Strengthening of the Walker Circulation in recent decades

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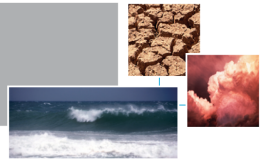
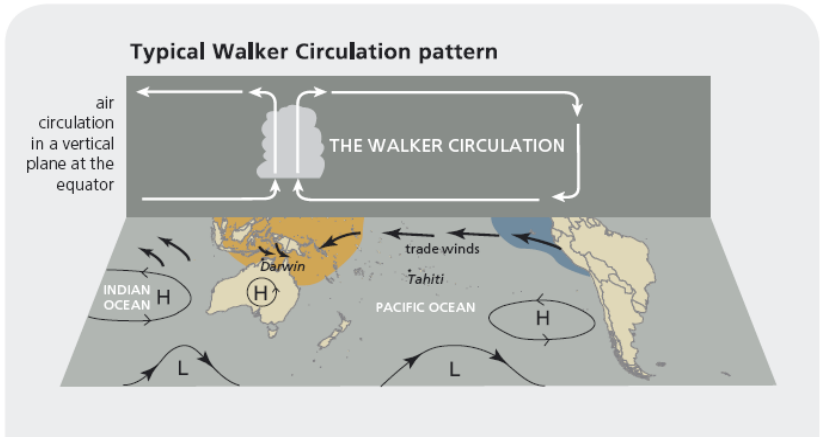
WCRP-ICTP DCVP Workshop, Trieste, Italy, Nov 16-20, 2015

Issues we'll address



- How has the Walker Circulation changed since 1900? In more recent decades?
- Do CMIP5 models simulate the observed trends since 1900 and 1980?
- If not, why not?
- What are implications of inconsistency for the confidence we have in projections?
- What are key challenges and opportunities?



Journal of Climate, 2015

Inability of CMIP5 Models to Simulate Recent Strengthening of the Walker Circulation: Implications for Projections

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ABSTRACT

This paper examines changes in the strength of the Walker circulation (WC) using the pressure difference

Acknowledgements

Jian-Jia Luo and Dietmar Dommenget

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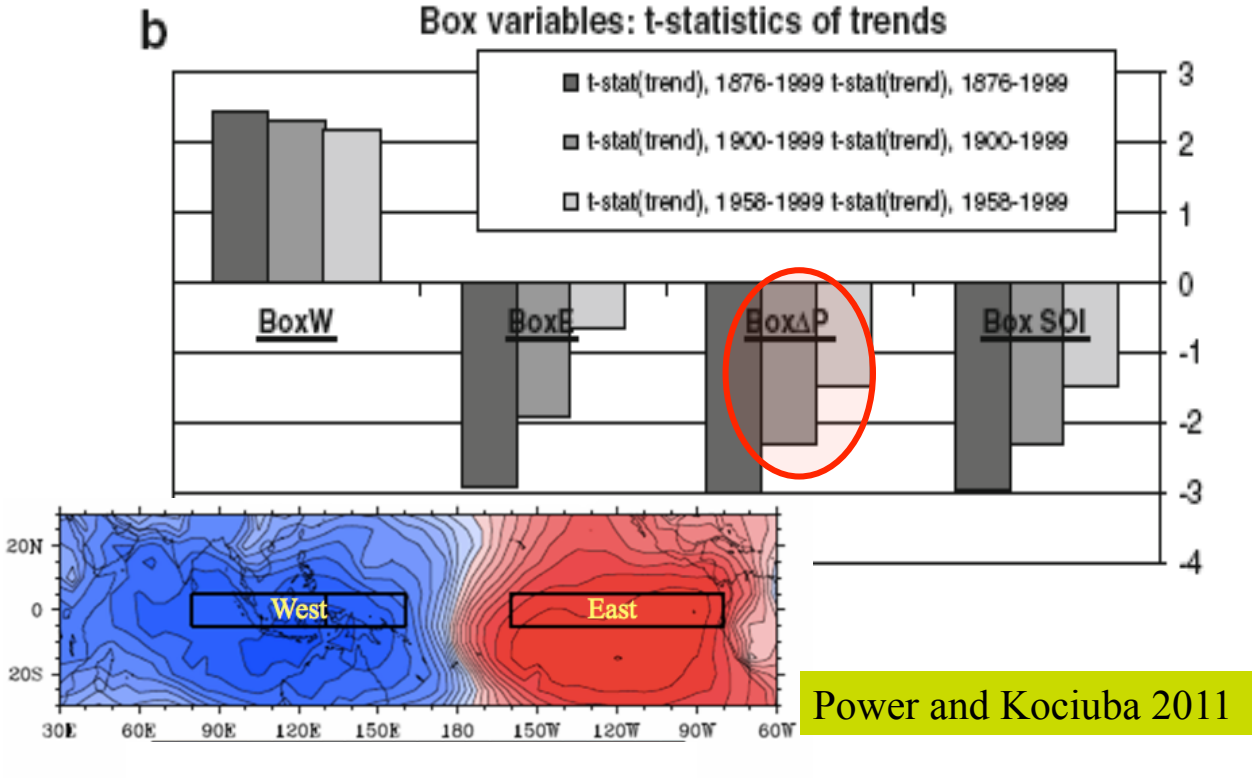
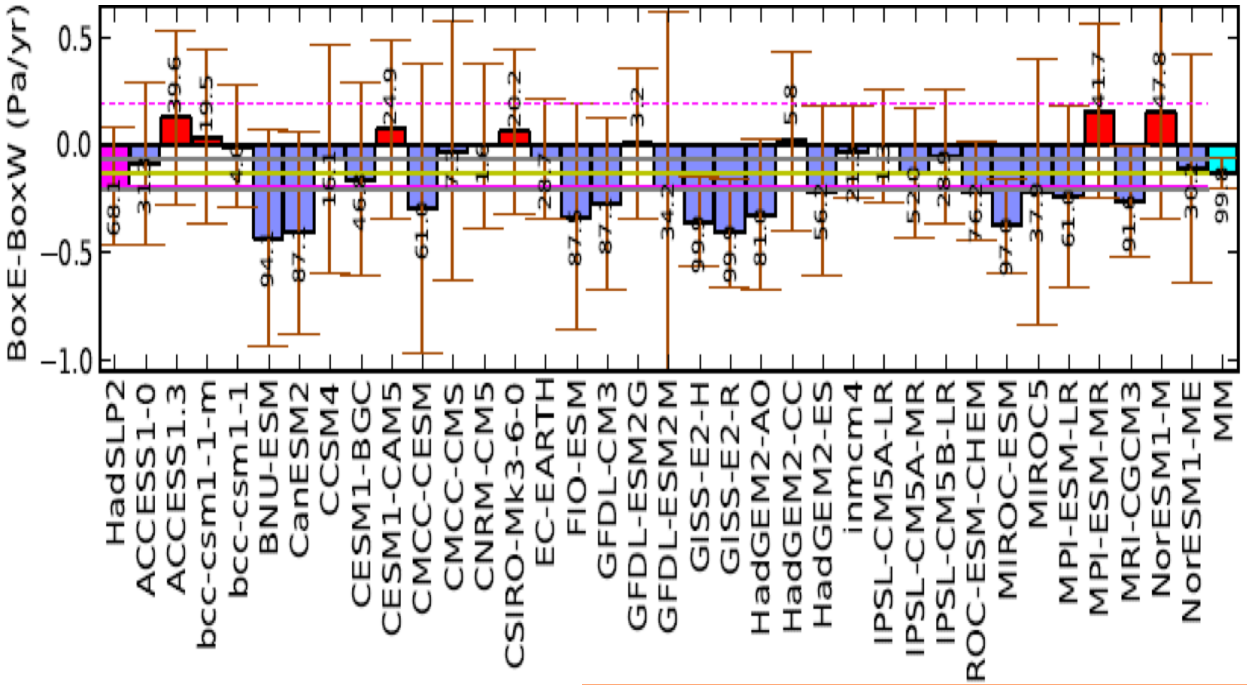
Walker circulation weakened over 20th century

