

BDA Project: Hurricane forecasting in Stan

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Hurricane introduction

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- Classified by their wind intensity at the eye wall.
- They can cause extreme levels of flooding and destroy many buildings.
- Monetary damages and loss of lives increase with an almost exponential character as a function of storm intensity.



Hurricane forecasting basics

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- *Rapid intensification*: forecasted better by dynamical models
- This project: a *statistical* model for *intensity*

Hurricane forecasting basics: the SHIPS data

The US government forecasting agency, the National Hurricane Center (NHC), uses a large number of models operationally. The models (together: the *model ensemble*) are used together with experienced meteorologists' judgment to provide the official forecast.

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- SHIPS: only a point estimate; our project: a predictive distribution

[illegible]

Hurricane forecasting basics: the SHIPS data

We are making *synoptic* models.

$$T = 0$$
[illegible]

Hurricane forecasting basics: the SHIPS data

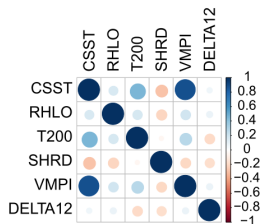
We are making *synoptic* models and choosing variables.

$$T = 0$$
[illegible]

Hurricane forecasting basics: our selection

We have not done statistical variable selection. Choice of variable subset is based on theory.

- **CSST**: (climatological) sea surface temperature
- **RHLO**: low-altitude relative humidity
- **T200**: air temperature at 200 mb (very high altitude)
- **SHRD**: wind shear between 850 and 200 mb
- **VMPI**: maximum potential intensity

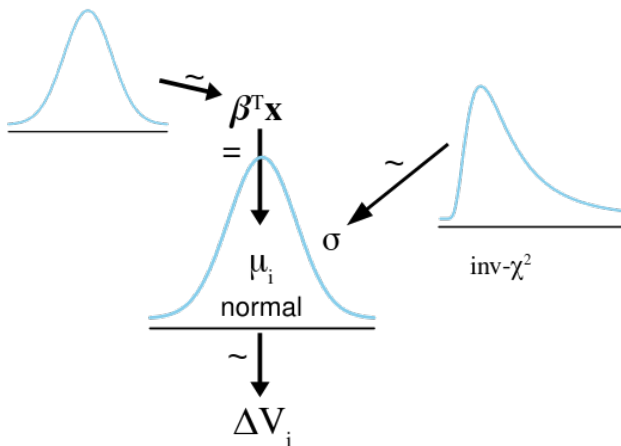


- for testing, we have variable sets *A*, *B*, *C*
- *A*: LAT/LON, VMAX, CSST, SHRD
- *B*: LAT/LON, VMAX, CSST, SHRD, VMPI
- *C*: LAT/LON, VMAX, CSST, SHRD, VMPI, RHLO, T200

Intensity change predictive model

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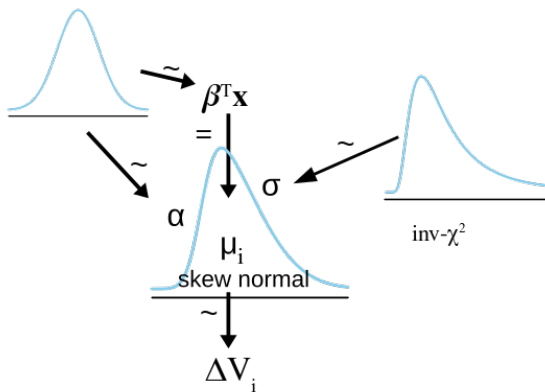
The SHIPS Blunder: a simple linear regression



Intensity change predictive model

Model 2: regression with skewness

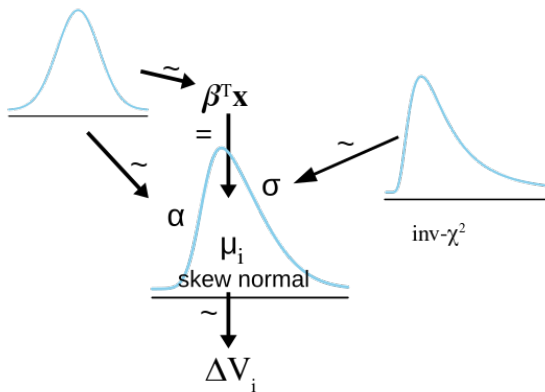
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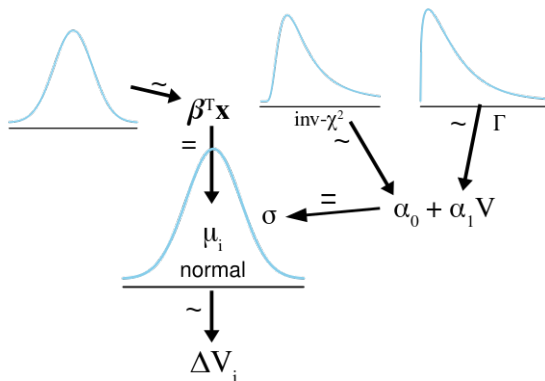
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- rapid intensification!



