Non-linear interaction between the lower-atmosphere and vegetation canopy flows

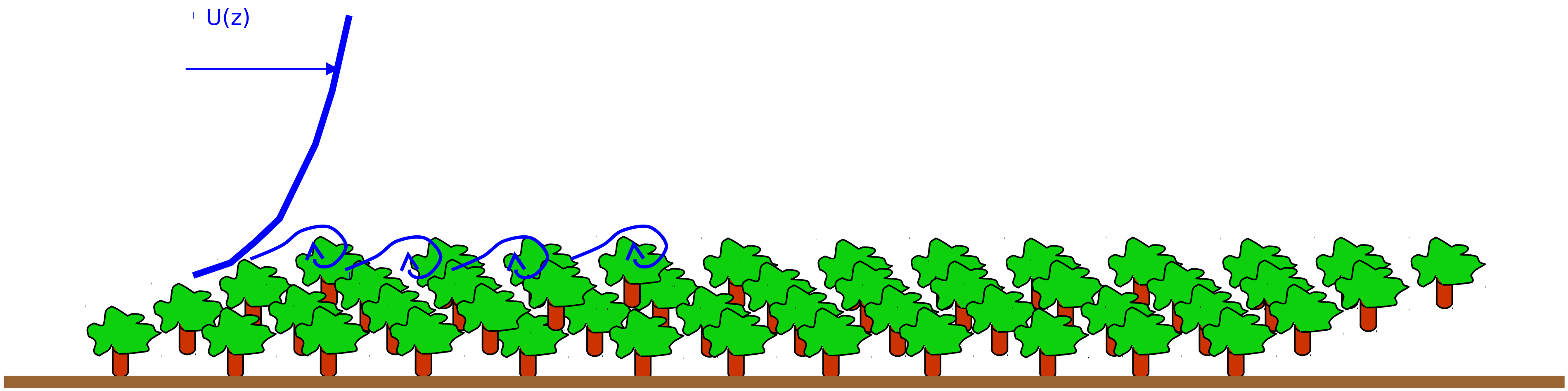
Laurent Perret[1,2]
[1]LUNAM Université, Ecole Centrale de Nantes, LHEEA UMR CNRS 6598, Nantes, France
[2]Institut de Recherche en Sciences et Techniques de la Ville (IRSTV), FR CNRS 2488, Nantes, France

Edward G. Patton[3]
[3]NCAR, Boulder, CO

AMS 21th Symposium on Boundary Layers and Turbulence, Leeds, June 2014

Context & Motivation

Flow over vegetation canopy in near-neutral configuration



- Mixing layer analogy explaining most of the statistical features (Finnigan, 2000)
- Model of the eddy organization in the canopy and RSL based on a double-hairpin structure (Finnigan, Shaw & Patton, 2009)
- But also presence of coherent structures in the atmospheric boundary layer (Lin et al, 1996, Drobinski et al, 2004)

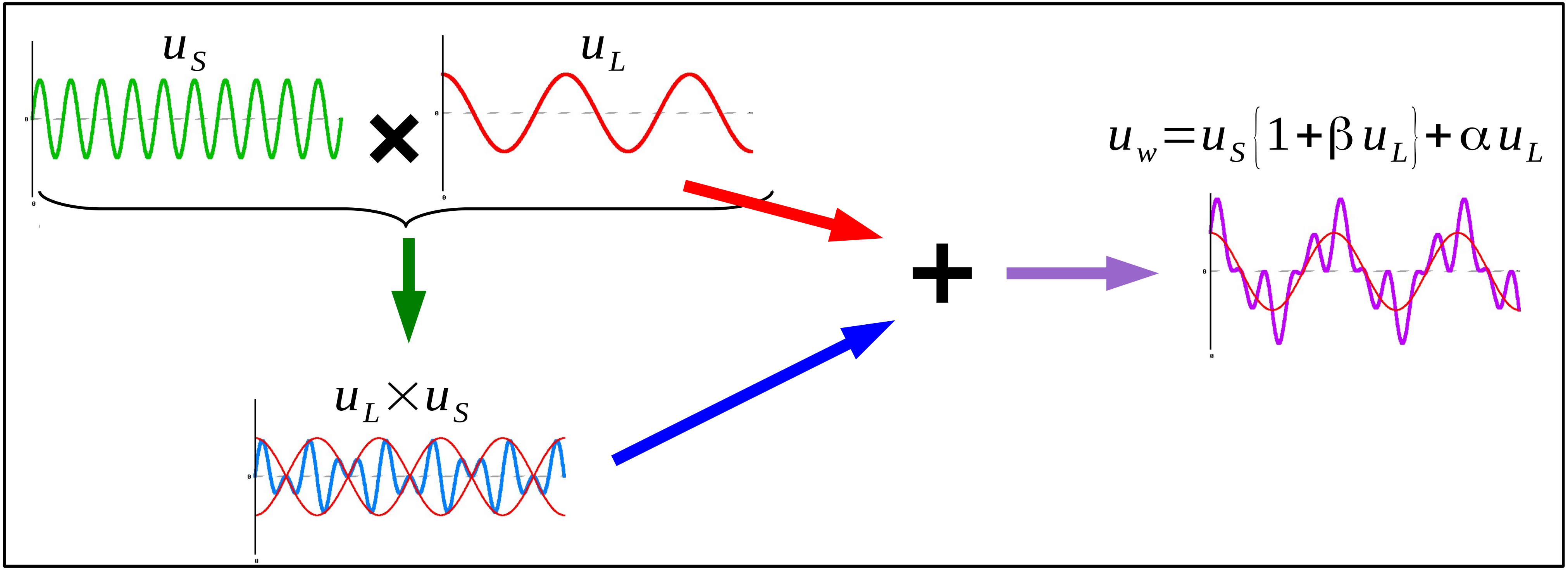
➡ Interaction, coupling mechanism ?

