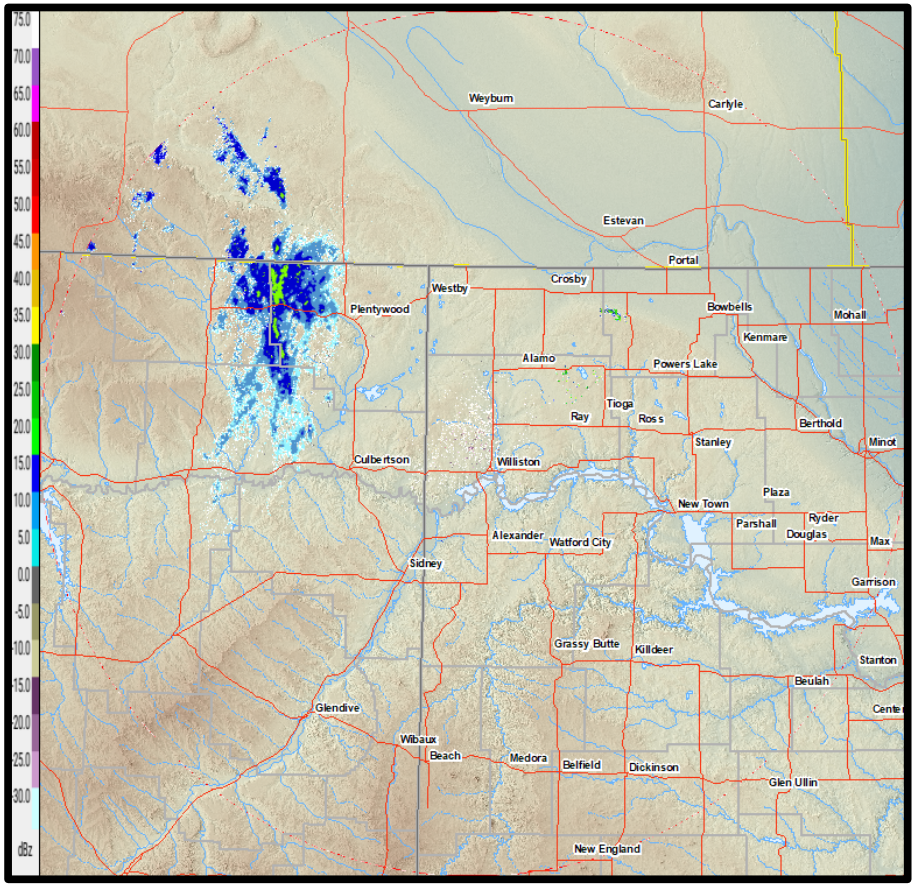
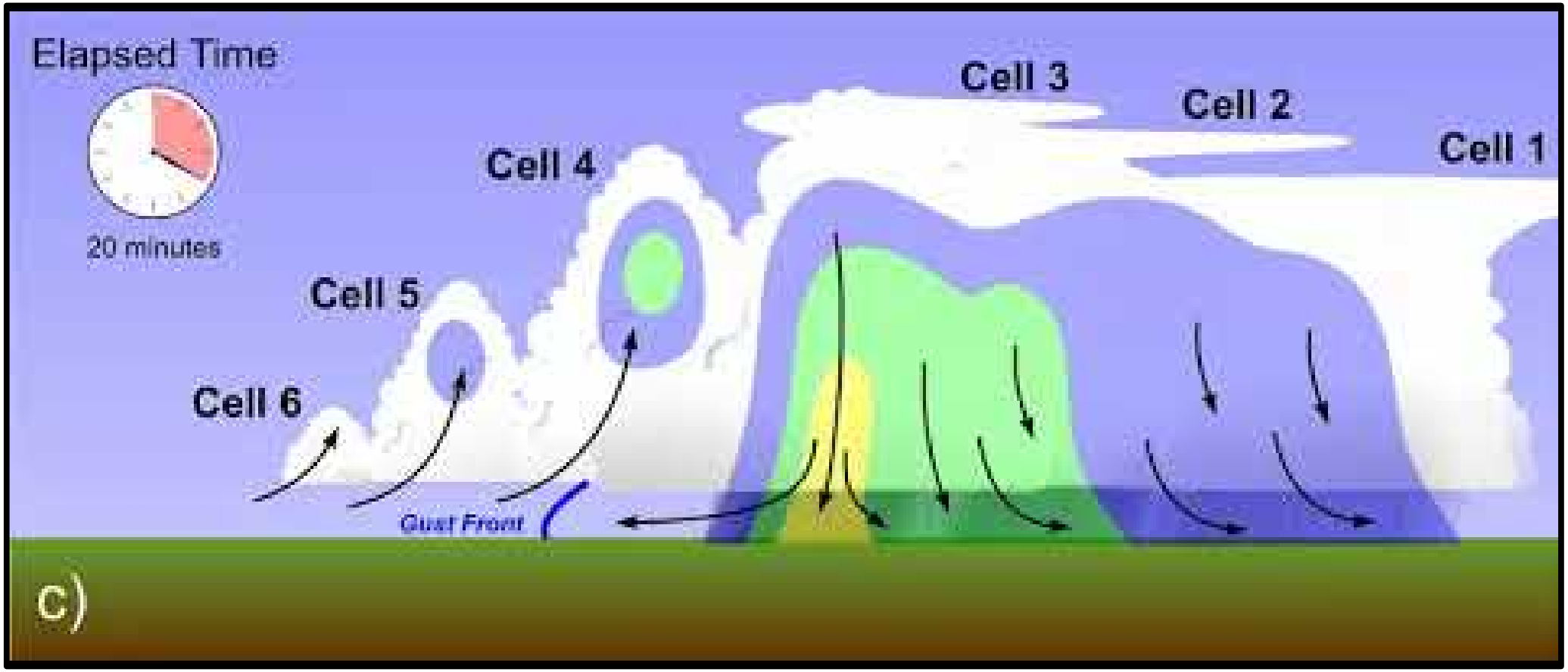
North Dakota Cloud Modification Project (NDCMP) Conceptual Model

