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On the Fine-scale Boundary-layer Dynamic Processes Leading to Extreme Gust Wind Events in East China: Insights Gained From Radar Wind Profiler Mesonet Observations

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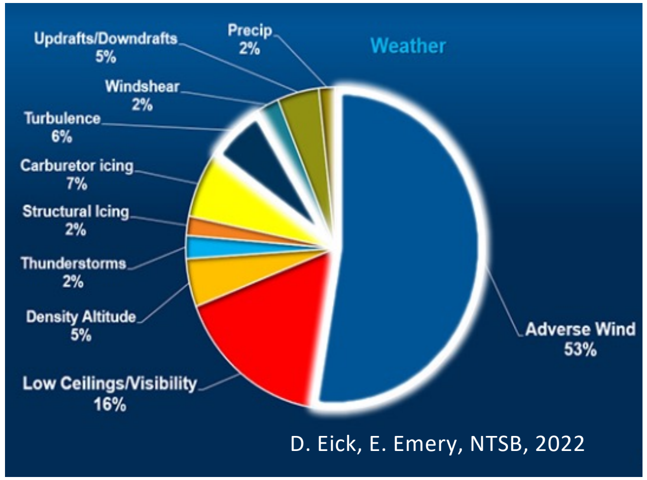
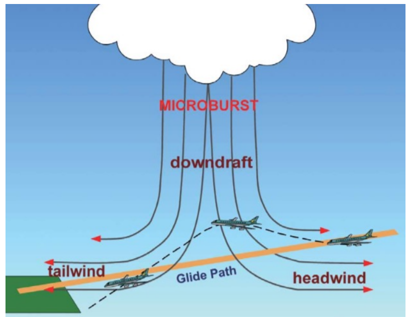
Why wind gusts?

- **Extreme wind gusts induced by convective systems frequently trigger severe socioeconomic losses and pose critical threats to transportation safety**

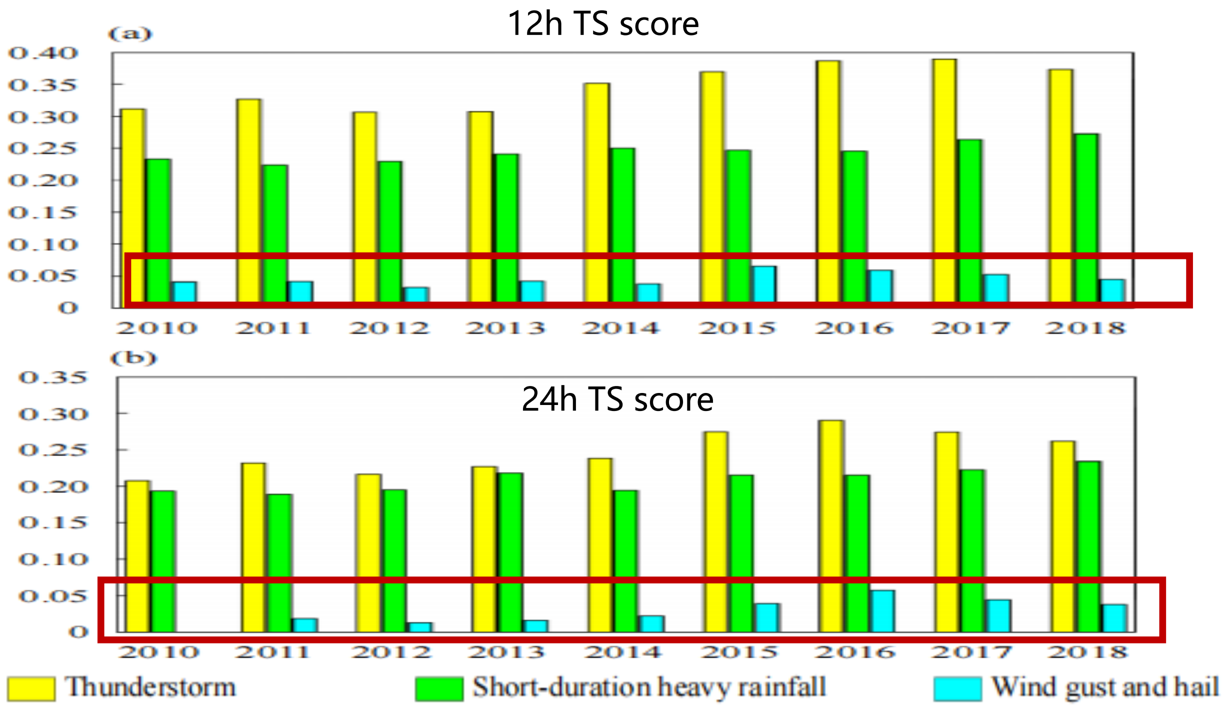
Weather related accidents, 2008-2020





Why gust winds?

- Considerable advances in NWP
- Operational numerical models still exhibit limited forecasting skill for extreme convective gust events.



Courtesy by NMC/CMA

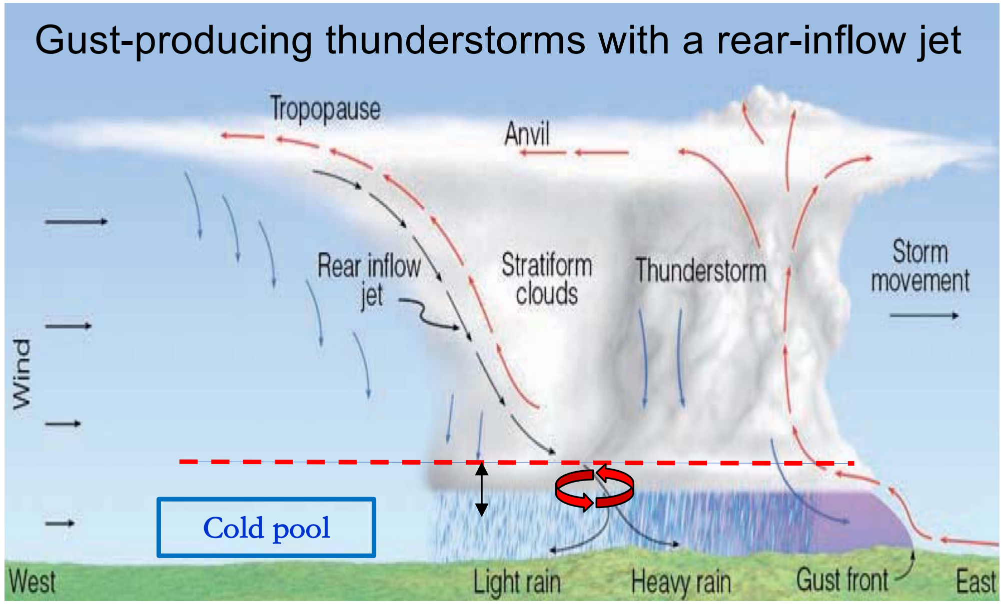
Common types of wind gusts?

