Climate Change Projections for the Lake Champlain Basin

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August 5, 2014

Vermont EPSCoR

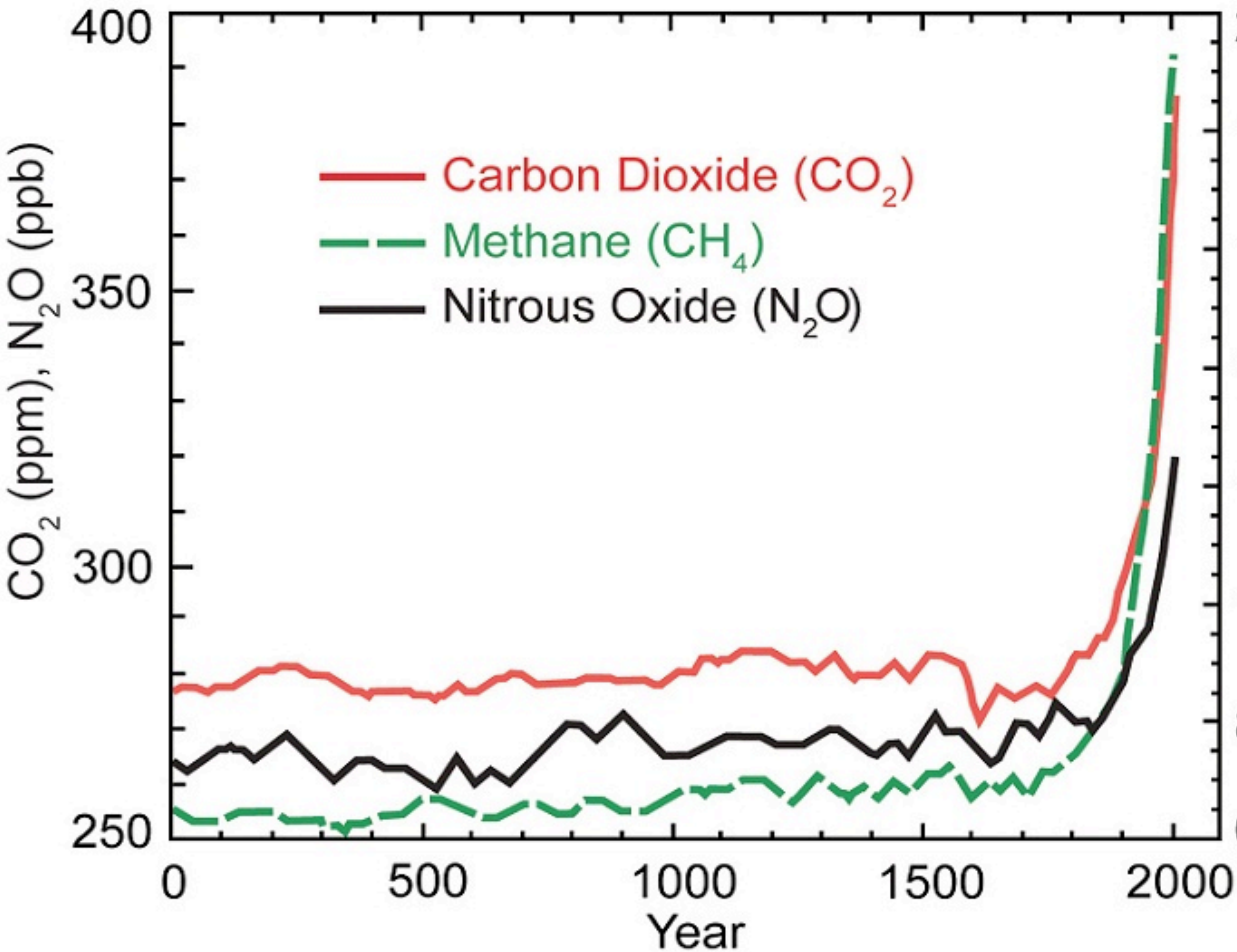
Experimental Program to Stimulate Competitive Research

The University of Vermont

Columbia University in the City of New York

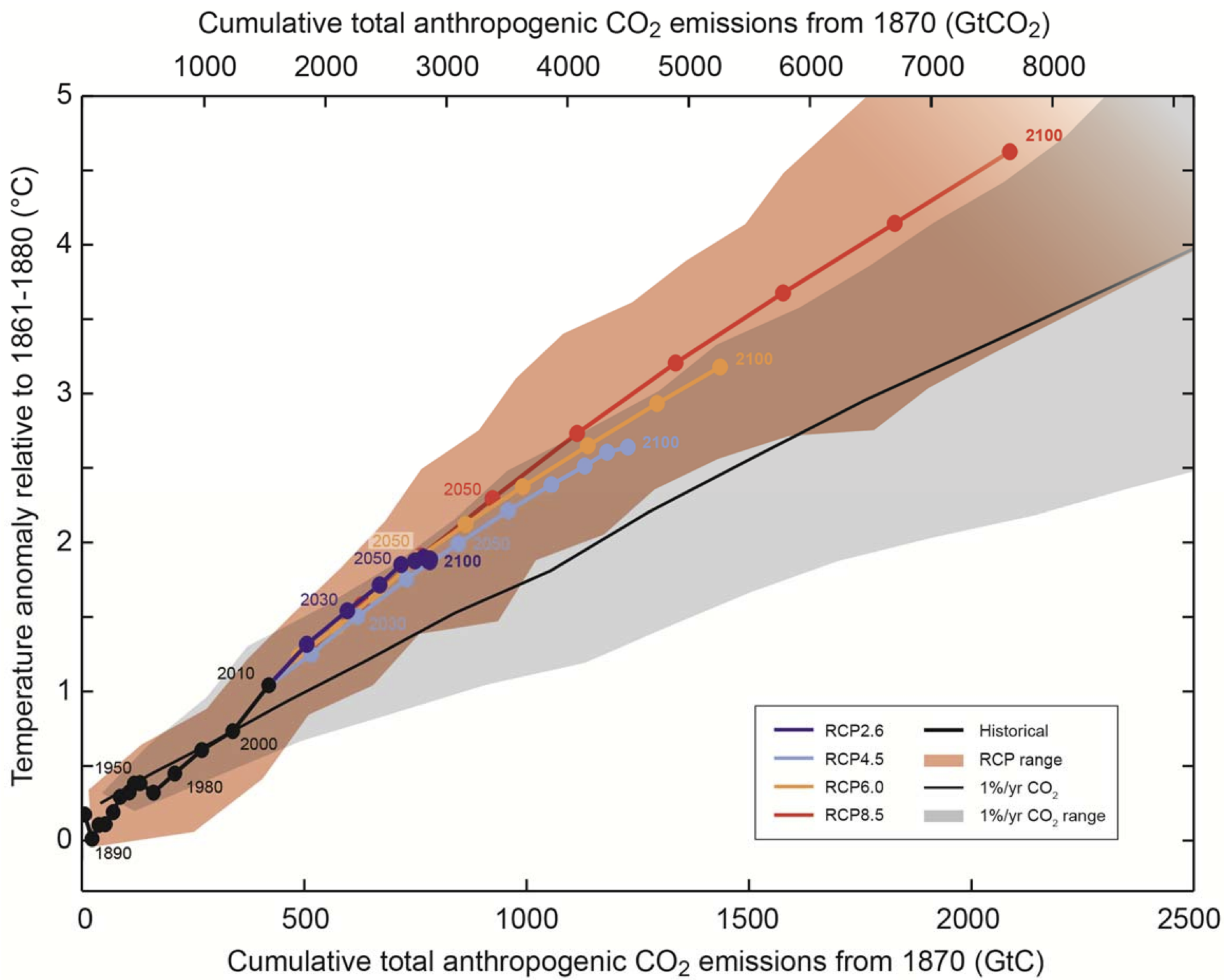
Dartmouth

Greenhouse Gas Concentrations Are Increasing



Source: USGCRP, 2009

Greenhouse Gas Concentrations Will Continue to Increase in the Future



Source: IPCC Fifth Assessment Report, 2013

VT EPSCoR Climate Team Key Questions

- How well can we simulate climate using numerical models?
- What is the local response of precipitation and temperature to climate change?
- What are the critical uncertainties in predicting climate change impacts?

