Electrical and Hydrometeor Structure of Thunderstorms that produce Upward Lightning

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Motivation

- The first studies based on observations of upward lightning (UL) are from the late 1930s and following decades, mainly at the Empire State Building and Mount San Salvatore in Switzerland.

- More recently, the use of lightning location systems (LLS) shows that the majority of UL is triggered by either a pure intra-cloud lightning or an in-cloud branching of positive polarity (positive cloud-to-ground) passing directly over tall (Warner et al. 2013; Saba et al. 2016; Warner et al. 2014; Schumann 2016), and a very small portion are self-initiated UL (Wang et al. 2008).

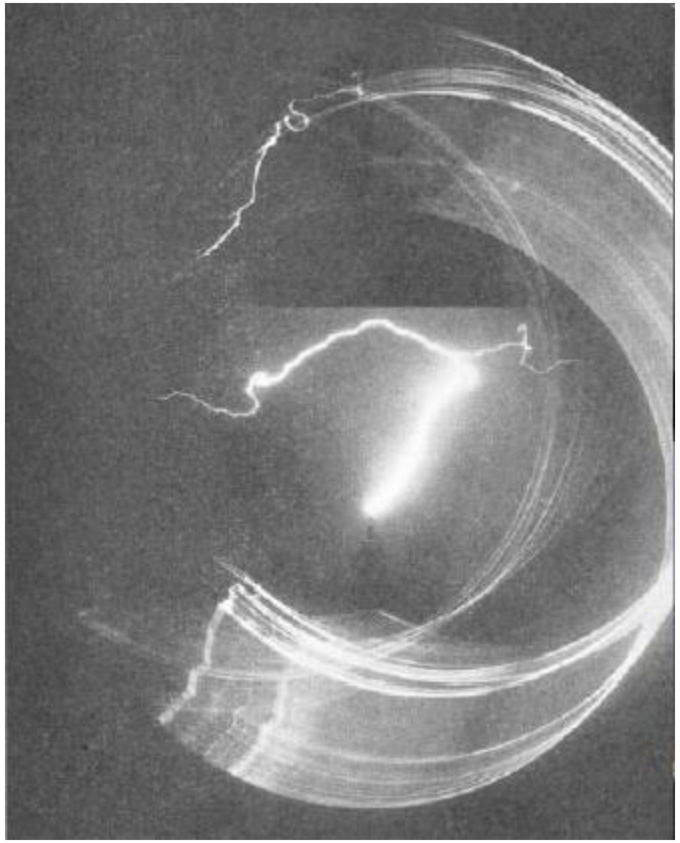


Fig 1 – UL triggered at the top of the Empire State Building (from McEachron 1939).

Motivation

- The studies mentioned systematically report that UL is observed in the decaying stages of the storm.
- This preferred region of stratiform precipitation where the IC branching of the parent CGs for UL propagates is indicative of a lower charge center.
- The strength and extent of the stratiform region is related to microphysical characteristics of the storm.

Fig 2 - UL triggered at the top of towers over Rapid City, SD USA (from Warner et al. 2013).

Objective

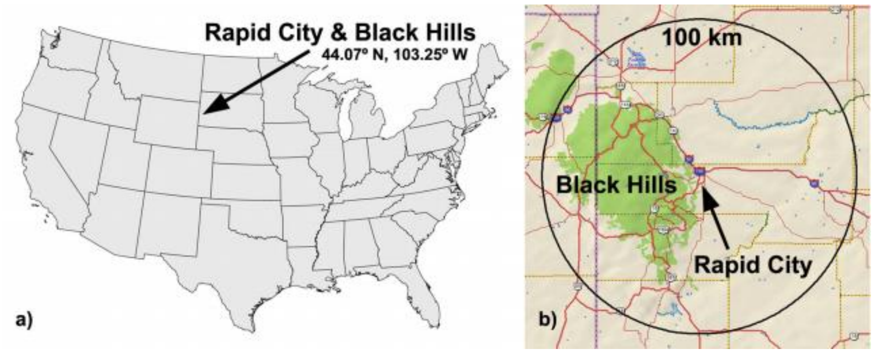
- This study aims to determine the hydrometeor characteristics of thunderstorms that produce upward lightning, especially in the lower layers of the stratiform region where the bidirectional leader of the parent CG propagates.

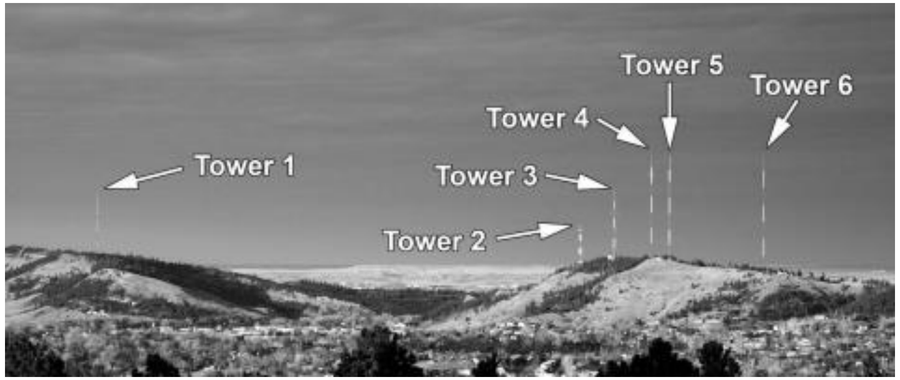
The following questions are addressed:

- What types of hydrometeors are present in the stratiform region?
- Are the stratiform layers uniform within the storm?
- Can they determine the path of the parent CG bidirectional leader and of the upward lightning?
- Can we infer or suggest a charging mechanism at the lower stratiform layers?

Location

Rapid City, SD USA





Sao Paulo, SP Brazil

Fig 3 – Location of Rapid City Towers (from Warner et al. 2013). Location of Jaragua peak in Sao Paulo city and the two main TV towers.

Data and Methods

Rapid City, SD USA

- 10 thunderstorms -> 28 UL
- S-band KUDX WSR-88D radar
- UPLIGHTS Lightning Mapping Array (LMA)

Sao Paulo, SP Brazil

- 17 thunderstorms -> 56 UL
- SPOL radars from FCTH
- BrasilDat total lightning and STARNET cloud-to-ground data

- Hydrometeor Identification (HID) using polarimetric radar data
- Partition reflectivity into convective-stratiform using the Steiner et al. (1995) algorithm.
- Charge center structure inferred from LMA data