Weakening over the 20th century



Power and Kociuba 2011

Trends in observations and CMIP5 models 1900-2012



Kociuba and Power, *J. Climate*, 2015

Earlier Conclusions:

- Both external forcing and internally generated variability needed to account for the observed weakening of the Walker Circulation over the twentieth century

- External forcing accounts for approximately 30%-70% of the observed weakening with internally generated climate variability making up the rest

Power and Kociuba, *J. Climate*, 2011

⇒Models and obs are consistent

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⇒Observed trend driven by combination of external forcing and internal variability

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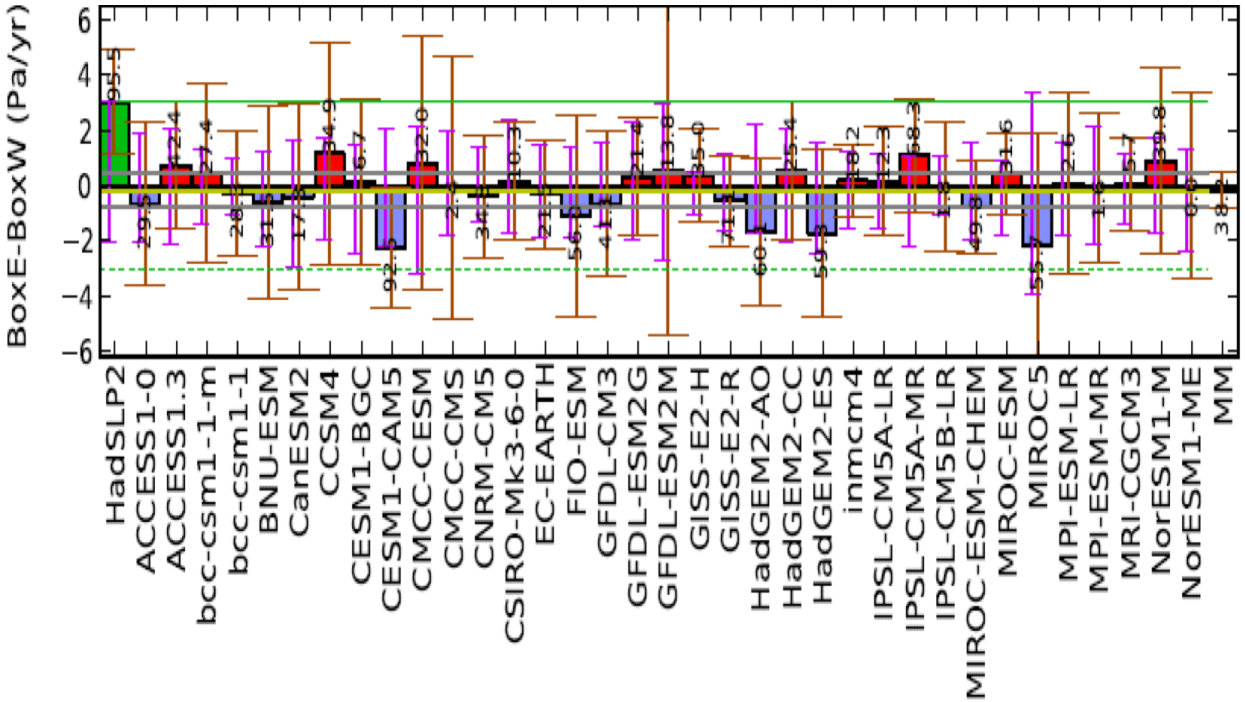
⇒Observed trend driven by combination of external forcing and internal variability