Source: The Nature Conservancy

Global Climate Models (GCMs) Predict Temperature and Precipitation

- GCMs solve the primitive equations (conservation of momentum, mass, and energy) to simulate fluid flow on a spherical surface
- Can be atmospheric (AGCM), oceanic (OGCM) or coupled atmospheric-oceanic general circulation models (AOGCM)
- AOGCMs are the core of full climate models
- Global spatial coverage
- Contain significant inaccuracies, coarse resolution



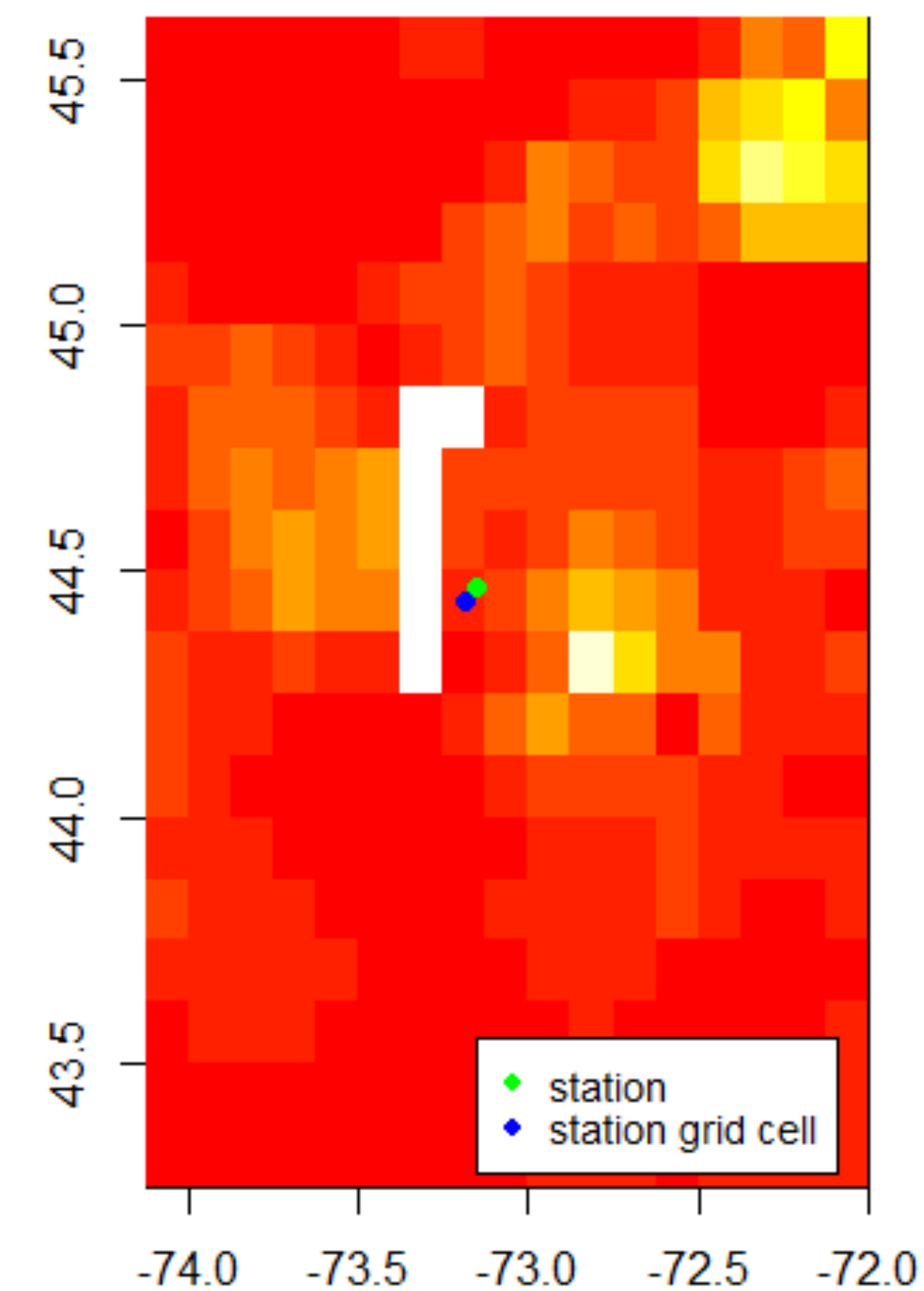
Atmospheric Radiation
Convective Clouds and Precipitation
Resolvable Scale Clouds and Precipitation
Planetary Boundary Layer
Ocean Model (AOGCM) or Fixed Sea Surface Temperatures with Ocean Flux Parameterization (AGCM)
Surface Physics

Statistical Downscaling Bias Corrects and Increases Resolution of GCM Projections

- Bias correct and downscale GCM data based on interpolated station observations
- Removes some inaccuracies of GCMs
- Increases spatial resolution, but limits spatial coverage
- Multiple methods and target observational datasets
- Statistically downscaled climate projections constrained by observational record or extrapolations of observational record

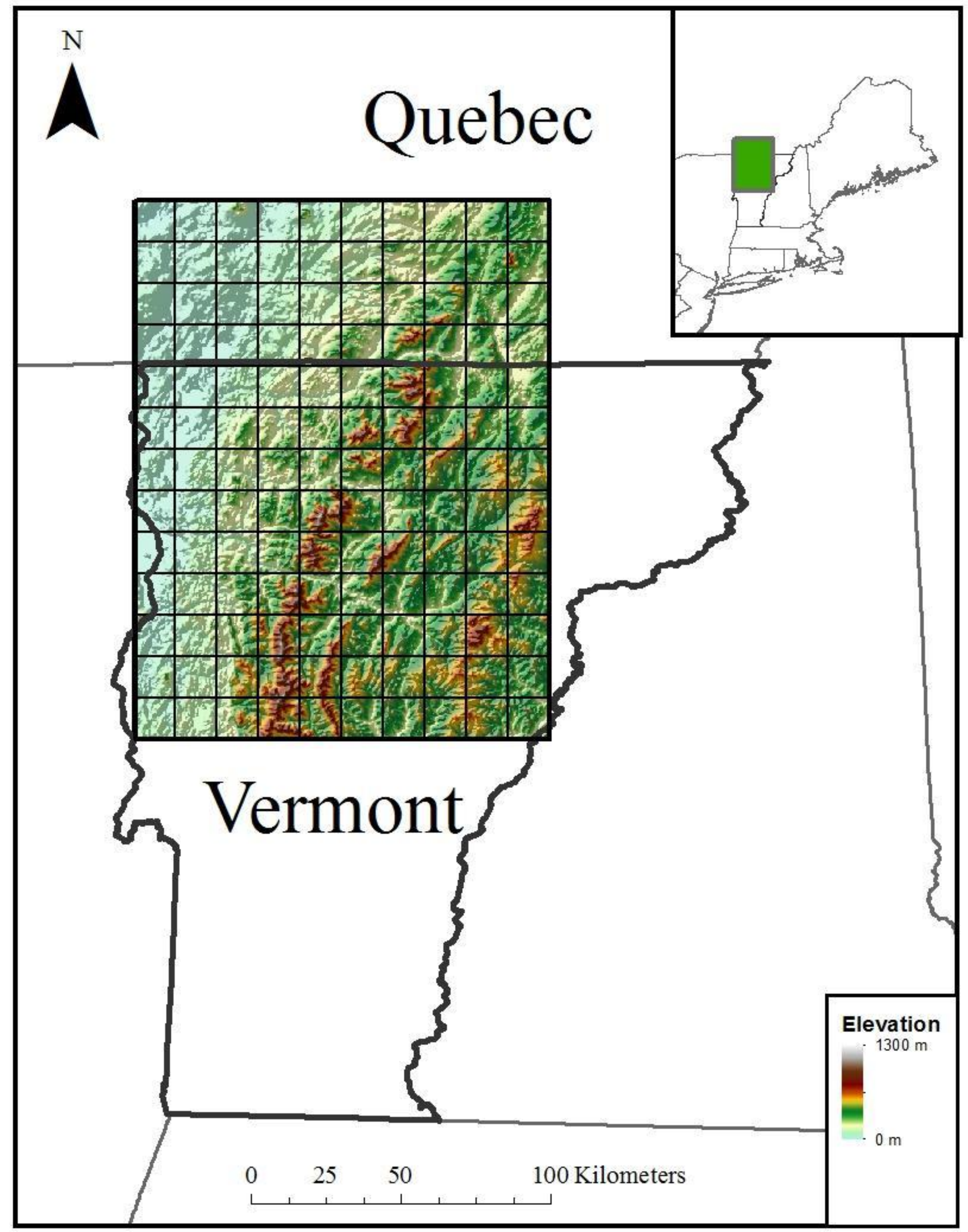

VT EPSCoR Climate Team Research Overview

- Completed
  - Assessment of an ensemble of intermediately downscaled (1/8 °) GCM projections over the Lake Champlain Basin
  - Guilbert, J., B. Beckage, J. M. Winter, R. M. Horton, T. Perkins, and A. Bomblies. 2014. Impacts of projected climate change over the Lake Champlain Basin in Vermont. *Journal of Applied Meteorology and Climatology*, 53(8): 1861-1875.
  - Developed methodology for very high resolution downscaling of intermediately downscaled data and processed initial ensemble members
- In Progress
  - Complete ensemble of very high resolution projections
  - Publish methodology and assessment of very high resolution dataset
  - Assist with integrating and evaluating downscaled products for IAM applications



