Characterizing Lightning's Response to the Spatial Distribution of Updraft Characteristics

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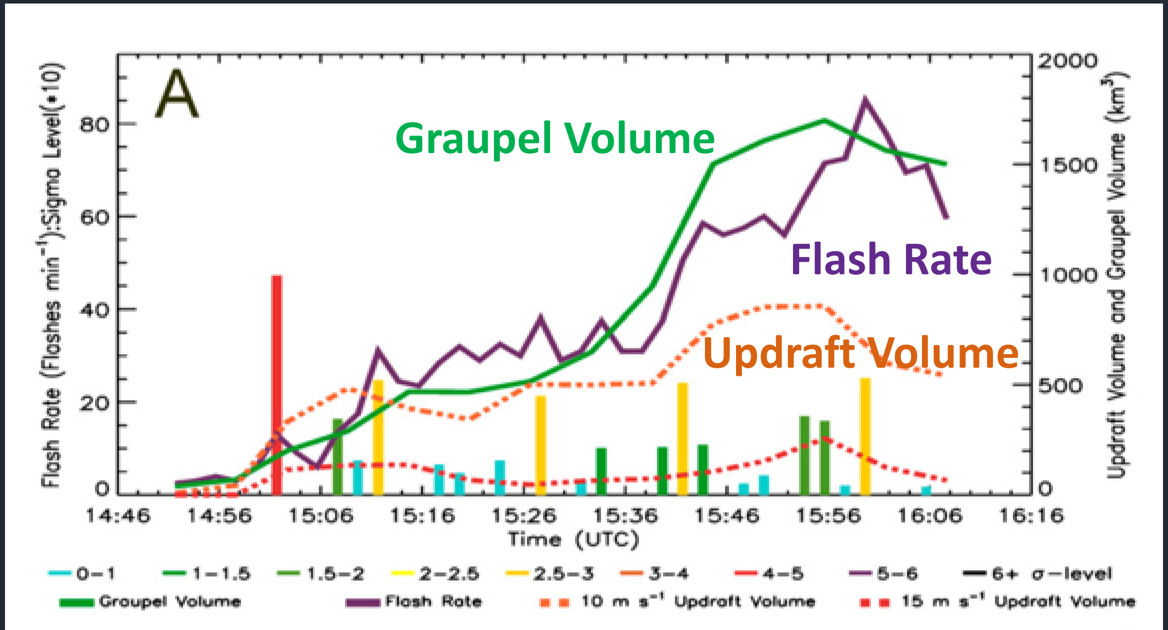
Lightning's Connection with Convective Intensity

- Research has shown the physical basis of lightning's relationship with the thunderstorm updraft (e.g., lightning jump) (Schultz et al. 2009, 2015, 2017; Darden et al. 2010; Gatlin and Goodman 2010)

- Lightning production connected with microphysics, microphysical properties of convection influenced by kinematics

- ***Better interpret lightning in the context of convective intensity*** by refining the understanding of connections between lightning and the mixed-phase updraft



Schultz et al. 2015, Fig. 15a

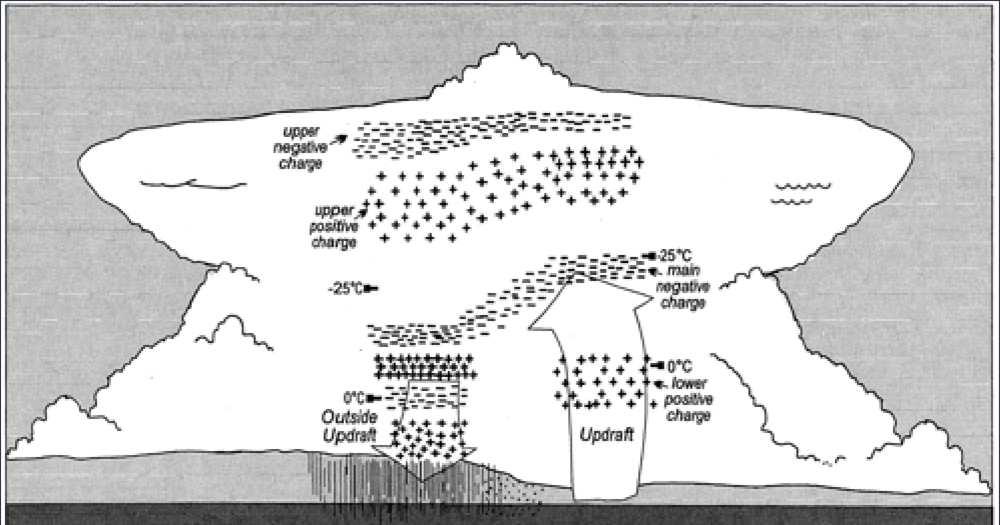
1. What are the details of lightning's response to kinematics of the mixed-phase updraft?

2. Are there meaningful spatial relationships?

Roles of Mixed-Phase Updraft

- Non-inductive charging: primary mechanism thought to result in electrification, lightning (Takahashi 1978)
  1. Particle-scale charge transfer via rebounding collisions between large, small ice in presence of supercooled water
  2. Cloud-scale charge buildup via differential sedimentation of charged particles

- Generally, convective updraft thought to
  1. Supply necessary mixed-phase microphysics
  2. Promote continued rebounding collisions
  3. Affect cloud-scale charge separation



Stolzenburg et al. 1998, Fig. 3

- Deep convection presents complex landscape of microphysical properties, distributions that affect charge structure (Stolzenburg et al. 1998)
  - Complexity attributed in part to gradients in vertical velocity, differential sedimentation, and horizontal flows (e.g., Bruning et al. 2010)

Roles of Mixed-Phase Updraft

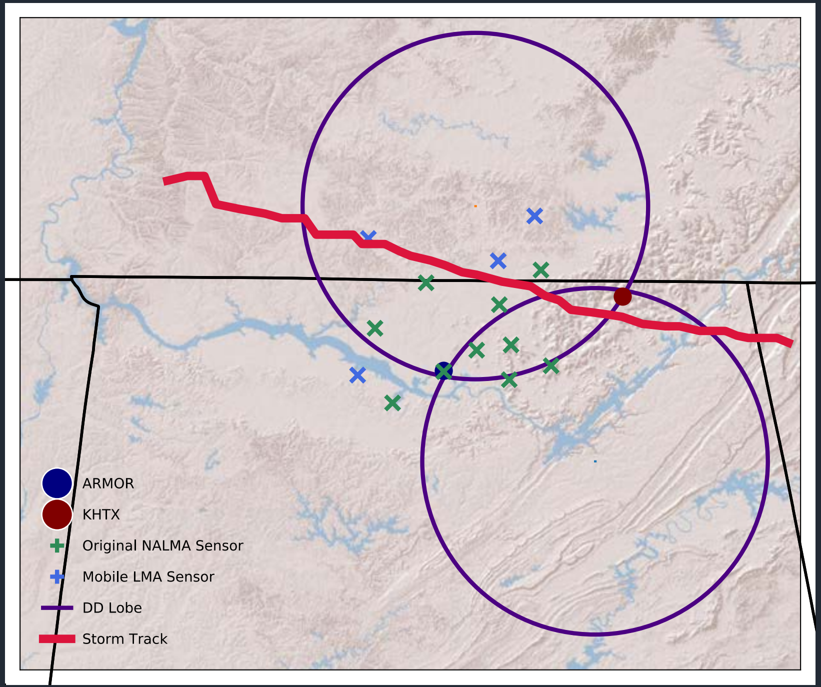
Refine context of lightning in convective intensity by addressing spatial complexities of mixed-phase updraft that affect lightning properties by influencing microphysics distributions and charging

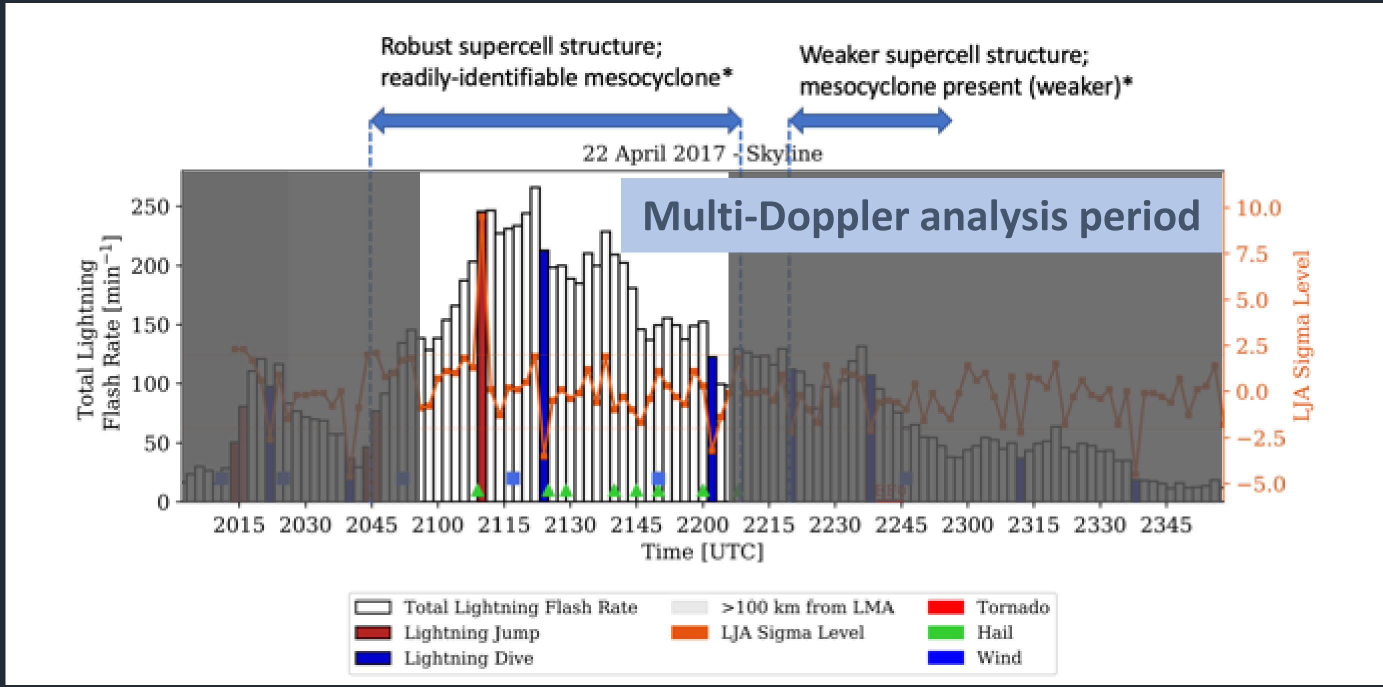
- **In-depth case study analysis** -> statistics from multiple storms