Rapid City, SD USA

22 Jun 2014 – 3 UL

- Horizontal reflectivity from S-band KUDX WSR-88D radar

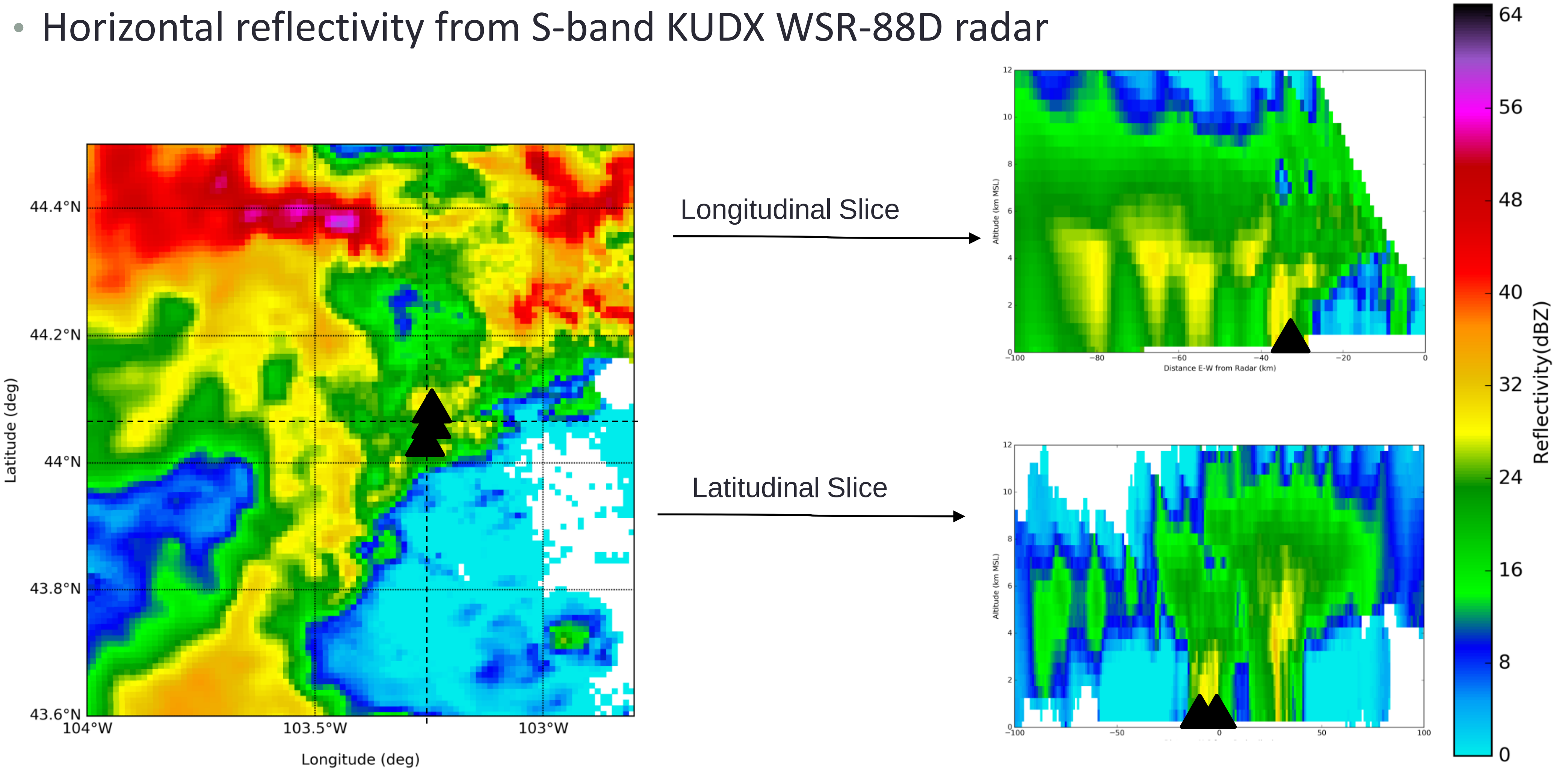


Fig 4 - Horizontal reflectivity (dBZ) from S-band KUDX WSR-88D radar at 3.0 km and cross sections at 0221 UTC. Black triangle indicates the towers.

Rapid City, SD USA

22 Jun 2014 – 3 UL

- HID and Steiner et al. (1995) classification

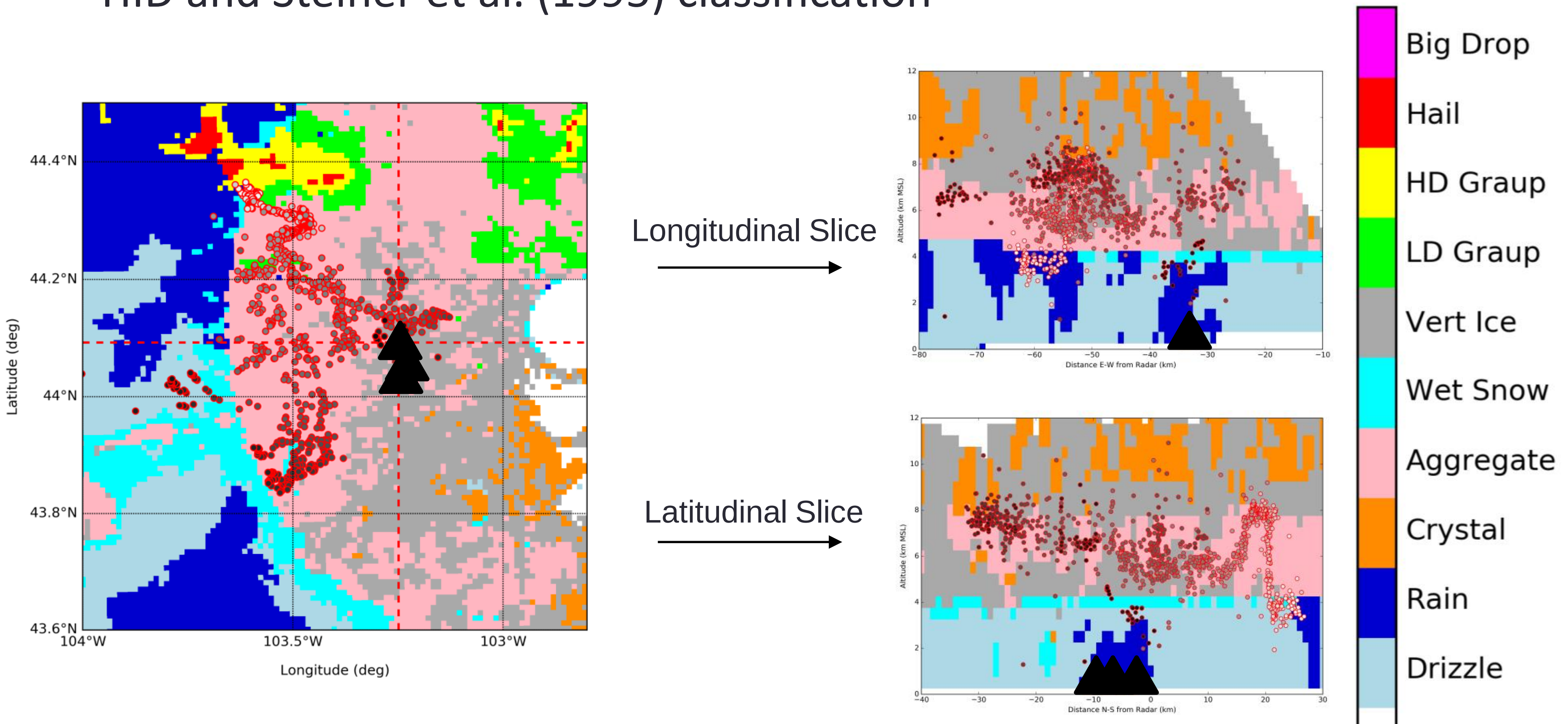


Fig 5 – HID from S-band KUDX WSR-88D radar at 4.5 km and cross sections at 0221UTC and LMA VHF source points (grayscale). Black triangles indicates the towers.

