Testing Western Everglades Restoration Project ecological resilience outside the physical model time domain

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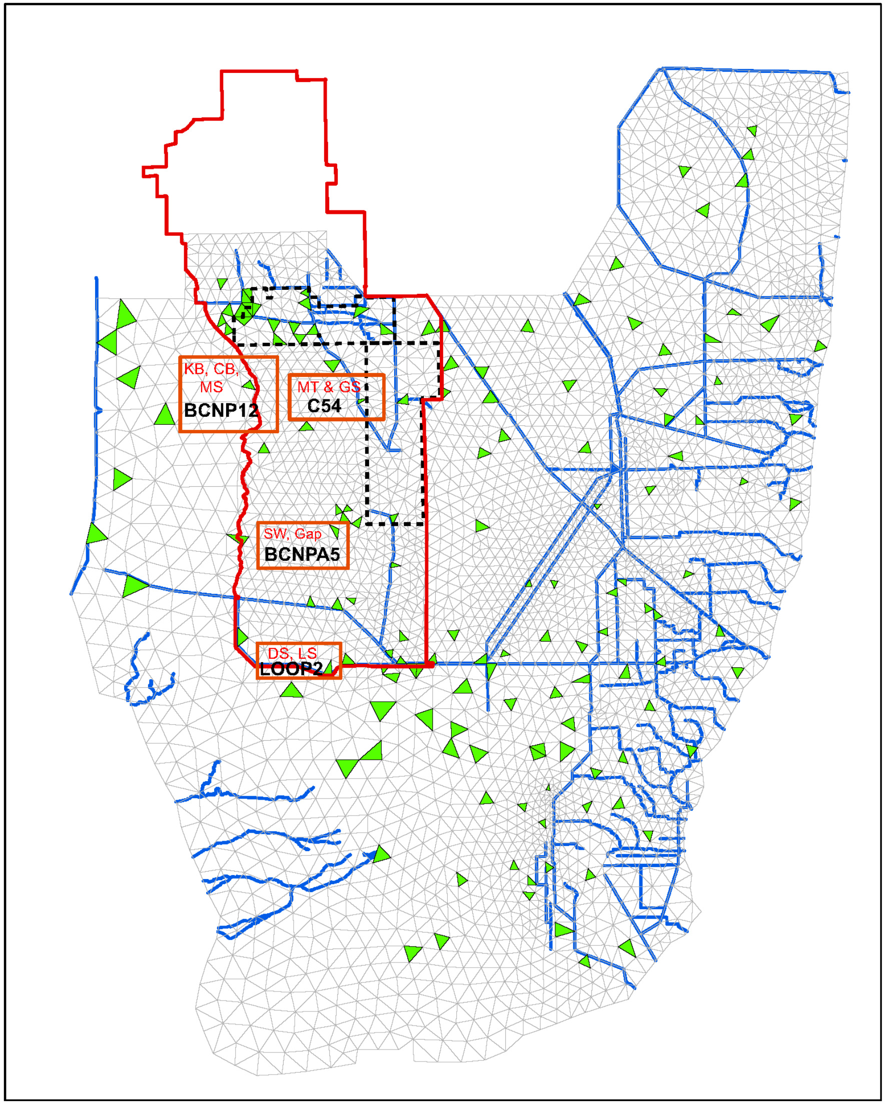
Presentation highlights

- WERP Ecological Resilience Measure (purpose and Role)
- Resilience definition and measures
- Resilience Predictive Formula (Hydrologic Model Emulator)
- Formula Results
- Application
- Conclusion

WERP Gages MAP for Resilience PM

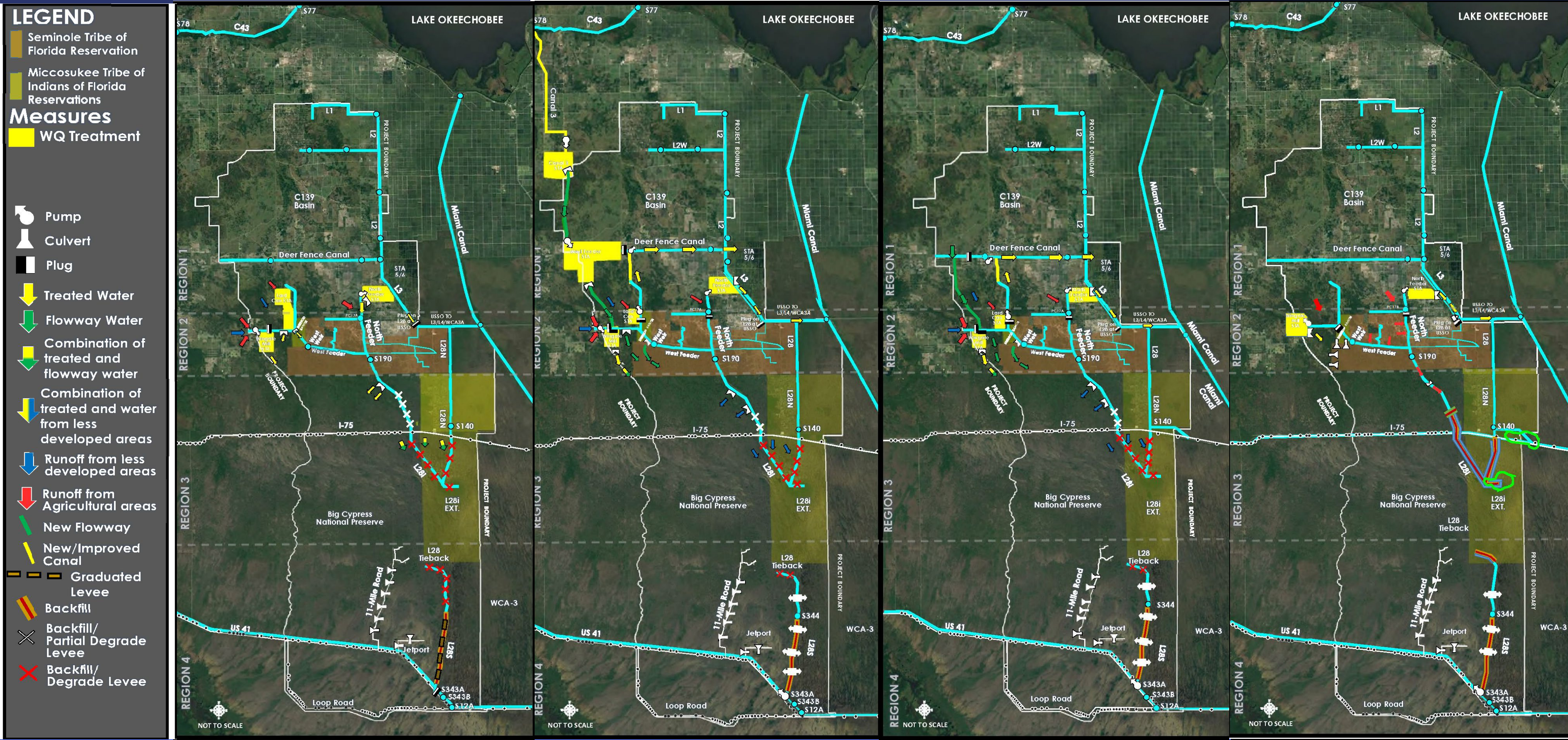


WERP Ecological Resilience Measure Purpose, Role and Measure

- we seek to rank the WERP alternate plans on how well they improve conditions for the project objectives while remaining within the planning constraints
- Well-thought-out assumptions can be applied across the array of plans during modeling to produce the rankings
- The purpose of the WERP ecological resilience measure is to rank the alternate plans on their ability to sustain their ecological benefits in the face of ecological uncertainty and adversity
- Identify a stress test tool of challenging the project alternatives with different conditions

