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Atmospheric River Effects on Precipitation and Snowpack in California during the 2008-09 Cold Season

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1. Motivation and Background

- Atmospheric rivers (ARs), narrow and intense filaments of moisture fluxes originating in the tropical and/or subtropical oceans, account for over 90% of the poleward atmospheric moisture transport and have a profound impact on the weather and hydrology on the cold season water cycle in California's mountainous region.
- Previous studies showed that extreme hydrologic events in the region are related with a few intense moisture flux events (Soong and Kim 1996; Kim 1997; Neiman et al. 2002; Ralph et al. 2006; Kim and Kang 2007).
- The impact of he ongoing global climate change on AR is an important concern in the US Pacific coastal region for the mitigation of the climate change impact on hydrology-related sectors (flood forecasting, water resources).
- Quantitative effects of AR and the capability of regional models in simulating ARs have not been examined.

2. Objectives

- Quantify the impact of AR events on the 2008-09 cold season hydrology in California.
- Evaluate the JIFRESSE RESM based on the WRF-ARF model in simulating the large-scale flows and regional hydrology for seasonal time scales utilizing recent observations, reanalysis, and state-of-the-art snowpack assimilation products.

3. Experiment

- A continuous simulation for the 2008-09 cold season (October 2008 - March 2009) using the WRF-ARW model (version 3.0.1), *a time scale for seasonal forecasts*.
- A March 2005 AR event in a 5-day leadtime run, *a typical short-term NWP time scale*.
- The *Kain-Frisch convection* scheme, *GCE cloud microphysics* scheme, *NOAH LSM*, *Dudhia-SW* and *RRTM* schemes for the short- and longwave atmospheric radiative transfer, respectively, and *YSU PBL* scheme have been employed in the simulation.
- The large-scale boundary forcing data have been obtained from the ERA-Interim reanalysis at 1.5° horizontal resolutions and at 6-houry temporal resolutions.

4. Model domain: One-way nested

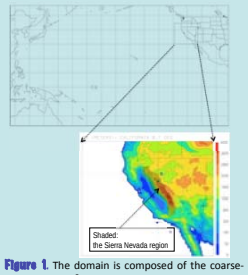


Figure 1. The domain is composed of the coarse-resolution (0.4°) pan-Pacific domain (PP) and the fine-resolution (0.1°) California domain (CA) one-way nested within PP. The domain is designed for investigating the links between ARs and the tropical (PP) as well as their impact on California's hydrology (CA) in a single numerical experiment.

5. Evaluation: PWV in a March 2005 AR event

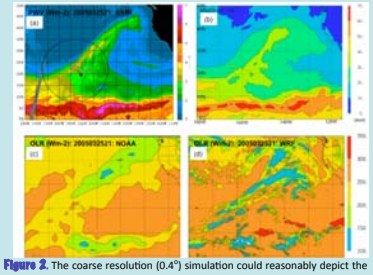


Figure 2. The coarse resolution (0.4°) simulation could reasonably depict the observed PWV and OLR over the eastern Pacific Ocean associated with March 25, 2005 AR event 5 days after the initialization time: (a) PWV from SSMI retrievals, (b) Simulated PWV, (c) OLR from the Satellite-based NOAA analysis, and (d) the simulated OLR.

This suggests that the WRF model run on the PP domain possesses useful skill in simulating/forecasting AR events at the time scales for short-term NWP.

6. 2008-09 Cold Season Hindcast

- The short-term hindcast study shows that the WRF-ARW model may possess useful skill in simulating the overall evolution of the atmospheric circulation over the Pacific Ocean prior to the land-falling AR event.
- The model in seasonal-scale simulation is examined in a 2008-09 cold season (October 2008 – March 2009) hindcast, again driven by the ERA-Interim reanalysis.
- From visual inspection of daily PWV and 850hPa water vapor fluxes in the ERA-Interim data, 8 AR-like events that affected California are identified for the 5-month period (Table 1).

