Effects of transfer processes on marine atmospheric boundary layer
or
Effects of boundary layer processes on air-sea exchange

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Effect of transfer process on MABL

Swell

Long waves create form drag

Upward momentum flux

Quasi-frictional decoupling at the surface

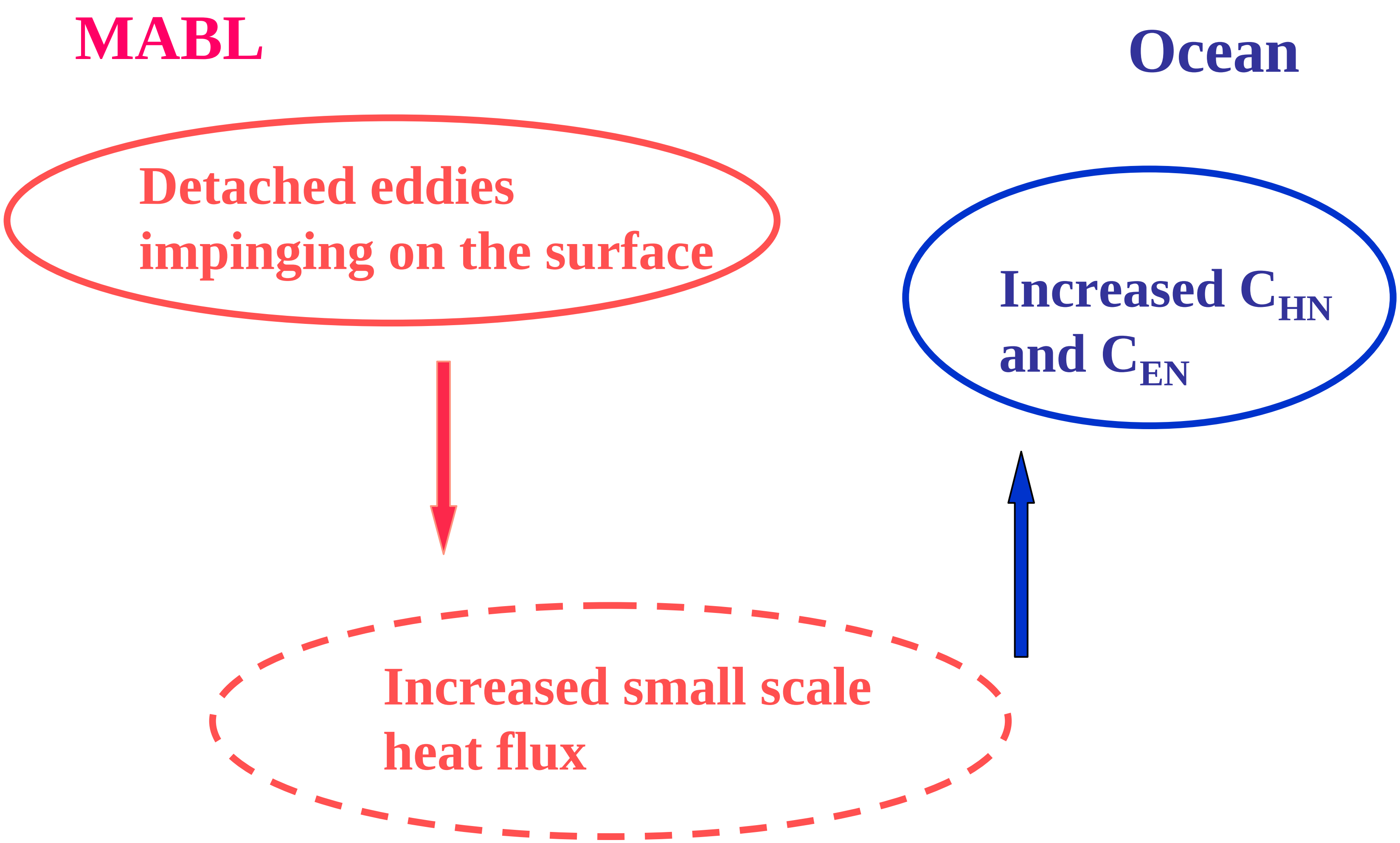
Ocean

MABL

Turbulence resembles free convection conditions

Effect of MABL process on air-sea exchange

UVCN regime



In models air-sea exchange is described through Monin-Obukhov similarity theory a theory which is well tested over land

but

is it valid over the ocean?

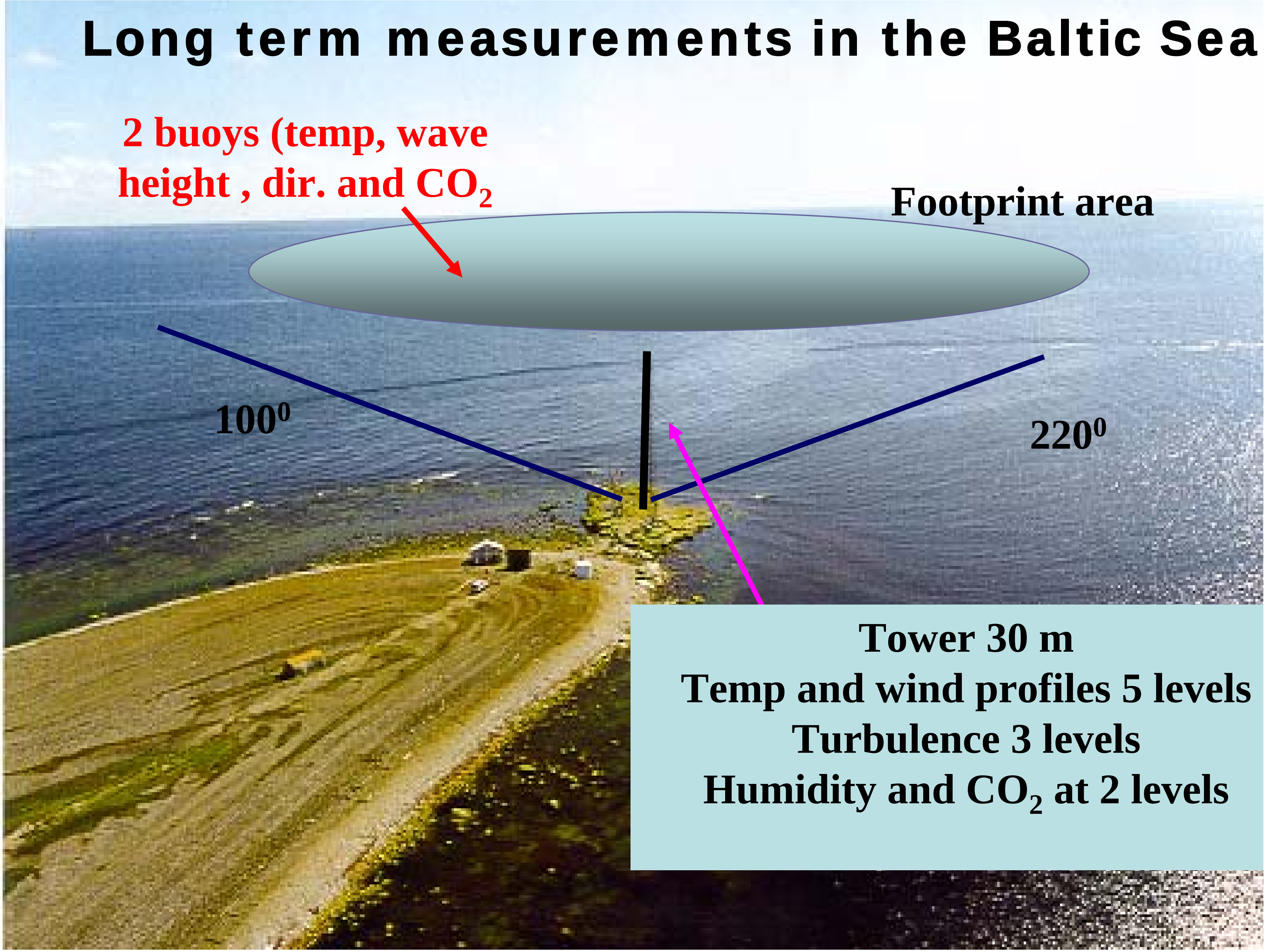
What are the differences ?

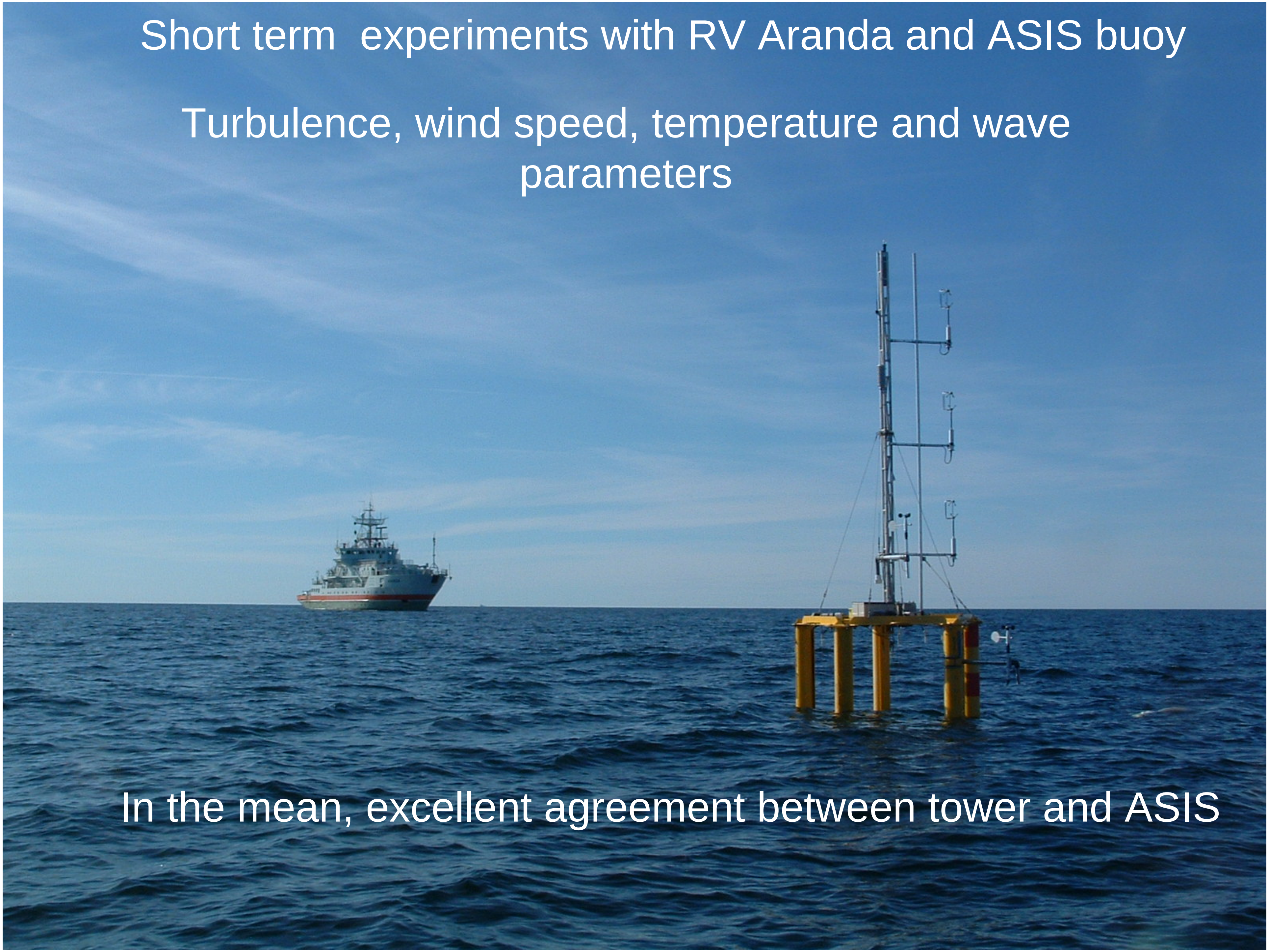
Large heat capacity

Small diurnal variation

Roughness (waves) increasing with increasing wind speed

Long term measurements in the Baltic Sea




Short term experiments with RV Aranda and ASIS buoy
Turbulence, wind speed, temperature and wave parameters
In the mean, excellent agreement between tower and ASIS

