Model surface temperature errors near SGP: Diagnosing the causes

An overview of the CAUSES project

GASS GEWEX WCRP Global Atmospheric System Studies ASR Atmospheric System Research Met Office PCMDI RGCM

The CAUSES project team:

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Romain Roehrig, Eric Bazile:	CNRM, Meteo-France/CNRS	CNRM (NWP & climate)
Anning Cheng, Kuan-Man Xu:	NASA Langley	CAM5-IPHOC
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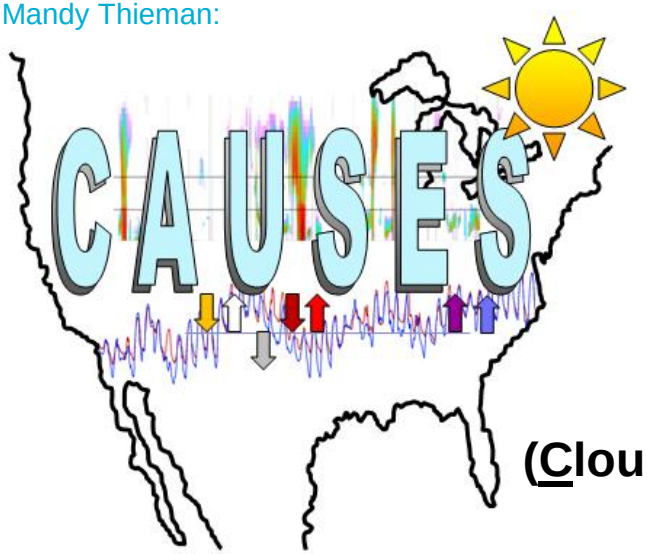
Mandy Thieman:	Science Systems & Applications, Inc.	VISST



(Clouds Above the United States and Errors at the Surface)

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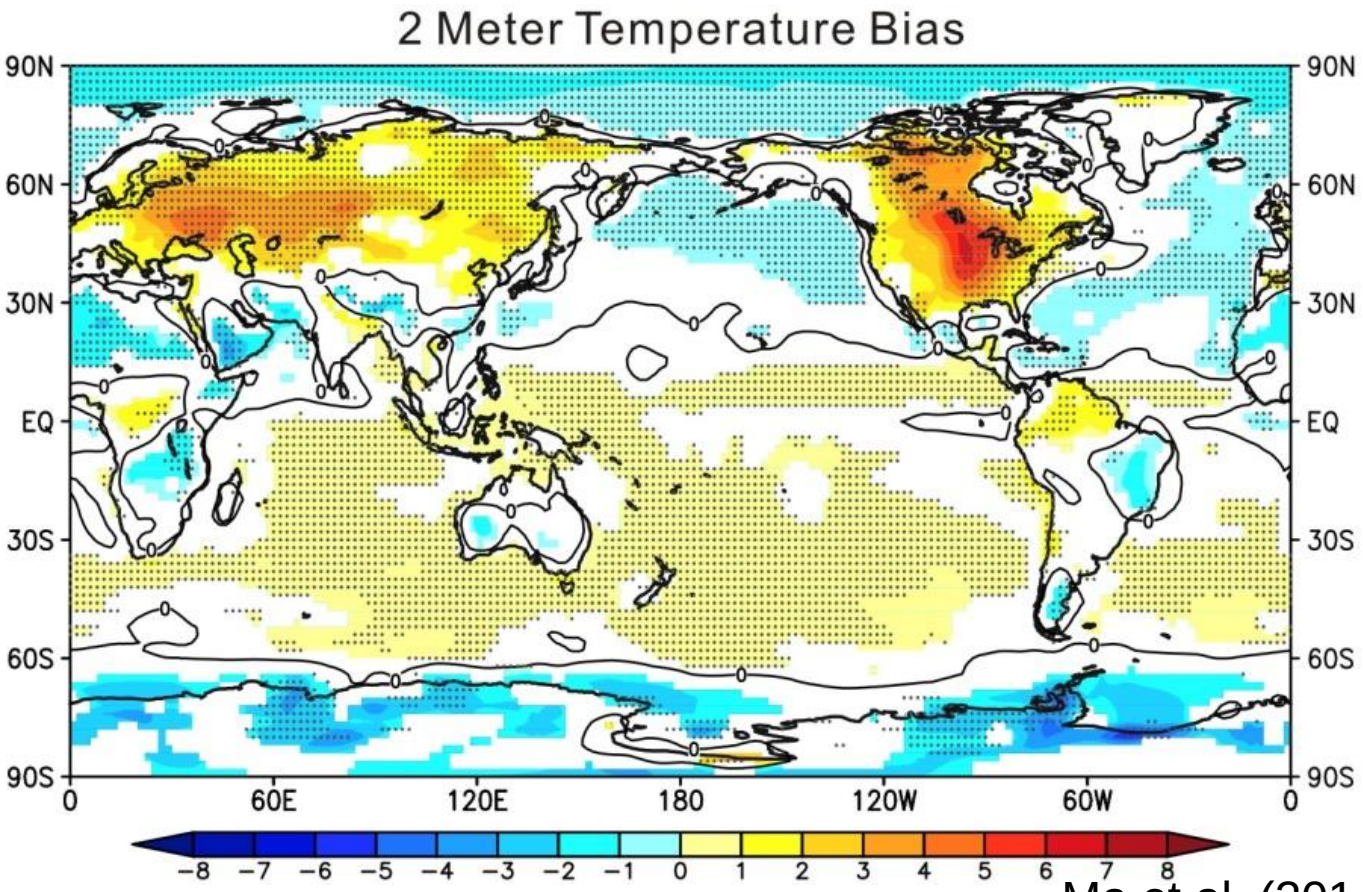
Introduction



Ma et al. (2014)

Shading: CMIP5 ensemble-mean screen-temperature bias.

Stippling: where majority of same GCMs have a bias of the same sign, when running for 5-days from an analysis in NWP mode.

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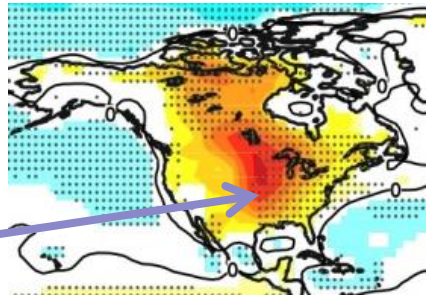
Introduction



There is a large bias in the Midwest.

Use data from **Southern Great Plains** (SGP) site (located within region of warm bias).
Site is operated by the US Department of Energy's (DoE) Atmospheric Radiation Measurement (**ARM**) programme.

Choose a period with the richest possible source of observations. So can perform the most detailed analysis possible.

Focus on April-August 2011, which includes **MC3E** (Midlatitude Continental Convective Cloud Experiment: 22 April to 6 June 2011).

So, within **GASS** (GEWEX-Global Atmospheric System Studies) and **ASR** (DoE's Atmospheric System Research programme), have set-up:

A comparison project aiming to evaluate clouds, radiation, precipitation and surface-exchange in several weather and climate models using ground-based observations to better understand the reasons for the surface temperature error.

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CAUSES Experiment Overview

Pilot Study

Proof-of-concept study compared just 2 models (MetUM and CAM5): Van Weverberg et al (2015).

Experiment 1

- 5-day hind-casts, starting from ERA-Interim analyses at 00Z for each day of April to August 2011.
- For column over SGP,
  - sub-hourly, profile of all thermodynamics, cloud cover, condensate & surface and TOA fields.
- For CONUS region, re-gridded onto 1 deg x 1 deg grid.
  - Hourly fields 2d fields of surface fluxes, precip and TOA radiation

Experiment 2

- Multi-month atmosphere-only hind-casts. Start each on first day of month of JFMAMJJA (2011).
- For CONUS region, re-gridded onto 1 deg x 1 deg grid
  - 3-hourly 2d fields of surface fluxes, precip and TOA radiation

Experiment 3

- AMIP-style 10-year climate simulation (2000-2011)
- For CONUS region, re-gridded onto 1 deg x 1 deg grid
  - Monthly mean, 2d fields of surface fluxes, precip and TOA radiation
- SGP column, sub-hourly, profile of all thermodynamics, cloud cover, condensate.

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CAUSES Project Output

As of February 2018: 4 new CAUSES papers accepted in JGR-Atmos

- Morcrette et al (2018) Introduction to CAUSES
- Ma et al (2018) On the role of surface energy budget errors
- Van Weverberg et al (2015) Attribution of surface radiation biases
- Zhang et al (2018) Diagnosis of the Summertime Warm Bias in CMIP5 at SGP

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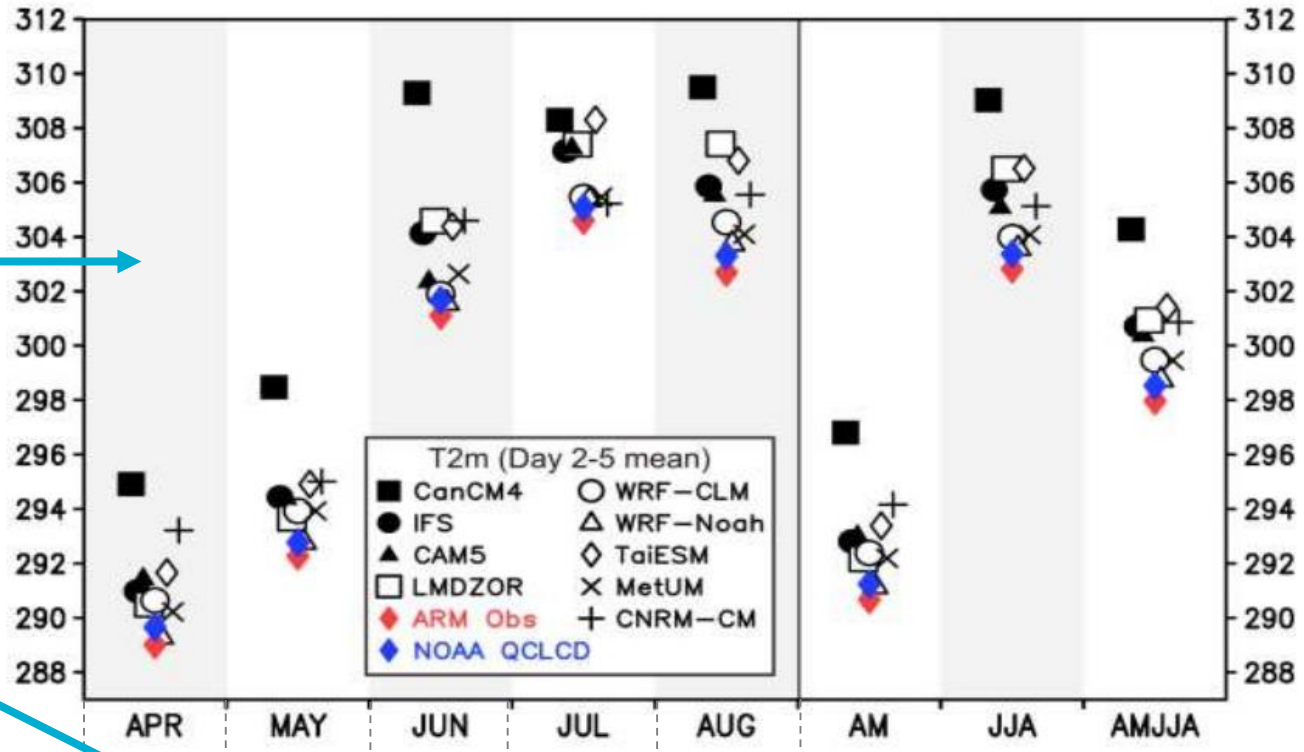
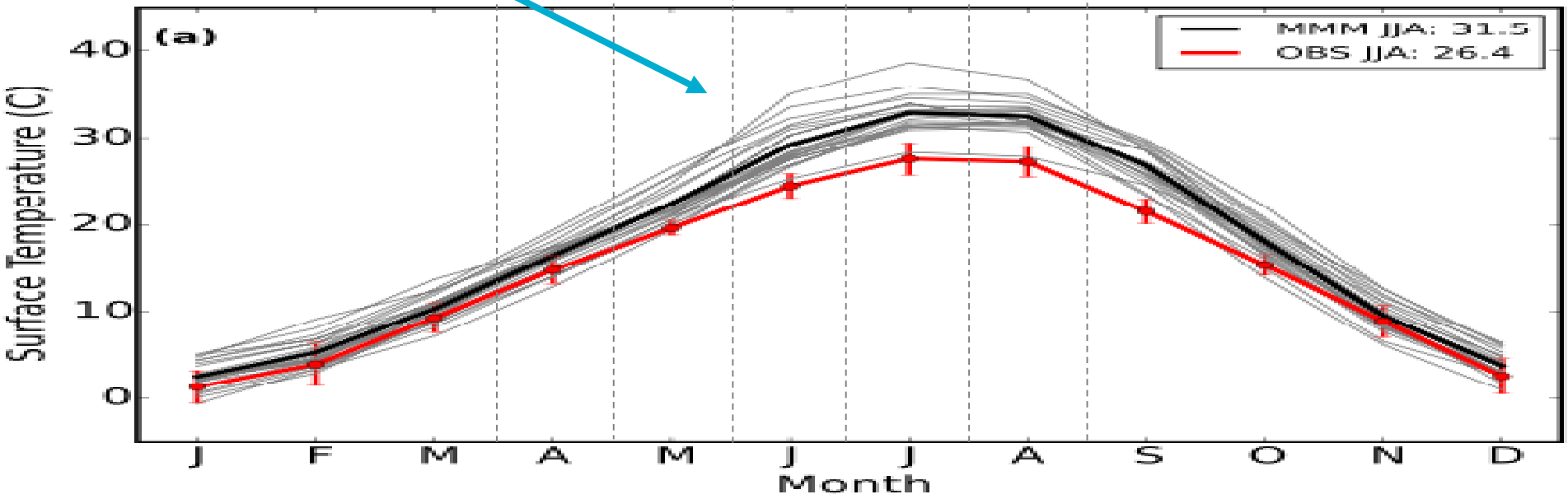
Warm bias seen at SGP in CAUSES initialised hind-cast runs…

…have similar bias to those seen in CMIP5 multi-model ensemble.

