Observation of ozone vertical mixing due to KH instability in tropical tropopause layer

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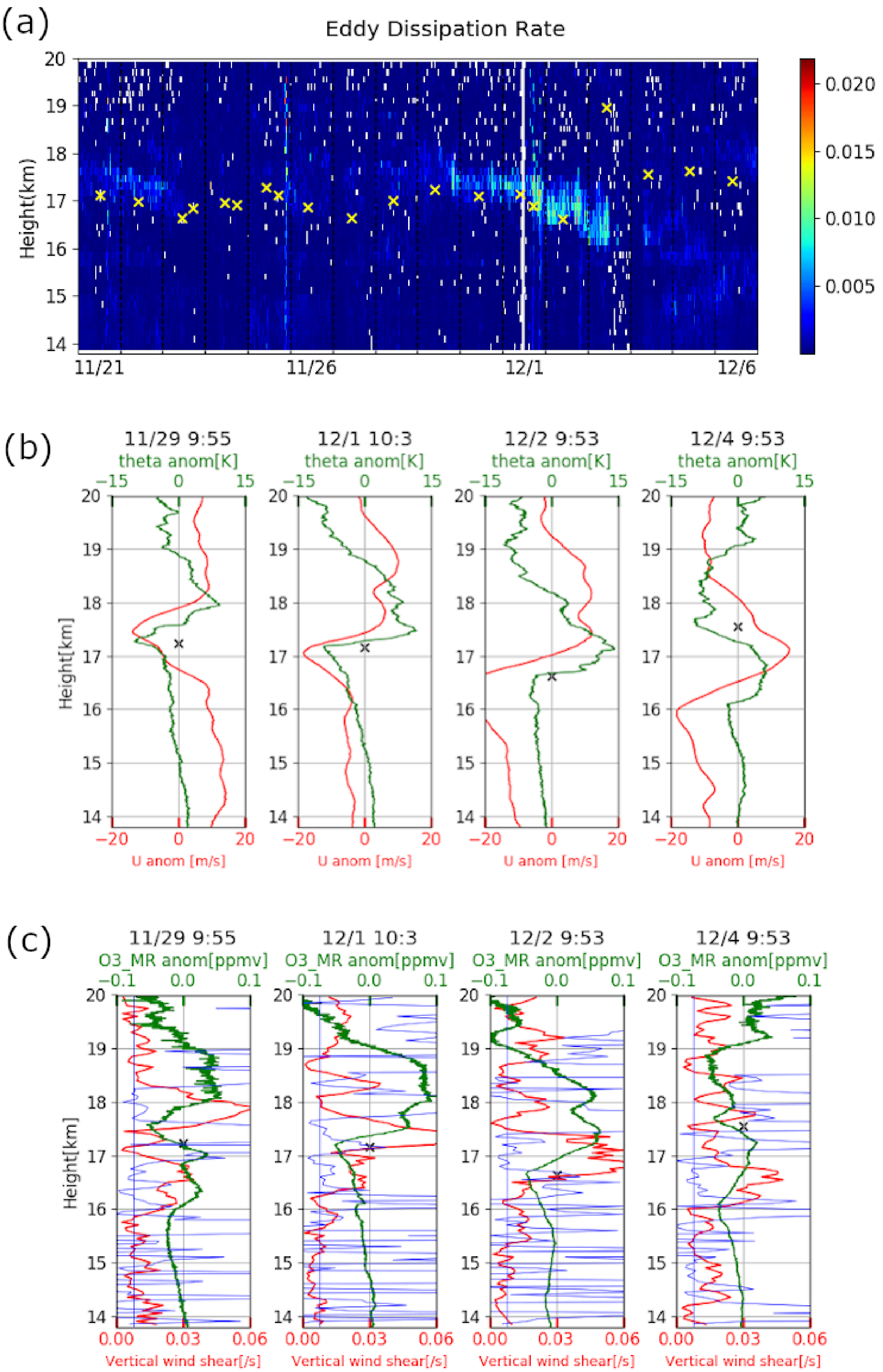
The tropical tropopause layer (TTL) is a transition region between the troposphere and the stratosphere peculiar to the tropical zone. Physical and chemical processes in the TTL are important because they affect Stratosphere-Troposphere Exchange (STE). However, there have been few direct observations of TTL, and most previous researches have focused on large-scale waves, so the details of smaller processes related to TTL and STE are still unknown. In this study, we analyzed small-scale turbulence near the TTL region and the associated transport using the data of observation campaign conducted in collaboration with STRATEOLE-2 (TTL / lower stratospheric observation project using super pressure long duration balloons). In particular, we investigated whether the Kelvin-Helmholtz instability, which was shown to occur in TTL in previous studies, affects the vertical distribution of ozone.

We use the data obtained by ozone and GPS sondes released from the Equatorial Atmospheric Observatory in West Sumatra, Indonesia from November 21 to December 6, 2019, and the data observed with the Equatorial Atmospheric Radar (EAR) during the same period.

Figure (a) shows the turbulence intensity calculated from the EAR spectral width data, and the crosses indicate the tropopause defined as the lowest temperature (Cold Point Tropopause; CPT). The feature of CPT jump and strong turbulence observed on December 2-3 is similar to previous observations, suggesting the breaking of equatorial Kelvin waves. Figures (b) and (c) are the profiles of four sonde observations before and after the CPT jump. Figure (b) shows the deviation from the mean of the zonal wind (red) and the potential temperature (green), and (c) shows the vertical wind shear (red), deviation of ozone mixing ratio (green), and Richardson number (blue) (blue vertical line indicates Ri = 0.25). The phase shift between the zonal wind field and the temperature field shown in (b) is similar to that of the equatorial Kelvin wave, and propagates downward with increasing amplitude. The vertical wind shear shown in (c) is large in the altitude regions where the zonal wind anomaly shown in (b) suddenly changes from negative to positive and the amplitude is large (17.5-18 km altitude on November 29, moving downward with time). In this altitude regions, although the Richardson number does not always satisfy the condition in which KH instability occurs (Ri <0.25), the features of wind shear and Brunt-Väisälä frequency (not shown) are consistent with previous studies, suggesting the existence of KH billows. In the same altitude regions, the amount of ozone increases with altitude.

We have conducted direct observations of TTL and have shown that KH billows caused by strong vertical shear due to the increase in the amplitude of the zonal wind before and after the equatorial Kelvin wave breaking may cause vertical mixing of ozone. As a future work, we will investigate whether other factors than atmospheric mixing are related to the fluctuation of ozone amount.

Keywords: Tropical tropopause layer, Stratosphere-Troposphere Exchange, Kelvin-Helmholtz instability


(a)
Eddy Dissipation Rate
Height(km)
20
19
18
17
16
15
14
11/21
11/26
12/1
12/6
0.020
0.015
0.010
0.005
(b)
11/29 9:55
12/1 10:3
12/2 9:53
12/4 9:53
theta anom[K]
−15
0
15
Height[km]
U anom [m/s]
−20
0
20
(c)
11/29 9:55
12/1 10:3
12/2 9:53
12/4 9:53
O3_MR anom[ppmv]
−0.1
0.0
0.1
Height[km]
Vertical wind shear[/s]
0.00
0.03
0.06