Diurnal cycles in the NCAR climate model

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Community Climate Model-

developed and maintained by NCAR since 1983

Latest versions:

- Community Climate System Model 4 (**CCSM4**) was released April 1, 2010
- Includes a new atmospheric *component: Community Atmospheric Model* 4 (**CAM4**)

Only two months later:

- Community Earth System Model 1 (**CESM1**) was released June 25, 2010
- Includes a new atmospheric component: Community Atmospheric Model 5 (**CAM5**)

Both **CCSM4** and **CESM1** participate in CMIP5 experiments that are the base for IPCC AR5

www.cesm.ucar.edu

Why study the diurnal cycle in a global climate model?

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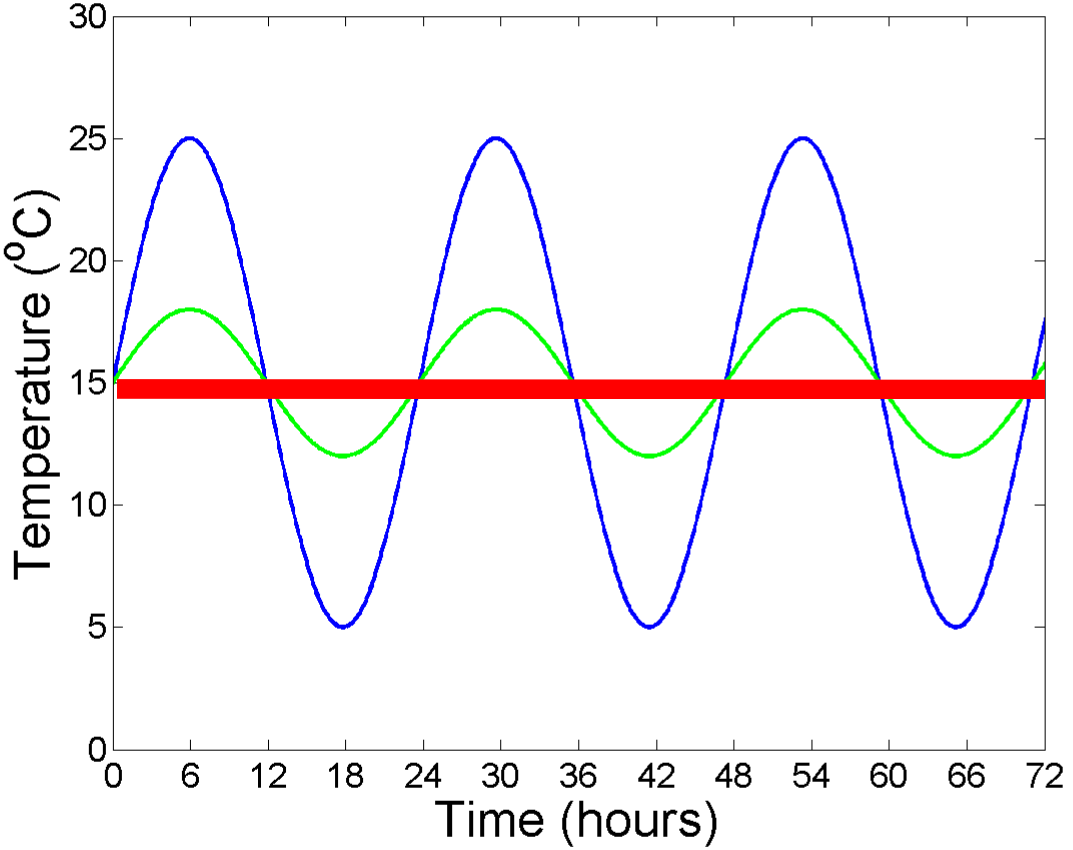
- CAM4 and CAM5 allow us to compare two fundamentally different PBL scheme in the same framework
- Both are coupled to the same land model
- The new modules added to Earth System Models (aerosol, dynamic vegetation etc) are dependent on near-surface variables
- Climate models have not really been evaluated using near-surface observations – except for the monthly mean 2-m temperatures

Importance of diurnal cycle



Monthly mean

Turbulent surface fluxes important part of the global climate

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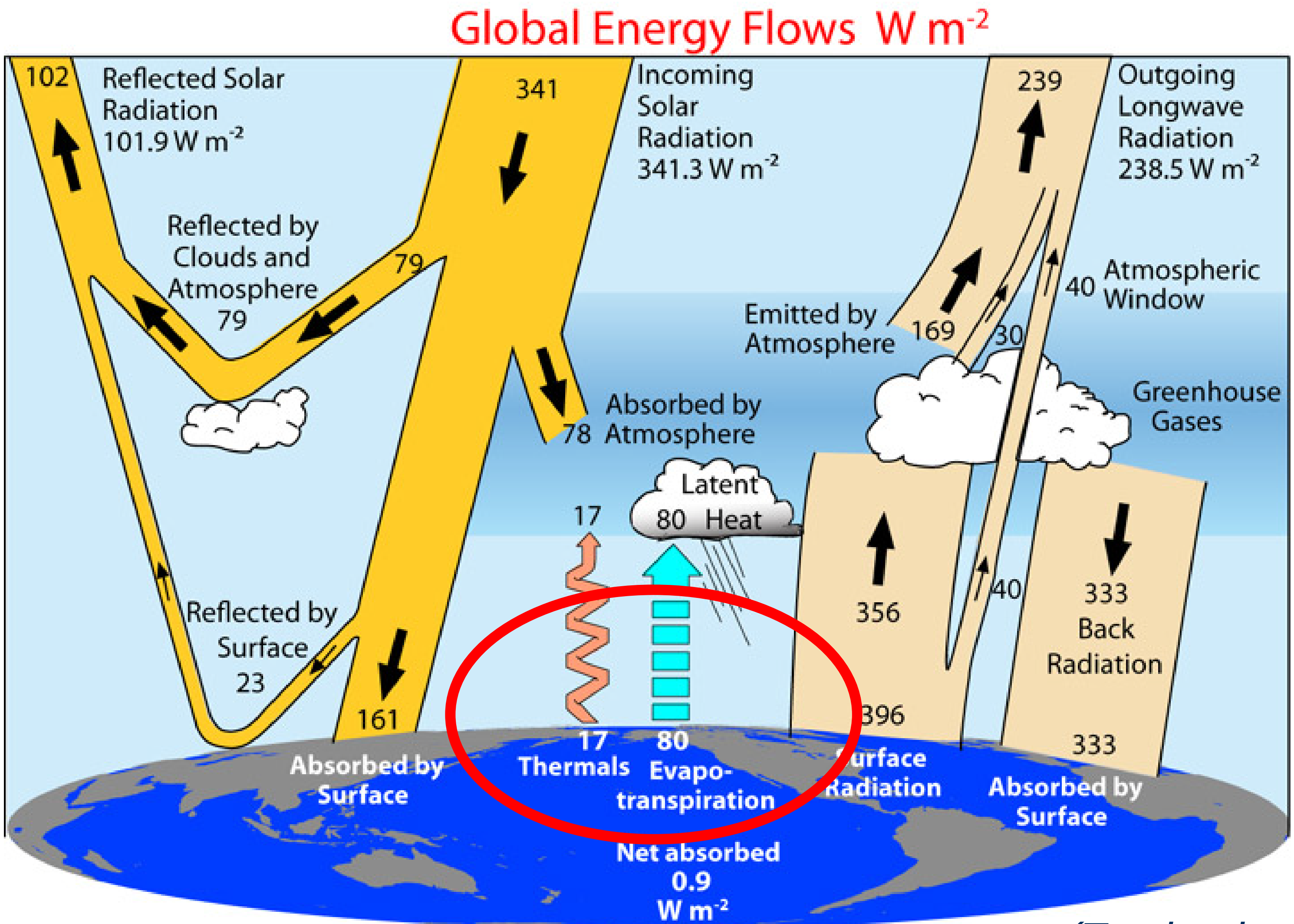

(Trenberth et al. 2009)

Flux towers with eddy correlation measurements used in this study

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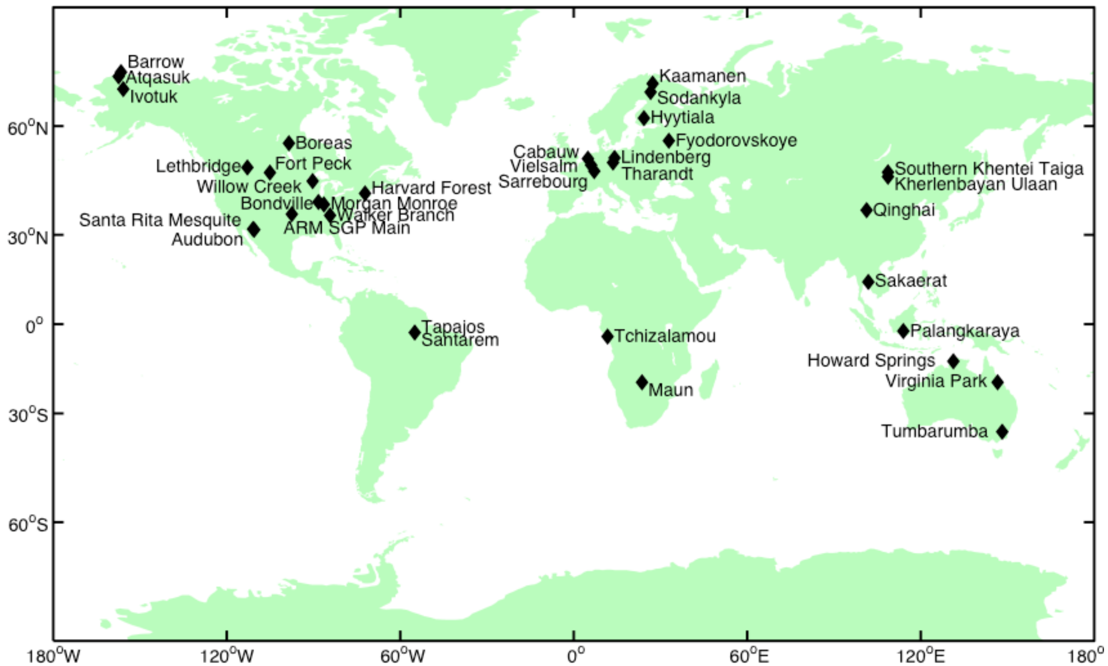
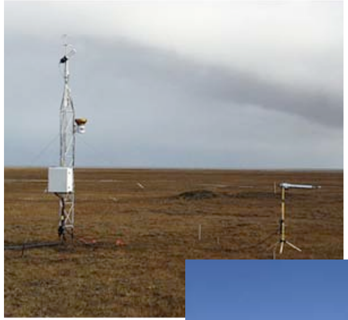
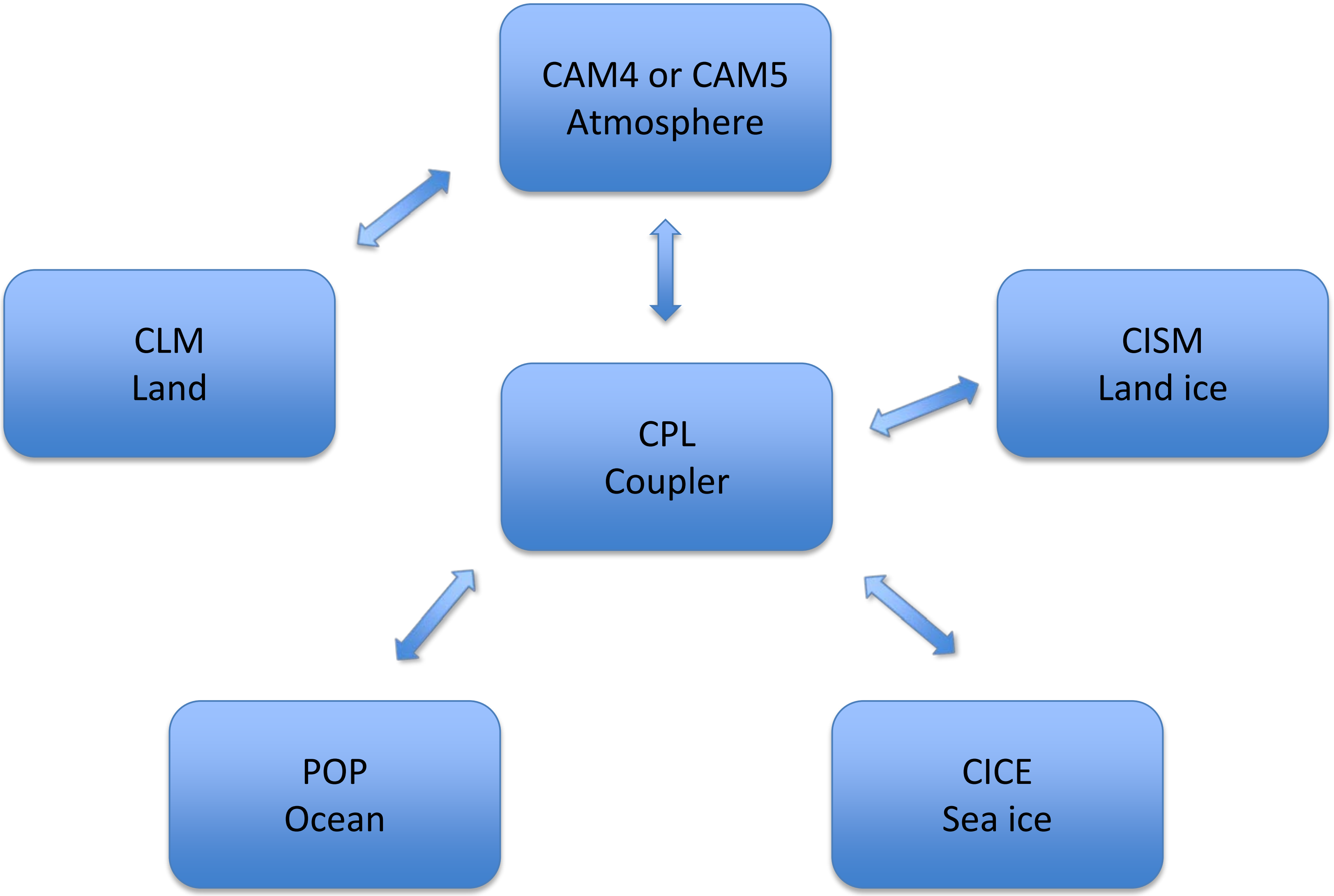




- 2 – 12 years of measurements
- selected to cover different climate zones
- reasonably horizontal homogeneous

