Preliminary Uncertainty Analysis of Selected Hydrodynamic and Ecological Models in the Louisiana Coastal Area Ecosystem Restoration Plan

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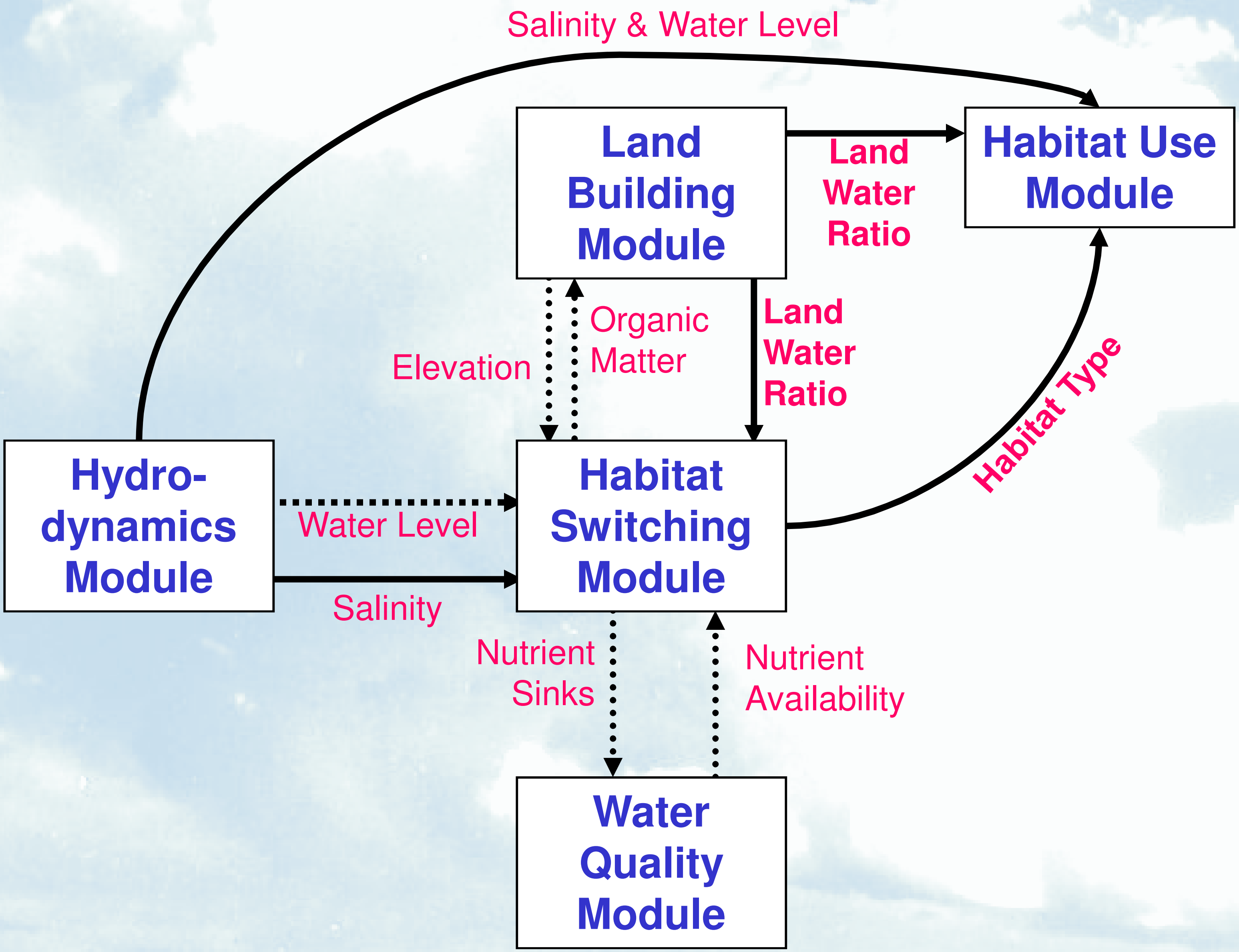
Background

- Louisiana is experiencing nationally critical coastal wetland erosion and land loss
- Key causes are reduction in freshwater and sediment inputs
- Louisiana Coastal Area (LCA) study was developed to establish framework for solving Louisiana coastal problems.
- The Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) effort was initiated to develop a modeling tool for evaluation of restoration alternatives and their environmental benefits.
- CLEAR model combines a set of linked modules as an ecosystem forecasting tool for geophysical processes, geomorphic features, and ecological succession.

Linkage of CLEAR Modules

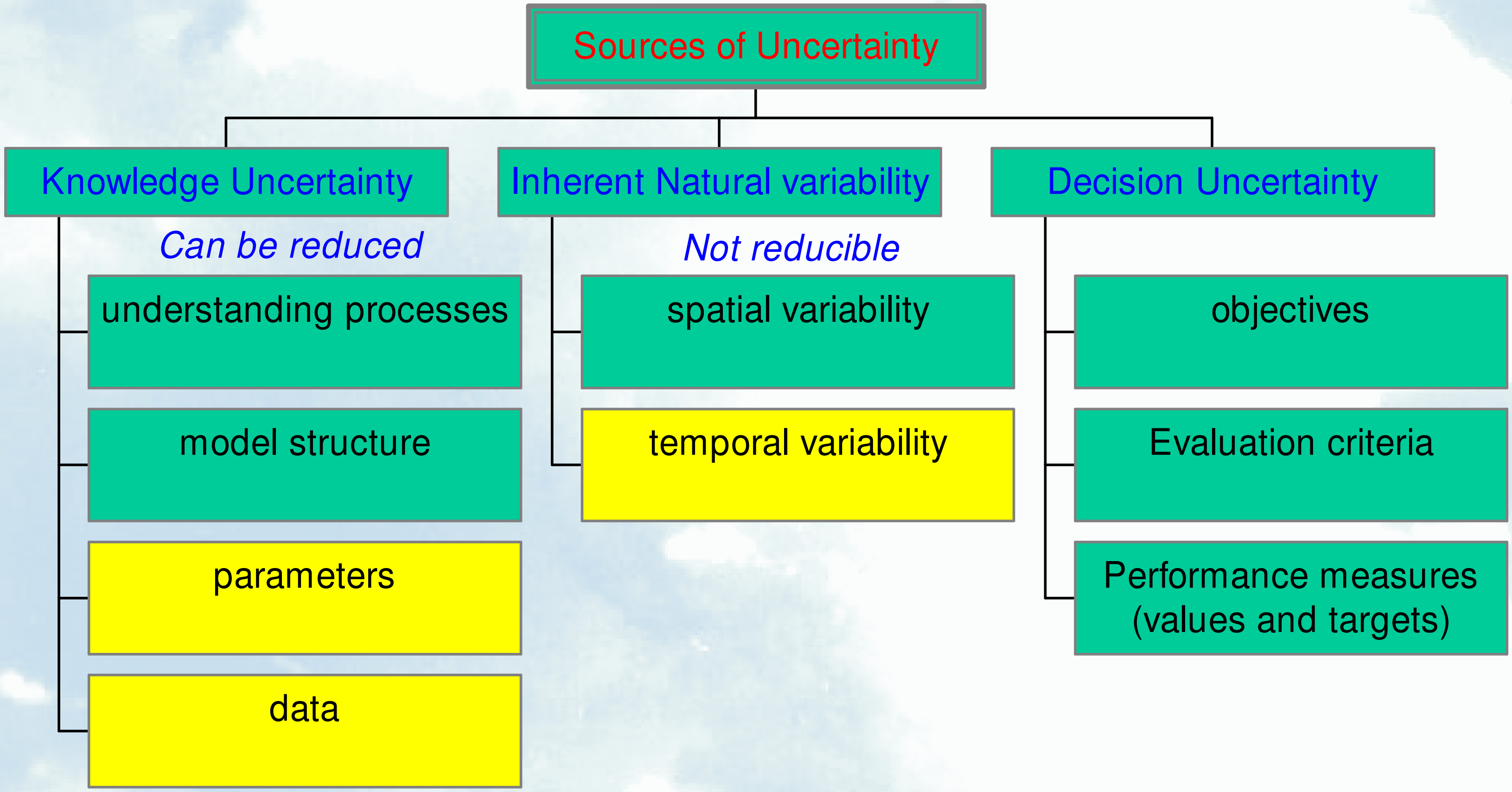


Models are not perfect

For the purpose of the CLEAR modeling effort, model uncertainty can be defined as:

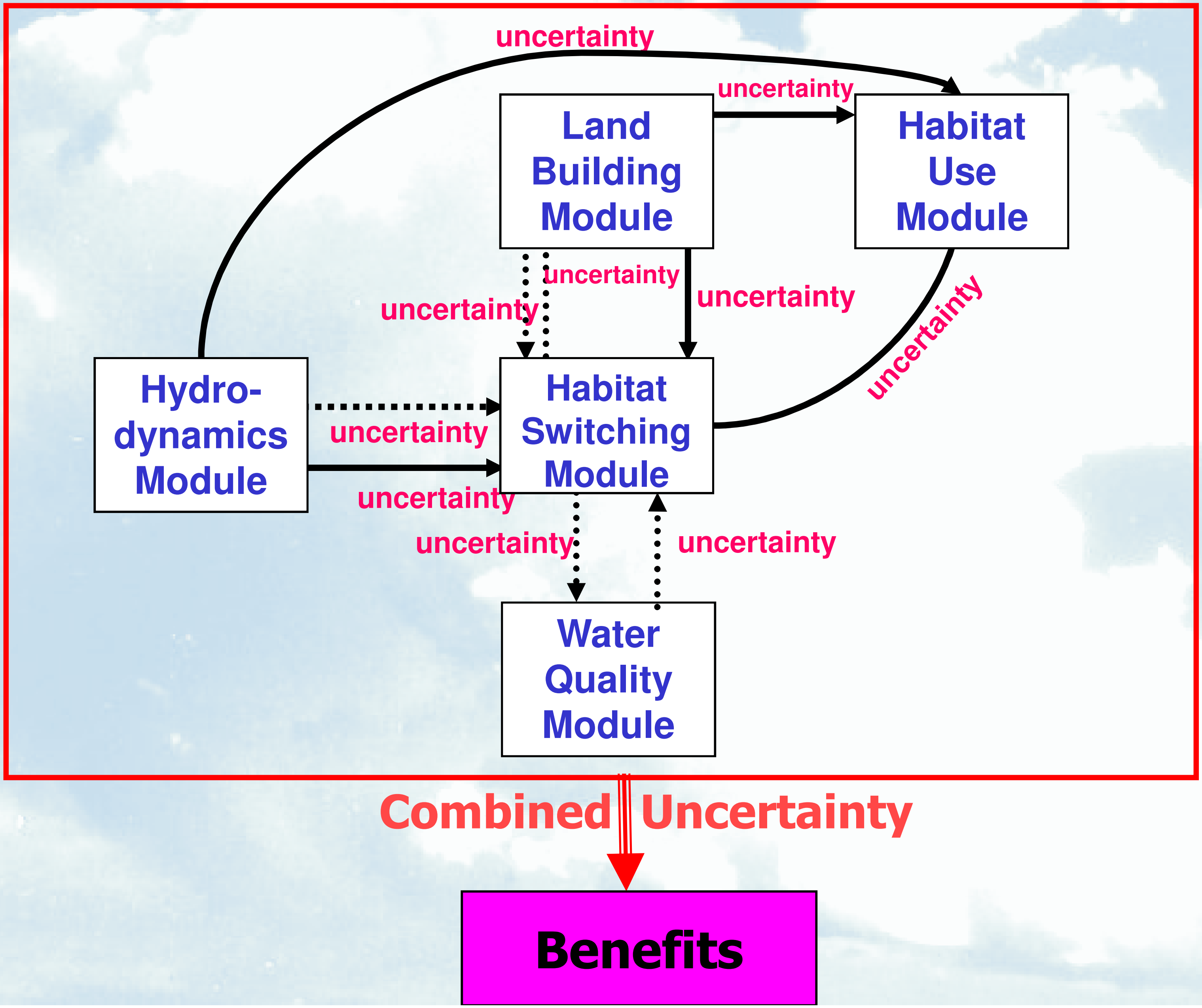
The unpredictable deviation of model predictions from the actual response of the ecosystem

Sources of Uncertainty



Sources:
Baecher et al., 2000
Loucks et al., 2002
LCA draft report, Chapter 13

Propagation of Uncertainties



Why quantify uncertainty?

