Surface wave processes in air-sea interaction

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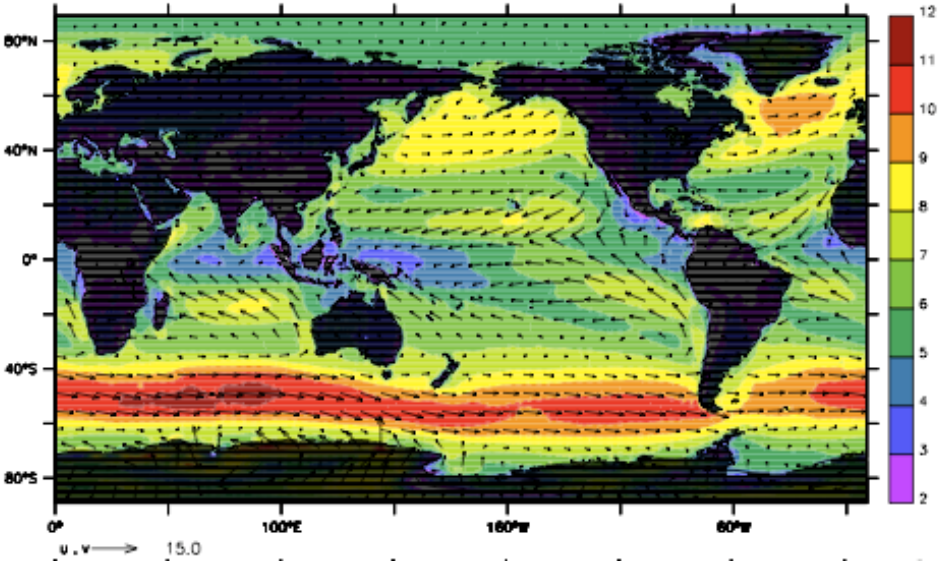
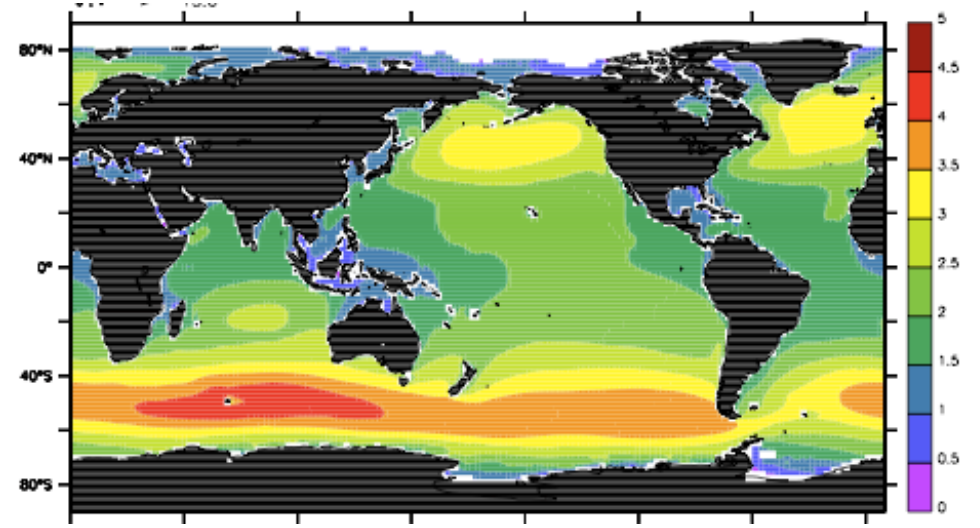
Introduction

- Wave processes in the ABL
- Wave processes and ocean current profile
- Wave processes and ocean mixing
- A global perspective

Global perspective: ERA-40



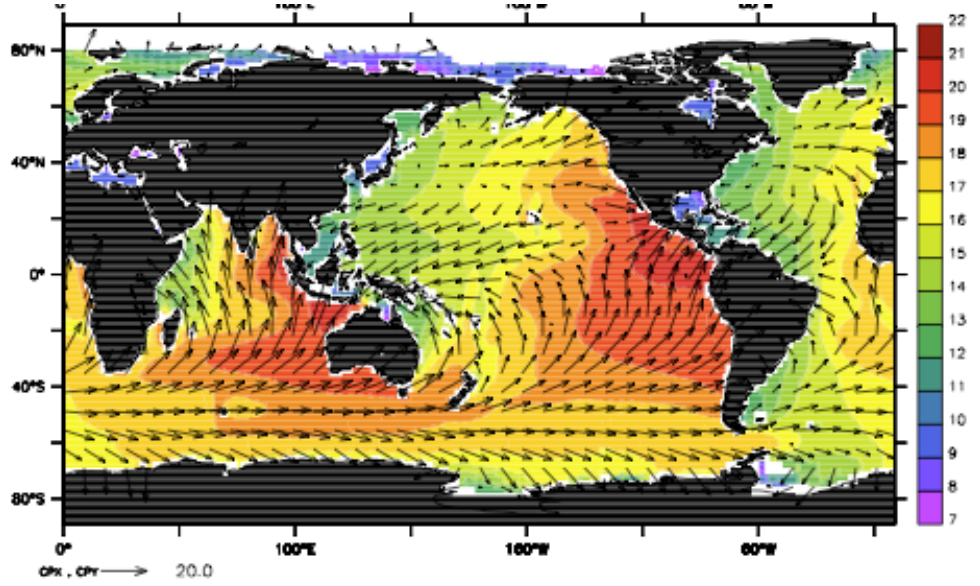


40 year climates of:

10m winds (ms^{-1})

Significant wave height (m)

Peak phase speed (ms^{-1})



