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Seminar 16: Multiscale Building Energy Modeling

Classification and Approach to Multiscale Building Energy Modeling

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Learning Objectives

- Understand what multi-scale modeling is in both general and building energy modeling contexts.
- Classify multi-scale models based on their approach and scale characteristics.
- Understand the difficulties associated with multiscale modeling

Acknowledgements

- Sandia National Laboratories Building Systems Engineering Department for 7 years of progressive thought concerning new applications about building energy modeling
- Thanks to my God and Savior, Jesus Christ.
- My wife Marina and kids Sophia, Amanda, Miguel, Francesca, Cordelia, Timothy, and Trinity

Outline/Agenda

- Multiscale modeling
  - Definition
  - Purposes
  - Classification
  - Approaches
  - Words of caution
  - Conclusion – plan ahead when you are asked to create a multiscale model

Be careful

- Our imaginations think we understand something until a specific question interrupts our fantasy
- This presentation aims to help others avoid approaching multiscale modeling of building energy systems naively

Multiscale modeling definition

- A multiscale model resolves more than one scale of time, space, or complex systems such that desired sensitivities to the lowest scale dynamics are retained at the highest scale.
- Building energy examples:
  - Whole building energy model (WBEM) (lowest level: pumps, chillers, HVAC zones network etc..; highest level – whole building energy performance) (2 –scales)
  - Campus-wide building energy model (lowest level – same as WBEM, highest level – campus energy performance) (3-scales*)
  - Regional integrated assessment model (lowest level – aggregate building response, highest level – regional energy/water demand forecasts – complex systems interaction with social decision making, climate, and water-systems) (3-4 scales)

*The lowest scale may not be populated with actual systems data

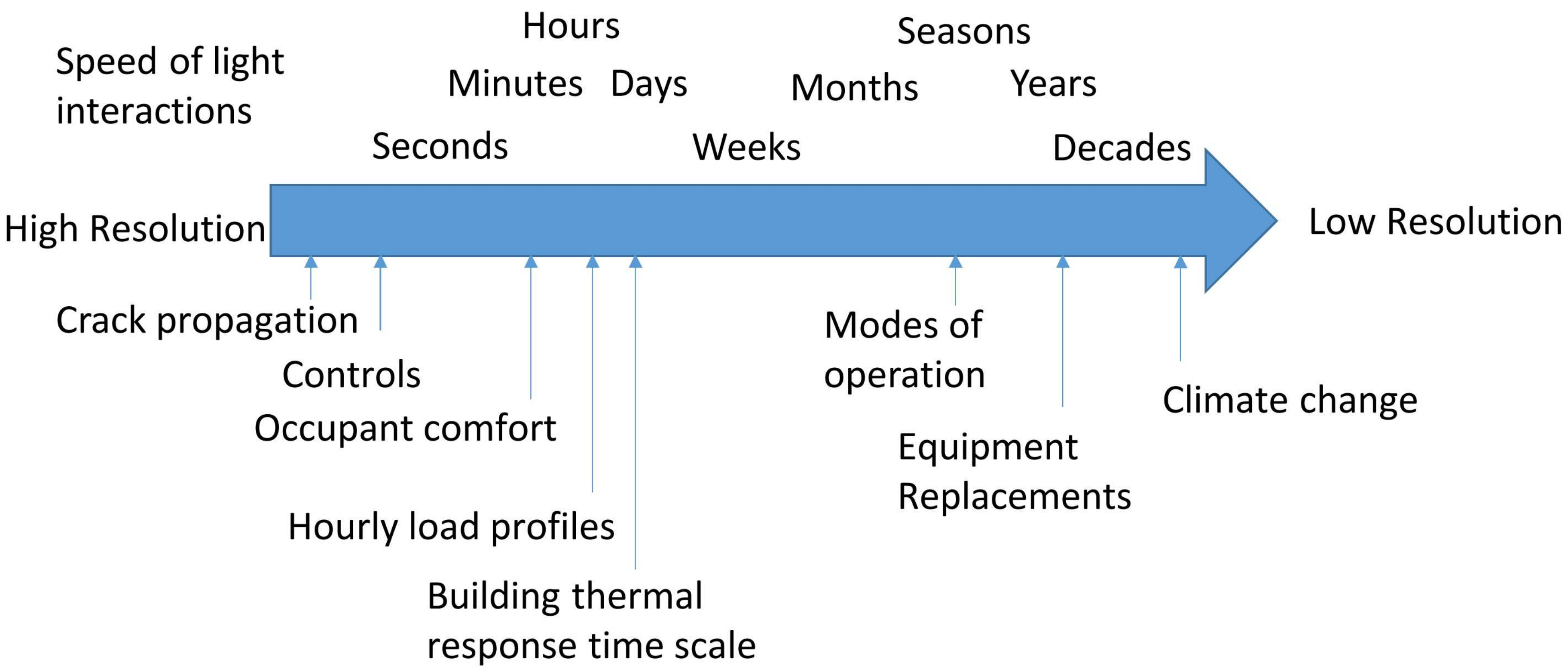
Conventional multiscale vs. multiscale in this presentation

- Complex systems – A system that has many parts that interact in ways that may include nonlinearity, time delayed feedback, and adaptation of interaction relationships and pathways
  - Complex systems are not included in “conventional” multiscale modeling
- “Conventional” multiscale modeling only focuses on complexity of multiscale physics in time and space
  - Crack propagation across designs (micro – macro, fatigue – short to long periods of time)
  - Turbulence resolution in fluid mechanics
  - Grain boundary interaction effects to macroscopic material properties
  - Chemical reactions in macroscopic flow conditions
  - Etc…
- This is a subset of what is discussed in this presentation

