P11A.3   **Dual Doppler Radar Analysis of the 3D Wind Fields Associated with Subtropical Squall Lines**

P.W. Chan *
Hong Kong Observatory, Hong Kong, China

A.M. Shao
College of Atmosphere Science, Lanzhou University, Lanzhou, China

1.   INTRODUCTION

Located in a subtropical coastal area, Hong Kong is often affected by squall lines in the summer time.   An understanding of the wind fields associated with the squall lines would be useful to their monitoring and forecasting.   In Szeto and Chan (2006), a squall line case in 2005 was studied using convection-resolving numerical modelling.   The present paper focuses on the retrieval of the 3D wind fields in selected squall line cases using dual Doppler analysis of weather radars.

Section 2 briefly summarizes the characteristics of the radars used in this paper.   The dual Doppler wind retrieval method is described in Section 3.   The two case studies are presented in Sections 4 and 5. Conclusions are given in Section 6.

2.   RADARS IN THIS STUDY

The two radars used in this study are the Hong Kong radar at Tate's Cairn and Guangzhou radar, which are separated by about 100 km.   The Hong Kong radar ($22^{o}21'36''$N $114^{o}12'54''$E) is an S-band radar located at around 585 m AMSL on top of a hill with a Nyquist velocity of 35.8 m/s.   It scans at 12 different elevation angles from 0.5^{o} to 34.7^{o}.   The volume scan takes about 6 minutes to complete. The Guangzhou radar ($23^{o}00'14''$N $113^{o}21'18''$E) is also an S-band radar.   It is located at about 180 m AMSL with a Nyquist velocity of 26.3 m/s.   Scanning is made at 9 different elevation angles, from 0.5^{o} to 19.5^{o}.   The 6 elevation scans between 0.5^{o} to 6° are used in this study.   The volume scan takes about 6 minutes.

3.   DUAL DOPPLER ANALYSIS METHOD

Before the analysis, the radar data are interpolated into a Cartesian grid.   The grid has 640 x 640 points with a size of 800 m.   In the vertical, the radar data extend from the ground up to 5000 m with a resolution of 500 m.

A two-step variational method as described in Yang and Qiu (2006) is employed here to analyze the radial velocity data from the two radars.   This method has been used in the dual Doppler analysis of a LIDAR and a radar at an airport (Chan and Shao, 2007).   Only a summary of the method is given here. The retrieval process involves the minimization of a cost function in the following form:

Corresponding author address: P.W. Chan, Hong Kong Observatory, 134A Nathan Road, Hong Kong email: pwchan@hko.gov.hk

$$J(u,v,w) = J_B + J_{r1} + J_{r2} + J_E + J_C + J_P \qquad (1)$$

where (u,v,w) is the 3D wind field to be retrieved.

Each term in Eq. (1) is discussed below. J_B is related to the background wind field, given by:

$$J_B = \frac{1}{2}\sum_{i,j,k}[W_{uB}(u - u_B)^2 + W_{vB}(v - v_B)^2$$
$$+ W_{wB}(w - w_B)^2] \qquad (2)$$

where the W's are the weighing factors and the subscripts B refer to the background wind field obtained by minimizing Eq. (1) without considering the J_B term in Eq. (2), i.e. setting the weights $W_{uB}=W_{vB}=W_{wB}=0$.

J_{rm} (m=1 and 2, the index of the radar) is related to the convergence of the retrieved radial velocities (i.e. component of the retrieved wind vector along the direction of the measurement radial of the radar) to the observed radial velocities from the two radars.   It is given by:

$$J_{rm} = \frac{1}{2}\sum_{i,j,k}W_{rm}(v_{rm} - v_{rm}^{obs})^2 . \qquad (3)$$

In determining the retrieved radial velocity, the fall velocity W_T of rain drop is included:

$$v_{rm} = \frac{(x - x_m)u + (y - y_m)v + (z - z_m)(w - w_T)}{\sqrt{(x - x_m)^2 + (y - y_m)^2 + (z - z_m)^2}}$$

where (x, y, z) is the grid point, (x_m, y_m, z_m) is the location of the radar, and (u, v, w) is the retrieved velocity.   The fall velocity is based on an empirical relationship with the reflectivity of the radar echo (Yang and Qiu, 2006).

