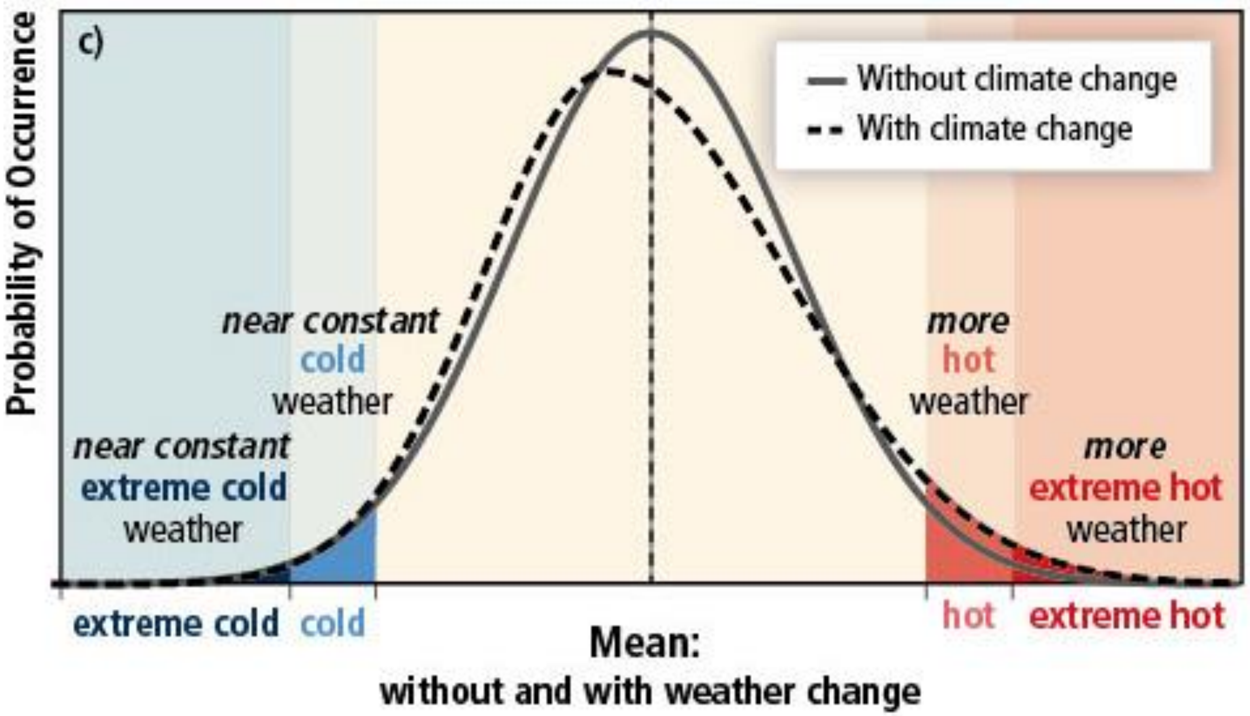
Future and Extreme Weather Data



Source: IPCC Special Report, 2012 *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation:* Cambridge University Press.

Argonne, Oak Ridge & Sandia National Laboratories
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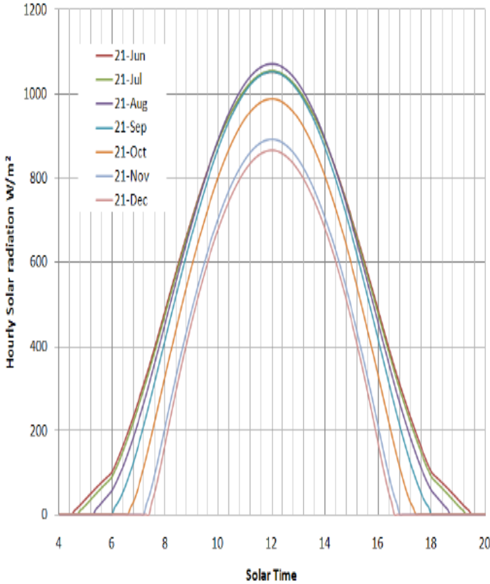
WBS 3.5.5.63

Project Summary

Objective and outcome

- Bring the enormous amount of data already produced through DOE HPC climate change simulations to the A/E/C design community
- Develop a set of future weather data for use in net-zero building design and retrofits and energy and carbon analysis
- Develop a model for generating current and future extreme weather data for use in designing building more resilient buildings and building retrofits



Stats

Performance Period: 2022-2024

DOE budget: $1200k, Cost Share: $0

Milestone 1: ANL Release First Future Weather Data

Milestone 2: ORNL Release First Future Weather Data

Milestone 3: SNL Release First MEWS Model

Core Team and Partners

Argonne: R. Muehleisen, J. Kim, Z. Zeng, J. Li,

ORNL: J. New, B. Bass, M. Dumas, F. Li, D. Rastogi, S. Kao

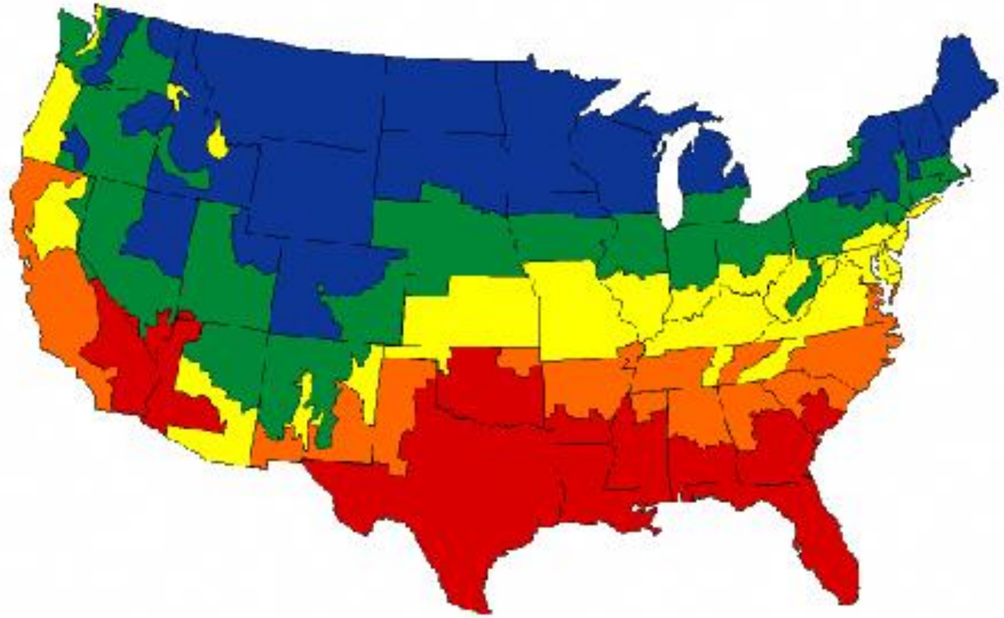
SNL: D. Villa

Problem: Building Design Practice Needs Accurate Data

- **A key component of decarbonizing existing buildings and designing new buildings for net-zero energy and carbon is an understanding of local weather and climate**
  - Building Massing and Envelope Design All Rely on Accurate Local Weather Data
  - HVAC Selection and Sizing and Typically Uses 1% or 0.4% Extreme Hot/Cold Hours