Intensity change predictive model

Model 3: regression with a linear model for standard deviation

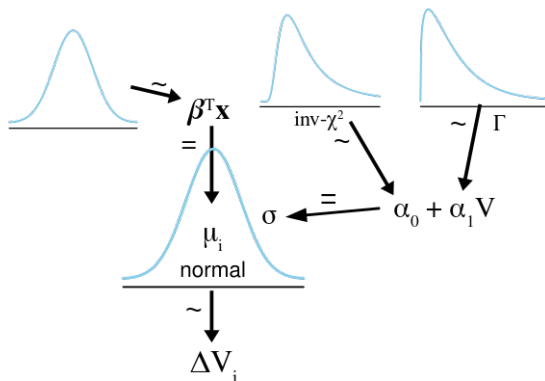
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Intensity change predictive model

Model 3: regression with a linear model for standard deviation

- fewer storms reach higher values of VMAX
- allow for higher variance to account for larger historical uncertainty



Models: some remarks

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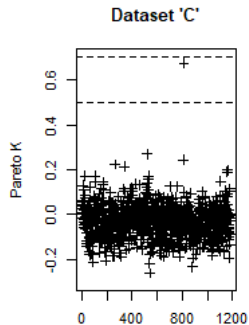
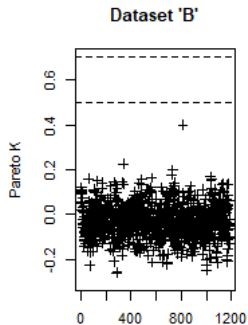
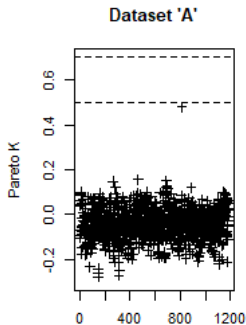
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- poor problem setup! True model is the laws of physics, but we are fitting a regression
- models were programmed in Stan; sampling with `rstan` resulted in no divergences or issues except for the skew model and the issue was solved by increasing max tree depth to 15

Forecasting: Model Comparison

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Dataset comparison for the **linear regression model** (LOOCV)

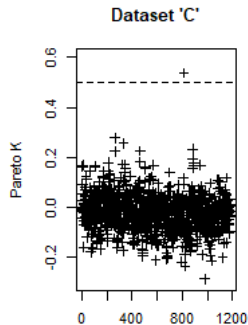
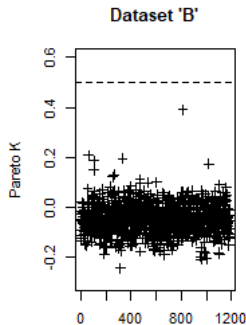
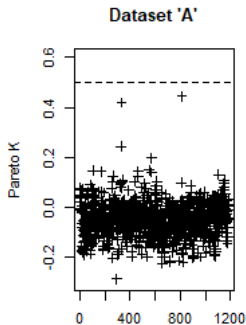
Dataset	elpd_diff	se_diff
C	0.0	0.0
<i>B</i>	-25.0	6.5
<i>A</i>	-27.4	6.3



Forecasting: Model Comparison (2)

Dataset comparison for the **skewed regression model** (LOOCV)

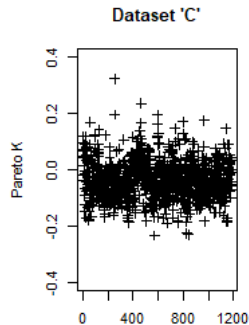
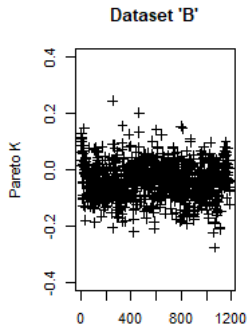
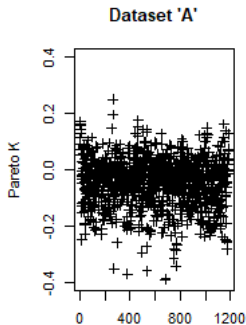
Dataset	elpd_diff	se_diff
C	0.0	0.0
<i>B</i>	-23.2	6.2
<i>A</i>	-28.7	6.2



