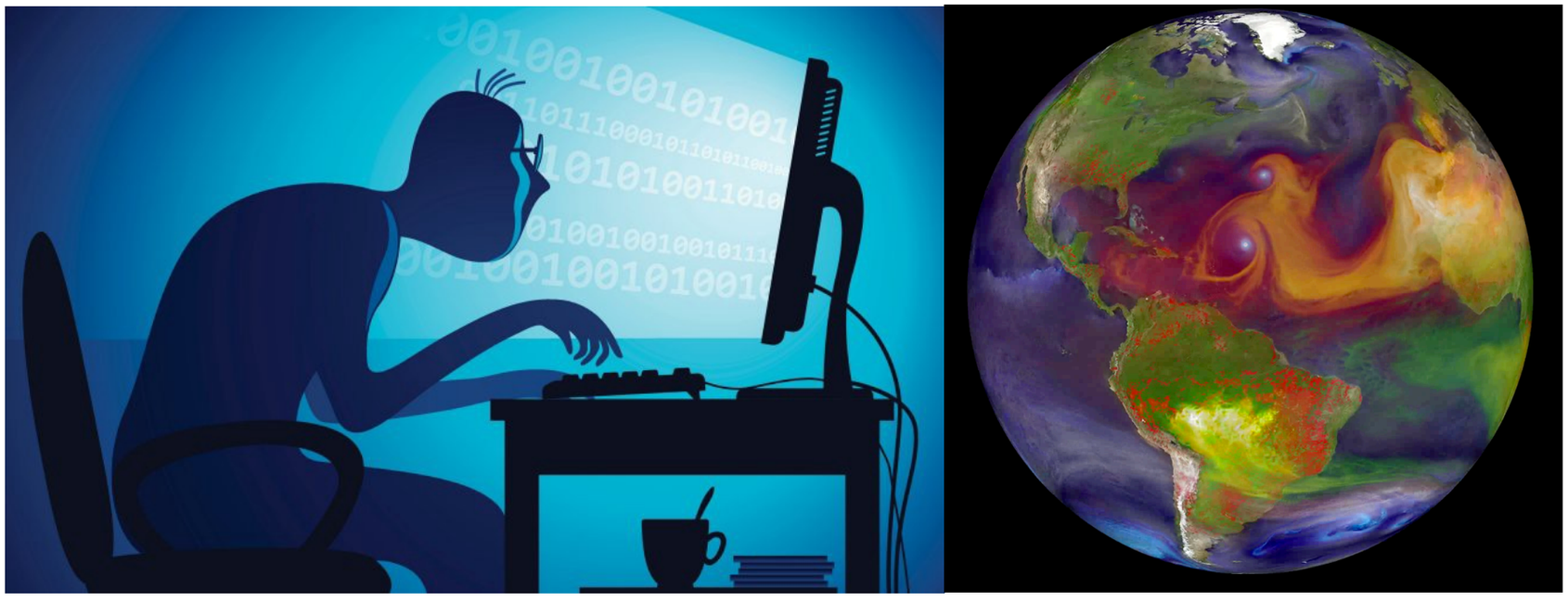
National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

