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CEREO

BioEarth Bias Correction Paper

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BioEarth All-hand Meeting, WSU, Feb. 20, 2013

Background

- Originally prepared for a Climatic Change special issue on regional-scale earth system modeling (RESM) (Editor: Yang, Zong-Liang, UT Austin)

- Two sections: 1) an introduction to BioEarth and 2) a research section in which we are investigating the impacts of bias correcting versus not bias correcting model-simulated meteorological data on a set of land surface variables.

- After a conversation between Jenny Adam and Zong-Liang Yang just YESTERDAY, it looks like Liang prefers that we split this paper into two, and submit the first to Climatic Change, and the second elsewhere. I will discuss results for this second paper here.

What is bias and bias-correction?

- Bias: the correspondence between a mean forecast and mean observation averaged over a certain domain and time. (WMO – WWRP 2009-1, 2009) (*Ehret et al., 2012, Hydrology and Earth System Sciences*)
- In climate change impact studies, "bias" is widely used as "any discrepancy of interest between a model output characteristic and the "truth"" (*Ehret et al., 2012*)
- Bias-correction: the correction of model output towards observations.

Why?

- Causes of bias (*Ehret et al., 2012*):
- imperfect model representations of atmospheric physics;
- incorrect initialization or errors in the parameterization chain;
- incorrect boundaries for RCMs;
- incorrect energy balance closure;
- climate variability;
- Inadequate reference data sets used for model parameterization and validation;
- uncertainties conveyed from the GCM to the RCM (*Teutschbein and Seibert, 2010; Rojas et al, 2011*)

How bias could be reduced?

Ehret et al., 2012:

- Improving the models
- Multi-model ensembles
- Empirical-statistical bias-correction (BC) as a post-processing step: monthly mean correction, delta change method, multiple linear regression, analog methods, local intensity scaling, **quantile mapping**, fitted histogram equalization, and gamma-gamma transformation.

Assumptions of BC (Ehret et al., 2012)

- Reliability
- Effectiveness: without introducing unwanted side effects
- Time invariance
- Completeness
- Minor role of spatiotemporal field covariance
- Minor role of feedbacks among variables
- No bias due to offsets
- Bias can be associated with typical timescales

This is especially important for hydrological considerations, as hydro-meteorological atmospheric **and land-surface processes interactions are complex and non-negligible**. **BC impairs these advantages by altering spatiotemporal field consistency, relations among variables and conservation principles**. In addition, it remains doubtful that BC methods parameterized on observed climate will hold under changing climate conditions.

BC and Non-BC experiment met data

Table 1# List of climate scenarios for this study. All WRF downscaled climate data used ECHAM5-A1B scenario as boundary condition (Salathe et al., 2010, 2012).

Time Period	Source	Bias Correction [1)]	Name/Description
1970-1999	Observed	-	Observed / Generated from meteorological stations with 1/16th degree. Maurer et al., 2002; Hamlet et al., 2007; Elsner et al., 2010
	WRF	T & P	BC1980s / Both T and P are bias-corrected
	WRF	T	BC_T_NBC_P1980s / only T is bias-corrected
	WRF	P	NBC_T_BC_P1980s / only P is bias-corrected
	WRF	None	NBC1980s / Neither T nor P are bias-corrected
2010-2039	WRF	T & P	BC2020s
	WRF	T	BC_T_NBC_P2020s
	WRF	P	NBC_T_BC_P2020s
	WRF	None	NBC2020s
2040-2069	WRF	T & P	BC2050s
	WRF	T	BC_T_NBC_P2050s
	WRF	P	NBC_T_BC_P2050s
	WRF	None	NBC2050s

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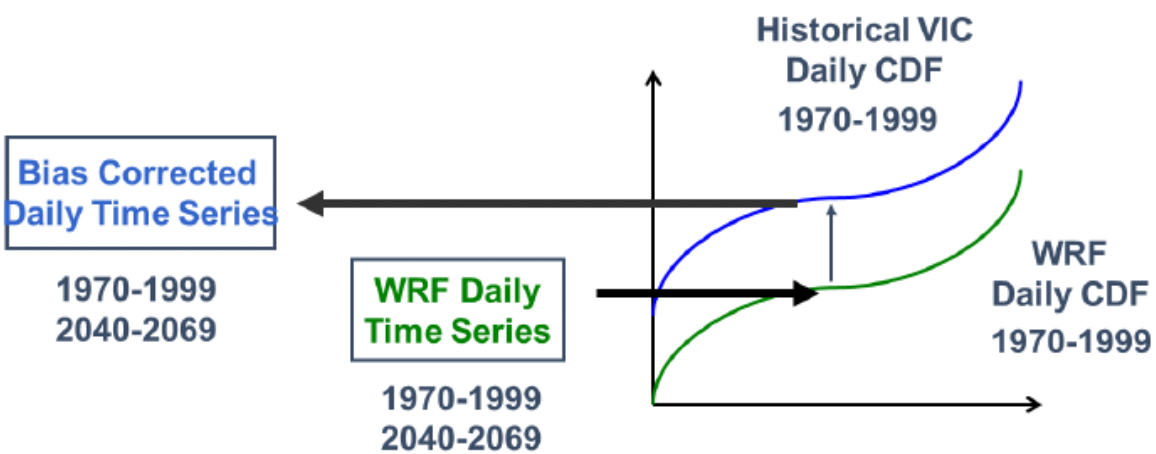
Statistical Downscaling and Bias Correction

