Parameterization of Langmuir turbulence

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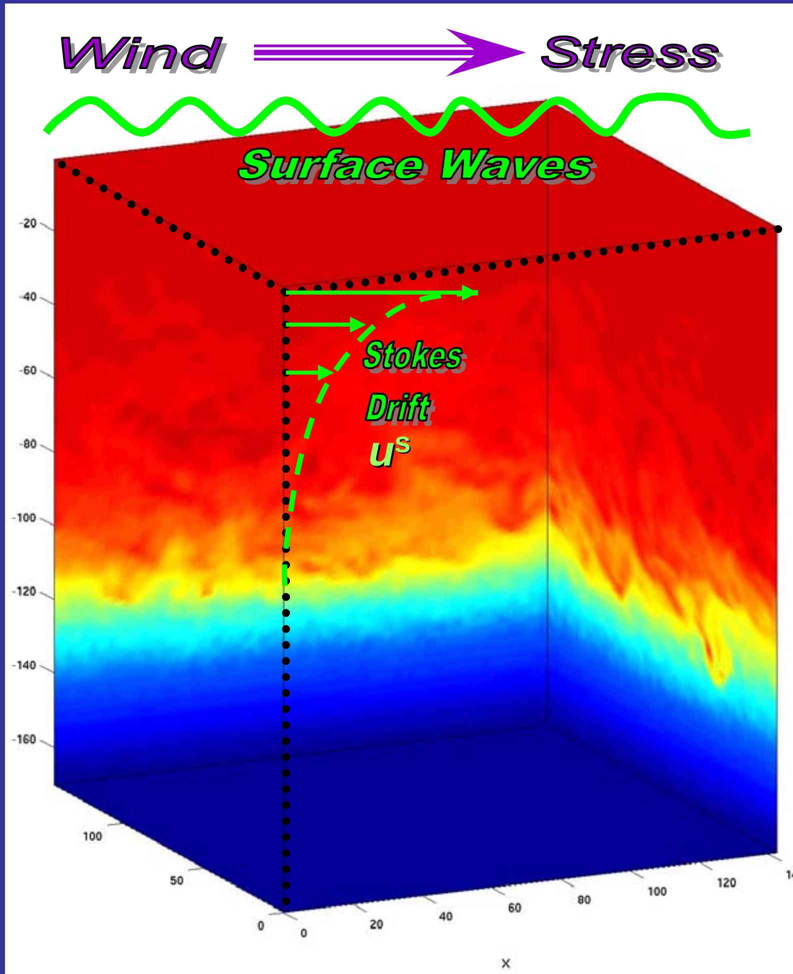
Support: Typhoon DRI
DoD HPC resources

Collaborator Eric A. D'Asaro



Methods

1) Modeling upper ocean turbulence with Large Eddy Simulation (LES) techniques

2) Comparing with turbulence observations from Lagrangian floats in wind & wave – driven mixed layers, below & near hurricanes & typhoons.

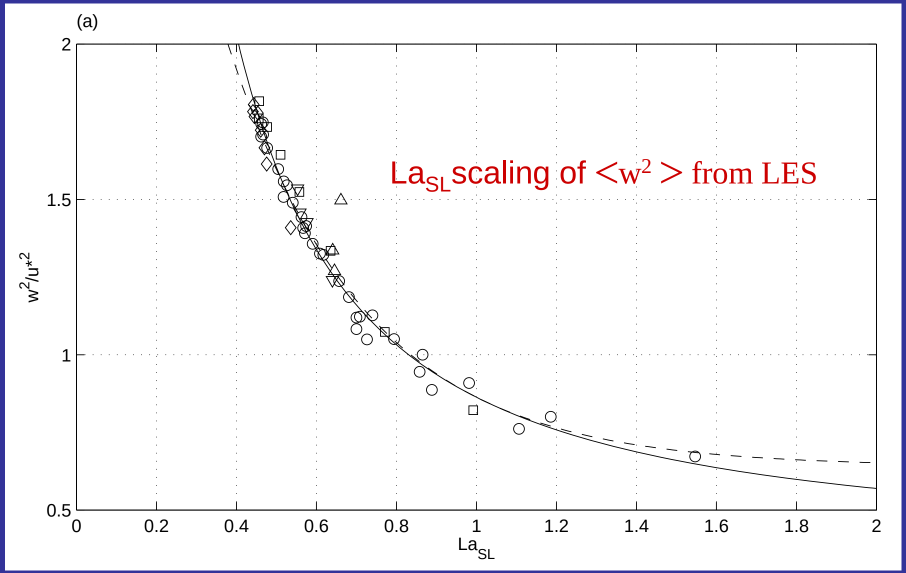
3) Parameterizing the effects of surface waves on upper ocean turbulence and mixed layer evolution in KPP and in second moment q^2-q^2l type closures (e.g. M-Y 2.5, in NCOM)

