A WAVY OCEAN BOUNDARY LAYER

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GIVEN :

— OCEAN MODEL • Bousinesq MOM-6 • **Wave-Average Bousinesq** (WAB)

— FORCING • Surface Buoyancy, B_0 • Wind Stress, $\vec{\tau} = (\tau_u, \tau_v)$ • **Stokes Drift**, $\overrightarrow{Us}$

— OCEAN STATE • Buoyancy, $\Theta(z)$ • Eulerian Velocity, $\vec{U}(z)$

COMPUTE BOUNDARY LAYER :

— DEPTH • h

— TURBULENT VERTICAL FLUXES • Buoyancy, $\langle w\theta \rangle$ • Momentum, $\langle w\vec{u} \rangle$

— VERTICAL MIXING TENDENCIES • $\partial_t \Theta = -\partial_z \langle w\theta \rangle$ • $\partial_t \vec{U} = -\partial_z \langle w\vec{u} \rangle$

Boundary-Layer ($0 < \sigma = -z/h < 1$): LES & CvMIX

- $\langle w\theta \rangle = K_S\,(-\partial_z \Theta + \gamma_\theta)$
- $\langle wu \rangle = K_U\,(-\partial_z U + \gamma_U)$; Along shear
- $\langle wv \rangle = K_V\ \boldsymbol{\gamma_V}$; Across shear

- $\gamma_\theta \propto B_0$
- $\gamma_U = 0$?
- $\boldsymbol{\gamma_V} \propto \tau_V$

- $K_{M,S} = w_{M,S}\ h\ \mathbf{G}(\sigma)$; $K_M = K_U = K_V$ (CvMIX Assumption)
- $w_{M,S} = \dfrac{\kappa\ u_*\ h}{\boldsymbol{\Phi_{M,S}}(z/\mathbf{L})\ \boldsymbol{\chi_{M,S}(\xi)}}$; $\sigma < \boldsymbol{\sigma_c}$

- $\boldsymbol{\chi_{M,S}} \le 1$; $0 \le \boldsymbol{\xi} \le 1$

- $h = \dfrac{Ri_C\,(|\boldsymbol{\Delta V}(h)|^2 + \boldsymbol{V_t^2})}{\Delta\Theta(h)}$
- $\boldsymbol{V_t^2} \propto w_* = (-B_0\ h)^{1/3}$, for Pure Convection ($B_0 < 0$, $\vec{\tau} = \overrightarrow{\mathbf{U}s} = 0$)

MOM-6 : JRA 1958-2018

Equation Set	$X_{M,S}(\xi)$	σ_c	$G(\sigma)$ $\sigma = -z/h$		ΔV		
MOM-6 Control-0	1.0 $\xi=0$	0.1	cubic $\sigma(1-\sigma)^2$	w_S		0	0
WAB	< 1 $(0<\xi<1)$	1.0	$G_c(\sigma)$	$w^* < w_S$		τ_v	WW3 WAVY
WAB	< 1 $(0<\xi<1)$	1.0	$G_c(\sigma)$	$w^* < w_S$		τ_v	0 CALM
Mixing	>>MORE	MORE	<LESS	<LESS	>MORE	LESS	>MORE

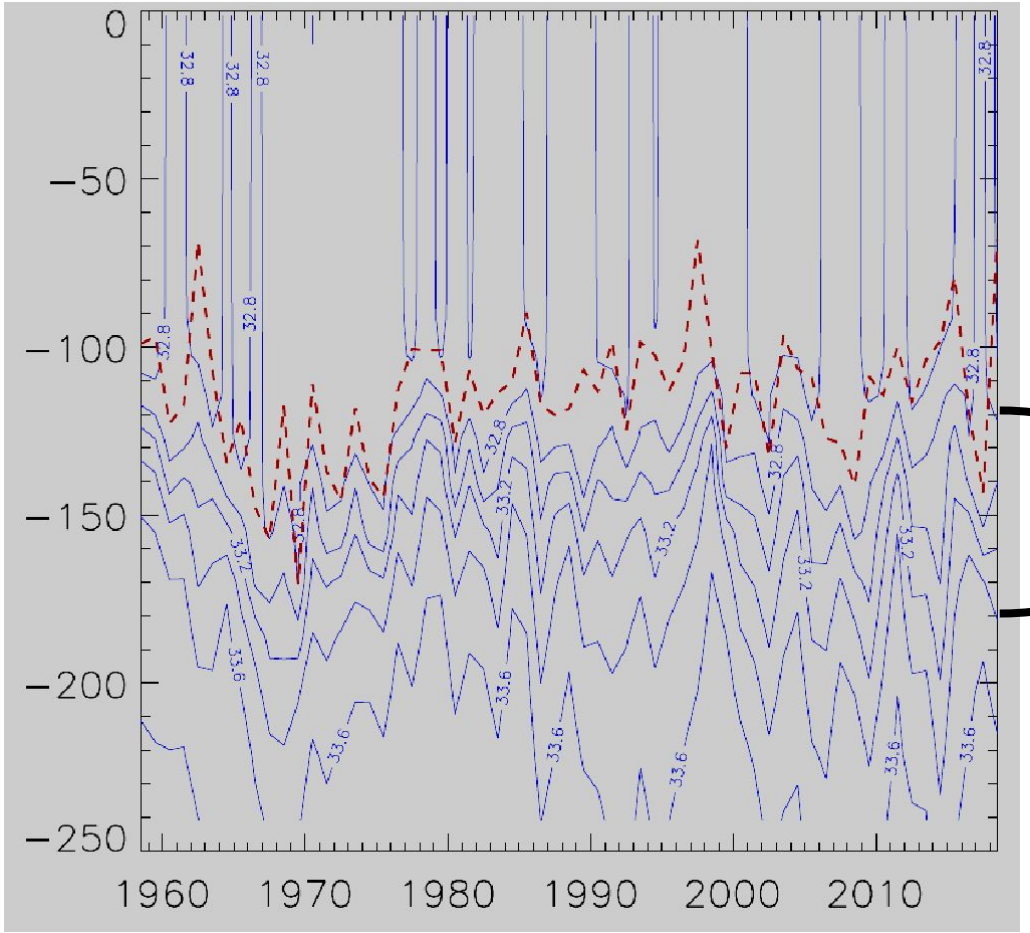
- $w_{M,S} = \dfrac{\kappa\ u*\ h}{\Phi_{M,S}(-z/L)\ \chi_{M,S}(\xi)}$; $\sigma < \sigma_c$

