COUPLING MARINE ATMOSPHERIC BOUNDARY LAYER WINDS TO THE OCEAN SURFACE

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ONR COUPLED BOUNDARY LAYERS AND AIR-SEA TRANSFER EXPERIMENT, LOW WINDS

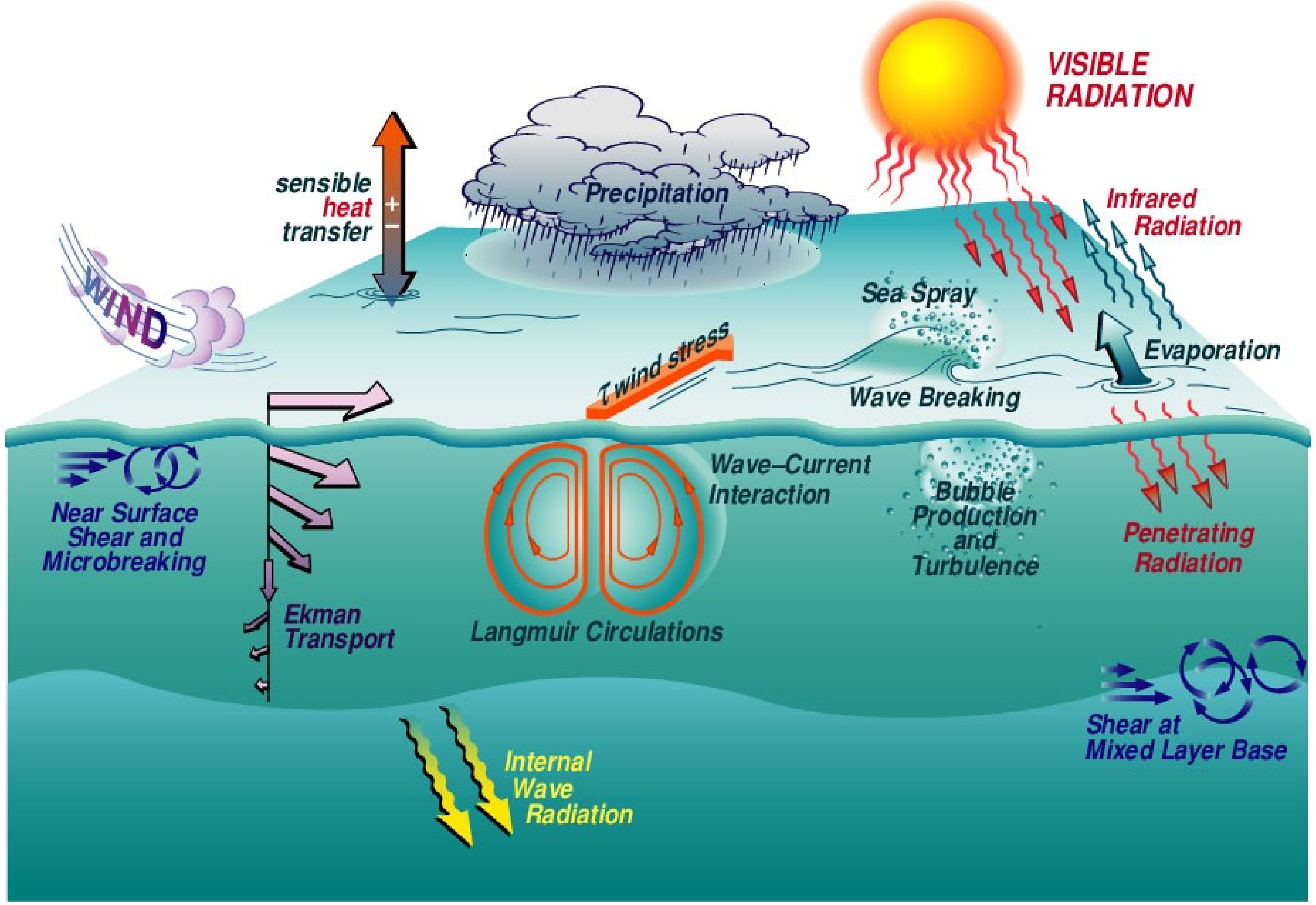


Image credit WHOI

Reviews:

Edson *et al* (BAMS, 2004)
[CBLAST Low]

Wanninkhof *et al* (ARMS, 2009)
[Air-sea gas exchange]

Sullivan & McWilliams (ARFM, 2010)
[Coupling winds, waves & currents]

D'Asaro (ARMS, 2011)
[Ocean turbulence]

Veron (ARFM, 2015)
[Ocean spray]

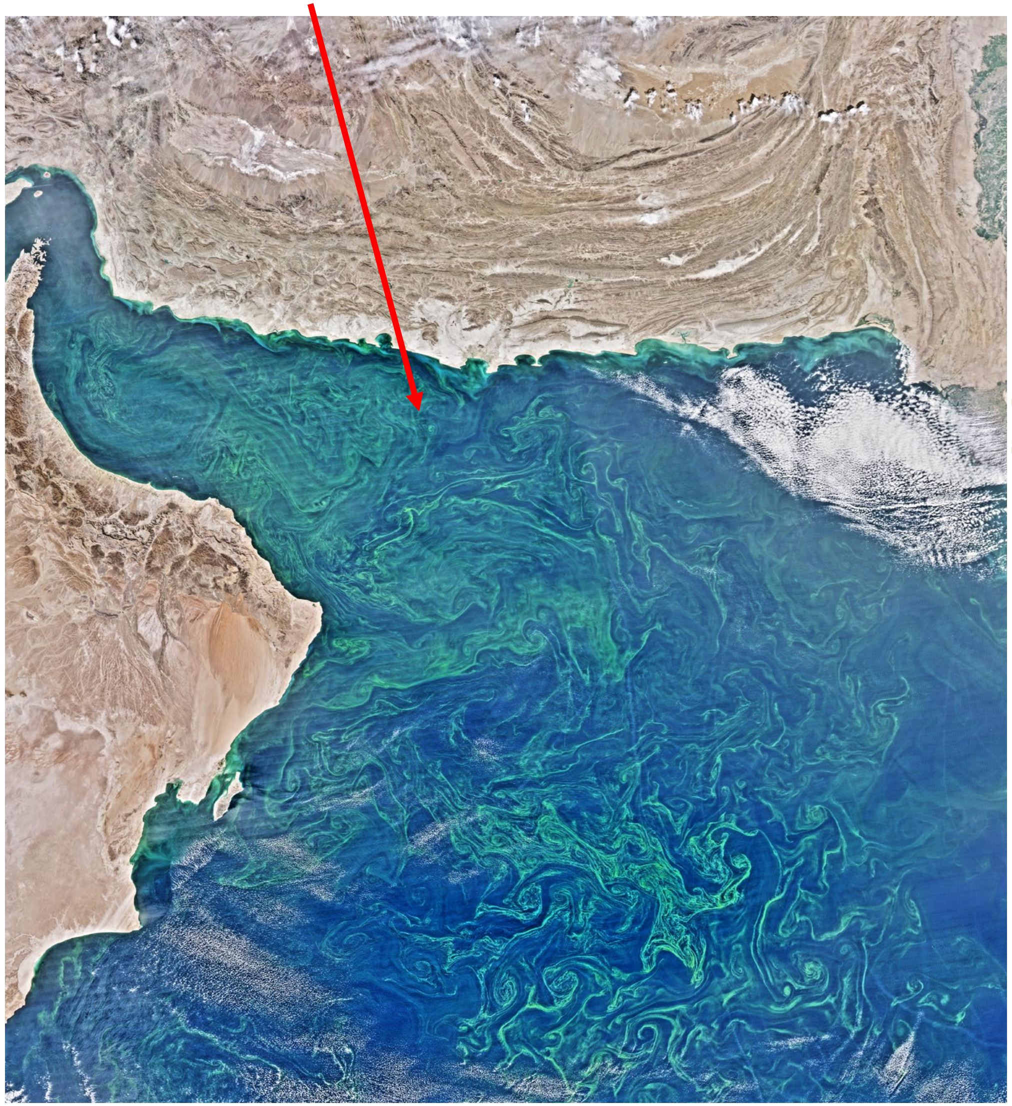
Wind Waves Workshop
(Procedia IUTAM, 2018)

