17A.3 STATISTICAL SIGNATURE OF THE SURFACE WAVES IN THE WIND OVER THE OCEAN

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1. INTRODUCTION

The surface waves at sea introduce a perturbation $\tilde{\mathbf{u}}$ to the the mean flow $\overline{\mathbf{u}}$ and distort the wind turbulence $\mathbf{u}'$ in the marine atmospheric boundary layer in a way that permits a decomposition of the wind velocity $\mathbf{u} = \overline{\mathbf{u}} + \mathbf{u}' + \tilde{\mathbf{u}}$. The perturbation $\tilde{\mathbf{u}}$ is responsible for the wind-wave momentum and energy transfer, but also, by moving the refractive inhomogeneities in the air, it influences the propagation pattern of electromagnetic signals. While the spatio-temporal structure of this perturbation defines the mechanism of wind-wave interaction, the perturbation's statistical composition affects the intensity, phase, and angle of arrival variation of the signals being transmitted. In the past, extensive effort has been devoted to studying the influence of the turbulent motion on radio-frequency, optical or acoustic signal propagation. However, because of the limited observational and theoretical information regarding the wave signature in the wind, virtually nothing has been known about the surface wave influence on signal transmission.

Observations over the coastal Atlantic in the summer of 2003 during the Coupled Boundary Layers Air-Sea Transfer (CBLAST) experiment illustrate the wave-modulation in the first tens of meters above the water surface. Most of the data collection during the experiment took place at the Air-Sea Interaction Tower observatory (Figure 1) located South of Martha's Vineyard, Massachusetts in a water depth of 15 meters. Four ultrasonic anemometers measuring wind velocity and air temperature at 20Hz, 3 hygrometers registering water vapor fluctuations at 20 Hz, and two pressure sensors sampling at 8Hz were deployed along a vertical mast. Surface waves directly beneath the instruments mast were measured by a microwave sensor.

The wave-induced fluctuations can dominate the atmospheric motion in the first tens of meters above the surface. The turbulence intensity $\langle(\mathbf{u}')^2\rangle$ in the atmospheric boundary layer increases primarily with the wind speed $|\overline{\mathbf{u}}|$, while the wave-induced fields are linearly related to the wave spectrum. Consequently, the wave modulation of the air flow $\tilde{\mathbf{u}}$, which is blurred by the turbulence at moderate and high winds, becomes directly observable at low winds. Figure 2 shows shows 100 seconds of unprocessed measurements of horizontal along-wind velocity, vertical velocity, pressure and surface elevation. The atmospheric boundary layer motion is organized and coherent with the waves. With height the wave signature in velocity is clearly decaying. The vertical decay in pressure is much less pronounced. With wind speed and turbulence intensity increase the wave-induced fluctuation are no longer observable directly. However, assuming the wave effects and turbulence to be uncorrelated, an optimal filtering method still allows to separate them reliably in measured signals (Hristov et al. (1998)).

2. ATMOSPHERIC MOTION STATISTICS AND SIGNAL PROPAGATION PATTERNS

A signal propagating through a media is affected by the motion of the refractive inhomogeneities. Statistical descriptions of the propagation pattern, such as time correlations of the field (electromagnetic or acoustic), variation of the signal intensity, fluctuations of the signal's phase or angle of arrival, are influenced by the statistics of the media motion (Chernov (1967), Tatarskii (1967), Ishimaru (1978), Wheelon (2001)). Quantities commonly occurring in propagation descriptions, e.g. in the radar equation (Ishimaru (1978)), are the characteristic function (i.e. the Fourier transform counterpart of the probability density) of the velocity field $\chi_{\mathbf{u}}$, the characteristic function of the two-point differences of the velocity field (Tatarskii (1967)) $\chi_{\Delta \mathbf{u}_K}$, as well as the characteristic χ_n and structure $D_n \equiv \langle [n(\mathbf{r}_1) - n(\mathbf{r}_2)]^2 \rangle$ functions of the atmospheric refractivity (Tatarskii et al. (1992)). Such statistical quantities are studied at length for the case turbulence. As especially at low winds the atmospheric motion in the boundary layer at sea is dominated by wave modulation (Figure 2), for such a potentially important yet completely unstudied case here we will determine these statistical functions. For the purpose, we will employ information on the dynamics of the wind-wave coupling and the sea surface statistics.

