Predicting and Projecting the Frequency of Extreme Marine Events on Time Scales of Days to Decades with a Focus on Coastal Flooding

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MEOPAR

Overview of Talk

- Overview of MEOPAR, a new national network
- Predicting storm surges with lead times up to 10 days
- Projecting flood probabilities over coming decades

MEOPAR in a Nutshell

- New network of centers of excellence
- **M**arine **E**nvironmental **O**bservation **P**rediction and **R**esponse
- Reducing vulnerability to marine hazards and emergencies
- Established in 2013, headquartered at Dalhousie
- $25M over 5 years from NCE program
- May be renewed twice
- Involves 50 researchers from 12 universities
- Partners include EC, DFO, DND, DRDC, Lloyds Register, ICLR, ...

MEOPAR
Universities and Projects

A Relocatable Atmosphere-Ocean Prediction System

Who: Dr. Harold Ritchie, Environment Canada/ Dalhousie University

What: A relocatable atmosphere-wave-ocean forecast system that can be set up within hours of a marine emergency.

Impact: Provide forecasts (hours to days) of physical properties of ocean and atmosphere to help guide response to an emergency. System to be transferred to Environment Canada for operational use.

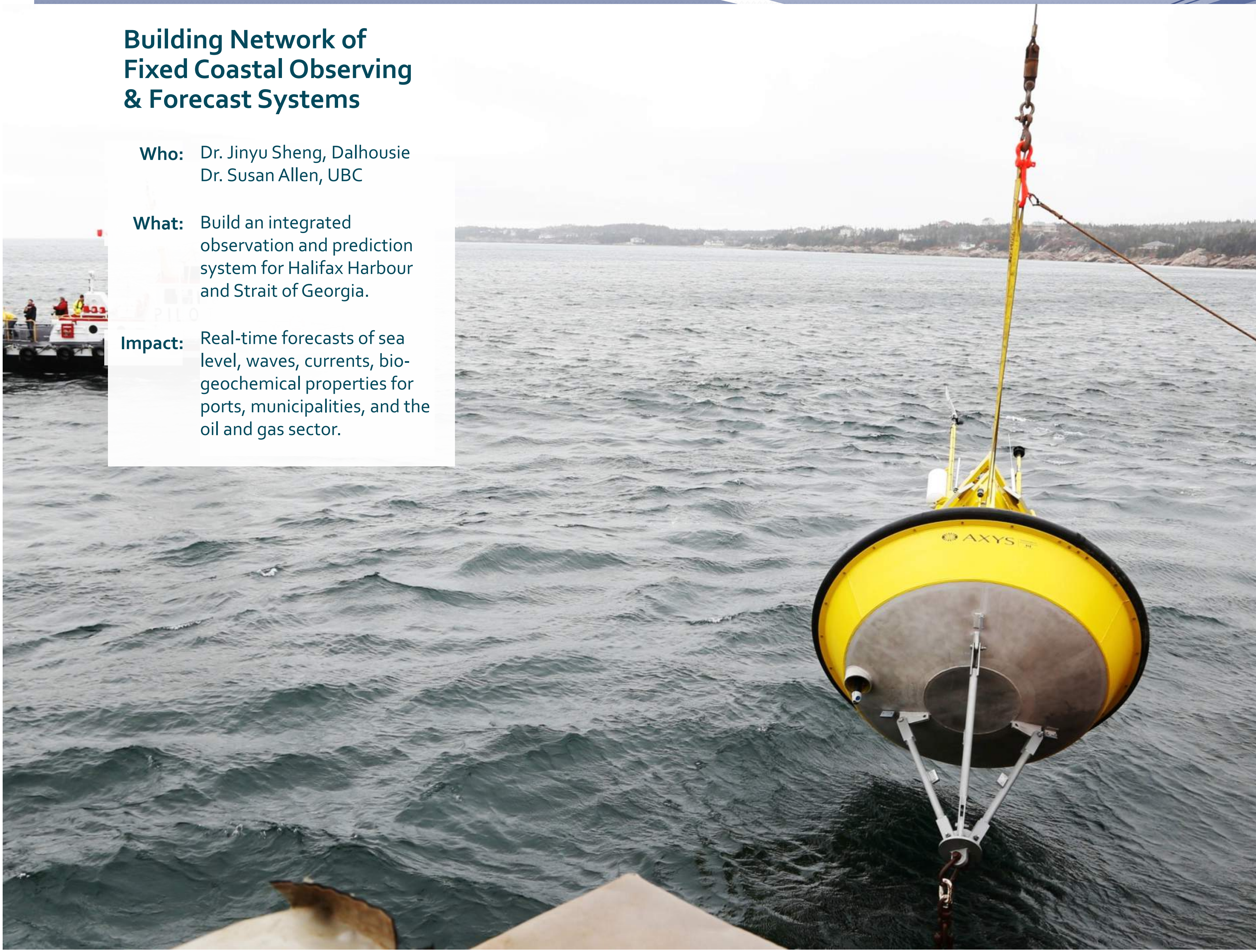
Photo credit: ArcticNet

Building Network of Fixed Coastal Observing & Forecast Systems

Who: Dr. Jinyu Sheng, Dalhousie
Dr. Susan Allen, UBC

What: Build an integrated observation and prediction system for Halifax Harbour and Strait of Georgia.

Impact: Real-time forecasts of sea level, waves, currents, bio-geochemical properties for ports, municipalities, and the oil and gas sector.



Improving Surface Drift Forecasts

Who: Dr. Dany Dumont, UQAR

What: Improve surface drift forecasts in seasonally ice-infested seas. Some buoys deployed by the UQAR ice canoe team.

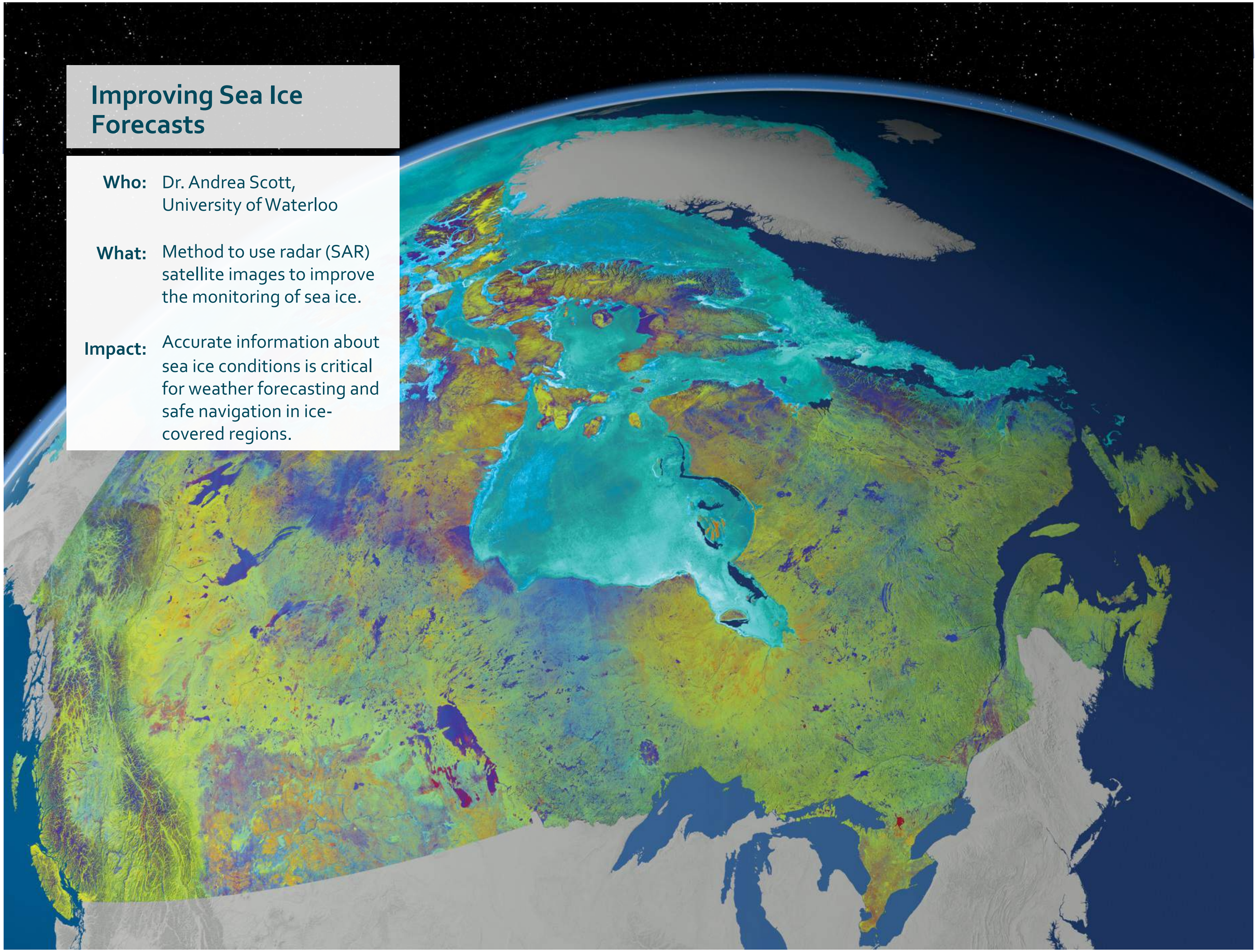
Impact: Respond to emergencies along Canadian coasts e.g., a person or oil patch. Time is key in ice-infested water.

Improving Sea Ice Forecasts

Who: Dr. Andrea Scott, University of Waterloo

What: Method to use radar (SAR) satellite images to improve the monitoring of sea ice.

Impact: Accurate information about sea ice conditions is critical for weather forecasting and safe navigation in ice-covered regions.



Climate Change and Extreme Events in the Marine Environment

Who: Dr. Gregory Flato, Environment Canada/ Uvic

What: Develop ways to assess and visualize changes in the marine environment and the associated risks on climate time scales.

