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著者(和文)	TaoTao
Author(English)	Tao TAO
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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	Tao Tao		指導教員（主）： Academic Supervisor(main)	大風　翼
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This thesis targets on understanding the realistic wind features of tornado by means of meteorological models. To accomplish this target, works are done on two aspects: to understand the mechanism of tornado, and to estimate the universality of the resolved tornadic wind features. The thesis consists of following chapters. A meteorological model, Weather Research and Forecast with large-eddy simulation implemented (WRFLES) is used to reproduce a realistic tornado process. First, the performance of WRFLES in resolving strong wind is validated in a common strong wind condition, a typhoon case (Chapter 2). After validation, the WRFLES successfully reproduces the 2012 Tsukuba tornado. The lifetime mechanism of the tornado is investigated in Chapter 3 (tornadogenesis) and Chapter 4 (maintenance and dissipation). In Chapter 5, the resolved near-ground wind features are presented and its universality is demonstrated via a series of parameter tests using an idealized meteorological model, Cloud Model 1 (CM1).

Chapter 2 validates the performance of WRFLES on resolving wind features of different scales in typhoon Jebi 2018. The simulated typhoon shows good agreement with the observations, including typhoon track, wind velocity histories at meteorological stations and a wind velocity profile near the landing point. The horizontal roll structures (HRS) are resolved by grids of 250-m horizontal size, while finer-scale turbulence could only be resolved by grids of 50-m horizontal size. The HRS can increase the wind speed at low levels by transporting high-momentum flow from upper levels to the low levels. The HRS are more evident in the flow coming from the sea area. If the flow comes from the mountainous area, the wind perturbation caused by the terrain undulation would distort the HRS and consequently make the HRS disorganized.

Chapter 3 investigates the tornadogenesis mechanism of the 2012 Tsukuba tornado which is reproduced by WRFLES, concerning the circulation source responsible for the tornadogenesis. Circuits initiated from near-ground vortices (including a pre-tornadic vortex and the incipient tornado) are backward traced, to reveal the circulation generation mechanism. According to Kelvin's circulation theorem, the time change in the circulation is only caused by baroclinity and friction. Circulation analyses show that the frictional term caused by surface drag is the dominant circulation source. The surface drag generates crosswise vorticity near the ground, which is tilted (or firstly exchanged to streamwise vorticity then tilted) into vertical vorticity when air parcels enter the tornado cyclonically. The rear-flank downdraft (RFD) surge triggers the tornadogenesis by enhancing near-ground convergence, however, the RFD surge is not necessarily associated with baroclinically generated vorticity which was mentioned in previous studies.

Chapter 4 investigates the mechanism of maintenance and dissipation (M&D) of the 2012 Tsukuba tornado, focusing on the role of RFD in the M&D. How RFD wrapping influences the tornado's intensity is examined via analyzing the circulation import process from different inflow regions. During the early period of the dissipation, as the RFD is intensified, the contribution of RFD to the circulation of the tornado becomes significant (increases by about 2×10^4 m^2s^{-1}), while the total circulation import of the tornado decreases because the intensified RFD hinders more circulation import from the eastern inflow (decreases by about 3×10^4 m^2s^{-1}). The circulation of RFD is generated by surface drag. Extra vortices, which are initiated along the primary rear-flank gust front (RFGF), interact with the tornadic vortex in forms of merging or replacement. The intensified RFD plays a crucial role in the vortex replacements between the original tornado and the EVs. The RFD wrapping suppresses the updraft in the original tornado and causes it to dissipate. Meanwhile, a secondary RFGF in the intensified RFD moves forward quickly and merges with the primary RFGF, which enhances the near-ground convergence and strengthens the EV into a new tornado.

Chapter 5 presents the wind characteristics of the 2012 Tsukuba tornado simulated by WRFLES, and validates its universality via a series of parameter tests of different surface drag coefficients using CM1. The WRFLES-simulated tornado exhibits transition from single vortex to vortex ring, and finally to multi-vortex structures in its lifetime, which is caused by the weakening updraft. The temporal velocity peaks of near-ground horizontal velocity frequently occur, which could be caused by the convergence of tornado itself or by the gust front of RFD outflow. Both cases are important for wind-engineering research concerning similar velocity magnitude and occurring frequency. For the later case, the gust front results in a strong low-level jet below 100 m AGL. Among the inflow of tornado, larger wind fluctuation is found on the rear side of the tornado which is caused by the mixing effect of downdraft. In parameter tests, the behavior of RFD, tornadic vortex pattern and turbulence of wind inflow show similarity to the WRFLES-simulated tornado especially in the later life time, partly proving the universality of tornado mechanism and wind features.

Finally, Chapter 6 summarizes the findings of each chapter and points out the limitations and future work.