i. Characteristic function of the velocity field. To proceed, a reasonable simplifying assumption can be that the turbulence $\mathbf{u}'$ and the wave-induced fields $\tilde{\mathbf{u}}$ are statistically independent. Their joint probability density function then satisfies $P_{\mathbf{u}',\tilde{\mathbf{u}}}(\mathbf{u}', \tilde{\mathbf{u}}) = P_{\mathbf{u}'}(\mathbf{u}')P_{\tilde{\mathbf{u}}}(\tilde{\mathbf{u}})$ and for the statistical average of the fluctuating wind velocity

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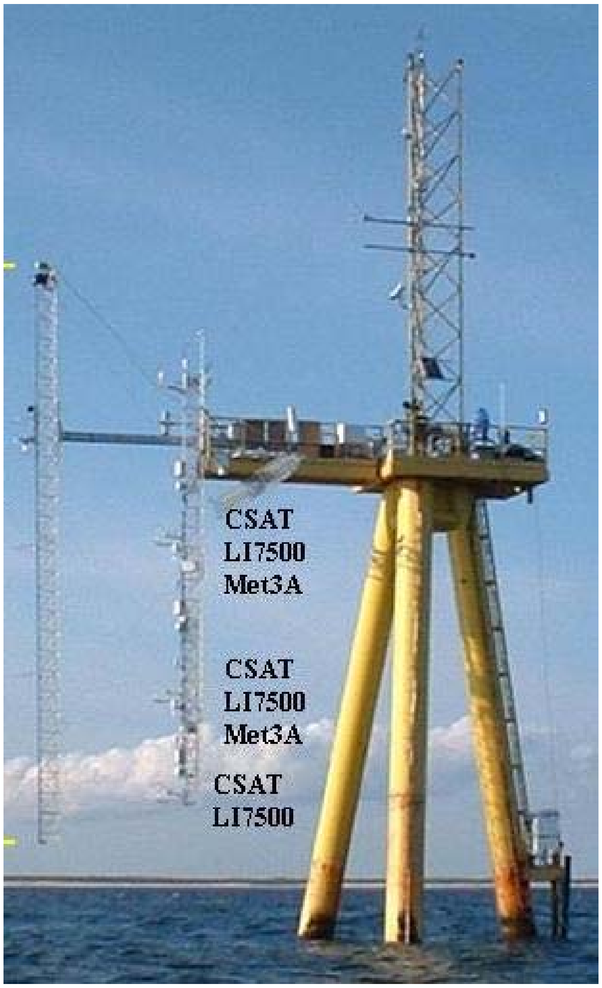

Figure 1: Air-Sea Interaction Tower during the Coupled Boundary Layers Air-Sea Transfer (CBLAST) experiment with the instruments mast. A photograph by Dr. J. Edson.

$\mathbf{u}_f = \mathbf{u}' + \tilde{\mathbf{u}}$ we have

$$\begin{aligned}\overline{\mathbf{u}_f} &= \int\int (\mathbf{u}' + \tilde{\mathbf{u}}) P_{\mathbf{u}'\tilde{\mathbf{u}}}(\mathbf{u}', \tilde{\mathbf{u}})\, \mathrm{d}\mathbf{u}'\, \mathrm{d}\tilde{\mathbf{u}} \\ &= \int\int \mathbf{u}_f P_{\mathbf{u}'}(\mathbf{u}') P_{\tilde{\mathbf{u}}}(\mathbf{u}_f - \mathbf{u}')\, \mathrm{d}\mathbf{u}_f\, \mathrm{d}(\mathbf{u}_f - \mathbf{u}').\end{aligned}$$

