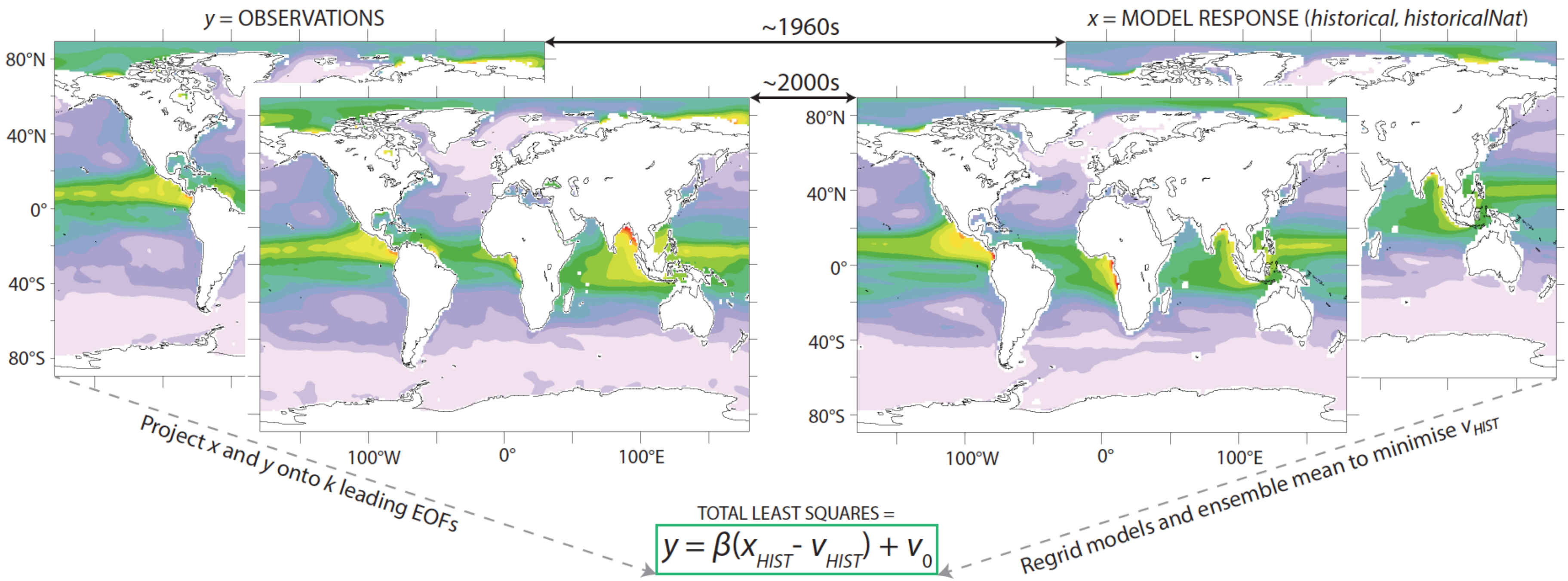
# Detection and attribution of observed changes in upper ocean stratification

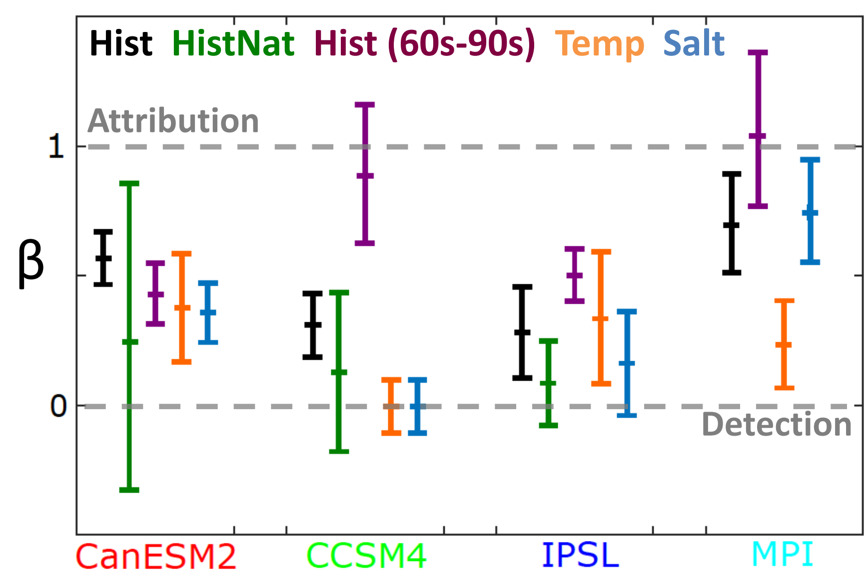
Oliver Andrews & Corinne Le Quéré, Tyndall Centre, UEA, UK




**Motivation:** Observed & projected surface warming and freshening → stratification → impacts on ventilation & ecosystems (light, nutrients)

**Method:** Optimal fingerprinting applied to CMIP5 models and observations for change in upper ocean density stratification (0– 200 m), sample piControl to estimate $V_0$

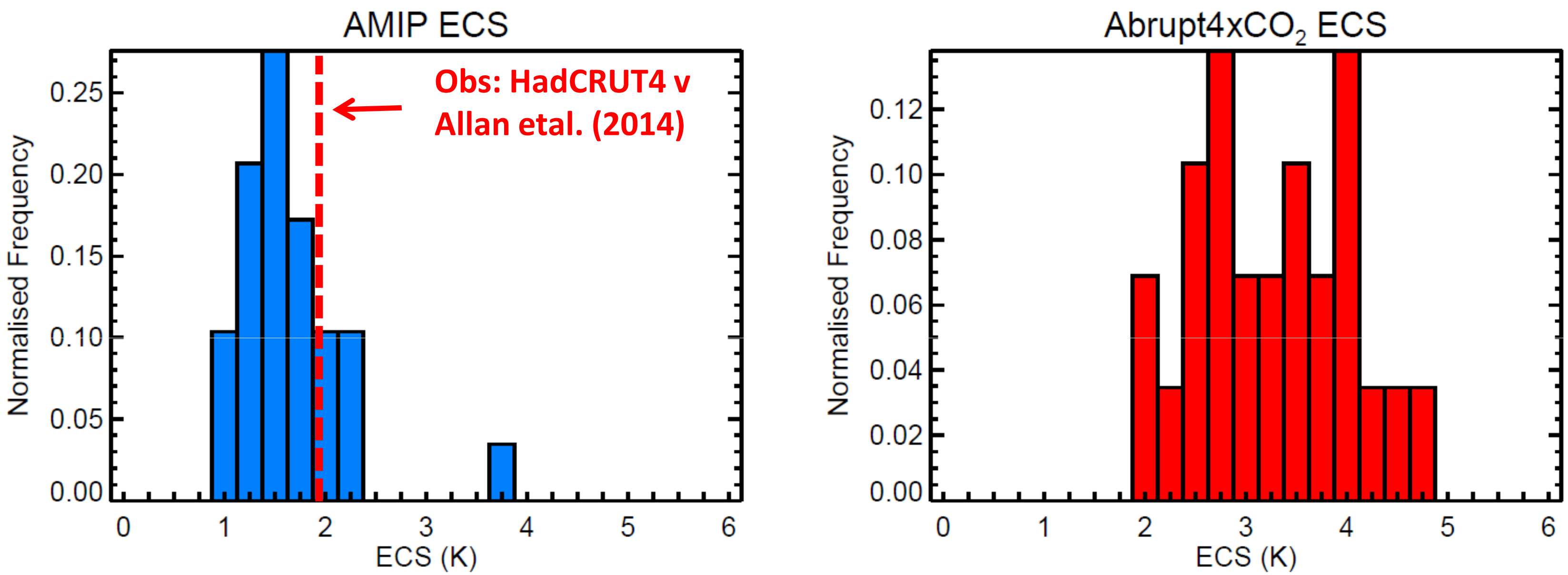
**Results:** Detectable change (β > 0) in observed stratification in response to **ALL** external forcings**,** cannot be explained by **historicalNat** fingerprint → most models overestimate response (β < 1), response detected above $V_0$



# The inconstancy of climate feedbacks

Timothy Andrews[1], Jonathan Gregory[1,2] & Mark Webb
[1]Met Office Hadley Centre; [2]NCAS-Climate, Uni. of Reading

*Is climate sensitivity estimated from the historical record biased low?*

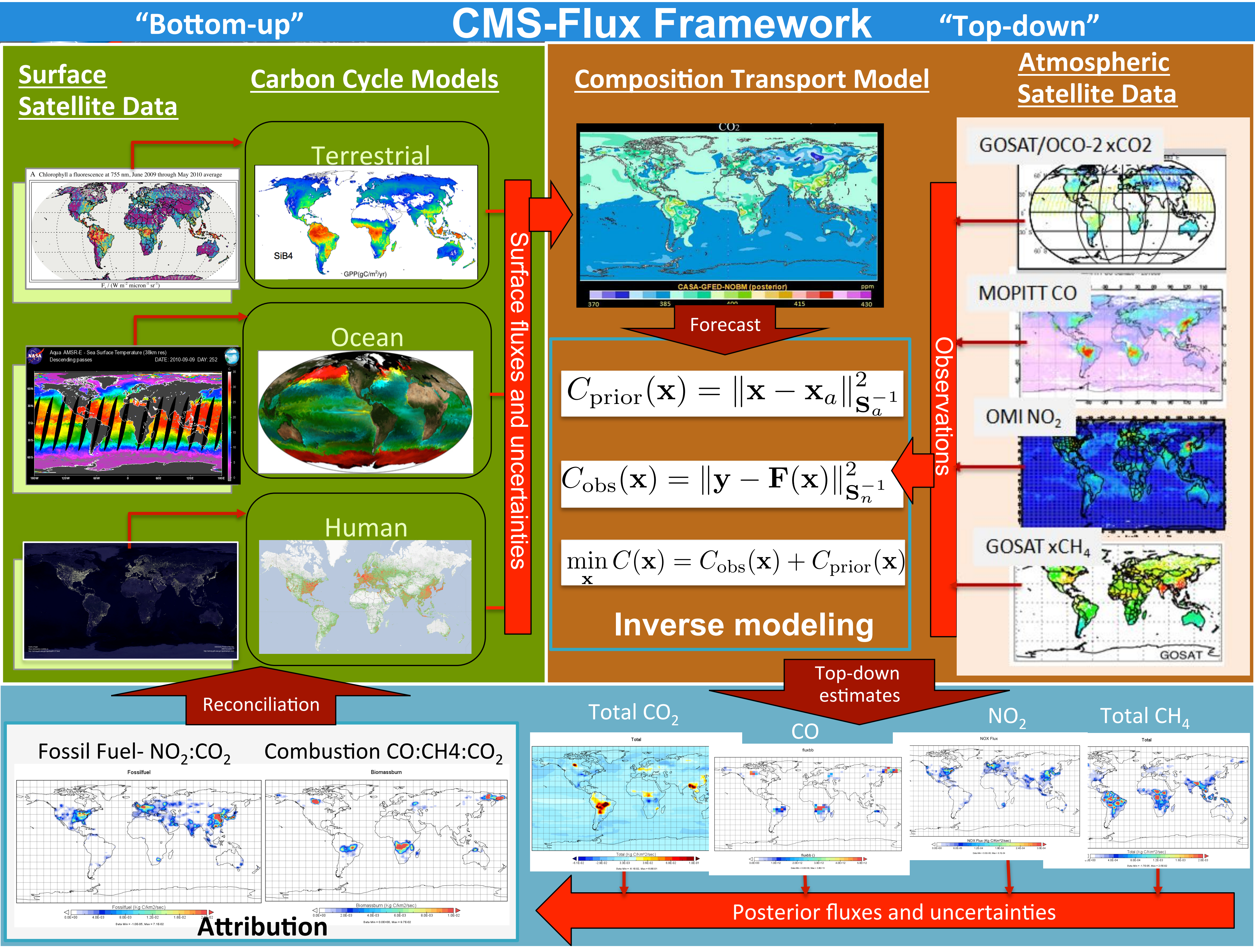



• Observations and AGCMs forced with observed SSTs show strong negative feedbacks and hence low ECS values (~1-2K) if feedback strengths are assumed constant.

• Targeted AGCM experiments – included in the CFMIP3/CMIP6 experimental design – forced with idealised & observed SST warming patterns are introduced to understand:

(i) the physical processes & mechanisms

(ii) the implication for observed estimates of climate sensitivity

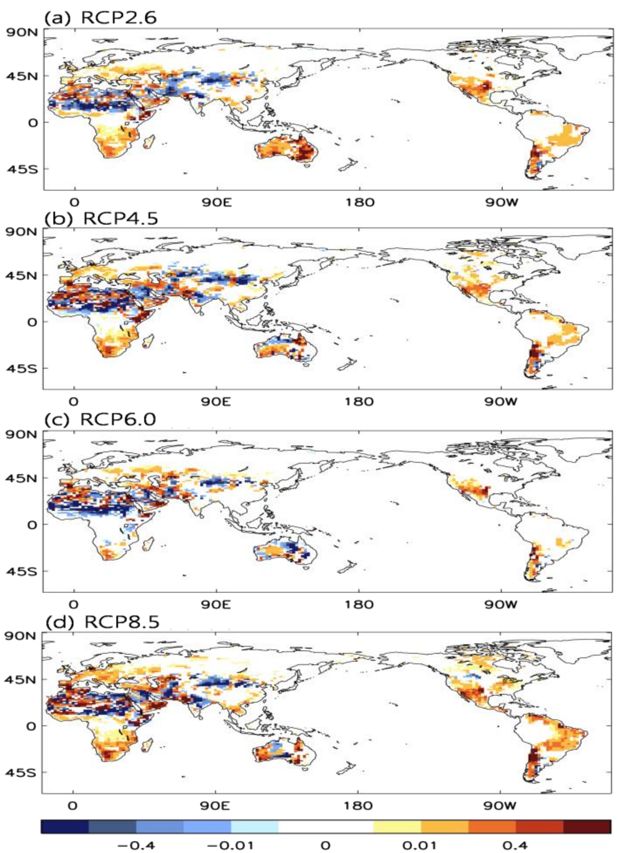

"Bottom-up"
CMS-Flux Framework
"Top-down"
Surface Satellite Data
Carbon Cycle Models
Composition Transport Model
Atmospheric Satellite Data
Terrestrial
Ocean
Human
Surface fluxes and uncertainties
Forecast
$C_{\text{prior}}(\mathbf{x}) = \|\mathbf{x} - \mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$
$C_{\text{obs}}(\mathbf{x}) = \|\mathbf{y} - \mathbf{F}(\mathbf{x})\|^2_{\mathbf{S}_n^{-1}}$
$\min_{\mathbf{x}} C(\mathbf{x}) = C_{\text{obs}}(\mathbf{x}) + C_{\text{prior}}(\mathbf{x})$
Inverse modeling
Observations
GOSAT/OCO-2 xCO2
MOPITT CO
OMI $NO_2$
GOSAT x$CH_4$
Reconciliation
Top-down estimates
Fossil Fuel- $NO_2$:$CO_2$
Combustion CO:CH4:$CO_2$
Total $CO_2$
CO
$NO_2$
Total $CH_4$
Attribution
Posterior fluxes and uncertainties

# Analysis of the Future Emission Changes in Mineral Dust Aerosol in CMIP5

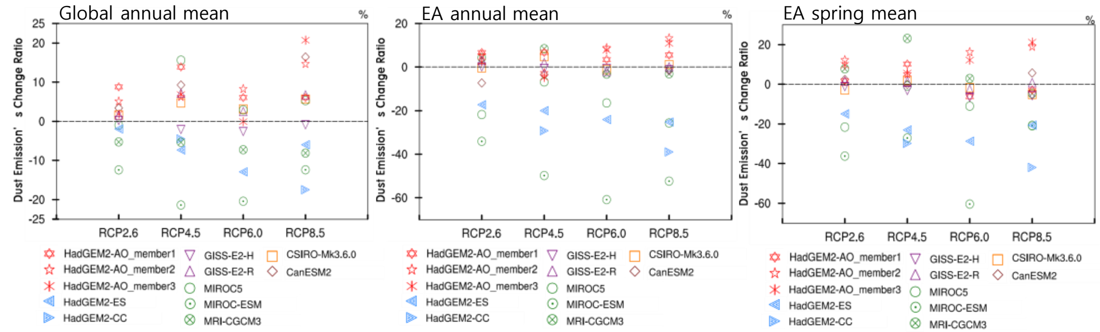
Young-Hwa Byun, TaeHee Kim, Kyung-On Boo, Johan Lee, ChunHo Cho
National Institute of Meteorological Sciences, Korea Meteorological Administration