Data set from Agile experiment in lake Ontario 1994-95

A 15- m research vessel Agile was equipped to measure waves and turbulence with

- **Sonic R2A**
- **Thermocouple**
- **Licor**
- **Wave staff array**

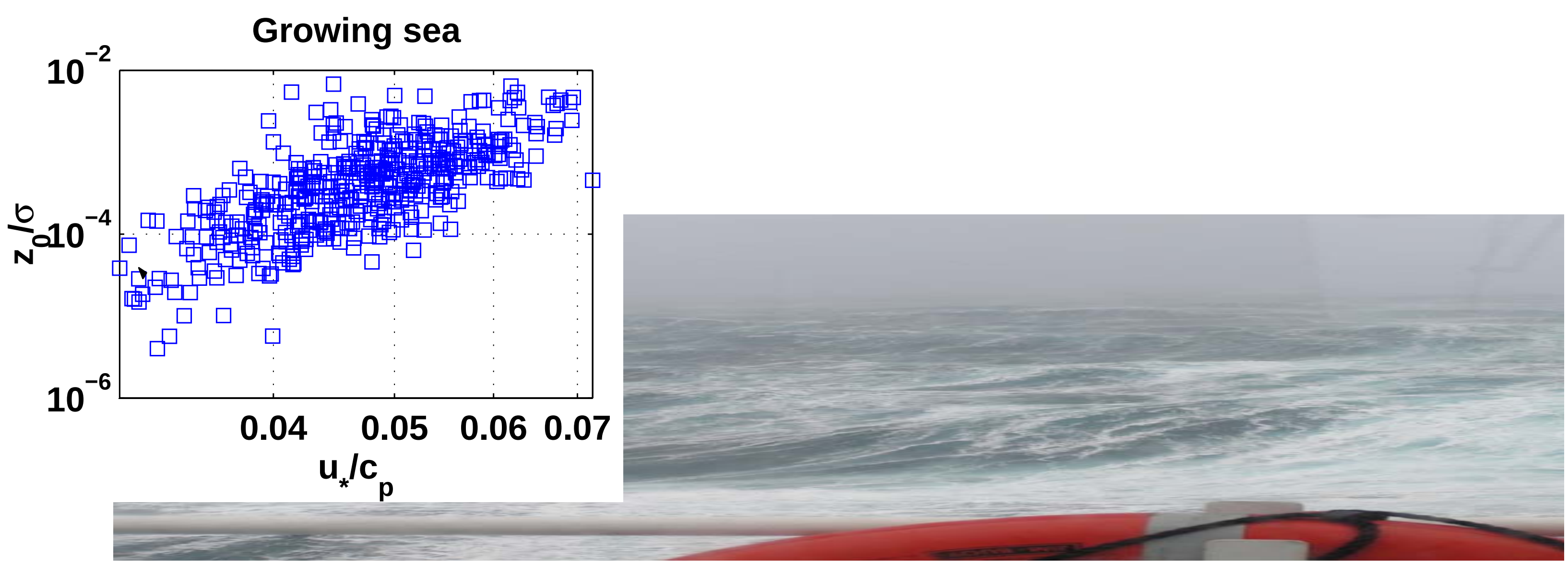
Measurements were performed at 7.8 m during two autumn periods

Growing sea (slow waves)
Unstable stratification

- **Monin-Obukhov similarity theory is valid**

but

roughness length, z_o, is a function of wave age



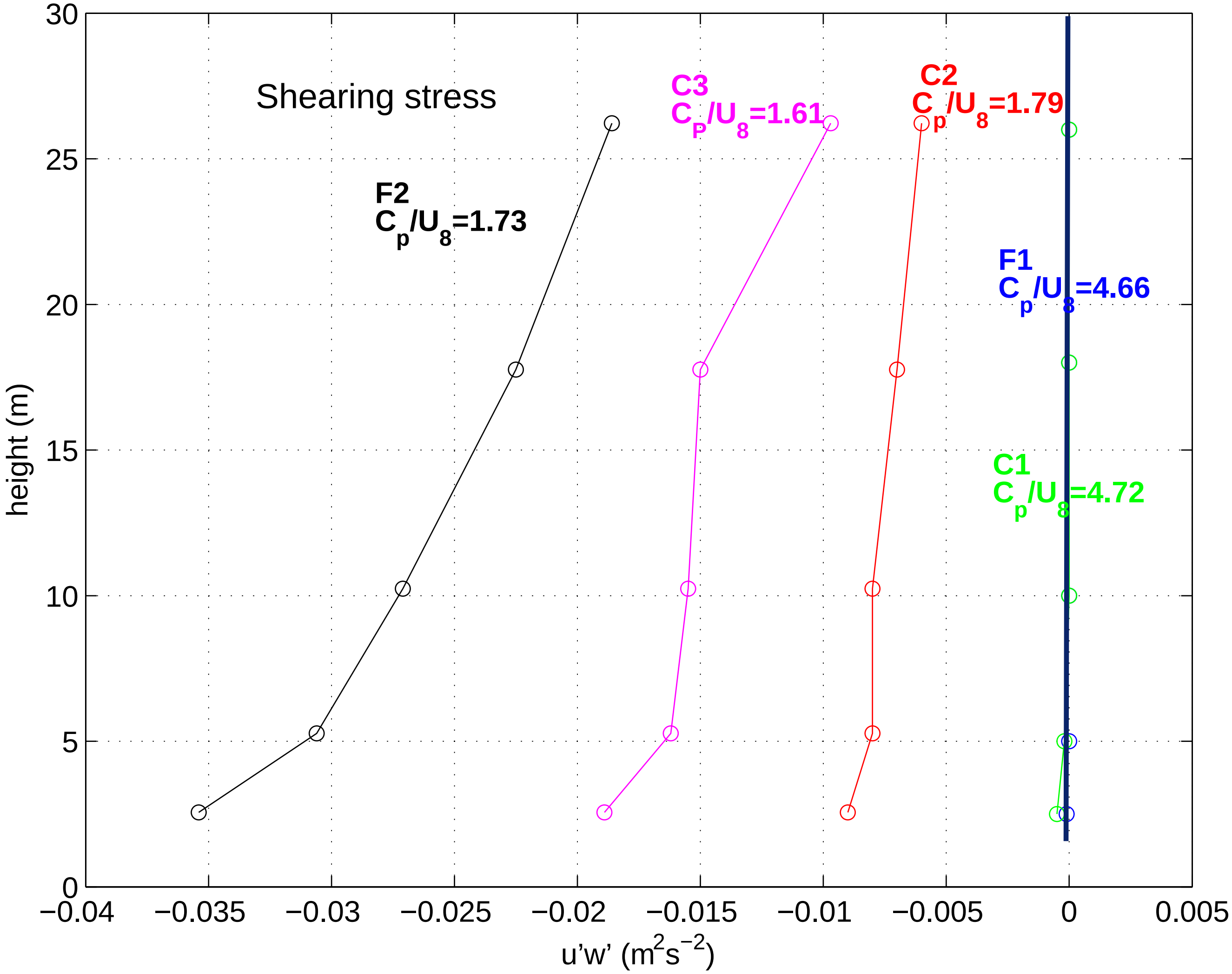
Swell
(long waves traveling faster than the wind)
and
unstable stratification

- **A quite different type of boundary layer develops**

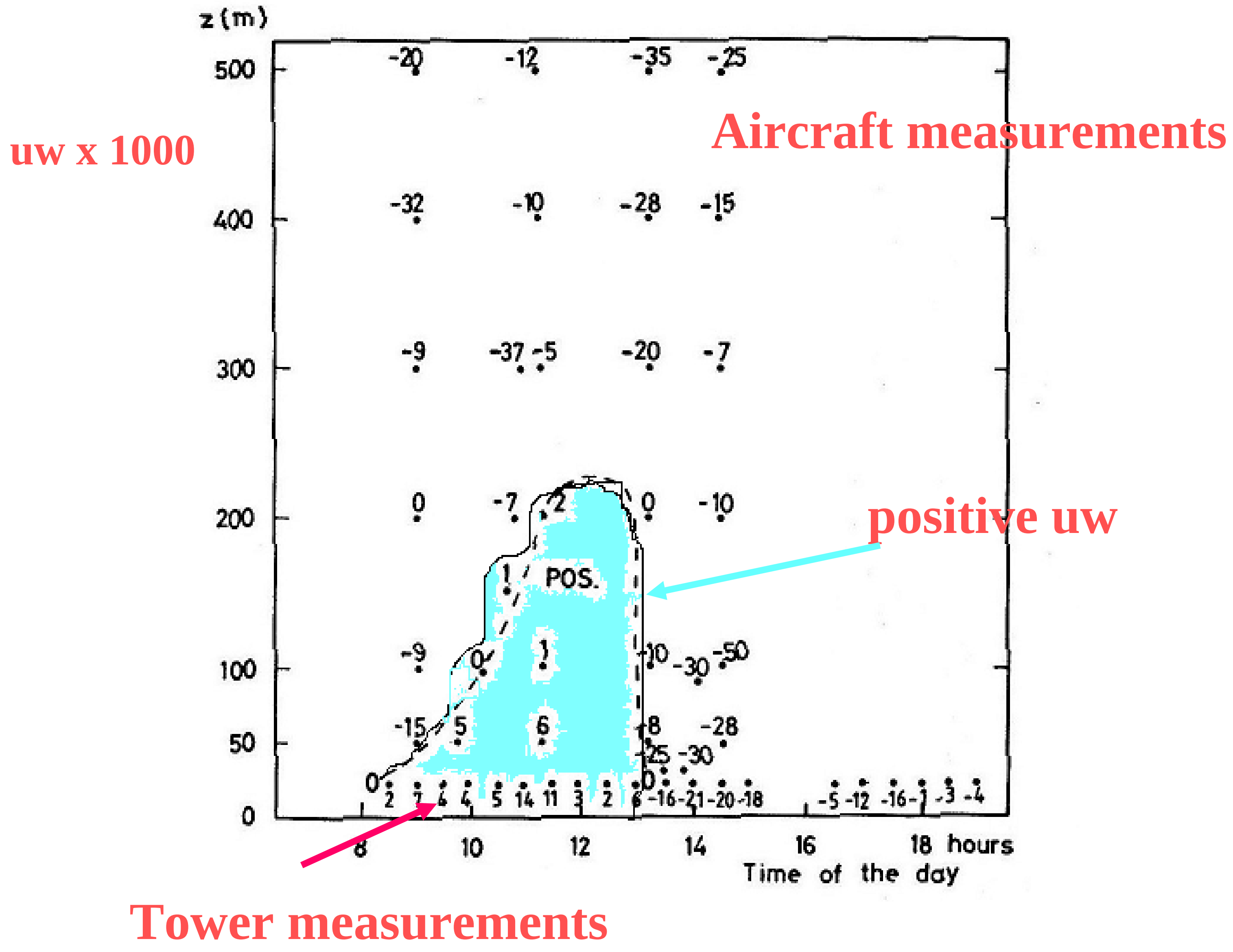
The swell driven BL is characterized by

- **Small or positive momentum flux**
- **Low level jet**
- **M-O scaling does not hold**
- **The vertical extent can be global**
- **Turbulence spectra resemble free convection conditions**
- **Swell represents reverse atmospheric-ocean coupling**

