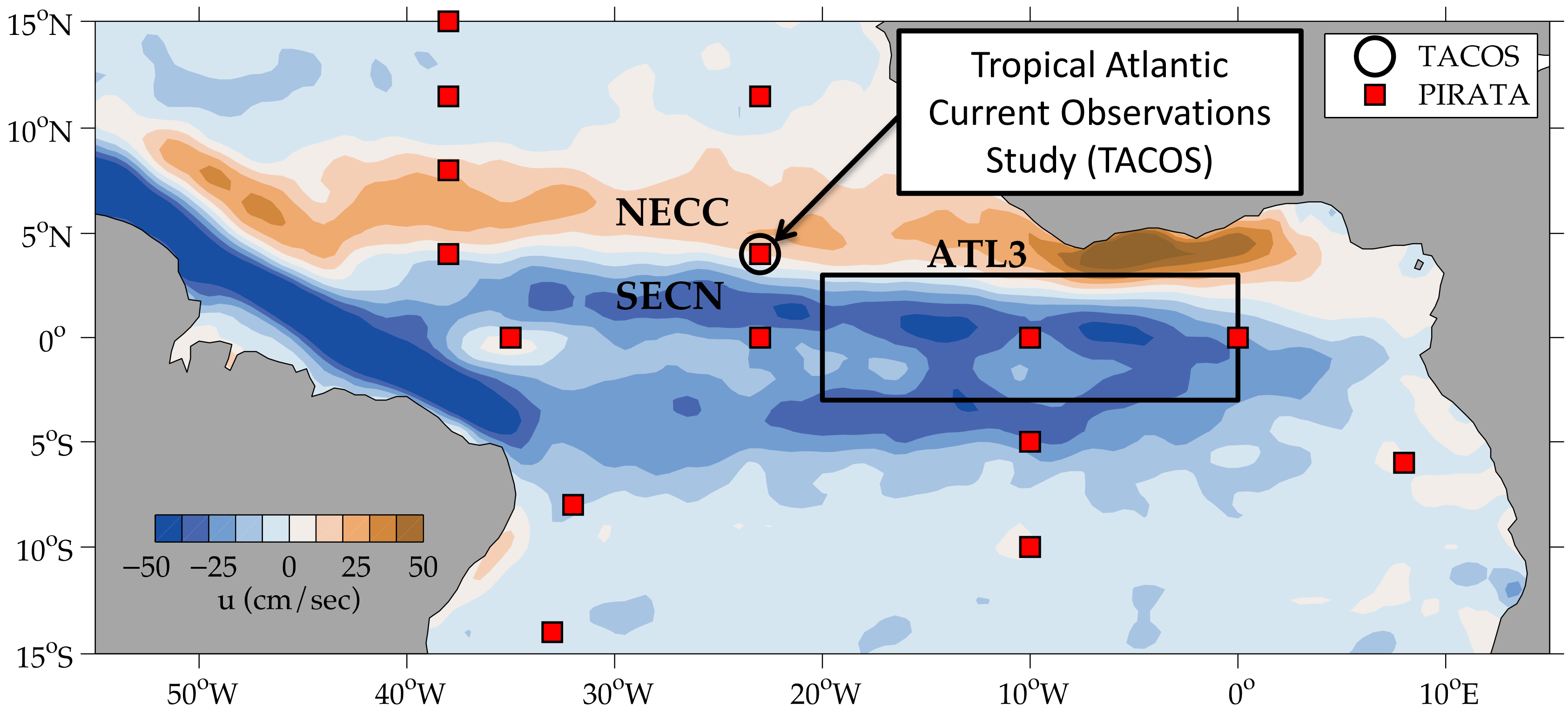
Upper ocean horizontal velocity and vertical shear in the tropical North Atlantic

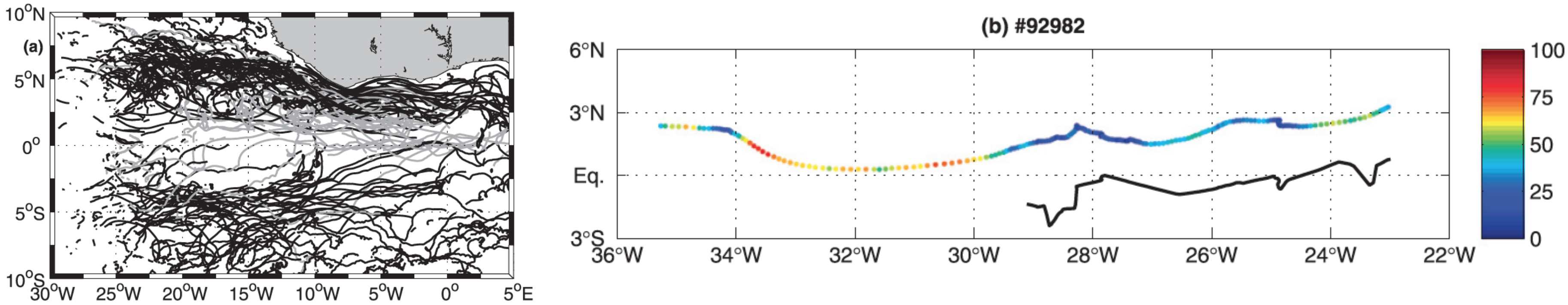
Renellys Perez, Gregory Foltz, Rick Lumpkin, Claudia Schmid, Jonathan Christophersen



Red squares: PIRATA moorings (subset), **Black circle:** Location of TACOS. Color shading: mean near-surface zonal velocity from Lumpkin and Johnson (2013) drifter climatology.

PNE funding: NOAA's Ocean Observation and Monitoring Division, TACOS funding: NOAA/AOML

More measurements needed to observe velocity in the upper 100m

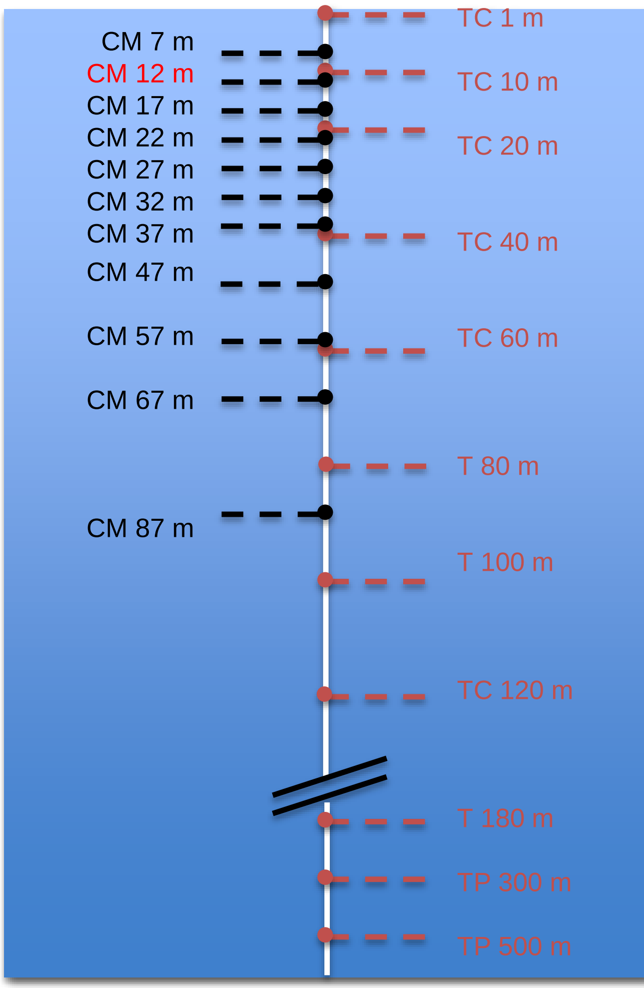


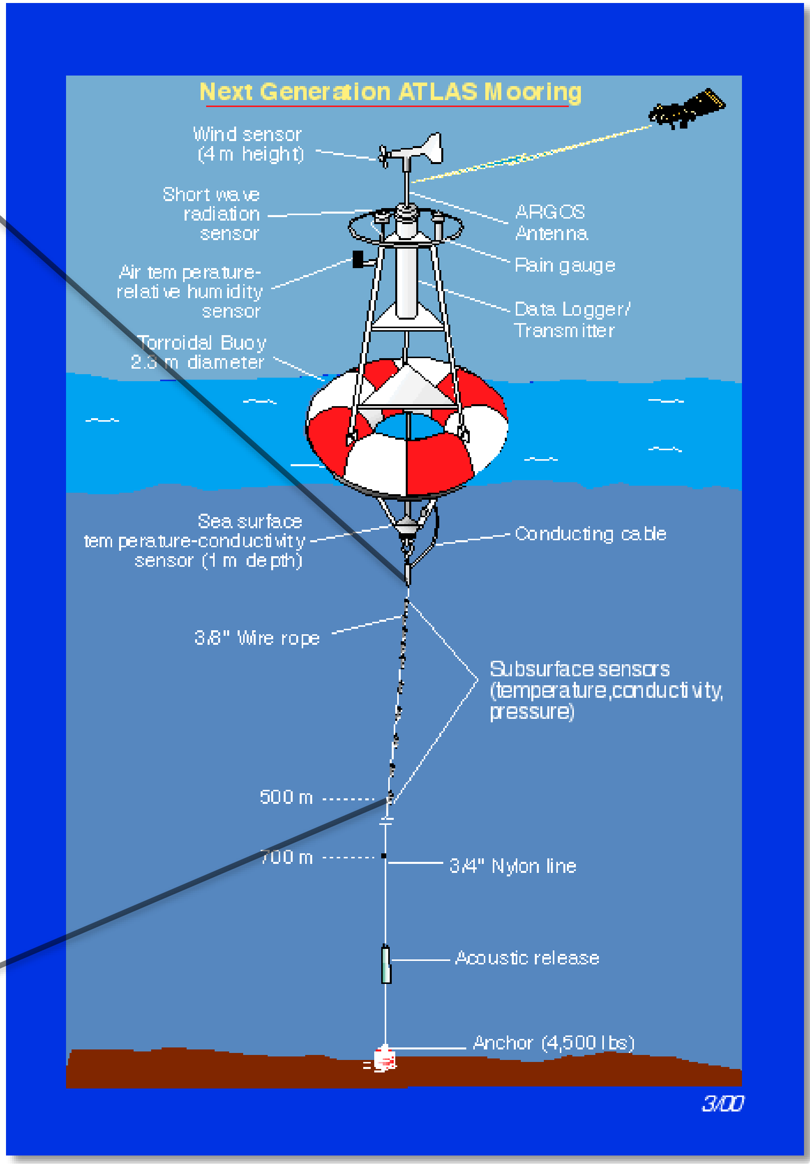
Trajectories of tropical Atlantic drifters from Hormann, Lumpkin, Perez (JTECH, 2013)

Drifters quickly **diverge** away from the equator and don't often cross the cold tongue front. **ADCP sections** provide high resolution spatial information, but many samples are needed to avoid **aliasing** and there is **little data from surface to 30 m**. Difficulty using **satellite data** to infer geostrophic and wind-driven motions because of **proximity to the equator**. **Moored current measurements** needed in upper 100m.

Questions: How are upper ocean velocity and shear modified by wind forcing events and tropical instability waves? How do currents and shear impact temperature, salinity, ocean advection, mixing/turbulence, and air-sea fluxes?

TACOS-1 acoustic current meters at 4N, 23W

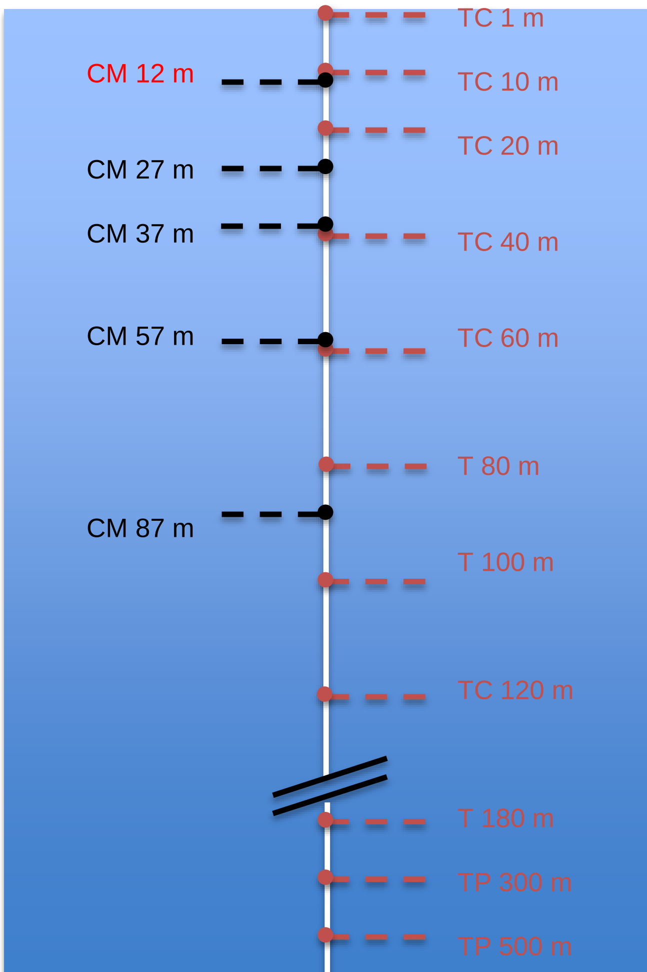


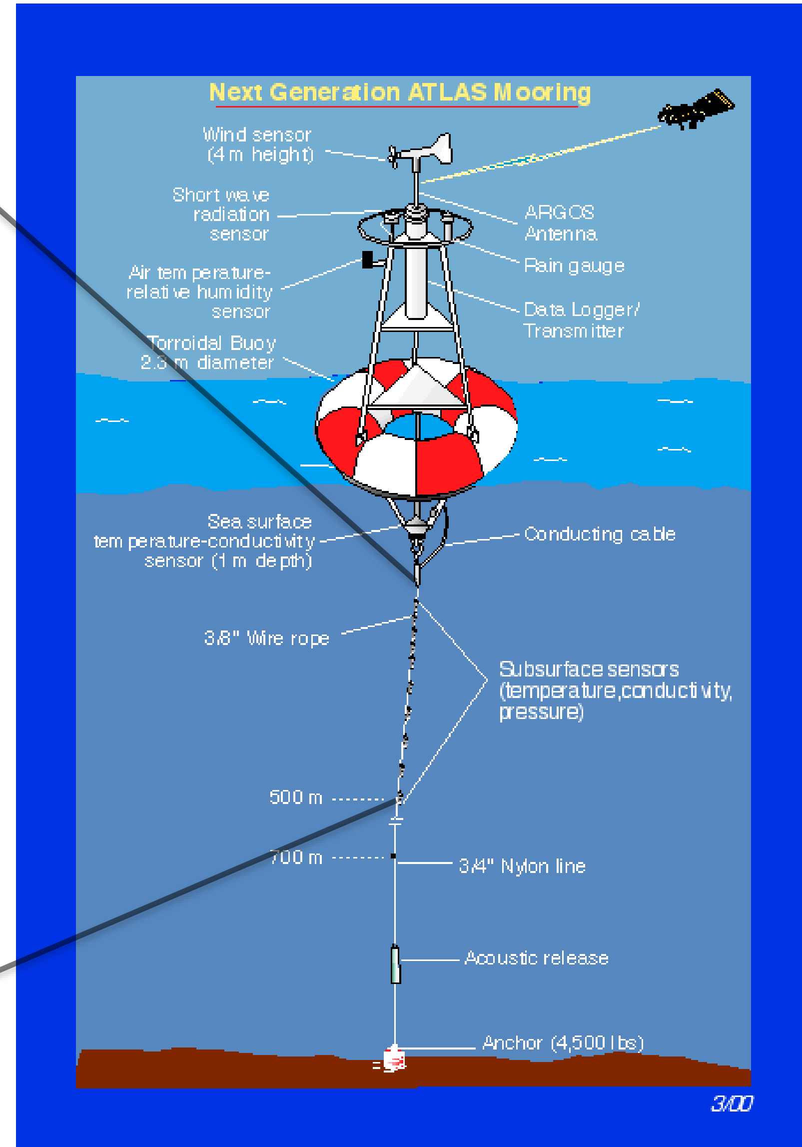


March 2017: 10 TACOS acoustic current meters deployed (PNE 10m: 2006-17).

