

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>

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 Loikith², and Antonio Monge³
¹JPL/Caltech, ²California State U. LA, ³Portland 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)	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• 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`
- password: **cordex**

- Remote desktop

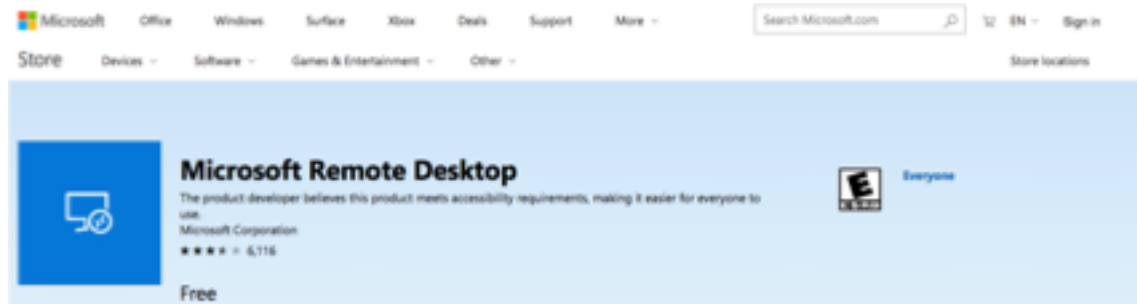


WIFI

- LAN_1: password is **1qazxcvb**
- LAN_2: password is **9ijnbvcx**

Prerequisite software to run remote desktop

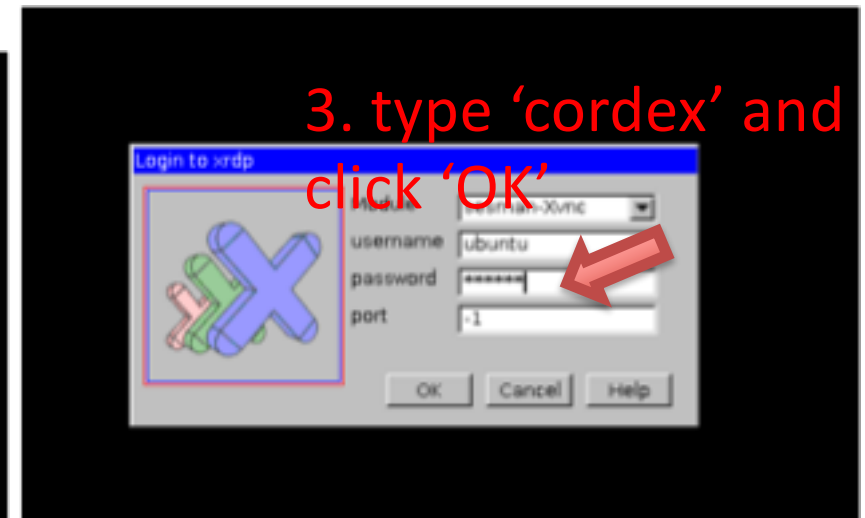
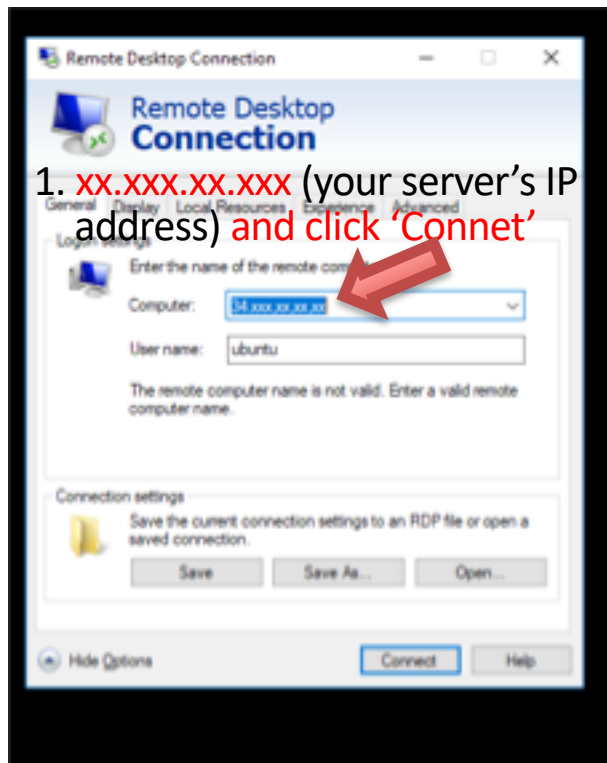
- ~~Linux based system~~
- Windows laptops: Microsoft Remote Desktop



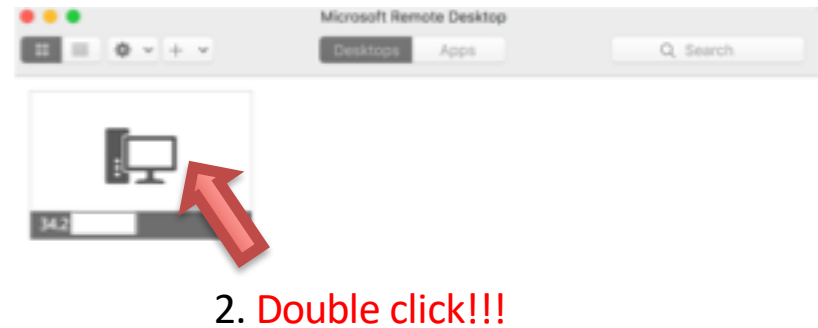
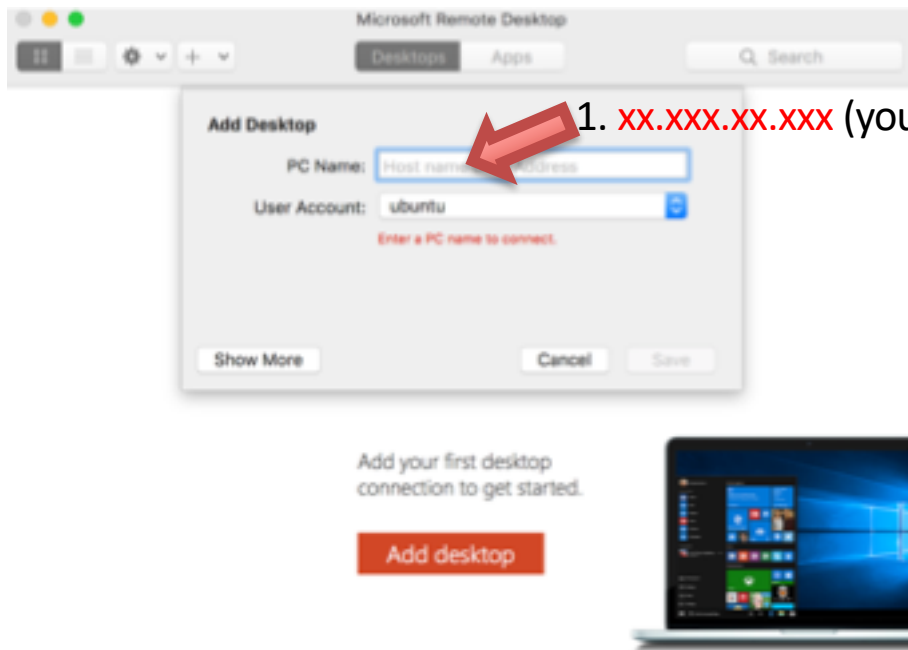
- Macbooks: Microsoft Remote Desktop **10**
(do not use version 8)



