Hurricane Clustering: A New Reality?

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Tuesday 7th May 2019

Disclaimer

The views expressed in this presentation are those of the speaker and not necessarily of the

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Based on the Bank Underground Article

https://bankunderground.co.uk/2018/05/22/us-hurricane-clustering-a-new-reality

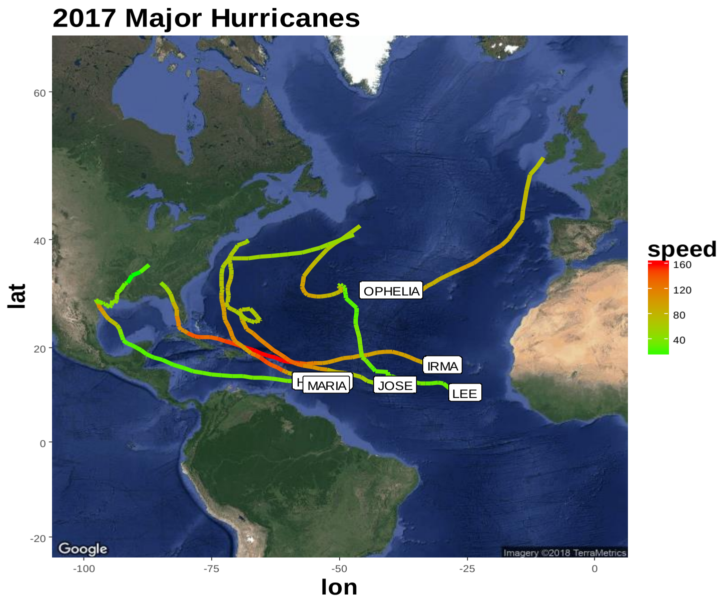
by Alex Ntelekos, Dimitris Papachristou and Juan Duan

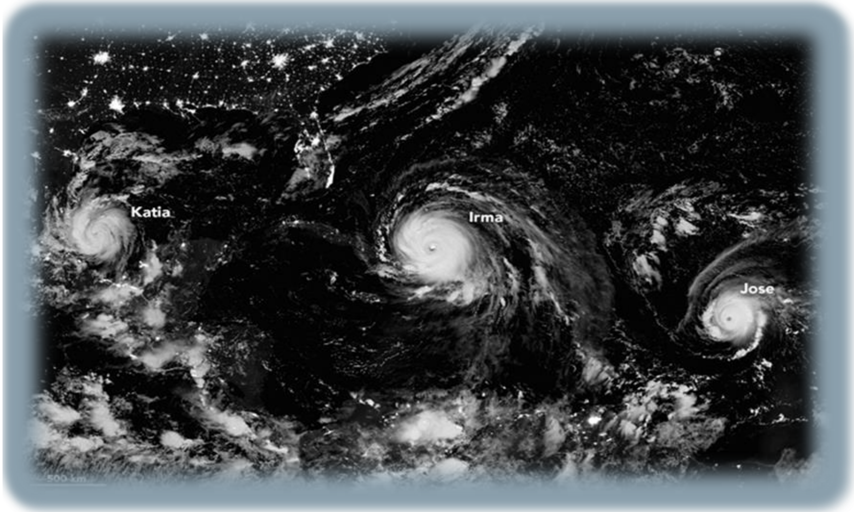
Questions to be discussed

Has the frequency of North Atlantic hurricanes increased?

Do hurricanes come in clusters?

What are the risk management implications of the above?

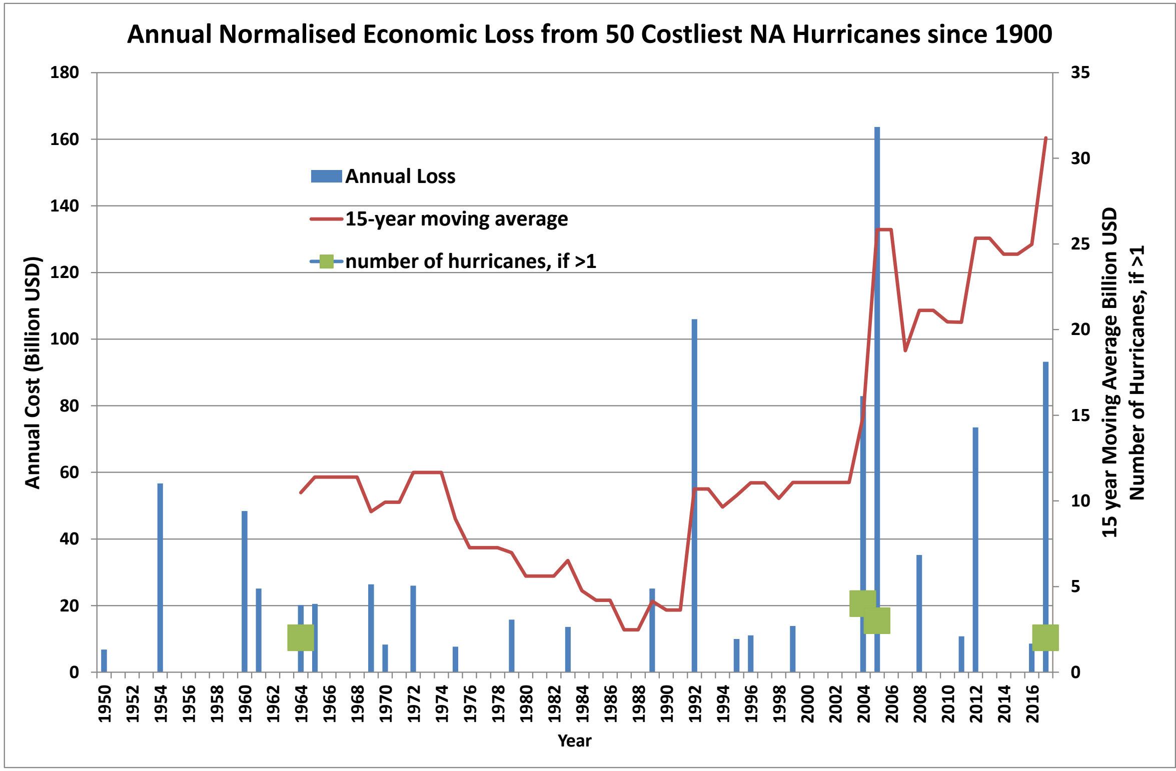




Normalised Economic Losses of the 50 Costliest N.A. Hurricanes since 1900 (graph since 1950)

- Based on Weinkle J et al (2018)
- Historical losses approximately adjusted for both inflation and exposure

- **Increasing Trend**
- In the last few decades hurricane losses are driven by both
  - the single very big hurricane and
  - **higher frequency of several costly hurricanes**
- **Frequency has become more material**