TACOS-2 acoustic current meters at 4N, 23W

Real-time data: www.pmel.noaa.gov/pirata/



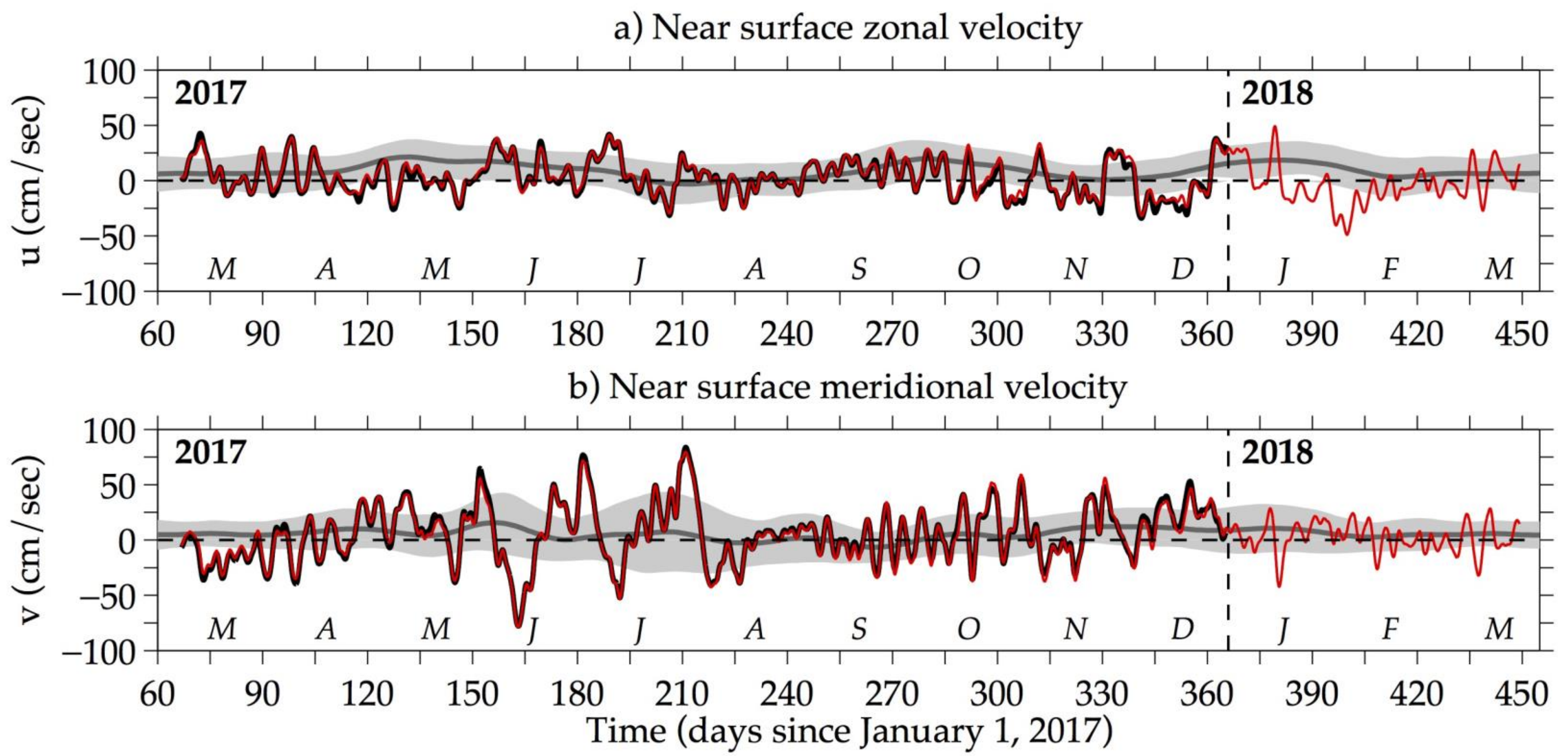


March 2018: 4 TACOS acoustic current meters (loaned from PMEL).

Observations in the first year of TACOS (March 6, 2017 to March 26, 2018)

Perez, R. C., G. R. Foltz, R. Lumpkin, C. Schmid: Observing upper ocean horizontal velocity and vertical shear in the tropical North Atlantic Ocean. To be submitted, *J. Geophys. Res.*

TACOS-1 and PNE near-surface currents at 4N, 23W

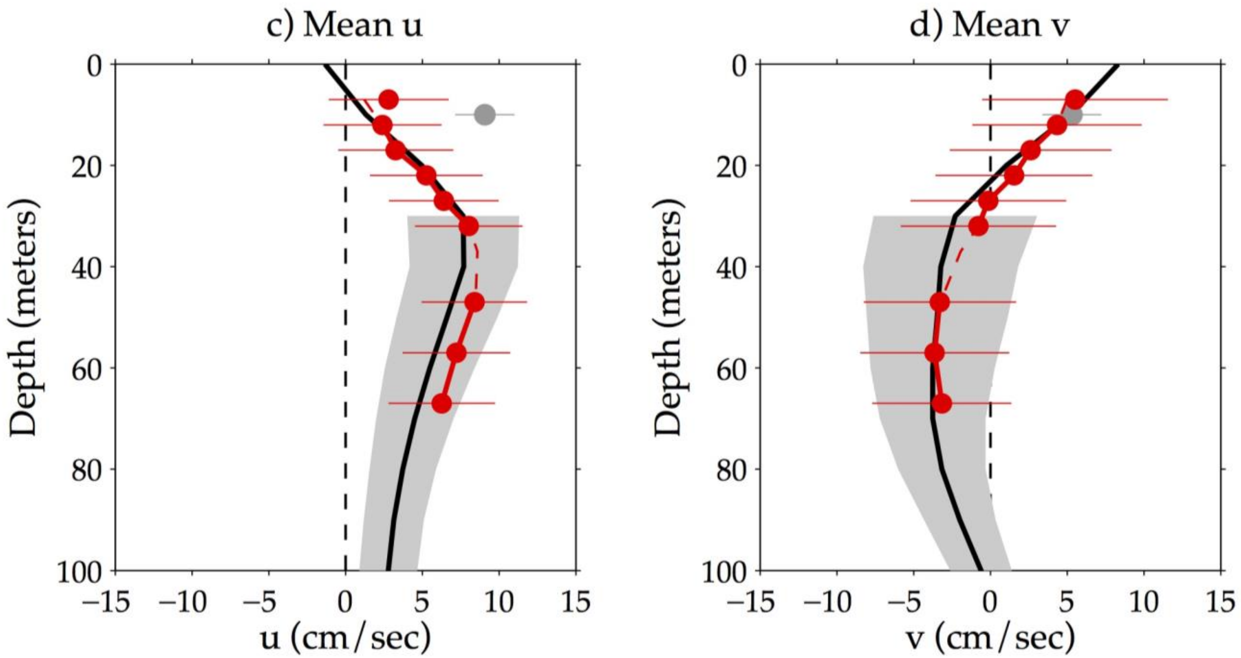


Black lines: TACOS velocities at 7 m (48-hr low-pass, 300 days)

Red lines: PNE velocities at 12 m (48-hr low-pass, 381 days)

Gray lines and shading: PNE climatological velocities at 10 m (30-day low-pass, 12 years)

TACOS-1 comparison with shipboard ADCP and 10-m PNE current meter at 4N, 23W



Gray symbols: PNE 10-m means and standard errors*

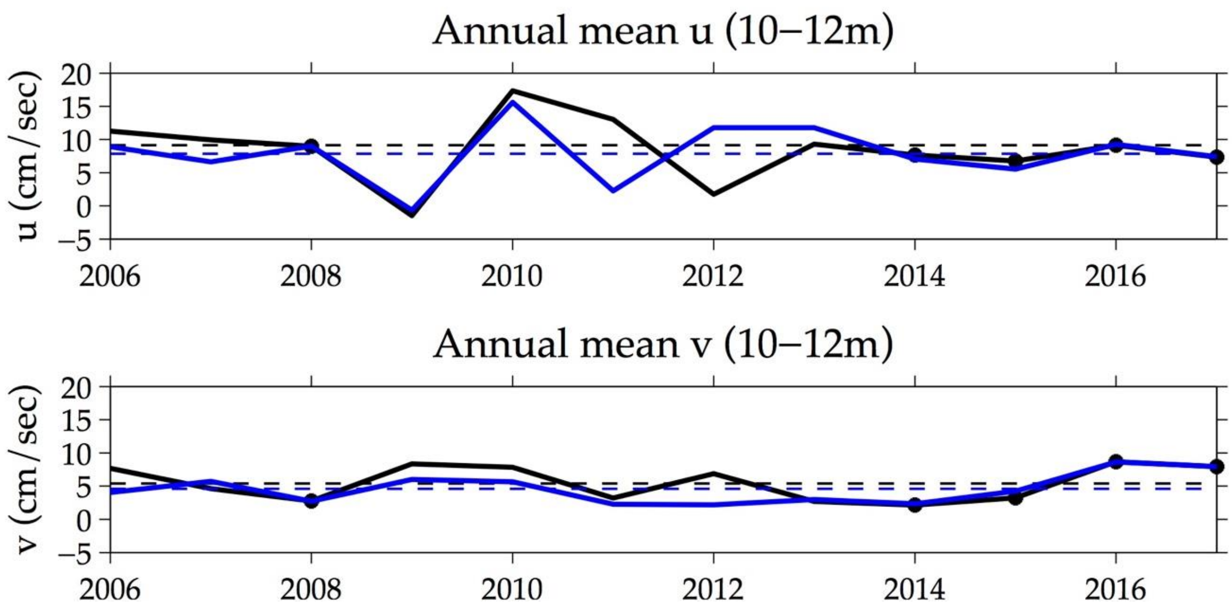
Red symbols: TACOS-1 means and standard errors

Red dashed lines: Interpolation/extrapolation of TACOS-1 values

Black line, gray shading: ADCP+Drifter means, standard errors*

**following Perez et al. (2014)*

How representative is an annual mean at 4N, 23W?



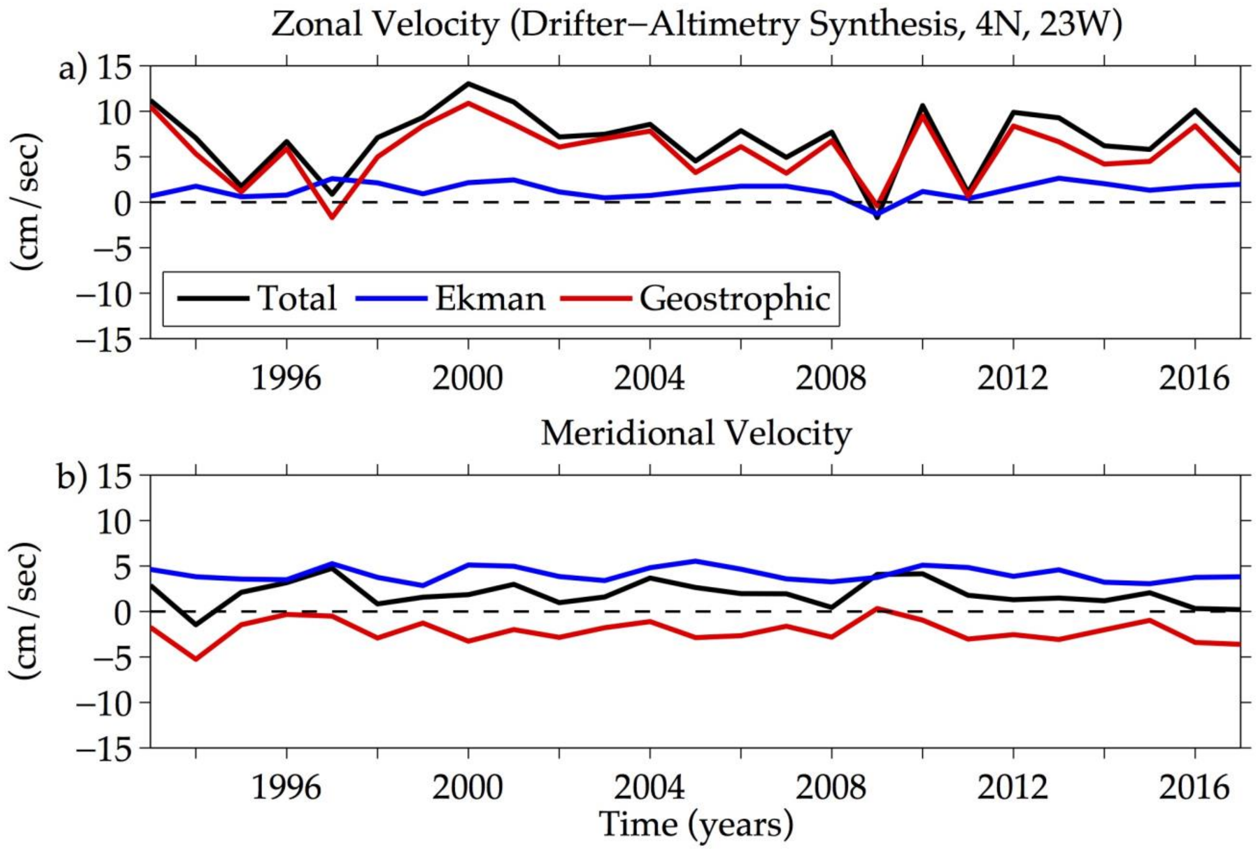
Temporal gaps in PNE mooring velocity data can alias **intraseasonal variability** into the annual means.

