Diagnosis of the Summertime Warm Bias in CMIP5 Climate Models at the ARM Southern Great Plains Site

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ARM Atmospheric Radiation Measurement

ASR Atmospheric System Research

RGCM

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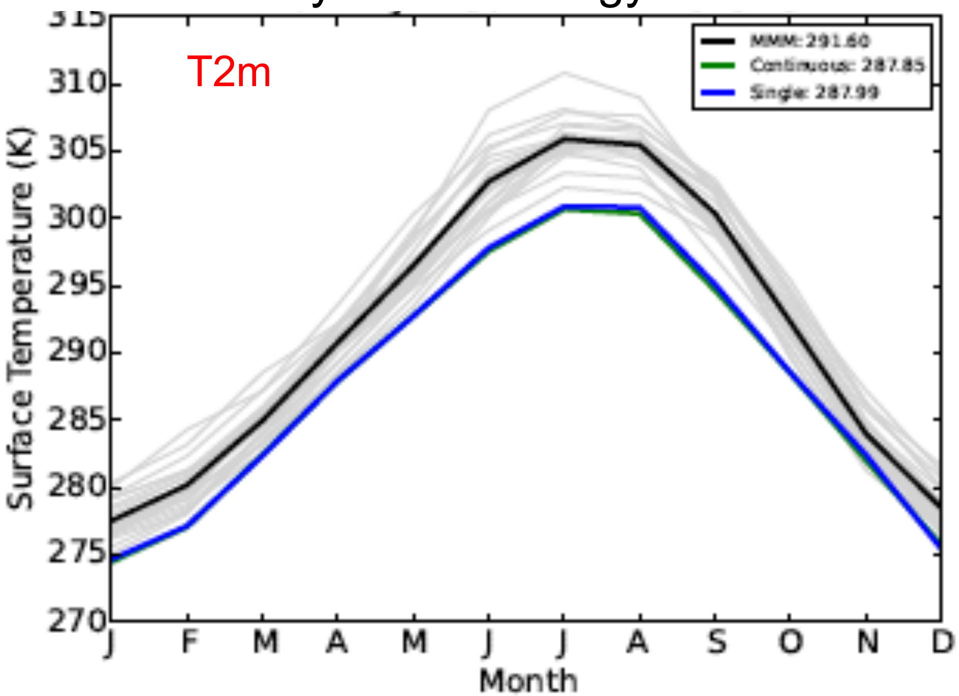
Warm bias exhibited in CMIP5 AMIP Climate Simulations over ARM SGP site