Context & Motivation

Recent finding in smooth-wall boundary layer and channel flows

Mathis, Hutchins & Marusic, JFM, 2009, 2011;

➡ Amplitude modulation of the near-wall turbulence by the larger-scales



➡ Same mechanism in atmospheric flow over vegetation canopy ?

Methodology

Analysis based on a 3d volume corresponding to a time instance of a LES (Patton et al. 2012) with the parameters:

- Vegetation specified by a height-dependent foliage area density and an element drag coefficient;
- Canopy height: h = 20m, 10 grid points;
- Domain dimensions:

$$\begin{cases} L_x \times L_y \times L_z = 5120 \times 5120 \times 2048\, m^3 \\ N_x \times N_y \times N_z = 2048 \times 2048 \times 1024 \end{cases}$$

- Main parameters (u*, Q*, L and w* evaluated at canopy top): *weakly convective*

U_g (m s^{-1})	V_g (m s^{-1})	u_* (m s^{-1})	Q_* (m K s^{-1})	z_i (m)	L (m)	$-z_i/L$	w_* (m s^{-1})
10	0	0.86	0.2	998	-226	3	1.92

Development of methods based on third-order statistics:

Use of auto- and cross-bispectra and bicoherence

(Patton, EG, Shaw RH, Finnigan JJ (2012) *Influence of convective instability on canopy and roughness sublayer turbulence*. In proc of the AMS 20th Symp on Bound Layers and Turb, Boston, MA, 2012, Paper 12B.2)

Auto-Bispectrum: definition

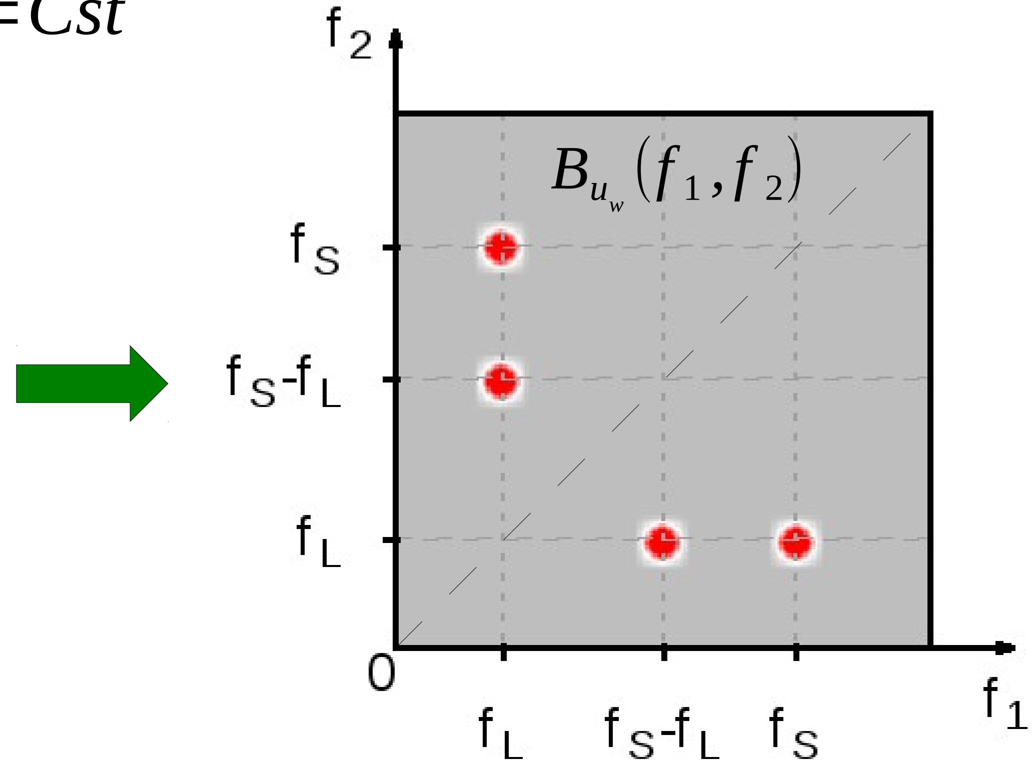
- Auto-bispectrum of u(t) defined as: $B_u(f_1,f_2)=\langle \hat{U}(f_1)\hat{U}(f_2)\hat{U}^*(f_3)\rangle$

- Account for *non-linear coupling* between 3 frequencies linked by

$$\begin{cases} f_1+f_2=f_3 \\ \varphi_1+\varphi_2-\varphi_3=Cst \end{cases}$$

- If u_S and u_L are pure sine waves:

$$u_w=u_S\{1+\beta u_L\}+\alpha u_L$$



where $\hat{U}(f)=|\hat{U}(f)|e^{i\varphi(f)}$ with $\begin{cases} |\hat{U}(f)|: \text{ amplitude of the wave of frequency f} \\ \varphi(f): \text{ phase of the wave of frequency f} \end{cases}$