⇒The world is simple!

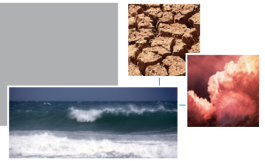
⇒Climate science is sooo easy!

Changes over the last few decades

Trends in observations and CMIP5 models 1980-2012



1980-2012



- Observed, statistically significant strengthening of Walker circulation over 1980-2012
- No CMIP5 models exhibit a trend this large
- CMIP5 models are evenly split on increases and decreases over this period
- No models exhibit statistically significant trends over this period
- MMM <0, but weak, not statistically significant

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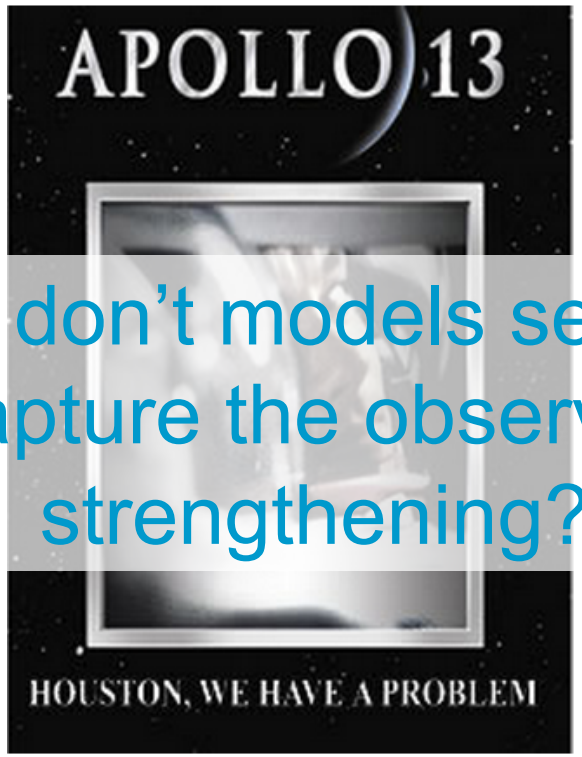
Recent interdecadal strengthening of the Walker Circulation

- Sohn et al. (2013) 1999-2008 (SST, wind, convection, MSLP)
- Sohn and Park (2010) 1998-2005 (SSMI data)
- L'Heureux et al. (MSLP) 1982-2011
- England et al. (2014) strengthening of the trade winds, 1993-2011
- …


APOLLO 13
might
HOUSTON, WE HAVE A PROBLEM



Why don’t models seem to capture the observed strengthening?

Can internal variability explain the inconsistency?

- *i.e.*, does the observed trend primarily arise from unusually large internal variation in the real world?
- How unusual?
  - Change is statistically significant
  - It is unusual in terms of observed variability
  - Is it also unusual in terms of model variability?

Variability in pre-industrial runs

- 32 CMIP5 models with long pre-industrial runs
- Runs 200-1156 years long, average≈500 years
- 17,357 years of output
- Trends calculated for all possible 33-yr windows
- 11+ and 15- events, or 1.5 events/millennium – a rare event
- Only one model (GFDL-ESM2M) has multiple events

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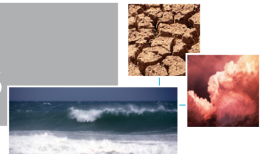