Comparing with $\overline{\mathbf{u}_f} = \int \mathbf{u}_f P_{\mathbf{u}_f}(\mathbf{u}_f)\, \mathrm{d}\mathbf{u}_f$ one finds that $P_{\mathbf{u}_f}(\mathbf{u}_f) = \int P_{\mathbf{u}'}(\mathbf{u}') P_{\tilde{\mathbf{u}}}(\mathbf{u}_f - \mathbf{u}')\, \mathrm{d}(\mathbf{u}_f - \mathbf{u}')$ and, as a Fourier transform of a convolution is the product of the individual Fourier transforms,

$$\chi_{\mathbf{u}_f} = \chi_{\mathbf{u}'}\, \chi_{\tilde{\mathbf{u}}}, \tag{1}$$

i.e. the characteristic function conveniently factorizes into turbulent and wave-induced multipliers.

A suitable approximation regarding the sea surface statistics would be to view it as an ergodic random surface consisting of multiple statistically independent Fourier harmonics (Eckart (1953), Longuet-Higgins (1957a), Longuet-Higgins (1957b), Hristov et al. (2008)). Invoking the Central Limit Theorem one could conclude that surface elevations follow a Gaussian distribution, as illustrated in Figure 3 by field data collected over the open ocean during the the Rough Evaporation Duct (RED) experiment (Anderson et al. (2004), Hristov et al. (2008)).

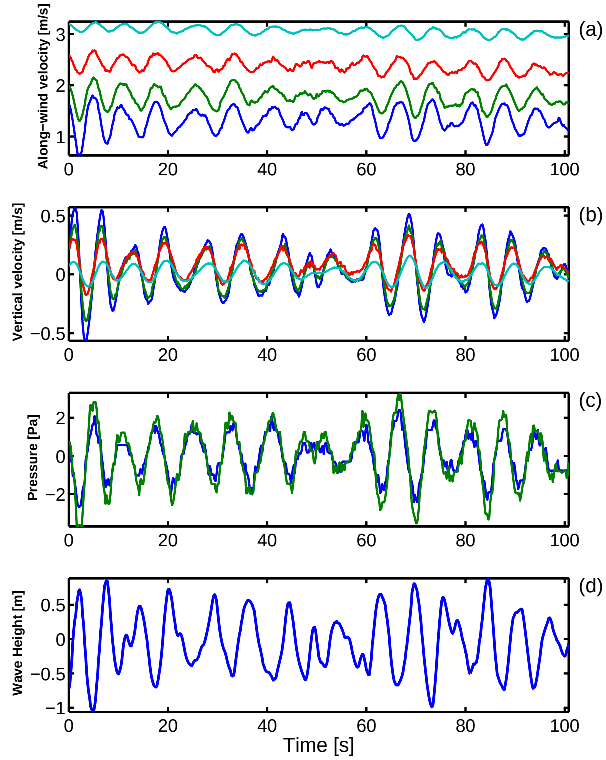

Figure 2: *A low-wind regime frequently observed during CBLAST. Time-series over 100s of (a) horizontal along-wind velocity, (b) vertical velocity, (c) pressure, and (d) surface elevation. The colors in the velocity plots correspond to instruments heights, in the order blue (the lowest), green, red and cyan (the highest).*

To describe the dynamics of wind-wave coupling, let us assume a constant-stress turbulent atmospheric boundary layer over the ocean. Then the mean horizontal velocity follows a logarithmic dependence on height $\overline{\mathbf{u}} = U(z)\hat{\mathbf{x}}$, $U(z) = (u_*/\kappa)\log(z/z_0)$, where u_* is the friction velocity, κ is the von Karman constant, and z_0 is the surface roughness. The horizontal velocity $\tilde{U}(z; c/u_*)$ and the vertical velocity $\tilde{V}(z; c/u_*)$ resulting from the monochromatic surface wave $\eta = ae^{\mathrm{i}k(ct-x)}$, $ak \ll 1$, linearly perturbing the mean flow $\overline{\mathbf{u}} = U(z)\,\hat{\mathbf{x}}$, are (Miles (1957), Hristov et al. (2003))

