Comparison between the sea-breeze circulation day and normal day Reynolds stress anisotropy in the lower atmospheric region

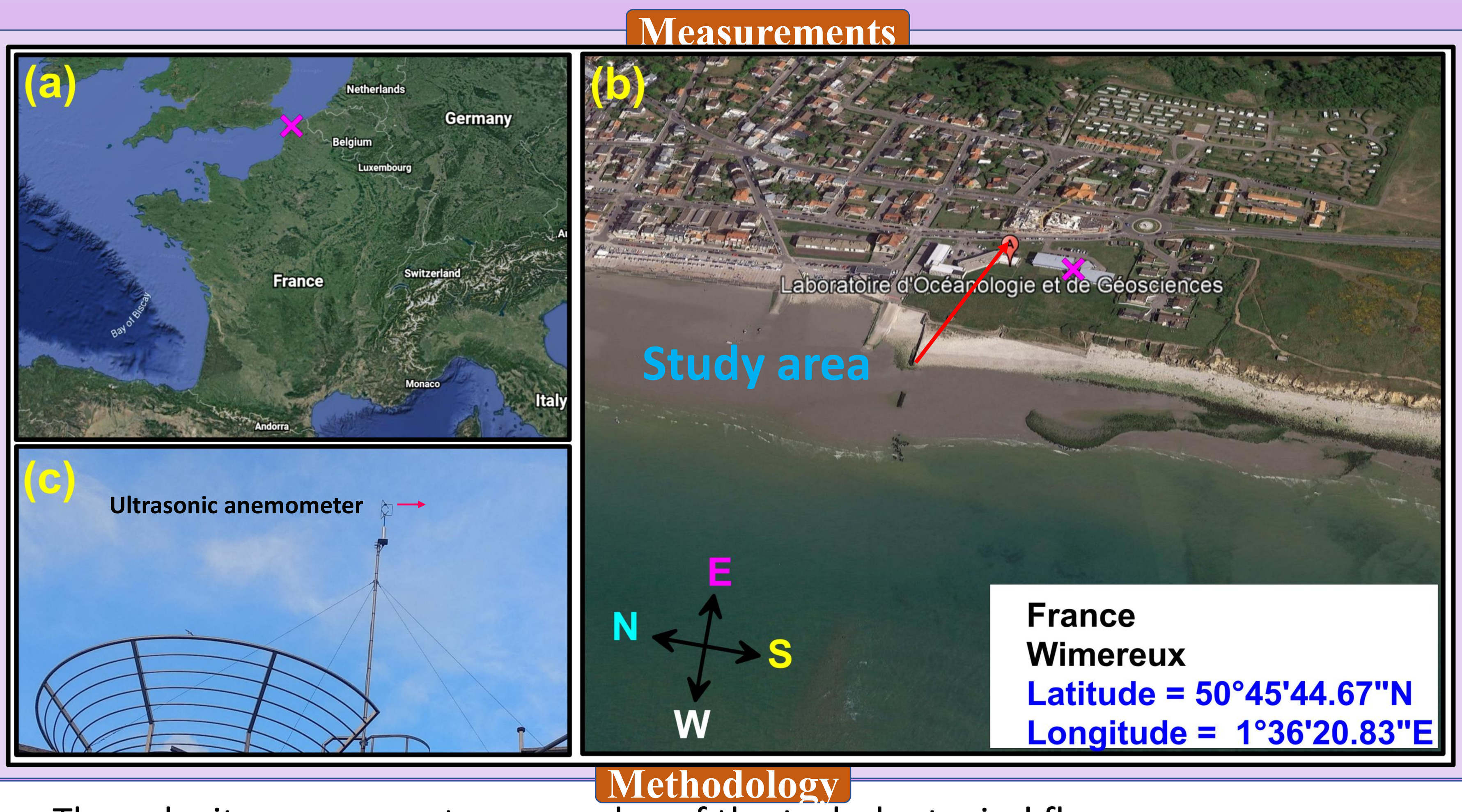
Sayahnya Roy[1], Alexei Sentchev[1], François G. Schmitt[1], Patrick Augustin[2], Marc Fourmentin[2]

1 Laboratoire d'Océanologie et de Géosciences (LOG), CNRS, Université de Lille, Université du Littoral Côte d'Opale (ULCO), France; 2 Laboratoire de Physico-Chimie de l'Atmosphère (LPCA), Université du Littoral Côte d'Opale (ULCO), Dunkerque, France.

