External influences on precipitation mean state and variability

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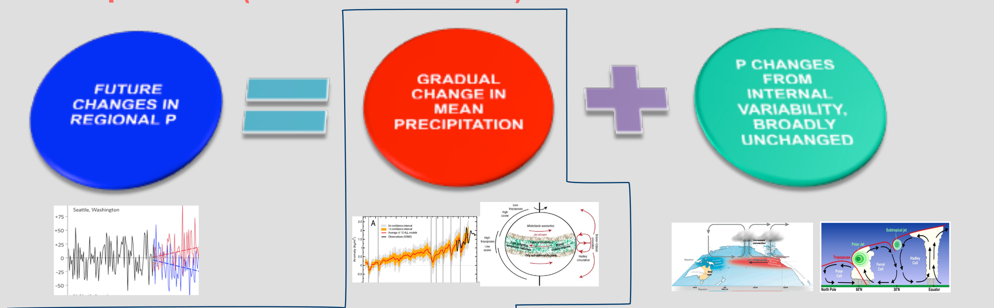
The relative contribution of drought precursors may change in response to global warming

Introduction

Changes in global (ocean and land) precipitation are among the most important and least well-understood consequences of climate change.

In a simple case (Collins et al. 2010)...

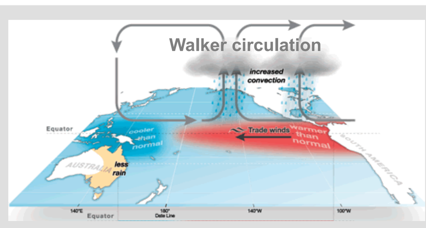


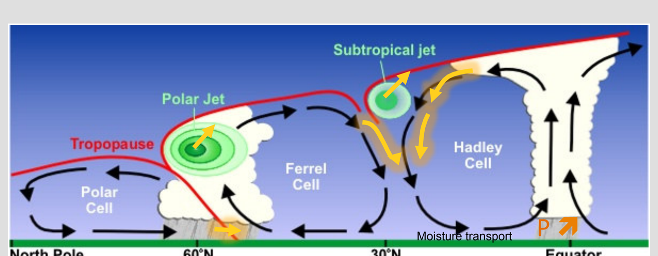
- Is this already occurring (detection)?
- Can we attribute it to specific external forcings (attribution)?

- Will ENSO change in the future?
- Will ENSO teleconnections change in the future, invalidating this scenario?

ENSO: primary source of drought variability in many regions via teleconnections

El Niño

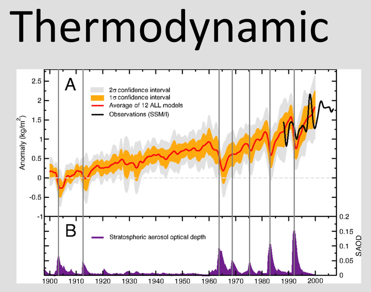




- Warmer/wetter tropical eastern Pacific
- Drier than usual in Indonesia and part of Australia
- Equatorward retreat of subtropical dry zones

Alternative drought precursors expected in a warming world

Thermodynamic

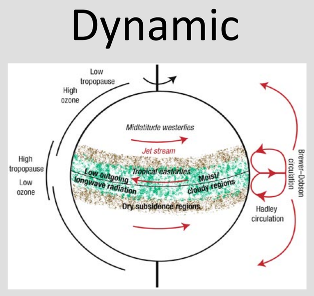


Santer et al 2007

Intensification of current zonal wet-dry patterns

- Clausius-Clapeyron: water vapor increases ~ exp(T)
- Held & Soden 2006: wet regions get wetter, dry regions get drier

Dynamic



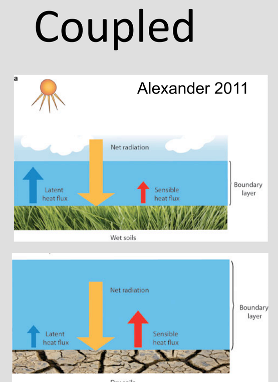
Seidel et al 2007

Latitudinal redistribution of global precipitation

- Ozone depletion and increasing GHG both expected to shift circulation poleward
- Observational evidence that major features are shifting poleward