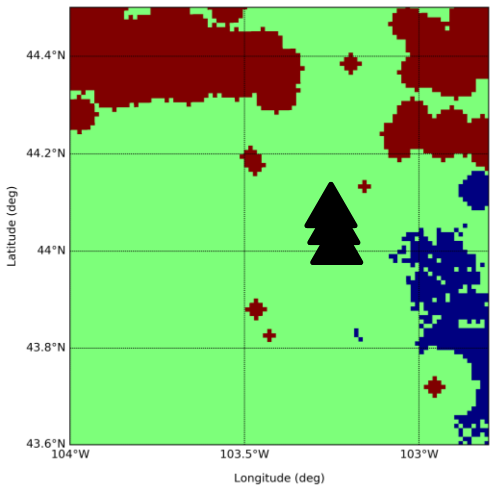


Fig 6 - Partition reflectivity into convective (brown)-stratiform (green) using the Steiner et al. (1995) algorithm at 3.0 km. Unclassified (blue).

Rapid City, SD USA

28 Jun 2014 – 1 UL

- Horizontal reflectivity from S-band KUDX WSR-88D radar

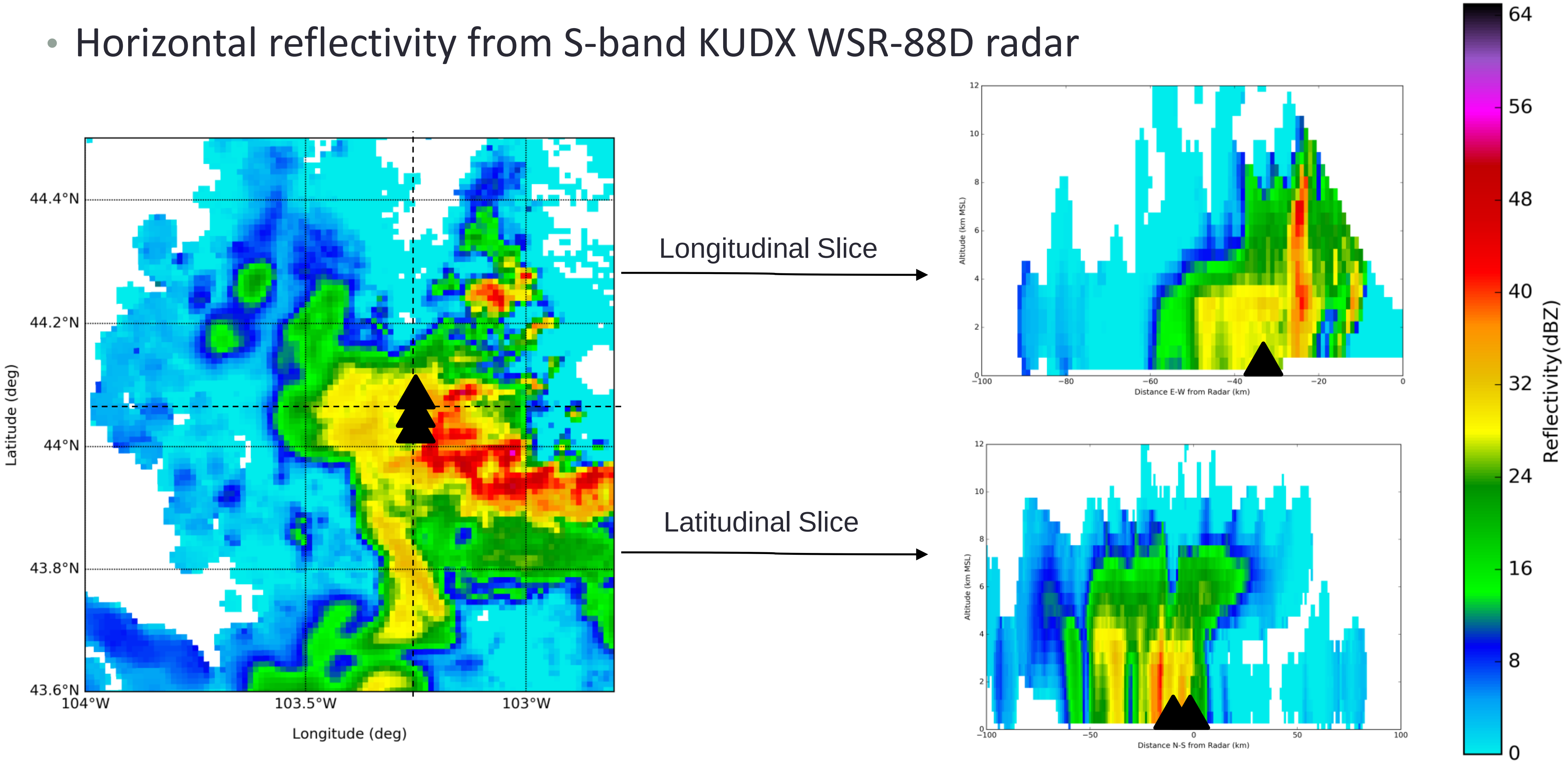


Fig 7 - Horizontal reflectivity (dBZ) from S-band KUDX WSR-88D radar at 3.0 km and cross sections at 2347 UTC. Black triangle indicates the towers.

