Tools and Resources Currently in Place and in Development to Help Planning Adaptation to Sea Level Rise in South Florida

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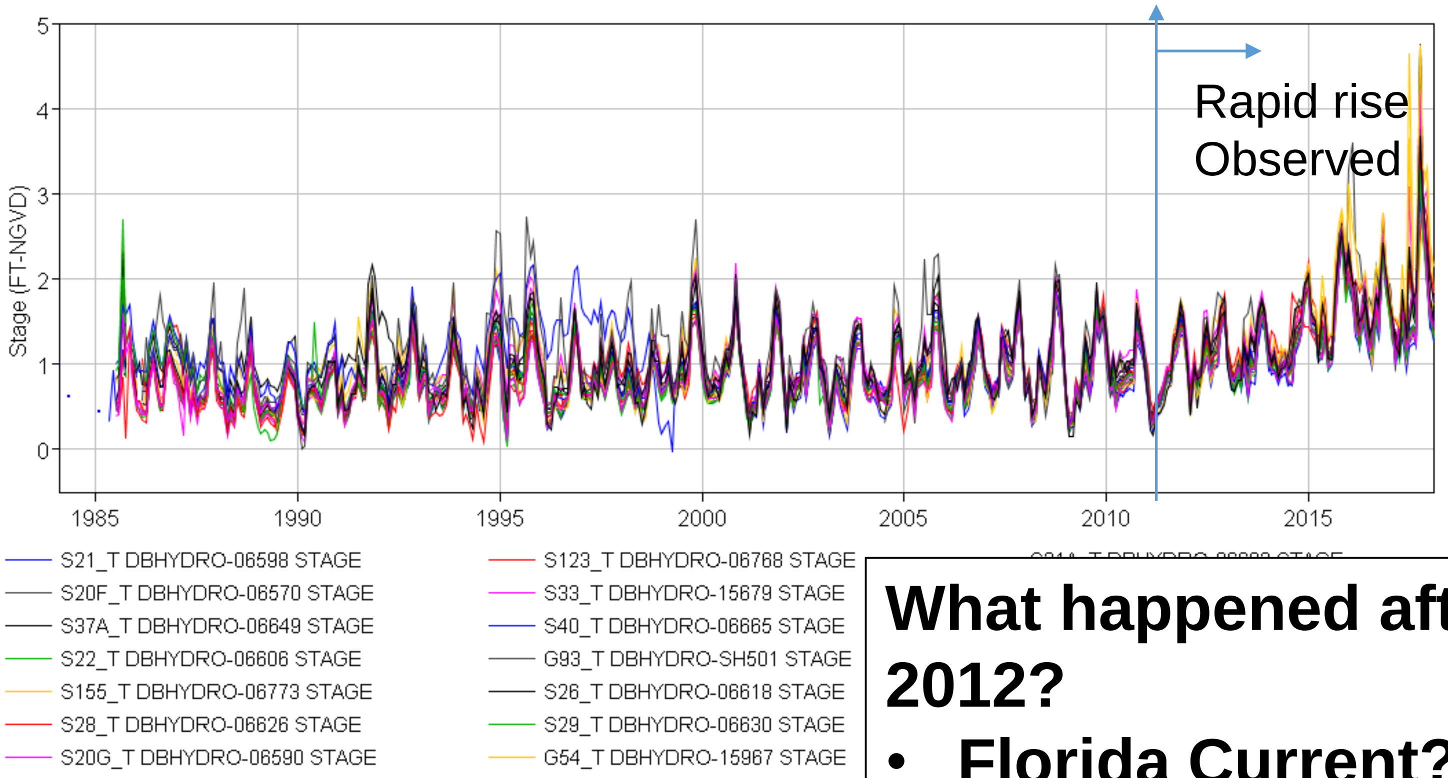
Sea Level Hotspots from Florida to Maine
Drivers, Impacts, and Adaptation
April 23 -25, 2019 | Norfolk, Virginia

South Florida : Low topography, High groundwater table, Sandy soils and porous limestones, One of the most complex water management systems in the world

Outline

- Why tools are needed?
- Current tools
  - Design water levels
  - Compound Flooding
  - Adaptive pathways
- Future plans for tool development

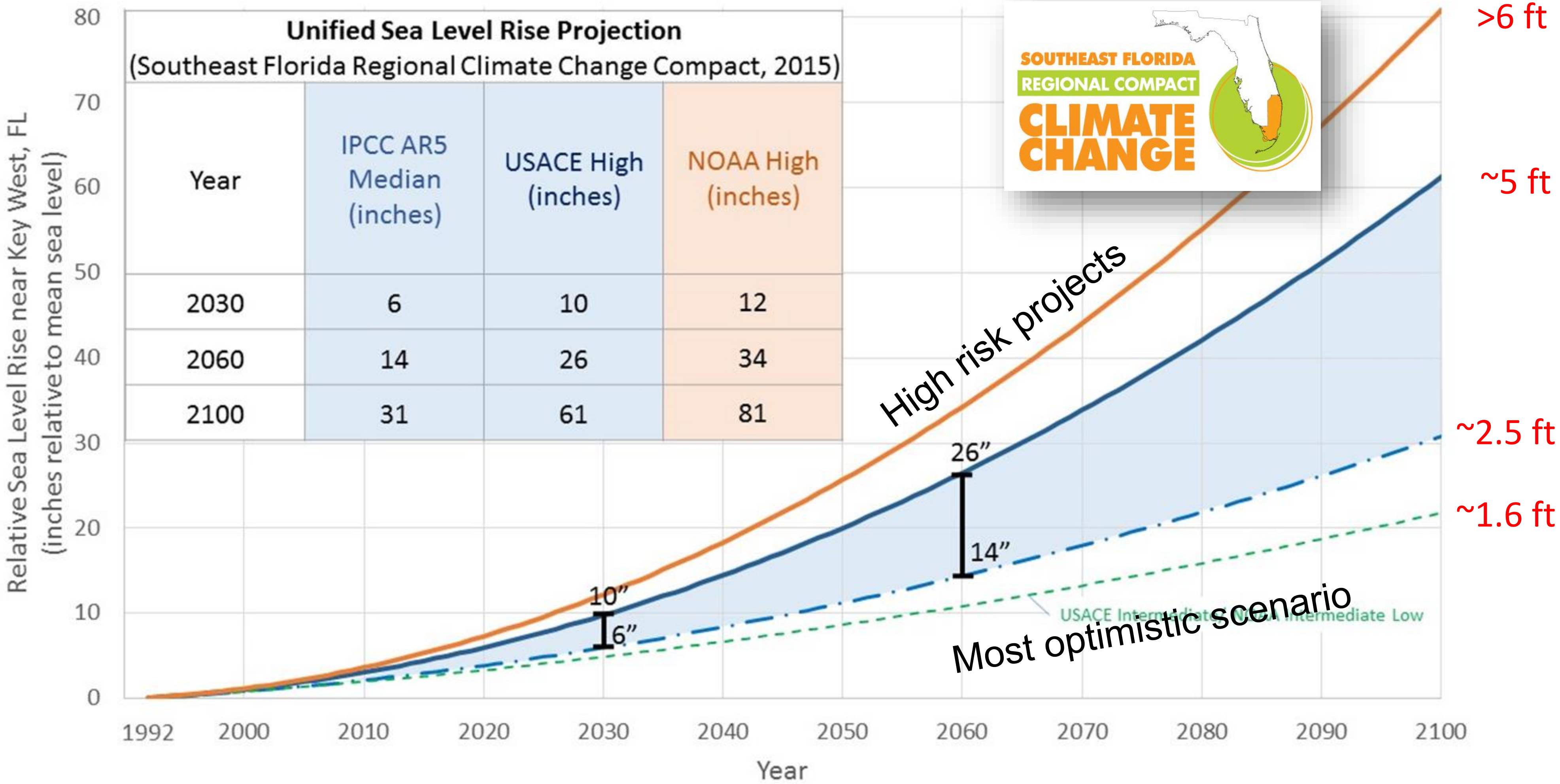
Coastal Discharge Structures in South Florida



What happened after 2012?

- **Florida Current?**
- **Ocean Warming?**
- **ENSO, NAO?**

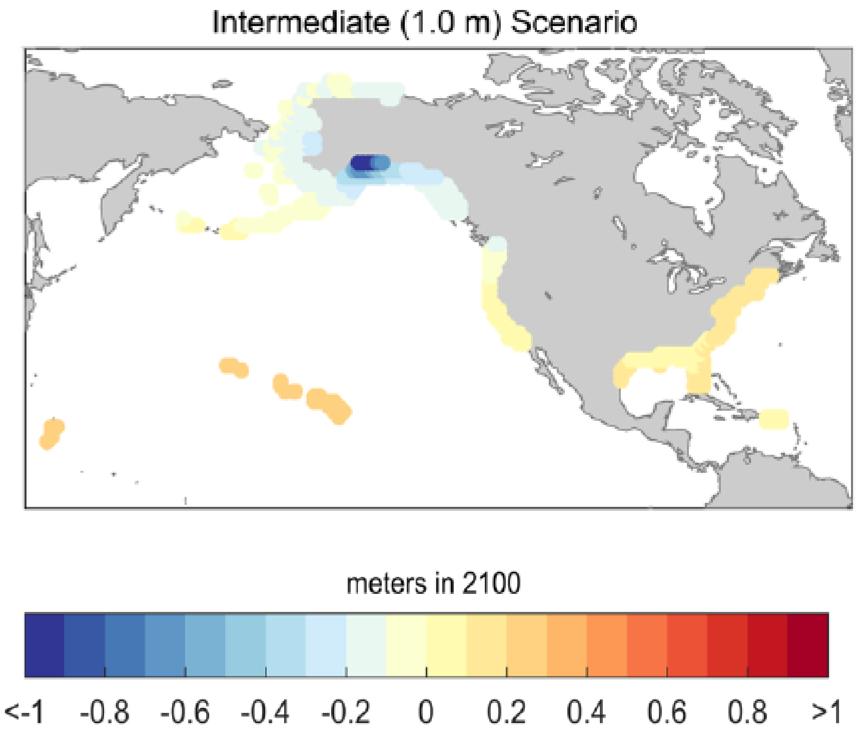
Unified Sea Level Projections



Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

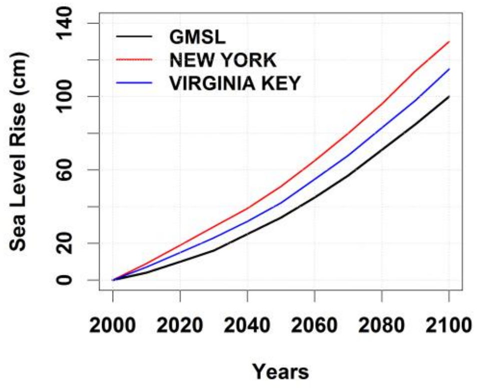
Regional Sea Level Projections

- Both Hall et al. (DoD 2016) and Sweet et al. (NOAA 2017) accounted for all components



