Large-eddy simulation of idealized hurricanes at different sea surface temperatures

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Abstract: Idealized hurricanes show different characteristics at different sea surface temperatures in six nested domains down to 62 m grid size. Four cases were conducted, with sea surface temperatures of 26°, 27°, 28°, 29℃, respectively. Some interesting phenomena are obtained. First, for both the maximum of instantaneous wind velocity and time-averaged wind velocity, domain 6 (62m) converges to domain 5 (185m). Second, for sea surface temperature of 26°, domain 5 does not have small-scale turbulent structures, but the other three cases all have, this is also a new discovery relative to the previous work of R. Rotunno *et al.*. Another important phenomenon is that the distribution function of velocity changes between 27° and 28° case, and has different shapes between the 26°, 27° cases and the 28°, 29° cases, the latter ones having a second peak, which maybe means that the hurricane structure changes as sea surface temperature changes.

1. Introduction

R. Rotunno *et al.* (2009) found that a transition to randomly distributed, small-scale turbulent eddies occurs when the grid size decreases from 185 to 62 m at sea surface temperature (sst) of 26.3°. Here we found that at sst of 28°, the same phenomenon occurs earlier than 62 m, at grid sizes between 556 and 185 m. In this study, we further investigate the influence of sst and grid size on hurricane intensity and turbulent structure.

2. Simulation settings

The simulated period	2007_09_01_00:00:00~2007_09_07_00:00:00 (UTC)					
Algorithm	WRF			WRF-LES		
Domain	1	2	3	4	5	6
Horizontal grid distance (m)	15000	5000	1666.67	555.56	185.18	61.72
Horizontal grid number	405*405	301*301	598*598	598*598	598*598	967*967
Vertical layer number	87					
Time step (s)	60	20	6.67	2.22	0.74	0.25
Start time(dd_hh)	01_00	01_00	01_00	05_00	06_00	06_18
End time(dd_hh)	07_00	07_00	07_00	07_00	07_00	06_22

Tab. 1 The basic WRF simulation settings

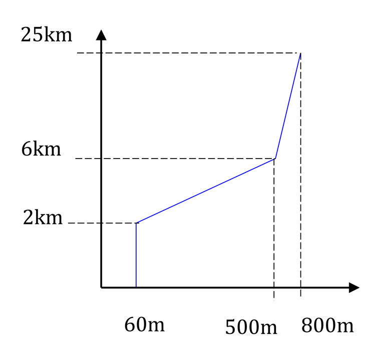

Fig. 1 Vertical levels

The cloud physics scheme is the WSM6 and the PBL mixing is handled by the YSU scheme. The Revised MM5 Monin-Obukhov surface layer model was adopted. The cumulus parameterization and radiative scheme are not considered. The air-sea exchange uses Donelan Cd plus Const z0q represents the heat and momentum. For domains D1-D3, the vertical and horizontal turbulence processes are separated. While, for domains D4-D6, a three-dimensional turbulence-kinetic-energy equation appropriate for LES was used.

The initial velocity field represents an incipient TC-like axisymmetric vortex with maximum lowest-level wind of 15 m/s, radius of maximum wind of 82.5 km, and radius of zero wind of 412.5 km. The Coriolis parameter is spatially uniform with its value at 20° latitude. There is no mean shear and the initial thermodynamic profile was perturbed to match the sst differences.

3. Results

3.1 Wind velocity time history

Figure 2 shows that the hurricane peak strength increases as the grid size decreases, and an important phenomenon is that for both the maximum of instantaneous wind velocity and time-averaged wind velocity, domain 6 (62m) converges to domain 5 (185m), which means that for the hurricane intensity, a horizontal grid size about 200 m is sufficient. Note also that the peak for 27° is sometimes higher than that for 28° C.