- $K_{M,S} = w_{M,S}\, h\, G$
- $\langle wv \rangle = K_M\, \gamma_v$

- $h = \dfrac{Ri_C\,(|\Delta V(h)|^2 + V_t^2)}{\Delta\Theta(h)}$

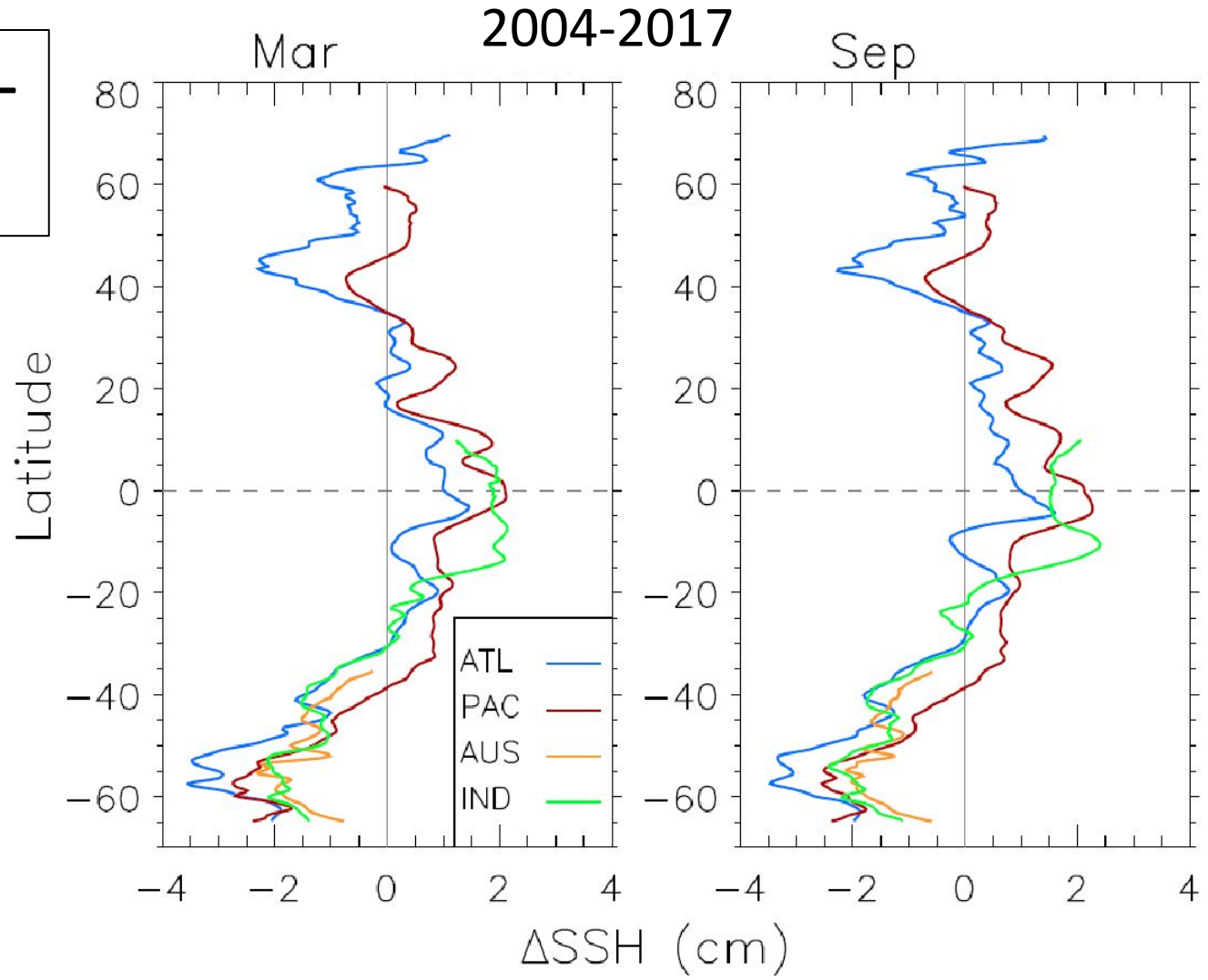
METRICS : Winter Halocline at owsP

1 JRA cycle of Feb Salinity at owsP ; WAVY (13)



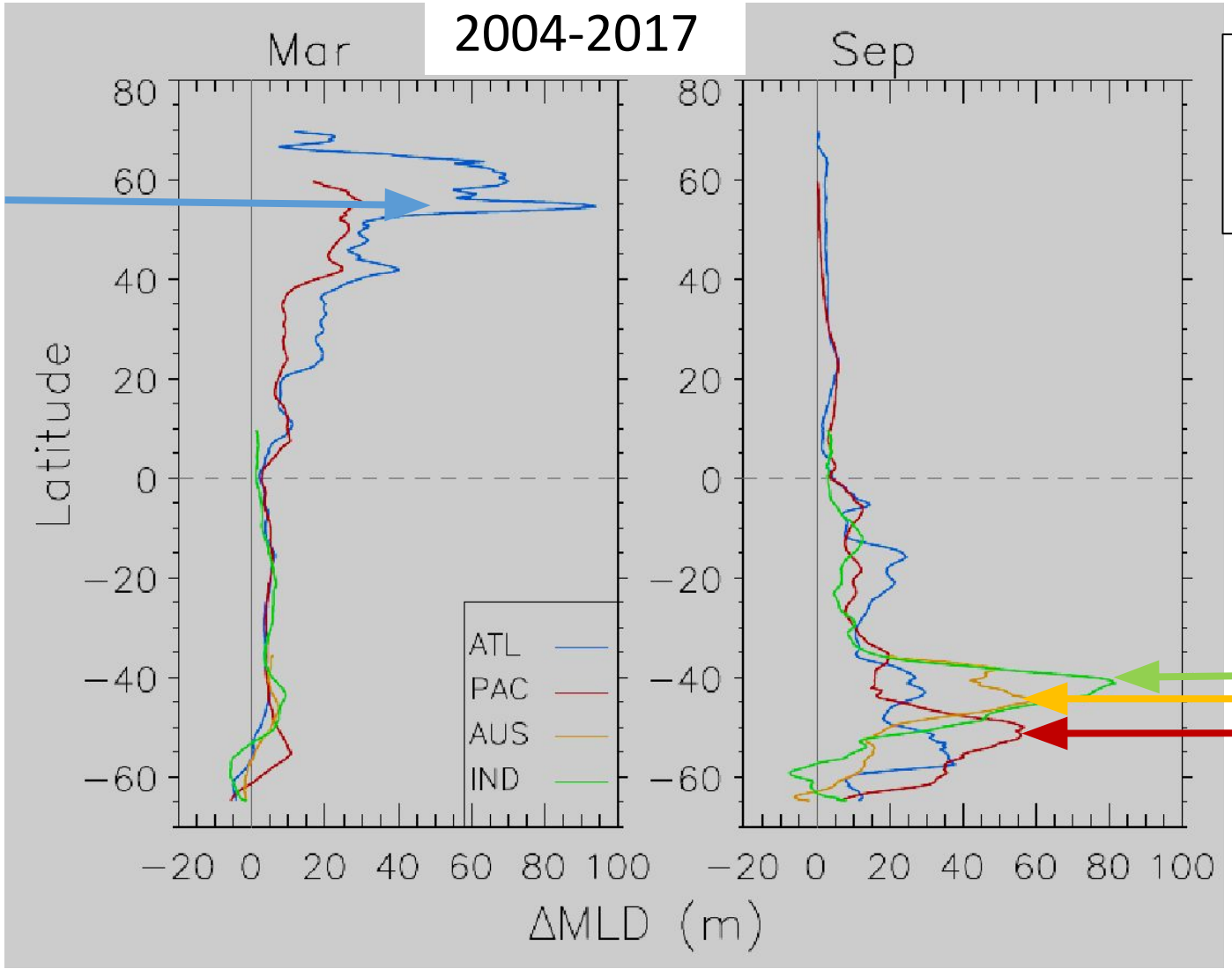
WAVE EFFECTS: Sea Surface Height

WAVY (13) – CALM (14)



WAVE EFFECTS: Mixed Layer Depth (m)