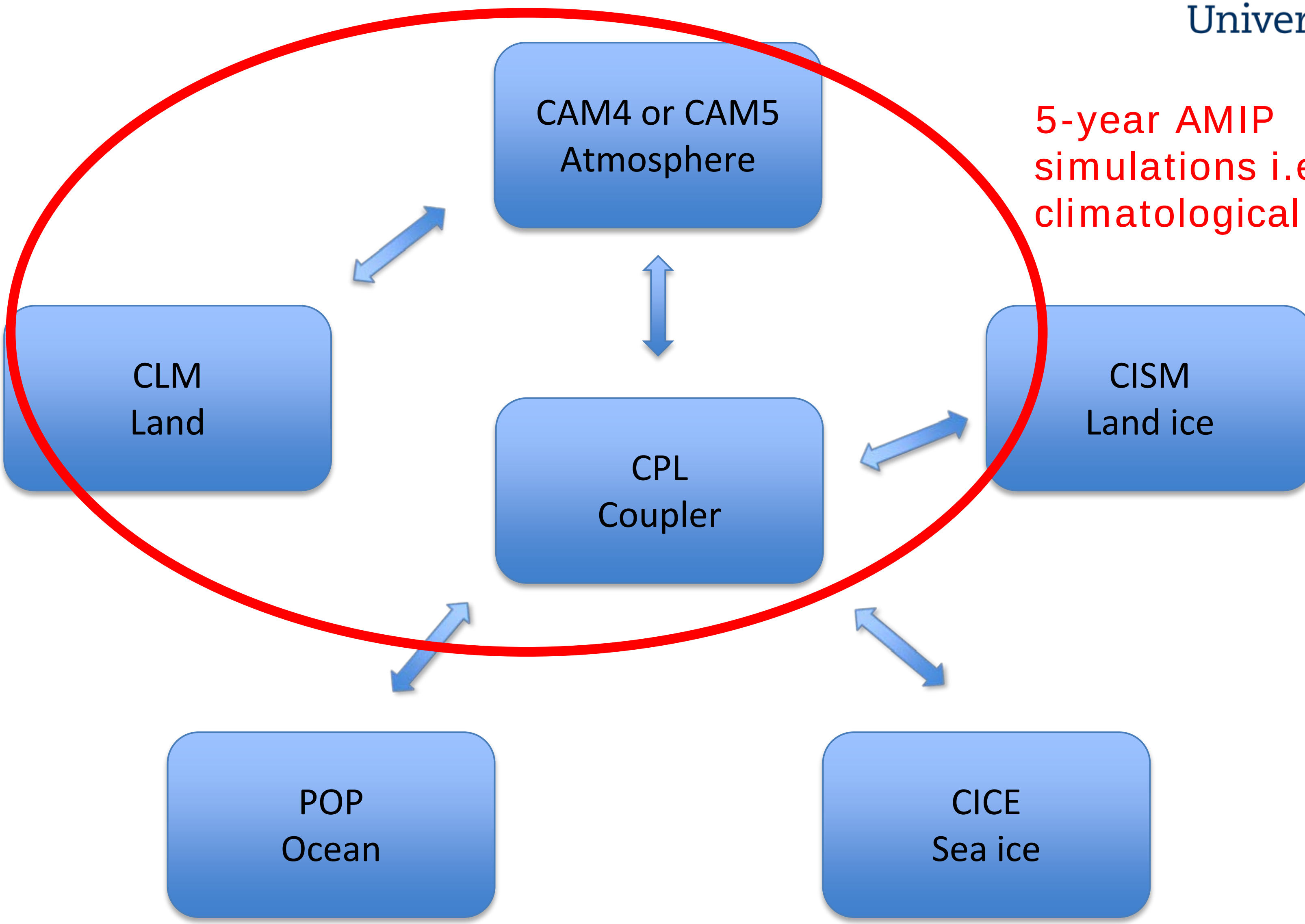
The datasets were provided by Ameriflux, CarboEurope, AsiaFlux, CarboAfrica,Ozflux which are all part of the FLUXNET network, as well as by NCAR/EOL

Community Earth System Model V1



Community Earth System Model V1

5-year AMIP simulations i.e. climatological SST



Community Atmosphere Model

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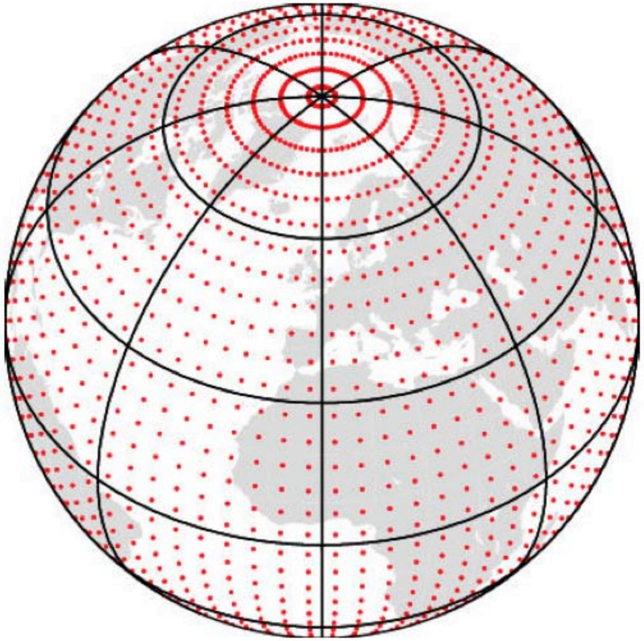
Finite volume grid, 0.9 x 1.25 degree resolution

CAM 4: 26 vertical levels (lowest model level at ~ 60m)
CAM 5: 30 vertical levels (lowest model level at ~ 60m, the 4 extra levels are placed below 2200 m)



Some major updates in CAM5:

- cloud micro- and macrophysics
- radiation
- aerosols
- shallow convection
- turbulence parameterization

CAM4 and CAM5 use the same land model Community Land Model 4 (CLM4), except for the carbon nitrogen cycle model, which is only used in CAM4

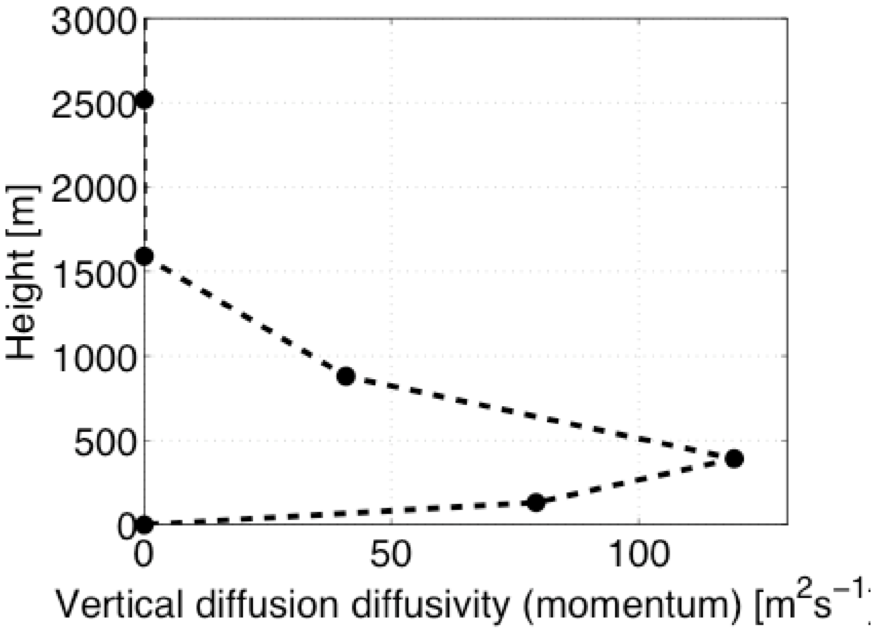
CAM4

First order, non-local, K-profile scheme

The diffusivity K is a function of the boundary layer height calculated using a **dry** bulk Richardson number

Richardson number based free atmosphere turbulence

Always some background turbulence



(Holtslag and Boville,1993)

CAM5

1.5 order, TKE based scheme

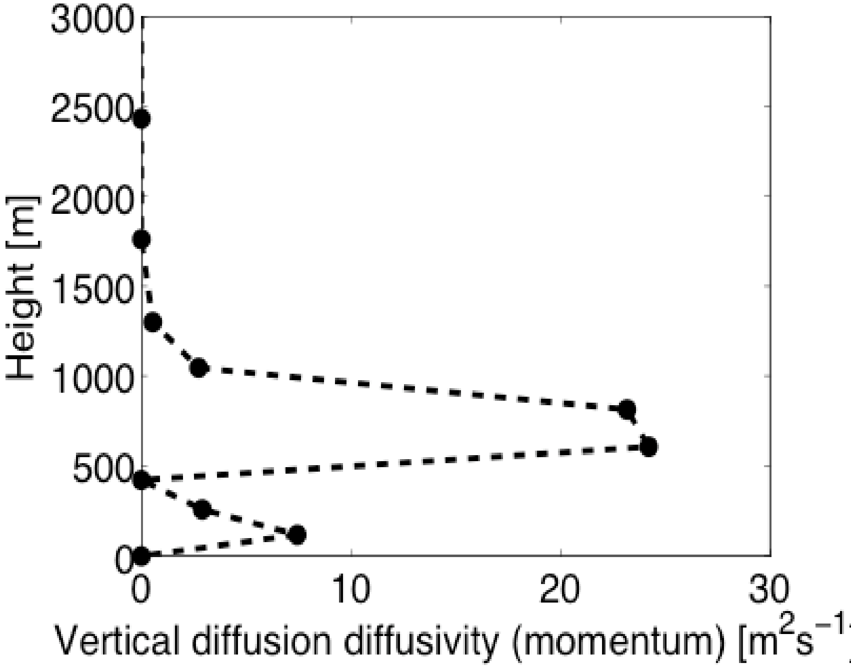
The diffusivity K is a function of the diagnostic turbulent kinetic energy (TKE) in each turbulent layer

Diagnoses turbulent layers using a **moist** Richardson number in each layer

Allows several turbulent layers

Turbulence completely shut off when Ri > 0.19

No background turbulence



(Bretherton and Park, 2009)