- ❖ Users might wrongly attribute too much accuracy to model predictions and infer unrealistic differences between restoration scenarios when no differences actually exist!

- ✓ Information about uncertainties of model predictions is essential to guide the selection among alternative restoration projects.

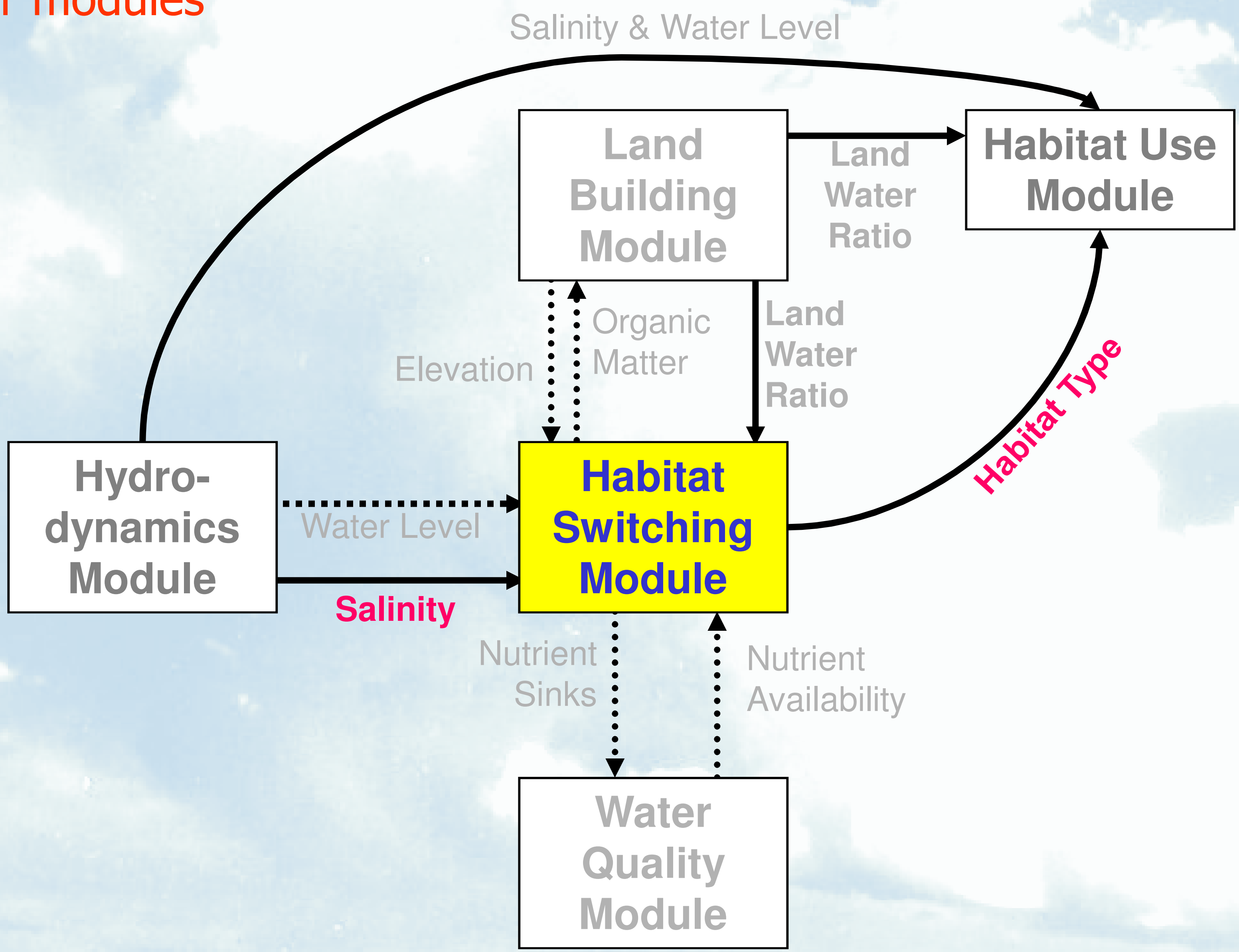
- ❖ Users might digest all sources of uncertainties and wrongly conclude that model predictions are useless!

- ✓ Quantifying uncertainties associated with model predictions is critical to ensure that predictions are properly interpreted.

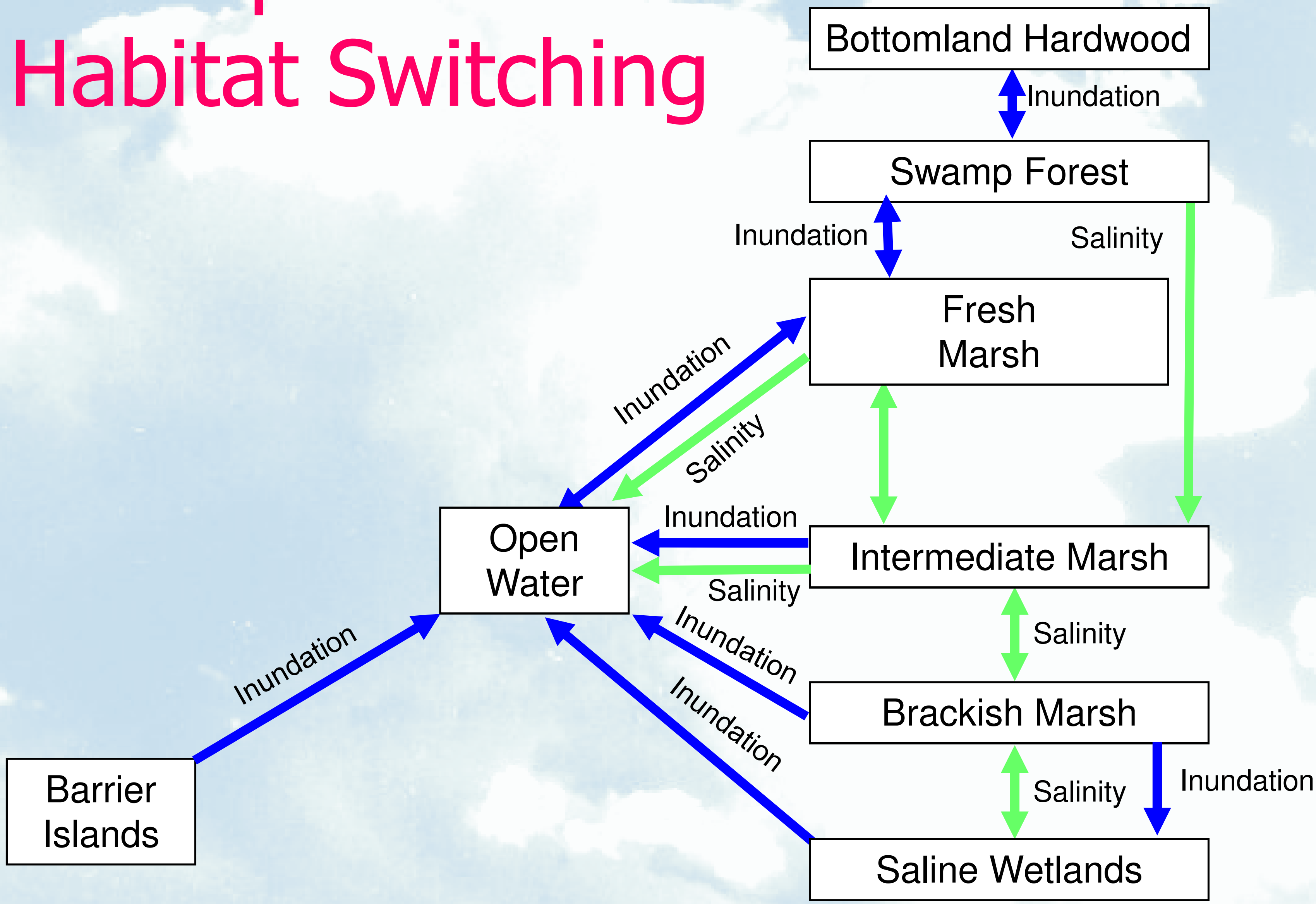
A complete model uncertainty analysis involves:

- Identification of all sources of uncertainty that contribute to probability distributions of each input or output variable
- Specification of marginal and joint probability distributions of input variables and parameters
- Propagating these uncertainties through the different modules
- Constructing probability distributions of model outputs and their performance measures

