TDWR-LIDAR dual Doppler analysis of 2D wind field associated with subtropical squall lines

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1. INTRODUCTION

Located in a subtropical coastal area, Hong Kong is often affected by squall lines in the summer. Detailed analysis of the wind field associated with the squall line would help the monitoring and forecasting of this intense convective weather phenomenon. In Chan and Shao (2007b), the 3D wind fields of some squall line cases in the southern China were studied using dual Doppler analysis of the radars in Hong Kong and Guangzhou at a horizontal resolution of 800 m. In the present paper, the 2D wind fields of squall lines would be analyzed to find out the salient features of the wind distribution near the ground at a higher horizontal resolution (viz. 100 m). The results would have applications in the day-to-day analysis and forecasting of the severe squalls in a localized area, such as the neighbourbood of an airport.

The wind data in this study are measured by the Doppler Light Detection And Ranging (LIDAR) system (location in Figure 1) inside the Hong Kong International Airport (HKIA) and the Terminal Doppler Weather Radar (TDWR) (location in Figure 1) serving the airport. These two instruments are mainly used in the provision of windshear alerting services to the arriving/departing aircraft. They perform surveillance scans overlapping in the airport area. Though the scans are made at different heights above the ground, the presence of both sets of radial velocity measurements in the overlapping area would be useful for dual Doppler analysis. Technical specifications of the LIDAR and the TDWR are given in Shun and Lau (2002) and Shun and Johnson (1995) respectively.

The dual Doppler analysis method is summarized in Section 2. Two examples of 2D analyzed wind fields are described in Section 3. Section 4 is devoted to conclusions of the study.

2. RETRIEVAL METHOD

Details of the retrieval method are given in Chan and Shao (2007a). Only a summary of the method would be given here. The retrieval method is based on a parameter identification technique and the parameter used in this paper is the radial velocity of the LIDAR/radar. Backscattered power from the LIDAR is not used as the parameter because it shows beam-to-beam variability arising from the fluctuations of the output power. Following the same retrieval method for the LIDAR data, the radial velocity instead of the reflectivity is used as the parameter in the 2D wind retrieval for the radar data. The 1-degree Plan Position Indicator (PPI) scans of the LIDAR and 0.6-degree PPI scans of the TDWR are used in this dual Doppler analysis. The height of the LIDAR scanner and TDWR antenna is about 50 and 60 m AMSL respectively. At the location of the LIDAR, the 0.6-degree PPI scan of the TDWR has a height of about 175 m AMSL.

The basis of the retrieval is the minimization of the following cost function:

$$J(u,v) = J_1 + J_{2l} + J_{2r} + J_3 + J_4 + J_5 + J_{6l} + J_{6r}.$$
 (1)

The meaning of the various terms is given as follows. The first term on the right hand side of Eq. (1) is the background term:

$$J_1 = \sum_{i,j} W_1[(u - u_B)^2 + (v - v_B)^2]$$
(2)

The summation is made over the grid points (*i*,*j*). (u_B , v_B) is the background velocity to be described later, and (u,v) is the velocity to be retrieved. *W*'s are the weighting coefficients.

The terms J_{2l} and J_{2r} in Eq. (1) are measures of the difference between the observed (v_{rm}^{obs}) and the retrieved (v_r) radial velocities as given by:

$$J_{2m} = \sum_{i \ i} W_{2m} (v_{rm} - v_{rm}^{obs})^2$$
(3)

where m = I for LIDAR and = r for TDWR.

The terms J_3 , J_4 and J_5 in Eq. (1) are the smoothing terms involving the divergence, vorticity and Laplacian of the retrieved velocity field respectively. They are given by:

$$J_{3} + J_{4} + J_{5} = \sum_{i,j} [W_{3}(\Delta x)^{2} (\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y})^{2} + W_{4}(\Delta x)^{2} (\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y})^{2} + W_{5}(\Delta x)^{4} (\nabla^{2} u + \nabla^{2} v)^{2}].$$
(4)

Here $\Delta x = \Delta y = 100$ m is the grid size in the retrieval domain.

The last terms J_{6l} and J_{6r} in Eq. (1) are the conservation constraints given by:

$$J_{6m} = \sum_{i,j} \sum_{n} \left[W_{6m} \left(\frac{\partial v_{mm}^{obs}}{\partial t} + u \frac{\partial v_{rm}^{obs}}{\partial x} + v \frac{\partial v_{rm}^{obs}}{\partial y} \right)^2 \right]$$
(5)

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The index *m* stands for the instrument (*I* for LIDAR and *r* for TDWR). The index *n* is the time index and it is involved in the time derivative of the observed radial velocity. In the current scanning strategies of the instruments, the PPI scans of the LIDAR and the TDWR are updated every 6 minutes and 1 minute (in the hazardous weather mode when intense convective weather occurs in the vicinity of the airport) respectively. To conduct the dual Doppler analysis, the TDWR PPI scan data that are closest to the time of the PPI scan of the LIDAR is adopted. Three consecutive sets of scan data at about 6-minute interval are used in the 2D wind retrieval in this paper.