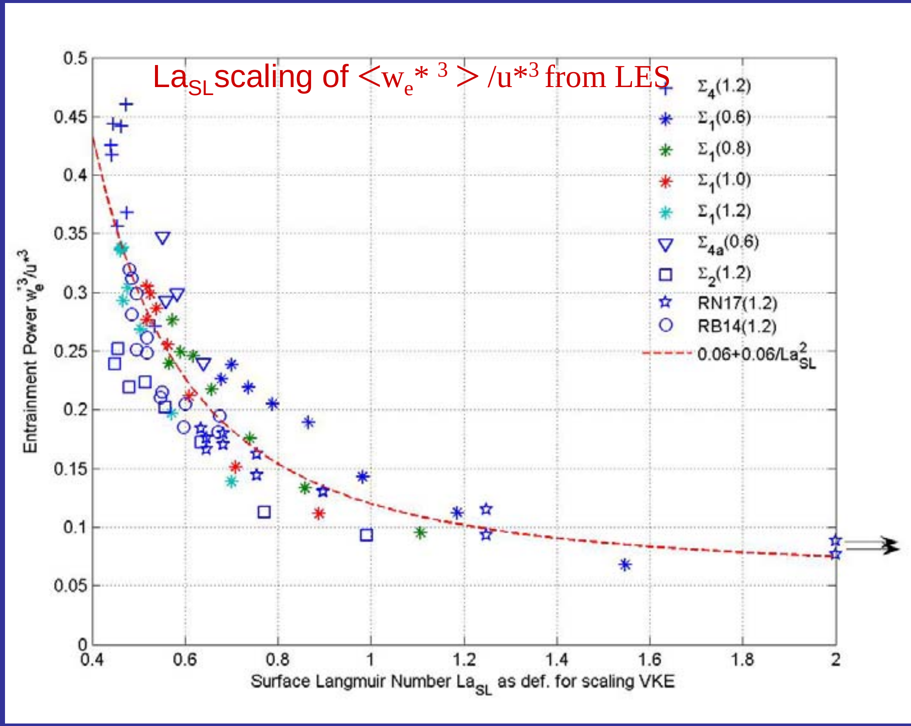
$$\frac{D}{Dt}(q^2) - \frac{\partial}{\partial z}\left[q\ell S_q \frac{\partial}{\partial z}(q^2)\right] = -2\overline{uw}\left(\frac{\partial U}{\partial z} + \frac{\partial u_S}{\partial z}\right) - 2\overline{vw}\left(\frac{\partial V}{\partial z} + \frac{\partial v_S}{\partial z}\right) + 2\beta g\overline{w\theta} - 2\frac{q^3}{B_1\ell}$$

$$\frac{D}{Dt}(q^2\ell) - \frac{\partial}{\partial z}\left[q\ell S_l \frac{\partial}{\partial z}(q^2\ell)\right] = E_1\ell\left(-\overline{uw}\frac{\partial U}{\partial z} - \overline{vw}\frac{\partial V}{\partial z}\right) + E_6\ell\left(-\overline{uw}\frac{\partial u_S}{\partial z} - \overline{vw}\frac{\partial v_S}{\partial z}\right) + E_3\ell(\beta g\overline{w\theta}) - E_2\frac{q^3}{B_1}\left[1 + E_4\left(\frac{\ell}{\kappa\ell_w}\right)^2\right] + E_5(2\Omega)q^2\ell$$

Stokes drift $\mathbf{u}^s$ drives '<u>vortex force</u>' production in TKE (q^2) (McWilliams et al., 1997) and length scale (q^2l) equations (Kantha & Clayson, 2004)

Steady State LES of Langmuir turbulence





Scaling of bulk ML Vertical TKE:

Harcourt & D'Asaro (2008): $\langle w^2 \rangle /u^{*2} \sim La_{SL}^{-4/3}$

Uses a 'Surface Layer Langmuir Number La_{SL} using near-surface mean $\langle \mathbf{u}^s \rangle$.

Consistent Lagrangian float $\langle w^2 \rangle$observations.

Scaling entrainment power:

Energy rate to entrainment $\langle w_e^3 \rangle /u^{*3} \sim La_{SL}^{-2}$

LES of wide variations in wind & wave forcing

BUT not much inertial shear.

Kantha & Clayson (2004) model:

$$\frac{Dq^2}{Dt} - \frac{\partial}{\partial x_k}\left[q l S_q \frac{\partial q^2}{\partial x_k} \right] = 2\left[-\overline{u_i' u_j'}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial u_i^S}{\partial x_i} \right) - \boldsymbol{\beta} g_j \overline{u_j' \boldsymbol{\theta}'} - \frac{q^2}{B_1 l} \right]$$

Vortex force production added to M-Y of Kantha & Clayson (1994)

$$\frac{Dq^2 l}{Dt} - \frac{\partial}{\partial x_k}\left[q l S_l \frac{\partial q^2 l}{\partial x_k} \right] = -E_1 l \overline{u_i' u_j'}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial u_i^S}{\partial x_i} \right) - E_3 l \boldsymbol{\beta} g_j \overline{u_j' \boldsymbol{\theta}'} - \frac{q^3}{B_1}\left(1 + E_2 \left(\frac{l}{\kappa d_w} \right)^2 \right)$$

K_H $\quad$ K_M

$$\overline{w' \boldsymbol{\theta}'} = -S_H q l \frac{\partial \overline{\boldsymbol{\theta}}}{\partial z}, \qquad \overline{v' w'} = -S_M q l \frac{\partial \overline{v}}{\partial z}$$

$$S_H = \frac{A_2 (1 - 6A_1 / B_1)}{1 - 3A_2 G_H (6A_1 + B_2 (1 - C_3))}$$

$$S_M = A_1 \frac{(1 - 6A_1 / B_1 - 3C_1) + 9(2A_1 + A_2 (1 - C_2)) S_H G_H}{1 - 9A_1 A_2 G_H}$$

Stability functions

$$G_H = -\frac{l^2}{q^2} \boldsymbol{\beta} g \frac{\partial \boldsymbol{\theta}}{\partial z}, \qquad G_M = \frac{l^2}{q^2}\left| \frac{\partial \vec{u}}{\partial z} \right|^2, \qquad S_l = S_q = S_H, \qquad A_i, B_i, C_i, E_i = const$$

Problem: Stability functions do not depend on CL forcing.