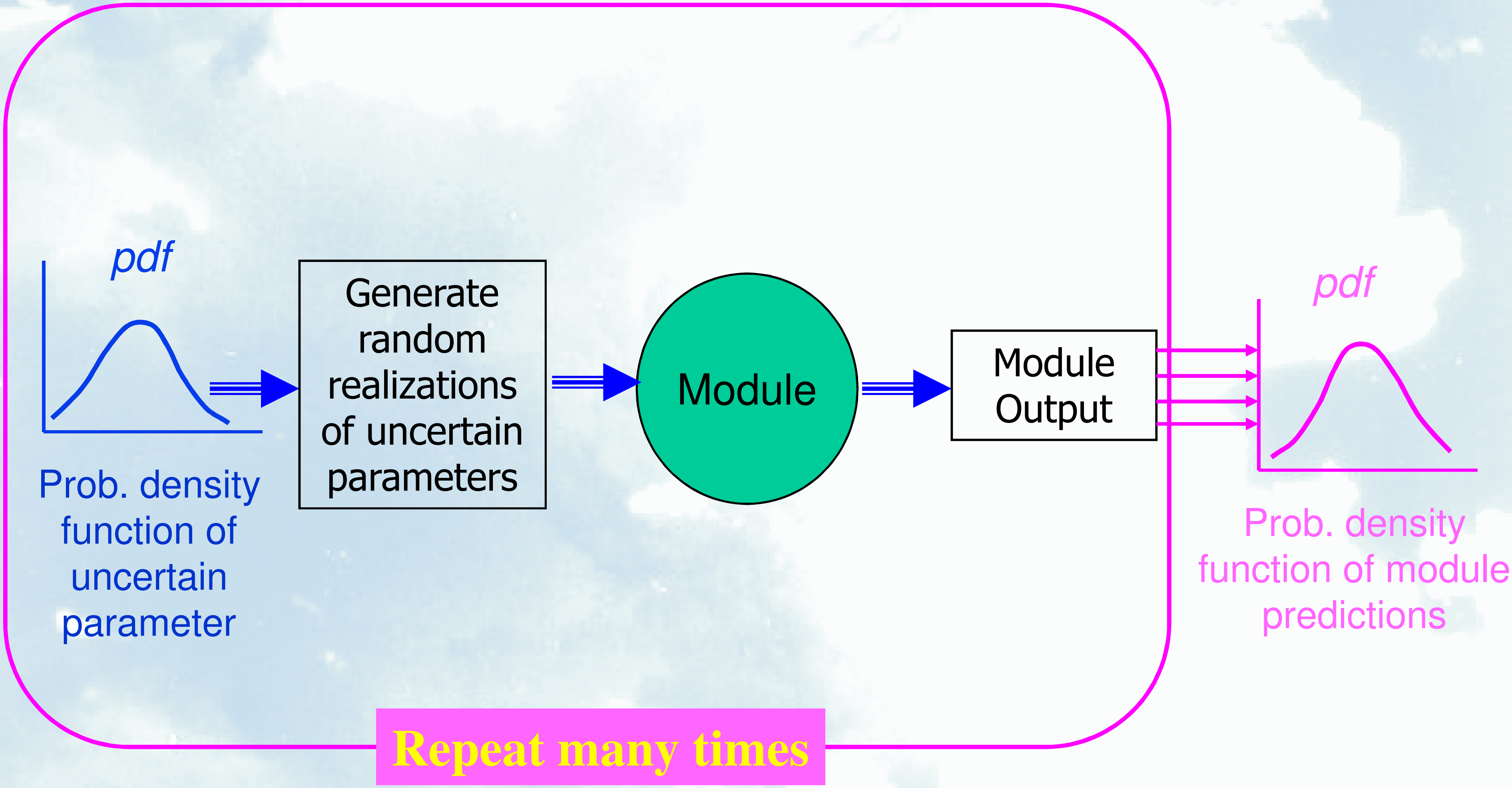
Instead, we will focus on one module and its interactions with other modules



Conceptual Model Habitat Switching



Tools: Monte Carlo Simulations



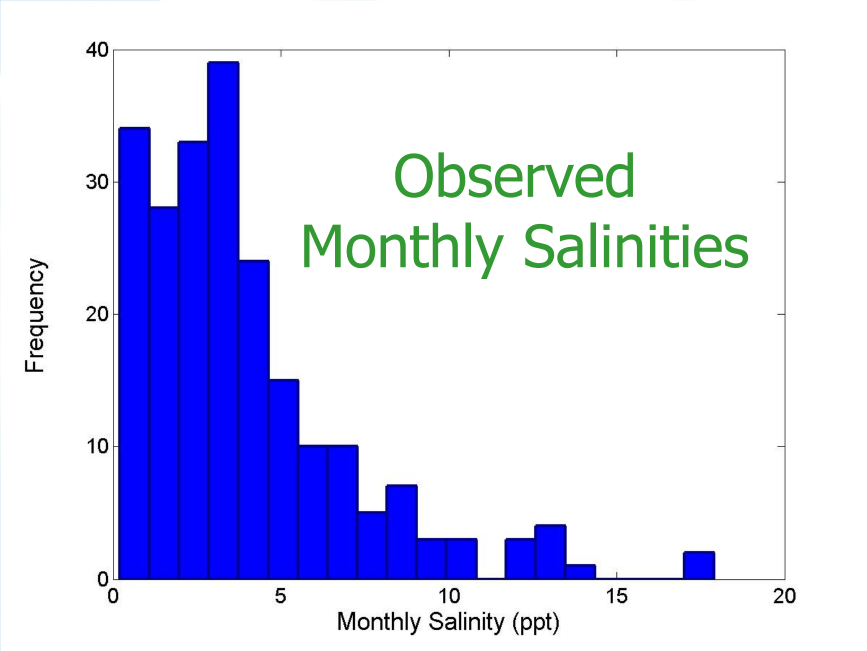
Selected Uncertainty Analysis Examples

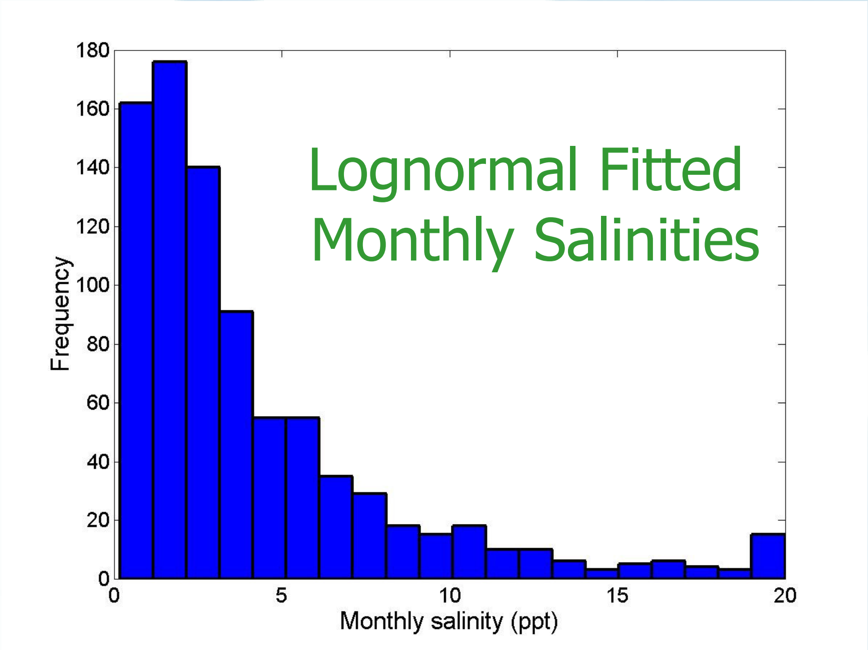
Objective:

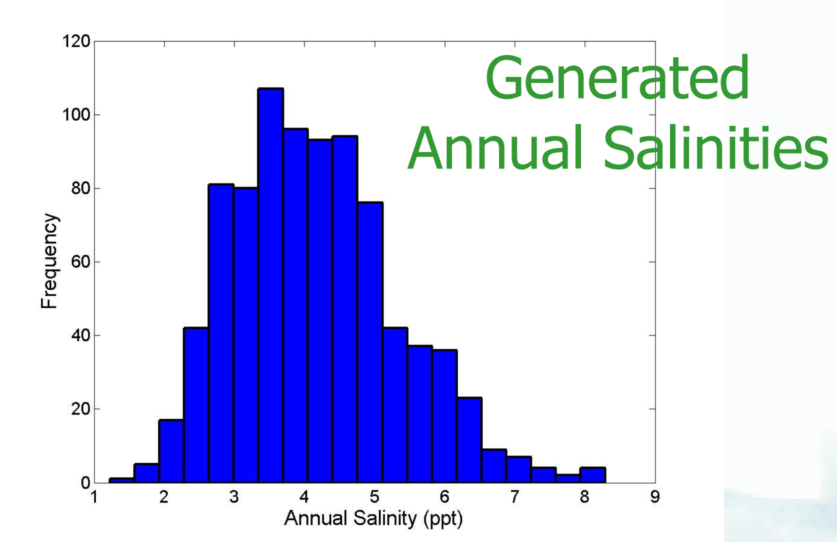
Investigate the Effect of the following Uncertainties on the Predictions of the Habitat Switching Module:

1. Effect of Hydro-climatic Variability
   - Dry versus wet years
   - Global climate change
2. Effect of Natural Variability
   - Annual Salinity
3. Effect of Parameter Uncertainty
   - Salinity switching thresholds
4. Effect of Data Uncertainty
   - Salinity input data as predicted by the Hydrodynamic (HD) modules

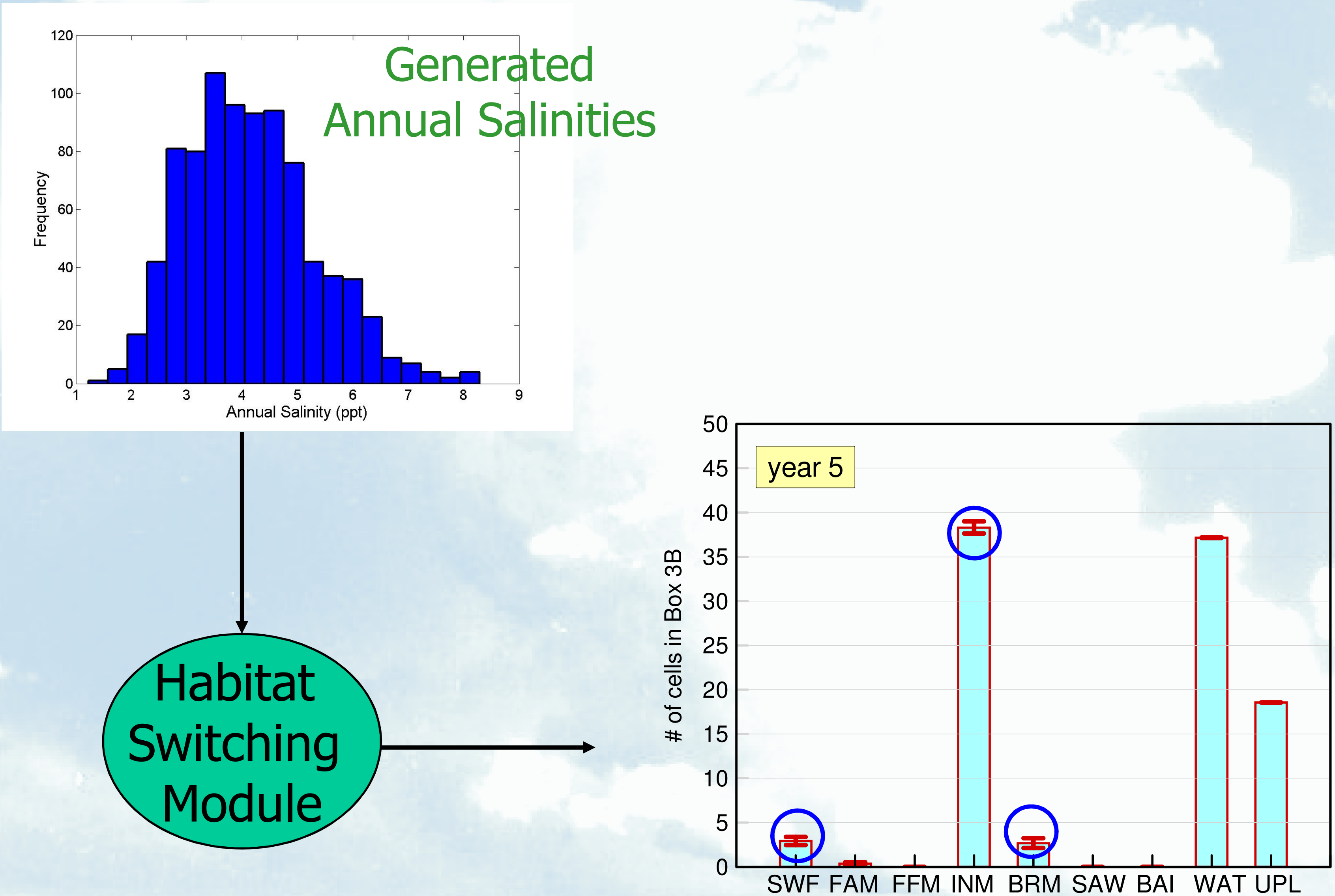
Effect of Natural Variability of Salinity