Rapid City, SD USA

28 Jun 2014 – 1 UL

- HID and Steiner et al. (1995) classification

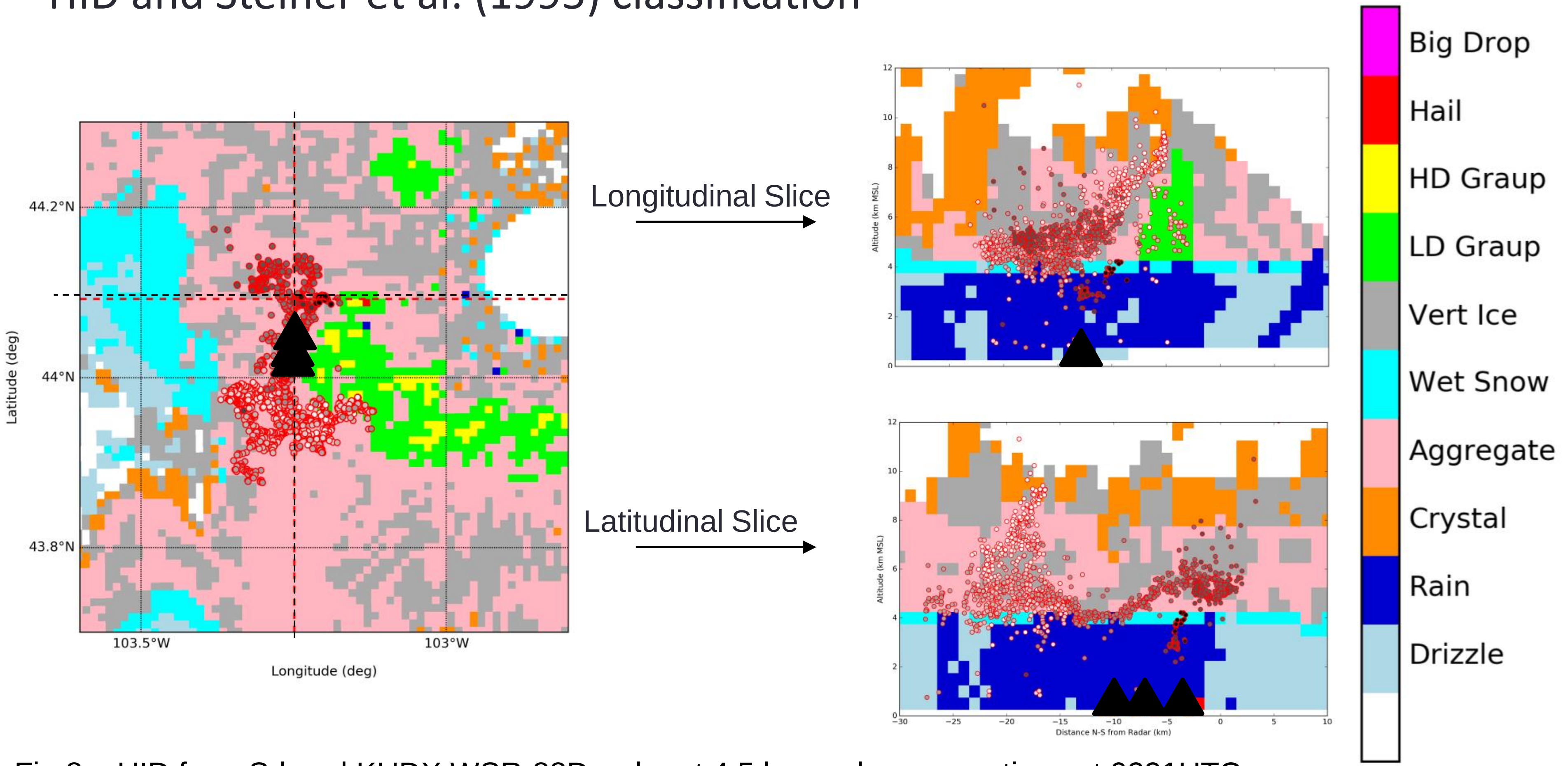


Fig 8 – HID from S-band KUDX WSR-88D radar at 4.5 km and cross sections at 0221UTC and LMA VHF source points (grayscale). Black triangle indicates the towers.

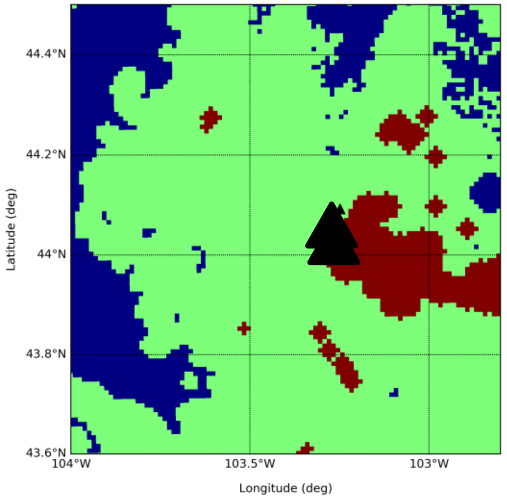


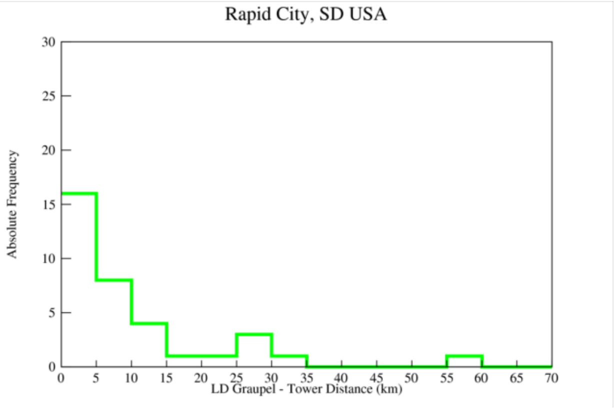
Fig 9 - Partition reflectivity into convective (brown)-stratiform (green) using the Steiner et al. (1995) algorithm at 3.0 km. Unclassified (blue).