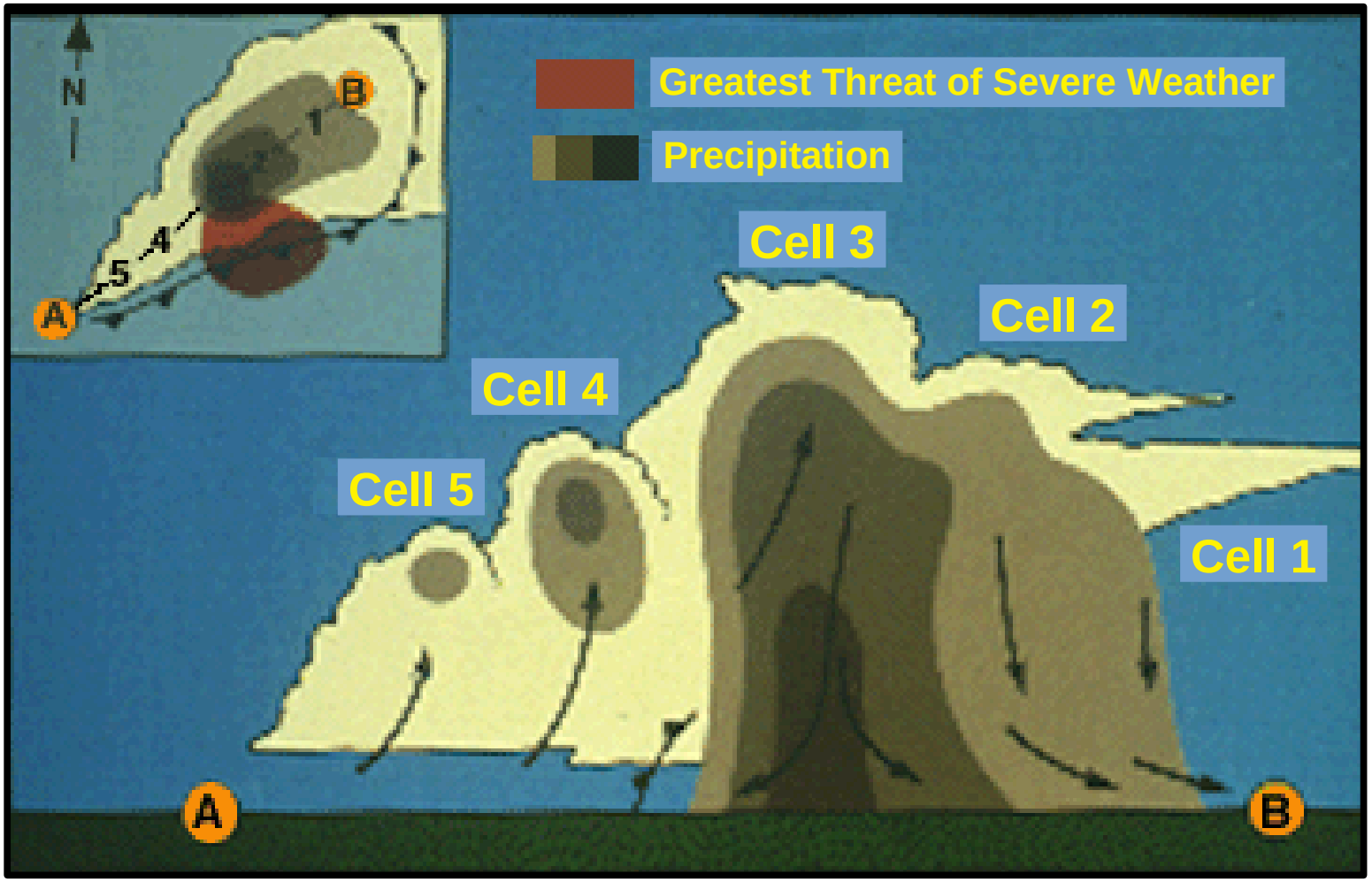


Multicell Cluster Storm (Isolated)



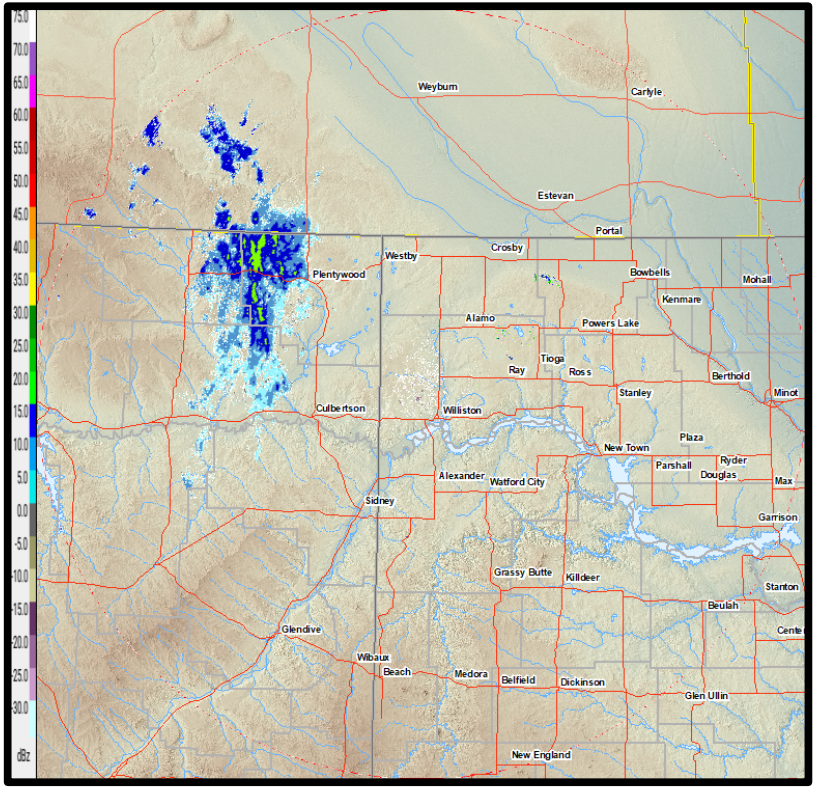
https://www.youtube.com/watch?v=Th2DfZp__bI

Multicell Cluster Storm (Isolated)



Precipitation Increase from Cloud Seeding

- The intent is to glaciate portions of the cloud, initiating ice development minutes earlier than would naturally have been the case.
  - Accelerate hydrometeor growth sufficiently to allow the cloud to produce precipitation-sized hydrometeors during its short lifetime (microphysical effects)
  - Adding buoyancy which may stimulate updrafts and prolong the cloud lifetime as well (dynamic effects)



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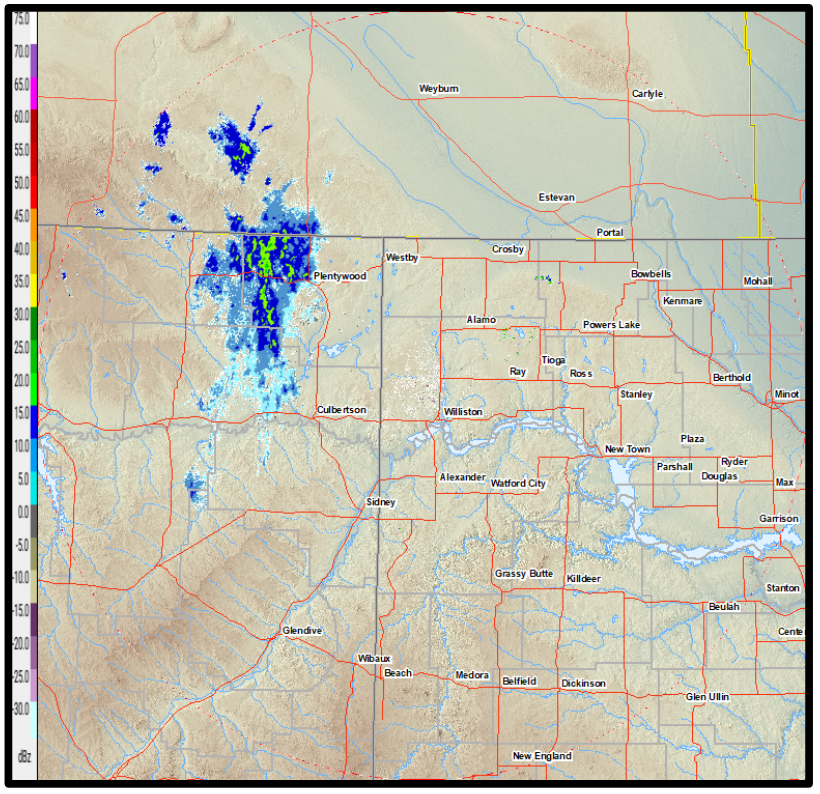
Natural Hail Process – Main Updraft

- The **main updraft** of a **mature thunderstorm**, which is responsible for a large fraction of the storm's total mass flux, also supports the larger hydrometeors (hailstones) as they grow.
- Primary hailstorm updrafts are usually tilted and frequently possess speeds between **30 and 40 m s^{-1}**, which greatly facilitate the production of large hail (Nelson 1983).



