National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

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Evolution not Revolution:
Charting a realistic path forward?

Gavin Schmidt, NASA GISS

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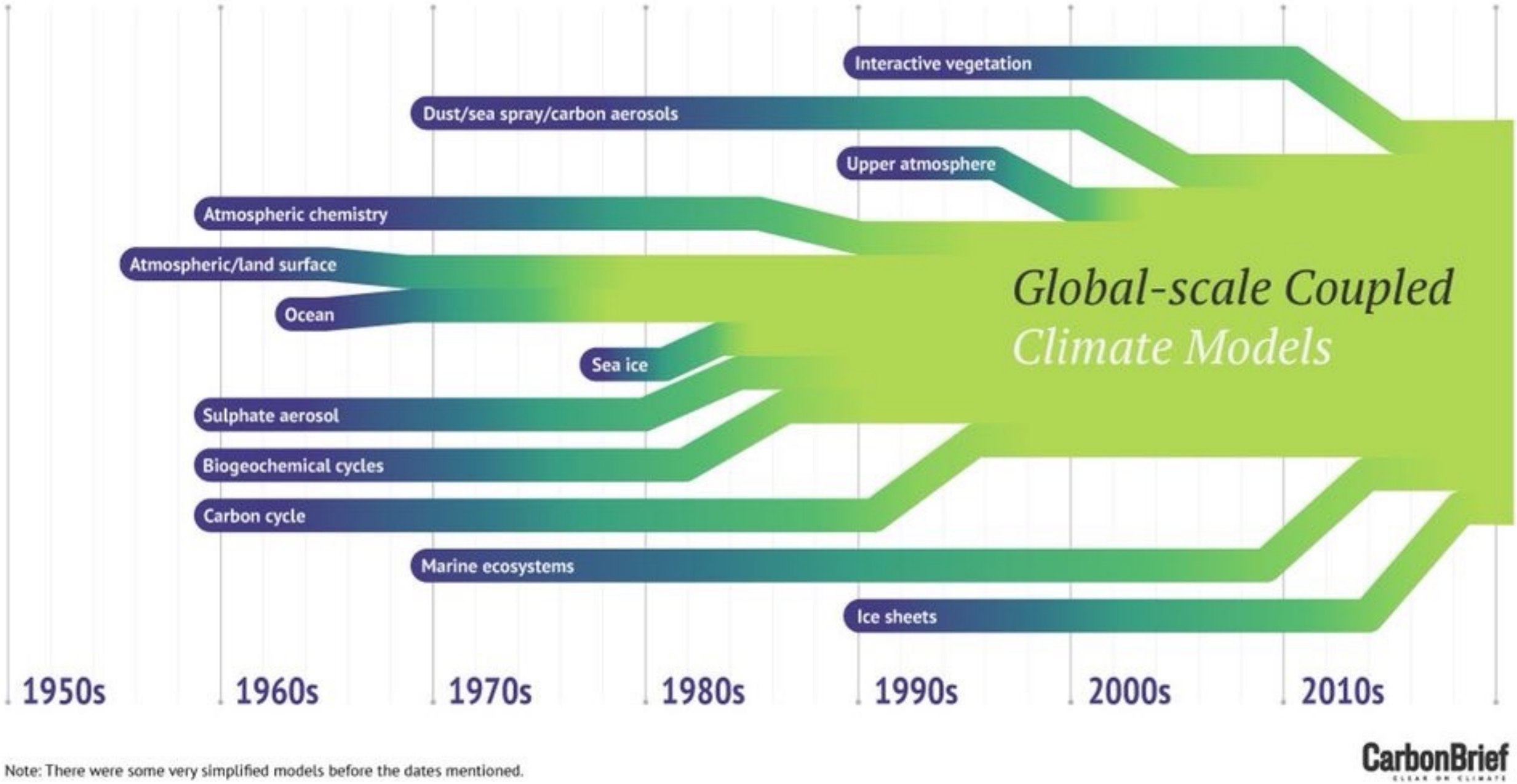
Wouldn’t it be great if…

…there was an overarching theory that predicted climate sensitivity from first principles?

…we could design parameterizations that always gave the right emergent response?

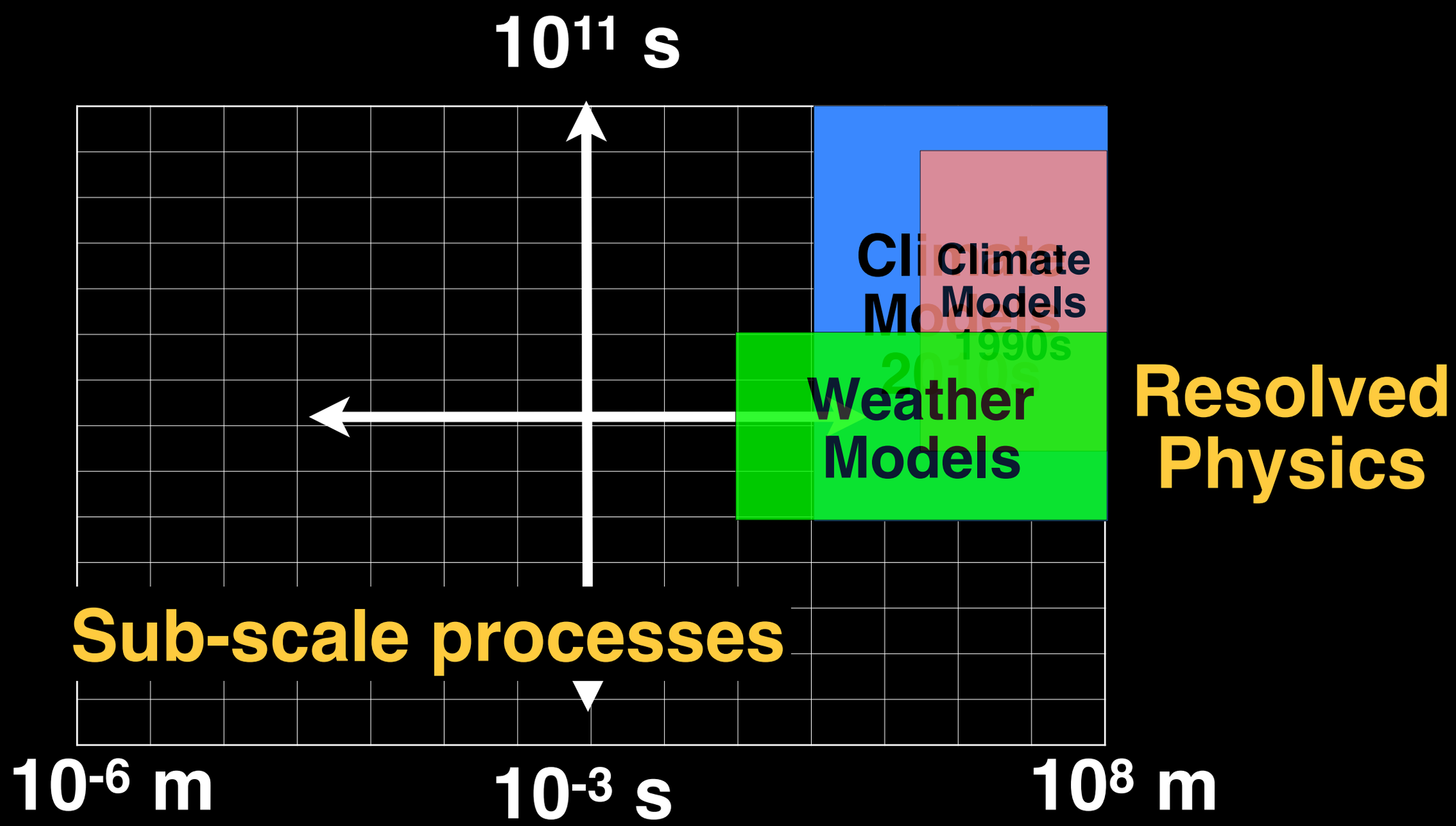
… GCMs were more aesthetically pleasing?

…no people were involved in scientific progress?

