# Hail Risk Assessment Using Space-Borne Remote Sensing and Reanalyses

## SUMMARY

### Key Points

- Of the three primary severe convective storm hazards, hail, tornadoes, and straight-line wind gusts, hail is the costliest hazard for the insurance industry, generating about 70% of average annualized losses.
- Hail catastrophe models (CatModels) are used by reinsurance to estimate risk to an insurer's portfolio. CatModels are developed with climatologies that define hail storm frequency and severity, but hail climatologies are difficult to derive over developing nations without hail reporting or climate-quality weather radar observations.
- This NASA Applied Sciences Disasters program project combines reanalyses (e.g. ERA-5 and MERRA-2) with geostationary and low-Earth-orbiting (LEO) imager data to develop new hailstorm climatologies and regional CatModels.

### Service

- Disaster risk reduction (DRR)

### End User(s)

- General Public
- Industry
- Local communities
- Researchers

### Intermediate User(s)

- The international severe weather research community
- Upper-troposphere and lower stratosphere exchange community

## Application(s)

- Geostationary IR brightness temperature is used to detect and characterize overshooting convective cloud tops using long-term satellite data records. Passive microwave hail storm detection databases and reanalyses are used to filter out overshooting tops in environments that are not supportive of hailstorm formation. Filtered overshooting cloud tops are aggregated across data and then clustered in space and time into storm events, representing the full lifetime of a storm cell or cluster of cells within an anvil cloud. Properties such as the length, width, movement speed and intensity of the storm event are defined. Stochastic modeling is used to simulate storm events over a 25,000 year period, with properties that match the climatology derived from geostationary imager data. Hail streaks are randomly placed within each simulated storm event. A 25,000 year period is used in these simulations to estimate losses when applied to an insurance portfolio at varying return periods, such as a 1-in-200-year event. A 1-in-200-year event is used throughout industry for regulatory purposes to determine the capital an insurance company must withhold to cover losses from a catastrophic event.

## Essential Climate Variables

### —Atmosphere

- Precipitation, Clouds

## Climate Data Records

- MSG SEVIRI 10.8 micron IR brightness temperature
- NASA TRMM and GPM passive microwave imager (TMI and GMI) brightness temperature
- GOES-8 to -15 10.7 micron IR brightness temperature
- GOES-R series 10.3 micron IR brightness temperature

## Agencies

- EUMETSAT
- NOAA
- NASA

## Satellite Observations

- Meteosat Second Generation SEVIRI 10.8 micron brightness temperature
- TRMM and GPM passive microwave imagery at 10, 19, 37, and 89 GHz
- GOES-8 to -15 10.7 micron IR brightness temperature
- GOES-R series 10.3 micron IR brightness temperature

## Sustainability

- The Willis Re Hail Catastrophe Model is used operationally within the reinsurance and insurance industry

## DESCRIPTION

Hail losses are relatively frequent in South Africa. Seven of the top 10 insured natural catastrophe events since the 1970s have been associated with hail, with upwards of 45% of the total value of insured motor and property claims from natural perils over that period caused by hail damage.

Faced with this kind of risk, a firm understanding of the potential financial impacts of a devastating 50-year hailstorm or the expected loss over the next 10 years in South Africa is critical.

Applications of hail catastrophe risk model outputs include:

- Pricing reinsurance contract layers for purchasing protection in the local and international reinsurance markets
- Assessing capital adequacy and responding to regulatory solvency requirements
- Portfolio management and optimisation

Such models have moved on in leaps and bounds in recent years as improved scientific understanding and modelling techniques have converged. As an example, Willis Re's recently launched new Hail Catastrophe Risk Model that quantifies the risk from damaging hail events across South Africa, has involved an extensive, ongoing collaboration with Willis Research Network partners at the Karlsruhe Institute of Technology (KIT) in Germany and NASA's Langley Research Centre, supported by the NASA Applied Sciences Disasters Program.

