Nowcasting Thunderstorms for the 2008 Summer Olympics

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1. Introduction

The Beijing 2008 Forecast Demonstration Project (B08FDP) is planned to take place during the summer of 2008 that will include the period of the summer Olympic Games in Beijing, China. This demonstration is sanctioned by the World Meteorological Organization (WMO), World Weather Research Program (WWRP). The demonstration will include state-of-the-art forecast systems from Beijing, Hong Kong, Australia, Canada and the United States. The focus will be on forecasting convective storms for the nowcasting time period (0-6 hours).

In preparing for B08FDP this paper presents statistics on the climatology of thunderstorms in the Beijing area and forecast challenges that are likely to be encountered during the FDP. The statistics are based on Beijing local data from a C-band radar and surface observations. Examples of forecast challenges associated with thunderstorm initiation and evolution are based on the Beijing S-band radar which was commissioned in the summer 2006. This radar has characteristics very similar to the U.S. WSR-88D (NEXRAD); it routinely observes clear-air insect return to ranges of 100-150 km, making it possible to monitor boundary layer convergence lines.

The metropolitan area of Beijing is on a flat plain located at the foot of the Yan Shan Mountains that are about 1-2.5 km high that extend roughly in a northeast to southwest line to the west and north of the city (see Fig 1). Beijing is at an altitude of only 30 m and is open to the south and east to the influx of very warm moist air. Significant forecast challenges present themselves in the vicinity of Beijing in response to this very humid air impinging on the nearby mountains. Thunderstorms frequently initiate over the mountains and move to the southeast. Sometimes these storms dissipate on reaching the foothills and other times grow and organizing into major squall lines. A variety of boundary layer convergence lines frequent the plains and play a significant role in storm initiation and evolution. Beijing also appears to trigger thunderstorms.

There will be a particularly rich data set available during the B08FDP within the selected forecast area (500 by 500 km) centered on Beijing (red rectangle in Fig 1). This includes 4 CINRAD Doppler radars (China New Generation Radar), soundings at 6 hour intervals from 5 sites, 136 automated weather stations and 30 GPS receivers.

The B08FDP is being organized similar to the very successful Sydney 2000 Forecast Demonstration Project that was 2 months long centered on the time of the Sydney 2000 Summer Olympic Games. The goal of the Sydney FDP was to demonstrate the capability

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of modern forecast systems, and to quantify the associated benefits in the delivery of a real-time nowcast service (Keenan et al. 2003). A special issue of Weather and Forecasting (Feb, 2004) was dedicated to papers reporting on the Sydney FDP.

While the focus of the Sydney FDP was on a 0-1 hour nowcast of thunderstorms and associated hazards; the focus of B08FDP will be to extend to the 0-6 hour period. This period is typically refereed to as the nowcasting time period. Included in the nowcasting will be warnings for hail, high winds, heavy rain and lightning. The warnings will be based on the Canadian Radar Decision System (CARDS) from Environment Services of Canada. The following systems will forecast radar reflectivity or precipitation rate a) Beijing Auto-Nowcaster (BJANC, 0-1 h) from the Beijing Meteorological Bureau originally developed by NCAR, b) Short Term Ensemble Prediction System (STEPS, 0-6 h, Seed 2006) from the Bureau of Meteorological Research Centre (BMRC), Australia, c) Short-range Warnings of Intense Rainstorms in Localized Systems (SWIRLS, 0-6 h) from the Hong Kong Observatory, d) Niwot (0-6 h) from the National Center for Atmospheric Research, USA, e) Thunderstorm Interactive Forecast System (TIFS, 0-1 h) from BMRC, this includes the Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) System originally developed at NCAR, f) Global/Regional Assimilation and Prediction System (GRAPES, 0-6h) from the China Meteorological Administration and g) MAPLE (0-6 h; German and Zawadzki, 2002) developed by McGill University and operated by Weather Decision Technologies. Most of these systems blend numerical model techniques with observational techniques. A unique opportunity exists to generate a consensus product on the likelihood of precipitation utilizing all the systems.

Section 2 will describe the climatology of thunderstorms in the Beijing area based on surface station data and from a C-band radar located within the city of Beijing. Section 3 will present an hourly climatology of radar echo frequency as observed with the Tianjin S-band radar that is located 150 km southeast of Beijing. Section 4 will present convective storm forecast challenges that occurred in the Beijing vicinity as observed with the Beijing S-band radar. Section 5 is a summary.

2. Thunderstorm Climatology

Statistics on convective events for the Beijing area were obtained based on 12 years (1994-2005) of data from 20 weather stations located in the area outlined by the white counties surrounding Beijing shown in Fig1. The months May through September were included. In Figs 2 and 3 an event was considered to occur in the Beijing vicinity if any one of the 20 stations reported the event. Fig 2 shows the number of thunderstorms days (thunder heard at one of the weather stations), heavy rain days (>50 mm in 24 h), high wind (>11 m/s) days and hail days (>5 mm diameter) for each month May through September based on the 12 year data sample. The probability of a day with severe weather (heavy rain, high winds or hail) is 22.4%. Fig 3 shows the probability of a thunderstorm day is 44.8 % during this 5 month period. The probability peeks at 61% in June with July and August close behind.

Utilizing 3 years of data from the C-band radar labeled BJRC in Fig 1 the origin of thunderstorms reaching Beijing was examined as well as the synoptic situation. The large majority (79%) of thunderstorms (> 30 dBZ) occurring in the Beijing vicinity are associated with storms moving from a westerly direction (SW through NW). The occurrences were classified into three synoptic situations. Forty-nine percent of the thunderstorm episodes occurred with a Mongolian cold vortex, 37% with a trough approaching from the west and 14 % with a subtropical high.

3. Hourly Frequency of Convection

Utilizing data from the Tianjin radar which is 150 km from Beijing the frequency of radar echo > 35dBZ was determined for each hour. The data was obtained from 41 rain episodes when radar data was available from the years 2002-2005 totaling 667 hours of data. The data sample is far from complete, data were collected when forecasters observed or anticipated storms. Care must be exercised when interpreting diurnal trends because of the limited data set.

Fig 5 shows the resulting frequency plots at 2 hour intervals. The most notable features is the southward progression of the maximum frequency between 1630 and 0030 local Beijing time[5]. That is the maximum frequency of thunderstorms moves from the mountains south to the Bohai Sea from late afternoon to midnight.

4. Forecast Challenges

The Beijing S-band radar became available during the summer of 2006. The eight most active convective precipitation episodes were selected to identify very short period forecasting challenges that would likely be encountered during the FDP. For each of the episodes boundary layer convergence lines were identified and entered into the NCAR Auto-Nowcaster (Mueller et al 2003) for easy viewing in a time lapse mode along with surface mesonet data. Unfortunately satellite data were seldom available.

