CAUSES: Warm bias contribution from surface energy budget

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with

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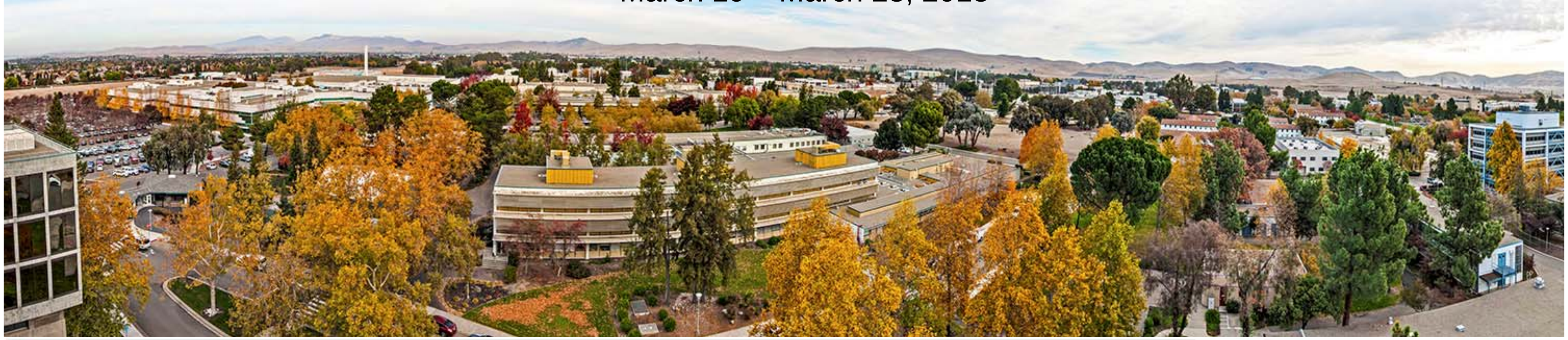

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Outline

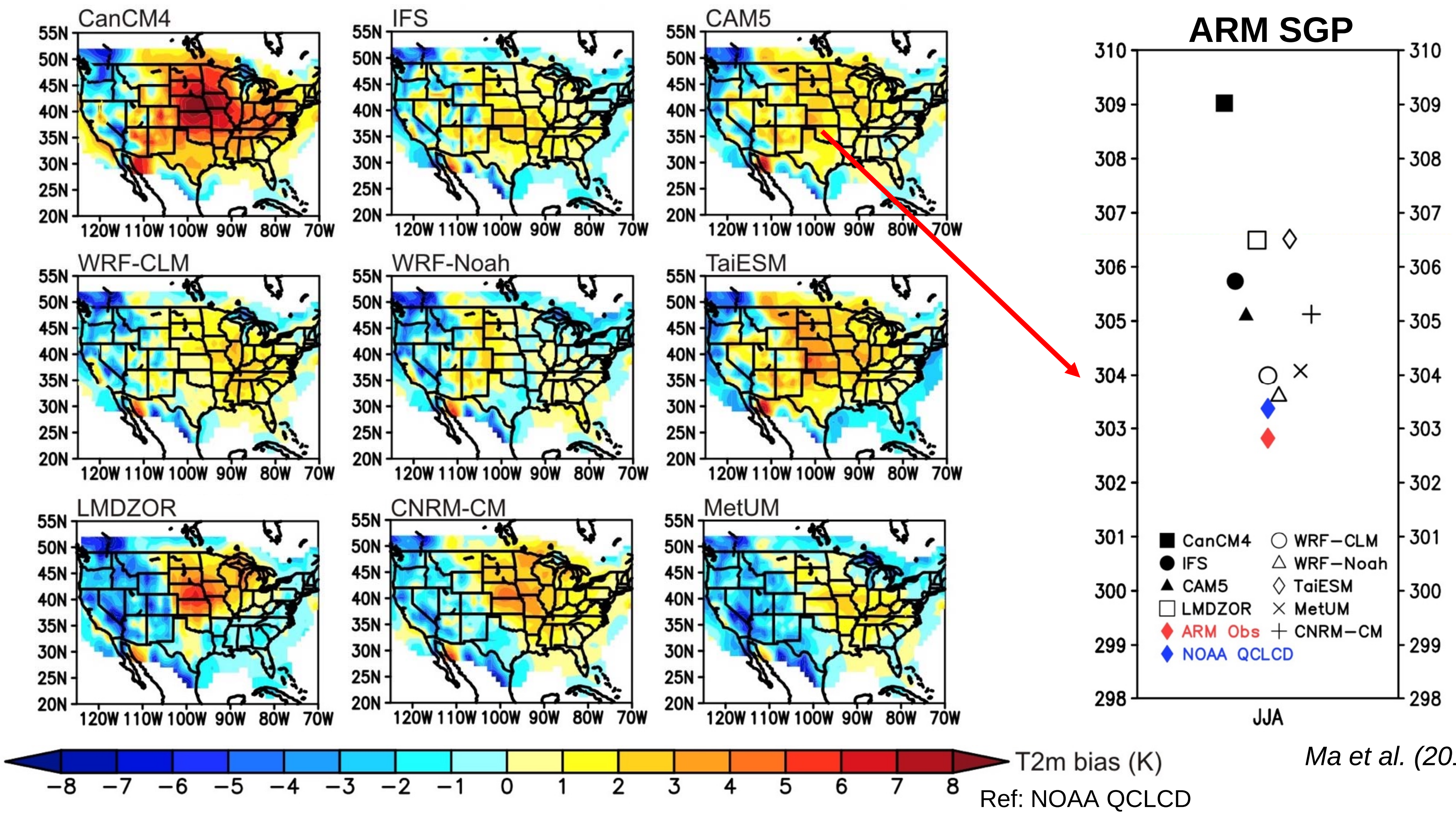
- Surface energy budget analysis
- Theoretical interpretation of warm bias contribution
- Water budget analysis
- Ongoing work: Testing impact of land model changes on warm bias simulations with CAM5/CLM4.
  - Bare-ground resistance to evaporation and the vegetation minimum stomatal conductance were increased globally (following Ian Williams et al 2016 JGR)

Science Questions to Address

- Identify surface energy budget errors in relationship to T2m errors in the models and to identify common robust features in model biases.

