Meteorology and Market Design for Grid Services What new science do we need to know?

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Before we jump in.. – a few definitions

- Weather is the instantaneous, hourly, daily, and weekly variability of temperature, sunlight, precipitation, winds, storms, etc., for any region
- Weather forecasting is based on 'deterministic models' out to about 10 days or so. Confidence in predictions rapidly degrades over time.
- Sub-seasonal to seasonal (S2S) represents the prediction time scale from weeks to months. It is generally stochastic, using phases of various modes of variability: MJO; monsoons; planetary waves; El Nino; PDO; etc., combined with weather forecasting
- Climate is the average of weather over multiple years, generally a decade or longer. Climate is characterized by trends and pdf's
- Climate change involves a low frequency trend (e.g., warming) and/or pdf's of extreme events (e.g., more frequent storms)

Outline

- National Challenges
- Weather and climate – state of the science
- Energy sector – what is needed from the meteorological community
- What science is in the pipeline

Some relevant national challenges

- Energy security and Climate solutions
  - Design and deploy low carbon emitting energy technologies
  - Uninterrupted and affordable supply
  - Innovative dynamic distributed grids with energy storage
  - Modeling – design for the future and measure progress in achieving goals for national challenges
- International economic competitiveness
  - Who will capture the new energy markets involving clean technologies and next generation grids?
- Public expectations
  - Uninterruped and affordable energy supply
  - Resilience in view of extreme events
  - Equitable solutions

View from the risk and finance sectors

- Energy sector decisions depend on certainty of weather-climate predictions
  - Resilient designs; continuity of affordable supply; minimize risks of cascading failure
  - Evaluation of risk associated with different finance instruments

- Most decision-makers use climate model output from the IPCC or the NCA, and these data have major shortcomings
  - Coarse grid: 50 km to 100 km resolution, don’t capture many regions of interest
  - Sub-seasonal to seasonal not usually included; and S2S predictions are sub-par
  - Uncertainty methodologies for climate models and financial decisions not harmonized

- Energy analysis requires a systems approach, to assess vulnerability and risk of exceeding the set of distributed thresholds as well as guide future investments
  - Energy-water nexus is important
  - Investment time scales: 30 year bonds; infrastructure lifetime at 50-100 years

View from the energy engineering sector

- Wind power sector is introducing really large turbines
  - Heights exceeding 220 m and width 200 m for offshore use
  - Designs underway for large offshore floating anchored turbines
  - Onshore wind production often in complex mountainous terrain

- Solar energy facilities and the grid
  - Grid connectivity, and local storage, are essential when in remote regions
  - Decentralized production, e.g., local solar facilities and on rooftops

- Grid dynamics, load balance, and stability
  - Predicting and responding to changing energy demand, over large geographic region
  - Predicting and maximizing energy production from, e.g., wind and solar
  - Local and regional microgrids and energy storage

What the weather models can tell us in support of day to day operations

- Local area models can achive 1 km resolution, while forecast models are generally coarser at 10 km resolution
- Models and predictions are reasonably good for flat terrain far from any boundary, especially for near-neutral stratifications
- Predictions seriously break down in and near heterogeneous complex terrain, e.g., near coastlines, in the mountains, and during highly stratified conditions
  - low level jets
  - internal boundary layers
  - gravity waves (and wave breaking) in the overlying inversion
  - Nonstationary turbulence
- Climate models have much coarser grids, e.g., 15 km to 100 km, and are not suited for operations, but they are useful for designs, planning and financial risk.

