EXTREME WEATHER (And SNAP)

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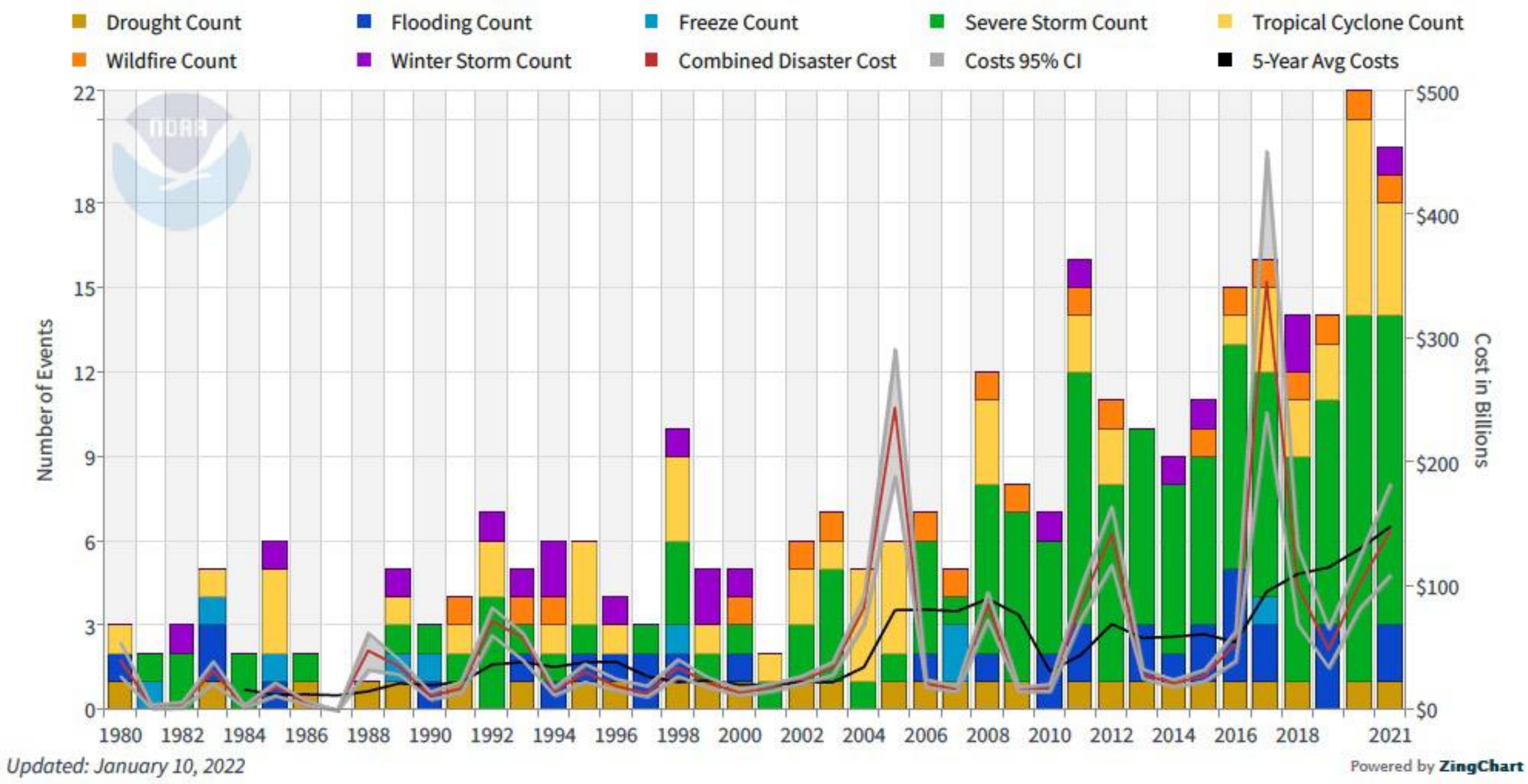
Frequency and Cost of Billion Dollar Weather Events

