WIND WAVE MODEL PERFORMANCE IN RELAXING WIND SEAS

Russel P. Morison & Michael L. Banner
(UNSW)
Jose Henrique Alves (NCEP)
Peter Sullivan (NCAR)

Motivation

- Standard scenarios for evaluating wind wave model performance focus on fetch- or duration-limited **growth** situations.
- In this study we investigate model performance for
- (i) **initial growth under wind forcing**
- (ii) a **rapid attenuation of the wind forcing**.
- These diagnostics provide critical tests of the sea state dependence underpinning the ability of the source terms to respond to changes in the wind speed.
- The model performance is tested against data recorded during growth and relaxing wind sea conditions (FAIRS).
- This is **work in progress.**

Modeling Overview

Radiative transfer equation (deep water, no currents)

The radiative transfer equation for describing the evolution of the wave height spectrum $F(\mathbf{k})$ is given by:

$$\frac{\partial F}{\partial t} + \mathbf{c}_g \cdot \nabla F = S_{tot}$$

where

- $F=F(k,\theta)$ is the directional wave spectrum
- c_g is the group velocity
- $S_{tot} = S_{in} + S_{nl} + S_{ds}$ is the total source term.
- S_{in} is the *atmospheric input spectral source term*
- S_{nl} is the *<u>'exact'</u> nonlinear spectral transfer source term representing nonlinear wave-wave interactions within the spectrum*
- S_{ds} is the spectral *dissipation rate due primarily to wave breaking*

Wind Input Source Function S_{in}

Many variants are in use, based on observations and/or theory. We evaluated several and settled on a modified version of **Janssen (1991)** (basis of ECMWF wave forecast model) :

- based on Miles critical layer theory
- tuned to agree with Snyder and Plant empirical observations, but includes sheltering of wind input to shorter waves to reconcile modeled and observed wind stress

-has a viable spectral distribution for U_{10} from **6-100** m/s

-Banner and Morison 2010 modified Janssen, further modified to include an flux from the waves to the atmosphere, when C is larger than U.

$$S_{in}(k, \theta) = \alpha(k, \theta) E(k, \theta) .$$

$$\alpha(k, \theta) = \varepsilon\, \beta(k, \theta)\, \omega\, (u_*^{red}(k) \cos\theta / c)^2$$

$$\beta(k, \theta) = J_2 \mu (\ln(\mu))^4 / \kappa^2 - 2\kappa(\cos(\phi) - c/U) \quad \text{where } J_2{=}1.6 \quad \text{(Janssen (1991) used 1.2).}$$

$$\beta(k, \theta) = 0 \ \text{ for } \mu > 1 .$$

$$\mu(k, \theta) = (u_*/c)^2\, (g z_0 / u_*^2)\, \exp(J_1 \kappa / (u_* \cos\theta / c)^2)$$

$$u_*^{red}(k_n) = \sqrt{[\tau_{tot} - \sum_{i=1}^{n} (\tau_w(i) + \tau_{bw}(i))] / \rho_{air}}$$

$$z_0 = \frac{0.01 u_*^2}{g} \Big/ \sqrt{1 - C_0(\tau_w / \tau)}$$

Saturation Threshold-based Dissipation Rate S_{ds}

• based on treating spectral bands as nonlinear wave groups. Uses a low power of the spectral saturation ratio (~steepness ratio) to simulate observed threshold behaviour *[extension of Alves & Banner (JPO, 2003)]*

$$S_{ds}(k,\theta) = [C_1 * D * (\tilde{\sigma} - \tilde{\sigma}_T)/\tilde{\sigma}_T)^{a_1} + C_2 * D * E_{tot} * k_p^{\;2}\;](\sigma/\sigma_m)^{a_2}\;\omega F(k,\theta)$$

‘local S_{ds}’ **‘non-local S_{ds}’**

This formulation uses

• normalized azimuthally-integrated saturation:

• measured threshold of the normalized spectral saturation (Banner et al., JPO, 2002) with a_1=2

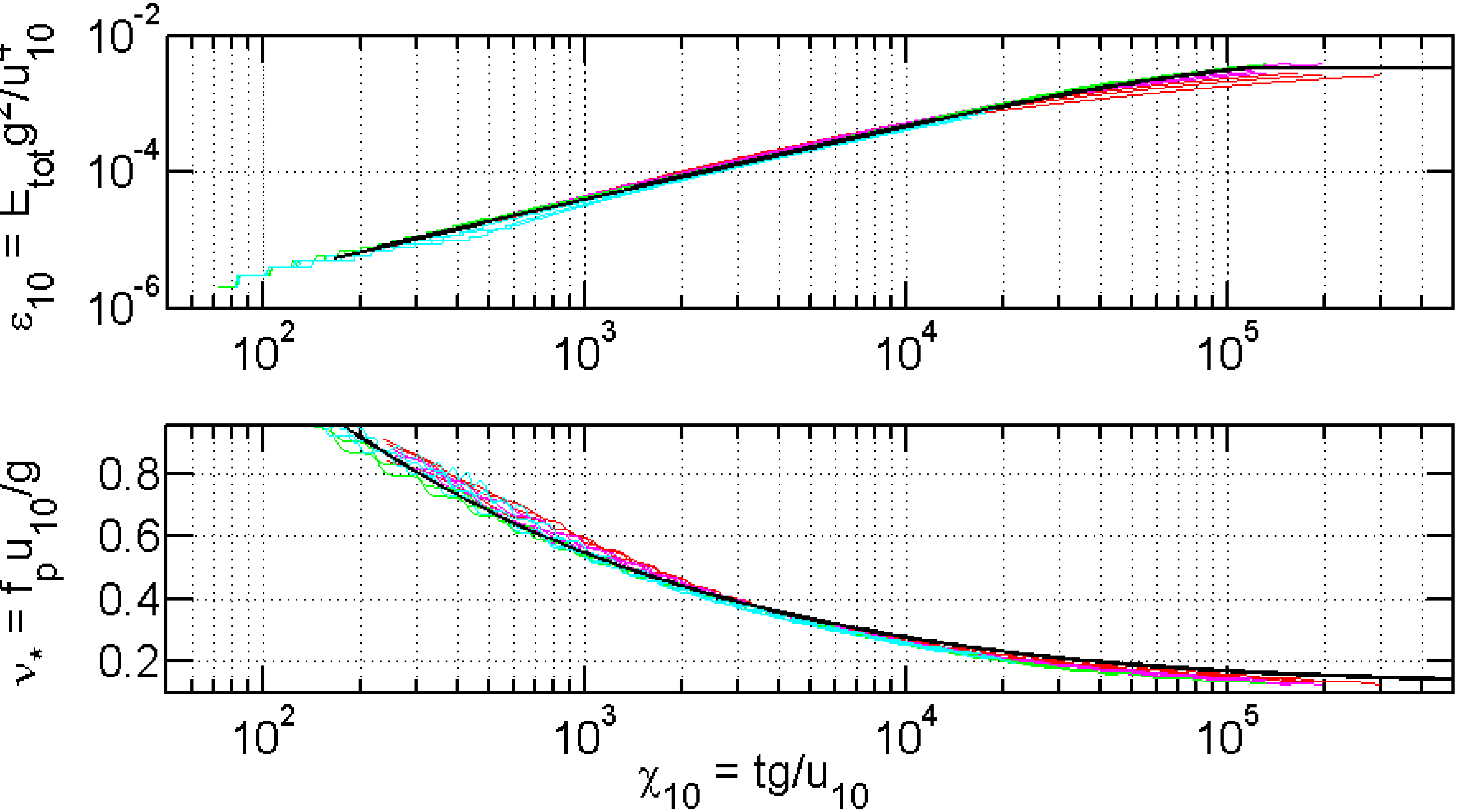
• tail exponent a_2 = 4 to match dissipation to input behavior in the spectral tail

