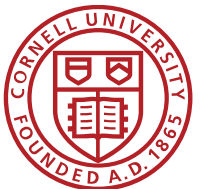

Stochastic Weather Generator

Preparing Input Data & Evaluating Model Performance



Cornell University®

Najibi, N., Steinschneider, S. (2023). Stochastic Weather Generator v2.0, Software, MIT License, Creative Commons Attribution 3.0 United States. <https://github.com/nassernajibi/WGEN-v2.0>;
<https://doi.org/10.5281/zenodo.7311768>

Contents



Cornell University

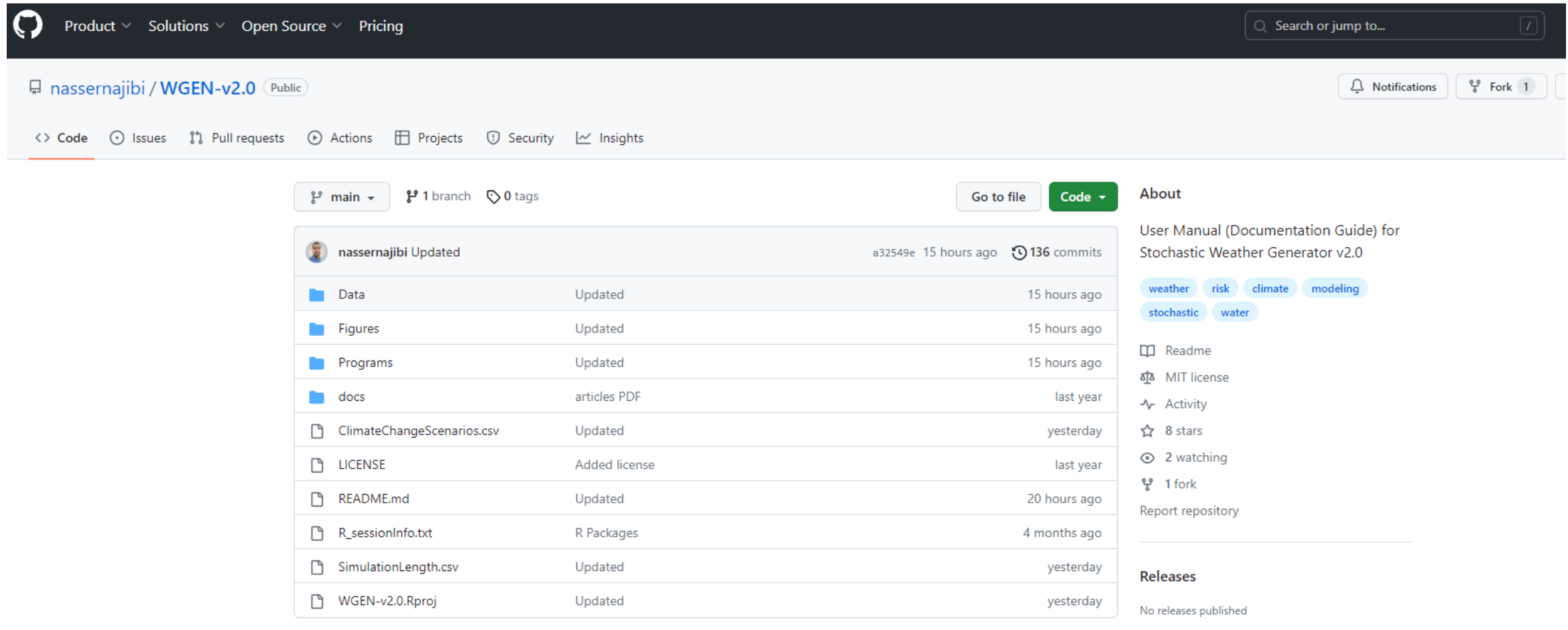
- 1) Access/Download Model
- 2) Repository Organization
- 3) Preparing Input Data
 - A. Surface weather (meteorological) data
 - B. Large-scale atmospheric circulation data
 - C. Exogenous covariates data
- 4) Run the Model and Evaluate Model Performance
- 5) Generating Output Files

1) Access/Download Scripts

1) Access/Download Scripts

- **GitHub:** You can *clone* the repository to your machine

<https://github.com/nassernajibi/WGEN-v2.0>



The screenshot shows the GitHub repository page for `nassernajibi / WGEN-v2.0`. The repository is public and has 1 branch and 0 tags. The file list includes:

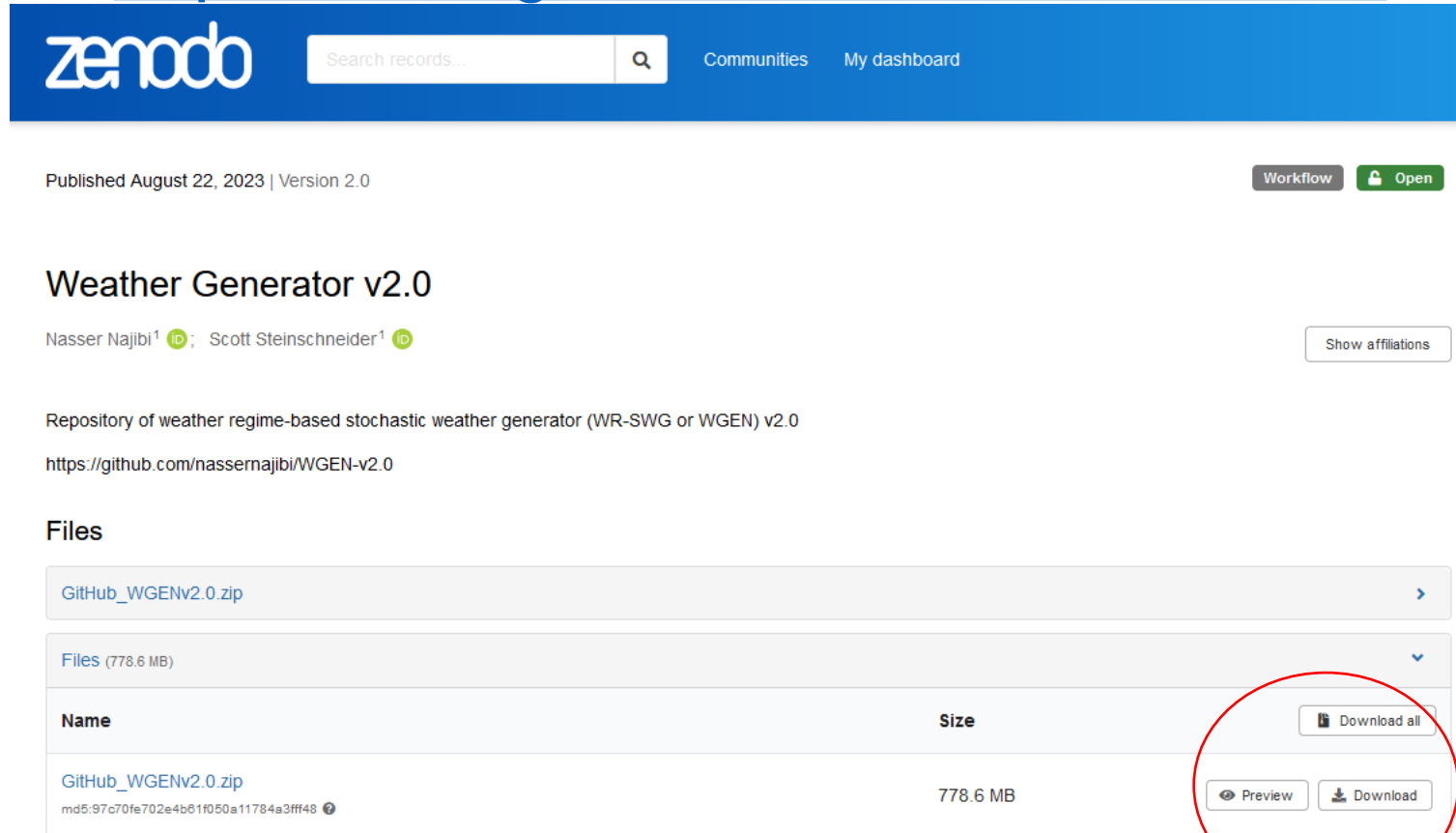
File/Folder	Update Type	Time
Data	Updated	15 hours ago
Figures	Updated	15 hours ago
Programs	Updated	15 hours ago
docs	articles PDF	last year
ClimateChangeScenarios.csv	Updated	yesterday
LICENSE	Added license	last year
README.md	Updated	20 hours ago
R_sessionInfo.txt	R Packages	4 months ago
SimulationLength.csv	Updated	yesterday
WGEN-v2.0.Rproj	Updated	yesterday

The right sidebar shows the repository's "About" section, which includes a description: "User Manual (Documentation Guide) for Stochastic Weather Generator v2.0". It also lists tags: weather, risk, climate, modeling, stochastic, and water. The repository has 8 stars, 2 watchers, and 1 fork. The "Releases" section indicates that no releases have been published.

1) Access/Download Scripts

- **Zenodo:** Alternatively, you can download the entire zipped folder (with more data) from Zenodo via this DOI link:

<https://doi.org/10.5281/zenodo.7311768>



The screenshot shows the Zenodo record page for 'Weather Generator v2.0'. The header is blue with the Zenodo logo, a search bar, and links for 'Communities' and 'My dashboard'. Below the header, it says 'Published August 22, 2023 | Version 2.0' and has 'Workflow' and 'Open' buttons. The title 'Weather Generator v2.0' is followed by the authors 'Nasser Najibi¹' and 'Scott Steinschneider¹'. A 'Show affiliations' button is to the right. The description reads: 'Repository of weather regime-based stochastic weather generator (WR-SWG or WGEN) v2.0' and provides the GitHub link 'https://github.com/nassemajibi/WGEN-v2.0'. Under the 'Files' section, there is a table with one file: 'GitHub_WGENv2.0.zip' (778.6 MB). The file name is a blue link. To the right of the file name is a 'Download all' button. Below the file name is a 'Preview' button and a 'Download' button. A red circle highlights the 'Preview' and 'Download' buttons.

