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Improved wind dynamics for coastal forecasting

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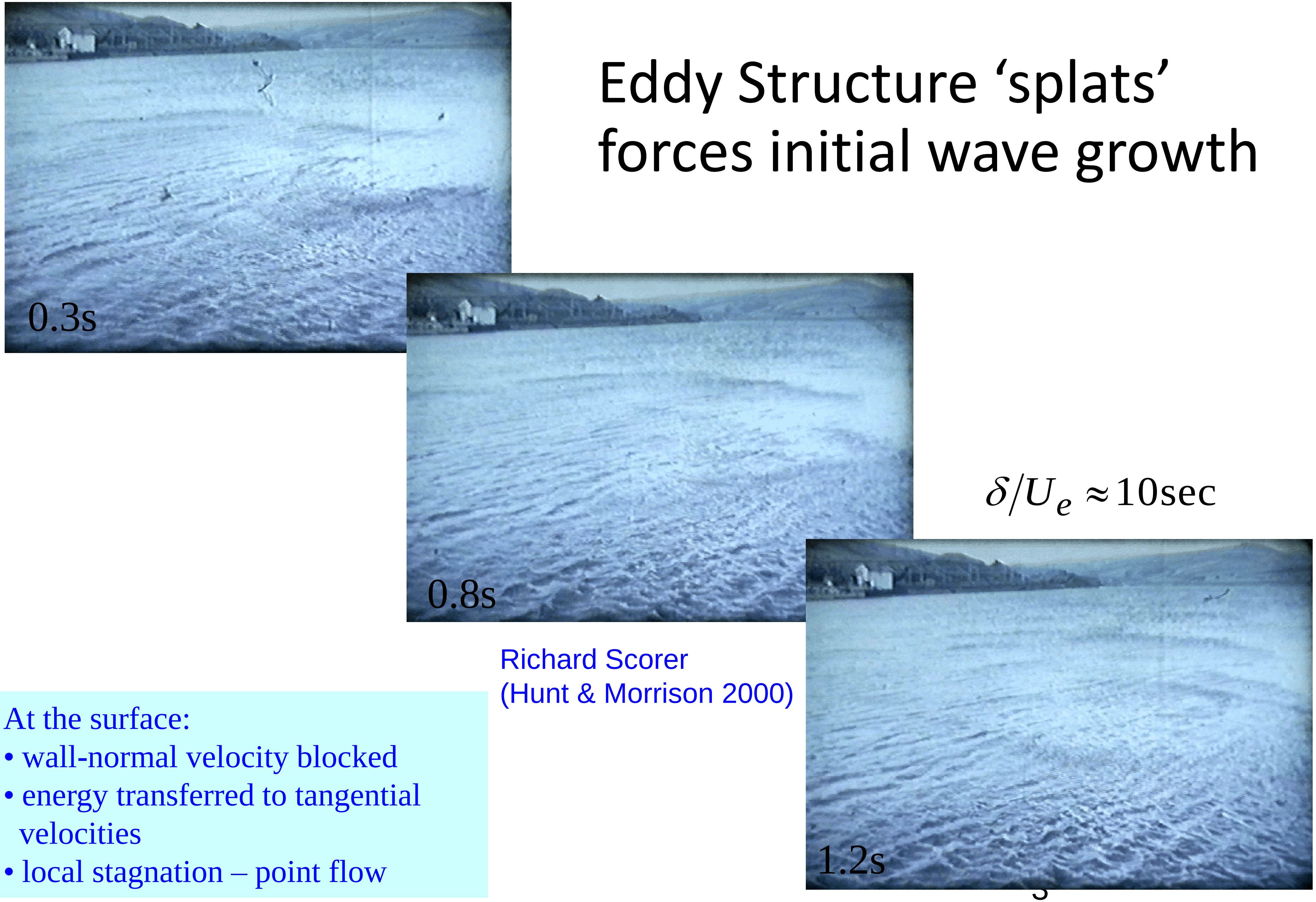
Recent developments in wind–wave modelling leading to significant results

•Low amplitude waves -Thin layer, quasi-steady/unsteady analyses of wind over waves with low slopes (H<<L),- turbulence in and above surface layer –large effects (‘cats eyes’) in critical thin layers

•Non-linear Waves and turbulence with moderate slopes ; models : LES_>URANS > Organized (Inhomogeneous; modal) Eddy Simulation

•Wave group dynamics and Complex Physics for turbulent breaking waves over rough surface, effects of spray/droplets
-> spectra and statistics

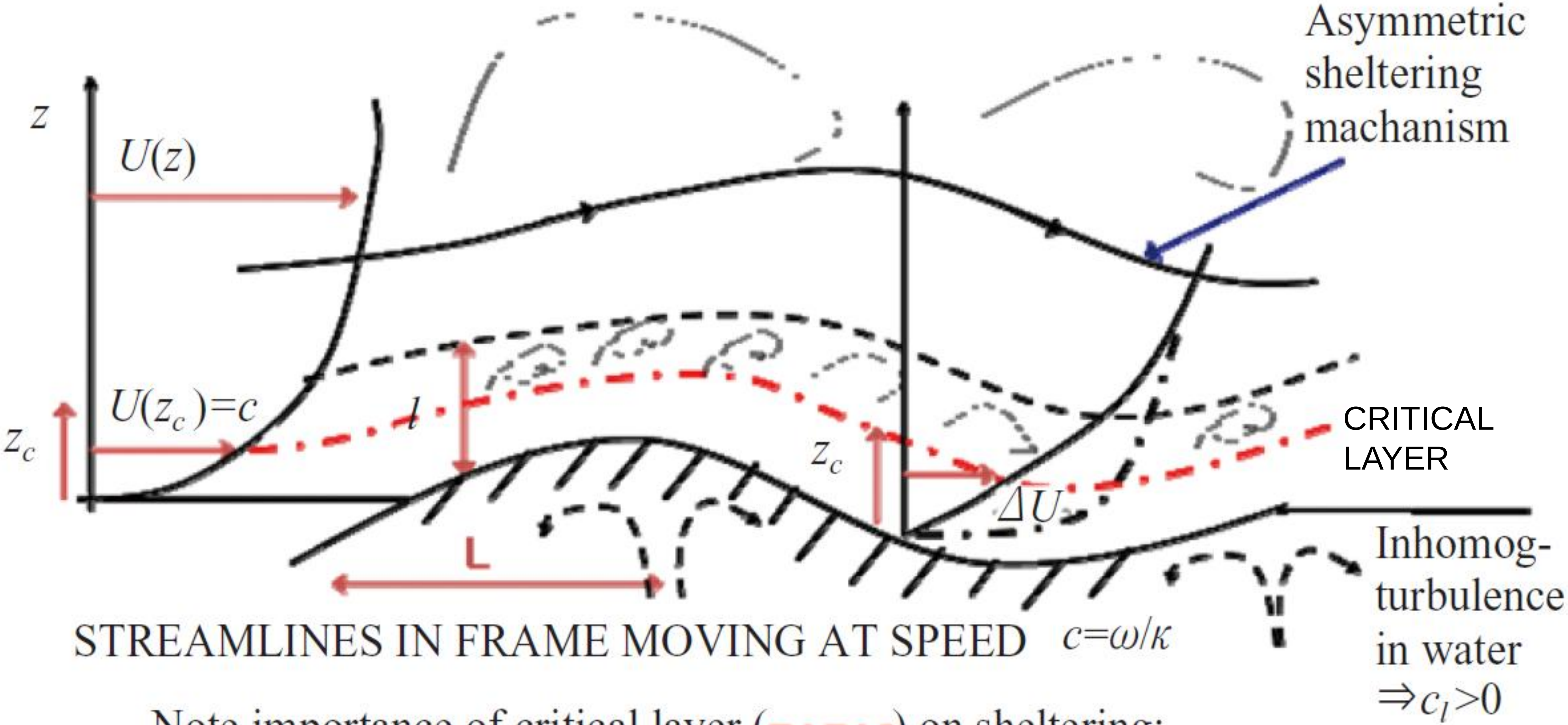
Eddy Structure ‘splats’ forces initial wave growth