- Economic Loss different from Insured
- Limitations in data/methodology

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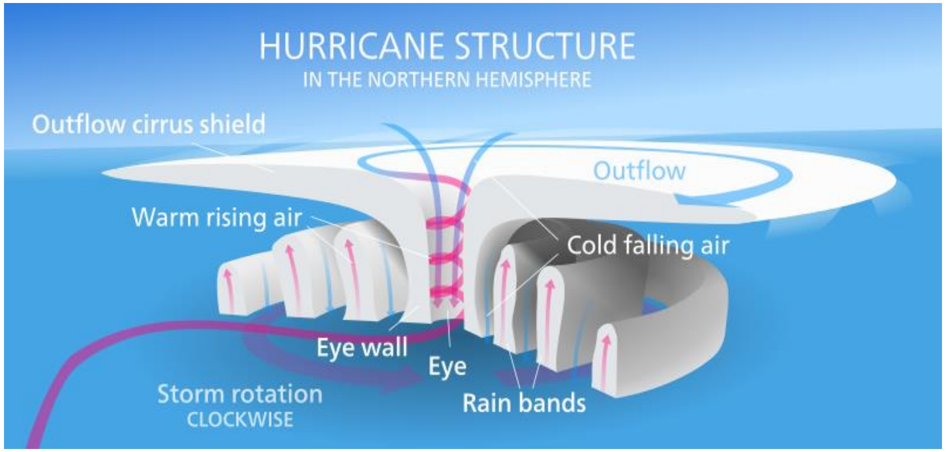
How is this different from other work?

- Climatologists focus more on the physics of hurricanes
  - Use of different measures such as Power Dissipation Index (PDI)
- Updated work of academics
- We focus on insurance related issues
  - Major hurricanes
  - High level validation
  - Impact

What do we cover?

- Groups of major hurricanes
  - Climatology and Features
- Change in frequency and volatility over time
  - Actual vs Modelled
- US Landfalls
- Implications

Tropical Storms, Hurricanes, Major Hurricanes



Tropical cyclone categories (Saffir-Simpson)

- **Tropical Depression (<34kn or <63km/h)**
- **Tropical Storm / named storm (34 – 63kn or 63-118 km/h)**
- **Hurricane:**
  Cat 1 (64-82kn or 119-153 km/h) and
  Cat 2 (83-95kn or 154-177 km/h)
- **Major Hurricane:**
  Cat 3 (96-112kn or 178-208km/h),
  Cat 4 (113-136kn or 209-251km/h),
  Cat 5 (>136kn or >252kmh)

- **An efficient heat engine (see Emanuel K. (2006))**

Our Research

- Examines the trends in the annual **number** of **major** hurricanes in the North Atlantic
  - Major hurricane: hurricane of category 3 or higher on the Shaffir-Simpson scale (>95knots) **at some point in their life-time**. (Basin-wide)
  - When we are considering landfalls
    - we consider landfalls at Continental US. This means landfalls at latitudes higher than 24 degrees north (which includes Bermuda)
    - We consider all landfalls of hurricanes which became major at some points in their lives. These hurricanes they did not necessarily make landfall as major hurricanes.
- Looks into the risk implications for insurers

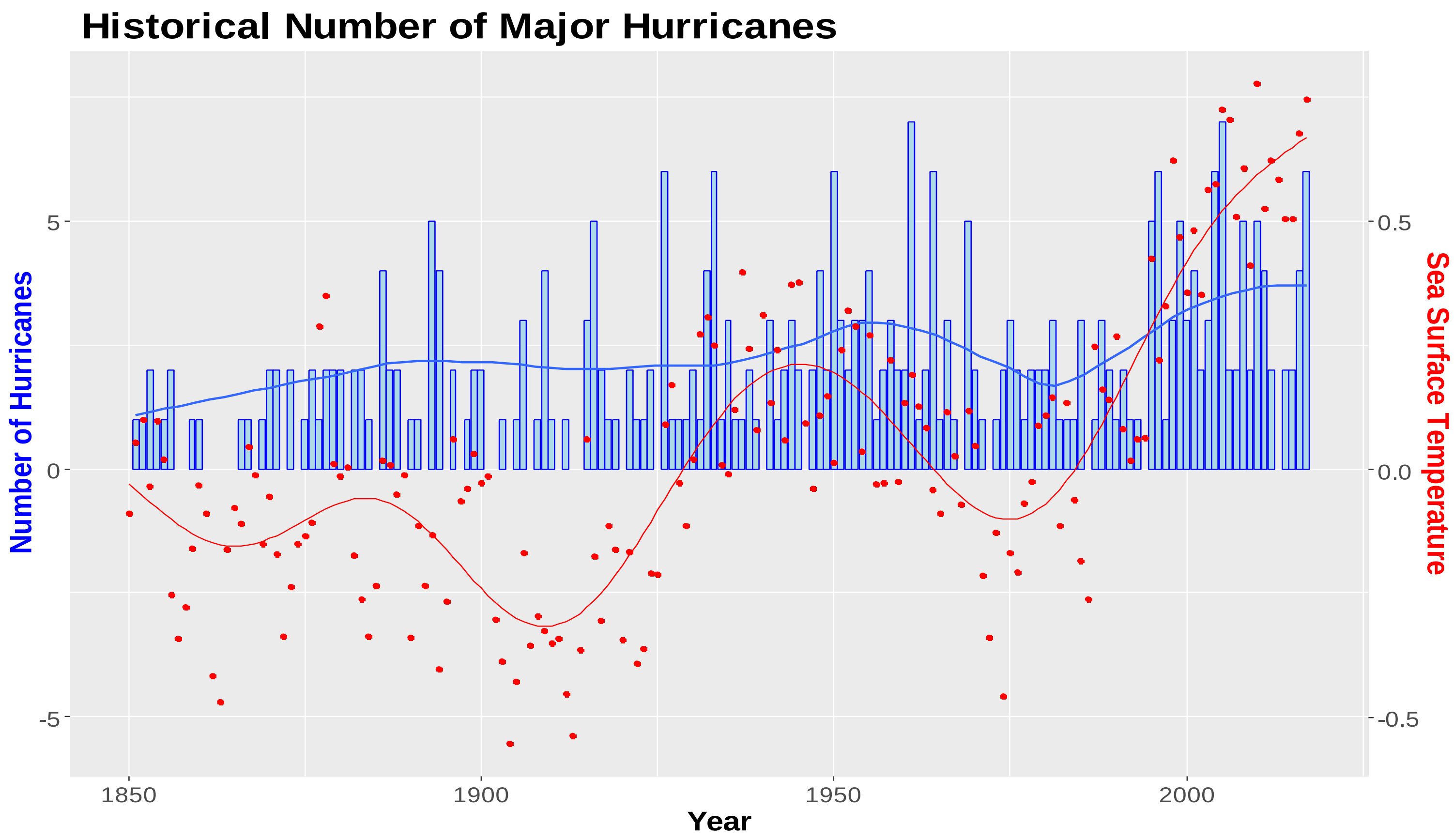
Focus on number of major hurricanes, but

Focus on frequency (numbers), but frequency NOT the only factor:

Location and Exposures	• Hurricane Sandy (2012) made landfall in NJ, NY and CT as a tropical storm, but exposures were high, size was huge, tide was high and surge
Intensity at Landfall	
Rainfall, Surge and Flooding	• The majority of fatalities are caused by flooding and surge • Flooding is not covered for residential properties
Size of hurricane	• The larger the hurricane, the larger the affected area and the longer it takes to pass through an area
Forward speed of hurricane	• The forward speed of the hurricane adds to its anti- clockwise wind speed. Slow down increase rain damage
Other	

Major Hurricanes Frequency follows North Atlantic Sea Surface Temperature Trend?

