Precipitation regime change in Western North America: The role of Atmospheric Rivers

Alexander Gershunov[1,2], Tamara Shulgina[1,2], Rachel E.S. Clemesha[2], Kristen Guirguis[1,2], David W. Pierce[2], Michael D. Dettinger[3], David A. Lavers[4], Daniel R. Cayan[2], Suraj D. Polade[5], Julie Kalansky[1,2] and F. Martin Ralph[1,2]

[1]Center for Western Weather and Water Extremes (CW3E), [2]Climate, Atmospheric Science and Physical Oceanography (CASPO), Scripps Institution of Oceanography, University of California San Diego, USA, [3]United States Geologic Survey, Carson City, Nevada, USA, [4]European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK, [5]Finnish Meteorological Institute, Helsinki, Finland

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Introduction

Daily precipitation in California has been projected to become less frequent even as precipitation extremes intensify, leading to uncertainty in the overall response to climate warming. Precipitation extremes are historically associated with Atmospheric Rivers (ARs), the filamentary features of the low troposphere that deliver intense pulses of water vapor onshore and largely drive the hydroclimate of the region. Sixteen global climate models are evaluated for realism in modeled historical AR behavior and contribution of the resulting daily precipitation to annual total precipitation over Western North America. The five most realistic models display consistent changes in future AR behavior, constraining the spread of the full ensemble.

Study Objectives:

- ***Estimate historical and projected AR activity along the U.S. West***
- ***Examine the changing contribution of ARs to daily precipitation***
- ***Discuss the impacts on the precipitation regime in California***

Data and Methods

An automated AR detection scheme[1] (ARDT) was applied daily to an ensemble of 16 Global Climate Models (GCMs, Tab. 1) over the historical period (1950–2005) and future (2006–2100) projected under Representative Concentration Pathway 8.5 (RCP8.5) scenario from Phase 5 of the Coupled Model Intercomparison Project (CMIP5). The ARDT methodology for detecting landfalling ARs using criteria of integrated vapor transport (IVT) exceeded 250 kg m^{-1} s^{-1}, integrated water vapor (IWV) greater than 15 mm, and length above 1500 km is described in Gershunov et al. 2017[1]. The ability of GCMs to accurately represent the historical AR climatology, specifically seasonal cycle of AR landfall frequencies and the contribution of ARs to total annual precipitation along the West Coast, was quantified by comparison against earlier developed NCEP/NCAR Reanalysis-based AR catalog[1] (SIO-R1, Fig. 1). The five most realistic GCMs (Real-5), were identified and highlighted in Table 1.

Daily precipitation data[2] on a 6x6 km grid was used to assess observed AR-related precipitation. Localized Constructed Analog statistical downscaling[3], trained on the Livneh et al.[2] data, was used for the same purpose in the 16 GCMs historical simulations and projections.

