NASA Earth Exchange (NEX) Workshop Hands-on Series

Climate Downscaling with NEX Sandbox

Weile Wang

with contributions from

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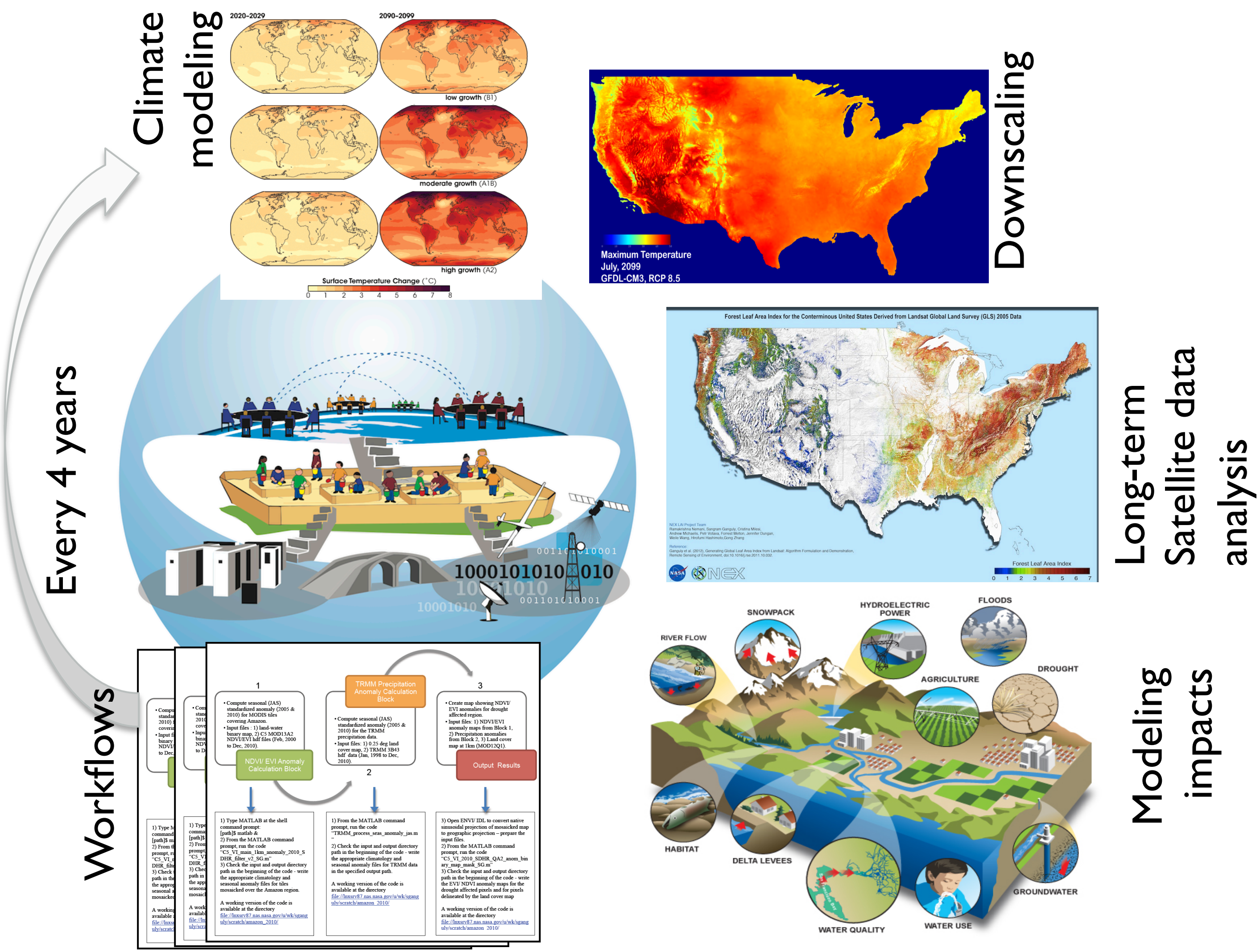
July 21, 2016

Outline

1) NEX for National Climate Assessment
2) Climate Downscaling Background
3) Getting an Account on NEX Sandbox
4) Hands-on Example: Bias Correction in Climate Downscaling
5) Exercises and Discussion Topics

NEX for National Climate Assessment



Downscaled Climate Datasets on NEX

DCP30 (Downscaled Climate Projections at 30arc sec)
Domain/Resolution: CONUS, ~800m
Frequency: Monthly
Variables: Tmax, Tmin, and Precip
No of CMIP5 models: 34
Baseline Data: Daly et al., 2002

LOCA (Localized constructed analogs)
Domain/Resolution: CONUS, ~6km
Frequency: Daily
Variables: Tmax, Tmin, Precip;
Humidity, Windspeed (in progress)
No of CMIP5 models: 32
Baseline Data: Livneh et al. 2013

GDDP (Global Daily Downscaled Climate Projections)
Domain/Resolution: Global, ~25km
Frequency: Daily
Variables: Tmax, Tmin, and Precip
No of CMIP5 models: 21
Baseline Data: Sheffield et al. 2006

BCCA (Bias Corrected Constructed Analogs)
Domain/Resolution: CONUS, ~12km
Frequency: Daily
Variables: Tmax, Tmin, Precip
No of CMIP5 models: 21
Baseline Data: Maurer et al. 2002

Climate Downscaling Background

RECLAMATION NCAR USGS Santa Clara University CLIMATE CENTRAL SCRIPPS INSTITUTION OF OCEANOGRAPHY

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections

This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.

Welcome | About | Tutorials | Projections: Subset Request | Projections: Complete Archives | Feedback | Links

Downscaled CMIP5 climate and hydrology projections' documentation and release notes available here.

Summary

This archive contains fine spatial resolution translations of climate projections over the contiguous United States (U.S.) developed using two downscaling techniques (monthly BCSD Figure 1, and daily BCCA Figure 2), CMIP3 hydrologic projections over the western U.S. (roughly the western U.S. Figure 3), and CMIP5 hydrology projections over the contiguous U.S. corresponding to monthly BCSD climate projections.

Archive content is based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report, and the phase 5 (CMIP5) multi-model dataset that is informing the IPCC Fifth Assessment.

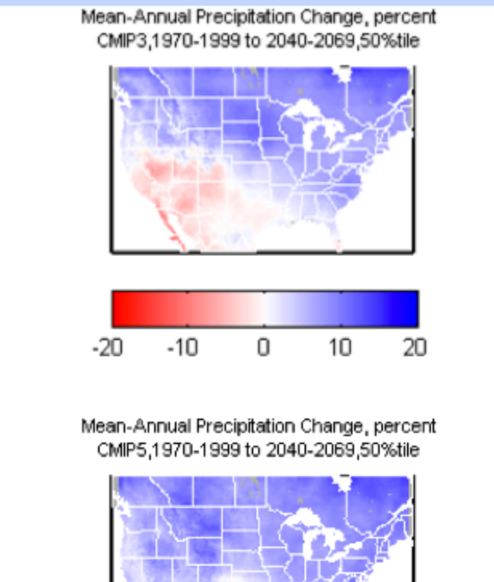
For information about downscaled climate and hydrology projections development, please see the About page.

Purpose

The archive is meant to provide access to climate and hydrologic projections at spatial and temporal scales relevant to some of the watershed and basin-scale decisions facing water and natural resource managers and planners dealing with climate change. Such access permits several types of analyses, including:

- assessment of potential climate change impacts on natural and social systems (e.g., watershed hydrology, ecosystems, water and energy demands).
- assessment of local to regional climate projection uncertainty.
- risk-based exploration of planning and policy responses framed by potential climate changes exemplified by these projections.

Figure 1. Central Tendency Changes in Mean-Annual Precipitation over the contiguous U.S. from 1970-1999 to 2040-2069 for BCSD3, BCSD5, and Difference.



http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

Climate Downscaling Background (continued)

Hosted by University of Colorado Boulder

Powered by ESGF and CoG

Welcome, **Guest**. | Login | Create Account

NCPP

National Climate Predictions & Projections Platform

*You are at the **CoG-CU** node*

Home | About Us | Resources | Contact Us | **Technical Support**

Downscaling-2013
- Home
- Agenda and Presentations
- Participants
- Logistics and Details
- Friday Hike Photos

Description
- Motivation
- Principles and Values
- Scope and Outcomes
- Contributions to NCPP
- Workshop Evaluation

Evaluation framework
- Overview
- Protocols
- Metrics

Workshop Tools
- Evaluation Data Search
- Evaluated Datasets
- List of Metrics
- List of Variables/Indices
- Metadata for Downscaling
- Metadata Tools
- OCGIS & ClimateTranslator
- ClimateTranslator Access
- Downscaling Portals Table
- Visualization

