# Is anthropogenic subtropical drying and expansion already occurring?

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DoE Climate Modeling meeting September 2011

Seager, R., N. Naik and G. Vecchi, 2010: Thermodynamic and dynamic mechanisms for large-scale changes in the hydrological cycle in response to global warming. *J. Climate*, **23**, 4651-4668.

Seager, R. and N. Naik, 2011: A mechanisms-based approach to detecting recent anthropogenic hydroclimate change. *J. Climate*, in press.

Also:

Wu, Y. et al. 2011 Atmospheric circulation response to an instantaneous doubling of carbon dioxide, Parts I and II. *J. Climate*, submitted. **See poster session**

IPCC AR4 models project a robust, potent, imminent, drying of the global subtropics and latitudinal expansion of subtropical dry zones

drier change in P-E (mm/day) wetter  $0.1$  $0.2$  $-0.2$  $-0.1$  $0.3$ -0.3 Winkel Tripel projection centered on -90.0°E

Change in P-E (2021-2040 minus 1950-2000)

That will impact southwest North America

*Is this happening?*



## Where are we now?

Coming out of the deep 'turnof-the-century' drought across the West but with intense La Nina + warm tropical Atlantic induced drought in south and Mexico. Is the drought in part human-caused?



### September 13, 2011 **U.S. Drought Monitor** Drought Impact Types Intensity: D0 Abnormally Dry Delineates dominant impacts D1 Drought - Moderate A = Agricultural (crops, pastures, D2 Drought - Severe grasslands) D3 Drought - Extreme H = Hydrological (water) D4 Drought - Exceptional USDA The Drought Monitor focuses on broad-scale conditions.

Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm

Released Thursday, September 15, 2011 Author: Mark Svoboda, National Drought Mitigation Center

### Lake Powell pool elevation



## GPCC station data precipitation trends



Vary depending on time period - because of sampling of decadal variability

*1979-2007*

NCEP-NCAR and ERA-40 agree that southern tropics have expanded based on tropopause height definition. **Only** reproduced in GCM with change in radiative forcing



Deser et al. (2010) c.f. Polvani et al. (2011) - it's the ozone How can we tease out any emerging anthropogenic signal from the tremendous natural variability?

Aim to move beyond analysis of single variables (e.g. *P, T,u,v*) with little attention to mechanisms ....

Idea: a more comprehensive approach is based on a mechanisms analysis of the (multivariate) moisture budget examining both change and variability

### Data:

•15 IPCC AR4 models make all the needed data available. •Climate change is 2045-2065 minus 1961-2000. •For internal variability, compute first EOF of annual mean P-E - it is always ENSO - and composite La Ninas minus El Ninos.

*NCEP, ERA and MERRA Reanalyses contain spurious trends to changing satellite observing systems so instead we use as the stand-in for the real atmosphere:*

(*shock! horror!*) Ground truth is the Compo et al. (2011) 20th C Reanalysis (20CR) - SST-forced, surface pressure assimilating, free of spurious trends. Also an SST forced 16 member CCM3 ensemble.

#### Breakdown anomalies in the moisture budget into mean circulation dynamics (*MCD*), thermodynamic (TH) and transient eddy (TE) and transient eddy (TE) contributions: not humidity, a term relation dynamics (MCD) δMCD = −  $\overline{D}$  $\mathbf{P}$   $\mathbf{P}$  $\mathsf{n}$ ean cir $\mathsf{a}$ . . . . .<br>. . . . .  $\overline{\phantom{a}}$ tion dynamics (MCD),  $\sum_{i=1}^n \sum_{i=1}^n \sum_{j=1}^n \sum_{j$  $t$ n anomalies in the moisture budget into  $\hskip1cm \Box$ can chiculation dynamics  $T(T, T)$  and transient addy  $(T)$ the analysis of the analysis of the analysis of hydroclimate change it has a set of hydroclimate change it has

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 $\mathbf{h}_\text{eff}=\mathbf{h}_\text{eff}+\mathbf{h}_\text{eff}$  influenced only by changes in the mean circulation is called the dynamic influenced only by changes in the dynamic is called the dynamic influenced the dynamic is called the dynamic inf