In addition to the Beijing S-band, data were available from the Tianjin S-band (TJRS in Fig 1) and occasionally the Shijiazhuang S-band (SJZRS in Fig 1). These China CINRAD radars have operating capabilities very similar to the WSR-88D radars in the U.S. Clear-air return from insects is very extensive, often beyond 100 km in range, thus making it suitable for detecting and monitoring the movement of boundary layer convergence lines. As mentioned in the Introduction and apparent in Fig 1 Beijing lies at the foot of the Yan Shan Mountains on a low flat plain that is open to very warm and moist air to the south and southeast. Thus it is expected that the presence of these topographic feature will have a significant impact on forecasting convective storms in the Beijing vicinity.

Table 1 lists selected forecast challenges for the eight convective precipitation episodes along with the general synoptic situation, an assessment of whether the transition between the plains and the mountains affected the evolution of storms and contributed to the forecast challenge and the low-level winds. Effects could be different stability conditions from mountains to the plains and blocking or lifting of south and south east

[5] All times in this paper are local Beijing time which is UTC plus 8 hours.

flow by the mountains. In eight of the 15 forecast challenges it was felt the mountains contributed to the challenge.

The following subsections provide a brief description of the forecast challenges for each of the eight convective precipitation episodes and an attempt to identify factors affecting storm evolution. Because of space limitations radar image are provided for just a few of the events. Based on two-a-day soundings from Beijing and hourly surface temperature and dew point measurements an estimate is made of the stability conditions during the time of the convective event. The purpose is to present the situation as would be available in real-time to the forecaster or nowcasting system. The absence of satellite data is unfortunate and most likely will be available at 30 min intervals during the FDP. Also the column integrated water vapor from the 20 GPS stations were not available, but are expected during the FDP. Soundings will be available every 6 hours during the FDP.

June 12-13, 13-02 local

Forecast challenge 1 - A mostly stratiform rain band (Fig 5a) slowly moved eastward through the mountains. Upon reaching the foothills it rapidly intensified (Fig 5b), between 1800 and 1900 local, into a solid convective line with reflectivities in access of 55 dBZ. The soundings at 0800 and 2000 are probably not representative of the air that was lifted to initiate the deep convection since there is considerable CIN and very little Cape for surface parcels having the characteristics of the Beijing mesonet stations. Thus forced lifting of near surface air from the plains over the mountains was not likely. As observed by radar the winds in the lowest kilometer that were approaching the mountains were easterly. As would be expected with stable air the mountains acted as a barrier to this easterly flow and the surface stations and radar indicated the low-level easterly winds turned northeasterly paralleling the mountains as the air approached the foothills. The more likely scenario for the development of deep convection in this case was that stratiform rain sufficiently moistened the air around 1 km height near the foothills to allow this air to become unstable when it was lifted over the mountains by the southerly winds at that height.

Forecast challenge 2 – The above convective line (Fig 6a) rapidly dissipated (Fig 6b) after 1930 as it moved onto the plains. The radar indicated that near surface air over the plains was likely being lifted by the gust front into the convective line. As indicated by the 2000 sounding this air was very stable and dissipation was to be expected.

June 27-28, 19-05 local

Forecast challenge 3 – Between 2200 and 2345 an extensive area of intense thunderstorms initiated over the city of Beijing (Fig 7). Radar showed the first clouds and precipitation echoes formed in a short line on the west side of Beijing (Fig 7a and b), just on the plains side of the foothills. All but one storm and cloud formed over the plains. For this nocturnal event no near surface convergence lines were observed in either the radar or mesonet data. The radar showed the wind in the lowest 2 km to be southeast as much as 15 m/s just above the surface (Fig 7b). There appeared to be no terrain blocking of this flow. The sounding taken at 2000 showed that near surface air parcels with the characteristics of the Beijing AWS stations (temperatures between 29 and 31 C and dewpoints between 19 and 22 C) were unstable. It would be expected that this instability coupled with the low-level air beginning to rise over Beijing in anticipating of lifting over the mountains would be suffice for the development of deep convection as observed. The mystery in this case is why initiation began when it did. There are other storms that initiated to the southeast of Beijing at about the same time which suggests there may have been some larger scale feature such as mid-level cooling that triggered the initiation.

July 05, 1000-2200 local
Forecast challenge 4 – Between 1425 and 1530 three storms initiated over Beijing (Fig 8). The Mesonet stations indicated a very weak convergence area running through the city which was only weakly suggestive on the radar. The feature would normally not receive attention. The radar indicated the winds were very light near the surface and became northwest a few 100 km above the surface. The initiation took place between soundings. Both soundings suggested there was some CIN to overcome but there was considerable CAPE. There was a gust front moving toward the city from the northeast. However, it likely did not influence the storm initiation over the city. There is no obvious trigger for the initiation of these Beijing storms. The third storm reached 65 dBZ and a spectacular horseshoe shaped gust front was produced by these storms (Fig 8c).

Forecast challenge 5 – Following the development of the above gust front significant storm growth and development of a squall line took place between 1620 and 1920. This growth was associated with the collision of gust fronts. There were no surface stations where the initiation occurred, but with stability conditions like those for forecast challenge 4 forced lifting by boundaries should have been suffice to initiate storms.

July 9-10, 1300-1000
Forecast challenge 6 – Late evening initiation of a long line of thunderstorms occurred along the foothills from 1954-2132 local (Fig 9). The mesonet stations showed very light northerly winds indicative of barrier flow. However this northerly flow must have been shallow since the radar indicated easterly/southeasterly flow in the lowest kilometer. It also indicated the air was moving up the foothills; this lifting should have been sufficient to overcome the small amount of CIN indicated by the 2000 sounding. The challenge is why initiation occurred when it did. There are no obvious precursors. Around 1600 the easterly flow gradually increases a couple m/s but not an obvious precursor.

Forecast Challenge 7 – From 2245-2353 the northern half of the above line of thunderstorms dissipated without moving from the foothills. At the same time there was disorganized initiation over the plains that was likely caused by elevated processes. The dissipation over the northern foothills was likely because the storm steering flow was parallel to the foothills and no gust front formed. The lack of a gust front may be the result of the lack of dry air in the observed sounding. The reason for the occurrence of scattered initiation over the plains is not understood, however it is probably not surface based. It is not apparent why only part of the line dissipated.

Forecast challenge 8 – Between 2357 and 0224 the surviving storms along the southern part of the foothills (discussed in forecast challenge 7) organized and moved onto the plains. This was caused by the development and merger of two gust fronts. It is not apparent why these gust fronts formed when they had not earlier (precipitation loading?). The gust fronts were relatively weak.

Forecast challenge 9 - Between 0224 and 0426 the above complex slowly dissipated. At this time the air mass was stabilizing and the gust front was not very strong. In addition the gust front tended to move away from the storms. This is the typical problem of not knowing the stability of the airmass the gust front is encountering. However, general nowcasting rules would dictate dissipating the storms if dissipation is noted and the boundary relative steering flow is not favorable.