Air Conditioning Square Footage Range by Climate Zone

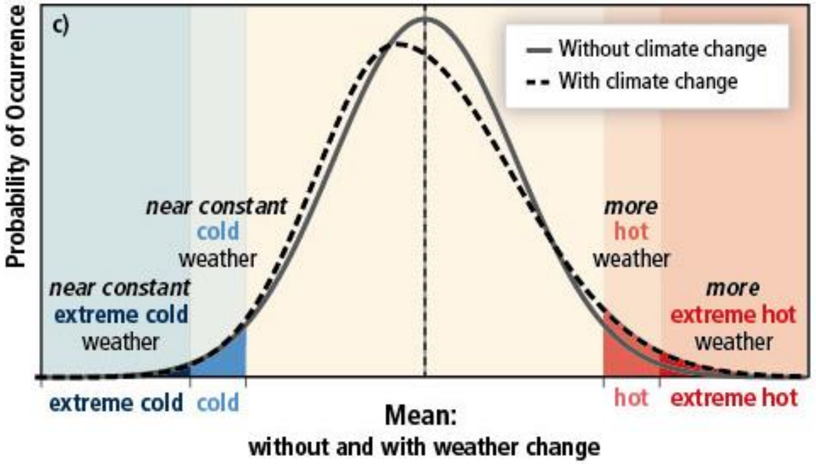
	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
4 Tons	2101 - 2400 sf	2151 - 2500 sf	2201 - 2600 sf	2251 - 2700 sf	2301 - 2700 sf
5 Tons	2401 - 3000 sf	2501 - 3100 sf	2601 - 3200 sf	2751 - 3300 sf	2701 - 3300 sf



Problem: Climate Change will Create New/Different Weather

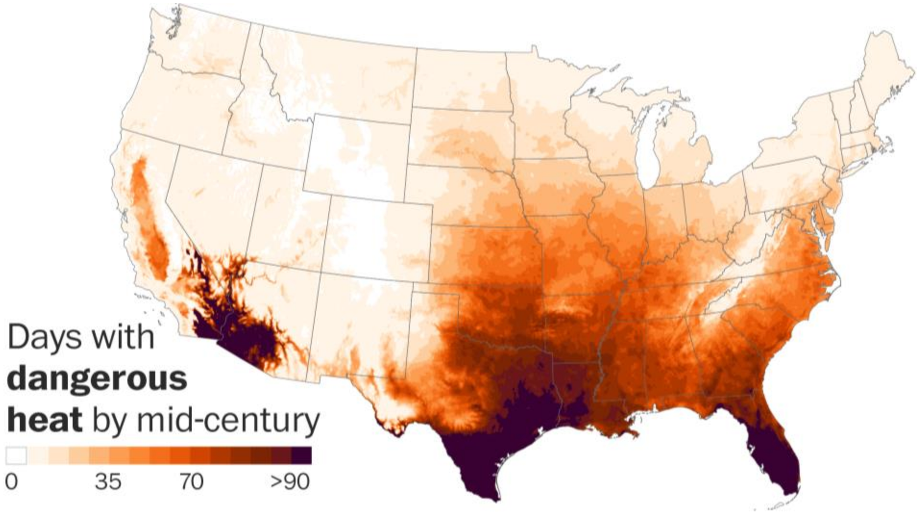
Climate Change Will Affect Weather

- Increased average and peak temperatures
- Increased intensity, duration, and frequency of extreme weather (heat and cold waves, drought, flood, wildfire, tornados, hurricanes, ...)



At risk populations affected most

- Lower income regions will suffer disproportionately to extreme weather events
- Building retrofits and better new building design are needed to mitigate this problem



- **Better estimates of hourly future weather and current/future extreme weather are needed** to start developing mitigation for existing buildings and properly designing new buildings to handle to achieve net-zero emissions by 2050
- Both individual designs and codes/policies need to reflect relevant building lifetimes

Alignment and Impact

BTO has Goals for Decarbonization, Energy Equity and Env. Justice

- **Impact of better data is hard to quantify until it is put into policy, but is also undeniable:**
  - Better climate/weather data <u>will</u> improve building design to best address future climate thus reducing future carbon emissions
  - Better climate/weather data <u>will</u> improve EEEJ through building design to help mitigate climate change and reduce weather related distress of historically marginalized building occupants
- **Success is getting building codes, ratings, and standards to require using future weather as part of their design criteria**
  - This will help codes and standards to help "future proof" themselves
  - Can immediately become part of stretch codes and codes and certifications like 189.1, LEED, WELL, PHIUS, ZERH

Approach (Current)

Currently designers typically deal with the situation in one of four ways:

1. Ignore the problem and design as usual	• Results in poor building designs for future weather with increased carbon footprint and more health/comfort problems for residents
2. Oversize/Overdesign buildings to accommodate unknown future weather	• Results in higher costs and increased carbon footprint
3. Use weather data from another climate zone	• Does not account for expected increased in intensity, duration, and frequency (IDF) of extreme weather and might not be accurate
4. "Morph" current weather data to match trends of climate model predictions	• Does not account for extreme weather IDF increases • Does not properly model linkages of temperature, humidity, wind, and solar

Approach (Current)

Currently designers typically deal wi... ...ation in one of four ways:

1. Ignore the problem anc... design as usual

...re weather with increased ...nfort problems for

2. Oversize/Overd... buildings to acc... unknown future

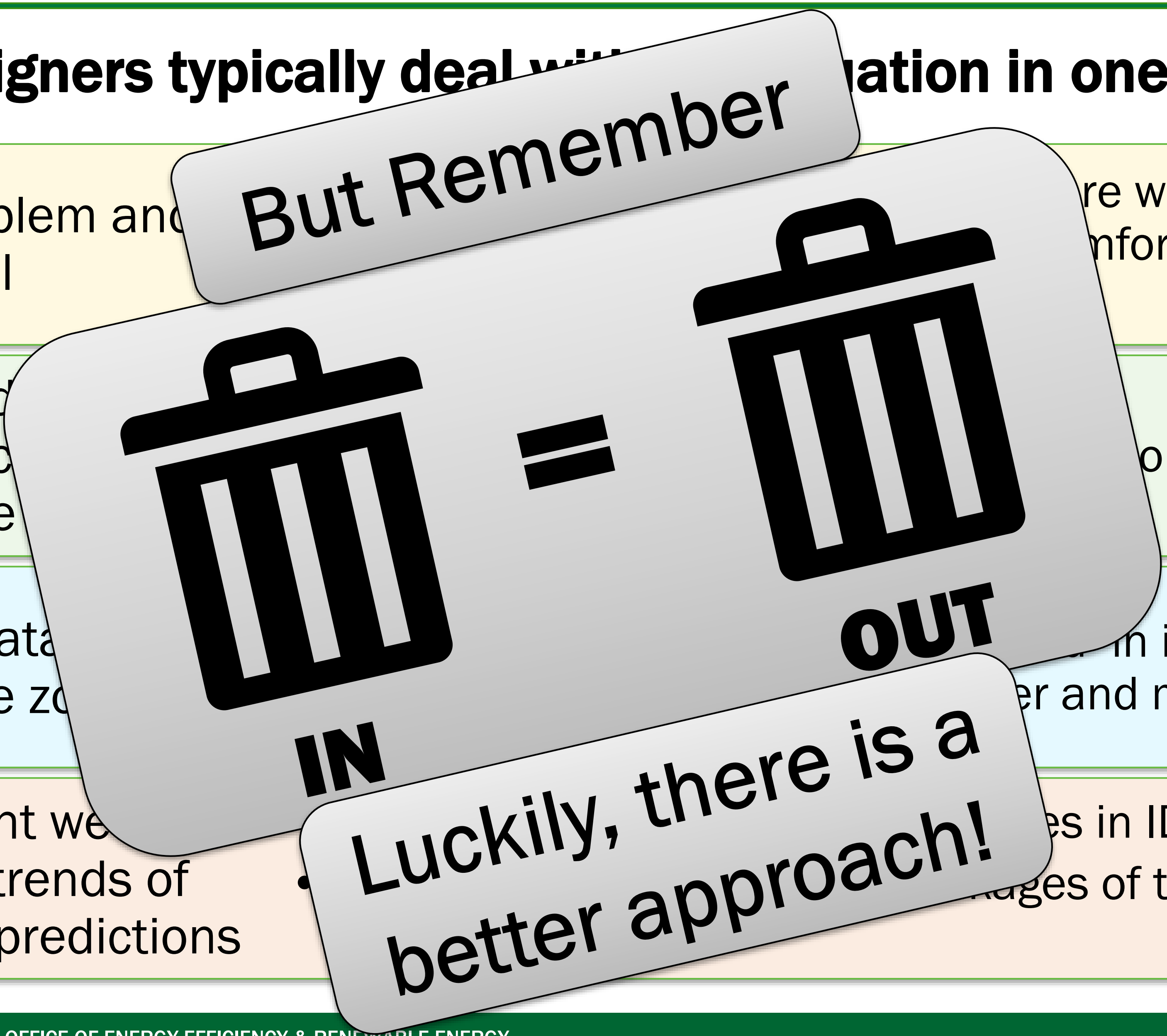
...on footprint

3. Use weather data... another climate zc...

...in intensity, duration, and ...er and might not be accurate

4. "Morph" current we... data to match trends of climate model predictions

...es in IDF of extreme weather ...ges of temperature, humidity,



Project Approach, Progress, and Future

Three Teams: Complementary Data Project Goals

Argonne NATIONAL LABORATORY

- Dynamic Downscaling at 4km & 12km over CONUS
- 2045-2054 and 2085-2094
- Multiple RCP-SSCP
- Releasing full data files over entire CONUS grid allowing for time coincident future weather analysis at any geographic scale
- 10's of TB of data to be released

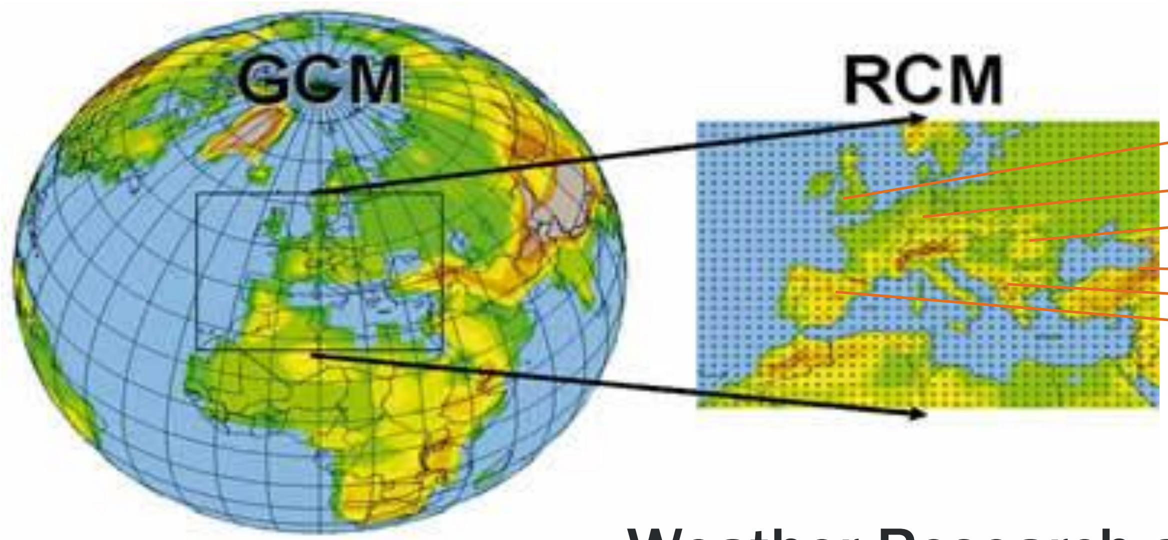
OAK RIDGE National Laboratory

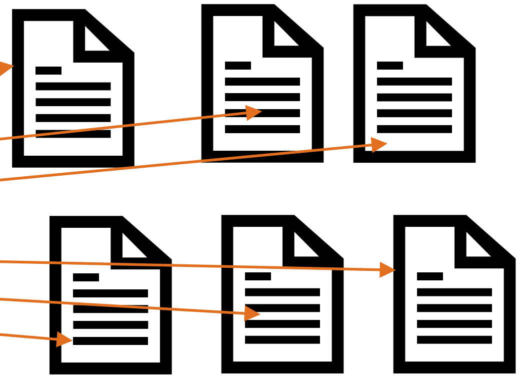
- Combination of Dynamic Downscaling and Statistical
- 2020-2100
- Multiple RCP-SSCP
- Releasing fTMY at multiple locations in each climate zone
- PB of data processed to 10's of GB

Sandia National Laboratories

- Developing Statistical Models for Extreme Weather Generation
- First for Current Weather, next for Future Weather with various RCP-SSCP

Argonne Approach: Dynamic Downscaling with WRF





Global Circulation Model (GCM) predicts climate change on large, whole earth grid (50-250 km)

- 100’s of Millions of DOE HPC core hours
- Not funded by BTO $

Weather Research and Forecast Model (WRF) predicts hourly future weather on a 4-12 km grid over CONUS

- 100’s of Millions of DOE HPC core hours
- Slightly funded by BTO $

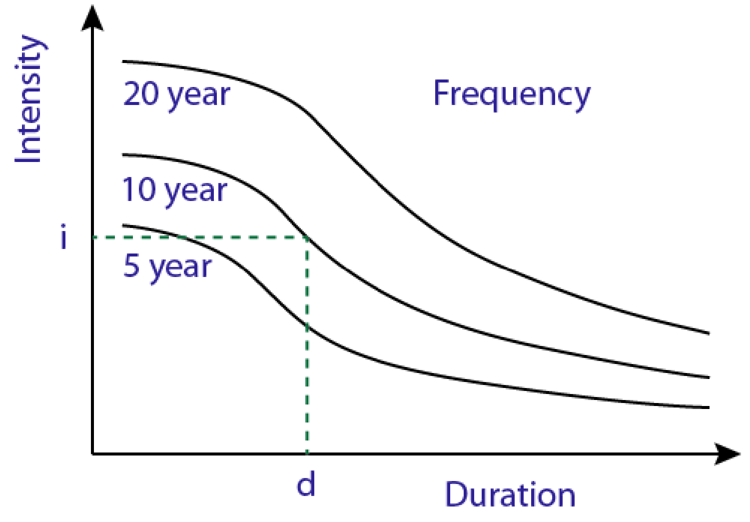
Postprocessing extracts useful local data and generates weather files in formats that can be used in analysis and design

Primarily funded by BTO $

Argonne Approach

- Dynamic downscaling using Weather Research Forecast (WRF) model ensures predicted weather follows laws of atmospheric physics
  - This allow for time coincident weather file generation for entire grid balancing region
- Generates the expected variations in intensity-duration-frequency of extreme weather predicted by climate modeling
- Core downscaling work has resulted in dozens of peer reviewed publications and is extremely well cited

- **Navier Stokes Eqs. in Lower Atmosphere**
- **Radiative Heat Balance in Outer Atmosphere**
- **Air-Soil-Water Coupling**