$$\tilde{U}(z; c/u_*) = -\frac{u_*}{\kappa}\frac{\mathrm{d}\phi(z; c/u_*)}{\mathrm{d}z}\eta(x,t) \tag{2}$$

$$\tilde{V}(z; c/u_*) = \mathrm{i}k\,(u_*/\kappa)\,\phi(z; c/u_*)\,\eta(x,t), \tag{3}$$

where ϕ is the wave perturbation's stream function satisfying the Rayleigh equation

$$\phi'' - k^2\phi - U''(U-c)^{-1}\phi = 0. \tag{4}$$

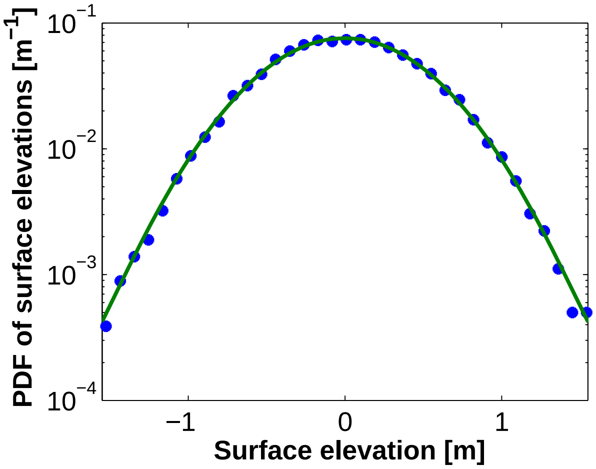

Figure 3: *Probability density function of the sea surface elevations obtained form 1 hour of point measurements (blue dots) in the open ocean during the Rough Evaporation Duct (RED) Experiment (Anderson et al. (2004), Hristov et al. (2008)). The continuous green line is the best fit Gaussian.*

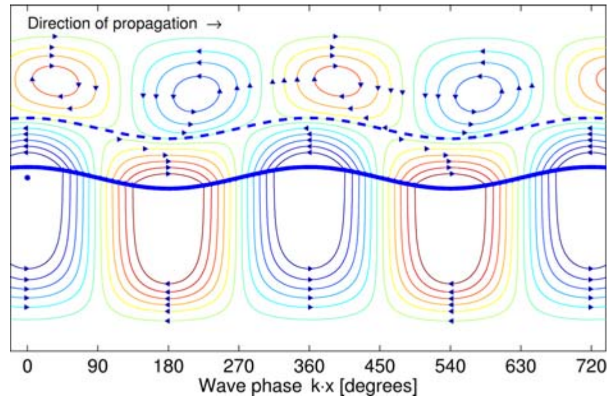

Figure 4: The wave-coherent flow streamlines as reconstructed according to the critical layer theory of Miles (1957). The solid line represents the air-water interface and the dashed line is the critical height. The whole eddy structure is propagating to the right following the wave. A Fourier sum of such flows over the wave spectrum forms the actual flow over the waves (Hristov et al. (2003)).

The streamlines corresponding to $\{\tilde{U}(z; c/u_*), \tilde{V}(z; c/u_*)\}$ are shown in Figure 4. Observing that the wave-induced fields (2) and (3) are linearly related to the wave field η (a Gaussian surface) and recalling the theorem stating that a linear transform preserves the Gaussianity of a random process (Parzen (1962)), one concludes that the observed velocity $\tilde{\mathbf{u}}$ induced by the entire wave spectrum is a Gaussian random process. Its probability density function and characteristic functions are then

$$P_{\tilde{\mathbf{u}}}(\tilde{\mathbf{u}}) = (2\pi\sigma^2_{\tilde{\mathbf{u}}})^{-1} \exp\left[-|\tilde{\mathbf{u}}|^2/\left(2\sigma^2_{\tilde{\mathbf{u}}}\right)\right],$$
$$\chi_{\tilde{\mathbf{u}}}(\mathbf{k}_s\tau) = \exp\left[-(k_s^2\sigma^2_{\tilde{\mathbf{u}}}\tau^2)/2\right].$$