Impact: The fishing industry and coastal communities could. e.g., use risk maps to manage their exposure to extreme weather events.

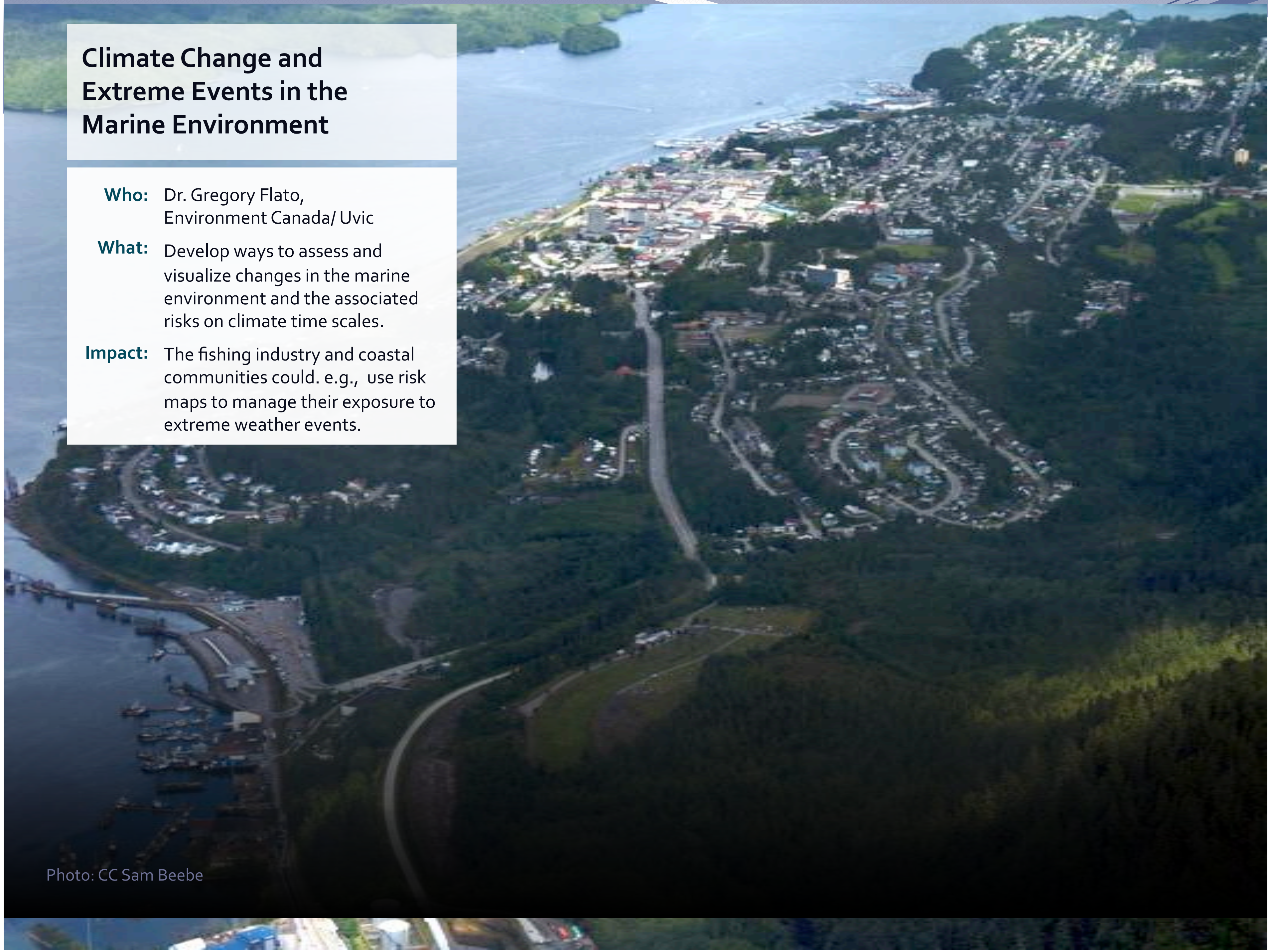


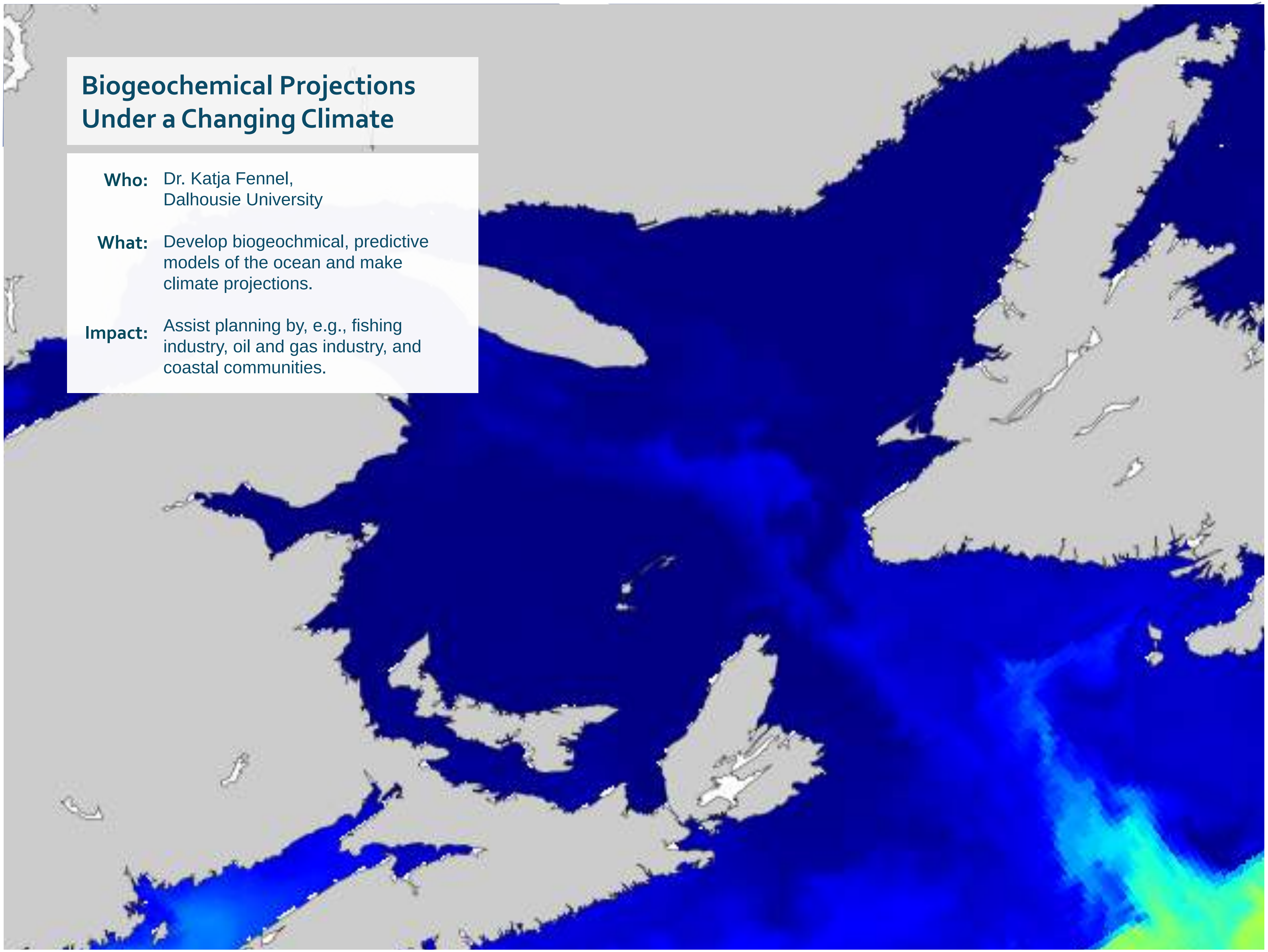
Photo: CC Sam Beebe

Biogeochemical Projections Under a Changing Climate

Who: Dr. Katja Fennel, Dalhousie University

What: Develop biogeochmical, predictive models of the ocean and make climate projections.

Impact: Assist planning by, e.g., fishing industry, oil and gas industry, and coastal communities.



User-Driven Monitoring of Adverse Marine and Weather States in the Eastern Beaufort Sea

Who: Dr. David Atkinson, UVic

What: Assess how large-scale weather patterns adversely impact marine transport and industrial activity in eastern Beaufort Sea.

Impact: Ensure marine operators, coastal communities and emergency response operators have access to weather forecast information to help plan operations.