- Atlantic Multi-decadal Oscillation (AMO), sulphate aerosols in atmosphere
- Solid Lines are smoothing curves



Issues with the Data

Hurricane data (HURDAT)

- Aircraft Reconnaissance in the 40s
- Satellite imaging in the 60s
  - micro wave and GPS waves
- Possible missing hurricanes before 50s

Sea Surface Temperature data (NOAA SST)

- Ships: wooden buckets or engine room
- Satellites: radiation
- Floats and drifts complimenting each other
- Different sea depths

Records for only three peaks of SST cycle

- Scientist use indirect methods to extend the period over which have information on SST and hurricanes (paleotempestology)

We analyse Major Hurricanes after 1950

Hurricane Groups and their Climatology

Hurricane Groups

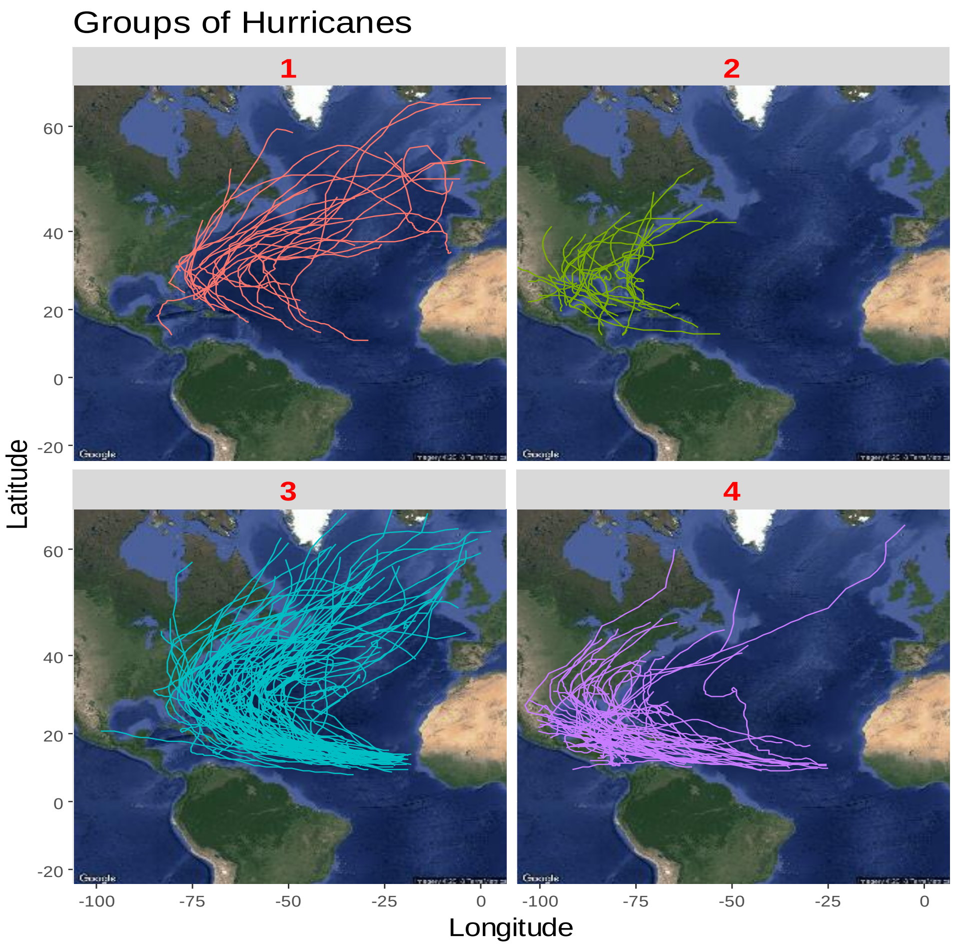
Different statistical clustering methods give different groups of hurricanes

Hurricane Groups were created by statistical cluster analysis by Professor Suzanna Camargo http://www.ldeo.columbia.edu/~suzana/