Auto-Bispectrum: properties

- $B_u(f_1, f_2) = 0$ if no coupling between f_1, f_2 and f_3
- Directly linked to the skewness by: $\langle u^3(t) \rangle = \sum_{f_1, f_2} \Re\left(B_u(f_1, f_2)\right)$
- *Cross-bispectrum* can be defined as well

$$B_{uvv}(f_1, f_2) = \langle \hat{U}(f_1)\hat{V}(f_2)\hat{V}^*(f_3) \rangle$$

Interaction between u(t) and v(t)

- *Bicoherence*: normalized bispectrum

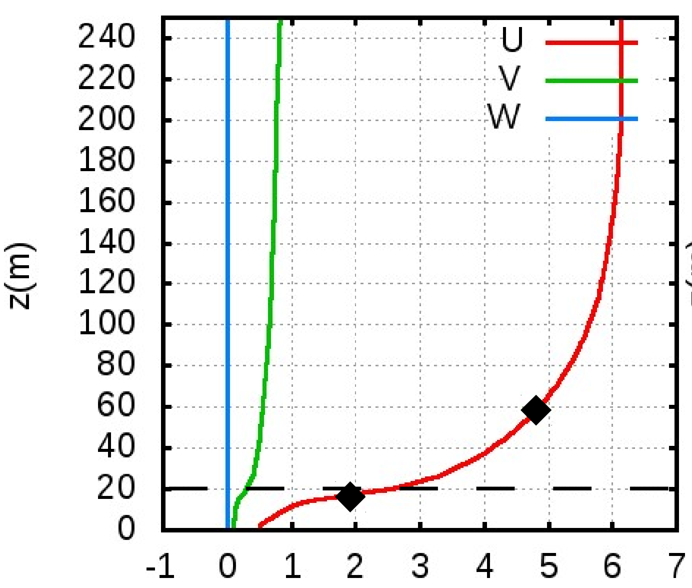
$$b_{uvv}(f_1, f_2) = \frac{\left|B_{uvv}(f_1, f_2)\right|}{\left(\left\langle \left|U(f_1)V(f_2)\right|^2 \right\rangle . \left|V(f_3)V^*(f_3)\right|\right)^{1/2}}$$

- Use of wavelet transform (*Morlet mother wavelet*, Milligen et al., 1995)
- Scale decomposition in the longitudinal direction x

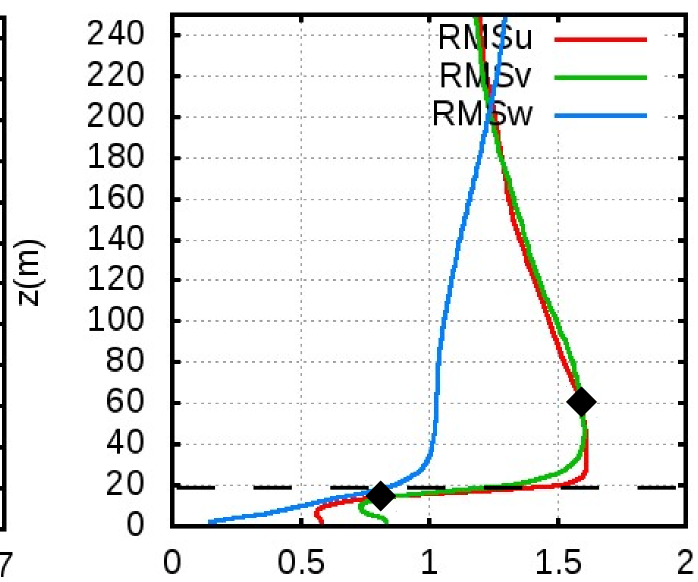
Results: one-point statistics

Velocity statistics: Averages over the horizontal plane

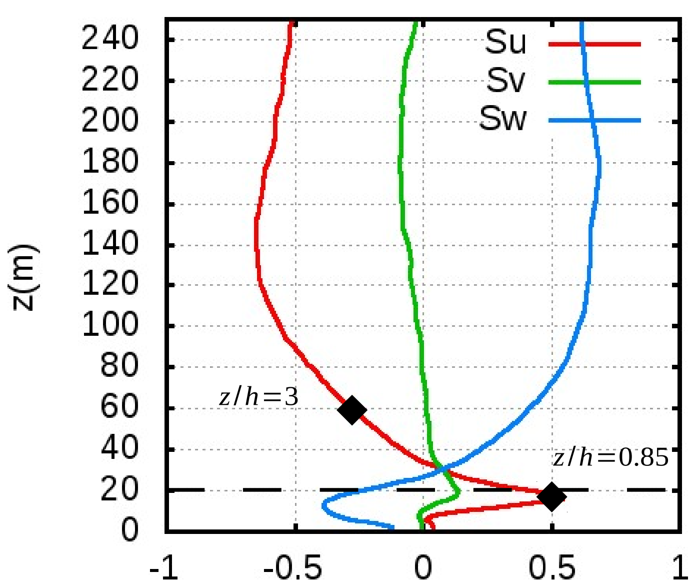
Mean velocity (m/s)