Gaps limit our ability to estimate robust annual means and quantify interannual variability.

Black solid line: PNE 10-12m annual mean velocities
Black circles: years with less than 4 month data gaps
Blue solid line: ePIRATA 10-m annual mean velocities *following Foltz et al. (2018)*

TACOS-1 means were weak because we missed a strong event in January-February 2017.

Observed year-to-year variability is largely geostrophic

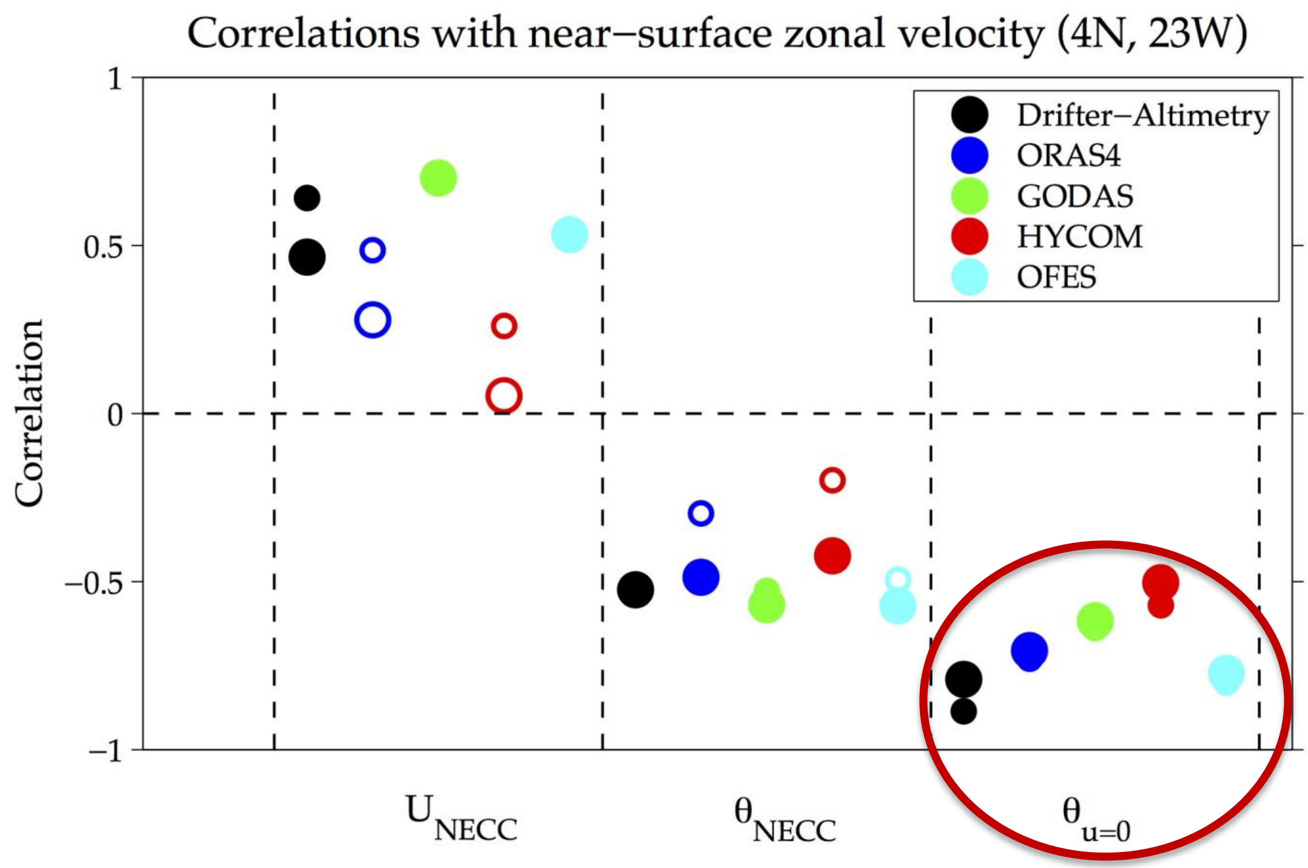


Black lines: Drifter-altimetry annual mean 15-m velocity *(following Lumpkin and Garzoli, 2011)*

Blue lines: Ekman component

Red lines: Geostrophic component

What causes year-to-year variability of near-surface zonal velocity at 4N, 23W?

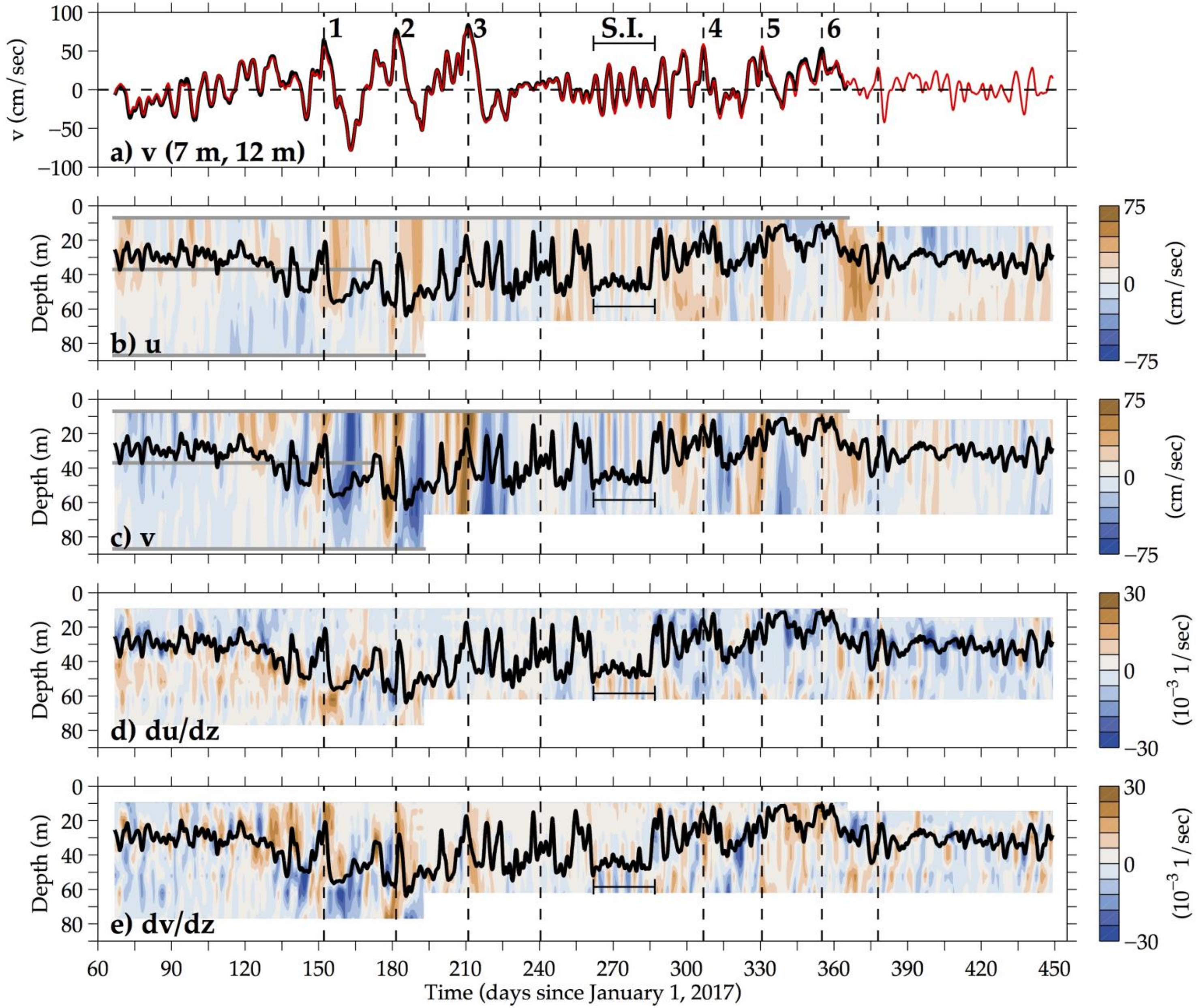


Near-surface u is most strongly related with the latitude of the SECN-NECC boundary ($\theta_{u=0}$)

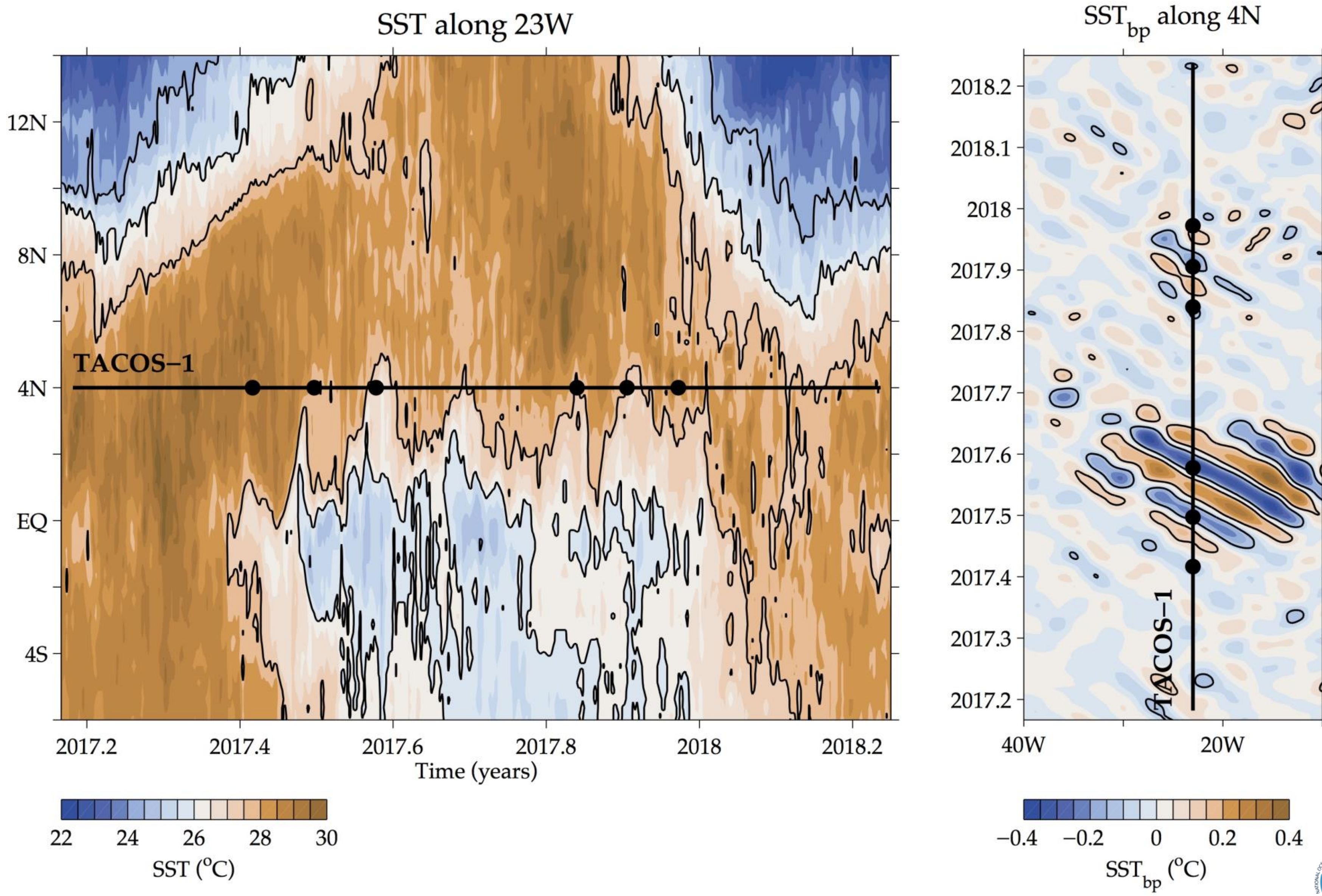
Lowest correlation between peak NECC zonal velocity and near-surface u, found in models where NECC is well north of 4N

Small circles: Correlations for 2000-2015
Large circles: Correlations for full model/obs record
Filled circles: Correlations significant at 95% level