- Identify the relative error contributions in the surface radiation and evaporative fraction (EF: the ratio of latent heat flux to the sum of latent and sensible heat fluxes) to the T2m bias.

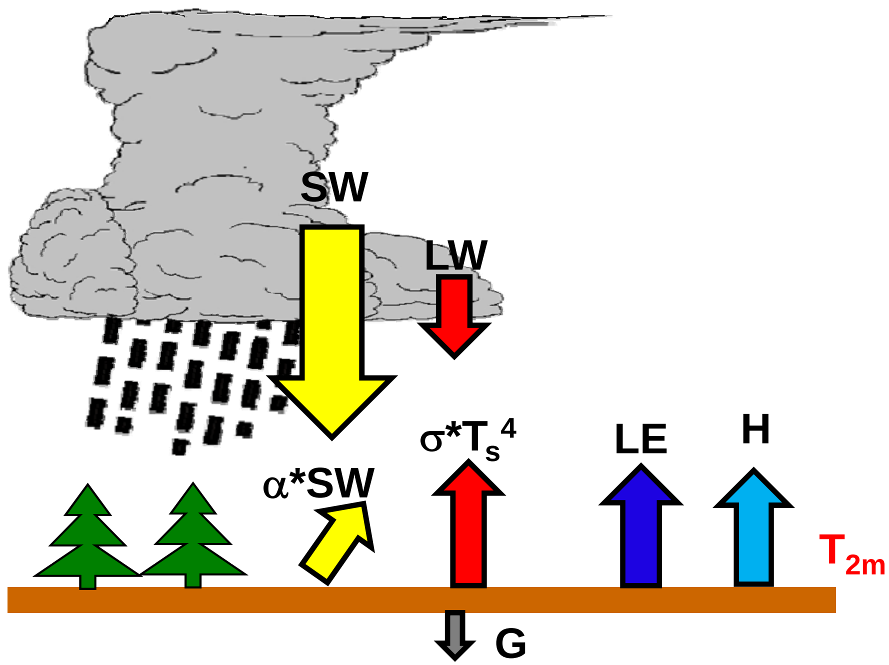
2 meter temperature bias (2011, Day 2-5 JJA mean)



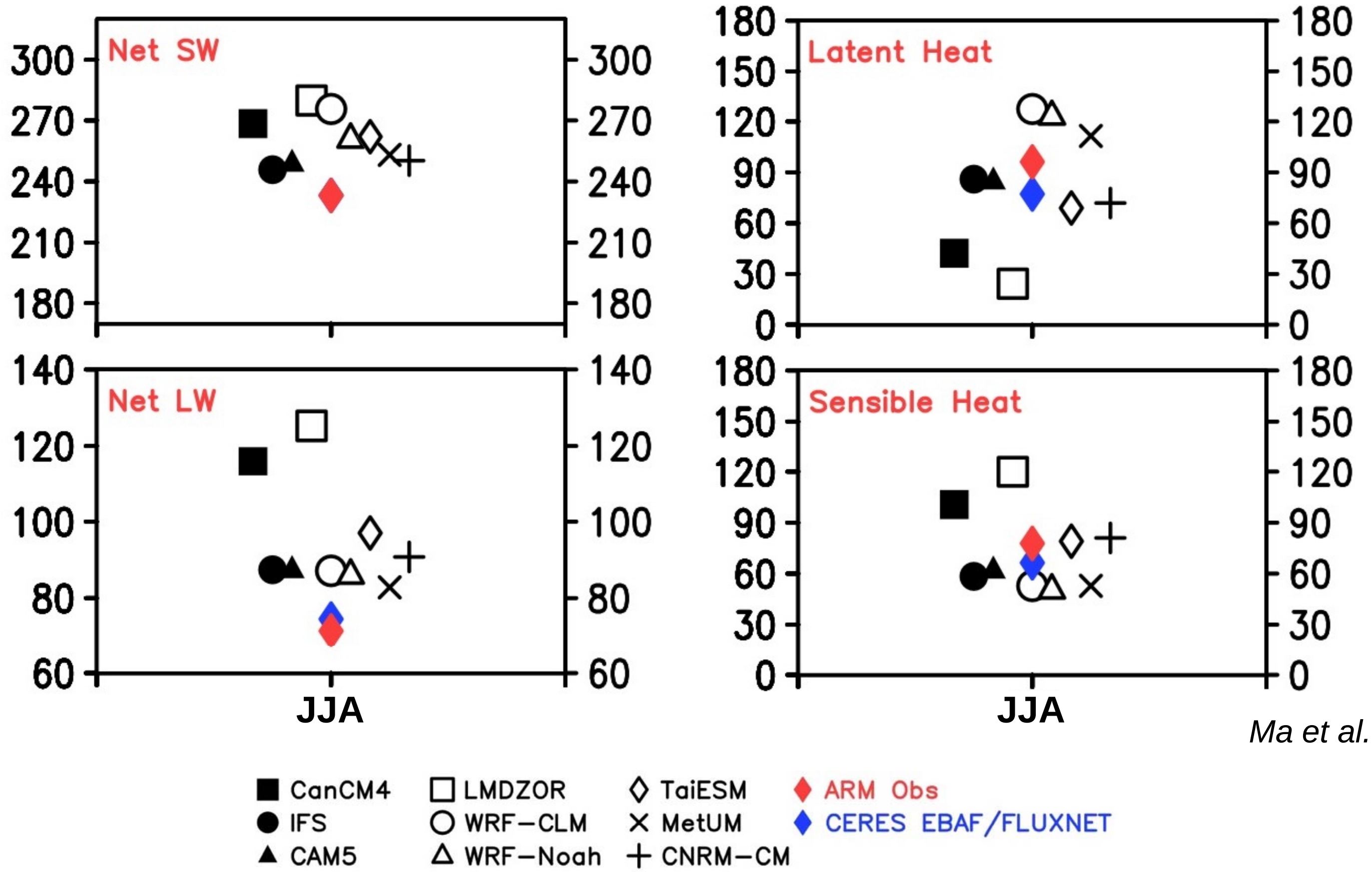
Ma et al. (2018)

- All model simulate warm T2m bias over the central U.S.
- Warm bias is more significant in June-August than in April-May.

