HAIL CLIMATOLOGY OF AUSTRALIA BASED ON LIGHTNING AND REANALYSIS

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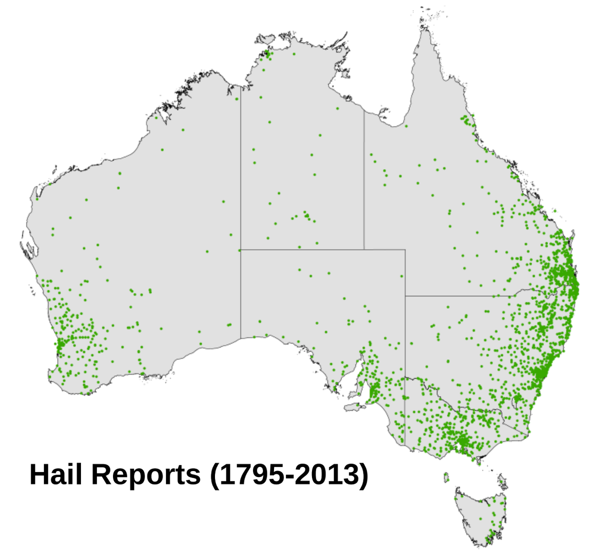
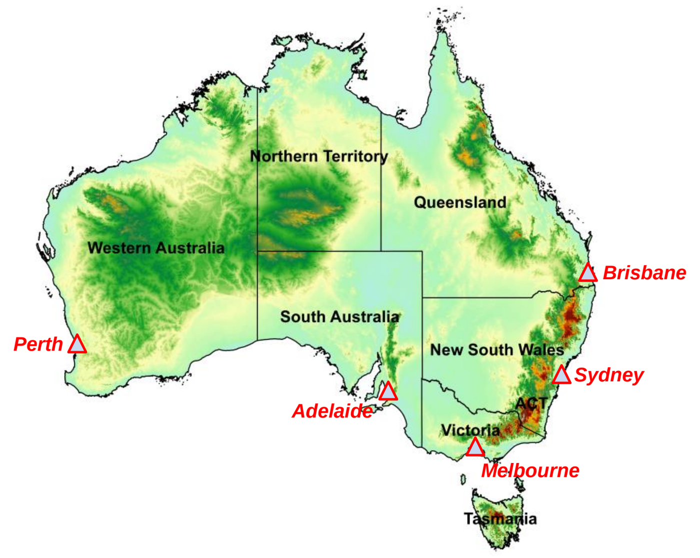
1. MOTIVATION FOR STUDY

Due to the highly uneven distribution of population in Australia, reporting of severe convective storms experiences major shortcomings. Relative concentration of storm reports is much greater along the southeast coast of the country where major population centers such as Sydney, Melbourne, and Brisbane are located. In order to fill in the gaps and estimate the appropriate severe storm frequency in low population regions, other data sources are sought. Gridded output from numerical models and remotely sensed observations are two that offer a method to achieve this. Reanalysis-based severe environments can indicate the potential for severe weather, and lightning indicates the realization of convection. The combination is expected to relate to the occurrence of severe weather.



Hail Reports (1795-2013)



2. DATASETS

A. Storm Reports

Hail reports are retrieved from the Australia Bureau of Meteorology (BOM) Severe Storms Archive. This record exists for the period 1795-present, with the majority of entries occurring in more recent years.

B. Lightning

Data is from the Lightning Imaging Sensor (LIS; Christian et al. 1992) on board the Tropical Rainfall Measuring Mission (TRMM) satellite. The LIS is an optical sensor that detects above background level light flashes. The satellite only views an area for a short period of time a few times per day, so the total lightning activity is an underestimate, however over an extended period any spatial differences should even out. The orbital inclination of the satellite does not allow Tasmania and parts of southern Victoria to be in the field of view of the sensor.

C. Reanalysis

The NCEP Climate Forecast System Reanalysis (CFSR; Saha et al. 2010) is used to represent the atmospheric state. It is based on a coupled atmospheric-ocean model run at approximately 38 km resolution with 64 vertical levels. A GSI 3DVAR system assimilates observations every 6 hours. The product used is at 0.5° grid spacing on 37 pressure levels.