July 10, 1030-1800

Forecast challenge 10 – A band of mostly stratiform precipitation slowly moved eastward through the mountains and slowly dissipated on reaching the plains. However along the north portion of this band some convective storms did form on reaching the plains. The biggest challenge was forecasting the formation of a major squall line on the plains just east of Beijing about 50 km in advance of this dissipating stratiform band. The initiation occurs on a convergence line and evolved into a large squall line. The surface parcel that would have been lifted by the convergence line would be 26C/23C. This leaves only a little CIN to overcome which should have been possible at the convergence line. The radar showed a convergence line about one hour in advance of the initiation, however it did not show a boundary along the northern portion of the developing squall line; this is a mystery.

July 12 0100-1100

Forecast challenge 11 - A squall line moved southeast through the mountains. About 0330 this nocturnal squall line intensified and organized better as it neared the foothills. It had an associated very strong gust front. As the squall line moved onto the plains (0430-0530) it dissipated, however it immediately reformed on the gust front just in advance of the older storms. This new convection became a squall line with a strong gust front and solid intense line. The boundary stayed with the storms. The northern part of the line eventually dissipated but the southwest part stayed strong. This case is marked by a strong gust front. The soundings did not support what was observed; there was too much CIN to overcome. If the mesonet is correct the surface temperatures are no higher 28C with a dewpoint of 22C.

July 24 1000-2400

Forecast challenge 12 – Between 1100 and 1400 numerous wide spread unorganized storms initiated in the mountains and moved SE. They dissipated as they moved onto the plains. The 0800 sounding was stable, however there was considerable cooling in the 900 – 700 mb layer between the 0800 and 2000 soundings. The real challenge was knowing when and how much the atmosphere will cool.

Forecast challenge 13 – Between 1200 and 1900 numerous storms initiated and grew along the foothills and plains. Two westward moving boundaries from storms to the east and northeast played a major role in initiating storms and intensifying decaying storms moving off the mountains. The interaction of the gust front with the foothills seemed to be particularly effective in initiating storms. The boundaries and storms moved in opposite direction thus there was a tendency for the storms to be short lived. However, the intensity and number of storms was very impressive for this situation where the boundaries and storms were moving in opposite directions. Destabilizing of the sounding between 0800 and 2000 probably played a significant role. The challenge was to anticipate these gust fronts would initiate so much convection.

August 1, 1100-2100

Forecast challenge 14 – Between 1130 and 1230 unorganized thunderstorms initiated over the mountains and organized into a line of storms by 1530 with a gust front. This was just before reaching the foothills. The surface winds were light from S to SE. Radar indicated light 1-2 km deep SE winds. There was no indication of barrier flow, thus the air was likely unstable. A surface parcel of 34/19C would leave only a little CIN to overcome which would be easy with lifting over the foothills. Dry air indicated by the sounding no doubt helped develop gust fronts. Thus intensification of the developing line when it reached the foothills was not surprising.

Forecast challenge 15 – The above convective line intensified as it moved onto and across the plains (1630 – 2000) becoming a squall line with a strong gust front. There were several gust fronts that collide with this gust front that significantly enhanced the squall line. Particularly important were three gust fronts that collided with the primary gust front. The first about 1600 from storms in the mountains NE of Beijing, the second from the south at about 1800-1900 and third from the south about 1900.

5. Summary

Thunderstorms are particularly likely in the Beijing area when there is a synoptic trough approaching from the west or a Mongolian Vortex at upper levels and the boundary layer winds are from the south or southeast. Monitoring the stability of the airmass over the plains is important to anticipate whether storm initiation or dissipation will be likely near the foothills.

The foothills played a major role in the evolution of convective storms that impact the greater Beijing area. Storm initiation occurred when southeast winds were blowing upslope. Existing convective lines or even a stratiform band intensified when moving from the mountains to the foothills. In contrast existing convective lines or disorganized regions of cells would at times dissipate when moving from the mountains to the plains. The stability of the air impinging on the foothills is obviously an important factor in forecasting whether intensification or dissipation is likely. The radar can be a valuable tool in assessing the stability of this air by observing if it is being blocked by the mountains or is flowing up and over the mountains. Six hourly soundings will also help asses the stability of an air mass that is impinging on the mountains. On two occasions the city itself seemed to be responsible for assisting in storm initiation, however, precursors to allow nowcasting of these storms was not apparent.

Gust fronts play a significant role in initiating or intensifying storms and it was important to monitor there location and movement to anticipate new storm development. Colliding gust fronts also often initiated or intensified storms. The development of gust fronts seemed to be favored when there was a significant depth of dry air below cloud base and/or there was dry air at mid and upper levels. An established gust front moving through the mountains would likely maintain existing and/or initiate new storms when it reached the foothills. Gust fronts impinging on the foothills also initiated storms. It is unknown how representative these eight cases are of what will be observed during the FDP but it certain the presence of the mountains will added to the forecast challenge.

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Table 1. Selected forecast challenges from the summer of 2006 in the vicinity of Beijing.

Date (local)	Forecast Challenge	Synoptic Regime	Mountain-Plain effect	Low-level Winds
June 12-13 13-02	1) Squall line development 2) Squall line dissipation	Mongolian Cold Vortex	1) yes 2) yes	Barrier flow E/NE
June 27-28 19-05	3) Storms initiation over Beijing	Small Ridge	3) yes	Strong SE
July 5 10-22	4) Storm initiation over Beijing 5) Squall line development	Mongolian Cold Vortex	5) no 6) no	Sfc. very light Radar NW above 200m
Jul 9-10 13-10	6) Convective line initiation 7) Convective line partial dissipation 8) Convective complex growth 9) Convective complex dissipation	Trough from West	7) yes 8) no 9) no	Very light N
July 10 10-18	10) Initiation squall line	Trough from West	10) yes	Barrier flow Shallow easterly,
July 12 01-11	11) Squall line dissipation and reformation	Mongolian Cold Vortex	11) yes	Sfc. light S Radar SSE
July 24 10-24	12) Mountain storm initiation 13) Convective complex initiation and growth	Weak trough from west	12) no 13) yes	E
Aug 01 11-21	14) Convective line development along foothills 15) Squall line development and intensification	Trough from west	14) yes 15) no	S-SE

