PRINCETON UNIVERSITY

UNIVERSITY OF Southampton

Investigating soil moisture-evapotranspiration coupling in CMIP5 models

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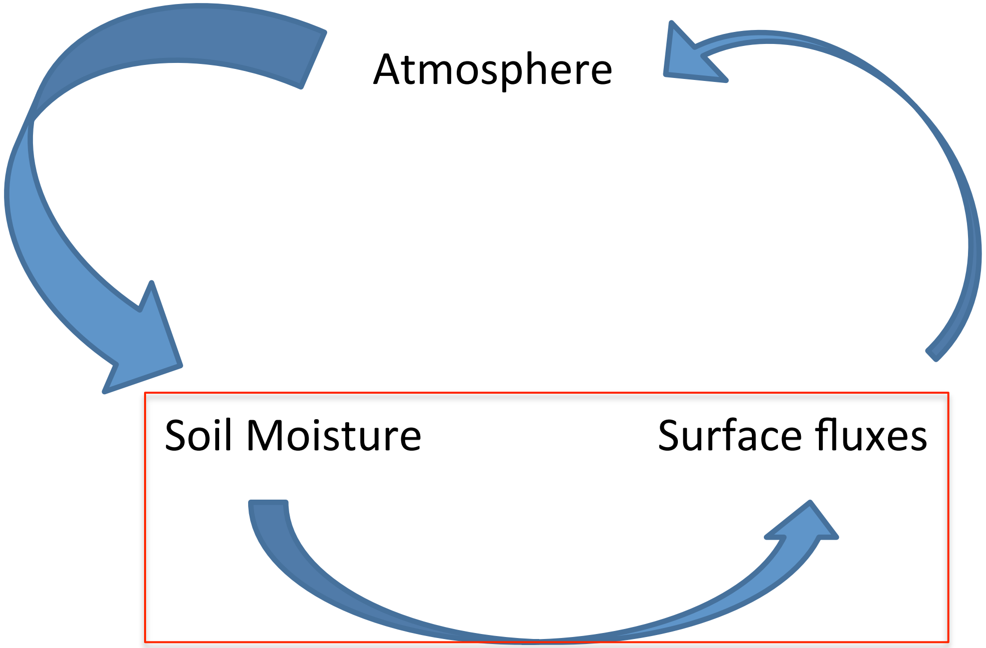
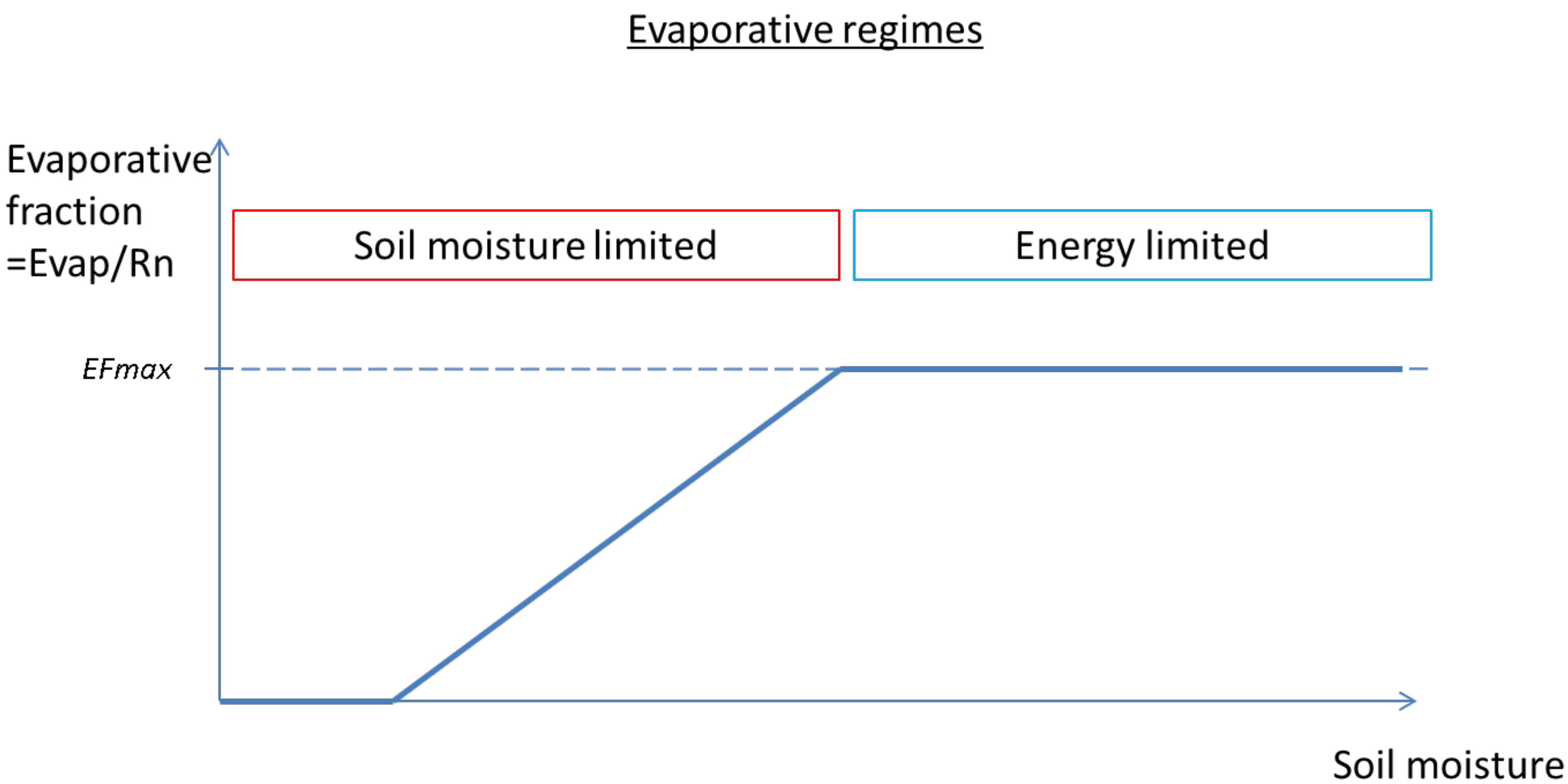
WGNE-WSE 2017. Session: Atmosphere-land-ocean-cryosphere interactions

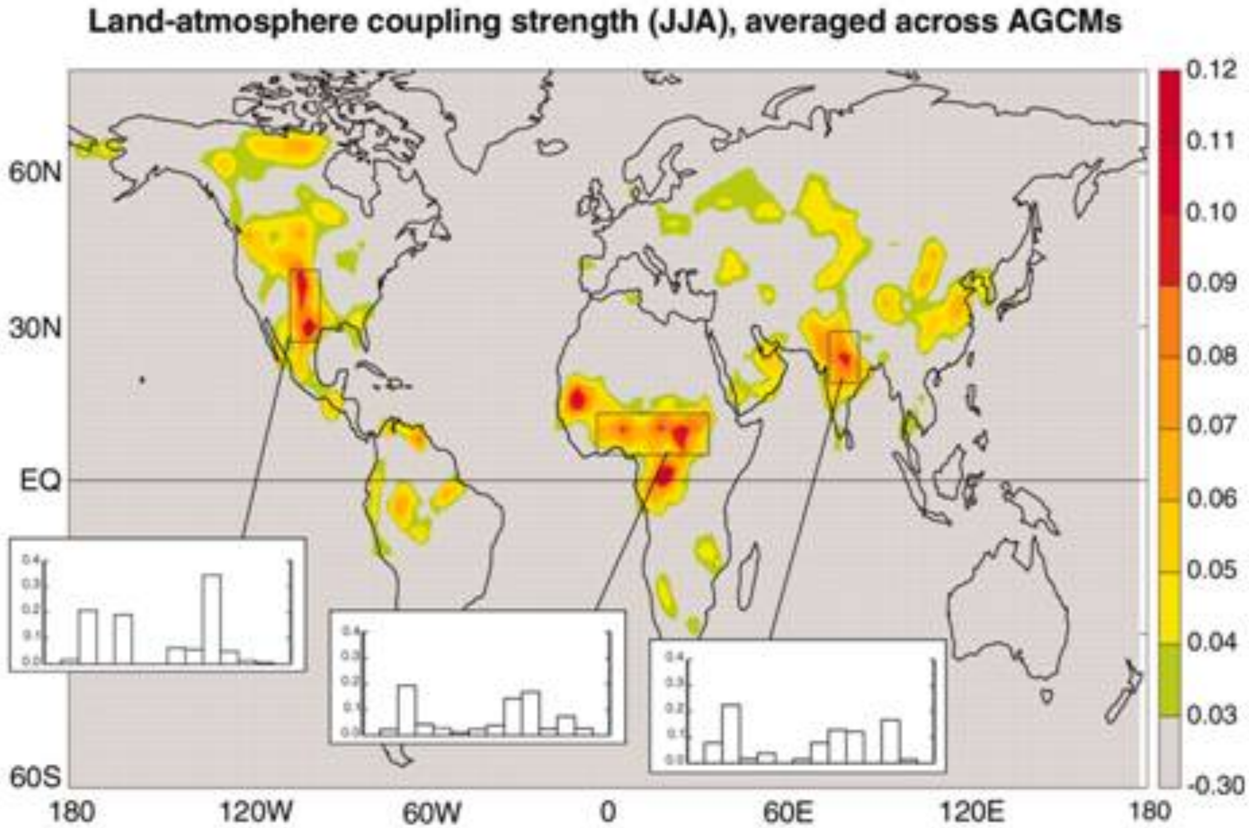
Soil moisture-atmosphere coupling



Control of Soil Moisture (SM) on Evapotranspiration (ET) is a necessary (but not sufficient) condition for SM-atmosphere coupling.



Soil moisture controls surface fluxes in drier environments.



GLACE-I results, Koster et al. 2004)

SM-ET coupling accounts for the largest part of model uncertainty in intra-seasonal SM-P coupling in GLACE-I experiment (Guo et al. 2006).

Outline

- Characterize SM-ET coupling in CMIP5 models
- Links with mean climate
- Links with ET partitioning
- Implications for climate change

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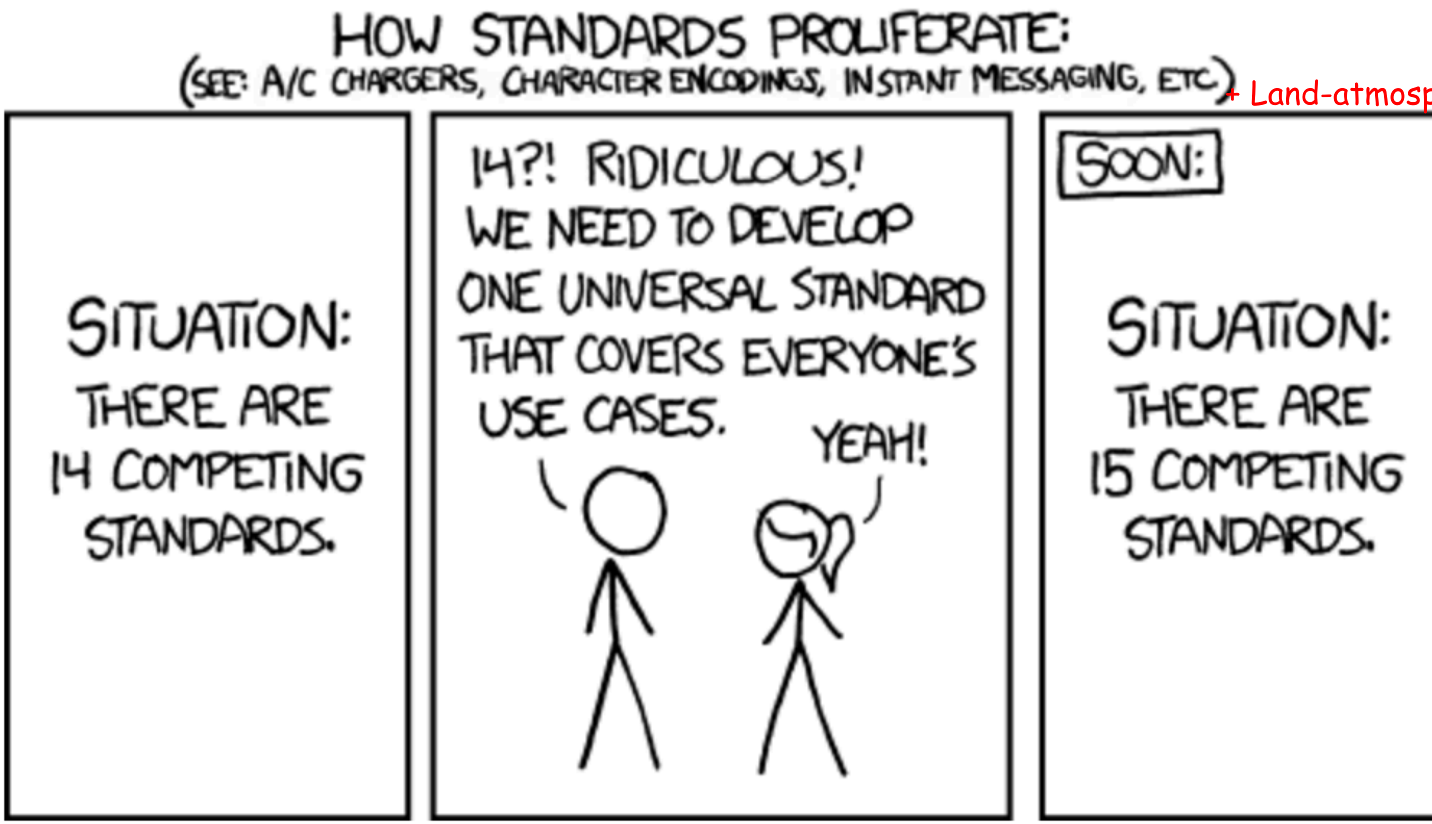