Salathé, E.P., A.F. Hamlet, M. Stumbaugh, S. Lee, R. Steed (2012) Estimates of 21st Century Flood Risk in the Pacific Northwest Based on Regional Scale Climate Model Simulations.

WRF Daily Downscaling Method

- WRF output is first regridded to 1/16th degree
- Then, for each VIC grid cell:



1. WRF 12-km resolution data were regridded to 1/16th degree using Symap algorithm;
2. Regridded precipitation and temperature data were then bias corrected using a quantile mapping approach (Wood et al. 2002) applied at daily time step.

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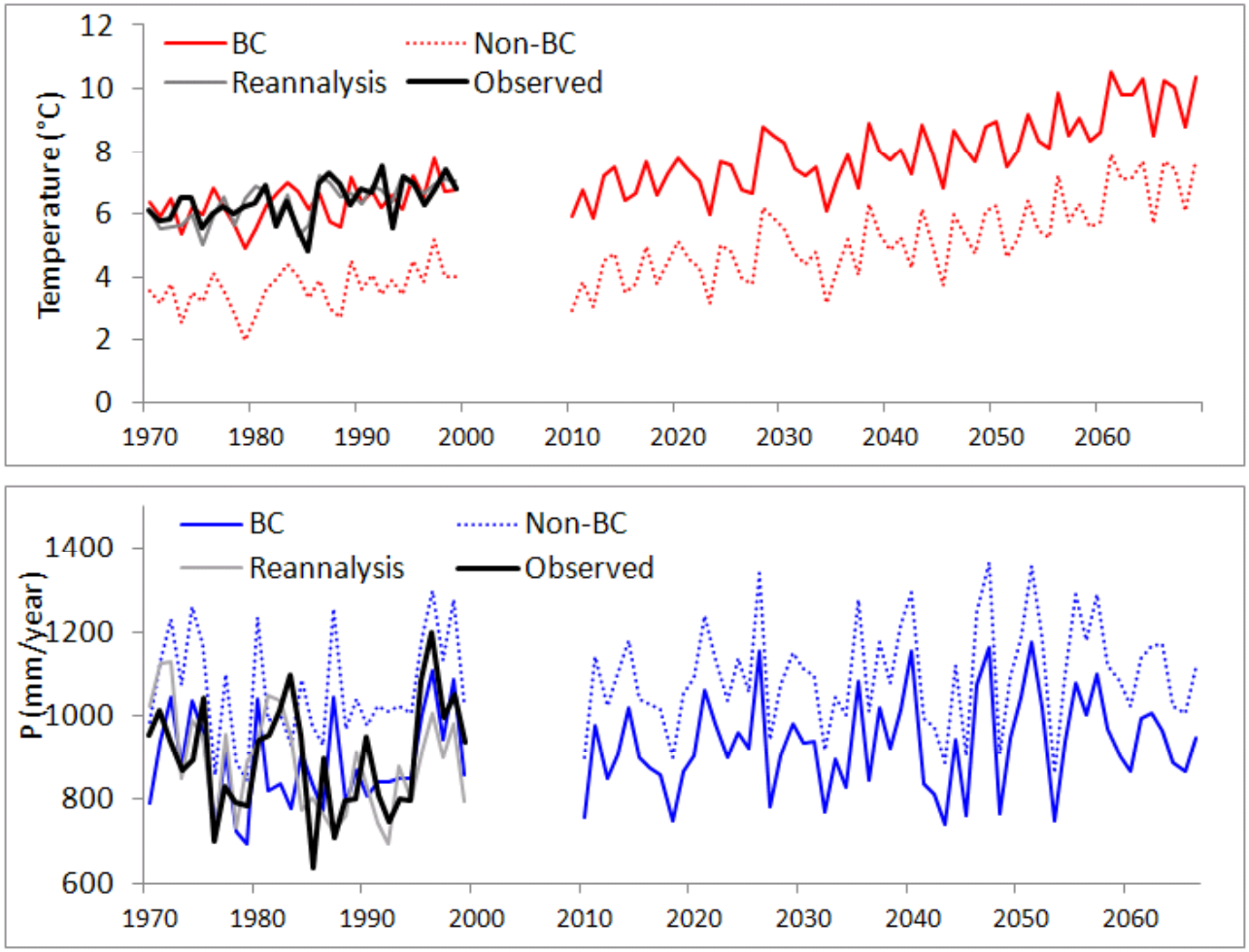
BC & Non-BC climate data