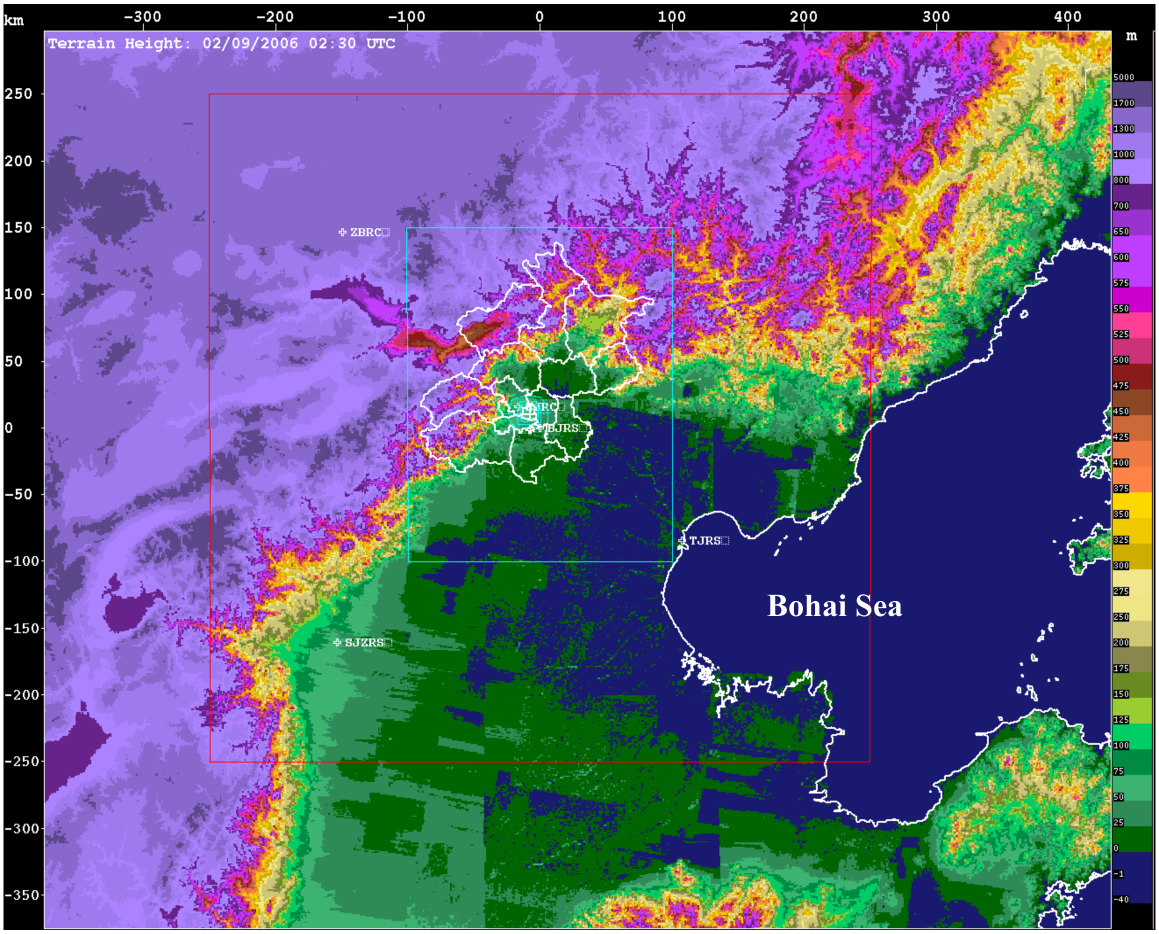


Fig 1. Topography in the vicinity of Beijing, The Beijing circle roads are shown in blue. The terrain elevation is color coded in meters with the scale on the left. The 5 letter designation indicated radar locations. The red rectangle is the general forecast area for the B08FDP. The blue rectangle is the forecast verification area. The counties outlined in white indicate the area of the climatology studies in Section 3.

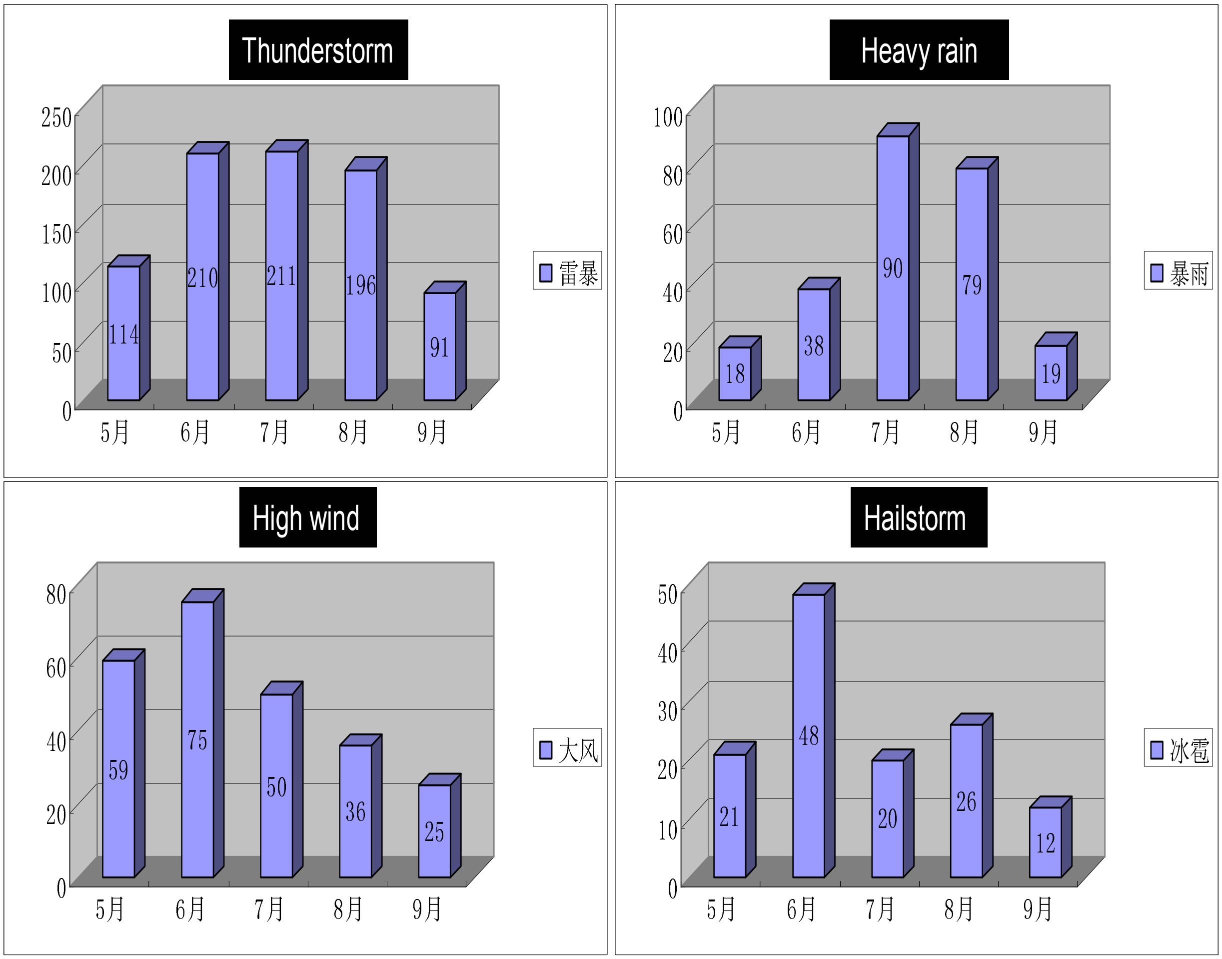


Fig 2. Monthly number of days with convective events in the Beijing vicinity for a 12 year period based on 20 weather stations; a) thunderstorms, b) heavy rain (define), c) high wind (define), and hail (define). The months are numbered 5 (May) thru 9 (September).