Surface energy budget analysis



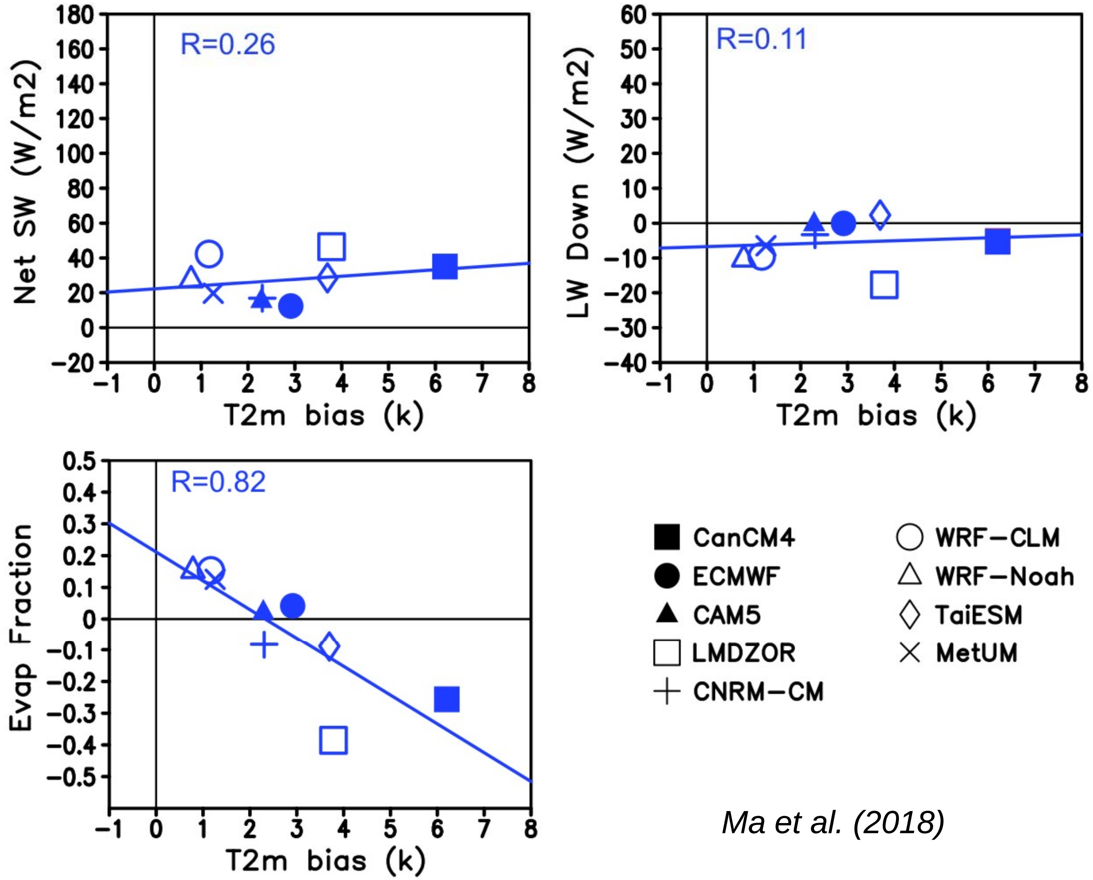
JJA mean surface energy budget at ARM SGP



Ma et al. (2018)

- All models overestimate surface net shortwave flux mostly due to cloud problems.
- All models overestimate surface net longwave flux consistent with warm T_{2m} bias.
- There is no consistent mean bias sign in the sensible or latent heat fluxes.

Connection between T_{2m} bias and surface energy budget bias



Ma et al. (2018)

- Models with larger negative evaporative fraction (EF: latent/(latent+sensible)) bias magnitudes are likely to simulate larger T_{2m} mean bias on seasonal time scales.

Theoretical interpretation of warm bias contribution

- Excess radiation absorbed directly heats the surface causing a warm bias.
- If evaporation is suppressed, radiative heating (even if unbiased) will be used to heat the surface instead of evaporating water causing a warm bias.

Theoretical interpretation of warm bias

$$SW + LW = SH + LH, \quad (1)$$

$$SW' + LW' = SH' + LH', \quad (2)$$

$$SW' + LW' = (\gamma SH)', \quad \gamma = 1 / (1 - EF) \quad (3)$$

$$(SW' + LWDN') - SH_{mod}\gamma' = LWUP' + \gamma_{obs} SH', \quad (4)$$

$$(SW' + LWDN') - SH_{mod}\gamma' = \left(\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}\right) T'_{2m}, \quad (5)$$

$$(SW' + LWDN') - EF'\gamma_{obs}(SH_{mod} + LH_{mod}) = \left(\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}\right) T'_{2m}, \quad (6)$$

$$T'_{2m} = \frac{(SW' + LWDN')}{\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}} - \frac{EF'\gamma_{obs}(SH_{mod} + LH_{mod})}{\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}}, \quad (7)$$