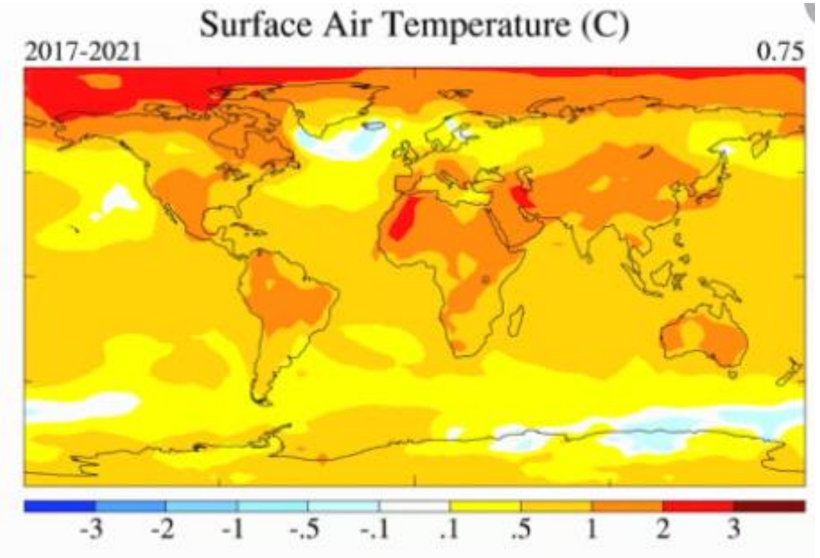
Meteorological phenomena can occur within the vertical extent of sweep area of turbine blades

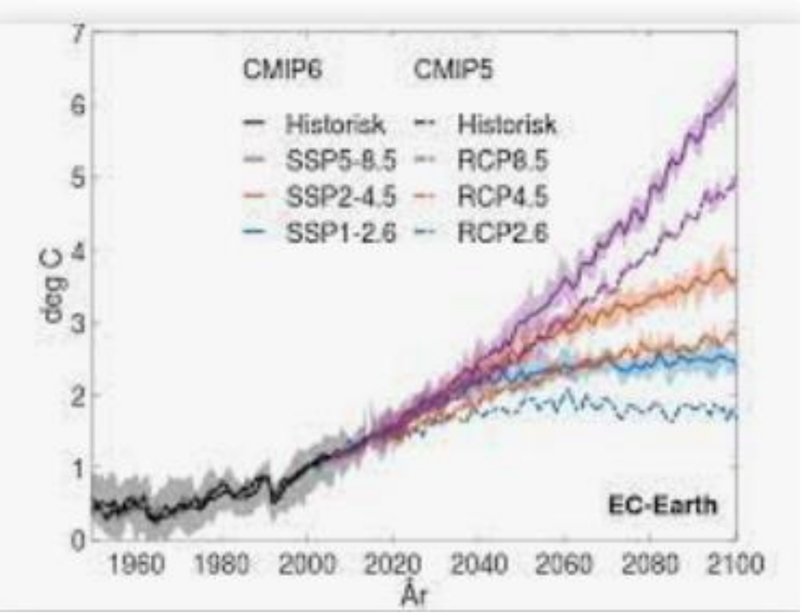
The Biden administration is pressing for offshore wind development off the coast of California that would use floating turbines like these, seen near Aberdeen, Scotland. Jeff J Mitchell/Getty Images

Climate Models – their utility is design, risk, investment

What the coarse-grid climate models are already telling us

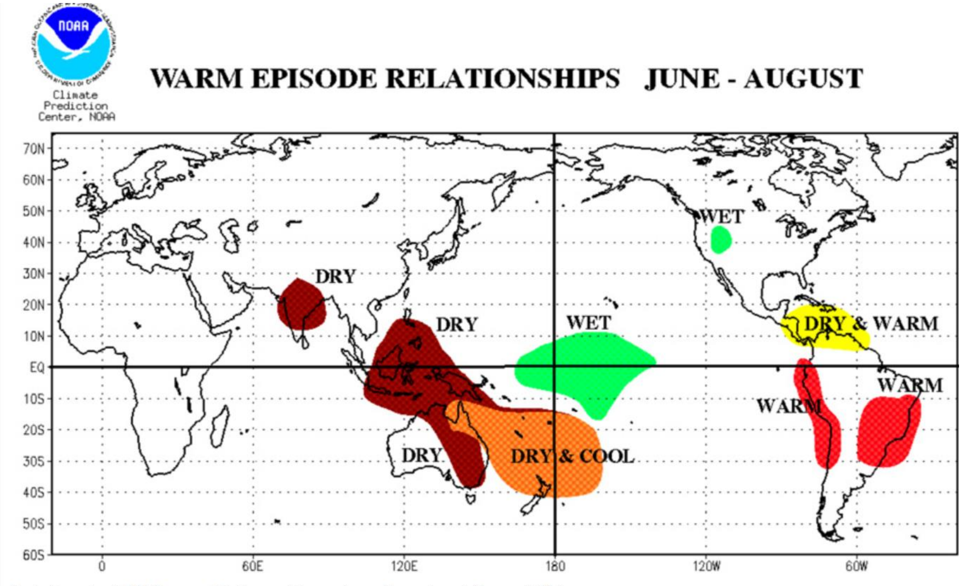
- The climate is warming across the planet, but there is enormous geographic variability in the rate of warming
  - Most warming in northern latitudes
- We should expect that the climate will continue to warm for the next few decades, independently of GHG policies
- There is enormous interannual variability for different geographies
  - El Nino, Atlantic Oscillation, and other patterns can drive seasonal, annual, and sub-decadal variabilities
- The pdf of weather variability and extremes is expanding





