Aerosol forced tropical rainfall changes in low- and high-res AGCMs

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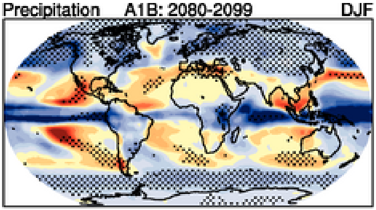
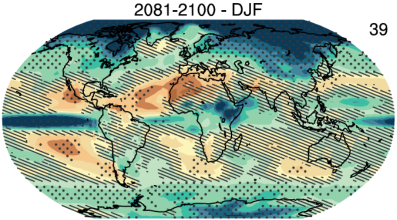
Forced changes to regional tropical rainfall remain poorly constrained

AR4



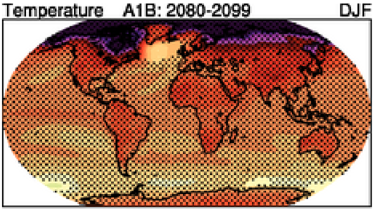
AR5



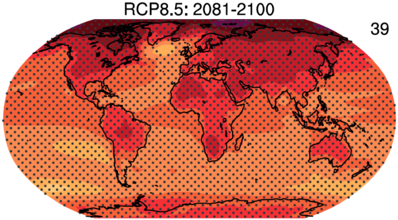
Cool colors=wettening. Warm colors=drying.
Stippling=confident. Hatching=not confident.
DJF shown; similar story year-round.

...despite confidence in δT and well-developed theories linking δT with δP

AR4



AR5



Stippling=confident. (AR5 is now annual mean)

Mean T change: “rich-get-richer”; Hadley cell expansion

e.g. *Chou & Neelin 2004*, *Held & Soden 2006*

Spatial pattern change: “warm-get-wetter”; ITCZ shift towards warmer hemisphere

e.g. *Ma & Xie 2013*, *Frierson & Hwang 2012*

Prescribed SST AGCM simulations can untangle mean and spatial pattern effects

For example, δT induced by historical aerosol emissions:

(as simulated by GFDL AM2.1-slab ocean)

Full $=$ Mean $+$ (Full $-$ mean)

Triplet of AGCM experiments, one for each SST anomaly field

c.f. *Ma & Xie 2013*

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Zonal mean response: "Rich-get-poorer" and ITCZ movement, but model dependence re: when/how much

Sahel wet season: models respond to mean δT differently but to spatial pattern similarly

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A trio of prescribed SST experiments clarifies the mechanisms involved

Equilibrium SST anomalies taken from slab ocean-AM2.1 (“SM2.1”) simulations: PI atmos except PD aerosols

Compare to PI control; from *Ming & Ramaswamy 2009*

Add these anomalies to climatological observed SSTs and use to drive AGCM

Same annual cycle repeated each year

Previous work: use to investigate meridional energy fluxes

Hill et al 2014

Identical trio in 3 GFDL AGCMs to identify robust features

AM2.1*: CMIP3 generation
*with aerosol cloud interactions

AM3: CMIP5 generation
Same resolution; improved physics

HiRAM: high resolution
At cost of simplified physics

AM2.1 replicates zonal mean δP from its parent SM2.1 aerosol experiment

Throughout annual cycle

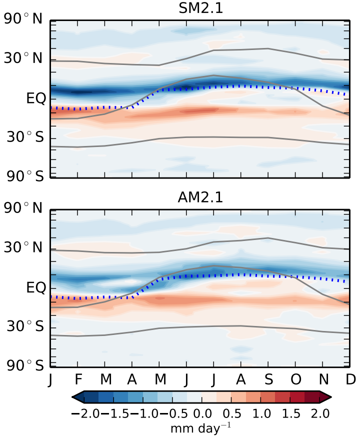
At least to 1st order

ITCZ southward shift clear

As expected

Justifies focus on AGCM runs

At least for zonal mean δP



Cool colors=drying

Blue dots=ITCZ

Grey curves=Hadley cell boundaries

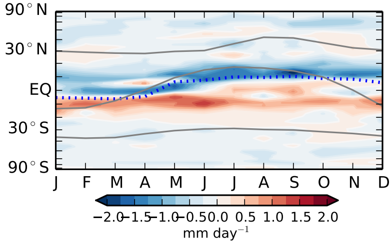
Zonal mean δP is linear to mean/spatial pattern decomposition year-round

At least to 1st order

Some exceptions

So can think of mean and pattern change separately

Then just add them up



Sum of δP annual cycle in aerosol mean and spatial pattern experiments.

