A GENERAL PURPOSE RISK ASSESSMENT SYSTEM SUPPORTING BLACK SWAN THEORY

FRAMEWORK FOR INTEGRATING COMPLEX UNCERTAIN SYSTEMS (FICUS)

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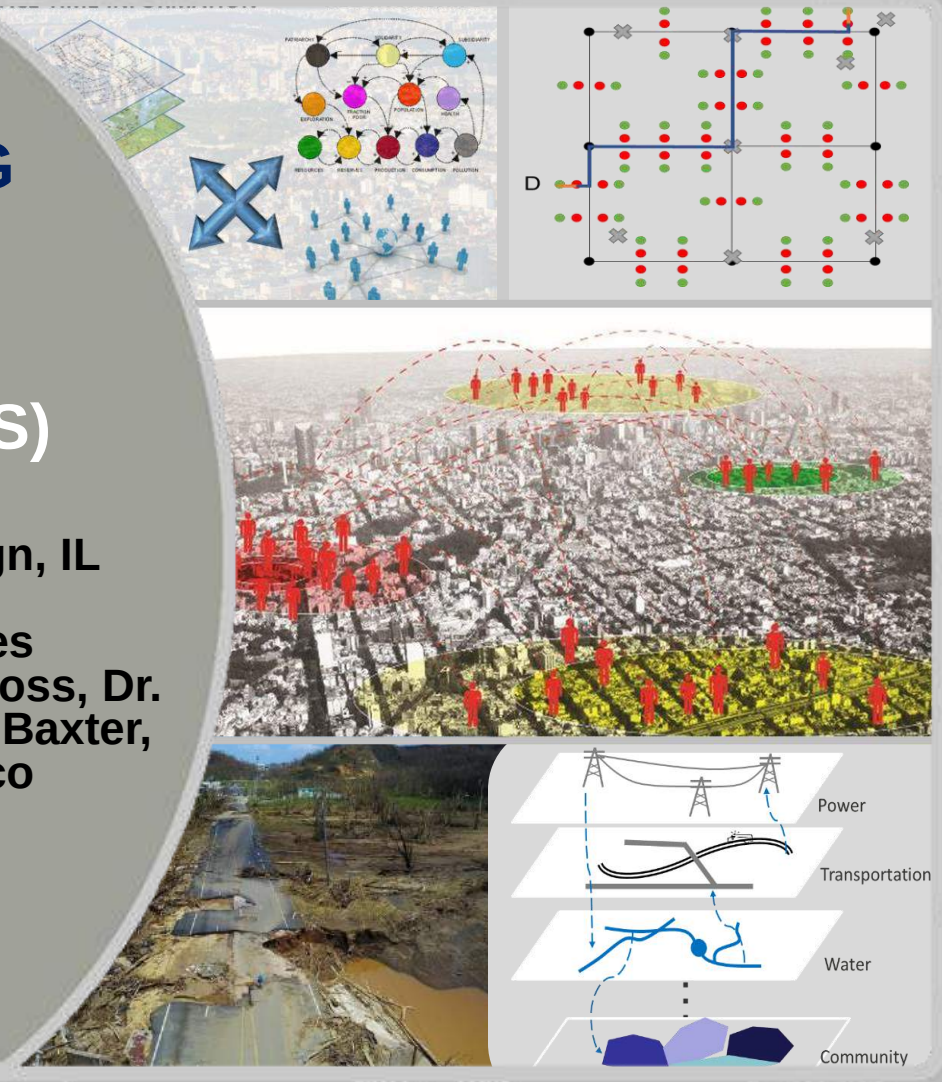

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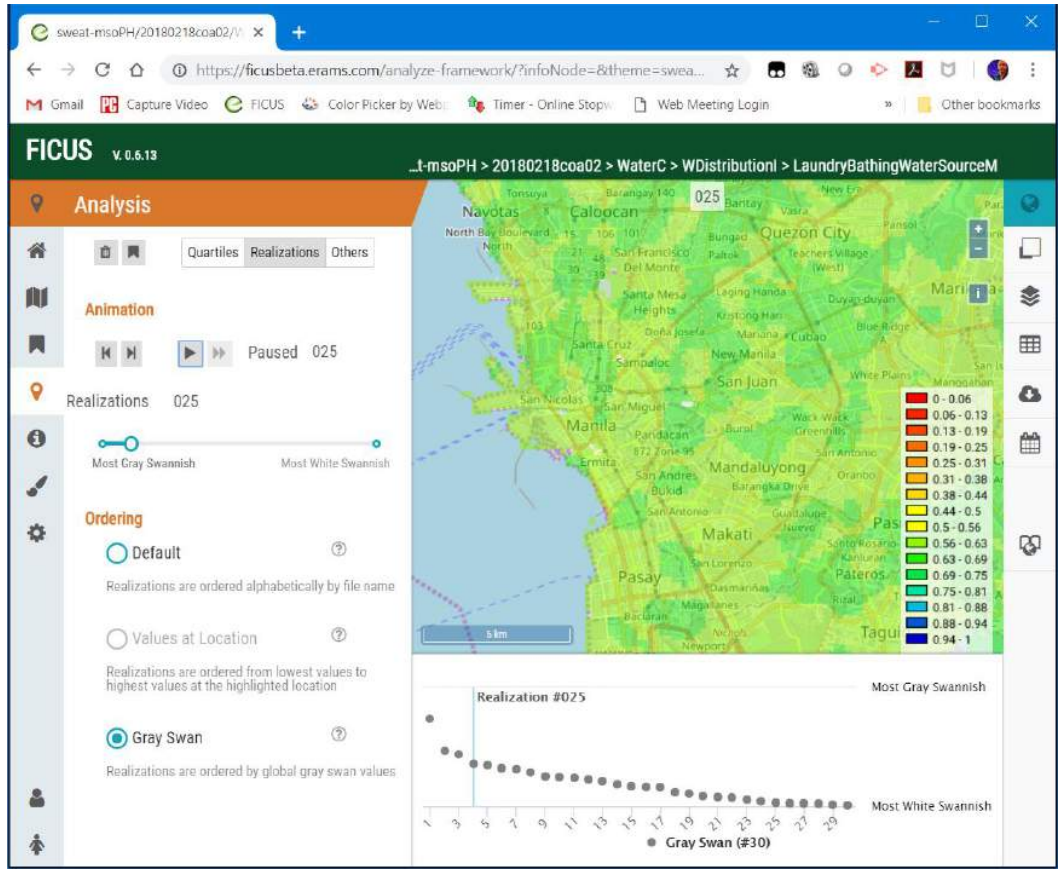
Abstract

Risk assessment for geospatial activities are constantly undermined by plans that have been created by multiple organizations for unfamiliar geographies, involving imprecise data model and uncertain model parameters. Moreover, those responsible often have little capacity to communicate about complex geo-temporal patterns with fellow information creators, analysts, and planners across the globe. Over the past decade, the University of Illinois at Urbana-Champaign (UIUC), Colorado State University (CSU), and the US Army Corp of Engineers' Engineer Research & Development Center (ERDC) has been collaborating to construct a neighborhood-scale social, infrastructural, and environmental modeling system that quantifies the uncertainty of all input data, propagates that uncertainty through tightly coupled space-time models, and visually presents uncertainty information and intuitive insights to planners and analysts. The Framework Incorporating Complex Uncertain Systems (FICUS) is a computational framework that supports all the functions of a general purpose geographic and temporal analysis system with a focus on risk assessment.

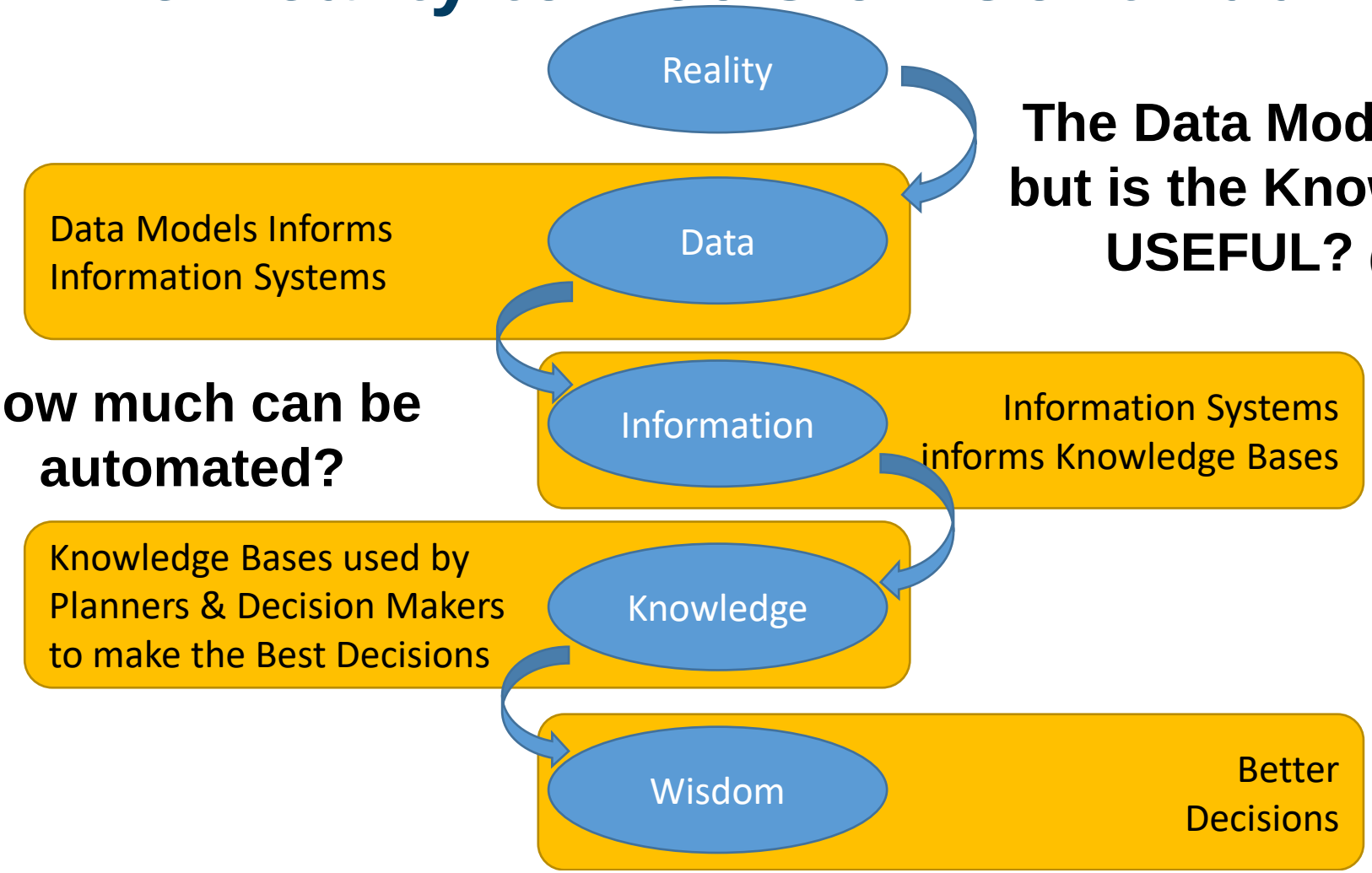
This presentation will discuss the theoretical and practical benefits of using an uncertainty quantifying, uncertainty propagating, and uncertainty visualizing geographic information system for risk assessment with a case study in the Philippines. We will focus our discussions on the techniques that minimize cognitive issues of understanding risk and extend Black Swan Theory concepts for quantitative risk assessment.