Multiscale modeling history

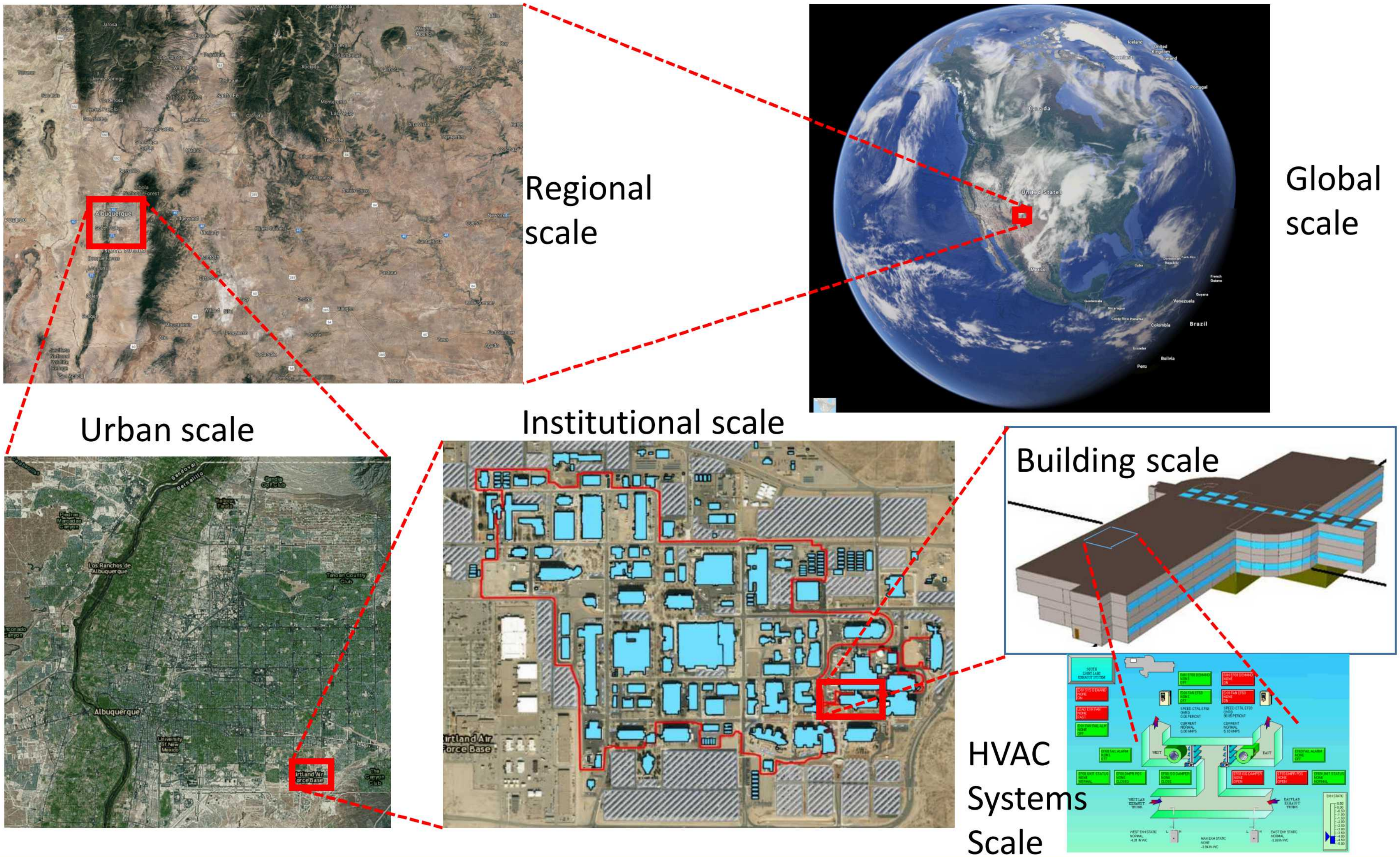
- Driven by increased predictive need
  - Cancelation of nuclear testing
    - The recent surge of multiscale modeling from the smallest scale (atoms) to full system level … was birthed from an unlikely source. Since the … reduc[*tion of*] nuclear underground tests … the idea of simulation-based design and analysis concepts were birthed. Multiscale modeling was a key in garnering more precise and accurate predictive tools (Horstemeyer, 2018)
  - National security
    - Policy assessment tools
- Enabled by growing computational capacities
  - Parallel computing