Differences between bias-corrected and non-bias-corrected in climate change

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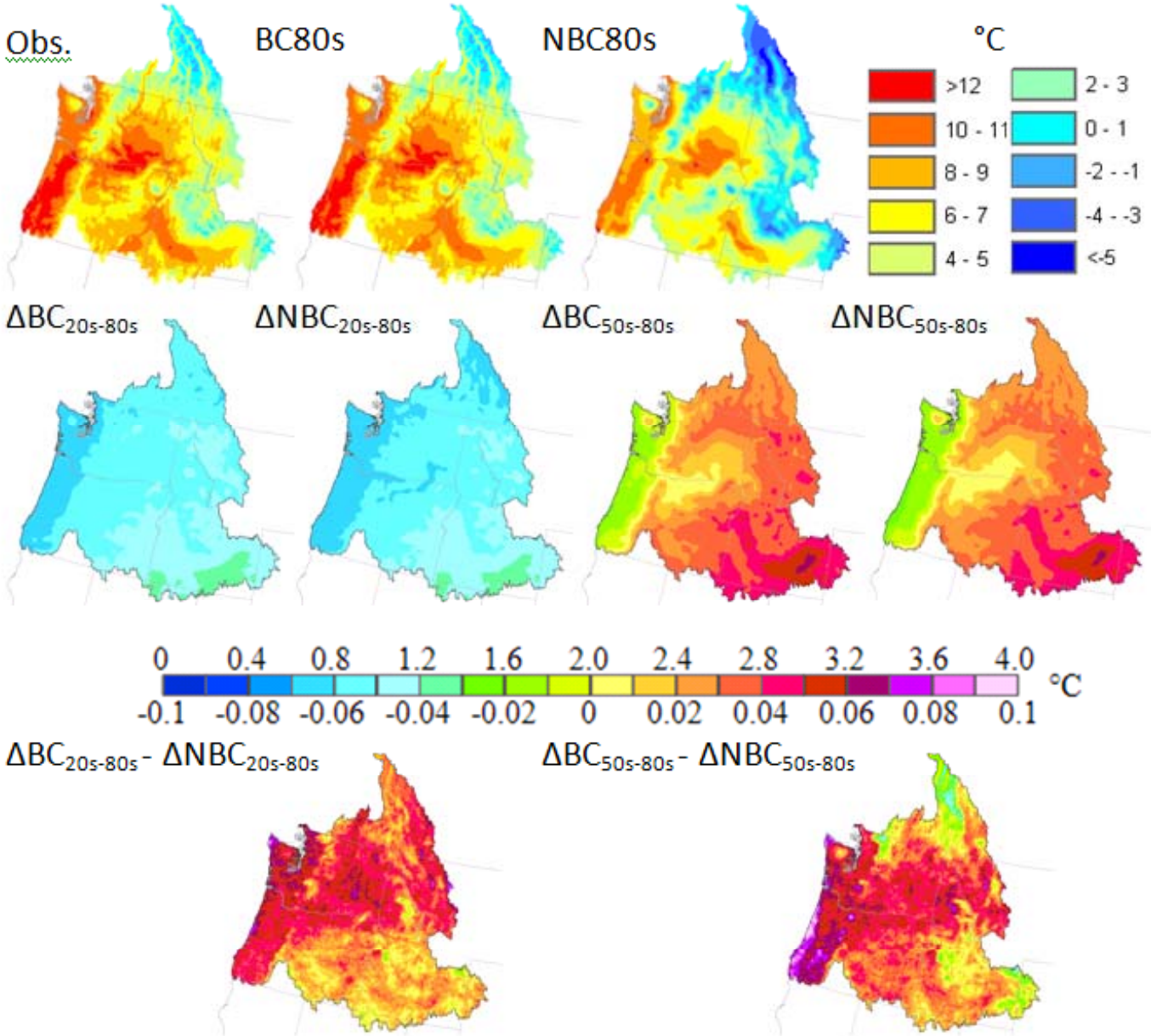
Temperature (°C)