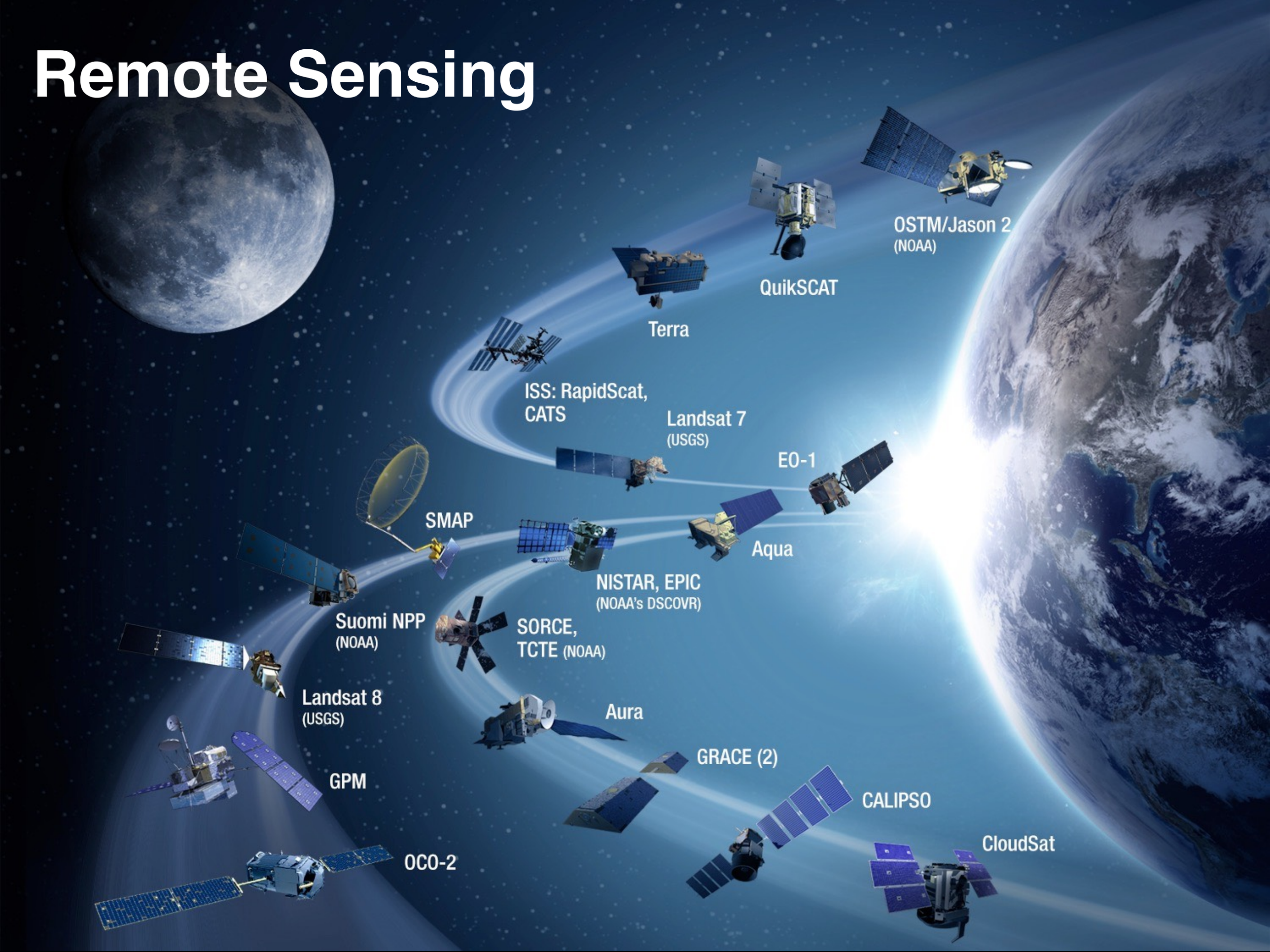


Zeke Hausfather

14 Orders of Magnitude



Remote Sensing



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GISS-E2 Contributions to CMIP5

Experiment	years/expt	No. of simulations	total model years	archive size (TB)
historical+Ext	162	36	5832	4.5
rcp26	95+200	3	885	0.8
rcp45	95+200	18	5310	5.4
rcp60	95+200	3	885	0.3
rcp85	95+200	3	885	0.8
past1000	1000+155	16	18480	14
lgm	100	2	200	0.2
midholocene	100	2	200	0.2
historicalMisc+ Nat+GHG	155	102	15810	13
amip	155	12	1860	2.5
1pctCO2	140	6	840	0.5
abrupt4xCO2	150	6	900	0.5
Spin-ups	~500	~11	~5500	N/A
Controls	~1000	8	8000	3.7
Total		228	~ 66K	~50

6 model versions:
2 x oceans
- Russell
- HYCOM

3 x atm. composition:
- non-interactive
- interactive
- including parameterised AIE

Multiple forcings:
- single forcings
- collections
- alternates

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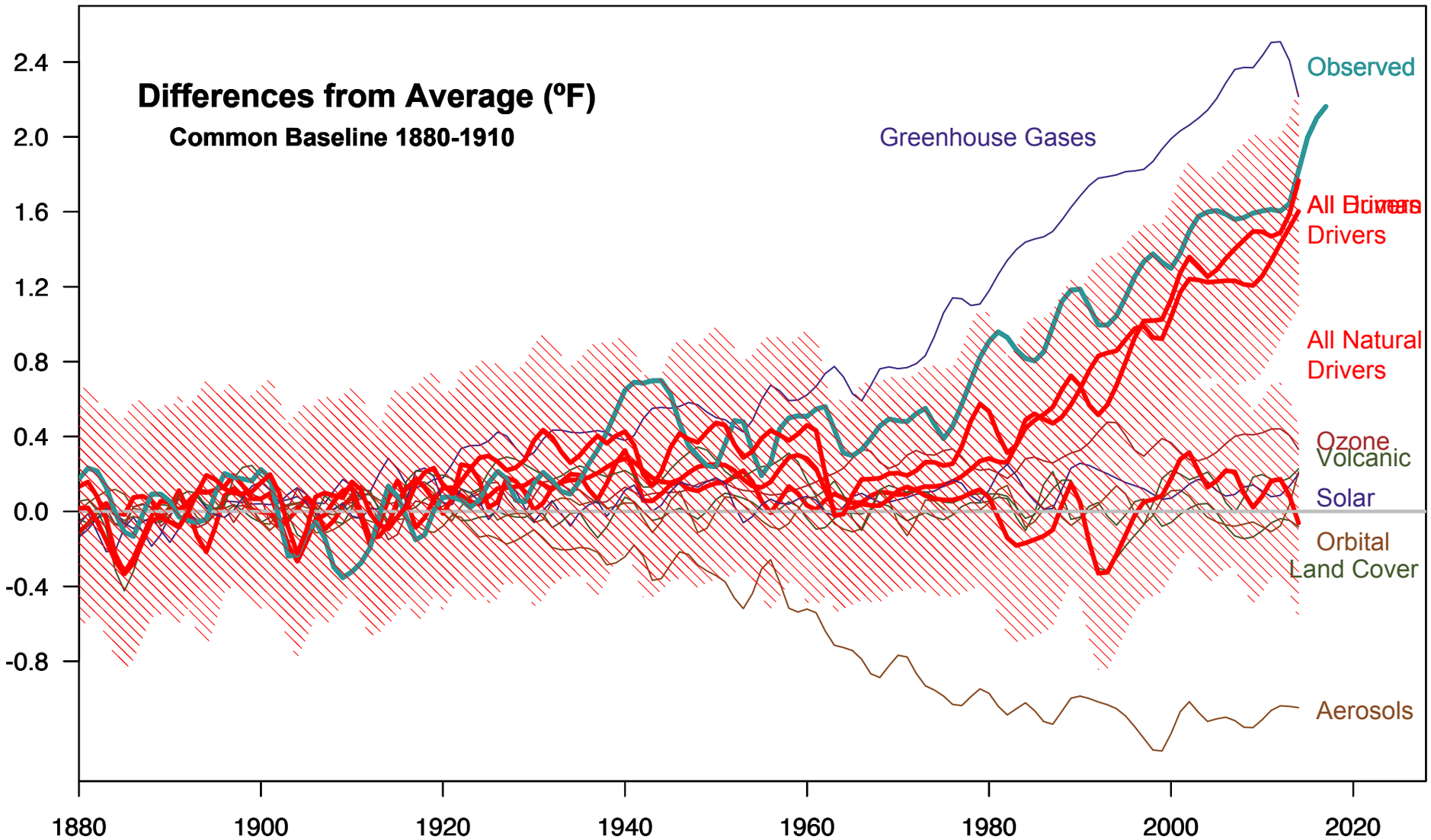
Early CMIP6 results



GISS E2.1G - CMIP6 forcings - simple AIE - 4yr smooth

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Issues/needs

Better coordinated data analytics

GCMs in DA

Parameterization development and tuning

Paleo-climate “out of sample” tests

Complexity *and* Coherence

Exploration of structural uncertainty

(= “arbitrary and ad hoc coding decisions”)

The process-based diagnostic challenge

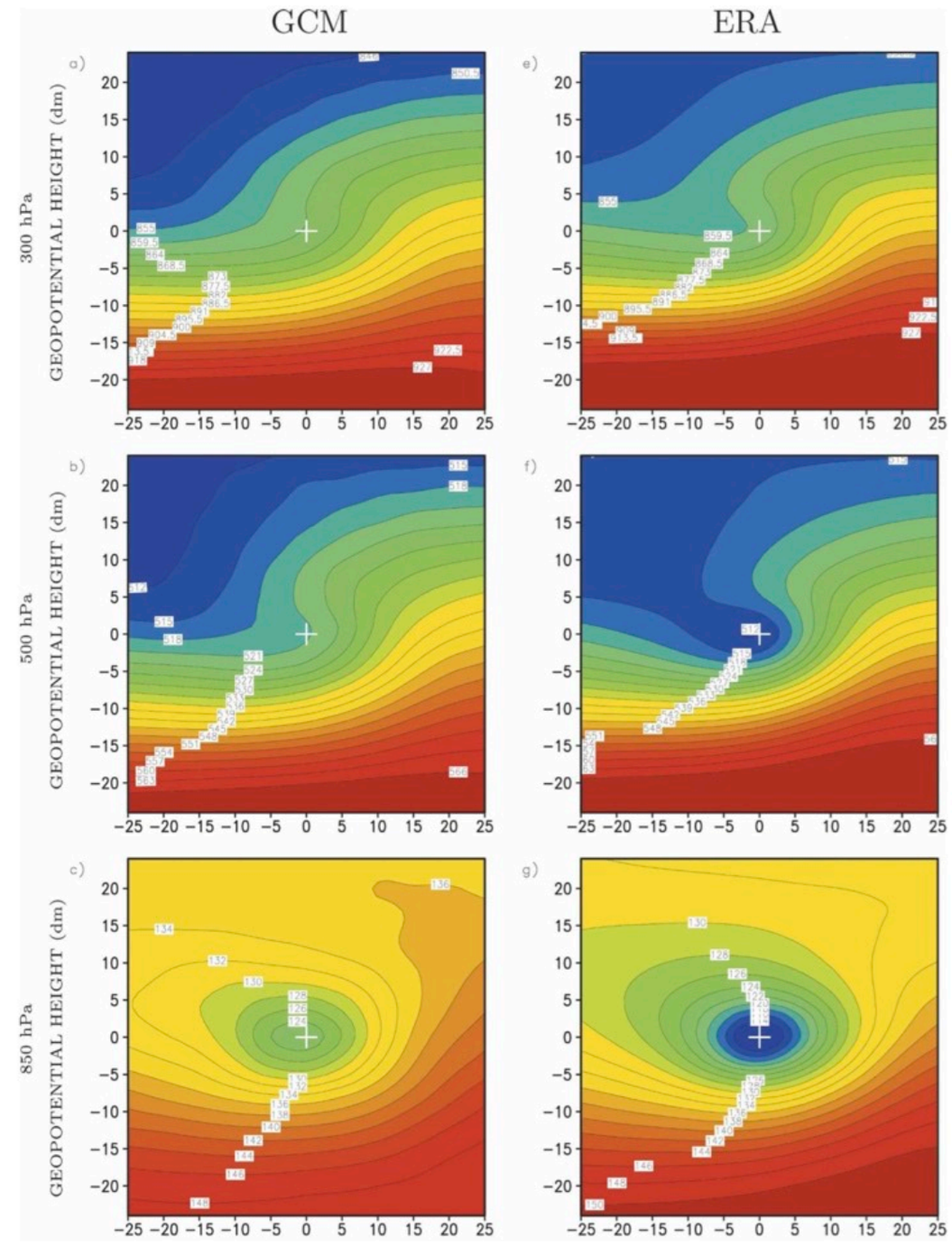
Imagine....