Alternate Plans to WFWO2 (Base)

WALT1R WALT3R WALT3RNL WALTH

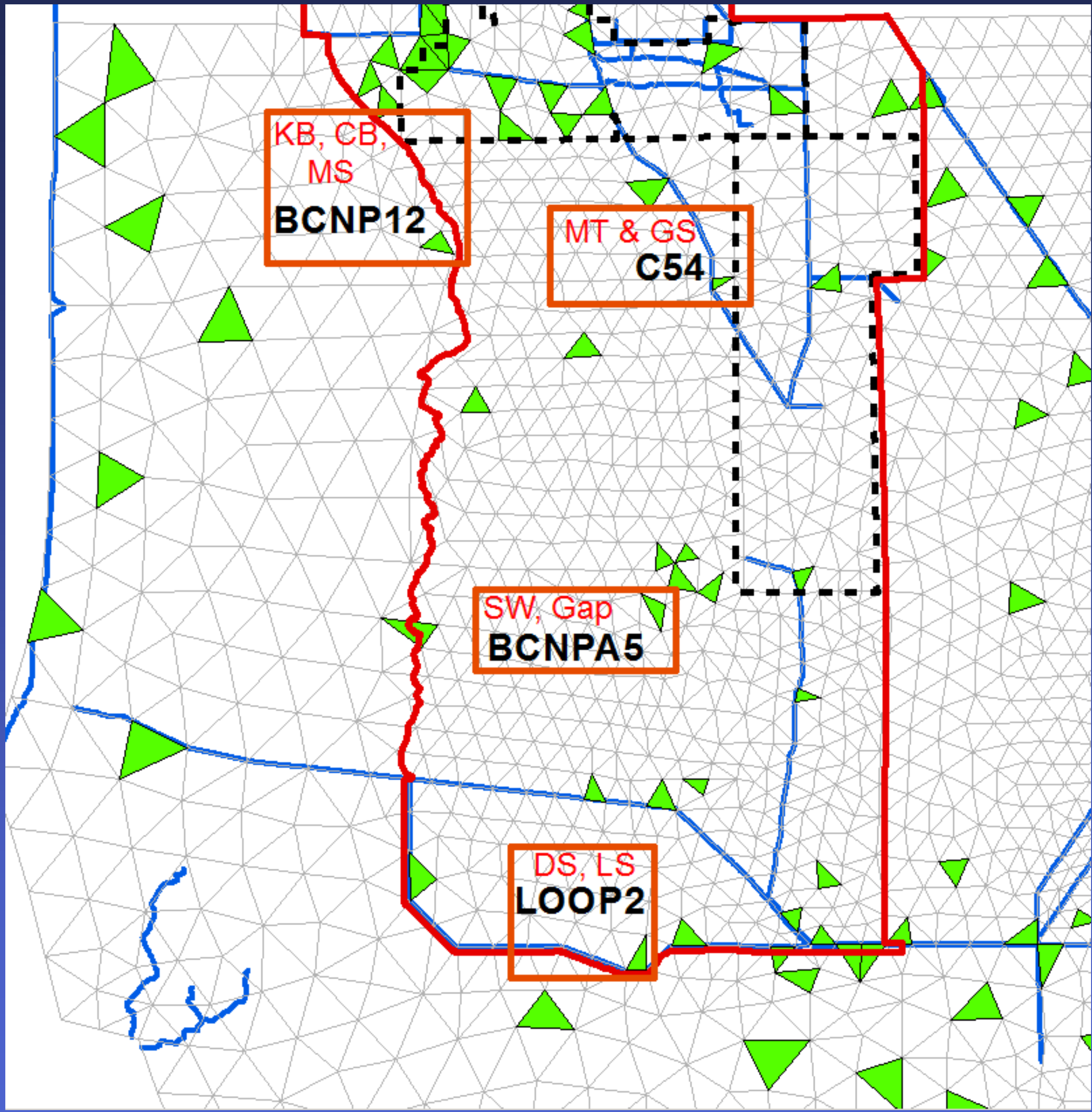


Resilience Measures

Name	Measure quantification
Fire Moderate Intensity Risk Index	The total sum of water depth below -0.5 ft.
Fire High Intensity Risk Index	The total sum of water depth below -1.5 ft.
Vegetation Annual Continuous Hydroperiod (May 1 - April 30)	Annual Frequency Distribution of day count of water depth above ground surface
Vegetation Annual Minimum 17-day Water Depth (June 1 – October 31)	Frequency Distribution
Vegetation Annual Maximum 17-day Water Depth (November 1 – May 31)	Frequency Distribution

Resilience Measure Locations

BCNP_BCNP12
BCNP_BCNPA5
BCNP_LOOP2
C54



Period of Records

- The resilience is how the performance holds under different climatic conditions.
- Main Model period of record 1965-2005
- Two Additional different periods of record are considered
  - 1914-1964
  - 2006-2016
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Objective

- Develop a statistical model for the WREP to predict stage (the basis for te aforementioned performance measures) at the aforementioned four gage locations under any alternative scenario for the aforementioned periods of record.
- Flow and PET can not be input predictors for the model since they are not available outside the regional model Period of Record.
- Therefore, the challenge is to develop a recursive model of stage based on rainfall only.
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Approach

- Develop an AutoRegressive Neural Network based formula with eXogenous variable (ARX) to predict stage as function of rainfall.
- The stage is the autoregressive variable where rainfall is the exogenous variable.
- Apply the formula to the aforementioned locations for the aforementioned periods of record to predict stage.
- Use stage to calculate the aforementioned Resilience Measures.

ARX predictive formula Outline

- Model formulation.
- Data preparation and partition
- Data transformation using Principal Component Analysis
- Neural Network, ANN, Parameterization
- Application

ARX predictive formula
The Model

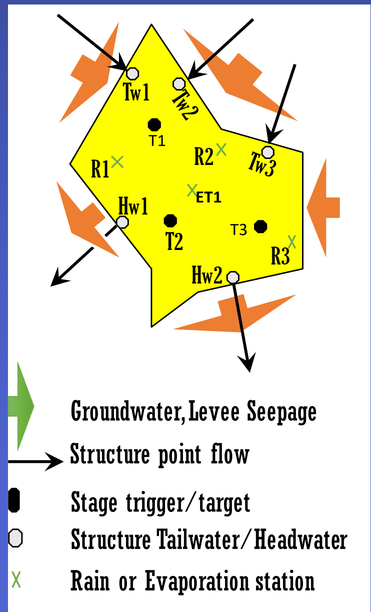
ARX represented by Multivariate State Space Models implemented as Autoregressive Artificial Neural Networks model with exogenous input. They are formulated to honor the physical system dynamics of a given region and provide a robust means to emulate more detailed physical models or observed data. (Example is Water Conservation Area 2A in CEPP)

Formulation

Simple form $Stg_t = f(Stg_{t-1}, Rain_t)$

$$s_t = \sum_{i=0}^{q-1} \Gamma_i u_{t-i} + \sum_{j=1}^{p} \Phi_j s_{t-j} + \nu + \omega_t$$