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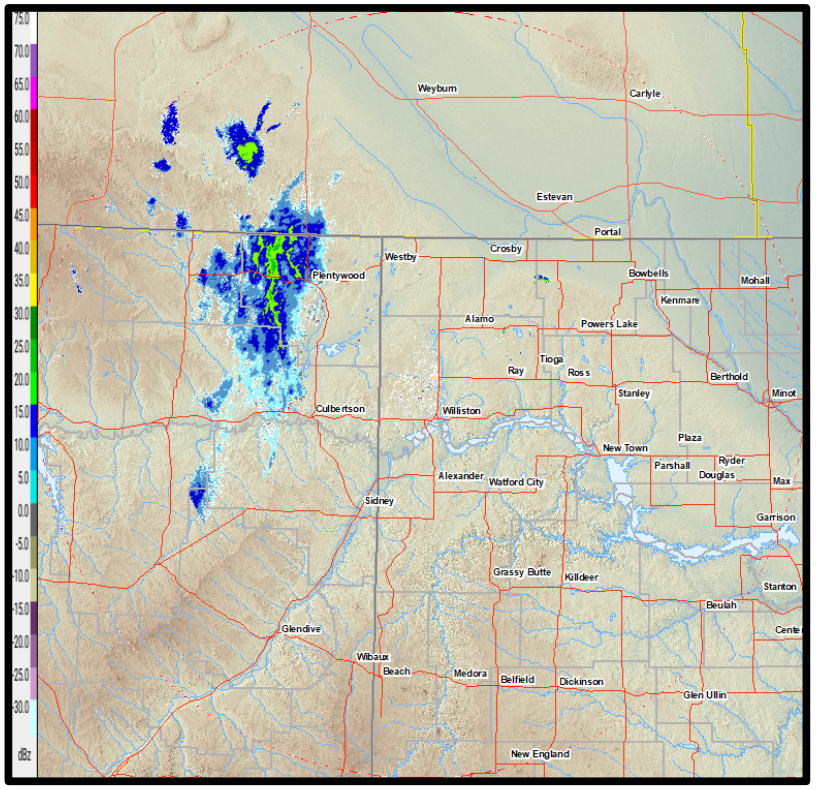
Natural Hail Process – Feeder Clouds

- **Feeder clouds**, which flank mature thunderstorm cells, develop significant quantities of supercooled liquid water (**SLW**).
- Significant ice development typically does not occur until cloud top temperatures are **-15 to -20** °C.



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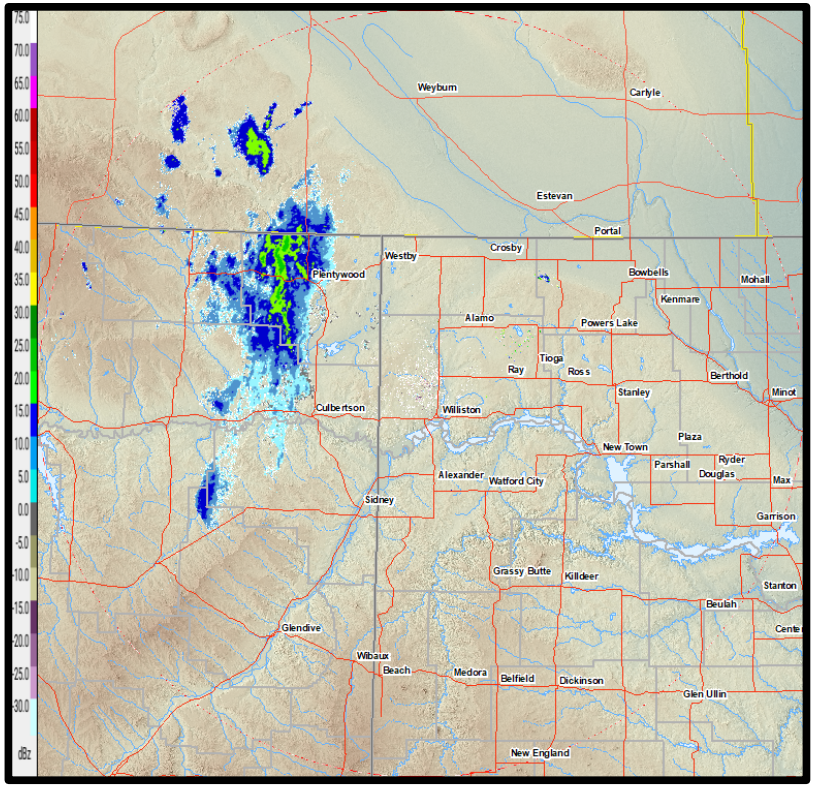
Natural Hail Process – Slow Development

- Due to **slow development** of rain that results from the natural cold-rain precipitation process in typical feeder clouds, precipitation-sized hydrometeors (ice/water) development typically has only recently occurred at the time of merger with the mature cell.
- Cloud bases of such feeder clouds are typically still rain-free with significant concentrations of millimeter and larger **graupel (potential hail embryos)** remain aloft within the feeder cloud.



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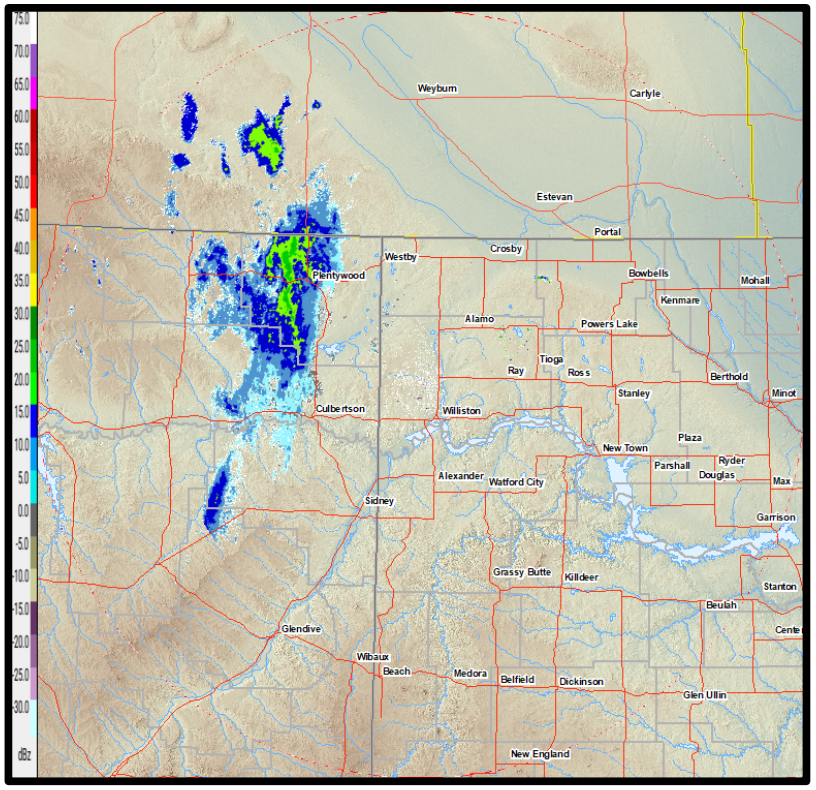
Natural Hail Process – Hail Embryos

- Graupel particles then become hail embryos after either a) being transported to or ingested by the mature updraft, or b) remaining within the feeder cloud updraft as it matures and becomes dominant.
- In either case, the initially small embryos are transported into the supercooled upper reaches of the storm by the updrafts.
- Ensuing hydrometeor growth is rapid; hailstones become too large to have any chance of melting completely during fallout. Damaging hail reaches the ground.