3. METHODOLOGY

The years 1998 to 2012 are chosen because all 3 datasets exist for that period. Lightning flashes are binned on the CFSR grid and aggregated to lightning days. To represent a severe hail environment, the Significant Hail Parameter (SHIP) is calculated from the atmospheric variables in CFSR.

$$SHIP = \frac{(CAPE) * (w) * (\Gamma_{700-500mb}) * (-T_{500mb}) * (Shear_{0-6km})}{4.2 * 10^6}$$

Two modifications to this are introduced: the shear is required to have a minimum value of 10 m s^{-1}, and the CAPE is not allowed to exceed 2000 J kg^{-1}. A severe hail environment is identified by the maximum daily (00 to 00 UTC) SHIP exceeding a value of 0.5.

On a daily basis the intersection of a severe environment and lightning is calculated for each grid cell and aggregated for the 15 year period. A model to predict hail days for all grid cells is tuned to the 5 largest cities by population (Sydney, Melbourne, Brisbane, Perth, Adelaide), where the number of reports in the archive is assumed to be accurate.

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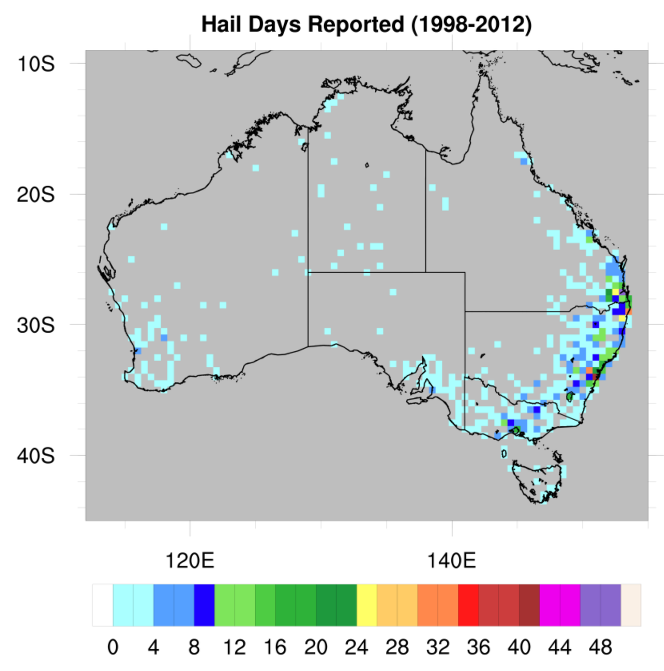
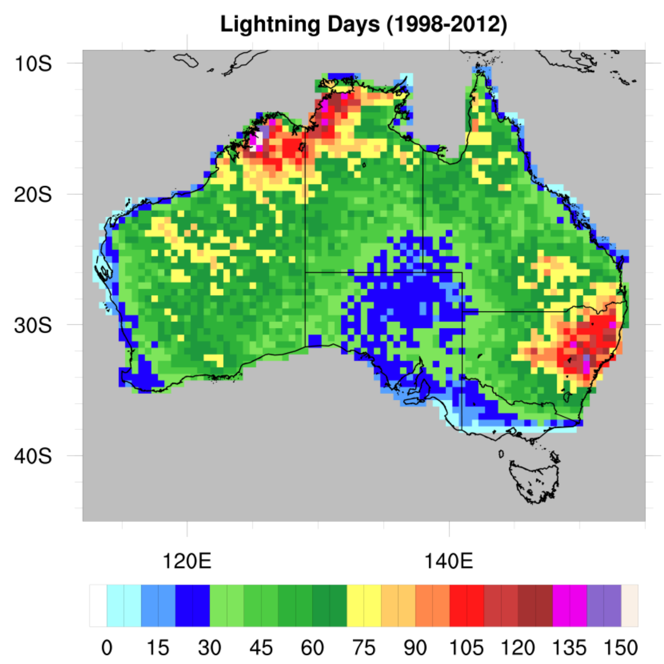
4. REPORT, LIGHTNING, AND ENVIRONMENT CLIMATOLOGY