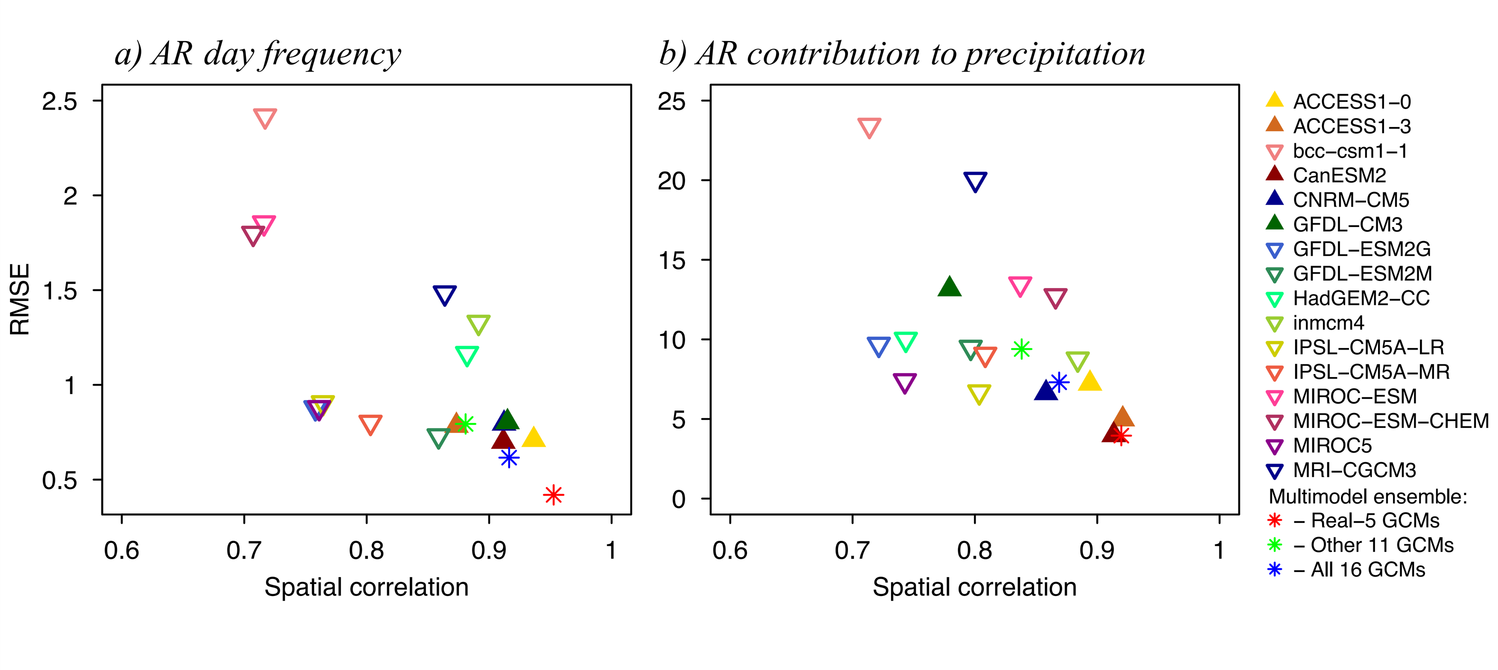

Figure 1. *The agreement between each of the GCMs (triangles) and the NCEP/NCAR R1-based climatologies of (a) AR day frequency by month and landfalling latitude and (b) AR contribution to annual total precipitation estimated using LOCA-downscaled GCM precipitation[3] and gridded observed data[2]. Asterisks show the agreement between observed and multimodel ensemble average climatologies of all 16 GCMs (blue), Real-5 (red), and the Other 11 GCMs (green).*

Historical and projected AR activity

Models simulate a broad range of AR land-falling activities (Fig.2, and Tab.1). The Real-5 GCMs display upward trends during the current half-century and continue to rise until the end of the century significantly.

Table 1. *Change in AR characteristics for each of the GCMs for the future (2051-2100) according to RCP 8.5 scenario is estimated in percentage (%) relative to the correspond AR characteristics estimated for the historical (1951-2000) period. The table rows with an Italic font highlight the statistics of Real-5 GCMs. See the paper for details.*

Model	Change (%) in max AR IVT	Change (%) in AR frequency	Change (%) in AR duration
ACCESS1.0	*10 %*	*26 %*	*19 %*
ACCESS1.3	*11 %*	*25 %*	*23 %*
BCC-CSM1.1	9 %	8 %	17 %
CanESM2	*12 %*	*23 %*	*25 %*
CNRM-CM5	*10 %*	*20 %*	*20 %*
GFDL-CM3	*14 %*	*19 %*	*24 %*
GFDL-ESM2G	8 %	31 %	13 %
GFDL-ESM2M	8 %	26 %	14 %
HadGEM2-CC	12 %	43 %	33 %
Inmcm4	5 %	5 %	14 %
IPSL-CM5A-LR	14 %	22 %	29 %
IPSL-CM5A-MR	10 %	31 %	22 %
MIROC5	5 %	32 %	12 %
MIROC-ESM	9 %	22 %	21 %
MIROC-ESM-CHEM	9 %	19 %	30 %
MRI-CGCM3	6 %	10 %	15 %
Real-5 GCMs average	11 %	21 %	22 %
Other 11 GCMs aver.	9 %	20 %	19 %
All 16 GCM average	10 %	21 %	21 %