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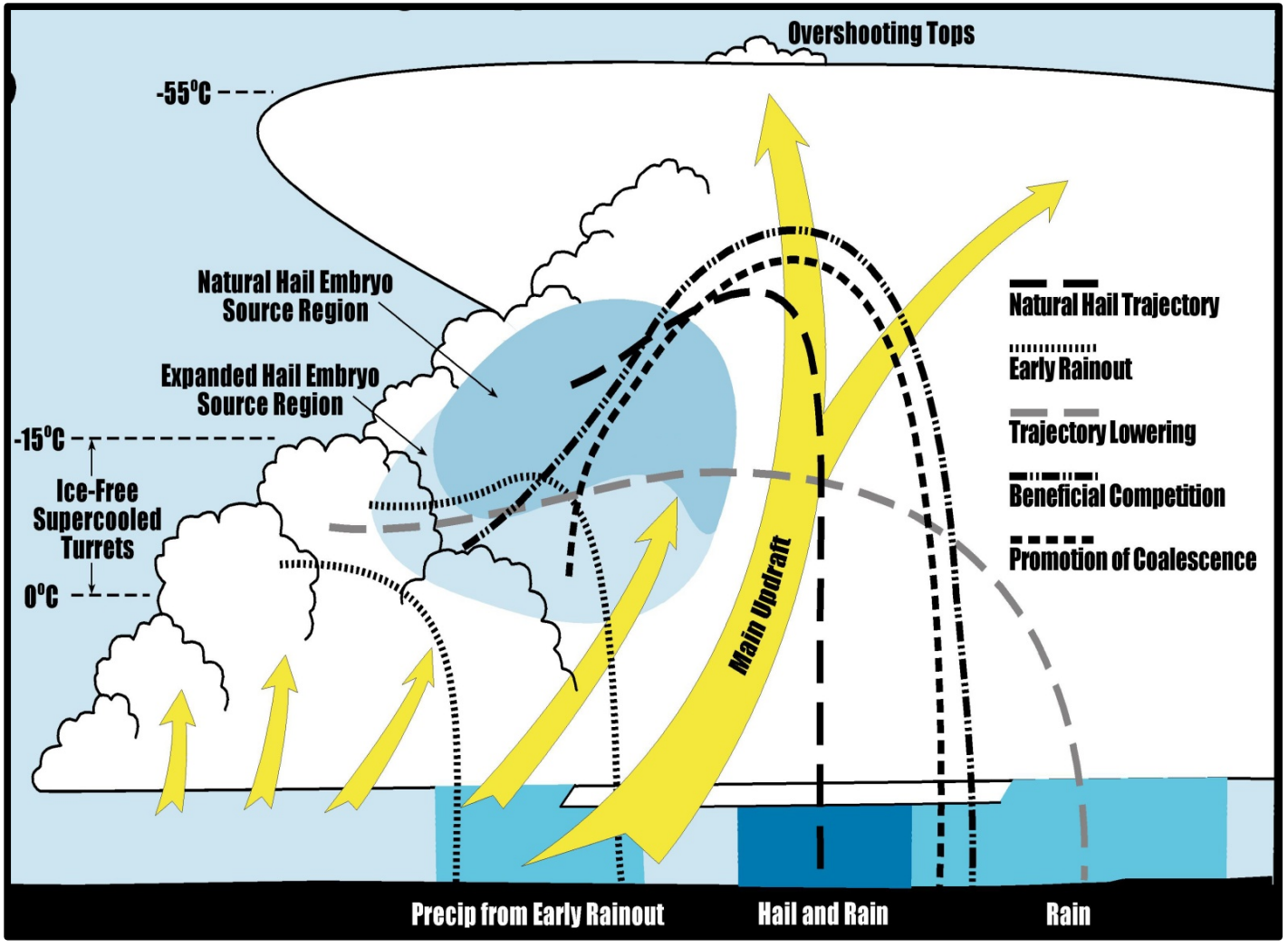
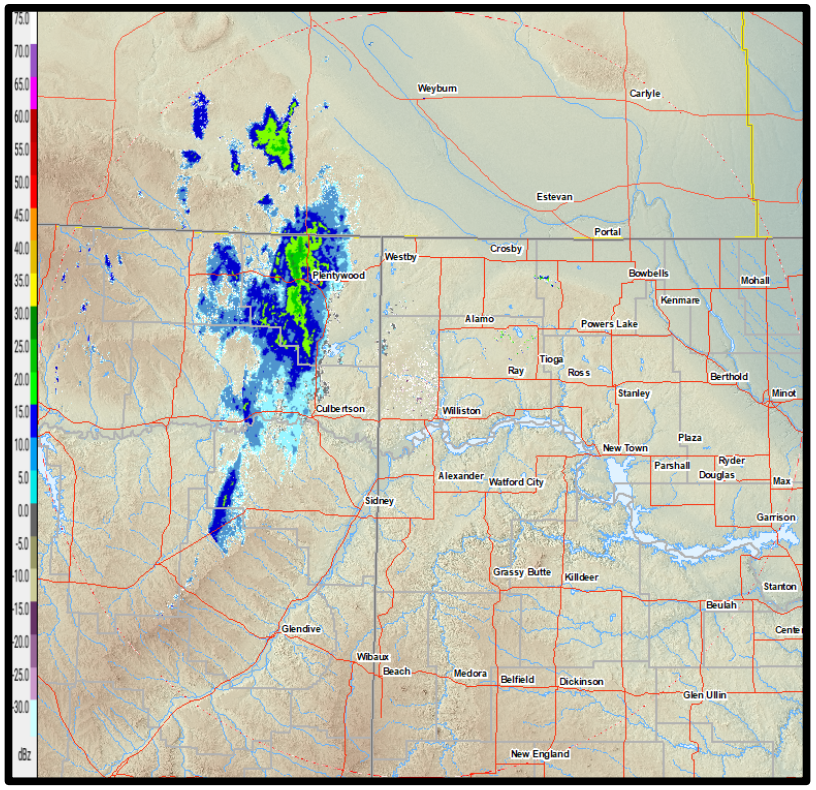
Cloud Seeding Conceptual Model



NDCMP

Cloud Seeding Hypothesis: Ice Development

- Treatment with glaciogenic nuclei of supercooled clouds, within the flanking line as they grow through the -10 °C temperature level, will initiate significant ice development **minutes before** it would otherwise occur.



