MUレーダーで観測された下層大気の大振幅ケルビン・ヘルムホルツ波の統計的研究

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Extensive studies of large-amplitude Kelvin-Helmholtz billows in the lower atmosphere with the MU radar

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Kelvin-Helmholtz (KH) instabilities can have significant impacts on atmosphere dynamics, clouds, aircraft security, optical wave propagation, etc. In the present work, characteristics of large amplitude (larger than 150 m) KH billows are analyzed, with emphasis on the turbulent properties.

First, a quite exhaustive review of papers dealing with KH instabilities observed by remote sensing techniques in the troposphere up to the tropopause altitude is presented. In particular, almost all the studies describing KH billowing structures reported values of Richardson number Ri larger than 0.12 (0.27 in average, i.e., close to the critical value of 0.25).

Second, results of observations of KH billows in the height range 1.32-20.34 km using the 46.5-MHz Middle and Upper Atmosphere radar (MUR; Shigaraki MU Observatory; 34.85N, 136.10E) are described. The data were collected during several observation periods (for a total of about 600 hours) when MUR was operated in range imaging mode at a high time resolution mode (20-24 s) vertically and in oblique directions (10 deg. off zenith). Several trains of KH braids, signature of KH billows in the height-time cross-sections of radar echo power, are described in detail. Except for very few cases (two possible cases are described in the paper), trains of KH braids are not followed by layer splitting which can result from breaking and turbulent mixing. A particular event shows some sort of turbulent plumes at the base of a nearly neutralized layer in the tropopause region: additional balloon data suggest that they might be the result of almost complete but still active turbulent mixing generated by a KH instability, though the billow stage was not observed at earlier times.

Statistics on the characteristics of the observed KH braids are also presented. Some of these results are found to be in very close agreement with those already presented by Browning (1971), for example, using a high-resolution UHF scanning radar. Despite the 271 identified cases, large-amplitude KH billows in the lower atmosphere are not ubiquitous since they were present less than 1% of the time and height only in the present datasets. The typical depth, horizontal wavelength, depth-to-wavelength ratio of the detected KH braids are about 600 m, 2600 m and 0.22, respectively up to the altitude of 16.5 km. They are thus relatively shallow and the quasi absence of layer splitting may suggest that they are more usually generated when Ri falls just below 0.25 (so that the large-amplitude KH billows are not sufficiently energetic for breaking and mixing), confirming the past results. 10-min averaged vertical shears of horizontal wind are 23 m s^{-1} km^{-1} in average when the KH braids are observed. Echoes associated with the KH braids are isotropic making doubtful the direct effect of KH billows on mean vertical wind velocity biases reported in the literature.

Finally, attempt of estimates of energy dissipation rate *e* and vertical eddy diffusivity K associated with the KH billows are made from the measurements of Doppler spectrum variance assuming that Ri is smaller than but close to 1/4 at the stage of development of the KH instabilities. Mean values of *e* and K are found to be typically about 1 mW kg^{-1} and 3 m^2 s^{-1}, respectively. These values have been commonly reported from earlier radar measurements at lower resolutions for turbulent layers. Some of those turbulent layers were likely trains of KH billows.