Equilibrium model, dropping all transport divergence & Coriolis terms:

$$\overline{u'^2} = q^2(1-6A_1/B_1)/3 - 6A_1 l q^{-1}\,\overline{u'w'}\,\partial_z \overline{u}\,, \qquad \overline{v'^2} = q^2(1-6A_1/B_1)/3 - 6A_1 l q^{-1}\,\overline{v'w'}\,\partial_z \overline{v}$$

$$\overline{w'^2} = q^2(1-6A_1/B_1)/3 + 6A_1 l q^{-1}\left[\boldsymbol{\beta} g\,\overline{w'\boldsymbol{\theta}'} - \overline{u'w'}\,\partial_z u^S - \overline{v'w'}\,\partial_z v^S\right]$$

$$\overline{v'w'} = -3A_1 l q^{-1}\left[\left(\overline{w'^2} - C_1 q^2\right)\partial_z \overline{v} - \boldsymbol{\beta} g\,\overline{v'\boldsymbol{\theta}'} + \overline{v'^2}\partial_z v^S + \overline{u'v'}\,\partial_z u^S\right]$$

$$\overline{v'\boldsymbol{\theta}'} = -3A_2 l q^{-1}\left[\overline{v'w'}\,\partial_z \overline{\boldsymbol{\theta}} + (1-C_2)\overline{w'\boldsymbol{\theta}'}\,\partial_z \overline{v} \qquad\qquad \right]$$

$$\overline{u'v'} = -3A_1 l q^{-1}\left[\overline{u'w'}\,\partial_z \overline{v} + \overline{v'w'}\,\partial_z \overline{u}\right], \qquad \overline{\boldsymbol{\theta}'^2} = -B_2 l q^{-1}\,\overline{w'\boldsymbol{\theta}'}\,\partial_z \overline{\boldsymbol{\theta}}$$

Solution requires momentum flux down Stokes gradient!

$$\overline{u'w'} = -lq\left(S_M \partial_z \overline{u} + S_M^S \partial_z u^S\right), \qquad \overline{v'w'} = -lq\left(S_M \partial_z \overline{v} + S_M^S \partial_z v^S\right), \qquad \overline{w'\boldsymbol{\theta}'} = -lq S_H \partial_z \overline{\boldsymbol{\theta}}$$

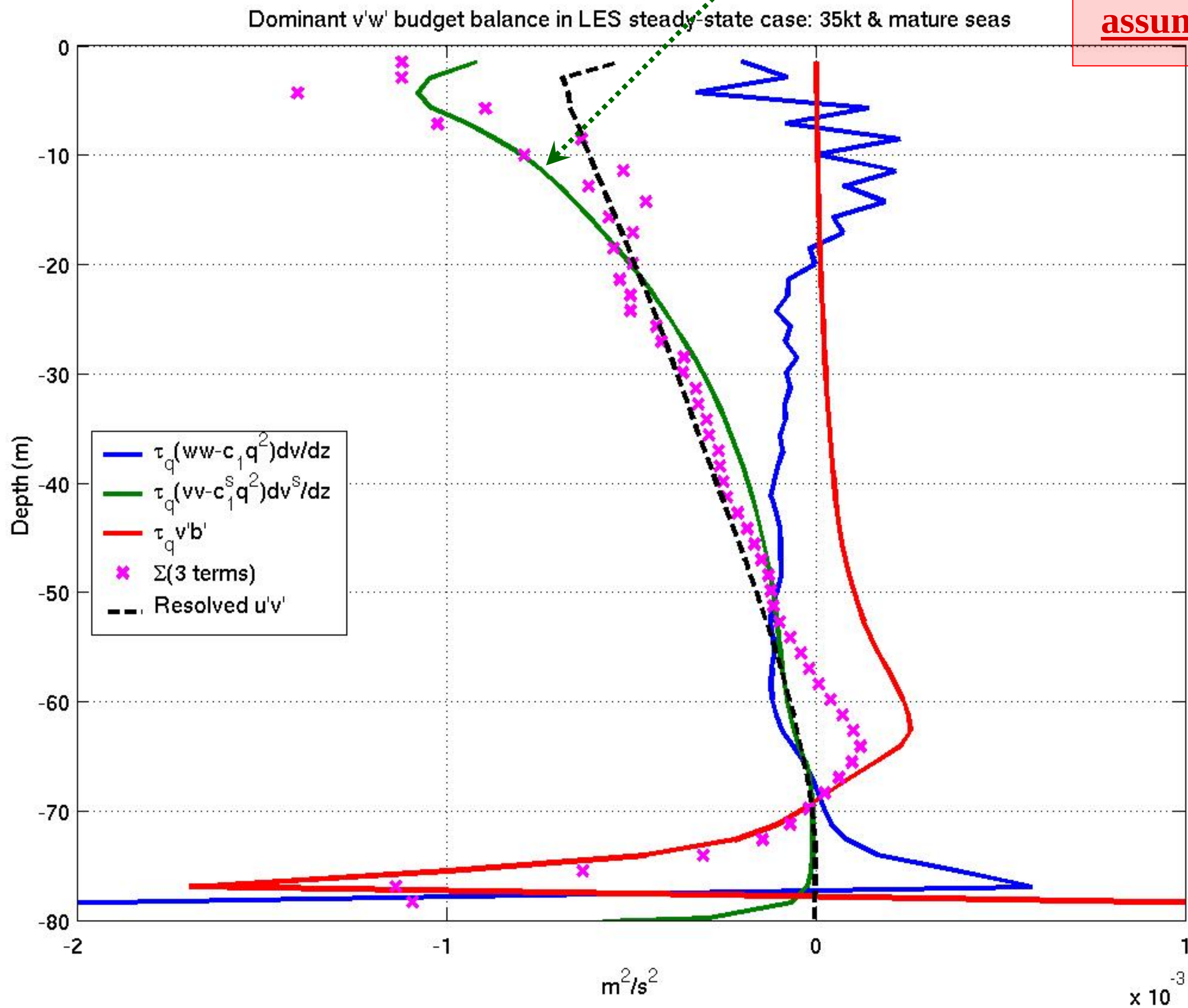
LES check:

$$\overline{v'w'} = -3A_1 l q^{-1}\left[\left(\overline{w'^2} - C_1 q^2\right)\partial_z \bar{v} - \boldsymbol{\beta} g\, \overline{v'\boldsymbol{\theta}'} + \left(\overline{v'^2} - C_1 q^2\right)\partial_z v^S + \overline{u'v'}\,\partial_z u^S\right]$$

