Training session on Regional Climate Model Evaluation System (RCMES)

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June 27, 2018

http://rcmes.jpl.nasa.gov

http://climate.apache.org

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Acknowledgement

- My special thanks of gratitude to the workshop organizers.
- Regional Climate Model Evaluation System (RCMES) team

  Duane Waliser (PI), Huikyo Lee (co-I), Alexander Goodman, Peter Gibson, Elias Massoud, Brian Wilson, Paul Loikith[2], and Antonio Monge[3]

  [1]JPL/Caltech, [2]California State U. LA, [3]Portland State U.
- **Virtual Information-Fabric Infrastructure (VIFI)** team led by Prof. William Tolone at U. of North Carolina, Charlotte
- Parallelized BCSD codes from Dr. TJ Vandal
- NASA Earth eXchange (NEX) team at NASA Ames center

RCMES Training Outline (08:45-10:45)

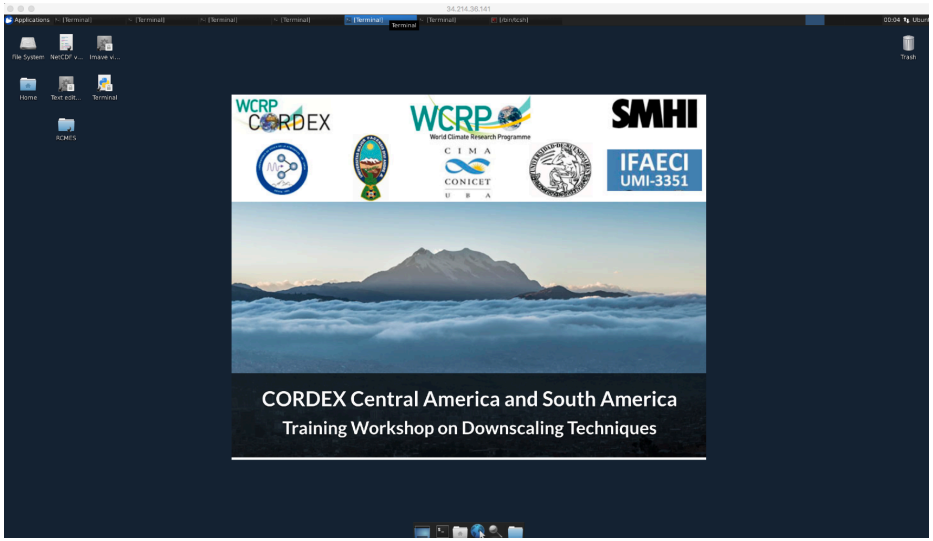
Time	Agenda Item	Process/presentations/materials
08:45-09:00	Welcome and connect to Amazon Elastic Compute Cloud (EC2)	• Check the IP address of the assigned server • Connect to the server using Microsoft Remote Desktop (or terminal software)
09:00-09:20	Activity #1 : Correct biases in CORDEX RCM simulations	• Quantile-based bias correction of CORDEX CAM/SAM simulations using satellite-based precipitation observation data • Presentation: Systematic evaluation of CORDEX RCMs using RCMES
09:20-09:50	Activity #2 : Pointwise Statistical downscaling using RCMES	• CMIP5 temperature and precipitation datasets for present and future climate • Compare the IPCC climate change scenarios • (RCP 4.5 vs. RCP 8.5)
09:50-10:20	Activity #3 : Download and visualize the NEX-GDDP data	• NASA Earth Exchange Globally Daily Downscaled Projections (NEX-GDDP) in Amazon Simple Storage Service (S3) • Presentation: Toward the future of Big climate data analysis in the cloud
10:20-10:45	Activity #4 : Analyze the bias corrected RCM output	• Presentation: What powers RCMES and how to get involved with development

Two different ways to connect to the virtual Linux machine on Amazon Web Service

- SSH connection using your terminal application
- Prerequisite software
  - terminal: putty, xshell, xterm)
  - X Server: Xming, XQuartz)
  - NetCDF/HDF viewer: Panoply
  - (Optional) sftp client: xftp, FileZilla

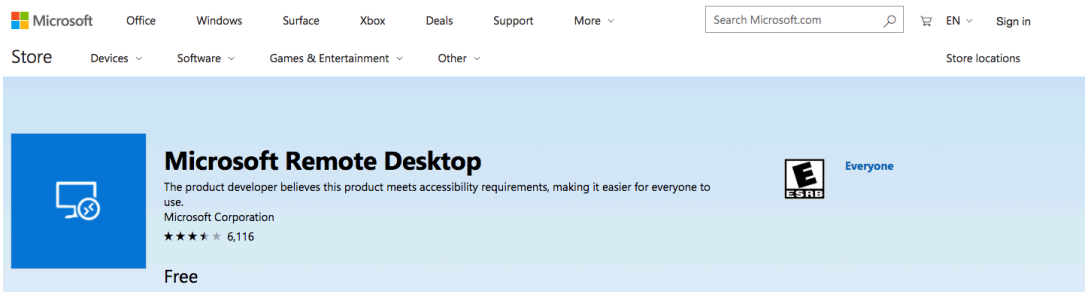
- ssh -Y ubuntu@xx.xxx.xx.xxx (your machine's IP address)
- password: cordex

- Remote desktop



Prerequisite software to run remote desktop

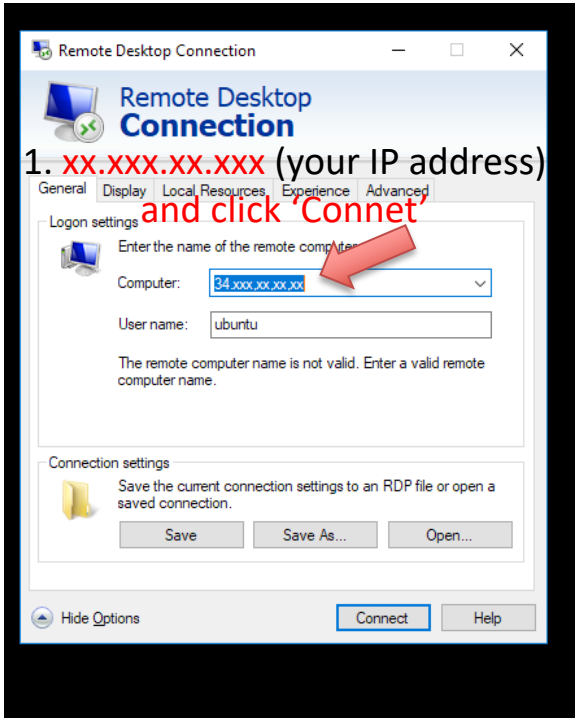
- ~~Linux based system~~
- Windows laptops: Microsoft Remote Desktop



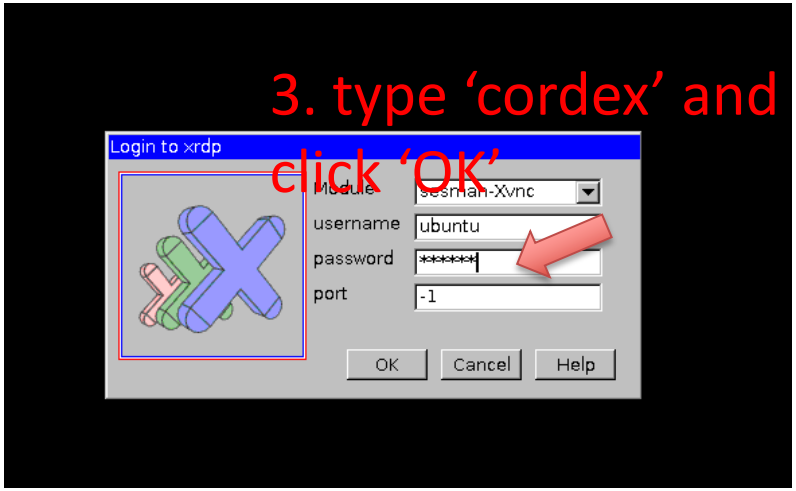
- Macbooks: Microsoft Remote Desktop **10**

(do not use version 8)

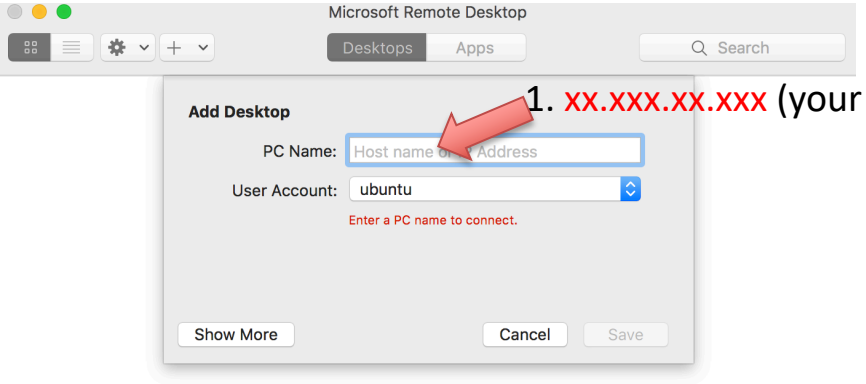
Set up your remote desktop (Windows)



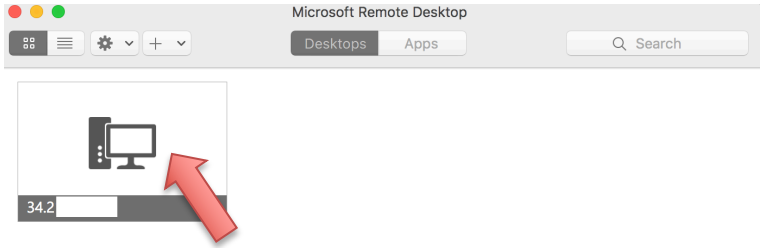
2. Click 'OK'