The model, which was launched in February 2021 as a greatly more sophisticated solution than its predecessor, features a comprehensive stochastic hail catalogue, developed by hail experts at KIT (Punge et al. (2017) using EUMETSAT Meteosat Second Generation (MSG) geostationary satellite data between 2005 and 2018. After applying the latest NASA hail detection algorithms to the MSG data, KIT has been able to map the distribution of observed hail frequency and severity. Events and their attributes were then simulated for a 25,000-year period to generate an extensive catalogue of hail events, with their footprints and parameter distributions reflecting observations in South Africa.

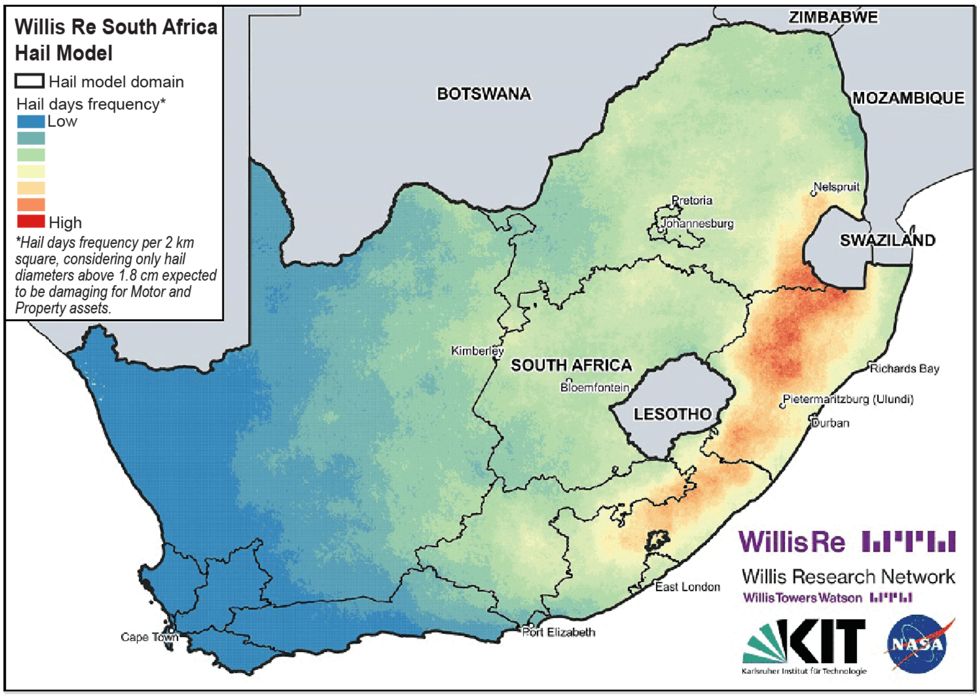



**Figure 1:** Frequency of hail days across South Africa, taken from Willis Re's South Africa Hail Model for Property and Motor classes (source: Willis Re)

Hail forms in intense updraft regions within thunderstorms. These rising updrafts create unique and detectable patterns called overshooting cloud tops (OTs) in satellite infrared cloud top temperature observations, collected every 15 minutes by sensors such as MSG's Spinning Enhanced Visible and InfraRed Imager (SEVIRI). Additionally, ice particles within intense convection and hailstorms scatters microwave radiation emitted by the surface before it can reach a satellite sensor, leading to BT depressions observed by passive microwave imagers such as those aboard the Tropical Rainfall Measurement Mission (TRMM) and the Global Precipitation Measurement Mission (GPM) satellites. Furthermore, hailstorms generate notable BT depressions in lower frequency (10-37 Ghz) passive microwave observations. These multispectral signals have been recently combined with human spotter hail reports to derive hail probability and detect storms likely to have produced hail (Bang and Cecil 2019, 2021). These detection methodologies are particularly important in regions where on-the-ground hail reports are limited, such as in South Africa. NASA is extensively applying these same OT-detection algorithms to generate reliable records of hail occurrences in satellite-imaged, hail-prone parts of the world, including North America and South America.