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Mean cooling drives “rich-get-poorer” strongest in AM2.1

Tropical mean SST anomaly from SM2.1 $= -1.1$ K

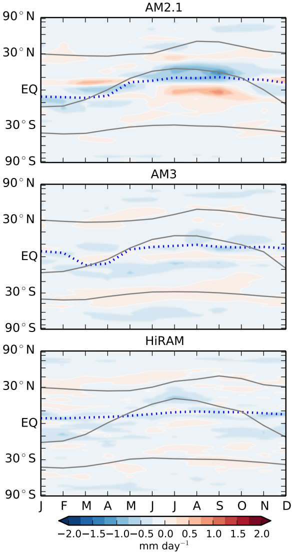
Recall: applied at every ocean gridpoint

Thermodynamic scaling theory: mostly drying, esp. at ITCZ

Since $\delta\overline{T} < 0$

Seems to hold in AM2.1, especially in JAS

Weaker in AM3 and HiRAM



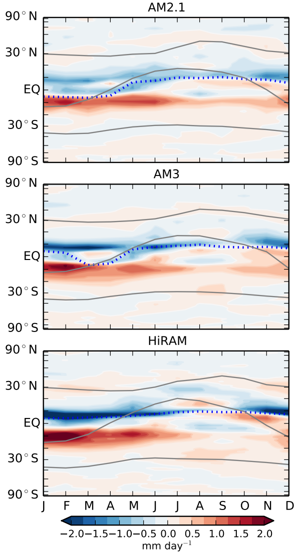
SST spatial pattern pushes ITCZ south weakest during JAS

Strongest magnitudes in HiRAM

Weakest in AM2

ITCZ shift weaker in JAS

Esp. in HiRAM



Full case: models differ in JAS due to both mean and pattern differences

ITCZ shift weaker in JAS for AM3 and HiRAM

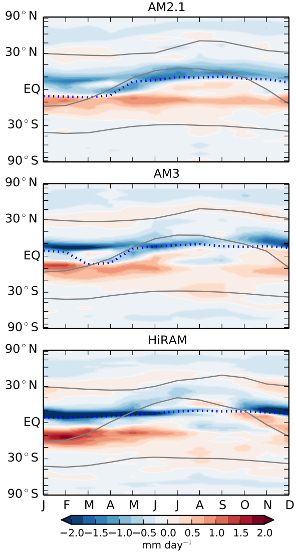
Less seasonal variation in AM2.1

Model differences stem from both mean and spatial pattern

Compensate each other in AM2.1

Why does uniform cooling yield strong JAS δP in AM2.1 only?

Not obviously traceable to climatological P differences



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Model responses to uniform δT differ over Sahel and elsewhere

Known result for uniform warming

Held et al 2005

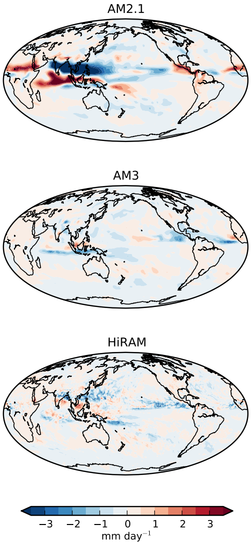
Strong wettening in AM2.1

Slight drying in AM3;

weak/mixed in HiRAM

AM2.1: also weakening of Asian monsoons

Dipole there drives zonal mean



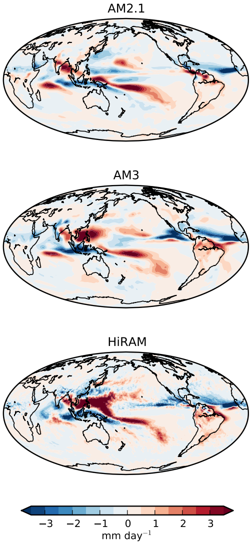
Sahel dries in response to spatial pattern in all three models

Despite very different behavior elsewhere

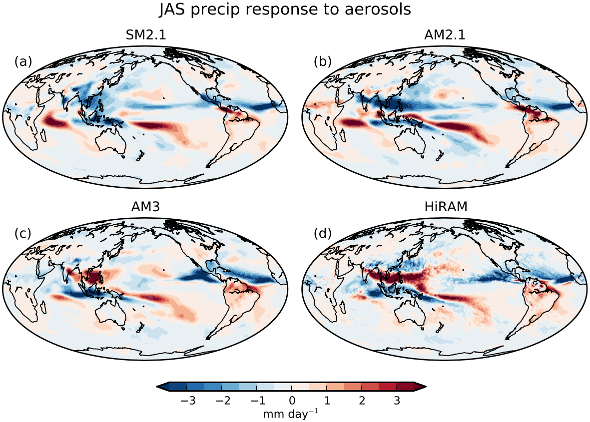
E.g. intense wettening of NW equatorial Pacific in HiRAM

Southward shift of Atlantic ITCZ

Extends over land to Sahel



Full case: AM2.1 doesn't match SM2.1 over Sahel



SM2.1, like AM3 and HiRAM, says mild Sahel drying

Despite agreeing on drying of nearby Atlantic ITCZ

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Response to SST spatial pattern changes more model robust than to mean cooling/warming

System must compensate for NH cooling relative to SH

Hill et al 2014: can only be accomplished via ITCZ movement

True irrespective of model details

Whereas unifom -1.1K more subtle energetically: model idiosyncracies can run wild

Obvious next question: Why such disagreement over uniform δT?

Or do we just ignore the AM2.1 behavior?

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Manuscript in prep for *GRL*
and available soon at my website

Thanks for useful discussions: Leo Donner, Isaac Held, Gabriel Lau