

Storm Dynamics Leading to Rare and Severe Hailstorms: Case Studies over Singapore

Isaac Tan^{1,2}



Cathryn Birch¹, Simon Peatman¹, Muhammad Eeqmal Hassim², Wee Kiong Cheong², Kai Yuan Zheng², Ryan Neely¹, Lindsay Bennette¹, Freya Addison¹

¹University of Leeds, UK

²Meteorological Service Singapore, Singapore

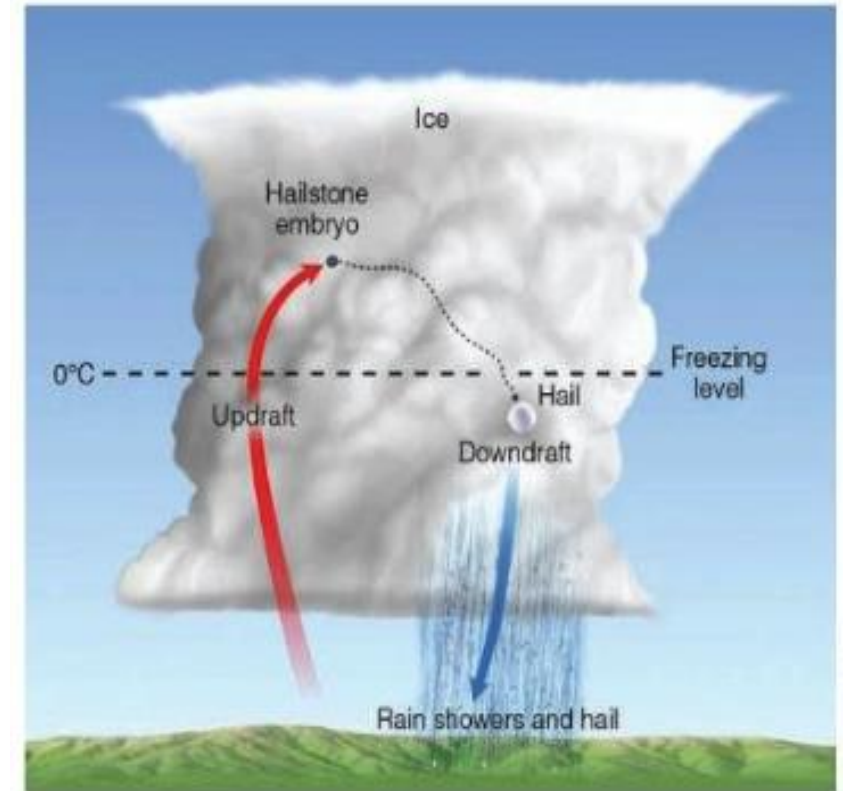
- Formation of hail and rarity of hail occurrences over Singapore
- Study aims and methods
- Pre-convective environmental profiles
- Further analysis of in-situ and remote sensing observations
- Summary

How is hail formed?



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- Hail growth via the accretion of supercooled liquid water droplets in intense thunderstorms (Ahrens and Henson, 2016).
- Violent updrafts carry graupel particles aloft well above the freezing level, which collide with supercooled droplets and grow at their expense (Kumar, 2017).
- Tilted updrafts promote lateral growth of graupel – more time above freezing level.
- Dry mid-level tropospheric layer reduces hail melt as it falls.



Simple hail schematic (Ahrens and Henson, 2016, Fig. 7.31)

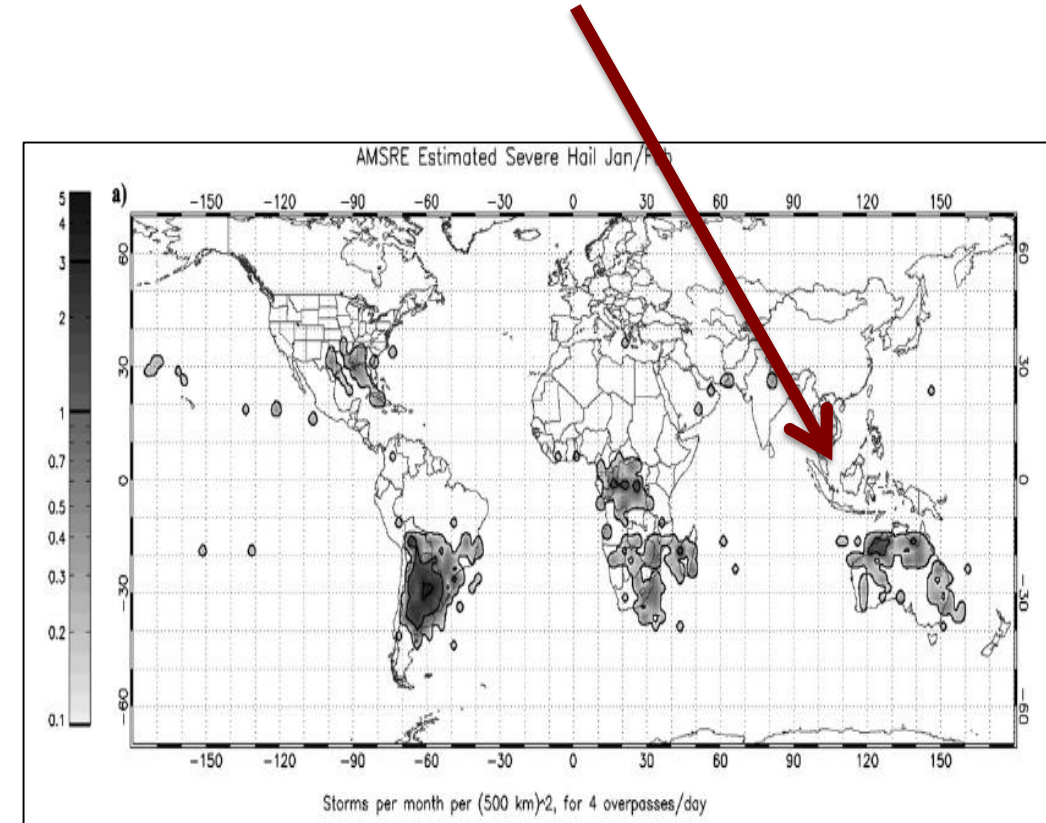
The rarity of hail over Singapore



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- Frequency of hail decreases seaward, poleward, and equatorward (Lemons, 1942).
- Singapore is a small island surrounded by sea – generally unfavourable for hail formation.
- Tropical regions characterised by warmer and thicker atmosphere – higher freezing level (MSS 2018b).
- Only 6 cases of hail reported at the surface between 2008-2018.
- Almost no literature that specifically investigates hail occurrences over Singapore and the wider Maritime Continent region.

Singapore



Estimated severe hail global climatology (Cecil and Blankenship, 2012, Fig. 7a)

- To understand the dynamical and microphysical processes that might have resulted in rare hail occurrences over Singapore:
 - Favourable synoptic conditions for hailstorms in tropical Southeast Asia.
 - Analysis of ground-based remote sensing and in-situ observations
- Is it possible to forecast hailstorm events in this region?