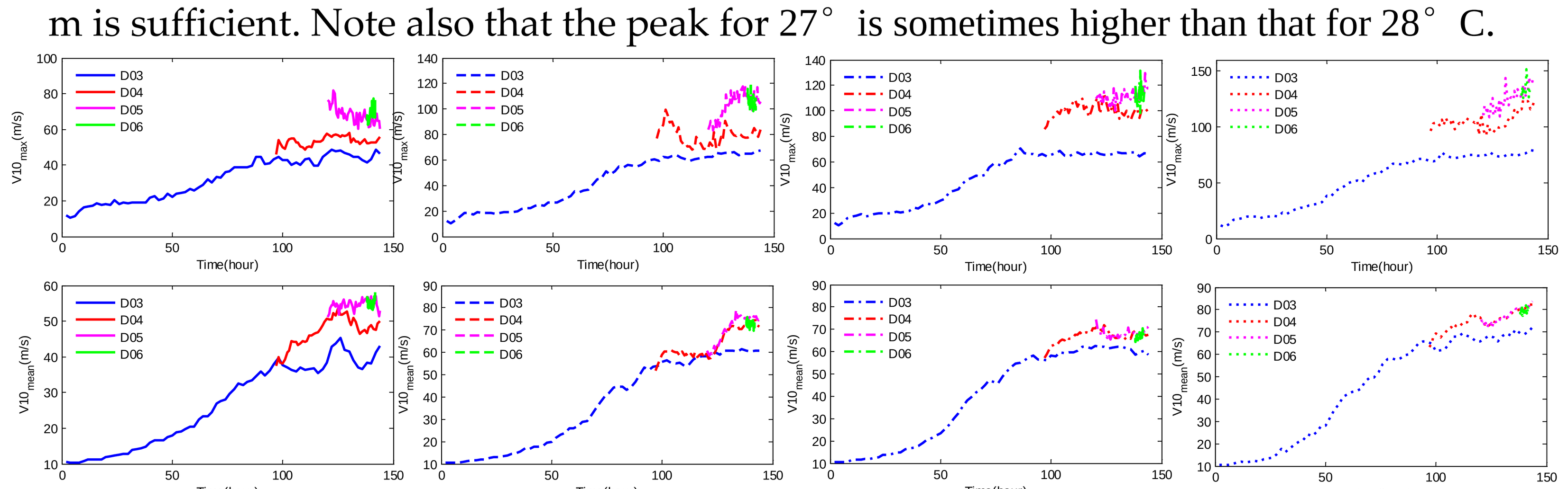

Fig. 2 The maximum of instantaneous (upper) and time-averaged (bottom) 10 m wind velocity. Subfigures represent 26°, 27°, 28°, 29℃ from left to right . Time average is 1 and 10 minutes for domains D6 and D5.

