Creating dynamically downscaled seasonal climate forecast and climate projection information for the North American Monsoon region suitable for decision making purposes

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Presentation Outline

A comment on recent events

Motivation and some review from last year’s presentation

Regional climate modeling methodology

Warm-season seasonal climate forecasts and climate change projections

Consideration of extreme events

Conclusions

Acknowledgments:

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米女性下院議員らに銃乱射、6人死亡13人負傷

【トゥーソン（米アリゾナ州南部）＝西島太郎】8日午前10時（日本時間9日午前2時）頃、アリゾナ州トゥーソンのショッピングモールで、民主党の女性下院議員ガブリエル・ギフォーズ氏（40）が有権者との対話集会をしていたところ、男が突然拳銃を乱射した。

連邦判事や9歳の少女を含む6人が死亡、頭部を撃たれたギフォーズ議員ら13人が負傷した。同議員は銃弾が頭を貫通する重傷を負ったが、緊急手術で一命を取り留めた。男はその場で取り押さえられた。

地元メディアによると、逮捕されたのは近くに住むジャレッド・ロフナー容疑者（22）。ギフォーズ議員の背後から接近し、乱射したという。捜査当局は同議員を狙ったとみている。共犯者がいる可能性もある。同容疑者は精神的に不安定な状態だったという。オバマ米大統領は「国にとっての悲劇だ」とする声明をホワイトハウスで読み上げた。

ギフォーズ議員は2006年にアリゾナ州から下院議員に初当選。民主党親健派で、昨年の中間選挙で3選を果たした。夫は米航空宇宙局（NASA）の宇宙飛行士。

（2011年1月9日20時32分 読売新聞）
Our community has suffered a tremendous loss. We grieve and remember the victims.

Climate change in Arizona has been a concern of our local congresswoman during her tenure.

In that vein, we hope this work will be of benefit to the citizens of Arizona and the United States.

U.S. Representative Gabrielle Giffords
Shot and critically wounded January 8. Six others died, including her staff member
North American monsoon characteristics:

- Monsoon is a seasonal maximum in precipitation in northwest Mexico that progresses into Southwest U.S.
- Characterized by a rapid increase in thunderstorm activity in early summer.
- Thunderstorms largely driven by terrain forcing.
- Synoptic-scale forcing required for intense, organized convection.

Average rainfall in western Mexico during summer monsoon (Douglas et al. 1993)
Societal importance of the North American Monsoon

Severe weather hazard

- Microburst
- Flash flood
- Landslide
- Lightning
- Dust storm
- Wildfire

Climate Impacts

- Agriculture
- Ecosystems
- Water supply
- Water demand
- Power use
- Extreme heat
Diurnal Cycle of Convection

Crucial for Precipitation

Convective clouds form over the mountains in the morning.

By afternoon and evening storms propagate to the west towards the Gulf of California where they can organize into mesoscale convective systems if there is sufficient moisture and instability.

It’s likely that a resolution less than 5 km is necessary to represent this process correctly in regional models.

(Nesbitt et al. 2008)
Intraseasonal variability
*Helps convection organize and intensify*

Includes:
- Easterly waves
- Tropical cyclones
- Low level moisture surges
- Upper level disturbances
- Madden Julian Oscillation

(Moloney et al. 2008)
Monsoon Interannual Variability
Remote teleconnections

Idea: Atmospheric teleconnections that originate in the western Pacific (and maybe other places) affect the distribution and amount of rainfall, especially in the early part of the summer.

The dominant spatial pattern of precipitation anomalies (SPI) in early summer.

Its relationship to large-scale circulation (500-mb height anomalies).

Ciancarelli et al. (2009)
Most global climate models cannot resolve the North American monsoon well—including CFS Southern Arizona and northern Sonora
Monthly average precipitation from IPCC models during the previous century

Historical average of simulations (sres_20c3m) 1970-2000

(Francina Dominguez)
Dynamical Downscaling Methodology with WRF

- Use WRF configuration for UA operational forecasting at 32 km grid spacing over contiguous U.S. and Mexico
- 9 CFS ensemble members per season (1982-2000 Apr – Jun. initializations)

**Dynamic core**
- Conservation Equations and diffusion

**Microphysics**
- Single moment 3-class

**Radiation**
- Goddard SW RRTM LW

**Land surface**
- NOAH

**Convection**
- Kain-Fritsch

**Boundary layer**
- MJY Scheme

**Boundary Forcing**
- Lateral boundary and spectral nudging

**Coarse resolution driving data**
- TYPE 2: NCEP-NCAR Reanalysis
- TYPE 3: CFS Warm Season Reforecasts
- TYPE 4: Select IPCC AR4 models
Dramatic improvement in the climatology of monsoon precipitation accounted for by a much better representation of the diurnal cycle of convection.
GCM forecast: CFS Component of NCEP Seasonal Forecasts

- Uses results from Climate Forecast System (CFS) AOGCM at T62 resolution
- 15 ensemble members initialized in late spring from NCEP Reanalysis II
- Results indicate very marginal performance for precipitation forecast skill in the Southwest U.S. region

Spatial distribution of retrospective CFS model forecast skill (% anomaly correlation) of the 15 member ensemble forecasts of JJA. (Saha et al. 2006)
JJ SPI Anomaly Correlation: using new NOAA precipitation data product (similar to PRISM)
Anomaly Correlation for NAME Regions:
Standardized Precipitation Index
Global and regional model data vs. CPC obs.

