A global perspective on winds, waves and coupling:
Some reasons to model waves

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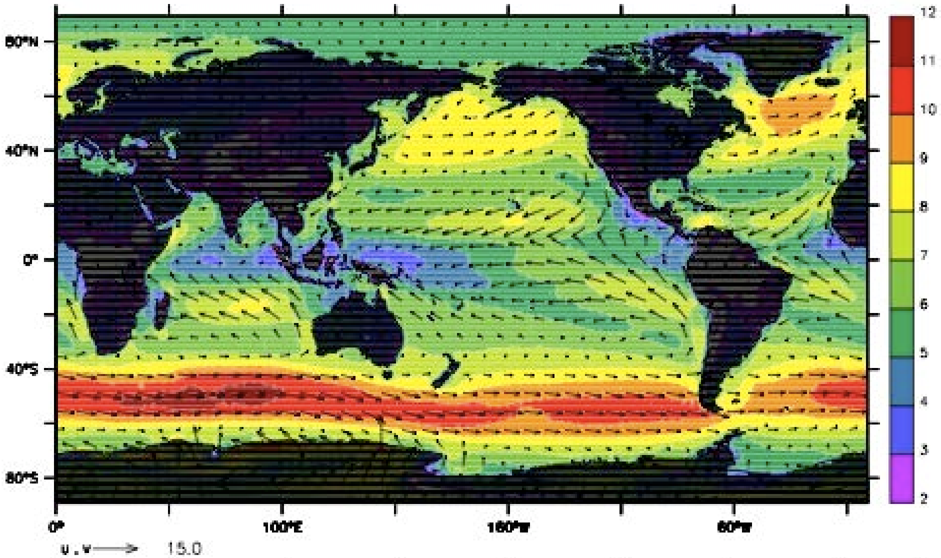
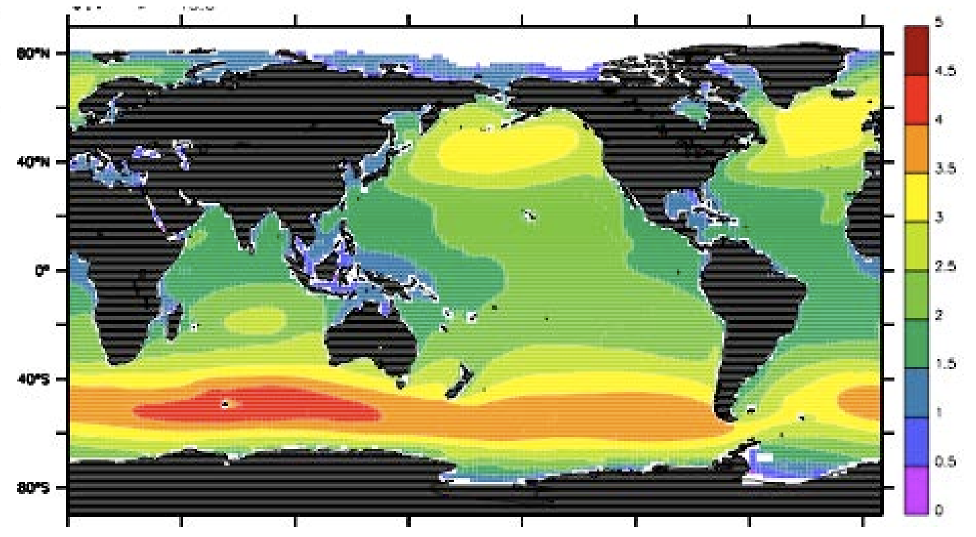
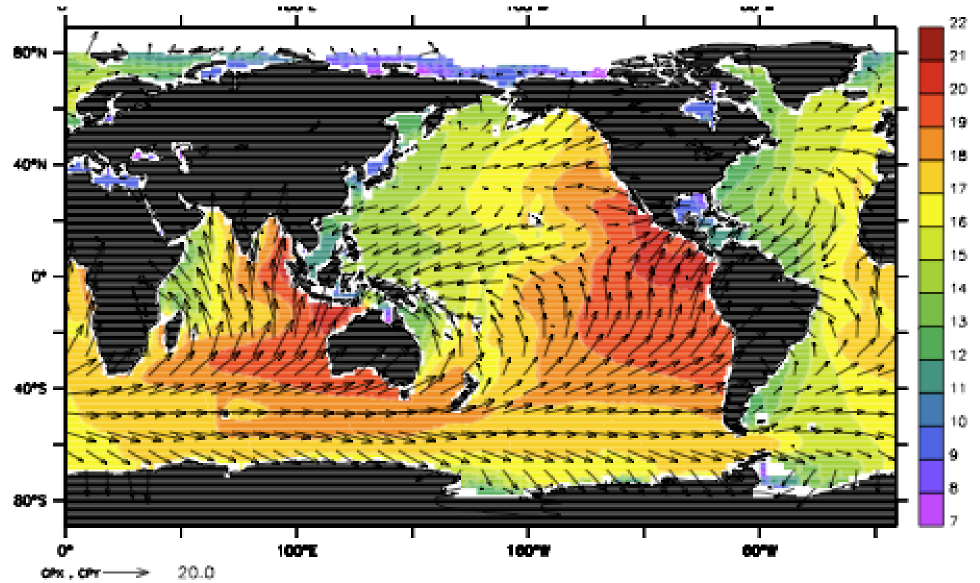
Introduction

- 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})