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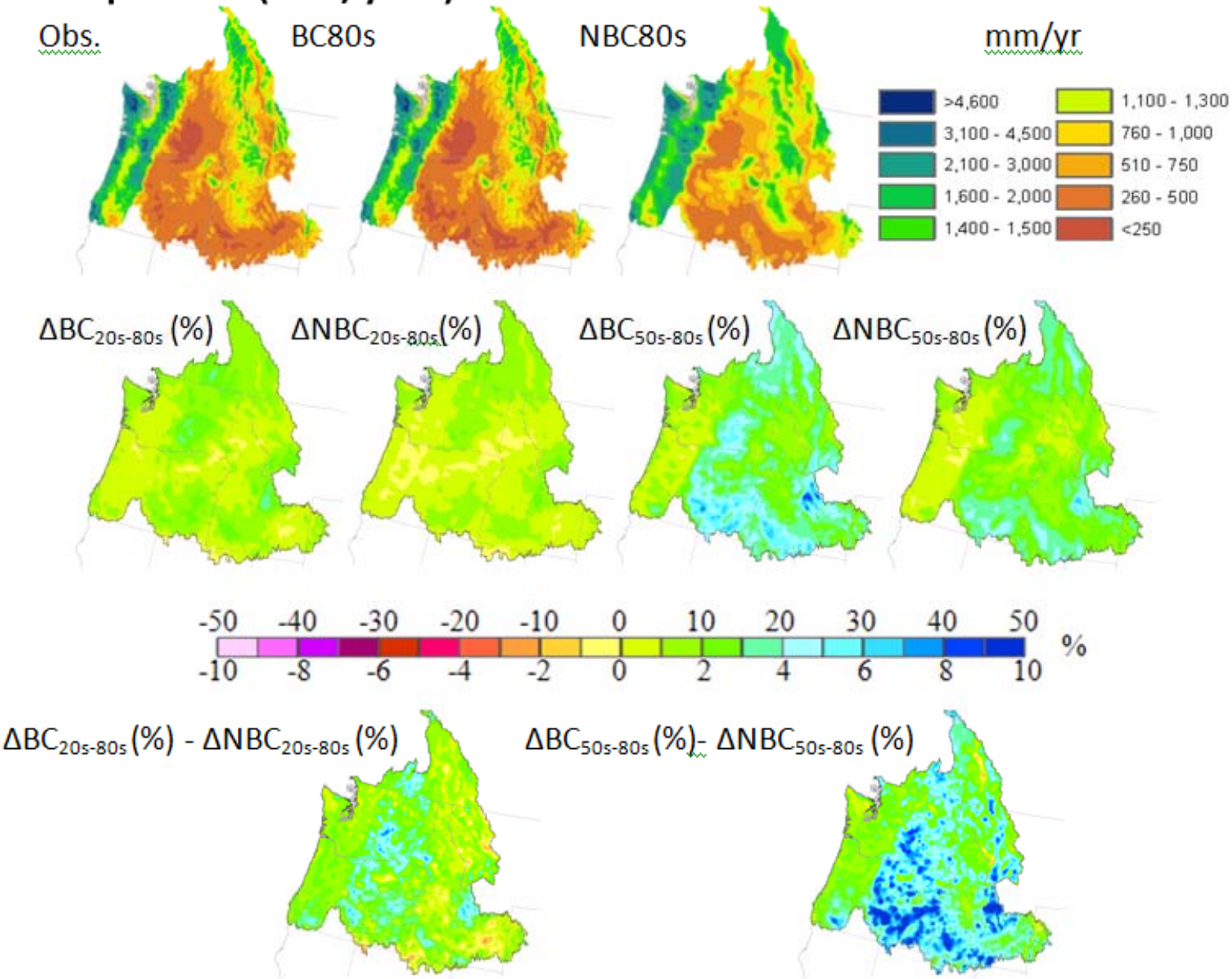
Precipitation (mm/year)