- *q,p* → input and output maximum time delays (model orders)
- *n, m* → number of state and exogenous variables
- ***u*** → *mxq* residual exogenous input (flow, rainfall, and ETp) matrix
- ***s*** → *p x n* residual state variable (stage) matrix
- Γ → *nxm* exogenous coefficient matrix
- Φ → *p x p* state transition matrix
- ν → bias vector
- ω → random vector with zero mean and a covariance Matrix



ARX predictive formula
Data Selection and Preparation

- Rainfall: 7 Basins averaged rainfall

C139	*East_Collier*	*ENP*	*Feeder*	*L28*	*L28_Gap*	*WCA3A*

- Stage: 6 gage locations

BCNP12	BCNPA5	LOOP2	C54	3A-28	3A-SW

- ARX general form is $Stg_t = f(Stg_{t-1}, \mathrm{Rain}_t)$

DATA Partition and Standardization

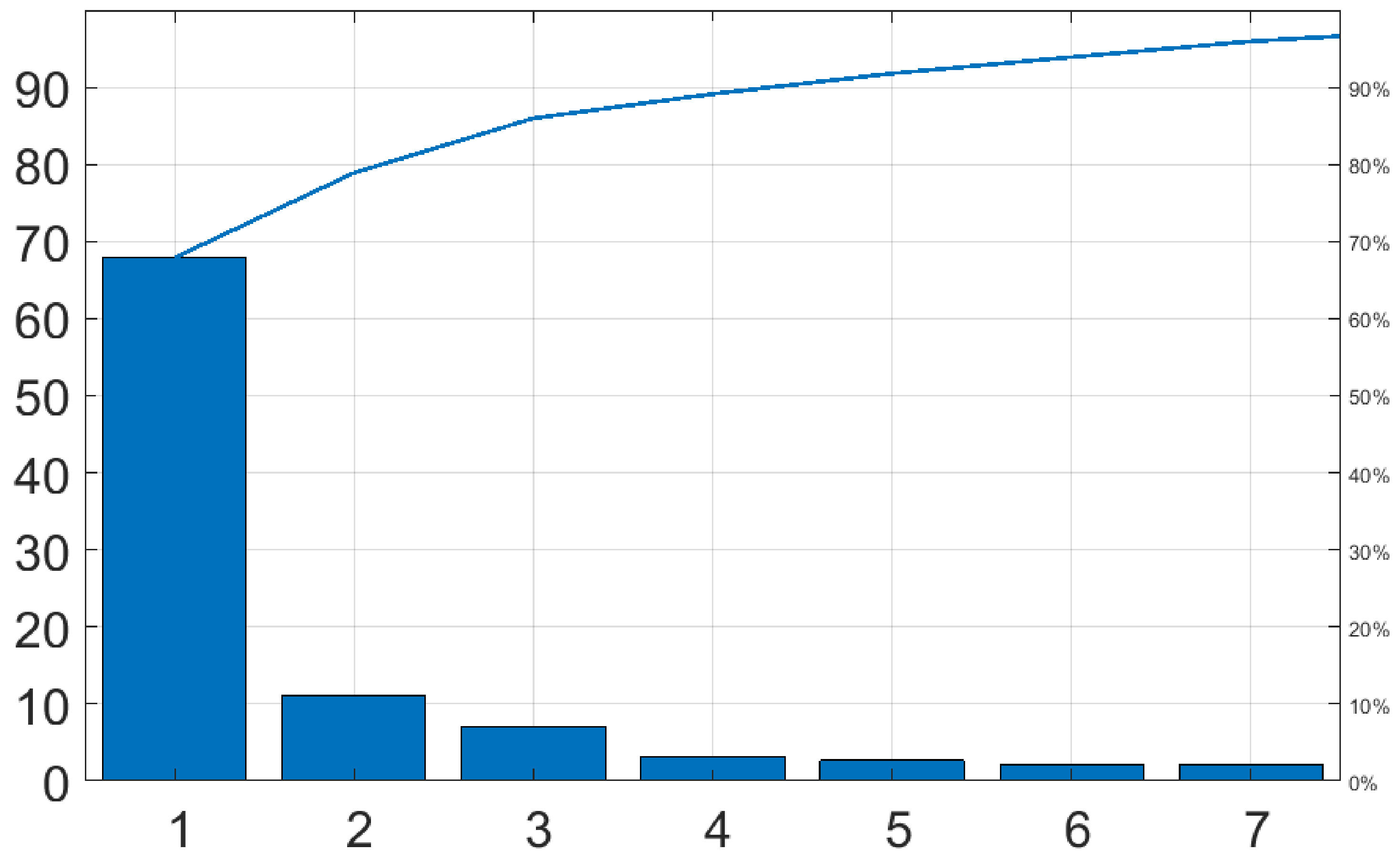
- 1965-1989 Modeling period,
  - 1965-1983 Development period
  - 1984-1989 Verification period
- 1990-2000 Validation period

- Data for week t is standardized:

$$x_{t,i} = \frac{s_{t,i} - \mu_i}{\sigma_i}$$

- μ_i and σ_i are the <u>modeling data</u> mean and standard deviation for time series i

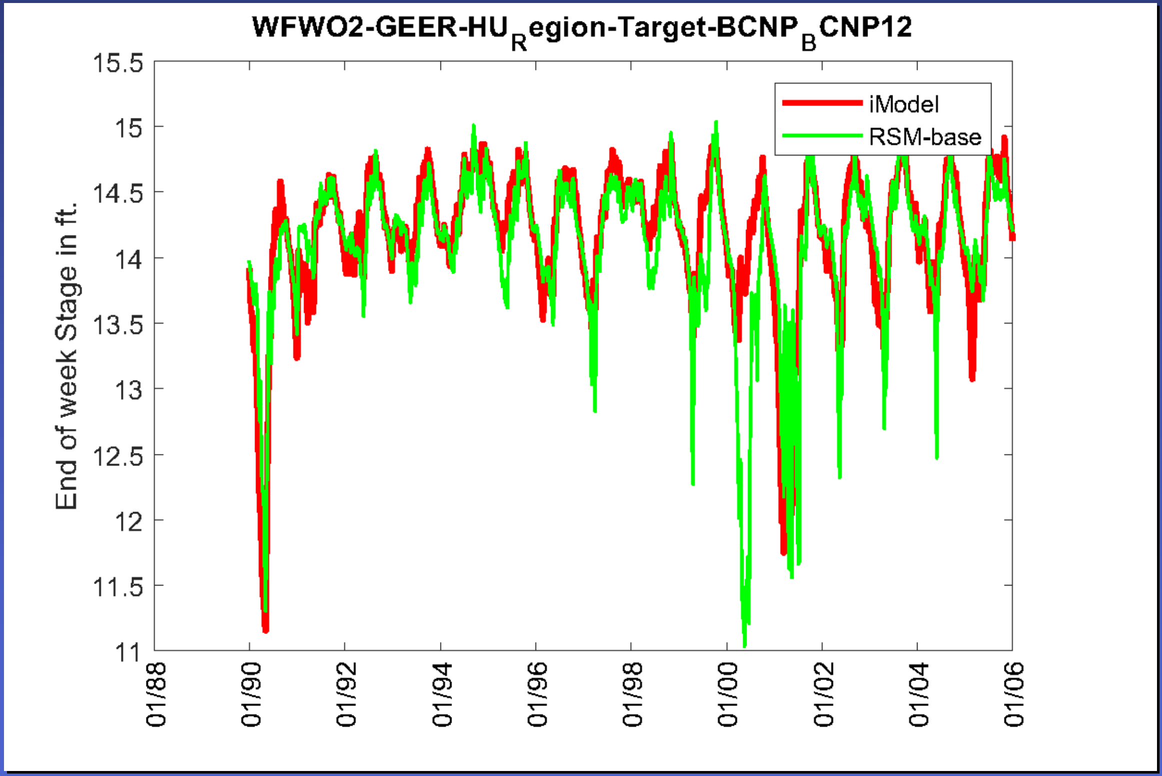
ARX predictive formula Principal Components