Velocity rms (m/s)

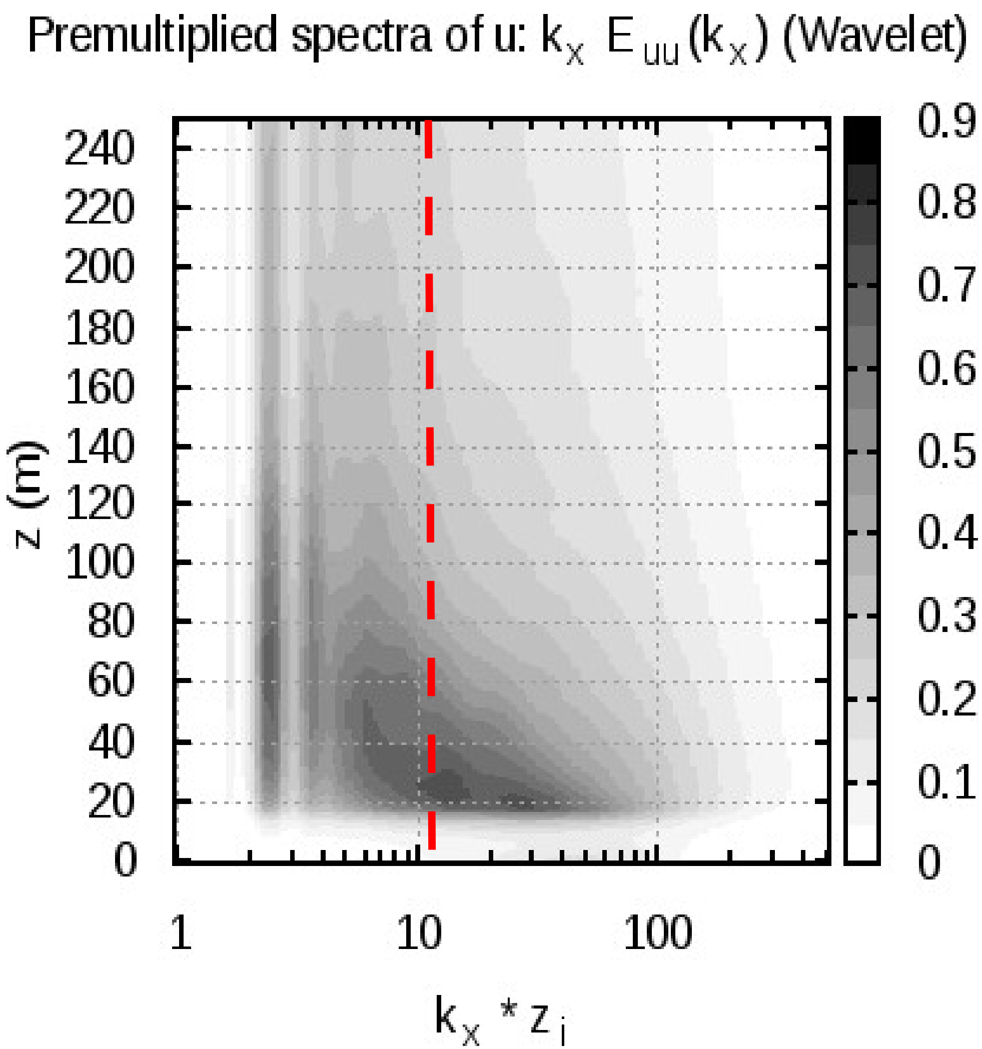


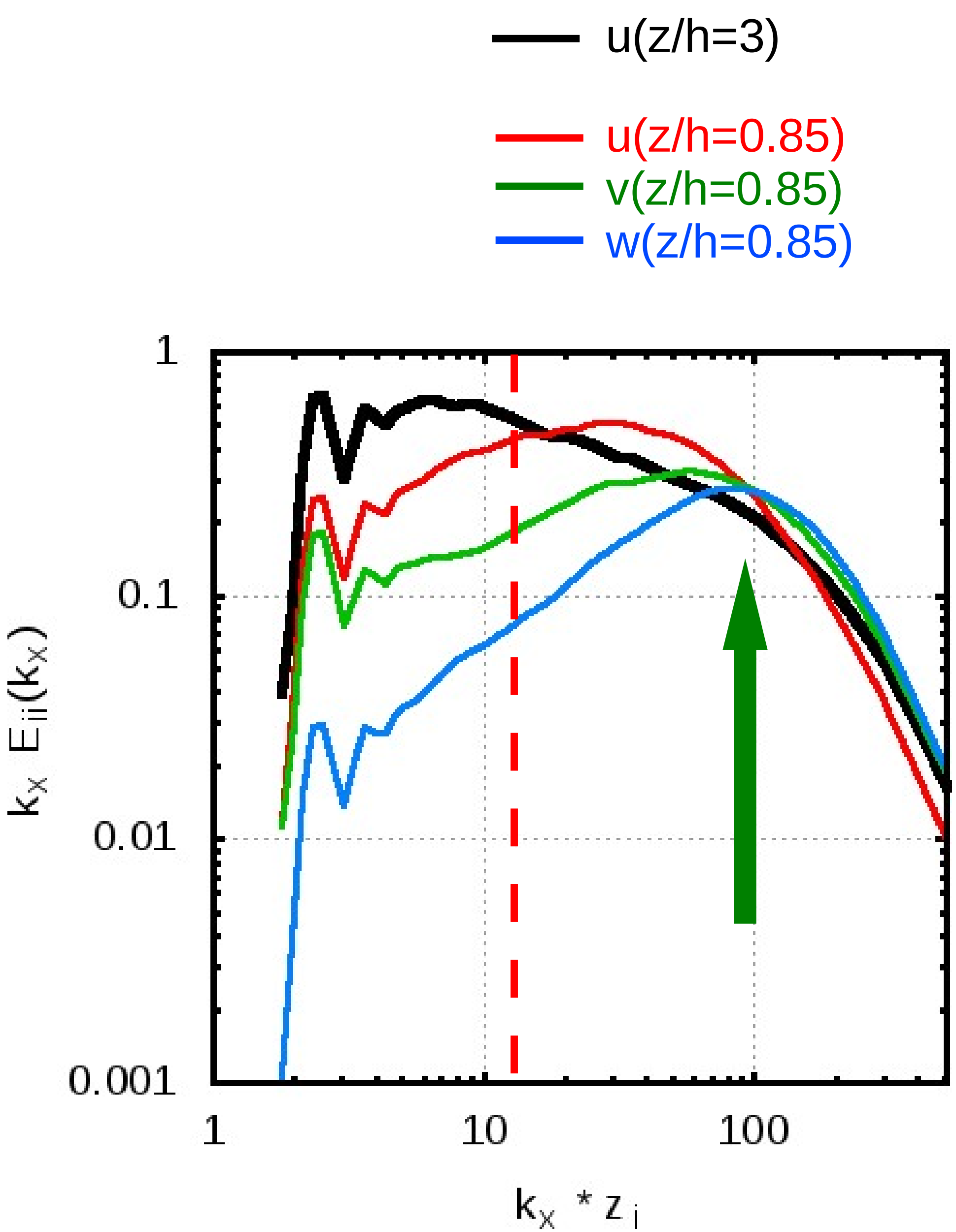
Velocity skewness



- Longitudinal velocity U
- Transversal velocity V
- Vertical velocity W

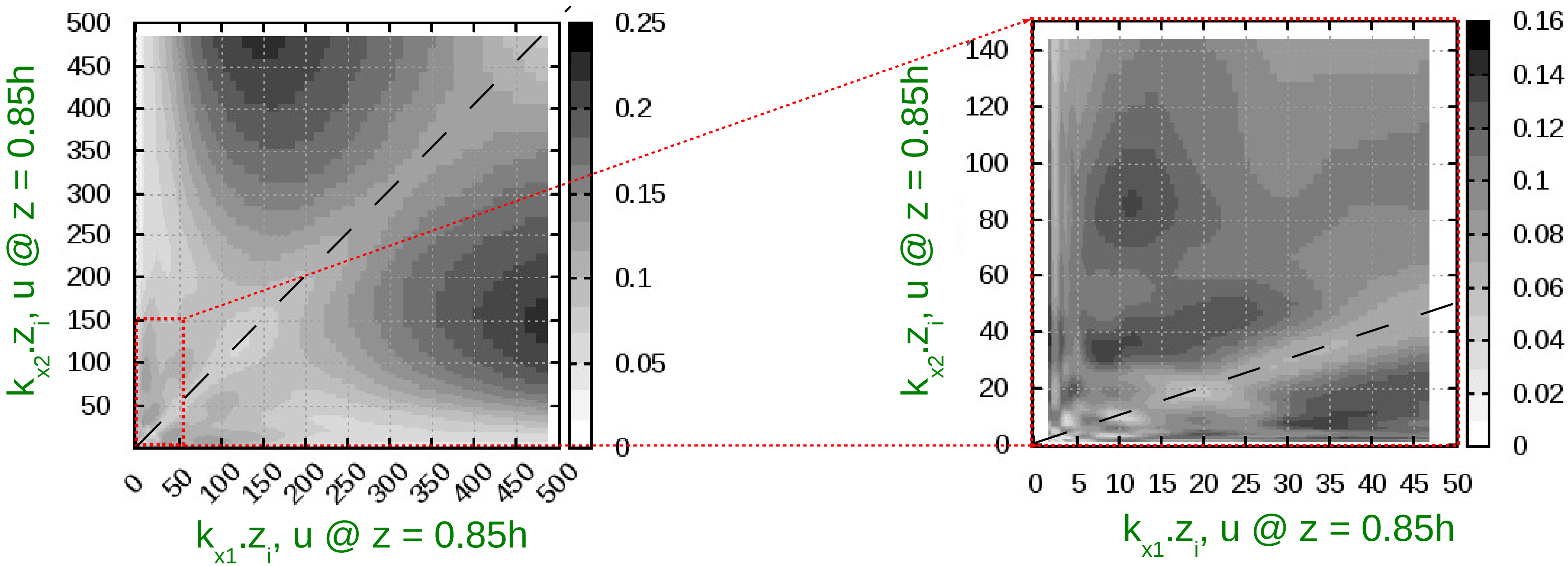
Wavelet energy spectra of velocity





Auto-Bicoherence @ z/h = 0.85

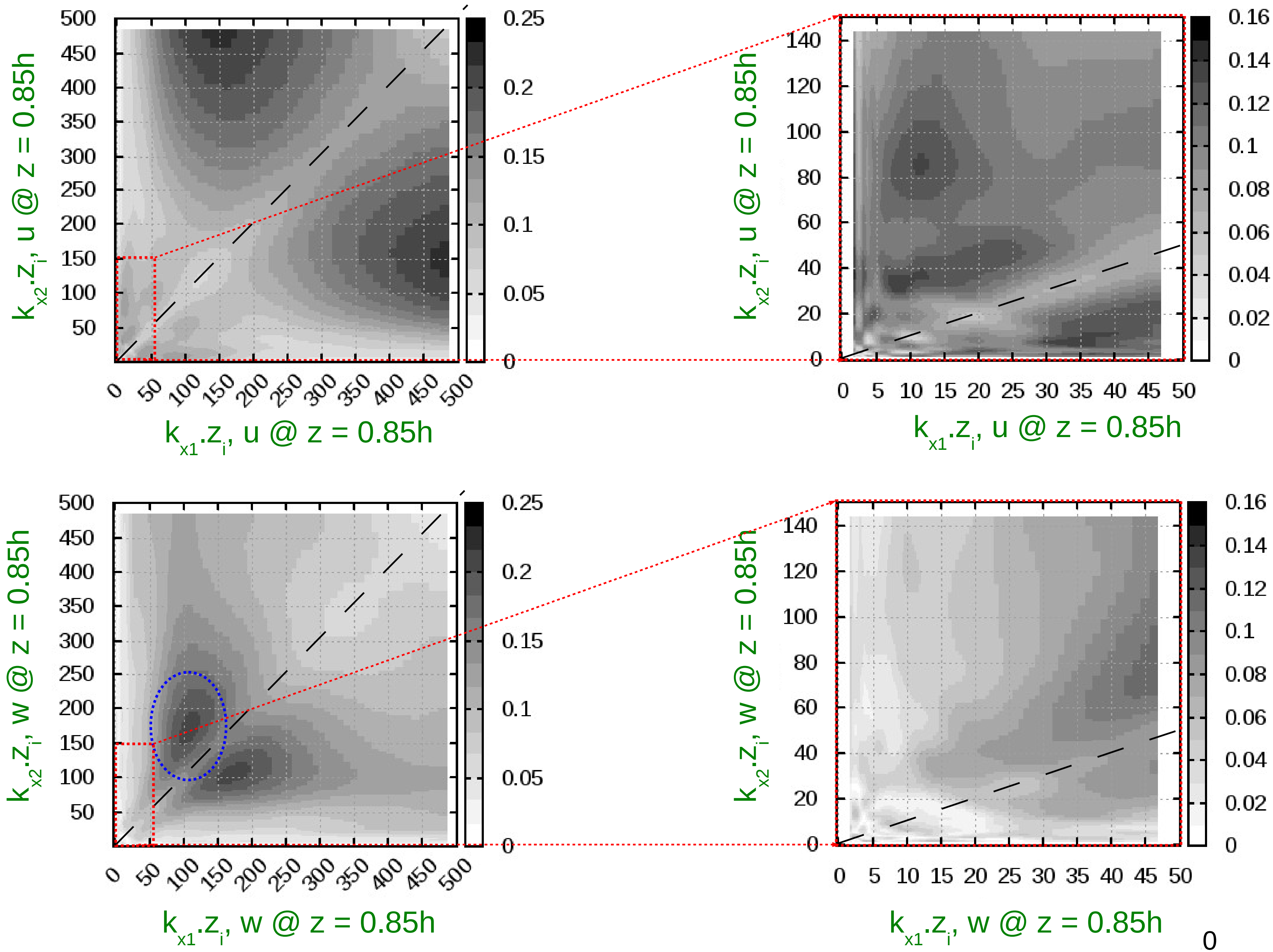