How do these look in ERA-Interim

Waves and the ABL

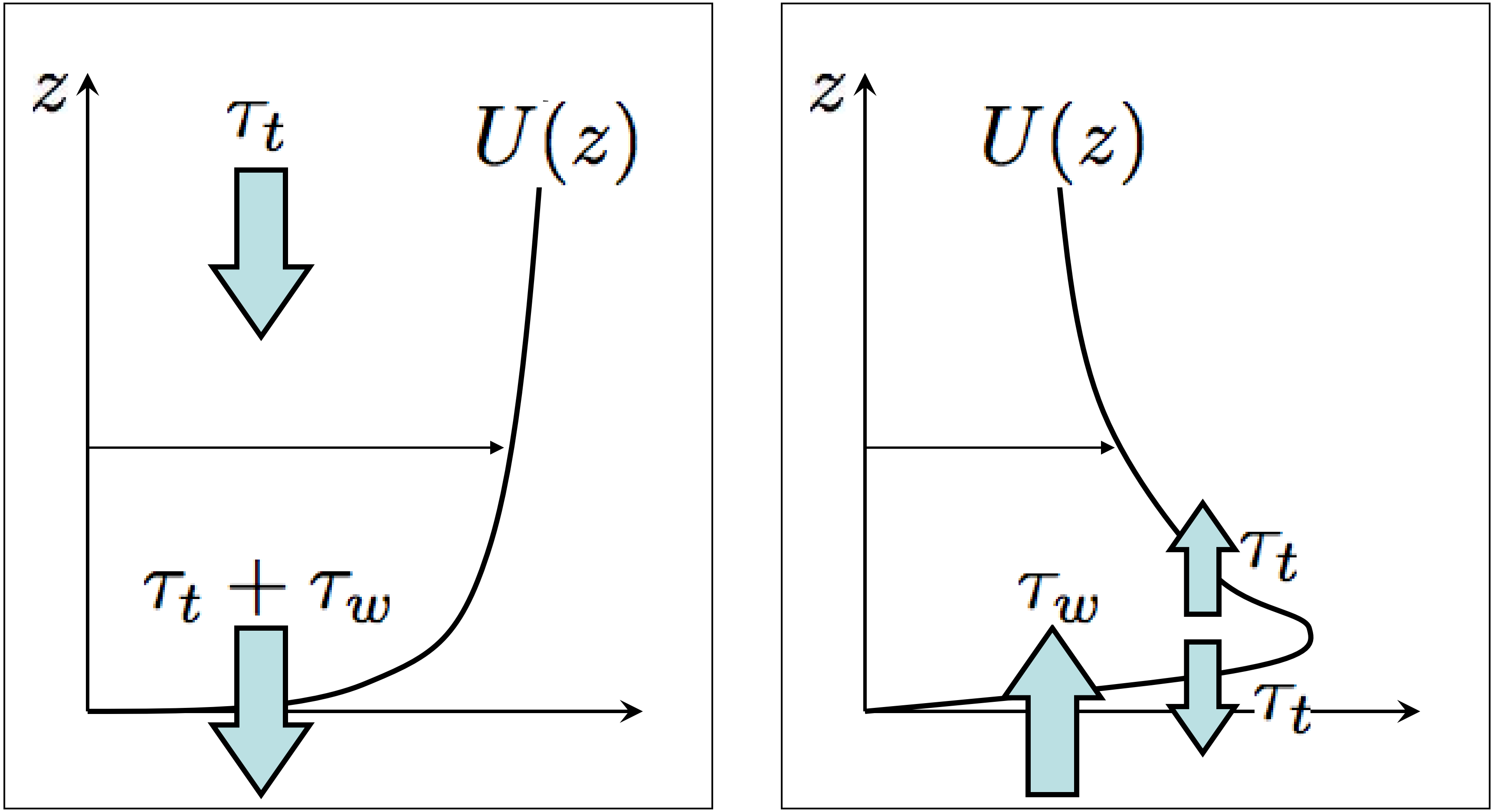
Wind driven waves

&

Wave driven winds

Wind wave regimes

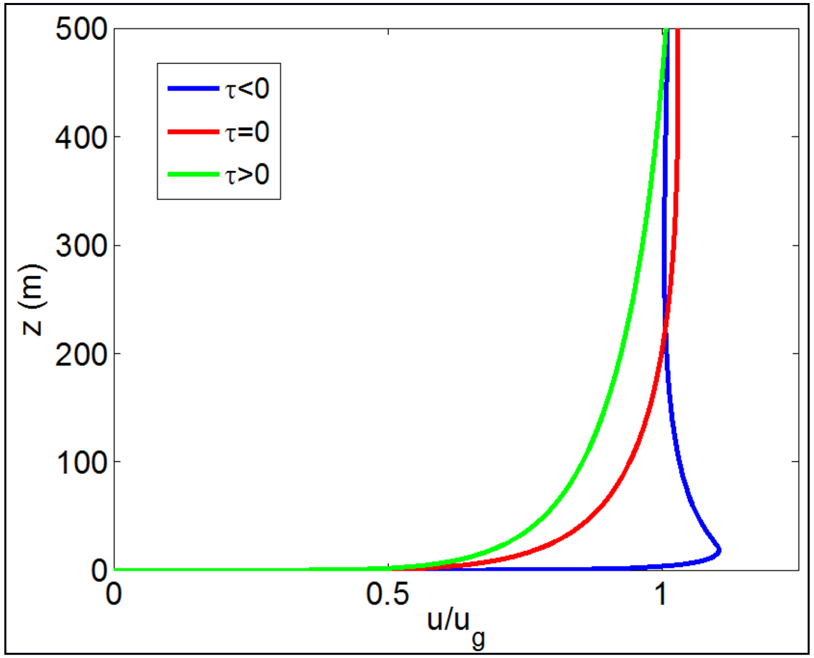
Strong winds over slow waves | Weak winds over fast waves