The limiting factor associated to this methodology is the length of available satellite imagery. In South Africa, the MSG SEVIRI infrared imager provides consistent, high spatio-temporal resolution observations back to 2004. But with 14 years of hail data, how can one be confident in assessing the risk from all potential hail occurrences and sizes?

This is where KIT's stochastic simulation methodologies come in. By simulating the full range of plausible hail events, represented by modelling the characteristics of historical event distributions, they create a comprehensive catalogue, containing hundreds of thousands of individual simulated hail events. Simulated events can be described not only by their annual frequency of occurrence, but also contain important attributes including mean hail diameter and time of day of occurrence. In total, KIT defined nearly 235,000 hail events with diameters between approximately 2cm and 20cm that would have potential to cause damage to insured motor and property assets.

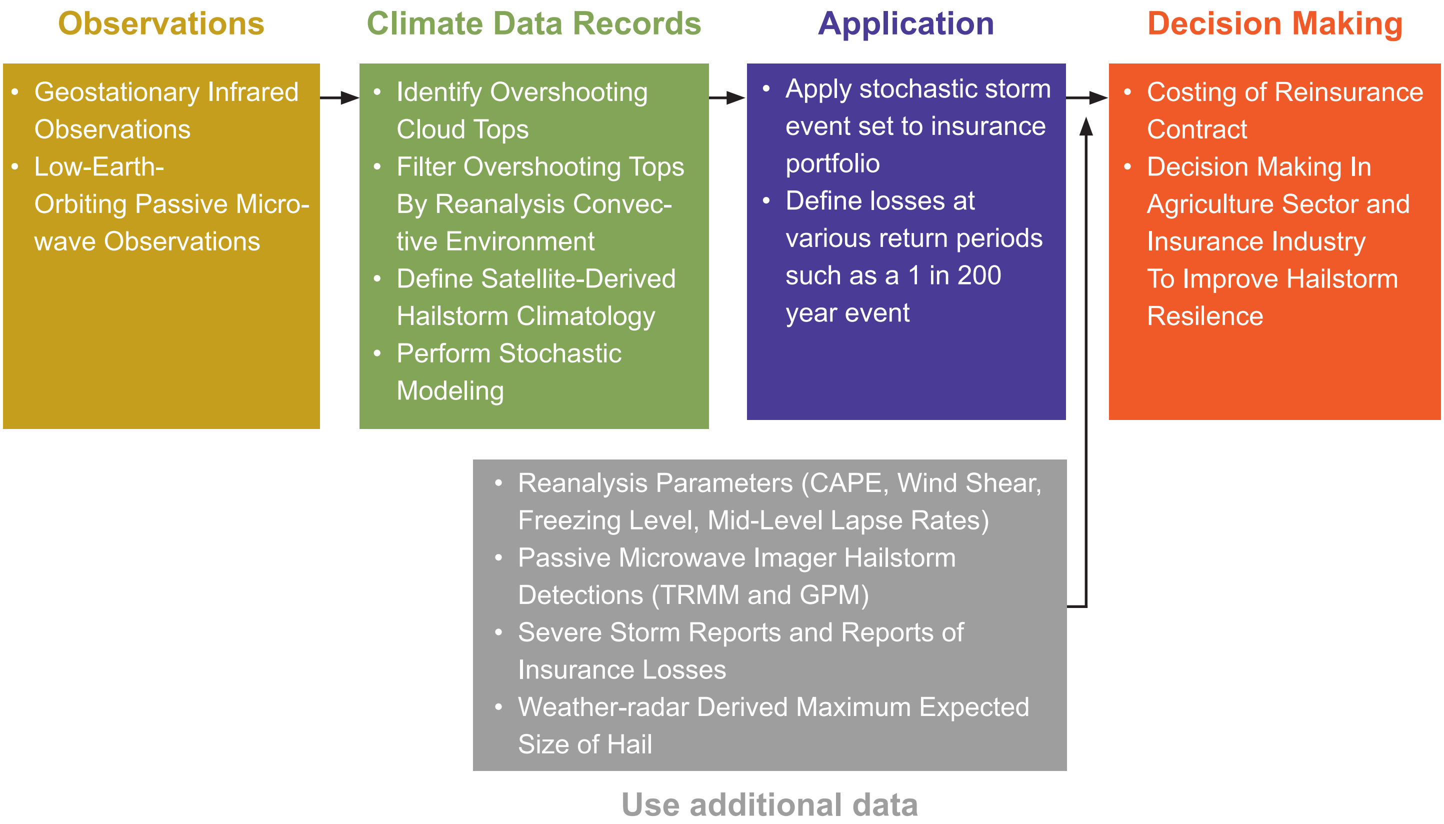
By comparing early iterations of the hazard event set generation with known claims locations, this provides confidence in characterising those areas with higher frequency of damaging hail. One of the additional challenges with understanding hail risk to vehicles is day and night variability. As some commuters return home and park their cars in garages, and commercial fleets are stored in covered warehouses, the average susceptibility of those exposures to hail damage decreases. The 'time-of-day' of occurrence in KIT's hail catalogue enables distinguishing between events occurring during the day and the night,and modelling of the average change in risk associated with daily mitigation practices.