time scale τ_q

Dominant term

Additional closure assumption



Solution: $\overline{u'w'} = -lq\left(S_M \partial_z \overline{u} + S_M^S \partial_z u^S\right)$, $\overline{v'w'} = -lq\left(S_M \partial_z \overline{v} + S_M^S \partial_z v^S\right)$, $\overline{w'\boldsymbol{\theta}'} = -lqS_H \partial_z \overline{\boldsymbol{\theta}}$

$$S_H = \frac{D_{H0}D_{M1}D_{S1} + D_{H2}D_{M0}D_{S1} + (D_{H3}D_{M1} + D_{M3}D_{H2})D_{S0}}{D_{H1}D_{M1}D_{S1} - D_{H2}D_{M2}D_{S1} - (D_{H3}D_{M1} + D_{M3}D_{H2})D_{S2}}$$

$$S_M^S = (D_{S0} + D_{S2}S_H)/D_{S1}, \qquad S_M = (D_{M0} + D_{M2}S_H + D_{M3}S_M^S)/D_{M1}$$

Stability functions: Much more complicated!!

$$D_{S0} = A_1(1 - 6A_1/B_1 - 3C_1^S), \quad D_{S1} = 1 - 9A_1(A_2G_H + A_1G_V), \quad D_{S2} = 9A_1A_2C_2^SG_H$$

$$D_{M0} = A_1(1 - 6A_1/B_1 - 3C_1), \; D_{M1} = 1 - 9A_1(A_2G_H + 4A_1G_V),$$

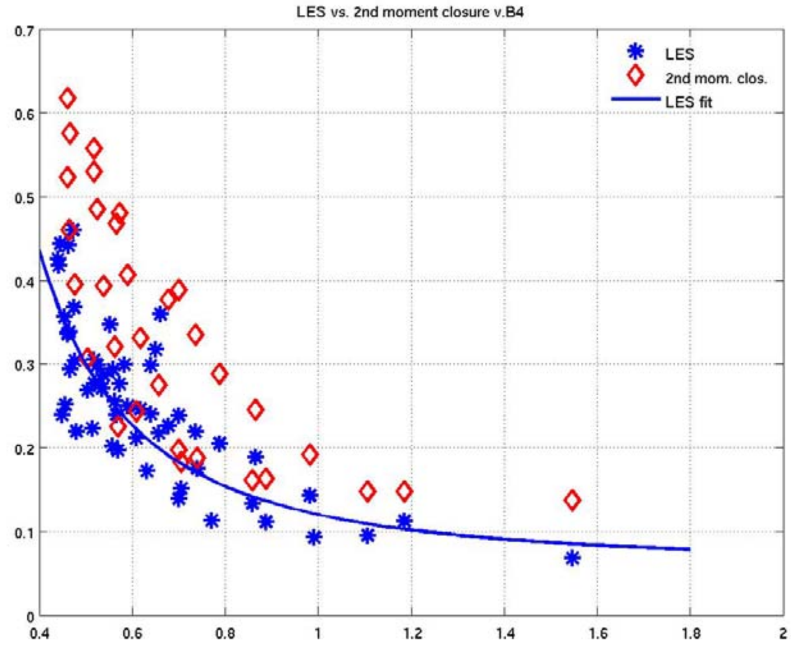
$$D_{M2} = 9A_1(2A_1 + A_2(1 - C_2))G_H, \; D_{M3} = 27A_1^2G_S$$

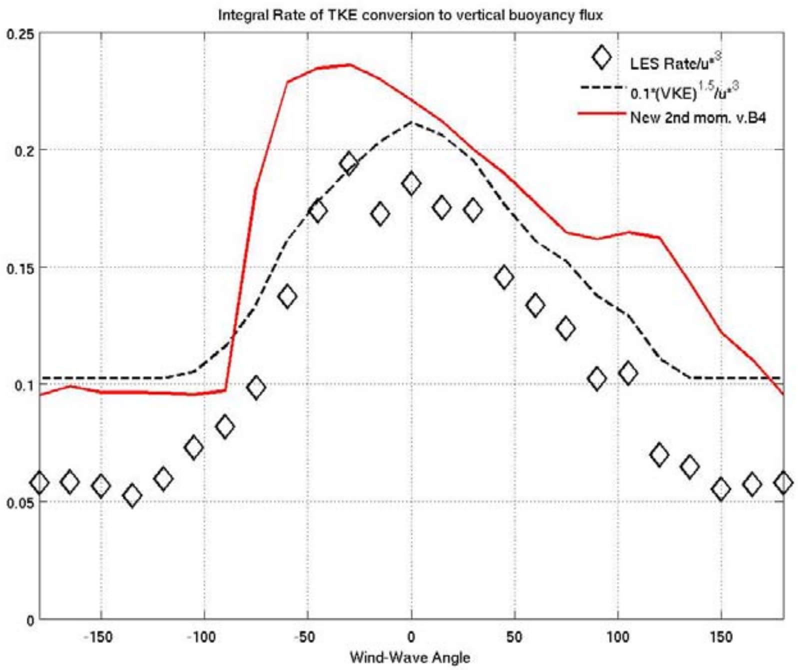
$$D_{H0} = A_2(1 - 6A_1/B_1), \qquad D_{H1} = 1 - 3A_2\left[\left(6A_1 + B_2(1 - C_3)\right)G_H + 3A_2(1 - C_2)G_V - 3A_2C_2^SG_S\right)\right],$$

$$D_{H2} = 9A_2G_V(2A_1 + A_2), \qquad D_{H3} = 9A_2G_S(2A_1 + A_2)$$

New n.d. forcing functions

$$G_H = -\frac{l^2}{q^2}\boldsymbol{\beta}g\frac{\partial\boldsymbol{\theta}}{\partial z}, \qquad G_M = \frac{l^2}{q^2}\left|\frac{\partial\vec{u}}{\partial z}\right|^2, \qquad G_V = \frac{l^2}{q^2}\frac{\partial\vec{u}}{\partial z}\cdot\frac{\partial\vec{u}^S}{\partial z}, \qquad G_S = \frac{l^2}{q^2}\left|\frac{\partial\vec{u}^S}{\partial z}\right|^2$$





