

A Probabilistic Rule-Based Method of Predicting Storm Surge

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Outline

- Aim
- Storm surge
- Application to the North Sea
- Probabilistic rule-based method
- Results
- Error estimates in prediction
- Conclusions



Aim

- Investigate applicability of probabilistic rule-based method to short-term prediction of storm surge
 - Is the method accurate?
 - Is the probabilistic nature useful in terms of uncertainty?
 - Could the method be applied to regions where hydrodynamic models would be too expensive to set-up and run operationally?
- Apply to region with well understood physical system (North Sea) and operational hydrodynamic model for comparison



Storm surge

- Long wavelength $\sim O(100\text{km})$, long period $\sim O(\text{hrs})$
- Setup by meteorological disturbances
- Exhibits rotational effects and tidal interaction
- Poses significant flood risk to coastal communities



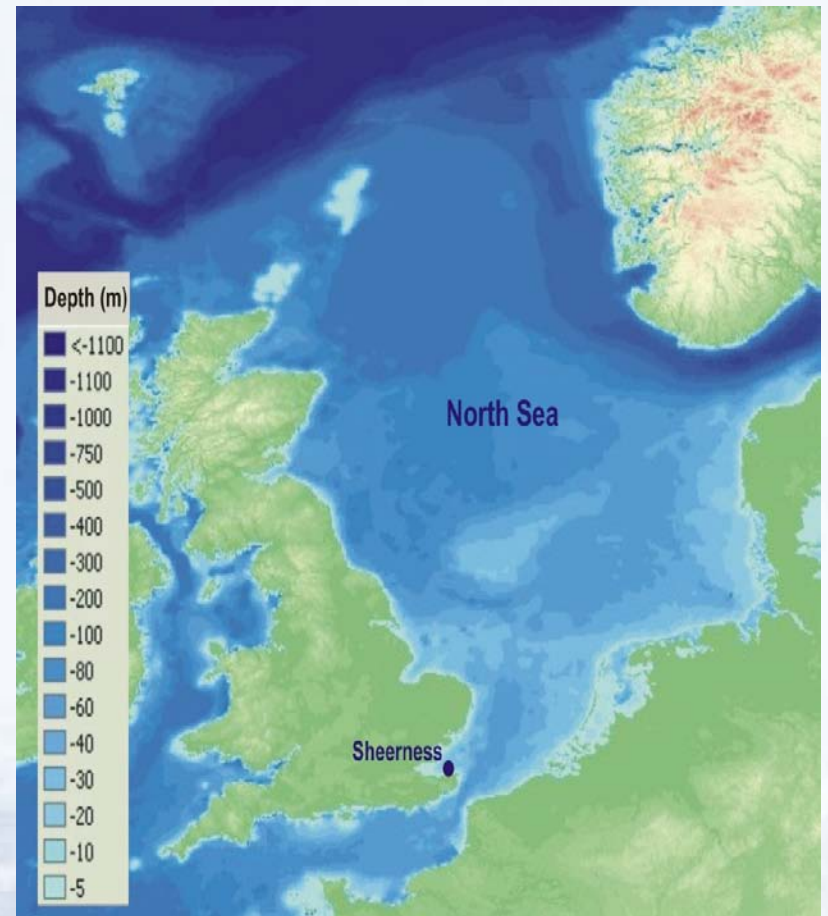
Flooding in New Orleans from Hurricane Katrina