Coupled

Alexander 2011



Reduction in local soil moisture and P recycling

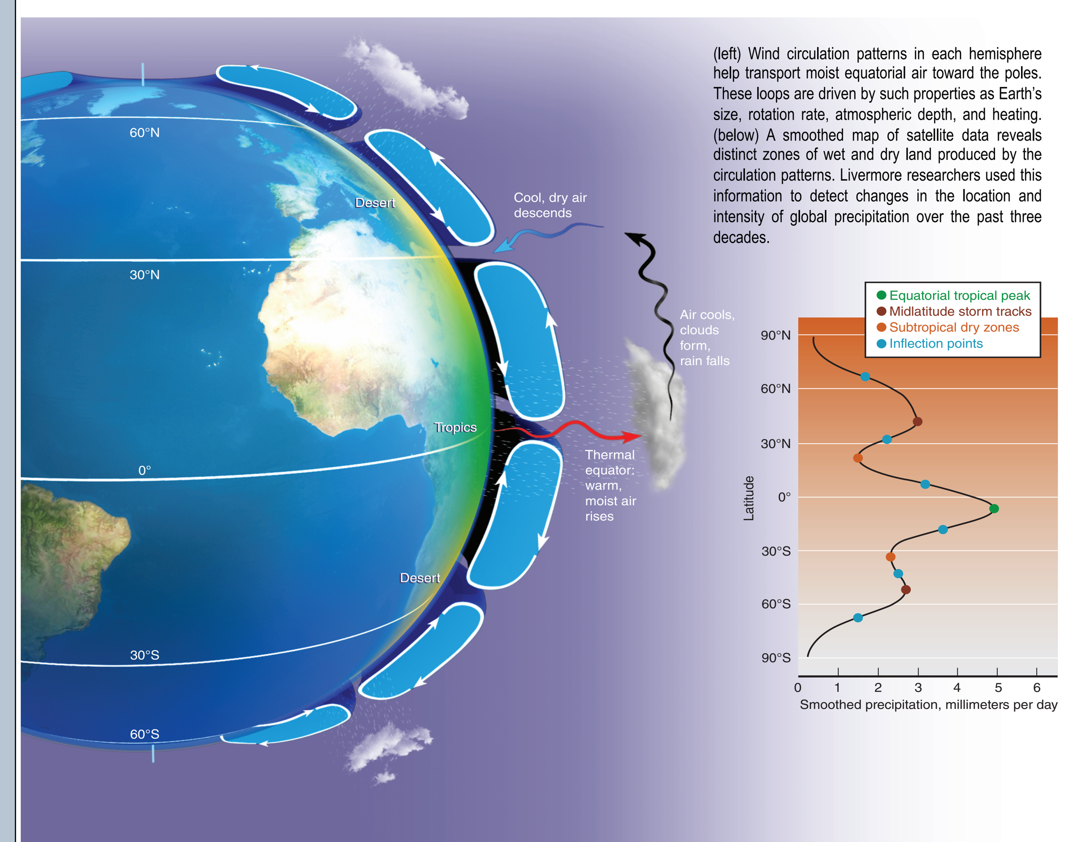
Can we see theses changes emerge in the observations?

Methods

- Observations: Global Precipitation Climatology Project (GPCP); 33 years of data (1980-2012)
- Boreal winter (Dec-Jan-Feb) means
- 70+ simulations of the "historical" + "RCP8.5" climate that include climate noise + natural forcings + human forcings ("world with us")
- Control simulations to obtain ~20k years of climate noise ("world without us")

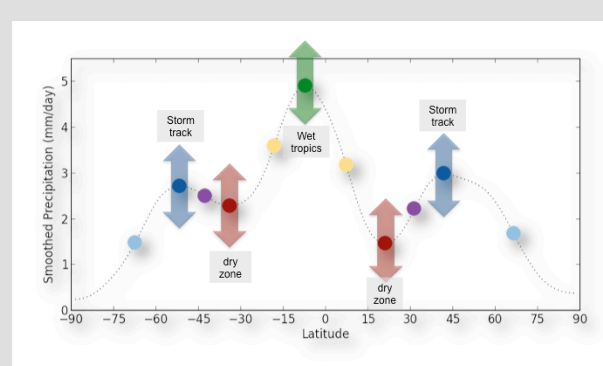
Historical changes in zonal-mean precipitation

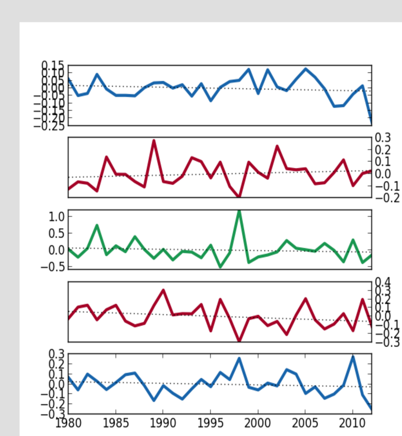
Smooth and Zonally average DJF Precipitation



Rendering by Kwei-Yu Chu

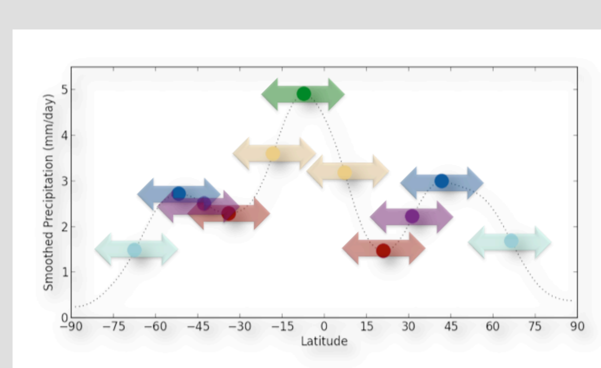
Thermodynamic indicator T(t)