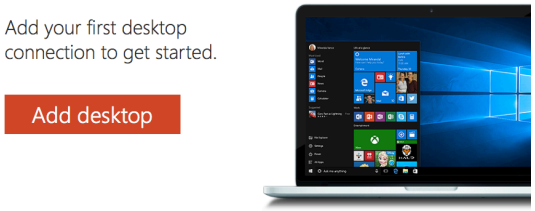
Set up your remote desktop (Mac)



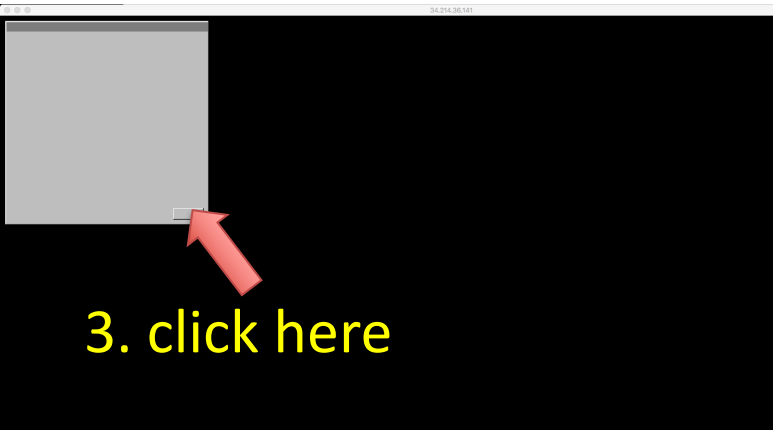
1. xx.xxx.xx.xxx (your IP address)

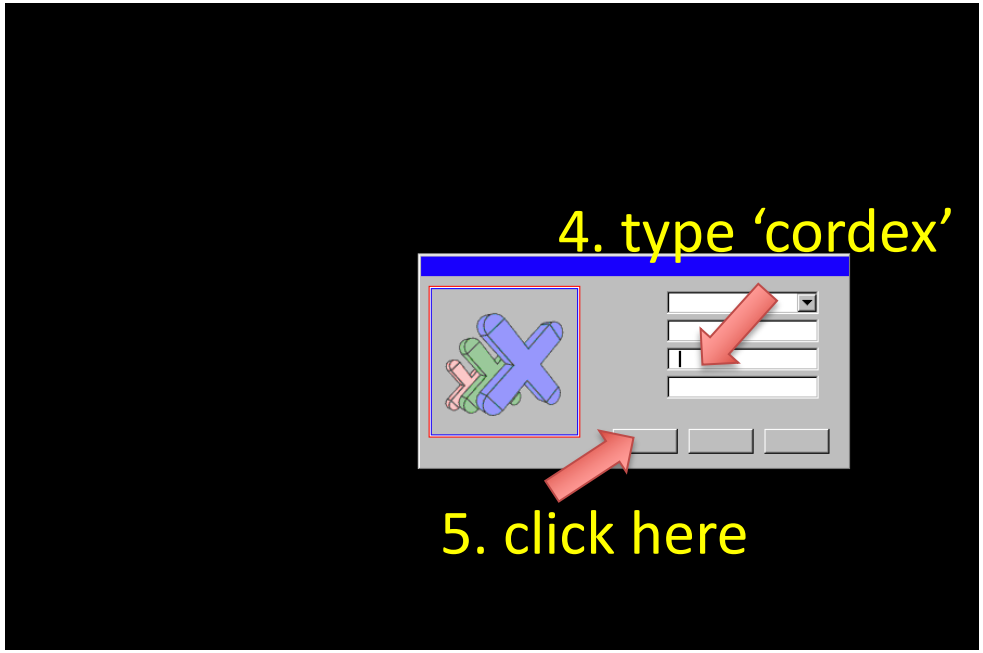


2. Double click!!!



Bugs in the Mac version





- **Activity #1**

: Correct biases in CORDEX RCM simulations

- Activity #2

: Pointwise Statistical downscaling using RCMES

- Activity #3

: Download and visualize the NEX-GDDP data

- Activity #4

: Analyze the bias corrected RCM output

Running the bias correction script

(courtesy of Dr. TJ Vandal at NASA Ames, https://github.com/tjvandal/bcsd-python)

1. Open Terminal and type `cd RCMES`

(Two options: please choose one of them)

2-1. To correct biases in a RegCM4 simulation for the CORDEX Central America,

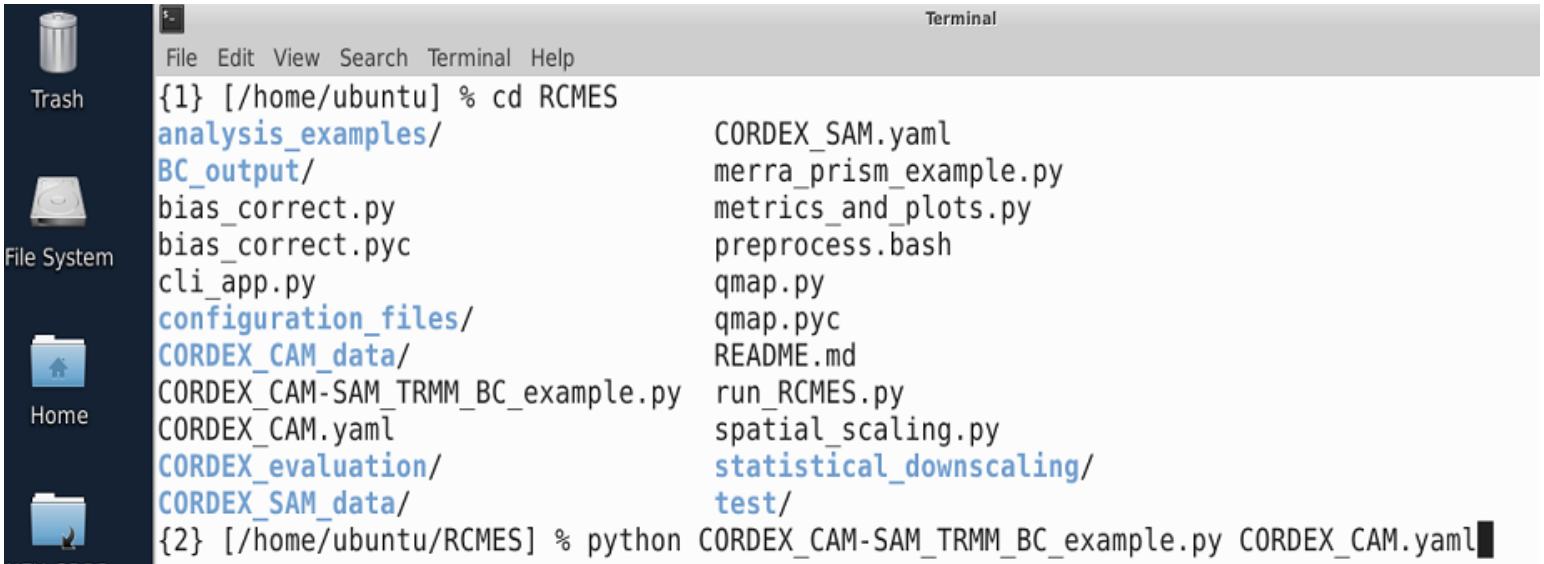
```
python CORDEX_CAM-SAM_TRMM_BC_example.py CORDEX_CAM.yaml
```

Python script — Configuration file

2-2. To correct biases in a RCA4 simulation for the CORDEX South America,

```
python CORDEX_CAM-SAM_TRMM_BC_example.py CORDEX_SAM.yaml
```

(Running 2-1 or 2-2 uses 15 CPUs and takes about 45-60 minutes.)



Bias Correction of CORDEX simulations

- The two CORDEX RCM simulations have high spatial resolution (~44 km) relative to CMIP GCMs.

- ~~BCSD~~ => BC : spatial disaggregation (SD) may not be necessary thanks to the high resolution of CORDEX simulations.

Quantile mapping to correct simulated precipitation using TRMM observations (1)

- Inside the configuration file (CORDEX_CAM.yaml)

fobserved: TRMM_regridded_RegCM4-3_CAM-44.nc

observed_varname: TRMM_daily_pr

fmodeled_present: pr_CAM-44_MPI-M-MPI-ESM-MR_historical_r1i1p1_ICTP-RegCM4-3_v4_day_19980101-20131231.nc

fmodeled_future: pr_CAM-44_MPI-M-MPI-ESM-MR_rcp85_r1i1p1_ICTP-RegCM4-3_v4_day_20830101-20991231.nc

modeled_varname: pr

(Observation)
Read TRMM_daily_pr from TRMM_regridded_RegCM4-3_CAM-44.nc

(Simulation for the present climate)
Read pr from pr_CAM-44_***_19980101-20131231.nc

(Simulation for the future climate)
Read pr from pr_CAM-44_***_20830101-20991231.nc

Quantile mapping to correct simulated precipitation using TRMM observations (2)

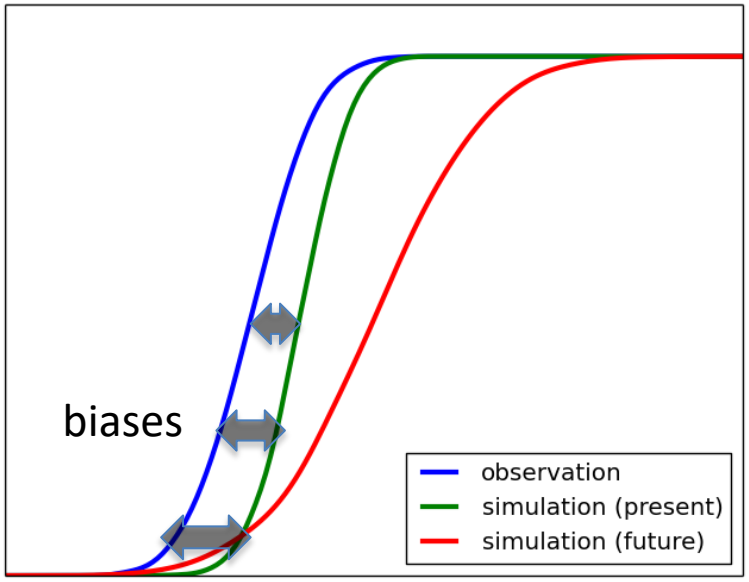
- At each RCM grid point, biases in simulated precipitation are is corrected for each quantile (0.5-99.5%) by comparing two cumulative distributions from TRMM and the RCM (±15 days).