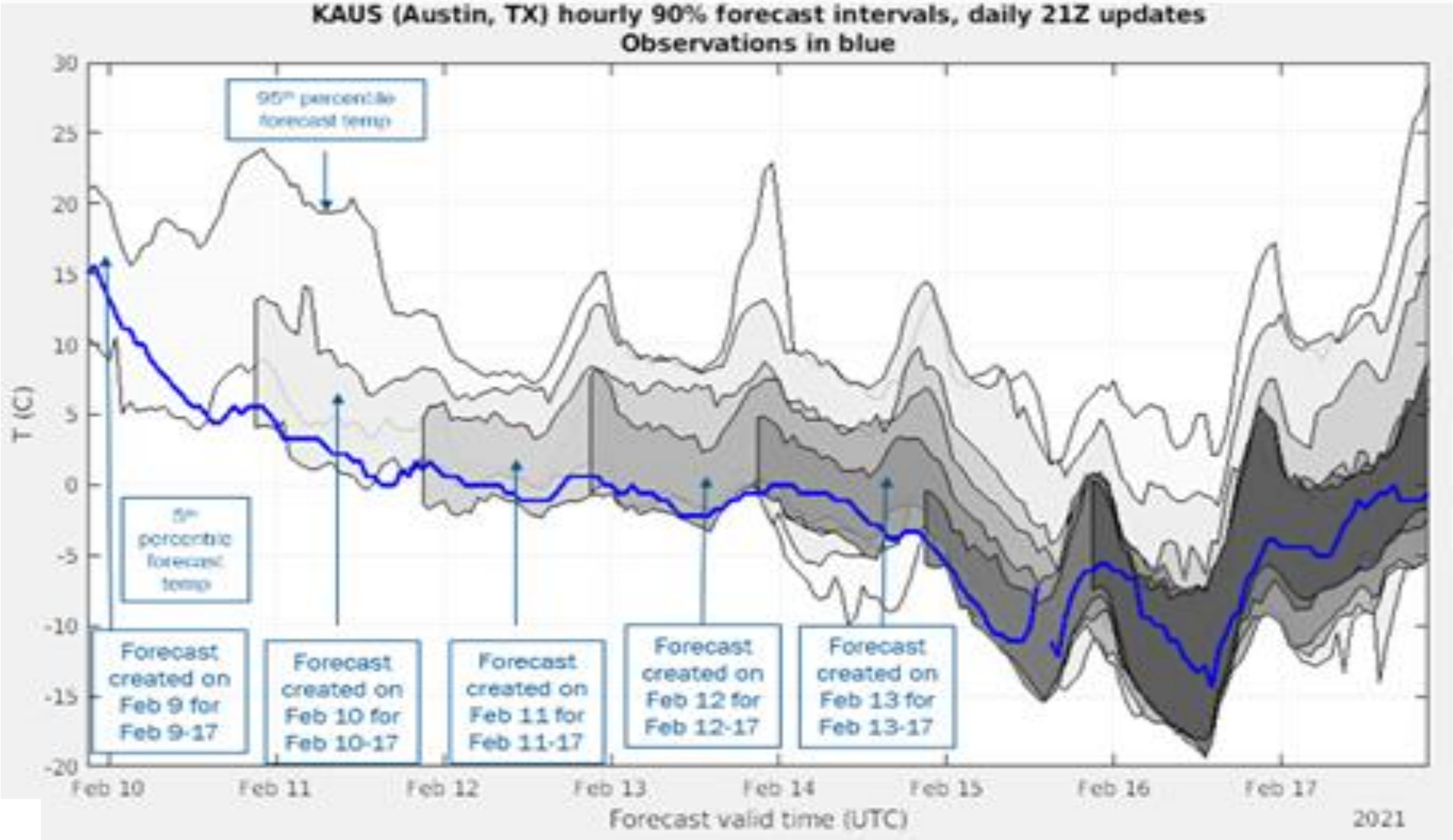
Time Frame	# of $1B+events/ year	$B Impact/ year
1980’s	2.9	17.8
1990’s	5.3	27.4
2000’s	6.2	51.8
2010 – 2014	11.9	81.0
2015 – 2019	13.8	107.0
2017 – 2019	14.6	153.0
2020	22.0	95.0