and Dr James Kossin http://www.ssec.wisc.edu/~kossin/

updating their 2010 paper to include hurricanes up to and including 2017

https://journals.ametsoc.org/doi/10.1175/2010JCLI3497.1



Climatology of Hurricane Groups

Group 1

Further from the Equator,

usually not very strong,

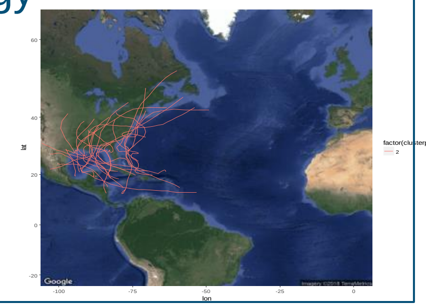
curve up, few landfalls

Group 2

Gulf, no time to gather energy

High probability of landfall

Example: Katrina, Harvey

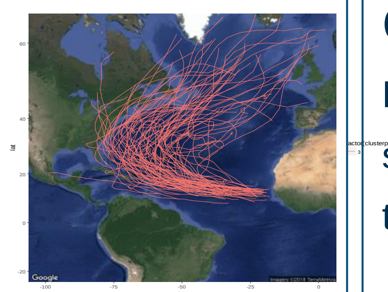


Group 3

Near the equator and east

time to gather energy,

curve up



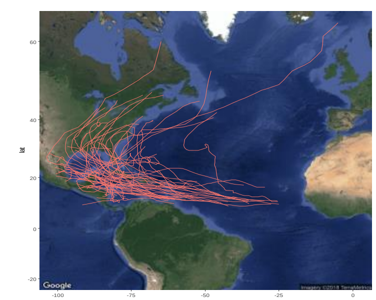
Example: Hugo, Florence

Group 4

Near the equator and west

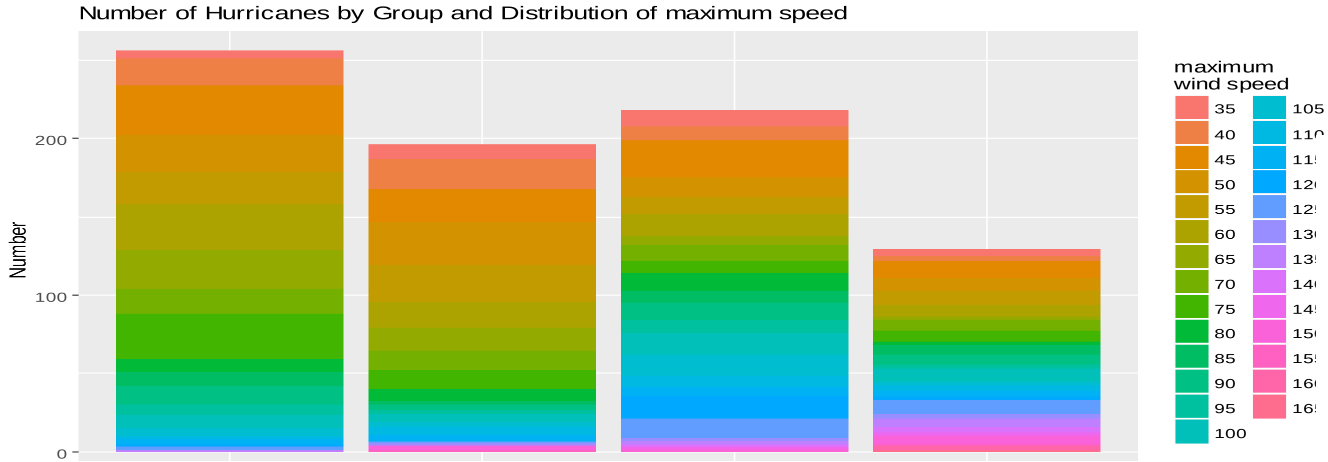
straight paths

towards Florida and Gulf

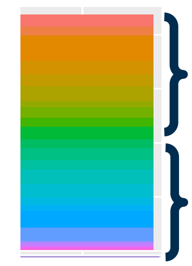


Example: Andrew, Irma, Maria

Groups 3 & 4 stronger hurricanes-Group 2: high count, likely landfalls



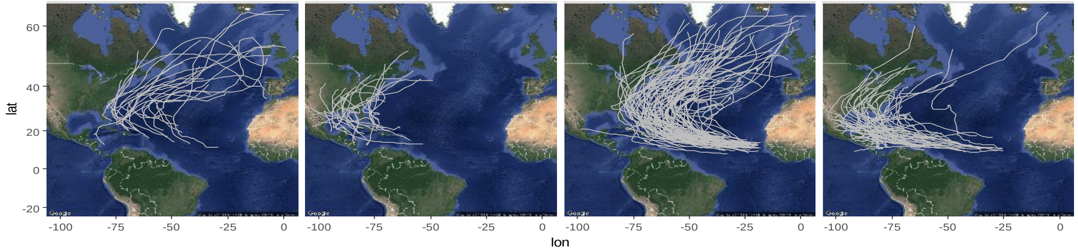
Legend



TS, HU

Major HU

	Group 1	Group 2	Group 3	Group 4	All
# of major hurricanes	23	24	76	53	**176**
US landfalls	5 (22%)	21 (87%)	16 (21%)	27 (51%)	**69 (39%)**



Hurricane Groups

Grouping of hurricanes helps analysis and understanding

- Climatology (location, SST, energy, etc.)
- Areas of landfall and intensity
- Probabilities of landfall
- Different groups are affected by different factors

Statistical Cluster Analysis

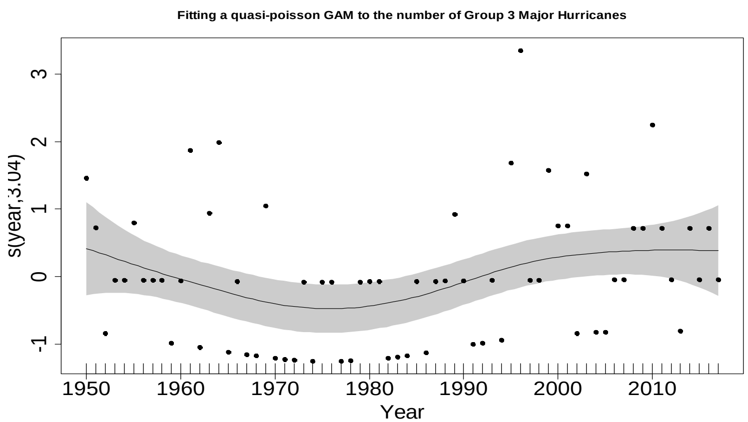
- Grouping not unique, it depends on the statistical clustering method and parameters

Has the Frequency of Major Hurricanes Increased?

Numbers and Volatility of major HU have been increasing (groups 3 &4)

Groups 1 & 2 fairly stable, small reduction

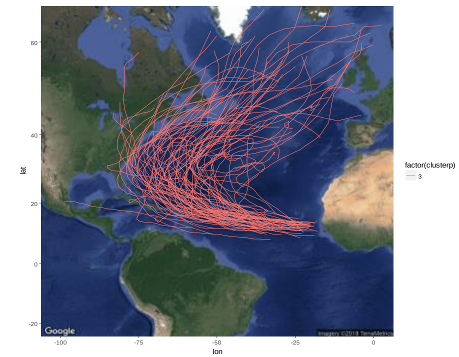
Log Scale

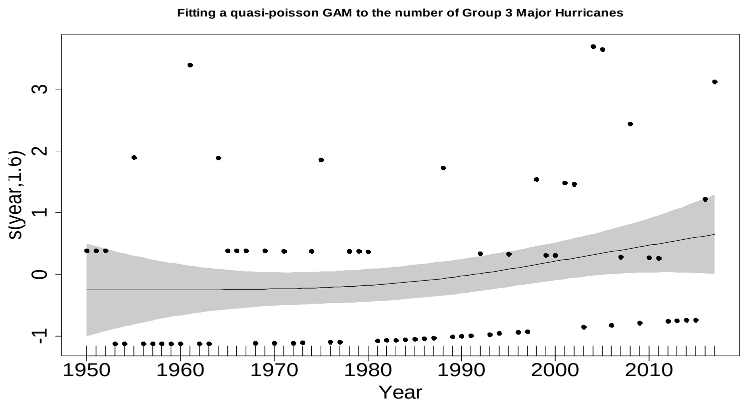


Group 3:

Periodic pattern?

Poisson

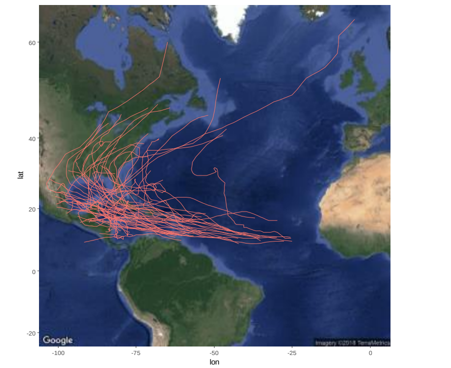




Group 4:

Statistically Significant increase

Volatility higher than Poisson



Shadows: 95% C.I.