Source: xkcd.com

Outline

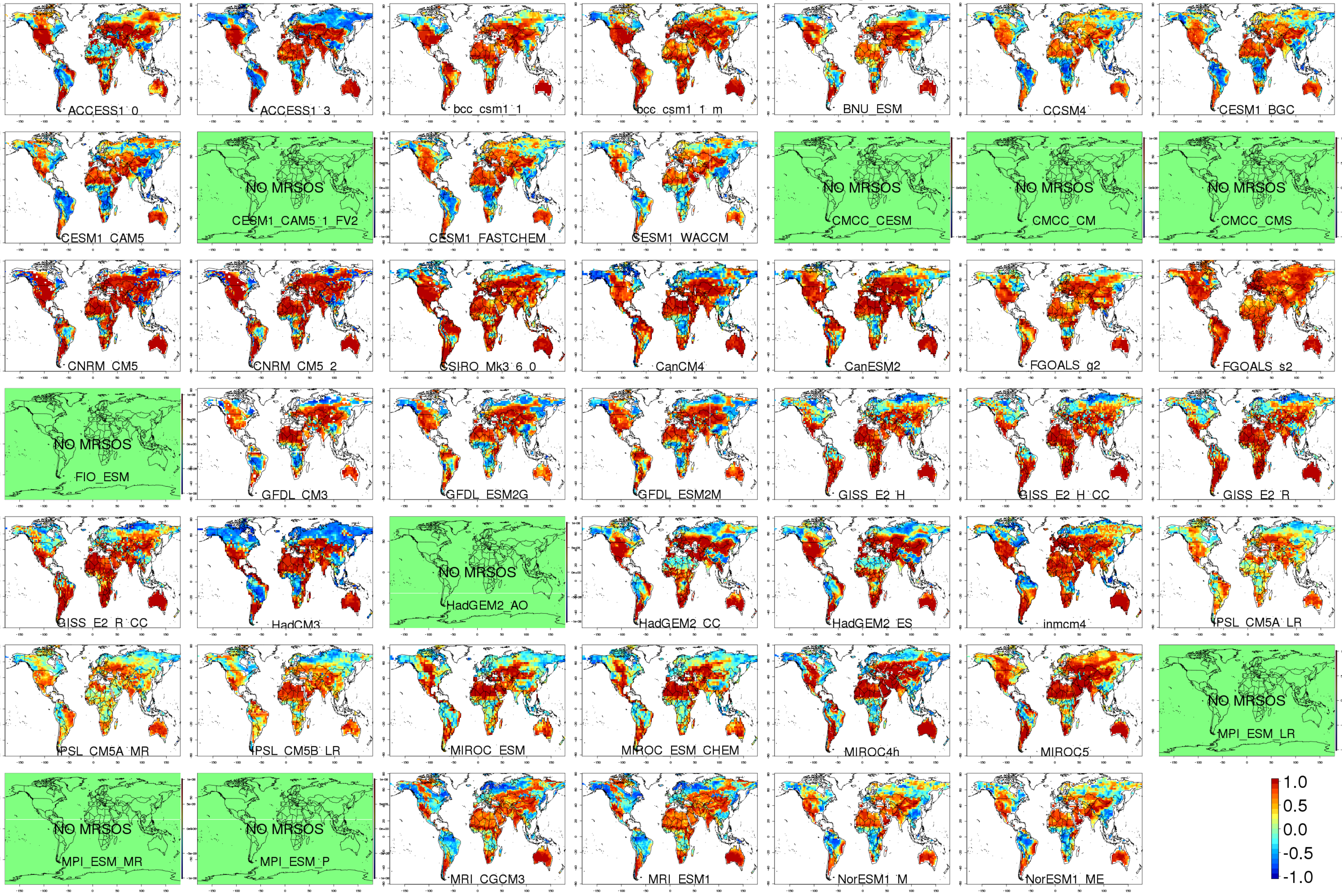
- Characterize SM-ET coupling in CMIP5 models

Interannual correlation, over 1950-2005, between summer-averaged variables X_1 and X_2 (JJA in NH, DJF in SH).

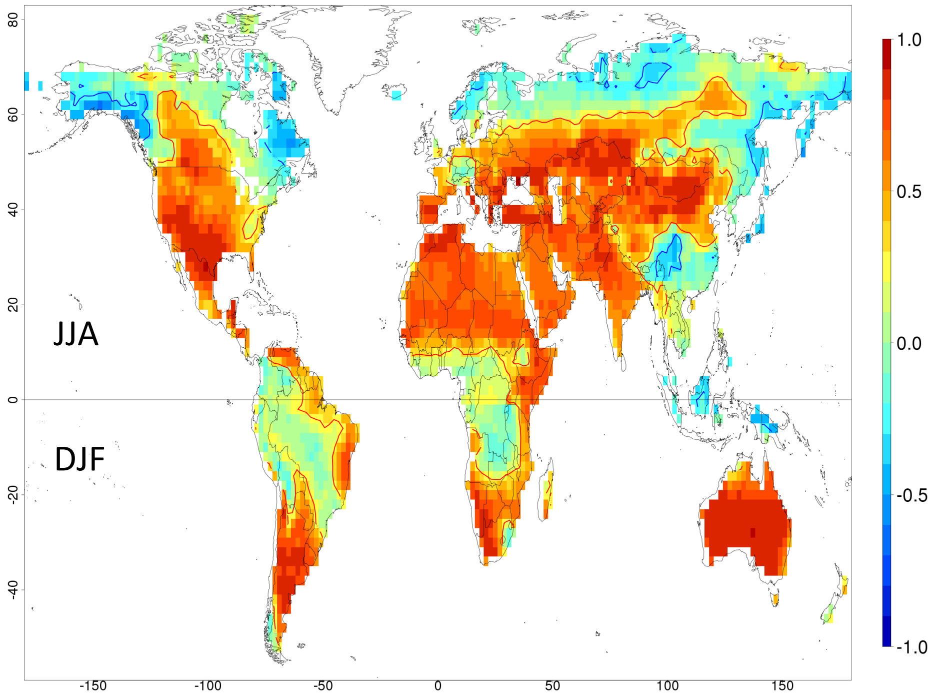
E.g., cor(SM, ET).

We use MRSOS (top-10cm soil moisture) – more comparable across models, and more relevant for surface climate, than total SM.

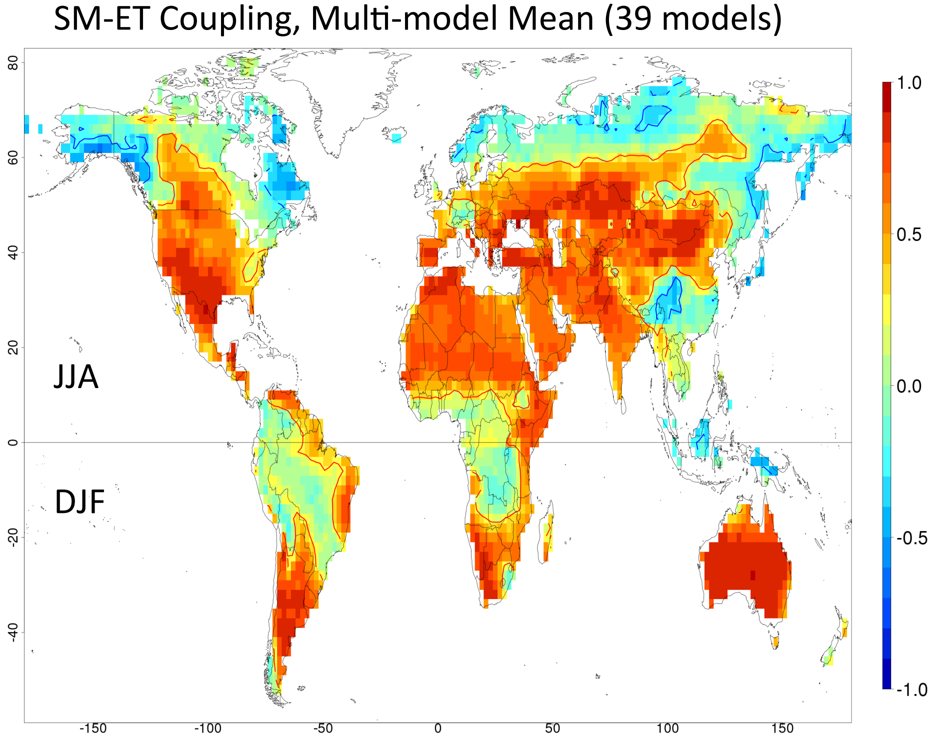
Cor(SM surf., ET) = "Coupling"

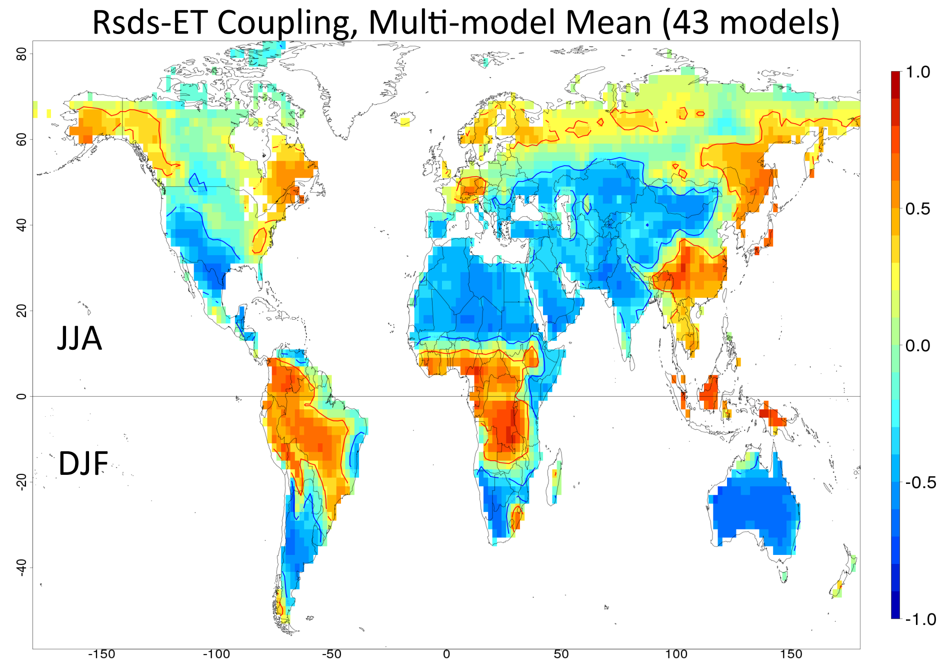


SM-ET Coupling, Multi-model Mean (39 models)



Coupling > 0 in dry subtropical and mid-latitudes
Coupling ~ 0 or <0 in Tropics and high latitudes





Coupling > 0 in dry subtropical and mid-latitudes

Coupling ~ 0 or <0 in Tropics and high latitudes

Rsds-ET coupling > 0 in Tropics

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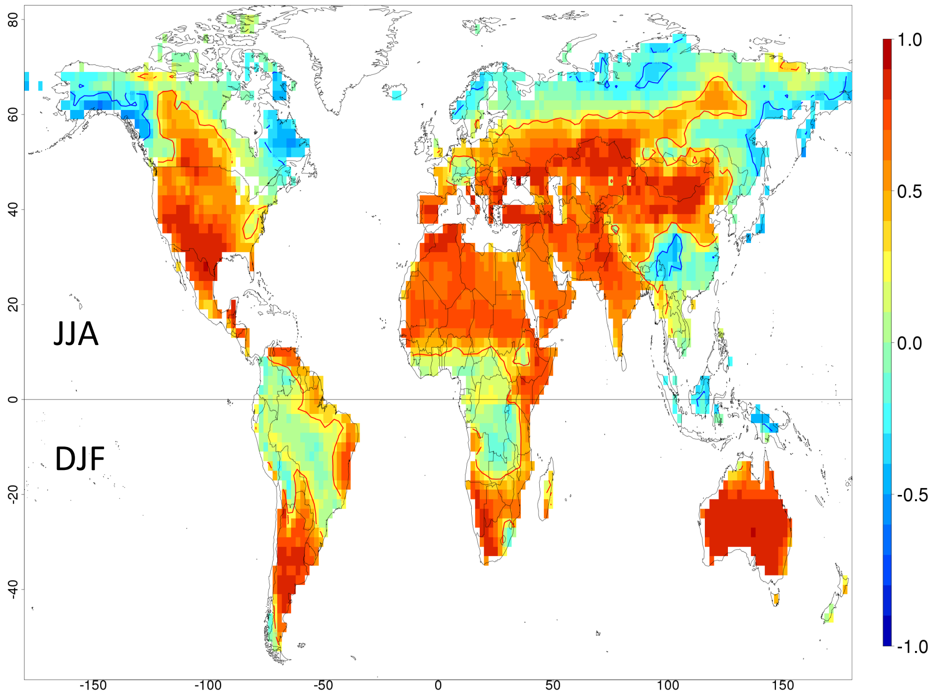
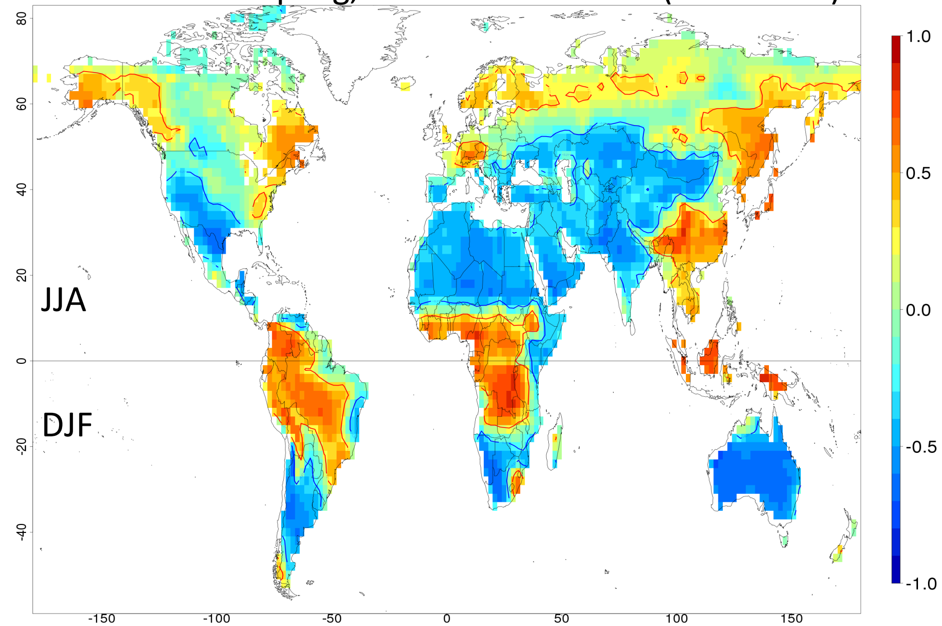
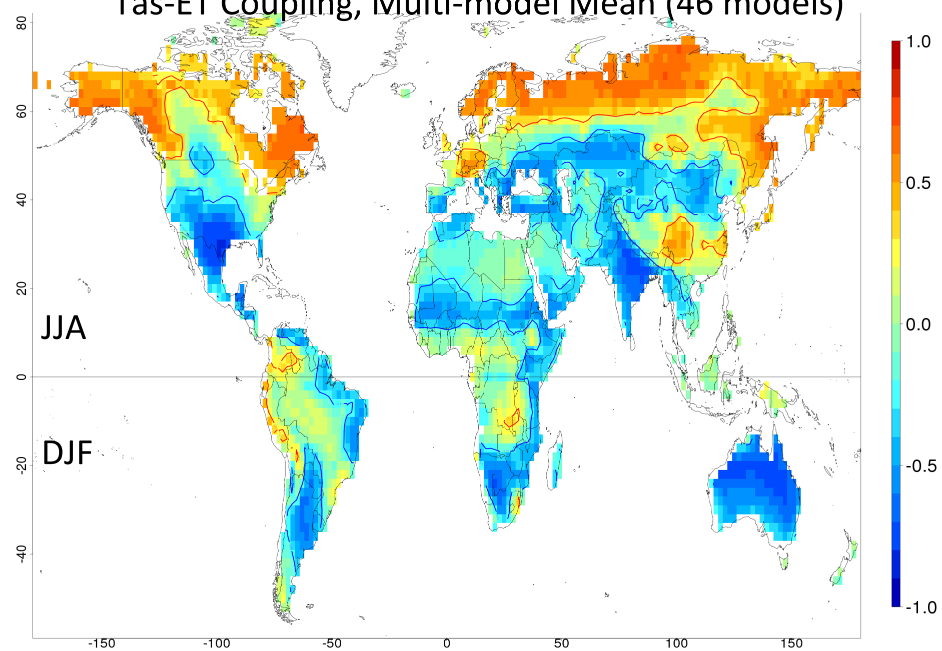
SM-ET Coupling, Multi-model Mean (39 models)