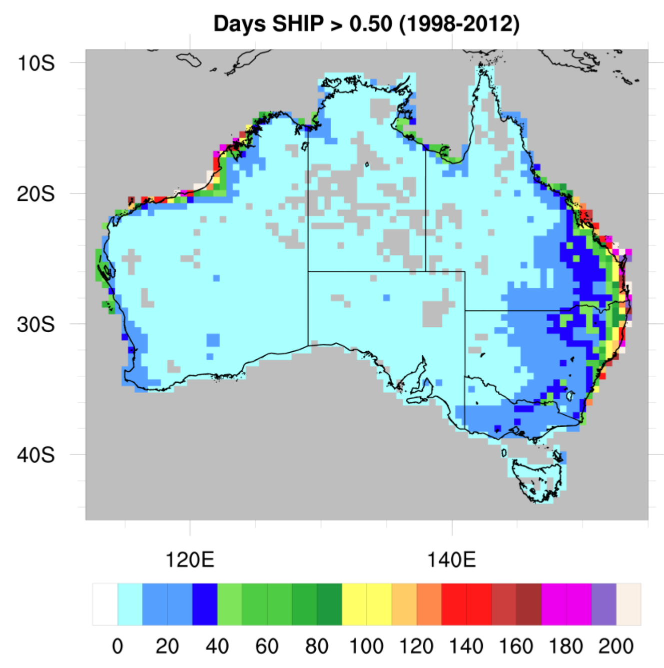


Total hail days gridded at 0.5° for period shown. The vast majority of reports occur along the southeast coast, where most of the population resides. Major cities can be identified by local maxima in hail days.

Total lightning days gridded at 0.5° for period shown. Greatest activity is along northern coast of Western Australia and Northern Territory, and a secondary maximum in New South Wales.

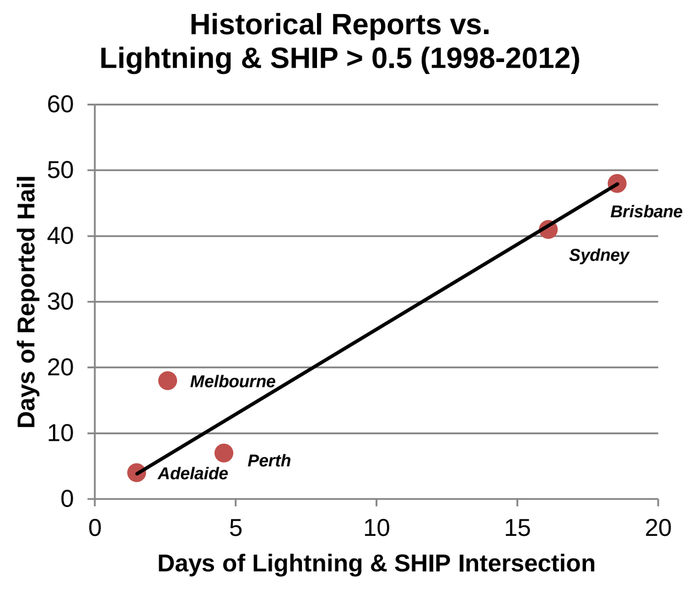
Greater convective activity along the northern coast is related to the influence of the Indo-Australian Monsoon in which flow is predominantly from the northwest during the wet season. In the mid-latitude regions, differences at the coasts are related to ocean currents. The west is a cold current, which provides a more stable environment, reducing convective activity. The warm current in the east combined with mountainous terrain near the coast provides a more conducive environment for thunderstorms to develop.