Broadband spectrum of time and space scales

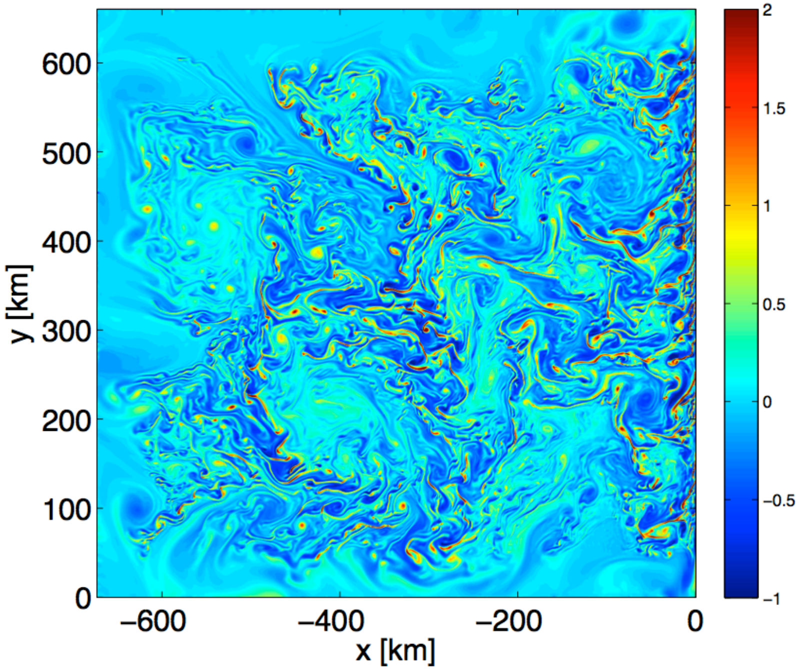
mm (bubbles, spray) ⟷ 100’s m swell ⟷ 10’s km surface heterogeneity

OCEAN SUBMESOSCALE TURBULENCE, L_x~ [0.1 – 10] km

Plankton patterns, Arabian Sea



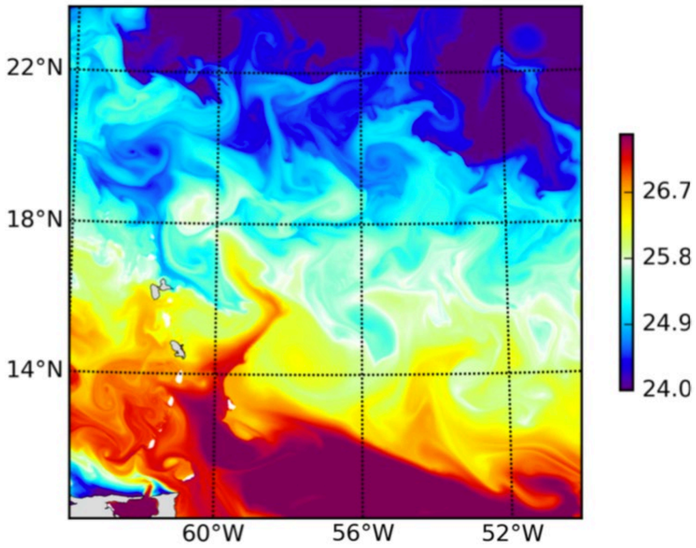
Submesoscale turbulent ``soup” with fronts, instabilities, vortices, and SST anomalies in the upper ocean, ROMS (UCLA)



Vorticity ζ

Coupled WRF+ROMS with 1D BL parameterizations exist!

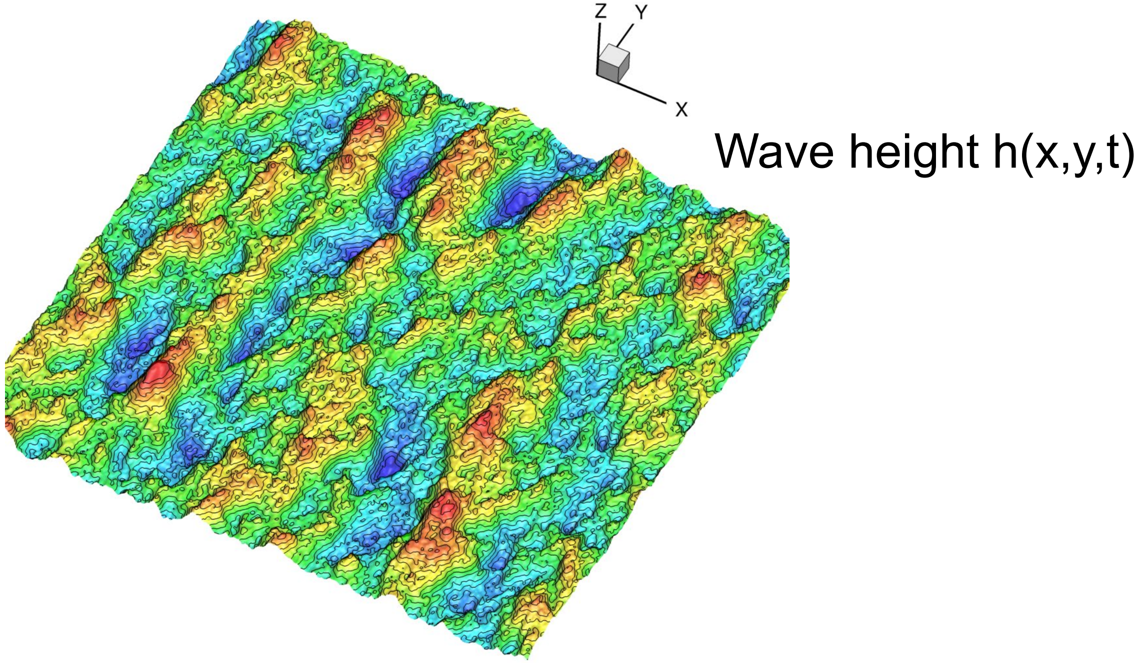
SST



LES EXAMPLES OF 1-WAY COUPLING WITH AN OCEAN SURFACE: GRID MESH 10^9 POINTS

Surface waves:

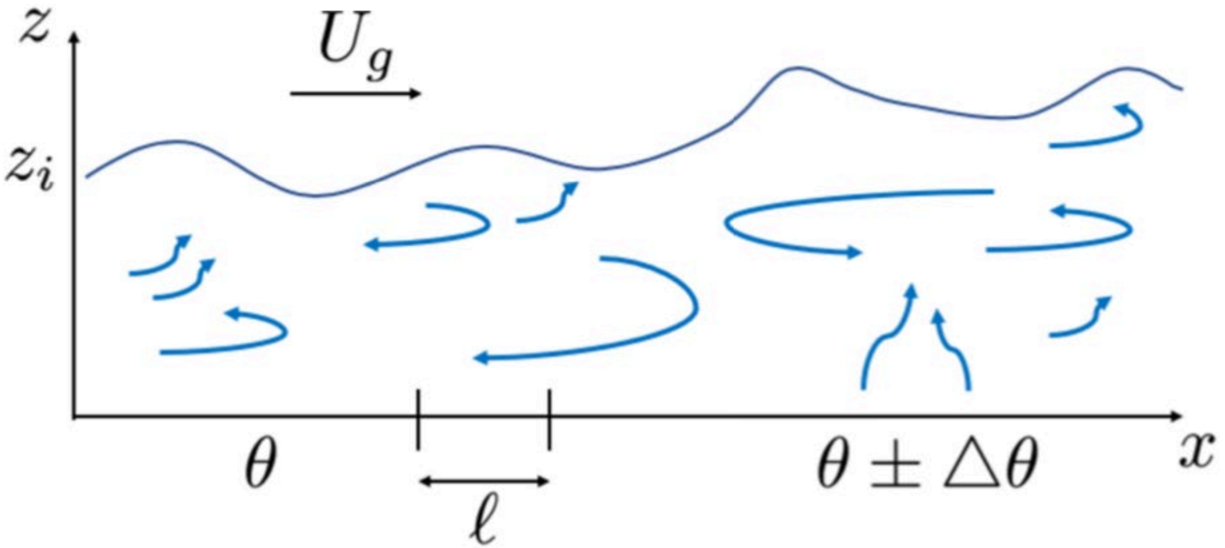
- Surface fitted time varying grid
- Imposed time varying spectrum of waves



Wave height h(x,y,t)

Heterogeneous SST:

- Imposed warm and cold fronts, and filaments
- "Fourier-fringe" technique to control inflow-outflow turbulence
- Run 2 LES concurrently!