Argonne Progress

- **Organized first stakeholder meeting to get input from industry**
- **Developed tools to process Argonne's 12km and 4 km CCSM4 and CCSM5 seeded WRF model runs and extract data at all grid points**
  - Extract 3hr data from 12 km WRF runs and 1 hr data from 4km WRF runs
- **Have extracted raw WRF atmospheric data files at all 300,000+ grid points for 12km RCP 8.5 data for 2045-2054 and 2085-2094**
  - RCP 4.5 @ 12km to come soon, 4 km data after that
- **Have interpolated 12 km, 3hr data to 1 hr**
  - Used cubic splines for T, RH, Atmospheric Pressure, and Wind
  - Regenerated complete hourly solar (GHI, DHI, and DNI) solar from cloudy sky model with cloud cover estimated from 3hr WRF data

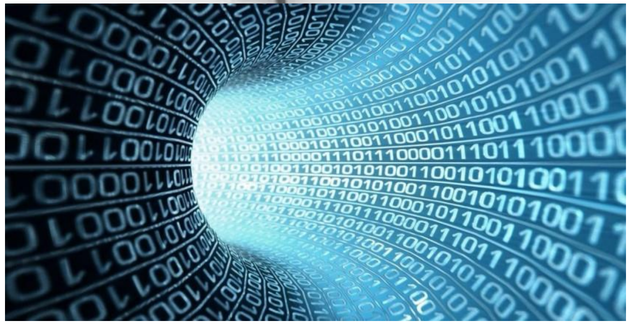
Argonne Future Work

- **Will make weather files available to other labs (e. g. NREL) for DOE R&D as they come available**

- **Plan to make ANL data publicly available through ANL Climate Risk and Resilience Portal**
  - All data will include *DETAILED* descriptions explaining methods and history of the data
  - This is 10's of TB of data, so still working out details

- **More stakeholder meetings (early summer and mid fall) to better understand industry needs and plan data rollout from all 3 labs**

- **Webinars and press releases to inform public**



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- Kim, J. 2023. "The Links between Climate Change and Environmental Justice". Presented at ASHARE 2023 Winter Conference

- Zobel et al. 2018. Evaluations of high-resolution dynamically downscaled ensembles over the contiguous United States. Clim Dyn 50, 863–884

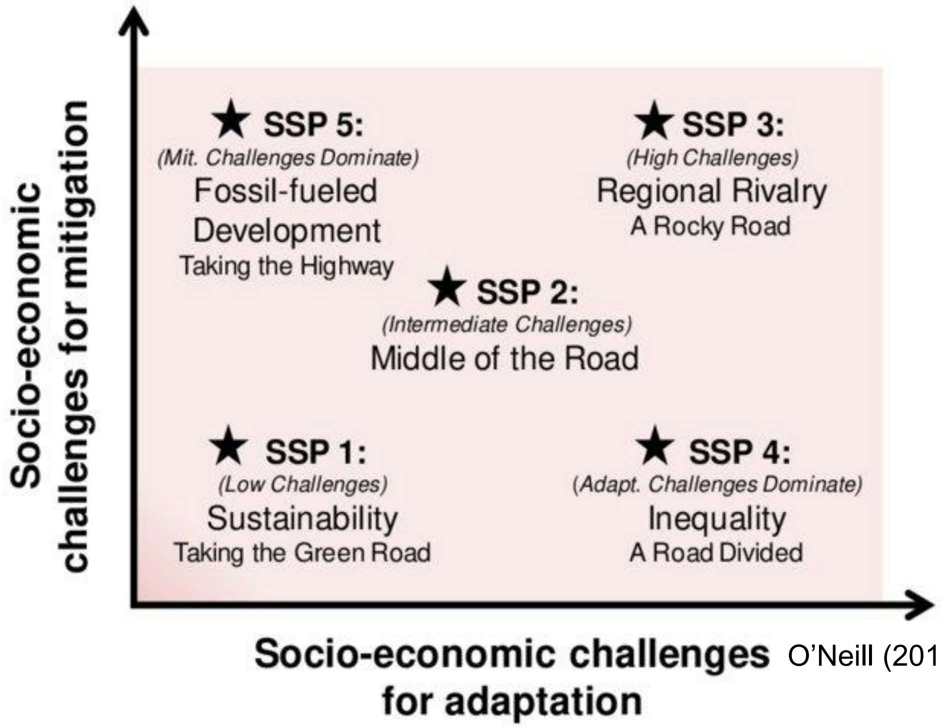
- Zobel, et al. 2017. High-Resolution Dynamical Downscaling Ensemble Projections of Future Extreme Temperature Distributions for the United States. Earth's Future 5, 1234–1251.

Oak Ridge Approach, Progress, and Future

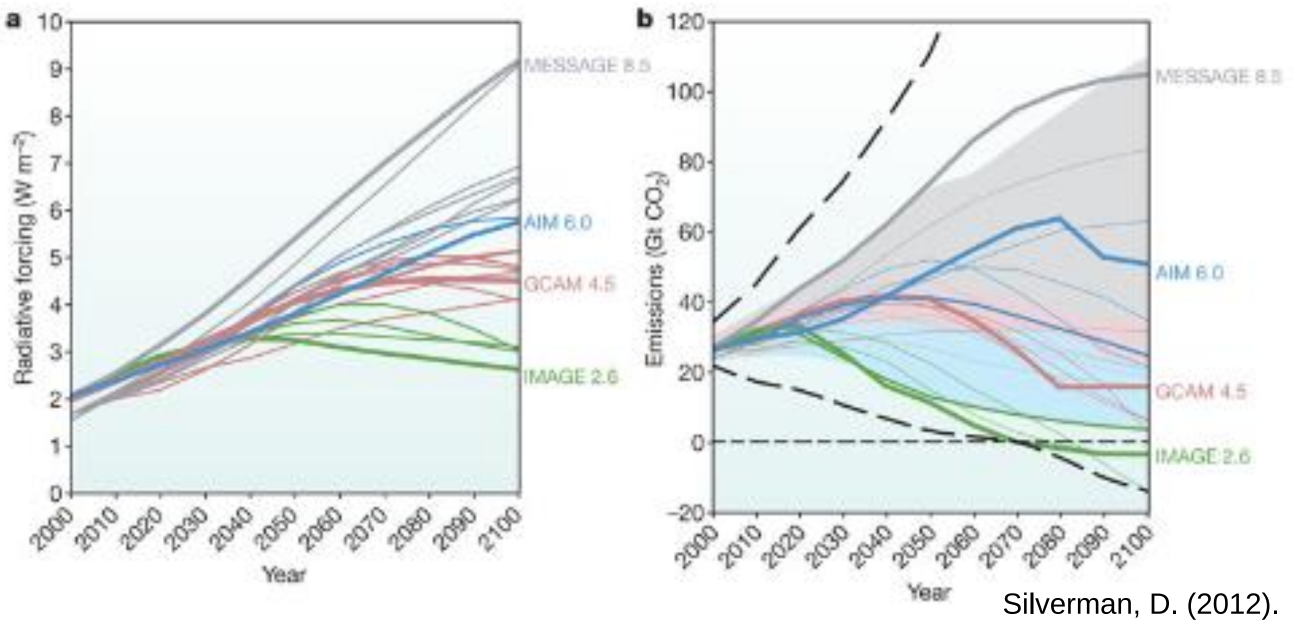
Visual summary of IPCC scenarios

- Intergovernmental Panel on Climate Change (IPCC) created Shared Socioeconomic Pathways (SSPs) to define different future baseline worlds
  - Varying factors such as population, technological, and economic growth

- IPCC created Representative Concentration Pathways (RCPs) to set pathways for greenhouse gas concentrations
  - Named for amount of radiative forcing by the year 2100
  - Based on future climate policies



O'Neill (2016).



Silverman, D. (2012).

Global Climate Model Variability

- Convert IPCC model data to meteorological variables for building simulation (2020-2100)
- Three levels of sophistication
  - Individual future years (as with historical years) may be outliers; how to account for multi-year/temporal variability?
  - There are many different climate models from institutions studying climate around the world; how to account for model variability?
  - There are many grid points that may not be within a region of interest or have multiple points within the area of interest; how to account for spatial variability?