$\delta/U_e \approx 10\text{sec}$

Richard Scorer
(Hunt & Morrison 2000)

At the surface:
- wall-normal velocity blocked
- energy transferred to tangential velocities
- local stagnation – point flow



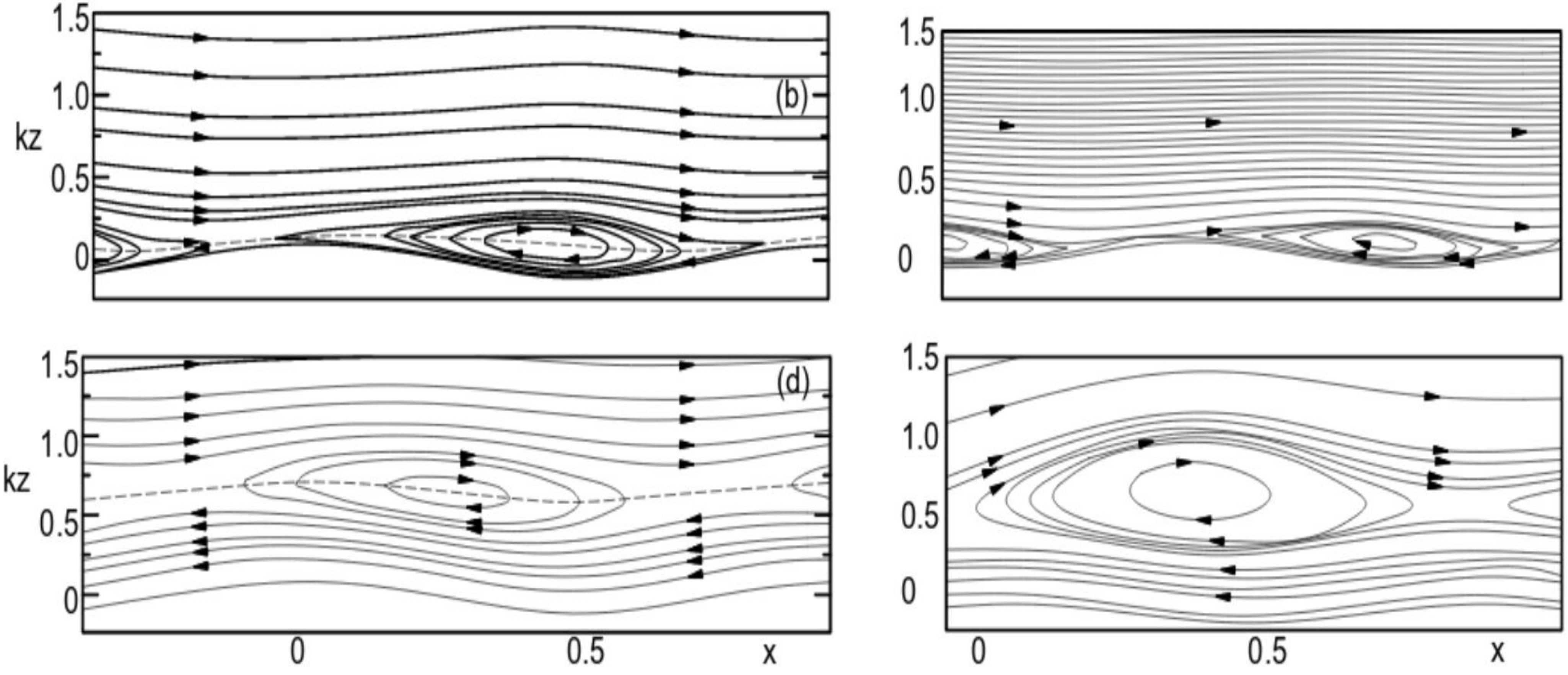
STREAMLINES IN FRAME MOVING AT SPEED $c=\omega/\kappa$

Note importance of critical layer (- · - · -) on sheltering;

→ wave growth as z_c/h Increases (<1); then decreases ($z_c/h > 1$)

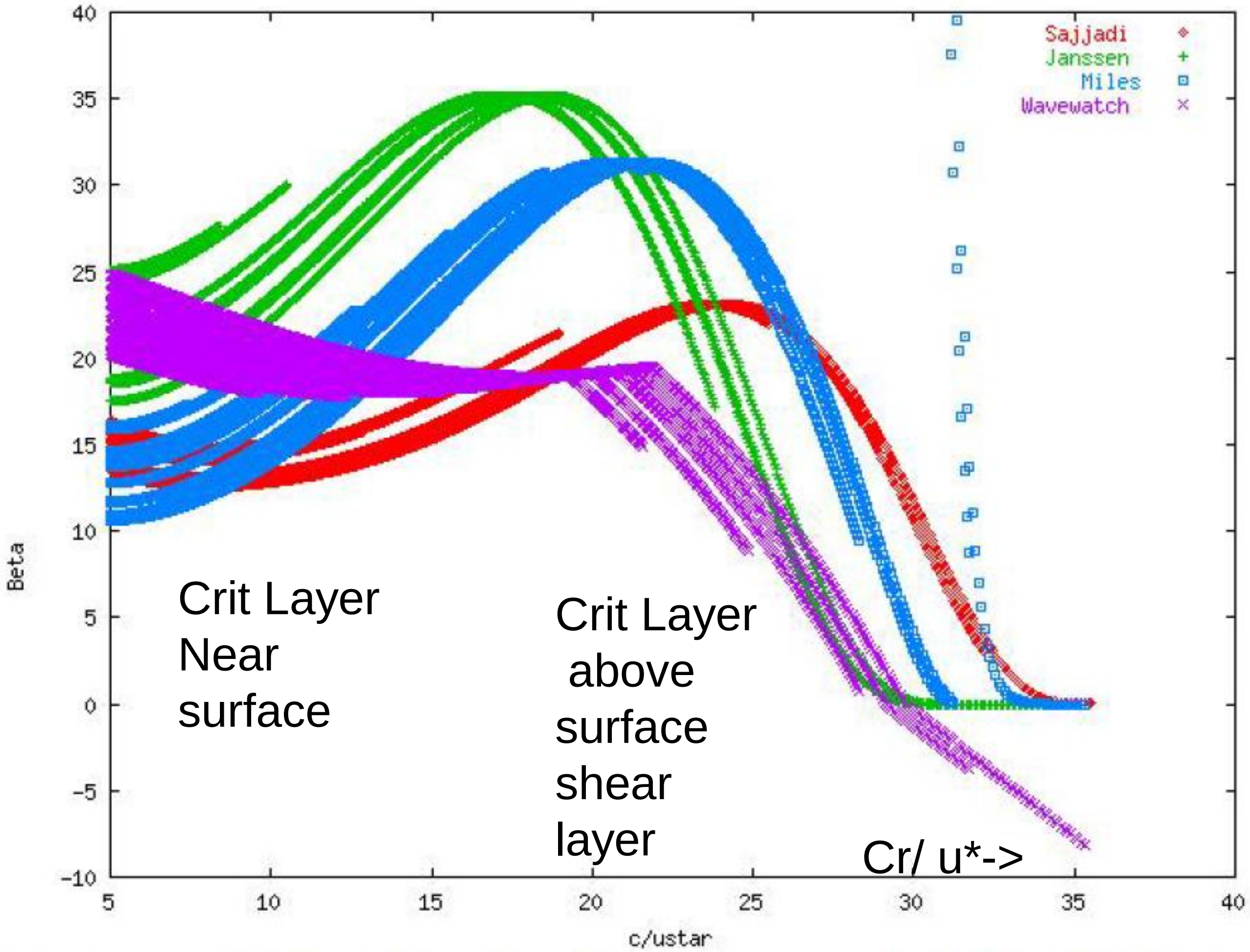
Sheltering leads to reduction in wind speed by ΔU