Waves and the ABL

Wind driven waves

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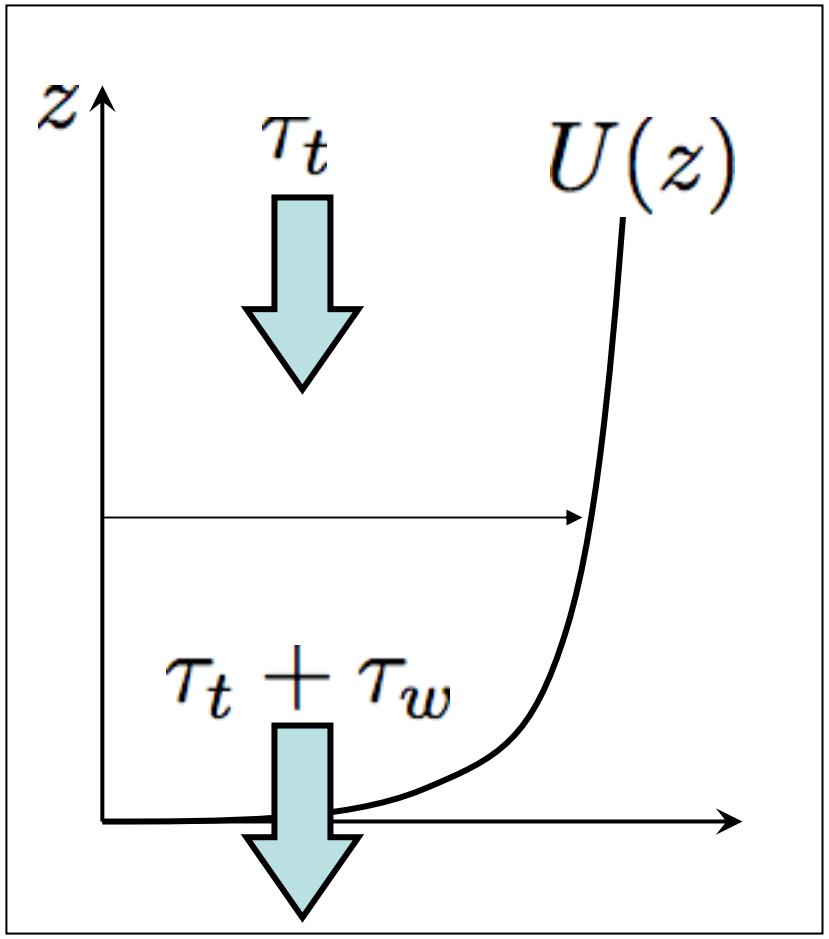
Wave driven winds