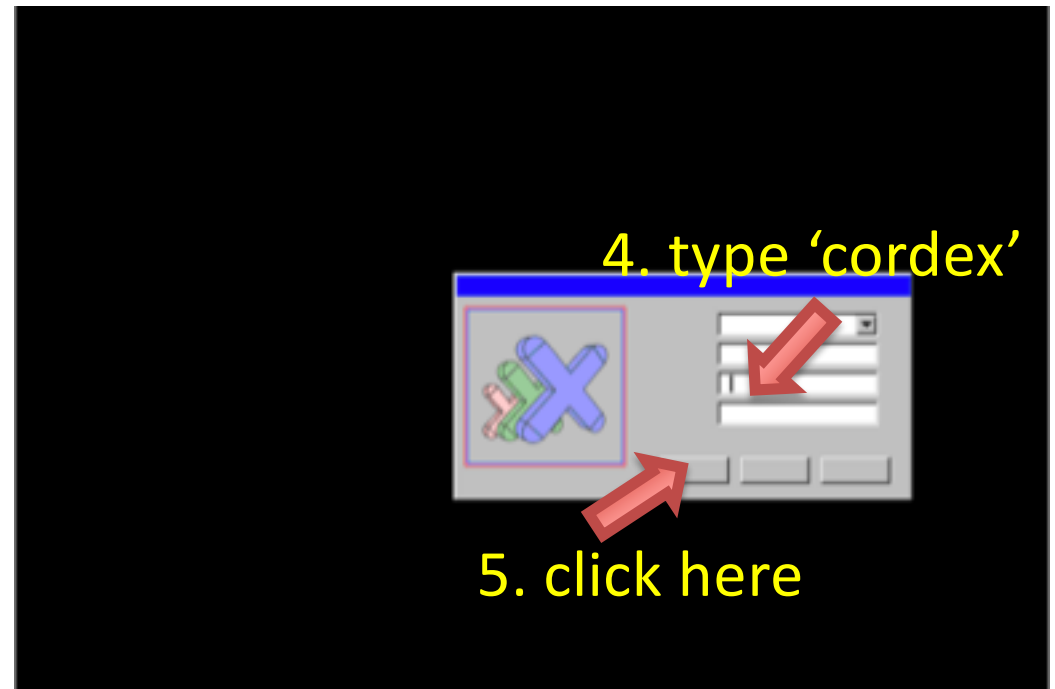
Set up your remote desktop (Windows)



Set up your remote desktop (Mac)