• nonlocal dissipation rate component

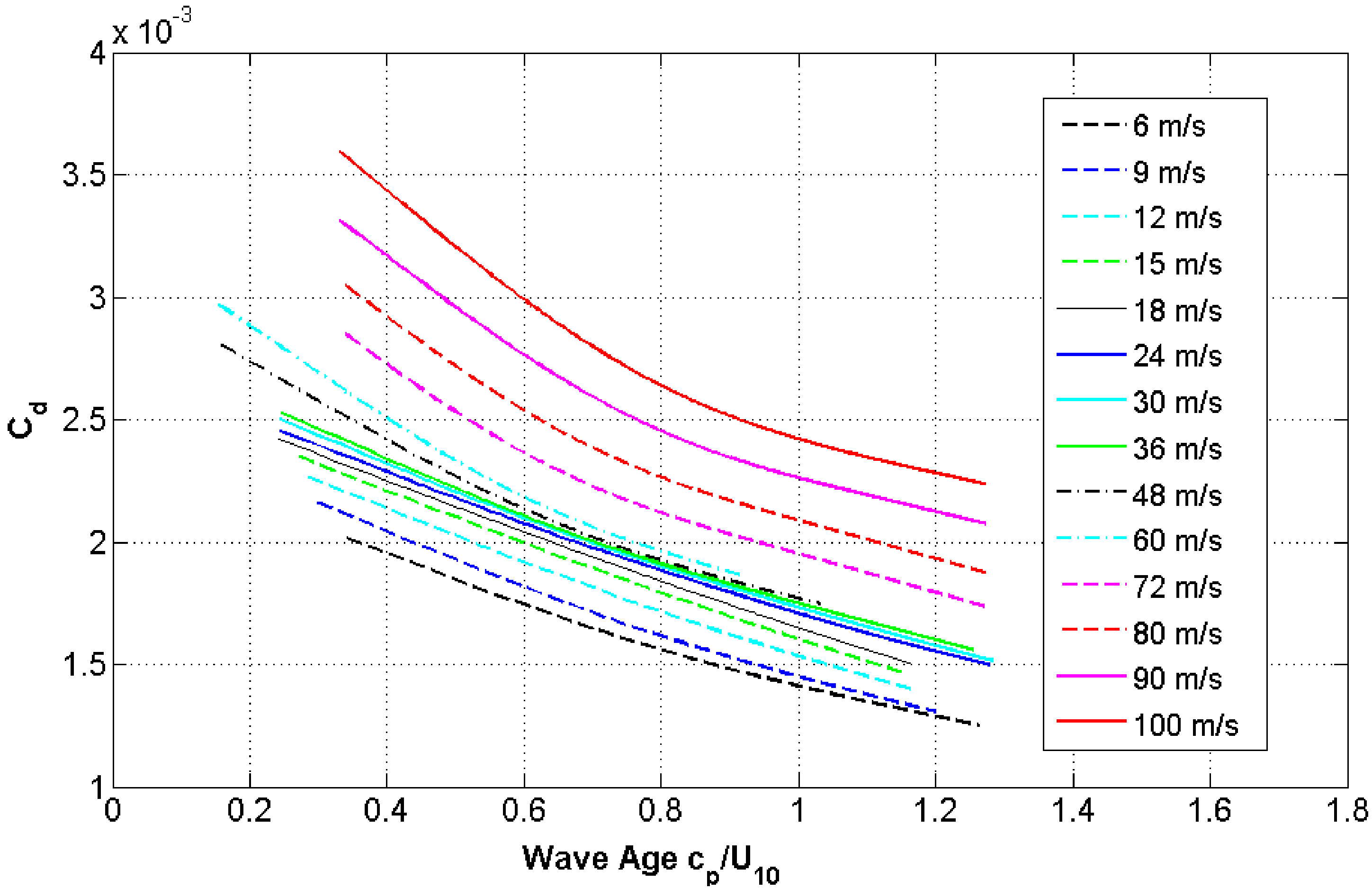
• coefficient D for the local S_{ds}: non-dimensional and linear in the wind speed to match to the wind input term.

• C_1 and C_2 constants

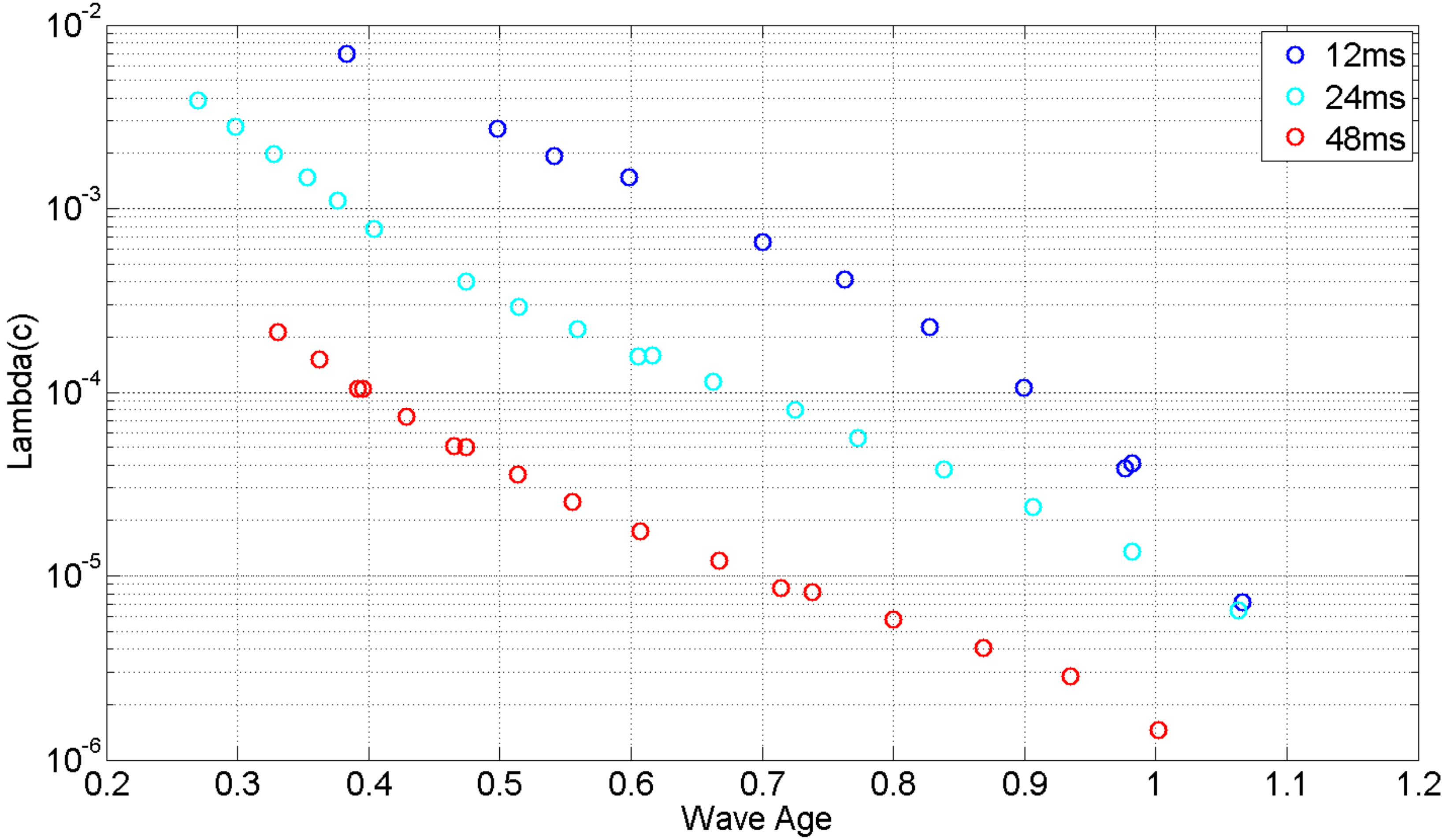
Duration-limited Evolution of Non-dimensional Wave Energy and Peak Frequency for Winds from 6-100 m/s (no limiters)