Longitudinal velocity U



Auto-Bicoherence @ z/h = 0.85

Longitudinal velocity U

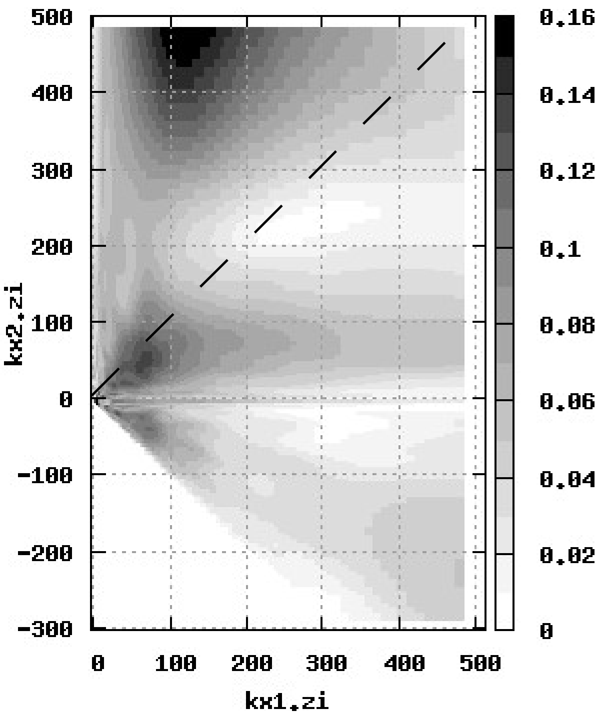
Vertical velocity W



One-point cross-Bicoherence @ z = 0.85h

$b_{uvv}^{w}(a_1, a_2)$

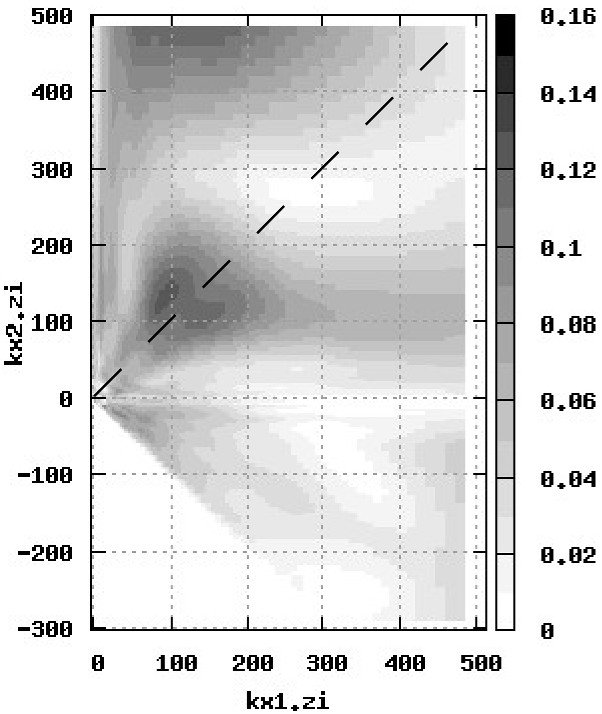
v @ z = 0.85h



u @ z = 0.85h

$b_{uww}^{w}(a_1, a_2)$

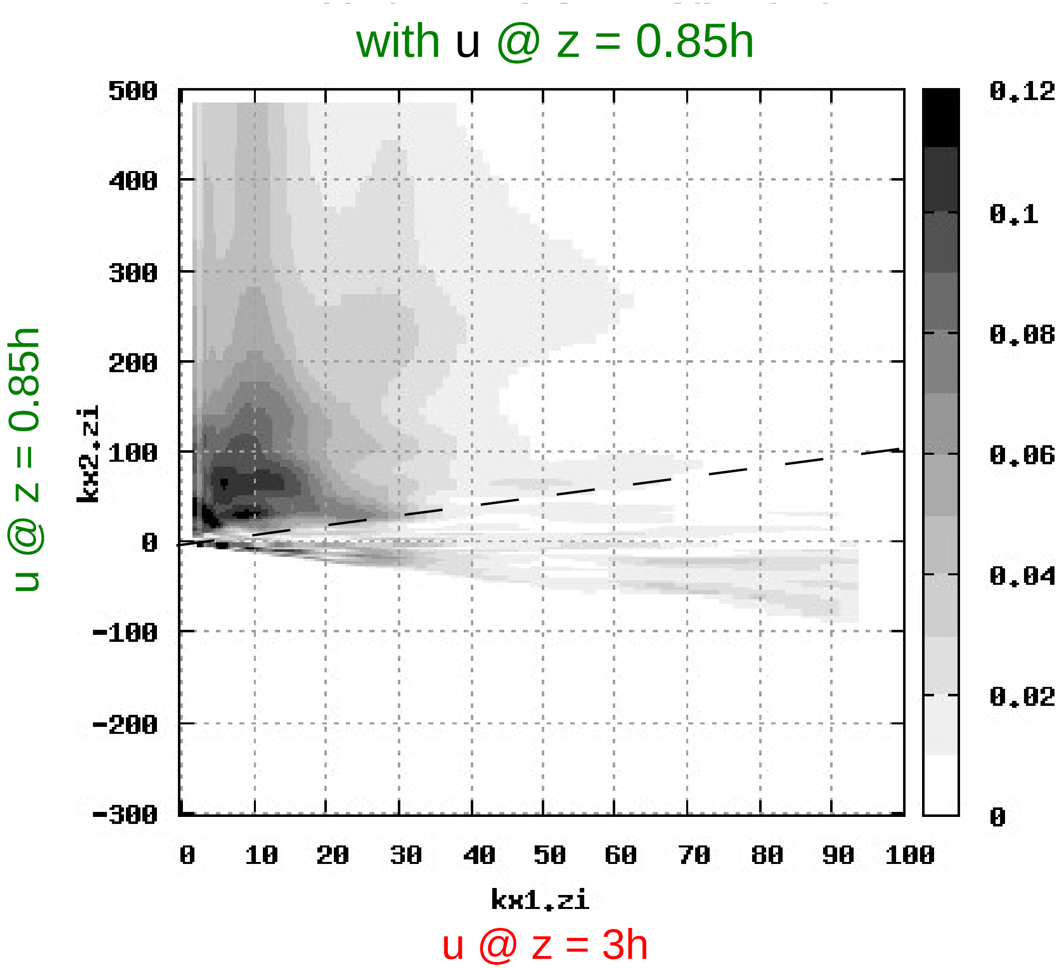