Abstract

This study shows the comparison between the sea-breeze circulation (SBC) day and normal day turbulent characteristics and the Reynolds stress anisotropy in the lower atmospheric region. The Reynolds stress tensor is responsible for the dissipation and transportation of mean kinetic energy. Variability of the turbulent kinetic energy due to the Reynolds stress anisotropy modulates the air quality. A 20 Hz Ultrasonic anemometer was deployed in the coastal area of northern France to measure the temporal wind variability for the duration of one year five months. The SBC was detected by a change in wind direction from the West to the East during the day time. We found the axial component of the turbulent kinetic energy is higher than the other two through an axisymmetric expansion, and energy ellipsoid has a cigar shape due to SBC. During this time the dominance of small scale zonal turbulent motions was observed. Also, the probability of a higher degree of wind anisotropy due to SBC generates large mean kinetic energy within the lower troposphere.

Measurements



Methodology

The velocity components u, v, and w of the turbulent wind flow are decomposed into a mean part and fluctuating part as

$$u = \overline{u} + u', v = \overline{v} + v', w = \overline{w} + w'$$

The Reynolds stress tensor is a symmetric second-order tensor, given by

$$\tau = R_{ij} = \begin{bmatrix} \overline{u'^2} & \overline{u'v'} & \overline{u'w'} \\ \overline{v'u'} & \overline{v'^2} & \overline{v'w'} \\ \overline{w'u'} & \overline{w'v'} & \overline{w'^2} \end{bmatrix}$$

decomposed into isotropic and anisotropic parts

$$R_{ij} = R_{ij}^{iso} + R_{ij}^{aniso}$$

decomposition of Reynolds stress tensor

$$R_{ij}^{iso} = \frac{1}{3} R_{kk}\delta_{ij} = \frac{1}{3} \mathrm{K}^2 \delta_{ij}; \; R_{ij}^{aniso} = R_{ij} - R_{ij}^{iso}$$

$$\mathrm{K}^2 = 2\,TKE$$

$$\chi_{ij} = \frac{R_{ij}^{aniso}}{R_{kk}} = \frac{R_{ij}}{R_{kk}} - \frac{\delta_{ij}}{3} = \begin{bmatrix} \frac{\overline{u'^2}}{\Psi} - \frac{1}{3} & \frac{\overline{u'v'}}{\Psi} & \frac{\overline{u'w'}}{\Psi} \\ \frac{\overline{v'u'}}{\Psi} & \frac{\overline{v'^2}}{\Psi} - \frac{1}{3} & \frac{\overline{v'w'}}{\Psi} \\ \frac{\overline{w'u'}}{\Psi} & \frac{\overline{w'v'}}{\Psi} & \frac{\overline{w'^2}}{\Psi} - \frac{1}{3} \end{bmatrix}$$

$$\delta_{ij}(i \neq j) = 0; \quad \delta_{ij}(i = j) = 1$$

$$\Psi = \overline{u'^2} + \overline{v'^2} + \overline{w'^2}$$

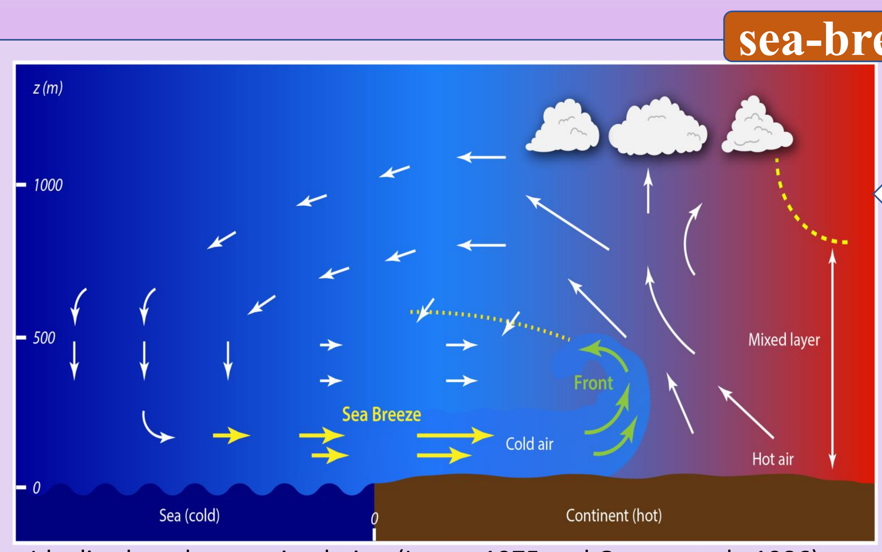
$$|\chi_{ij} - \lambda\chi_{ij}| = 0 \quad \Rightarrow \quad \lambda_1^3 - I\lambda_2^3 + II\lambda_3 - III = 0$$