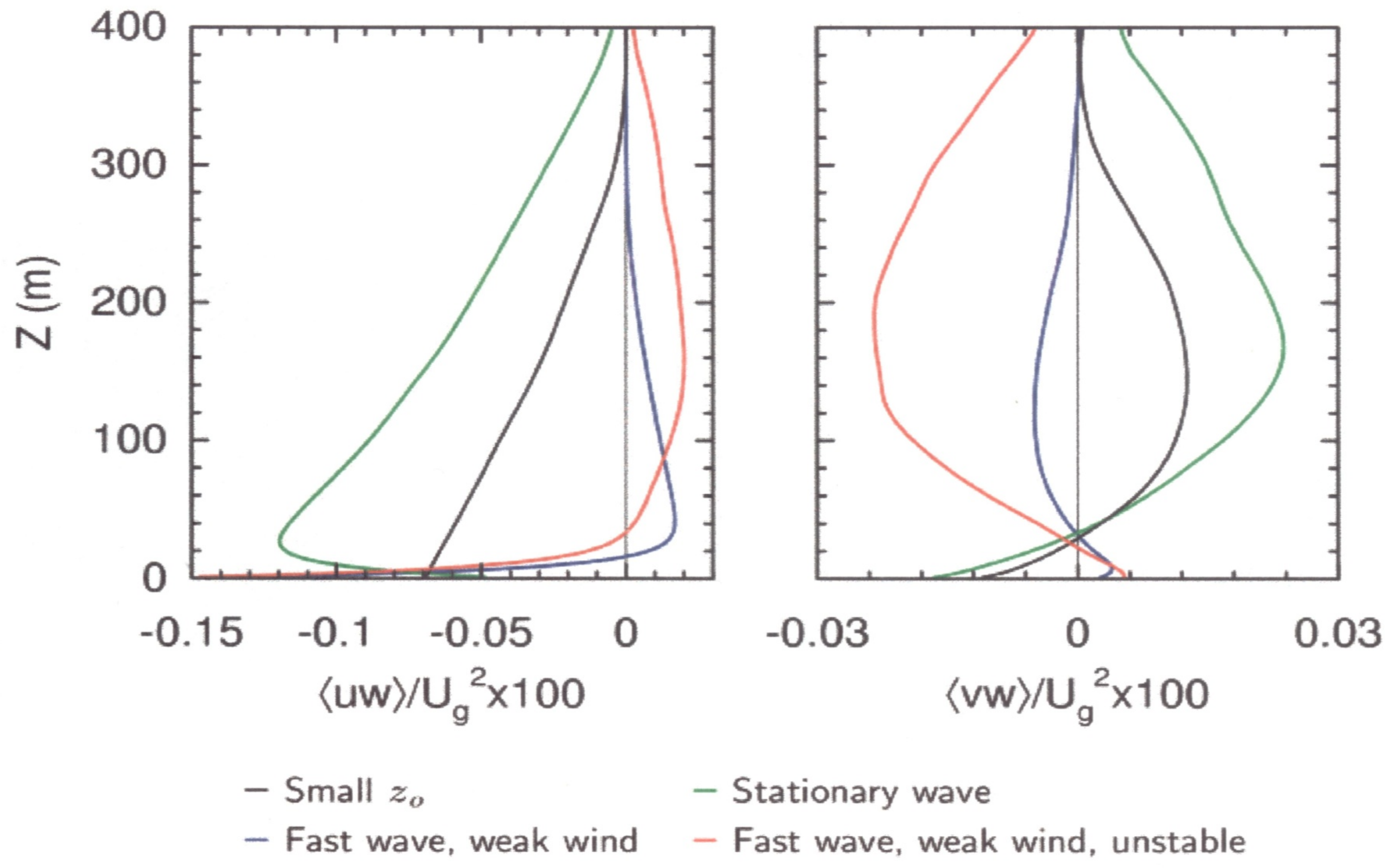
Small momentum flux



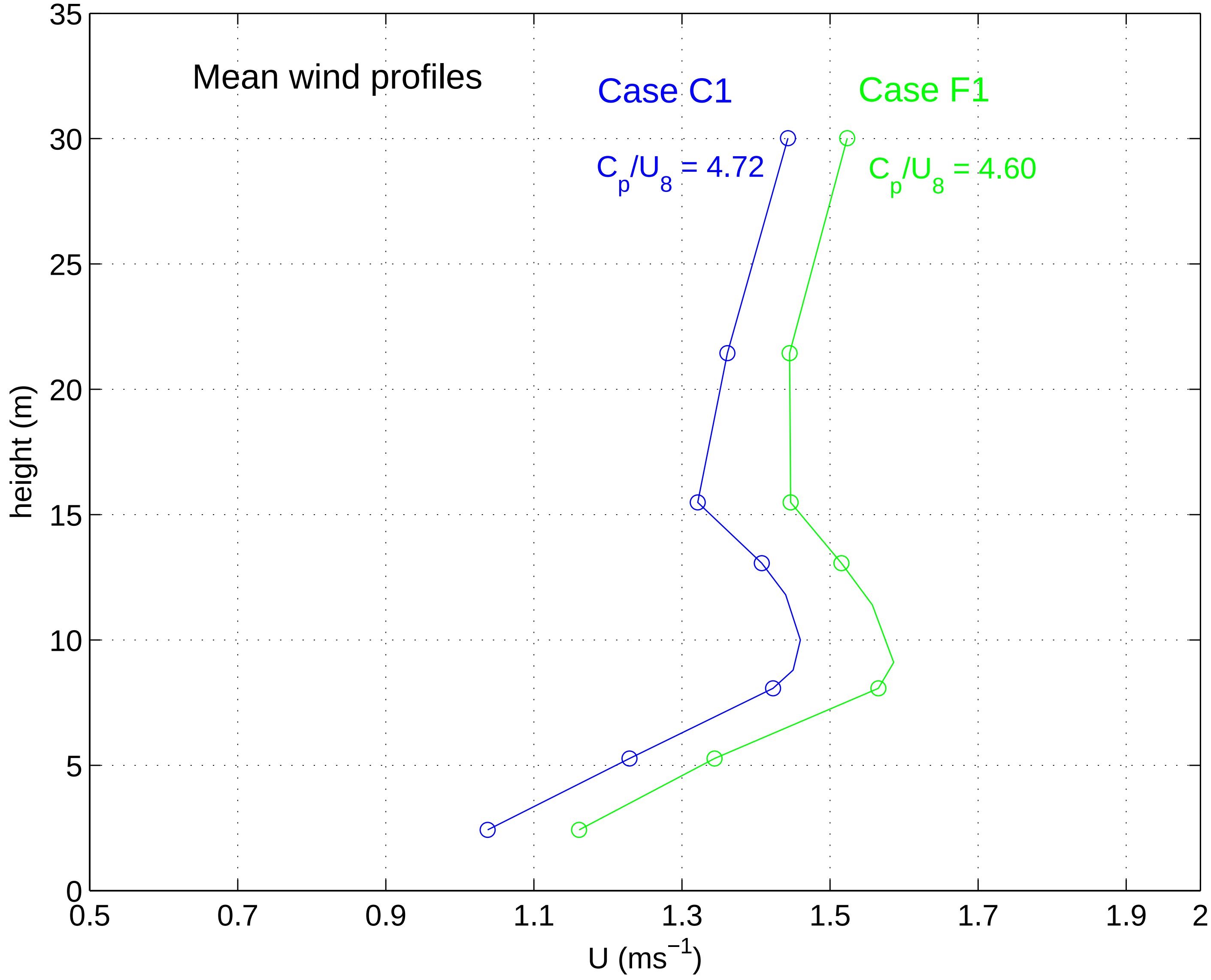
Positive momentum flux

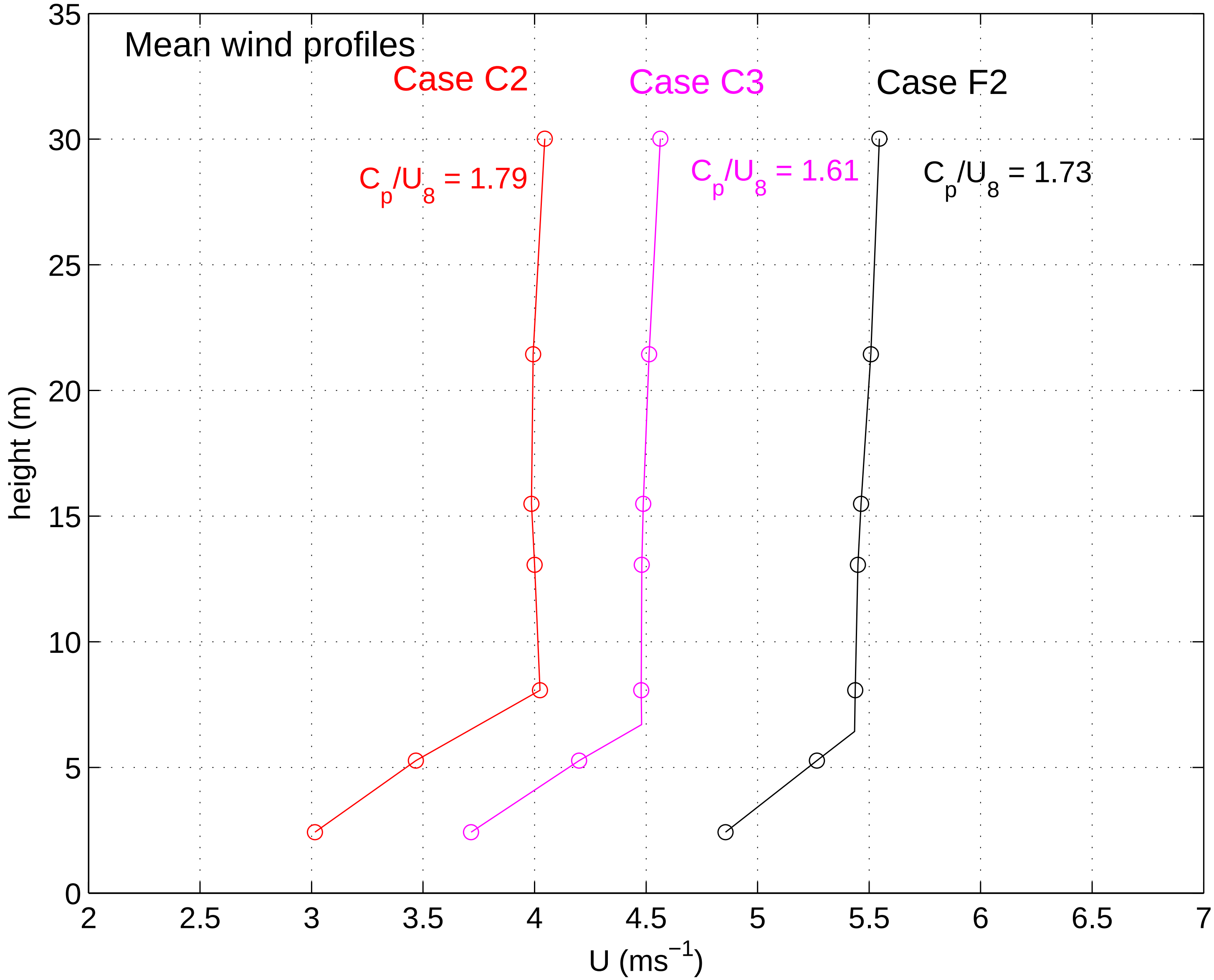


LES simulations Peter Sullivan

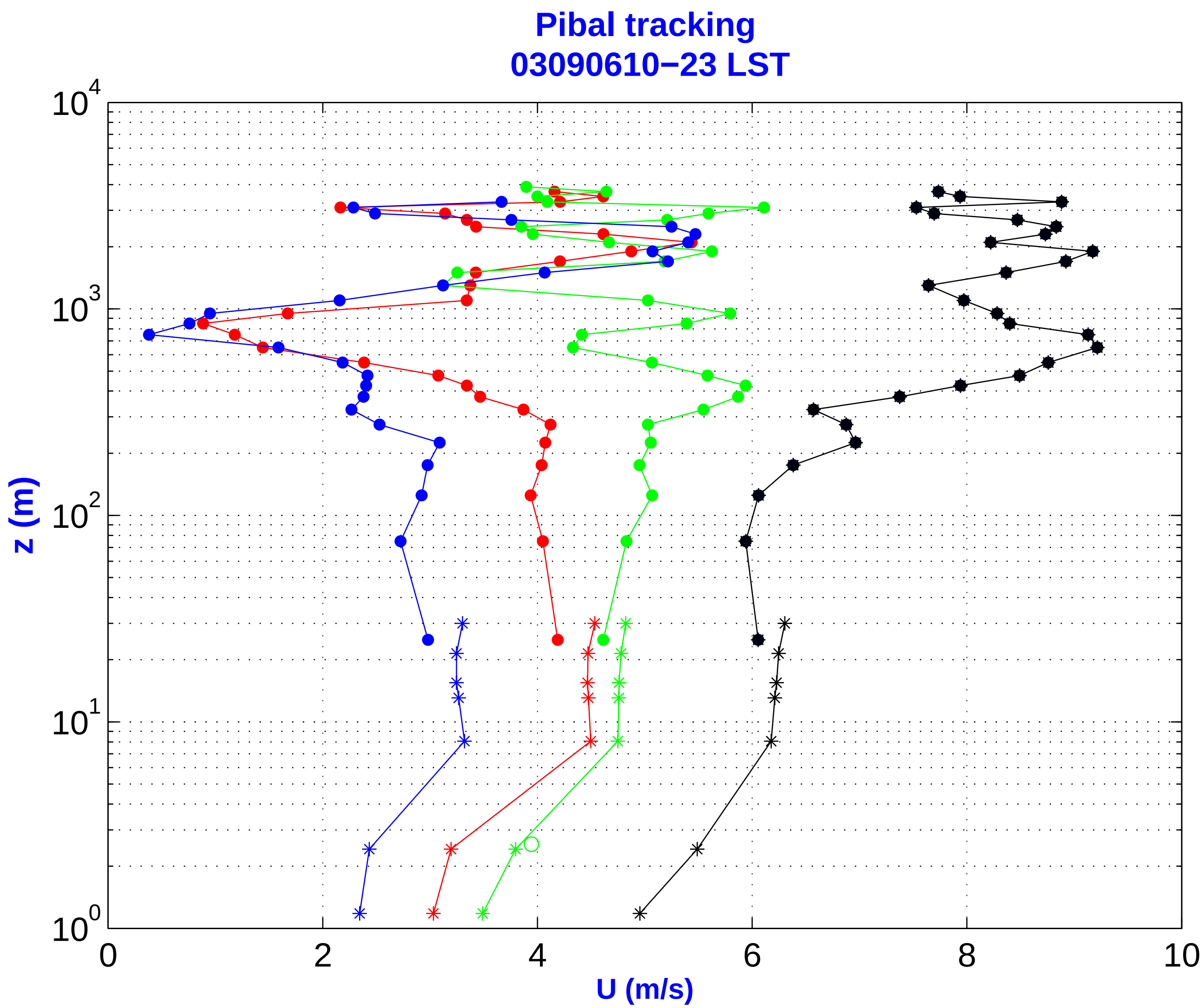


Low level jet

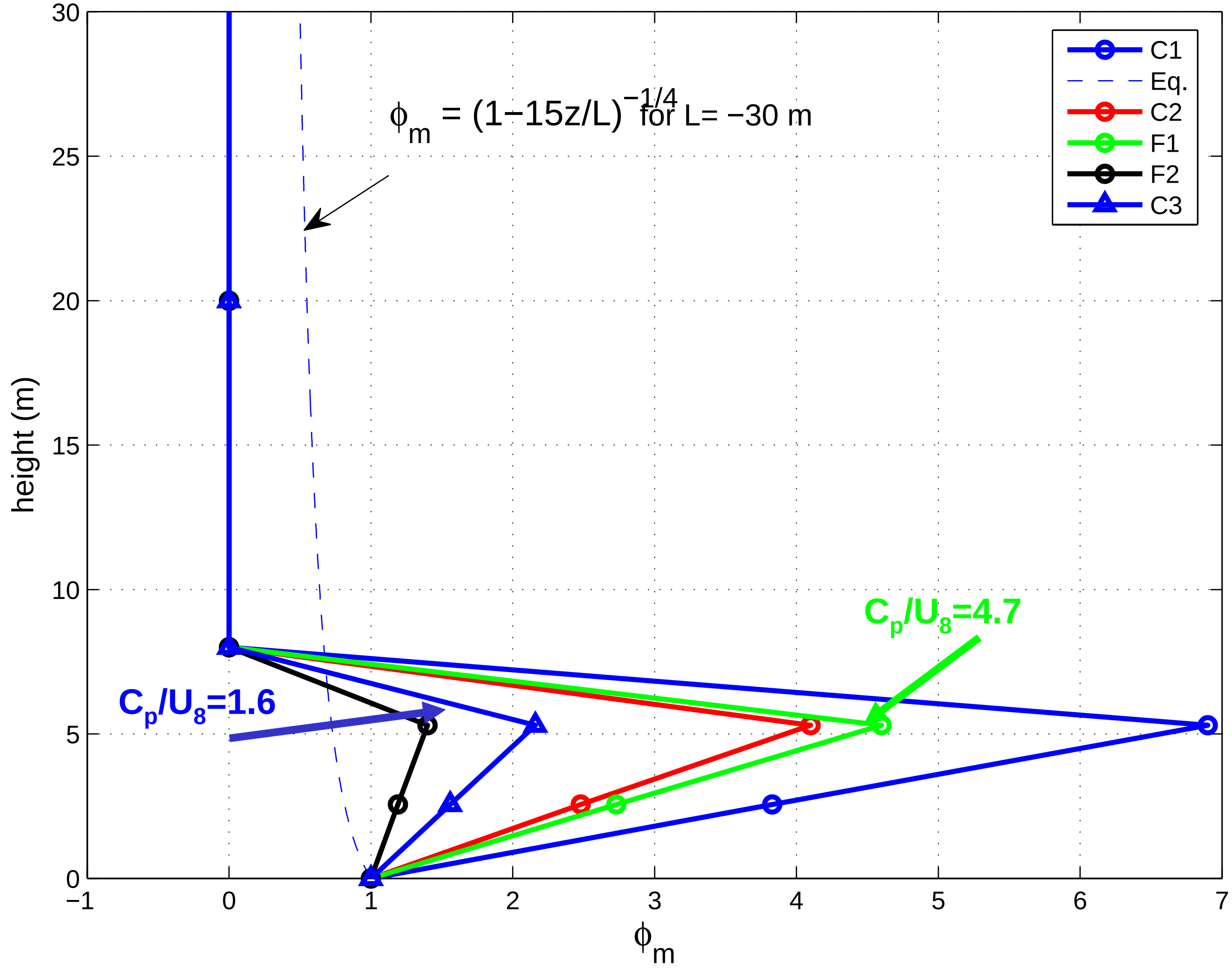



Mean wind profiles
Case C2
Case C3
Case F2
C_p/U_8 = 1.79
C_p/U_8 = 1.61
C_p/U_8 = 1.73
height (m)
U (ms^{-1})
0
5
10
15
20
25
30
35
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7

