The Frequency of Severe Weather Events

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Agenda

- Event frequency modeling: importance and challenges
  - Establishing the appropriate frequency for each event
  - Establishing the appropriate arrival model (e.g. Poisson, negative binomial, compound, empirical, etc.)
  - Examples: Atlantic Hurricane, US Severe Convective Storm
- Near term (climate-conditioned) frequency models
  - Examples: Atlantic Hurricane, Asia Typhoon
- Supplementing the historical record through numerical weather modeling
  - Example: European Windstorm
- Q&A

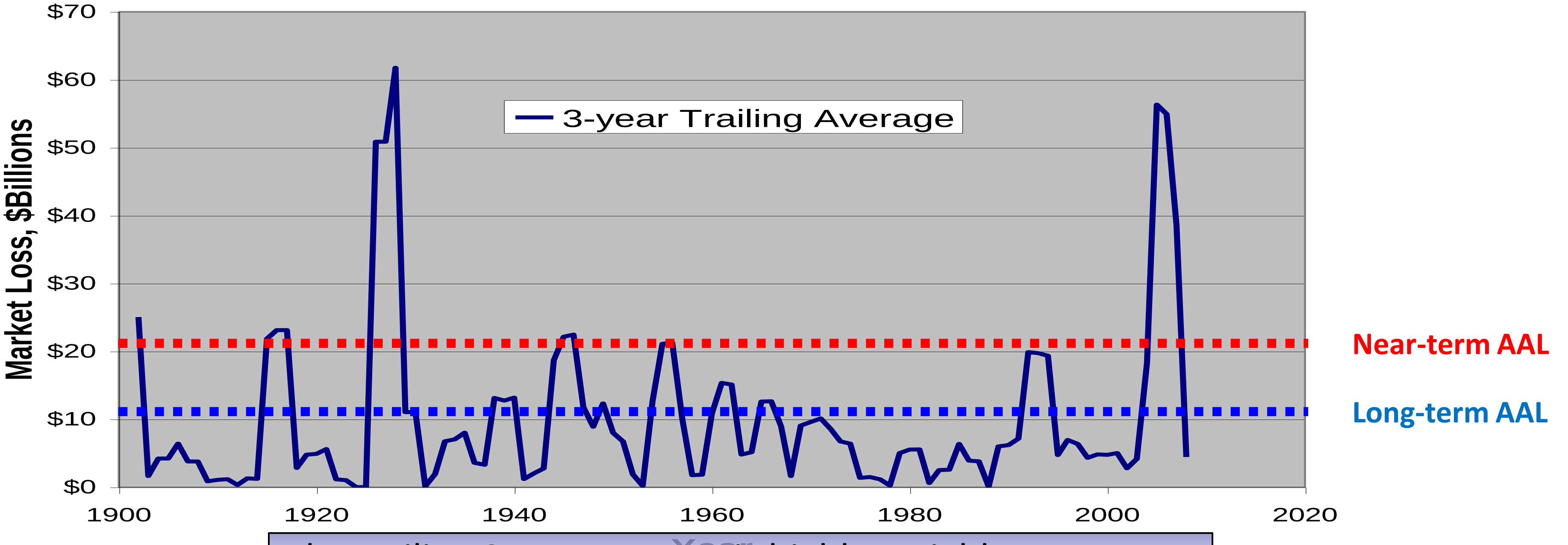
Event Frequency Modeling: Importance and Challenges (Opportunities) (1)

- Year-to-year volatility of losses
- Limited length and quality of record
  - Even ~110 years of US hurricane landfall data is limited, e.g. with respect to major hurricanes in the Northeast: is the 1938 storm a 1-in-110 event? 1-in-75? 1-in-150?
- Uncertainties in the data
  - Uncertainties in TC best track data are significant, especially (but not only) prior to the satellite era (~pre 1970)
  - Single 'definitive' data set for the Atlantic (HURDAT) gives false sense of certainty
  - Multiple agencies maintain similar data in the Western North Pacific, providing a glimpse into the uncertainties

Event Frequency Modeling: Importance and Challenges (Opportunities) (2)

- Non-meteorological trends in observational data
  - e.g. trend in EF2+ tornado frequencies since 1950
- Dependence of event frequencies on various aspects of the climate
- Spatial and temporal clustering of events
- Correlation among weather perils

Annual hurricane losses are volatile



The trailing 3 year average is highly variable

Average annual loss ~ $11 billion
Standard deviation ~ $22 billion

- More Than 2/3 of the <u>Normalized</u> Losses Have Come From a Dozen Seasons
- Individual Seasons Have Contributed > 10% of the <u>Normalized</u> Losses Since 1900

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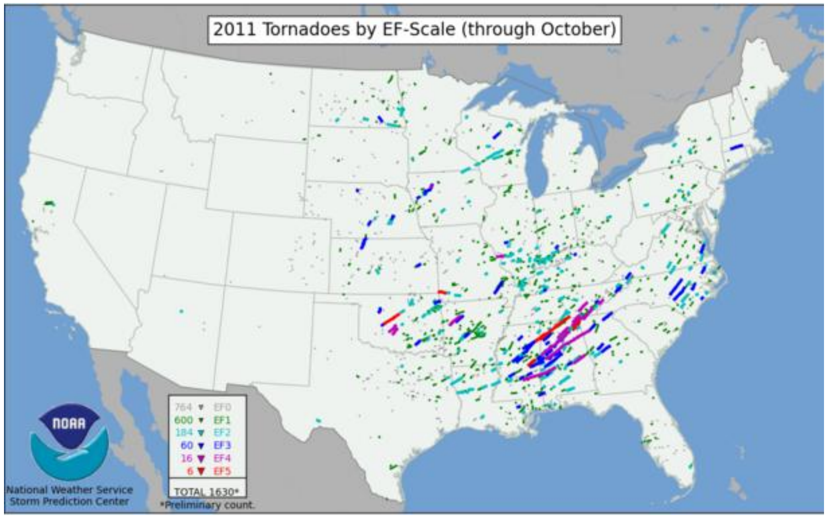
CONTINENTAL UNITED STATES HURRICANE STRIKES 1950-2011*

NOAA's NATIONAL CLIMATIC DATA CENTER ▪ ASHEVILLE, N.C.

2011 – What happened

	2011	Maximum Observed
Tornado Days	179	211 (2000)
Tornadoes	1700	1817 (2004)
Most in single day	200 (27 Apr)	Was 128 (1974)
Fatalities	551 (3rd)	~700 (1925)
Longest Track	132 miles(AL-TN)	235 miles (LA-MS, 1953)
# EF4-EF5	22 (4th)	36 (1974)
# EF5	6 (2nd)	7 (1974)



- Aggregate Loss exceeded $25 Billion
- 6 events had losses > $1 Billion (2 were $7+ Billion)

http://www.spc.noaa.gov/wcm/2011-jan-oct_sm.png

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Historical Data Issues - Tornado

- From the 1950s to the mid 1980s (pre Doppler radar)
  - Frequencies of F0 / F1 tornadoes have been underestimated
  - Severity of F2 to F5 tornadoes have been overestimated in some cases
- Frequency ratios among F2-F3-F4-F5 over the period 1950 to present are reliable
- Trend line in overall touchdown frequency is derived from post-1990 data
  - ~400 touchdowns/year in 1950
  - ~1200 touchdowns/year at present
  - No meteorological reason for this trend
- Trend line is used to correct historical data set
- Expert peer review to confirm the approach (Dr. Harold Brooks, NWS)

