SWOT CalVal Planning Meeting

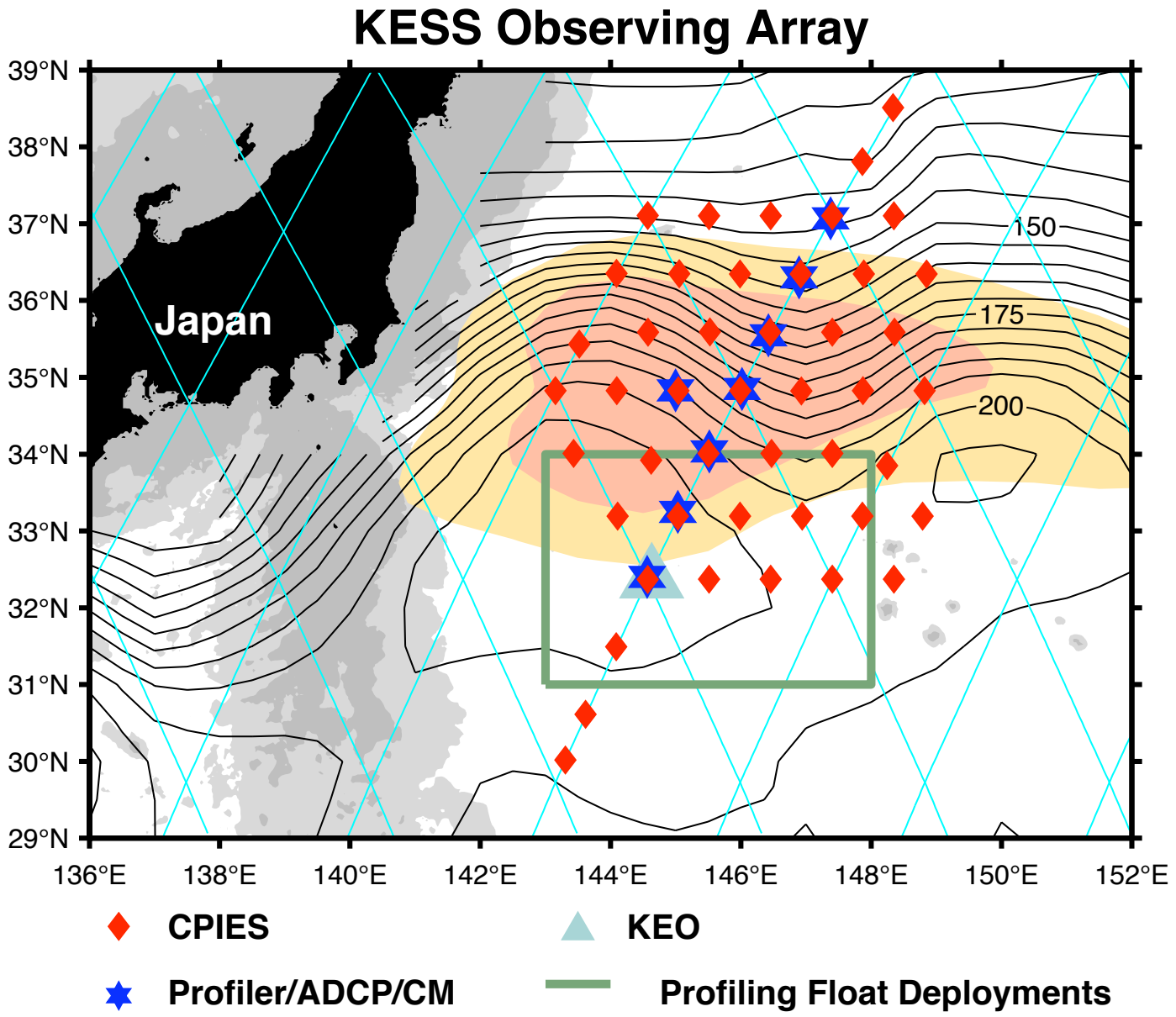
NASA-JPL, Pasadena, CA -- 2016-Jun-16

D. R. Watts, K. Donohue (URI) & M. Andres (WHOI)

- PIES –
  - What are they?
  - How do we use them to get SSH?

- PIES_SSH uncertainty –
  - Where does it come from?
  - What measurements will reduce uncertainty?

Kuroshio Extension System Study (KESS, 6/2004- 6/2006)



PIES
(Pressure-recording Inverted Echo Sounder)

- Emits 12 kHz sound pulses
- Measures τ = round-trip travel time from bottom to surface
- Measures bottom pressure (P_{bot}) – resolution < 1 mm
- A robust empirical relationship exists between τ and vertical profiles T(P), S(P), δ(P)

➔ geopotential Φ

SSH COMPRISES STERIC AND MASS-LOAD PARTS

Sea Surface Height (η) after IB compensation:

$$(\eta' - IB) = \Phi'/g + P'/\rho g$$

Where $(\bullet)'$ = anomaly from mean

Φ = Geopotential Height
(0 re near-bottom nominal isobar, like 4000 or 5000 dbar)