The standard deviation $\sigma^2_{\tilde{\mathbf{u}}} = \sigma^2_{\tilde{u}} + \sigma^2_{\tilde{v}}$ is evaluated from (2), (3), and (4)

$$\begin{pmatrix} \sigma^2_{\tilde{u}} \\ \sigma^2_{\tilde{v}} \end{pmatrix} = \left(\frac{u_*}{\kappa}\right)^2 \int \begin{pmatrix} \phi'(\phi')^* \\ k^2\phi\phi^* \end{pmatrix} S_{\eta\eta}\, \mathrm{d}\mathbf{k},$$

where $S_{\eta\eta}(\mathbf{k}) = \langle \eta(\mathbf{k})\eta^*(\mathbf{k})\rangle$ is the surface waves spectrum and the integrals are taken over the range of surface waves wave vectors $\mathbf{k}$. In moderate and high wind conditions generally $\sigma_{\tilde{\mathbf{u}}} < \sigma_{\mathbf{u}'}$, i.e. $\chi_{\tilde{\mathbf{u}}}(\mathbf{k}_s\tau)$ will decay slower with $\mathbf{k}_s\tau$ than $\chi_{\mathbf{u}'}(\mathbf{k}_s\tau)$.

ii. Characteristic function of a passive scalar. Consider a passive scalar n in the marine atmospheric boundary layer and a vertical distribution of its average $N(z) = \overline{n}$. The wave displaces vertically a column of air with stratified distribution $N(z)$ of the scalar, thus causing a fluctuation in scalar value. The wave perturbation of the wind causes a vertical displacement δz of an air flow streamline

$$\delta z = \int \tilde{V}\mathrm{d}t = -c^{-1}(u_*/\kappa)\phi(y, c/u_*)\eta.$$

The wave-induced perturbation $\tilde{n}$ of the scalar's profile $N(z)$ due to stream line displacement is then $\tilde{n} = -\left(\mathrm{d}N/\mathrm{d}z\right)\delta z$ or

$$\tilde{n} = -\left(\frac{\mathrm{d}N}{\mathrm{d}z}\right)\left(\frac{u_*}{\kappa}\frac{\hat{\mathbf{x}}\cdot\mathbf{k}}{\sqrt{gk}}\right)\phi(z, \mathbf{k})\eta(\mathbf{k}). \quad (5)$$

This linear relationship between the driving wave field η and the wave-induced scalar fluctuation $\tilde{n}$ implies that the scalar fluctuation, integrated over the wave spectrum, is Gaussian. Its standard deviation $\sigma_{\tilde{n}}$ takes the form

$$\sigma^2_{\tilde{n}} = \left(\frac{u_*}{\kappa}\frac{\mathrm{d}N}{\mathrm{d}z}\right)^2 \int \frac{(\hat{\mathbf{x}}\cdot\mathbf{k})^2}{gk}\left(\phi\phi^*\right) S_{\eta\eta}(\mathbf{k})\, \mathrm{d}\mathbf{k}.$$

iii. Characteristic function of the two-point velocity differences $\Delta\mathbf{u} = \mathbf{u}(\mathbf{r}_1) - \mathbf{u}(\mathbf{r}_2)$ determines the variance of the signal's intensity at the receiver (Tatarskii (1967)). Considering the wave-induced velocity in the wind $\tilde{\mathbf{u}}$, the decomposition $\Delta\mathbf{u} = \Delta\mathbf{u}' + \Delta\tilde{\mathbf{u}}$ applies. In addition, we will assume $\Delta\mathbf{u}'$ and $\Delta\tilde{\mathbf{u}}$ to be both statistically independent and uncorrelated. Although the two-point velocity difference for turbulence $\Delta\mathbf{u}'$ cannot be strictly Gaussian[1], deviations from Gaussianity can be accounted for as corrections to the Gaussian distribution by means of cumulant expansion. Also, the possible deviations from Gaussianity for $\Delta\mathbf{u}'$ carry no restrictions on