Time Scales



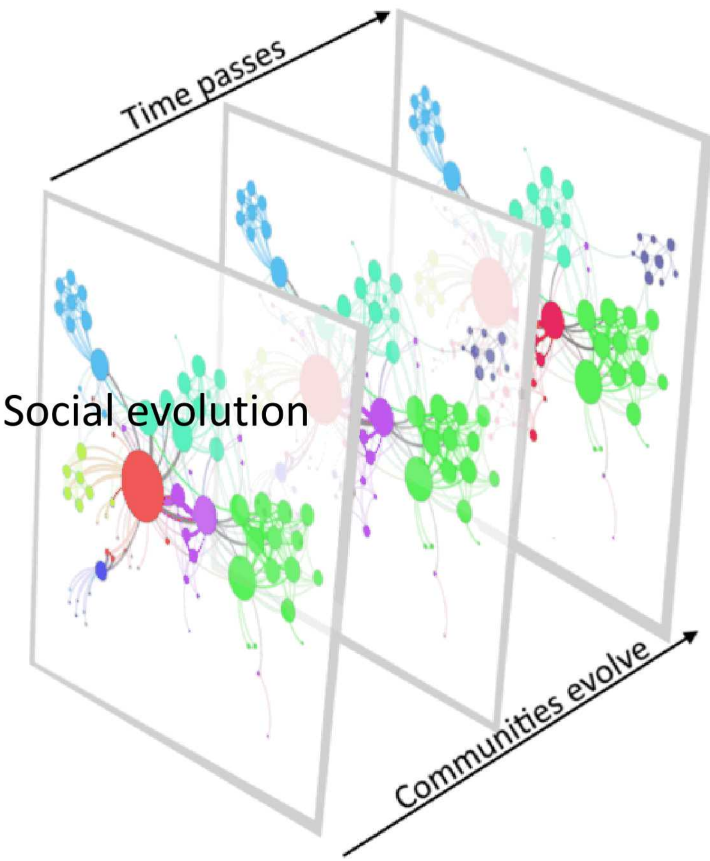
Temporal Resolution

Spatial Scales



Complex System Scales – time/space dependence is non-homogenous

Complex systems are systems whose behavior is intrinsically difficult to model due to the dependencies, competitions, relationships, or other types of interactions between their parts or between a given system and its environment. *Wikipedia*



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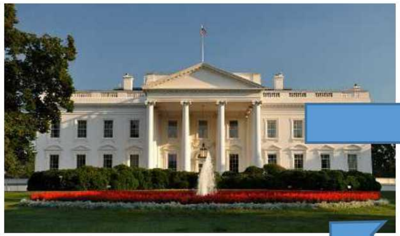

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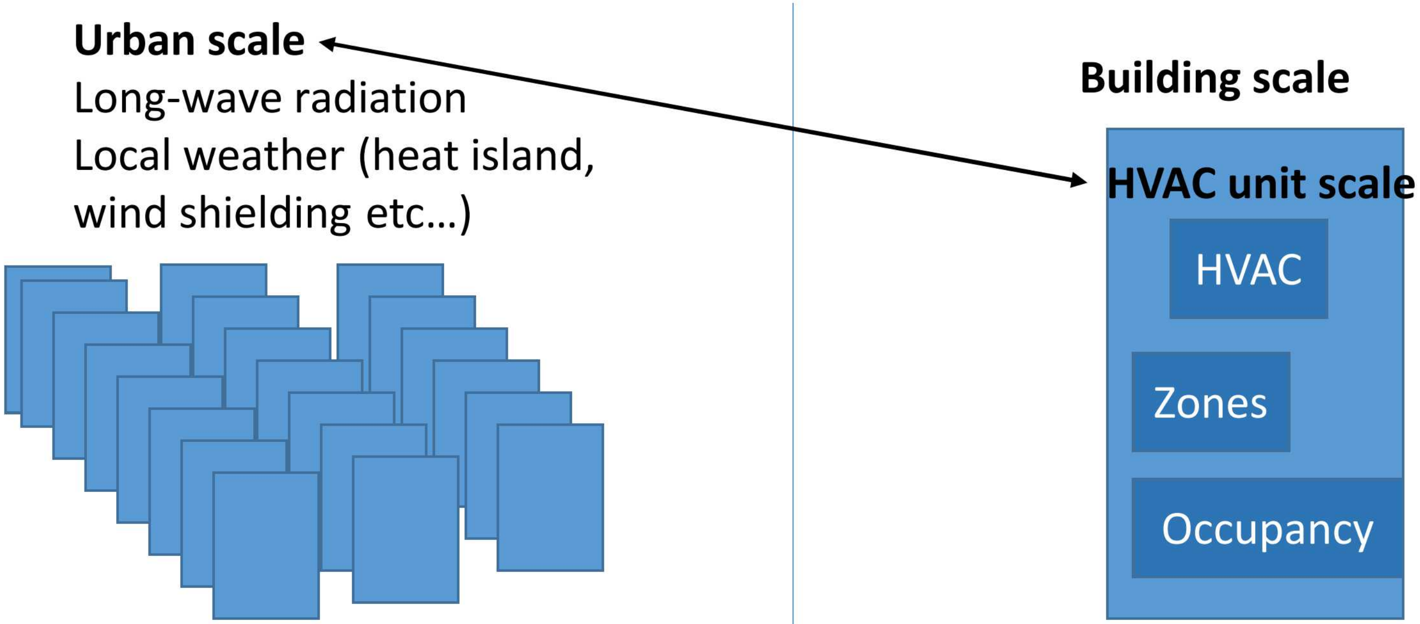
Purpose for multiscale modeling