g = Gravity

P = Bottom Pressure

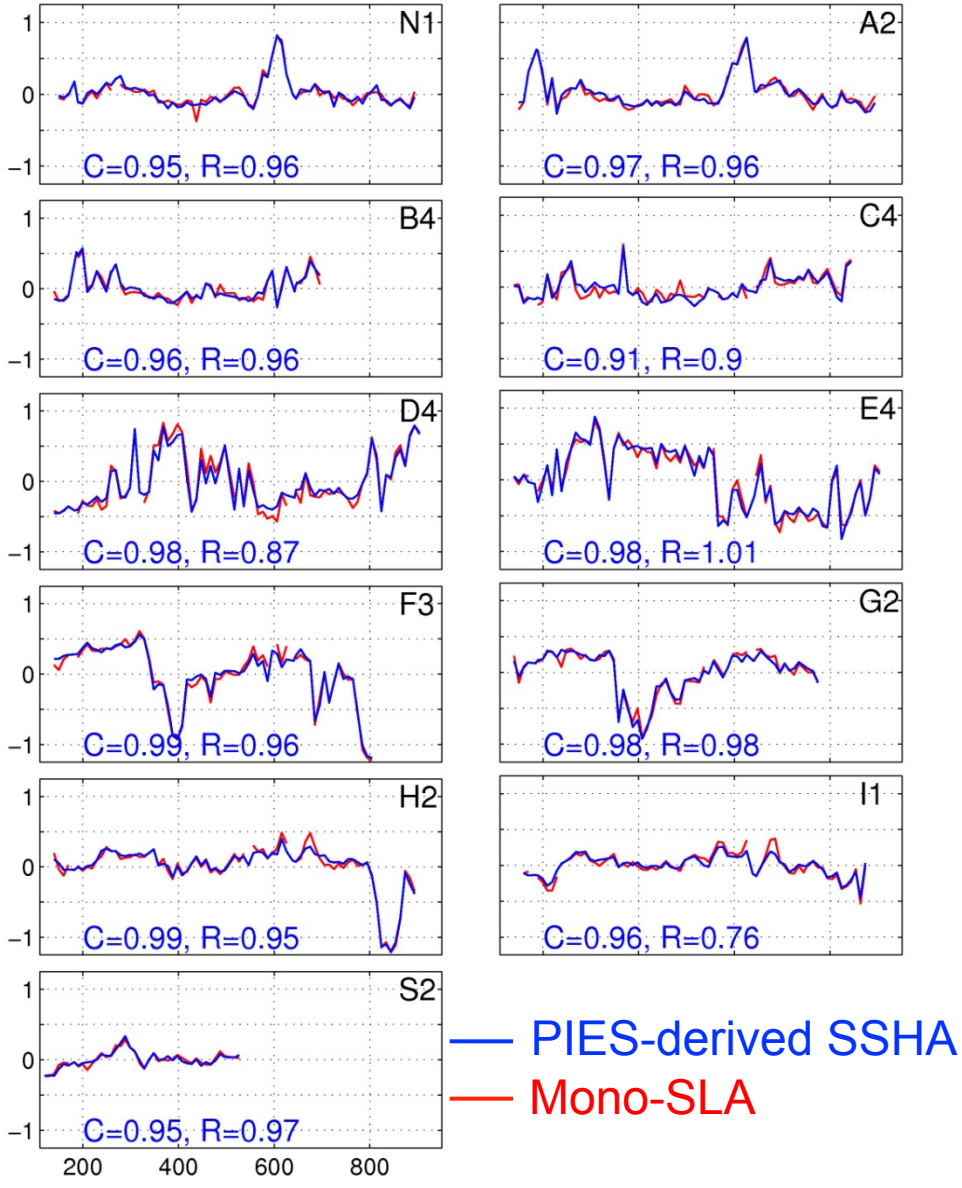
ρ = Density

Typical sizes…

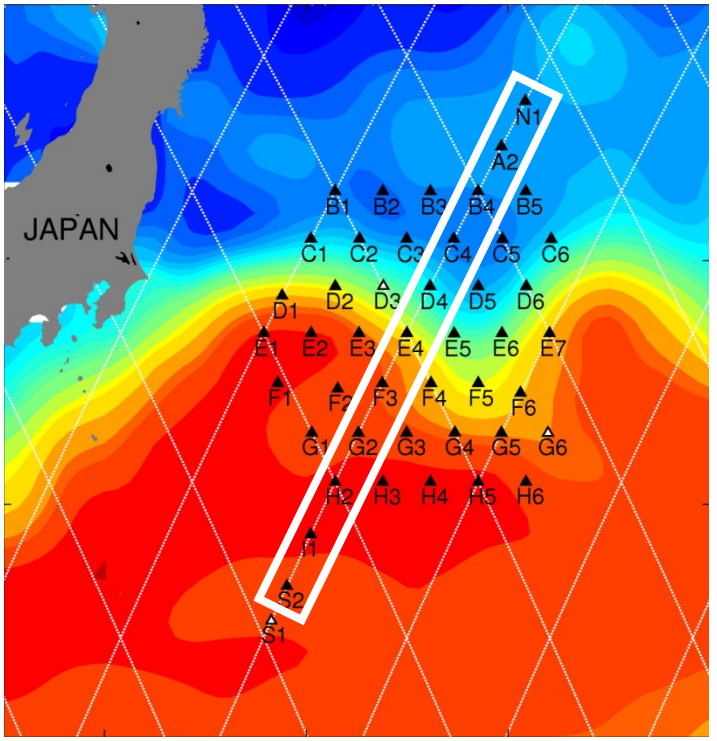
	Φ'/g (m)	$P'/\rho g$ (m)	η' (m)	σ_η (std dev) (m)
Kuroshio Jet	1.3	0.5	1.7	0.2
Quiet Intervals	0.3	0.2	0.4	0.1
Meanders, Rings	1.0	0.3	1.2	0.15

Steric and mass-load parts have similar amplitudes but different processes and different spectra and different lateral scales

Mono-SLA and PIES-derived SSHA



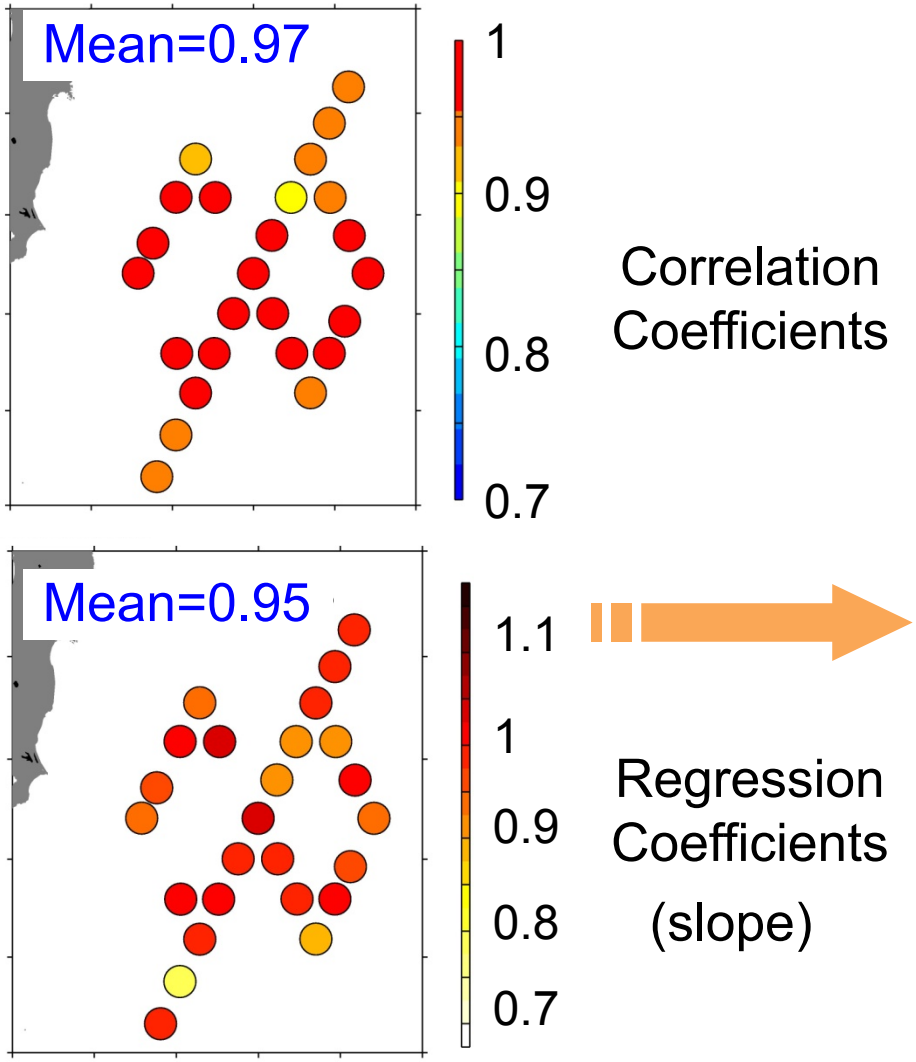
Park et al., J.Oceanogr. 2012



PIES data were interpolated to times when Jason-1 passed overhead.