Annual cycle climatology

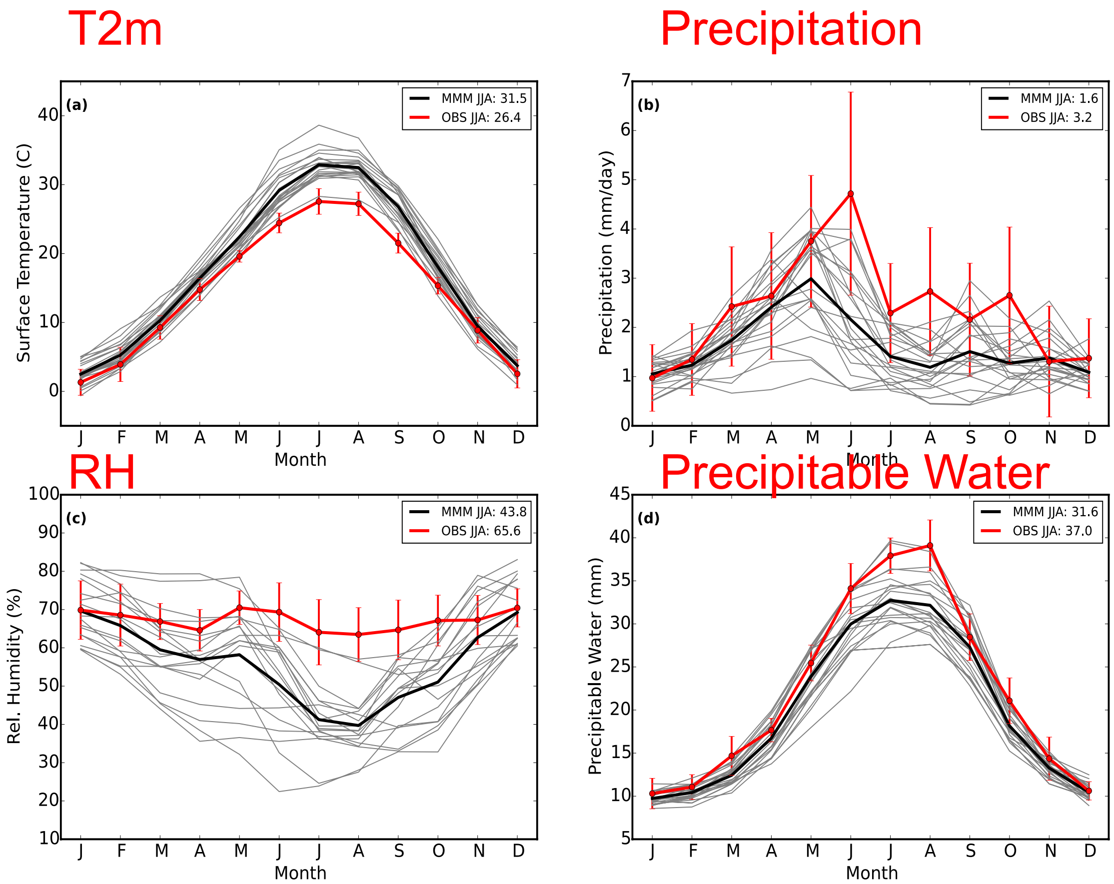


- **AMIP simulation:**
  Eliminate SST bias introduced by coupled simulations

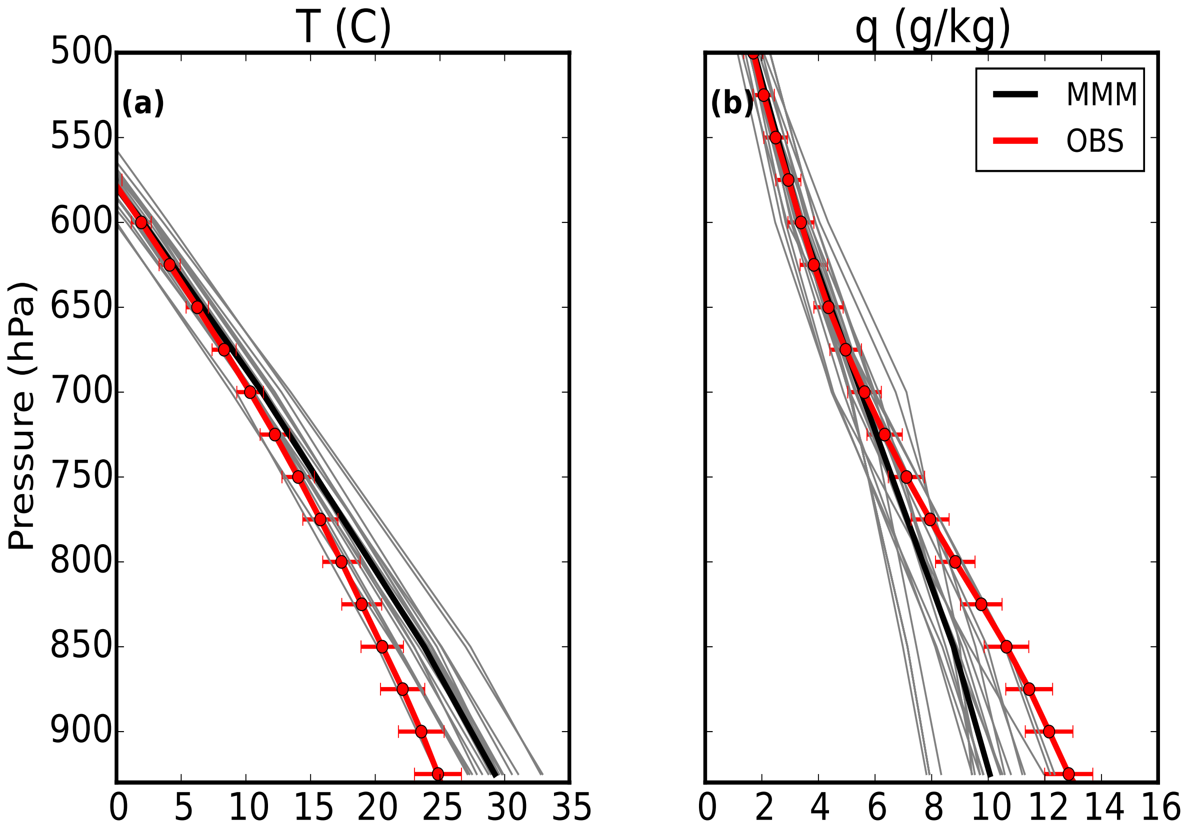
- Warm bias exhibits year around for most CMIP 5 models.
  ~ 3.6 K in Annual mean
  ~ 5.2 K in JJA