- ORNL proposes an existing technique to rule them all.

Typical Meteorological Year (TMY)

- Typify weather conditions at a location over a period of time
- Representative month selection
  - Sandia Method
    - Considers statistical representation of several weather variables
      - Dry bulb, dew point, wind velocity, solar radiation
    - Cumulative Distribution Functions (CDFs) are calculated based on each weather variable/statistic combination
    - Each month's variable/statistic combination CDF is compared to the long-term CDF using Wasserstein Distance
    - A <u>weighted</u> sum of the distances is used
    - The months with the lowest weighted sum distances are selected and concatenated

Typical Meteorological Year (TMY)

2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

TMY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	2011	2018	2014	2016	2016	2012	2017	2018	2015	2013	2019	2019

Future Typical Meteorological Year (fTMY): One Climate Model

2090	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2091	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2092	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2093	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2094	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2095	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2096	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2097	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2098	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2099	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

fTMY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	2090	2094	2094	2096	2092	2090	2099	2093	2096	2098	2091	2092

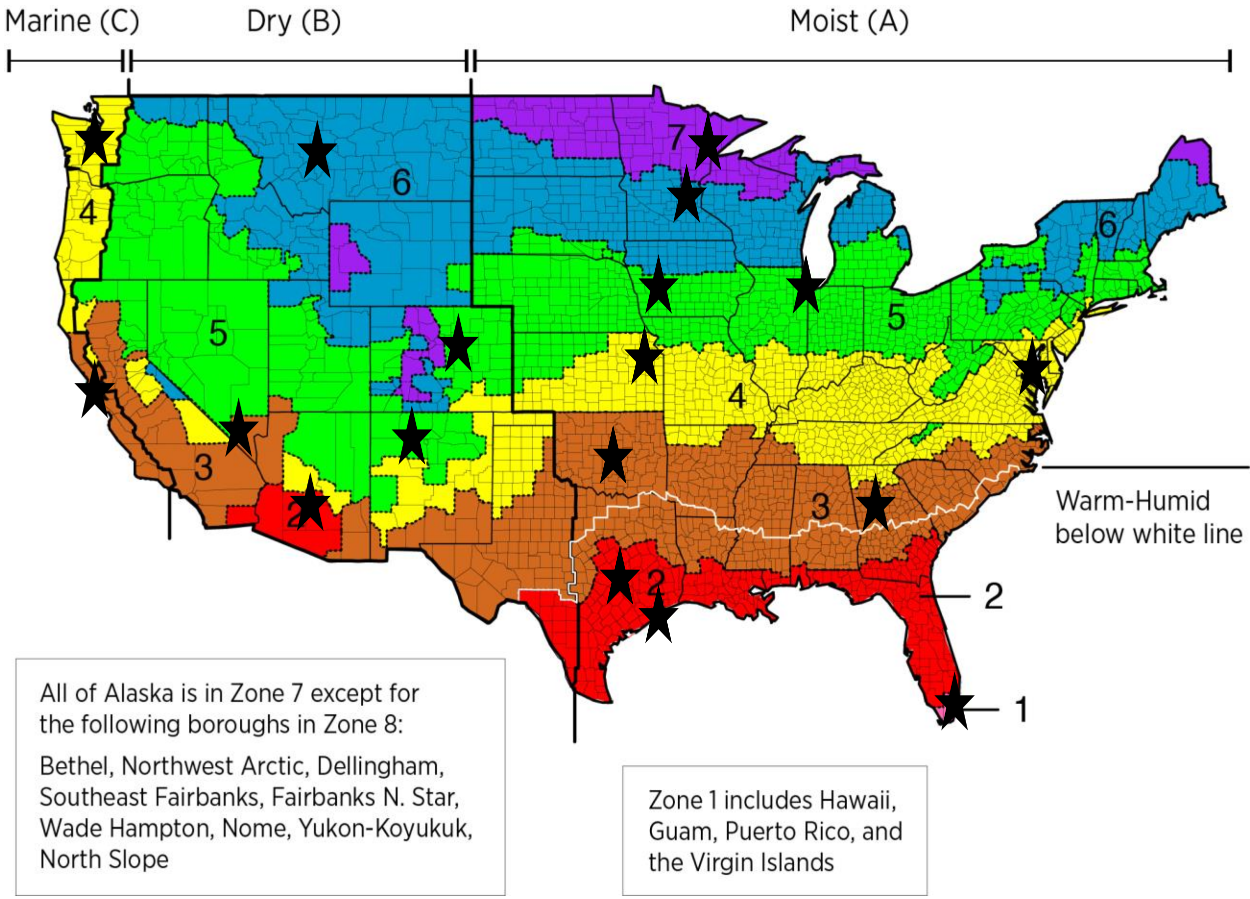
fTMY: Multiple Climate Models

2090a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2090b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2091a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2091b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2092a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2092b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2093a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2093b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2094a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2094b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2095a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2095b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2096a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2096b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2097a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2097b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2098a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2098b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2099a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2099b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2100a	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2100b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

fTMY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	2091a	2096b	2093a	2098b	2091a	2100b	2090a	2095b	2093b	2098a	2091a	2099b

Developing fTMY Weather Files

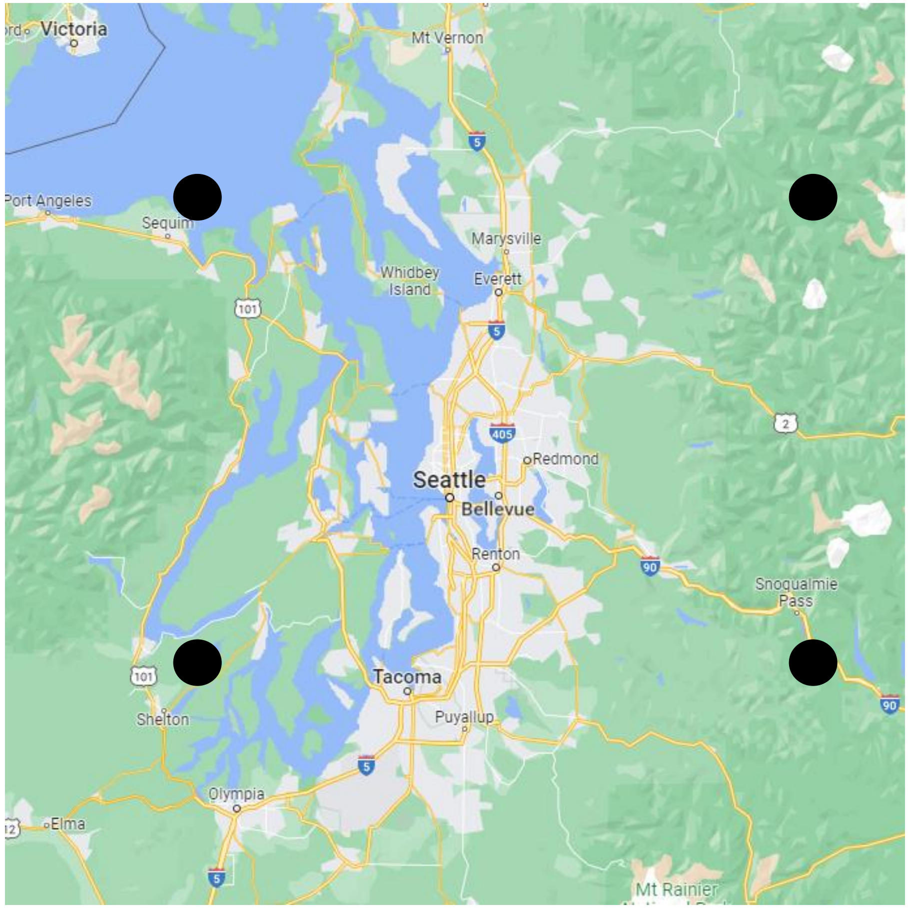
- SSP 5, RCP 8.5
- 2020-2100
- 18 cities in United States
  - Representative cities from each US climate zone
- 6 Climate Models from various climate institutions around the globe
  - ACCESS-CM2
  - BCC-CSM2-MR
  - CNRM-ESM2-1
  - MPI-ESM1-2-HR
  - MRI-ESM2-0
  - NorESM2-MM
- 9 Weather Variables
  - Air Temp
  - Longwave
  - Shortwave
  - Vapor Pressure
  - Vapor Pressure Deficit
  - Relative Humidity
  - Precipitation
  - Wind
  - Pressure