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/tivandal/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
```

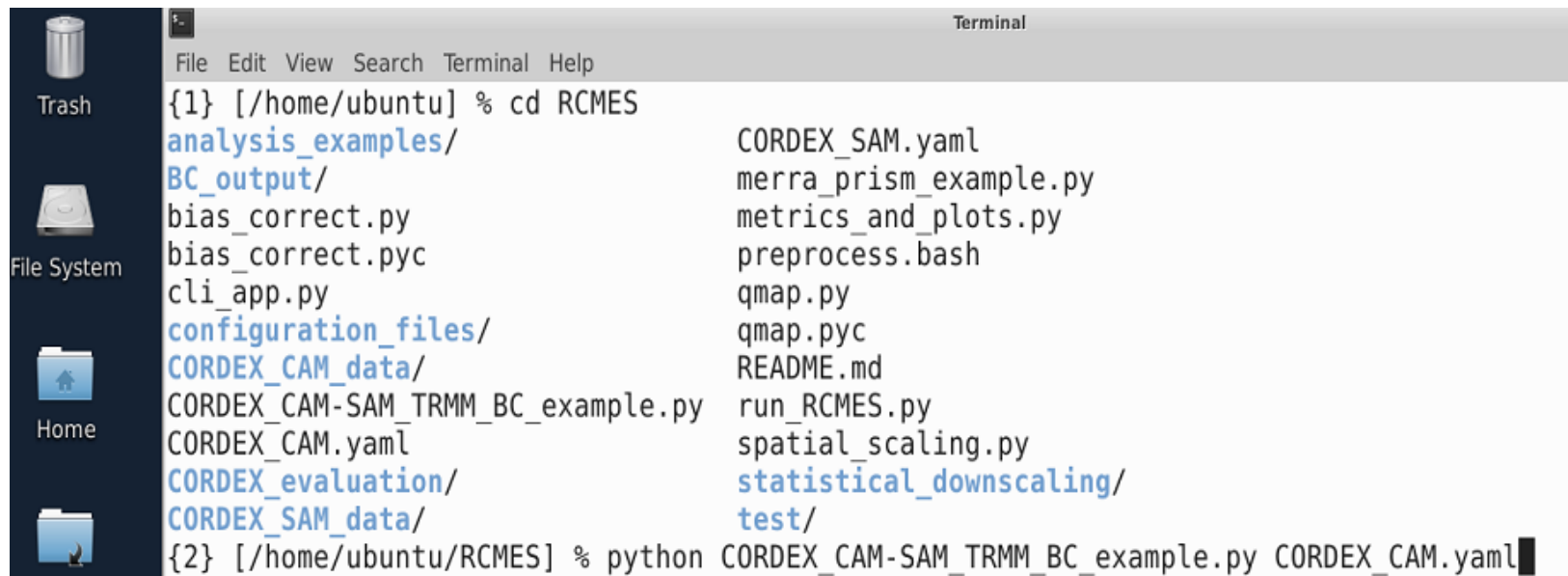
Python script

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 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 present climate)

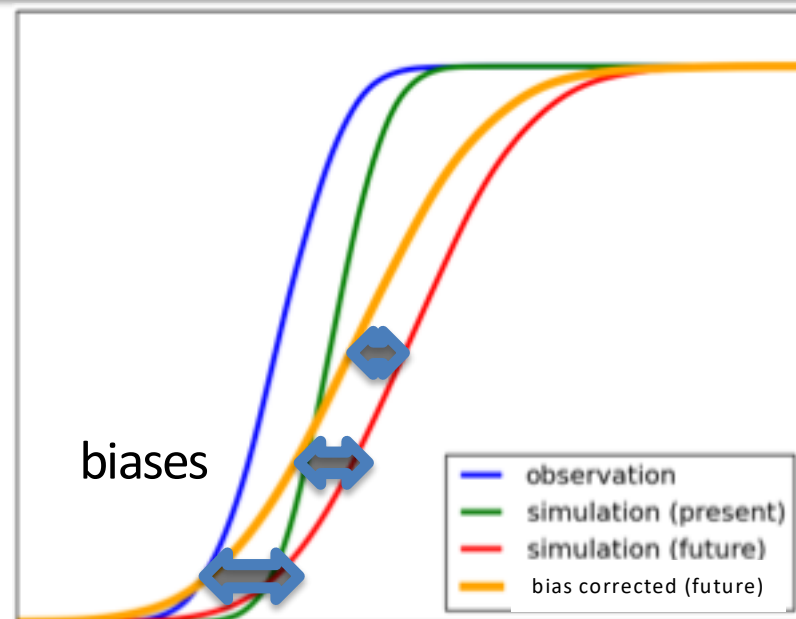
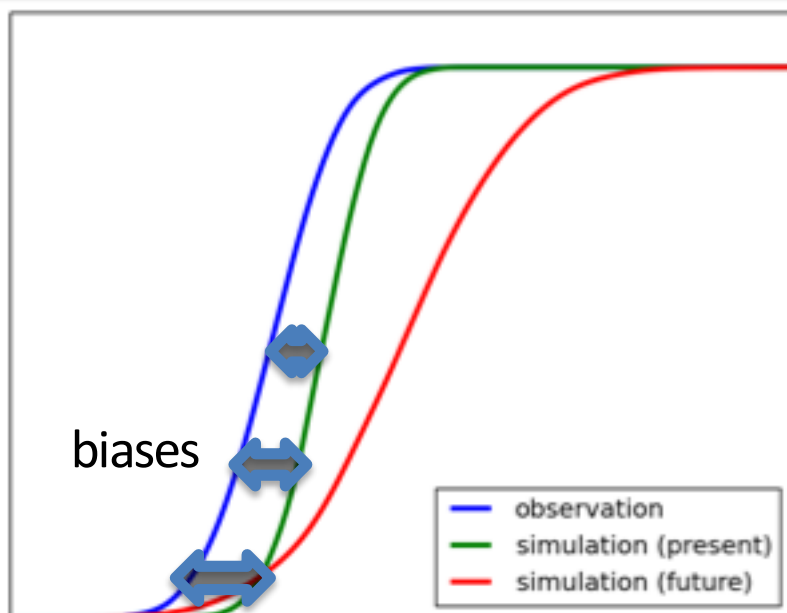
pr_CAM-44_***_19980101-20131231.nc

(Simulation for the future climate)

pr_CAM-44_***_20830101-20991231.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

- : Download and visualize the NEX-GDDP data

- Activity #4

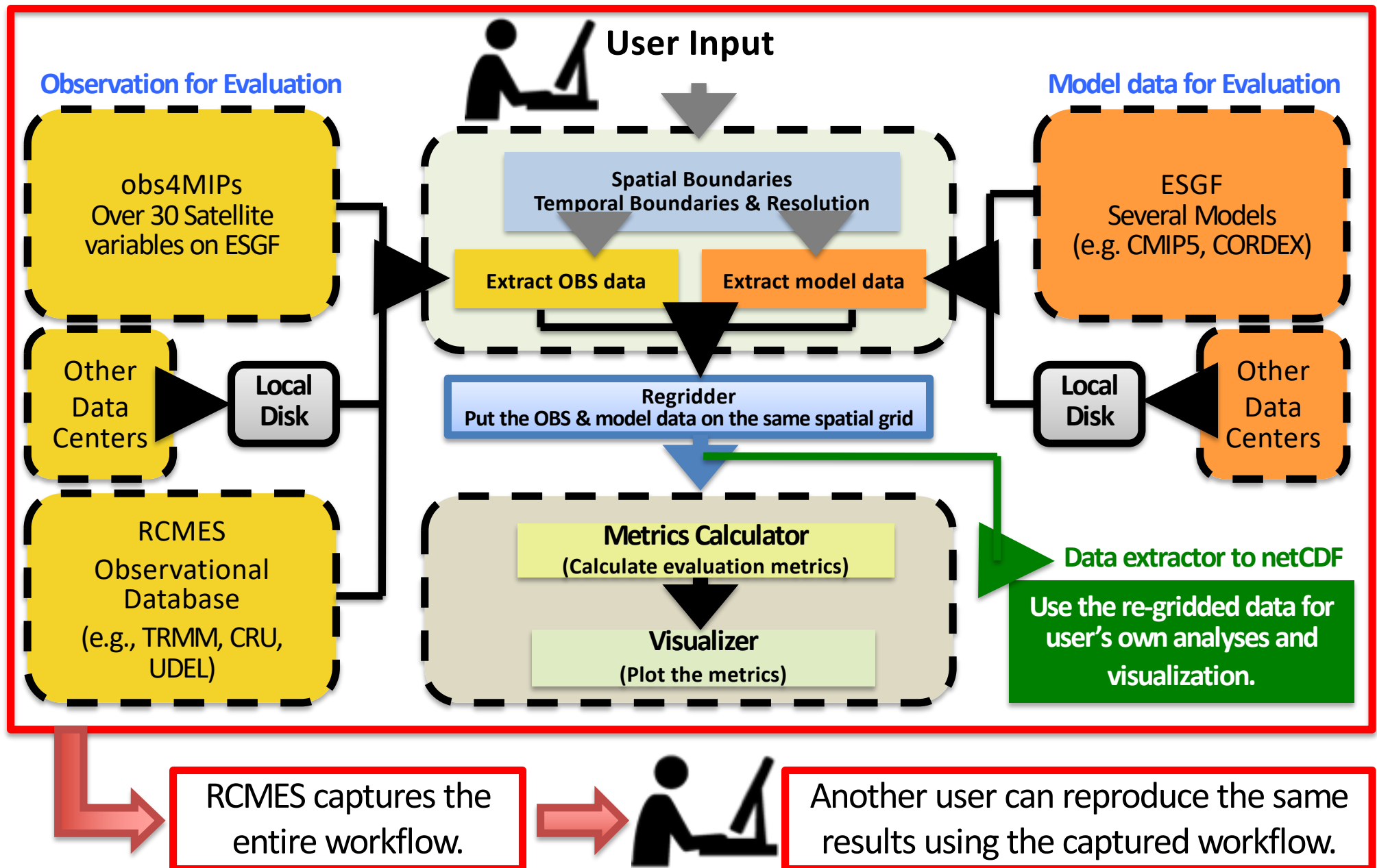