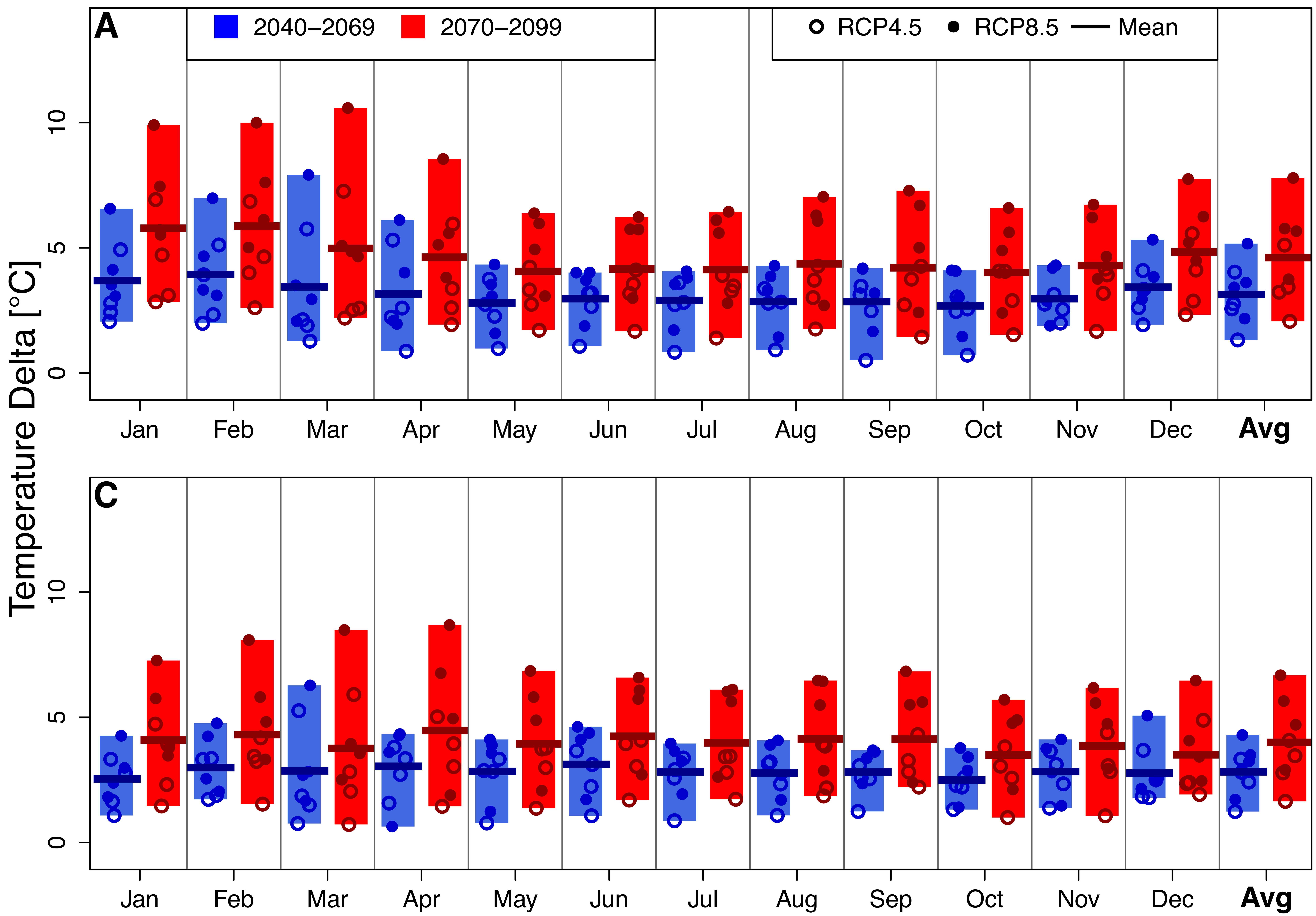
Impacts of Projected Climate Change Over the Lake Champlain Basin in Vermont

- Difference between mid-century (2040-2069), end-of-century (2070-2099) and historical (1970-1999) climate
- Two Representative Concentration Pathways (RCPs): 4.5 and 8.5
- CMIP5, 4 GCMs: CSIRO-MK3 (wet), IPSL-CM5 (dry), MIROC-ESM (warm), INM-CM4 (cool)
- Bias-Corrected with Constructed Analogues (BCCA; Brekke et al., 2013)