Levee breach during the 1953 North Sea flood

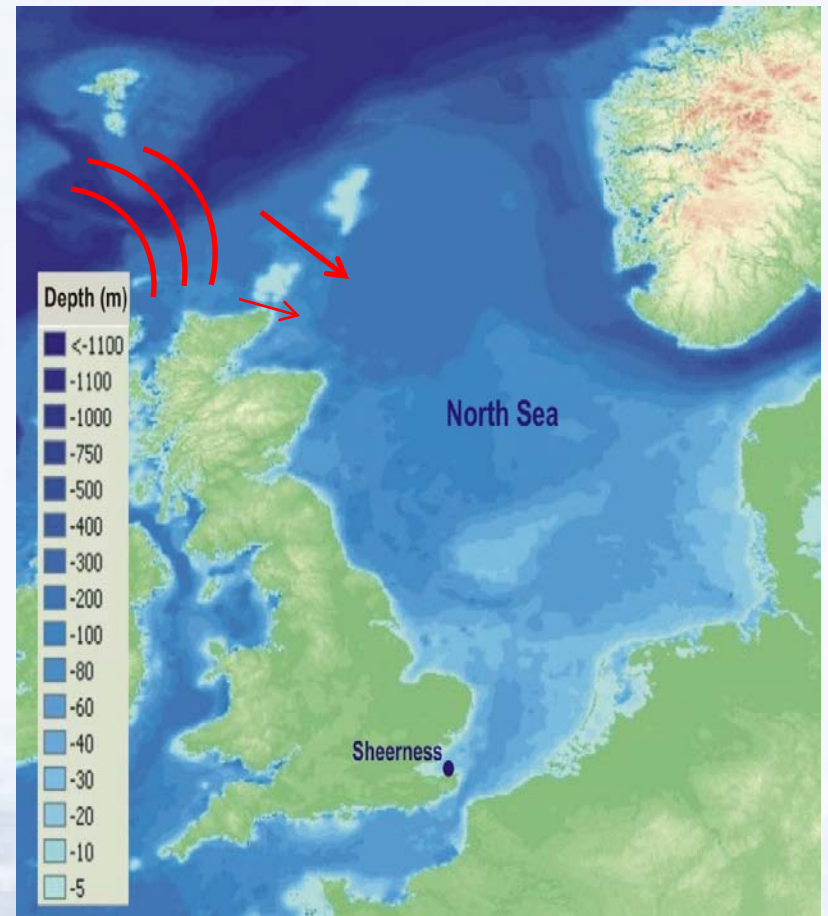
North Sea

- Sea on Continental Shelf



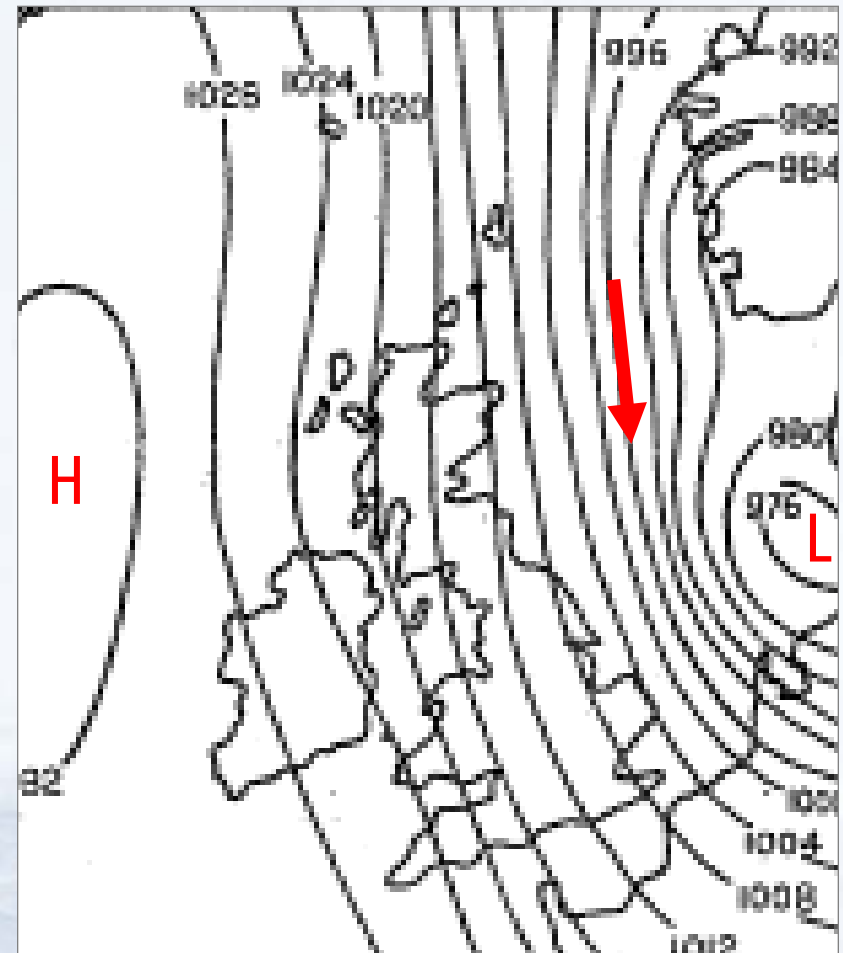
North Sea

- Sea on Continental Shelf
- Mechanisms of storm surge:
 - External surge from north



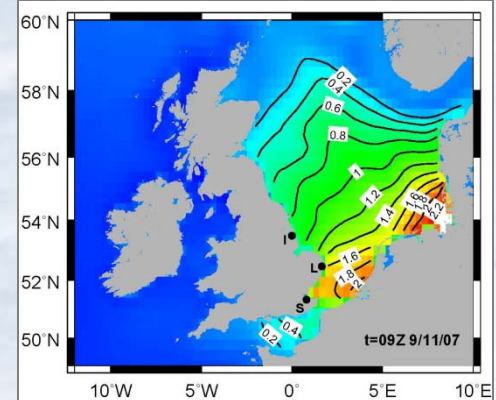
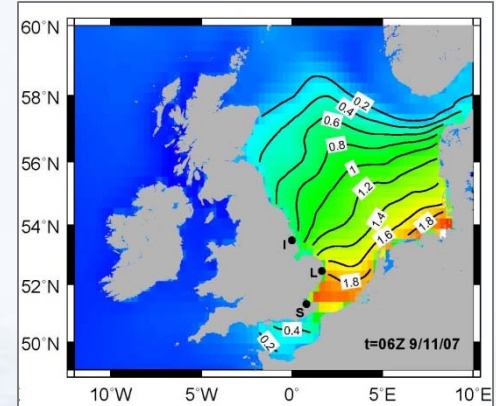
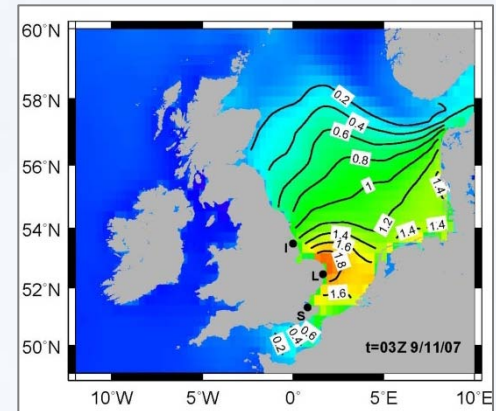
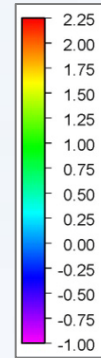
North Sea

- Sea on Continental Shelf
- Mechanisms of storm surge:
 - External surge from north
 - Internally, positive (negative) surge setup by strong wind field into (out of) the basin
 - Inverted barometer effect over column of water



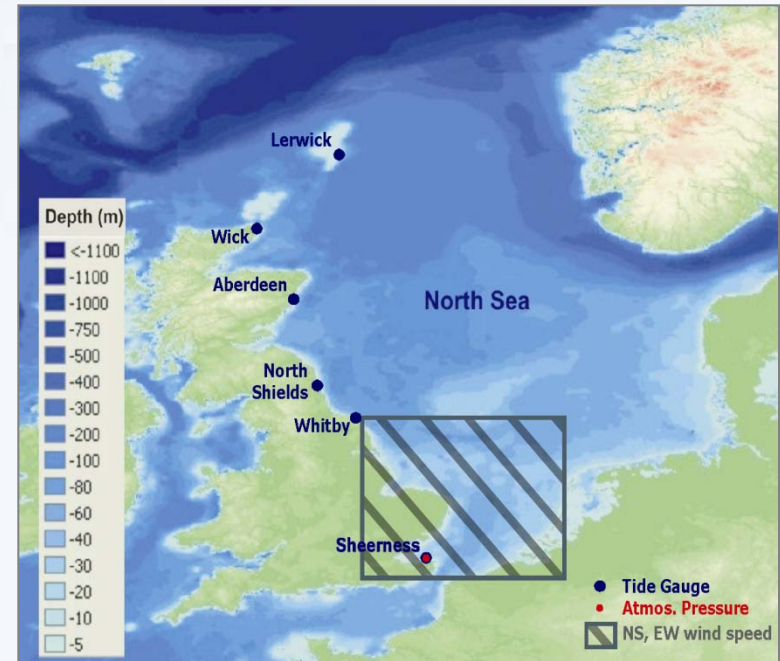
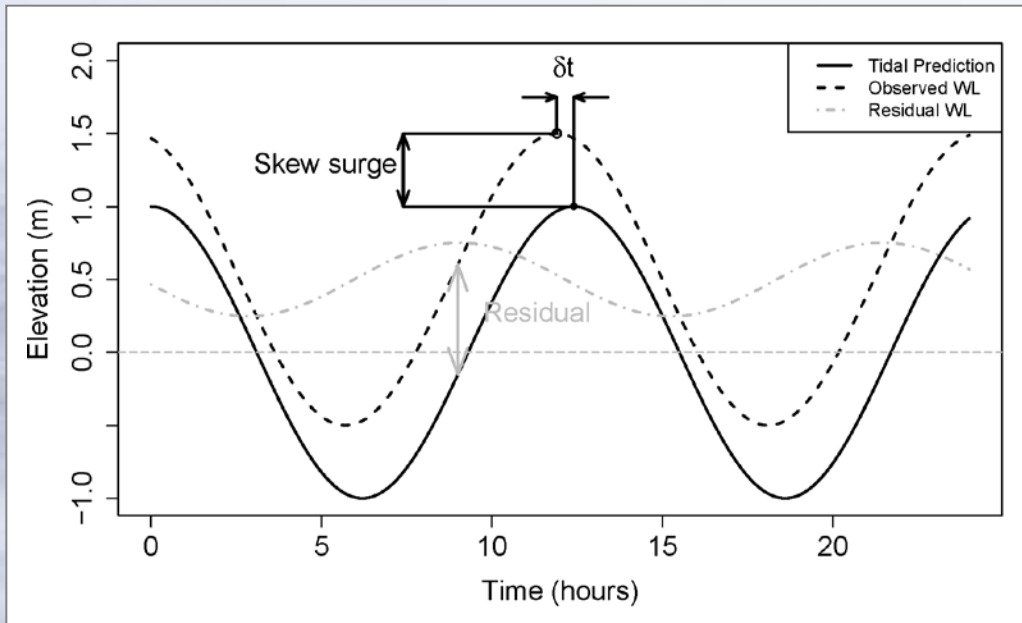
North Sea