- Reanalysis: find mid-latitude storms
- Satellites: Create composite
- Models: Create composite
- Models: Create pseudo-satellite views
- Compare processes...

Estimated completion time using current technology?

- Years.

Need multivariate/parallel time-space-model-ensemble member filter combined with multi-variate compositing/analysis



Bauer and Del Genio, 2006

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Multiple, diverse single column case studies: LES—> SCM —> GCM

Conditions	Case study
dry convective boundary layer	idealized [Bretherton and Park 2009]
dry stable boundary layer	GABLS1 [Bretherton and Park 2009]
marine stratocumulus	DYCOMS-II RF02 [Ackerman et al. 2009]
marine trade cumulus (shallow)	BOMEX [Siebesma et al. 2003]
marine trade cumulus (deep, raining)	RICO [van Zanten et al. 2011]
marine stratocumulus-to-cumulus transition	SCT [Sandu and Stevens 2011]
continental cumulus	RACORO [Vogelmann et al. 2015]
Arctic mixed-phase stratus	M-PACE [Klein et al. 2009]
mid-latitude synoptic cirrus	SPARTICUS [MÃ¼hlbauer et al. 2014]
tropical deep convection	TWP-ICE [Fridlind et al. 2012]
continental deep convection	EUROCS II [Guichard et al. 2004]

Stratocumulus to trade-cumulus transition

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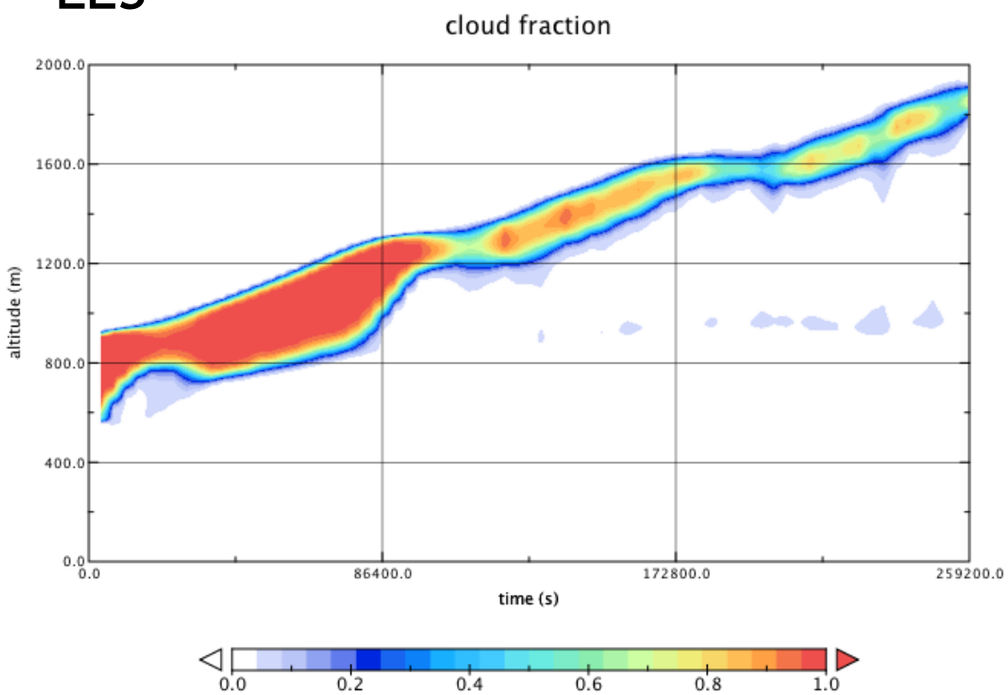
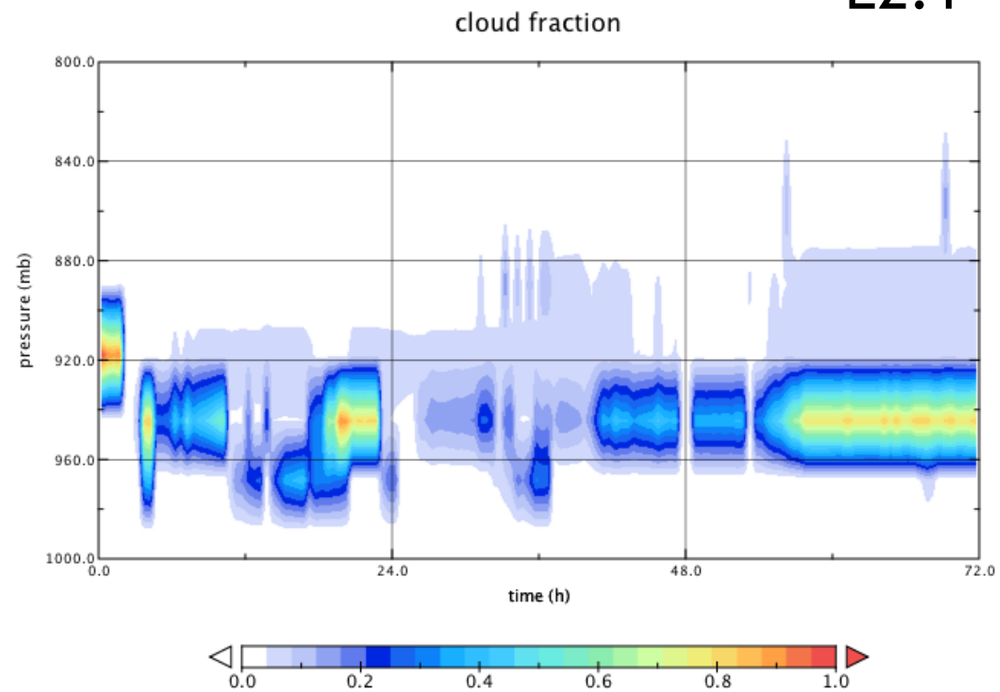
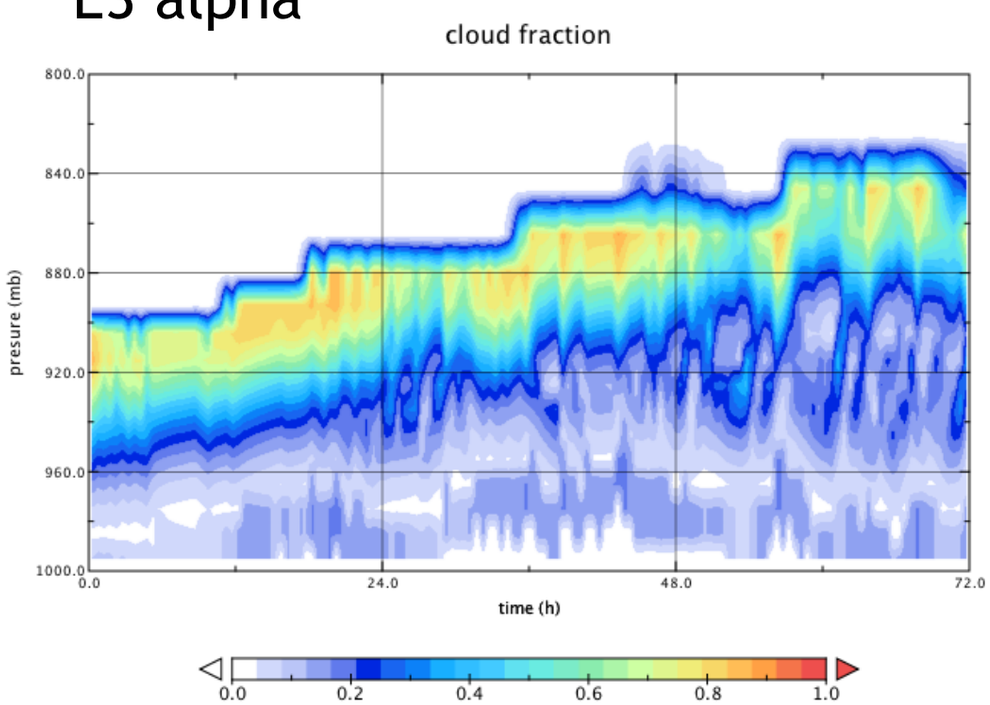
LES