- Characterize distributions of vertical motion in three-dimensional space
- Consider flash properties, including size, initiation and propagation location, and inferred polarity

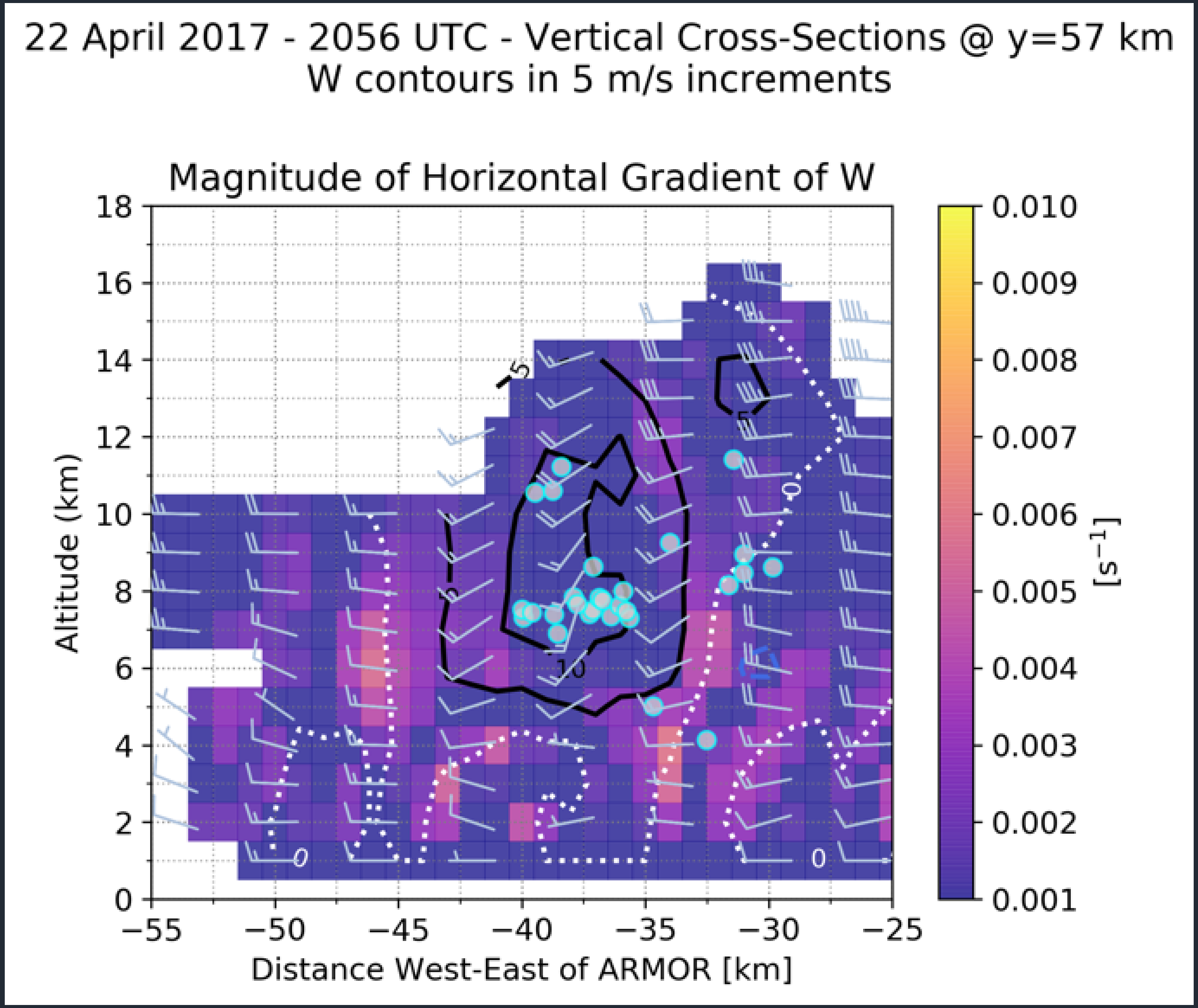
Case Study – 22 April 2017

- Supercell thunderstorm sampled during VORTEX-SE intensive operations period
  - Produced large hail (1.00” – 1.75”), damaging wind reported
  - Instrumentation:
    - Radar: C-band Advanced Radar for Meteorological Operations and Research (ARMOR), S-band WSR-88D (KHTX); hydrometeor identification (Dolan et al. 2009, 2013) and 3DVAR dual-Doppler analysis (Shapiro et al. 2009, Potvin et al. 2012)
    - Lightning: North Alabama Lightning Mapping Array (NALMA); LMATools flash clustering (Bruning 2013), 2-sigma lightning jump algorithm (Schultz et al. 2009, 2017)



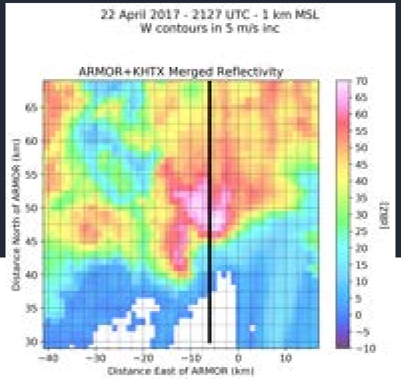


Case Study – 22 April 2017

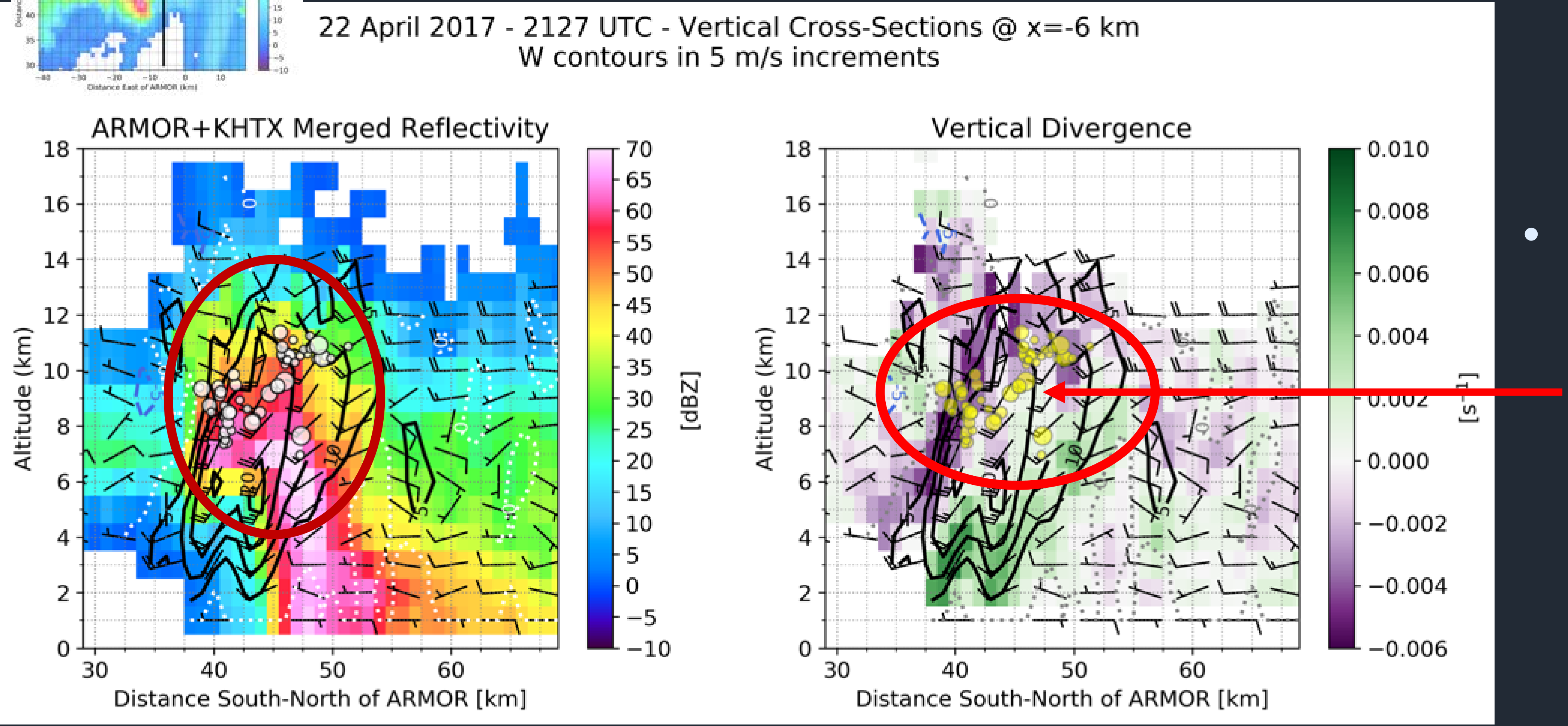


- Vertical velocity contours
  - Solid black: 5 m s^{-1} min., +5 m s^{-1} increments
  - White or gray dotted: 0 m s^{-1}
  - Blue dashed: -5 m s^{-1} max., -5 m s^{-1} increments
- Wind barbs: along-plane flow
- Plotted points: VHF lightning flash initiation locations
- Radar reflectivity: merged ARMOR and KHTX
- Vertical divergence, dw/dz
- Magnitude of horizontal gradient of vertical velocity, $|\nabla_H w|$

