Convective-Permitting Simulations of Extreme Weather and Climate Events in El Salvador with the Weather Research and Forecasting Model

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Introduction and Motivation

Within the Americas, northern Central America is 'ground zero' for the most profound impacts of climate change. A 'perfect storm' of contributing factors include: intensification of the mid-summer drought (or *canicula*), more extreme storms, and relatively high socioeconomic vulnerability. In this study, we focus on the country of El Salvador (Fig. 1), which already has some existing infrastructural capacity for weather forecasting and modeling with their Ministry of Natural Resources and Environment (MARN). Due it its complex topography and predominance of convective precipitation (Fig. 2), the application of high resolution convective-permitting modeling in this particular country is likely to be useful in the representation of extreme weather and climate events.

MARN has documented examples of recent high impact, extreme weather and climate events, that are representative of what would be expected to occur in association with ongoing climate change. The objective of this study is perform retrospective simulation of three significant events performed with the Weather Research and Forecasting (WRF) model, to assess if a convective-permitting model can generate reasonable representation of event precipitation, as necessary for the purpose of impacts assessment. We use WRF in a nested grid configuration with physics nominally similar to the operational forecasting configuration used at the University of Arizona, using ERA-Interim and CFSR reanalysis data as boundary forcing (Fig. 3). Model results are compared with corresponding precipitation observations from MARN and satellite products, as well as GOES-IR Imagery and NARR data.

Figure 1: Location of El Salvador in Central America

Figure 2: View of San Miguel Volcano in El Salvador during rainy season.

Figure 3: WRF grid configuration for study simulations. Grid spacing (km) indicated.

Extreme Case One: Mesoscale Convective System, November 7-8, 2009

Very intense and concentrated rainfall occurred in the central part of El Salvador resulted in 198 deaths and $315 million in loss and damage. There was a recorded maximum of precipitation 300 mm within 6 hours. A common feature in model simulations and satellite imagery is the presence of tropical cyclone 'Ida' located east of the Yucatan peninsula. No simulated precipitation occurred on the CP domain that exceeds 100 mm, irrespective of source of reanalysis boundary forcing (Fig. 4, top). Though WRF fails to reasonably capture this event, satellite derived precipitation also seriously underestimates it as compared to the MARN rain gauge network (Fig. 4, bottom). Satellite imagery at the height of the event shows a highly localized nocturnal MCS, which seems to develop in association with terrain forcing of San Vicente volcano in a regime of weak southeasterly flow at 800-hPa caused by a low-level disturbance located off the coast (Fig. 5).

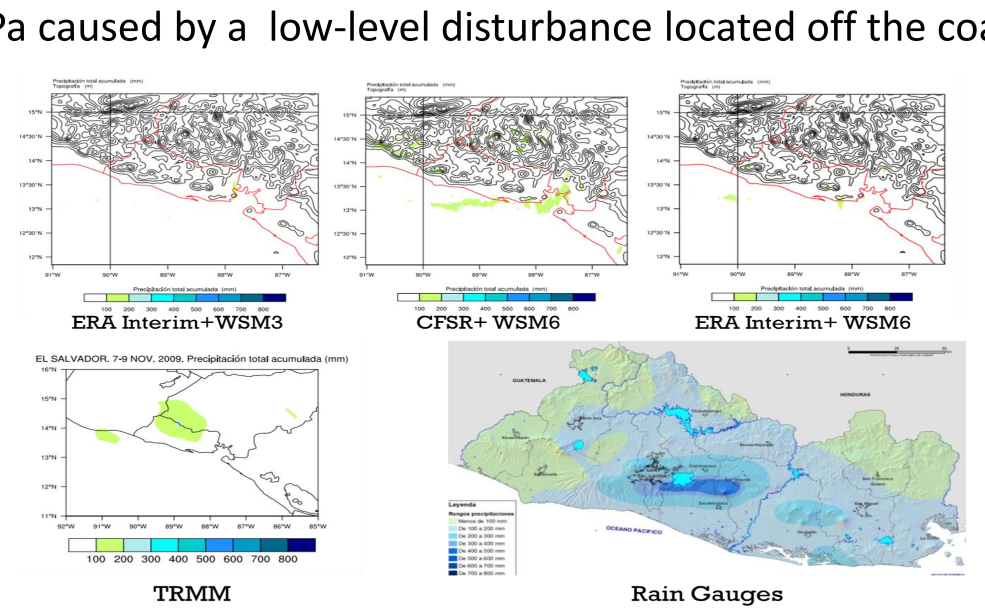

Figure 4: Top: WRF model simulated total precipitation (mm) on CP 3 km grid for Nov. 7-8 event using various combinations of microphysical parameterizations and reanalysis boundary forcing, as indicated. Bottom: Equivalent results from TRMM and MARN rain gauge network.