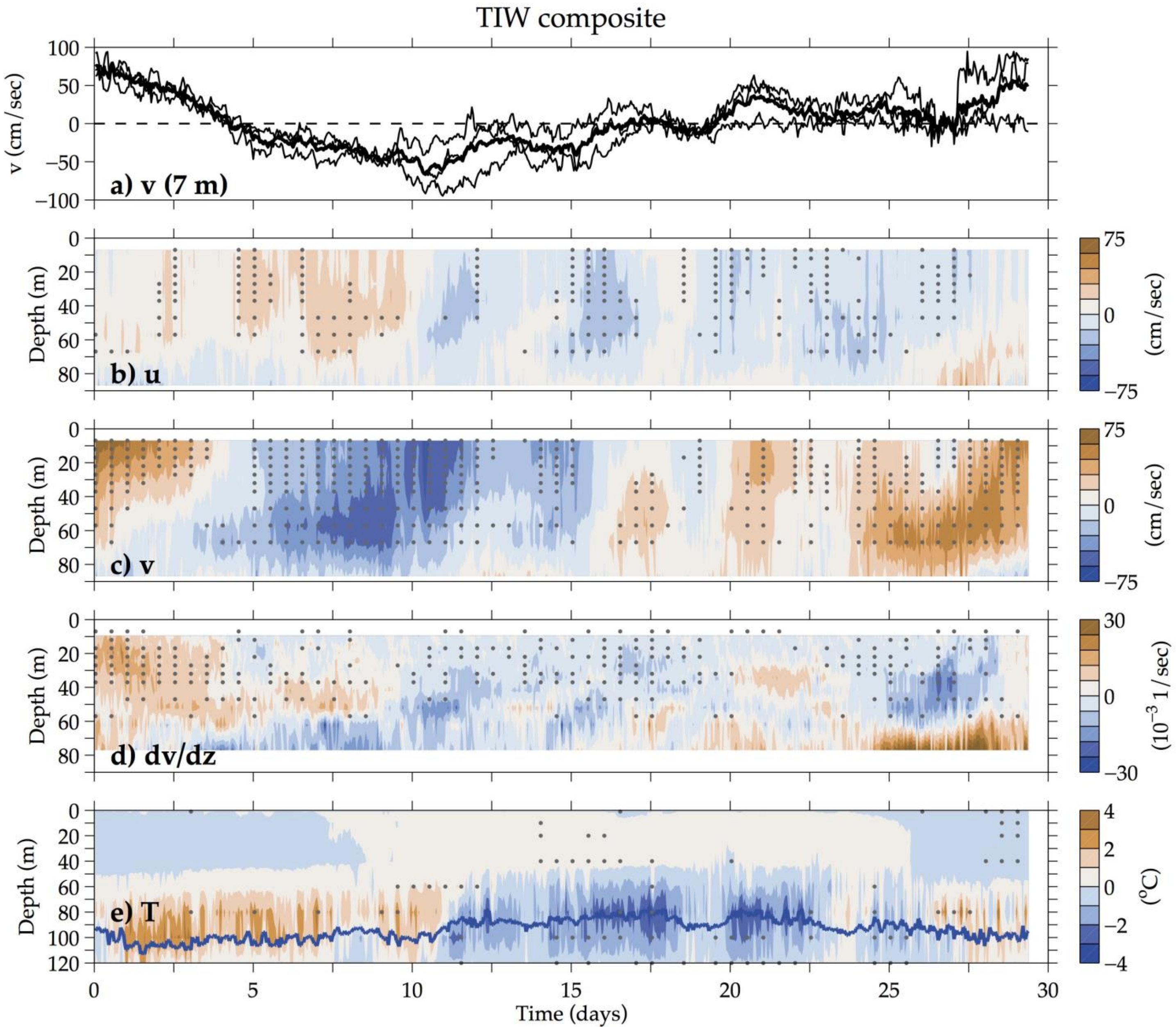
TACOS-1 vertical-temporal evolution



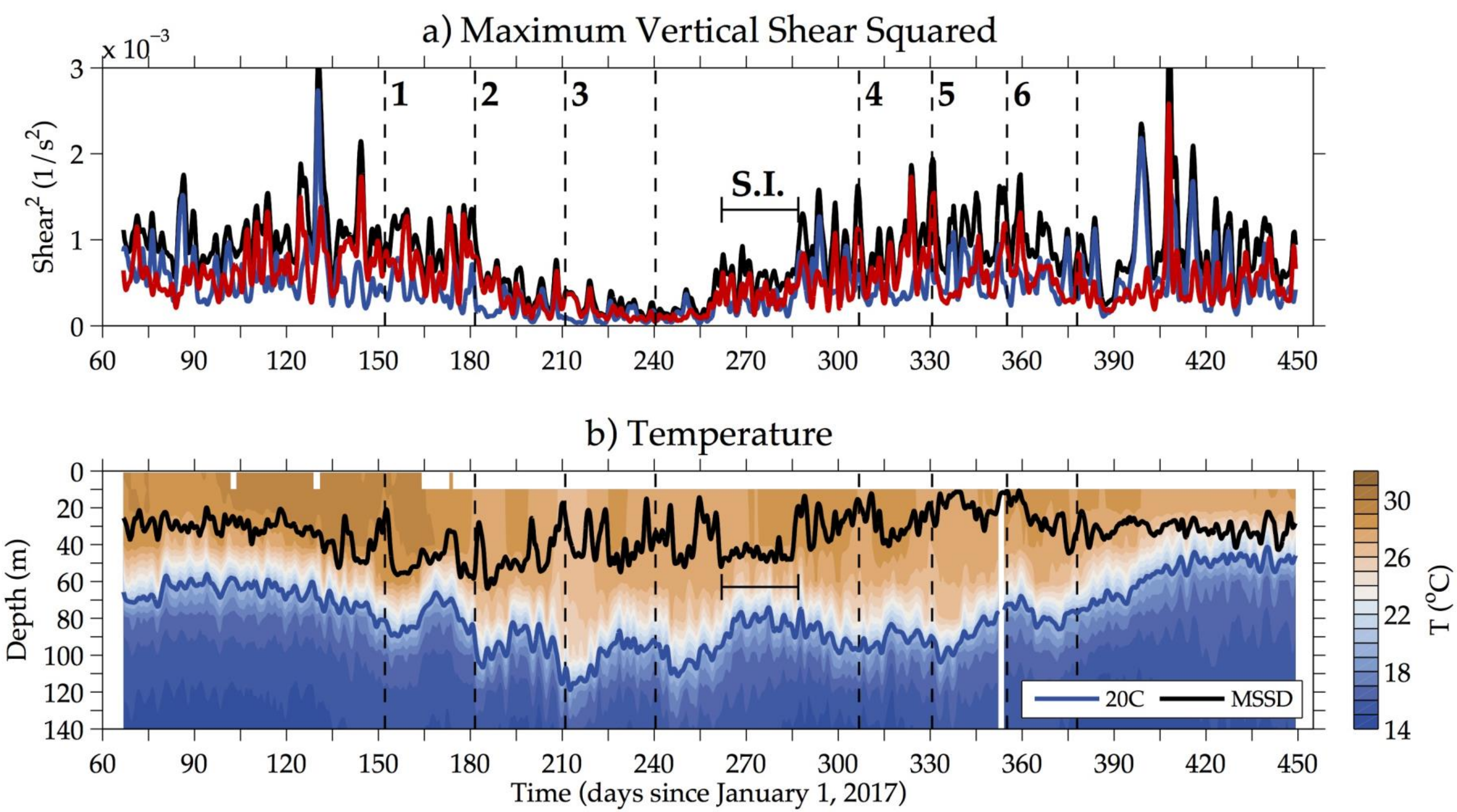
Satellites capture SST signature of TIWs



Composite of the first three TIWs



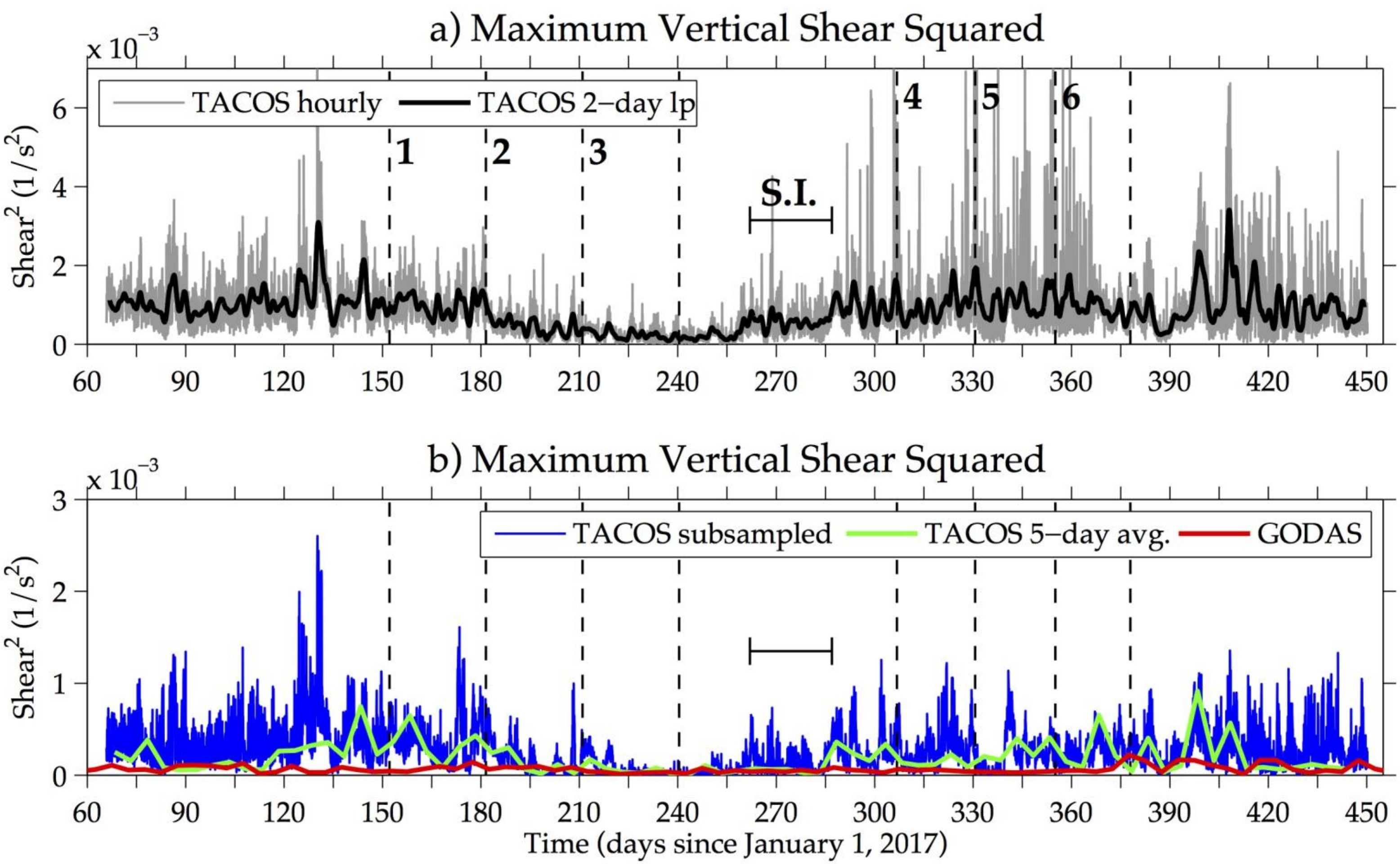
Evolution of maximum shear squared and thermocline depth



Shears were largest in spring 2017 and winter 2018 before/after TIWs.

Meridional contribution to shear often exceeds **zonal contribution**.

Largest vertical shears are at high-frequencies, fine vertical scales, and seasonally modulated



Deployment of a limited number of instruments (e.g., TACOS-2) will reduce ability to detect largest shears around 27 to 37 m depth.

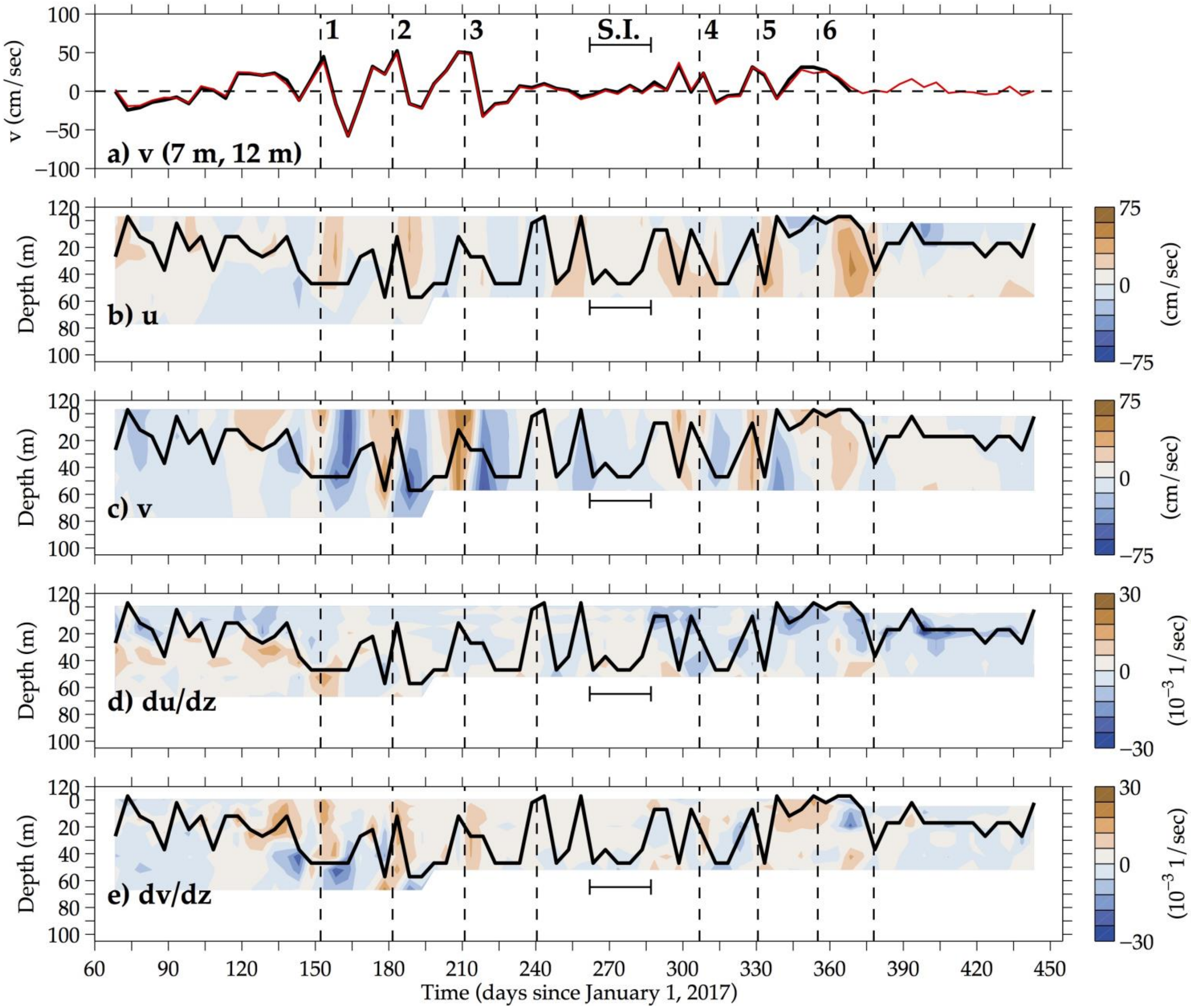
Summary and conclusions from TACOS-1

TACOS provides a novel continuous-in-time view of horizontal currents and vertical shear in the tropical North Atlantic (4N, 23W), which influence local temperature variations from the surface down to the thermocline.