Numerical simulation of the mean velocity profile of turbulent wind driven, low slope -shallow waves, demonstrating the significance of critical layers near and above surface shear layer , depends on cr/u*



Energy transfer rate (Beta) vs. wave speed cr/u* with ci > 0 fo different wavelengths-significant differences

Beta
-growth rate



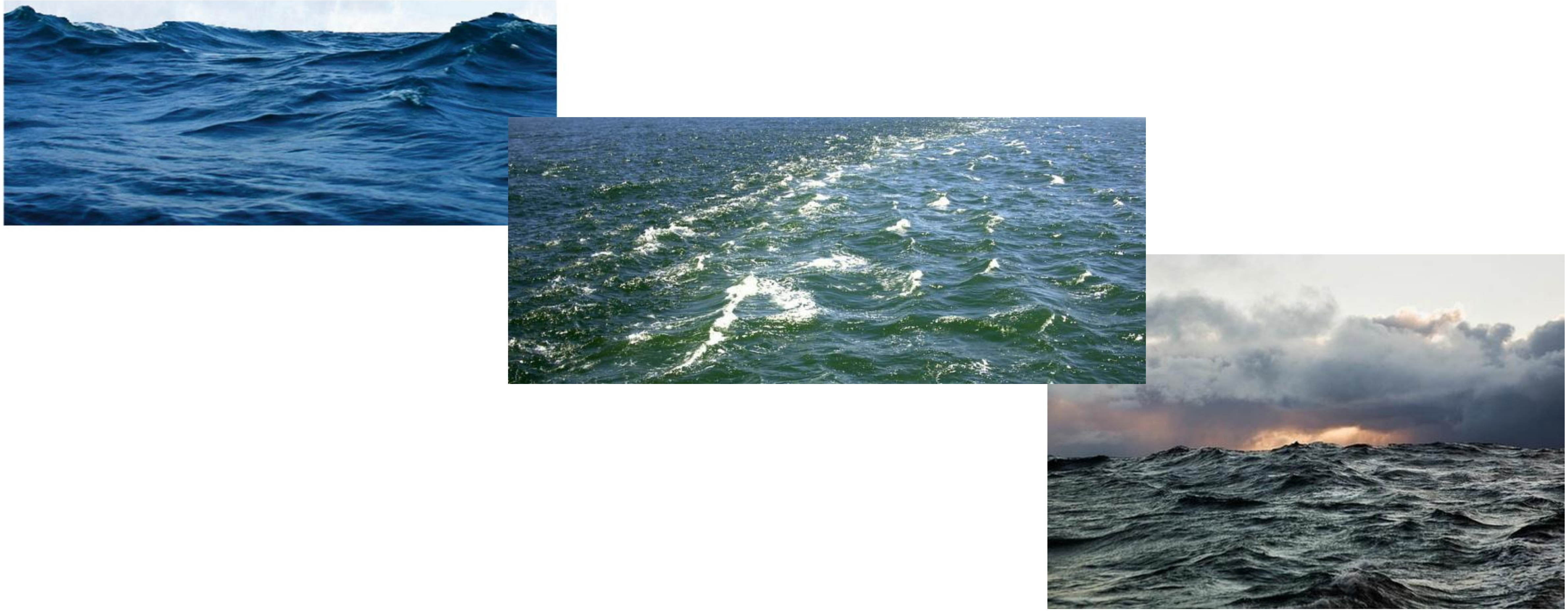
Crit Layer
Near
surface

Crit Layer
 above
surface
shear
layer

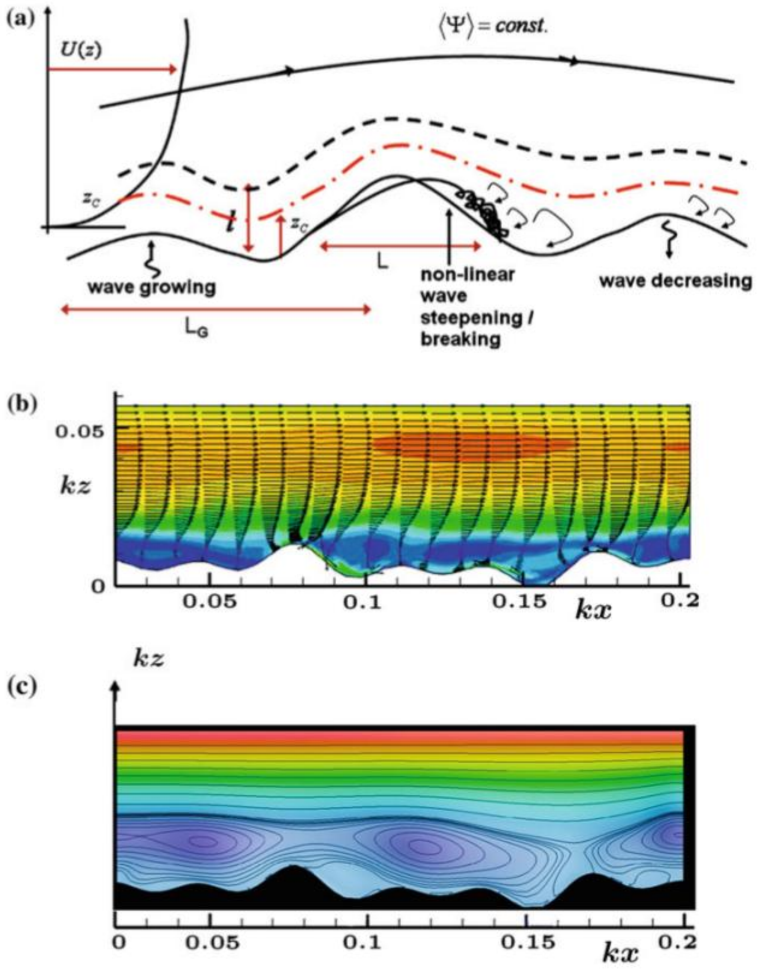
Cr/ u*->

Figure 4. Solutions of β from Miles (blue, [1]), Janssen (green, [3]), WAVEWATCH (purple, [5]) and Equation 1 (red, [4]) for a 10 ms $^{-1}$ wind and peak phase speeds ranging from 2-12 ms $^{-1}$

Wind over wave group (SHD 2014, see Ayati et al 2014)