The weighting coefficients are taken as: $W_1 = 0.1 (1/m^2 s^{-2})$, W_{2l} and $W_{2r} = 1 (1/m^2 s^{-2})$, $W_3 = W_4 = W_5 = 0.1 (1/m^2 s^{-2})$ and W_{6l} and $W_{6r} = 10^4 (1/m^2 s^{-4})$. They are chosen empirically in this paper to ensure that the constraints have proper orders of magnitude.

The background velocity field in Eq. (2) is determined by expanding it in terms of second-order Legendre polynomials. The cost function for retrieval is similar to Eq. (1), except that the first term vanishes (i.e. setting $W_1 = 0$).

3. TWO EXAMPLES

The 2D wind fields of two squall line cases in 2007 are studied in this paper. The first case occurred on 17 April 2007. Synoptically, a trough of low pressure at the surface crossed the coast of southern China in the evening of that day. Strong southwesterly winds prevailed to the south of the trough, and northerly winds to the north pushed the trough southwards. The intersection between the southwesterly flow and the northerly jet showed up clearly in the radial velocities of the LIDAR (upper panels in Figure 1) and the TDWR (middle panels in Figure 1). Apart from that, strong cyclonic flow with vortex-like features also appeared to the west and northeast of HKIA, as highlighted in Figure 1.

The above-described features in the horizontal wind field are well captured in the retrieved wind field based on dual Doppler analysis of the LIDAR and the TDWR data. The wind fields are displayed as wind barbs in the middle panels in Figure 1 and plotted in colour contours for the horizontal wind speed in the lower panels of the same Figure. The following features are found in the plots:

- (a) Fresh to strong southwesterly flow occurred ahead of the surface trough. There were short waves and streaks of higher wind speed embedded in the flow.
- (b) Northwesterly jets appeared to the north of the surface trough. The horizontal wind speed could reach 23 m/s or more. Two jets were found (lower panels of Figure 1): one in association with the cyclonic flow to the northeast of HKIA and another in between the two major cyclonic flow areas.
- (c) Two major areas of cyclonic flow with vortex-like features were found to the west and northeast of HKIA. They are normally associated with streaks of strong southwesterly winds. Similar vortices have been reported in the study of squall lines in the U.S. (e.g. Trapp and

Weisman, 2003).

To find out whether the above observations are specific for a particular squall line case only, analysis of another event on 18 May 2007 is conducted. In the afternoon of that day, a surface trough of low pressure developed over inland areas of southern China and moved to the coast. At about 09 UTC, the trough moved south-southeastwards across HKIA, as shown in the radial velocity data of the LIDAR (upper panels in Figure 2) and the TDWR (middle panels of Figure 2).

The 2D wind field and distribution of the horizontal wind speed as given in dual Doppler analysis are shown in Figure 2. Many features observed in the squall line case on 17 April 2007 are also found in the present event. Strong southwesterly flow and northwesterly jet in excess of 23 m/s appeared on the two sides of the surface trough. Two areas of cyclonic flow with vortex-like features existed to the west and northeast of HKIA. Once again, there were streaks of strong southwesterly flow in association with these areas.

4. CONCLUSIONS

Two typical squall line cases in 2007 in southern China have been studied using dual Doppler analysis of the radial velocity data from the surveillance scans of the lowest elevation angles of the LIDAR and the TDWR at HKIA. The analysis method is based on parameter identification technique for the radial velocities. Many salient features of the 2D wind field near the ground are found in both cases. Cyclonic flow with vortex-like features appears to the west and northeast of the airport. Strong winds are found in the southwesterly flow and the northwesterly jet in association with these cyclonic flow areas. Based on limited case studies, it seems that the monitoring of the occurrence and the movement of the cyclonic flow features would be useful in the short-term forecasting of severe squalls for a localized area, e.g. in aviation weather services. For that purpose, the dual Doppler analysis provides a clearer depiction of the distribution of strong winds in comparison to the radial velocity data from a single instrument. More squall line cases would be studied in the future to see how common the 2D wind field features as observed in the present study could be in the squall line events at the south China coast.

The LIDAR and TDWR are complementary in the monitoring of the squalls. The former works best in non-rainy weather, whereas the latter has good signal returns in rain. For instance, in the second case discussed above, the LIDAR's data coverage is limited to the north of the airport at 09:24 UTC, 18 May 2007. TDWR provides good data coverage in the area concerned at that time, revealing the cyclonic flow and the northwesterly jet associated with the squall line to the north of the airport. The use of LIDAR and TDWR data together ensures continuous monitoring of the evolution of the squall line.

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Figure 1 Radial velocity distributions of 1-degree PPI scans of the LIDAR in the vicinity of HKIA at 12:10 and 12:12 UTC, 17 April 2007 with the gust fronts depicted by broken red curves (upper panels). The middle panels show the radial velocity distribution from 0.6-degree PPI scans of the TDWR and the 2D analyzed wind field at the same time. The horizontal wind speed distribution of the 2D analyzed wind field is plotted as colour contours in the lower panels.



Figure 2 Similar to Figure 1, but for the squall line case on 18 May 2007 at the time 09:18 and 09:24 UTC on that day.