Florida

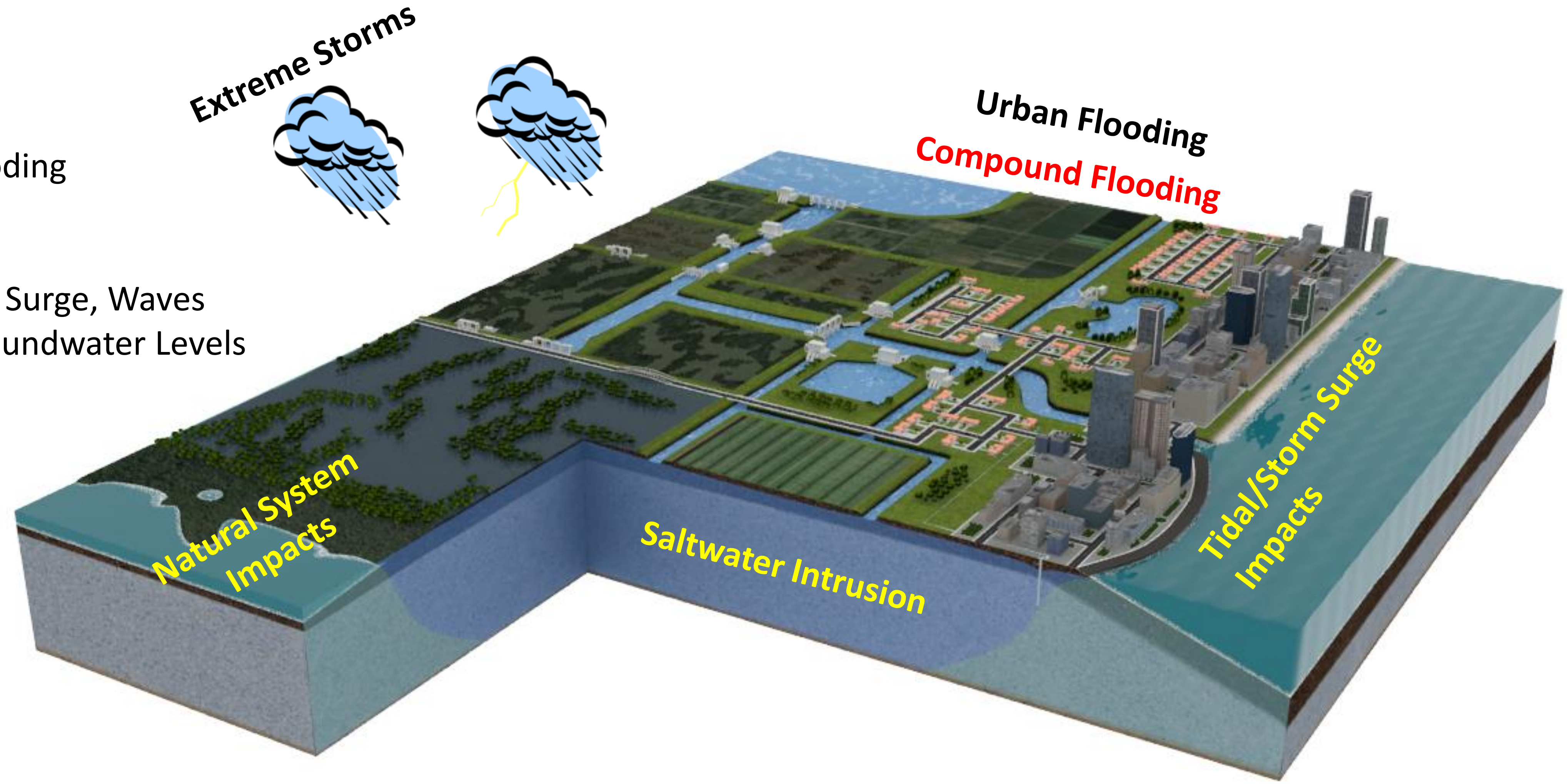
Regional
Sea Level
Curves



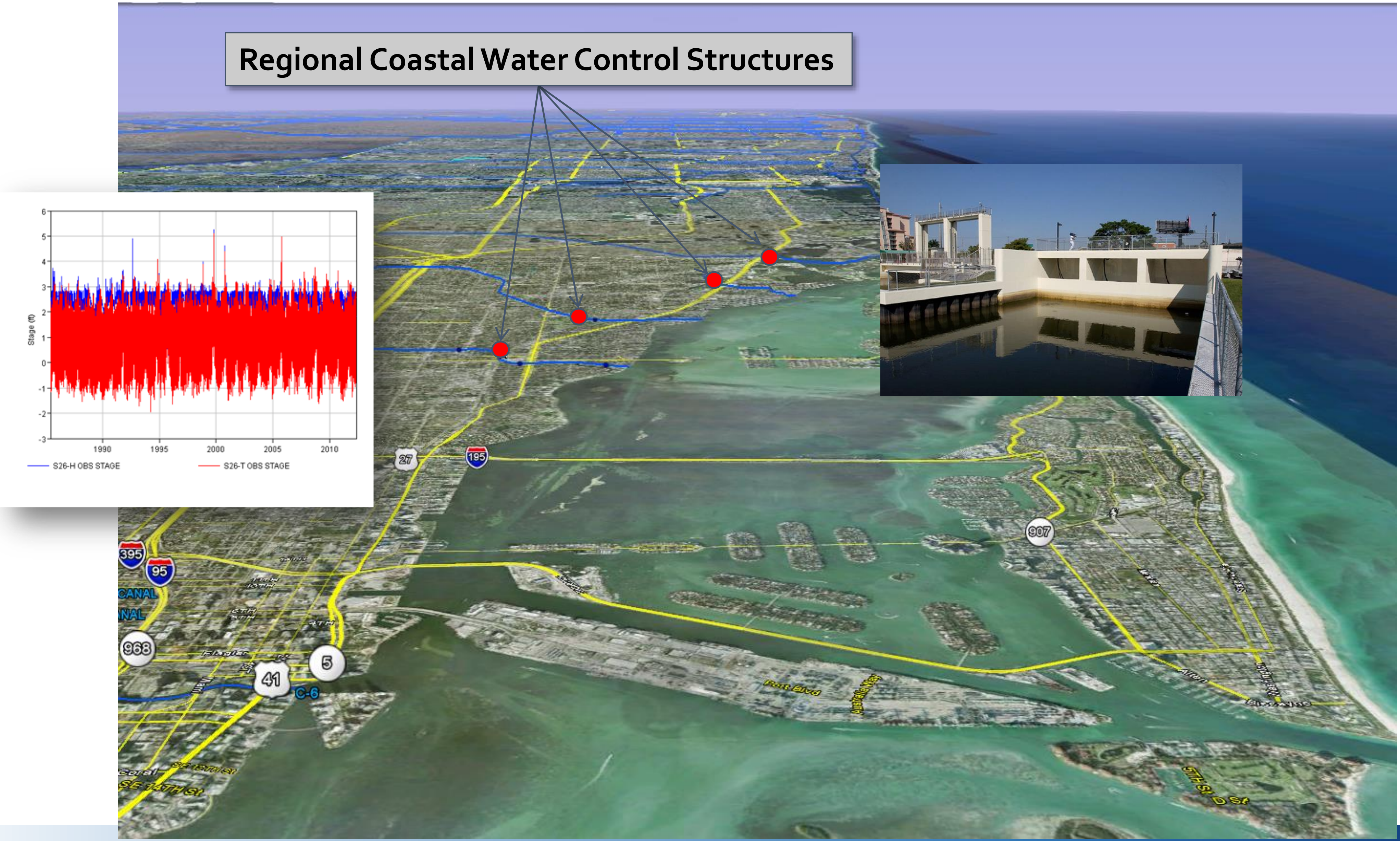
South Florida Case

Compound Flooding
Caused by

- Rainfall
- Tides, Storm Surge, Waves
- Elevated Groundwater Levels

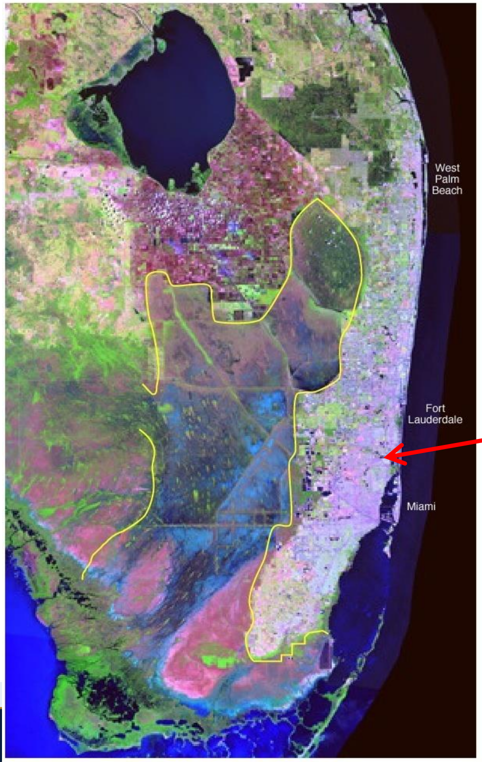


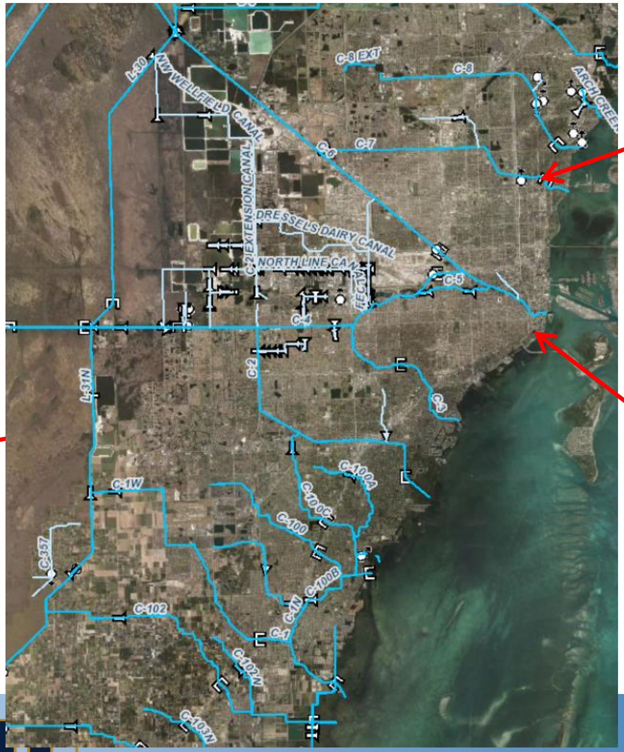
Regional Coastal Water Control Structures

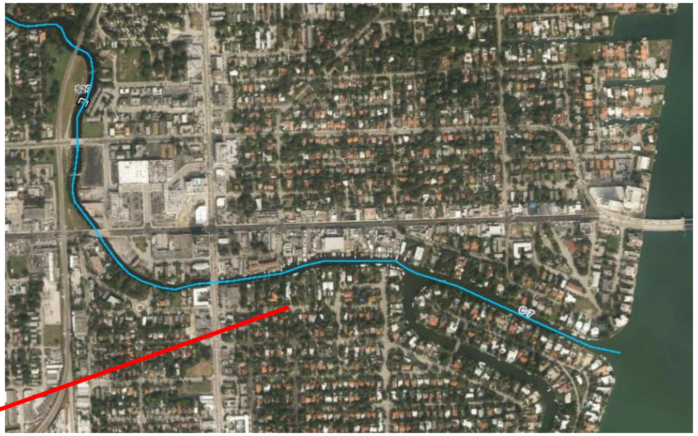


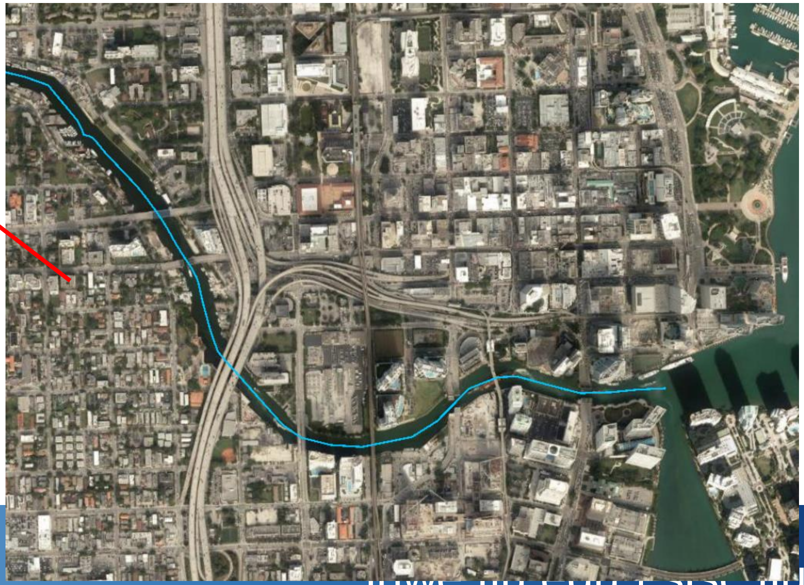
Level of Service Program for Flood Protection