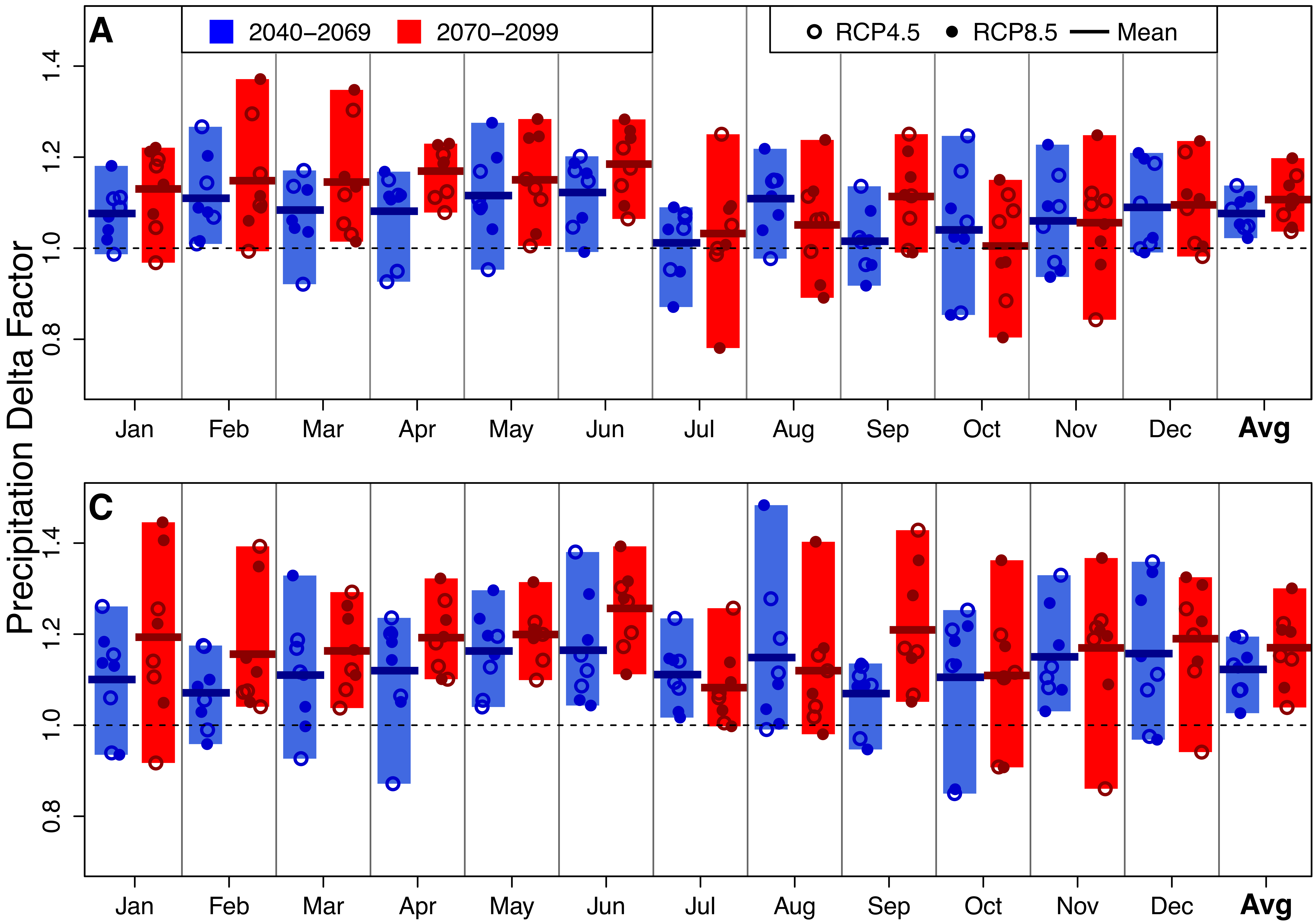
Source: Guilbert et al., 2014

Temperature Will Increase



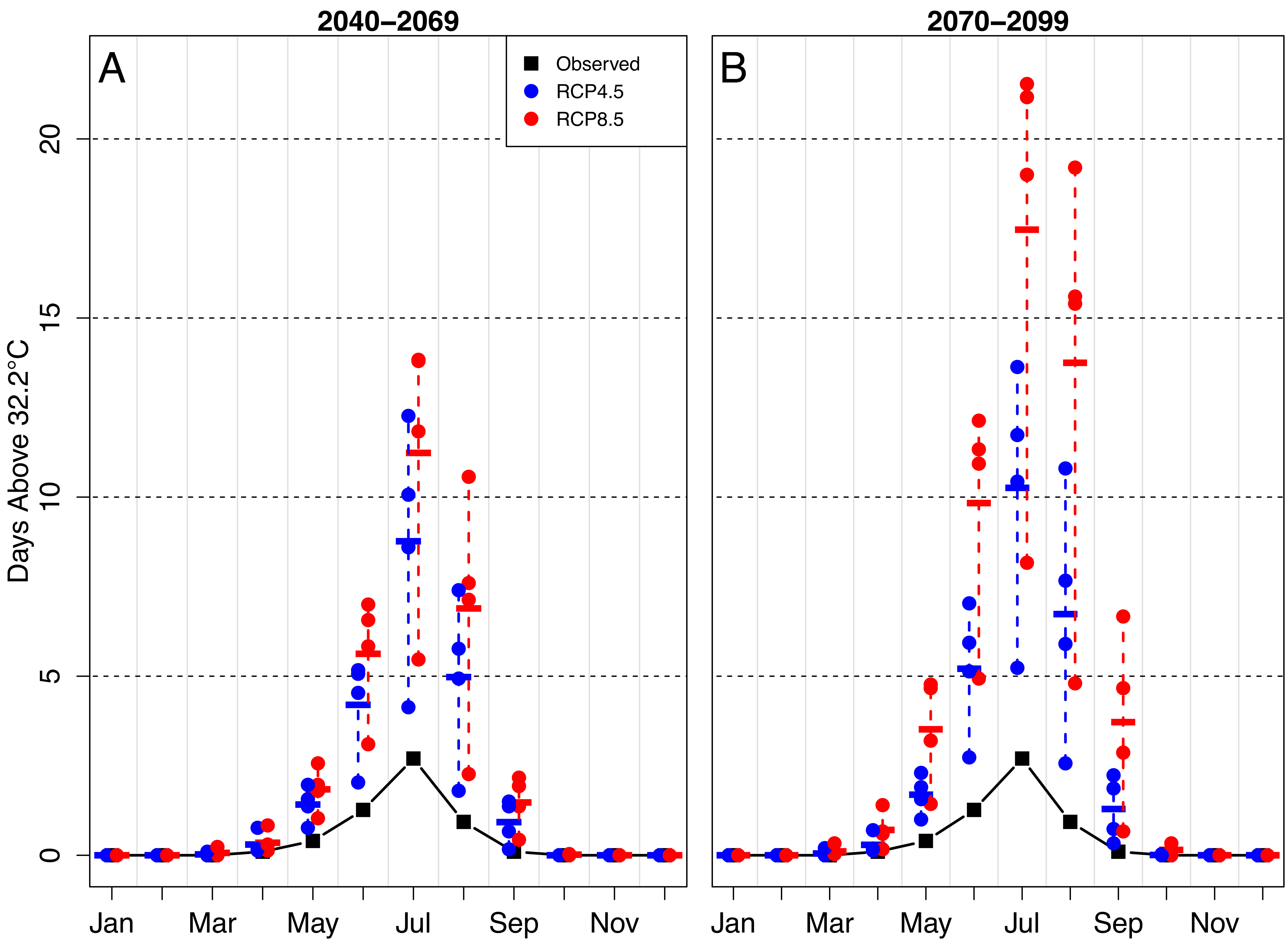
Source: Guilbert et al., 2014

Precipitation Is Likely to Increase



Source: Guilbert et al., 2014

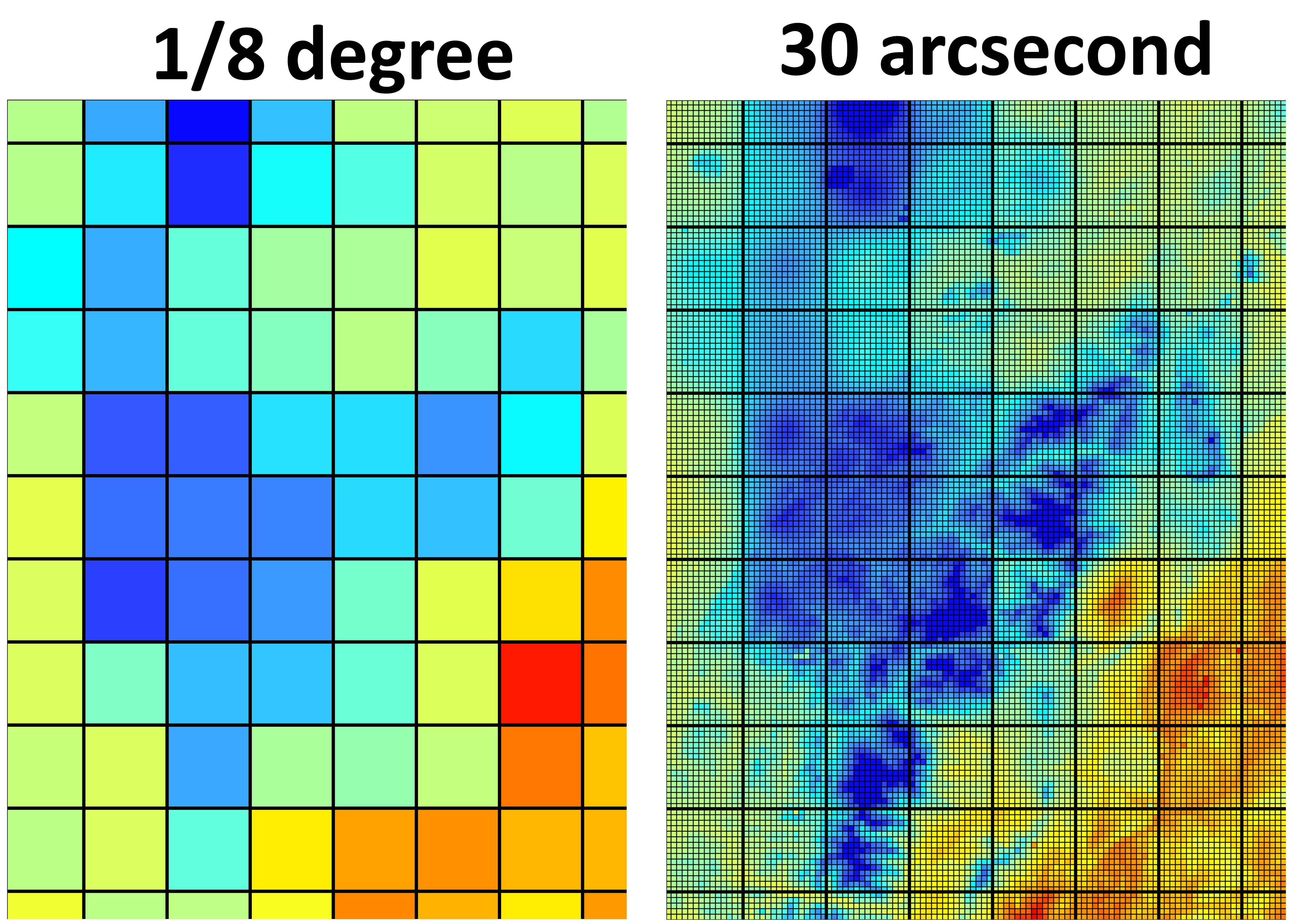
Hot Days (> 90 °F) Will Increase



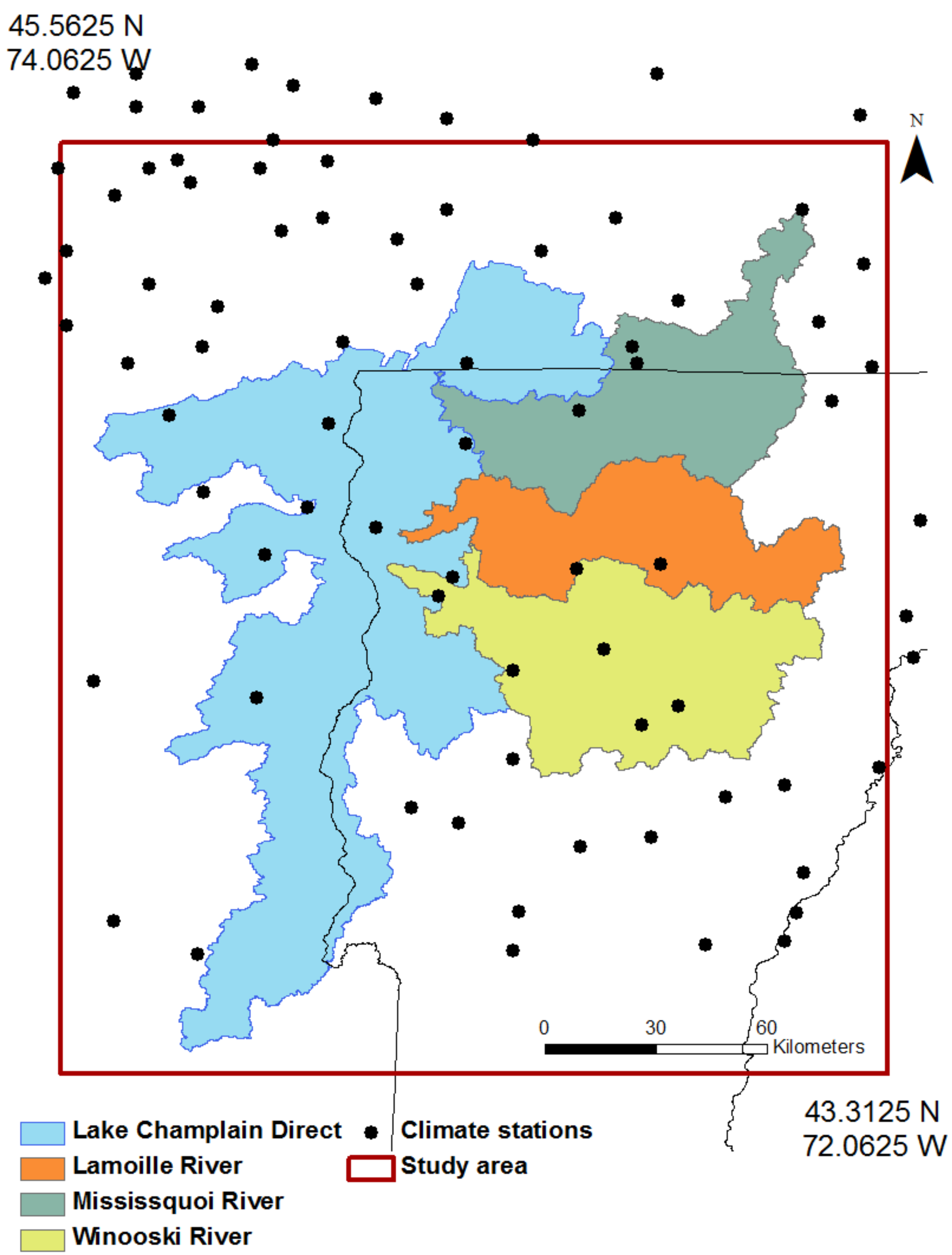
Source: Guilbert et al., 2014

Leverage Topographic Data to Create Very High Resolution Climate Scenarios

- Downscale intermediately downscaled products (1/8 °, ~12 km) to 30 " (~1 km) using elevation, which is accurate and readily available at 1 km resolution
  1. Derive observed temperature and precipitation lapse rates: $\Delta T/\Delta z$, $\Delta P/\Delta z$, from station data
