Polarimetric and multi-Doppler radar observations of electrified and unelectrified wildfire smoke plumes

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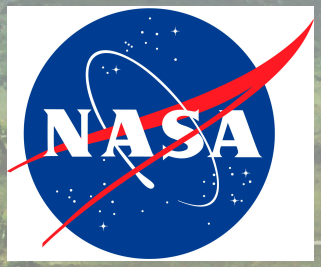
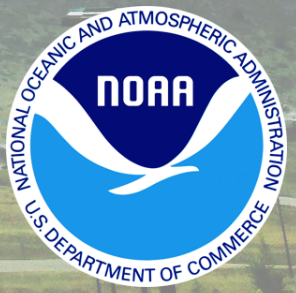




Deep Convective Clouds and Chemistry (DC3)

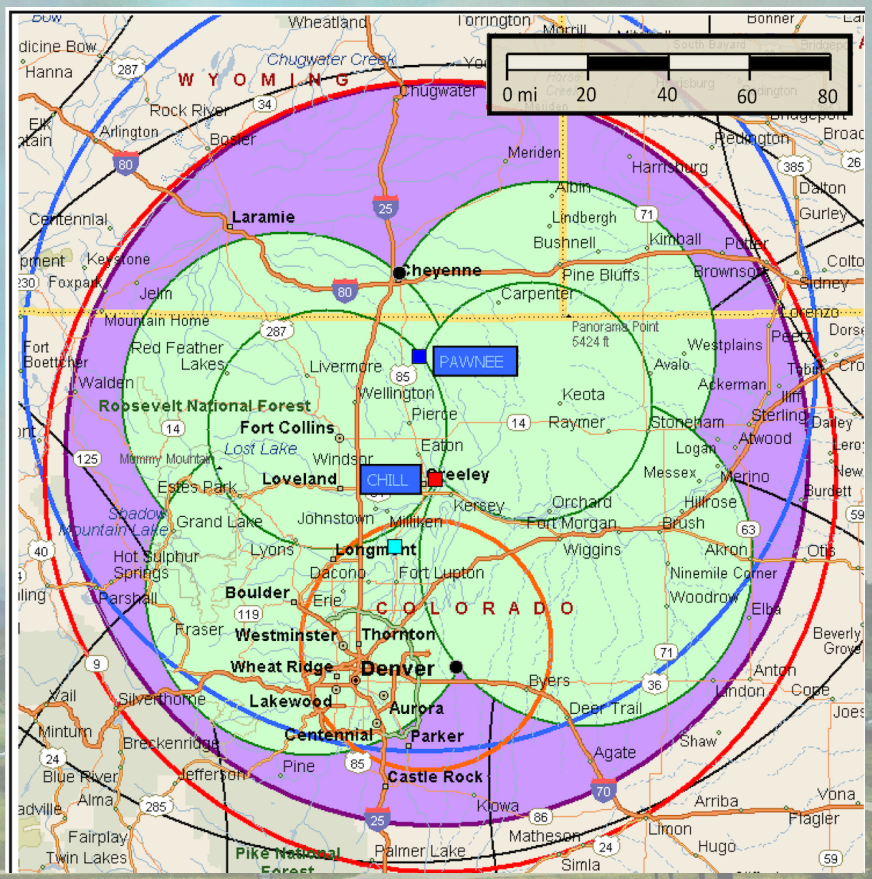
Goal - Diagnose chemical impacts of thunderstorms on the upper troposphere

Unique DC3 observations in Colorado

- Polarimetric radar (CSU-CHILL)
- Multiple-Doppler radar network
- 3-D Lightning Mapping Array (LMA)

Wildfires abundant in Colorado in 2012

Three times pyrocumulus grew to high altitudes and produced intracloud lightning during rapid fire growth (Hewlett Gulch, High Park, and Waldo Canyon fires)



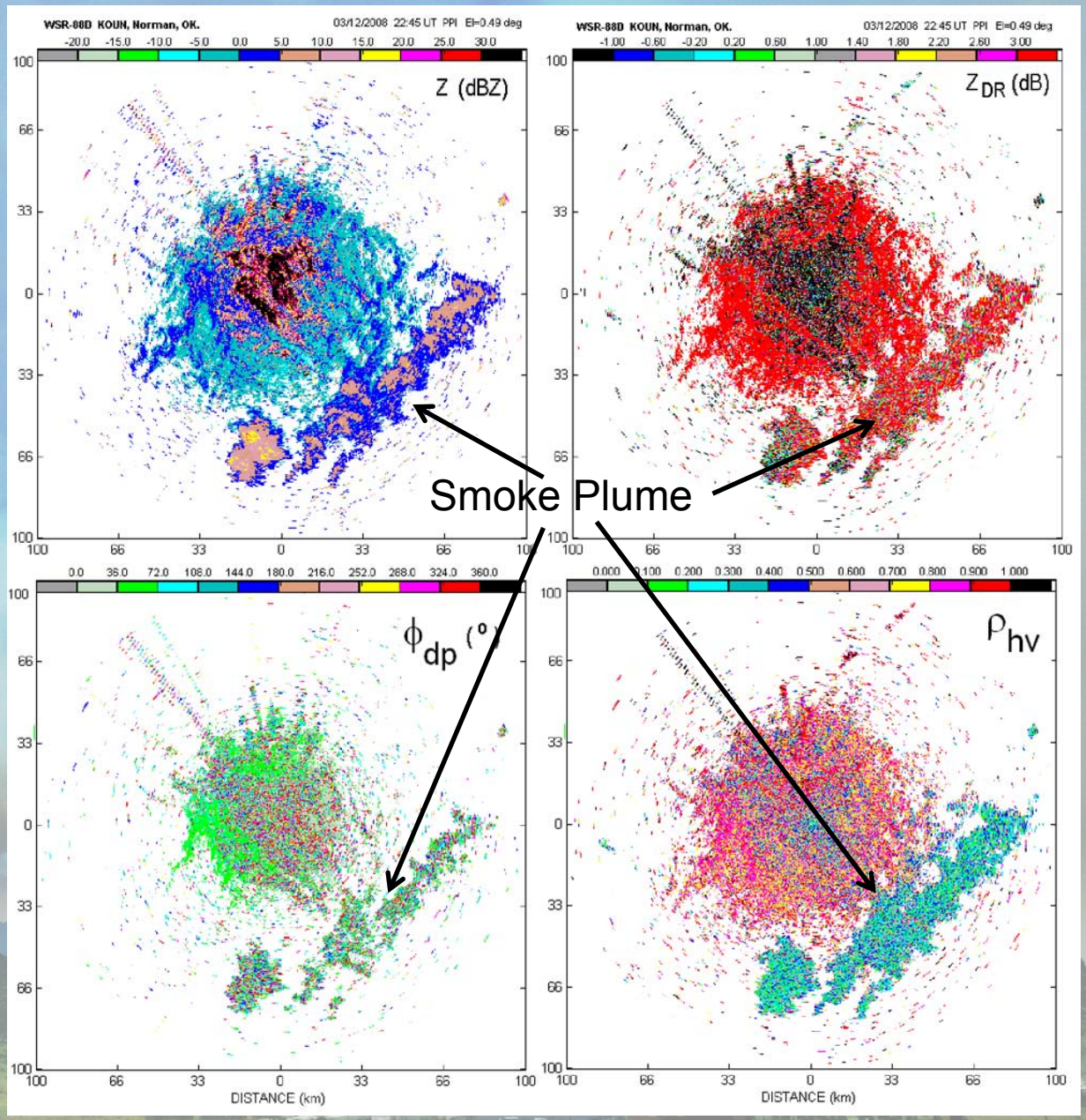
What does smoke look like to S-band polarimetric radars?

