On Air-Sea Interaction in the Gulf of California and its Effect on North American Monsoon

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ABSTRACT

The North American Monsoon (NAM) is a seasonal change in the sub-tropical circulation that supplies 60-80% of annual rainfall in northwestern Mexico and 30-40% in the US southwest. Regional climate models have shown that summer precipitation prediction over North America is poorest in the NAM region. An understanding of the NAM's principal processes is essential for improving global and regional climate modeling.

In this study, we suggest a partial mechanistic understanding of the NAM in the local scale that explains how the inversion over Gulf of California (GC) controls the low-level moisture. The proposed hypothesis is supported by satellite observations, ship soundings launched over the GC, and regional model (WRF) simulations.

A set of carefully designed simulations of WRF is used to investigate the dependence of NAM precipitation, onset and circulation on SSTs along the Mexican coastline and in the GC. Enhanced observational data from North American Monsoon Experiment (NAME) field campaign in summer 2004 is used to evaluate the modeling results. WRF simulations show that warmer GC SSTs tend to enhance low-level moisture flux during this period and as a result more precipitation occurs over the foothills of Sierra Madre Occidental (SMO) and over US southwest. However, simulated inversions are stronger than rawinsonde observations and consequently show dry bias in free troposphere. This discrepancy may represent an opportunity to improve WRF performance over North America during summer.

1. Introduction

The North American Monsoon (NAM) provides about 60%-80%, 45% and 35% of the annual precipitation for northwestern Mexico, New Mexico (NM) and Arizona (AZ), respectively (Douglas et al. 1993; Higgins et al. 1999). An intercomparison of regional climate models by Mearns et al. (2012) has shown that summer precipitation prediction over North America is the most underestimated in the NAM region. NAM rainfall is relevant to the amplification and northward shift of the upper level anticyclone over the southwestern US, called the monsoon anticyclone or monsoon high (Carleton et al. 1990; Higgins et al. 1999).

Several studies investigated the importance of GC SSTs on NAM rainfall. An empirical study of six monsoon seasons by Mitchell et al. (2002) indicated that no monsoon precipitation was observed in the NAM region when GC SSTs did not exceed 26°C. They also showed that 75% of June-August precipitation in Arizona-New Mexico region occurred 0-7 days after the northern GC SSTs exceeded 29.5°C.

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Although various observational and modeling studies showed some characteristics of the NAM, a mechanistic understanding of the NAM is still elusive. In this study, we offer a partial mechanism that addresses mesoscale processes. Section 2 discusses the relationship between GC SSTs, inversion cap and relative humidity based on both observations and numerical simulations. Conclusions are presented in section 3.

2. Results

In this research, we utilized sea surface temperature (SST) and rainfall amount observed from satellite, temperature and moisture profiles from ship soundings launched over the GC, and regional scale model simulation over the NAM region by WRF.

Following Mitchell et al. (2002), we have analyzed three other monsoon seasons at higher resolution regarding SST and AZ rainfall amounts, resulting in similar findings. All these findings indicate rainfall begins after the northern GC SST exceeding a threshold of 29.5°C. The mechanism for this relates to the marine boundary layer (MBL) over the northern GC (figure 1). For SSTs < 29°C, the air over GC is capped by a strong inversion located ~ 50-200 m above the surface, restricting moisture to MBL in GC. Once SSTs exceed 29°C, the inversion becomes as weak as 2°C, allowing MBL moisture to mix with air in free troposphere. As a result, relative humidity of lower 2000m of troposphere is higher than 55%. This results in a deep, moist layer that can be advected inland to produce thunderstorms.

A set of carefully designed simulations using WRF is conducted to investigate the dependence of NAM precipitation and onset on SSTs in the GC (figure 2). WRF is able to simulate moisture flux parallel to the GC axis during the 2004 monsoon onset (figure 3). Also, WRF tends to produce higher moisture flux when GC SSTs are warmer. In agreement with observations, WRF simulations show that warmer GC SSTs tend to weaken the inversion that caps the GC MBL and increase low-level moisture during this period. This leads to the rainfall enhancement in AZ region. However, WRF simulates a stronger inversion compared to observational soundings and as a result, moisture profiles in WRF simulations are drier compared to observational soundings (figure not shown). This might explain the underestimation of rainfall in WRF simulations compared to observations as shown in figure 3.

3. Conclusions

We suggest a mechanism to physically understand key processes governing NAM. The mechanism at the local scale is related to the MBL over northern GC. The strong low-level inversion, capping the top of shallow MBL, weakens with increasing SST and generally disappears once SSTs exceed 29°C, which allows the trapped MBL moisture to mix with free tropospheric air. This leads to a deep, moist, well-mixed layer that can be transported inland to form thunderstorms. WRF simulations generally agree with the observations and represent higher moisture flux and precipitation due to increase in GC SSTs. However; WRF overestimates the inversion and underestimates the moisture profile and rainfall. This discrepancy may represent an opportunity to improve WRF performance during summer over North America.