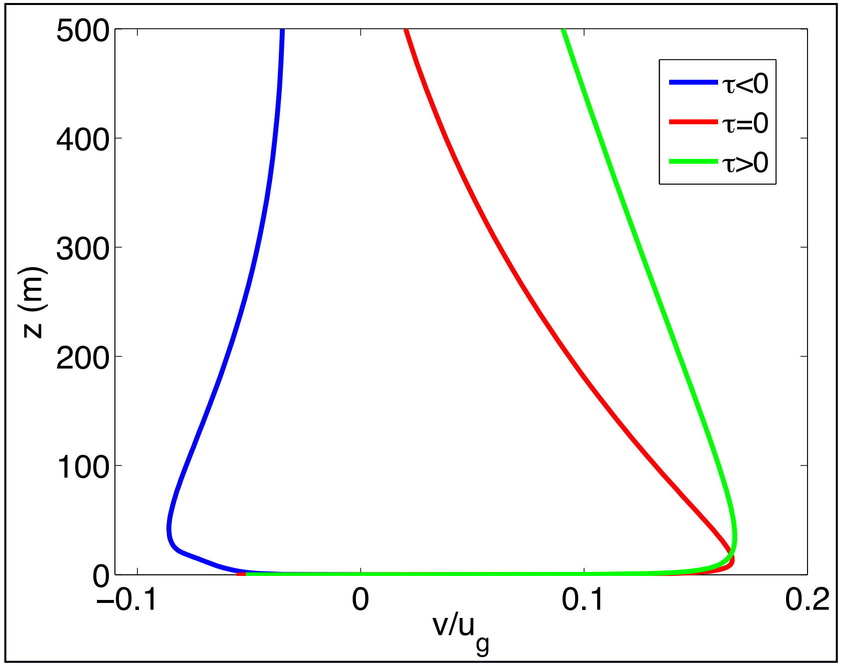


Wind driven waves | Wave driven winds

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

Boundary layer structure



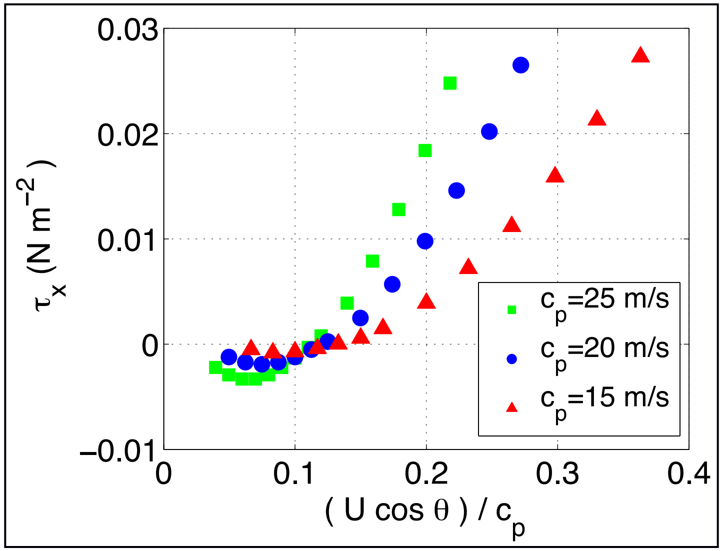


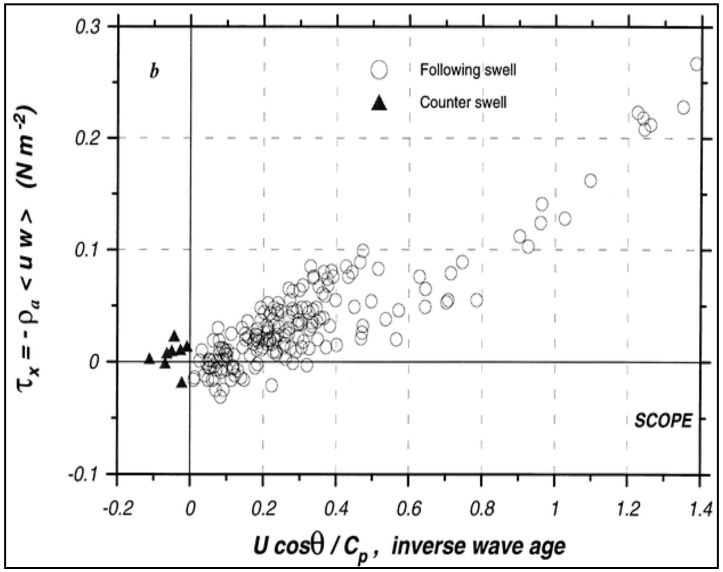
Simple 1d model with wave-induced stress shows:

- 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).

