Characteristics Analysis and Influence of Environmental Variability on Idealized Simulations for a Long-lived Bow Echo with High Percentage of Positive Cloud-to-Ground Lightning

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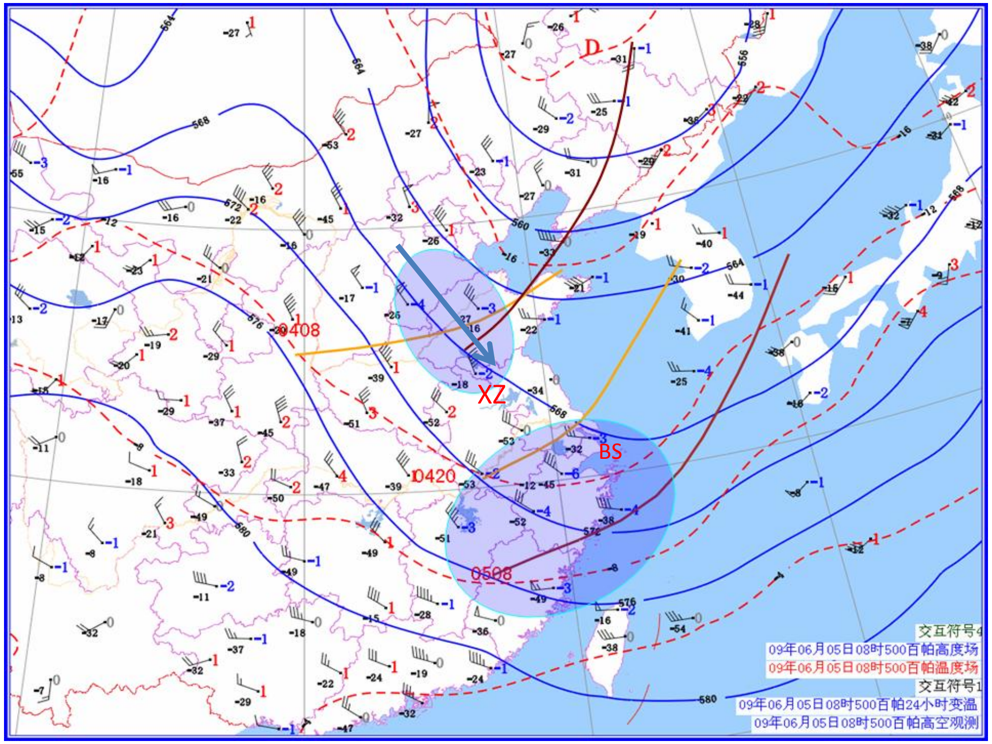
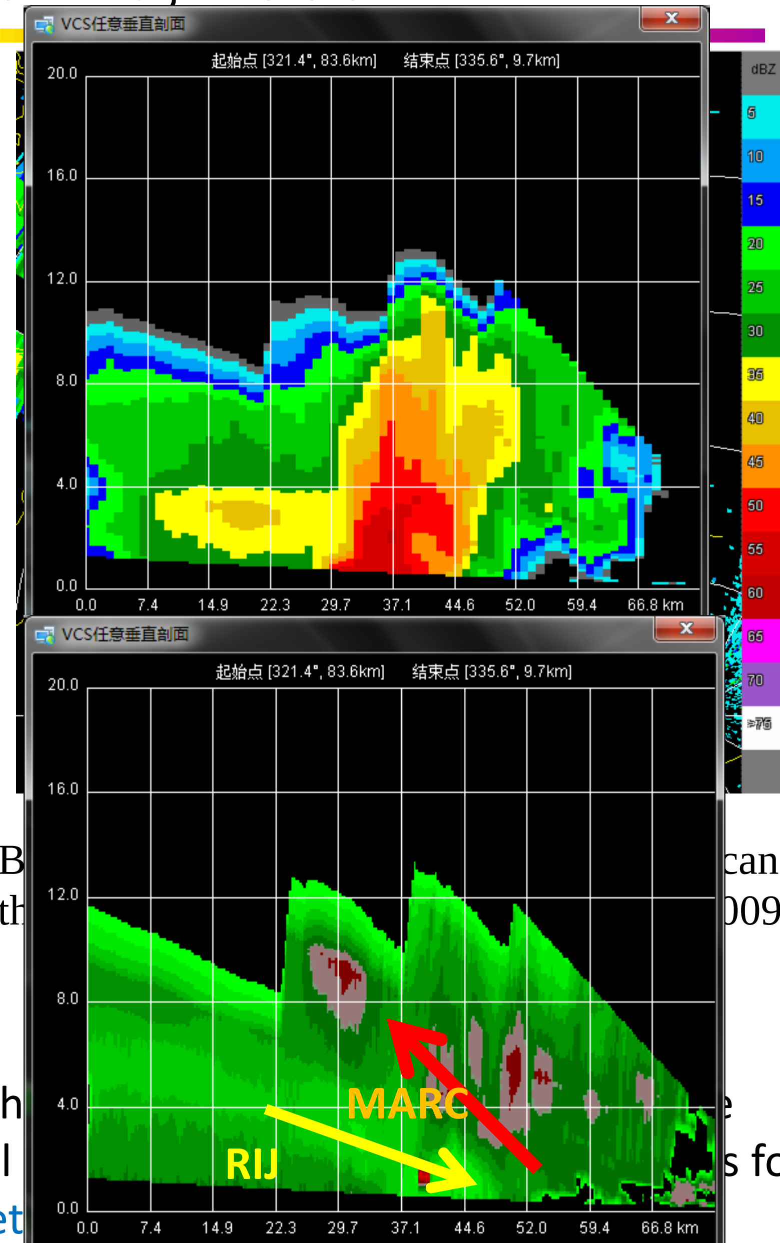
A Long-lived MCS with a Bow Echo in mid- East China coast on Jun. 5, 2009



Synoptic analysis of 08:00(BJT)
500 hPa (trough with brown, previous trough with orange, and temperature change in last 24 hours with shaded sky-blue) on Jun 5, 2009. (Soundings: XZ-Xuzhou, BS-Baoshan)
Behind a aloft trough, jets, lower FL, increasing lapse rate



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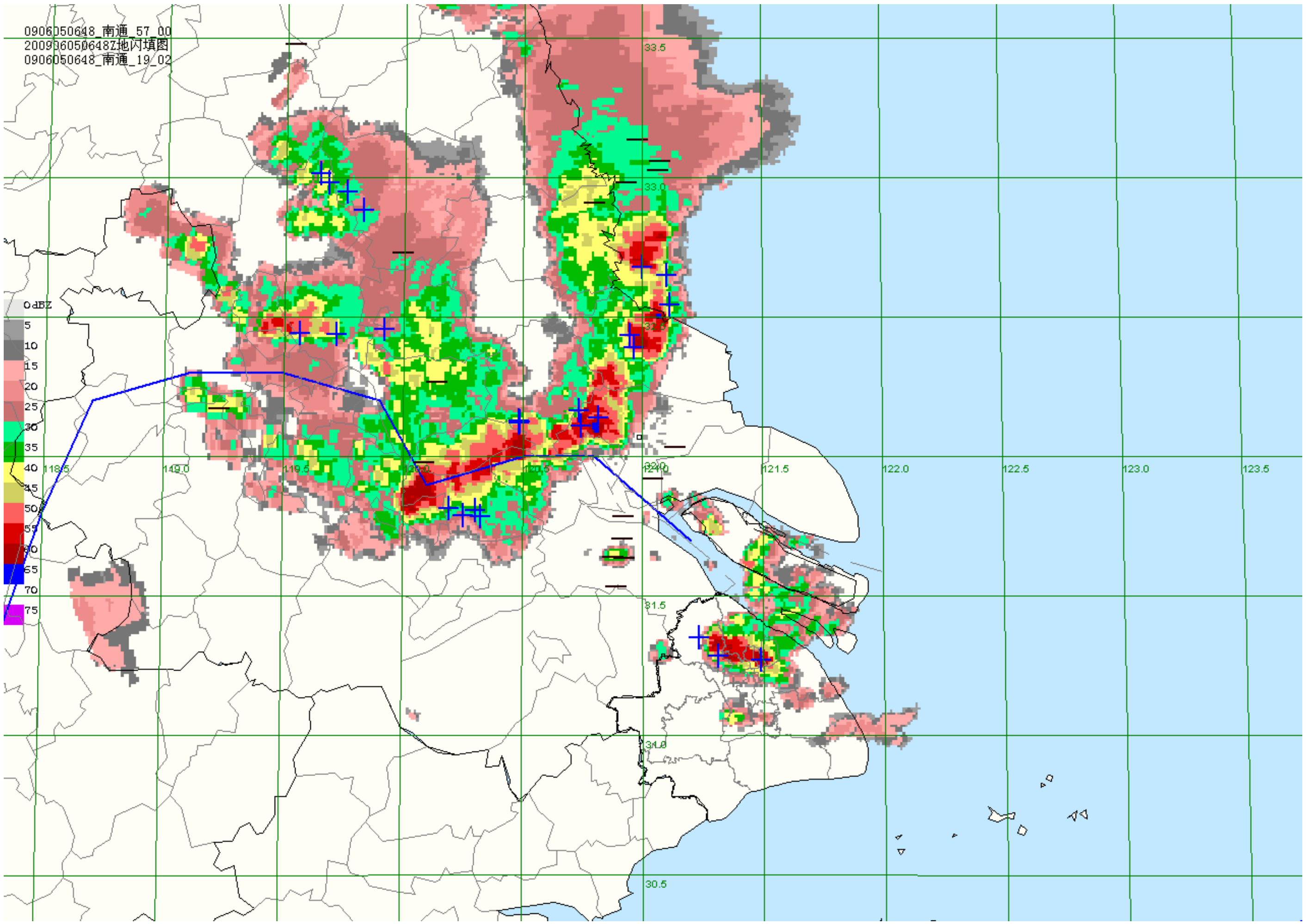
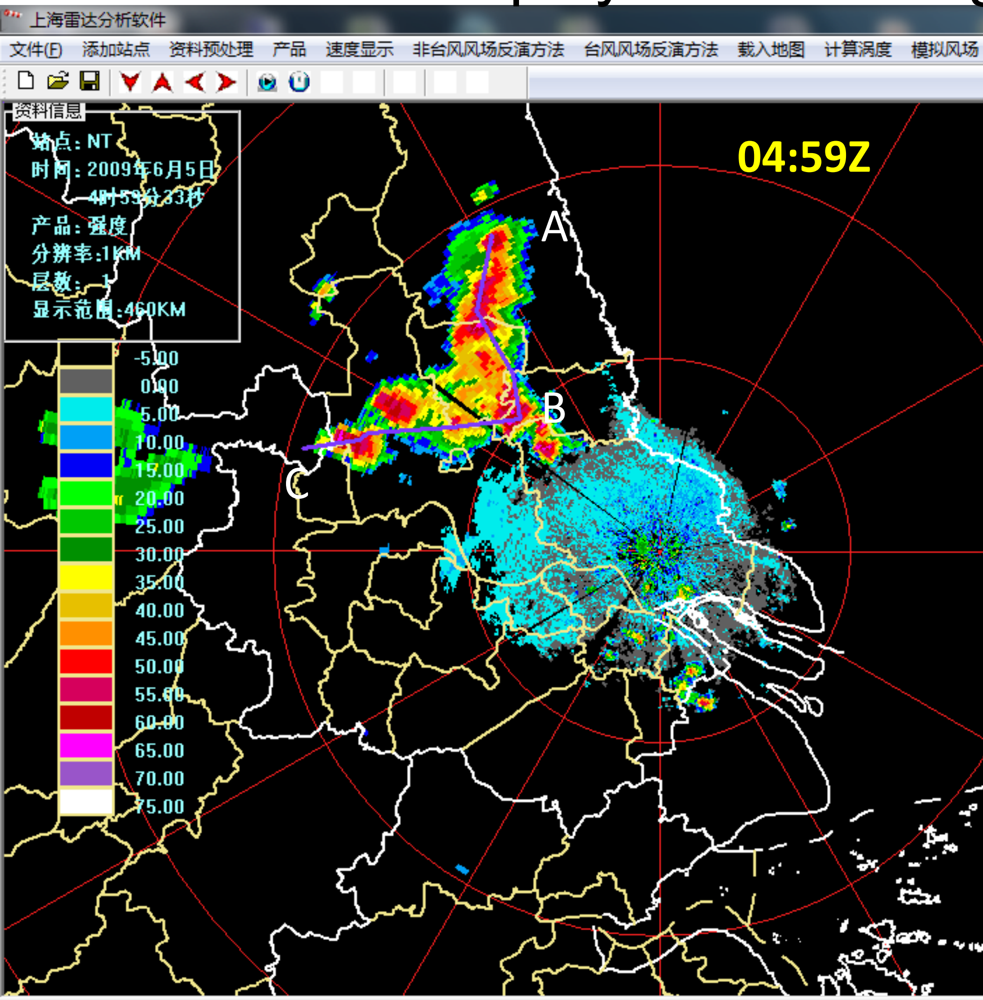
On June 5, 2009, a long-lived squall line with a bow ech … e environment, and brought widely distributed large hail … s for Jiangsu, Shanghai, and Zhejiang. (Yin et al., 2010; Dai et