Name	Size
GitHub_WGENv2.0.zip md5:97c70fe702e4b61f050a11784a3ff48	778.6 MB

Unzip to a directory
in your local hard
drive.

2) Repository Organization

2) Repo Organization












Stochastic Weather Generator

Name	Date modified	Type ^	Size
10 items			
File (1)			
LICENSE	11/10/2022 11:06 AM	File	2 KB
File folder (4)			
Data	12/4/2023 12:22 PM	File folder	
docs	11/8/2022 1:58 PM	File folder	
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WGEN-v2.0	12/4/2023 12:27 PM	R Project	1 KB
Text Document (1)			
R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

- R Project: WGEN-v2.0
 - “Data”
 - “Programs”
 - “Figures”
- .csv’s for Run Specs

2) Repo Organization

R Project: WGEN-v2.0

Name	Date modified	Type ^	Size	10 items
File (1)				
 LICENSE	11/10/2022 11:06 AM	File	2 KB	
File folder (4)				
 Data	12/4/2023 12:22 PM	File folder		
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You m
prese
repos

You must run this R project (double-click) to **preset** your R main working directory to this repository.

2) Repo Organization

“Data”

Name	Date modified	Type	Size
File (1)			
LICENSE	11/10/2022 11:06 AM	File	2 KB
File folder (4)			
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10 items

output.data.files

processed.data.files

raw.data.files

simulated.data.files

sharable_link_dataset

5 items

where you place your data!

2) Repo Organization

“Data”

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10 items

output.data.files

processed.data.files

raw.data.files

simulated.data.files

sharable_link_dataset

5 items

where you can find output files!

2) Repo Organization

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10 items



Name

- output.data.files
- processed.data.files
- raw.data.files
- simulated.data.files
- sharable_link_dataset

5 items



processed data required for the model
(internal model use)

2) Repo Organization

“Data”

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10 items



Name

5 items

- output.data.files
- processed.data.files
- raw.data.files
- simulated.data.files**
- sharable_link_dataset



simulated data (weather regimes and local weather) are here in R data formats (internal model use)

2) Repo Organization

“Programs”

Name	Date modified	Type	Size
File (1)			
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File folder (4)			
Data	12/4/2023 12:22 PM	File folder	
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Text Document (1)			
R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

10 items



Name

- functions
- config.simulations
- process.meteorology
- run.stochastic.weather.generator

4 items



core model scripts
(internal model use)

2) Repo Organization

“Programs”

Name	Date modified	Type	Size
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R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

10 items



Name

4 items

- functions
- config.simulations
- process.meteorology
- run.stochastic.weather.generator



User-specific changes can be applied here for more advanced uses of model.

Does not have to be modified for standard model use.

2) Repo Organization

“Programs”

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4 items	
Name	
functions	
config.simulations	
process.meteorology	
run.stochastic.weather.generator	




You need to execute this script first to get your meteorology data ready!

2) Repo Organization

“Programs”












Name	Date modified	Type	Size	<div>10 items</div> <div></div>
File (1)				
 LICENSE	11/10/2022 11:06 AM	File	2 KB	
File folder (4)				
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Name	4 items
functions	
config.simulations	
process.meteorology	
run.stochastic.weather.generator	

Run stochastic weather generator,
generate output files, and create
figures!

2) Repo Organization












“Figures”

Name	Date modified	Type ^	Size	10 items
File (1)				
 LICENSE	11/10/2022 11:06 AM	File	2 KB	
File folder (4)				
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 WGEN-v2.0	12/4/2023 12:27 PM	R Project	1 KB	
Text Document (1)				
 R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB	

All diagnostic figures will be here

2) Repo Organization

Run Specs (.csv files)

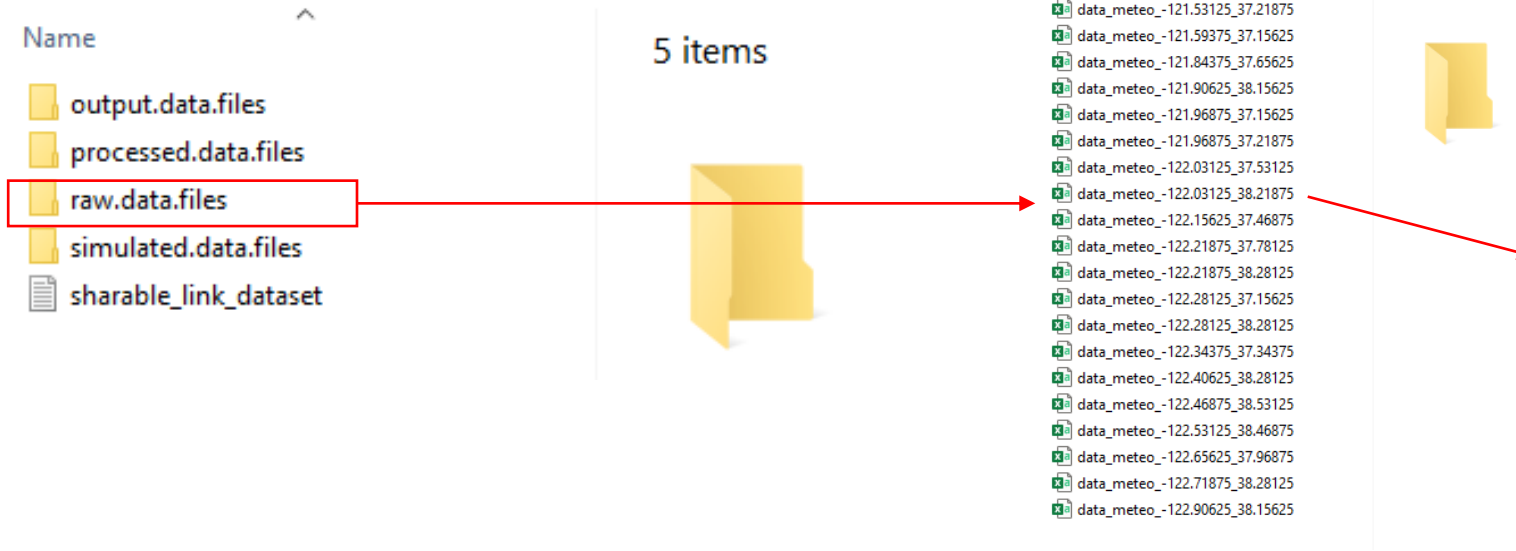
Name	Date modified	Type ^	Size	10 items
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User inputs for climate change scenarios and length of simulated data. Only the former needs to be adjusted for standard model use.

3) Preparing Input Data

3 A) Surface weather (meteorological) data

./Data/raw.data.files/



AutoSave Off data_meteo_-121.53125_37.21875

File Home Insert Page Layout Formulas Data Review View

Paste Font Alignment

A1 1915

	A	B	C	D	E	F	G
1	1915	1	1	0	14.37	4.61	
2	1915	1	2	0	13.19	6.63	
3	1915	1	3	9.552	10.56	6.97	
4	1915	1	4	8.597	11.27	6.61	
5	1915	1	5	5.661	9.98	5.67	
6	1915	1	6	9.284	9.93	7.6	
7	1915	1	7	2.97	11.93	5.39	
8	1915	1	8	10.076	11.2	9.19	
9	1915	1	9	6.372	11.37	3.47	
10	1915	1	10	0	13.22	2.78	
11	1915	1	11	9.319	12.35	4.59	
12	1915	1	12	12.091	10.11	5.43	
13	1915	1	13	3.867	10.77	9.53	
14	1915	1	14	3.029	10.66	9.14	
15	1915	1	15	2.271	10.1	3.62	

data_meteo_-121.53125_37.21875

Important Formatting Constraints

- **File format: *.csv**
- **Continuous records, no NAs or gaps are allowed**
- **Should contain leap years**
- **At least two files (gages, gridded locations, etc.)**
- **All site files should have identical dates**

3 A) Surface weather (meteorological) data

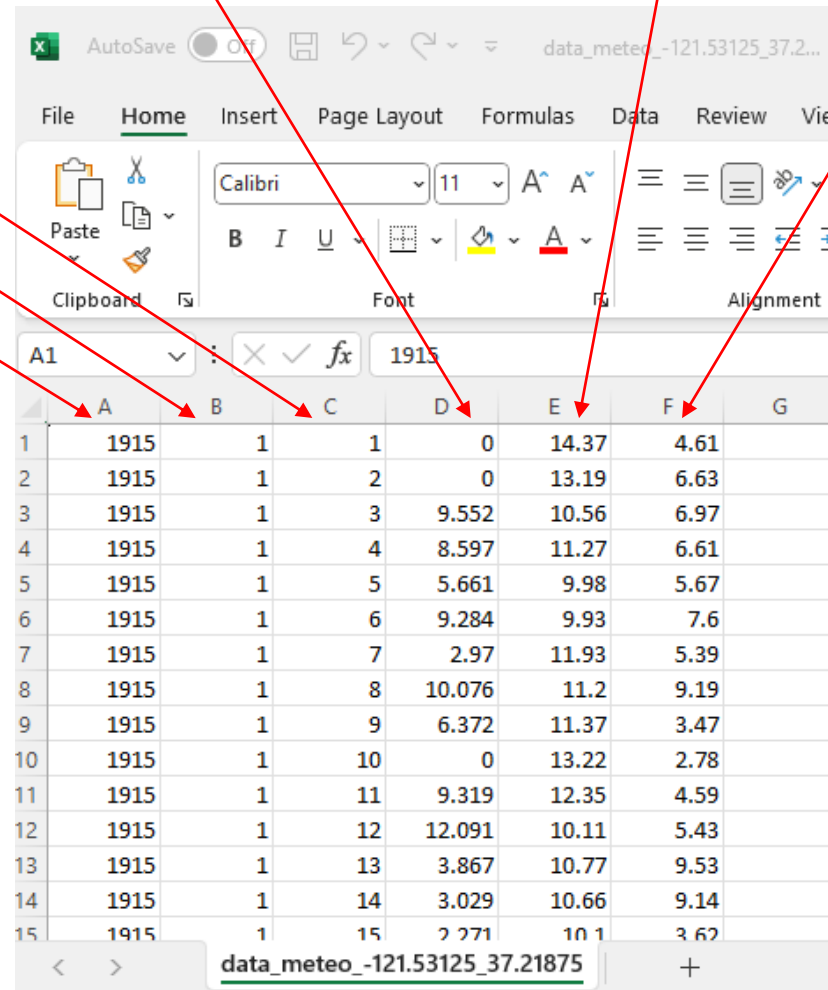
./Data/raw.data.files/

YYYY MM DD

Precipitation [mm]