Dominated by Mie/ Rayleigh scattering

Z_H large (> 30 dBZ) near fire but smaller further away (< 30 dBZ) as larger ash particles precipitate out

Z_{DR} large (> +1 dB) due to horizontally aligned, oblate ash particles

Low ρ_{HV} (< 0.4) due to variety of particle shapes and sizes, leads to noisy Z_{DR} and ϕ_{DP} signals



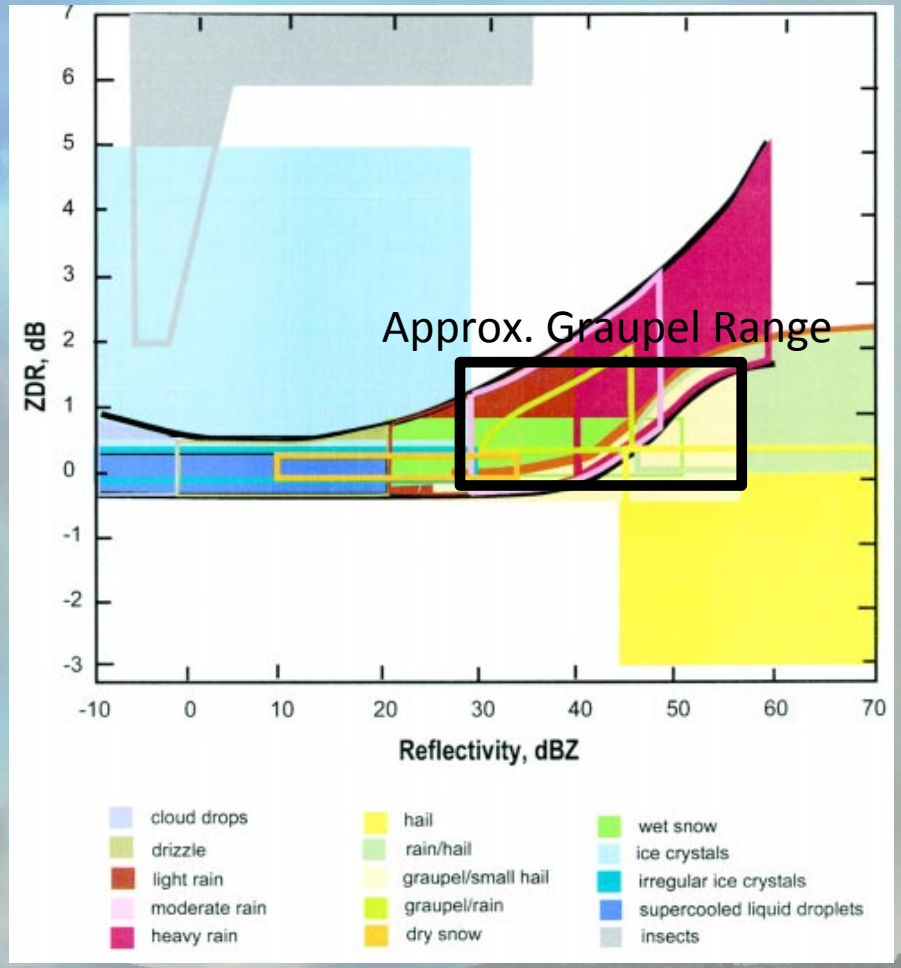
Melnikov et al. (2008; GRL)

What does lightning-producing convection look like to S-band polarimetric radars?

Host of studies, from Workman and Reynolds in the 1940s to the present, suggest that vigorous convection containing significant amounts of graupel is needed to produce lightning

Graupel associated with Z_H > 30 dBZ, Z_{DR} & K_{DP} near zero to positive values, and high ρ_{HV}

Lang and Rutledge (2011; MWR) – Convection without 30 dBZ above the freezing altitude has only ~10% chance to be concurrently producing lightning. Most exceptions were remnants of earlier, lightning-producing convection



Vivekanandan et al. (1999; BAMS)

What do pyrocumulus clouds look like to S-band polarimetric radars?

Well, that's a good question!

Visual appearance suggests abundance of smoke/ash at lower altitudes and liquid water aloft

Satellite studies (e.g., Lindsey and Fromm 2008) suggest significant amounts of small ice are present when pyro-Cu clouds reach high altitudes

Single-pol radar studies (e.g., Rosenfeld et al. 2007) have observed Z_H > 40 dBZ in core of intense lightning-producing pyro-Cb. Graupel?

