Investigating soil moisture-evapotranspiration coupling in CMIP5 models

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

E.g., $\text{cor}(SM, ET)$.

We use MRSOS (top-10cm soil moisture) – more comparable across models, and more relevant for surface climate, than total SM.
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\[ \text{Cor(SM surf., ET)} = \text{“Coupling”} \]
Coupling > 0 in dry subtropical and mid-latitudes
Coupling ~ 0 or <0 in Tropics and high latitudes
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Rsd$\Delta$-ET coupling $> 0$ in Tropics
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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
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Models that are more SM-limited are less energy-limited, and vice-versa.

Coupling $> 0$ in dry subtropical and mid-latitudes
Coupling $\sim 0$ or $< 0$ in Tropics and high latitudes
Rsds-ET coupling $> 0$ in Tropics
Tas-ET coupling $> 0$ in high-latitudes
Model spread greater on periphery of area of positive SM-ET coupling and in Tropics.

What causes the spread?
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Correlation across 39 models between summer Mean P and SM-ET Coupling

Models with lower precipitation are more soil moisture limited.
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Estimate of SM-ET coupling based on \( P_{\text{obs}} \) (CRU and U.Del) and regression with model spread

Difference between multi-model mean coupling and \( P \)-based estimate

Systematic regional model biases?
Models where ET is more SM-limited tend to have lower ET and to be warmer.
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.
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Miralles et al. (2016)

ET partitioning is poorly constrained by observations.

Wang et al. (2014)
Different ET components are differently coupled with SM.
Different ET components are differently coupled with SM. Greater model spread for SM-Tran coupling.
Different ET components are differently coupled with SM. Greater model spread for SM-Tran coupling, which explains more of spread in SM-ET coupling.
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Mean $E_{soil}/ET$ vs SM-ET coupling, across 32 models

Mean $E_{veg}/ET$ vs SM-ET coupling, across 35 models

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

Models with more $E_{soil}$ appear more soil moisture-limited.
Models with more $Tran$ appear less soil moisture-limited.
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Annual LAI (m$^2$/m$^2$), 25 models, Present
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ET partitioning is influenced by vegetation amount (LAI) – which is not *entirely* determined by Pr.
The land $\Delta ET$ is subtle, and important for general aspects of land-ocean contrast changes ($T, q, P$...)

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The land $\Delta$ET is subtle, and important for general aspects of land-ocean contrast changes ($T$, $q$, $P$...). 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)
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Cor($\Delta$tas, Tas) across 40 models

Models with higher present-day summertime temperatures tend to warm more.
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Cor($\Delta$tas, Tas) across 40 models

Cor($\Delta$tas, 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.
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**Cor(\textit{local} \Delta\text{tas}, \text{Tas}) across 40 models**

**Cor(\textit{local} \Delta\text{tas}, \text{SM-ET coupling}) across 33 models**

\textbf{local} \Delta\text{tas}(i,j,m) = \Delta\text{tas}(i,j,m) - \text{mean}(\Delta\text{tas}( :, :, m))

Models with higher present-day summertime temperatures and greater SM-ET coupling tend to warm more \textbf{locally} (local amplification when large-scale warming is removed).
$\Delta T_{as} = f(\text{SM-ET coupling, } \Delta P)$ 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.