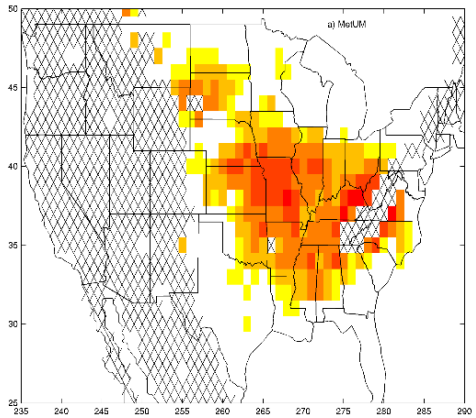


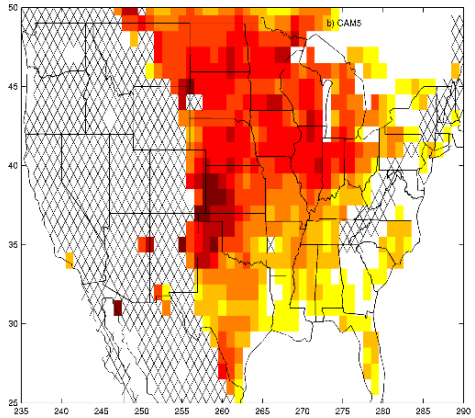


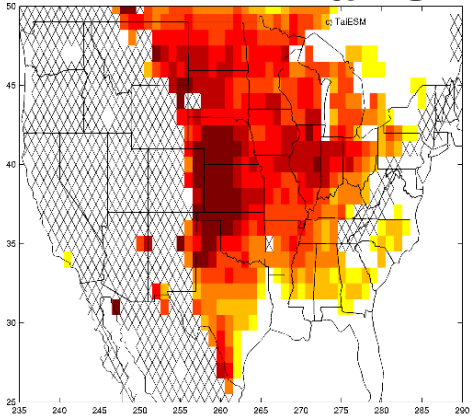
Ma *et al.* (2018) and Zhang *et al.* (2018)

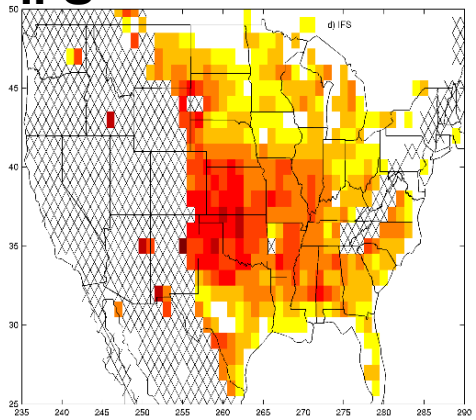
Mean T2M error

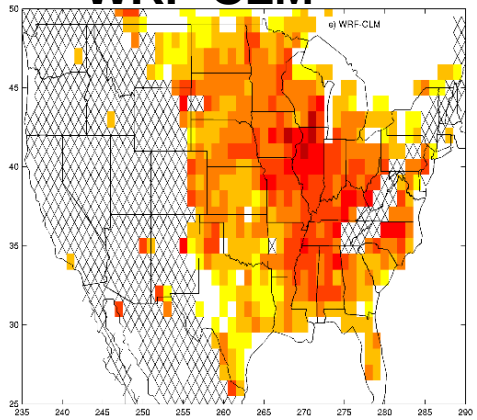
(Day 2-to-5 mean; April-Aug mean)

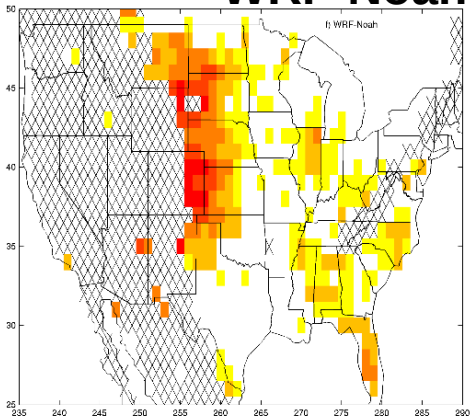


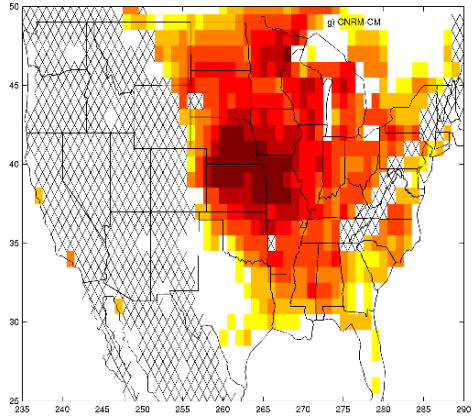


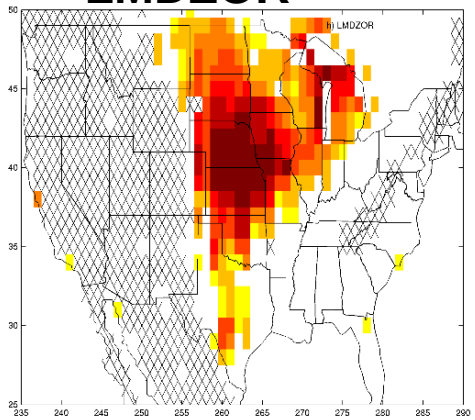


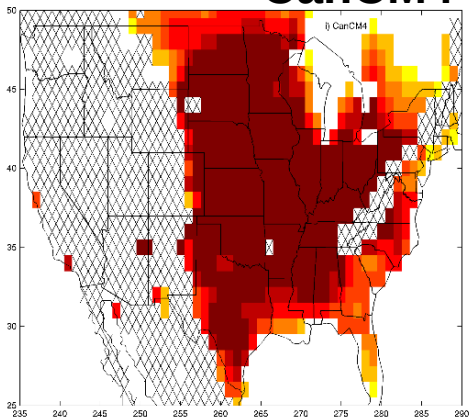








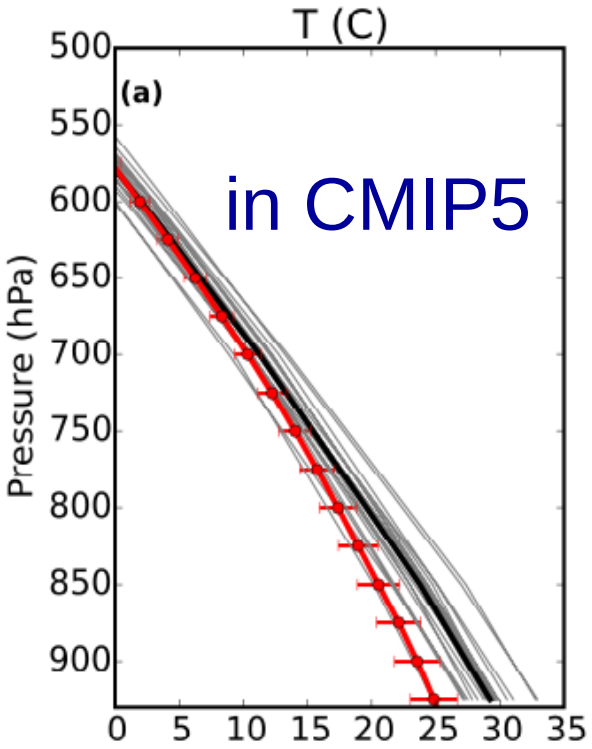




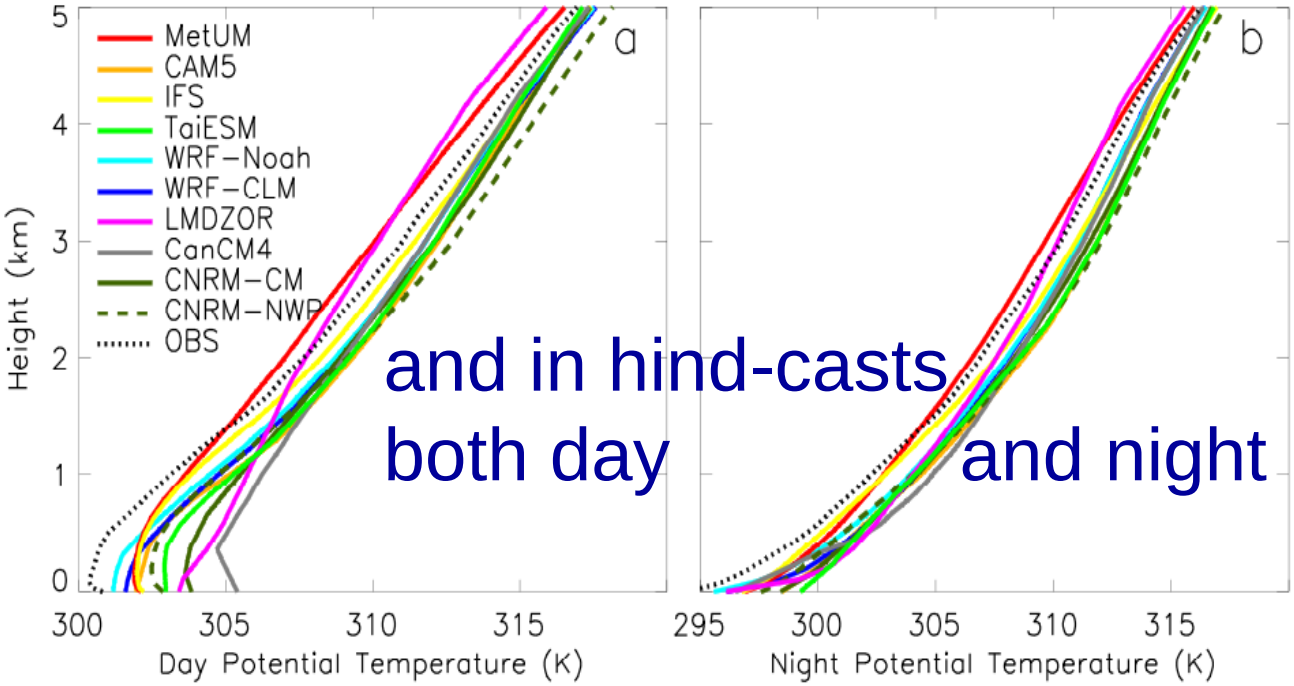
Morcrette *et al.* (2018)

Warm bias is not just at surface.

It extends several km into atmosphere



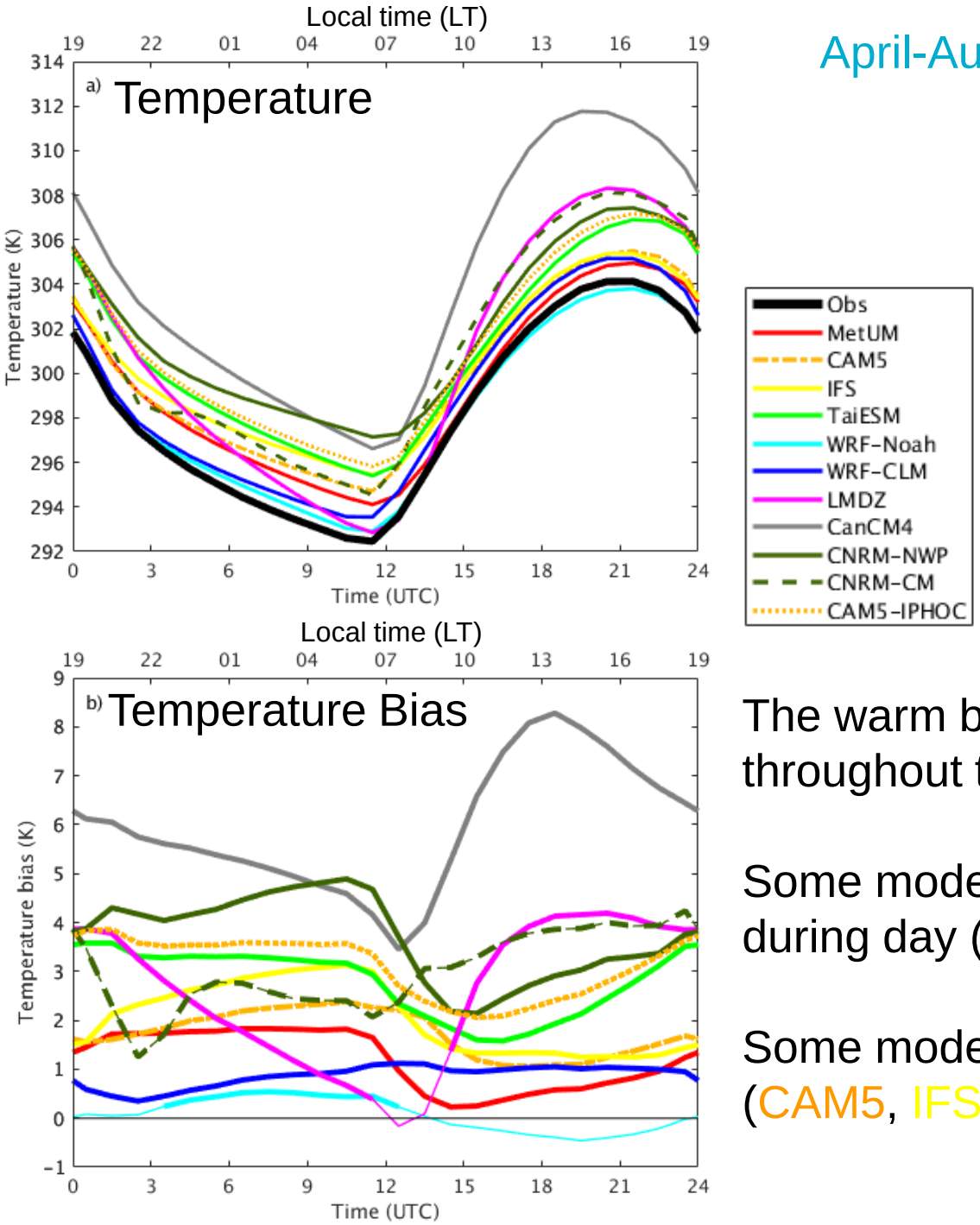
in CMIP5



and in hind-casts both day and night

Zhang *et al.* (2018) and Morcrette *et al.* (2018)

April-Aug mean diurnal cycles at SGP



The warm bias is NOT uniform throughout the day.