FRAMEWORK FOR INTEGRATING COMPLEX UNCERTAIN SYSTEMS (FICUS)

The Framework Incorporating Complex Uncertain Systems (FICUS) is a computational framework, currently in development at ERDC, UIUC, and CSU, that supports all the functions of a general purpose geographic and temporal analysis system with a focus on risk assessment.



The Reality to Decision Continuum

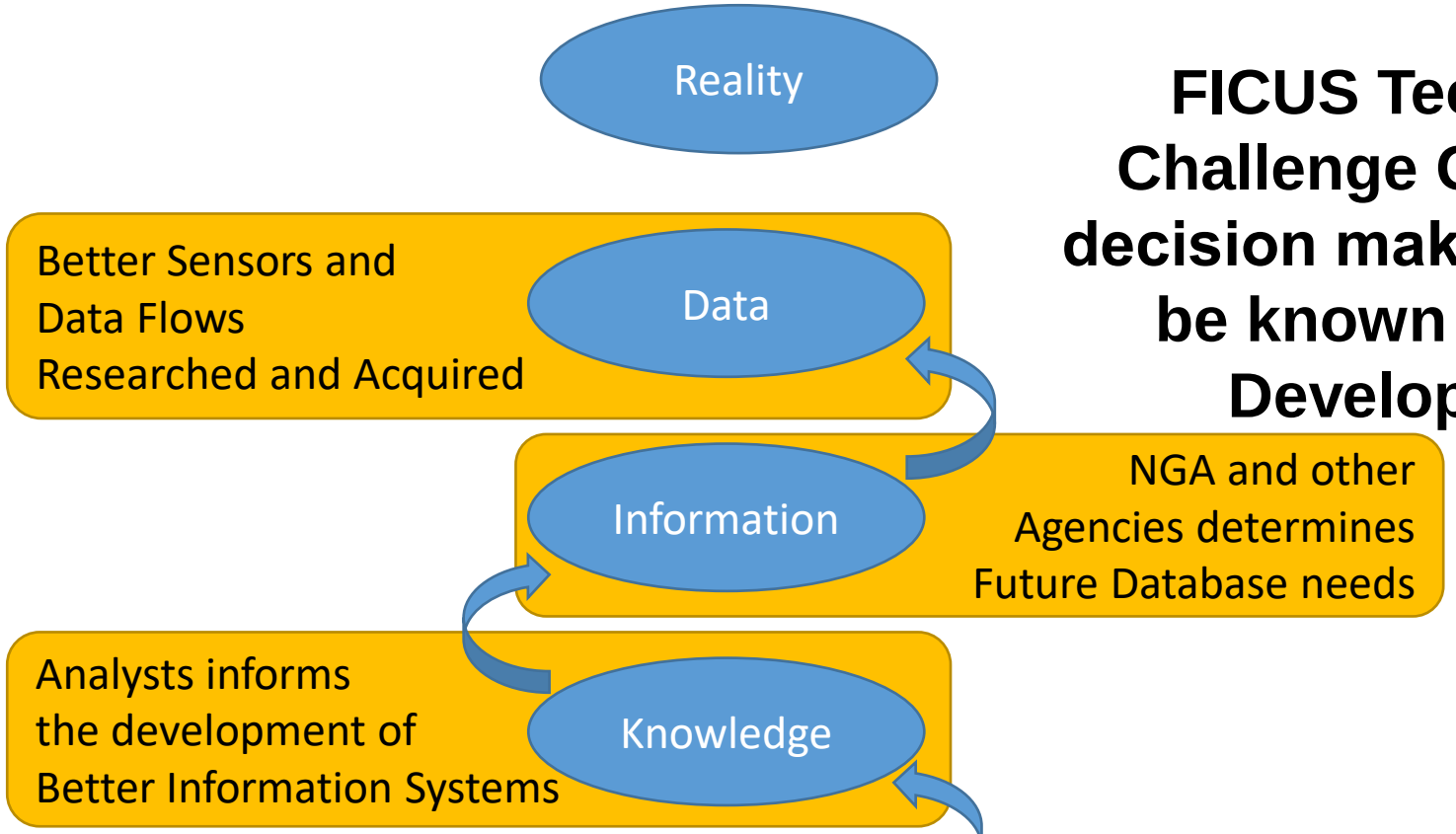


The Data Model IS wrong, but is the Knowledge Base USEFUL? (George Box)

How much can be automated?

A FICUS Theoretical Challenge: Communicating Uncertainty to Decision Makers

Sensor, Info System, or Analysis Improvement



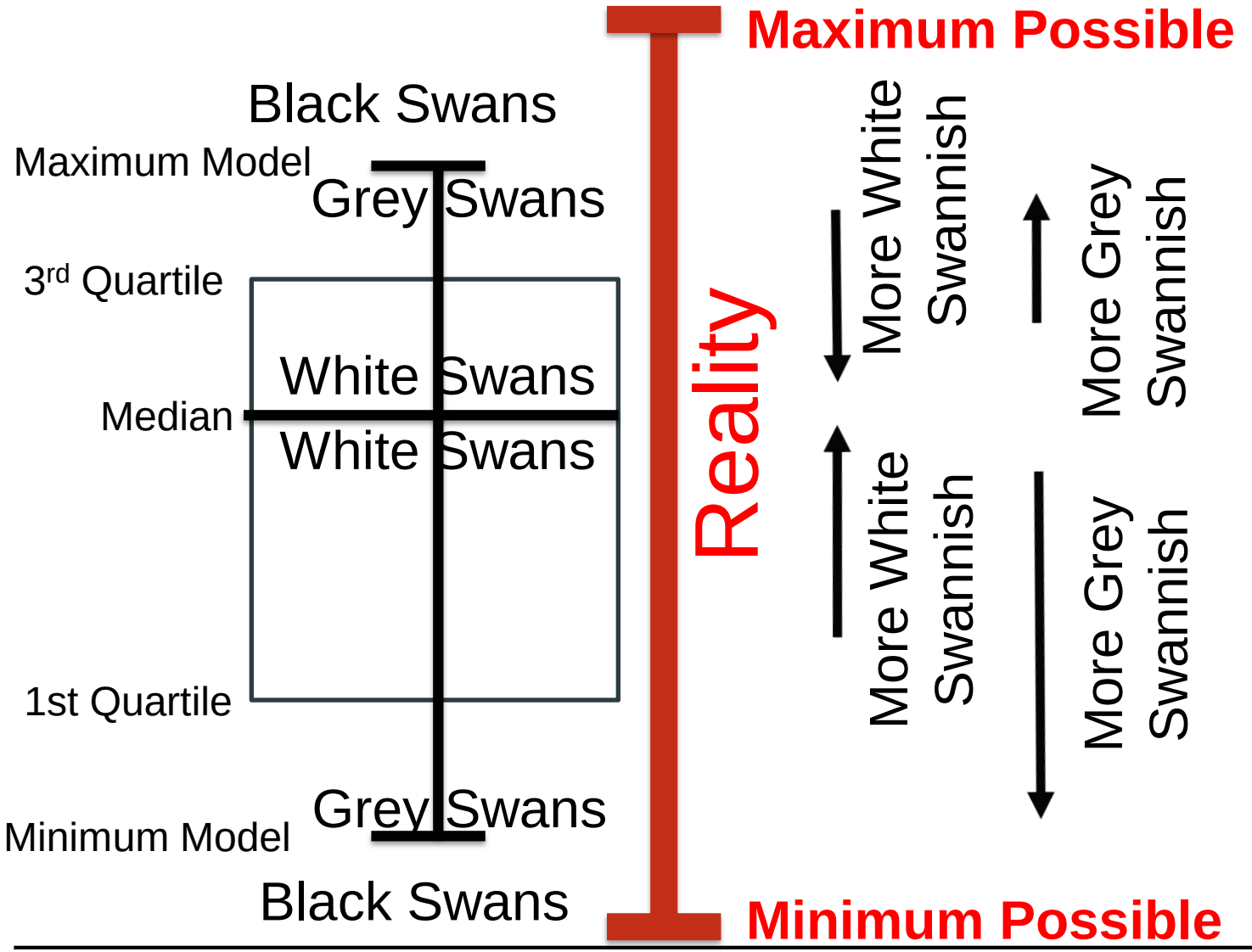
FICUS Technical Challenge One: Can decision makers' needs be known to Data Developers?

FICUS Technical Challenge Two: Can Planners communicate with Data Developers in Real Time to Improve Decision Making?

Nassim Taleb's Black Swan Theory, Including Grey Swans

- Black Swan Events: **Unpredictable highly improbable events**
- White Swan Events: **Expected highly probable events**
- Grey Swan Events: **Predictable less probable events** not accounted for in decision making.
- The `Grey Swannish' of an event: The more unlikely a predictable event is, the more Grey Swannish that event is