- : Analyze the bias corrected RCM output

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

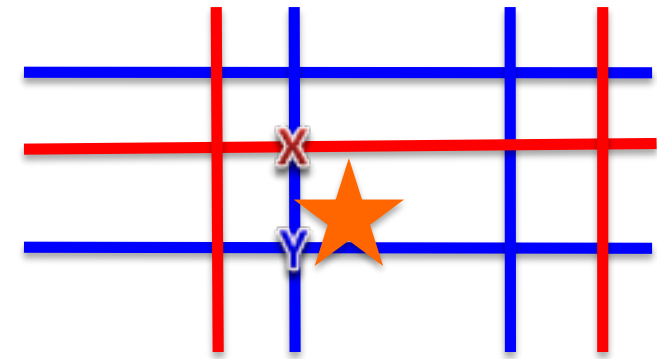
- Lee et al. (2018) in GMDD under review.
- Python-based open source software powered by the Apache Open Climate Workbench (OCW)
- Main components
 - 1) Database of observations
 - 2) Toolkit for facilitating systematic evaluation of CORDEX RCMs using satellite observations
 - 3) Statistical downscaling 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



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

$$Y = f(X)$$

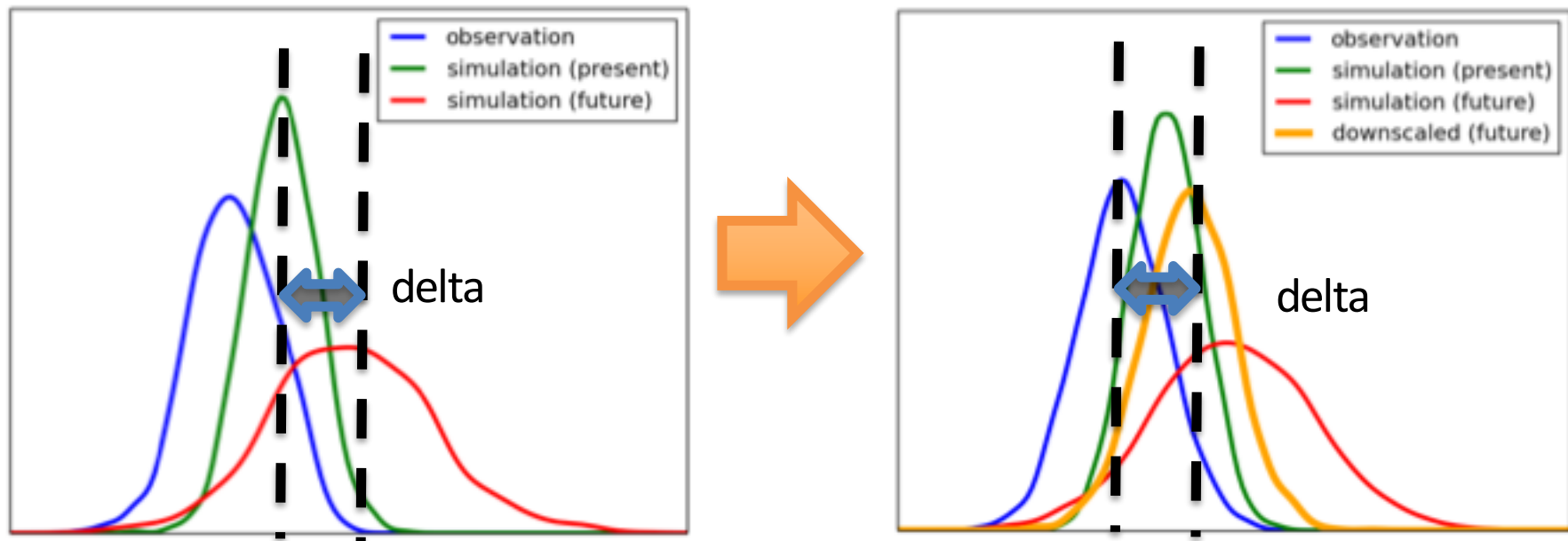
- Four different methods for model calibration (Stoner et al., 2013)