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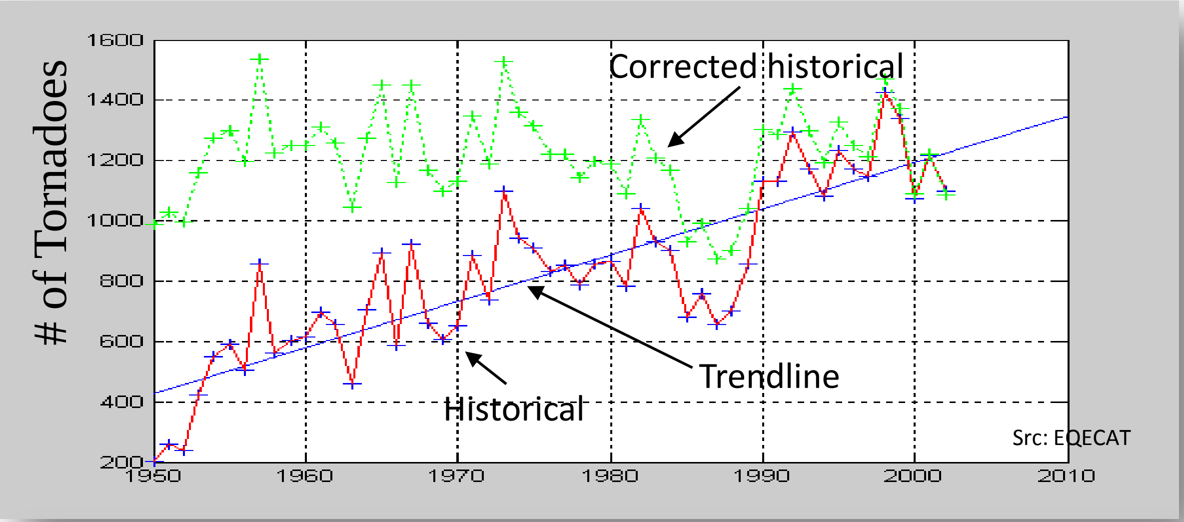
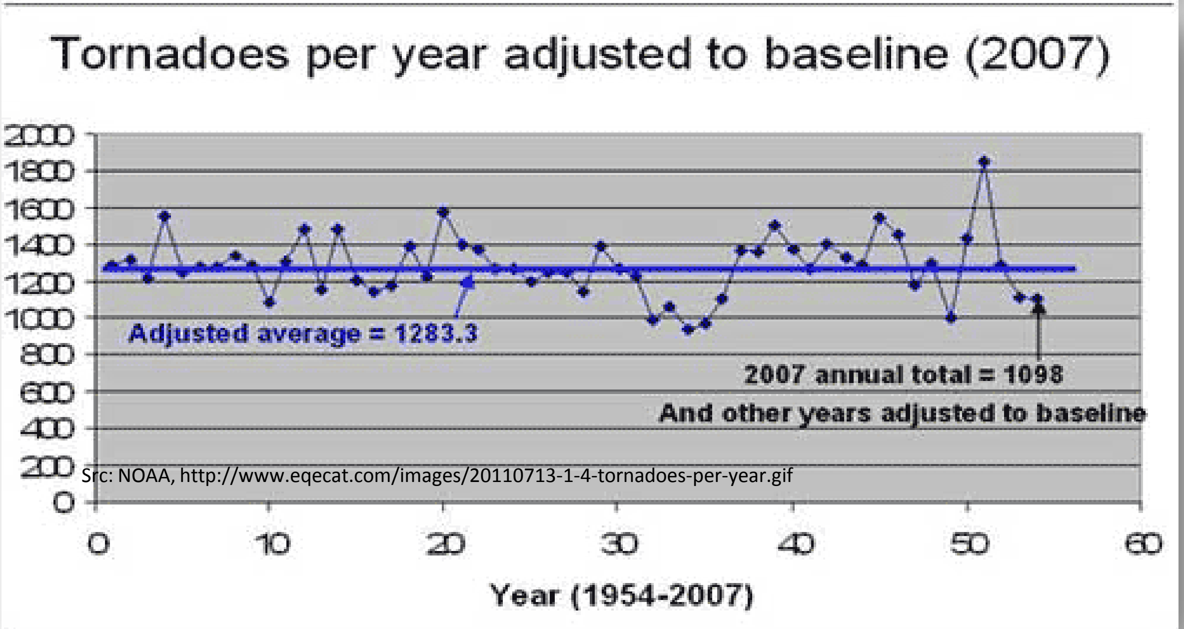
Tornado Frequency





Event Definition

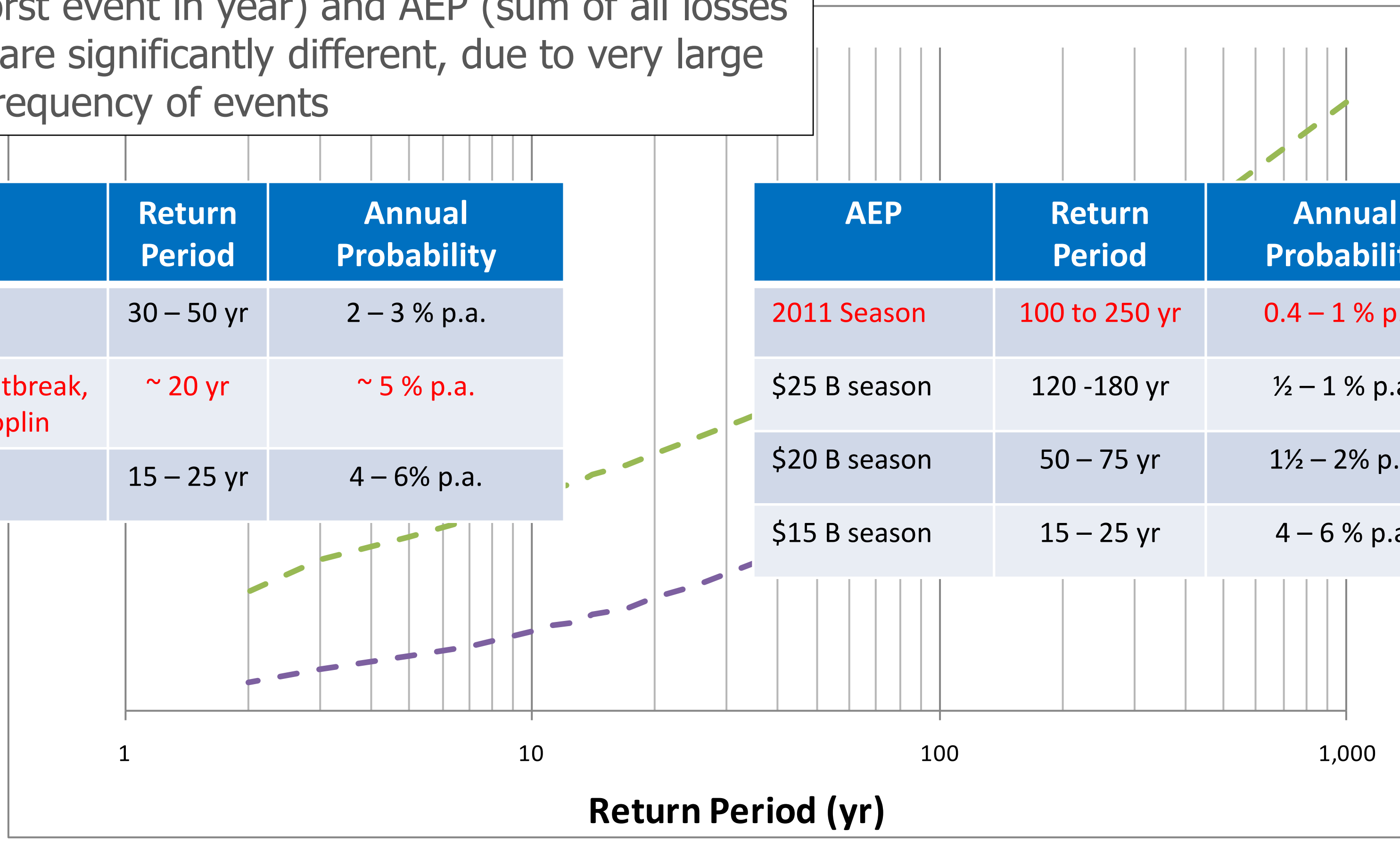
- Events defined from insurance occurrence perspective
  - Spatial clustering (groups of tornado and hail polygons)
  - Temporal clustering (negative binomial frequency distribution)
  - Events defined generally as storm systems (not limited to 72 hours; consistent with PCS catalog)