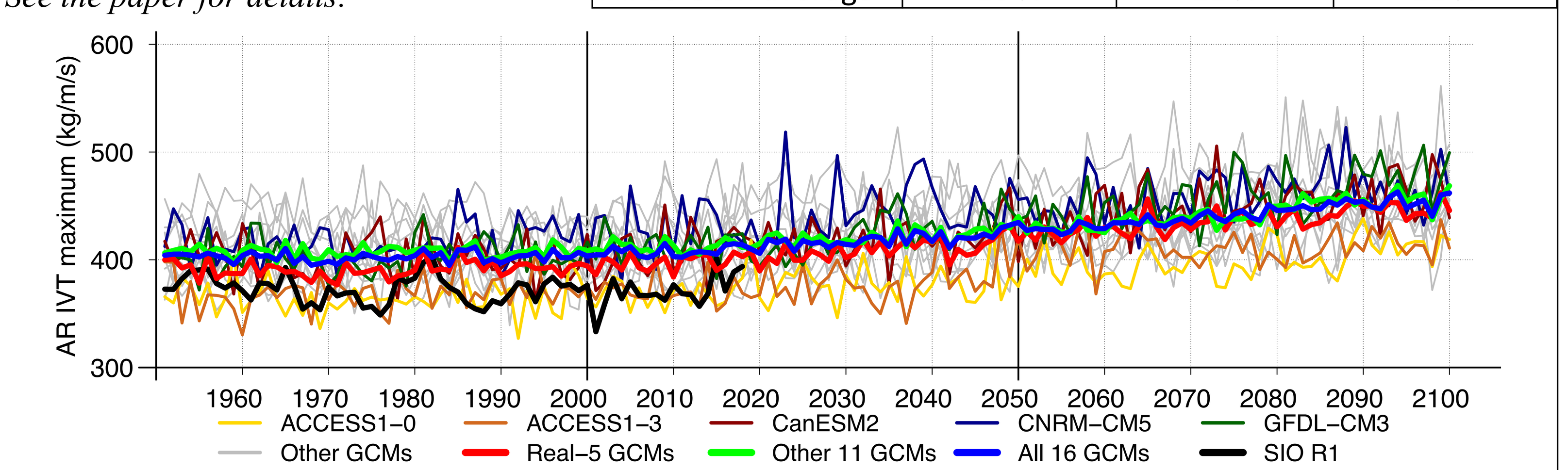

Figure 2. *Annual average max IVT for ARs landfalling upon* ***the West Coast*** *[20–60N] in historical and projected epochs. Real-5 GCMs are plotted in thin colored lines, other GCMs - in gray. Thick curves represent the ensemble averages of the Real-5 GCMs (red), the other 11 GCMs (green), and the full ensemble of 16 GCMs (blue). The thick black curve shows the observed (SIO-R1) variability.*

Change in precipitation frequency

AR contribution to total precipitation in the future increases by about 15% in the Pacific Northwest and 20% in coastal California (Fig.2). The most intense AR-related precipitation drives up average precipitation intensity (not shown), while all precipitation frequency is decreasing and the frequency of AR-related precipitation contributions is increasing according to the Real-5 GCMs.

