INCREASES IN PUGET SOUND ESTUARINE FLOOD RISK UNDER CLIMATE CHANGE

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CLIMATE IMPACTS GROUP

INTRODUCTION

Near coastal environments have been identified as some of the most likely to be impacted by climate change. Observed changes in Puget Sound sea level and flood magnitudes are in line with those projected by previous climate change impacts studies. Current understanding of the combined effects of these changes is relatively low and has promoted us to explore the ways in which these two influence near coastal ecosystems and infrastructure. Specifically, this project examines the effects of climate change on estuarine water surface elevations by exploring the combined effects of sea level rise and riverine flooding. The project utilizes a chain of numerical models to quantify the climate change altered hydraulic conditions expected in two estuaries in the Puget Sound (the Skagit and Nisqually Rivers).

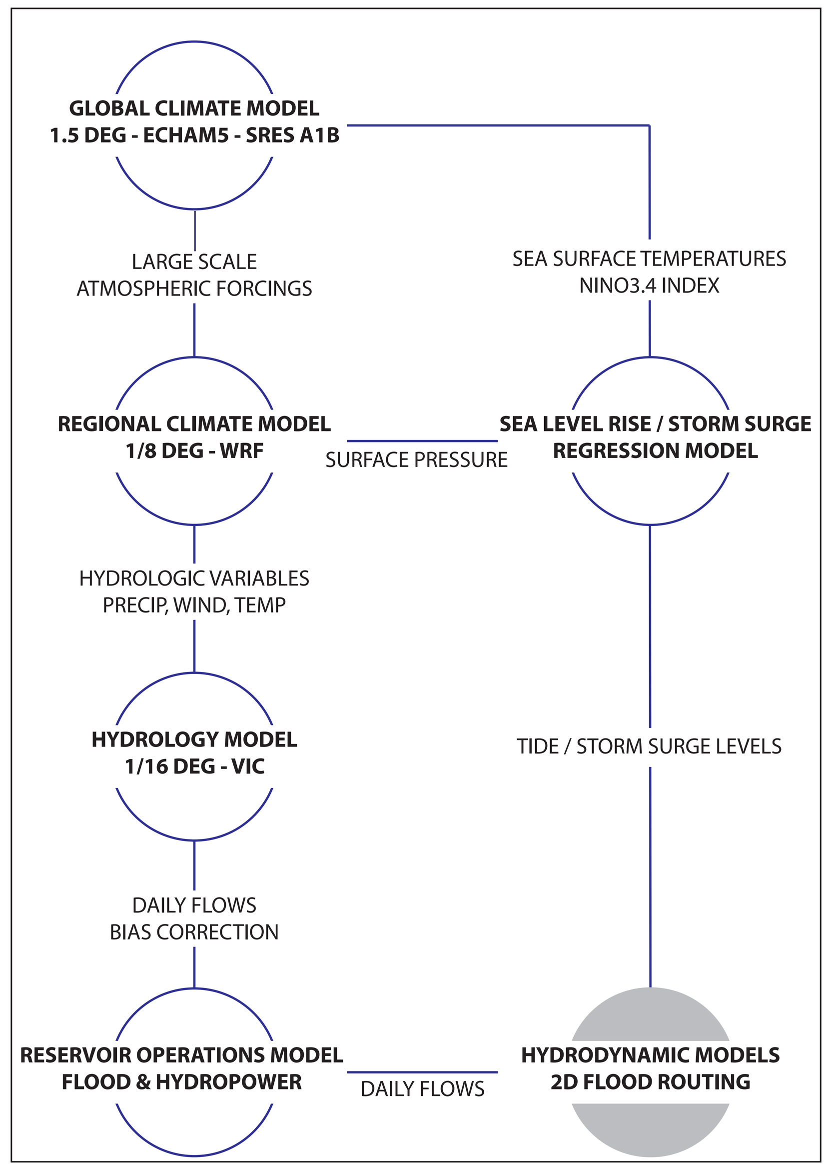
Figure. Map showing the two study locations.