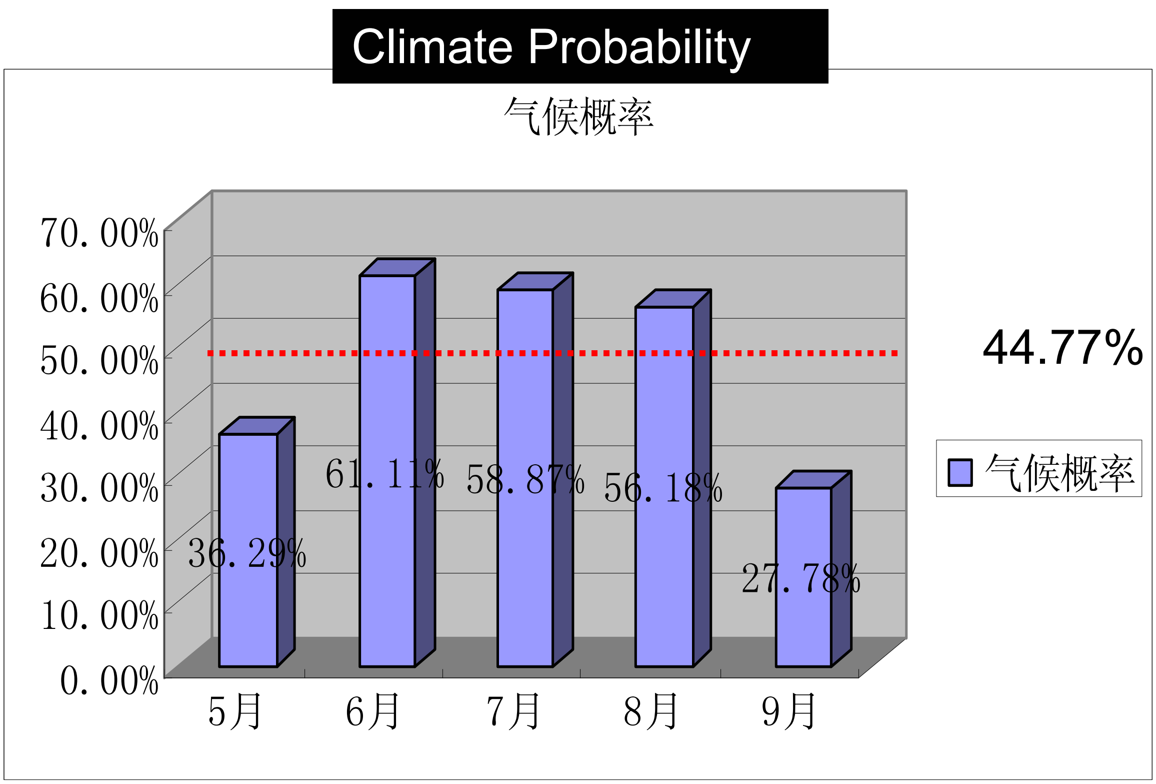
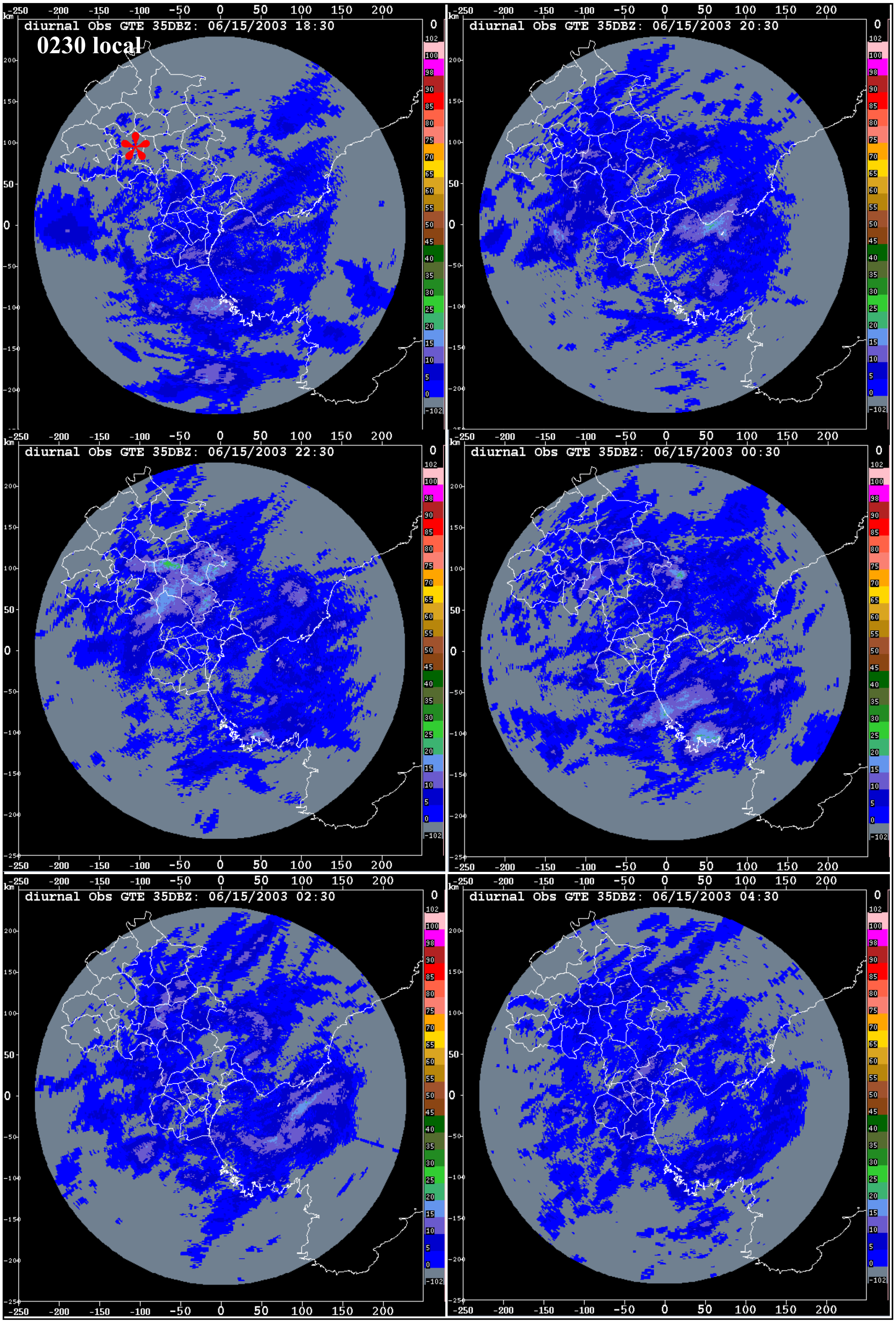