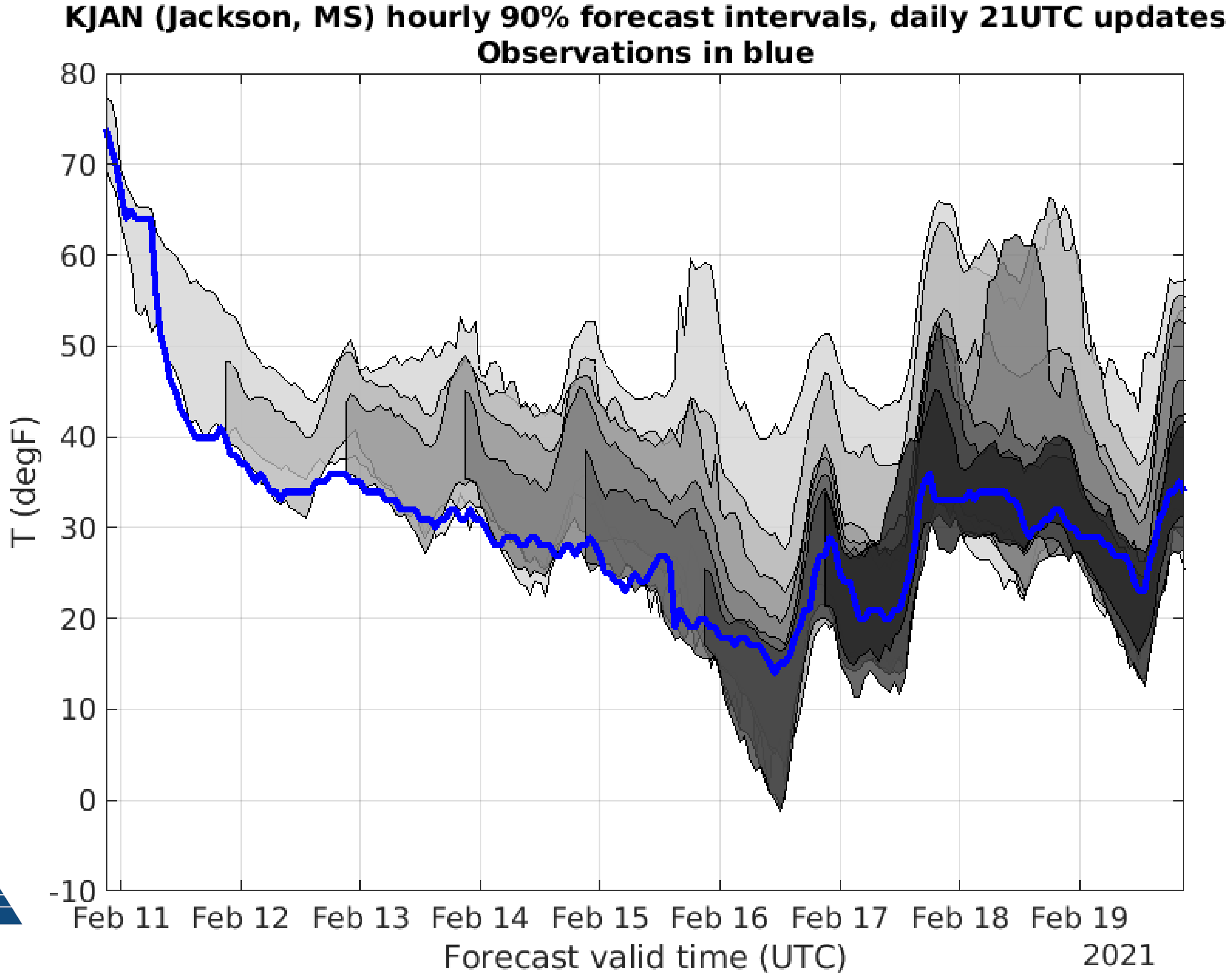
Impacts of Climate Change

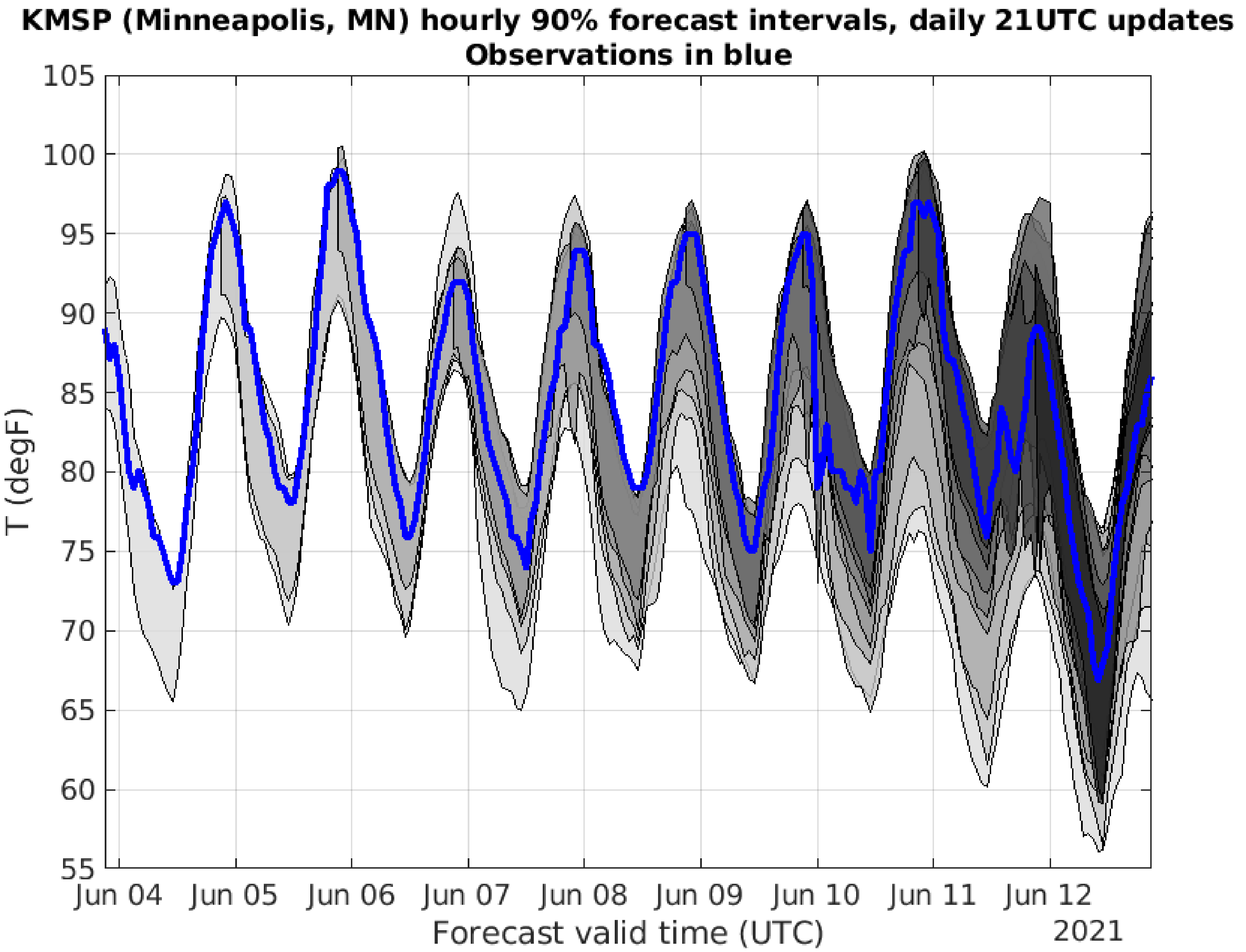


Average number of $1B+ extreme weather events increased from 2.9/year in 1980s to 17.2/year in last 5 years
Average annual cost of $1B+ weather events increased from $17.8 B/year in 1980s to $148.4 B/year in last 5 years