J_E is the constraint due to conservation of reflectivity.   It is given by:

$$J_E = \frac{1}{2}\sum_{i,j,k,n}W_E E^2 \qquad (4)$$

where E is calculated from

$$E = \frac{\partial \eta}{\partial t} + u\frac{\partial \eta}{\partial x} + v\frac{\partial \eta}{\partial y} + w\frac{\partial \eta}{\partial z}$$

and η is the reflectivity of the radar echo.   Index n refers to the time.   In the present analysis, three time slots (i.e. a period of 6 minutes x 3 = 18 minutes)

would be used to retrieve the wind field at a particular moment.

J_C is the constraint due to continuity equation, and is given by:

$$J_C = \frac{1}{2} \sum_{i,j,k} W_C \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} - kw \right)^2 , \qquad (5)$$

where $k = -\partial (\ln \rho_0) / \partial z$.

Finally, J_P is the smoothing term:

$$J_P = \frac{1}{2} \sum_{i,j,k} [W_{uP}(\nabla^2 u)^2 + W_{vP}(\nabla^2 v)^2 + W_{wP}(\nabla^2 w)^2] \quad (6)$$

where ∇^2 is the Laplacian operator.

The values of the various weighing factors are: $W_{uB}=W_{vB}=W_{wB}=1.0$, $W_{rm}=1.0$, $W_E=0.01\ d^2$, $W_C=100d^2$, $W_{uP}=W_{vP}=1.0\ d^2$, and $W_{wP}=0.25\ W_{uP}$, in which d is the horizontal grid size.

4. THE CASE ON 9 MAY 2005

This case has been discussed and analyzed using numerical weather prediction model in Szeto and Chan (2006). Squalls reaching 64 knots affected Hong Kong on that day. An empty container box collapsed at the container terminal in Hong Kong in severe squalls, causing one death and two injuries.

A squall line developed in the strong southwesterly flow south of a trough of low pressure over southern China in the morning of 9 May 2005 and moved towards Hong Kong gradually. Before noon, two bow-shaped echoes were observed in the radar (Figure 1). From the retrieved 3D wind field, each bow echo is associated with a wave in the southwesterly flow within the boundary layer. Upward motion can be found at the location of the wave (Figure 2), though the magnitude appears to be rather small considering the intensity of the convective activity. At the same time, bands of upward and downward motion are found behind the bow echo. From the plot of the horizontal wind magnitude (Figure 3), two jets reaching 25 m/s could be identified inside the boundary layer, namely, the southwesterly jet along the coast and the west-southwesterly jet at the rear of the bow echo at the western coast of Guangdong (location in Figure 1).

Shortly after noon, one of the bow echoes was crossing the Pearl River Estuary and edged closer to Hong Kong (Figure 4). From the analyzed wind field, there is upward motion (Figure 5) and low-level convergence (Figure 6) at the location of this bow echo. Vertical cross-section across this echo (section A-B in Figure 4) shows that there is wavy motion at the rear and significant upward motion inside the intense radar echoes (Figure 7). The west-southwesterly jet behind the bow echo also moved further eastwards to Hong Kong (compare Figure 8 with Figure 3). It is possibly a rear inflow jet associated with the squall line.

5. THE CASE ON 18 AUG 2006

The case on 18 August 2006 is considered because the squall line moved in a direction (southwestwards) totally different from that in the case discussed in Section 4 (eastwards). The formation of the squall line is also different – it appeared to be triggered by solar heating in the daytime and sustained into the evening due to convergent flow along the south China coast in the lower troposphere. Gusts in excess of 50 knots were recorded in Hong Kong during the passage of the squall line.

Before midnight on that day, a squall line developed over inland areas of Guangdong and moved southwestward towards Hong Kong under the influence of the northeasterly flow. From the retrieved wind field (Figure 9), there is wind speed convergence (northerly winds of 10 m/s decreasing to about 5 m/s) and directional convergence (between north to northeasterly winds and west to southwesterly winds) at the location of the intense radar echoes. Bands of upward and downward motion are found at the squall line in the retrieved vertical velocity field (Figure 10). On the other hand, no significant vertical motion is observed in the stratiform clouds at the rear of the intense echoes.