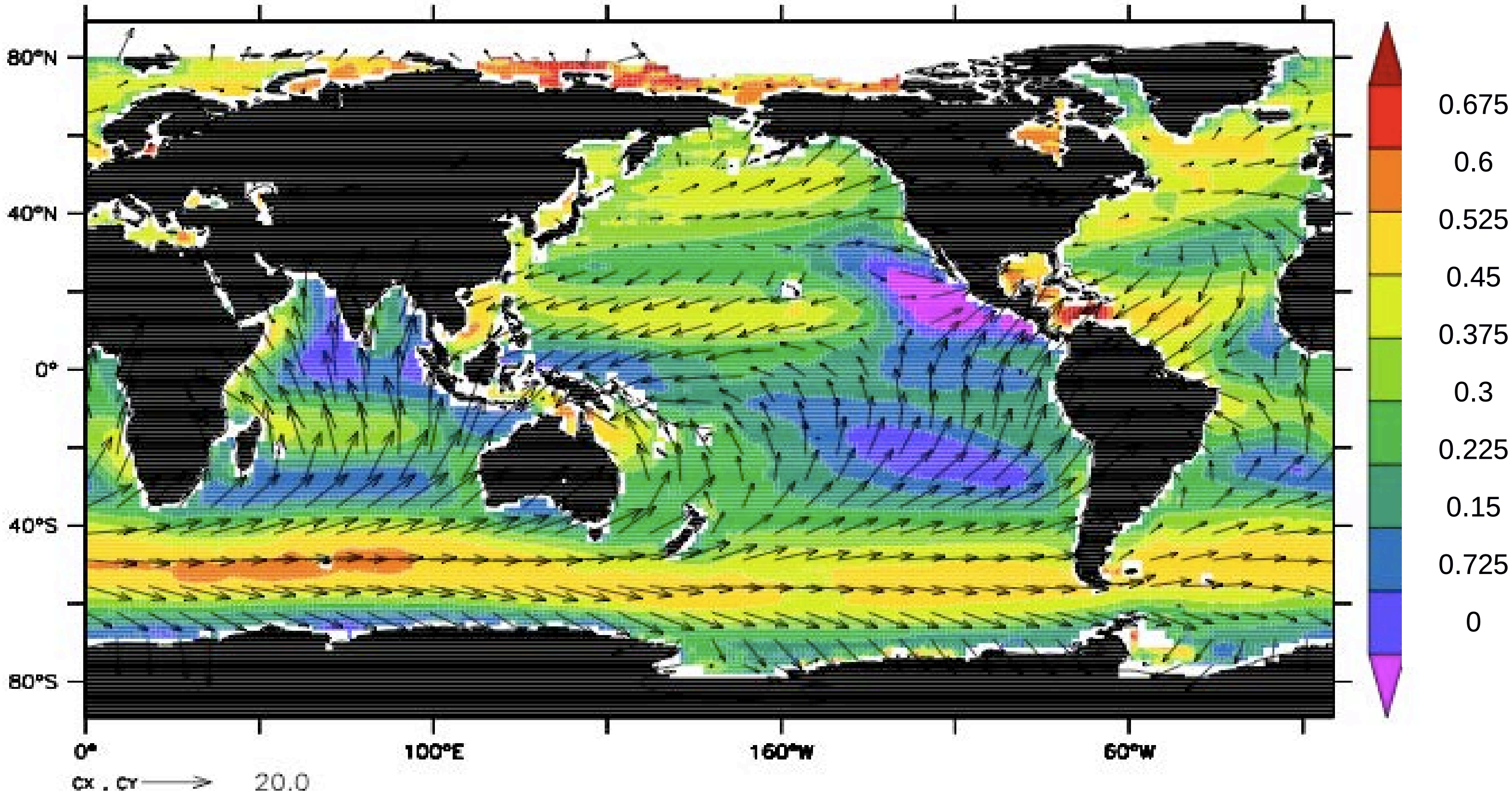
Global perspective: ERA-40

- $U\cos\theta/c_p > 0.8$ 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



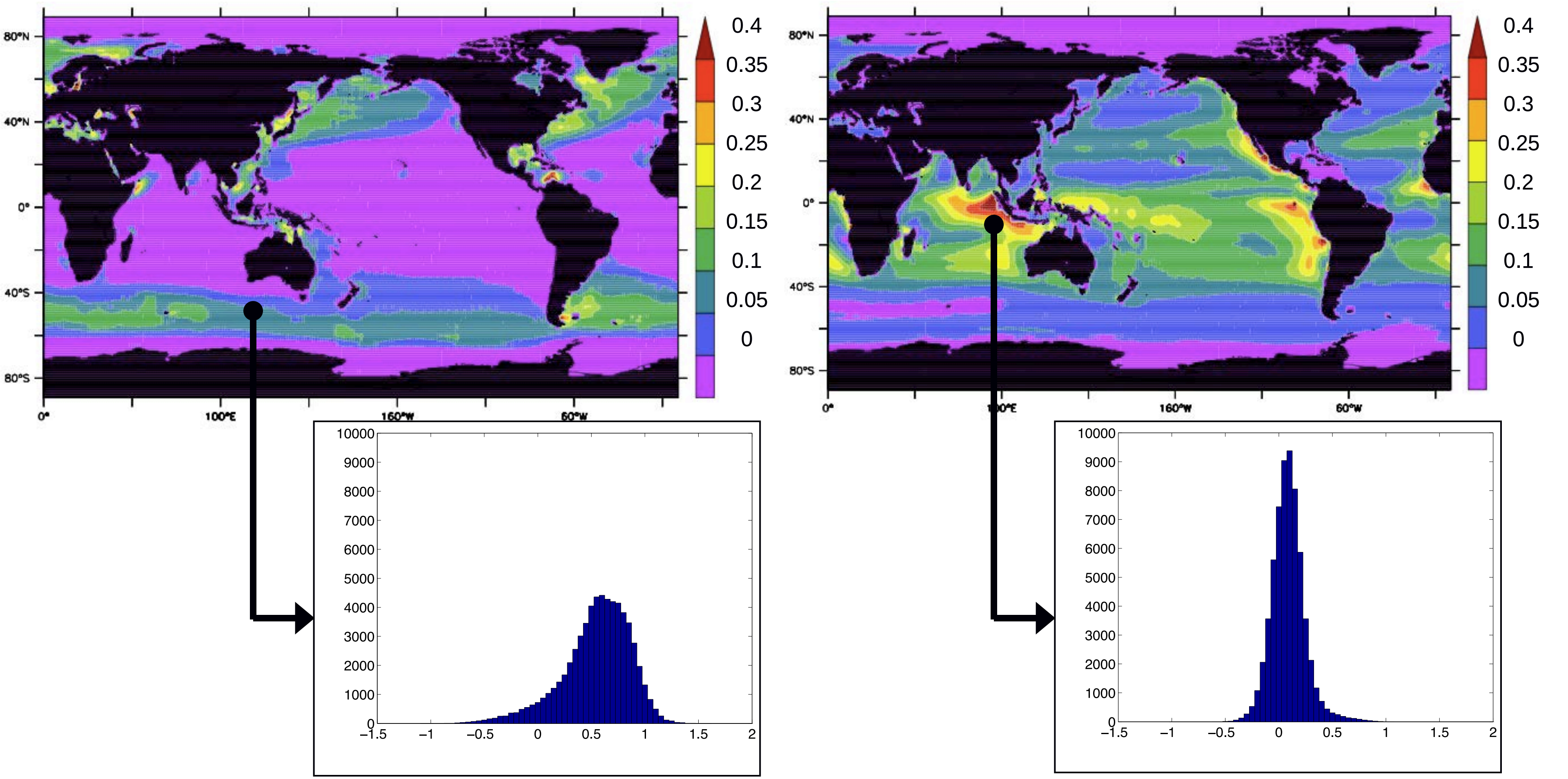
Source and sink regions

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 mixing

Langmuir turbulence

Image: Stephen Monismith

Analysis: tke budget

- Average over: horizontal planes + time
  - – 1d profiles
  - – Towards parameterisation