  2. Adjust variables to the reference elevation using lapse rate and intermediate resolution (1/8 °) elevation dataset
  3. Interpolate data with inverse distance weighting to increase spatial resolution
  4. Create very high resolution variables by adjusting interpolated data using lapse rate and high resolution (30 ") elevation dataset



Derive Lapse Rates with an Assumed Functional Form and MLE



- Calculate the relationship between elevation (z), temperature (T), precipitation (P), and latitude (ϕ)

$$T = \alpha z + \beta \phi + T_0$$

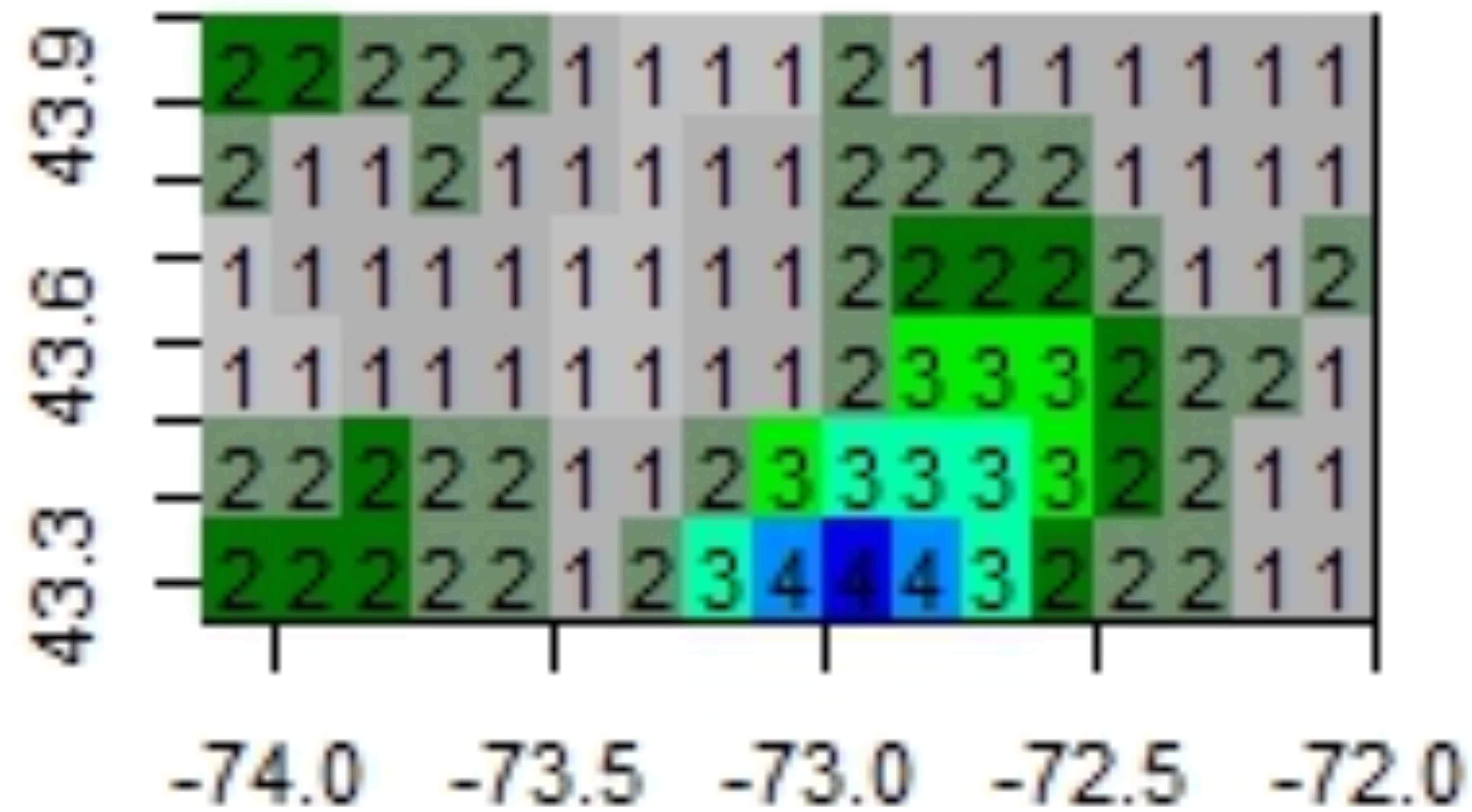
$$P = P_0 \left[\frac{1 + \chi(z - z_0)}{1 - \chi(z - z_0)} \right]$$

- Maximum Likelihood Estimation (MLE) with station observations to find α, β, and χ