- Sea on Continental Shelf
- Mechanisms of storm surge:
 - External surge from north
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 - Inverted barometer effect over column of water
 - Rotational effects → coastally-trapped boundary wave travelling cyclonically around basin.



Data

- To predict storm surge at Sheerness up to 8 hour ahead, from tide gauge and atmospheric data
- Use skew surge: Difference between observed maximum water level and predicted high tide in each tidal cycle



Probabilistic method

- Data driven
- Bayesian approach

$$P(A | B) = \frac{P(B | A)P(A)}{P(B)}$$

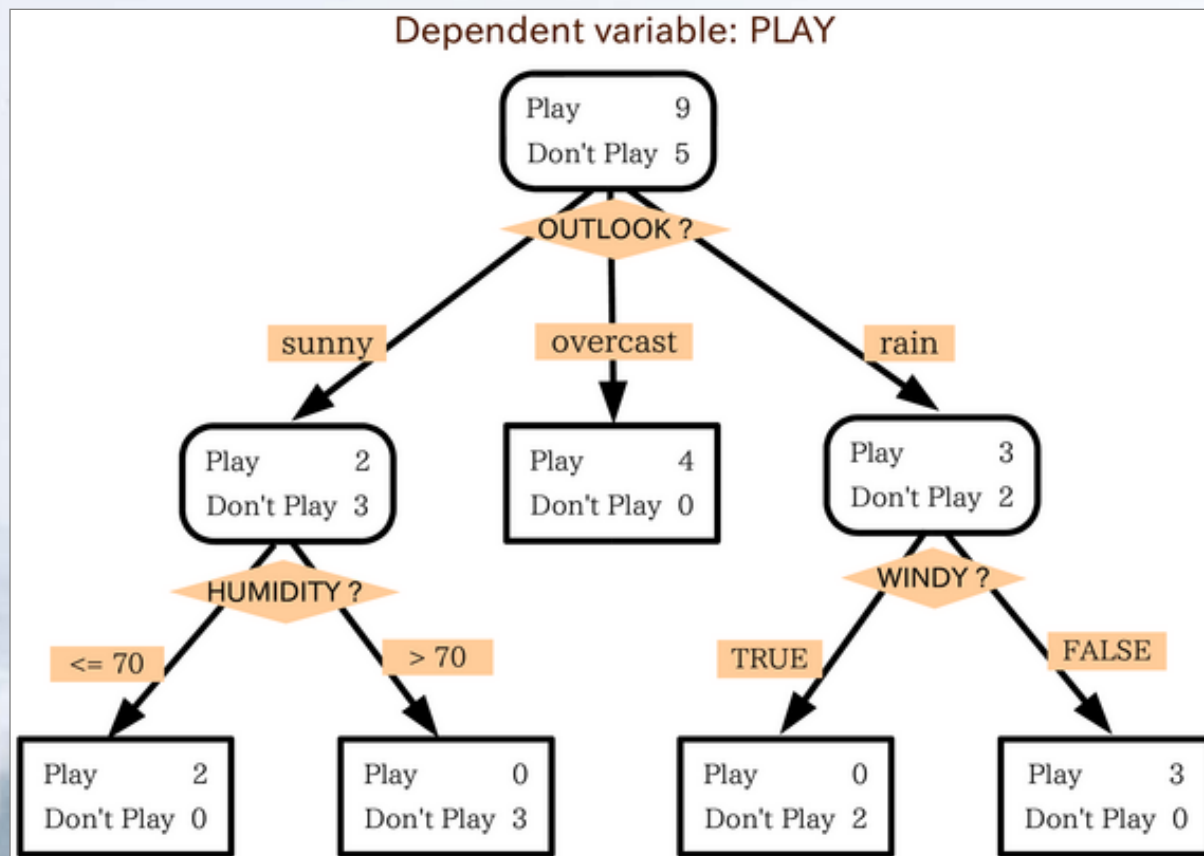
→ statistical model

- Gives probabilistic predictions
- Tree structure
- Entropy heuristic from information theory