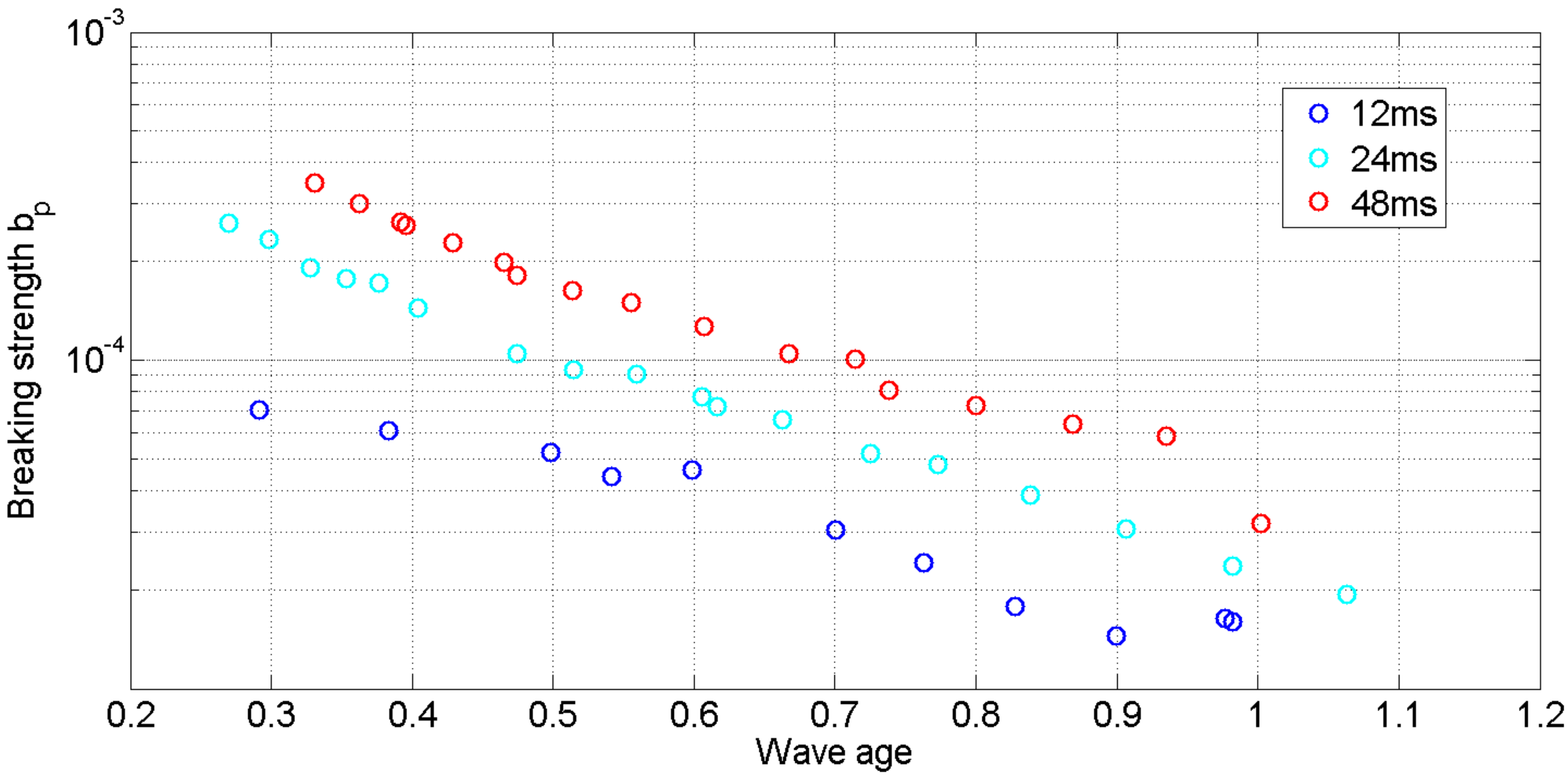
Model performance for predicting wind stress (stable to 100 m/s windspeeds – no limiters)



Predicted Variation of Λ (spectral density of the breaking crest length per unit area) with Wave Age for the Dominant Wind Waves for various U_{10}



Predicted Variation of breaking strength b with Wave Age for the Dominant Wind Waves for various U_{10}



FAIRS (2000) Experiment

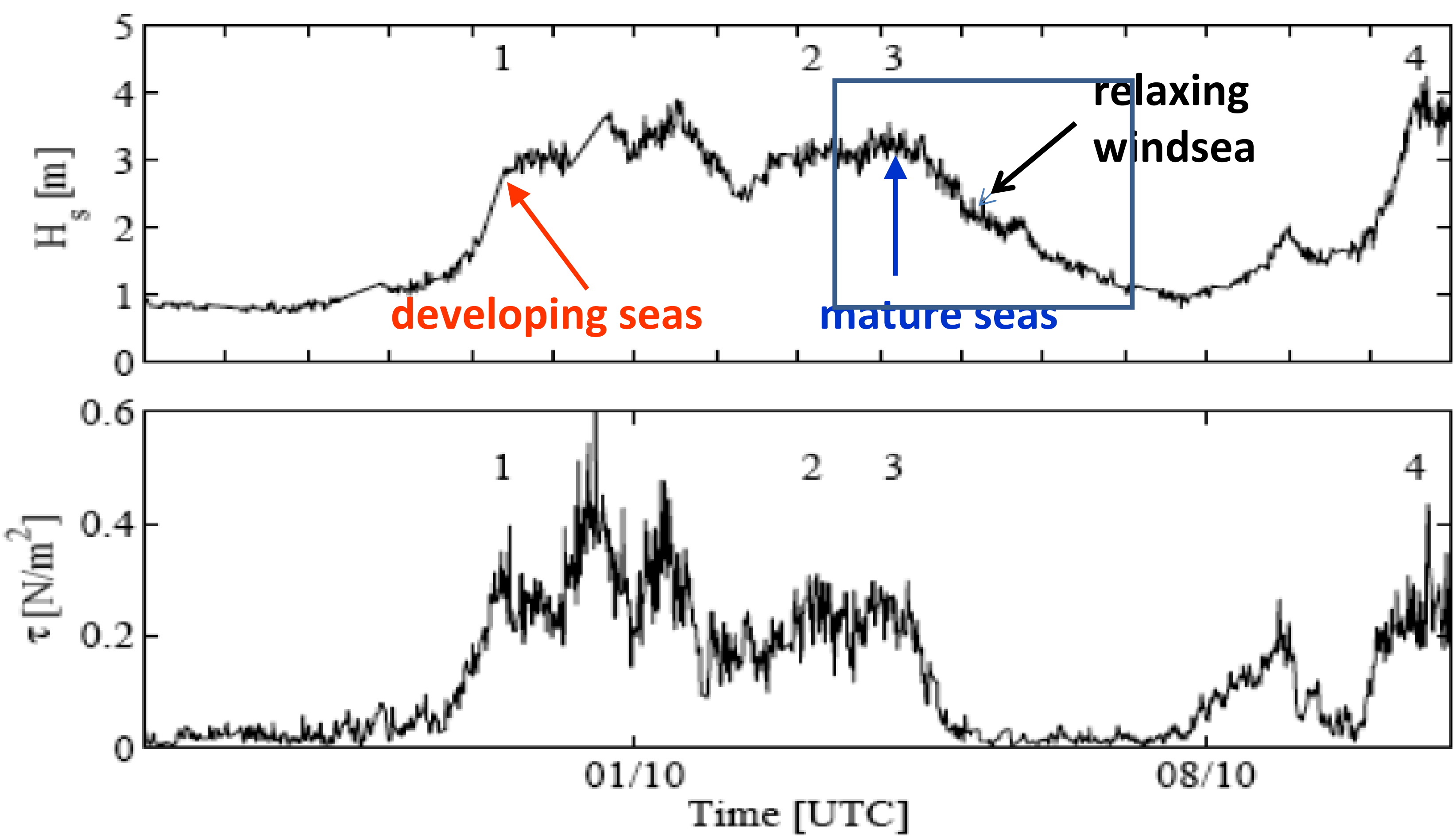
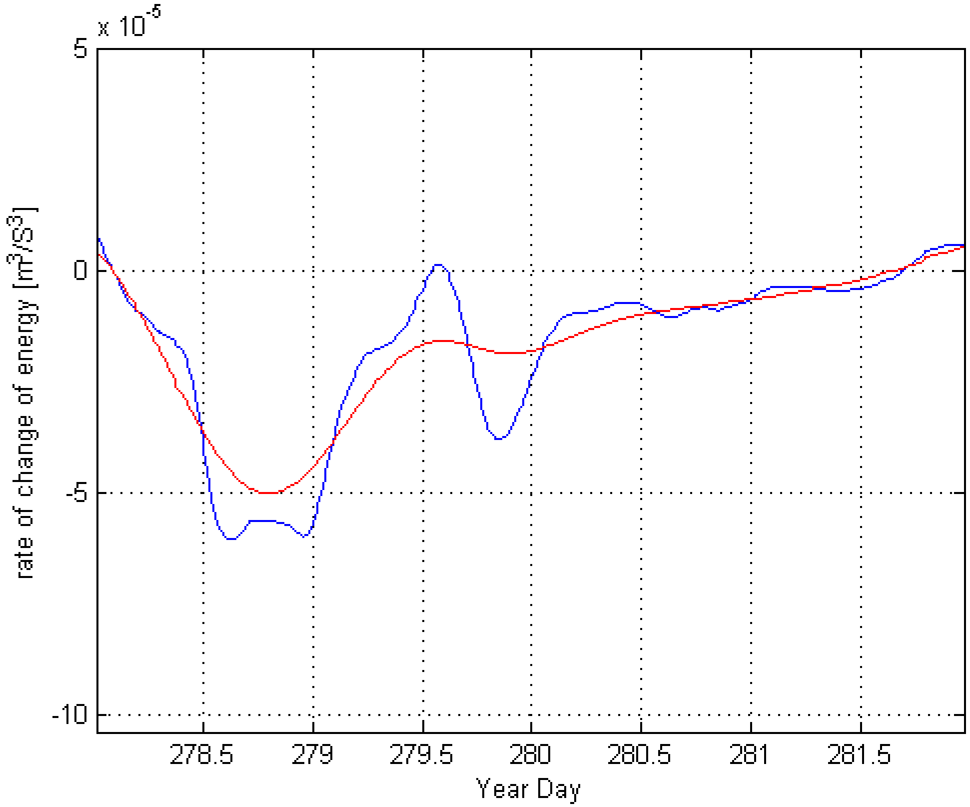


