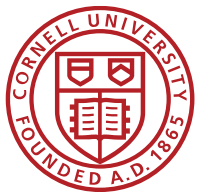
Stochastic Weather Generator

Preparing Input Data & Evaluating Model Performance



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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

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   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

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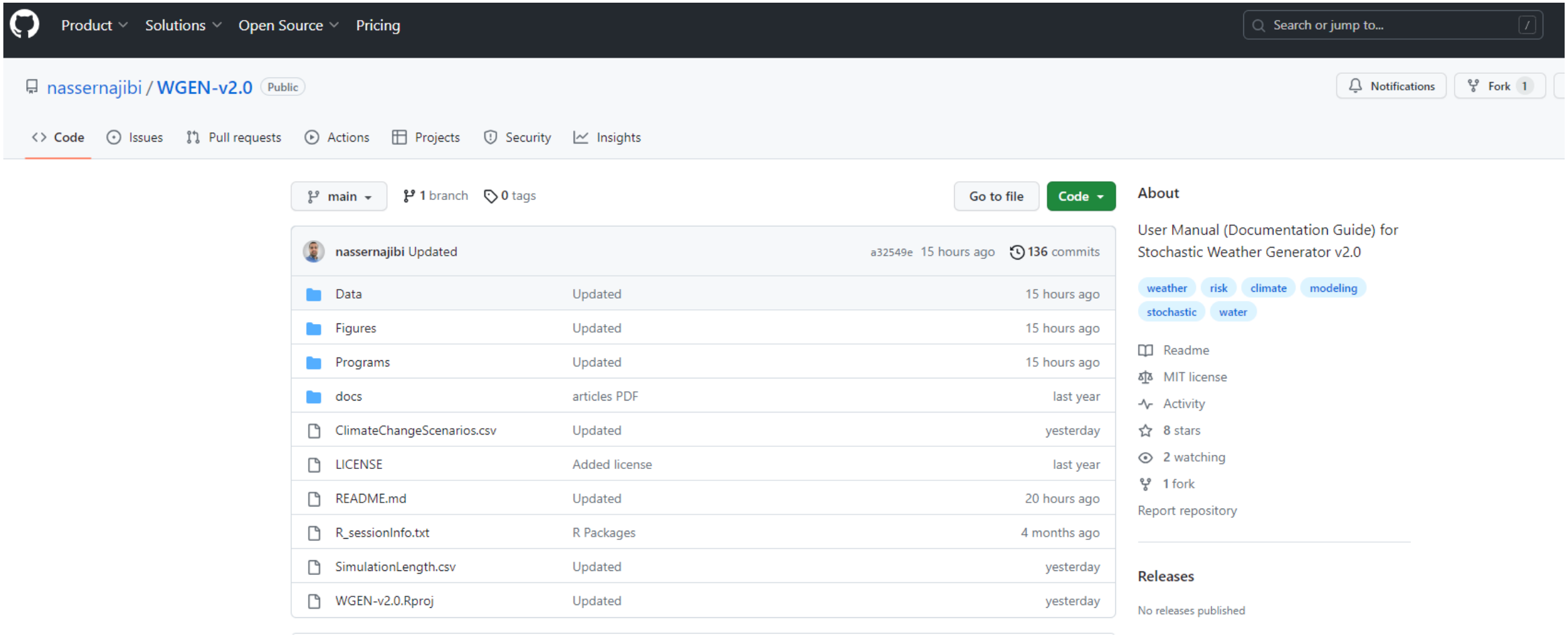
- **GitHub**: You can *clone* the repository to your machine

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



[4]

1) Access/Download Scripts

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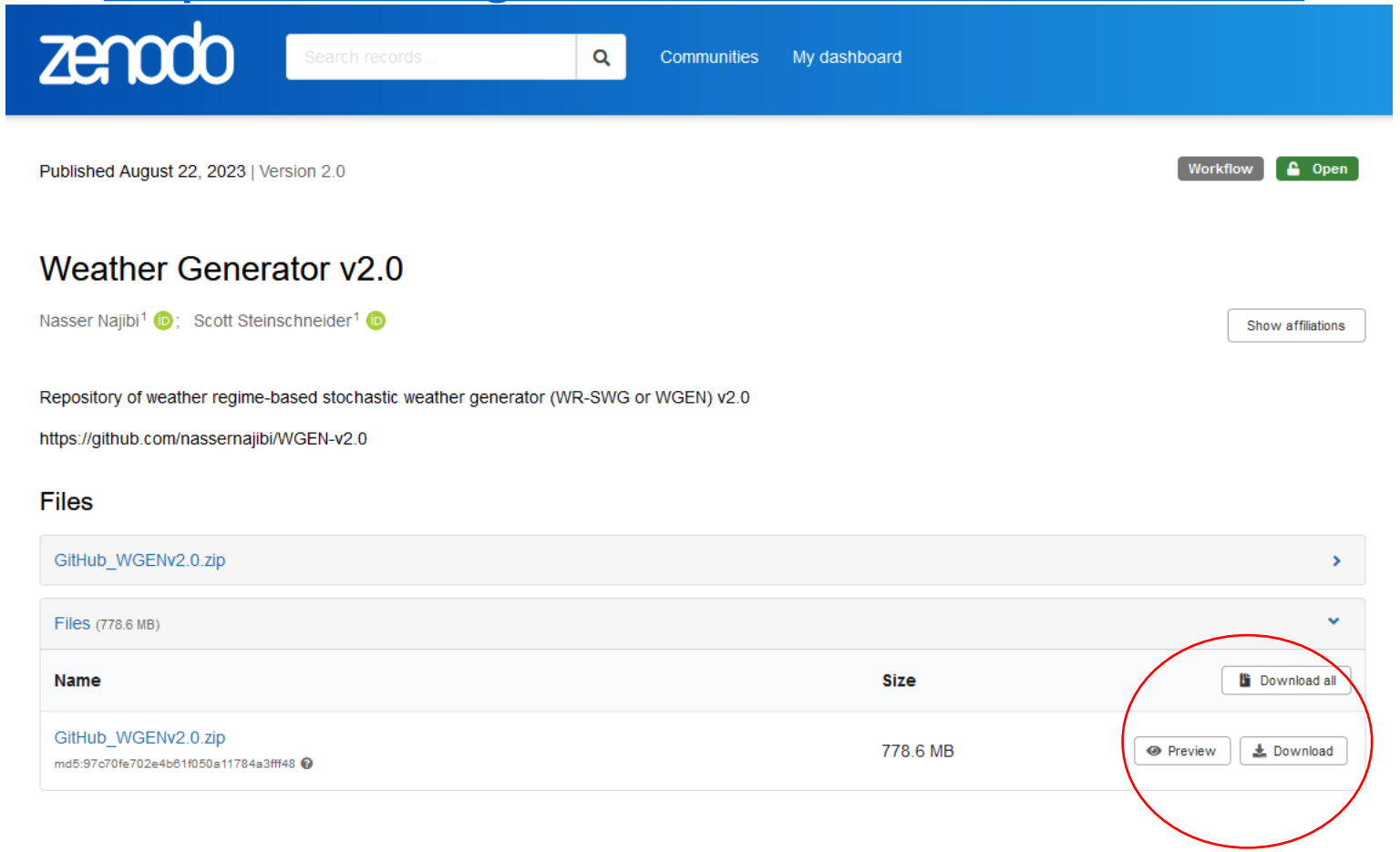
- **Zenodo**: Alternatively, you can download the entire zipped folder (with more data) from Zenodo via this DOI link:

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



Unzip to a directory in your local hard drive.

[5]

2) Repository Organization

2) Repo Organization

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Stochastic Weather Generator

Name	Date modified	Type	Size
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	
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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

10 items

- R Project: WGEN-v2.0
  - "Data"
  - "Programs"
  - "Figures"
- .csv's for Run Specs

(*LICENSE*, *README.md*, and *R_SessionInfo.txt* are auxiliary GitHub files and will not be discussed)

2) Repo Organization

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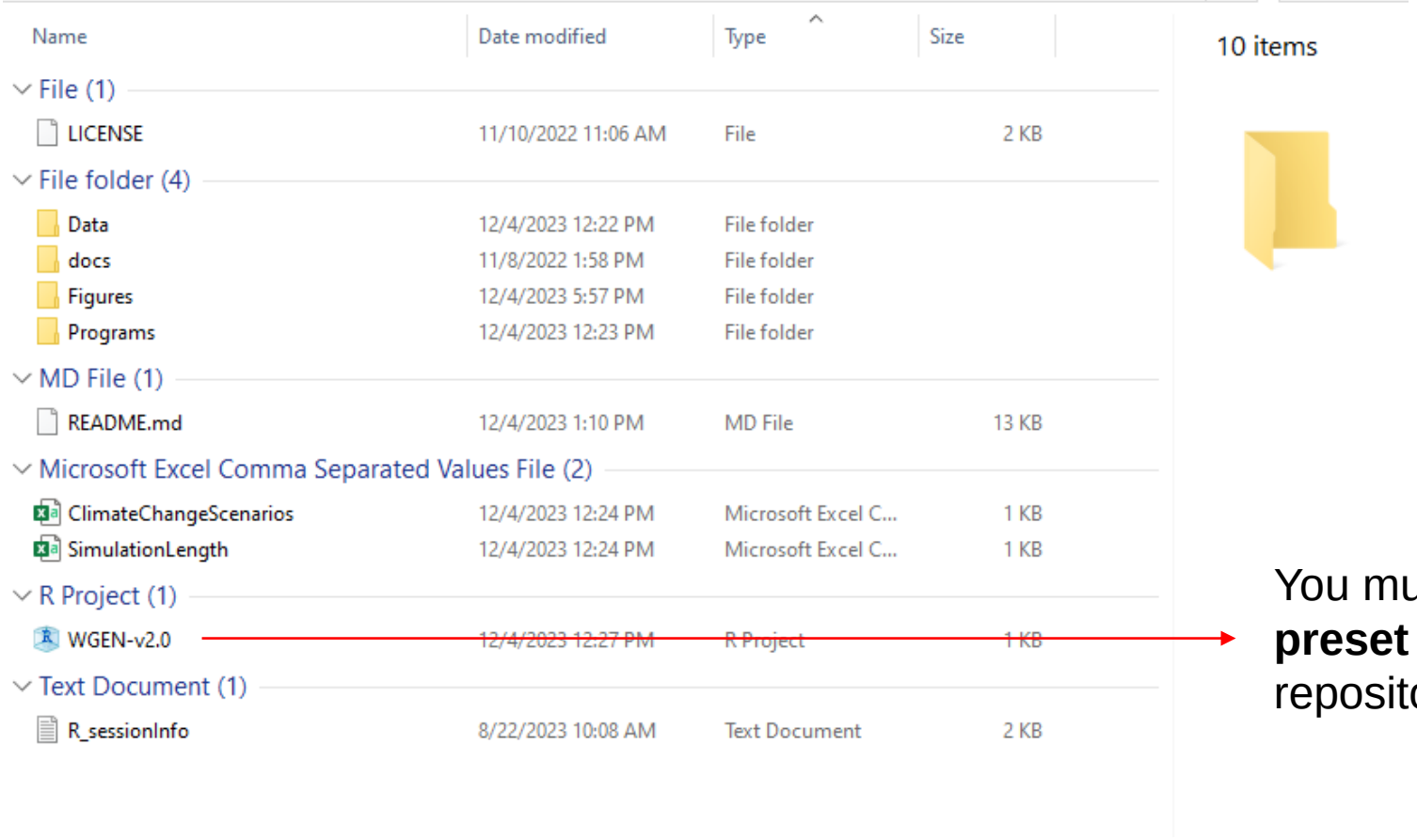
R Project: WGEN-v2.0



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

2) Repo Organization

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"Data"

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

- 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

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"Data"

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where you can find output files!