Sullivan et al.(JAS, 2014, 2020)

Entry #: V0074

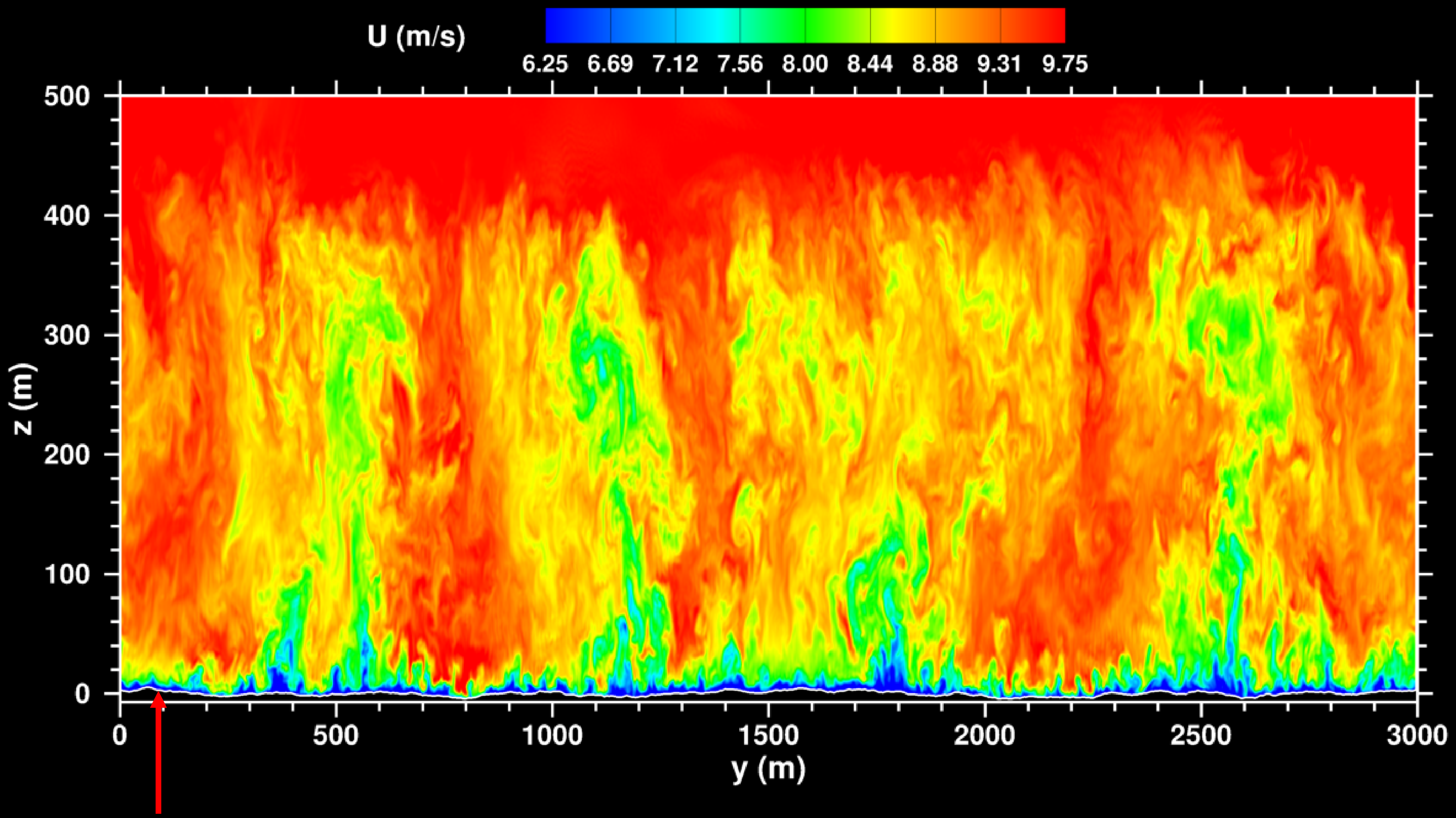
Large Eddy Simulations of Marine Atmospheric Boundary Layers