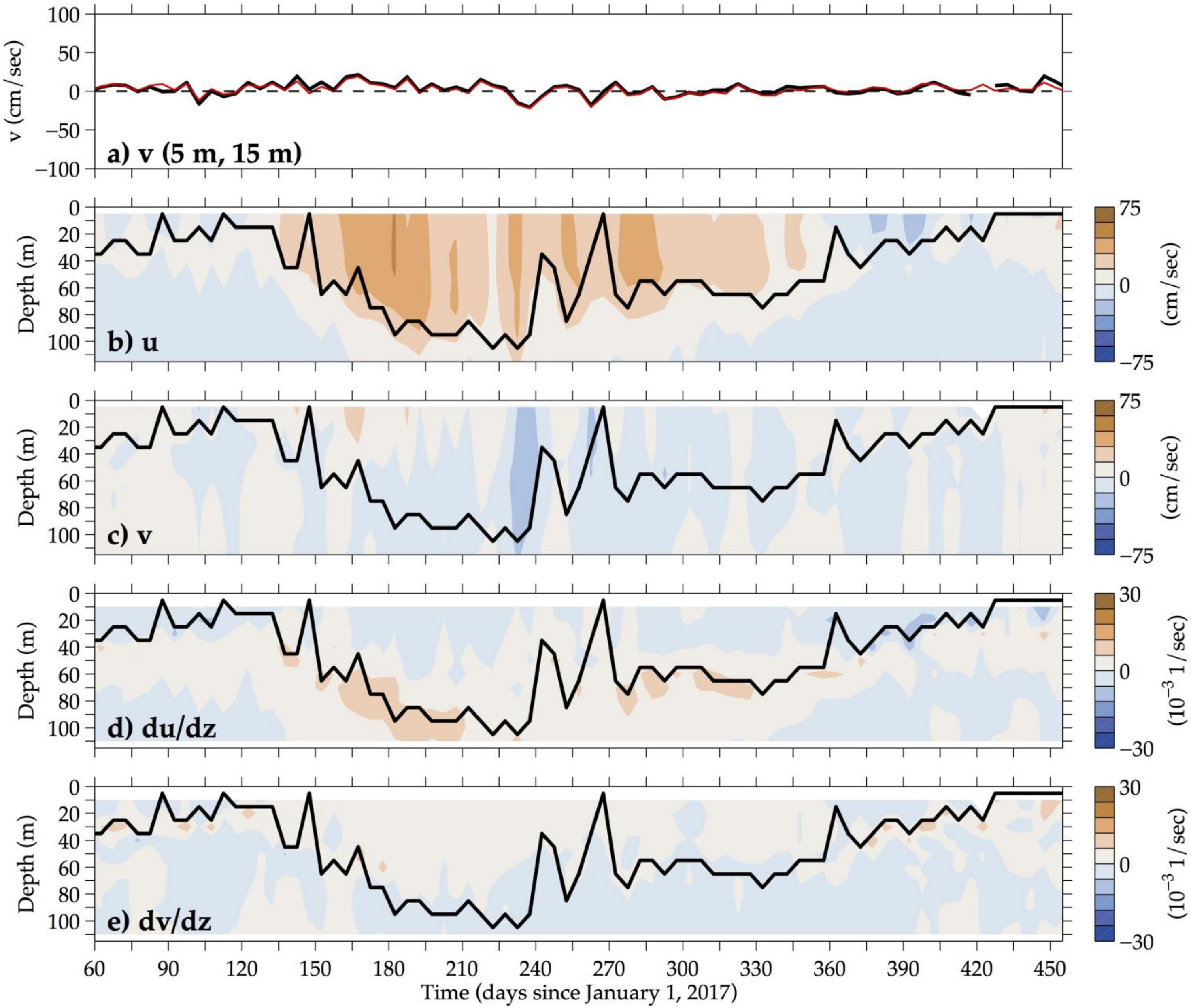
These data yielded several new insights/surprises:

- Mean zonal velocity and vertical shear were strongest between 32-37 m
- Near-surface mean eastward currents were weaker than expected
- Energetic TIWs were observed despite the anomalously warm cold tongue
- Despite large meridional velocity fluctuations associated with TIWs that extended down to 87 m, only modest vertical shears were observed during the first set of TIWs
- Instead, the vertical shears were largest in spring 2017 before the first set of TIWs, and in fall/winter 2018 during/after the second set of TIWs
- High vertical and temporal resolution needed to capture strong vertical shear events, and models likely underrepresent velocity and shear perturbations

TACOS 5-day averages still capture TIWs



GODAS 5-day averages don't capture rich structure



Diurnal analysis of TACOS-1 data

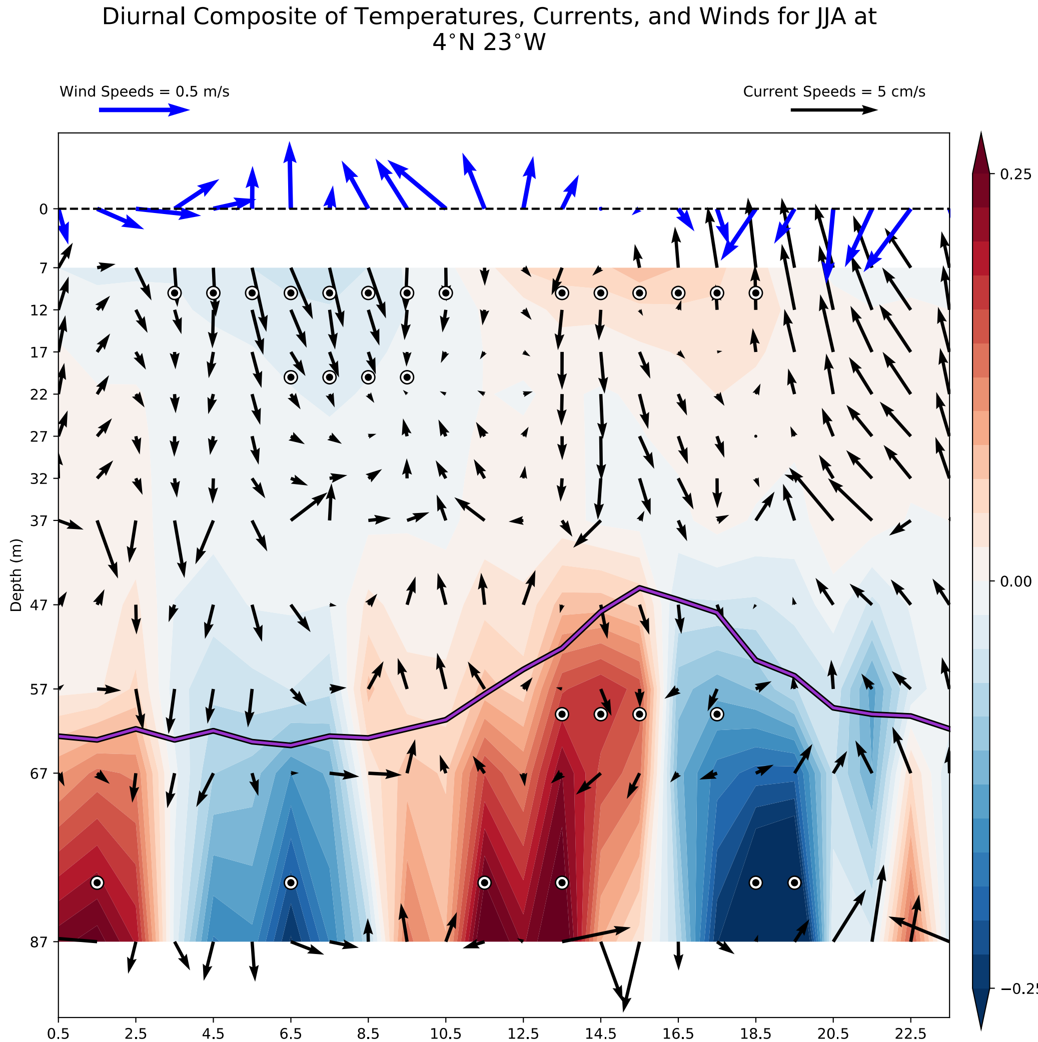
Diurnal cycle analysis

(courtesy of Jonathan Christophersen)

Diurnal variations in winds, temperature, mixed layer depth, and meridional velocity in June-August.

Northward acceleration of flow as surface warms and MLD shoals.

Semi-diurnal variations in temperature and velocity below the mixed layer likely due to semi-diurnal tides, play a large role in seasonal cycle of mixing.



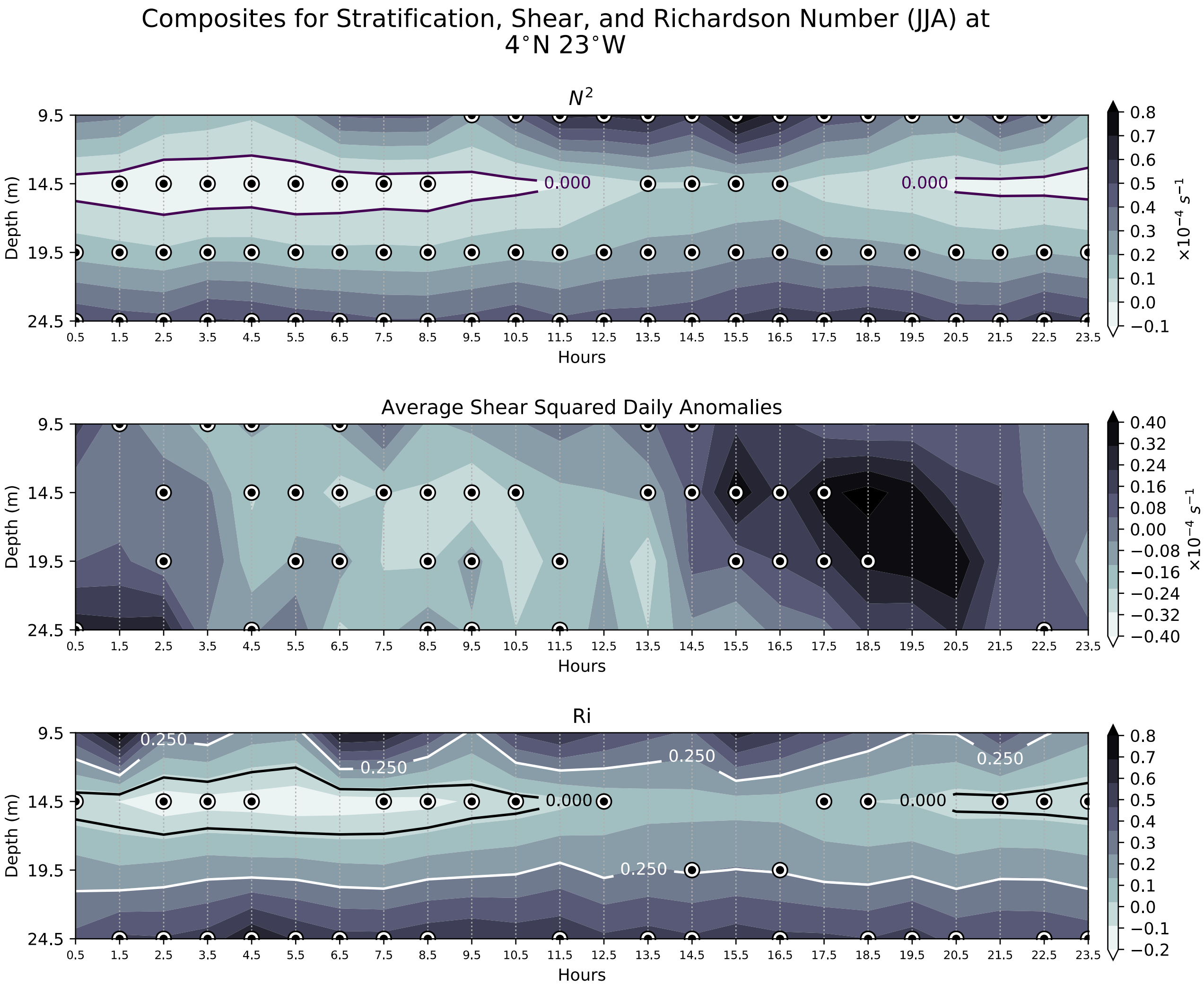
Diurnal cycle analysis

(courtesy of Jonathan Christophersen)