NY Scientific Data Summit June 12 2019

Challenges in Climate Science in an Era of Big Data



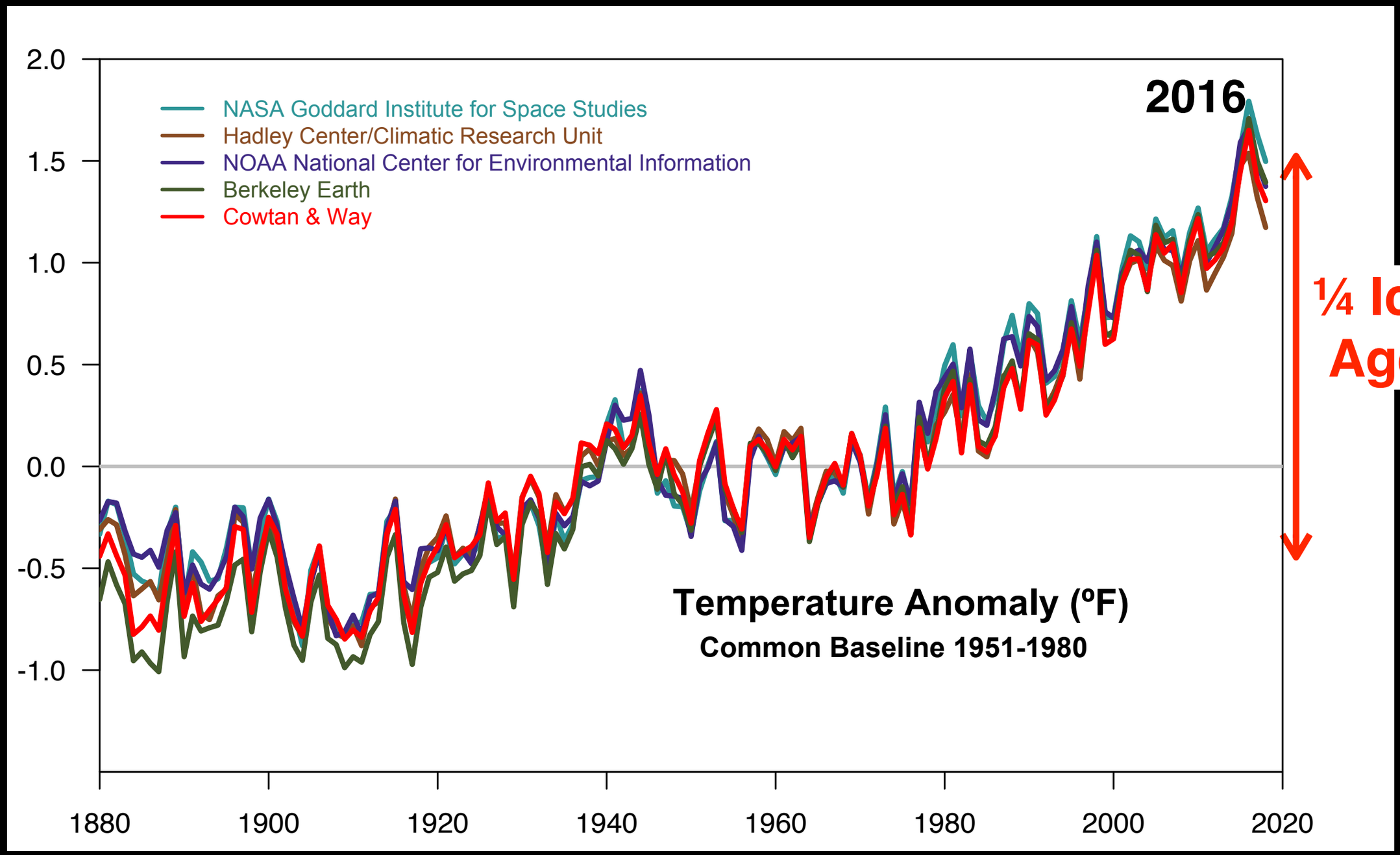
Gavin Schmidt, NASA GISS

Medenhall Glacier, Alaska 1894

Medenhall Glacier, Alaska 2004

Gary Braasch

Baffin Island 2012


2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
NASA Goddard Institute for Space Studies
Hadley Center/Climatic Research Unit
NOAA National Center for Environmental Information
Berkeley Earth
Cowtan & Way
2016
¼ Ice Age
Temperature Anomaly (ºF)
Common Baseline 1951-1980
1880
1900
1920
1940
1960
1980
2000
2020

SUBROUTINE OPACY (TEMP,RHO,CHEMX,CHEMZ,TOTK,DKDT,DKDRHO)