- ERA-Interim reanalysis data (1979-2018) and University of Wyoming Skew-T soundings – pre-convective environment (all 6 hail cases).
- Ground-based weather station data – surface observations during hail days.
- Weather radar – S-band, Doppler, and Dual-polarisation to identify the hail core based on a variety of parameters.
- Wind profiler radar – vertical profile of winds from the surface to ~650 hPa.
- Lightning detection sensors – to investigate the spatial lightning density

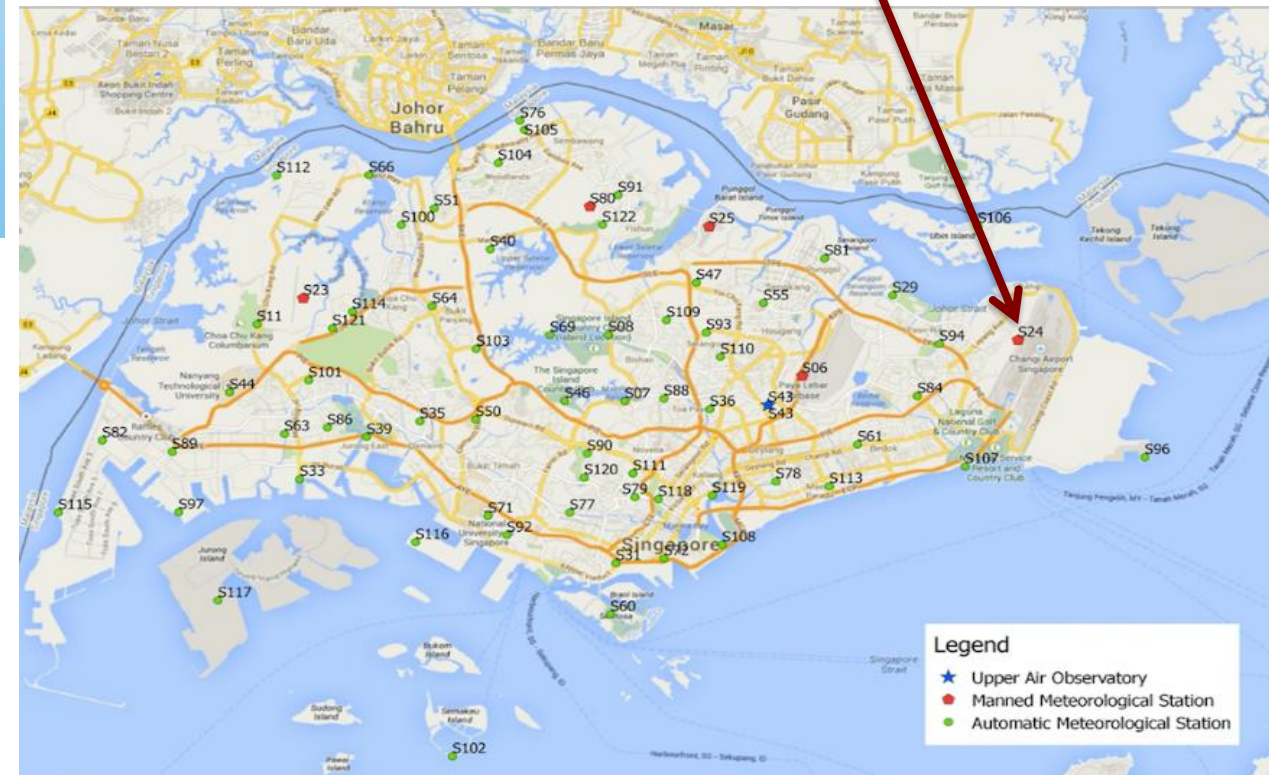


Weather radar and wind profiling data from the Changi Climate Station over eastern Singapore.

Four lightning detection sensors over the northern, southern, eastern, and western regions.

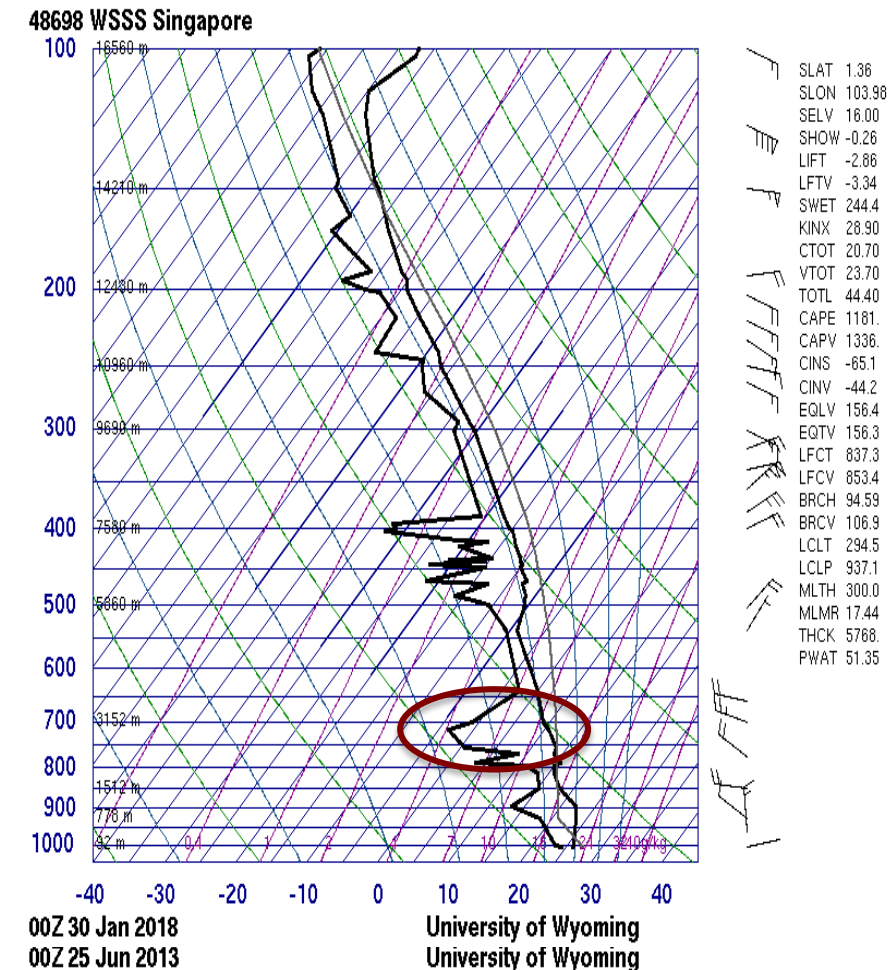
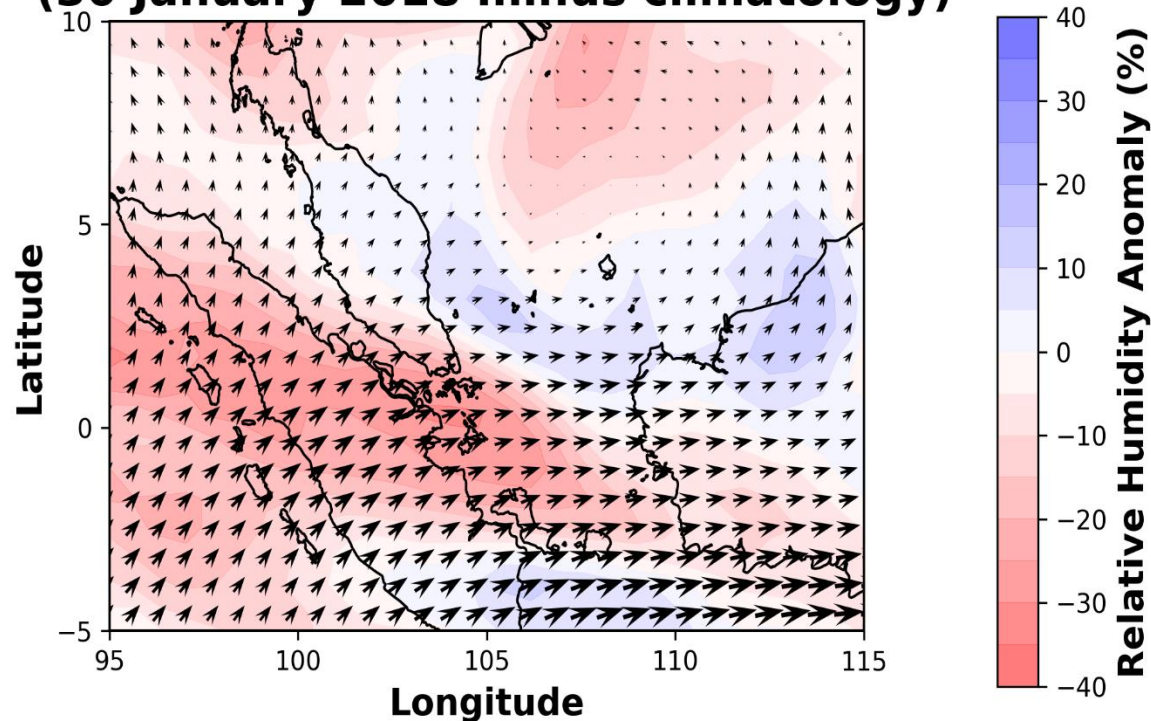
Ground-based weather station data taken from several sites in each of the 5 sectors of Singapore for 2 detailed case studies on 25 June 2013 and 30 January 2018