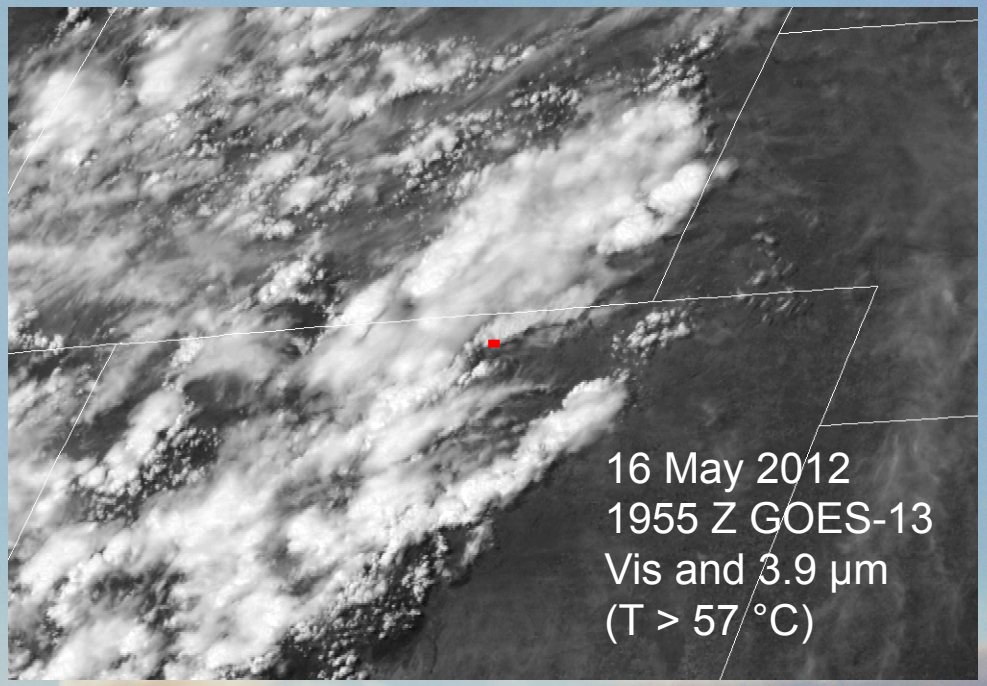
Arizona Pyrocumulus
(Wikimedia Commons)

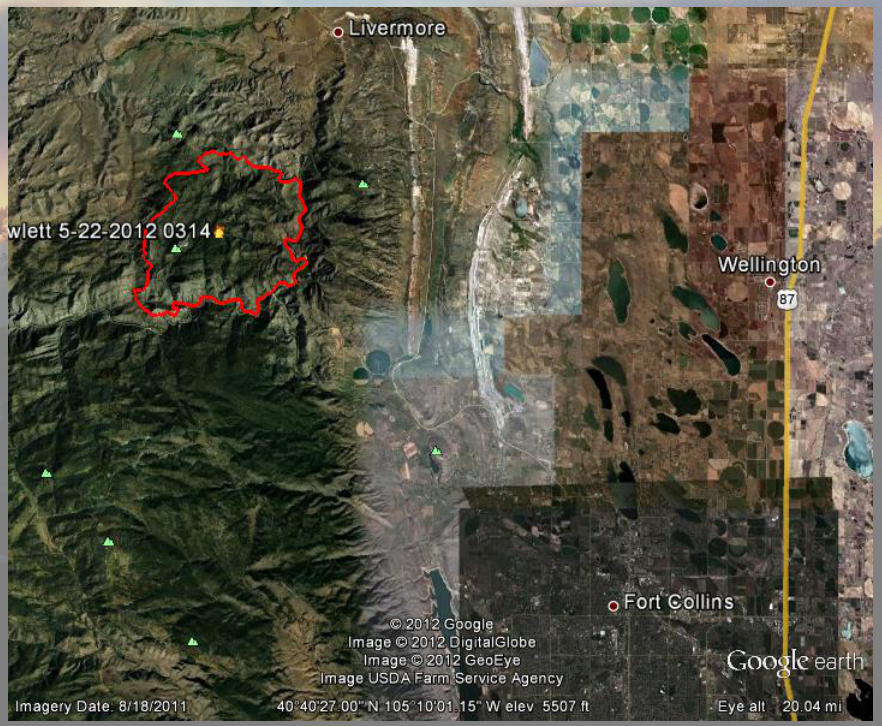
Hewlett Gulch Fire

Started 14 May 2012
Contained 22 May 2012

Burned 7,685 acres
(~4,000 acres on 16 May)