"Modeled Market" Loss Curves

OEP (worst event in year) and AEP (sum of all losses in year) are significantly different, due to very large overall frequency of events

OEP	Return Period	Annual Probability
$10 B event	30 – 50 yr	2 – 3 % p.a.
Apr 2011 outbreak, May 2011 Joplin	~ 20 yr	~ 5 % p.a.
$5 B event	15 – 25 yr	4 – 6% p.a.

AEP	Return Period	Annual Probability
2011 Season	100 to 250 yr	0.4 – 1 % p.a.
$25 B season	120 -180 yr	½ – 1 % p.a.
$20 B season	50 – 75 yr	1½ – 2% p.a.
$15 B season	15 – 25 yr	4 – 6 % p.a.



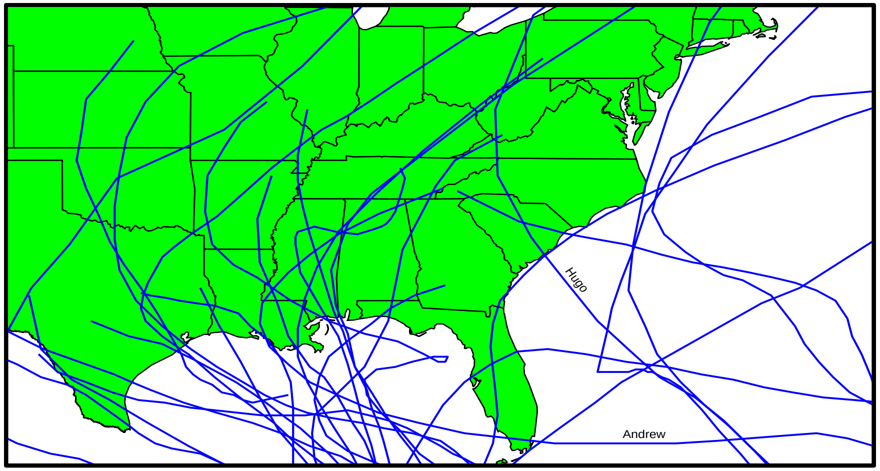
2011 was an exceptional year with several very large events - but it was not unforeseen

Near term frequency models

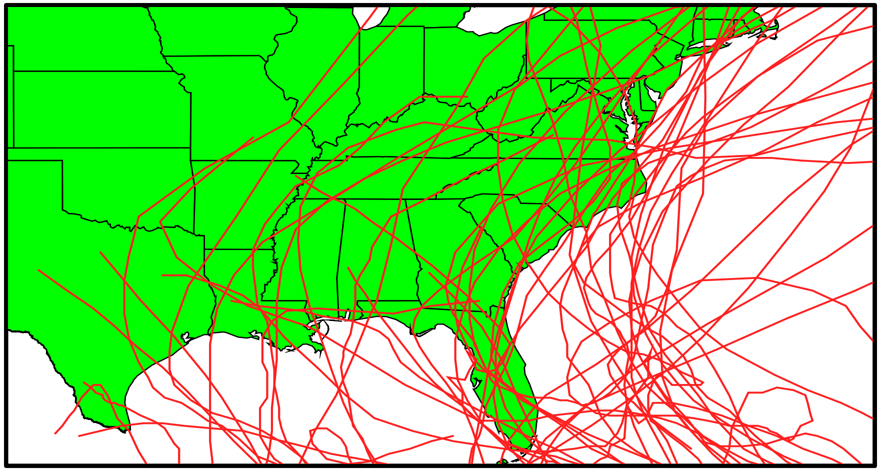
Major Factors influencing Atlantic Hurricanes

Cycle	What	Influence	Cycle Frequency
ENSO	An interannual cycle of Warm vs. Cool SST in the equatorial Pacific Ocean	Warm (El Niño) phase inhibits hurricane activity; Cool (La Niña) produces favorable conditions for hurricane activity	Average 5 years with high variability. Ability to change phase rapidly
NAO	North-south dipole of anomalies associated with basin-wide changes in the intensity and location of the North Atlantic jet stream	Influences general storm paths (Gulf vs. Atlantic	Considerable interseasonal and interannual variability
AMO	Variation in sea surface temperature (SST) in the North Atlantic Ocean	Warm phase enhances hurricane activity; Cool phase inhibits hurricane activity	50-70 years
Azores-Bermuda High	A high pressure system in the North Atlantic Ocean which can influence steering patterns	A strong/extensive high will steer storms westward toward N. America; A weak high, will let storms turn northward	No cycle identified
Saharan Air Layer	Extremely dry air at mid-levels of the atmosphere which can be transported into the tropical Atlantic	Extremely dry air impedes hurricane development	No cycle identified

Cat 3+ Hurricane Activity During AMO Cycles



Cool AMO
28 CAT 3+ events in 51 years
Frequency of 0.55 per year



Warm AMO
49 CAT 3+ events in 62 years
Frequency of 0.79 per year

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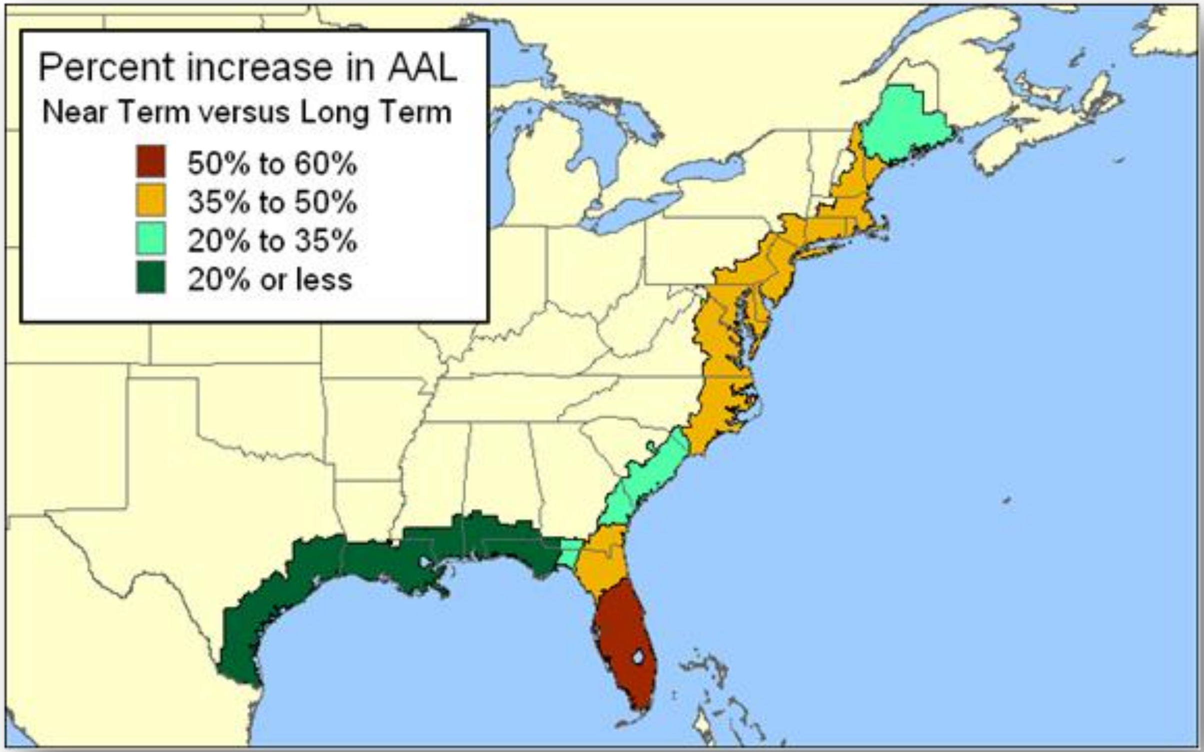
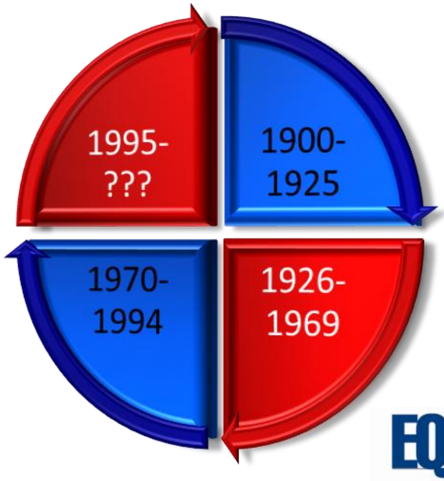
Percent Increase in AAL from the Long-Term to the Near-Term Model