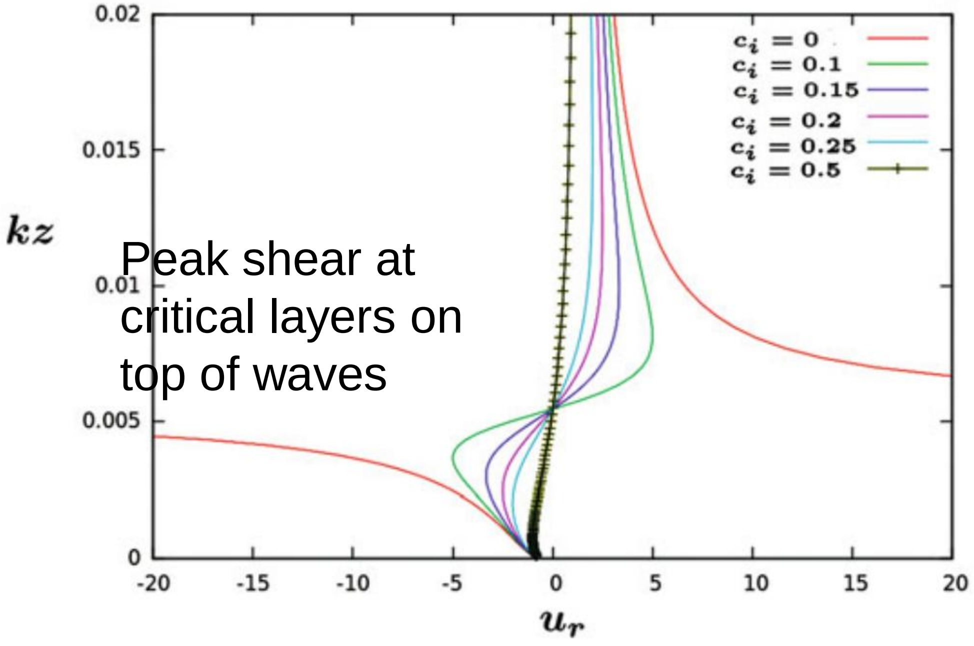


Wind flow over WAVE GROUPS to show additional drag effects of asymmetric critical layer and separation, ci=0 (non growing waves)

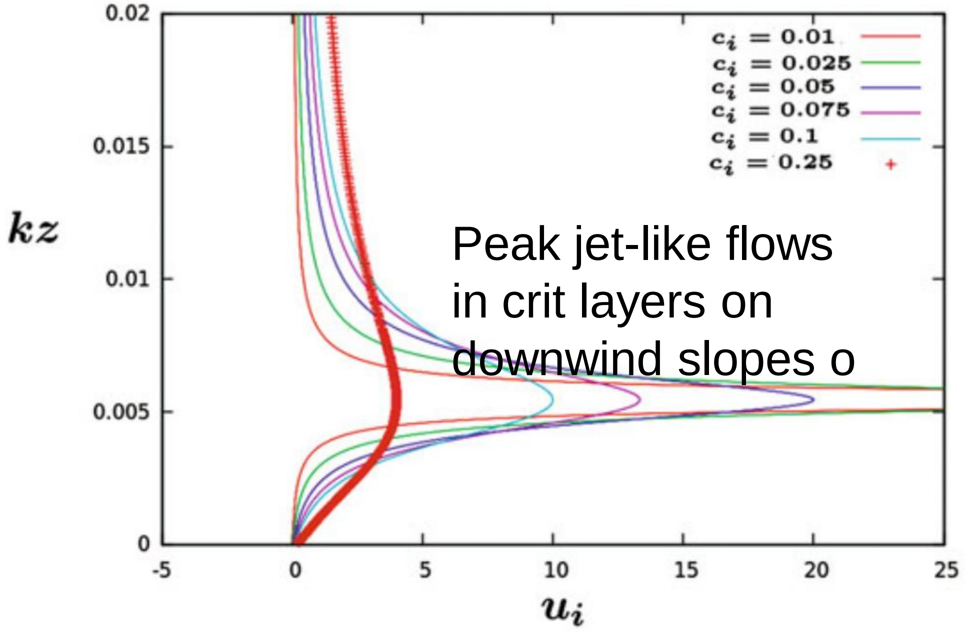


Inviscid monochromatic unsteady wave growth– Integral analysis (M;L); layer analysis (BHC,SHD)

- Vertical profiles of the in-phase and out of phase components of the GROWING horizontal velocity perturbations ur, ui , as a function of c i /u* , showing the singularity as ci /u* -> 0.



Peak shear at critical layers on top of waves



Peak jet-like flows in crit layers on downwind slopes o

Cat’s Eye Structures with new algorithm for z0 and drag -steady sinusoidal waves

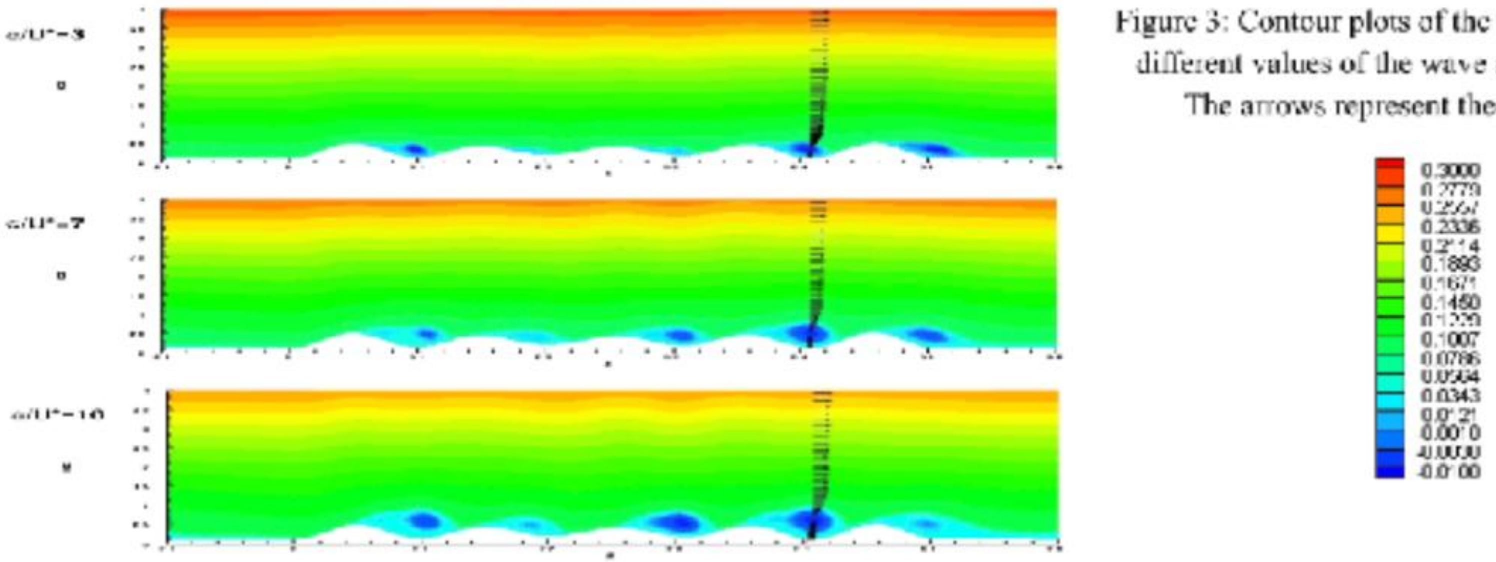


Figure 3: Contour plots of the stream function for different values of the wave age for the group. The arrows represent the velocity field