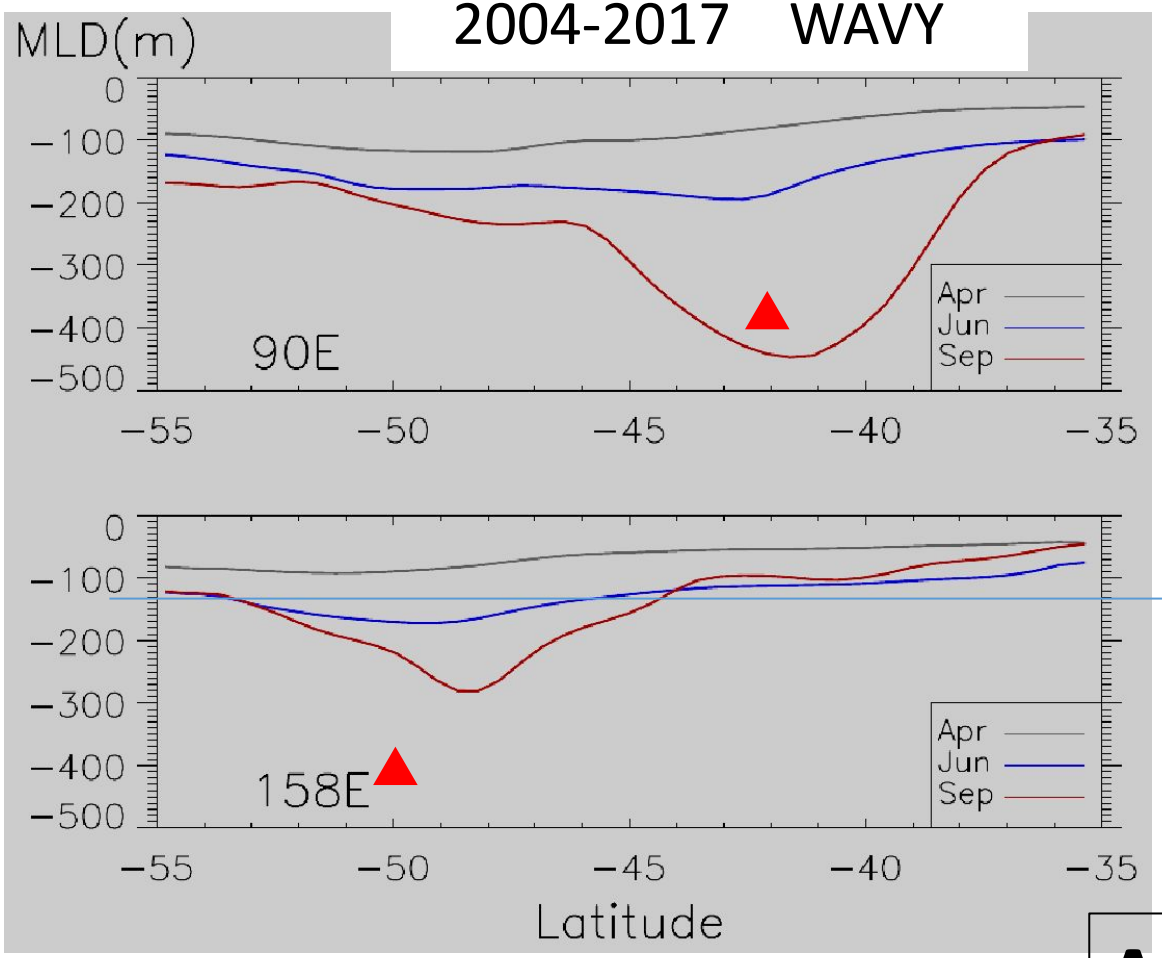
Lab Sea

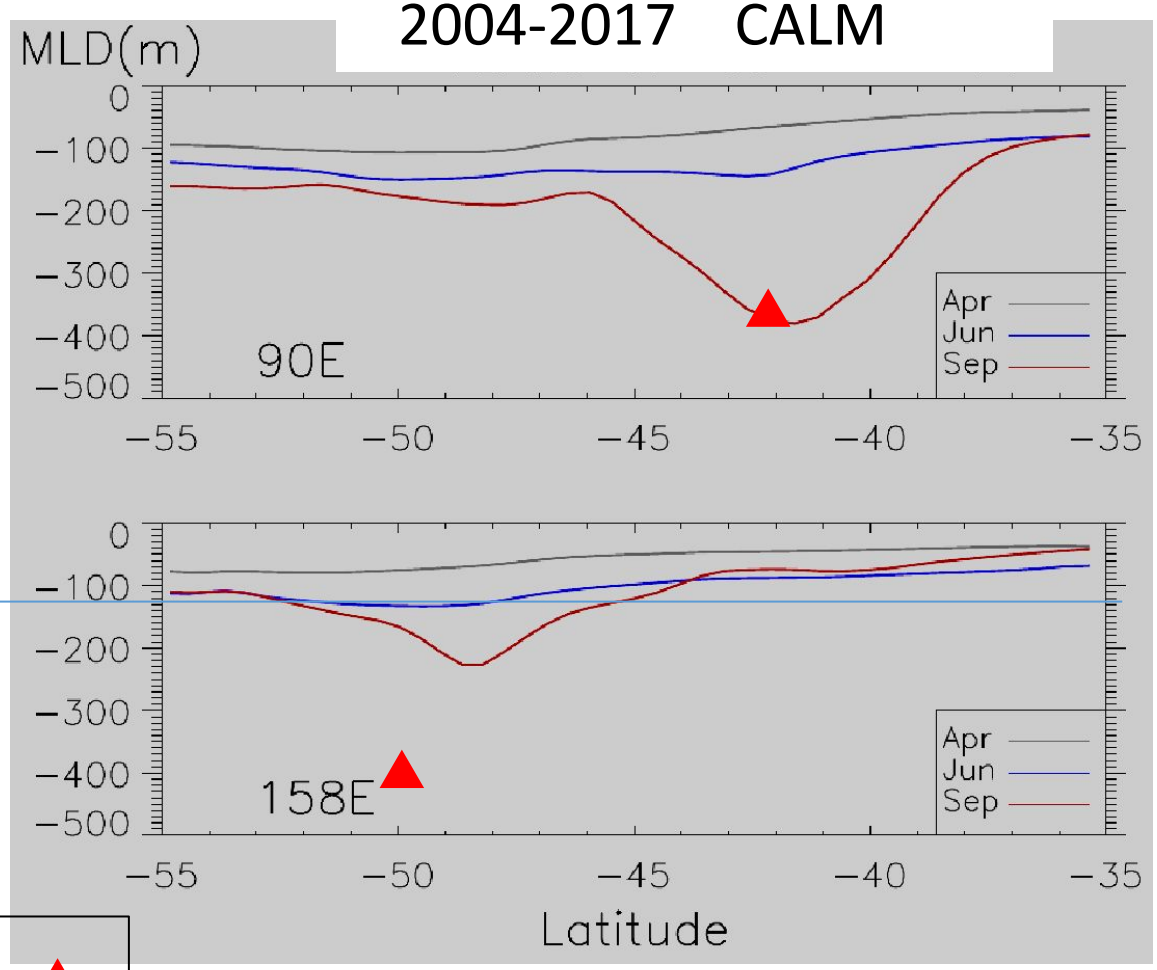


WAVY (13) – CALM (14)

Deep Mixing Bands

SO Deep Mixing (DuVivier et al., 2019)