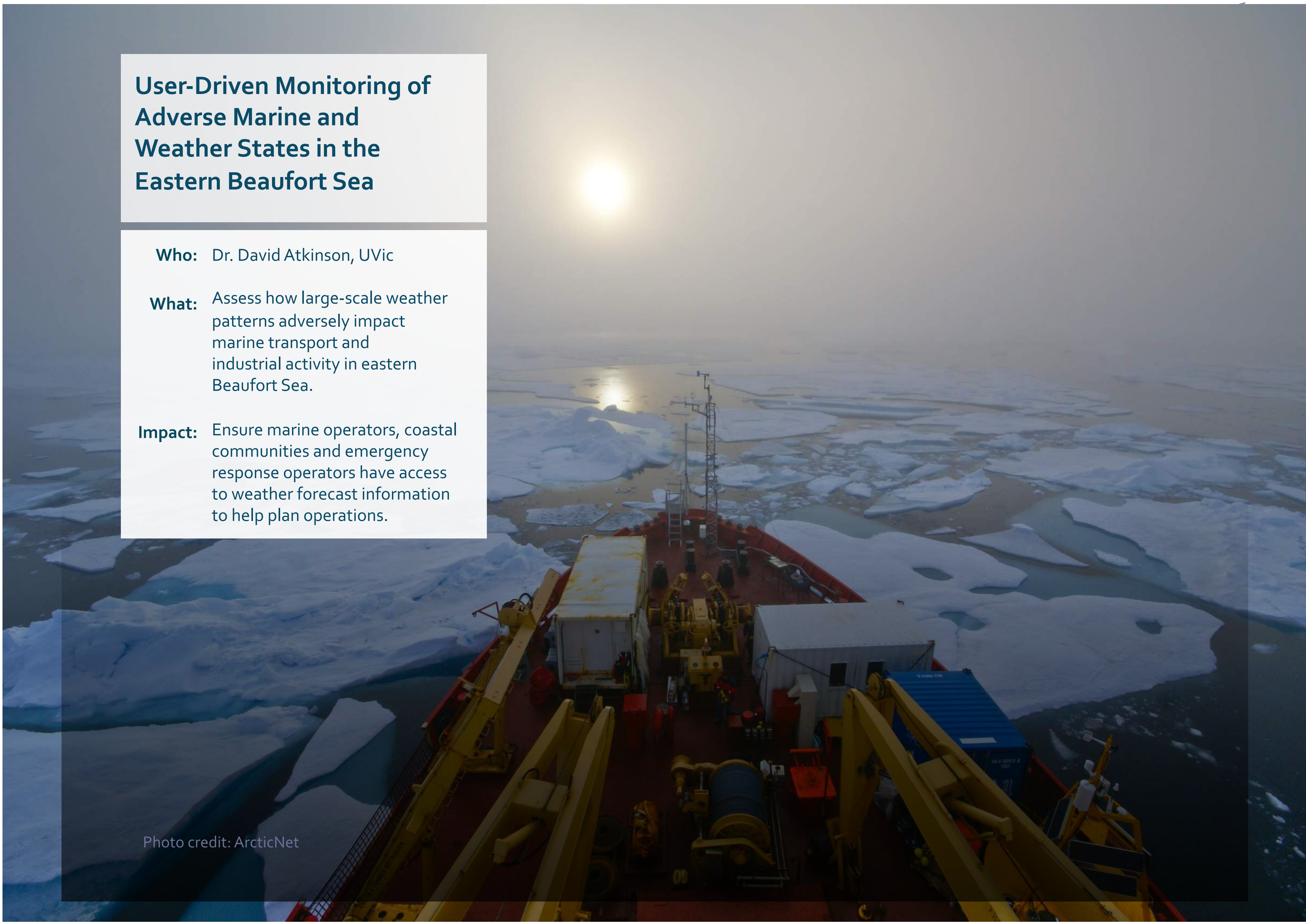


Photo credit: ArcticNet

MEOPeople

Training highly qualified personnel is one of MEOPAR's most important objectives.

MEOPAR'S Outcomes

INFORMED SOCIETY

- More people using research results
- Information about the ocean readily available

COORDINATED CANADIAN APPROACH

- Bringing together researchers, industry, and NGOs
- Better techniques & policies
- Hazard management

TRAINED PEOPLE

- Ocean skills
- Student mentoring

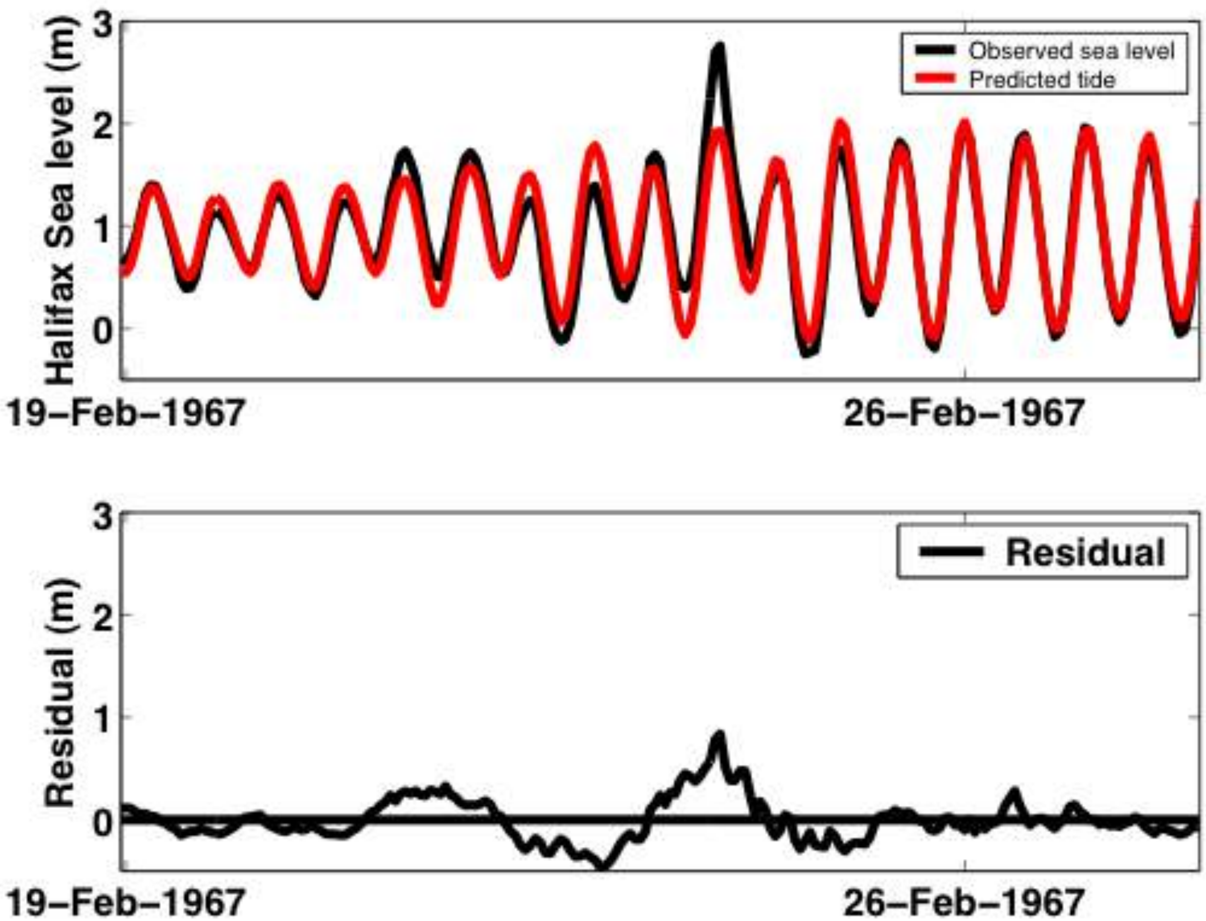
Predicting Storm Surges With Lead Times up to 10 Days

Storm surges are an ever present danger in eastern Canada

Home damaged by the storm surge of December, 2010 Sainte Luce, Quebec

http://joansullivanphotography.com/STILLS/Climate-change

Flooding is Caused by Tide and Surge



$$\eta = \eta_T + \eta_S$$

Halifax
February 1967

Forecasting Storm Surges

Surge models are usually based on two simple physical principles expressed by the following equations:

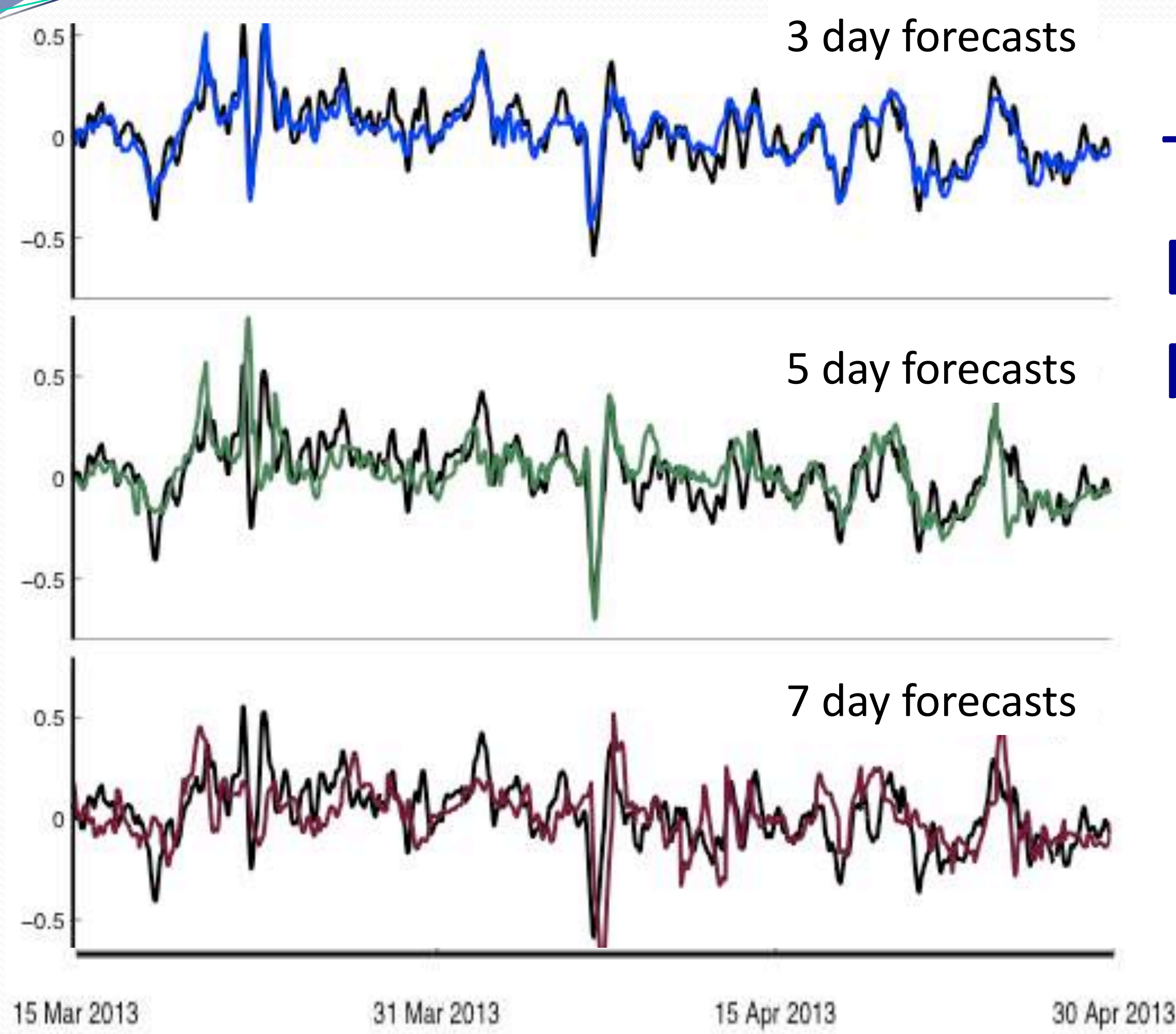
$$\frac{Du}{Dt} = -f \times u - g\nabla(\eta - \eta_p) + \frac{\tau}{H} - \frac{c_d |u| u}{H}$$

$$\frac{\partial \eta}{\partial t} + \nabla \cdot (uH) = 0$$

Discretize on a grid with realistic coastlines and water depths.
Integrate through time with forecast wind to forecast surge.