Changi Climate Station



- Mid-level dry intrusions – negative relative humidity (RH) anomalies as the key ingredient for hail to reach the surface.

ERA-Interim Relative Humidity Anomalies at 700 hPa (30 January 2018 minus climatology)

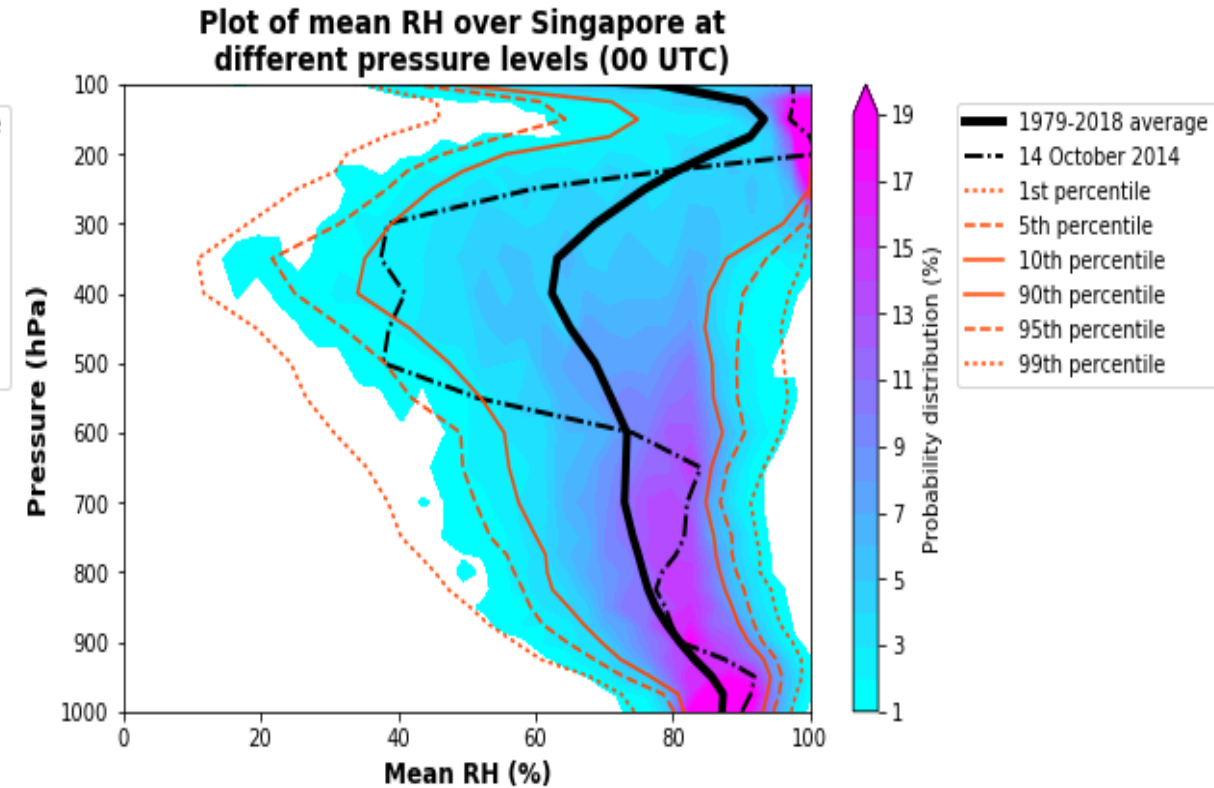
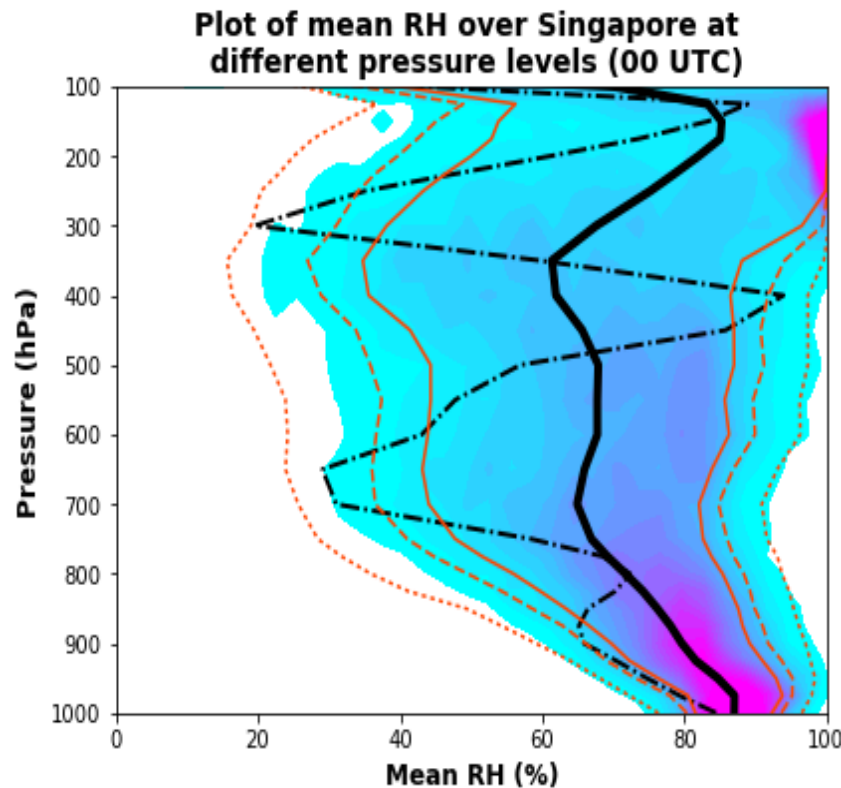