[1]Due to the existence of a third order structure function $D_{rrr}(r)$ of $\Delta\mathbf{u}'$, as indicated by the Kolmogorov equation

$$D_{rrr}(r) = -\frac{4}{5}\varepsilon r + 6\nu\frac{\mathrm{d}D_{rr}}{\mathrm{d}r}.$$

the Gaussianity of $\Delta\tilde{\mathbf{u}}$, the latter following from the fact that $\Delta\tilde{\mathbf{u}}$ is linearly related to the Gaussian wave field η. Here we will seek to determine the characteristic function $\chi_{\Delta \mathbf{u}_K}$ for the $\mathbf{K}$-component of the two-point velocity difference (Tatarskii (1967))

$$\chi_{\Delta u_K(\mathbf{r}_1,\mathbf{r}_2)}(K\tau) \equiv \langle \exp\left[\mathrm{i}K\tau\left(u_K(\mathbf{r}_1,t)-u_K(\mathbf{r}_2,t)\right)\right]\rangle_u$$

within a Gaussian approximation for both $\Delta\mathbf{u}'$ and $\Delta\tilde{\mathbf{u}}$. For Gaussian fields

$$\chi_{\Delta u_K(\boldsymbol{\rho})}(\mu) = e^{-\frac{1}{2}\mu^2\langle[\Delta u_K(\boldsymbol{\rho})]^2\rangle},$$

where $\Delta u_K(\boldsymbol{\rho}) = \frac{1}{K}\mathbf{K}\cdot\Delta\mathbf{u}(\boldsymbol{\rho}) = \frac{1}{K}K_i\Delta u_i(\boldsymbol{\rho}) = \frac{1}{K}K_i\left[u_i(\mathbf{r}+\boldsymbol{\rho})-u_i(\mathbf{r})\right]$, $\mathbf{K}$ being the wave-vector of the propagating signal, $\langle[\Delta u_K(\boldsymbol{\rho})]^2\rangle = \frac{1}{K^2}K_iK_jD_{ij}(\boldsymbol{\rho})$, and

$$D_{ij}(\boldsymbol{\rho},\mathbf{r},t) \equiv \langle[u_i(\mathbf{r}+\boldsymbol{\rho},t)-u_i(\mathbf{r},t)][u_j(\mathbf{r}+\boldsymbol{\rho},t)-u_j(\mathbf{r},t)]\rangle.$$

For uncorrelated $\Delta\mathbf{u}'(\boldsymbol{\rho})$ and $\Delta\tilde{\mathbf{u}}(\boldsymbol{\rho})$ the structure function splits into turbulent and wave-coherent components

$$D_{ij}(\boldsymbol{\rho}) = D'_{ij}(\boldsymbol{\rho}) + \tilde{D}_{ij}(\boldsymbol{\rho}).$$

Recalling that for statistically independent $\Delta\mathbf{u}'(\boldsymbol{\rho})$ and $\Delta\tilde{\mathbf{u}}(\boldsymbol{\rho})$, as in (1), the characteristic function factorizes into a turbulent and wave-induced factors, we obtain

$$\chi_{\Delta v_K(\boldsymbol{\rho})}(\mu) = \left[\chi_{\Delta u'_K(\boldsymbol{\rho})}(\mu)\right]\left[\chi_{\Delta\tilde{u}_K(\boldsymbol{\rho})}(\mu)\right].$$