Tmax [C]

Tmin [C]



	A	B	C	D	E	F	G
1	1915	1	1	0	14.37	4.61	
2	1915	1	2	0	13.19	6.63	
3	1915	1	3	9.552	10.56	6.97	
4	1915	1	4	8.597	11.27	6.61	
5	1915	1	5	5.661	9.98	5.67	
6	1915	1	6	9.284	9.93	7.6	
7	1915	1	7	2.97	11.93	5.39	
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11	1915	1	11	9.319	12.35	4.59	
12	1915	1	12	12.091	10.11	5.43	
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14	1915	1	14	3.029	10.66	9.14	
15	1915	1	15	2.271	10.1	3.62	

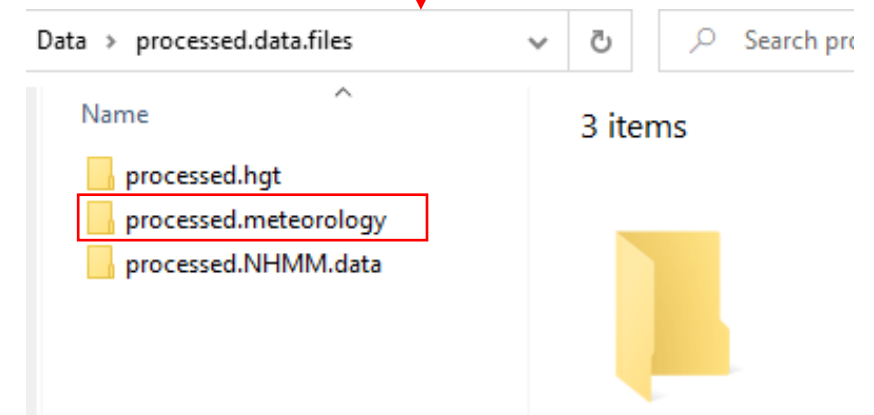
3 A) Surface weather (meteorological) data

`./Programs/process.meteorology.R`

After placing your input files in the `raw.data.files` folder, run `process.meteorology.R` script

```
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?
process.meteorology.R
1 rm(list=ls())
2
3 # #####
4 # This script provides the 'meteorology' input required for the WGEN run #
5 # #####
6
7 #-----
8 ##/ Step 1: Importing raw meteorological time series \##
9
10 ###----- raw data files MUST BE formatted as: yyyy mm dd P[mm] Tmax[C] Tmin[C] *.csv fi
11
12 dir.to.all.raw.files <- "./Data/raw.data.files/"
13 list.locations <- list.files(dir.to.all.raw.files) # list of gridded location or station
14 my.file <- read.table(paste0(dir.to.all.raw.files,list.locations[1]),sep=" ",")
15 start_date <- paste(my.file[1,1],my.file[1,2],my.file[1,3],sep="-")
16 end_date <- paste(my.file[my.file[,1]==start_date,1],my.file[my.file[,1]==start_date,2],my.file[my.file[,1]==start_date,3],sep="-")
```

Final processed meteorology file will be saved here (internal model use)



`./Data/processed.data.files/processed.meteorology/`

3 B,C) Pre-Made WR Simulation

`./Data/simulated.data.files/WRs.out/`

Data > simulated.data.files

Name

WGEN.out

WRs.out

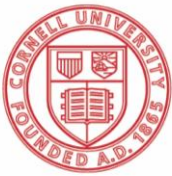
We have already identified historical weather regimes (1948-2021) and simulated ~1000 years of new weather regimes for use in weather generator simulations

Any observational weather data (in raw.data.files) outside of 1948-2021 will be dropped if you use these pre-made WRs.

```
final.NHMM.non_param.output.rds
```

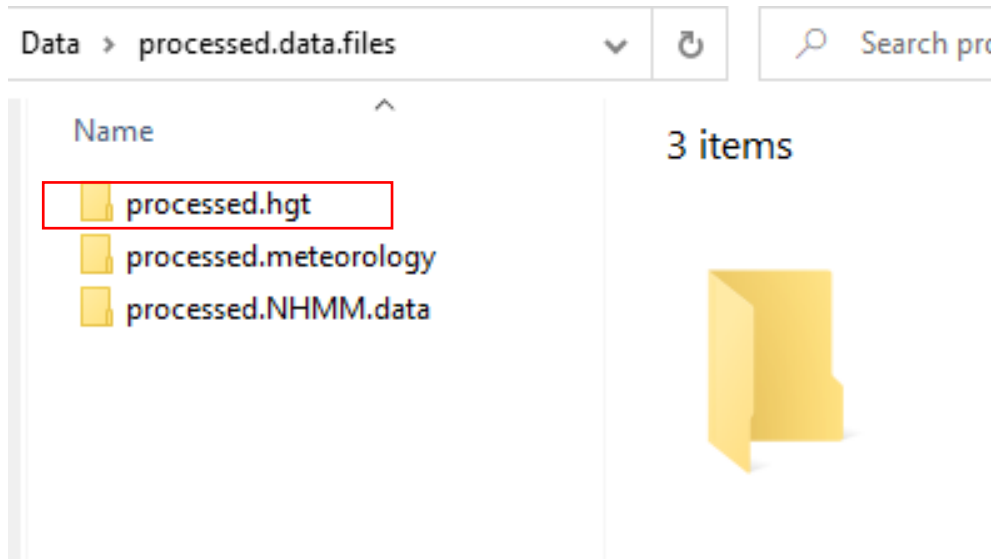
The RDS file above is provided in both the GitHub and Zenodo repositories.

3 B) Atmospheric circulation data for NHMM



Cornell University

`./Data/processed.data.files/processed.hgt/`



*** For advanced uses only; only available on Zenodo, not GitHub**

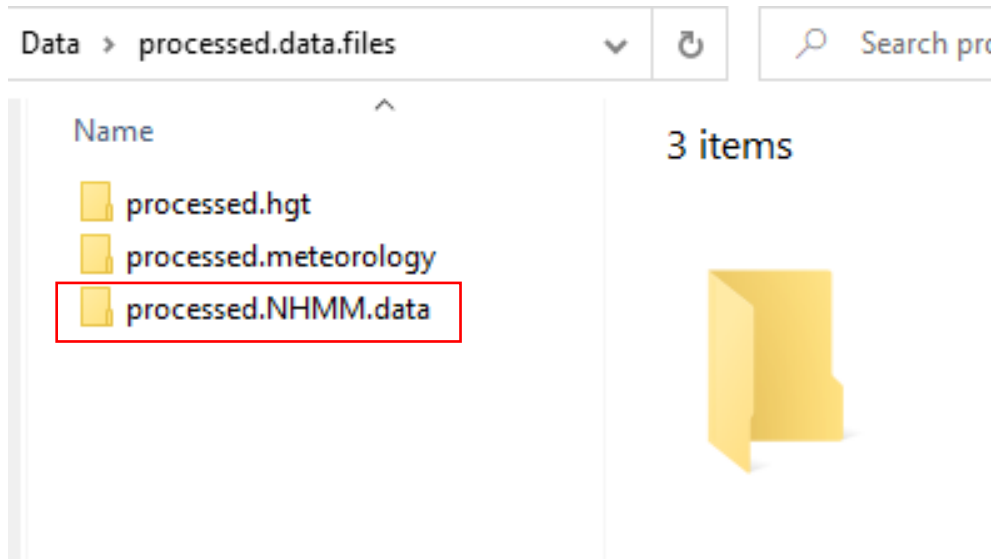
An .RDS data file of 500 hPa geopotential height anomalies should be provided, with days along the rows and gridded coordinates (longitude, latitude) along the columns for the region of interest.

The geopotential height data must be centered by month for each grid cell (i.e., anomalies) to identify weather regimes:

```
hgt.500.Pacific.NorthAmer.synoptic.region_19480101_20211231.rds
```


3 C) Exogenous covariates for NHMM

`./Data/processed.data.files/processed.NHMM.data/`



*** For advanced uses only; only available on Zenodo, not GitHub**

An .RDS data frame should be provided, with the first column as dates (daily), and the remaining columns as covariates

We used principal components (PCs) of a wetness index for the cold season

`paleo.norm.4.cold.PCs.dates_extracted.rds`

4) Run the Model and Evaluate Model Performance

4) Run Stochastic Weather Generator

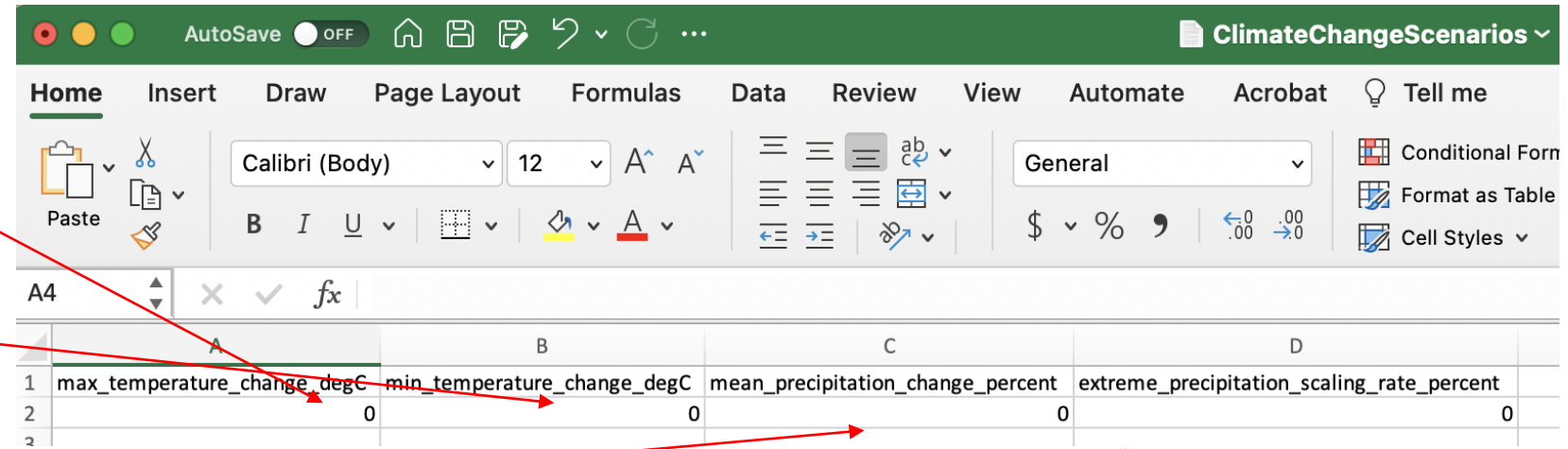
Follow these 5 steps in this order!