- Black: Multi-model mean
  Green: Continuous forcing (Variational analysis) 3x3 Deg. domain mean
  Blue: Single point at central facility (ARMBE)

Bias characteristics: Annual Cycle of Monthly Mean



Bias characteristics: Vertical Profile of JJA Mean



- T and q bias decrease with increasing height
- Below 850mb, most models show warm and dry bias.

What contribute to the T2m bias?

- **Surface Energy Budget Analysis**

  $(1 - \alpha)$ SWDN+LWDN = LWUP + LH + SH+ G

  - **Surface Radiative Flux Biases**

    Net-SW error = $(1- \alpha_{obs})$ SWDN clr,err +$(1- \alpha_{obs})$SWDN cre,err -

    α_{err} SWDN obs - α_{err} SWDN err

    $\text{NetLW}_{\text{err}} = \text{LWUP}_{\text{err}} + \text{LWDN}_{\text{clr,err}} + \text{LWDN}_{\text{cre,err}}$

  - **Turbulent Flux and Soil Moisture Biases**

    Evaporative Fraction (EF = LH/(LH+SH))

- **Atmospheric Water Cycle Budget Terms**

$$\frac{\partial PW}{\partial t} = E - P + MFC$$

Surface Energy Budget Terms: JJA mean bias

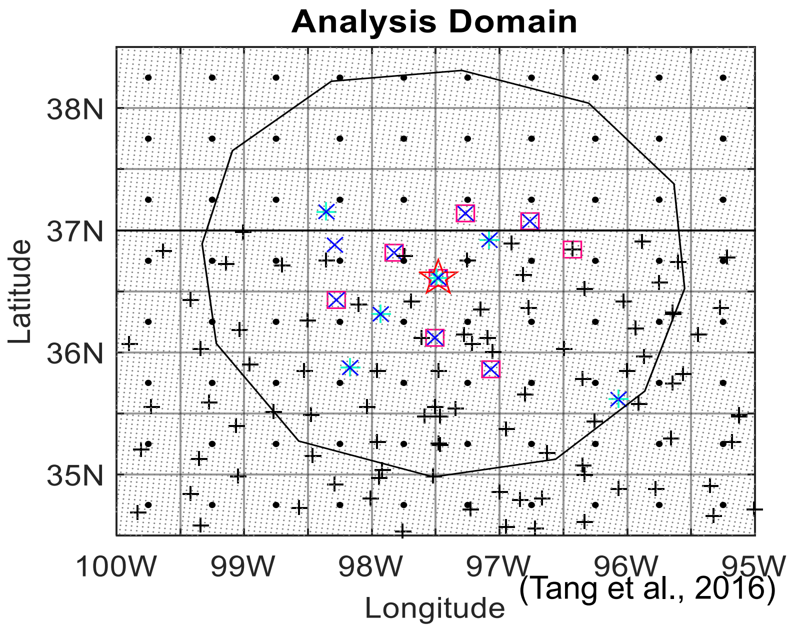
$$(1 - \alpha)\ SWDN + LWDN = LWUP + LH + SH + G$$

For multi-model mean:

- Net SW bias ~30 W/m^2
- Net LW bias. ~ -38 W/m2
- SH bias ~28 W/m^2
- LH bias ~40 W/m^2

Observations

3x3 Deg. domain mean
At SGP central facility



(Tang et al., 2016)

Most of the data are from the ARM Continuous Forcing Dataset.