C(O)ONLY

FORTRAN STATEMENT

Any intervals

C ← FOR COMMENT

STATEMENT NUMBER

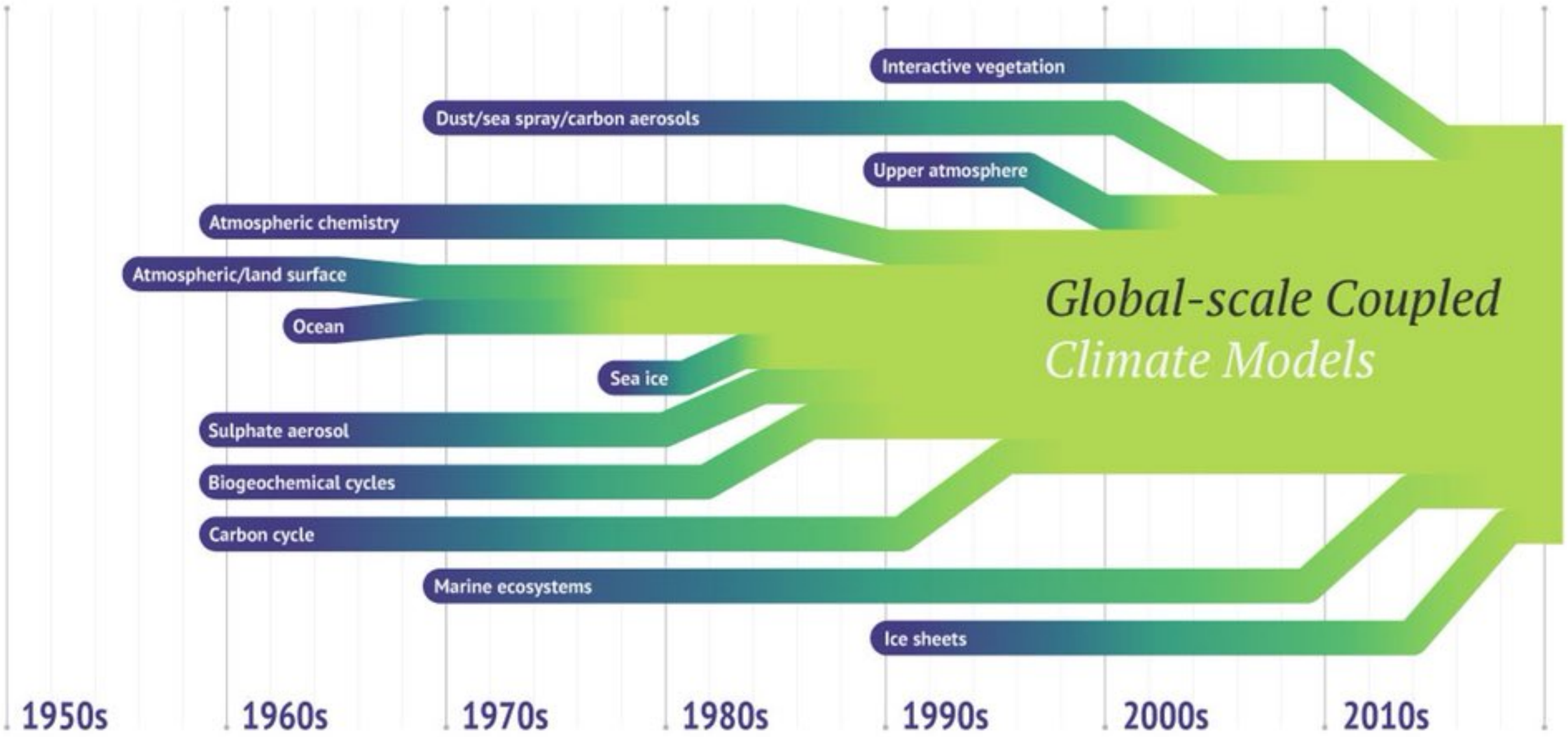
CONTINUATION

ID