$\lambda_1, \lambda_2, \lambda_3$ are the eigenvalues of χ and the invariants are I, II, III

$$I = \chi_{ij} = 0; \quad II = -\chi_{ij}\chi_{ji}/2; \; III = \chi_{ij}\chi_{jk}\chi_{ki}/3$$

A nondimensional degree of anisotropy $D_a = \frac{III/2}{(II/3)^{1.5}}$

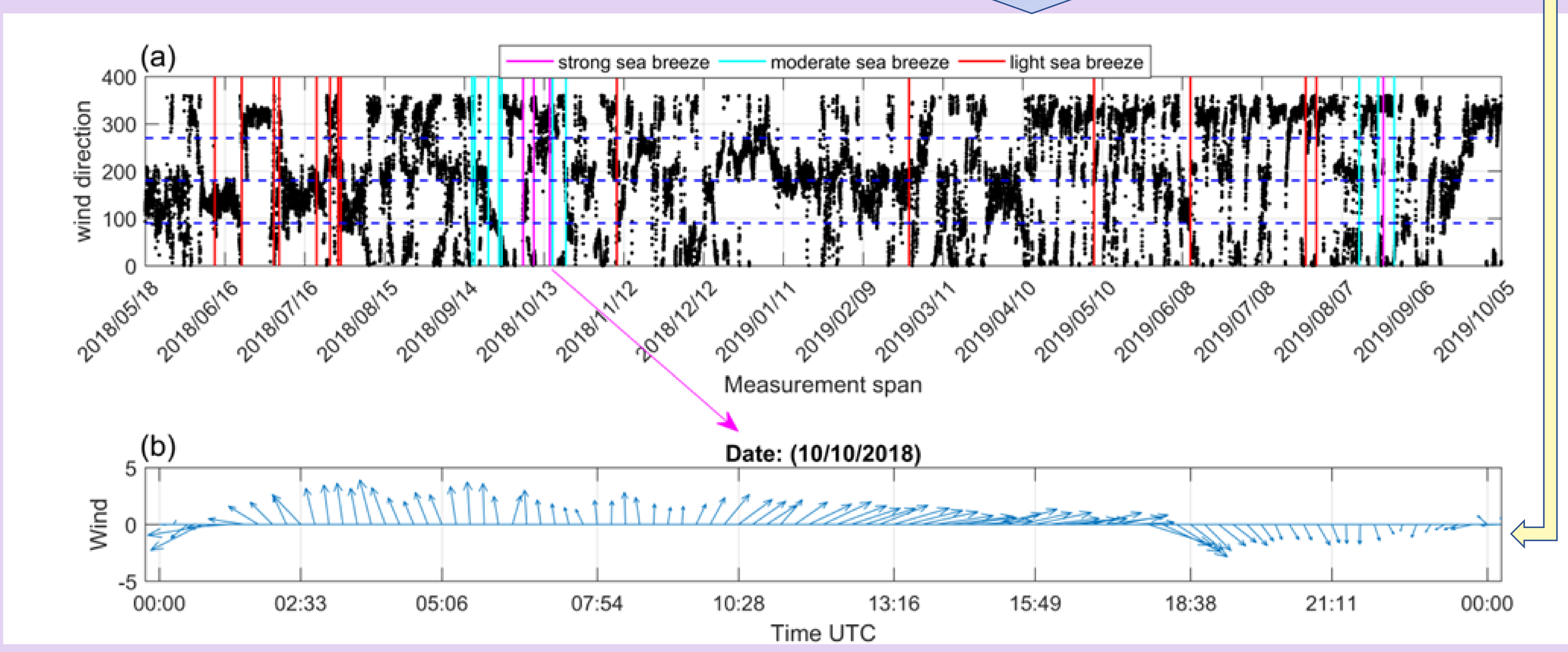
sea-breeze circulation



Idealized sea breeze circulation (Lyons, 1975 and Ogawa et al., 1986)