The climate in CESM1 (CAM5)
2m temperature

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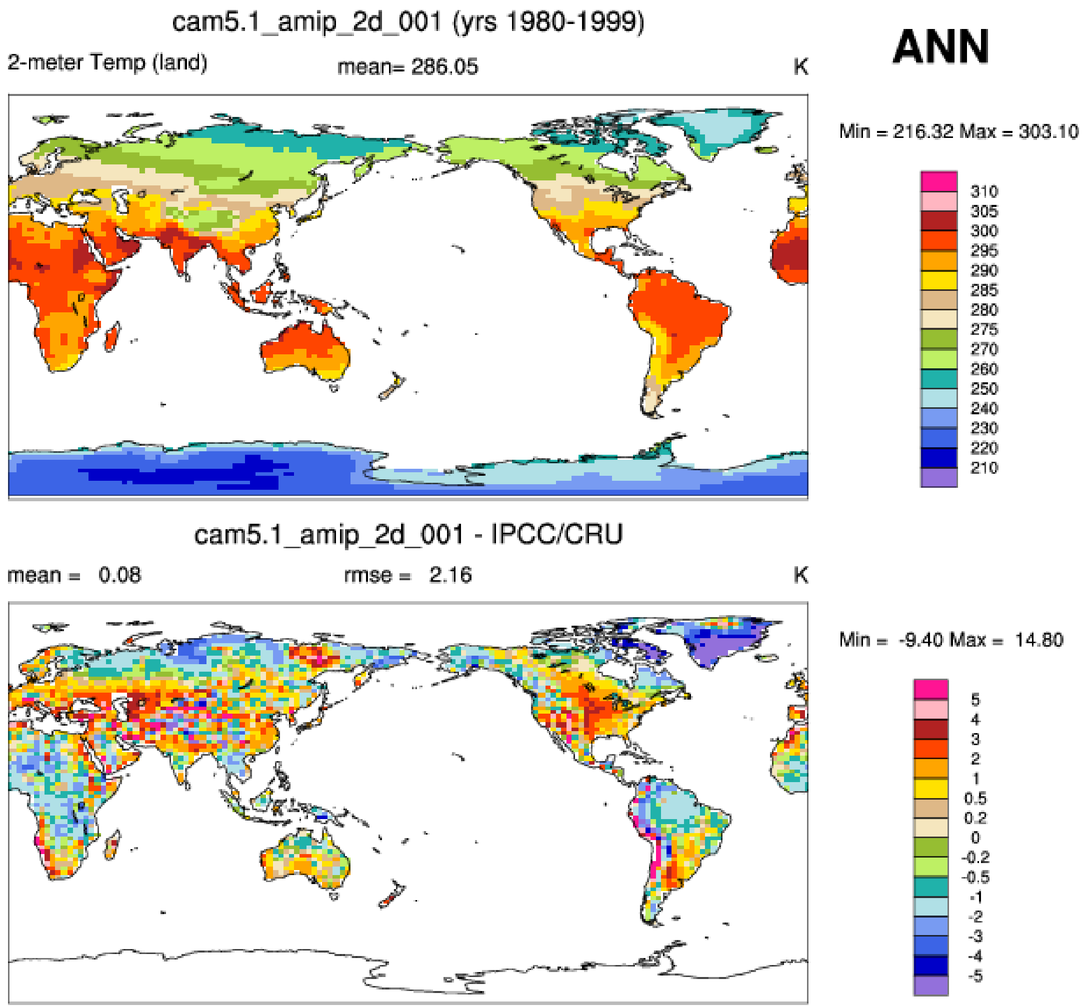
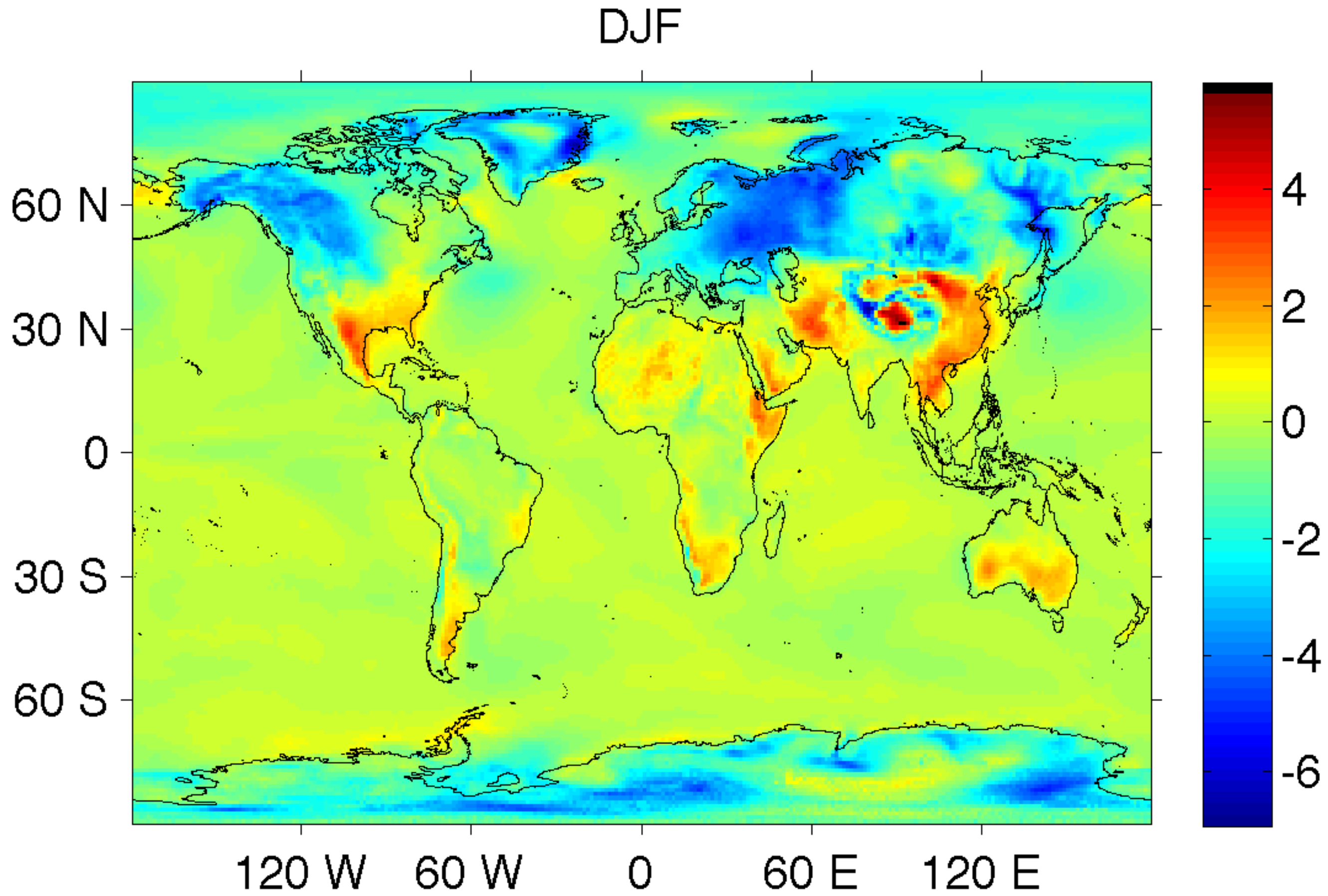
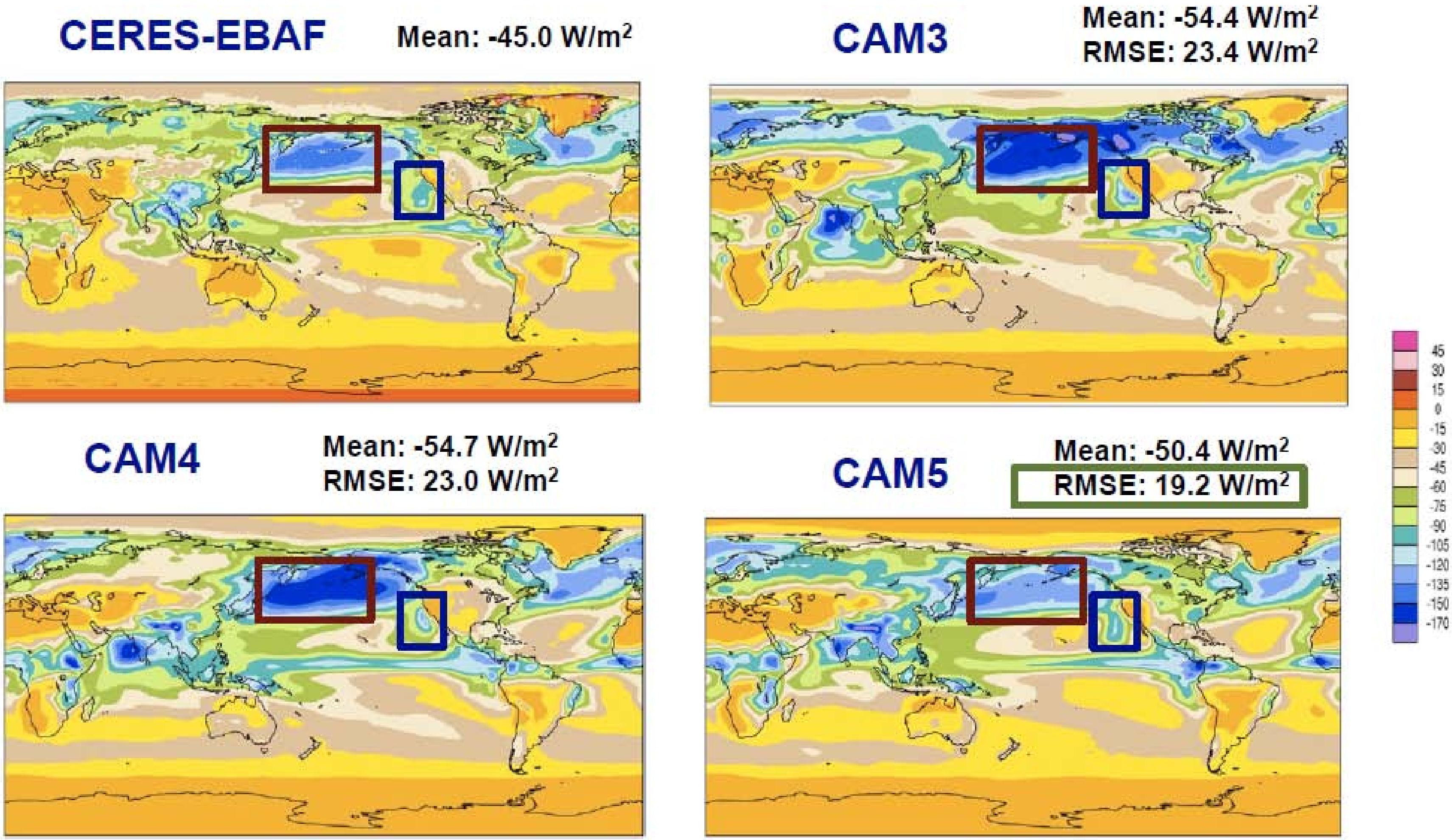


T_{2m} CAM5-CAM4
winter



The climate in CESM1

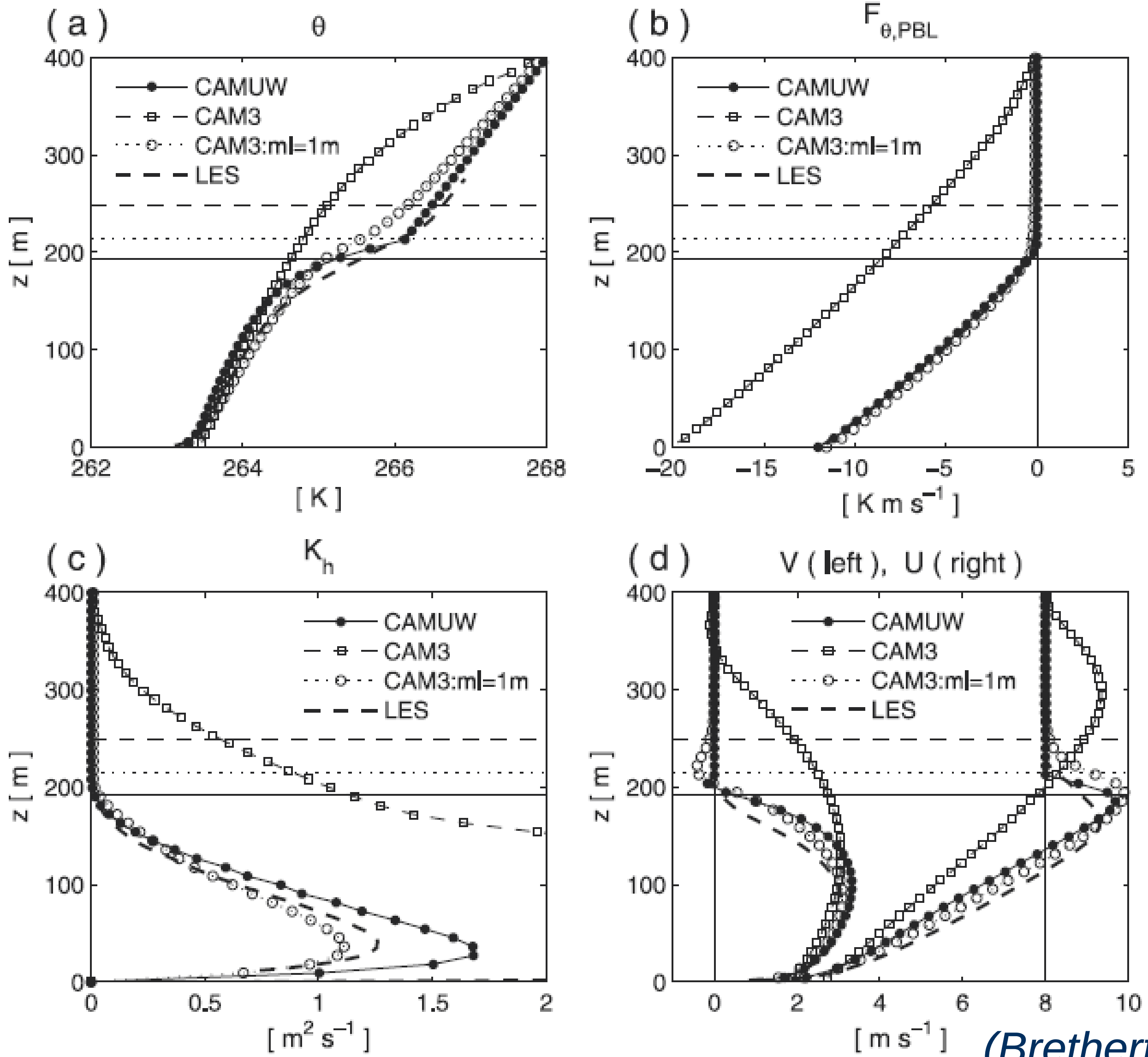
Short wave cloud forcing



- Excessive SWCF in North Pacific (in CAM3 and CAM4) is reduced in CAM5.
- CAM5 improves stratocumulus and trade cumulus
- CAM5 reduces RSME error (true even if compared to ERBE)

(thanks to C Bretherton and C Hannay)

CAM4 and CAM5 GABLS1 case

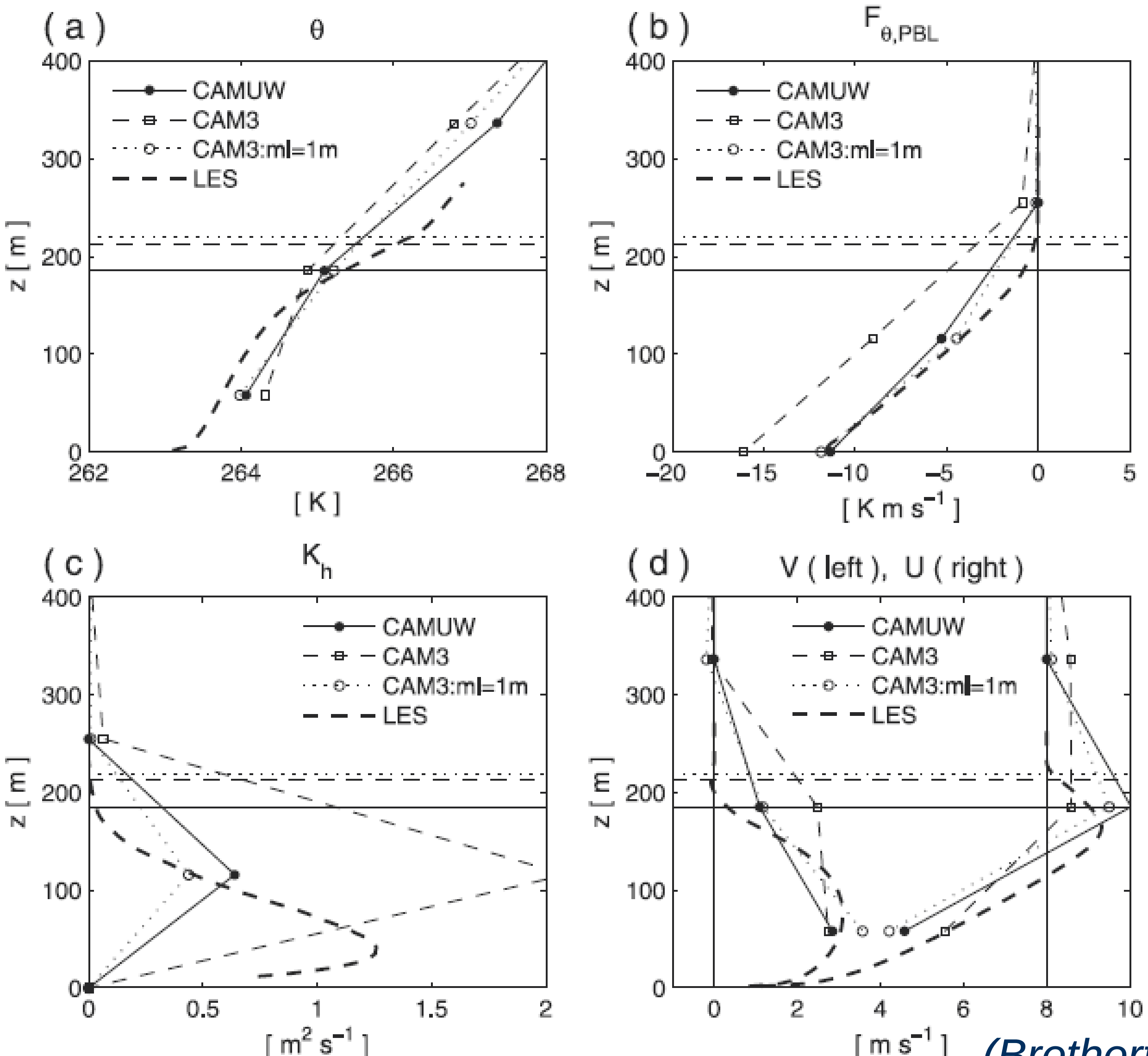


CAM3 = CAM4
CAMUW = CAM5

Note: high vertical resolution and short time step

(Bretherton and Park, 2009)