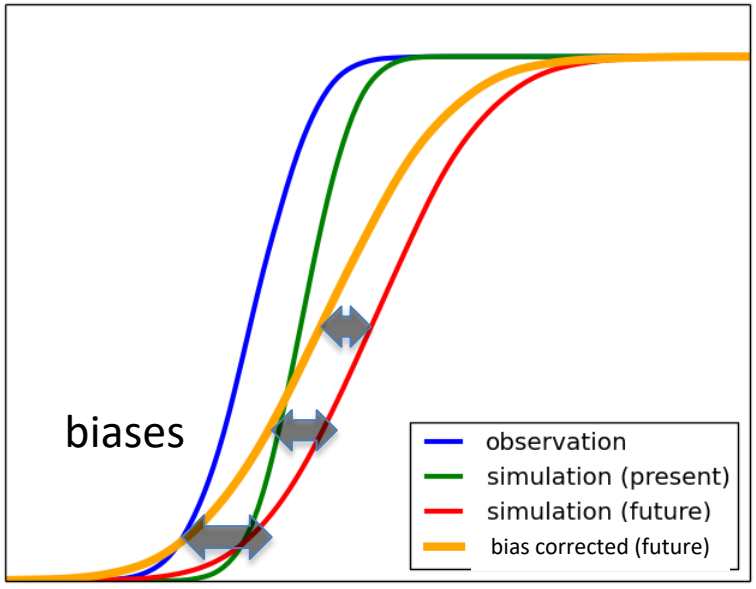
(Observation)
TRMM_daily_pr for 19980101-20131231

(Simulation for the future climate)
pr_CAM-44_***_20830101-20991231.nc

(Simulation for the present climate)
pr_CAM-44_***_19980101-20131231.nc

(Bias corrected future simulation)
BC_pr_CAM-44_***_20830101-20991231.nc





- Activity #1

: Correct biases in CORDEX RCM simulations

- **Activity #2**

: Pointwise Statistical downscaling using RCMES

- Activity #3

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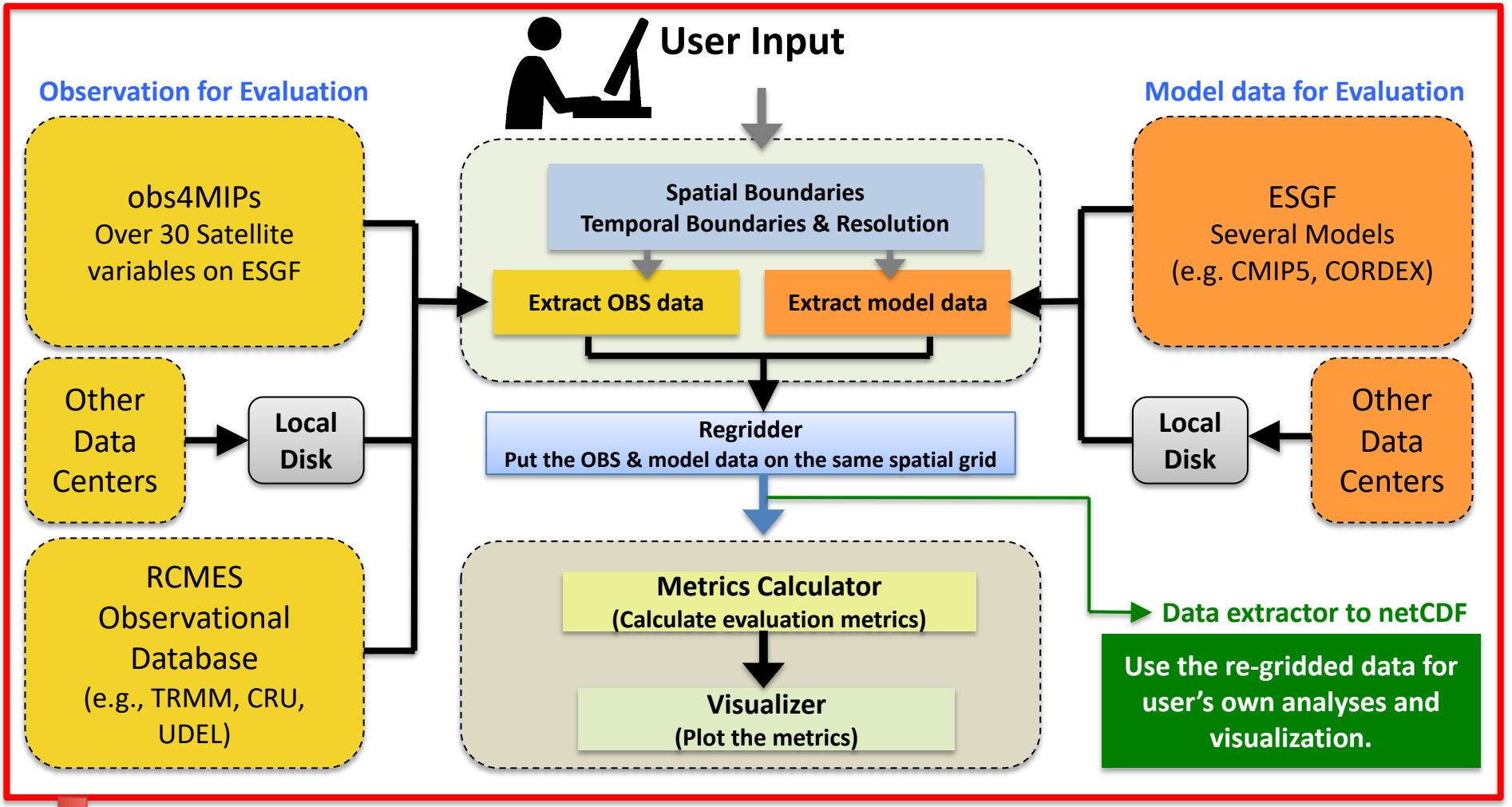
: Analyze the bias corrected RCM output

The Regional Climate Model Evaluation System (RCMES, https://rcmes.jpl.nasa.gov)

- Lee et al. (2018) in GMDD under review.
- Python-based open source software powered by the Apache Open Climate Workbench (OCW)
- Main components
  1) Database of observations
  2) Toolkit for facilitating systematic evaluation of CORDEX RCMs using satellite observations
  3) Statistical downscaling of coarse-resolution GCM output
  4) Stand-alone scripts for data processing and visualization based on OCW

Regional Climate Model Evaluation System

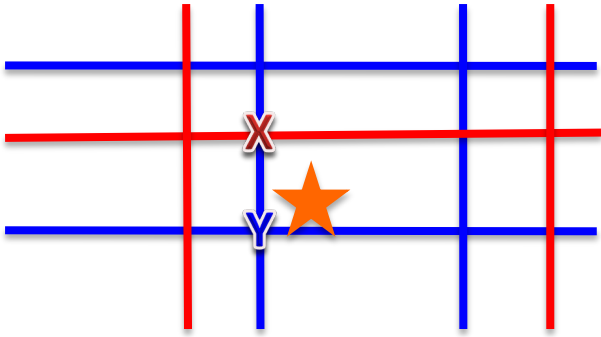
High-Level Architecture



RCMES captures the entire workflow.

Another user can reproduce the same results using the captured workflow.