S. Florida: Low topography, High groundwater table, sandy soils and porous limestones, complex water management systems.









Information Needs for Adaptation

- Projections of Total Water Levels for various Return Periods and Sea Level Rise Scenarios
- How to deal with Nonstationarity in designs
- Compound Flooding. How do we estimate joint probabilities (Rainfall, Total Water Level, Groundwater)
- Dealing with uncertainty in Adaptation Planning

Tools

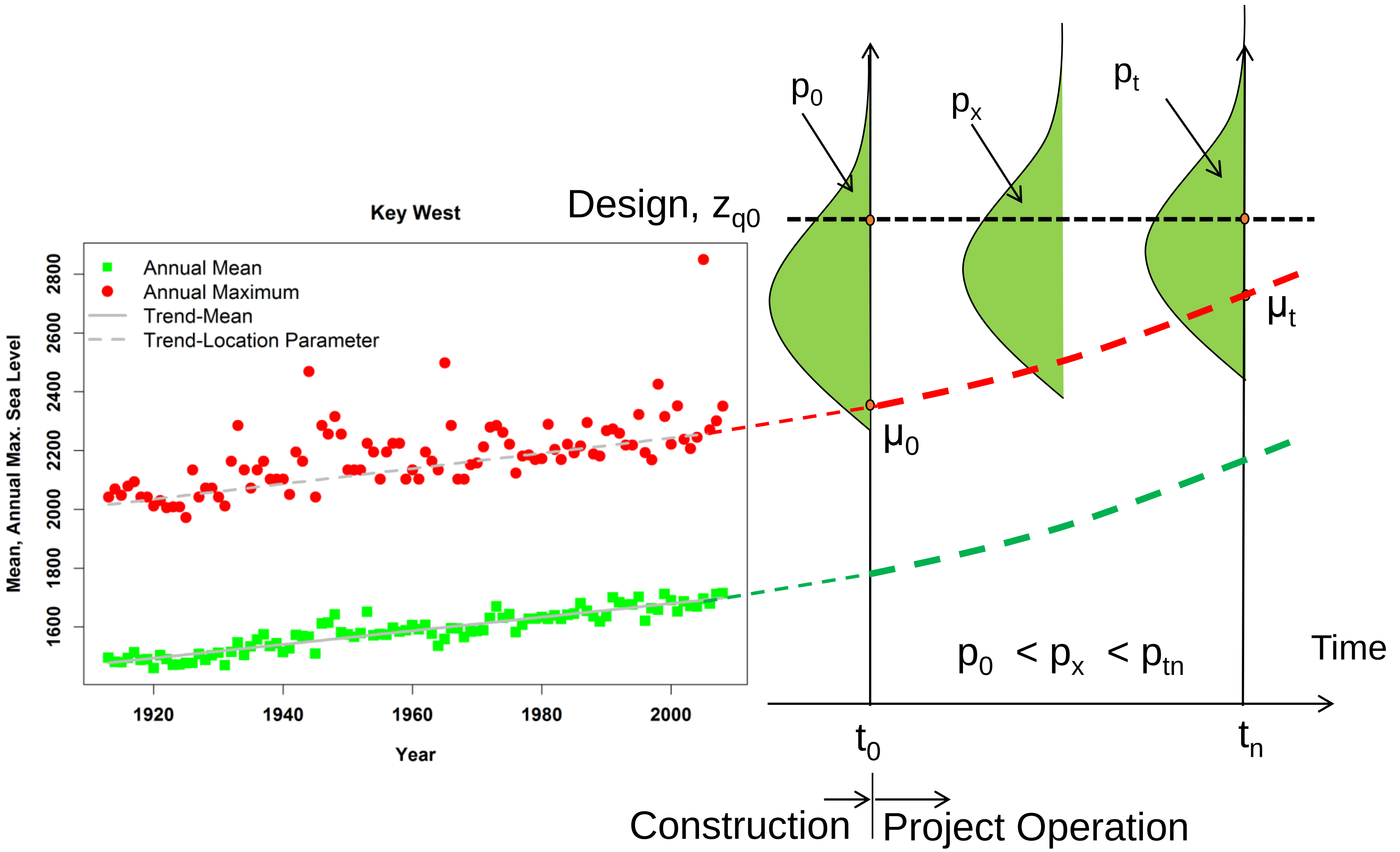
Current:

- New paradigm for return period and risk under nonstationarity
- Empirical Simulation Techniques for Design Water Levels
- Assessment of Compound Flooding
  - Copulas
  - Generation of Synthetic Events
- Deep Uncertainty Methods

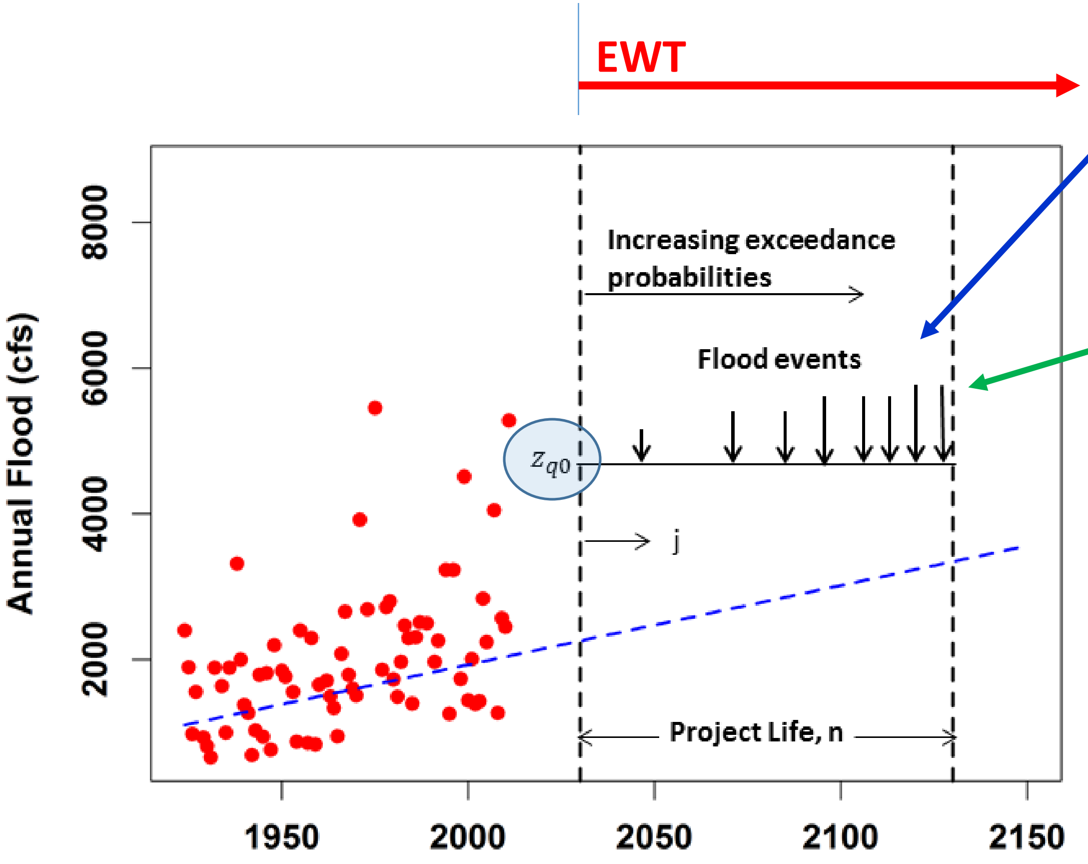
Future

- Hybrid Statistical and Dynamical Modeling Approach (TESLA)

Designing for Sea Level Rise



Hydrologic Design considering Nonstationarity



AAR: Design for average p_t

DLL: What level should we design to maintain a specified risk (e.g. 5%)

ENE: What level should we design for if we can tolerate, say m events over the life

Design Criteria

- ❑Expected Waiting Time (EWT)
- ❑Expected Number of Events (ENE)
- ❑Design Life Level (DLL) – Risk Based

"Return Period" Under Nonstationary

- Return Period is defined as the "expected time for the first exceedance (waiting time)"

$$T = E[X] = \sum_{x=1}^{\infty} x f(x) = \sum_{x=1}^{\infty} x p_x \prod_{t=1}^{x-1} (1 - p_t)$$

- Coley (2013) provides a nice simplification:

$$T = E[X] = 1 + \sum_{x=1}^{\infty} \prod_{t=1}^{x} (1 - p_t)$$

Note: Since p_t is a function Z_{q0} (initial design or p_0), this can also be used to find Z_{q0} for a given T

Risk and Reliability (Nonstationary)

- **Risk**

$$R = \sum_{x=1}^{n} f(x) = \sum_{x=1}^{n} p_x \prod_{t=1}^{x-1} (1 - p_t) = 1 - \prod_{t=1}^{n} (1 - p_t)$$

- **Reliability:**

$$R_\ell = \prod_{t=1}^{n} (1 - p_t)$$

Example Models: Block Maxima

- For GEV:

$$p_t = 1 - exp\left\{-\left[1 + \xi\left(\frac{z_{q_0} - \mu(t)}{\sigma(t)}\right)\right]^{-1/\xi}\right\}$$

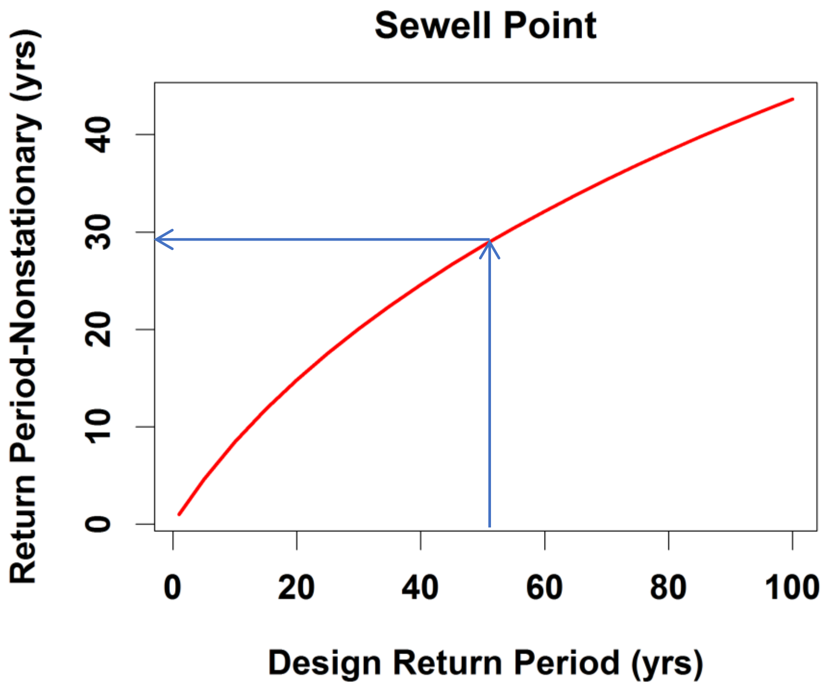
$$\mu(t) = \beta_0 + \beta_1 t;\ \sigma(t) = \sigma; \xi(t) = \xi$$

$$\mu(t) = \beta_0 + \beta_1 t + \beta_2 t^2;\ \sigma(t) = \sigma; \xi(t) = \xi$$

