A climate sensitivity estimate using an Earth System model with a fully dynamic 3D ocean

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1. Background and Introduction

- **Climate sensitivity (CS)**, **vertical ocean diffusivity** and **effects of anthropogenic sulfates** are key climate model parameters
- They are typically estimated by comparing ensembles of model runs to observations in a likelihood-based manner
- Parameters giving a good fit to observations receive high likelihood, those that do not receive low likelihood
- Typically simplified models are used
- We employ an Earth System model with a fully dynamic 3D ocean component

2. Earth System Model and its Emulator

- We use University of Victoria Earth System Climate Model version 2.8 **[UVic ESCM]** (Weaver et al., 2001) with forcing improvements described in Olson et al. (2012)
- K_{bg} varies vertical diffusion on the ocean. Range: 0.1-0.5 cm^2 s^{-1}.
- Climate sensitivity is varied by an additional longwave feedback parameter f^*. CS range: 1.1-11.2 °C.
- A_{sc} is a multiplicative factor for the anthropogenic sulfate albedoes. Range: 0-3 (unitless).
- We perform equilibration runs at year 1800 conditions, then run transient ensemble with 250 different parameter combinations for years 1800-2010
- **Gaussian Process Emulator** is used to approximate model output at arbitrary parameter combination

3. Observational Constraints

- Global average atmospheric/ocean surface temperature (T) from the HadCRUT3 dataset, years 1850-2006 (Brohan et al., 2006)
- Global total ocean heat content change in the 0-700 m layer (OHC700) for years 1950-2003 (Domingues et al., 2008)
- Global total ocean heat content change in the 0-3000 m (OHC3000) layer, for years 1953-1996 (Gouretski and Koltermann, 2007)

Selected References

Brohan, P., Kennedy, J. J., Harris, I., Tett, S. F. B., and Jones, P. D. (2006). J. Geophys. Res. [Atmos.], 111(D12).

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Gouretski, V., and Koltermann, K. P. (2007), Geophys. Res. Lett., 34(L01610).

Olson, R., Sriver, R., Goes, M., Urban, N. M., Matthews, H. D., Haran, M., and Keller, K. (2012). J. Geophys. Res. [Atmos.], 117(D04103).

Weaver, A. J., et al. (2001). Atmos. Ocean., 39(4):361-428.

4. Statistical Model and MCMC

- Each parameter combination receives a likelihood based on how well the corresponding run matches the observations
- The residuals between the model and observations for diagnostic i are modeled as an AR1 process with autocorrelation ρ_i and innovation standard deviation σ_i
- There is an additional bias term for temperature, b
- Physical (K_{bg}, CS, and A_{sc}) and statistical parameters (σ_i, ρ_i, and b) are estimated jointly using Markov Chain Monte Carlo (MCMC) method
- Posterior probability distribution functions (pdfs) are created

5. Priors

- **"UNIF"** experiment uses uniform priors over ranges used
- **"NONUNIF"** experiment uses non-uniform priors for K_{bg} and CS to incorporate evidence from earlier studies following Olson et al., 2012

6. Results

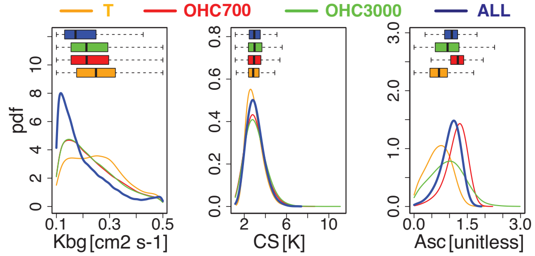

Figure 1: Posterior pdfs from the assimilation of different diagnostics. CS mode for 'ALL' is 2.8 °C.

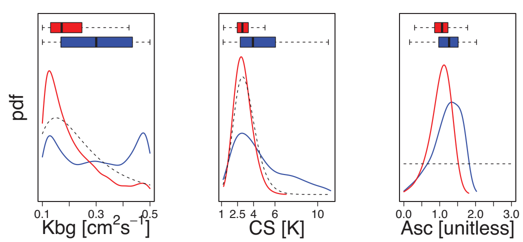

Figure 2: Sensitivity of posterior pdfs to priors. All three diagnostics were used as constraints. **Red: NONUNIF** experiment, **blue: UNIF** experiment, **dashed: prior** in the NONUNIF experiment

4. Results (cont'd)

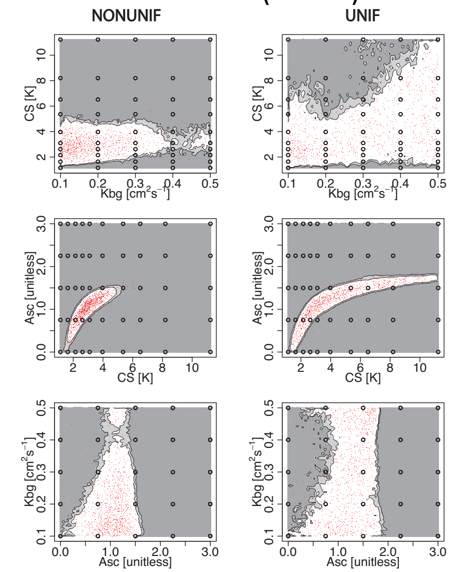

Figure 3: Bivariate joint pdfs for model parameters from the assimilation of all three diagnostics jointly.

7. Caveats

- We only consider a subset of uncertain climate parameters
- We only use a single Earth system model
- We do not include all past climate forcings

8. Conclusions

- CS estimates are broadly considered between the diagnostics
- CS correlated with K_{bg} and aerosol effects
- Using all diagnostics together marginal CS mode is 2.8 °C, while the 95% posterior credible interval is from 1.7 to 4.9 °C.

Acknowledgements

Support of this work was provided by USGS, Canadian Foundation for Climate and Atmospheric Sciences (CFCAS GR-7059), and NSF through the Center for Climate and Energy Decision Making. This Center has been created through a cooperative agreement between the National Science Foundation (SES-0949710) and Carnegie Mellon University. All errors and opinions are those of the authors.