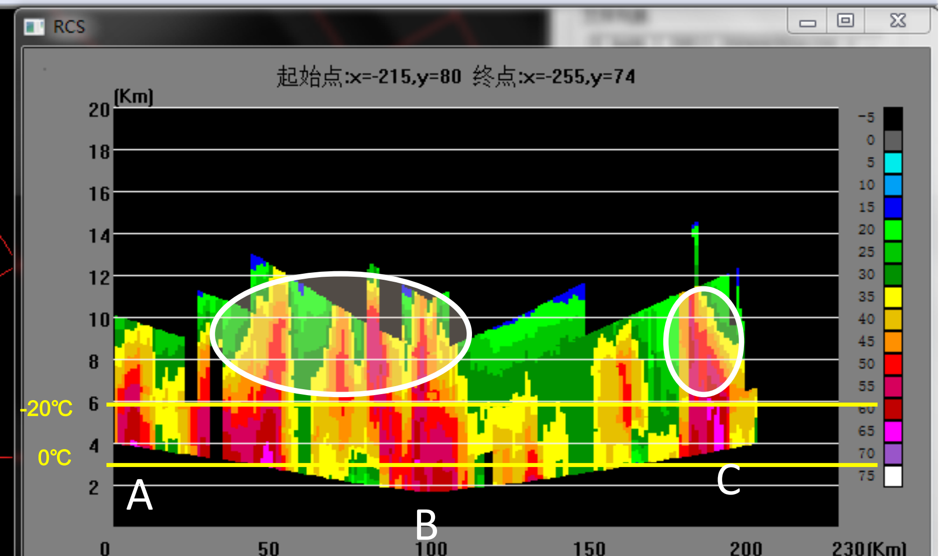
Nantong Radar and ADTD lightning observations
Phase I: 04Z-09Z, Jun. 5, 2009

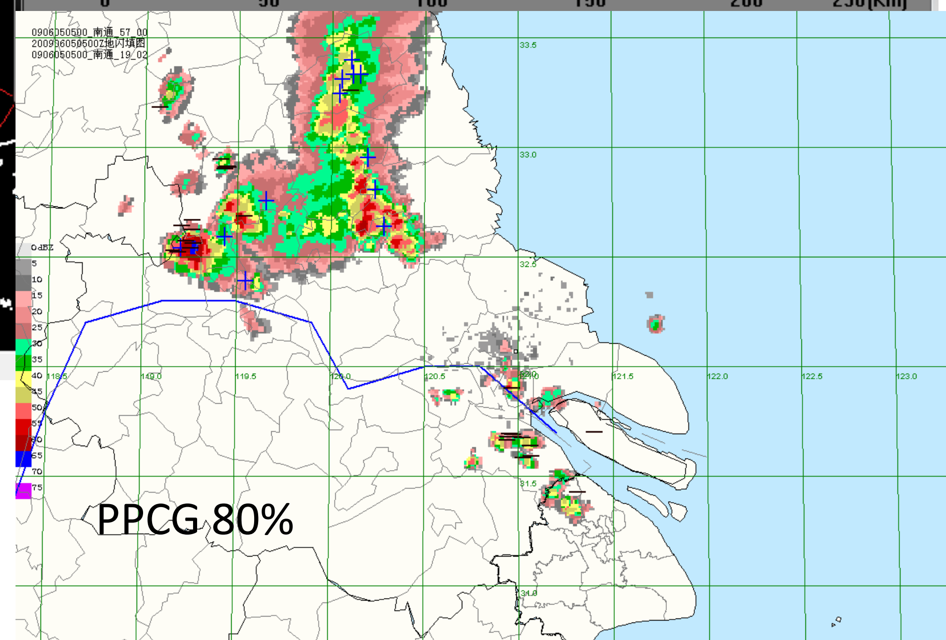


Base reflectivity (in dBZ) from 1.5 degree scan of the Nantong CINRAD and 6-min cloud-to-ground (CG) lightning flashes (blue '+' denotes positive CG, black '-' negative CG) from the national ADTD lightning detection network 04Z-09Z of June 5, 2009

NanTong 0.5 deg Reflectivity and multi-point cross section display with the heights of -20℃ and 0℃ (1/5)