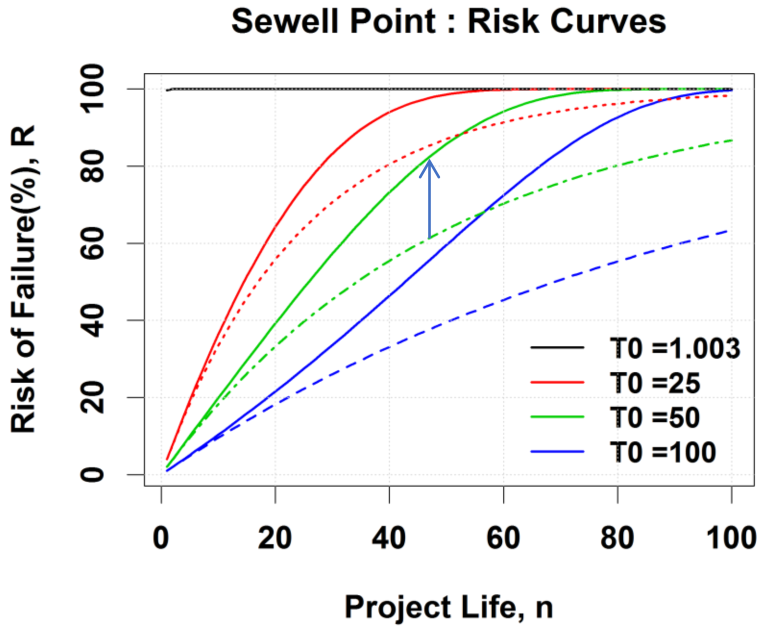
$$\mu(t) = \beta_0 + \beta_1 NINO3(t);\ \sigma(t) = \sigma; \xi(t) = \xi$$

$$\mu(t) = \beta_0 + \beta_1 . MSL(t);\ \sigma(t) = \sigma; \xi(t) = \xi$$

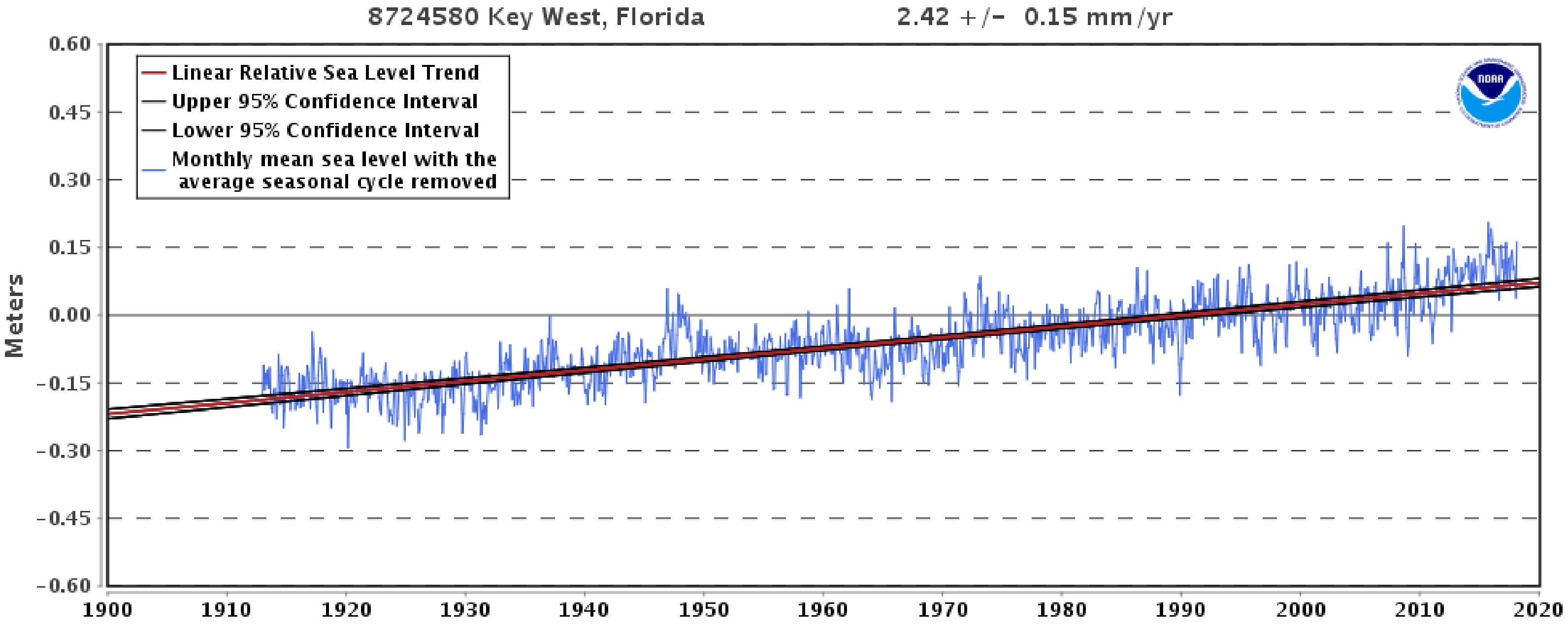
Return Period (EWT) and Risk Curves for Sewell Point, VA