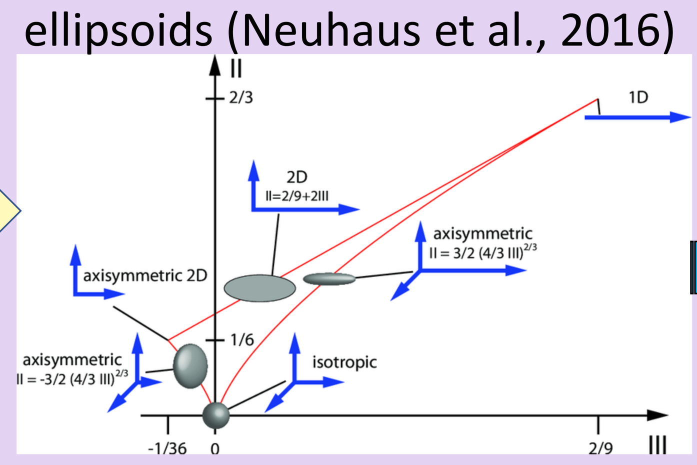
A shift in wind direction from offshore to onshore identified as SBC

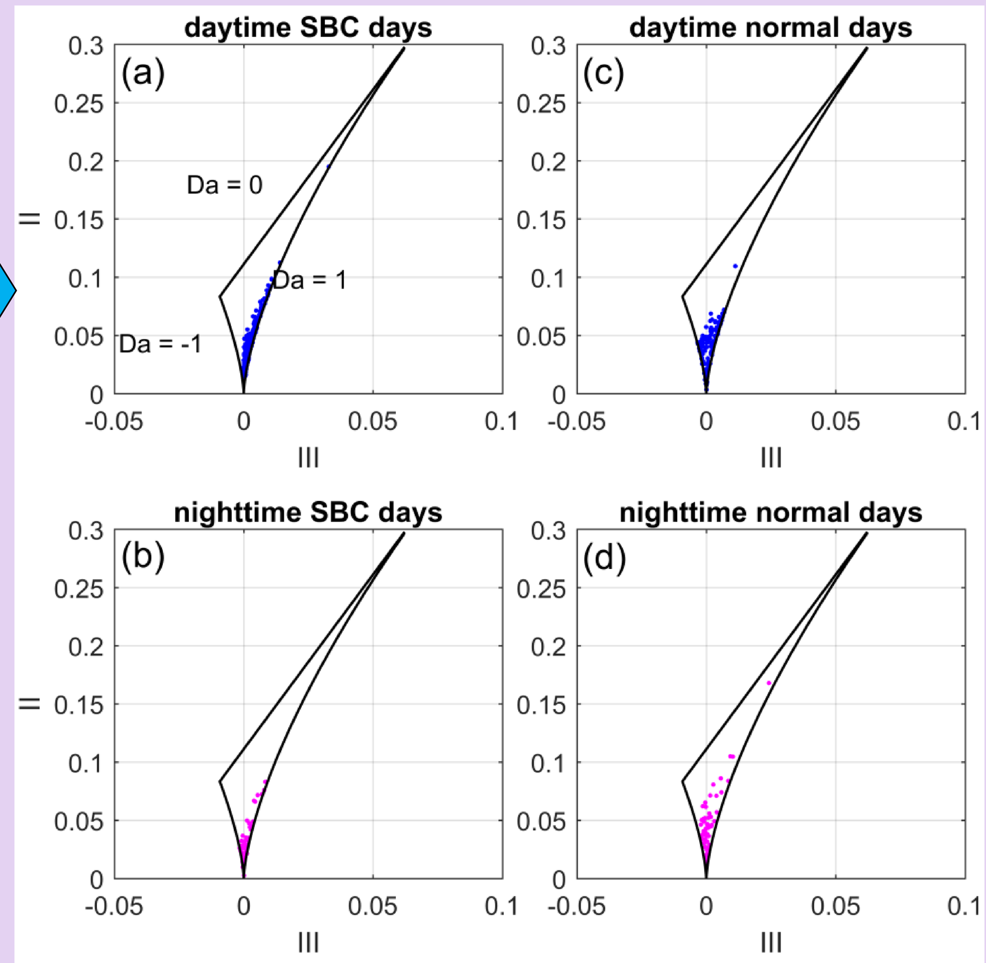
Observed 28 SBC over one year five months period within the lower troposphere