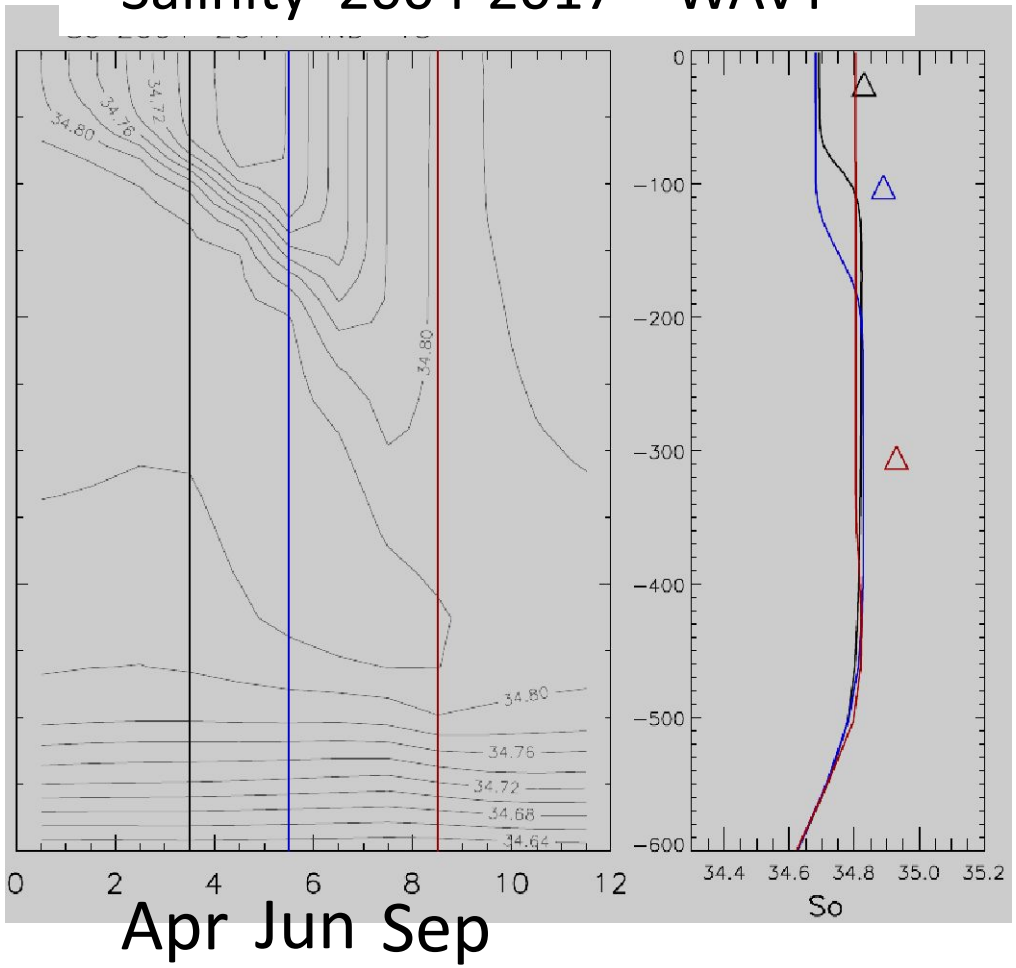


ARGO ▲

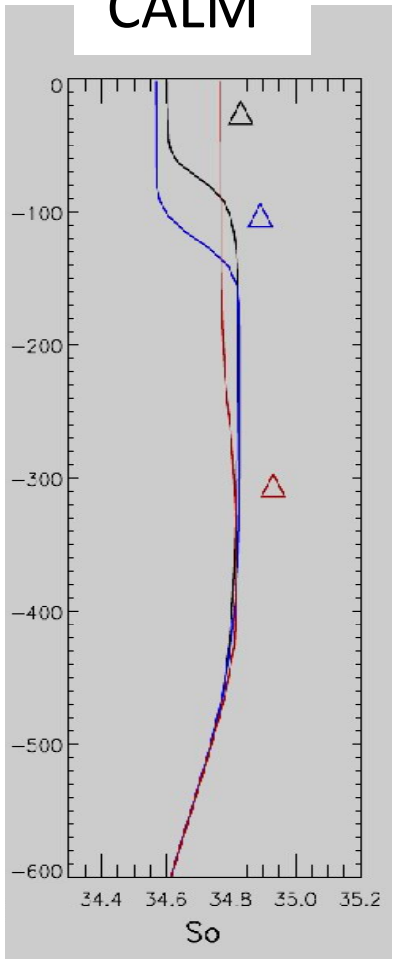
SO Deep Mixing: Indian (90°E ; 40°S)

△ **ARGO @ MLD**