Lightning Distribution within Vertical Updraft Structure

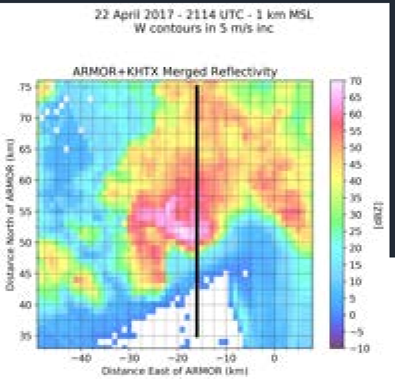


- Lightning flash initiation points located in vertical motion > 10 m s^{-1}

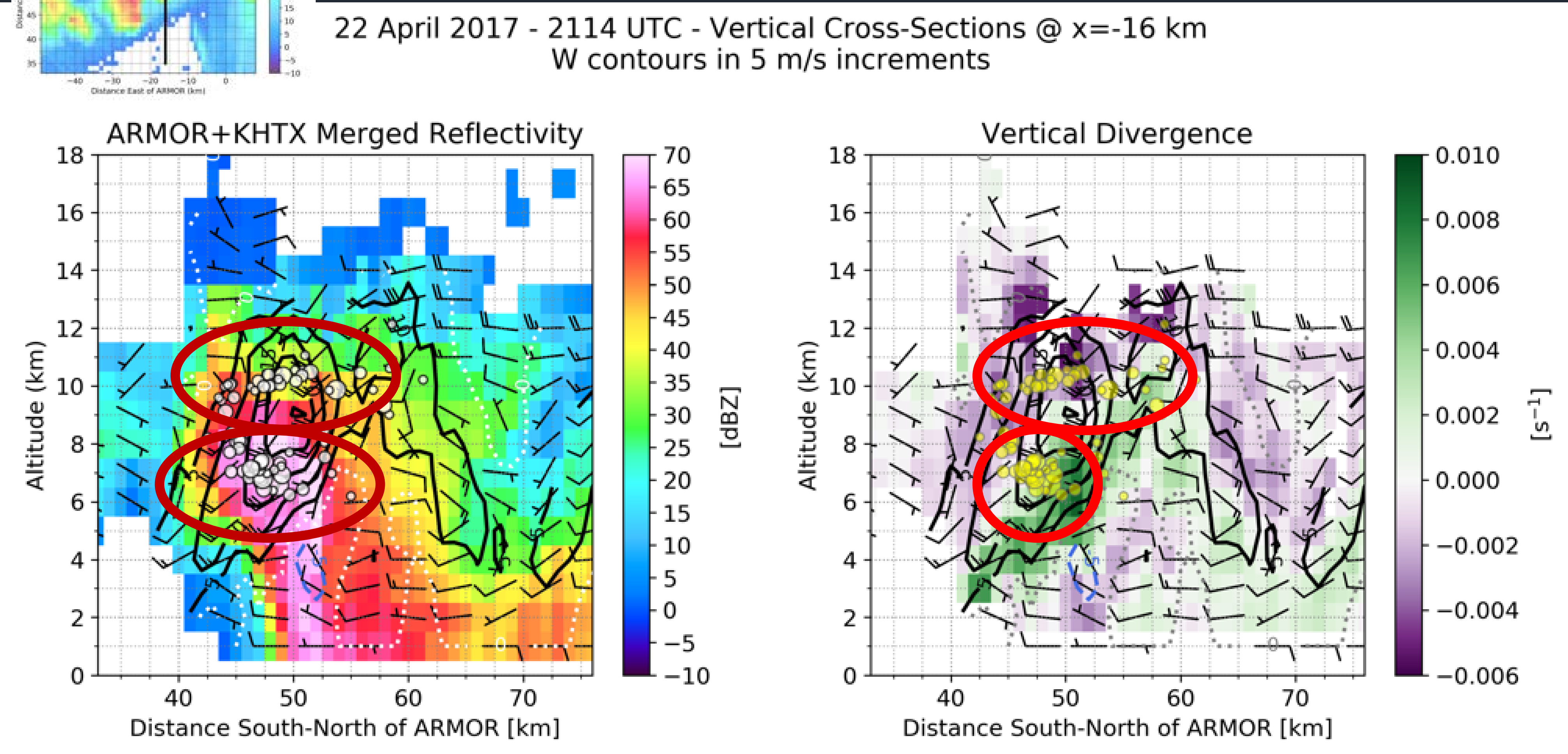


- Flashes primarily initiate in regions of weak vertical divergence, convergence

Lightning Distribution within Vertical Updraft Structure



- Lightning jump period - flash initiations maximized at updraft base, peak
- Flash initiations occur outside of core of maximum vertical velocity (25 m s^{-1}), no other strong patterns with respect to W values



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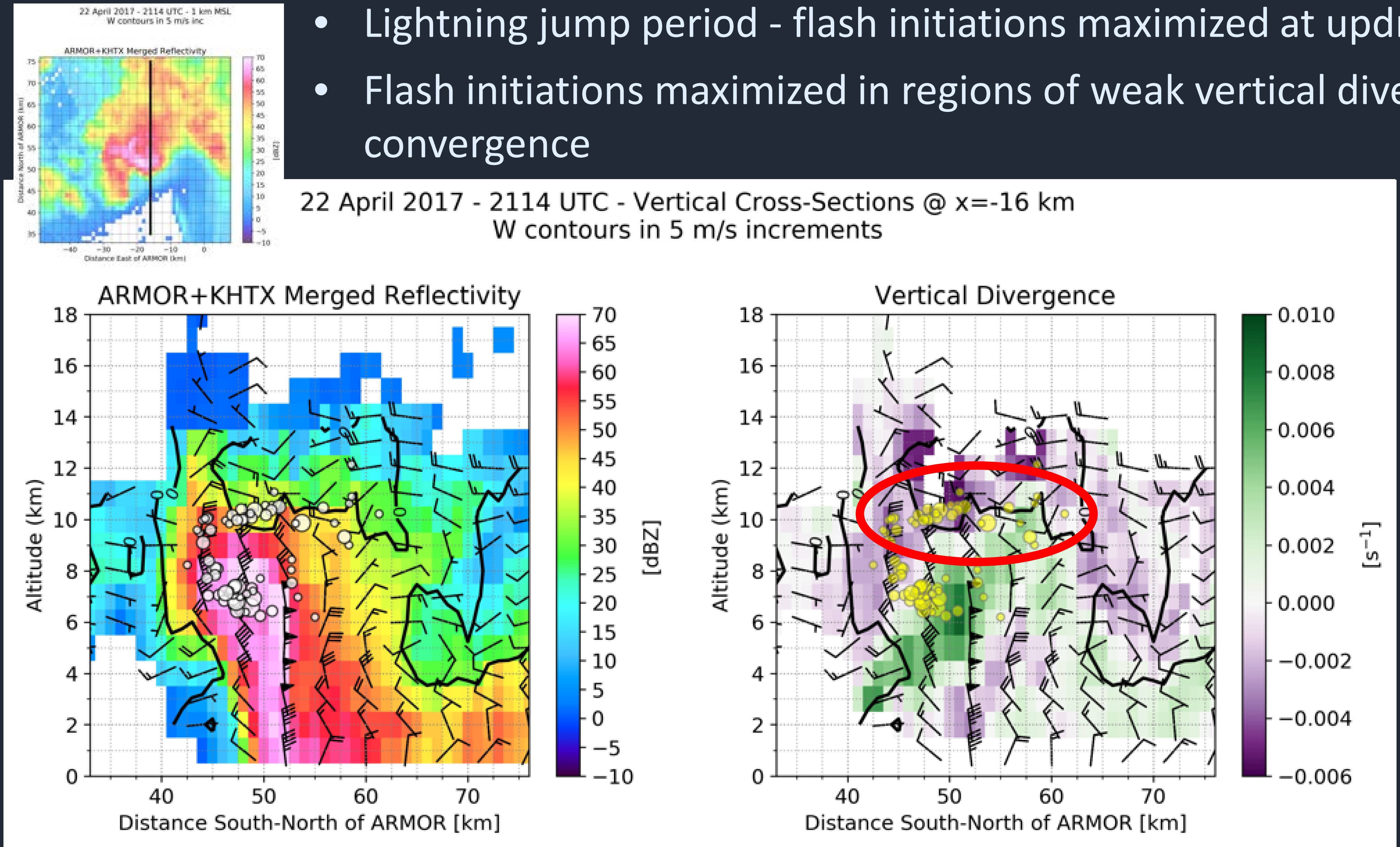
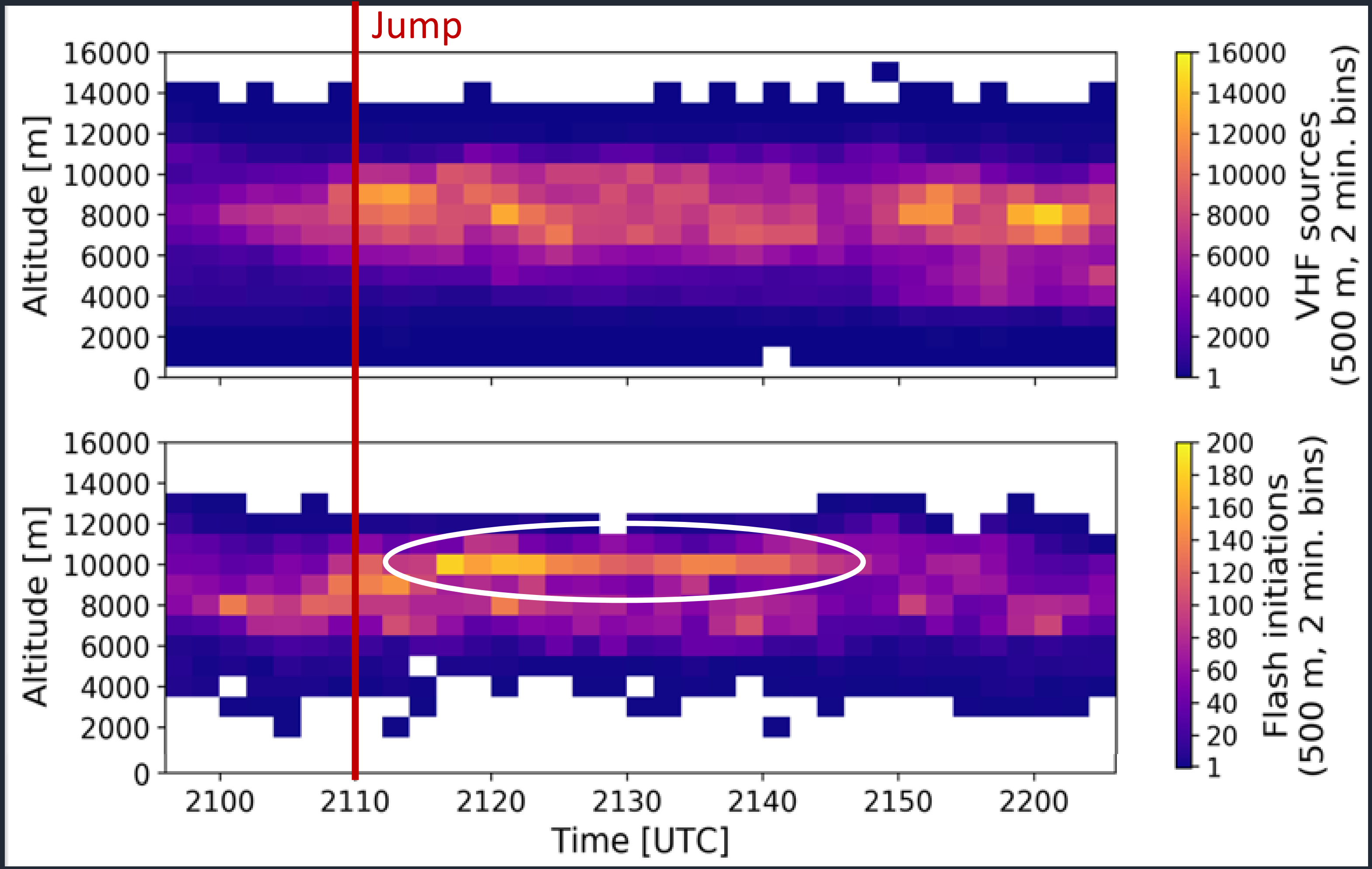