 $\rho_w g \delta(P - E) \approx \delta T H + \delta M C D + \delta TE - \delta S,$  $\delta T H = \int_{}^{p_s}$  $\overline{0}$  $\nabla \cdot (\mathbf{\bar{u}}_{20} \left[ \delta \bar{q} \right]) dp,$  $\delta MCD = \int_{}^{p_s}$  $\overline{0}$  $\nabla \cdot ([\delta \bar{\mathbf{u}}] \, \bar{q}_{20}) \, dp,$  $\delta TE = \int_{}^{p_s}$  $\overline{0}$  $\nabla \cdot \delta(\overline{\mathbf{u}'\mathbf{q}'}) dp.$  $J_0$  referred to  $20$  $\delta MCD = -\int_{\Omega} \nabla \cdot (\left[\delta \bar{\mathbf{u}}\right] \bar{q}_{20}) dp,$  $\iint$ )  $dp$ ,  $\delta T F = \int^{p_s} \nabla \cdot \delta(\overline{\mathbf{u}' \alpha'}) d\alpha$ 

δT H and the term influenced only by changes in the mean circulation is called the dynamic

climate change:  $\delta(\cdot) = (\cdot)_{21} - (\cdot)_{20}$ , internal

where subscripts 20 and 21 indicate 20 and 21 indicate 20th Century and 21st Century values of the quantity va<br>Century values of the quantity values of the quantity values of the quantity values of the quantity values of

in parentheses. The parentheses is the parenthese service of the parentheses in the parentheses in the parentheses.

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The term influence only by change:  $\sigma(\cdot) = (\cdot)_{21} - (\cdot)_{20}$ , wariability:  $\sigma(\cdot) = (\cdot)_{LN} - (\cdot)_{EN}$ ,  $\delta(\cdot) = (\cdot)_{21} - (\cdot)_{20},$  internal  $\delta(\cdot) = (\cdot)_{LN} - (\cdot)_{EN},$ variability:

where subscripts EN and LN indicate typical EN and LN indicate typical El Niºno and La Niºna values of the qua<br>Classical El Niºna values of the quantity electronic typical El Niºna values of the quantity electronic typica

change in the boundary term.

### MMM - Climate Change



Tropical wetting, subtropical drying strongly influenced by rising *q* and intensified moisture convergence and divergence. Mean circulation change weaker tropical circulation, Hadley Cell expansion - also important as well as TE intensification and poleward shift. *'Thermodynamics mediated.'*

#### MMM - Natural Variability  $\delta(P - E)$  δTH 0˚ 30˚E 60˚E 90˚E 120˚E 150˚E 180˚ 150˚W 120˚W 90˚W 60˚W 30˚W lon 60˚S 30˚S 0˚ 30˚N 60˚N ಿದ -4  $-2 -1 -6$ -0.3 -0.1 -0.1 -0.1 -0.1 -0.1 -0.1 -0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.3 0.3 0.6 1 1 1 1.5 0˚ 30˚E 60˚E 90˚E 120˚E 150˚E 180˚ 150˚W 120˚W 90˚W 60˚W 30˚W lon 60˚S 30˚S 0˚ 30˚N 60˚N <u>ਕਿ</u>ੰ -0.6 -0.3  $-0.1$   $-0.1$ -0.1 -0.1 -0.1 -0.1 -0.1 -0.1  $+0.1$ 0.1  $0.1$ 0.1 0.1 0.1 0.1  $0.1$ 0.1 0.3  $0.6 - 30.3$  $\delta MCD$   $\delta T E$ 0˚ 30˚E 60˚E 90˚E 120˚E 150˚E 180˚ 150˚W 120˚W 90˚W 60˚W 30˚W lon 60˚S 30˚S 0˚ 30˚N 60˚N <u>ក</u>្ -5 -4  $-3$   $-2$  -1 -0.6 -0.6 -0.6 -0.3 -0.3 -0.3 -0.3 -0.3 -0.1  $-0.1$   $-0.1$ -0.1 -0.1 -0.1 -0.1 -0.1 -0.1 -0.1 -0.1  $0,1$ 0.1 0.1  $0.1$ 0.1  $0.3$  0.3 0.3 0.3 0.6 0.6  $1$   $1$ 1.5 2 90°E 120°E 150°E 180° 150°W 120°W 90°W 60°W 30°W lon 60˚S 30˚S 0˚ 30˚N 60˚N  $\frac{1}{2}$ ಕೆ -0.1 -0.1 -0.1 -0.1 0.1  $0.1$  $0.1$ 0.1 0.1 0.1 0.3 0.3