$$E = -\sum_{j=1}^n P(F_j) \log_n P(F_j)$$

Probabilistic method

- IF-THEN rules in tree structure

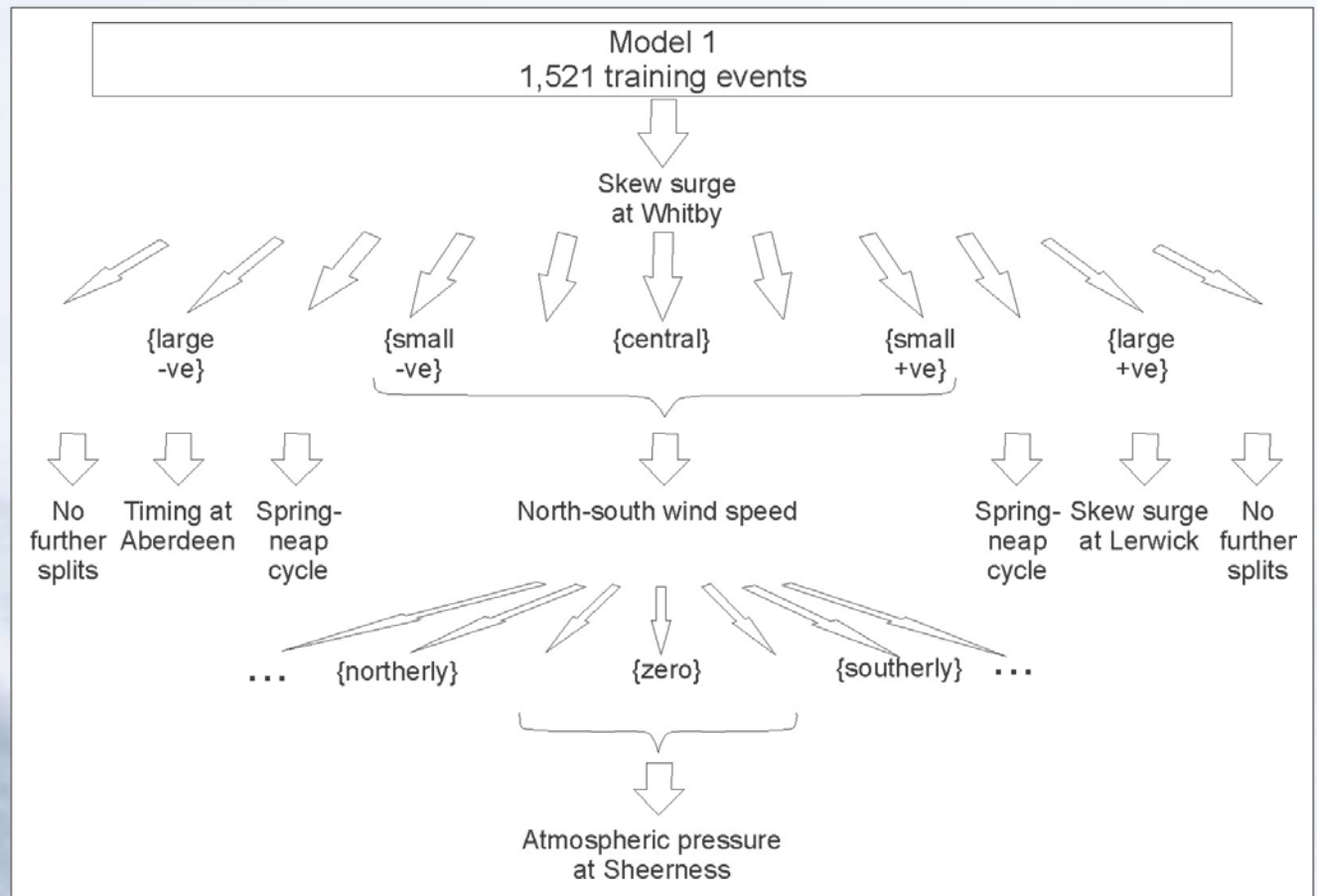


Rules

IF skew surge at Whitby is "central"
AND north-south wind speed is "around zero"

THEN

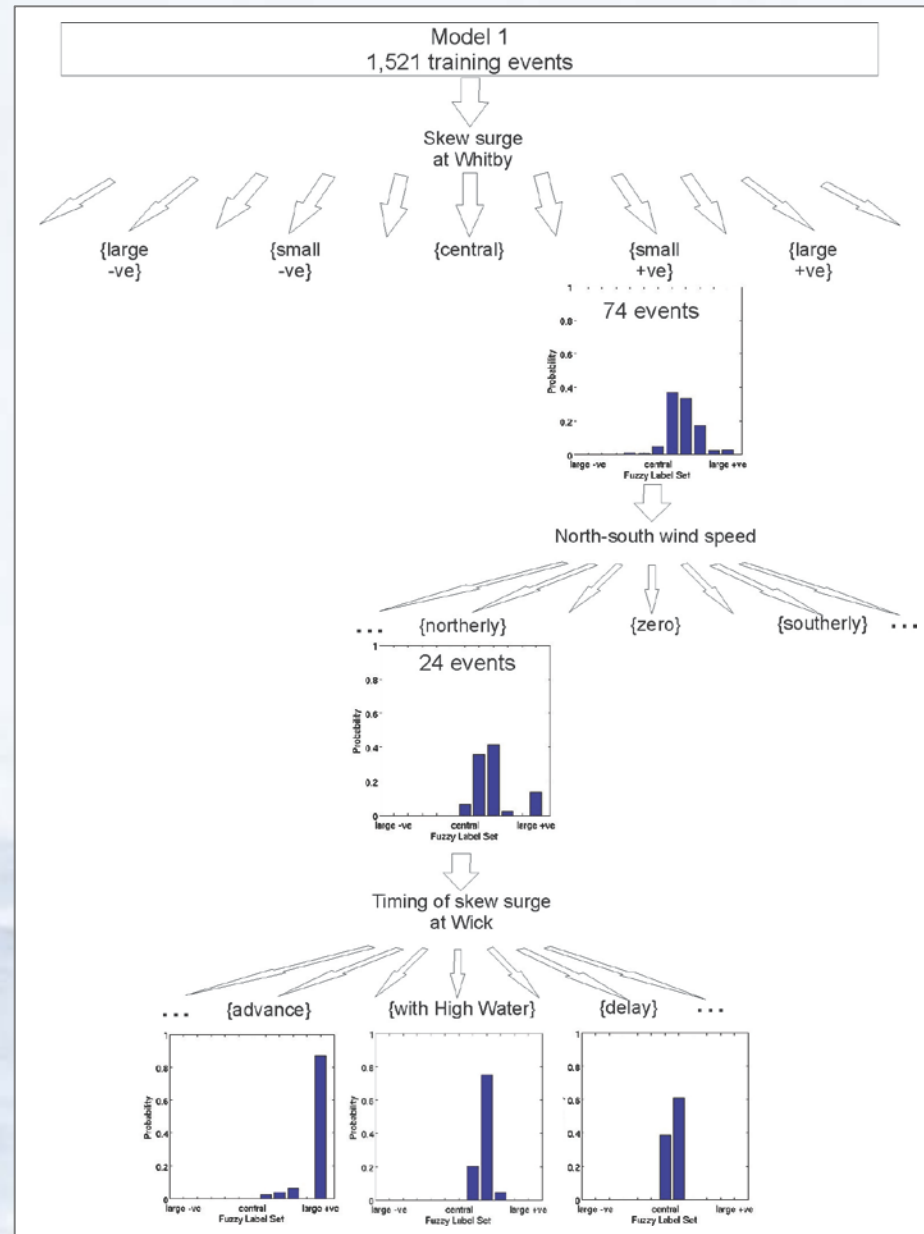
most information about skew surge at Sheerness is provided by atmospheric pressure at Sheerness