Near-term Frequency Models vs. Predictions/Forecasts

- EQECAT's near-term Atlantic Hurricane probabilistic loss model is a conditional loss model based upon the status of the AMO cycle.
- It is a representation of the risk, conditional on the presence of a set of aspects of the climate system that are significant for tropical cyclone development and intensification (warm AMO)
- It is NOT a prediction of what will happen over the next 5 years, let alone the next season



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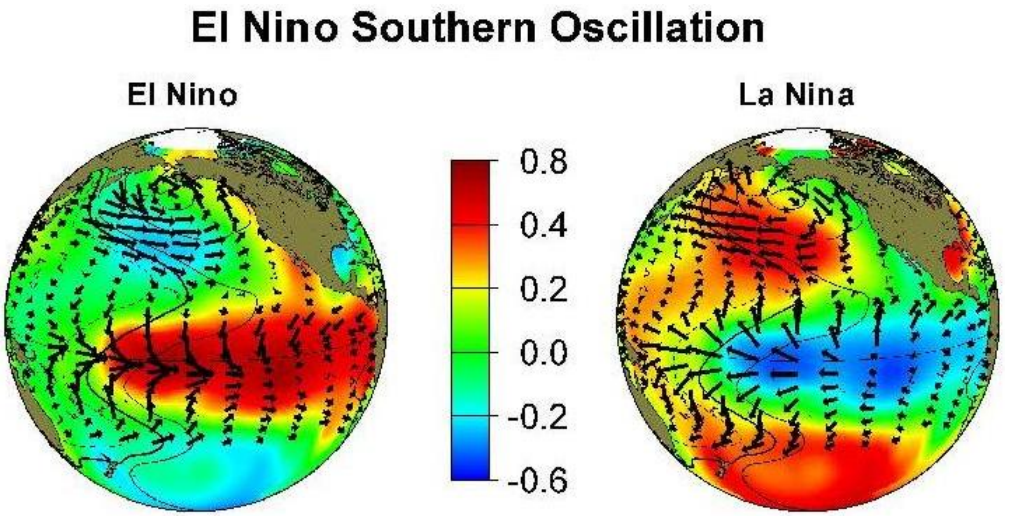
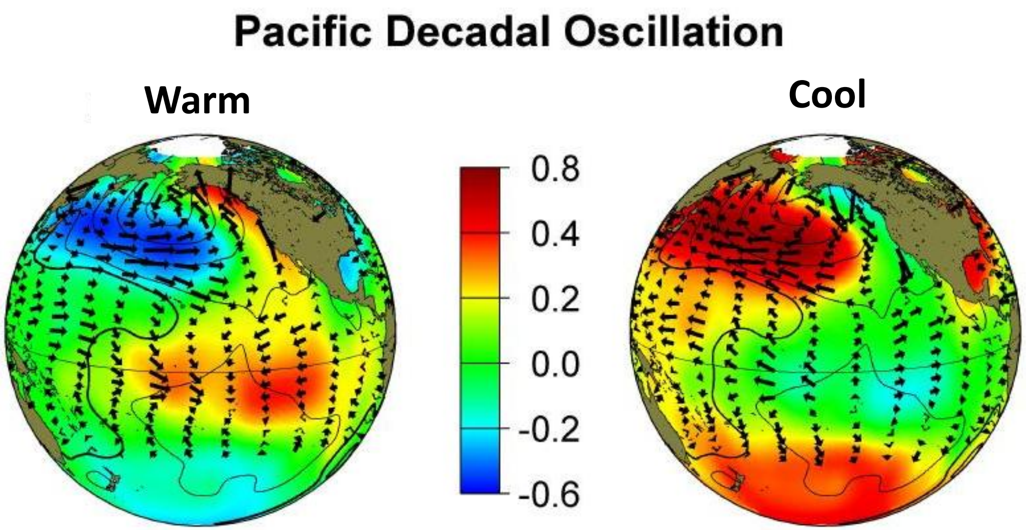
Main Factors of WNP TC activity

- El Niño Southern Oscillation (ENSO) - roughly 2-7 years
  - WARM Phase (El Niño)
    - Above average SST in the tropical Pacific - frequent El Niño Events
    - Storms form farther south and east than normal; more time to develop
  - COOL Phase (La Niña)
    - Below average sea surface temperatures in the genesis region
    - Storms tend to form farther west; less time to develop before landfall or re-curvature



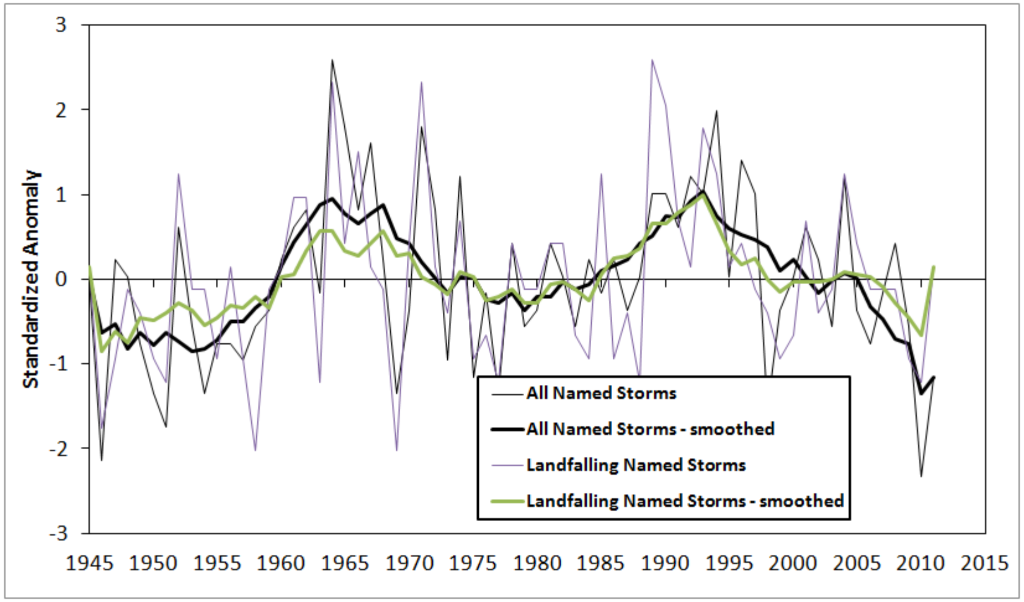
Main Factors of WNP TC activity

- Pacific Decadal Oscillation (PDO) - roughly 20-30 years in each mode
  - WARM Phase (1976-2008)
    - Above average SST in the tropical Pacific - frequent El Niño Events
    - More favorable environment for development of typhoons
  - COOL Phase (1945-1975; 2009-present)
    - Below average SST in the tropical Pacific - frequent La Niña Events
    - Less favorable environment for development of typhoons