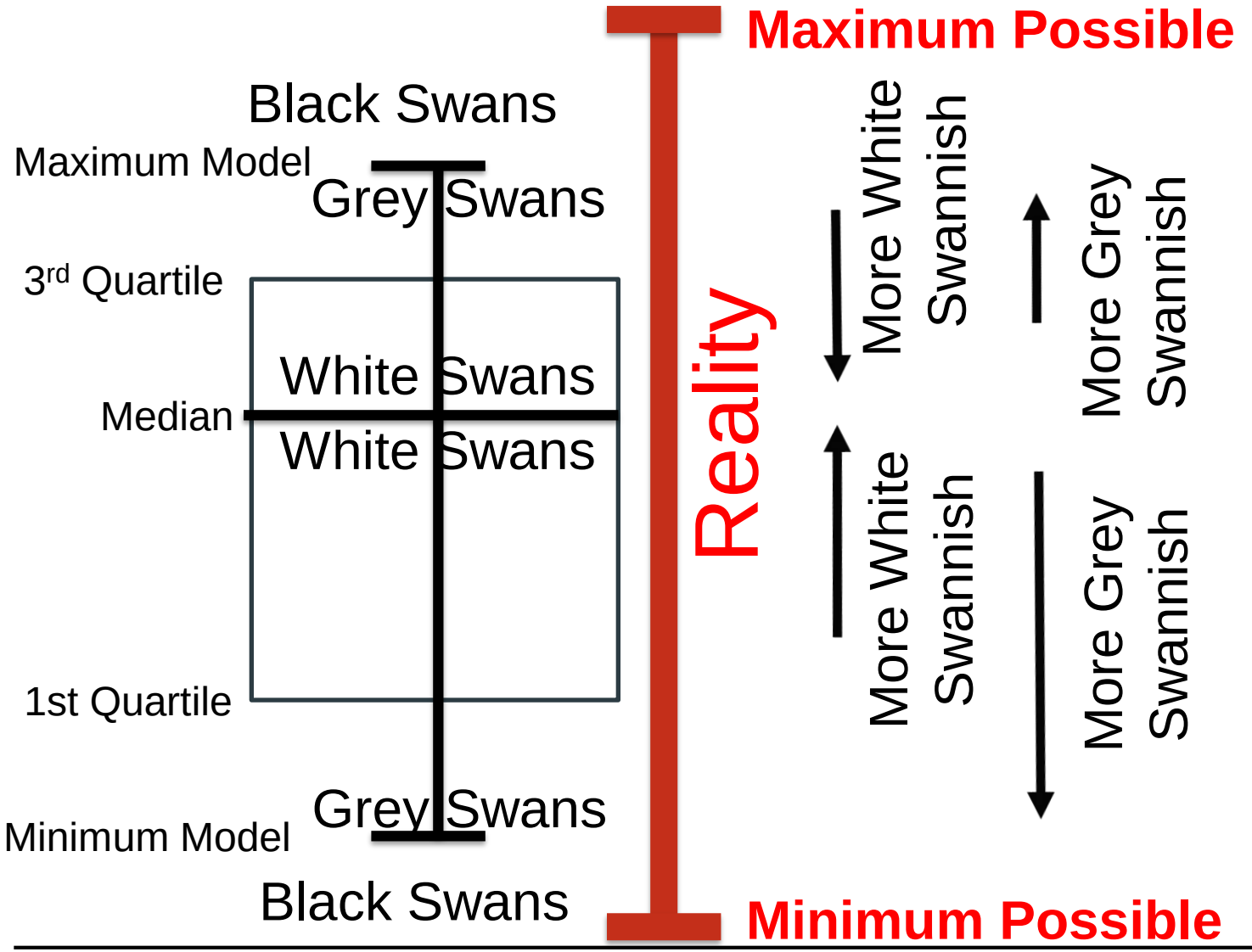
Black Swan Theory Data Model



Data model box plot provides error estimates:

All data should be represented as quantiles, with quartiles providing an elegant way to measure wrongness, bias, data model arrogance, and data model meekness

Wrong Black Swan Theory Data Model

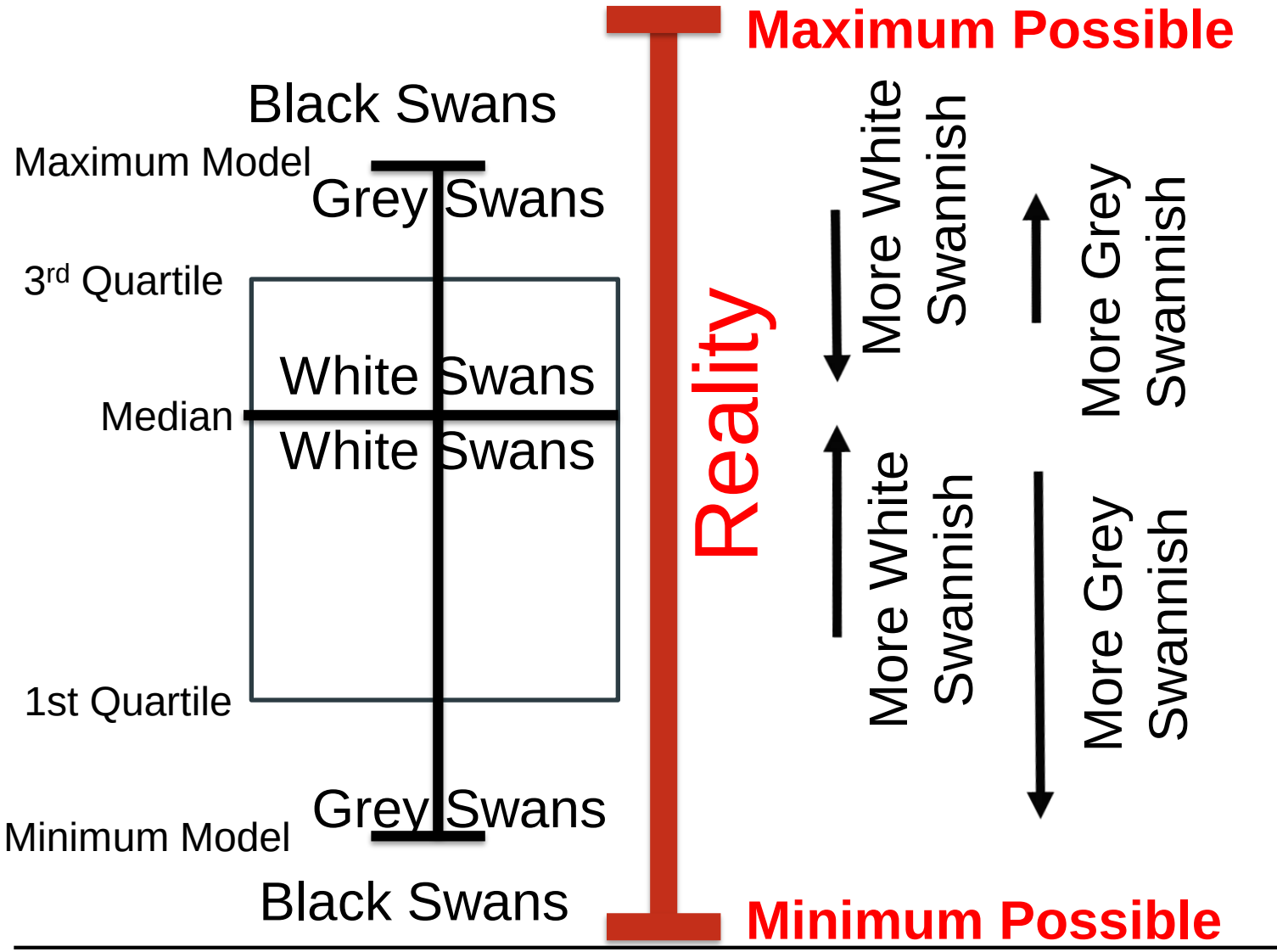


Wrong Model: When ANY ground truth is higher than maximum or lower than minimum

Must be adjusted or replaced immediately

Time to eliminate the George Box quote "All models are wrong but some are useful" as an excuse for wrong models trying to represent reality

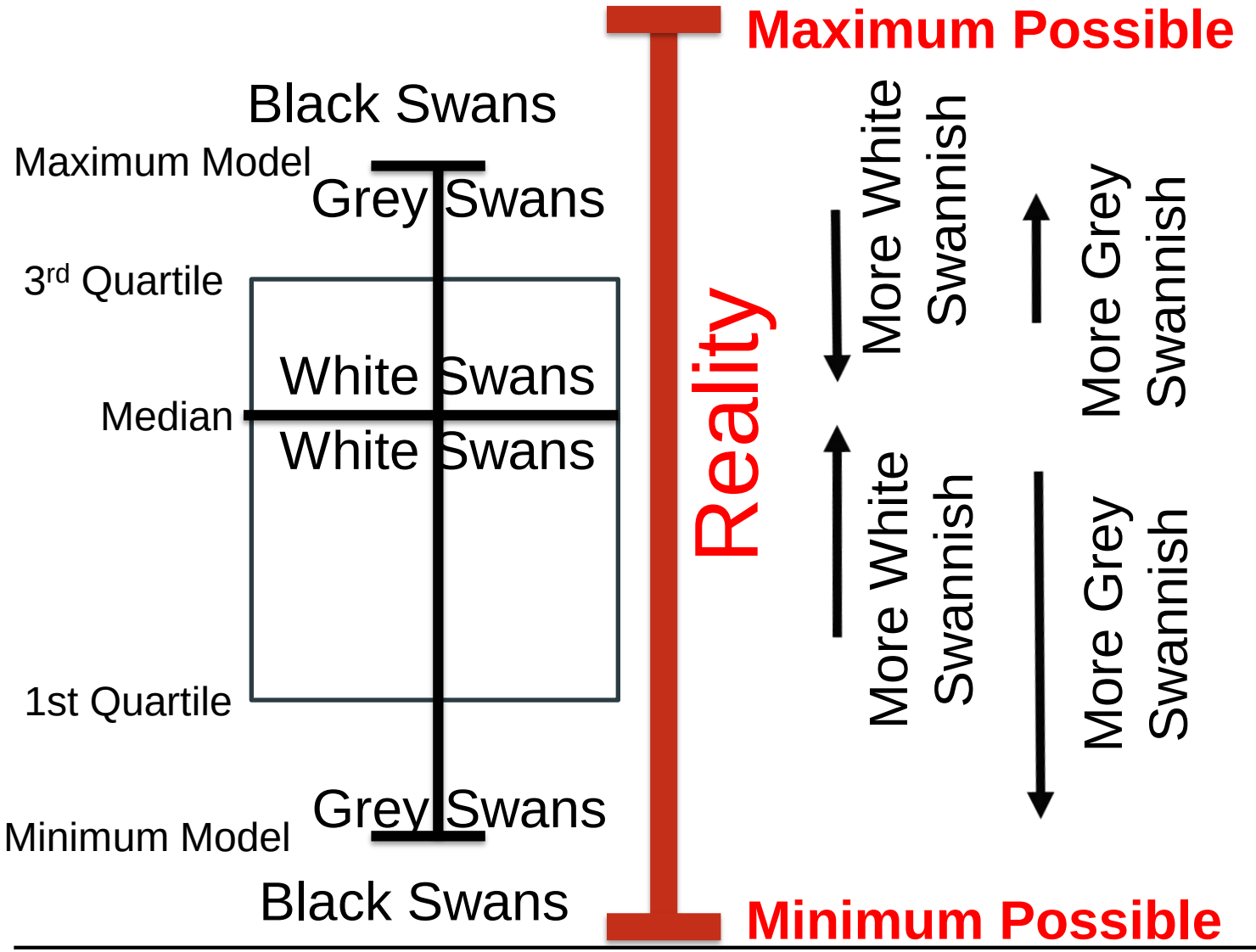
Biased Black Swan Theory Data Model



Biased Model: When statistical tests of ground truth are confident that median value (or quartiles) are biased

Must be adjusted or replaced immediately

Arrogant or Meek Black Swan Theory Data Model



Arrogant or Meek: When statistical tests of ground truth are confident that too many or too few data samples are outside of Inter-Quartile Range