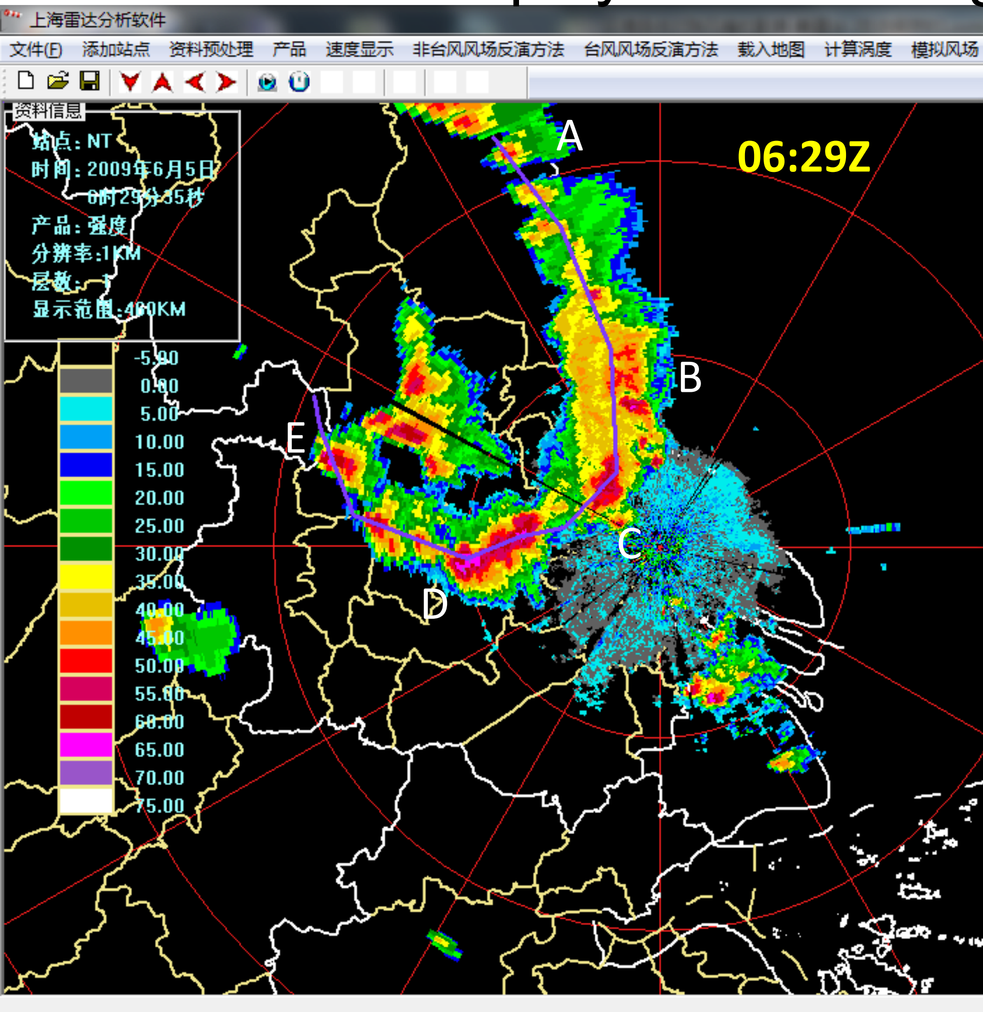


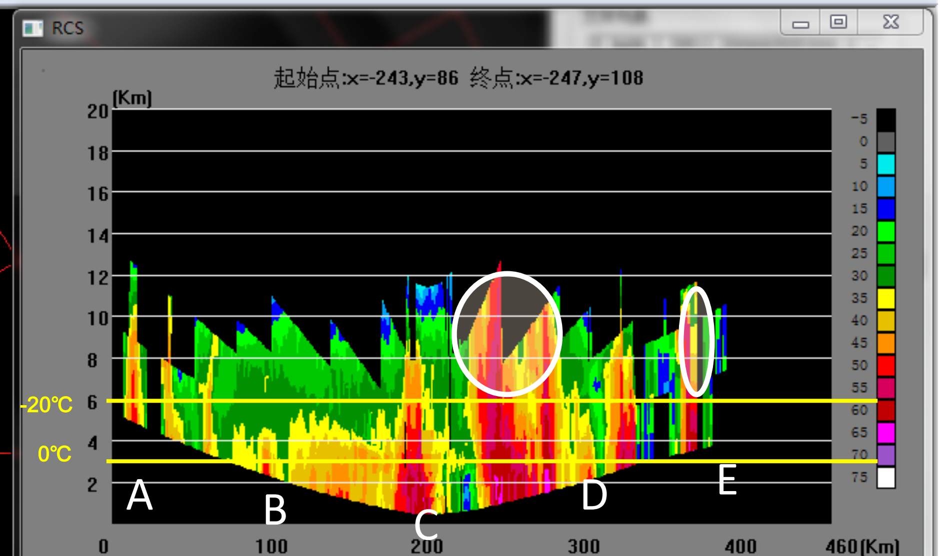


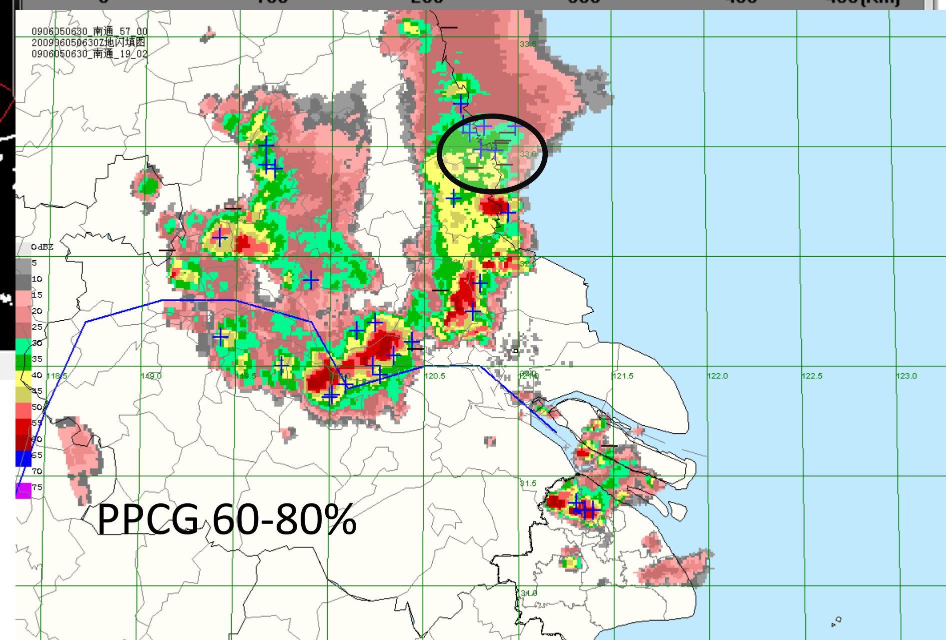


Reflectivity of radar 1.5 deg PPI and CG lightning

NanTong 0.5 deg Reflectivity and multi-point cross section display with the heights of -20℃ and 0℃ (2/5)

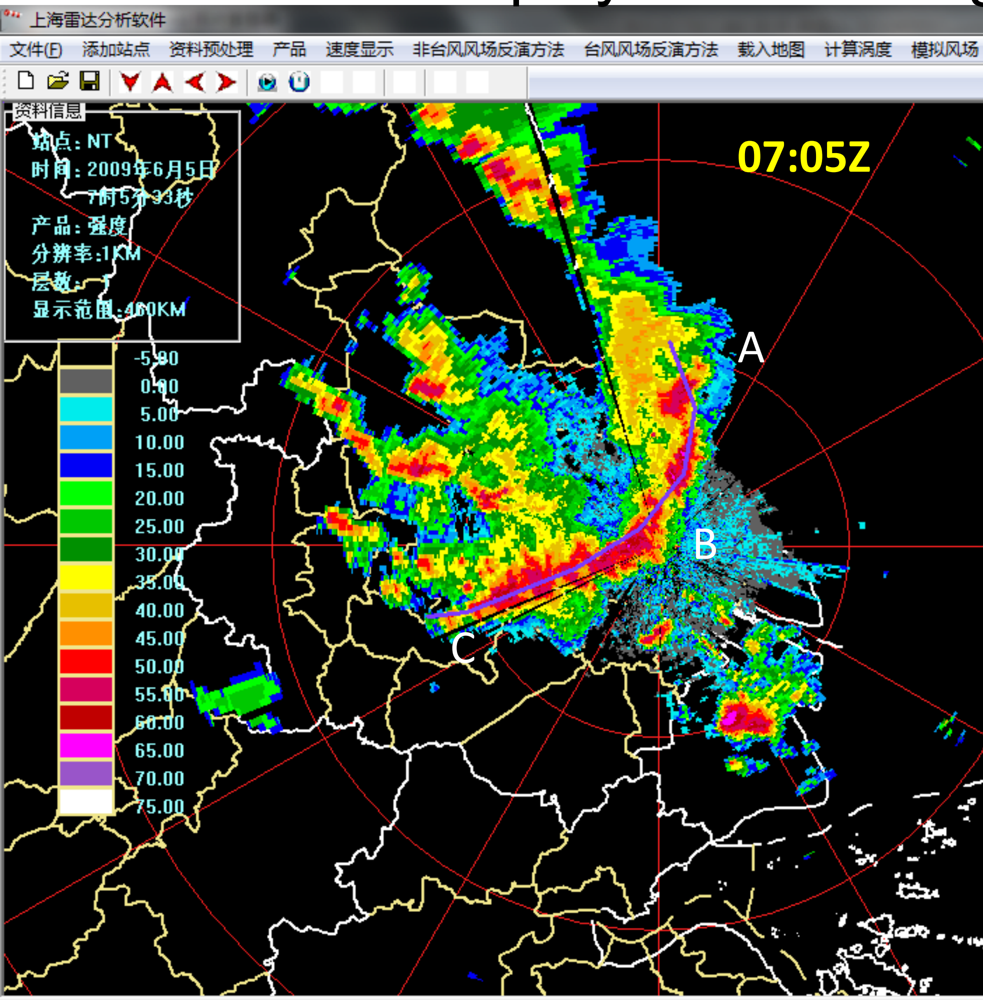


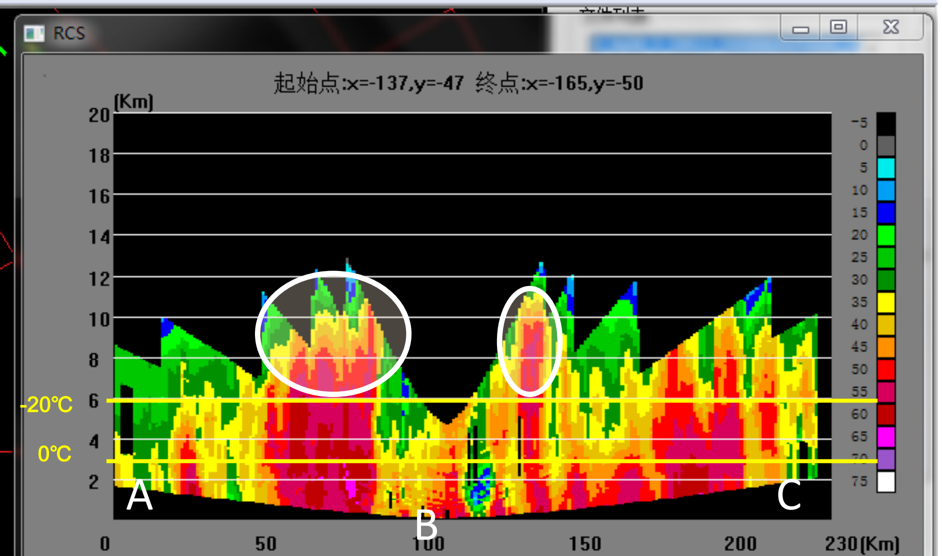


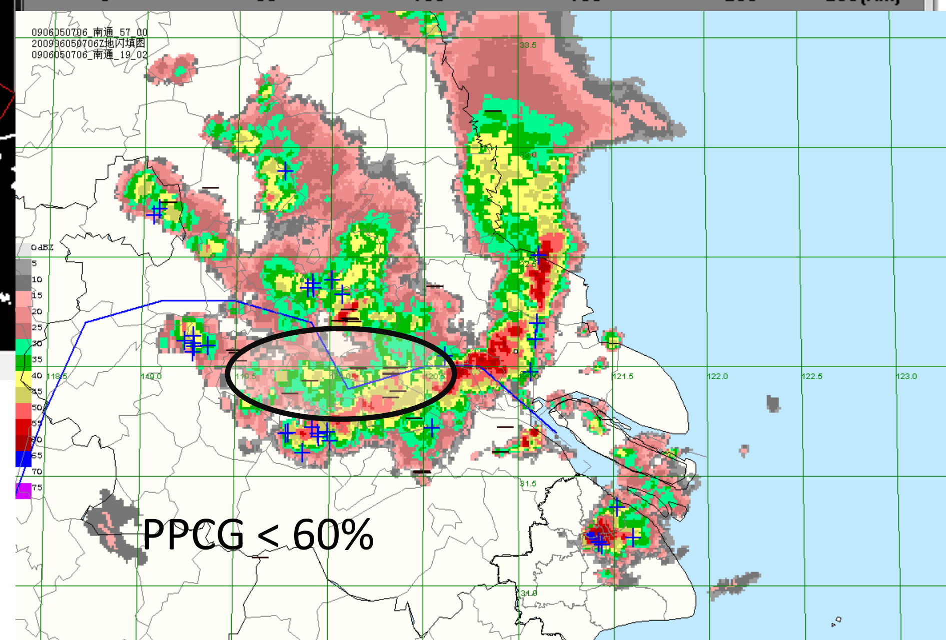


Reflectivity of radar 1.5 deg PPI
and CG lightning

NanTong 0.5 deg Reflectivity and multi-point cross section display with the heights of -20℃ and 0℃ (3/5)