Effect of Temporal Natural Variability of Salinity



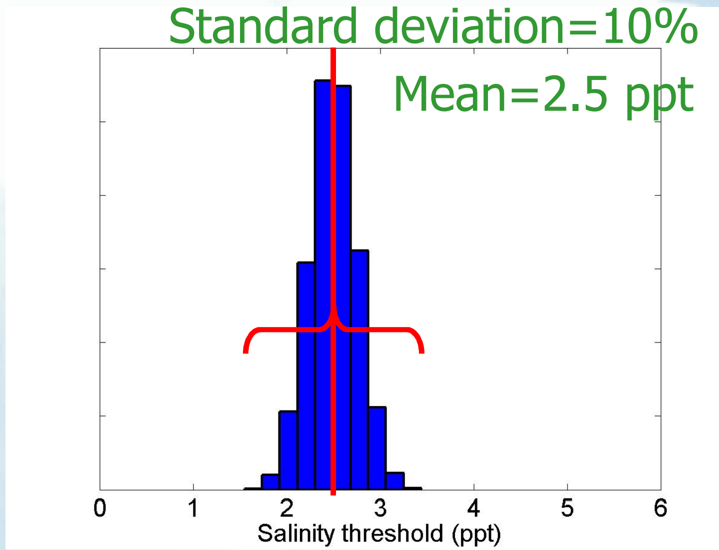
Effect of Uncertainty in Model Parameter:
switcher thresholds of habitat switching module

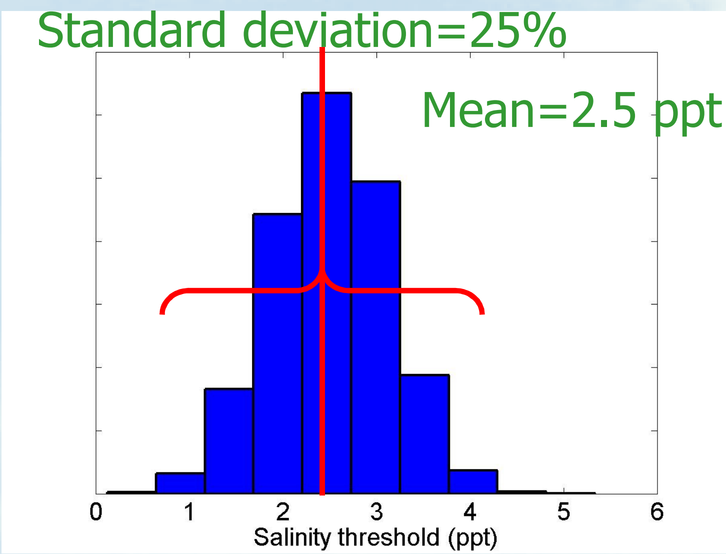
Based on average annual salinities of each habitat:

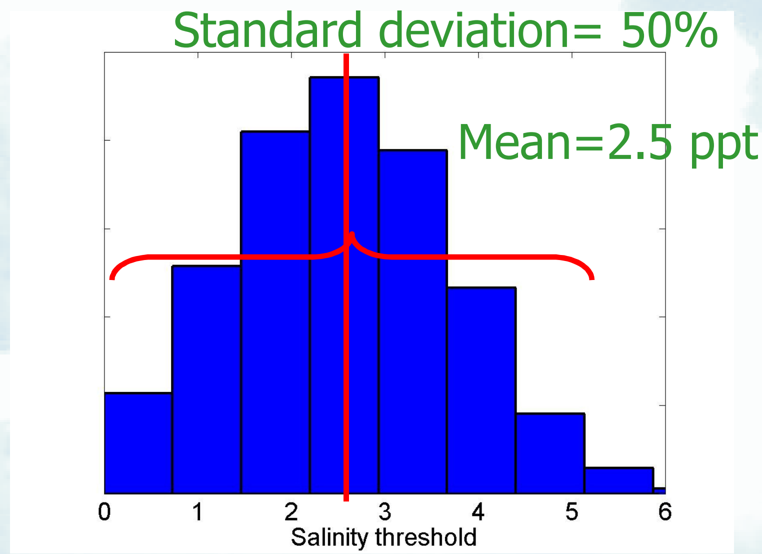
	Time 1 habitat						
Time 0 habitat	**UPL**	**SWF**	**FAM**	**INM**	**BRM**	**SAW**	**WAT**
UPL	always						
SWF		always					
FAM			<2.5	2.5-9			>9
INM			<1	1-6	6-15		>15
BRM				<6	6-15	>15	
SAW					=15	>15	
WAT							

UPL: Upland
SWF: Swamp forest
FAM: Fresh marsh
INM: Intermediate marsh
BRM: Brackish marsh
SAW: Saline wetland
WAT: Water