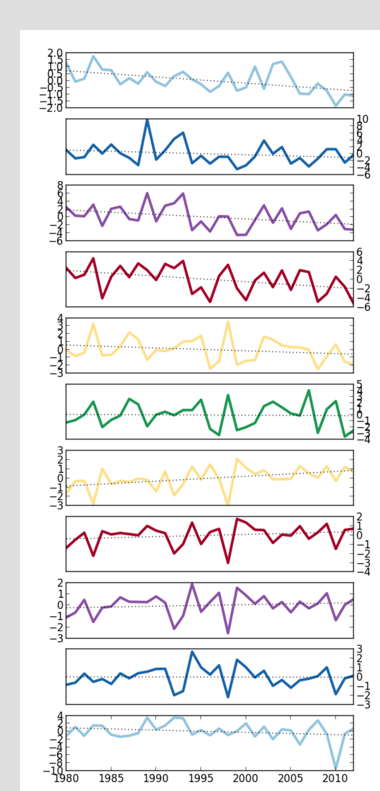




1980-2012 intensity anomaly at peaks/troughs
How wet is the wettest latitude? *How dry* is the driest?

Dynamic indicator D(t)





1980-2012 latitude anomaly at peaks/troughs
Where are the wettest and driest latitudes?

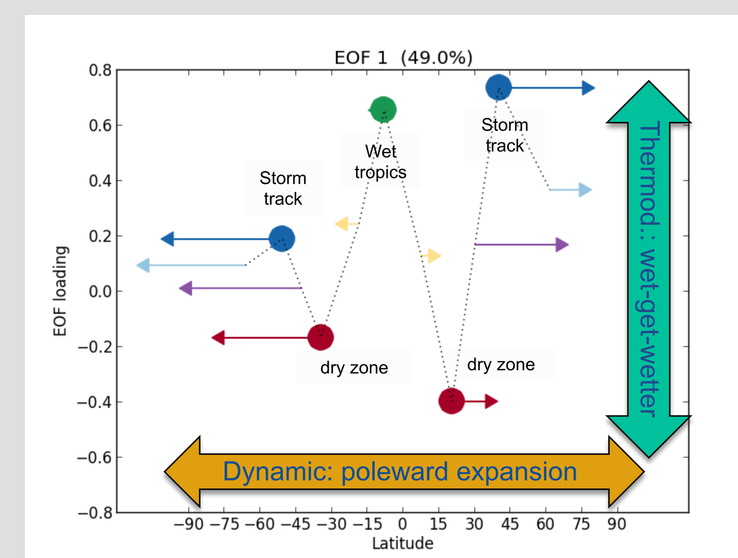
Identification of human fingerprint in zonal-mean precipitation

Fingerprint = Spatial pattern expected in response to external forcing

How do we get it?

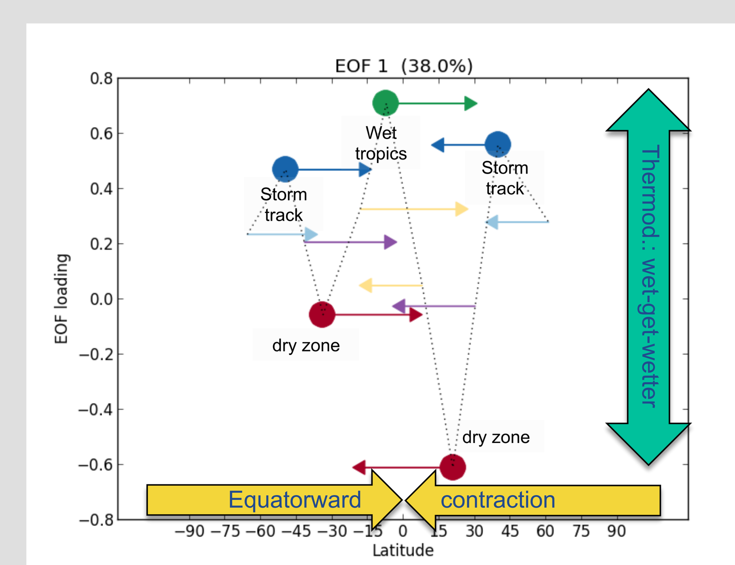
1. Average over historical simulations (world with us) → beat down noise (uncorrelated noise across simulations)
2. Fingerprint = first EOF of multimodel average → extract mode of variability explaining most of the variance