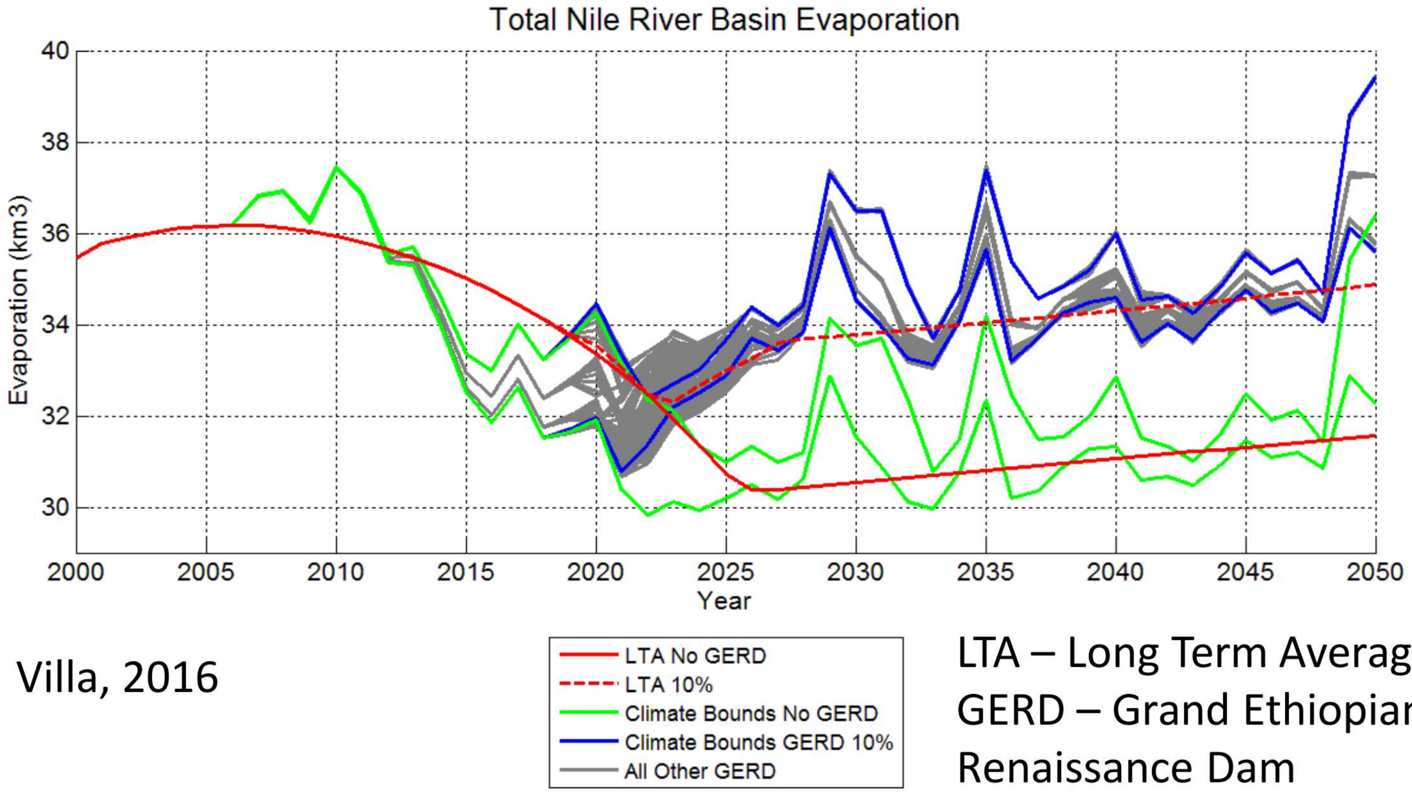
- Generalized production of difficult to produce boundary conditions



See Miller et. al., 2018

Purpose for multiscale modeling

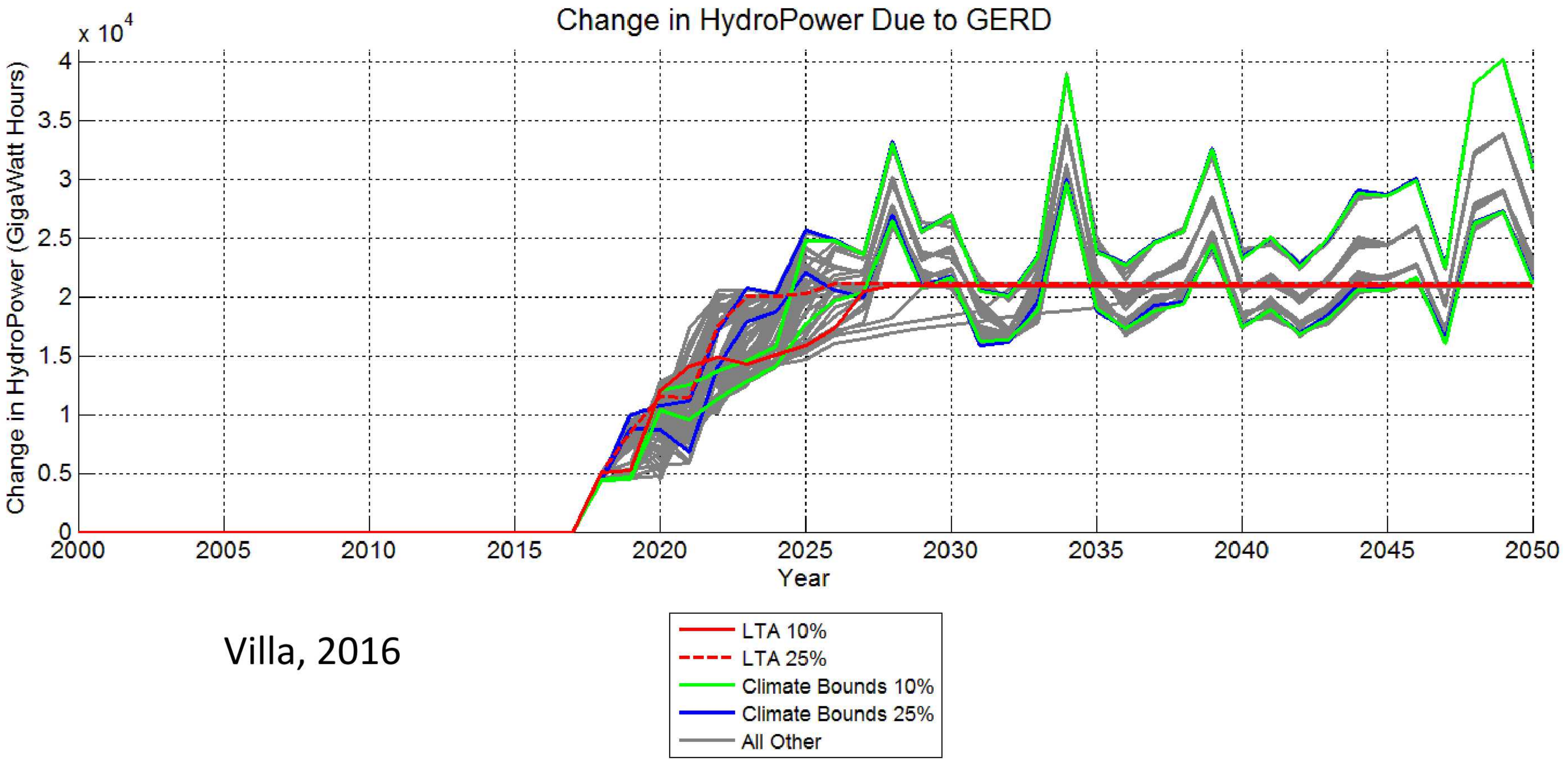
- Exploration of previously unavailable dynamics
  - Regional policy with considerations for climate
  - Tradeoff between competing variables