Table 1. California-affecting AR Events in the 2008-09 cold season

Date	AR - Landfall locations
20081004	Northern California
20081005	Southern California, near Santa Barbara
20081222	Northern California
20081223	Southern California
20090223	California coast to the north of Santa Barbara
20090224	California coast to the north of Santa Barbara
20090302	Northern California
20090303-05	Southern California

7. Obs & Simulated PWV fields during the 2008-09 Cold Season

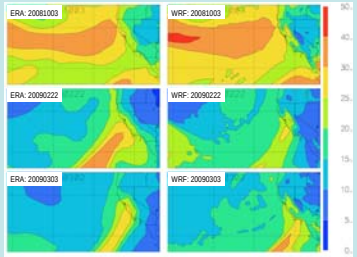


Figure 3. The coarse-resolution cold season hindcast over the PP domain could simulate a number of AR-like events throughout the season. This shows that the WRF model also possesses some skill in simulating and/or forecasting AR events at seasonal time scales.

Despite the success in simulating the AR-like events throughout the season, the agreements between the simulated and ERA-Interim analysis are largely qualitative, especially for those events during the later part of the cold season.

8. Spatial Anomaly Correlation between the hindcast and ERA-Interim

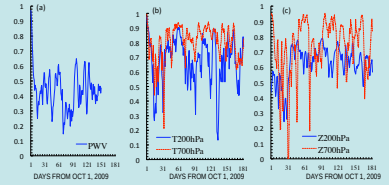


Figure 4: Examine the daily anomaly correlation between the PP-domain hindcast and the ERA-Interim reanalysis, a measure of how well the large-scale circulation patterns are simulated in the regional hindcast.

- Examine the anomaly correlations in (a) PWV and (b) temperatures and (c) geopotential heights at the 200hPa and 700hPa levels.
- (*Figure 4a*) The PWV spatial anomaly correlation coefficients remain 0.3-0.6 after the first 15-day period.
- (*Figure 4b & 4c*) The spatial anomaly correlation coefficients are larger for the upper-air geopotential height and temperature than PWV
- After the initial adjustment period (~15days), the model performance in simulating the key large-scale patterns within the domain varies widely, however, does not show systematic drift over the remaining period.

9. The Percentage of the Season-Total Precipitation in the Sierra Nevada Region (Figure 1) associated with the 2008-09 AR-like Events (Table 1): WRF (0.1°), NCEP-URD (0.25°), SNODAS Input (0.00833°)

	All Sierra Nevada			Northern Sierra Nevada			Southern Sierra Nevada		
	WRF	URD	SNODAS	WRF	URD	SNODAS	WRF	URD	SNODAS
Season Total (mm/day)	4.6	3.1	3.8	5.1	3.7	4.6	2.8	1.9	1.9
AR (% Season)	20	28	26	22	32	28	17	16	17

- The AR-like events are, with the URD raingauge analysis as the reference dataset, associated with 17-32% of the season total precipitation in the Sierra Nevada region.
  - The AR-like events *have affected the northern Sierra Nevada region more than the southern Sierra Nevada region*.
- The hindcast has significantly underestimated the amount of AR precipitation in the northern Sierra Nevada.
  - The AR-precipitation percentage in the WRF hindcast shows much smaller contrast between the northern and southern Sierra Nevada region compared to the two observationally-inferred precipitation analyses.
  - The hindcast generally overestimates the seasonal precipitation totals in all of the Sierra Nevada regions.
- The SNODAS input precipitation data agrees closely with the URD data in all of the Sierra Nevada regions.
  - The data may be useful for a surrogate for observed precipitation data.

10. Daily SWE in the Sierra Nevada

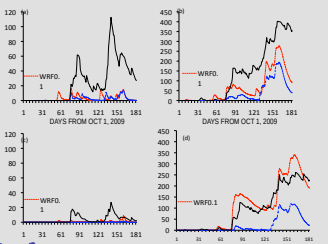


Figure 5. The daily SWE (mm) from the SNODAS assimilation and the seasonal hindcast at two different spatial resolutions: (a) Below 1500m, northern Sierra Nevada (SN), (b) above 1500m, northern SN, (c) below 1500m, southern SN, and (d) above 1500m, southern SN.