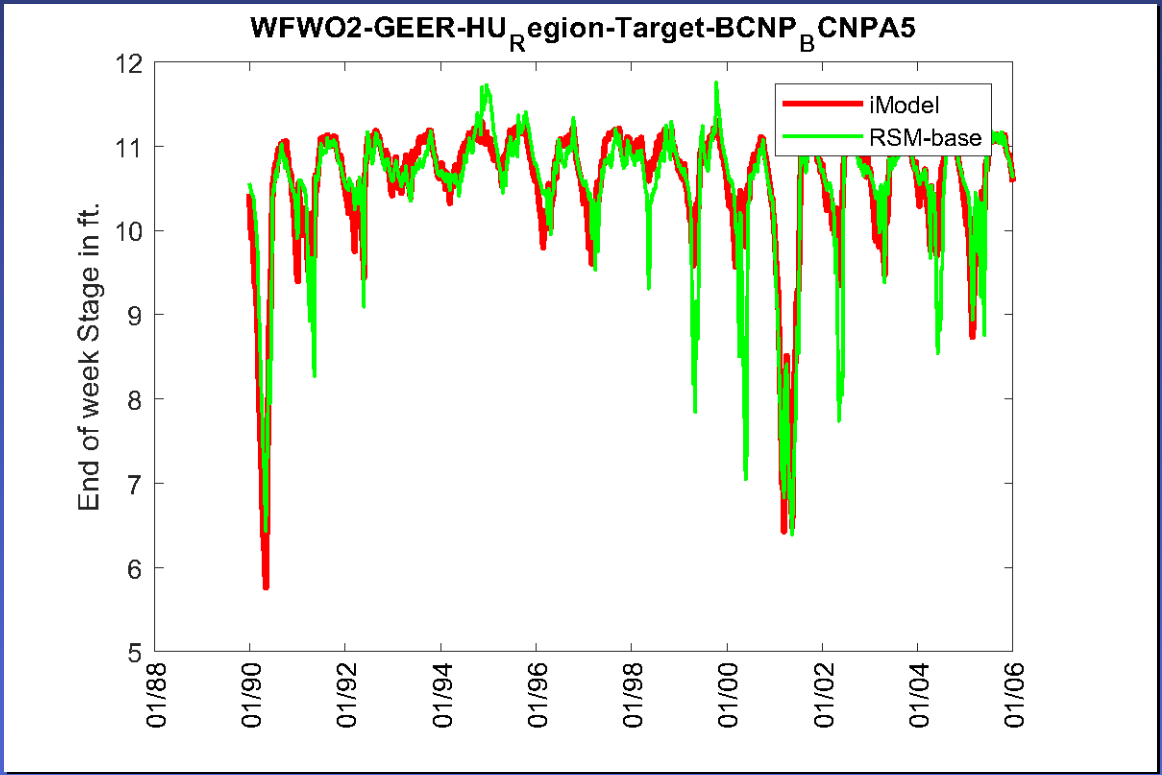
ARX predictive formula Testing for 1990-2005 period

- Test ARX by applying at the 4 locations of interest during the testing period
- (Called iModel in the plot legend)

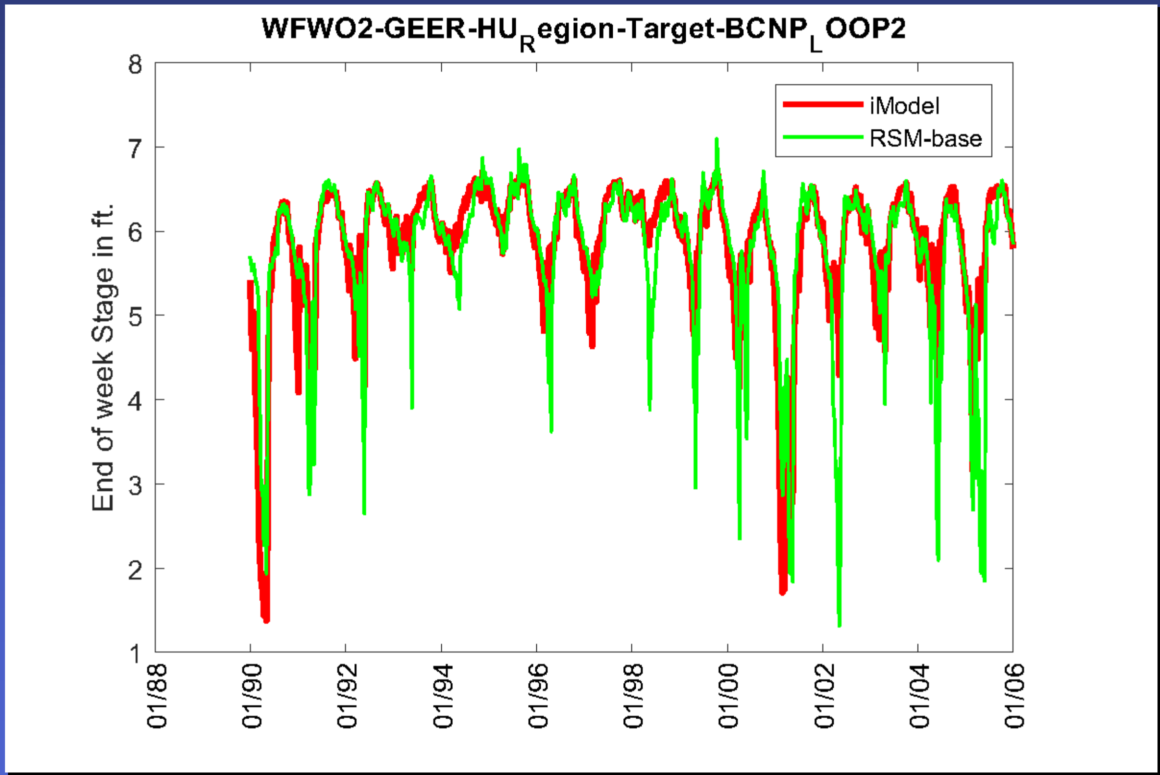
ARX predictive formula Testing for 1990-2005 period