The Gaussianity of $\mathbf{K}\cdot\Delta\tilde{\mathbf{u}}$ and $\mathbf{K}\cdot\Delta\mathbf{u}'$ (linear functions of the Gaussian processes $\Delta\tilde{\mathbf{u}}$ and $\Delta\mathbf{u}'$, see Gikhman and Skorokhod (1969),) leads to

$$\chi_{\Delta\tilde{u}_K(\boldsymbol{\rho})}(\mu) = e^{-\frac{1}{2}\mu^2\langle[\Delta\tilde{u}_K(\boldsymbol{\rho})]^2\rangle}$$
$$\chi_{\Delta u'_K(\boldsymbol{\rho})}(\mu) = e^{-\frac{1}{2}\mu^2\langle\left[\Delta u'_K(\boldsymbol{\rho})\right]^2\rangle}$$

where

$$\langle[\Delta\tilde{u}_K(\boldsymbol{\rho})]^2\rangle = \frac{1}{K^2}K_iK_j\tilde{D}_{ij}(\boldsymbol{\rho})$$
$$\langle\left[\Delta u'_K(\boldsymbol{\rho})\right]^2\rangle = \frac{1}{K^2}K_iK_jD'_{ij}(\boldsymbol{\rho}).$$

For isotropic homogeneous turbulence

$$D'_{ij}(\boldsymbol{\rho}) = D'_{tt}(\rho)\delta_{ij} + \left[D'_{rr}(\rho)-D'_{tt}(\rho)\right]\rho_i\rho_j/\rho^2$$

with D'_{rr} being the structure function of the radial (longitudinal to $\boldsymbol{\rho}$) velocity and D'_{tt} is the structure function of the transversal (normal to $\boldsymbol{\rho}$) velocity.

Now, consider

$$\tilde{D}_{ij}(\boldsymbol{\rho},\mathbf{R}) \equiv \langle[\tilde{u}_i(\mathbf{R}+\boldsymbol{\rho})-\tilde{u}_i(\mathbf{R})][\tilde{u}_j(\mathbf{R}+\boldsymbol{\rho})-\tilde{u}_j(\mathbf{R})]\rangle,$$

where $\mathbf{R} = Z\hat{\mathbf{z}}+\mathbf{H} = Z\hat{\mathbf{z}}+X\hat{\mathbf{x}}+Y\hat{\mathbf{y}}$ and $\boldsymbol{\rho} = z\hat{\mathbf{z}}+\mathbf{h} = z\hat{\mathbf{z}}+x\hat{\mathbf{x}}+y\hat{\mathbf{y}}$. With wave field $\eta(\mathbf{R}) \equiv A(\mathbf{k})e^{-\mathrm{i}\mathbf{k}\cdot\mathbf{H}}$ let us rewrite (2) and (3) as

$$\tilde{U}_i(\mathbf{R}) = \Phi_i(Z,\mathbf{k},u_*)A(\mathbf{k})e^{-\mathrm{i}\mathbf{k}\cdot\mathbf{H}}$$
$$\tilde{U}_i(\mathbf{R}+\boldsymbol{\rho}) = \Phi_i(Z+z,\mathbf{k},u_*)A(\mathbf{k})e^{-\mathrm{i}\mathbf{k}\cdot(\mathbf{H}+\mathbf{h})}.$$

The wave velocity induced by the entire wave spectrum is then $\tilde{u}_i(\mathbf{R}) = \int\Phi_i(Z,\mathbf{k},u_*)A(\mathbf{k})e^{-\mathrm{i}\mathbf{k}\cdot\mathbf{H}}\,\mathrm{d}^2\mathbf{k}$ and the covariance is the ensemble average

$$\langle\tilde{u}_i(\mathbf{R})\tilde{u}_j(\mathbf{R})\rangle \equiv \frac{1}{\mathcal{V}}\int_{\mathcal{V}}\tilde{u}_i(\mathbf{R})\tilde{u}_j(\mathbf{R})\,\mathrm{d}^3\mathbf{R}.$$