Working Groups
- Working Group Resources
- Working Group Roles

Downscaling WG
- Downscaling Teams
- GFDL Perfect Model

Agriculture WG
- Agriculture Home
- Outcomes

Ecosystems WG
- Ecosystem Home
- Outcomes

Human Health WG
- Health Home
- Human health impacts
- Case studies
- Outcomes

Water WG

Workshop Agenda & Presentations

NCPP Quantitative Evaluation of Downscaling Workshop 12-16 August, 2013

mp4 & mpv links are presentation videos, ppt & pdf links are presentation slides

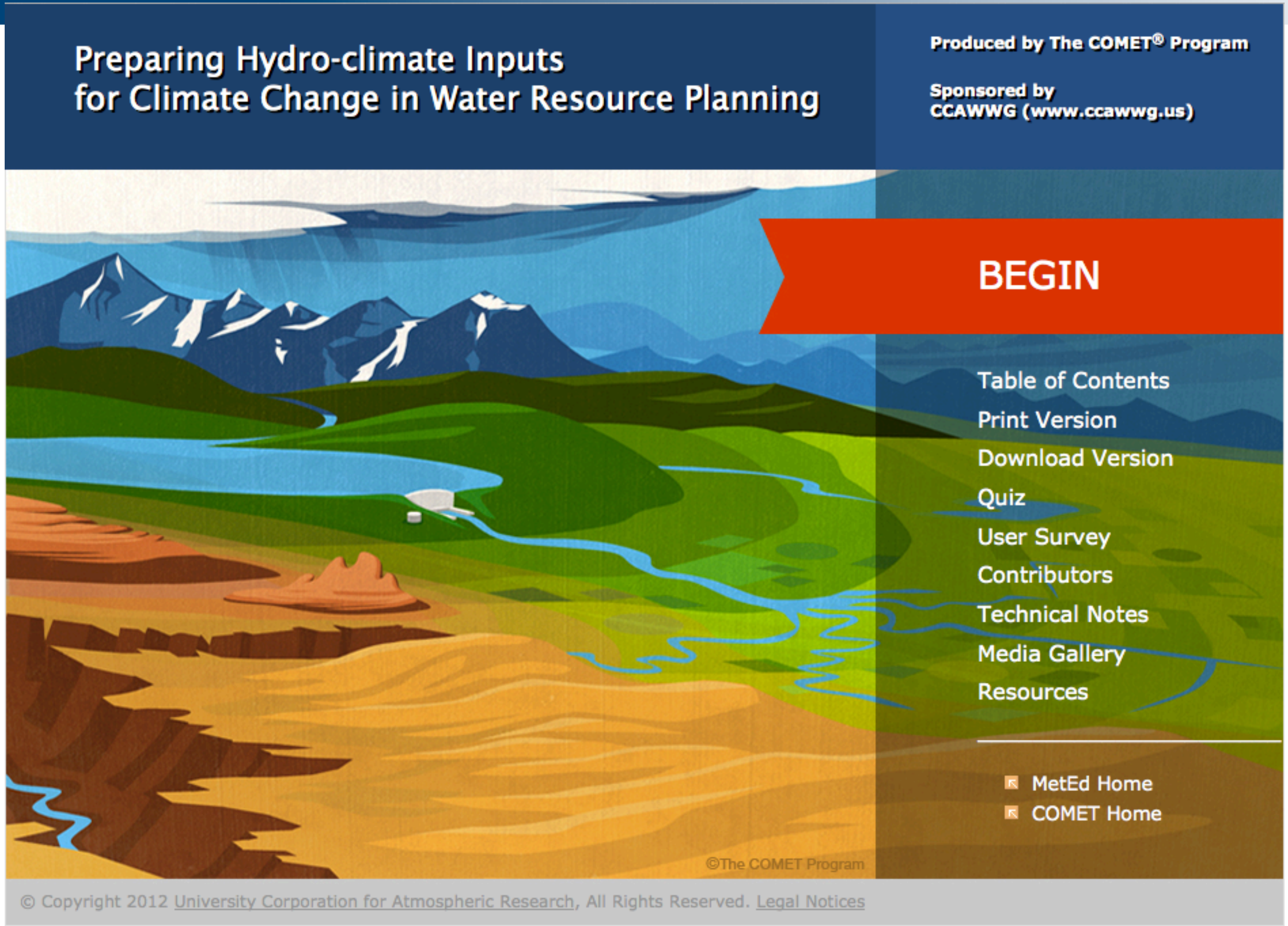
Jump to the bottom

Monday - August 12th

Room	Time	Session	Speaker/Facilitator	Details
	8:00-8:50	***Registration***		
FL2-1022	**8:50-9:30**	**Welcome Remarks**		
	8:50-9:00	***Workshop Logistics***		Fire exits, bathrooms, internet access
	9:00-9:10	***Welcome from NCAR*** | m4v	Tom Bogdan	
	9:10-9:20	***Welcome from NOAA CPO*** | mp4	Wayne Higgins|	Overview of workshop, key objectives, expectations for the next few days.
	9:20-9:30	***Evaluation approach of NCPP: Building Community*** | mp4 | ppt	Ricky Rood	Expectations for the next few days; working groups; community of practice.
FL2-1022	**9:30-10:10**	**Motivation and Framework for Evaluation of Downscaling**		
	9:30-9:50	***NCPP Evaluation Framework: the Practitioner's dilemma and overall approach*** | mp4	Joe Barsugli	Based on the NCPP white paper – presentation of the framework for evaluation of downscaled projections, protocols, need for standardization.
	9:50-10:10	***How to use the workshop website in the COG environment*** | mp4	Sylvia Murphy	Navigation, Wiki, Data Search
FL2- Cafeteria Atrium	**10:10-10:35**	**Break and introductions**		Use 5 minutes to introduce yourself to 5 people
FL2-1022	**10:35-12:20**	**Motivation and Framework for Evaluation of Downscaling (cont.)**		
	10:35-10:55	***Evaluation approach of NCPP: Climate Translator - Evaluation platform v.0*** | mp4 | pdf	Caspar Ammann	Introduction to the NCPP Evaluation platform v.0. How were the evaluations done, search tools, images. Examples of what you can find and how this is useful.
	10:55-11:15	***Evaluation approach of NCPP: Metadata – Describing models and methods*** | mp4 | pdf	Allyn Treshansky	Metadata/CIM. We will demonstrate some web-based tools to view information about downscaling methods, and compare among models.

https://earthsystemcog.org/projects/downscaling-2013/

Climate Downscaling Background (continued)



https://www.meted.ucar.edu/

Climate Downscaling Background (continued)

U.S. Climate Resilience Toolkit

Steps to Resilience | Case Studies | Tools | Topics | Expertise

Search

Climate Resilience in Alaskan Communities: Catalog of Federal Programs

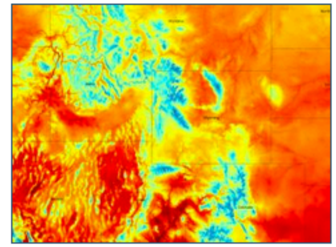
Communities in Alaska that face challenges associated with coastal erosion, flooding, and other climate-related risks can use this catalog to find information, technical assistance programs, and potential funding resources.

Read more ›

Climate-Smart Conservation: Putting Adaptation Principles into Practice

Natural resource managers and conservation professionals can use this guide to help them incorporate climate considerations into their work.

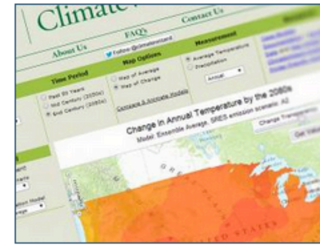
Read more ›



ClimateData.us

Zoom to any location in the contiguous United States and move a slider across the map to compare projected changes in temperature and precipitation. Compare conditions by decade under a mitigation scenario (reduced emissions) and a high-emissions scenario.

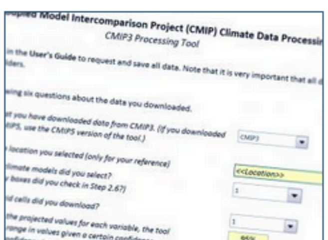
Read more ›



ClimateWizard

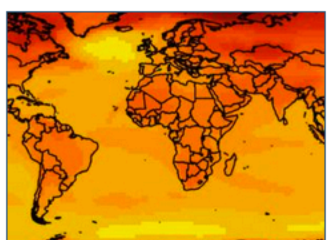
Retrieve maps of weather observations for the past 50 years or projections for temperature and precipitation in the future. Compare the projected impacts of different emissions scenarios for a single state, country, or across the entire globe.

Read more ›



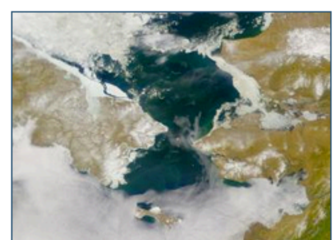
CMIP Climate Data Processing Tool

Transportation planners can use this Microsoft Excel®-based



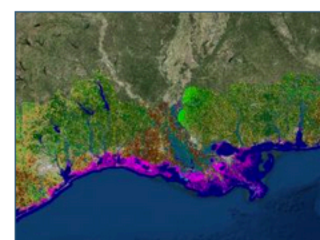
CMIP5 Global Climate Change Viewer (GCCV)

Display past and future temperature and precipitation



Coastal Change Analyses for Western Alaska: Interactive Map

View analyses of coastal change



Coastal Change Analysis Program (C-CAP) Land Cover Atlas

Examine land cover classifications

Access and Analyze NEX Datasets from

- NEX Sandbox
- Amazon Web Services
- Google Earth Engine
- PlanetOS
- Other platforms

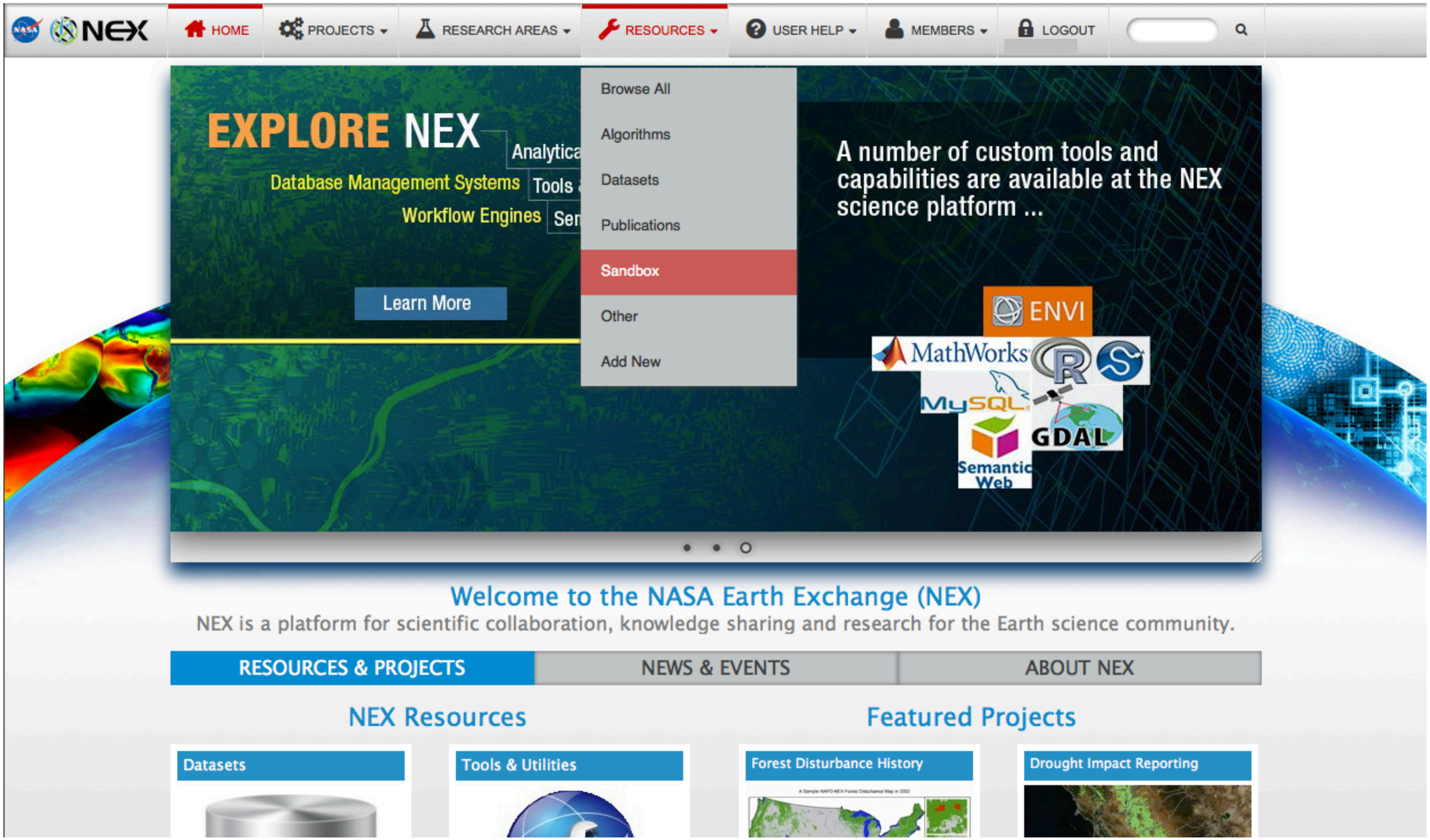
amazon web services

Google earth engine
a google.org project

PLANET OS

Getting an NEX Sandbox Account

Getting an NEX Sandbox Account (continued)



Getting an NEX Sandbox Account (continued)

HOME | PROJECTS | RESEARCH AREAS | RESOURCES | USER HELP | MEMBERS | LOGOUT

NEX Sandbox

The NEX team wants to see what users can do when they are given a computing platform with NEX datasets. The NEX Sandbox allows NEX users to run their own code using NEX datasets.