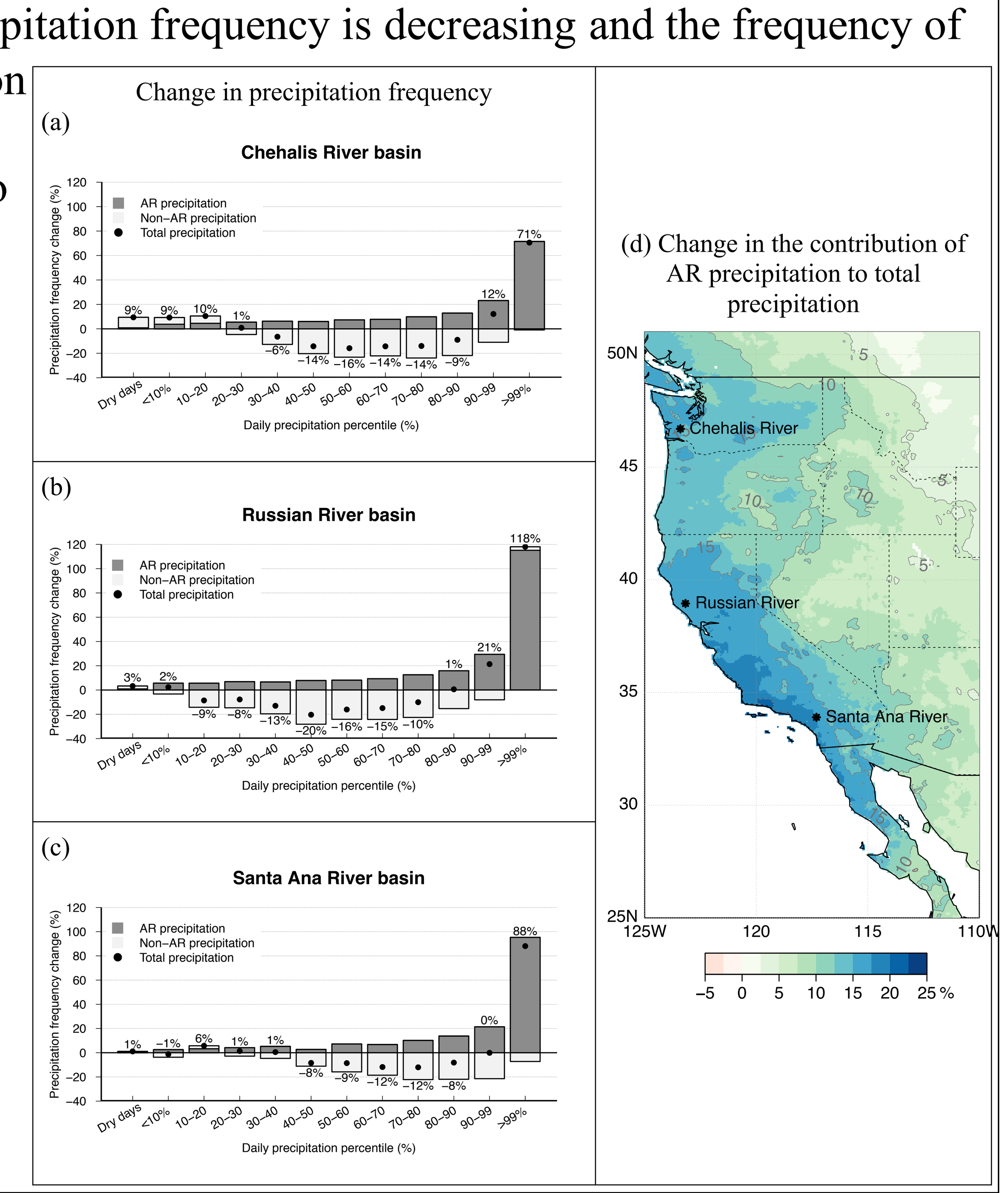

Figure 3*. Future changes in daily precipitation frequency binned by percentile ranges of daily intensity (% of historical climatology). Results represent ensemble averages for the Real-5 LOCA-downscaled GCMs for the Chehalis, Russian and Santa Ana river basins (a–c, respectively). Changes in total precipitation are denoted by dots and associated values; AR-related precipitation (for each AR day and the following day) – dark grey bars; and non-AR precipitation – light grey bars. Panel (d) illustrates Real-5 ensemble average change in the contribution of AR-related precipitation to total precipitation (in % of historical contribution).*

Impact on precipitation regime

The stronger increasing trends in AR-related precipitation (Fig.4b) and a weaker decreasing trend in non-AR-related precipitation (Fig. 4c) combine to increase the total precipitation in California (Fig.4a), according to the Real-5 GCMs as compared to the rest of the full ensemble of 16 GCMs. The same mechanisms operate over a larger west-coastal domain, but they do not exert as much impact on precipitation volatility in the Northwest (not shown).