Villa, 2016

LTA – Long Term Average
GERD – Grand Ethiopian Renaissance Dam

Purpose for multiscale modeling



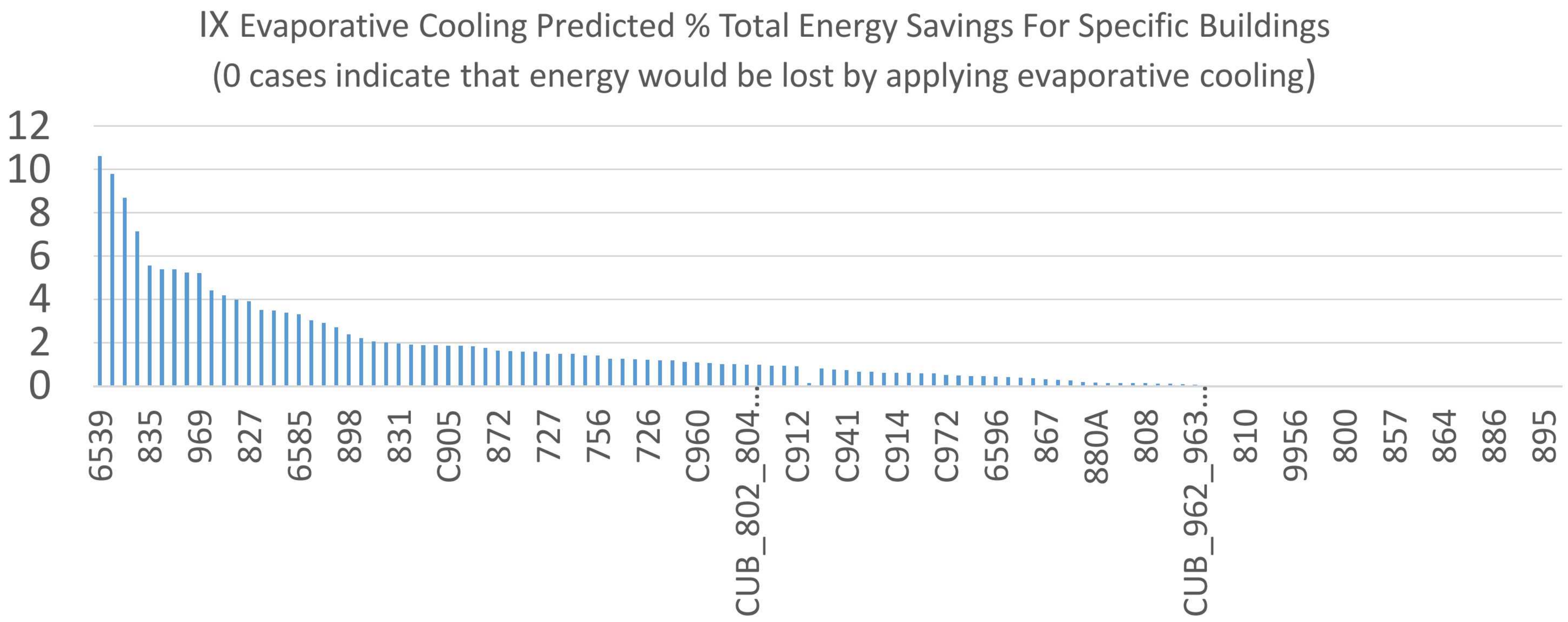
Villa, 2016

Purposes for multiscale modeling

- Planning of future systems
- Planning for existing systems
- Provides a consistent framework for testing design or retrofit hypotheses

Purpose for multiscale modeling

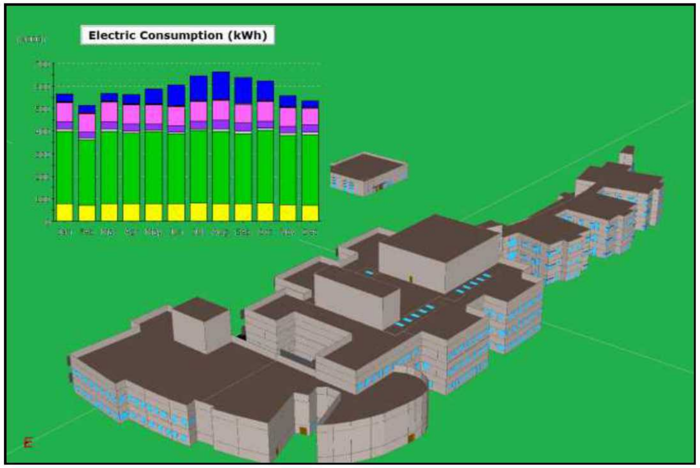
- Optimal planning with heterogenous model output



Purpose for multiscale modeling

- Ready-to-use, data-rich models for analysis that are also used at higher levels for multiscale purposes
    - WBEM fleet used by modelers for building centric analyses
    - WBEM systematically maintained and auto-calibrated to energy data for energy audit compliance
    - Corporate software that coordinates the entire fleet for energy savings scenarios
- This use case is taking a long time to develop

100-1000’s of Models



Classification

- Overall model purpose
  - **(IEE)** Informational / Exploratory / Education
    - Aesthetic
    - Provides a compelling narrative
  - **(FPF)** Planning/design for future unbuilt systems
    - Decision making framework with guidance from simplified physics
    - Inputs are highly uncertain
  - **(PMB)** Planning and maintenance for built systems
    - Challenged by need for specific inputs for useful results
  - **(TBP)** Tracking built system performance/energy analytics
    - Empirical validation needed
    - Inputs are difficult to obtain
  - **(NSP)** Natural system projection
    - Climate, water cycle, etc…
  - **(MPC)** Model predictive control
    - High consequence
    - Real time
    - A nascent field – has anyone accomplished MPC for a multiscale model?
  - Others??