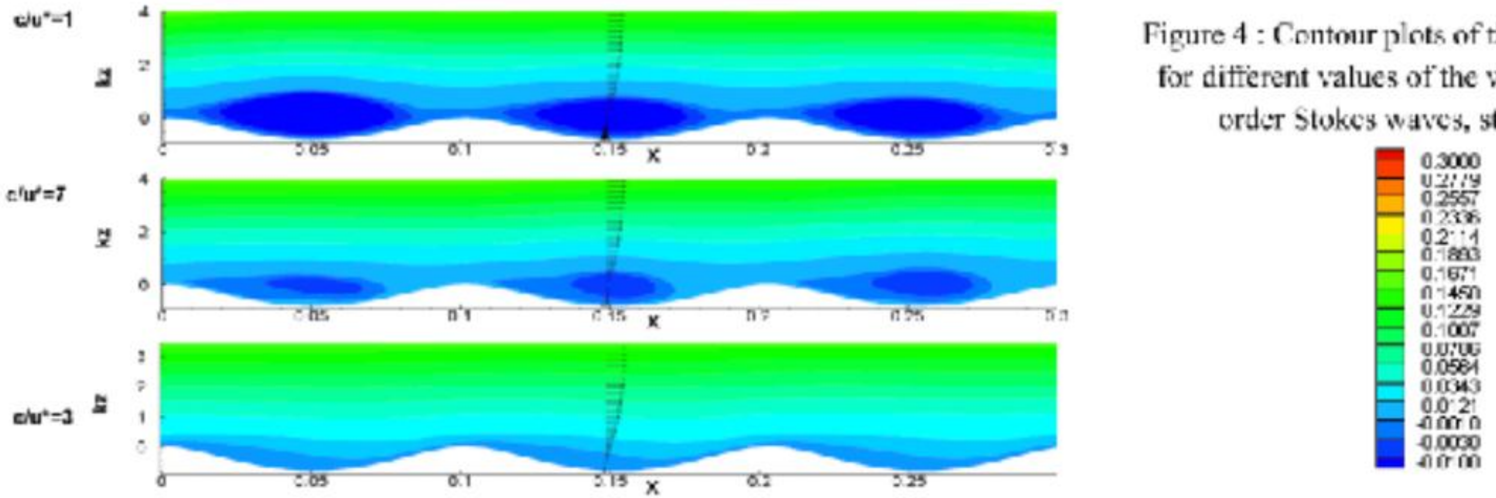
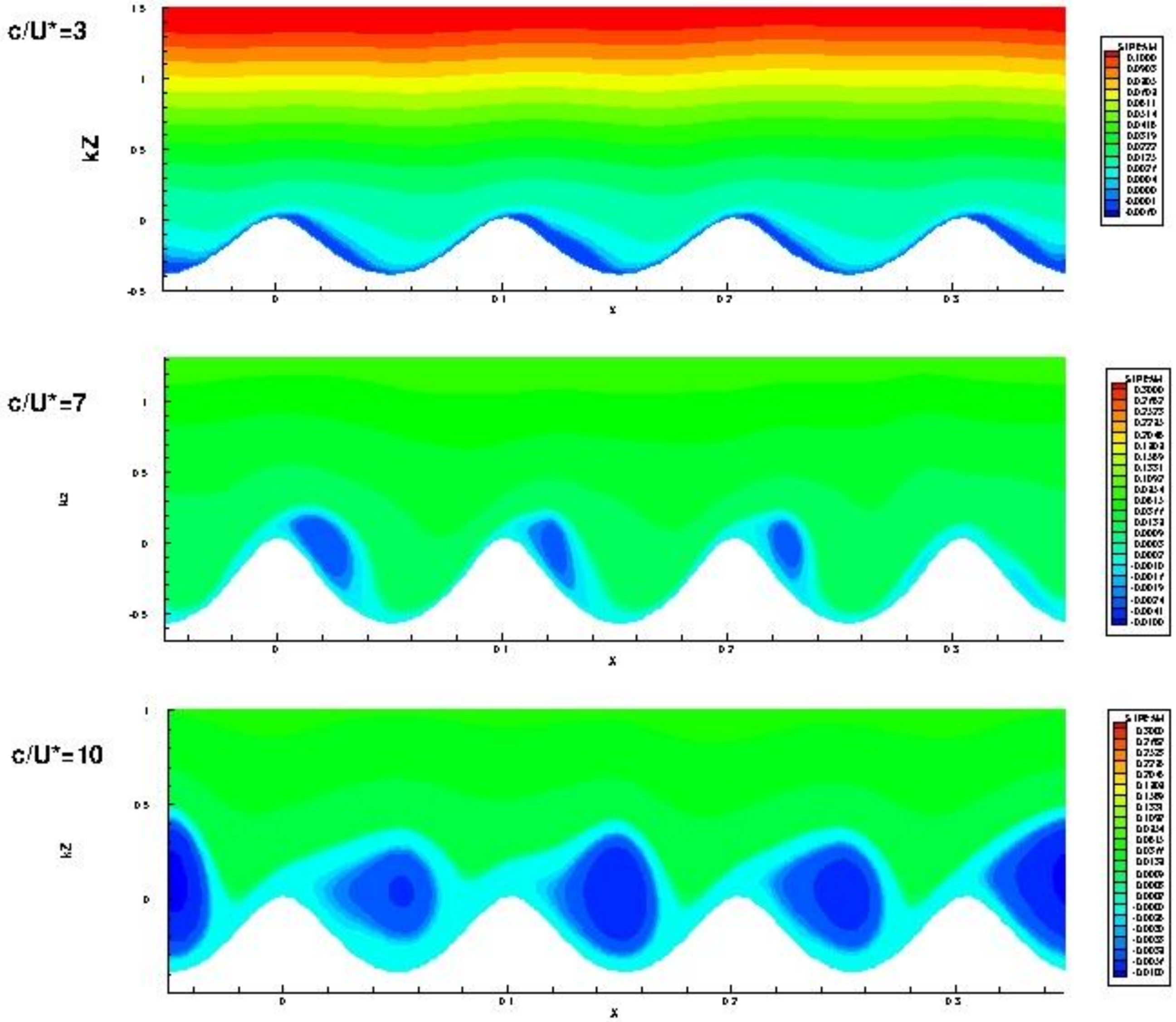


Figure 4 : Contour plots of the stream function for different values of the wave age for third order Stokes waves, steepness=0.3

