Spin-down process caused by vortex-induced sea-surface cooling

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1. Introduction

A vortex in the atmosphere induces sea-surface cooling (SSC), a decrease in sea-surface temperature (SST) by passage of a vortex. When the vortex is stationary, SSC appears immediately beneath the vortex. SSC plays a role in delaying vortex merger events, which are an intensification process from a several discrete mesovortices to a single ring (Wada, 2009). However, SSC little affects a structural change of the single ring at the mature phase. During the mature and decaying phases, a vortex decays as SST or the upper ocean heat content decreases immediately beneath the vortex. The decaying process of a vortex is influenced by both atmospheric and oceanic environmental conditions and their interactions. We need to understand how SSC affects the decaying process of a vortex under a unique atmospheric condition. In addition, this report addresses an issue whether or not the value of SST alone determines the intensity of the single ring. To investigate them, idealized numerical experiments were performed with reference to Wada (2009) using a nonhydrostatic model coupled with a multilayer ocean model developed at the Meteorological Research Institute in the Japan Meteorological Agency (hereafter MRIJMA).

2. Experiment design

MRINHM covered a 600 km x 600 km square computational domain with a horizontal grid spacing of 2km. MRINHM had 40 vertical levels with variable intervals from 40 m for the lowermost (near-surface) layer to 1180 m for the uppermost layer. MRINHM had maximum height approaching nearly 23 km. The time step of MRINHM was 6 s. The length of the time step of the ocean model was six times that of MRINHM. The Coriolis parameter was uniformly set to 5.0×10^{-5} (nearly 20ºN).

A water depth in the multilayer ocean model coupled with MRINHM was uniformly set to 1000 m. Initial SST was set to 30ºC, the initial temperature at the base of the mixed layer to 29ºC, the initial temperature at the base of the thermocline to 18ºC and the initial temperature at the bottom to 5ºC. Initial salinity was set to 35 at all levels. The initial mixed-layer depth was set to be 30 m, the initial thermocline thickness to 170 m and the initial third-layer thickness to 800 m. The third layer thickness was assumed to be unaffected by entrainment during the integration.

Table 1 summarizes the idealized numerical experiments performed using the MRINHM with and without being coupled with the ocean model. The initial vortex and thermal conditions were the same as those given by Wada (2009). The integration time was 81 h (108 h in OC54) with results output every 30 min. The sensitivity of vertical turbulent mixing in the ocean model was also evaluated using two tuning parameters: m_d=17.5 and m_d=175. The parameter m_d is associated with turbulent kinetic energy flux produced by breaking surface waves.

Table 1 Summary of key parameters of idealized MRINHM numerical experiments with and without coupling with the ocean model.

Experiment	Integration time	Beginning hour of coupled model
CTL	81 h	0 h
OC	81 h	27 h
OC54	108 h	54 h

3. Results

Figure 1 indicates that CP rapidly decreases from nearly 21 h to 42 h in OC54, indicating that the vortex rapidly intensifies when SST underneath the vortex is not changed and remains high. High value of m_d leads to high CP, indicating that rapid intensification of the vortex is suppressed in CTL and OC27, and a rapid increase in CP or a rapid weakening of strong intensity of the vortex in OC54. A difference in CP between two m_d values turns to be uniform at 81 h in all experiments. In OC54, CP monotonically decreases. Interestingly, the value of CP is nearly 985 hPa at 81 h

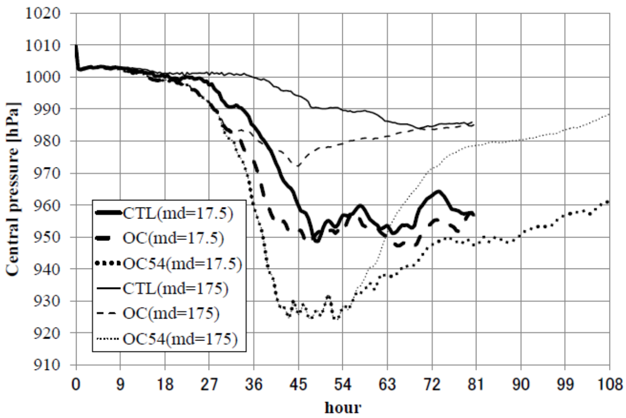

Figure 1 Time series of CP of the vortex every 30 minutes.

81h in CTL and OC, and at 108 h at OC54 when m_d = 175, whereas that is nearly 960 hPa when m_d = 17.5.

Figure 2 indicates that the variation of CP does not always correspond to that of SST when m_d = 175. The value of CP in CTL is almost the same as that in OC at 81 h and OC 54 at 108 h (nearly 22.8ºC) when m_d = 17.5. SST increases after 81 h in OC54 due to the input of solar radiation and horizontal numerical diffusion. A rapid decrease in SST (the amplitude is nearly 11ºC: Fig. 2) causes a rapid increase in CP (the amplitude is nearly 25 hPa: Fig. 1) from 54 h to 63 h in OC54 when m_d = 175, which is a characteristic of the impact of vortex-induced SSC on the vortex at the mature and decaying phases. The characteristic is different from that at the intensification phase.