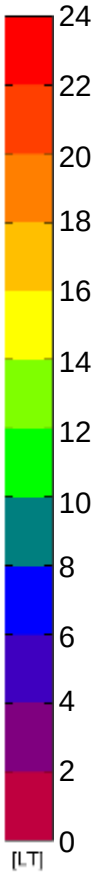
Some models have largest bias during day (CanCM4, LMDZ).

Some models have largest bias at night (CAM5, IFS, MetUM)

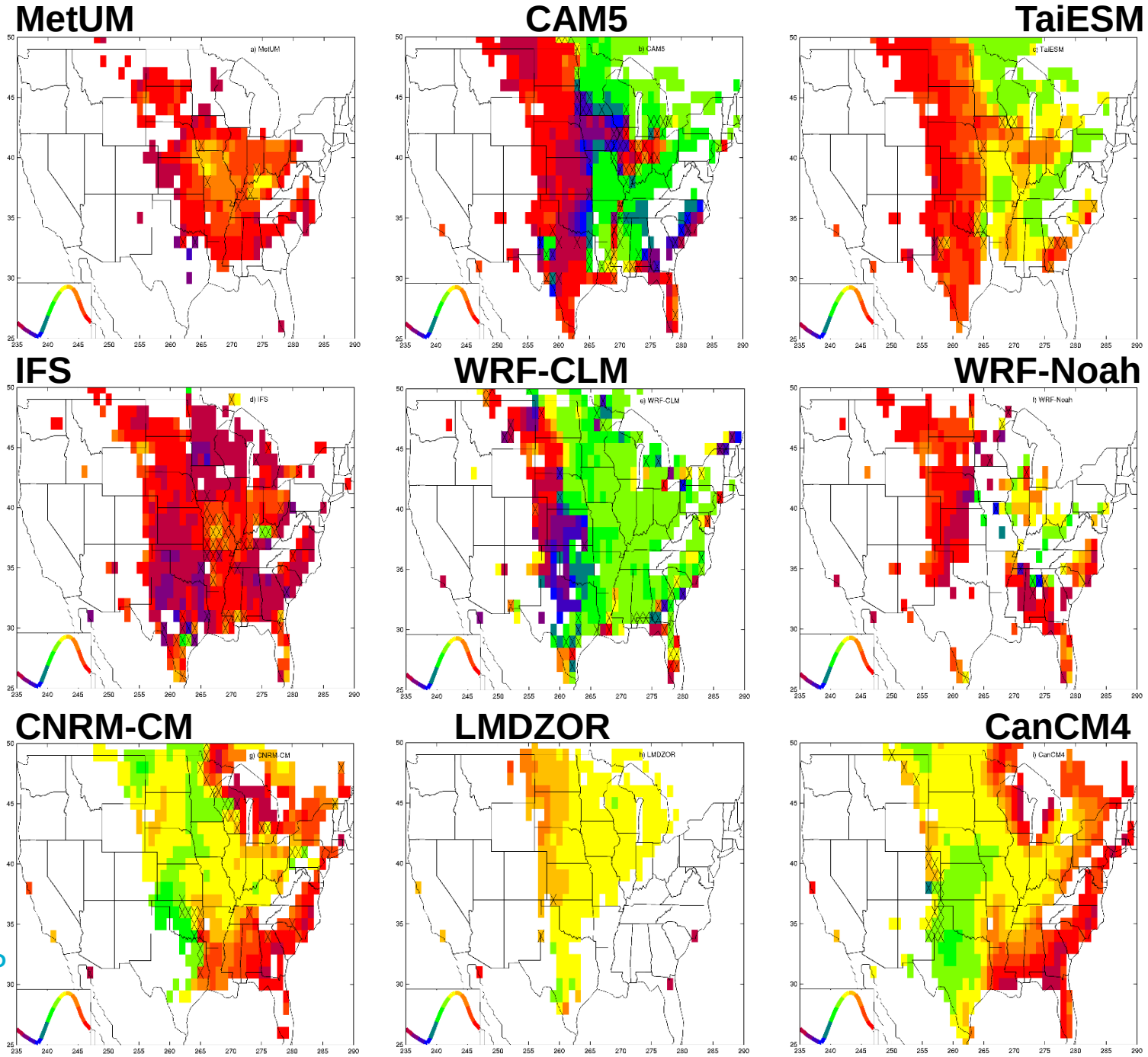
Morcrette *et al.* (2018)

Local time of max error

(Phase of diurnal cycle of T2M error from FFTs)

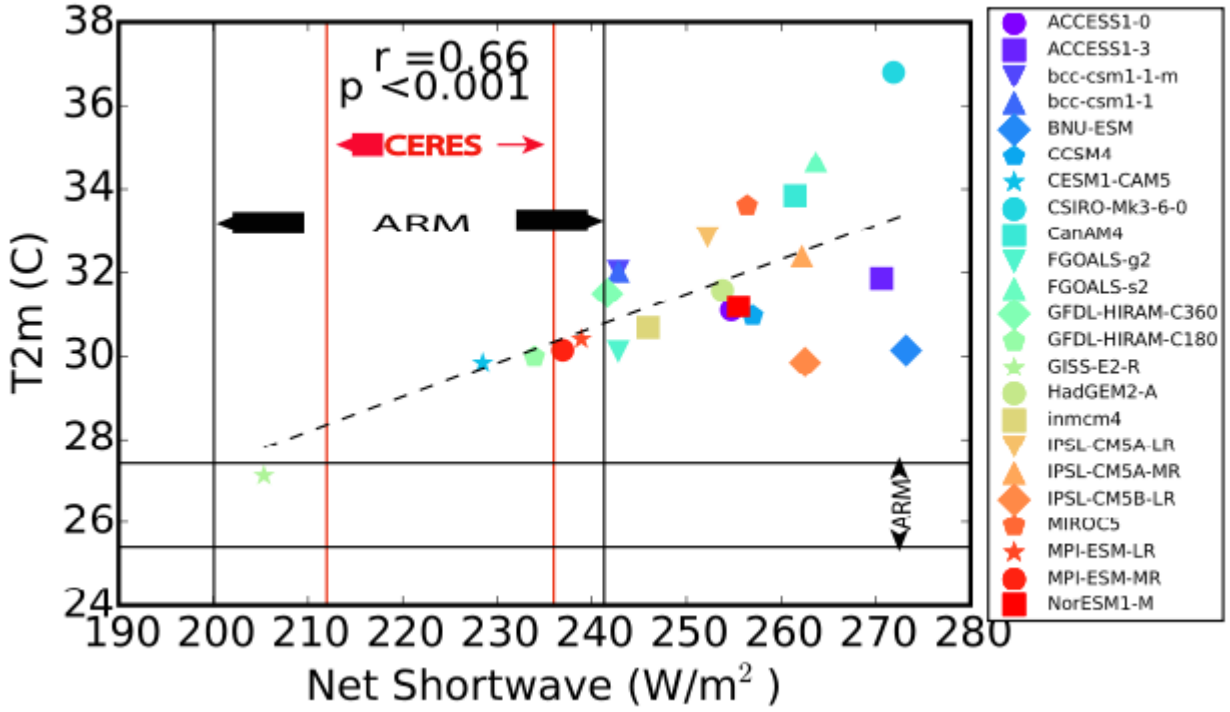


The phase of the error seen at SGP is seen over a large scale.



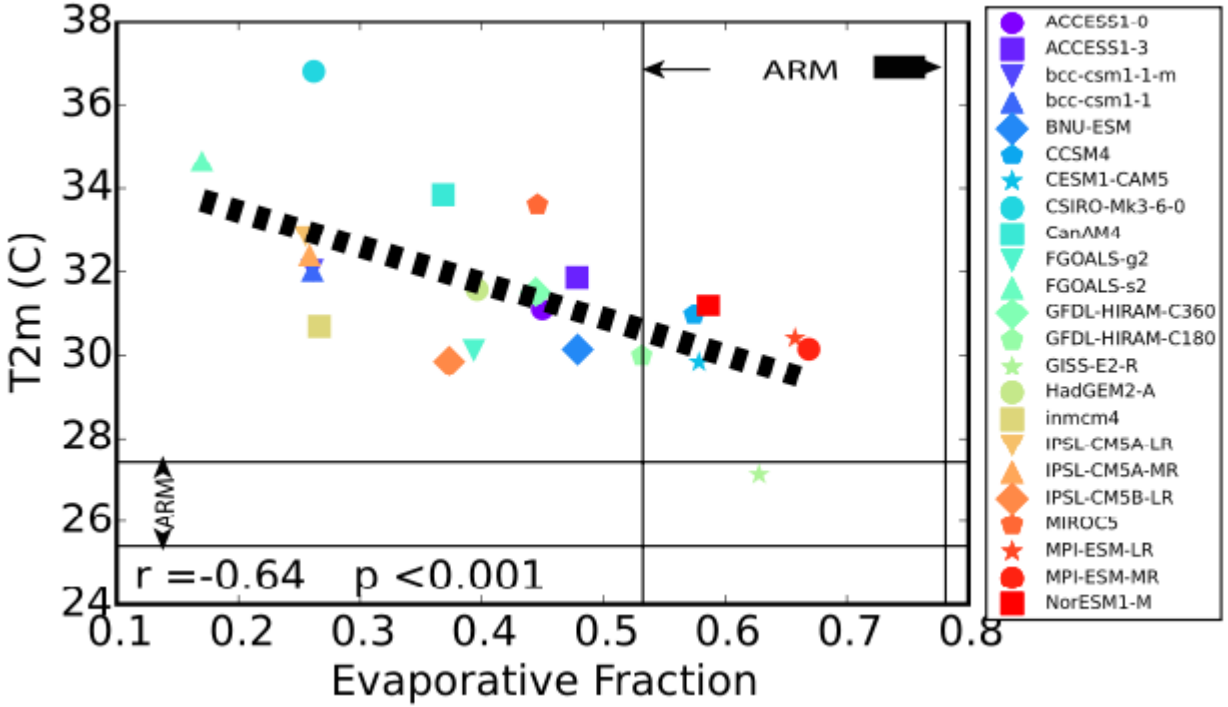
Morcrette *et al.* (2018)

CFMIP 5 models:
typically have too much net shortwave



Zhang *et al.* (2018)

CFMIP 5 models:
Evaporative fraction typically too low.



EF = LH / (SH+LH)

Zhang *et al.* (2018)

What matters most: radiation errors or evaporation fraction errors?