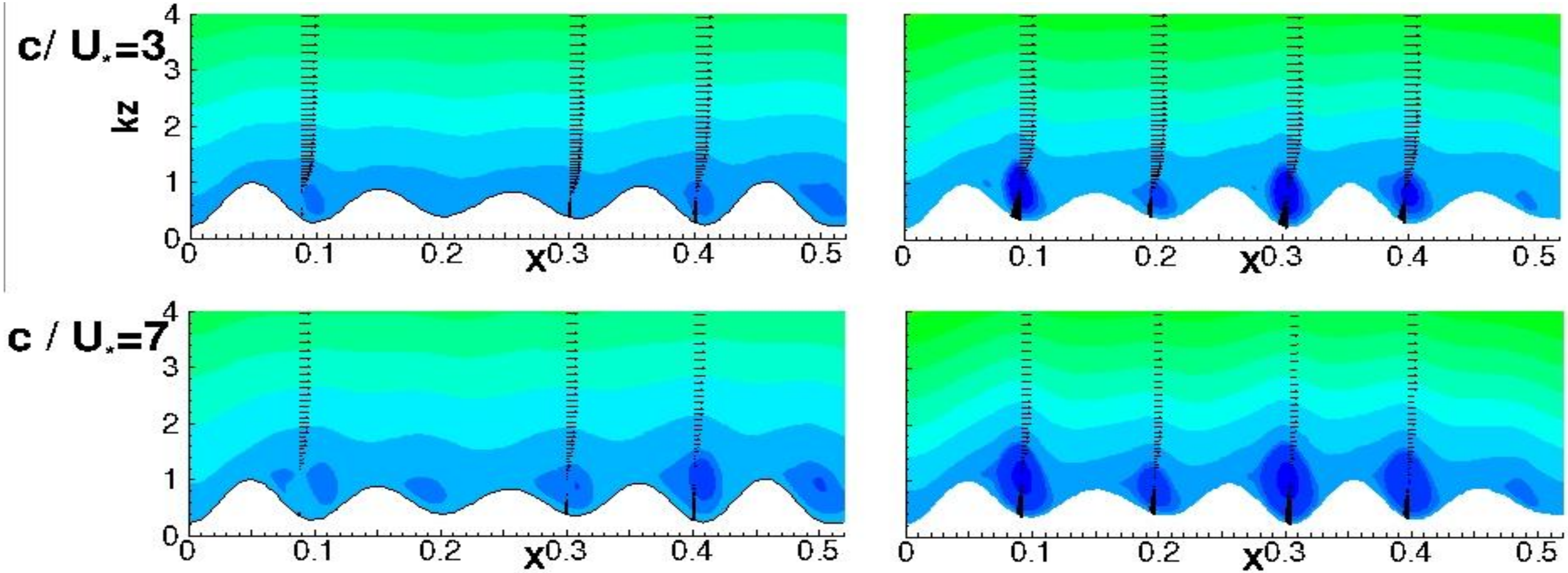
For both profiles, as the wave age increases, the cat-eye structures appear and grow. The largest ones eventually move over the peaks of the waves. As observed in our previous study [3], the wave-age does have an influence on the size and position of the cat's-eye structures and so on the position of the critical layer as expected.

Cat’s Eye Structures for Growing Waves



Cat’s Eye Structures with new algorithm for z0 and drag

Cat’s Eye Structures for Wave Groups
z0 with new algorithm (left), z0 with fixed value (right)

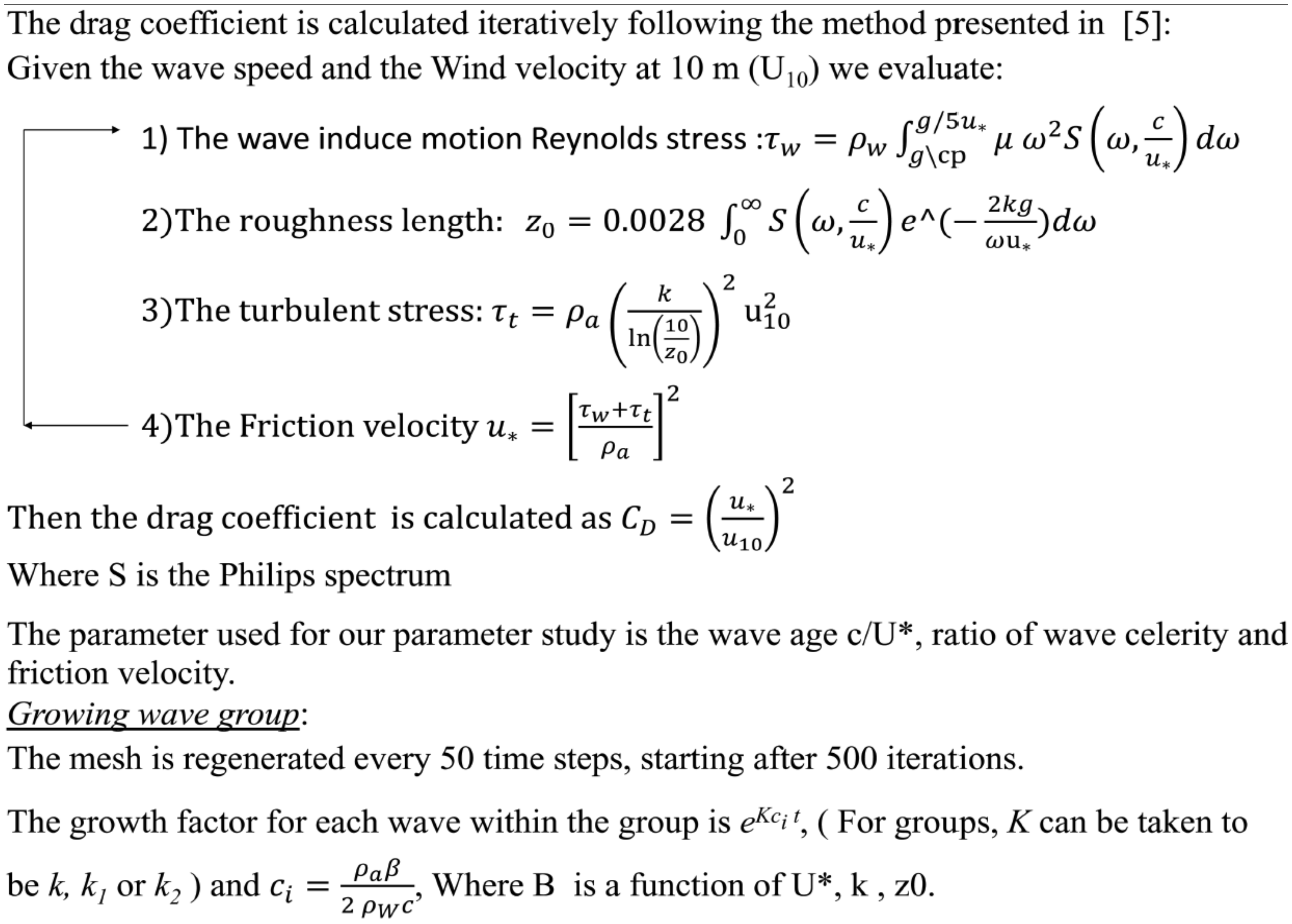


Zo with new algorithm

Zo with fixed value

Note new research -> better estimates of energy into waves.

Calculating roughness Zo and Drag over waves



The drag coefficient is calculated iteratively following the method presented in [5]:
Given the wave speed and the Wind velocity at 10 m (U_{10}) we evaluate:

1) The wave induce motion Reynolds stress :$\tau_W = \rho_W \int_{g\backslash \mathrm{cp}}^{g/5u_*} \mu\, \omega^2 S\left(\omega, \frac{c}{u_*}\right) d\omega$

2)The roughness length: $z_0 = 0.0028 \int_0^\infty S\left(\omega, \frac{c}{u_*}\right) e^\wedge(-\frac{2kg}{\omega \mathrm{u}_*}) d\omega$

3)The turbulent stress: $\tau_t = \rho_a \left(\frac{k}{\ln\left(\frac{10}{z_0}\right)}\right)^2 \mathrm{u}_{10}^2$

4)The Friction velocity $u_* = \left[\frac{\tau_W + \tau_t}{\rho_a}\right]^2$

Then the drag coefficient is calculated as $C_D = \left(\frac{u_*}{u_{10}}\right)^2$

Where S is the Philips spectrum

The parameter used for our parameter study is the wave age c/U*, ratio of wave celerity and friction velocity.

Growing wave group:

The mesh is regenerated every 50 time steps, starting after 500 iterations.