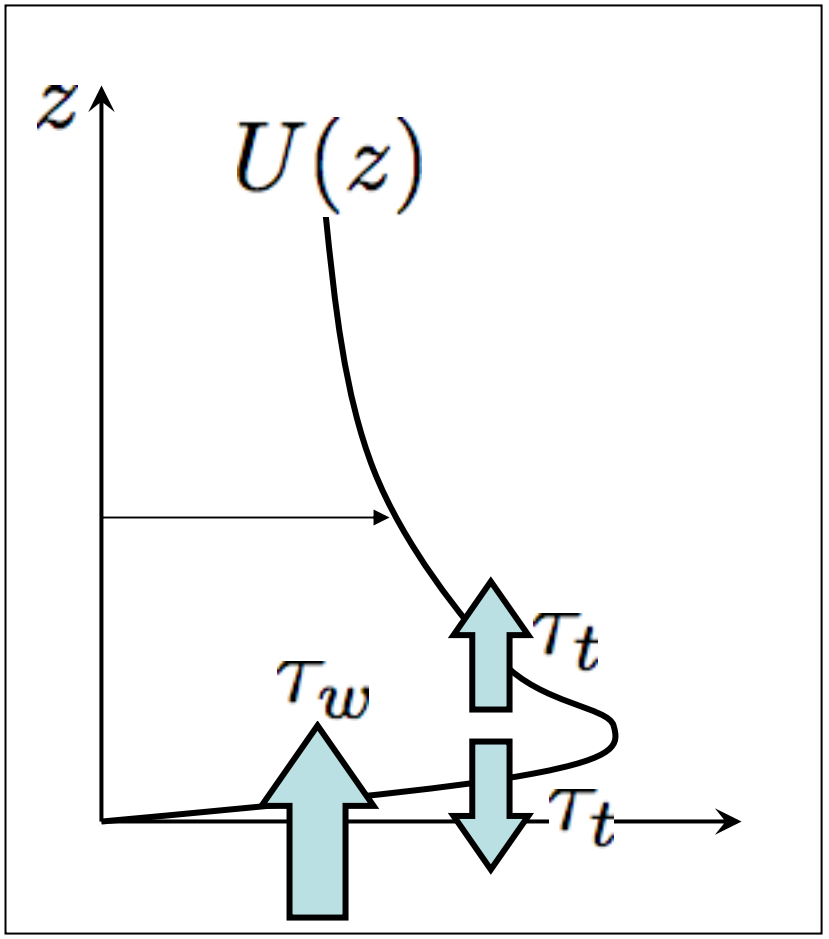
Wind wave regimes

Strong winds over slow waves



Wind driven waves

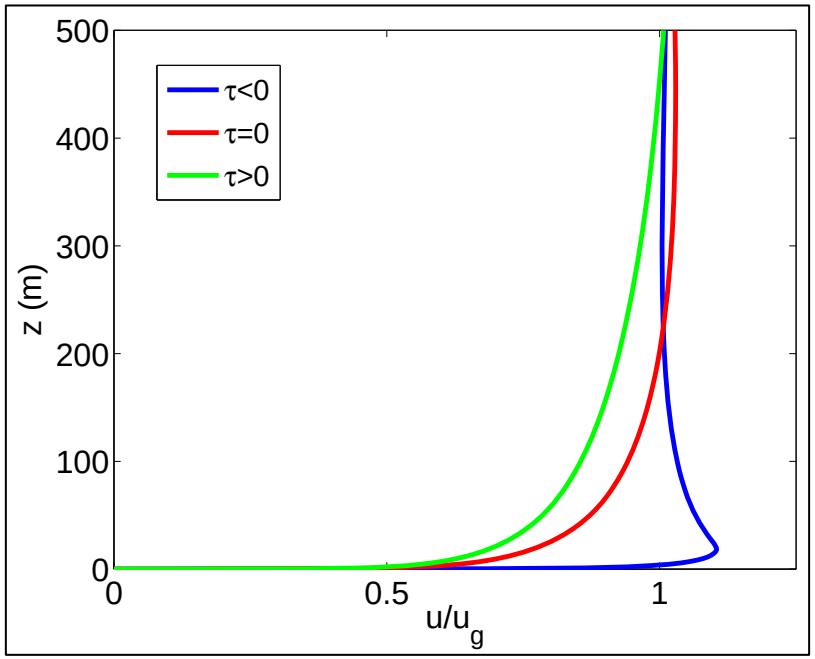
Weak winds over fast waves

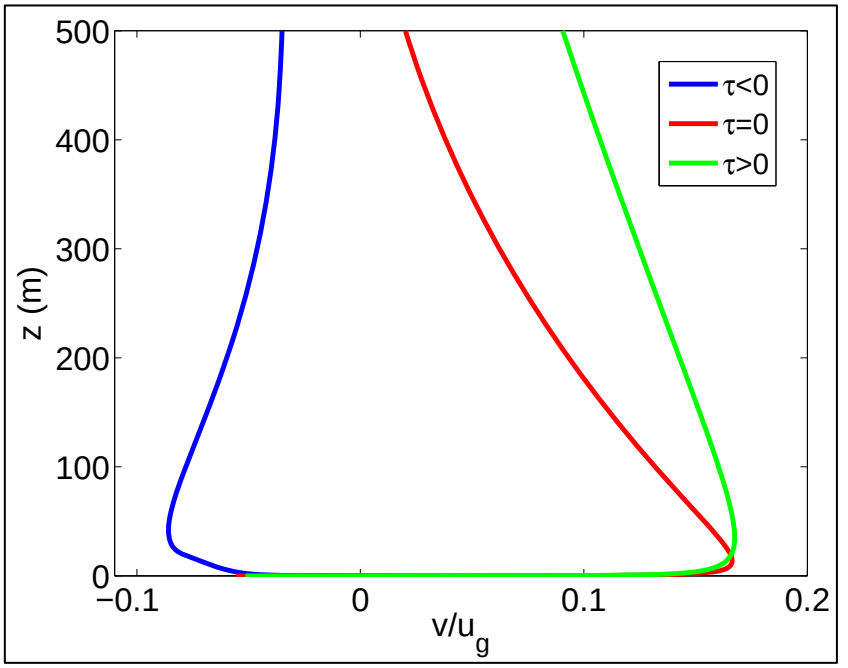


Wave driven winds

Belcher & Hunt 1998; Sullivan et al 2008; Hanley & Belcher 2008

Boundary layer structure



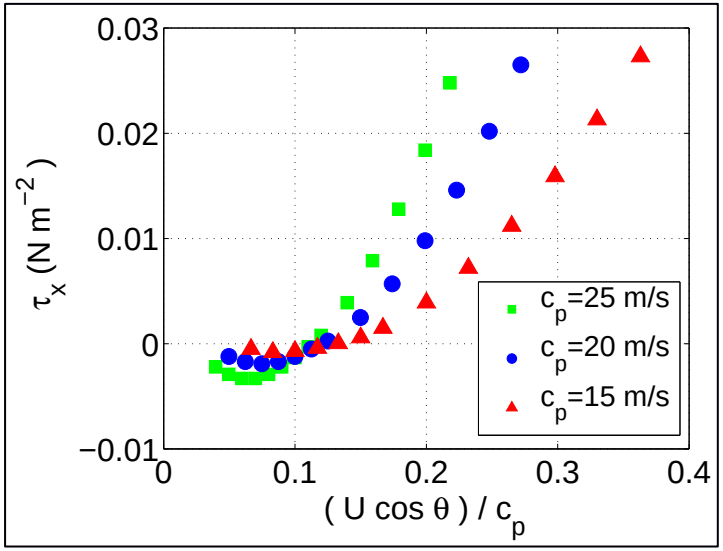


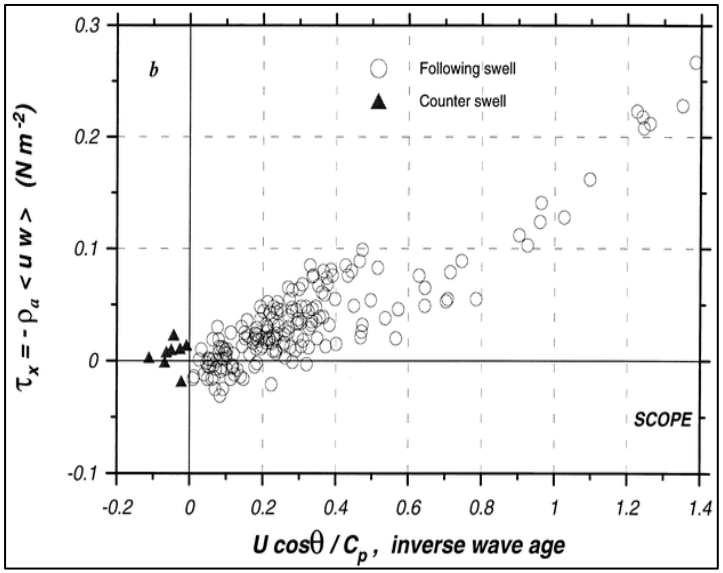
Simple 1d model with wave-induced stress shows:

- Waves change wind profile over entire boundary layer
- When $\tau_w < 0$:
  - a wave-driven jet is observed at z ~ 15 m.
  - the wind turns in the opposite direction to the Ekman case.

Smedman et al 1999; Edson et al 2007; Sullivan et al 2008; Hanley & Belcher 2008

Air-sea momentum flux





Total stress against inverse wave age, $U\cos\theta/c_p$

- Momentum flux reverses sign at an inverse wave age between 0 - 0.2
- Simple way to characterise the sign of τ
- This is in agreement with observations reported off the S. California coast by Grachev and Fairall (JPO, 2001).