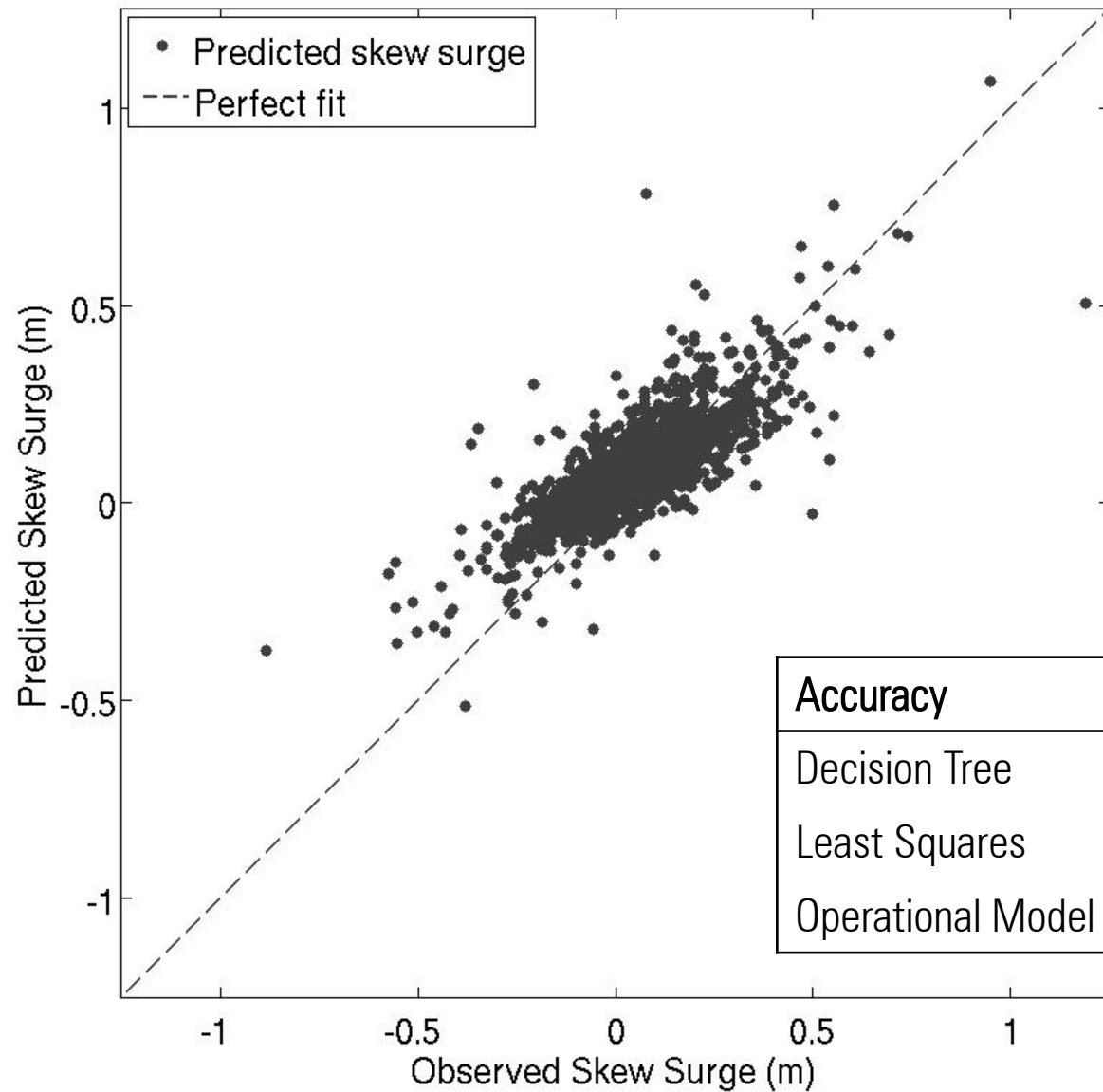
Rules

IF skew surge at Whitby is “small positive”
AND north-south wind speed is “moderate northerly”
AND timing of observed high water at Wick is “advanced”
THEN skew surge at Sheerness is likely ($P > 0.9$) to be “very large positive”

- Rules are generally consistent with our physical understanding

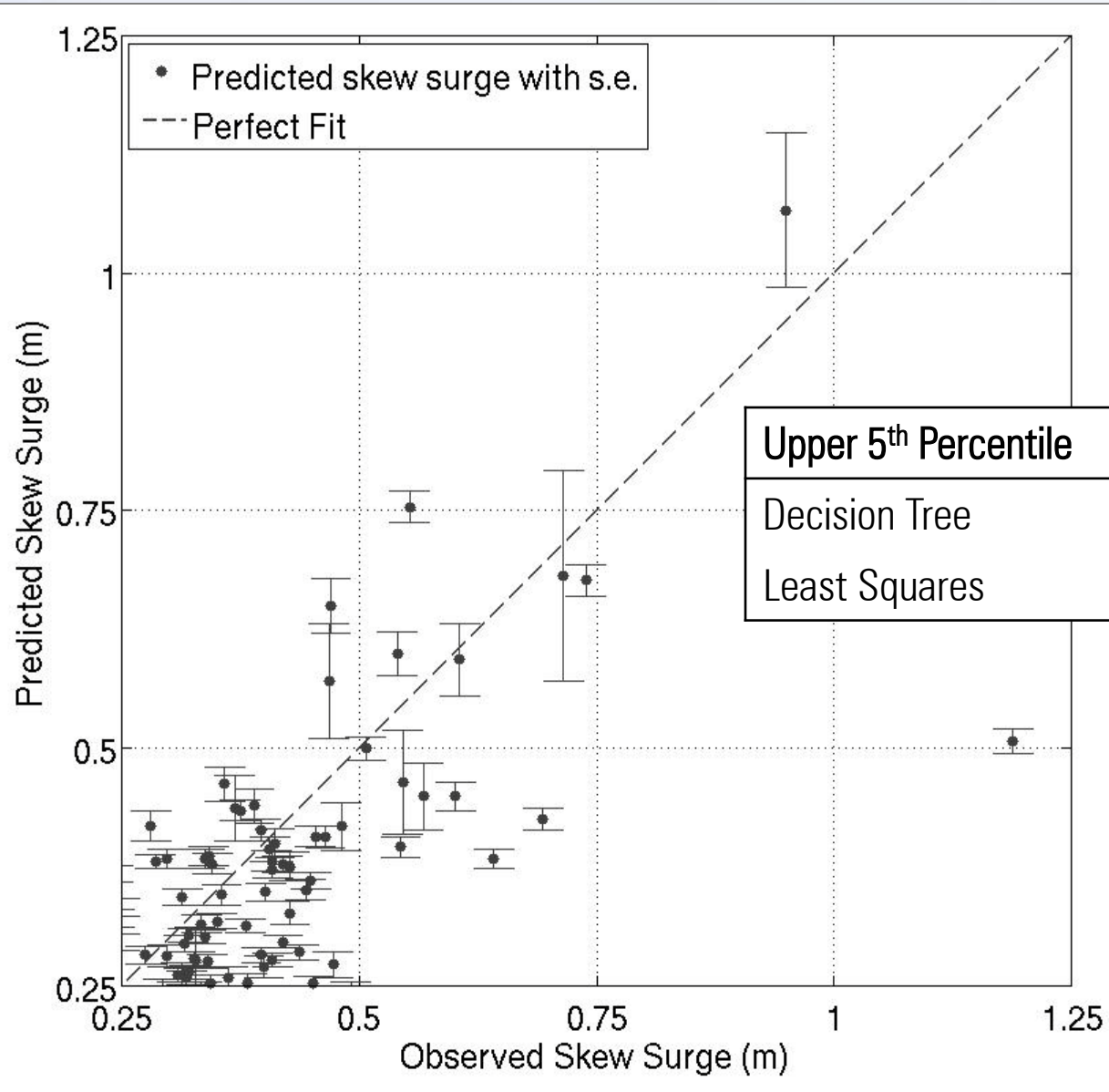


Results



Accuracy	AAE (m)	RMSE (m)	r^2
Decision Tree	0.08	0.11	0.62
Least Squares	0.08	0.10	0.64
Operational Model	0.07	0.13	0.71

Results



Upper 5 th Percentile	AAE (m)	RMSE (m)	r^2
Decision Tree	0.14	0.18	0.34
Least Squares	0.11	0.17	0.23

Extreme events

- November 2007 – event and prediction

LIVE BBC NEWS CHANNEL

Last Updated: Friday, 9 November 2007, 01:47 GMT

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Tidal surge 'poses grave danger'

A tidal surge in the North Sea has sparked severe flood warnings and evacuations on England's east coast.