Rsds-ET Coupling, Multi-model Mean (43 models)

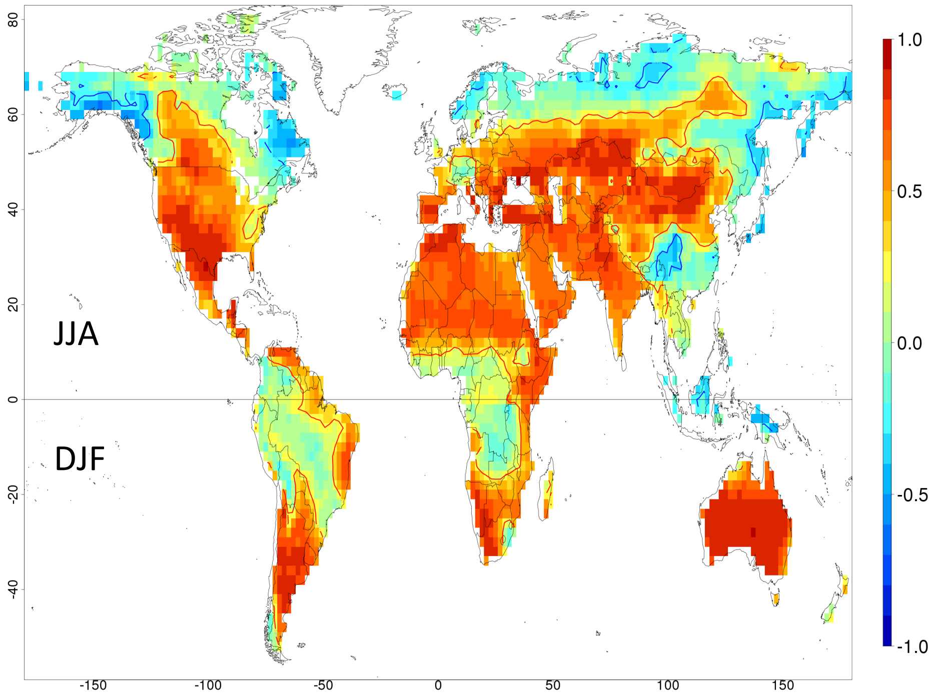


Tas-ET Coupling, Multi-model Mean (46 models)

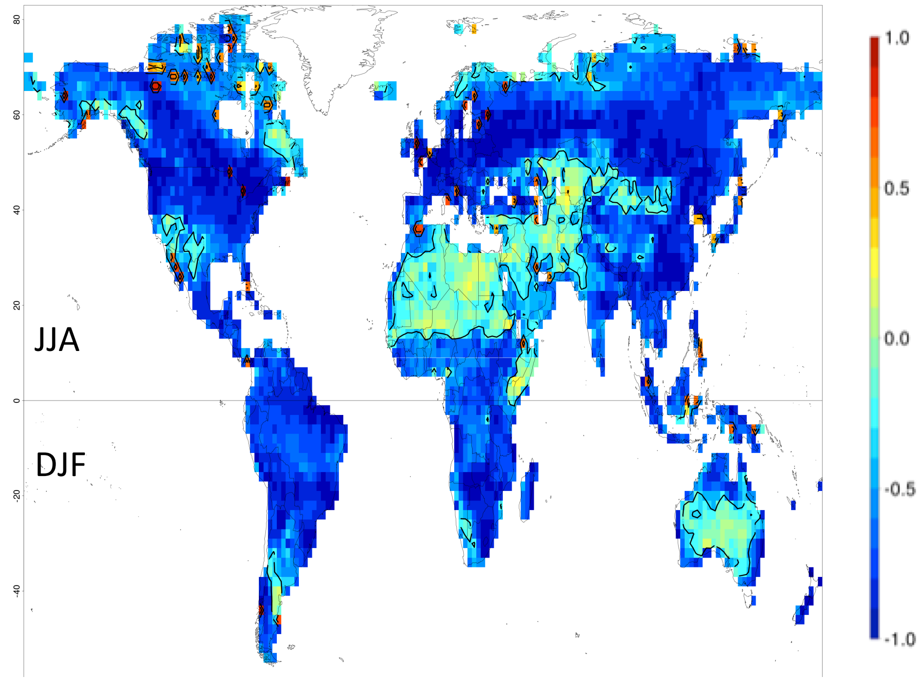


Coupling > 0 in dry subtropical and mid-latitudes
Coupling ~ 0 or <0 in Tropics and high latitudes
Rsds-ET coupling > 0 in Tropics
Tas-ET coupling > 0 in high-latitudes

SM-ET Coupling, Multi-model Mean (39 models)



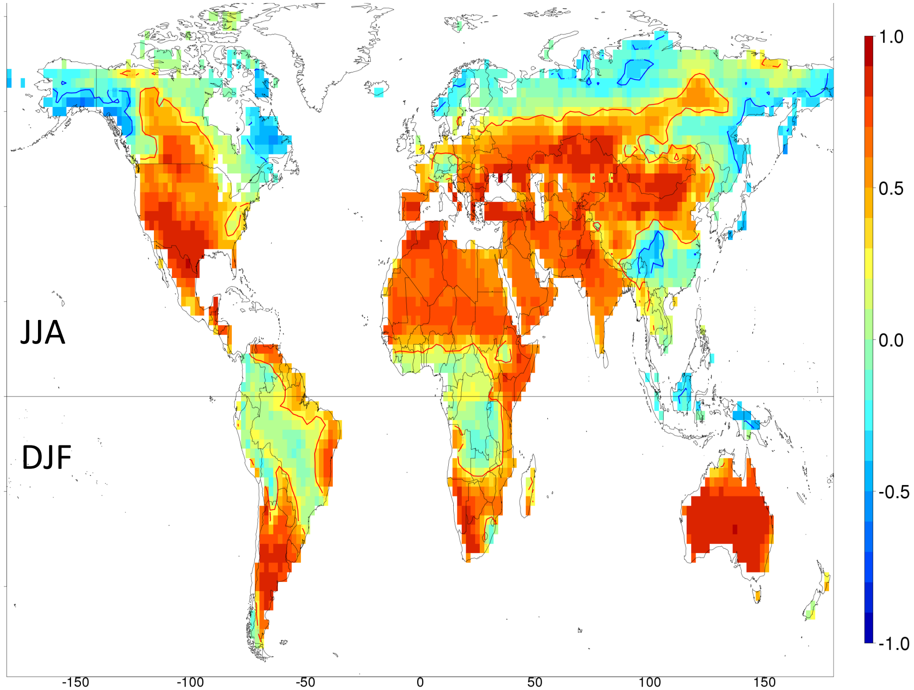
Cor(SM-ET Coupling, Rsds-ET coupling) across 39 models



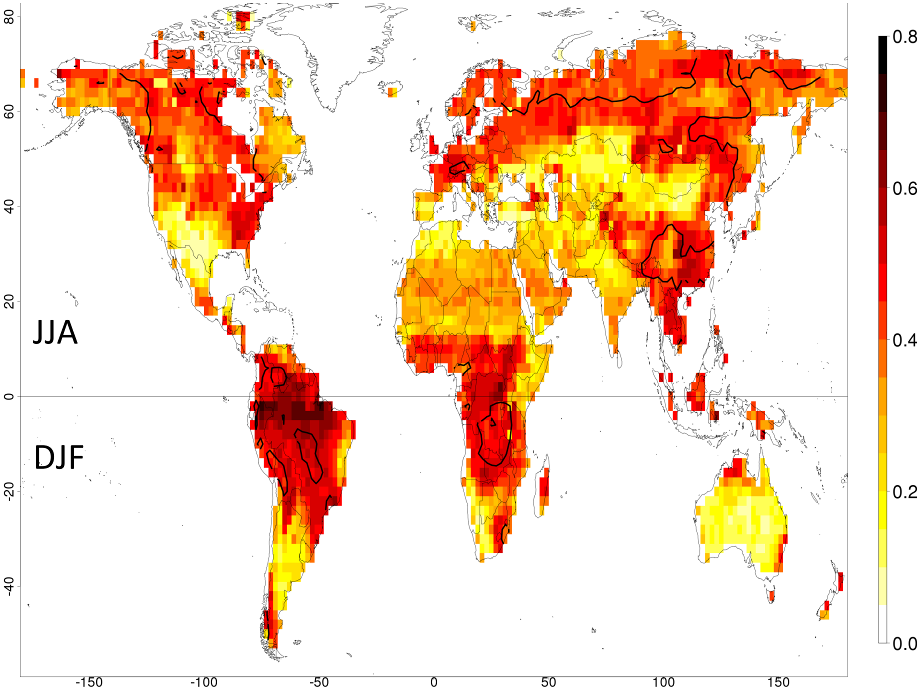
Coupling > 0 in dry subtropical and mid-latitudes
Coupling ~ 0 or <0 in Tropics and high latitudes
Rsds-ET coupling > 0 in Tropics
Tas-ET coupling > 0 in high-latitudes

Models that are more SM-limited are less energy-limited, and vice-versa.

SM-ET Coupling, Multi-model Mean (39 models)



SM-ET Coupling, Multi-model Std.dev. (39 models)



Model spread greater on periphery of area of positive SM-ET coupling and in Tropics.

What causes the spread?

Outline

- Characterize SM-ET coupling in CMIP5 models
- Links with mean climate
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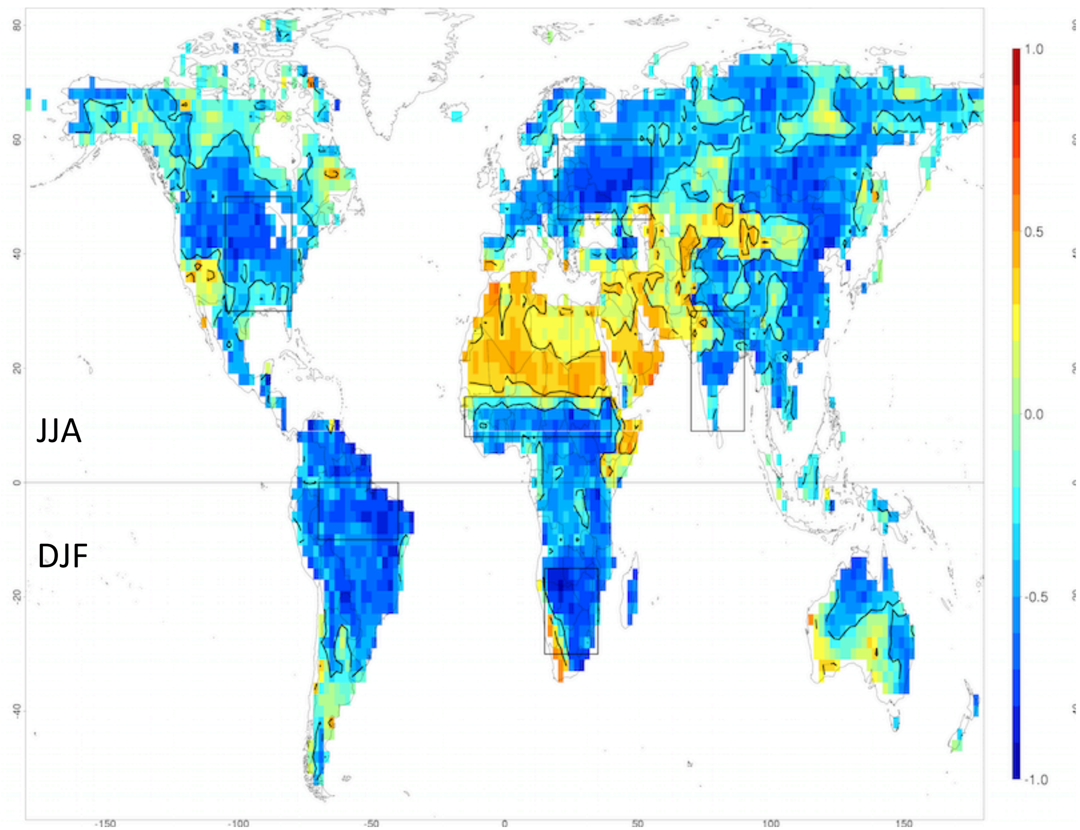
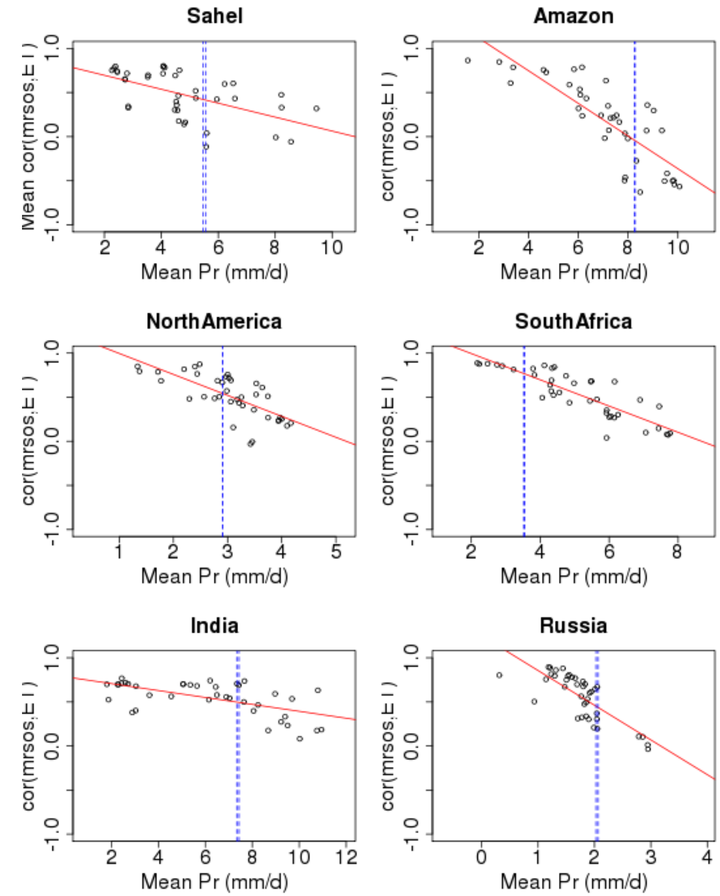
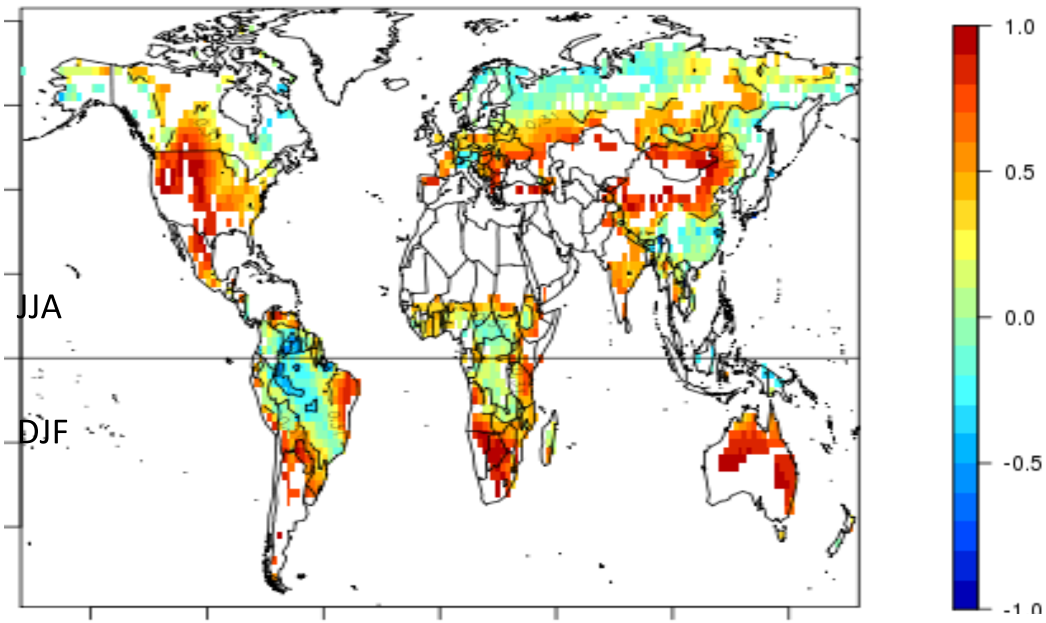
Correlation across 39 models between summer Mean P and SM-ET Coupling