The vertical extent is global



Φ_m calculated for five swell cases

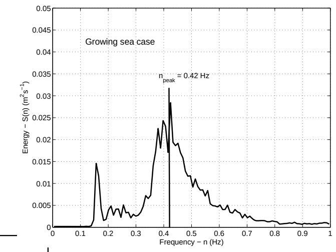


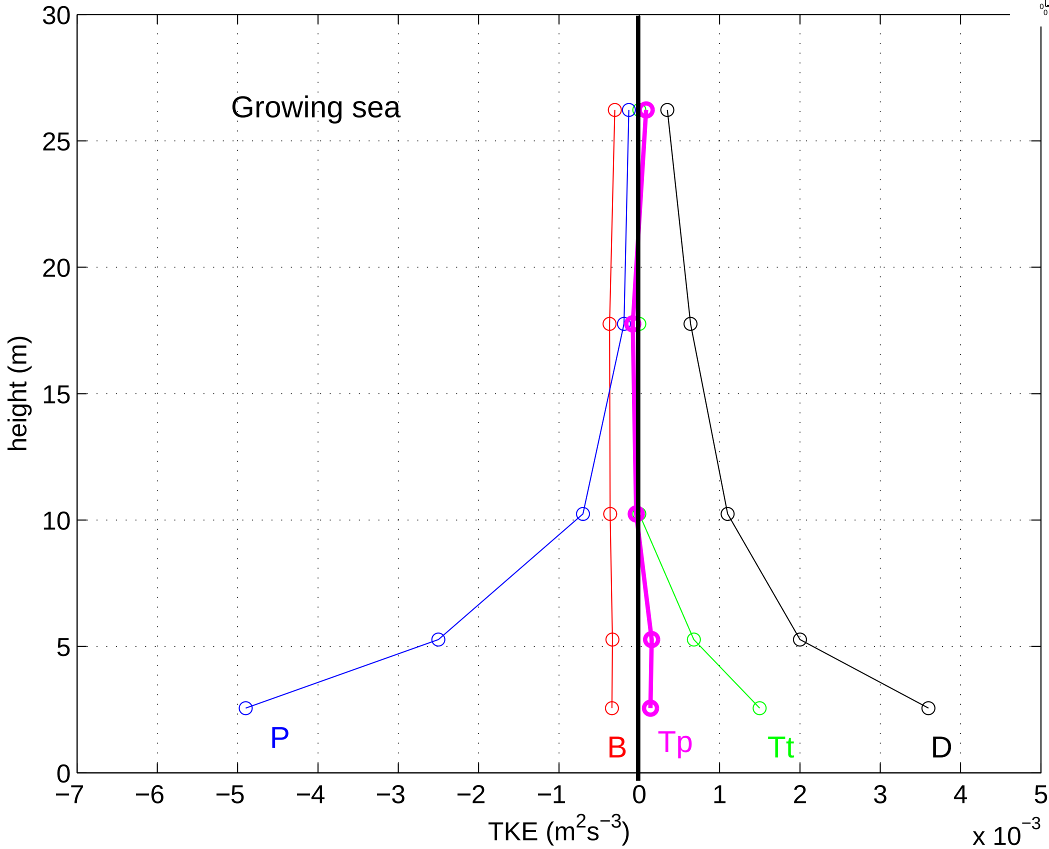
Turbulent kinetic energy budget

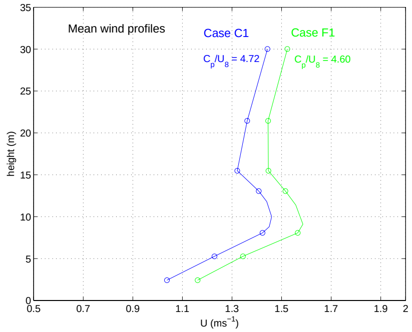
$$0 = \overline{u'w'} \cdot \frac{\partial U}{\partial z} - \frac{g}{T_o}\overline{w'\theta} + \frac{1}{\rho_o} \cdot \frac{\partial \overline{pw'}}{\partial z} + \frac{\partial \overline{w'e}}{\partial z} + \varepsilon$$