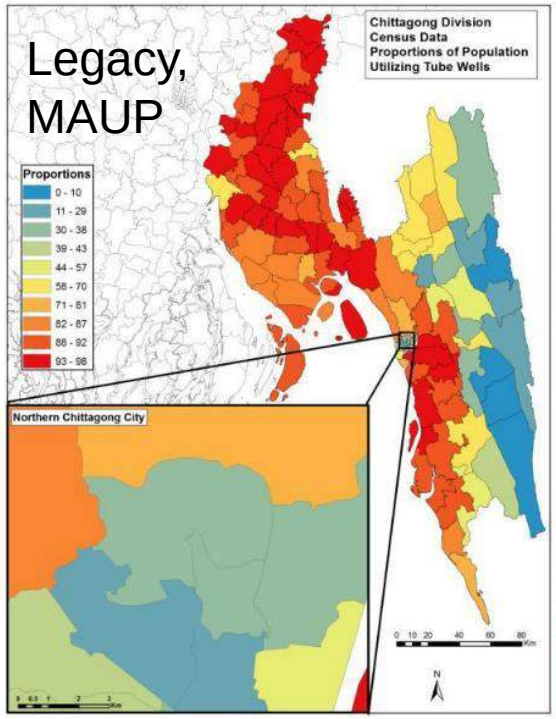
Tools in Data Model should adjust parameters to eliminate model arrogance or meekness

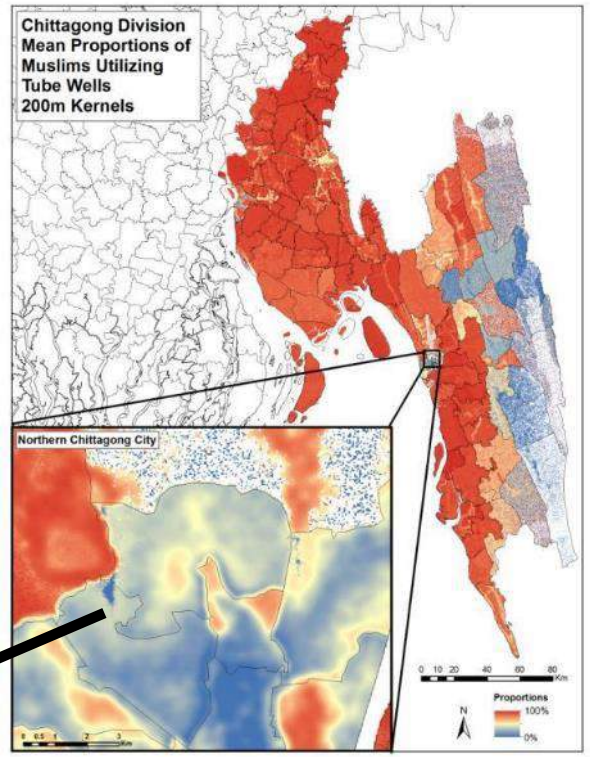
Population Attributes at Atomic Scale

- Multiple realizations (multi-verse) of simulated geotemporal located populations of individual households based on microdata or survey cases. I. e., IPUMS, USAID M-DHS
- Household and person attributes fitted to 1st and 2nd order properties of uncertainty based on census enumerations, infrastructure maps, ground truth information
- Attribute covariance `built in' due to complete survey cases as data structure
- Population simulator designed to allow all input variables, including forecasts, to be stochastic ranges of possible values

Demographic Analysis

- Stochastic Monte-Carlo demographic simulation
- Summary statistics maps are generated to provide error and uncertainty estimates
- Tools to develop hierarchical framework analysis with uncertainty



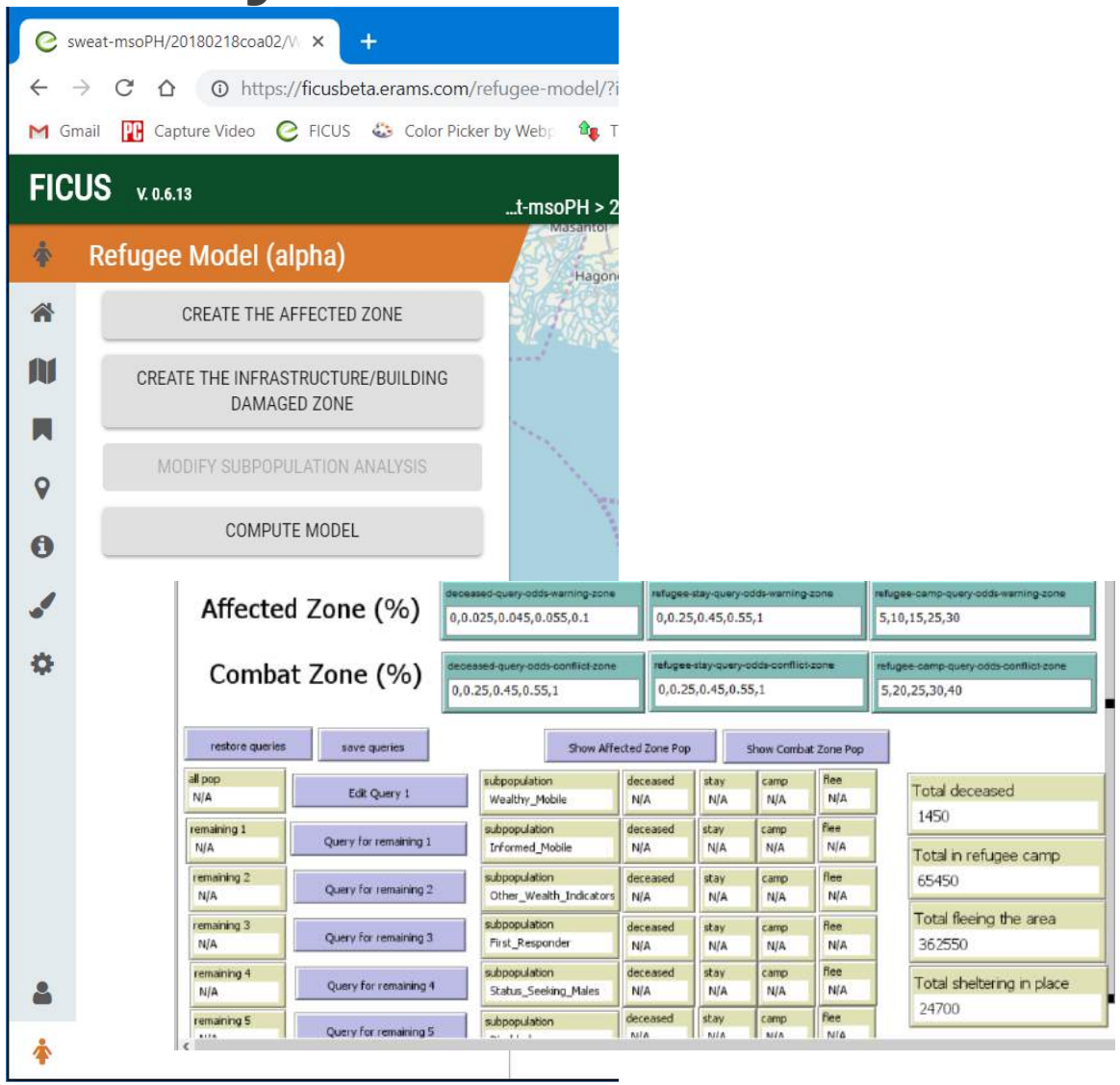


Analysis at atomic scale, then filtered

Generates space-time uncertainty quantified information about population at neighborhood scale

Population Analysis

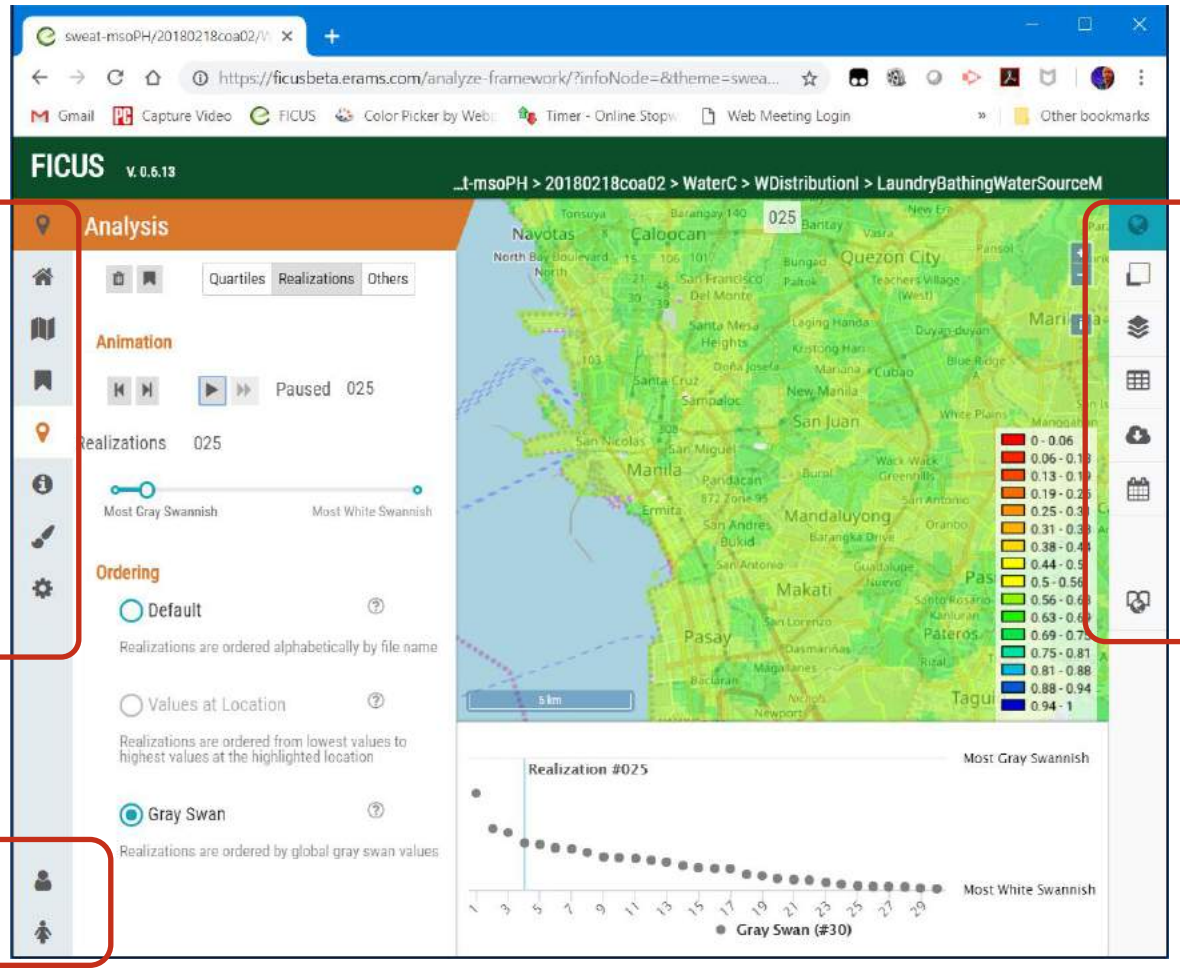
- Example application: Examine potential impacts of Battle of Marawi, May-Oct 2017, on population in Mindanao, Philippines
- Classify population across cohorts: flee to family/friends, shelter-in-place, move to IDP camp, become casualties
  - Identify locations and subpopulations based on open source information regarding siege
  - Estimate impacts based on range of possible outcomes per subpopulation. For example:
    - What is the likelihood that `non Muslim adult males' from the affected zone will become casualties? Is broken down into:
      - What is the minimum likelihood that `non Muslim adult males' from the affected zone will become casualties?
      - What is the maximum likelihood that `non Muslim adult males' from the affected zone will become casualties?
      - What is the median likelihood that `non Muslim adult males' from the affected zone will become casualties?
      - ....