❖ **Wind gust is a brief, sudden increase in wind speed that lasts less than 20 seconds and is often followed by a lull in intensity.**

- **Mechanical Gusts**
  - ✓ Caused by friction as air flows over rough terrain, hills, trees, or large buildings, creating turbulent eddies.
- **Thermal (Convective) Gusts**
  - ✓ Triggered by solar heating of the ground, where warm air rises and cooler air rushes down in a churning, gusty pattern.
- **Thunderstorm Outflow Gusts**
  - ✓ Formed by rain-cooled downdrafts hitting the earth's surface and spreading rapidly outward.
- **Frontal Gusts**
  - ✓ Associated with the leading edge of a passing cold front, bringing a sharp temperature drop and sudden wind surges.
- **Peak Gust**
  - ✓ The absolute highest instantaneous wind speed recorded during a specific observation cycle

Thunderstorm outflow gusts

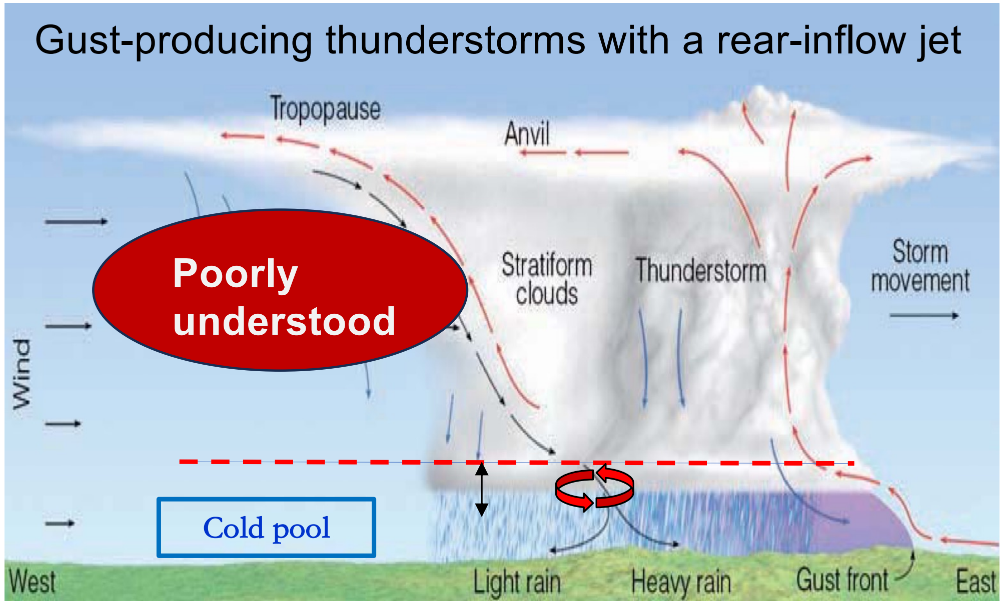
- The rear-inflow jet is a mid-level dynamical forcing that enhances downward momentum transport and ultimately generates severe thunderstorm outflow gusts at the surface



Credit by Ahrens, Meteorology Today

Thunderstorm outflow gusts

- The rear-inflow jet is a mid-level dynamical forcing that enhances downward momentum transport and ultimately generates severe thunderstorm outflow gusts at the surface
- Doppler weather radars provide 3D wind field measurements, yet resolving boundary-layer dynamical processes is challenging.



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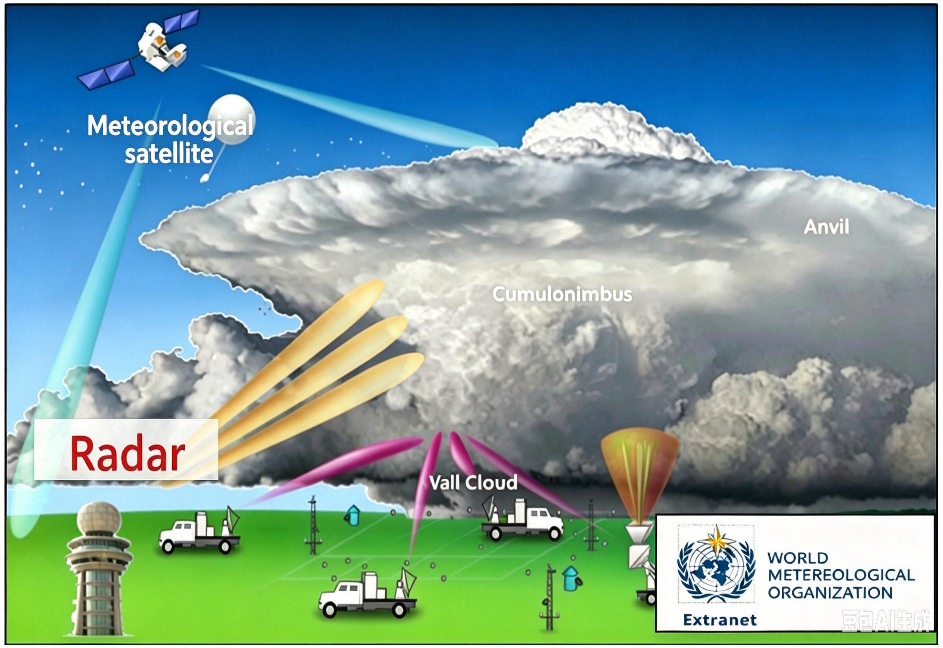
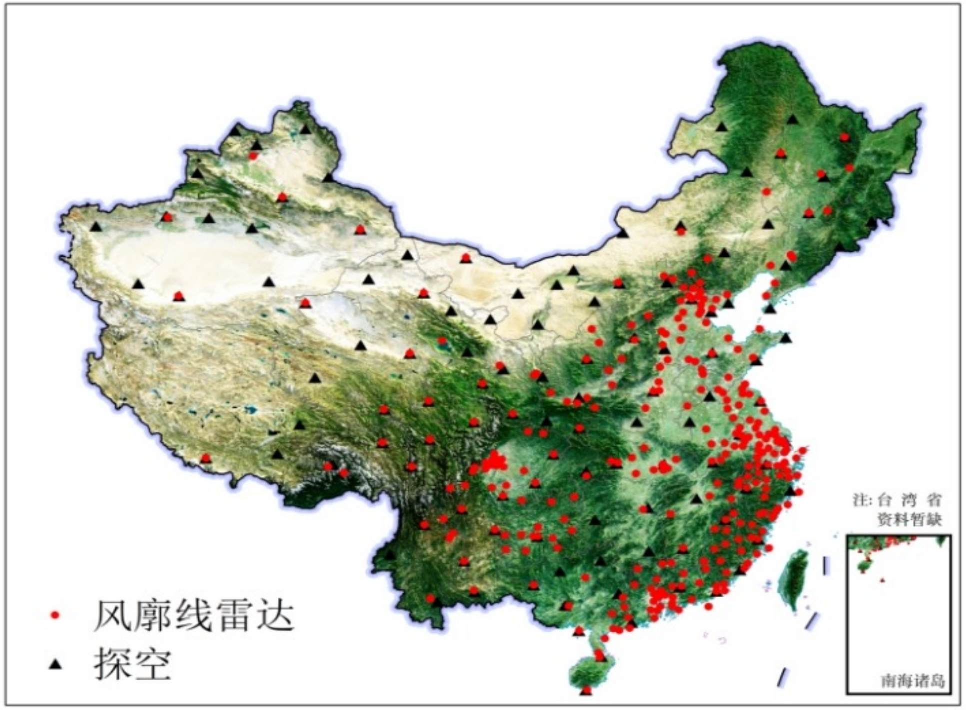
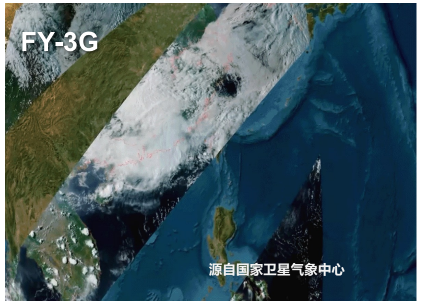


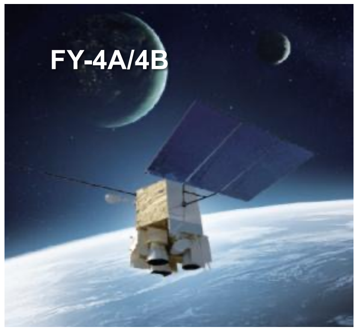
Below-cloud wind profiling measurements are desperately needed

Thunderstorm outflow gusts

- China has built the **densest** ground-based **wind profiling network** in the world
  - ✓ 400+ radar wind profilers
  - ✓ 200+ wind LiDAR
- Combined with multiple radars and satellites, it is possible to carry out **multi-scale process observation** of the extreme gust wind events.