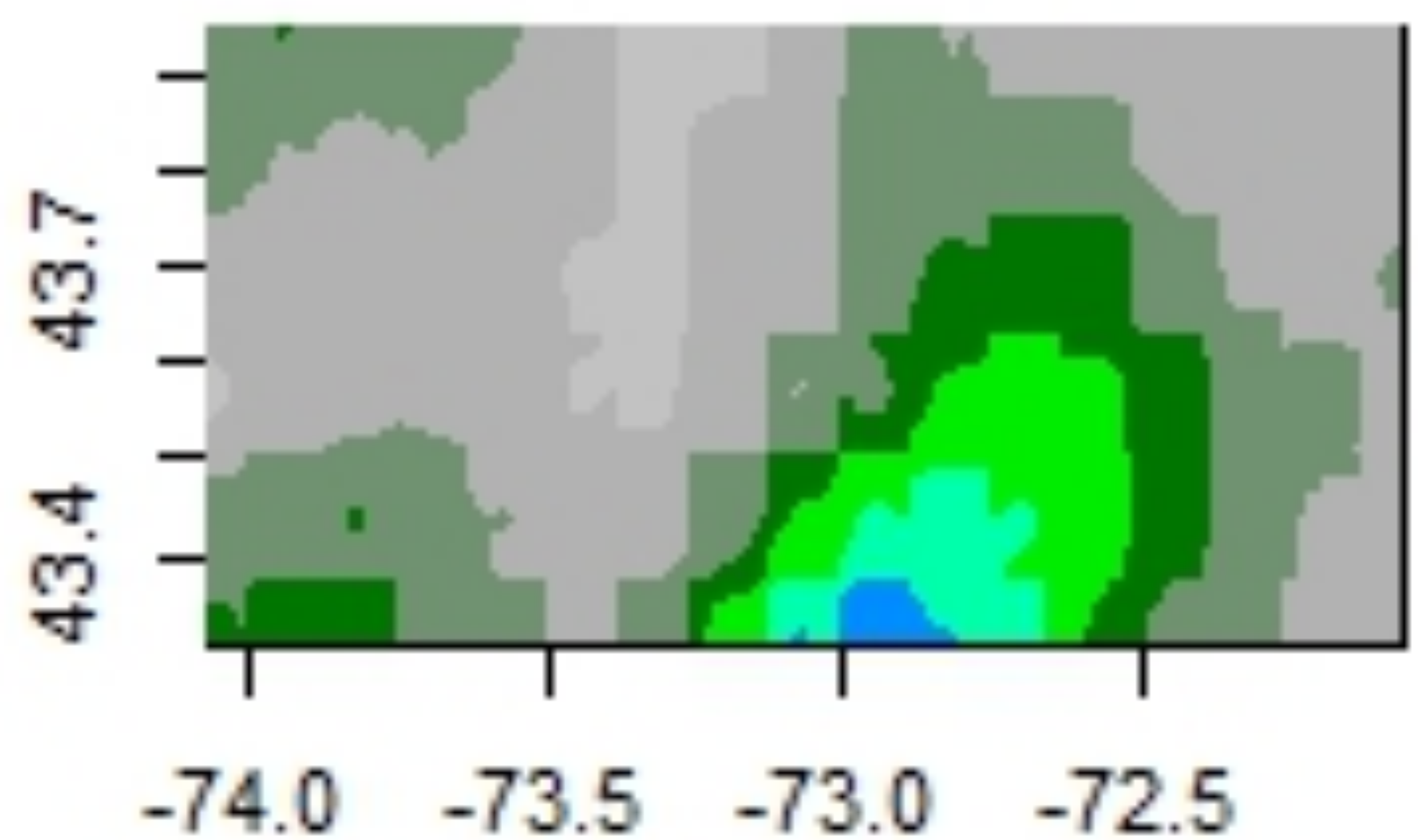
Source: Liston and Elder, 2006

Refine Climate Data Based on Elevation, Lapse Rates, and Interpolation

1/8 ° Precipitation Field at 200m



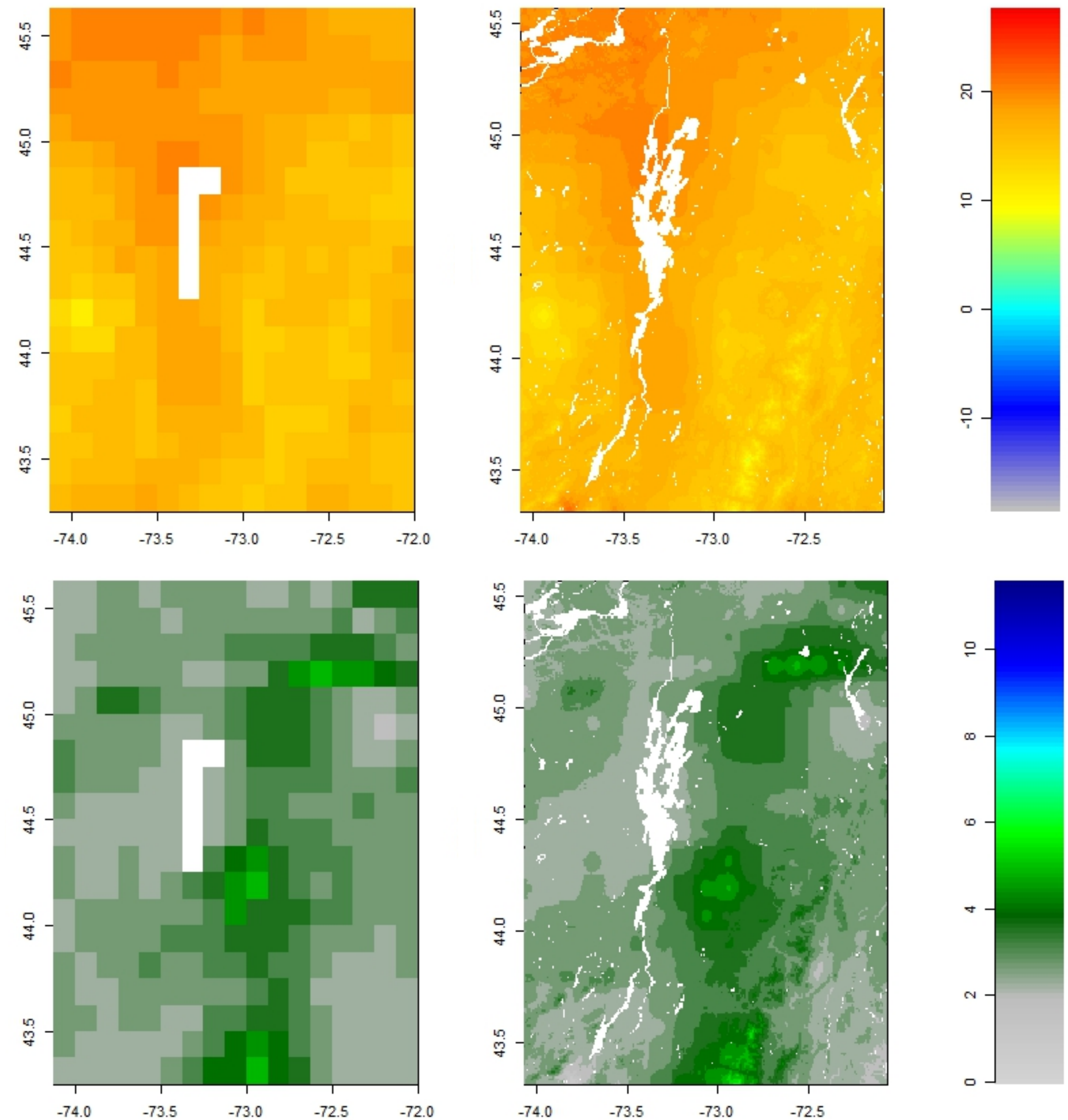
30 " Precipitation Field at 200m



- Adjust intermediate resolution (1/8 °) temperature and precipitation fields using α, β, χ, and z, ϕ at 1/8 ° to reference elevation
- Interpolate intermediate resolution (1/8 °) data to very high resolution (30 ")
- Adjust very high resolution (30 ") temperature and precipitation using α, β, χ, and z, ϕ at 30" to actual elevation

Very High Resolution Output

- Daily average temperature (top) and precipitation (bottom)
- May 25, 1950
- CSIRO ACCESS
- BCCA
- Inverse Distance Weighting

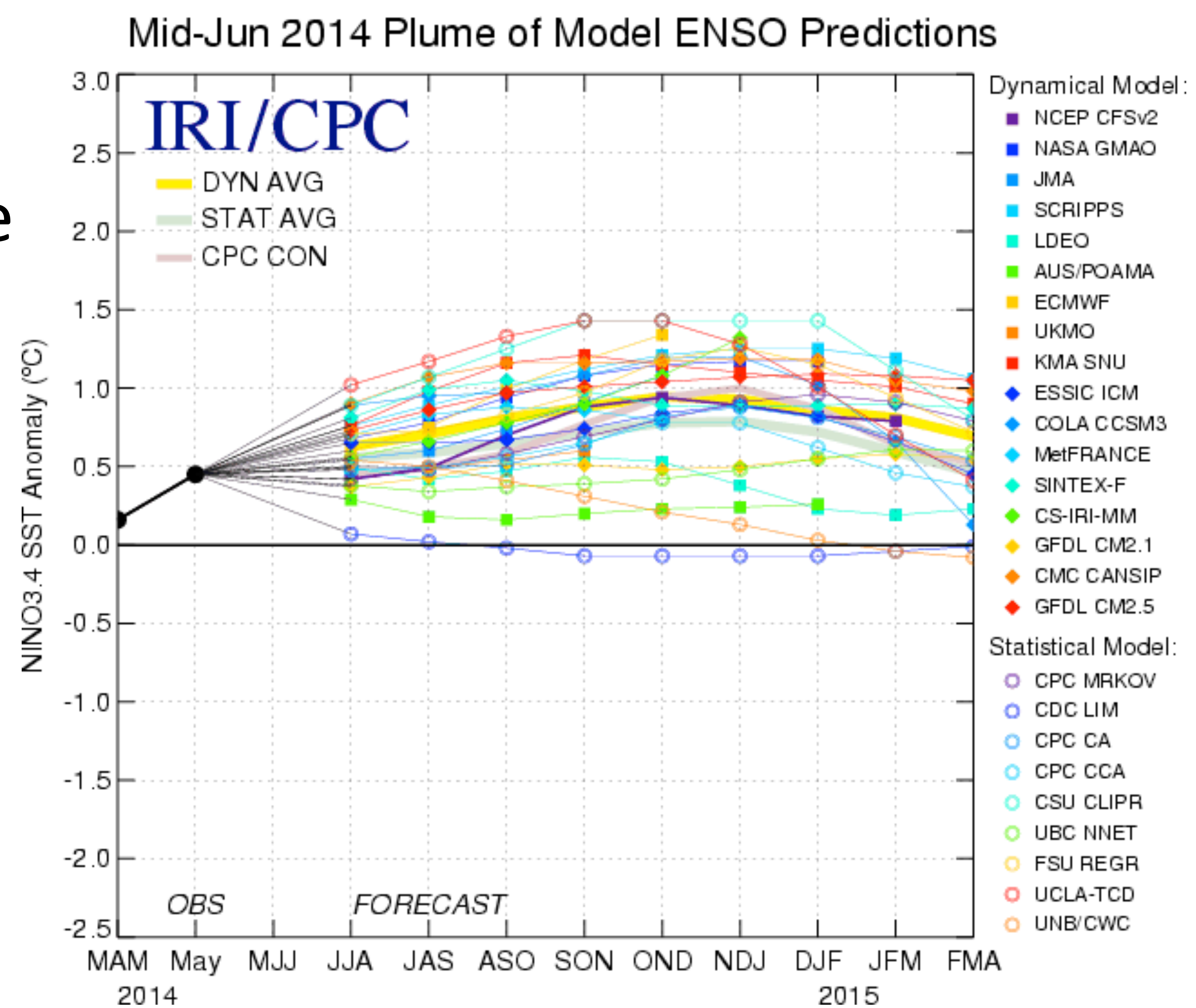


Ensemble of Intermediately Downscaled Climate Scenarios

Method	Project	Scenario	Time step	Time Period	Resolution	Domain	# of GCMs
ARR	CMIP3	A1B A2	Daily	1960-2099	1/8°	US + Canada	27
BCSD	CMIP3	A1B A2	Monthly	1950-2099	1/8°	US + Canada	15
BCSD	CMIP5	RCP4.5 RCP8.5	Monthly	1950-2099	1/8°	US + Canada	28
BCCA	CMIP3	A1B A2	Daily	1961-2000 2046-2065 2081-2099	1/8°	US + Canada	9
BCCA	CMIP5	RCP4.5 RCP8.5	Daily	1950-2099	1/8°	US + Canada	20
BCSD	CMIP5	RCP4.5 RCP8.5	Daily	1950-2100	1/16°	US	21