Our Surge Model and Domain

- Model is 2D, based on POM
- Shelf and deep water, Labrador to Gulf of Maine
- Driven by 10 day forecast winds and air pressure
- Deterministic (1/30°)
- Ensemble (1/12°)
- 1 March 2013 to 31 March, 2014



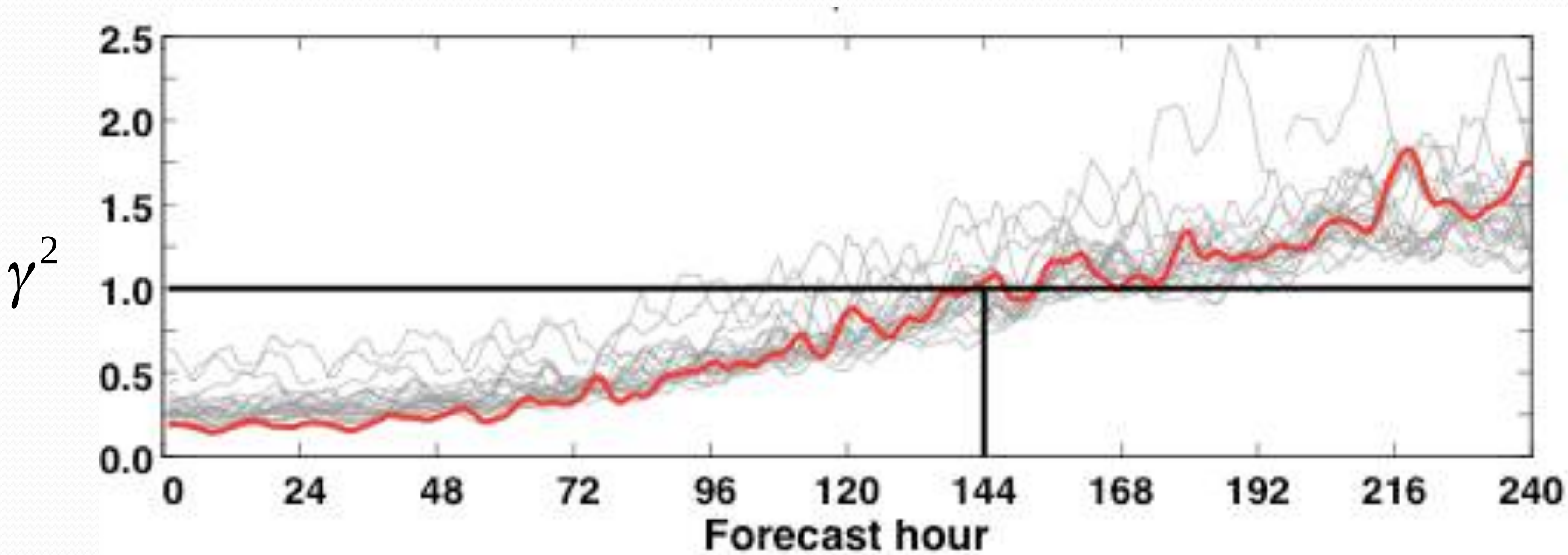
Typical Deterministic Forecasts

Rimouski
Observations in black

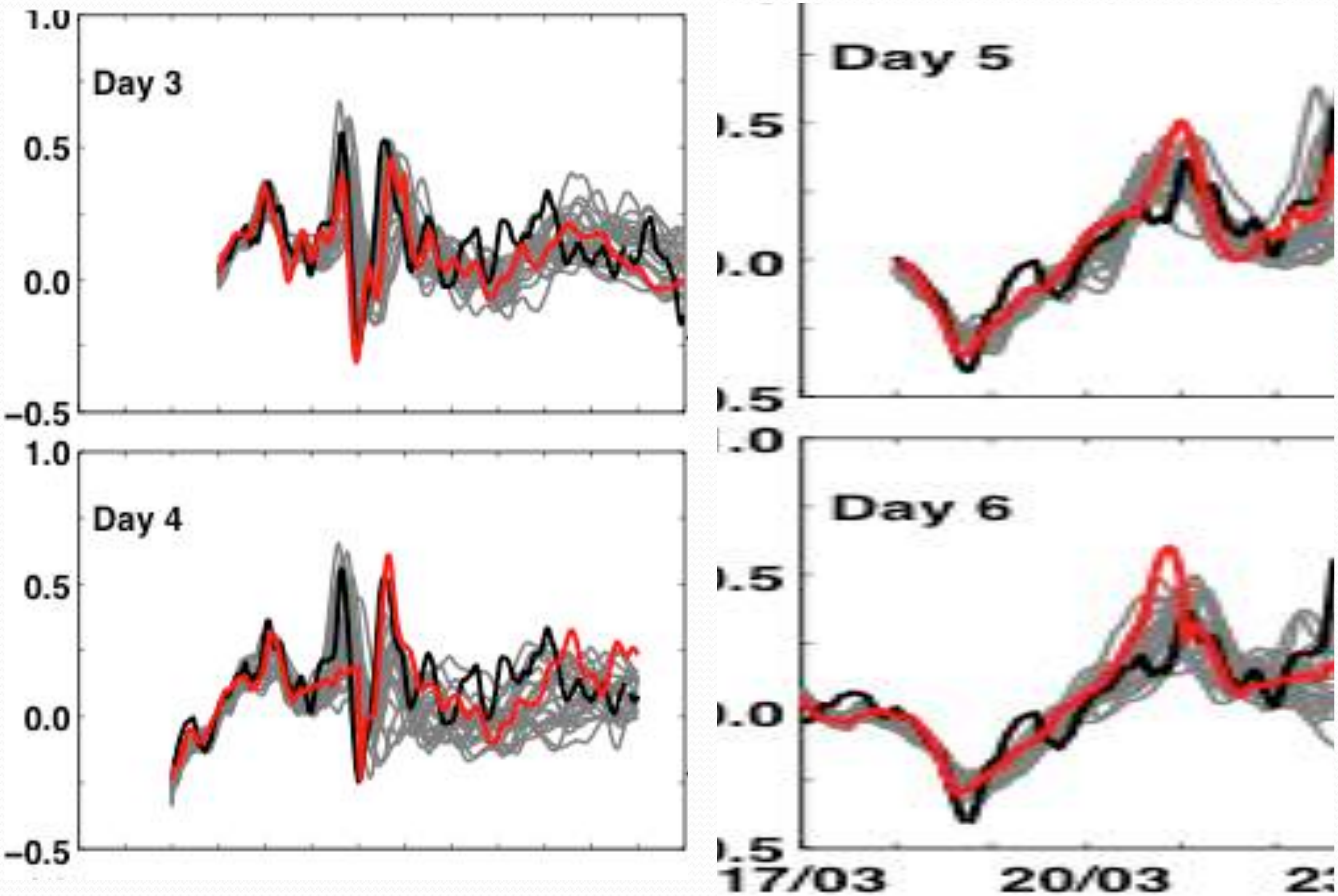
How Good are the Deterministic Forecasts?

For each of the 22 tide gauges calculate

$$\gamma^2 = \frac{\mathrm{var}(\eta_{obs} - \eta_{\mathrm{mod}})}{\mathrm{var}(\eta_{obs})} = \frac{error}{obs}$$