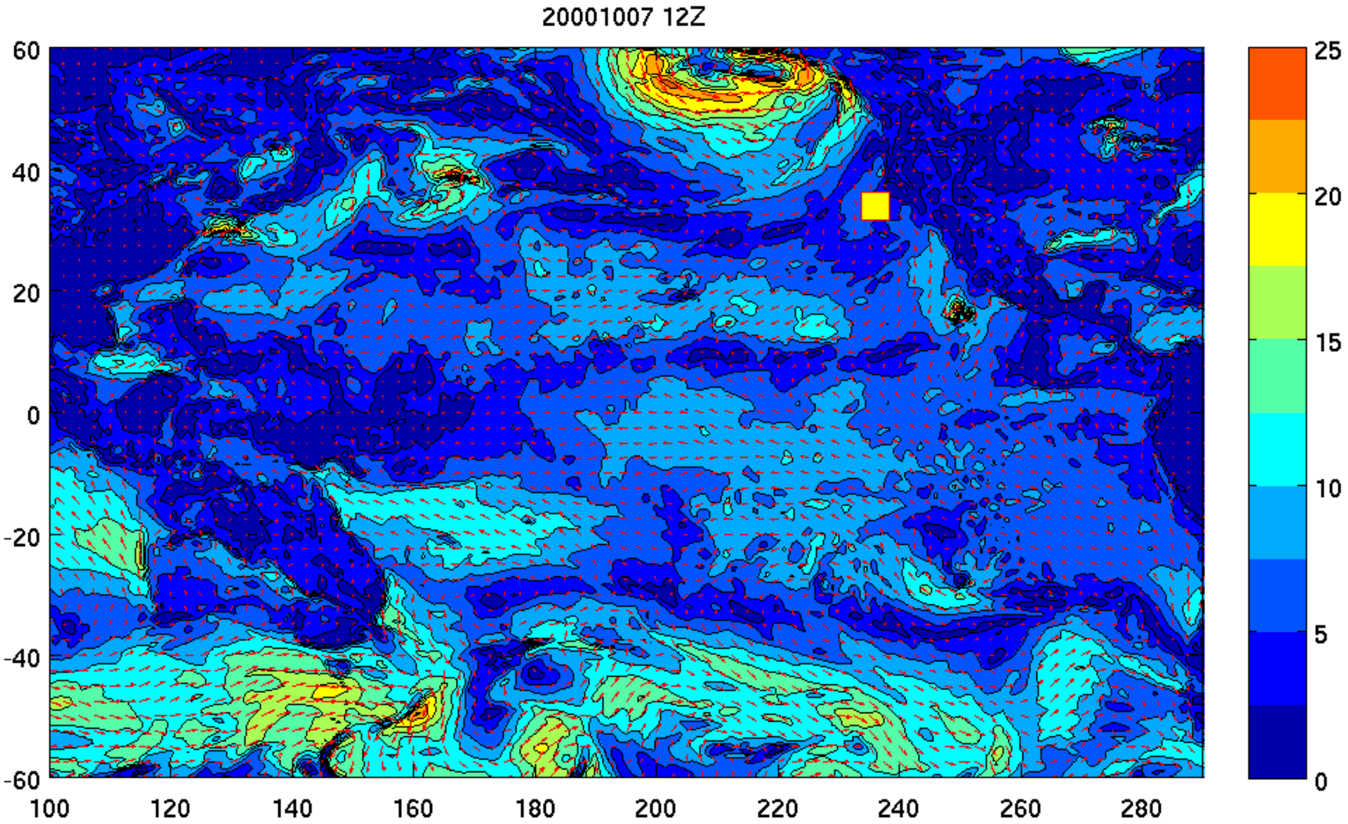
Figure 1. Significant wave height (H_s) and wind stress (τ) during the FAIRS experiment. The wind direction was around 300° for most of the observational period. Periods 1 (growing seas) and 3 (mature seas) are of particular interest in this study, during which the mean wind was measured to be 12 m/s.

Observed Wave Energy decay exponent for FAIRS

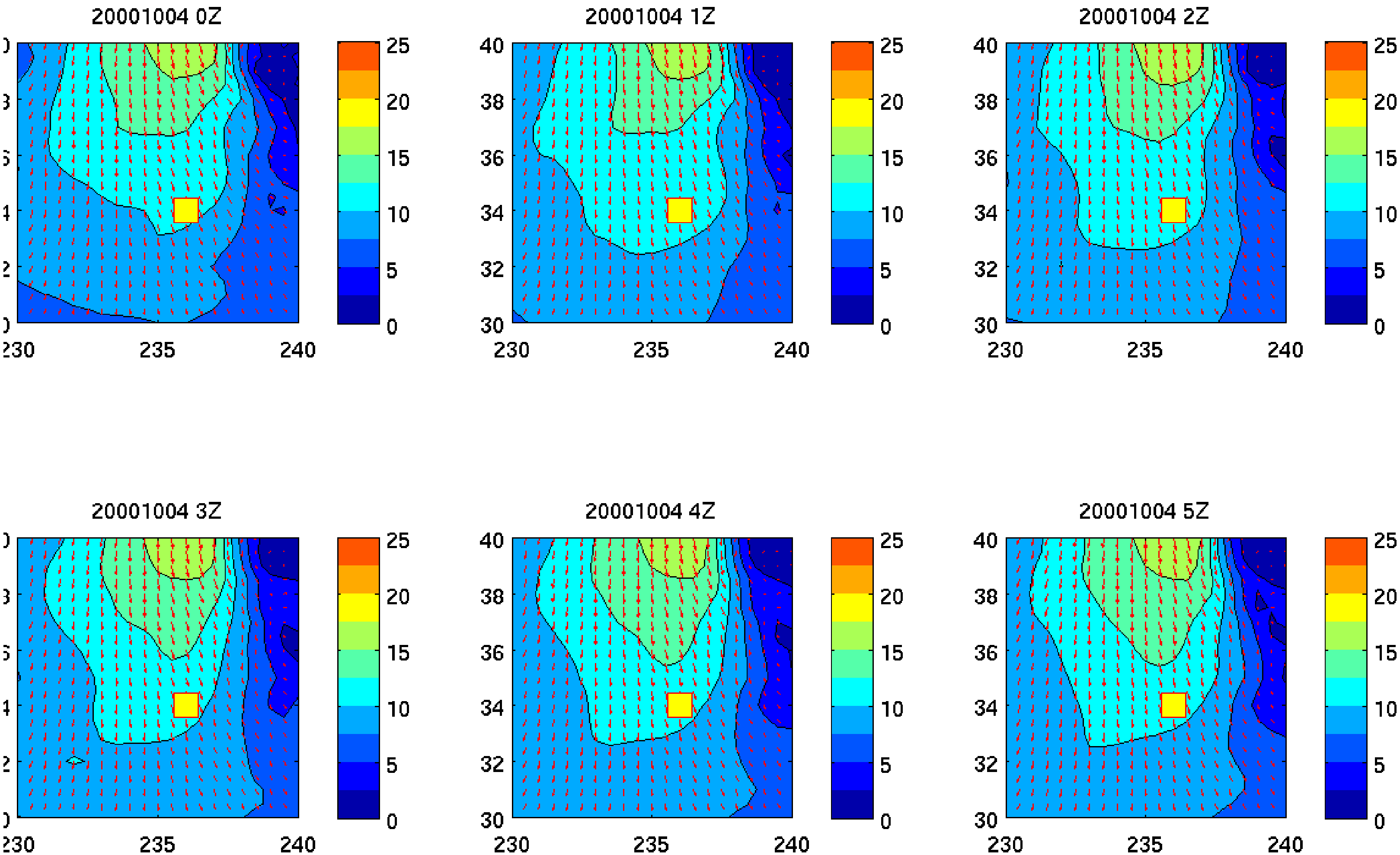


The mean decay exponent for the decay event is 2.3 x 10^-5.
This is **some 50 times faster** than typical swell decay .

