P40

Sensitivity to Madden-Julian Oscillation variations on heavy precipitation over the contiguous United States

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1

Abstract

The Madden–Julian Oscillation (MJO) is the most prominent mode of tropical intraseasonal variability in the climate system and has worldwide influences on the occurrences and forecasts of heavy precipitation. This paper investigates the sensitivity of precipitation over the contiguous United States (CONUS) in a case study (boreal 2004–05 winter). Several major storms affected the western and eastern CONUS producing substantial economic and social impacts including loss of lives. The Weather Research and Forecasting (WRF) model is used to perform experiments to test the significance of the MJO amplitude. The control simulation uses the MJO amplitude observed by reanalysis, whereas the amplitude is modified in perturbation experiments. WRF realistically simulates the precipitation variability over the CONUS, although large biases occur over the Western and eastern CONUS producing substantial economic and social impacts including loss of lives. Daily precipitation is aggregated in western, central and eastern sectors and the frequency distribution is analyzed. Increases in MJO amplitude produce moderate increases in the median and interquartile range and large and robust increases in extreme (90th and 95th percentiles) precipitation. The MJO amplitude clearly affects the transport of moisture from the tropical Pacific and Gulf of Mexico into North America providing moist rich air masses and the dynamical forcing that contributes to heavy precipitation.

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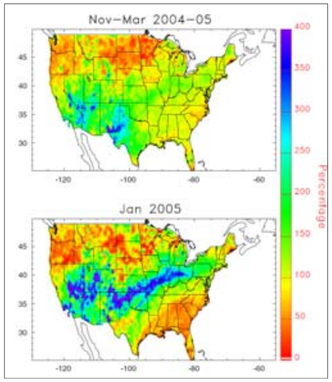


Fig. 1. (top) Total precipitation during 1 Nov 2004–31 Mar 2005 as departure from climatology; (bottom) departure from climatology of total precipitation during Jan 2005. Data: daily CPC-uni gridded precipitation 0.25-degrees lat/lon.

2004-2005 Winter Season

I. Major storms:18 December – 17 January 2004-05
  - 23 December: snow in Midwest
  - 28-29 December: precipitation in California
  - 2-5 January: heavy precipitation in Midwest
  - **7-11 January: heavy precipitation in California**
  - **11-13 January: heavy precipitation in Midwest**

II. Active MJO:
  - **18 December (phase 1) – 20 January (phase 8)**

III. Weak warm ENSO: June 2004 – February 2005; (~0.6C SSTA

IV. Strong NAO (1.4 standardized index)

V. Atmospheric rivers: early January 2005

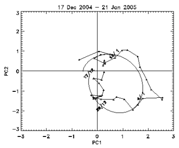
- 27 Dec-10 Jan: 16.97 inches in Los Angeles; wettest 15-day period on record
- 28 Dec-11 Jan: 13 feet snow at Sierras
- 6-11 Jan: Pr > 20 inches mountains Santa Barbara
- 13 Jan: > 1 inch rain in 24h Mississippi & Ohio Valley
- More than 20 people killed
- Tens of millions dollars in damage

How sensitive is heavy precipitation over the contiguous United States to the amplitude of the MJO?

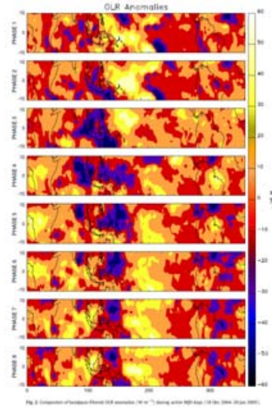
2

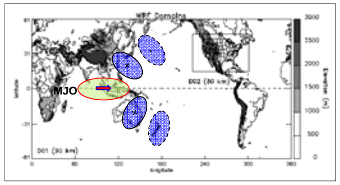
MJO evolution 2004-05

- 18 December (Phase 1), 19–24 December (Phase 2), 25 December–2 January (Phase 3), 3–8 January (Phase 4), 9–12 January (Phase 5), 13–16 January (Phase 6), 17–18 January (Phase 7), 19–20 January (Phase 8).
- Mean amplitude:1.34; close to historical median value 1.64



PC Phase evolution of MJO (solid: filtered index; triangles: RMM index)





- Numerical experiments: WRF model (3.5.1)
- Period: 18 Dec 2004 - 20 January 2005
  - 7-11 Jan: heavy precipitation in California
  - 11-13 Jan: heavy precipitation in Midwest
- Two domains: D01 90 km, D02 30 km
- One way nesting, 41 levels, 7 min time step D1
- Initial and boundary conditions: CFSR reanalysis, every 6hrs (including sea surface temperature)
- Parameterizations: WSM-5 microphysics, KF cumulus, M-O sfc layer physics, YSU PBL, unified Noah land-sfc physics
- Verification: CPC unified grid precipitation 0.25 lat/lon

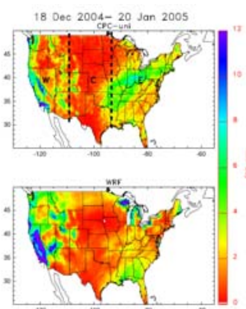
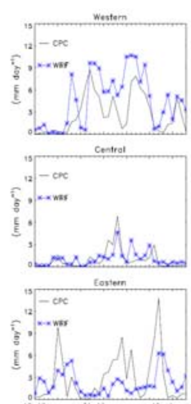


Fig. 5. (top) CPC-uni mean daily precipitation and (bottom) WRF mean daily precipitation (bias removed). Period: 18 Nov 2004–20 Jan 2005.