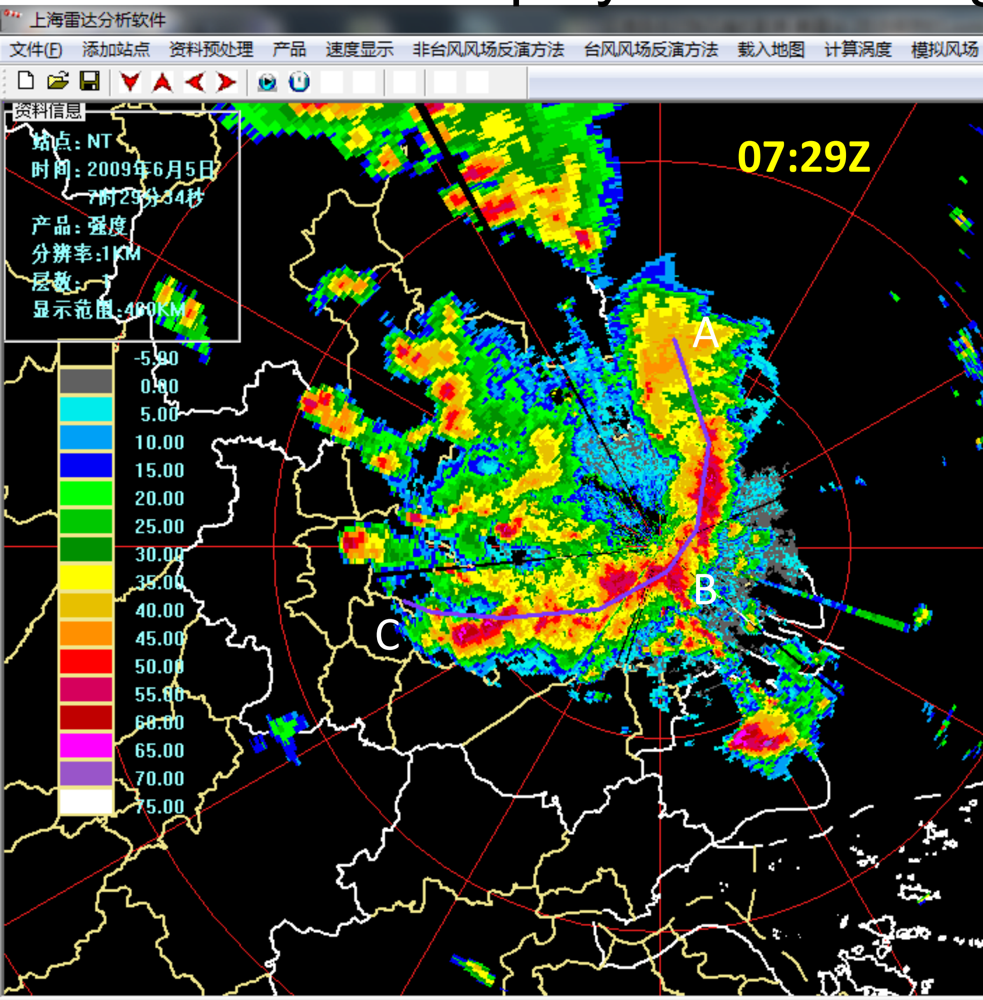


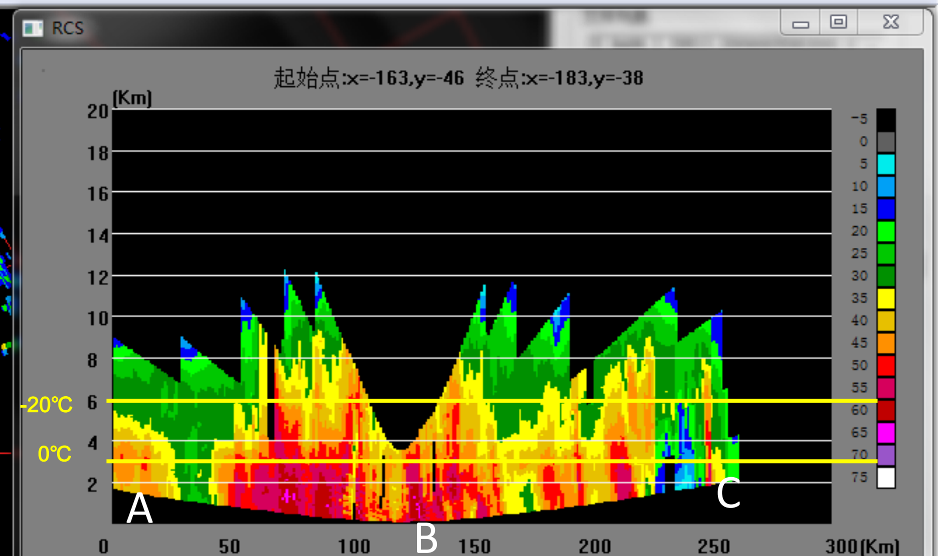


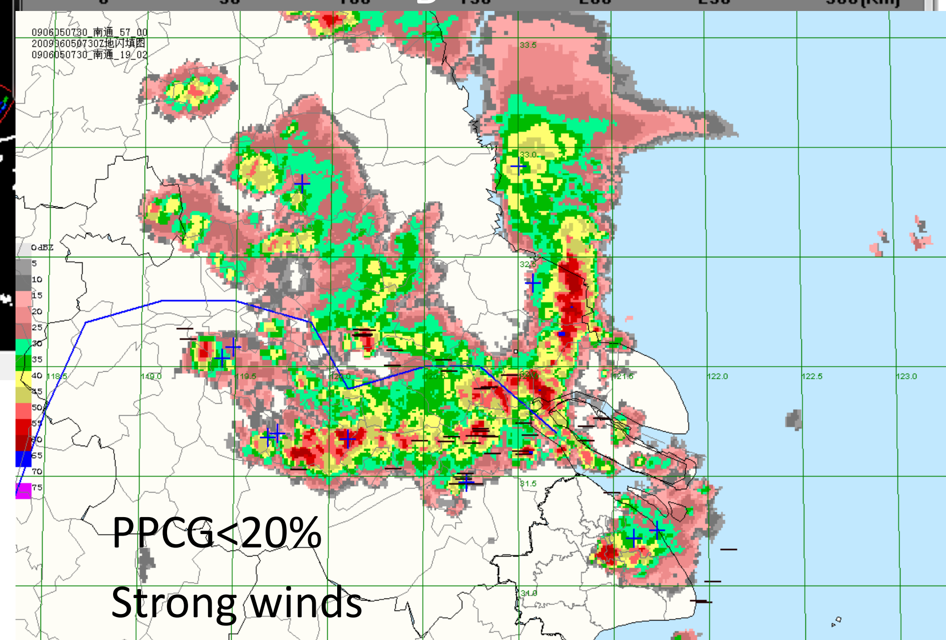


Reflectivity of radar 1.5 deg PPI and CG lightning

NanTong 0.5 deg Reflectivity and multi-point cross section display with the heights of -20℃ and 0℃ (4/5)