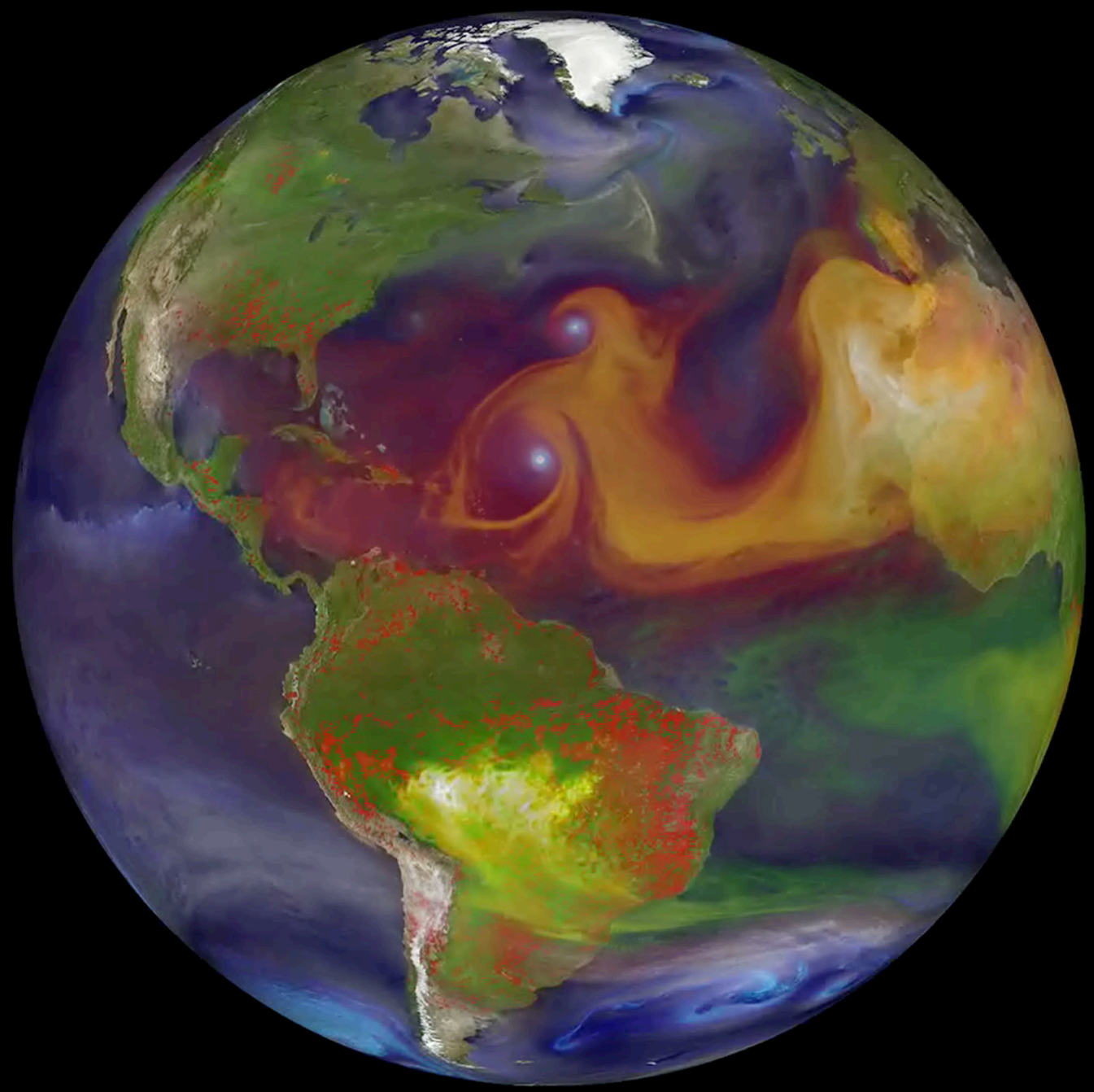
IBM 88857

SELECTE

Joshua Wolfe



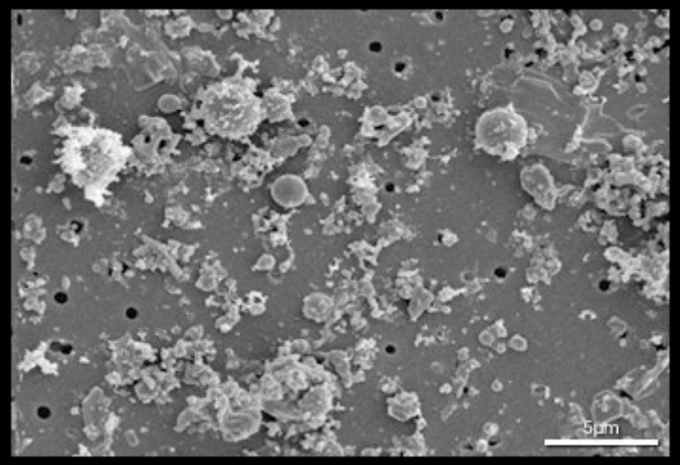
Zeke Hausfather



Fires
Sulfates
Dust
Organic C
Sea Salt