Human caused (accident), no burned structures or fatalities





16 May 2012

Morning and afternoon Denver soundings analyzed

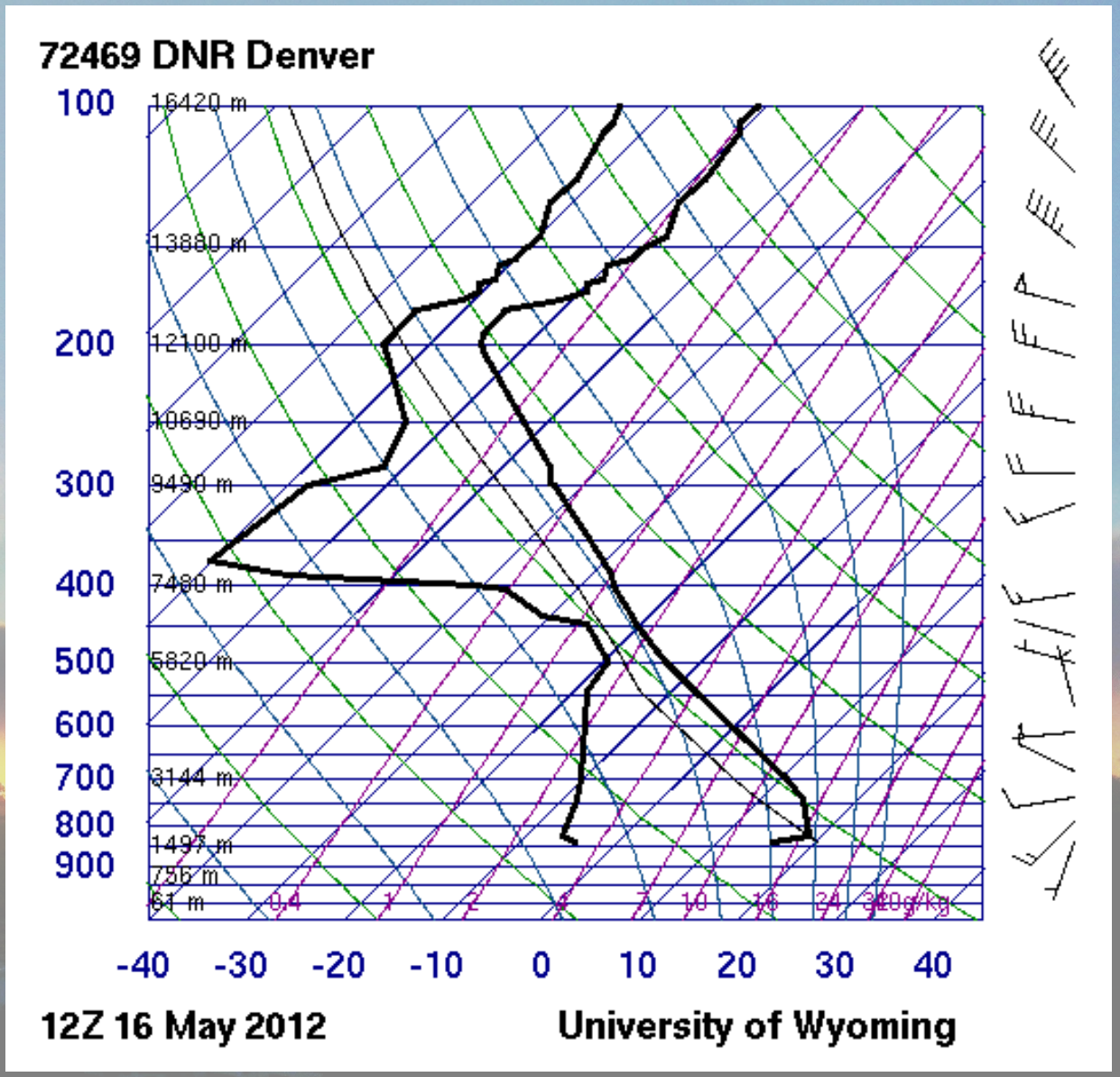
LCL = 4.5-4.9 km MSL (-5 to -10 °C)

H (-40 °C) = 9.1-9.2 km MSL

Winds near -40 °C were WSW at ~10 m s^{-1}

Deep dry-adiabatic layer above surface inversion

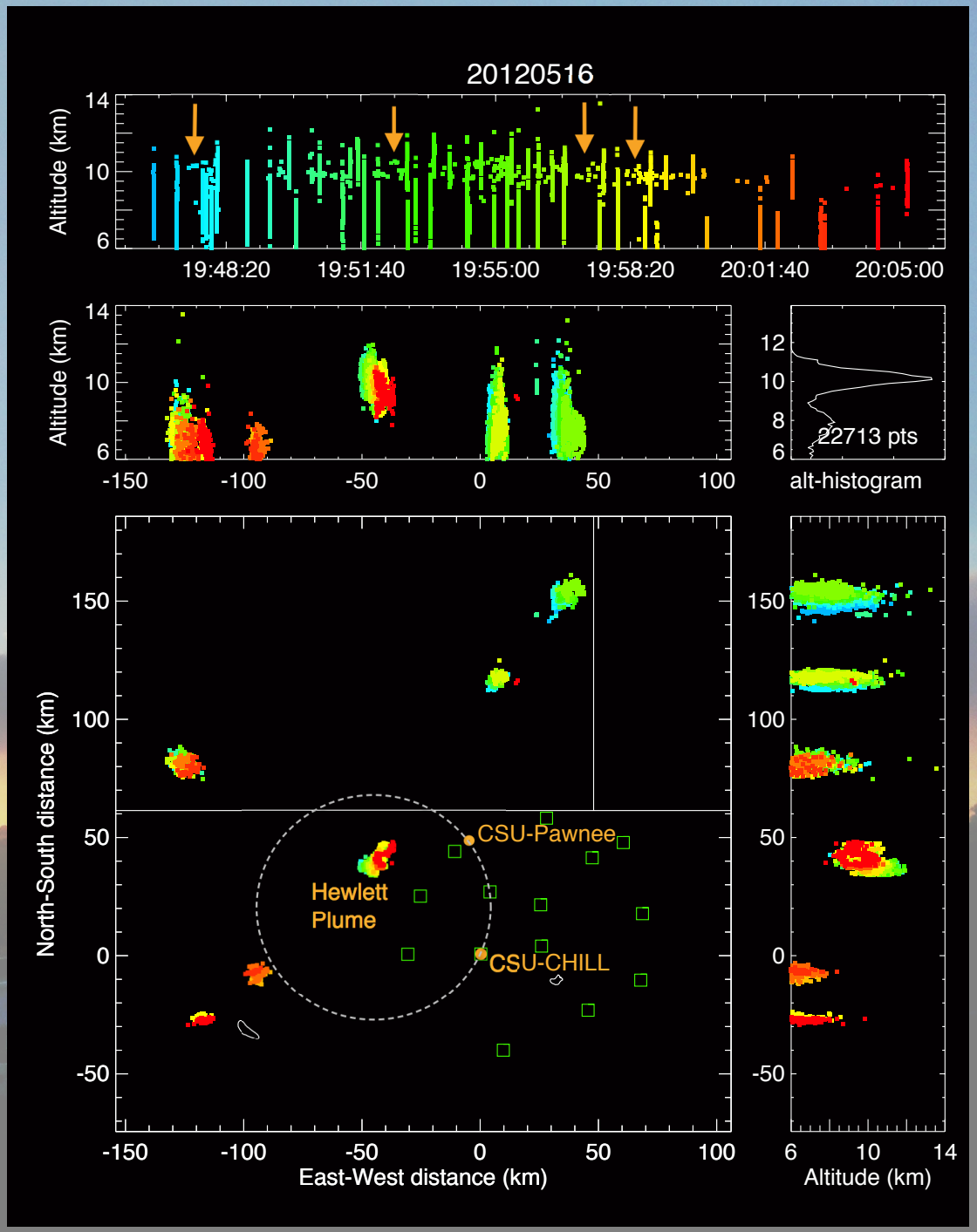
Classic dry, high-based convection scenario