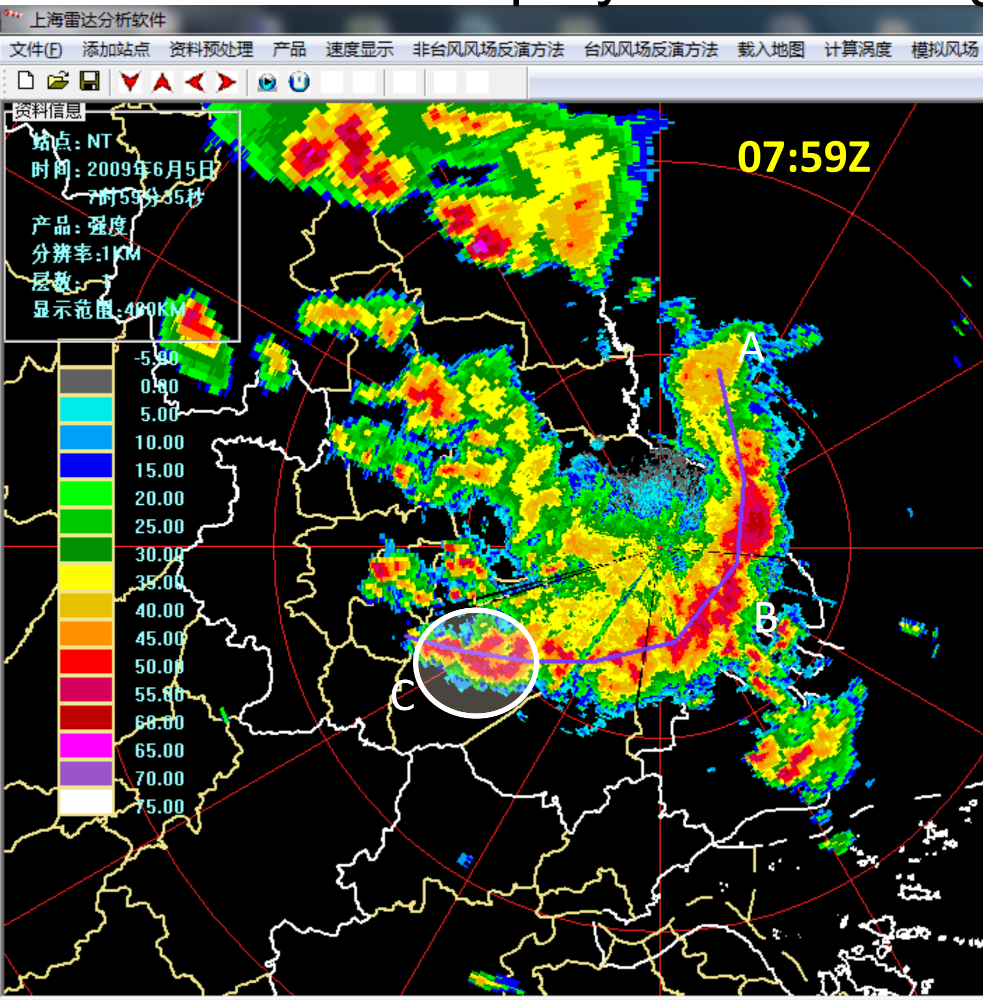


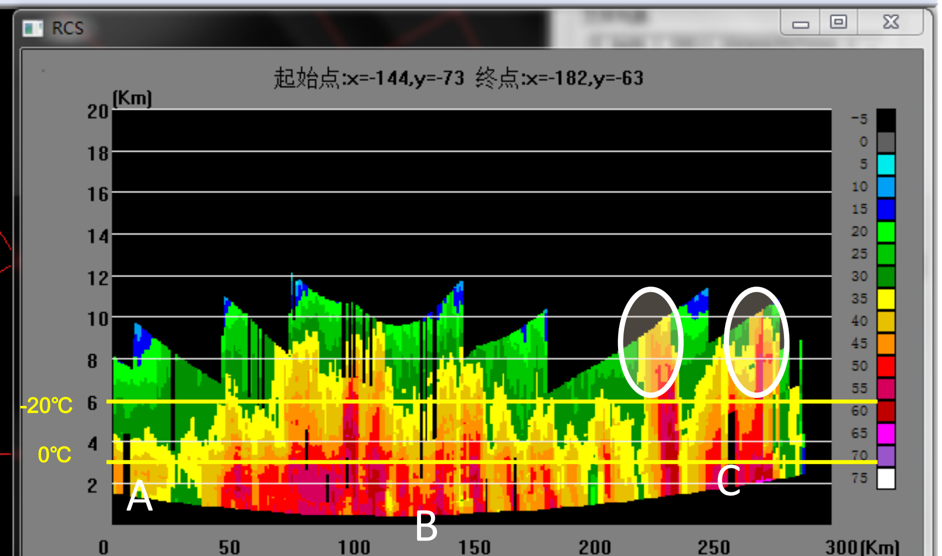


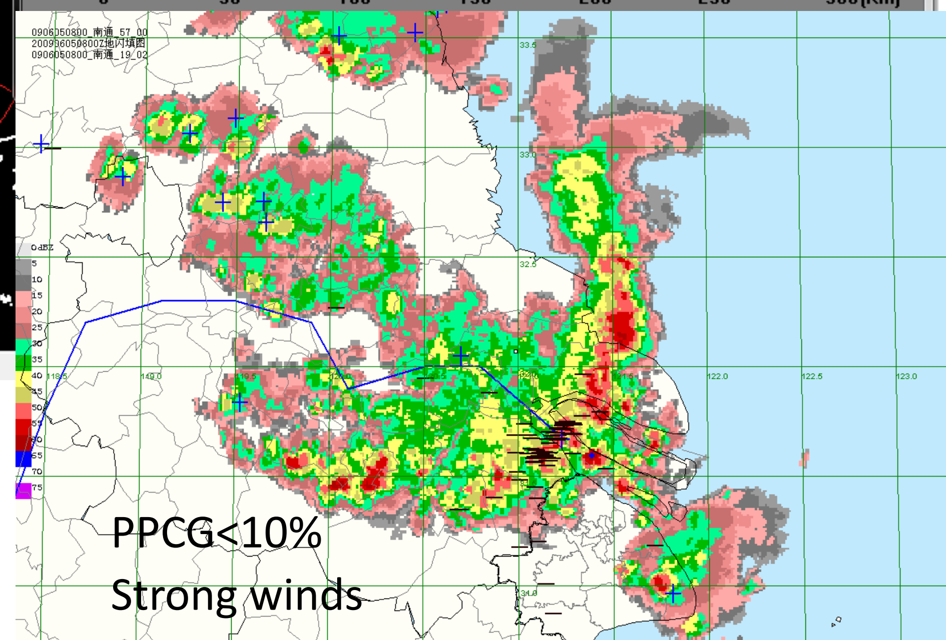


Reflectivity of radar 1.5 deg PPI and CG lightning

NanTong 0.5 deg Reflectivity and multi-point cross section display with the heights of -20℃ and 0℃ (5/5)

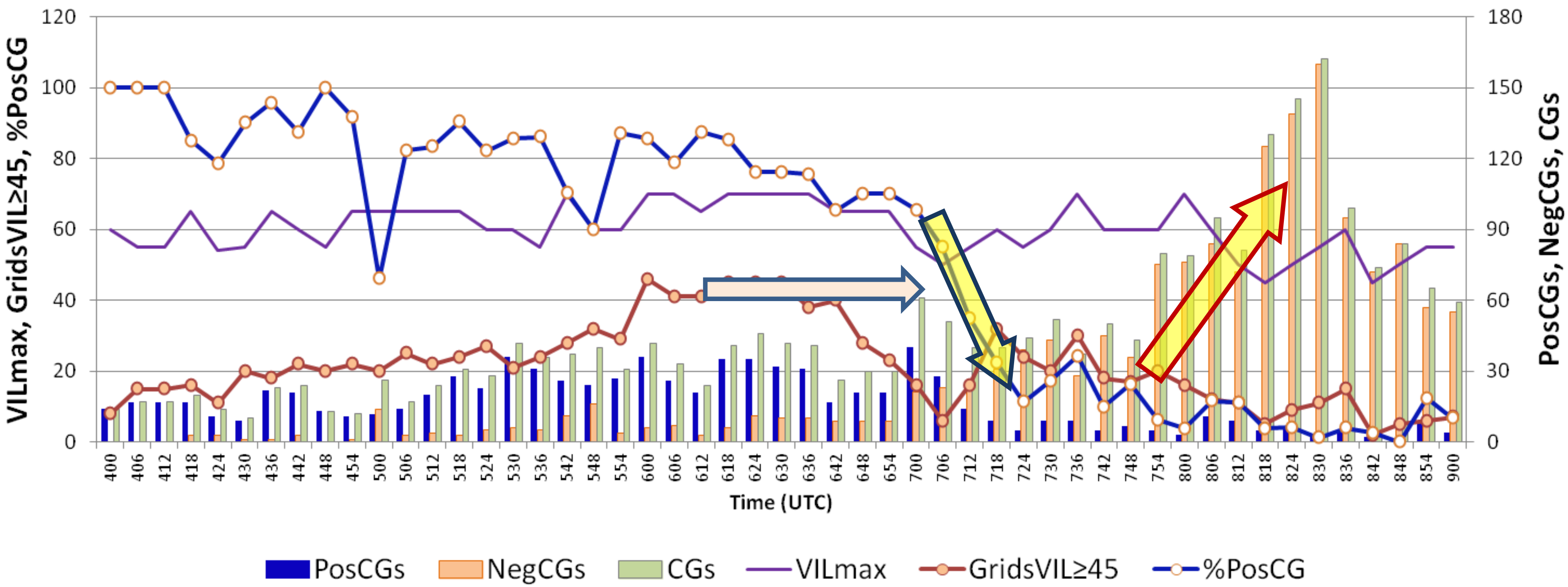






Reflectivity of radar 1.5 deg PPI and CG lightning

Storm structure and CG lightning in Phase I



Time series of 6-min (1) Nantong Doppler radar's VIL maximum (VILmax - kg/m^2, purple line) and Grids of VIL ≥ 45 kg/m^2 (GridsVIL, light brown line), (2) the ADTD +CG lightning proportion (%PosCG - %, blue line), +CG lightning (CGs, flash, blue bars), -CG lightning (NegCGs, flash, green bars), and total CG lightning (flash, light orange bars) , 0400-0900 Z, June 5, 2009

Positive CG in Storms/MCS

---(Rust et al. 1981; MacGroman 1988; Engholm et al. 1990; Saunders et al., 1991)