- **Investigation of future change in dust emission over the East Asian region (30-55°N, 80-145°E) based on CMIP5 model simulations**
- **10-model simulations with 4 RCPs (HG2-AO, HG2-ES, HG2-CC, GISS-E2-H, GISS-E2-R, MIROC5, MIROC-ESM, MRI-CGCM3, CSIRO-Mk360, CanESM2)**

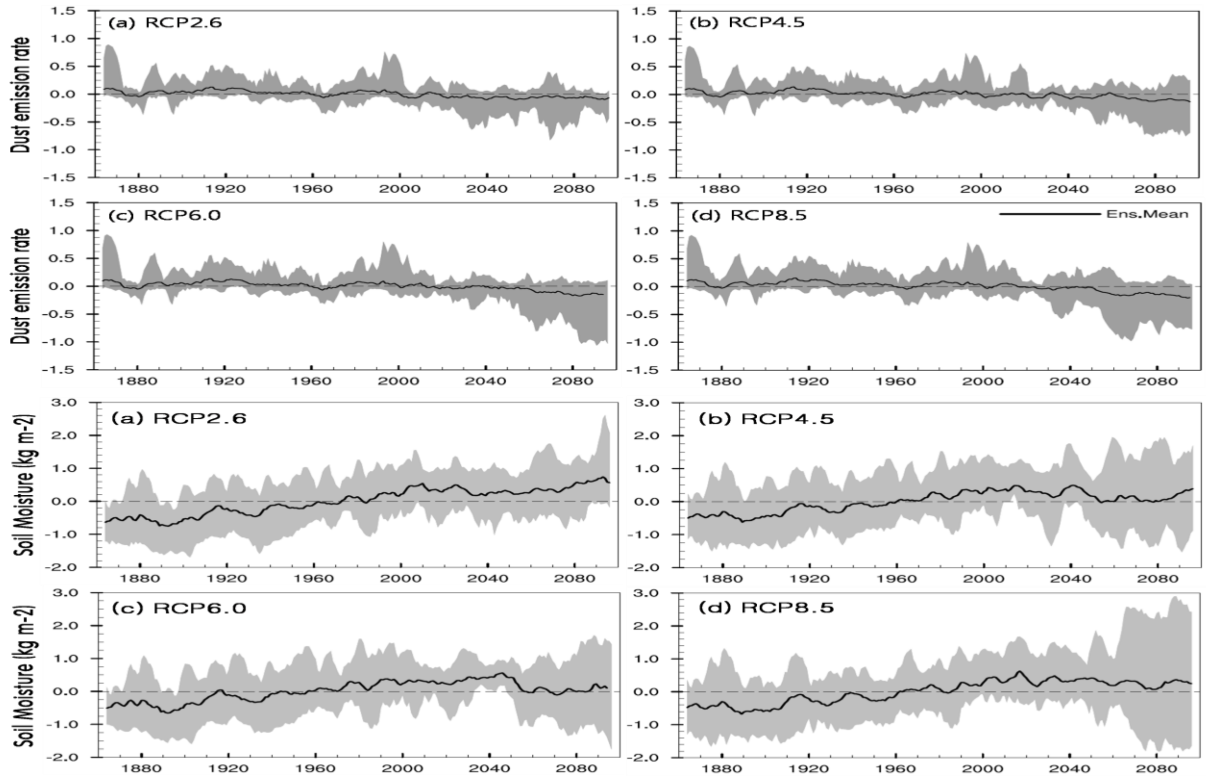
Change in dust emission rate
[ g km$^{-2}$ mon$^{-1}$ , (2071~2100) – (1971~2000) ]




Change in dust emission rate in each model [ %, (2071~2100) – (1971~2000) ]



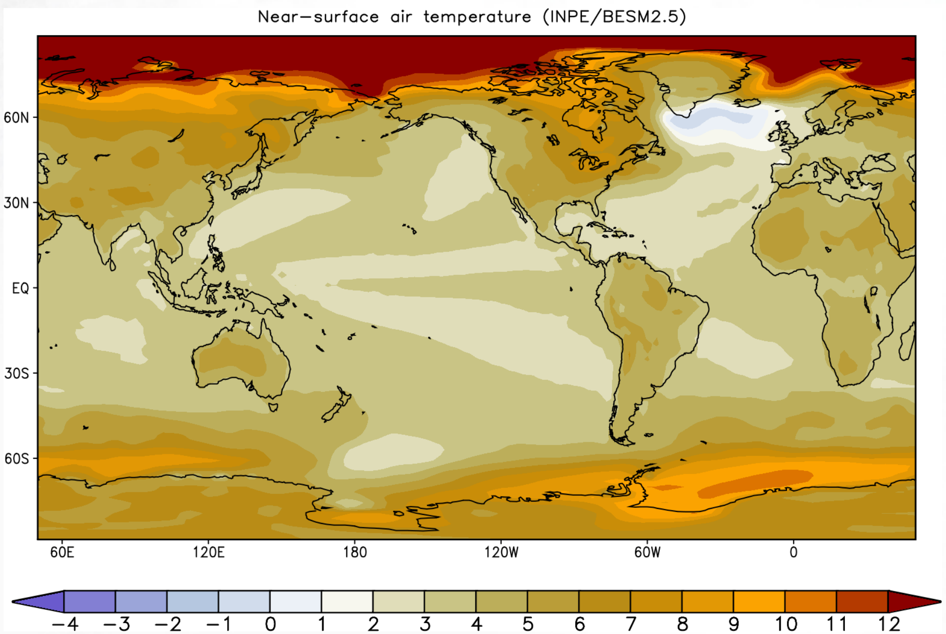

Annual mean dust emission rate (g km$^{-2}$ mon$^{-1}$) and soil moisture (kg m$^{-2}$) over the East Asia region

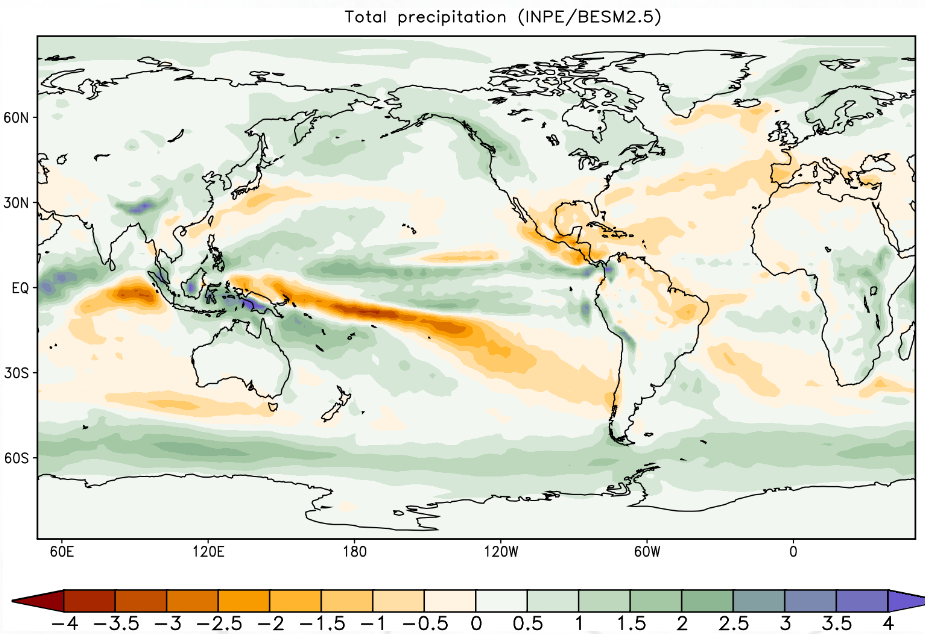


# Climate sensitivity of the Brazilian Earth System Model, version 2.5

Vinicius Capistrano, P. Reyes, S. Figueroa, E. Giarolla, C. Fonseca, M. Malagutti, M. Baptista, P. Nobre

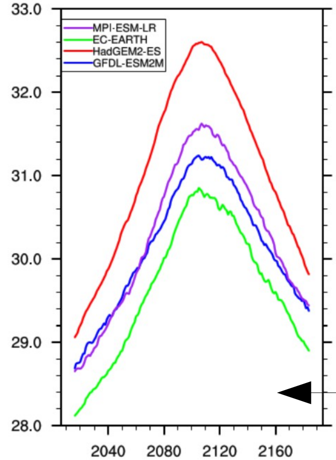
piControl vs. Abrupt4xCO2




Equilibrium Climate Sensitivity (ECS) of 2.95 K

Cloud Radiative Effect (CRE) of -0.11 W $m^{-2}K^{-1}$

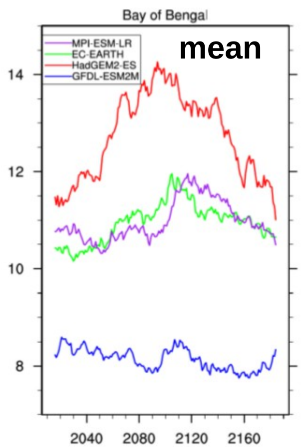


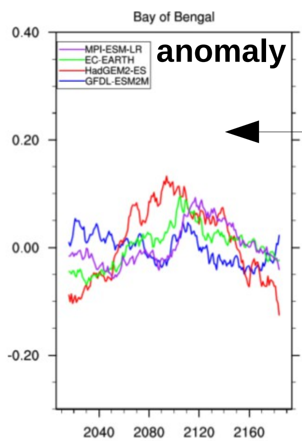

***JJAS mean SST***
*(0°N-20°N, 70°E-110°E)*

# Sensitivity and reversibility of monsoon systems to climate scenario forcing

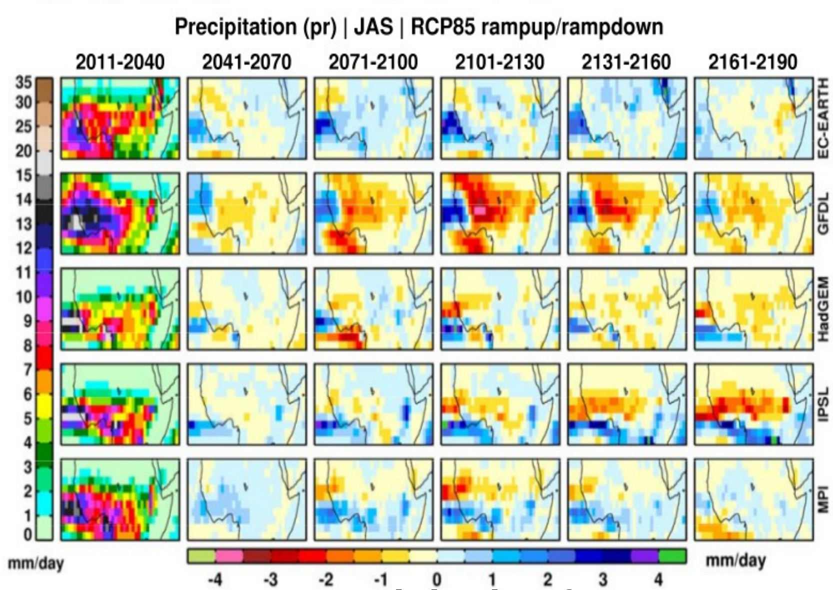
Shiyu Wang[1], Grigory Nikulin[1], Colin Jones[1,2] and Ralf Döscher[1],

[1]SMHI – Sweden, [2]University of Leeds, UK




**JJAS monsoon precipitation**




*30-year mean* ***JAS precipitation*** *for 2011-2040 and then simulated JAS 2m precipitation* ***anomalies***

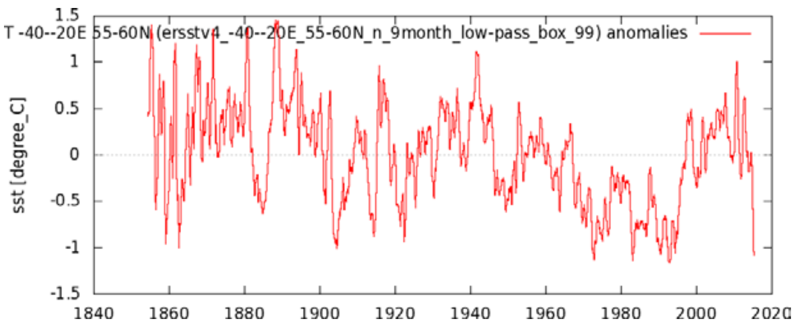
Response of monsoon variability to a 190 year ramp-up/ramp-down RCP8.5 forcing as simulated by five ESMs models (EC-Earth, HadGEM2-ES, MPI-ESM, GFDL- ESM and IPSL).

- **Inter-model spread** between the models is **still very large**. This is particularly the case with respect to precipitation responses over Africa and South Asia.
- The **South Asian monsoon rainfall** appears to show a general tendency to **increase as GHG forcing increases** which largely **reverses during the ramp-down** period.
- Over **West Africa, a large surface temperature response is seen through the ramp-up phase which is reversed during the ramp-down**.
- Models have widely different simulated precipitation climatologies over West Africa and **no clear signal** is seen **in terms of precipitation change** across the models. Likewise, there is **no consistent change in monsoon onset** or duration across the 2 models analysed.
- There is **little evidence of abrupt or irreversible changes** in any of the monsoon systems.
- Due to greatly differening simulations, **improved models seem to be a pre-requisite** before reliable estimates of future change in any of these three phenomena can be delivered.

# A catalogue of abrupt shifts in IPCC climate models

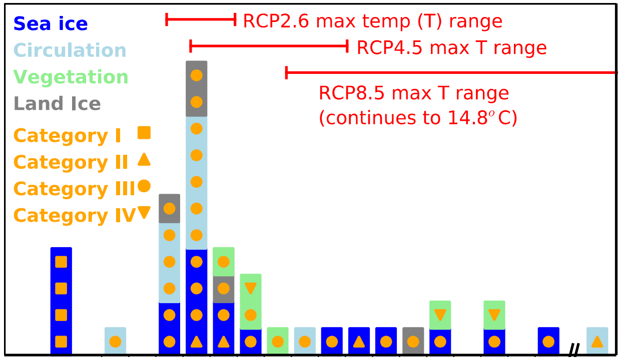
Sybren Drijfhout, Sebastian Bathiany, Claudie Beaulieu, Victor Brovkin, Martin Claussen, Chris Huntingford, Marten Scheffer, Giovanni Sgubin, Didier Swingedouw

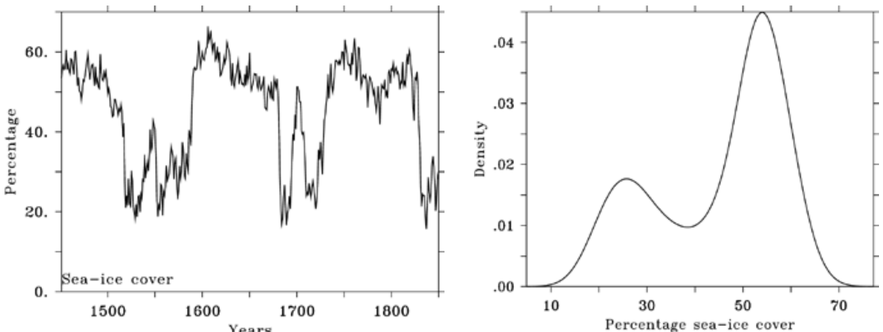
## Washington Post last week:
## Record Cold 'Blob' in North Atlantic: Sign of Future Climate Woes?