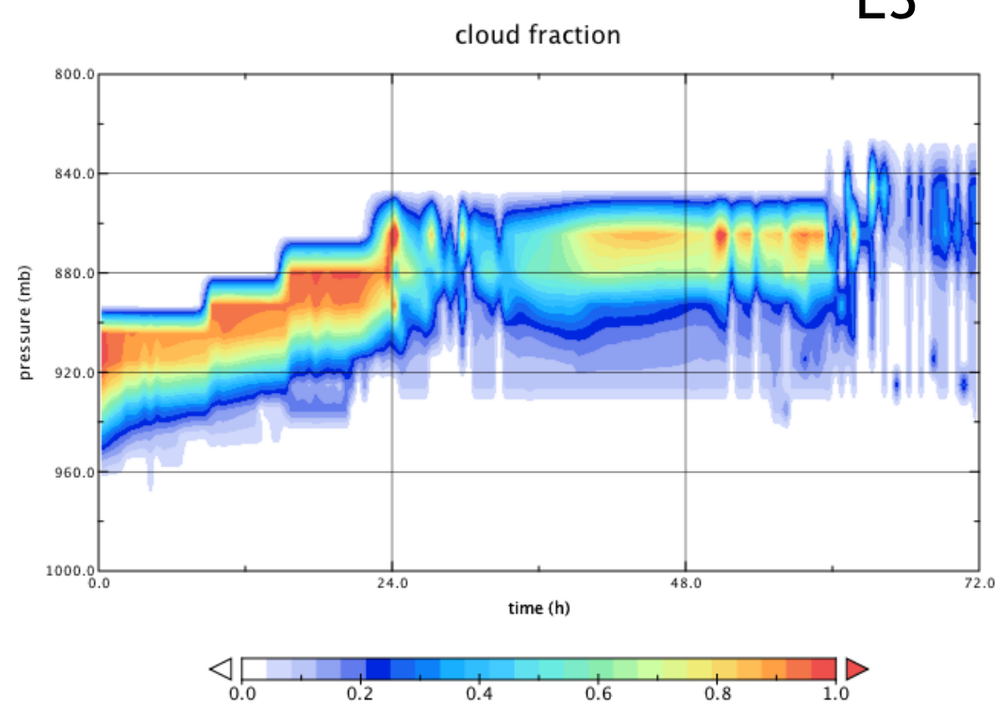
E2.1



E3 alpha



E3



Big improvements in representation of MJO

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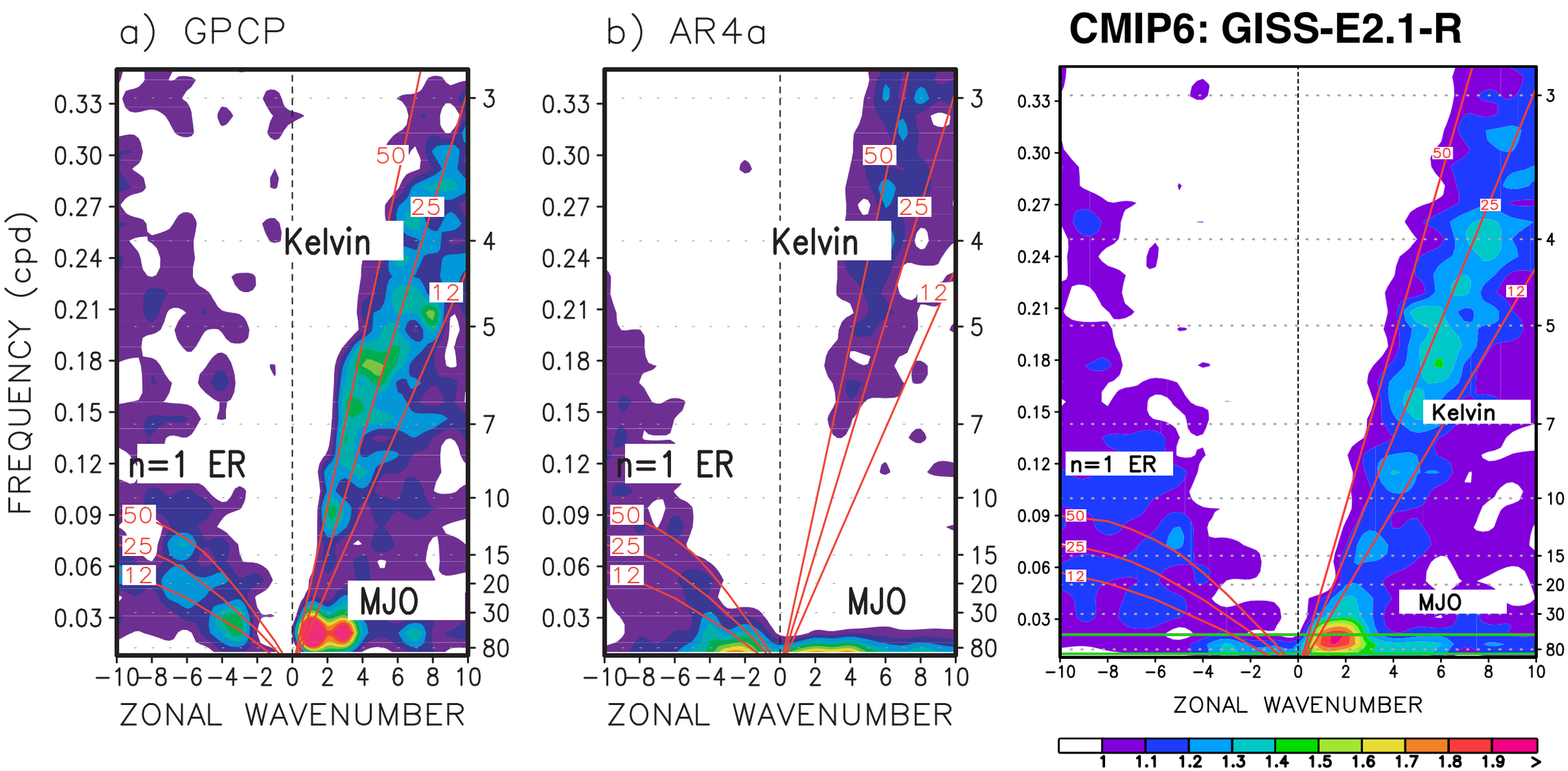
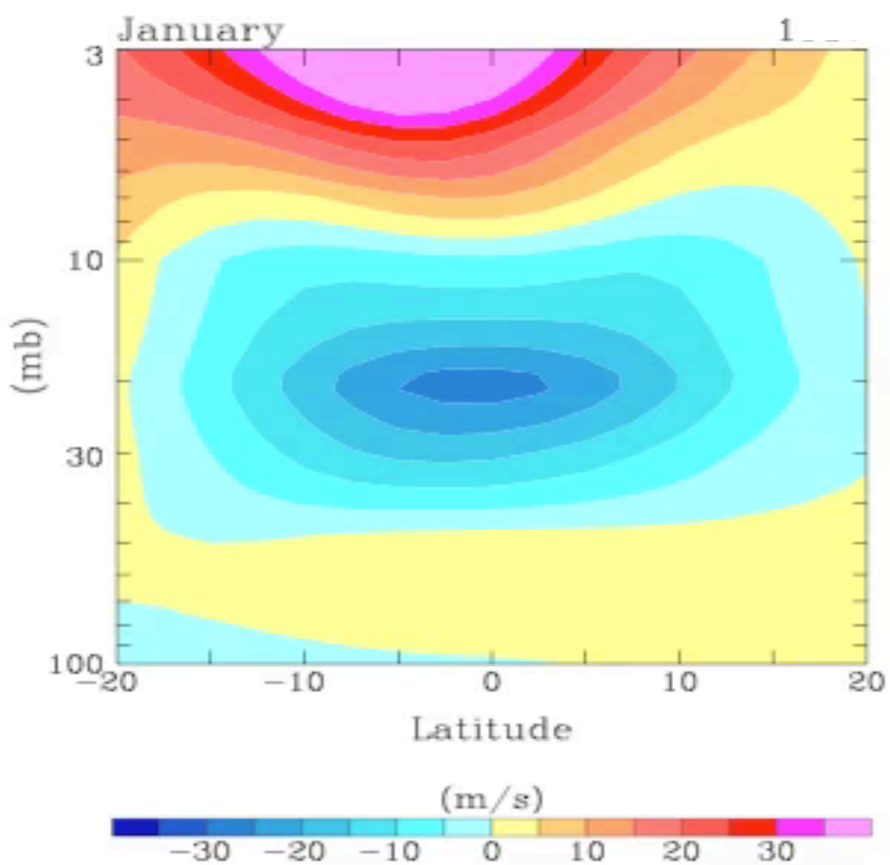


(Wheeler-Kiladis diagrams extended from Kim et al, 2012)