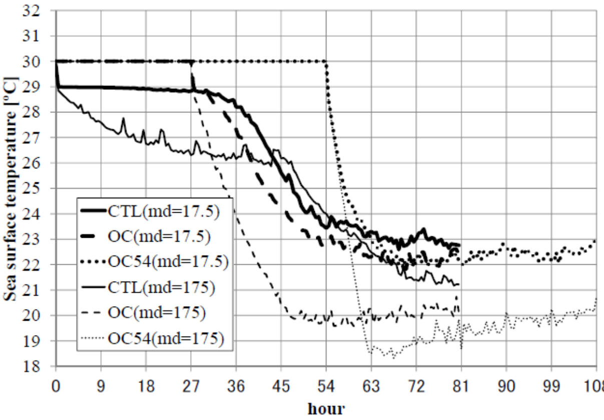

Figure 2 Time series of SST beneath a vortex every 30 minutes.

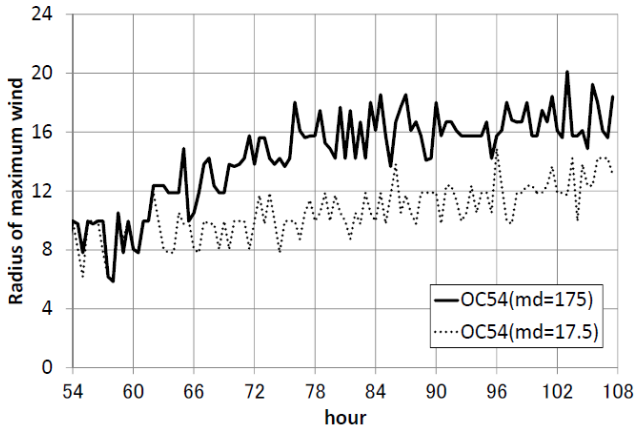

Figure 3 Time series of the radius of maximum wind speed every 30 minutes.

The radius of maximum wind speed (RMW) is nearly 8 km at 54 h (Fig. 3). RMW is extended to 12 km at 108 h in OC54 when m_d = 17.5 and is further extended to 16 km at the same hour in OC54 when m_d = 175. A difference of RMW becomes clear from 63 h to 78 h when a rapid decrease in SST terminates.

We investigate the impact of vortex-induced SSC on the gradient-wind balance of the vortex at 20-m height. Horizontal distribution of winds at 54 h (Fig. 4a) shows that the inflow around RMW is caused by anticyclonic agradient winds. Maximum winds at 81 h (Fig. 4b) are reduced to nearly 54.1 m s^{-1} from 62.0 m s^{-1}. However, the characteristics of the inflow and anticyclonic agradient winds at 81 h are not changed from those at 54h. In contrast, anticyclonic agradient winds are weak and resultant inflow becomes weak at 81 h when m_d = 175. The location of relatively strong agradient winds shift outward from the vortex's center, indicating the extension of RMW.

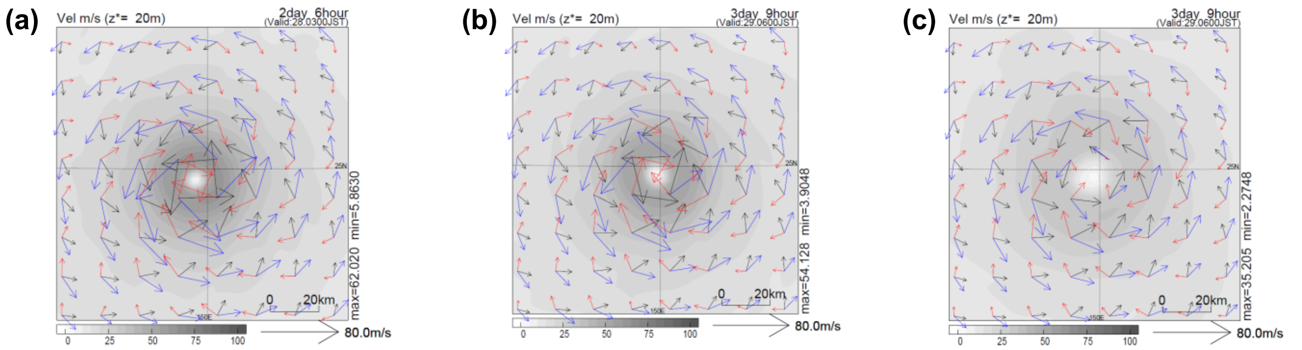

Figure 4 Horizontal distribution of winds (black), gradient winds (blue) and agradient winds (red) at 20-m height (a) at 54 h in OC54 when m_d = 17.5, (b) at 81 h when m_d = 17.5 and (c) at 81 h when m_d = 175.

4. Discussion and conclusion

A 'spin-down' process caused by vortex-induced SSC is characterized by the extension of RMW and suppression of the inflow owing to weakening agradient winds. In fact, static stability in the lower troposphere (particularly below 1000 m height) becomes relatively high in OC54 when m_d = 175 (not shown). High static stability is responsible for suppression of vertical velocity within the vortex (not shown) and resultant decrease in total water within the inner core, resulting in the weakness of pressure gradient around the location of RMW and in the reduction of horizontal winds in the lower troposphere. The reduction of winds affects both gradient and agradient winds so that both the inflow and tangential winds becomes weak. The extension of RMW is considered to be caused by weakening both inflow and angular momentum transport due to weakening surface friction.

This report describes a spin-down process caused by vortex-induced SSC. Main conclusions are:

1) CP at the mature phase is not uniquely determined by SST just beneath the vortex.
2) The impact of vortex-induced SSC on the evolution of the vortex at the mature and decaying phase differs from that at the intensification phase.
3) Vortex-induced SSC leads to an increase in static stability, resulting in the suppression of vertical velocity the reduction of total water within the inner core and the decrease in pressure gradient around RMW, and thus the extension of RMW owing to weakening both inflow and angular momentum conversation.

Acknowledgement

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References

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