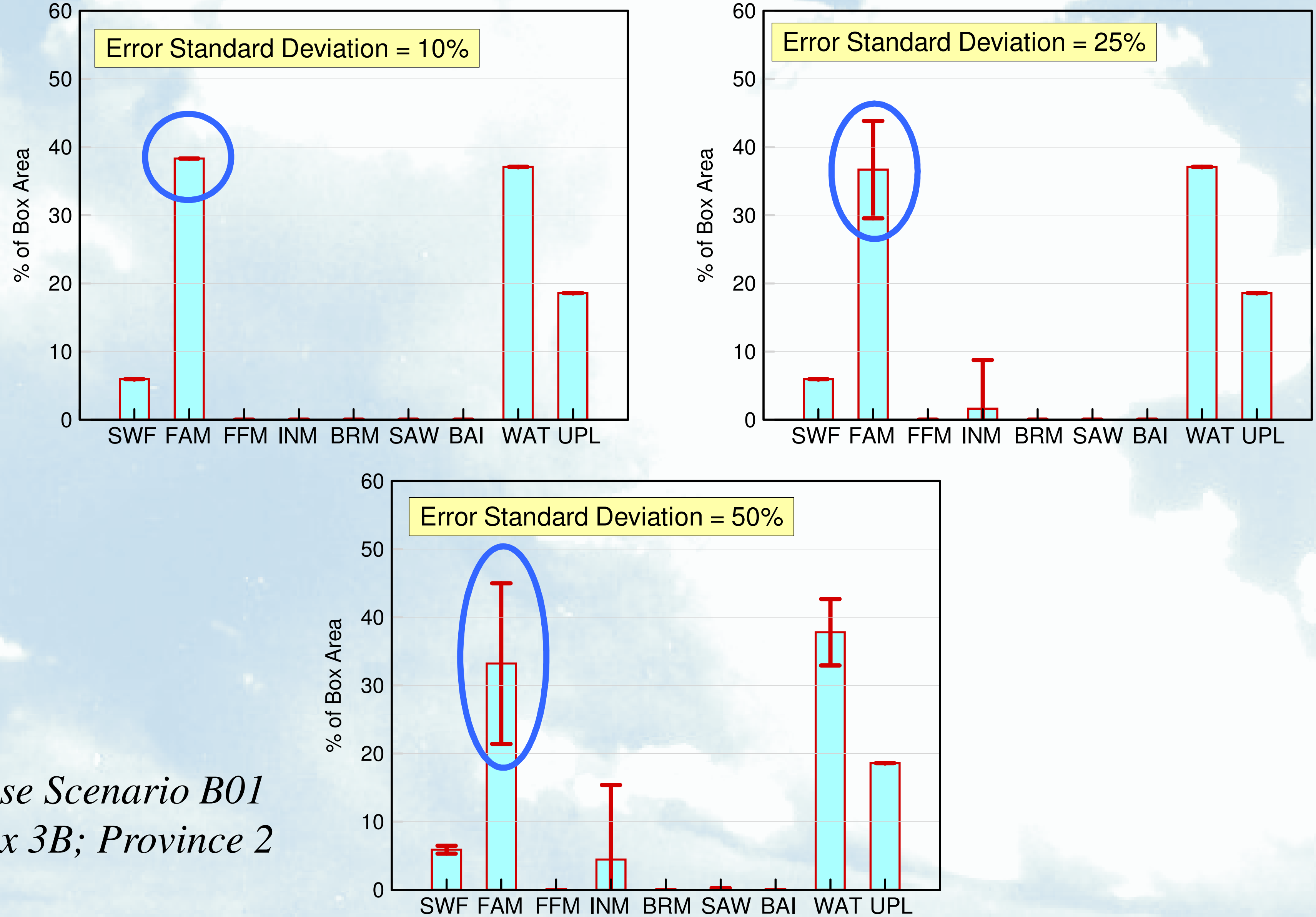
Pdf of salinity switching threshold







Effect of Uncertainty in Salinity Switching Thresholds

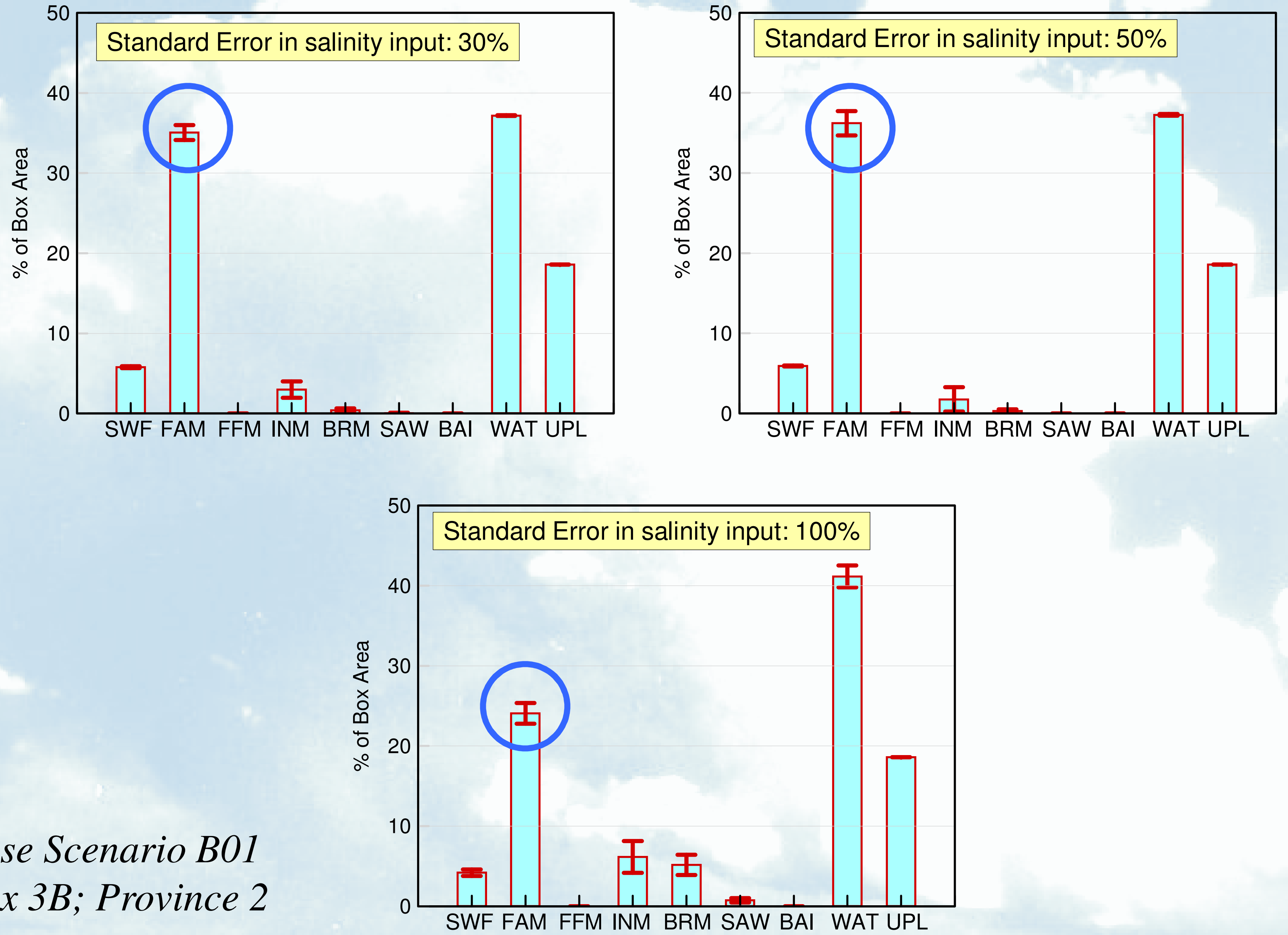


Base Scenario B01
Box 3B; Province 2

Data Uncertainty

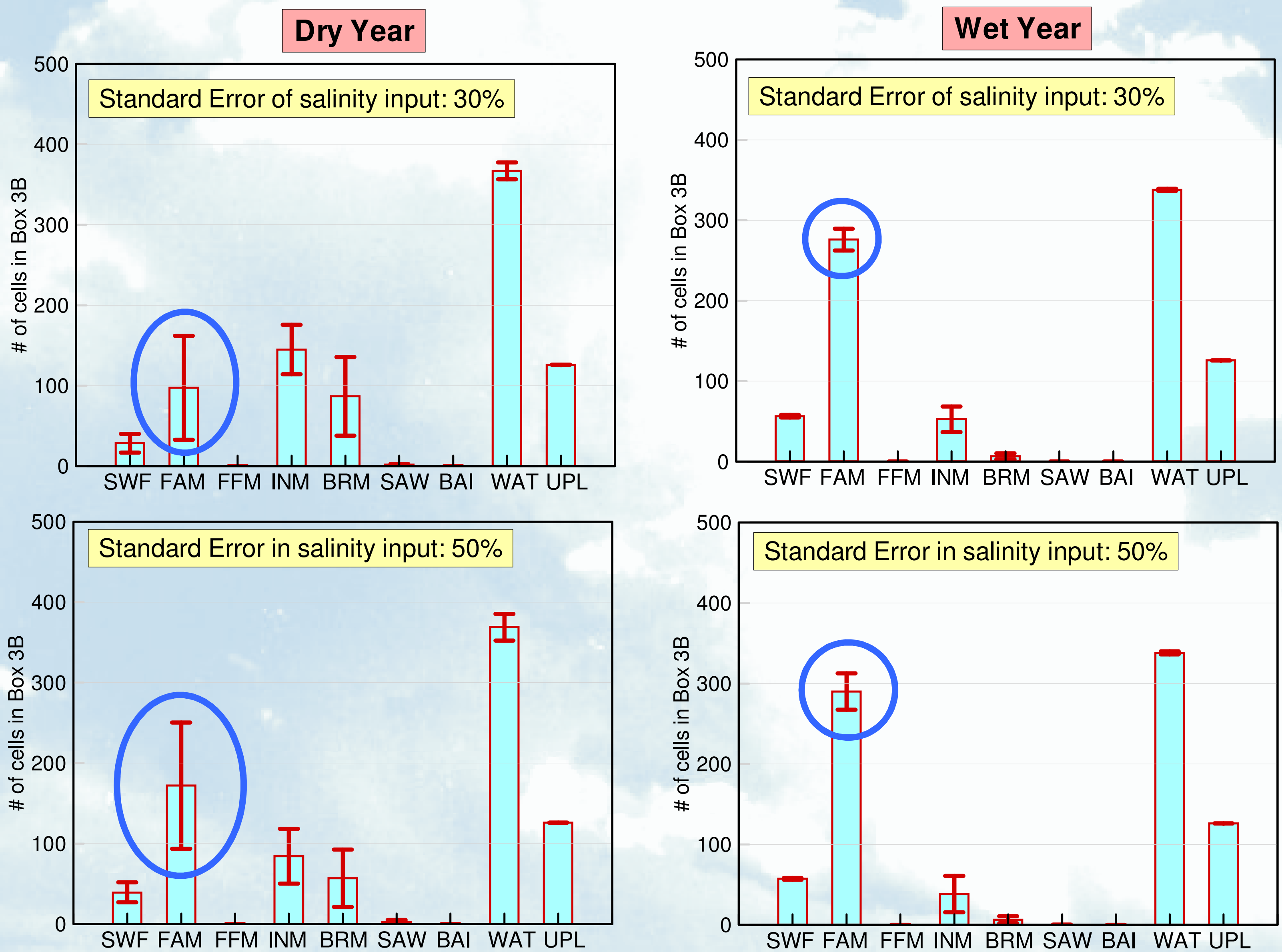
- Inputs to many of the CLEAR modules are mostly based on predictions from hydrodynamic (HD) models; these HD predictions can be associated with:
  - Random errors
  - Systematic errors

Effect of Uncertainty in HD Salinity Predictions: Random Error

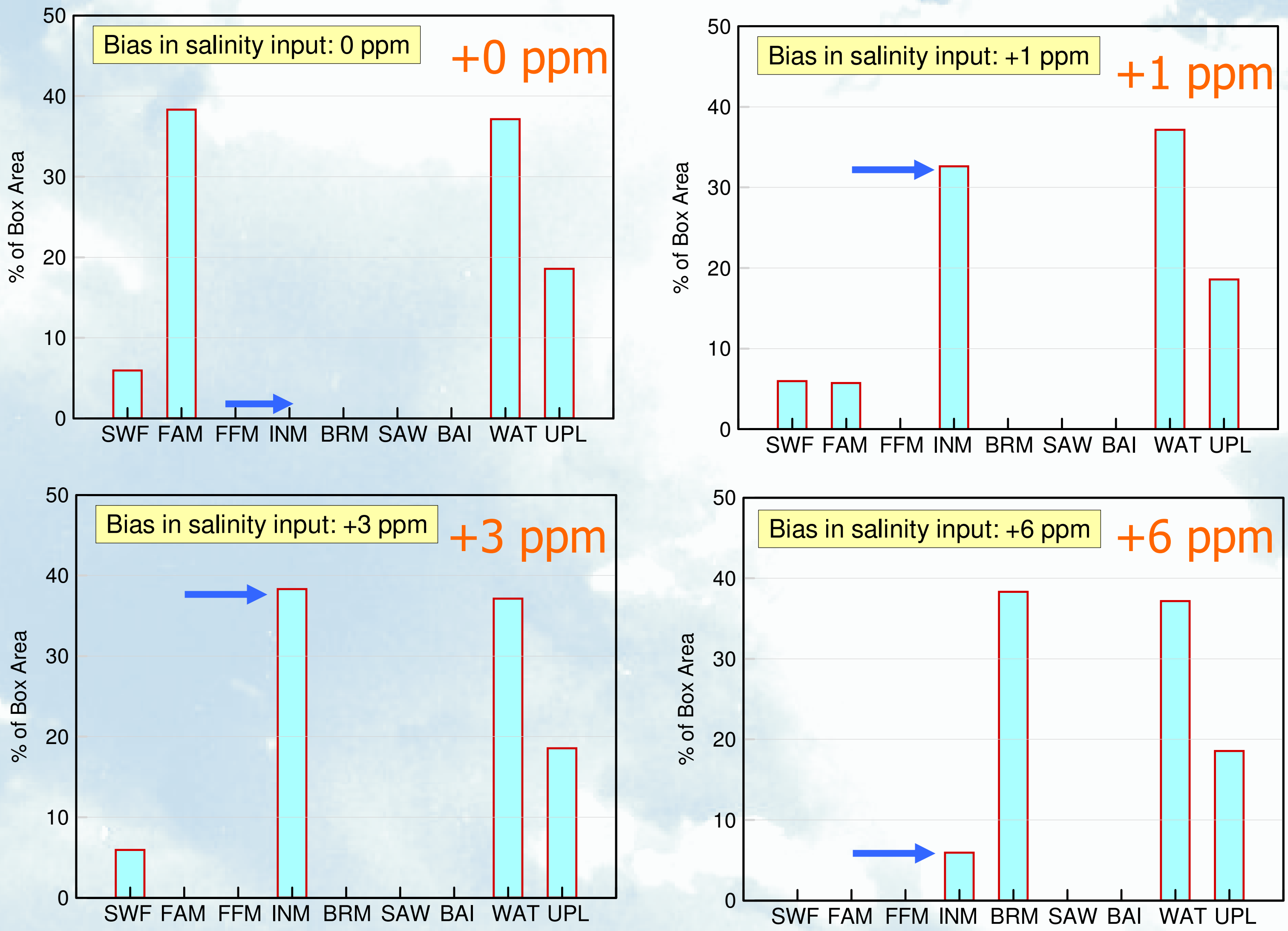


Base Scenario B01
Box 3B; Province 2

Effect of Uncertainty in HD Salinity Predictions: Extreme conditions



Uncertainty in HD Salinity Predictions: Bias



Base Scenario B01, Box 3B; Province 2

Summary:
Natural variability and climate change effects

- Systematic, persistent long-term changes in salinity levels have more impact on model predictions than local temporal variability in the salinity

Summary:
Effect of Uncertainty in Model Parameter

- Effect of uncertainties in parameters of habitat switching module (e.g., switching thresholds) can be significant
  - More research and data are required to improve the selection of these parameters

Summary:
Uncertainty in Hydrodynamic Salinity Predictions

- Effects of <u>random errors</u> in salinity predictions of hydrodynamic models are not significant (except in extreme conditions)

- Effects of systematic errors <u>(bias)</u> in salinity predictions of hydrodynamic models can be very significant
  - Make sure hydrodynamic models are CALIBRATED

What did we learn from these examples?

uncertainty analysis can help us to:

- Describe range of possible model outputs
- Estimate statistical characteristics of model outputs (mean, variance)
- Assign confidence intervals on model outputs or on functions of model outputs
- Describe model performance under different forcing conditions
- Estimate probability that performance measure will exceed a specified threshold
- Identify research needs and future data and model improvements

A complete uncertainty analysis of the CLEAR model faces the following challenges:

- The CLEAR modules are not conducive to complete uncertainty analysis.
- Lack of necessary information (e.g., marginal and joint probability distributions, parameter covariance functions)
- Large number of uncertain variables and parameters
- Data (and computational) requirements
- Lack of validation in some modules

What can be done?