More stratification and shear during afternoon

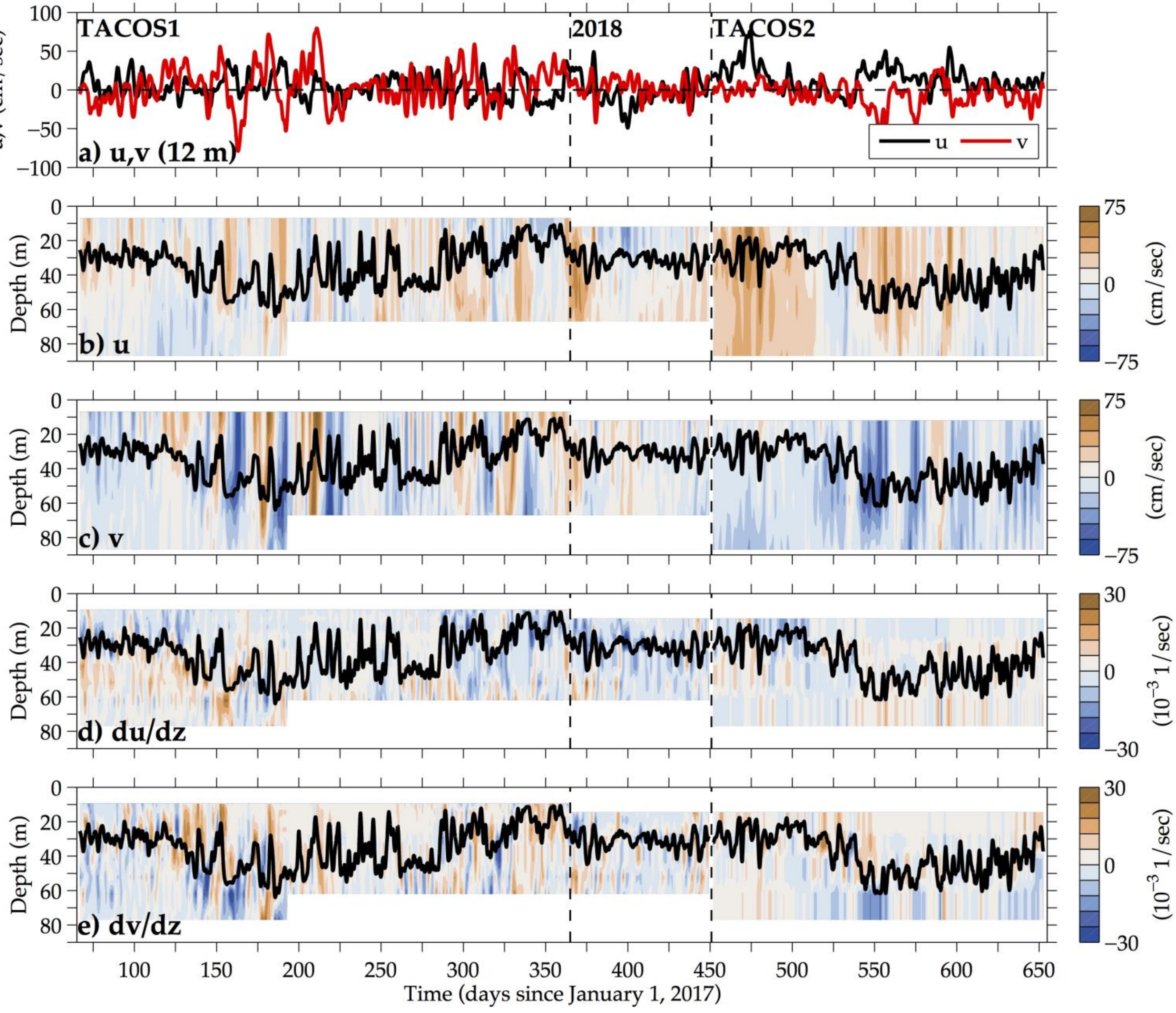
Richardson's number is mostly controlled by stratification

Flow most unstable around 14.5m depth, consistent with Cronin and Kessler (2009) and Wenegrat and McPhaden (2015)

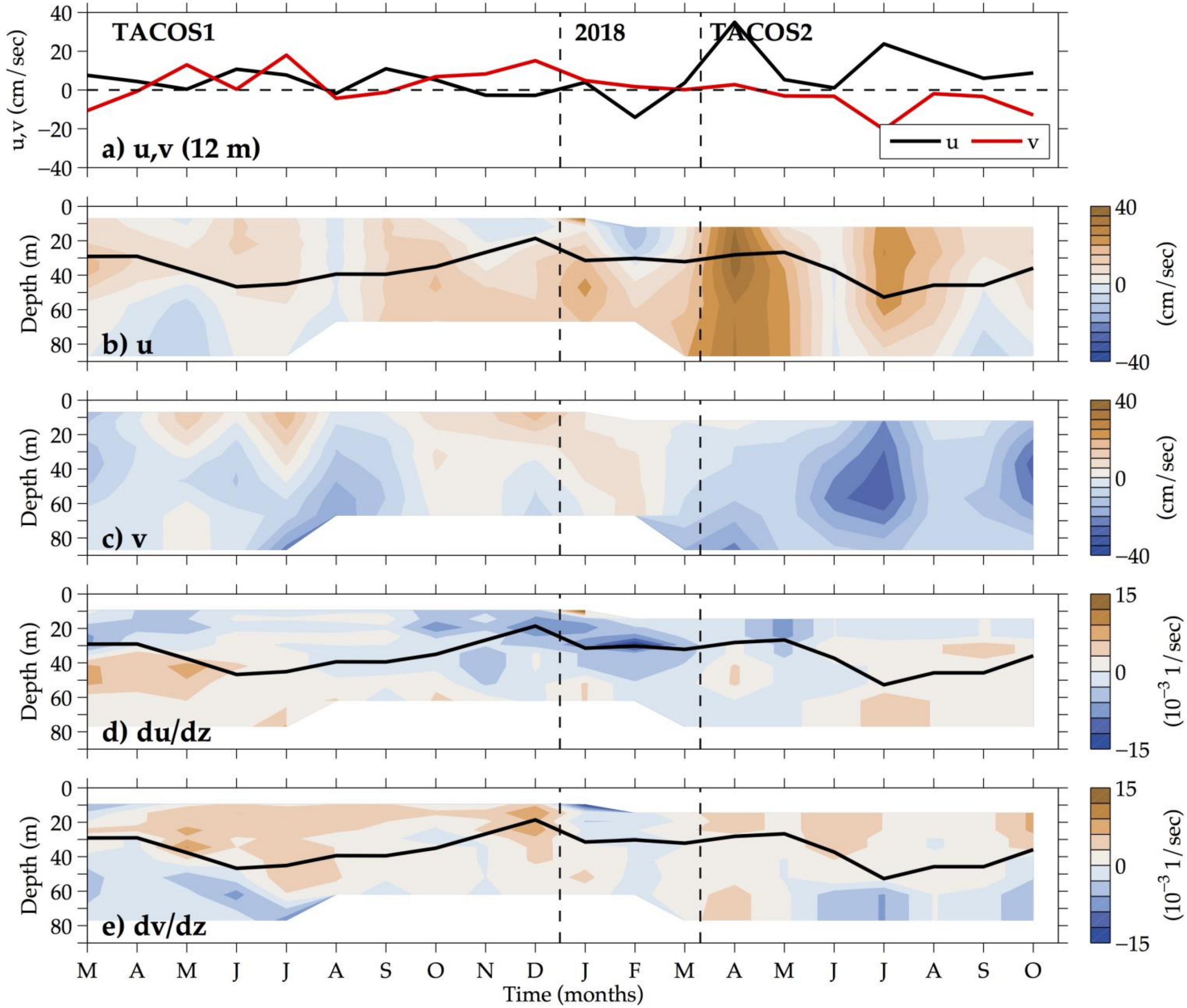


TACOS-1 and TACOS-2 data

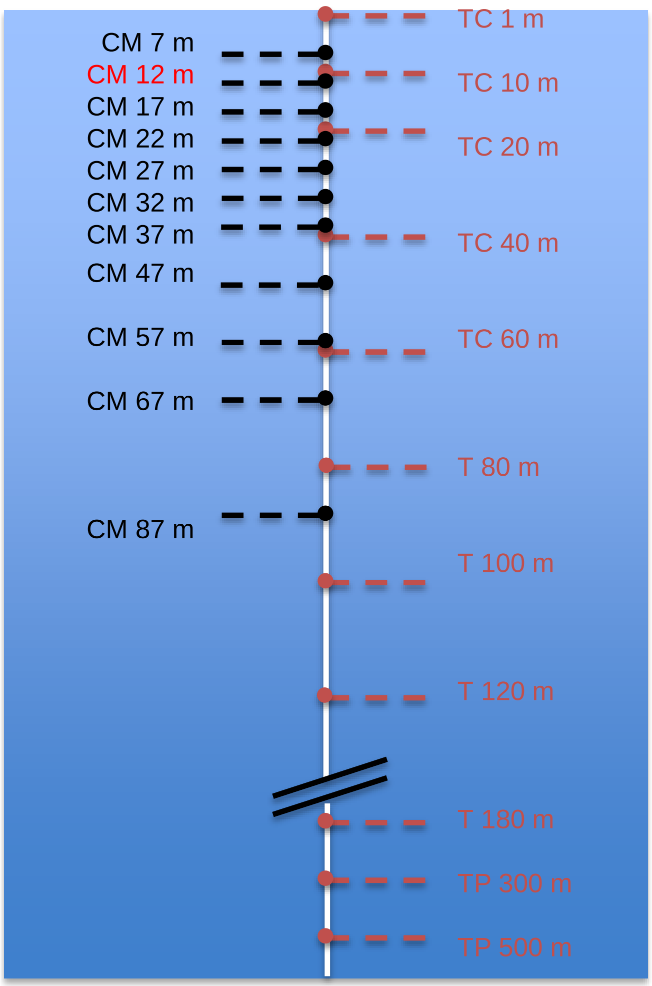
TACOS-1 & TACOS-2



Monthly means



TACOS deployment plans
Next 2-3 years



Feb-March 2019: Redeploy NOAA/AOML Aquadopps at 4N, 23W with 7-10 sensors (**TACOS-3**).

Recover in 2020 and decide where to redeploy in 2021. **Possibilities:** oxygen minimum zone region, main hurricane development region.

To avoid interruptions to TACOS record, an additional 10 point acoustic meters are needed to have a full set of spares for turn-arounds.

Thank you for your attention!

Questions:
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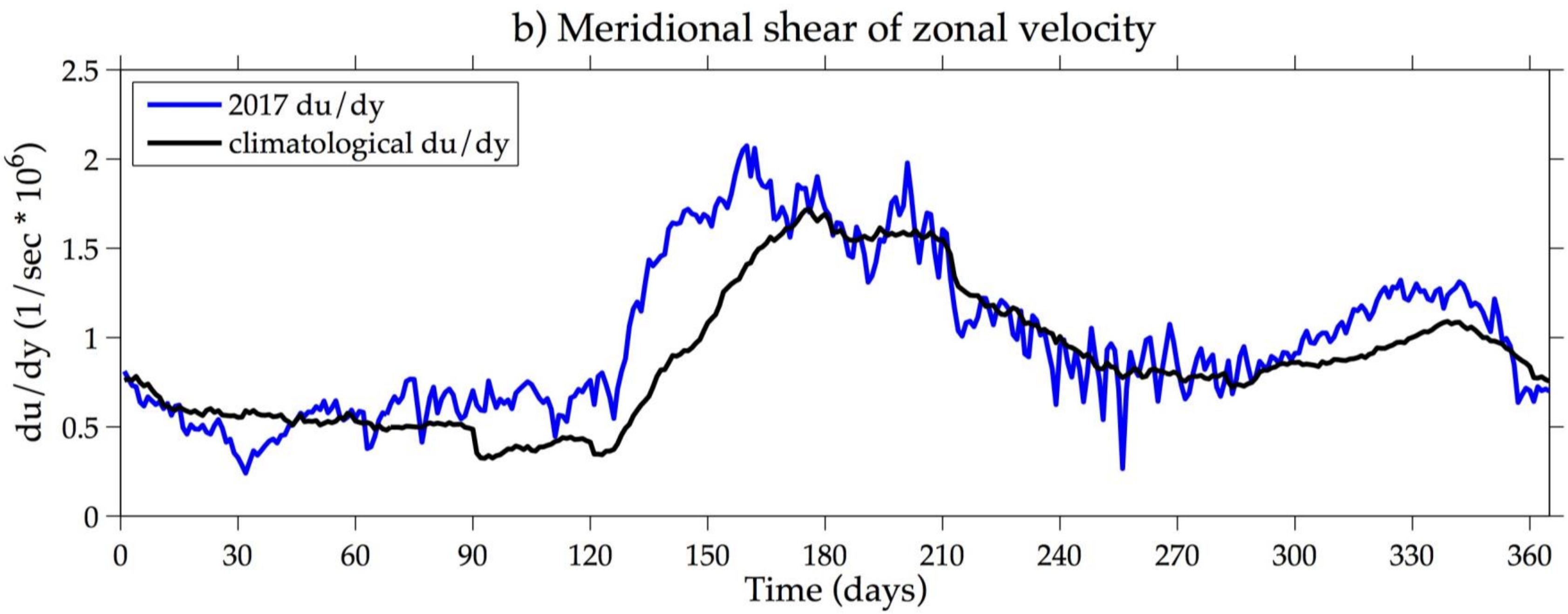
Extra slides

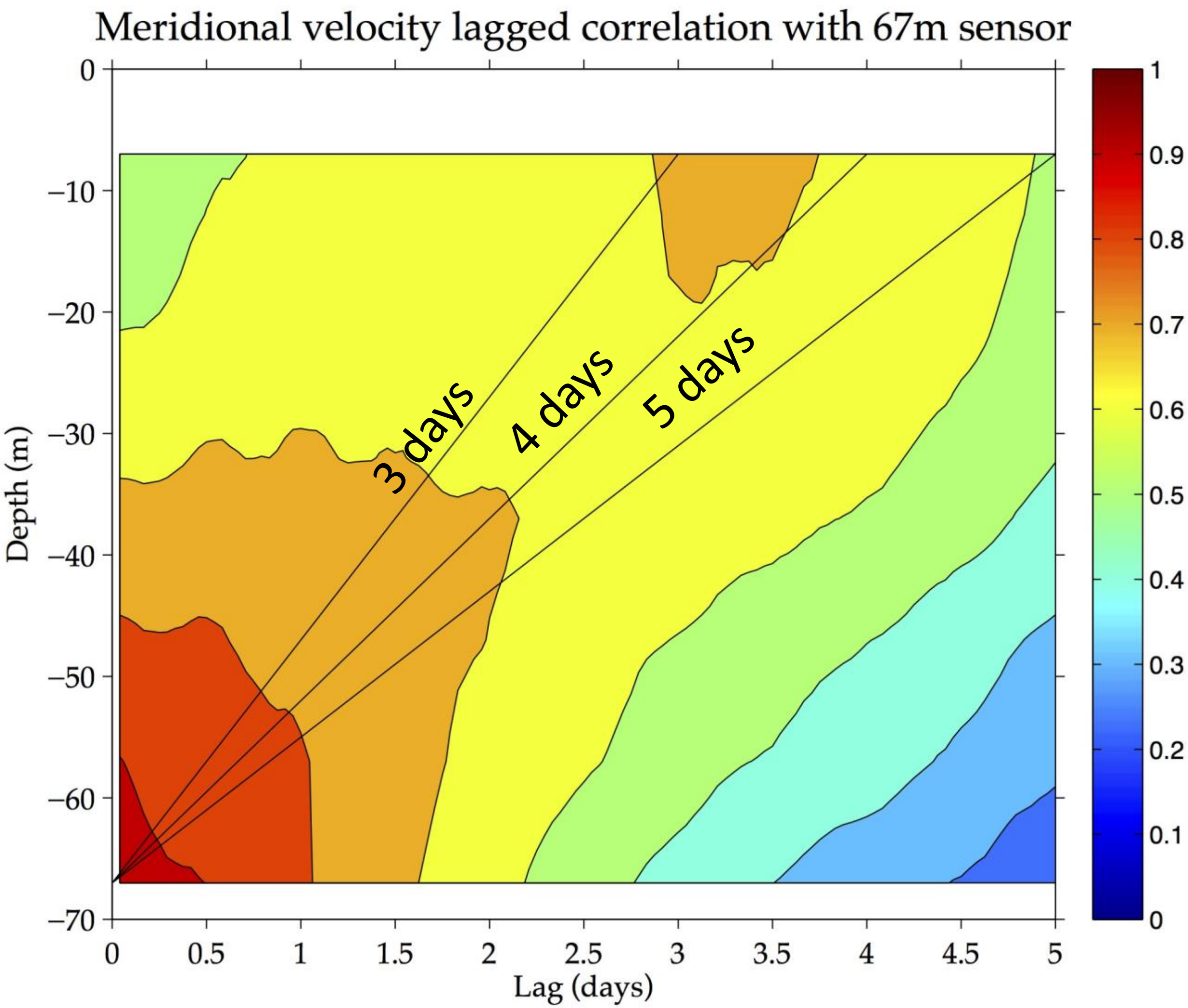
Strong TIWs were observed despite weak cold tongue in 2017 due to strong meridional shear