Getting a NEX Sandbox account

Please see the account sections below based on how you authenticate to the NEX Portal (NDC or OpenID) for steps to obtain an account. All accounts expire after six months of the account creation date.

NASA (NDC) Users

To obtain and use your NEX Sandbox account follow the steps below:

1. Complete the account request form
2. Log into the NEX Sandbox and do great things

Non-NASA (OpenID) Users

For OpenID users the NAS security team is requiring that their identity be vetted through an approved identity provider for level of assurance 2 (LOA2). OpenID authentication through Google is LOA1 so it is insufficient for the NEX Sandbox. The NEX team has chosen to use the LOA2 vetting service from Symantec (PDF).

Symantec will perform a credit check to verify your identity. To complete the vetting process with Symantec you will need the following:

1. Social Security Number
2. A phone number that can receive text messages. Symantec uses password and also sends a text message with a code for authentication to the Symantec site

Below are a the steps for obtaining a NEX Sandbox account:

1. Complete the account request form
2. Complete the LOA2 vetting process through Symantec
3. Log into the NEX Sandbox and do great things

If you have any questions or concerns about this process please contact us so we can help you.

Sandbox User Links

- Home
- Account Login Instructions
- Acceptable Use Guidelines
- Data Retention Guidelines
- System Availability
- User Documentation
- Contact Us

Sandbox System Status

All systems operational

Need help?
Visit our help center

Getting an NEX Sandbox Account (continued)

HOME | PROJECTS | RESEARCH AREAS | RESOURCES | USER HELP | MEMBERS | LOGOUT

NEX Sandbox Docs

A collection of useful documentation for NEX Sandbox users. If you cannot find what you are looking for please let us know.

How To Obtain Sandbox Account

Please review the process for obtaining a NEX Sandbox account:

1. Create a NEX portal account
2. Complete the NEX Sandbox account request form (login required)
3. Log into the NEX Sandbox and do great things!

All accounts expire after six months of the account creation date.

How To Login

Please review the login process for whatever type of account (NDC or OpenID + Symantec) that you have:

NASA (NDC) Users

1. ssh username@sandbox.nas.nasa.gov
2. When prompted for your password use your NDC password

Non-NASA (OpenID + Symantec) Users

1. Navigate to the login page. Follow the instructions to authenticate with Symantec
2. After authenticating with Symantec you will be sent to the NEX authentication server NEX Pass
3. NEX Pass will generate a one-time password that you will use when logging into the sandbox.nas.nasa.gov system
4. ssh username@sandbox.nas.nasa.gov
5. When prompted for your password use your NEX Sandbox password
6. When prompted for you NEX one-time password enter in the NEX one-time password that was generated and displayed in step 3

Account Limits

Sandbox User Links

- Home
- Account Login Instructions
- Acceptable Use Guidelines
- Data Retention Guidelines
- System Availability
- **User Documentation**
- Contact Us

Sandbox System Status

All systems operational

Need help?
Visit our **help center**

Logging in and Setting up the Environment

```
[unknown28cfdaf35c22:~]$ ssh -Y <Your_Username>@sandbox.nas.nasa.gov

--------------------------------------------------------------------------

This US Government computer is for authorized users only.  By accessing
this system you are consenting to complete monitoring with no expectation
of privacy.  Unauthorized access or use may subject you to disciplinary
action and criminal prosecution.

--------------------------------------------------------------------------


Password:
Last login: Tue Jul 19 23:20:44 2016 from 76-198-130-184.lightspeed.mtvwca.sbcglobal.net
[sandbox:~]$ ls
SummerSchool_2016  datapool
[sandbox:~]$ cd SummerSchool_2016/
[sandbox:SummerSchool_2016]$ ls
GDDP  GRACE  POINT_BC  SOFTWARE  environ.sh
[sandbox:SummerSchool_2016]$ source environ.sh
[sandbox:SummerSchool_2016]$ module avail

---------------------------- /usr/share/Modules/modulefiles ----------------------------
dot          module-git  module-info modules     null        use.own

----------------------------------- /etc/modulefiles -----------------------------------
openmpi-1.10-x86_64 openmpi-1.8-x86_64  openmpi-x86_64
[sandbox:SummerSchool_2016]$ module load openmpi-1.10-x86_64
[sandbox:SummerSchool_2016]$ 
```

Example 1: Bias-Correction of Climate Projection

```
[sandbox:SummerSchool_2016]$ ls
GDDP   GRACE   POINT_BC   SOFTWARE   environ.sh
[sandbox:SummerSchool_2016]$ cd POINT_BC/
[sandbox:POINT_BC]$ ls
MoffettField   Sangamner_India
[sandbox:POINT_BC]$ cd Sangamner_India/
[sandbox:Sangamner_India]$ ls
bc   mdl   obs
[sandbox:Sangamner_India]$ cd obs
[sandbox:obs]$ ls
compile_daily.py   local_day_clim_obs.csv   source_climate_india.csv
latlon.txt         local_day_clim_obs.png
```

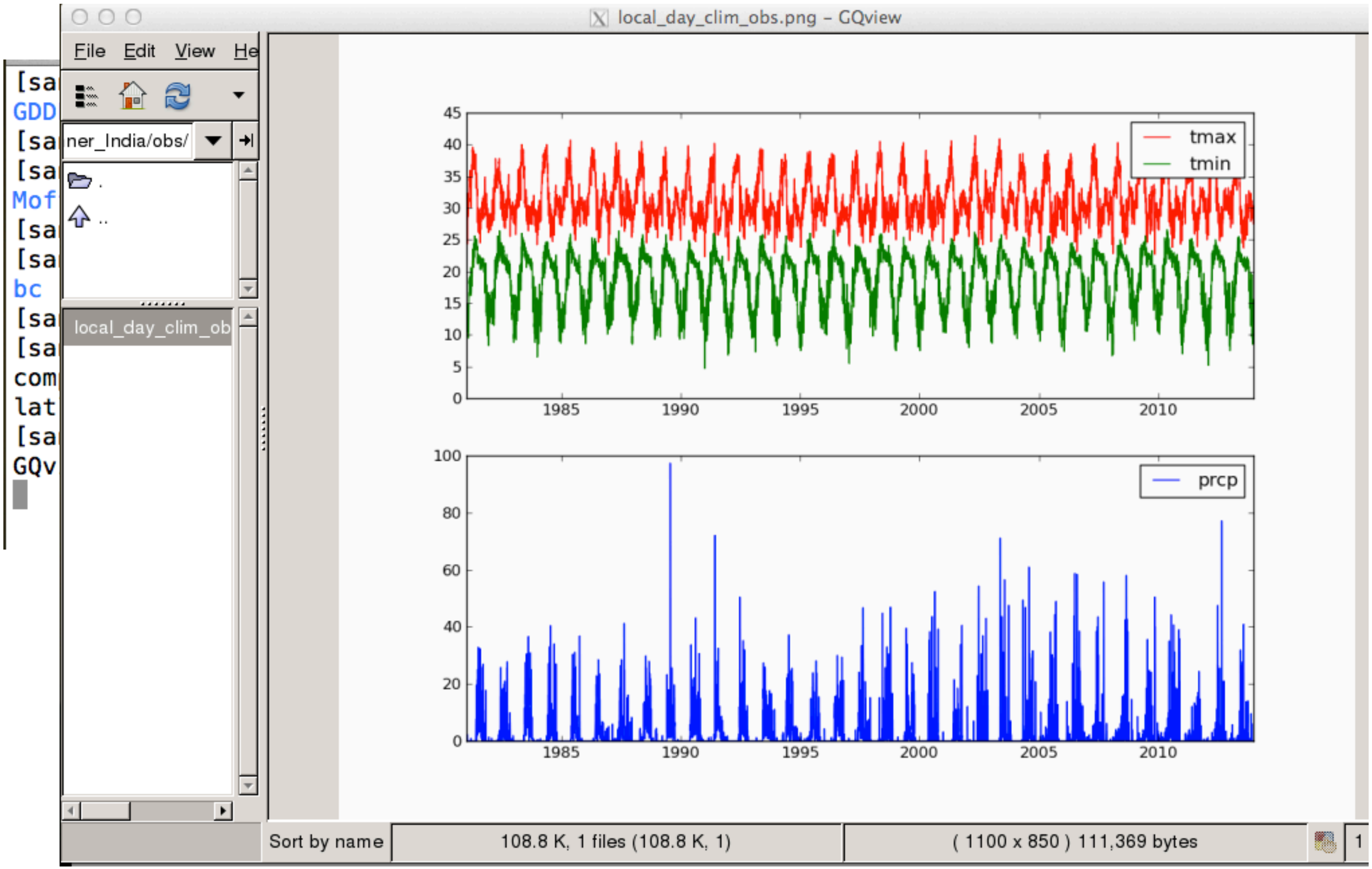
I am using the India case as the example. The Moffett Field case will be left as an exercise.

Observational Climate Records

```
[sandb
GDDP
[sandb
[sandb
Moffet
[sandb
[sandb
bc  mo
[sandb
[sandb
compil
latlon
[sandb
```

```
year, month, day, doy, tasmax, tasmin, pr
1981, 01, 01, 001, 2.840000e+01, 1.450000e+01, 0.000000e+00
1981, 01, 02, 002, 2.920000e+01, 1.440000e+01, 0.000000e+00
1981, 01, 03, 003, 2.960000e+01, 1.340000e+01, 0.000000e+00
1981, 01, 04, 004, 2.910000e+01, 1.290000e+01, 0.000000e+00
1981, 01, 05, 005, 2.940000e+01, 1.410000e+01, 0.000000e+00
1981, 01, 06, 006, 2.940000e+01, 1.270000e+01, 0.000000e+00
1981, 01, 07, 007, 2.770000e+01, 1.260000e+01, 0.000000e+00
1981, 01, 08, 008, 2.680000e+01, 8.800000e+00, 0.000000e+00
1981, 01, 09, 009, 2.550000e+01, 8.600000e+00, 0.000000e+00
1981, 01, 10, 010, 2.450000e+01, 1.060000e+01, 0.000000e+00
1981, 01, 11, 011, 2.530000e+01, 1.290000e+01, 0.000000e+00
1981, 01, 12, 012, 2.410000e+01, 1.310000e+01, 0.000000e+00
1981, 01, 13, 013, 2.440000e+01, 1.150000e+01, 0.000000e+00
1981, 01, 14, 014, 2.560000e+01, 1.140000e+01, 0.000000e+00
1981, 01, 15, 015, 2.670000e+01, 1.120000e+01, 0.000000e+00
1981, 01, 16, 016, 2.790000e+01, 1.260000e+01, 0.000000e+00
1981, 01, 17, 017, 2.900000e+01, 1.490000e+01, 0.000000e+00
1981, 01, 18, 018, 2.490000e+01, 1.390000e+01, 2.300000e+00
1981, 01, 19, 019, 2.430000e+01, 1.230000e+01, 0.000000e+00
1981, 01, 20, 020, 2.600000e+01, 1.170000e+01, 0.000000e+00
1981, 01, 21, 021, 2.760000e+01, 1.160000e+01, 0.000000e+00
1981, 01, 22, 022, 2.880000e+01, 1.170000e+01, 0.000000e+00
1981, 01, 23, 023, 2.940000e+01, 1.220000e+01, 0.000000e+00
1981, 01, 24, 024, 2.830000e+01, 1.380000e+01, 0.000000e+00
1981, 01, 25, 025, 2.810000e+01, 1.330000e+01, 0.000000e+00
local_day_clim_obs.csv                                       1,1
"local_day_clim_obs.csv" 12411L, 744642C
```