Time-averaged surface energy balance (for > 1week, neglect storage and GHF terms).

$$SWNET = LWNET + SH + LH$$

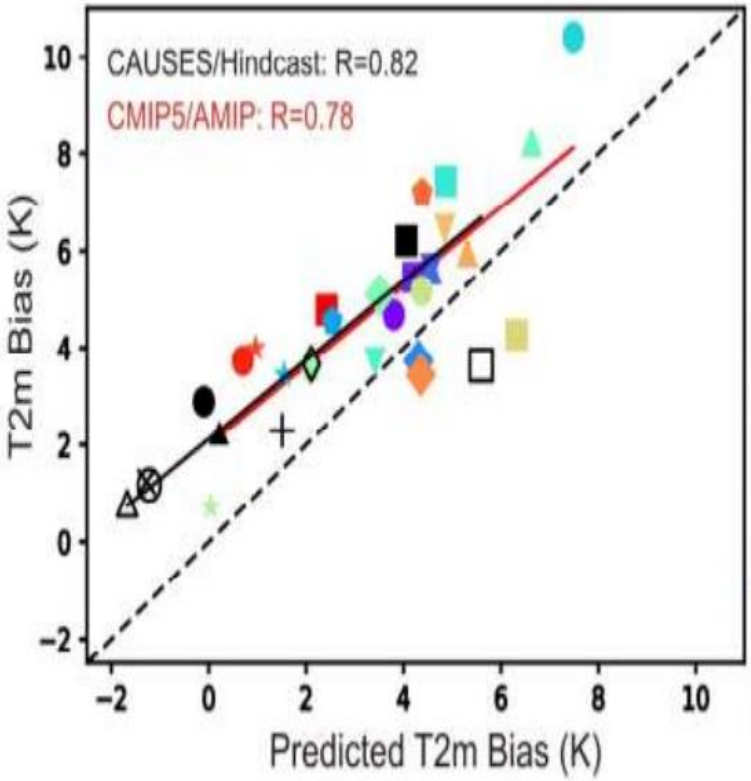
Use EF=LH/(SH+LH).
If balance hold for model and for obs, it must also hold for errors.
Define γ = 1 / (1-EF)

$$T'_{2m} = \frac{(SWNET' + LWDN')}{\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}} - \frac{EF'\gamma_{obs}(SH_{mod} + LHmod)}{\frac{\partial LWUP}{\partial T_{2m}} + \gamma_{obs}\frac{\partial SH}{\partial T_{2m}}}$$

Insert typical values

$$T'_{2m} = \frac{(SWNET' + LWDN')}{30\ Wm^{-2}K^{-1}} - \frac{2.5\ EF'(SH_{mod} + LHmod)}{30\ Wm^{-2}K^{-1}}$$

Ma *et al.* (2018)


CAUSES/Hindcast: R=0.82
CMIP5/AMIP: R=0.78
T2m Bias (K)
Predicted T2m Bias (K)
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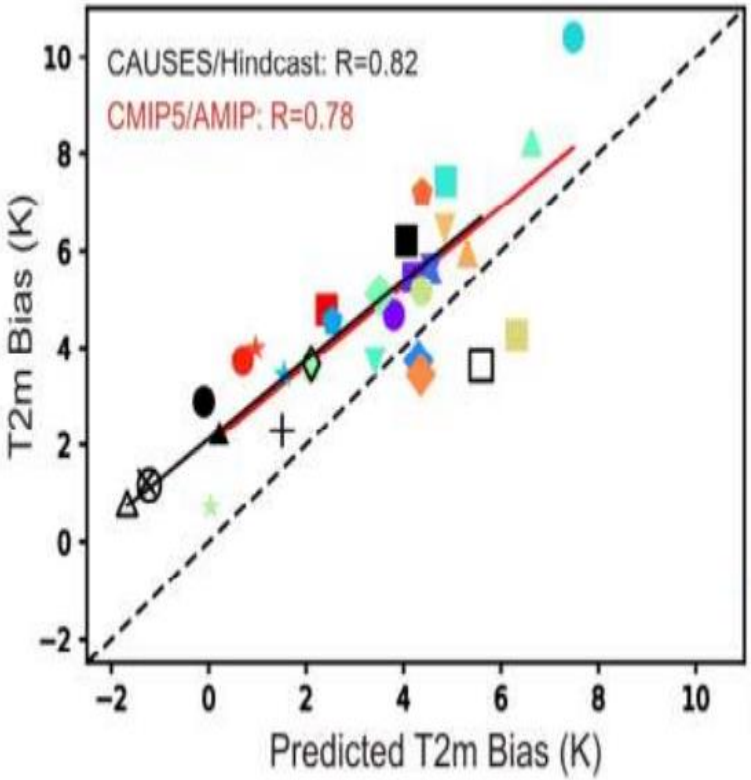
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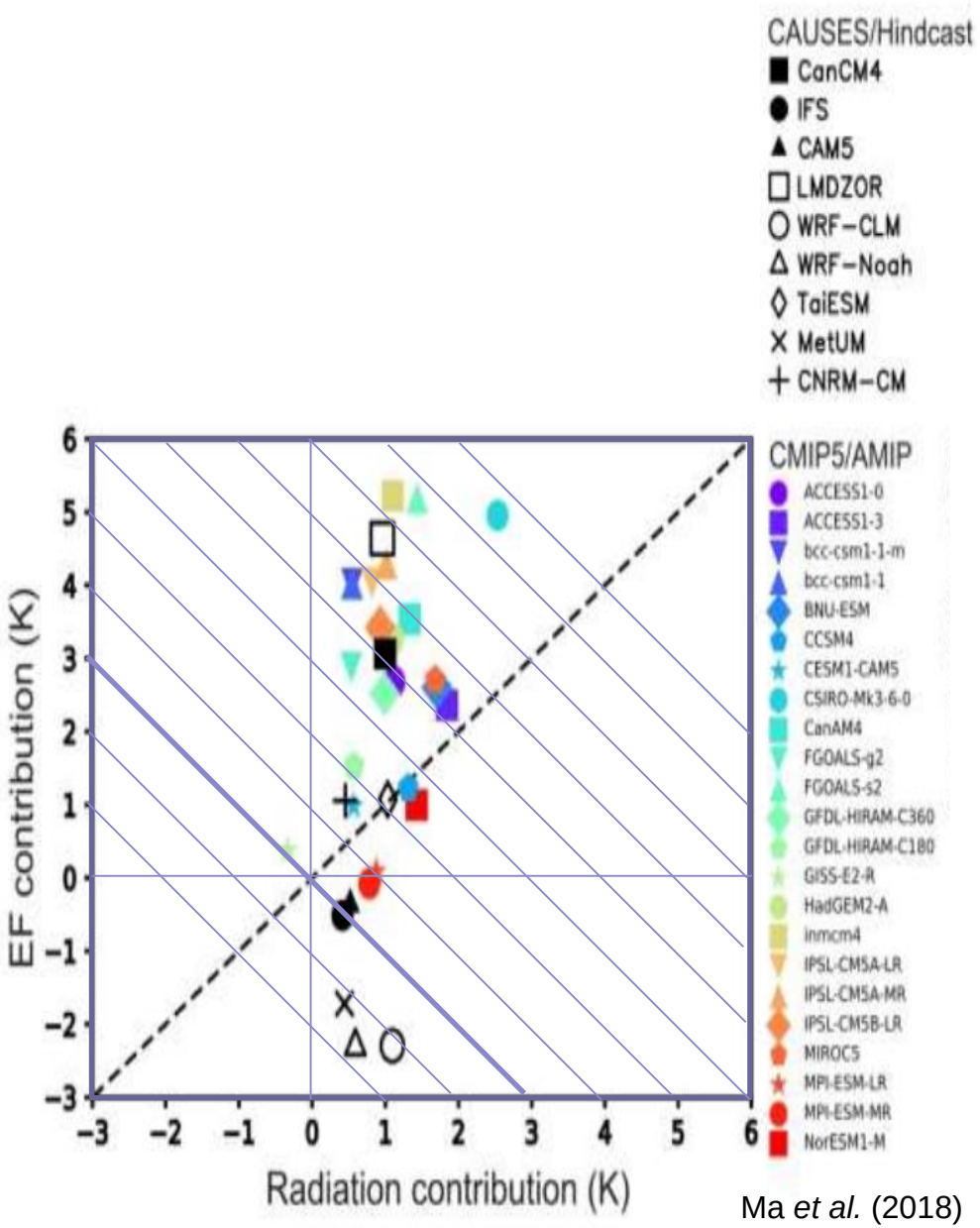
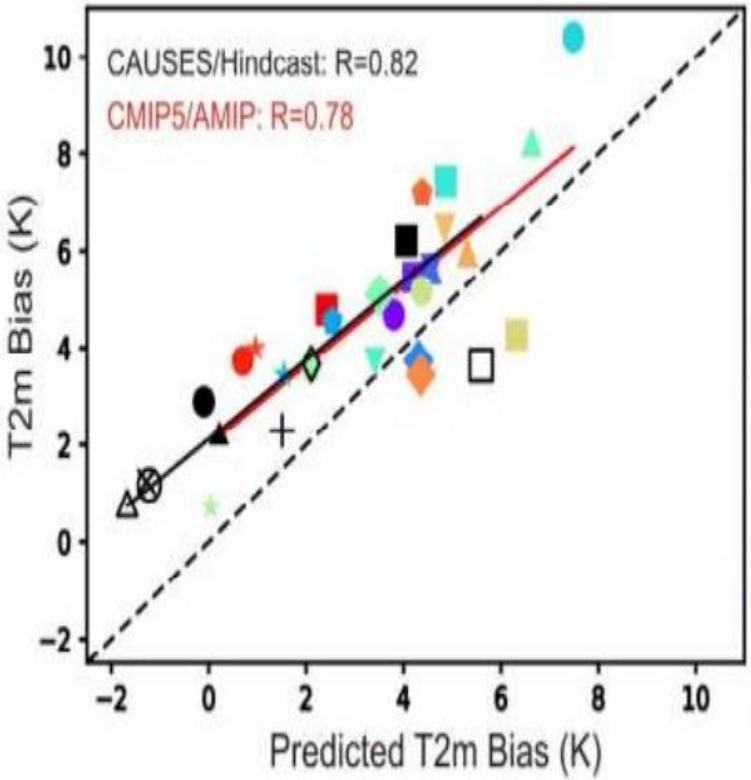

CAUSES/Hindcast
CanCM4
IFS
CAM5
LMDZOR
WRF−CLM
WRF−Noah
TaiESM
MetUM
CNRM−CM
CMIP5/AMIP
ACCESS1-0
ACCESS1-3
bcc-csm1-1-m
bcc-csm1-1
BNU-ESM
CCSM4
CESM1-CAM5
CSIRO-Mk3-6-0
CanAM4
FGOALS-g2
FGOALS-s2
GFDL-HIRAM-C360
GFDL-HIRAM-C180
GISS-E2-R
HadGEM2-A
inmcm4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MPI-ESM-LR
MPI-ESM-MR
NorESM1-M
EF contribution (K)
Radiation contribution (K)

Ma *et al.* (2018)



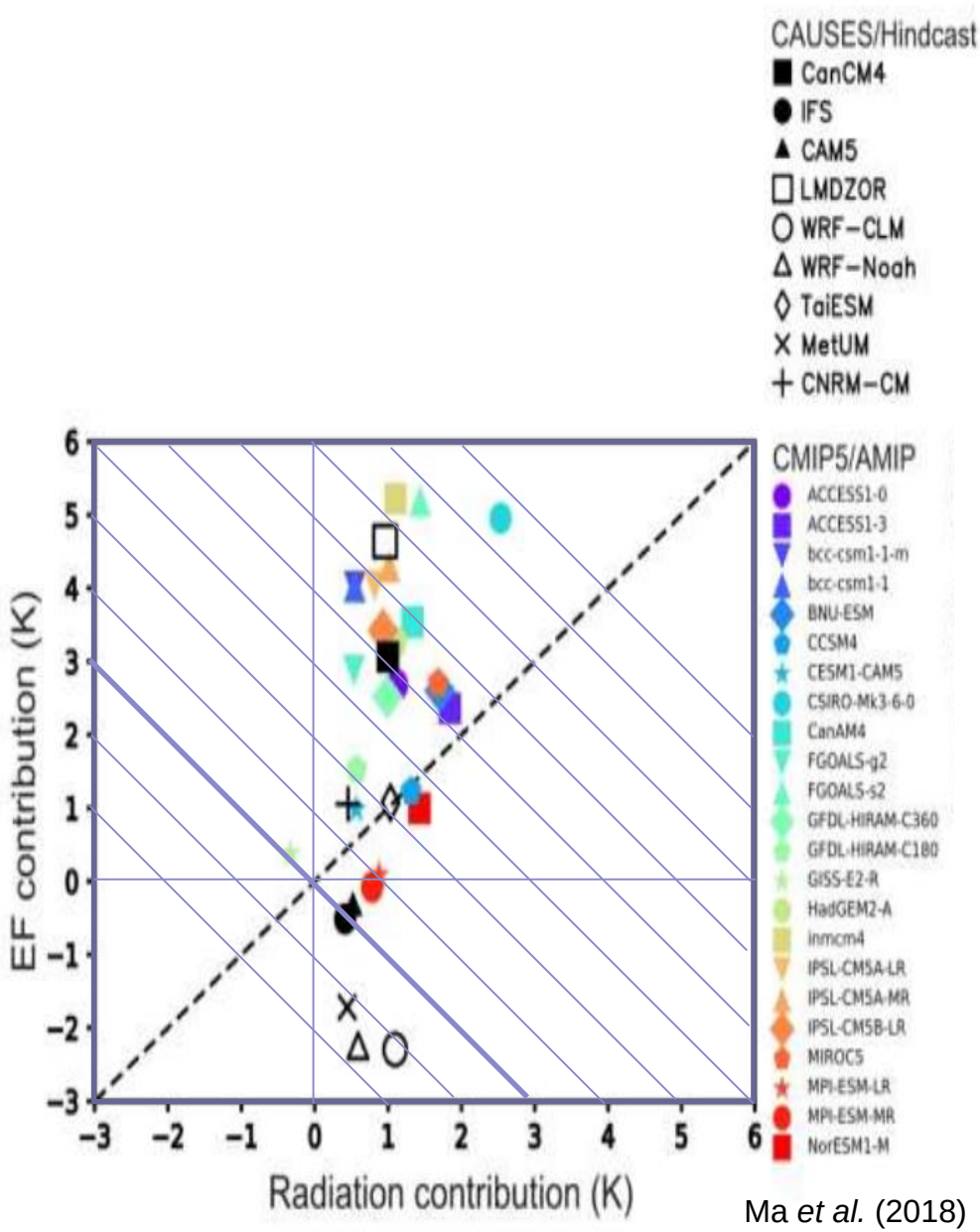
Quantifies relative contribution of EF and radiation errors.