Buoyant Production

Dissipation

$$\frac{De}{Dt} = -\overline{u'w'}\frac{\partial U}{\partial z} - \overline{v'w'}\frac{\partial V}{\partial z} - \overline{u'w'}\frac{\partial u_s}{\partial z} - \overline{w'b'} - \frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho}\overline{w'p'}\right) - \varepsilon \approx 0$$

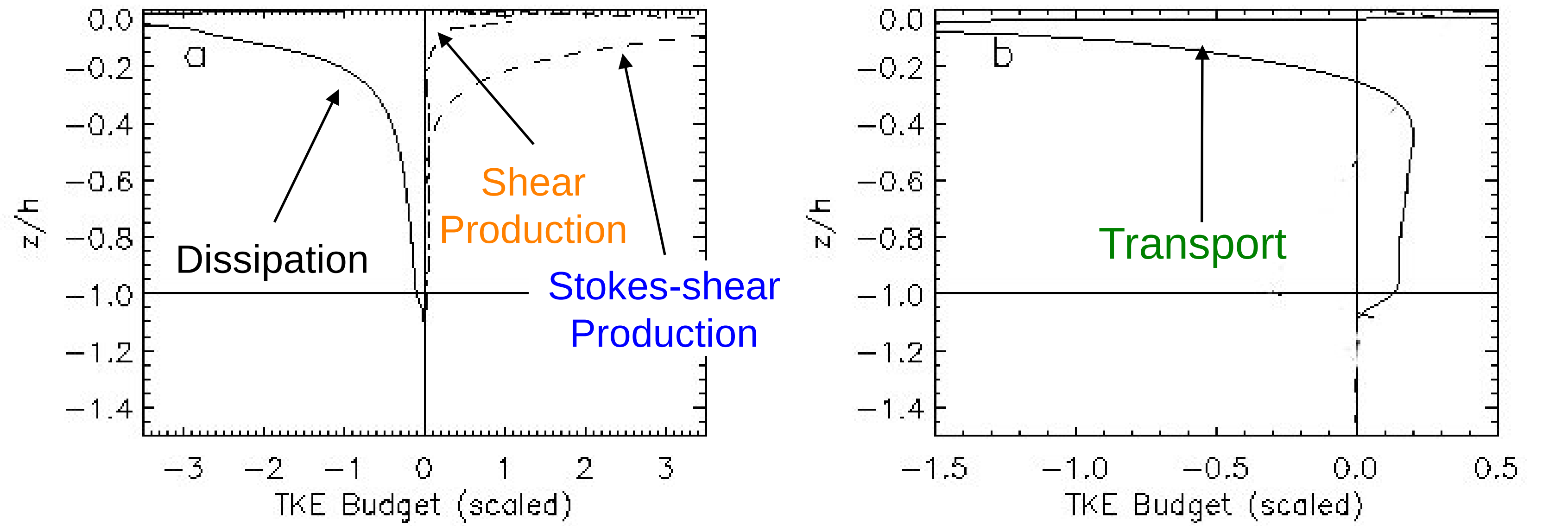
Shear Production

Stokes-shear Production

Transport

Grant & B (2009)