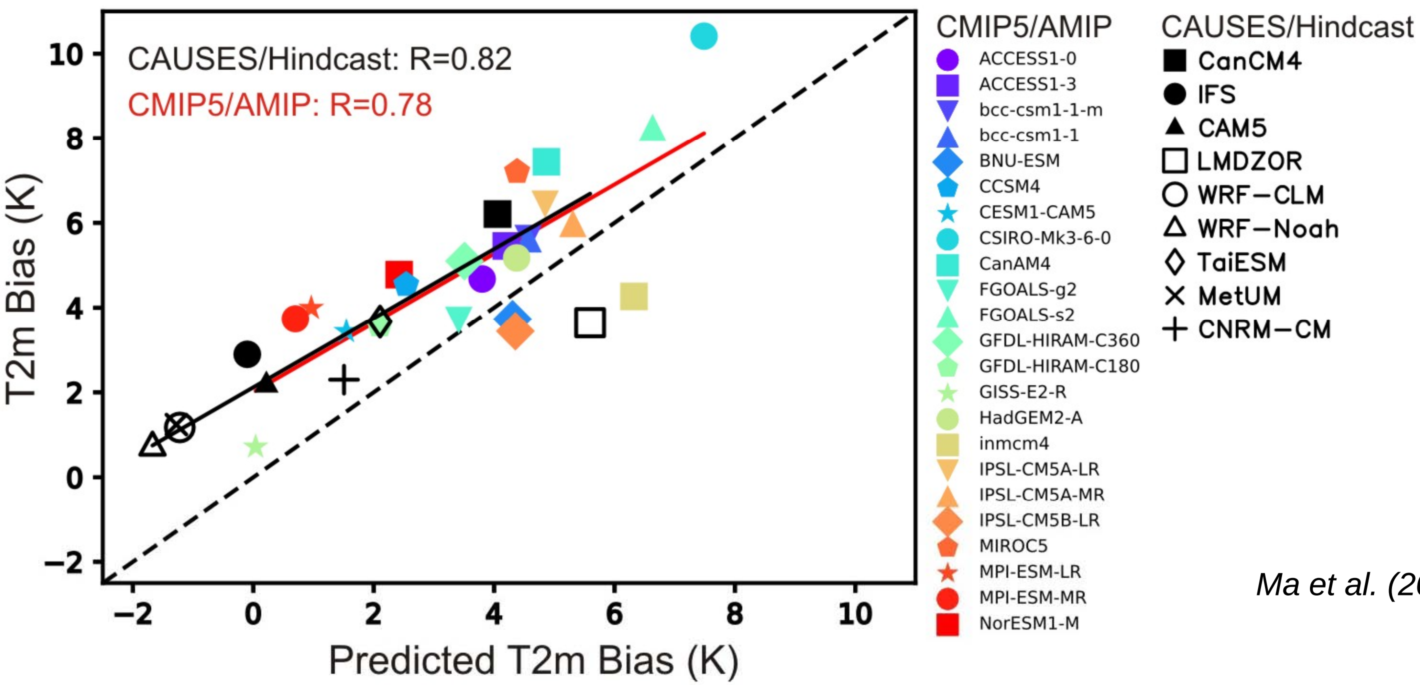
Given $\frac{\partial LWUP}{\partial T_{2m}} = 7$, $\frac{\partial SH}{\partial T_{2m}} = 9$, γ_{obs}=2.5 from model values and observations,

Ma et al. (2018)

$$T'_{2m} = \frac{(SW' + LWDN')}{30\ W\ m^{-2}K^{-1}} - \frac{2.5\ EF'(SH_{mod} + LH_{mod})}{30\ W\ m^{-2}K^{-1}}. \quad (8)$$