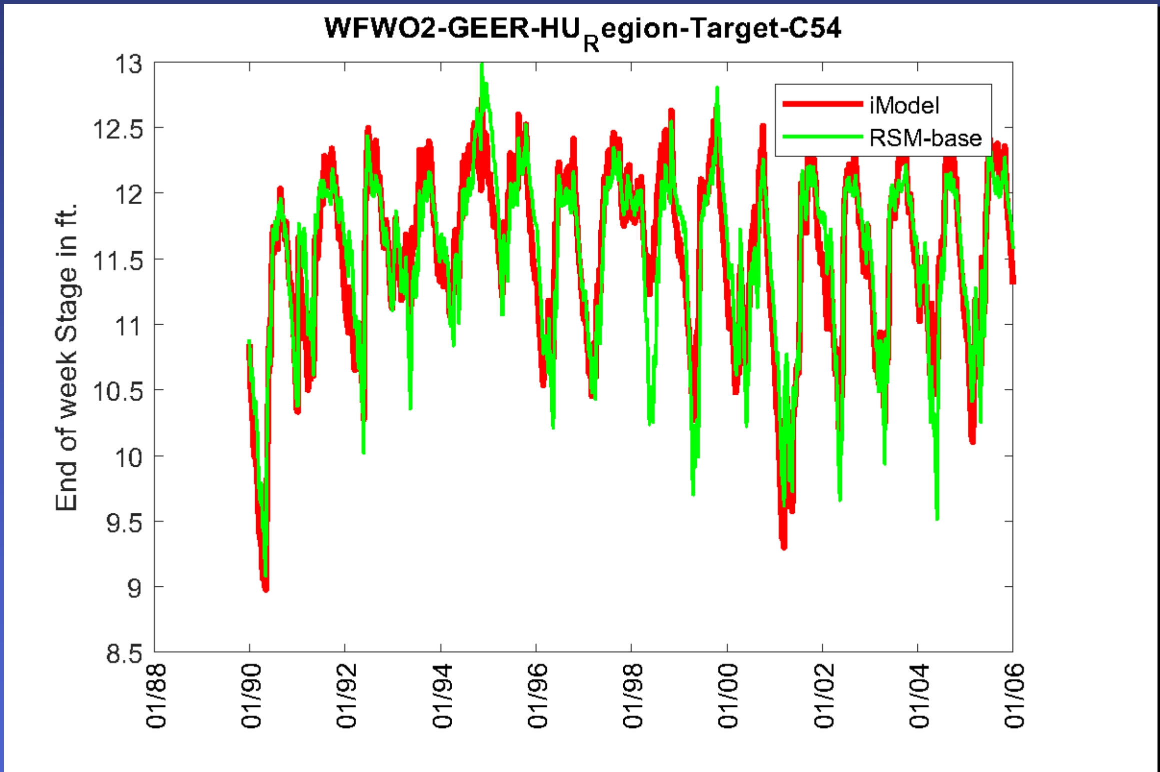
ARX predictive formula Testing for 1990-2005 period