Excellent agreement when both steric and mass-loading parts are included.

Mono-SLA and PIES-derived SSHA



Park et al., J.Oceanogr. 2012

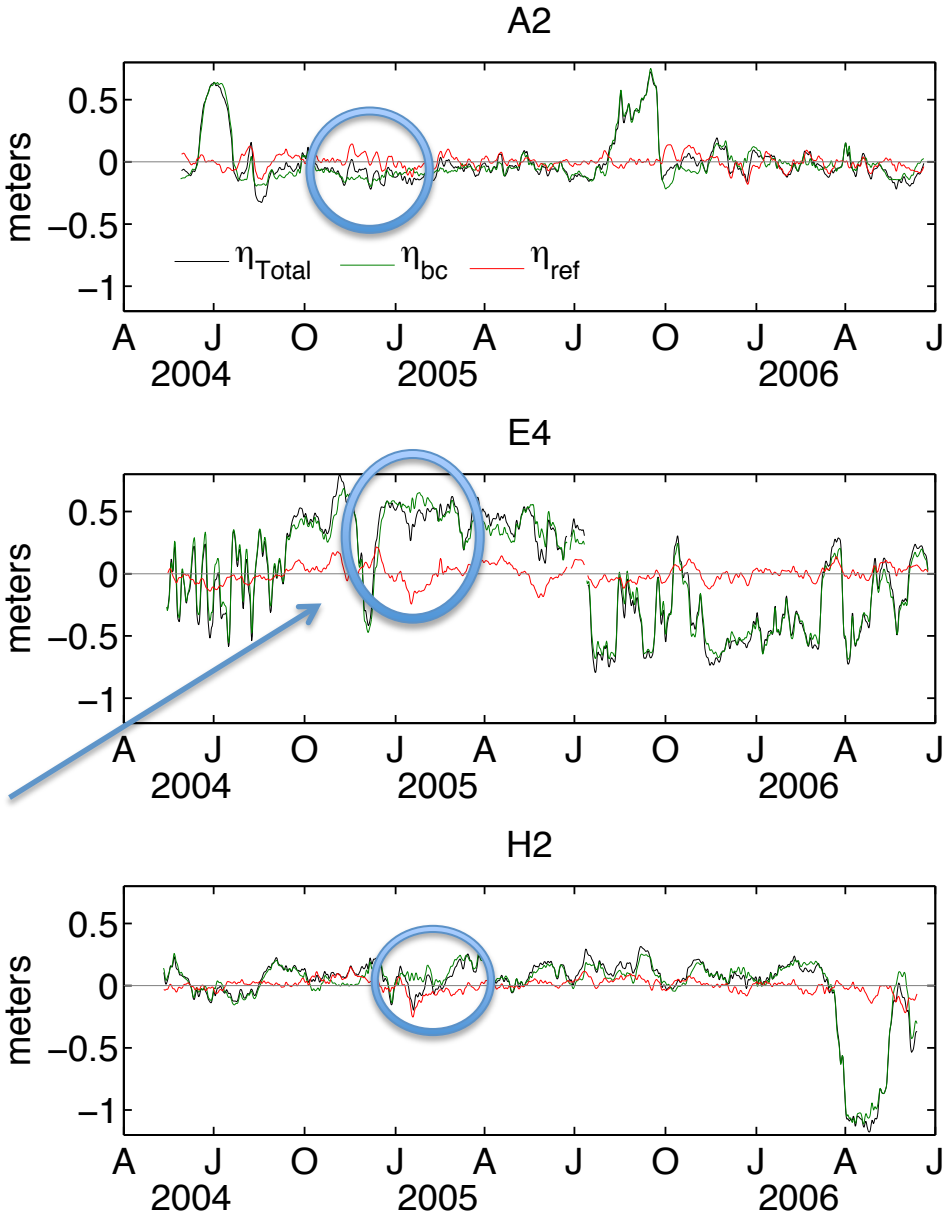
$$\eta_{tot} = \Phi'/g + P'/\rho g$$

$$= \eta_{bc} + \eta_{ref}$$

KESS northern, middle & southern sites

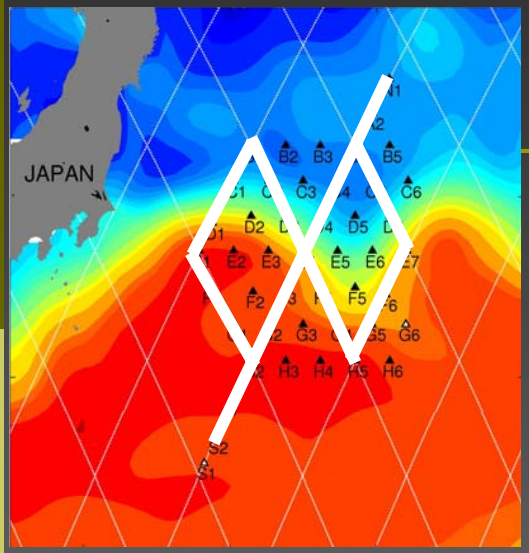
-steric part (bc) large

-mass-loading (ref) is important.



Rms Errors (along-track 26 sites)

Based on Kuroshio and Agulhas & better for SWOT



- Observed rms differences
  Mono-SLA 6.8 cm

- Predicted rms difference

$$\sqrt{(4.6 \text{ to } 5.1)^2 + (3.8 \text{ to } 8.7)^2 + 1.4^2} = \textbf{6.1 to 10.2 cm}$$

when error caused by geographical position mismatch between Jason-1 and PIES
= 1.4 cm (1 km offset)

- Error Budget for AVISO : 4.6-5.1 cm

GDR Corrected SSH	3.3 cm
Post-processing - IB	2.5-3.0 cm
- Tides	2.0-2.5 cm

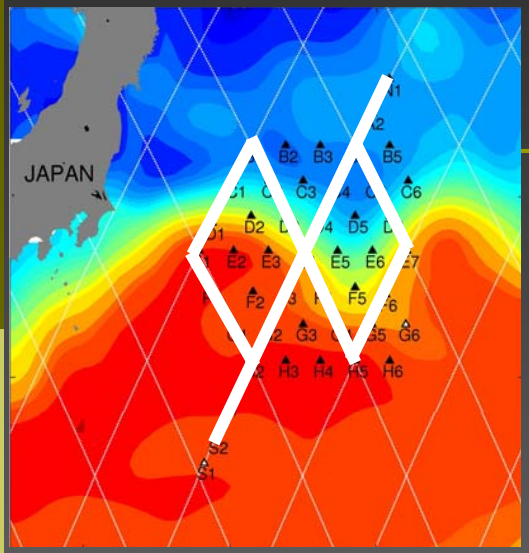
From Baker-Yeboah (2008)