Prioritizing the ***Engineering*** in Geoengineering

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Introduction

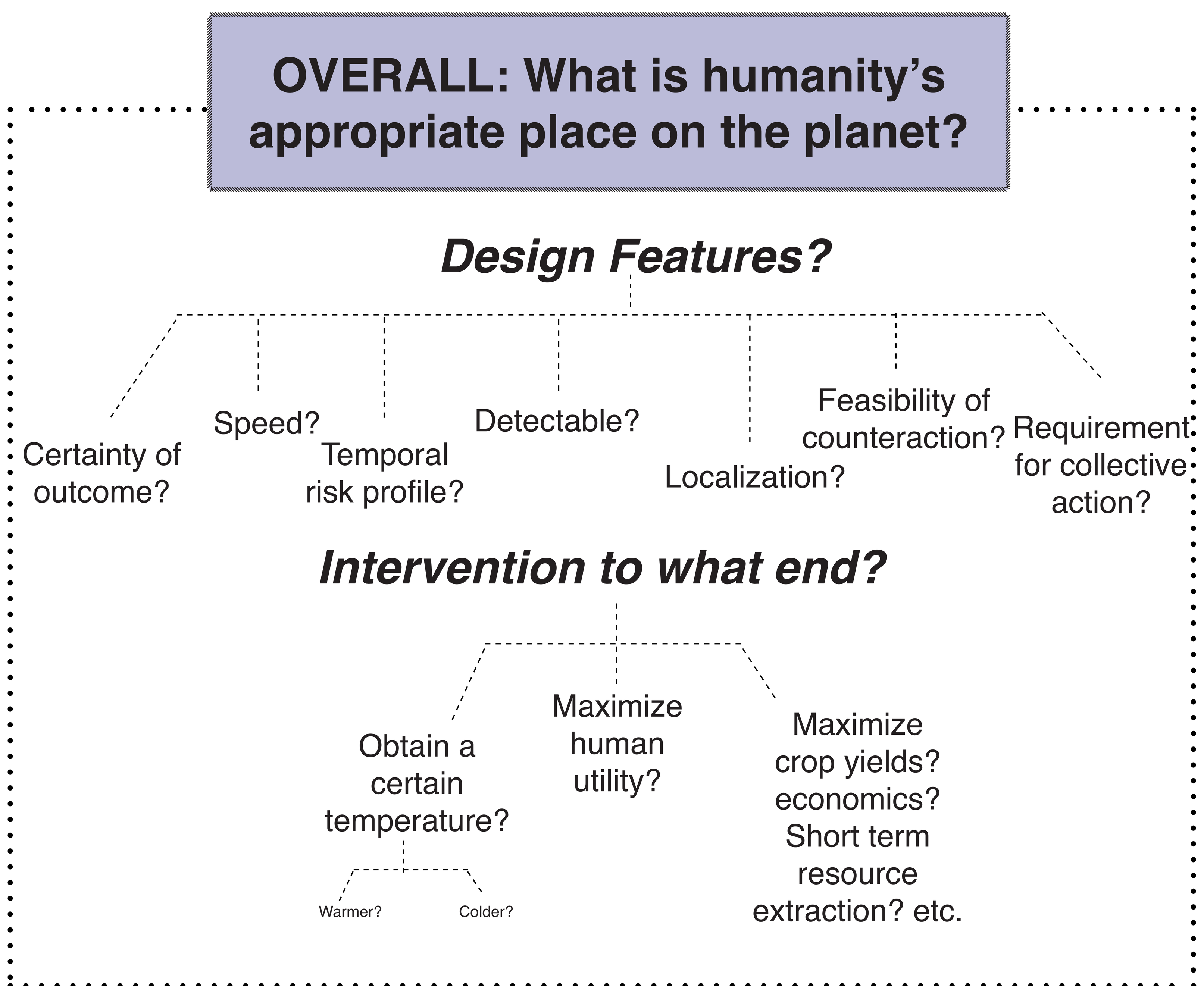
Research that is motivated by potential use, even in part, must address substantial normative components. Knowledge created through research from scientific description is different than normative design parameters defined by human-centric goals and purposes; a shift to the latter requires a shift to engineering norms and practices. A proposed research program in geoengineering considers potential use. As such, it bears similarity to engineering rather than scientific inquiry, despite current practitioners perceptions. Calls for public participation in this research program can be justified by the need to prioritize the normative components of research through consultation and engagement of clientele, a norm in engineering practice. Due to the scale and risk of geoengineering, this would include the general public.

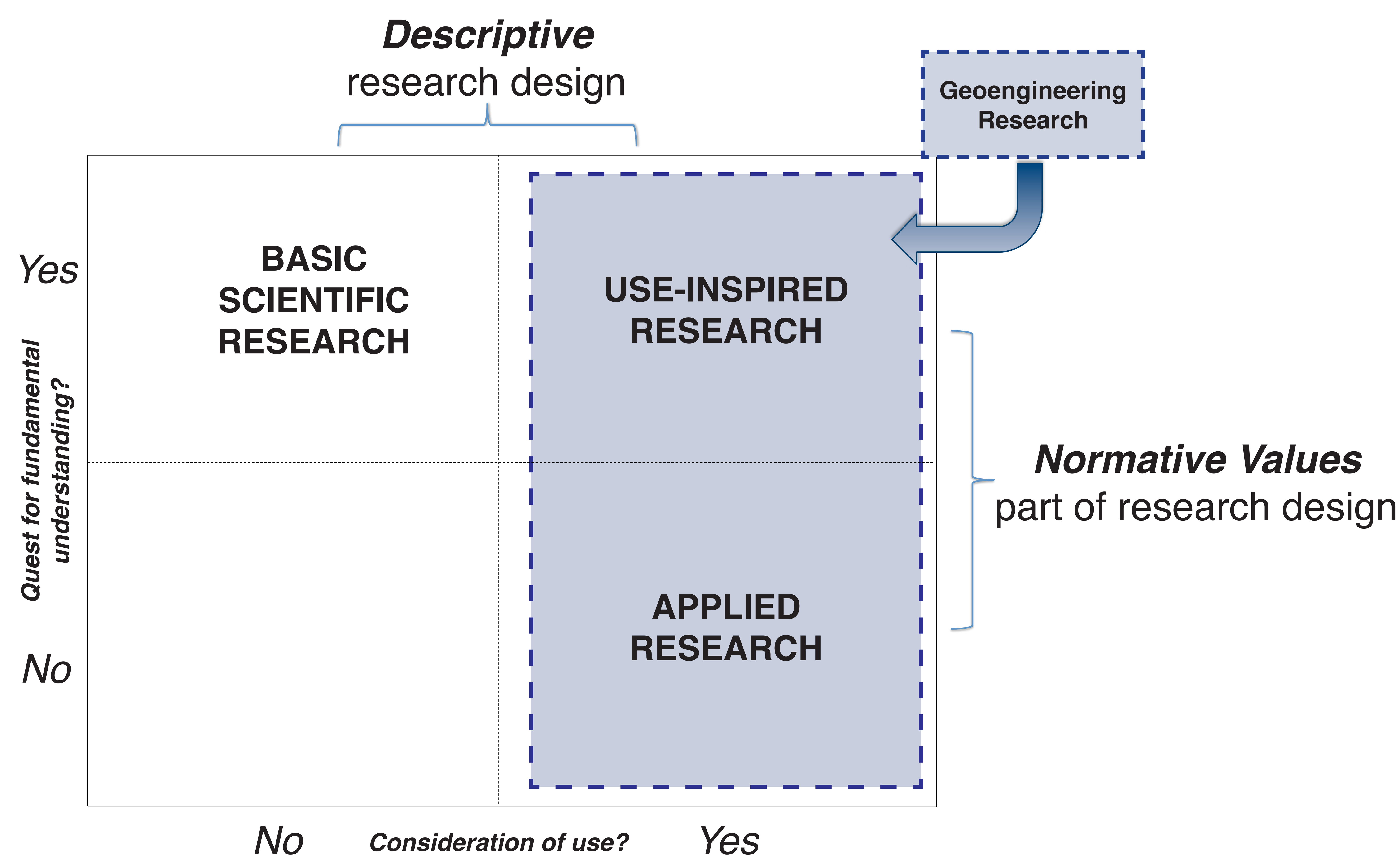
SRM research aims to both *understand* and *control* our climate.