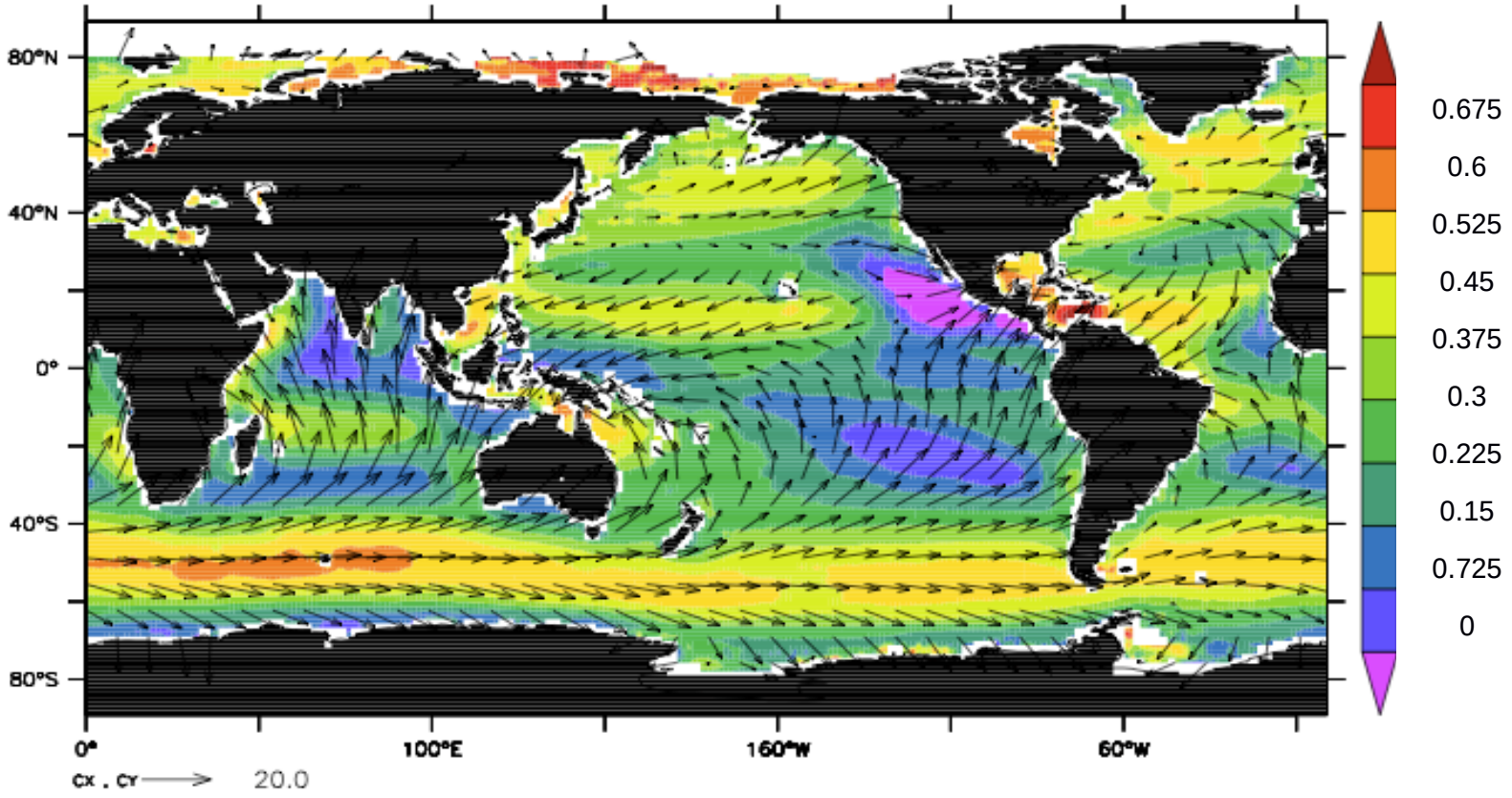
Global perspective: ERA-40

- $U\cos\theta/c_p > 0.8$ wind-driven wave
- $U\cos\theta/c_p < 0.15$ wave-driven wind

ERA-40 climatology of inverse wave age

$U\cos\theta/c_p$

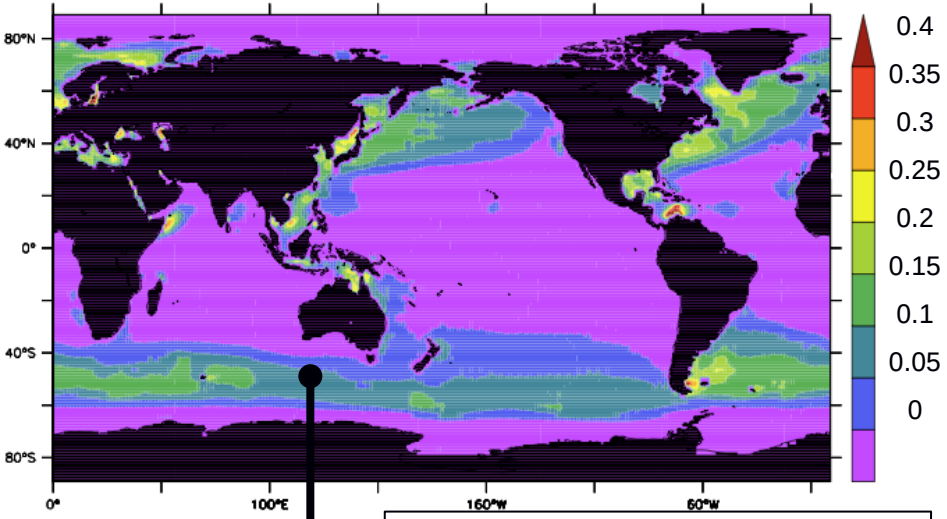
1958 to 2001

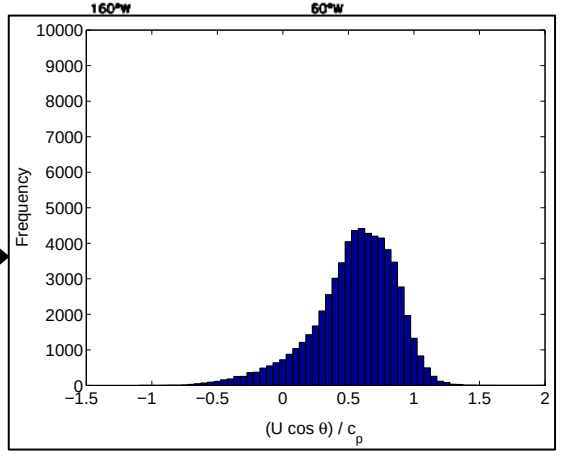


Source and sink regions

Frequency of occurrence of wind-driven waves averaged over 1958 to 2001.