Multi-Decadal Cycles in WNP TC activity

- Quiet Periods
  - Unfavorable conditions in the TC genesis region
  - Below normal basin-wide TC activity
  - 1945-1959, 1972-1984, and 1998-2012
- Active Periods
  - Favorable conditions for above normal TC activity
  - Development and intensification of major typhoons and more landfalls
  - 1960-1971, 1985-1997



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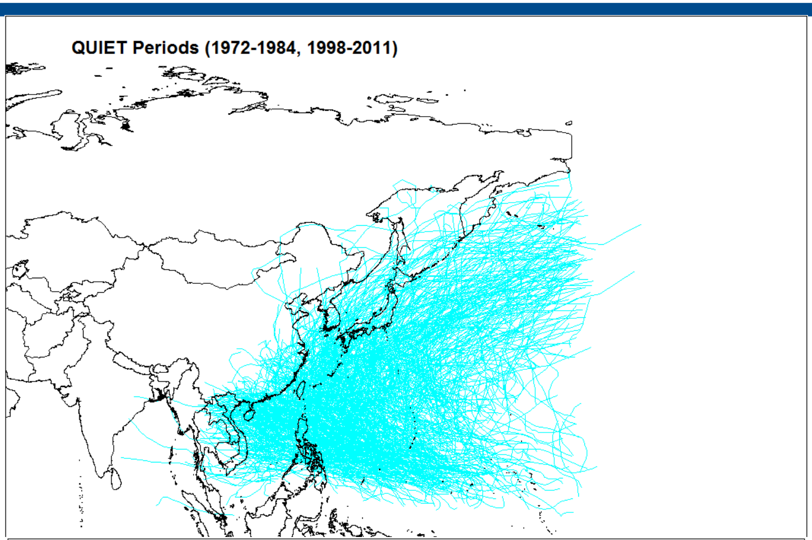
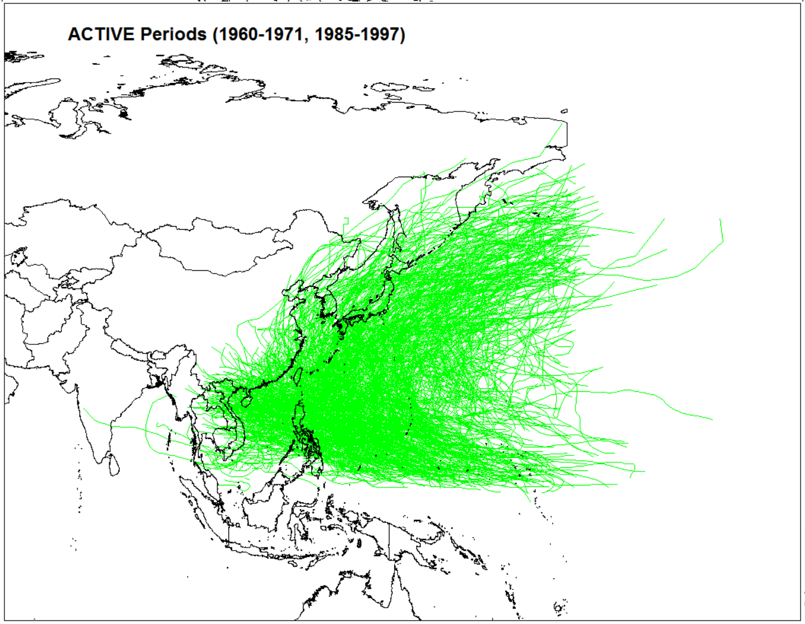
Multi-Decadal Cycles in WNP TC activity

- Quiet Periods
  - Genesis shifts westward
  - Less time to develop and intensify
  - Unfavorable conditions for genesis
- Active Periods
  - Genesis occurs in the far eastern tropical North Pacific
  - More time to develop and intensify into major typhoons
  - Favorable conditions for more genesis





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Historic Landfall Frequency Change – Quiet vs. Active periods

- Regionally varying landfall frequency
  - Basin-wide, about 52% of TCs have multiple landfalls
  - Significant changes in region 1 landfall frequency
  - Significant increase in major typhoon landfalls during active periods in regions 1 & 3
  - Less steep reduction in major typhoon landfalls in the quiet periods

Category	Region 1		Region 2		Region 3	
	MYS,PHL,THA,VNM		CHN, HKG, TWN		KOR, JPN	
	Quiet (Q1+Q2+Q3)	Active (A1+A2)	Quiet (Q1+Q2+Q3)	Active (A1+A2)	Quiet (Q1+Q2+Q3)	Active (A1+A2)
TS	-12%	19%	-8%	12%	-12%	19%
1	-10%	16%	-2%	3%	5%	-8%
2	-5%	1%	-21%	33%	-8%	12%
3	-11%	18%	-8%	13%	-1%	2%
4	-26%	41%	-19%	30%	-51%	82%
5	-30%	49%	-19%	30%	-51%	82%
All TCs	-12%	18%	-8%	13%	-7%	11%
Typhoons (SSI 1-5)	-12%	18%	-9%	14%	-4%	6%
Major Typhoons (SSI 3-5)	-19%	30%	-10%	16%	-16%	26%

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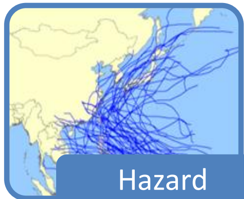
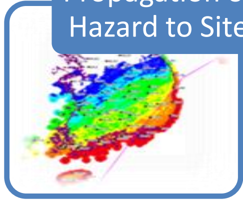
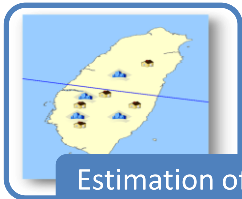
Modeling Methodology



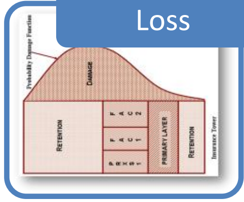
Hazard Definition



Propagation of Hazard to Site



Estimation of Damage



Estimation of Loss

- Historical data: basin-wide storm tracks combined from 4 data bases
- Includes all storm parameters
- Probablistic events: basin-wide simulation
  - Track simulation from genesis to decay for landfalling and by-passing events
  - Wind history simulation
  - Captures the impact of spatial and temporal clustering of events
- Storm surge and rainfall flooding models (on/off)

- High resolution windfield model
- Surface wind speed
  - Over-water winds
  - Wind asymmetry patterns
  - Improved treatment of Friction (LULC, TOPO)
  - Fetch distance and direction
- Local wind gust

- Vulnerability functions
  - By Coverage, Risk, Age and Height of buildings
- For each hazard intensity, the site information and appropriate vulnerability functions are used to assess the probability distribution of damage at each site
- Demand Surge (on/off)
- Loss data
  - The model results are validated with historical loss data