2) Repo Organization

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5 items

processed data required for the model (internal model use)

2) Repo Organization

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Name

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

5 items

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

2) Repo Organization

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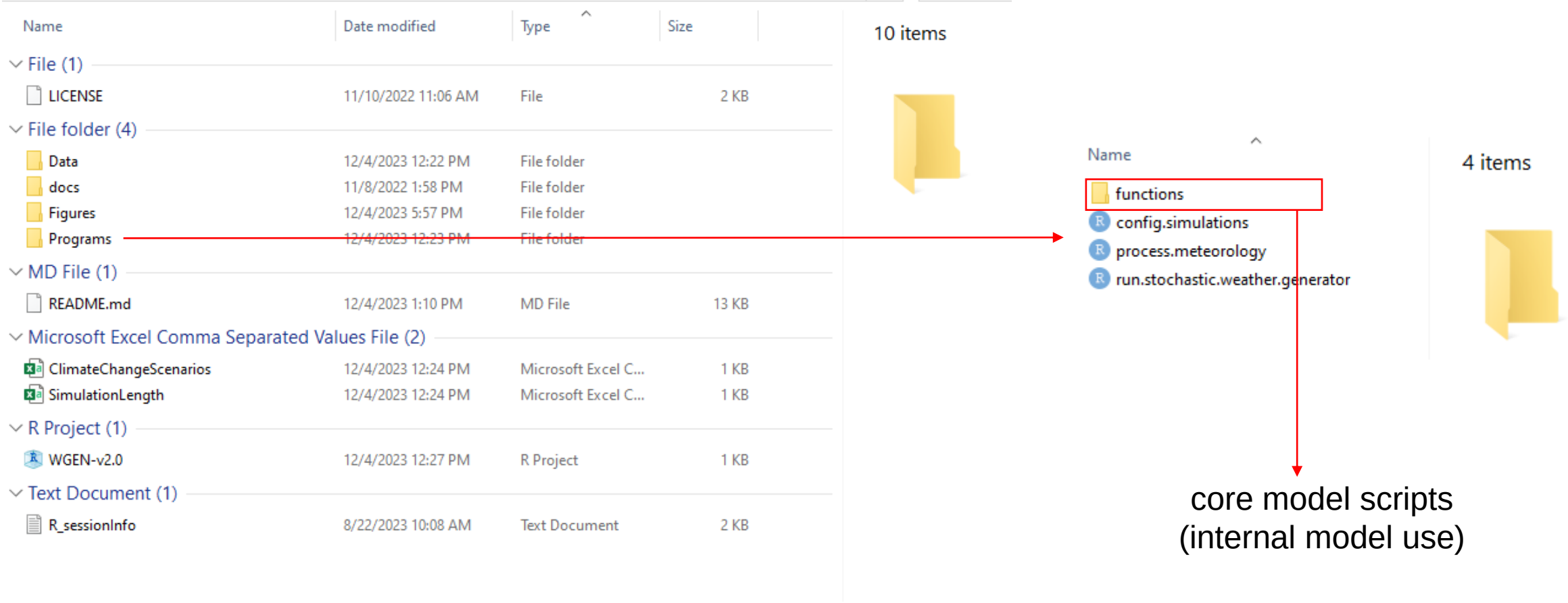
"Programs"



2) Repo Organization

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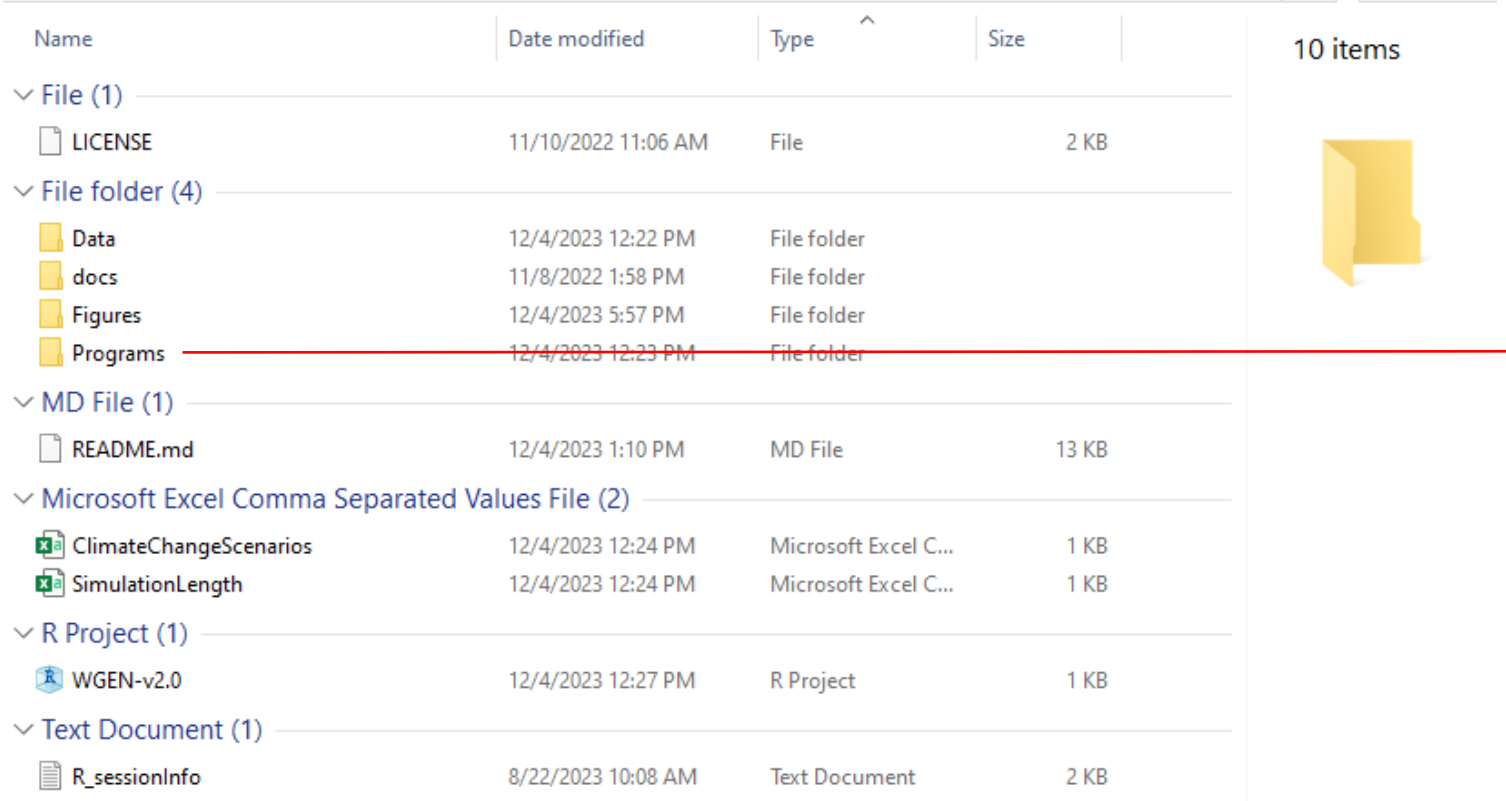
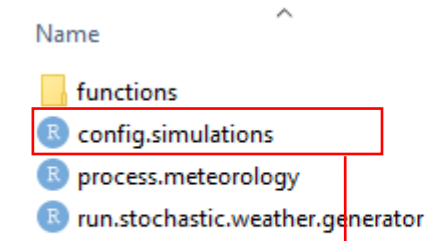
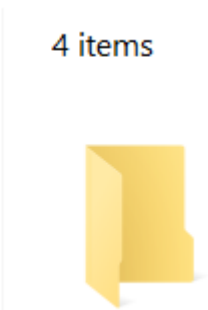
"Programs"







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

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"Programs"

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R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

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

4 items

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

2) Repo Organization

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"Programs"

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10 items

Name
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process.meteorology
run.stochastic.weather.generator

4 items

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

2) Repo Organization

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"Figures"

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File (1)			
LICENSE	11/10/2022 11:06 AM	File	2 KB
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R_sessionInfo	8/22/2023 10:08 AM	Text Document	2 KB