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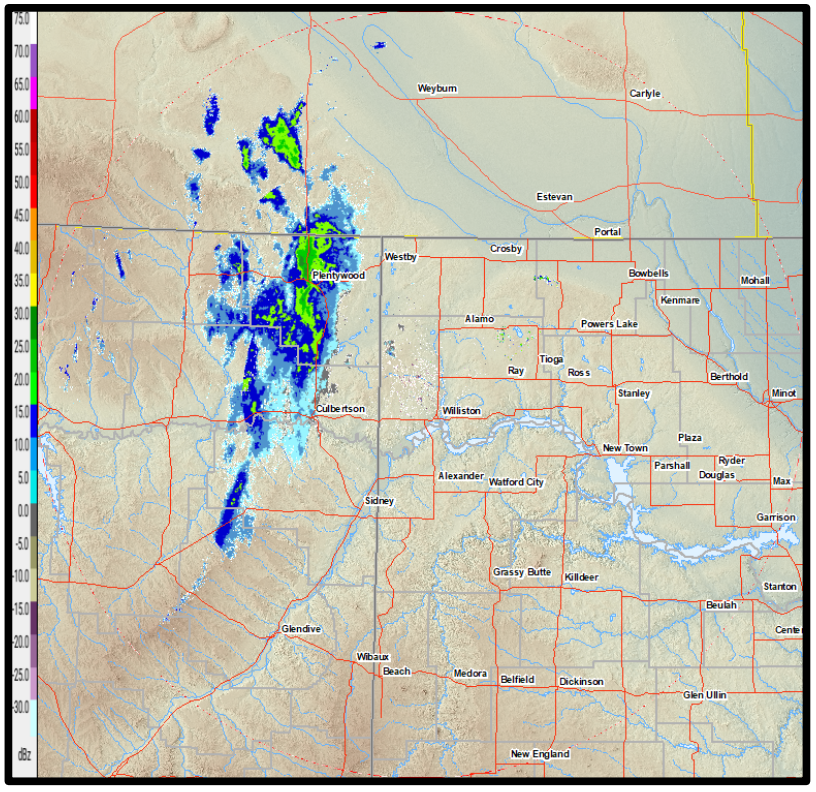
Cloud Seeding Hypothesis: Expected Results

- **Significant glaciation** of the treated feeder cloud is often the results.
- The release of the latent heat of fusion during glaciation resulting from seeding adds buoyancy to the feeder cloud.
- Much of the supercooled cloud water is converted to ice by either riming or deposition.
- Less supercooled liquid water remains in treated clouds than in untreated clouds.
- Precipitation mass within the feeder cloud is greatly enhanced.



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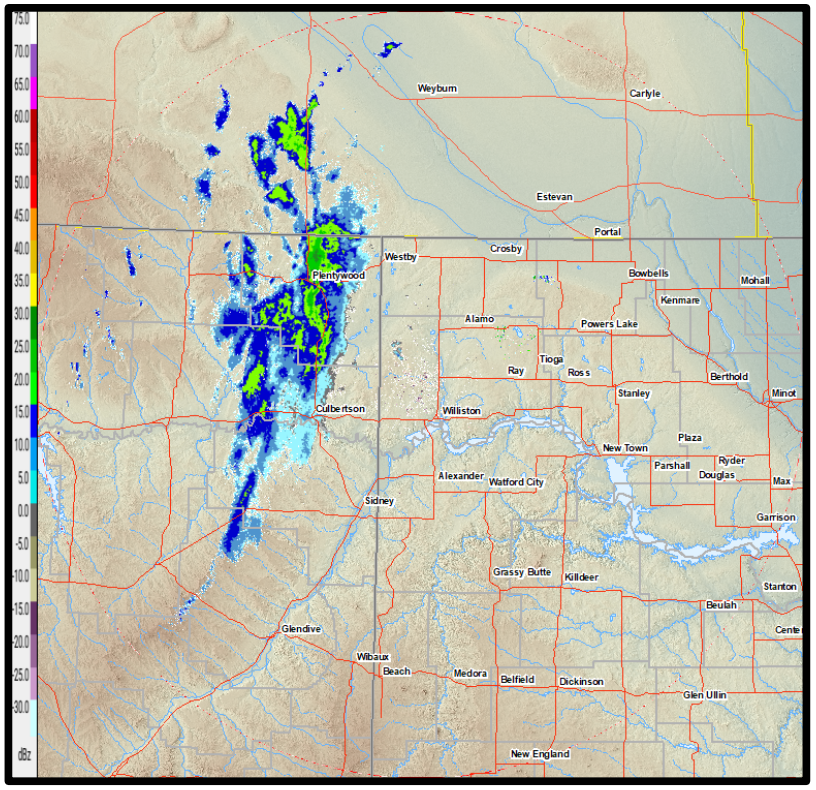
Cloud Seeding Hypothesis – Updrafts

- Updrafts in the treated feeder clouds remain significantly **weaker than those of the mature cell**.
- The developing hydrometeors (graupel) soon gain significant terminal velocities.



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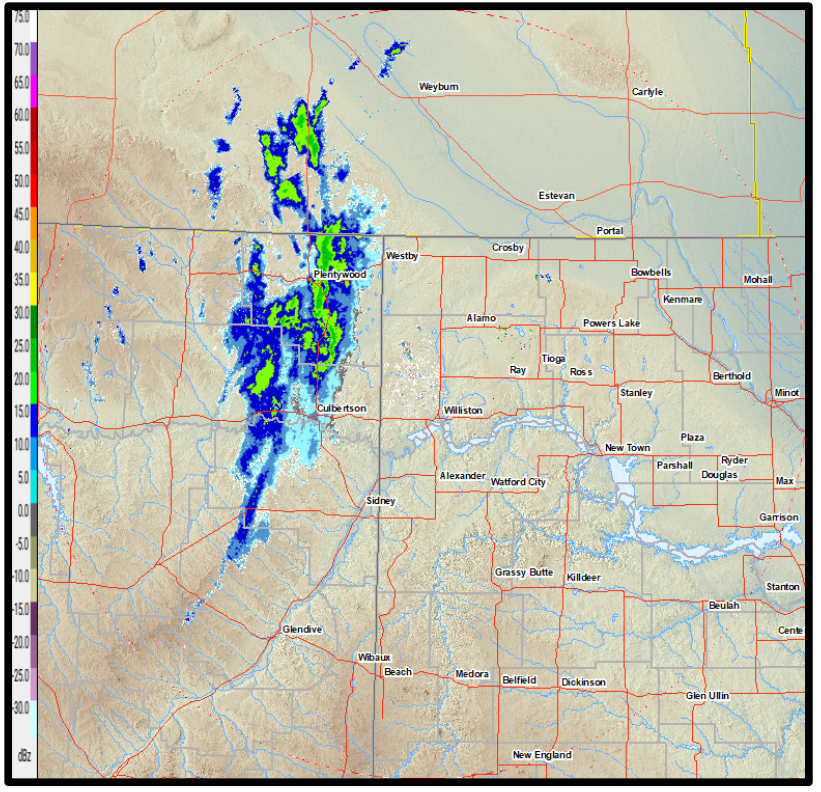
Cloud Seeding Hypothesis – Precipitation

- A developing precipitation shaft exists where there otherwise would have been a rain-free cloud base [**early rainout**].
- Because the hydrometeors are yet small (millimeters in diameter), **melting occurs** well before most particles reach the surface.