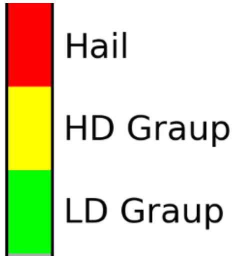
Rapid City, SD USA

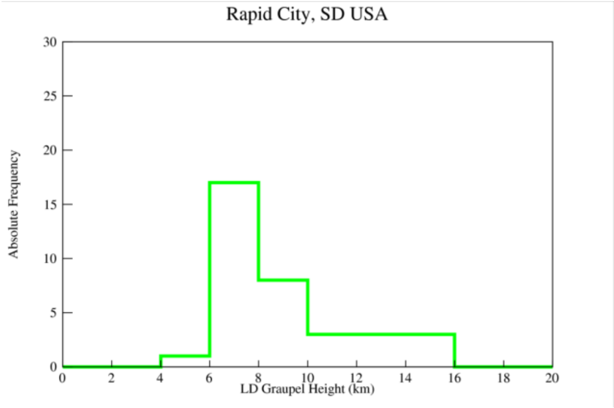
All Cases

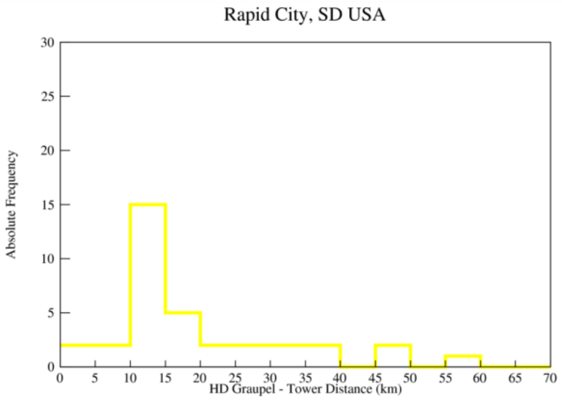
Minimum Graupel-Hail Distance

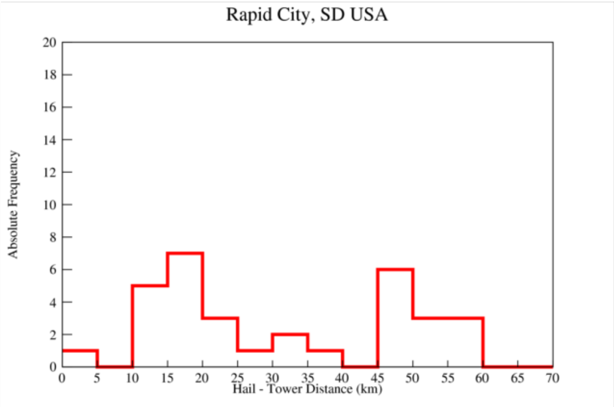
Maximum Graupel-Hail Height

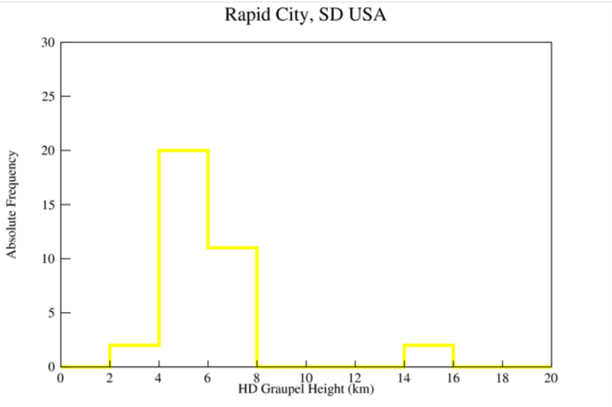












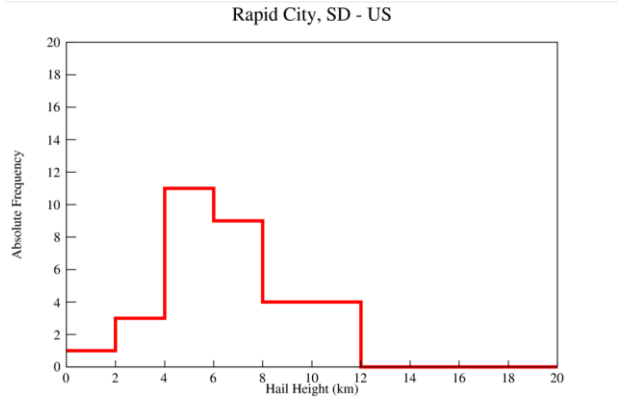


Fig 10 – Histograms for Minimum Graupel-Hail distance and Maximum Graupel-Hail height for all cases analised in Rapid City, SD USA.

Sao Paulo, SP Brazil

08 Sep 2015 – 6 UL

- Horizontal reflectivity from SPOL radar from FCTH

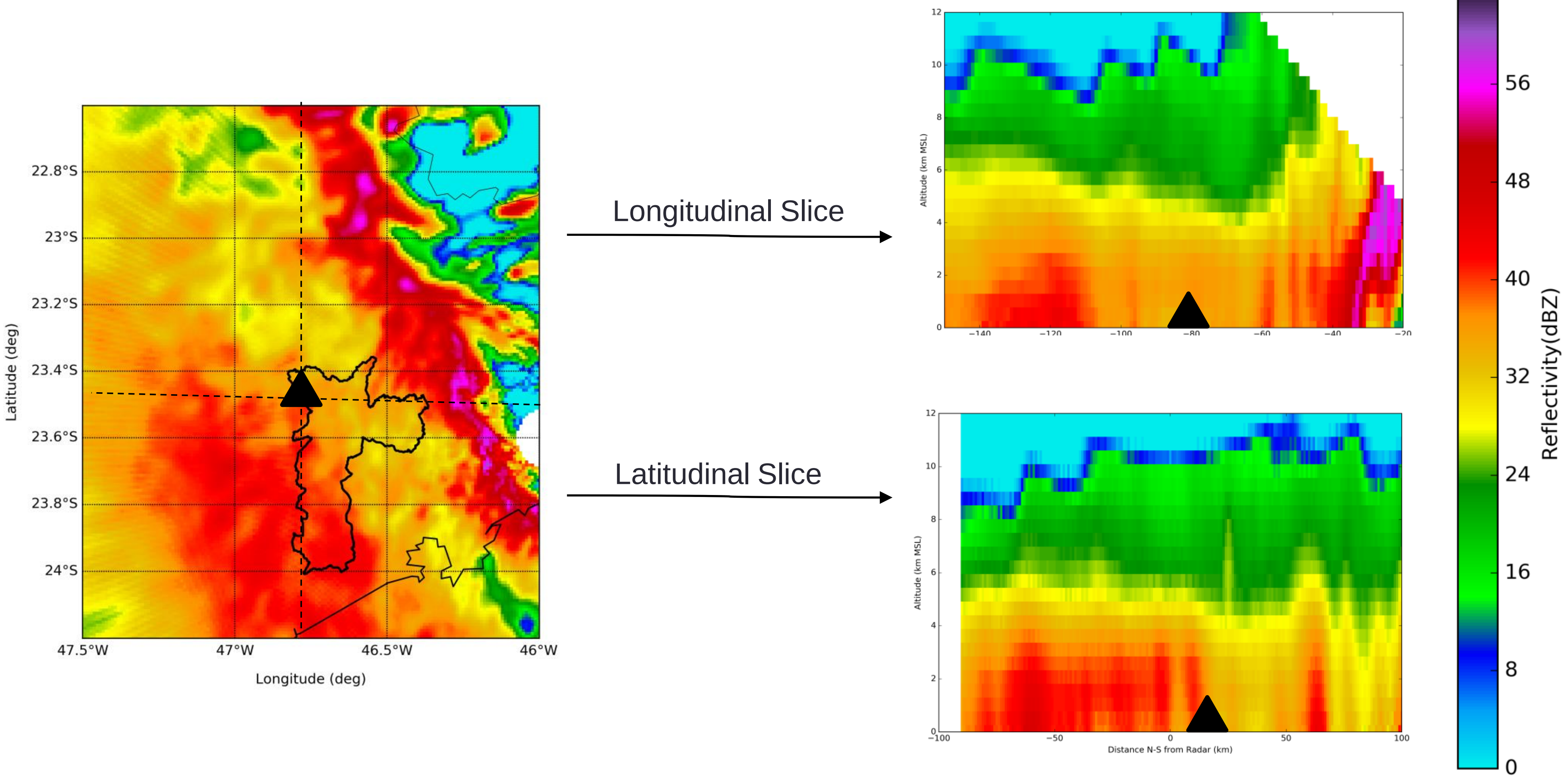


Fig 11 - Horizontal reflectivity (dBZ) from SPOL radar from FCTH at 3.0 km and cross sections at 2005 UTC. Black triangle indicates the towers.