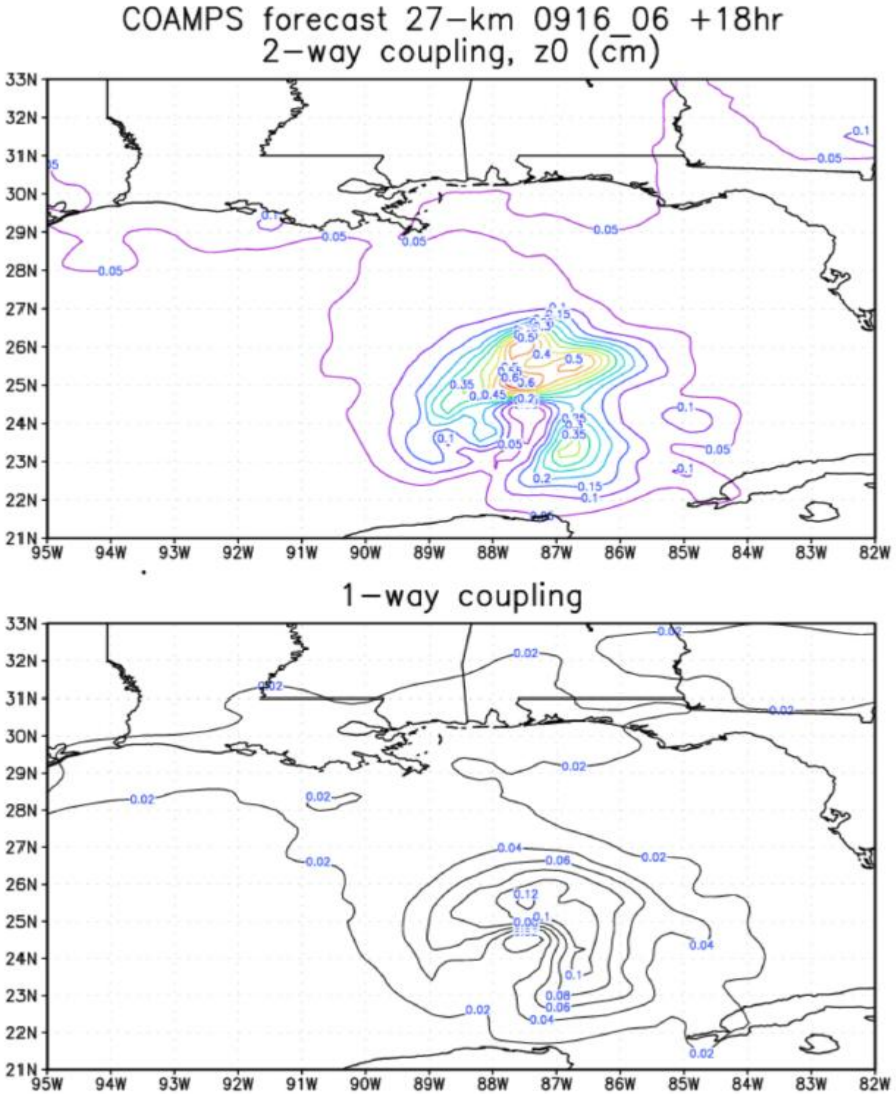
The growth factor for each wave within the group is $e^{Kc_i t}$, (For groups, *K* can be taken to be *k*, k_1 or k_2) and $c_i = \frac{\rho_a \beta}{2\, \rho_W c}$, Where B is a function of U*, k , z0.

Application to Hurricane (Gordon 2000)

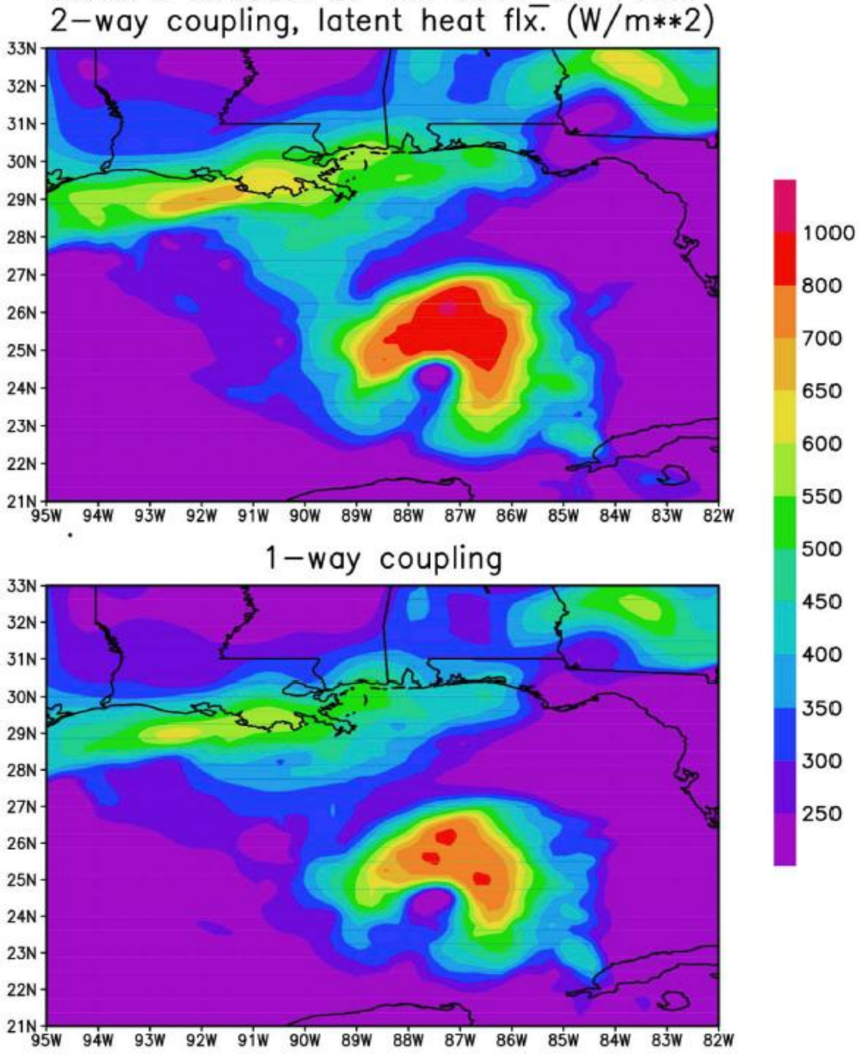
Accurate Drag and z0 leads better forecast (intensity and path)

Eg: 2 way coupling (Z0 from new scheme) vs. 1-way coupling Z0 (empirical)