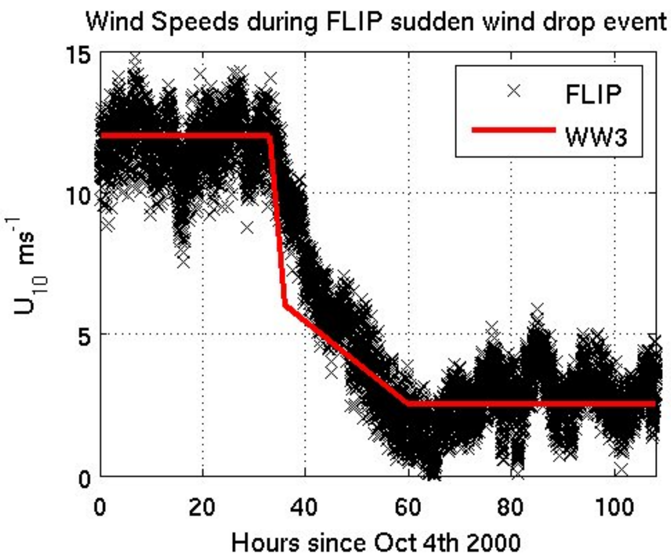
Synoptic conditions during FAIRS

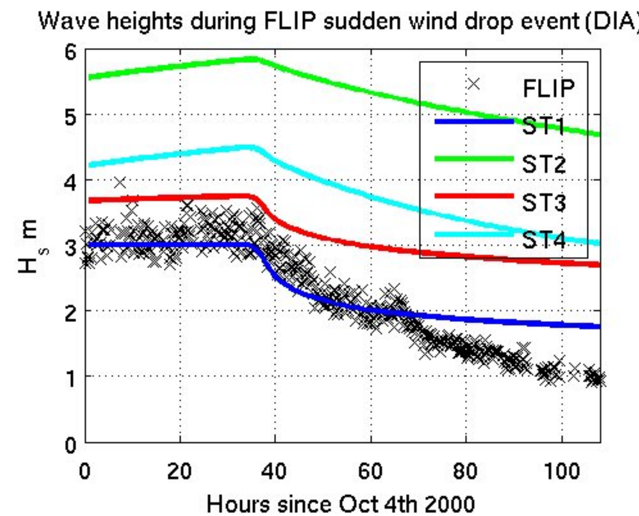


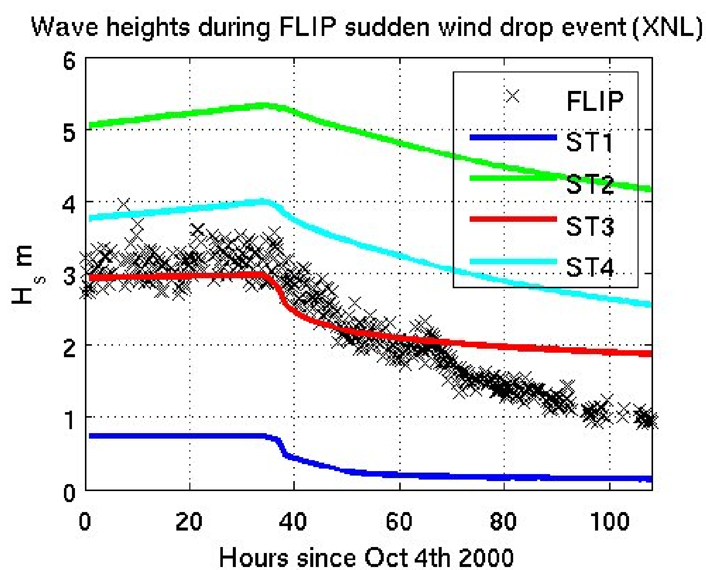
Synoptic conditions during FAIRS contd.