Sep 06-Apr 07
NASA/GSFC

14 Orders of Magnitude



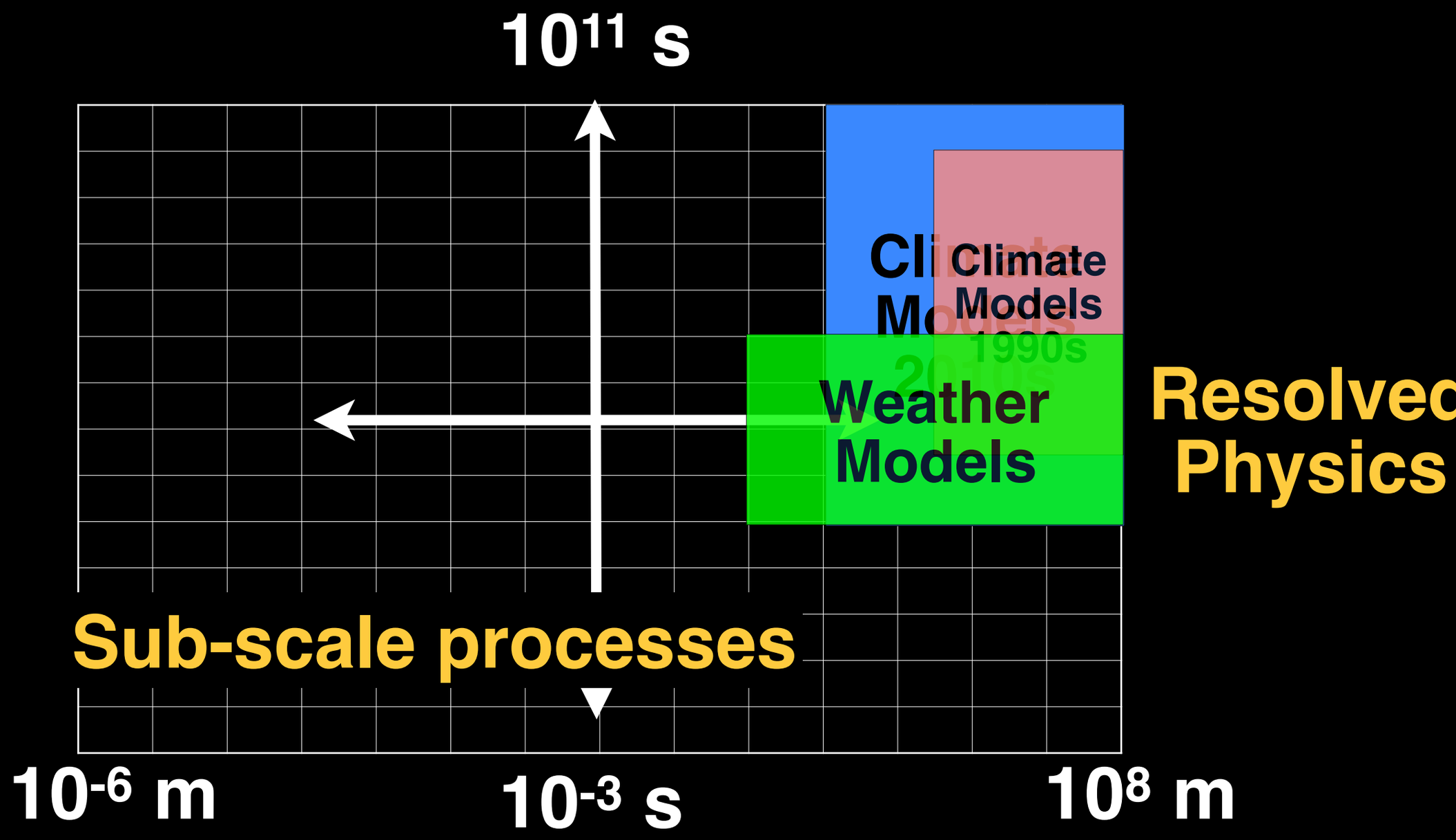
10^{-6} m

10^{11} s

10^{-3} s

10^{8} m

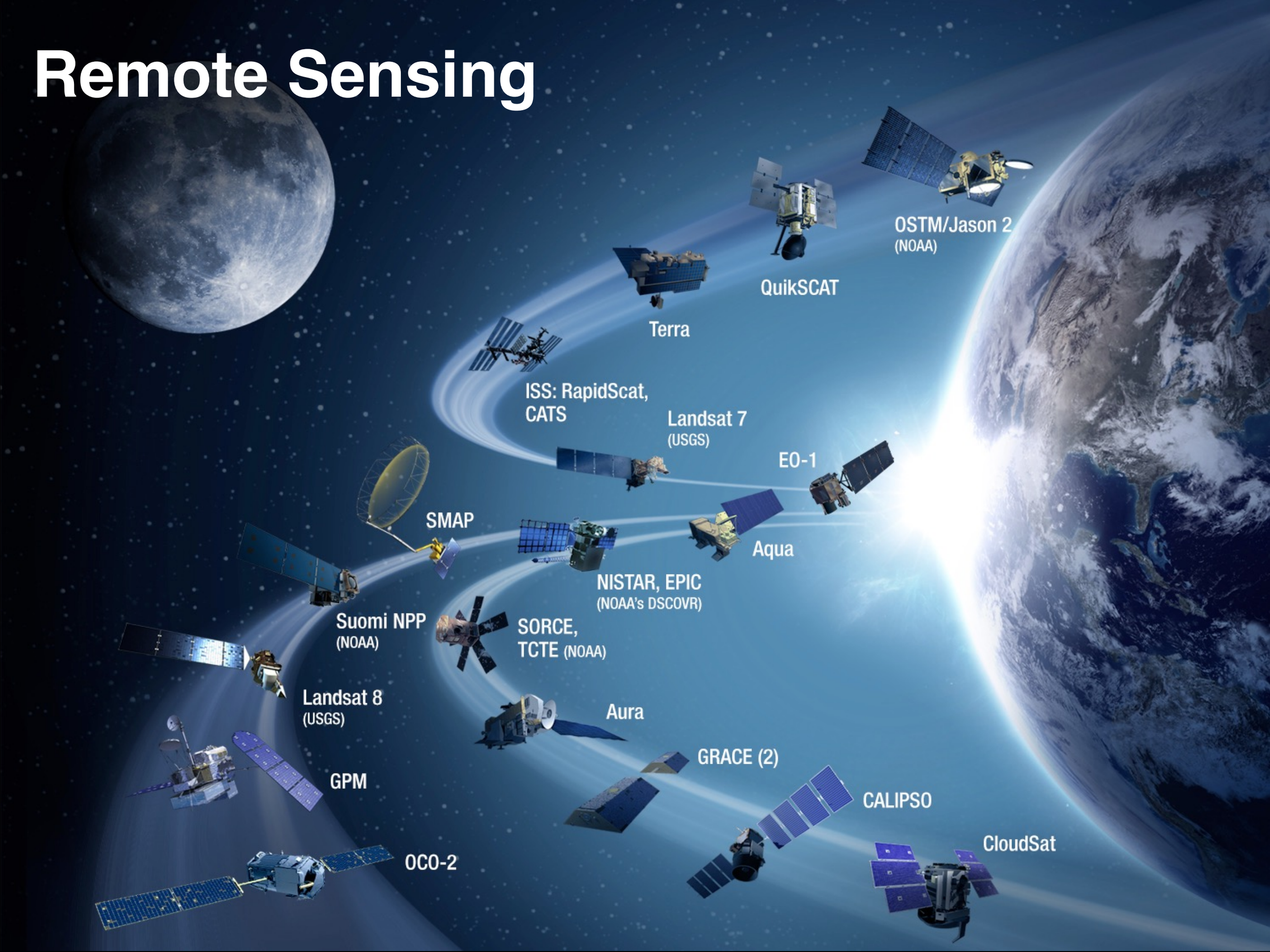
14 Orders of Magnitude



First Challenge

Building parameterizations that encapsulate sub-scale behaviours that are not explicitly resolved.