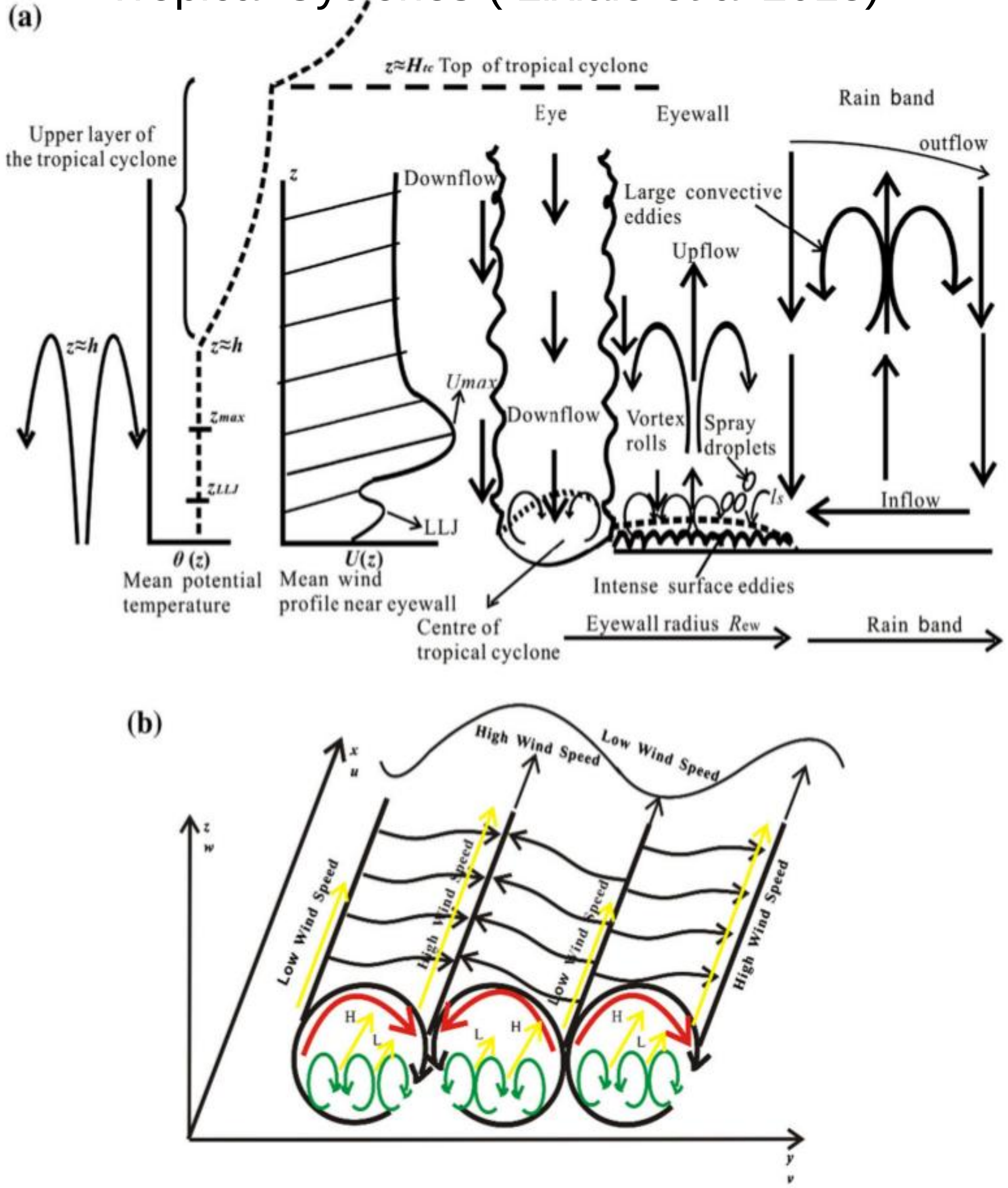
Roughness zo



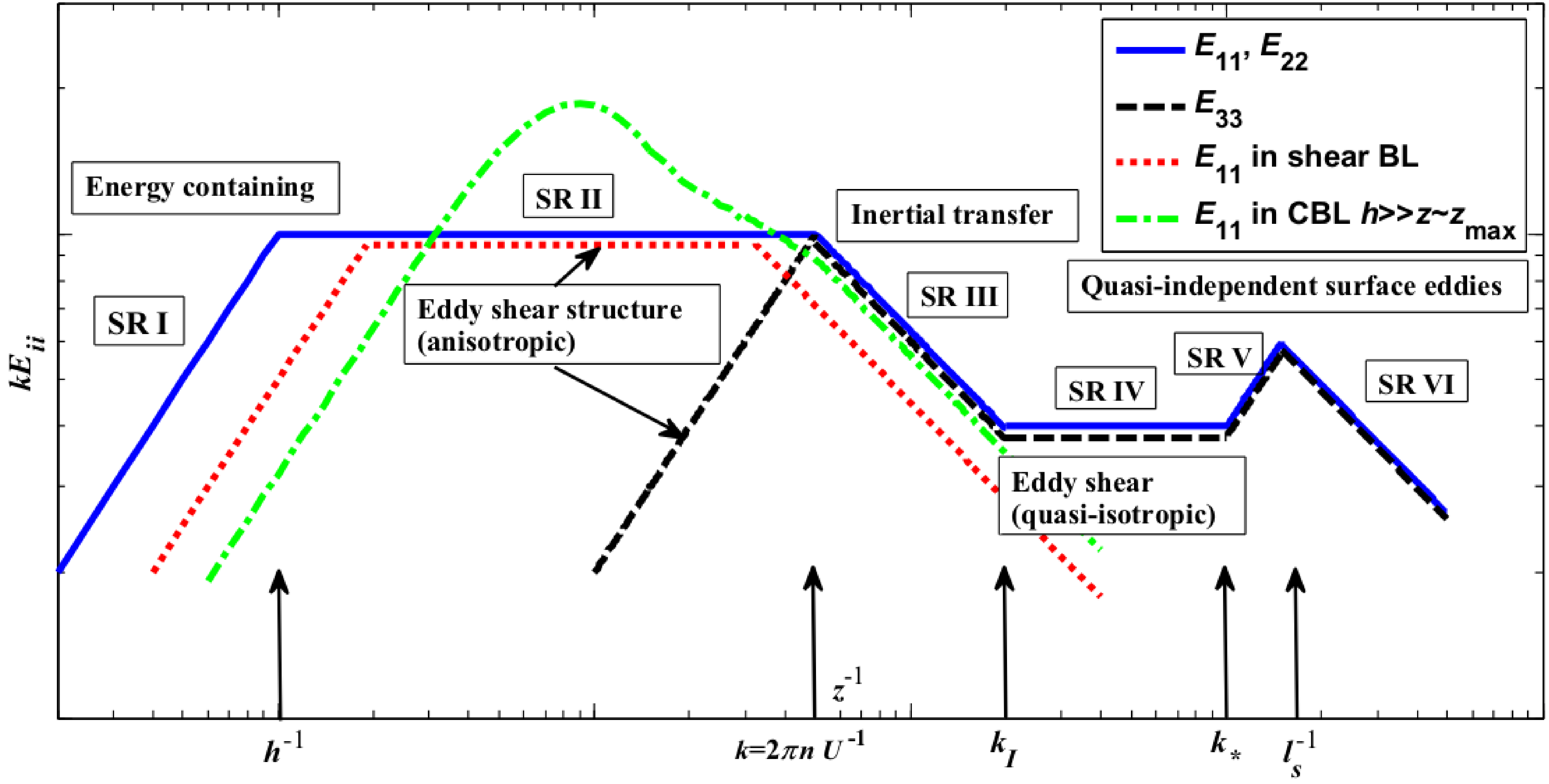
Latent heat flux



Turbulence and 2-phase structure near centre of Tropical Cyclones (Lixiaio et al 2015)



Turbulence wind spectra near surface in Tropical Cyclones - measurements by Lixao, Kareem ,JH…(BLM 2015)Note large scale shear/convection; small scale energy from spray /wave processes



Prospects and communication of wave research and practical applications

*Research in new theory, modelling, computational methods, and new experimental measurement/facilities for different wave-types

*Applications for improved operational forecasting for atmosphere/ocean/engineering waves and flows

*Note models should incorporate characteristic features and singularities (eg TC s) in these wave-turbulence-multiphase –thermodynamic systems.

End