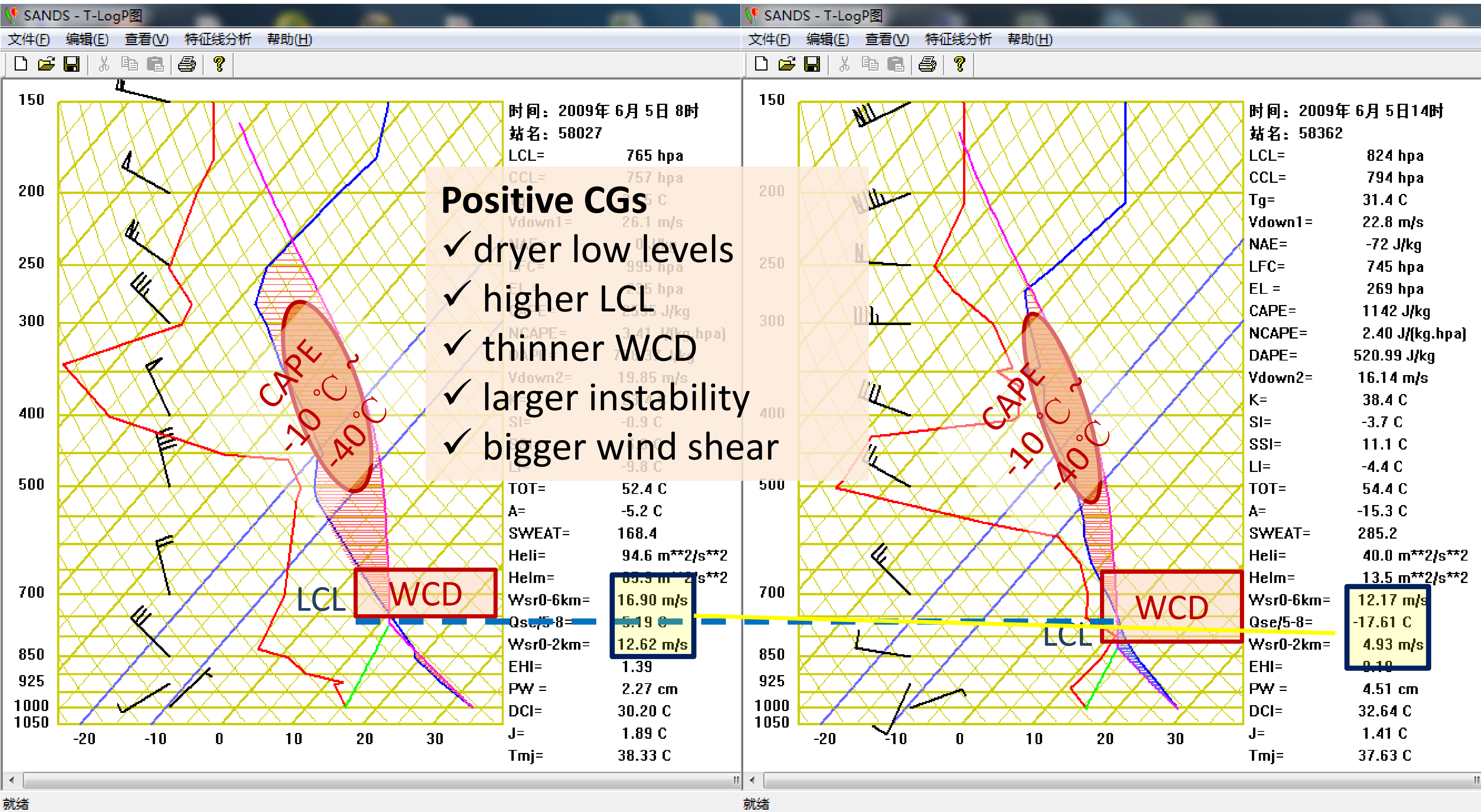
- ***Upper levels in the anvil severe storms*** - by the advection of positive charge from the major convection regions
- ***Adjacent to convective storms*** - associated with a local tilted electrical dipole
- ***Stratiform precipitation regions of MCSs***
  - by ***the advection of positive charge*** from the upper levels of the convective portions of the storm
  - by stratiform precipitation processes, related to ***ice-ice interactions with low supercooled liquid water contents***
- ***Inverted-polarity structure of severe storms***
  - positive graupel charging occurs at temperatures above a *"**charge sign reversal temperature**"*
  - *the **reversal temperature moves to lower temperatures** when the **liquid water content is increased***

Microphysics and Environmental Factors of Predominated +CG Storms (structure, dynamics)

----(Takahashi, 1978 ; Knapp ,1994; Williams et al., 2005; Carey and Buffalo, 2007)

- ***Microphysics***
  - ***larger cloud water concentrations in the mixed phase region*** via the ***non-inductive charging*** **(NIC)** mechanism, a favorable condition for the ***positive charging of large ice particles*** that may result in thunderclouds with ***a reversed polarity of the main cloud dipole***
- ***Environment conditions***
  - ***An elevated cloud base height*** **(CBH) /*Low sub-cloud moisture*** / ***shallow warm-cloud depth*** **(WCD)**
  - ***Broad and intense updrafts (*CAPE -10℃~ -40 ℃*) and high liquid water contents (LWC)*** **-** less entrainment of ambient air, transport a larger fraction of water content to the mixed-phase region
  - a drier low to mid-troposphere, higher cloud-base height, smaller ***warm cloud depth****, stronger conditional instability, larger 0–3 km AGL wind shear, stronger 0–2 km AGL storm relative wind speed, and larger buoyancy in the mixed-phase zone. (Carey and Buffalo, 2007)