Salinity 2004-2017 WAVY



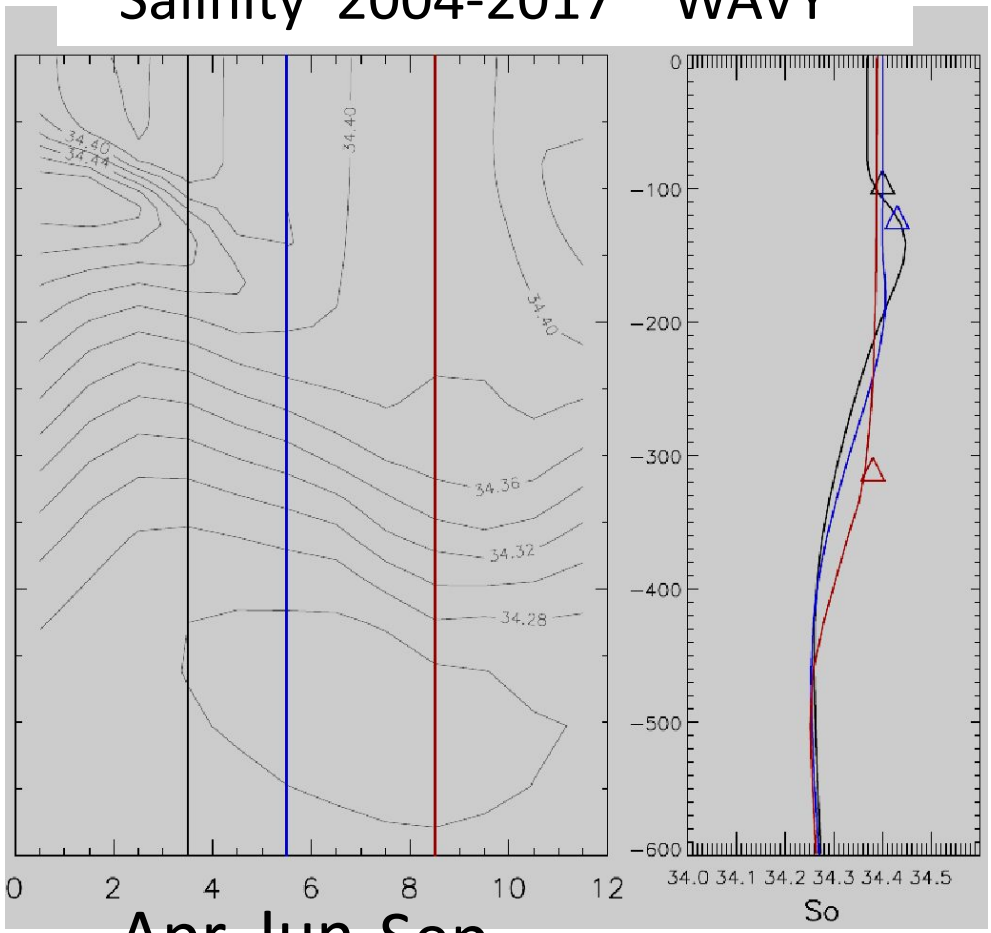
CALM



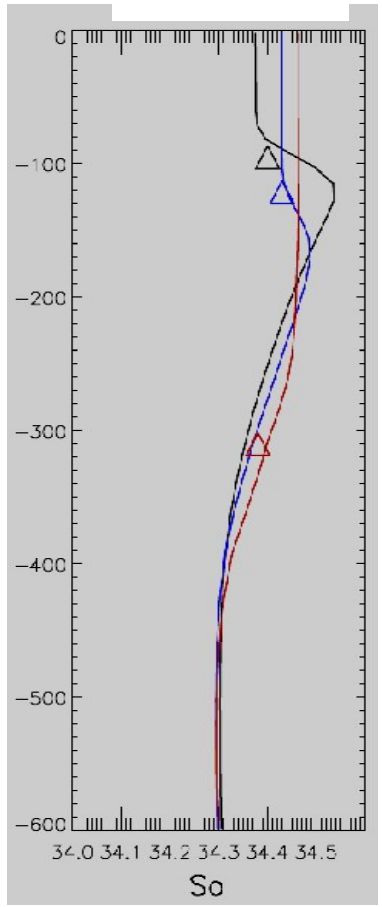
SO Deep Mixing: C-Pacific (145°W ; 51°S)