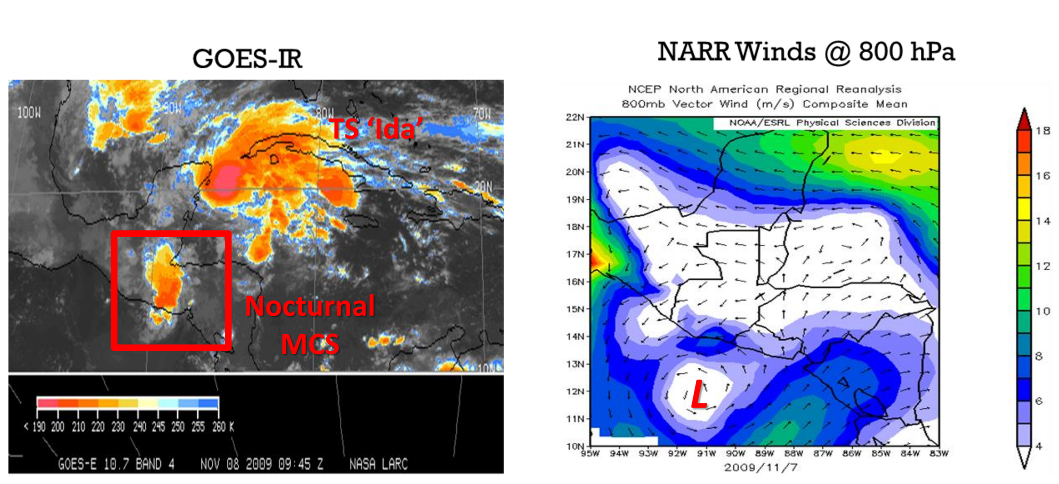

Figure 5: Left: GOES enhanced IR imagery at 945 UTC 8 Nov. 2009, near peak time of the precipitation event. Location of MCS indicated with a green box. Right: NARR winds at 800 hPa on 7 Nov., indicating a tropical disturbance (labeled L) and weak southeasterly flow over the region of MCS formation.

Conclusions and Future Work

- **For extreme weather cases where there are clear and strong large-scale climate influences on precipitation, for example as in the extreme case 2 of the tropical depression, WRF does a reasonable job simulating the precipitation response.**
- **Deterministically representing more localized MCS-type convective events in El Salvador that occur in an environment of relatively weaker synoptic forcing seems a big challenge, in both convective-permitting model simulations and satellite-derived precipitation.**
- **Convective-permitting modeling well captures local terrain influences on convective rainfall and the overall distribution of precipitation in El Salvador, provided reasonable boundary forcing.**
- **WRF used as a regional climate model realistically simulates precipitation responses associated with intensification of mid-summer drought.**
- **This initial research motivates our ongoing efforts to construct a long-term WRF model climatology within northern Central America using convective permitting modeling, that can be used to statistically assess changes in weather and climate extremes and their impact.**

Extreme Case Two: Tropical depression 12-E, October 10-19, 2011

Figure 6: Scenes of devastation in El Salvador caused by tropical depression 12-E. The damage to the agricultural sector alone (right) was nearly $100 million.

This tropical depression driven extreme precipitation event lasted 10 days, during which 42% of the average annual rainfall in El Salvador fell, and caused nearly $1 billion in damages (Fig. 6). A local maximum of 1531 mm of precipitation fell at one observing station, roughly equivalent to Hurricane Harvey in Houston. Because the reanalysis boundary forcing is clearly able to resolve the tropical depression, WRF simulated precipitation well matches MARN gauge observations, with greater amounts of precipitation over southern half of the country (Fig. 7). Volcanic peaks subject to direct low-level onshore flow on their southern slopes (Fig. 8, right) have precipitation in excess of 1000 mm, matching locations of highest cloud tops in satellite imagery (Fig. 8, left). As in the prior MCS case, there are discrepancies between TRMM and MARN gauge precipitation observations.