International Code Council (2012)

fTMY Weather File Development

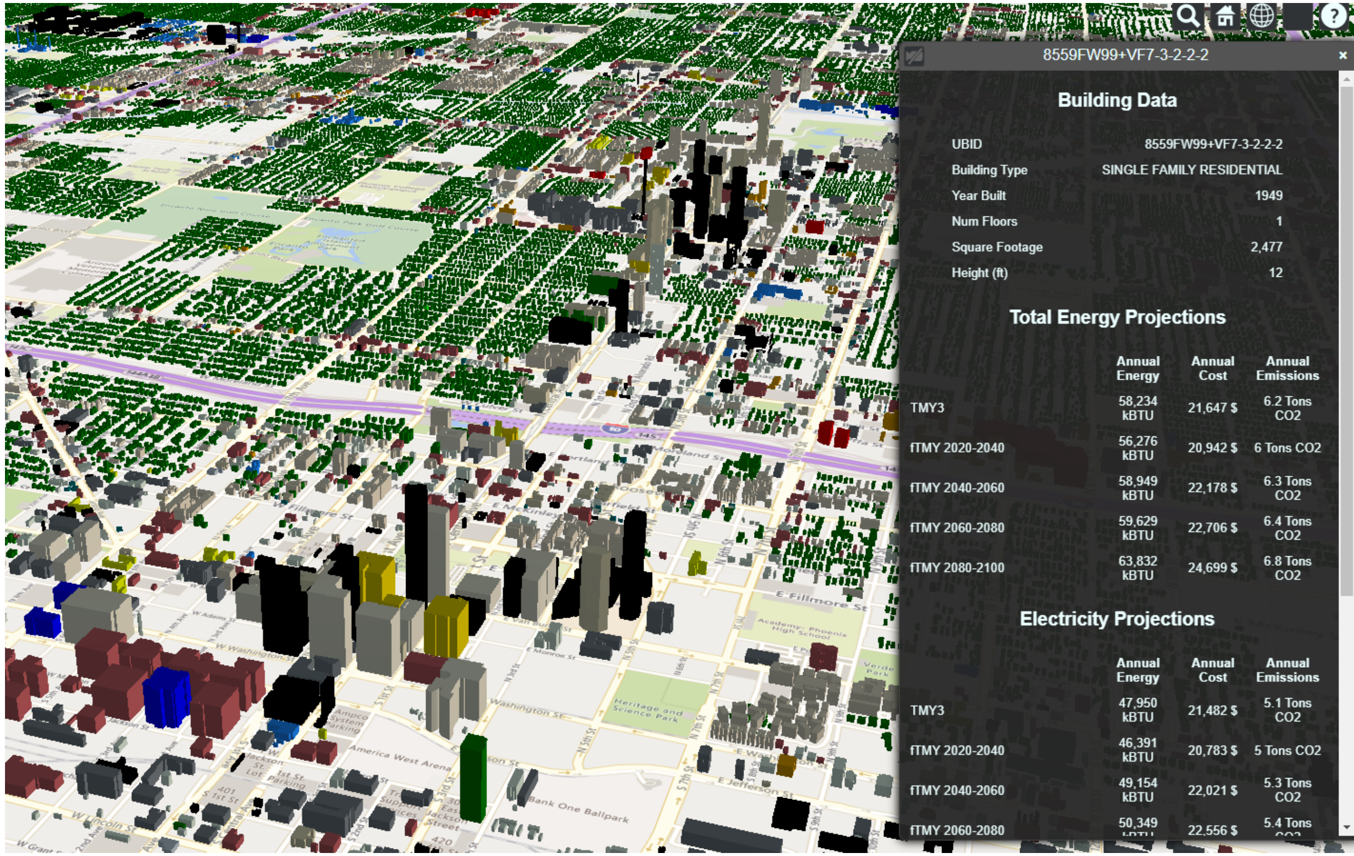
- Spatial resolution of climate models created need for downscaling
- Data was statistically downscaled to increase to better represent city (Rastogi 2022)
- Hourly data was obtained using Mountain Microclimate Simulation Model (MTCLIM)



● Global Climate Model Grid Points

fTMY Weather File Development

- 144 fTMY weather files were developed
- 20 year periods
  - 2020-2040
  - 2040-2060
  - 2060-2080
  - 2080-2100
- Formatted as Energy Plus Weather (EPW) files for use in EnergyPlus building simulation
- Will be made publicly available
- Can be used to assess how climate projections will impact building energy use in future years
  - Initial evaluations of Maricopa County, Arizona



https://evenstar.ornl.gov/autobem/phoenix

ORNL Conclusions

- GCM provide estimations of future weather under various socioeconomic and climate scenarios
- TMY are used to select a year of typical weather for a location by selecting representative months from various years
- fTMY data can be created based on the output climate model weather projections, reducing individual year variance
- fTMY data are representative of several different climate models, reducing individual model bias
- fTMY data can be used to assess how the built environment will be impacted by climate change

ORNL Bibliography

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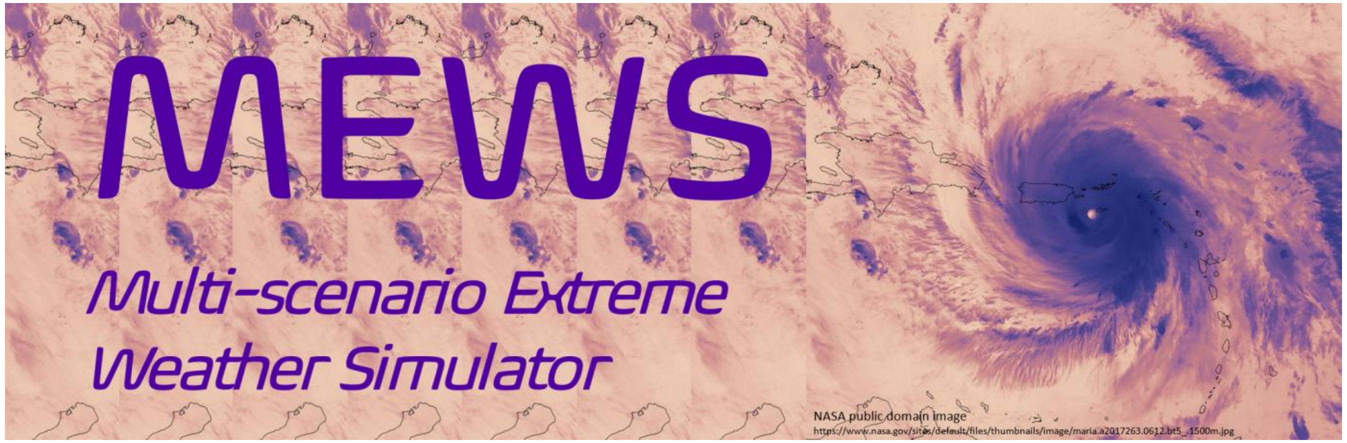
- Science Learning Hub. Pokap Akoranga Ptaiao. 2017. Climate models.
- Silverman, D. 2012. Emissions and radiative forcing models for IPCC 5 in 2013.