△ **ARGO @ MLD**

Salinity 2004-2017 WAVY



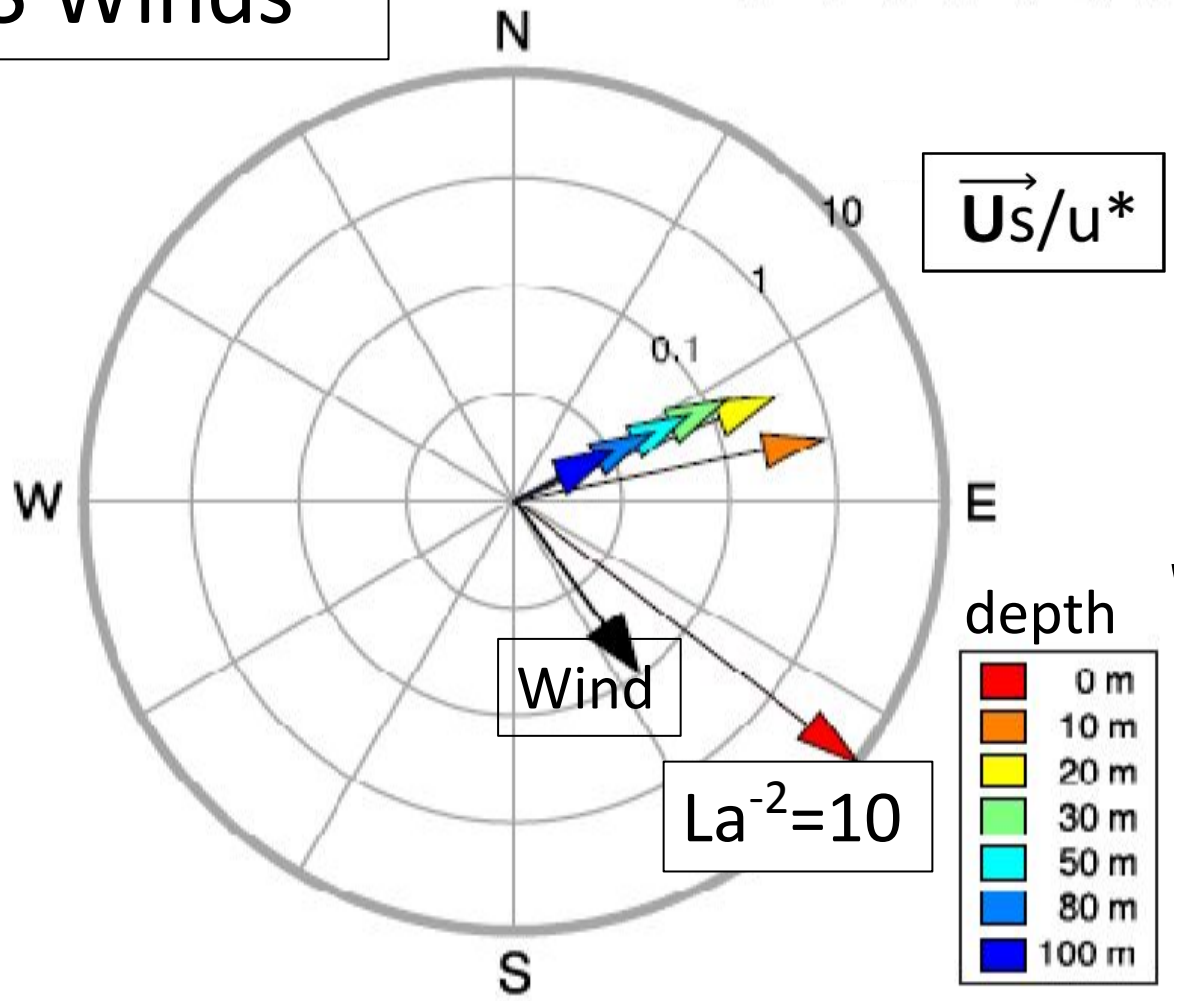
CALM



Stokes Drift, $\overrightarrow{Us}$: SOFS 12:00 June 8, 2010

WW3
SOFS Winds

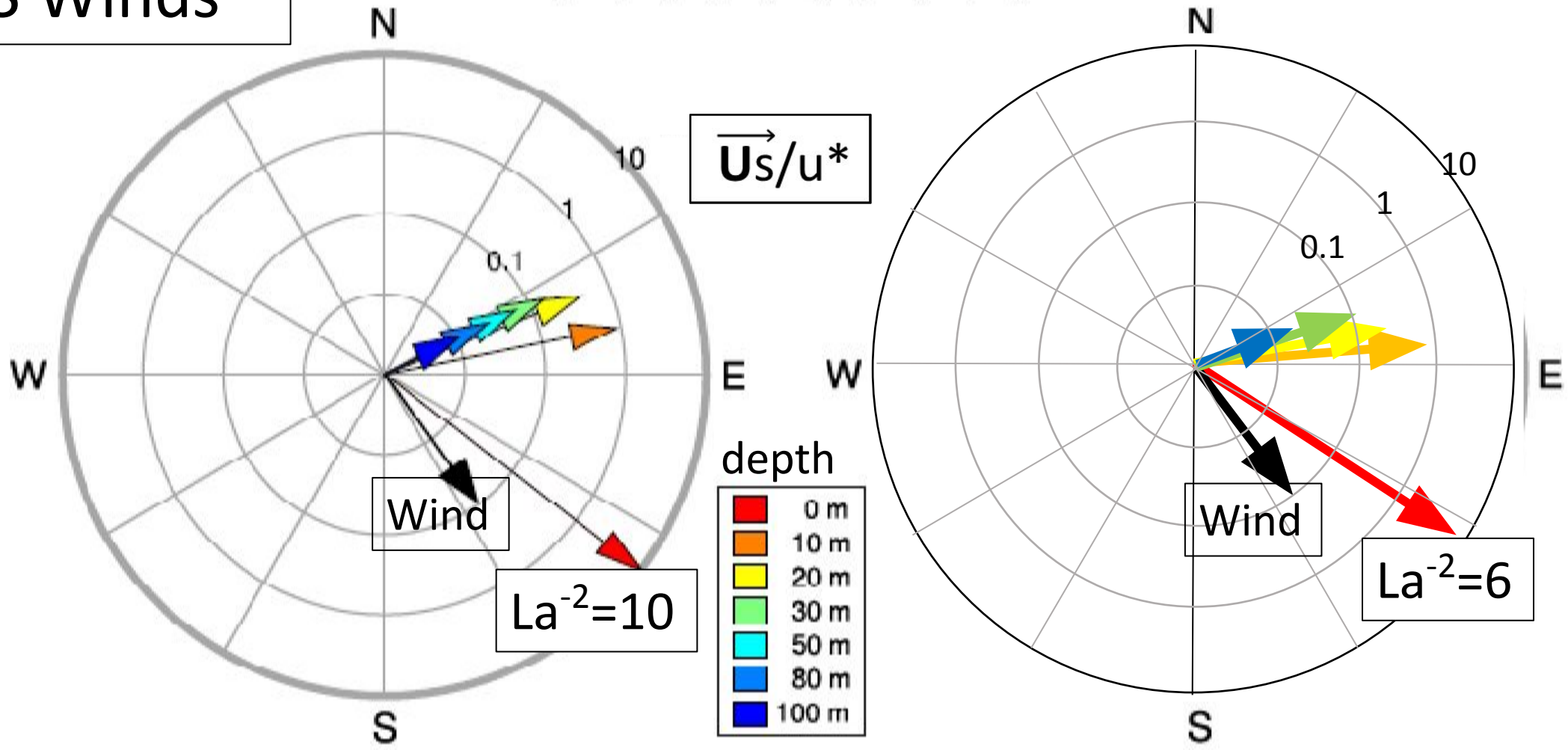
$$\overrightarrow{Us}(z) = \sum_{b=1}^{Nb=3} \overrightarrow{U_b} \exp(2\, k_b\, z)$$



Stokes Drift : SOFS 03:00 GMT June 8, 2010

WW3
SOFS Winds

$$\overrightarrow{Us}(z) = \sum_{b=1}^{Nb=3} \overrightarrow{U_b} \exp(2\, k_b\, z)$$