Radiation errors explain 0-2 K of the warm bias.

EF contribution varies more.

EF errors explain most of T error in models with large T error.

In models with small T error, EF error compensate for rad errors.

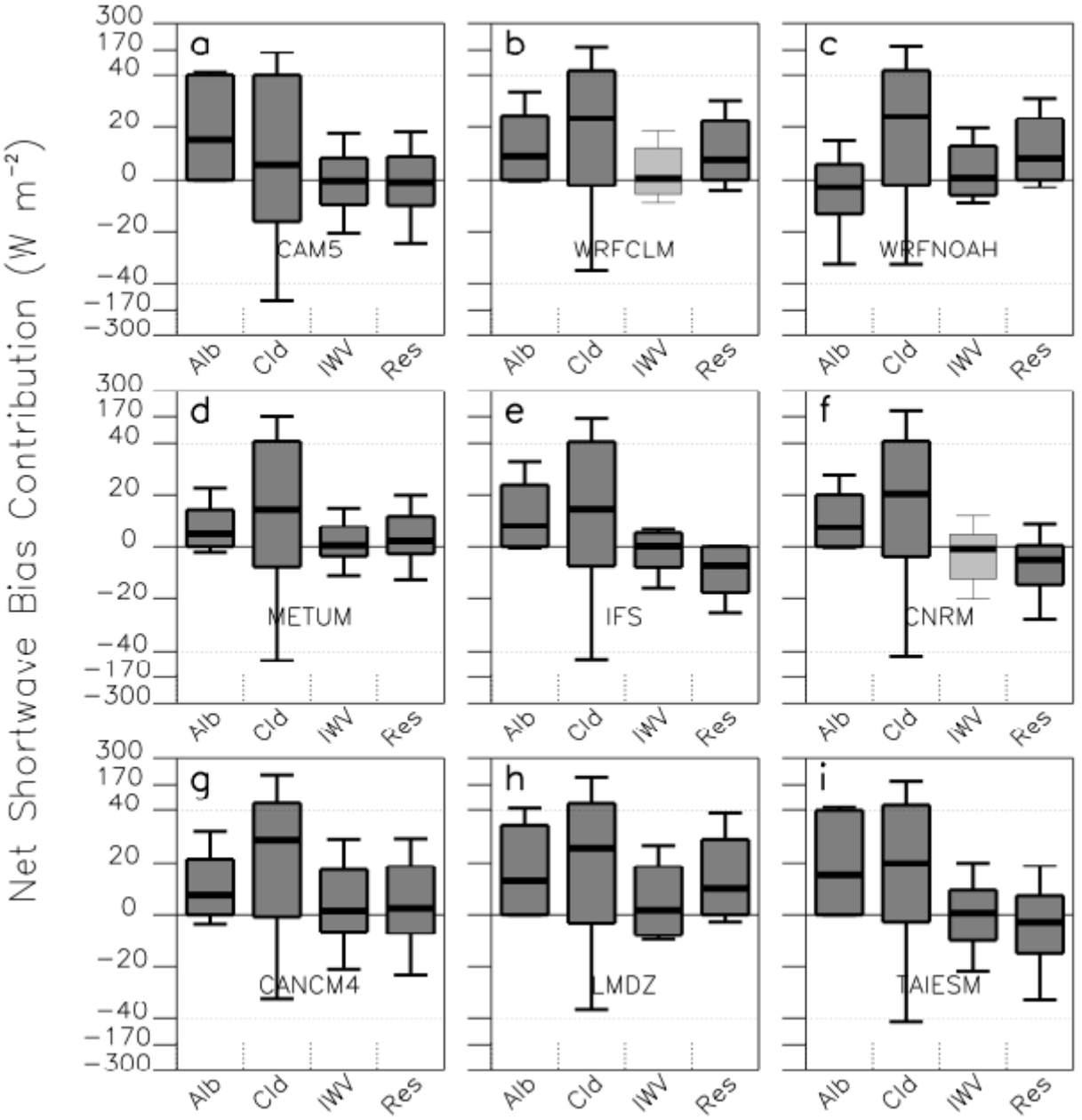


Ma *et al.* (2018)

What are radiation errors due to?

All models have a significant radiation error coming from clouds.

Which kind of cloud?



Van Weverberg *et al.* (2018)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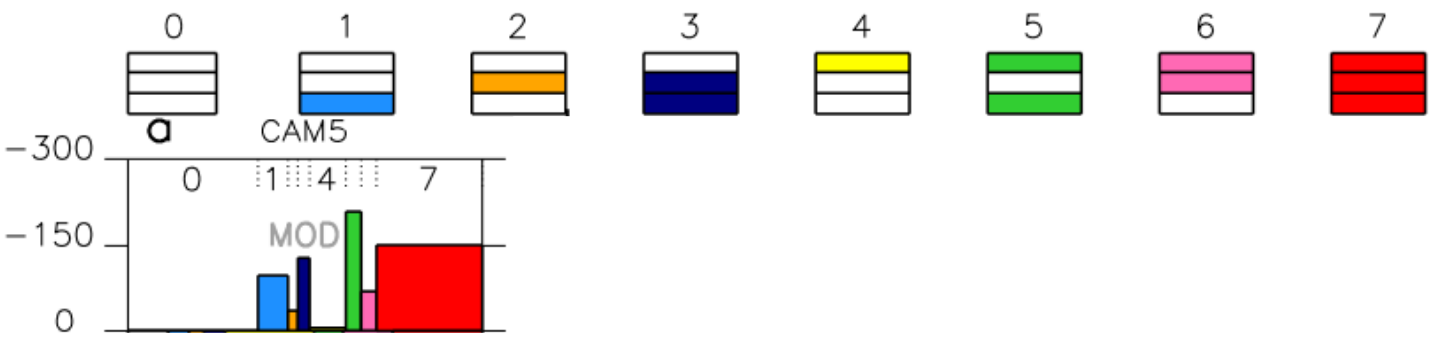
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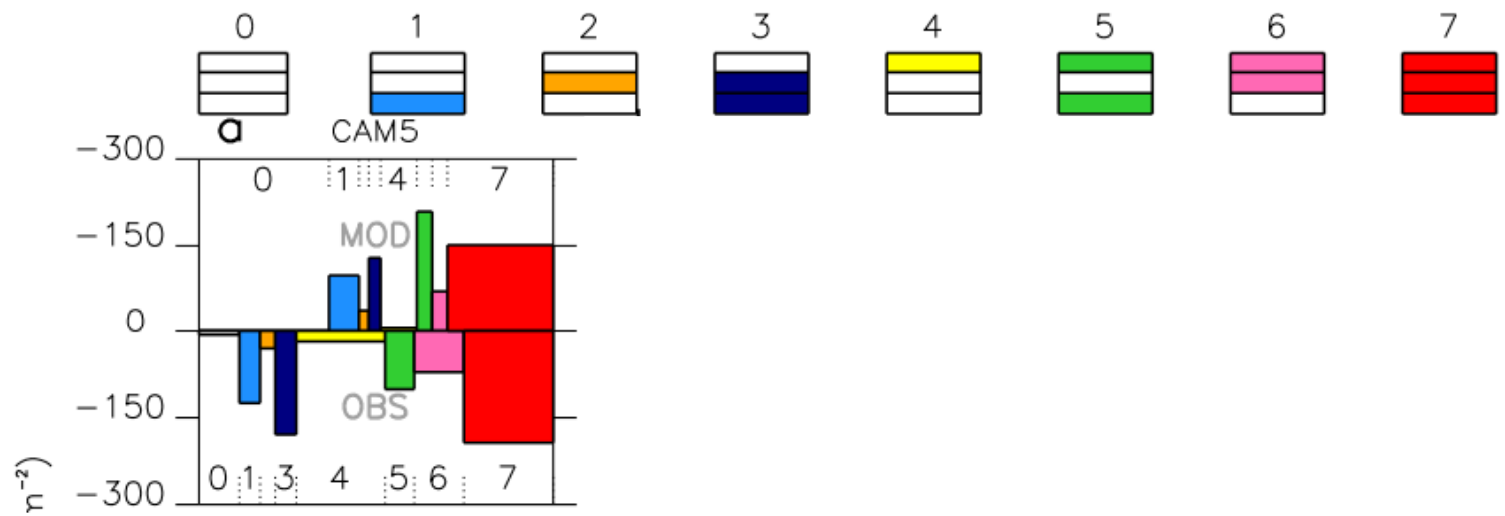
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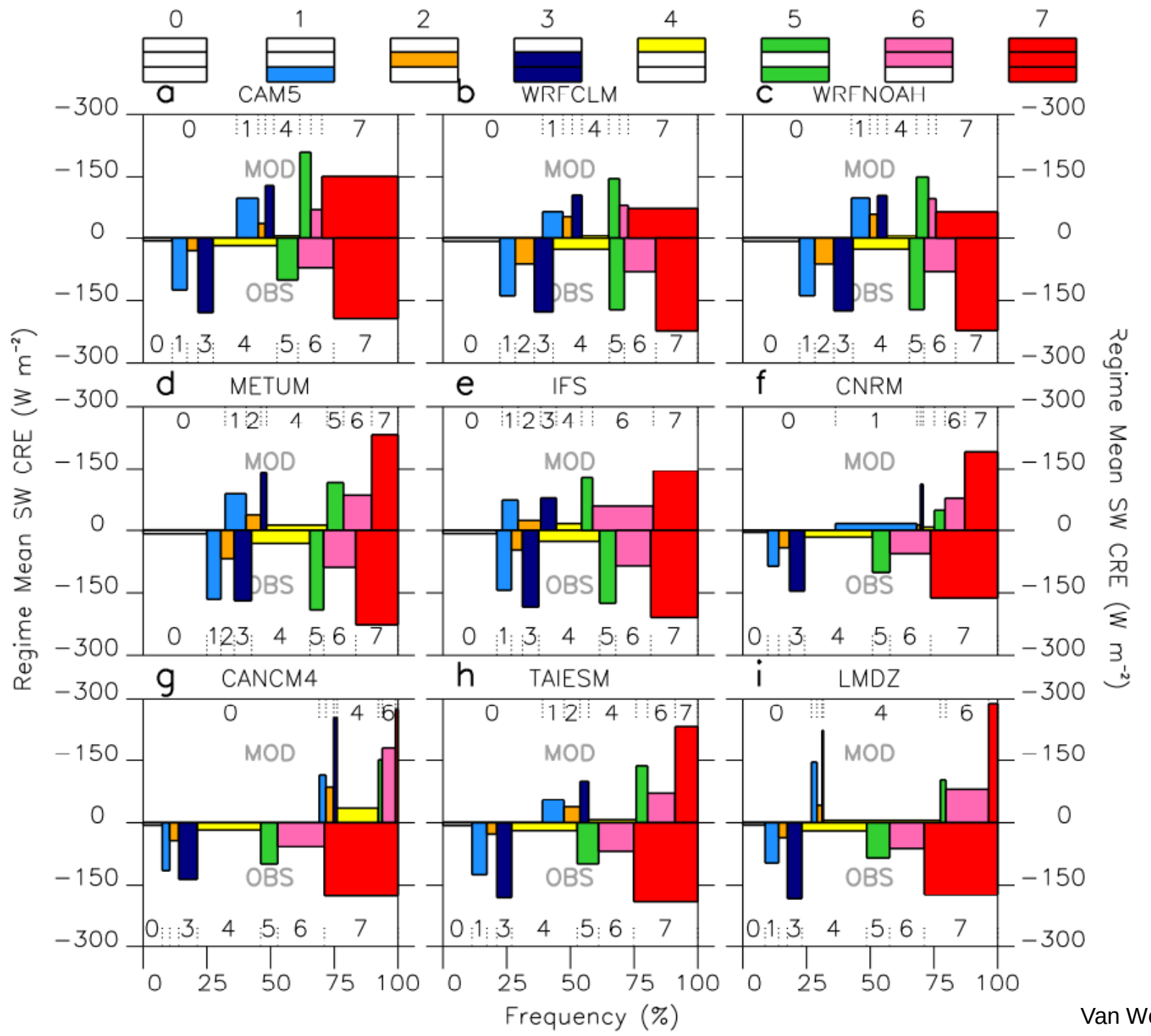
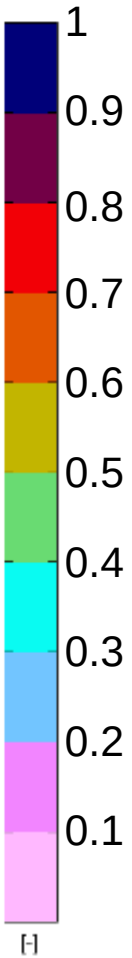
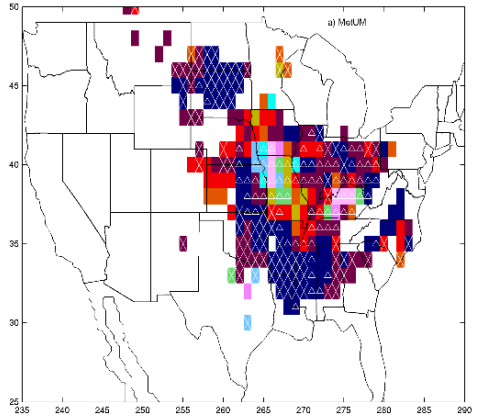


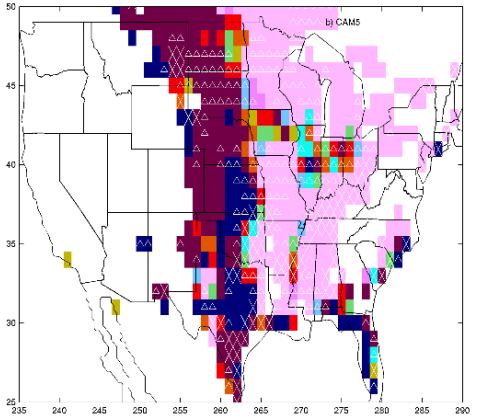
Van Weverberg *et al.* (2018)

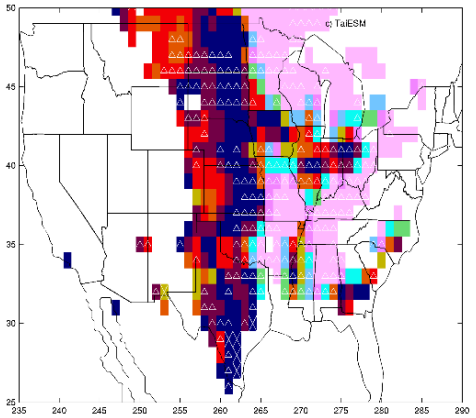
Correlation of T2M error at any point with T2M error at SGP.