ORNL Resources

- Canonical TMY - https://www.nrel.gov/docs/fy08osti/43156.pdf
- Code - https://github.com/klimaat/rnlyss/blob/master/rnlyss/tmy.py
- Visualization (1.5M in AZ through 2100) - https://evenstar.ornl.gov/autobem/phoenix/
- Downscaled data - https://doi.org/10.21951/SWA9505V3/1887469
- TMY EPWs available for feedback (with links to models/data)
  - Bass, Brett, New, Joshua R., Rastogi, Deeksha, and Kao, Shih-Chieh (2022). "Future Typical Meteorological Year (fTMY) US Weather Files for Building Simulation (1.0) [Data set]." Zenodo, doi.org/10.5281/zenodo.6939750, Aug. 2022. https://zenodo.org/record/6939750#.YwYzp3bMKUk

Sandia Approach, Progress, and future

Multi-scenario Extreme Weather Simulator (MEWS)



Problem

- Extreme weather will be increasingly costly and dangerous in the future
- There is a lack of resources that can be used directly for modelers to assess how extreme weather will affect future buildings
- Stochastic approaches are needed for multi-objective resilience analysis

Solution

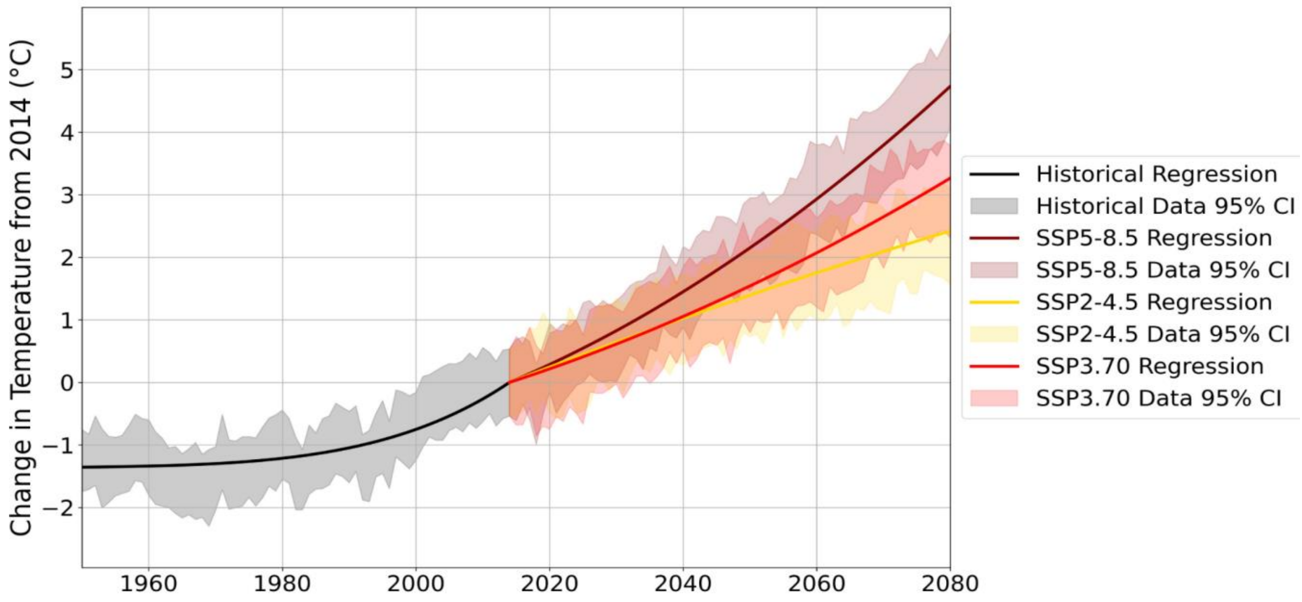
- Design an algorithm that provides localized extreme weather shifts for frequency and intensity
- Make this algorithm open-source software (https://github.com/sandialabs/MEWS)
- Verify the algorithm produces good fits