FICUS uses Catena

- Catena is a software framework & libraries for geospatial applications developed at CSU
  - Lightweight core
  - Plugin-based architecture
  - Focus on the app, not the framework

FICUS Cartography, Geotemporal UV



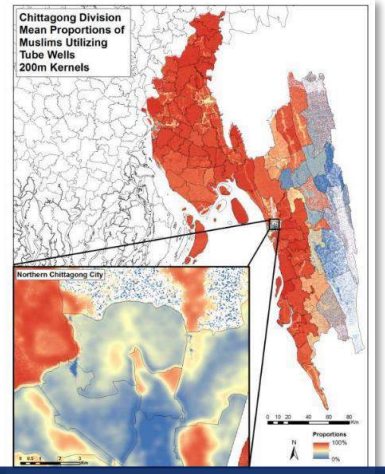
Catena: general purpose GIS w/out Uncertainty

Special Purpose Apps from Any Software, embedded w/in FICUS for UQ/UP/UV

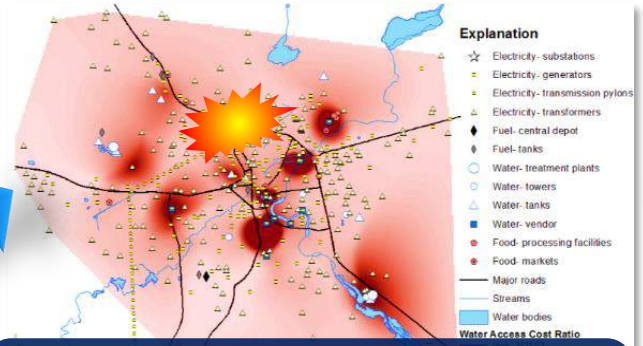
FICUS Component Goal (in development)

- FICUS will soon easily embed any OMS component into the FICUS UQ/UP/UV environment by wrapping the OMS component into a component that allows uncertainty propagation
- FICUS Components will allow stochastic adjustment of all OMS component outputs to correct Gray Swan wrongness, bias, arrogance, or meekness
- FICUS Components will allow for immediate uncertainty visualization of all inputs and outputs `linked and brushed' in the FICUS-UI to improve model communication

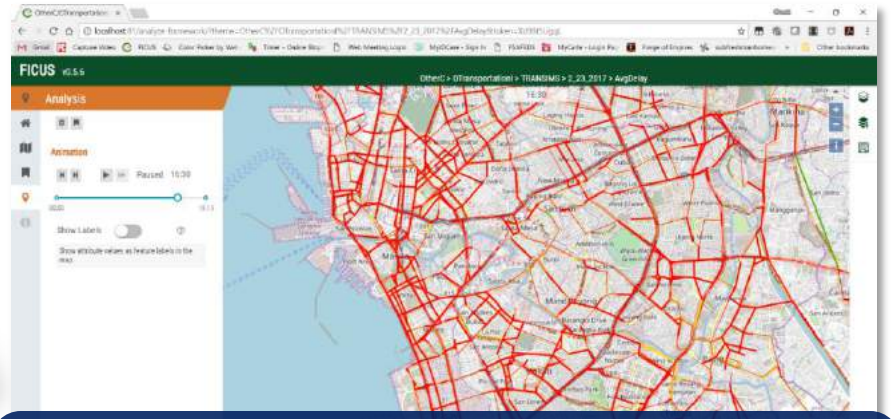
Uncertainty Propagation



Represent neighborhood population attributes



Analyze cascading effects of infrastructure damage (on people and other systems)

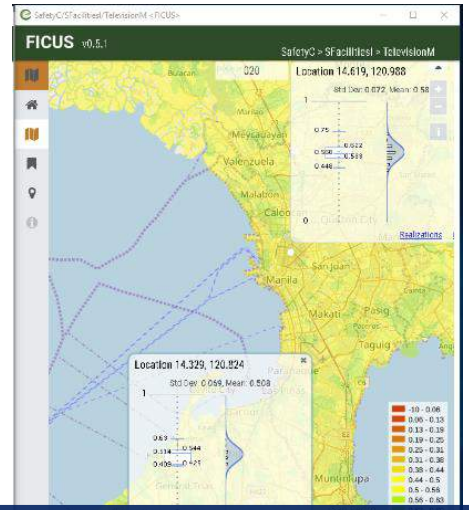


See dynamic changes in transportation flow based on damage and change in resource demand

FICUS Toolset

- Visualization Tool
- Population Model
- Infrastructure Interdependency
- Transportation Model
- Refugee Model
- Additional Models

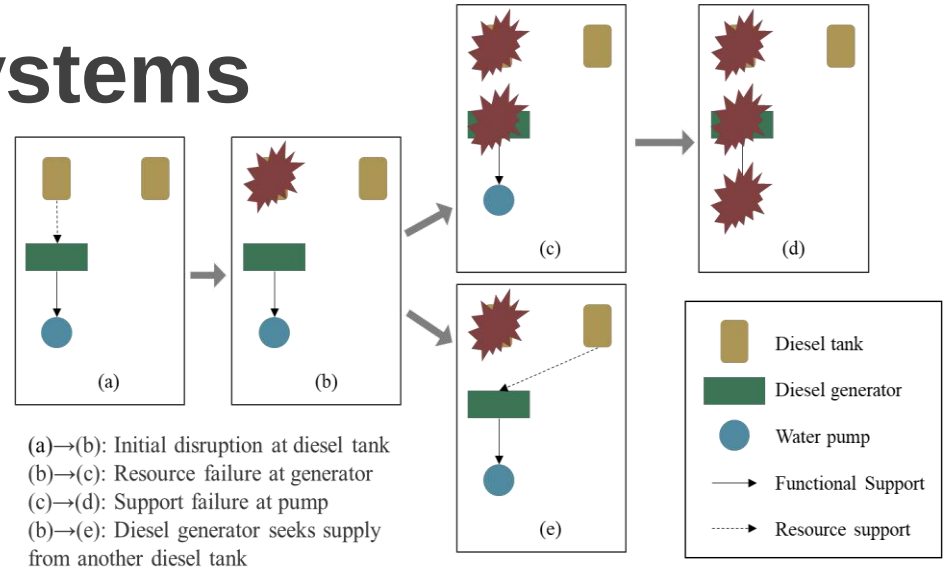
Filter model outputs through risk & decision framework



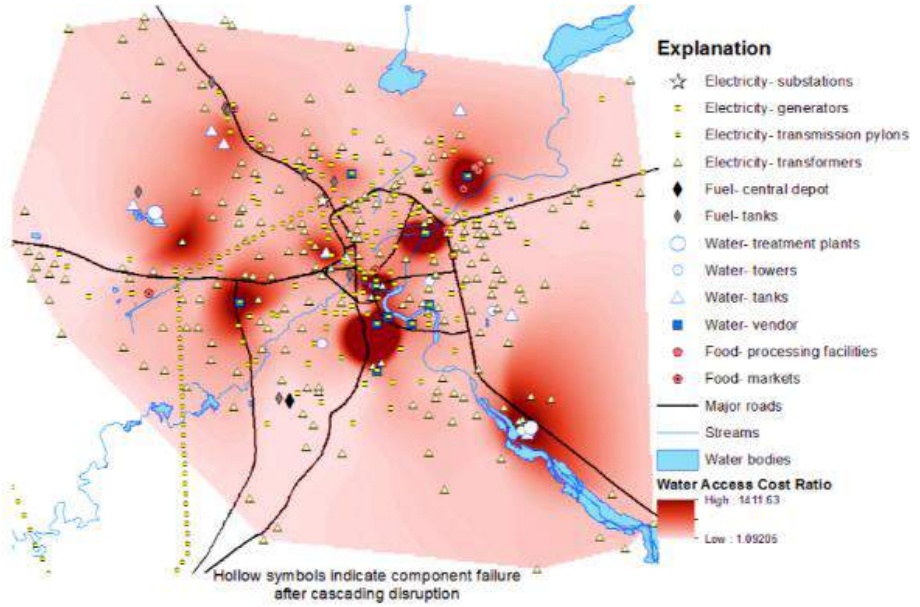
View analysis results through a web-service

Infrastructure System of Systems

- UIUC Civil Engineering leads effort
- Network infrastructure interdependency model
- Considers connections between different infrastructure types
- Connects ‘communities’ to infrastructure resources (proximity)
- Considers how change in resource capacity impacts population



(a)→(b): Initial disruption at diesel tank
(b)→(c): Resource failure at generator
(c)→(d): Support failure at pump
(b)→(e): Diesel generator seeks supply from another diesel tank