Sao Paulo, SP Brazil

08 Sep 2015 – 10 UL

- HID and Steiner et al. (1995) classification

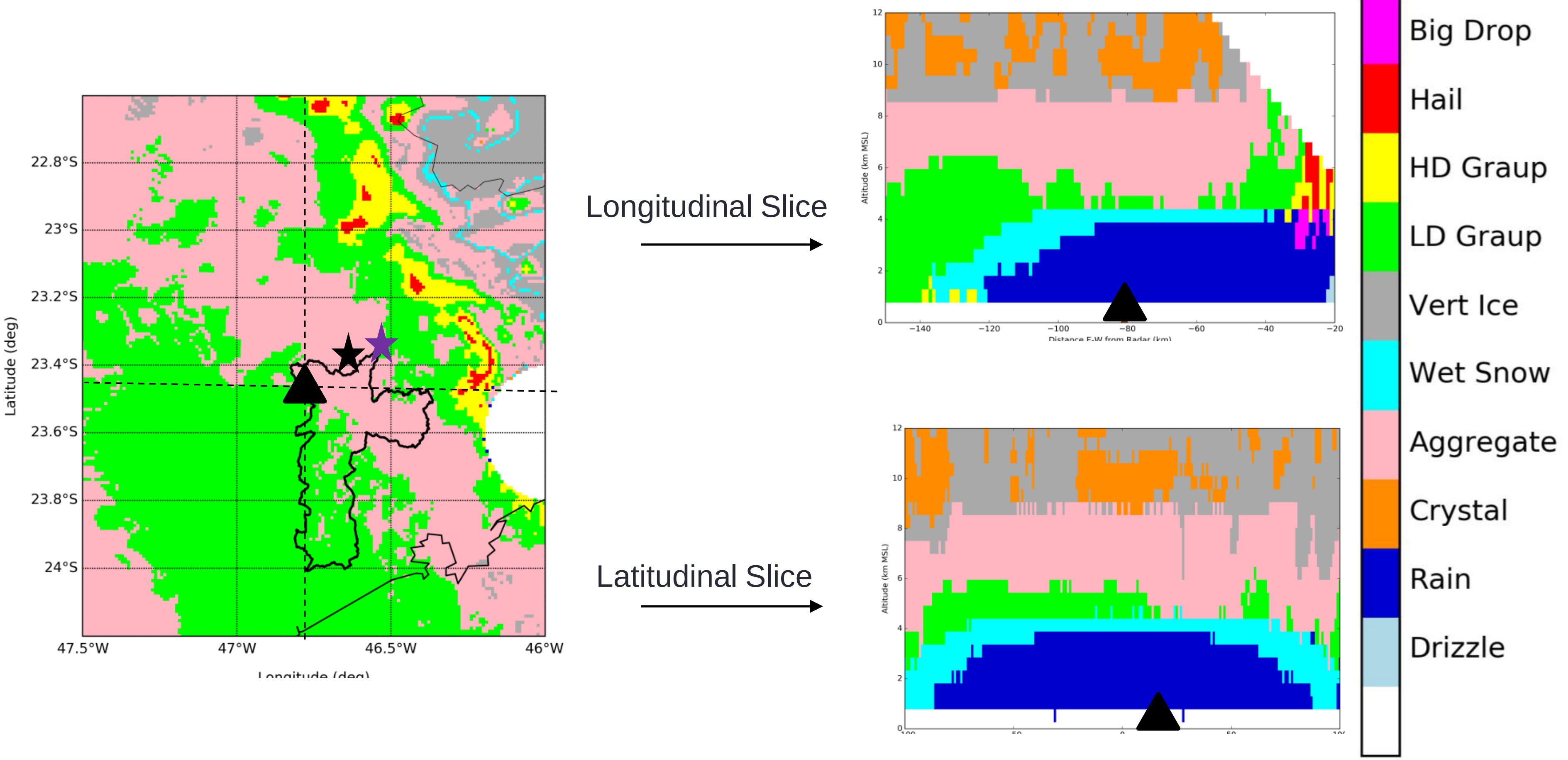


Fig 12 - HID from SPOL radar from FCTH at 4.5 km and cross sections at 2005UTC and BrasilDat total lightning points (stars – black: CG, purple: IC). Black triangle indicates the towers.

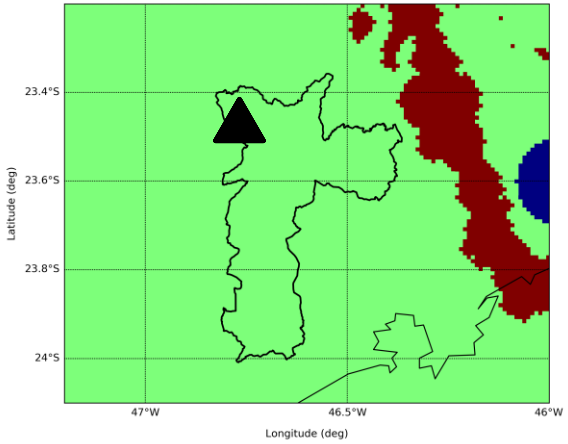


Fig 13 - Partition reflectivity into convective (brown)-stratiform (green) using the Steiner et al. (1995) algorithm at 3.0 km. Unclassified (blue).