Peter Sullivan, Scott Pearse

National Center for Atmospheric Research

Wave driven winds

U Contours in yz-plane, Ug = 10 m/s, Q_* = 0.01 K m/s



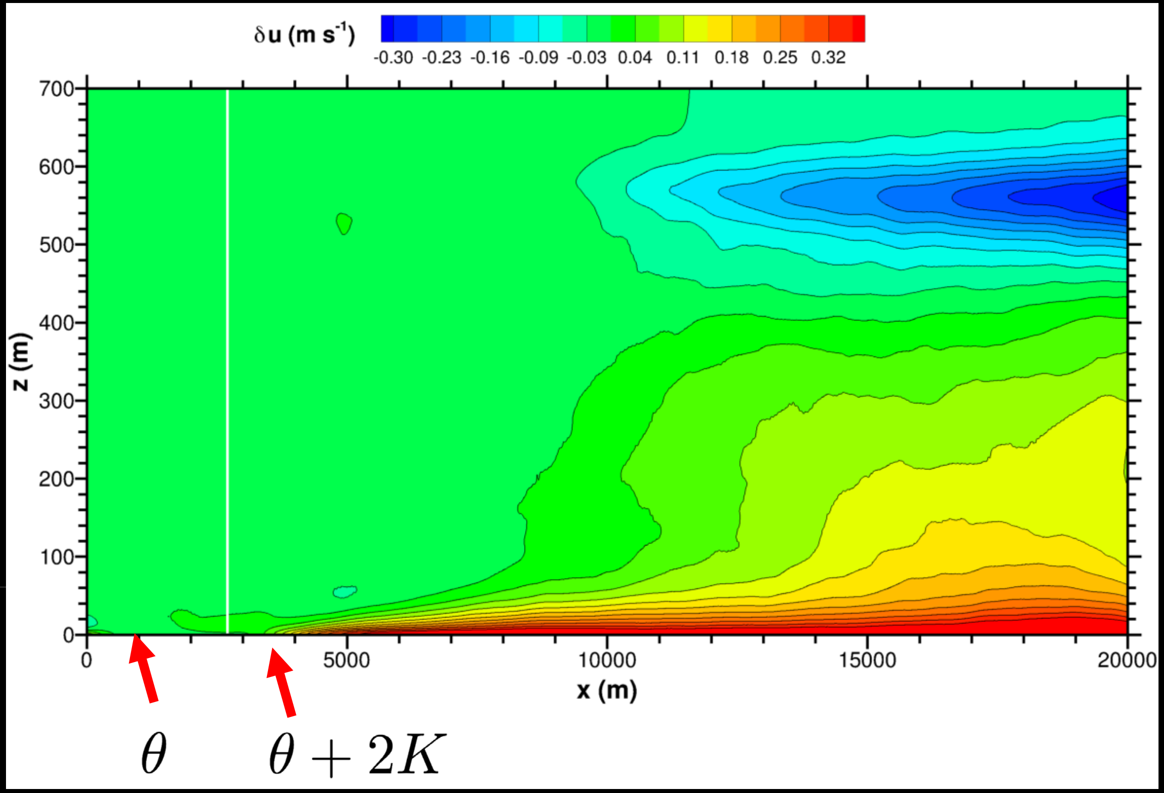
Wavy boundary: Hs ~ 6 m

Grid mesh: dx~3 m, dz~1 m

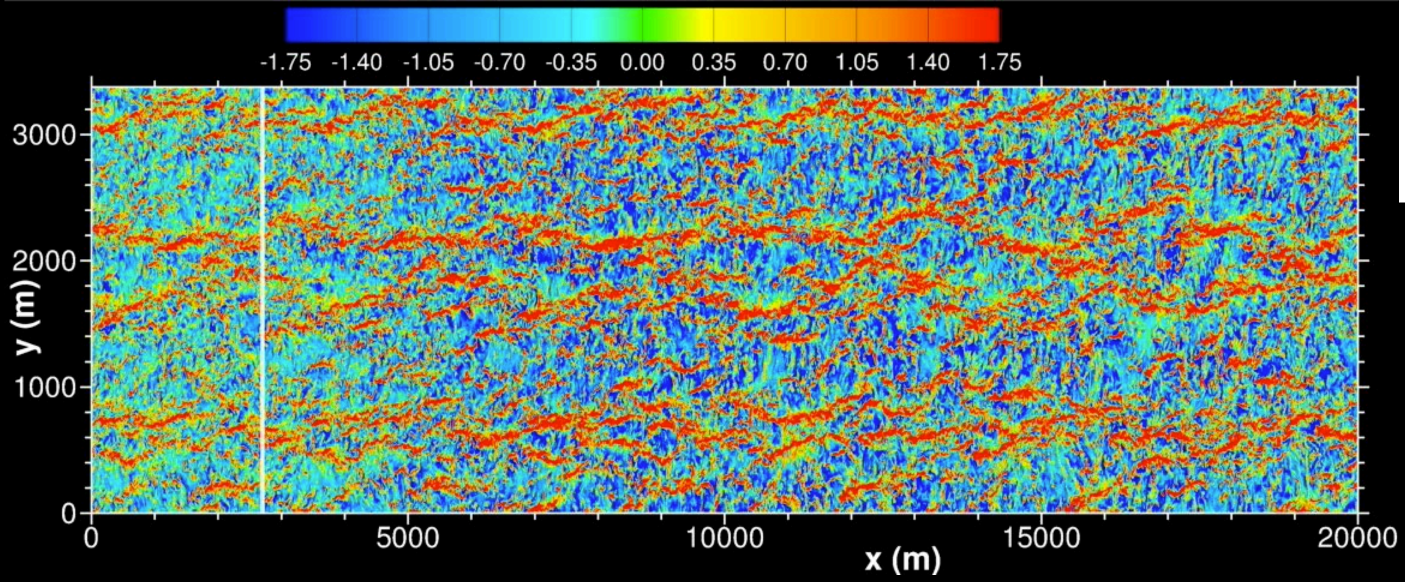
SPATIALLY EVOLVING BOUNDARY LAYER DOWNSTREAM OF A WARM SST FRONT

- Growing internal boundary layer
- Nonlinear in z vertical fluxes
- Intermediate maximum in w variance
- Impressive evolution distance
- Impact on entrainment
- Secondary circulations

Change in mean wind speed from upstream state



Vertical velocity w, z = 41 m
SST jump location indicated by white line



COMPUTATIONAL CHALLENEGES FOR SIMULATING TURBULENT WINDS WITH LES

Surface layer mechanics & drag:

- Waves, what scales support the wind stress as U varies?
  - critical layers
  - flow separation
  - non-separated sheltering
  - breaking
- Statistical, measured, phase-resolved waves?
- Non-linear wave models
- Algorithm complexity!

Non-equilibrium conditions:

- Remotely generated swell, wave age
- Mis-aligned winds and waves
- Unstable to stable stratification

Coupling:

- Heterogeneous SST and currents
- Finite depth water
- Ocean boundary layer plus submesoscale turbulence

Flat surface with measured drag?

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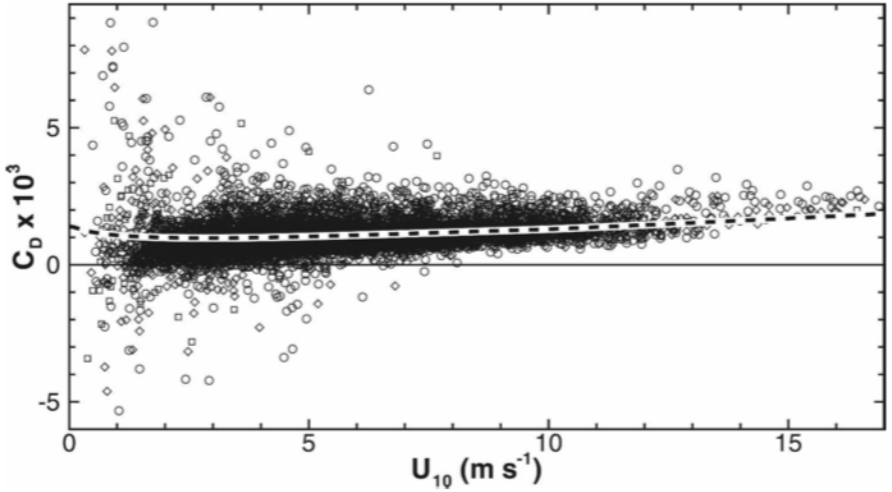


FIG. 3. Drag coefficients obtained from three measurement levels (squares, diamonds, circles) = (4.0, 6.0, 10.0) m during CBLAST (Edson et al. 2006); C_D is referenced to a 10-m height and neutral conditions. The TOGA COARE 3.0 parameterization is indicated by the dashed line. Note the negative values of C_D and increase in variability at low winds.

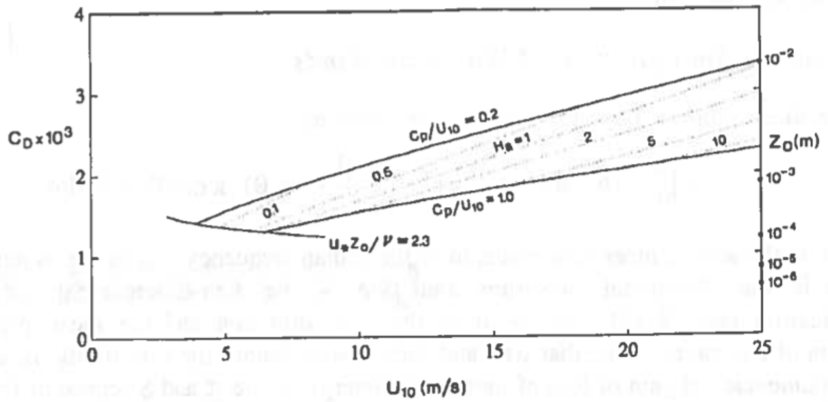
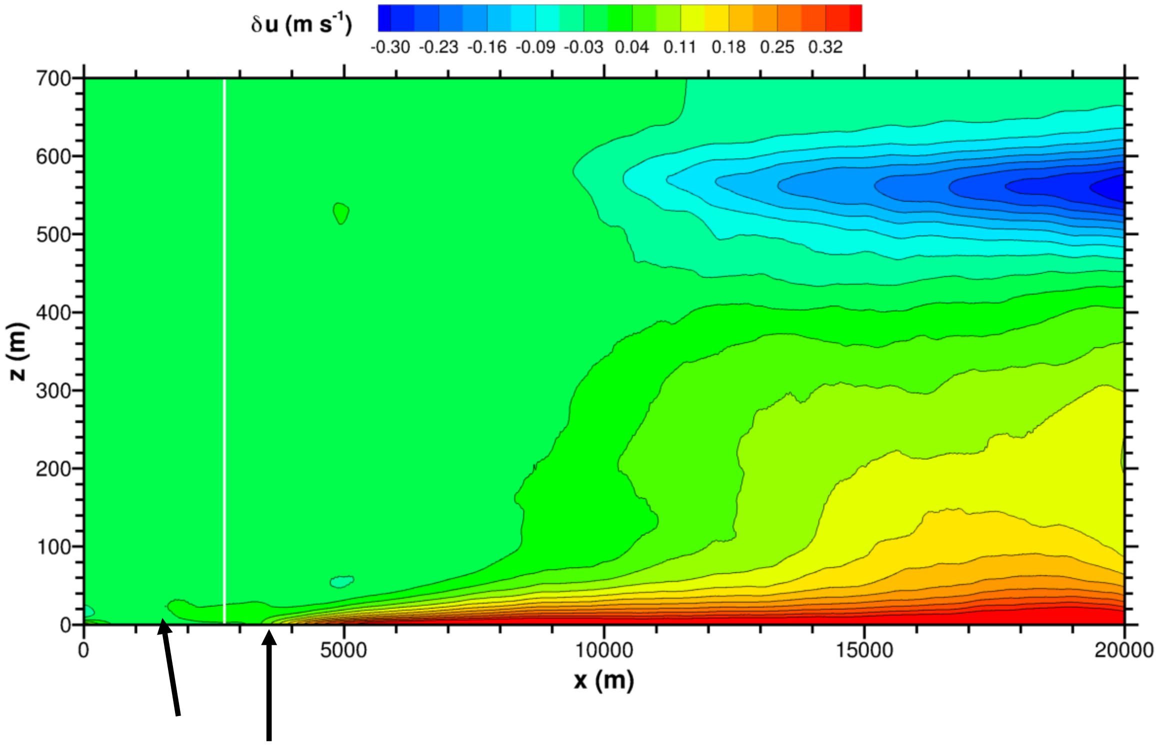