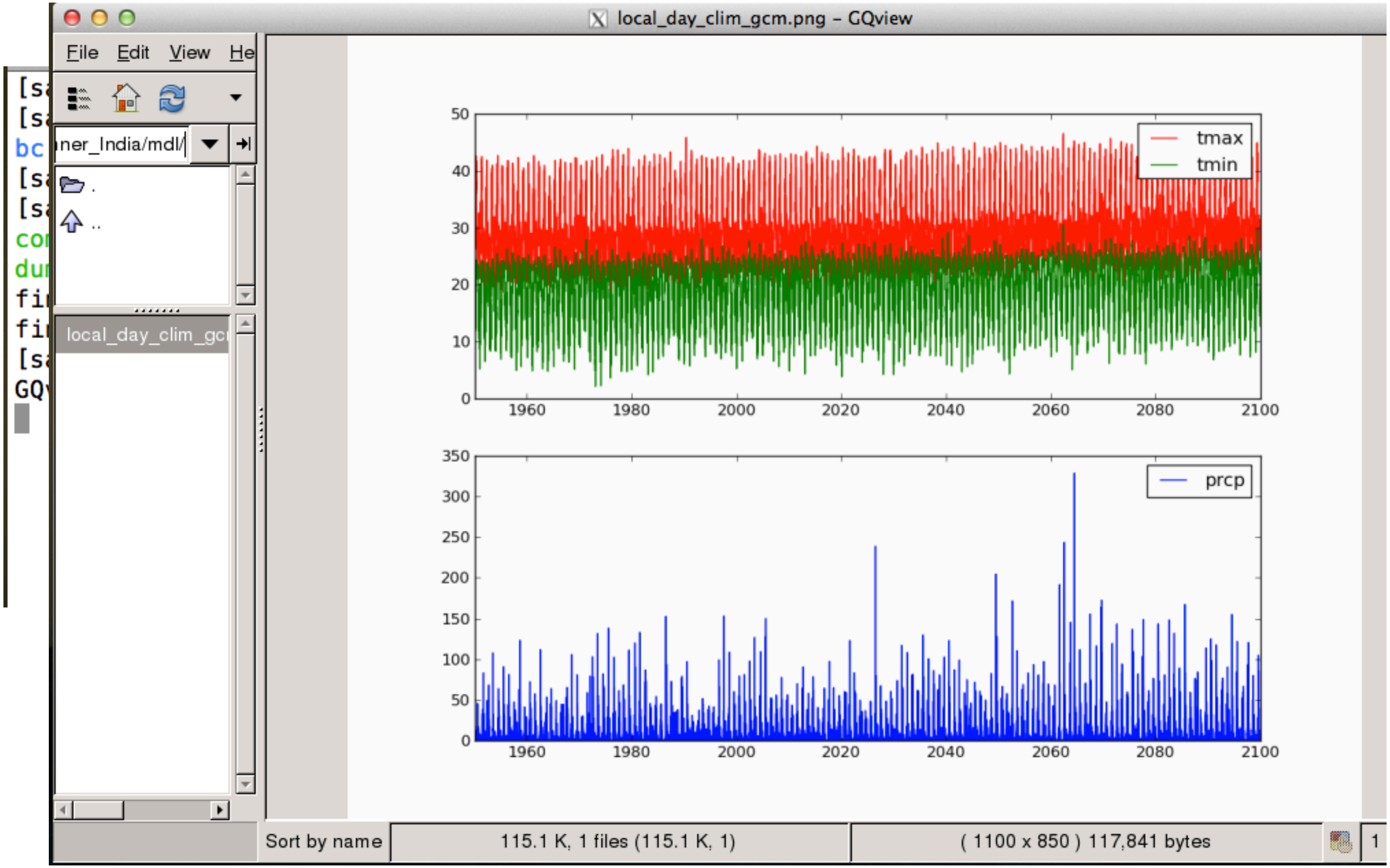
Observational Climate Records



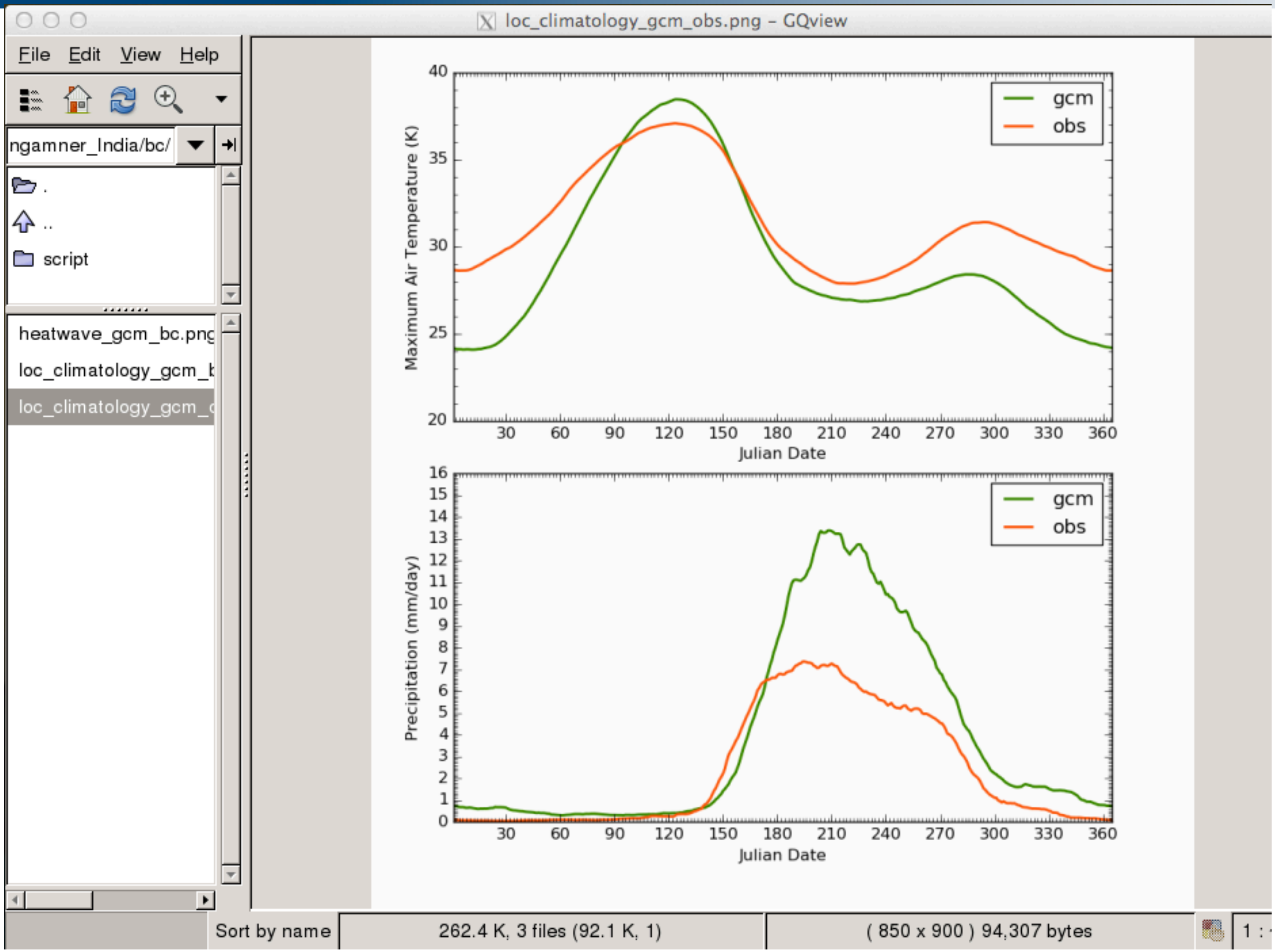
Corresponding GCM Simulations

```
[sandbox:obs]$ cd ..
[sandbox:Sangamner_India]$ ls
bc  mdl  obs
[sandbox:Sangamner_India]$ cd mdl
[sandbox:mdl]$ ls
combine_daily_ts.py      fin_list.tasmin         local_day_gcm_tasmax.csv
dump_day_climate_gcm.py  local_day_clim_gcm.csv  local_day_gcm_tasmin.csv
fin_list.pr              local_day_clim_gcm.png
fin_list.tasmax          local_day_gcm_pr.csv
[sandbox:mdl]$ gqview local_day_clim_gcm.png
GQview 2.1.5, This is a beta release.
```