3.2 Turbulence field

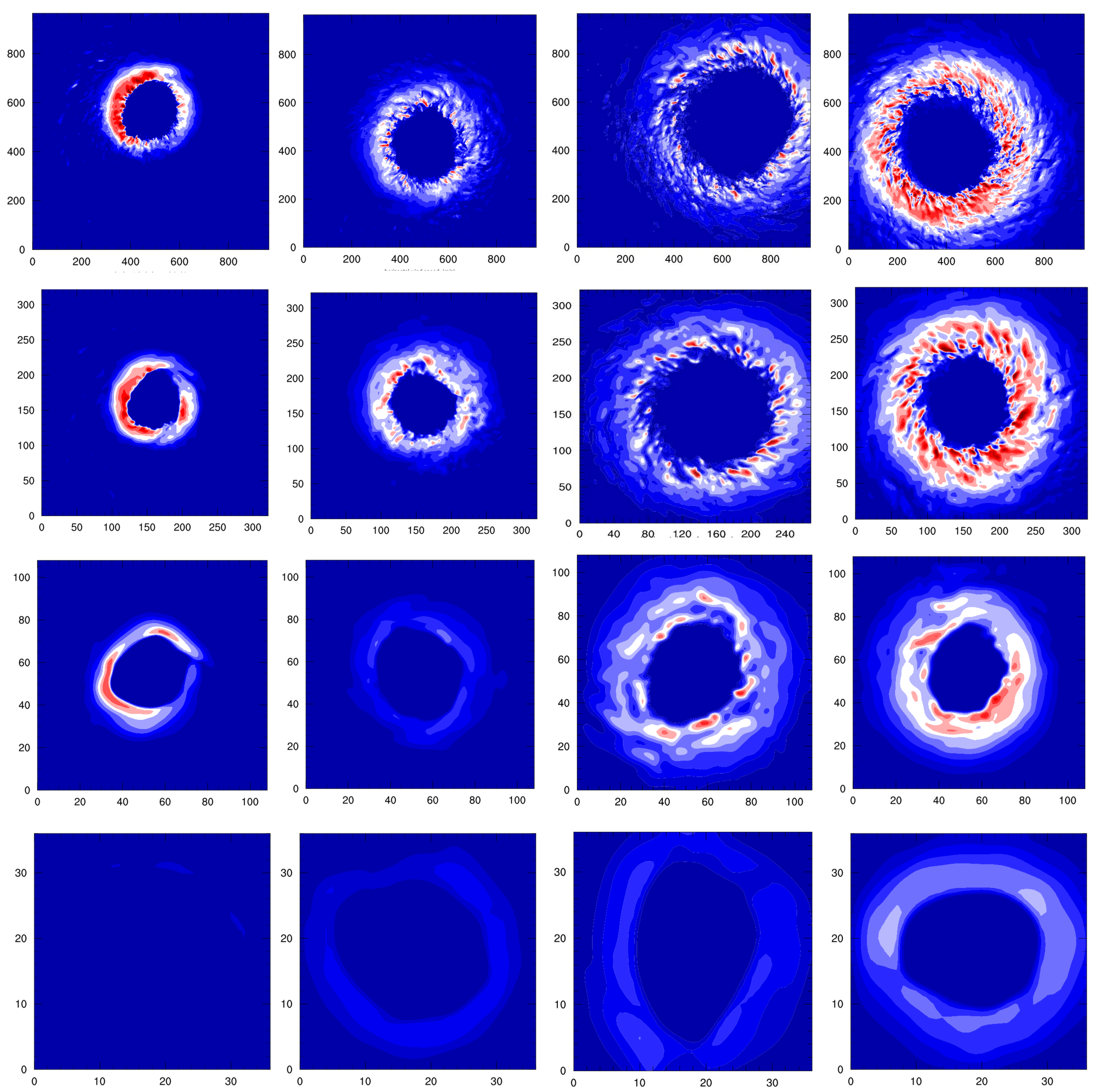

Fig. 3 Wind field of each domain of each case. Subfigures represent 26°, 27°, 28°, 29℃ from left to right, and domains D6, D5, D4, D3 from top to bottom. Here note that the 26° case (the left color bar) has a different scale from the other three cases (the right color bar)

Figure 3 shows the wind field of each domain for each case. For sst of 26°, the phenomenon is consistent with R. Rotunno *et al.* (2009), that transition to randomly distributed, small-scale turbulent eddies occurs between 185 and 62 m, while for other three cases, this transition occurs between 556 and 185 m, which means that the turbulent eddies resolved earlier as sst increases, the larger sst, the needed horizontal grid size that transition to small-scale turbulent eddies is coarser.