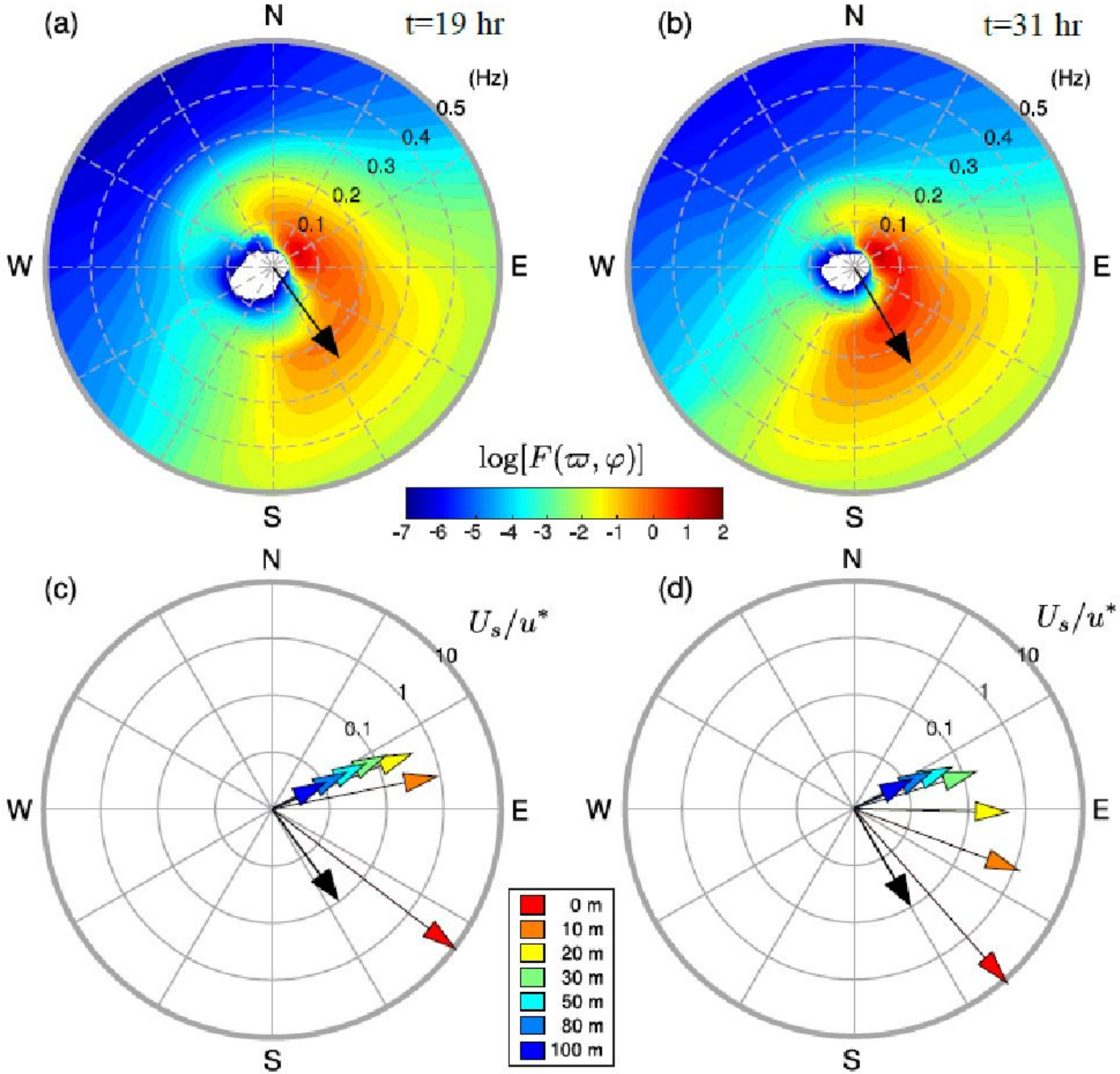


Conclusion

- WW3 surface waves have been coupled within the CvMIX KPP construct to be consistent with WAB LES solutions; $>> w_{M,S}$
- Stokes Drift: Nb=3 captures depth decay, but La ~ 30% high
- Waves deepen mixed layer; Move water volume to low latitudes
- Prior missing waves largely compensated (> G(σ), $Vt^2 \propto w_s$)
- Adding wave dependencies could double count
- Wave impacts depend on General Circulation and Forcing biases
- Cheaper waves for 2/3 MOM-6 with legacy waves?