CAM4 and CAM5 GABLS1 case

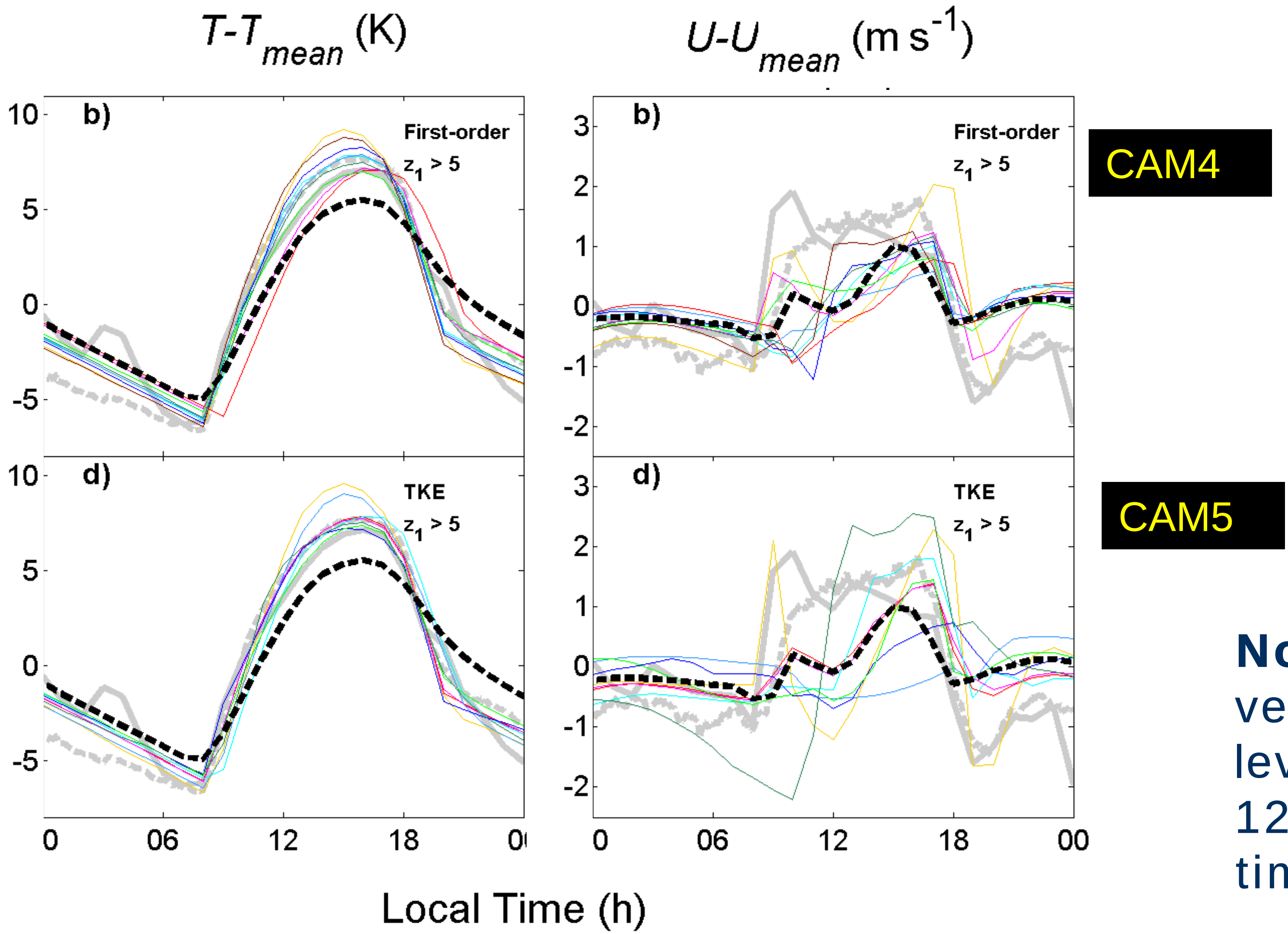


CAM3 = CAM4
CAMUW = CAM5

Note: 30 vertical levels and 1200s time step

(Bretherton and Park, 2009)

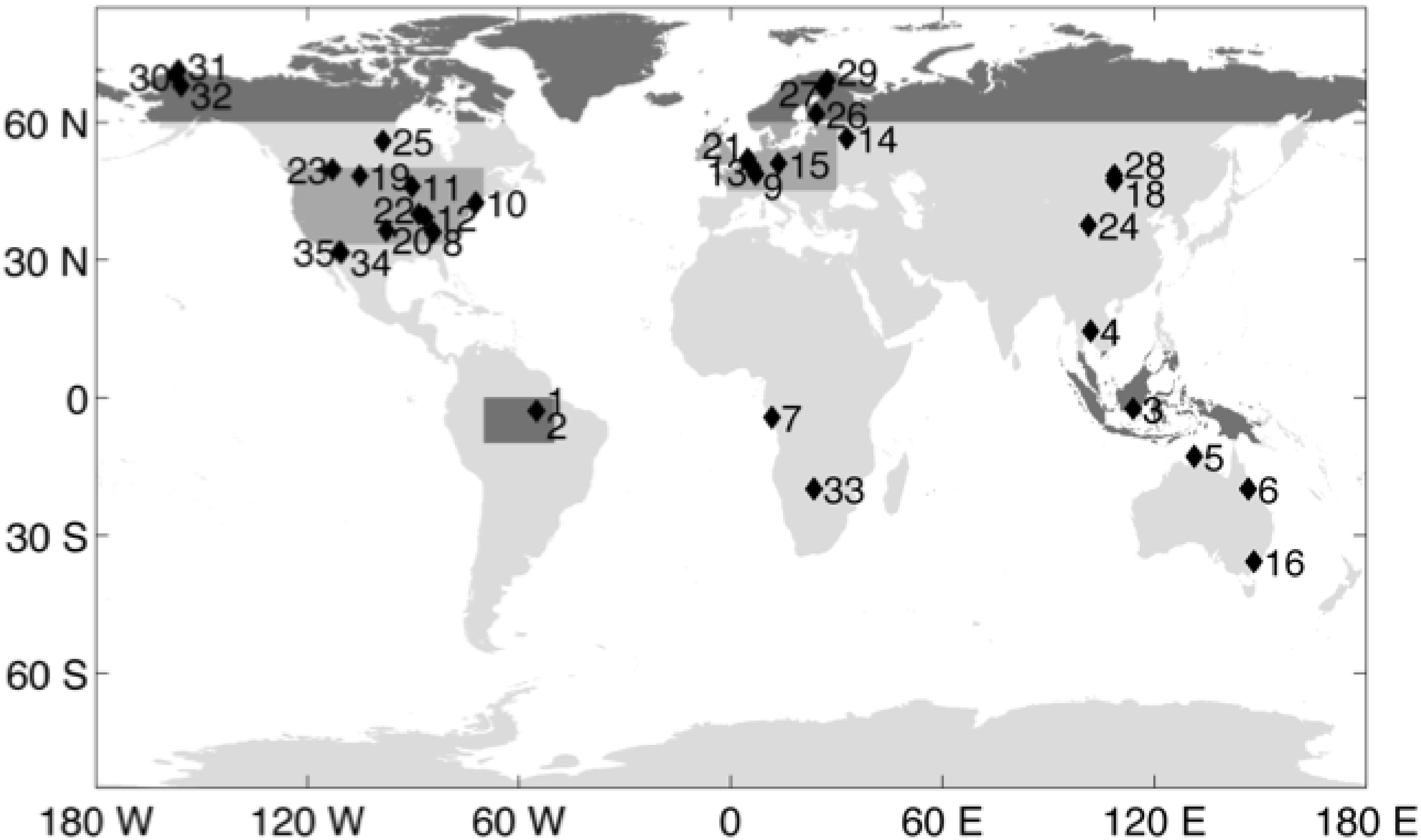
CAM4 and CAM5 GABLS2 case



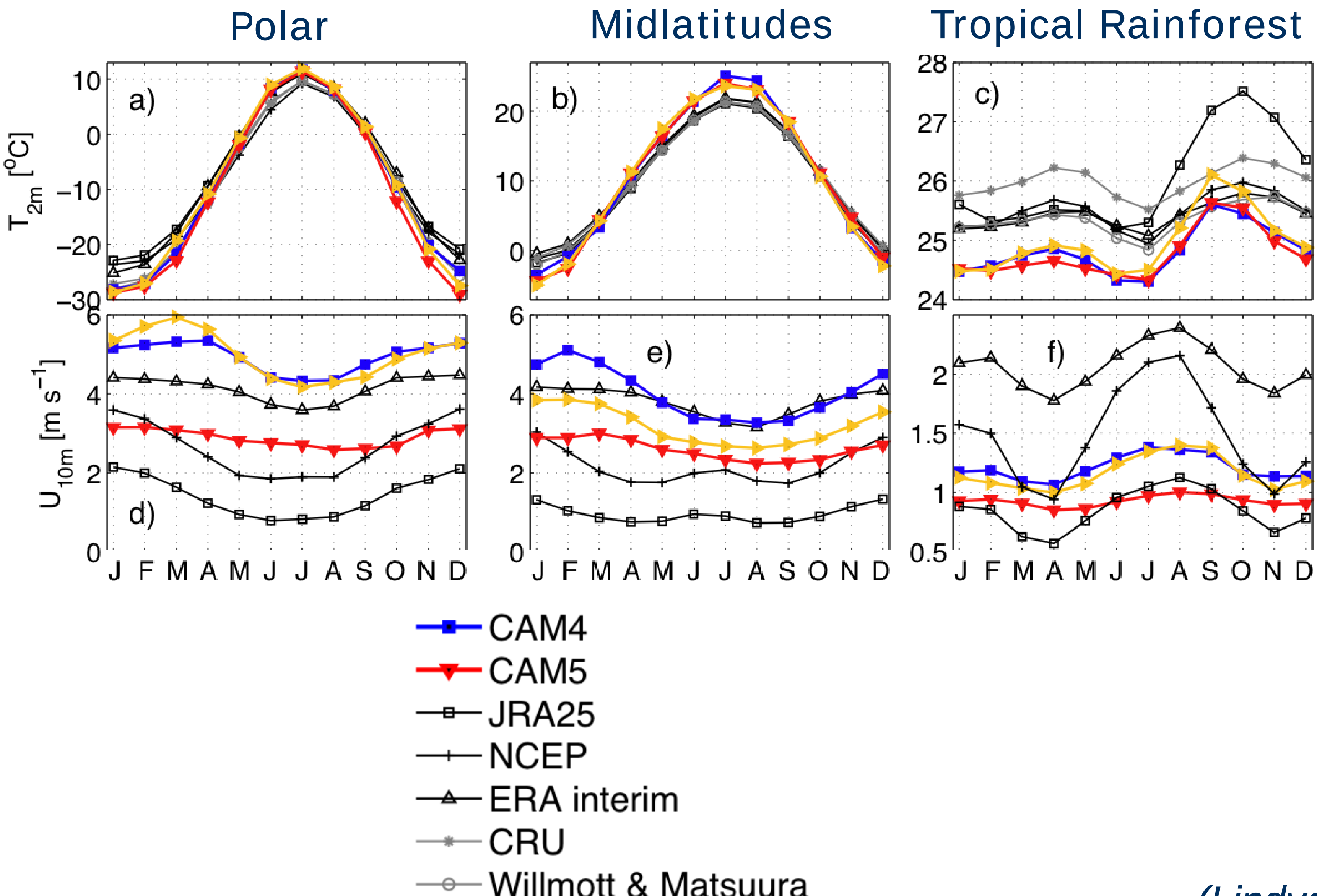
Note: 30 vertical levels and 1200s time step

(Svensson et al., 2011)

Three climate areas



Annual cycle



T_{2m} (°C)

U (m s^{-1})

(Lindvall et al., 2011)

Annual cycle

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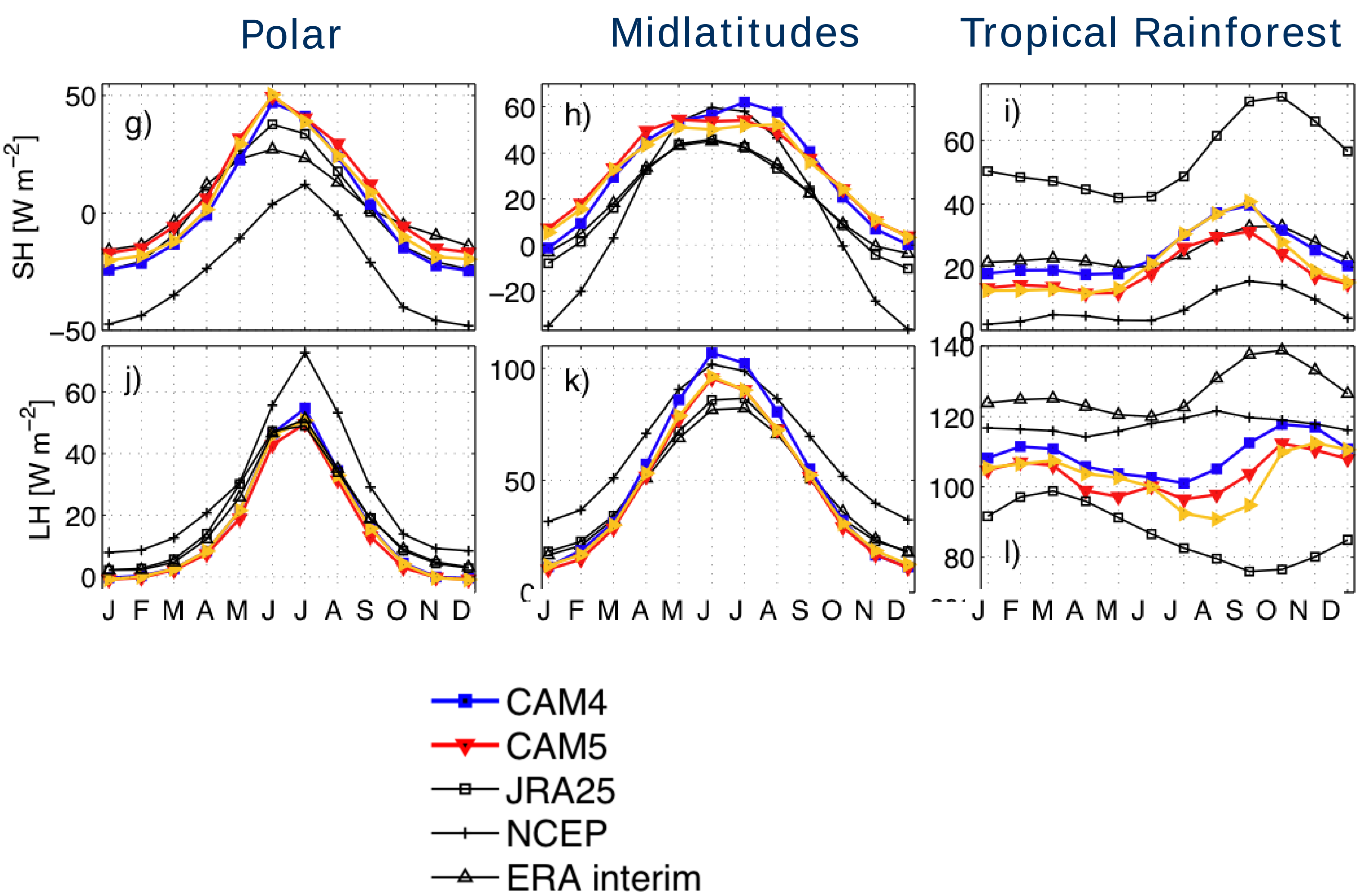