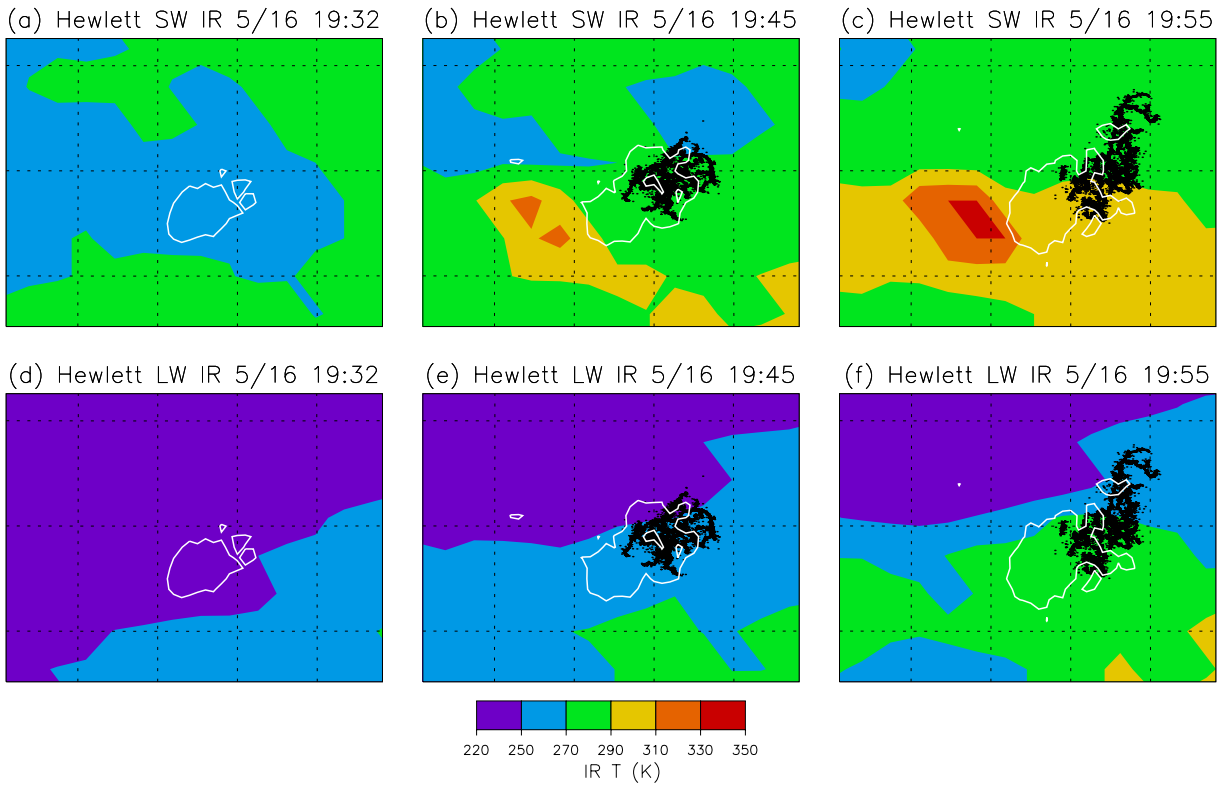


Afternoon dry, gusty mountain convection produced rapid fire growth

Pyrocumulus grew and produced lightning 1948-2005 UTC (20 flashes, 1.2 min^{-1}, typically with ~30 sec of precursor VHF bursts)

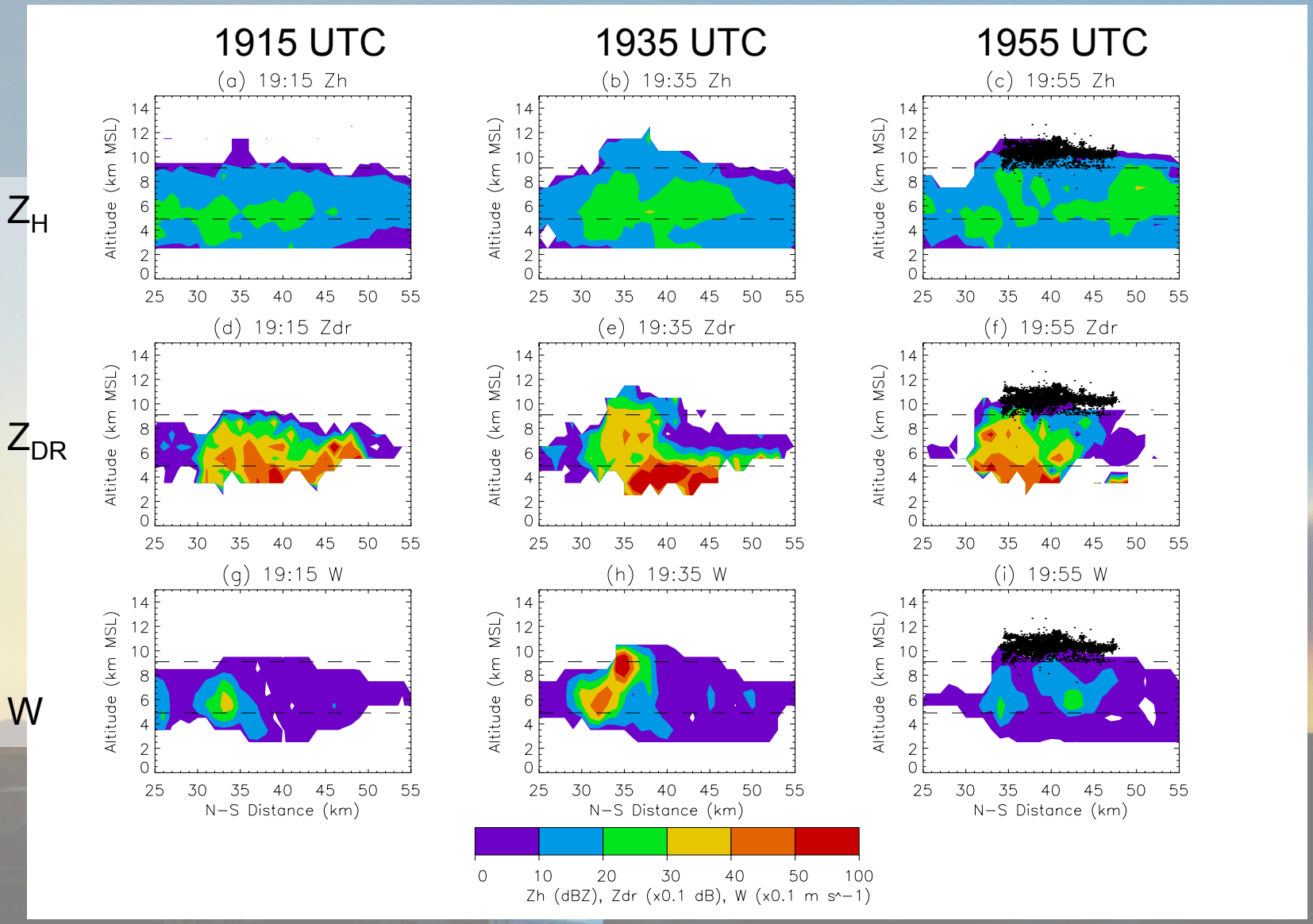
Lightning near center of western CHILL/Pawnee dual-Doppler lobe, while they were scanning the plume!