10 items

All diagnostic figures will be here

2) Repo Organization

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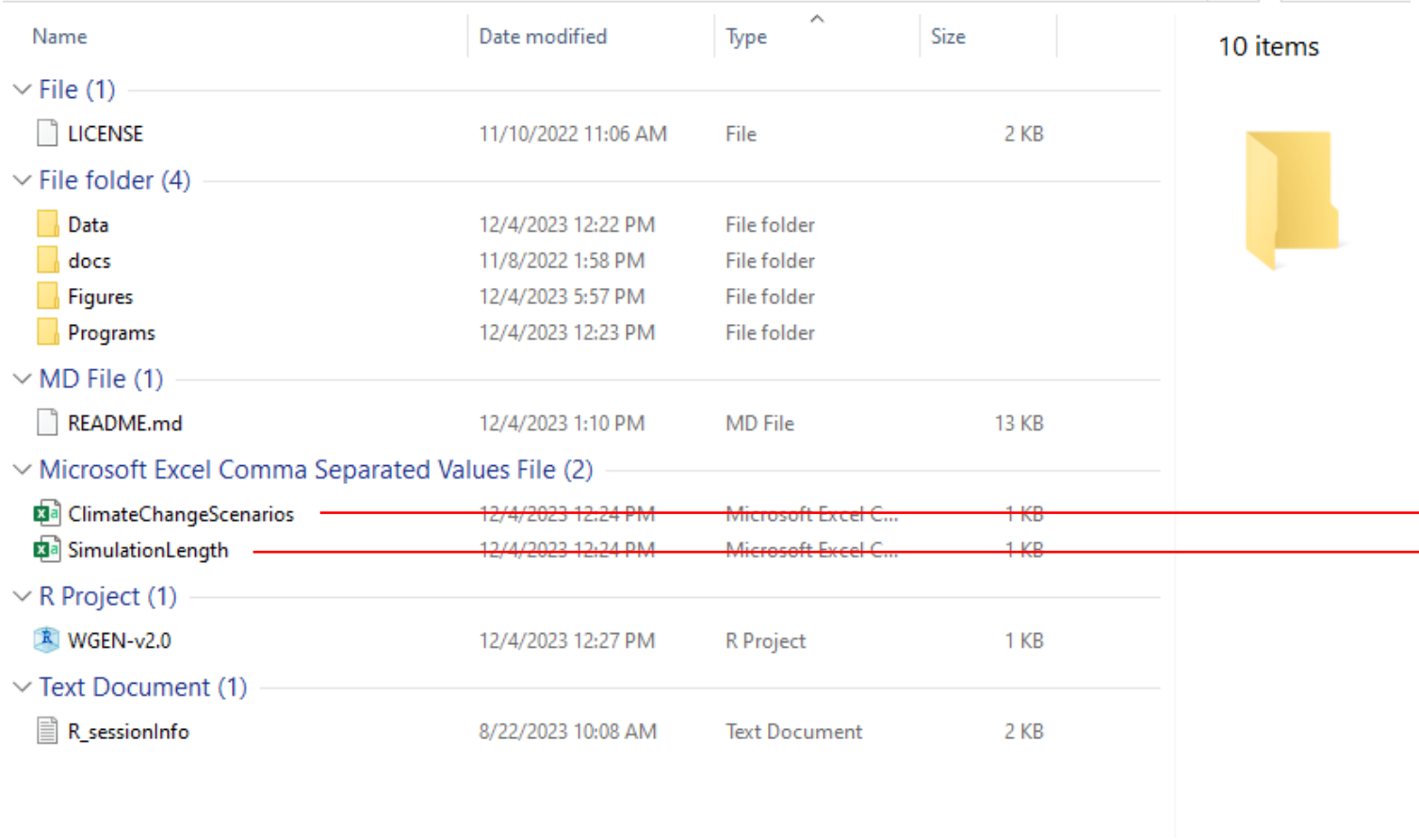
Run Specs (.csv files)



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

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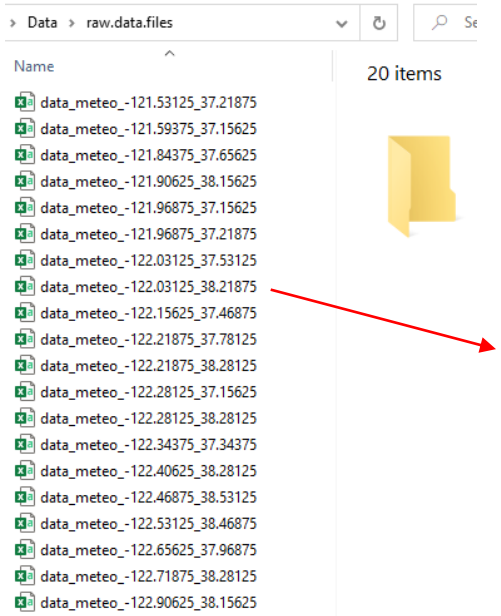
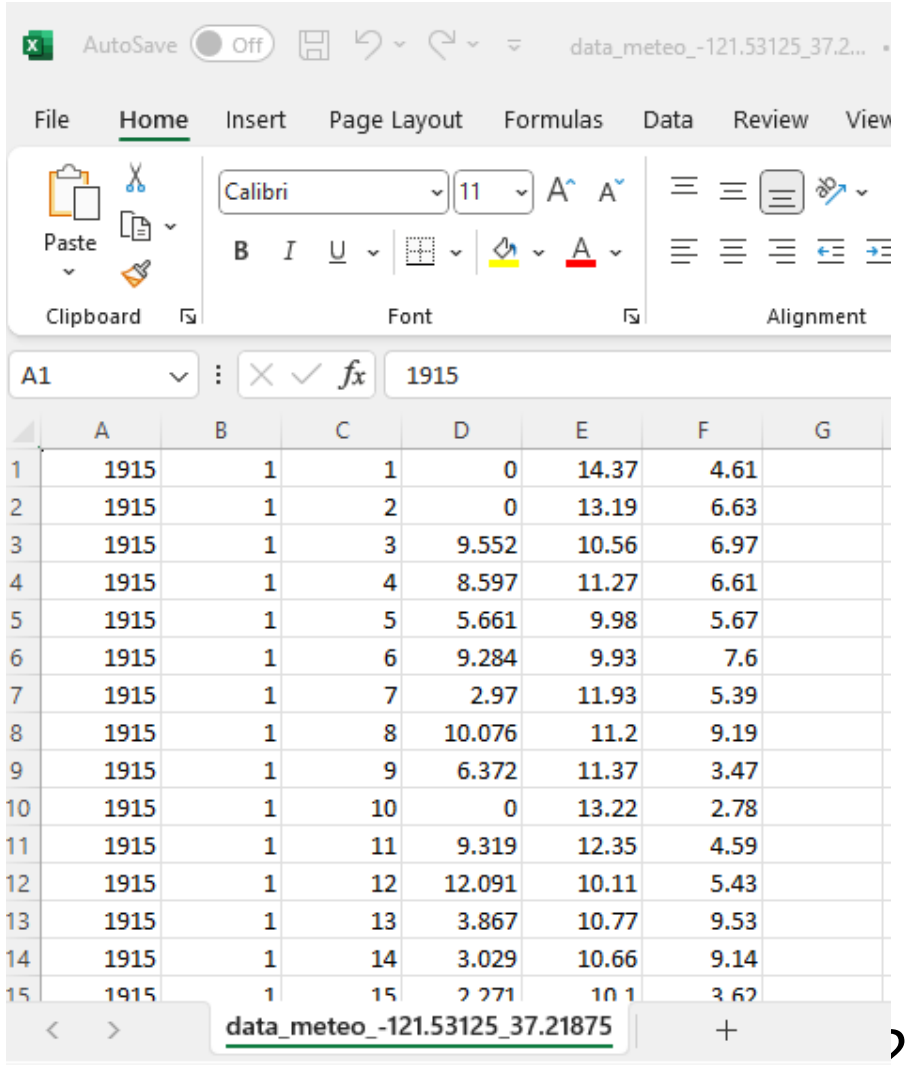
`./Data/raw.data.files/`





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

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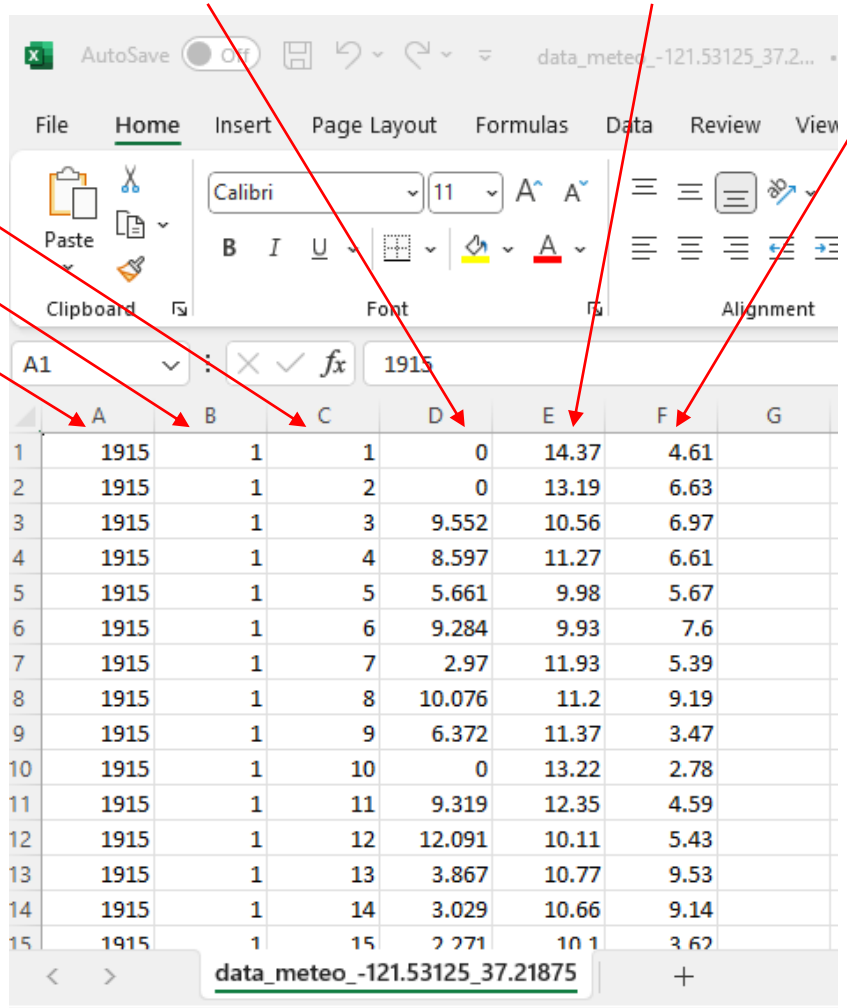
`./Data/raw.data.files/`

YYYY MM DD

Precipitation [mm]

Tmax [C]

Tmin [C]



	A	B	C	D	E	F
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

3 A) Surface weather (meteorological) data

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`./Programs/process.meteorology.R`

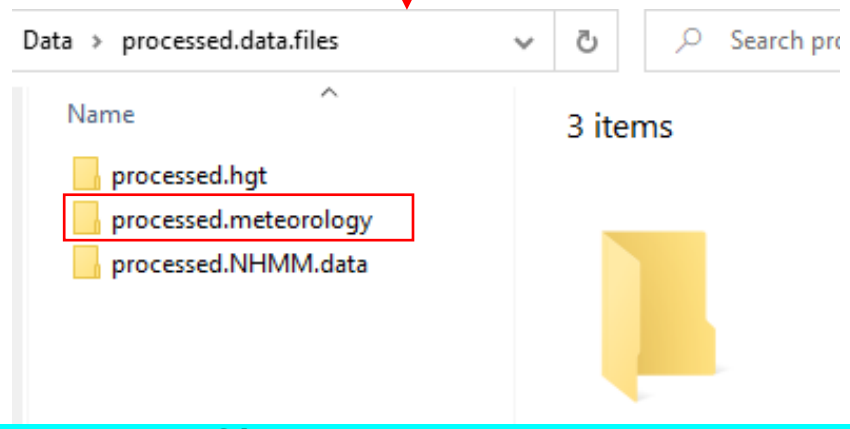
After placing your input files in the `raw.data.files` folder, run `process.meteorology.R` script