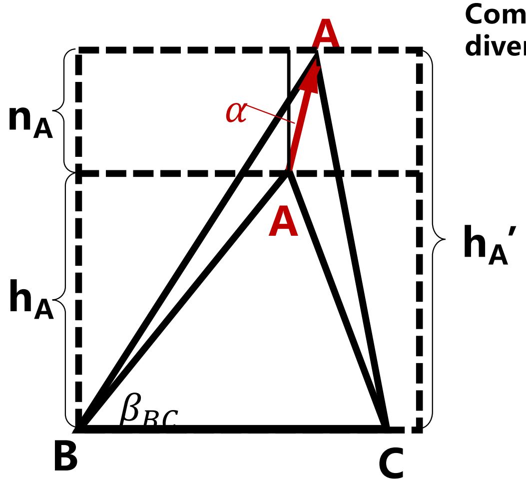




Dynamic Parameters Retrieved from the Triangular Network of RWPs

For any spherical triangle by 3 RWPs, divergence, vorticity and vertical velocity can be derived

- **The divergence flux is calculated by the area of the outflow in the triangle**



AA′ represents the wind at A
(wind speed: v, and wind direction: α)

Component of divergence at A: $$\Delta_A = \frac{A'BC - ABC}{ABC}$$

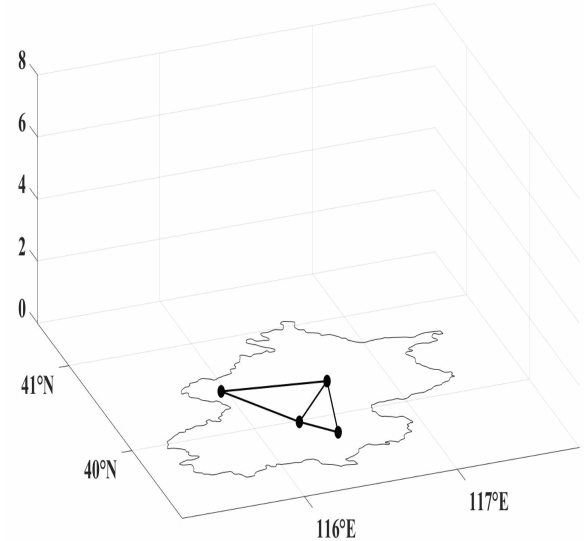
Then: $$\Delta_A = \frac{h_A' - h_A}{h_A}$$

or

$$\Delta_A = \frac{n_A}{h_A}$$

$$\boxed{\begin{aligned} \Delta_A &= \frac{v}{h_A}\sin(\beta_{BC} - \alpha) \\ \zeta_A &= -\frac{v}{h_A}\cos(\beta_{BC} - \alpha) \end{aligned}}$$

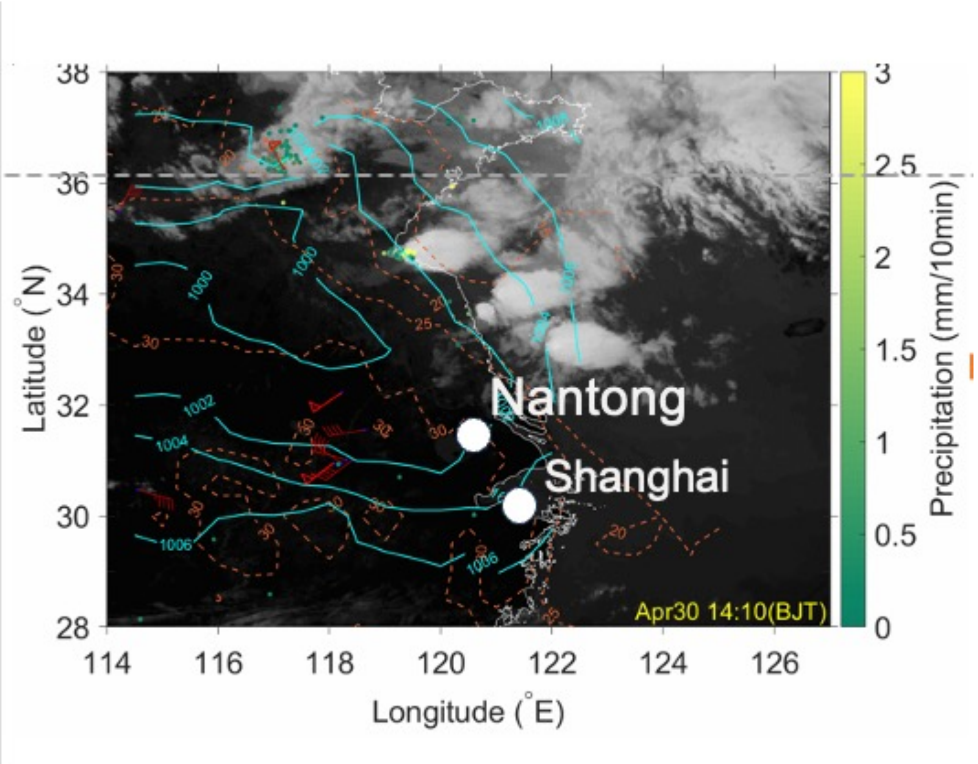
$$\boxed{\begin{aligned} \Delta &= \Delta_A + \Delta_B + \Delta_C \\ \zeta &= \zeta_A + \zeta_B + \zeta_C \end{aligned}}$$

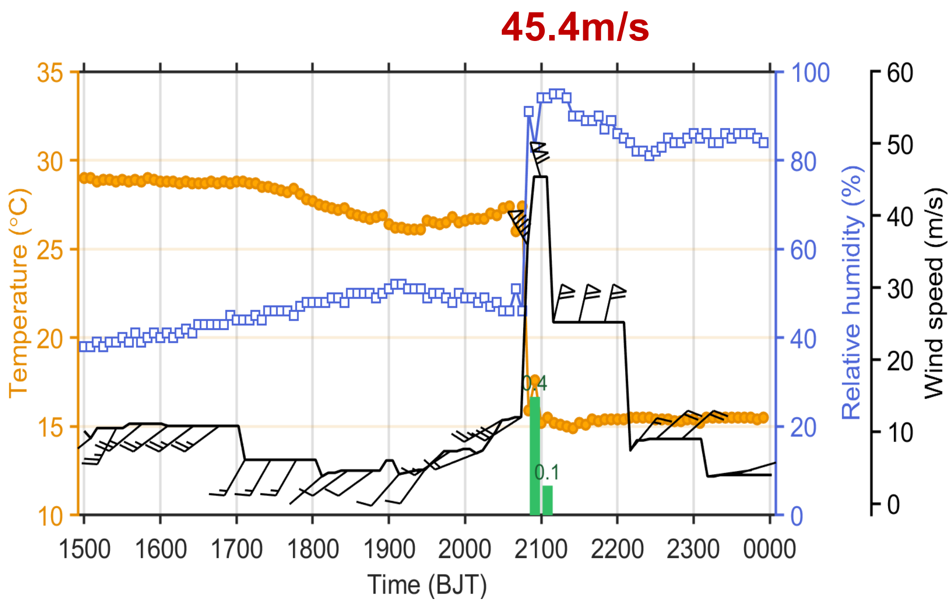


(Bellamy, 1949, BAMS; Guo et al., QJ 2023)

An extreme gust wind event in Nantong

- Wind speeds at 221 sites in this event broke the historical records of wind intensity.
- The extreme wind is associated with the downburst embedded in a mesoscale convective system (MCS), and the maximum wind reached 45.4m/s in Nantong, East China.