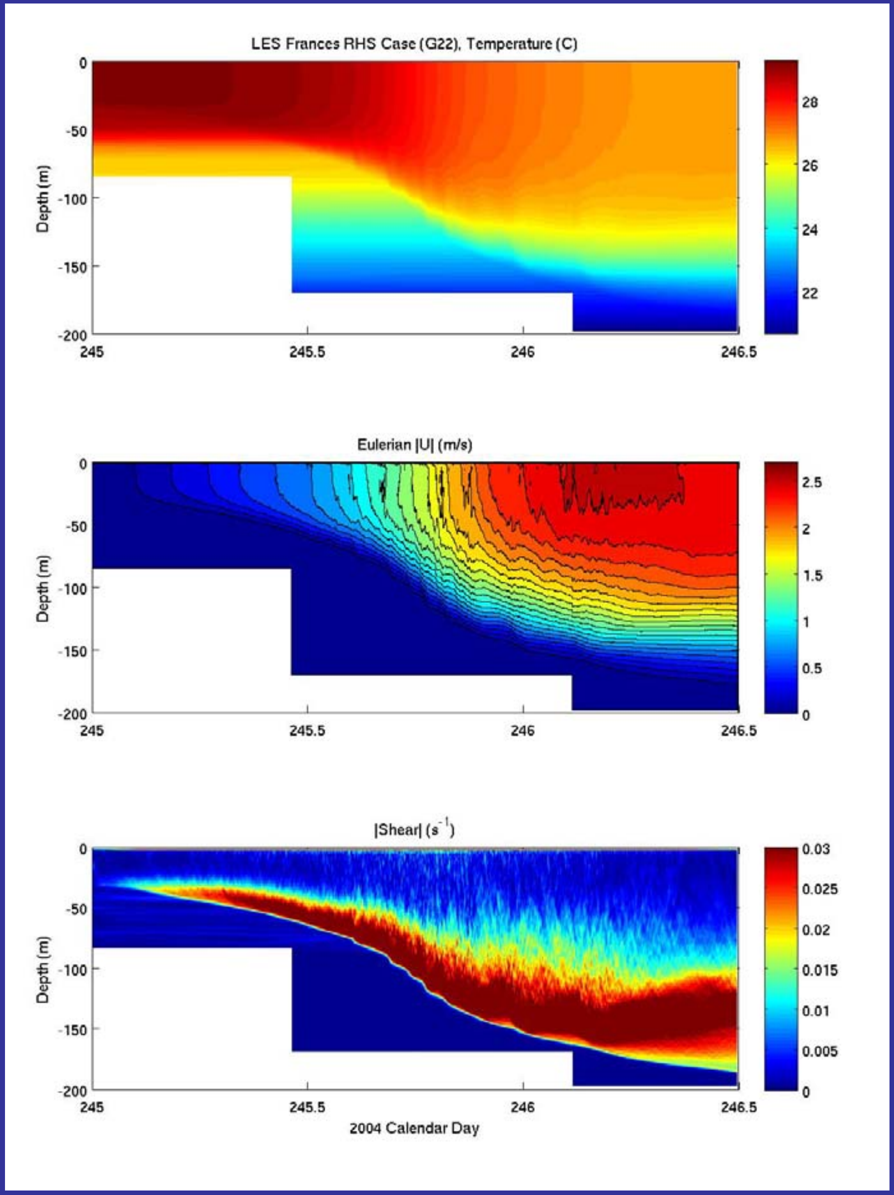
Entrainment power scaling: LES vs. closure:

Corresponding scaling of work rate with La_{SL} -- Closure model entrainment higher overall.

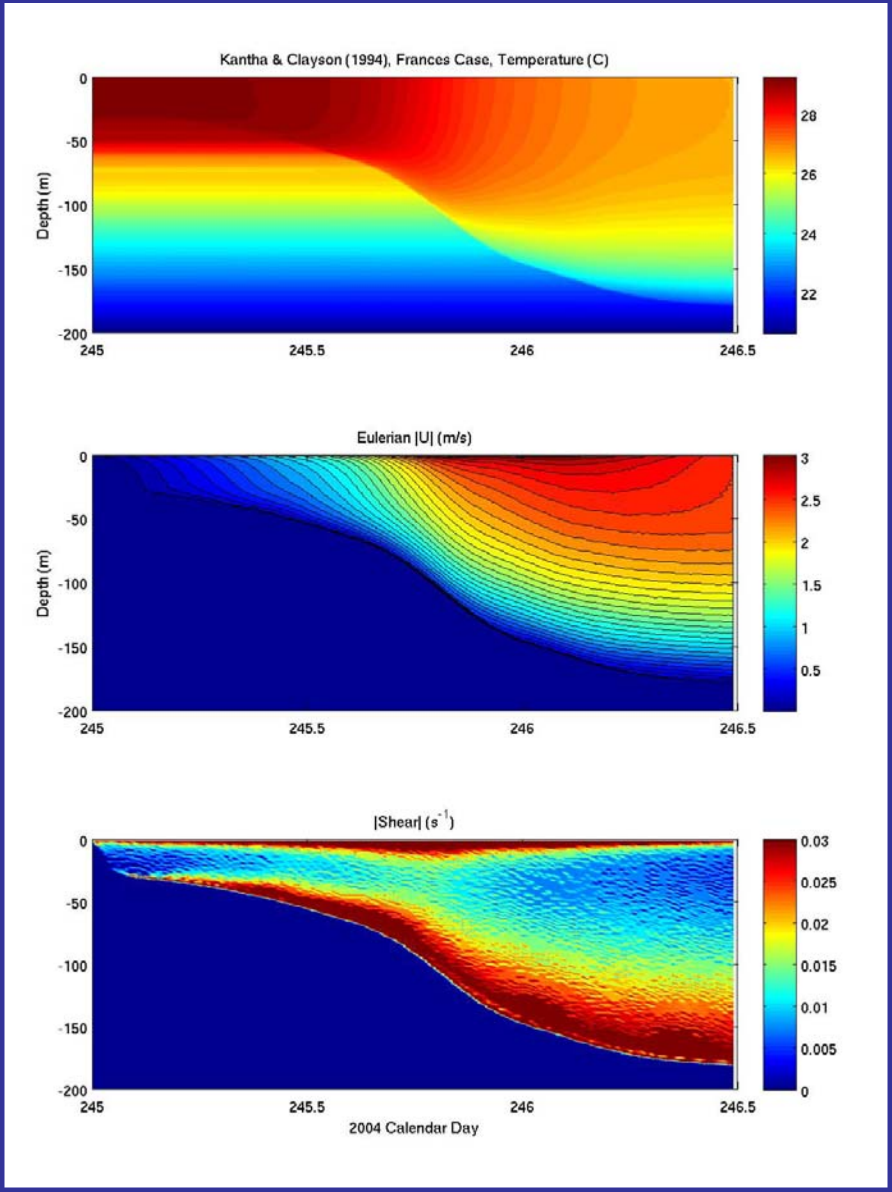
Similar response to angle between wind & waves -- skewness from Coriolis stronger.