CERES-EBAF data are also used for surface radiation

Partition the surface net SW error

Net SW error attribution (JJA mean):

Observational data set	Net SW error (W/m^2)	SW_{clr} error (W/m^2)	SW_{cre} error (W/m^2)	Albedo error (W/m^2) [absolute albedo error]
ARM	29.5 ± 15.4	4.9 ± 4.2	17.0 ± 11.6	6.9 ± 7.0 [-0.025 ± 0.025]
CERES-EBAF	26.2 ± 15.4	12.5 ± 4.3	12.2 ± 11.9	1.3 ± 7.0 [-0.005 ± 0.025]

- A cloud deficit results in excess solar radiation absorbed at the surface.
- For multimodel mean, cloud radiative error accounts for 58% (with respect to ARM) and 47%(to CERES-EBAF) of the net solar radiation error at the surface.
- The intermodel correlation coefficients between T2m bias and 3 error components are 0.65, 0.39, and 0.09 for cloud, clear sky, and α errors

$$\text{Net-SW error} = (1-\alpha_{obs})\,\text{SWDN clr,err} + (1-\alpha_{obs})\text{SWDN cre,err} - \alpha_{err}\,\text{SWDN obs} - \alpha_{err}\,\text{SWDN err}$$

why ARM and CERES give different clear sky values?

- The Radiative Flux Analysis product from ARM:

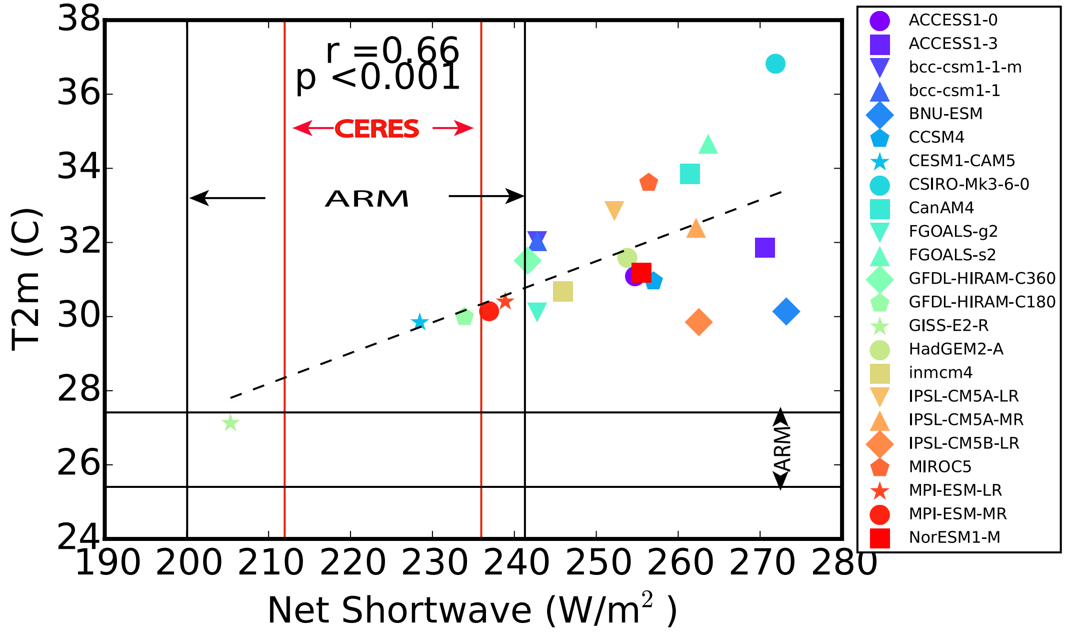
  Clear-sky fluxes are derived for identified clear-sky, empirical cosine fit based on solar angle to generate continuous data stream. It reflects ACTUAL Clear-sky fluxes.

- CERES and models:

  Clear-sky fluxes are calculated by removing the cloud but retaining aerosol and water vapor at cloudy time. Clear-sky fluxes are lower than ACTUAL clear-sky values.

Thanks to Seiji Kato, David Rutan and Chuck Long for helping to understand.

JJA mean: Net SW bias vs T2m bias across models



- Excess solar radiation absorbed at the surface for most models.
- Strong correlation between T2m and SWnet
- There would be a warm bias even no SW bias.