- Insurance information - insured values, limits, deductibles, etc. - is integrated with the probabilistic distributions of computed damage to determine the probabilistic distributions of insured loss

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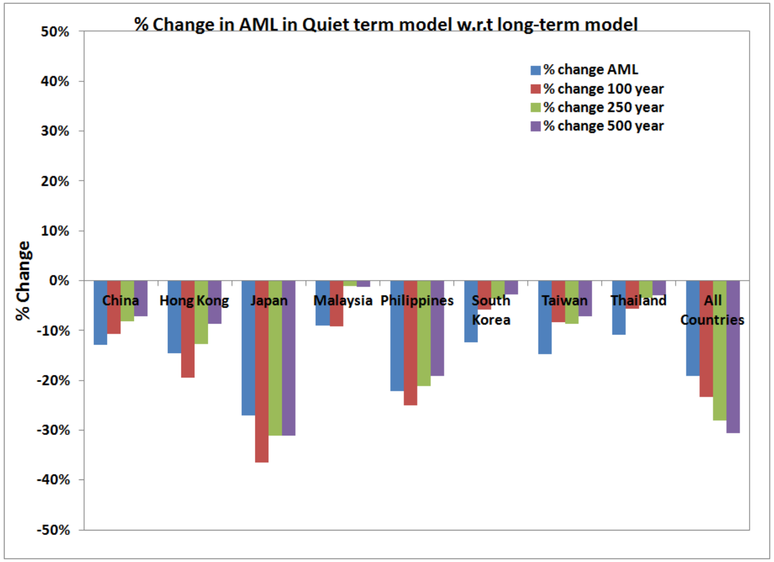
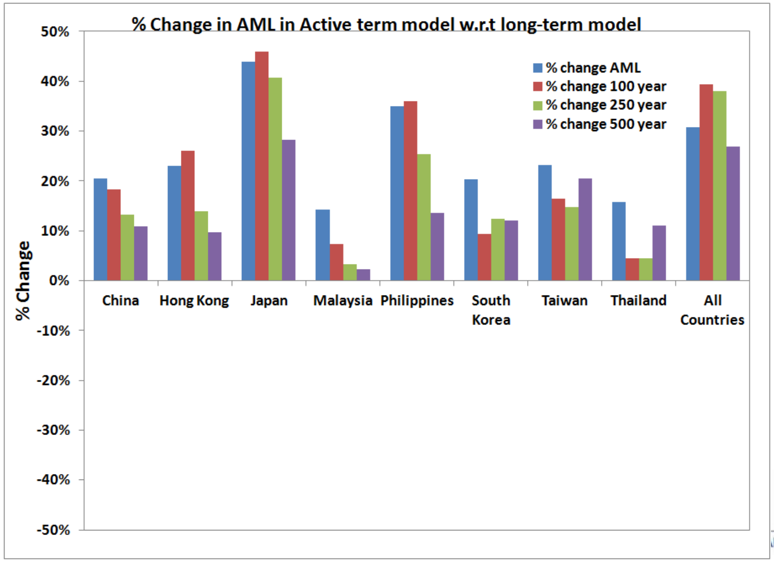
Modeled Basin-wide IMPACT OF TC activity changes

- During quiet periods
  - In general, losses are likely to reduce
  - Significant reduction in PHL, JPN
  - Moderate reduction in CHN, HKG, TWN
  - Minimal reduction in KOR, MYS, THL

- During active periods
  - In general, losses are likely to increase
  - Significant increase in PHL, JPN
  - Moderate increase in CHN, HKG, TWN, KOR
  - Minimal increase in MYS, THL

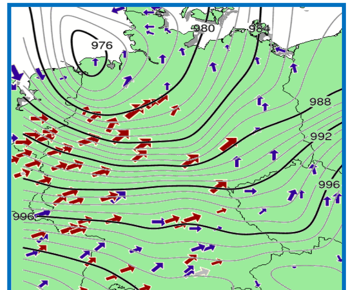




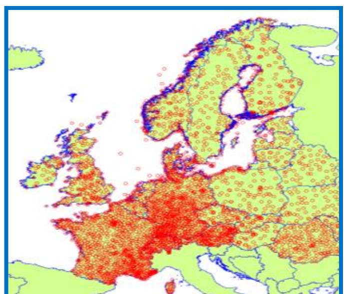
Supplementing the historical record through numerical weather modeling

Generation of Historical Storm Footprints

Options

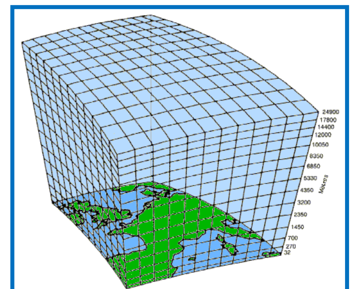


Pressure fields + gust parametrization



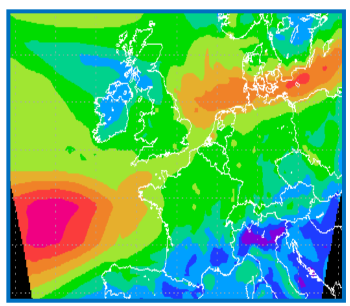
Gust measurements + interpolation

- Simulation length ≈ centuries
- Coarser spatial resolution
- All modules of the Earth System interacting (i.e. Atmosphere, Ocean, Ice, Vegetation, Chemistry)



AOGCM + downscaling

AOGCM = (global) Atmosphere-Ocean General Circulation Model



NWP mesoscale + gust parametrization

- Simulation length ≈ days
- Finer spatial resolution
- Atmosphere module at work "only"

NWP = (regional) Numerical Weather Prediction Model

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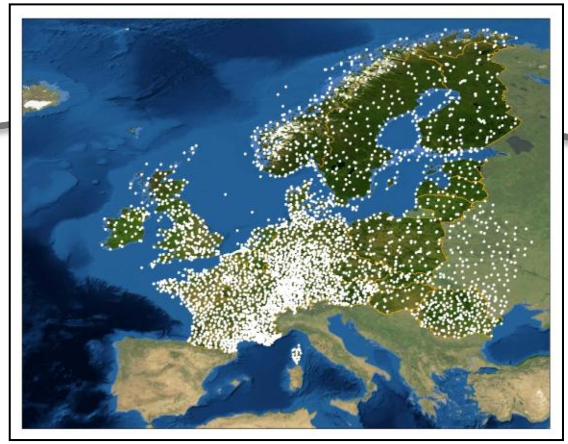
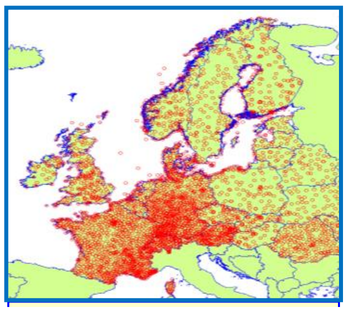
Generation of Historical Storm Footprints

Reasons

Met. Station density (~4000) and accuracy "Ground Truth"
(emulated by other methods)

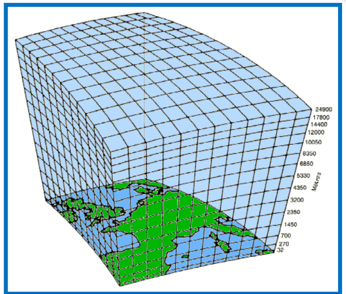




Measurements

Hybrid Hazard

<- complemented with->



AOGCM

Choice

Global and centuries-long perspective of a continuous AOGCM simulation
(not achieved by other methods)