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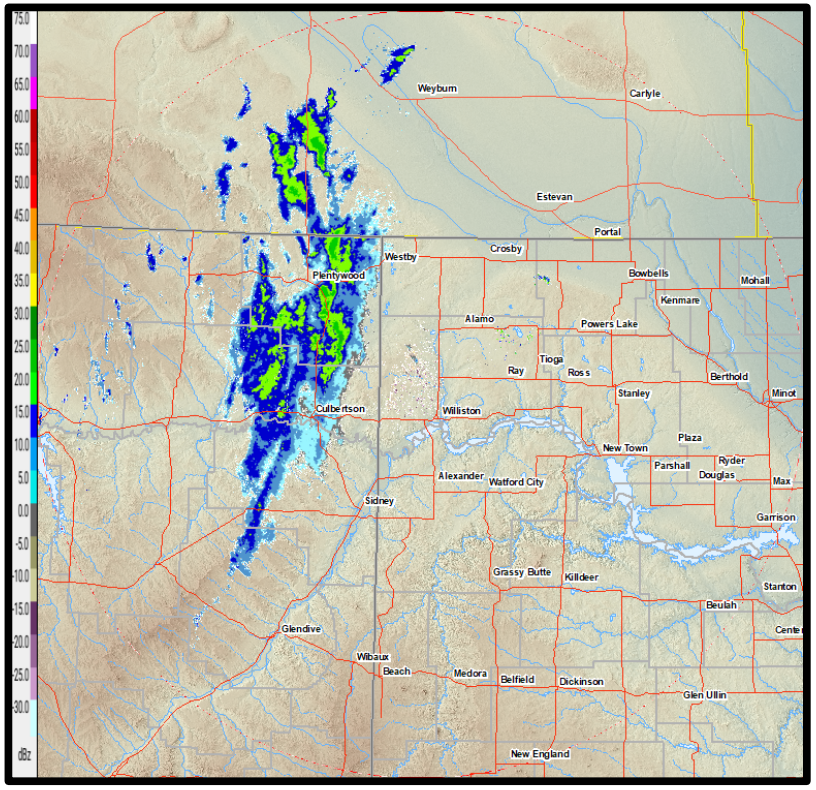
Cloud Seeding Hypothesis – Merger Occurs

- Because less Super-cooled Liquid Water (SLW) remains in the feeder cloud, **less freezing occurs within the main cell**.
  - Seeding accelerates the glaciation of the feeder cloud, **releasing the latent heat outside the mature cell**, depriving the main updraft of a source of energy.
- Buoyancy and strength of the mature updraft are reduced [**energy transfer**] **compared to similar natural clouds**.



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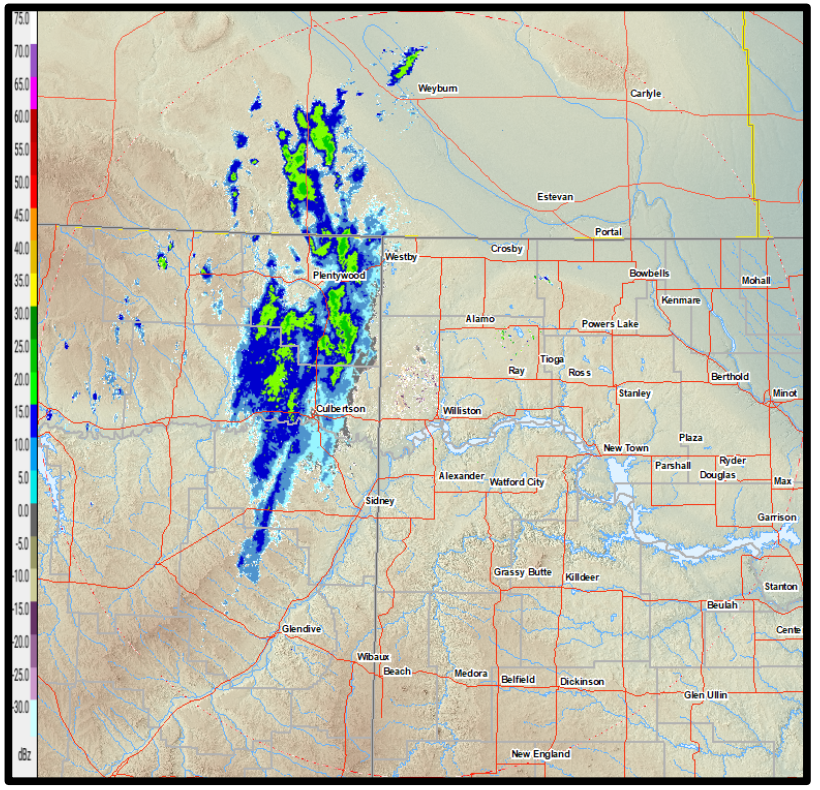
Cloud Seeding Hypothesis – Merger Occurs

- A significant population of precipitating hydrometeors is transported into, or ingested, by the mature cell as merger occurs.
- This results in additional mass loading, further slowing the mature updraft [**updraft loading**].



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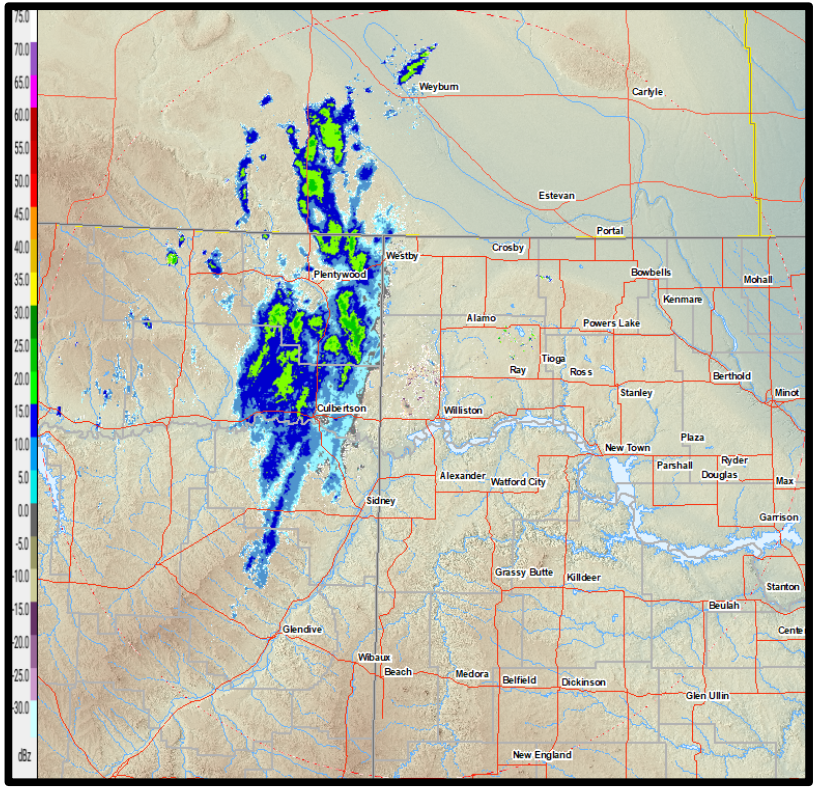
Cloud Seeding Hypothesis – Competition

- Hydrometeors produced by seeding continue to grow in the moisture-rich environment and “compete” with naturally occurring hydrometeors.
- This increased competition for supercooled liquid water necessitates natural hydrometeors in the seeded cloud growing smaller than they would naturally [**beneficial competition**].