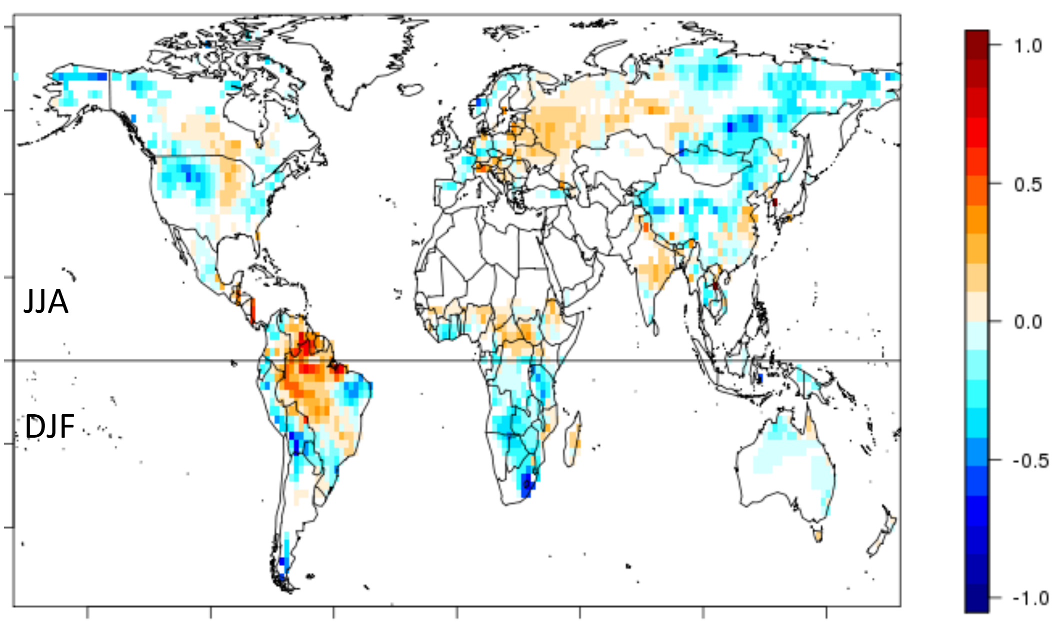


P Obs (CRU, U.Del.)

Models with lower precipitation are more soil moisture limited.



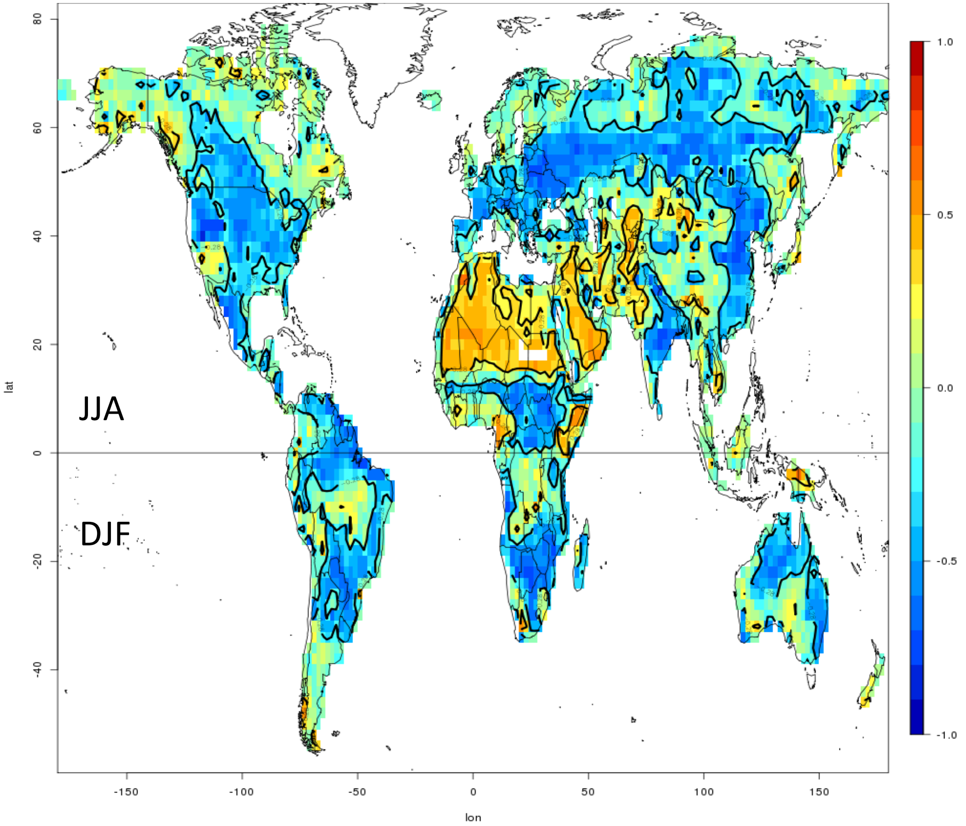
Estimate of SM-ET coupling based on P obs (CRU and U.Del) and regression with model spread



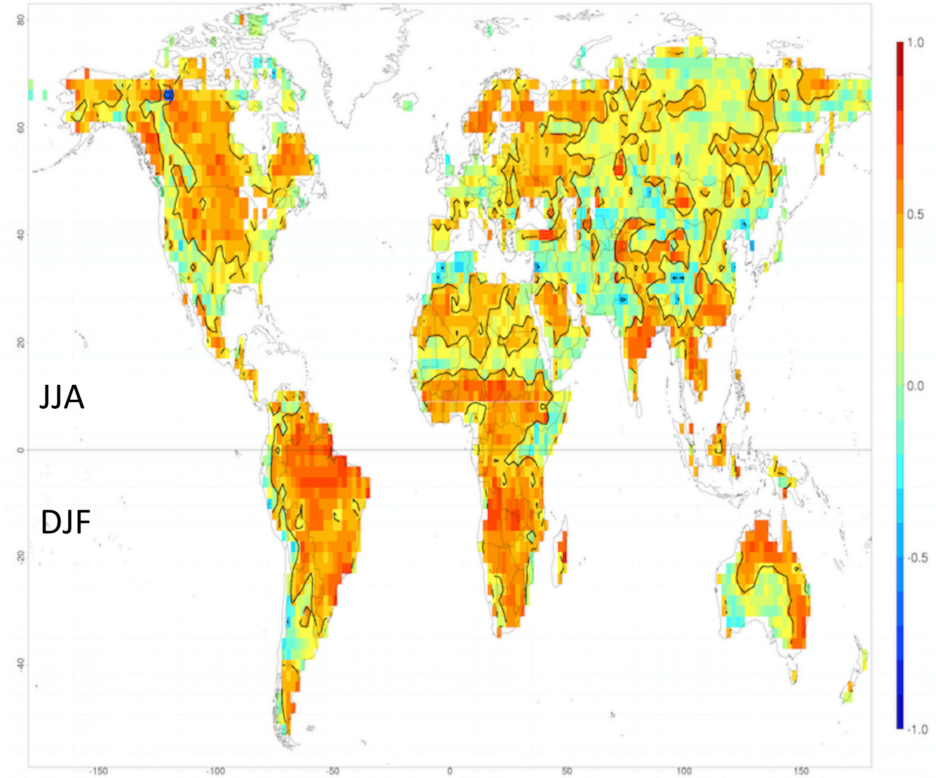
Difference between multi-model mean coupling and P-based estimate

Systematic regional model biases?

Correlation across 39 models between summer Mean ET and SM-ET Coupling

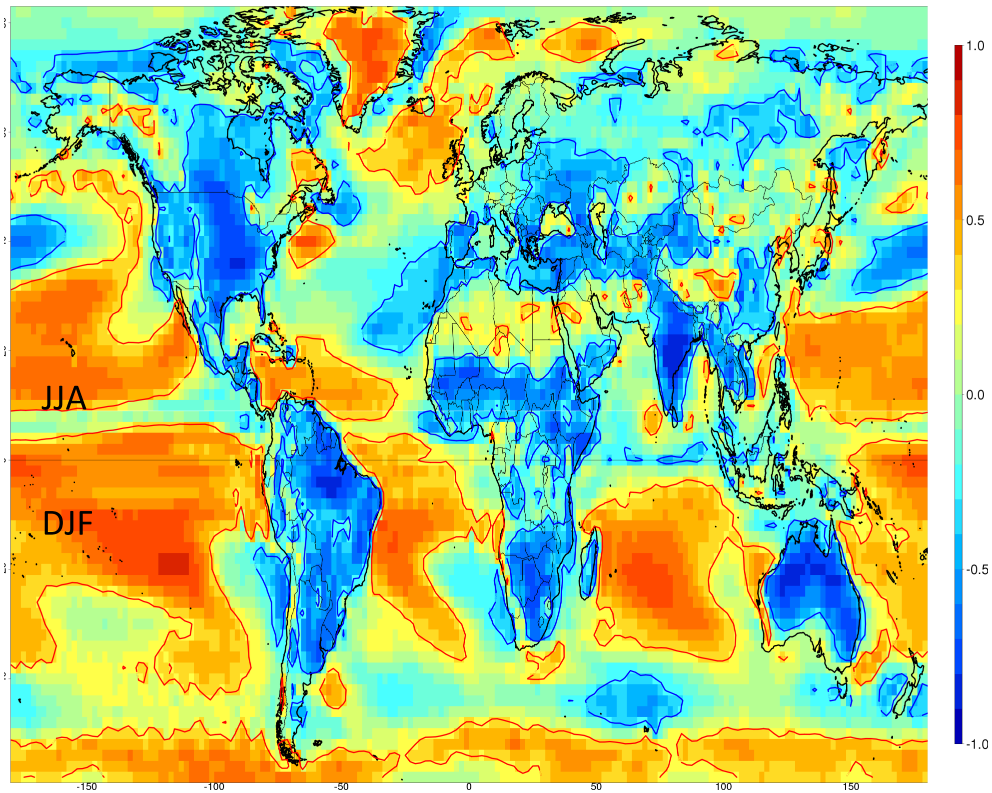


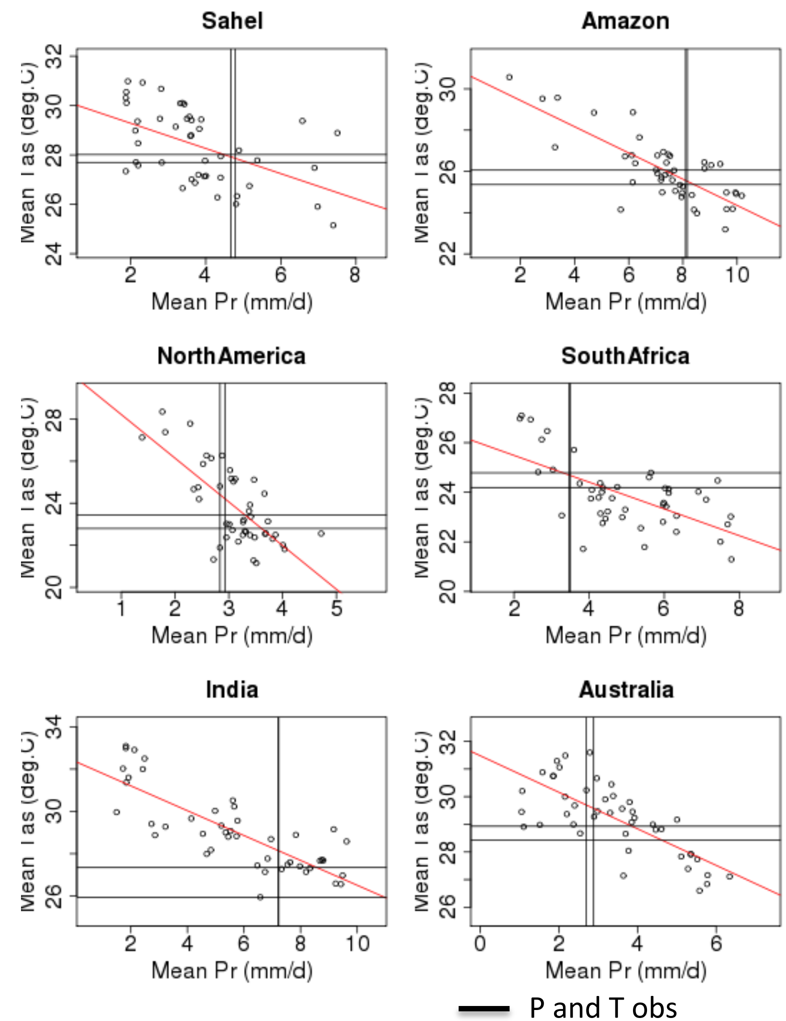
Correlation across 37 models between summer Mean Tas and SM-ET Coupling



Models where ET is more SM-limited tend to have lower ET and to be warmer.