Allowing for Uncertainty in Wind Forecasts



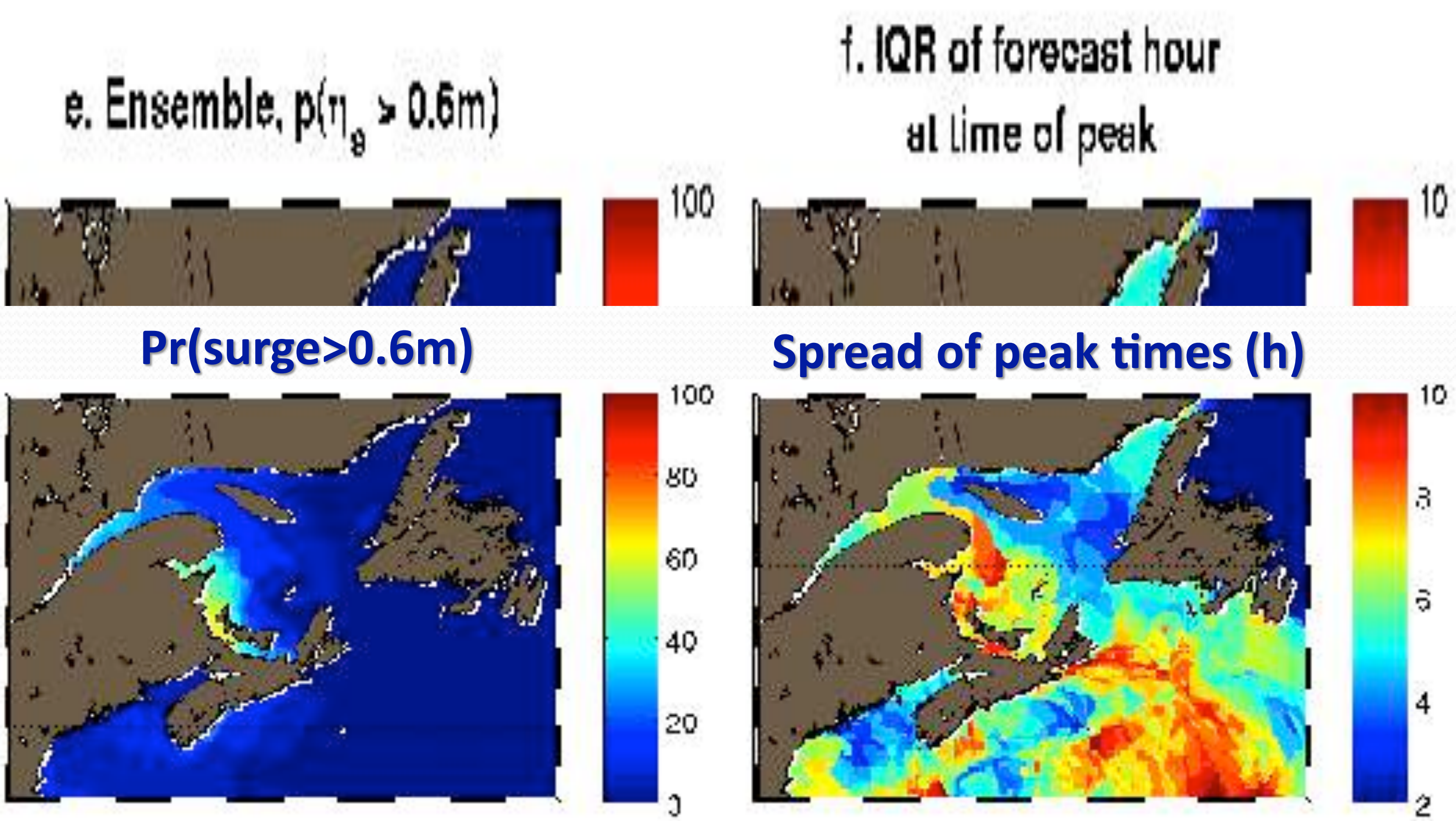
Rimouski
March 2013

Observed
Deterministic
Ensemble

Visualizing Ensemble Surge Forecasts

Pr(surge>0.4m) **Median of peak times (h)**

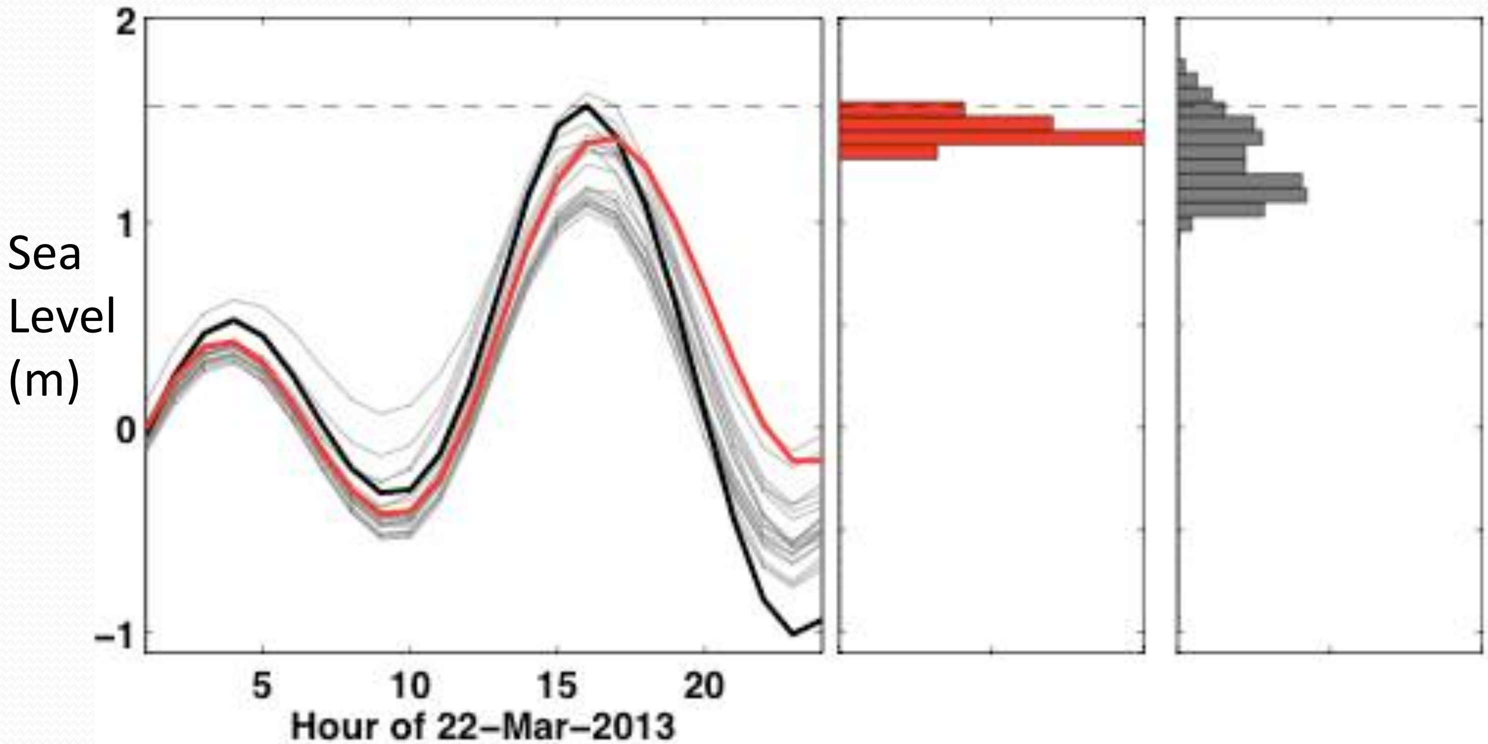
Pr(surge>0.6m) **Spread of peak times (h)**



5d forecast for
22 March 2013

5 Day Forecasts of Total Water Level

$$\eta = \eta_T + \eta_S$$



5d Forecasts for Rimouski 22 March 2013

Observed
Deterministic
Ensemble

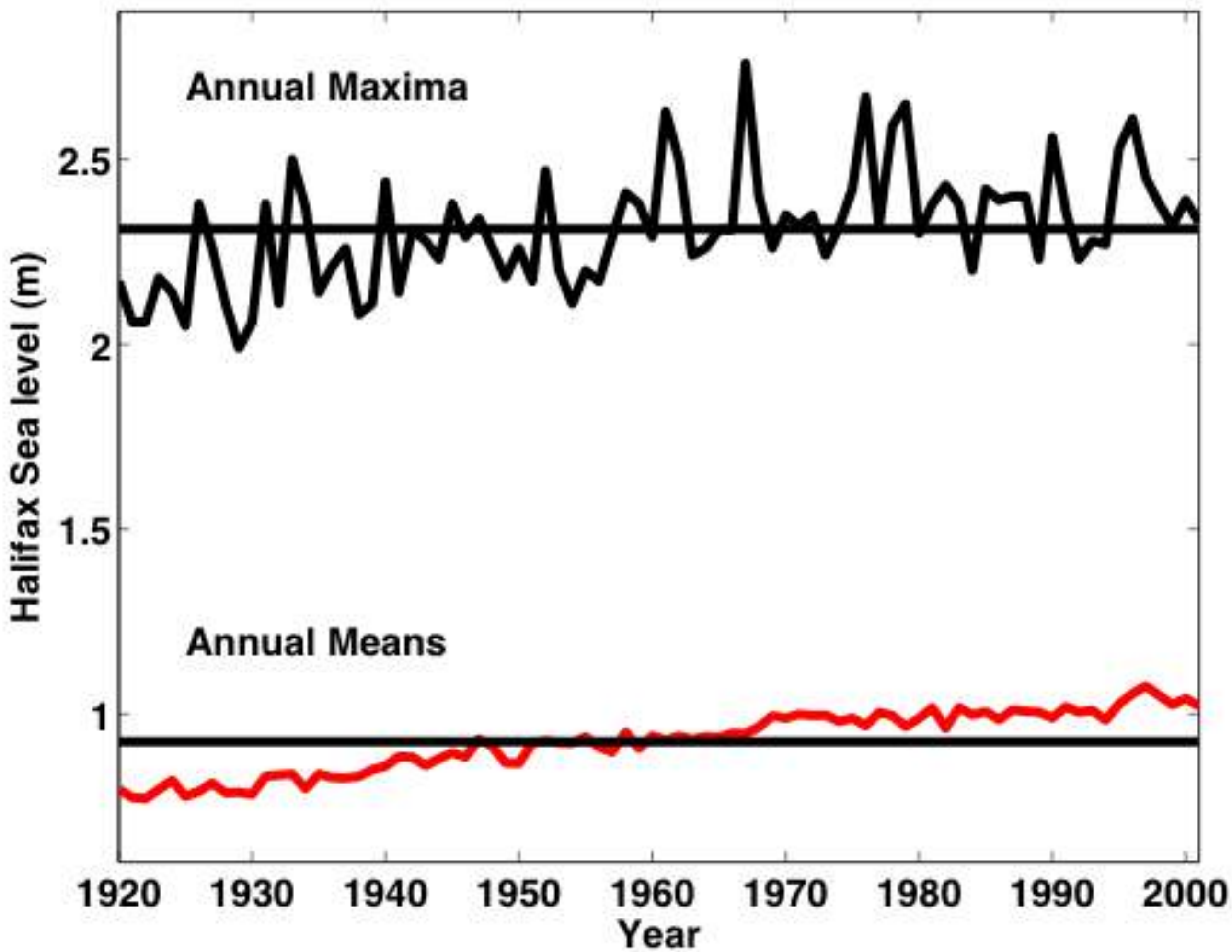
Projecting Flood Probabilities Over Coming Decades

Such information is needed for sensible adaptation strategies.