Meridional shear averaged in box between 30W and 10W, and 3N and 6N using drifter-altimetry synthesis data (Lumpkin and Garzoli, 2011)

SECN-NECC shear in 2017 was slightly stronger than climatological values in early summer and fall/winter, consistent with fairly energetic TIWs during that time

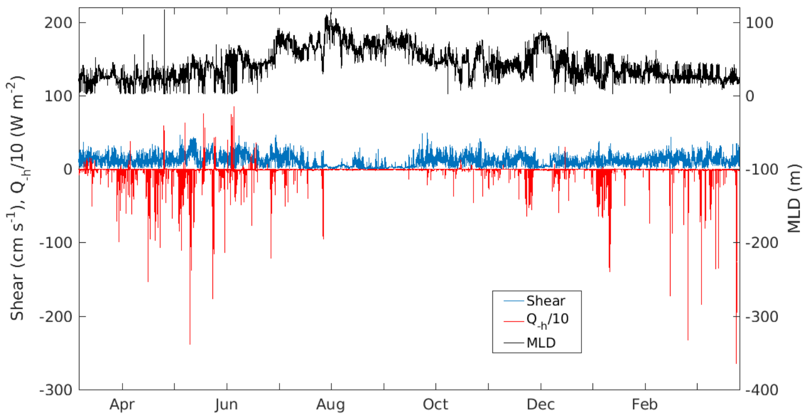
Vertical propagation during first three TIWs

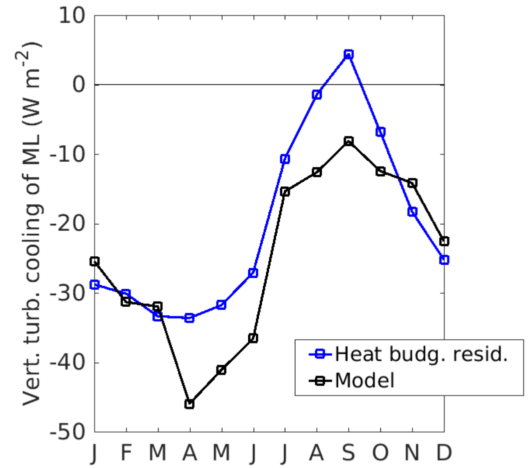


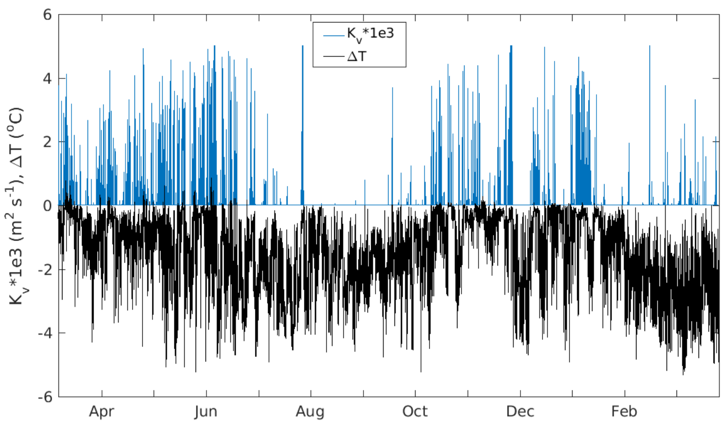
During first (second) three TIWs, we observe upward phase propagation, with vertical phase speeds of around 14.4 m/day (12.6 m/day)

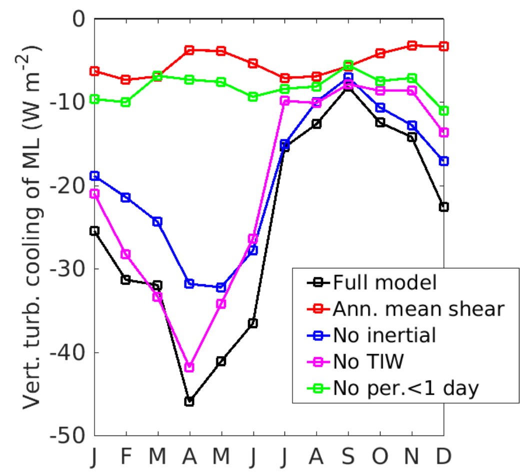
Mixing and vertical turbulent cooling using KPP

(courtesy of Greg Foltz)



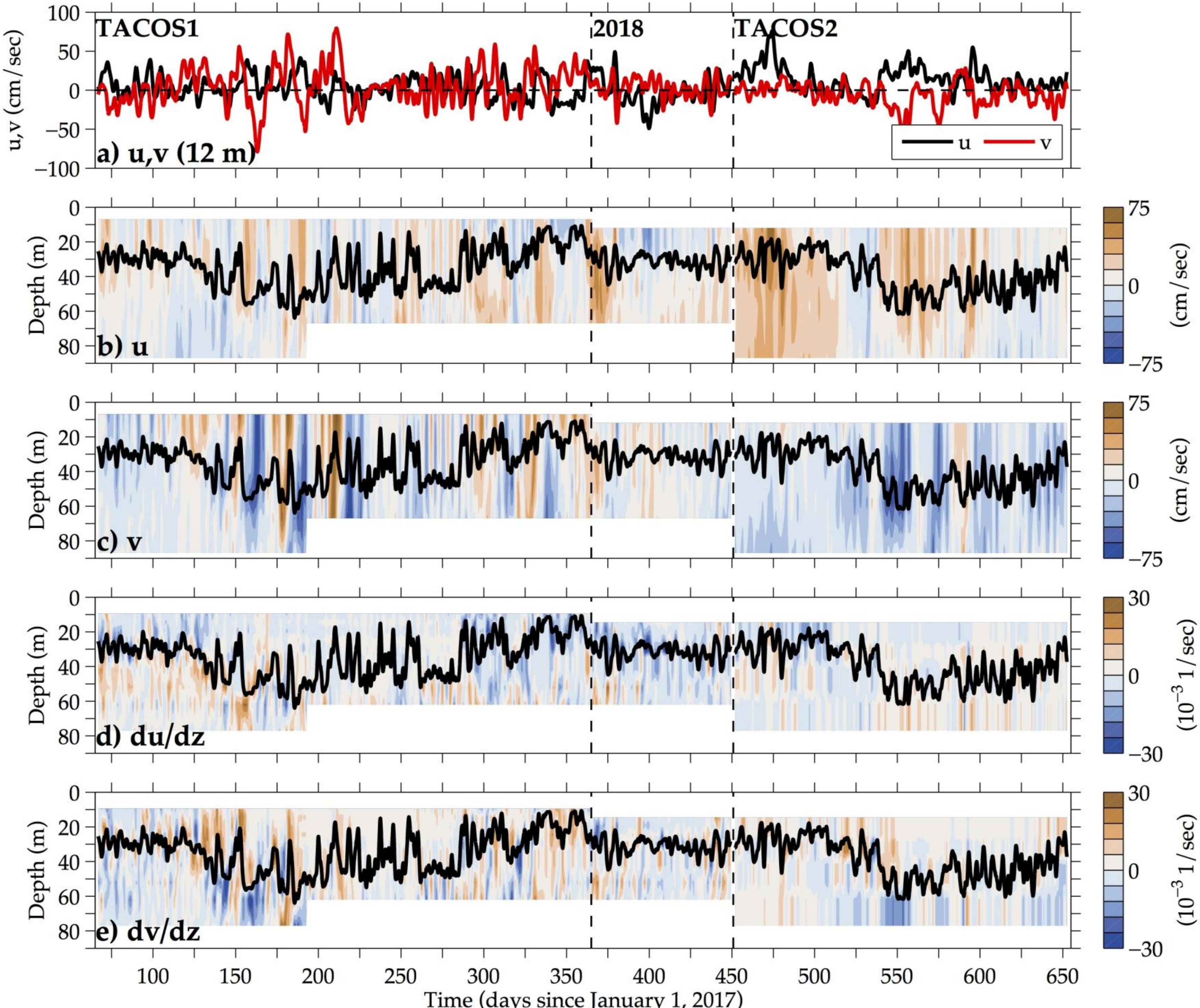




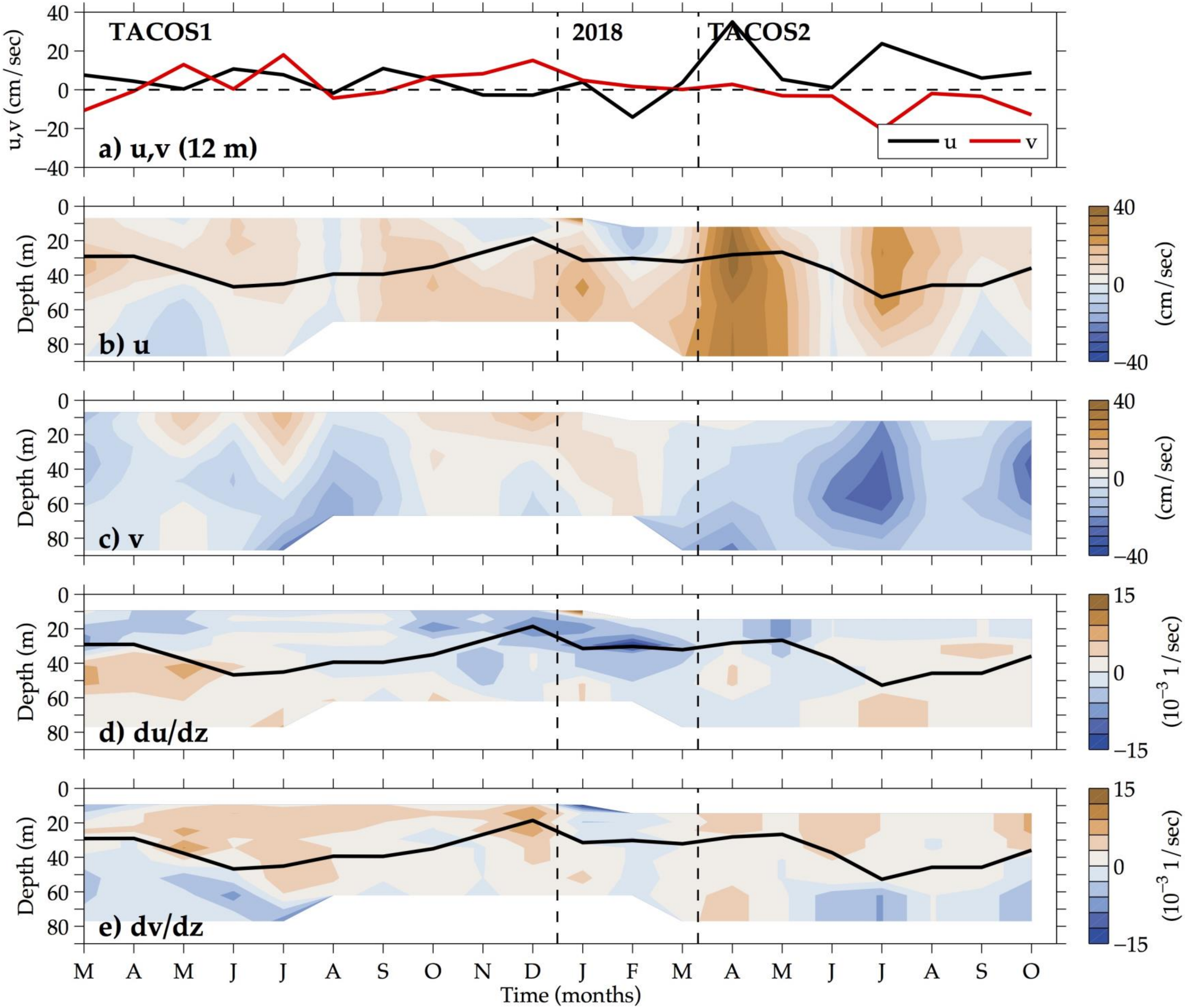


Highest mixing (K_v), turbulent cooling (Q_{-h}) at based of mixed layer when shear is large and ML is shallow