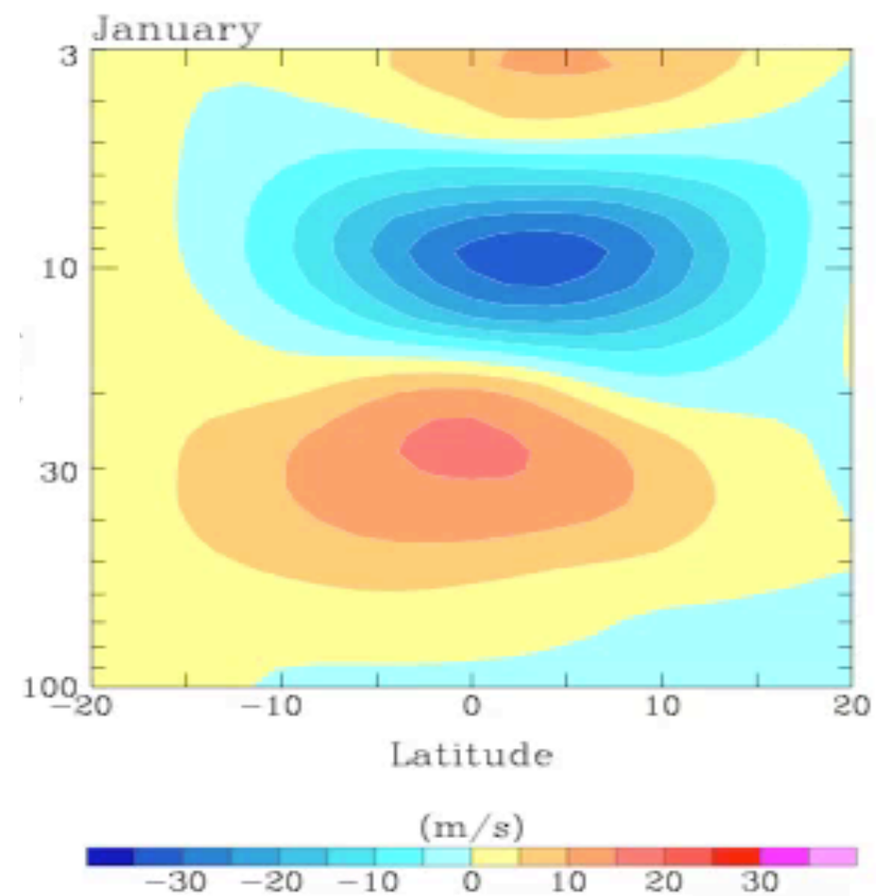
Self-generating stratospheric QBO

Tropical winds in lower stratosphere

Observations



GISS Model



102 Layers + Model Top 0.002 hPa

Rind et al (2014)

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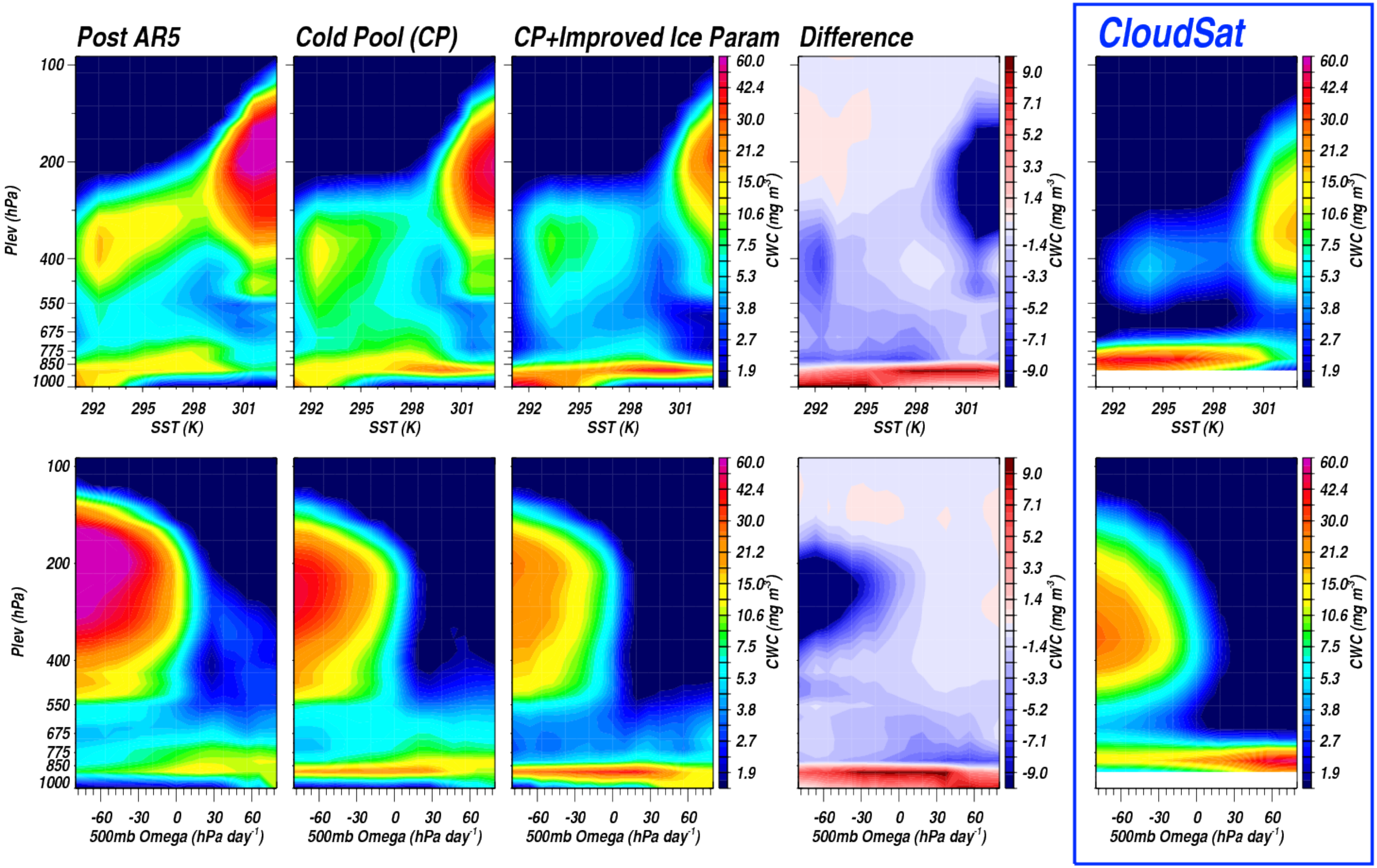
Comparison of vertical profile of cloud ice w/CloudSat



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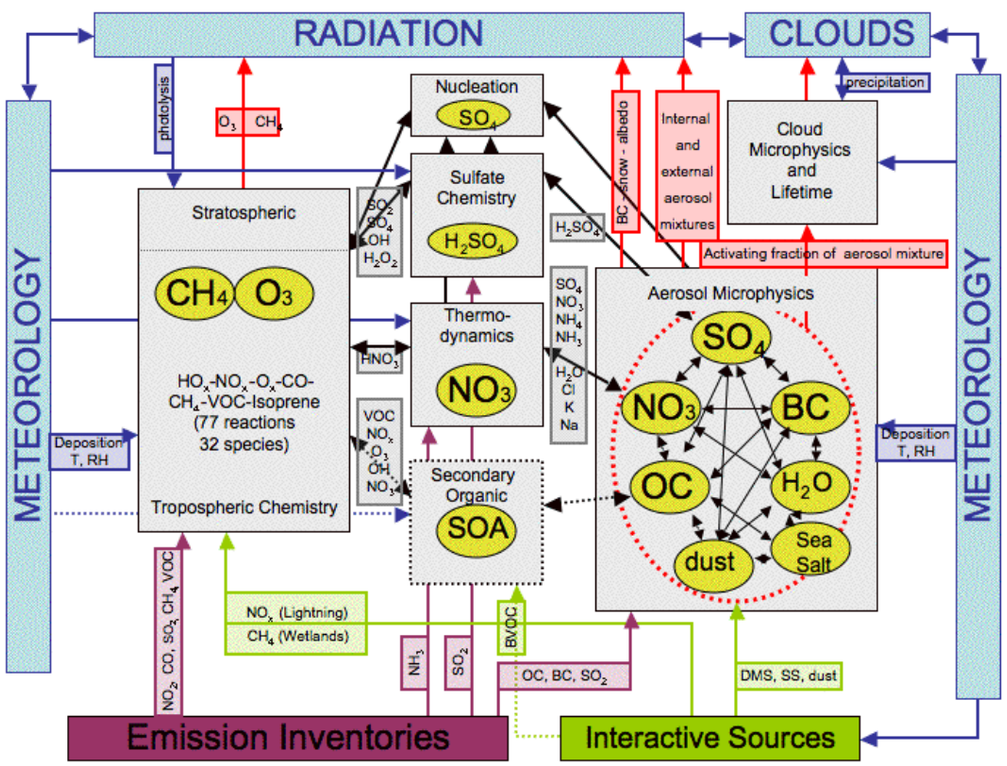
Representation of Volcanic Forcings: CMIP5 to CMIP6

CMIP5: Prescribed Stratospheric Volcanic AOD, Sato et al 1993, and updates
CMIP6: Prescribed Stratospheric Volcanic AOD , Luo et al (CMIP6 protocol)
Emission driven: Historical VolcanEESM (Neely, Schmidt, 2016)



NINT

Offline Ozone and Aerosol fields are read in

OMA

Interactive Chemistry and aerosol scheme
[Mass]

MATRIX

Interactive Chemistry and aerosol microphysical scheme
[Mass, Number, Mixing State]

Solar-only regression (~70 cycles)