Length + velocity scales



Stokes-shear Production

$$\frac{u_*^2 u_{s0}}{\delta} \quad \rightarrow$$

Transport Dissipation

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

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

Length scale is *h*

Scaling and regimes

	Velocity	Length
Langmuir turbulence:	w_{*L}	h
Wind driven turbulence:	u_*	h

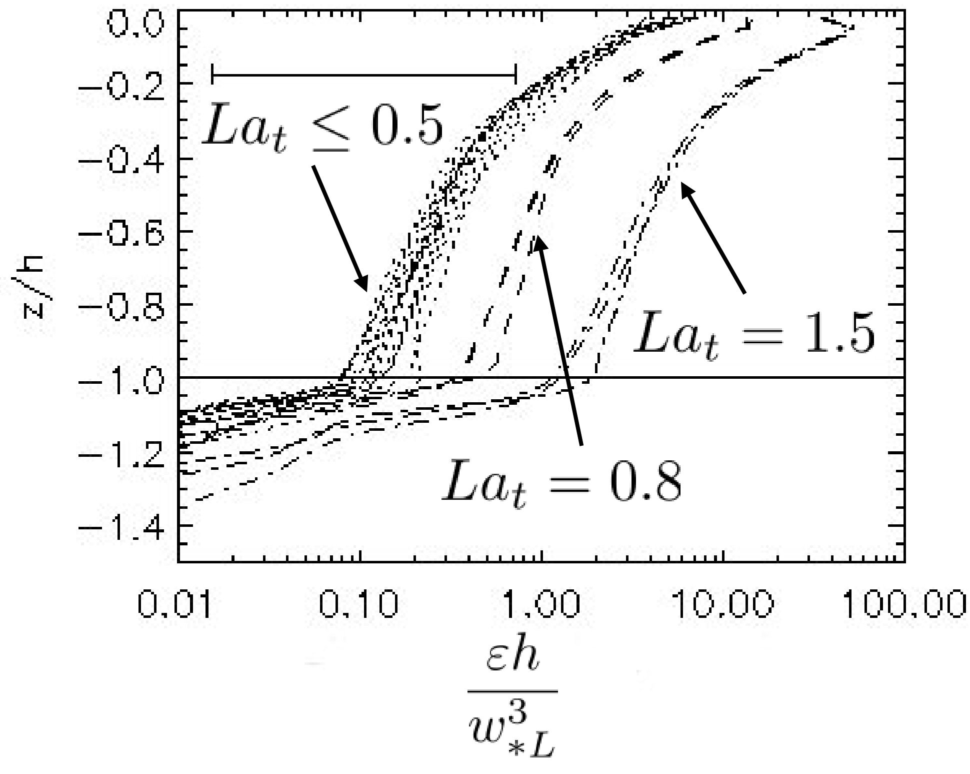
$$\frac{De}{Dt} = -\overline{u'w'}\frac{\partial U}{\partial z} - \overline{v'w'}\frac{\partial V}{\partial z} - \overline{u'w'}\frac{\partial u_s}{\partial z} - \overline{w'b'} - \frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho}\overline{w'p'}\right) - \varepsilon \approx 0$$

$$\frac{u_*^3}{h} \qquad\qquad \frac{w_L^3}{h}$$

$$\frac{-\overline{u'w'}\,\partial U/\partial z}{-\overline{u'w'}/\partial u_s} = \frac{u_*}{u_s} \equiv La_t^2$$