Research Goal

Provide a justification for the mounting calls for open and transparent public participation in future geoengineering research.

Some Normative Questions in Geoengineering





Adapted from Stokes (1997)

Policy Implications

1. In traditional scientific pursuits, scientists have the ability to define the goals, scope and method of experimentation (using norms and background from their discipline). In use-inspired research, researchers also find themselves in the role of engineers defining the purpose of a technology.
2. Imposing certain values onto research, by assuming normative parameters, will alienate the user (ex. speed of intervention or locus of control).
3. A geoengineering research program must prioritize normative aspects, adhering to engineering norms.
4. There is a vast and diverse client list that should be considered and engaged when contemplating the design of geoengineering research. This client list is bound to change at different stages of a project and may be initially limited to very few specific leaders and extend as wide as individual citizens.

Reference

D. E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation.* Washington, D.C.: Brookings Institution Press, 1997.

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Research Support

University of Calgary, Interdisciplinary Graduate Program

Center for Climate and Energy Decision Making (SES-0949710)

Institute for Sustainable Energy, Environment and Economy

Coping with Uncertainty of River Flood Forecasts

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Department of Engineering & Public Policy

Background

The National Weather Service (NWS) issues river forecasts up to five days ahead. Their accuracy decreases with increasing lead time and increasing deviance from the average gage height. There are five problems.

1. **The quality of river forecasts is poor.** Flood warnings beyond two days of lead time have little skill.
2. **The forecasts have not improved between 1983 and 2002** [2].
3. **NOAA has made the first steps to verify forecasts in 2006** [1] **but with unknown effect.**
4. **It is unknown how local emergency operators use these forecasts.** Studies on the use and benefits of river forecasts have failed to quantify their correct usage [4]. Discussing the use of climate forecasts by water resource managers Rayner *et al.* detect wide-spread ignorance as to the use of those forecasts [5].
5. **Despite the large uncertainties in forecast, there have been no studies on how to communicate its significat to decision makers.**

The National Oceanic and Atmospheric Administration (NOAA) has introduced systematic verification of river forecasts and initiated probabilitistic ensemble forecasting [3].

Without an integration of engineering and social sciences, NOAA´s technical improvements will not increase safety.

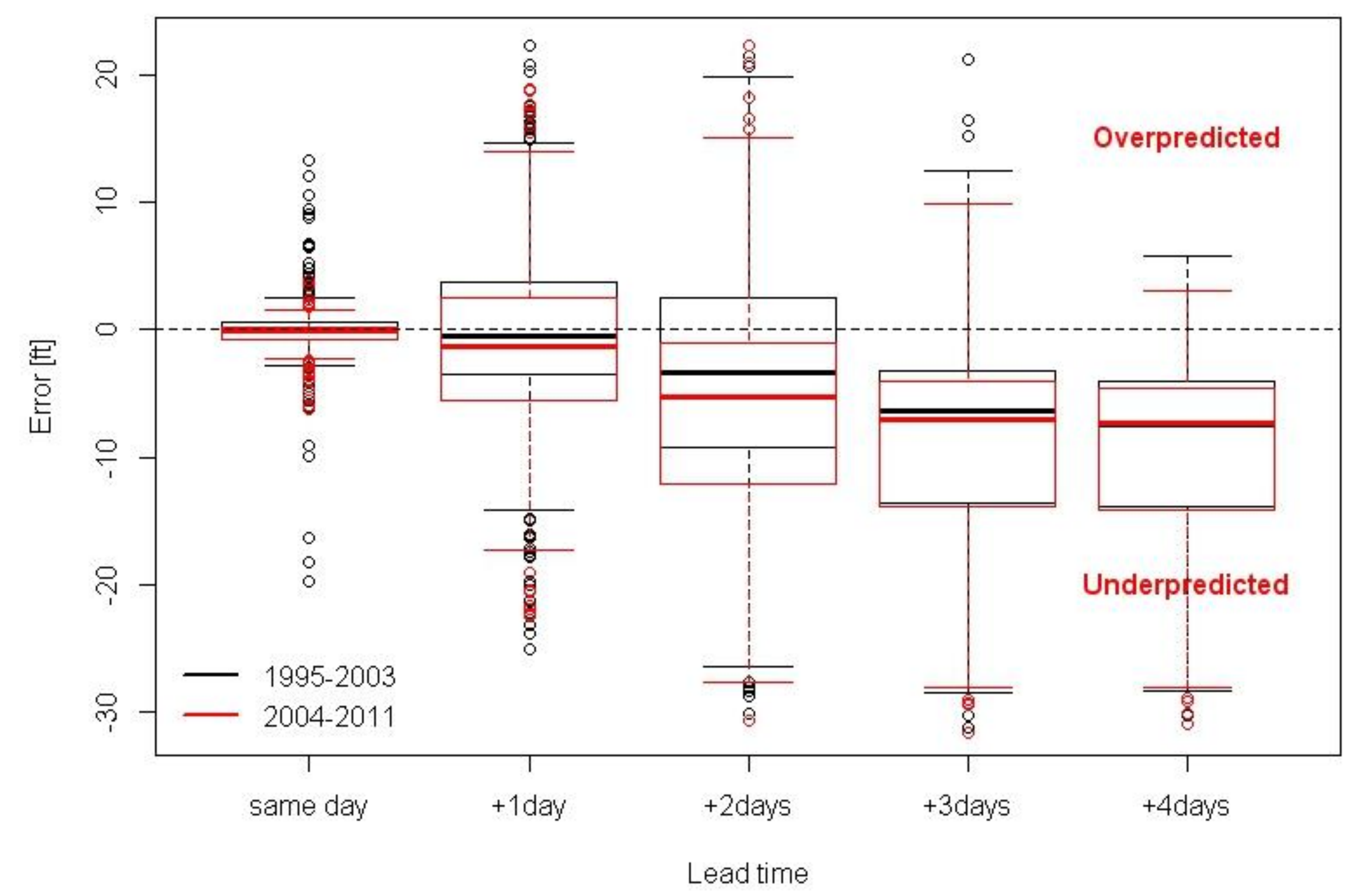

Figure 1: Comparison of error of river forecasts (forecast-observed) at Blackwell, OK on Chikaskia River for two time periods (1995-2003 and 2004-2011). Flood stage: 29ft., 90th percentile of observations: 7 ft. The difference between observation and forecasts increases with lead time. The error in the second time period is equal or worse than in the first. The variance decreased.

