = 0.99f, 1f, 1.03f, 1.04f, 1.05f

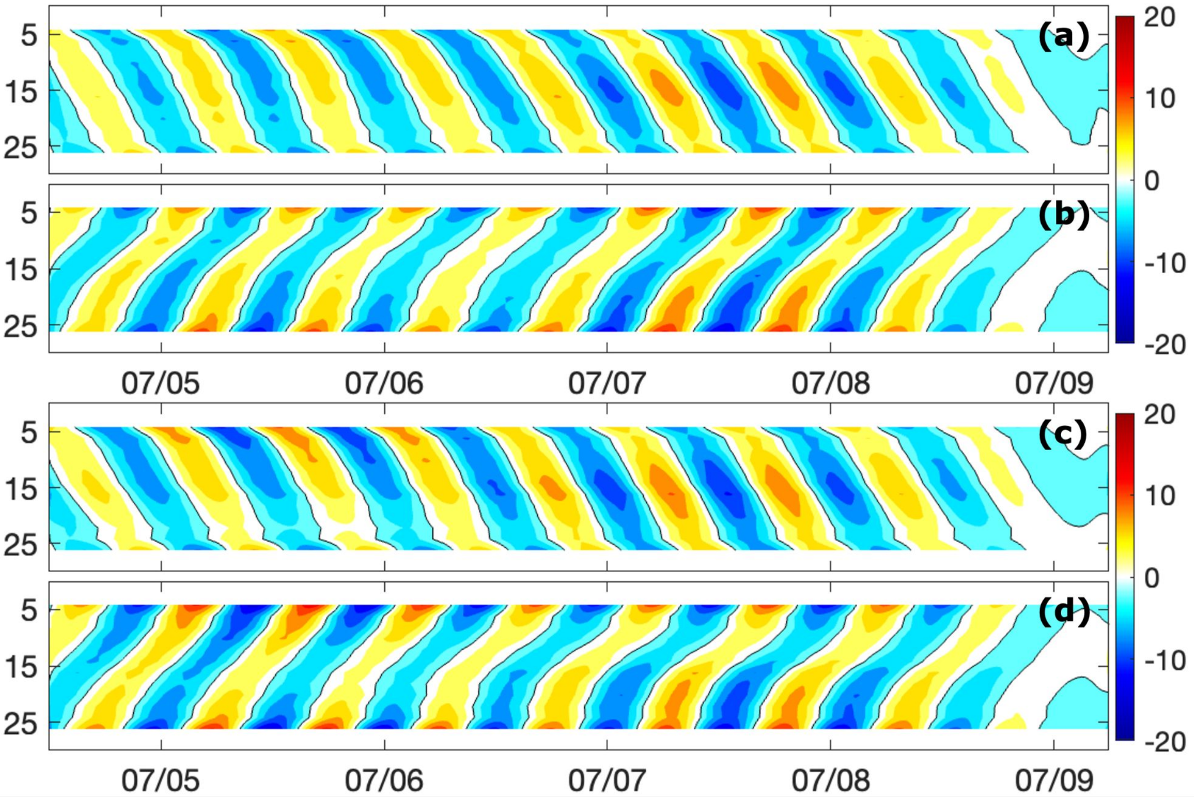
Decomposition v-velocity into upward & downward propagating waves

SD-1036

k_z ~ O(2π/50 rad m^{-1})

SD-1037

Gerkema & Zimmerman (2008) & WKB theory also estimate k_z but require stratification.



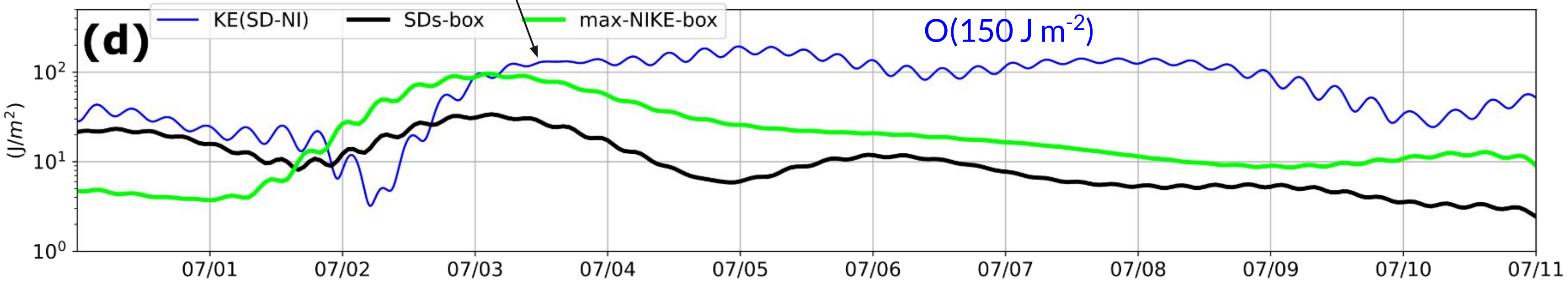
Estimate NIW Group velocity

- Following Kunze (1985, 1986)
  - $|Cg_H| \sim N^2K_H/(fk_z^2)$ (3)
  - $|Cg_z| \sim N^2K_H^2/(f|k_z|^3)$ (4)