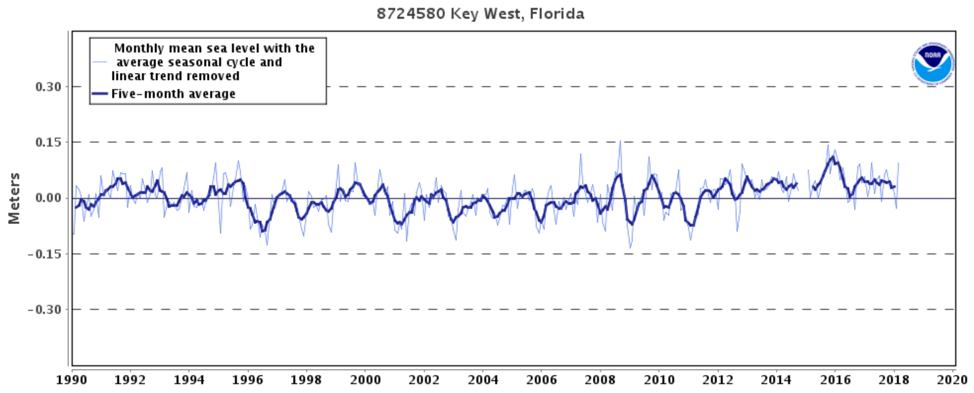


* USACE Intermediate Scenario

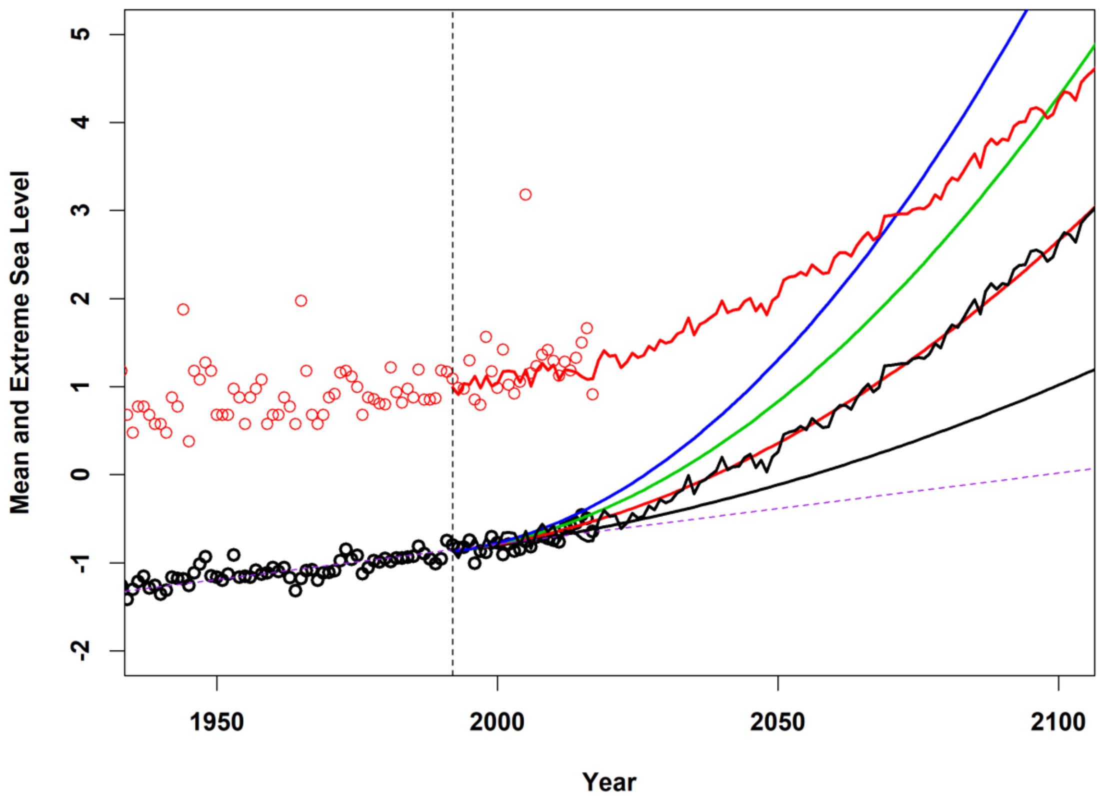


Key West Florida: Systematic Trend & Natural Variability

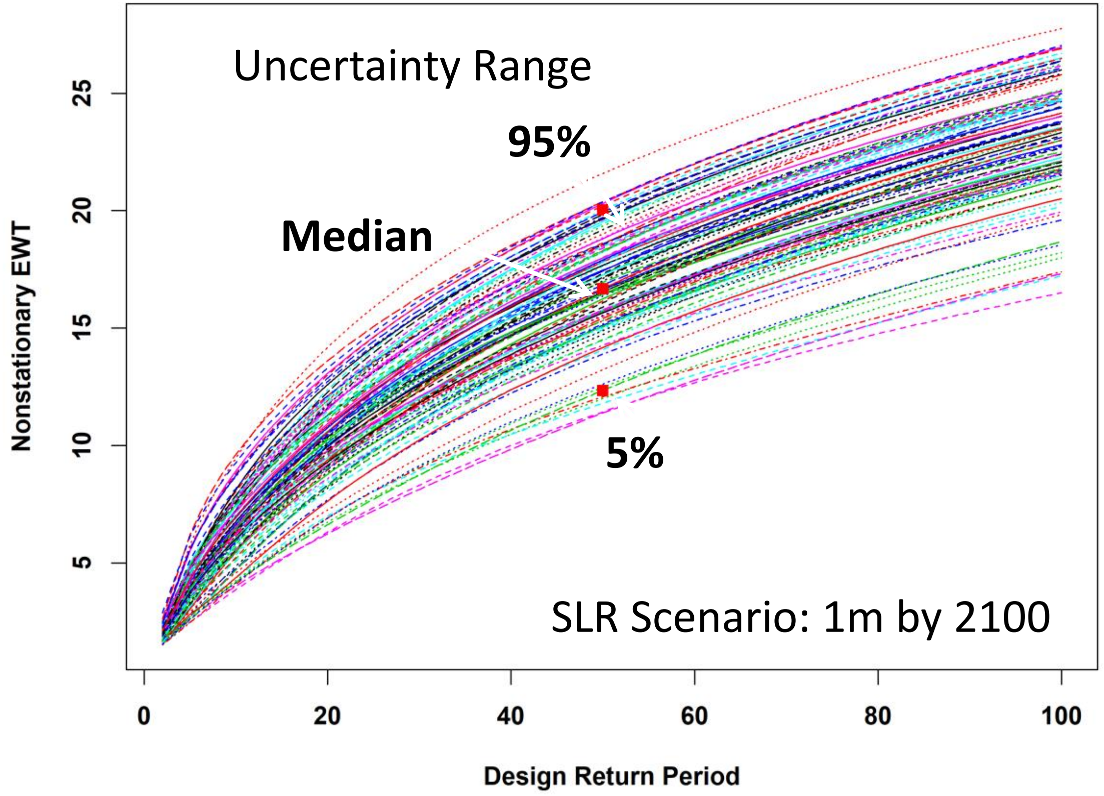




Monte Carlo Simulation of Systematic and Natural Variability



Probability Distribution of Expected Waiting Time



Empirical Simulation Technique: Monte Carlo Joint Probability Method

- **Preparation of boundary conditions at Tidal Structure**
- **Short records (~30 years). LOS Project requires tailwater elevation (return levels) for return periods, 2,5,10,25,50, and 100 years under various SLR scenarios**
- **Traditional EV techniques are not appropriate due to short records**
- **EST method develop by Goring et al (2011)**

Estimation of Extreme Sea Levels in a Tide-Dominated Environment Using Short Data Records

D. G. Goring[1]; S. A. Stephens[2]; R. G. Bell[3]; and C. P. Pearson[4]

MCJP Method

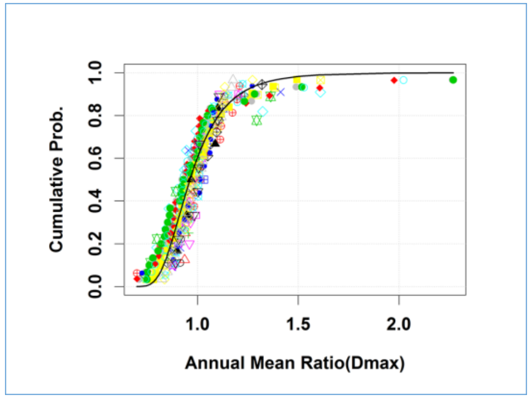
- Decomposition of the observed water levels into constituent components:
  - Astronomical tide and its residual (Utide, Cordiga 2011)-> NTR
  - Storm Surge & Sea Level Variation (both mean and inter-annual)
    - Wavelet Decomposition (lower frequency band to extract mean sea level variation)
    - Residual subject to a second level of wavelet decomposition to extract Storm Surge Component
    - Remainder assigned to tidal residuals
    - NR = MSLA + SS + TR

MJCP Method (Cont.)

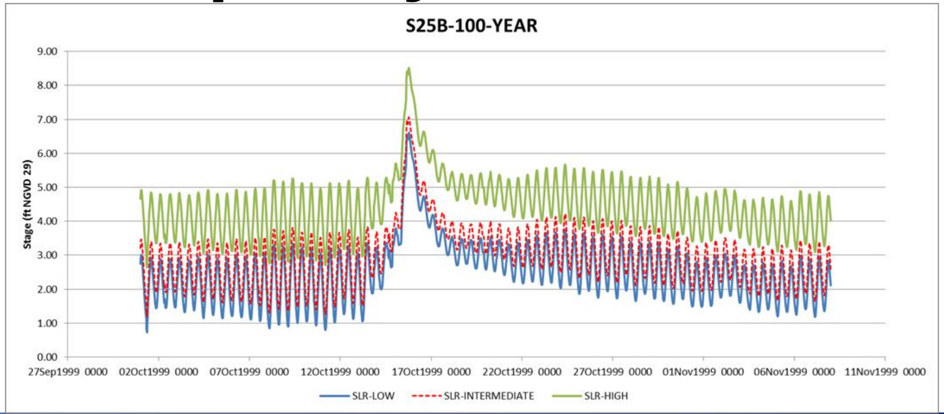
Monte Carlo Simulation

- **Simulate Tides, MSLA, SS, and TR in a Monte Carlo Framework**
- **15,000 to 20,000 years of 706 per year (tidal peaks)**
- **Larger extremes simulated by replace one storm surge value with a value drawn from a regional frequency distribution**