ARX predictive formula Testing for 1990-2005 period

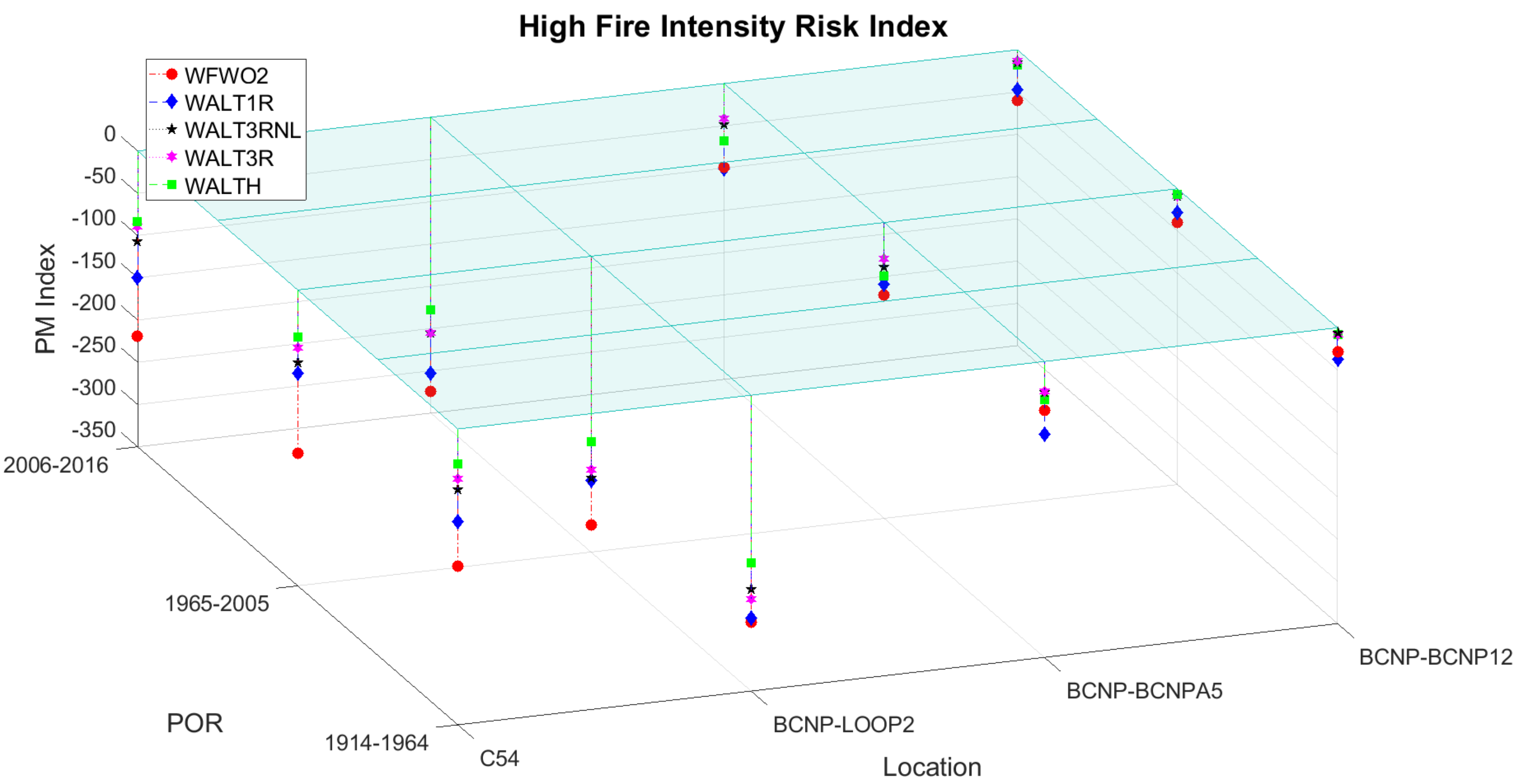


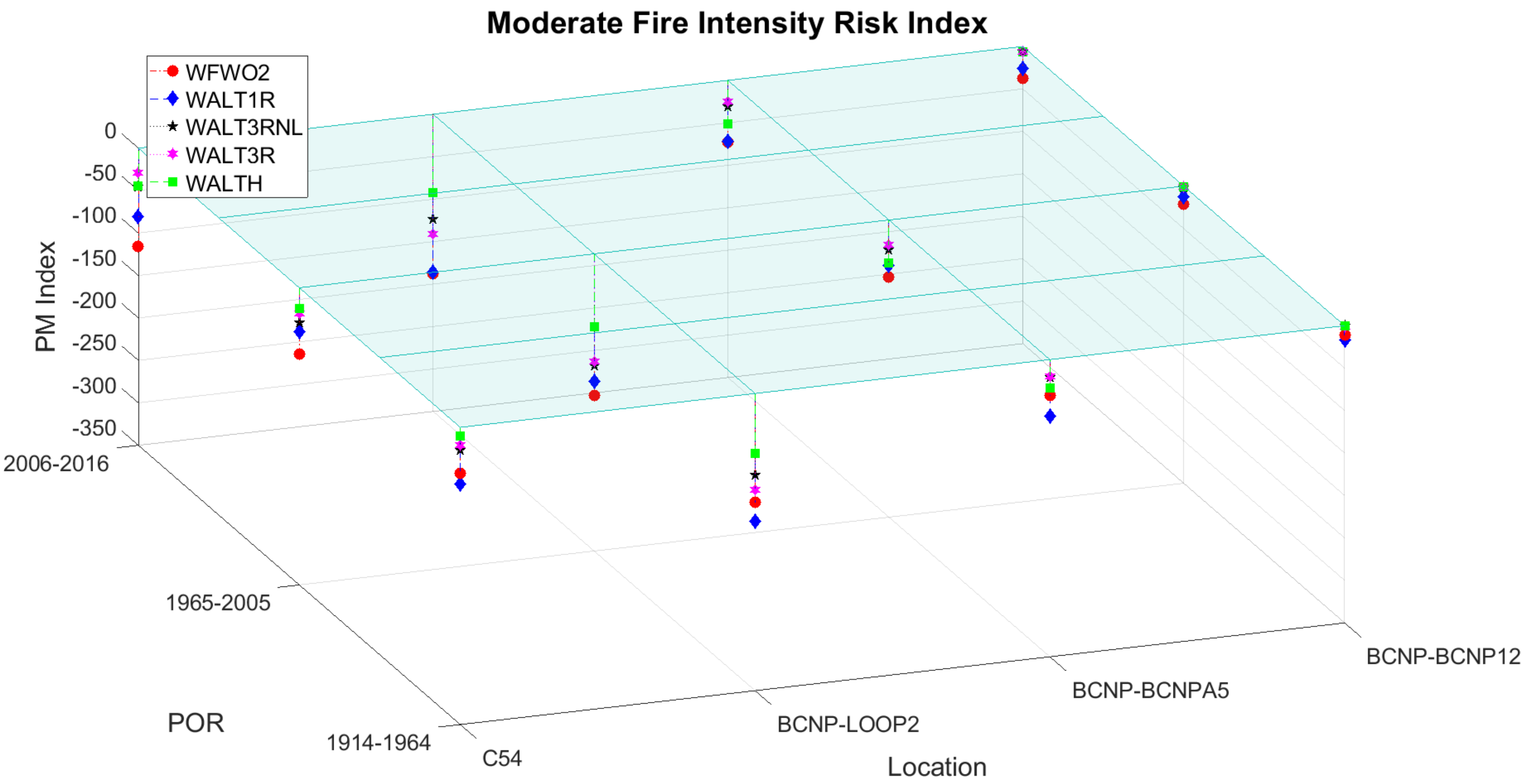
ARX predictive formula Testing for 1990-2005 period