3

Experiments

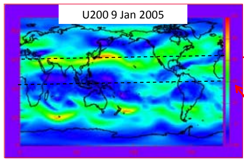
Control

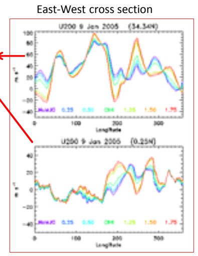
- Initialized 18 Dec 04 00 UTC run until 20 Jan 05 18 UTC
- Domain 01: grid nudging during 18 Dec - 20 Jan ---> CFSR
  - MJO signal retained
- One way nesting: signals enter boundaries in D02

Perturbation

- Initialized 18 Dec 04 00 UTC run until 20 Jan 05 18 UTC
- Domain 01: grid nudging 18 Dec- 20 Jan ---> perturbed field
  - MJO signal modified: removed, weaker or stronger
- One way nesting: signals enter boundaries in D02
- Intraseasonal signal: 20-100 days; 1-5 zonal wavenumbers (H, U, V, T, RH, surface to model top 10hPa)

Example of perturbation in the intraseasonal signal in D01 Domain





Intraseasonal signal (IS):
- 20-100 days; 1-5 zonal wavenumbers

Perturbed field ($U200_p$)

$$U200_p = U200 + a \times IS$$

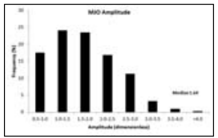
a = [-1, -0.75, -0.50, 0, 1.25, 1.50, 1.75]

Control experiment

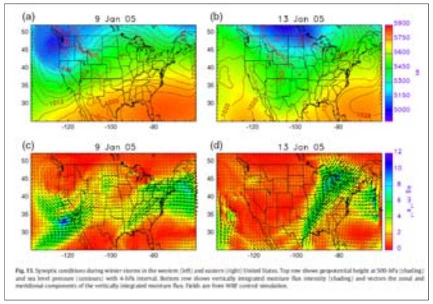
Sensitivity experiments

	MJO Amplitude						
Storm: California				07-11 Jan 05			
Mean	0	0.42	0.84	1.67	2.09	2.51	2.93
Percentile	N/A	9th	19th	Median	72th	84th	95th
Storm: Midwest				11-15 Jan 05			
Mean	0	0.27	0.54	1.08	1.35	1.62	1.89
Percentile	N/A	6th	12th	24th	46th	~Median	65th
Change in MJO Amplitude	Removed	Decreased to 25%	Decreased to 50%	CTRL	Increased by 25%	Increased by 50%	Increased by 75%

Weaker ← MJO → Stronger



Climatological distribution of MJO amplitudes (winter) 1979-2010



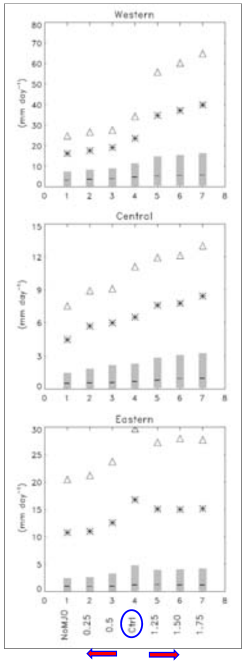


Fig. 12. Sensitivity of daily precipitation (mm day^{-1}) over the western (top), central (middle) and eastern (bottom) USA sectors. Different MJO signals: NoMJO, reduced to 0.25, 0.5, control (CTRL), increased by 0.25, 0.5 and 0.75. Interquartile range (box), median value (tick), 90th (star) and 95th (triangle) percentiles. Statistics are calculated from all grid points in each sector. Period: 18 Dec 2004–20 Jan 2005.

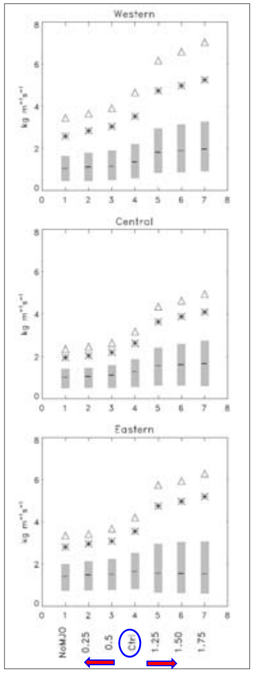


Fig. 13. Sensitivity of vertically integrated moisture flux intensity (Kg m^{-1} s^{-1}) over the western (top), central (middle) and eastern (bottom) USA sectors.

Conclusions

- 2004-05 winter season was characterized by extreme precipitation across southern states and parts of the Midwest
- The WRF model is used to perform experiments to test the significance of the MJO amplitude. The control simulation uses the MJO amplitude observed by reanalysis; perturbation experiments use modified intraseasonal signals.
- WRF realistically simulates the precipitation variability over the CONUS, although large biases occur over the Western and Midwest United States.
- Increases in MJO amplitude produce moderate increases in the median and interquartile range and large and robust increases in extreme (90th and 95th percentiles) precipitation.
- The MJO amplitude clearly affects the transport of moisture from the tropical Pacific and Gulf of Mexico into North America providing moist rich air masses and the dynamical forcing that contributes to heavy precipitation.