Compared to the case on 9 May 2005, the divergence field (Figure 11) looks less organized. Nonetheless, areas of low-level convergence could still be identified at the strong radar echoes near, for instance, 23°N 113.5°E and 22.5°N 113.9°E (indicated by arrows in Figure 11). The stratiform cloud region in general has slight divergent flow in the lower troposphere.

Vertical cross section across the strong echo at 23°N 113.5°E (location of the cross section in Figure 9) shows that there is significant upward motion inside the intense radar echoes (Figure 12). Once again, from the plot of the horizontal wind magnitude (Figure 13), a jet could be found behind the squall line and it appears to be the rear inflow jet.

6. CONCLUSIONS

Two squall line cases near Hong Kong are analyzed using 3D wind retrieval method based on the radial velocity data from Guangzhou and Hong Kong radars. As revealed in the retrieved wind field, they have some features in common:

(a) Convergent flow appears within the boundary layer at the locations of the strong radar echoes. It is associated with waves or wind speed/direction convergence.
(b) Upward motion could be identified at the convergent flow area.
(b) A jet is found at the rear of the squall line. It moves together with the strong radar echoes.

In general, the 3D wind field obtained from dual Doppler analysis looks reasonable, though the magnitude of the vertical velocity is on the low side considering the intensity of the convective development. The wind retrieval method presented in this paper has the potential application for wind analysis of severe convective storms in day-to-day weather forecasting.

Acknowledgement

References

Chan, P.W., and A.M. Shao, 2007: Depiction of complex airflow near Hong Kong International Airport using a Doppler LIDAR with a two-dimensional wind retrieval technique, to appear in *Meteorol. Zeitschrift, N.F.*

Szeto, K.C., and P.W. Chan, 2006: Numerical simulation of a severe squall event in Hong Kong. *23rd Conference on Severe Local Storms*, American Meteorological Society.