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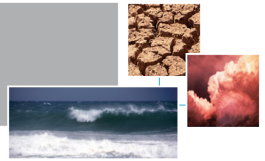
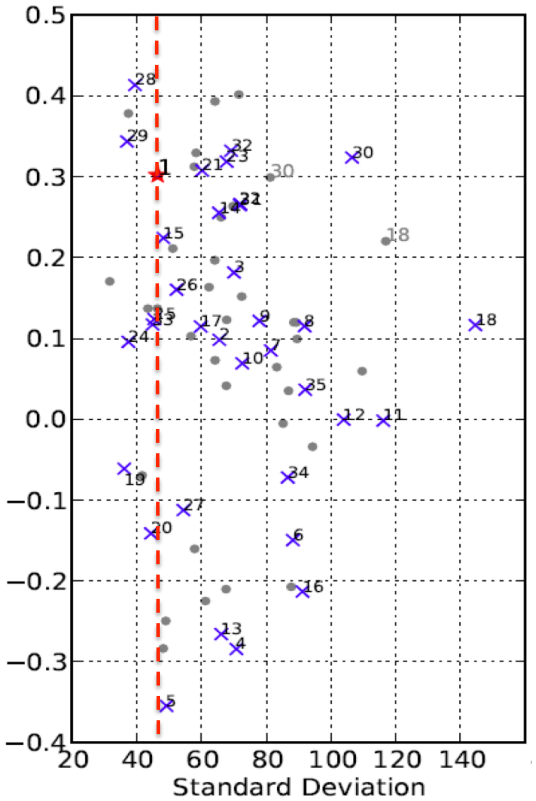
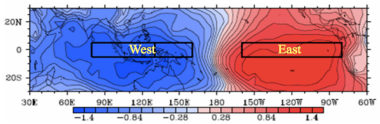
- **Trends as large as the observed trend arise only <u>rarely</u> from internal variability**



- Maybe the inconsistency arises because the internal variation in the real world is extraordinarily large?
- Or maybe the inconsistency is exacerbated because the modelled variability is too weak?

Simulation of basic statistics





1 OBS
2 ACCESS1-0
3 ACCESS1.3
4 bcc-csm1-1-m
5 bcc-csm1-1
6 BNU-ESM
7 CanESM2
8 CCSM4
9 CESM1-BGC
10 CESM1-CAM5
11 CMCC-CESM
12 CMCC-CMS
13 CNRM-CM5
14 CSIRO-Mk3-6-0
15 EC-EARTH
16 FIO-ESM
17 GFDL-ESM2G
18 GFDL-ESM2M
19 GISS-E2-H
20 GISS-E2-R
21 HadGEM2-AO
22 HadGEM2-CC
23 HadGEM2-ES
24 inmcm4
25 IPSL-CM5A-LR
26 IPSL-CM5A-MR
27 IPSL-CM5B-LR
28 MIROC-ESM-CHEM
29 MIROC-ESM
30 MIROC5
31 MPI-ESM-LR
32 MPI-ESM-MR
33 MRI-CGCM3
34 NorESM1-M
35 NorESM1-ME