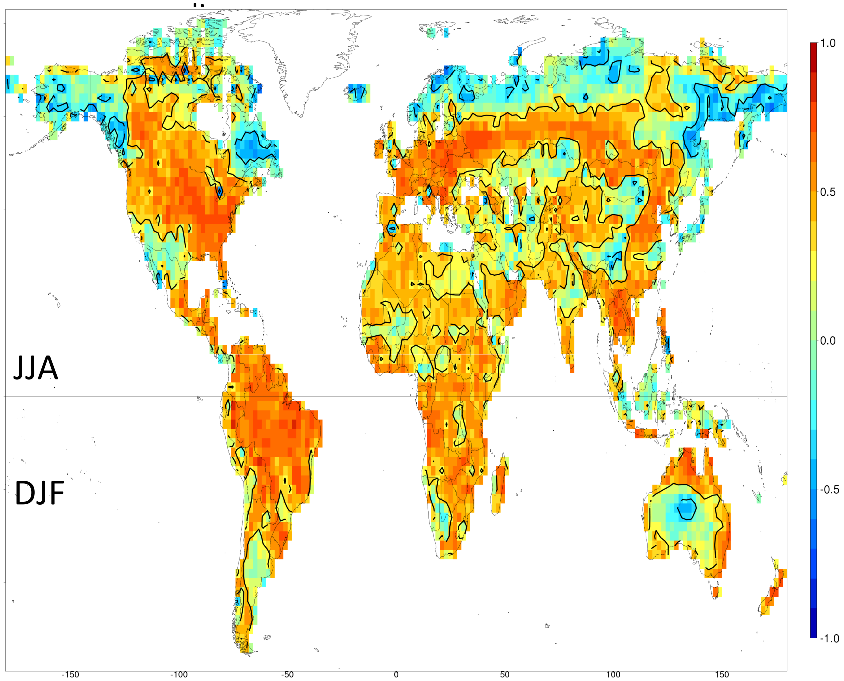
Correlations across 46 models between summer mean Tas and mean P



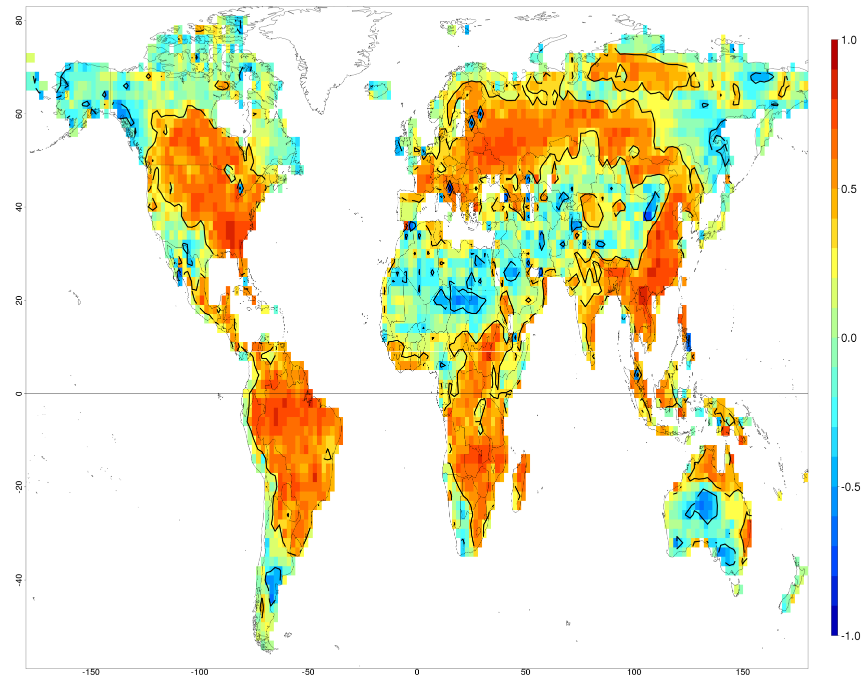


SM-atmosphere interactions (partly) induce a negative relationship between model Tas and Pr summertime biases.

Correlations across 39 models between interannual sd(Summer E) and SM-ET



Correlations across 37 models between interannual sd(Summer T) and SM-ET coupling



Models with stronger SM-ET coupling have greater ET and Tas (interannual) variability.

Outline

- Characterize SM-ET coupling in CMIP5 models
- Links with mean climate
- Links with ET partitioning
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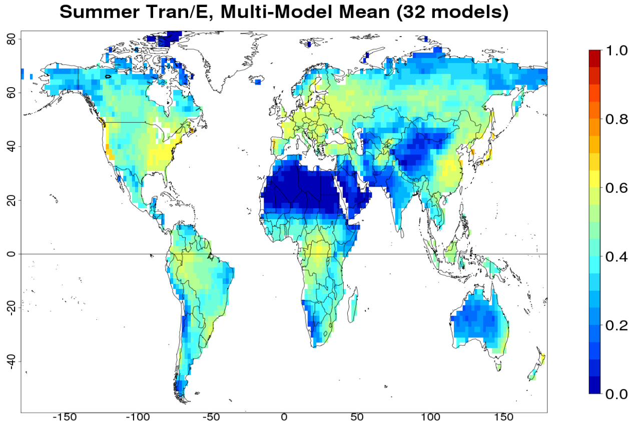
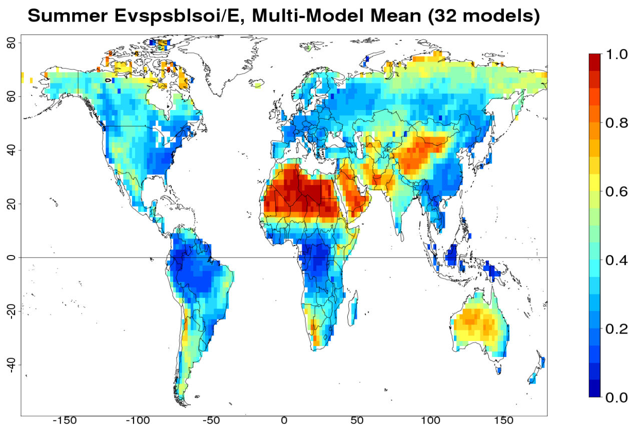
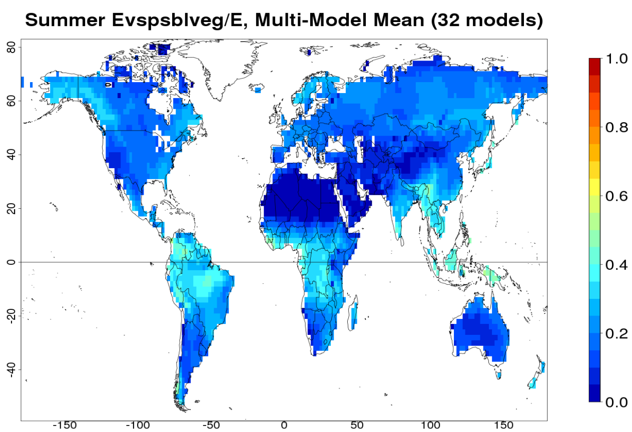
Tran/ET

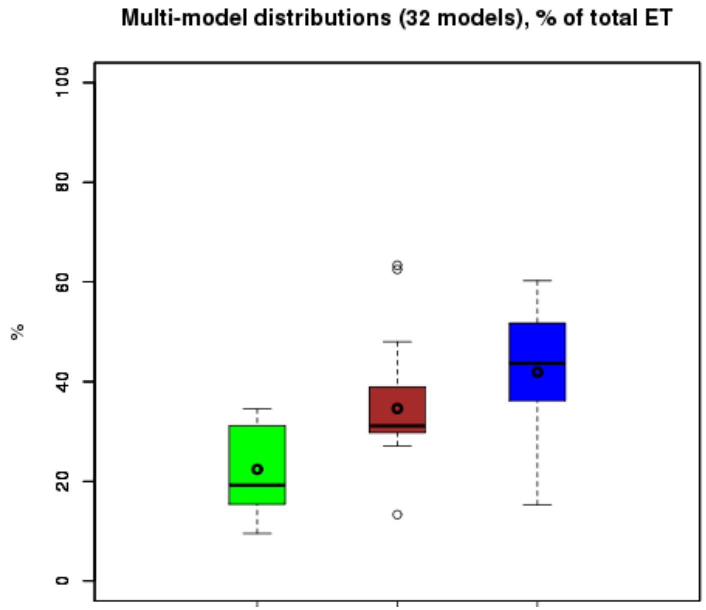


Esoil/ET



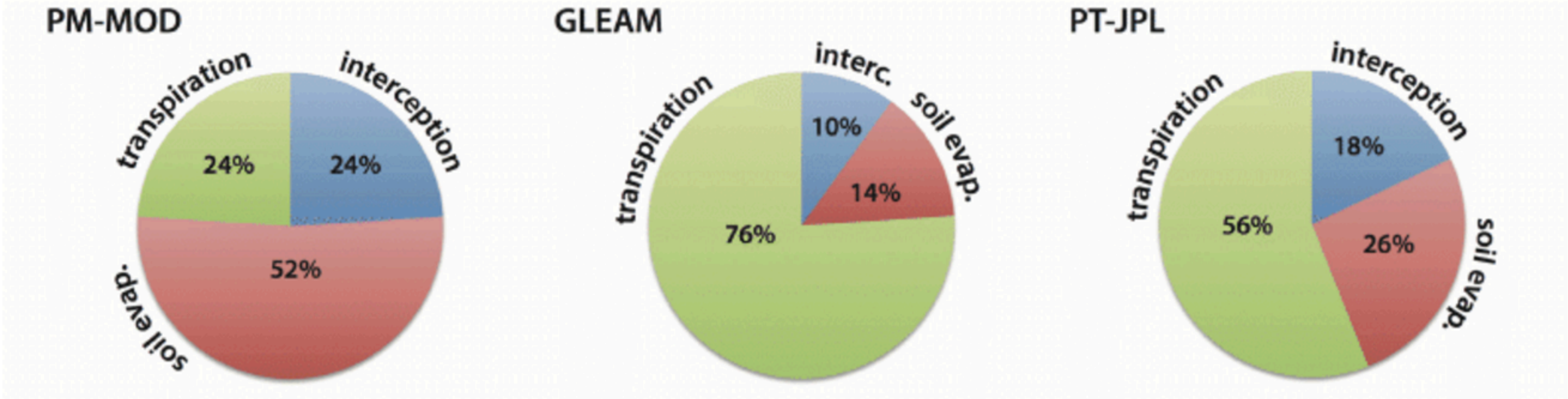
Eveg/ET





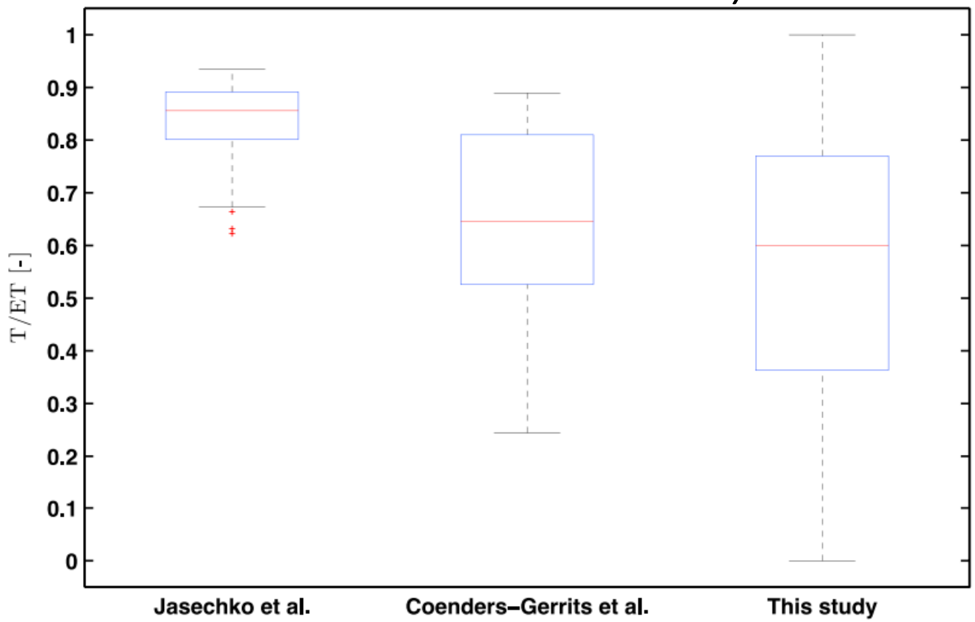
Eveg Esoil Tran

Large model spread in ET partitioning



Miralles et al. (2016)

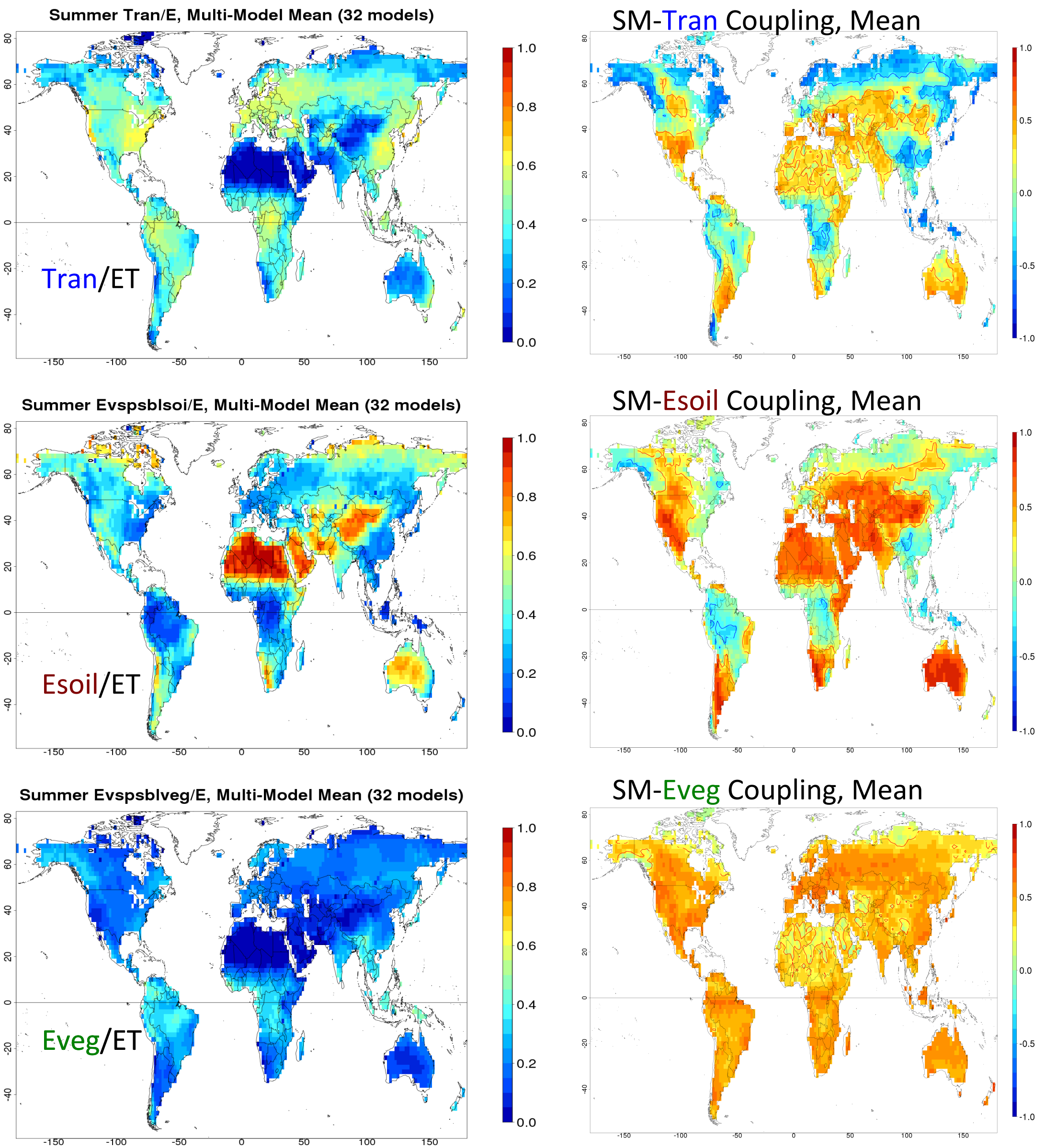
Obs-estimated Global Tran/ET



Wang et al. (2014)