Residents have been warned to watch the weather and tides

Prime Minister Gordon Brown has held an emergency Cobra committee meeting and the Environment Agency has warned of "extreme danger to life and property".

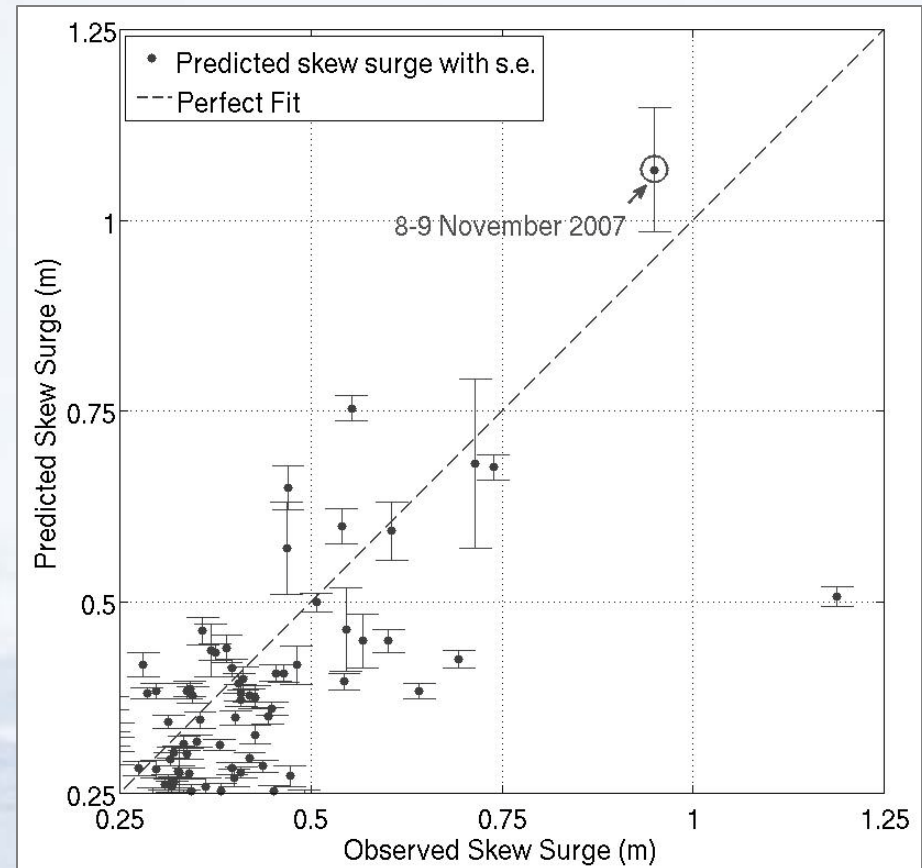
Norfolk and Suffolk have eight severe flood warnings. Parts of Essex, Lincs, North Yorks and Kent are also on alert.

Norfolk Police have visited 7,500 homes in Great Yarmouth to advise residents to leave the area.

They have been told to stay with family and friends outside the borough, or to move upstairs.

“ I hope our defences can cope but this is a pretty severe weather event and some of them may not ”

Baroness Young



Extreme events

- November 2007

IF

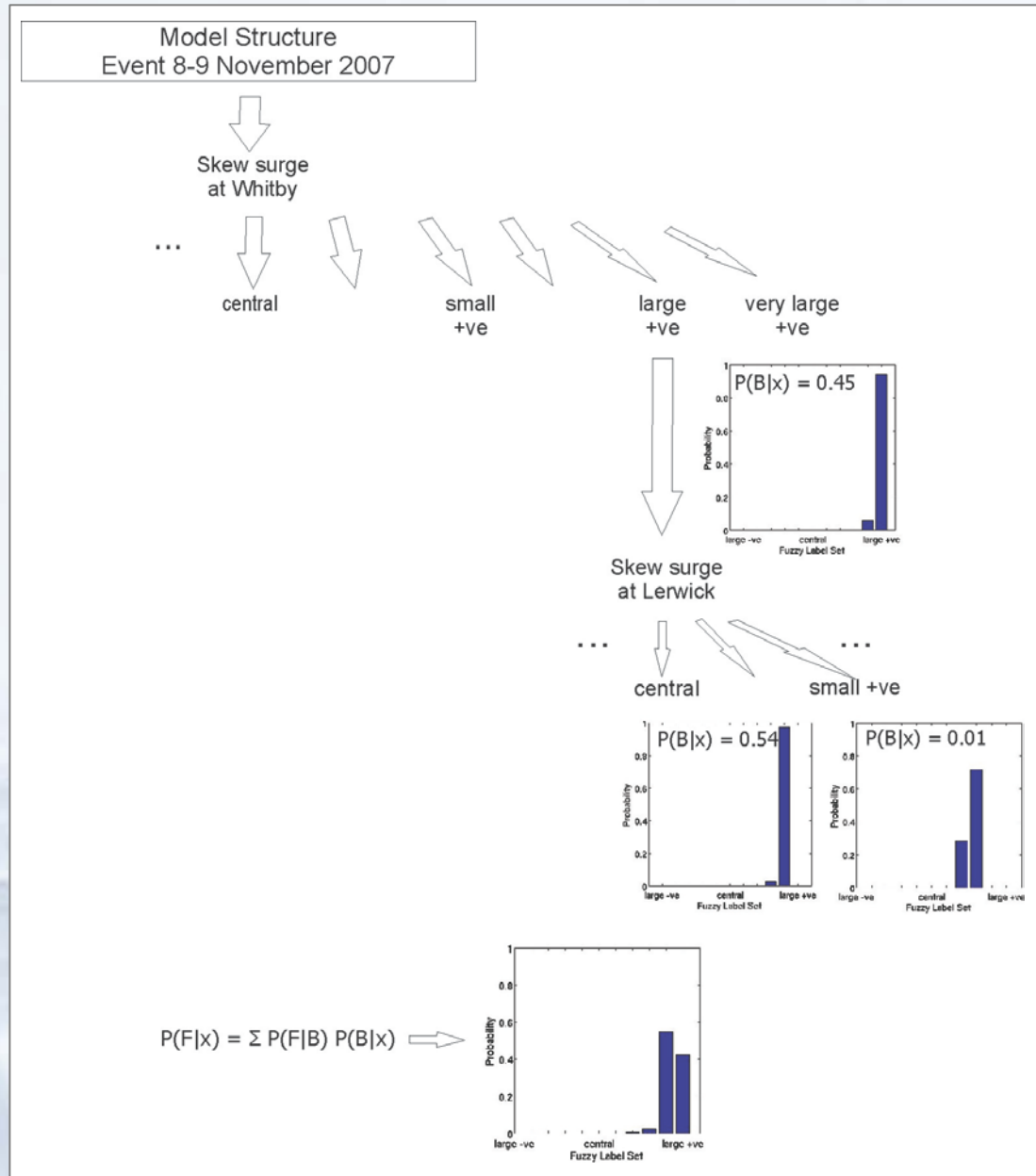
Skew surge at Whitby is
“large positive” or
“very large positive”