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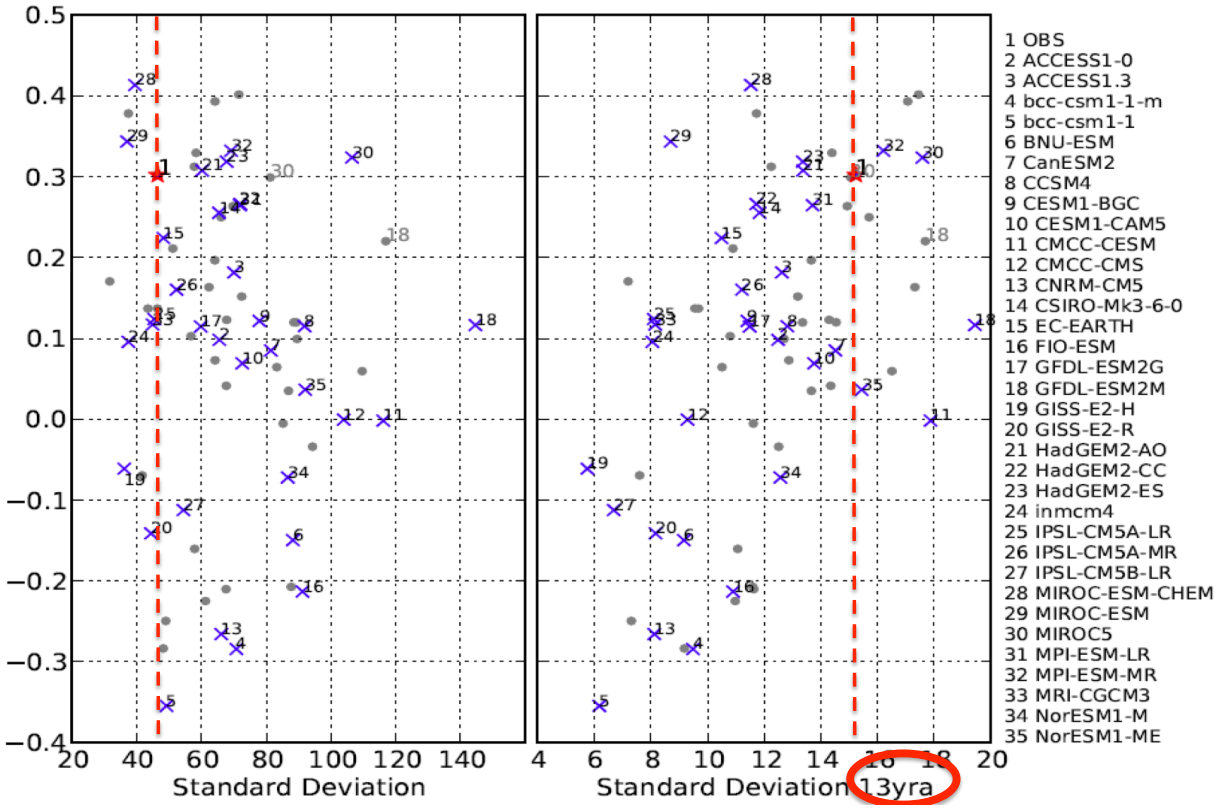
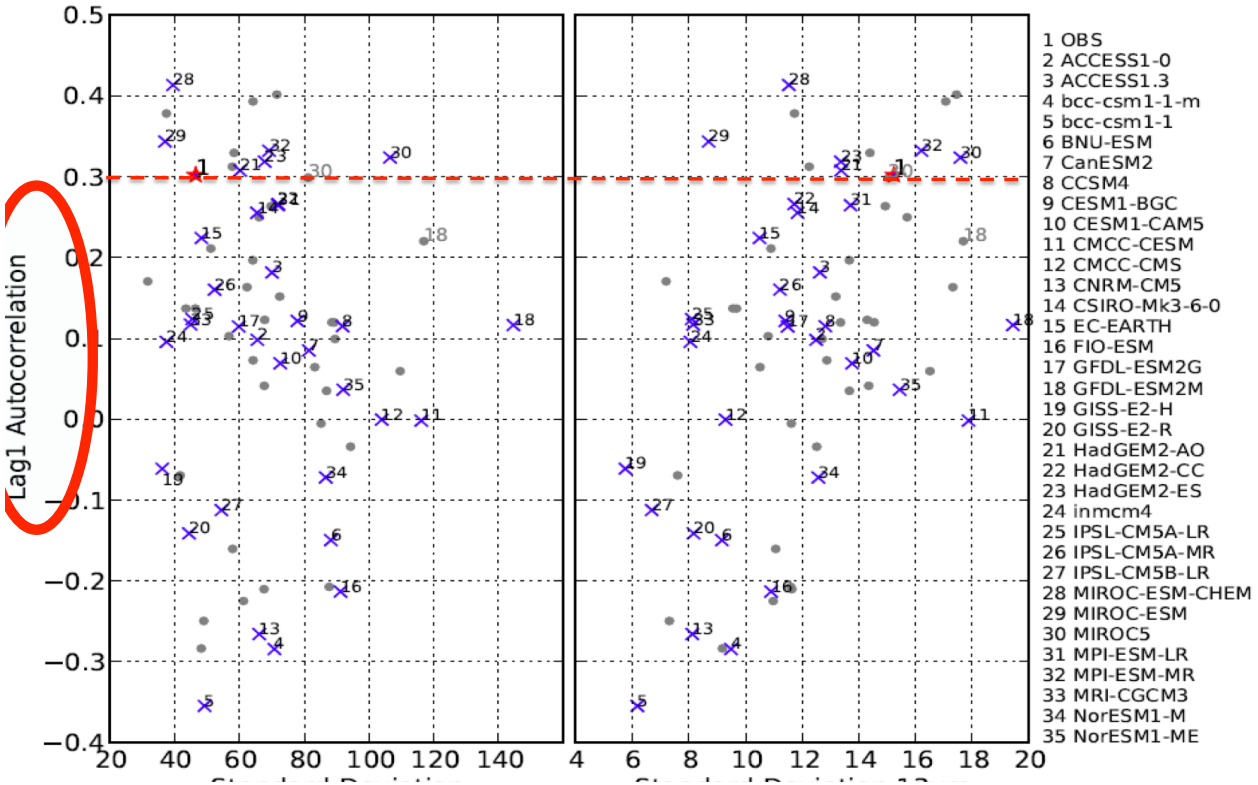
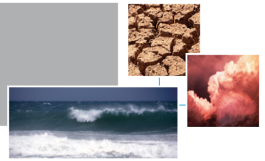
Simulation of basic statistics



Simulation of basic statistics





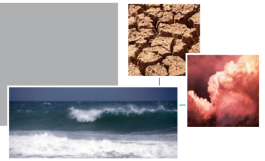
a(2) bias further reduces internally-driven decadal variability in the models

- Observations: -0.09, MMM: -0.3
- Spectral density of AR(2) process (Wilks 1995) is:

$$S(f,\rho_1,\rho_2) = \frac{4\sigma_N/n}{1 + C_1^2 + C_2^2 - 2C_1(1 - C_2)\cos(2\pi f) - 2C_2\cos(4\pi f)}$$

S(f, a(1)=0.3, a(2)= -0.1-β) ÷ S(f, a(1)=0.3,a(2)=-0.1) < 1, for T ≥ 9yr and β>0.