Classification (2)

- Number and type of scales
  - List each scale of time/space/complex systems
  - Create a matrix that summarizes how each scale will interact

Input / Output →	BEM	Grid	Power Plants
BEM	Expandable urban model with nearby structure shading – generalized capacity to add new BEM (hourly time step)	Adaptive response model to grid peaks (loose coupling).	No interaction
Grid	Add noise to aggregate results signal to scale to grid response at 1ms.	Scalable state-space model via simplified representations. Adaptive time step to capture grid dynamics	Aggregate supply loads to scalable grid model
Power Plants	No interaction		Static set of power plants with policy rules

Classification (3)

- Use the matrix in the previous slide to produce a model description
  - Especially emphasize the physical representation of each scale
    - Black box (purely statistical / data driven)
    - Gray box – some physical parameters for sensitivity but still data driven to characterize the parameters
    - White box – detailed physics and corresponding parameters

- My model (Institutional Transformation – Villa et al., 2017) is a

- TBP, 3-scale (institution-wide, building, building systems), deterministic, hourly model
  - The lowest scale (building systems) – is still in the process of being well-characterized

- Most other WBEM multiscale models are statistical using proto-typical buildings
- More work is needed to classify multiscale models effectively

Multiscale Modeling Approaches

A naïve approach is to think everything can be modeled between several scales

Approaches

- Bottom up
  - Physical accuracy / heterogenous dynamics

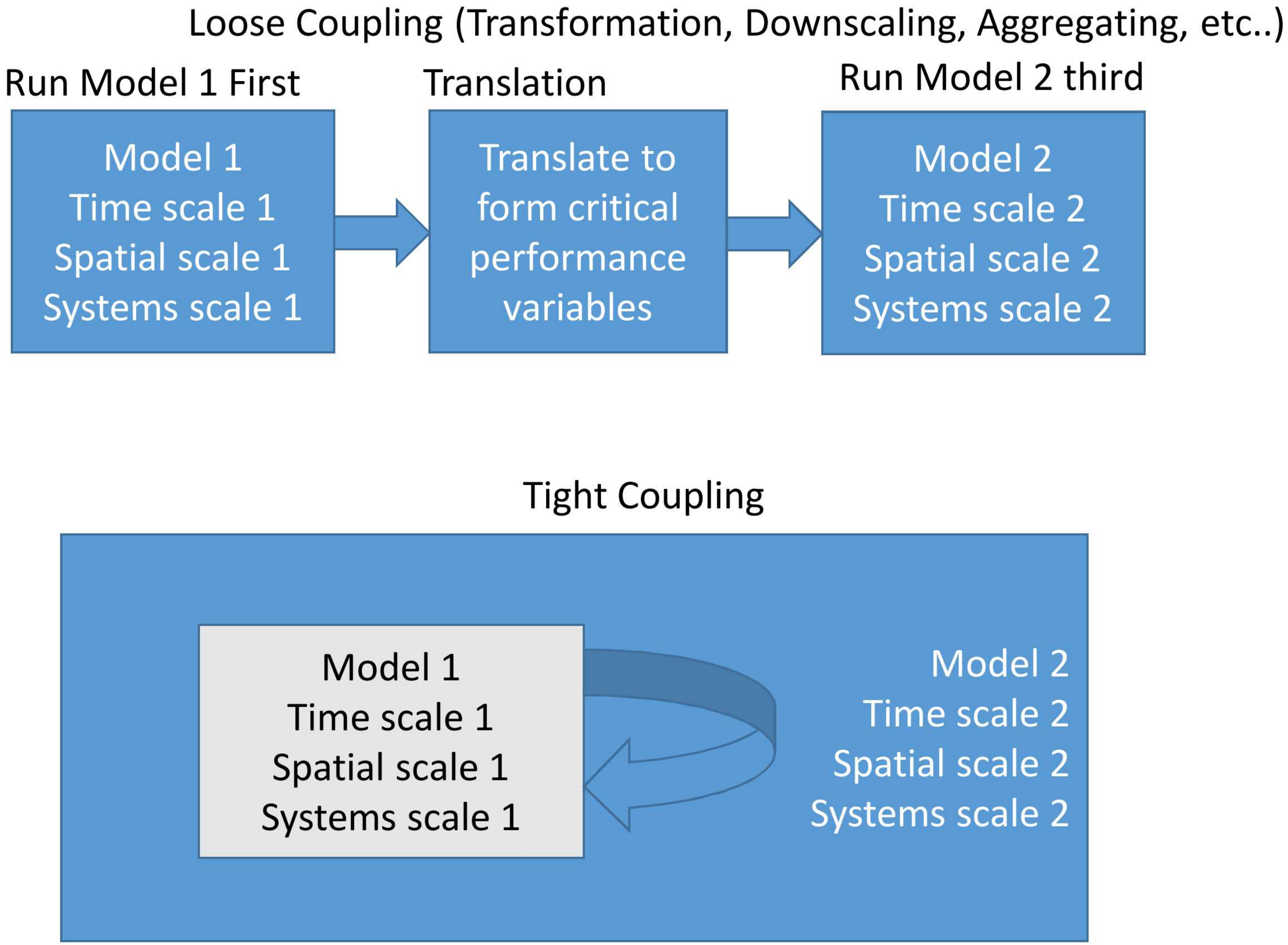
Each multiscale model is a composite of these two

- Top down
  - Computational efficiency / homogenous dynamics

Questions to ask

- Will different scale models be tightly or loosely coupled?
- What kind of translation needs to happen between the scales?
  - Statistical
  - Determinate
  - Reduced
  - Aggregated
- What are my use cases? (i.e. what dynamics matter?)
  - Links between scales may be unknown. Under such circumstances is a linear transform between variables sufficient?
- Do I need to account for uncertainty?
- How quickly does the model need to run to serve its purpose?