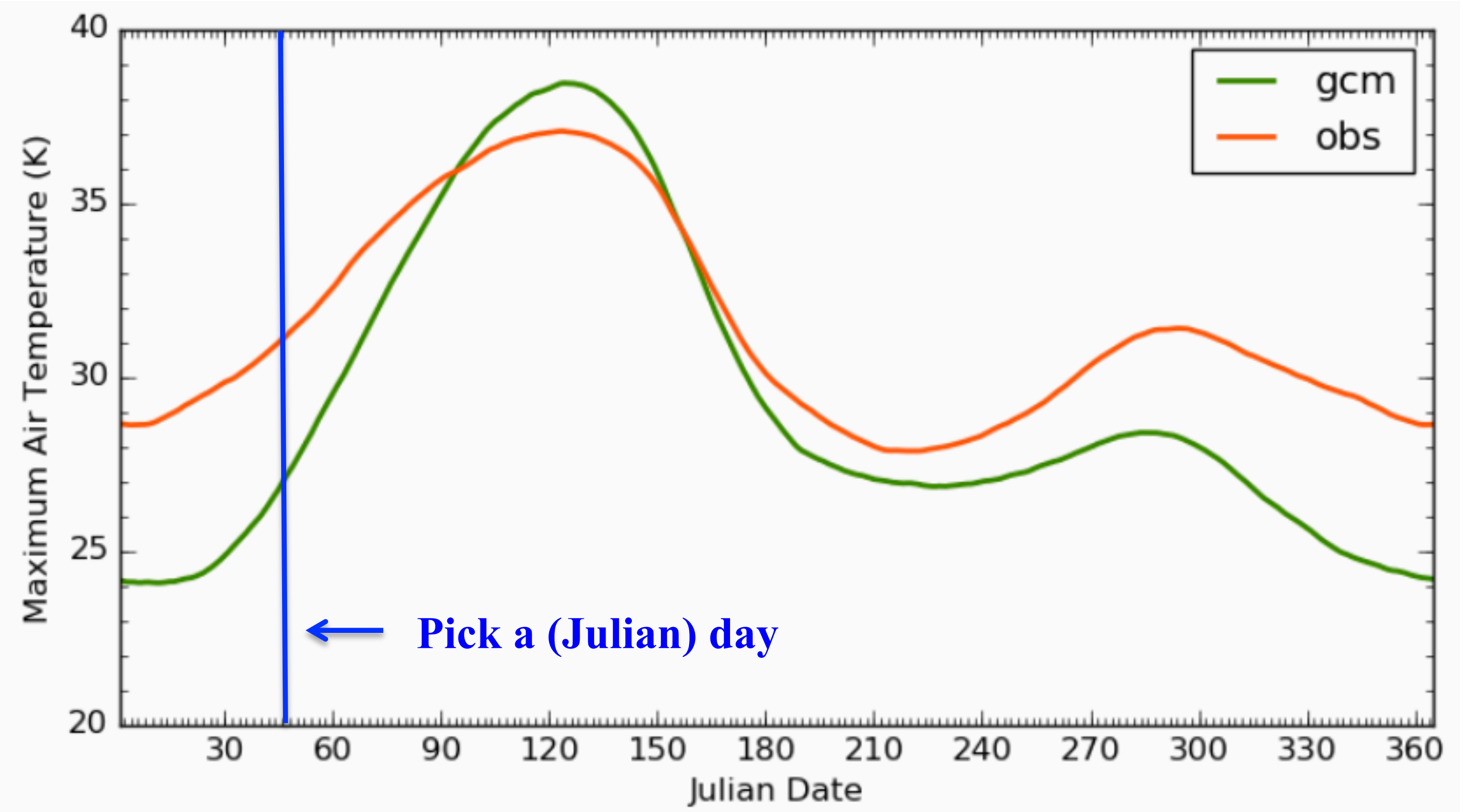
Corresponding GCM Simulations



Observation vs. Simulation: Climatology

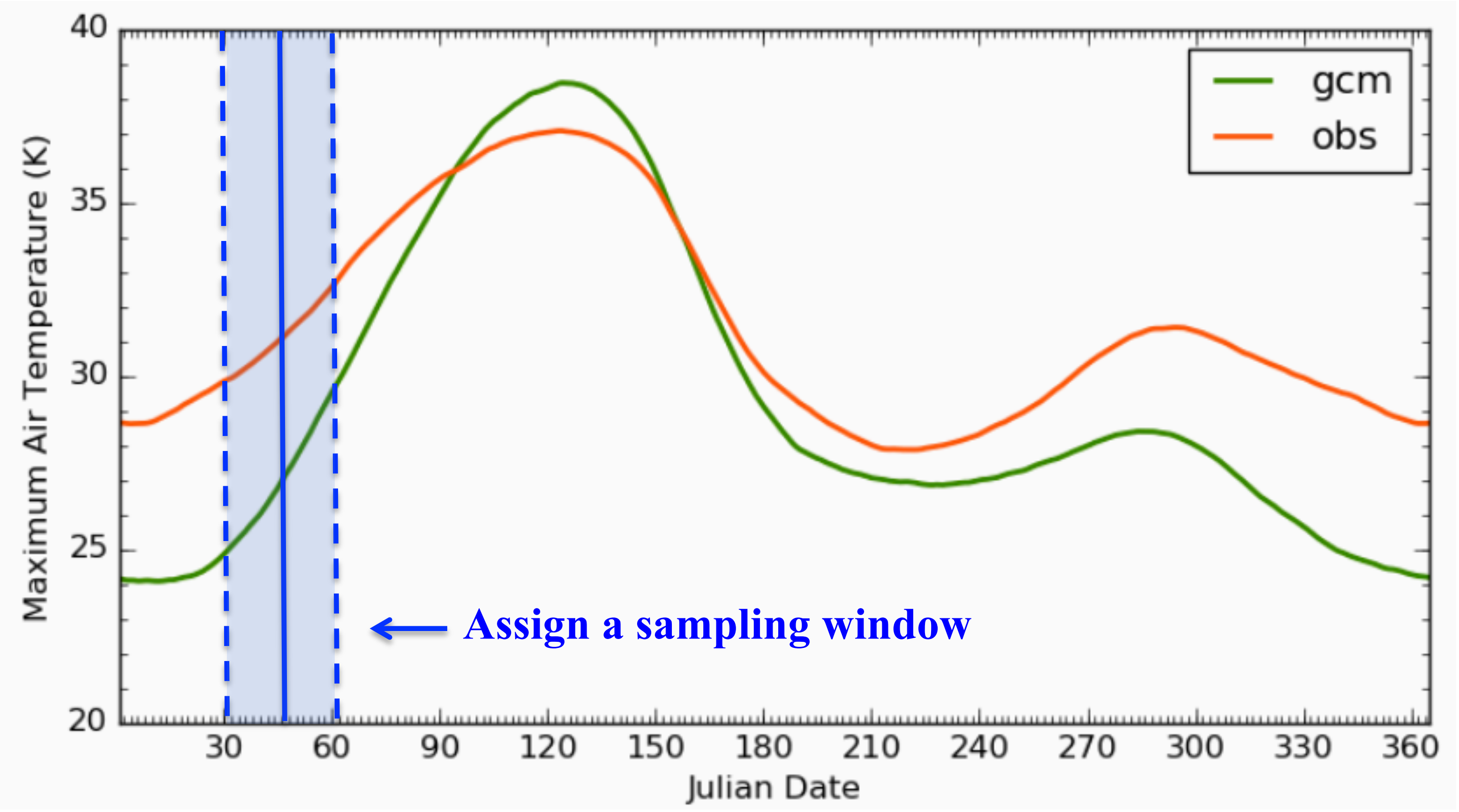


Bias-Correction Step by Step



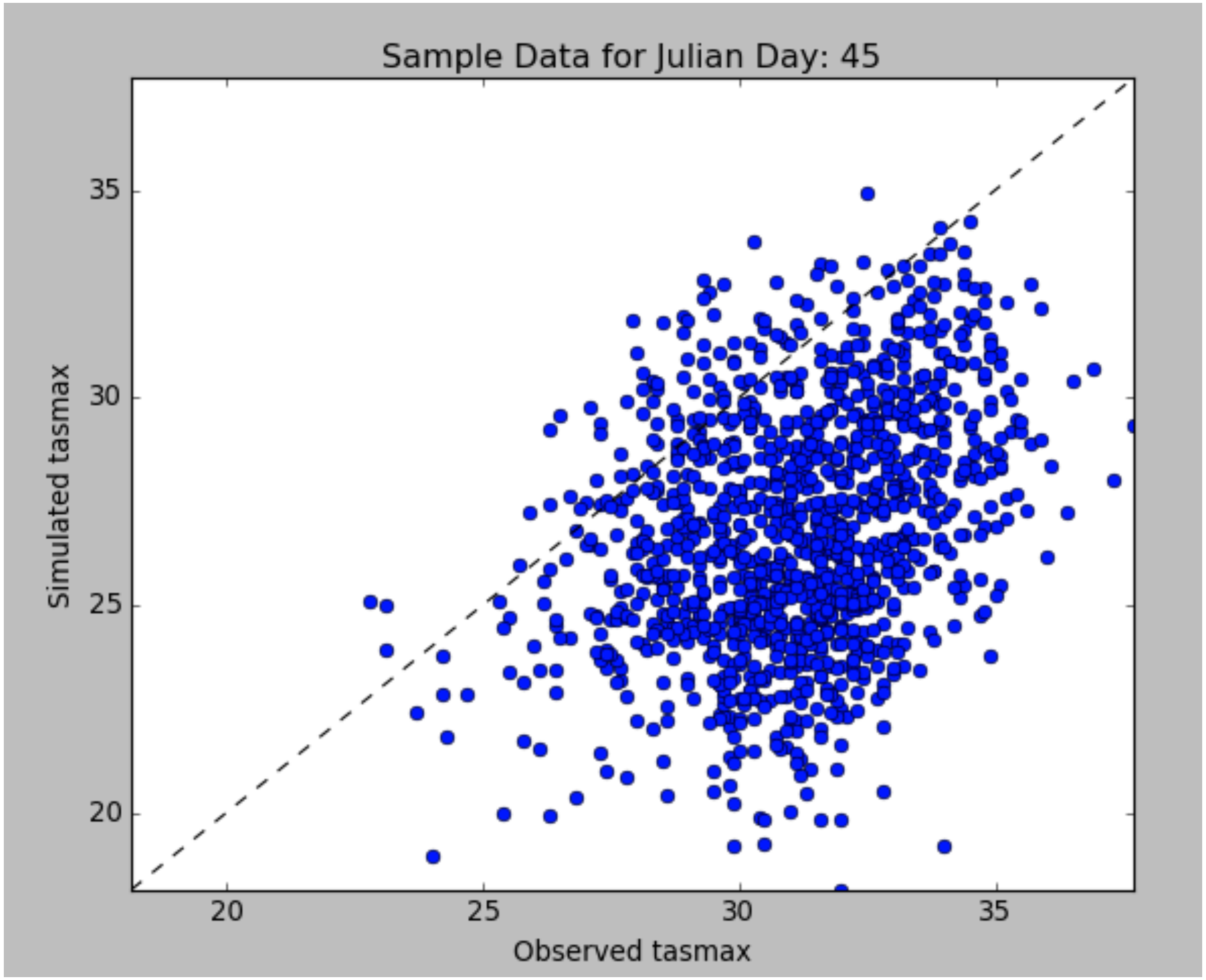
Question: How many sample points do you have for a particular J-day?

Bias-Correction Step by Step (continued)