Fingerprint expected in response to external forcing



Primary noise mode (ENSO)

ENSO mode cannot project on our fingerprint
This multivariate fingerprint acts as an automatic noise filter



Acknowledgements

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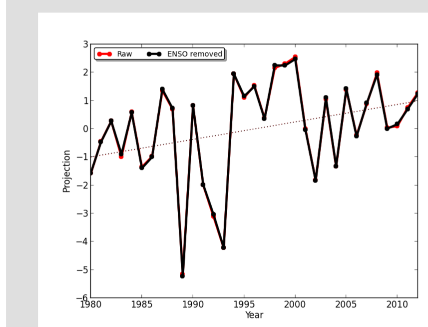
Alexander, L. (2011) Extreme heat rooted in dry soils, Nature Geoscience, 4, 12–13.
Collins, M. *et al.* (2010) The impact of global warming on the tropical Pacific ocean and El Nino. *Nature Geoscience* 3, 391-397
Held, I. & Soden, B. (2006) Robust responses of the hydrological cycle to global warming. Journal of Climate 19, 5686-5699
Marvel, K & Bonfils C. (2013) Identifying external influences on global precipitation, PNAS, 110(48):19301-19306
Santer BD, et al. (2007) Identification of human-induced changes in atmospheric moisture content. PNAS 104(39):15248–15253
Seidel DJ, Fu Q, Randel WJ, Reichler TJ (2007) Widening of the tropical belt in a changing climate. Nat Geosci. 1:21–24
Vecchi, G. & Wittenberg, A. (2010) El Niño and our future climate: where do we stand? Wiley Interdisciplinary Reviews-Climate Change 1, 260-270

This study, published in PNAS (Marvel and Bonfils, 2013) ,will also be featured in the June 2014 issue of LLNL's Science &Technology Review.

Observed trend is compatible with externally forced climate

Projection analysis

We project observed D(t) and T(t) anomalies onto fingerprint:
= measure the similarity between 1980-2012 data and fingerprint
→The positive trend in projection time-series means that the fingerprint is present and growing in the observations.



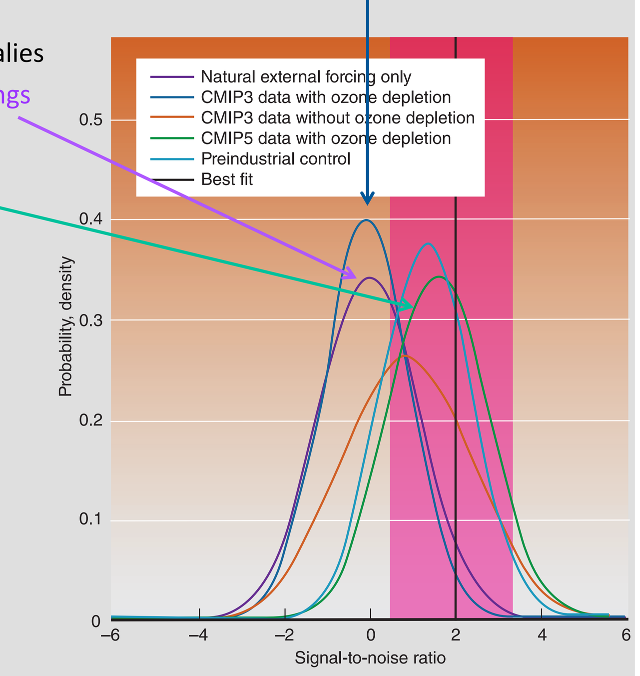
- Attempt to remove ENSO first has no impact (multivariate fingerprint is an efficient noise filter)

Observed trend cannot be explained by internal variability

We project D(t) and T(t) anomalies from hundreds 33-year periods of unforced climate (world without us) to obtain noise time-series
There is no reason for the fingerprint to project, except by chance
→ **Typical Signal-to-noise problem**

We also project D(t) and T(t) anomalies from runs forced with natural forcings alone, or various combinations of natural and human forcings.

This graph shows the probability distribution of the signal (that is, similarity of the fingerprint relative to the noise from naturally occurring climate variability). The observed signal matches predictions generated by climate models that include both natural and human-induced external forcings.



Rendering by Kwei-Yu Chu

This work, in a more global context

Future changes in P will be increasingly driven by human-induced mechanisms superimposed to intensified historical ENSO-driven P variability.

Results

This study provides evidence that human activities are affecting precipitation over land and oceans. Anthropogenic increases in greenhouse gases and stratospheric ozone depletion are expected to lead to a latitudinal intensification and redistribution of global precipitation. However, detecting these mechanisms in the observational record is complicated by strong climate noise and model errors. We establish that the changes in land and ocean precipitation predicted by theory are indeed present in the observational record, that these changes are unlikely to arise purely due to natural climate variability, and that external influences, probably anthropogenic in origin, are responsible.

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