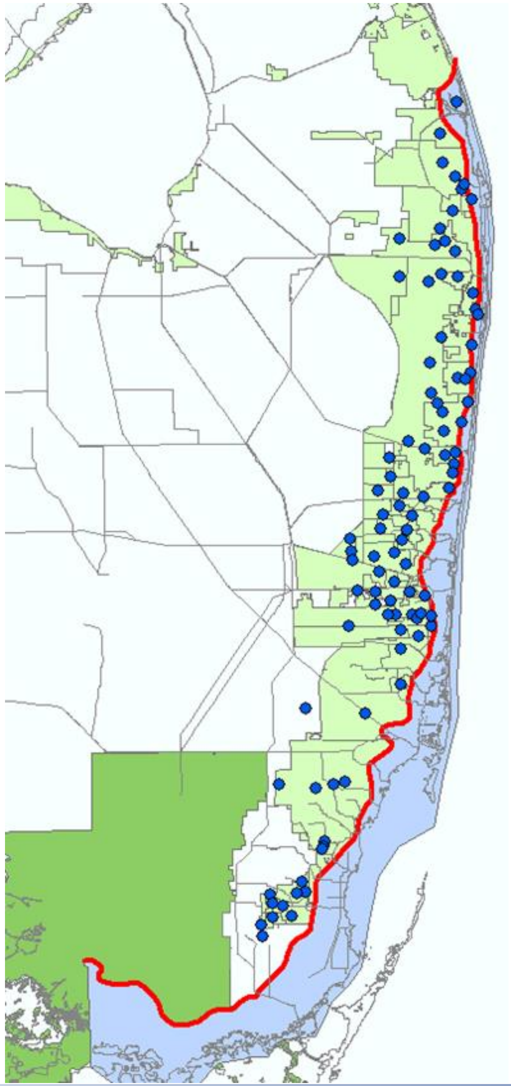
Regional Frequency Curve

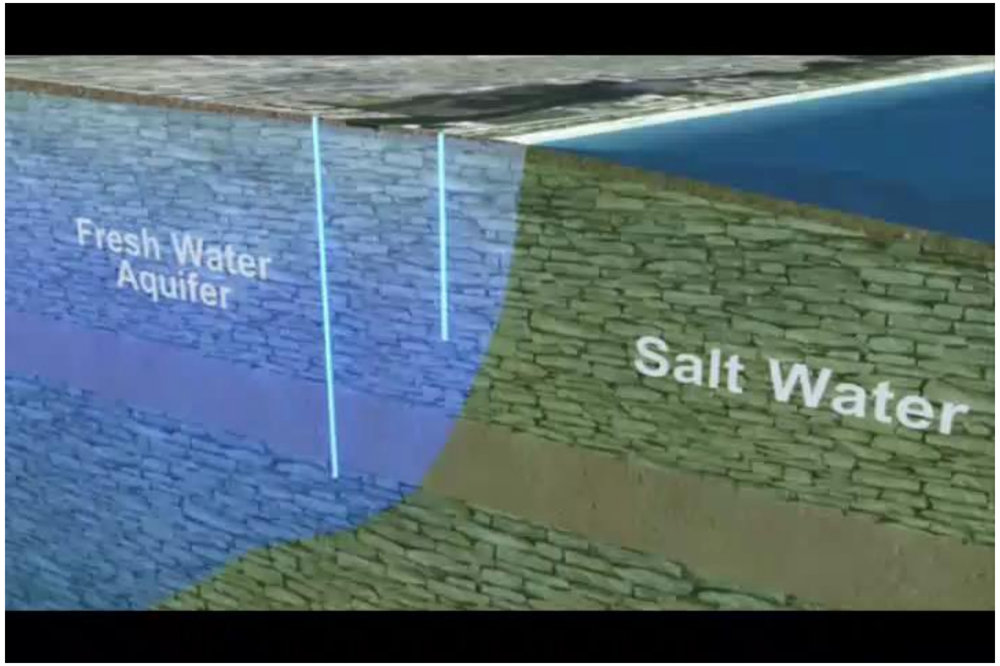


Final Product

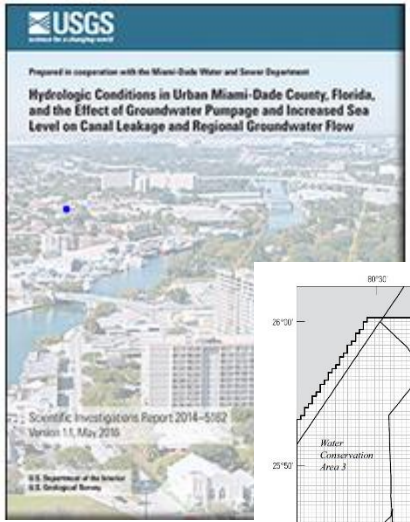


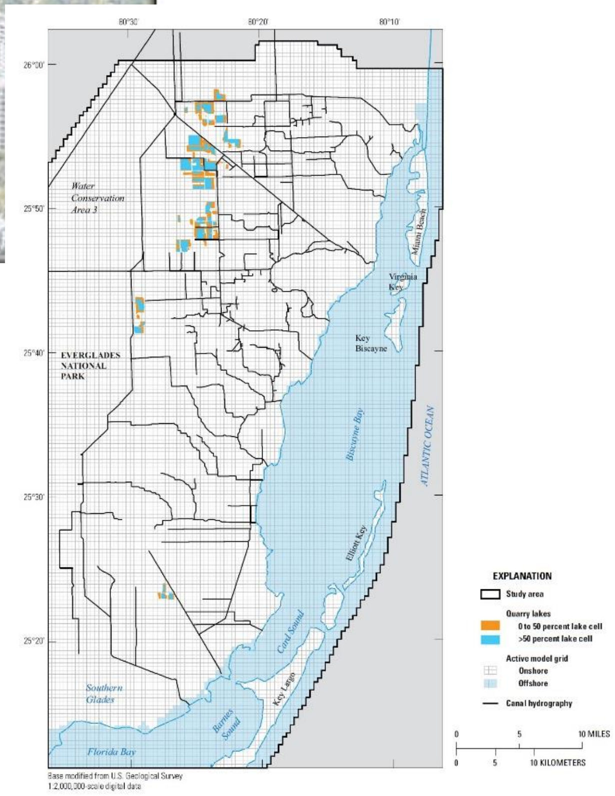
Sea Level Rise & Saltwater Intrusion





Groundwater Modeling

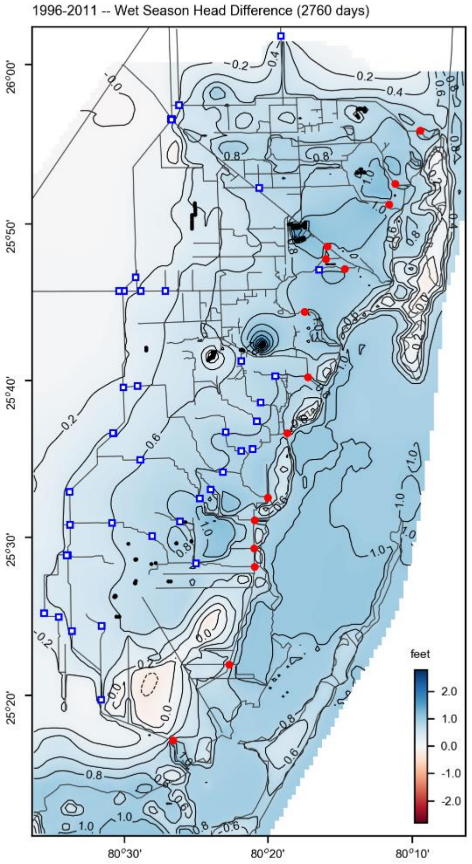




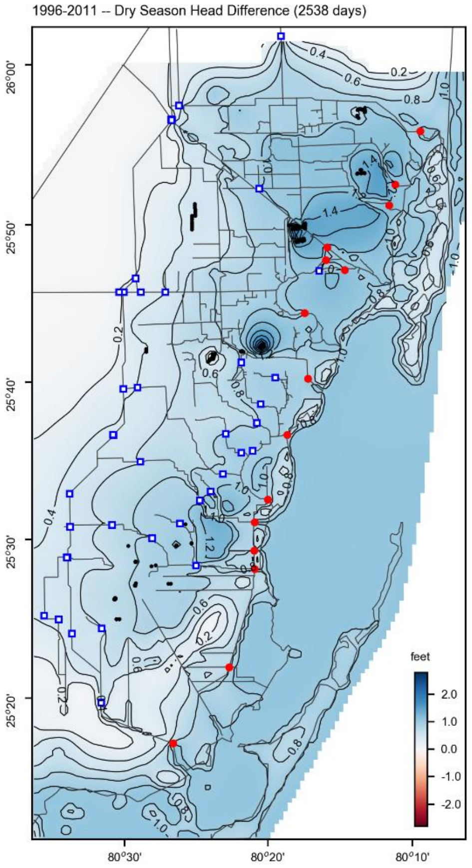
- **Developed by USGS for Miami Dade Water and Sewer Department (WASD)**
- **Most comprehensive ground water model with surface water routing capabilities**
- **Many of the processes need to be partially or fully re-worked to simulate the distant future (2060-2069)**

Preliminary Look at Results (increase in Water Table Elevation)

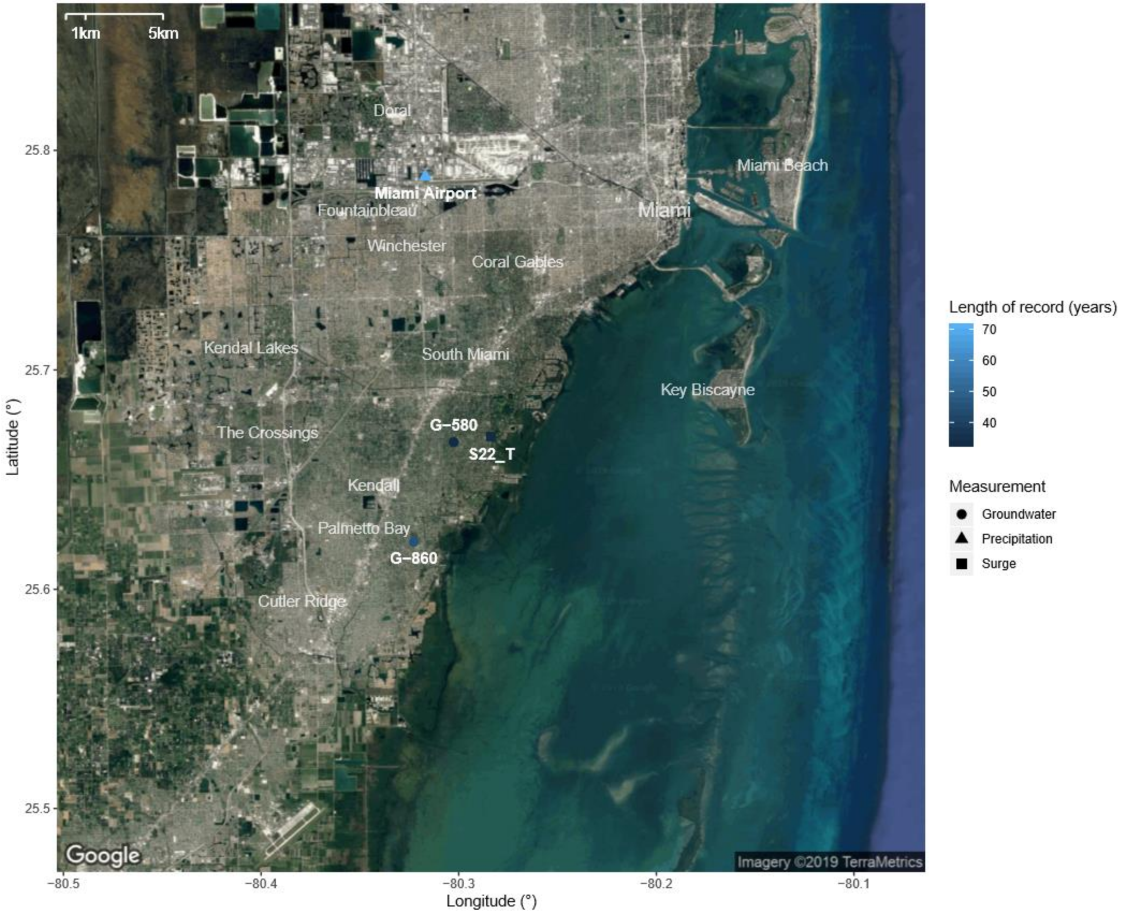
Wet Season



Dry Season



Compound Flooding: Copula Approach (UCF funded by SFWMD)



Rainfall:

Rain gauge at Miami Airport

Surge:

Pumping station S22_T

Groundwater:

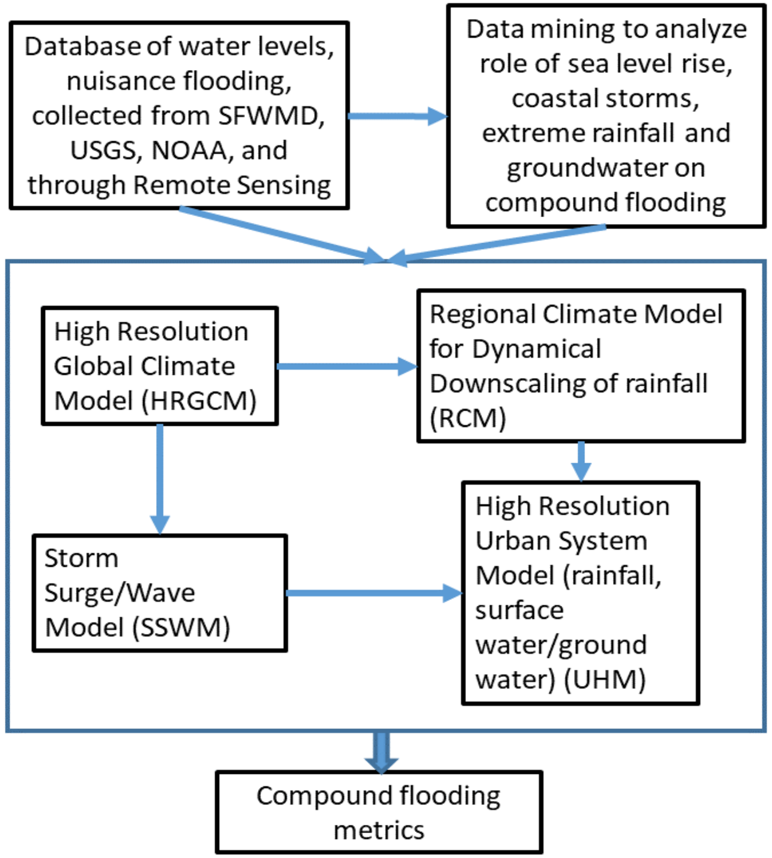
Well G-580 (& G-860)

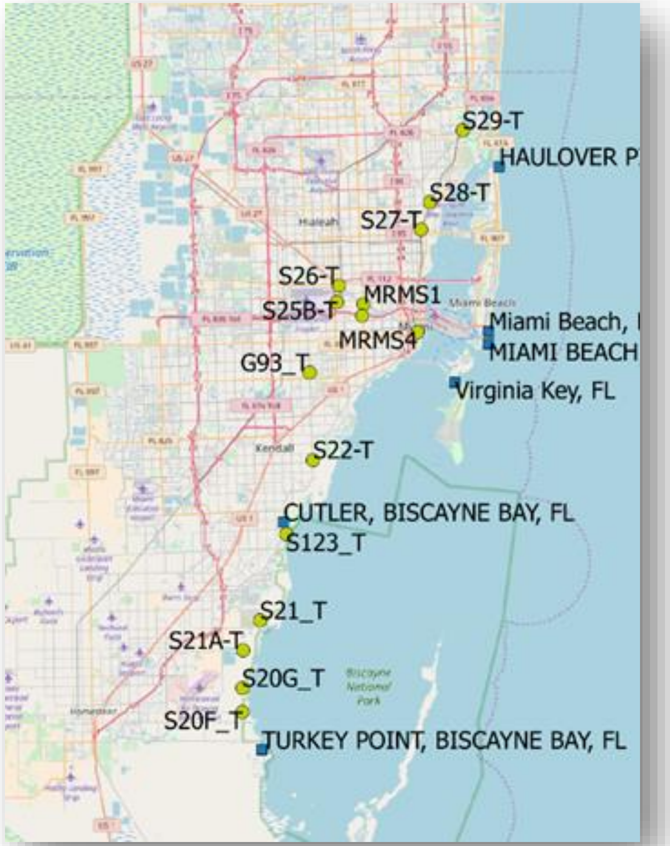
Dependence structure

- Independent
- Trivariate Gaussian copula
- Vine copula
- Heffernan and Tawn (2004) model

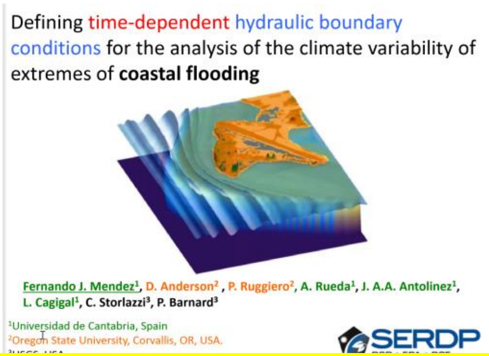
Synthetic Events of Compound Flooding

- **Compound Flooding Hazards due to Sea Level Rise, Coastal Storms, and Extreme Rainfall**