References

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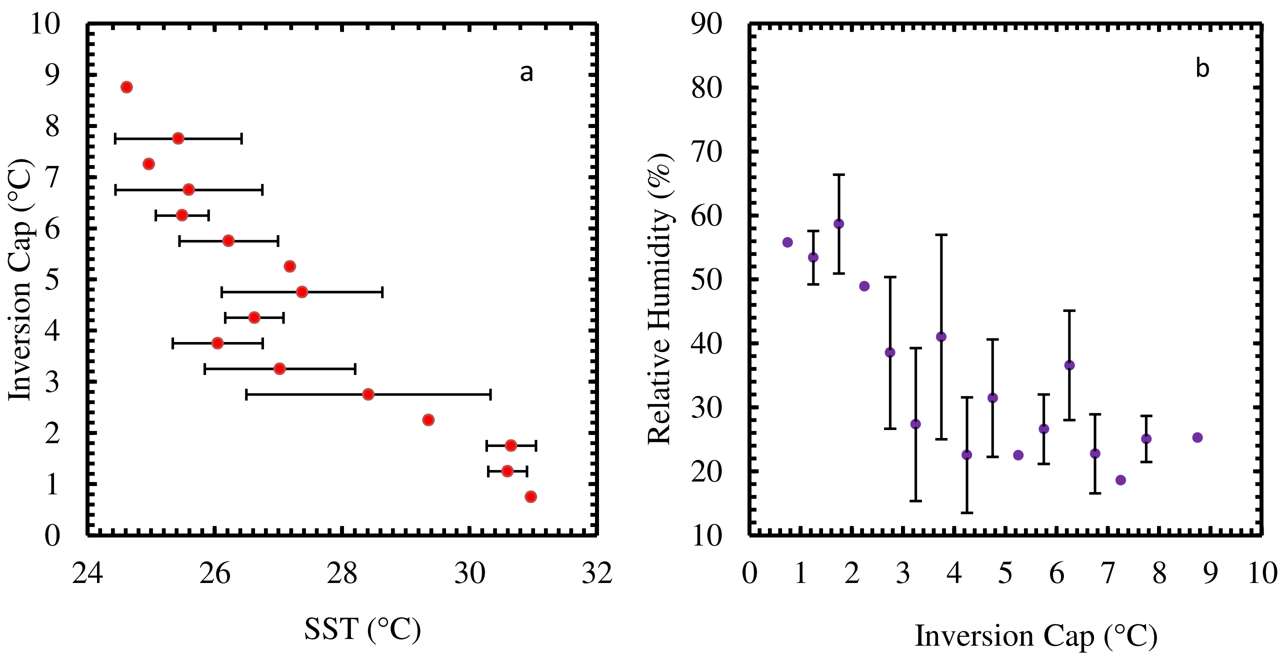


FIG 1. a) SST dependence of inversion cap based on mean SSTs and b) Inversion cap dependence of low-level RHs based on mean low-level RH for all rawinsondes onboard RV in GC during June and August 2004. Bars are indicative of standard deviations and data points with no standard deviation are based on less than 3 SSTs in (a) and based on less than 3 RHs in (b).

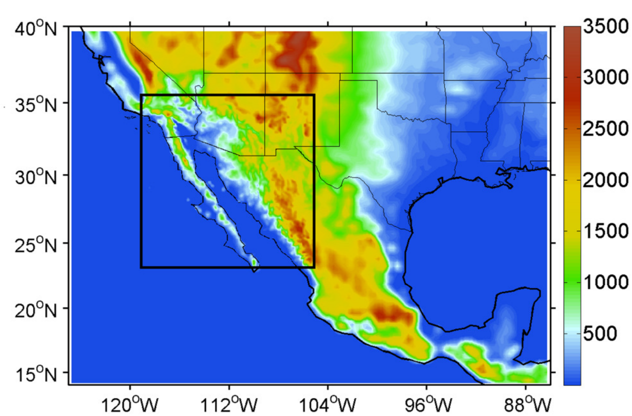
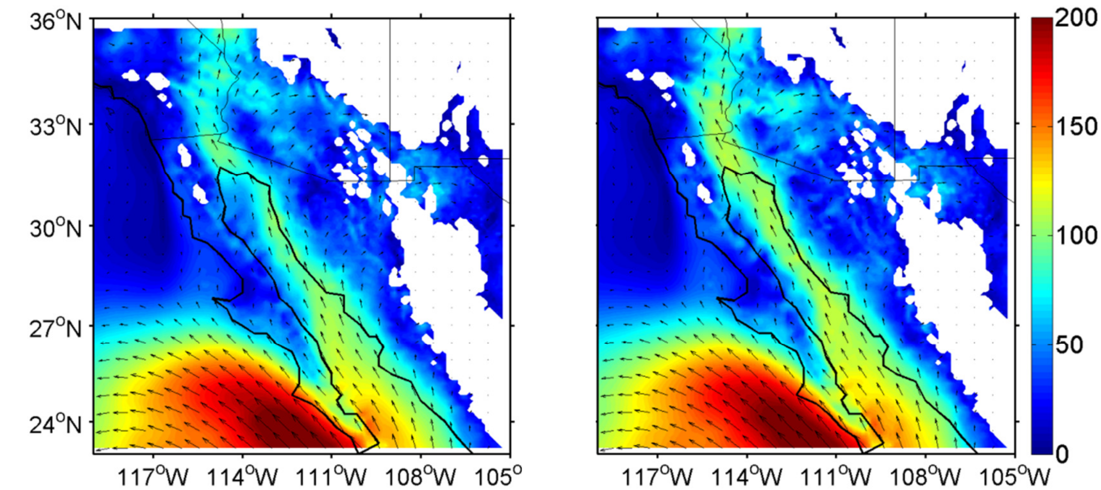


FIG 2. Terrain height and model domains for WRF simulations.



a b

FIG 3. Moisture Flux (in units of (g m kg^{-1} s^{-1}) integrated on 14 July 2004 and from surface to 850 hPa for a) WRF (SST: 26/28) and b) WRF (SST: 30/30)

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