→ Controls transition between regimes

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

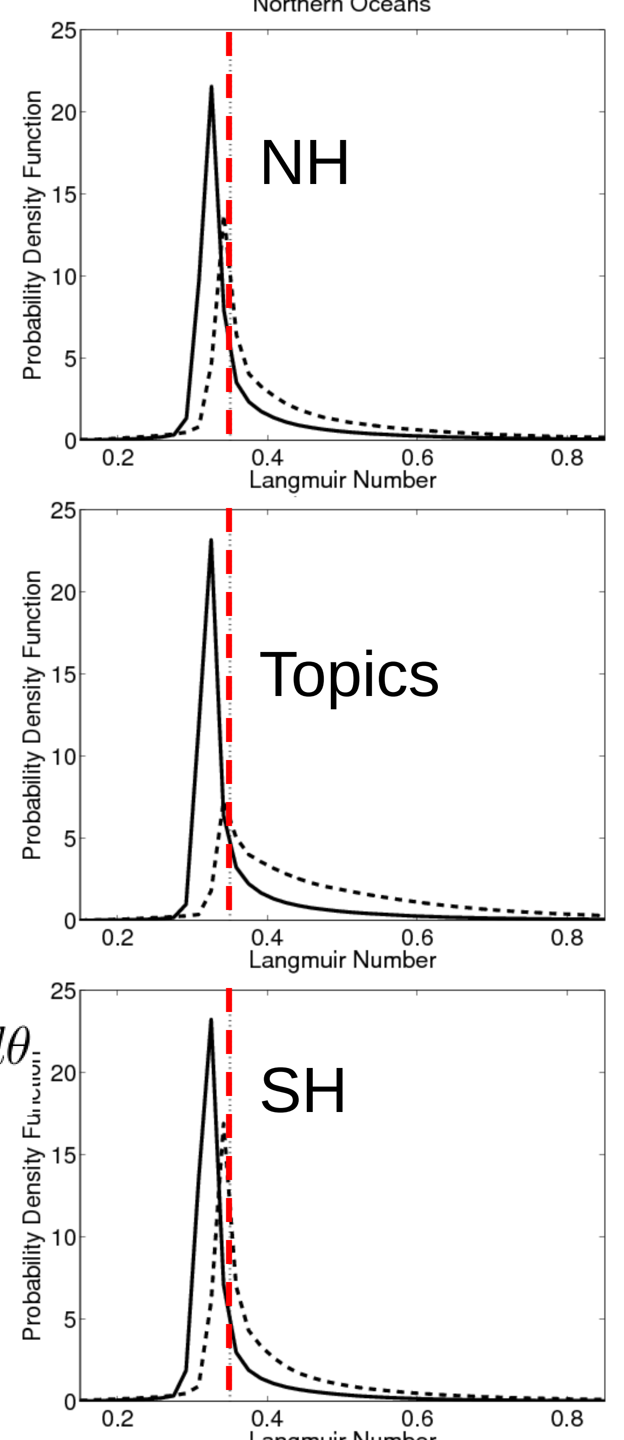
ECMWF Re-analysis

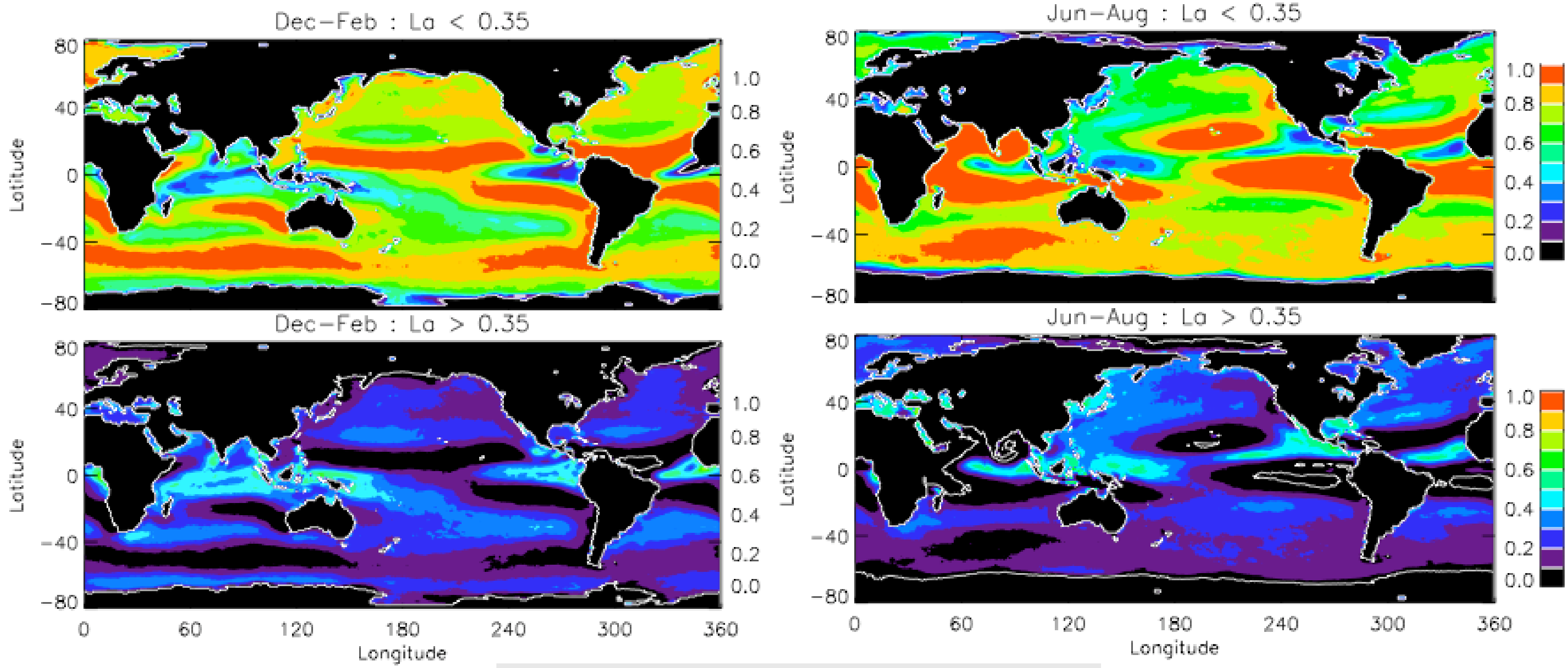
- 40 years gridded ‘analysis’
- Optimal combination of model and data
- Wave spectra from WAM

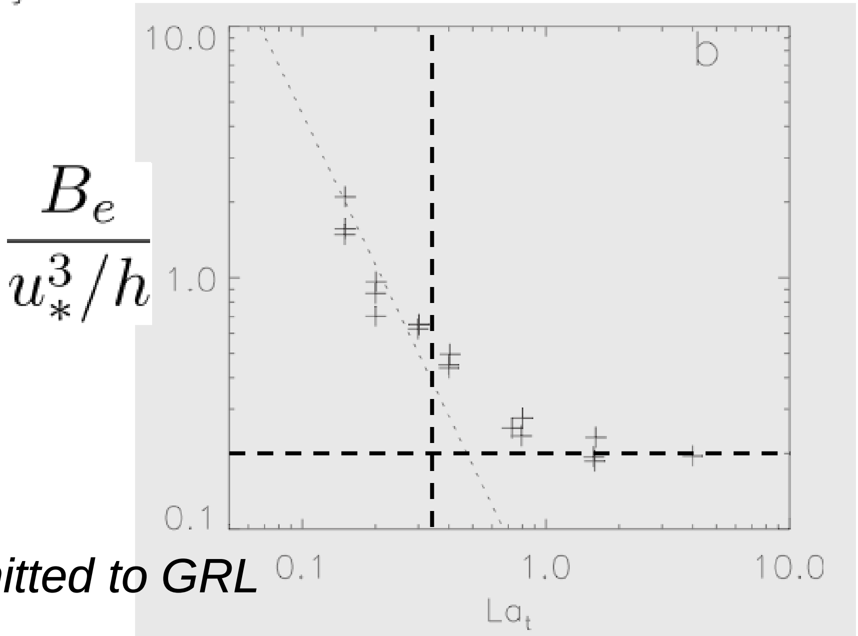
$$u_s = \frac{16\pi^3}{g}\int_0^{2\pi}\int_0^{\infty} f^3 F(f,\theta)\cos(\theta-\theta_w)\,df\,d\theta$$