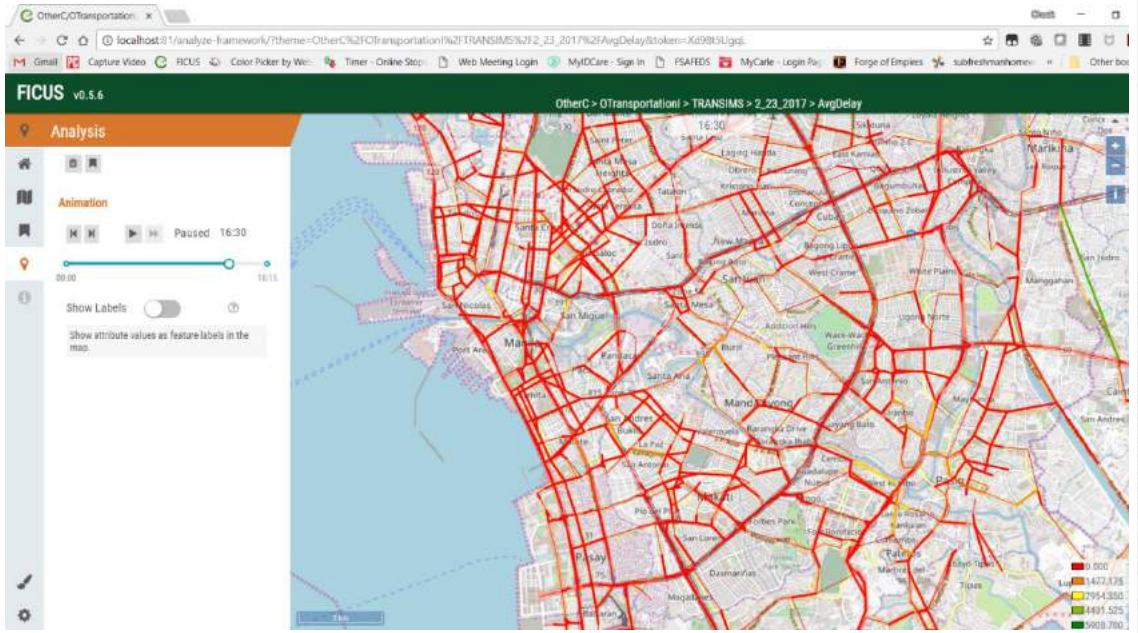


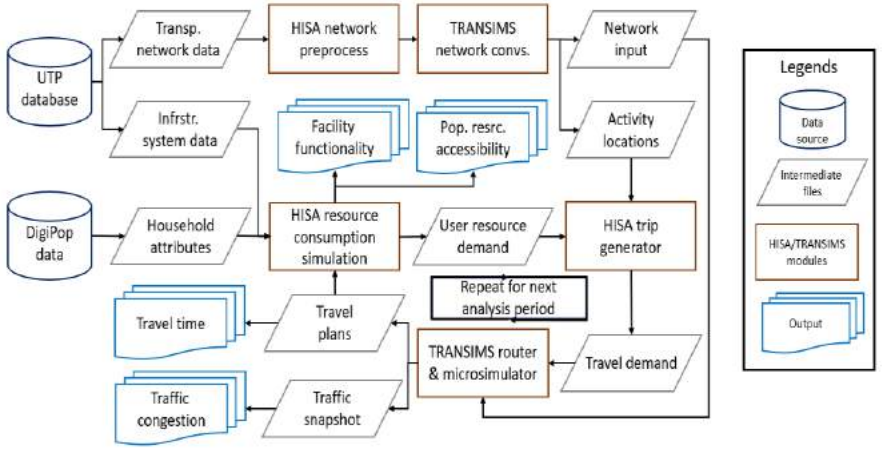
Relationship model that expresses the connection between infrastructure & population

Tight-coupled System of Systems Modeling

- Link demographic, infrastructure interdependency, and transportation models
- Using road network and population data, generates a set of activity locations for origins/destinations
- Enable near real-time movement analysis in the transportation network
- Determines impact of infrastructure failure on access to resources, and dynamic changes in traffic

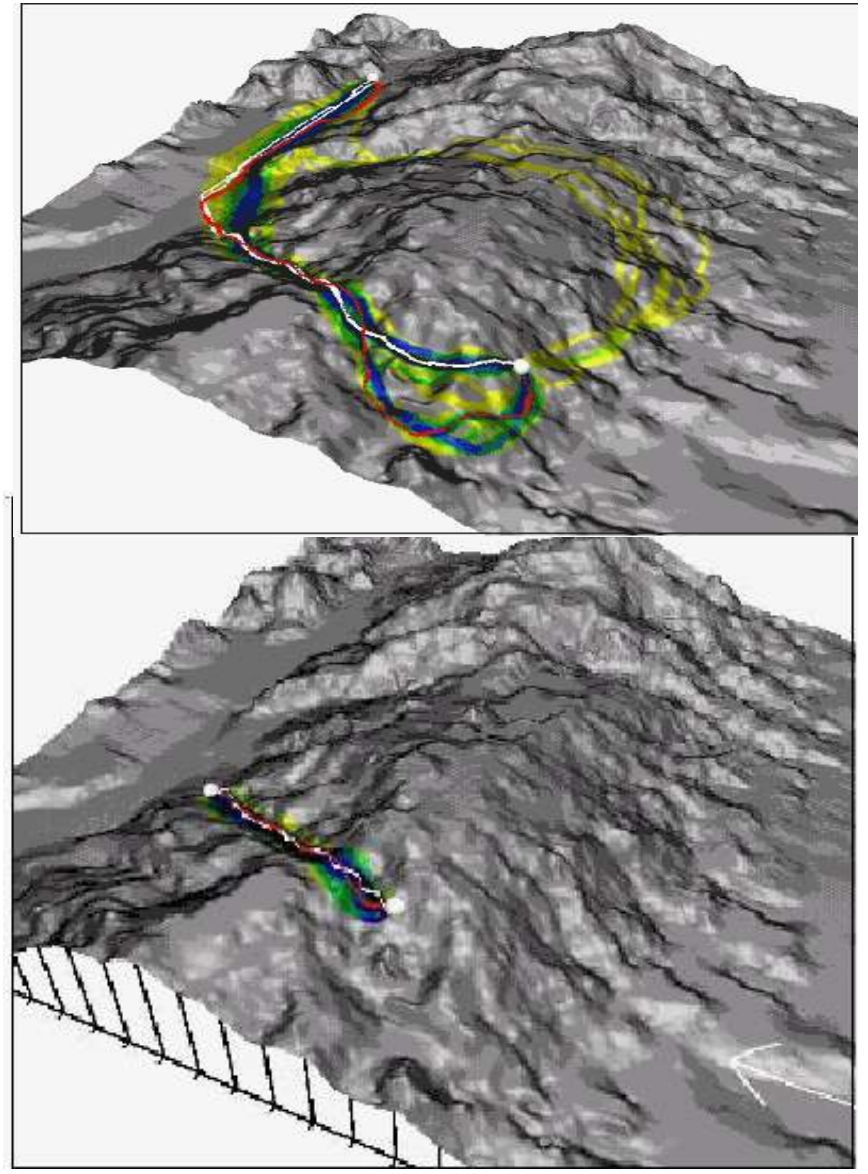
Develop dynamic transportation simulation influenced by resource capacities & population attributes





Heteroskedastic Uncertainty Verification Problem

- Heteroskedasticity: when the variability of a variable is unequal across the range (or geography)
- Heteroskedastic Uncertainty Verification Problem (HUVP) is the notion that verification for fitness for use of a data model to a geographic computational model is difficult because certainty of specific use cases will not guarantee certainty in other circumstances
- Simple Example (on right): Shortest Path Uncertainty Analysis using UQ 3' DEM data has uncertain results (top) or certain results (bottom) depending on model parameters even using the same dataset
- Complex Demographic Example: Microdata or surveys will seldom provide the appropriate stratification of random samples for important demographic variables for specific applications (urban/rural in USAID's M-DHS for example). Ergo, some applications will provide fit-for-use results from the same survey with other application results unfit-for-use
- Dr. Gerard Heuvelink has argued since the 1980's that Monte Carlo Simulation is the only technique that `can' provide uncertainty analysis, which FICUS uses as it's core.
- Computational Modelers need to adopt a "Manifesto for Antifragile Models" similar to Computer Science's Manifesto for Antifragile Software, antifragilesoftwaremanifesto.org



Antifragile ~~Software~~ Geo-temporal Analysis Manifesto

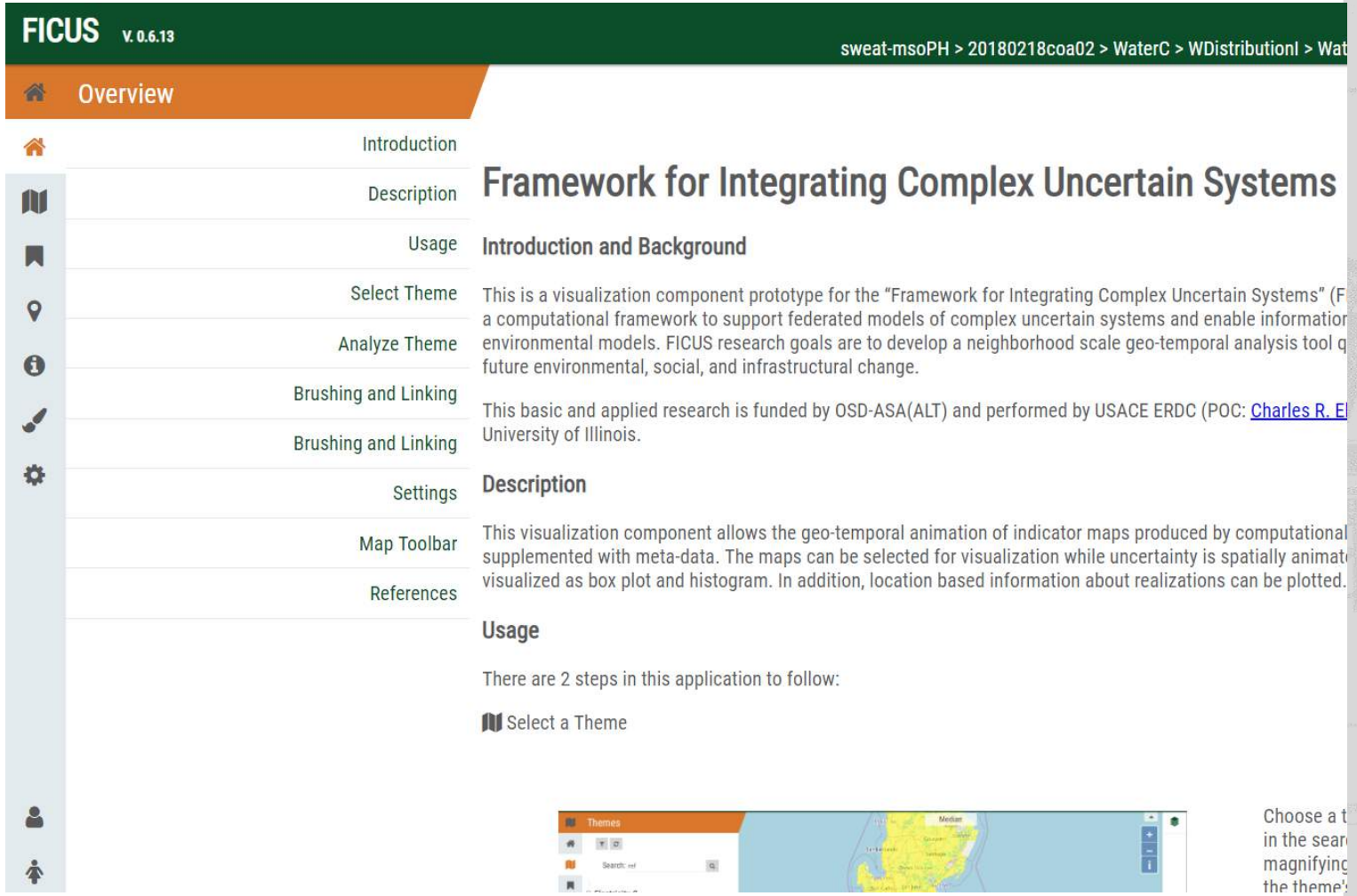
1. The customer: The main priority of Antifragility is so the satisfaction of the customer needs, delivering an antifragile system of systems. The system of systems includes all USG data collection flowing through geo-temporal computational models connected to decision makers with meta-system feedback loops to identify weaknesses in the analytic framework.
2. The context: We welcome changing scenarios where unexpected events (Black Swans) are the real paradigm shifting entities, or used to improve the analytic framework. We also welcome identifying wrongness, arrogance, and bias in our models to minimize poor decisions.
3. … 12.