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Experiments

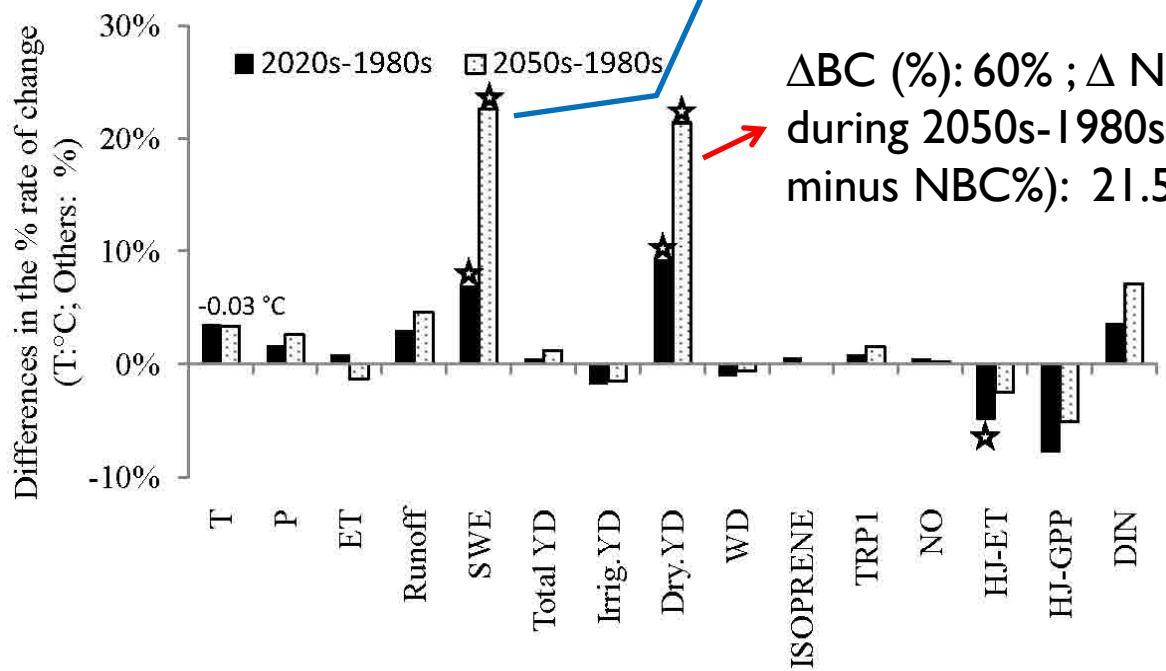
- **Objectives**: to investigate how bias-correction(BC) over regional climate model (WRF)'s climate data could affect estimations on changes in major hydrological variables (ET, runoff, snowpack, and nitrogen leaching), agriculture (crop yields and water demand), and VOC emissions over the future.

- WRF/Obs. Met data => VIC offline: ET, Runoff, & SWE (Snowpack Water Equivalence)
- WRF/Obs. Met data => VIC-CropSyst: Crop Yield, and water demand
- VIC-CropSyst (crop systems) + VIC offline: runoff => NEWS: Dissolved Inorganic Nitrogen leaching
- VIC-CropSyst (crop systems) + VIC offline: temperature, precipitation, radiation => MEGAN: VOC emissions

Results

SWE: ΔBC (%): -21.6% ; Δ NBC (%): -44.3% during 2050s-1980s. Differences (BC% minus NBC%): 22.7%

ΔBC (%): 60% ; Δ NBC (%): 38.6% during 2050s-1980s. Differences (BC% minus NBC%): 21.5%



Differences in the percentage rate of change between BC and NBC climate data and the simulated outputs driven by bias-corrected (BC) and non-bias-corrected (NBC) climate. They are calculated as [$\Delta BC_{20s\text{-}80s}$ (%) − $\Delta NBC_{20s\text{-}80s}$ (%)] for the period of 1980s-2020s and [$\Delta BC_{50s\text{-}80s}$ (%) − $\Delta NBC_{50s\text{-}80s}$ (%)] for the period of 1980s-2050s. As to T, it is total differences in Celsius degree, i.e. ($\Delta BC_{20s\text{-}80s}$ − $\Delta NBC_{20s\text{-}80s}$) for 2020s, and ($\Delta BC_{50s\text{-}80s}$ - $\Delta NBC_{50s\text{-}80s}$) for 2050s. T: annual mean temperature, P: average annual precipitation, ET: average annual evapotranspiration, Runoff: total runoff, SWE: Snowpack Water Equivalent on April 1, Total YD: total yield from all croplands; Irrig.YD: Yield from irrigated cropland; D. YD: Yield from dryland (non-irrigated cropland); WD: total irrigation water demand over irrigated cropland, HJ-ET: RHESSys modeled ET over HJ-Andrews watershed; HJ-GPP: RHESSys modeled Gross Primary Production (GPP) over HJ-Andrews watershed; DIN: NEWS modeled Dissolved Inorganic Nitrogen yield over the Columbia River Basin. The small stars under or above each column mean *P*-value < 0.05 for the t-test of differences between BC anomalies and NBC anomalies during period of 2020s and 2050s, respectively.