- Error Budget for PIES : 3.8-8.7 cm

Sea state scatter	0.2 cm
Sea state bias	0.1 cm
Tides	0.1 cm
Pressure drift	1.0 cm
Mooring motion	0.2 cm
Spline-curve Lookup	3.7-8.6 cm

Rms Errors (along-track 26 sites)

Based on Kuroshio and Agulhas & better for SWOT



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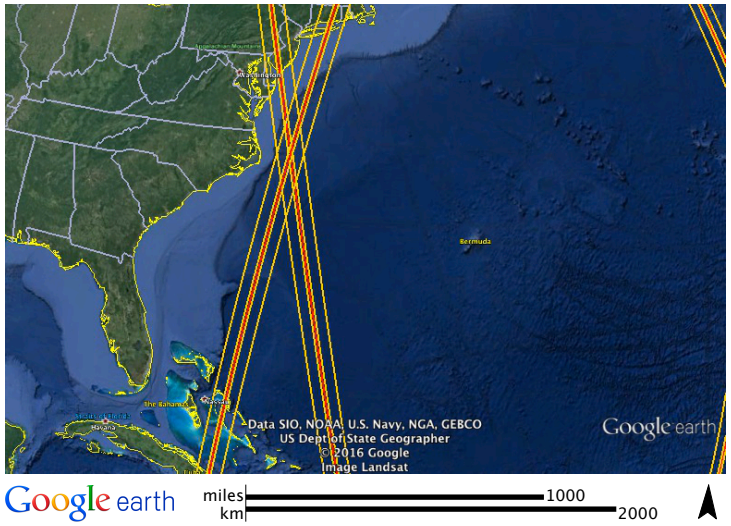
In order to improve the accuracy of independent SLA measurements, and to measure SLA on small 5-30 km lateral scales, where do we need more S,T,P measurements?

The main error contribution to SLA_{PIES} is from scatter in $\Phi(\tau)$ lookup.

Examine next…

- Estimate Φ_2' contributions from 2nd BC mode in full water column
- Bottom-intensified processes (TRW's, DWBC)
- Near-surface SQG processes and streamers (mixed layer to 150 m?)
- mid-column filaments (main pycnocline, 200 m – 700 m)



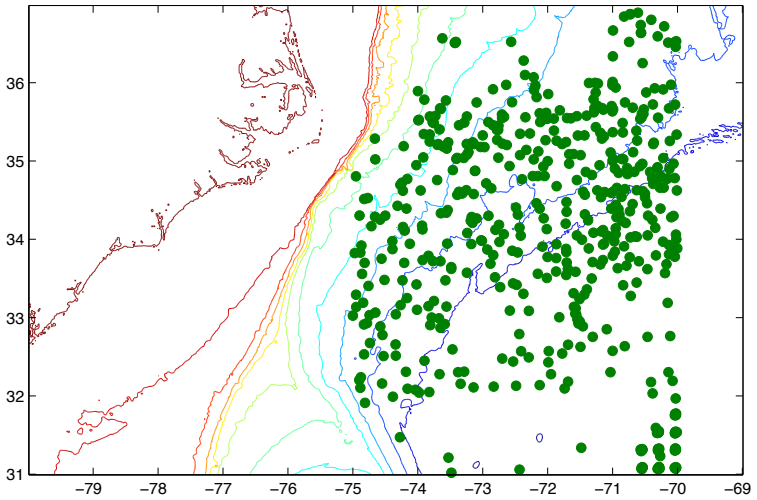
CTD profiles

➔

(ship & Argo)

for

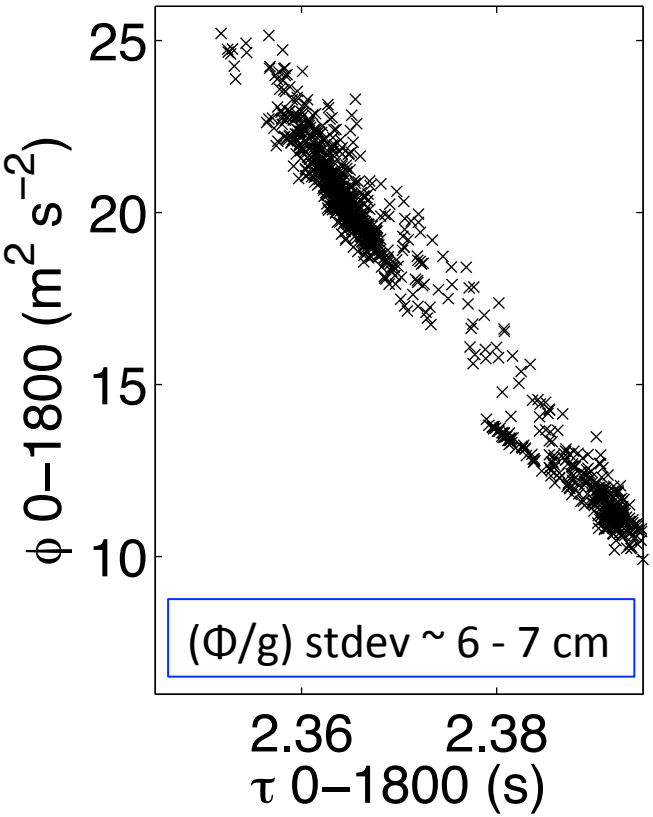
Φ *vs.* τ plots

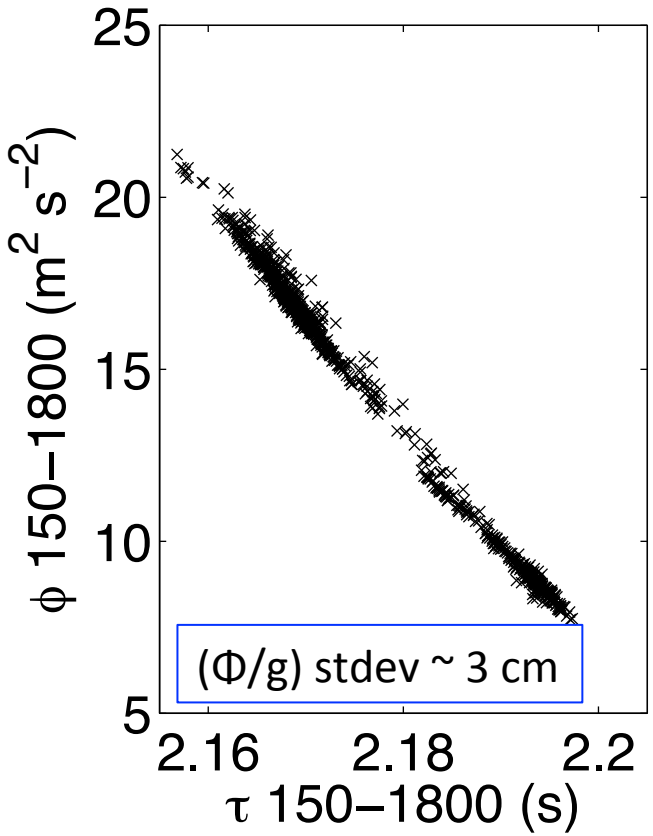


Much of the Φ(τ) scatter comes from top 150m.