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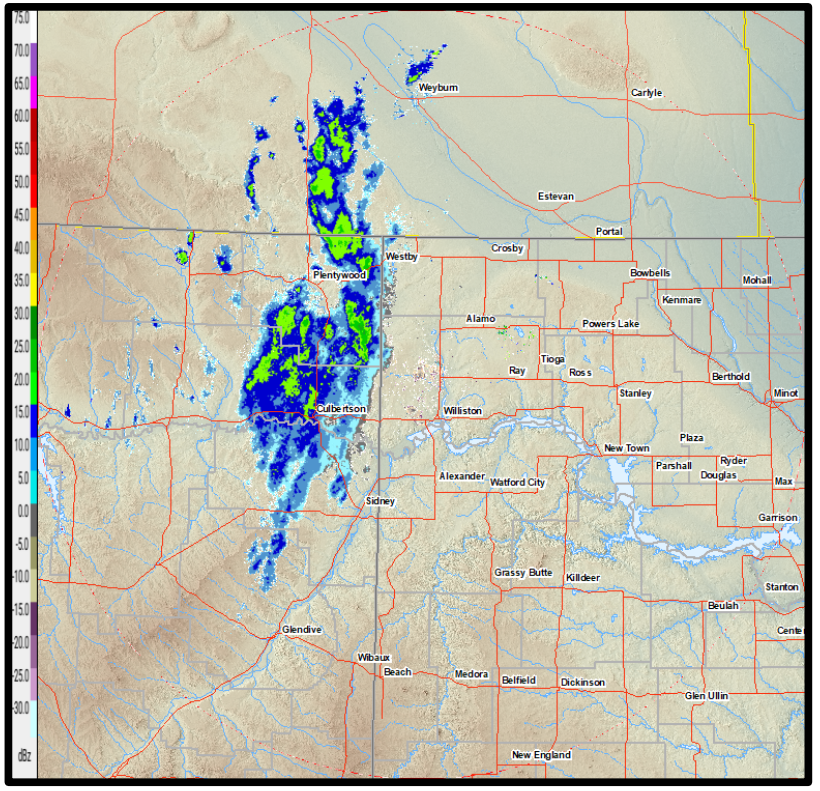
Cloud Seeding Hypothesis – Competition

- The large populations of precipitating ice-phase hydrometeors present in the feeder clouds at merger continue to **deplete the supercooled liquid** water resident within the mature updraft as rain-out continues [**trajectory lowering**].



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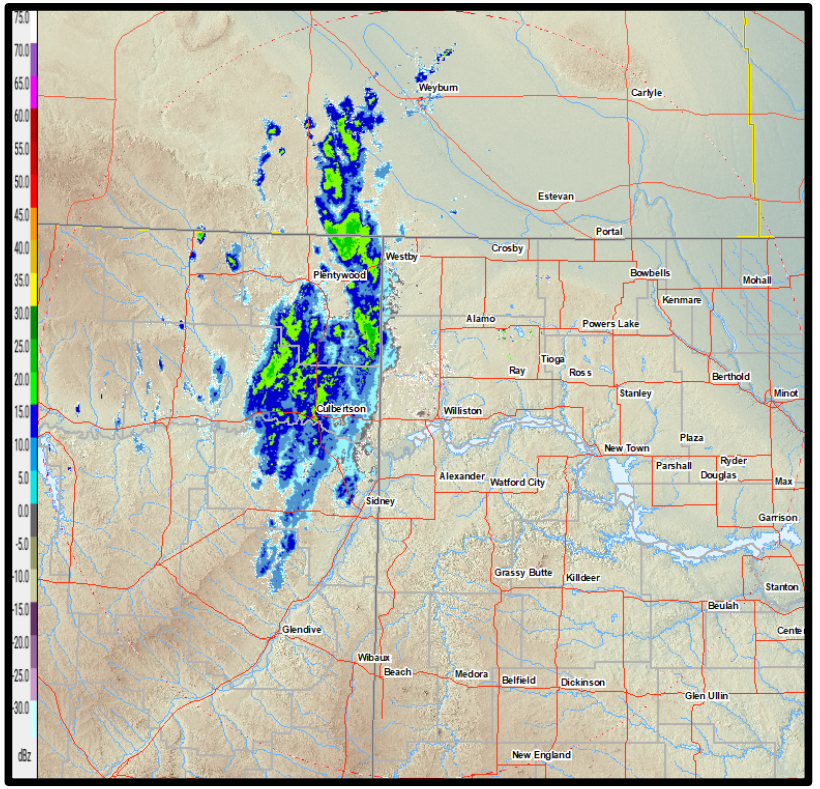
Cloud Seeding Hypothesis – Starvation

- The precipitation shaft [where the rain-free base previously existed] may partially restrict or block such inflow, reducing the "fuel supply" to the mature updraft [**fuel starvation**].



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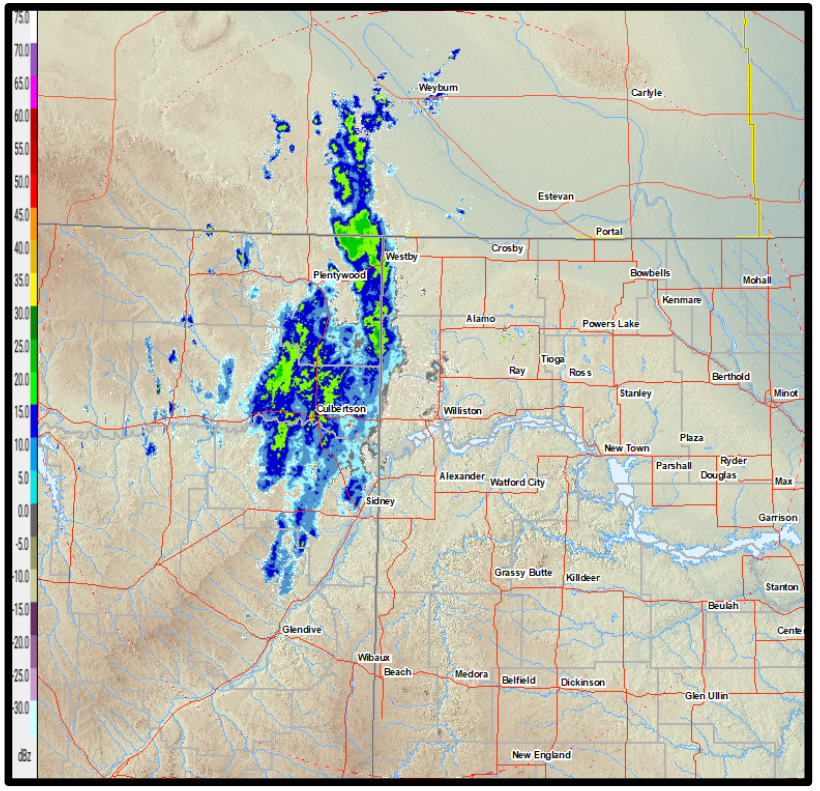
Cloud Seeding Hypothesis – Results

- Total supercooled liquid water is diminished in the mature updraft.
- The mature updraft is weakened by mass loading, reduced latent heat release within it, and possible fuel starvation.
- The environment is less favorable for the growth of hail.