The model also offers an innovative exposure disaggregation module, enabling clients to downscale their aggregated postcode exposures to a high-resolution modelling grid. Just under 4,000 four-digit postcodes are transformed to almost 400,000 individual exposure sites, each one characterised by the proportion of residential, commercial and industrial development.

To translate hail diameters into insured hail losses, we can apply representative damage functions for each of the key classes of motor and property business according to the relative damageability between residential, commercial or industrial assets. This can support informed reinsurance assessments based on loss estimates for an entire portfolio."

This satellite-driven hail risk assessment framework is portable to other geographic regions and geostationary satellites, though careful consideration of satellite image resolution, quality, and calibration throughout the data record is required.  This is especially the case if one seeks to determine if climate change is impacting severe storm activity, an application where a long-term, consistent data record is required. For example, a transition between the 4 km/pixel (at nadir) GOES-8 to -15 imager to the 2 km/pixel GOES-R series Advanced Baseline Imager (ABI) yielded a ~15% increase in detection rate for overshooting cloud tops (Cooney et al. 2021).  Infrared temperatures within overshooting tops in ABI imagery can be 5 K or more colder than historical GOES imagery. Adjustments to detection algorithm settings were made to try to account for resolution changes (Khlopenkov et al. 2021) yet such changes in detection performance are unavoidable, especially for small or weak overshooting than does not have a very prominent signal in the infrared imagery. If one seeks to try to identify each and every overshooting top evident in GOES-R ABI imagery with coarser resolution imagers, where spatial temperature gradients from the overshoot to surrounding anvil may only be 2 K, then there will be numerous false detections because 2 K spatial gradients often occur in non-convective clouds. The Meteosat First Generation (MFG) satellites provided a 17-year data record of IR brightness temperature at 5 km/pixel. Experience with analyzing this MFG imagery indicates that overshooting tops can be resolved, though their signal is further dampened due to larger pixel sizes and therefore detections may be limited to the more intense and prominent overshoots. The most intense storms from a satellite perspective are more likely to produce larger hail (Khlopenkov et al. 2021), so resulting climatologies from MFG or other imagery with comparable resolution could be used to identify where larger hail (i.e. 5+ cm diameter) is most likely to occur.

## INFORMATION FLOW




The case study could be improved with longer geostationary satellite data records, as well as more frequent passive microwave imager observations in the 10-89 GHz range.

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