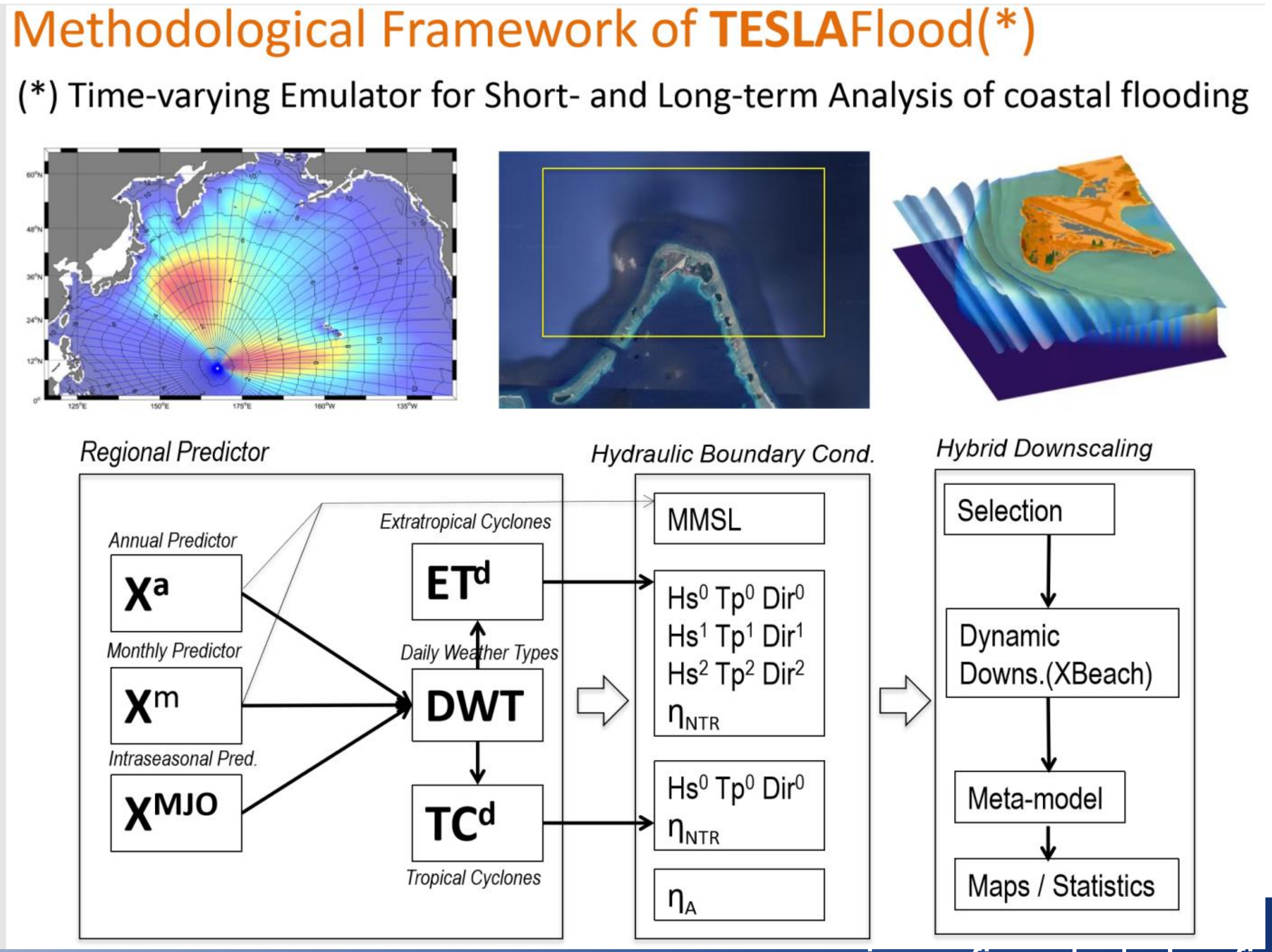


Time-Varying Emulator for Short- and Long-Term Analysis of Coastal Flooding


Defining time-dependent hydraulic boundary conditions for the analysis of the climate variability of extremes of coastal flooding

Fernando J. Mendez[1], D. Anderson[2], P. Ruggiero[2], A. Rueda[1], J. A.A. Antolinez[1], L. Cagigal[1], C. Storlazzi[3], P. Barnard[3]

[1]Universidad de Cantabria, Spain
[2]Oregon State University, Corvallis, OR, USA.



Developers:

<u>Oregon State University</u>

- Peter Ruggiero
- Dylan Anderson (PhD research)
    - Graduating soon)

<u>University of Cantabria</u>

- Fernando J. Mendez
- Ana Rueda
- Laura Cagigal

<u>USGS</u>

- Curt Storlazzi

Making a model of a model
(surrogate, meta-model, emulator)

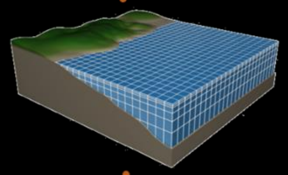
Inputs encompassing variability of total dataset

Case	dim1	dim2	dim3	…	dim21
#1	SLP_1	Hs_1	Tp_1		$M2_1$
#2	SLP_2	Hs_2	Tp_2		$M2_2$
#3	SLP_3	Hs_3	Tp_3		$M2_3$
…					
#N	SLP_N	Hs_N	Tp_N		$M2_N$

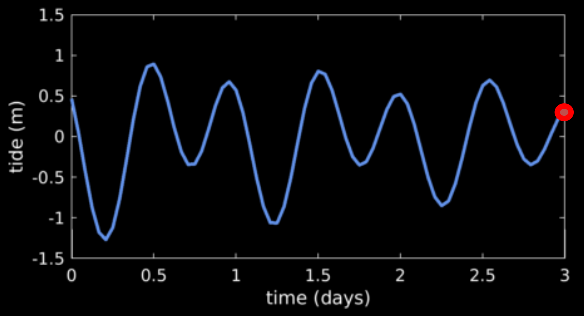
- MDA (Camus et al. 2011),
- Latin Hypercube (Parker et al. in review)

Develop a library of dynamic simulations

Dynamic simulation 1



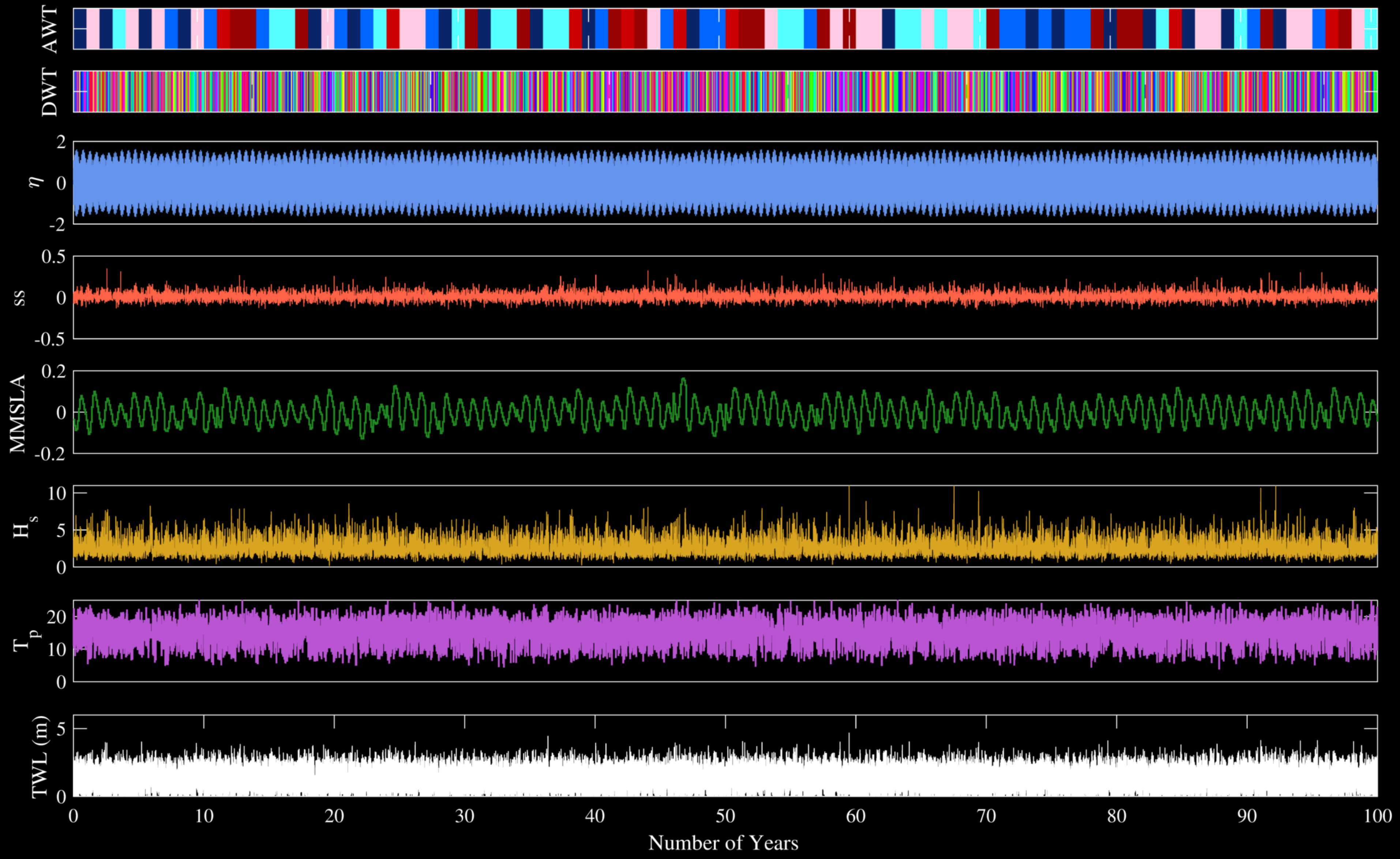
Dynamic simulation N



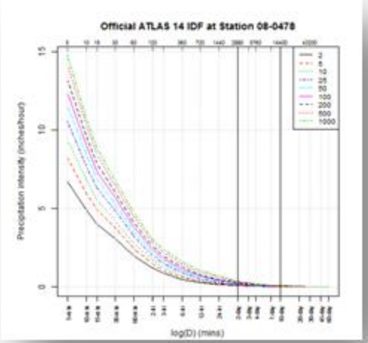
Surrogate model (interp. model of the model)

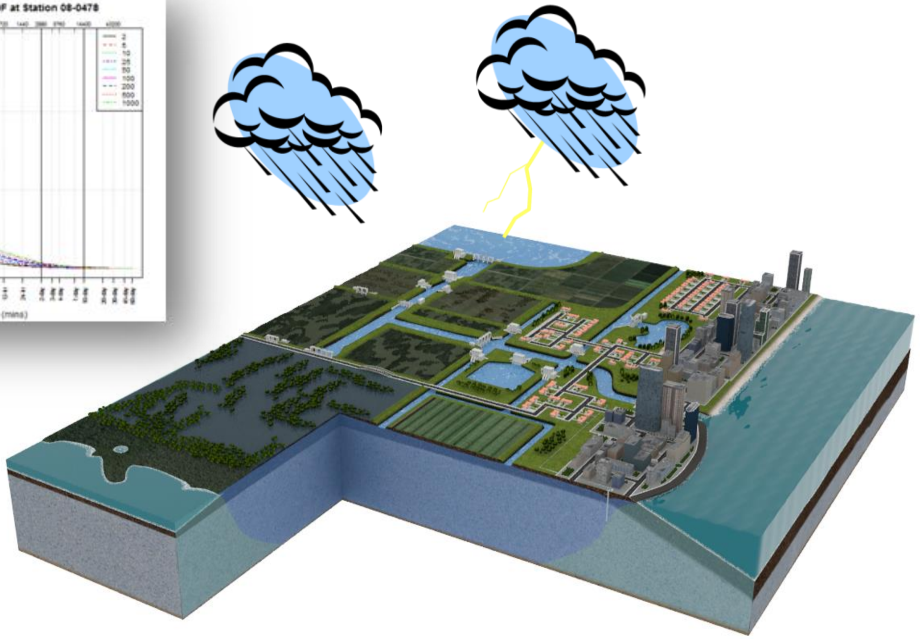
… “machine learning” …
Gaussian Process Reg.
Neural Networks
Radial Basis Functions
Design Trees
etc. etc.