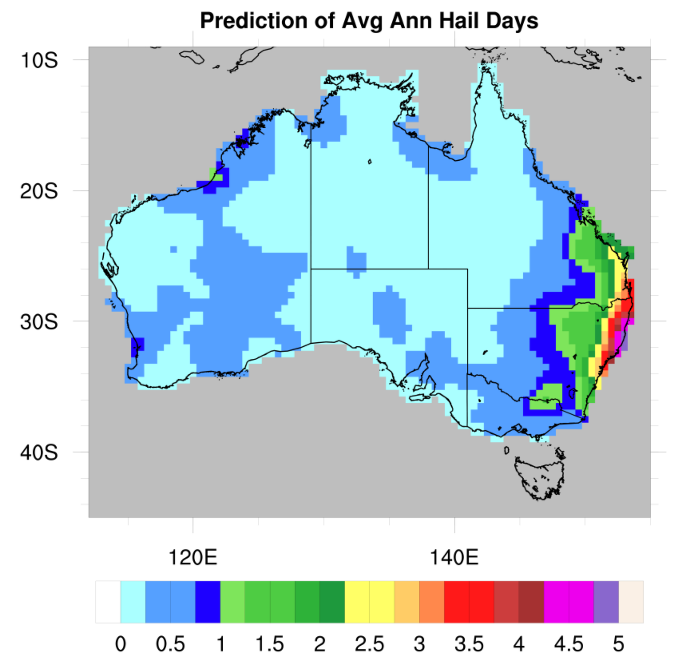


Total days SHIP exceeded 0.5 days gridded at 0.5° for period shown. Most frequent locations are coastal northern New South Wales and southern Queensland, as well as northern Western Australia. The decay as one heads inland is much more rapid for WA than the QLD/NSW. Some locations—particularly in the middle of the country—never exceed the threshold.

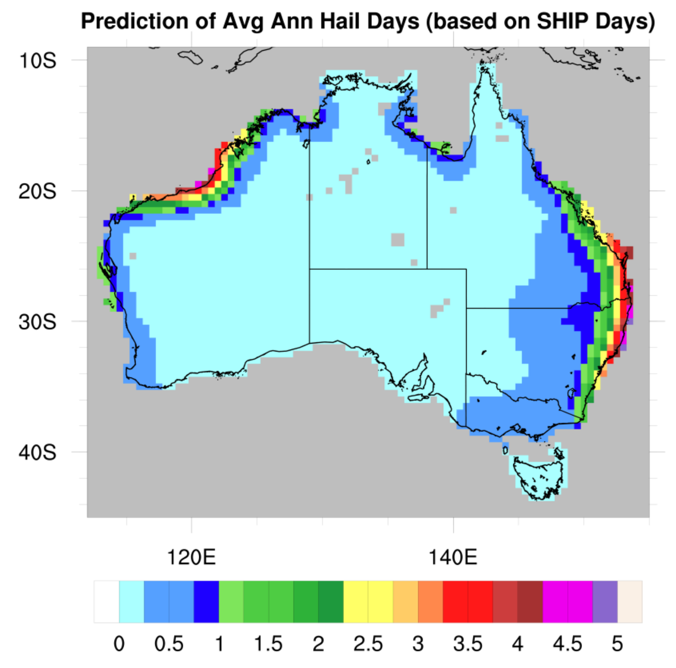
5. HAIL CLIMATOLOGY PREDICTION



The total days of intersection of lightning and severe environment is smoothed, and a linear equation is fit to the data for the grid cells containing the 5 largest cities by population. The intercept is constrained to zero to conform to the idea that zero days of lightning and SHIP should correspond to zero days of severe hail.



The map of predicted **average annual** hail days shows a clear maximum along the eastern coast, roughly between Sydney and Brisbane. Other small, local maxima occur along the northwest coast and around Perth, WA.



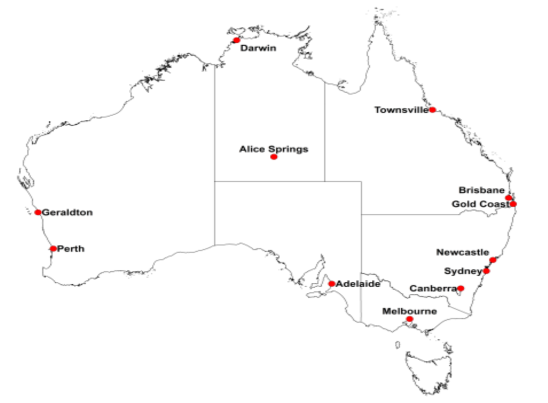
Following the same process, a prediction of hail days was done based only on the occurrence of SHIP > 0.5 (no lightning considered). The distribution is markedly different (essentially a smoothed version of the plot of days SHIP exceeded 0.5), particularly with the inland penetration of higher values and the maximum along the northwest coast.