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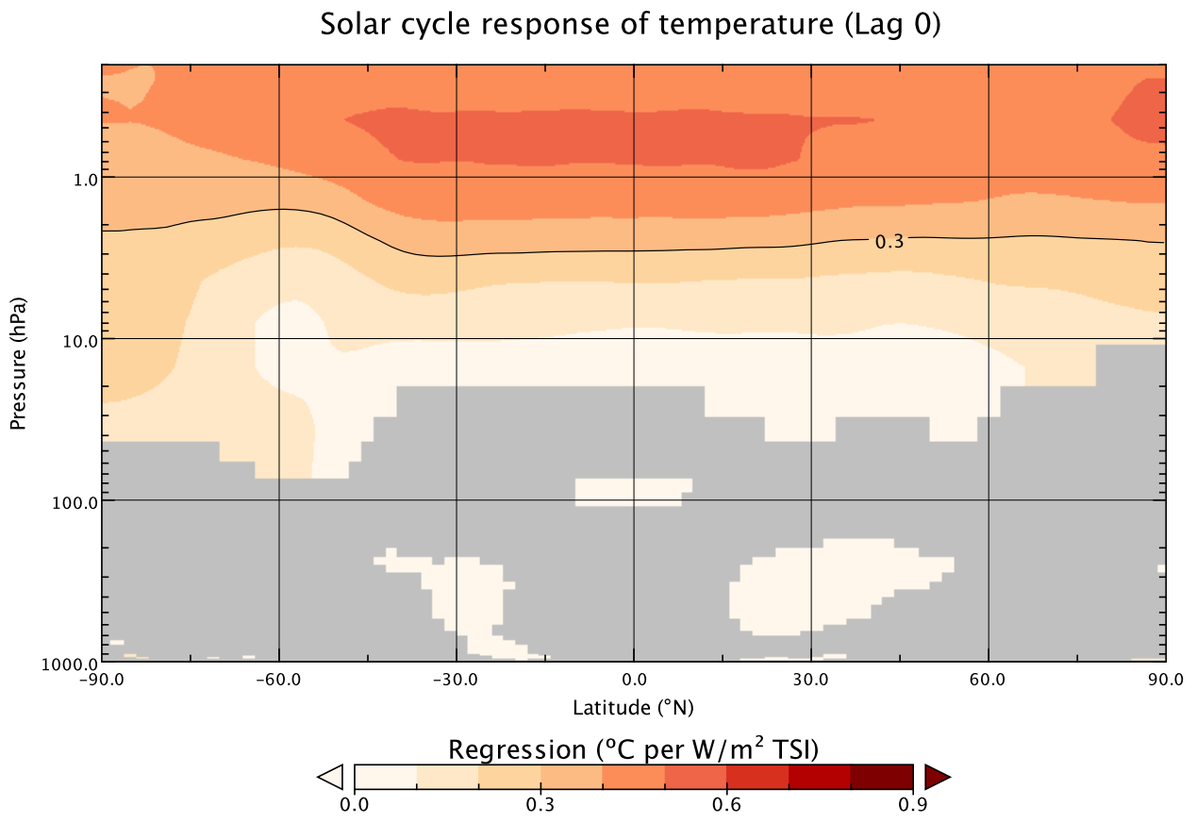
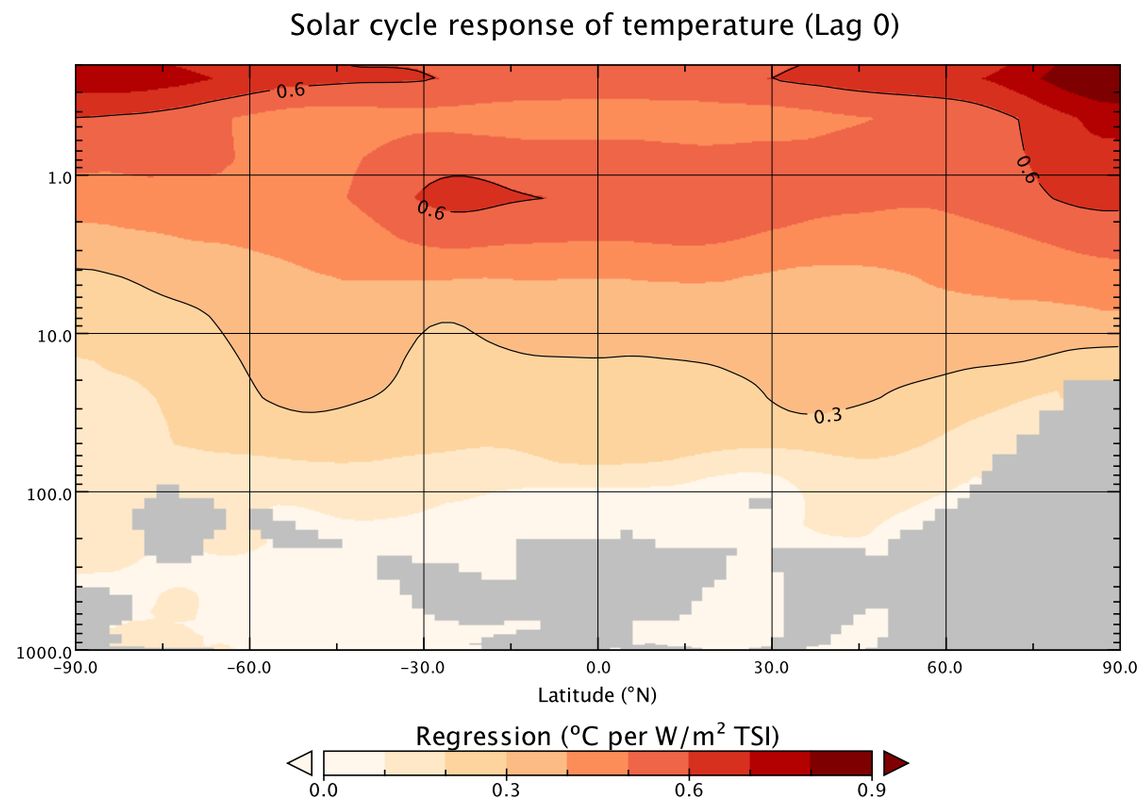
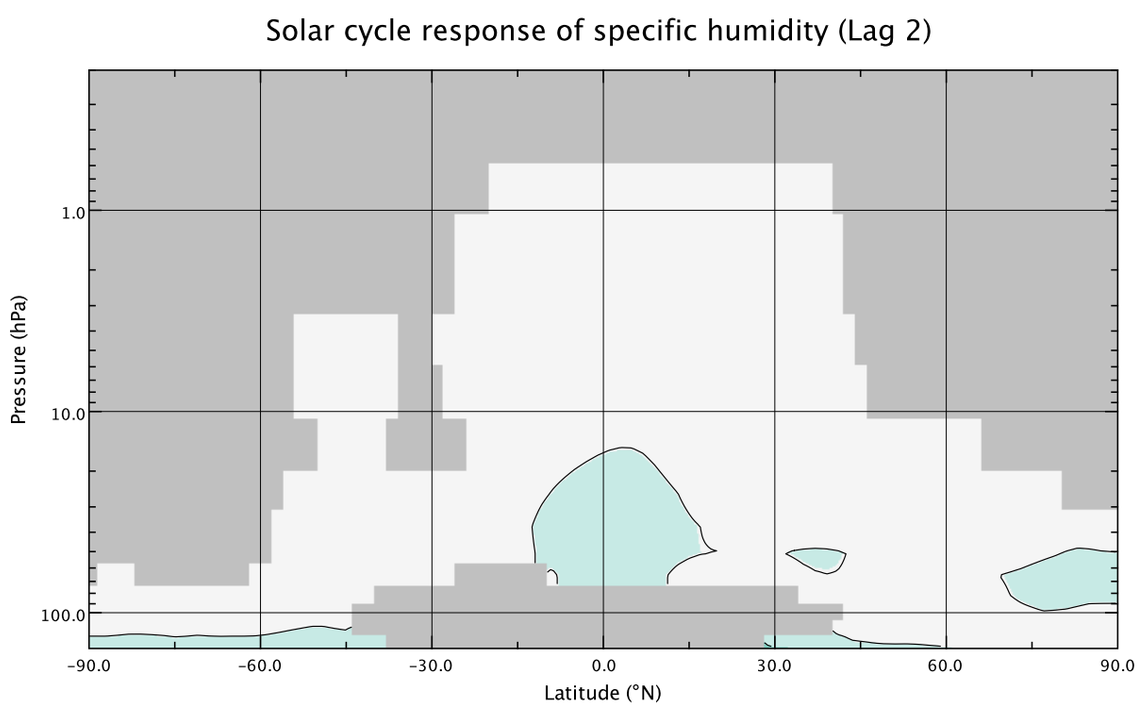
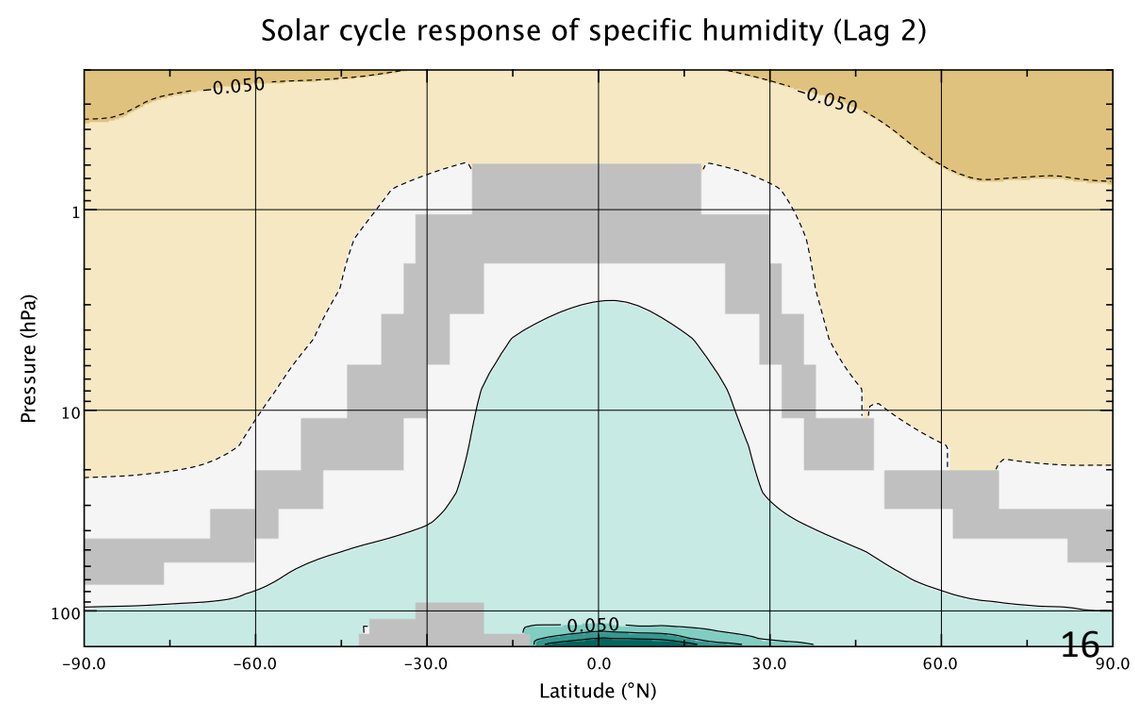