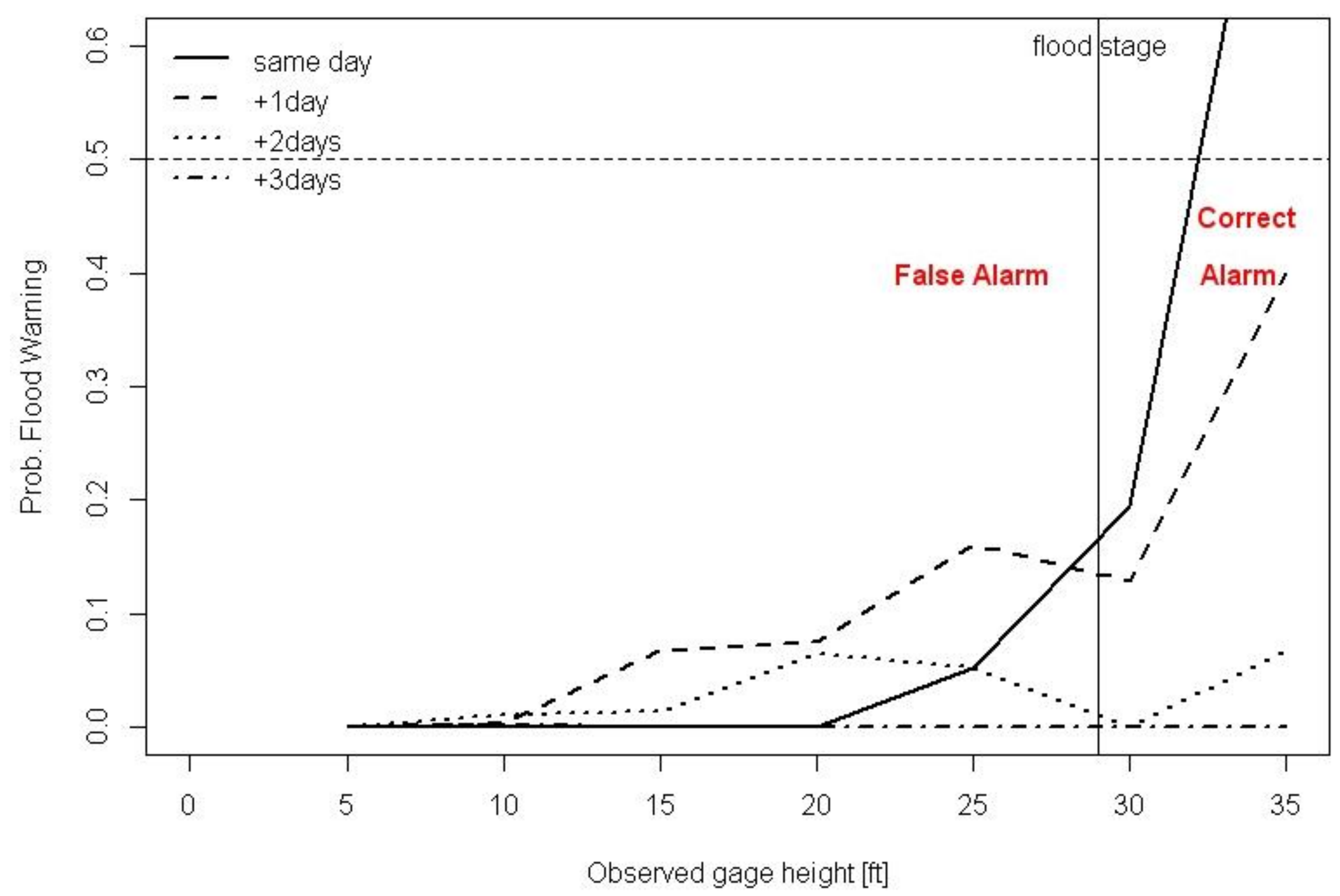

Figure 2: Probability that a flood warning was received depending on observed gage height for Blackwell, OK on the Chikaskia River 1995 –2011. It is unlikely that an emergency operator receives a flood warning. However, there are relatively many false alarms as well.

Objectives

- Update river forecast verification
- Quantify uncertainty in river forecasts
- Identify implications of uncertainty for emergency operators
- Assess emergency operators' handling of uncertainty
- Explore ways to communicate uncertainty
- Propose follow-up to NOAA's River Forecast Verification Plan

Preliminary Results

1. **Flood forecasts have not significantly improved between 1995-2011 (Figure 1).** It was previously found that forecasts did not improve from 1983-2002 [2].
2. **Flood forecasts underestimate the observed gage height (Figure 1).**
3. **The discriminability of flood forecasts is low.** Emergency operators are not warned for most floods. If they are warned, there is a considerable probability that no flood will occur (Figure 2).

Future Work

To make the efforts of verifiying flood forecasts and quantifying their uncertainty worth it, the following steps need to be taken.

1. **Examine the emergency operator's understanding of uncertainty.**
2. **Explore ways to ensure correct use of forecasts.**
3. **Quantify added value of improved forecasts.**

References

[1] National Oceanic and Atmospheric Administration (2006): *National Weather Service River Forecast Verification Plan,* Report of the Hydrologic Verification System Requirements Team. Silver Spring, MD

[2] Welles, E. *et al.* (2007): „Hydrologic Verification, A Call for Action and Collaboration", *American Meteorological Society*, April 2007, p. 503-511.

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[4] National Hydrologic warning Council (2002): *Use and Benefits of the National Weather Service River and Flood Forecasts,* Prepared by EASPE, Inc., May 2002.

[5] Rayner S. *et al.* (2005): „Weather Forecasts Are For Wimps: Why Water Resource Managers Do Not Use Climate Forecasts", *Climate Change* (2005) 69: 197-227.

Figure 3: Chikaskia River near Blackwell, OK. Flood Stage 29 feet; Left side: On 09/04/2002, stage 2.73 feet. Right side: On 10/05/2002, stage: 31.33 feet.