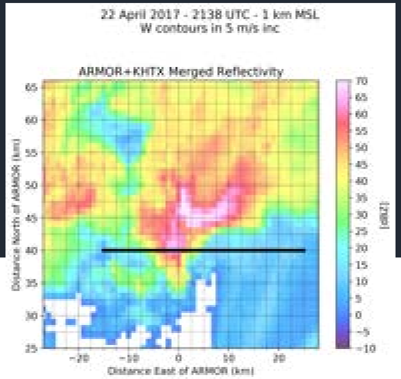
- Upper-level initiations align with $W_{particle}$ =0 m s^{-1}, (Lhermitte and Williams 1985, particle balance level)

Vertical Distribution of Lightning

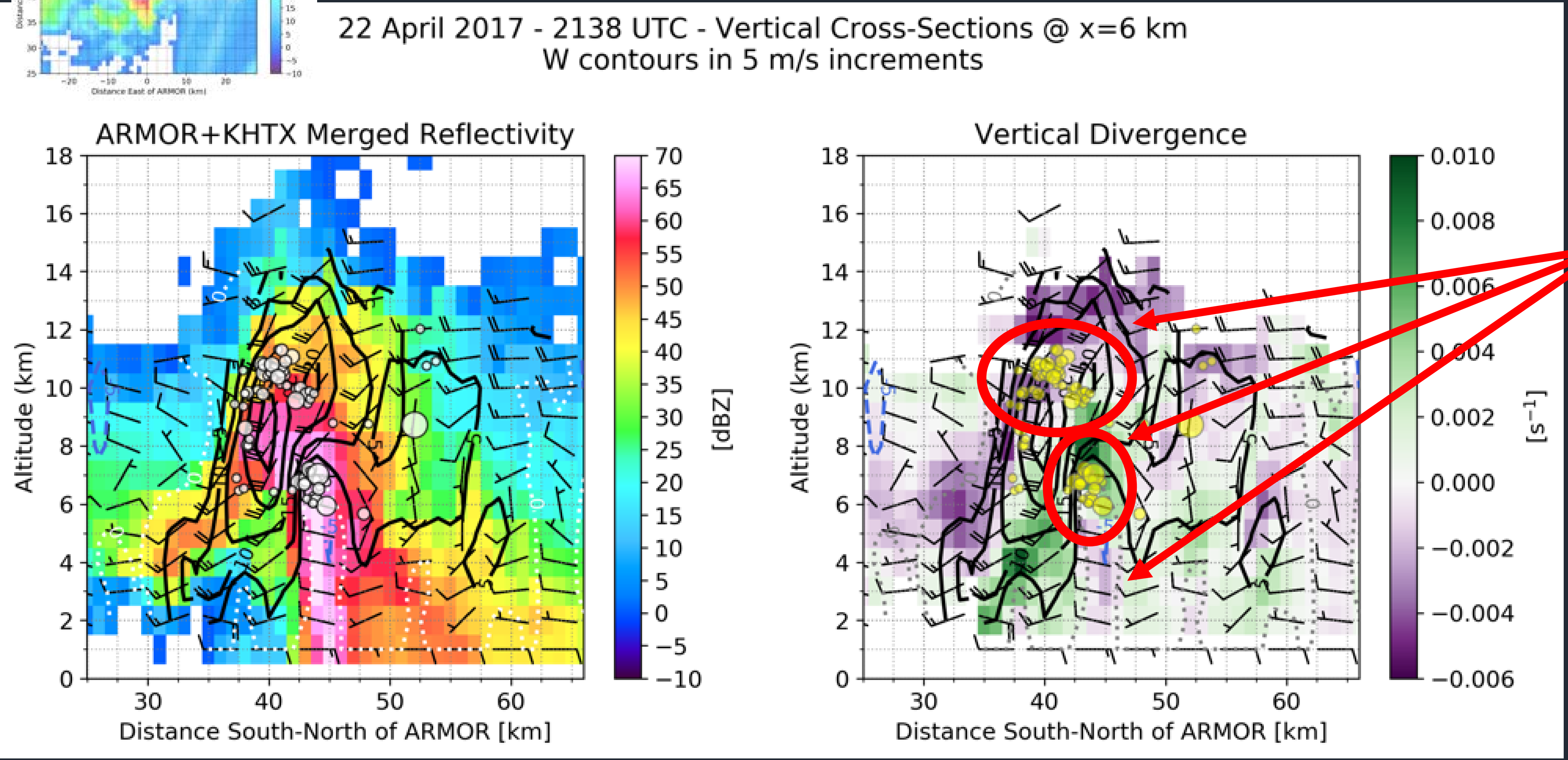


- Time-height cross-section of NALMA VHF sources and flash initiation locations
- Evidence of persistent signature associated with PBL in upper levels

Lightning Distribution within Vertical Updraft Structure



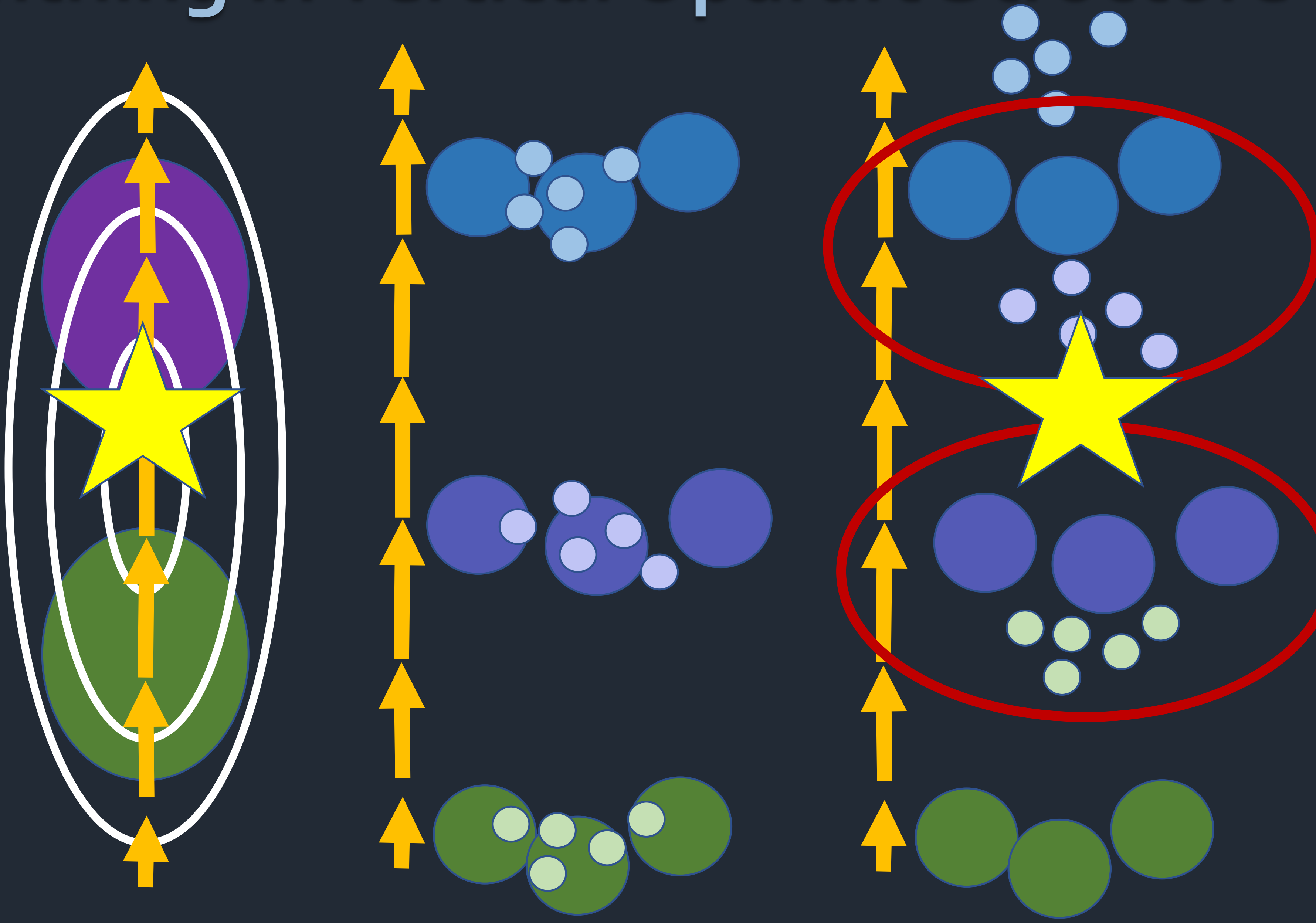
- Observe similar spatial patterns in more complex vertical velocity structure