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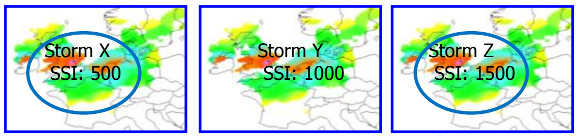
Event Sets

Measurement-based information ↔ used in complementary manner to reduce: ↔ **AOGCM-based information**
(1860-2000 ECHAM5/OM1 simulation)

Uncertainties

1) Historical Event Set

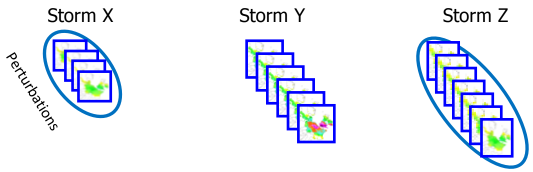
361 Historical storms
- Generated from gust wind speed data covering 1960-2012 period



50-year data set
<- Frequency of strongest storms
<- Spatial homogeneity of events

2) Stochastic Event Set (ELT)

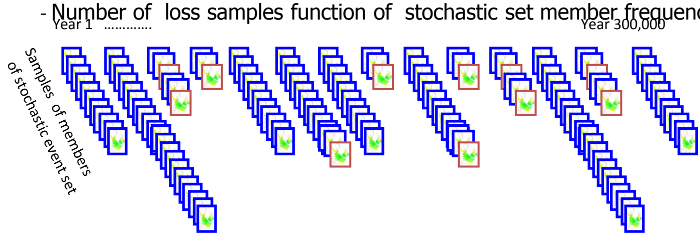
20,000 Storms
- Generated via perturbations of historical storm parameters
- Number of perturbations function of SSI of historical event



Physically-meaningful storm characteristic
<- Thresholds of perturbations
<- AOGCM-generated storms

3) Year Loss Table (YLT)

300,000 storm years
- Generated via simulation based on sampling from loss distributions
- Number of loss samples function of stochastic set member frequency



Clustering
<- Clustering,
<- Interdecadal variability

Storm Severity Index (SSI) = f(wind speed, area, duration)

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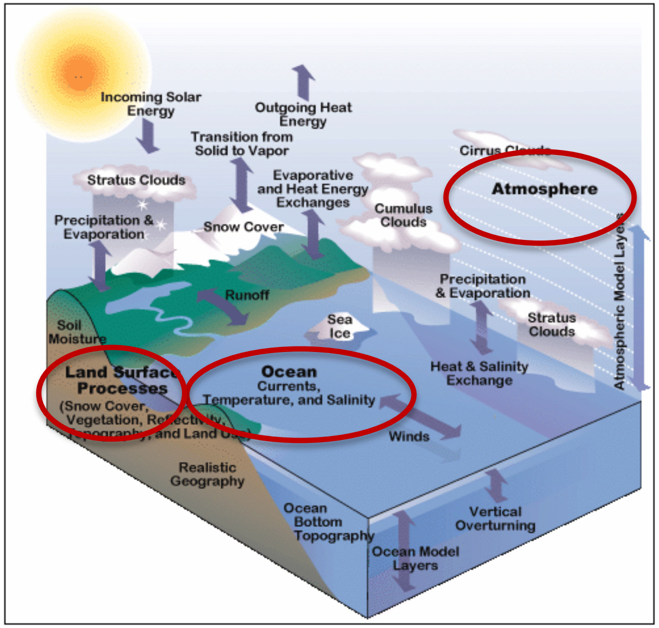
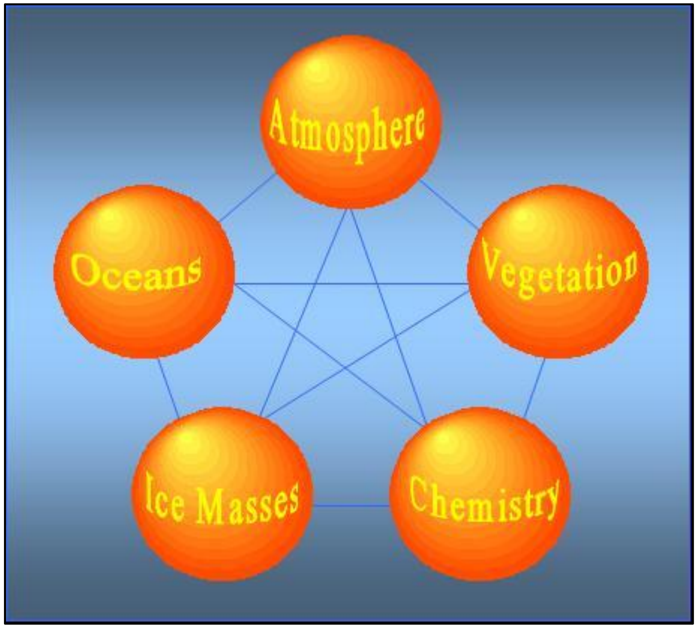
Atmosphere-Ocean General Circulation Model





- **Centuries-long interaction between major components of the Earth System**
- **AOGCM generates its own weather systems and (Daria-like, etc) storms**
- **Simulation used: ECHAM5/OM1 1860-2000 run (Free University of Berlin)**

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AOGCM Storm Tracking

Options

- Vorticity
- MSLP & Laplacian

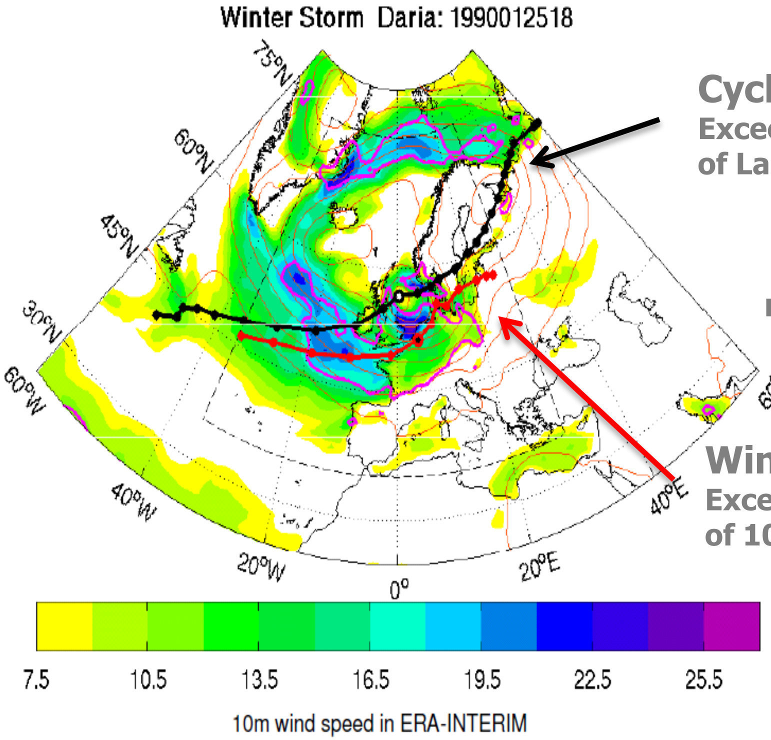
Choice

Murray & Simmonds modified for European conditions

Reasons

Robust
Calibrated for European conditions (similar number of events as observations)

Example: Daria



Cyclone track
Exceedence of 98th percentile of Laplacian (geostr. Vorticity)