 - Delta method (addition)
 - Delta method (bias correction)
 - Quantile mapping
 - Asynchronous linear regression
- The observational datasets in RCMES database can be used to determine the observation-model relationship.

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)

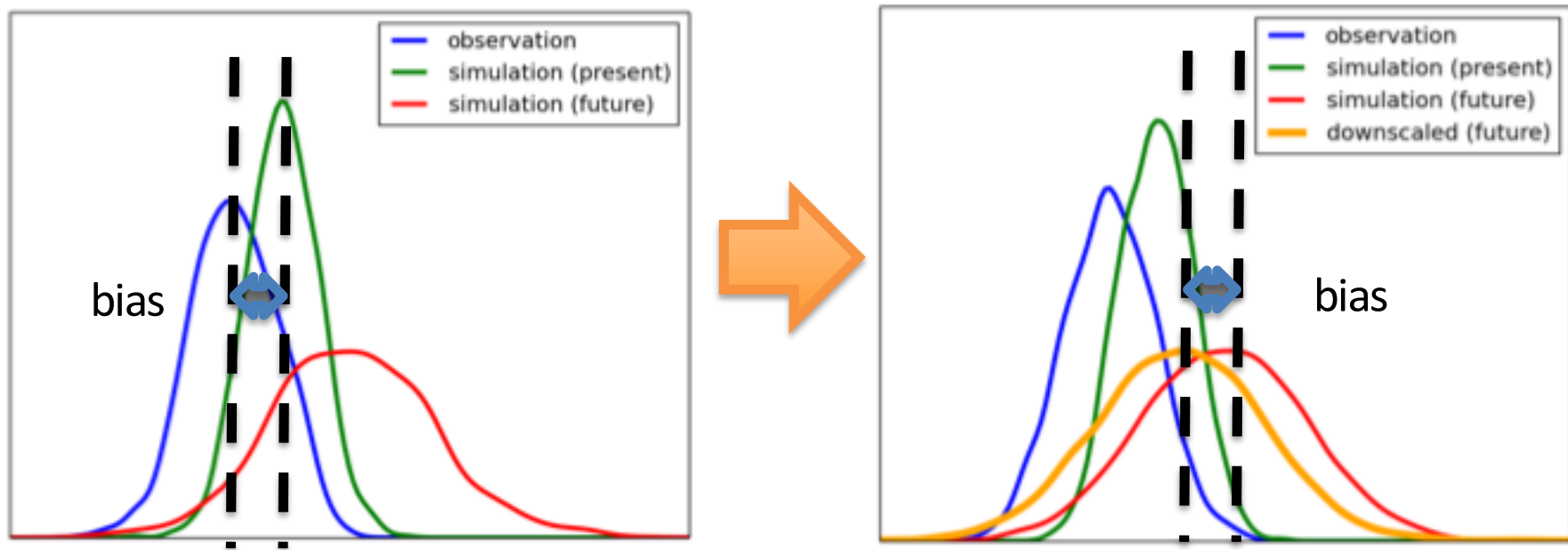


Delta method (Bias correction)

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)

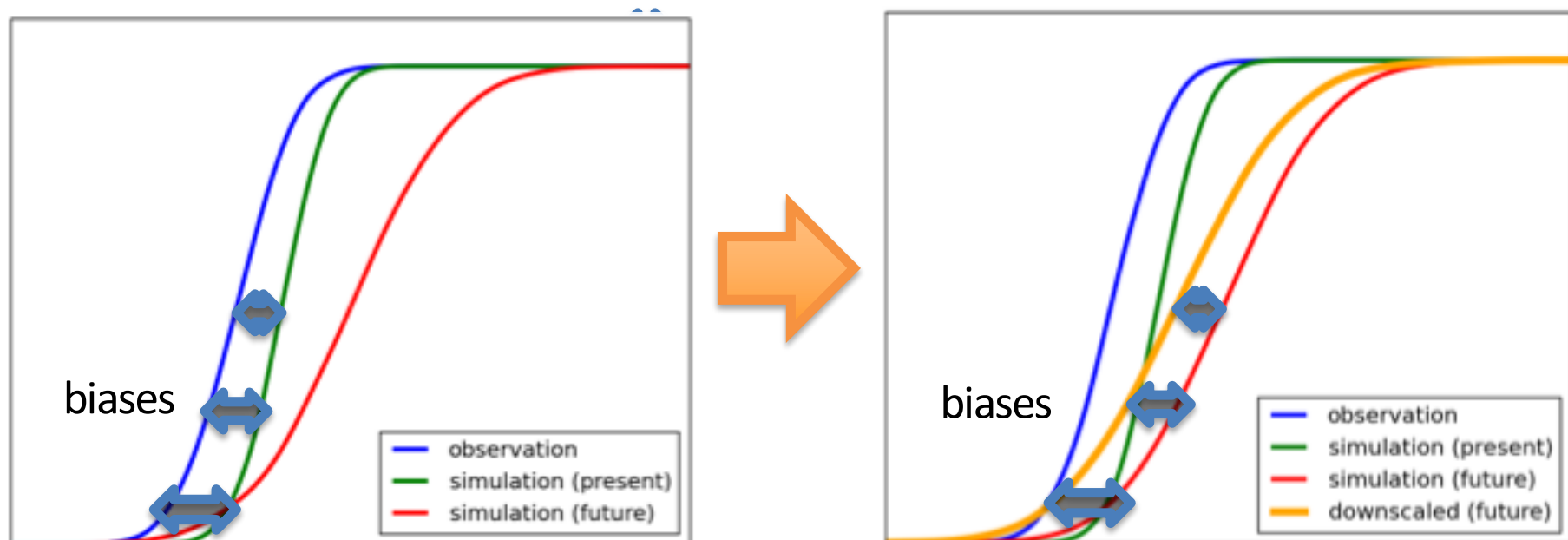


Quantile mapping

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.



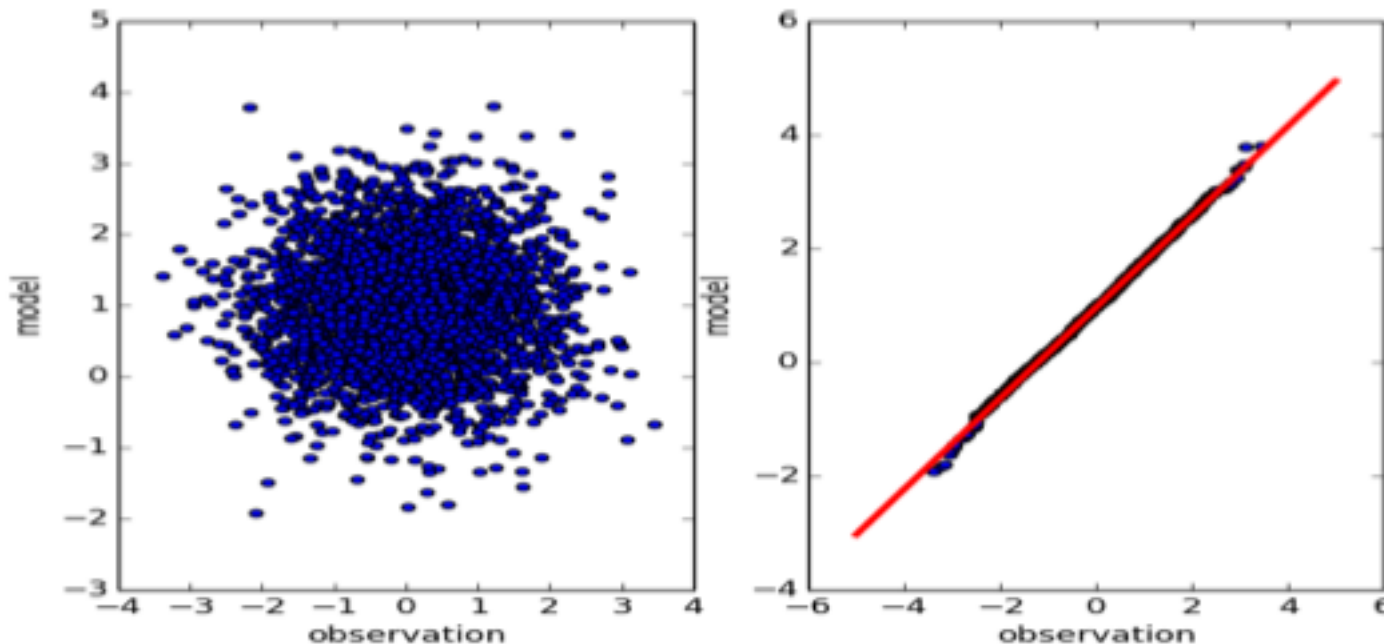
Asynchronous linear regression

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
```