Average Annual Hail Days

City (Grid Cell)	Reported	Predicted (Lightning & SHIP)
Sydney, NSW	2.7	2.8
Melbourne, Vic	1.2	0.5
Brisbane, Qld	3.2	3.2
Perth, WA	0.5	0.8
Adelaide, SA	0.3	0.3
Gold Coast, Qld	1.1	3.5
Newcastle, NSW	1.1	3.5
Canberra, ACT	1.1	0.9
Townsville, Qld	0*	0.3
Darwin, NT	0*	0.2
Geraldton, WA	0*	0.4
Alice Springs, NT	0*	0.1

**A neighboring grid cell has a greater value*

Table compares the reported and predicted number of hail days for select grid cells. The use of lightning and reanalysis data estimates the hail frequency to be greater in some lower population areas than what is reported in highly populated areas.

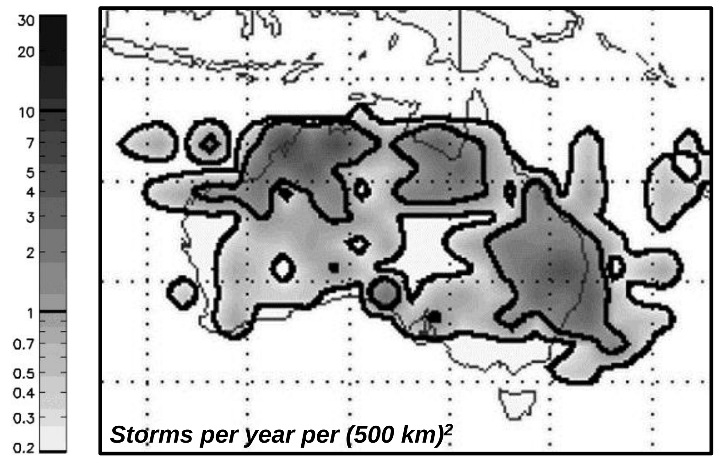


6. COMPARISON WITH OTHER STUDIES

While not explicitly a hail study, Brooks et al. (2003) estimated global severe thunderstorm environment days from reanalyses and found a similar pattern with maxima over eastern and northwestern Australia. Similarly, Allen and Karoly (2013) was an Australia-only study where locations of maxima in severe environments compared well with Brooks et al. (2003).

A global satellite-based hail climatology was produced by Cecil and Blankenship (2012) using AMSR-E measured brightness temperature deficits. The same eastern and northwestern Australia maxima were found along with another on the southern coast of the Gulf of Carpentaria.

AMSRE Estimated Severe Hail (from Cecil and Blankenship 2012)



7. SUMMARY

Lightning data from the LIS and CFSR-based severe environments were used to create a hail climatology for Australia. This version predicts a maximum along coastal New South Wales and southern Queensland, roughly between Sydney and Brisbane, where the majority of reports are located. This study provides a more complete view of hail risk for Australia, filling in gaps associated with a storm report-only based view. This information potentially is useful to those interested in hail risk such as catastrophe modelers, insurance companies, urban planners, and climate scientists.

Using only the severe index (SHIP) emphasized the northwest coast much more, and it did not extend the higher frequencies as far inland in the east. High individual frequencies of both severe environment and lightning along the northwest coast but lower frequency of predicted hail indicates that many severe environments do not initiate convection. This could be related to an abundance of convective inhibition or lack of trigger mechanisms.

Potential limitations to the data and method may limit the results:

1) Assumption that intersection of lightning and severe environment relate to severe hail
2) Assumption that reporting in 5 cities is accurate
3) Assumption of no biases in under-detection of lightning (due to limited satellite passes)
4) Melbourne is at the edge of the detection range of the sensor, so it does not fit the model

References

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Acknowledgements

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[1] AIR Worldwide (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 50 countries. More than 400 insurance, reinsurance, financial, corporate and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, site-specific wind and seismic engineering analyses, agricultural risk management, and property replacement cost valuation. AIR is a wholly-owned subsidiary of Insurance Services Office, Inc. (ISO) .

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