Figure 2. The relationship between drag coefficient and wind speed for various wave ages. The solid lines are for wave ages of 0.2 and 1.0 and the fully rough limit $u_{*a} z_0/v_a > 2.3$. The dotted lines are lines of constant significant height; the values indicated in meters. The corresponding roughness lengths are shown on the right-hand ordinate. (From Donelan et al., 1995).

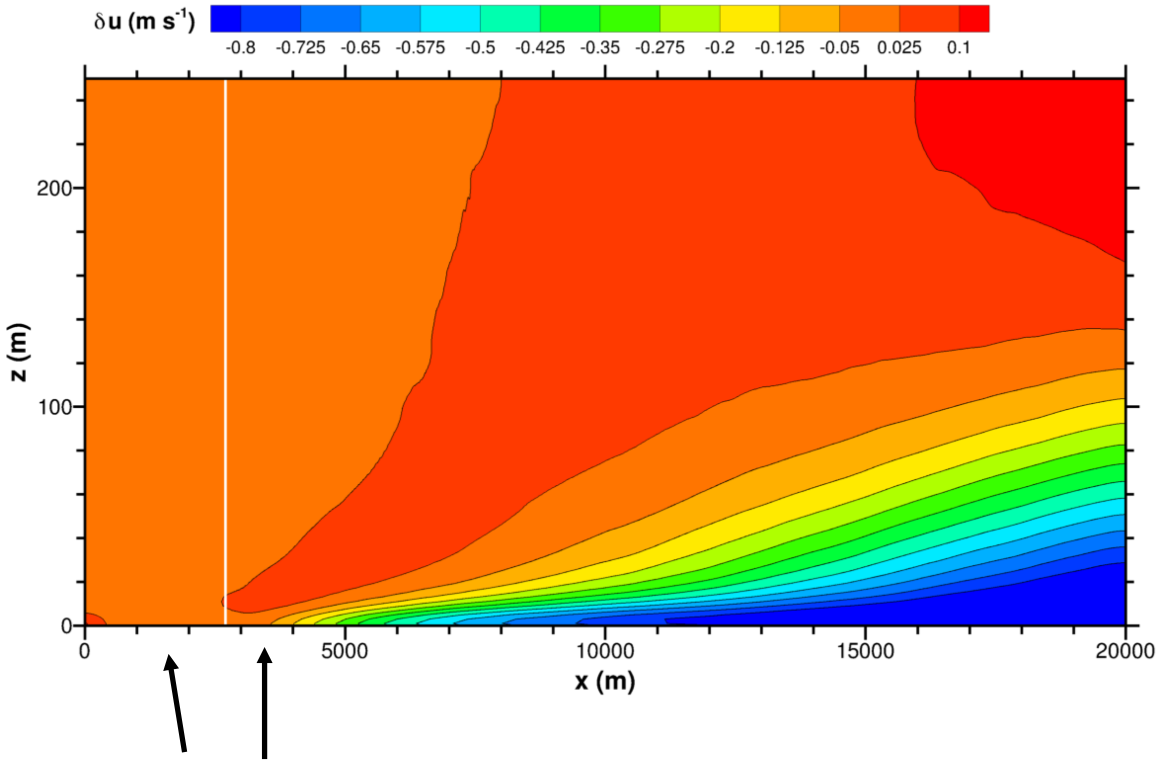
CHANGE IN WIND SPEED DOWNSTREAM OF AN SST JUMP: SPATIALLY EVOLVING BOUNDARY LAYERS