Courtesy Geert-Jan van Oldenborgh

**Does not pass our criteria!**




Eighteen out of 37 forced abrupt shifts occur in simulations for global warming levels below **2 degrees**, a threshold often proposed as a potentially safe upper bound on global warming.

**Peter Gleckler[1], Paul J. Durack[1]**, Ron Stouffer[2], Greg Johnson[3] and Chris Forest[4]

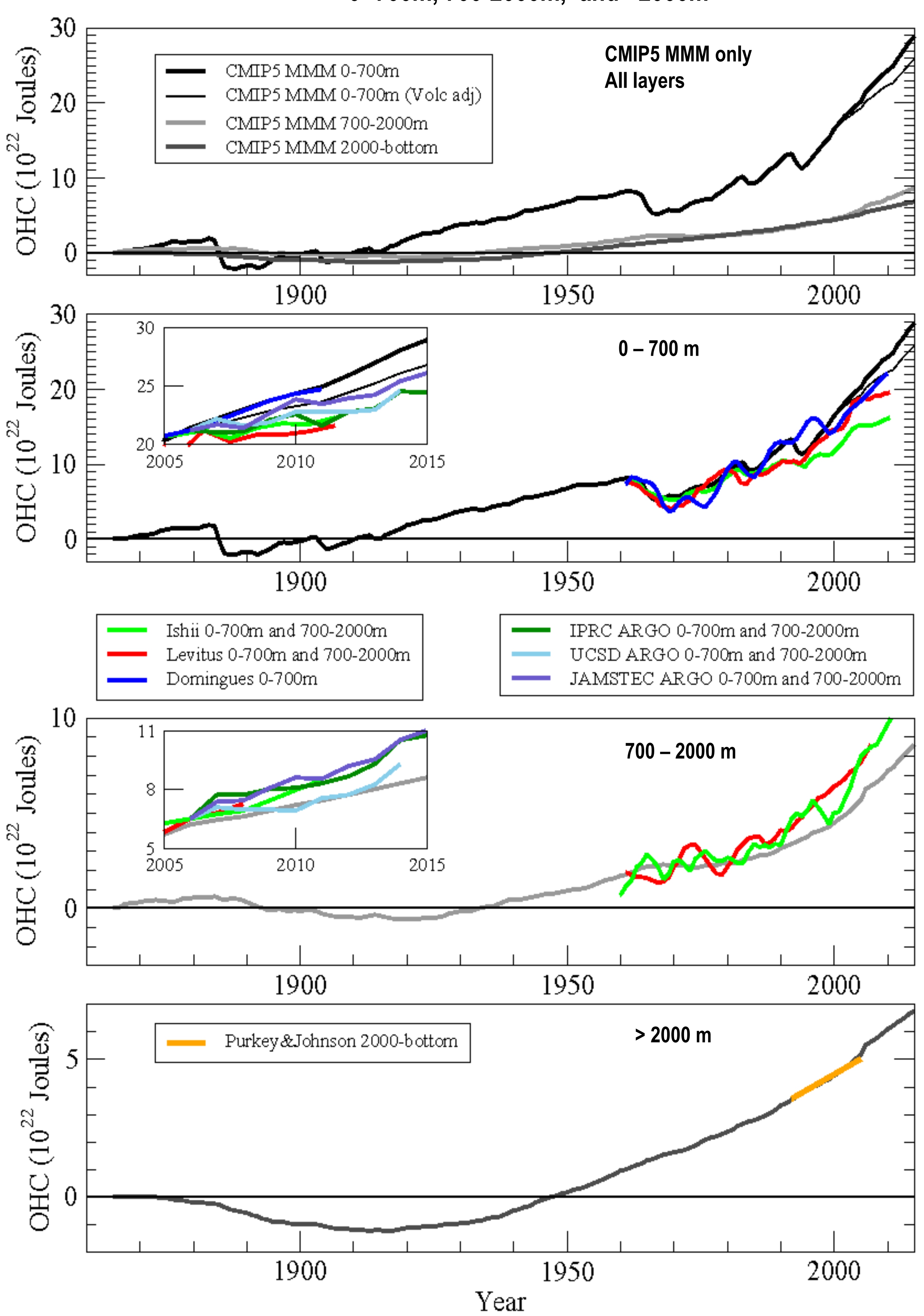
[1]Lawrence Livermore National Laboratory,

[2] GFDL, [3]PMEL and [4]Penn State

# Global Ocean Heat Content (OHC) Changes in CMIP5 from the Upper Layers to the Abyss

## CMIP5 MMM is consistent with estimates of OHC changes in the upper, intermediate and deep Ocean

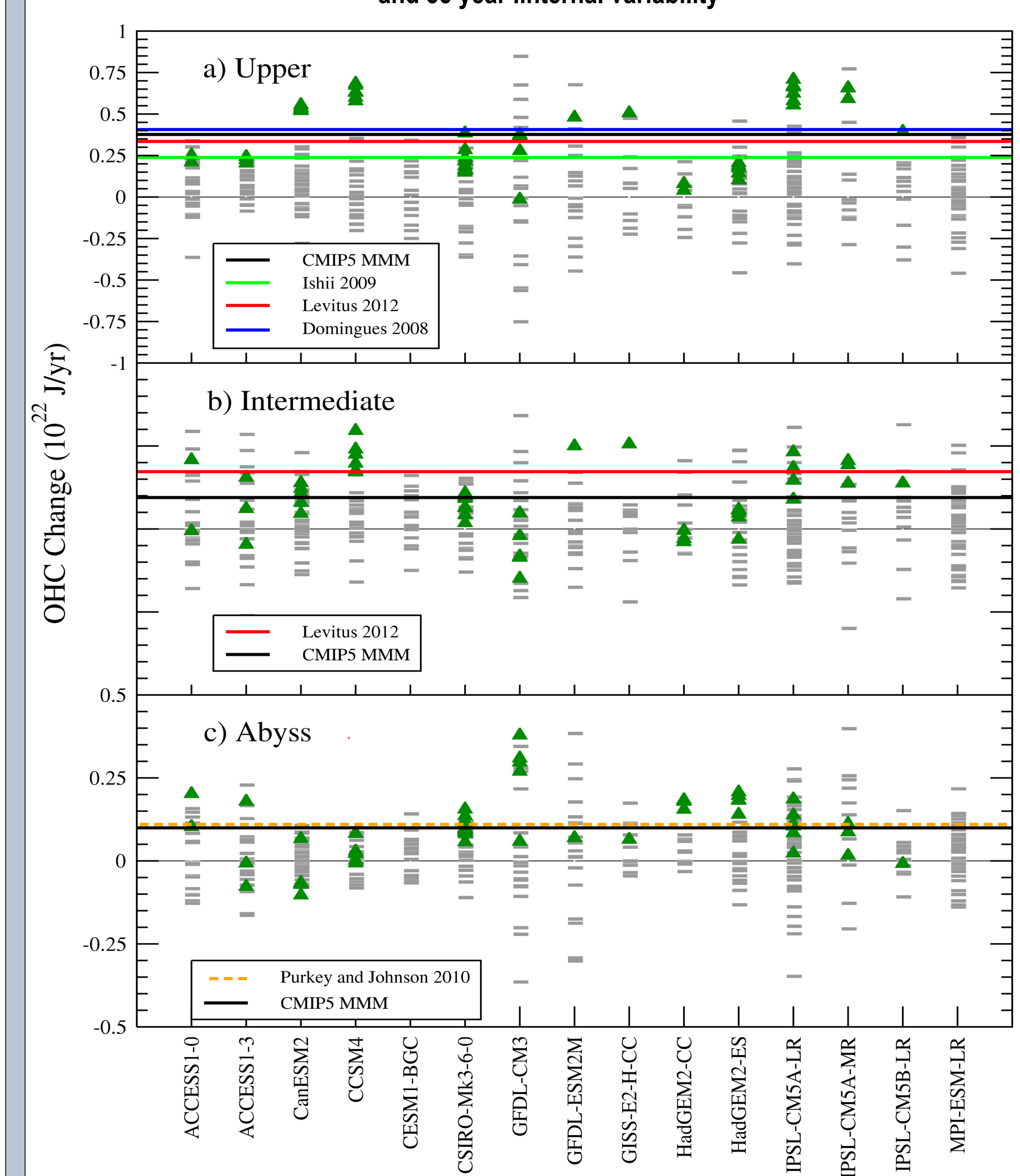
Observed and simulated OHC for three layers: 0 -700m, 700-2000m, and >2000m




- Levitus et al. and Ishii et al. suggest slowdown during surface warming hiatus but Domingues et al. does not – Argo 2002-2005 is a problem
- Argo period (2005-2105): CMIP5 MMM is on the high end of observational estimates in the upper layer whereas it is on the low end in the intermediate layer
- Deep layer agreement is very good, but likely at least in part coincidental

## Large intermodel differences in trends & variability but no evidence of a systematic bias across models

Observed and simulated OHC trends (1971-2005) and 35 year linternal variability

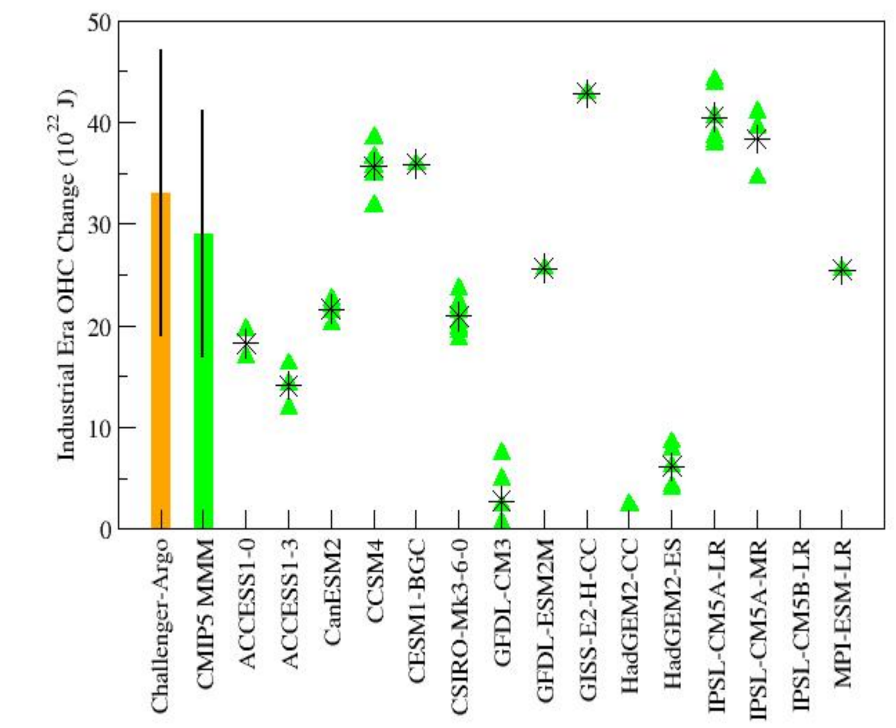



**Green triangles:** Trends from individual Historical realizations
**Grey dashes:** 35 year trends from non-overlapping chunks of model's picontrol

- For most models the forced trends (green triangle) are distinct from estimated internal variability, especially in the upper layer
- A few models are cooling in the intermediate layer – excessive indirect aerosol effects?
- Individual models straddle observed estimates in each layer and there is therefore no evidence of a systematic bias

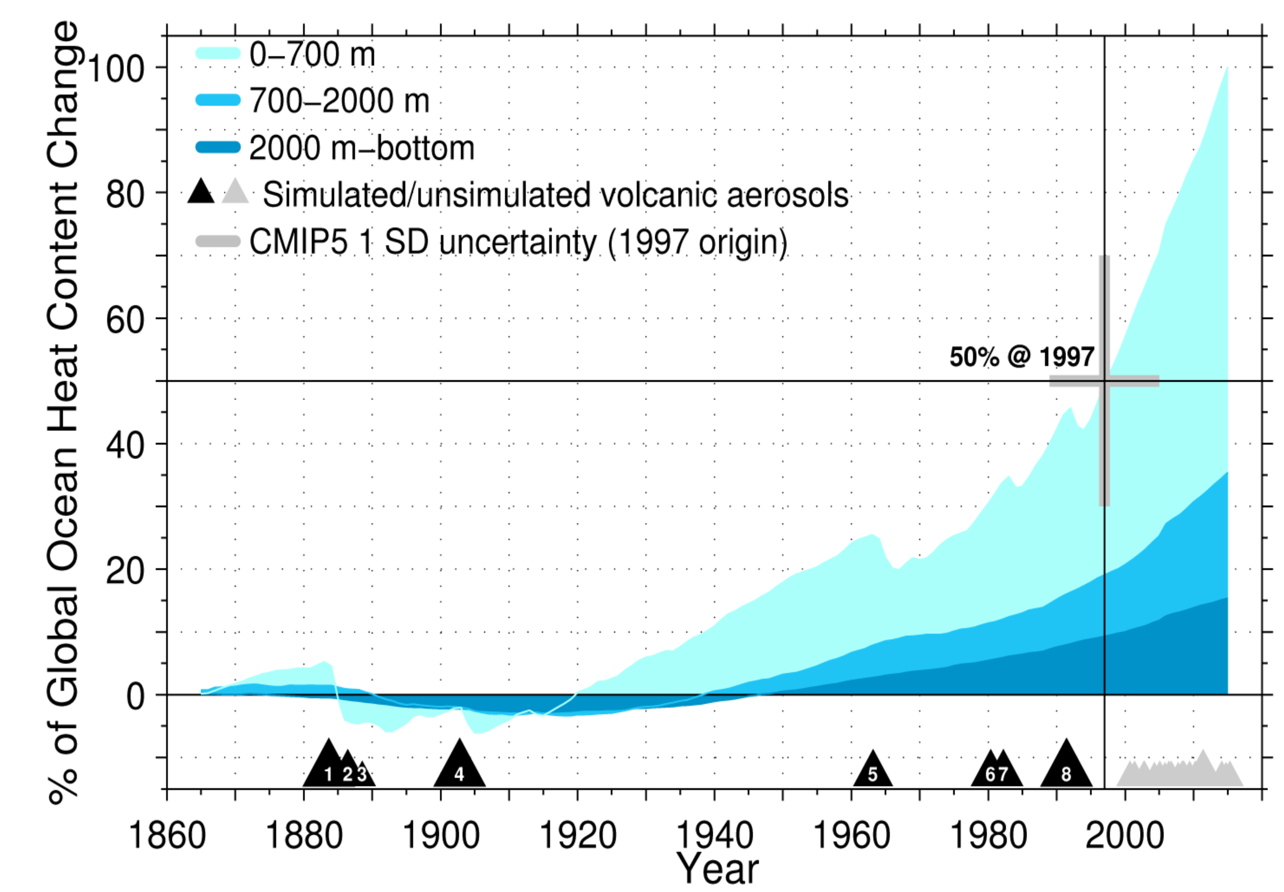
## Models and data suggest the industrial era global ocean heat uptake has doubled in recent decades

Observed and simulated Ocean heat uptake (1865-2015)




- CMIP5 MMM is consistent with Argo-Challenger estimates (~1875-2005; Roemmich [2012])
- Large spread in modeled OHU

Simulated Total Global Ocean Heat Uptake
Cumulative Distribution Function
Individual models are normalized by their OHC at 2015




CMIP5 MMM, which is consistent with observations in each layer, suggests:

- 50% OHU has occurred in recent decades
- 30% of OHU is in deeper ocean

## References

Roemmich, D., Gould W. J., Gilson J. 135 years of global ocean warming between the Challenger expedition and the Argo Programme. Nature Clim. Change, 2, 425-428. (2012)

Gleckler, P. J., P. J. Durack, R. J. Stouffer, G. C. Johnson and C. E. Forest. in review. (2015)