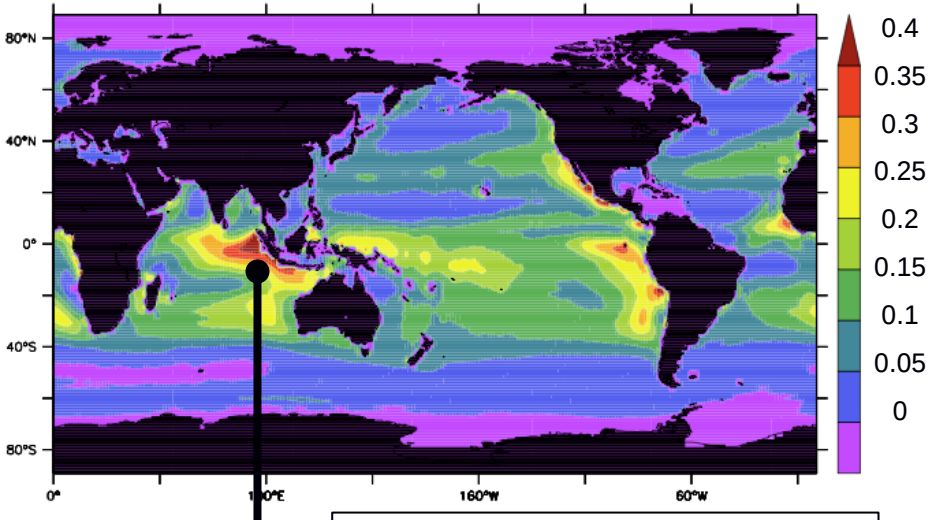
$U \cos\theta / c_p > 0.8$

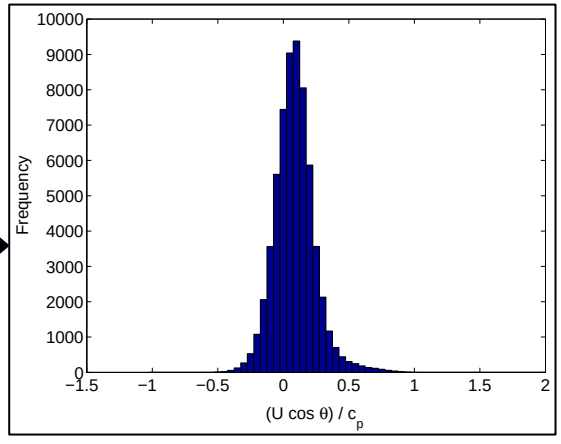




Frequency of occurrence of wave-driven winds averaged over 1958 to 2001.

$U \cos\theta / c_p < 0.15$





Waves and ocean mixed layer

Coriolis-Stokes forcing

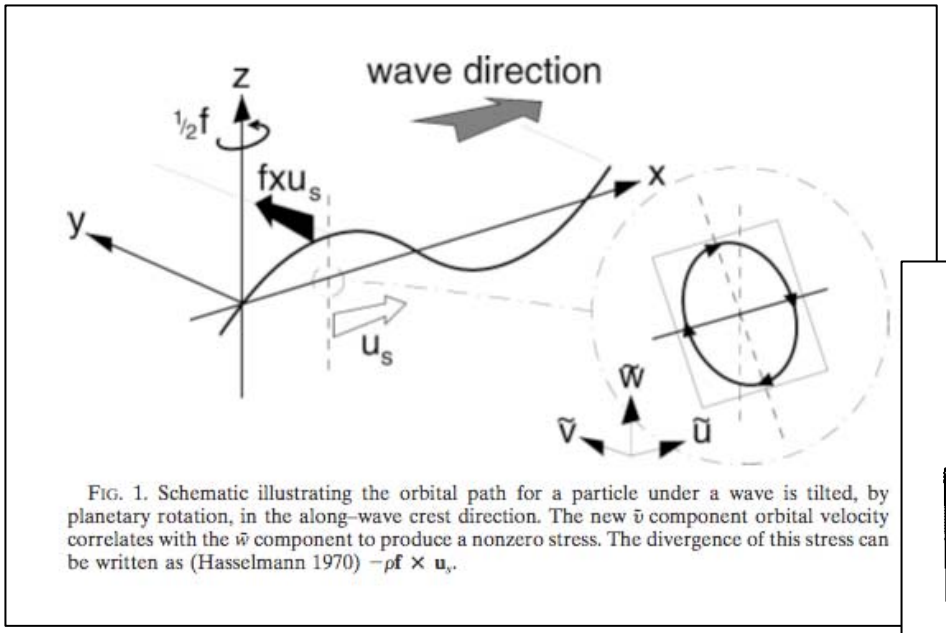
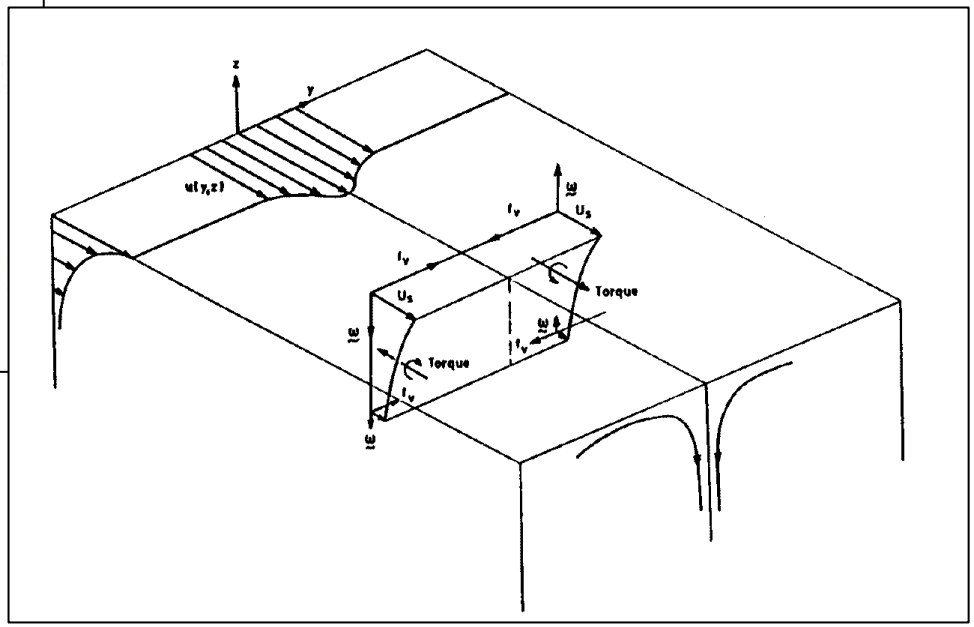


FIG. 1. Schematic illustrating the orbital path for a particle under a wave is tilted, by planetary rotation, in the along–wave crest direction. The new $\tilde{v}$ component orbital velocity correlates with the $\tilde{w}$ component to produce a nonzero stress. The divergence of this stress can be written as (Hasselmann 1970) $-\rho \mathbf{f} \times \mathbf{u}_s$.