T





q



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GISS modeling summary

Major improvements in atmospheric properties since CMIP5

Better representation of key modes of variability

Deeper understanding of forcing mechanisms and uncertainties

Greater potential for exploring interactions (solar/QBO/MJO/AO, Volcano/QBO/ENSO etc.)

GCM Parameterization Tuning: incorporating knowledge of observational uncertainty

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GCM Parameterization Free Parameter Tuning:
Using one product versus multiple, and considering observational biases.

*Observational bias ≠ retrieval product uncertainty estimates.

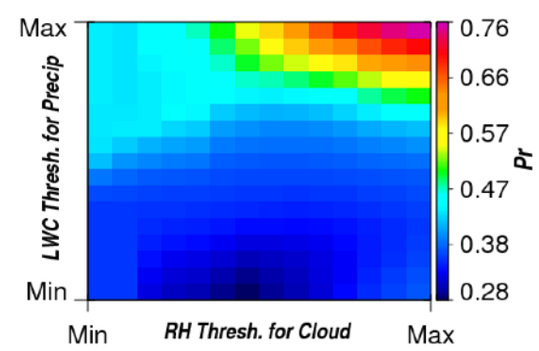
$$E^2 = \frac{1}{W} \sum_i \sum_j \sum_t w_{i,j,t} (F_{i,j,t} - R_{i,j,t})^2$$

E **is "model goodness" metric;**
F **is the model field;**
R **is the reference/truth;**
W **is the weighting term.**

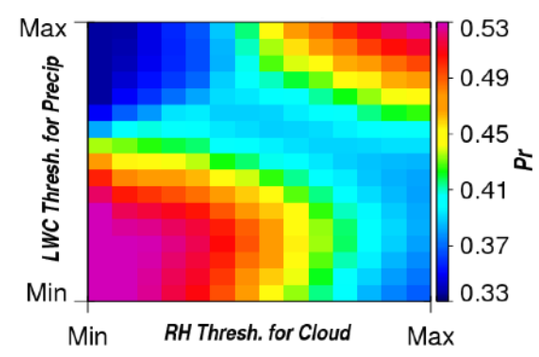
Incorporate obs. bias into '*W*'

(i.e. key component of our work: develop a regime- or region-aware weighting; penalize model less where observational biases are larger)

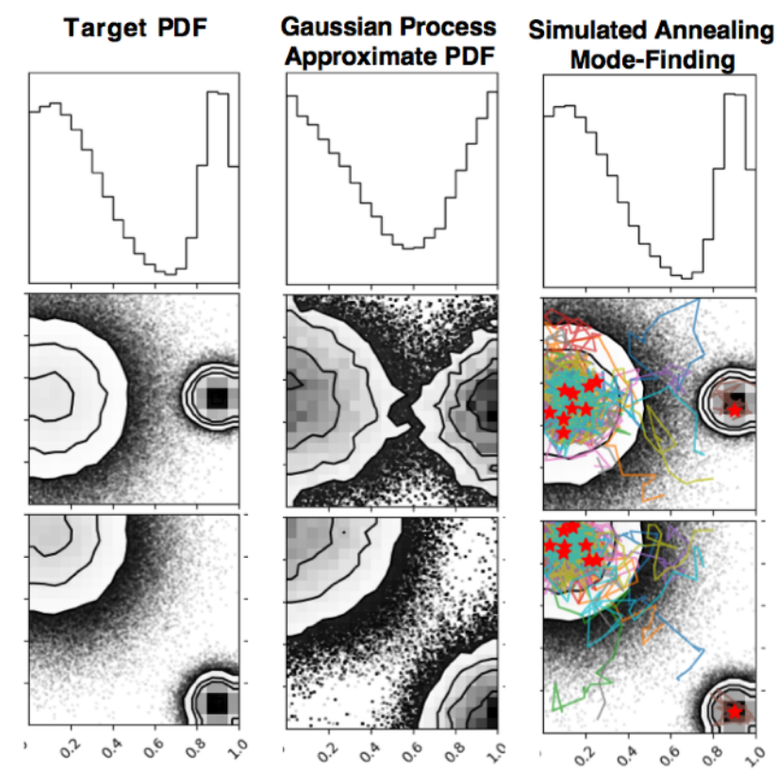
No Observational Bias



With Observational Bias

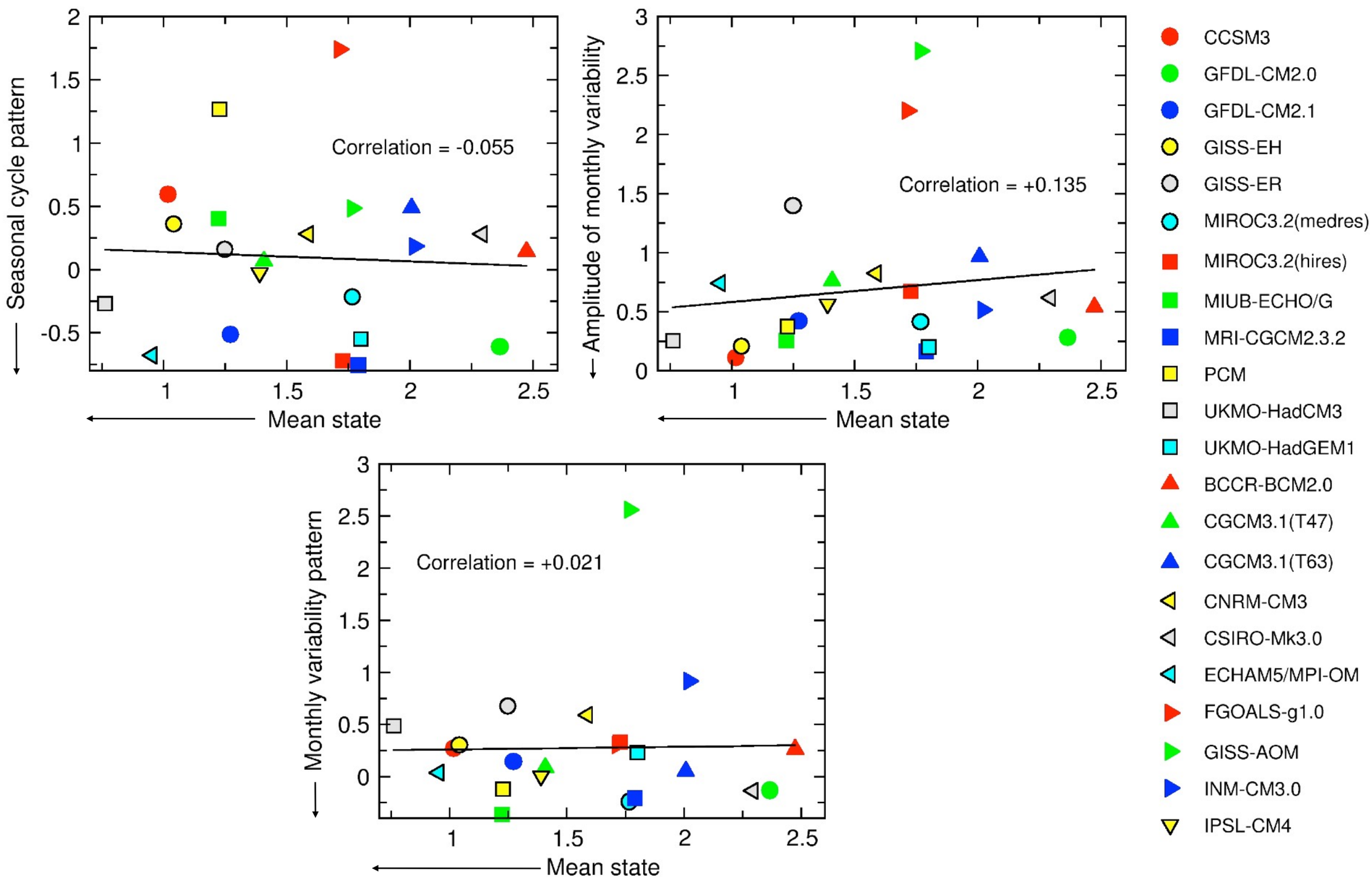


Use smart sampler to adjust parameters and find local maxima in goodness…



Elsaesser et al (in prep)