Tight and Loose Coupling



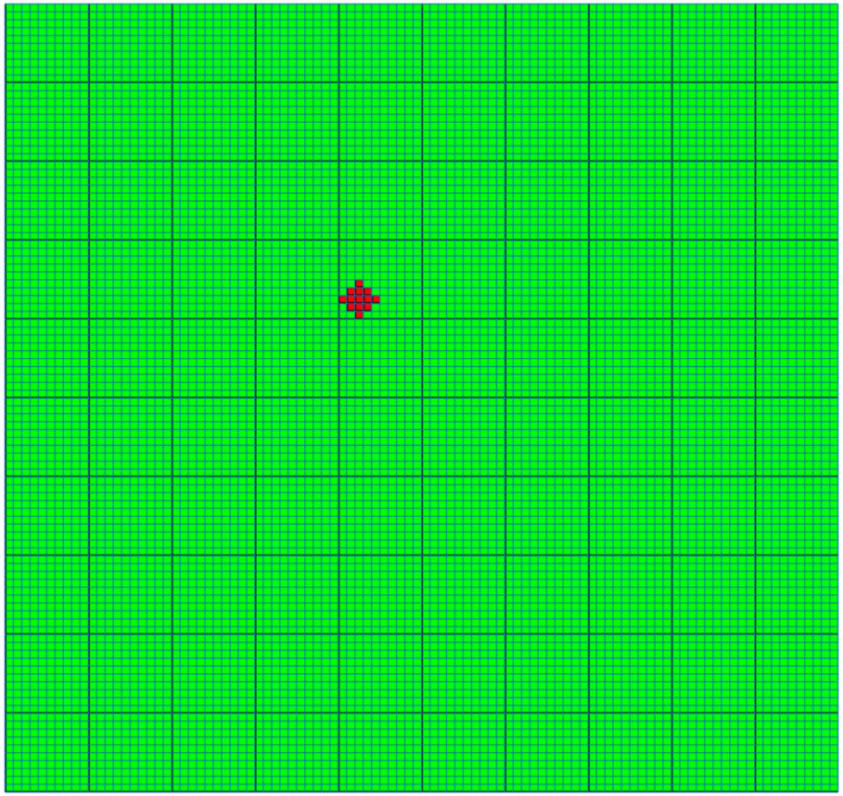
Efficient multiscale modeling

- Keeping multiscale problems computationally tractable is Important

Example:

  - 100x100 grid fully populated data
  - Green area aggregated to a 10x10 resolution
  - Red-scale full resolution 1x1
  - Special calculation for 10x10 all green areas touched by red

- Computational increase of speed for this example is = 114 (99 green + 13 red + 1 special boundary) elements instead of 10,000.
- Red elements can refocus anywhere in the domain producing detailed results only in areas that are needed



Reduction methods

- Linear – exact/approximate representation of high order model using a reduced order matrix
  - Craig-Bampton
  - Principal components analysis
- Nonlinear dimensionality reduction
  - Proper generalized decomposition –
    - Any dynamic system can be approximated by an infinite sum of separable functions
  - Machine learning and regression of low-order model parameters based on a high order model
- Physics complexity reduction (semi-empiricism)
  - 3-D fluid mechanics ≈ drag coefficient + Newton's law on discrete masses
- Statistical representations of a more complex population (prototypes)

Strength of Model Influence

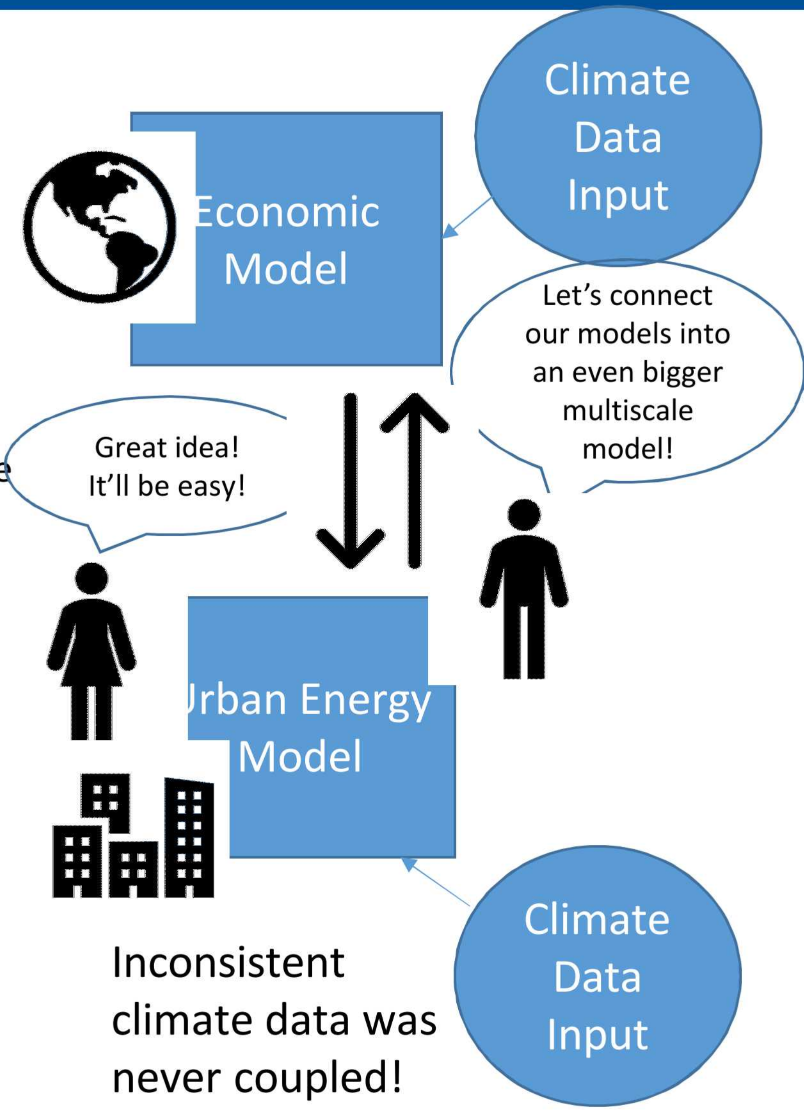
- Aesthetic
- Training
- Policy
- Planning
- Regulation
- Automated Feedback