Pre-convective environmental profiles (2)

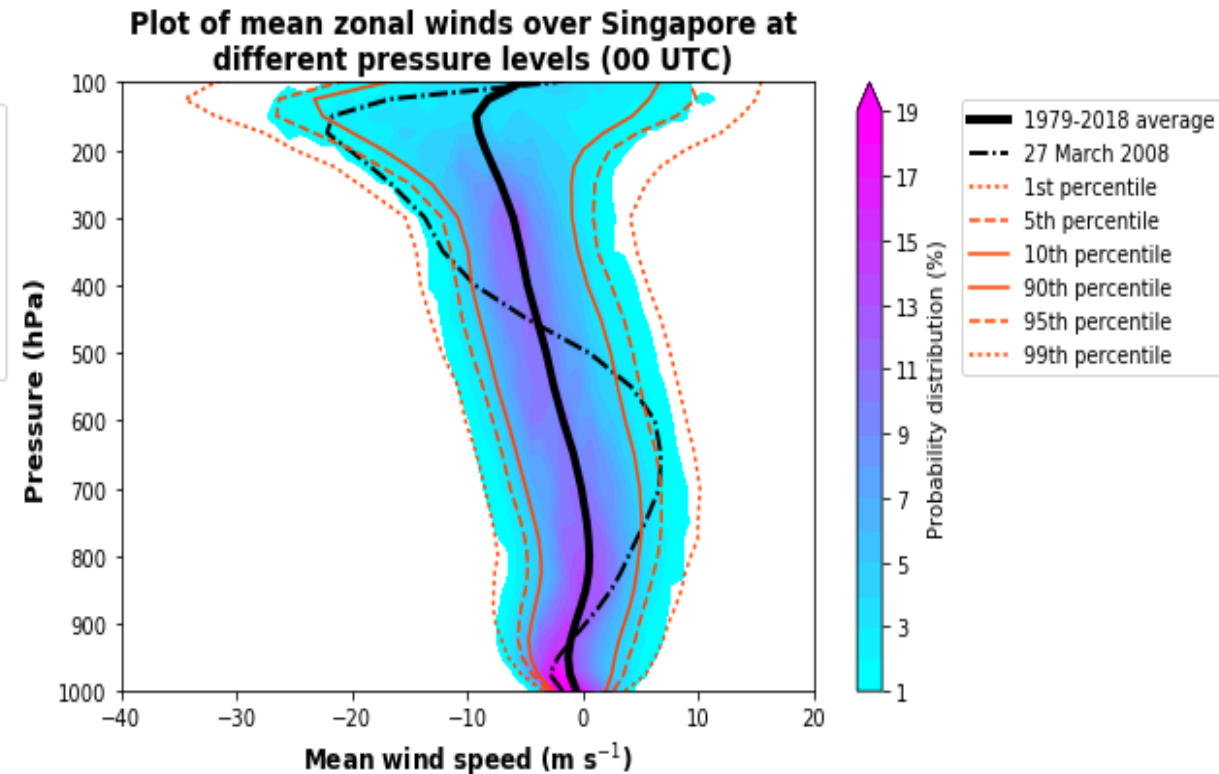
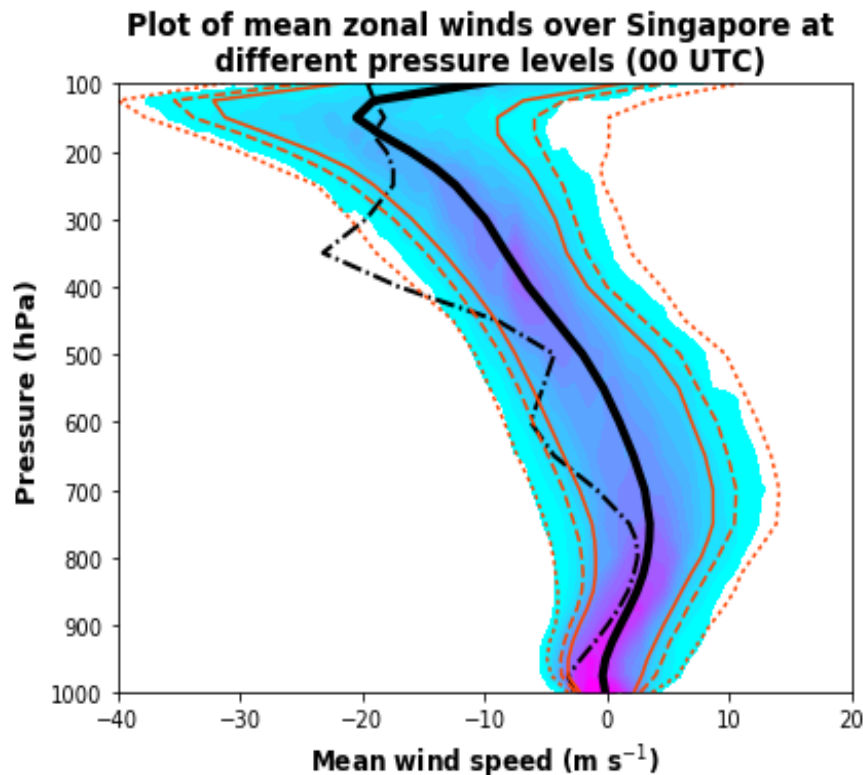


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- Dry intrusions are observed at mid-levels in vertical profiles of RH (ERA-Interim).



- Vertical wind shear in the zonal direction is also seen as a favourable indicator for hail reaching the surface.