$$La = \frac{u_*}{u_s \cos\theta}$$

Belcher et al *Submitted to GRL*







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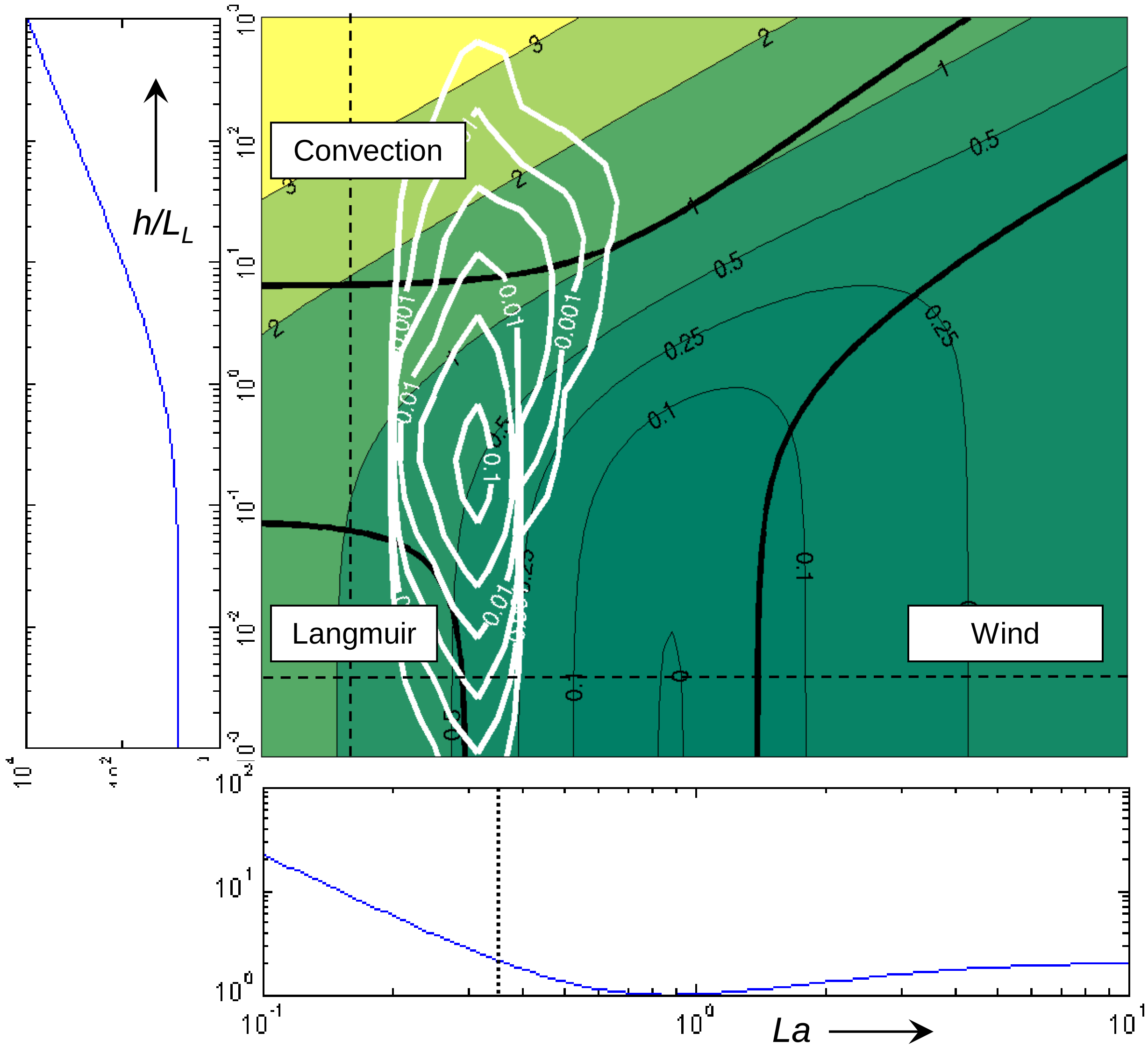

Regime diagram and joint distribution for Southern Ocean

Belcher et al *Submitted to GRL*

OSMOSIS

Ocean Surface Mixing, Ocean Sub-mesoscale Interaction Study

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New NERC-funded £4M project

April 2011 - September 2015

A consortium of

University of Reading	UEA
University of Bangor	NOC - Southampton
University of Oxford	NOC - Liverpool
University of Soton	SAMS
Met Office	

Summary

- Wave-driven winds are as important climatologically as wind-driven waves
- Langmuir turbulence is the norm in many regions and mixed Langmuir-shear turbulence elsewhere
- Priorities for wave modelling
  - Dissipation of swell
  - Wave swell interaction
  - High frequency tail and Stoke drift profile

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