Weather and climate patterns influenced by ‘modes of variability’

Table 1: Mode	Timescale	Location	Diagnostics
North Atlantic Oscillation/ Arctic Oscillation (NAO/AO)	7-60 days	Northern High Latitudes (Atl. Sector)	SLP
Madden-Julian Osc. (MJO)	20-80 days	Tropical Pacific	OLR, Precip (Daily)
El Niño/Southern Osc. (ENSO)	3-7 years	Tropical Pacific	SST, OLR, Water vapor, Precipitation
Quasi-Biennial Osc. (QBO)	2-3 years	Trop. lower stratos	U-wind
Southern Annular Mode (SAM)	7-60 days	South. High Lat.	SLP, U-wind
Pacific Decadal Osc. (PDO)	5-15 years	Pacific Ocean	SST



Typical impacts of El Niño on precipitations and temperatures: June - August. Source: NOAA
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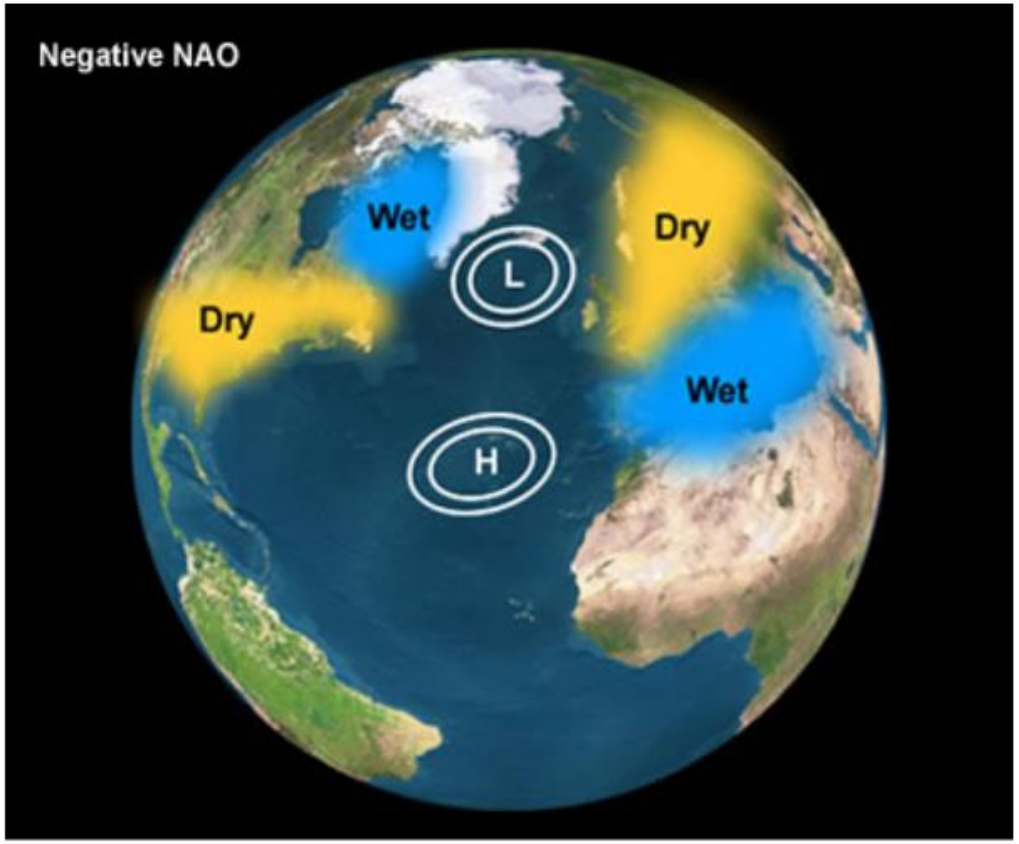
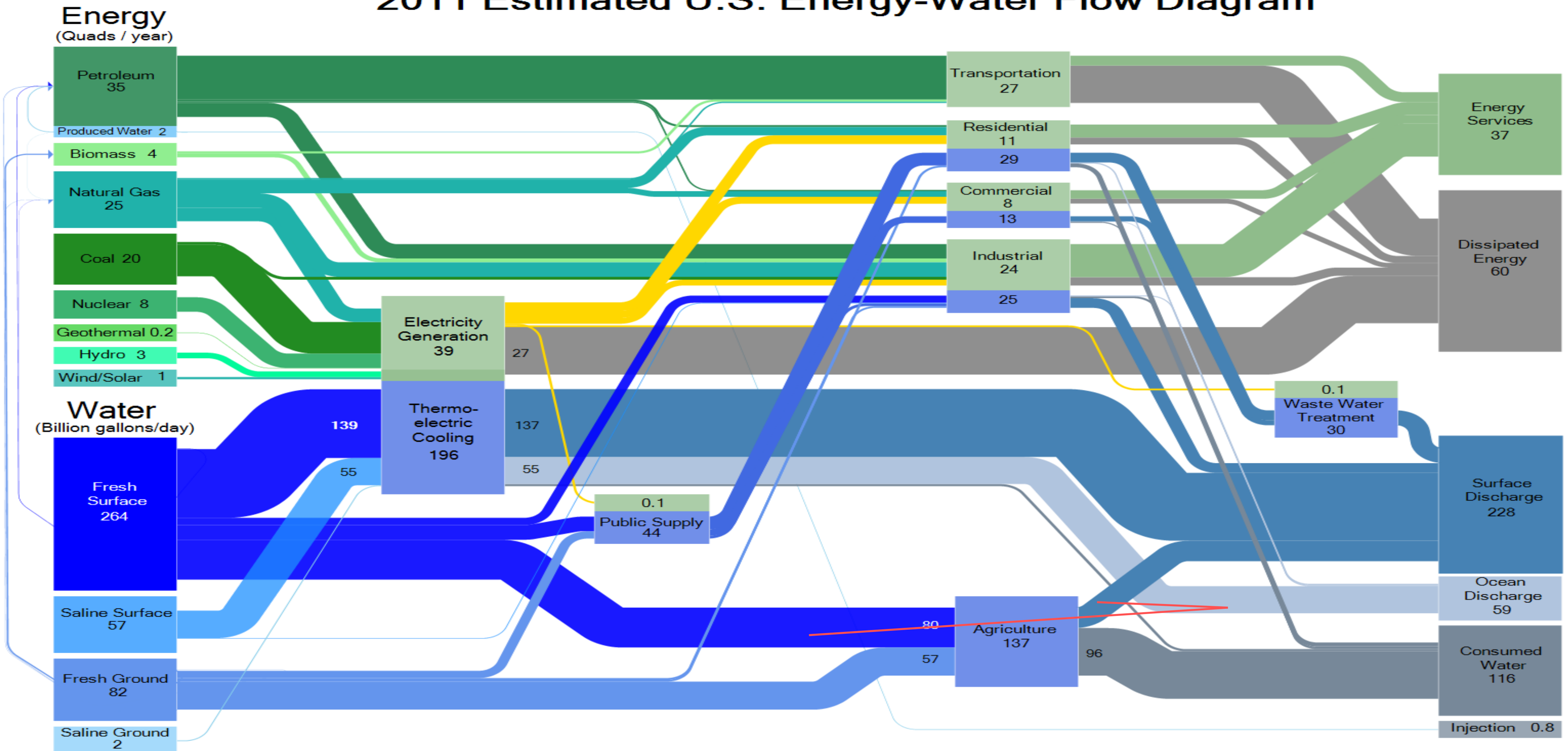