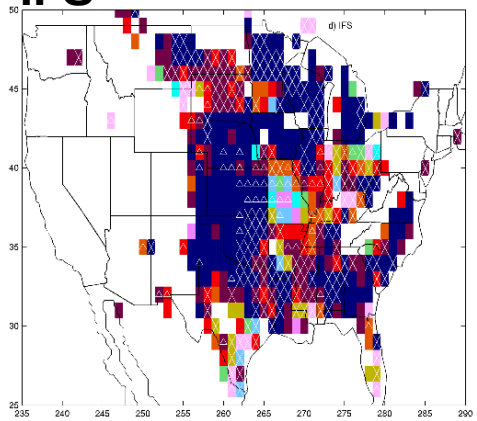
(Use April-Aug mean diurnal cycle)

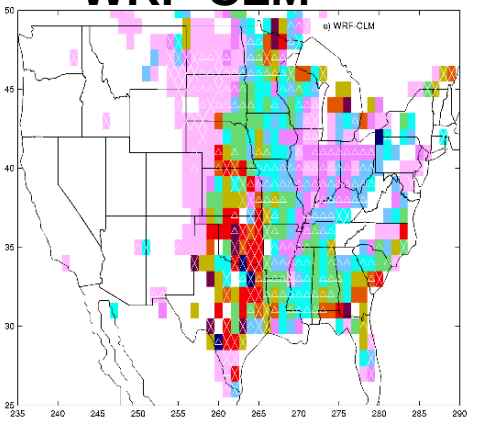


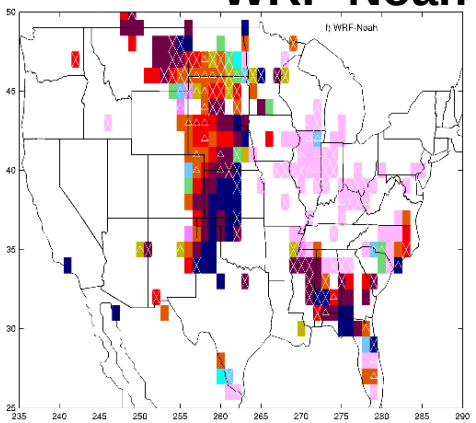


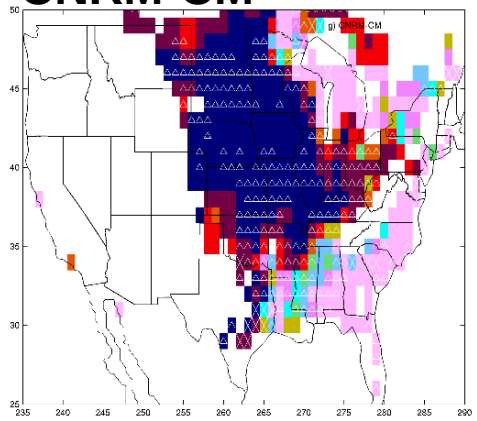


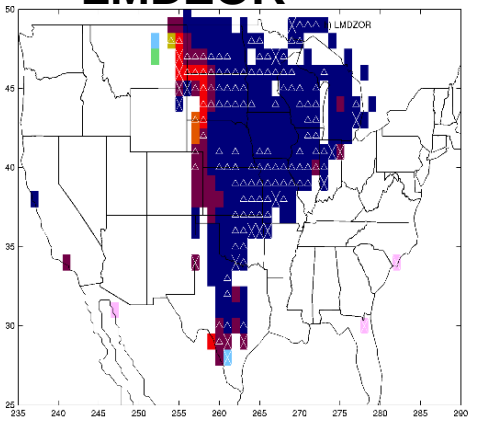


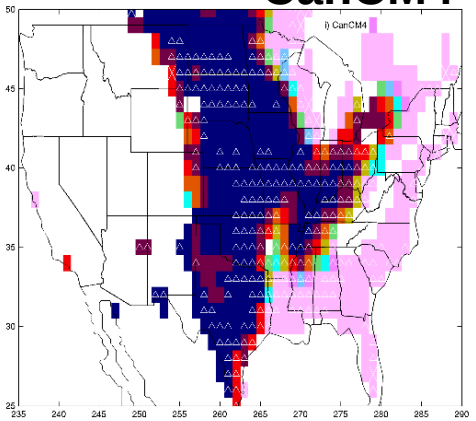












Morcrette *et al.* (2018)

Summary:

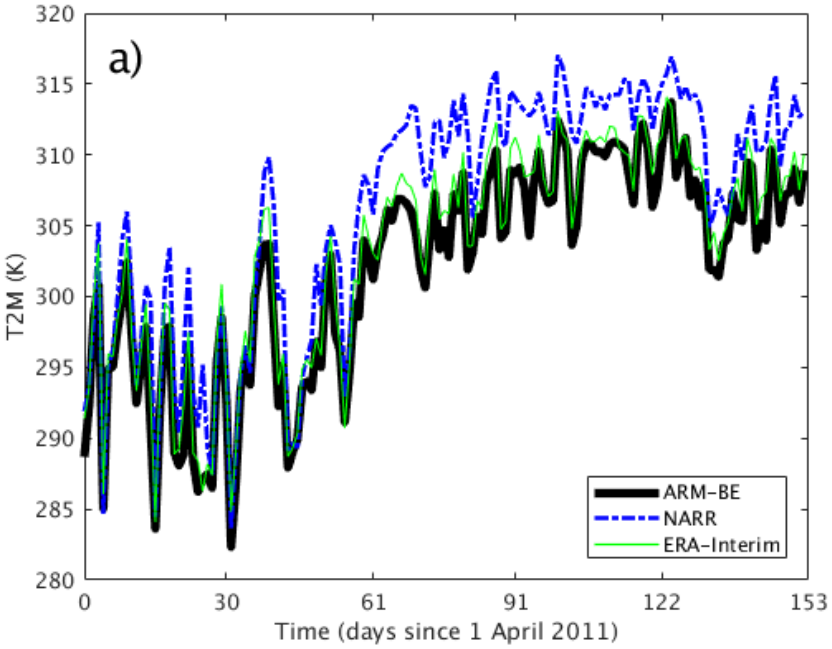
- 11 models ran 5-day hind-casts and most models have a warm screen-level temperature bias over parts of the American Midwest.
- Biases have large diurnal variations. Some models have largest error during day and others at night.
- Biases are not confined to surface.
- Theoretical derivation shows that EF error explains 0-5 Kelvin of the error
- Radiation error explain 0-2 Kelvin of the error.
- Radiation error is mainly due to cloud-radiative effects (and in one model also due to surface albedo).
- Most significant cloud type is the deep cloud regime. Either too rare or too optically thin.
- Cloud-types: Errors in frequency of occurrence can offset errors in mean radiative properties.
- Diurnal cycle of T2M error across large portion of the Midwest highly correlated with error at SGP. What we learn from SGP is likely to be representative of behaviour over wider area.

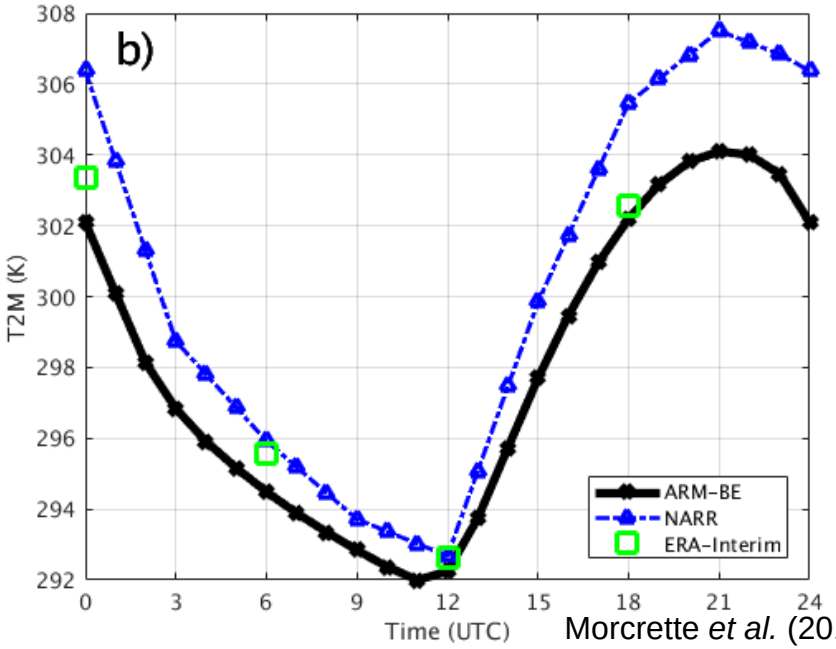
Extra slides

What shall we use for validating T2M?

ARM-Best-Estimate (good for SGP and 3deg x 3deg surroundings)
But need something for rest of CONUS.
Try:

- ERA-Interim
- North-American Regional Analysis (NARR)





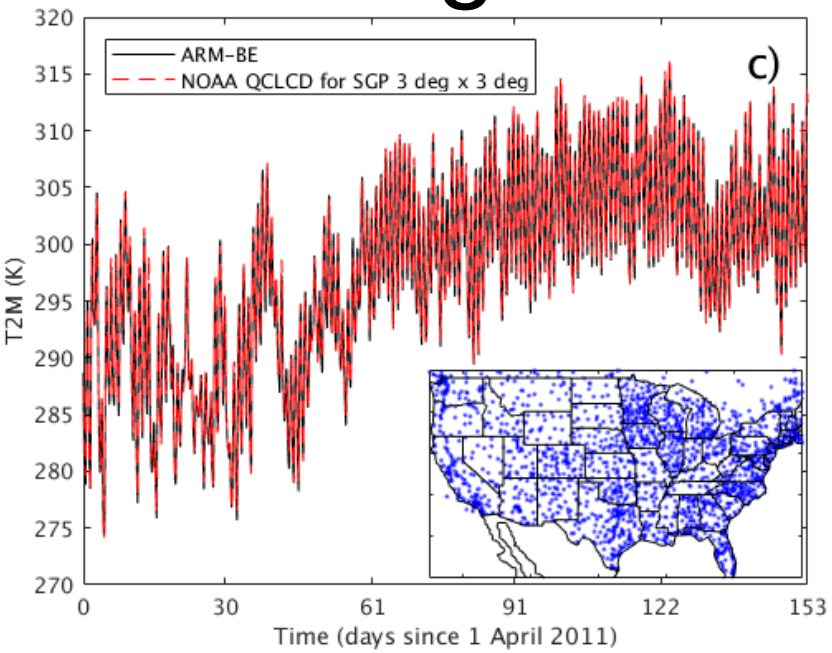
Morcrette *et al.* (2018)

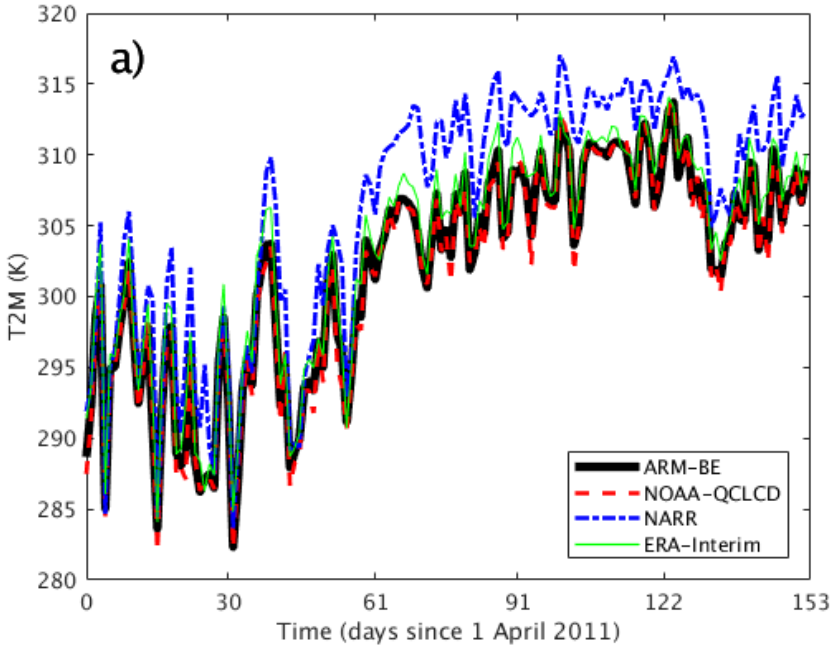
What shall we use for validating T2M?