February 2021 Austin Texas

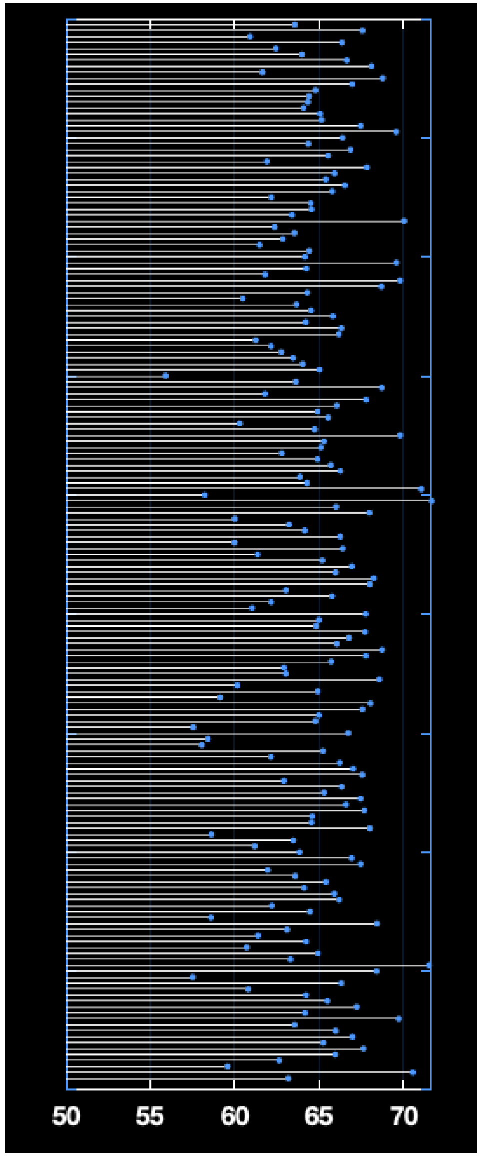



KJAN (Jackson, MS) hourly 90% forecast intervals, daily 21UTC updates
Observations in blue
T (degF)
80
70
60
50
40
30
20
10
0
-10
Feb 11
Feb 12
Feb 13
Feb 14
Feb 15
Feb 16
Feb 17
Feb 18
Feb 19
Forecast valid time (UTC)
2021


KMSP (Minneapolis, MN) hourly 90% forecast intervals, daily 21UTC updates
Observations in blue
T (degF)
105
100
95
90
85
80
75
70
65
60
55
Jun 04
Jun 05
Jun 06
Jun 07
Jun 08
Jun 09
Jun 10
Jun 11
Jun 12
2021
Forecast valid time (UTC)

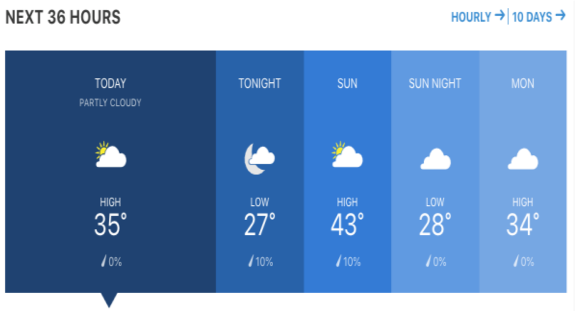
IBM/TWC calibrates each NWP model and combines them to generate forecasts at requested locations.

Probabilistic forecasts use data from ECMWF, ECMWF-Ens (51), GFS, GFS-Ens (32), NAM, & MPAS regional and global.

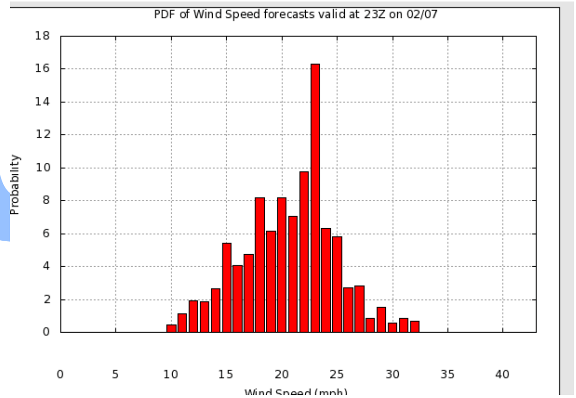


ML Calibration

Deterministic Forecasts



Probability Forecasts



Creating a Probabilistic Weather Forecast

1. IBM/ The Weather Company utilizes 87 different numerical weather prediction models (and their ensemble members) as inputs to their forecast system
2. Ensemble members are generated by varying assumptions about initial conditions and model physics. Ensembles in their raw form tend to be biased, and under-dispersive
3. Corrects the raw ensemble member data using Bayesian model averaging to adjust for systematic errors (bias correction), and calibrate the distributions for each output variable individually (spread the dispersion)
4. Rearranges the individual values into the rank order structure of the raw ensemble to create 100 synthetic weather system scenarios through use of Ensemble Copula Coupling–Quantile technique