- 1) Open R project (WGEN-v2.0)
- 2) Insert Input Data in .Data/raw.input.files
- 3) Process Input Data (Run process.meteorology.R)
- 4) Set Run Specifications
 - ClimateChangeScenarios.csv; SimulationLength.csv
- 5) Conduct Simulation, Create Plots, Output Simulations
 - Run.stochastic.weather.generator.R

4) Run Stochastic Weather Generator

`./ClimateChangeScenarios.csv`

- Temperature change [in °C] for Tmax (e.g., 0, 1, ...)
- Temperature change [in °C] for Tmin (e.g., 0, 1, ...)
- Mean precipitation change [in %] (e.g., 0, 12.5, ...)
- Extreme precipitation scaling rate [in %] (e.g., 0, 7, ...)



	A	B	C	D
1	max_temperature_change_degC	min_temperature_change_degC	mean_precipitation_change_percent	extreme_precipitation_scaling_rate_percent
2	0	0	0	0

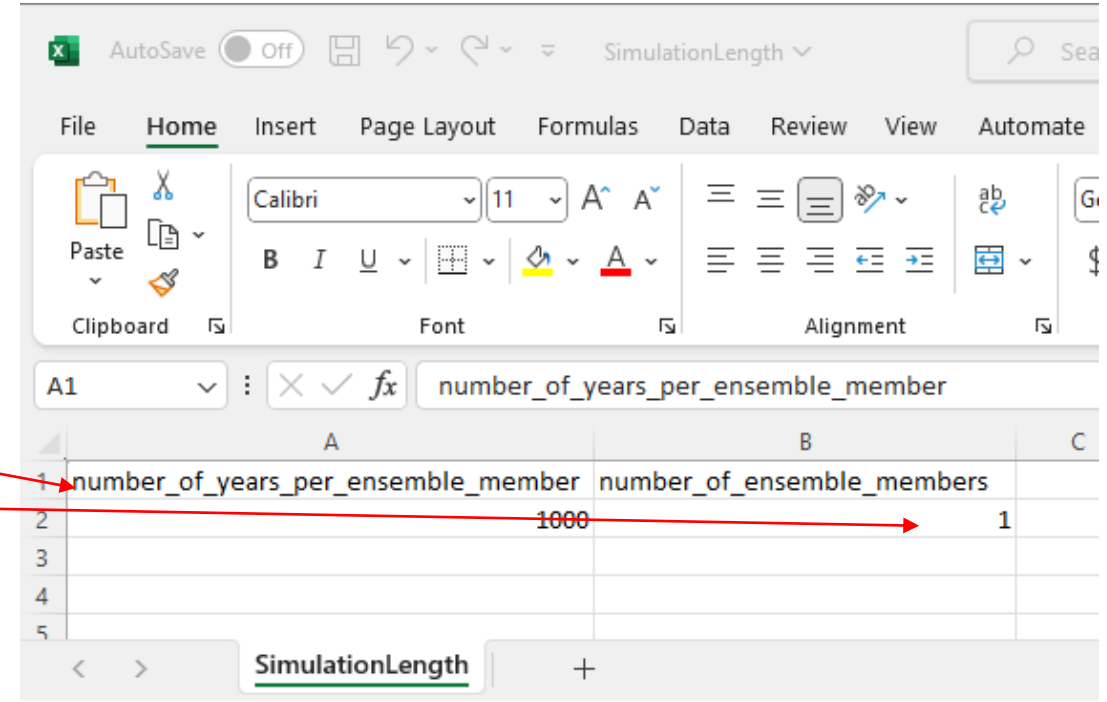
We set all equal to 0 for the baseline (no climate change) run (i.e., model calibration)
 *will revisit in the next presentation

4) Run Stochastic Weather Generator

`./SimulationLength.csv`

* For advanced uses only

- Number of years of data (e.g., 100, 500, 1000 years)
- Number of ensemble members (e.g., how many traces?)
- *Only applicable if user simulates new weather regimes (`use.provided.WRs=FALSE`)
- *Under the default configuration that uses weather regimes that are provided (`use.provided.WRs=TRUE`), the model will simulate 1000 years and 1 ensemble member.



	A	B	C
1	number_of_years_per_ensemble_member	number_of_ensemble_members	
2		1000	1
3			
4			
5			

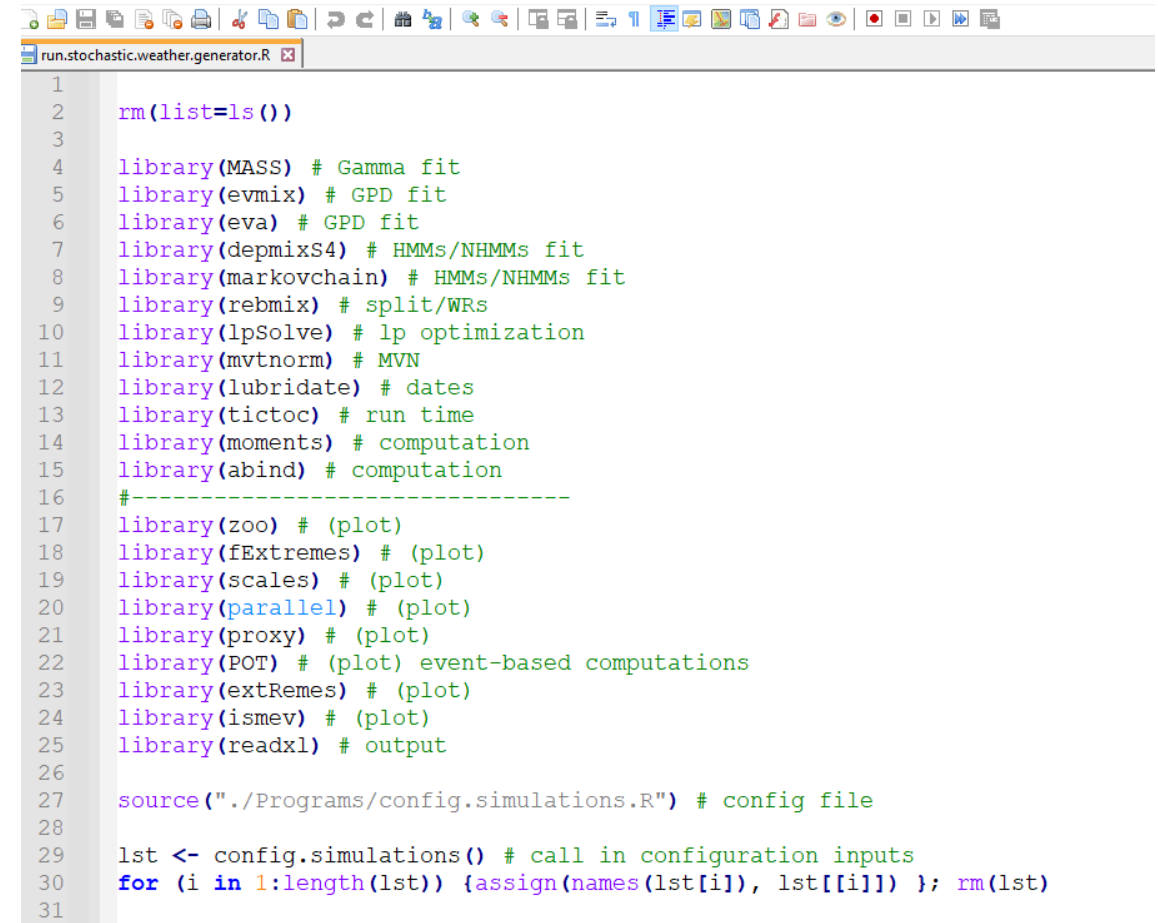
4) Run Stochastic Weather Generator

```
./Programs/run.stochastic.weather.generator.R
```

Libraries for computations and plotting

Use `install.packages("NAME")` to install individual library.

```
# List of packages to check and install
packages_to_install <- c("NAME1", "NAME2",...)
# Install packages if not already installed
install.packages(packages_to_install[!(installed.packages()
[, "Package"] %in% packages_to_install)])
```



```
1
2 rm(list=ls())
3
4 library(MASS) # Gamma fit
5 library(evmix) # GPD fit
6 library(eva) # GPD fit
7 library(depmixS4) # HMMs/NHMMs fit
8 library(markovchain) # HMMs/NHMMs fit
9 library(rebmix) # split/WRS
10 library(lpSolve) # lp optimization
11 library(mvtnorm) # MVN
12 library(lubridate) # dates
13 library(tictoc) # run time
14 library(moments) # computation
15 library(abind) # computation
16 #-----
17 library(zoo) # (plot)
18 library(fExtremes) # (plot)
19 library(scales) # (plot)
20 library(parallel) # (plot)
21 library(proxy) # (plot)
22 library(POT) # (plot) event-based computations
23 library(extRemes) # (plot)
24 library(ismev) # (plot)
25 library(readxl) # output
26
27 source("../Programs/config.simulations.R") # config file
28
29 lst <- config.simulations() # call in configuration inputs
30 for (i in 1:length(lst)) {assign(names(lst[i]), lst[[i]]) }; rm(lst)
31
```