P B T_p T_t D

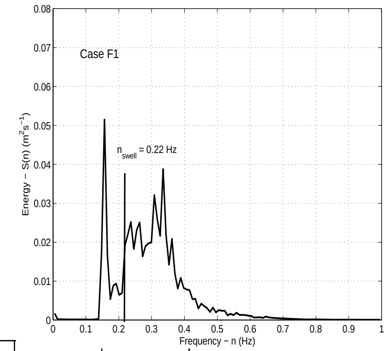
Turbulent energy budget
Growing sea

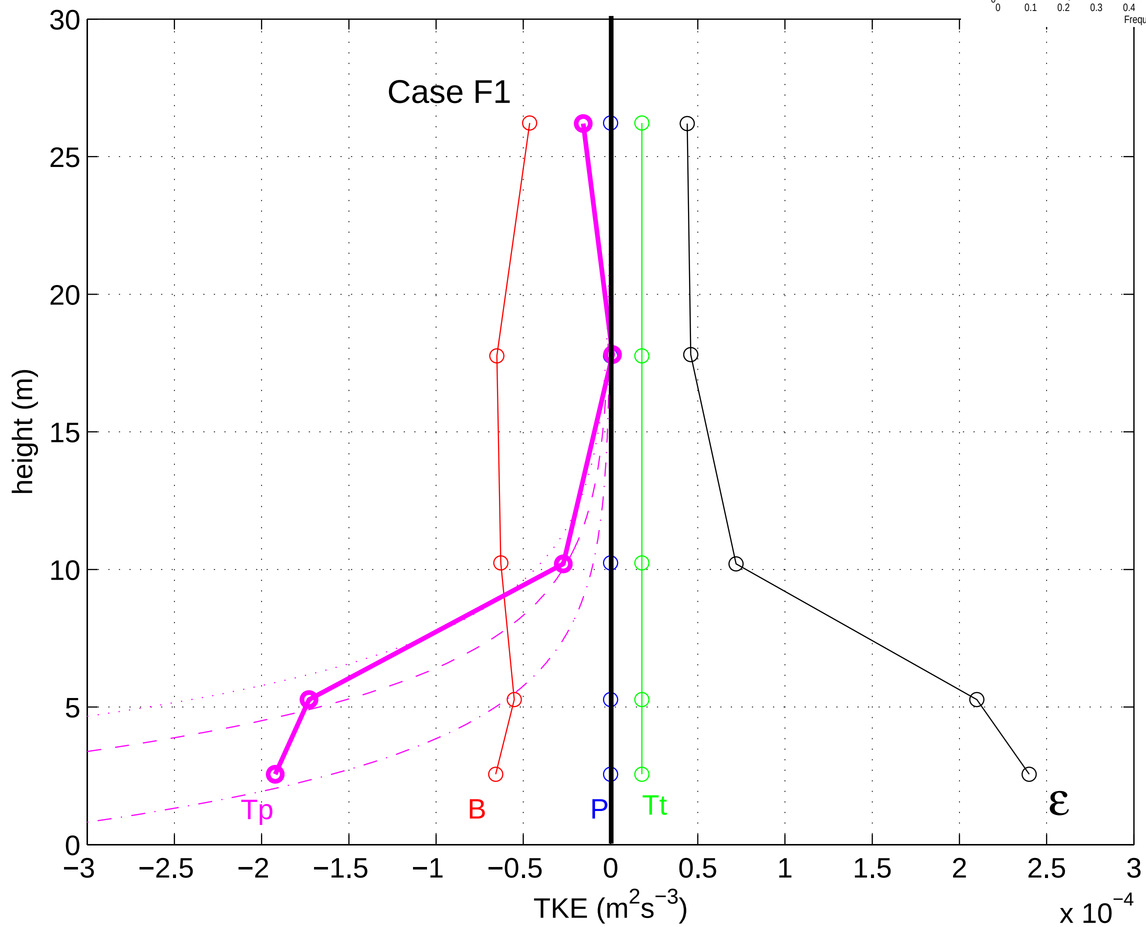


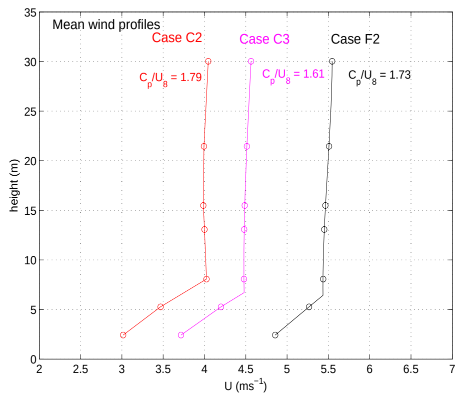




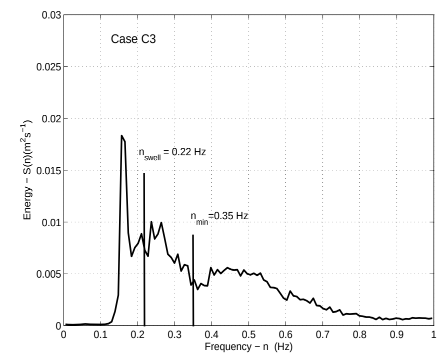
Turbulent energy budget $c_p/U=4.7$

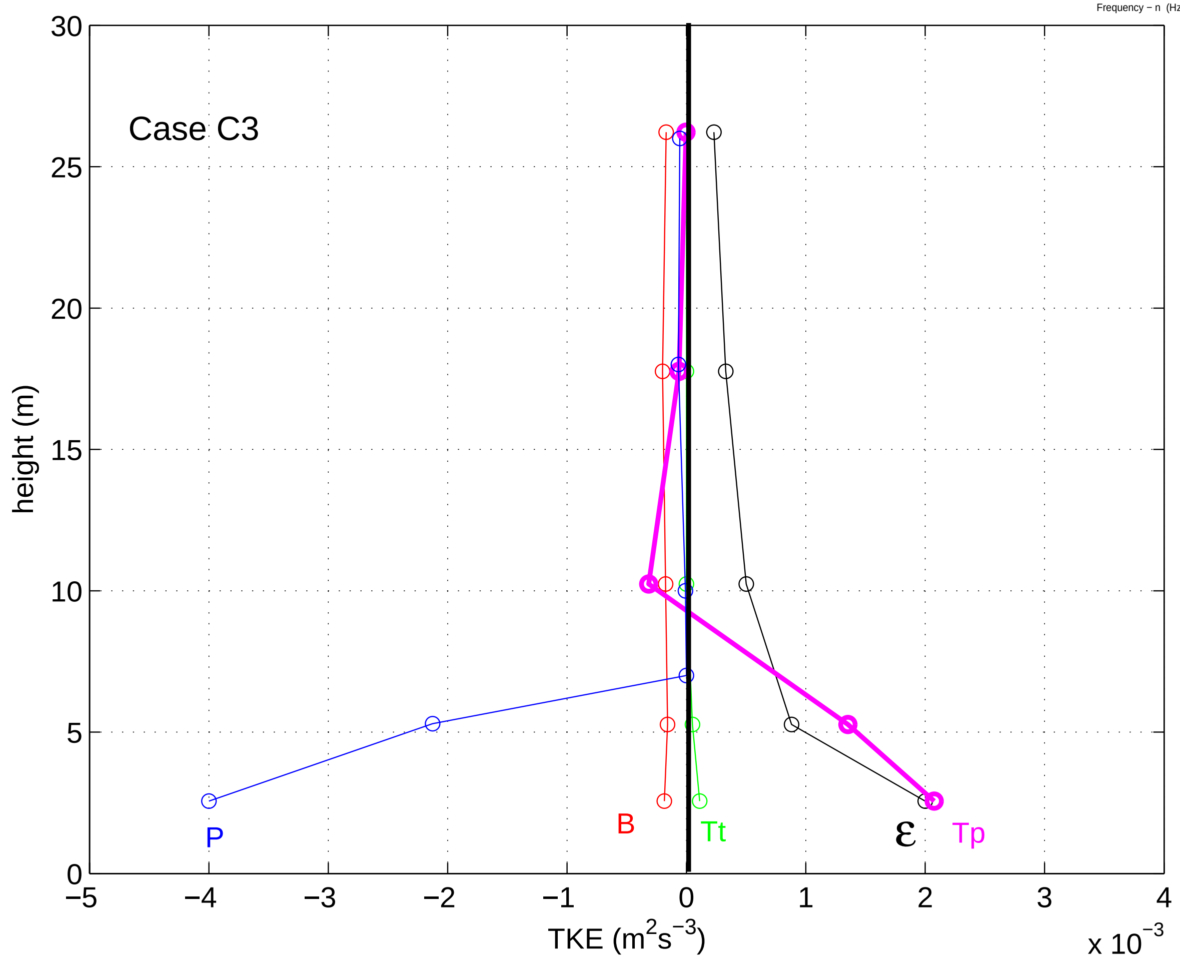






Turbulent energy budget c_p/U=1.6





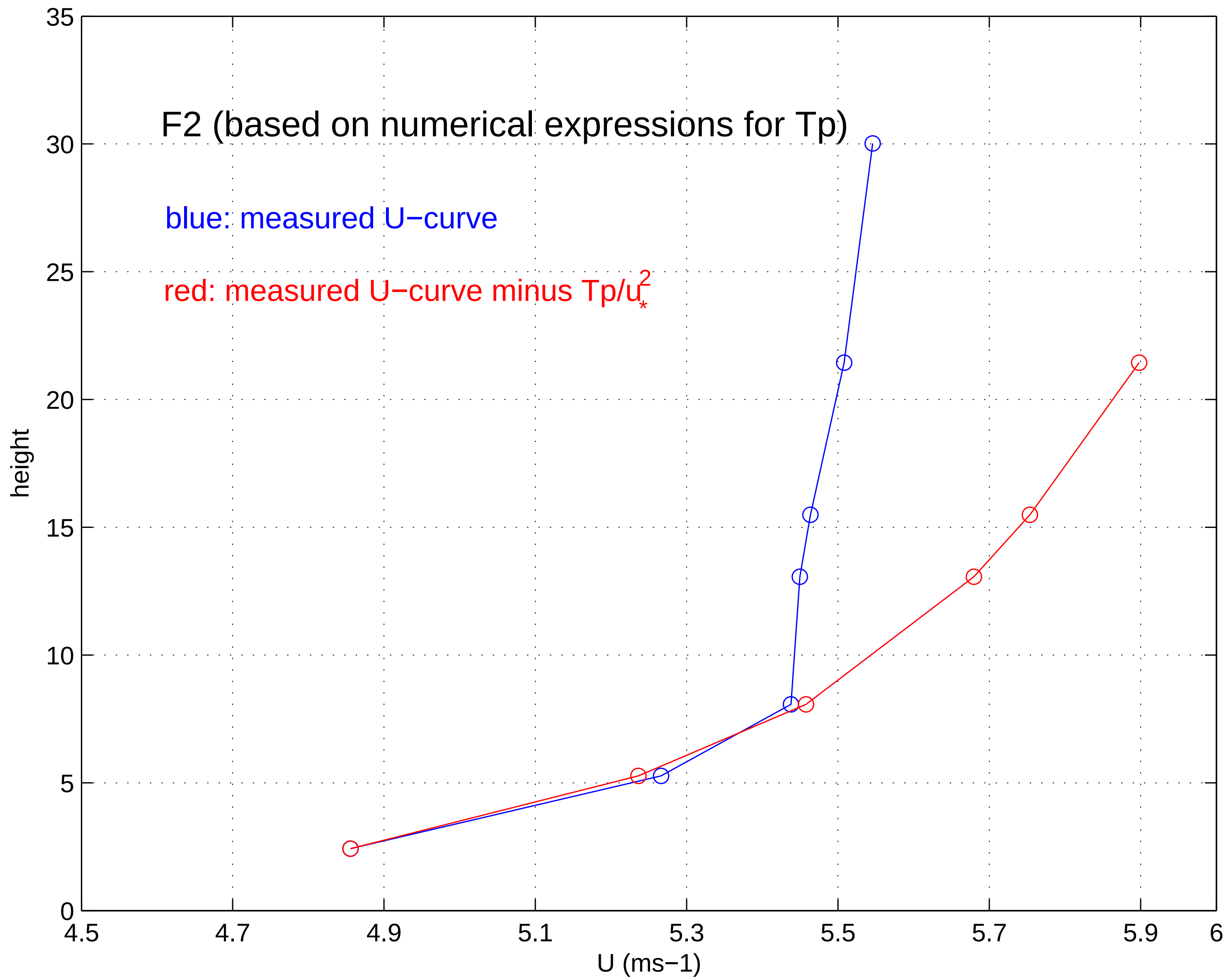
From the turbulence energy eq,

$$\frac{\partial U}{\partial z} = -\frac{1}{\overline{\overline{u'w'}}}\left(-\frac{g}{T}\overline{w'\theta_v'} + \frac{\partial}{\partial z}\frac{\overline{w'q'^2}}{2} + T_p + \varepsilon\right)$$

The effect of T_p can be isolated

$$\left(\frac{\partial U}{\partial z}\right)_{Tp} = -\frac{T_p}{\overline{\overline{u'w'}}}$$

$$U(z) - U(2.5m) = \int_{2.5m}^{z} \frac{T_p}{u_*^2} dz$$


F2 (based on numerical expressions for Tp)
blue: measured U−curve
red: measured U−curve minus Tp/u*2
height
U (ms−1)
35
30
25
20
15
10
5
0
4.5
4.7
4.9
5.1
5.3
5.5
5.7
5.9
6

Heat fluxes

All turbulent fluxes in models must be expressed as mean variables

Stanton number

Heat flux

$$C_H = \frac{\overline{w'\theta'}}{U(T_o - T_s)}$$

Wind speed

Air-sea temperature difference

In the same way for latent heat, C_E

Reduced to neutral stability

Von Karman constant=0.4

$$C_{HN} = \frac{\kappa^2}{\{\ln(z/z_0)\}\{\ln(z/z_{0T})\}}$$

Roughness length

Roughness length for temperature

In the same way for latent heat, C_{EN}

Heat fluxes, unstable stratification $\Delta T > 3^o$

- **Traditional parametrization (COARE algorithm) is valid**
- **No variation with wave age**