Warm SST Front



$\theta \quad \theta + 2K$

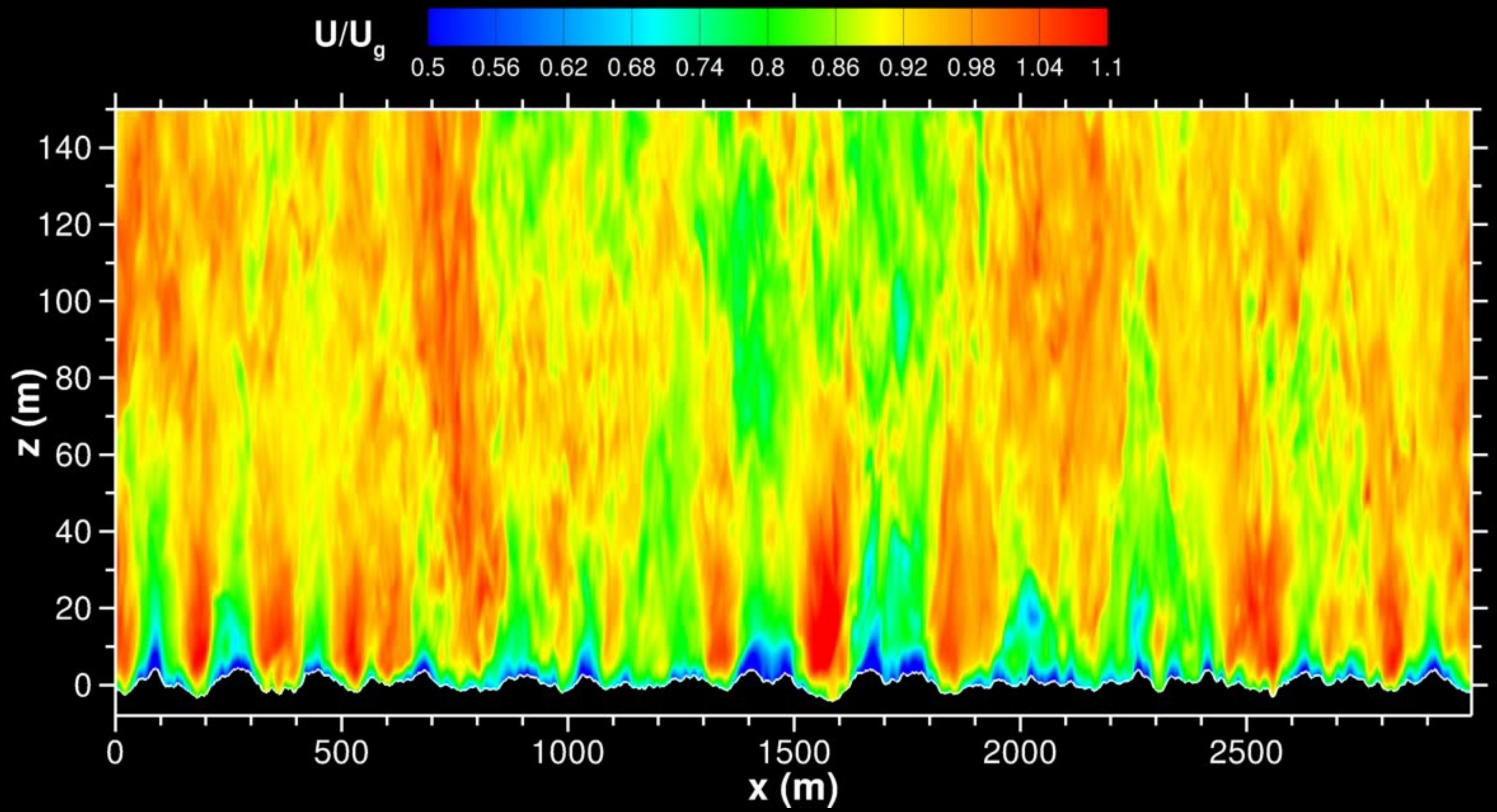
Cold SST Front

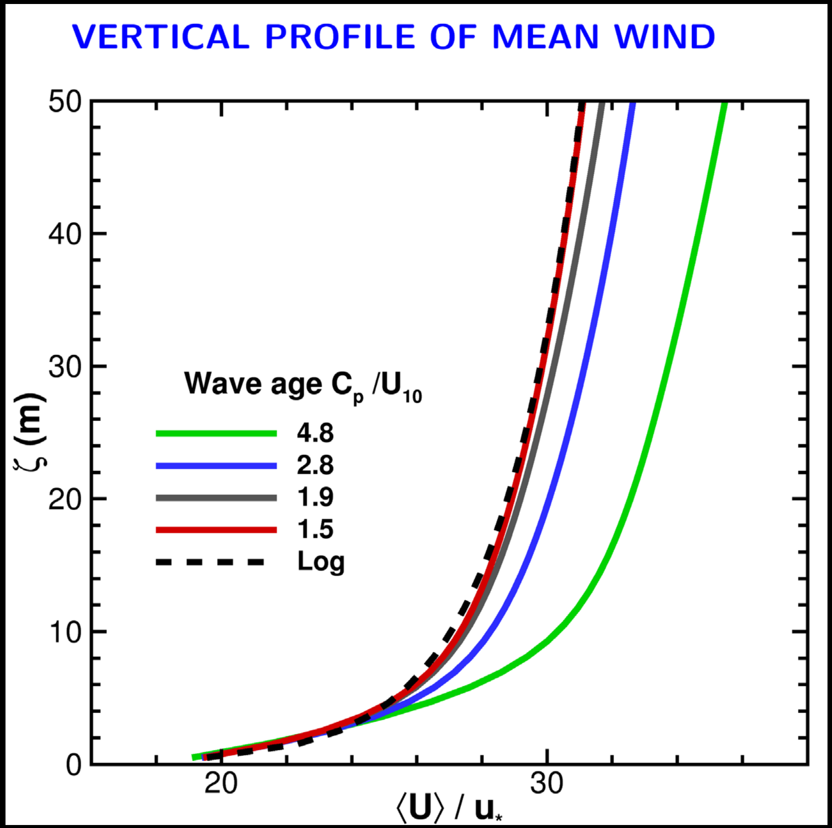


$\theta \quad \theta - 1.5K$

Sullivan et al (JAS, 2020)

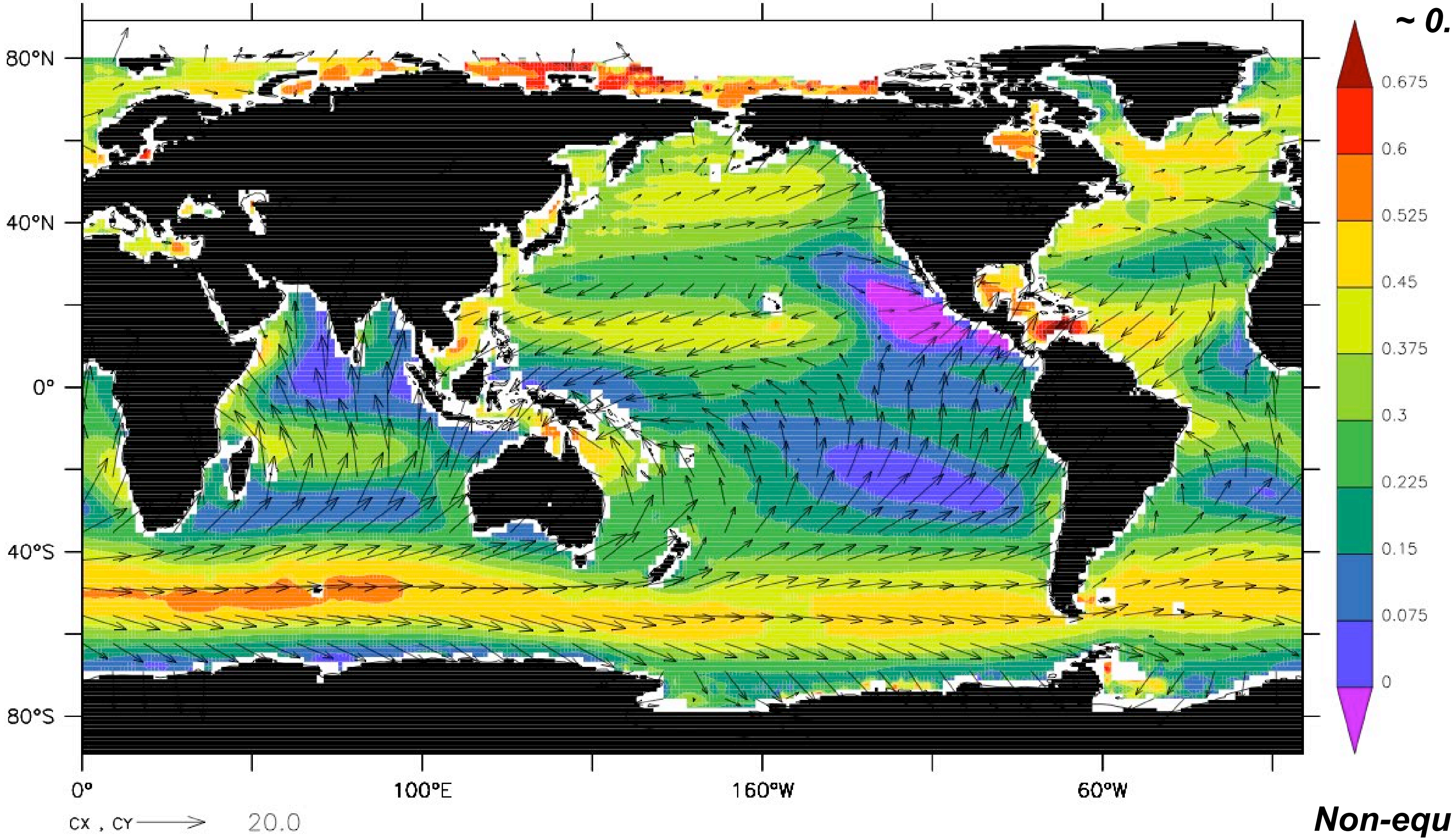
Normalized U/U_g contours in xz-plane, Wave age $C_p/U_a = 4.2$