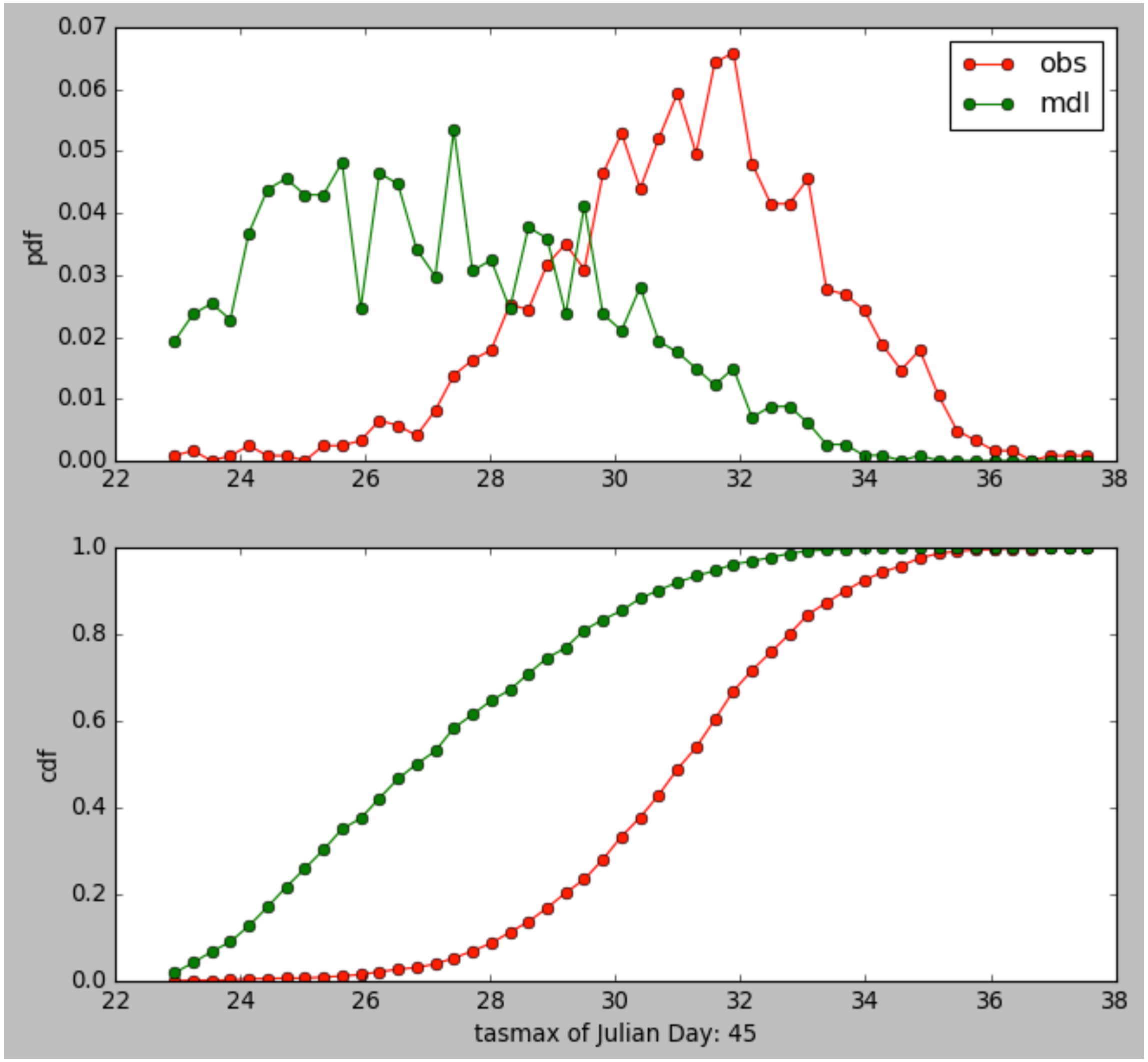


Solution: Use a window to increase the number of samples

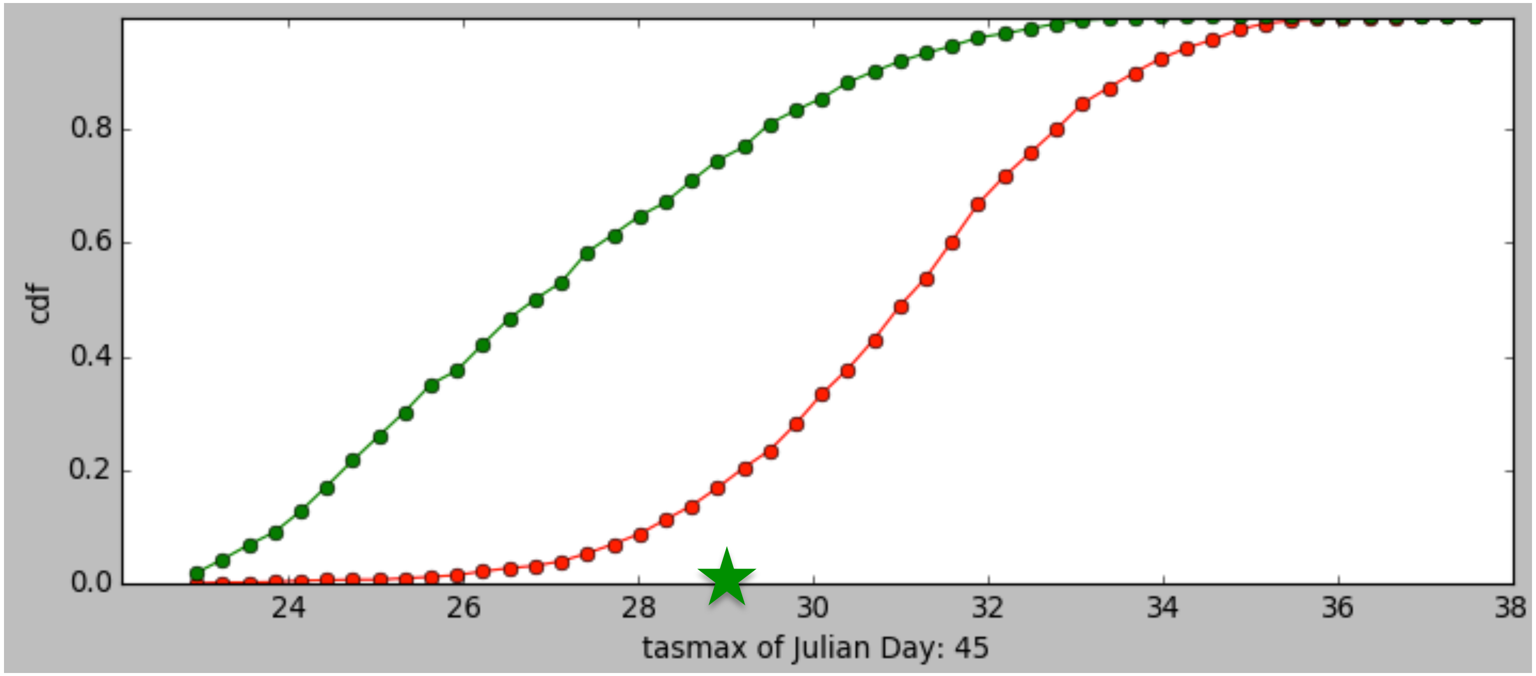
First Look of the Data



Generating PDF and CDF

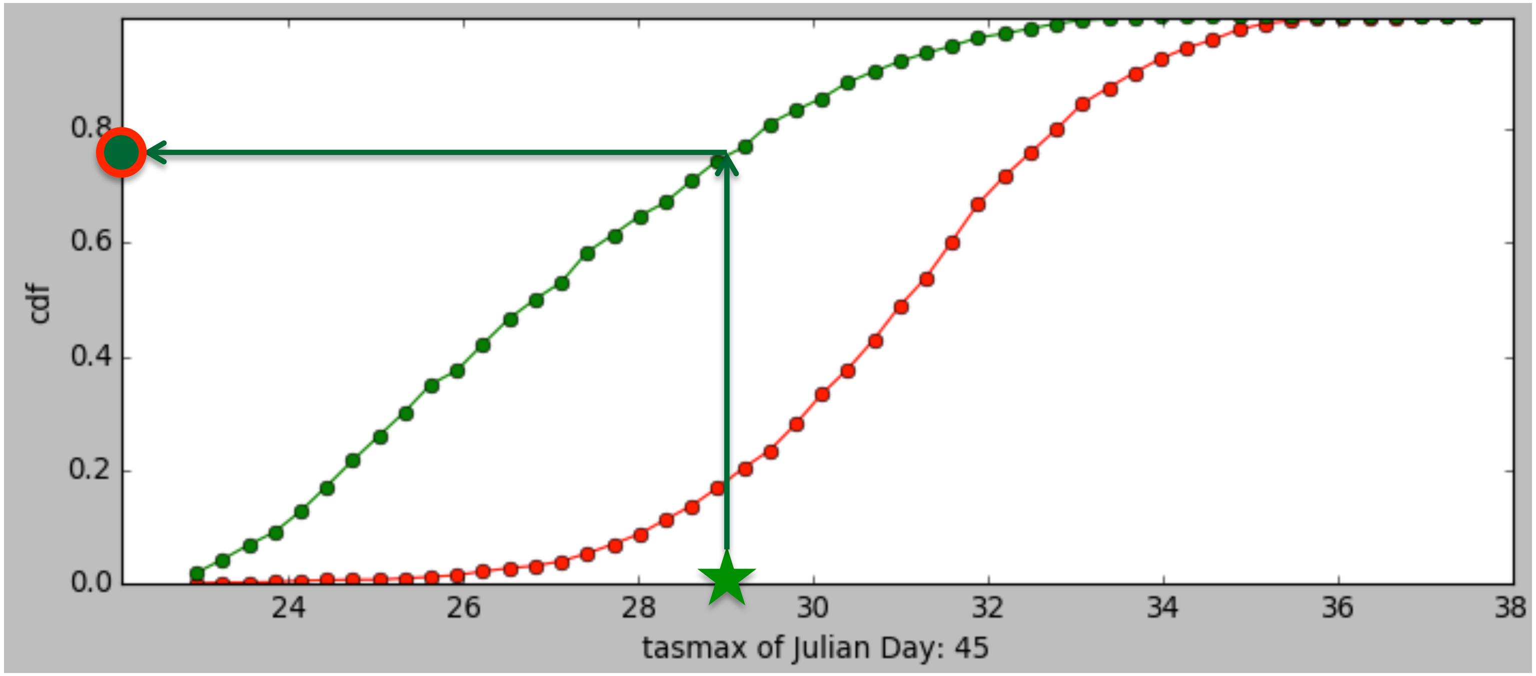


Quantile Mapping with CDF



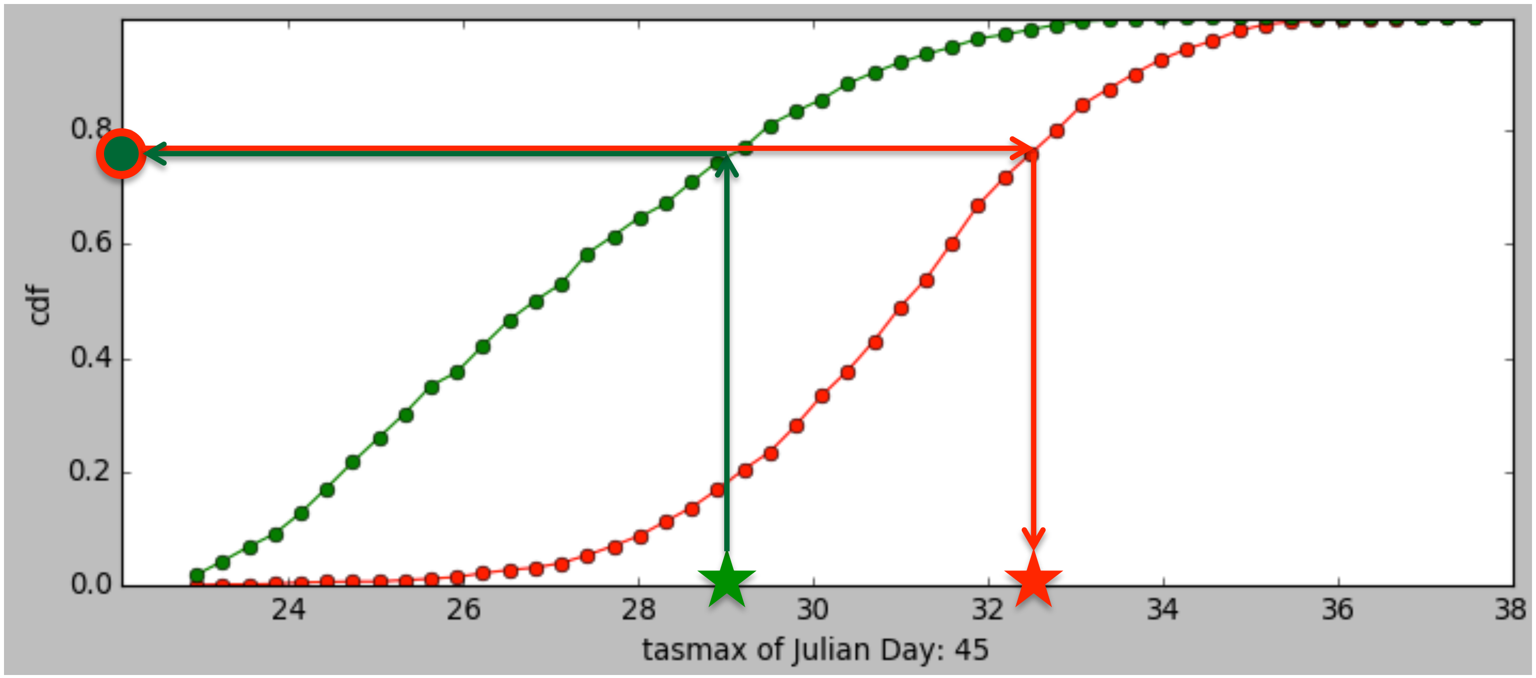
1. For a (raw) simulated T_raw of 29°C

Quantile Mapping with CDF