Sounding comparisons between MCS initiation and bow echo formation



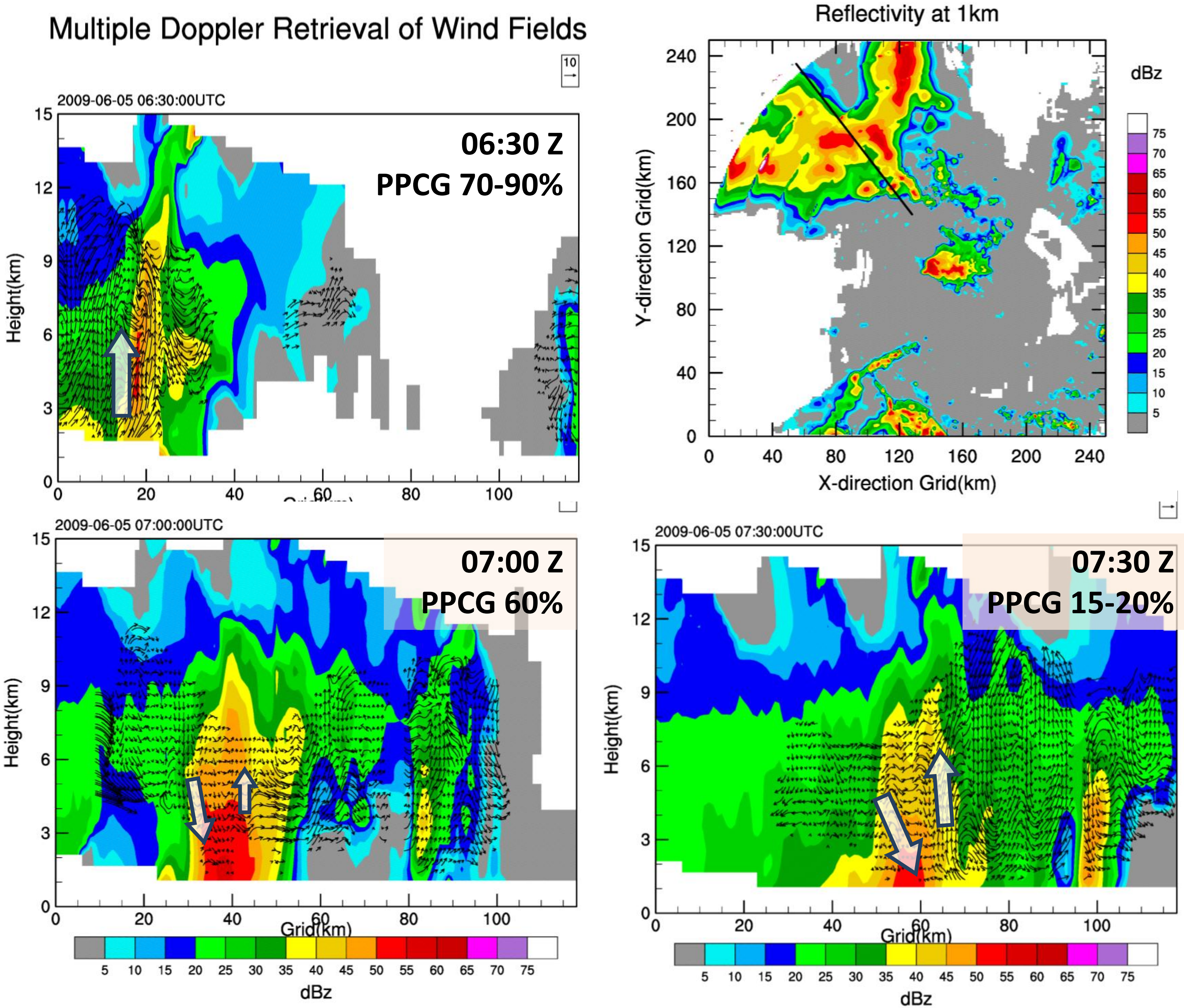
00Z 58027-Xuzhou sounding + 06Z T/Td

Upstream to MCS initiation

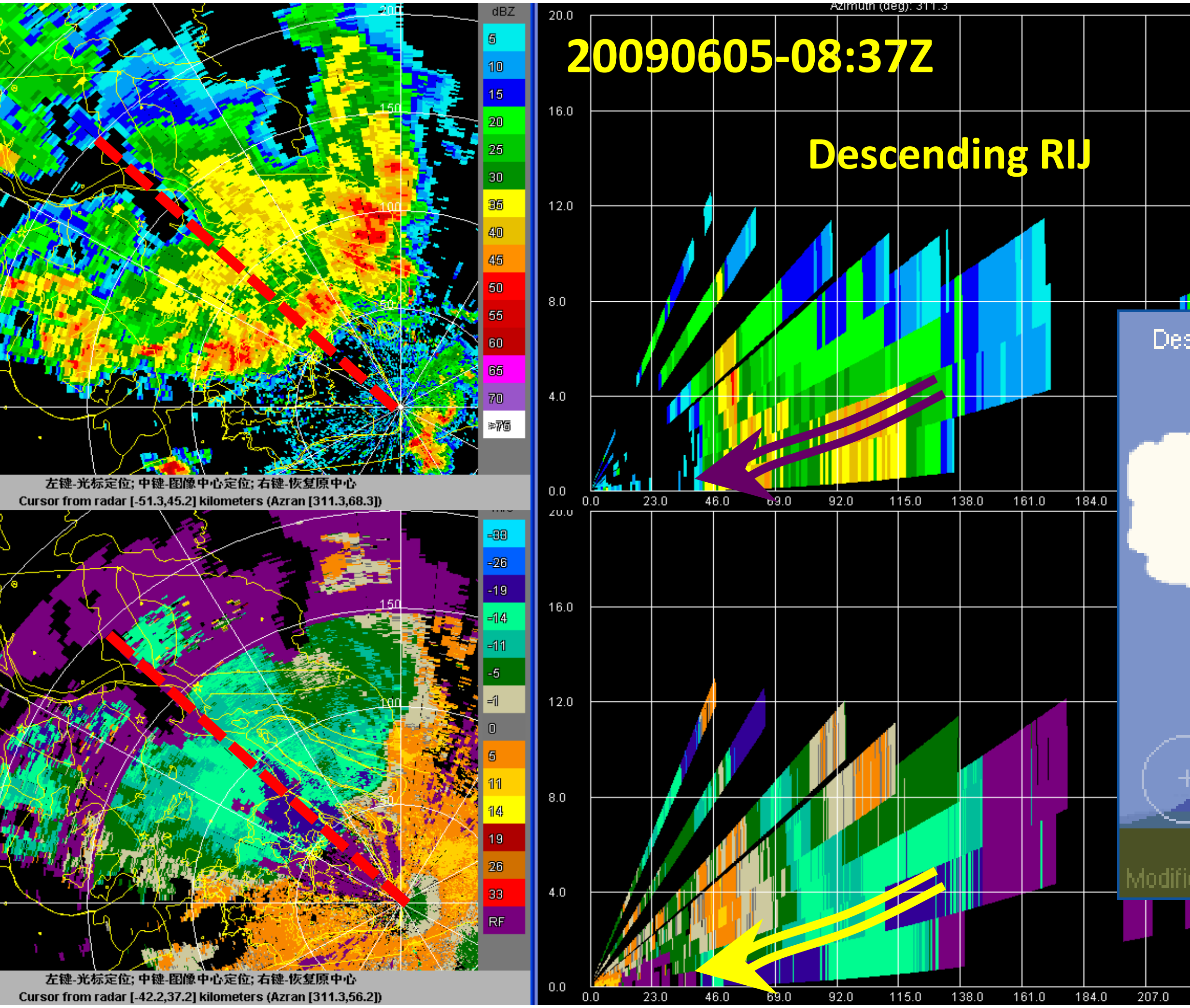
06Z 58362-Baoshan Sounding

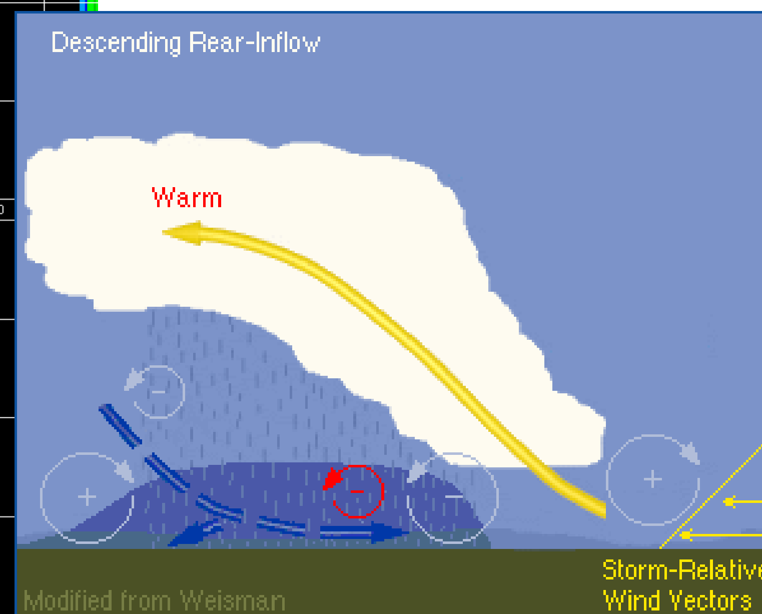
Bow echo formation

Multiple Doppler Retrieval of Wind Fields



A Descending Rear Inflow Jet after 07UTC

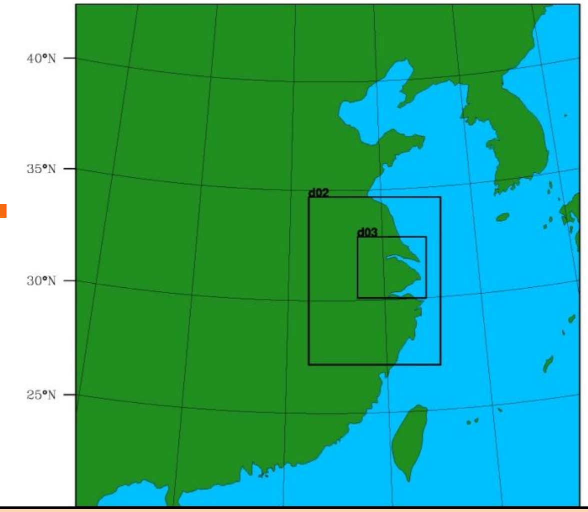




- weak-moderate environmental shear
- RIJ enhances the surface gust front

buoyancy gradient associated with the warm air in the ascending front to rear flow is less than the buoyancy gradient on the back edge of the cold pool, then the RIJ will descend to the ground

WRF simulation



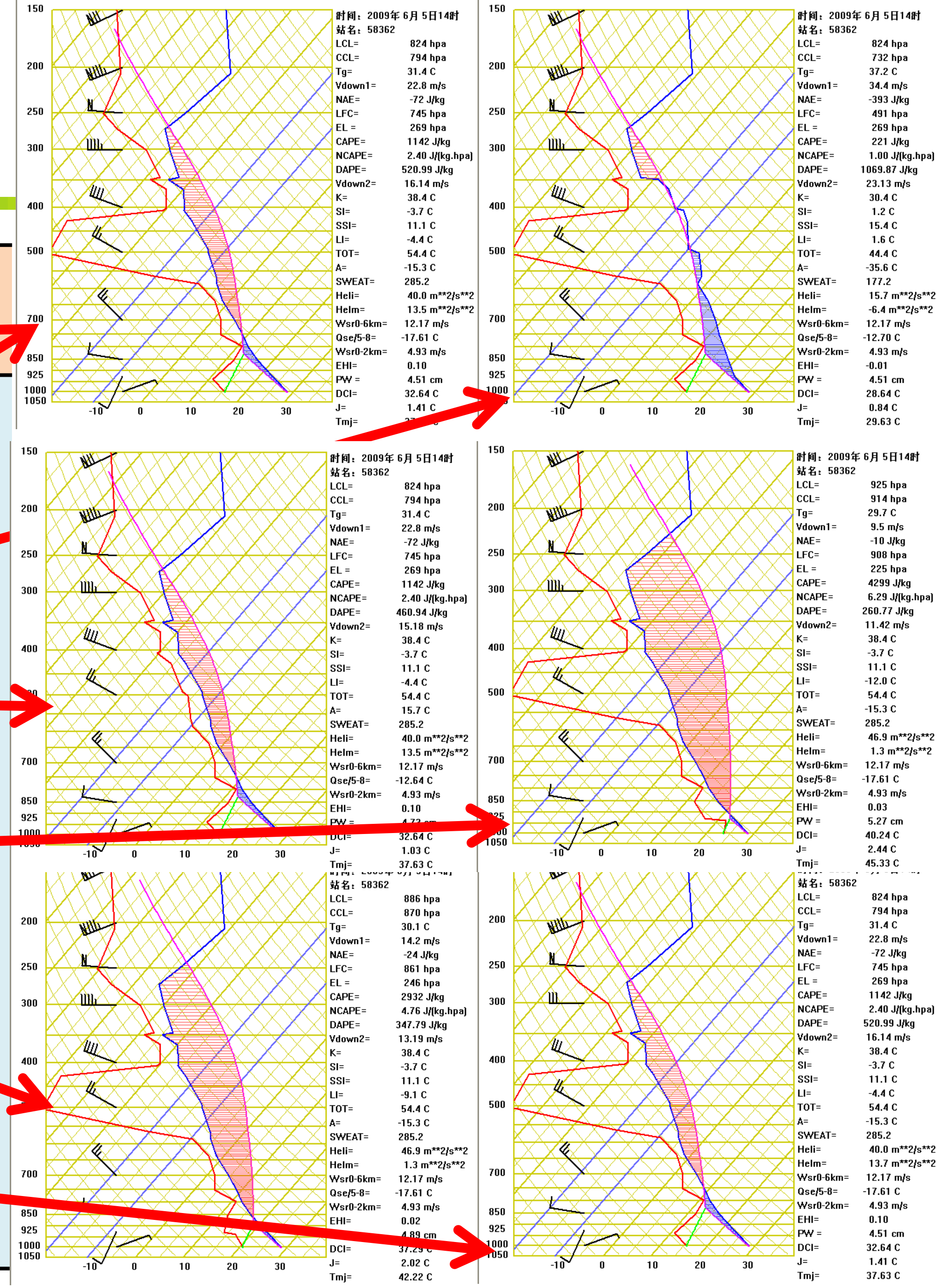
- Idealized simulation setup (Yuan 2015)

Sounding data: 20090605 06Z Baoshan 58362, Shanghai
H-Reso: 1x1km V-Reso: 51 levels, 400m
Microphysics scheme: Morrison double-moment (MP10)