During a negative NAO, only a weak pressure gradient exists and Southern Europe and Africa receive weak winter storms while Northern Europe and the Eastern United States are cold and dry

More frequent and severe extremes suggest greater emphasis on resilience

2011 Estimated U.S. Energy-Water Flow Diagram



Energy reported in Quads/year. Water reported in Billion Gallons/Day.

Policy and Institutional Changes

Land Use & Land Cover Change

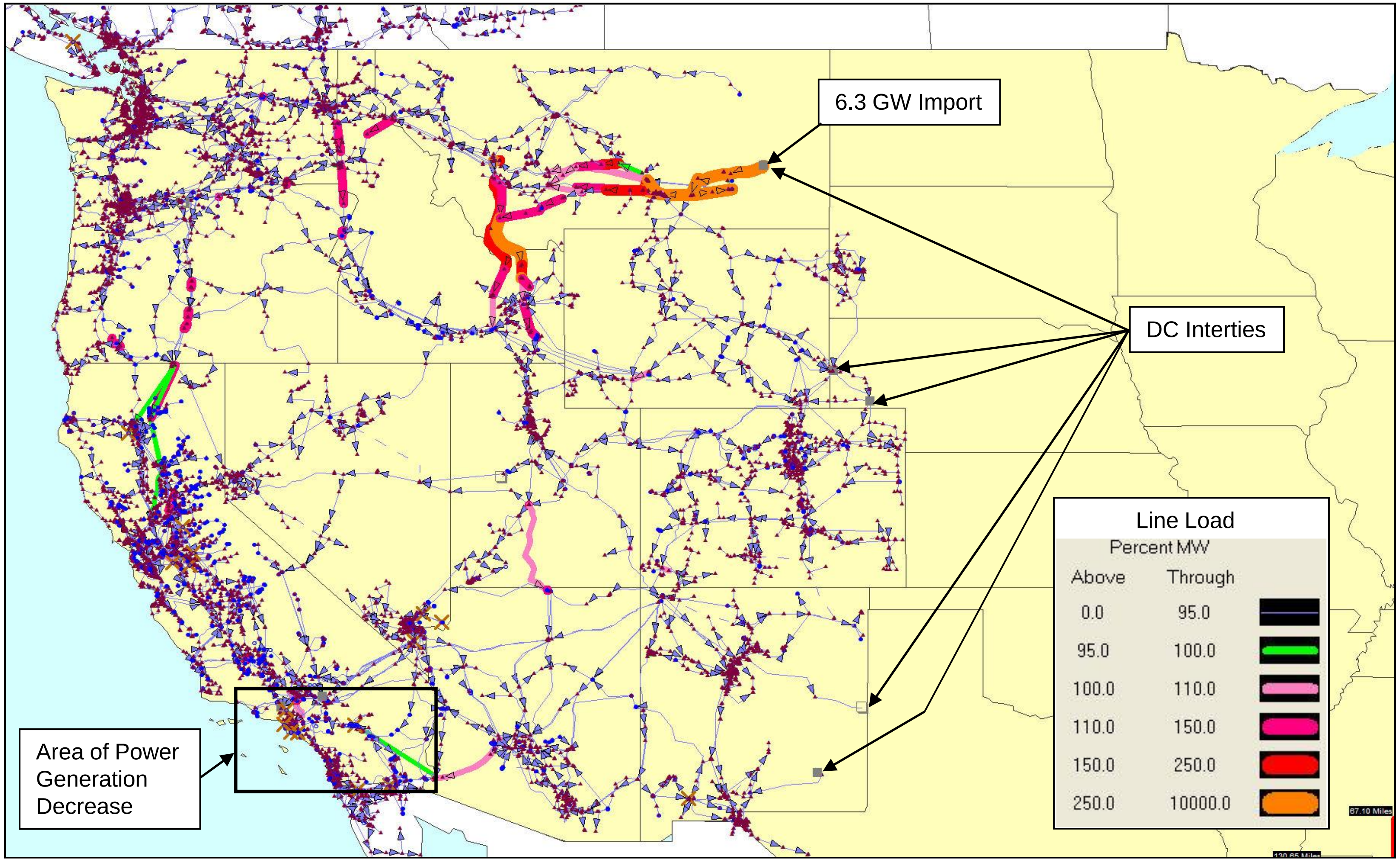
Stakeholder and Consumer Preferences

Population/ Migration

Urbanization & Infrastructure Dynamics

Regional Economic Development

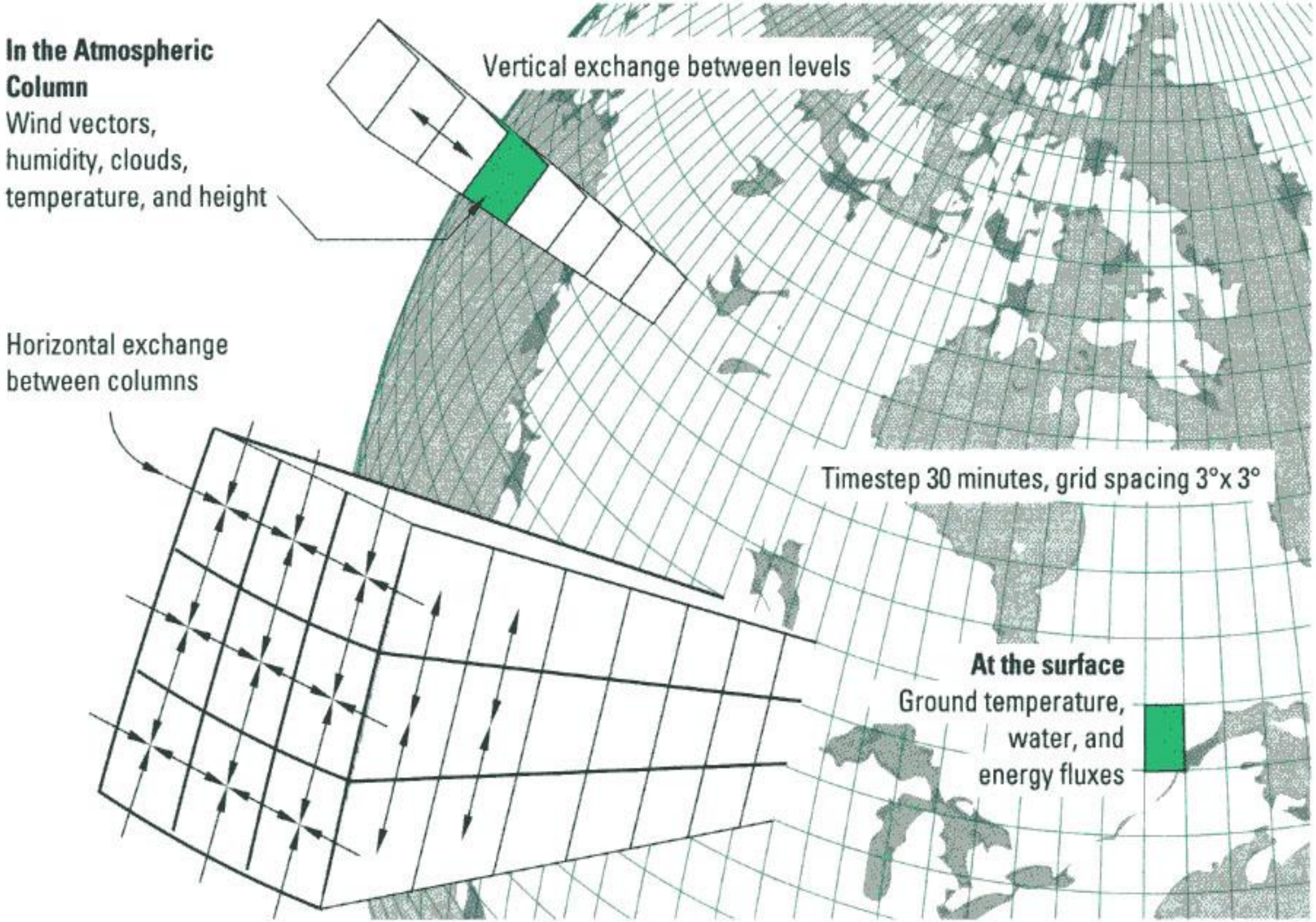
These Line Loads vary in degree of overload and therefore investment to relieve the overload