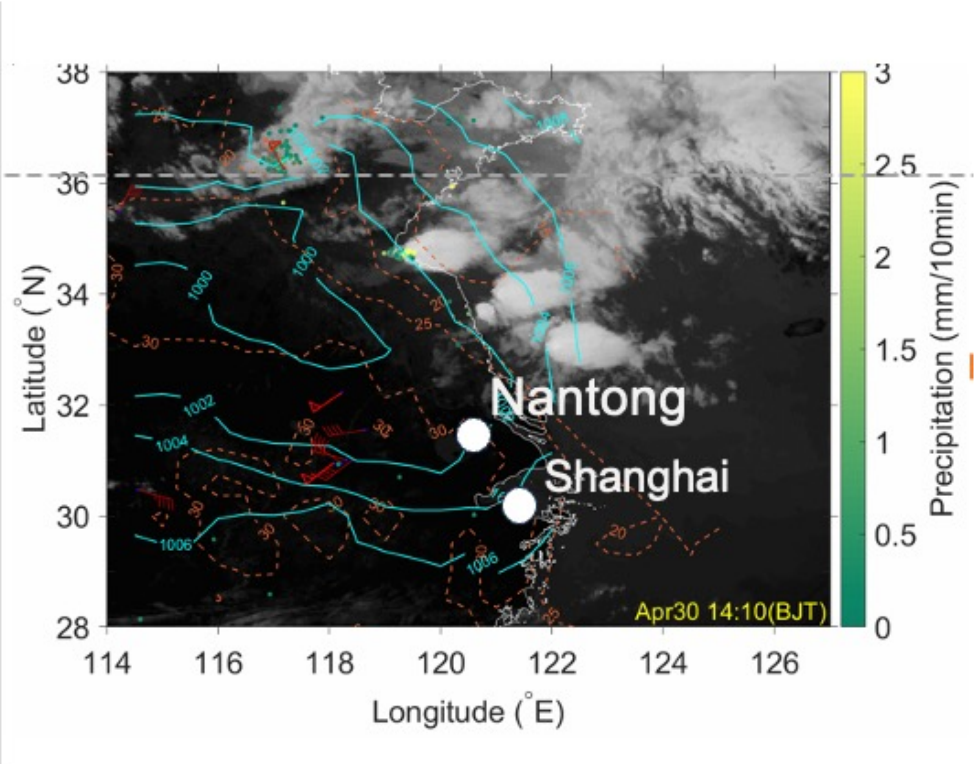


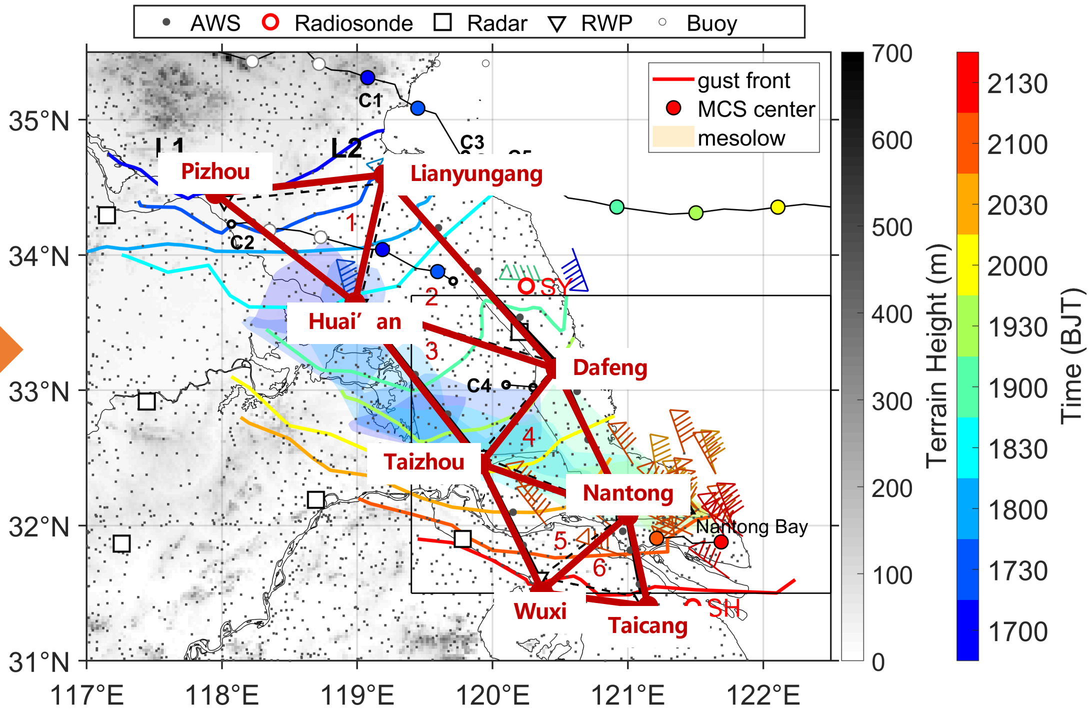


@ Nantong on Apr. 30th, 2021

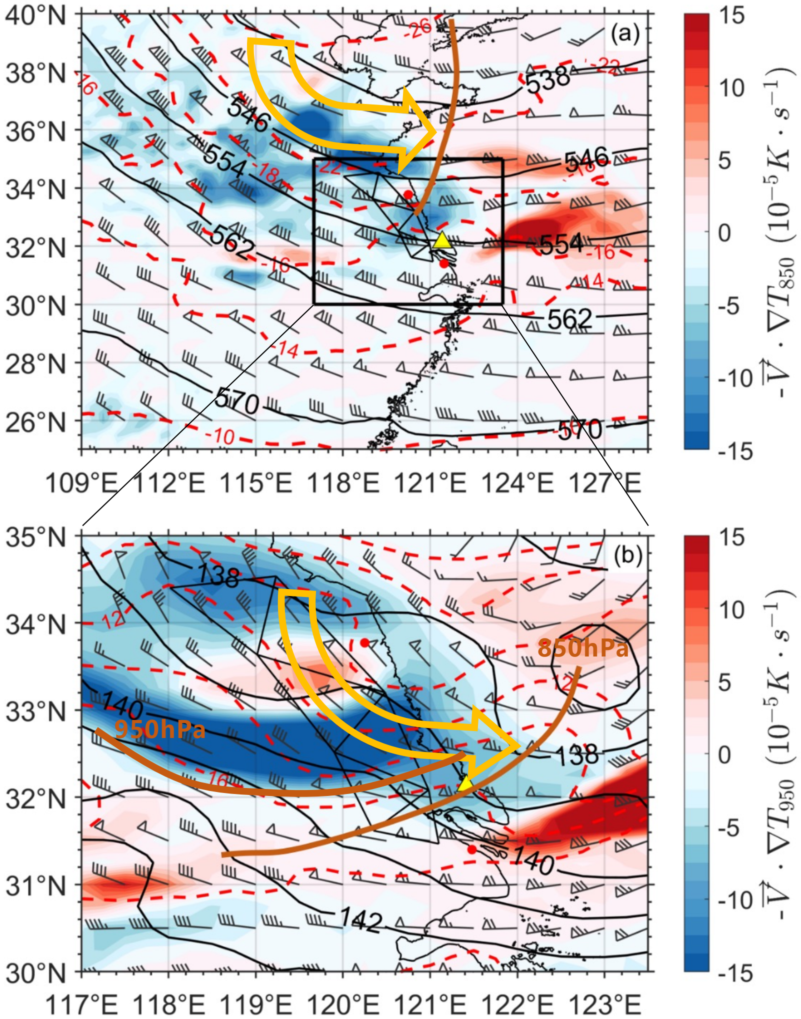
An extreme gust wind event in Nantong

- Wind speeds at **221 sites** in this event broke the historical records of wind intensity.
- The extreme wind is associated with the downburst embedded in a mesoscale convective system (MCS), and the maximum wind reached **45.4m/s** in Nantong, East China.
- Along the **propagation way of the squall-line gust front, 8 radar wind profilers (RWP)** are chosen to build a **mesonet** for the atmospheric dynamic analysis of this gust event.