PROJECT GOALS

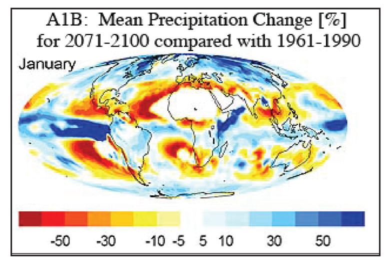
1. Incorporate Regional Climate Model (RCM) projections into ongoing climate impacts studies.
2. Use RCM projections to develop temporally consistent storm responses (future floods and storm surges).
3. Compare the RCM results to those of previous studies.
4. Use projected river flows and storm surges to evaluate physical flood impacts using hydrodynamic models.

PROJECT OUTLINE

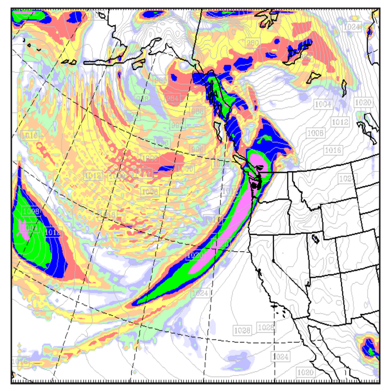
This project relies heavily on work previously completed by others, especially in regards to the complex climate and hydrologic modeling. The figure below outlines the process of developing local scale flood projections beginning with a global climate model.



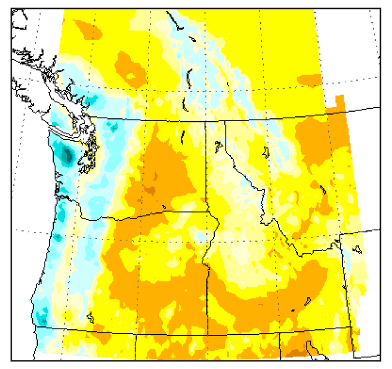
DATA



GLOBAL CLIMATE MODEL: The ECHAM5 climate model, SRES A1B, was used by Salathe et al. (2010) as the large scale forcing for the regional climate model. Monthly gridded equatorial sea surface temperatures (SSTs) were extracted from this large scale data set to include ENSO effects.

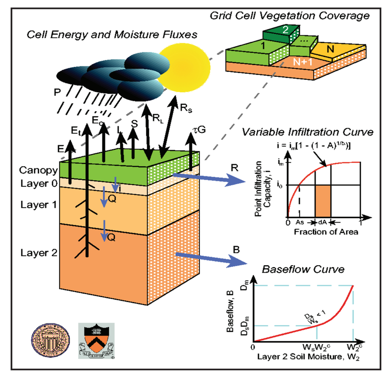


REGIONAL CLIMATE MODEL: The Weather Research Forecast (WRF) model was used to dynamically downscale GCM projections. Because WRF is run at higher spatial (1/8[th] degree) and temporal (6 minutes) resolutions that the large scale GCM, it provides much more realistic weather events than are otherwise possible. Additionally, dynamic downscaling allows weather patterns to change according to first principle relationships. The RCM outputs were also bias corrected to match historical statistics. Citation: Salathe et al. (2010).



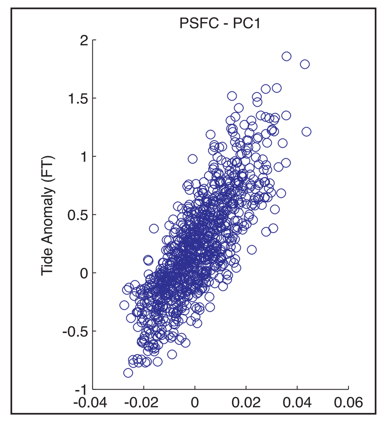
STATISTICAL DOWNSCALING: Statistical downscaling using the hybrid-delta method was used to downscale and the raw GCM data. This process projects the monthly changes indicated by the GCM onto a historical data set. A complete description of the methods used in developing the statistically downscaled climate data can be found in Hamlet et al. (2010).