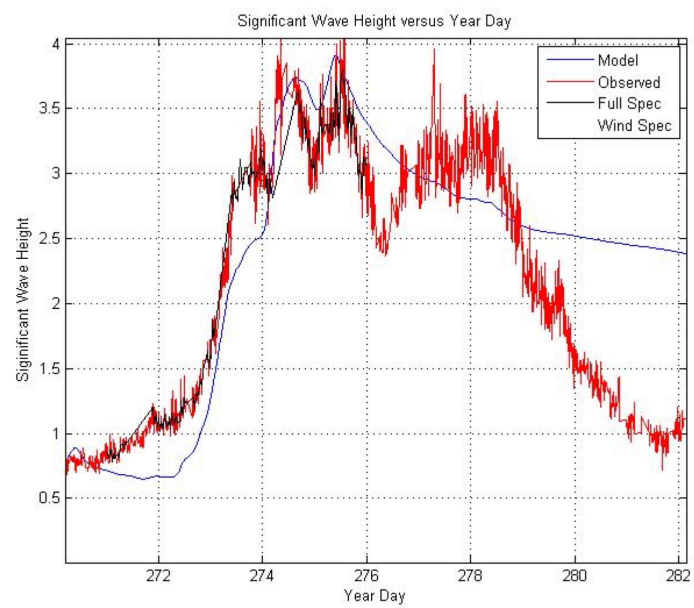


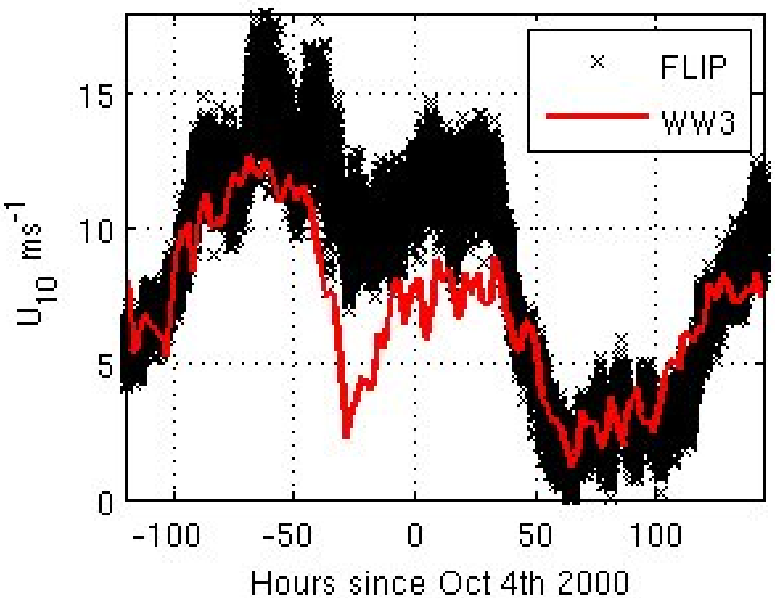
Forecasts of FLIP Sig. Wave height

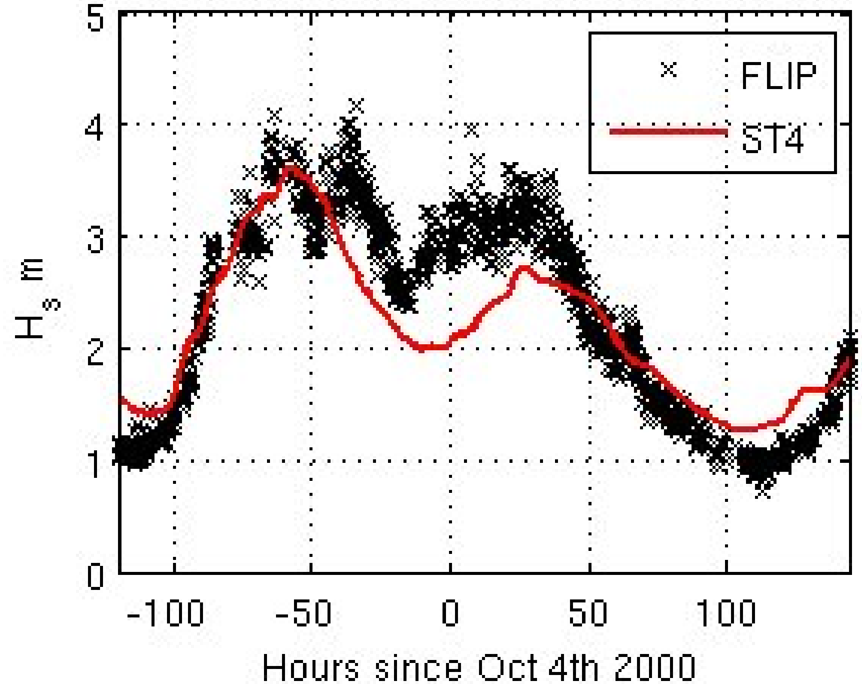


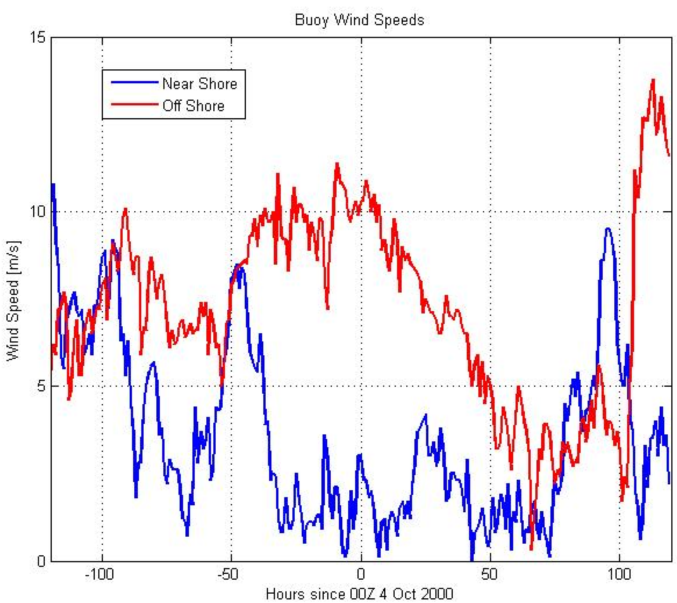


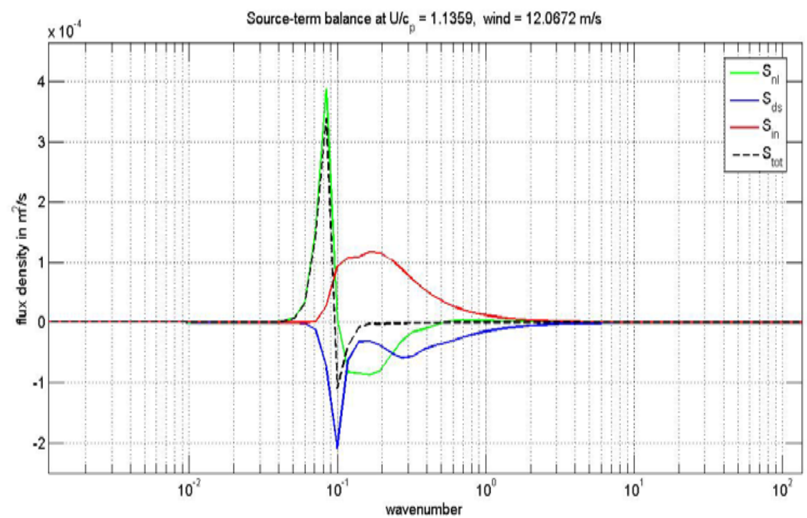





FLIP
WW3
U_{10} ms^{-1}
Hours since Oct 4th 2000

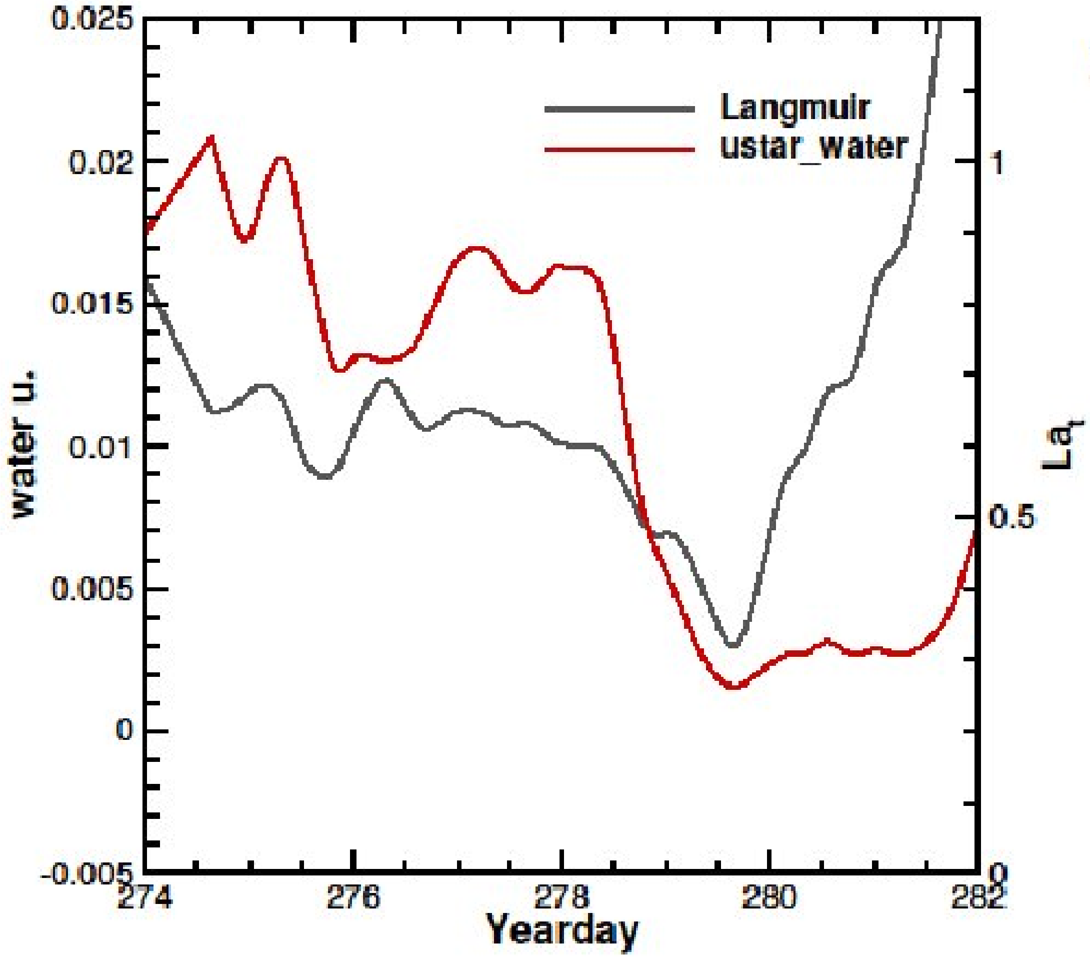

FLIP
ST4
H_s m
Hours since Oct 4th 2000


Buoy Wind Speeds
Near Shore
Off Shore
Wind Speed [m/s]
Hours since 00Z 4 Oct 2000


Source-term balance at U/c_p = 1.1359, wind = 12.0672 m/s
S_{nl}
S_{ds}
S_{in}
S_{tot}
flux density in m^2/s
wavenumber

Is Langmuir turbulence an important source of the wave energy dissipation rate in this case?