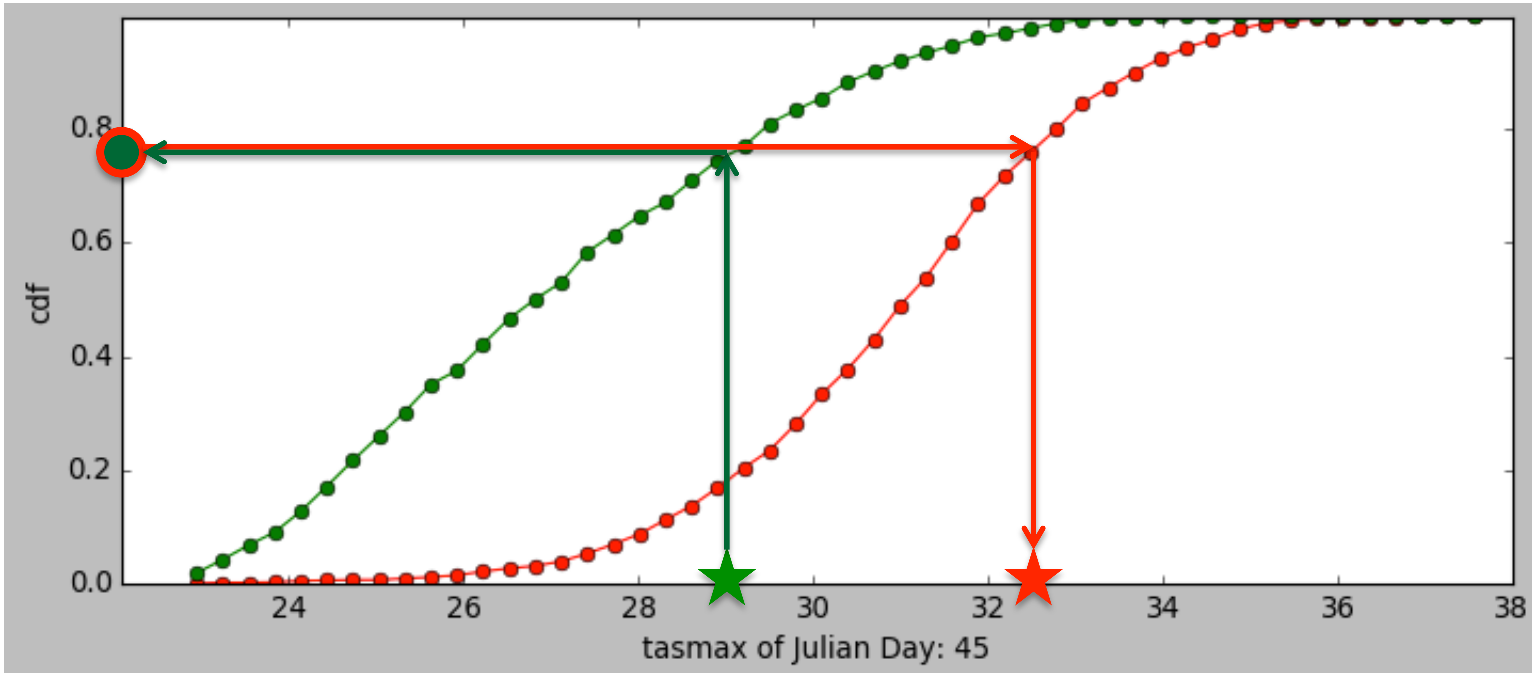
1. For a (raw) simulated T_raw of 29°C
2. Find the probability p(T<T_raw) = 0.78 based on CDF_gcm

Quantile Mapping with CDF



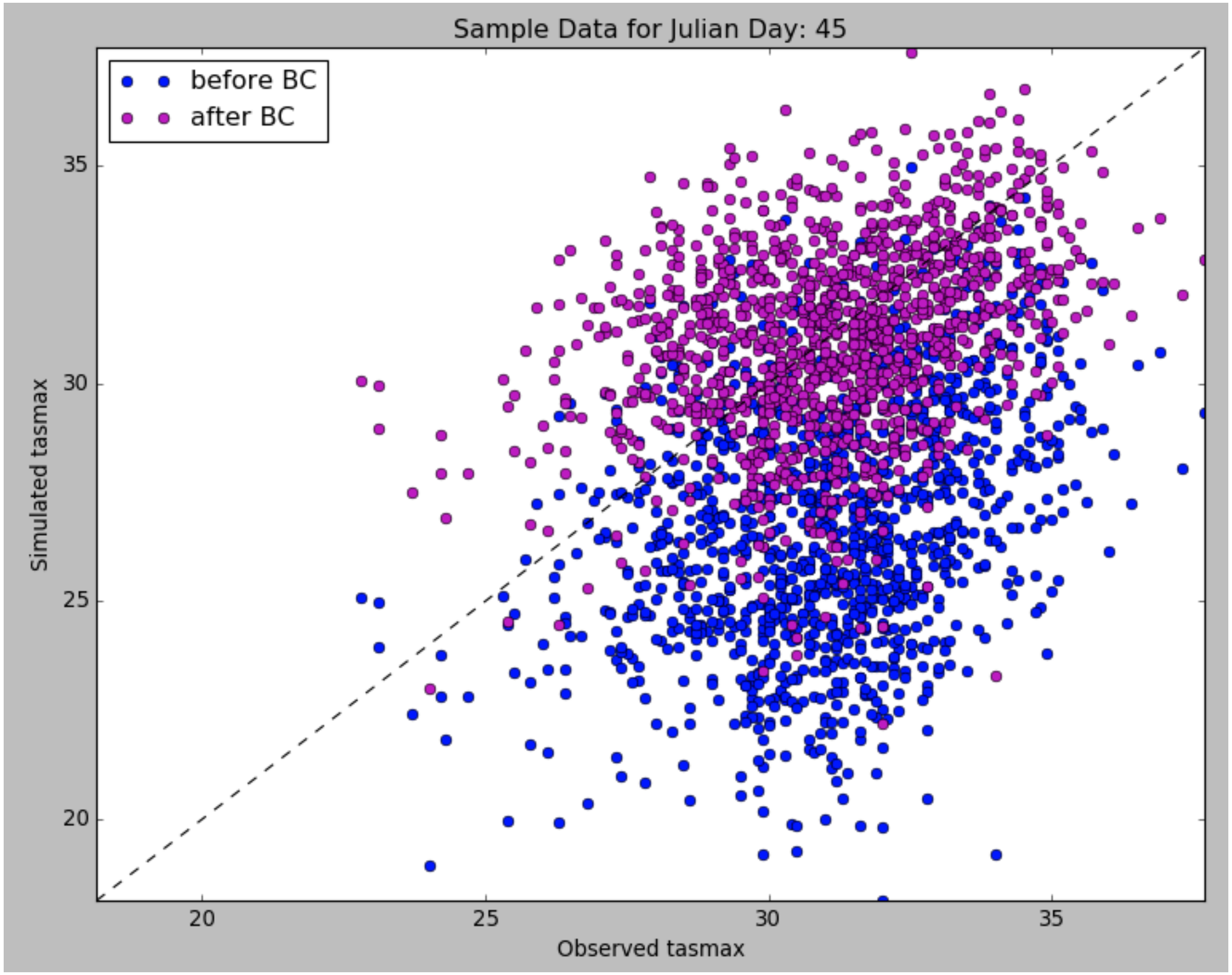
1. For a (raw) simulated T_raw = 29°C
2. Find the probability *p*(T<T_raw) = 0.78 based on CDF_gcm
3. On CDF_obs, find T_obs = 32.5°C, such that *p*(T<T_obs) = 0.78