Sao Paulo, SP Brazil

19 Dec 2015 – 10 UL

- Horizontal reflectivity from SPOL radar from FCTH

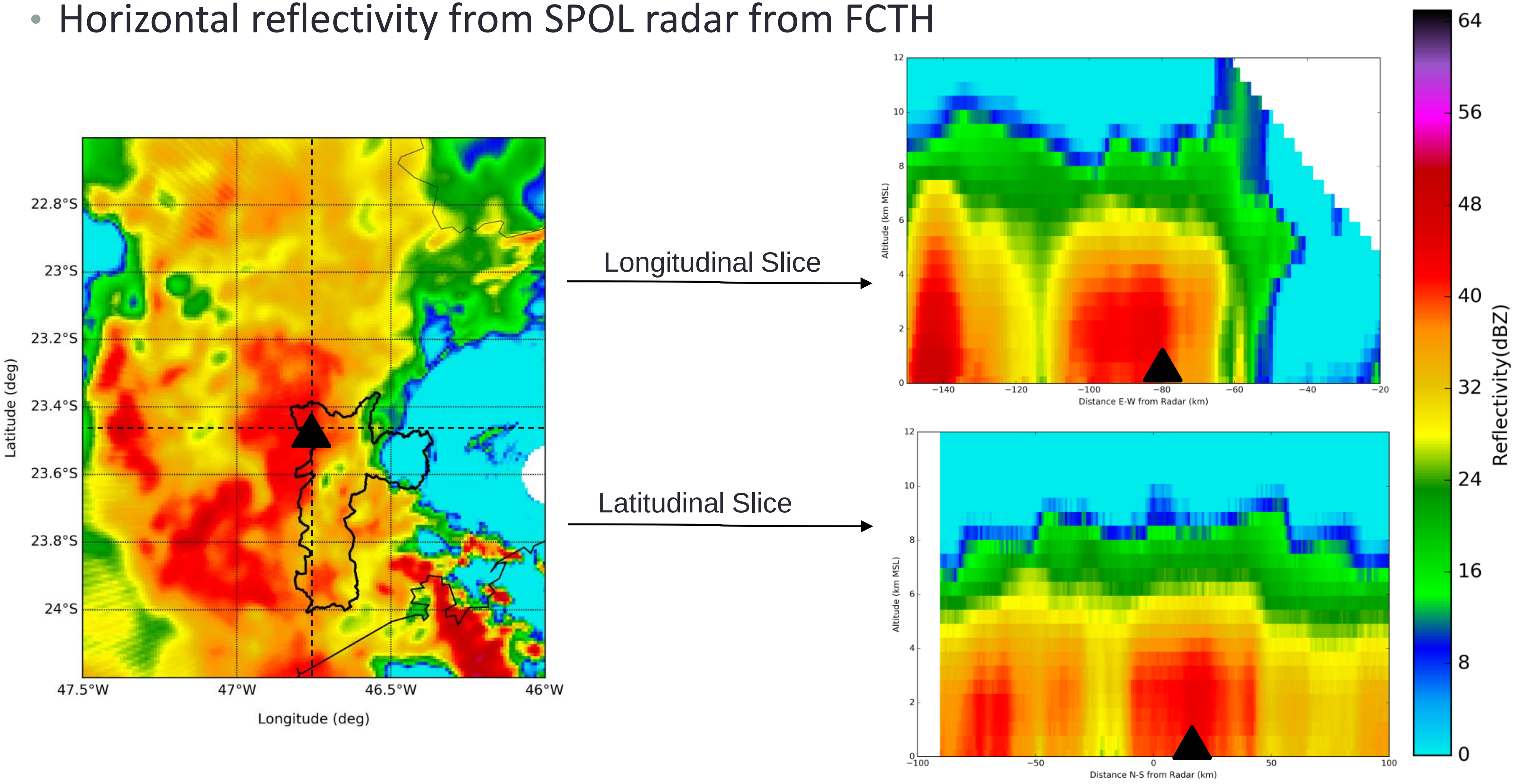
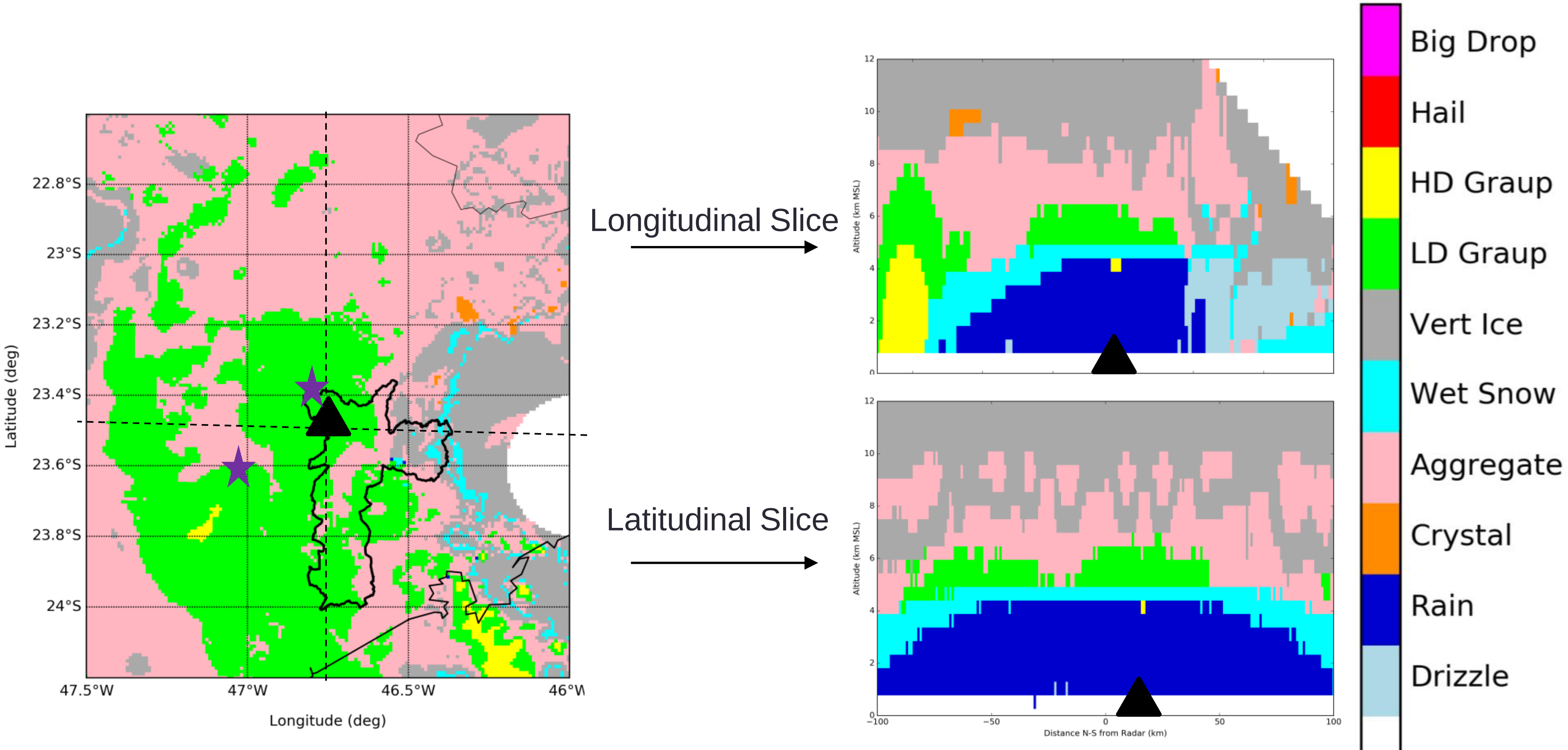


Fig 14 - Horizontal reflectivity (dBZ) from SPOL radar from FCTH at 3.0 km and cross sections at 2210 UTC. Black triangle indicates the towers.

Sao Paulo, SP Brazil

19 Dec 2015 – 6 UL

- HID and Steiner et al. (1995) classification



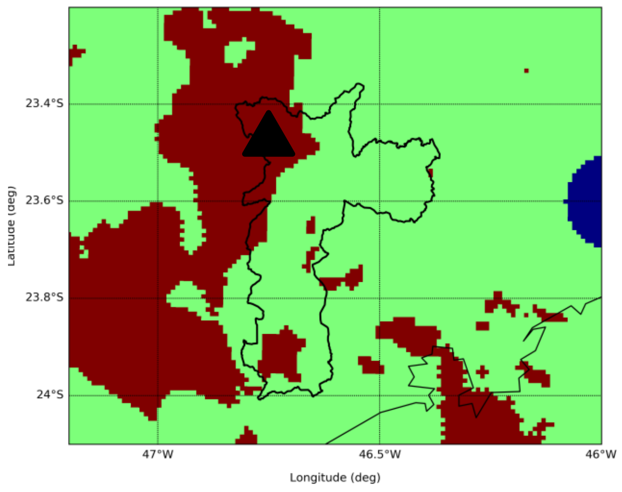


Fig 16 - Partition reflectivity into convective (brown)-stratiform (green) using the Steiner et al. (1995) algorithm at 3.0 km. Unclassified (blue).