Cause of the inconsistency



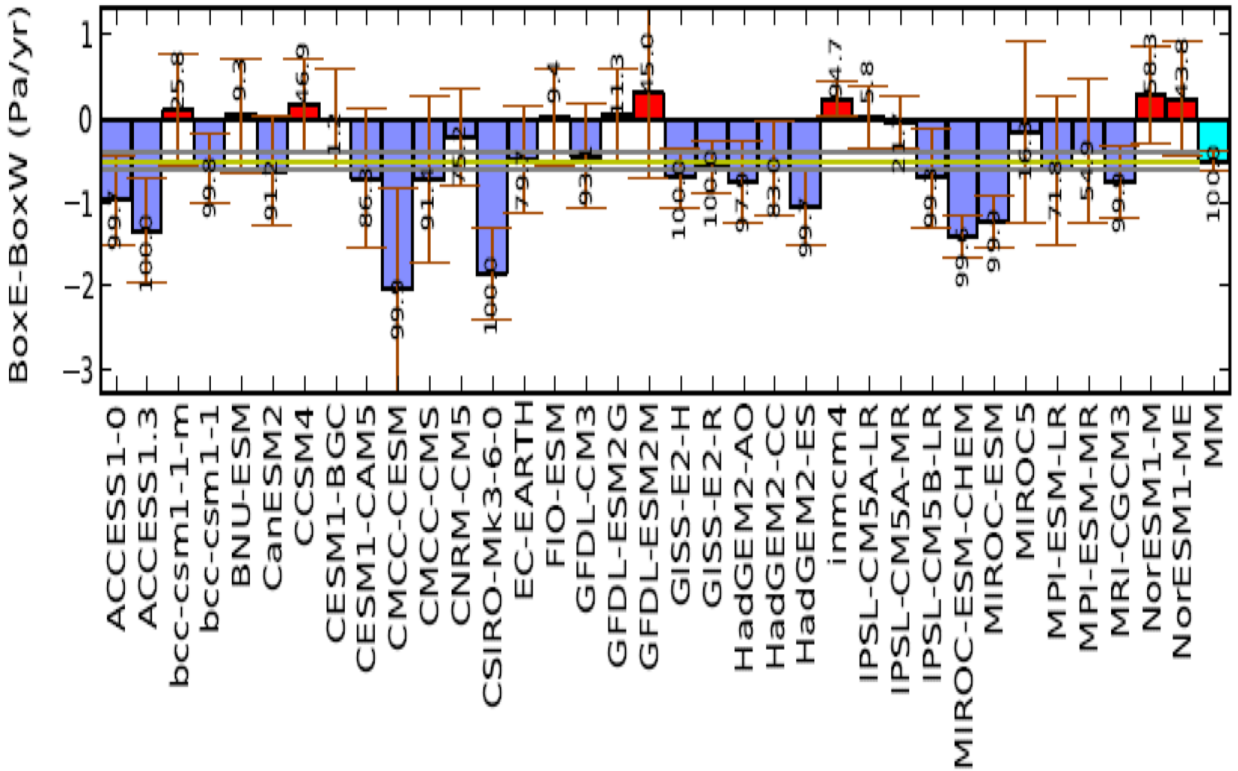
- Yes, modelled decadal variability does seem too weak
- This will contribute to inconsistency

- What else might be contributing?
  - Large internal variation in the real world
  - Forcing omitted from or misrepresented in models
  - Model response to forcing wrong

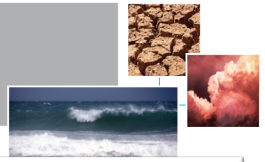
* We do not fully understand the reasons for the inconsistency

Projected changes

Projected trends CMIP5 models, 2013-2100



Confidence in projected change is

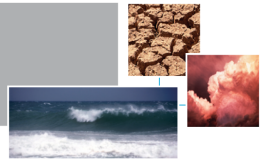


- enhanced by
  - general agreement among CMIP5 models
  - agreement between CMIP5 and CMIP3 projections
- reduced by
  - Our imperfect understanding of the inconsistency between models and observations over 1980-2012

Key outstanding issues:

- Do models overestimate the magnitude of the externally-forced 21st C weakening?
- Is the sign of externally-forced response over the 21st century misrepresented by models?

Challenges and opportunities



1. The Walker circulation is one of the world's most prominent atmospheric wind systems
2. It exhibited a marked strengthening over 30 years
3. This is a very major event in the recent history of the earth's climate system
4. We do not fully understand why!
5. Nor do we fully understand why models and observations seem to be inconsistent!
6. Challenges and opportunities: Redress (3) & (4)
   - Could prove to be a route to major advances in our understanding of climate variability and climate change in the Pacific

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Thank-you for listening!