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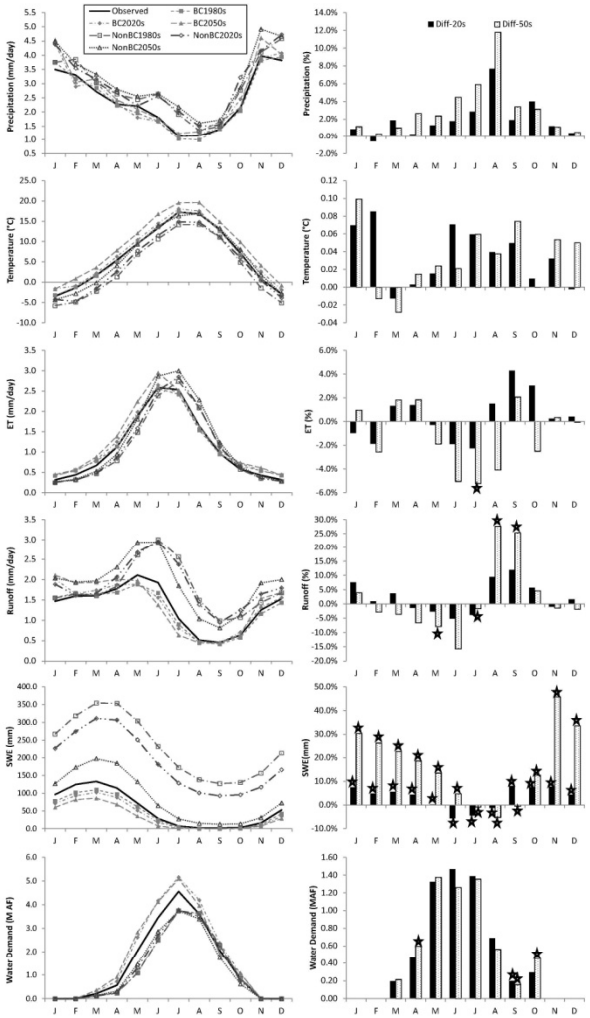
Monthly patterns



Seasonal patterns of differences in climate and simulated hydrological variables driven by bias-corrected (BC) and without bias-corrected (NBC) data. Left column is monthly mean (from January to December) over different scenarios and time periods; right column is the differences between BC- and NBC climate and modeled variables in two periods, i.e. 2020s-1980s and 2050s-1980s. The unit of Water Demand is Million acre-feet (MAF). Note: Precipitation, ET, Runoff, and SWE are difference in relative change in percentage, i.e. $(\Delta BC_{20s-80s}/BC_{1980s} \times 100\%) - (\Delta NBC_{20s-80s}/NBC_{1980s} \times 100\%)$ of each month for 2020s and $(\Delta BC_{50s-80s}/BC_{1980s} \times 100\%) - (\Delta NBC_{50s-80s}/NBC_{1980s} \times 100\%)$ of each month for 2050s; Temperature and water demand are difference in absolute change, i.e. $\Delta BC_{20s-80s} - \Delta NBC_{20s-80s}$ of each month for 2020s and $\Delta BC_{50s-80s} - \Delta NBC_{50s-80s}$ of each month for 2050s. The small stars under or above each column mean *P* value < 0.05 for the t-test of differences between BC anomalies and NBC anomalies for each month; The big star in diagram of SWE monthly differences means all months are significant ($P < 0.05$).

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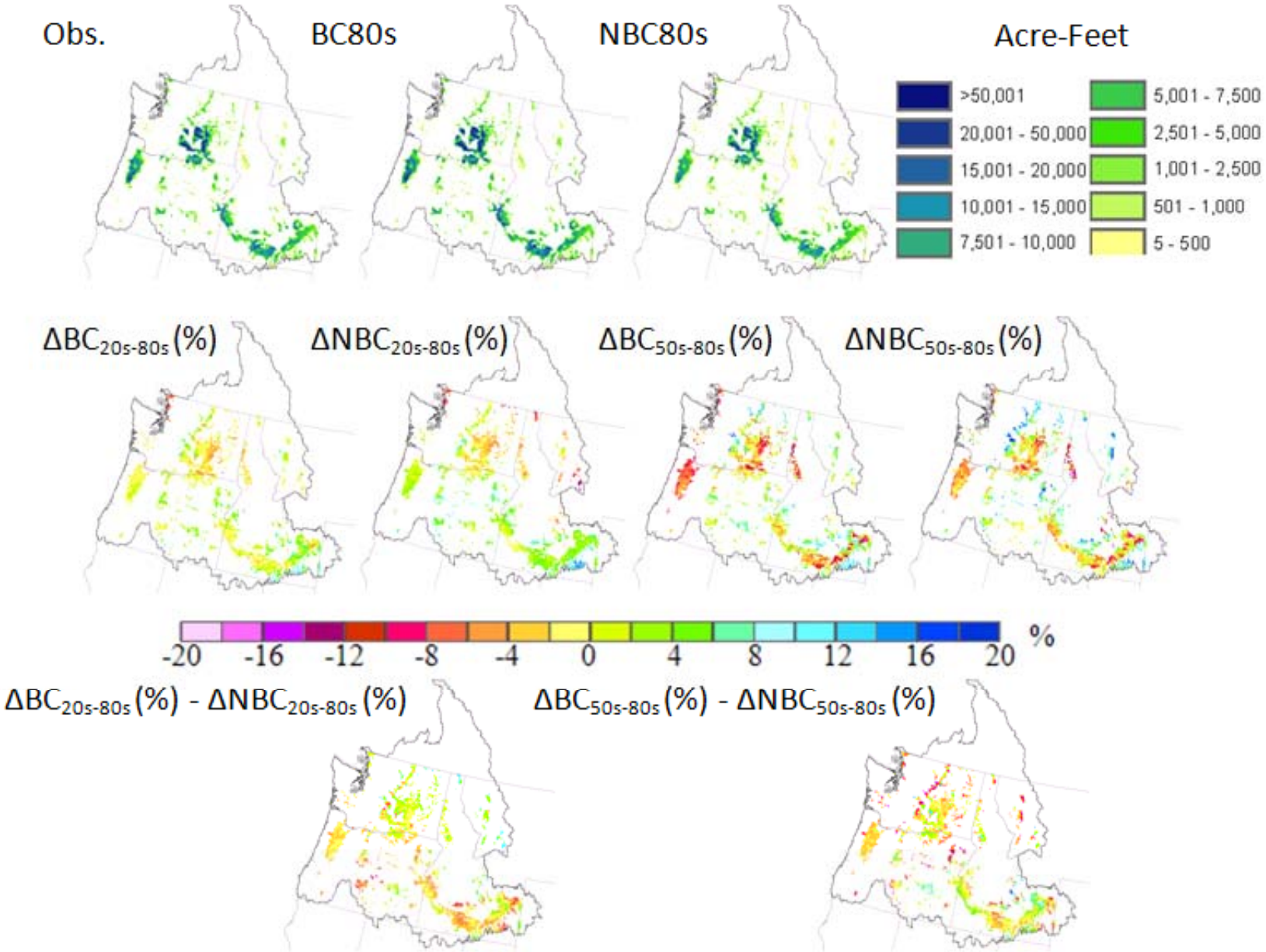
Irrigation Water Demand (Acre Feet)