Radiation Contribution

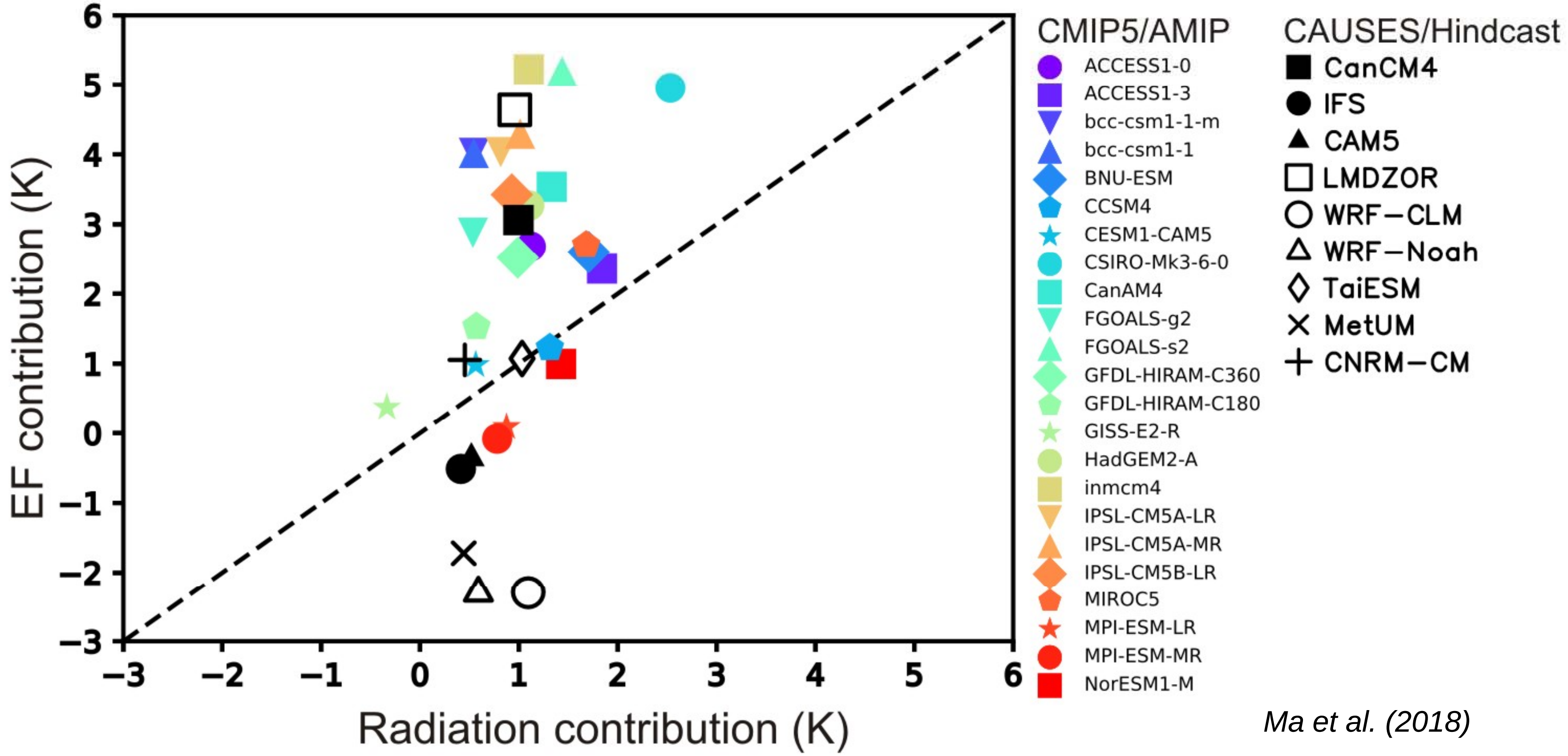
Evaporative Fraction Contribution



Ma et al. (2018)

- The approximate equation predicts the T2m bias reasonably well with the biases estimated from radiation and evaporative fraction biases.

Relative contribution of radiation and evaporative fraction biases

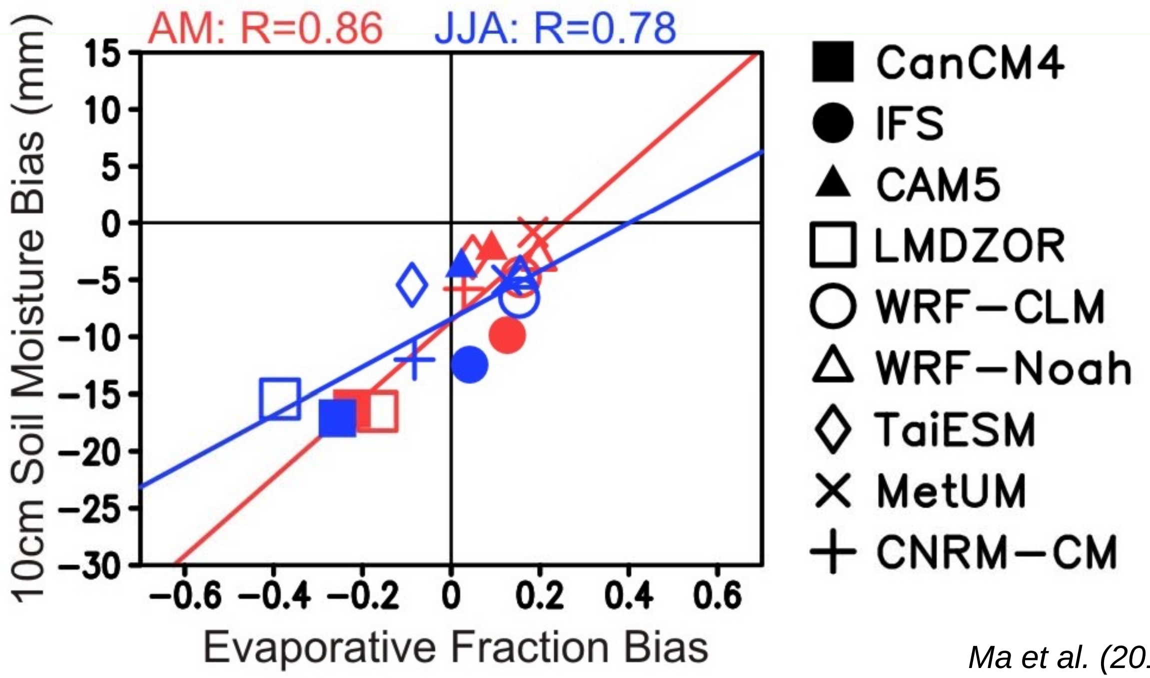


Ma et al. (2018)

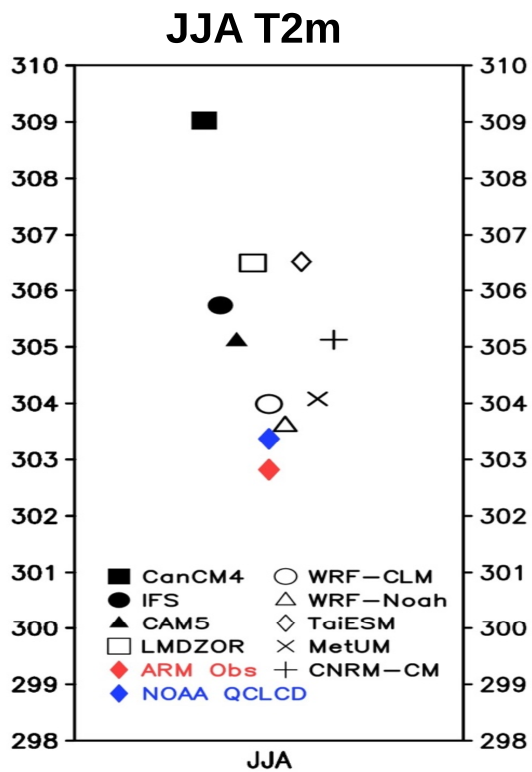
- Contribution from surface radiation biases (shortwave absorbed and downward longwave fluxes) is ~ 0.5 – 2 K for most models while contribution from evaporative fraction bias varies from ~ -2.5 to 5.5K.
- Long-term climate simulations (CMIP5/AMIP) show larger positive evaporative fraction biases than short-term hindcasts.