Acknowledgments

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Ocean acidification and its impacts: an expert survey

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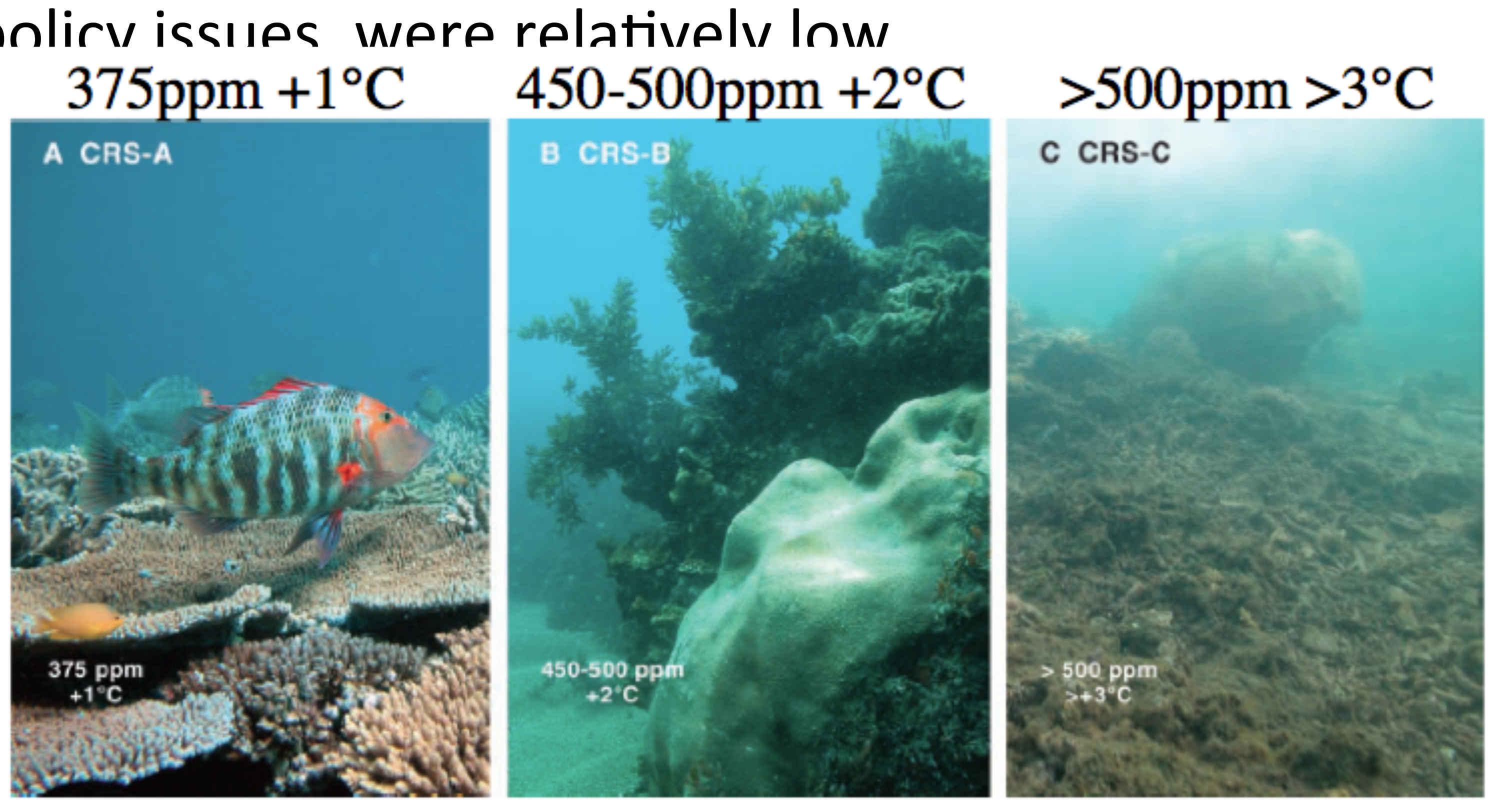
Abstract

The oceans moderate the rate and severity of climate change by absorbing massive amounts of anthropogenic CO_2. However, this absorption results in large-scale changes in seawater chemistry, which are collectively referred to as anthropogenic ocean acidification. Despite its potentially widespread consequences, the problem of ocean acidification has been largely absent from most policy discussions of CO_2 emissions, both because the science is relatively new and because the research community has yet to deliver a clear message to decision makers regarding the current state of knowledge. Here we report the results of the first expert survey in the field of ocean acidification. Fifty-three experts, who had previously participated in an IPCC workshop, were asked to assess 22 declarative statements about ocean acidification and its possible consequences. We find a relatively strong consensus on most issues related to past, present and future chemical aspects of ocean acidification, including the assertions that: non-anthropogenic ocean acidification events have occurred in the geological past; anthropogenic CO_2 emissions are the main (but not the only) mechanism generating the current ocean acidification event; and anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will be felt for centuries. Experts generally agreed that there will be impacts on biological and ecological processes and biogeochemical feedbacks, but for specific statements about the nature and extent of such impacts, levels of agreement were lower, with more variability across responses. Levels of agreement were higher for statements regarding calcification, primary production and nitrogen fixation than for those about impacts on foodwebs. The levels of agreement for statements pertaining to socio-economic impacts, such as impacts on food security, and to more normative policy issues, were relatively low.



Source: O. Hoegh-Guldberg et al., "Coral reefs under rapid climate change and ocean acidification," Science, 318, pp. 1737-1742, December 14, 2007.

Table 1: Summary of probabilistic judgments that statements 1-8 on chemical issues are true, sorted by self-reported level of knowledge. If respondents provided a range for a statement, the lower bound is used here. Full responses are reported in the Supplementary Information.

Statement / Assessed probability	Respondents reporting good or expert knowledge			Respondents reporting limited or no knowledge (or NR)		
	≥0.98	≥ 0.8 but <0.98	< 0.8	≥0.98	≥ 0.8 but <0.98	< 0.8
1. Anthropogenic ocean acidification is caused by CO_2 emissions to the atmosphere that end up in the ocean.	25	13	2	2	9	1
2. Non-anthropogenic ocean acidification events have occurred in the geological past.	13	4	1	9	15	8
3. Anthropogenic ocean acidification is currently in progress and is measurable.	27	9	1	0	12	4
4. The rate of CO_2 emissions is as important for determining ocean acidification impacts as is the total magnitude of emissions.	13	15	3	0	7	9
5. Over the next century, assuming business as usual CO_2 emission scenarios, anthropogenic ocean acidification will continue at a rate faster than non-anthropogenic acidification has ever occurred in the past 55 Myr.	6	9	5	3	9	17
6. Human activities beyond CO_2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions	16	8	6	3	10	10
7. The magnitude of future anthropogenic ocean acidification depends on CO_2 emission pathways.	18	8	2	2	4	13
8. Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries.	16	13	2	3	9	8