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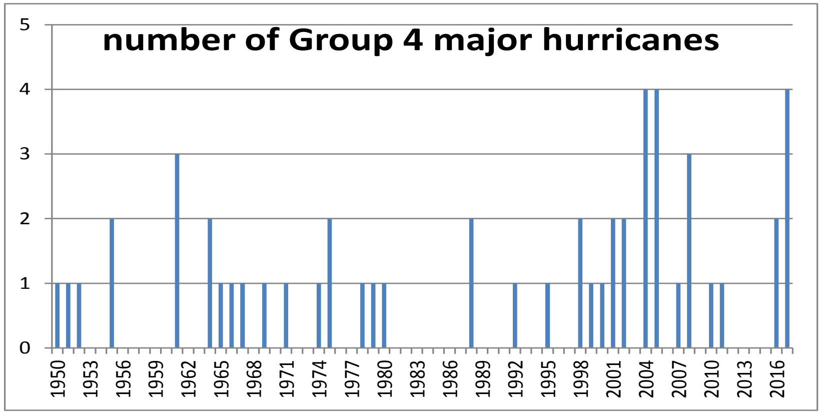
Discussion on Findings (1)

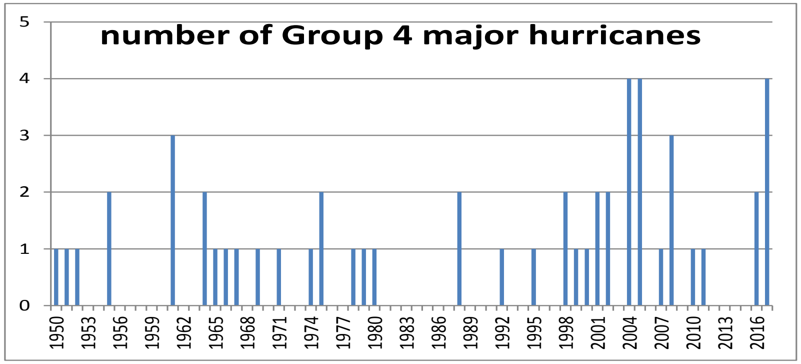
- The data is limited
  - Yes, in the future we may want to combine statistical models with atmospheric models
  - BUT, what we see in the data can **not** be ignored and it can be tested statistically
- Group 4 (1950 – 2017): Variance is ~50% higher than mean
  - Poisson fixed mean: About 1% probability of this happening by chance!
  - Probability is significantly lower if we consider period 1980 – 2017
- Group 4 (1950 – 2017): three years with 4 major hurricanes
  - Poisson fixed mean: about 2% probability of this happening by chance!
- Group 4 (1950 – 1979):
  - No obvious over-dispersion.
  - All is happening after 1980!



Discussion on Findings (2)

Small amount of data: you remove a point, you get a different model

- Yes, BUT
  - Group 4: Point with highest leverage is year 2017
  - Remove 2017 (1950–2016)->Group 4: variance 35% higher than mean. Poisson fixed mean: 3% probability of this happening by chance. Therefore over-dispersion is still there!



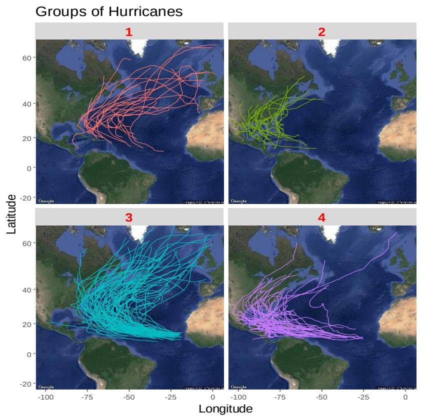
- Yes, BUT
  - Small amount of data does not necessarily mean unstable model
  - Remove any point from Group 3 and the model does not change much
  - Remove some points from Group 4 and the model changes:
    - Over-dispersion
    - Rapid unpredictable changes in model and mean – this is even worse!

Probability of multiple continental US landfalls of major hurricanes in a year

Actual Continental US Landfalls since 1950
Not many years with multiple events

Observed Major* Hurricanes US Landfalls 1950 - 2017				
Regional Groups	Number of Years		Return Periods	
	2+ major hurricanes	3+ major hurricanes	2+ major hurricanes	3+ major hurricanes
Group 1	0	0		
Group 2	2	0	1 in 34	
Group 3	2	0	1 in 34	
Group 4	6	1	1 in 11	1 in 68
All Groups	18	5	1 in 4	1 in 14

* Major at some point in its lifetime



Current fitted probabilities of multiple events higher than observed since 1950

Regional Group	2 or more major* hurricanes making landfall in the US		3 or more major* hurricanes making landfall in the US	
	Current Fitted (2018)	Observed	Current Fitted (2018)	Observed
Group 1	1 in 400	<1 in 500		
Group 2	1 in 25	1 in 34	1 in 250	
Group 3	1 in 20	1 in 34	1 in 180	
Group 4	1 in 7	1 in 11	1 in 30	1 in 68
All Groups	1 in 2.5	1 in 4	1 in 7	1 in 14

* Major at some point in its lifetime

<u>Assumptions:</u>

- Probability of landfall constant over time. We will revisit
- Group frequency assumed independent
- Negative Binomial for Group 4, Poisson for the other Groups

Recent Trends: Higher Number and Volatility

Increased expected numbers of major hurricanes (groups 3 &4)

- Group 3 and 4 hurricanes can hit areas with high exposures

Higher volatility in the number of Florida/Gulf hurricanes

- Giving rise to years with multiple major hurricanes (clustering)

Implications (discussion at the end)

- Parameterisation of cat models
- Risk management

Have we observed similar trends for US landfalls data?

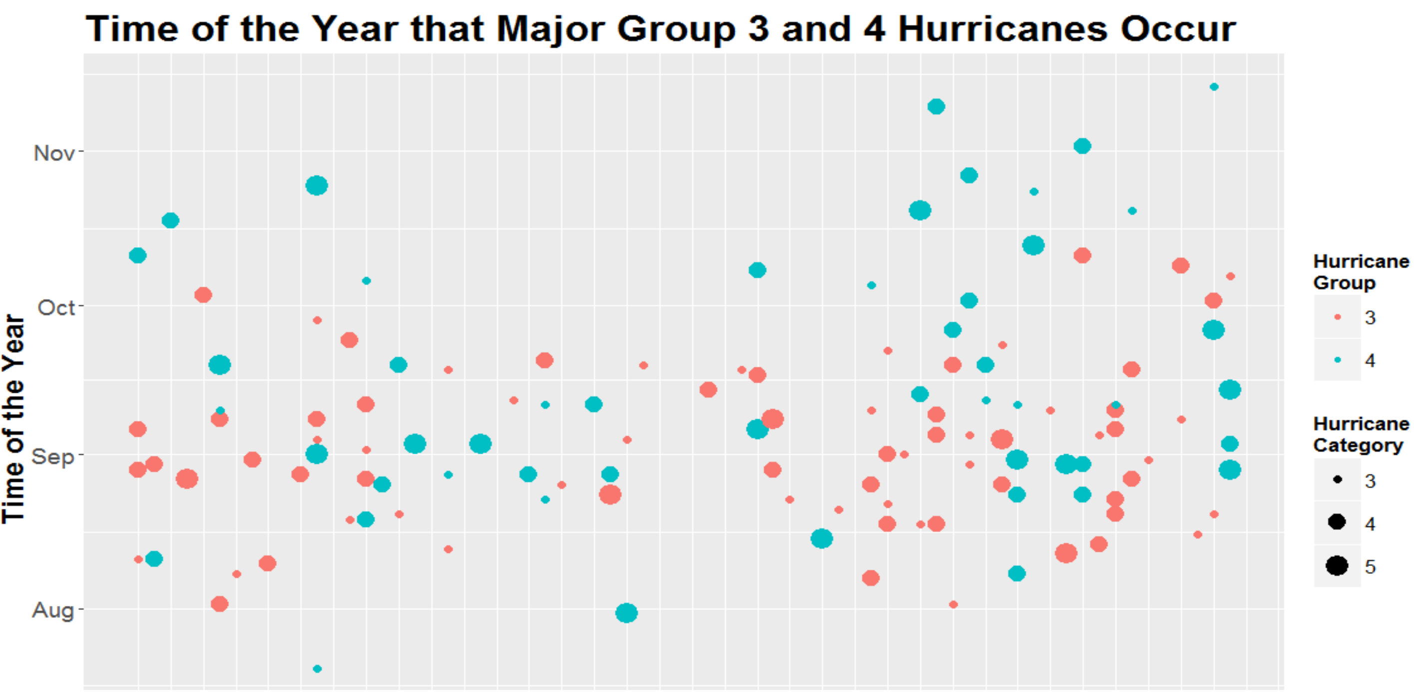
- Definition of landfall?
  - Landfall as major hurricane? How about Ike?
  - Landfall as hurricane? How about Sandy?
  - Any landfall?