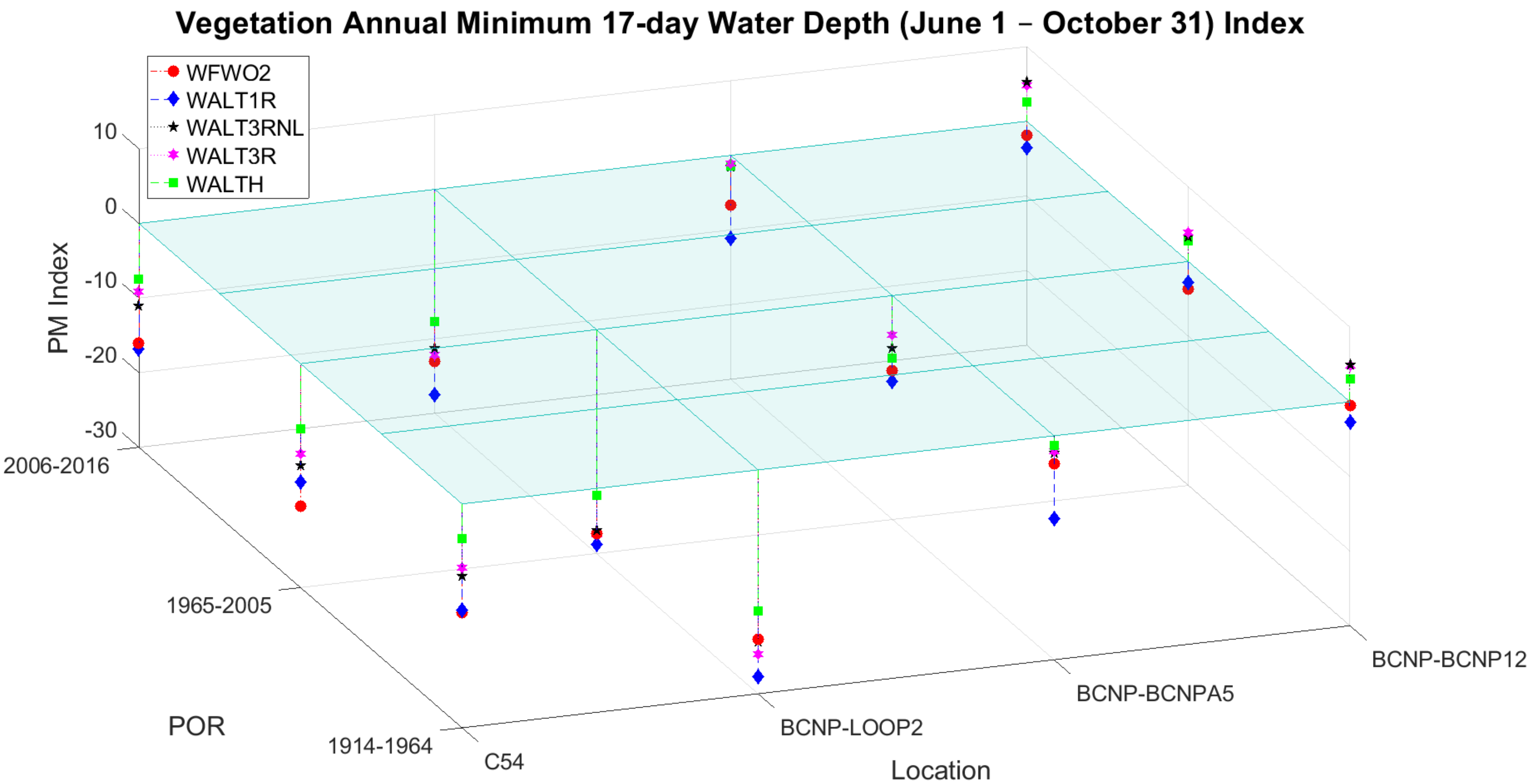


ARX predictive formula Application

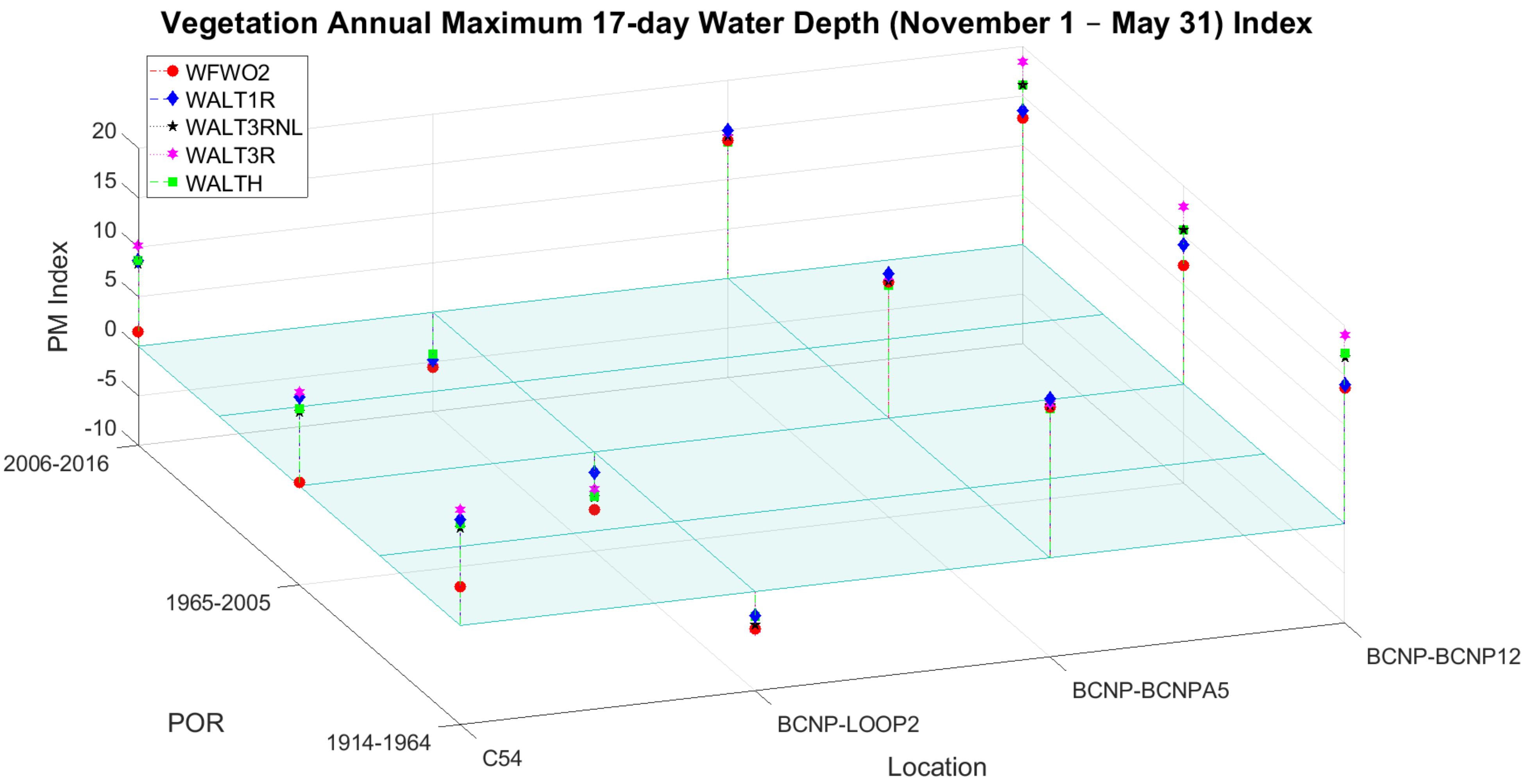
- Apply ARX formula to 5 alternatives and 3 Periods of record (5X3 = 15 runs) to predict stage at 4 gages per run.
- For each run, obtain the aforementioned 5 Performance Measures at the 4 gage locations
- For each PM, evaluate system's performance under each alternative at the different gage locations and the different PORs.

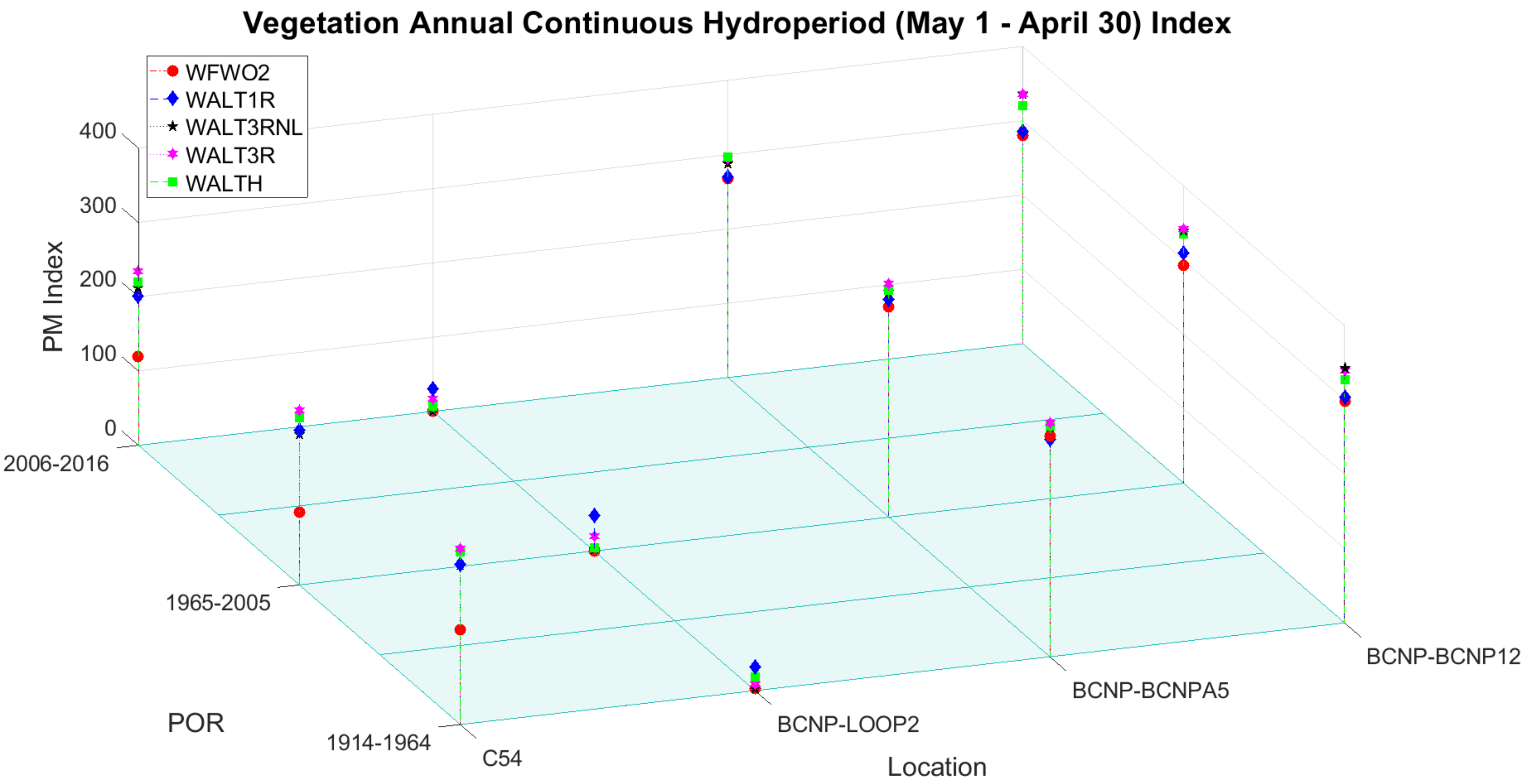

High Fire Intensity Risk Index
WFWO2
WALT1R
WALT3RNL
WALT3R
WALTH
PM Index
0
-50
-100
-150
-200
-250
-300
-350
2006-2016
1965-2005
1914-1964
POR
C54
BCNP-LOOP2
BCNP-BCNPA5
BCNP-BCNP12
Location