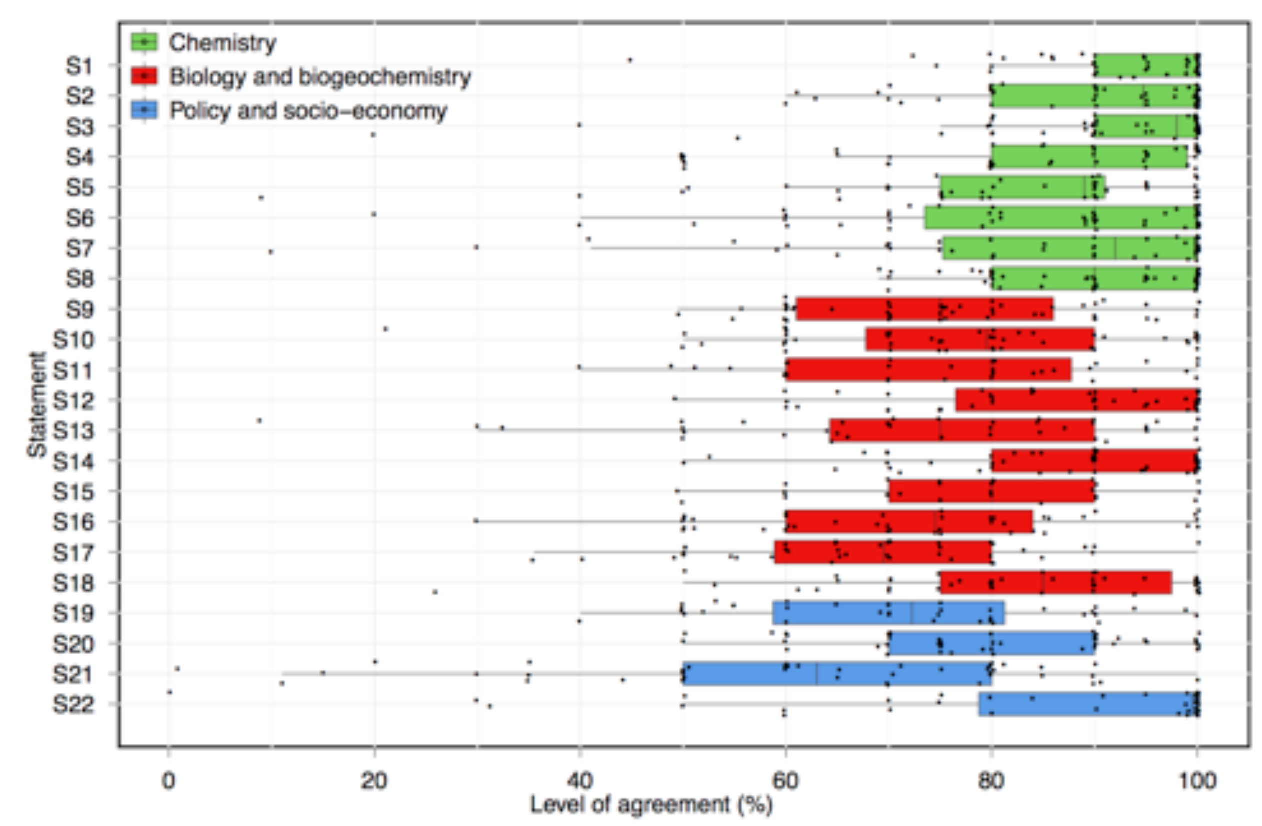
Table 3: Summary of probabilistic judgments that statements 19-22 on policy and socio-economic issues are true, sorted by self-reported level of knowledge. If respondents provided a range for a statement, the lower bound is used here. For statements 19 and 20, respondents were asked to consider ranges of pCO_2, pH, calcium carbonate saturation state, etc. projected for 2100 under business as usual CO_2 emissions. Full responses are reported in the Supplemental Information.

Statement / Assessed probability	Respondents reporting good or expert knowledge			Respondents reporting limited or no knowledge (or NR)		
	≥0.98	≥ 0.8 but <0.98	< 0.8	≥0.98	≥ 0.8 but <0.98	< 0.8
19. Anthropogenic ocean acidification will negatively impact food security	1	4	7	1	6	21
20. Anthropogenic ocean acidification will reduce the socio-economic value of some marine ecosystems	5	8	7	2	10	17
21. It is possible to define a threshold for ocean acidity, either globally or for some specific ecosystems or regions, that must not be exceeded	1	5	21	0	7	11
22. Some geoengineering approaches will not reduce anthropogenic ocean acidification	17	2	4	11	4	9

Table 2: Summary of probabilistic judgments that statements 9-18 on biological and biogeochemical issues are true, sorted by self-reported level of knowledge. If respondents provided a range for a statement, the lower bound is used here. For statements 9-14 and 16-18, respondents were asked to consider ranges of pCO_2, pH, calcium carbonate saturation state, etc. projected for 2100 under business as usual CO_2 emissions. Full responses are reported in the Supplemental Information.

Statement / Assessed probability	Respondents reporting good or expert knowledge			Respondents reporting limited or no knowledge (or NR)		
	≥0.98	≥ 0.8 but <0.98	< 0.8	≥0.98	≥ 0.8 but <0.98	< 0.8
9. Anthropogenic ocean acidification will adversely affect calcification for most calcifying organisms	3	11	21	0	4	11
10. Anthropogenic ocean acidification will stimulate primary production in some primary producers	7	6	9	1	6	19
11. Anthropogenic ocean acidification will stimulate nitrogen fixation in some nitrogen fixers	3	2	4	1	8	16
12. Some species or strains are tolerant when tested today at levels of anthropogenic ocean acidification projected for 2100	12	9	8	4	6	10
13. Some species or strains will be tolerant by 2100 because they have acclimated or adapted to anthropogenic ocean acidification	2	6	15	1	6	12
14. Anthropogenic ocean acidification will impact ecosystems, some of them negatively (e.g. coral reefs)	13	14	8	5	7	6
15. Recovery (e.g. of coral reefs) from past ocean acidification events has taken as long as 1 to 10 million years	1	5	2	2	6	16
16. Anthropogenic ocean acidification will reduce biodiversity	4	5	14	1	3	18
17. Anthropogenic ocean acidification will negatively impact higher trophic levels by altering food web structure	1	4	14	0	5	20
18. Anthropogenic ocean acidification will impact biogeochemical processes at the global scale	10	13	6	2	6	11

Figure 1: Box plot summary of the single estimates and mid-range values from respondents who have some level of expertise. The lower and upper ends of the boxes represent the 25% and 75% quantiles; the median (50% quantile) is shown as a vertical line inside each box; the lower and upper whiskers respectively represent the 25% quantile - (1.5 x interquartile range) and the 75% quantile + (1.5 x interquartile range). Values smaller than the lower whisker are outliers but are nevertheless taken into account to calculate median and quantiles.