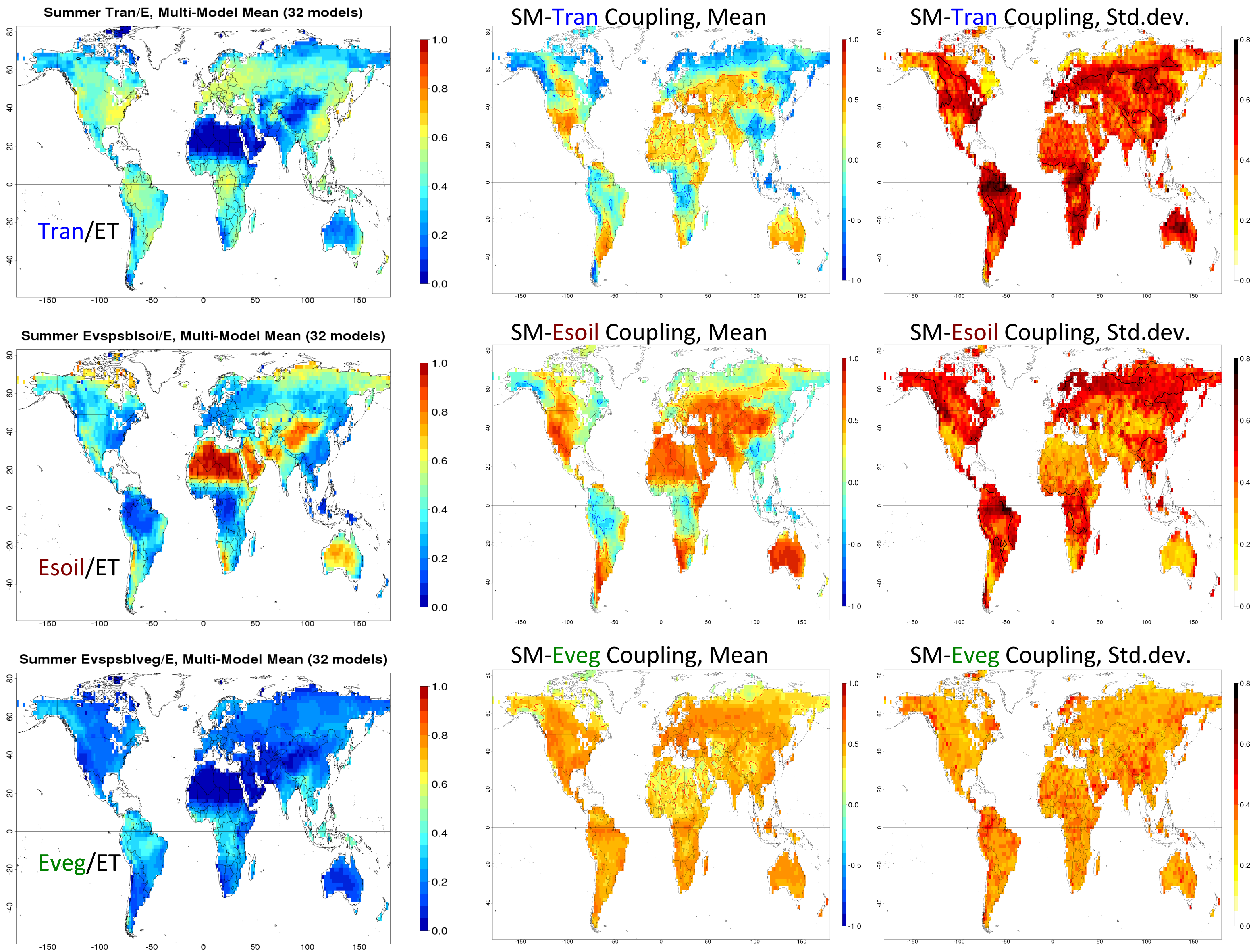
ET partitioning is poorly constrained by observations.

A. Berg, *Investigating soil moisture-evapotranspiration coupling in CMIP5 models*



Different ET components are differently coupled with SM.

A. Berg, *Investigating soil moisture-evapotranspiration coupling in CMIP5 models*



Different ET components are differently coupled with SM.
Greater model spread for SM-Tran coupling

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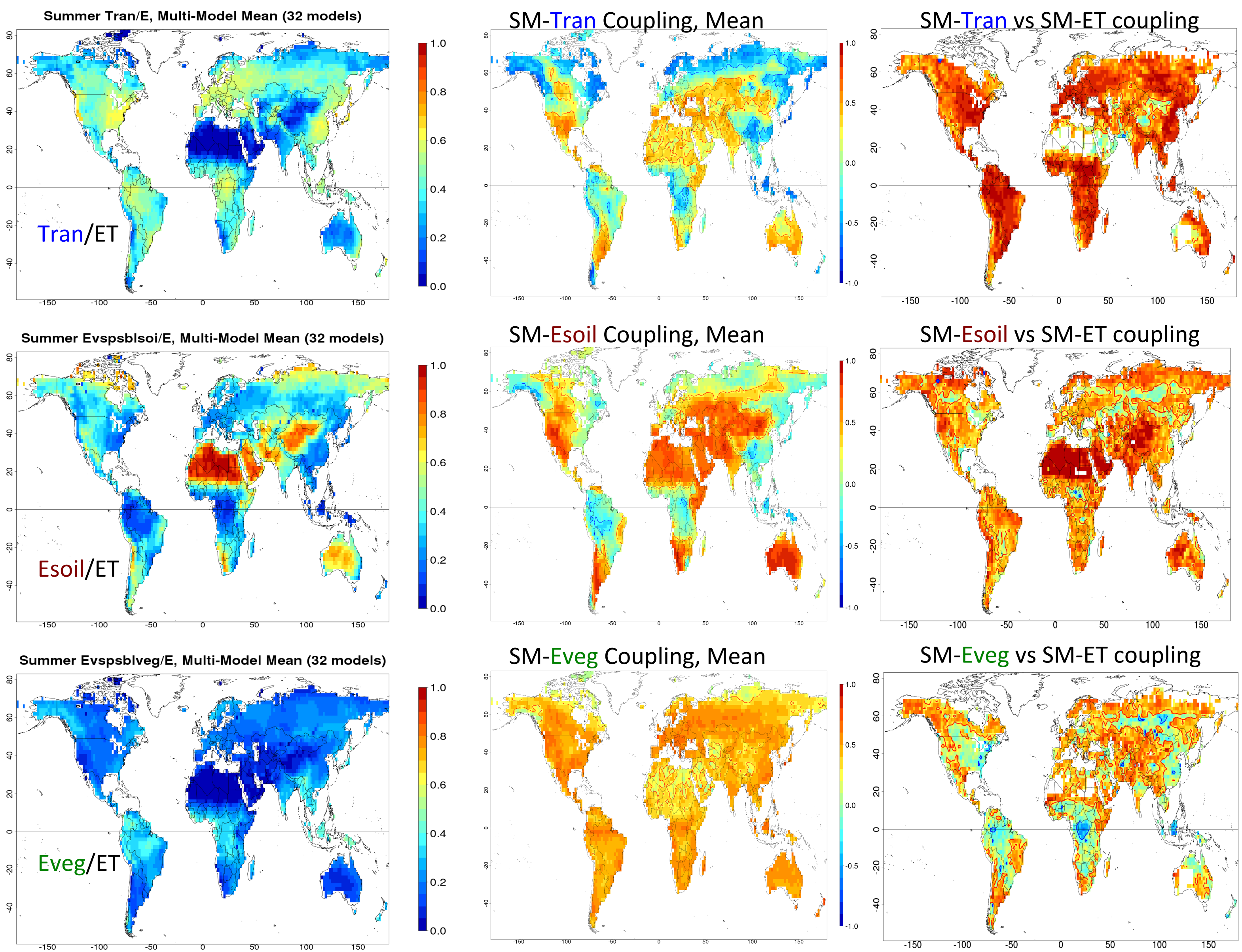
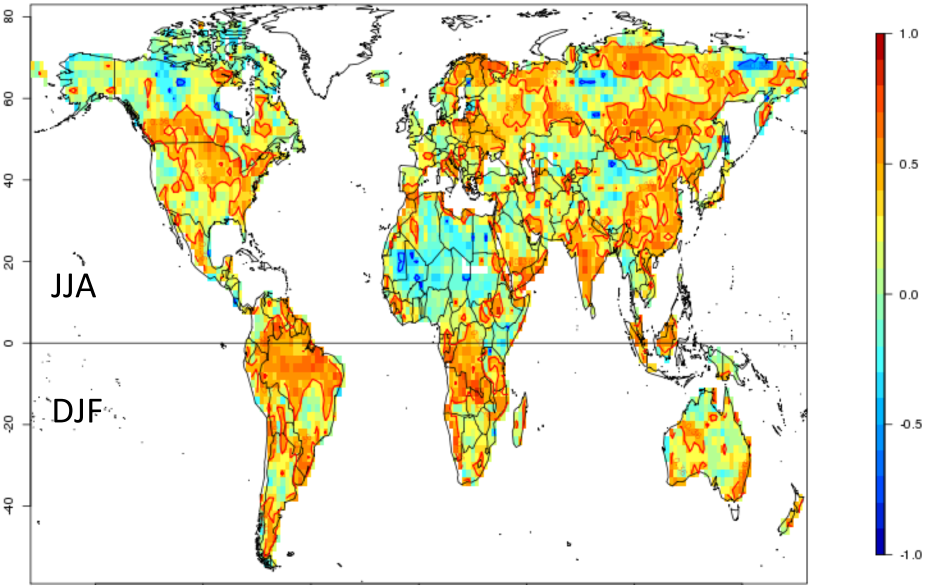


Different ET components are differently coupled with SM.

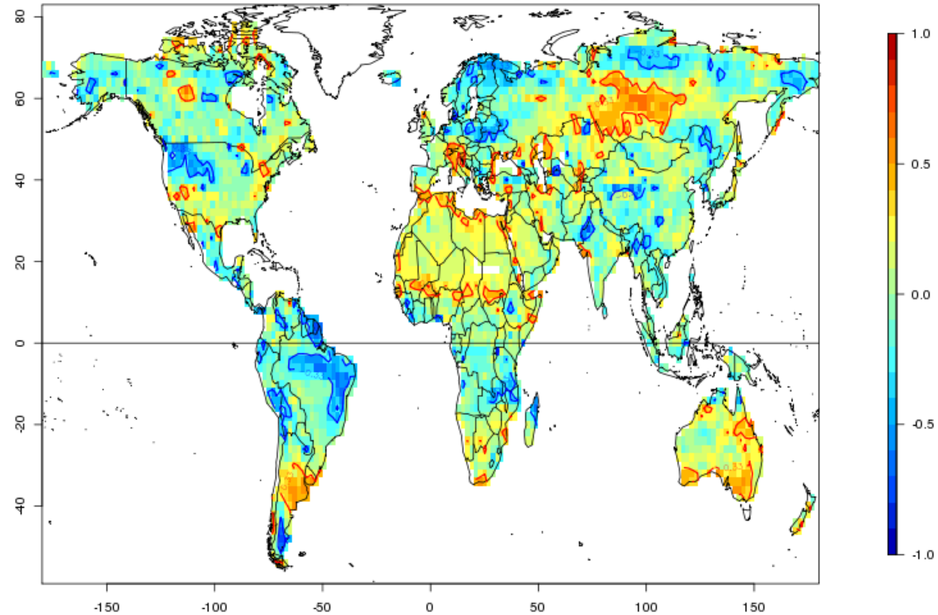
Greater model spread for SM-Tran coupling, which explains more of spread in SM-ET coupling.

A. Berg, *Investigating soil moisture-evapotranspiration coupling in CMIP5 models*

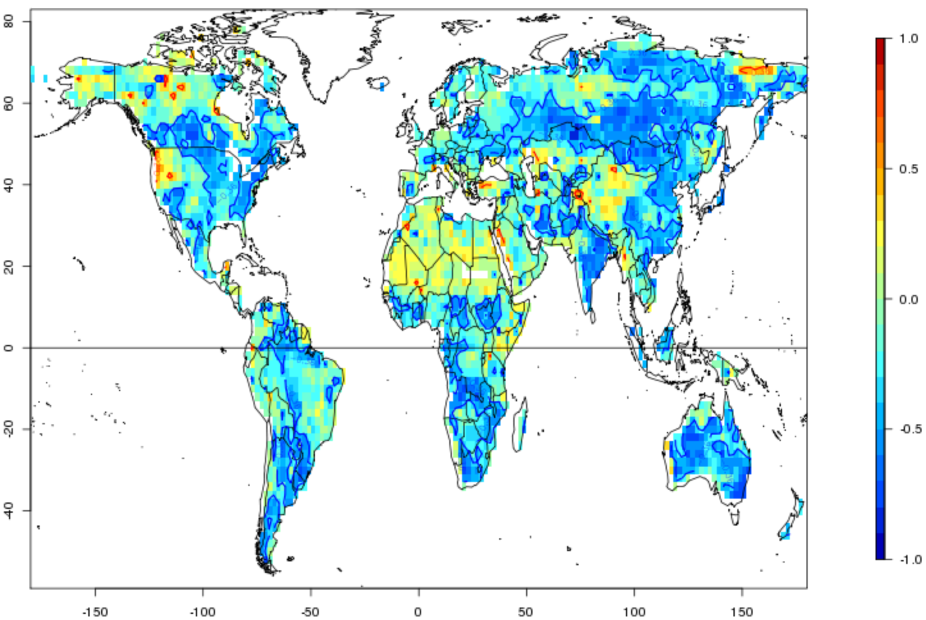
Mean Esoil/ET vs SM-ET coupling, across 32 models



Mean Eveg/ET vs SM-ET coupling, across 35 models

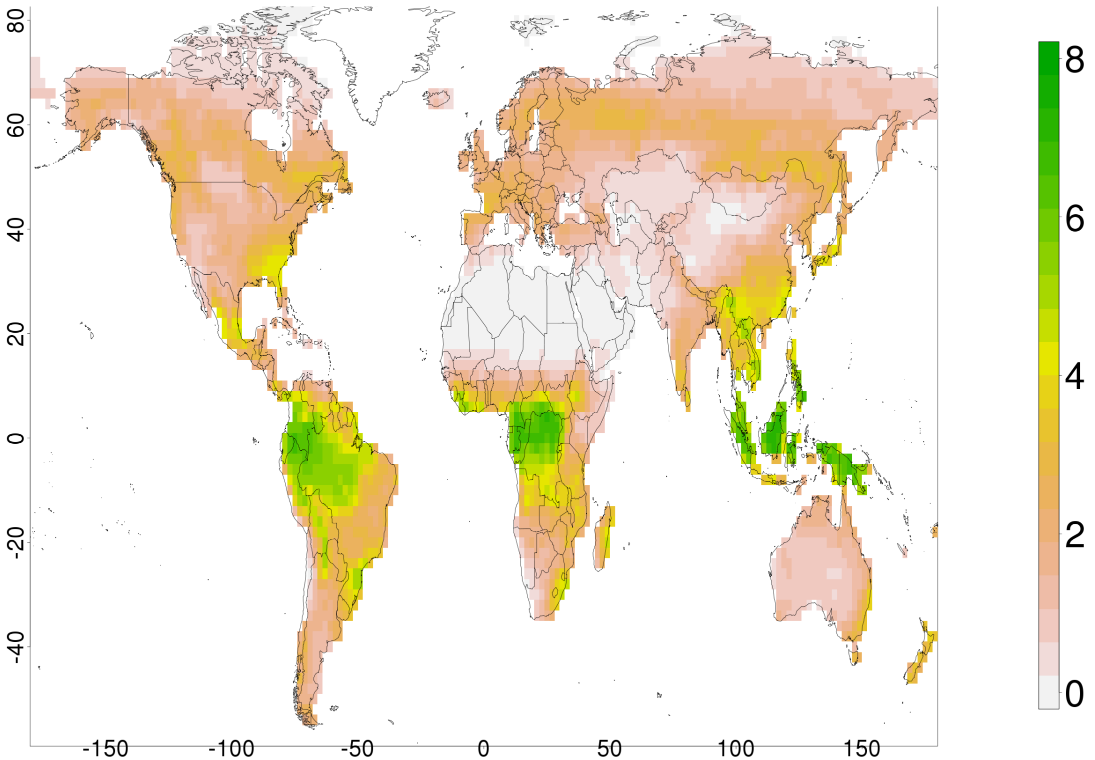


Mean Tran/ET vs SM-ET coupling, across 31 models

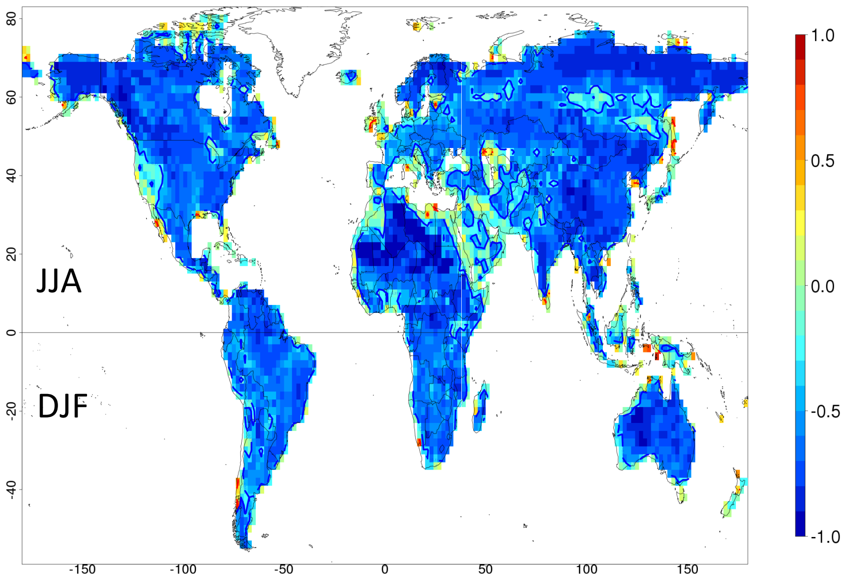


Models with more Esoil appear more soil moisture-limited.
Models with more Tran appear less soil moisture-limited.