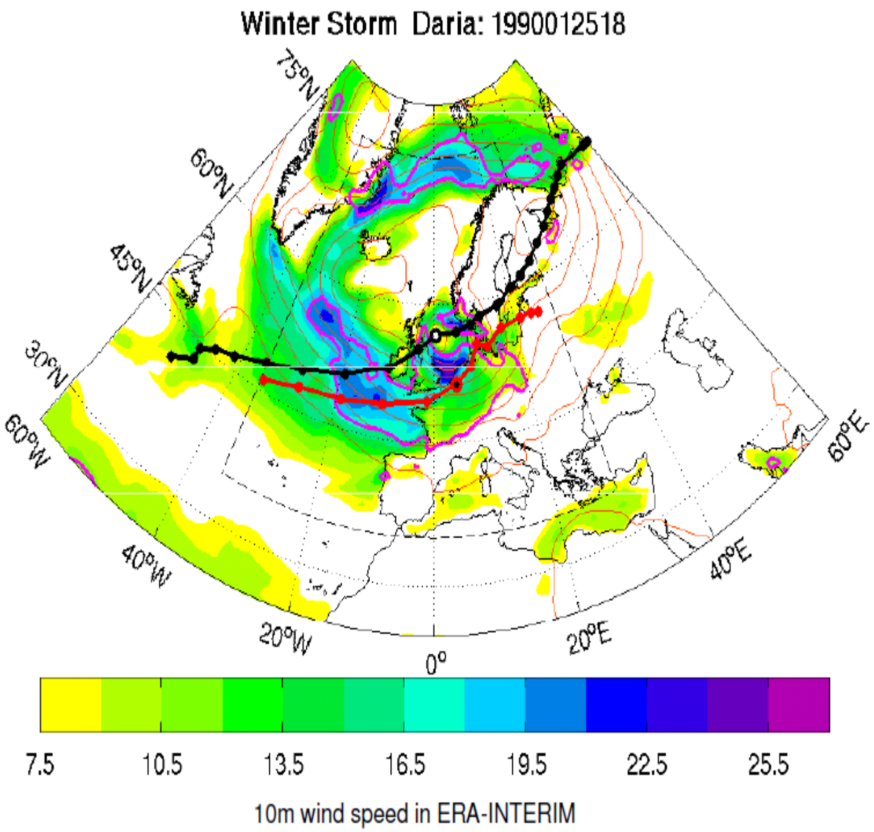
matched with

Wind storm track
Exceedence of local 98th percentile of 10m wind speed

Generated by:
Free University of Berlin

AOGCM Storm Tracking

Example: Daria

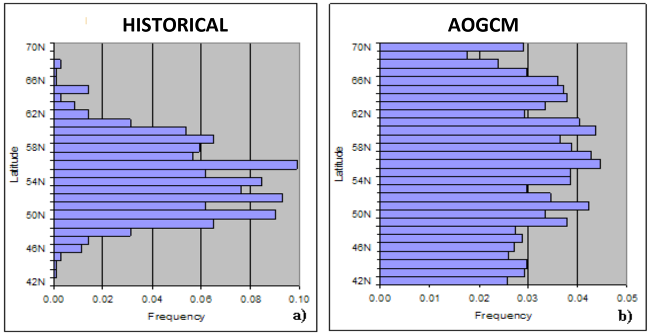


Generated by:
Free University of Berlin

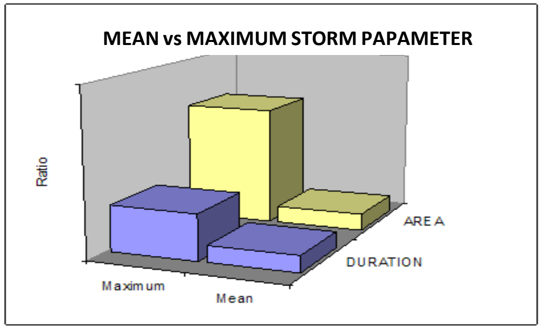
The example shown above is driven by Reanalysis data:
Free AOGCM runs produce "Daria-like" systems, but not on the actual date of the historical storm

AOGCM Results – Areas of Application

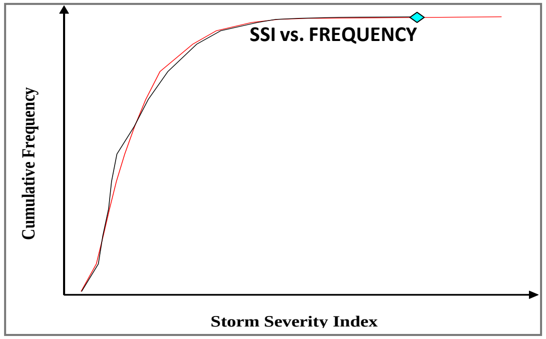
Spatial Completeness



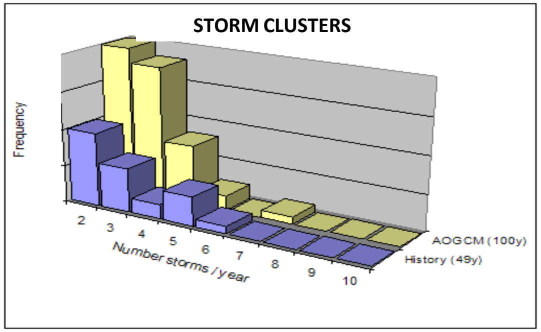
Perturbation Thresholds



Frequency of severe Storms *



Clustering Characteristics *



Storm Frequencies

Options

- 1/observation period (1/50) *Smaller storms*
- Auxiliary info from long AOGCM run *Most severe storms*
- Historical archives

Choice

Reasons

AOGCM gives auxiliary information about approximate return periods of strongest storms, i.e. Vivian or Daria-like events

AOGCM use (pre-requisites)

- Normalization of both sets
- Statistical match between AOGCM and observations (1960-2000)
- Stationarity of 1860-2000 AOGCM run
- Projection of 1960-2000 results onto 1860-2000 set

AOGCM indication

-> One stronger storm than 50 y history

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Storm Clustering

Options

- 50-year History
- Bootstrap on History
- AOGCM & History

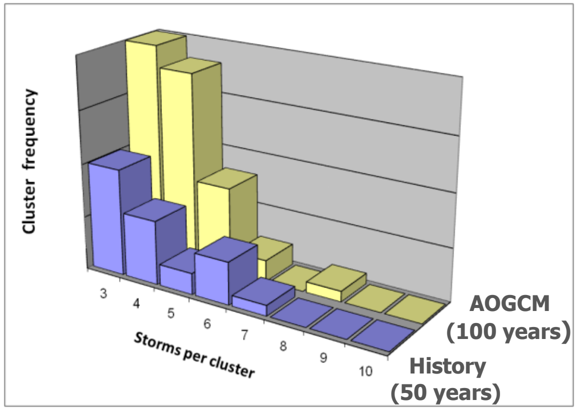
Choice

Reasons

Longer record
More robustness
Not yet observed patterns

Comparison of

- "Severe" historical storms (upper quartile in terms of SSI) in Eurowind Historical Event Set
- Equivalent of "Severe" storms in an ECHAM5 simulation



- AOGCM simulation ~confirms History (~twice as many events in100y than 50y)
- AOGCM tail is "smoother" than History

Implementation:

AOGCM result-based empirical-adjustment of Negative Binomial to generate outcomes for 300,000 years of the Yearly Loss Table

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Conclusions

- Although developing and validating the severity aspects of catastrophe models is a critical area with its own challenges, establishing the appropriate frequency for each stochastic event and the appropriate arrival model is probably at least as critical and challenging
- Challenges include limited length and quality of, and uncertainties and non-meteorological trends in, the historical data; and dependence of event frequencies on various aspects of the climate
- Solutions include statistically-derived near term frequency models, and supplementing the historical record via numerical weather modeling

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Thank You!

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