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 statior
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="-")
```

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



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

3 B,C) Pre-Made WR Simulation

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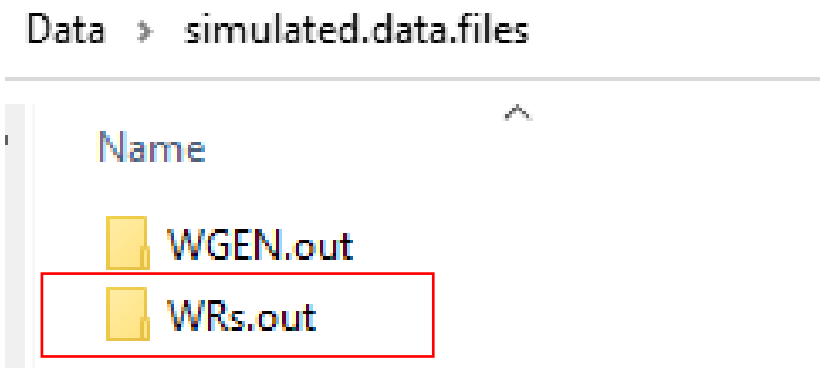
`./Data/simulated.data.files/WRs.out/`



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

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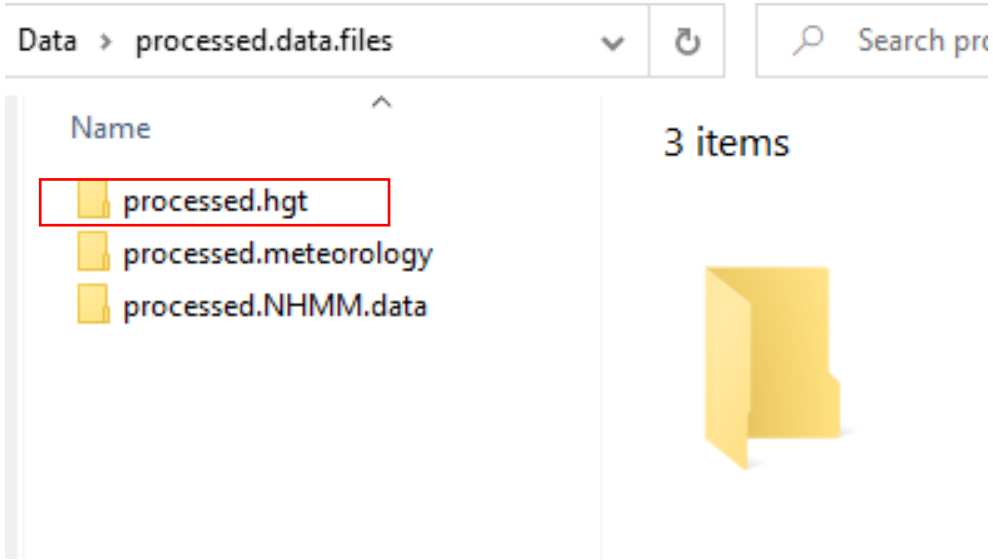
`./Data/processed.data.files/processed.hgt/`



*** 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

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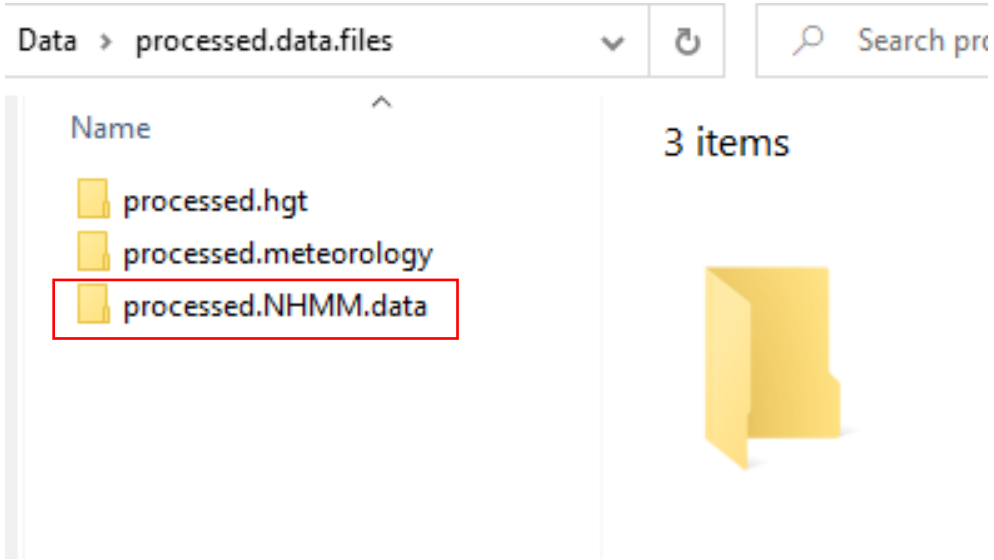
`./Data/processed.data.files/processed.NHMM.data/`



*** 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

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Follow these 5 steps in this order!

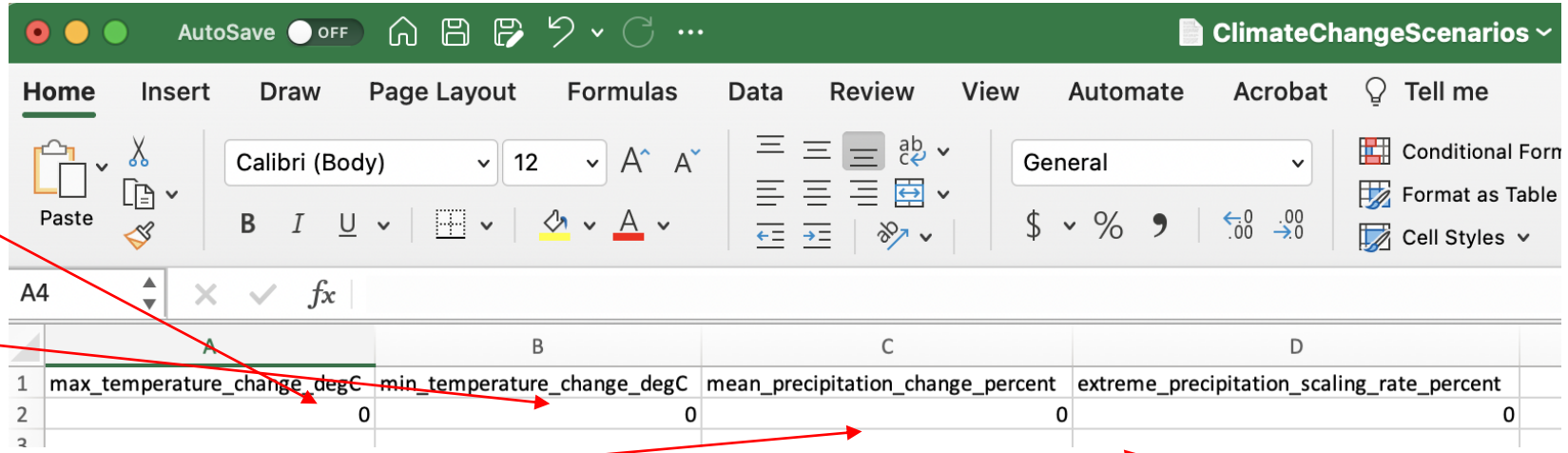
1) Open R project (WGEN-v2.0)
2) Insert Input Data in .Data/raw.input.files
3) Process Input Data (Run process.meteorology.R)
4) Set Run Specifications
   - ClimateChangeScenarios.csv; SimulationLength.csv
5) Conduct Simulation, Create Plots, Output Simulations
   - Run.stochastic.weather.generator.R

4) Run Stochastic Weather Generator

Cornell University

`./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, …)



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

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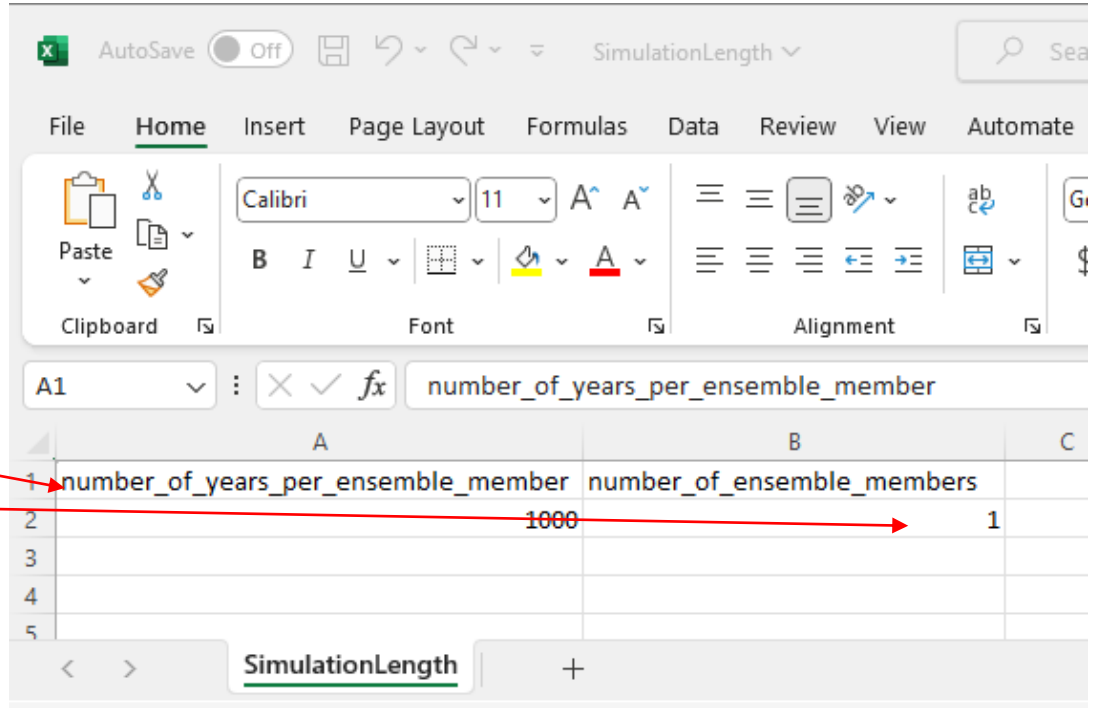
`./SimulationLength.csv`

*** 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.**



4) Run Stochastic Weather Generator

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`./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)])
```

run.stochastic.weather.generator.R

```r
rm(list=ls())

library(MASS) # Gamma fit
library(evmix) # GPD fit
library(eva) # GPD fit
library(depmixS4) # HMMs/NHMMs fit
library(markovchain) # HMMs/NHMMs fit
library(rebmix) # split/WRs
library(lpSolve) # lp optimization
library(mvtnorm) # MVN
library(lubridate) # dates
library(tictoc) # run time
library(moments) # computation
library(abind) # computation
#---------------------------------
library(zoo) # (plot)
library(fExtremes) # (plot)
library(scales) # (plot)
library(parallel) # (plot)
library(proxy) # (plot)
library(POT) # (plot) event-based computations
library(extRemes) # (plot)
library(ismev) # (plot)
library(readxl) # output

source("./Programs/config.simulations.R") # config file

lst <- config.simulations() # call in configuration inputs
for (i in 1:length(lst)) {assign(names(lst[i]), lst[[i]]) }; rm(lst)