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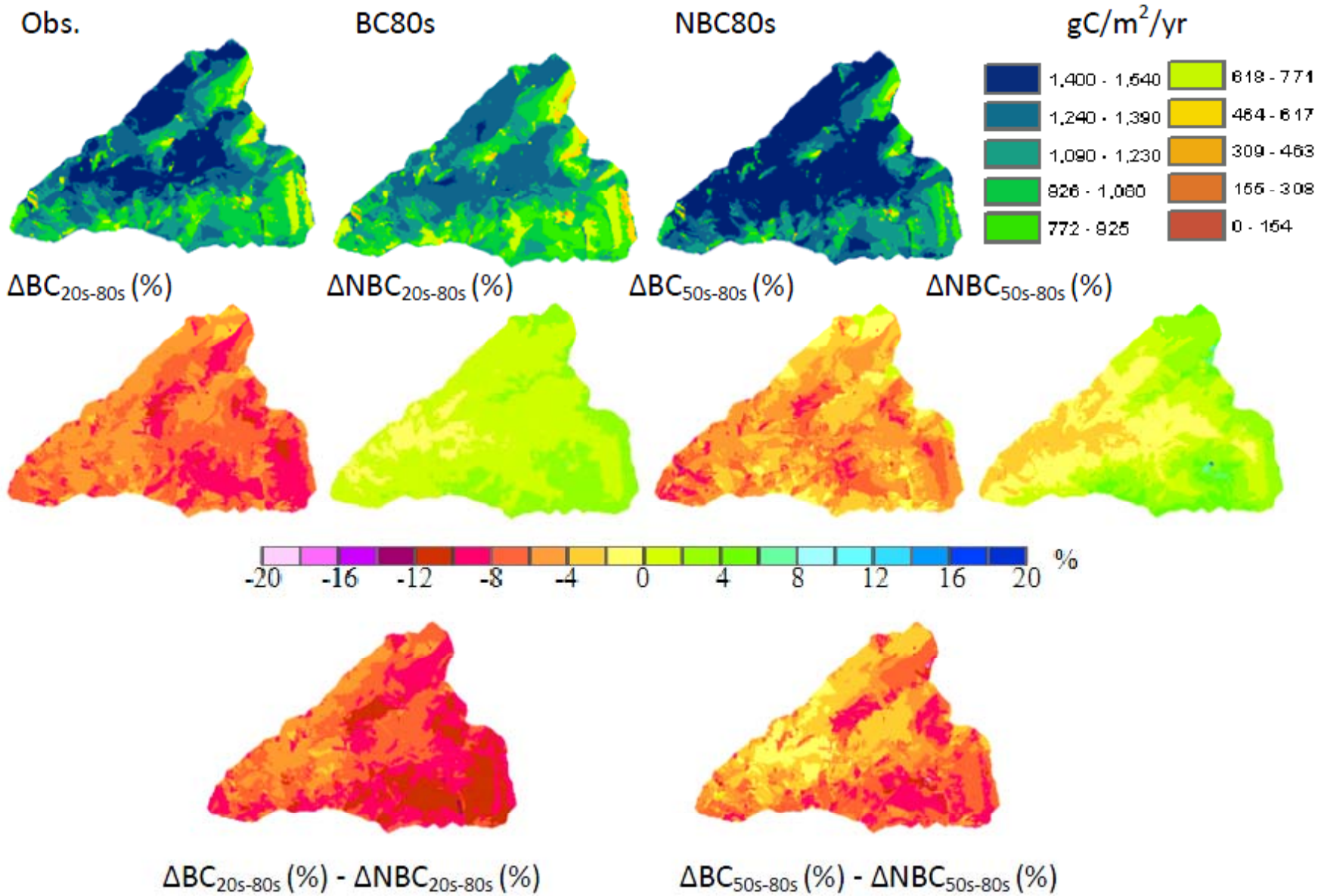
GPP (gC/m^2/yr)