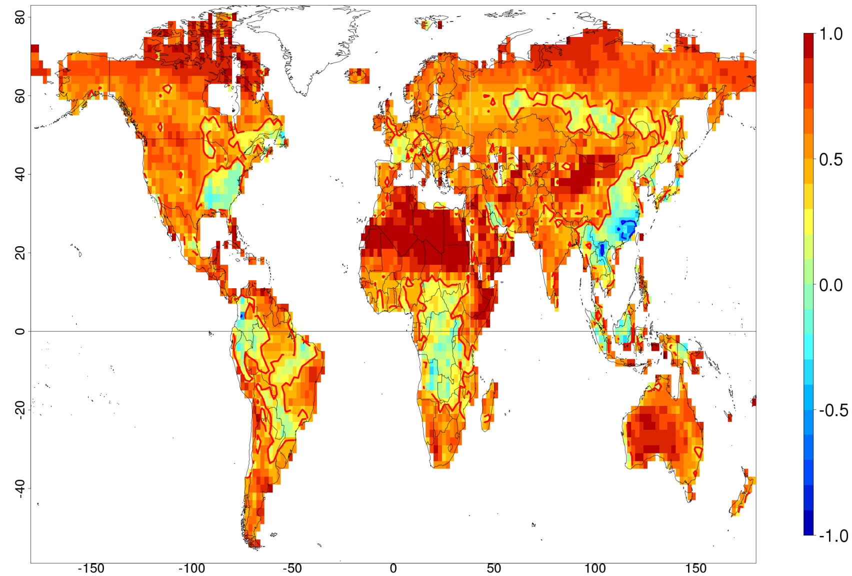
Annual LAI (m^2/m^2), 25 models, Present



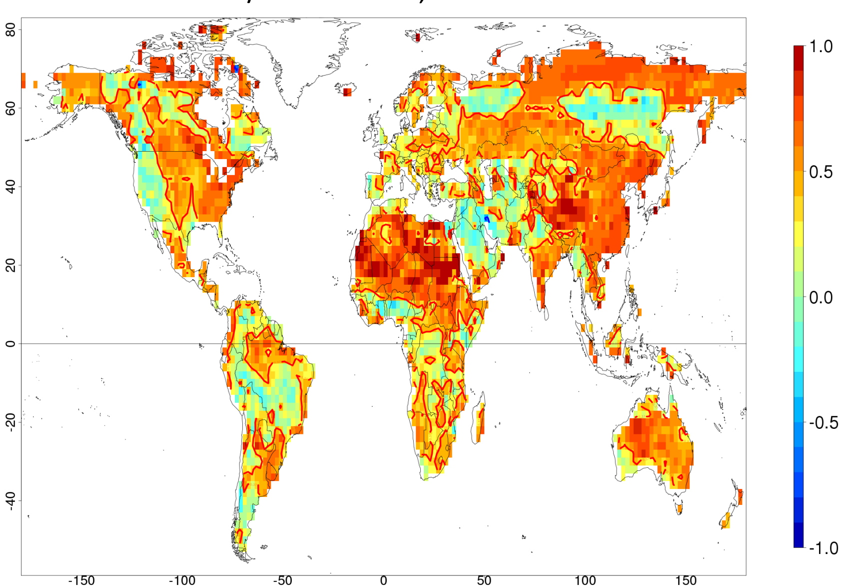
Mean Esoil/ET vs mean LAI, across 23 models



Mean Eveg/ET vs mean LAI, across 35 models



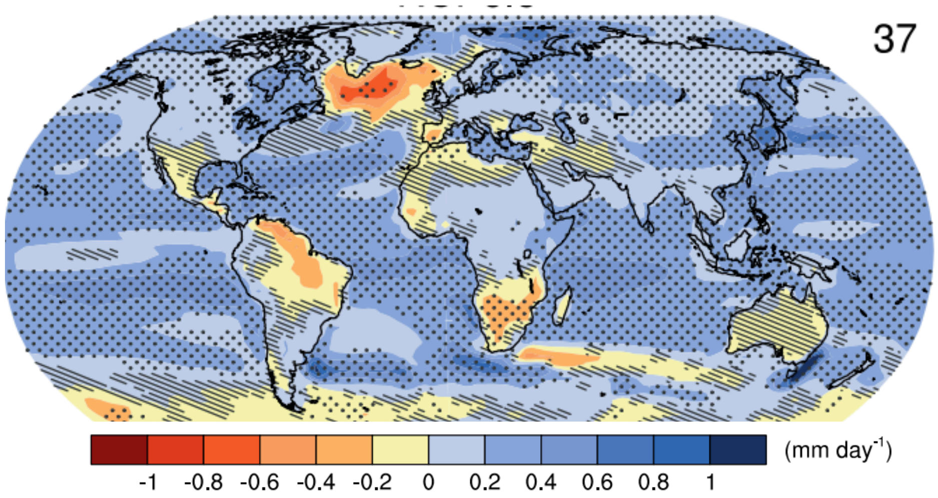
Mean Tran/ET mean LAI, across 23 models



ET partitioning is influenced by vegetation amount (LAI) – which is not *entirely* determined by Pr.

The land ΔET is subtle, and important for general aspects of land-ocean contrast changes (T, q, P…)

Future Annual ΔET (RCP8.5, mm/d)



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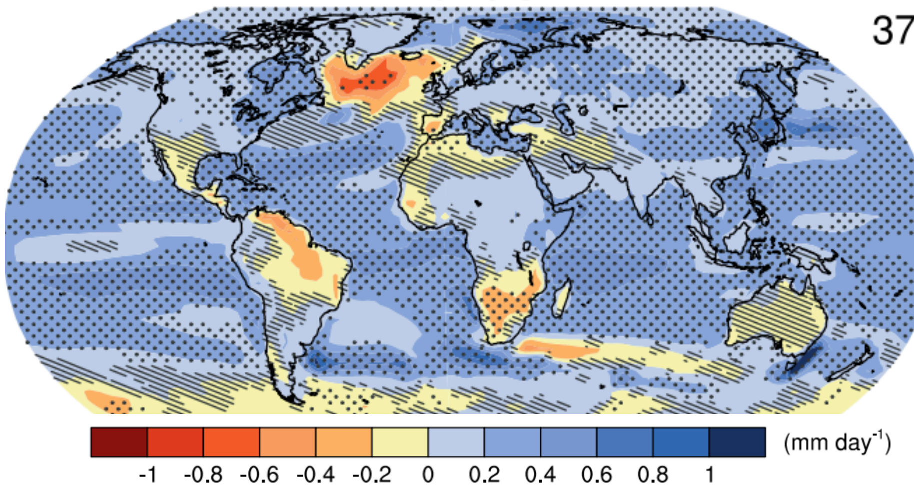
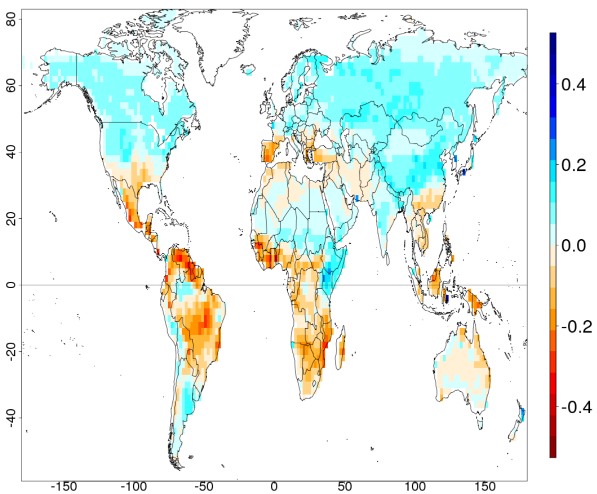
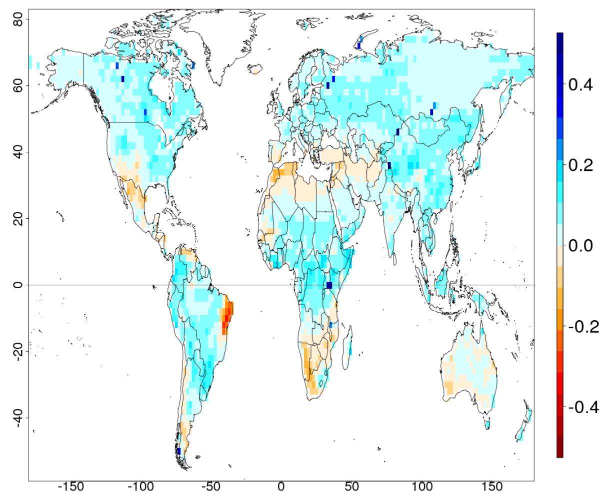


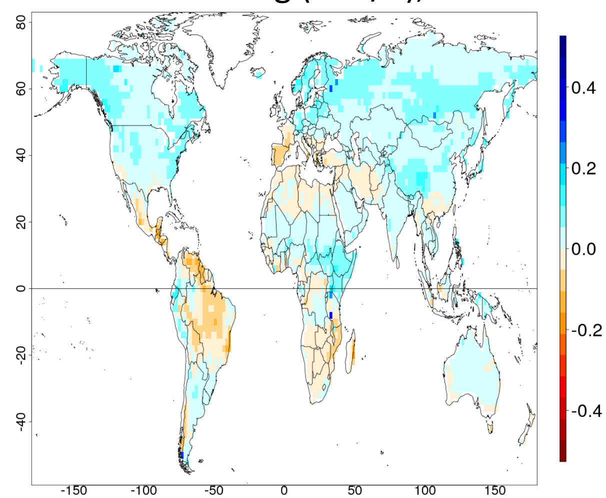
Annual ΔTran (mm/d), 24 models



Annual ΔEsoil (mm/d), 24 models



Annual ΔEveg (mm/d), 24 models



Different components of ET partitioning respond differently to climate change.

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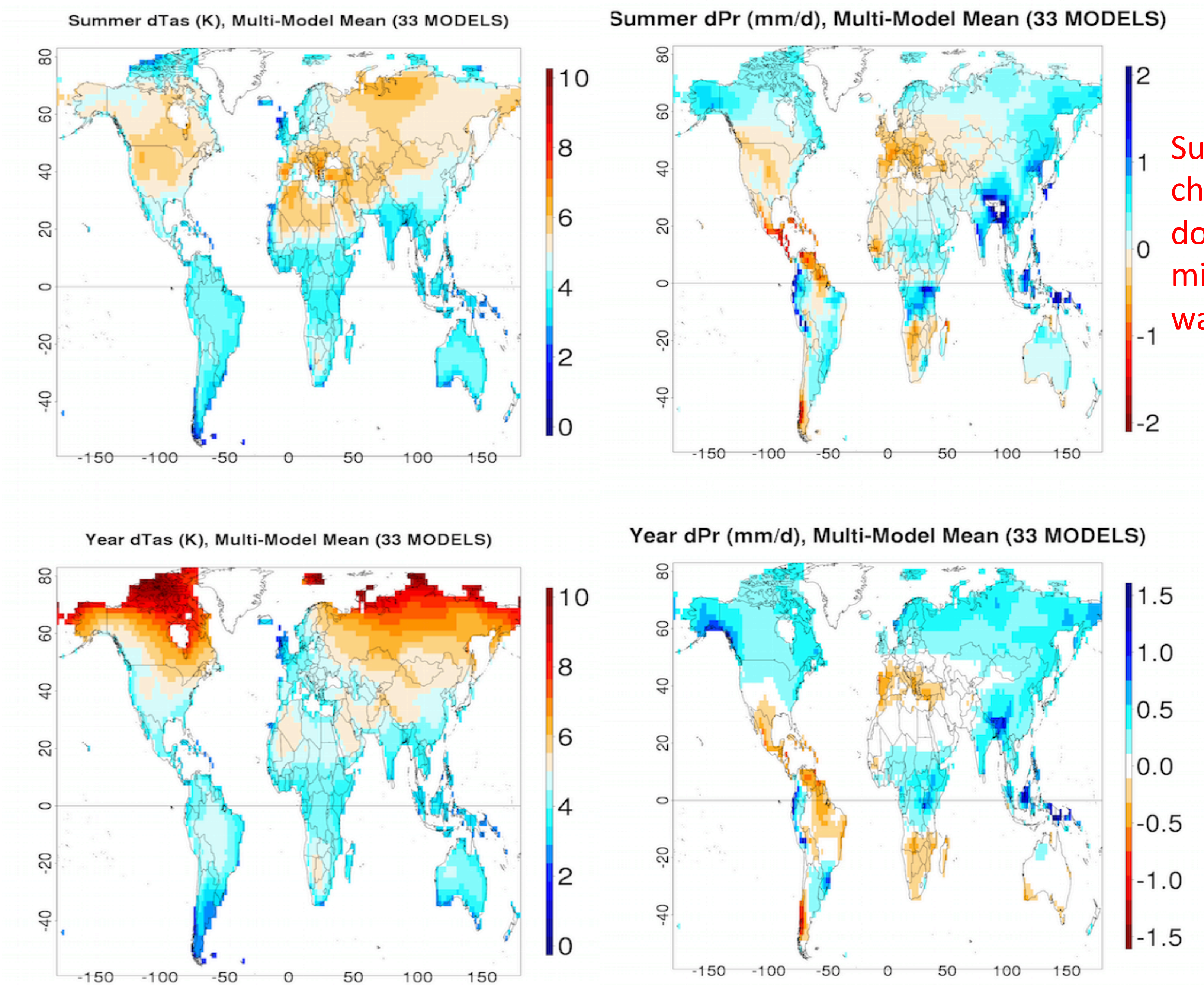
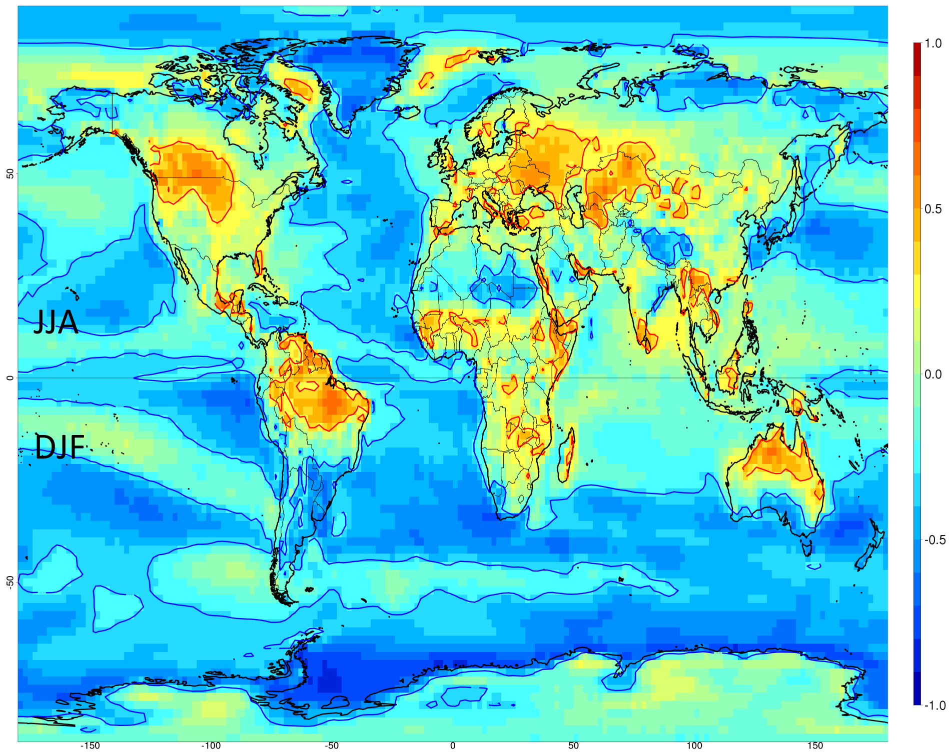