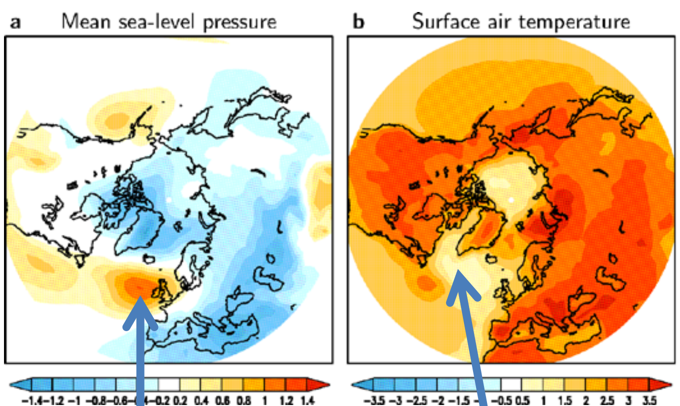
This work is supported by the Regional and Global Climate program for the Office of Science of the United States Department of Energy. This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-POST-676178

# Decelerating AMOC main cause of future west European summer atmospheric circulation changes

Reindert J. Haarsma, Frank M. Selten and Sybren Drijfhout (KNMI, Netherlands)

- **Weakening of AMOC is main cause for Atlantic high in future CMIP5 simulations**
- **Uncertainty in atmospheric summer response over Europe is connected to uncertainty in the AMOC response**

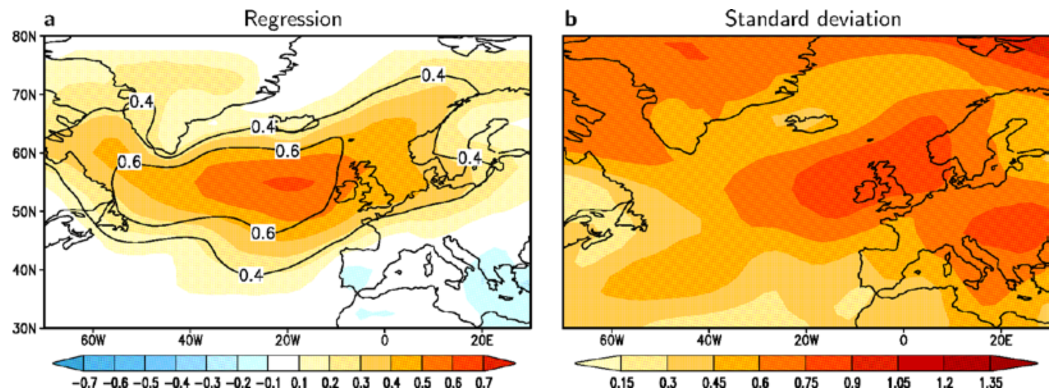
CMIP5 model mean response




"Atlantic high" "Warming hole"

Regression of MSLP on negative AMOC change

Standard deviation of MSLP



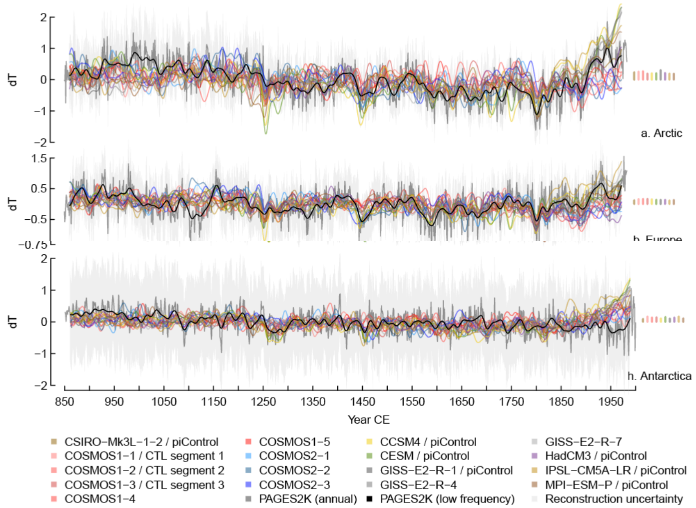

CMIP5 inter-model spread

*Haarsma et al., Env. Res. Lett, 2015*

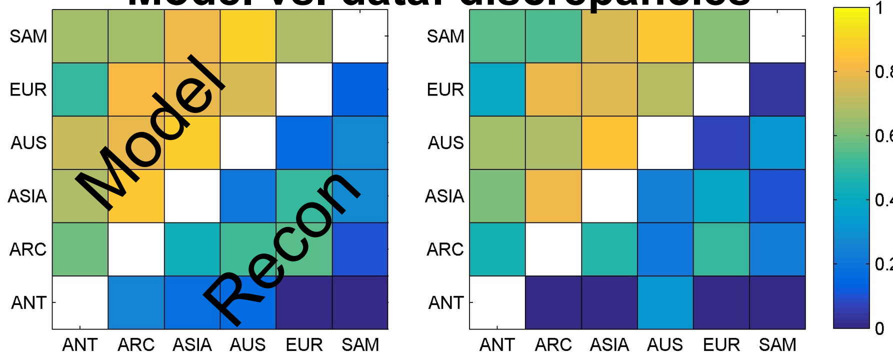
# PMIP3/PAGES2K integrated analyses of reconstructions & simulations

J.H. Jungclaus and the PAGES2k/PMIP3 group*

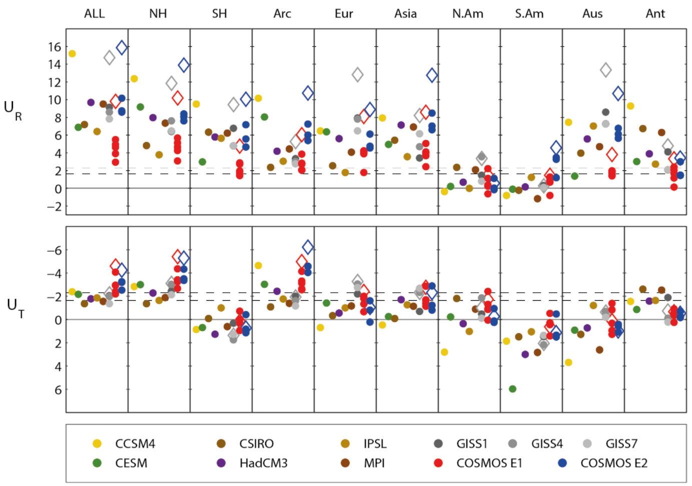
## Simple time series:




## Model vs. data: discrepancies




## Advanced methods:




**Conclusions:**

- models reproduce forced response compatible with reconstructions for Northern Hemisphere regions, in particular for the Arctic and Europe
- multiple realisations from single models and the multi-model ensemble improve test statistics
- agreement between simulations and PAGES2k regions is poor for the Southern Hemisphere
- simulations are regionally more coherent than reconstructions
- discrepancies may stem from model deficiencies, but also from the uncertainty in proxy-based reconstructions.

johann.jungclaus@mpimet.mpg.de

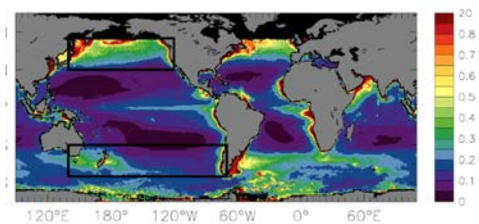
***PAGES2k/PMIP3** Group: O. Bothe, M. Evans, L. Fernández-Donado, E. Garcia Bustamante, J. Gergis, J. F. Gonzalez-Rouco, H. Goosse, G. Hegerl, A. Hind, J.H. Jungclaus, D. Kaufman, F. Lehner, N. McKay, A. Moberg, C.C. Raible, A. Schurer, F. Shi, J.E. Smerdon, L. von Gunten, S. Wagner, E. Warren, M. Widmann, P. Yiou, E. Zorita. Article in: **Climate of the Past Discuss.,11, 2483-2555, 2015**

# Zooplankton control on future changes in marine biological carbon fluxes

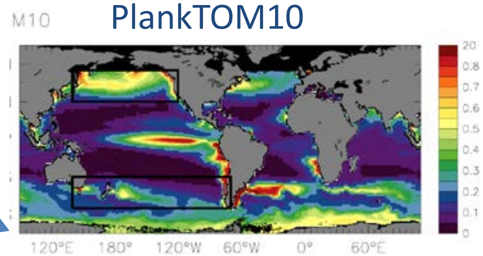
Corinne Le Quéré, Erik T Buitenhuis, Oliver Andrews, and Rósín Moriarty
Tyndall Centre for Climate Change Research, University of East Anglia, UK

## The Past

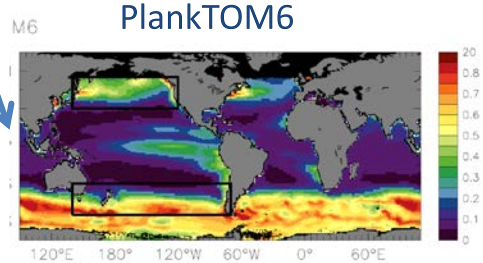
Surface Chla data




PlankTOM10



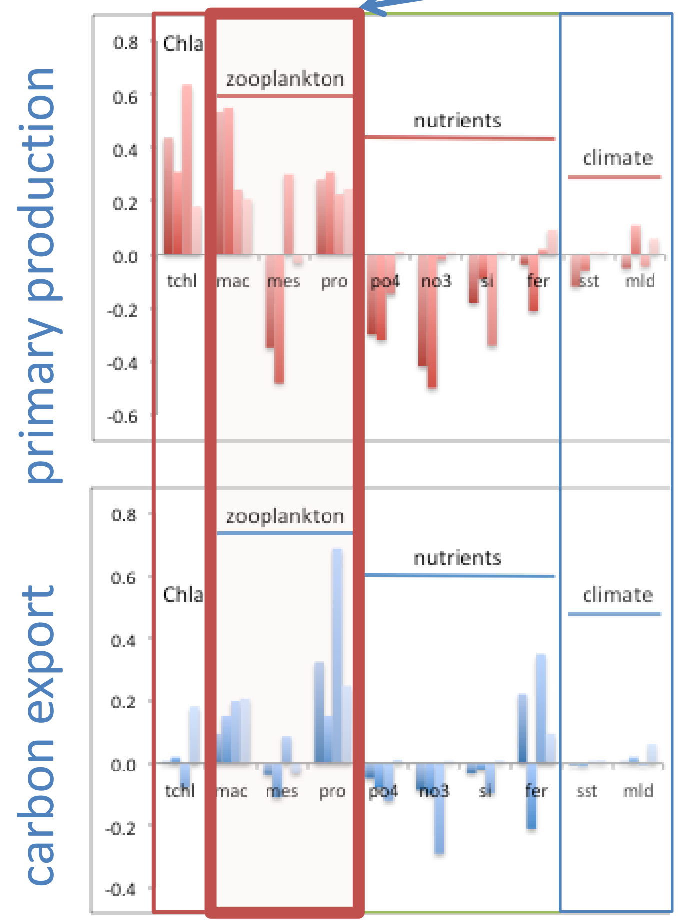

PlankTOM6




the overestimation of summer biomass in the Southern Ocean summer is reduced in a model with multiple zooplankton
(Le Quéré et al BGD 2015)

## The Future

zooplankton (again!) co-vary the most with changes in carbon fluxes, suggesting top-down rather than bottom-up control




Correlations of modeled changes in 2100 with explanatory variables

# CMIP5 Climate Projections for North America and Development of a Process-Oriented Model Diagnostics Framework

Eric D. Maloney, Yi Ming, Andrew Gettelman, David Neelin
NOAA MAPP CMIP5 and Model Diagnostics Task Forces

NOAA MAPP Modeling, Analysis, Predictions, and Projections

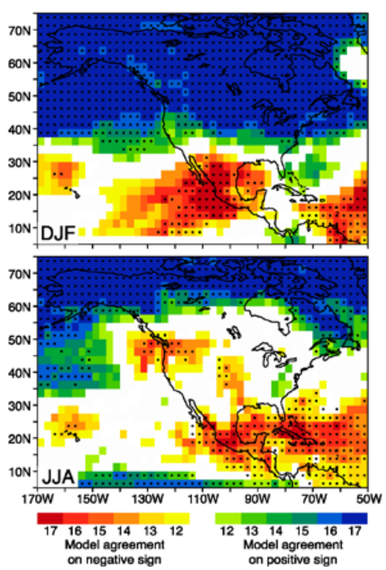
2230 JOURNAL OF CLIMATE VOLUME 27

SPECIAL North America in CMIP5 Models COLLECTION

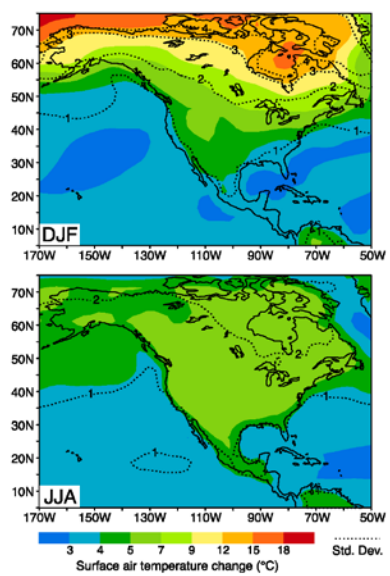
**North American Climate in CMIP5 Experiments: Part III: Assessment of Twenty-First-Century Projections***

ERIC D. MALONEY,[a] SUZANA J. CAMARGO,[b] EDMUND CHANG,[c] BRIAN COLLE,[c] RONG FU,[d] KERRIE L. GEIL,[e] QI HU,[f] XIANAN JIANG,[g] NATHANIEL JOHNSON,[h] KRISTOPHER B. KARNAUSKAS,[i] JAMES KINTER,[j,k] BENJAMIN KIRTMAN,[l] SANJIV KUMAR,[k] BAIRD LANGENBRUNNER,[m] KELLY LOMBARDO,[n] LINDSEY N. LONG,[o,p] ANNARITA MARIOTTI,[q] JOYCE E. MEYERSON,[m] KINGTSE C. MO,[p] J. DAVID NEELIN,[m] ZAITAO PAN,[r] RICHARD SEAGER,[b] YOLANDE SERRA,[e] ANJI SETH,[s] JUSTIN SHEFFIELD,[t] JULIENNE STROEVE,[u] JEANNE THIBEAULT,[s] SHANG-PING XIE,[h] CHUNZAI WANG,[v] BRUCE WYMAN,[w] AND MING ZHAO[w]

Precipitation Change




Temperature Change

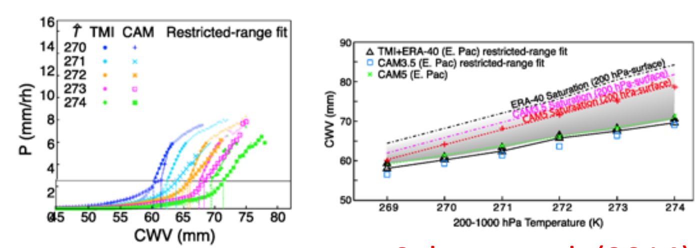



## Process-Oriented Diagnostics Framework

The newly christened NOAA MAPP Model Diagnostics Task Force is leading development of a software framework to entrain process-oriented diagnostics into model evaluation packages.