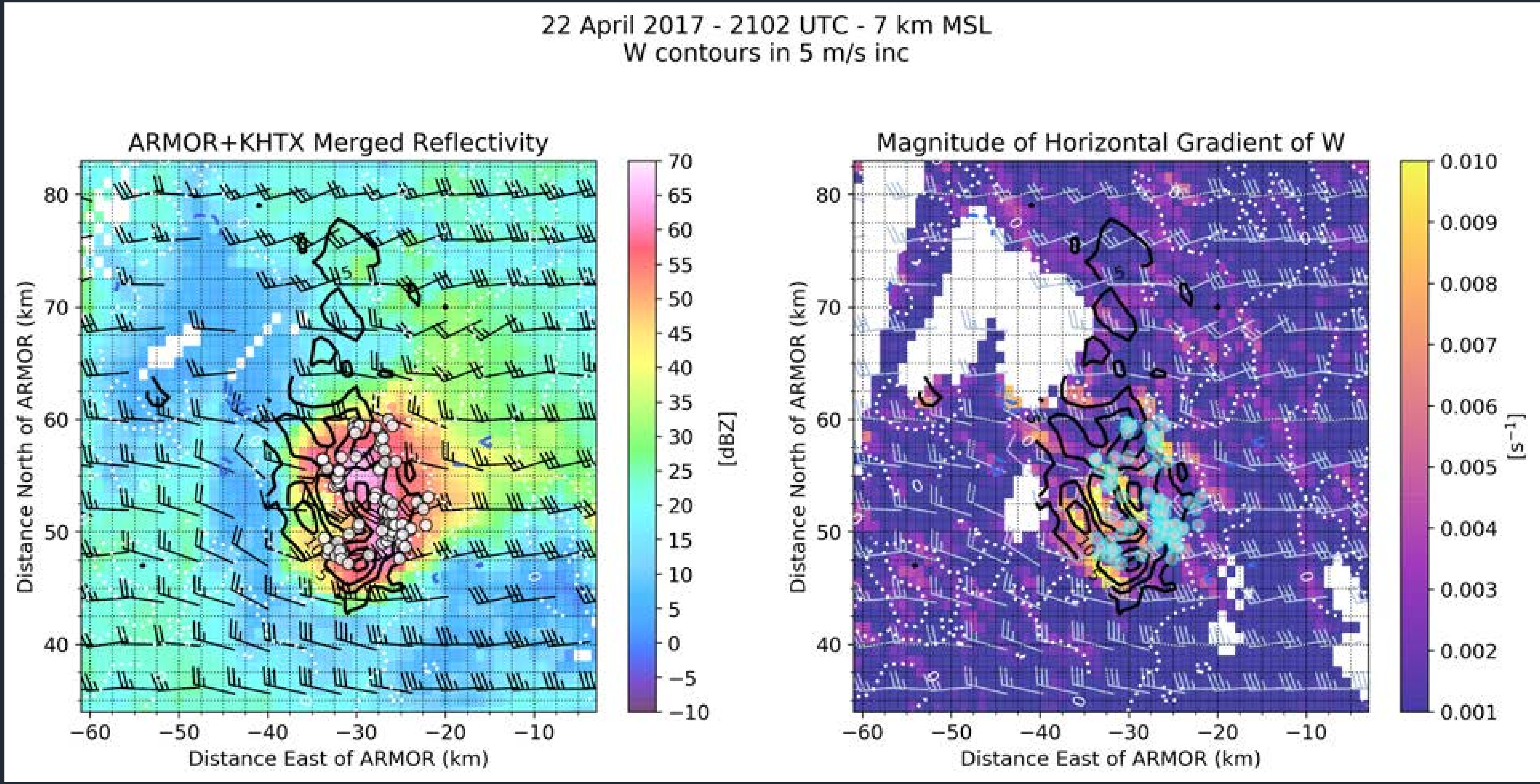
- Flash initiations occur between series of convergent, divergent, convergent regions
- Possibly indicative of multiple PBLs of different hydrometeor distributions

Summary: Lightning in Vertical Updraft Structure

- Vertical divergence presents variation in vertical motion, varying impacts on differing charged hydrometeor distributions
- Differential fall speed under influence of varying vertical motion redistributes charged particles into charge regions
- Lightning initiations favor non-divergence

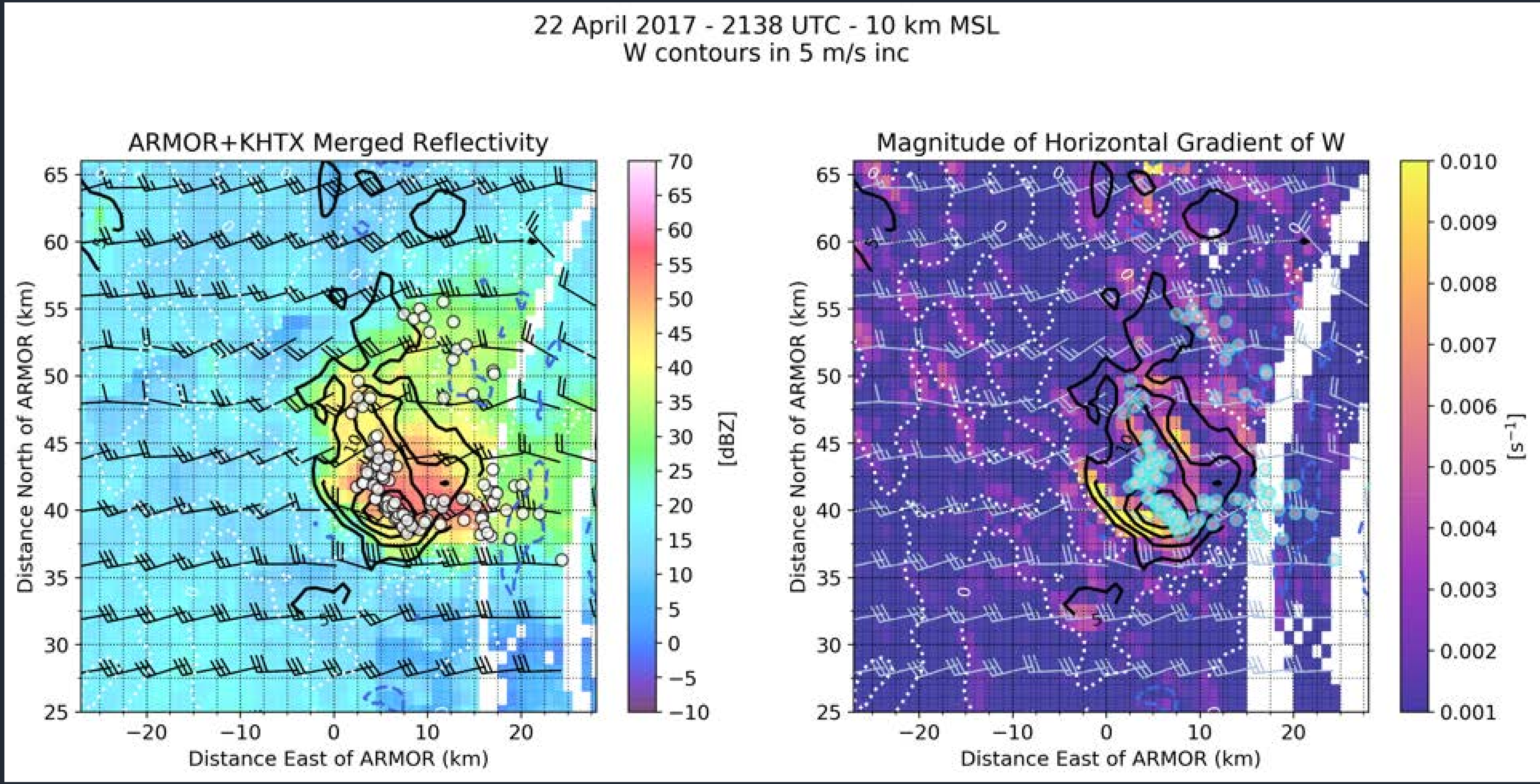


Lightning Distribution in Horizontal Updraft Structure



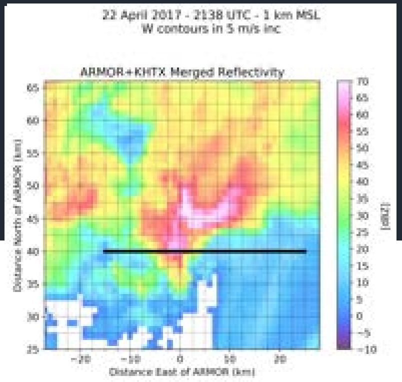
Lightning initiations occur in regions of weak horizontal gradients of vertical motion