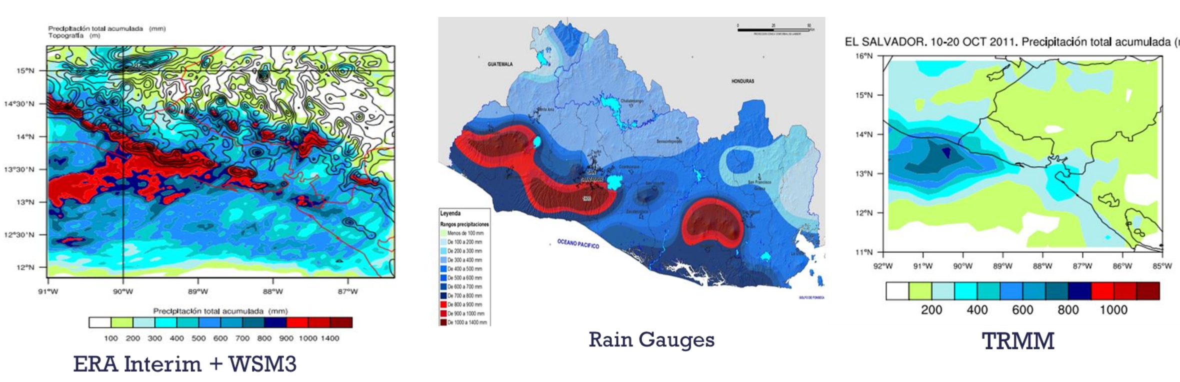

Figure 7: Left: Sample WRF simulated precipitation for tropical depression 12-E event on CP 3 km grid. Middle and right: Equivalent precipitation observations from MARN gauge network and TRMM.

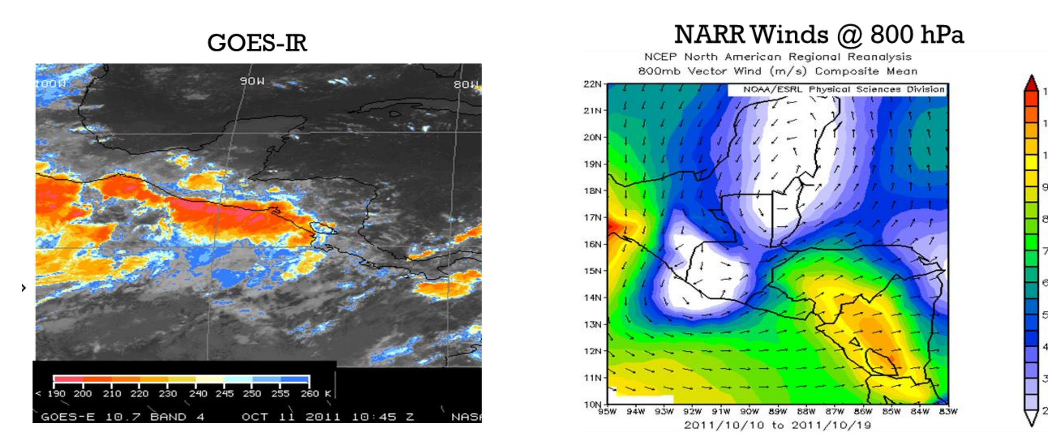

Figure 8: Left: GOES enhanced IR imagery at 1045 UTC 11 October 2011 during period of heavy precipitation in El Salvador. Right: NARR winds at 800 hPa averaged during the duration of the event