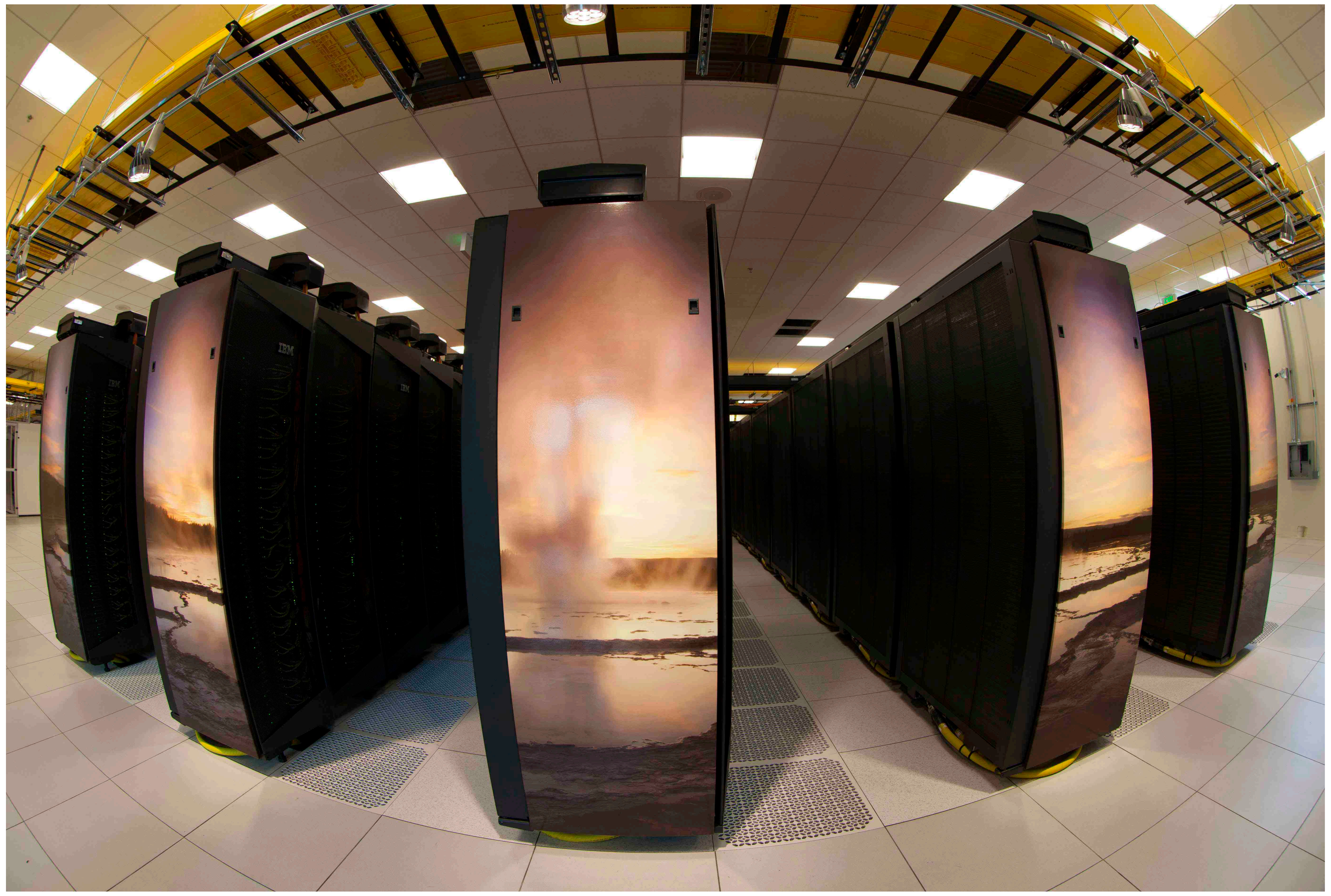
Why Use a GCM-Based Ensemble Approach?

- GCMs are the only tools that account for the complex set of processes that determine future climate, but they contain structural and practical inaccuracies (Murphy et al., 2004; Suckling and Smith, 2013; Macilwain 2014)
- "The best" climate change projection is as allusive as Champ
- Ensembles enable uncertainty assessment
- Can be combined with statistical methods (Macilwain, 2014)



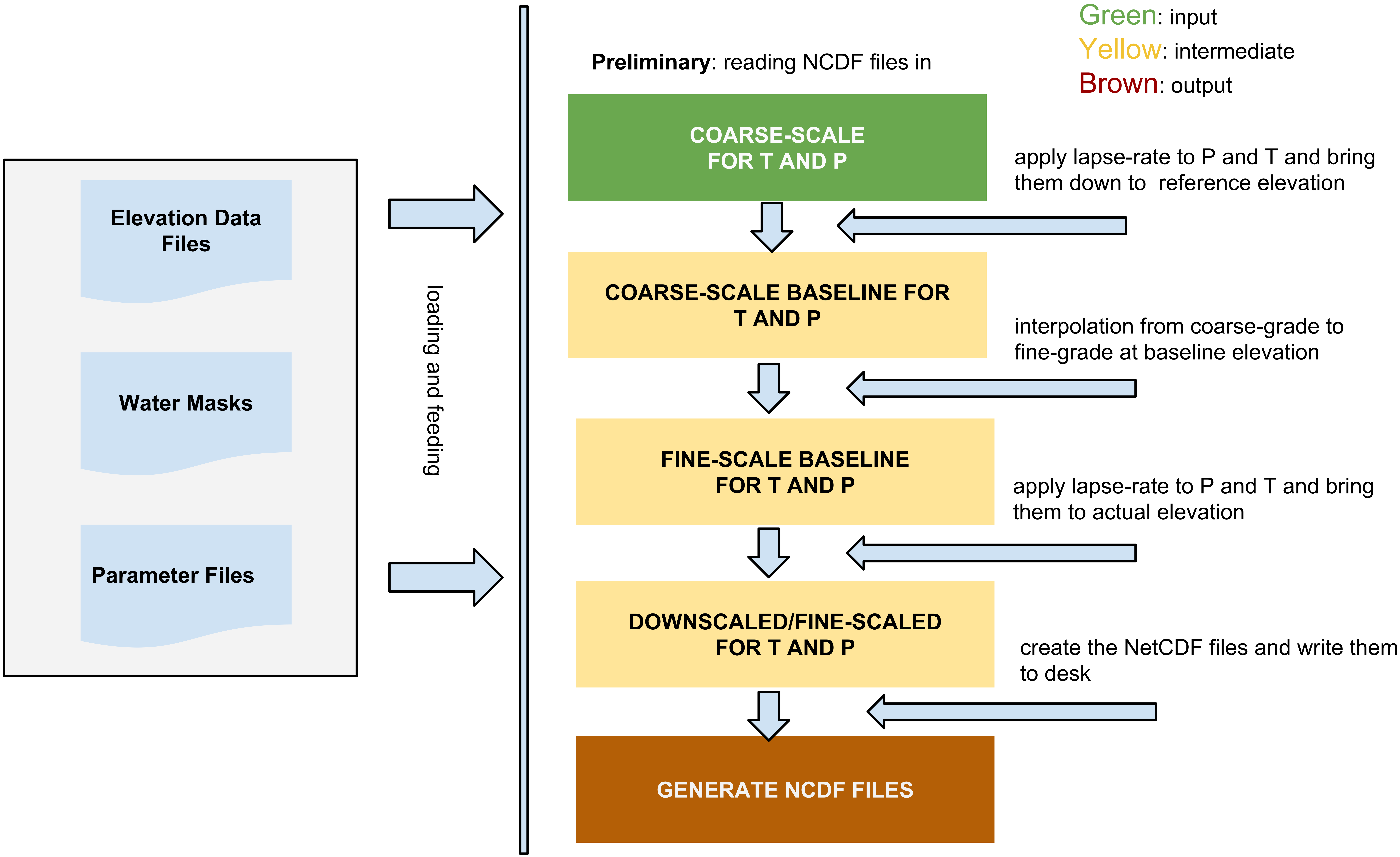
Ensemble Methods Facilitated by Big Data and Computation