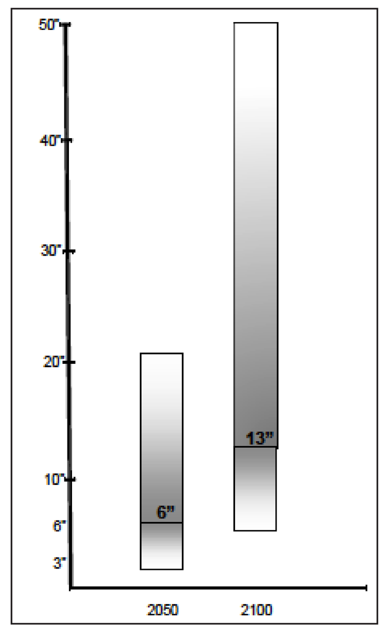
METHODS



HYDROLOGY MODEL: The Variable Infiltration Capacity (VIC) model was run at 1/16[th] degree resolution. All input variables (Tmin, Tmax, Wind, and Precip) were obtained from the bias corrected RCM outputs or the statistically downscaled GCM outputs. Routed VIC outputs were also bias corrected using a quantile mapping approach with USGS daily flows.

RESERVOIR MODELS: The reservoir models used in this study were constructed following the methodology outlined in Lee et al. (2011). In short, the models simulate reservoir operating policies at a daily timestep while meeting prescribed hydropower demands, minimum flow requirements and flood control targets.





SEA LEVEL RISE & STORM SURGE:

- The principle harmonic constituents were fit to the measured hourly water levels using a least-squares approach.
- These constants were then used to provide a time series of predicted hourly tides.
- The differences from the predicted and measured tides were summarized at a daily timestep.
- A regression approach was used for each month to estimate future water levels given a set of atmospheric variables from the GCM.
- An iterative process was used to determine which variables best described tidal anomalies experienced in the Puget Sound. Local pressure, the 1[st] and 3[rd] EOF signals, and ENSO were the only variables found to be significantly impactful on the anomaly.

$$Tide_{anom} = f(P, P_{3Day}, P_{PC1}, P_{PC3}, ENSO)$$

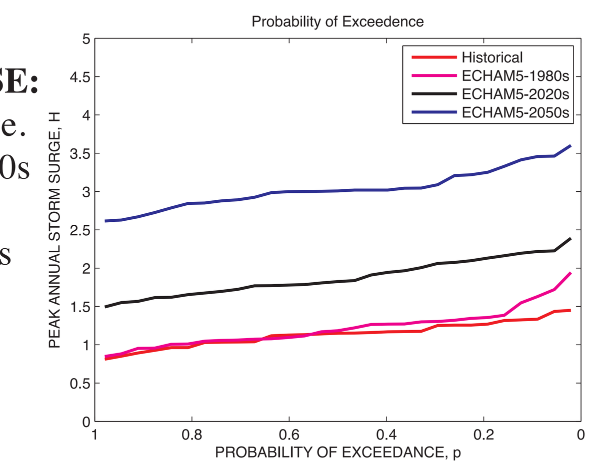
- Regression during stormy months yields R^2 >0.8.
- Sea level rise was uniformly added to the $Tide_{anom}$ for each time period based on projections outlined by Mote et al. (2008).