Heat fluxes, stable stratification

- **Low-level jets cause shear suppression leading to decreased fluxes**

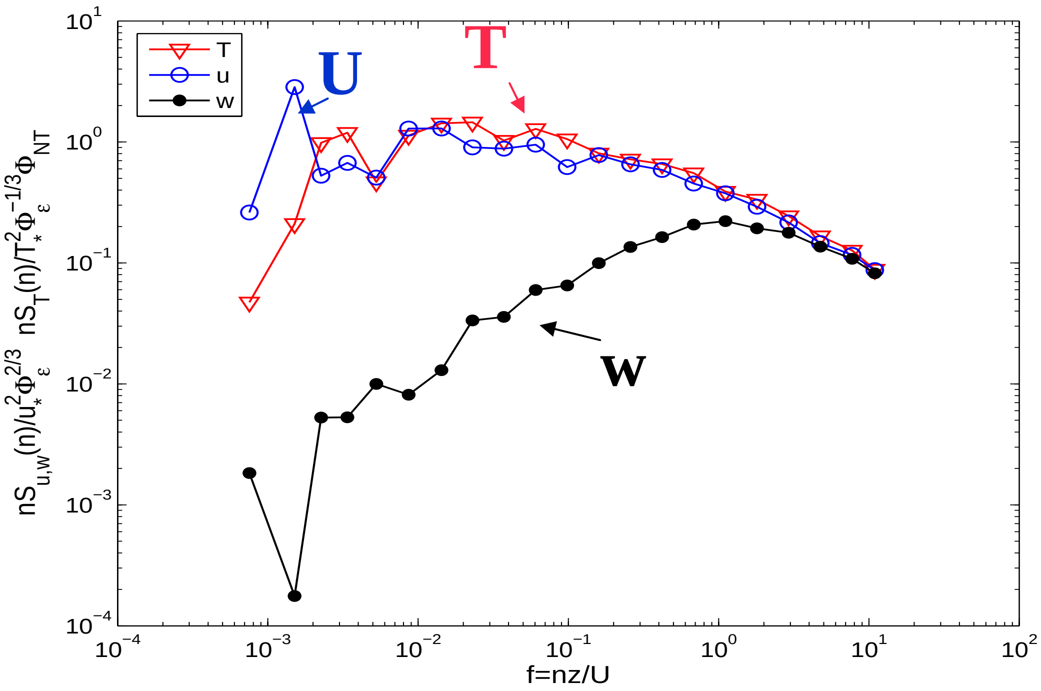
Heat fluxes, unstable stratification, very close to neutral

Wind speed > 10 m/s and $\Delta T < 3^{o}$

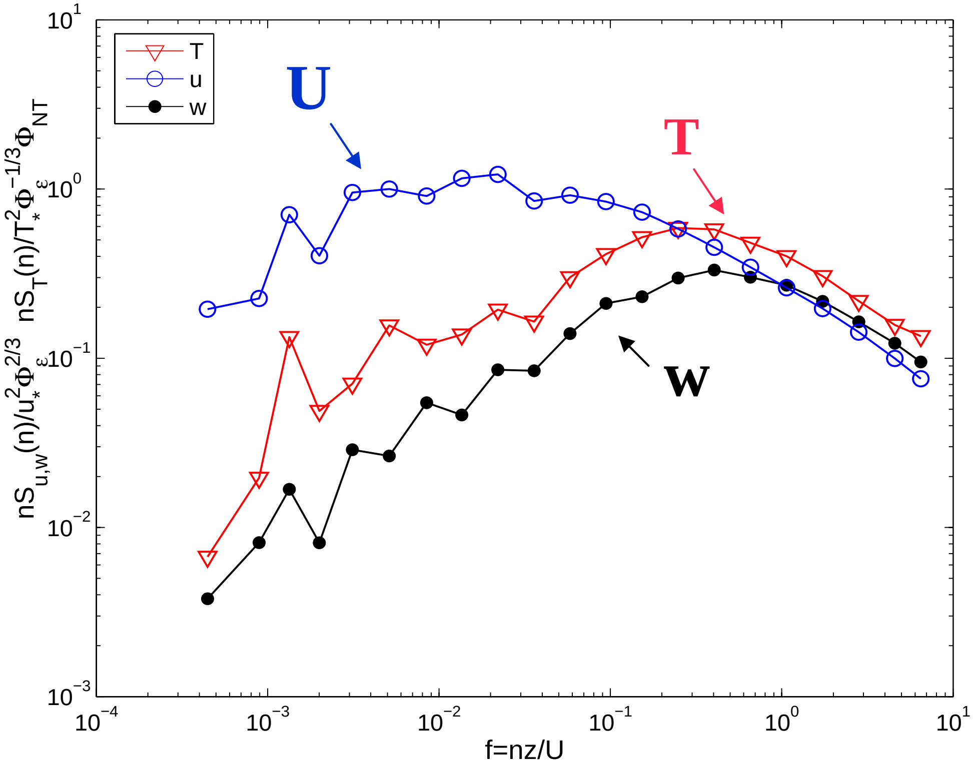
↓

Fluxes are underestimated with COARE algorithm

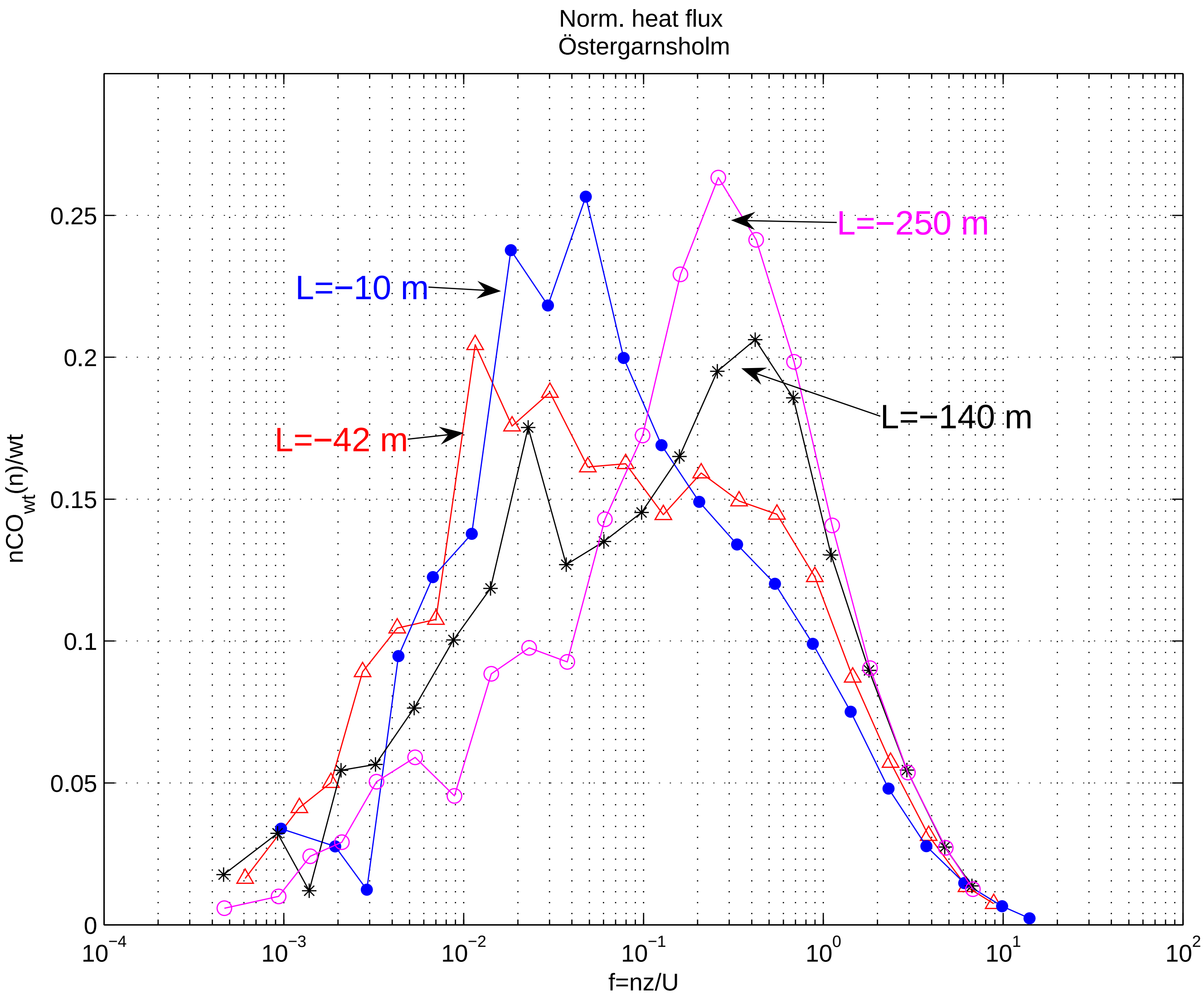
Unstable stratification -- horizontal rolls



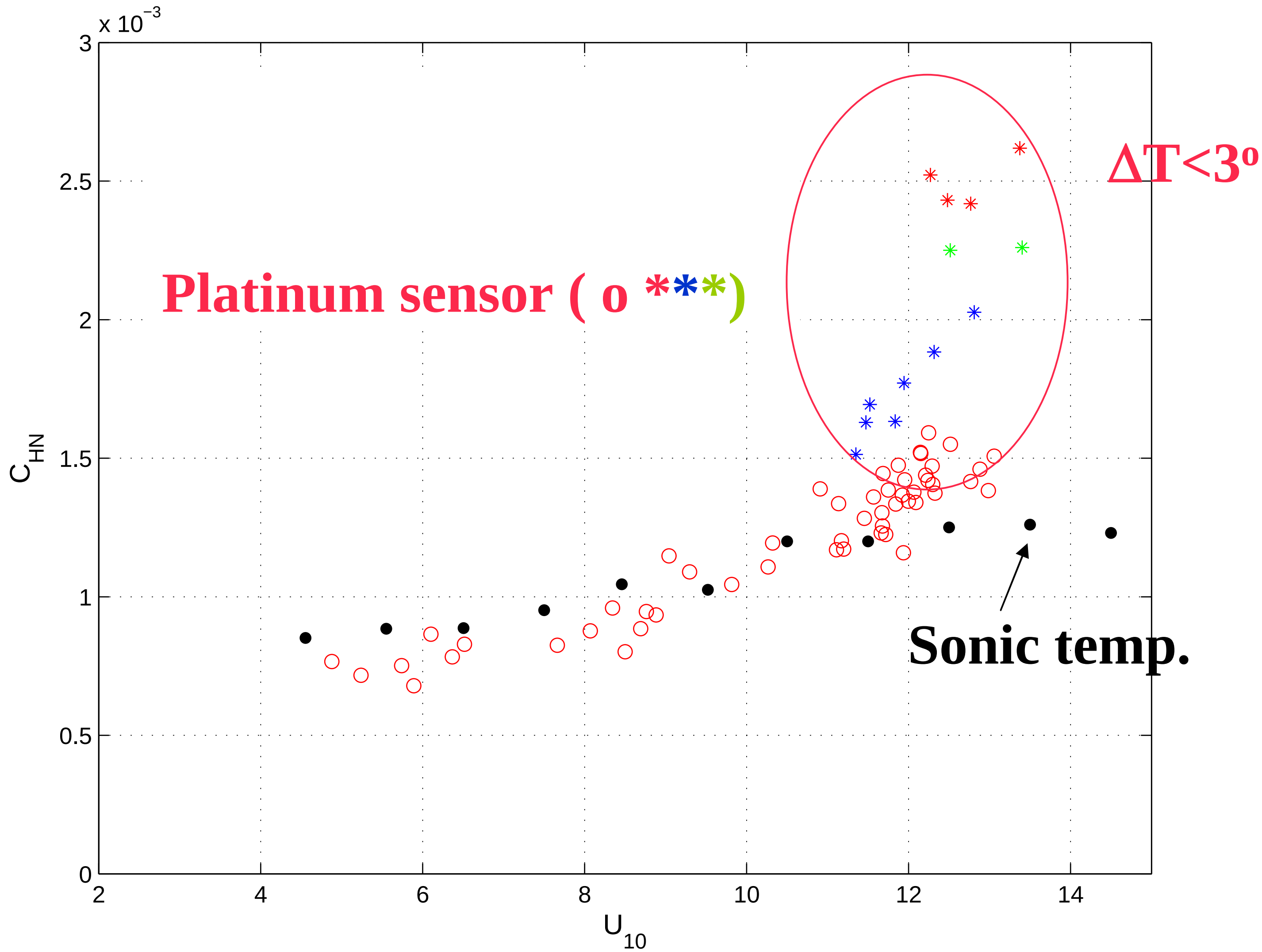
Unstable near neutral -- detached eddies