- The result is a probabilistic forecast wherein each of one hundred scenarios is equally likely
    - The predicted outcomes have been "spread" to deal with under-dispersion in the underlying weather models
    - The variables are internally consistent with each other in space and time (preserved the correlations among variables by preserving the weather system dependence template)
- Probabilistic forecasts are created on demand for hourly time steps out 15 days for any location.
    - Algorithms used to create synthetic probabilistic forecasts for hub height winds and solar from available probabilistically forecast parameters

SNAP Combines Weather Science with Power Systems Engineering and Economics Enhanced by Advanced Optimization and Cloud Computing

Traditional Probabilistic Resource Adequacy Assessment vs. SNAP

Traditional RAs

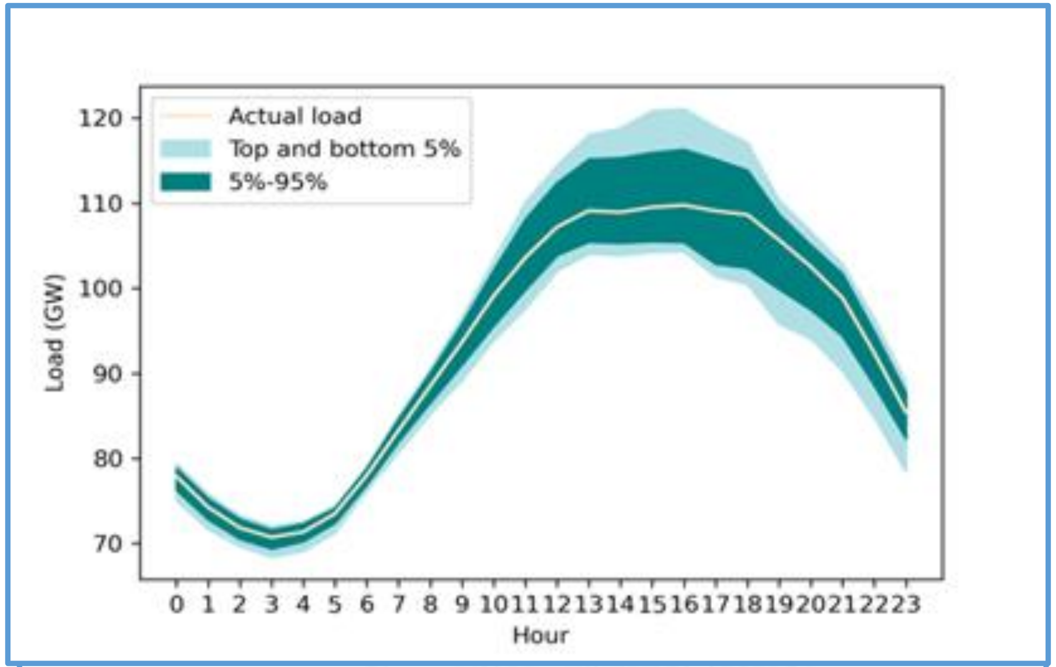
- Performed annually for future year(s)
- Use long-term forecast of weather conditions and load
- Run 1,000s Monte Carlo scenarios combining generation outages with a few dozen weather year scenarios
- Rely on highly stylized models of power systems:
  - Ignore most operational constraints and contingencies
  - Rely on pipes and bubble transmission models that ignore Kirchhoff Voltage Law
- Translate RA assessments into installed capacity requirements based on outdated metrics that do not have economic justification and not suitable for modern power systems
- Offer no metrics for assessing contribution of transmission to RA and make it virtually impossible to co-optimize generation and transmission investments
- Use the above to justify billions of $$ investments and cost recovery