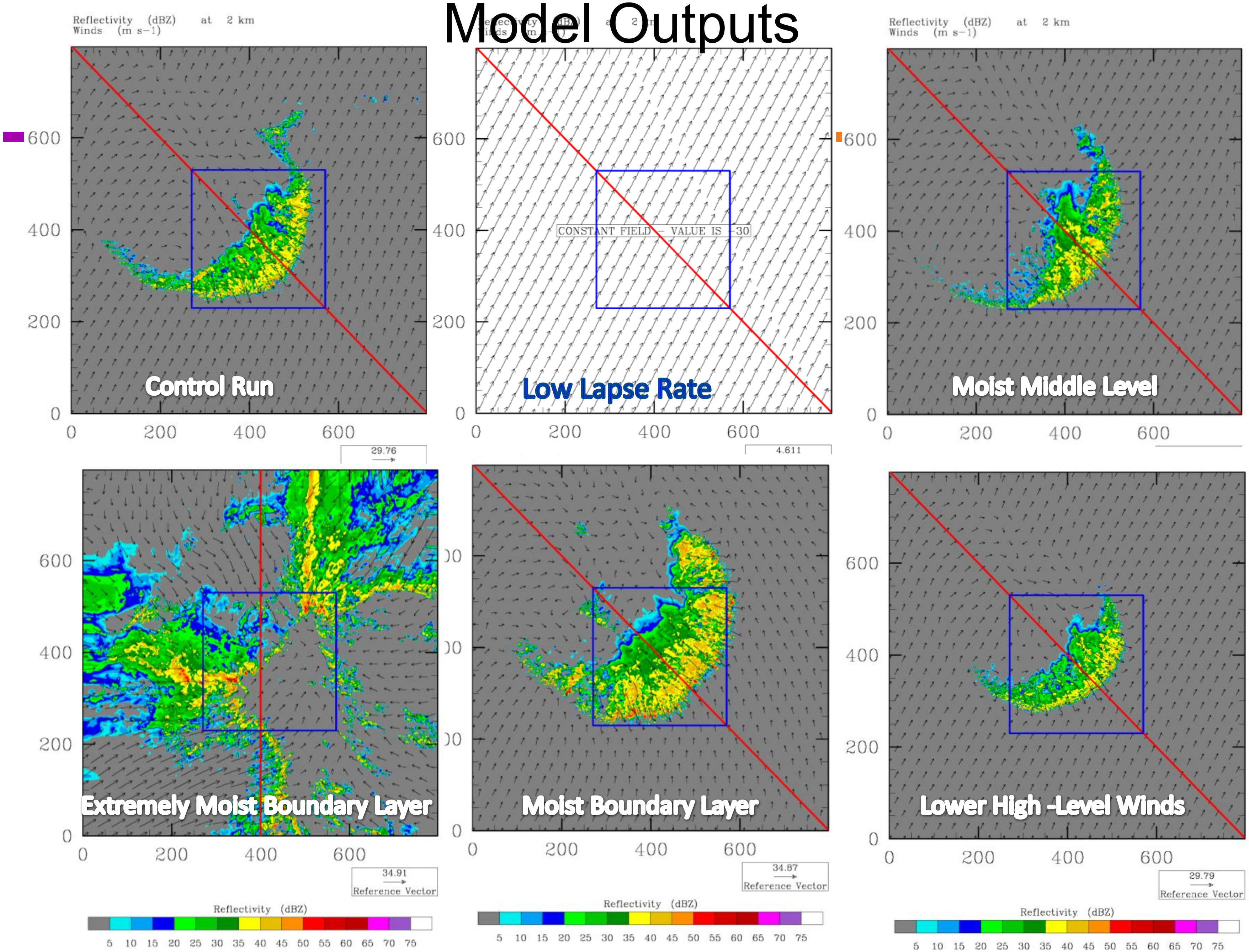
No.	ID	Scheme	Sounding Modification
1	***CTL***	**Control Run**	none
2	***LLR***	**Lower Lapse Rate**	decreased T850hPa and increased T500hPa and T300hPa
3	***MML***	**Moist Mid-level**	increased dew point between 400 and 600 hPa
4	***EMBL***	**Extremely Moist Boundary layer**	dramatically increased dew point between surface and 925hPa (+8℃ & +6℃)
5	***MBL***	**Moist Boundary layer**	increased dew point between surface and 925hPa (+5℃ & +3℃)
6	***LHLW***	**Lower High-level winds**	decreased wind speed between 300 and 500hPa

Modified Soundings

No.	ID	Scheme
1	***CTL***	Control Run
2	***LLR***	Lower Lapse Rate
3	***MML***	Moist Mid-level
4	***EMBL***	Extremely Moist Boundary layer
5	***MBL***	Moist Boundary layer
6	***LHLW***	Lower High-level winds

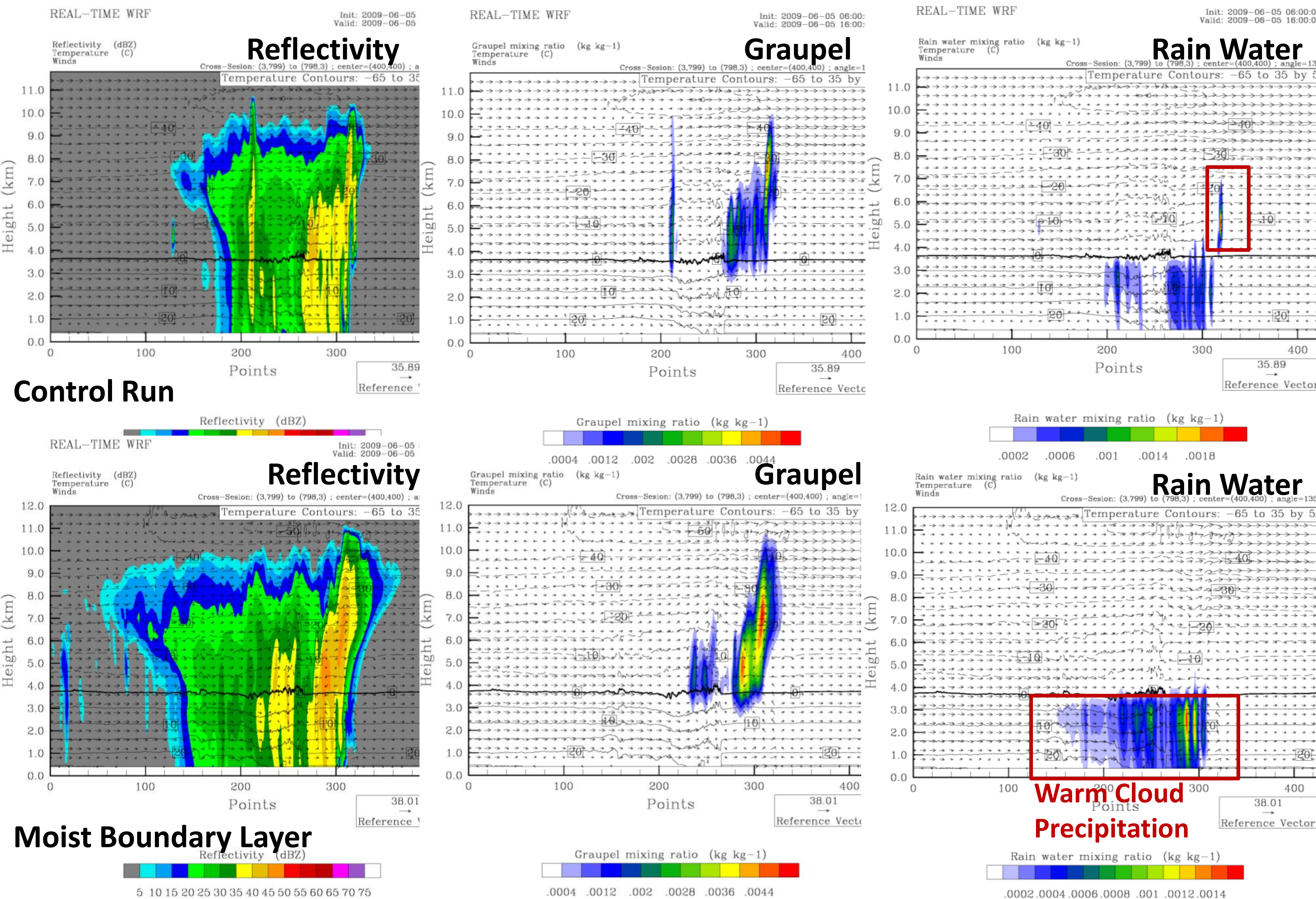


Model Outputs



Reflectivity and wind vectors at 2km height of the WRF idealized model for the Jun 5 squall line

Model reflectivity and water content comparisons



Summary (1/3)

- **MCS structure**
  - vertical cross sections along the core of the bow echo showed a strong wind gust front, a mid-altitude radial convergence (MARC), and a downward-sloping rear inflow jet (RIJ).
- **Lightning**
  - The bow echo was dominated by ***positive*** CG lightning flashes (percentage over 66%) at the early stages.
  - At its mature stage, a burst of negative CG flashes was found in the major convection areas.
  - The predominant positive CG lightning flashes were associated with ***rapid updraft intensification*** stages of the bow echo, and predominant negative CG flashes with ***updraft weakening***.
- Theme of the AMS2017 **-** "***Observations Lead the Way***"
  - New instruments - VHF lightning mapper, phased-array radar
  - High temporal resolution observations

Summary (2/3)

- **Environmental factors**
  - ***Vertical wind shear***:
    - Along the squall line's motion axis, strong ***surface to high-level vertical wind shear*** interacted with the cold pool to enhance the lifting at the leading edge of the convective system, which made the squall line live longer.
    - The ***medium-to-weak vertical wind shear*** at low levels made a downward-sloping rear inflow jet (RIJ) which spread out along the surface and caused widely distributed strong wind gusts.
    - The vertical and horizontal size of the MCS were sensitive to the strong vertical shear created by the ***high-level jets*** (based on model simulations)

Summary (3/3)

- **Environmental factors**
  - ***High lapse rate***
    - caused by the strong cold advection aloft over the warm advection at low levels was the crucial factor of a large convective energy or strong updrafts for this convective system.
  - ***Rapid increase of boundary humidity*** (along boundary layer convergence line)
    - may be the major cause of this deep convection case by providing a lower LFC and a larger CAPE
  - ***Dry layers*** at mid-levels and low-levels provided
    - evaporative cooling potential
    - shallow warm cloud depth
  - ***Warmer boundary ambient air***
    - enlarged the temperature difference between downdrafts and environment.

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Questions or Comments?