AND

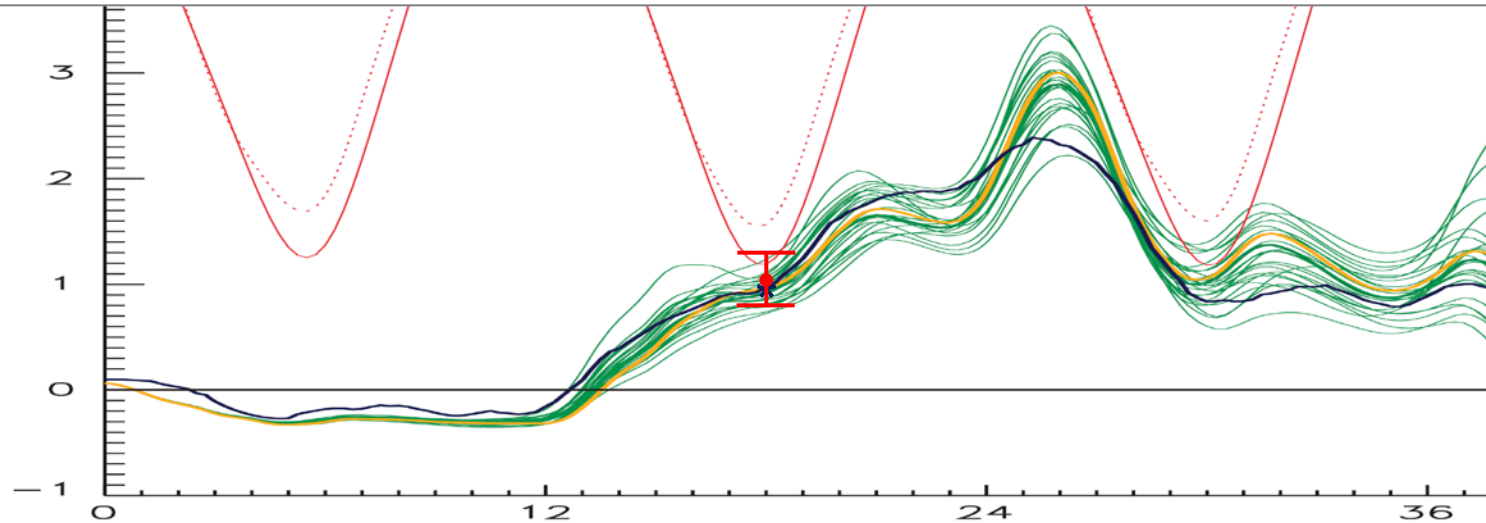
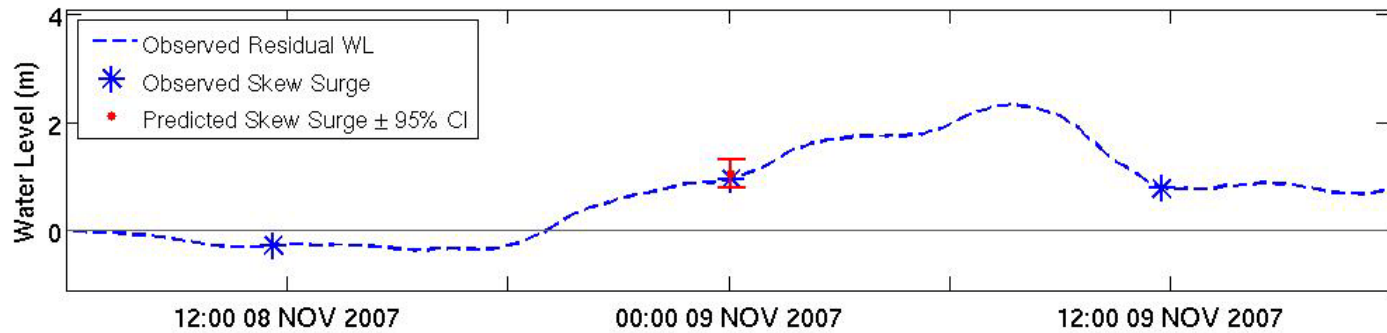
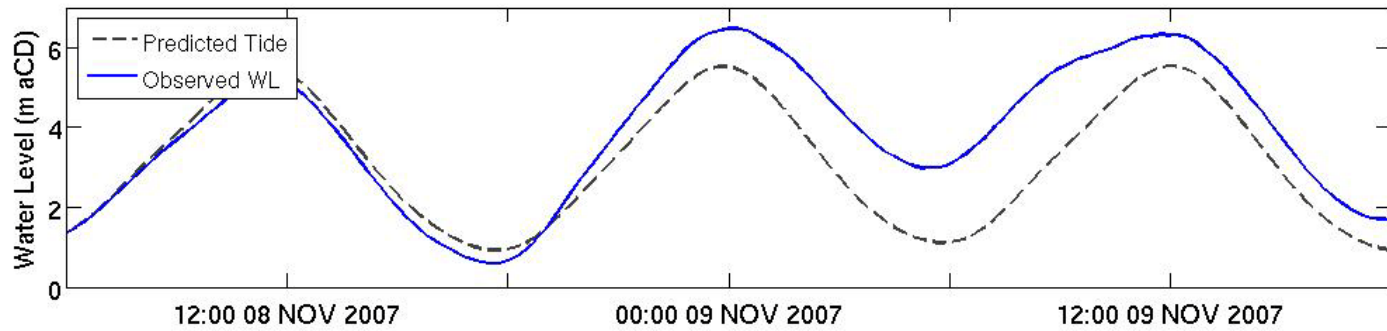
Skew surge at Lerwick is
“central” to “small positive”