Top – GOES SW IR
Bottom – GOES LW IR
White – 15-dBZ radar
Black Dots – LMA lightning

- Plume downwind of 3.9-μm IR hot spot
- Lightning shifted downwind of plume

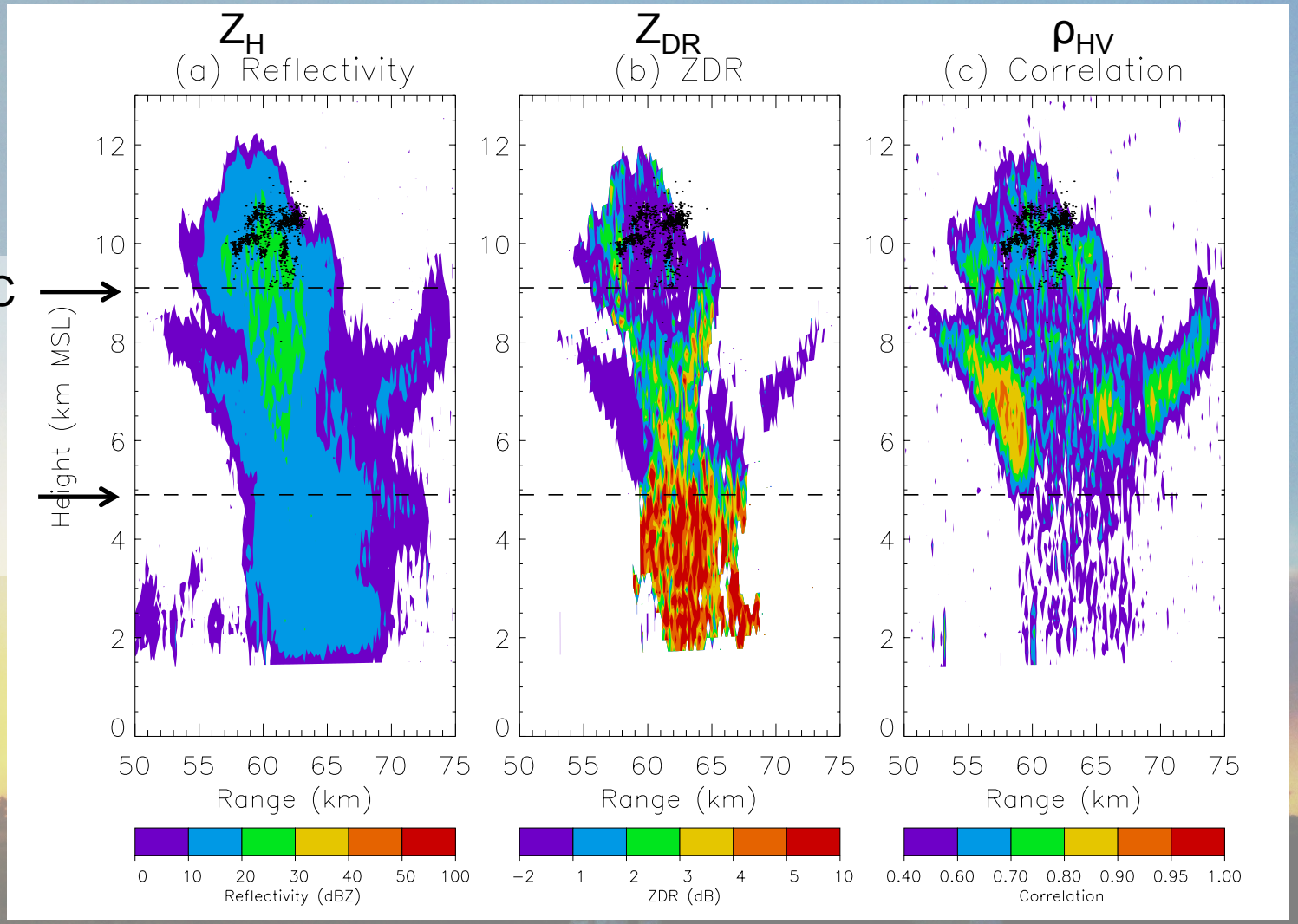


- Convective growth above H (-40 °C) driven by increased updrafts
- Lightning occurs at high altitudes (~ 10 km MSL), in lower Z_H and Z_{DR}

CHILL RHI
(1949 UTC)
LMA Flash
(1948 UTC)