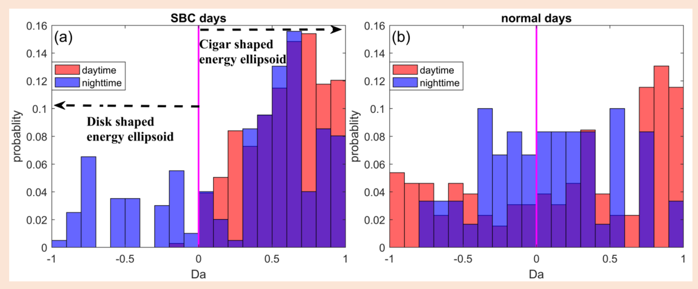
Results

Concept of the shape of energy ellipsoids (Neuhaus et al., 2016)





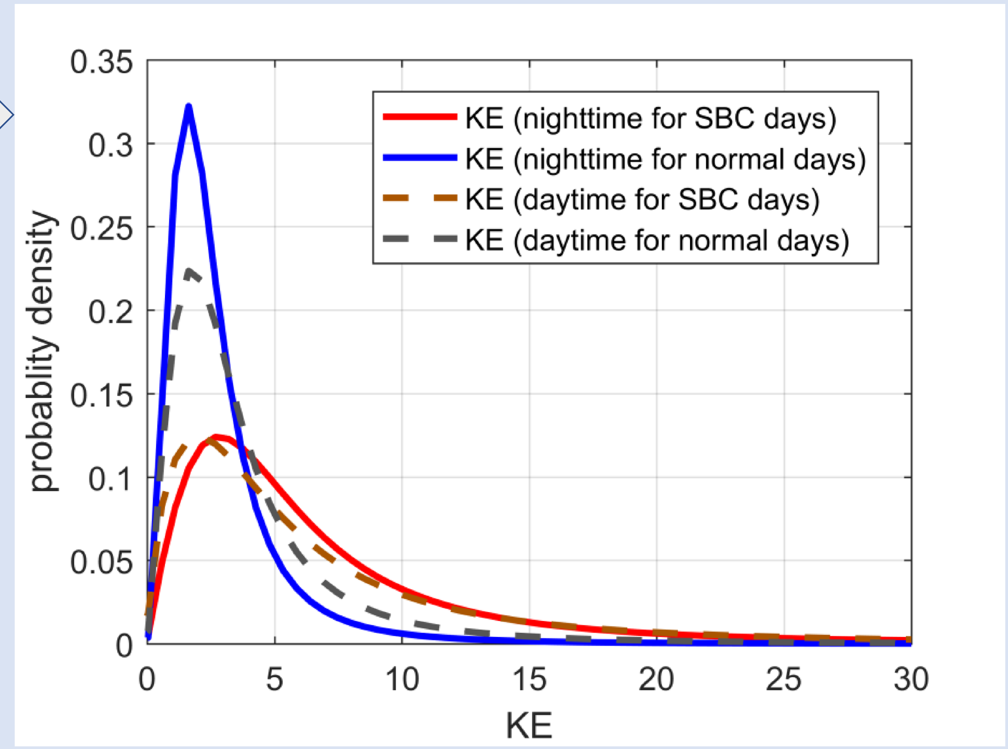
Probability of occurrence of cigar shaped energy ellipsoids are more during the SBC then normal days