THEN

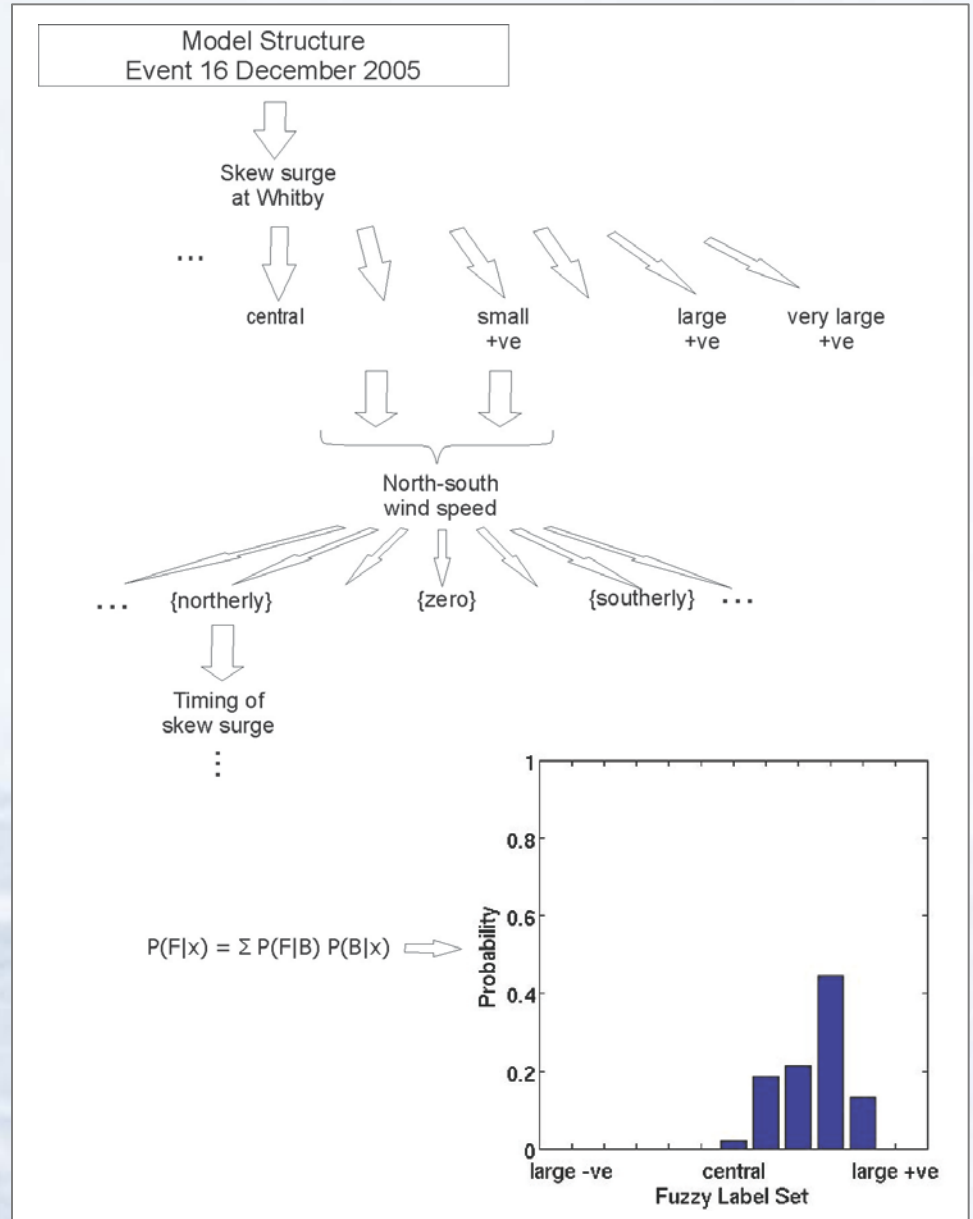
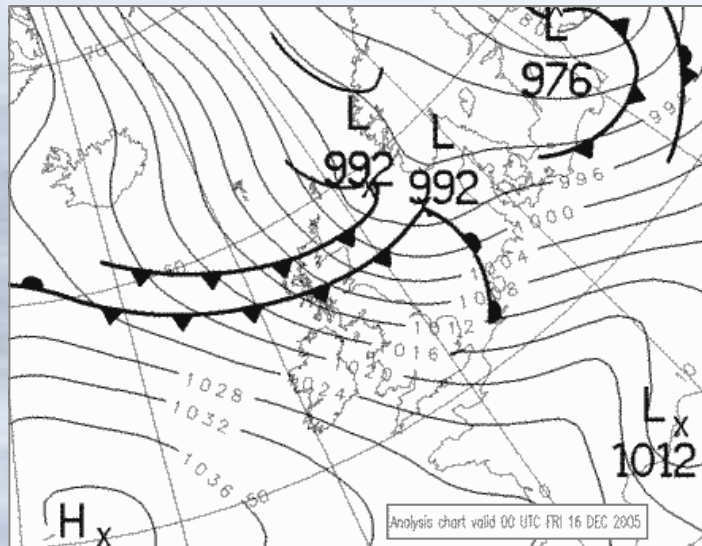
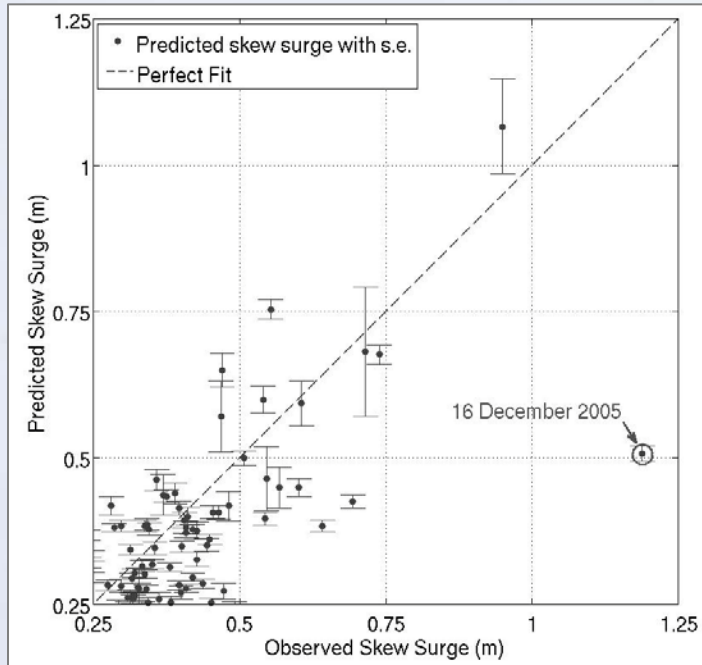
skew surge at Sheerness is
likely to be “large positive”
or “very large positive”



Operational model



December 2005 event



Conclusions

- A probabilistic, data-driven model is constructed to predict storm surge at Sheerness up to 8 hours ahead
- The approach uses available tide gauge and atmospheric data to determine statistical relationships in the data
- The model structure confirms the influence of external and internal storm surge generation in the North Sea
- Looking at individual, extreme events, the model is successful at identifying an external storm surge that grows within the basin. However, the model fails to identify a key event where the storm surge was internally generated in the southern North Sea.
- Natural error estimates are made on the outcome which are consistent with those made by the ensemble envelope of the operational forecast model. This suggests that the operational ensemble members 'cover' the range of probable outcomes (from available data of observed events).



Thank you for your attention

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