- Langmuir number and water u*during the FAIRS decay event



$$La_{tur} = (U_*/U_s)^{1/2}$$

LES OCEAN MODEL WITH WAVE EFFECTS

Momentum

$$\frac{\partial \overline{\mathbf{u}}}{\partial t} = -\nabla \cdot (\overline{\mathbf{u}}\,\overline{\mathbf{u}} + \boldsymbol{\tau}) - \hat{\mathbf{z}}\frac{g\overline{\rho}}{\rho_o} - \nabla \pi - \mathbf{f} \times \overline{\mathbf{u}}$$

$$\boxed{- \mathbf{f} \times \mathbf{u}^{St} + \mathbf{u}^{St} \times \overline{\boldsymbol{\omega}} + \sum_m \overline{\mathbf{A}}_i^m}$$

``Vortex Force"

Stochastic impulses

SGS TKE

$$\frac{\partial e}{\partial t} = \ldots \boxed{- \mathbf{u}^{St} \cdot \nabla e - \boldsymbol{\tau} : \nabla \mathbf{u}^{St} + \sum_m W^m}$$

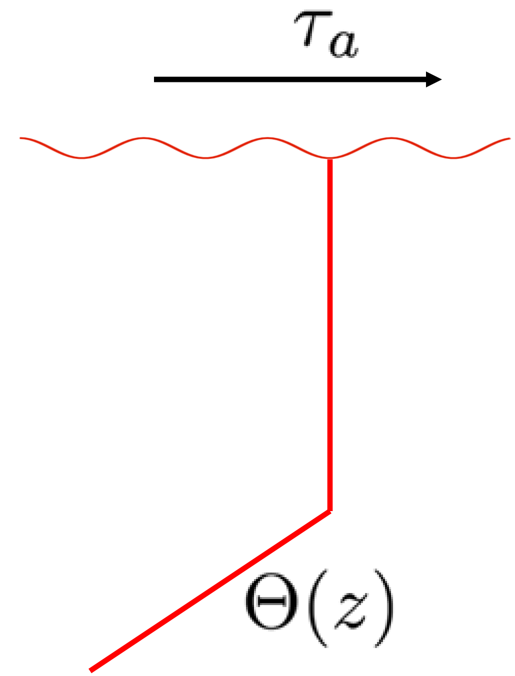
Breaker work

Density

$$\frac{\partial \overline{\rho}}{\partial t} = -\nabla \cdot (\overline{\mathbf{u}}\,\overline{\rho} + \mathbf{B}) - \boxed{\mathbf{u}^{St} \cdot \nabla \overline{\rho}}$$

Sullivan, McWilliams & Melville, JFM, 2007

FAIRS LES EXPERIMENTS



Problem Design

- $U_a \sim [12 \Rightarrow 2]$ m/s
- Neutrally stratified layer bounded below by a stable thermocline
- $h = -32$ m
- Wave age $1.2 < C_p/U_a < 8$
- NO stochastic wave breaking
- Craig & Banner (1994) surface breaking parameterization

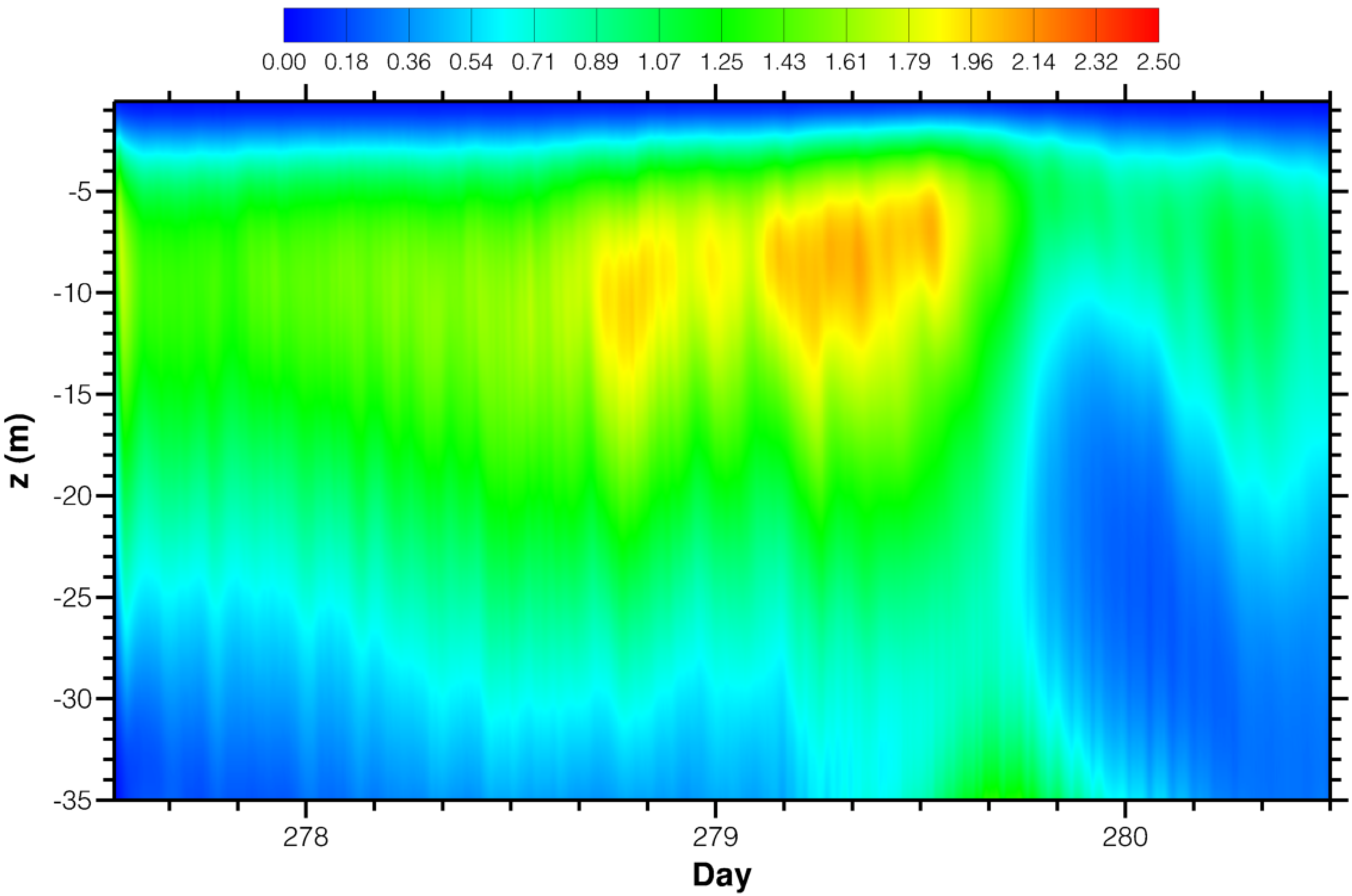
Process Studies

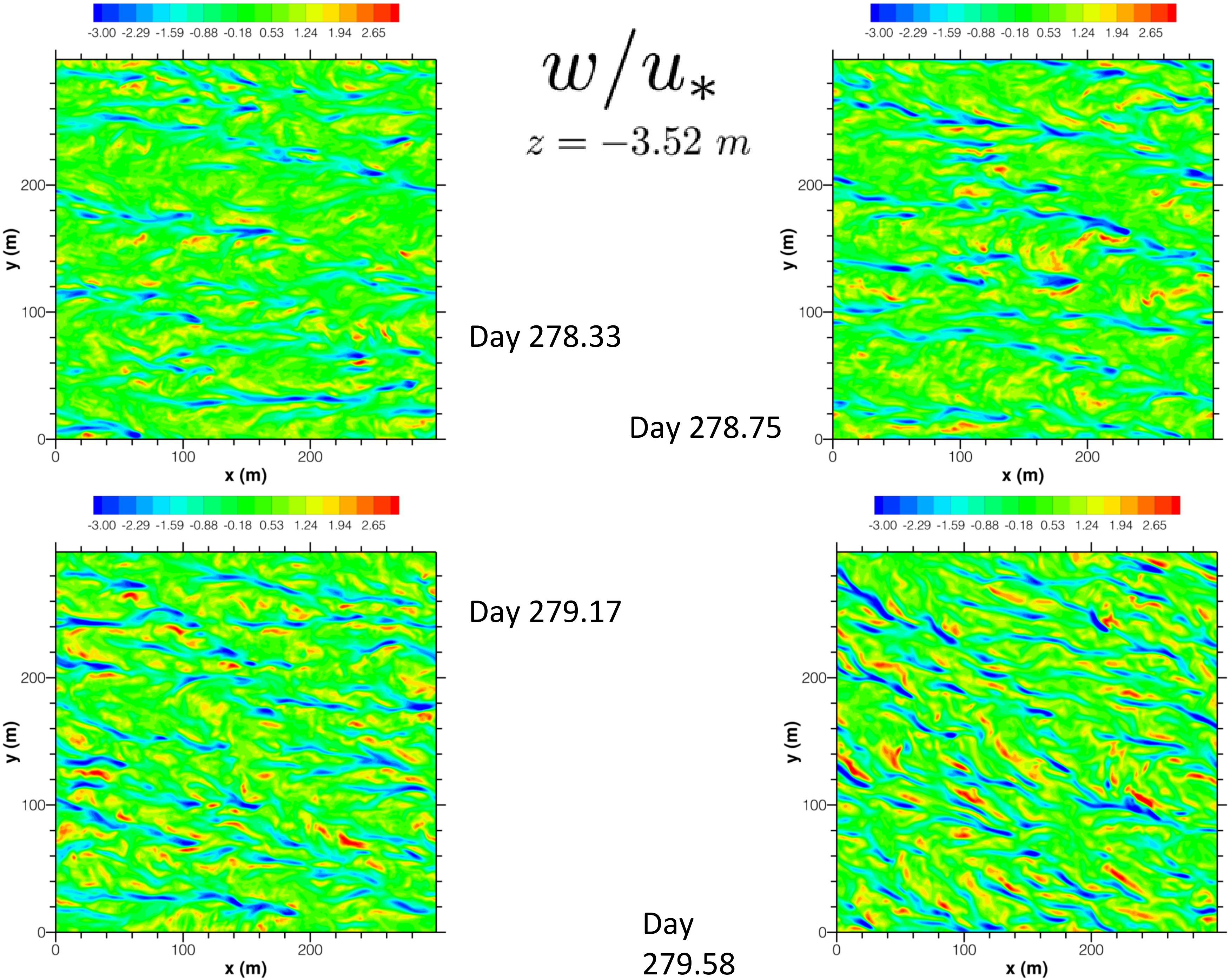
- Uniform surface stress with vortex force and surface breaking
- Monochromatic Stokes drift profile
- Decaying winds from FAIRS, period day [227.5-281]