Statistical downscaling using RCMES



- To statistically downscale CMIP5 variables at a specific location (star marker), RCMES uses statistical relationship between the nearest model grid point data (X) and observation grid point data (Y)

  : **simultaneous correction of both bias and collocation**

$$Y = f(X)$$

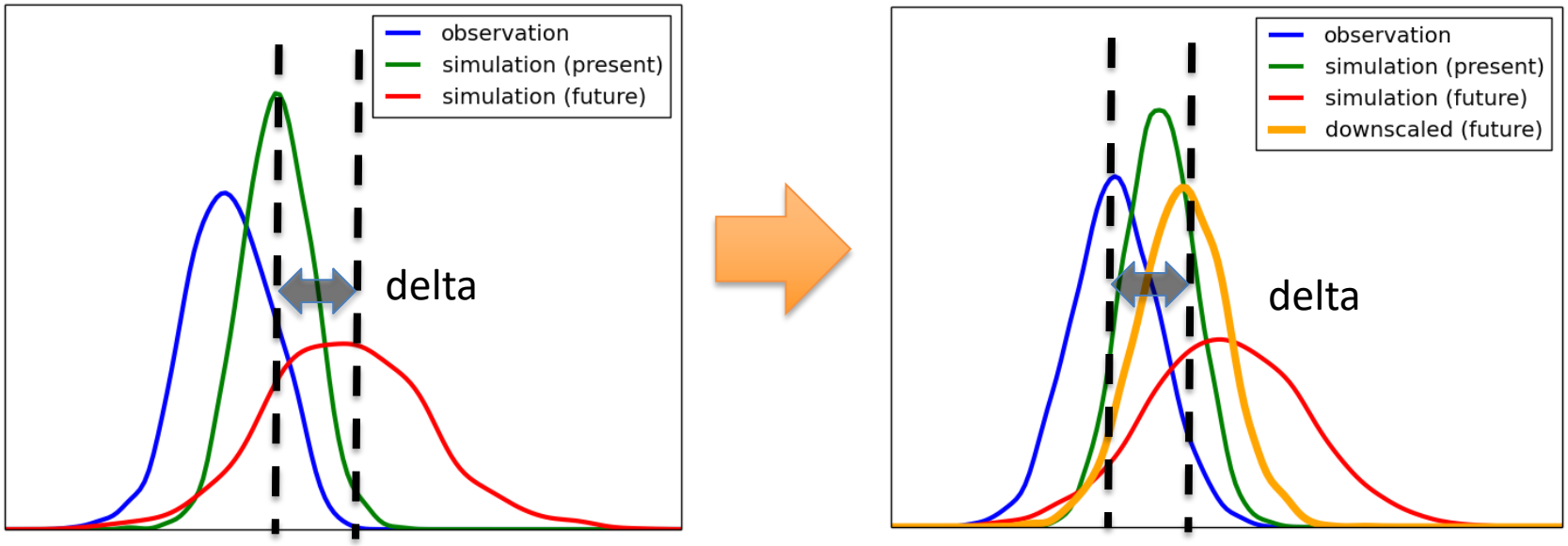
- Four different methods for model calibration (Stoner et al., 2013)
  - Delta method (addition)
  - Delta method (bias correction)
  - Quantile mapping
  - Asynchronous linear regression
- The observational datasets in RCMES database can be used to determine the observation-model relationship.

Delta method
(Delta addition)

Y_0: present observation, X_0: present simulation, X_1: future simulation

$$Y_1 = Y_0 + \bar{X}_1 - \bar{X}_0$$

- (future climate) = (present observation) + (mean difference between X_0 and X_1)

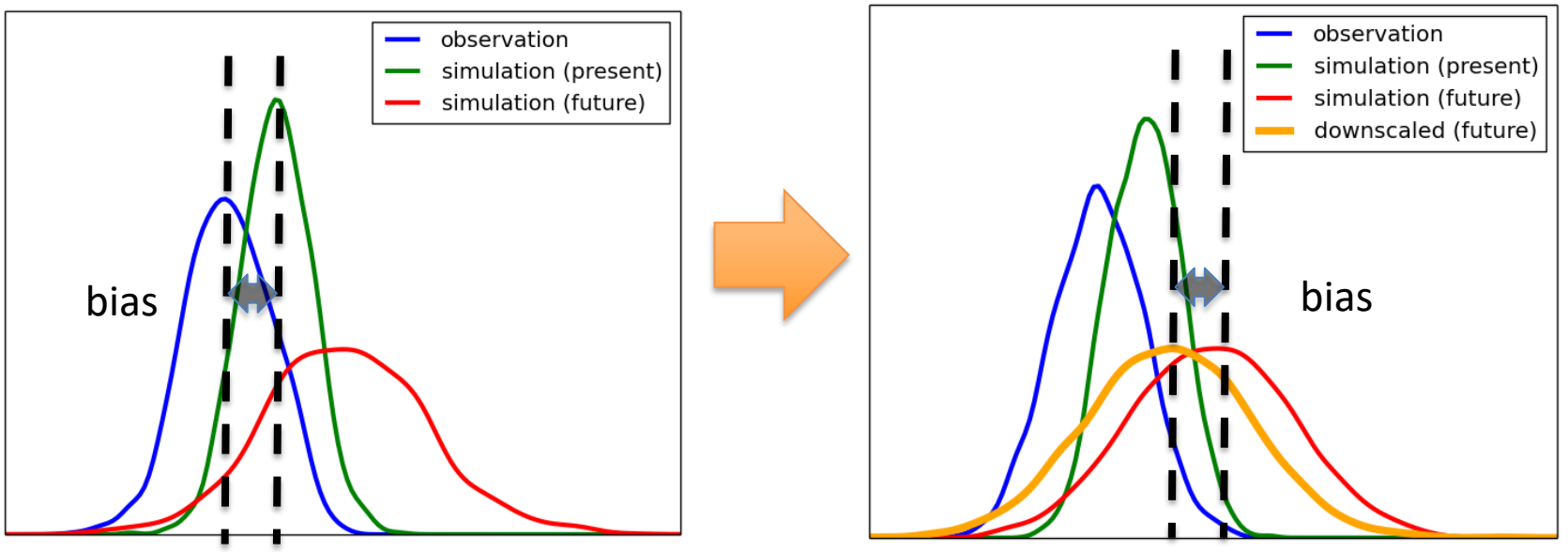


Delta method
(Bias correction)

Y_0: present observation, X_0: present simulation, X_1: future simulation

$$Y_1 = X_1 + \bar{Y_0} - \bar{X_0}$$

- (future climate) = (future simulation) + (mean bias)

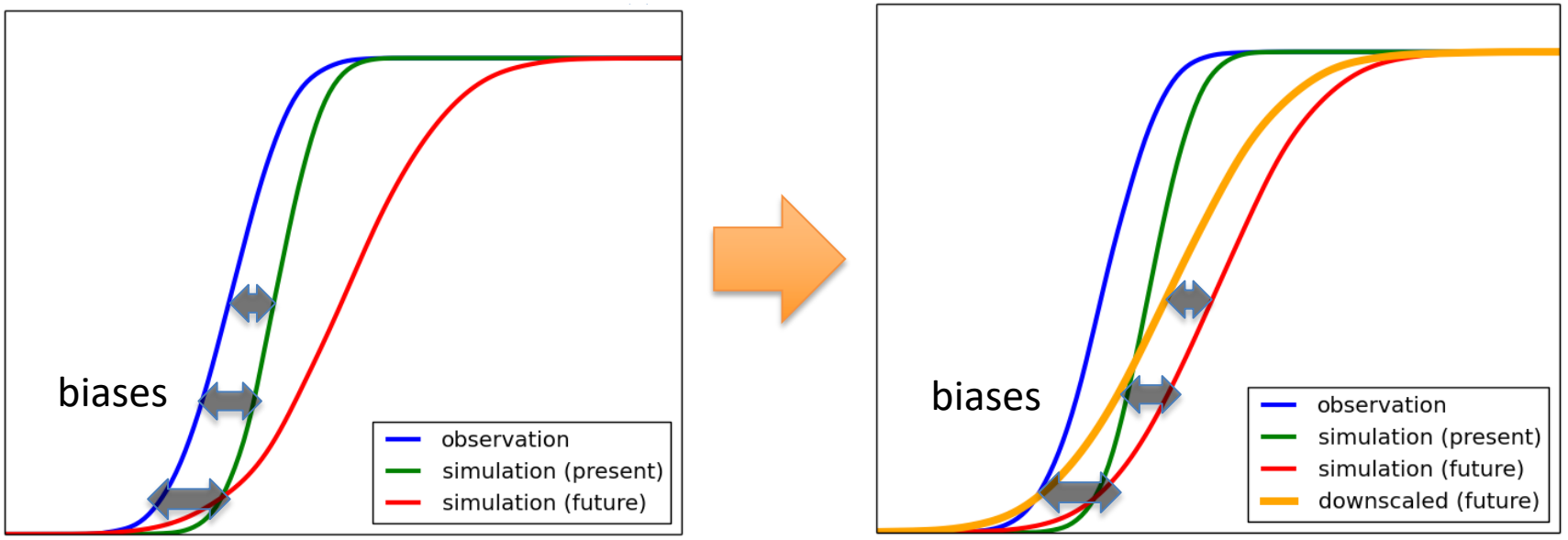


Quantile mapping

Y_0: present observation, X_0: present simulation, X_1: future simulation

$Y_1 = f(X_1)$ where f is bias correction function for each quantile ($Y_0 = f(X_0)$).

- (future climate) = (bias corrected future simulation)
- Bias is corrected for each quantile.