- $|Cg_H| \sim O(0.06 - 0.1)$ m s^{-1} (5~8 km day^{-1})
- $|Cg_z| \sim O(5\sim10$ m day$^{-1})$
- Limits of obs:
  - Given the $|Cg_H|$, the 12-hr window may be too long for relatively fast moving waves
  - The max of 10 km movement of the platform in a 12-hr window is not ideal

Estimate DI-NI-KE

Depth-integrated Near-Inertial kinetic energy



- Integrate only over the observed upper 6~30 m velocity profiles

Estimate NIW Energy Flux

- Energy flux: $F = |Cg_H| \cdot$ DI-NI-KE ⟵ Depth-integrated Near-Inertial kinetic energy

  $\rightarrow F = O(10\ W\ m^{-1})$

- Long-range propagation of NIWs from mostly deep water moorings around the world oceans: ~0.5 kW m^{-1} (Alford, 2003)

- Should the effective length scale of NIW associated with this storm to be O(100 km), the storm would generate ~O(10^{12} J) of NI-KE on the shelf for propagation away and/or turbulent dissipation

Summary

	Saildrone Obs.
Near-inertial current magnitude	$O(15\ cm\ s^{-1})$ ~ 1 week
Vertical structure	Mode-1 standing structure with node ~15 m
k_x / k_y	$O(-0.1\ rad\ km^{-1})$ Propagate NE-ward
k_z	$O(2\pi/50\ rad\ m^{-1})$
$\|Cg_H\|$	$O(6\sim8\ km\ day^{-1})$
$\|Cg_z\|$	$O(5\sim10\ m\ day^{-1})$

- The obs DI-NI-KE: same order of magnitude as those storm-generated NIWs over the continental shelves in the lower latitude.
- NIWs on eastern Chukchi shelf contribute less to global NI energy than those generated in the open ocean.
- Accelerated summer-sea ice retreat could be prone to more storm-driven NIW activities over Chukchi shelf.

Thank you! Questions?

Saildrone obs.