Partition the surface net LW error

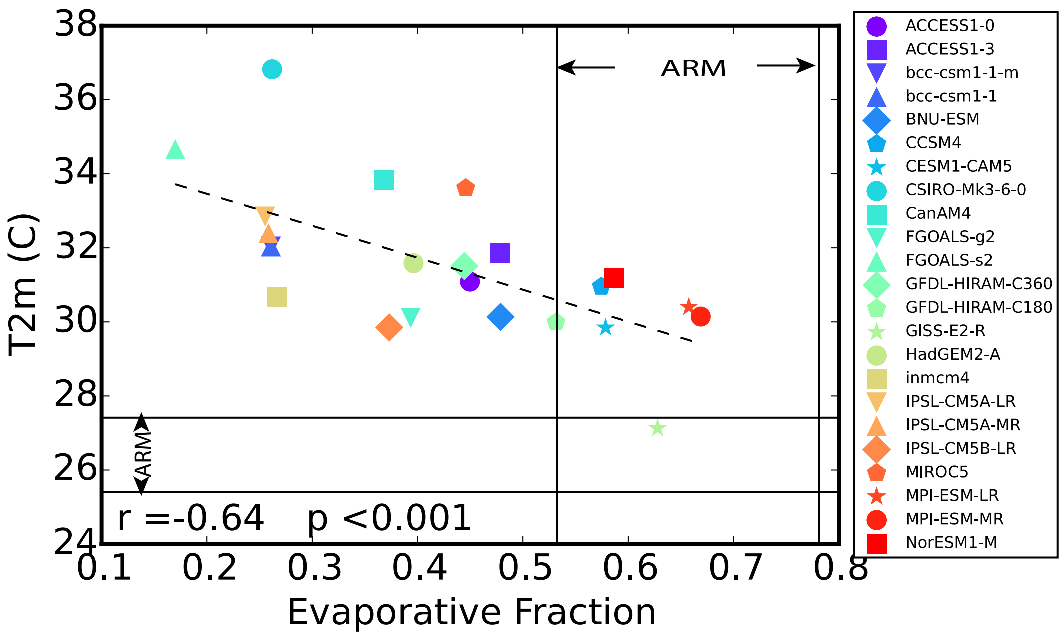
Net LW error attribution (JJA mean):

Observational dataset	Net LW error (W/m^2)	LWUP error (W/m^2)	LWDN-clr error (W/m^2)	LWDN-cre error (W/m^2)
ARM	-37.6 ± 15.7	-40.0 ± 14.8	12.0 ± 9.3	-10.0 ± 3.7
CERES EBAF	-40.3 ± 15.7	-33.0 ± 14.8	-4.3 ± 9.3	-3.4 ± 3.7

- LWUP error dominates

$$NetLW_{err} = LWUP_{err} + LWDN_{clr,err} + LWDN_{cre,err}$$

JJA mean: Evaporative Fraction vs T2m bias across models

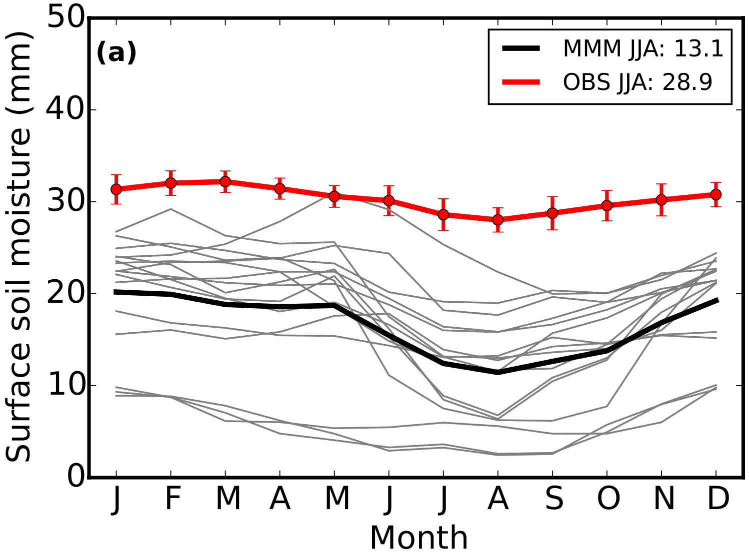


Evaporative Fraction:

EF= LH/LH+SH

- Anti-correlation between T2m and EF
- Even when EFs values are reasonable, T2m bias still exist, indicating both EF and radiation biases contribute to T2m bias.

Soil Moisture Deficit



- All models significantly underestimate the soil moisture throughout the year

- The low soil moisture content limits the availability of water for evaporation and thus reduces the evaporative fraction and contributes to a warmer surface indirectly.