-40 °C

LCL

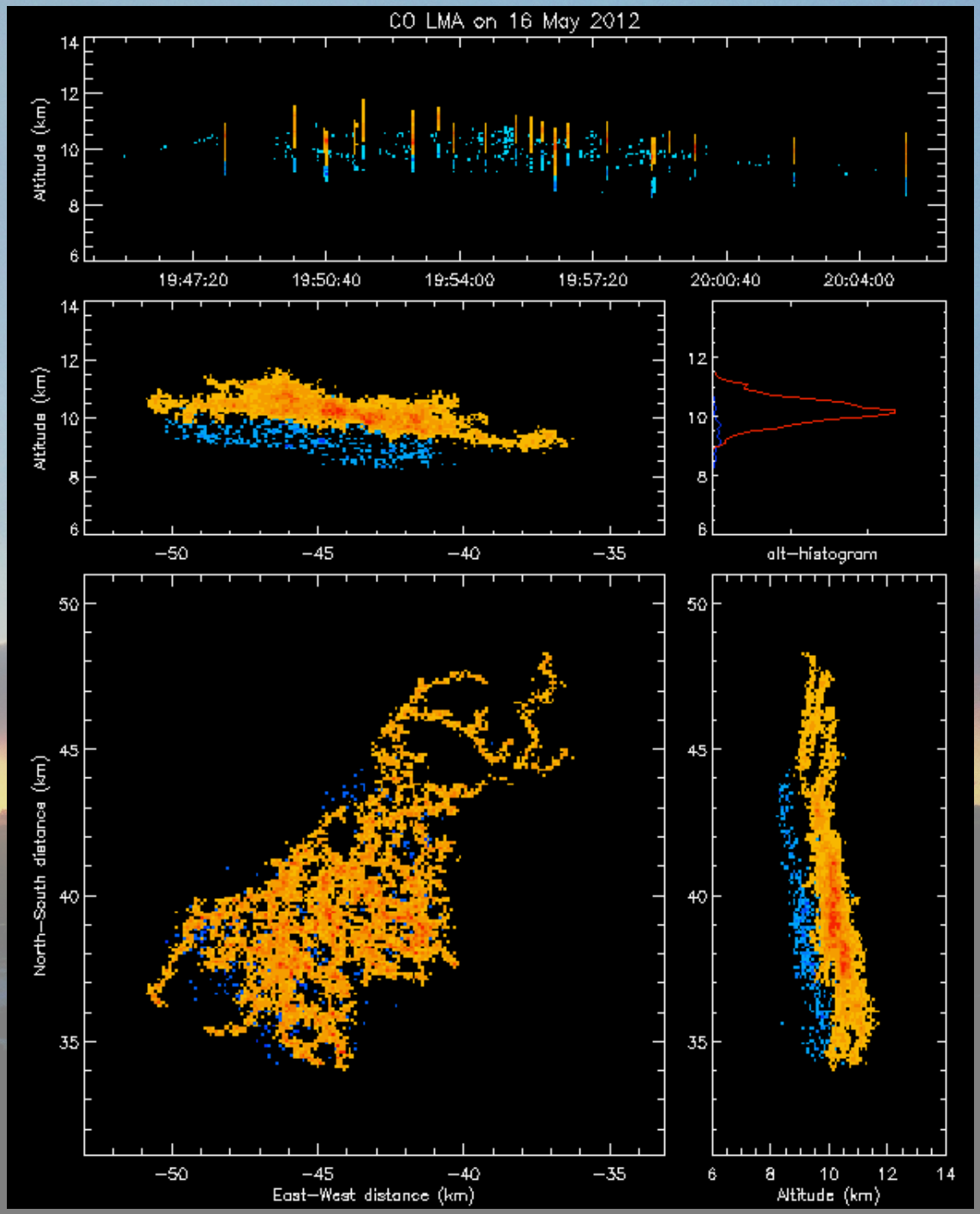


- Below LCL – High Z_{DR}/low ρ_{HV} indicating mostly smoke
- Above LCL – increasing ρ_{HV} and decreasing Z_{DR} – condensation/freezing?
- Mid-level cloud bookending plume – Low Z_{DR}/high ρ_{HV} relatively clean
- Near and above -40 °C altitude – ZDR -1 to +1 dB, ρ_{HV} ~0.6 or more
- Lightning occurred in this inferred ice/ash mixture

Lightning in plume gives microphysical insight as well

Note downward sloping due to subsiding hydrometeors downwind (NE) of core

Positive (orange) charge over negative (blue) – normal dipole

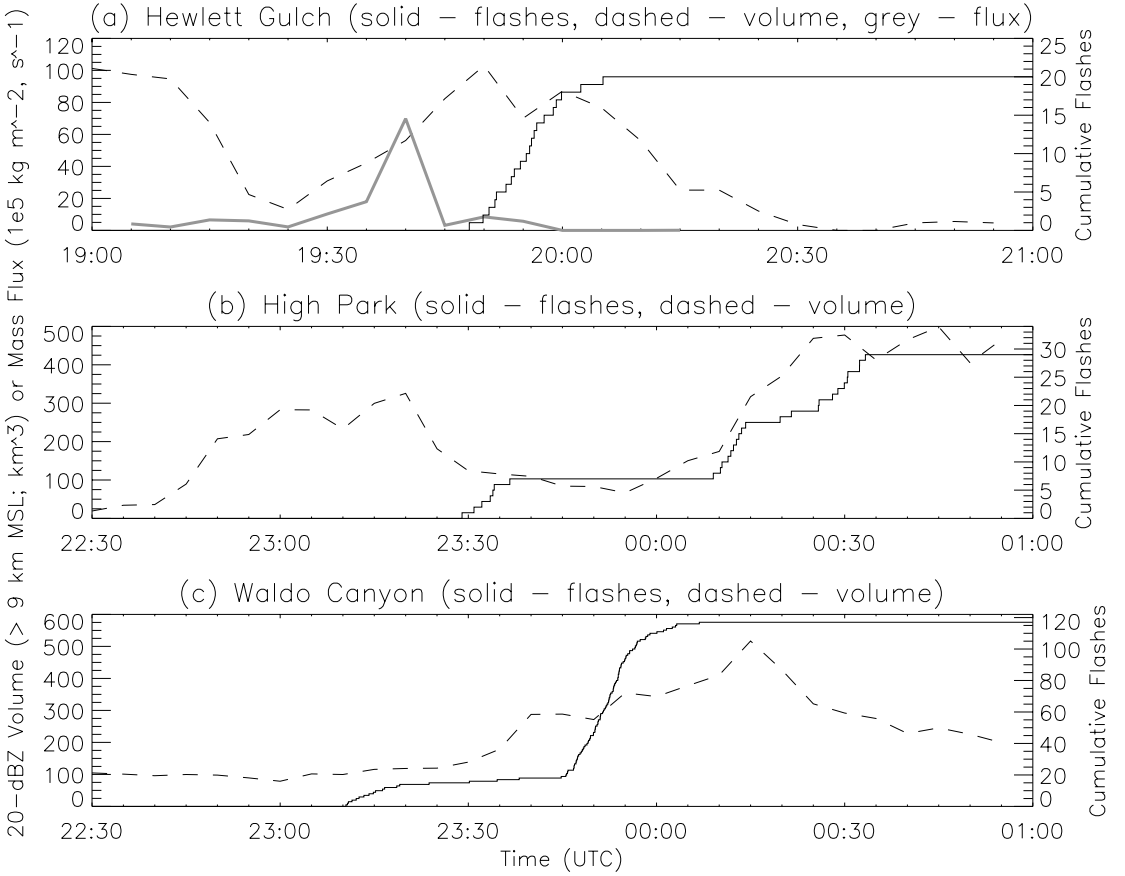


Lightning also occurred in pyrocumulus clouds above High Park (13 June) and Waldo Canyon (26 June) fires