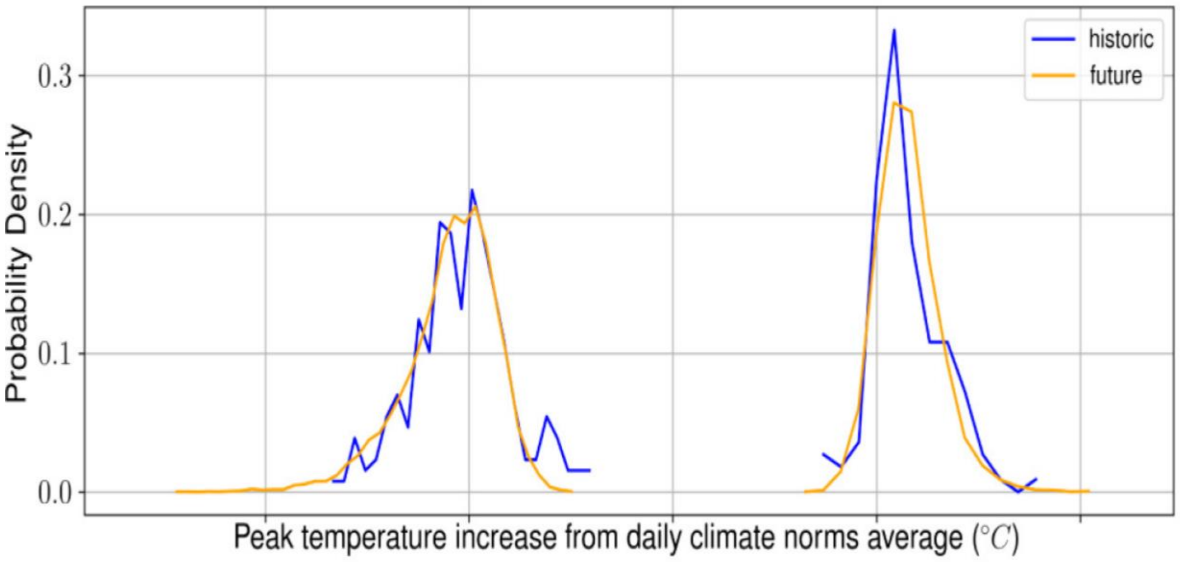
How it works: Method

Method

1. Create local average surface change anomaly polynomials for relevant SSP's

2. Optimize model fit to historic extreme temperature distributions



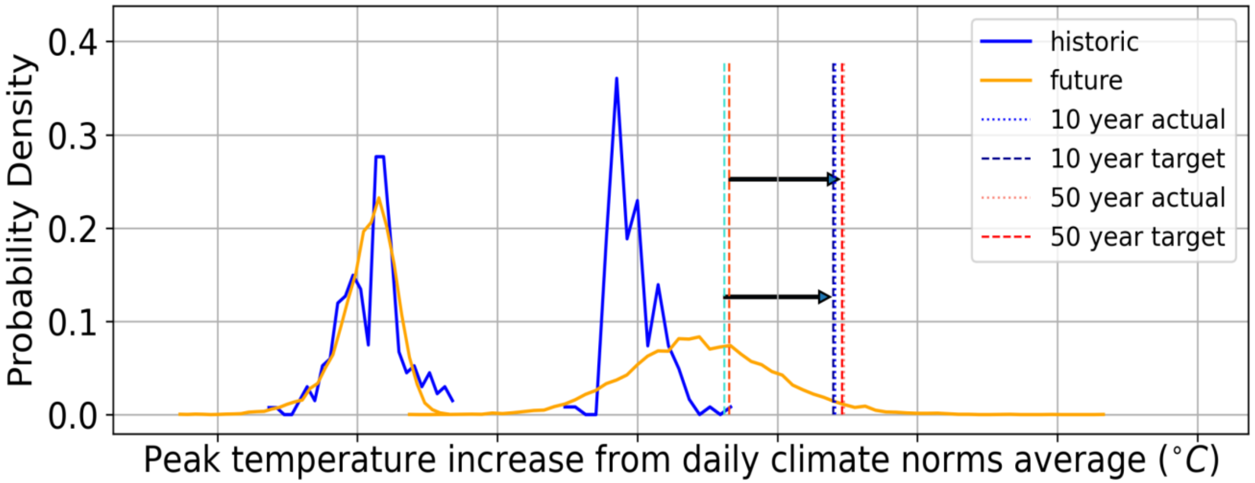


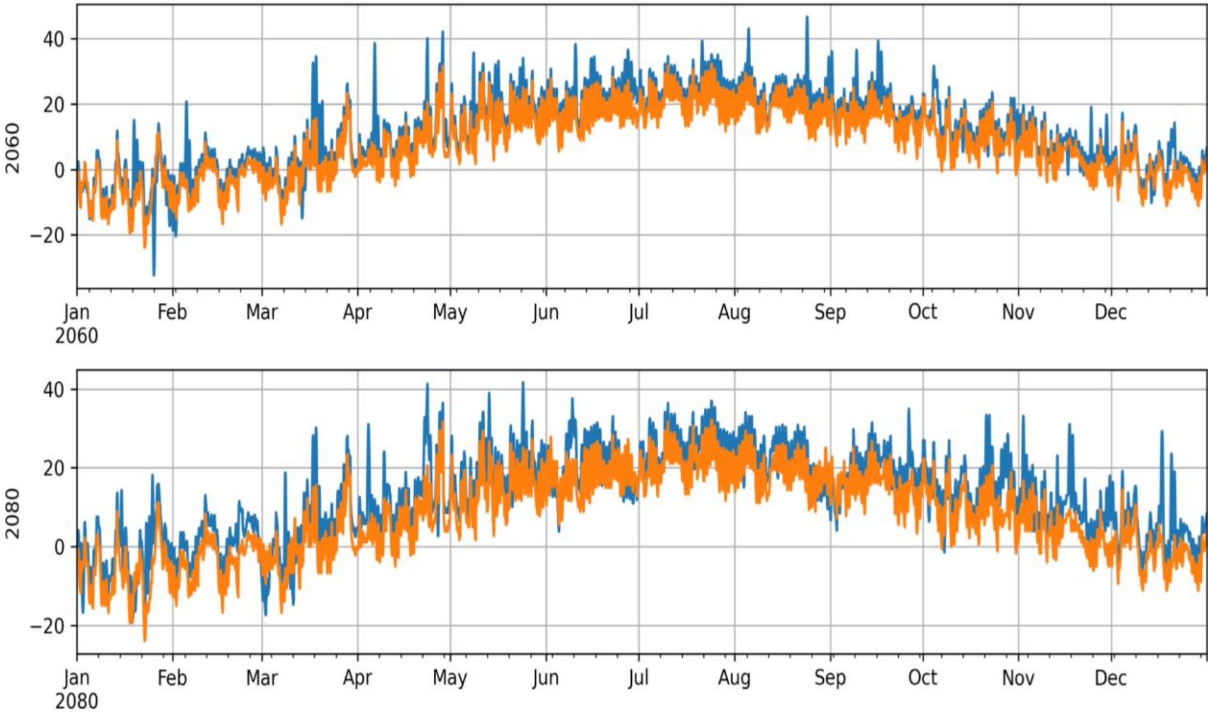
How it Works: Results

Result

3. Shifts in 10 and 50 year event's intensity and frequency

4. Output results as CSV and Energy Plus EPW weather files





Progress and Future

- **Version 1.1.0 released Feb 28th** https://github.com/sandialabs/MEWS/releases/tag/1.1.0
- **2 publications**
  - Villa, Daniel L., Tyler J. Schostek, Krissy Govertsen, and Madeline Macmillan. 2023. "A Stochastic Model of Future Extreme Temperature Events for Infrastructure Analysis." *Environmental Modeling & Software* https://doi.org/10.1016/j.envsoft.2023.105663.
  - Villa, Daniel L., Juan Carvallo, Carlo Bianchi, and Sang Hoon Lee. 2022. "Multi-scenario Extreme Weather Simulator Application to Heat Waves." *2022 Building Performance Analysis Conference and SimBuild co-organized by ASHRAE and IBPSA-USA* https://doi.org/10.26868/25746308.2022.C006
- **3 Presentations to ASHRAE and IEEE**
  - ASHRAE work statement using MEWS and other future weather products will be submitted May 15th
- **Use by 3 graduate students (2 dissertations, 1 thesis), Phius, and NREL**
- **Path Forward**
  - Implement the same algorithm for hurricanes/extreme precipitation (partially complete)
  - Connect directly to climate models so that other variables can be included (e.g. humidity)
  - Evaluate resilience issues by running heat wave BEM studies across all climate zones for various technologies

Thank You

Argonne, Oak Ridge, and Sandia National Laboratories
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WBS 3.5.5.63

REFERENCE SLIDES

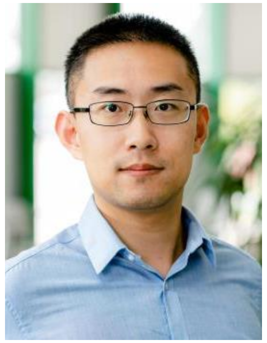
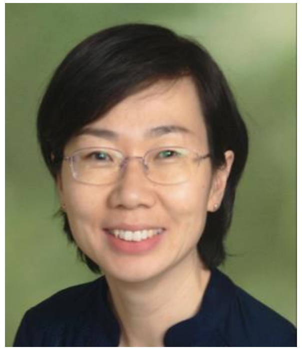
Project Execution

	FY2022				FY2023				FY2024			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Stakeholder Meetings												
Q2 Milestone: Sandia Releases First MEWS Model												
Q3 Milestone: ORNL Releases First Data												
Q4 Milestone: Argonne Releases First Data												
Current/Future Work												
Q3 Milestone: Stakeholder Meeting												
Q4 Milestone: Sandia MEWS Update												
Q4 Milestone: Sandia Releases Additional Data												
Q1 Milestone: Argonne Releases Additional Data												

- Delays in FY22 milestones from 6 mo delay in arrival of funds

Argonne, Sandia, and ORNL teams



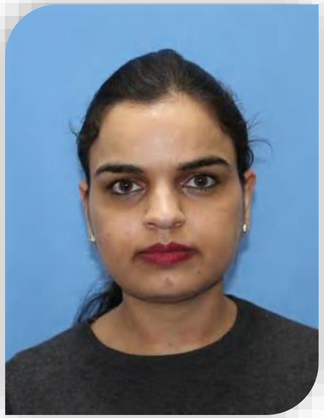




ANL: PI, Ralph Muehleisen Jeannie Kim Zhaoyun Zeng Jiali Wang

SNL: Daniel Villa








ORNL: Joshua New Brett Bass Melissa Dumas Frank Li Deeksha Rastogi Shih-Chieh Kao

EERE/BTO goals

(Not a template slide – for informational purposes only)

The nation's ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO's vision for a net-zero U.S. building sector by 2050