Increasing need for verification and validation

For building energy applications, multiscale modeling has not reached these

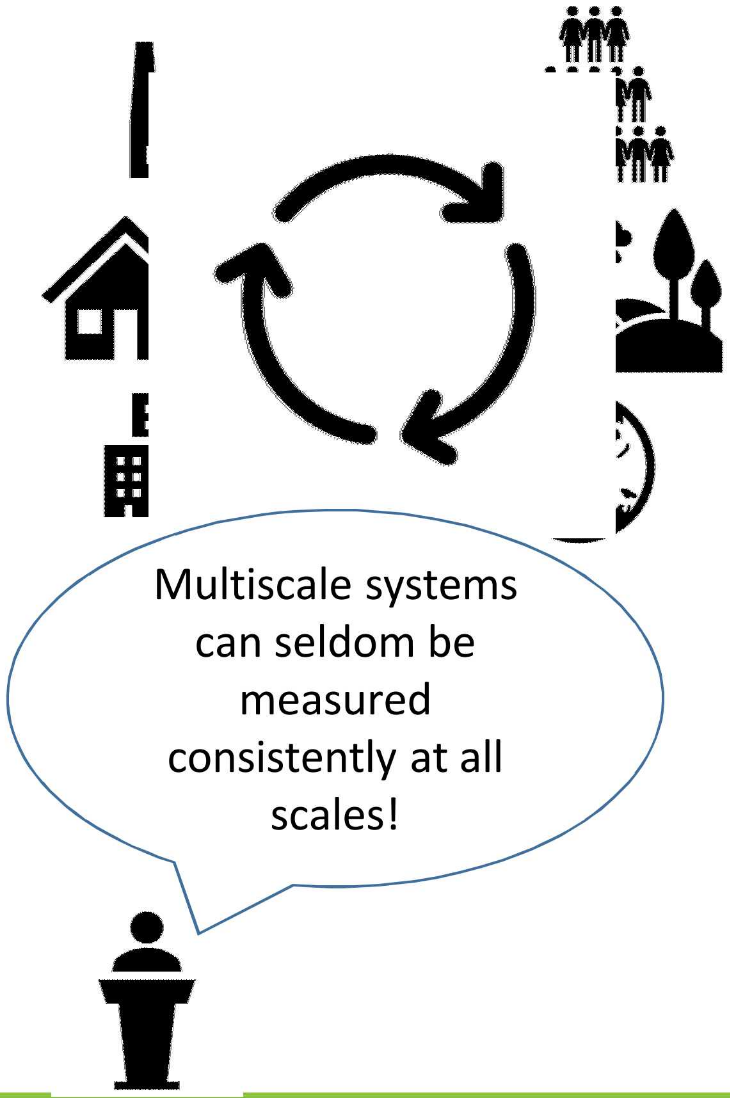
Keeping Multiscale Models Consistent is Hard!

- A huge challenge of multiscale modeling is keeping model boundaries between scales consistent
  - Example: A global food model includes a food production model, economic supply-demand and a climate model. The climate model incorporates a change in temperature which is translated into a change in water supply to the food model. Results provide a compelling, yet unvalidated, change in food production for the future
  - Problem: The food model has crop coefficients that are known to be temperature dependent but the dependency is not know, also increased temperature could have uncharacterized feedbacks to human behavior that affect the economy
- There can be so many variables that it is hard to know whether they are interrelated and no data exists to confirm so
- It is difficult to know if similar variables from models and data can be directly connected
  - Temperature does not mean the same thing between BEM and measurements!
    - BEM = zone average temperature
    - Sensor = temperature reading somewhere in the building (hopefully in the zone you think it is in)



Verification and Validation (V&V)

- Assure Quality:
  - Self consistency (last slide)
  - Consistency of individual parts (unit testing)
  - Historic consistency
    - Often easy to achieve as is usually the case with a mathematically underdefined system (i.e. there are infinities of correct answers)
  - Often validation of the entire multiscale scheme is impossible
  - Benchmark tests with a desirable* outcome
  - Decision/outcome record keeping
  - Live streams of data
  - Scripted V&V



* Good validation practice would use a known outcome but multiscale systems do not permit this. Benchmarks are still valuable because you can know that the model is behaving as you would expect as changes are made and the model is re-tested

Conclusion

- Plan carefully before entering into a multiscale modeling endeavor
- Classify your model and choose an approach
- Clearly communicate the limitations of your model and make sure you understand them yourself
- Assure modeling quality – create your own set of internal tests that help you gain confidence that some verification and validation can be replicated as changes are made

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Questions?

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