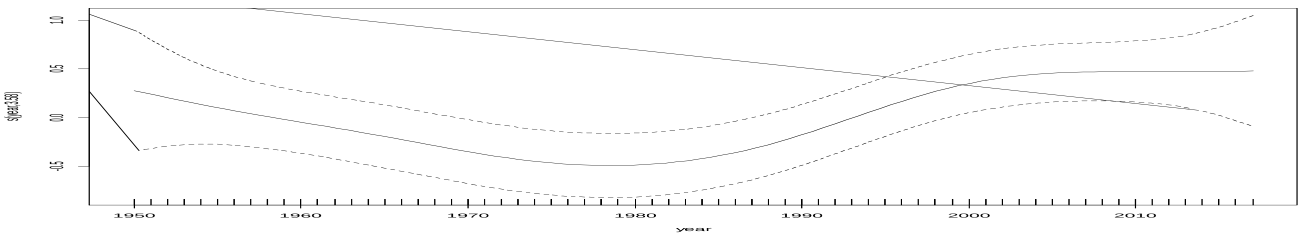
Under most definitions, we observe over-dispersion for landfalls as well

- There is not necessarily an equally obvious increasing trend in the number of landfalls
- There is not necessarily an obvious trend in the probability of landfalls of major hurricanes over time, given that the hurricane occurred
- Smaller numbers, higher statistical uncertainty

Late Hurricanes

Hurricane season extended in high frequency years





Time of the Year that Hurricanes Occur

In high frequency years group 4 hurricanes likely to also occur in October

Late major Hurricanes usually in Caribbean

Most of the late Major HU start in the Caribbean (group 4) and

have paths which tend to go north and east

with lower probability of hitting the US

However,

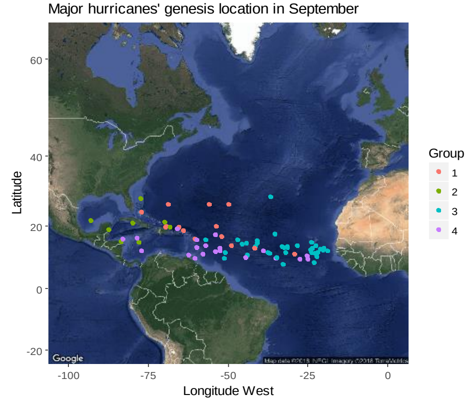
they could hit Florida or Gulf

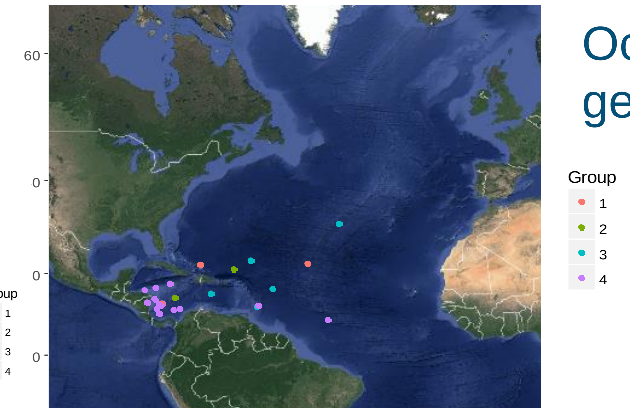
They can **intensify very quickly**.

Be ware of the late hurricanes

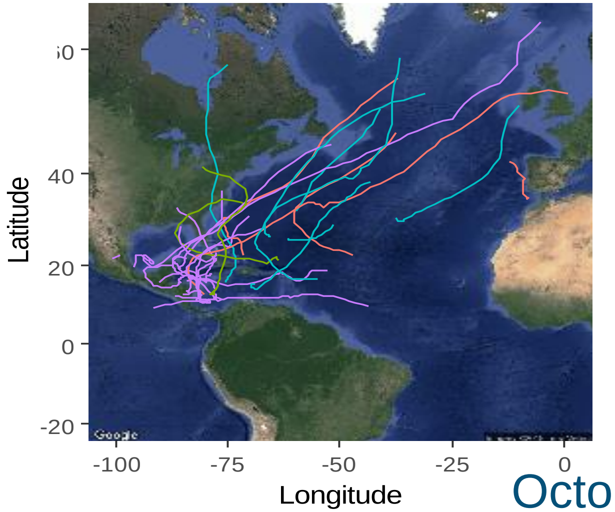
Wilma 2005, Michael 2018

September genesis





October genesis



October paths

Trends

Over dispersion and Increasing Trend of Group 4 hurricanes

Over dispersion of US Landfalls

Mother Nature protects the US east coast?

- Inverse relation between SST and vertical wind shear near the US? (e.g. Kossin (2017))

In high frequency years we observe October major hurricanes

- most of them wonder off to the North Atlantic and do not hit the US, but they can strengthen very rapidly

There is some evidence (not strong) of some “crowding out”

- There is a slight negative correlation between the number of Group 3 and 4 major hurricanes in a year recently

Implications

Implications of the observed trends in frequency (1)

- Choice of model parameters
  - Long term versus short term assumptions
- Choice of Stress Tests
- Communication of uncertainty
  - Communication to the Board
  - Communication between experts
- Validation
  - How are cat models validated independently?
- Should we aim for more integration of climate models with statistical models?

Implications of the observed trends in frequency (2)

- Risk management
  - Impact on capital requirements, impact on capital management
  - Depends on portfolio
- Reinsurance cover and pricing
  - Sideways exhaustion of reinsurance (October hurricanes)
  - Aggregate covers
- Operational preparedness
  - Claims management, risk adjusters, additional costs
- Loss Creep
- Other implications for society: storm surge and flooding

Some interesting relations could be investigated further

- Potential links between North Atlantic hurricanes and other atmospheric natural catastrophes, such as wildfires severe convective storms?
  - Different starting mechanism, but weather conditions may help the development of both

- Physical explanation of clustering?

- Potential links between the hurricanes in the North Atlantic and Pacific?