SH (W m^{-2})

SH (W m^{-2})

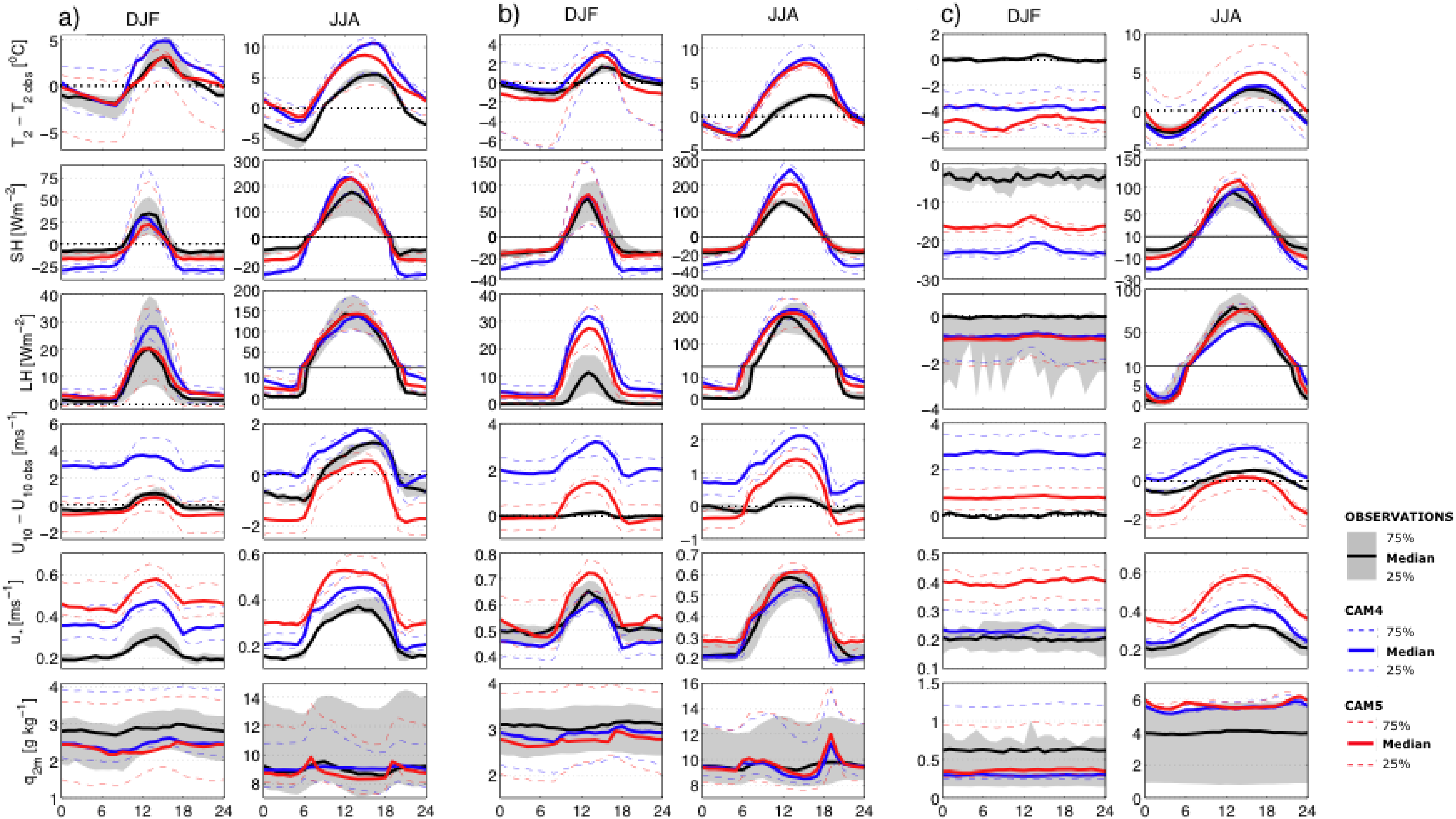
(Lindvall et al., 2011)

Diurnal cycle

Midlatitudes unforested

Midlatitudes forested

Arctic tundra and wetland sites



(Lindvall et al., 2011)

Diurnal cycle

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Midlatitudes forested

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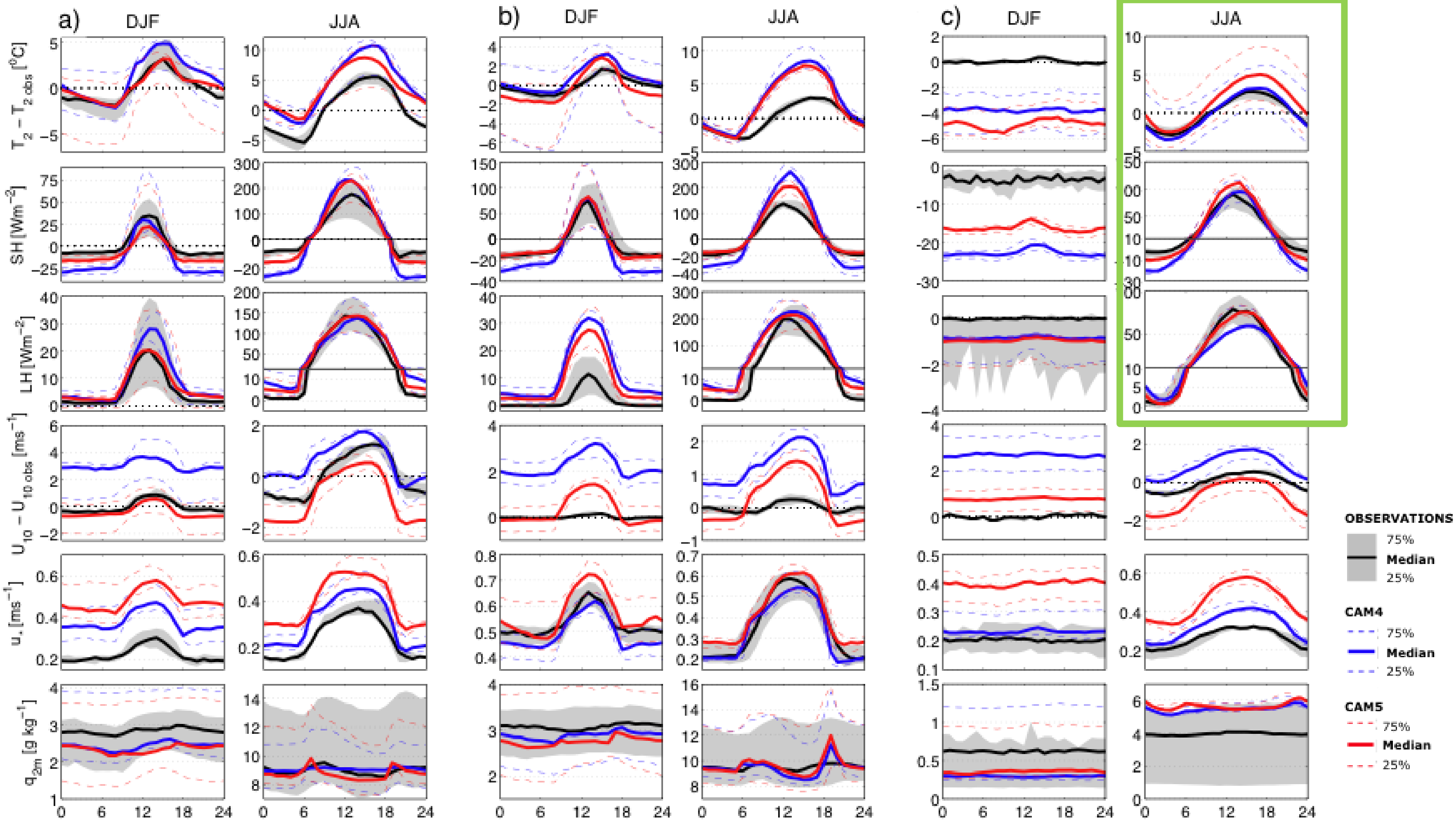


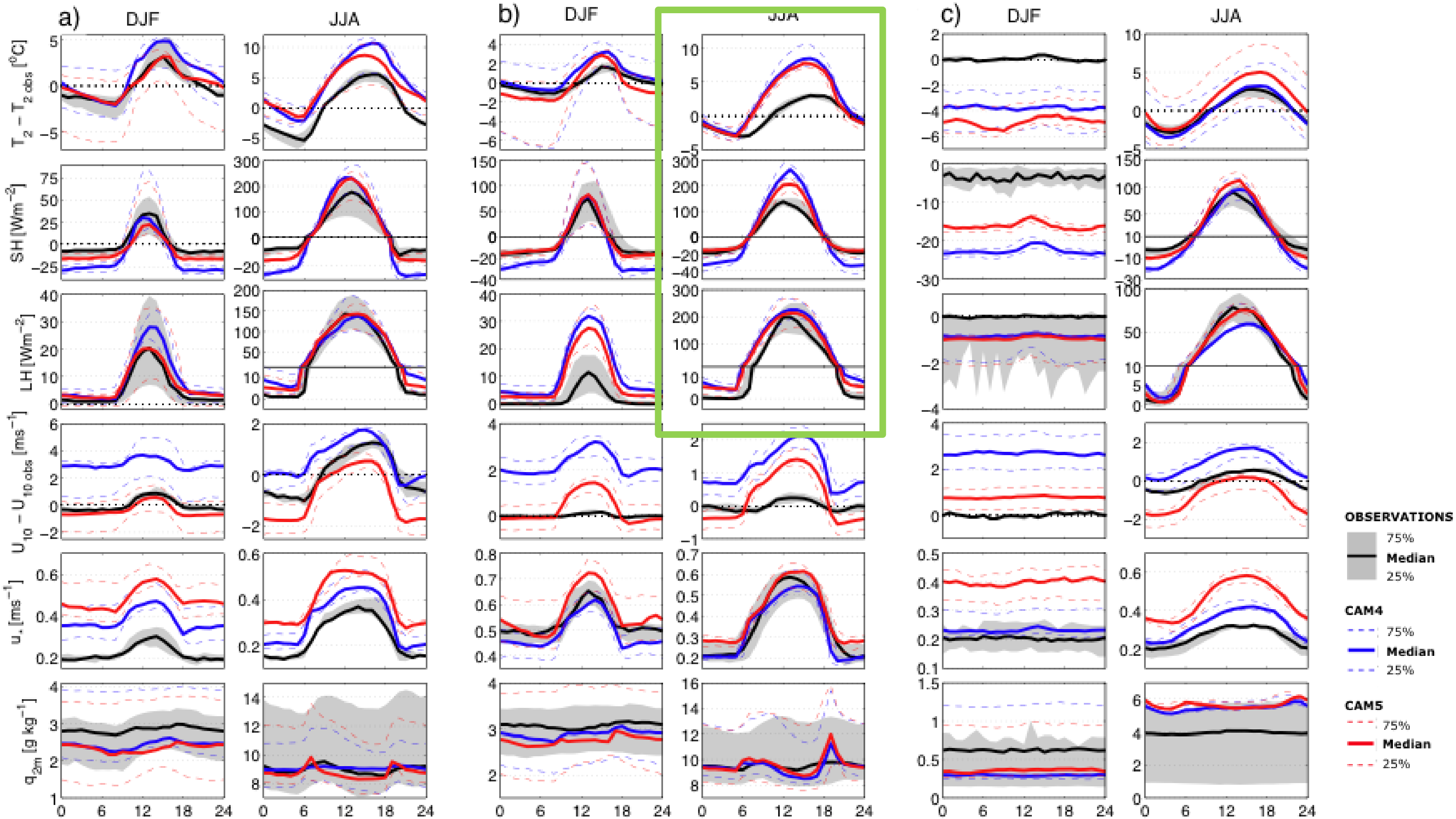
(Lindvall et al., 2011)