3.3 Wind velocity distribution

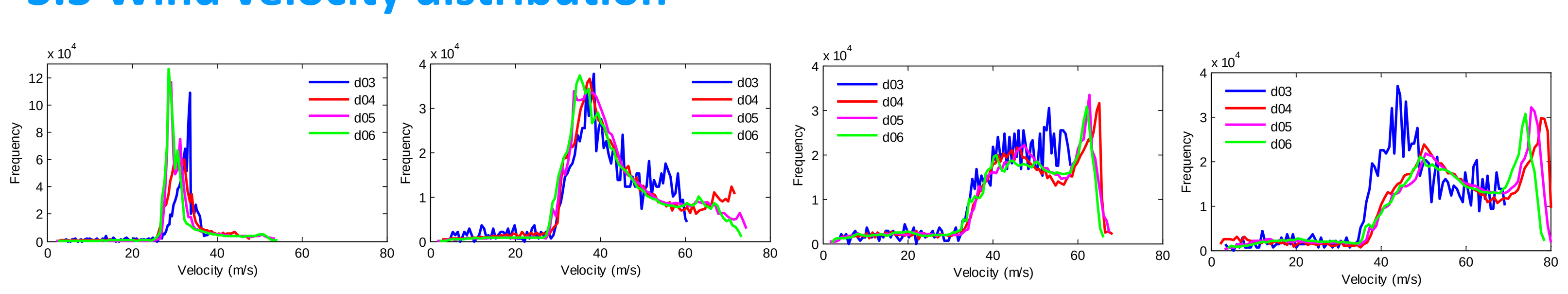

Fig. 4 The histogram distribution of wind velocity. Subfigures represent 26°, 27°, 28°, 29℃ from left to right

Figure 4 shows the histogram distribution of wind velocity of each domain for each case. Compared with the 26° and 27° cases, the 28° and 29° cases have an obvious second peak in the distribution for domains D4, D5, and D6. These can be explained by figure 5, which shows the radial distribution of wind velocity, we found that the second peak is due to a wide eyewall region, specifically, the flat region of figure 5 corresponds to the second peak value of figure 4, while the weaker cases have a sharper peak. Figure 6 shows the location of the distribution peak value of each case in domain 6, we also can clearly see that for 28° and 29° cases, this peak is located in the eyewall region.

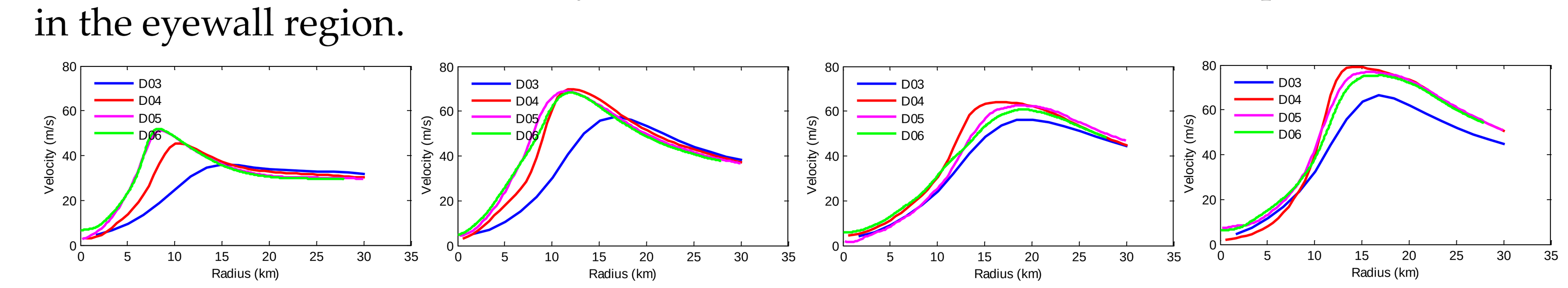

Fig. 5 The radial distribution of wind velocity. Subfigures represent 26°, 27°, 28°, 29℃ from left to right