Problem is conceptually similar to predicting total water levels 10 days into future.

Let's start by looking at some observations from the long Halifax sea level record.

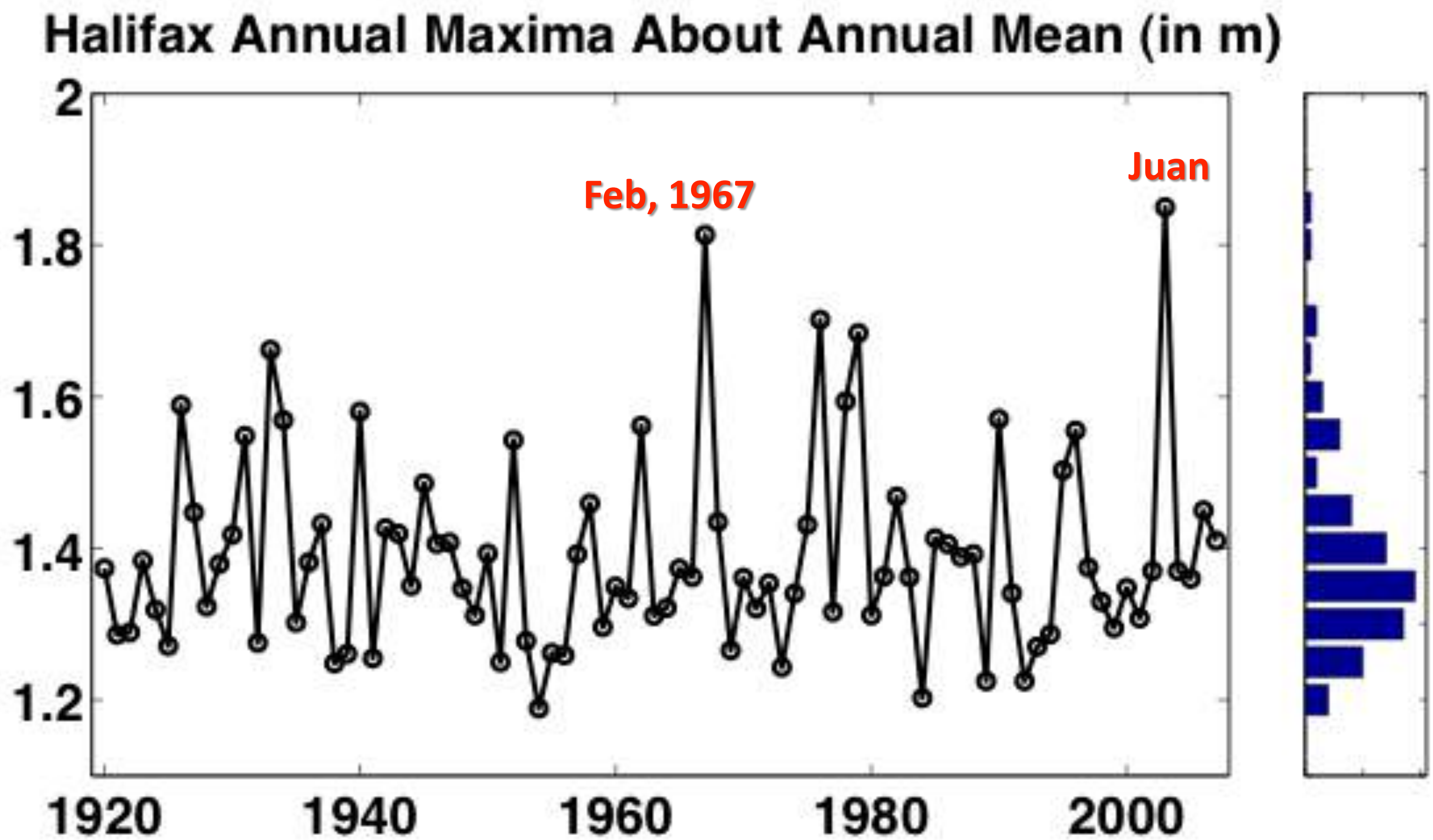
Annual Means and Maxima for Halifax



Halifax
1920-2001

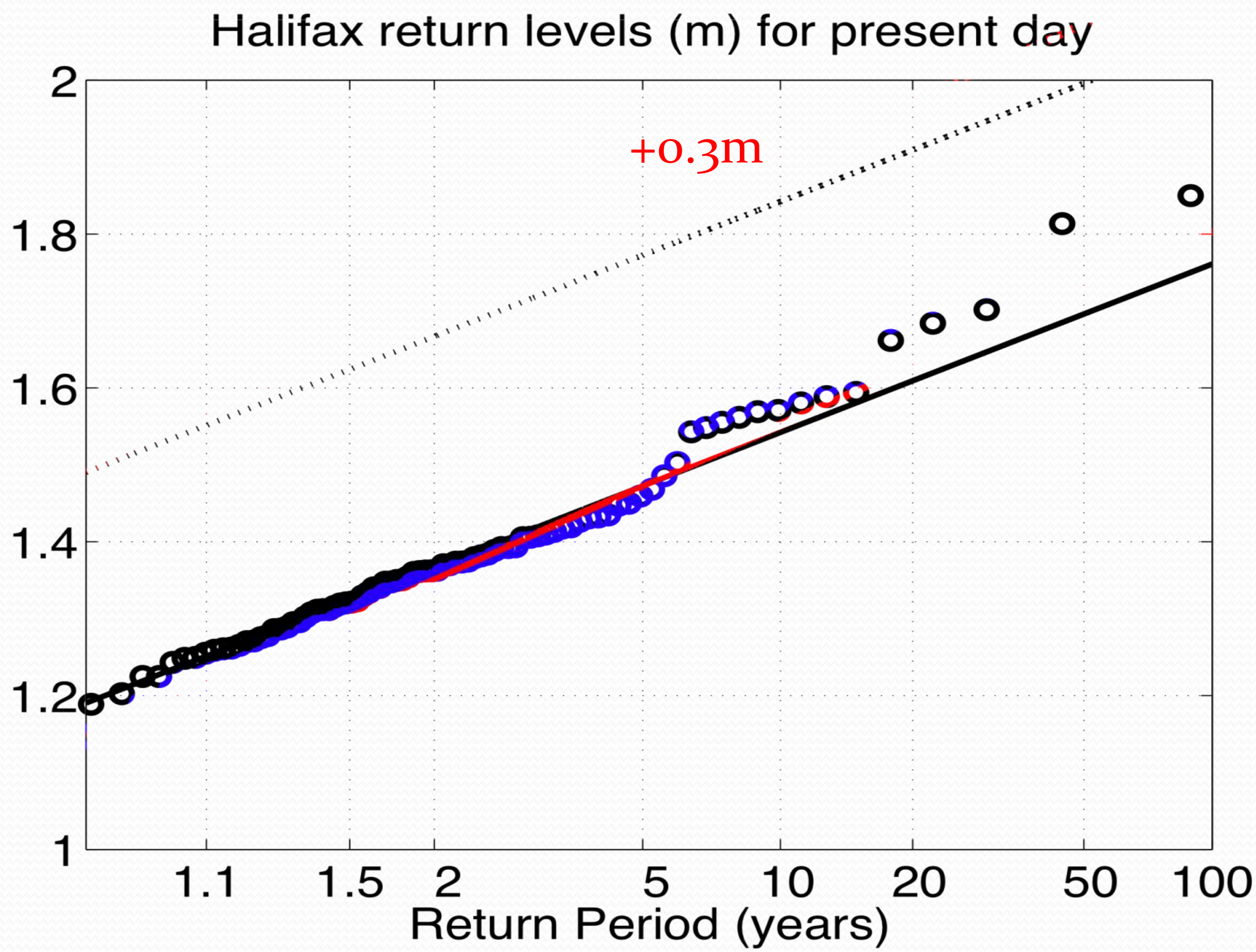
Offset due
to tides

Annual Maxima About Annual Means



Probability of Flooding Today

Halifax return level about mean (m)