Because individual models can only be calibrated and validated on unit test data available at development:

If we want to tightly couple multiple models, designed by different researchers, into systems with multiple feedback loops, we need a Framework for Integrating Complex Systems that can handle the Uncertainty so that the Analytic Framework is Antifragile.

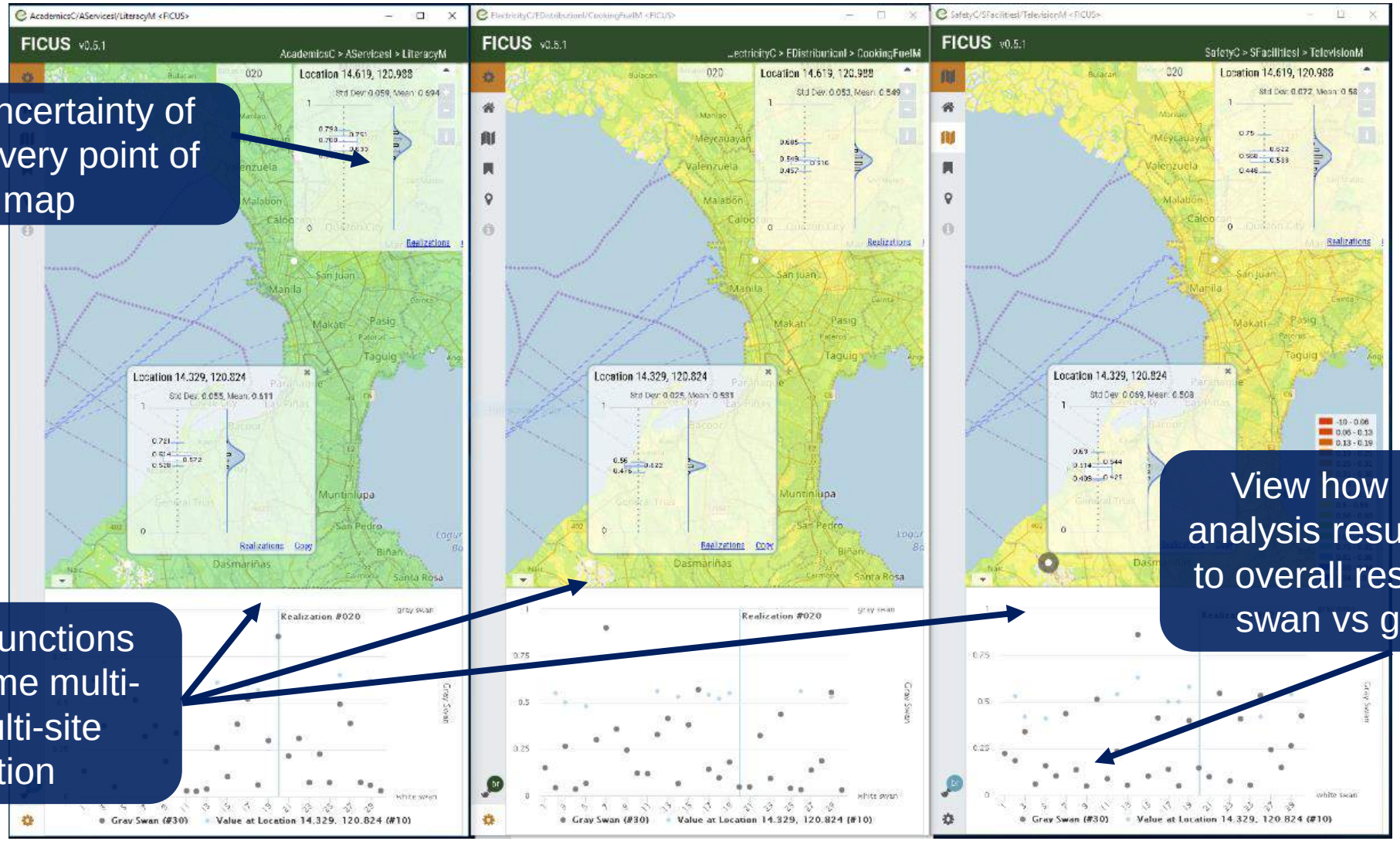
Play w/ FICUS Yourself

- In a hurry, advance two slides and go to ficusbeta.erams.com for a walkthrough of the cartographic components to the FICUS User Interface (or ficus.erams.com for the latest stable version)



FICUS Visualization Interface

View the uncertainty of results at every point of the map

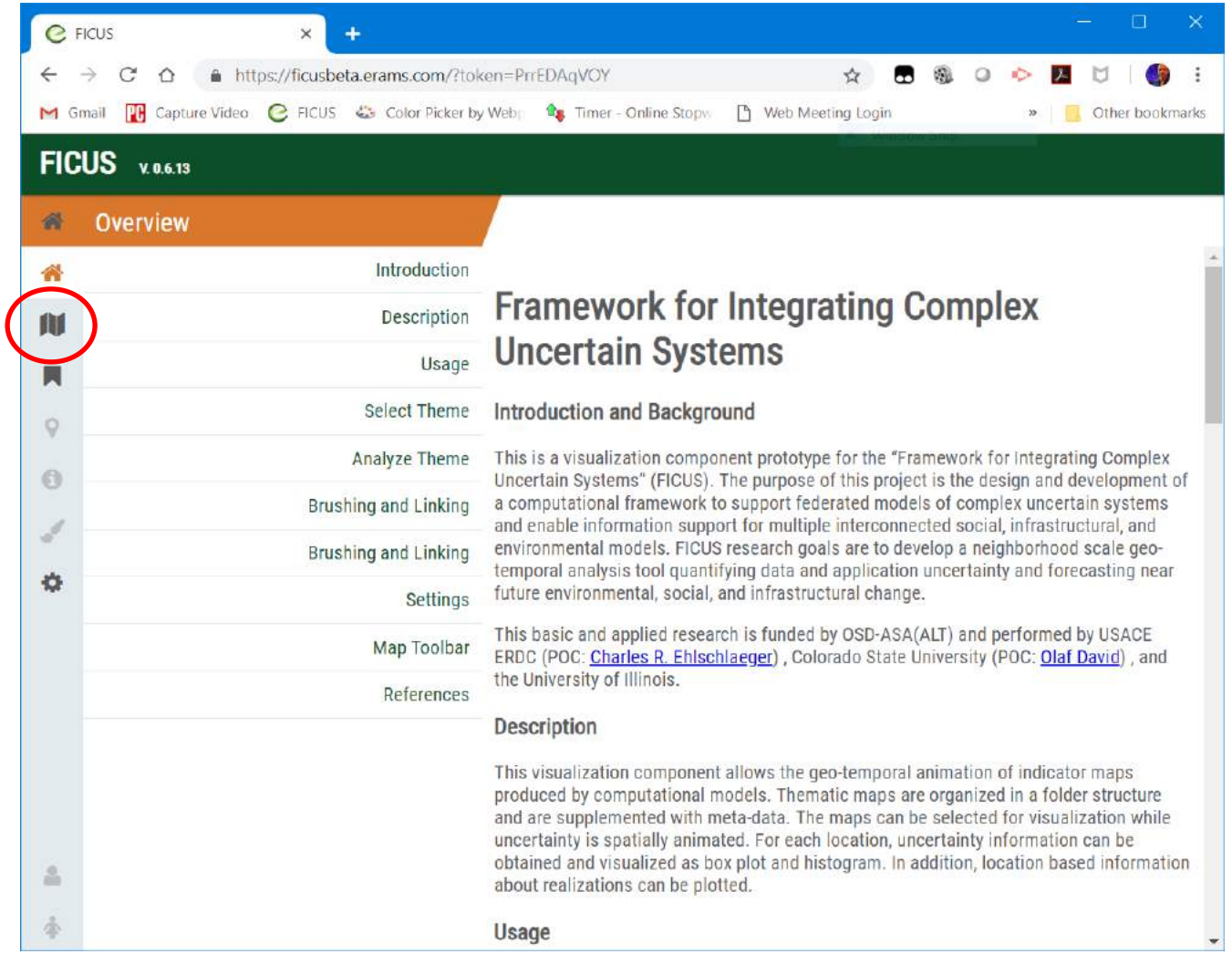


Link & Brush functions support real-time multi-user and multi-site collaboration

View how individual analysis results compare to overall results – white swan vs gray swan