VERTICAL PROFILE OF MEAN WIND

LES of a wave driven wind

GLOBAL CLIMATOLOGY OF INVERSE WAVE AGE
$U_a \cos(\phi)/C_p$ AVERAGED OVER 1958 - 2001



Equilibrium
~ 0.83

Non-equilibrium
winds and waves

Hanley, Belcher, Sullivan, JPO, 2010

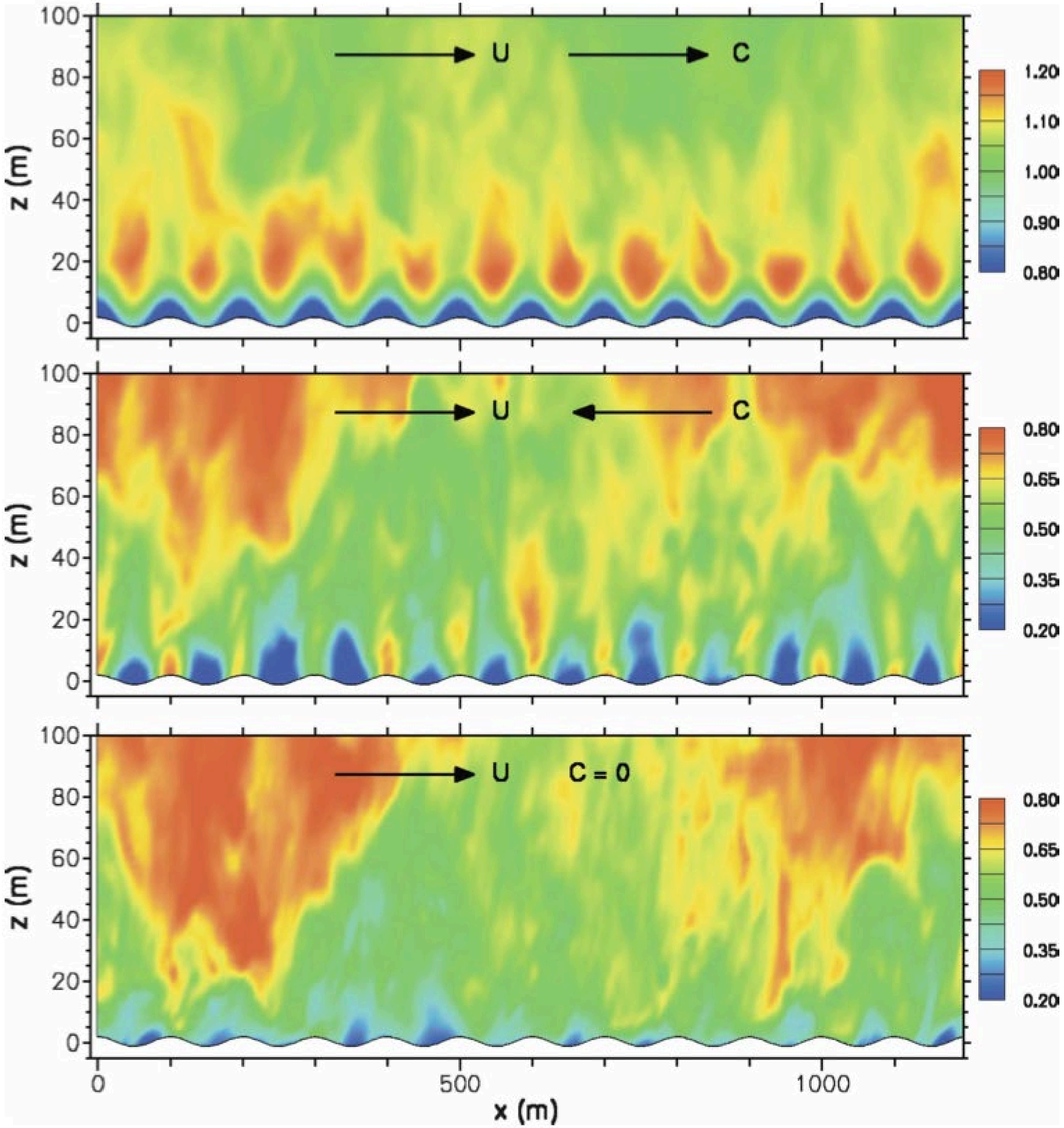


FIG. 5. Contours of the *u* component of the horizontal wind field for cases with moving and stationary surface waves. The nondimensional field shown is $\overline{u}/U_g$. (top) Wind following waves; (middle) wind opposing waves; and (bottom) stationary bumps. For each case the geostrophic wind $(U_g, V_g) = (5, 0)$ m s^{-1} and the wave slope $ak = 0.1$ where the wave amplitude $a = 1.6$ m. In the top and middle panels the wave phase speed $c = 12.5$ m s^{-1}. The color bar changes between the top and middle panels. Note the supergeostrophic winds near the surface in the top panel.

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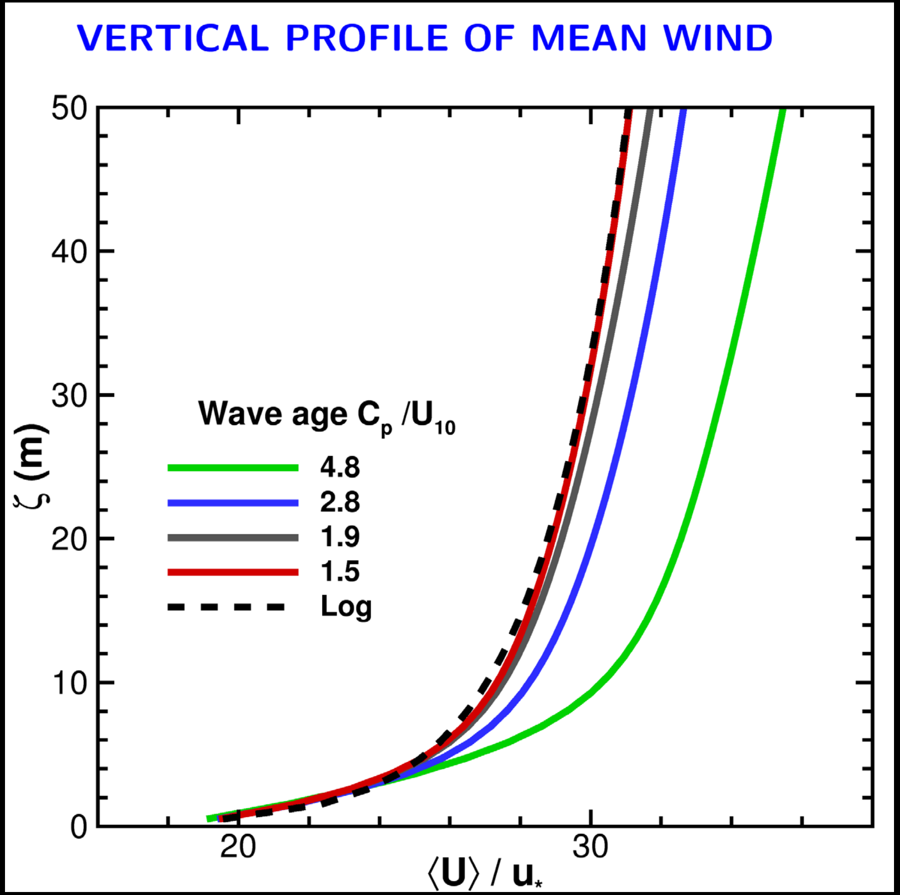
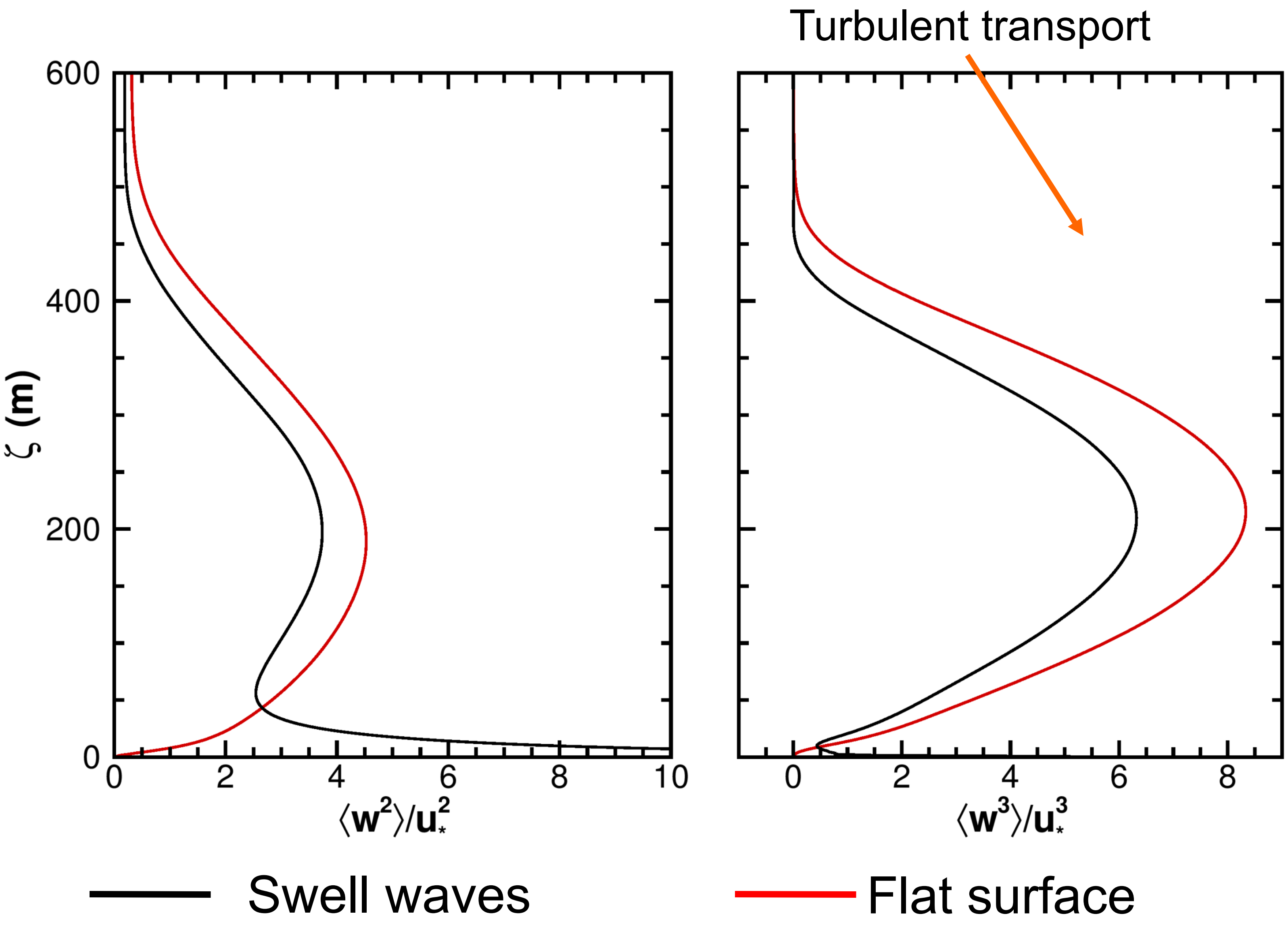