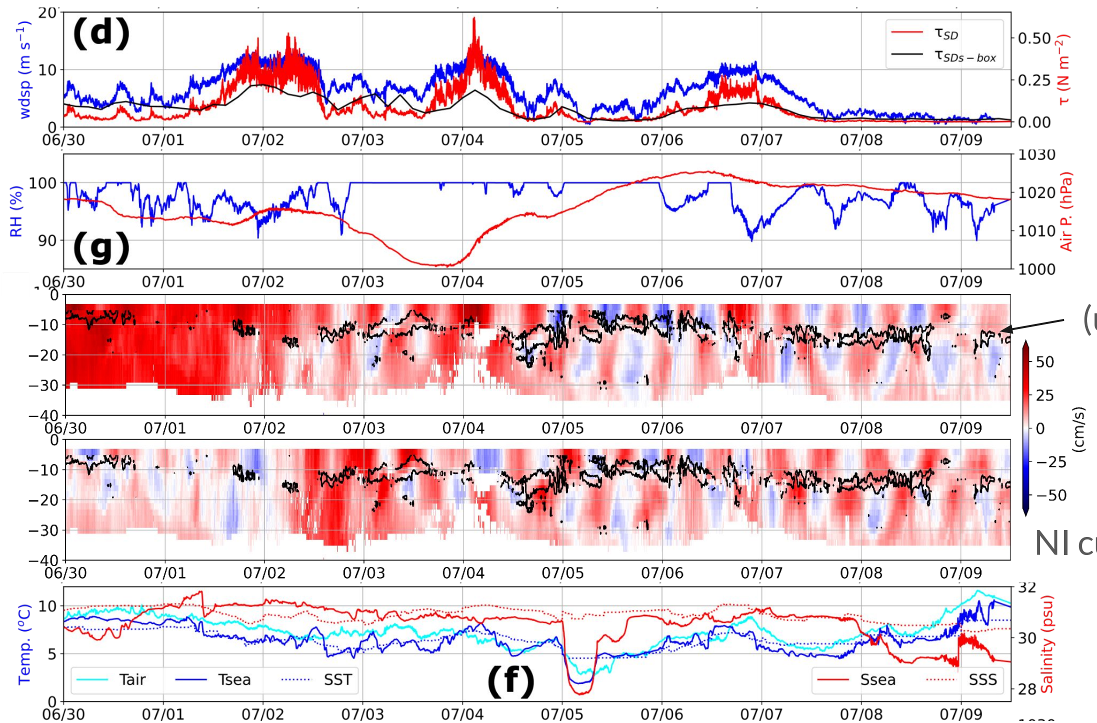
Wind

RH & Pres

U current

V current

T & S

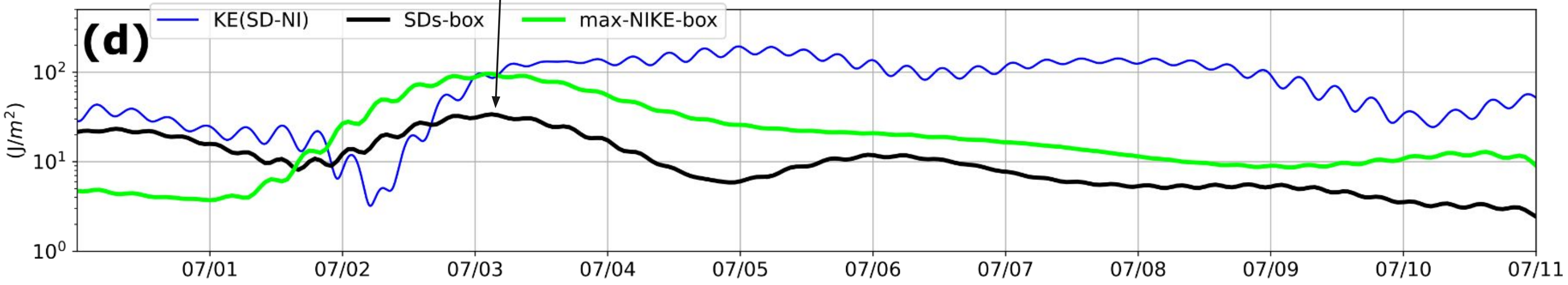


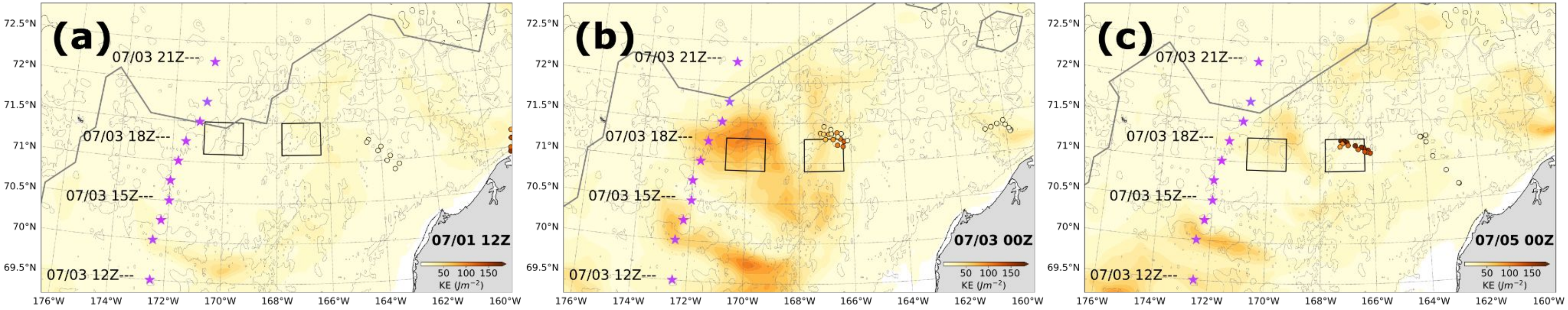
$(u_z^2+v_z^2)^{½} = 0.04\ s^{-1}$

NI current ~ $O(15\ cm\ s^{-1})$

Estimate DI-NI-KE

Depth-integrated Near-Inertial kinetic energy





- Bootstrap (1) & (2) for uncertainty of fits
- Criteria for φ_{fit-v}:
    - (1) R2 ($1-\Sigma(y_i-\hat{y}_i)^2/\Sigma(yi-\bar{Y})$)> 0.9
    - (2) Interval (25~75 percentile) < 0.05 radian (~2.8°)