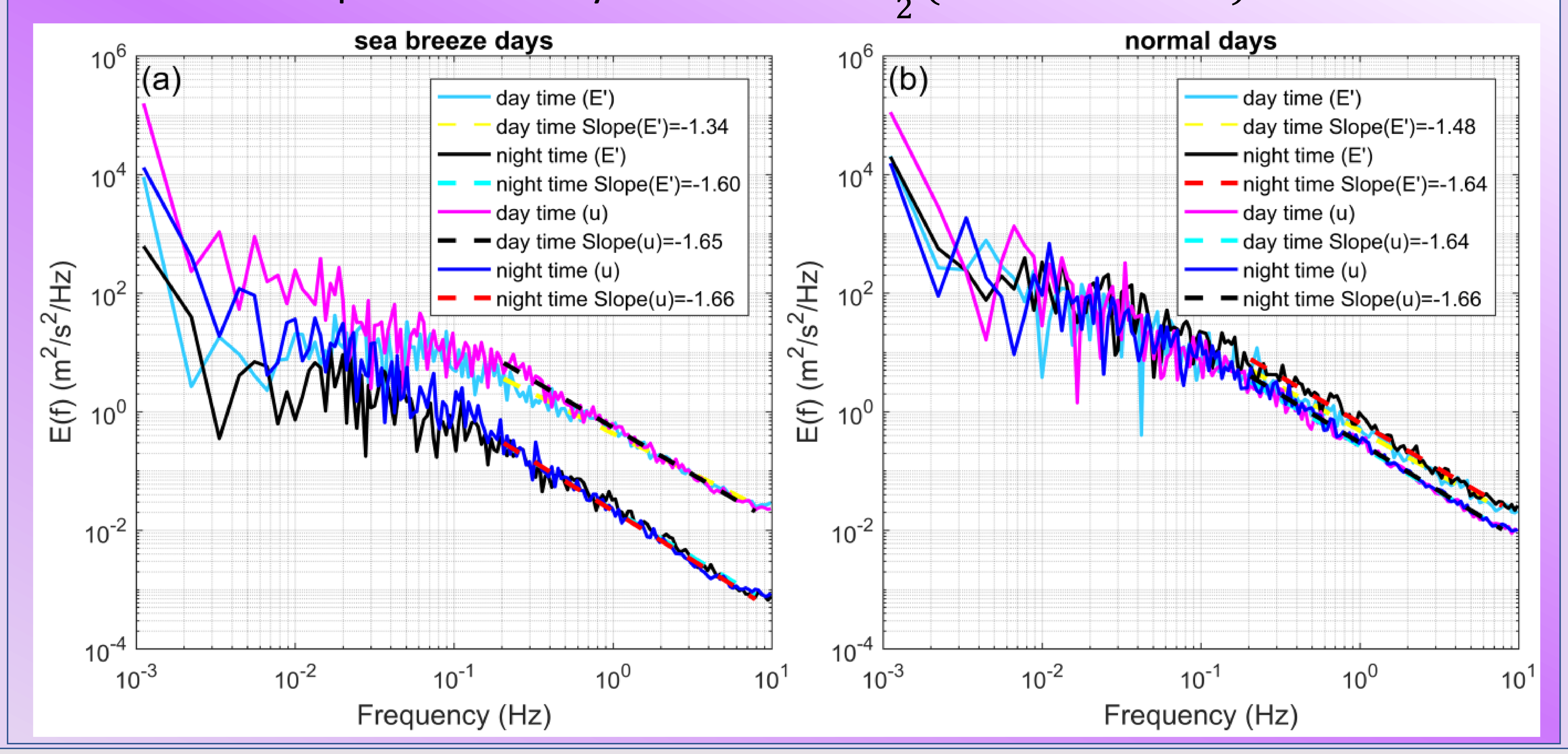
$$p(KE|\mu, \varsigma) = \frac{1}{\varsigma}\frac{1}{KE}\frac{e^{\eta}}{(1+e^{\eta})^2}$$

where $\eta = \log(KE) - \mu/\varsigma$

Probability of occurrence of large $KE(=\frac{1}{2}(u^2 + v^2 + w^2)$ = 5-20 m^2/s^2) during SBC days is 1.5 times larger than normal days.
Also, the higher degree of wind anisotropy generates large mean kinetic energy during SBC days within the lower troposphere .



Spectral density of u and $E' = \frac{1}{2}(u'^2 + v'^2 + w'^2)$



Conclusions

- 28 SBC was observed over one year five months period within the lower troposphere in the coastal area of northern France.
- The axial component of the turbulent kinetic energy is higher than the other two through an axisymmetric expansion, and the energy ellipsoid has a cigar shape during the daytime of the SBC days. While during the normal days, wind energy ellipsoid has both the axisymmetric contraction (disk shape) and expansion (cigar shape).
- The higher degree of wind anisotropy generates large mean kinetic energy within the lower troposphere during SBC days.
- The dominance of small scale zonal turbulent motions in the flow field during the daytime of SBC days.

sayahnya1110@gmail.com