Then, introducing $\langle A(\mathbf{k}_1)A^*(\mathbf{k}_2)\rangle = S_{\eta\eta}\delta(\mathbf{k}_1-\mathbf{k}_2)$, to determine $\tilde{D}_{ij}$ we need these covariances

$$\langle\tilde{u}_i(\mathbf{R})\tilde{u}_j(\mathbf{R})\rangle = \int\Phi_i(Z,\mathbf{k})\Phi_j^*(Z,\mathbf{k})S_{\eta\eta}(\mathbf{k})\,\mathrm{d}^2\mathbf{k}$$
$$\langle\tilde{u}_i(\mathbf{R}+\boldsymbol{\rho})\tilde{u}_j(\mathbf{R}+\boldsymbol{\rho})\rangle = \int\Phi_i(Z+z,\mathbf{k})\Phi_j^*(Z+z,\mathbf{k})S_{\eta\eta}(\mathbf{k})\,\mathrm{d}^2\mathbf{k}$$
$$\langle\tilde{u}_i(\mathbf{R}+\boldsymbol{\rho})\tilde{u}_j(\mathbf{R})\rangle = \int\Phi_i(Z+z,\mathbf{k})\Phi_j^*(Z,\mathbf{k})S_{\eta\eta}(\mathbf{k})e^{-\mathrm{i}\mathbf{k}\cdot\mathbf{h}}\,\mathrm{d}^2\mathbf{k}$$
$$\langle\tilde{u}_i(\mathbf{R})\tilde{u}_j(\mathbf{R}+\boldsymbol{\rho})\rangle = \int\Phi_i(Z,\mathbf{k})\Phi_j^*(Z+z,\mathbf{k})S_{\eta\eta}(\mathbf{k})e^{\mathrm{i}\mathbf{k}\cdot\mathbf{h}}\,\mathrm{d}^2\mathbf{k}.$$

For the low wind conditions, when the motion in marine atmospheric boundary layer is predominantly driven by the surface waves, the transfer functions $\Phi_i(Z,\mathbf{k},u_*)$ allow simplifications, which could deliver computational advantages. Unlike the structure function for homogeneous turbulence D'_{ij} commonly employed in atmospheric propagation studies, the wave-associated structure function $\tilde{D}_{ij}$ is anisotropic, reflecting the anisotropy of the surface wave field and the different significance of the vertical $\hat{\mathbf{z}}$ and the horizontal $\{\hat{\mathbf{x}},\hat{\mathbf{y}}\}$ directions. Also, there is a distinction between the spatial scales of the influence of the turbulence and of the wave signature on the propagation pattern. Considering the non-local covariance terms $\langle\tilde{u}_i(\mathbf{R}+\boldsymbol{\rho})\tilde{u}_j(\mathbf{R})\rangle, \langle\tilde{u}_i(\mathbf{R})\tilde{u}_j(\mathbf{R}+\boldsymbol{\rho})\rangle$ and ignoring the transfer functions Φ_i that do not depend on the horizontal coordinates, one observes that these non-local covariances have horizontal spatial extent as the correlation function of the wave field. Thus while the correlation function for turbulence vanishes (or the structure function saturates) at the integral scale of turbulence (Tatarskii et al. (1992)), the the non-local covariances $\langle\tilde{u}_i(\mathbf{R}+\boldsymbol{\rho})\tilde{u}_j(\mathbf{R})\rangle$ of the wave signature extend to scales of the order of the of the sea surface correlation distance.

3. SUMMARY

Wave-induced motion distinguishes the dynamics of the marine atmospheric boundary layer from the dynamics of the boundary layer over land. Observational data here demonstrated that at low wind conditions the wave modulation can dominate the air flow in the first tens of meters from the surface. Since the statistical composition of the motion in refractive media determines the propagation features of electromagnetic and acoustic signals, here we proposed an analytical model for the propagation-pertinent statistical structure of the wave-induced fields. Unlike the case of homogeneous turbulent medium, the influence of these wave-induced fields on signal transmission is clearly anisotropic and has a characteristic spatial scale of the sea surface, i.e. separate from the integral scale of the influence of the turbulent motion.

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