```

4) Run Stochastic Weather Generator

Cornell University

`./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

Cornell University

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

This function runs the model

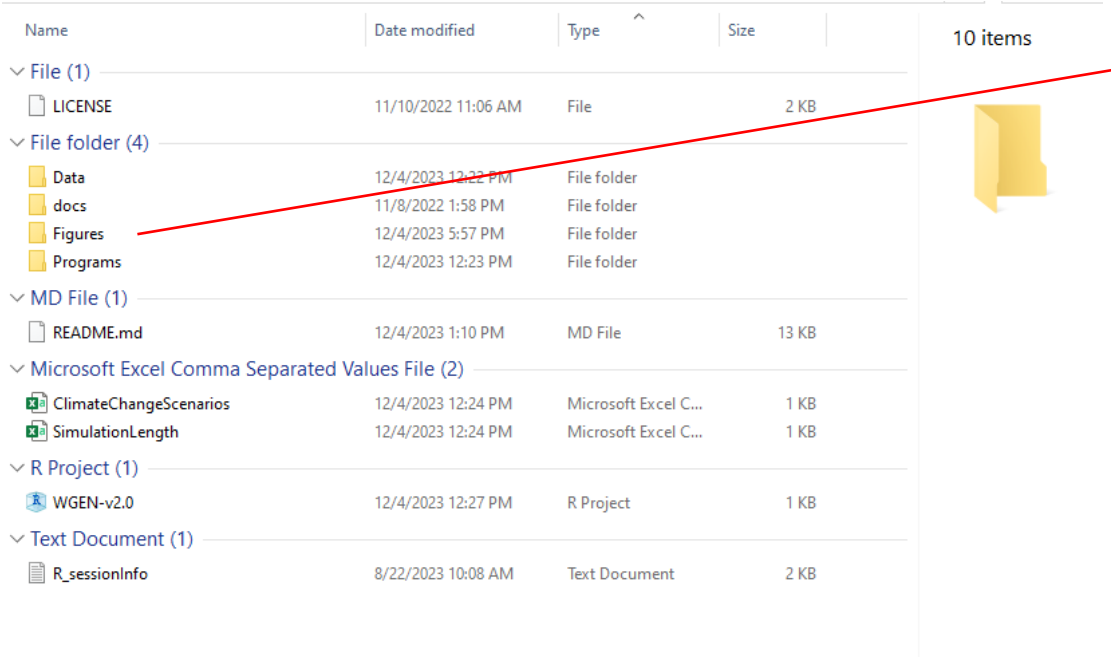
```
62
63  #**************************************
64  #--- Weather Generation Module ---#
65  execute.simulations()
66  # done. #
67
```

4) Evaluate Model Performance

Cornell University

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

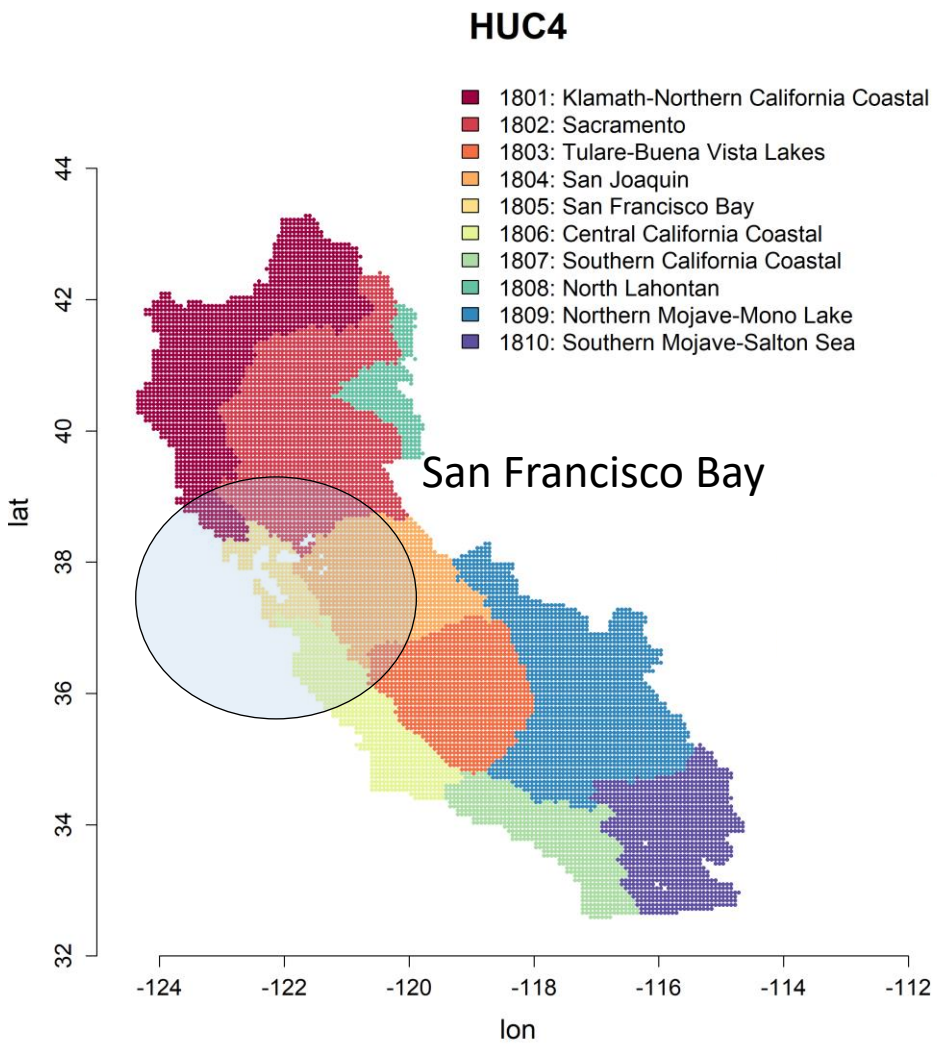
```
71  #************************************
72  # - create sample figures for selected scenario
73  # - generate individual output files in tab or text delimited formats
74
75  #this is the scenario (i.e., the row in ClimateChangeScenarios.csv) for which to make plots
76  selected_scenario = 1
77
78  #--- 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
```

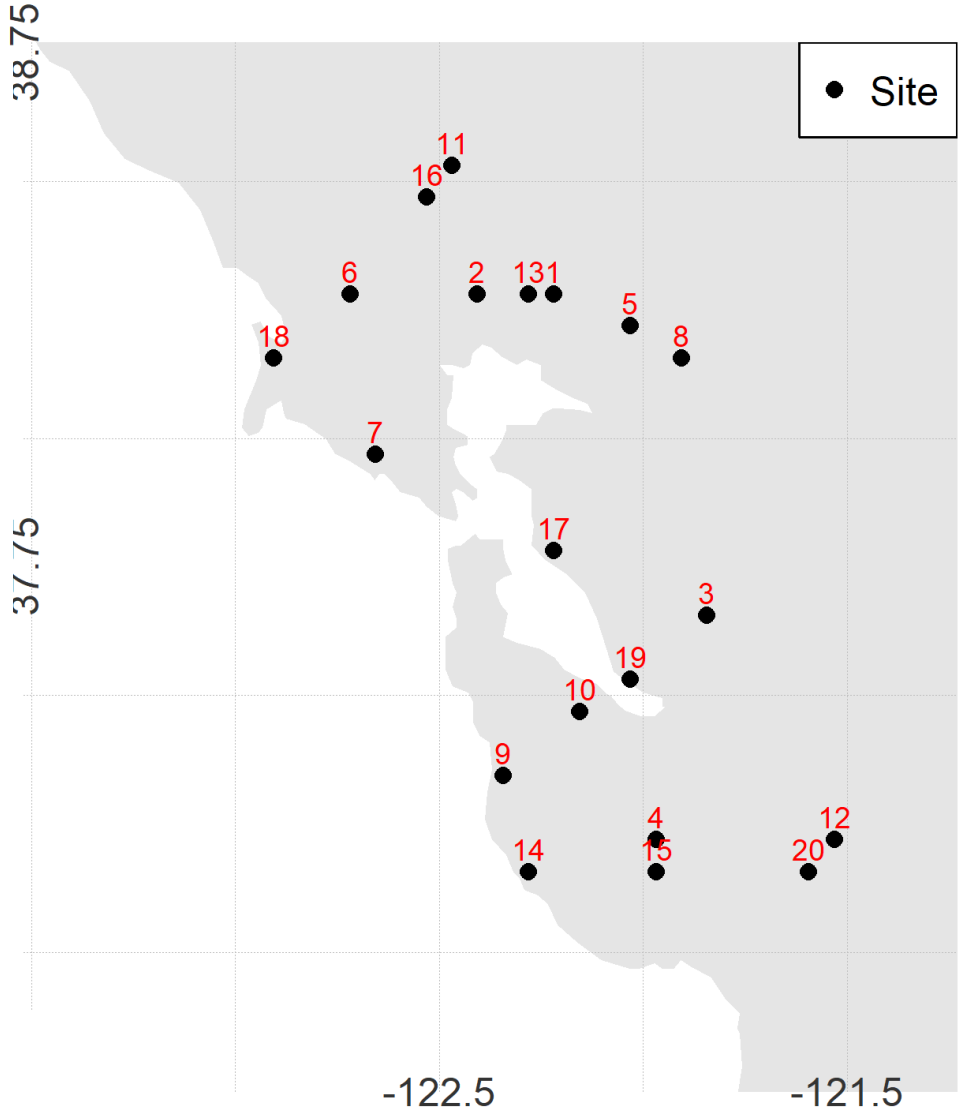


- List of 6 figures for simulation vs. obs.
- Designed to output simulation for a single climate change scenario at a time ("selected_scenario")
  - Will discuss further in next presentation