JJA Mean: Atmospheric Water Cycle Budget Terms

$$\frac{\partial\, PW}{\partial\, t} = E - P + MFC$$

- **JJA mean:**
  E = 3.51 mm/day; P = 3.25 mm/day; MFC = -0.22 mm/day

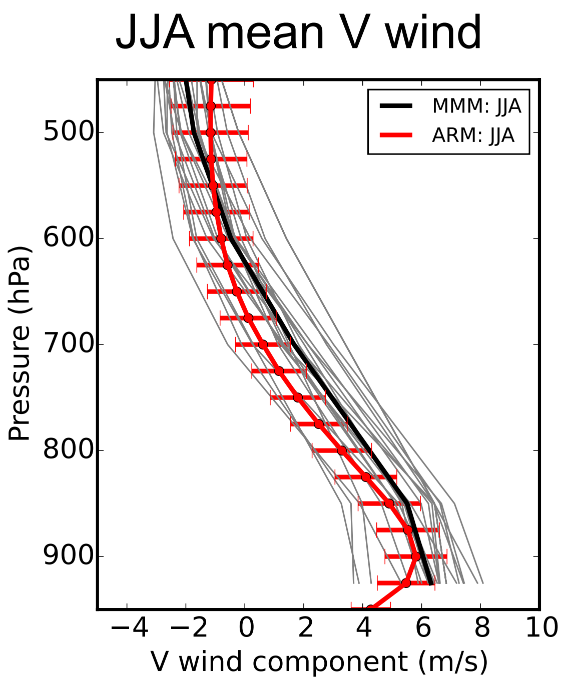
➢ precipitation is dominated by moisture provided locally by evaporation instead of through remote moisture sources

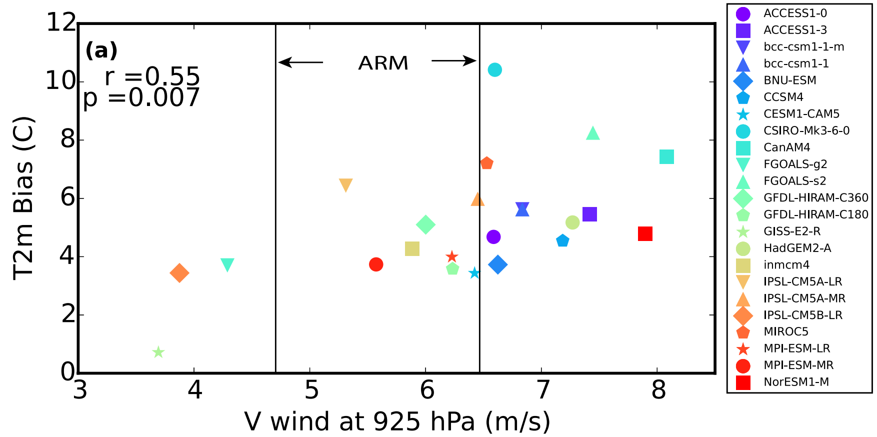
Inter-model correlations between JJA mean T2m and water cycle budget components

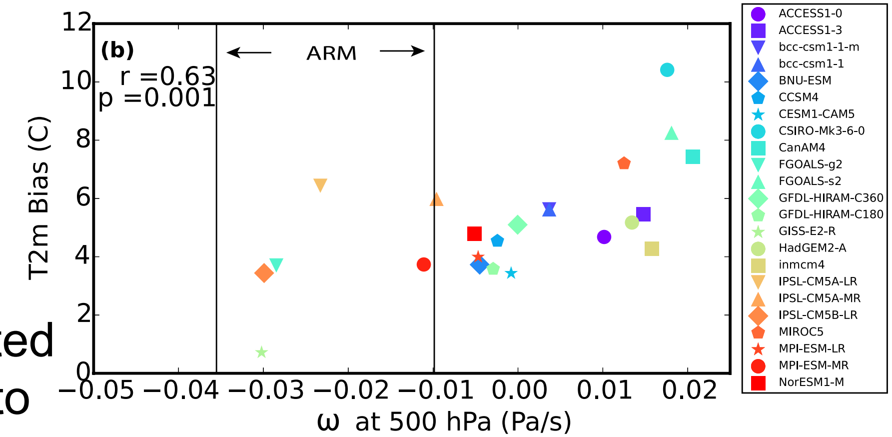
	P	E	P - E	MFC
T2m	-0.66	-0.59	0.21	0.21