## For internal variability - mostly ENSO - thermodynamic contribution is weak and *P-E* is *'Dynamics dominated'*.

### Compo - Natural Variability  $\delta(P - E)$  δTH











## IPCC AR4 mechanisms of internal P-E variability are remarkably similar to observed.

Tuesday, September 20, 2011

MMM omega  $(= dp/dt)$ 

Both climate change and La Nina have similar subtropical-tomidlatitude circulation features (poleward shifted easterlies and descent). Tropical changes are almost opposite

climate change in vertical velocity







So, despite similarity of extratropical *P-E* patterns, climate change and La Nina-induced subtropical-to-midlatitude drying:

1. have a different mix of dynamic and thermodynamic mechanisms

2. have different signatures in tropical circulation and thermal structure

Use this distinction to attribute post-1979 *P-E* change

### Post-1979 P-E change in 20CR  $P_{\text{oct}}$  1979  $P$  E shange in  $20 \cap P$

residual field contains any climate 'noise' that is not captured by the first two modes and

the IPCC AR4/CMIP3 estimate of the radiatively-forced change. Next, we compute the

Post-1979 because this is the satellite period used by others. Post-1979 because this is the satellite period used by others.

Divide P-E into that part explained by the first two EOFs (both ENSO) and a residual.  $\mathsf{E}[S]$  and a responsibility of the mechanisms responsible would are measured with  $\mathsf{E}[S]$ 

$$
P - E = \sum_{n=1}^{2} a_n(t) p_n(x, y) + (P - E)_R,
$$

 $\blacksquare$ are the residual: the residual patterns, pn(x, y), or P  $\epsilon$  variable by  $\epsilon$  variable by  $\epsilon$ Regress the contributions onto the PCs to get contributions to the residual:

$$
P - E = \sum_{n=1}^{2} a_n(t) (TH_n + MCD_n + TE_n) + TH_R + MCD_R + TE_R,
$$

describe the components of the residual contribution. The procedure is to obtain the

The first three terms on the first three terms on the right hand side of this equation describe the components of this equation describes  $\mathcal{L}_\text{max}$ 

 $\overline{C}$  and  $\overline{C}$  for  $\overline{C}$  for  $\overline{C}$  for  $\overline{C}$ . Compute trends in total, internal variability and residual. Compute trends in total, internal variability and residual.

The actual P-E trend does have widespread subtropical drying but also equatorial drying.

The part of this trend due to ENSO-variability largely explains the equatorial drying and some of the subtropical-to-midlatitude drying

The residual trend, with equatorial wetting, and subtropical-tomidlatitude drying has some GHG-driven character



Very similar results as from 20CR appear in the purely SST-forced GCM ensemble mean residual trends akin to AR4 post-1979 trends





## How do mechanisms of AR4 and residual trend compare?



P-E trends largely agree in structure and amplitude, agreement on MCD importance in tropics, TH contribution to wet-getwetter, dry-get-drier. All modest for 1979 to now, as expected.

Compo total trend



0˚ 30˚E 60˚E 90˚E 120˚E 150˚E 180˚ 150˚W 120˚W 90˚W 60˚W 30˚W lon

0

 $\begin{array}{|c|c|c|c|c|c|}\hline \text{0.5} & \text{0.5} & \text{0.5} \\\hline \end{array}$ 

For the SSTs, separation into ENSO trends and residual trends converts tropical east Pacific cooling into equatorial warming akin to AR4.



residual trend

### Conclusions

Clear distinction in the mechanisms of natural subtropical-to-midlatitude drought ('dynamics dominated') and anthropogenic subtropical drying ('thermodynamics mediated').

Allows mechanisms-based separation of post-1979 P-E change into that due to internal variability and a residual (which contains forced change) with equatorial-wetting and subtropical-to-midlatitude drying, as for AR4.

The mechanisms of residual P-E change, and associated circulation change, also consistent with AR4.

I.e. evidence, based on the inherently multivariate, moisture budget that hydroclimate change is occurring with amplitude and pattern consistent with AR4. But currently relatively small c.f. internal variability on interannual to decadal timescales.