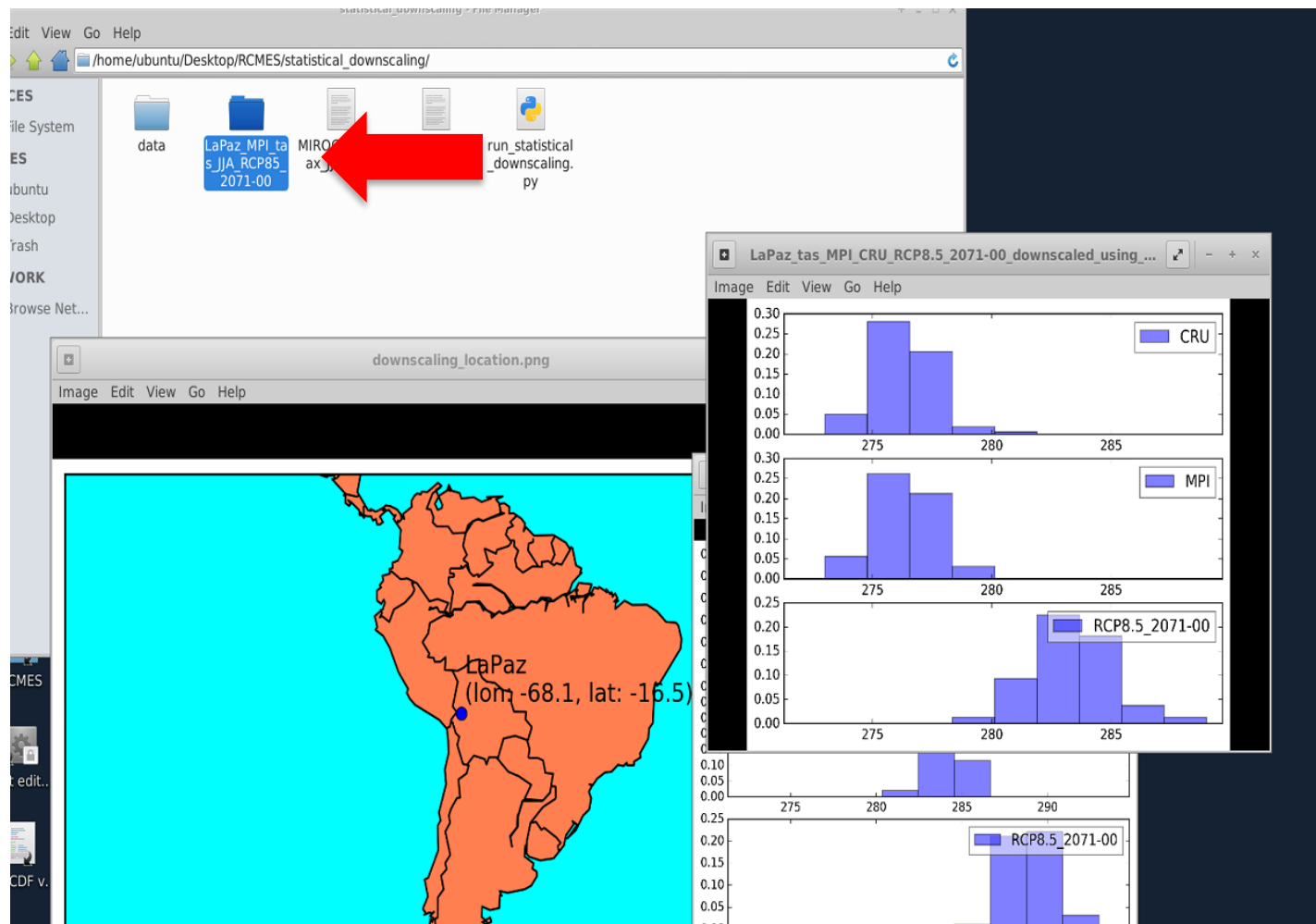
Python script

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] %
```

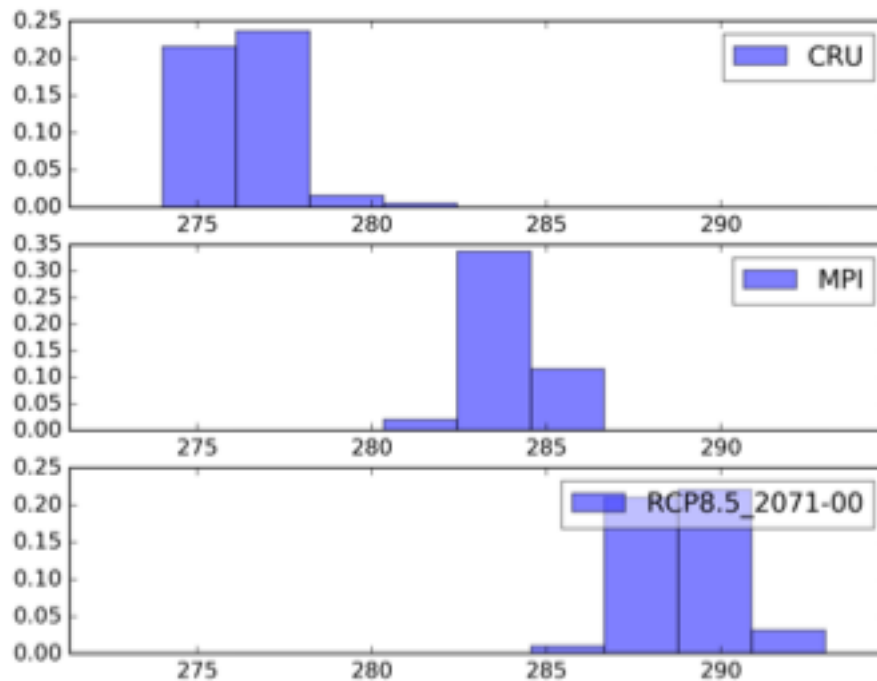
View the statistically downscaled tas results

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

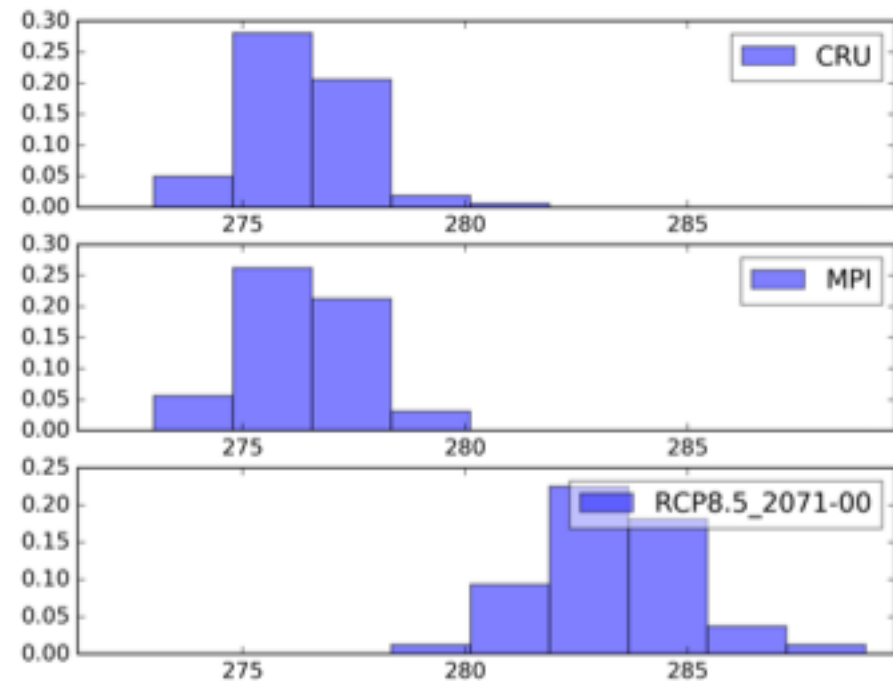


Quantile mapping of the near-surface air temperature for La Paz in JJA

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

Output folder name

downscaling_option: 3

location:

name: BuenosAires

grid_lat: -34.60

Search Google with the keyword 'latitude and longitude of XXX'

grid_lon: -58.38

month_index: !!python/tuple [6,7,8]

Season

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

(Options)

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

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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)

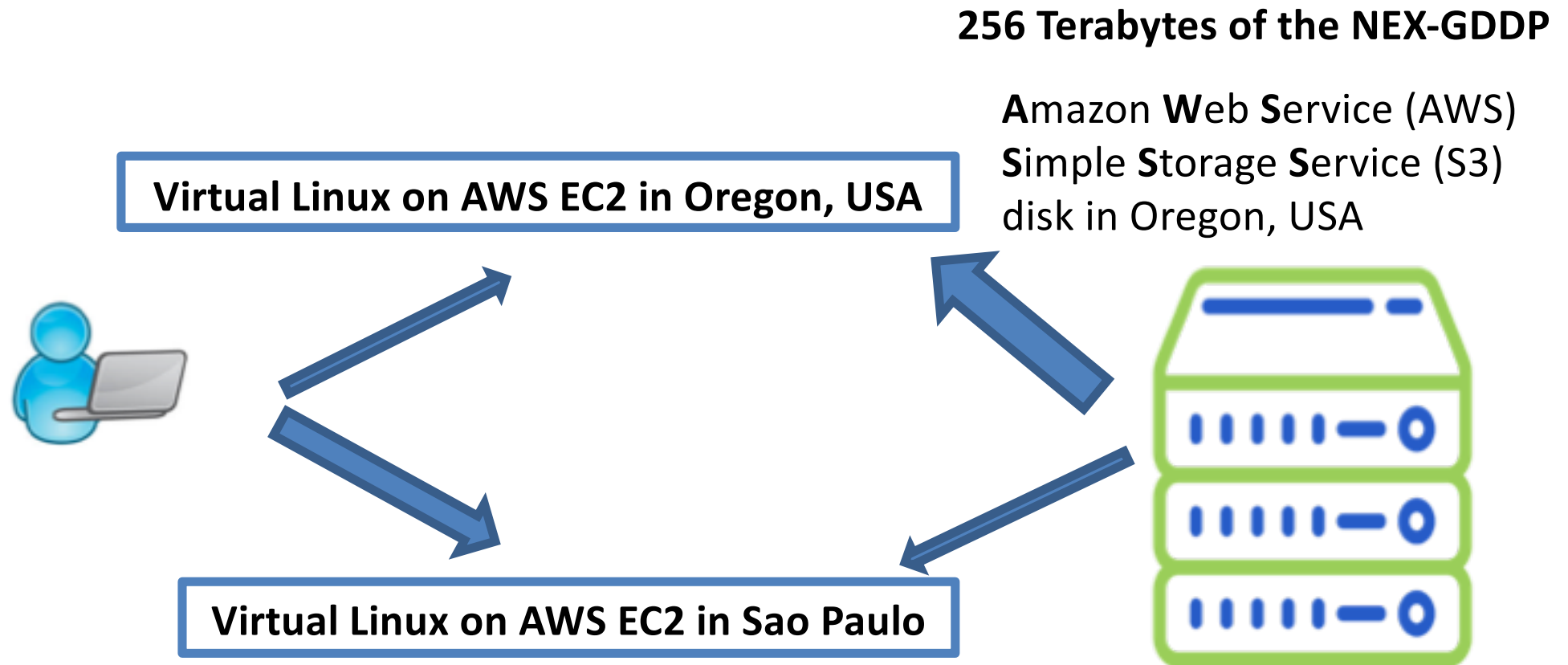
Bias-Correction Spatial
Disaggregation (BCSD)

Global Meteorological
Forcing Dataset
(observation, 1950-2005)



NEX-GDDP
: tasmax, tasmin, precipitation

Access to the statistically downscaled NEX-GDDP



- 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`

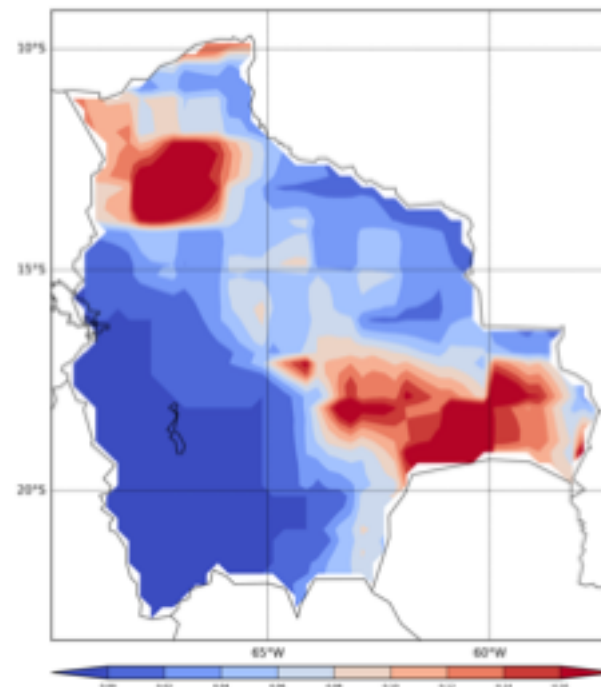
2. `./list`

3. `./download` How fast!

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

4. `python plot_NEX-GDDP_example.py`

Statistically downscaled
precipitation from NorESM1-M
model for June 2100



Apache Open Climate Workbench (OCW)

<https://climate.apache.org/>

Apache Open Climate Workbench

Downloads

Development ▾

Documentation ▾

Community ▾

ASF ▾



Apache Open Climate Workbench

Apache Open Climate Workbench is an effort to develop software that performs climate model evaluation using model outputs from a variety of different sources the [Earth System Grid Federation](#), the [Coordinated Regional Climate Downscaling Experiment](#), the [U.S. National Climate Assessment](#) and the [North American Regional Climate Change Assessment Program](#) and temporal/spatial scales with remote sensing data from [NASA](#), [NOAA](#) and other agencies. The toolkit includes capabilities for rebinning, metrics computation and visualization.