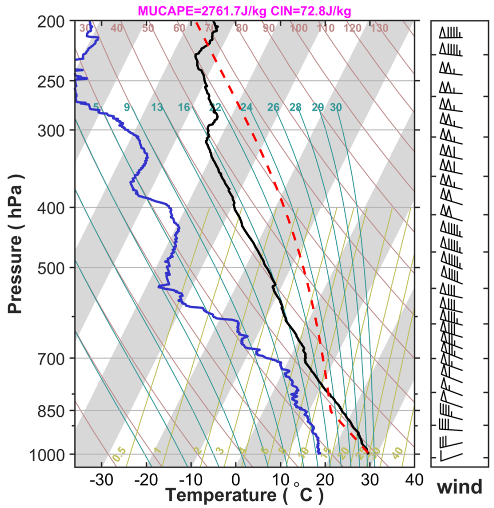


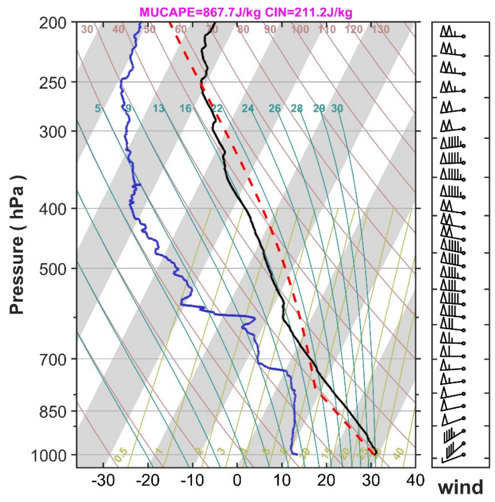


Synoptic-scale background



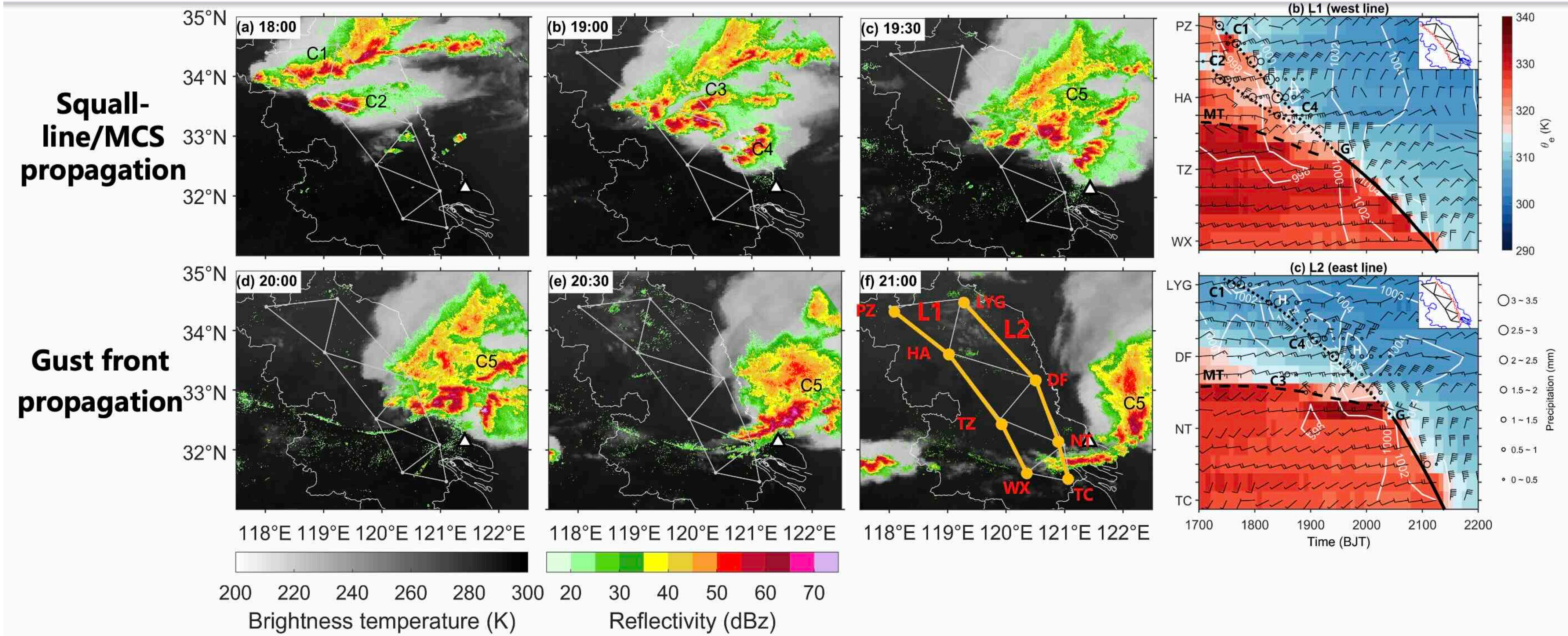
Soundings before the squall-line gust front





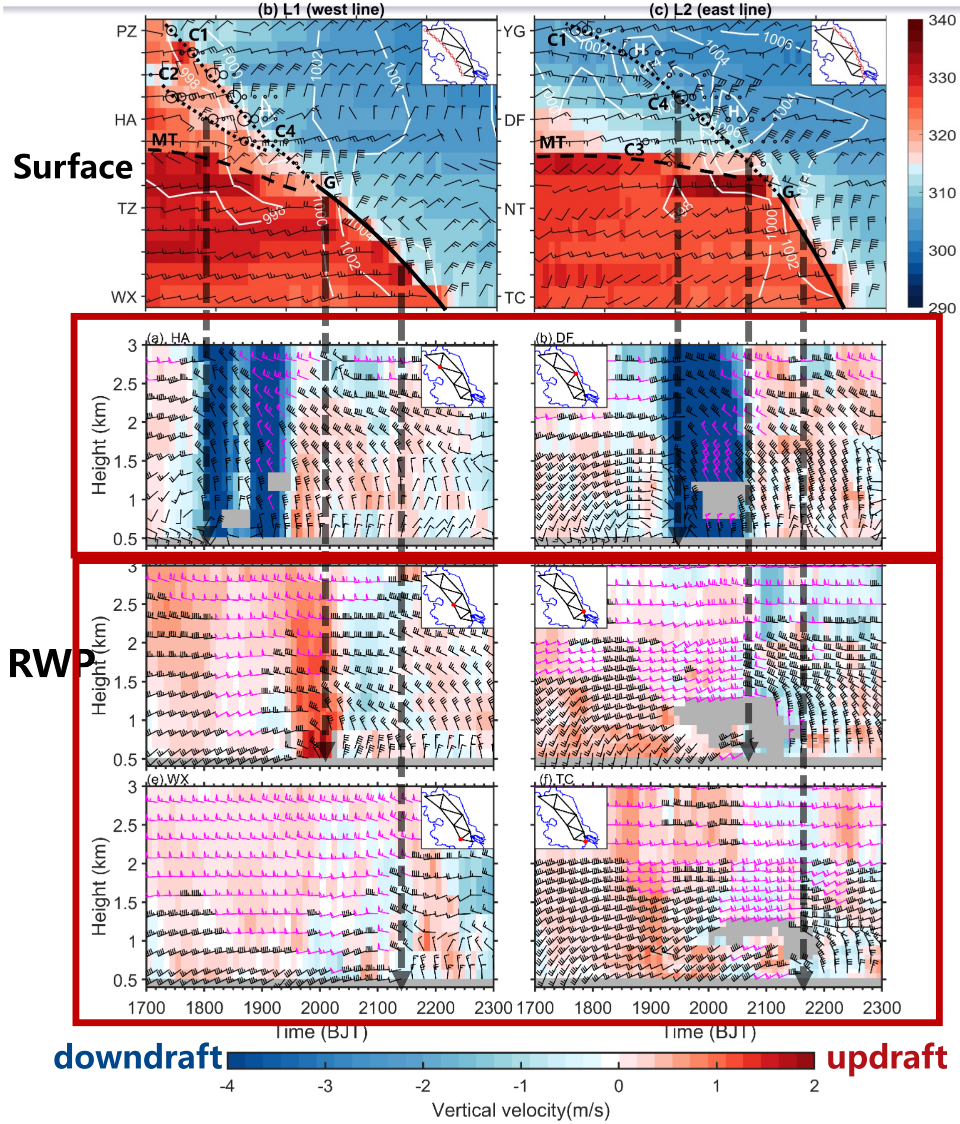
- Wind speeds reaches 40m/s and 24m/s, behind the 500hPa and 850hPa baroclinic trough.
- Strong cold advections are found after different layer troughs.
- High MUCAPE is found before the squall-line gust front, indicating unstable condition for MCS development.
- Dry lower levels are found in Shanghai, possibly enhancing evaporative cooling.