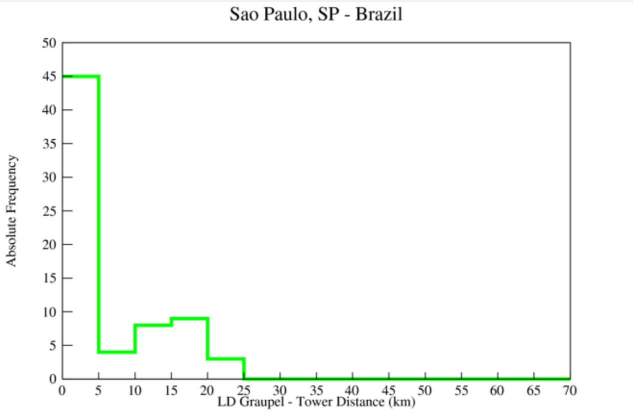
Fig 15 - HID from SPOL radar from FCTH at 5.0 km and cross sections at 2210UTC and BrasilDat total lightning points (stars – black: CG, purple: IC). Black triangle indicates the towers.

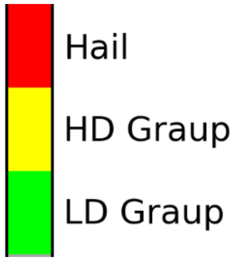
Sao Paulo, SP Brazil

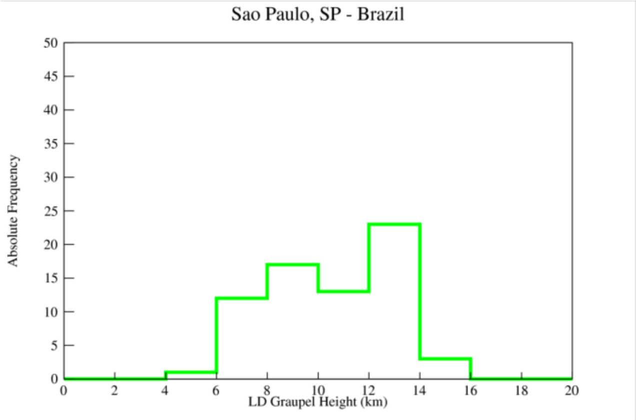
All Cases

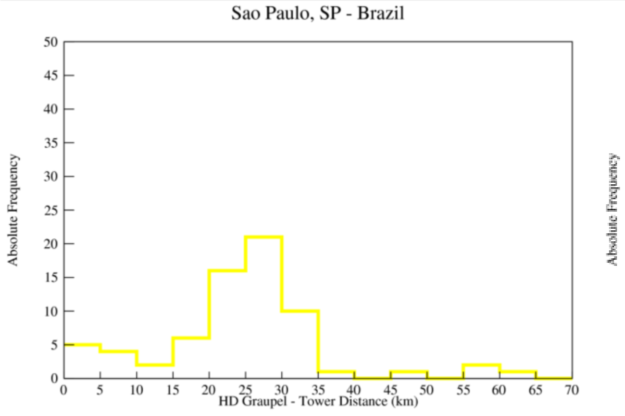
Minimum Graupel-Hail Distance

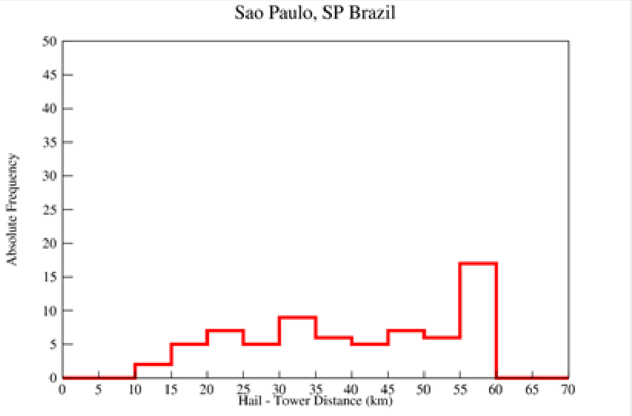
Maximum Graupel-Hail Height

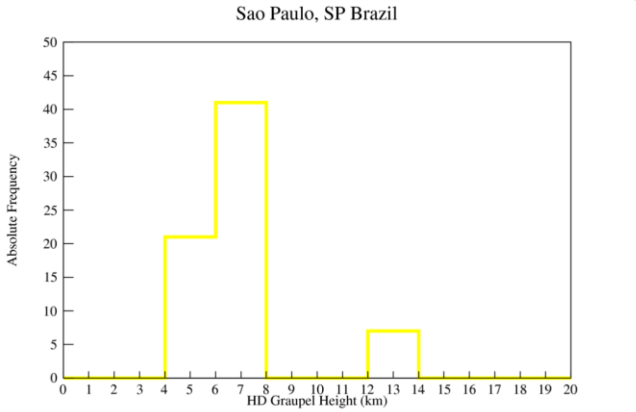












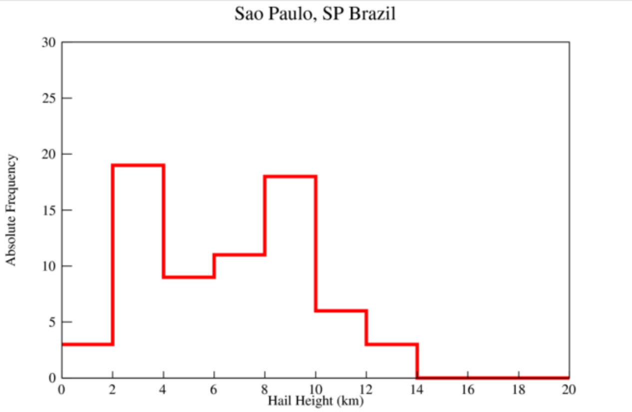


Fig 17 – Histograms for Minimum Graupel-Hail distance and Maximum Graupel-Hail height for all cases analised in Sao Paulo, SP Brazil.

Conclusion

- In most cases, LD graupel above the towers indicated the presence of light convective processes in the stratiform part of the convective systems, which may be giving the necessary support to horizontal leader propagation that triggers UL.
- A few events had classified HD graupel immediately above the towers, suggesting either more pronounced convection or possibly melting graupel. However, usually HD graupel was displaced more than 10 km away
- In the 84 UL registered events, there was never hail right over the towers - minimum hail distance ranged from 10 to 60 km between both locations.

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