***Process-Oriented Diagnostic:***

- Goes beyond a simple diagnosis of whether a model can simulate a phenomenon or aspect of climate to provide physical insight into why
- Targets a specific physical process or emergent behavior and can guide parameterization improvement




Sahany et al. (2014)

Poster 13 in Session 4

# Evaluation of the forest biomass in CMIP5 models over the northern high-latitudes


Jiafu Mao[1,*], Cheng-En Yang[2], Forrest M. Hoffman[3], Daniel M. Ricciuto[1], and Joshua S. Fu[2]

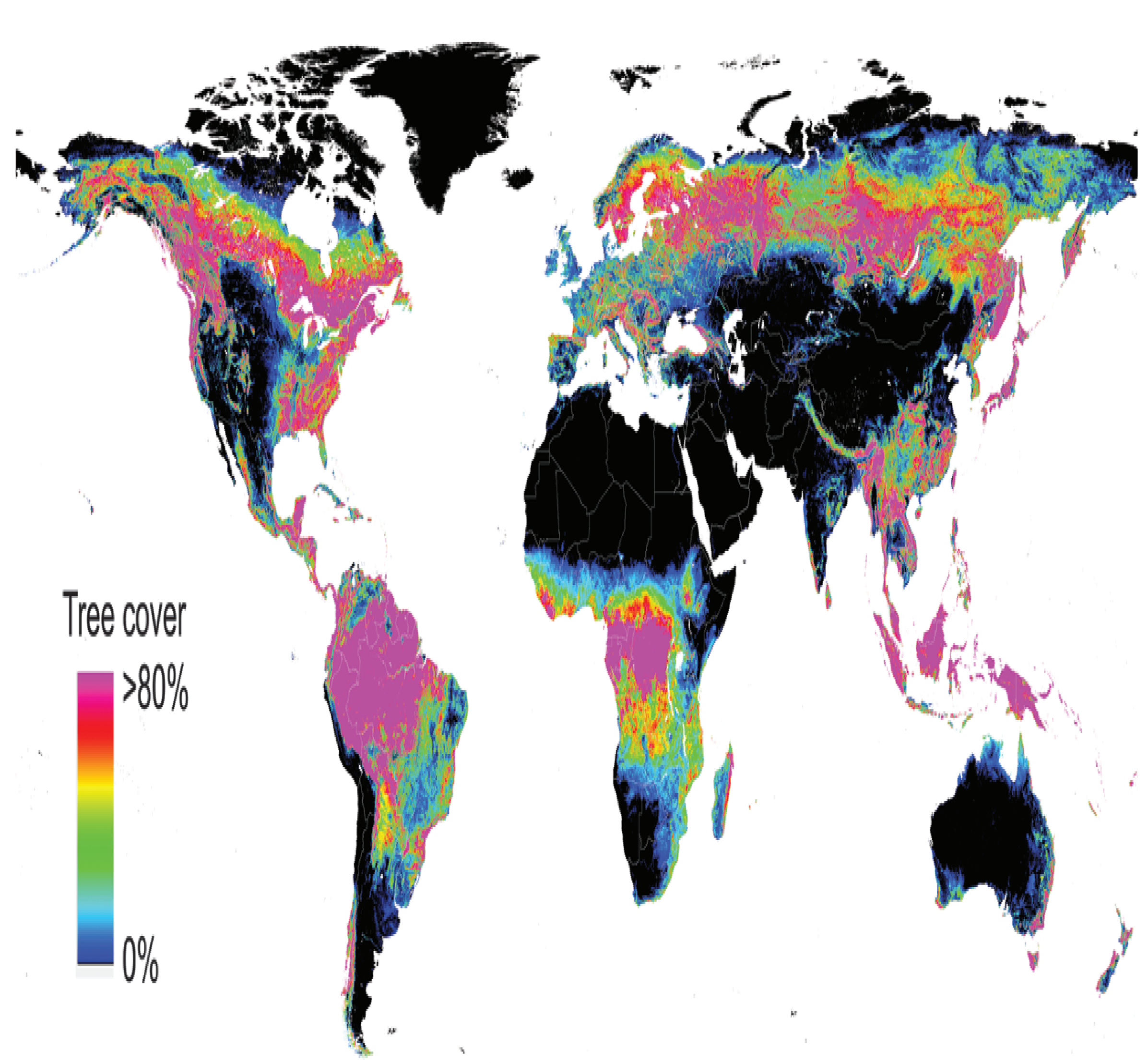
[1]Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN

[2]Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN

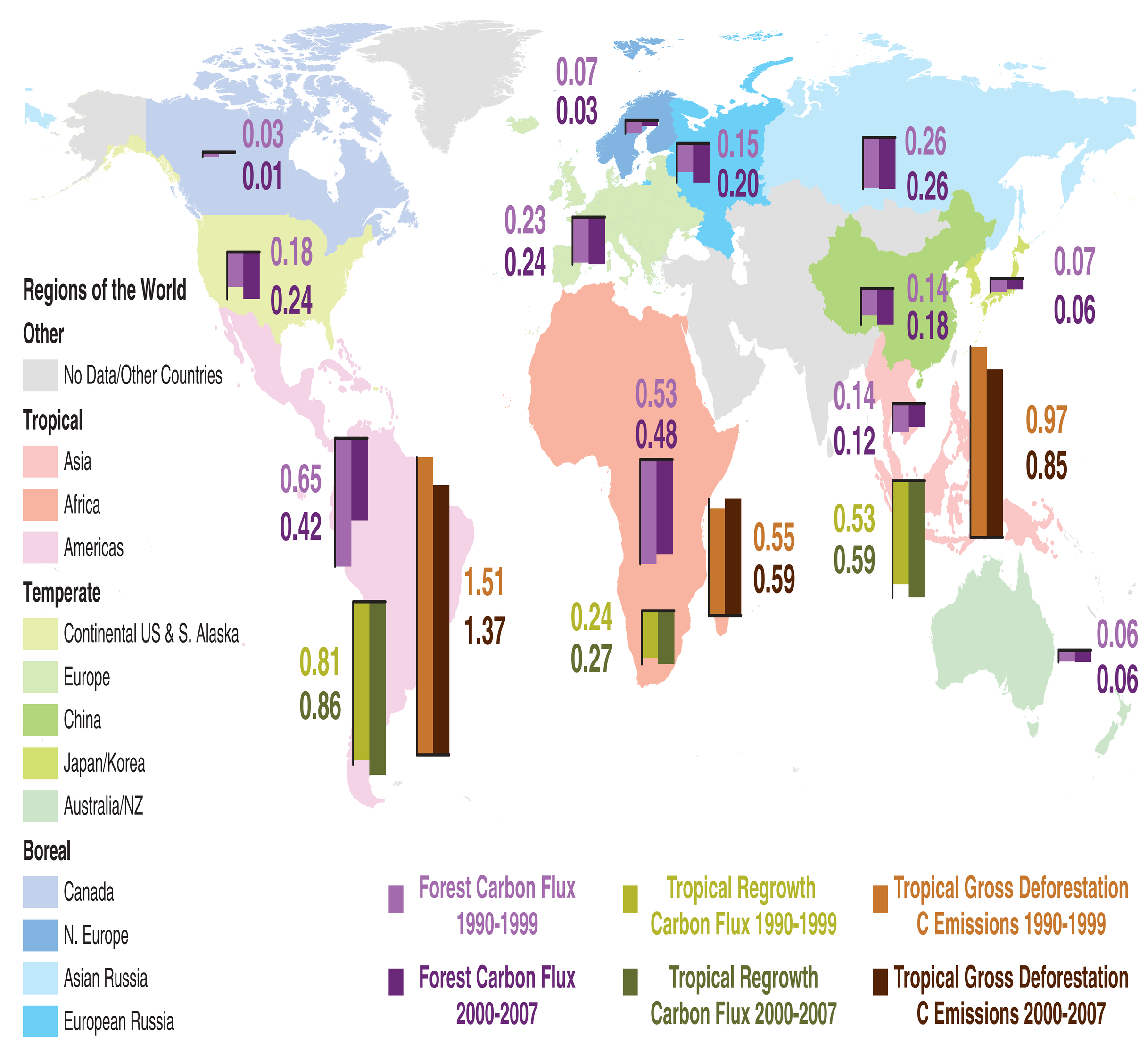
[3]Climate Change Science Institute and Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN


Climate Change Science Institute
Oak Ridge National Laboratory

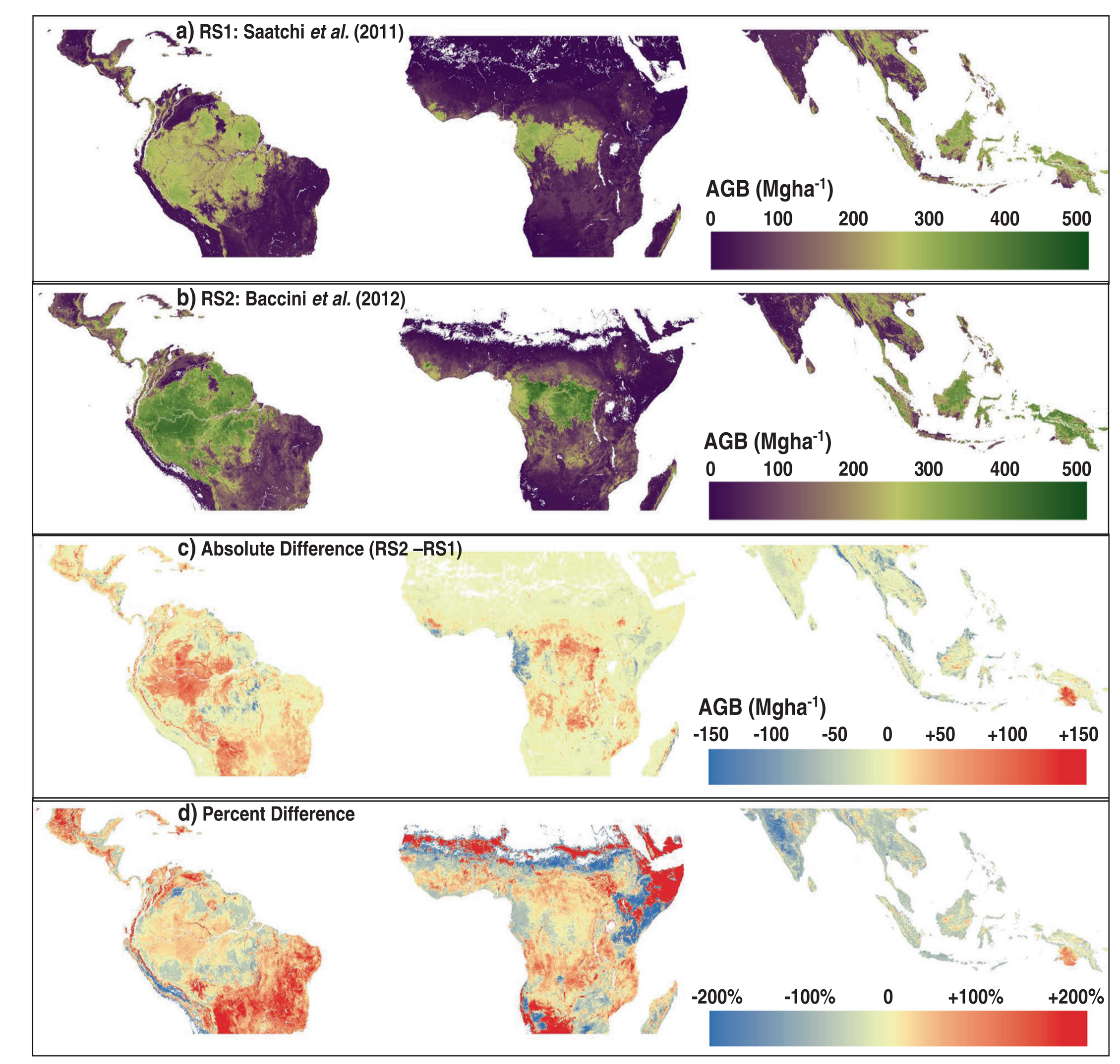
U.S. Department of Energy
Office of Science