Forecasting: Model Comparison (3)

Dataset comparison for the **Changing variance model** (LOOCV)

Dataset	elpd_diff	se_diff
<i>C</i>	0.0	0.0
<i>B</i>	-32.6	8.2
<i>A</i>	-37.1	8.2



Forecasting: Model Comparison (4)

Model comparison using the Dataset C (LOOCV)

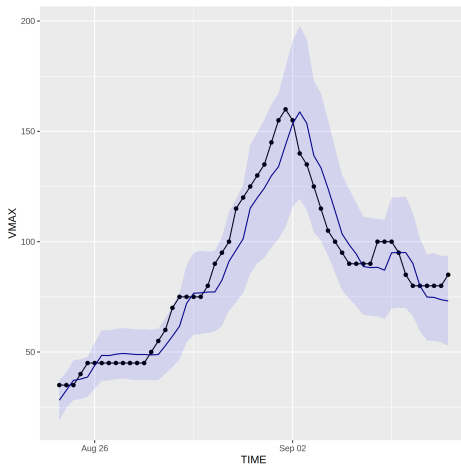
Model	elpd_diff	se_diff
Variance	0.0	0.0
Skew	-176.3	27.8
Linear	-205.5	34.9

Marginal posteriors

- θ_1 : constant term
- θ_2, θ_3 : latitude, longitude
- θ_4 : sea surface temperature (CSST)
- θ_5 : relative humidity (RHLO)
- θ_6 : wind shear (SHRD)
- θ_7 : maximum potential intensity (VMPI)
- θ_8 : air temperature at 200 mb (T200)
- θ_9 : intensity at storm core (VMAX)

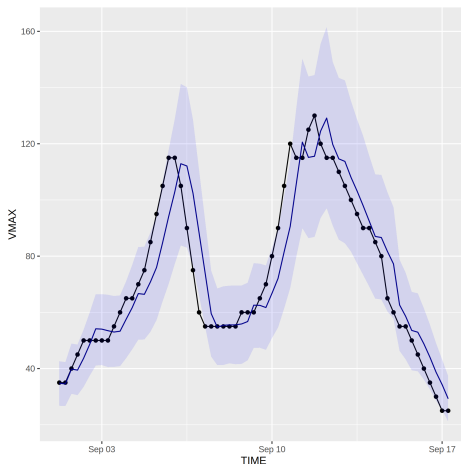
Forecasting: checking predictions

Hurricane Dorian 2019. The image shows a 90% credible interval.
Black dotted line: true VMAX



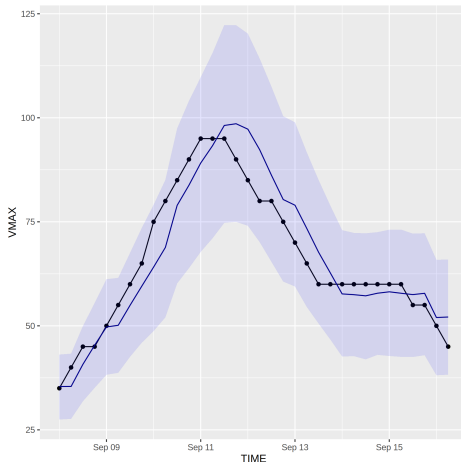
Forecasting: checking predictions

Hurricane Florence 2018. The image shows a 90% credible interval.
Black dotted line: true VMAX



Forecasting: checking predictions

Hurricane Helene 2018. The image shows a 90% credible interval.
Black dotted line: true VMAX



Concluding section

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Further development ideas:

- variable selection in full SHIPS dataset

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- variable selection in full SHIPS dataset
- more time series autoregressive components
- use LGEM model (will explain)

A final takeaway

“The hurricane will be moving through an environment of low vertical wind shear, a moist mid-level atmosphere, and increasing upper-ocean heat content, and this is ideal for some additional intensification. However, given that the SHIPS models do not show any significant change in the intensity, the NHC forecast keeps Irma a powerful hurricane through five days.” — NHC 5AM advisory Sep. 5th

While the NHC published the advisory, Irma was undergoing rapid intensification from 130 to 175 knots over a span of only a few hours.

Conclusions & contact info

- Takeaway: the SHIPS model is terrible!
- Simple changes to the predictive distribution can improve the model
- Further development using Bayesian methods seems promising and there are several possible directions

More at our Github repo:

<https://github.com/jnlb/bda-hurricane-modeling>

The SHIPS website: http://rammb.cira.colostate.edu/research/tropical_cyclones/ships/index.asp

Contact info:

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- rocket-chat: @jnlb

Additional information