Relationship between different measures of present-day model skill

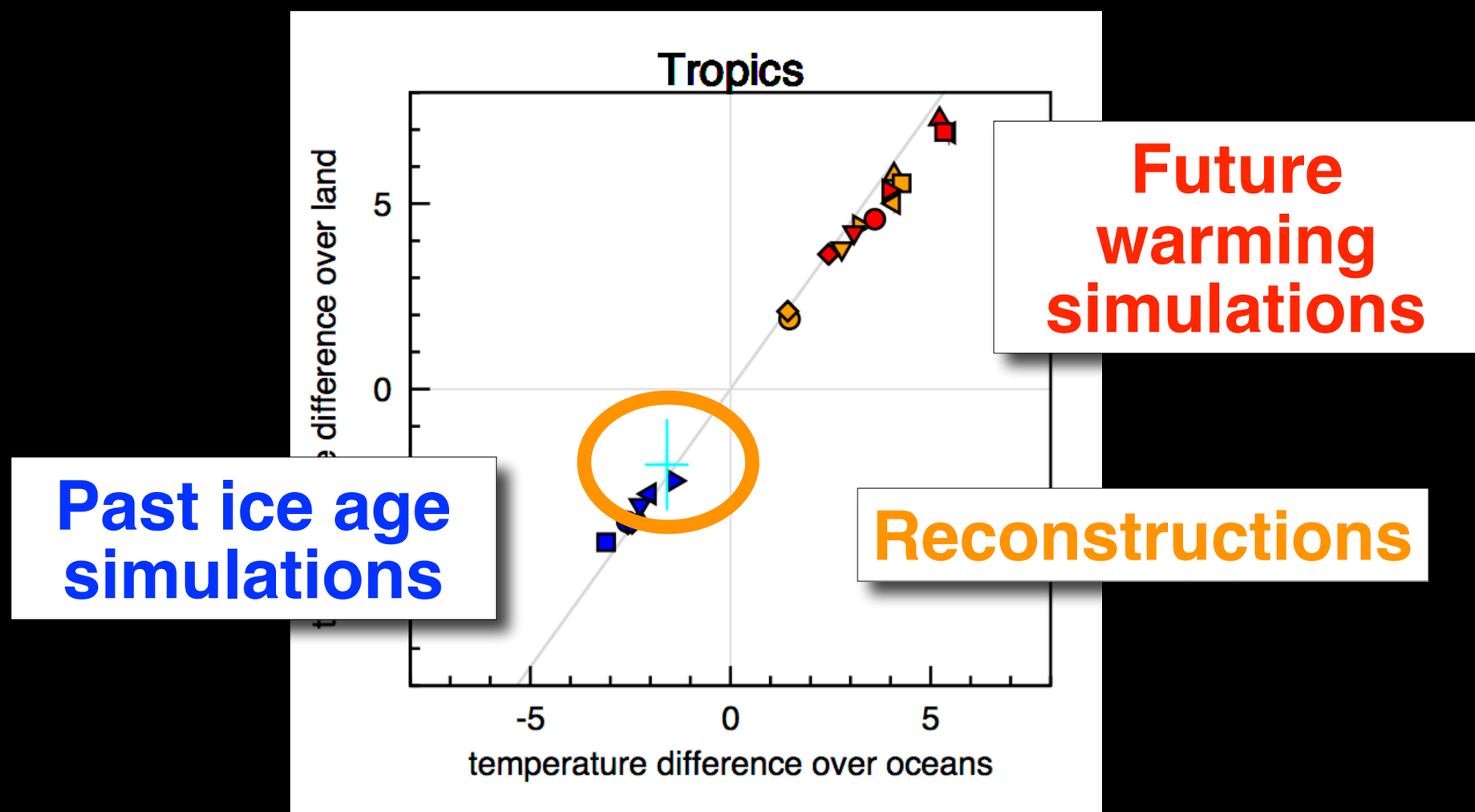


Santer et al, 2012

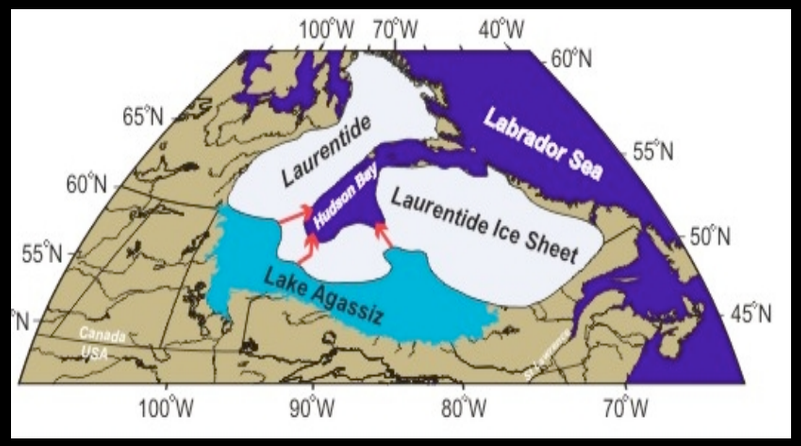
“… from what has actually been, we have data for concluding with regard to that which is to happen thereafter.”

James Hutton (1788)

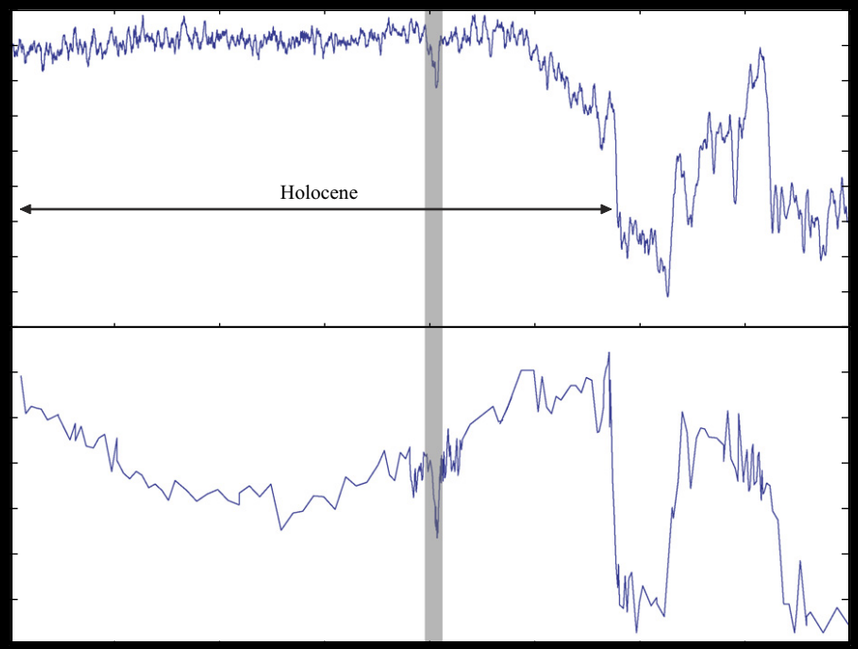
Land-Ocean contrasts are robust in past and future



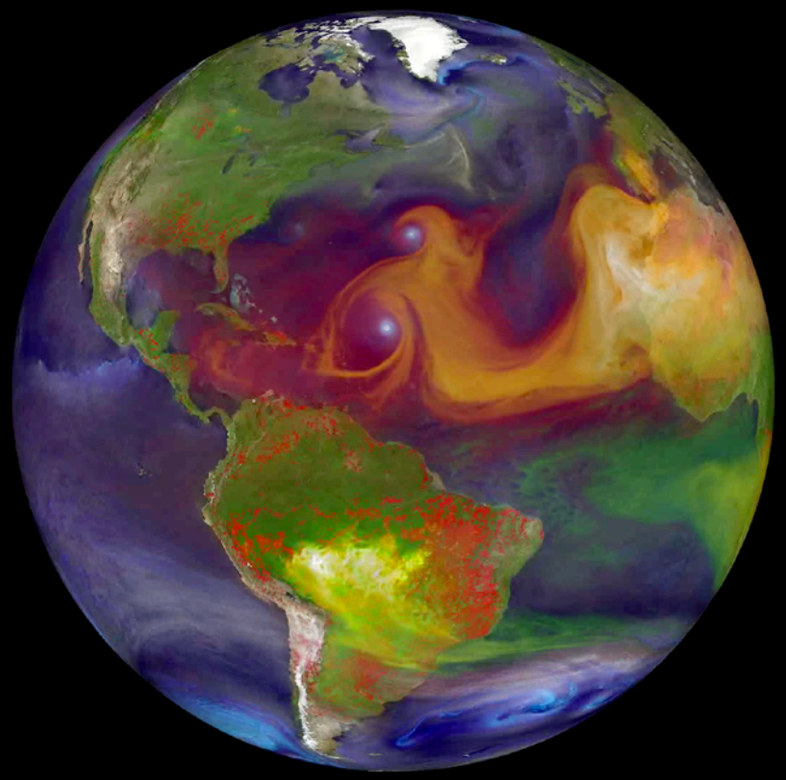
Masa Kageyama (Schmidt et al, 2014)



A lake burst 8000 years ago...



...changed ocean circulation and left traces in Greenland ice...



... providing an out-of-sample test for the same models that predict ocean, dust and CH_4 changes in the future.

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Points I'd like to make

Enhanced data analytics goes hand in hand with more efficient model development

Paleo-climate "out of sample" tests remain essential for building credibility in projections

Need to increase complexity *and* coherence

Exploring structural uncertainty is essential

Current efforts may not be totally optimal, but they are headed in the right direction