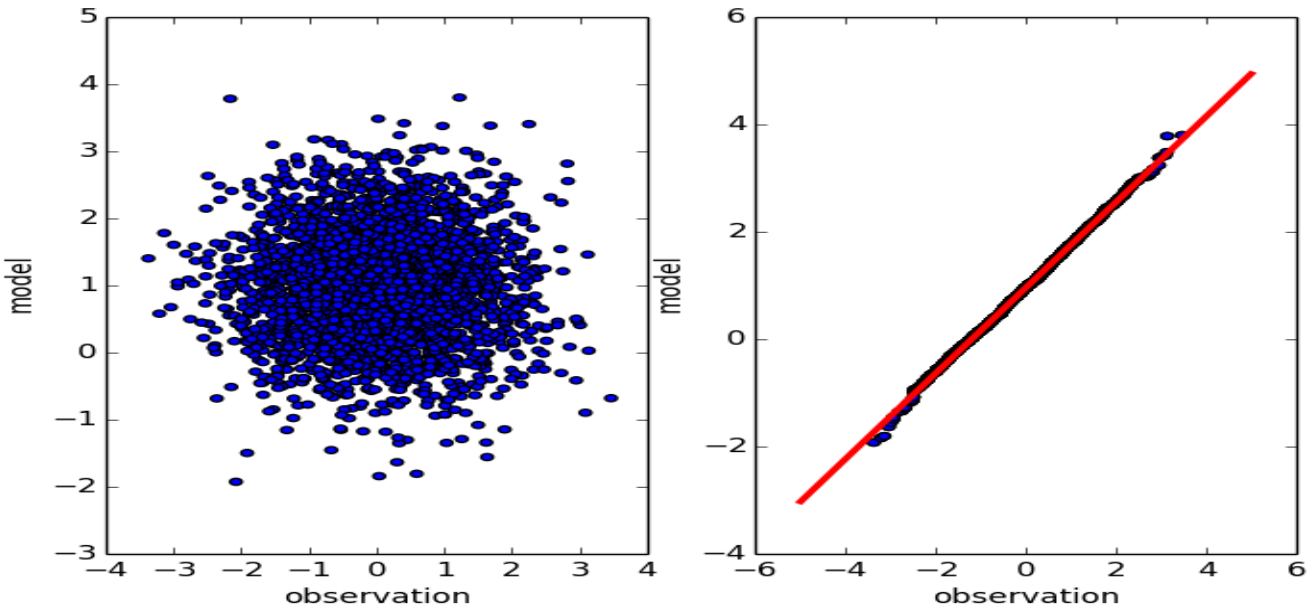


Asynchronous linear regression

Y_0: present observation, X_0: present simulation, X_1: future simulation
Y_0', X_0', X_1': sorted in ascending order

$Y_1' = a\dot{X}_1' + b$ where $Y_0' = a\dot{X}_0' + b$. a and b are the slope and intercept for the least square regression line.

- The linear relationship between observation and present simulation is determined after sorting them in ascending order.



Statistical Downscaling using RCMES

1. Open Terminal and `cd RCMES/statistical_downscaling/`
2. To run the statistical downscaling script, type

```
python run_statistical_downscaling.py MPI_tas_JJA.yaml
```

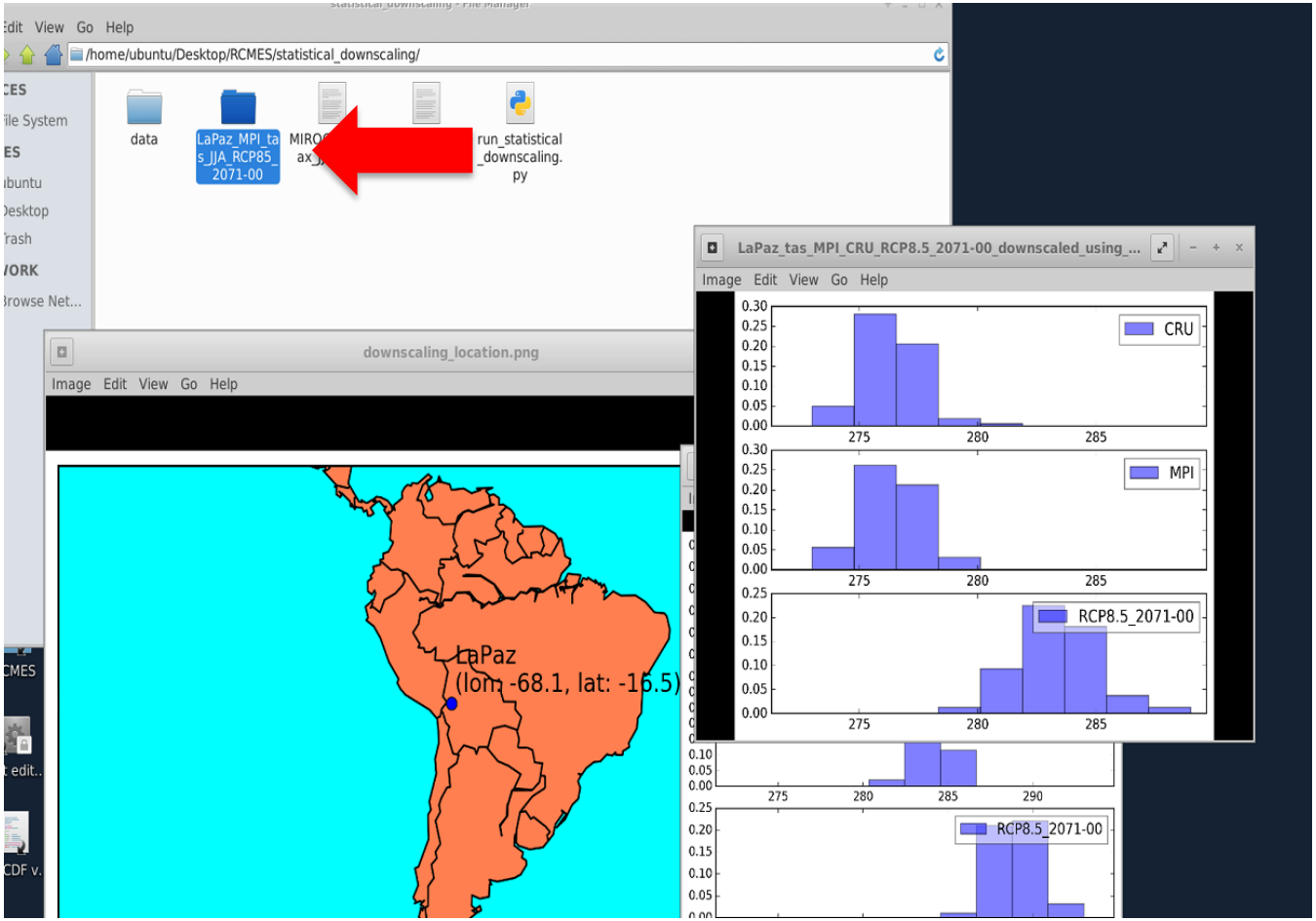
Python script

Configuration file

```
{13} [/home/ubuntu] % cd RCMES/statistical_downscaling/
data/  LaPaz_MPI_tas_JJA_RCP85_2071-00/  MIROC5_tasmax_JJA.yaml  MPI_tas_JJA.yaml  run_statistical_downscaling.py
{14} [/home/ubuntu/RCMES/statistical_downscaling] % python run_statistical_downscaling.py MPI_tas_JJA.yaml
Reading the configuration file  MPI_tas_JJA.yaml
Processing CRU  data
Loading ./data/tas_cru_monthly_1981-2010.nc into an OCW Dataset Object
CRU values shape: (times, lats, lons) - (360, 360, 720)

Loading ./data/tas_Amon_MPI_decadal1980_198101-201012.nc into an OCW Dataset Object
MPI values shape: (times, lats, lons) - (360, 96, 192)

RCP8.5_2071-00:MPI values shape: (times, lats, lons) - (360, 96, 192)

Temporal subsetting for the selected month(s)
Spatial aggregation of observational data near latitude 10.75 and longitude 106.67
Creating a statistical downscaling object
asynchronous_regression: Downscaling model output
Plotting results
Generating spreadsheet
{15} [/home/ubuntu/RCMES/statistical_downscaling] %
```

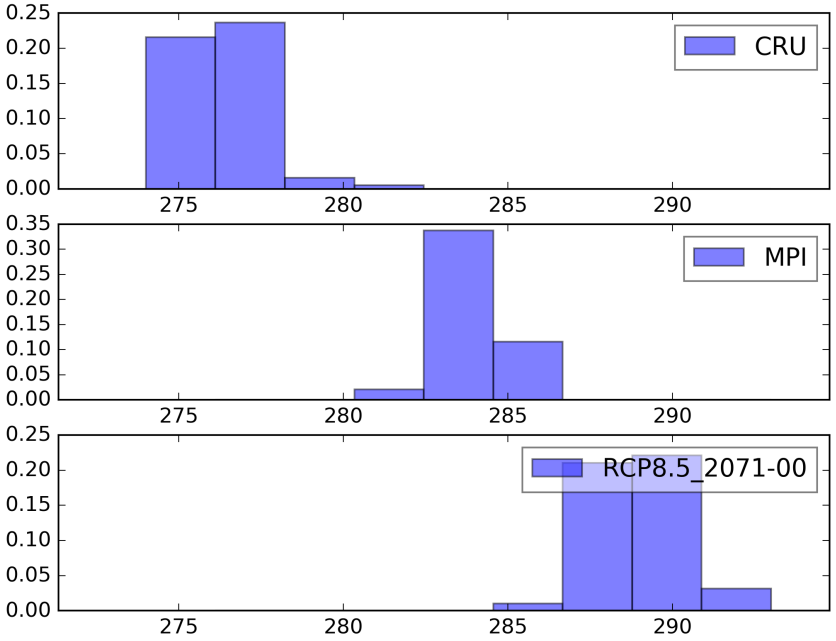
View the statistically downscaled tas results

- The results can be found in statistical_downscaling/LaPaz_MPI_tas_JJA_RCP85_2071-00 folder