- The WRF model substantially underestimates SWE in the SN region:
  - The underestimation is most serious in the low-elevation regions
  - The underestimation is more serious in the coarse resolution run.
  - The fine-resolution SWE simulation agrees well with the SNODAS data in the southern Sierra Nevada region.

11. Daily Cumulative Precipitation in the Sierra Nevada

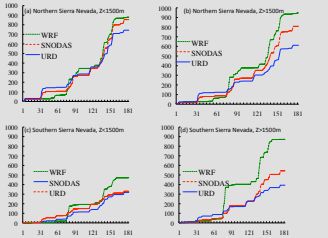


Figure 6. The cumulative precipitation (mm) from the URD, SNODAS input, and the fine-resolution hindcast: (a) <1500m, northern SN, (b) >1500m, northern SN, (c) <500m, southern SN, d) >1500m, southern SN.

- **Precipitation may not be the cause for the SWE underestimation**:
  - The fine-resolution hindcast generally overestimates precipitation in both evaluation datasets.
  - The overestimation of precipitation is most serious in the high elevation southern Sierra Nevada region.
  - The SN precipitation is similar in both hindcasts.

12. Daily Freezing-level Altitudes

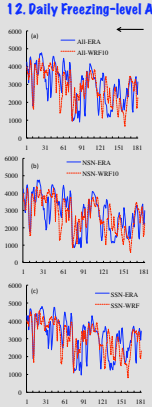
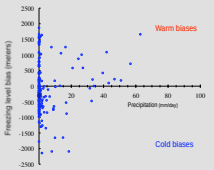


Figure 7. Daily freezing-level altitudes (m) over the Sierra Nevada in the ERA-Interim analysis & the 0.1°-resolution hindcast: (a) All SN, (a) northern SN, and (c) southern SN.

Figure 8. The errors in freezing-level altitudes according to the amount of daily precipitation in the 0.1° hindcast.



- Evaluation of the simulated daily freezing-level altitudes over the Sierra Nevada against the ERA-Interim reanalysis shows significant warm biases over the region (Figure 7).
- The warm biases are especially large during major precipitation events in the earlier part of the season (Figure 7).
- The relationship between the simulated daily precipitation over the Sierra Nevada region and the biases in the freezing-level altitude shows the occurrence of significant warm biases during heavy precipitation events (Figure 8).
  - Positive freezing level biases imply warm biases in the simulation.
- The results in Figures 7 and 8 show that the simulation is warm biased during heavy precipitation events.
  - The occurrence of warm biases during major precipitation period explains the underestimation of SWE in the seasonal hindcast, at least partially.
- The errors in simulating SWE in this study appears to be closely related with the errors in temperature simulations

Summary and Conclusions

IN order to understand the impact of land-falling ARs on the hydrology in the Sierra Nevada region during the 2008-09 cold season, a nested modeling experiment has been performed using the WRF-ARW model in conjunction with large-scale forcing data from the ERA-Interim reanalysis.

THE metrics selected for the measures of model performance for the larger, coarse resolution domain suggests that *the WRF-ARW possesses some skill in simulating the temporal and spatial variations of the large-scale circulation within the domain for the time scale corresponding to a season*, a key for successful seasonal and extended period NWP based on dynamical modeling.

THE evaluation also shows that the agreement between the hindcast and the observed data are largely qualitative, especially for the period after the first 10-15 days of the hindcast period.

BOTH the seasonal hindcast and precipitation analysis data show that *20-30% of the season-total precipitation in the Sierra Nevada region is associated with AR-like events*. They also show that *the AR-like events have affected northern Sierra Nevada region more than the southern Sierra Nevada*. The model could not depict such north-south variations in the observed precipitation data.

THE hindcast underestimates the SWE in the Sierra Nevada region. The underestimation is most noticeable in the low-elevation regions (<1500m), northern Sierra Nevada, and in the coarse-resolution run.

FURTHER examination of the hindcast data shows that the biases in the simulated SWE are mainly related with warm biases, especially during heavy precipitation periods in the early part of the cold season.

Acknowledgement

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