Diurnal cycle

Midlatitudes unforested

Midlatitudes forested

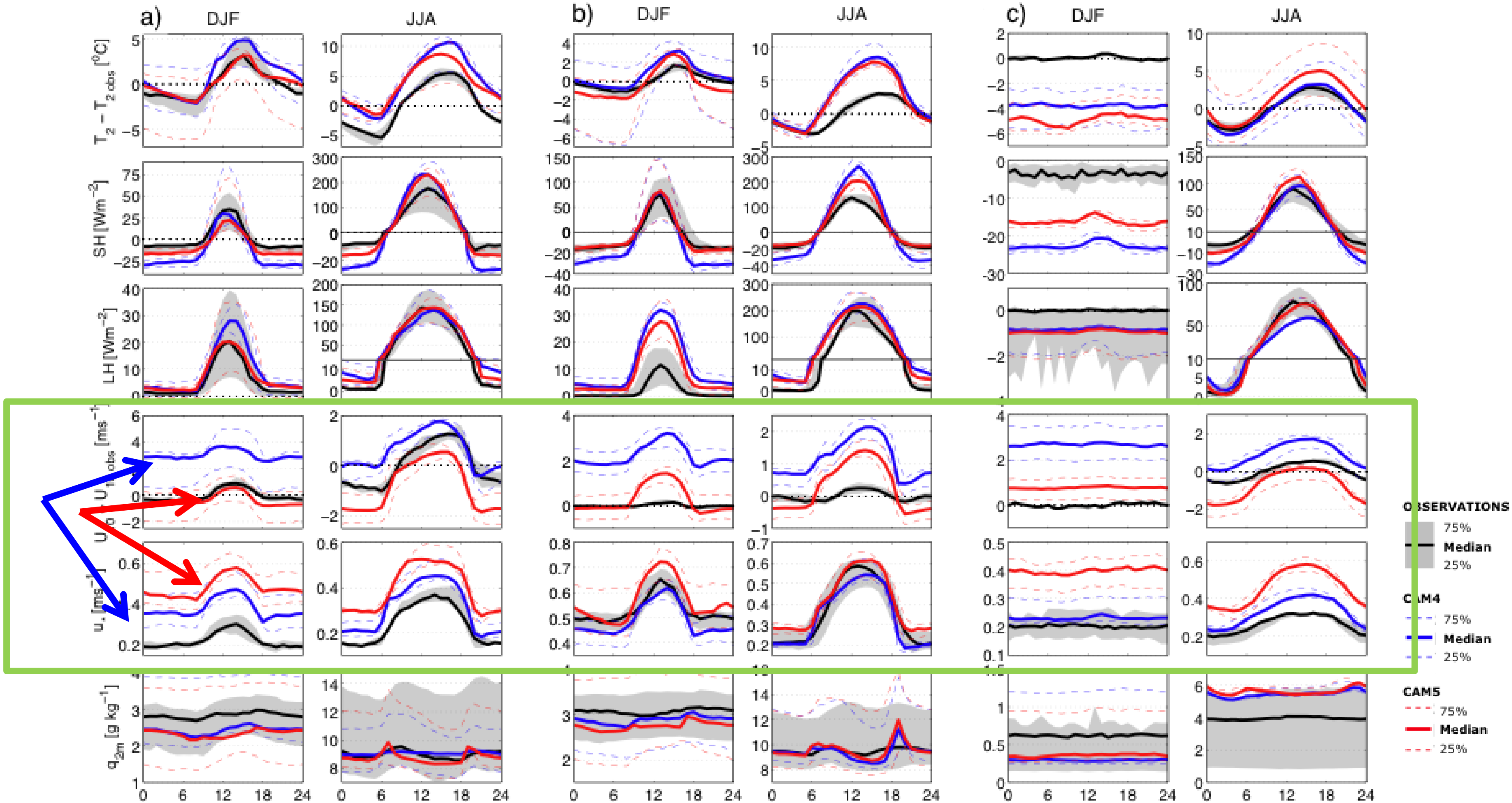
Arctic tundra and wetland sites



(Lindvall et al., 2011)

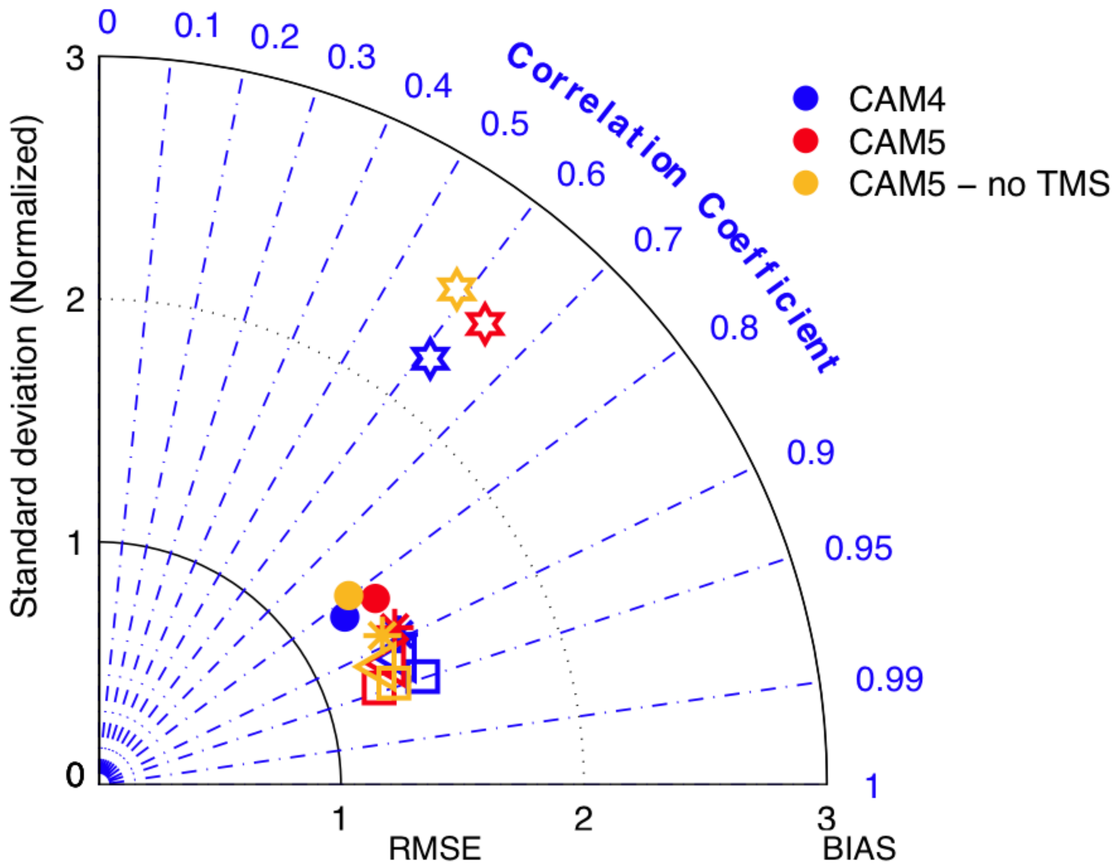
Diurnal cycle

Midlatitudes unforested | Midlatitudes forested | Arctic tundra and wetland sites



(Lindvall et al., 2011)

Observed and simulated median monthly diurnal cycles

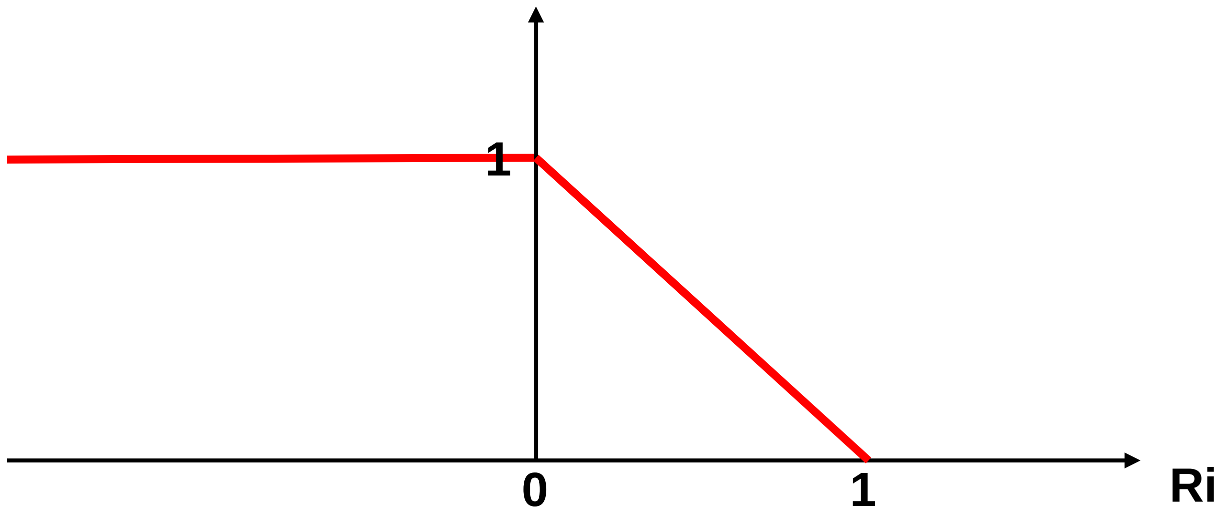


	RMSE CAM4	RMSE CAM5	RMSE CAM5noTMS	BIAS CAM4	BIAS CAM5	BIAS CAM5noTMS
✳ T_{2m} [K]	2.9	3.4	4.2	0.21	0.11	0.12
□ SH [W m^{-2}]	22.6	21	21.6	0.67	0.74	–0.78
◁ LH [W m^{-2}]	22.2	17.1	19.1	13.6	9.5	10.3
✡ U_{10m} [m s^{-1}]	2.2	0.95	2.2	1.3	–0.26	1.2
● u_* [m s^{-1}]	0.12	0.17	0.12	0.019	0.097	0.017

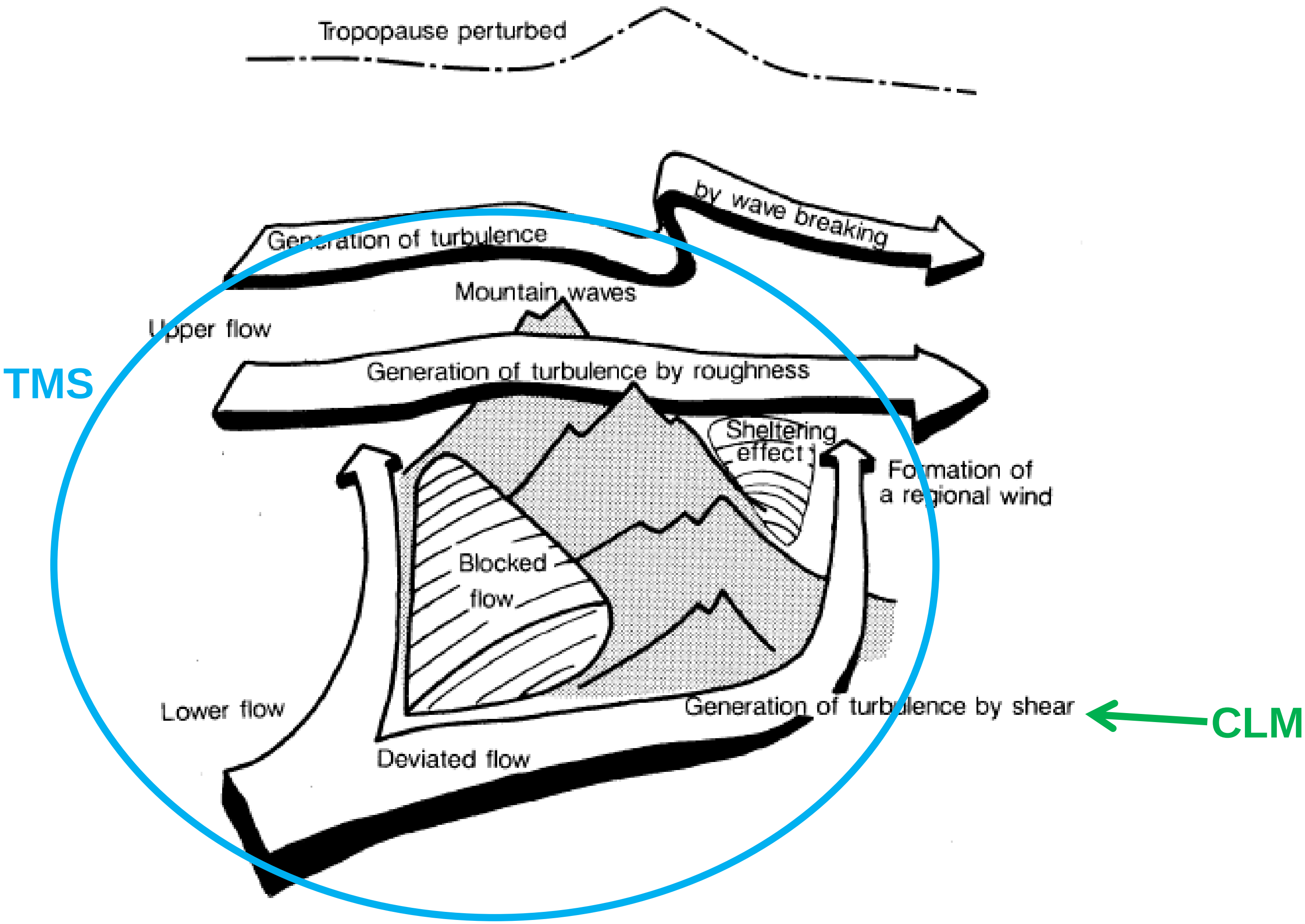
(Lindvall et al., 2011)

Turbulent Mountain Stress (TMS)

- Added to improve the general circulation
- Enhancement of the surface drag due to subgrid-scale terrain, basically increases surface rougness to z_{0_oro}
- Applied when Ri < 1 based on function below



Subgrid scale orographic drag



CLM and CAM interactions

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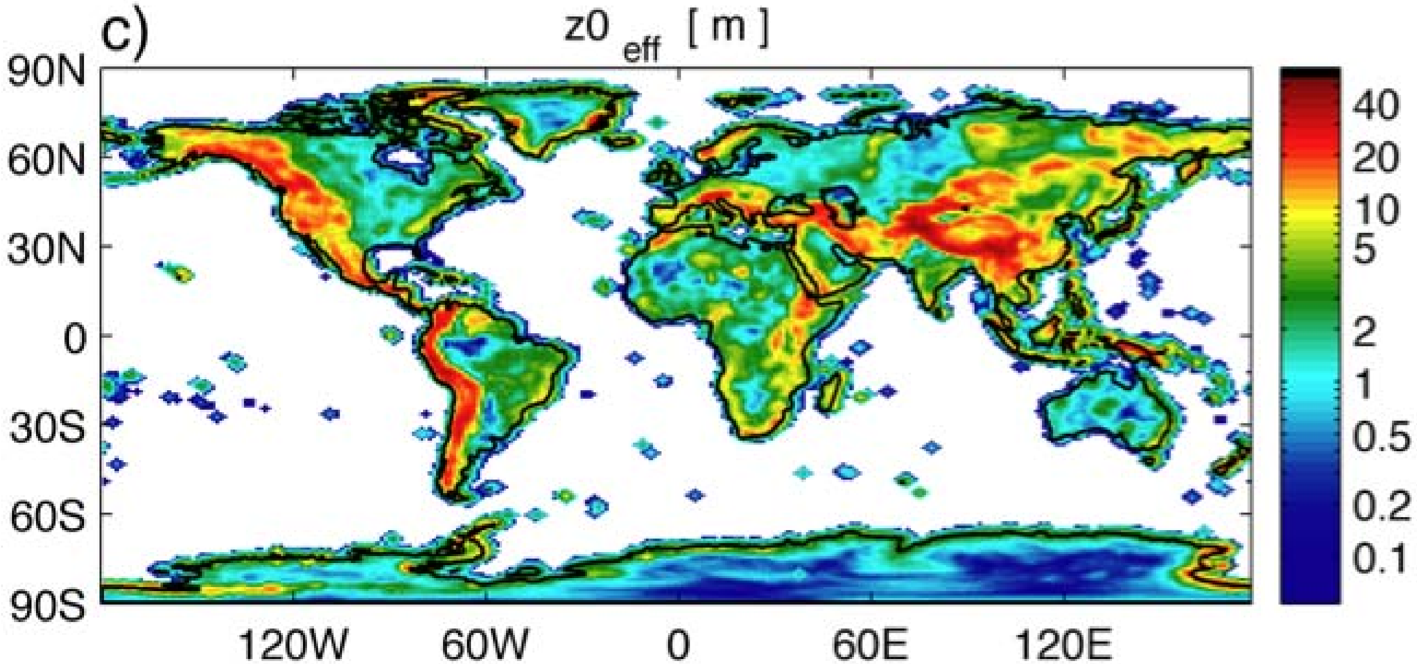
CAM4