Similar scenario:

- Rapid fire growth (IR hot spot)
- Pyro-Cu development above -40 °C
- Intracloud lightning at high altitudes in areas of inferred ice

Bulk time series suggest increasing 20-dBZ echo above 9 km MSL associated with the occurrence of lightning (> 30 dBZ not necessary)



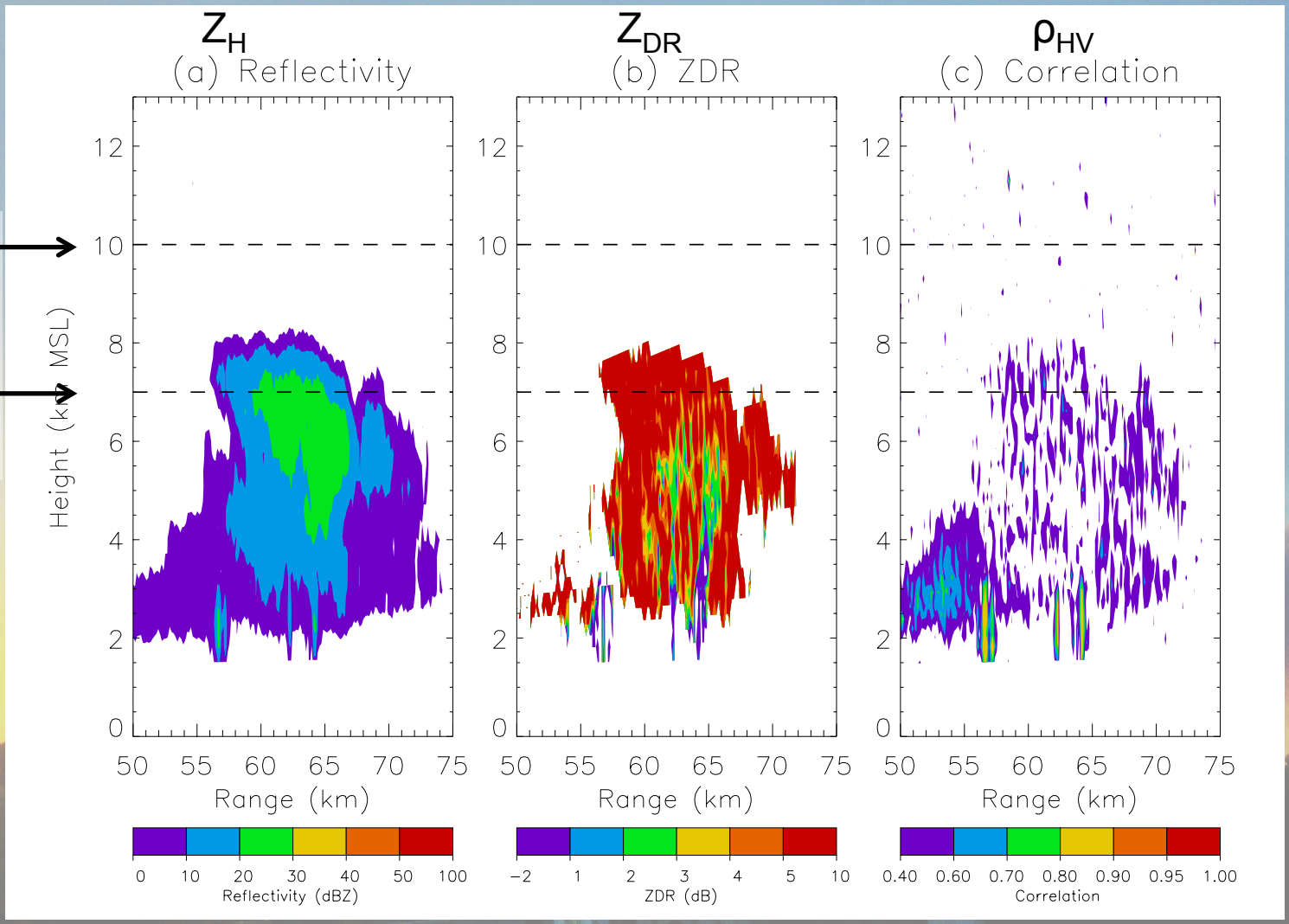
Hewlett Gulch multi-Doppler synthesis: Convective updraft pulse occurs prior to lightning

High Park/Waldo Canyon: no multi-Doppler or polarimetric during lightning

High Park Fire
22 June 2012
CHILL RHI
(1956 UTC)

-40 °C →

LCL →



- What about non-lightning-producing plumes?
- Many examples during DC3!
- Only smoke signature evident in polarimetric data
- No growth above -40 °C

Conclusions

Ice needed to be present before lightning occurred in pyrocumulus clouds

Lightning occurred mainly at high altitudes, T < -40 °C

But is it graupel? Z_H seems too low! However:

- Avila et al. (2011) – Significant charge transfer can occur in ice-ice collisions without supercooled liquid water
- Mansell and Ziegler (2013) – Increasing CCN reduced graupel mass density, suggesting lower Z_H in smoke-modified clouds for same graupel number concentration

Applications?

- Lightning updates faster than satellite/radar and coverage can be better – Early warning on rapidly growing fires?
- Lightning indicates significant high-altitude ice – Implications for upper troposphere composition and radiative feedbacks?
- NLDN did not detect these small IC flashes – LMA needed?