4) Evaluate Model Performance

Cornell University



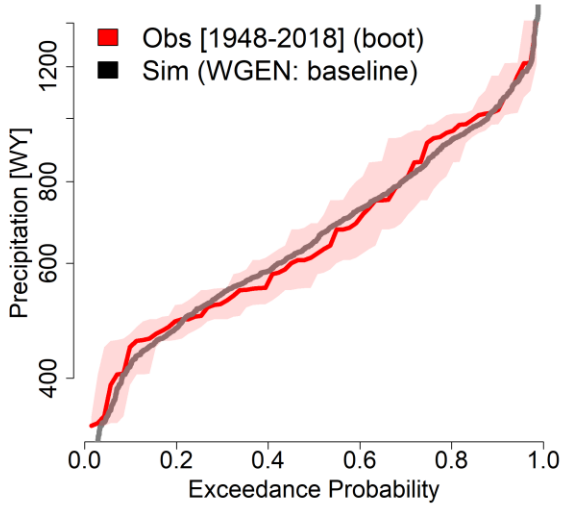


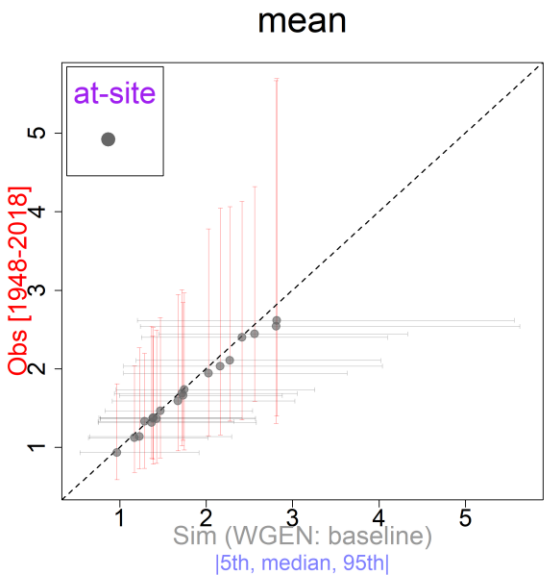
[34]