Questions

- WW3 on 2/3 MOM-6 grid ~ MOM-6
- Simpler wave model and/or more bands increase La ?
- Optimize mixing for CESM-3 General Circulation and Forcing ?


(a)
t=19 hr
(b)
t=31 hr
N
W
E
S
(Hz)
0.5
0.4
0.3
0.2
0.1
$\log[F(\varpi,\varphi)]$
-7 -6 -5 -4 -3 -2 -1 0 1 2
(c)
(d)
U_s/u^*
10
1
0.1
0 m
10 m
20 m
30 m
50 m
80 m
100 m

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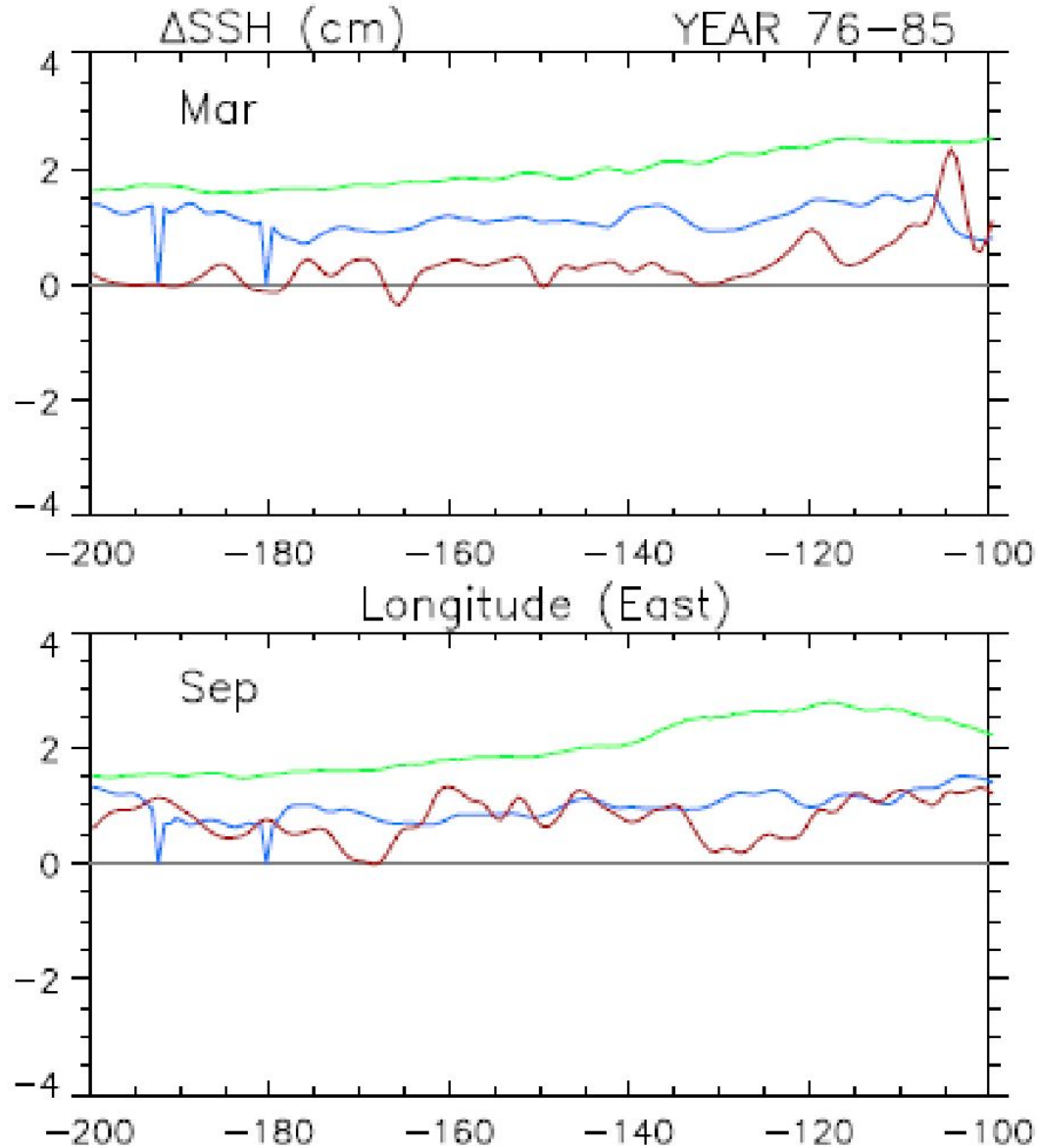
ΔSSH (cm)
YEAR 76–85
Mar
Sep
4
2
0
−2
−4
−200
−180
−160
−140
−120
−100
Longitude (East)