Summary

Both expected frequency and volatility of major hurricanes have increased

- Groups 3 and 4 major hurricanes can cause significant insurance losses

Major hurricanes are likely to occur closely to each other in time

There are implications for

- Choice of model parameters and communication of model parameters
- Choice of Stress Tests
- Risk management
- Capital requirements and capital management
- Reinsurance pricing and cover?
- Operational preparedness

Statistical analysis can group together hurricanes with similar climatology

- Grouping can help understanding and analysis

How could we best combine weather/climate models with statistical models?

Thank you
Any questions?

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References 1

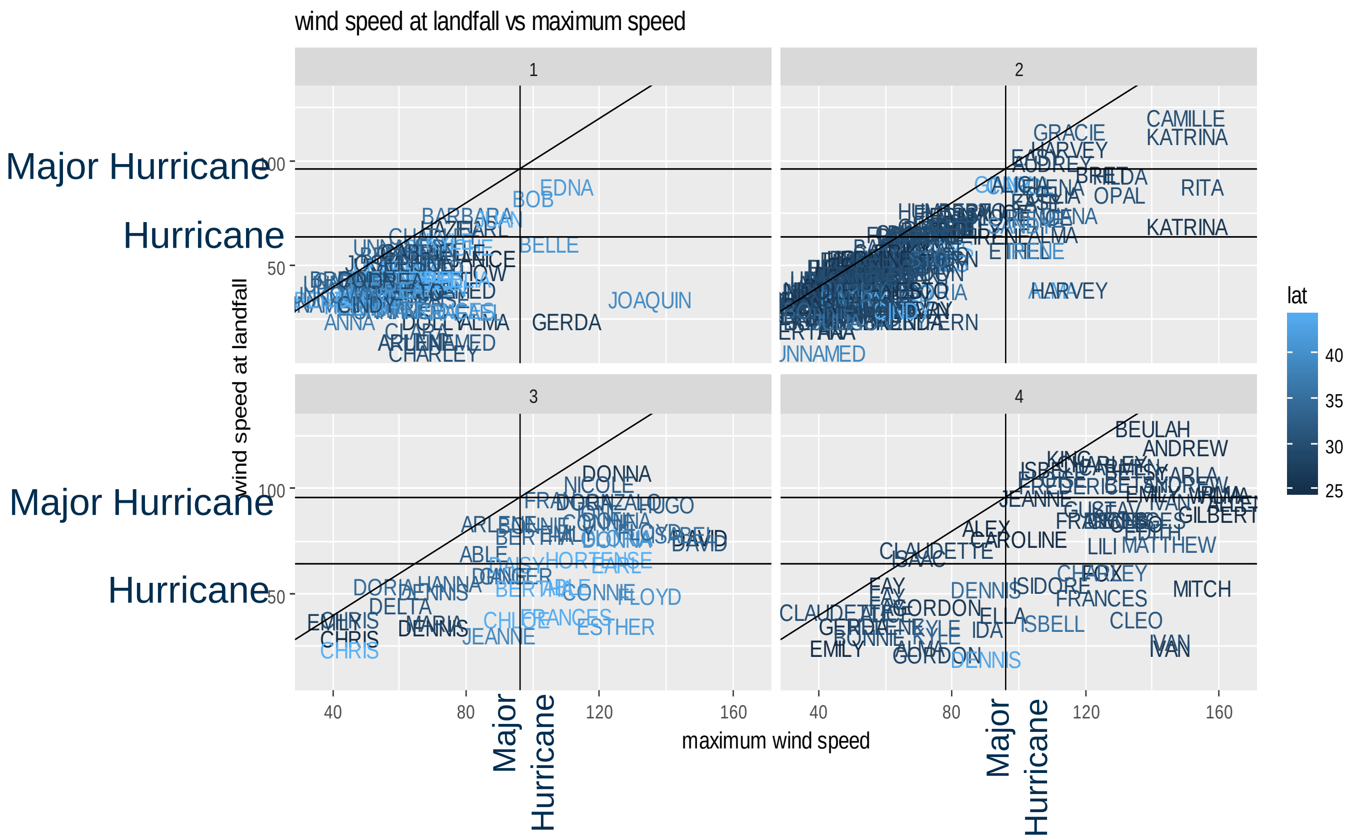
- Alexander-Turner R. et al (2017) How Robust Are the Surface Temperature Fingerprints of the Atlantic Overturning Meridional Circulation on Monthly Time Scales?, Geophysical Research Letters, p. 1
- Gaffney S. J. (2007) Probabilistic clustering of extratropical cyclones using regression mixture models, Clim Dyn, p.423
- Holland G. J. et al (2017) Heightened tropical cyclone activity in the North Atlantic: natural variability or climate trend?, Philosophical Transactions of the Royal Society, p. 2695
- Jagger T. H. et al (2012) Hurricane Clusters in the Vicinity of Florida, American Meteorological Society, p. 869
- Kennedy J. J. (2013) A review of uncertainty in in situ measurements and data sets of sea surface temperature, Reviews of Geophysics,p. 1
- Emanuel K. (2003) Tropical Cyclones, Annu Rev Earth Planet Sci, 31, 75
- Emanuel K. (2005) Increasing destructiveness of tropical cyclones over the past 30 years, nature vol 436, p 686
- Emanuel K. (2006) Hurricanes: Tempests in a greenhouse, Physics Today, August 2006, p.74
- Emanuel K.. (2007) Environmental Factors Affecting Tropical Cyclone Power Dissipation, American Meteorological Society, p. 5497
- Emanuel K. (2017) Hurricane Physics, presentation
- Knutson T. R. et al (2015) Global Projections of Intense Tropical Cyclone Activity for the Late Twenty-First Century from Dynamical Downscaling of CMIP5/RCP4.5 Scenarios, American Meteorological Society, p. 7203
- Knutson T.R. et al (2008) Simulated Reduction in Atlantic Hurricane frequency under 21st Century Warming Conditions, nature geoscience

References 2

- Kossin J.P. et al (2010) Climate Modulation of North Atlantic Hurricane Tracks, American Meteorological Society, p. 30157
- Kossin J. P. (2017) Hurricane intensification along United States coast suppressed during active hurricane periods, nature vol 541, p. 390
- Maloney E. D. (2000) Modulation of Hurricane Activity in the Gulf of Mexico by the Madden-Julian Oscillation, science, p. 2002
- Moore G. W. K. et al (2017) Amplification of the Atlantic Multidecadal Oscillation associated with the onset of the industrial-era warming, nature, p. 1
- Murakami et al (2016) Statistical–Dynamical Seasonal Forecast of North Atlantic and U.S. Landfalling Tropical Cyclones Using the High-Resolution GFDL FLOR Coupled Model, American Meteorological Society, p. 2101
- Nakamura et al (2009) Classifying North Atlantic Tropical Cyclone Tracks by Mass Moments, American Meteorological Society, p. 5481
- Villarini G. (2010) Modeling the Dependence of Tropical Storm Counts in the North Atlantic Basin on Climate Indices, American Meteorological Society,
- Villarini G. et al (2012) U.S. Landfalling and North Atlantic Hurricanes: Statistical Modelling of Their Frequencies and Ratios, American Meteorological Society, p. 44
- Weinkle J. et all (2018) Normalized hurricane damage in the continental United States 1900-2017, nature sustainability,