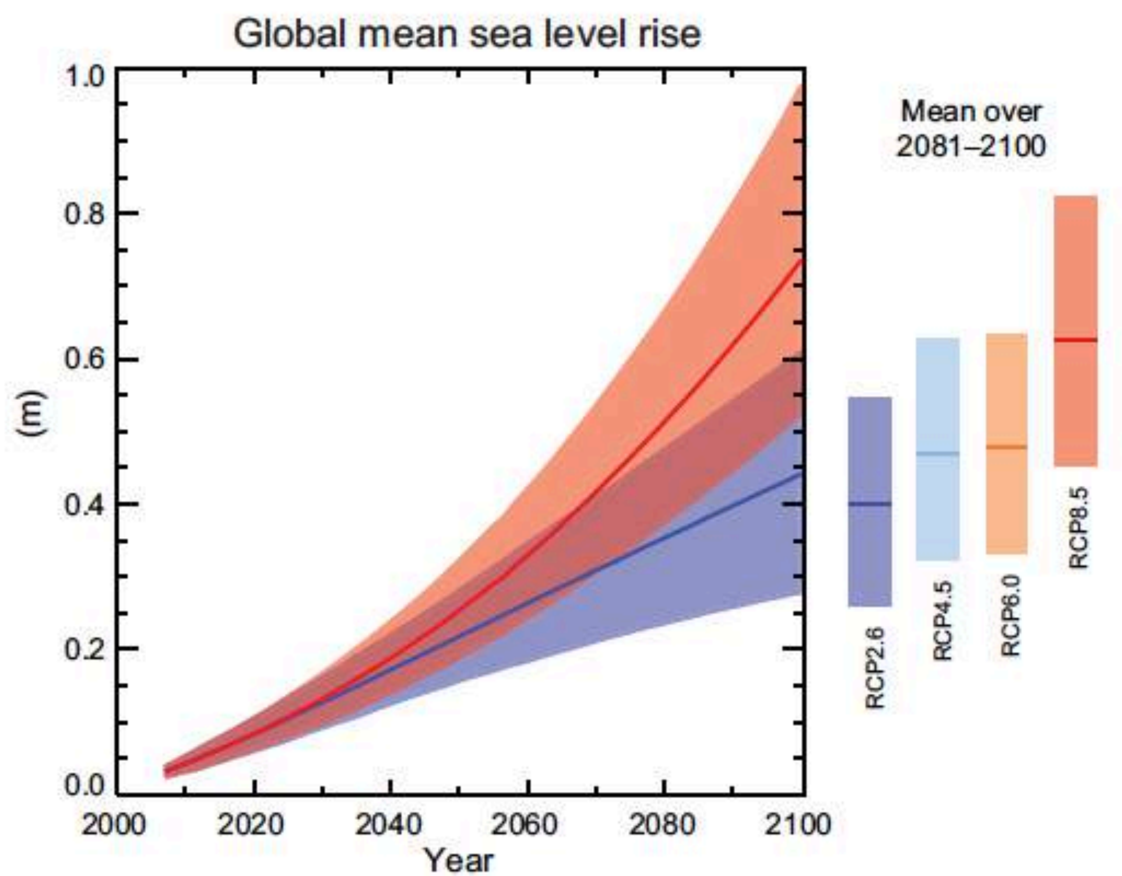
Return period (years)

100y Projections of Flood Probabilities

Simplest approach: Assume mean sea level will increase by fixed amount and just raise return levels. "Deterministic".

But sea level increase over next century is highly uncertain (e.g., uncertain emission scenarios, model errors).

Projected Sea Level Rise Over Next Century



IPCC, 2013: Summary for Policymakers. Figure SPM.9

"medium confidence"

How can we include such uncertainty in projections of flooding probability? What are the practical implications?

Projecting Probability of Total Water Level

Write annual maximum as sum of annual mean and a deviation:

$$\eta = \eta_A + \eta_D$$

Assume pdfs for these two components are of form:

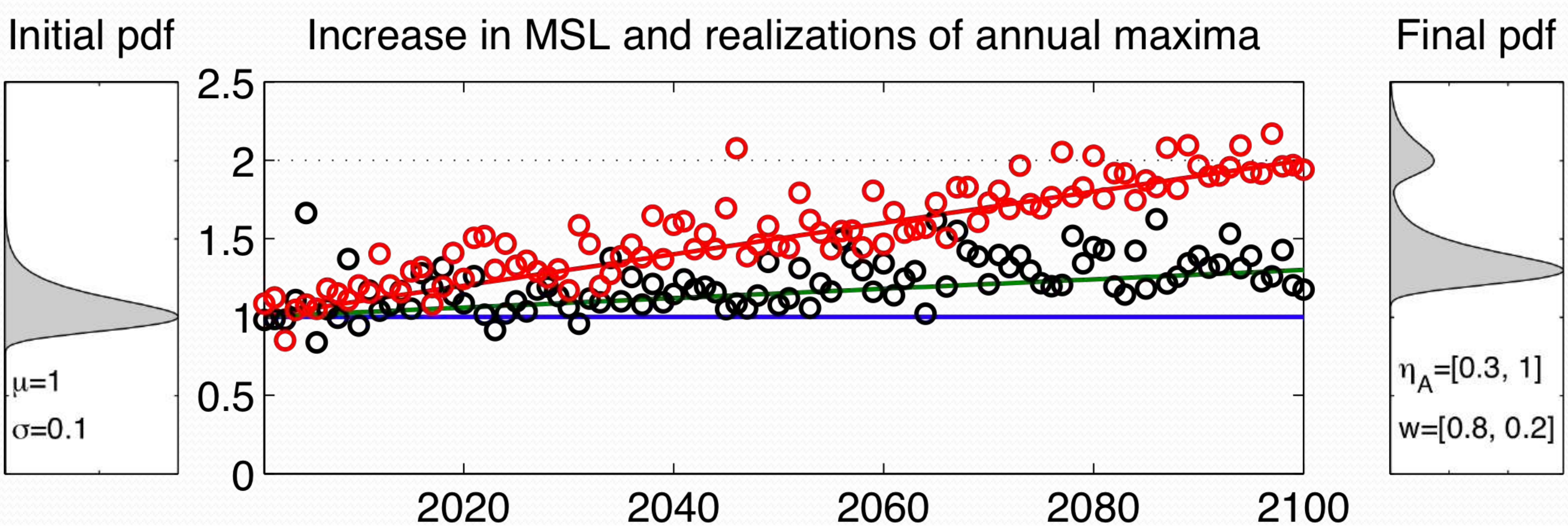
$$p(\eta_A) = w_1\delta(\eta_A - \eta_{S1}) + w_2\delta(\eta_A - \eta_{S2}) + \ldots$$
$$p(\eta_D) = \phi_G(\eta_D)$$

The pdf of annual maximum is convolution of these two pdfs.

Idealized Example

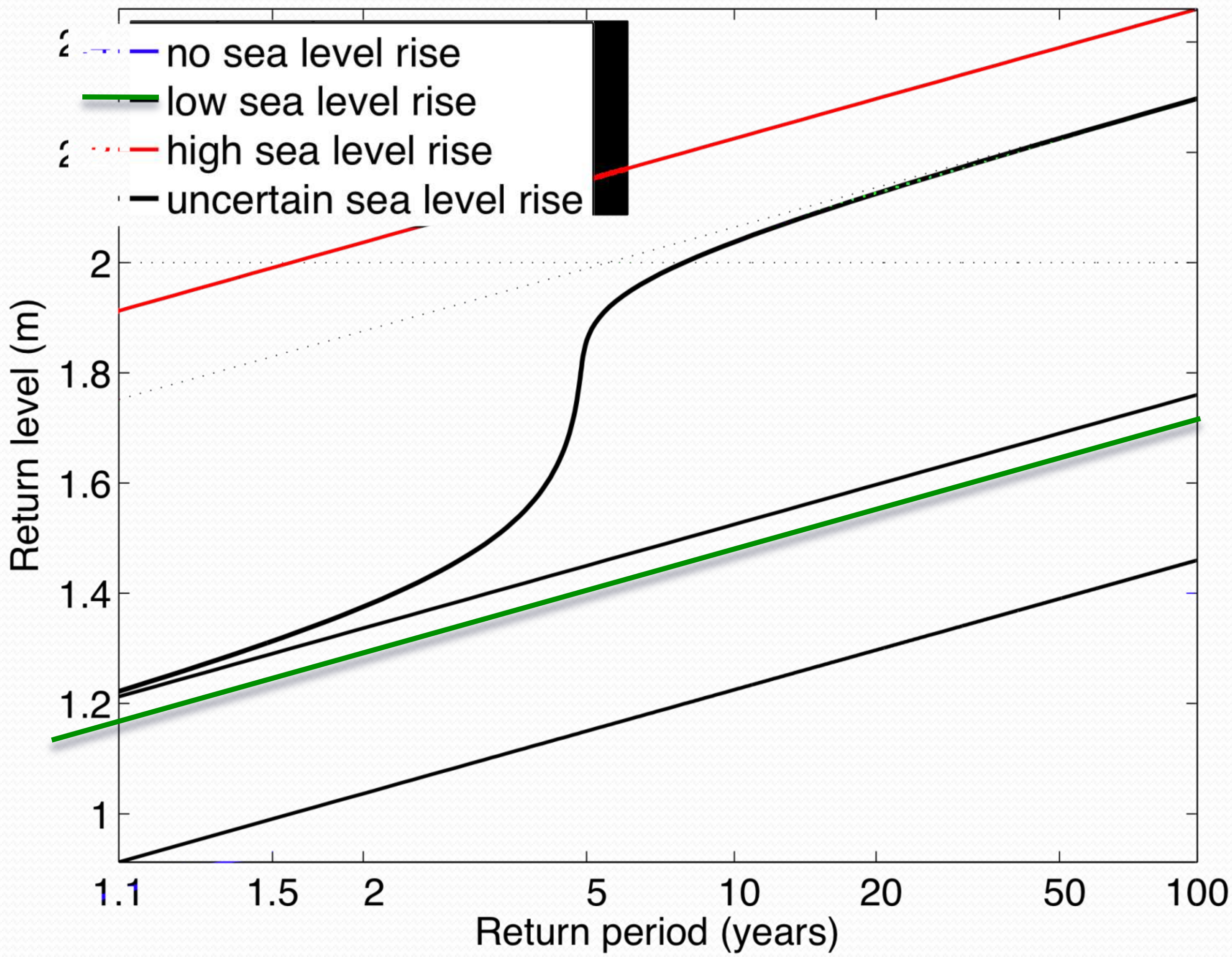
Assume there are only possible SLR scenarios:

S1: Sea level rises at 0.3m per century P(S1)=0.8
S2: Sea level rises at 1.0m per century P(S2)=0.2