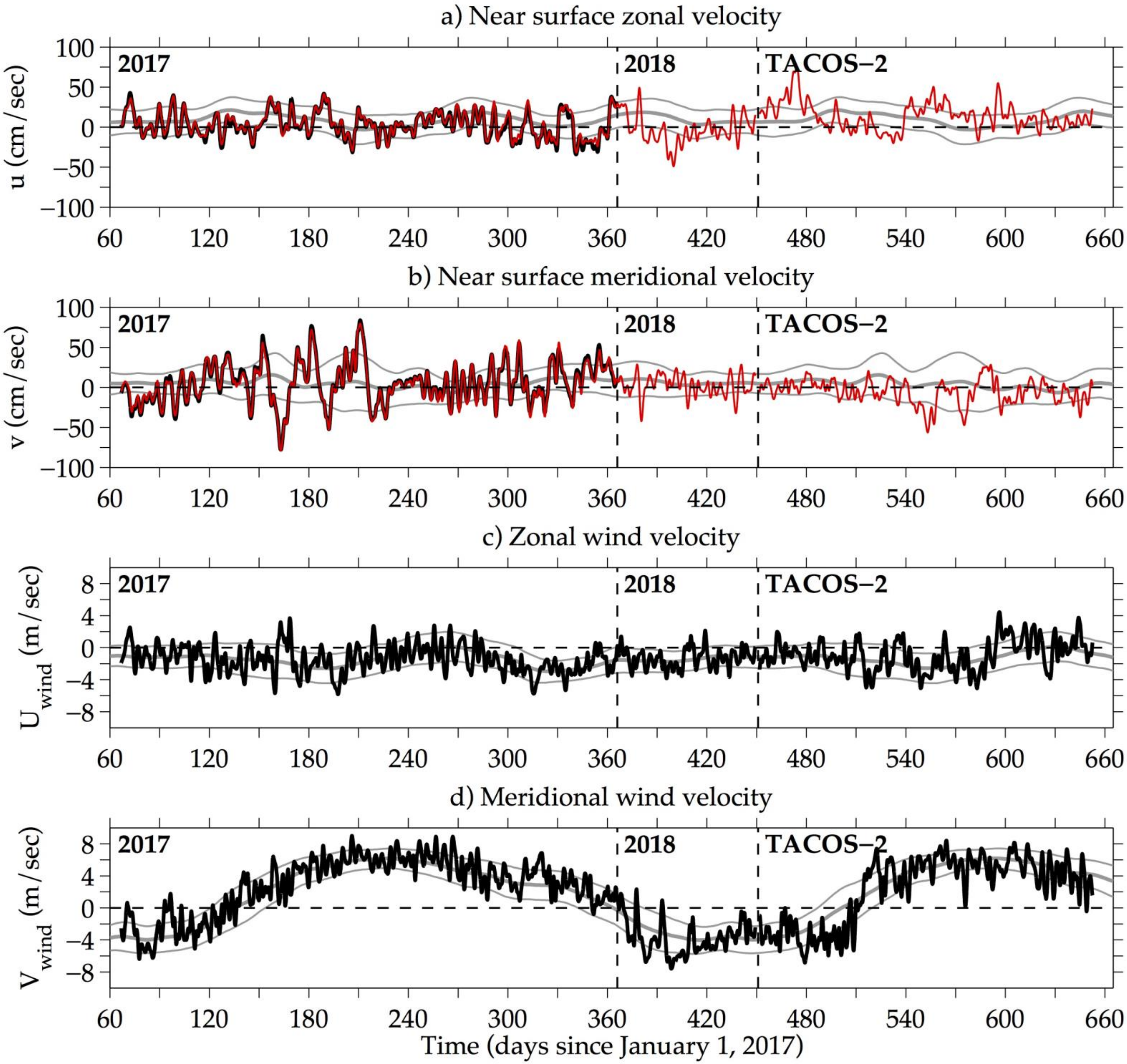
High-freq. forcing, near-inertial waves, and TIWs important for ML vertical turbulent cooling

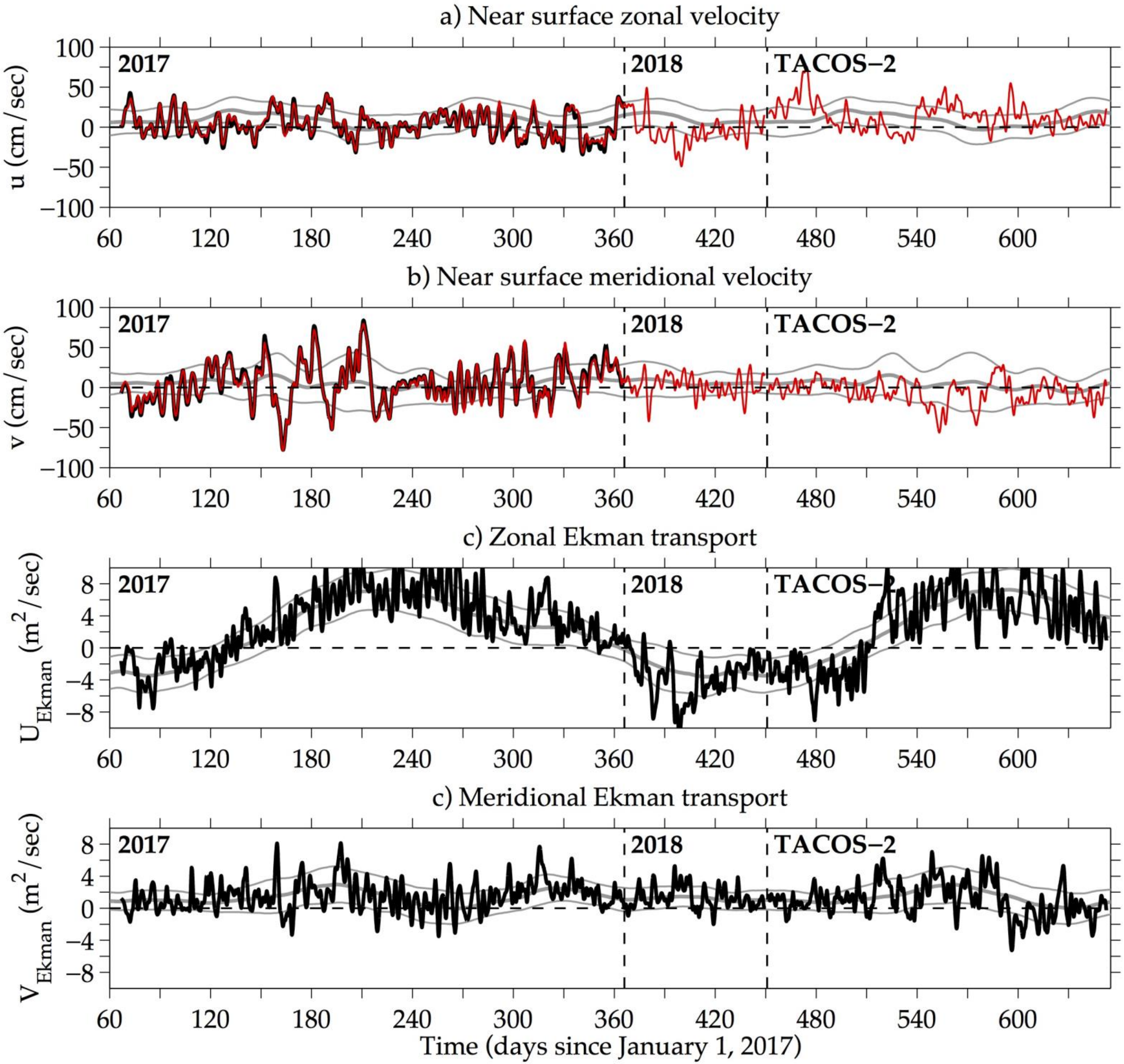


TACOS1
2018
TACOS2
u
v
a) u,v (12 m)
u,v (cm/sec)
b) u
c) v
d) du/dz
e) dv/dz
Depth (m)
(cm/sec)
(10^{-3} 1/sec)
Time (days since January 1, 2017)

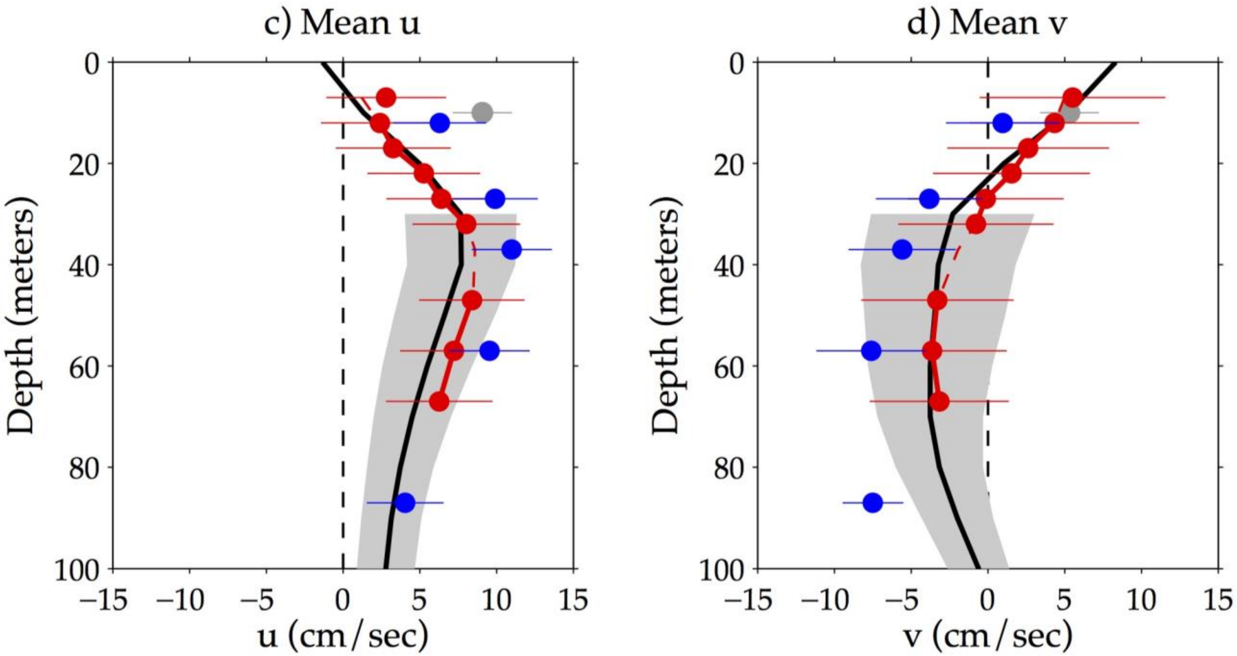


TACOS1
2018
TACOS2
u,v (cm/sec)
a) u,v (12 m)
u
v
b) u
c) v
d) du/dz
e) dv/dz
Depth (m)
(cm/sec)
(10^{-3} 1/sec)
M A M J J A S O N D J F M A M J J A S O
Time (months)

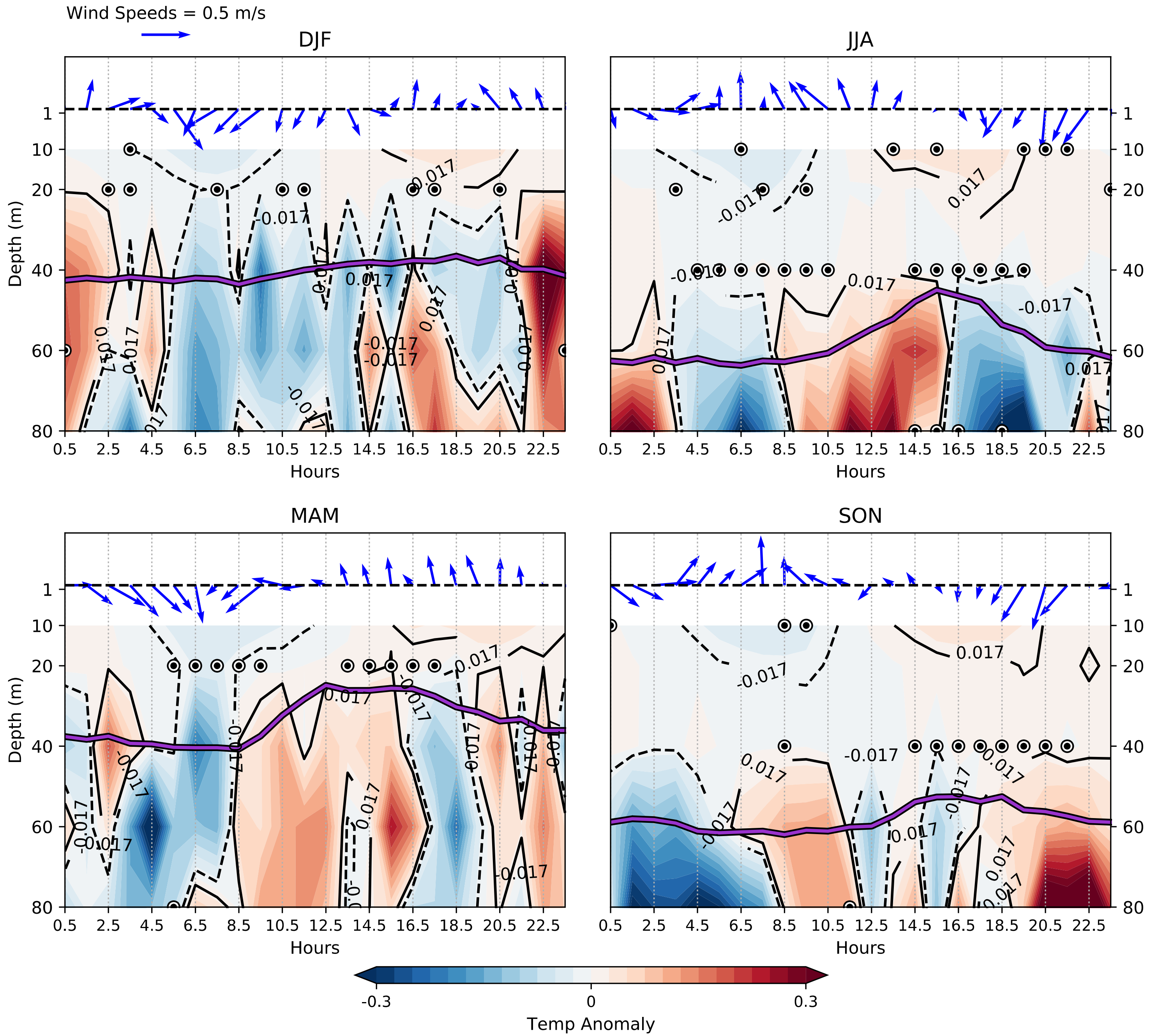

a) Near surface zonal velocity
u (cm/sec)
2017
2018
TACOS−2
b) Near surface meridional velocity
v (cm/sec)
c) Zonal wind velocity
U_{wind} (m/sec)
d) Meridional wind velocity
V_{wind} (m/sec)
Time (days since January 1, 2017)



a) Near surface zonal velocity
u (cm/sec)
2017
2018
TACOS−2
b) Near surface meridional velocity
v (cm/sec)
c) Zonal Ekman transport
U_{Ekman} (m^2/sec)
c) Meridional Ekman transport
V_{Ekman} (m^2/sec)
Time (days since January 1, 2017)


c) Mean u
d) Mean v
Depth (meters)
0
20
40
60
80
100
−15
−10
−5
0
5
10
15
u (cm/sec)
v (cm/sec)

Diurnal Composite of Temperatures, Currents, and Winds During TACOS at 4°N 23°W



Composites for Stratification, Shear, and Richardson Number (JJA) at 4°N 23°W