Quantile Mapping with CDF

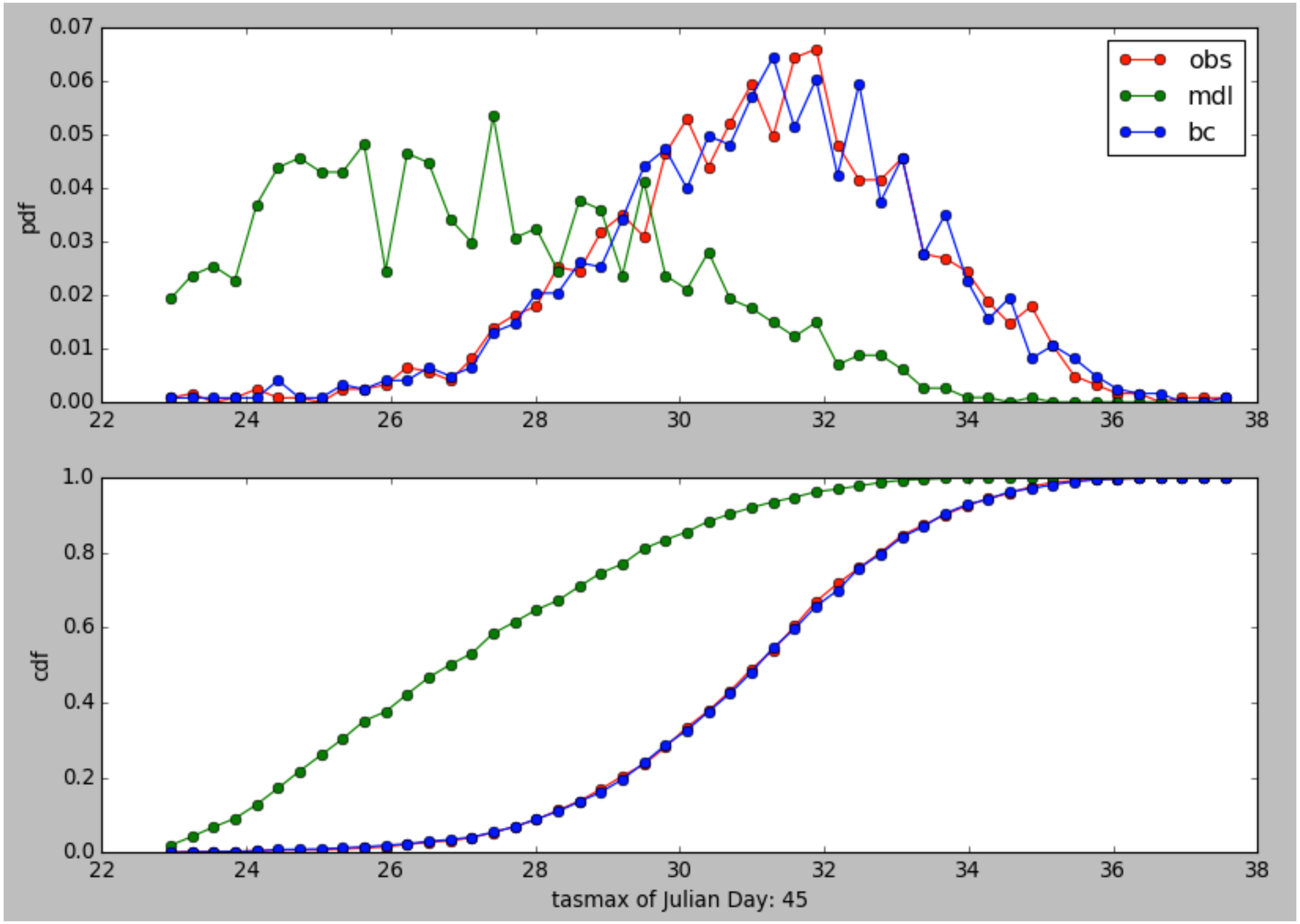


1. For a (raw) simulated T_raw = 29°C
2. Find the probability p(T<T_raw) = 0.78 based on CDF_gcm
3. On CDF_obs, find T_obs = 32.5°C, such that p(T<T_obs) = 0.78
4. Assign the bias-corrected simulation T_bc to 32.5°C

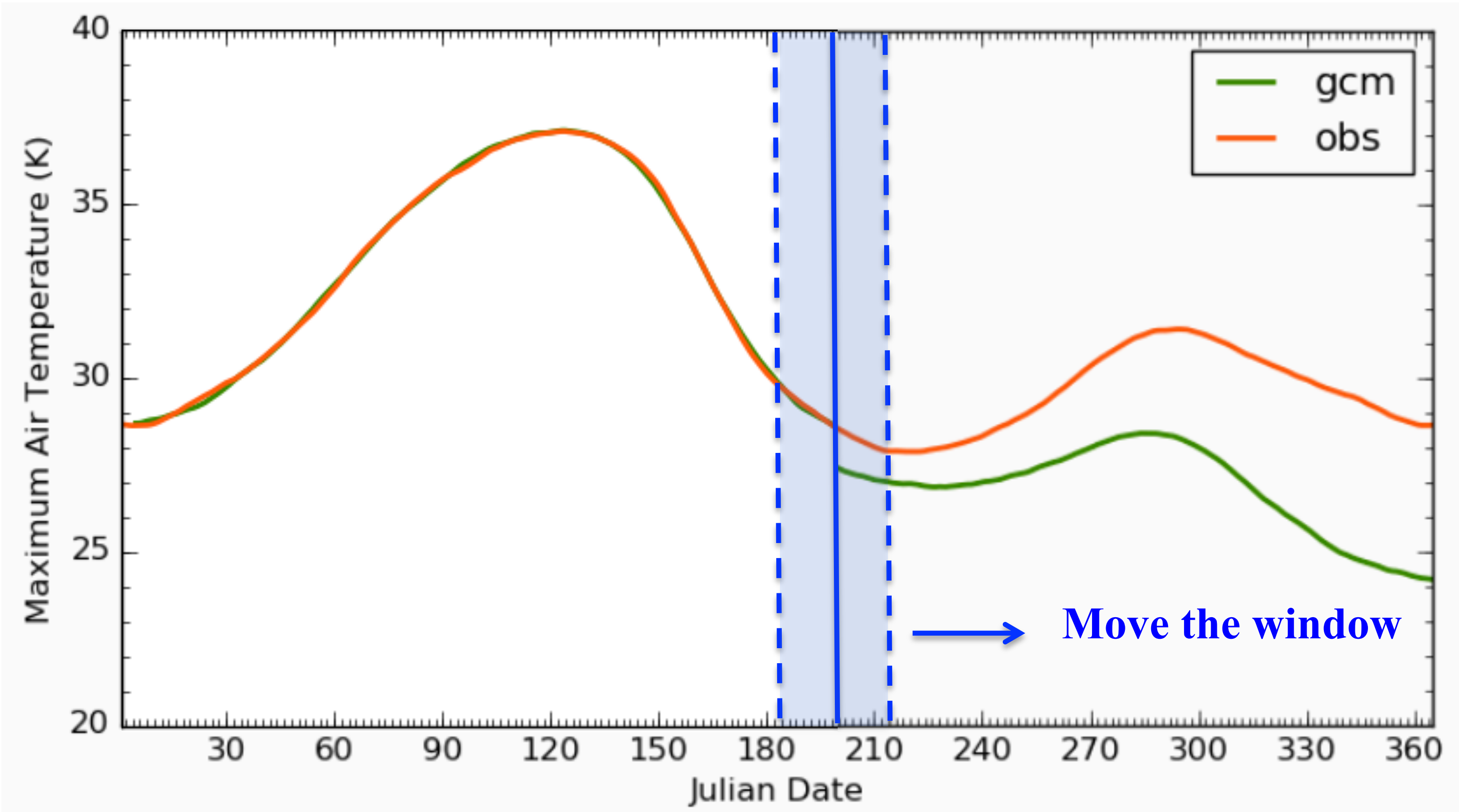
The Results: Scatter-Plot



The Results: PDF and CDF



Bias-Correction for All Days



Repeat the process for every day and you are (almost) done!

The Python Code

```
[sandbox:Sangamner_India]$ ls
bc  mdl  obs
[sandbox:Sangamner_India]$ cd bc/script/
[sandbox:script]$ ls -1
bias_correction_daily.py
bias_correction_test.py
calc_daily_climatology.py
count_heatwave_annual.py
plot_daily_climatology.py
[sandbox:script]$
```

```
#------------------------------------------------------------
if __name__ == '__main__':

    # for simplicity, below we used some "hard-coded" argu
    # we will use the period 1950 - 2006 as the baseline t
    baseyr_s = 1981
    baseyr_e = 2010

    jday_test = 45
    DOY = 365
    var = 'tasmax'

    # 1. load the observation data
    fdata = 'local_day_clim_obs.csv'
    nmeta_obs = 1
    data = numpy.loadtxt(fdata, dtype='f4', delimiter=',',
    year_obs  = data[:, IDX_LIST['year']].astype('i4')
    doy_obs  = data[:, IDX_LIST['doy']].astype('i4')
    yr_s_obs = year_obs[0]
    yr_e_obs = year_obs[-1]
    nyrs = yr_e_obs - yr_s_obs + 1
    clm_obs  = data[:, IDX_LIST[var]]
    clm_obs = clm_obs.reshape(nyrs, DOY)
    year_obs = year_obs.reshape(nyrs, DOY)
    doy_obs = doy_obs.reshape(nyrs, DOY)
    # adjust the data to baseline years
bias_correction_test.py
```

The Python Code

```python
# 3. process the data for the specified jday
NWIN_DAY = 40
jday_array = numpy.arange(1, DOY+1, dtype='i4')

jd = jday_test
jd_mask = calc_daily_mask(jd, jday_array, NWIN_DAY)

x_obs = clm_obs.compress(jd_mask, axis=-1)
y_mdl = clm_mdl.compress(jd_mask, axis=-1)

if var.lower() == 'pr':
    detrend = False
else:
    detrend = True
#fi
y_bc = bc_cdf_match(x_obs, y_mdl, indx_s, indx_e, detrend)
```

bias_correction_test.py 272,1

The Python Code

```
def bc_cdf_match(x_obs, y_mdl, base_s, base_e, detrend=True, cdf_smooth=True):
    # detrend the data
    (mask_obs, trend_obs, anom_obs) = safe_detrend(x_obs, detrend)
    (mask_mdl, trend_mdl, anom_mdl) = safe_detrend(y_mdl, detrend)
    mask_base = mask_mdl[base_s:base_e] & mask_obs

    anom_obs = anom_obs.compress(mask_base, axis=0)
    trend_obs = trend_obs.compress(mask_base)
    anom_mdl2 = anom_mdl[base_s:base_e].compress(mask_base, axis=0)
    trend_mdl2 = trend_mdl[base_s:base_e].compress(mask_base)

    # calculate the CDFs for the obs and the base data
    (N, M) = anom_obs.shape
    cdf_obs, bin_obs, bin_obs_e = calc_cdf(anom_obs.flatten(), (N*M)/2, cdf_smooth)
    cdf_mdl2, bin_mdl2, bin_mdl2_e = calc_cdf(anom_mdl2.flatten(), (N*M)/2, cdf_smooth)

    (N, M) = anom_mdl.shape
    # mapping anom_mdl to probabilities with CDF_mdl2
    prob_mdl = val2cdf(cdf_mdl2, bin_mdl2, anom_mdl.flatten())
    # and then re-mapping it back to corrected climate anomalies using CDF_obs
    anom_mdl = cdf2val(cdf_obs, bin_obs, prob_mdl)

    # adjust the mean of the trend in the base window
    trend_mdl += (trend_obs.mean() - trend_mdl2.mean())
    anom_mdl = anom_mdl.reshape(N, M)
    for i in range(M):
        anom_mdl[:, i] += trend_mdl
    # end_for

    return anom_mdl.copy()
# end_def bc_cdf_match
bias_correction_test.py [+]                                  162,4          55%
```

Exercises

1. Apply the provided codes to bias correct climate projections for Moffett Field, California (observations and GCM simulations are provided);

2. Apply the provided code to analyze future changes of heat-wave frequency and intensity based on GCM projections before and after bias corrections.

Discussion Questions

1. **Temporal Stationary Assumption:** in correcting future climate projections, the bias-correction methodology assumes that the PDFs/CDFs of the climate variables are largely stationary in time. But ***climate is changing***! How should we address this issue? Discuss possible solutions in terms of their pros and cons.

2. **Spatial Scale Differences between observations and simulations:** In-situ climate observations are influenced by localized meteorological conditions and often have large variability. In comparison, climate variables from GCM simulations represent the "mean" state over large (~100km) grid cells. With such spatial scale differences considered, should we directly compare GCM projections with observations from individual stations? Or what do you think may be a better approach?

Discussion Questions (continued)

3. **Spatial Disaggregation:**in practice most downscaling procedures need to interpolate/extrapolate bias-corrected climate projections to higher-resolution grid points. There are multiple algorithms to achieve this task, including Spatial Disaggregation (SD), Constructed Analogs (CA), and Localized Constructed Analogs (LOCA). Read the references provided below and discuss the features of these methods, respectively.

4. **Uncertainty Evaluation:** Think about how to evaluate the skills and uncertainties of different downscaling methods. Indeed, this is a difficult research problem. The NCPP 2013 Downscaling Workshop (https://www.earthsystemcog.org/projects/downscaling-2013/) was dedicated to this problem. Read/watch the presentations from the workshop website and pick a topic that is particularly interesting to you to discuss in the class.

Thank You!

(Stay tuned for more NEX workshop hands-on lectures!)