- Volume
  - Downscaling three variables, precipitation, minimum temperature, and maximum temperature, for **150 ensemble members** - unique combination of GCM, intermediate downscaling method, and interpolation method
  - Each downscaled variable requires over **240 compute hours** on **NCAR's Yellowstone supercomputer** distributed over **150 cores**, and over **27 GB** of disk space
  - Established a public **GLOBUS** end-point at UVM to speed data transfer to and from Yellowstone
- Veracity
  - Downscaling process subjected to external review and algorithmic cross-validation, and QA/QC check was established for each downscaled variable

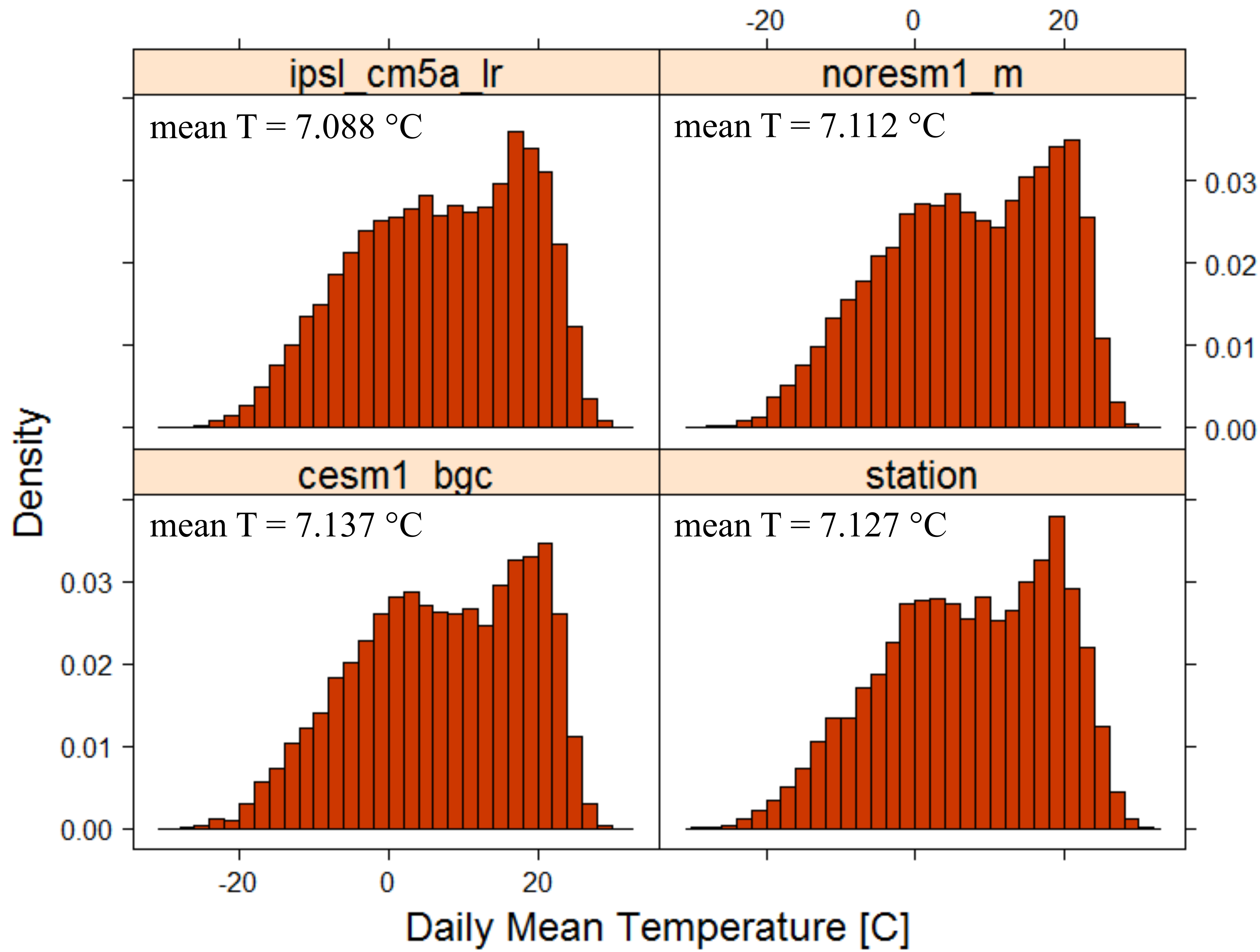


Source: ucar.edu

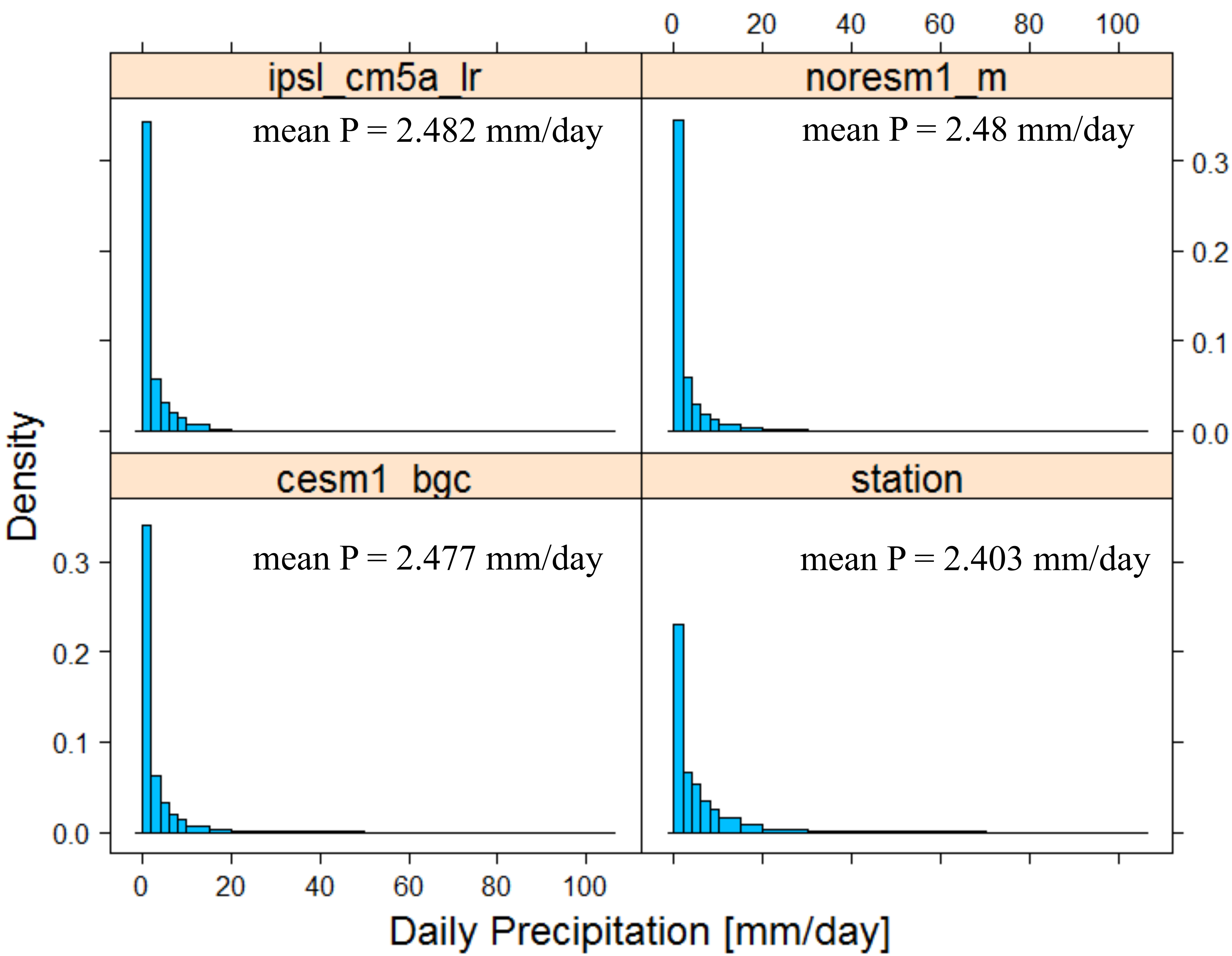
Pegasus Downscaling Workflow for Integration with IAM



Very High Resolution Output: Burlington Temperature Histograms



Very High Resolution Output: Burlington Precipitation Histograms



Capacity Development, Disciplinary Engagement, and Community Outreach

- **WRF Tutorial on Climate Modeling**: National Center for Atmospheric Research (NCAR), Jul. 2013
- **Workshop on Quantitative Evaluation of Downscaling**, National Center for Atmospheric Research, Aug. 2013
- **Sierra Club of the Upper Valley Presentation**: "Climate Change over the Northeast: Projections and Impacts on Flooding and Agriculture", Nov. 2013
- **AGU Fall Meeting Convener**: "General Circulation Model Downscaling for Impact, Vulnerability and Adaption Assessments: Methodologies and Applications, Dec. 2013
- **15th Annual WRF Users' Workshop on Climate Modeling**, National Center for Atmospheric Research, Jun. 2014
- **AGU Fall Meeting Convener**: "Characterizing, Understanding, and Modeling Climate Extremes", Dec. 2014