And much of that is due to seasonal warming, for which we can adjust.

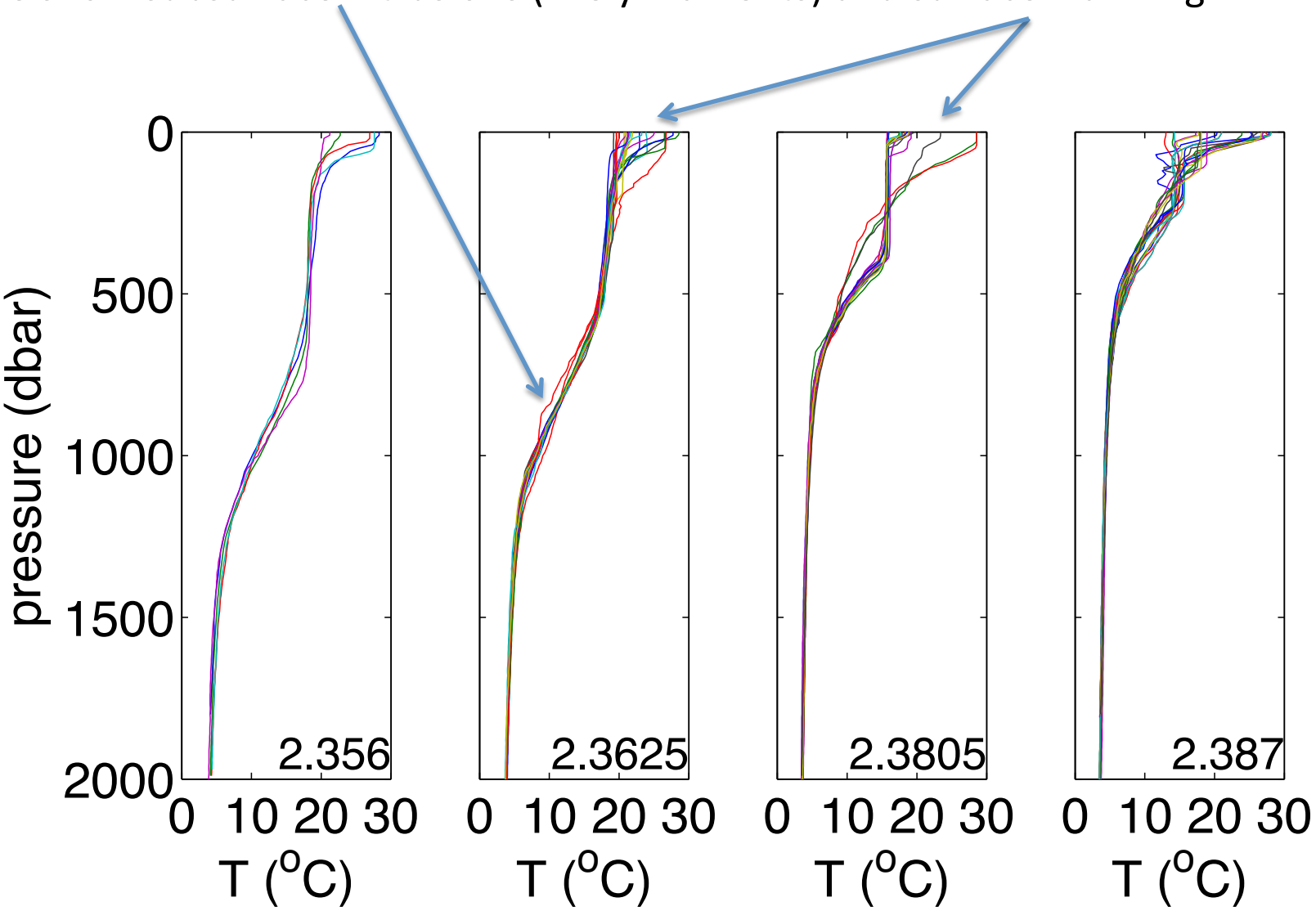
Less scatter than Agulhas & KESS.

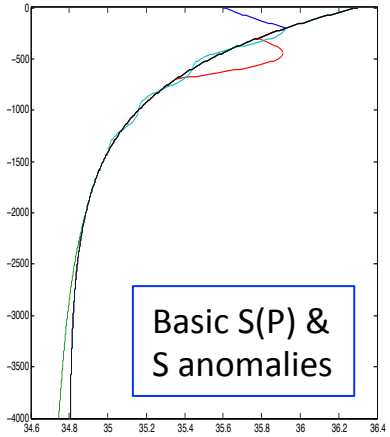


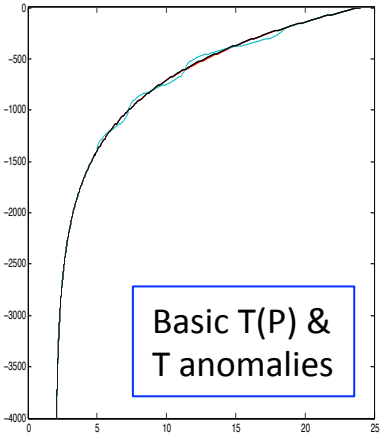


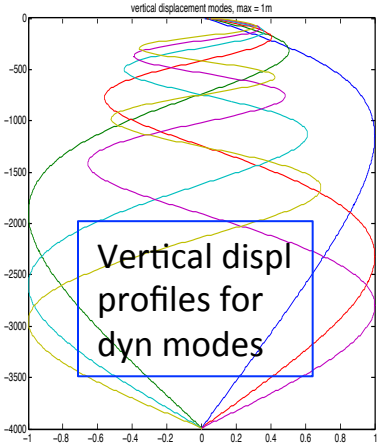
For guidance about what causes scatter in $\Phi(\tau)$ examine temperature profiles, grouped in narrow bins of τ (1 ms).