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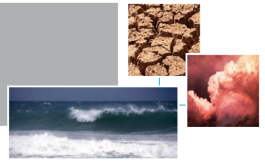
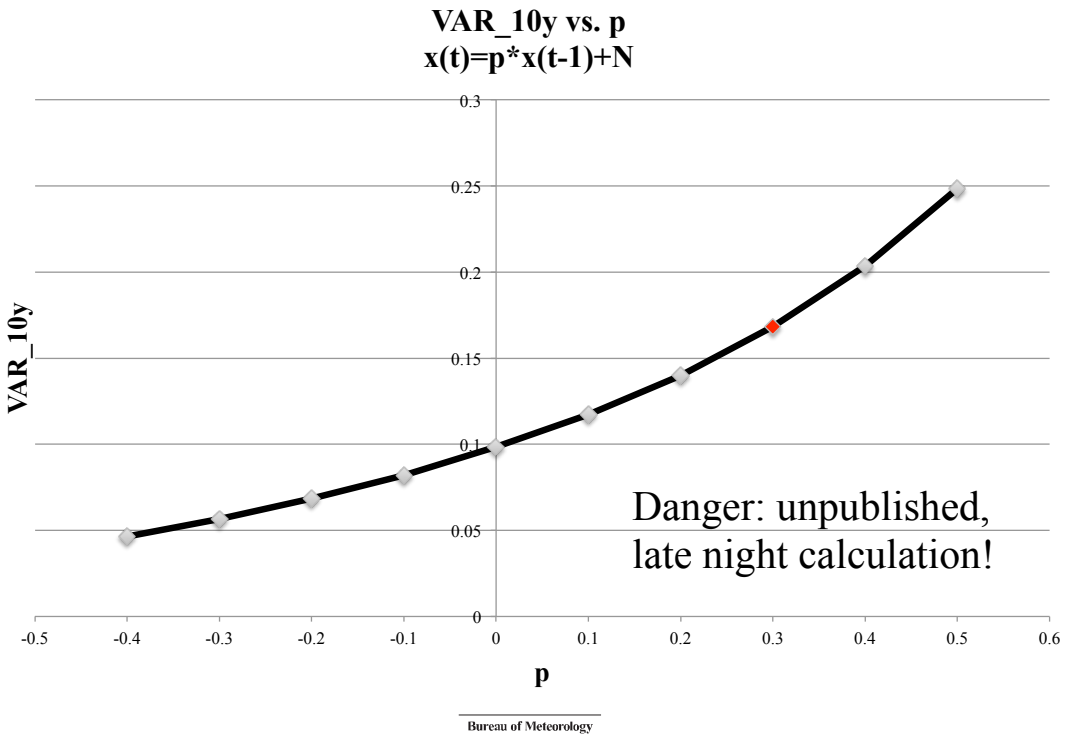
WCRP-ICTP DCVP Workshop
Trieste, Italy, Nov 18, 2015

Summary

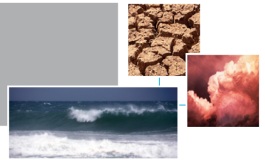


- =>Large internal variability seems to dominate the observed trend
- Models underestimate the magnitude of trends and internal decadal variability – despite higher than observed variability on interannual time-scales!
- This occurs because models have a
  - lag 1yr autocorrelation that tends to be too small
  - A lag 2yr autocorrelation that tends to be negative and too large in magnitude
- But maybe forcing or response to forcing is in error too?

Illustration: Monte Carlo Experiments



Methods and resources



- Trends over 1980-2012 in MSLP gradient
- HadSLPr (UK Meteorological Office)
- 35 CMIP5 climate models,
  - HIST and RCP8.5 spliced
  - 1900-2012, 1980-2012

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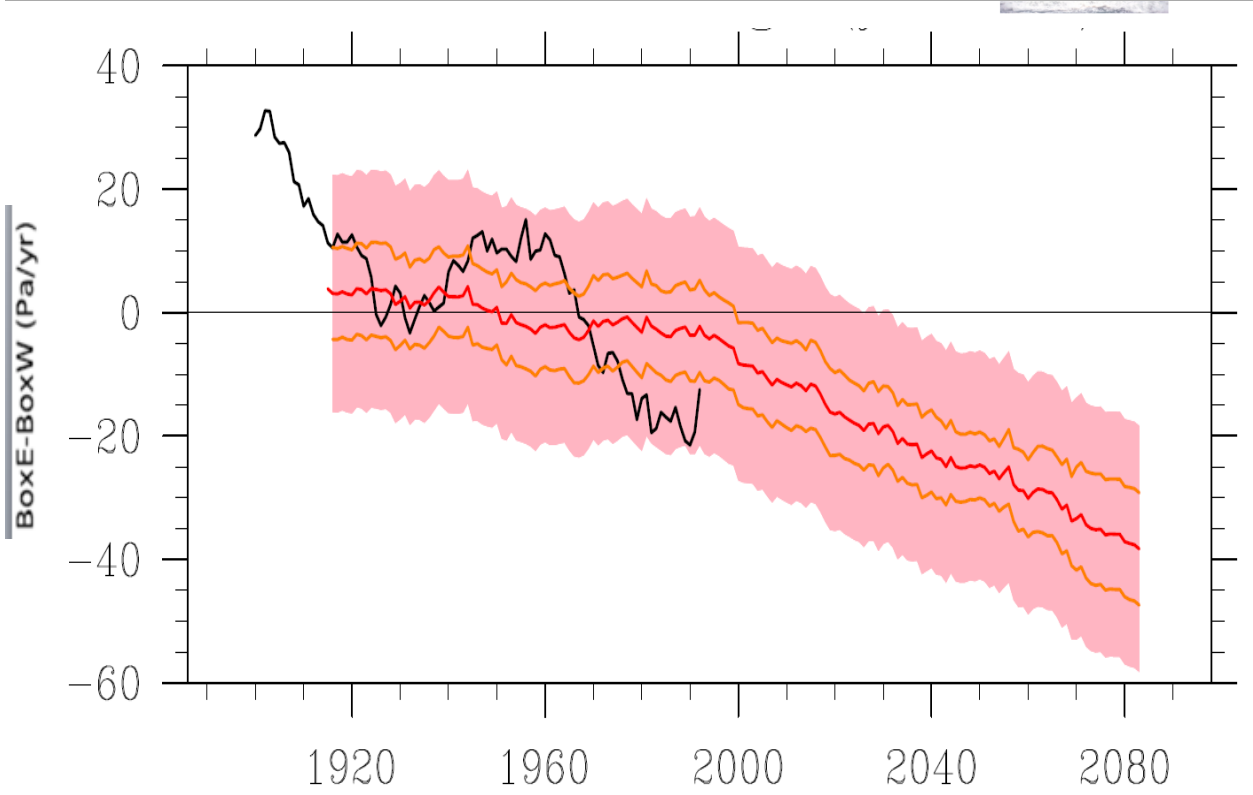
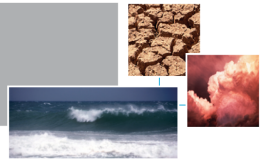
Variability and change in the Walker Circulation over the 20th and 21st centuries:



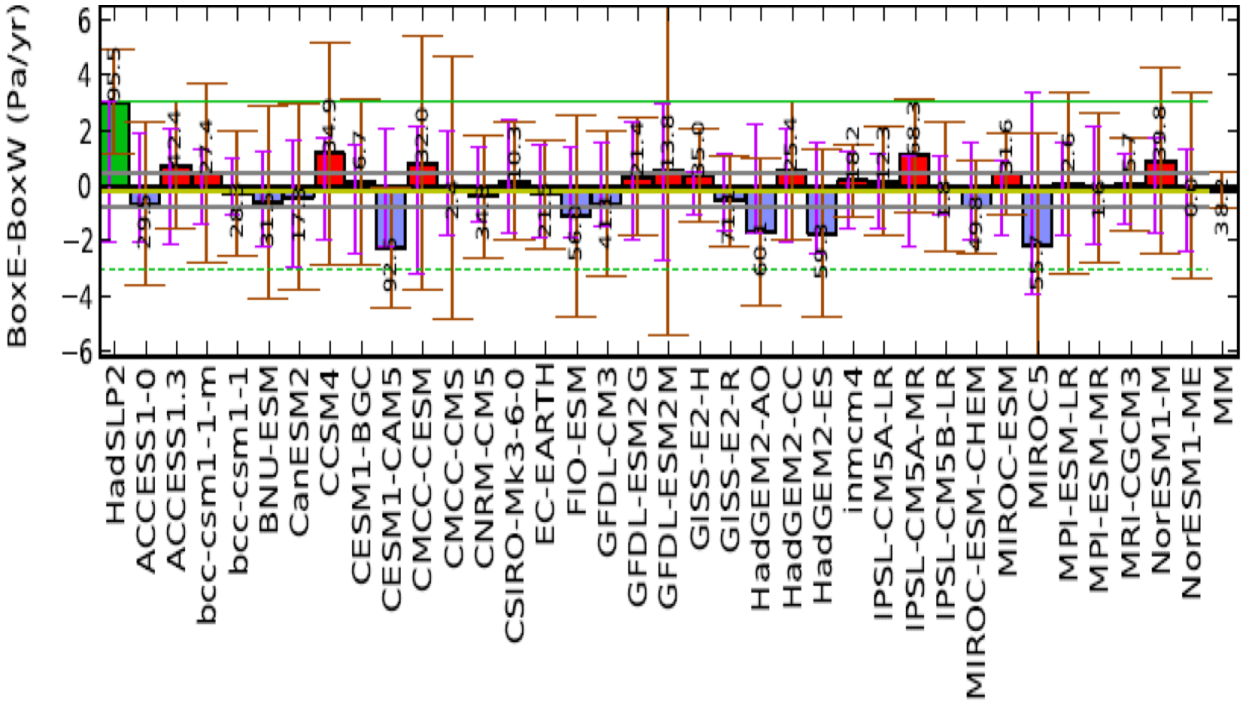
What causes the inconsistency?



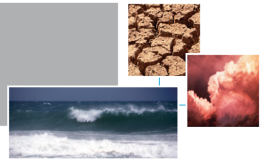
- Maybe the observed trend is entirely due to an unusually large internal variation in the real world
- Or maybe the inconsistency arising from a not-so-large internal variation in the real world accompanied by:
  1. Forcing omitted from or misrepresented in models
  2. Model responses to forcing that are wrong

  [Consistency would be enhanced if correction of (1) and (2) produced a larger MMM change]

Trends in observations and CMIP5 models 1980-2012



Some possible reasons for apparent inconsistency



- Forcing omitted from or misrepresented in models
- Model response to forcing wrong
- Extraordinarily large internal variation in the real world
- Other?