Summer climate change: dominated by mid-latitude warming/drying

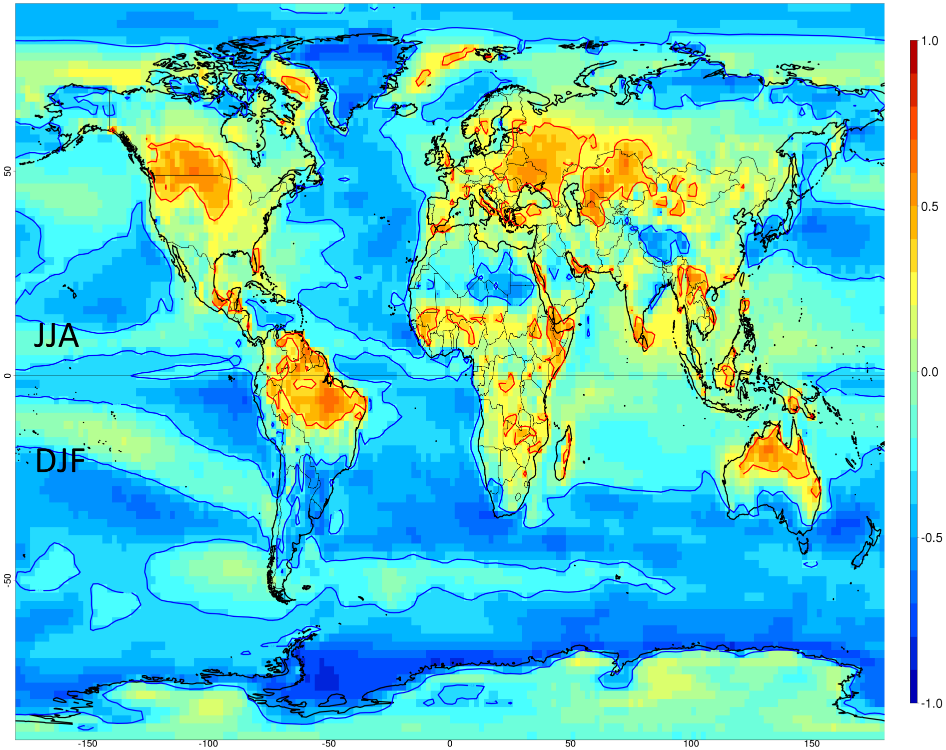
(Annual change)

Cor(Δtas, Tas) across 40 models

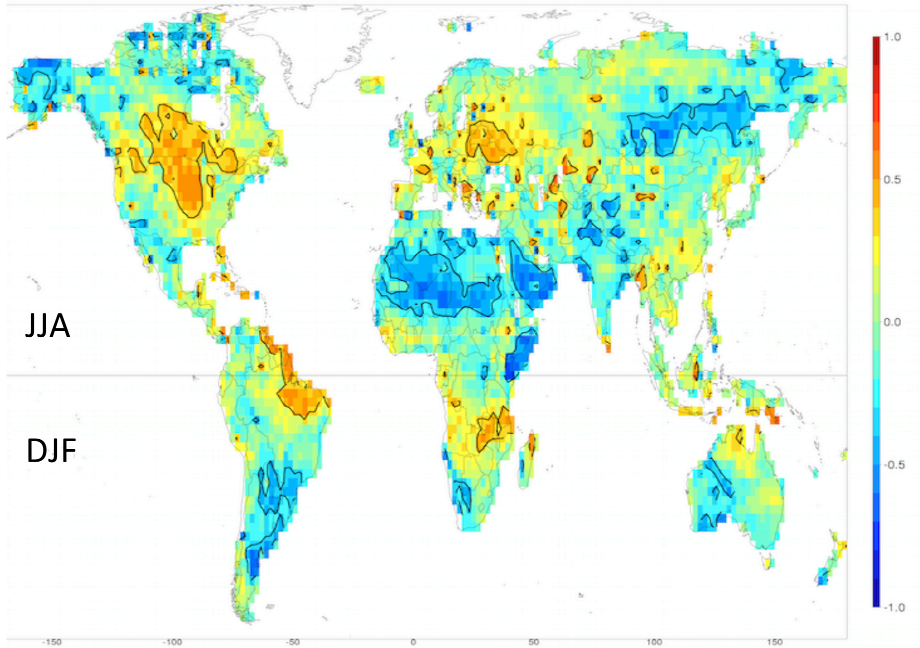


Models with higher present-day summertime temperatures tend to warm more.

Cor(Δtas, Tas) across 40 models



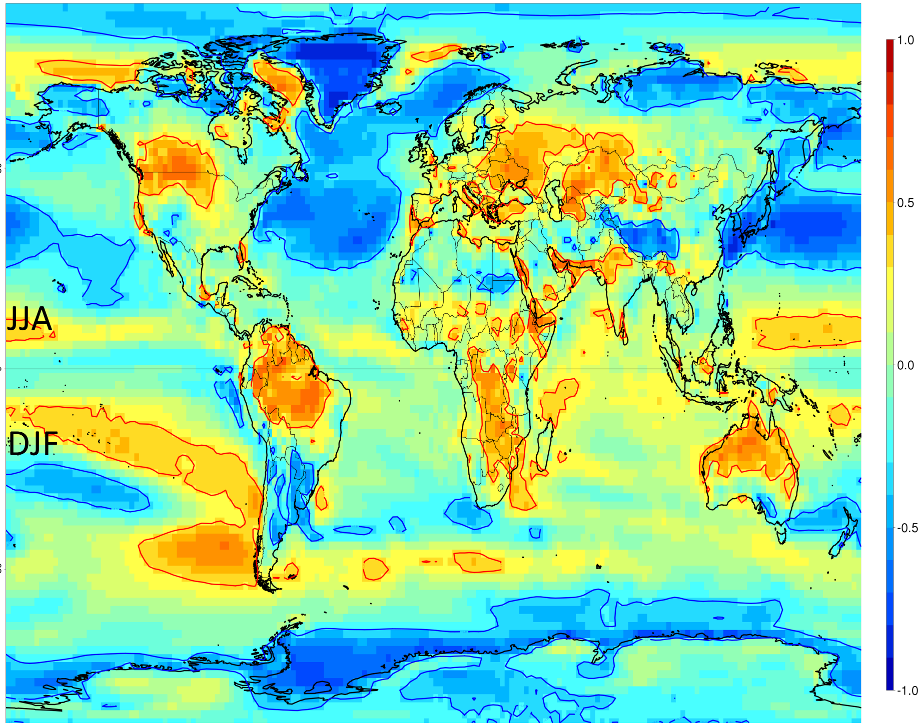
Cor(Δtas, SM-ET coupling) across 33 models



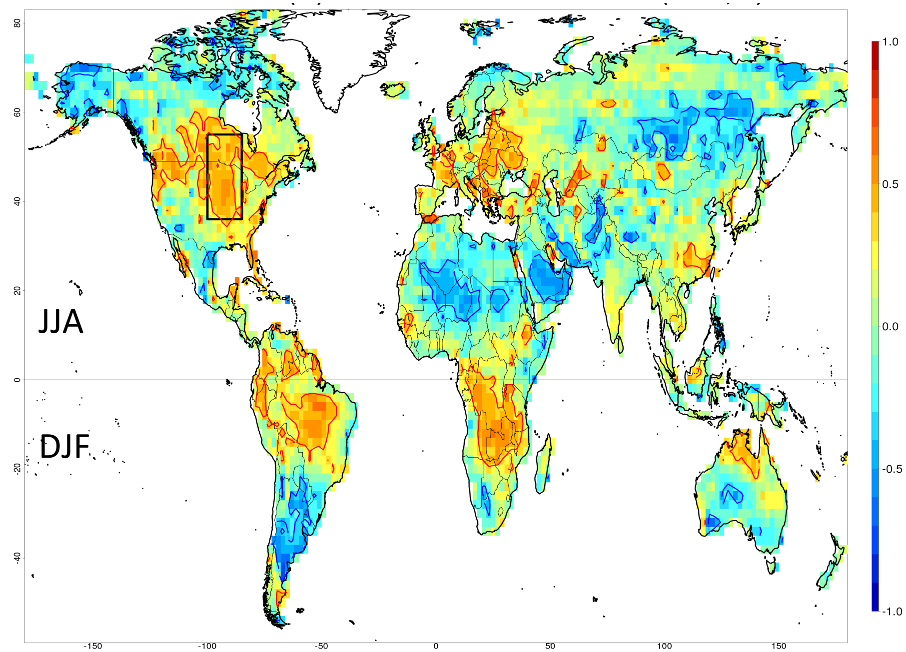
Models with higher present-day summertime temperatures tend to warm more.

In the context of summertime Precip decrease, models that are already more SM-limited in the present tend to warm more in the future.

Cor(**local** Δtas, Tas) across 40 models



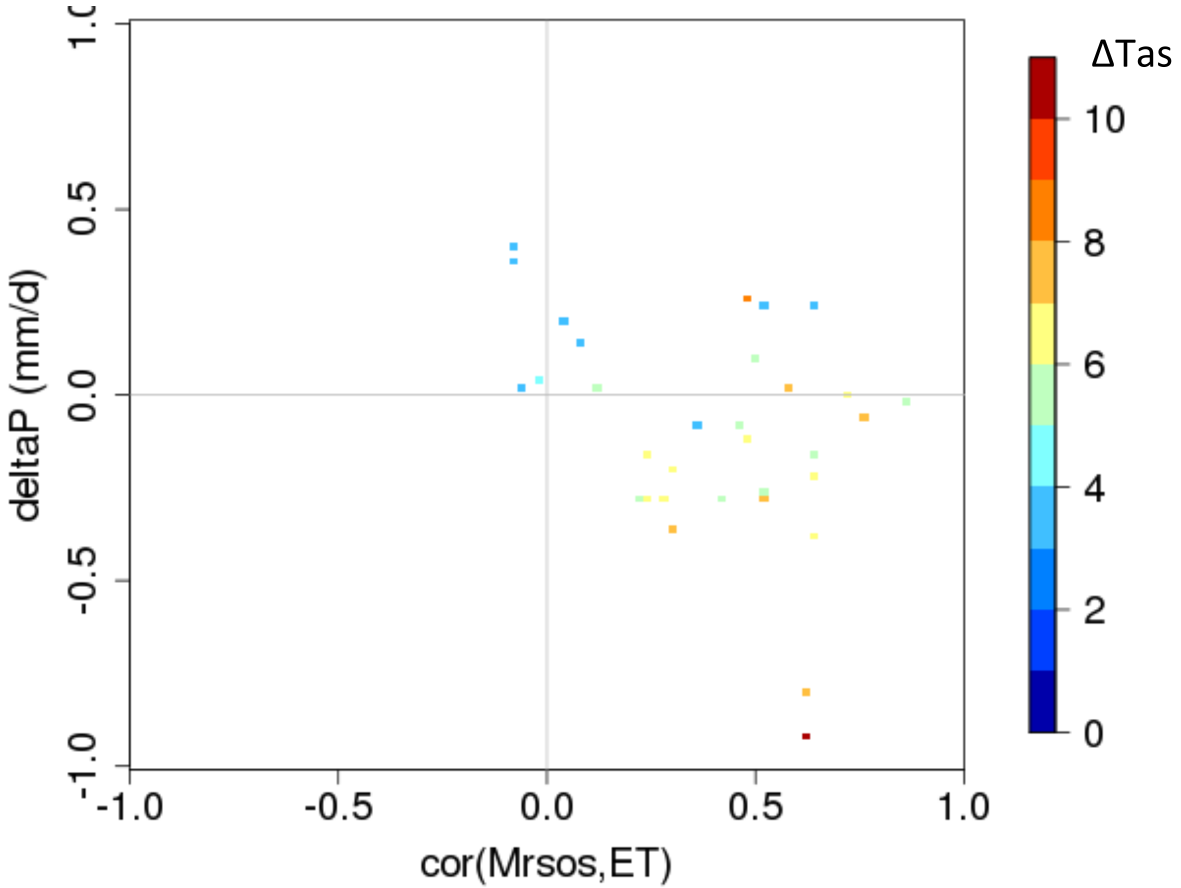
Cor(**local** Δtas, SM-ET coupling) across 33 models



local Δtas(i,j,m)=Δtas(i,j,m) - mean(Δtas(:,:,m))

Models with higher present-day summertime temperatures and greater SM-ET coupling tend to warm more **locally** (local amplification when large-scale warming is removed).

ΔTas = f(SM-ET coupling, ΔP) over Great Plains



Over Great Plains, models that get drier tend to warm the most. These also tend to be the more SM-limited models to begin with.

Conclusions

- Large diversity in SM-ET coupling in CMIP5 models.
- Primarily reflects (but also feedbacks on) differences in mean hydroclimate in models.
- How models partition ET (which varies a lot) influences SM-ET coupling. Most of model spread seems to be associated with Plant Transpiration.
- In some regions of the northern mid-high latitudes, greater SM-ET coupling enhances summertime warming; models may be too dry/warm to begin with.