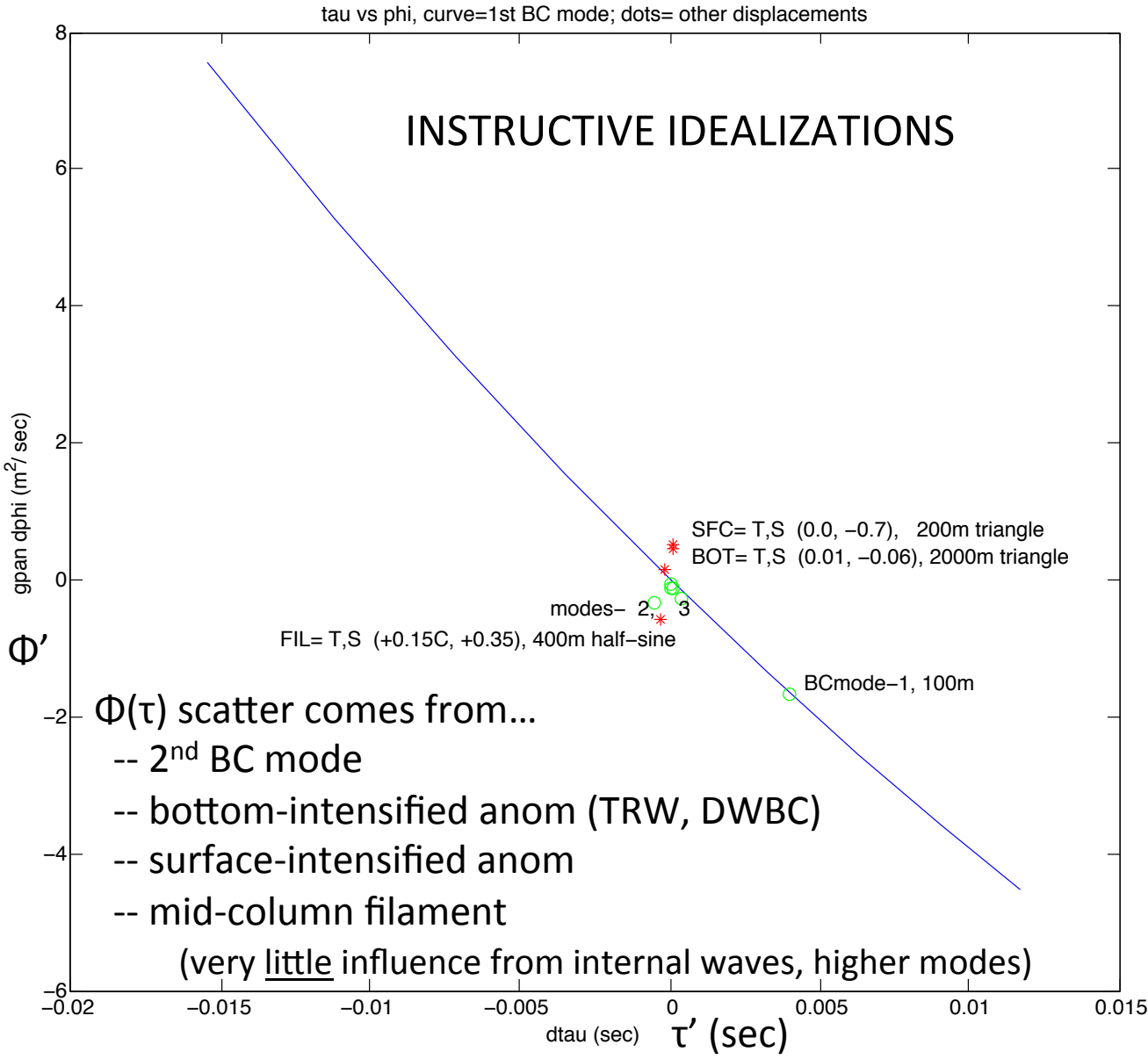
These show subsurface intrusions (likely filaments) and surface warming




Basic S(P) &
S anomalies


Basic T(P) &
T anomalies


vertical displacement modes, max = 1m
Vertical displ
profiles for
dyn modes


tau vs phi, curve=1st BC mode; dots= other displacements
INSTRUCTIVE IDEALIZATIONS
gpan dphi (m2/ sec)
Φ'
dtau (sec)
τ' (sec)
SFC= T,S (0.0, −0.7), 200m triangle
BOT= T,S (0.01, −0.06), 2000m triangle
modes− 2, 3
FIL= T,S (+0.15C, +0.35), 400m half−sine
BCmode−1, 100m
Φ(τ) scatter comes from…
-- 2nd BC mode
-- bottom-intensified anom (TRW, DWBC)
-- surface-intensified anom
-- mid-column filament
(very little influence from internal waves, higher modes)

Combine CPIES with moorings, having many S, T, P recorders vertically, to determine S', T' anomalies relative to the GEM profile, will give the most accurate Φ measurement.

Laterally space some CPIES closely (~5km).

Additional CPIES can be added to observe longer lateral scales.

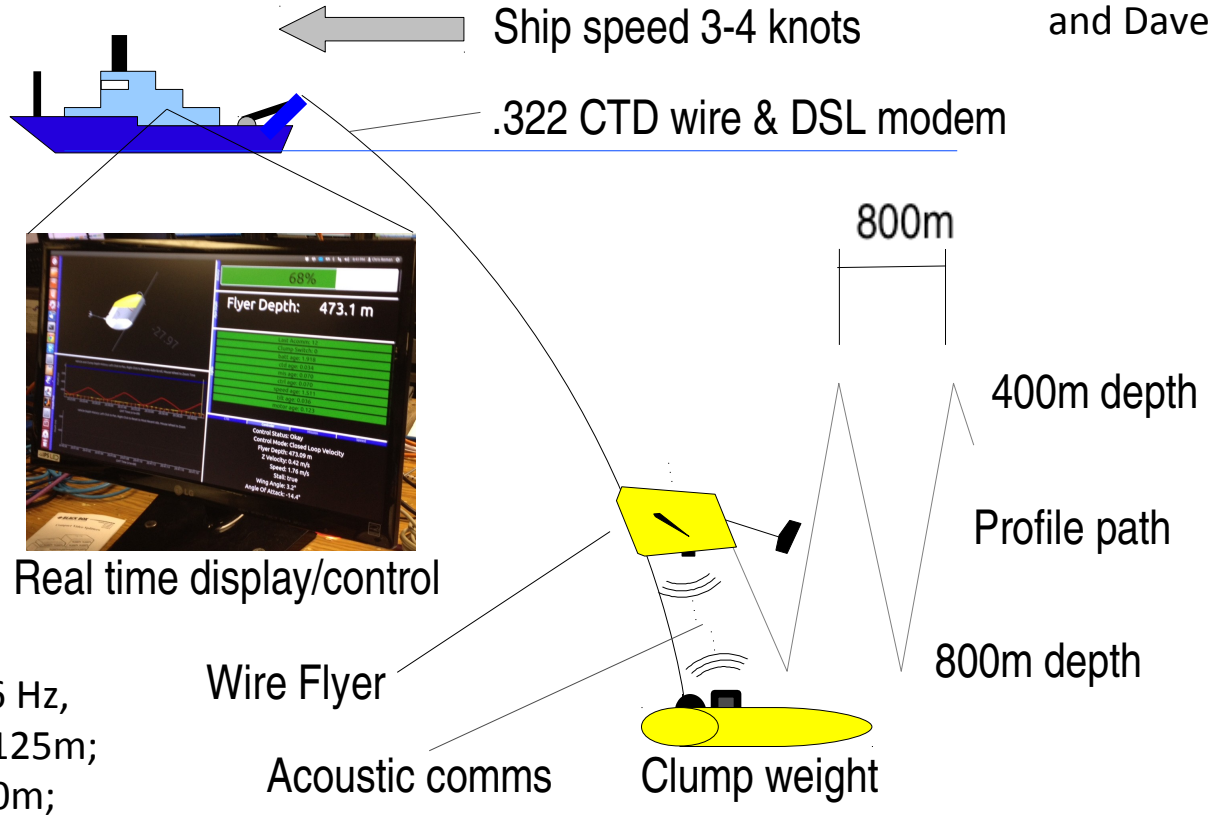
Final points…
While the focus of this presentation is on understanding and reducing noise in full water column geopotential height Φ' estimated from PIES τ,