Hypothesis for value added: Best to worst performance should be

**Reanalysis Downscaling:** “Perfect LBC”
**CFS-WRF** Downscaled Seasonal Forecast
**Original CFS** global model data
Overall dynamical downscaling leads to improvement in early warm season seasonal forecast precipitation in the core monsoon region, especially in northern Mexico. Less impressive improvement for Arizona.
Anomaly Correlation for NAME Regions:
Standardized Precipitation Index
Global and regional model data vs. CPC obs.

Zonal correlation coefficient (June/July)
JJ Temperature Anomaly Correlation: with U. DEL data

NCEP Reanalysis

CFS model

WRF Downscaled NCEP Reanalysis

WRF Downscaled CFS model

\( \sigma(\text{OBS,REAN}) \)

\( \sigma(\text{OBS,CFS}) \)

\( \sigma(\text{OBS,WRF[REAN]}) \)

\( \sigma(\text{OBS,WRF[CFS]}) \)
Monsoon Ridge Position at Onset (Late June, July)

Climatology delayed

Climatology accelerated

(Castro et al. 2001)
Dominant REOF of JJ downscaled precipitation and relationship to 500-mb height anomalies

WRF-Reanalysis

WRF-CFS

Normalized 500-mb Height Anomaly

Principal Component Regression
“Well Performing” IPCC AR4 models for dynamical downscaling of A2 emission scenario (1967-2081)

MAJOR LOGISTICAL PROBLEM: VERY DIFFICULT TO GET REQUIRED DAILY DATA FROM MODELING CENTERS!
SAME STORY WITH AR5 :-(

Ranking of IPCC-AR4 models for Southwest U.S., based on similarity with historical data and convergence in the future (Dominguez et al. 2009)
Caveats to downscaled results I’m about to show...

From only one completely dynamically downscaled IPCC AR4 model for one scenario—though it is a “good” one in terms of its representation of climatology and interannual variability.

Results so far are provocative, in terms of existing AR4 projections, and certainly require consideration of additional models for more robust conclusions.

CPC Observations

Original HadCM3

WRF-HadCM3 Downscaled TYPE 4

200 mm/mo
Annual precipitation climatology for Arizona

No summer monsoon rainfall simulated by GCM!
Dominant REOF of JJ downscaled precipitation and relationship to 500-mb height anomalies
Change in WRF-HadCM3 dynamically downscaled precipitation in Arizona

How is greater early monsoon precipitation realized??
Increase in precipitation intensity during monsoons is major concern...and that is already happening globally!

Regions where disproportionate changes in heavy and very heavy precipitation during the past decades

Documented as either an increase (+) or decrease (-) compared to the change in the annual and/or seasonal precipitation (Trenberth et al. 2007)
La Niña + global warming??
Are recent “Biblical” floods a harbinger for what will happen in Arizona this summer?

Pakistan flooding in 2010

Australia flooding in 2011
Correlations between WRF-HadCM3 Niño 3 anomalies vs. monthly precipitation anomalies in the Salt-Verde show positive winter – negative summer relations (1969-2000).

This has been shown in the literature using observed data (Castro et al. 2001).
We use a “Poisson–GP model” to characterize the statistical distribution of extreme events. (Katz et al. 1999, 2002, 2010).

We don’t use GEV theory because it is limited to block maxima, and we would loose information.

Consists of a Poisson process to model the occurrence of an exceedance of a high threshold and a generalized Pareto (GP) distribution to model the excess over the threshold.
Maximum daily precipitation (mm) associated with 20 year return period
Change in maximum daily precipitation associated with 20-year return period
Same for winter… and it’s even more dramatic!
Extreme event precipitation example: IOP2 from NAME (July 2004)
Simulation of selected extreme events at high resolution in NWP mode.
NAME field campaign, IOP 2 (July 2004)
Conclusions

UNSUITABILITY OF GCMs FOR WARM SEASON: Global climate models cannot resolve warm season, monsoonal climates well—a major caveat in the IPCC AR4 climate change projections of drying in subtropical regions including: Southwest U.S. and Mexico, west Africa, India, northern Australia, and South America.

RCMs CAN ADD SUBSTANTIAL VALUE: With an appropriate simulation design, a regional climate model can represent the warm season precipitation because it can resolve the mesoscale processes that lead to rainfall. RCMs may make North American monsoon seasonal forecasting feasible, and this work leads the way for next phase of MRED
Conclusions

NATURAL VARIABILITY MUST BE CONSIDERED: Naturally occurring modes of climate variability (e.g. ENSO, PDO) is critical, as that is what is responsible for generation of climate extremes. As, some global models perform better than others in this regard a multimodel average ensemble approach may not be the best way.

EXTREME EVENTS MATTER: Observations and our model analyses indicate that extreme precipitation events will increase in the future. High resolution NWP type modeling of extreme events in future regional climate model simulations will provide information at the spatial scale necessary for climate change decision making and adaptation.