MODEL RUNS

Time Period	Climate Scenario	Hydrologic Source	Storm Surge Source	Sea Level Rise (cm)	Description
1970-1999	Historical	Gridded Observations	Observations	0	
1970-1999	HD - 2040s	H.D. - ECHAM5 - 2040s	WRF - Reanalysis	43	Hybrid Delta 2040s using WRF reanalysis as time consistent storm surge forcings.
1970-1999	HD - 2080s	H.D. - ECHAM5 - 2080s	WRF - Reanalysis	97	Hybrid Delta 2080s using WRF reanalysis as time consistent storm surge forcings.
1970-1999	ECHAM5-1980s	WRF – ECHAM5	WRF – ECHAM5	0	WRF - ECHAM5 20[th] century climate run.
2010-2039	ECHAM5-2020s	WRF – ECHAM5	WRF – ECHAM5	20	WRF - ECHAM5 SRES A1B, 2010 – 2039.
2040-2069	ECHAM5-2050s	WRF – ECHAM5	WRF – ECHAM5	55	WRF - ECHAM5 SRES A1B, 2041 – 2069.

RESULTS

SEATTLE STORM SURGE



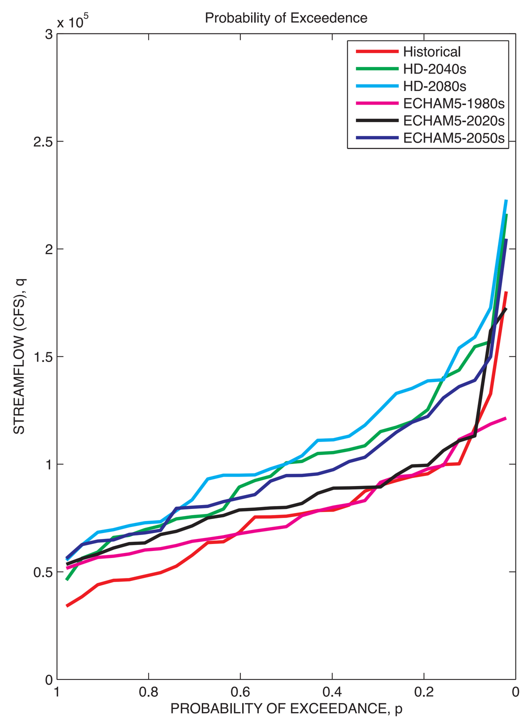
STORM SURGE / SEA LEVEL RISE:

- Minimal change in actual storm surge.
- Good match between ECHAM5 1980s and Historical 1980s time periods.
- Change in peak annual storm surge is dominated by sea level rise.

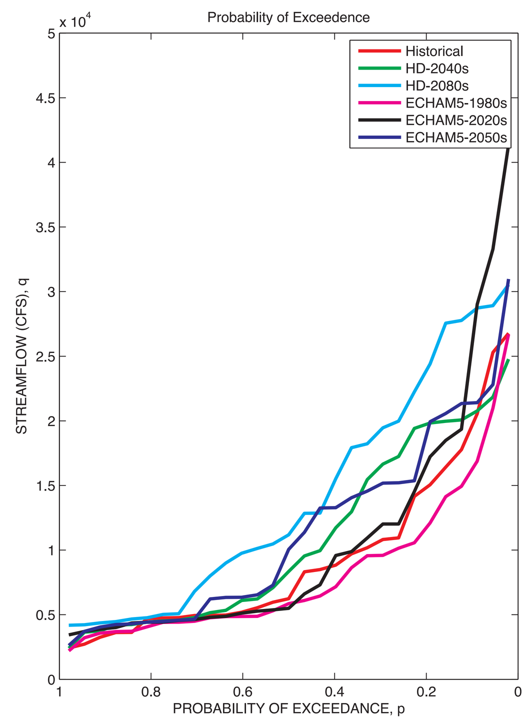
PEAK ANNUAL FLOW:

- Skagit River: WRF shows modest increases in flood magnitude while the H.D. shows increases up to 20%.
- Nisqually River: WRF runs show very large increases in flood magnitudes (up to 85%).
- Both rivers overall show increases in flood magnitude.