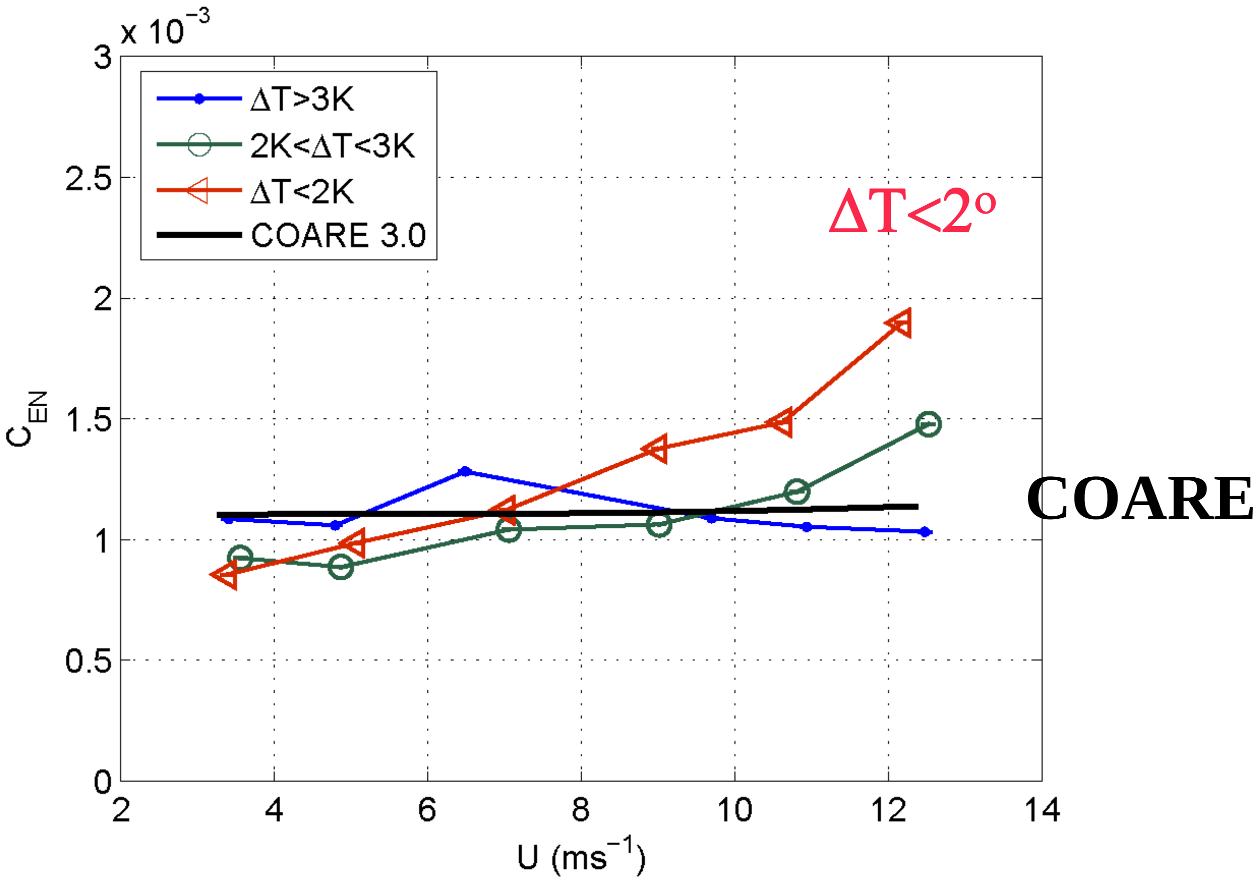
Normalized heat fluxes



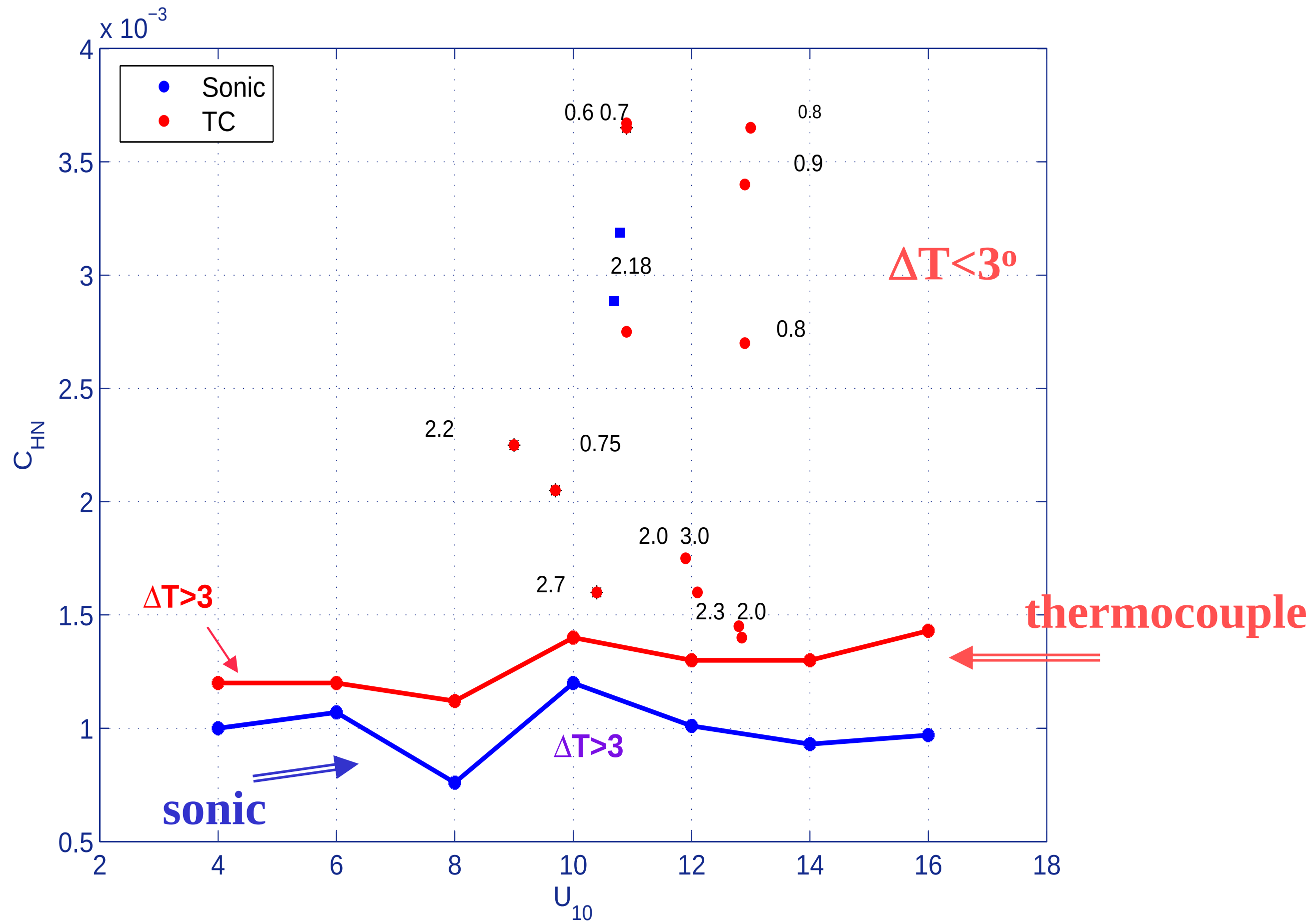
Heat flux from Östergarnsholm



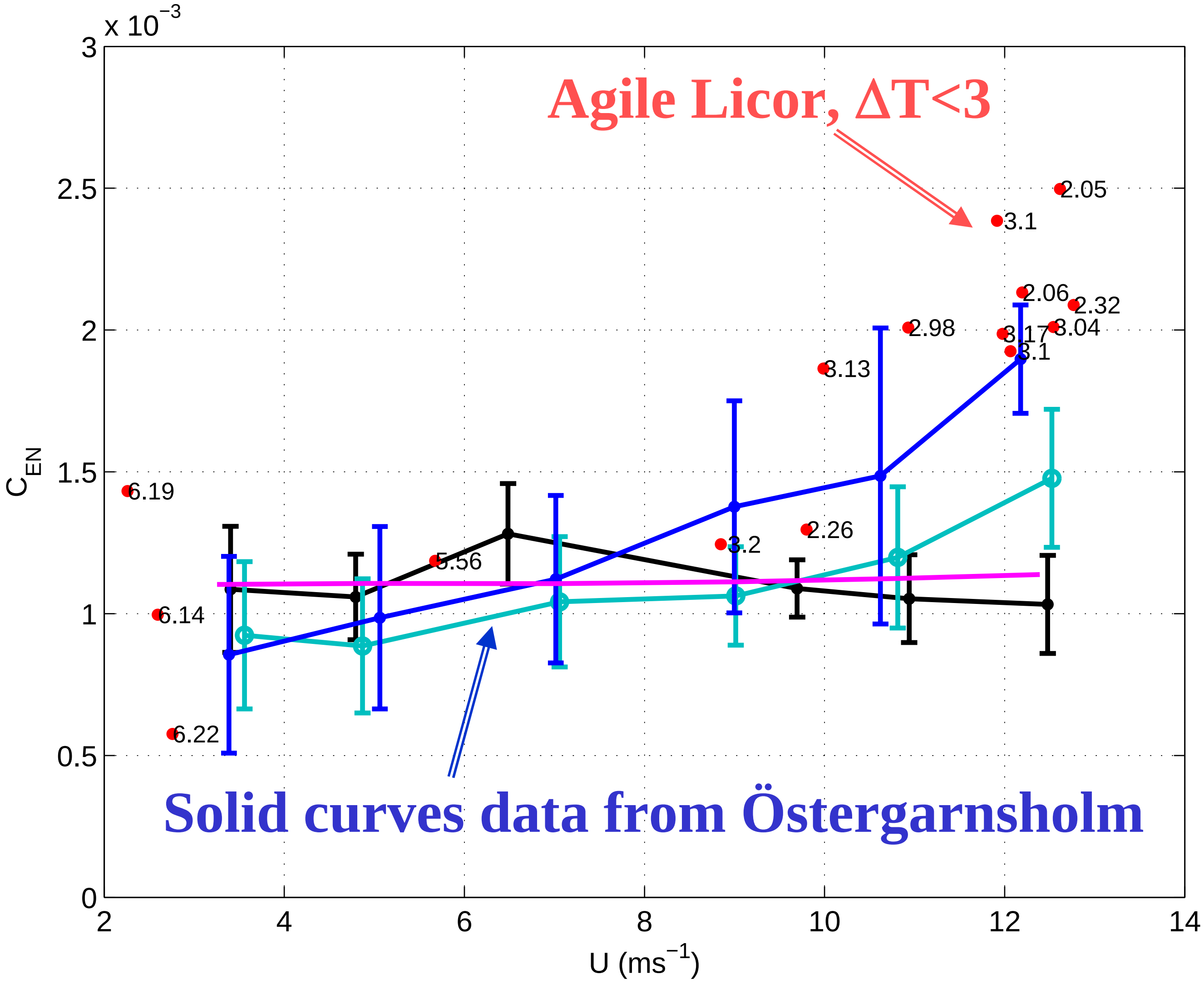
Latent heat flux, Östergarnsholm



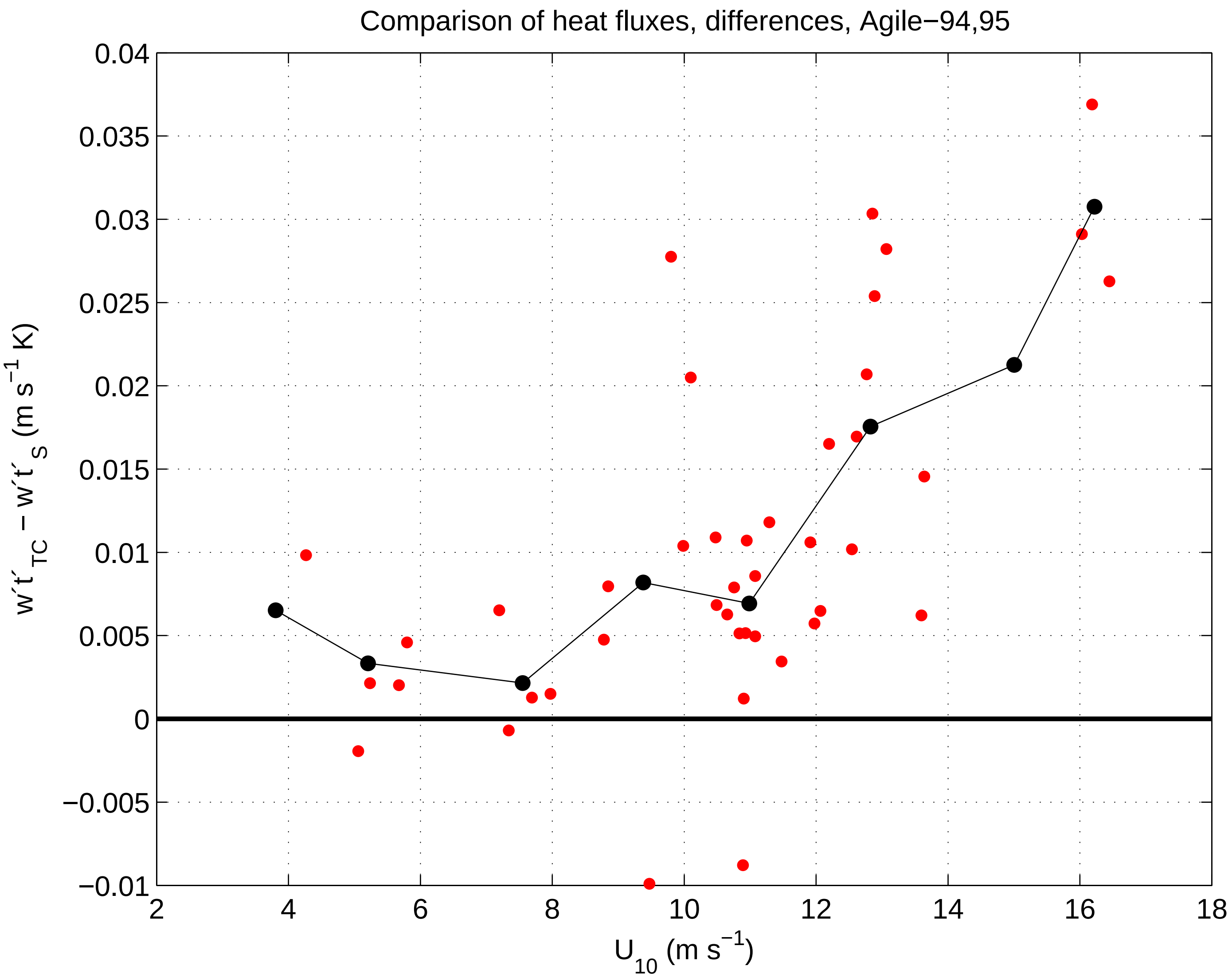
Agile heat flux



Agile latent heat flux



Agile heat flux: $(wt)_{TC}$ - $(wt)_{sonic}$

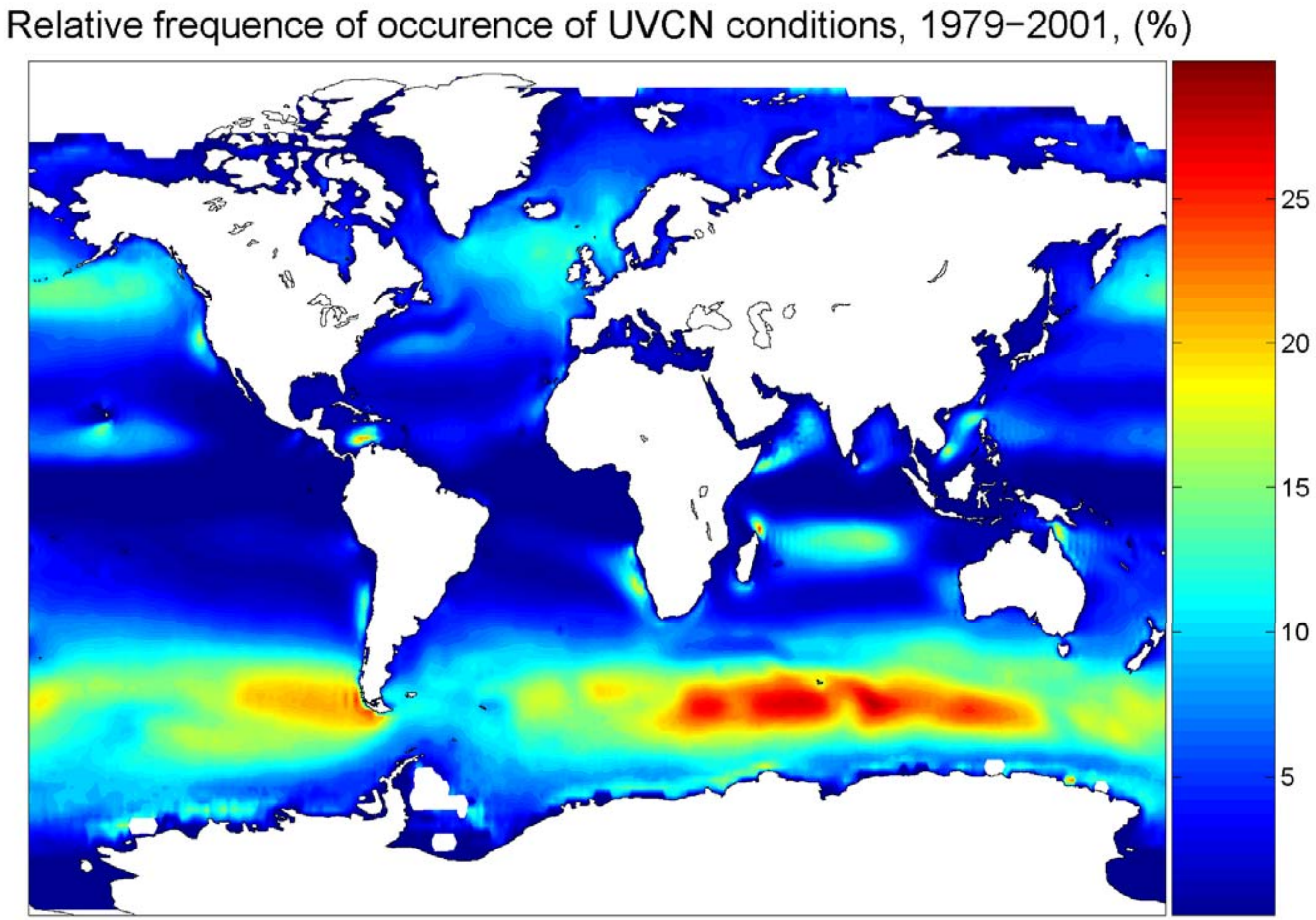


The unstable very close to neutral regime

- **The UVCN regime is defined for $\Delta T<3^{o}$ and U>10m/s**
- **It is found both over land and sea in the lowest region (z<15 m) of the surface layer**
- **Small scale heat flux is a result of detached eddies originating from the upper part of the surface.**

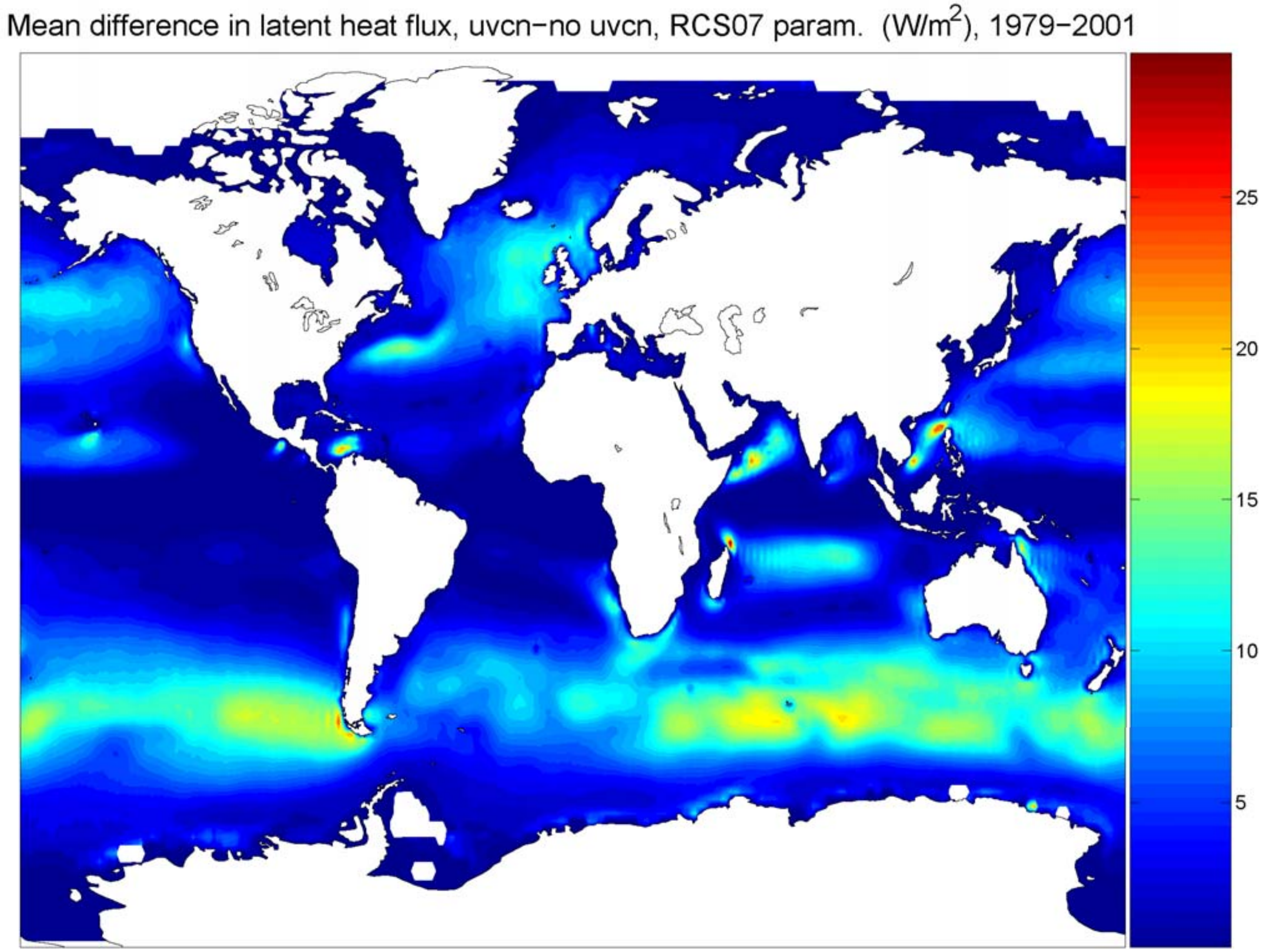
  This is in contrast to a convective surface layer ruled by horizontal rolls.

Frequency (%) of occurrence of UVCN conditions



ERA-40 reanalysis

Increase (W/m^2) in latent heat flux with UVCN regime included



ERA-40 reanalysis

Global mean values of the increase of heat fluxes with UVCN regime included

- **Sensible heat flux= 0.8 W/m^2**
- **Latent heat flux (evaporation)= 2.4 W/m ^{2}**
- **The effect of increased anthropogenic greenhouse gases (2006) on net radiation = 2.63±0.26 W/m ^{2}**

Conclusions

Unstable stratification

- **M-O similarity theory is only valid for growing waves**

During swell the MABL is characterized by

- **Low-level jet (LLJ) at 5-10 m height**
- **Constant wind speed above LLJ**