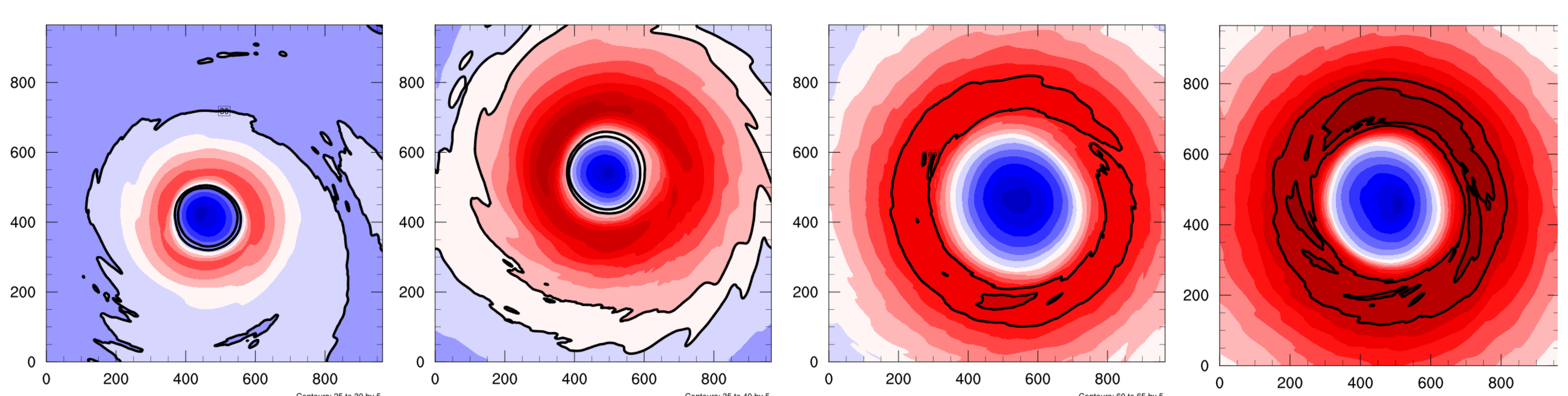

Fig. 6 Time-averaged wind field of domain 6 of each case. Subfigures represent 26°, 27°, 28°, 29℃ from left to right, between the solid black lines is the peak of the wind velocity distribution

3.4 Sea surface inflow angle

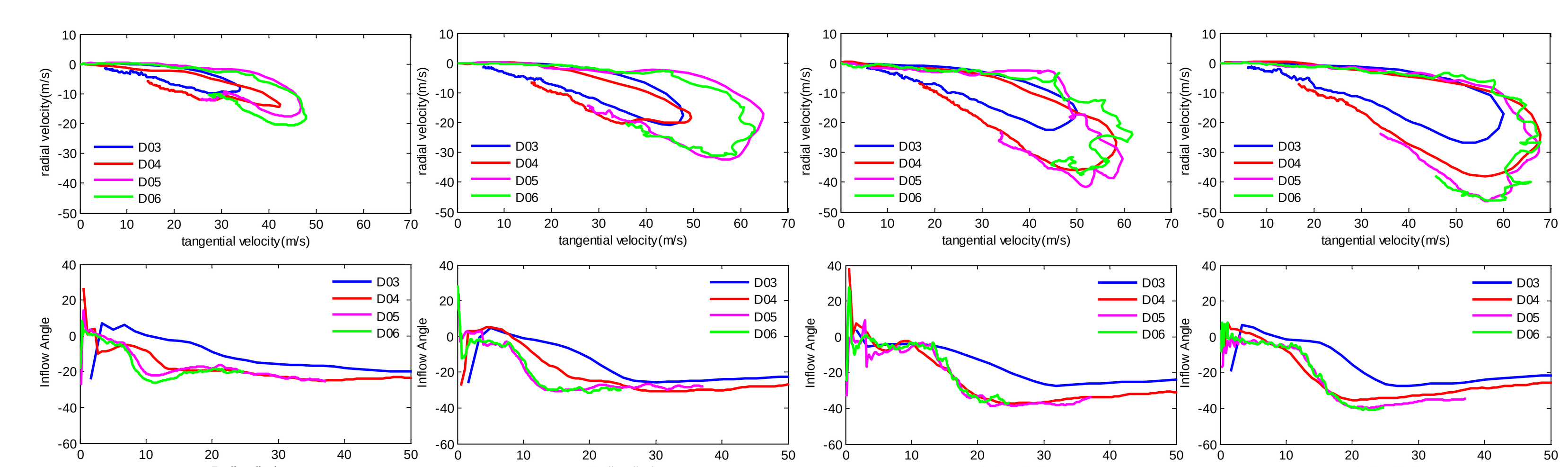

Fig. 7 The relation of tangential and radial velocity (upper) and sea surface inflow angle (bottom) of each domain of each case. Subfigures represent 26°, 27°, 28°, 29℃ from left to right.

The larger sst or domain, the larger surface inflow angle, this is consistent with the characteristics of radial wind velocity.

References

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