- CLM calculates turbulence fluxes at the surface
- Used as boundary conditions for the PBL scheme
- Same stability functions in CLM as in PBL scheme

CAM5

- CLM calculates turbulence fluxes at the surface
- TMS adds surface stress in CAM, thus a larger surface stress is used as boundary condition
- This extra drag reduces the wind speed in lowest layer
- Not the same stability functions in CLM, PBL and TMS

Calculated z_{0_oro}

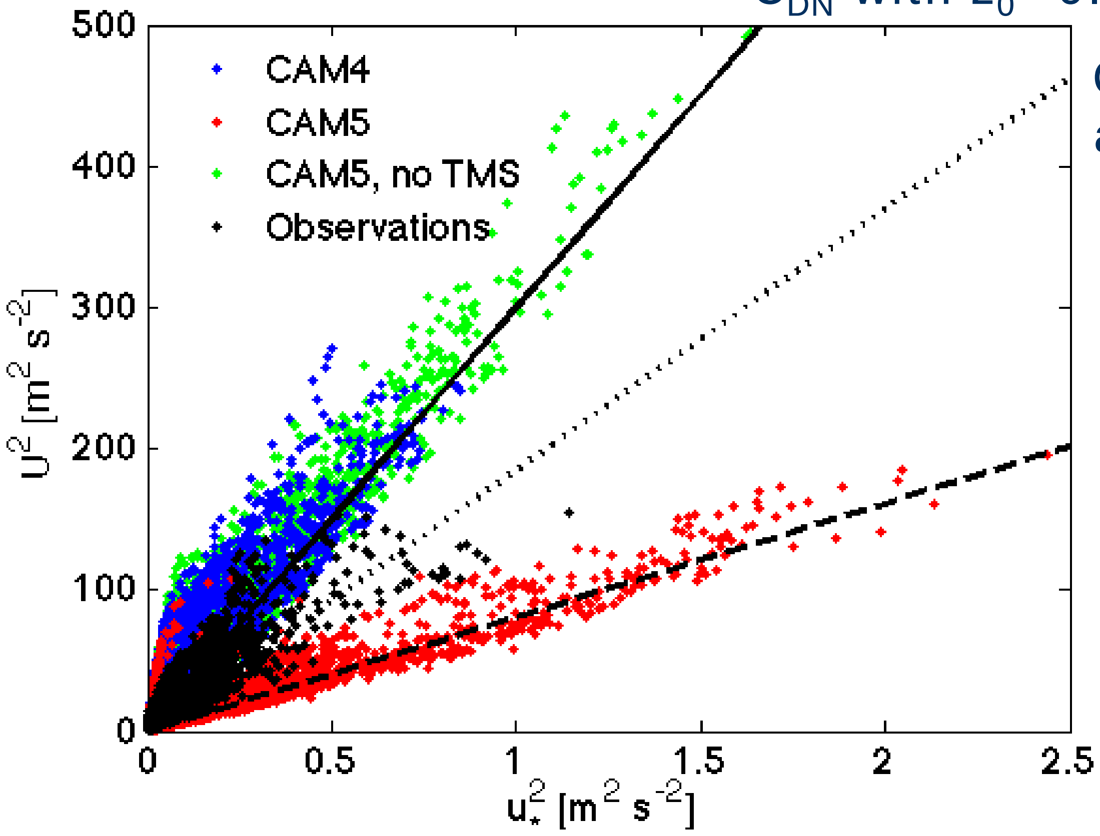


At SGP:

z_{0_oro} = 1.7m

z_0 = 0.06 m

Neutral drag coefficient for SGP



C_{DN} with z_0=0.06 m

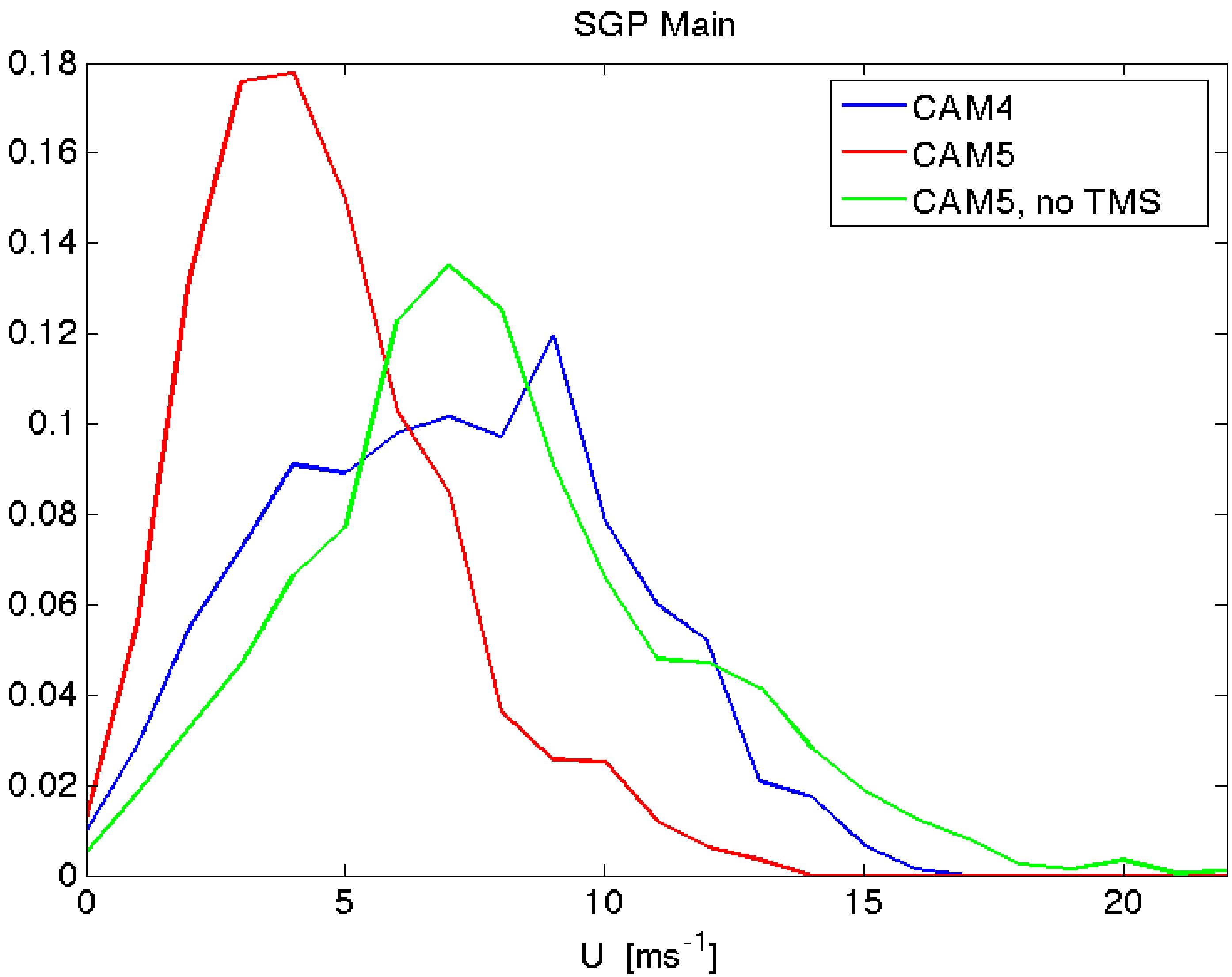
C_{DN} with z_0=0.06 m and ref height for obs