LES vs 2nd moment M-Y closure (Kantha & Clayson,1994), i.e. NCOM
Wave forcing from WW3 model (by Il-Ju Moon)

LES

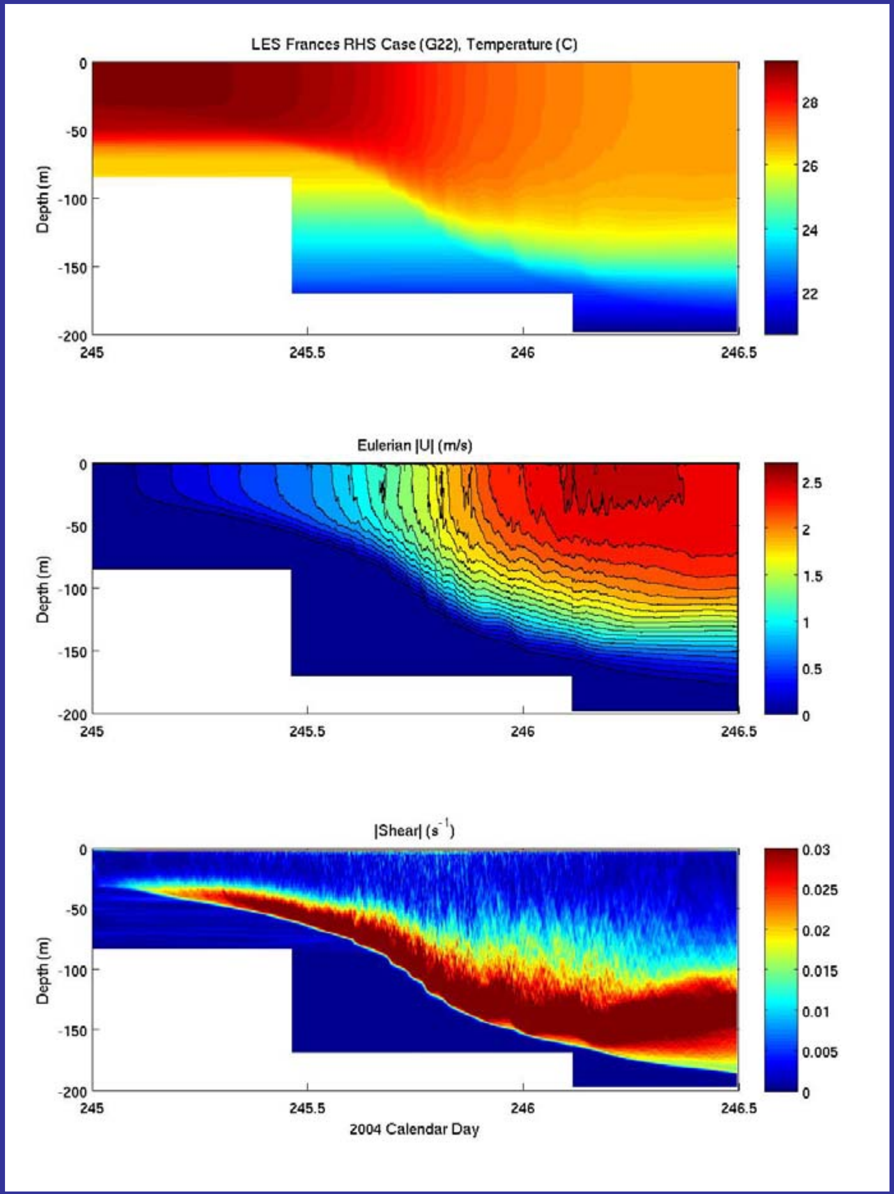


Kantha & Clayson (1994)