Lightning Distribution in Horizontal Updraft Structure

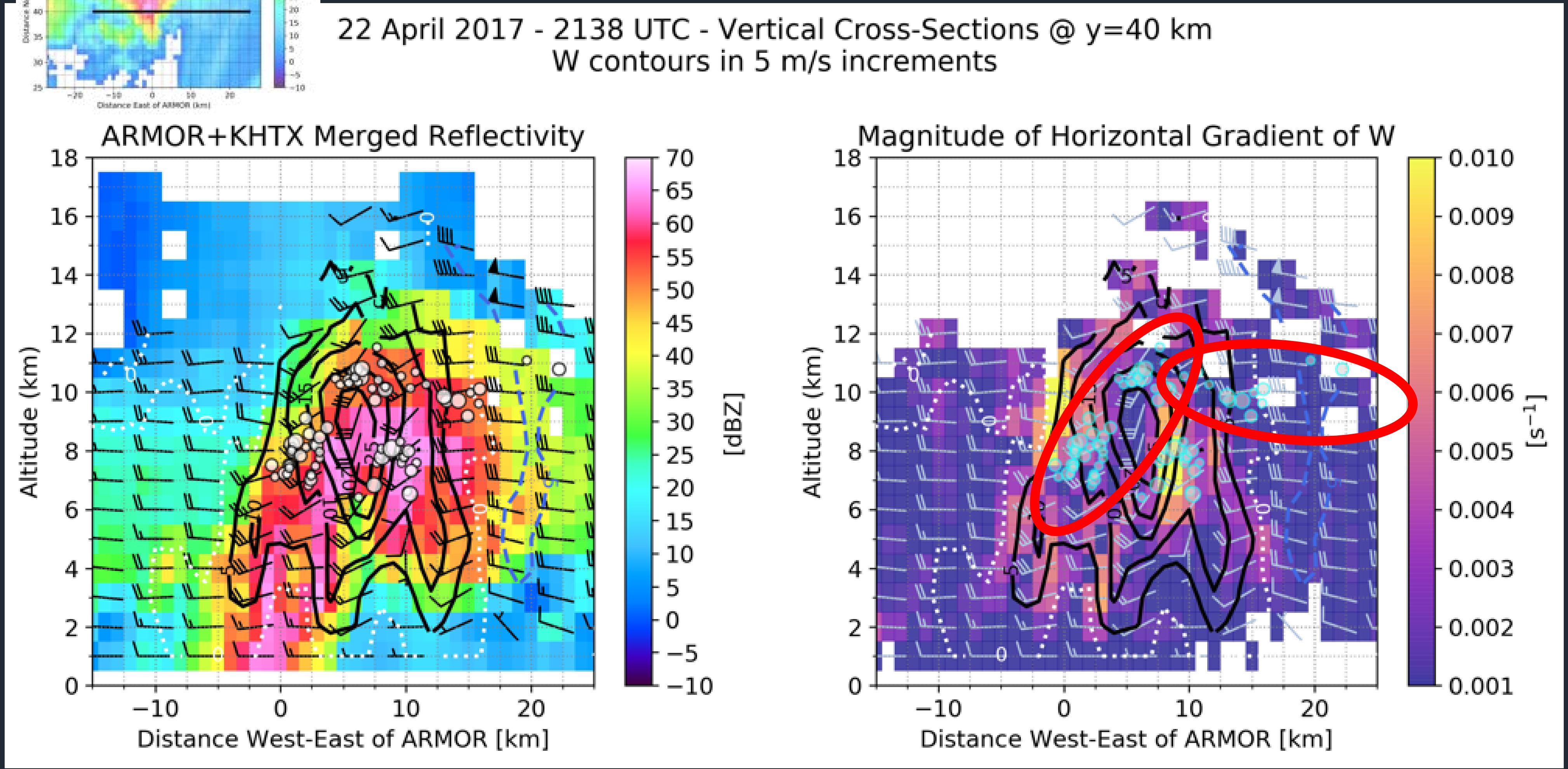


- Lightning initiations occur in regions of weak horizontal gradients of vertical motion
- Initiations also occur within regions of maximum vertical motion (near peak of updraft)

Lightning Distribution within Vertical Updraft Structure



- Flash initiations typically located in regions with a weak horizontal gradients in vertical motion



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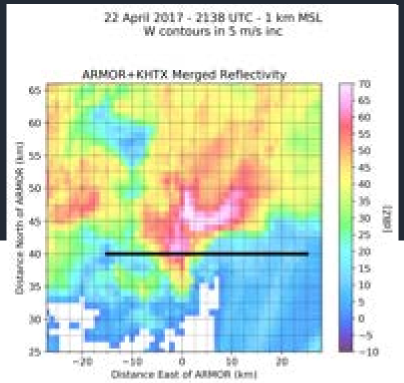

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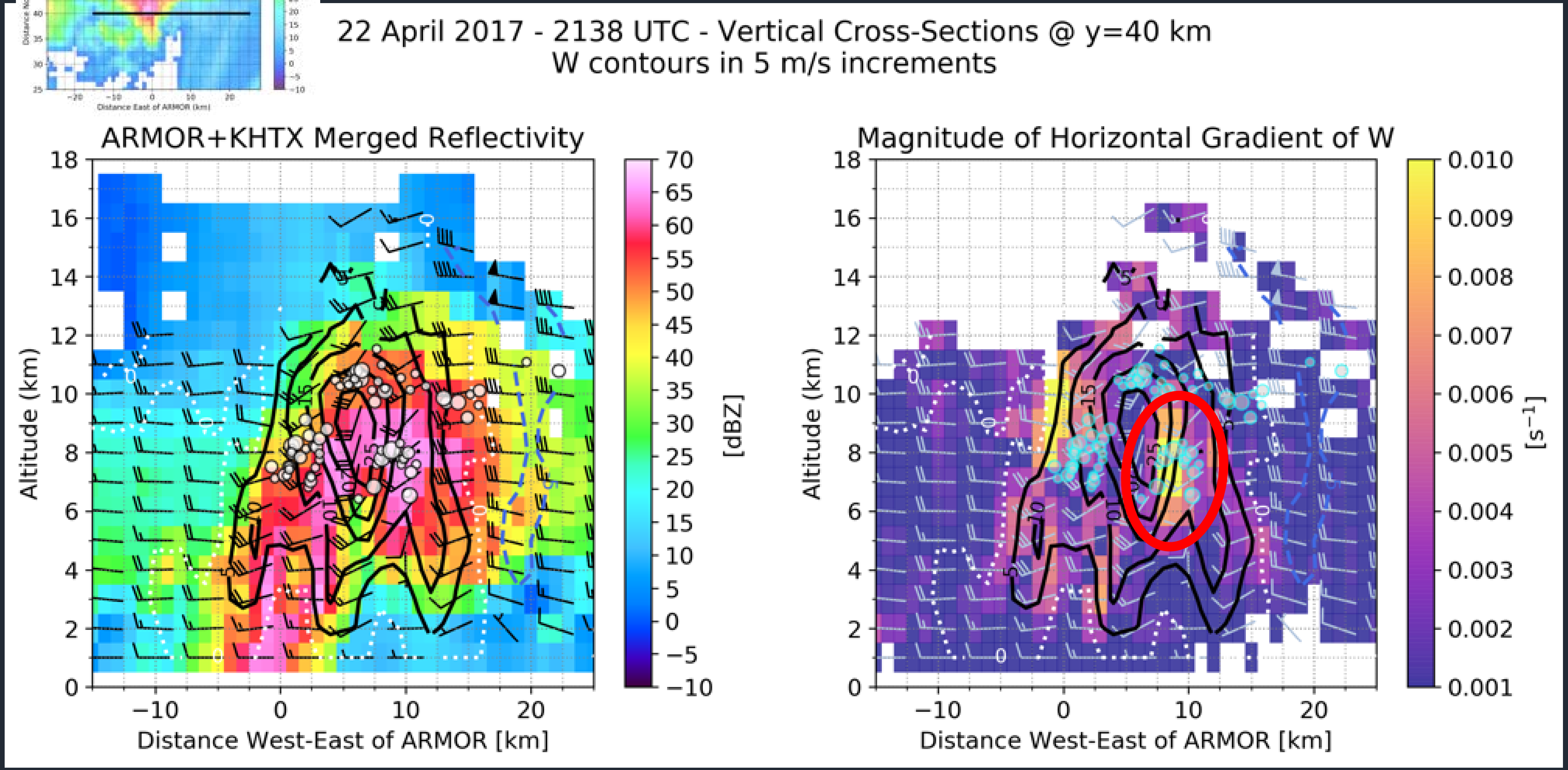
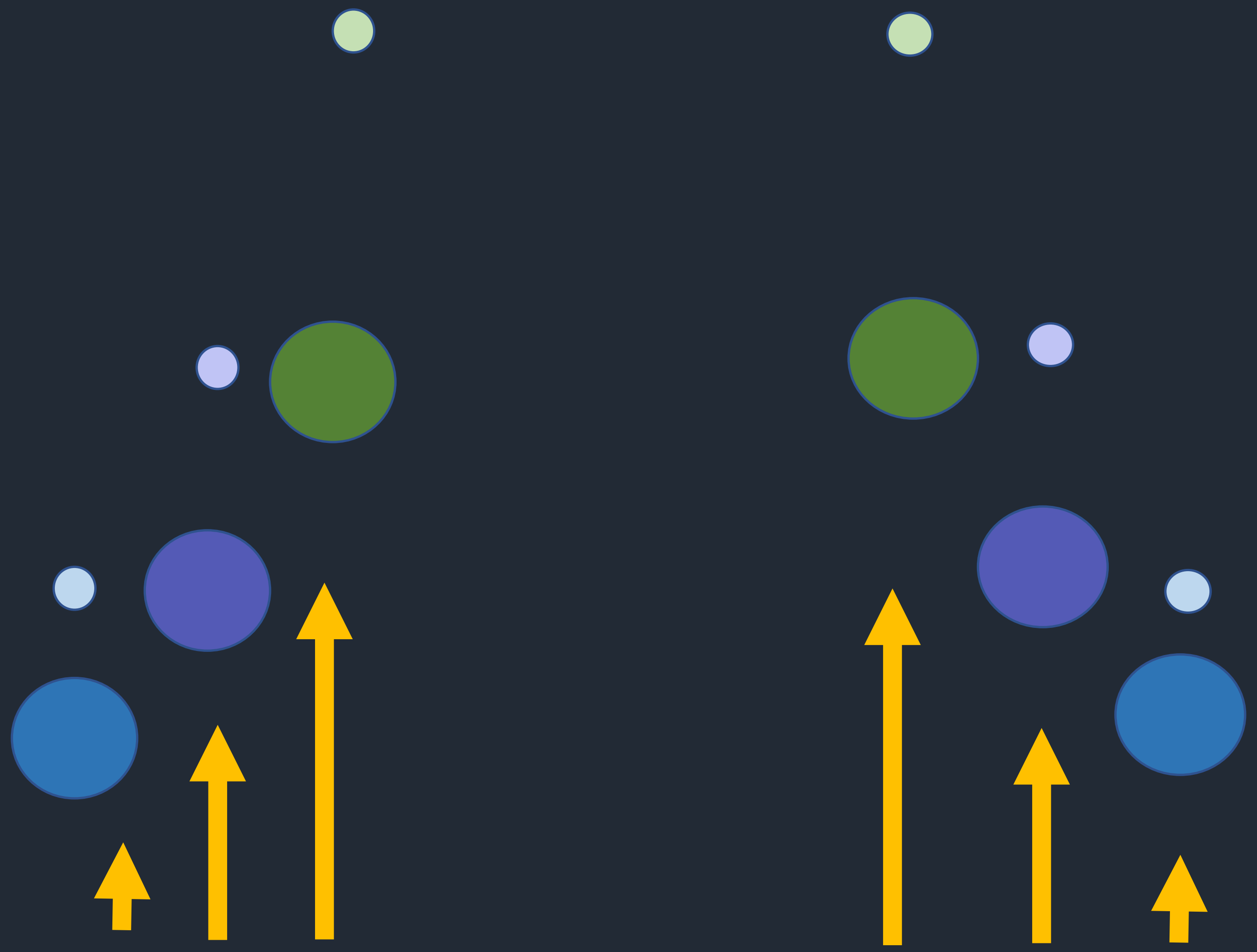