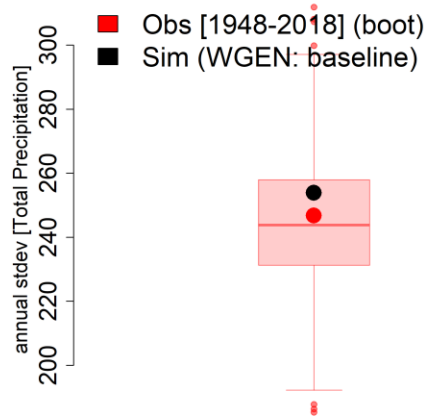
4) Evaluate Model Performance

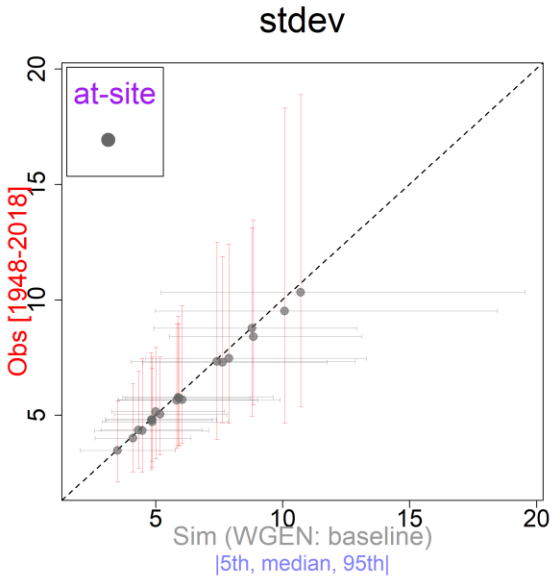
`./Figures/`

Precipitation







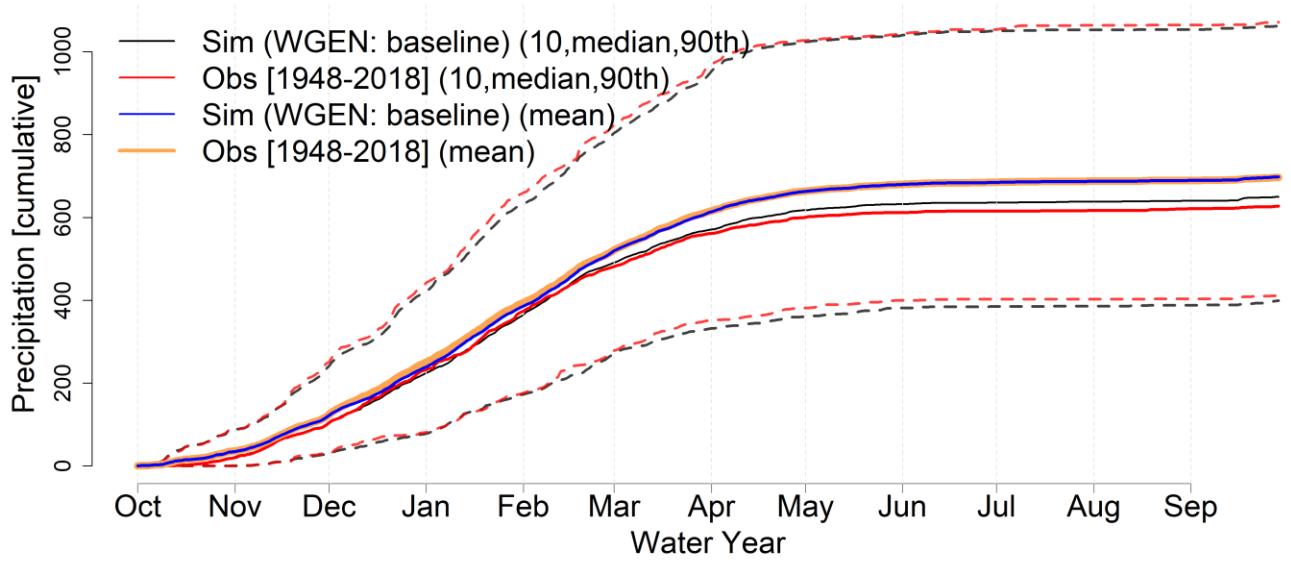


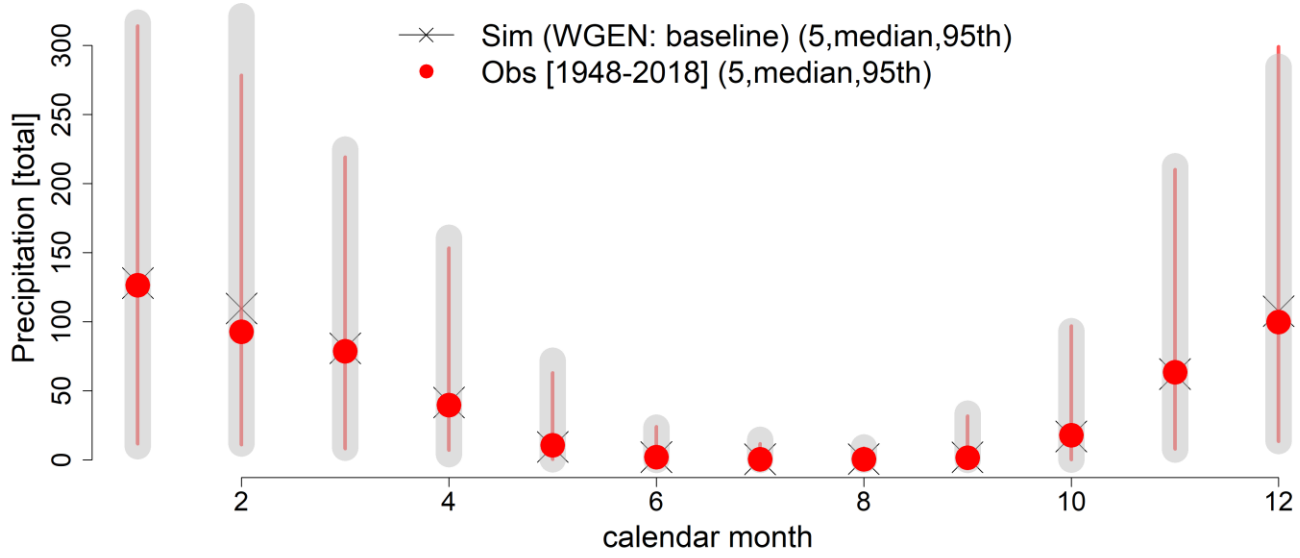
4) Evaluate Model Performance

Cornell University

`./Figures/`

Precipitation



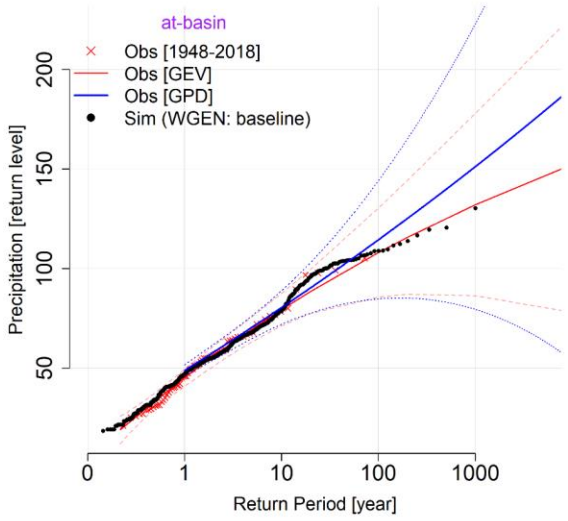


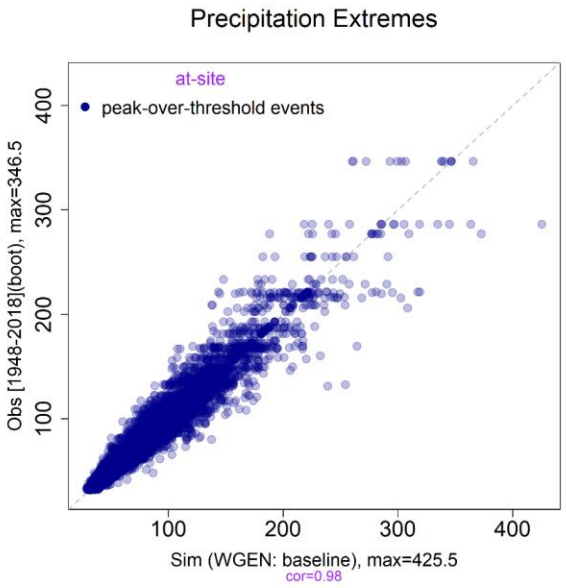
4) Evaluate Model Performance

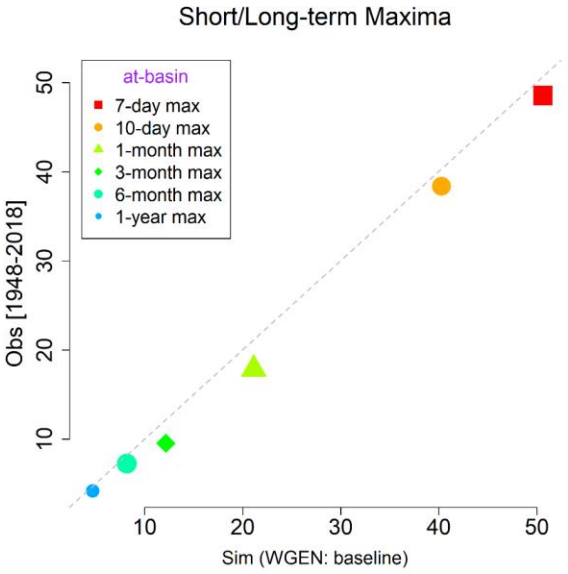
Cornell University

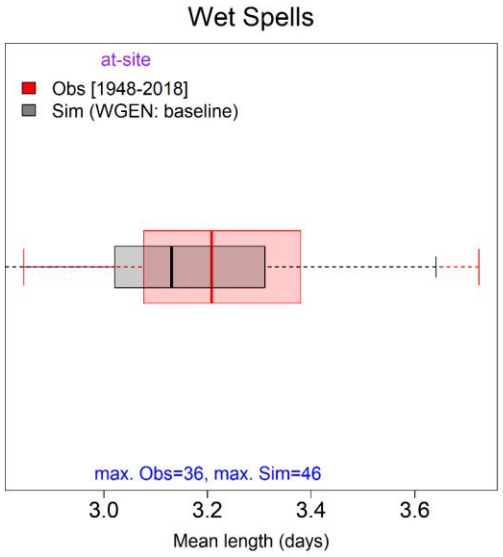
`./Figures/`

Precipitation







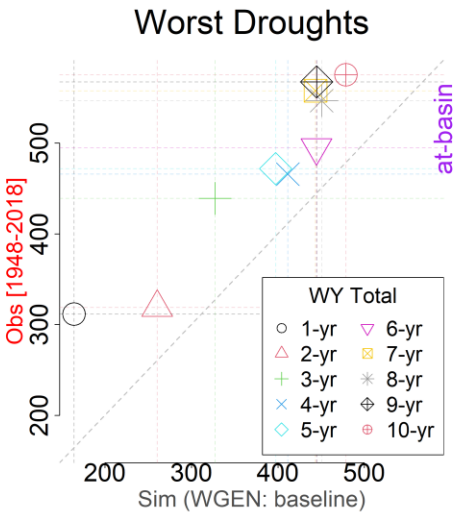


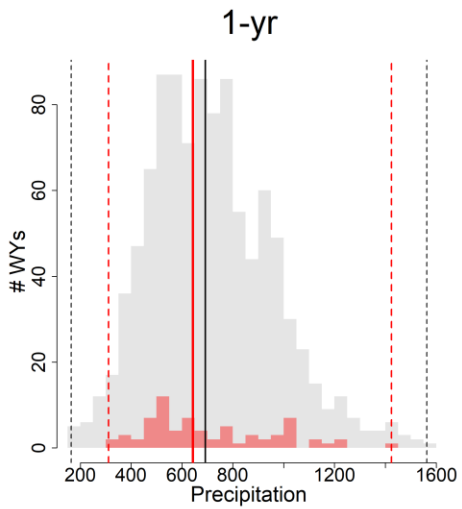
4) Evaluate Model Performance

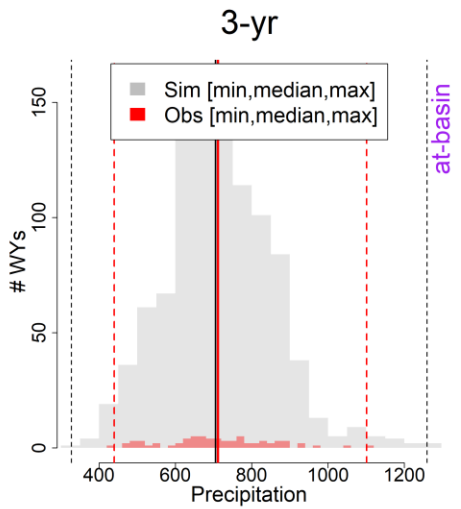
Cornell University

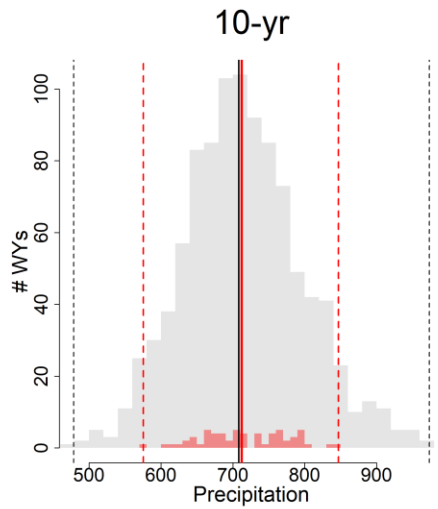
`./Figures/`

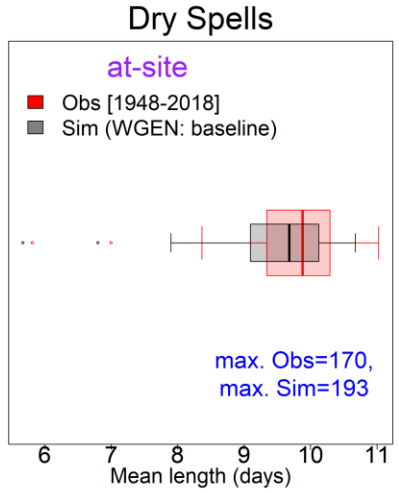
Precipitation

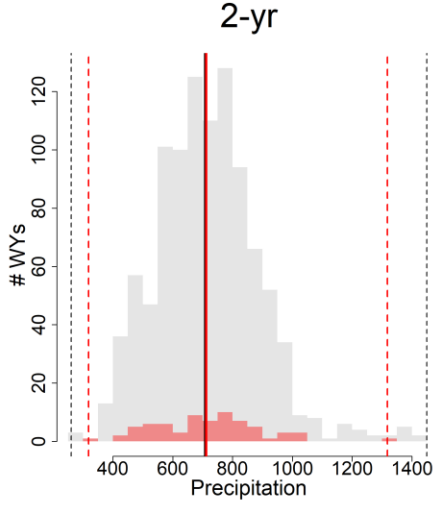


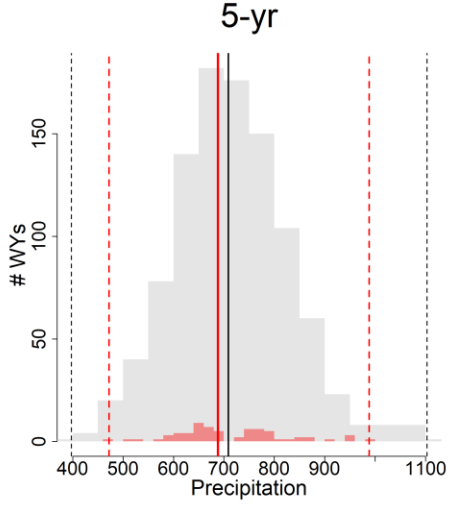


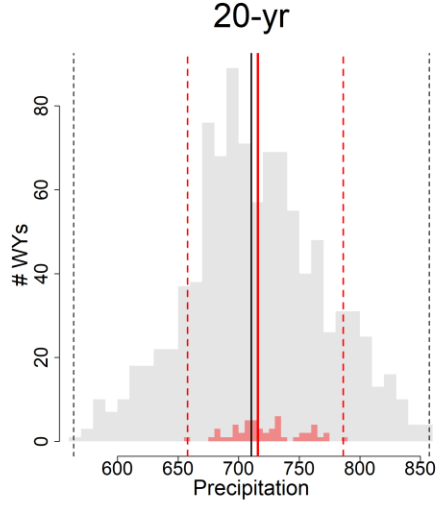










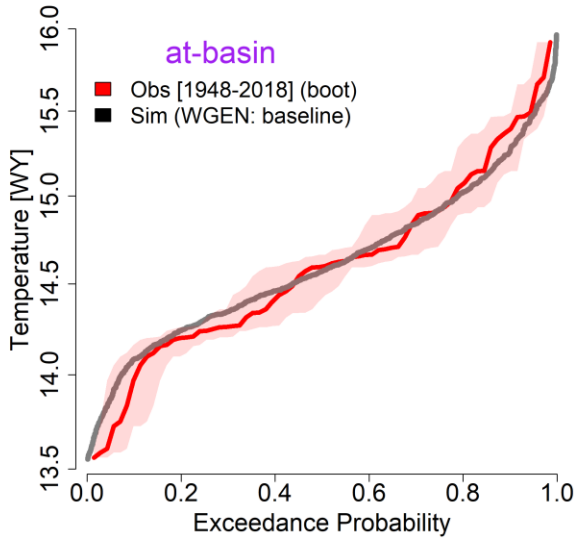


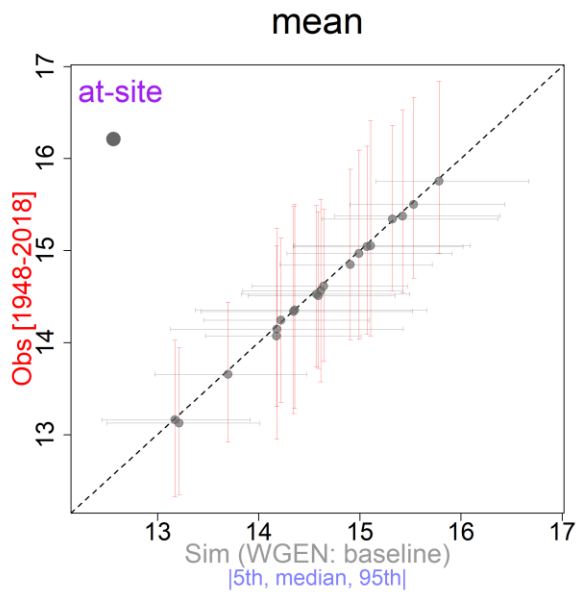
4) Evaluate Model Performance

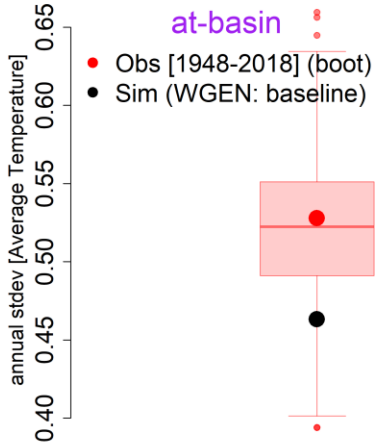
Cornell University

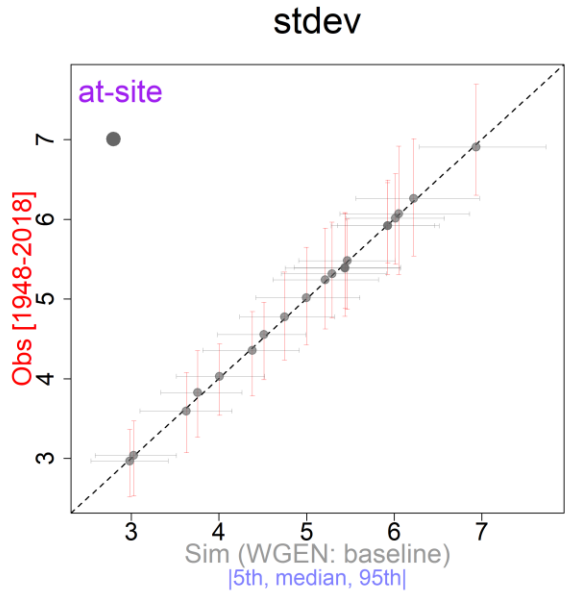
`./Figures/`

Temperature (mean)