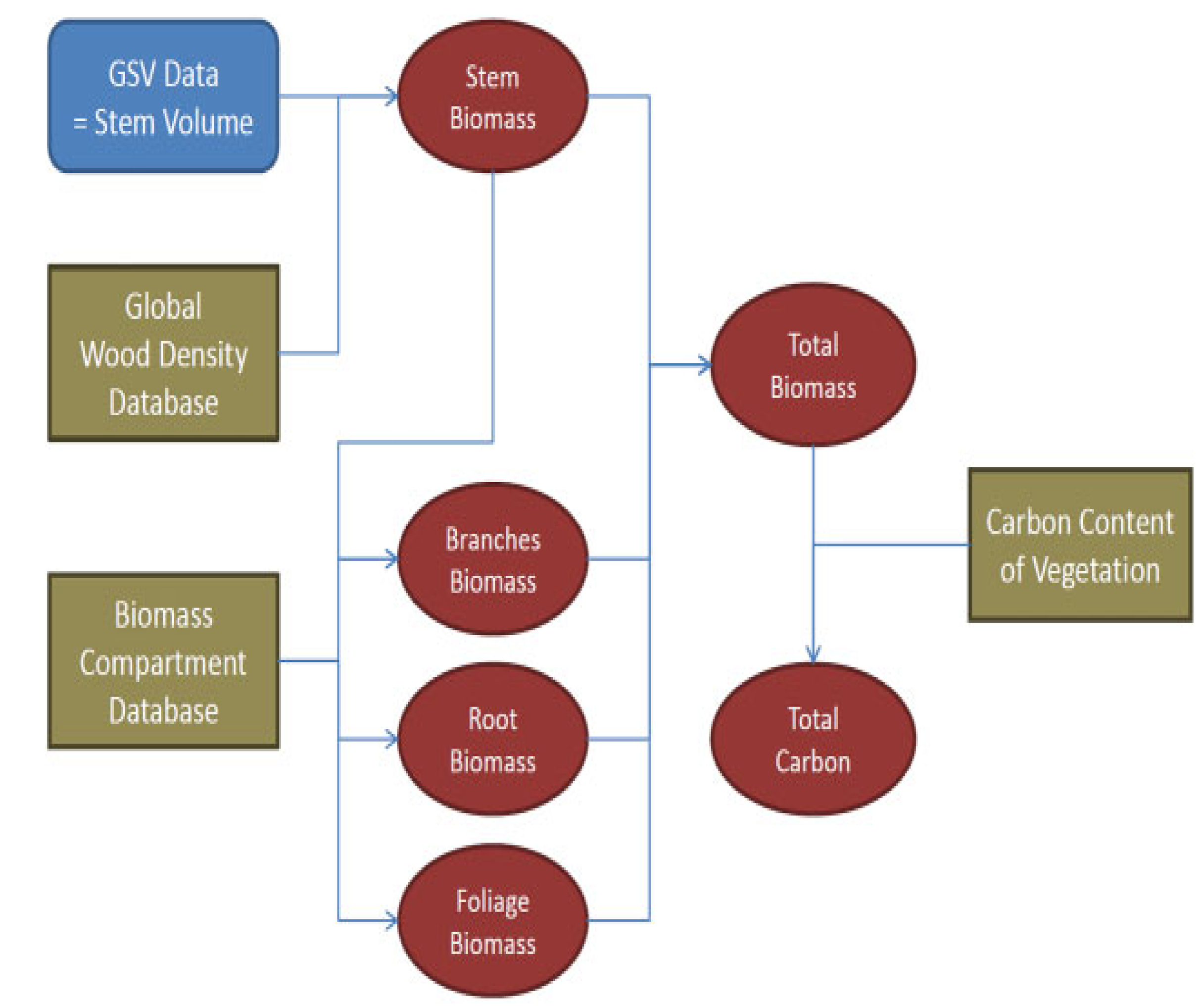

Hansen et al. 2013, Science



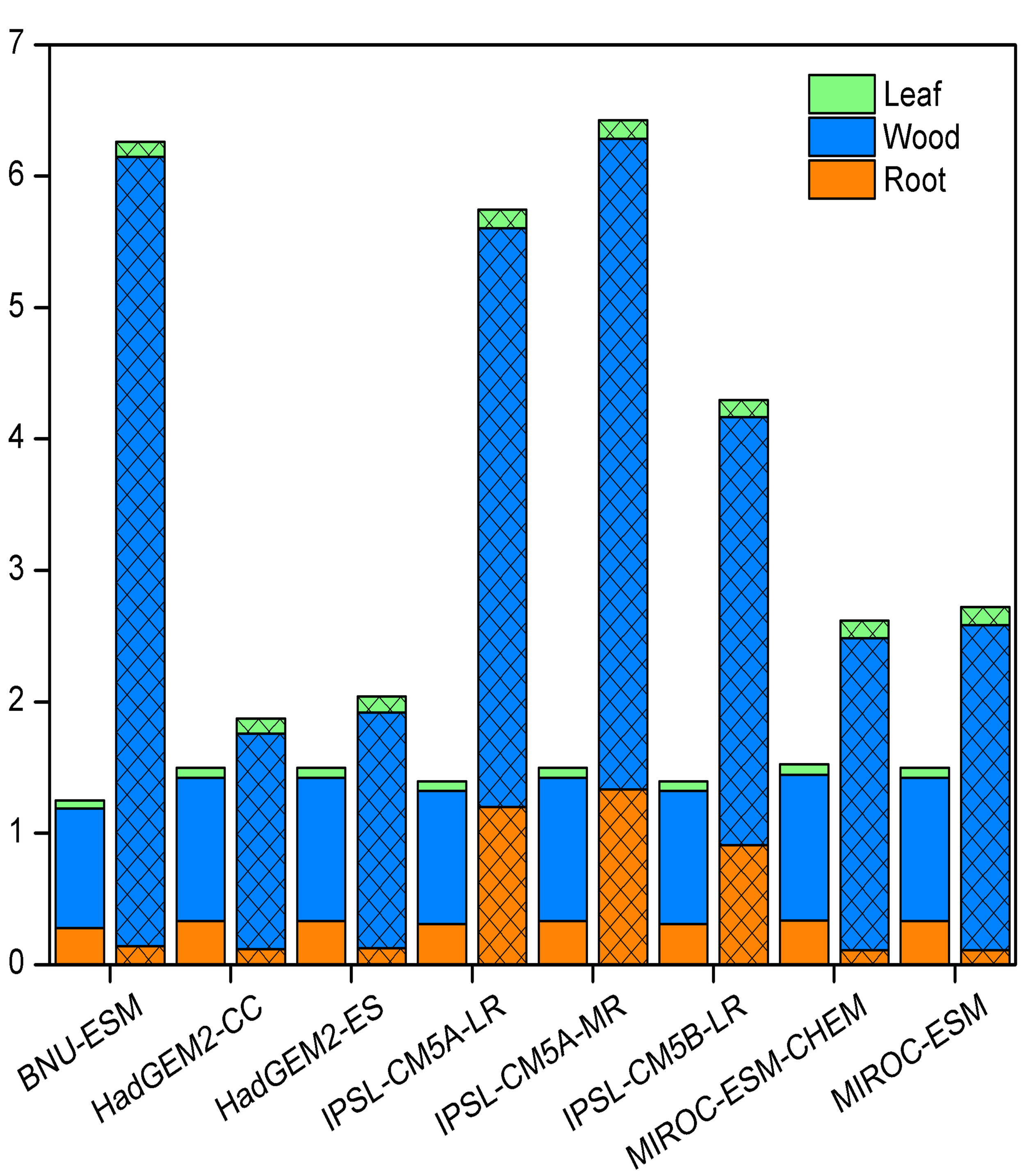

Pan et al. 2011, Science



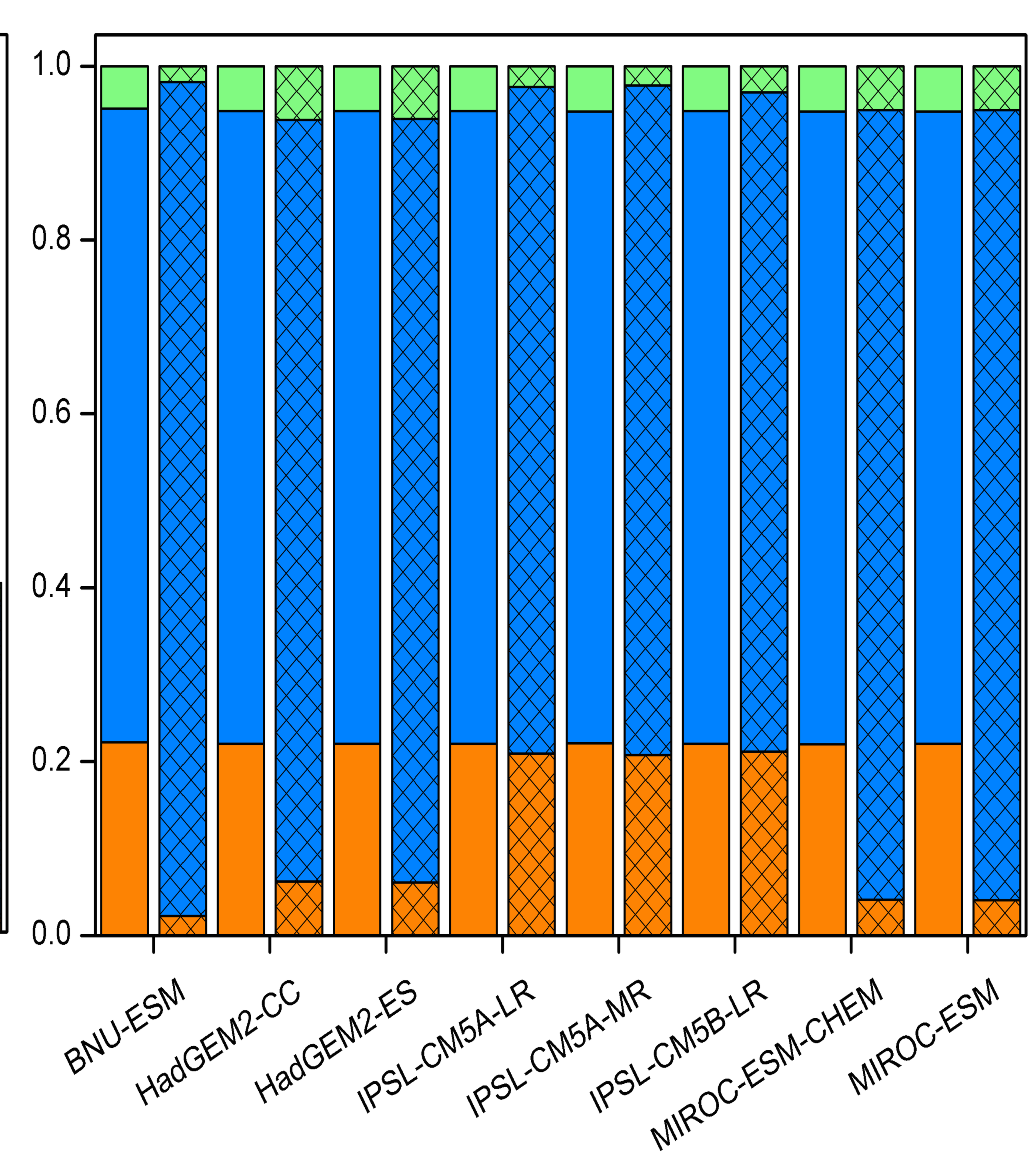

Saatchi et al., 2011, PNAS; Baccini et al., 2012, NCC; Mitchard et al. 2013, CBM; Liu et al., 2015, NCC



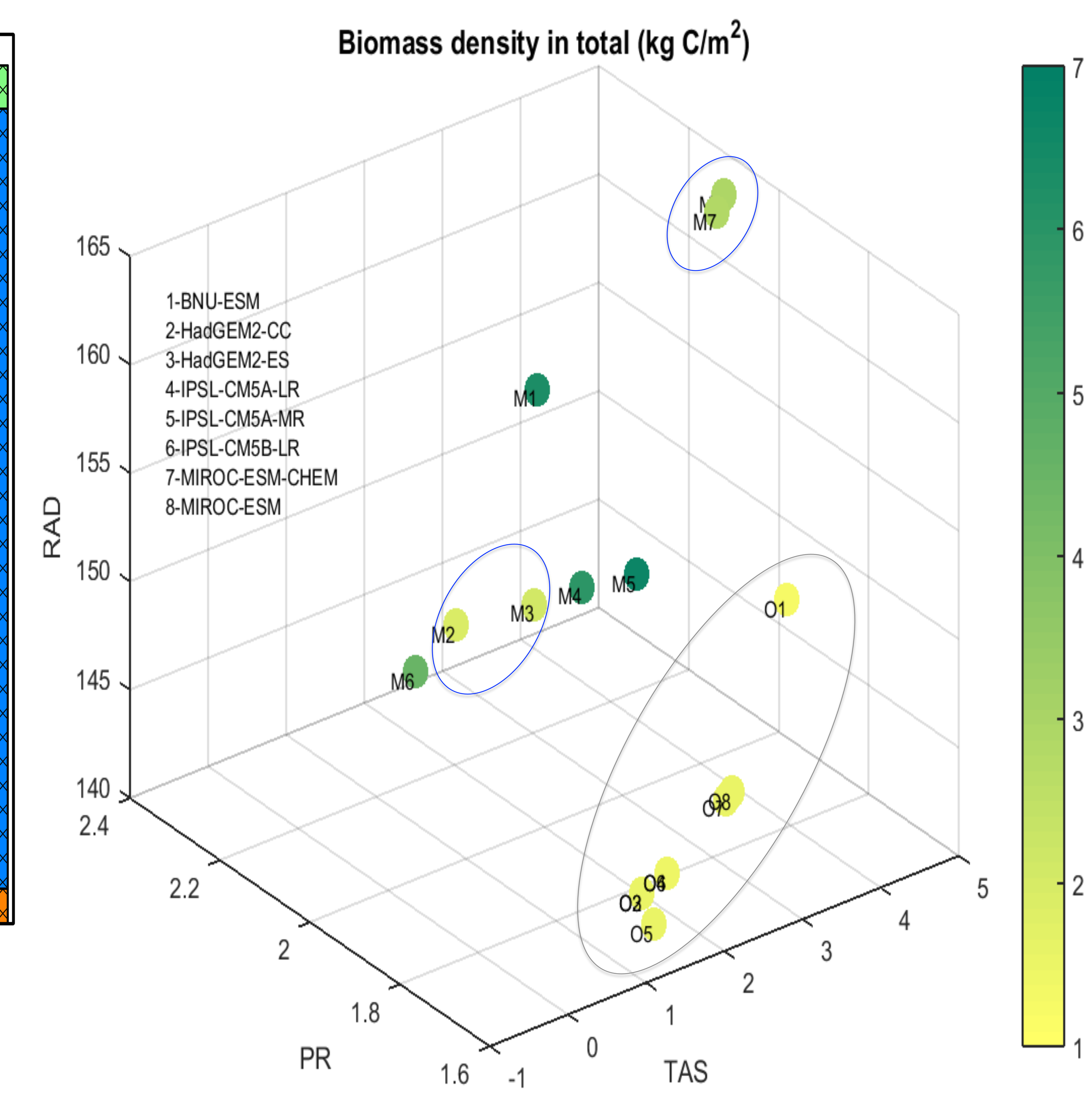

Thurner et al. 2014, GEB



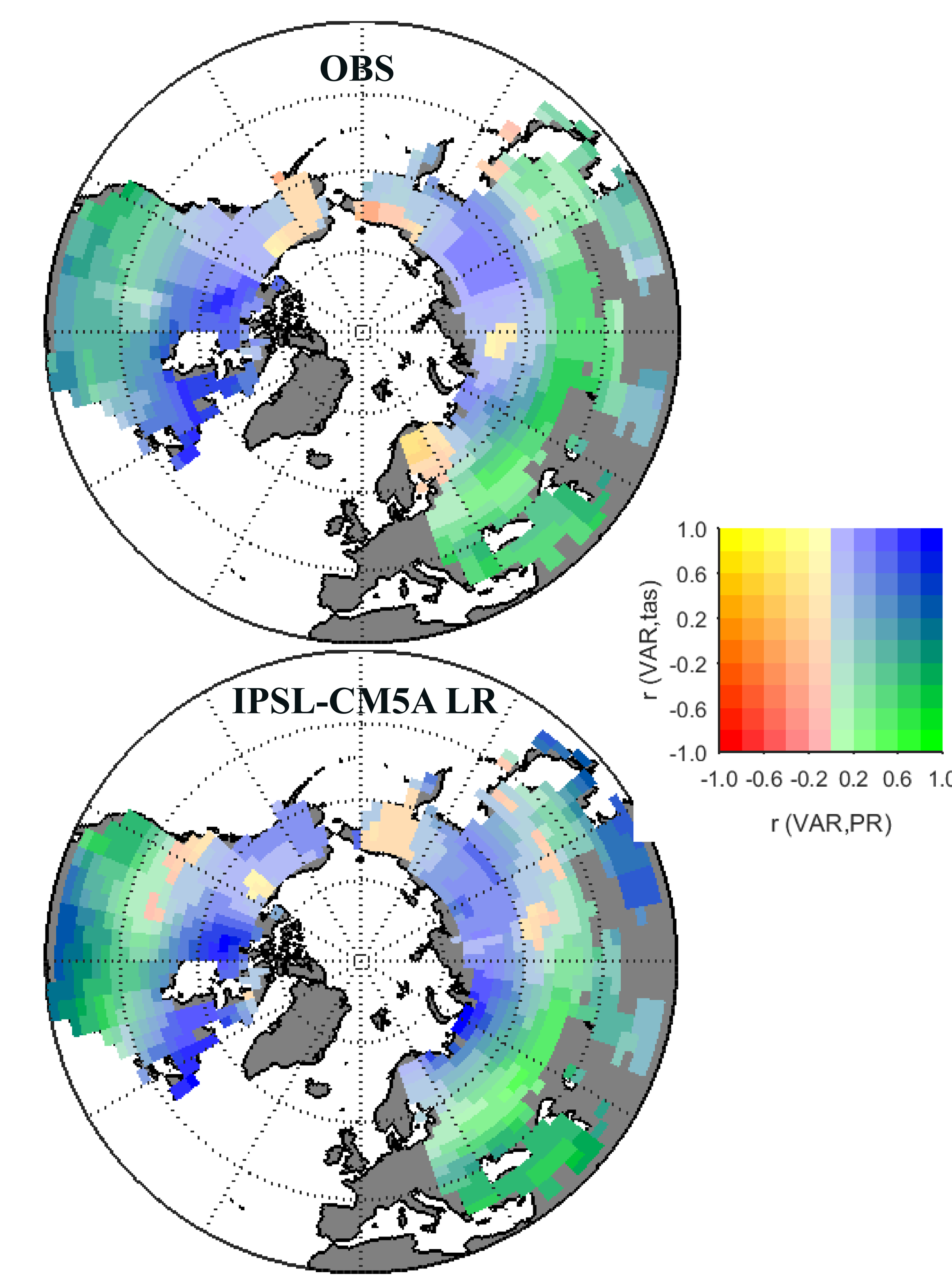

Biomass density of tree components (Kg C/m$^{-2}$)




Normalized biomass density




Mean biomass density in climate space




Covariation of total biomass density, precipitation and temperature


Sponsored by the U.S. Department of Energy, Office of Science, Biological and Environmental Research (BER) programs, and performed at Oak Ridge National Laboratory (ORNL). ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725. Please contact maoj@ornl.gov for further information.

# A mechanism for ENSO amplitude changes under enhanced radiative forcing in CMIP5 models

Harun Rashid, Anthony Hirst and Simon Marsland, *CSIRO Oceans and Atmosphere, Melbourne, VIC, Australia*

- The impact of global warming on ENSO has been shown to be uncertain in the CMIP3/5 ensembles.
- But the individual CMIP5 models show a rich spectrum of behavior: from a strongly reduced to a strongly enhanced ENSO amplitude.
- What determines this differing behavior among the models?