Apache Open Climate Workbench 1.0.0 Released

September 24, 2015

The Apache Open Climate Workbench team is pleased to announce the 1.0.0 release! This release addresses no less than 52 issues, bugs, and improvements. For a full breakdown of the work packaged into this release please see the [release report](#).


Some important features this release packs include statistical downscaling capabilities such as Delta Method, Quantile Mapping and Quantile Regression, configuration driven evaluation improvements, better plot support to config based evaluations and a brand new module to calculate area mean and standard deviation with given subregion information.

Download




We urge all users to upgrade to this version immediately. Please let us know how you are using OCW over on the [community mailing lists](#).

Finally, please see our [1.1 Roadmap](#) for an idea of the next line of development.

Source at github.com/apache/climate

 This repository

Pull requestsIssuesGist

apache / climate

mirrored from [git://git.apache.org/climate.git](https://git.apache.org/climate.git)

Watch 8Star 17Fork 36

CodePull requests 4PulseGraphs

Mirror of Apache Open Climate Workbench

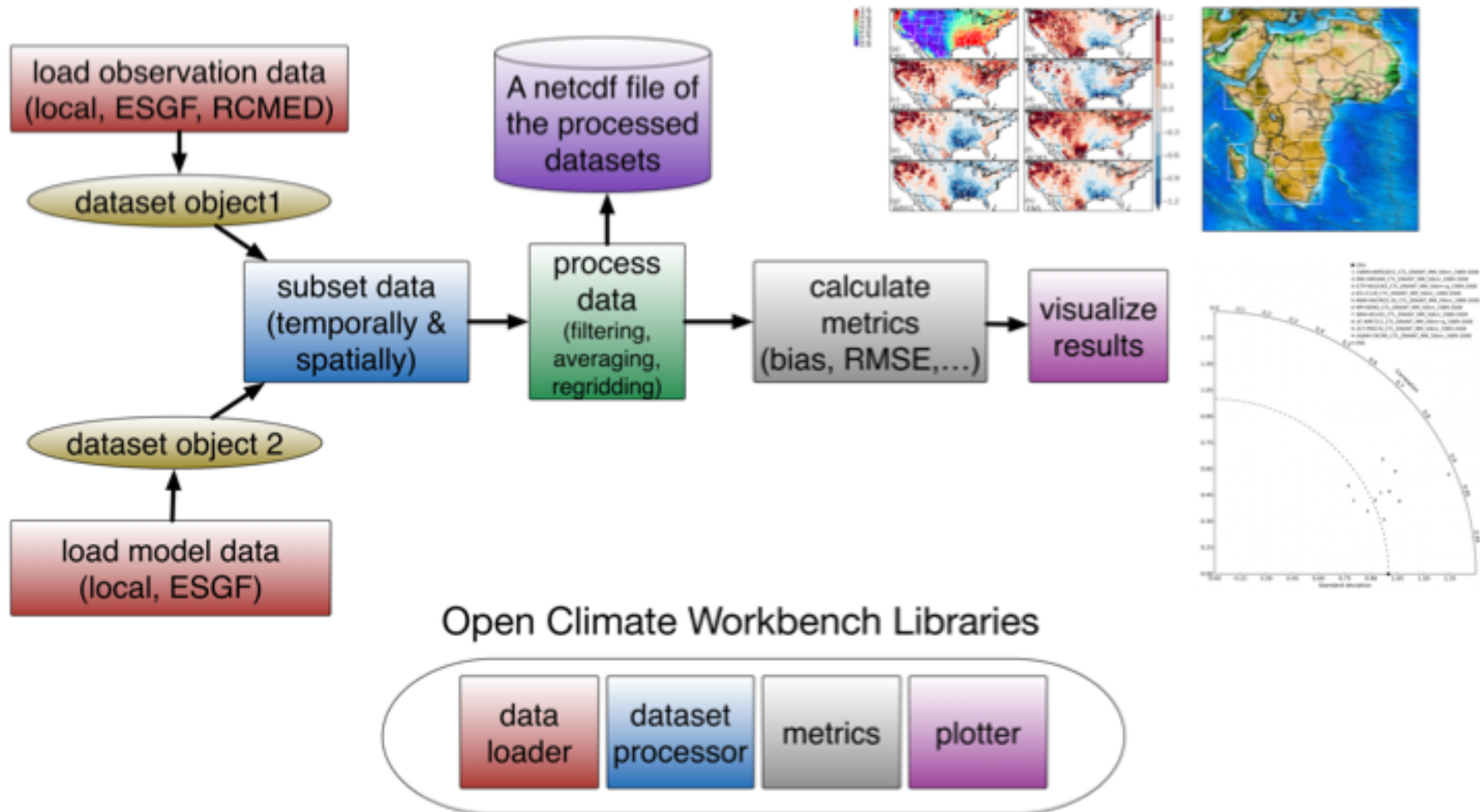
1,791 commits16 branches7 releases13 contributors

Branch: masterNew pull requestNew fileUpload filesFind fileHTTPShttps://github.com/apache,Download ZIP

huikyole CLIMATE-771 - Critical bugs in LAT_NAMES and LON_NAMES in local.pyLatest commit fd6debb 10 days ago

RCMES	CLIMATE-770 - Make boundary checking optional in spatial_regrid	12 days ago
docs	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
easy-ocw	Resolve CLIMATE-560 : Does not assume installation directory within e...	3 months ago
examples	Examples that use dataset_processor.temporal_rebin have been updated	a month ago
mccsearch	Resolve CLIMATE-559. Merge PR #142.	a year ago
obs4MIPs	Add Resources sheet into excel spreadsheet. It is no longer necessary...	2 years ago
ocw-ui	CLIMATE-572 Address deprecation and WARN's in ocw-ui/frontend npm ins...	12 days ago