Discretization

- $X_L = Y_L = 300m, Z_L = -150m$
- $N_x = N_y = 256, N_z = 256$
- $\Delta_x = \Delta_y = 1.17m, \Delta_z \approx [0.5 - 1.5]m$
- $N_{steps} > 60,000$

W-variance in the OBL for Decaying Seas

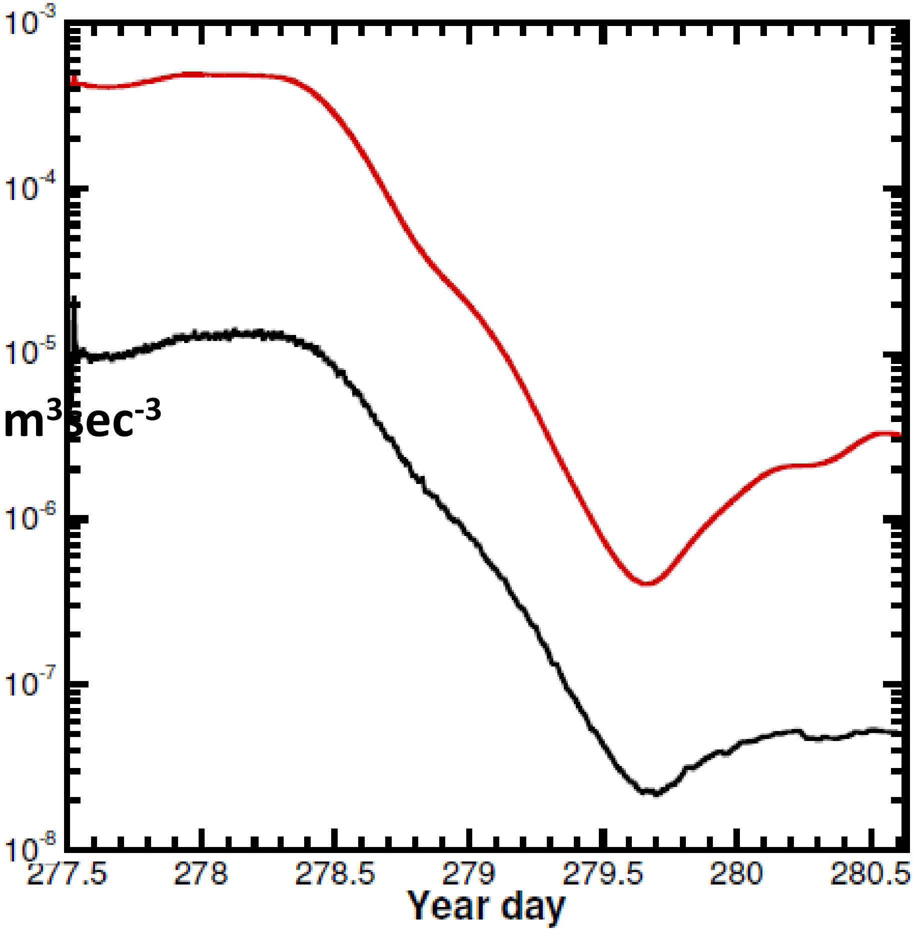




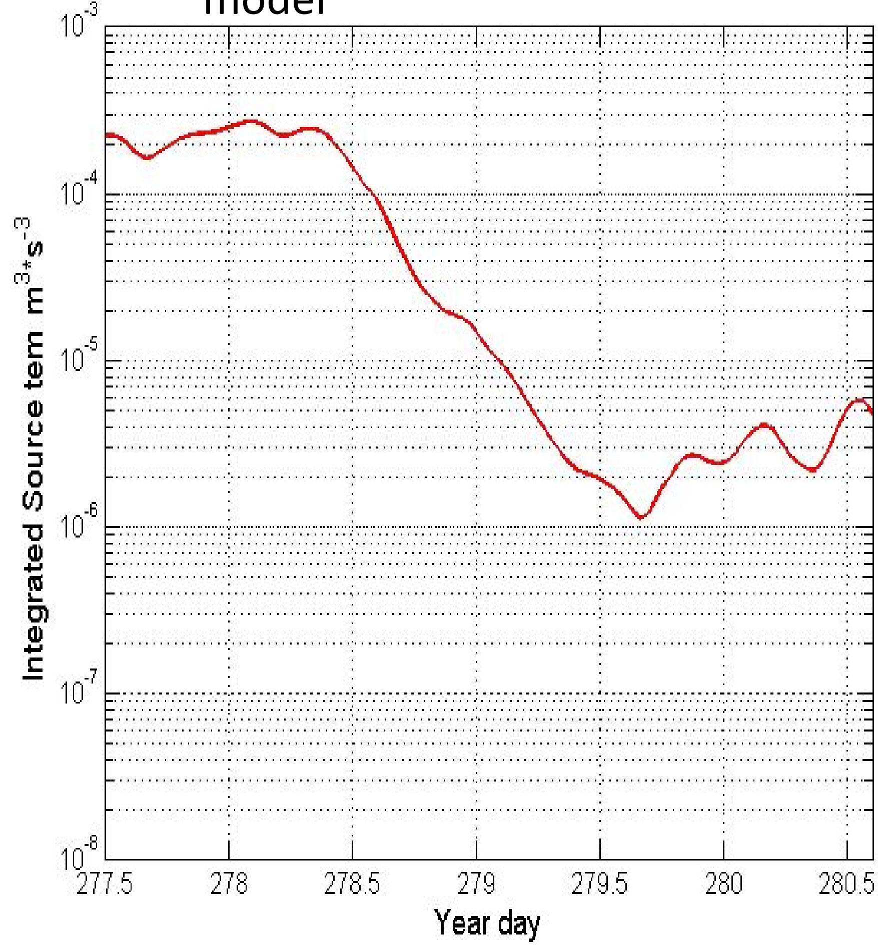
w/u_*
$z = -3.52\ m$
Day 278.33
Day 278.75
Day 279.17
Day 279.58
-3.00 -2.29 -1.59 -0.88 -0.18 0.53 1.24 1.94 2.65
y (m)
x (m)

LES Calculation of Upper Ocean Dissipation Rate and Input Energy Flux to Langmuir Turbulence

Total Water dissipation rate &
Energy flux to Langmuir cells



Integrated Sds from wave model



Conclusions

- Energy flux to Langmuir cell generation does not account for the for the significant observed wave energy dissipation rate.
- current source terms are also unable to account for this, although we are unsure of the winds, which we are further investigating.