- Overlap of flash initiations with strong gradients in vertical motion occur in coincidence with cross-flow

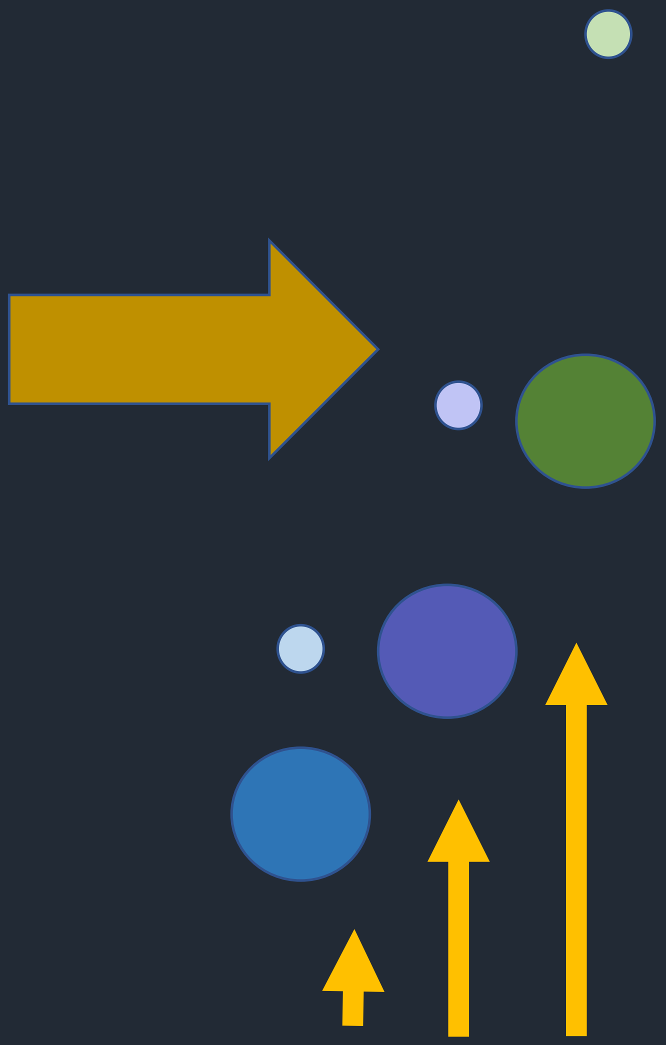
Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion



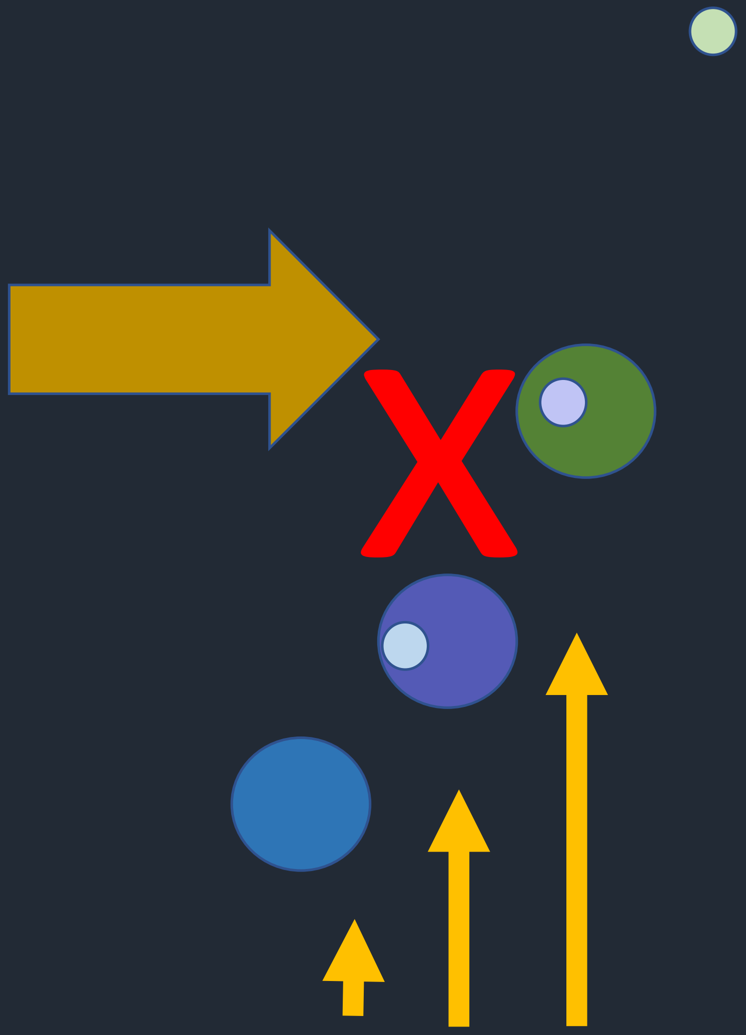
Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion
- Depending on direction of flow with respect to main updraft,



Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion
- Depending on direction of flow with respect to main updraft, charge particles may become mixed -> reduce potential & lightning initiation



Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion
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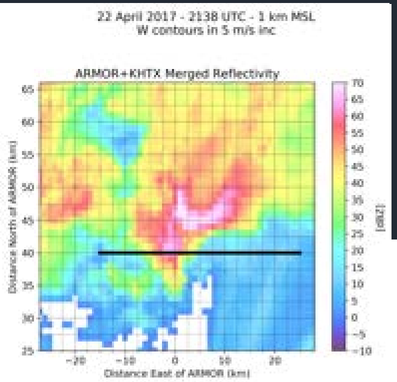
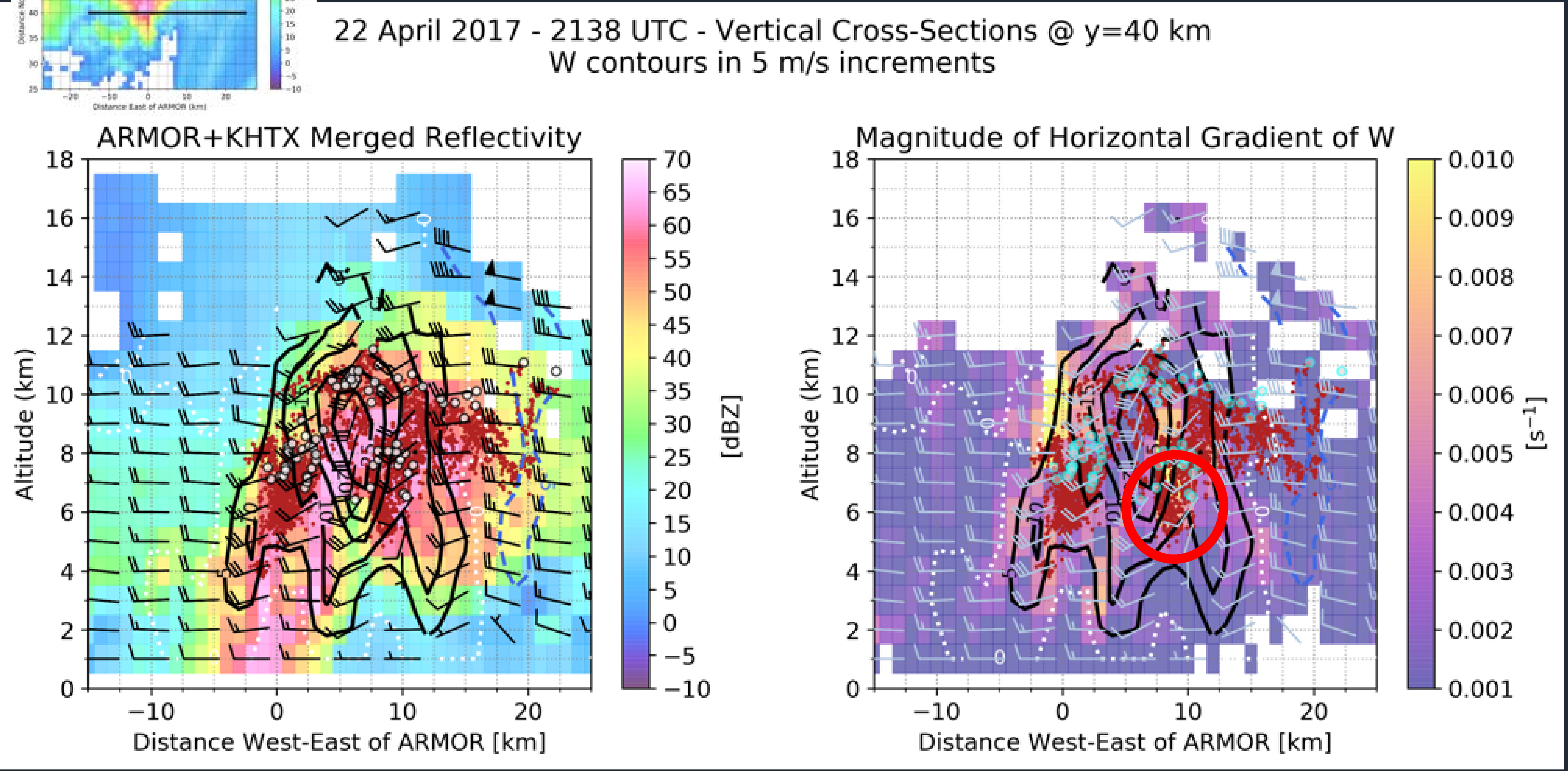
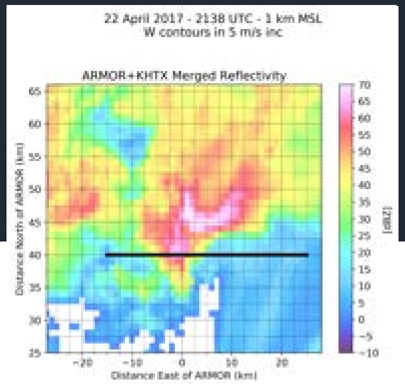


- Flash initiations typically located in regions with a weak horizontal gradients in W
- Overlap of flash initiations with strong gradients in vertical motion occur in coincidence with cross-flow



- In LMA-based charge analysis, see evidence of charge separation around gradient in vertical motion

Lightning Distribution within Vertical Updraft Structure



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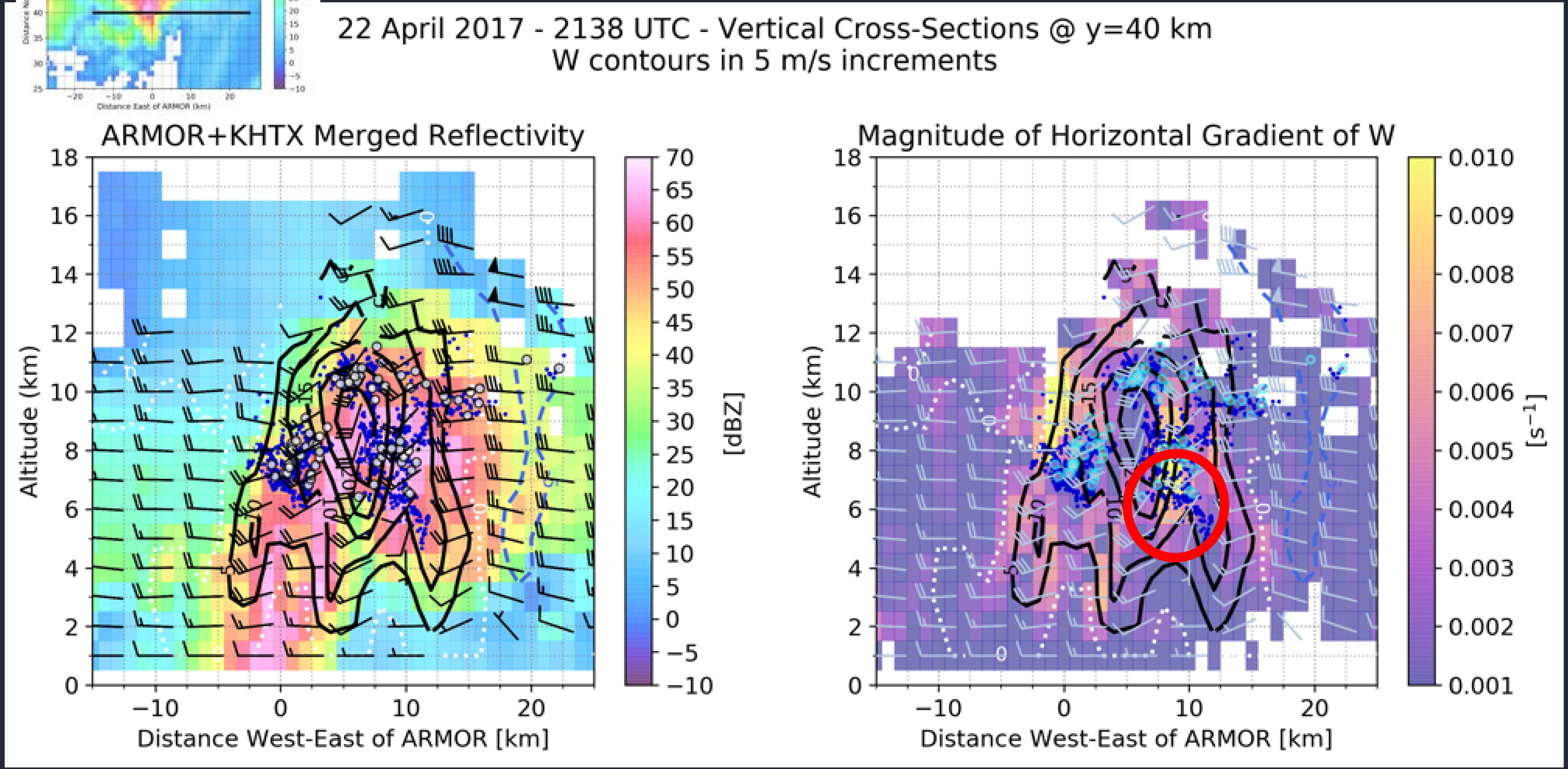

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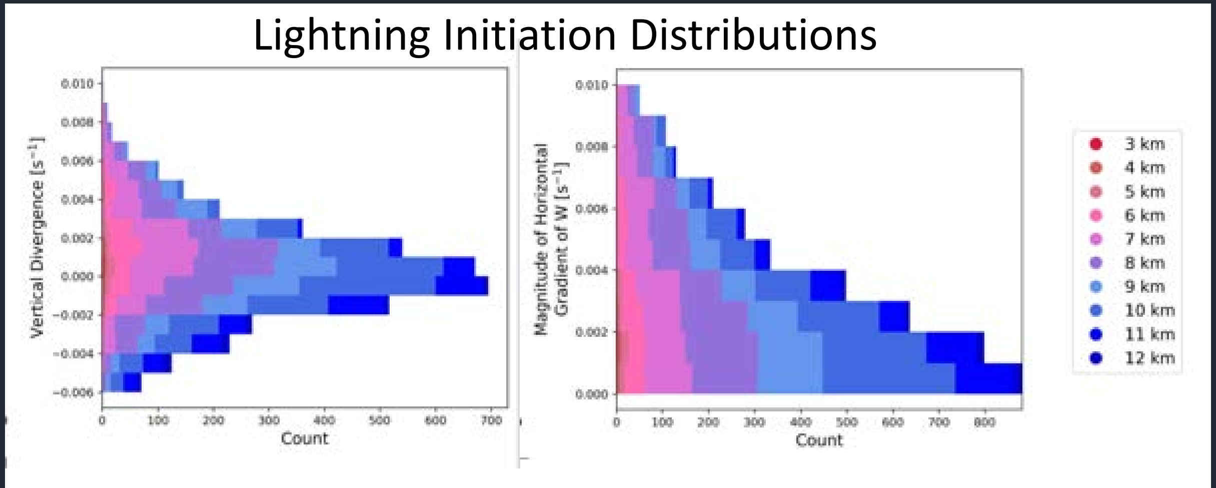
Summary and Future Work

- Lightning locations spatially related with updraft characteristics; specifically where changes in W are negligible in the horizontal and negligible or decreasing in the vertical
  - Consistent results over storm analysis period, 2056-2206 UTC
  - Spatial behavior also subject to effects of advection (e.g., Bruning et al. 2010)



- Microphysics response to updraft characteristics also suggests vertical divergence related to storm-scale charge separation
  - Similarities with Lhermitte & Williams's (1985) particle balance level discussion
- Implications: Spatial relationships influence bulk lightning, updraft trends that inform on intensity – additional observations needed to quantify added benefits
- Future work: Electrification modeling planned to quantify microphysics vs. kinematic influence on charge arrangement and effects on lightning location, frequency

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