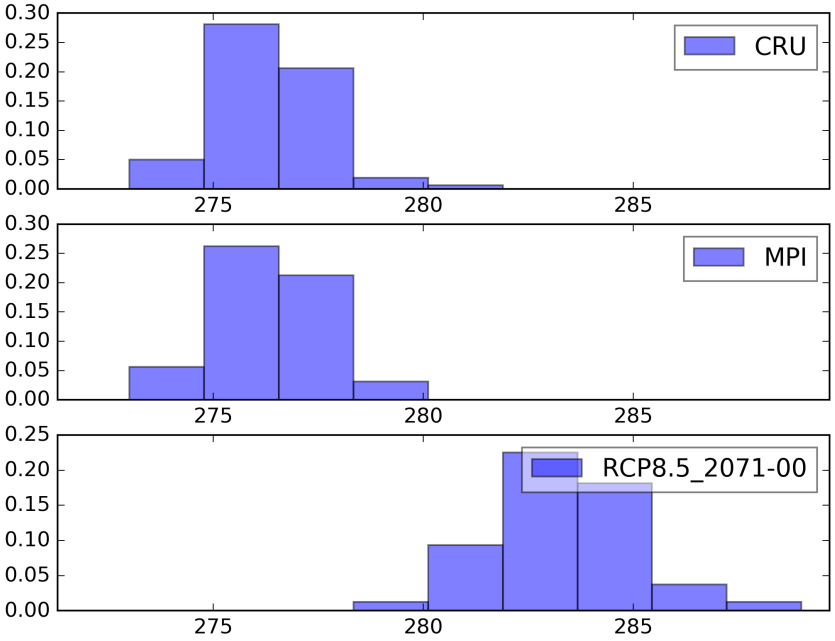


Quantile mapping of the near-surface air temperature for La Paz in JJA

Original model output



Statistically downscaled model output



Run another example: taxmax in Buenos Aires

```
python run_statistical_downscaling.py MIROC5_taxmax_JJA.yaml
```

Python script

Configuration file

Make your own example by editing the yaml file

```
case_name: BuenosAires_MIROC5_tasmax_JJA_RCP85_2071-00
downscaling_option: 3
location:
   name: BuenosAires
   grid_lat: -34.60
   grid_lon: -58.38
month_index: !!python/tuple [6,7,8]
reference:
   data_source: local
   data_name: CRUs
   path: ./data/tasmax_cru_monthly_1981-2010.nc
   variable: tasmax
model:
   data_name: MIROC5
   variable: tasmax
   present:
      path: ./data/tasmax_Amon_MIROC5_decadal1980_198101-201012.nc
   future:
      scenario_name: RCP8.5_2071-00
      path: ./data/tasmax_Amon_MIROC5_rcp85_207101-210012.nc
```

Output folder name

Search Google with the keyword ‘latitude and longitude of XXX’

Season

(Options)
1. **tas**, **tasmin**, and **tasmax**
2. **RCP 4.5** and **8.5**
3. (**2041-2070**) and (**2071-2100**)

- Activity #1

: Correct biases in CORDEX RCM simulations

- Activity #2

: Pointwise Statistical downscaling using RCMES

- **Activity #3**

: Download and visualize the NEX-GDDP data

- Activity #4

: Analyze the bias corrected RCM output

NASA's Earth Exchange (NEX, https://nex.nasa.gov)

- NEX is a platform for scientific collaboration, knowledge sharing and research for the Earth science community.
- The new project, Open NEX, is aimed at making a number of important datasets more accessible.

NASA Earth Exchange
Global Daily Downscaled Projections (NEX-GDDP)

CMIP5 historical and RCP 4.5/8.5 simulations (from 21 models, 1950-2100)

Global Meteorological Forcing Dataset (observation, 1950-2005)

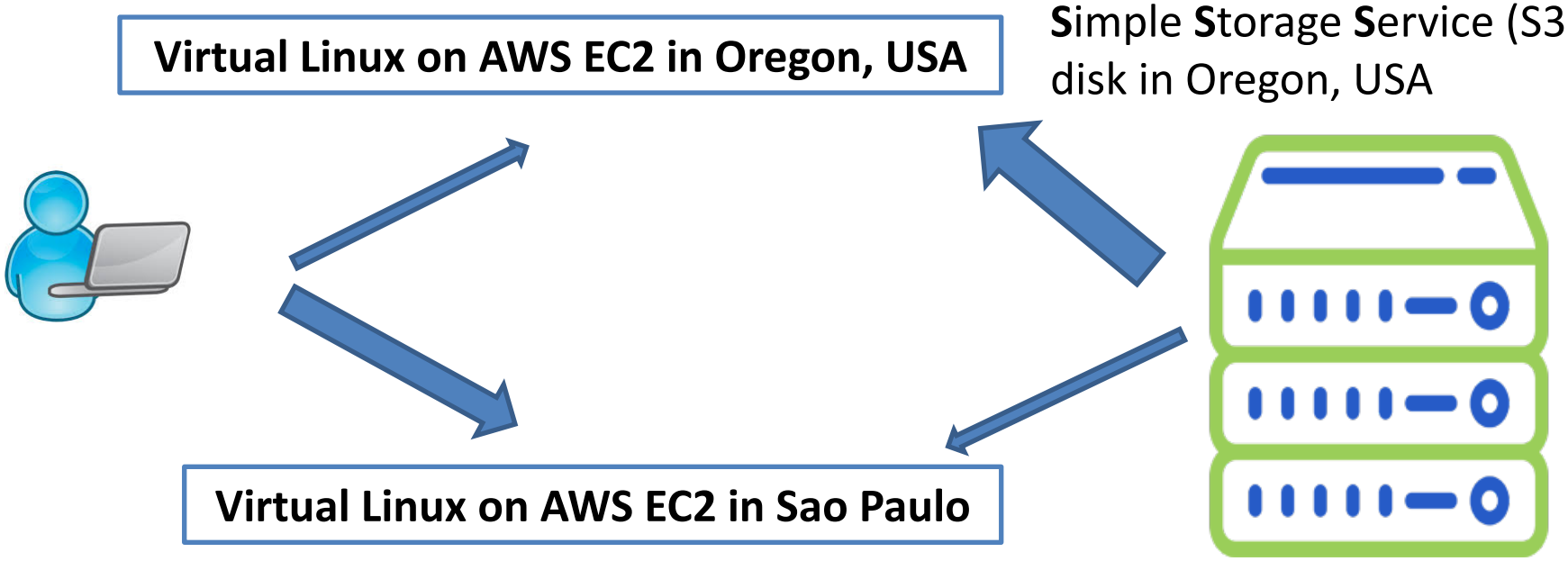
Bias-Correction Spatial Disaggregation (BCSD)

NEX-GDDP
: tasmax, tasmin, precipitation

Access to the statistically downscaled NEX-GDDP

256 Terabytes of the NEX-GDDP

Amazon **W**eb **S**ervice (AWS)
Simple **S**torage **S**ervice (S3)
disk in Oregon, USA



- The NEX S3 is mounted in your linux EC2.
- Open terminal and type `df -h`

What are inside s3://nasanex?

[/home/ubuntu] % `aws s3 ls s3://nasanex`

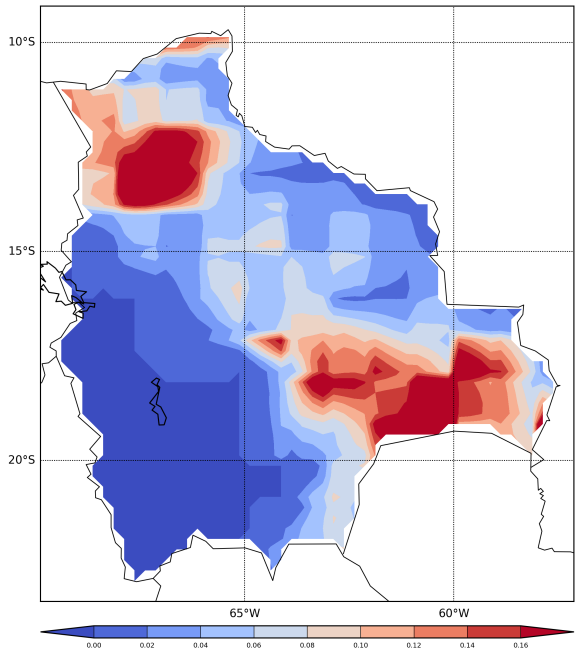
PRE AVHRR/
PRE CMIP5/
PRE LOCA/
PRE Landsat/
PRE MAIAC/
PRE MODIS/
PRE NAIP/
PRE NEX-DCP30/
PRE NEX-GDDP/