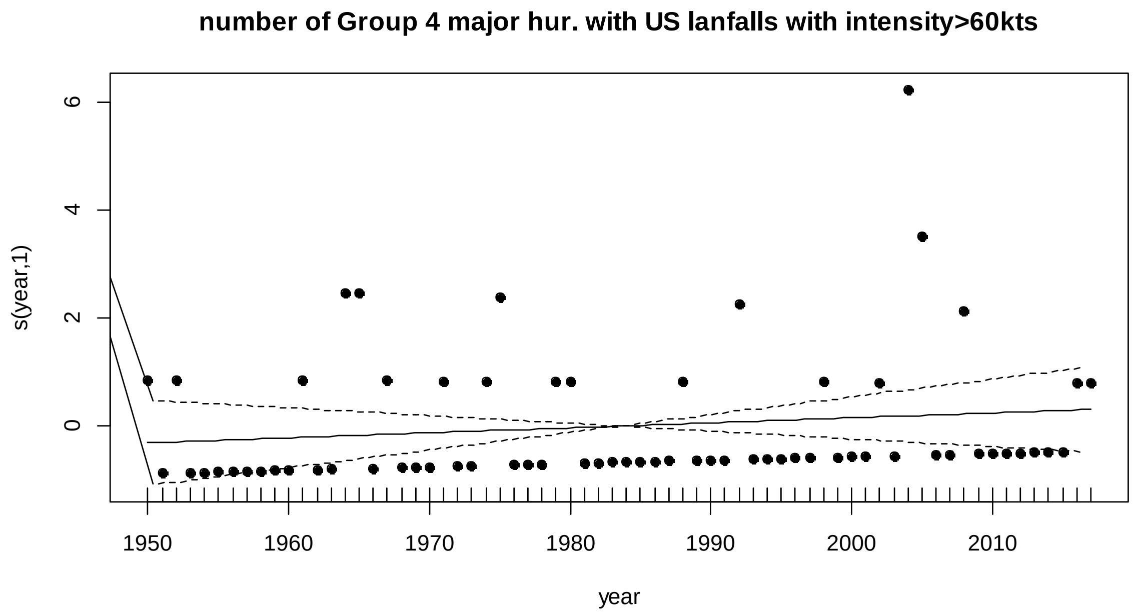
Appendix A:Most major HU at some point in lifetime make landfall at least as HU

- Major HU at some point in their lives do not necessarily make landfall as major HU.

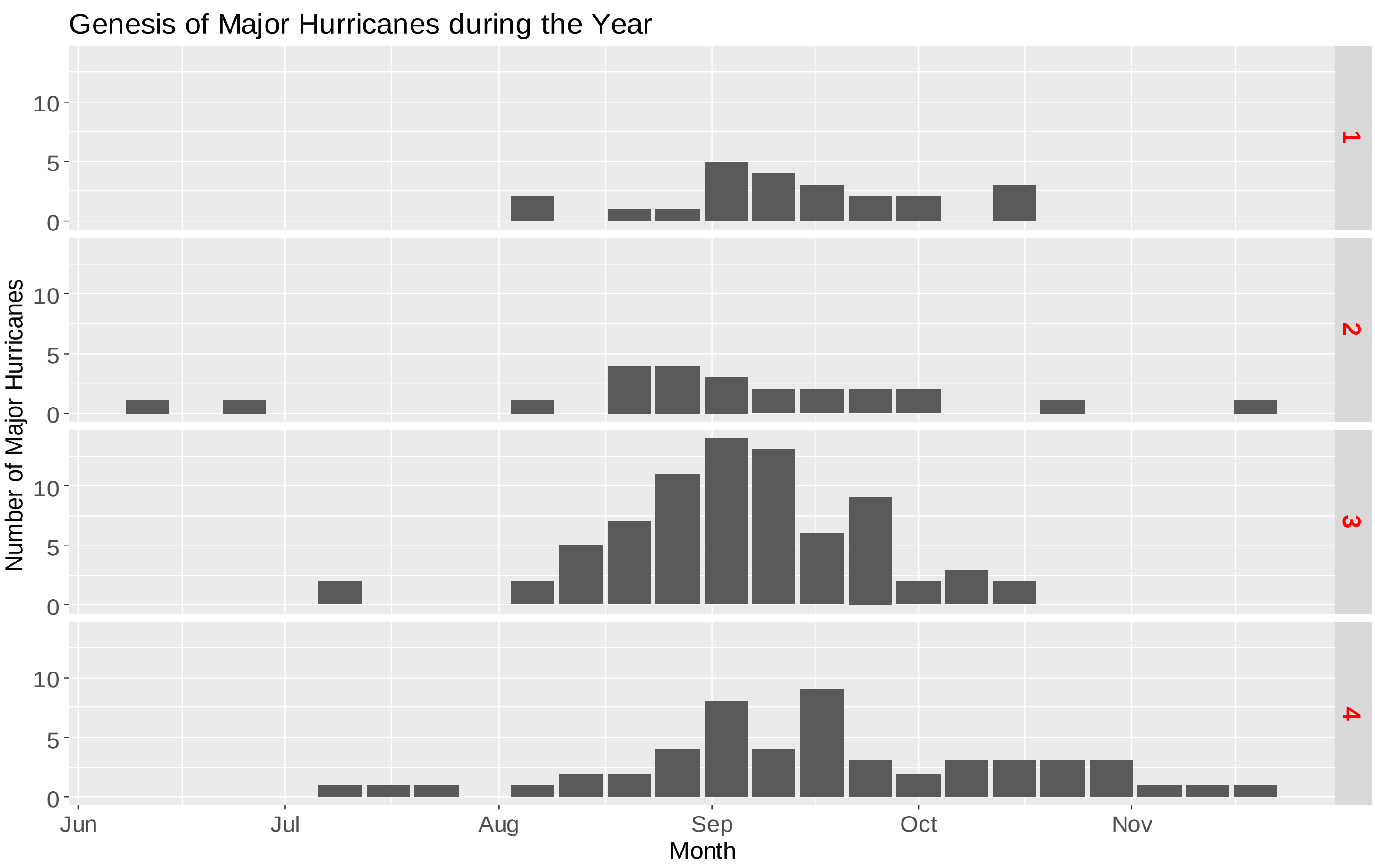


Appendix B: Have we observed similar trends for US landfalls? An example

- Group 4, major hurricanes which make US landfalls with wind speeds >60kts
- Over-dispersion, but not strong increasing trend.
- Wind Shear? Papers by Knutson et al (2008) and Kossin (2017)



Appendix C: Most major hurricanes occur between mid-August and end-September



Peak 1st part of September

Groups 1&2 more spread over the year

Group 3 more concentrated in a few weeks

Group 4 two peaks

Appendix C: Do hurricanes come in clusters?

Most major hurricanes occur in the short period mid-August to mid-September

- it is likely that major hurricanes will occur close in time

Experiment

- Assume independent daily increments ($\sim Poisson(\lambda_t)$):
- Result: probability of around 50% that Group 3 hurricanes will occur within two weeks of each other
- given that more than two hurricanes occur in a year, it is likely that they will occur close to each other

Implications for operational preparedness