Extreme Case 3: Intensified mid-summer drought, July 2012

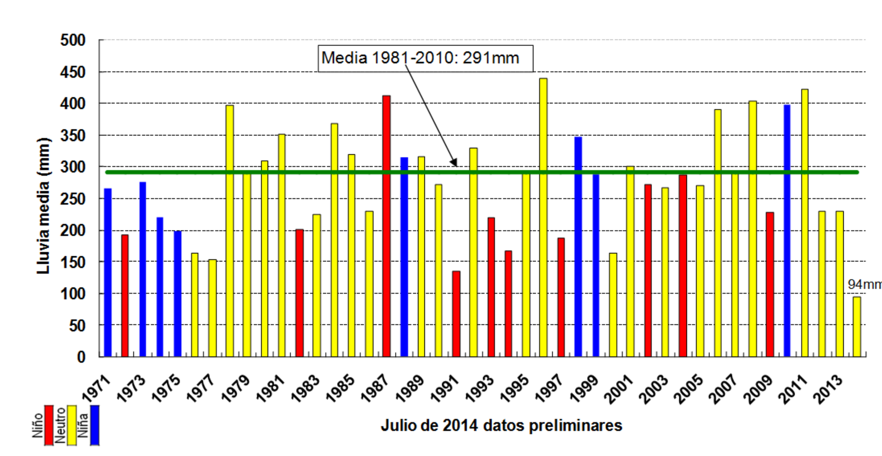

Figure 9: Average annual July (Julio) rainfall (lluvia) for El Salvador (1971-2014). The period 2012-2014 has generally been one of more intensified mid-summer drought. The average (media) for 1981-2010 period indicated.

During a three year period 2012-2014, El Salvador experienced record low July precipitation totals (Fig. 9). These dry July months reflect the intensification of the mid-summer drought. Whereas most dry Julys in the past have been associated with ENSO, the more recent dry Julys have occurred in ENSO-neutral conditions. To demonstrate the application of WRF as a regional climate model for simulation of drought at sub-seasonal to seasonal timescales, we chose to simulate July 2012. This period was characterized by anomalous high pressure over northern central America (not shown), with anomalously dry conditions in the eastern half of El Salvador (Fig. 10, middle and right). The pattern of model-simulated precipitation similarly shows a large gradient in precipitation going from west to east across the country (Fig. 10, left). The spatial expression of the drought extends further north and east into Honduras. Where substantial precipitation does occur in the western half of the country, it is enhanced in the vicinity of terrain features in both observed and model precipitation. A similar expression of drought exists in the coarser WRF model grids (not shown).

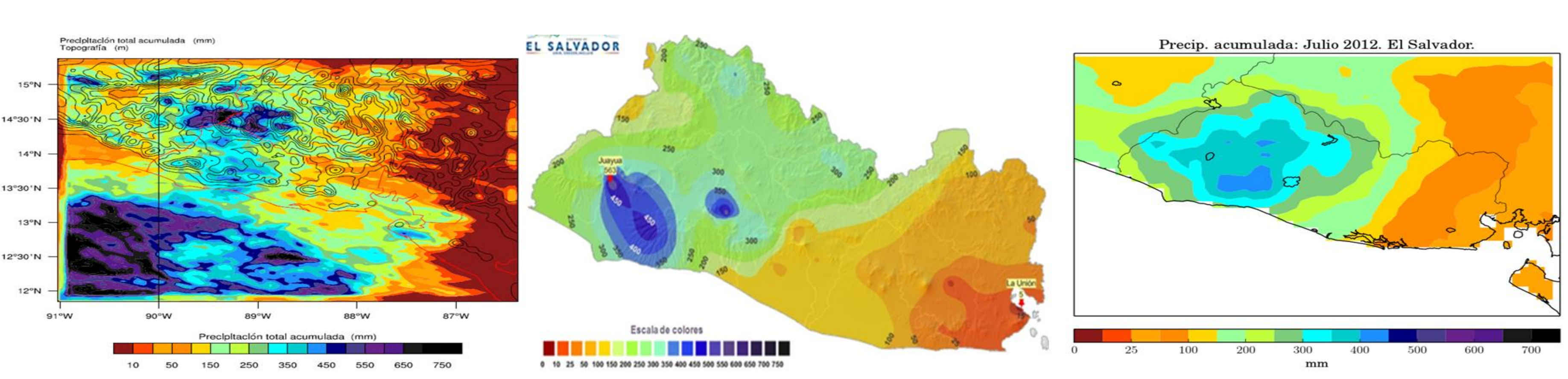

Figure 10: Left: Sample WRF simulated precipitation result on CP 3 km grid for July 2012. Middle and right: Equivalent observed precipitation results from MARN rain gauge network and CHIRPS daily precipitation product.

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