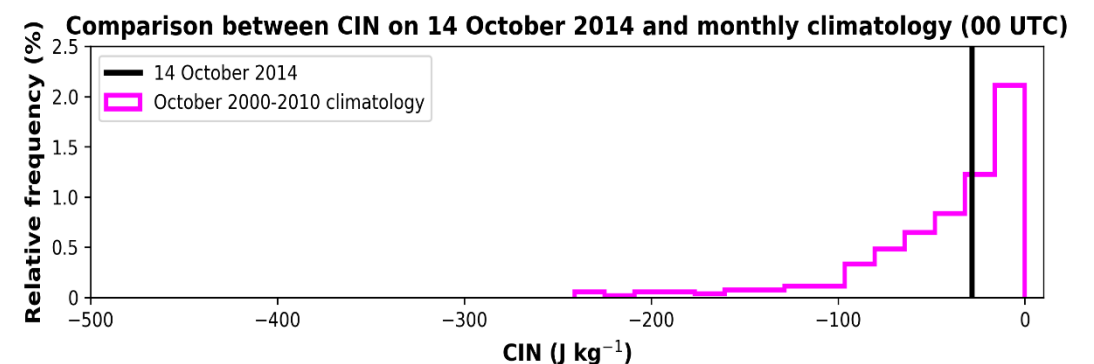
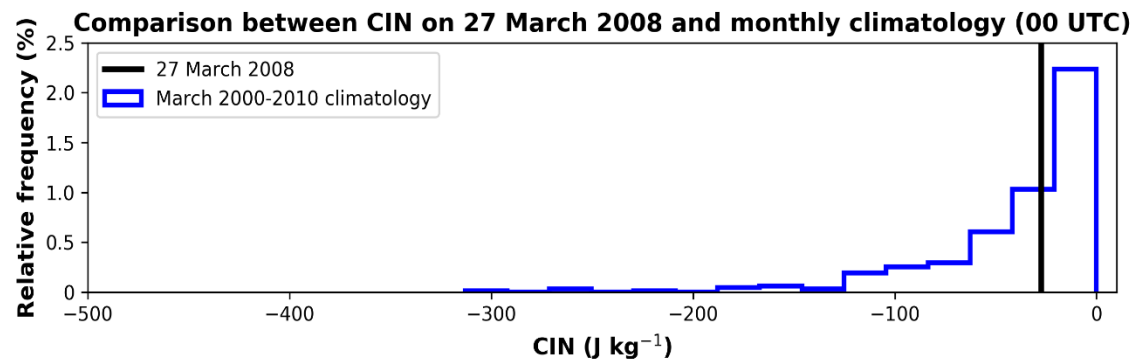
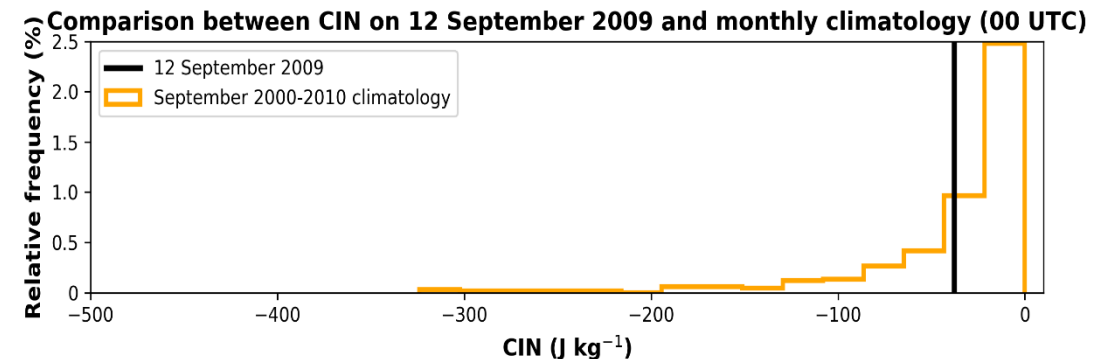
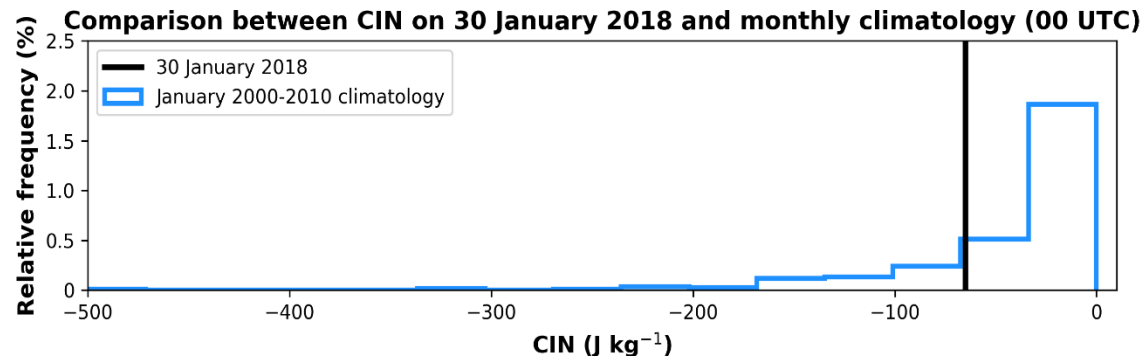
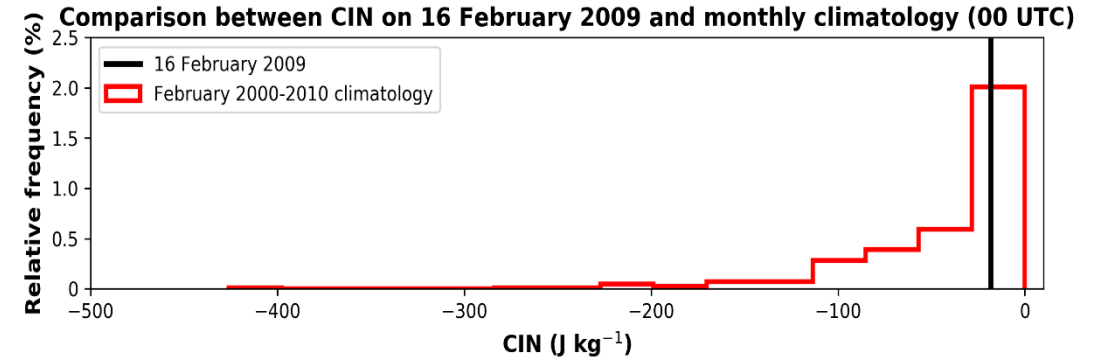
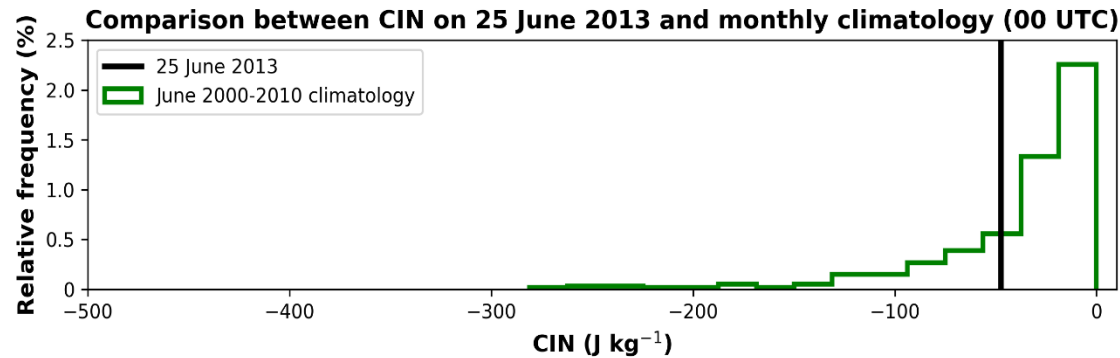


Pre-convective environmental profiles (4)



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- Conditional instability is sufficient for the formation of severe thunderstorms