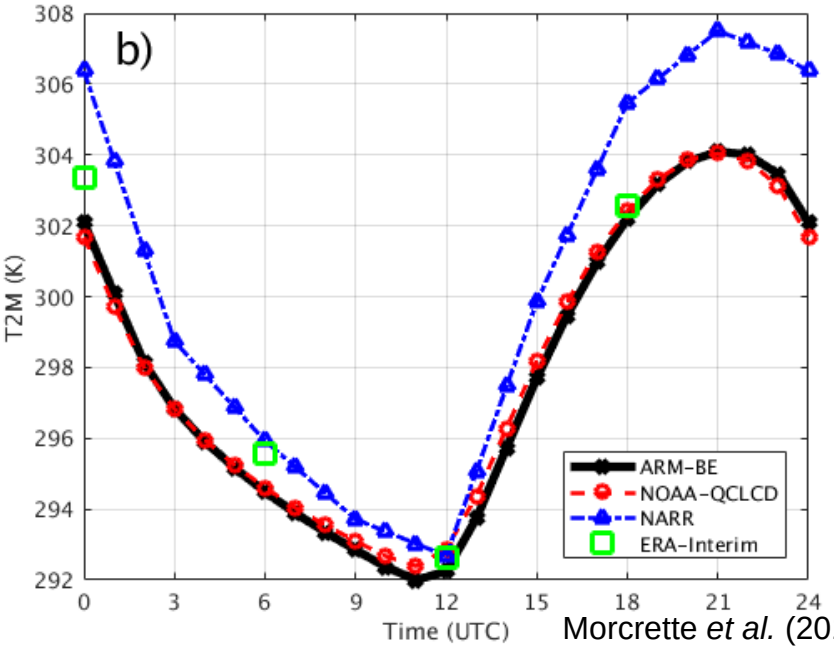
Hourly from April-Aug 2011.

Take obs from ~2000 NOAA "Quality controlled local climate data" (QCLCD) sites.

Produce gridded data set.

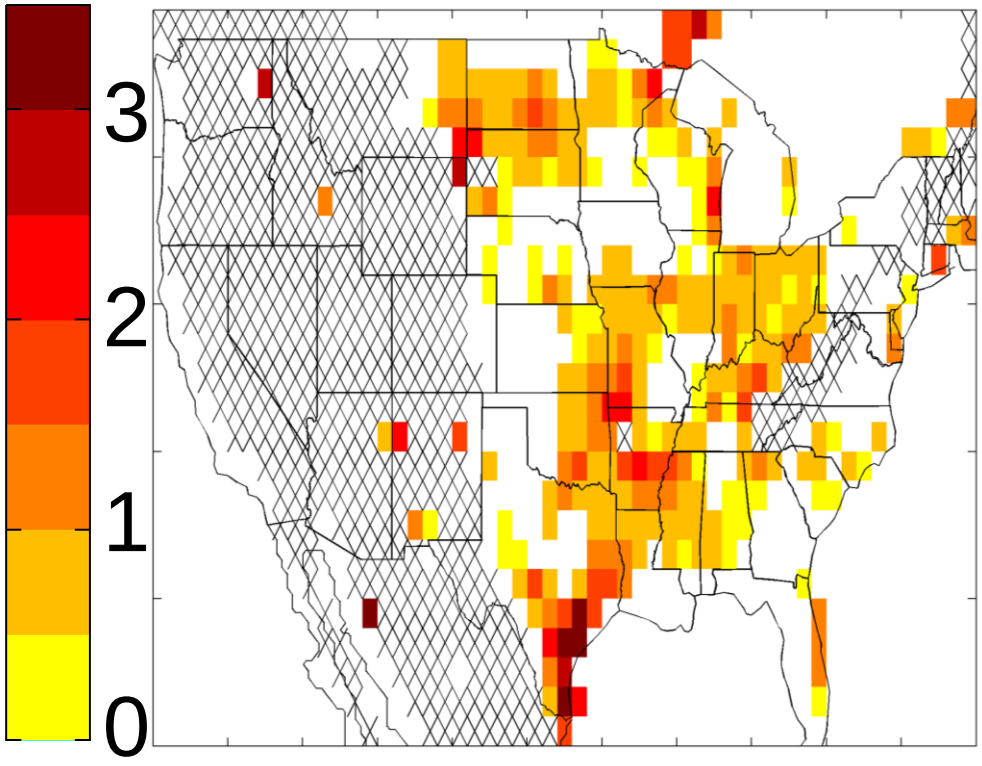






Morcrette *et al.* (2018)

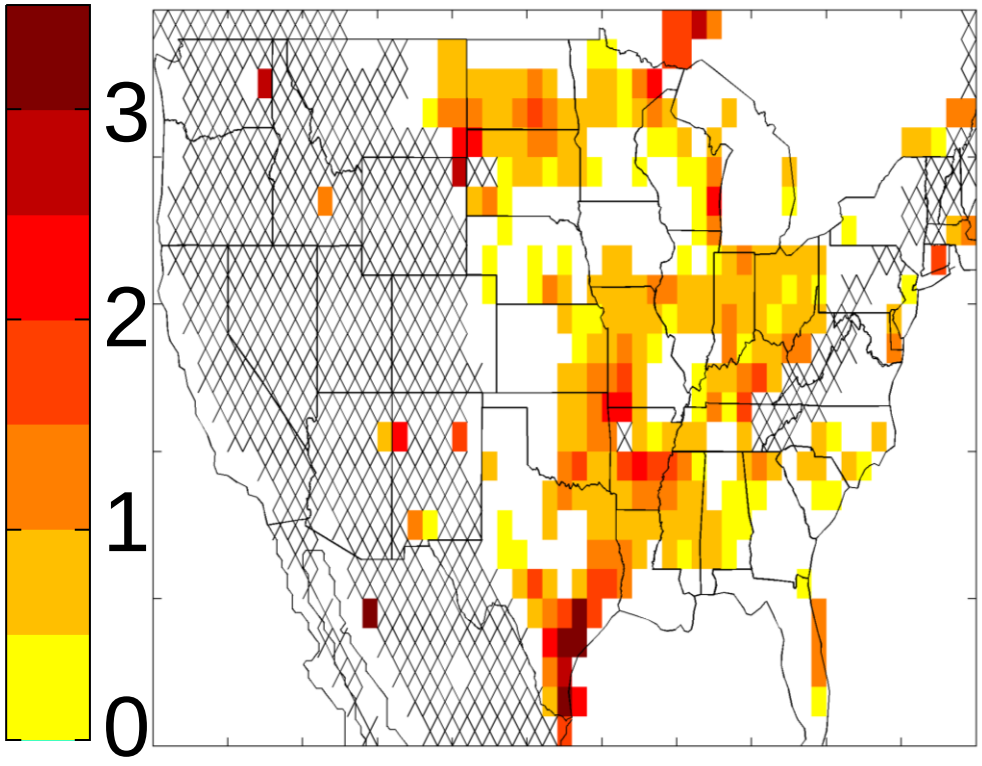
How extensive is ERA-Interim bias seen at SGP?

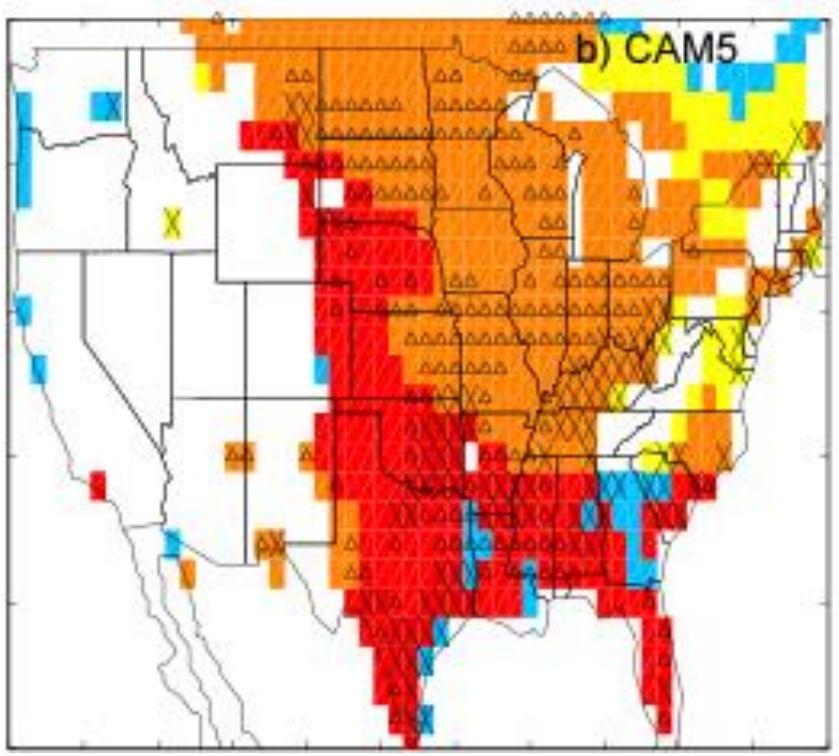


Is that going to corrupt simulations initialised from ERA-Interim?

Morcrette *et al.* (2018)

How extensive is ERA-Interim bias seen at SGP?





X = ERA-I is biased

Δ = ERA-I is biased but model is significantly warmer.

There is a warming **and** a warm bias

There is a warming

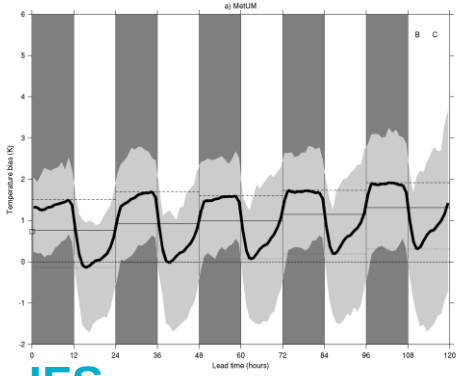
There is a warm bias

Nothing

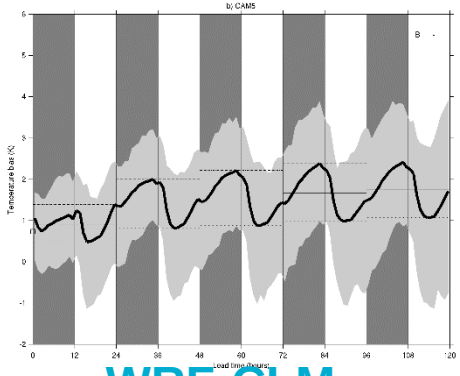
Is that going to corrupt simulations initialised from ERA-Interim?

Morcrette *et al.* (2018)