Surface, satellite and radar observations

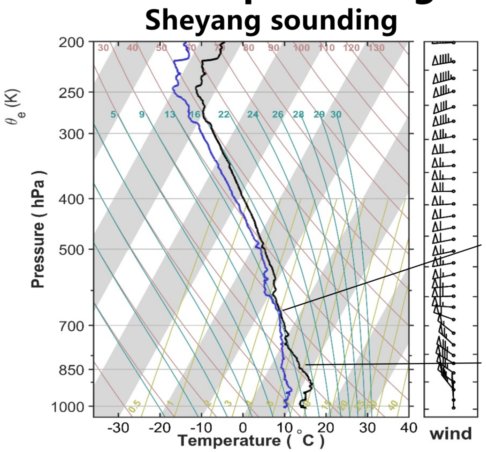


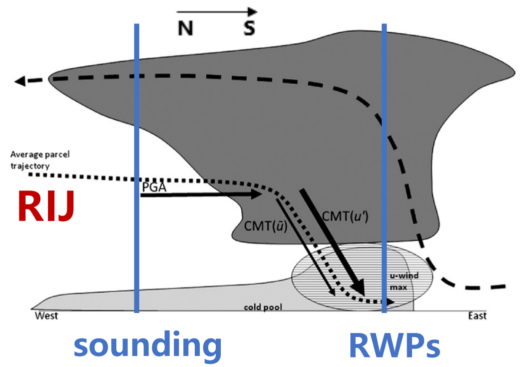
- **This entire event can roughly be divided into two stages: a squall-line/MCS propagation stage and a gust front propagation stage.**
- **MCS propagation: θ_e decreases over 15K, local mesohighs (H) forms along the front.**
- **Gust front propagation: little precipitation, large wind and θ_e shears are found.**

Vertical dynamic structures: RWP mesonet analysis



After the squall-line gust front





(Mehoney and Lackmann. 2009, 2011)

MCS propagation stage:

- Obvious wind shear below 3km， wind directions turned northerly.
- Strong downdrafts are found behind the squall-line.

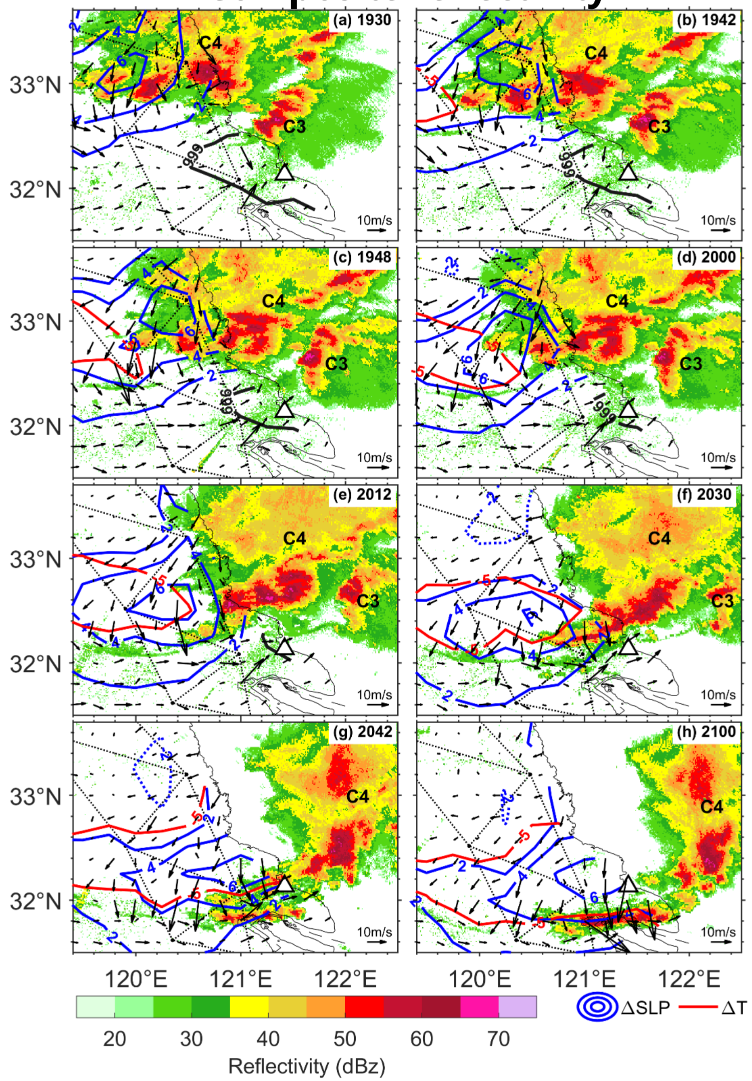
Gust front propagation stage:

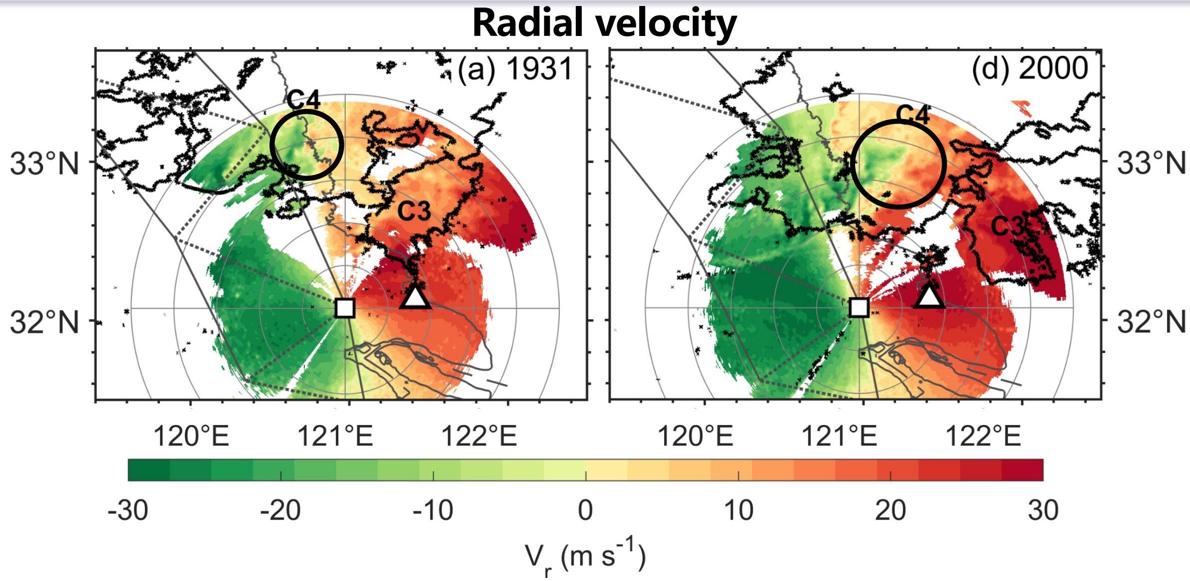
- Updrafts ahead, weak downdrafts behind the gust front
- Area with >20m/s show downward propagation before the gust front, indicating the coupling of upper layer flows with the PBL flows.

Rear-inflow jet (RIJ):

- Both MCS and gust front propagations show northerly wind accompanied with downdrafts.
- In the wake low, dry adiabatic lapse rate indicates dry air descending.