Integrative meteorological observations, modeling, simulation, and prediction research

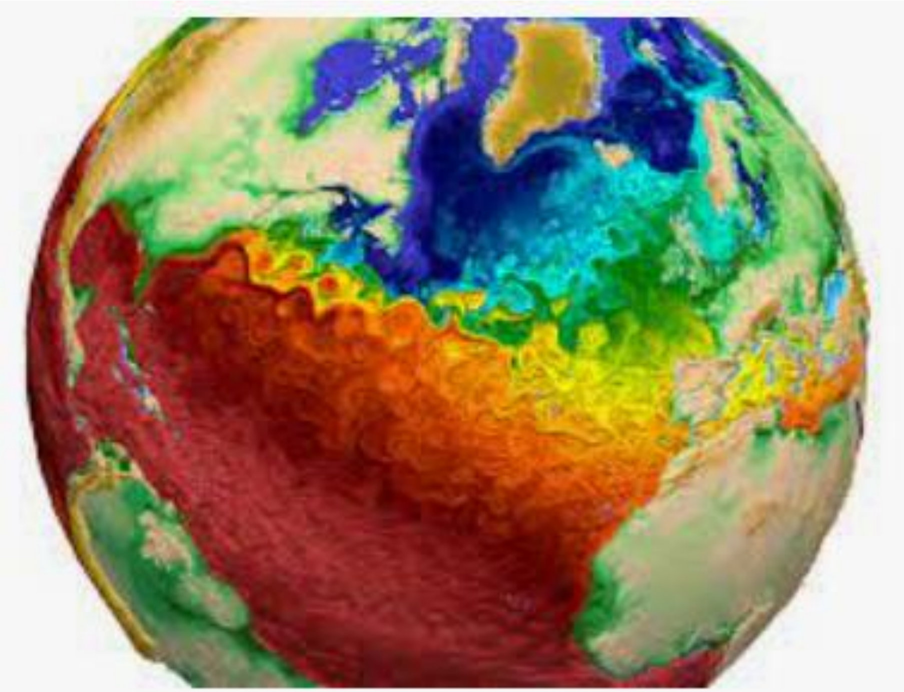
Some framing questions

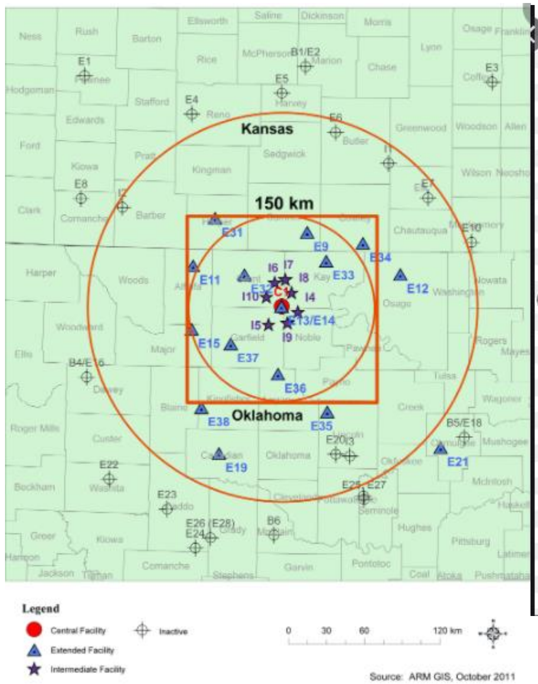
- What are the combinations of thresholds for all components within a system of infrastructures that can trigger a failure (e.g., blackout)?
- Which mix of meteorological precursors distributed over an extended region can lead to cascading failure, e.g., spatial correlations, anomalous boundary layer shear, non-stationary turbulence, etc.?
- What can be inserted into, e.g., the electric grid, reservoir operations, management practices, etc., to maintain affordable and uninterrupted services?