Yang, Y., and C.J. Qiu, 2006: Analysis on mesoscale circulation within a heavy rain system using Doppler radar data. *Plateau Meteorology*, **25**, 925-931 (in Chinese with English abstract).
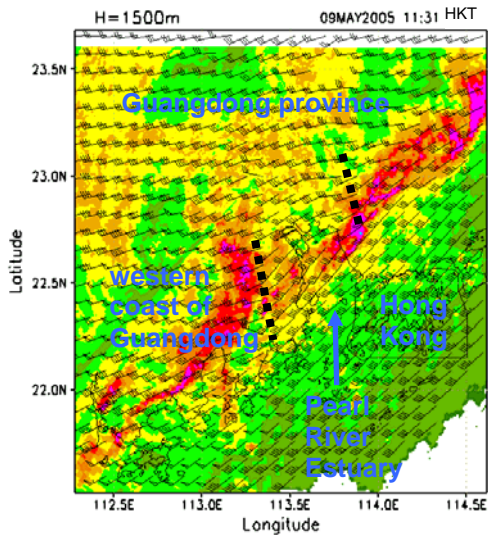
Figure 1   Radar reflectivity and horizontal wind vector at 1500 m AMSL at 11:31 HKT, 9 May 2005.   Axes of westerly waves are indicated by broken lines
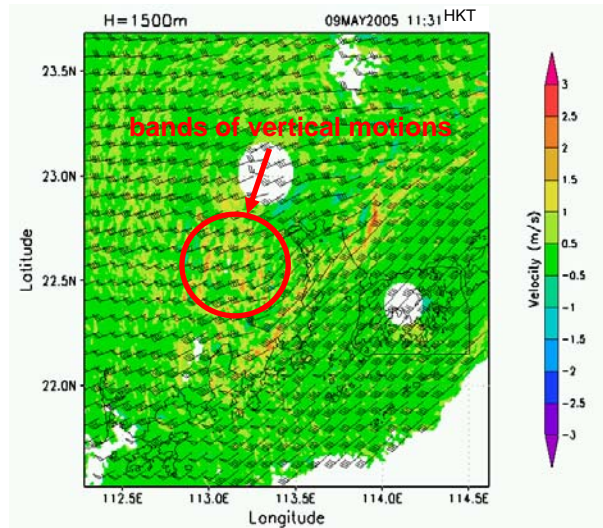
Figure 2   Vertical velocity and horizontal wind vector at 1500 m AMSL at 11:31 HKT, 9 May 2005.
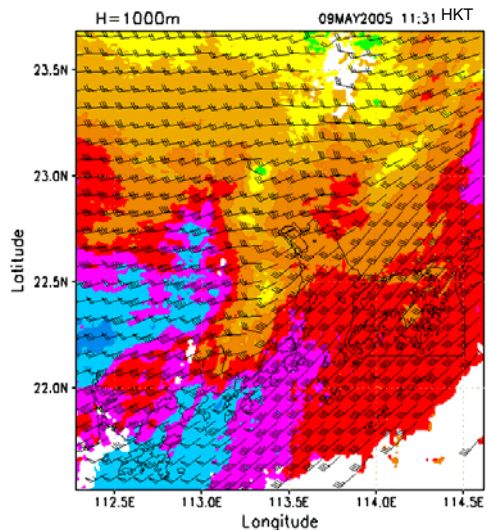
Figure 3   Magnitude of horizontal wind at 1000 m AMSL at 11:31 HKT, 9 May 2005.
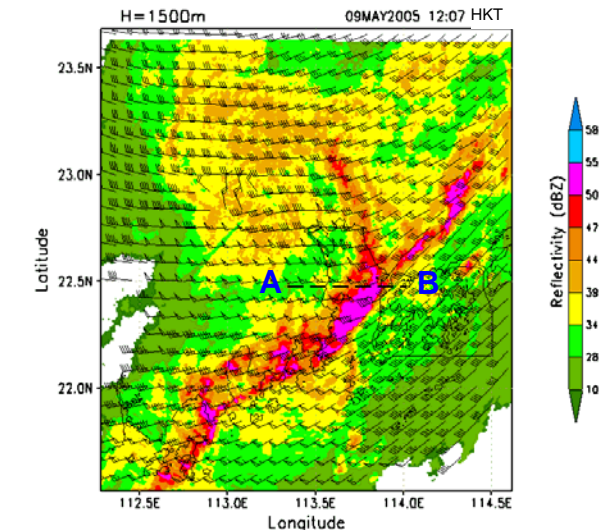
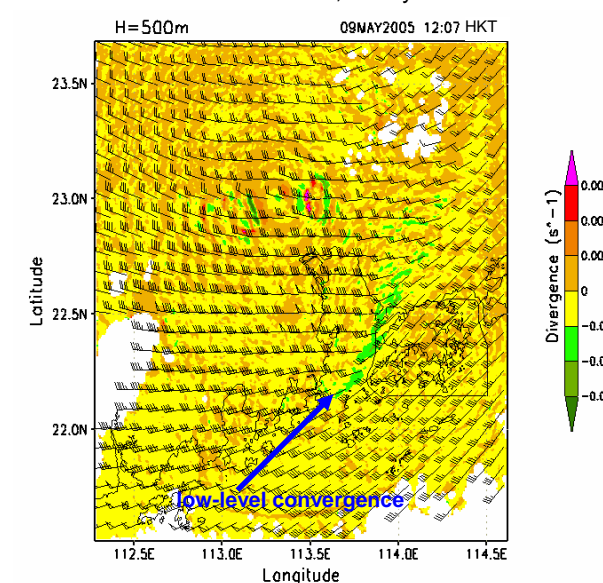Figure 4   Radar reflectivity and horizontal wind vector at 1500 m AMSL at 12:07 HKT, 9 May 2005.
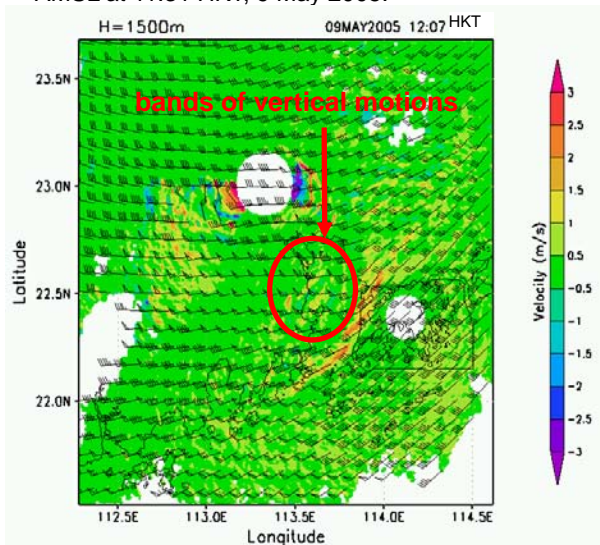
Figure 5   Vertical velocity and horizontal wind vector at 1500 m AMSL at 12:07 HKT, 9 May 2005.