- **Small or positive momentum flux varying with height**
- **Energy is transported from waves to atmosphere by pressure transport term T_p**

Mixed seas

As soon as a small portion of the waves are travelling faster than the wind (mixed seas) MABL is slowly changing from an ordinary boundary layer to a ‘swell dominated ‘ boundary layer and

Monin-Obukhov similarity theory is not valid

During stable stratification wave effects are small

Heat fluxes

- **The dynamics of the MABL influence the air-sea exchange of sensible and latent heat.**

- **When the convective boundary layer is ruled by horizontal rolls the well known COARE algorithm is valid.**

- **When detached eddies originating from the upper part of the surface layer is present (UVCN regime) the heat fluxes are increased and the Φ_h-function goes to zero**

Why has not the UVCN regime been observed earlier?

- **sonic temperature fails to measure temperature fluctuations correctly when σ_T is small (high wind speed, small ΔT)**

- **data with small ΔT are often removed from the data set**

- **measurements are taken at heights above the UVCN layer.**

Thanks to

- **Ulf Högström, Erik Sahlee, Anna Rutgersson, Hans Bergström, Cecilia Johansson, MIUU**
- **Will Drennan, RSMAS, Miami, Kimmo Kahma and Heidi Pettersson, FMRI, Helsinki**
- **Phd-students: Andreas Karelid , Björn Carlsson, Maria Norman, Alvaro Semedo**
- **Former Phd-students: Cecilia Johansson Birgitta Källstrand, Anna Rutgersson, Anna Sjöblom, Xiaoli Guo Larsen**