Large Eddy Simulation of Craik-Leibovich equations:

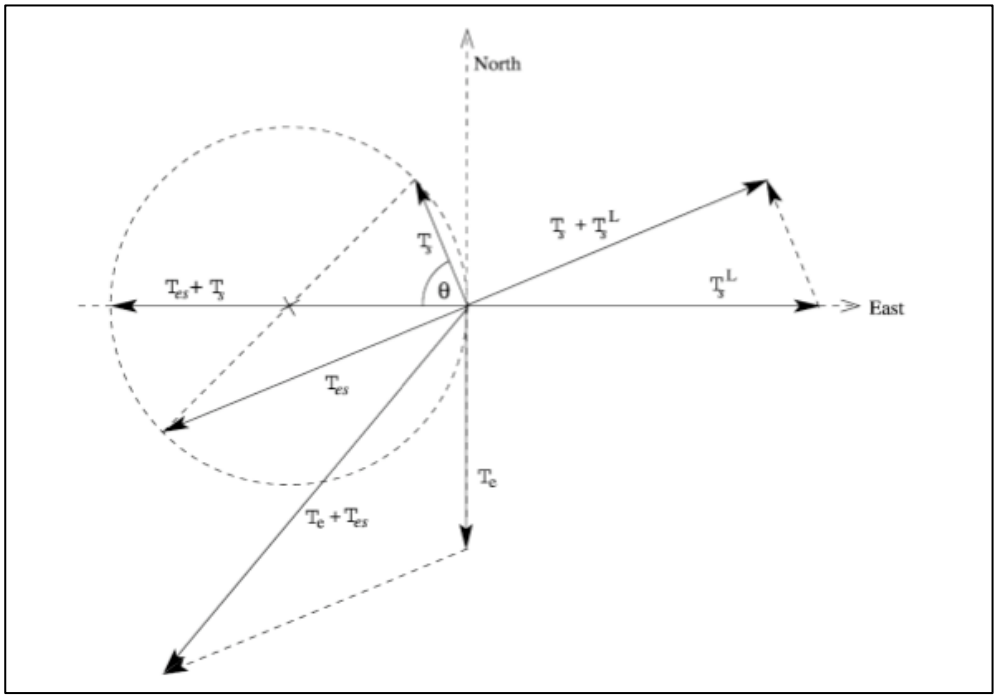
$$\frac{\partial \vec{u}}{\partial t} + \vec{u}.\nabla\vec{u} - \vec{f} \times \left(\vec{u} + \vec{u}_s\right) = -\nabla p + \vec{u}_s \times \vec{\omega} + SGS$$

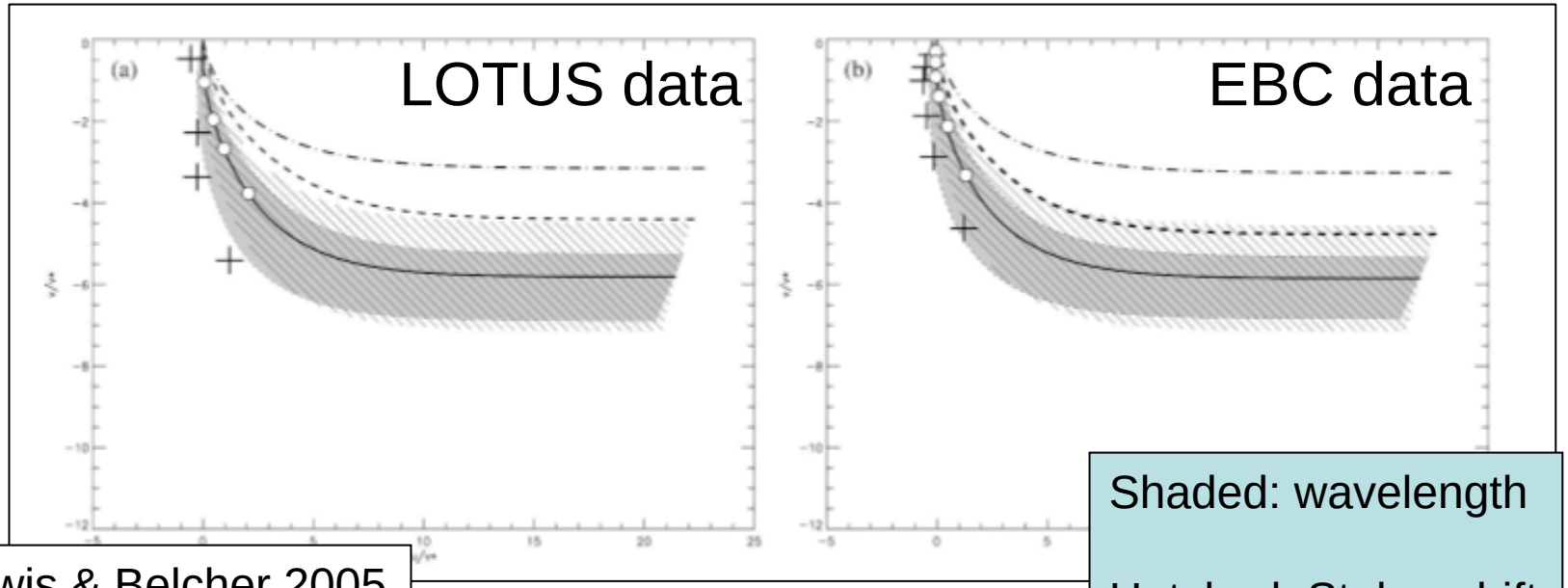
Skyllingstad & Denbo 1995; McWilliams et al 1997; Polton et al 2005

Mean current profile

Comparison with obs:

- Assume wind and waves in equilibrium with wind
- Relate amplitude and wavelength to wind stress for FDS
- Represent waves by single sine