4) Run Stochastic Weather Generator

`./Programs/run.stochastic.weather.generator.R`

Default will use the provided WRs

`use.provided.WRs=TRUE`

```
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?
run.stochastic.weather.generator.R
33  #*****
34  #--- Weather Regimes Module ---#
35  #use provided WRs
36  if (use.provided.WRs){
37    final.NHMM.output <- readRDS('./Data/simulated.data.files/WRs.out/final.NHMM.non_param.output.rds')
38    weather.state.assignments <- final.NHMM.output$WR.historical # this is the historical WRs
39    num.states <- length(unique(as.vector(weather.state.assignments))) #number of WRs in the model
40    dates.sim <- final.NHMM.output$dates.sim
41    markov.chain.sim <- final.NHMM.output$WR.simulation
42    dates.synoptics <- final.NHMM.output$dates.historical
43    #simulate your own WRs
44  } else{
45    final.NHMM.output <- execute.WRs.non_param.NHMM()
46    weather.state.assignments <- final.NHMM.output$WR.historical # this is the historical WRs
47    num.states <- length(unique(as.vector(weather.state.assignments))) #number of WRs in the model
48    dates.sim <- final.NHMM.output$dates.sim
49    markov.chain.sim <- final.NHMM.output$WR.simulation
50    dates.synoptics <- final.NHMM.output$dates.historical
51  }
52  rm(final.NHMM.output) # for memory
```

More detail simulating your own weather regimes can be found here:

Najibi, N., Steinschneider, S. (2023). A Process-Based Approach to Bottom-Up Climate Risk Assessments: Developing a Statewide, Weather-Regime based Stochastic Weather Generator for California, pp.1–67, Biological and Environmental Engineering, Cornell University, Ithaca, NY, August 2023. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Resources-for-Water-Managers/Files/WGENCalifornia_Final_Report_final_20230808.pdf

4) Run Stochastic Weather Generator

```
./Programs/run.stochastic.weather.generator.R
```

This function runs the model

```
62
63  #*****
64  #--- Weather Generation Module ---#
65  execute.simulations()
66  # done. #
67
```


4) Evaluate Model Performance

`./Programs/run.stochastic.weather.generator.R`

```

71 *****
72 # - create sample figures for selected scenario
73 # - generate individual output files in tab or text delimited formats
74
75 #this is the scenario (i.e., the row in ClimateChangeScenarios.csv) for which to make plots
76 selected_scenario = 1
77
78 #--- figures ---#
79 # arguments are labels for x and y-axes
80 start_time <- Sys.time()
81 create.figures.baselines.stacked(scenario = selected_scenario)
82 Sys.time() - start_time
83

```

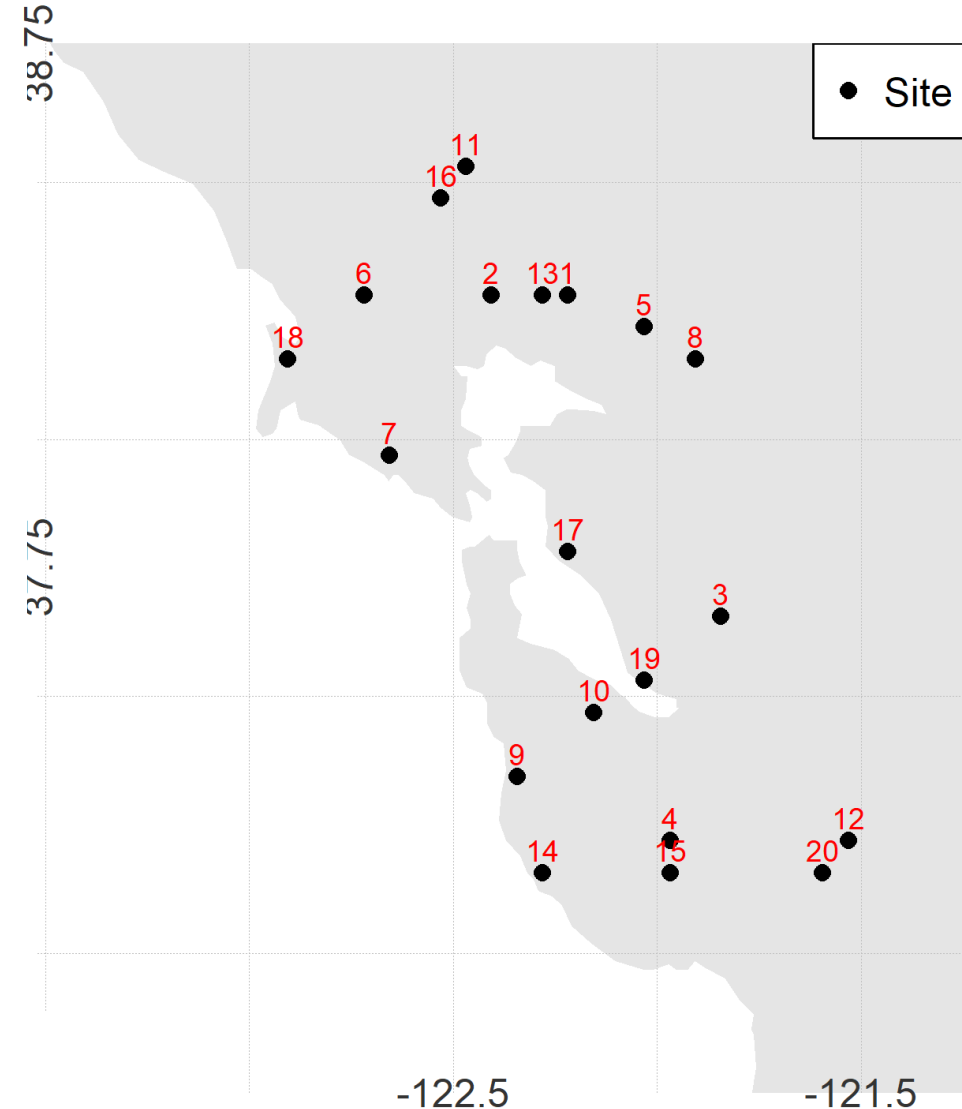
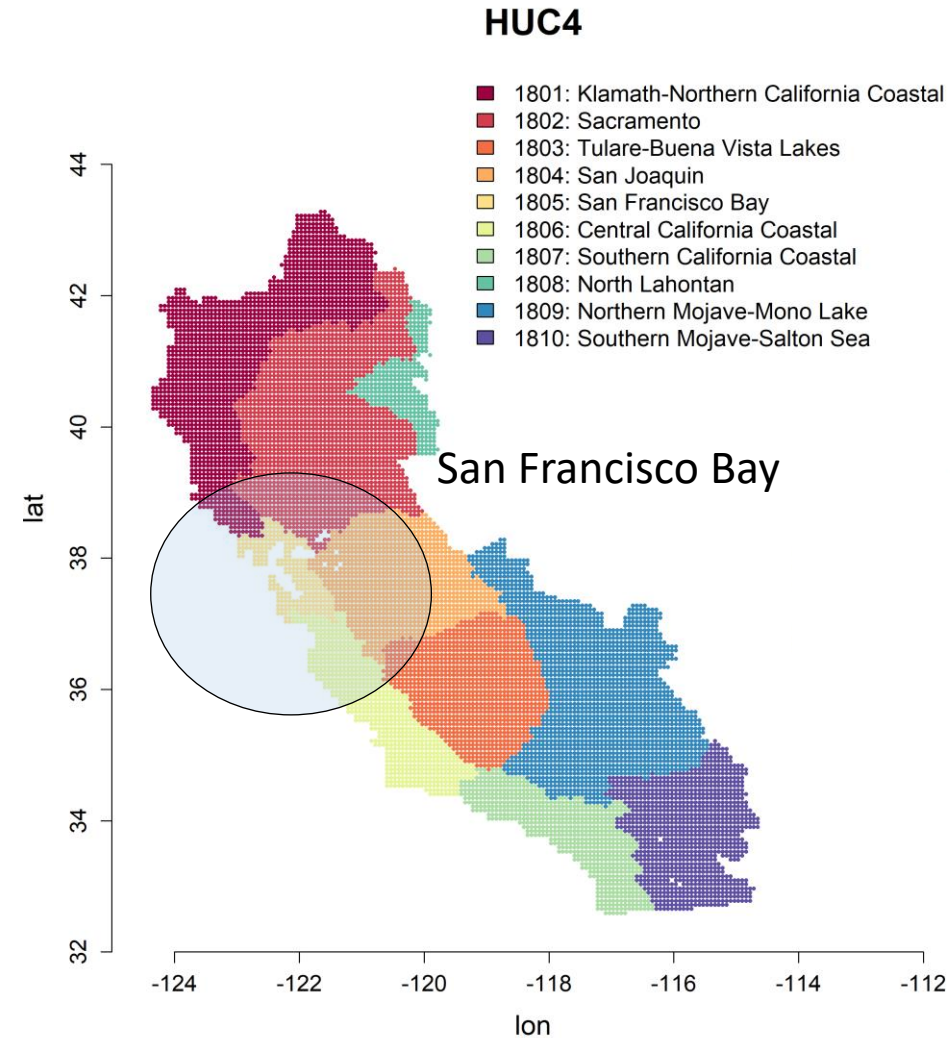
Name	Date modified	Type	Size
10 items			
File (1)			
LICENSE	11/10/2022 11:06 AM	File	2 KB
File folder (4)			
Data	12/4/2023 12:22 PM	File folder	
docs	11/8/2022 1:58 PM	File folder	
Figures	12/4/2023 5:57 PM	File folder	
Programs	12/4/2023 12:23 PM	File folder	
MD File (1)			
README.md	12/4/2023 1:10 PM	MD File	13 KB
Microsoft Excel Comma Separated Values File (2)			
ClimateChangeScenarios	12/4/2023 12:24 PM	Microsoft Excel C...	1 KB
SimulationLength	12/4/2023 12:24 PM	Microsoft Excel C...	1 KB
R Project (1)			
WGEN-v2.0	12/4/2023 12:27 PM	R Project	1 KB
Text Document (1)			
R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