Fig 3. Thunderstorm probability per month in the vicinity of Beijing.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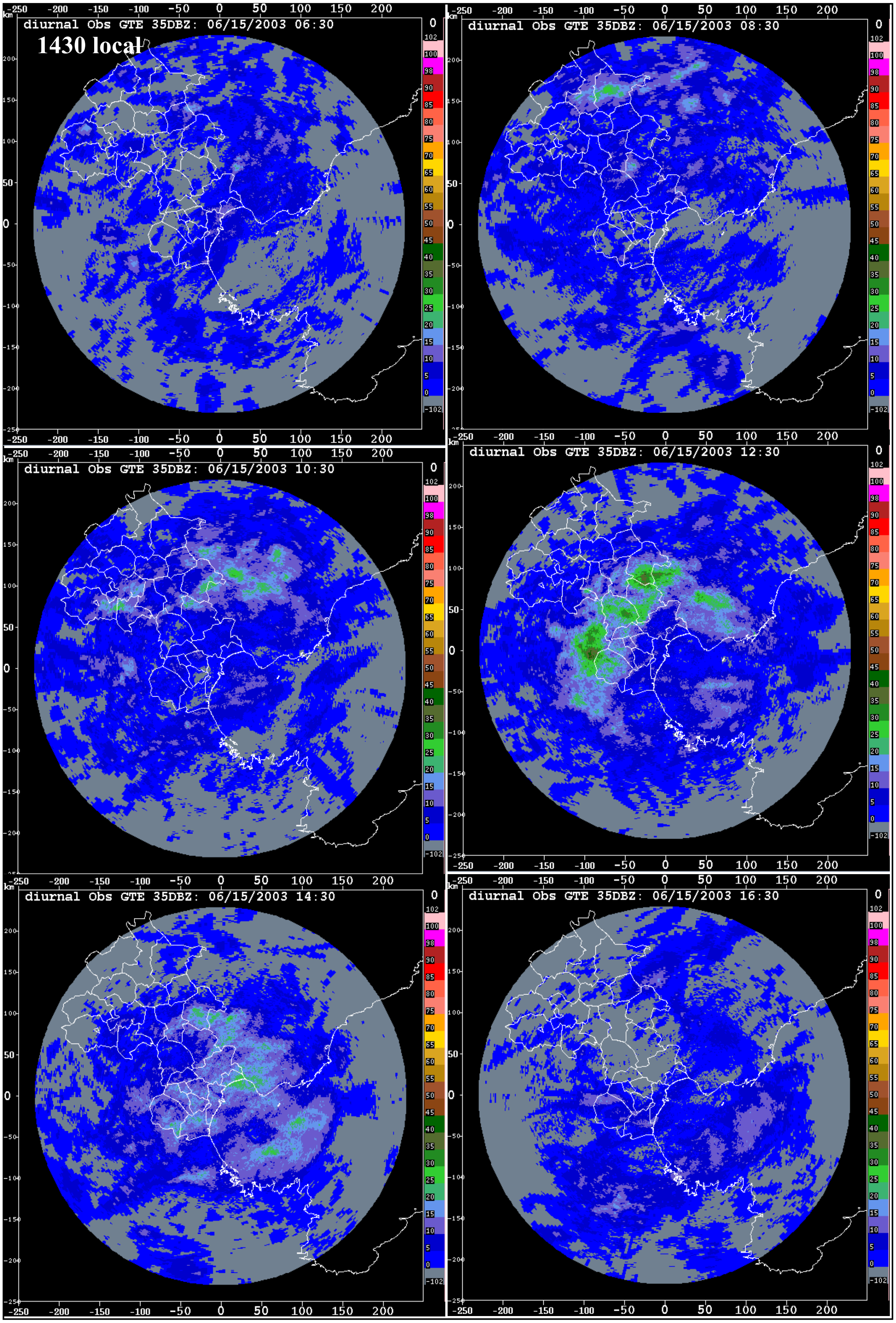

Fig 4. Number of times each hour radar echo exceeded 35dBZ. Based on 667 hours of data from 41 convective precipitation episodes from 2002-2005 from the Tianjin S-band radar. The red asterisk in the first panel marks the location of Beijing. The radar data extends 250 km.

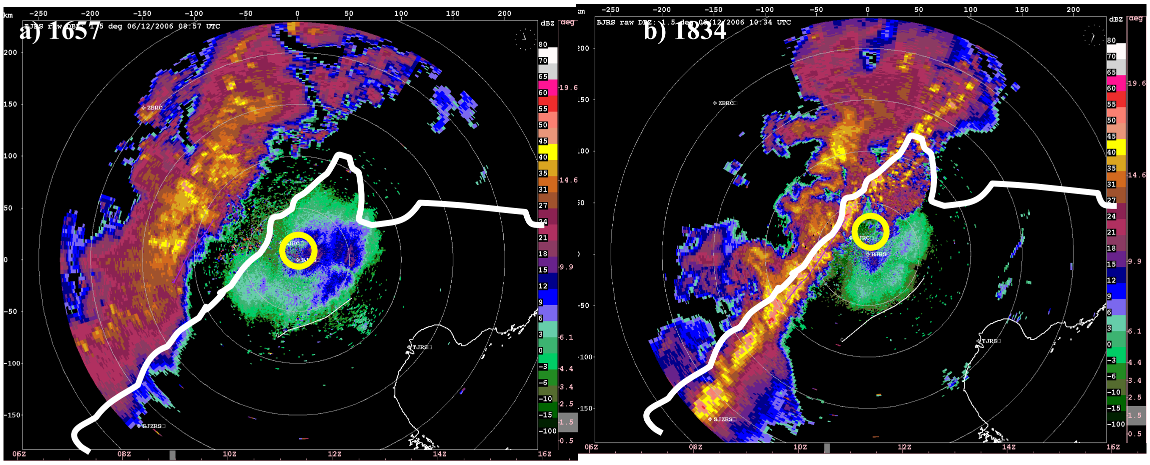

Fig 5. Forecast challenge 1. June 12, development of a convective line from a stratiform rain band upon reaching the foothills. The white line marks the boundary between the plains and foothills. The yellow circle represents the city of Beijing.

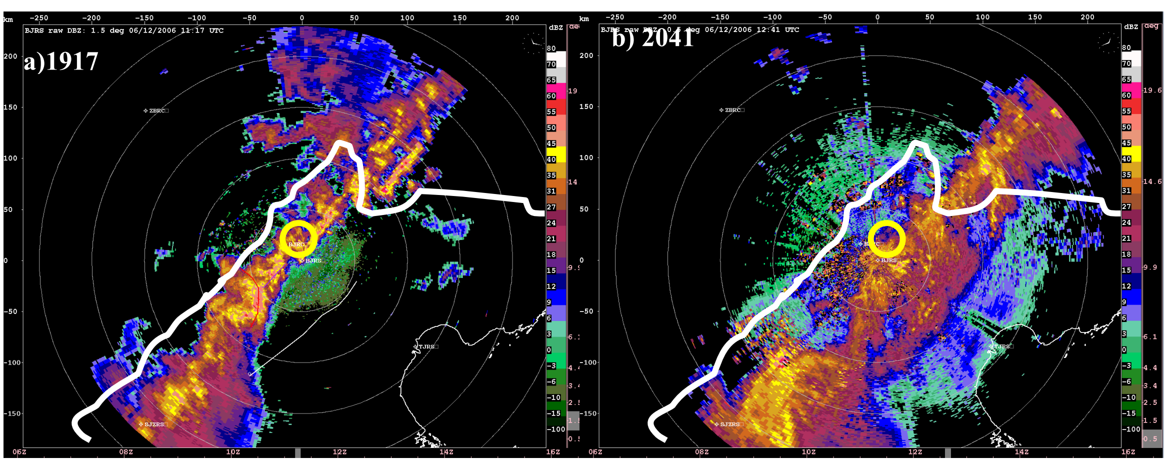

Fig 6. Forecast challenge 2. June 12, dissipation of a convective line when moving from foothills to the plains.