Acknowledgement

We thank the respondents for their participation in the study (for full list see the supplementary information). Mandy B. Holbrook assisted with the web design of the survey, Avani Kaushik helped with data formatting, and Tatiana Donnay helped producing Figure 1. Discussions with Michael Mastrandrea were instrumental in designing the survey. This work is a contribution to the "European Project on Ocean Acidification" (EPOCA) which received funding from the European Community's Seventh Framework Program under grant agreement n° 211384 and to the MedSeA project. Preparation of the online survey and analysis of the results at Carnegie Mellon were supported by the center for Climate and Energy Decision Making (through a cooperative agreement between the National Science Foundation and Carnegie Mellon University (SES-0949710)).

Hurricane Modification and Adaptation in Miami-Dade County, Florida

Kelly Klima[1], Ning Lin[2], Kerry Emanuel[3], M. Granger Morgan[4], and Iris Grossmann[4]

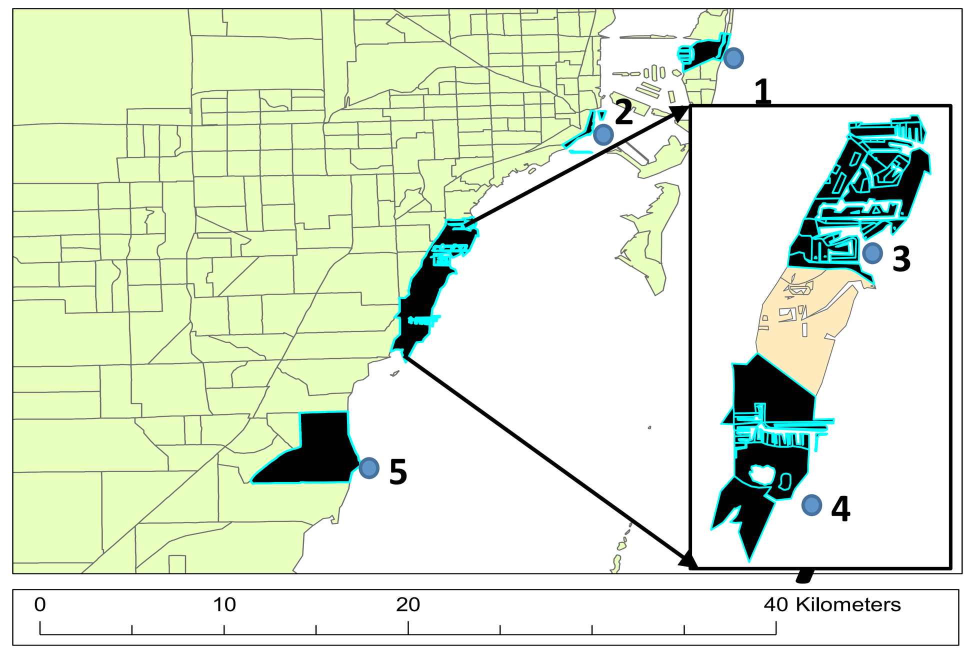
The problem: Annual losses from tropical cyclones (TCs) in the United States are estimated to average about $10-billion/year *(1)*. Damages can be caused by wind, storm surge, and floods. Some U.S. coastal areas experience high TC wind speeds and contain geophysical features vulnerable to storm surges and flooding. Since the Miami-Dade County coastline contains a range of topography, bathymetry, and infrastructure with different susceptibilities to TCs, optimal policy choices regarding methods to reduce TC damages depend strongly on locale. Various adaptation techniques, including "hardening", are available to reduce damages from TCs*(2-3)*. Strategies to reduce the intensity of a TC, while still hypothetical, offer a very different approach to reducing damages *(4)*.

The research: We investigate tropical cyclone wind and storm surge damage reduction for five areas along the Miami-Dade County coastline either by hardening buildings or by the hypothetical application of wind-wave pumps to modify storms. We calculate surge height and wind speed as functions of return period and sea surface temperature reduction by wind-wave pumps. We then estimate costs and economic losses with the FEMA HAZUS-MH MR3 damage model *(5)* and census data on property at risk. Surge damages are best reduced through a surge barrier. Wind damages are best reduced by a portfolio of techniques that, assuming they work and are correctly deployed, include wind-wave pumps.

References:

1. Pielke, R. A. Jr.; Gratz, J.; Landsea, C. W.; Collins, D.; Saunders, M. A.; Musulin, R. Normalized hurricane damage in the United States:1900–2005. *Nat. Hazards Rev*. 2007, 9, 29–42.
2. FEMA 247. Against the Wind: Protecting Your Home from Hurricane and Wind Damage, December 1993.
3. FEMA P-805. Protecting Your House From Flood Damage: Mitigation Ideas For Reducing Flood Loss, October 2010.
4. National Oceanic and Atmospheric Administration. HURRMIT:The Identification and Testing of Hurricane Mitigation Hypotheses. http://www.ofcm.noaa.gov/ihc09/Presentations/Session10/s10-01Woodley.ppt (accessed December 14, 2009).
5. Multi-hazard Loss Estimation Methodology Hurricane Model, HAZUS-MH MR3 Technical Manual; Department of Homeland Security, Federal Emergency Management Agency, Hardening Division: Washington, DC, 2009.

1 Five landfall locations along the Miami-Dade county coastline were chosen for varying topography, bathymetry, and population



2 Florida Division of Emergency Management suggested a variety of hardening techniques

Shutters

Dikes

Improved roof-wall and roof-deck connections

Raising Buildings

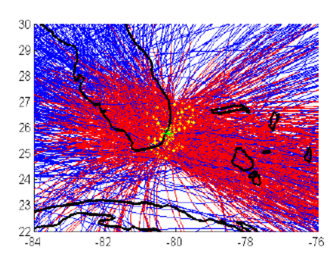
Courtesy of 123RF, FEMA, Hurricane Proof, Matthews House Movers

3 We specified climatological variables in scientific models to calculate return periods of wind and storm surge

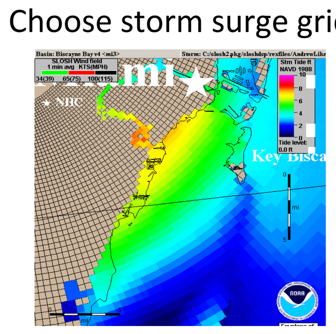
Climate variables

Modification

Downscaling Model (MIT): Create event sets



SLOSH (NHC): Choose storm surge grids



Return periods of wind in area of interest

Return periods of storm surge in area of interest

4 We used HAZUS MH-MR3 to calculate total aggregate damages from combinations of damage reduction techniques

Return periods of wind or storm surge in area of interest

Empirical damages as a function of building type

Census data (population, building type)