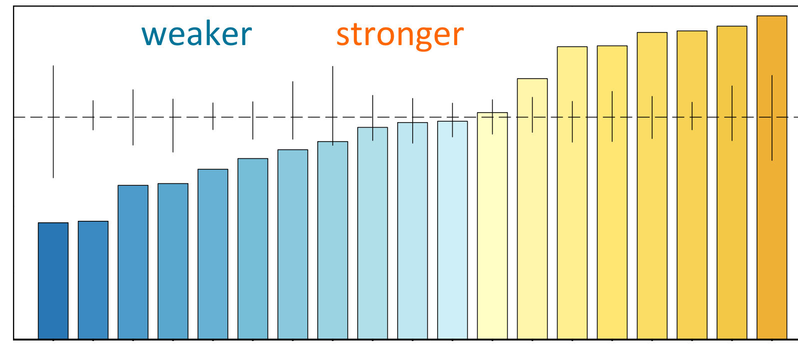
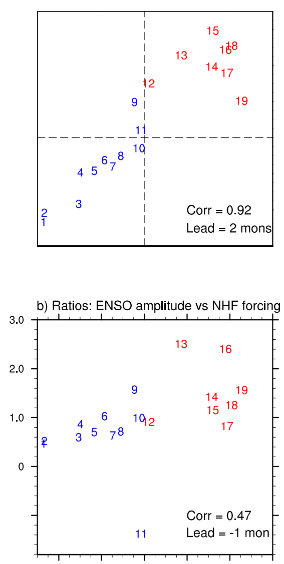



Fig. 1. Changes in ENSO amplitude in the abrupt4xCO2 experiments w.r.t. the piControl experiments in CMIP5.



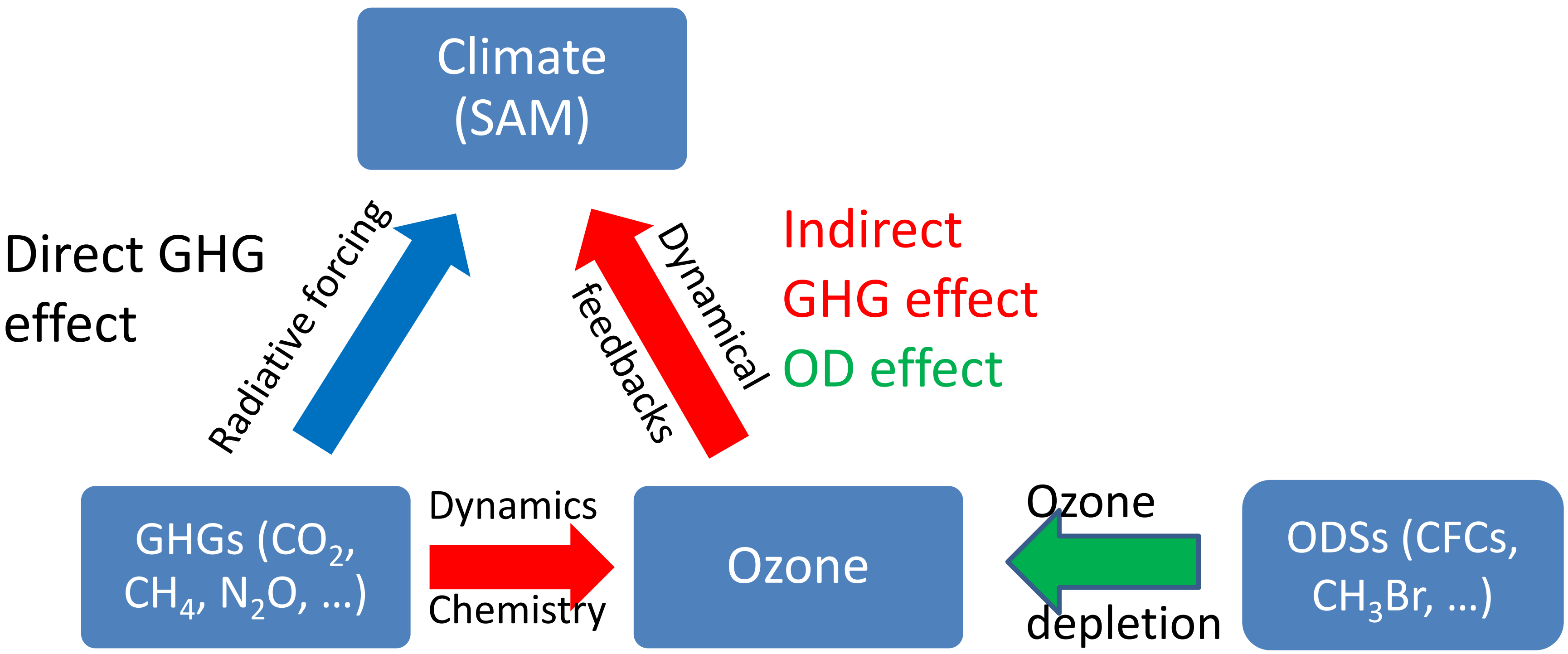

1) GISS-E2-H
2) GISS-E2-R
3) NorESM1-M
4) GFDL-ESM2M
5) IPSL-CM5A-MR
6) CCSM4
7) GFDL-CM3
8) BNU-ESM
9) HadGEM2-ES
10) GFDL-ESM2G
11) IPSL-CM5A-LR
12) ACCESS1-0
13) MRI-CGCM3
14) ACCESS1-3
15) MPI-ESM-P
16) CSIRO-Mk3-6-0
17) IPSL-CM5B-LR
18) MPI-ESM-MR
19) MIROC5

- We find that the changes in ENSO amplitude are strongly correlated (r = 0.92) with the changes in zonal wind stress forcing efficiency of SST in the equatorial Pacific.
- The coupling between the low-level zonal wind and deep convection in the central Pacific is found to be crucial in determining the nature of ENSO response to GW.

More details may be found in the poster.

# Ozone-mediated forcing of the Southern Annular Mode by Greenhouse Gases

O. Morgenstern[1], S. M. Dean[1], G. Zeng[1], M. Joshi[2], N. L. Abraham[3], and A. Osprey[4]
[1]NIWA, New Zealand [2]U. East Anglia, Norwich, UK [3]U. Cambridge, UK [4]U. Reading, UK



# Regional Climate Variability and Change Since 850 C.E.

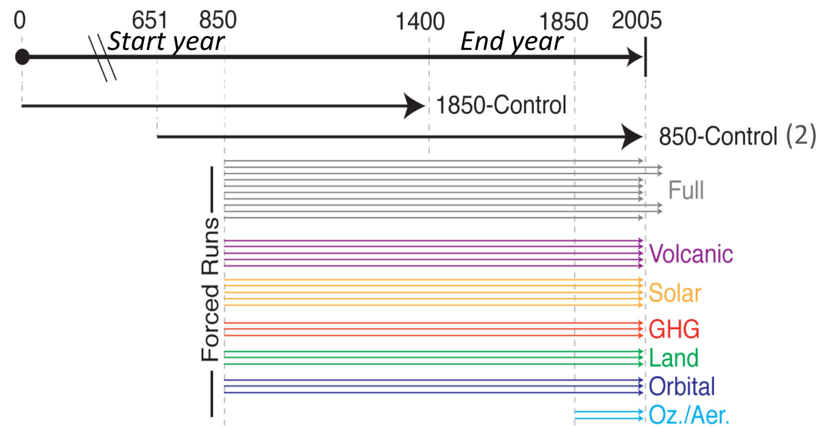
## Considering Internal Variability When Assessing Differences in CMIP5 past1000 Simulations

### Last Millennium Ensemble (LME)

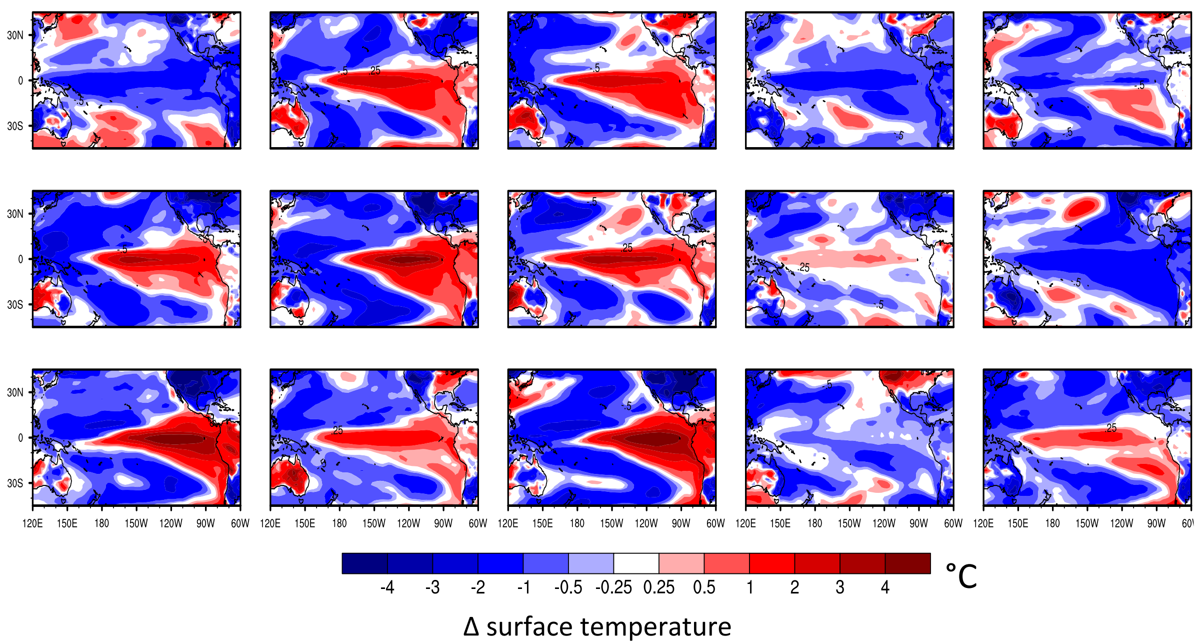
CESM1 (CAM5): ~ 2° resolution atmosphere and land, ~ 1° resolution ocean and sea ice.

Three long control runs to assess internal variability.

29-member ensemble set (850-2005 AD) includes single and full forcing simulations.




### Post-Tambora, Winter 1816/1817




A proxy-based study suggested the probability for El Niño to occur following large tropical eruptions doubled.

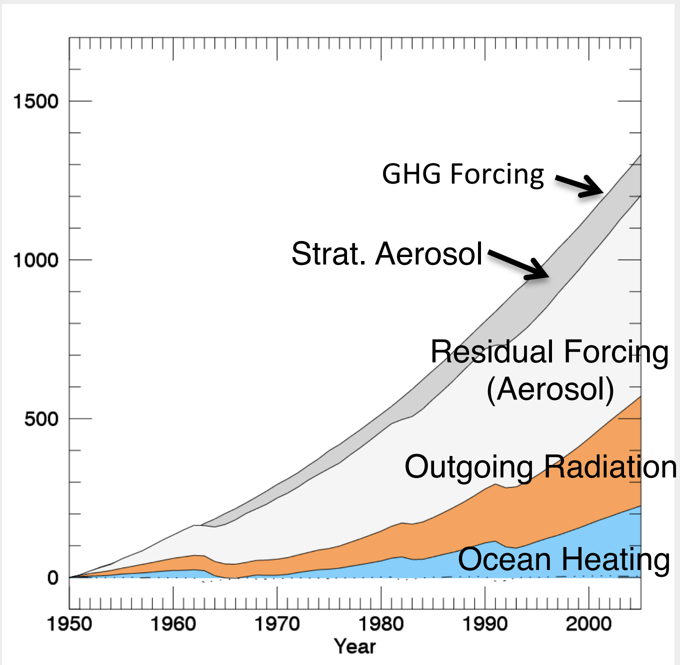
- *9 (60%) of the individual members with volcanic forcing exhibit El Niño warming in second winter after the April 1815 Tambora eruption.*
- *But other 6 members show a neutral or La Niña response.*

# The Earth's Energy Budget across CMIP5 Models

Robert Portmann & Erik Larson

## Cumulative Energy Budgets

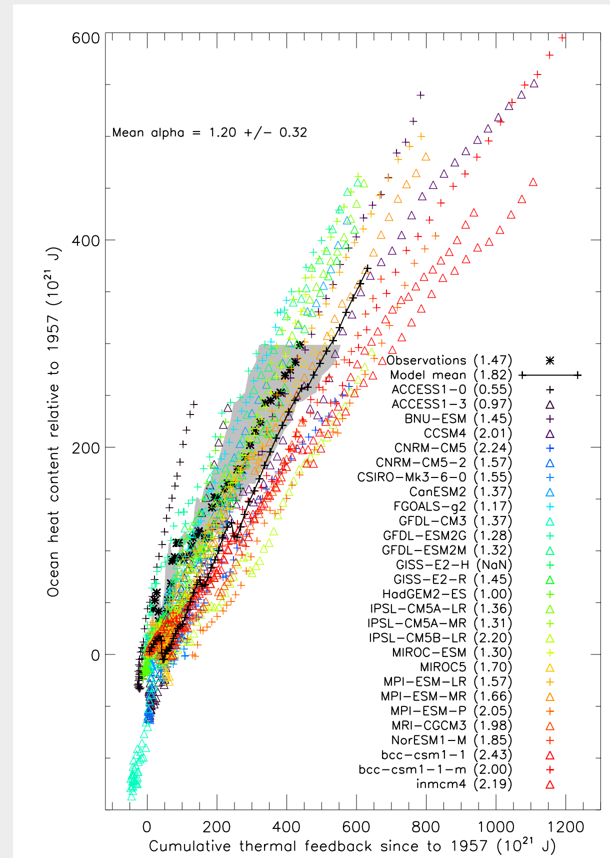
CMIP5 Models




Similar to Observational study of Murphy et al. 2009 but using models

- How well can we estimate energy budgets from models?
- What are the limits of drift removal?

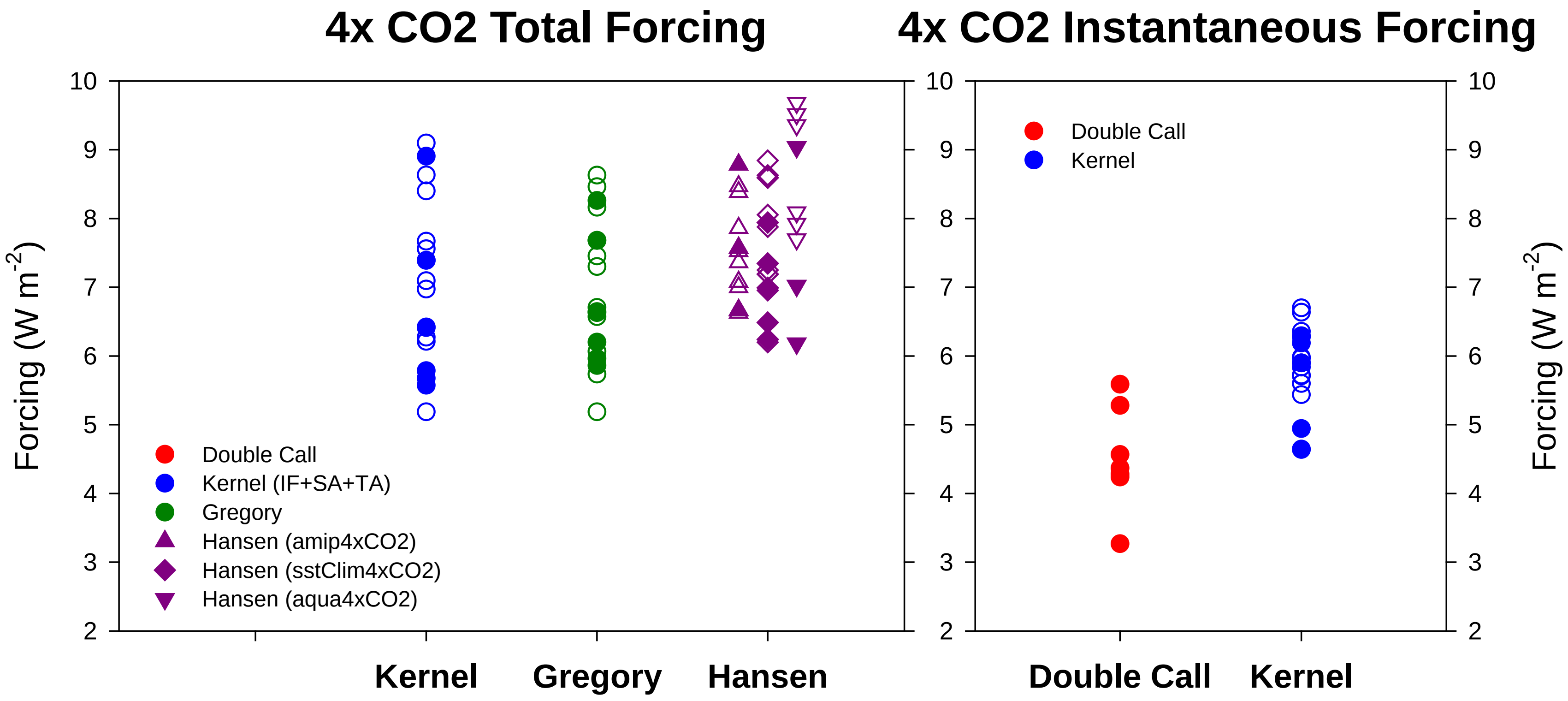
## Emitted vs. Retained Energy since 1950 (Time series)




Multi-dimensional test of models against observations.