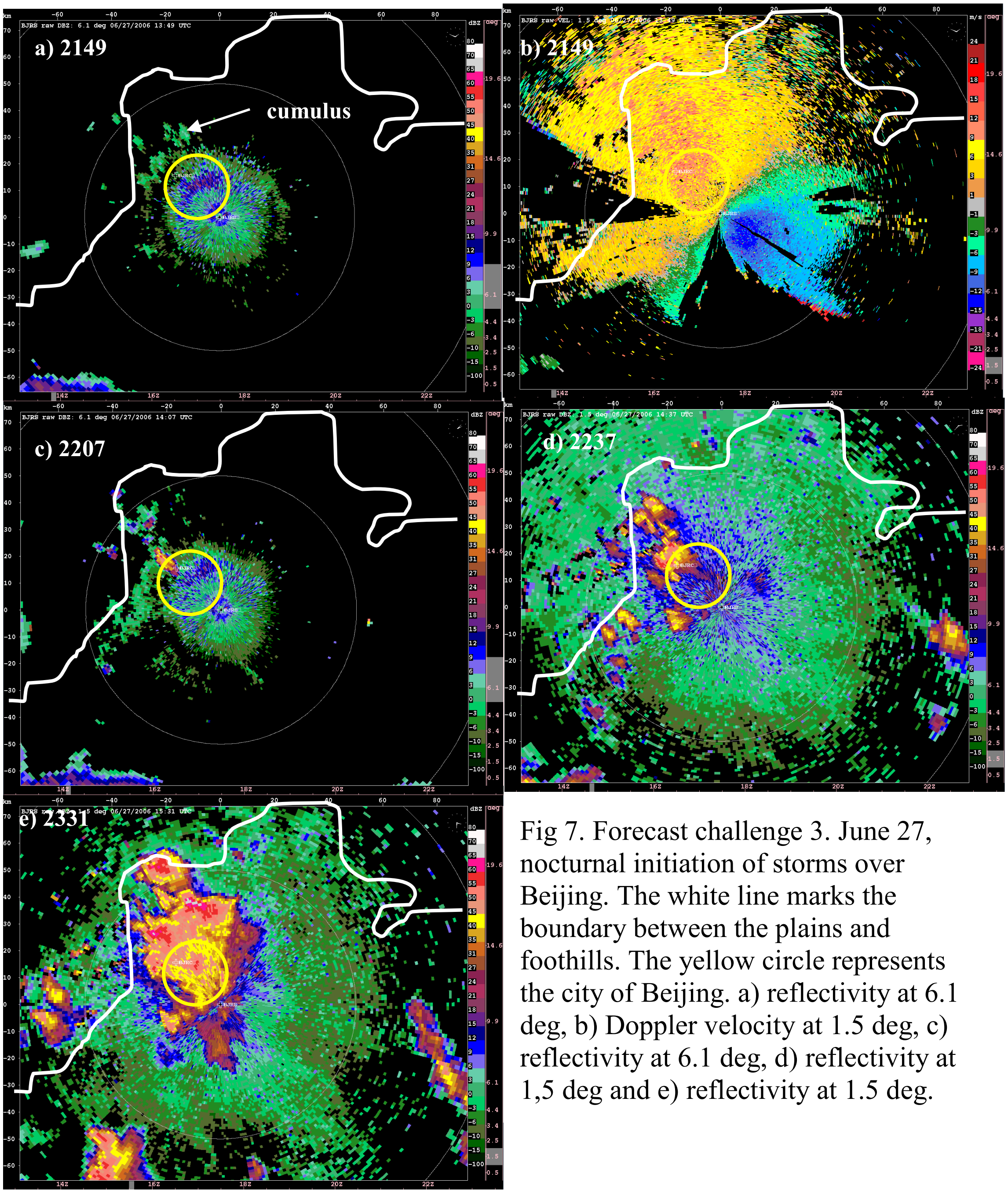

Fig 7. Forecast challenge 3. June 27, nocturnal initiation of storms over Beijing. The white line marks the boundary between the plains and foothills. The yellow circle represents the city of Beijing. a) reflectivity at 6.1 deg, b) Doppler velocity at 1.5 deg, c) reflectivity at 6.1 deg, d) reflectivity at 1,5 deg and e) reflectivity at 1.5 deg.