San Diego Synthetic Record

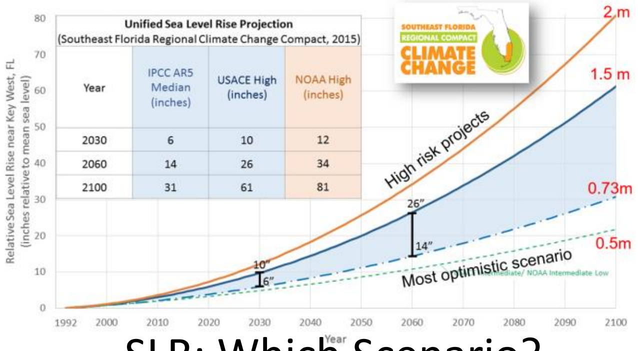


Uncertainties in the Nonstationary Environment





Rainfall Extremes: IDF Curves



SLR: Which Scenario?

Gulf Stream Episodic?

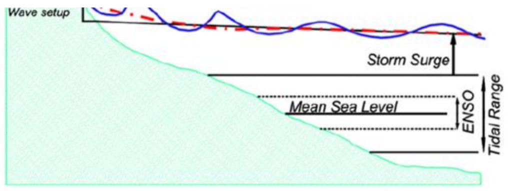


Fig. 2. Diagram illustrating the contributions to sea level due to tides, storm surge and wind-generated waves.

Future Storminess?

Dynamic Adaptive Policy Pathways (DAPP)

Decisions are made over time in dynamic interaction with the system and cannot be considered independently.

- An approach that explicitly includes decision making over time and sequences of decisions (pathways) under uncertainty.
- Supports planners to design a dynamic adaptive plans: short-term actions, long-term options, adaptation signals.

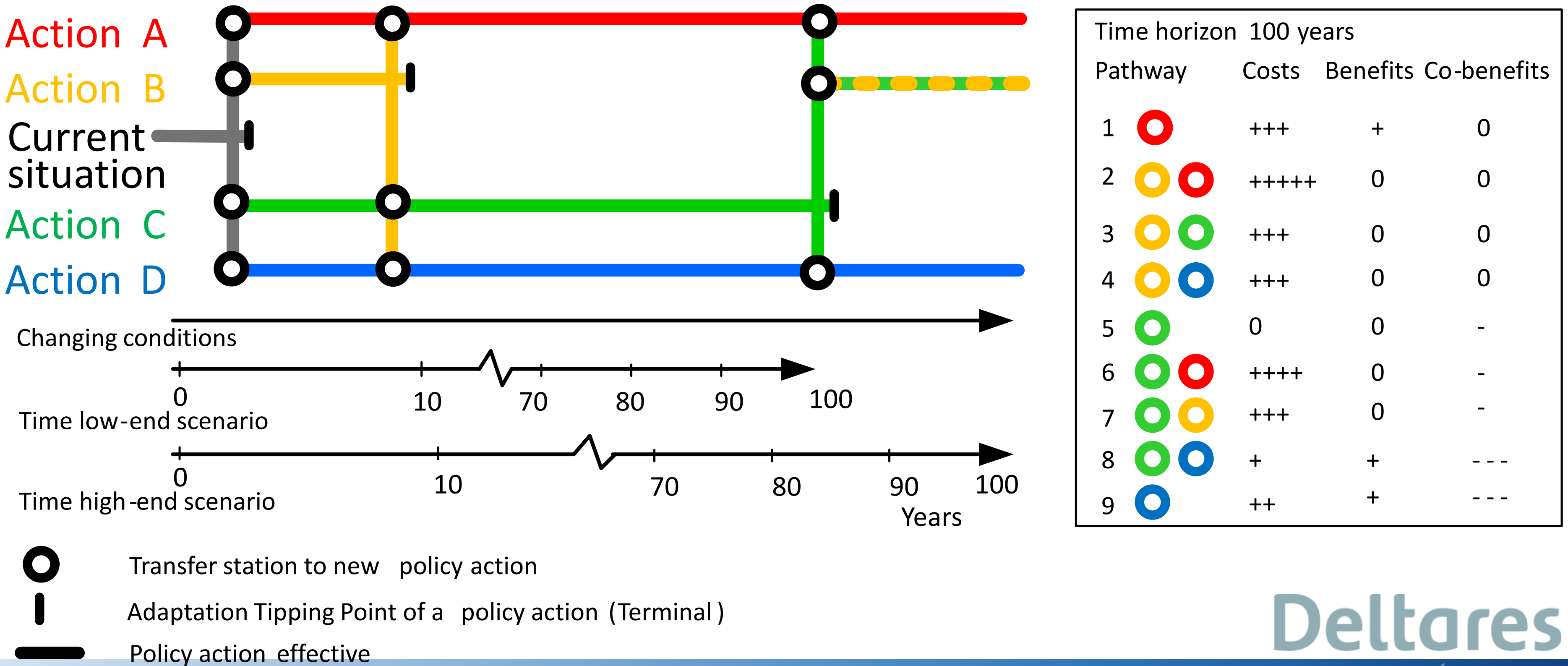
“Different roads leading to Rome”

Deltares
Enabling Delta Life

Haasnoot et al. (2013) Glob. Env. Change. 10.1016/j.gloenvcha.2012.12.006

Adaptation Pathways

Adaptation pathways maps show **different possible sequences of decisions** to achieve objectives. A scorecard helps to evaluate the pathways and decisions.

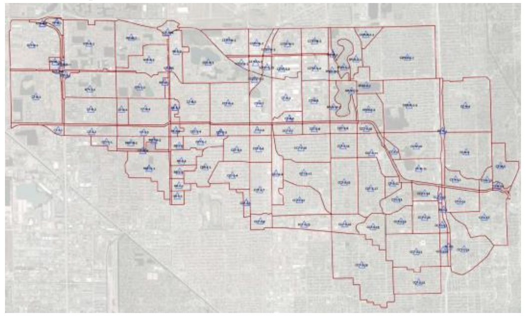


Haasnoot et al. (2013) Glob. Env. Change 10.1016/j.gloenvcha.2012.12.006

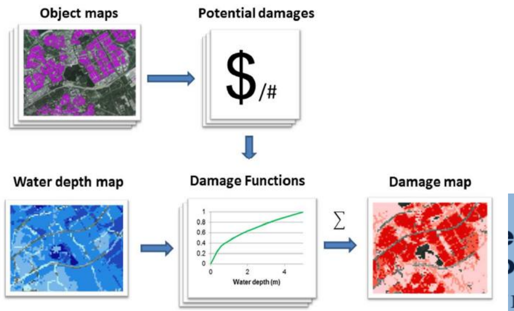
Flood Risk Management in Miami-Dade County (with Deltares

Hydrologic Drivers:
Rainfall; Storm Surge
Sea Level Rise

Hydrodynamic Model
XPSWMM

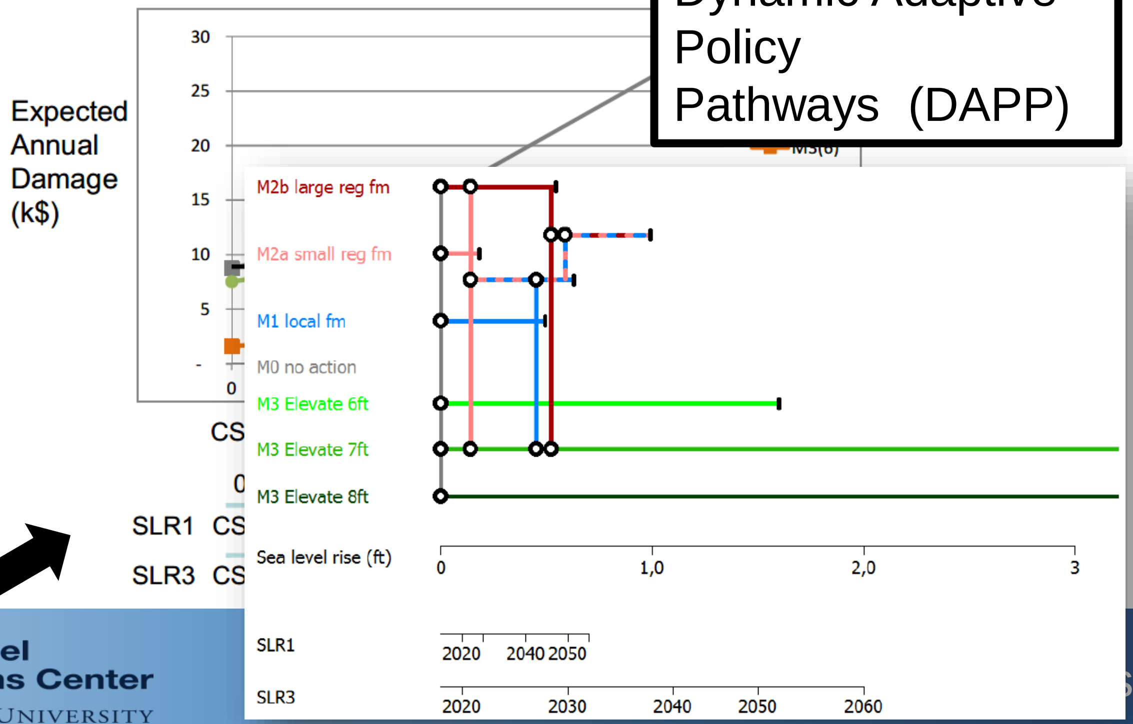


Delft-FIAT damage model



Adaptation Options:
- M1:Local Flood Mitigation (flood walls, pumps)
- M2:Regional Flood Mitigation (Forward pumping at outlet)
- M3:Land-use mitigation (elevate buildings, roads)

Dynamic Adaptive Policy Pathways (DAPP)



Questions?

KEY Research papers

Revisiting the Concepts of Return Period and Risk for Nonstationary Hydrologic Extreme Events

3

Jose D. Salas, M.ASCE[1]; and Jayantha Obeysekera, M.ASCE[2]

Quantifying the Uncertainty of Design Floods under Nonstationary Conditions

Jayantha Obeysekera, M.ASCE[1]; and Jose D. Salas, M.ASCE[2]

J. Hydrol. Eng. 2014.19:1438-1446.

Frequency of Recurrent Extremes under Nonstationarity

Jayantha Obeysekera, M.ASCE[1]; and Jose D. Salas, M.ASCE[2]

(paper published online: J. Hydrologic Engineering)

Techniques for assessing water infrastructure for nonstationary extreme events: a review

J.D. Salas[a], J. Obeysekera[b], and R.M. Vogel[c] (Hydrological Sciences Journal)