# An Assessment of Radiative Forcing in CMIP5

**Eui-Seok Chung and Brian Soden**
**University of Miami**



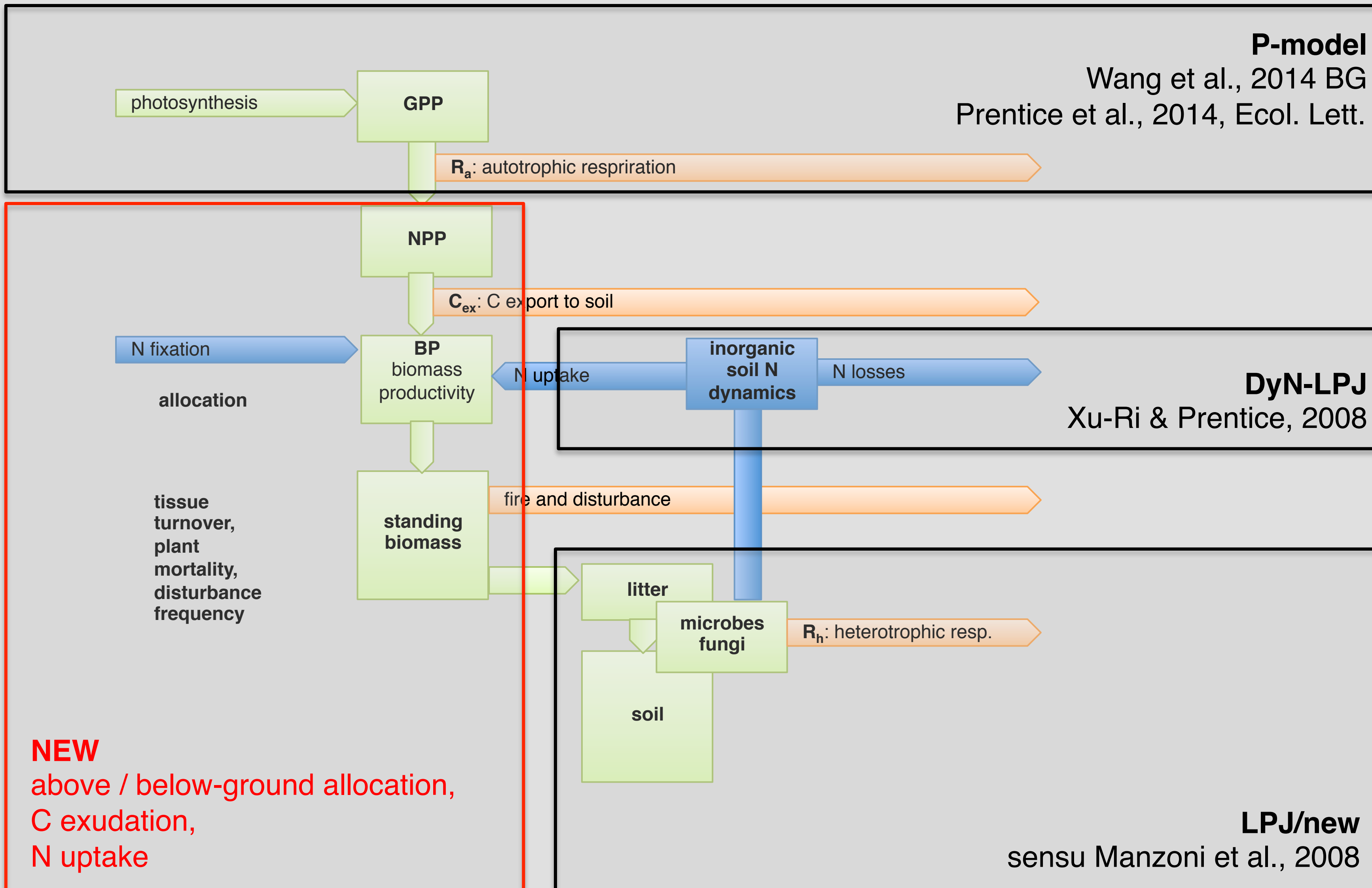

- Radiative forcing remains a significant uncertainty in projections of climate change
- Modeling centers should calculate and archive radiative forcing as part of CMIP6.

Imperial College London

# How should we represent terrestrial carbon-nitrogen cycle interactions in Earth system models? A roadmap for model development

Benjamin D. Stocker[1], I. Colin Prentice[1,2]

[1]Department of Life Sciences, Imperial College London, Silwood Park, Ascot, SL57PY, UK [2]Department of Biological Sciences, Macquarie University, North Ryde, Australia



# Bidecadal North Atlantic ocean circulation variability controlled by timing of volcanic eruptions

Swingedouw et al.

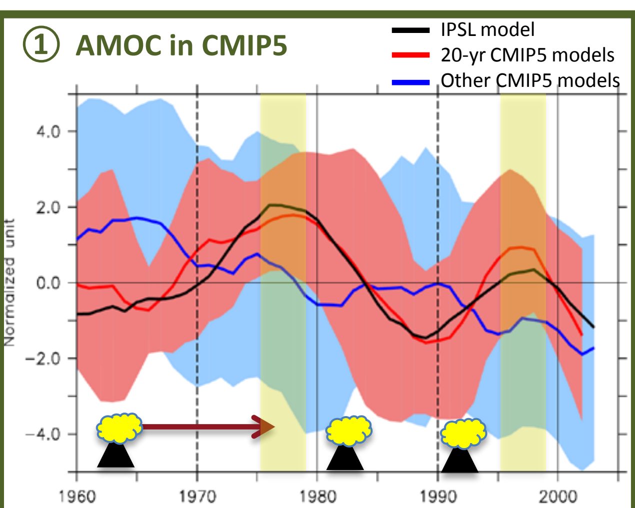
**What is the impact of volcanic eruptions of decadal variability in the North Atlantic?**

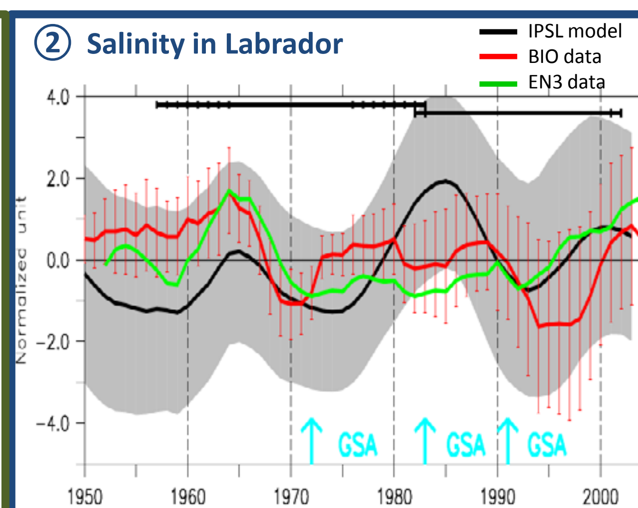
Use of CMIP5 models, *in situ* data and last millennium proxy data to show:

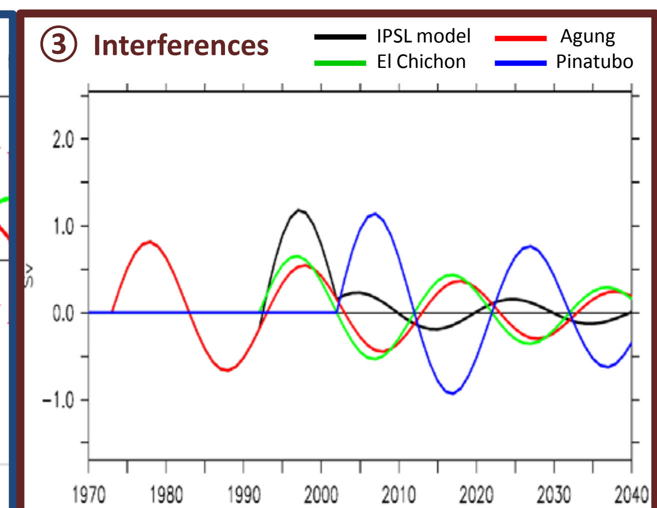
① A reset of 20-yr variability in the Atlantic Overturning (AMOC)

② Explanation for some recent Great Salinity Anomalies (GSA)

③ Interferences for the AMOC over the recent period

# Sensitivity of Regional Climate to Global Temperature and Forcing

Claudia Tebaldi, Brian O'Neill and Jean François Lamarque (NCAR)

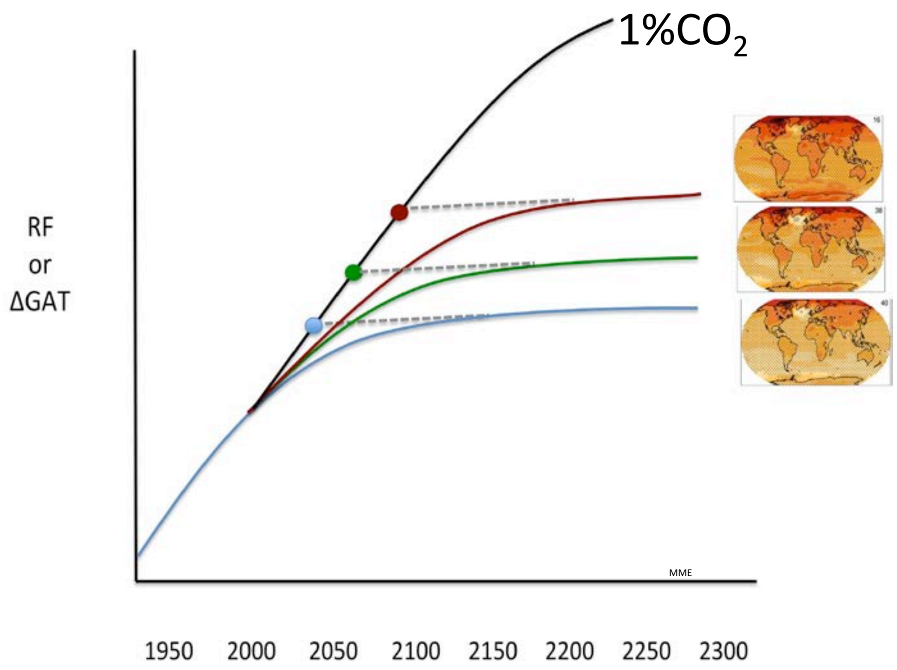
**At what magnitude of change in Global Average Temperature or Radiative Forcing do we start experiencing *significant* change "on the ground"?**

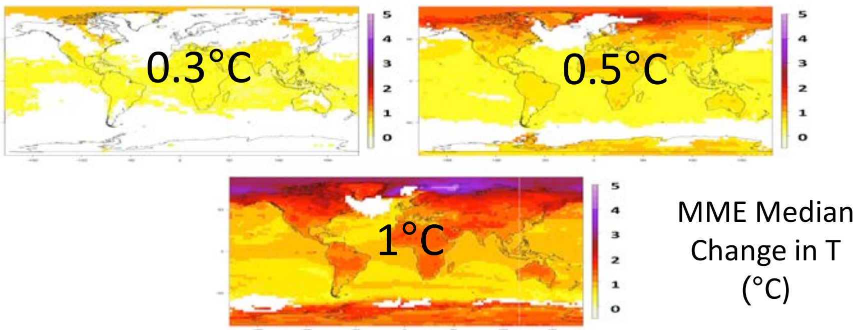
**Why do we ask?**

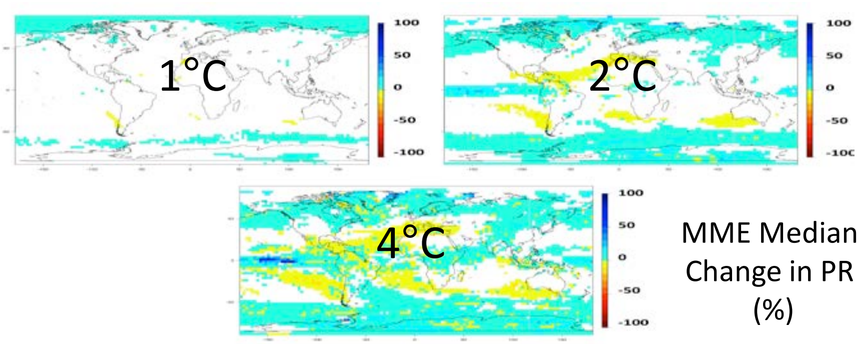
**mitigation costs/overshoots/missing targets:**

*e.g., If instead of stabilizing climate at 2C we stabilize it at 2.5C, does that matter for impacts? It would definitely cost less for mitigation…*

**experimental design of new scenarios:** *How far apart do scenarios need to be to justify running them through ESMs? How close do they need to be to approximate what has not been run and still be consistent with SSPs' assumptions?*



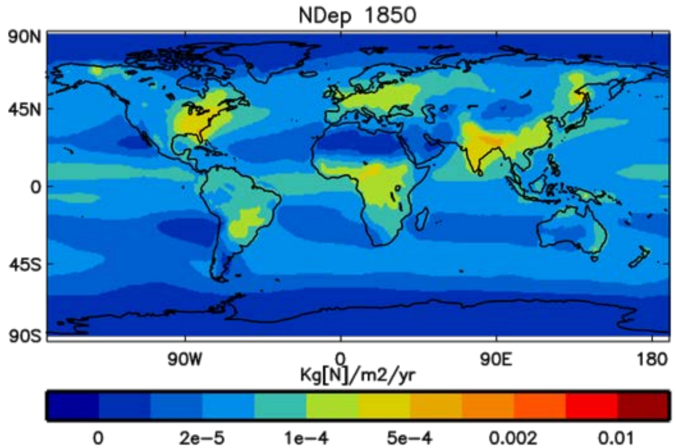



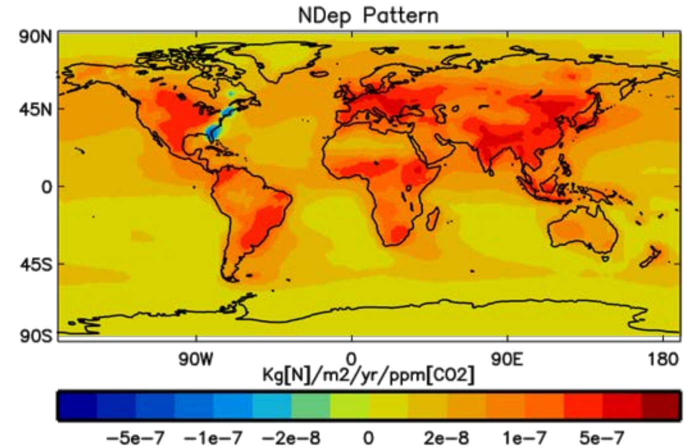

*We acknowledge the WCRP's Working Group on Coupled Modelling and we thank the climate modeling groups for producing and making available their model output.*

Met Office
Hadley Centre

# Carbon Feedbacks in the JULES Carbon-Nitrogen land surface model.

Exeter University and Met Office Hadley Carbon Cycle Group




C4 MIP includes experiments for diagnosing Carbon feedbacks for models with interactive Nitrogen cycles.

We propose a method for generating Nitrogen Deposition Forcing

In JULES-CN Nitrogen limitation reduces the net carbon uptake