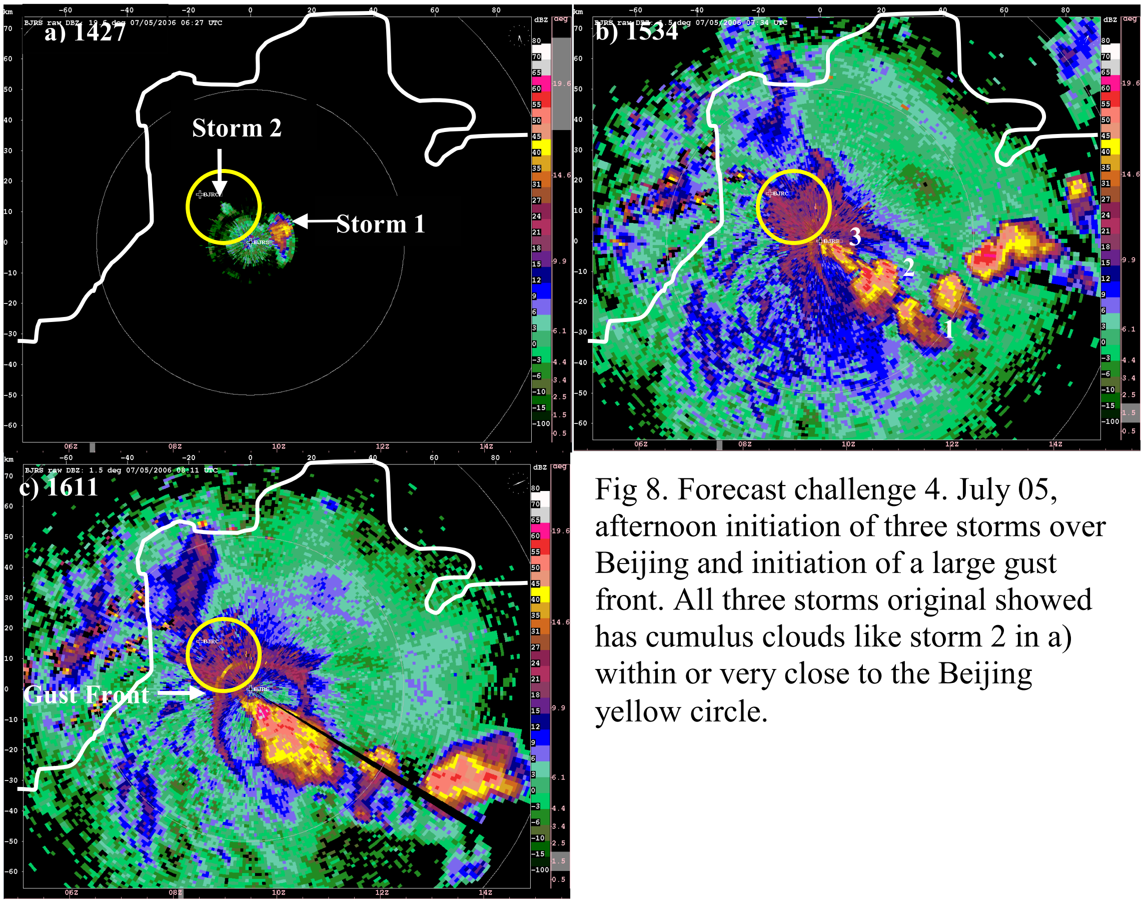

Fig 8. Forecast challenge 4. July 05, afternoon initiation of three storms over Beijing and initiation of a large gust front. All three storms original showed has cumulus clouds like storm 2 in a) within or very close to the Beijing yellow circle.

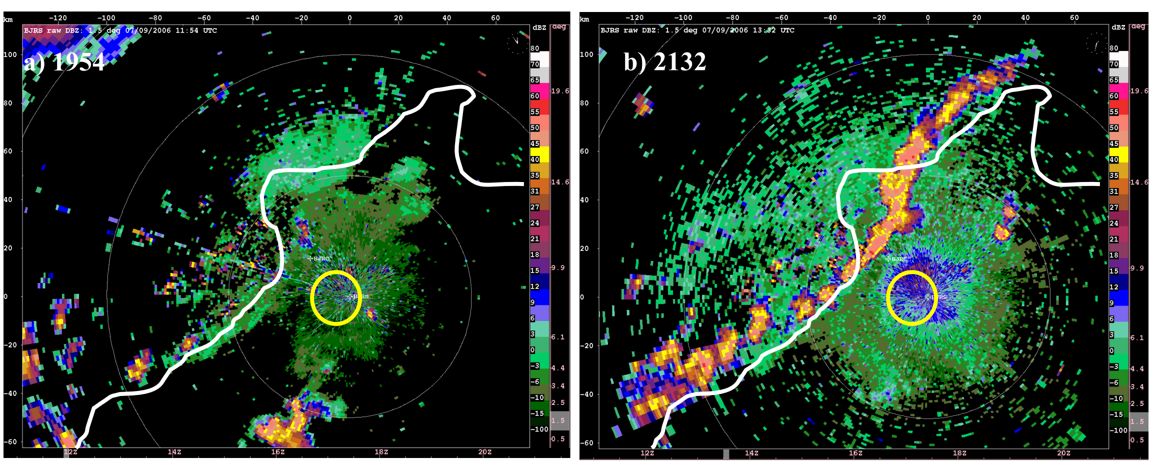

Fig 9. Forecast challenge 6. July 09, late evening initiation of a line of thunderstorms along the foothills.

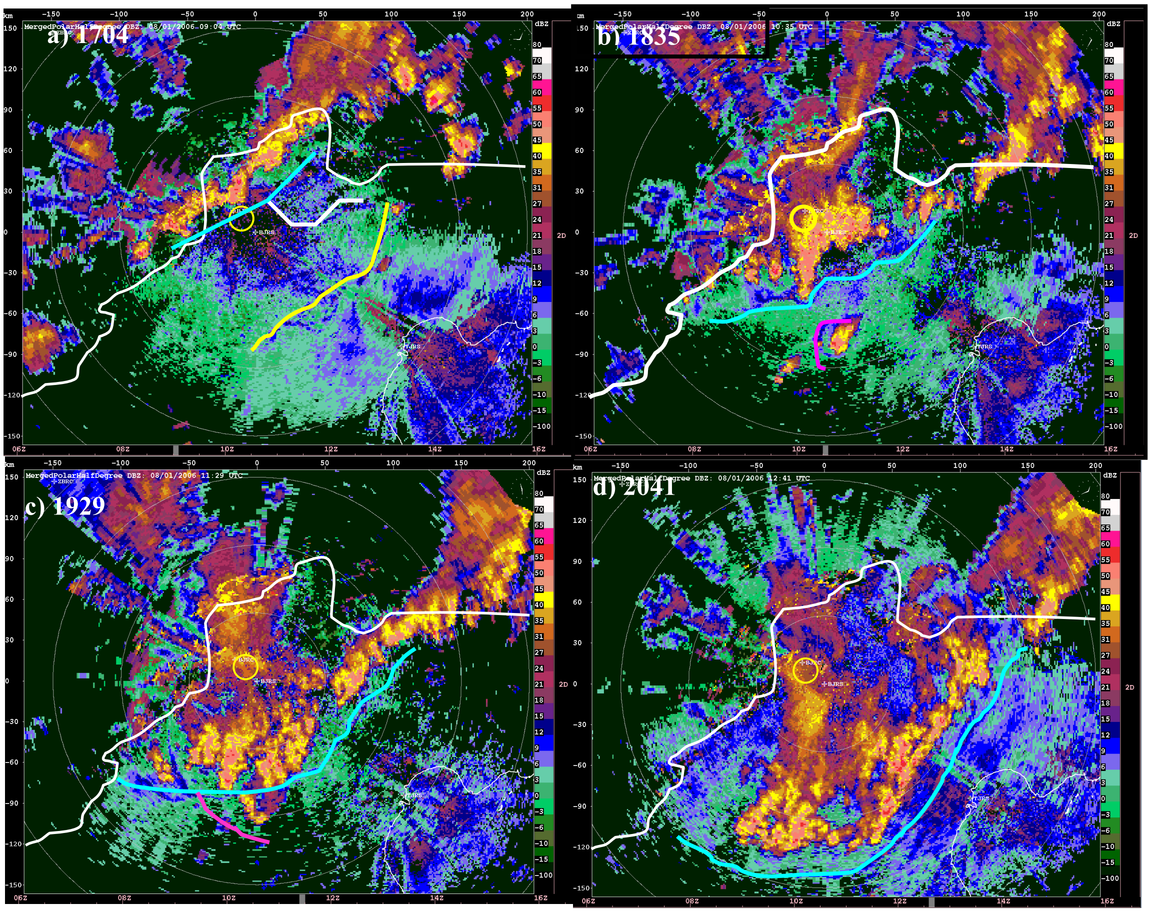

Fig 10. Forecast challenge 15. 01 August, development of a squall line along the foothills and intensification on the plains. Colliding gust fronts played a significant role in intensifying the squall line.