LOTUS data

EBC data

Shaded: wavelength

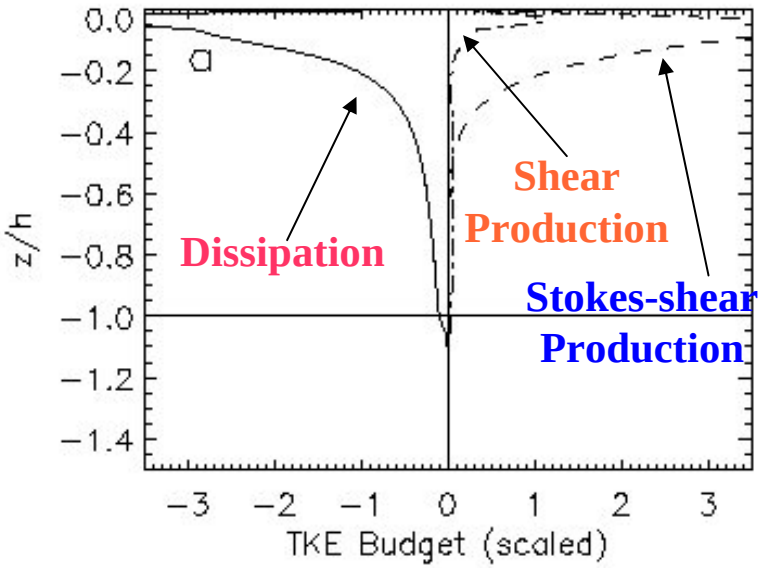
Hatched: Stokes drift

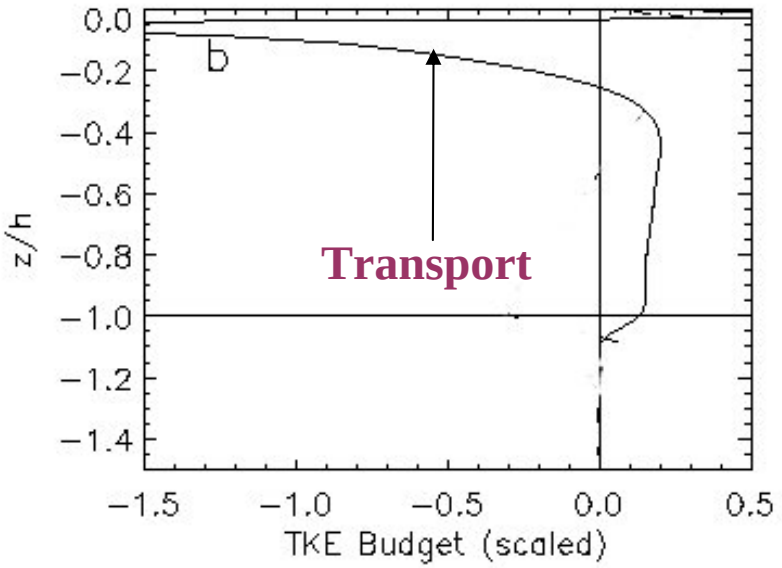
Polton, Lewis & Belcher 2005

Waves and ocean mixing

Langmuir turbulence

Scaling Langmuir turbulence





$$-\overline{u'w'}\frac{\partial \overline{U}}{\partial z} - \overline{v'w'}\frac{\partial \overline{V}}{\partial z} - \overline{u'w'}\frac{du_s}{dz} + \overline{w'b'} - \frac{\partial}{\partial z}\left(\overline{w'E} + \frac{1}{\rho}\overline{w'p'}\right) - \epsilon = 0$$

Shear Production | **Stokes-shear Production** | **Transport** | **Dissipation**

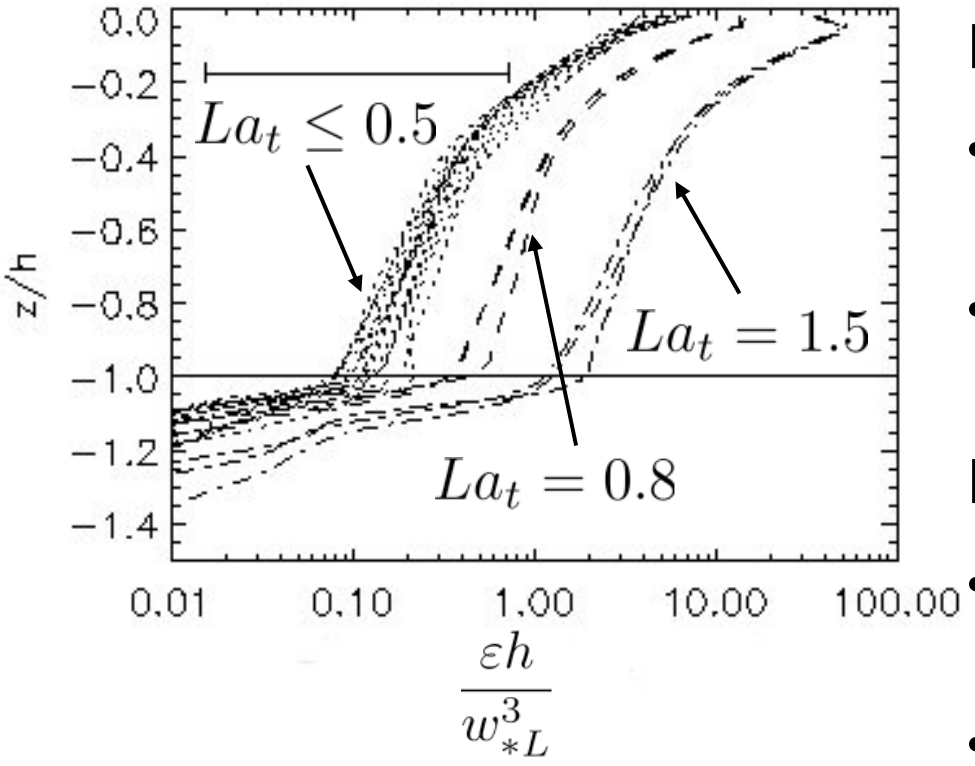
$$\frac{u_*^2 u_{s0}}{\delta} \quad \rightarrow \quad \frac{u_*^2 u_{s0}}{\delta}\frac{\delta}{h} \quad \sim \quad \frac{w_{*L}^3}{h}$$

$$w_{*L} = (u_*^2 u_{s0})^{\frac{1}{3}} = \frac{1}{La_t^{\frac{2}{3}}} u_*$$

$$La_t = (u_*/u_s)^{\frac{1}{2}}$$

Grant & Belcher Submitted

Towards a parameterisation...