List, download and visualize NEX-GDDP

1. Open terminal and `cd NEX-GDDP`
2. `./list`
3. `./download` How fast!
4. `python plot_NEX-GDDP_example.py`

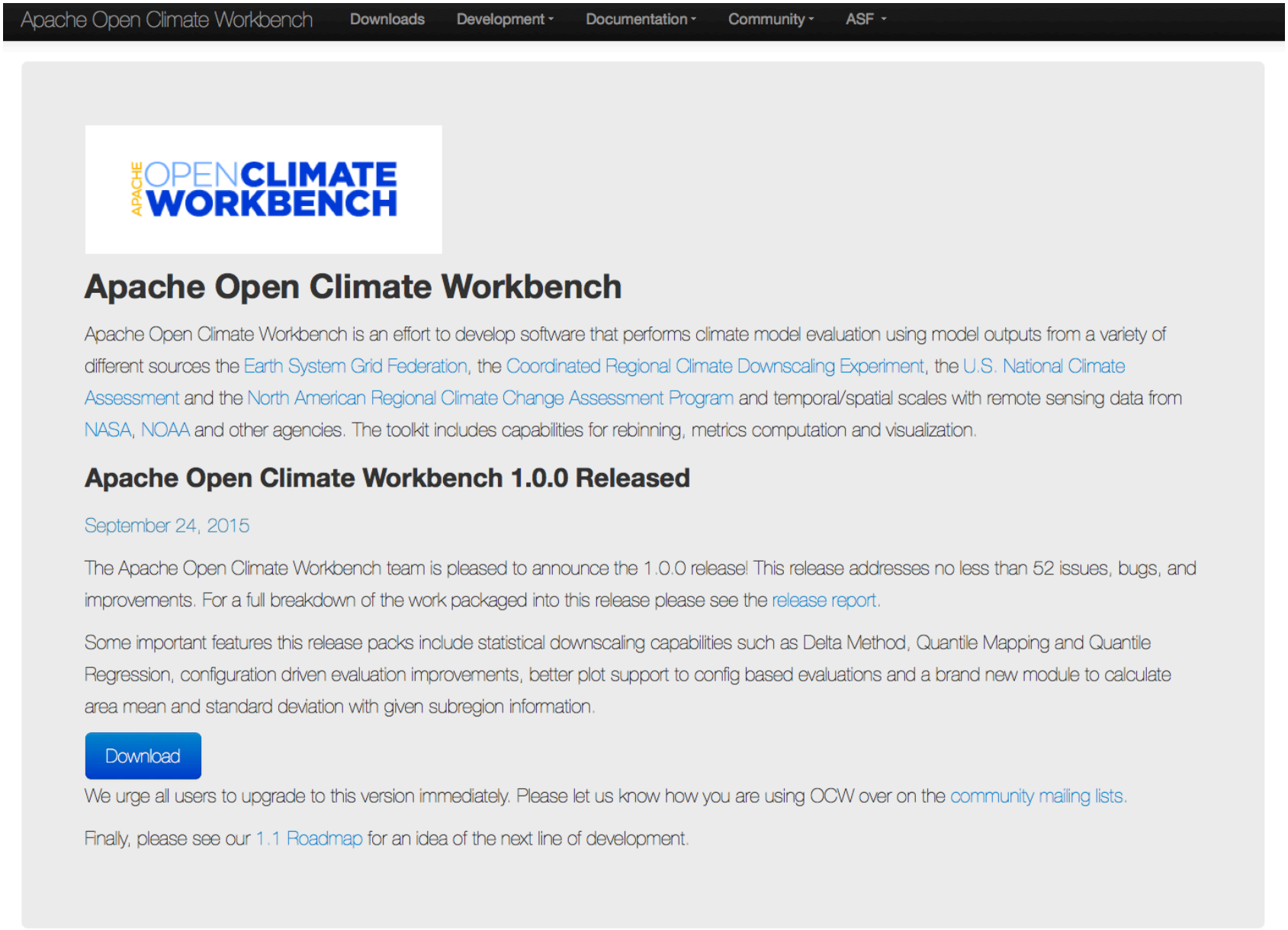
This script is an example of Open Climate Workbench, an open-source Python library that comprise RCMES.

Statistically downscaled precipitation from NorESM1-M model for June 2100

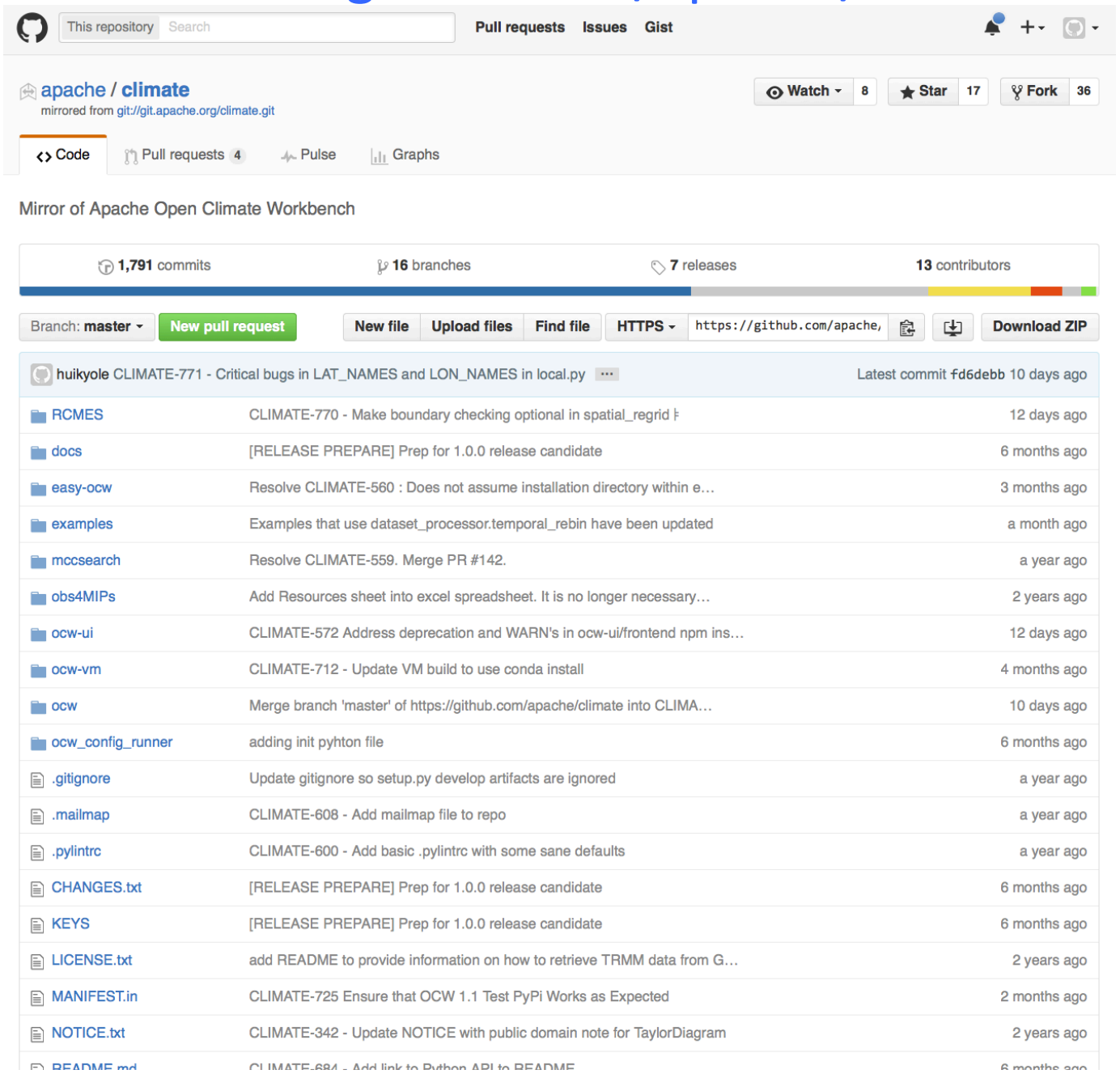


Apache Open Climate Workbench (OCW)

https://climate.apache.org/



Source at github.com/apache/climate



Running RCMES using configuration files:

a complete start-to-finish workflow to evaluate multi-scale climate models using observational data

load observation data (local, ESGF, RCMED)

dataset object1

dataset object 2

load model data (local, ESGF)

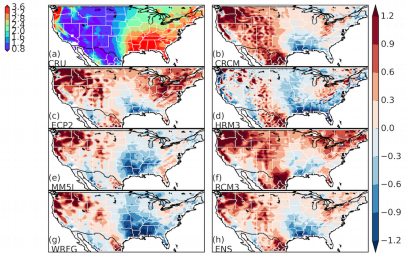
subset data (temporally & spatially)

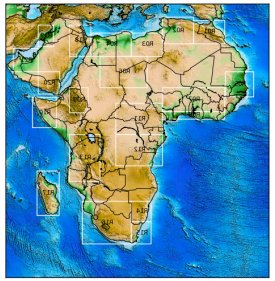
process data (filtering, averaging, regridding)

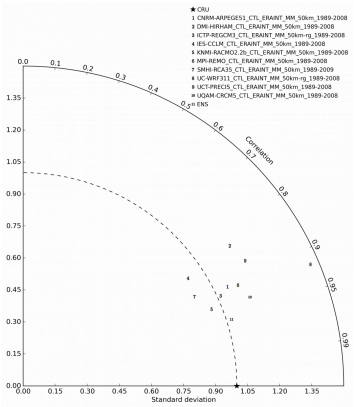
A netcdf file of the processed datasets

calculate metrics (bias, RMSE,…)