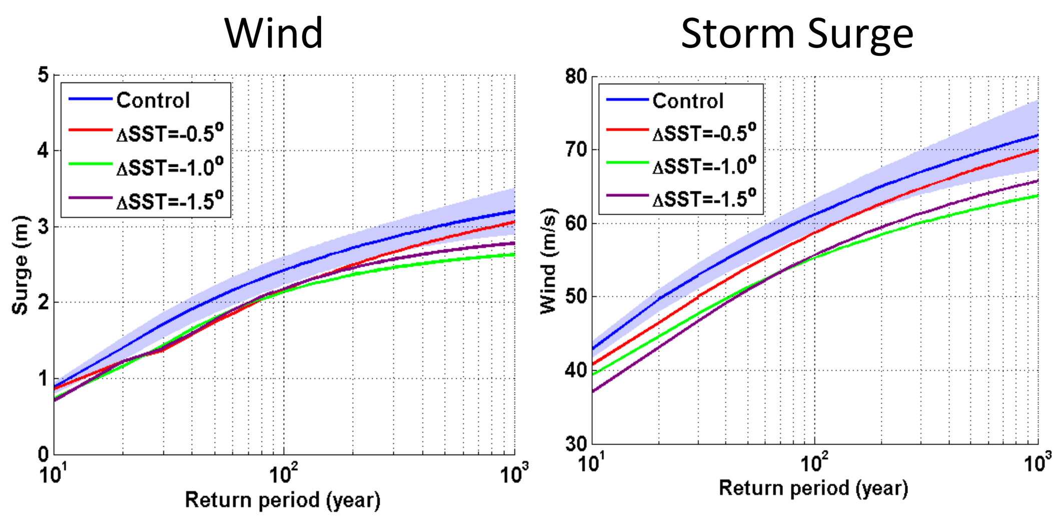
Hurricane or Flood Model (HAZUS) Create wind or storm surge distribution by census block

Damage Model (HAZUS) calculates damage per building as a function of wind or storm surge only (no floods)

Damage Model (HAZUS) aggregates damages

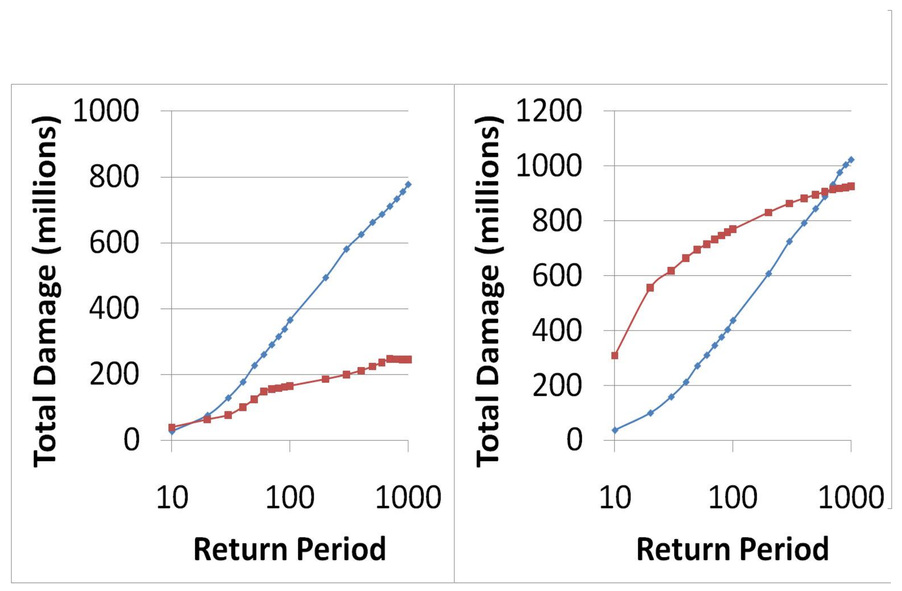
Damage Value in Area of Interest

5 Wind and storm surge return period curves, or exceedance probability curves, were calculated for each region



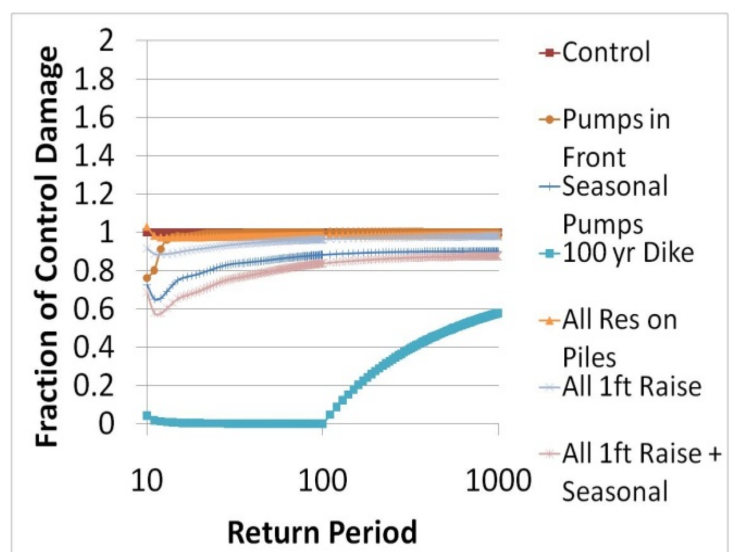
Region 2 shown, Regions 3-5 are similar
Region 1 has lower storm surge values

6 Regions experience more surge damages for short return periods, and more wind damages for long periods



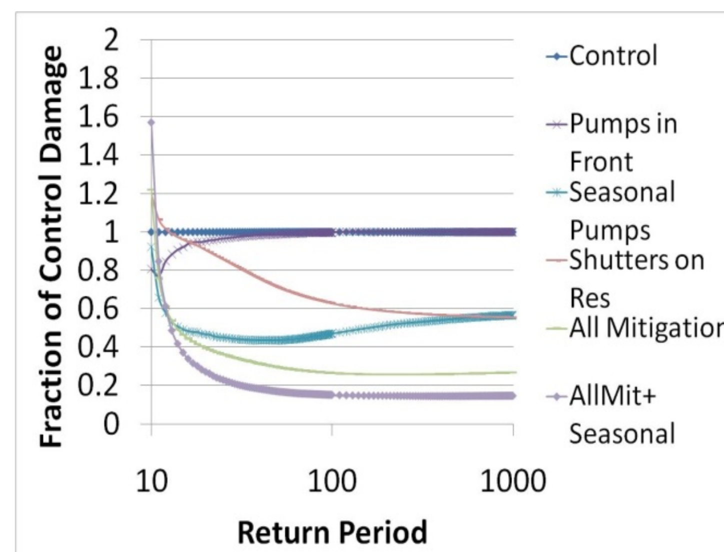
Region 1 Region 2
= Wind, = Storm Surge

7 Storm surge net costs are best reduced through a surge barrier (e.g., dike, dam, retaining wall)



Region 2 shown, Regions 3-5 are similar
Region 1 has lower seasonal expected fraction of control damage

8 Wind net costs are best reduced by a portfolio of techniques including tropical cyclone modification



Region 2 shown, other Regions are similar

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