- List of 6 figures for simulation vs. obs.
- Designed to output simulation for a single climate change scenario at a time (“selected_scenario”)
 - Will discuss further in next presentation

4) Evaluate Model Performance



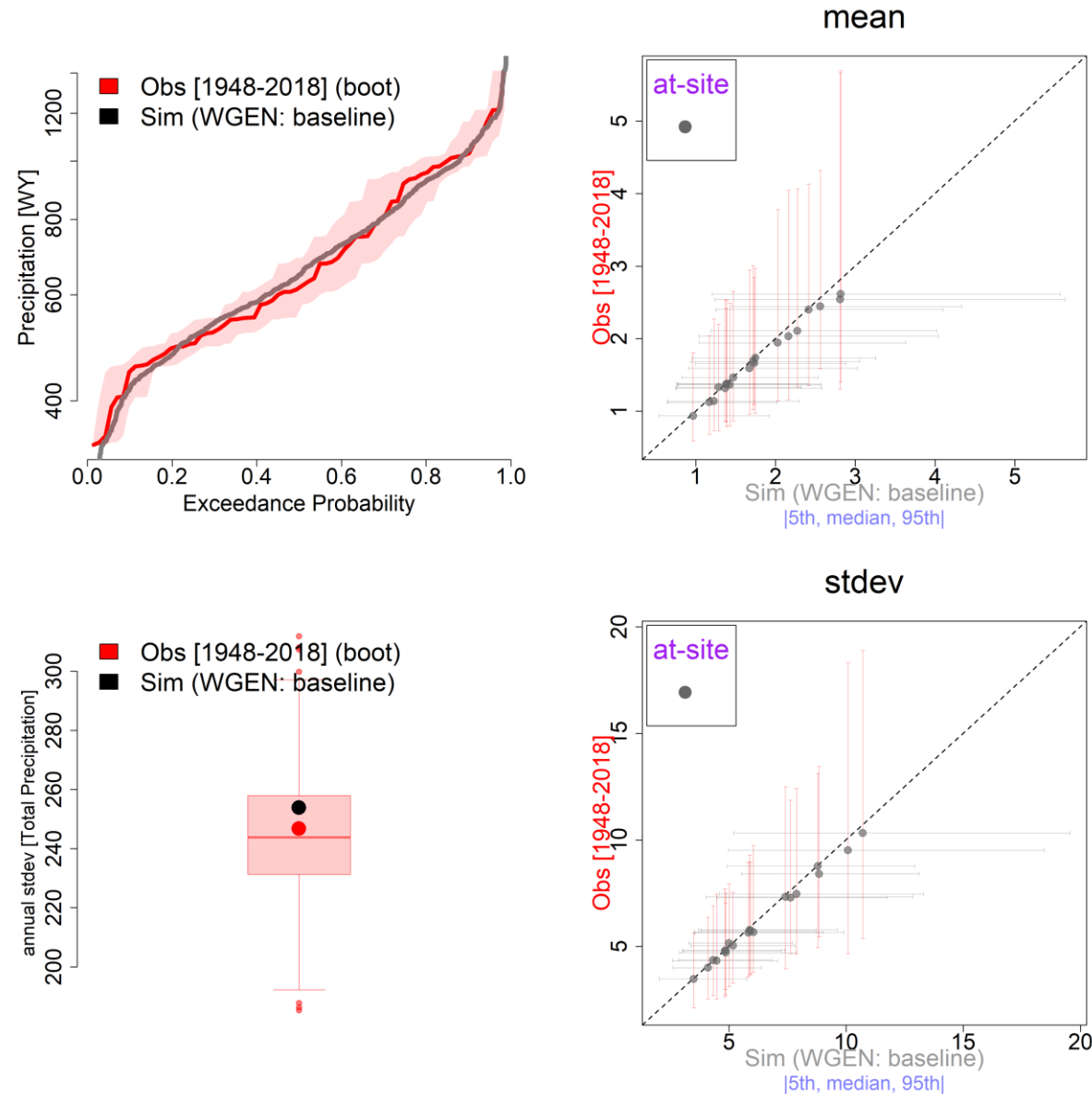
Cornell University



4) Evaluate Model Performance

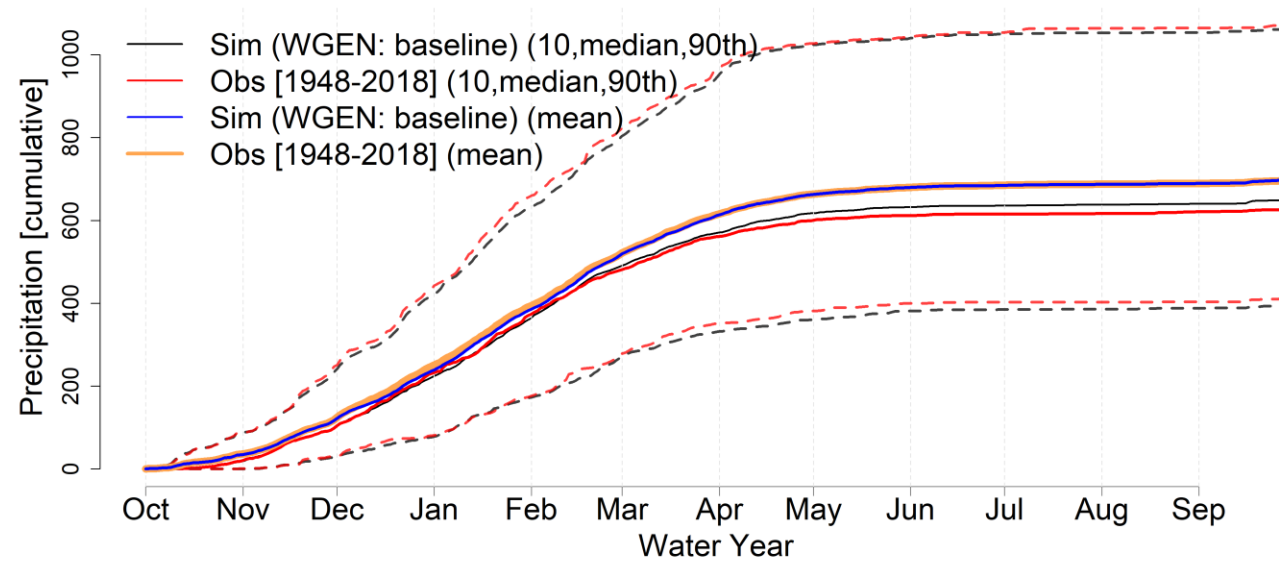