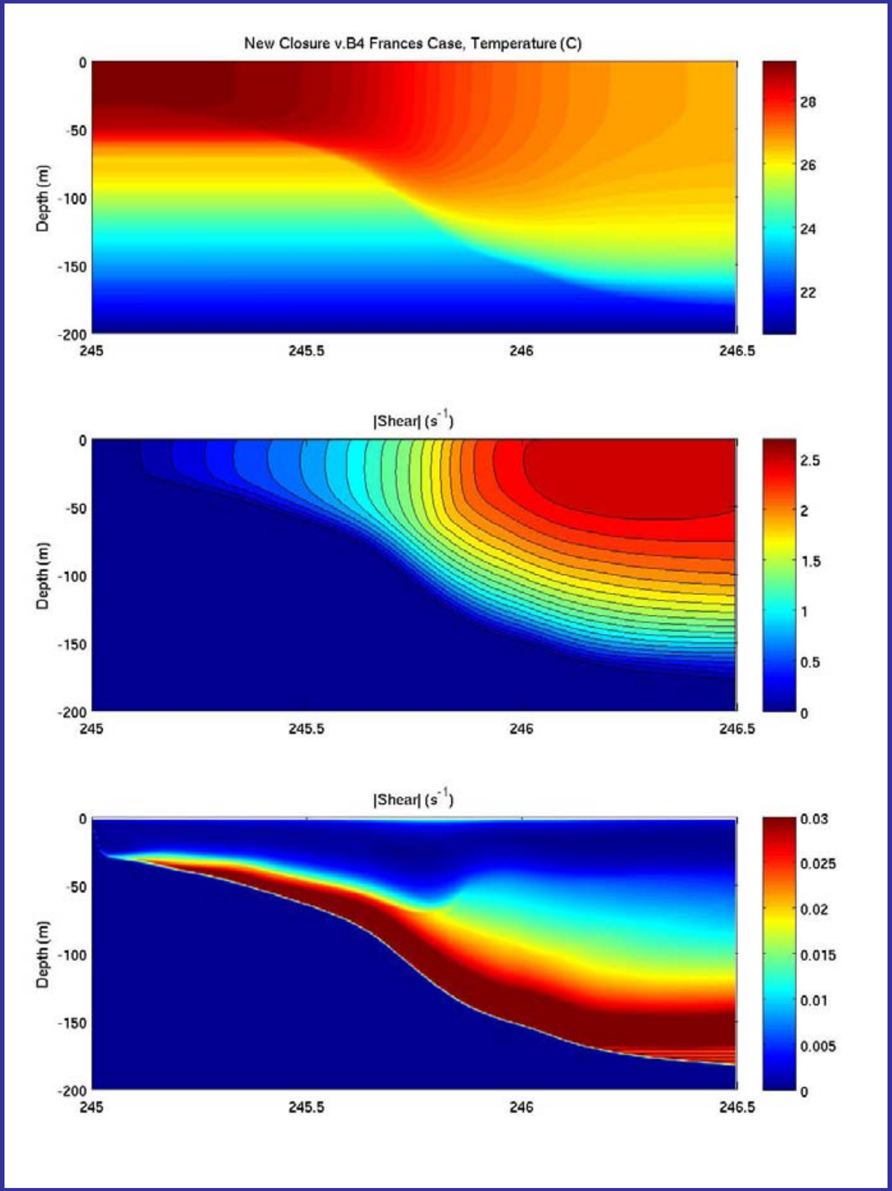


LES vs recent new 2nd moment closure

LES



New 2nd moment closure v.B4



<u>Entrainment physics across cyclone:</u>

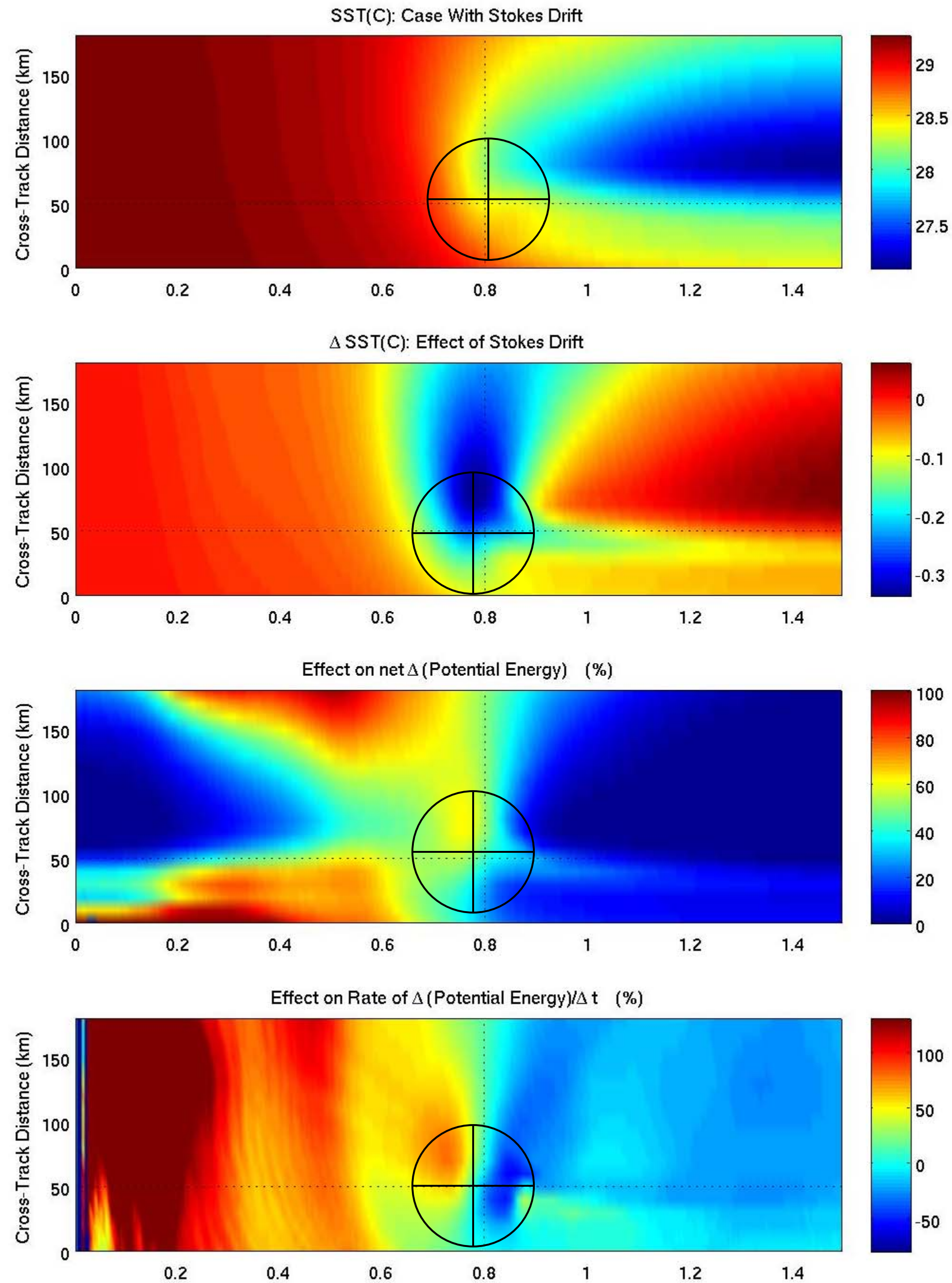
Final wake formation dominated by mixing driven by inertial shear.