1) remember also that bottom current meters are important for leveling and dedrifting the bottom P' measurements.

2) Wire-flyer = new fine lateral AND vertical scale capability combined

WIRE FLYER

developed at URI by
Chris Roman, Dave Hebert,
and Dave Ullman



FastCat CTD 16 Hz,
vertical res. 0.125m;
horiz res. ~ 500m;
transects ~ 178km

Shipboard surveys: *in situ* calibration CTD profiles for cPIES; with LADCP/ SADCP;
estimate shear-to-strain ratios;
unprecedented horizontal and vertical structure of streamers and filaments

END -- QUESTIONS?

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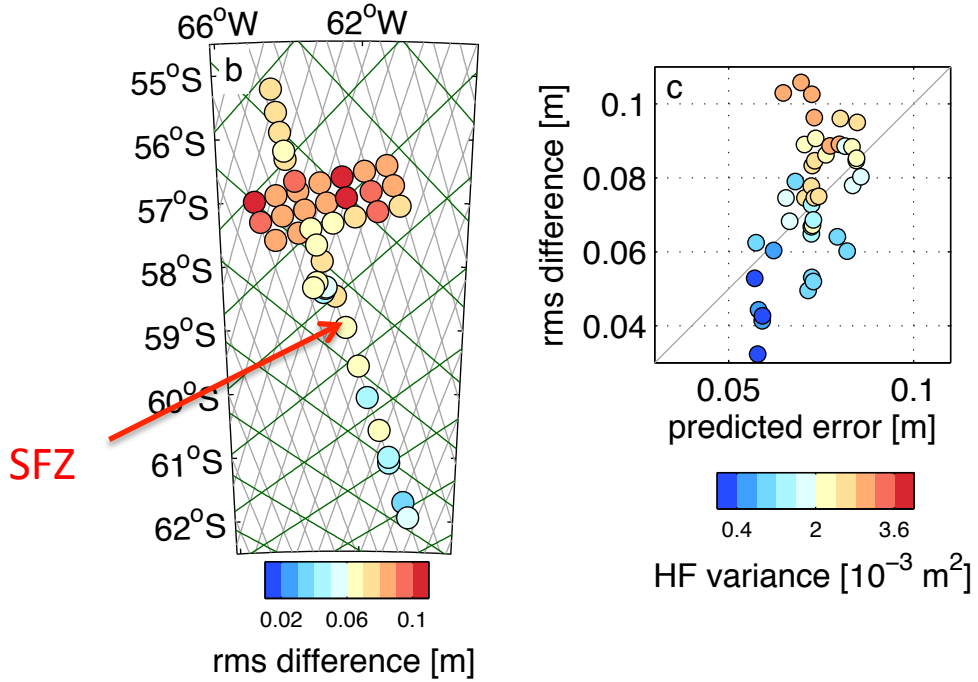
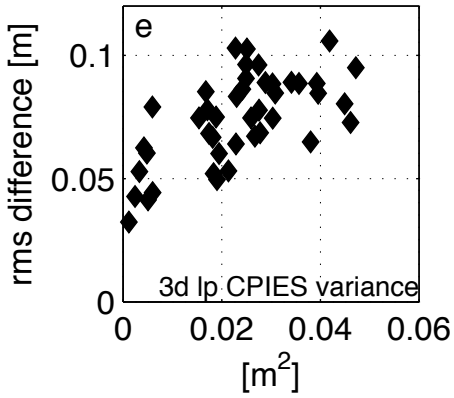
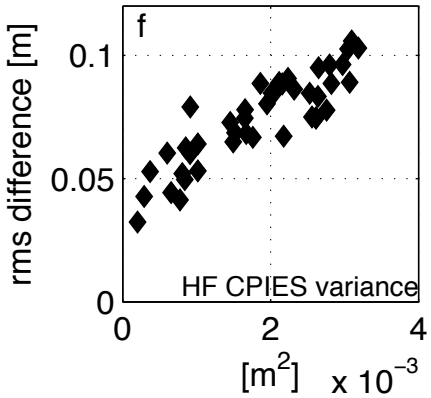
- PIES intro; τ and P,T
  - $(SSH' - IB') = \Phi'/g + P'/(g \rho)$
  - τ integral & geopotential Φ integral; plot Φ *vs* τ with scatter; signal/noise ratio
  - Published examples of PIES measuring SSH, compared to altimeter SSH; uncertainties
- GOAL implied for SWOT calval:
  - Understand the measurement accuracy of SSH from SWOT, particularly on lateral scales from 5 km – 100 km
  - Compare against local independent trusted measurements of SSH
- Detail PIES_SSH uncertainty; where do we need more STP measurements?
  - T(P) and S(P) profiles and wiggles affecting τ' and Φ' differently
  - Surface/ bottom / mid-column anomalies
  - Higher dynamical modes (2nd mode – implications near DWBC?
  - Measurement error – P drift; CPIES geostrophic leveling (deploy 6+ mos in advance?)
- Implied/ deduced lateral scales of features

Drake Passage (cDrake experiment)

AVISO MSLA predicted mapping and CPIES errors agree well with observed rms differences.







Much of the $|\eta_{alt} - \eta_{PIES}|$ difference in excess of 0.05 m arises from high frequency <20 d variance that was unresolved by the Jason 10 d sampling.