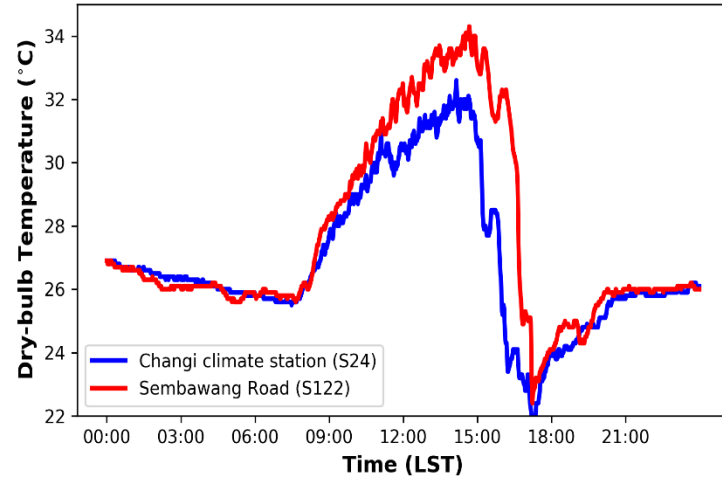


Ground-based weather station data

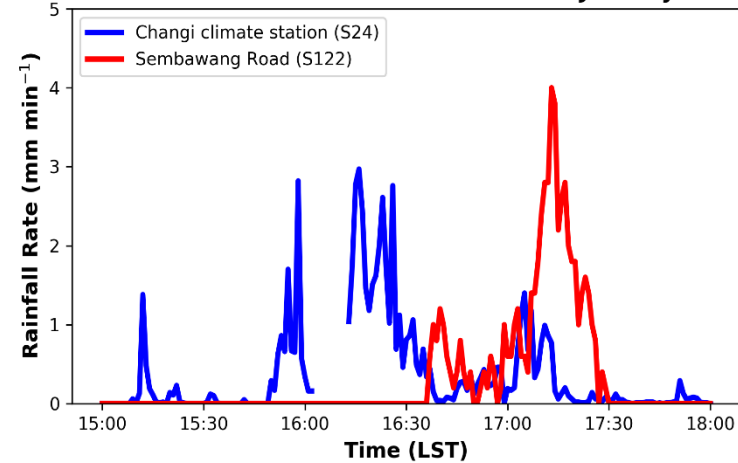


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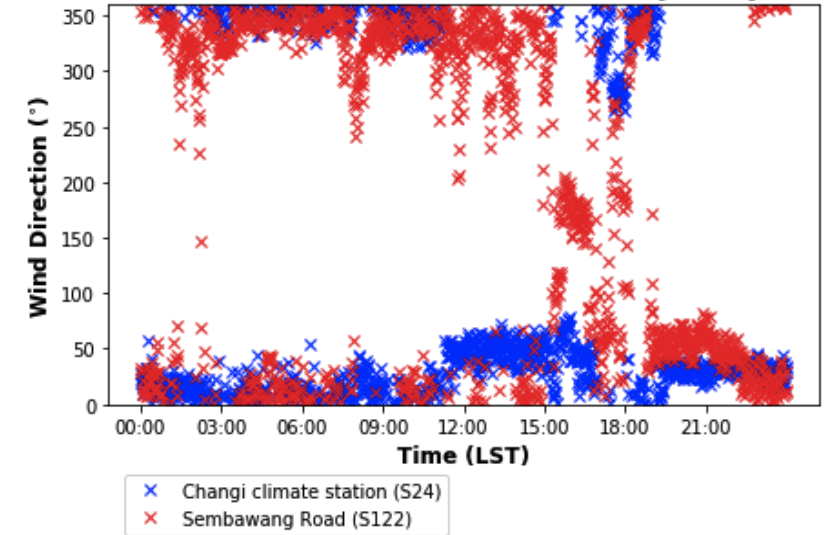
Time Series of 1-min Dry-bulb Temperature on 30 January 2018



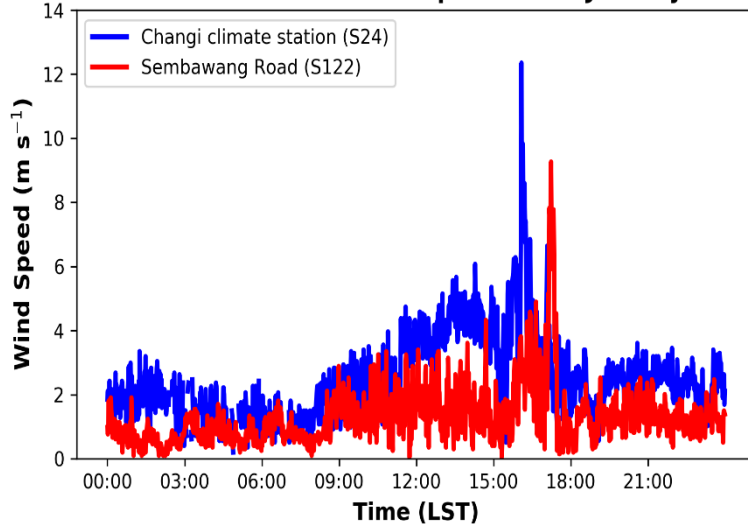
Time Series of 1-min Rainfall Rate on 30 January 2018



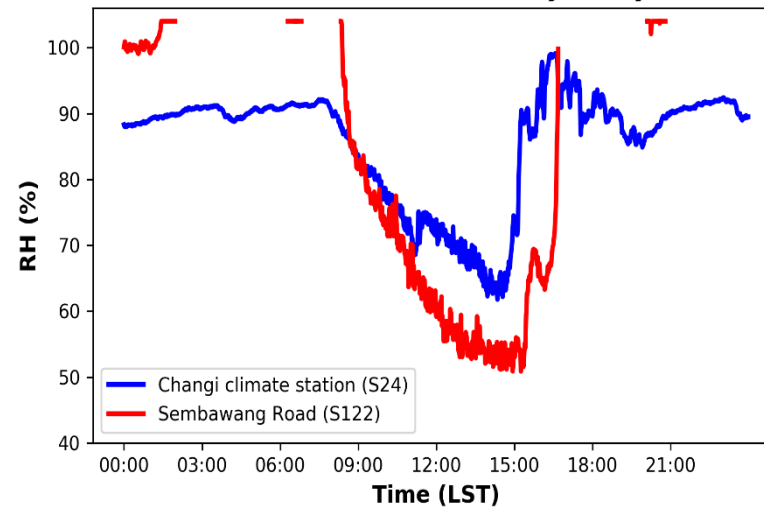
Time Series of 1-min Wind Direction on 30 January 2018