./Figures/

Precipitation

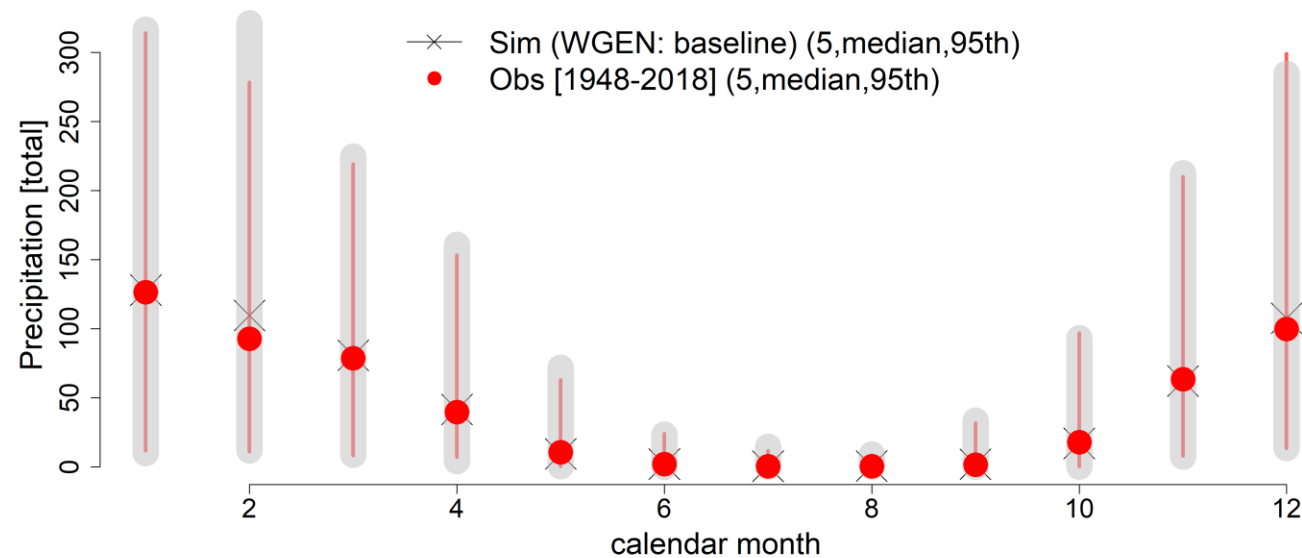


4) Evaluate Model Performance

./Figures/



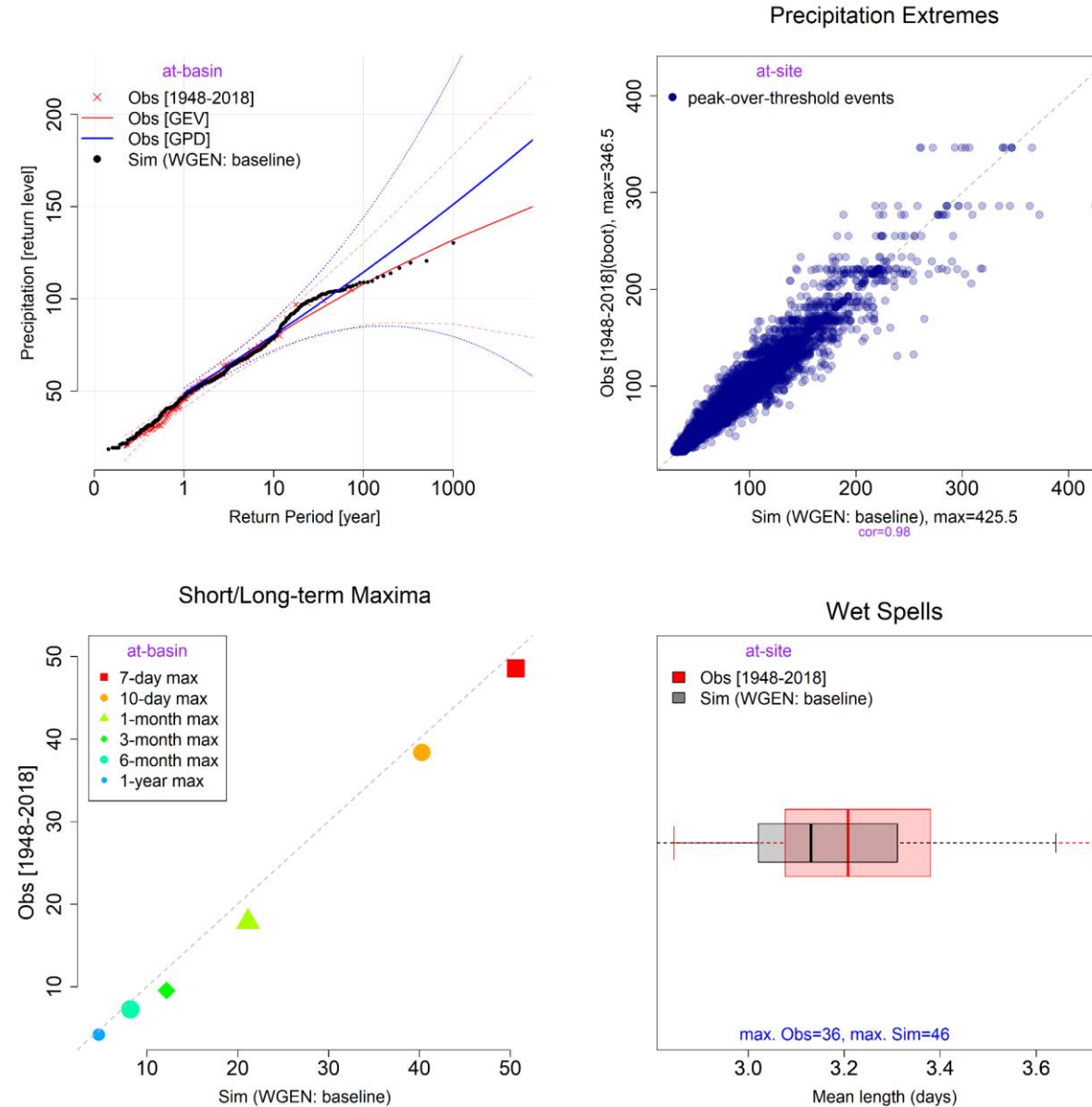
Precipitation



4) Evaluate Model Performance

./Figures/

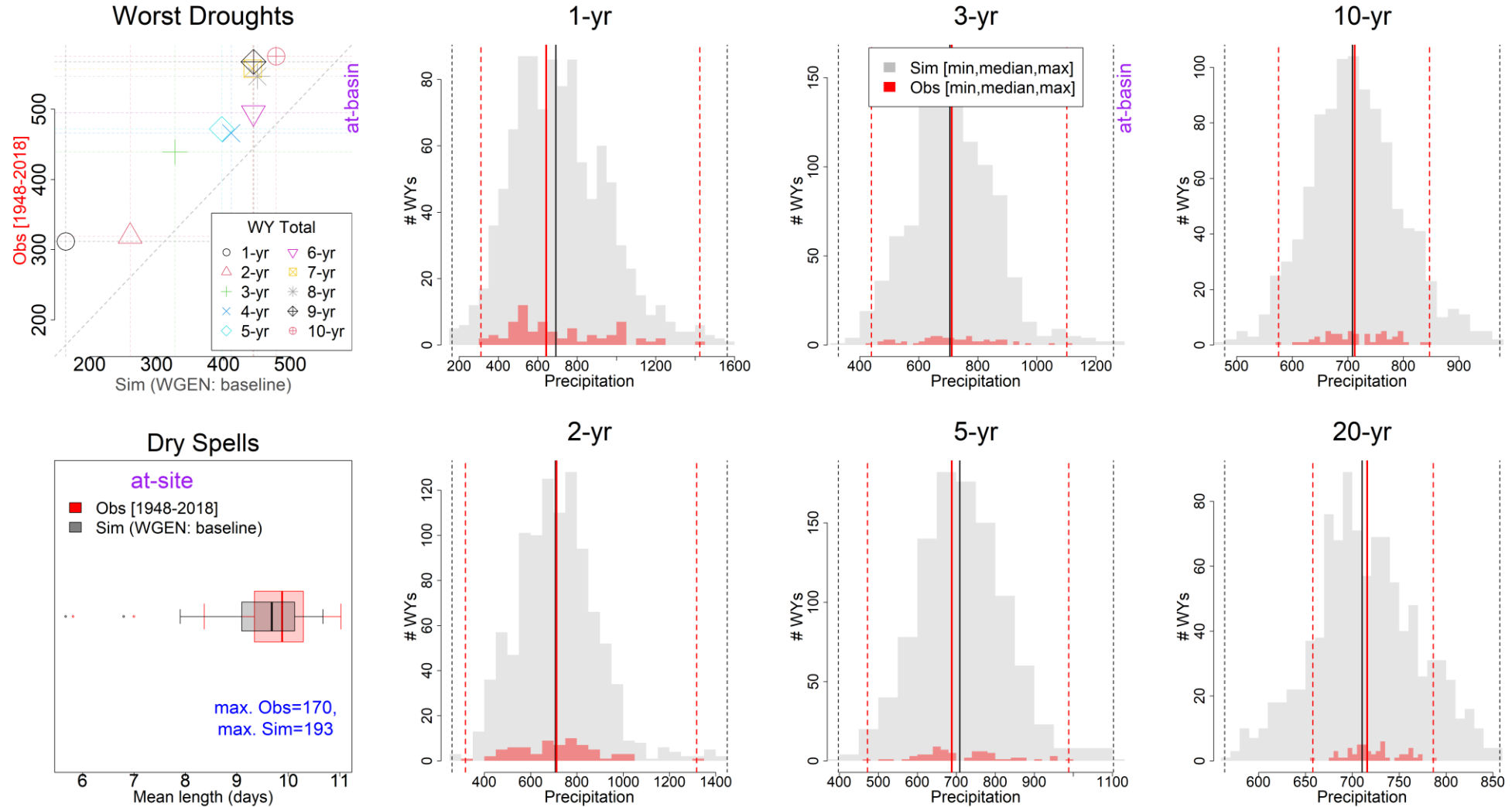
Precipitation



4) Evaluate Model Performance

[./Figures/](#)