Water budget analysis

Relationship of EF and soil moisture/precipitation



Ma et al. (2018)



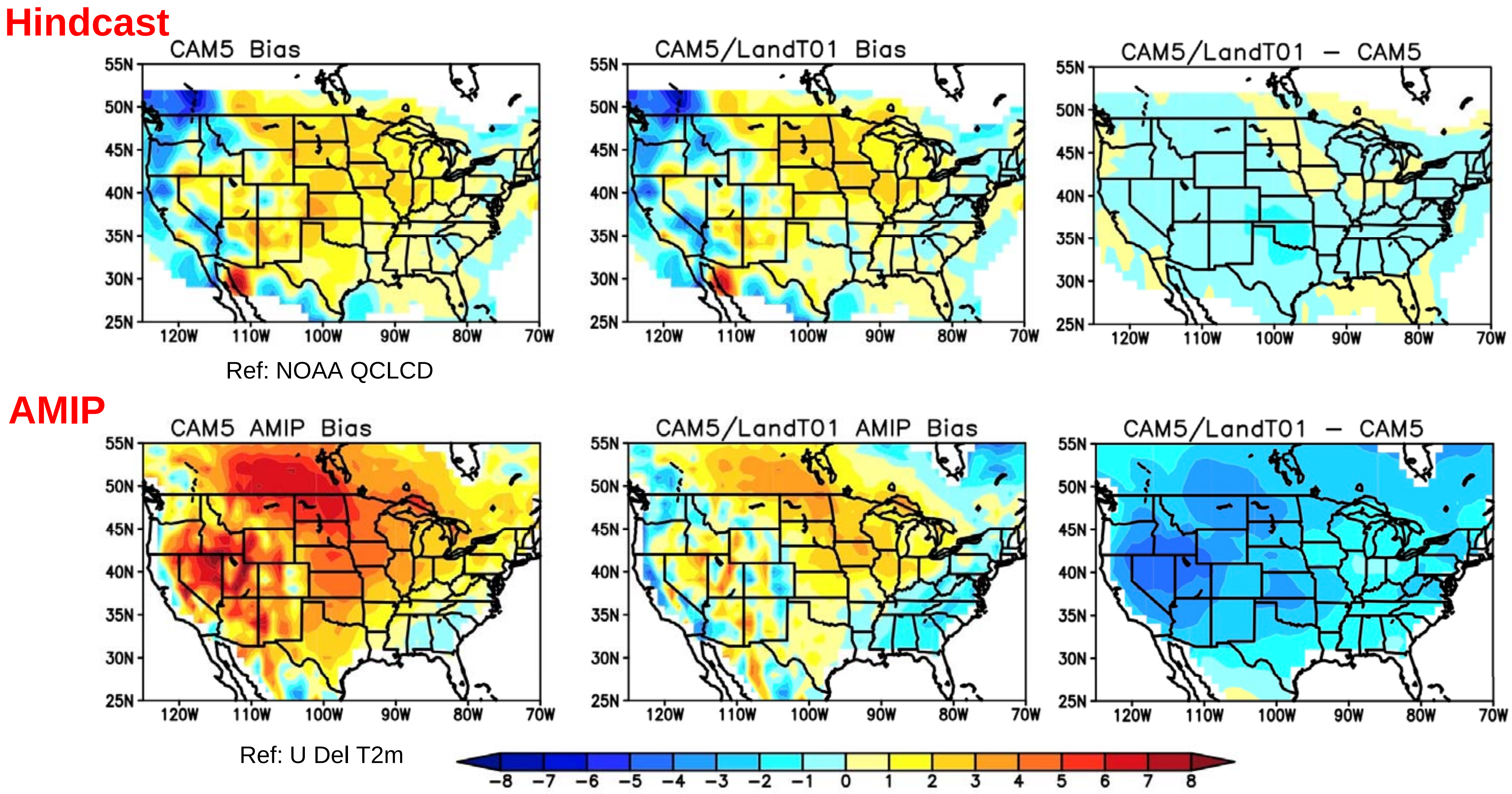
- EF mean bias is largely correlated with soil moisture mean bias.
- Day-to-day changes in the soil moisture are largely affected by the seasonal accumulated precipitation minus accumulated evaporation (P-E).
- Positive EF bias (more evaporation) can compensate for radiation bias.

Testing impact of land model changes on the warm bias simulations

- Bare-ground resistance to evaporation and the vegetation minimum stomatal conductance were increased globally (following Ian Williams et al 2016 JGR)