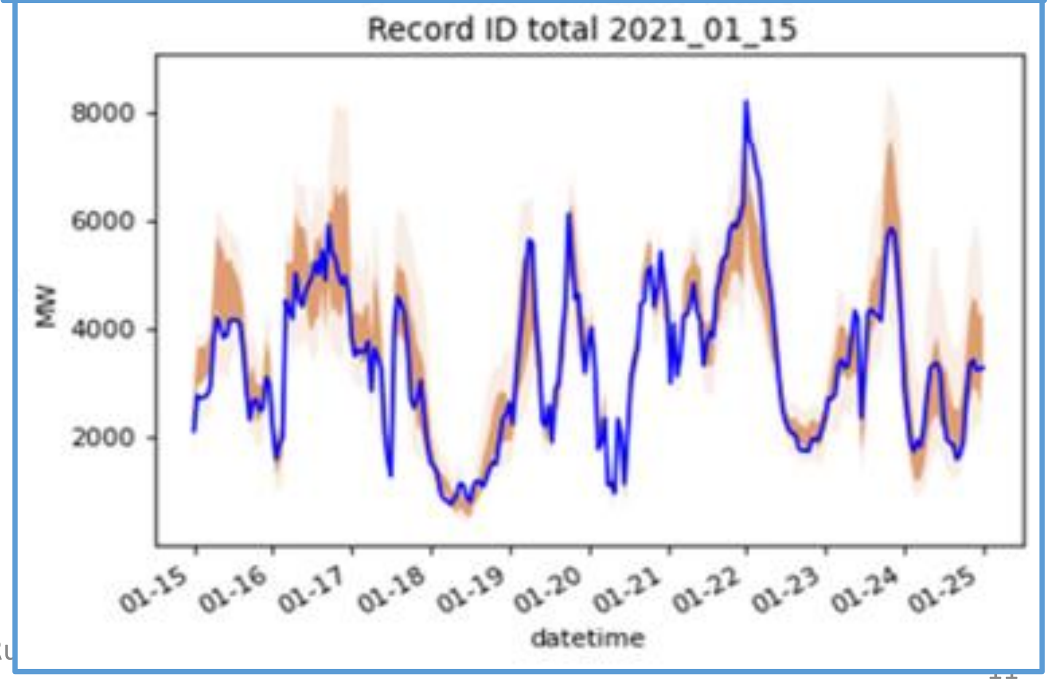
SNAP

- Performed daily for the next 1 -3 – 5 days
- Relies on modern weather science and technology to generate 100+ probabilistic short-term weather forecasts (PFs) and uses probabilities that can be empirically validated
- Runs 10,000 – 100,000 Monte Carlo scenarios combining PFs with generation *and <u>transmission</u>* <u>outages</u>
- Relies on validated models of the MMS level of details that
  - use SCUC to factor in operational constraints and perform contingency analysis
  - Run SCOPF on physical network models
- Evaluates and monetizes contribution of each generation, demand-side and transmission asset to system adequacy
- Sends nodal economic signal to investors in generation, transmission and demand resources
- Effectively provides spot pricing for adequacy that is consistent with the physics of the system

Weather to Energy

- SNAP uses a combination of machine learning and other statistical modeling tools to generate 100 probabilistic scenario forecasts of
  - load by MISO zone,
  - wind and solar by generating unit





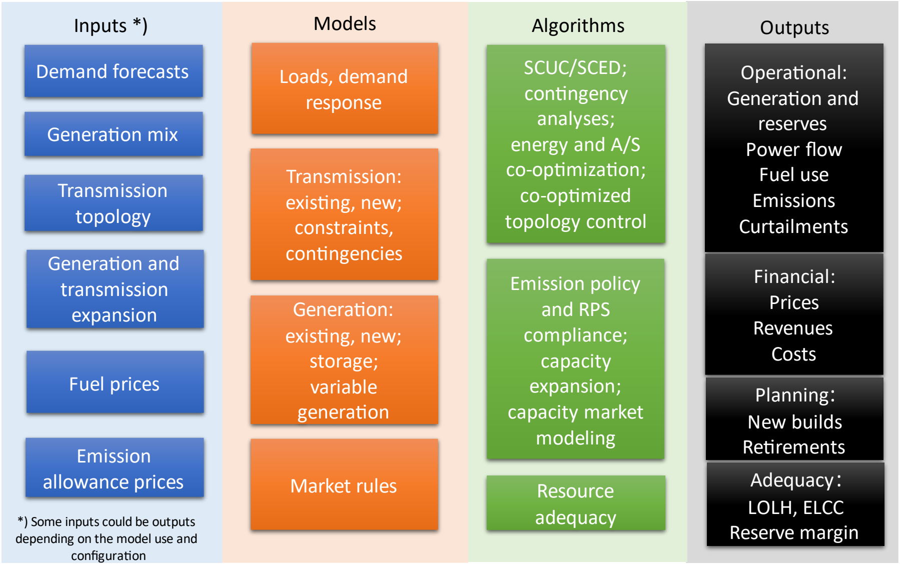
ENELYTIX® as a SNAP Platform

powered by PSO

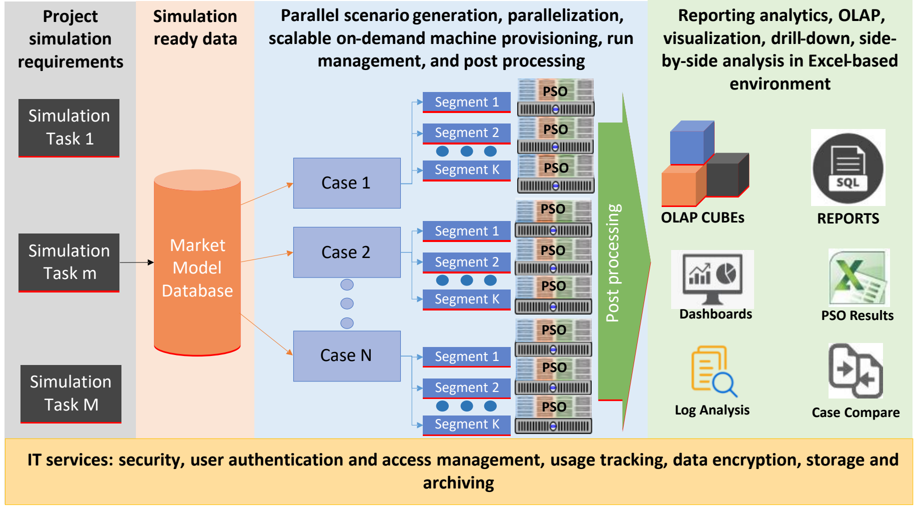
- Market modeling engine *Power Systems Optimizer* (PSO) by Polaris uses IBM's CPLEX MIP solver
- High fidelity tool similar to RTO's Market Modeling Systems or operationally advanced production costing models
- Purposely designed to handle high volumes of optimization tasks required for SNAP
- Built-in variance reduction approach for Monte Carlo simulations