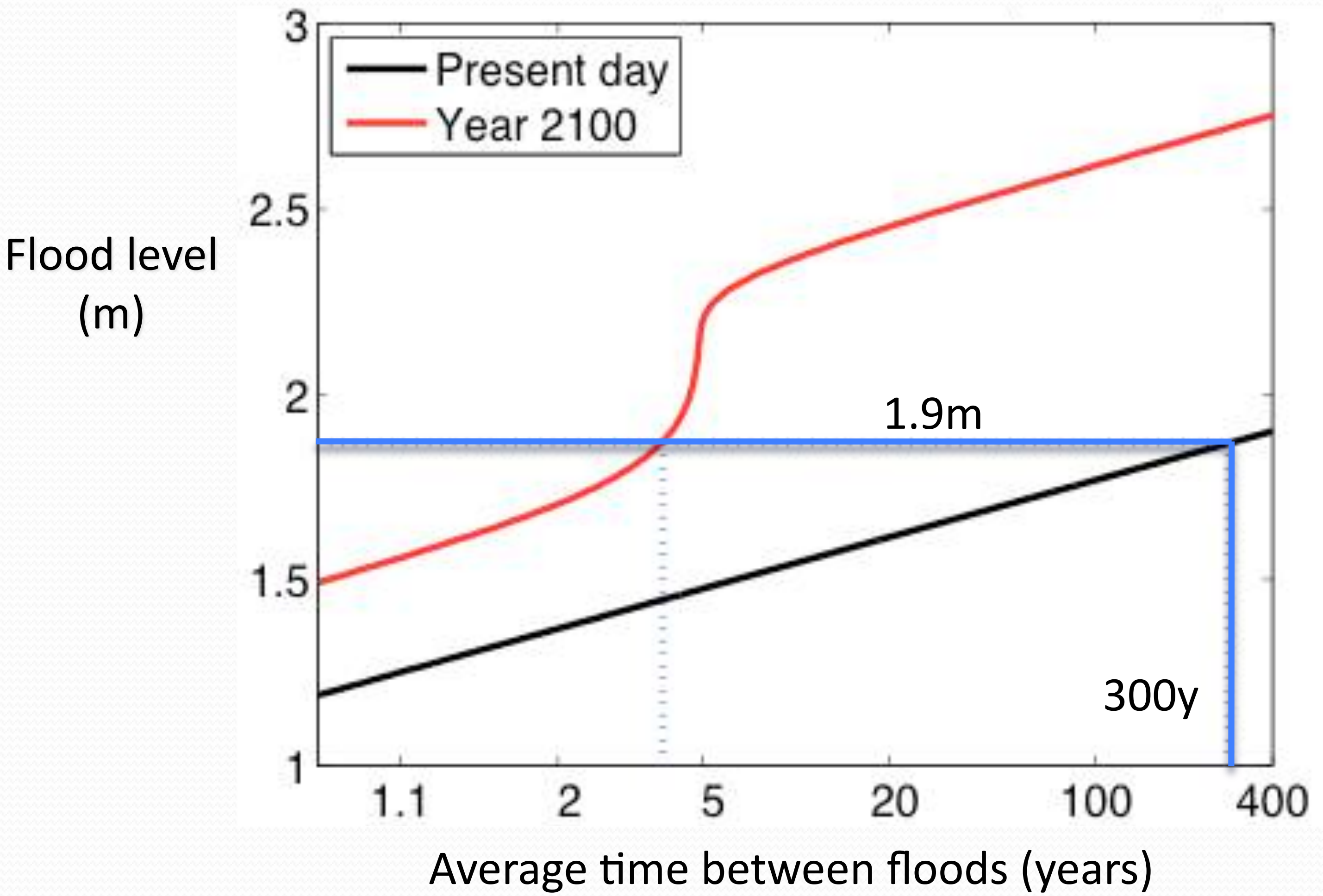
Impact of Uncertainty on Return Levels

Return level for Idealized Example (m)



Return period (years)

What Should Halifax Expect Today?



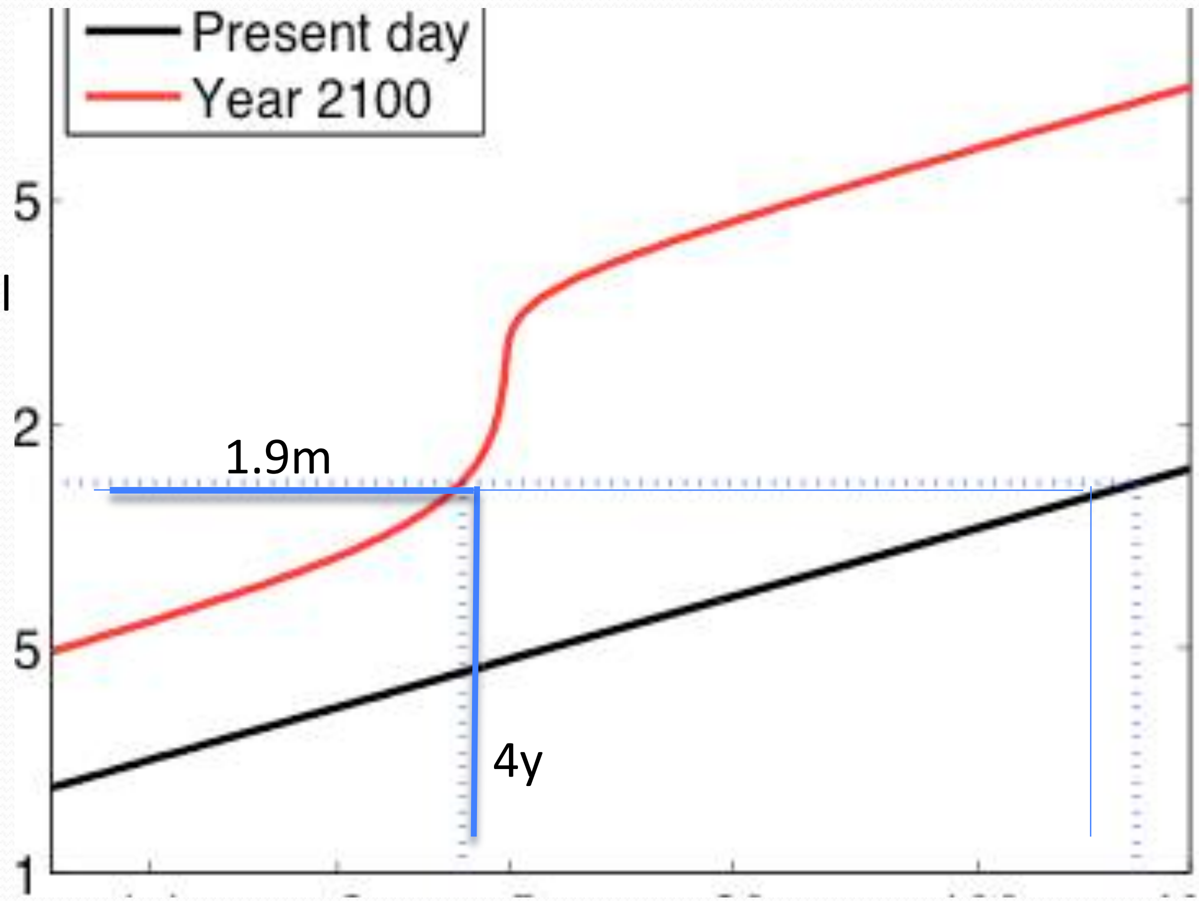
Impact of 1.9m on Downtown Halifax

Expect one every 300y if present conditions prevail

Charles et al., 2011

What Should Halifax Expect in 2100?

Flood level (m)



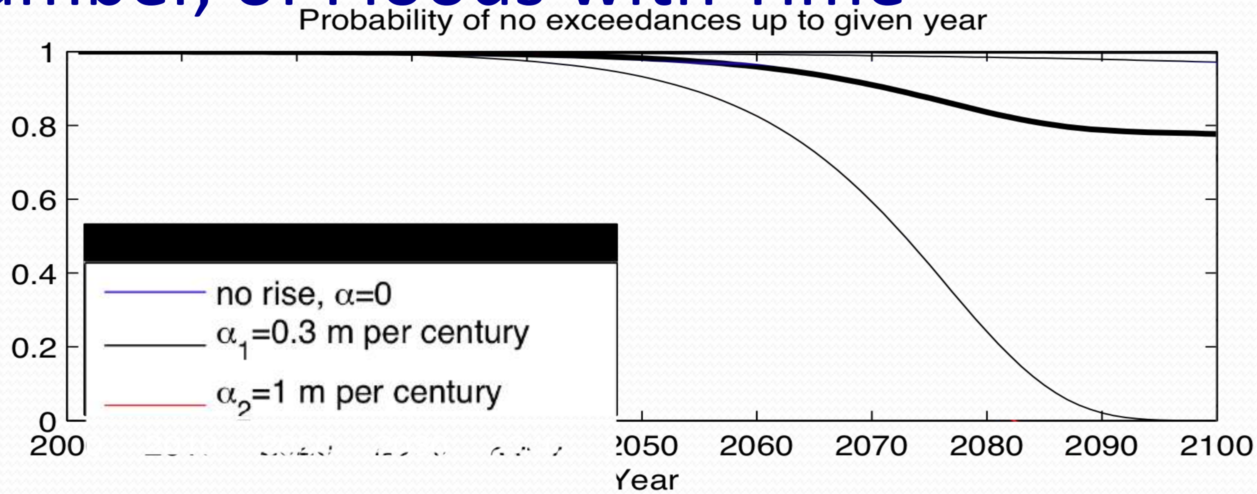
Average time between floods (years)

Probability of exceeding high flood levels is determined by more extreme, but less likely, scenarios

Conclusions

- Trend toward probabilistic predictions and projections of sea level, based on ensembles and expert knowledge.
- Uncertainty is not a sign of bad models or science.
- Surge predictions are improving (known unknowns). Expect rapid improvements over next five years.
- Climate projections more complex (unknown unknowns?) Better understanding may lead to greater uncertainty.
- Work presented here illustrates a small part of the research being conducted by MEOPAR.

Impact of Uncertainty on Probability, and Number, of Floods with Time



Critical level Is 2 m