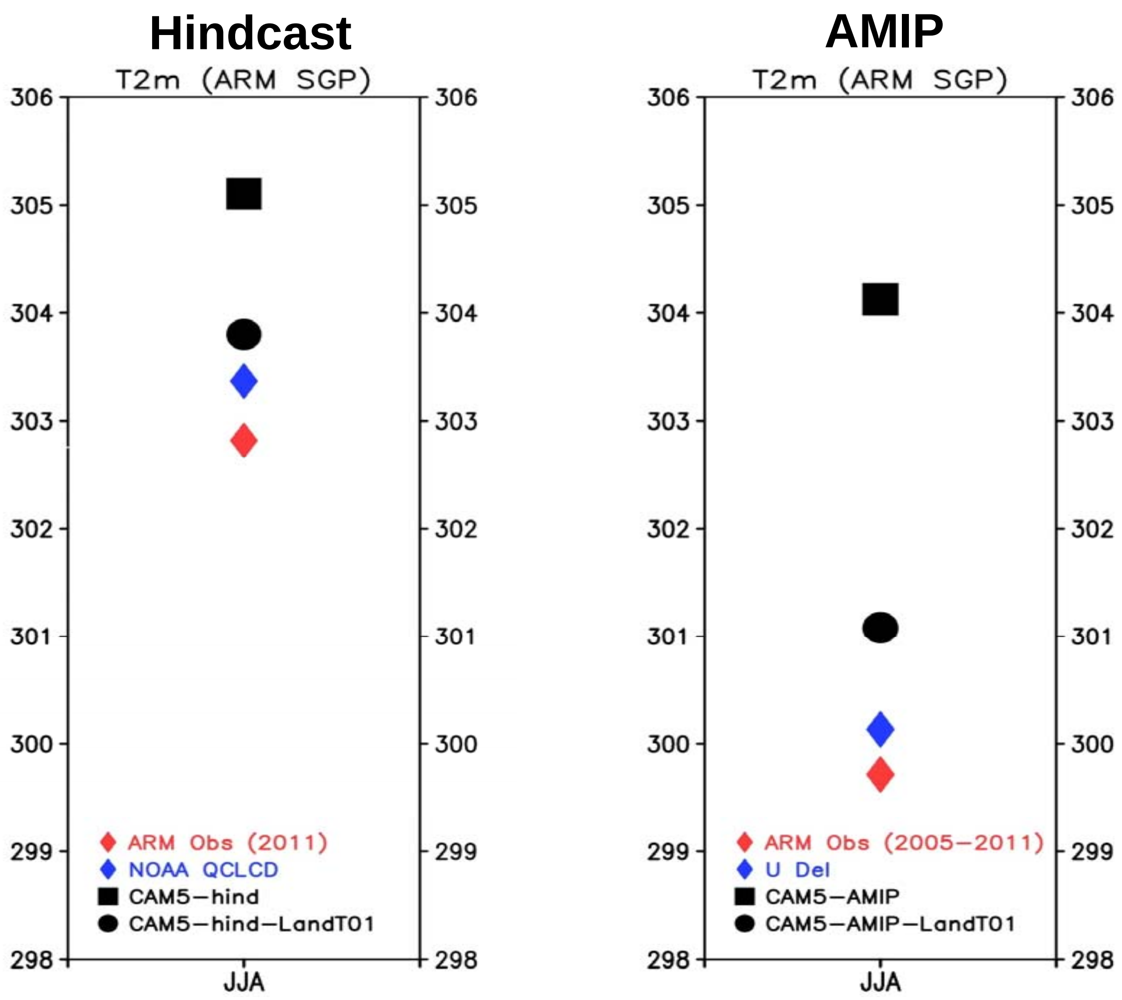
- Experiments:
  - 5-day long hindcasts for June 01 to August 31, 2011
  - AMIP simulation for 1996-2012 (2005-2011 for analysis)

2 meter temperature



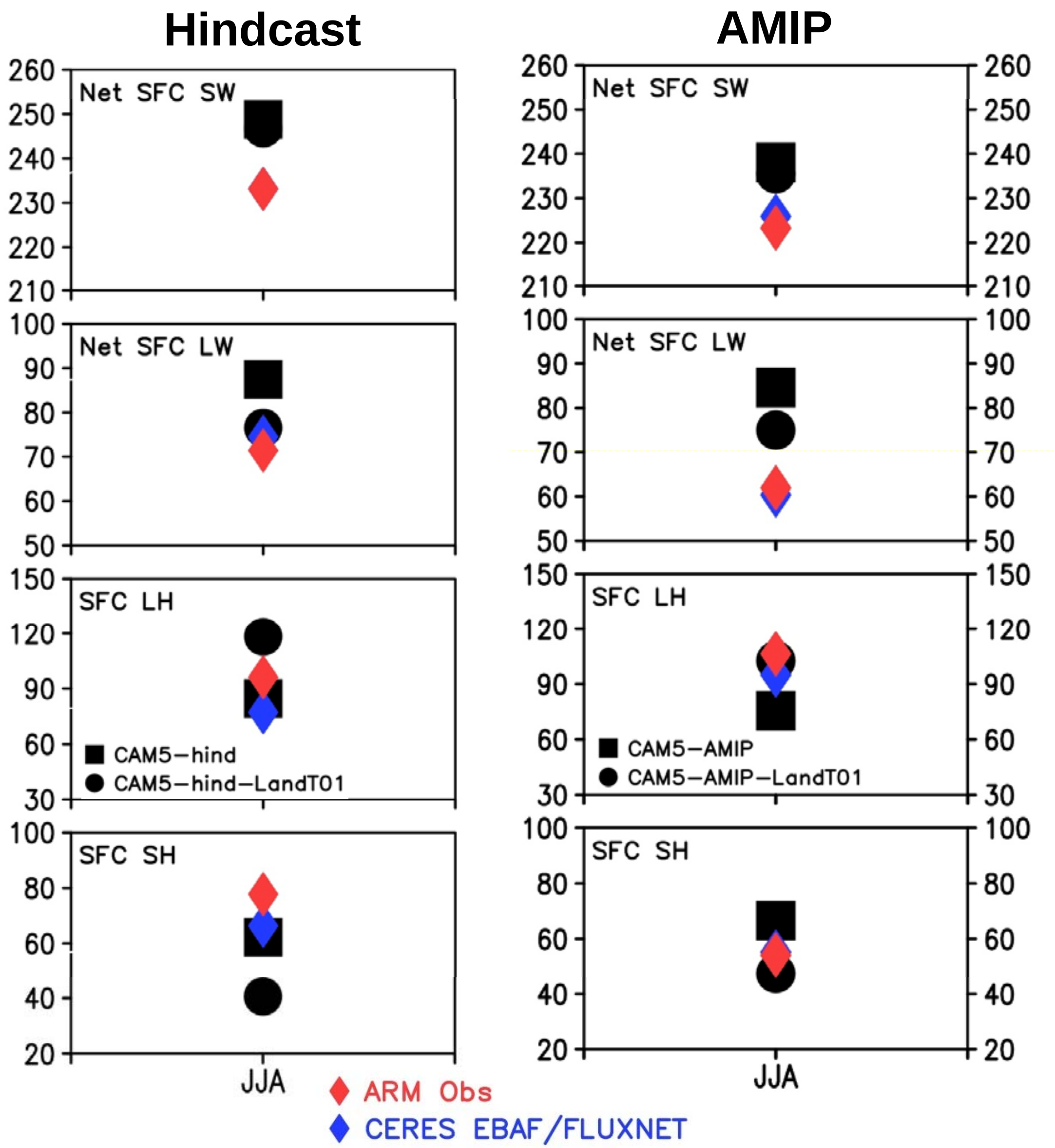
- The warm T2m bias is generally improved with changes in the land model.
- The warm T2m bias is significantly reduced in the AMIP simulation.