Time Series of 1-min Wind Speed on 30 January 2018



Time Series of 1-min RH on 30 January 2018

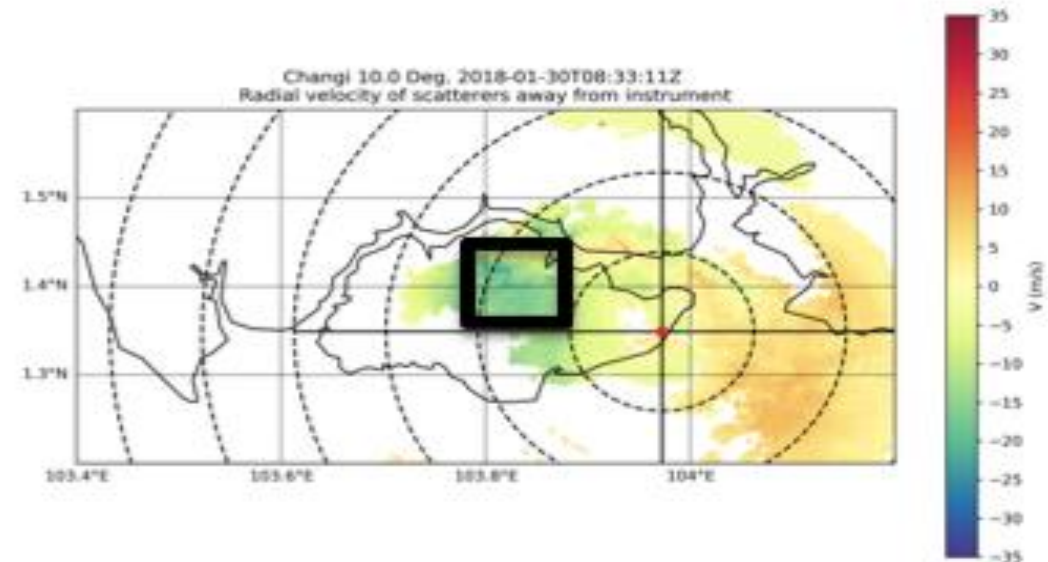
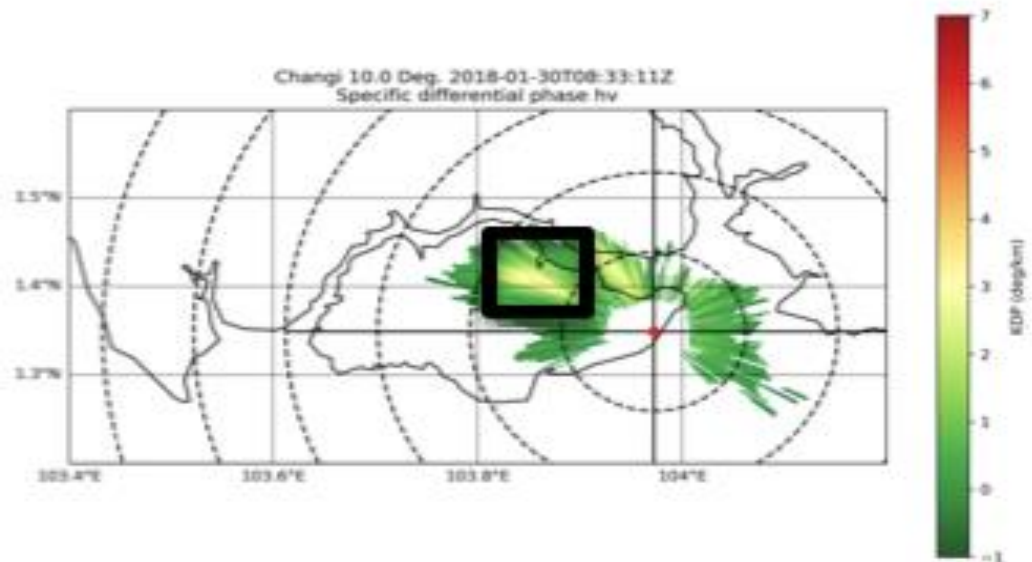
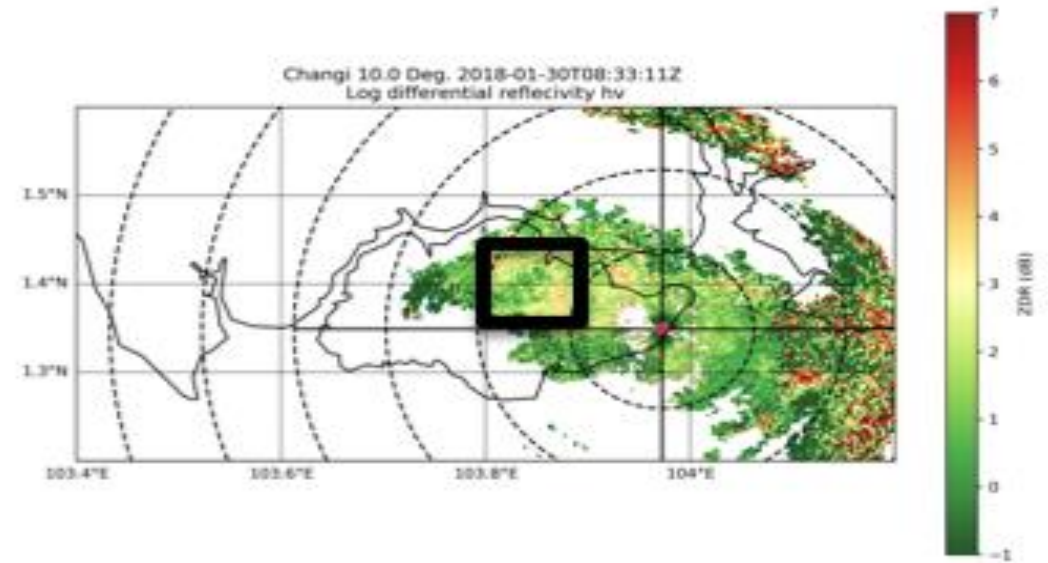
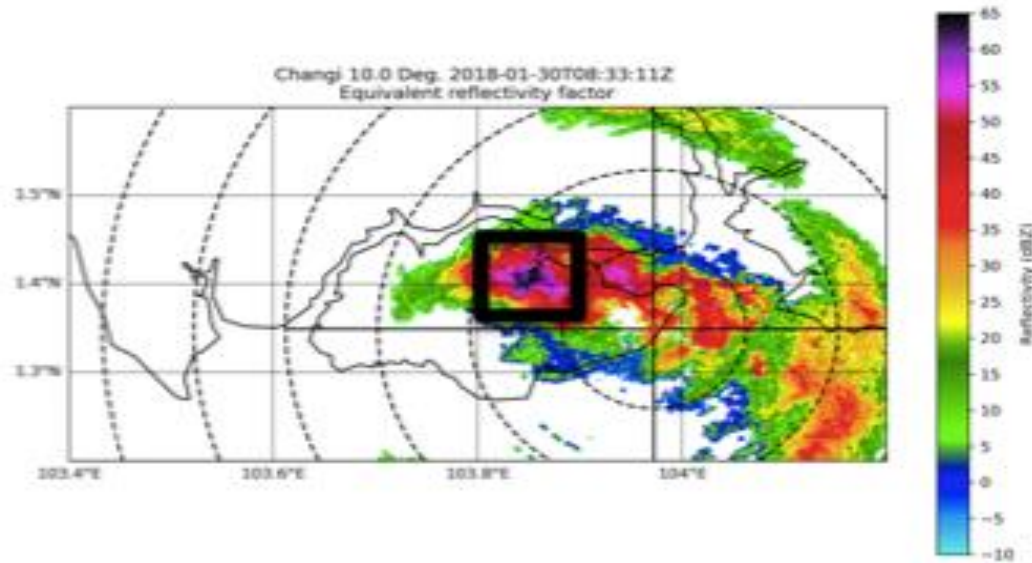


1-minute resolution
ground-based weather
station data was only
available for the 30
January 2018 case