Figure 6   Divergence field at 500 m AMSL at 12:07 HKT, 9 May 2005.
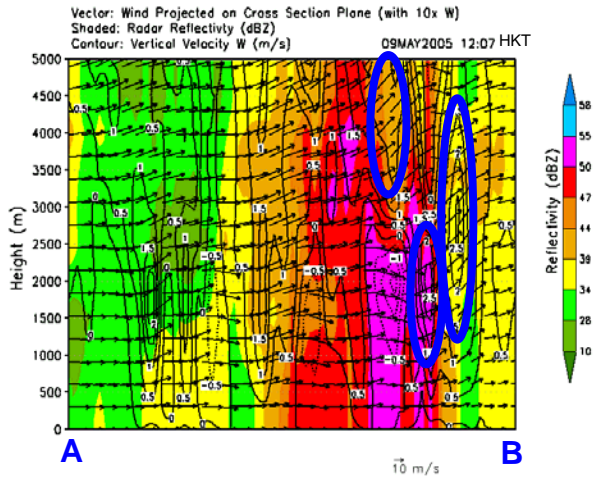
Figure 7   Vertical cross section (location in Figure 4) of radar reflectivity and the wind component projected on the cross-sectional plane at 12:07 HKT, 9 May 2005. Significant upward motions are enclosed in blue.
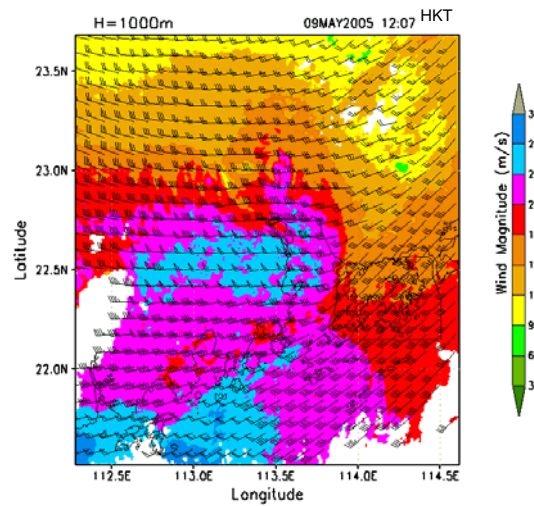

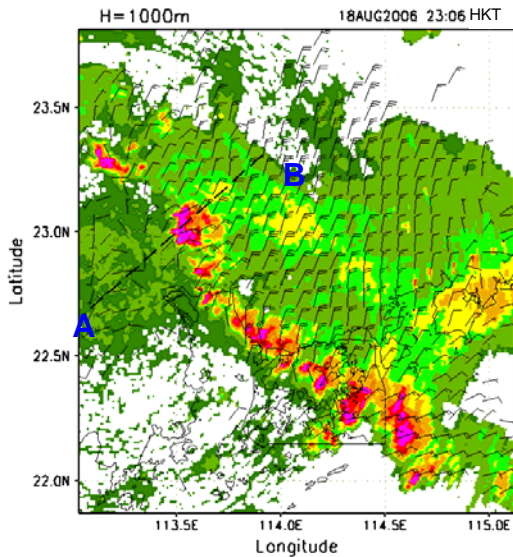Figure 8   Magnitude of horizontal wind at 1000 m AMSL at 12:07 HKT, 9 May 2005.