Mesoscale vortex: S-band Doppler radar analysis





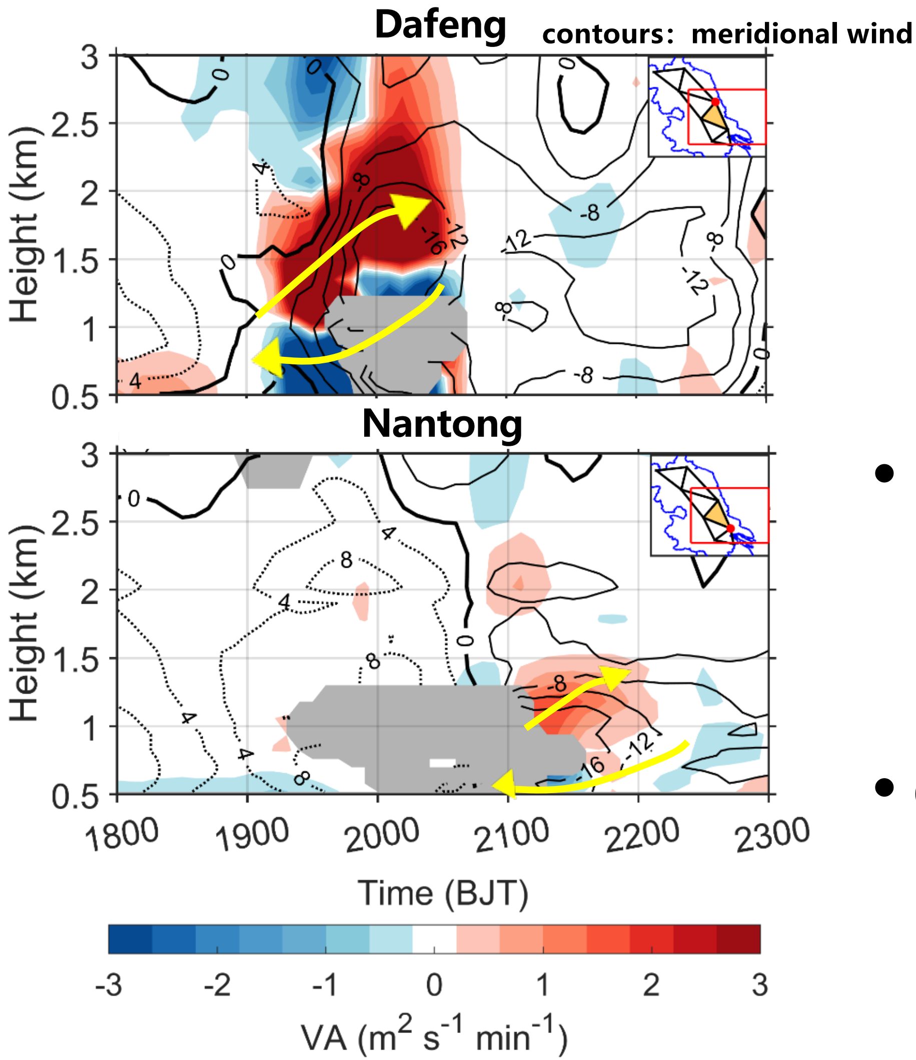
- The downdraft generates a **positive barotropic zone**, and spreads to form a **cold pool**, the front edge forms **a linear echo (gust front).**
- Radar reflectivity gradually develops into a comma-shape, showing a certain **convergence feature**, and the radial velocity indicates the existence of **a mesoscale vortex**.

Wet downdraft and the northwest flow behind the mesoscale vortex may strengthen the RIJ
Leads to intensification of surface wind speed

Downward momentum transport from RWP mesonet

MCS propagation

Gust front propagation



Meridional vertical momentum transport

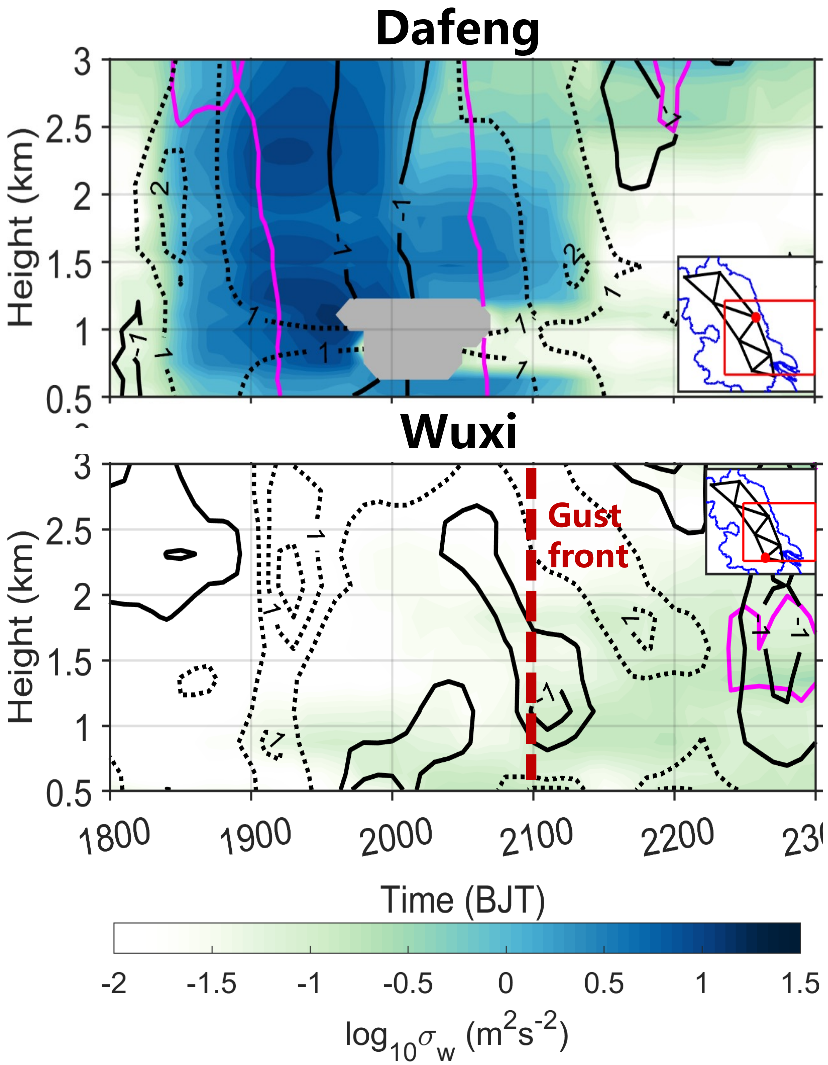
$$\frac{\partial v}{\partial t} = -U \cdot \nabla v \underbrace{- w\frac{\partial v}{\partial z}}_{VA} - \frac{1}{\rho}\frac{\partial p}{\partial y} - fu$$

- **MCS propagation:**
  - **Strong downward momentum transport shows in RIJ.**
  - **Upward momentum transport is found along the front.**
- **Gust front propagation:**
  - **Convection inhibited by the upper downdraft leads to low development of momentum transport.**

Turbulence transport from RWP mesonet

MCS propagation

Gust front propagation



Vertical turbulence kinetic energy

$$\sigma_w = \overline{w'^2}$$

Turbulence intensity

Skewness

$$S_w = \frac{\overline{w'^3}}{(\sigma_w)^{3/2}}$$

Turbulence transport direction

MCS propagation:

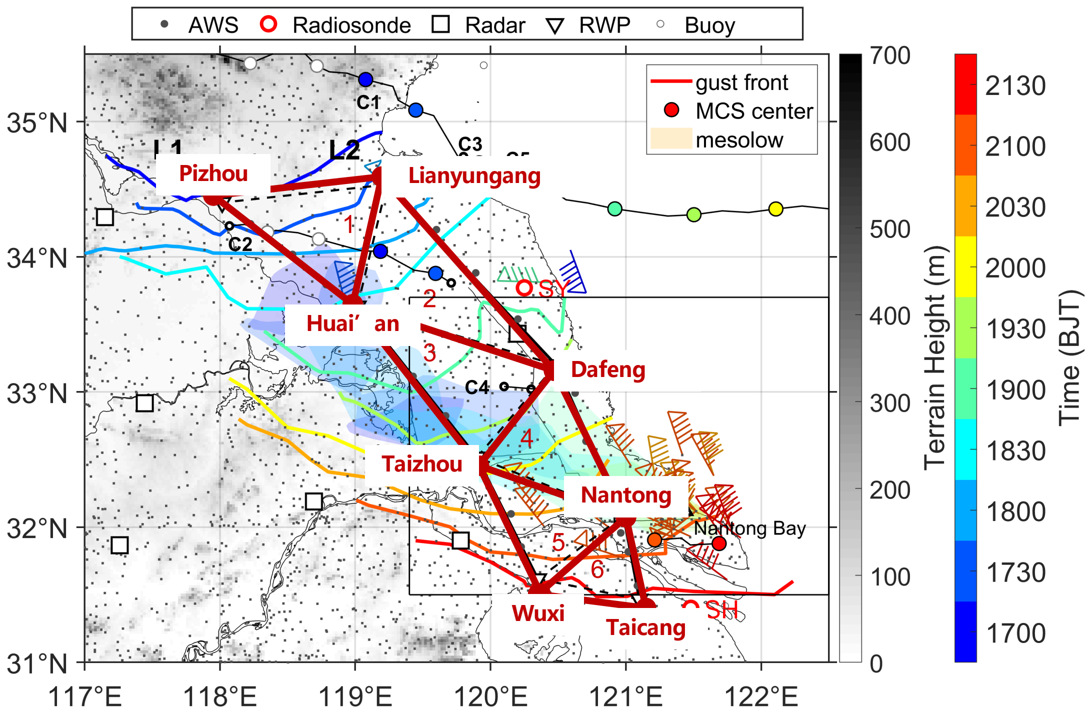
- Strong convective cloud with strong turbulence.
- Turbulence intensity weakens in RIJ, accompanied by downward transportation.

Gust front propagation:

- Turbulence is much weaker, but intensifies after the gust front.
- Downdraft above the cold pool relates to the strong downward transport of turbulence.

Variation of divergence and vorticity during the extreme gust event

- From the RWP mesonet we have built, 6 dynamical triangles are created
- Vorticity and divergence profiles are calculated based on the triangular algorithm



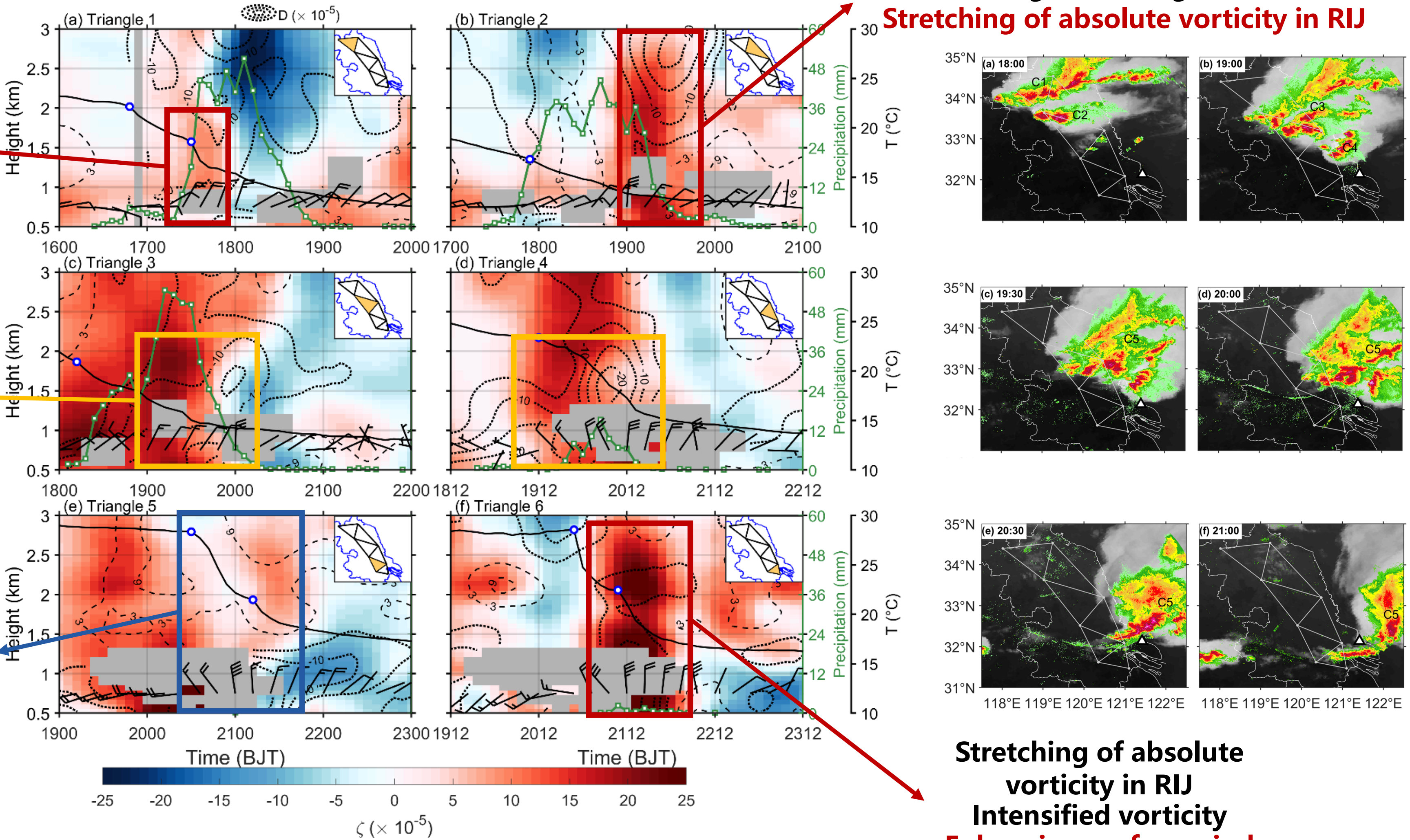
Variation of divergence and vorticity during the extreme gust event

MCS propagation
Positive vorticity

MCS development
Strong convergence +deep positive vorticity

No obvious evaporative cooling
Convergence above cold pool
Divergence at higher levels

Convergence at higher levels
Stretching of absolute vorticity in RIJ



Stretching of absolute vorticity in RIJ
Intensified vorticity
Enhancing surface wind

Take-home messages

- **RWP mesonet obs. capture multi-scale dynamical processes of wind gusts**
  - **Large-scale:** Pronounced baroclinicity with large-scale troughs in a high wind speed background.
  - **Meso-vortex:** Radar radial velocity shows mesovortex development that amplifies gust-front rear flow.
  - **Downward momentum transport:** Meridional horizontal momentum downdraft accelerates low-level flow, with prominent turbulent transport.
  - **Gust front:** Vortex stretching, RIJ and wet downdraft promote gust-front formation and intensification.

- **Limitations of RWP mesonet**
  - The fixed triangular configuration fails to resolve smaller-scale atmospheric flow features.
  - Signals are readily attenuated by hydrometeors, resulting in blind zones within precipitating clouds.
- **Integration of weather Doppler radar and RWP mesonet enables the reconstruction of seamless 3D wind fields.**

Thanks

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ResearchGate: https://www.researchgate.net/profile/Jianping-Guo-3

References:

- Guo, X., ***Guo, J.,*** Li, N., et al. 2026. Observed multiscale dynamical processes responsible for an extreme gust event in Beijing, ***Atmospheric Chemistry and Physics***, 26, 2391–2409, https://doi.org/10.5194/acp-26-2391-2026.
- Chen, T., ***Guo, J.*,*** Guo, X. et al. (2024). On the multiscale processes leading to an extreme gust wind event in East China: Insights from radar wind profiler mesonet observations. ***J. Geophys. Res. Atmos.***, 129, e2024JD041484. https://doi.org/10.1029/2024JD041484
- Guo, X., Guo, J., et al. (2023). Vertical divergence profiles as detected by two wind profiler mesonets over East China: implications for nowcasting convective storms, Quarterly Journal of the Royal Meteorological Society, 149(754), 1629-1649, https://doi.org/10.1002/qj.4474