- We need to have a feasible strategy to conduct incomplete, yet informative, uncertainty analysis
- This practical strategy should provide us with probability distributions of the uncertain model predictions

Recommended Steps to Conduct Uncertainty Analysis for the CLEAR Model: Short Term

1. Identify the significant sources of uncertainty that impact the outcome of the proposed restoration projects.

2. Use sensitivity analysis to identify a narrower set of independent input variables and parameters that are most significant.

3. Construct probability density functions for the selected uncertain variables and parameters.

Recommended Steps to Conduct Uncertainty Analysis for the CLEAR Model: Short Term

4. Use Monte-Carlo random sampling simulations (or other methods) to propagate the uncertainties of the identified parameters and variables using a probability distribution formulation.

5. Use the derived probability distributions to make quantitative assessment about the likelihood that a certain restoration project will meet a pre-specified performance target.

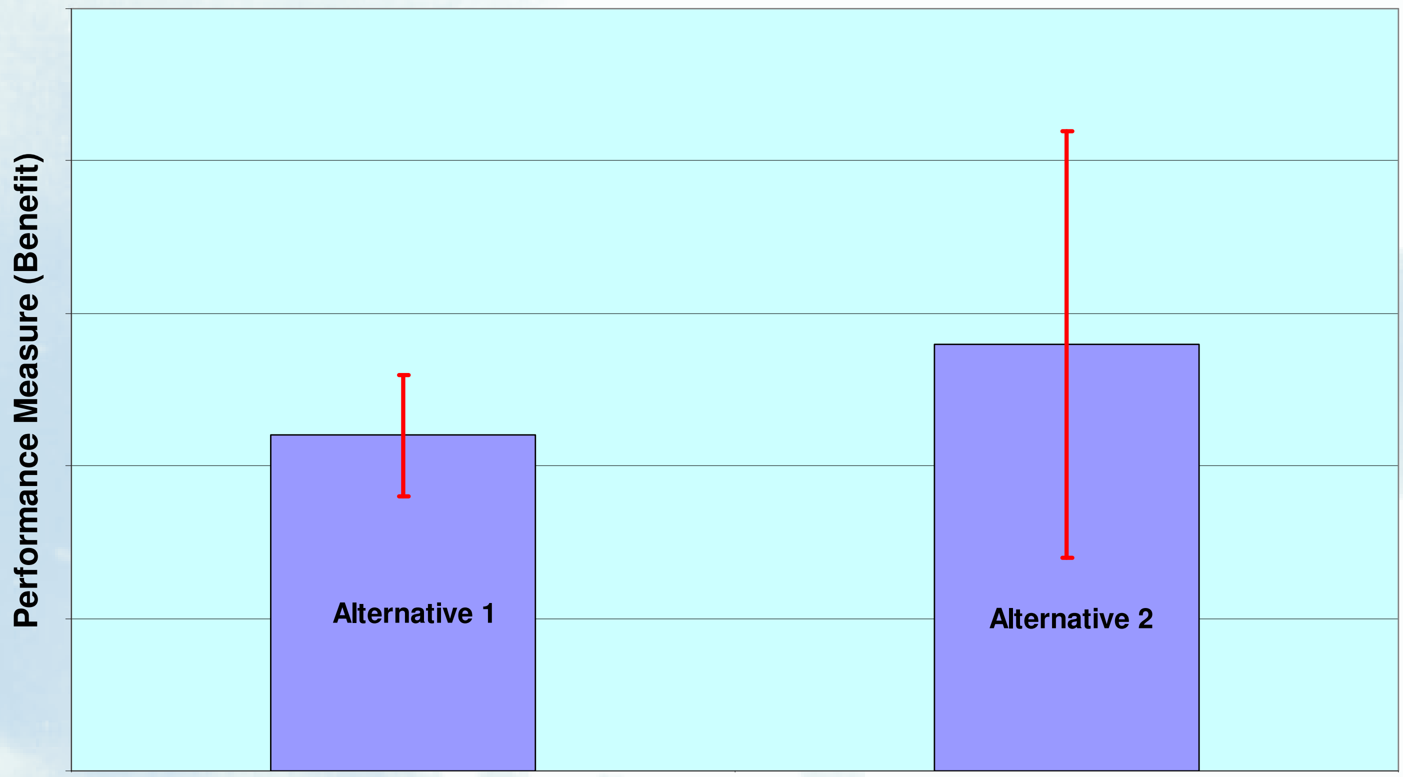
6. Use the derived probability distributions and their confidence intervals to compare and select amongst the alternative proposed restoration projects.

Long Term Strategy:

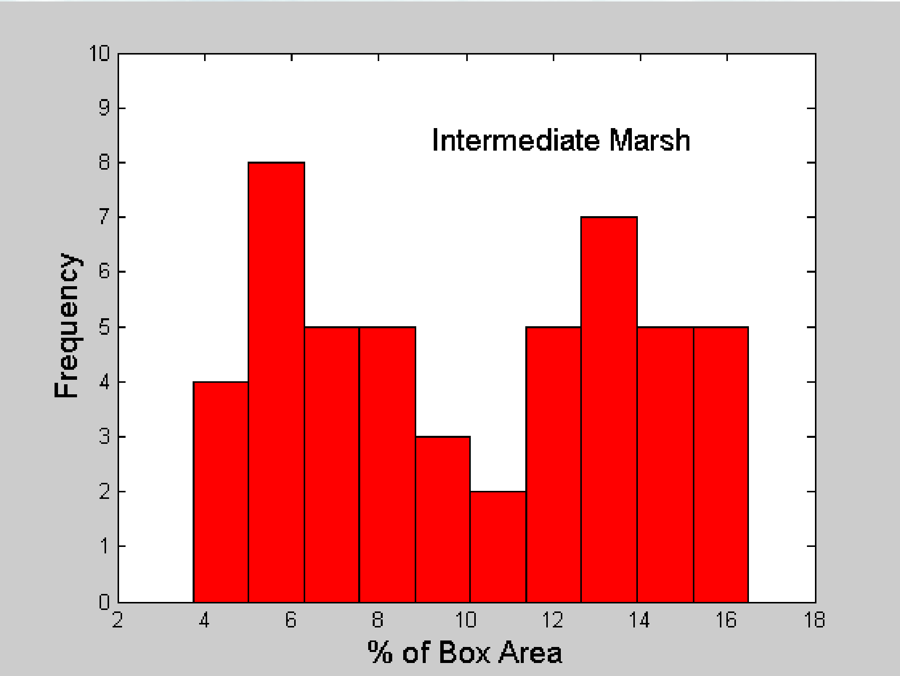
- Model calibration and validation
- Model restructuring
- Acquisition of reference baseline data sets
- …….
- …….

End

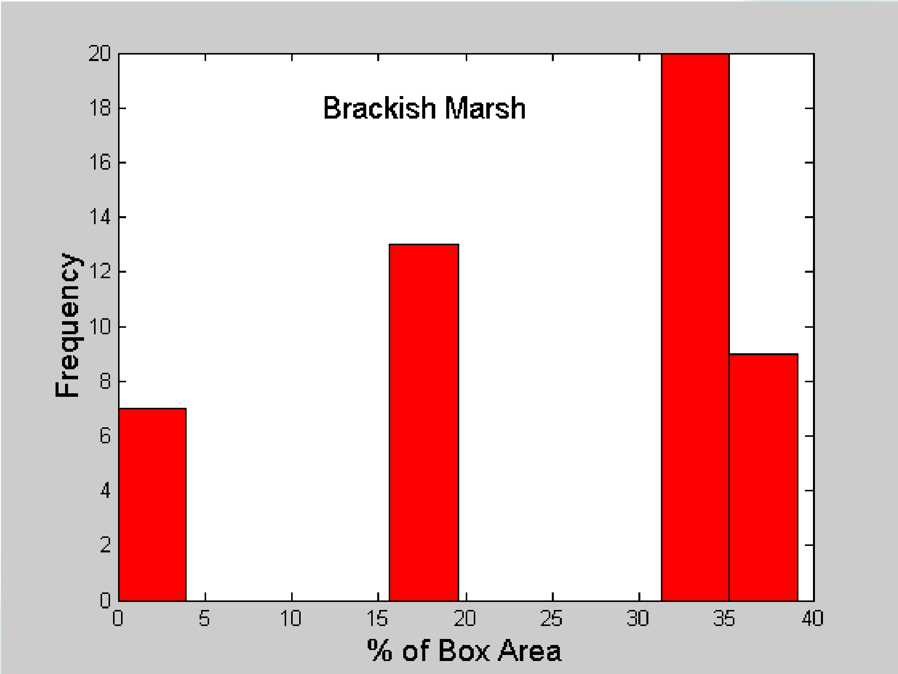
Thank You!


Performance Measure (Benefit)
Alternative 1
Alternative 2

Examples of Probability Distributions of Habitat Switching Output



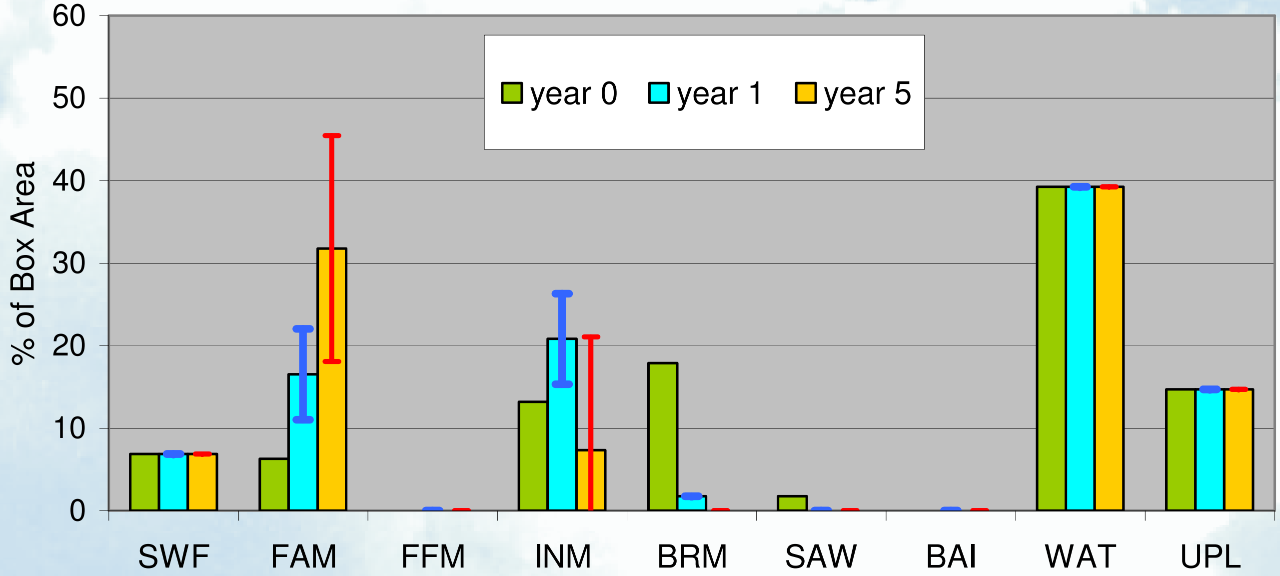
Effect of uncertainty in salinity input
(Dry year, 50% error in salinity input)