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Attribute effects of BC T & BC P

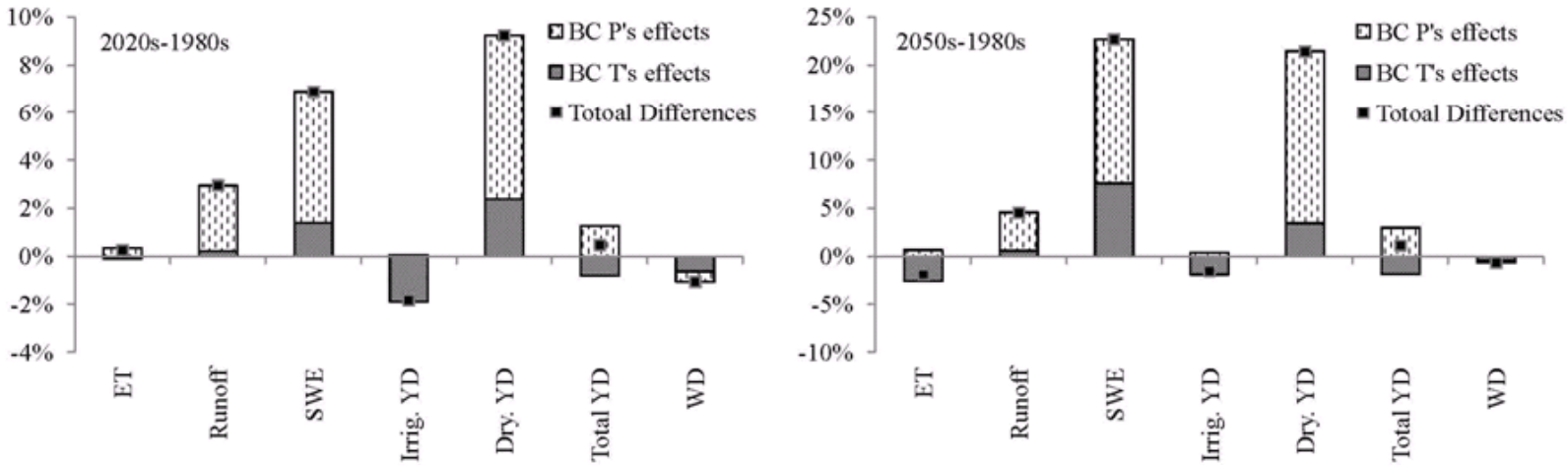

Figure 6# Contributions of bias-corrections (BC) on temperature (T) and precipitation (P) to the total differences of modeled changes in major hydrologic variables and crop yield between BC and Non-BC (NBC) climate driving forces. Left panel: during period of 1980s-2020s; and right panel: during 1980s-2050s. ET: average annual evapotranspiration, Runoff: total runoff, SWE: Snowpack Water Equivalent on April 1, Total YD: total yield from all croplands; Irrig.YD: Yield from irrigated cropland; Dry. YD: Yield from dryland (non-irrigated cropland); WD: total irrigation water demand over irrigated cropland. Total differences are calculated as $\Delta BC_{T\&P}(\%) - \Delta NBC_{T\&P}(\%)$; BC T's effects are calculated as: $\{[\Delta BC_{T\&P}(\%) - \Delta NBC_{T}BC_{P}(\%)] + [\Delta BC_{T}NBC_{P}(\%) - \Delta NBC_{T\&P}(\%)]/2$; BC P's effects are calculated as: $\{[\Delta BC_{T\&P}(\%) - \Delta BC_{T}NBC_{P}(\%)] + [\Delta NBC_{T}BC_{P}(\%) - \Delta NBC_{T\&P}(\%)]/2$.

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Major conclusions

- Using RCM modeled climate data directly without bias-correction in climate change impact studies could lead to large bias due to system errors of RCM model and none-linear responses of ecological and hydrological process to climate change;
- Even though the delta change of T (shifted) and P (scaled) are well reserved after bias-correction, this post-process process could produce big uncertainties in quantifying impact of climate change due to impairing spatiotemporal field consistency, relations among variables, and conservation principles.