T_{2m} at ARM SGP



- T_{2m} is improved (still warmer than observations) with changes in CLM4.

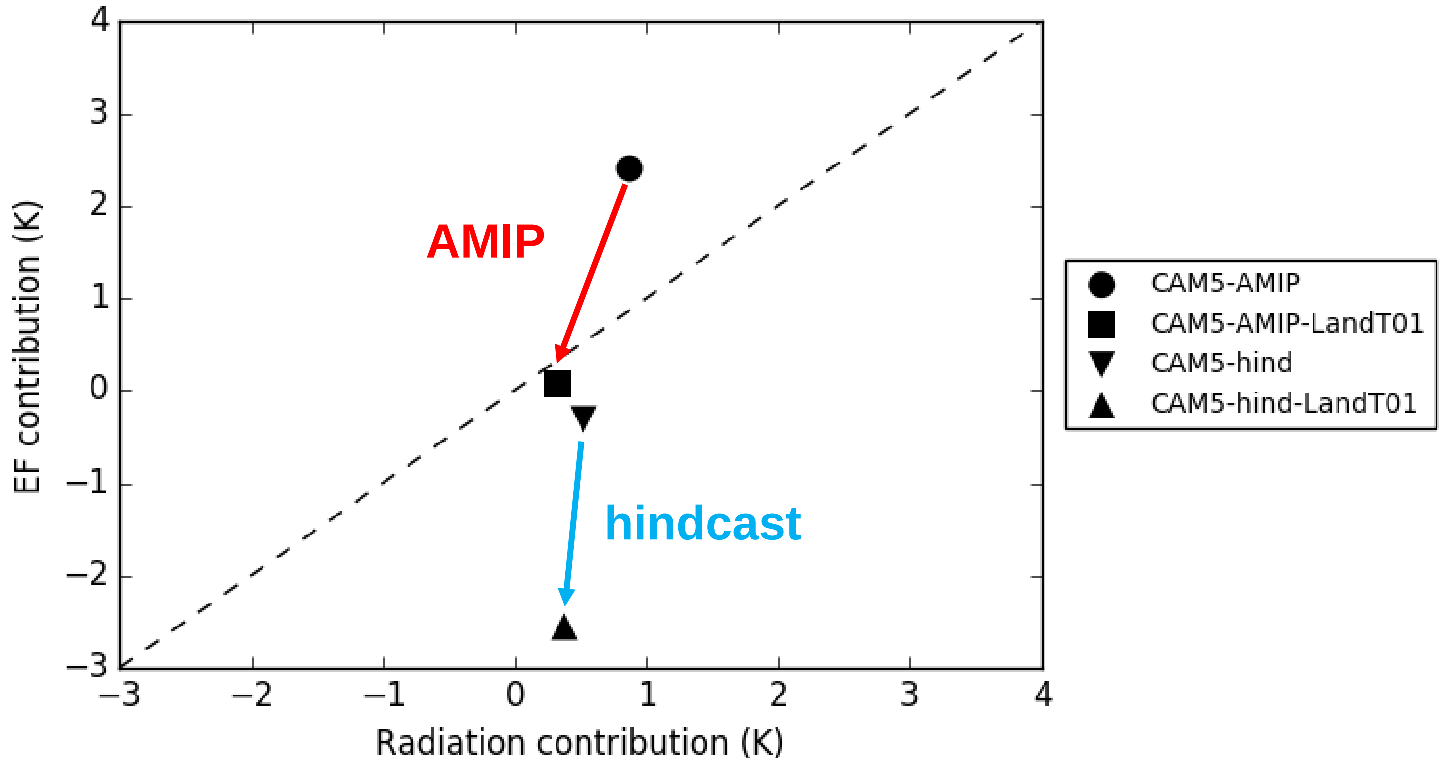
Surface fluxes at ARM SGP



Compared to default CAM5 simulations:

- Slightly decrease in net shortwave flux.
- Smaller net longwave flux due to smaller surface temperature.
- Larger LH but smaller SH heat fluxes with land modification.
- The AMIP simulations of turbulent fluxes are closer to observations.

T_{2m} bias contribution from Radiation and Evaporative Fraction



$$T'_{2m} = \frac{(SW' + LWDN')}{30 W\, m^{-2} K^{-1}} - \frac{2.5\, EF' (SH_{mod} + LH_{mod})}{30\, W\, m^{-2} K^{-1}}$$

Summary

- Warm bias is mainly due to (1) too much SW (atmospheric model problem) and (2) too low evaporative fraction (atmospheric and land model problem).
- Too much SW are primarily due to underestimates in the radiative effects of deep convective clouds (Too infrequent deep convection or insufficiently reflective clouds when deep convection occurs).
- Too low EF are primarily due to low soil moisture and precipitation.
- EF errors explain most of the temperature bias in the models with large warm biases, but they compensate for the radiation error in the models with small temperature bias.
- Warm bias is smaller with the changes in the bare-ground resistance to evaporation and the vegetation minimum stomatal conductance. The improvement of T2m is more significant in the AMIP simulation.

Thank you and questions?

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