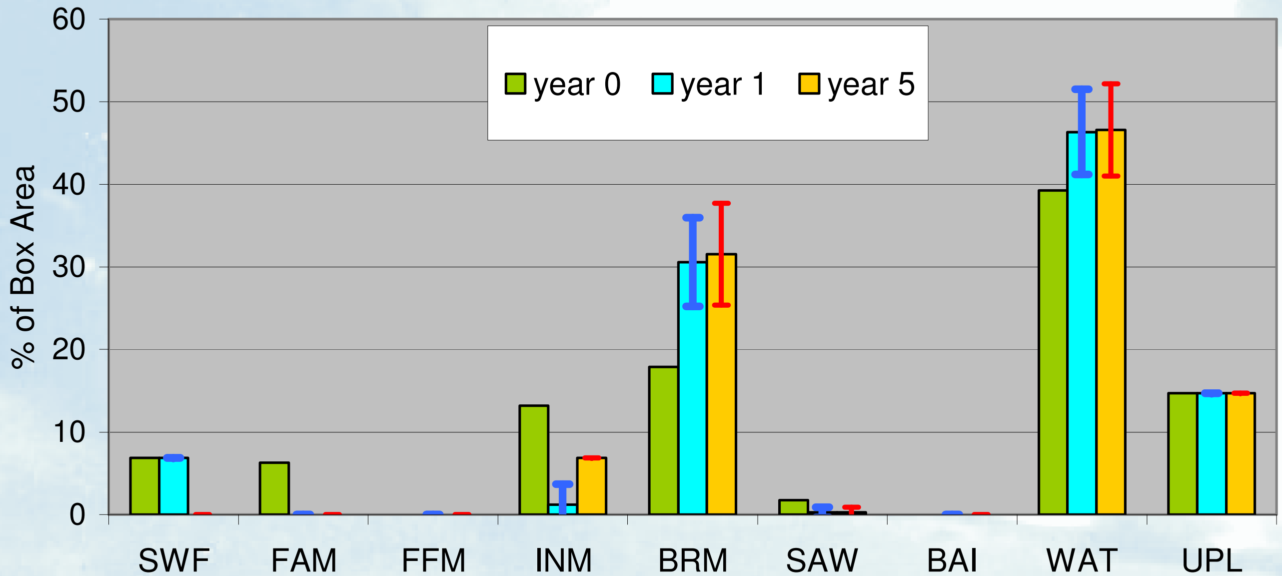
Effect of uncertainty in switching thresholds
(Dry year, 50% error in salinity thresholds)

Effect of Uncertainty in Switching Thresholds

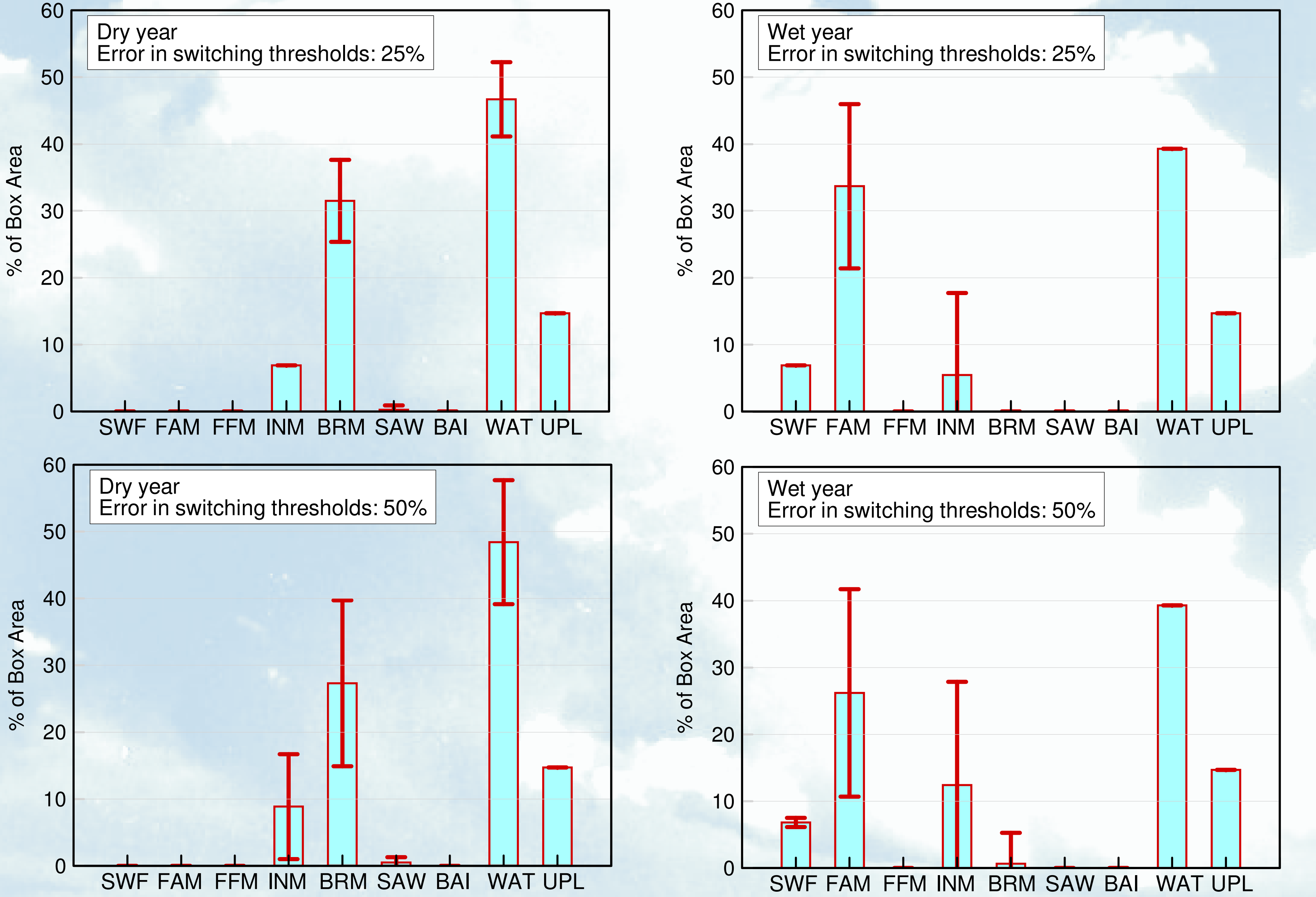
Wet Year
(25% error)



Dry Year
(25 % error)



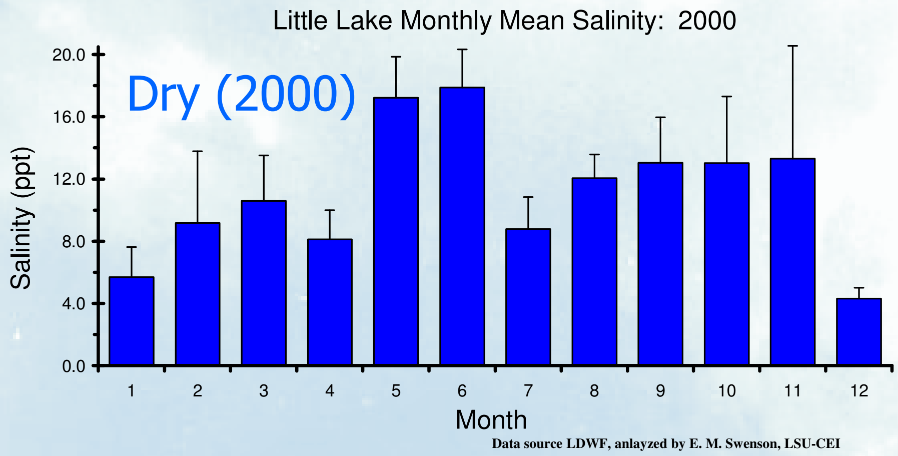
Effect of Uncertainty in Salinity Switching Thresholds On Habitat Switching Output

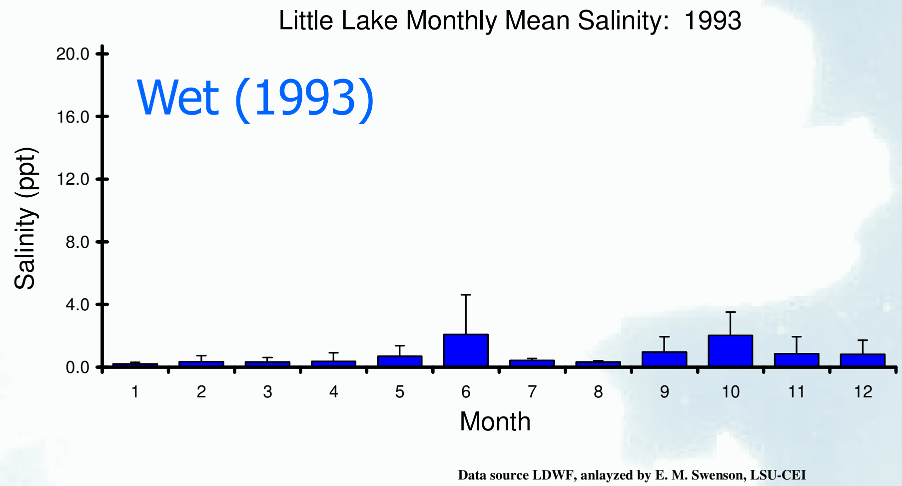


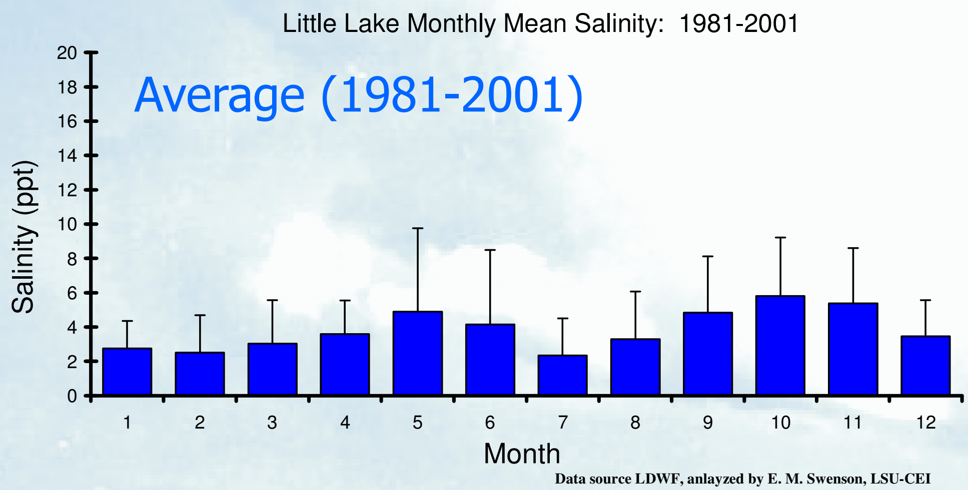
How to quantify uncertainty?