ocw-vm	CLIMATE-712 - Update VM build to use conda install	4 months ago
ocw	Merge branch 'master' of https://github.com/apache/climate into CLIMA...	10 days ago
ocw_config_runner	adding init python file	6 months ago
.gitignore	Update gitignore so setup.py develop artifacts are ignored	a year ago
.mailmap	CLIMATE-608 - Add mailmap file to repo	a year ago
.pylintrc	CLIMATE-600 - Add basic .pylintrc with some sane defaults	a year ago
CHANGES.txt	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
KEYS	[RELEASE PREPARE] Prep for 1.0.0 release candidate	6 months ago
LICENSE.txt	add README to provide information on how to retrieve TRMM data from G...	2 years ago
MANIFEST.in	CLIMATE-725 Ensure that OCW 1.1 Test PyPI Works as Expected	2 months ago
NOTICE.txt	CLIMATE-342 - Update NOTICE with public domain note for TaylorDiagram	2 years ago
README.md	CLIMATE-684 - Add link to Python API to README	6 months ago

Running RCMES using configuration files: a complete start-to-finish workflow to evaluate multi-scale climate models using observational data



- 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`

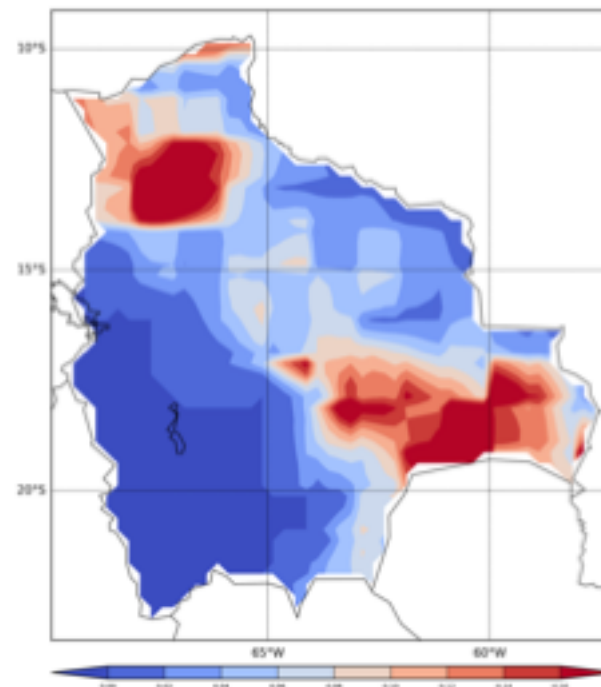
2. `./list`

3. `./download` How fast!

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

4. `python plot_NEX-GDDP_example.py`

Statistically downscaled
precipitation from NorESM1-M
model for June 2100



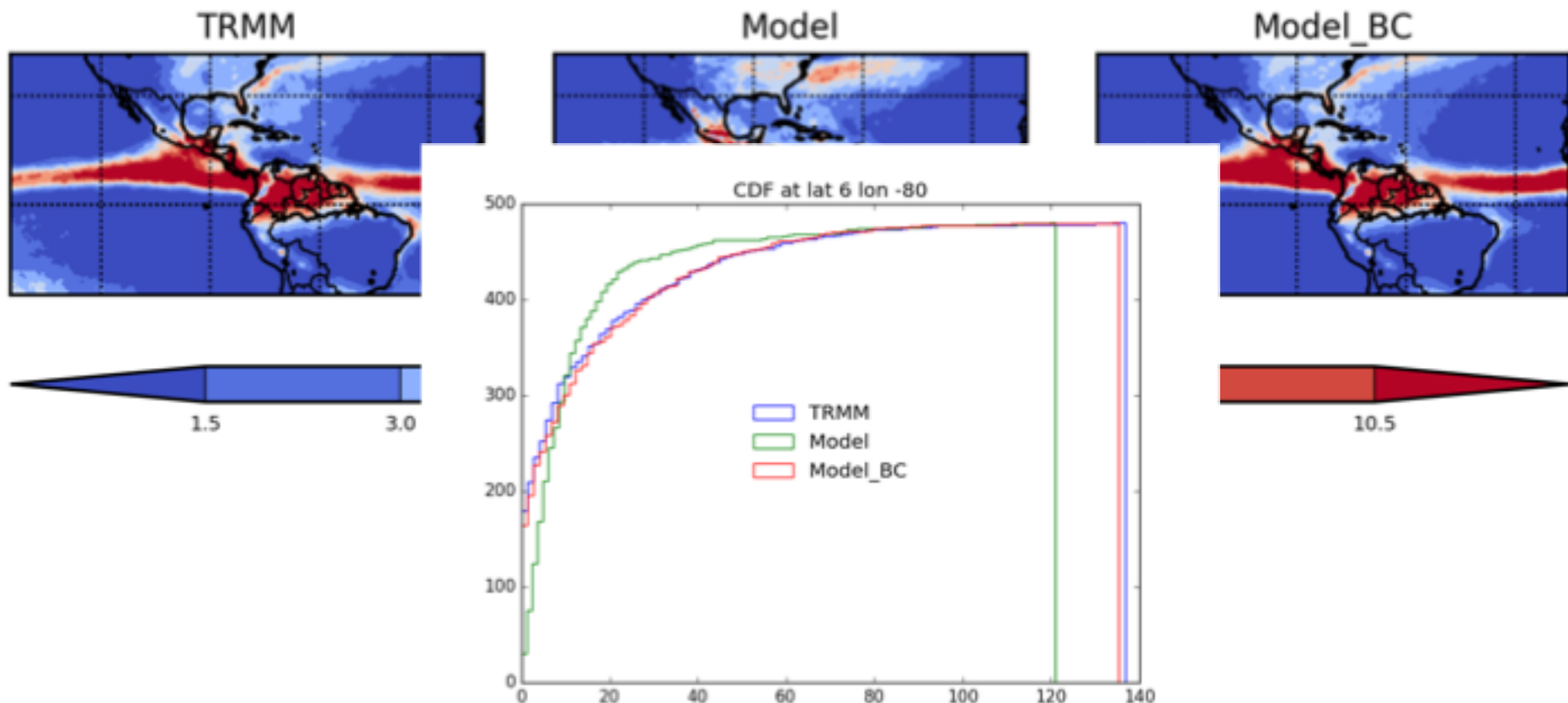
Compare TRMM, original RCM, and bias corrected RCM

1. Open terminal and `cd RCMES/analysis_examples`

2. `python check_bias_correction_CAM.py`

`python check_bias_correction_SAM.py`

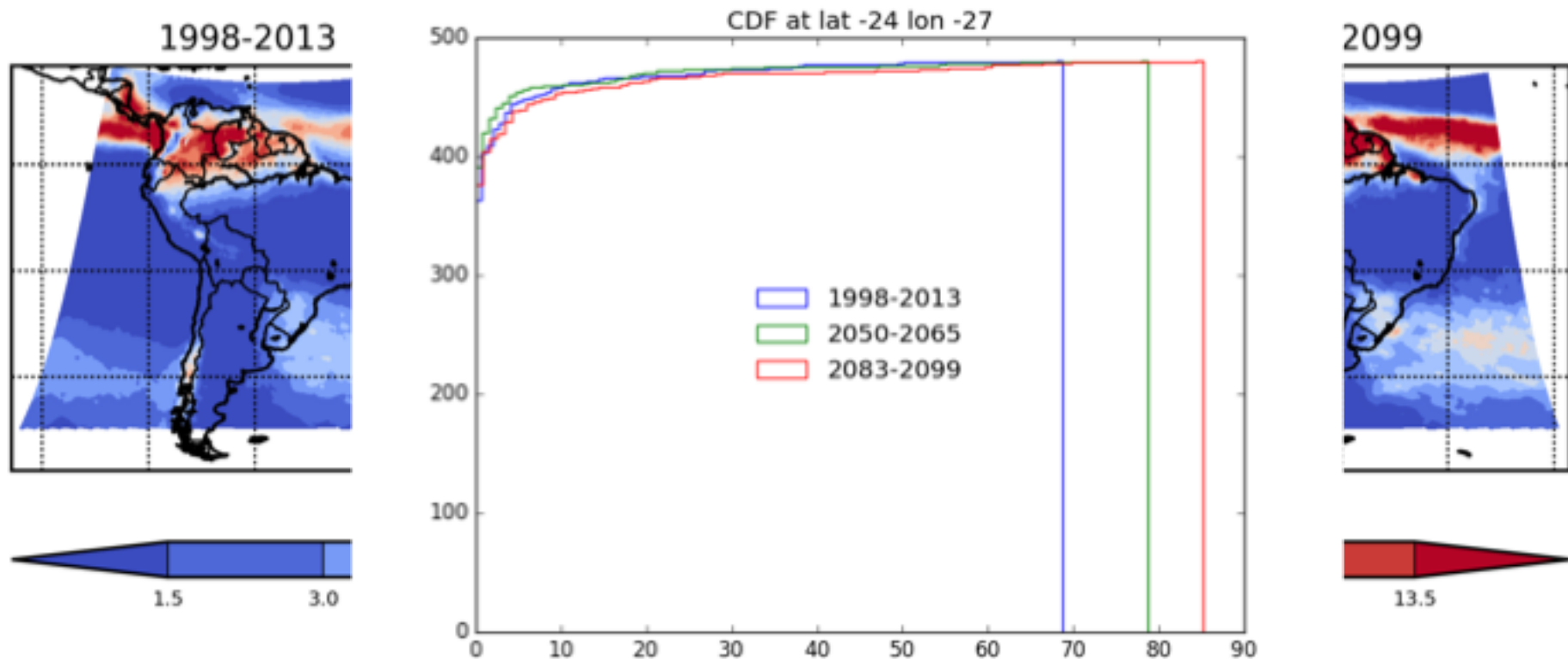
OCW-based script



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
```

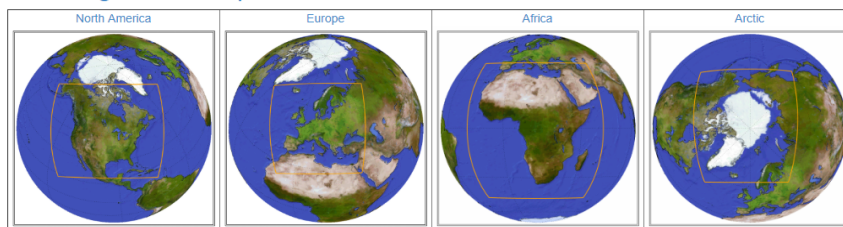
```
python compare_present_and_future_SAM.py
```



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.

Quick Navigation - Jump to Evaluations



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
	Upwelling Shortwave Radiation (TOA)	Annual	Summer	Winter

<https://rcmes.ipl.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

Kyo Lee: huikyo.lee@jpl.nasa.gov