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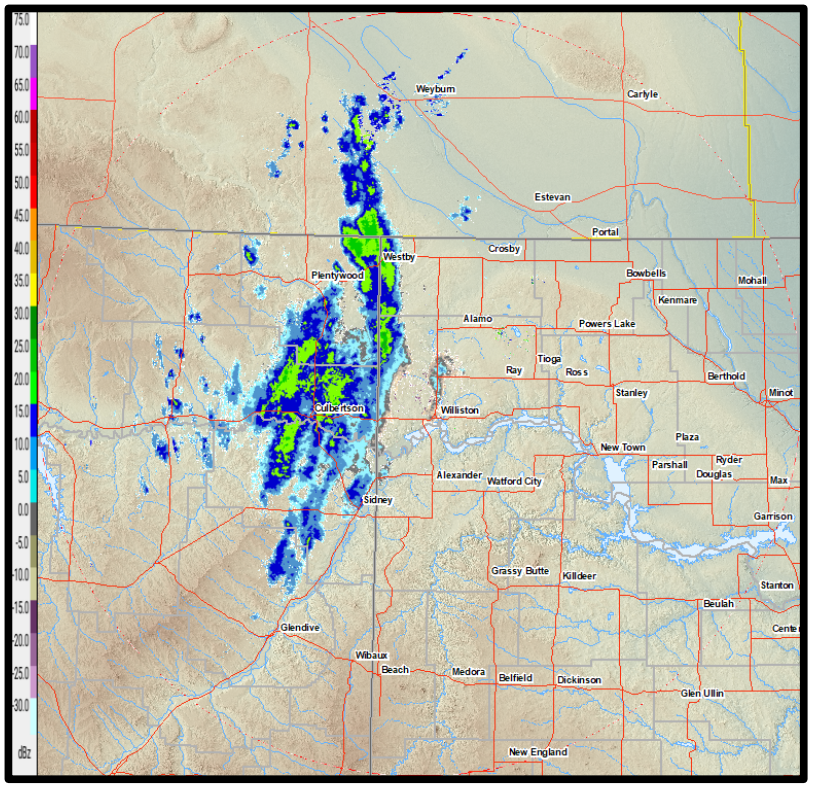
Cloud Seeding Hypothesis – More Rain

- The rain-shaft of the storm is broadened by early rain-out
- Some areas that would otherwise not have received measurable precipitation, now do precipitation as a result of seeding.
- Some areas that would have received locally intense precipitation receive less intense precipitation.



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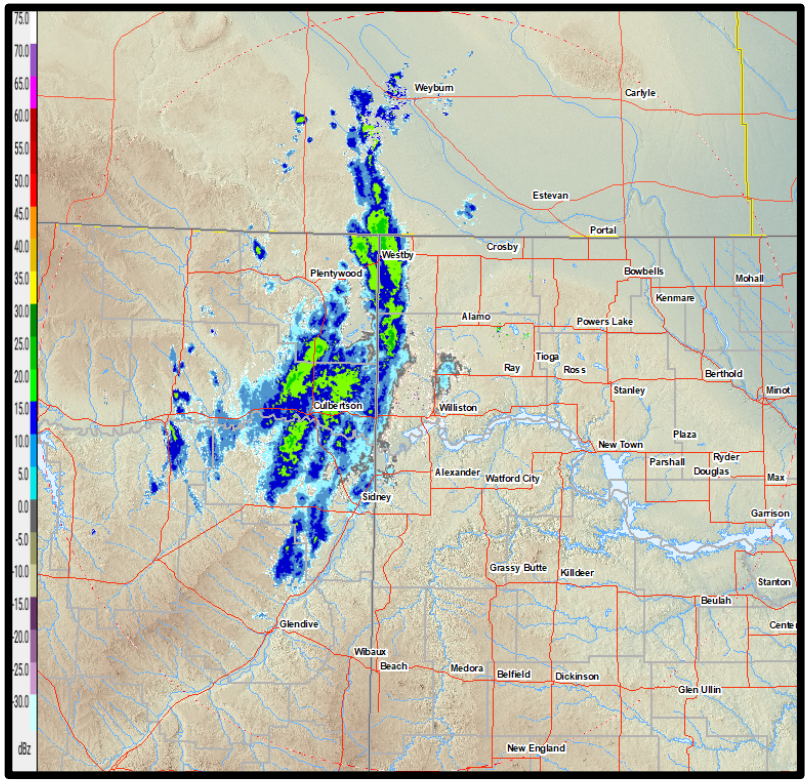
Cloud Seeding Hypothesis – Important Note

- Seeding the primary updraft of a mature storm has little effect on the storm, and will not effectively diminish hail development.



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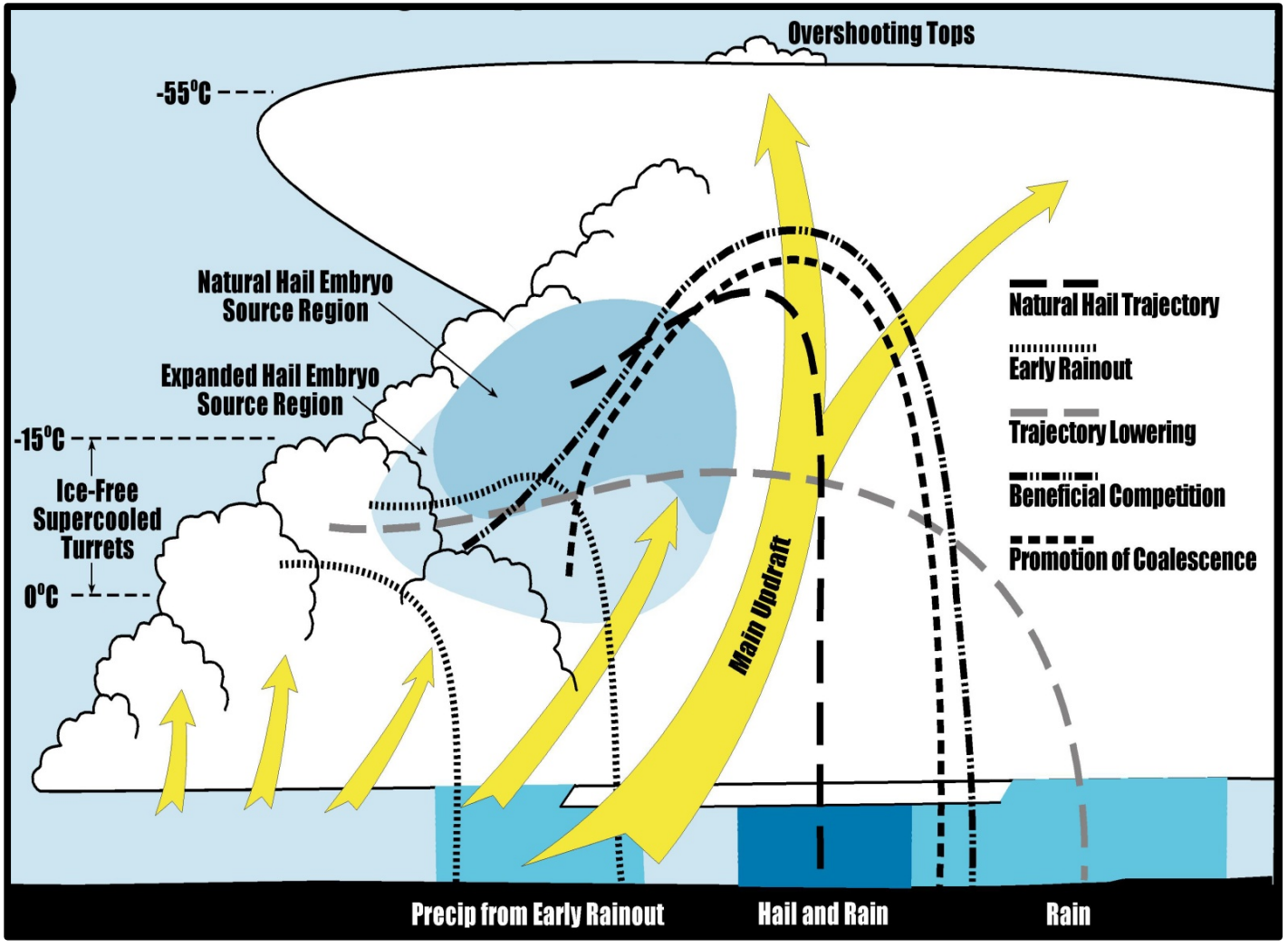

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