Figure 9   Radar reflectivity and horizontal wind vector at 1000 m AMSL at 23:06 HKT, 18 August 2006.
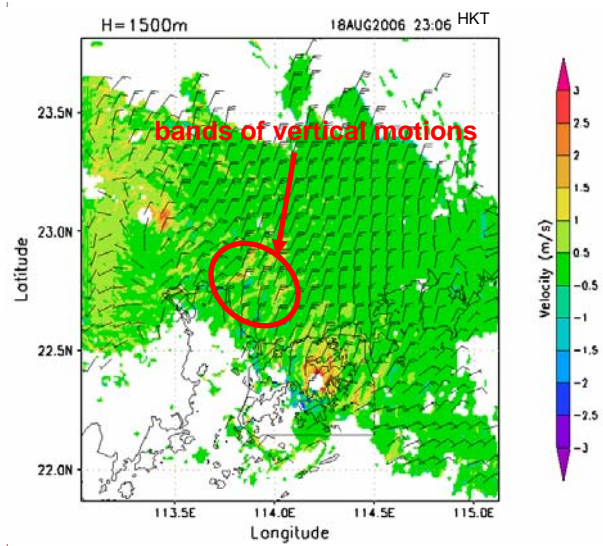

Figure 10   Vertical velocity and horizontal wind vector at 1500 m AMSL at 23:06 HKT, 18 August 2006.
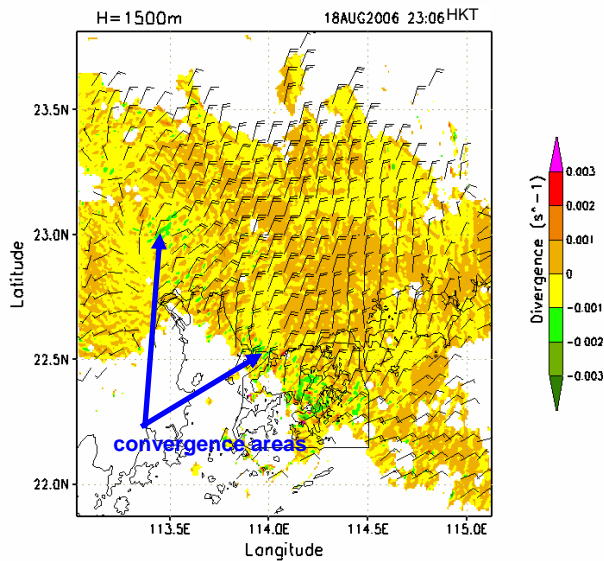

Figure 11   Divergence field at 1500 m AMSL at 23:06 HKT, 18 August 2006.
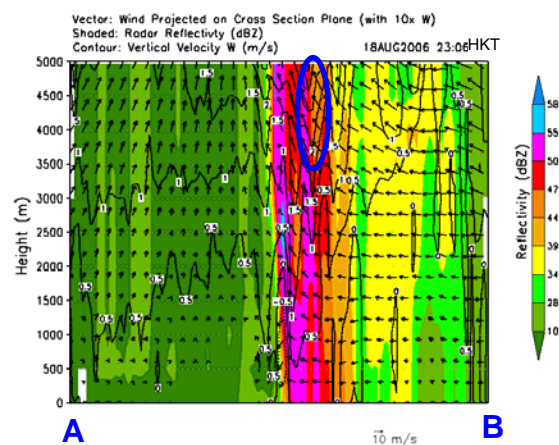

Figure 12   Vertical cross section (location in Figure 9) of radar reflectivity and the wind component projected on the cross-sectional plane at 23:06 HKT, 18 August 2006.   Significant upward motion is enclosed in blue.
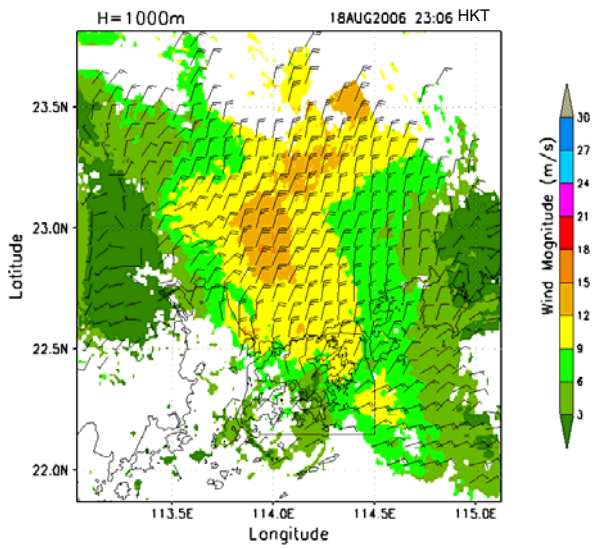
Figure 13   Magnitude of horizontal wind at 1000 m AMSL at 23:06 HKT, 18 August 2006.