- Since models underestimate P and P correlates to T2m slightly stronger than E, ➔ the lack of P may be more important

Impact of the Low-Level Jet







- Intermodel spread is large
- 925hPa wind speeds are overestimated
- Positive intermodel T2 m correlation to 925hPa V wind and ω at 500 hPa

Summary

- Modeled summertime climate over the Southern Great Plains is too warm and dry in CMIP5 AMIP simulations
- Overestimated surface shortwave radiation and underestimated evaporative fraction contribute to the warm bias
- Overly strong low-level-jets and subsidence are associated with the warm bias through their control over surface energy and water budgets.
- Bias from large-scale circulation can complicate the attribution process for pinpointing deficiency in model physical processes. More advanced simulation techniques, such as hindcast approach used in CAUSES project, may be more useful in addressing model physical deficiencies.

Thank you

JJA mean: cross model correlation

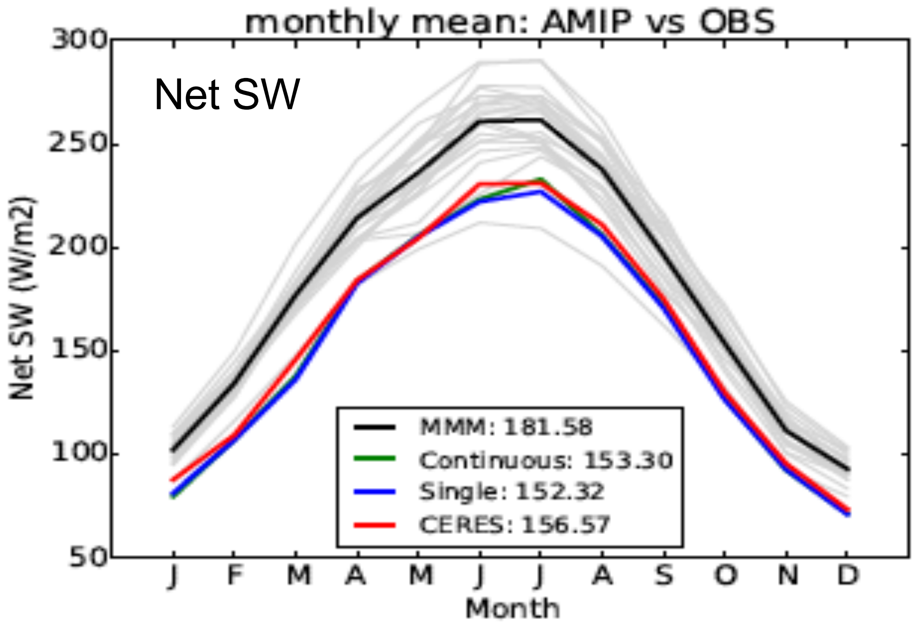
Table 7
Summary of Intermodel Correlation Between JJA Mean Variables Selected From Aspects of the Circulations, Water Cycle Budget, and Surface Energy Budget

		V at 925 mb	V^*q at 925 mb	Convergence at 925 mb	ω at 500 mb
T2 m	Surface energy budget	**0.55**	0.19	−0.31	**0.63**
Net SW		**0.50**	0.28	−0.32	**0.43**
EF		−0.14	0.40	−0.05	−0.31
Precipitation	Water cycle budget	−0.06	0.31	−0.02	−0.32
Evaporation		−0.06	**0.48**	−0.10	−0.23
$P - E$		0.03	**−0.46**	0.16	−0.01
PW		−0.04	**0.45**	−0.05	0.02
V at 925 mb	Large-scale circulation	**1.0**	**0.80**	**−0.81**	**0.81**
V^*q at 925 mb		**0.80**	**1.0**	**−0.74**	**0.57**
Convergence at 925 mb		**−0.81**	**−0.74**	**1.0**	**−0.77**
ω at 500 mb		**0.81**	**0.57**	**−0.77**	**1.0**

Note. Numbers in bold indicate that the correlations are statistically significant with p value less than 0.05.

What contribute to the T2m bias?

Contribution of solar radiation error at surface



Based on both **CERES (Red)** and **ARM data (Blue and Green)**,
models have strong net solar radiation bias (25~29 W/m^2 in annual mean)