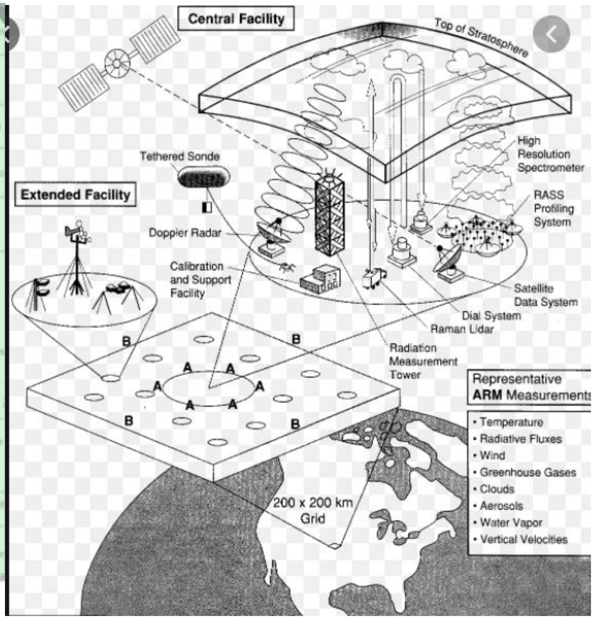


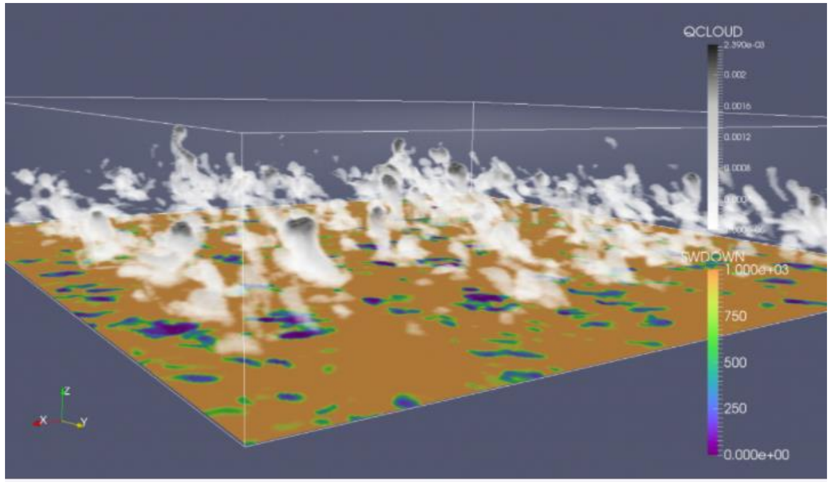
In the Atmospheric Column
Wind vectors, humidity, clouds, temperature, and height
Vertical exchange between levels
Horizontal exchange between columns
Timestep 30 minutes, grid spacing 3°x 3°
At the surface
Ground temperature, water, and energy fluxes

Energy Exascale Earth System Model (E3SM) and higher resolution simulations









Thanks to LASSO, a cloud model simulation (above) can now more easily than ever be compared with observational data.

Ideal approach – scientists and stakeholders work together

- Demonstration projects to capture a larger number of anomalous meteorological and wind shear events
- Co-design improvements to predictive models and simulations, with more resilient designs for energy system components
- Add in machine learning where appropriate
- Harmonize UQ methodologies
- Demonstrate value added to energy designs and financial risk
- Push limits on resolution and computing

THANK YOU !