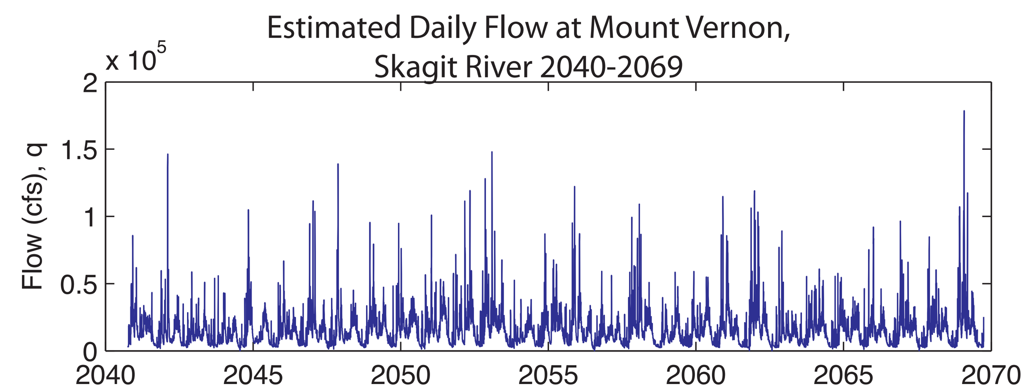
SKAGIT RIVER

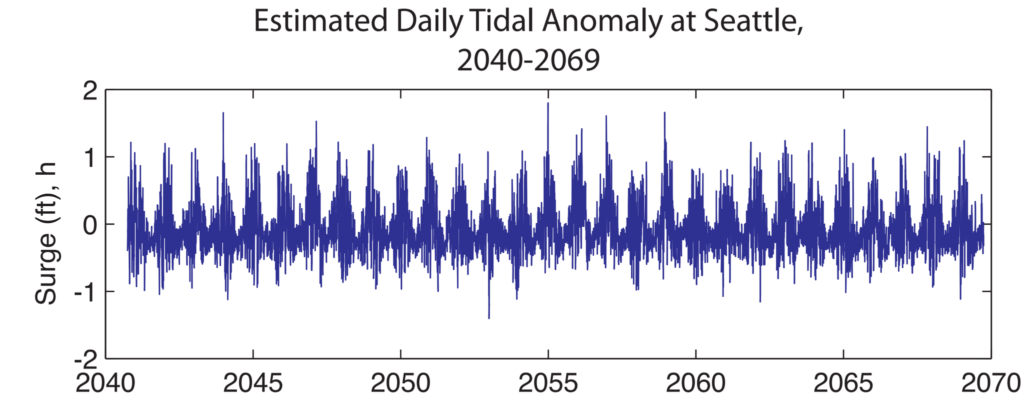


NISQUALLY RIVER



TEMPORALLY CONSISTENT PROJECTIONS:

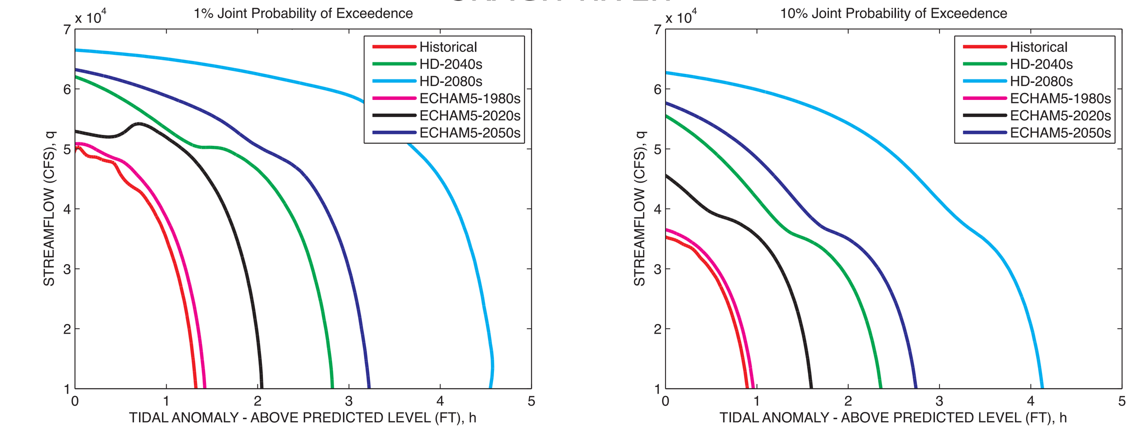




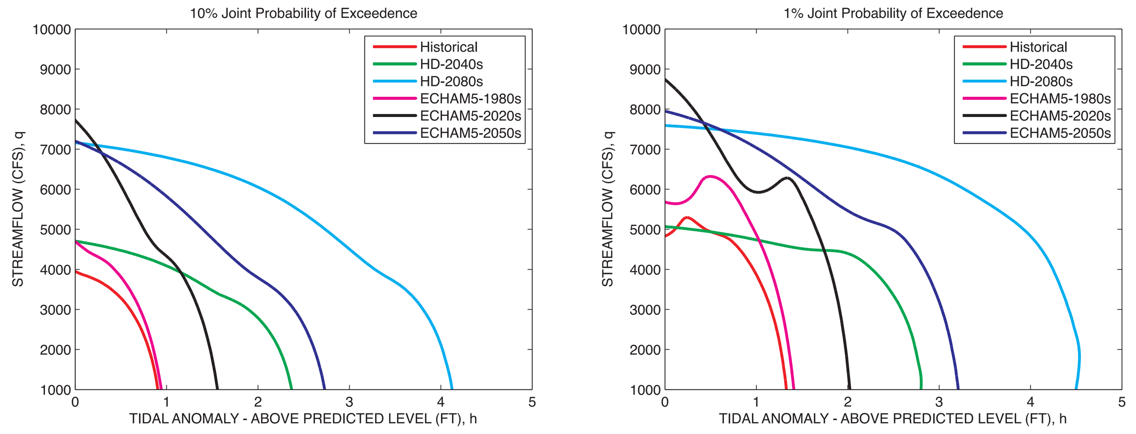
JOINT PROBABILITY

- Pairing peak monthly tidal anomaly (surge) with corresponding daily flow, the joint probability of exceedence is calculated.
- The figure below shows the joint probability distribution for p = 0.10 and p = 0.01 (Note that these figures are peak monthly values, as opposed to peak annual as shown earlier).

SKAGIT RIVER



NISQUALLY RIVER



DISCUSSION

- Using regional climate model results, we demonstrate a process for developing and implementing temporally consistent climate change projections into future flood risk studies.
- A monthly regression approach was successfully developed to estimate storm surge.
- The modest increases in Skagit flood peaks produced by WRF requires further study.
- The development of joint probability functions facilitates informed scenario selection for hydrodynamic modeling studies.

FUTURE WORK

1. Use hydrodynamic models to evaluate impacts of increased flood risk.
2. Develop methods to estimate storm surge closer to estuary.
3. Expand methodology to other Puget Sound estuaries.

REFERENCES

1. Hamlet, A.F., P. Carrasco, J. Deems, M.M. Elsner, T. Kamstra, C. Lee, S-Y Lee, G. Mauger, E. P. Salathe, I. Tohver, L. Whitely Binder, 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://www.hydro.washington.edu/2860/report/.
2. Lee, Se-Yeun, A.F. Hamlet, 2011: Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.
3. Mote, P.W., A. Peterson, H. Shipman, W.S. Reeder, and L. Whitely Binder, 2008: Sea level rise in the coastal waters of Washington. Report for the Climate Impacts Group, University of Washington, Seattle.
4. Salathé, E.P., Leung, L.R., Qian, Y., and Zhang, Y., 2010. Regional climate model projections for the State of Washington. Climatic Change, dot:10.1007/s10584-010-9849-y.

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