– *ENELYTIX cloud-based architecture is primarily designed for fully automated massive parallel case generation, resource provisioning, execution and post processing*

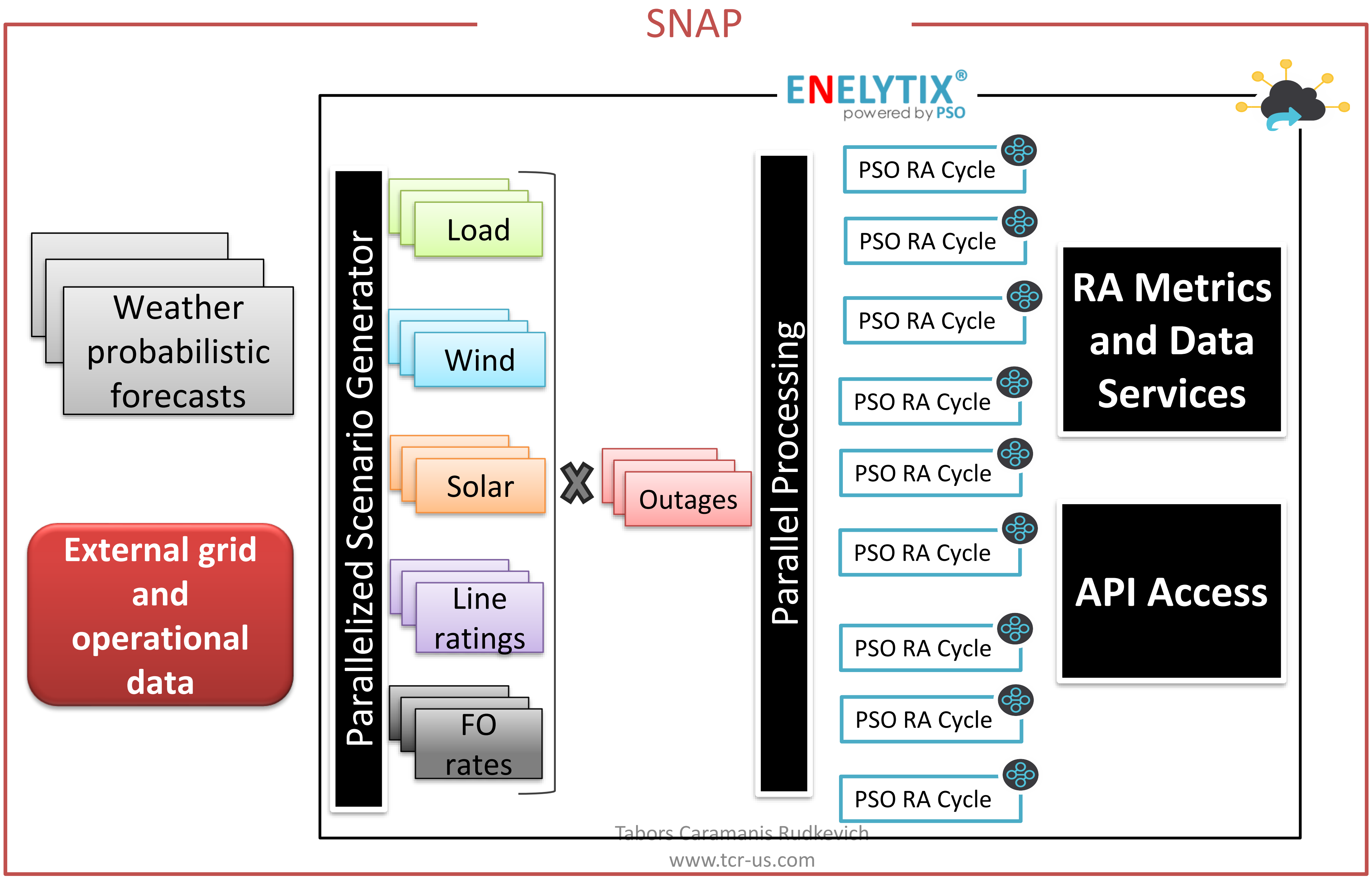
PSO Schematics



ENELYTIX Schematics



SNAP Schematics



SNAP Computations

SNAP

SNAP calculations:

Objective Function: minimize production (bid/offer) cost plus cost of unserved load at VOLL