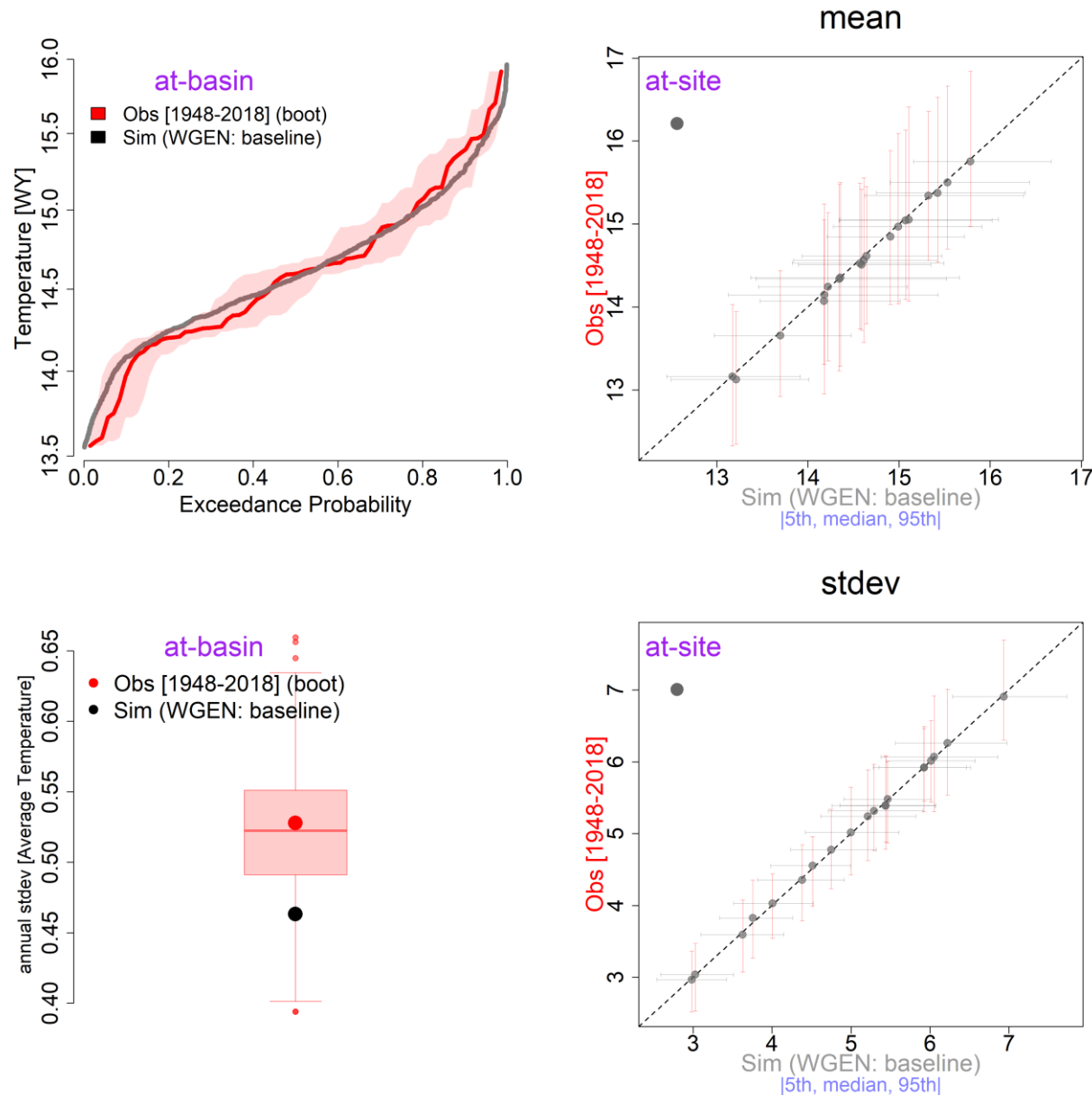
Precipitation



4) Evaluate Model Performance

./Figures/

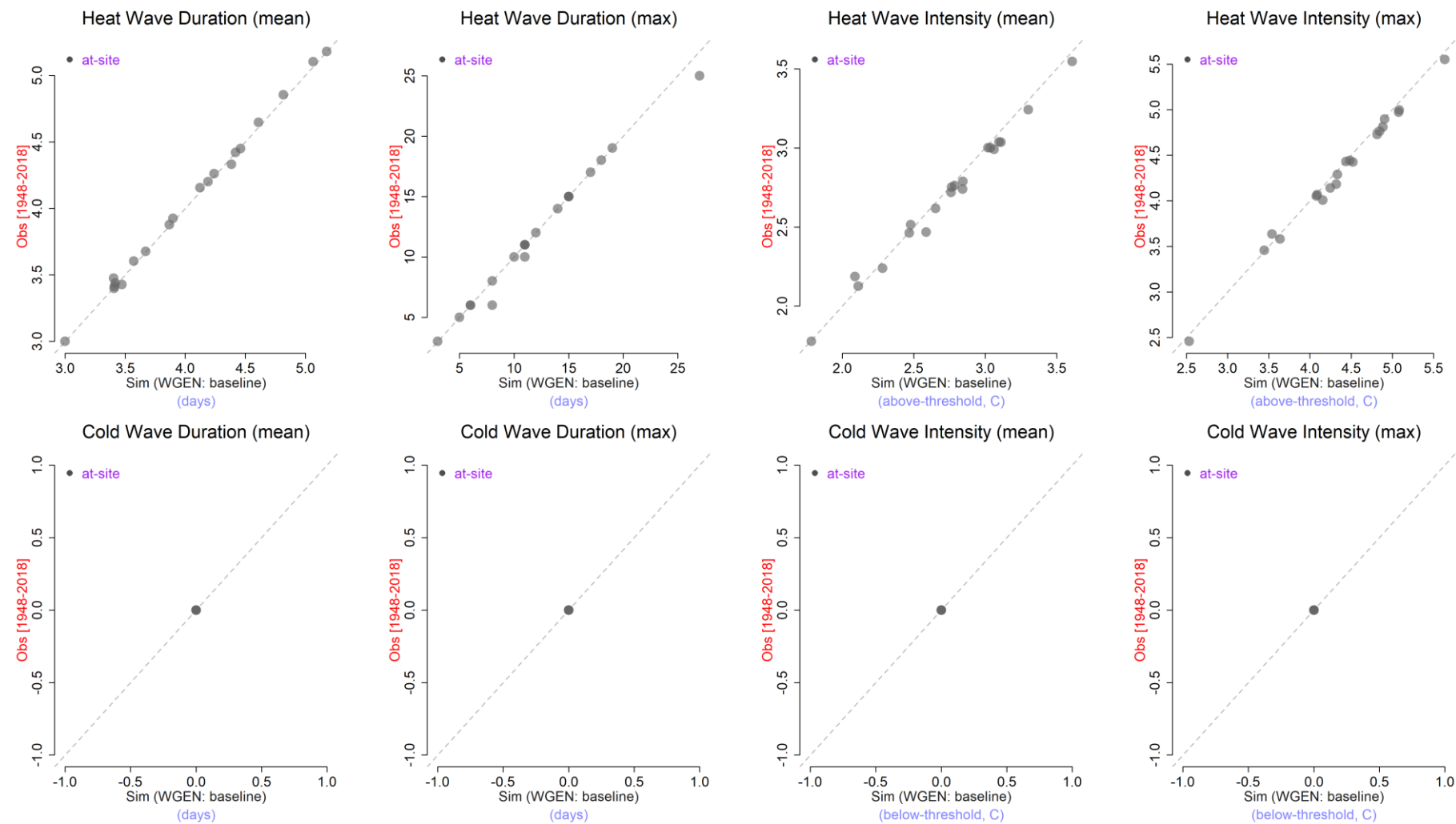
Temperature (mean)



4) Evaluate Model Performance

./Figures/

Temperature (max, min)



5) Generating Output Files





















5) Generating Output Files

```
./Programs/run.stochastic.weather.generator.R
```

```
84
85 #--- outputs ---#
86 # YYYY, MM, DD, P(mm), Tmax(C), Tmin(C) in .csv individual lat/lon file #
87 # for simulated data #
88 create.delimited.outputs(scenario = selected_scenario)
89
90
```

- File format: *.csv
- Leap years are maintained
- Designed to output simulation for a single climate change scenario at a time (“selected_scenario”)
 - Will discuss further in next presentation

```
./Data/output.data.files/
```

< > output.data.files	
Name	
	data_meteo_-121.53125_37.21875.csv
	data_meteo_-121.59375_37.15625.csv
	data_meteo_-121.84375_37.65625.csv
	data_meteo_-121.90625_38.15625.csv
	data_meteo_-121.96875_37.15625.csv
	data_meteo_-121.96875_37.21875.csv
	data_meteo_-122.03125_37.53125.csv
	data_meteo_-122.03125_38.21875.csv
	data_meteo_-122.15625_37.46875.csv
	data_meteo_-122.21875_37.78125.csv
	data_meteo_-122.21875_38.28125.csv
	data_meteo_-122.28125_37.15625.csv
	data_meteo_-122.28125_38.28125.csv
	data_meteo_-122.34375_37.34375.csv
	data_meteo_-122.40625_38.28125.csv
	data_meteo_-122.46875_38.53125.csv
	data_meteo_-122.53125_38.46875.csv
	data_meteo_-122.65625_37.96875.csv
	data_meteo_-122.71875_38.28125.csv
	data_meteo_-122.90625_38.15625.csv

5) Generating Output Files

./Data/output.data.files/

< > output.data.files

Name
data_meteo_-121.53125_37.21875.csv
data_meteo_-121.59375_37.15625.csv
data_meteo_-121.84375_37.65625.csv
data_meteo_-121.90625_38.15625.csv
data_meteo_-121.96875_37.15625.csv
data_meteo_-121.96875_37.21875.csv
data_meteo_-122.03125_37.53125.csv
data_meteo_-122.03125_38.21875.csv
data_meteo_-122.15625_37.46875.csv
data_meteo_-122.21875_37.78125.csv
data_meteo_-122.21875_38.28125.csv
data_meteo_-122.28125_37.15625.csv
data_meteo_-122.28125_38.28125.csv
data_meteo_-122.34375_37.34375.csv
data_meteo_-122.40625_38.28125.csv
data_meteo_-122.46875_38.53125.csv
data_meteo_-122.53125_38.46875.csv
data_meteo_-122.65625_37.96875.csv
data_meteo_-122.71875_38.28125.csv
data_meteo_-122.90625_38.15625.csv

AutoSave Off sim_meteo_-121.53125_37.21875...

File Home Insert Page Layout Formulas Data Review

Paste Clipboard Font

Calibri 11 A⁺ A⁻ B I U Font Color Background Color

A1

	A	B	C	D	E	F	G
1	1	1	1	0	8.1	0.41	
2	1	1	2	0	8.61	-1.36	
3	1	1	3	0	7.99	0.19	
4	1	1	4	0	10.37	0.81	
5	1	1	5	0.21	12.4	4.9	
6	1	1	6	0.7	10.02	1.64	
7	1	1	7	0	11.16	1.99	
8	1	1	8	0	13.21	3.86	
9	1	1	9	1.41	11.55	3.53	
10	1	1	10	1.28	9.41	1.7	
11	1	1	11	0	11.01	3.41	
12	1	1	12	0	10.44	3.5	
13	1	1	13	0	12.64	2.33	
14	1	1	14	0	15.31	6.07	
15	1	1	15	0	17.42	7.54	
16	1	1	16	0	21.63	9.56	

sim_meteo_-121.53125_37.21875

YYYY MM DD (synthetic)

P [mm] Tmax [C] Tmin [C]

	A	B	C	D	E	F	G
368158	1008	12	17	0	13.25	3.61	
368159	1008	12	18	0	12.3	4.34	
368160	1008	12	19	0	11.5	4.92	
368161	1008	12	20	0	10.79	4.75	
368162	1008	12	21	0	12.55	4.74	
368163	1008	12	22	0	11.79	1.54	
368164	1008	12	23	0	11.44	2.78	
368165	1008	12	24	0	15.31	4.12	
368166	1008	12	25	3.92	17.18	8.32	
368167	1008	12	26	22.99	10.27	6.49	
368168	1008	12	27	0.28	12.23	7.5	
368169	1008	12	28	7.42	12.44	6.85	
368170	1008	12	29	0.57	10.05	5.87	
368171	1008	12	30	0.75	11.19	6.25	
368172	1008	12	31	19.85	11.96	6.57	
368173							

sim_meteo_-121.53125_37.21875