VERTICAL PROFILE OF MEAN WIND

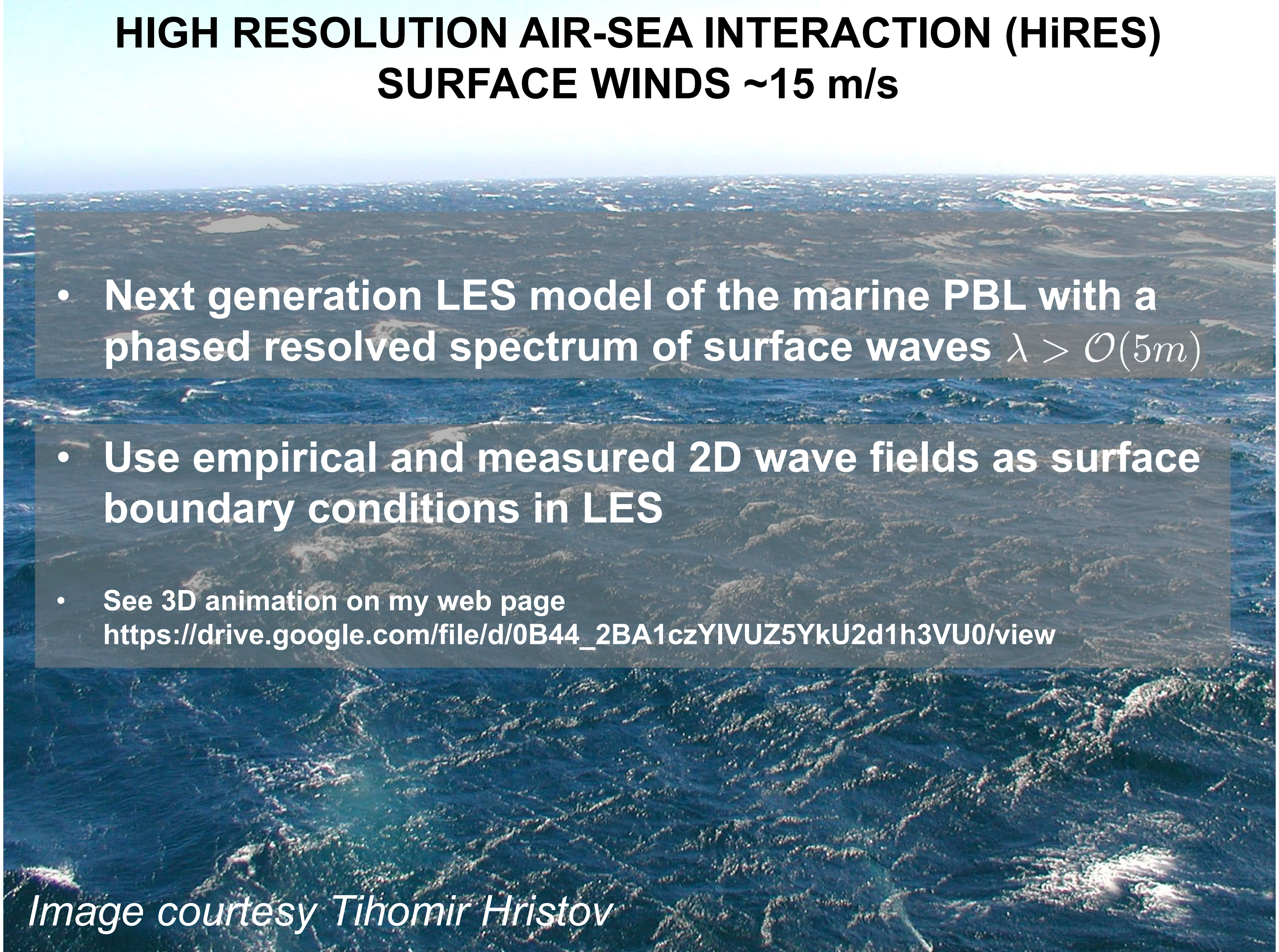
$$U_g = 10\, m/s \quad C_p/U_a = 2.3 \quad Q_* = 0.01\, K\, m/s$$

VERTICAL VELOCITY MOMENTS OVER 3D WAVES WITH SURFACE HEATING



Turbulent transport

HIGH RESOLUTION AIR-SEA INTERACTION (HiRES)
SURFACE WINDS ~15 m/s



- **Next generation LES model of the marine PBL with a phased resolved spectrum of surface waves** $\lambda > \mathcal{O}(5m)$
- **Use empirical and measured 2D wave fields as surface boundary conditions in LES**
- **See 3D animation on my web page https://drive.google.com/file/d/0B44_2BA1czYIVUZ5YkU2d1h3VU0/view**

Image courtesy Tihomir Hristov

(U,W) Vectors and Pressure over Active Breakers