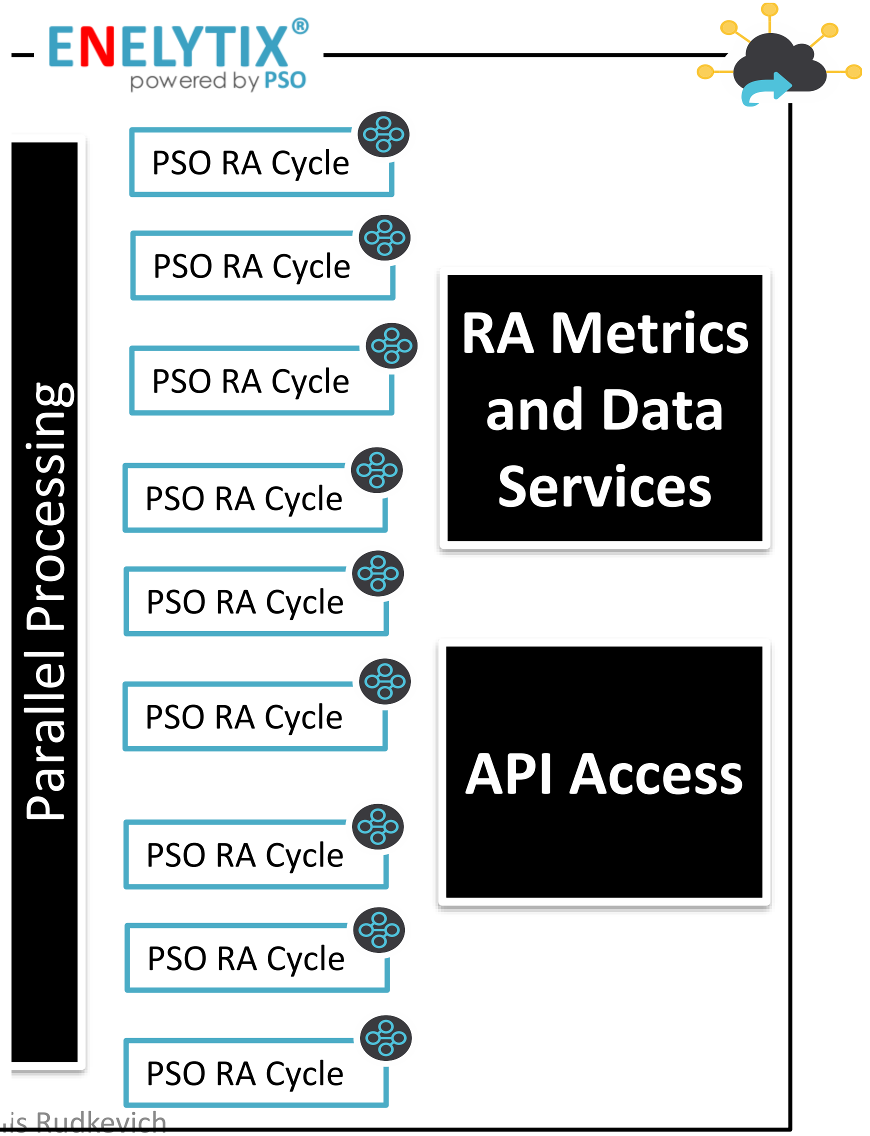
Generators offers as submitted Day-ahead

Reliability Interruption Bids (RIBs) at offer levels as submitted into DA market (presumably below VOLL)

SCUC/SCED: 100,000+ Monte Carlo scenarios played out for each hour

-- **If no inadequacy events occurs**, scenario is noted. Scenario Nodal Adequacy Price (SNAP) is effectively zero at all locations

-- **if an inadequacy event occurs**, the event sets SNAP value at VOLL or RIB at inadequacy location. SNAP for all other locations is set using standard shadow price mathematics



SNAP Schematics

SNAP

Summary Metrics:

Area level: EUE, LOLH, LOLE, Marginal Unserved Energy

Nodal Level:

Adequacy Price (AP) – expected value of SNAP at each location

Resource Adequacy Payment (RAP) expected adequacy revenues (SNAP x MW delivered) accrued to the resource

Load Adequacy Payment (LAP) – expected cost of serving load (SNAP x served MW)

Transmission Adequacy Payment (TAP) – expected value of adequacy flows (delta SNAP x MW flow) of a transmission facility

Adequacy Rent – the non-negative difference between the sum of all load payments and the sum of all resource receipts

Other nodal adequacy metrics specific for variable resources, storage, advanced transmission technologies (topology control, dynamic line rating) and demand resources

RA Metrics and Data Services

API Access

Evaluation of Computational Feasibility

Category	Results
Number of VMs used	500
Number of Monte Carlo draws per VM	200
Analysis type	Day-ahead (SCUC/SCED over 24-hr horizon)
Variance reduction method used	Stratified Sampling
LOLH: MISO-North	0.0034 hrs per day. (Compare to 0.5 hrs per year/ 0.0014 hrs per day standard).
LOLH: MISO-South	0
Capacity payment to generators in MISO-N vs MISO-S	$688/MW-Day vs. $0/MW-day
Precision of the estimate	3%
Turn-around time	~45 min
Total VM time	~300 hours
Total VM cost	~$200 On-demand / ~$120 Spot

Anticipated Benefits of SNAP

- **Long-term benefits**: saving in investments costs in generation and transmission
- **Short-term benefits**: reduced cost in scheduling operating reserves temporarily and locationally

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