- ✓ Model validation is a key factor for performing uncertainty analysis!
  - ✓ Problem: Lack of validation (for some modules)
  - ✓ Problem: some models are difficult to validate (e.g., habitat use)

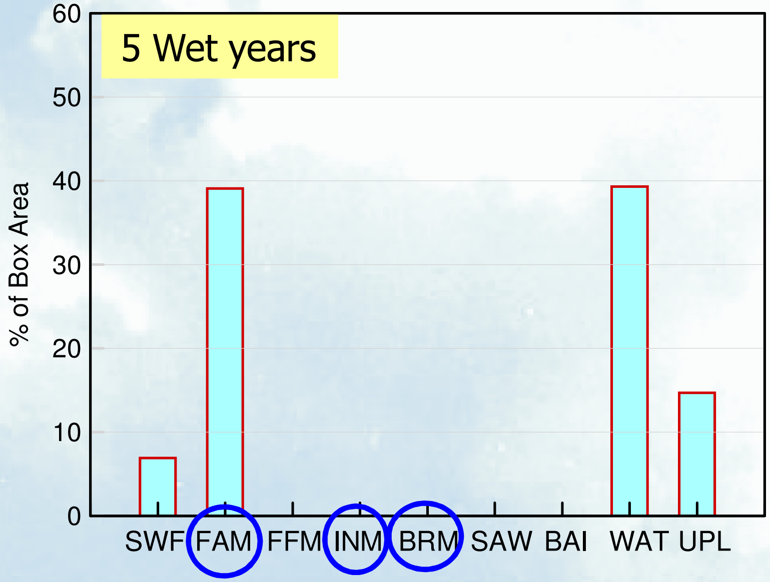
Effect of Hydro-climatic Variability

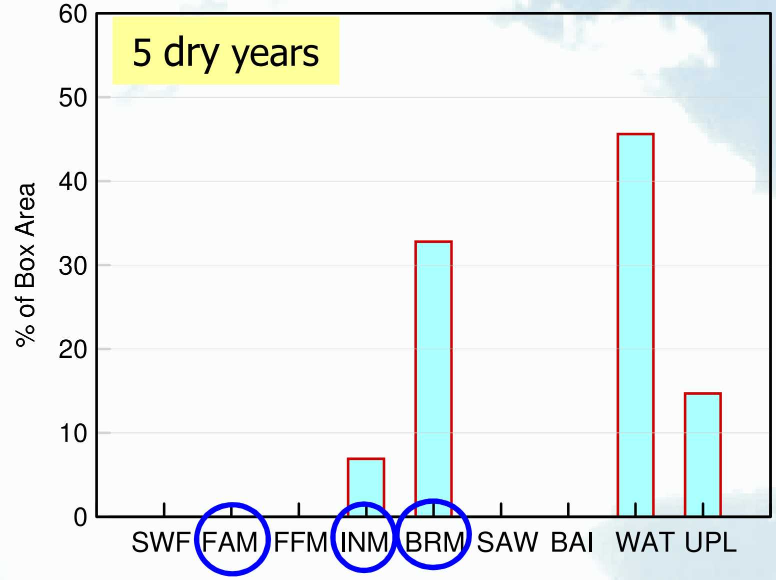


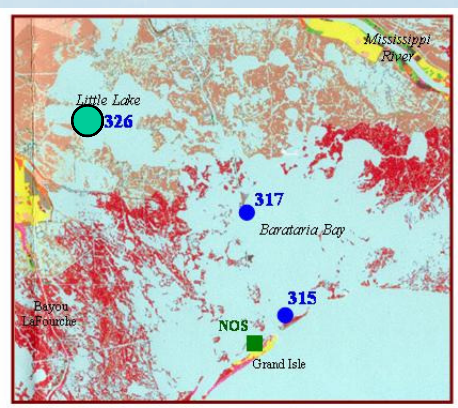




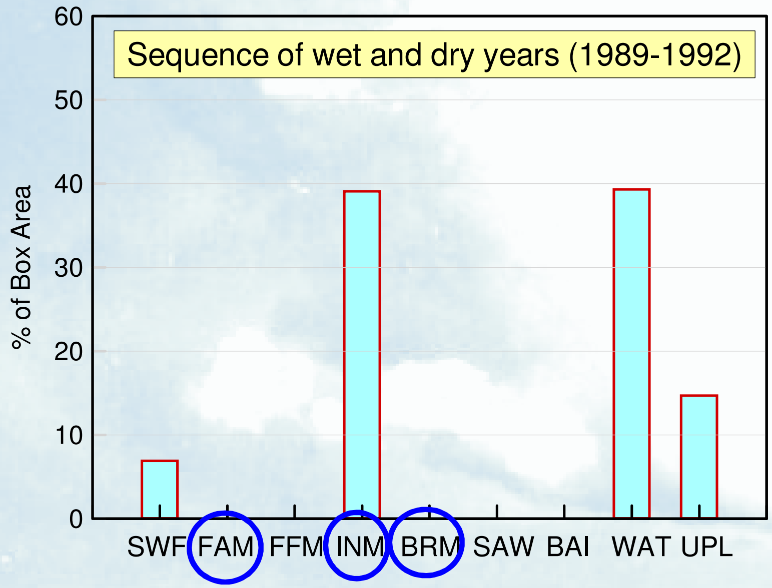
Effect of Hydro-climatic Variability





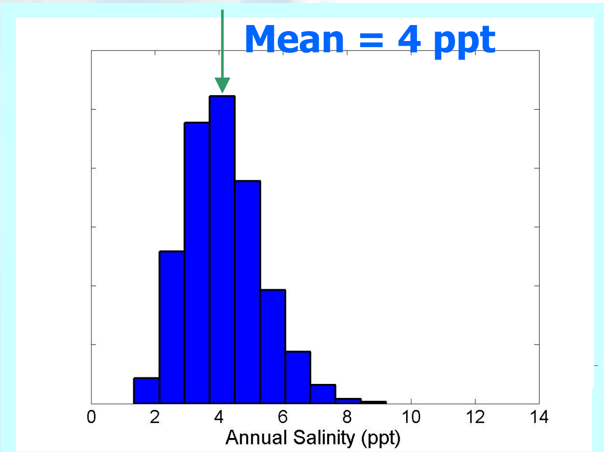


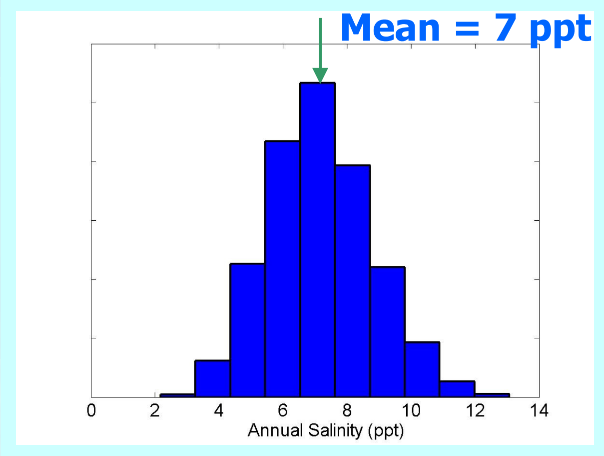
Box 3B; Province 2

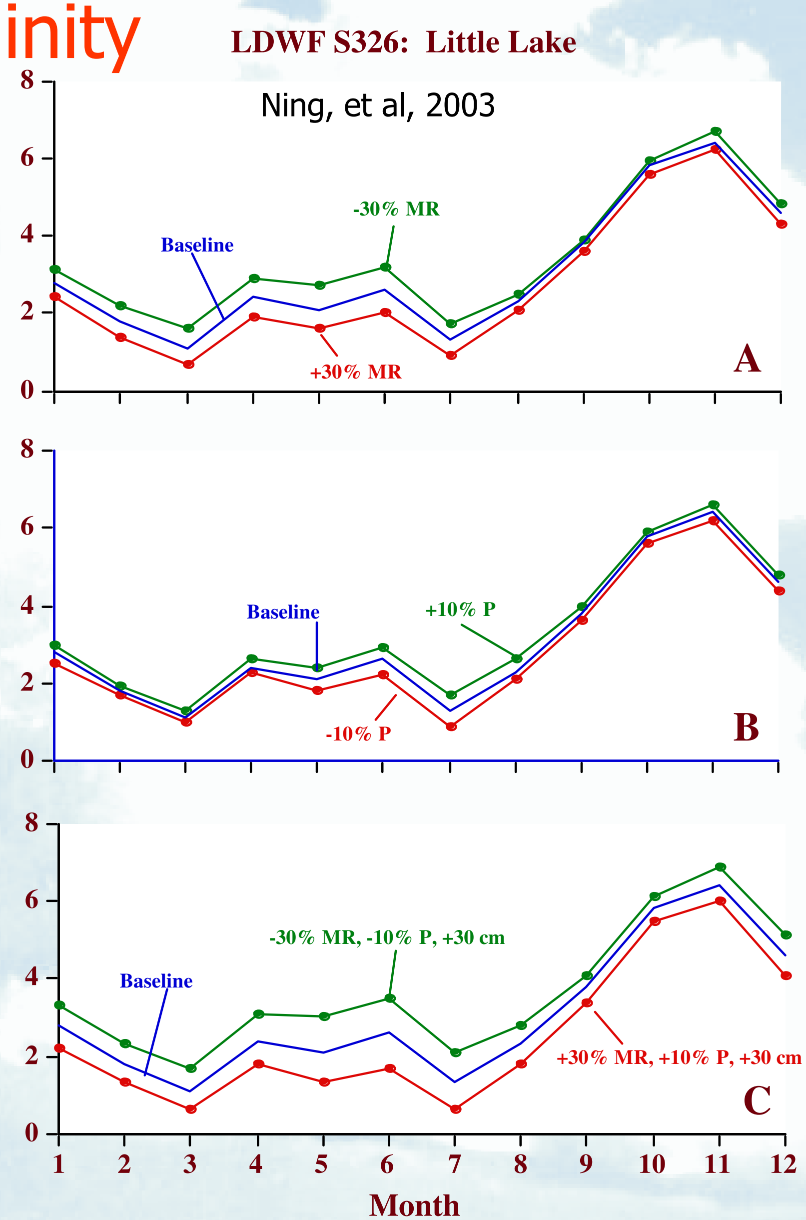


Effect of Global Climate Change:

Long-term increase in salinity







Effect of Global Climate Change:

Increase in salinity levels