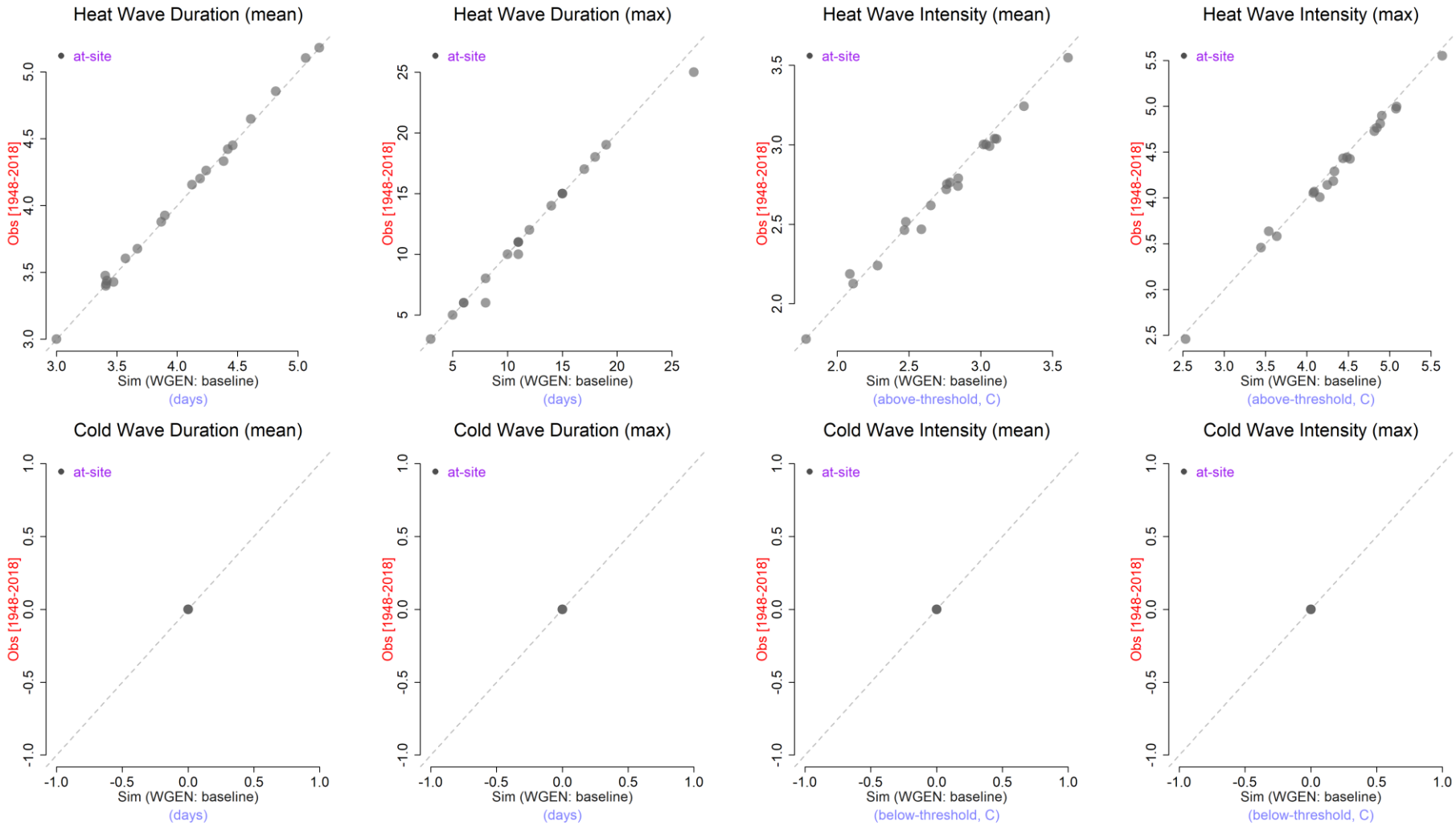


4) Evaluate Model Performance

Cornell University

`./Figures/`

Temperature (max, min)



5) Generating Output Files

5) Generating Output Files

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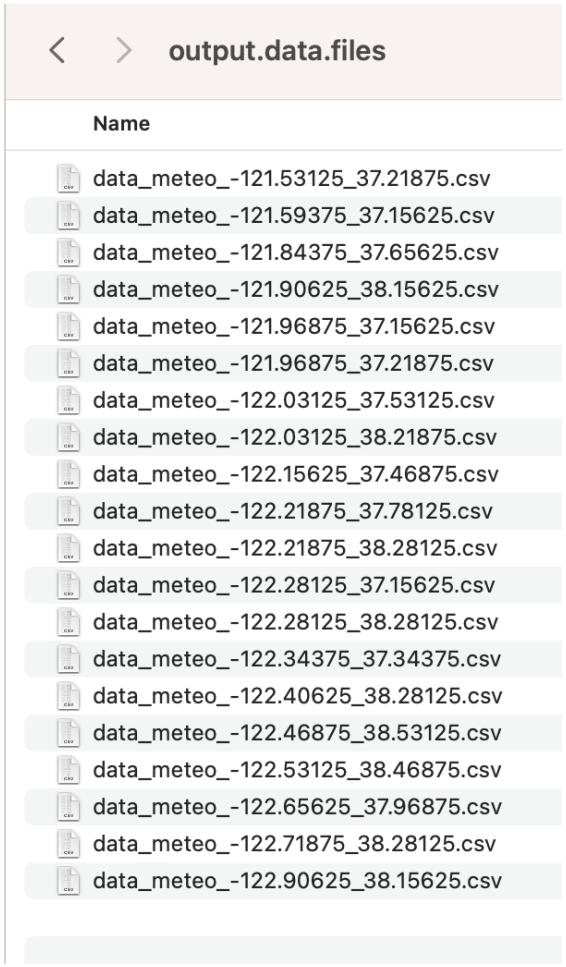
`./Programs/run.stochastic.weather.generator.R`

```
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
```

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

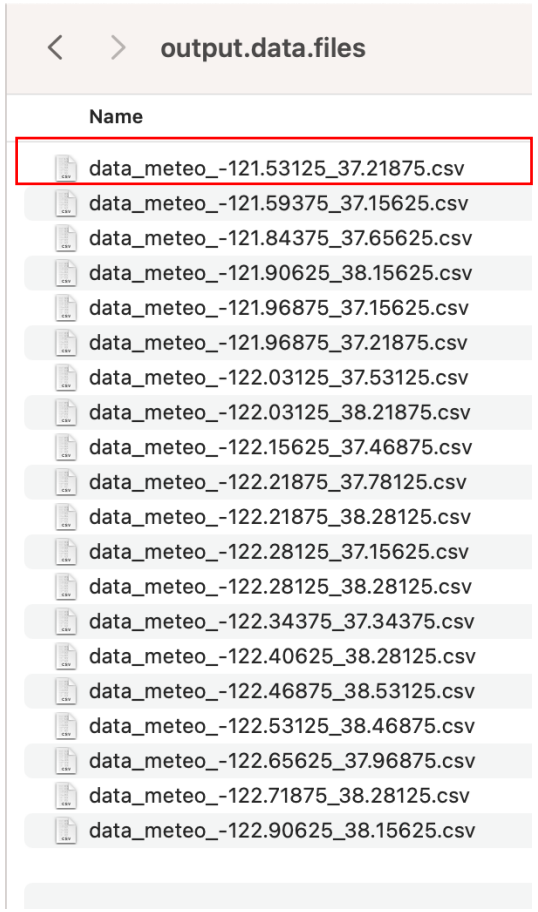


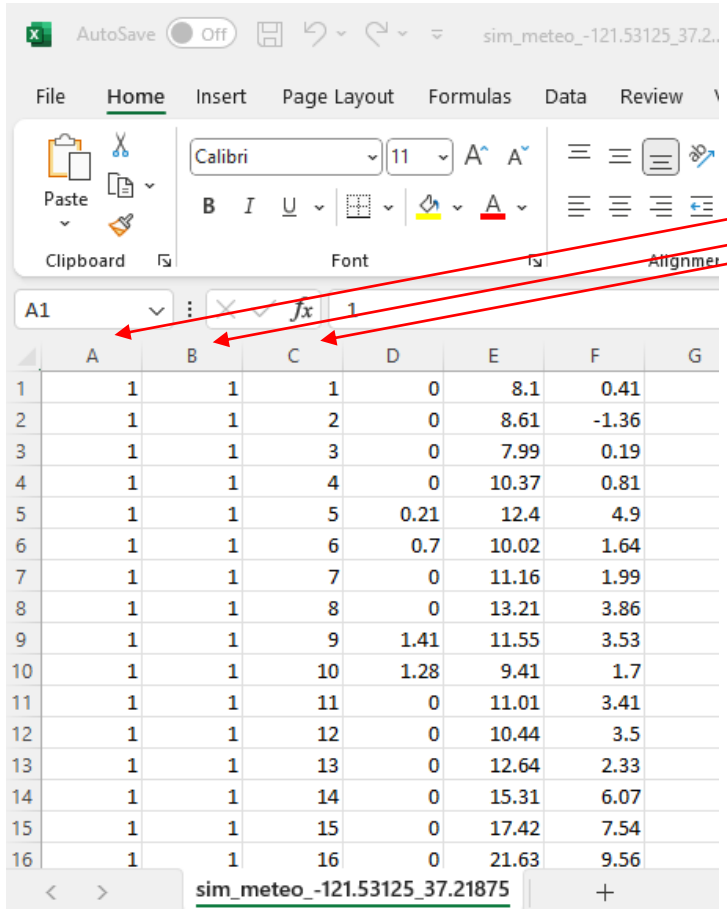
- File format: *.csv
- Leap years are maintained
- Designed to output simulation for a single climate change scenario at a time (“selected_scenario”)
  - Will discuss further in next presentation

5) Generating Output Files

Cornell University

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





	A	B	C	D	E	F
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

YYYY MM DD (synthetic)

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

	A	B	C	D	E	F
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