visualize results







Open Climate Workbench Libraries

data loader

dataset processor

metrics

plotter

- Activity #1

: Correct biases in CORDEX RCM simulations

- Activity #2

: Pointwise Statistical downscaling using RCMES

- Activity #3

: Download and visualize the NEX-GDDP data

- **Activity #4**

: Analyze the bias corrected RCM output from Activity #1

List, download and visualize NEX-GDDP

1. Open terminal and `cd NEX-GDDP`
2. `./list`
3. `./download` How fast!
4. `python plot_NEX-GDDP_example.py`

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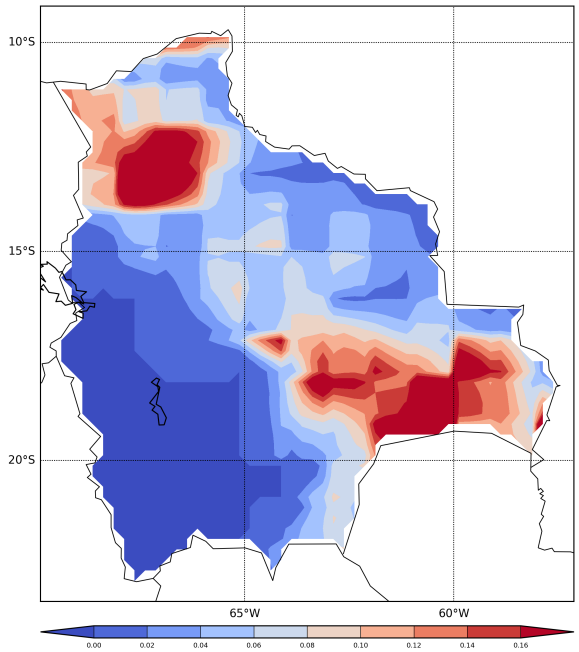
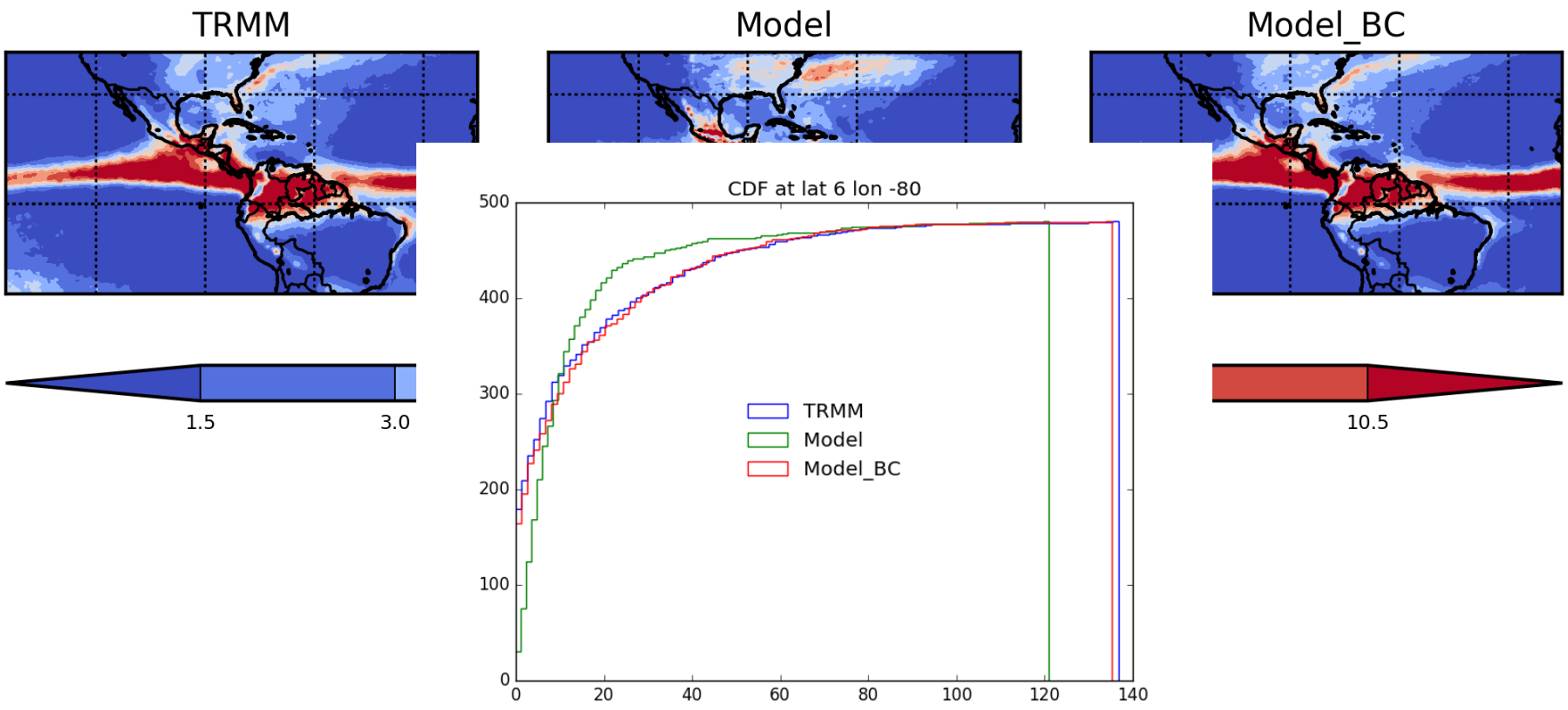
Statistically downscaled precipitation from NorESM1-M model for June 2100



Compare TRMM, original RCM, and bias corrected RCM

1. Open terminal and `cd RCMES/analysis_examples`
2. `python check_bias_correction_CAM.py`
   `python check_bias_correction_SAM.py`

OCW-based script



How does the bias-corrected precipitation look like in the future (in June, 1998-2013 vs. 2050-2065 vs, 2083-2099)?

```
python compare_present_and_future_CAM.py
```

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python compare_present_and_future_SAM.py
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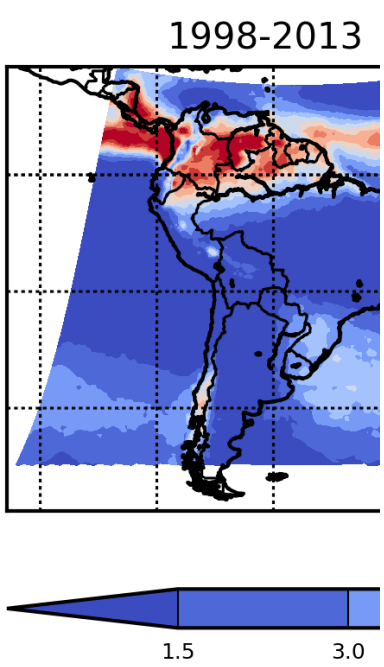
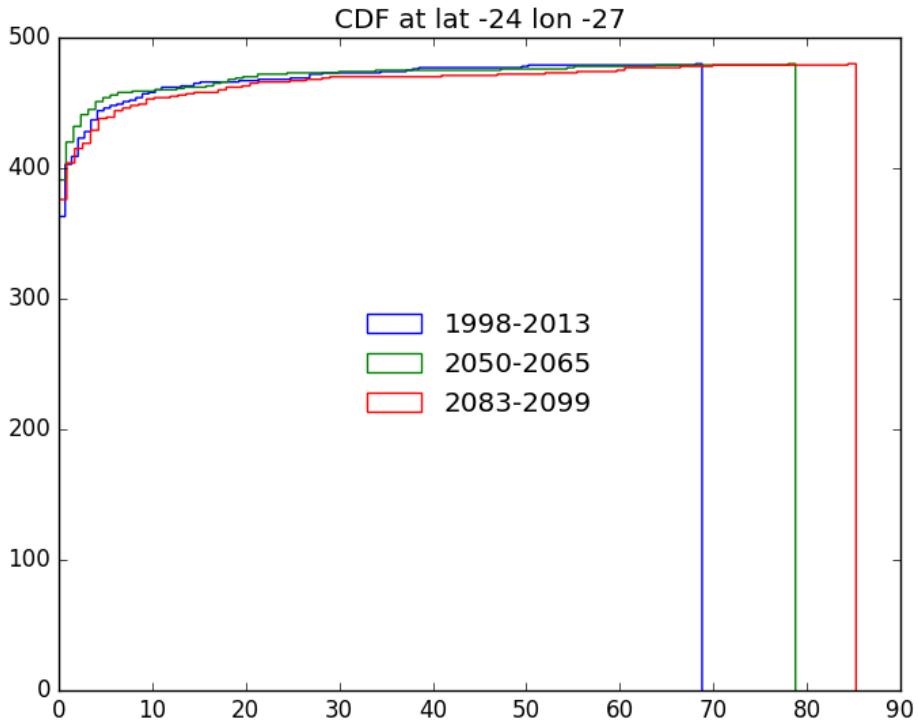
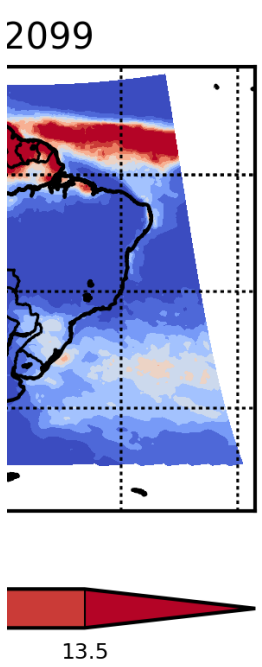
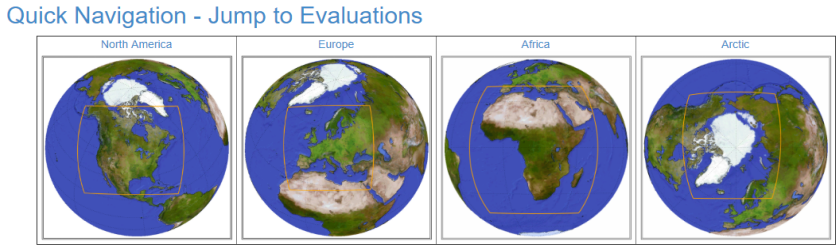






Future Direction

- Development is ongoing…
  - Adding more metrics to assure traceability and reproducibility of model evaluation results.
  - Growing user and developer base by utilizing AWS and OpenNEX datasets.
- Develop a comprehensive model evaluation system for the United States National Climate Assessment and CORDEX.



Results

North America Evaluations

Reference Dataset	Variables	Results Page by Seasons		
CERES-EBAF	Downwelling Longwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Longwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Longwave Radiation (TOA)	Annual	Summer	Winter
	Downwelling Shortwave Radiation (Surface)	Annual	Summer	Winter
	Downwelling Shortwave Radiation (TOA)	Annual	Summer	Winter
	Upwelling Shortwave Radiation (Surface)	Annual	Summer	Winter
	Upwelling Shortwave Radiation (TOA)	Annual	Summer	Winter

https://rcmes.jpl.nasa.gov/content/cordex-evaluation

Where to find more information:

- http://rcmes.jpl.nasa.gov
- http://climate.apache.org/
- Email team members or dev@climate.apache.org
- https://nex.nasa.gov

Lee et al. (2018), Regional Climate Model Evaluation System powered by Apache Open Climate Workbench v1.3.0: an enabling tool for facilitating regional climate studies, GMDD under review.

Contact

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