Moderate Fire Intensity Risk Index
WFWO2
WALT1R
WALT3RNL
WALT3R
WALTH
0
-50
-100
-150
-200
-250
-300
-350
PM Index
2006-2016
1965-2005
1914-1964
POR
C54
BCNP-LOOP2
BCNP-BCNPA5
BCNP-BCNP12
Location



Vegetation Annual Minimum 17-day Water Depth (June 1 – October 31) Index
WFWO2
WALT1R
WALT3RNL
WALT3R
WALTH
PM Index
10
0
-10
-20
-30
2006-2016
1965-2005
1914-1964
POR
C54
BCNP-LOOP2
BCNP-BCNPA5
BCNP-BCNP12
Location


Vegetation Annual Maximum 17-day Water Depth (November 1 – May 31) Index
WFWO2
WALT1R
WALT3RNL
WALT3R
WALTH
PM Index
20
15
10
5
0
-5
-10
2006-2016
1965-2005
1914-1964
POR
C54
BCNP-LOOP2
BCNP-BCNPA5
BCNP-BCNP12
Location


Vegetation Annual Continuous Hydroperiod (May 1 - April 30) Index
WFWO2
WALT1R
WALT3RNL
WALT3R
WALTH
PM Index
400
300
200
100
0
2006-2016
1965-2005
1914-1964
POR
C54
BCNP-LOOP2
BCNP-BCNPA5
BCNP-BCNP12
Location

Global Performance Index

- To enable comparison of Alternative performance. For each of the five PMs, compile all results across gages and periods of records, S_{pm}.
- Obtain mean and standard deviation μ_{pm} and σ_{pm}
- Standardize all $S_{pm} \rightarrow x_{pm}$
- Global Performance Index

$$x_{pm,i} = \frac{s_{pm,i} - \mu_{pm}}{\sigma_{pm}}$$

$$\text{AltIndex(i)} = \sum_{pm=1}^{5} x_{pm,i}$$

Global Performance Index

•Do the following for each Performance Measure *Pm*,

- Compile all results across gages, PORs, and Alternatives into one dimensional array V_{pm}
- Obtain associated μ_{pm} and σ_{pm}
- Standardize all data
- Global Performance Index → a measure of alternative performance for each PM.
- Overall Performance Index → a measure overall alternative performance

$$x_{pm,i} = \frac{s_{pm,i} - \mu_{pm}}{\sigma_{pm}}$$

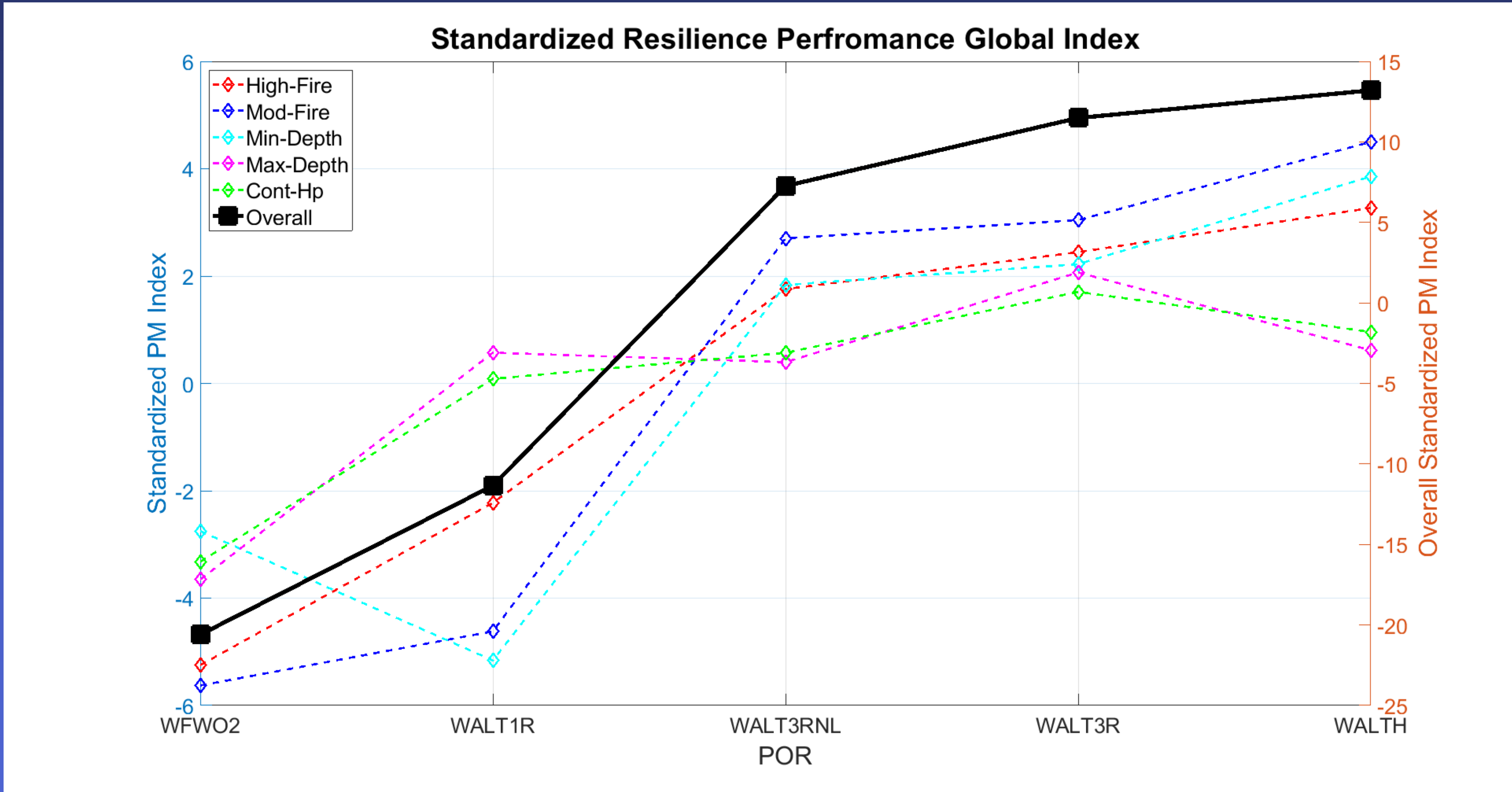
INDEXalt(i)=$\sum_{pm=1}^{5} x_{pm,i}$

Global and Overall Standardized Performance Index

	WFWO2	WALT1R	WALT3RNL	WALT3R	WALTH
High Fire	-5.25	-2.22	1.76	2.45	3.27
Moderate Fire	-5.63	-4.62	2.70	3.05	4.50
aMin_Dp	-2.75	-5.16	1.83	2.22	3.85
aMax_Dp	-3.66	0.57	0.40	2.07	0.62
aCHP	-3.32	0.09	0.57	1.71	0.96

	WFWO2	WALT1R	WALT3RNL	WALT3R	WALTH
Total	-20.60	-11.35	7.26	11.49	13.20

Global and Overall Performance Index



- QUESTIONS ?