Lang turb changes:

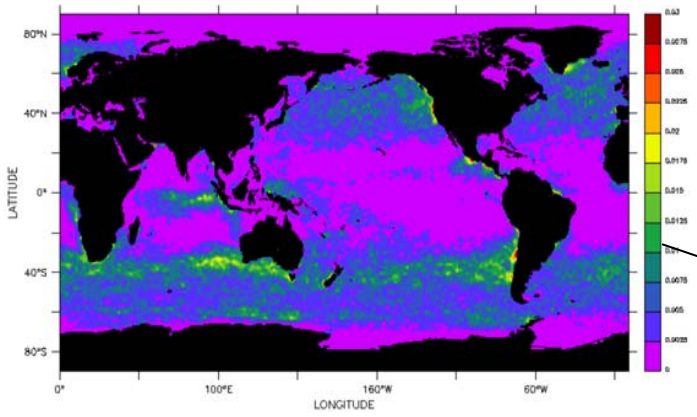
- Entrainment process at thermocline
- Non-local mixing because transport important cf. CBL

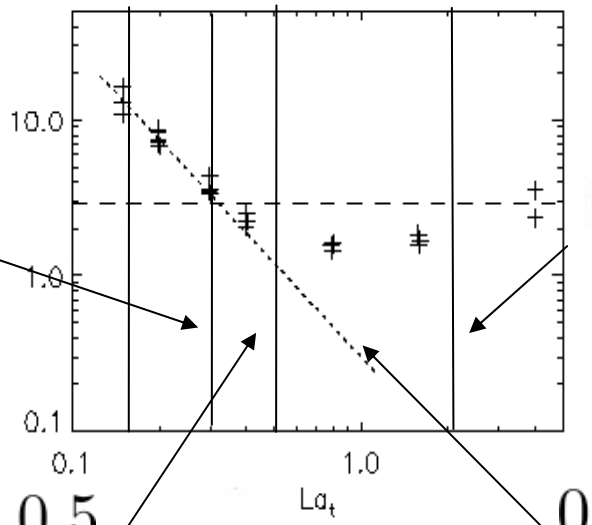
Requires parameterisation

- KPP is based around non-local CBL with shear effects
- Will use scaling developed here to incorporate LT into KPP-model

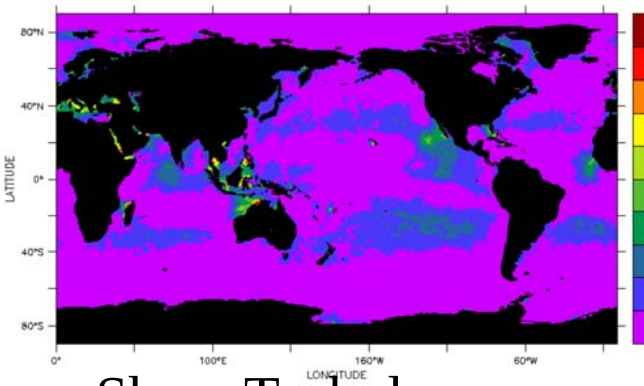
A global perspective: ERA-40

$0.15 \leq La_t \leq 0.3$



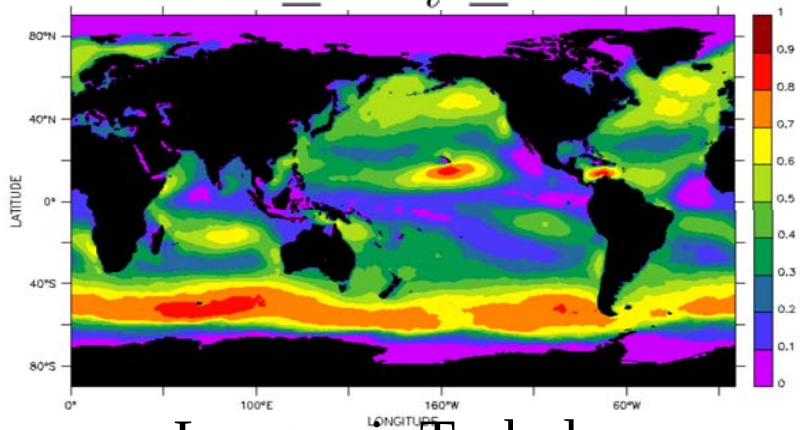


$2 \leq La_t$



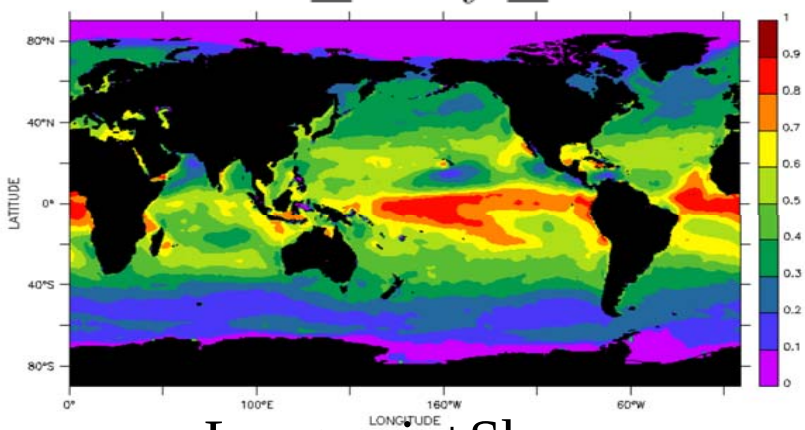
Shear Turbulence

$0.3 \leq La_t \leq 0.5$



Langmuir Turbulence

$0.5 \leq La_t \leq 2$



Langmuir+Shear

Summary

- Wave-driven winds are as important climatologically as wind-driven waves
- Waves change current profile through Coriolis-Stokes forcing
- Langmuir turbulence is the norm in many regions and mixed Langmuir-shear turbulence elsewhere
- Large-scale models do not represent these processes

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