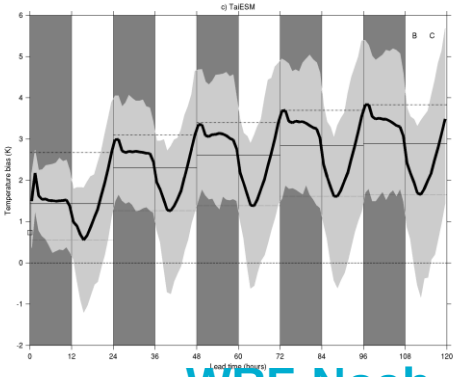
MetUM



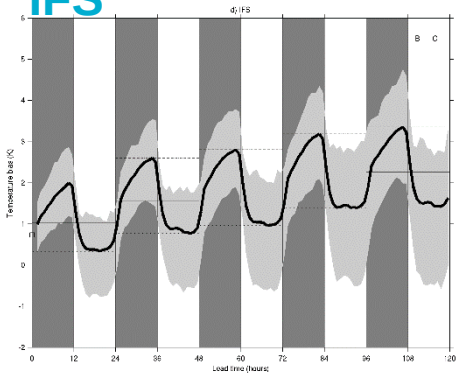
CAM5



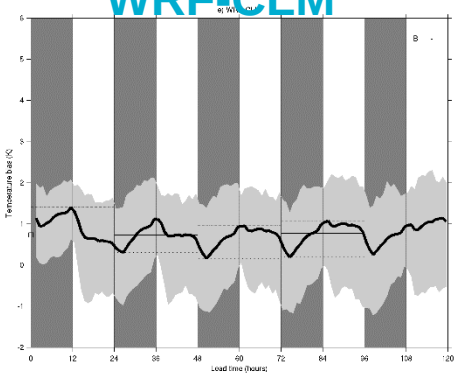
TaiESM



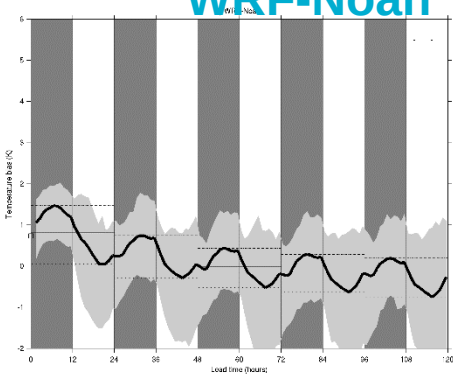
IFS



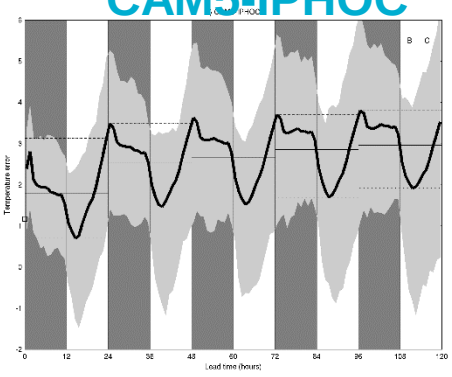
WRF-CLM



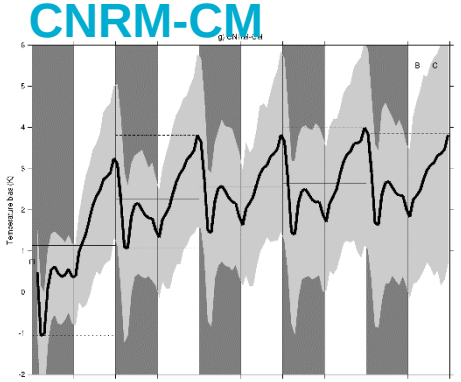
WRF-Noah



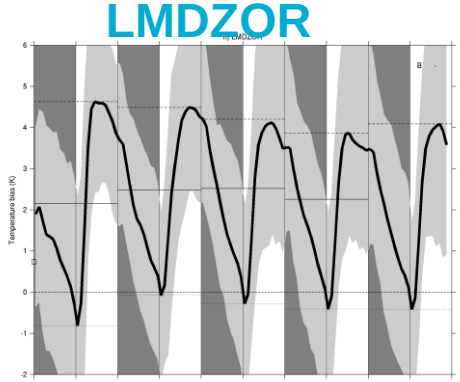
CAM5-IPHOC



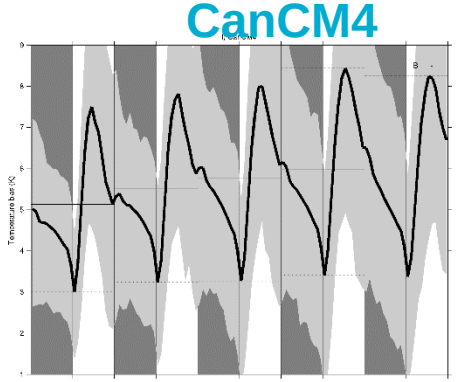
CNRM-CM



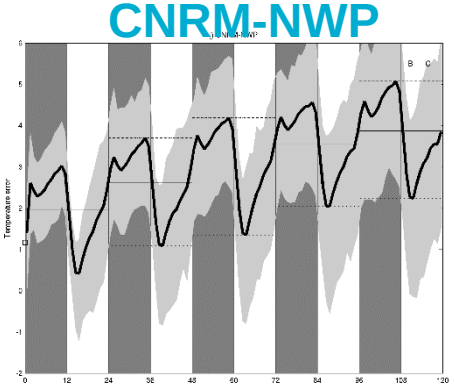
LMDZOR



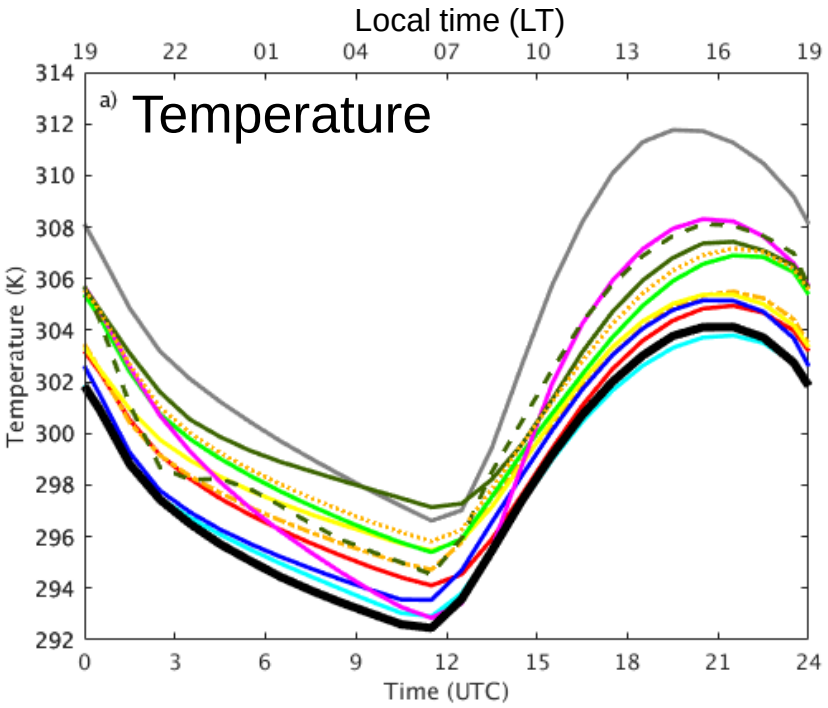
CanCM4

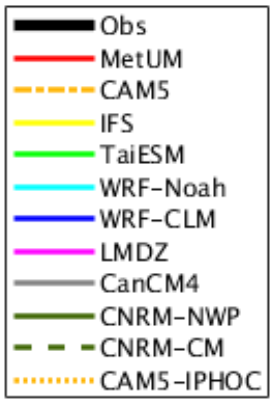


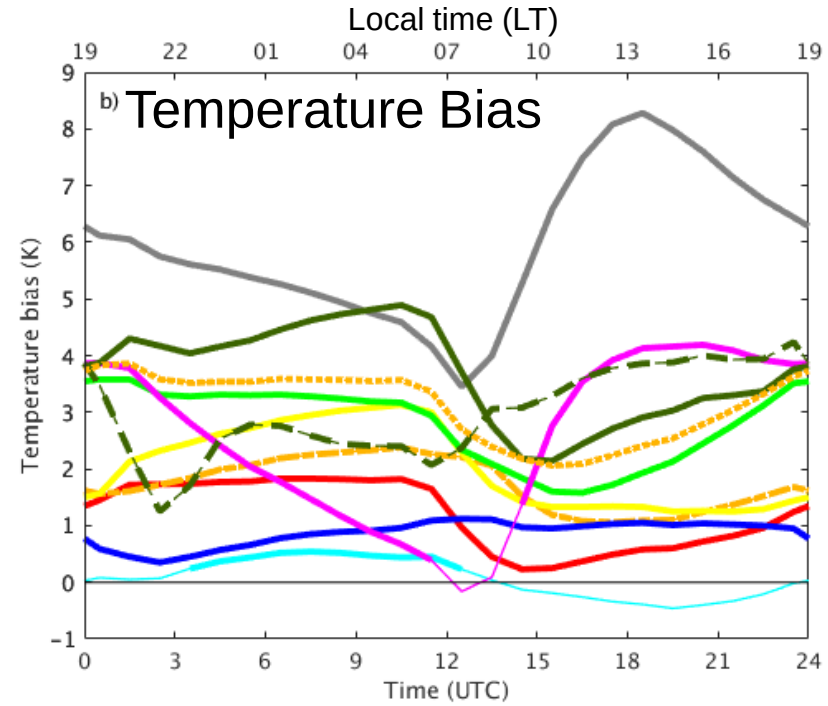
CNRM-NWP

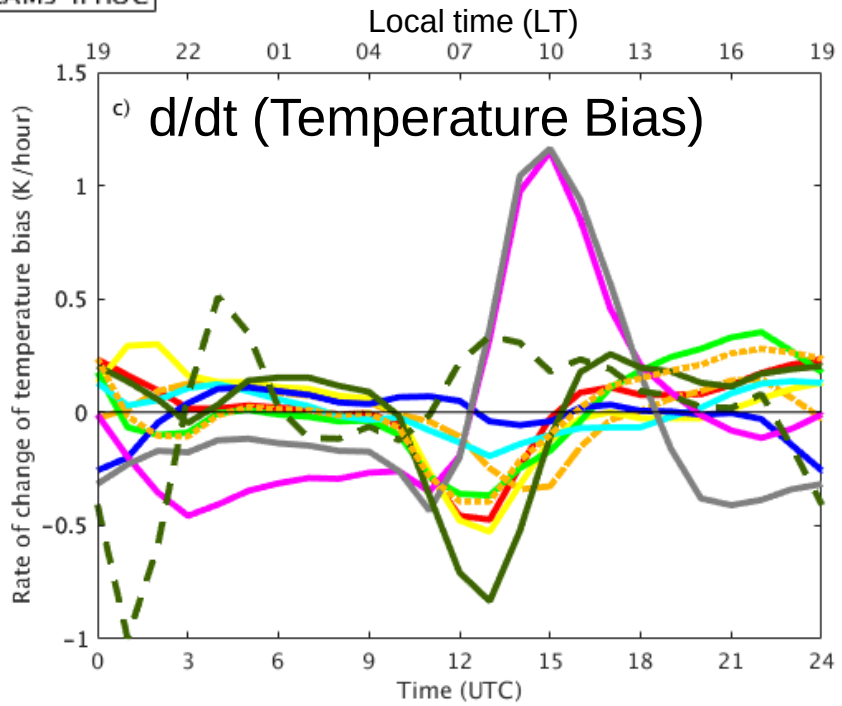


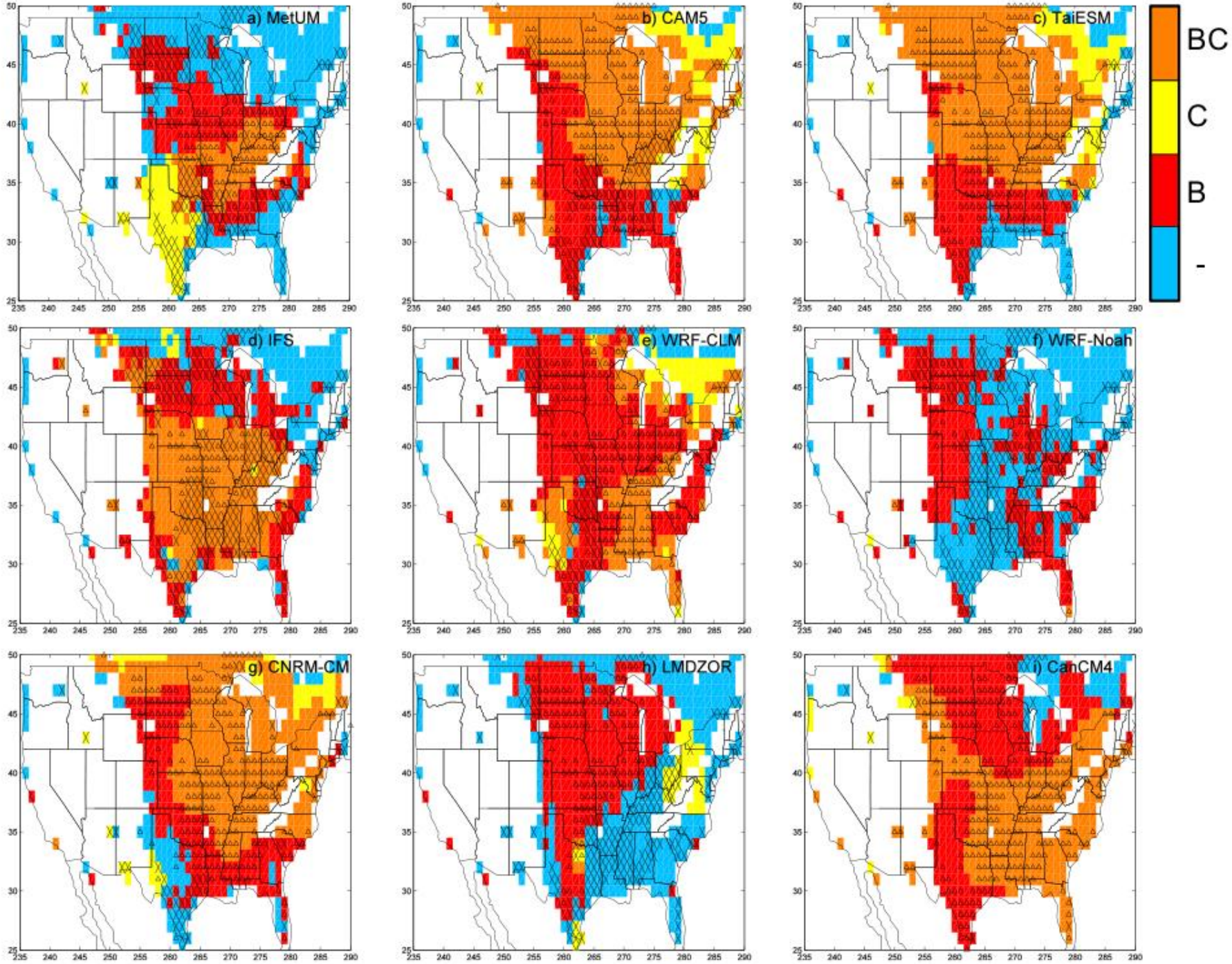
April-Aug mean diurnal cycles at SGP










a) MetUM
b) CAM5
c) TaiESM
d) IFS
e) WRF-CLM
f) WRF-Noah
g) CNRM-CM
h) LMDZOR
i) CanCM4
BC
C
B
-