C_{DN} with z_0=1.7 m

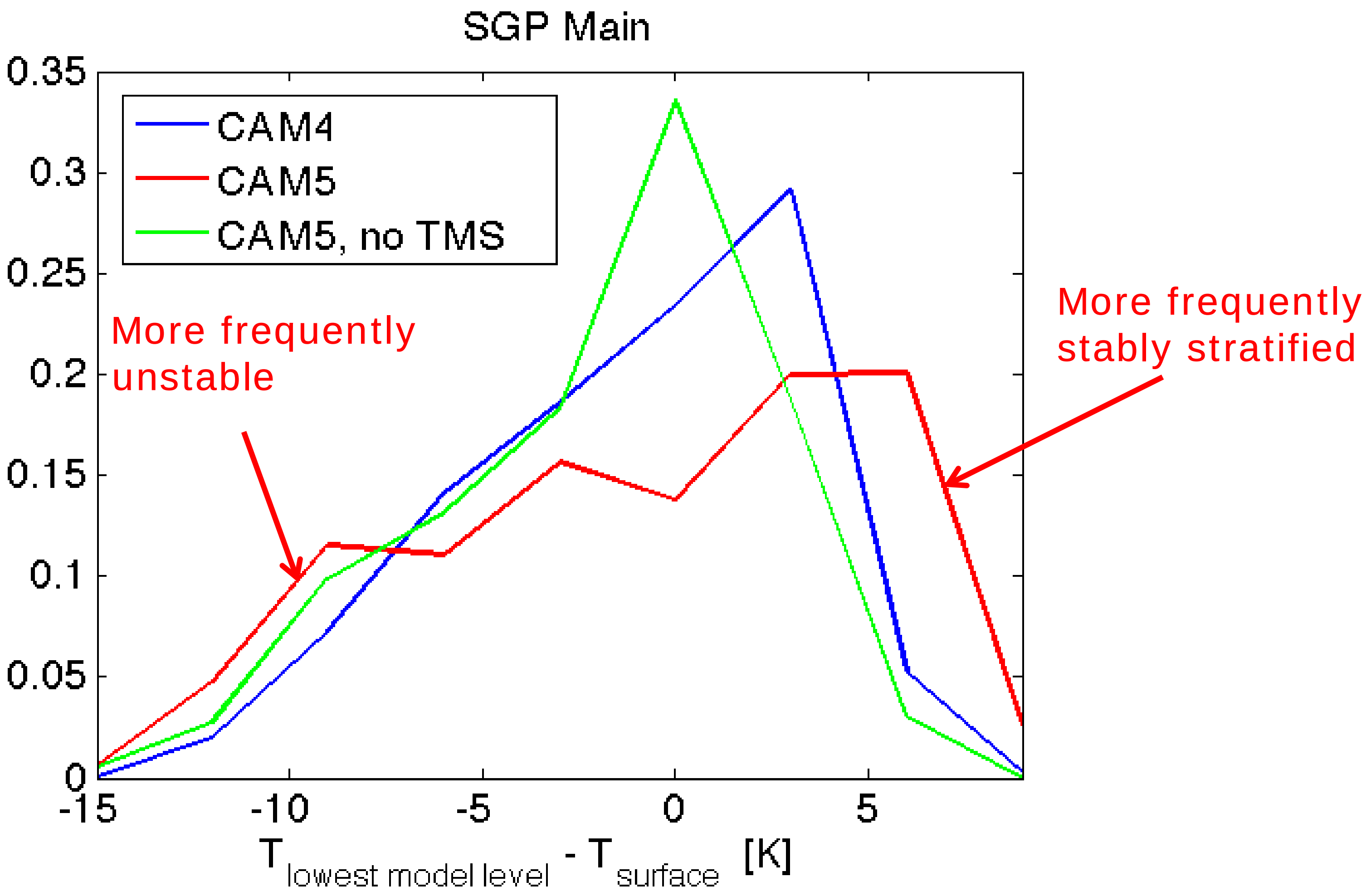
$$u_*^{\,2} = C_{DN} U_{ref}^{\,2}$$

$$U_{ref} = \frac{u_*}{k} \ln\left(\frac{z_{ref}}{z_0} \right)$$

Wind speed is reduced…



Temperature gradients increase



Surface heat fluxes almost the same

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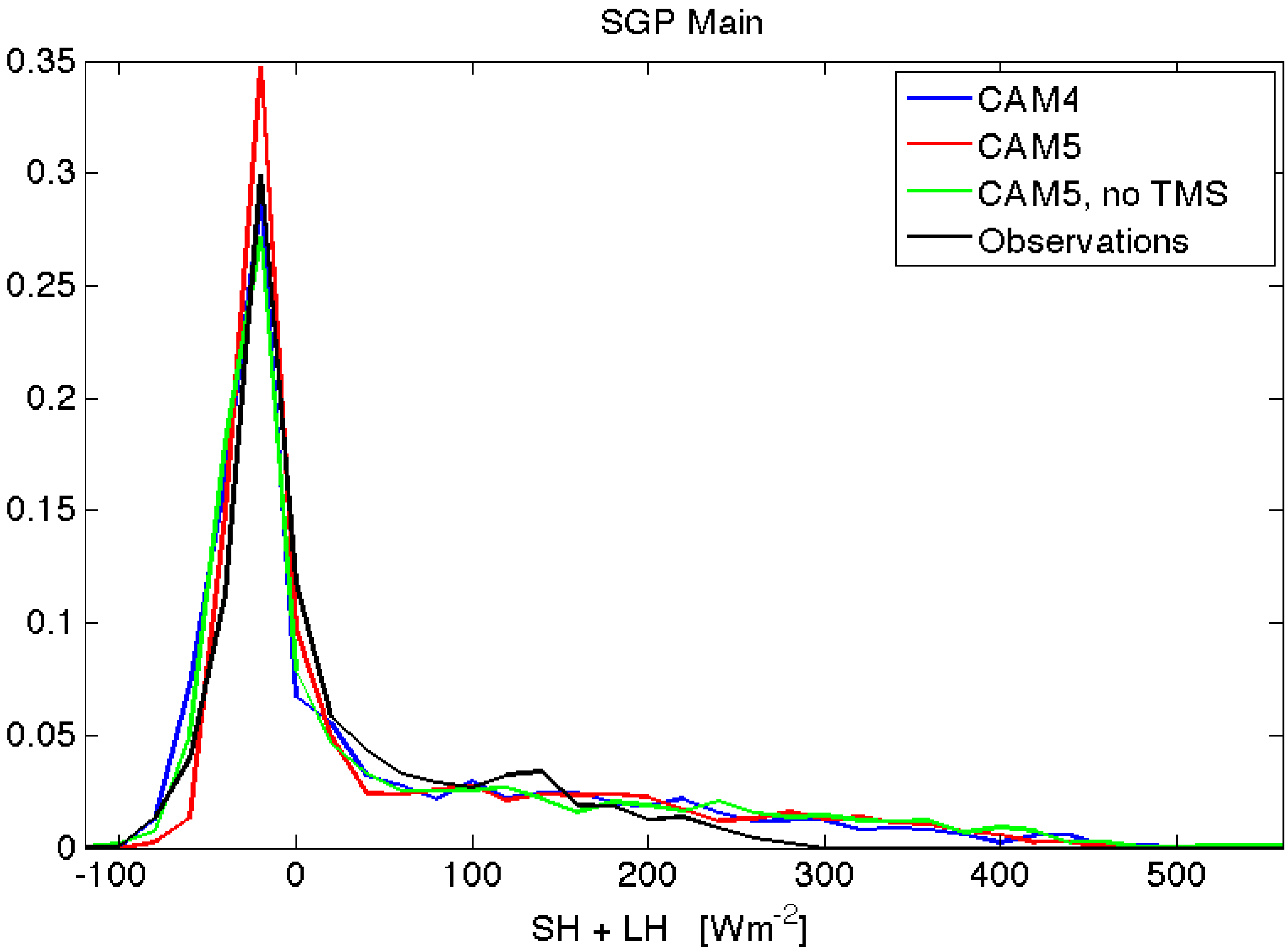
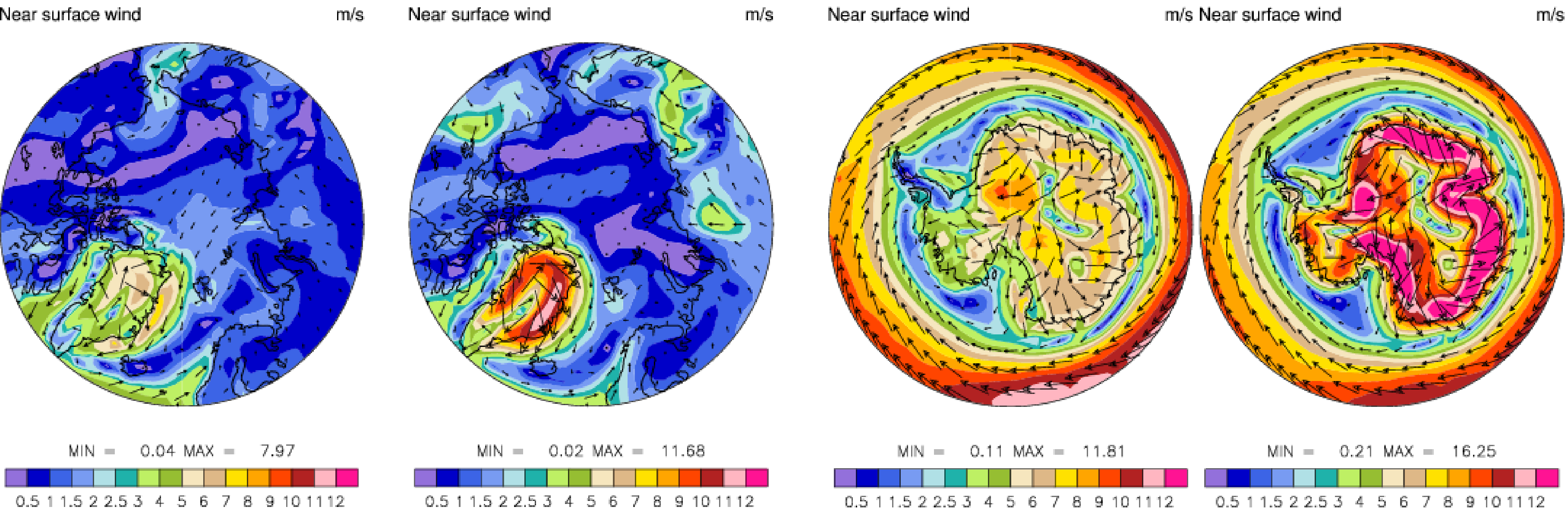
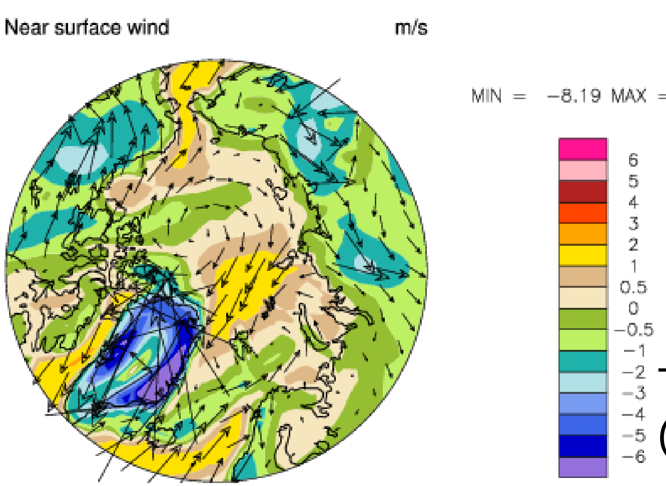


Effect of turbulent mountain drag

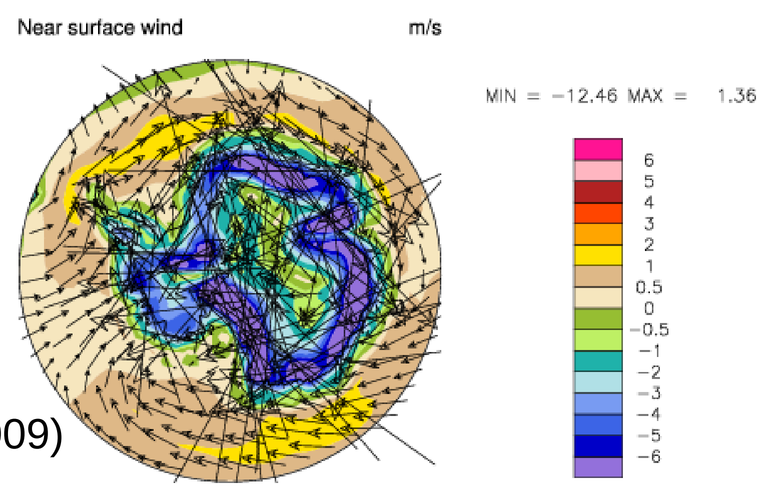
TMS | No TMS | TMS | No TMS



camdev23_cam3_6_28_u117_tms - camdev23_cam3_6_28_u117



camdev23_cam3_6_28_u117_tms - camdev23_cam3_6_28_u117



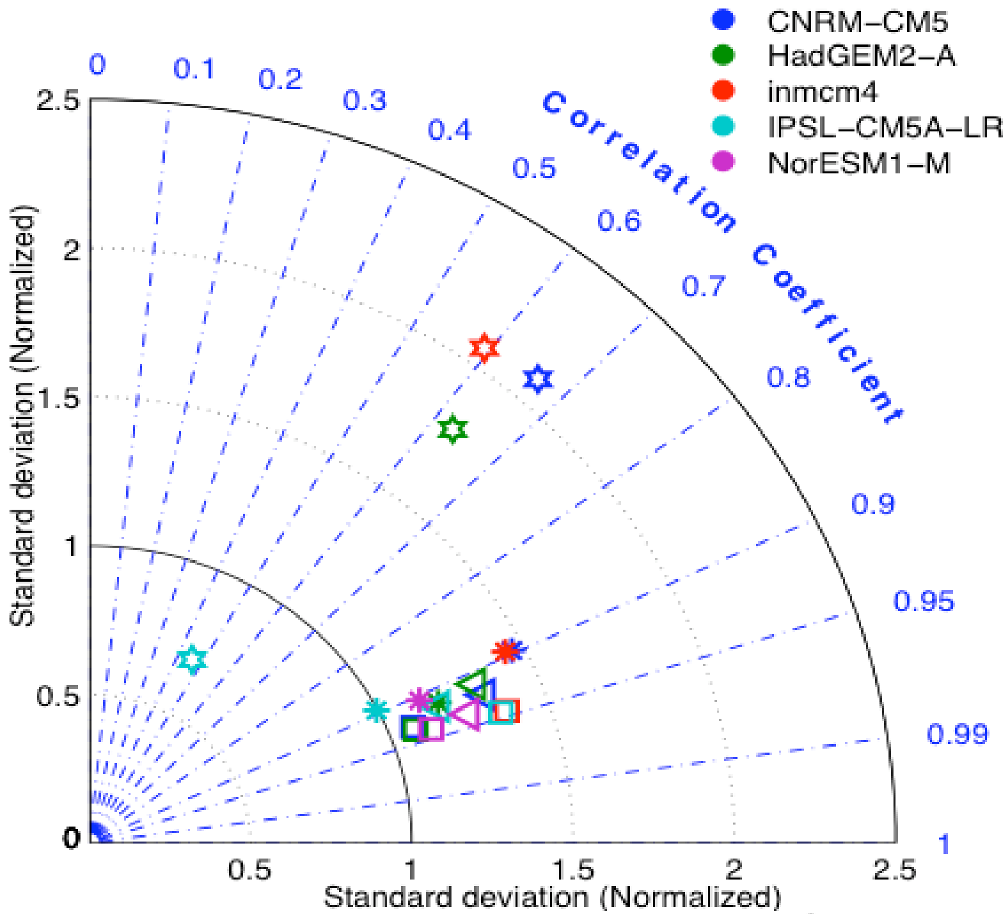
Track 5, CAM (December 2009)

Summary

Evaluation of the diurnal cycle in two versions of the Community Atmosphere Model in CESM1 using flux-station observations reveal:

- Diurnal cycles are too large
- Both models are too cold in winter at high latitudes and CAM5 has a larger cold bias than CAM4
- Climatolological surface turbulent heat fluxes are similar in CAM4 and CAM5 even though the winds are much reduced in CAM5
- The model compensates the lower wind gradients with larger temperature gradients
- Turbulent Mountain Stress is not optimally introduced in CAM5 but it gives much improved general circulation

Preliminary results for other climate models from CMIP5



BIAS

	CNRM–CM5	HadGEM2–A	inmcm4	IPSL–CM5A–LR	NorESM1–M
✱ T_{2m} [K]	0.46	0.53	–0.99	0.88	0.59
□ SH [$W\ m^{-2}$]	–4.2	2.9	4	1.06	–3.5
◁ LH [$W\ m^{-2}$]	5.1	8.3	15	8.3	11
✡ U_{10m} [$m\ s^{-1}$]	0.33	0.24	0.55	0.17	–

Preliminary results for other climate models from CMIP5

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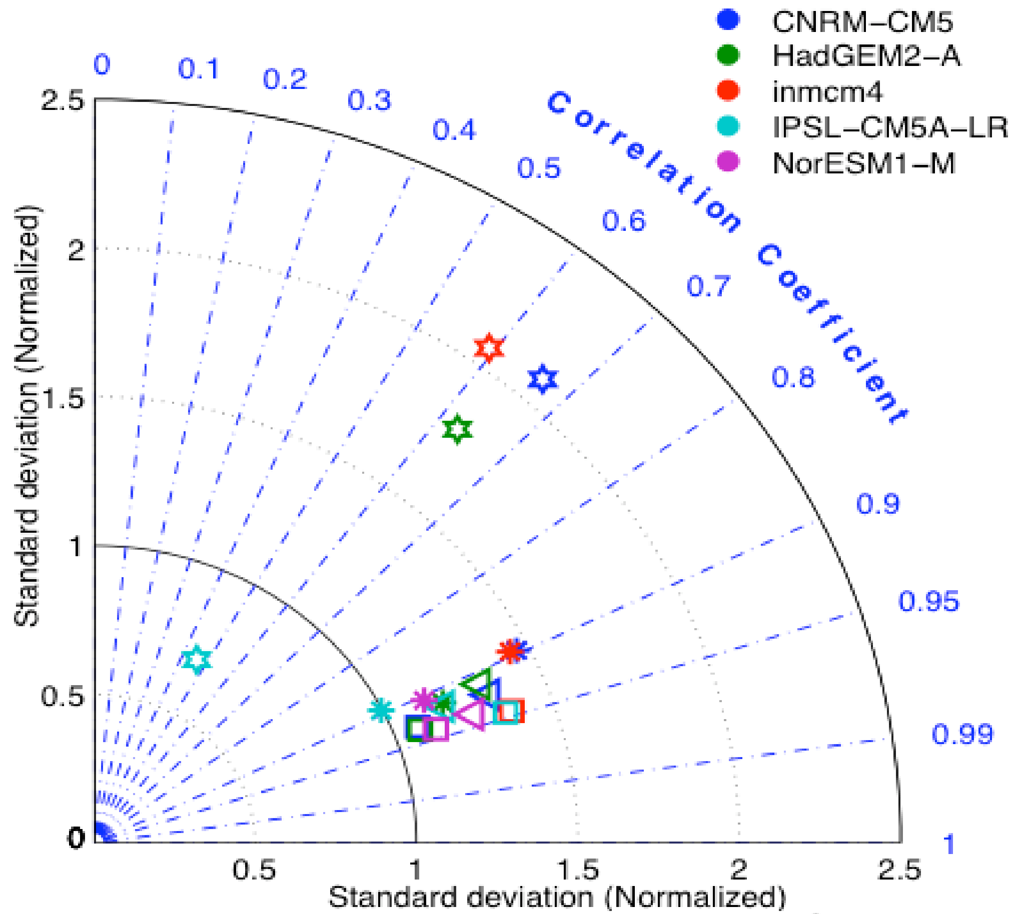

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