Intermediate state, timing of wake below cyclone shifted by Stokes drift.

Below maximum winds, cooling is 50% more: reduced 1 C vs 2/3 C .

Mixing enhanced ahead of cyclone, damped to rear.

Combined effects cancel and are also much less than shear-driven mixing.



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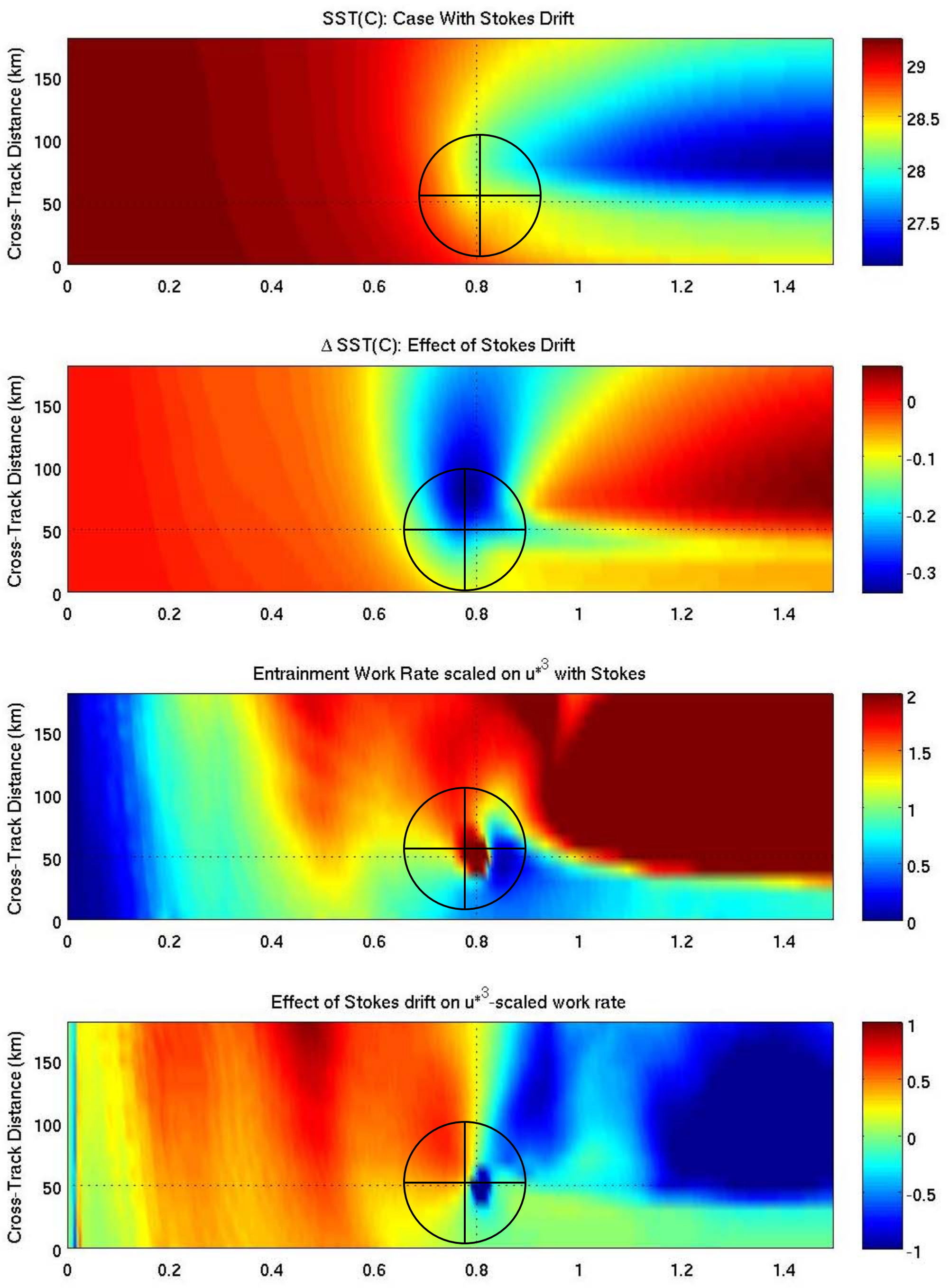

Wave-modified turbulence closure and LES (P. Sullivan too) need wind & wave forcing from Typhoons to simulate ITOP turbulence observations. Best: archived wave model data (WW3, SWAN) verified against remote & in-situ observations.

Seeking collaboration to put into modified closure in wave-ocean coupled model.

Lots of SST, Ocean Color imagery prepared for field cruise operations in small geographic domains still available at itop.org/data/harcourt . Includes some daily AVISO maps -- AVISO archives weekly maps. Other original satellite data archived at NODC & others, so …. should we archive any of this imagery?