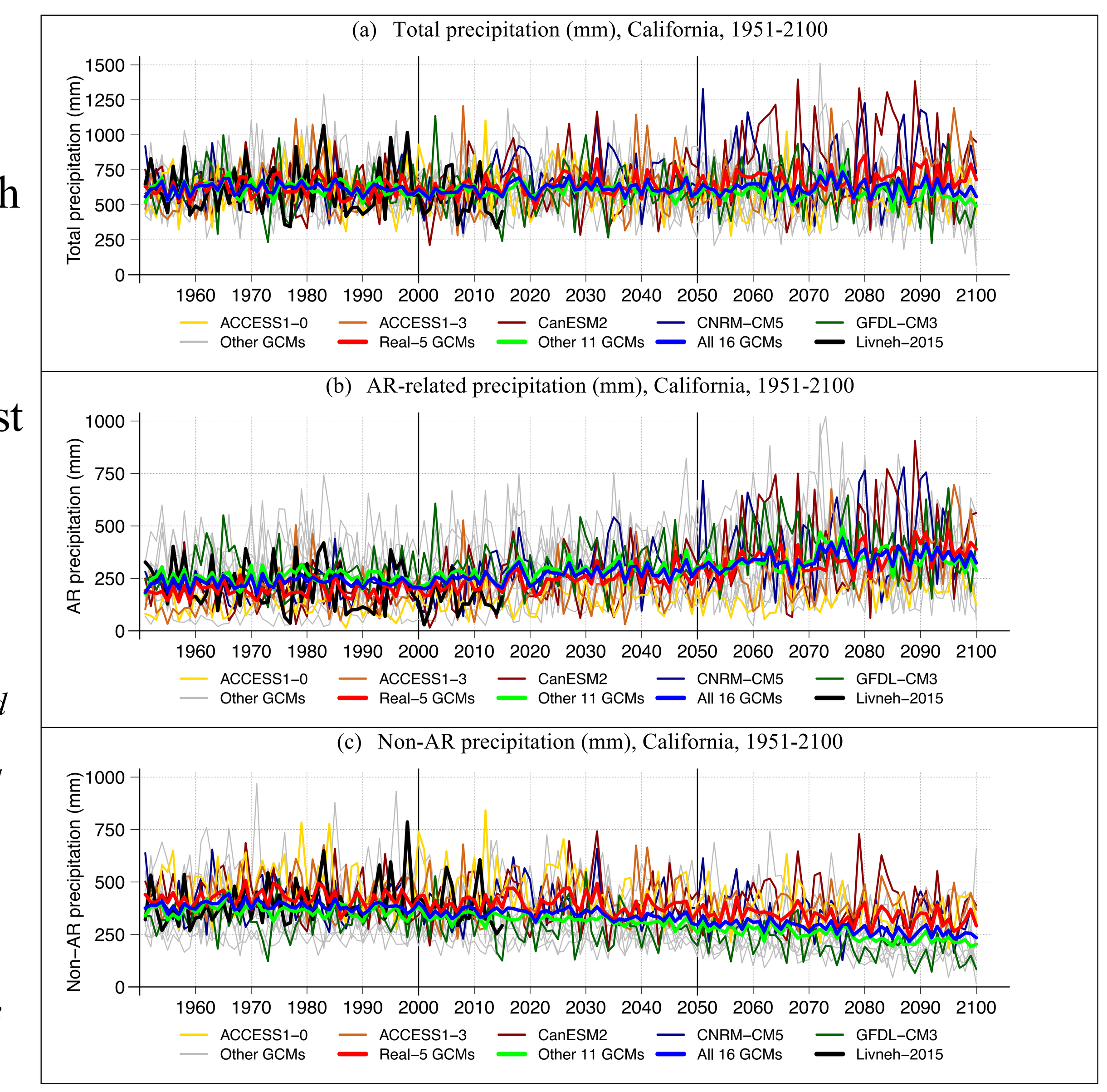

Figure 4*. Annual total (a), AR-related (b) and non-AR related (c) LOCA-downscaled precipitation spatially averaged over* ***California*** *during historical and projected time periods. The color code of the results plotted is the same as Fig.2.*

Conclusions

- 16 GCMs are evaluated for realism in modeled historical AR behavior and contribution to annual total precipitation over U.S. West.
- The five most realistic models project increasing year-to-year variability of total annual precipitation, particularly over California, where change in total annual precipitation is not projected with confidence.
- Focusing on three representative river basins along the West Coast, we show that, while the decrease in precipitation frequency is mostly due to non-AR events, the increase in heavy and extreme precipitation is almost entirely due to ARs.

This research demonstrates that examining meteorological causes of precipitation regime change can lead to better and more nuanced understanding of climate projections.

References and Acknowledgements

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