w @ z = 0.85h

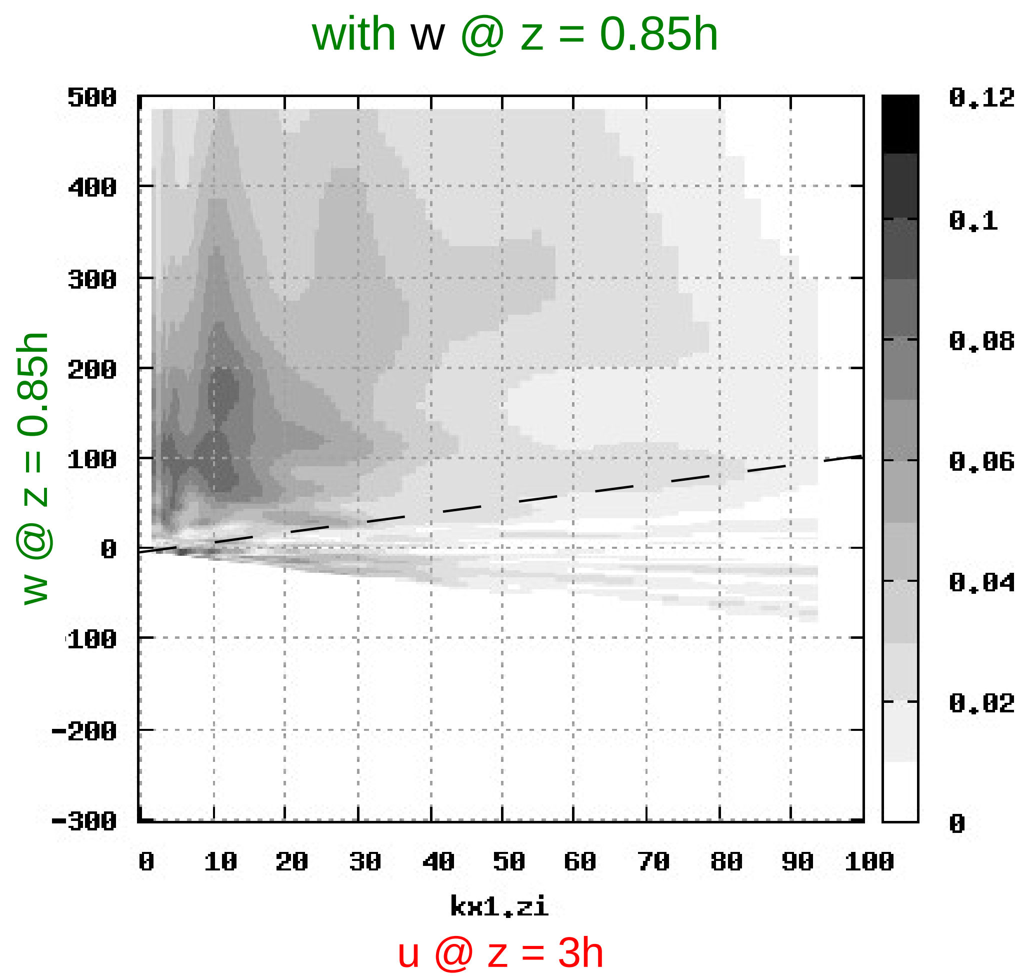


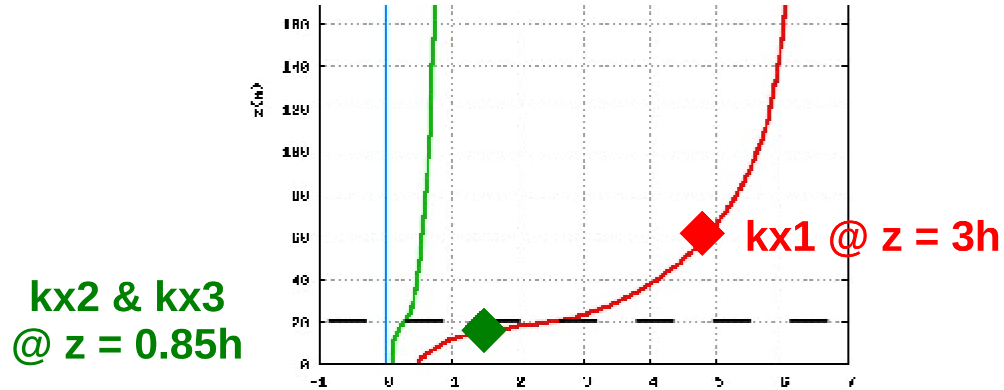
u @ z = 0.85h

- For the 3 components: non-linear interactions among smaller-scales
- Non-linear interactions between large- and smaller-scales within u
- Non-linear interactions between canopy-scales within w
- Non-linear interactions between large-scales of u and smaller-scales of w

Two-point Cross-Bicoherence: u @ z = 3h







Conclusions and perspectives

Conclusion from the bispectral analysis:

- Non-linear interactions among all scales;
- w bears the footprint of canopy-scale interaction;
- Non-linear interactions between larger-scales of u and smaller-scales of the 3 components;
- Coupling associated to modes of large vertical extent.

Future plans:

- Diagnostic tool for non-linear interaction detection;
- Influence of the stability condition on the non-linear interactions;
- Quantitative estimation of non-linear coupling and energy transfer and modeling;
- Extension to experimental data from the CHATS campaign

Thank you for your attention