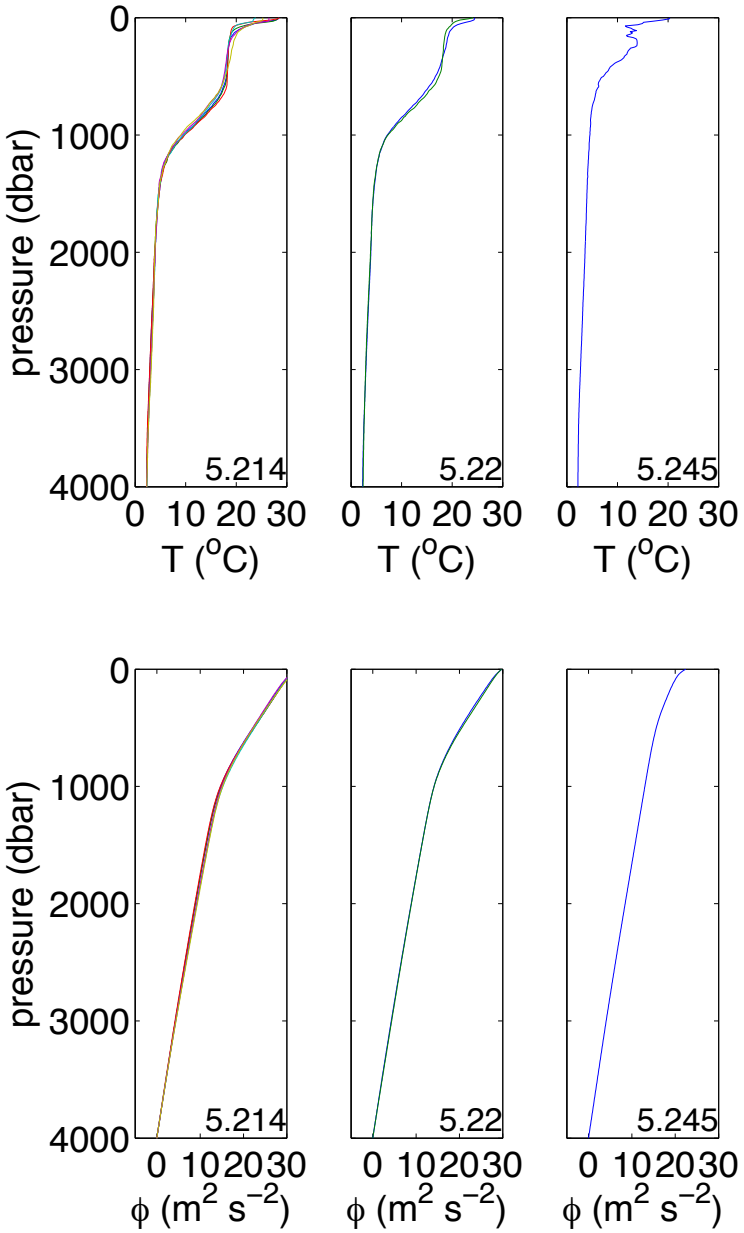
PIES
(Pressure-recording Inverted Echo Sounder)

- Emits 12 kHz sound pulses
- Measures τ = round-trip travel time from bottom to surface
- Measures bottom pressure (P_{bot}) – resolution < 1 mm
- A robust empirical relationship exists between τ and vertical profiles T(P), S(P), δ(P)

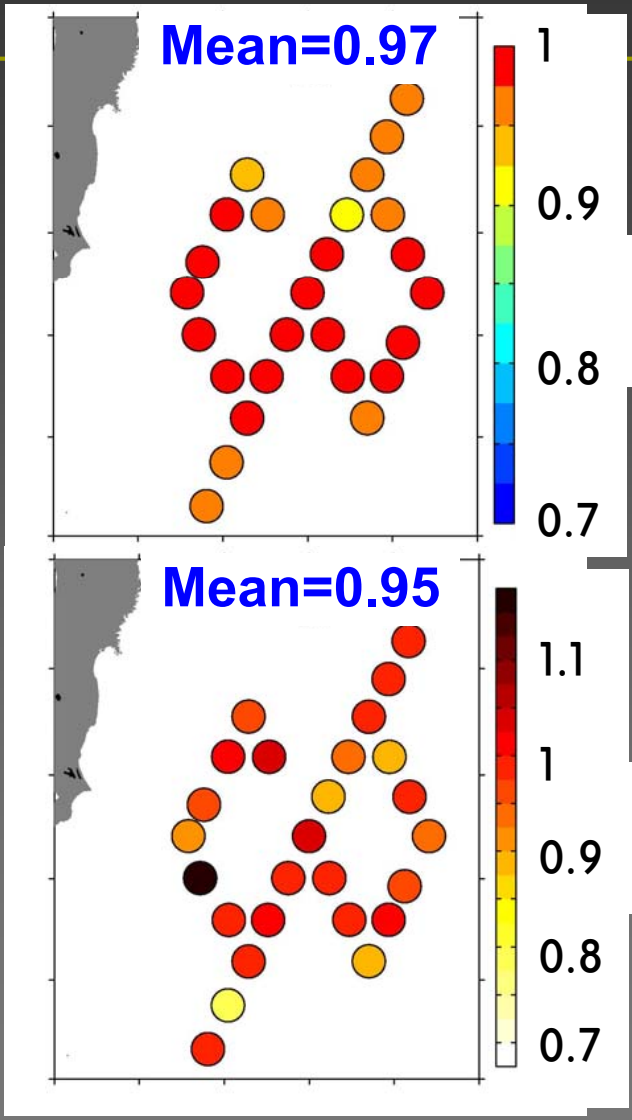
➔ geopotential Φ

$\tau = \int (1/c) dz$

$\Phi = \int (1/\rho) dp$

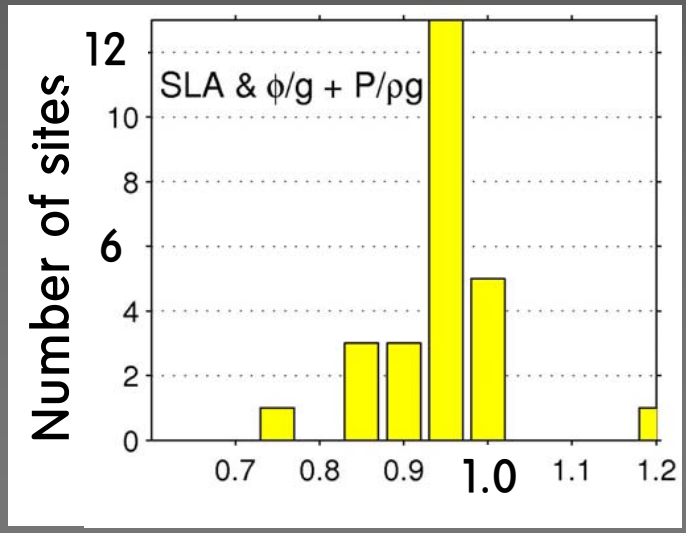

pressure (dbar)
0
1000
2000
3000
4000
5.214
5.22
5.245
0 10 20 30
T (°C)
ϕ (m² s⁻²)

Mono-SLA and PIES-derived SSHA



Correlation Coefficients

Regression Coefficients (slope)



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