Play w/ FICUS Yourself

- ficusbeta.erams.com



Play w/ FICUS Yourself 2

Then click

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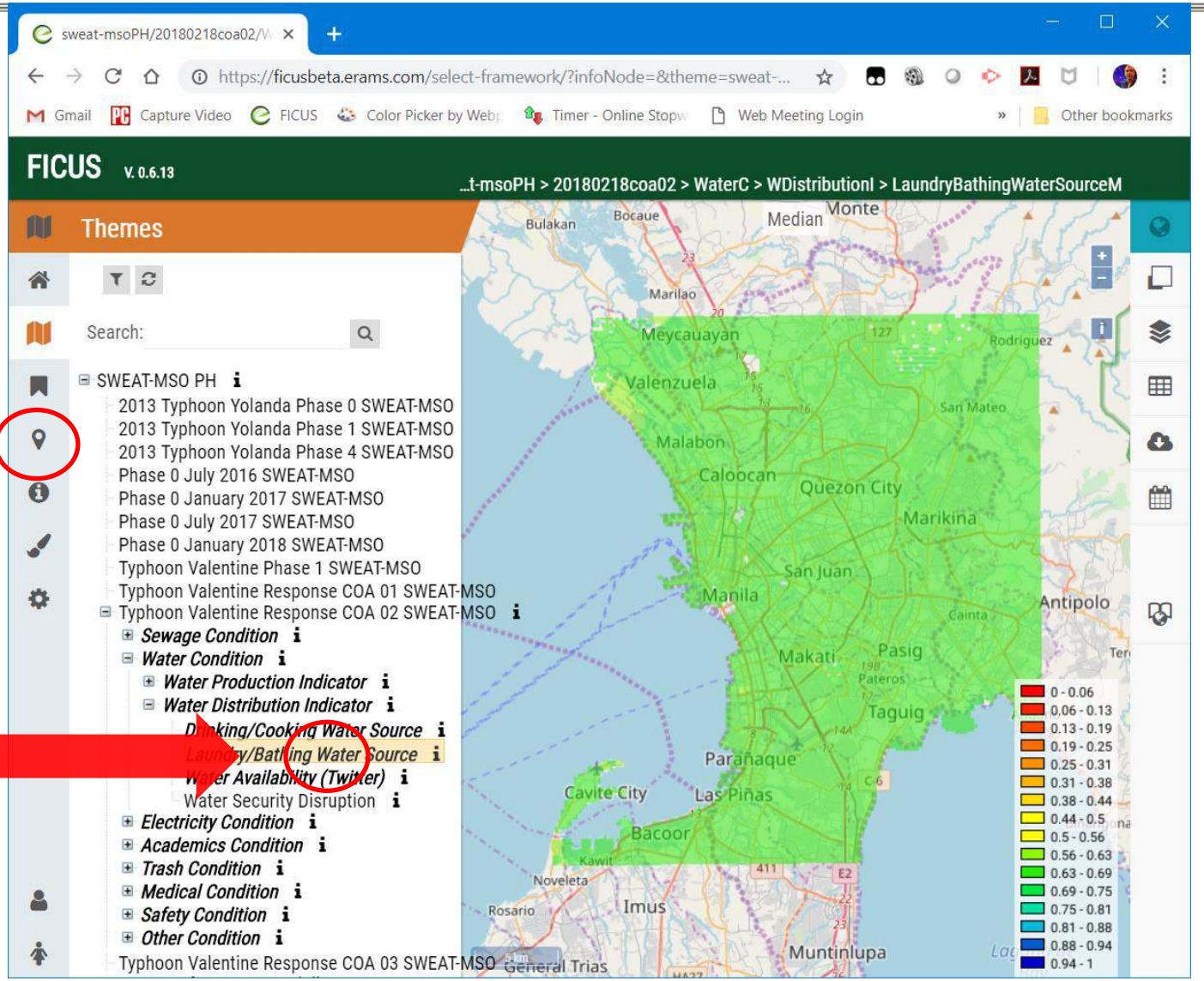
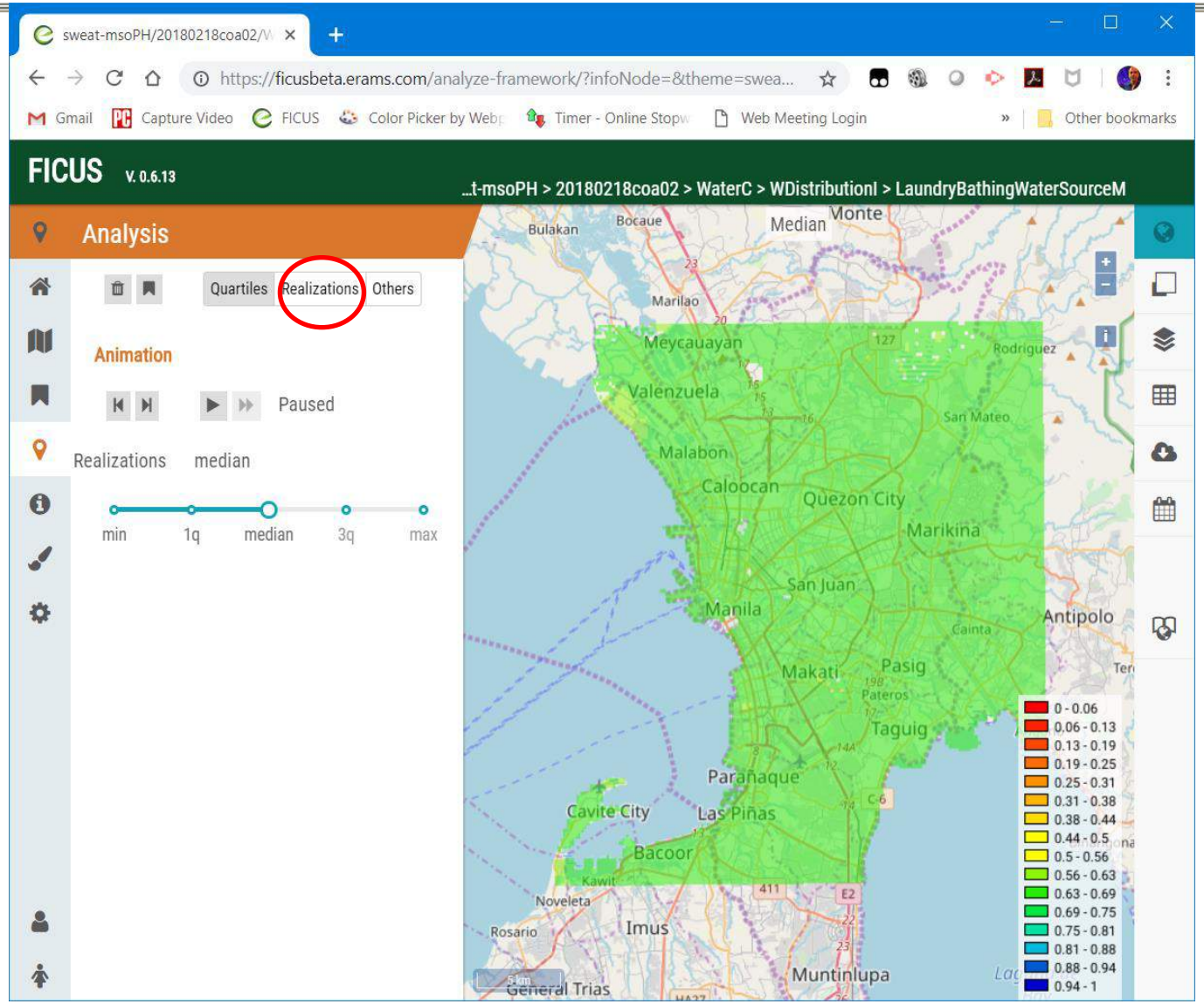
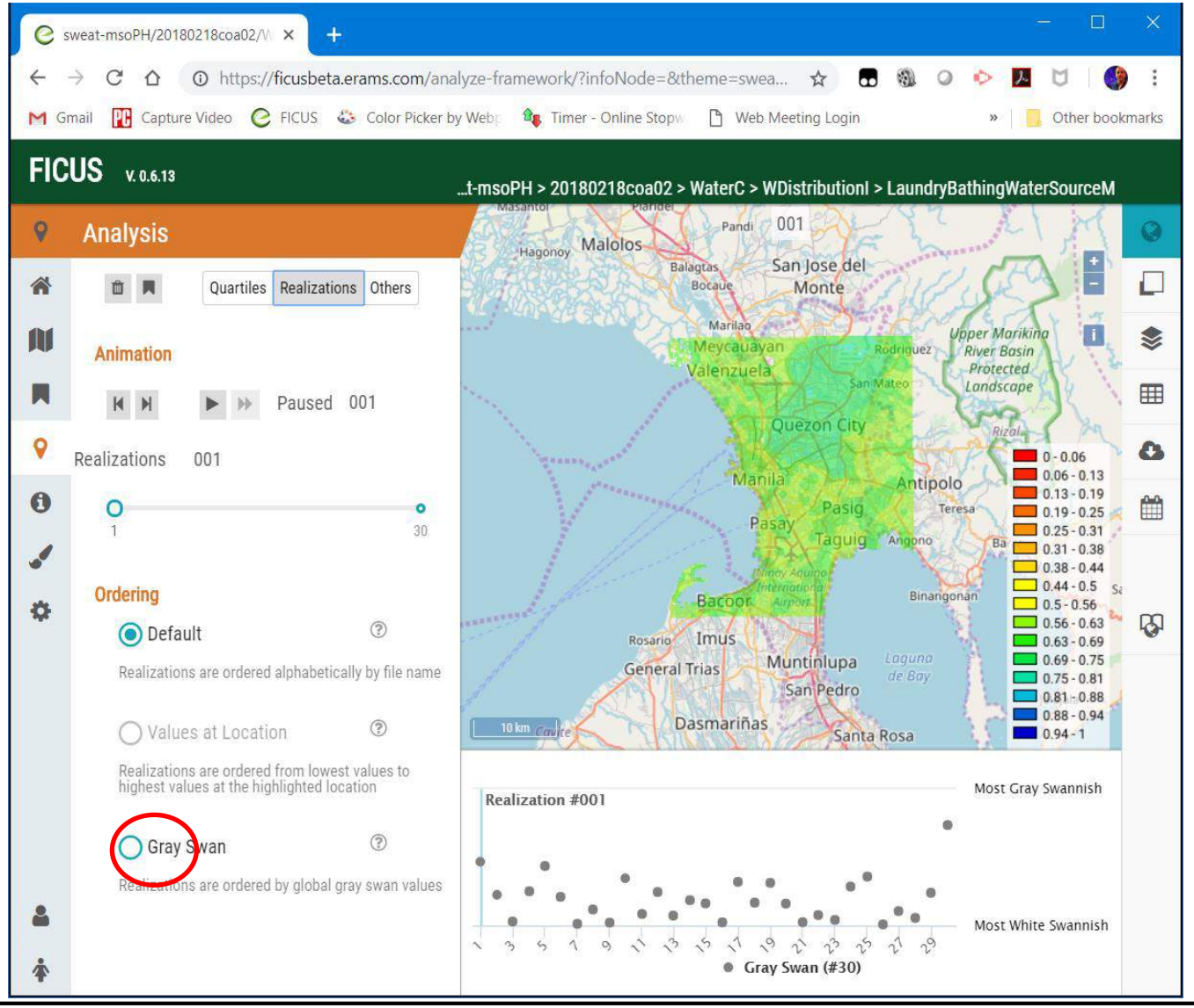


Play w/ FICUS Yourself 3



Play w/ FICUS Yourself 4



Closing Remarks

- Eliminating Uncertain Geographic Context Problem (UGCoP) requires application-specific options not found in legacy GIS, which FICUS prototypes
- FICUS Risk Assessment reduces Heteroskedastic Uncertainty Verification Problem issues
- FICUS Risk Assessment techniques provide connection between decision making knowledge gaps and improved data collection, necessary for true risk analysis
- Distributed Geotemporal Risk Analysis representing complex systems requires novel data models, application development methods, and cartographic techniques not available in current GIS
- Contact Dr. Ehlschlaeger for employment opportunities, or sabbaticals
- Contact Dr. Ehlschlaeger and Dr. David for collaborative research opportunities

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QUESTIONS?