Changi weather radar plots – useful radar parameters



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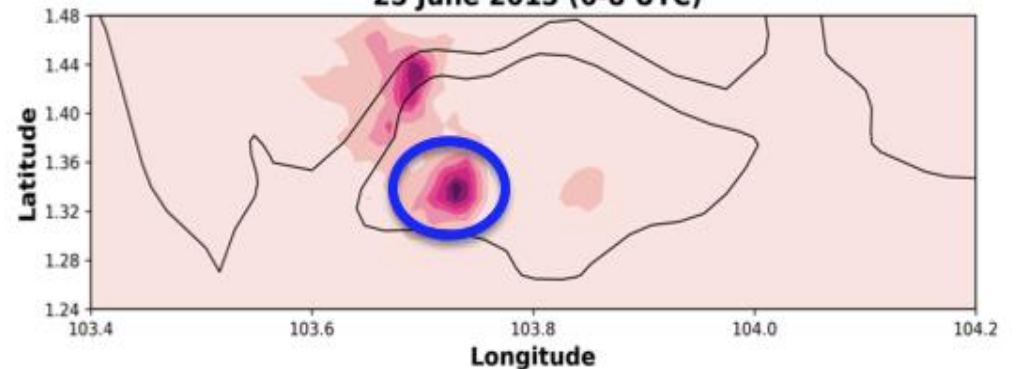


Lightning strikes density vs. radar reflectivity

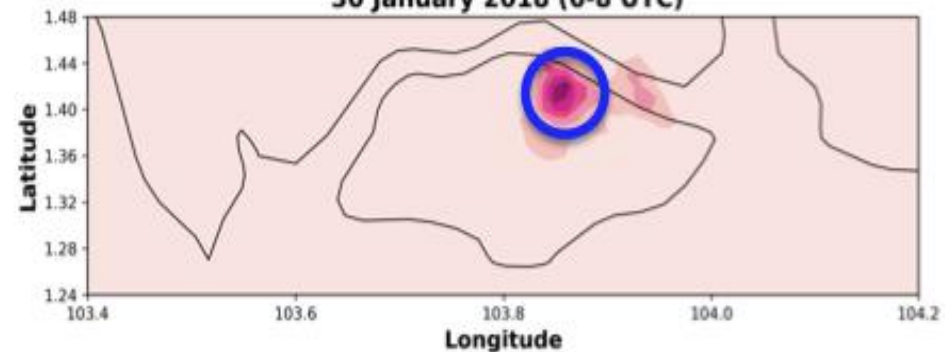


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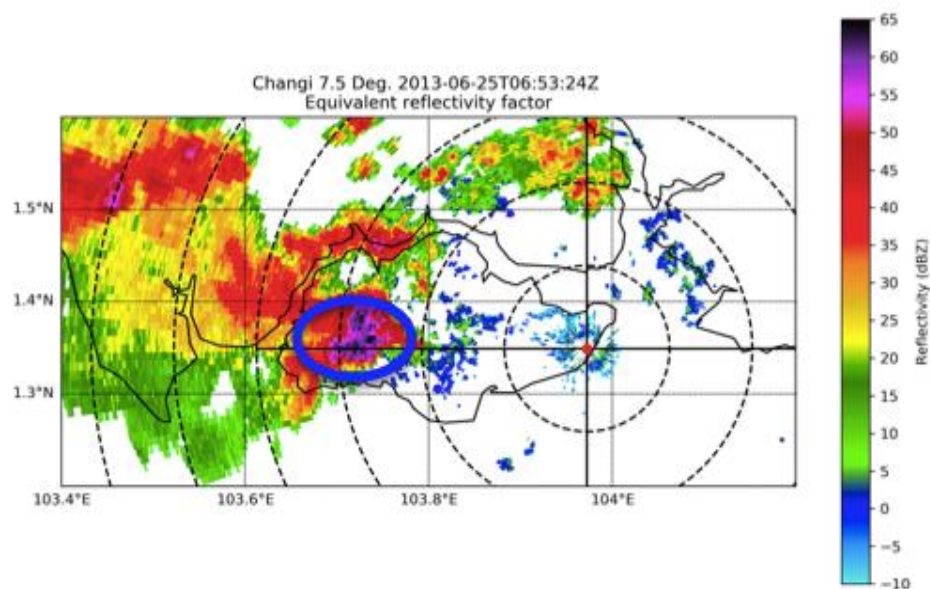
Density of lightning strikes during the hail event on
25 June 2013 (6-8 UTC)



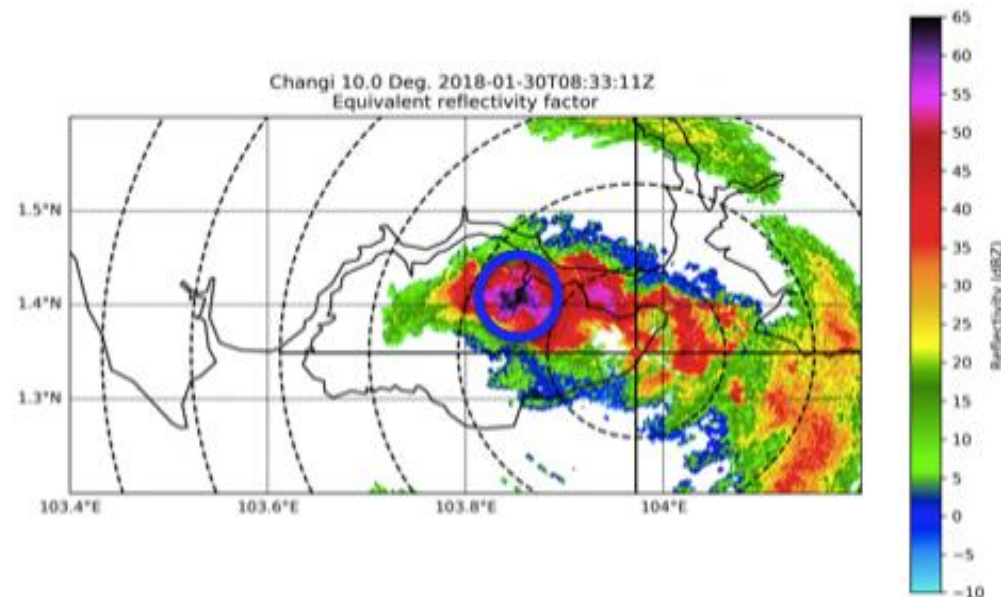
Density of lightning strikes during the hail event on
30 January 2018 (6-8 UTC)



Changi 7.5 Deg. 2013-06-25T06:53:24Z
Equivalent reflectivity factor



Changi 10.0 Deg. 2018-01-30T08:33:11Z
Equivalent reflectivity factor



- Pre-convective environment characteristics:
 - Conditional instability (moderate-high CAPE, weak-moderate CIN),
 - Vertical wind shear
 - Dry mid-tropospheric intrusions.
- Weather station data:
 - Intense rainfall rates
 - Strong winds – strong downdrafts and cold pool outflows
 - Sharp decreases in dry-bulb temperature
- Weather radar data – combining radar reflectivity with:
 - Differential reflectivity
 - Specific differential phase
 - Radial velocity
- Clear correlation between the hail core and lightning strikes density



Thank you
ee15i2t@leeds.ac.uk