Remote Sensing



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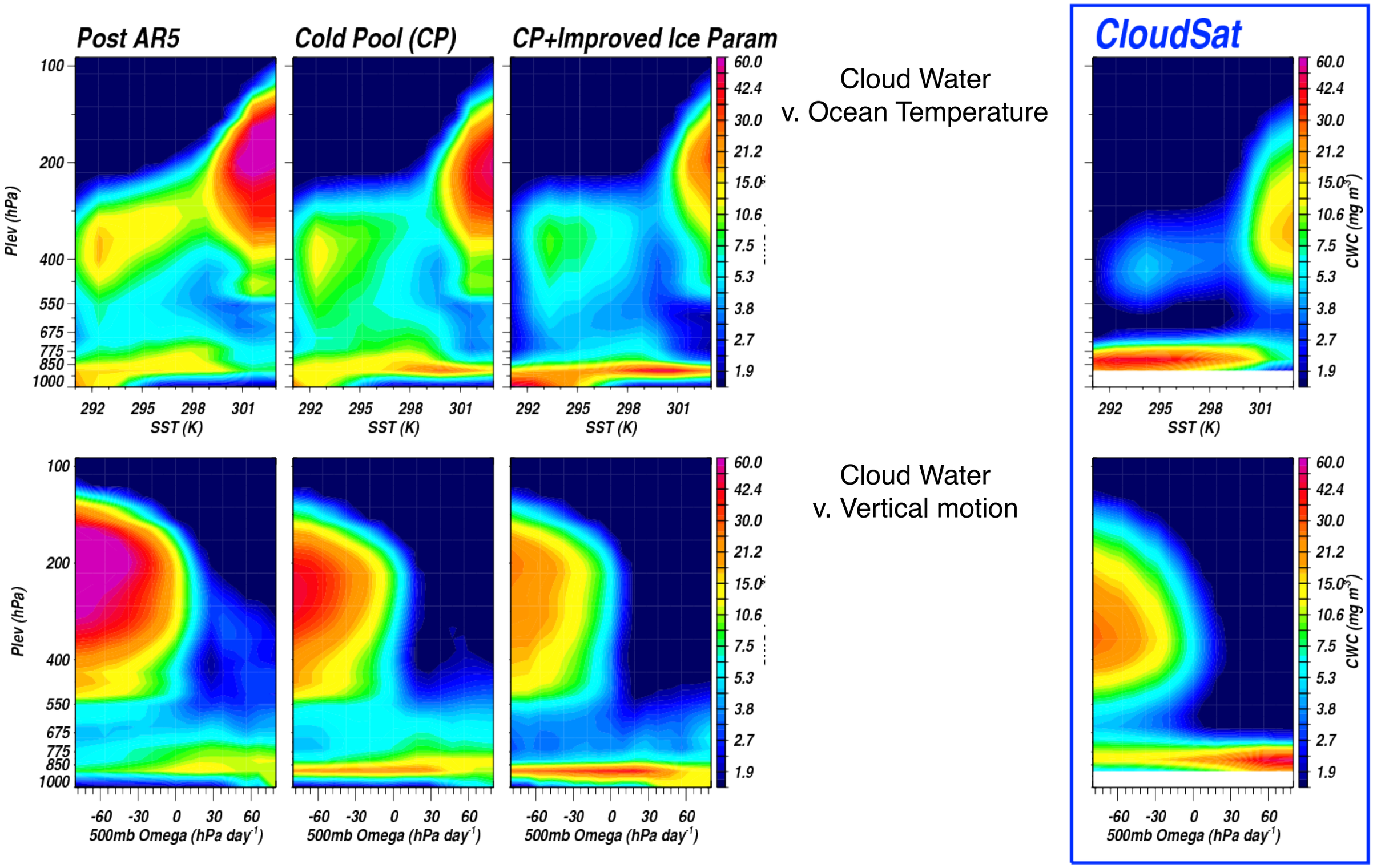
Comparison of vertical profile of cloud water content against CloudSat



Cloud Water
v. Ocean Temperature

Cloud Water
v. Vertical motion

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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 [Mühlbauer 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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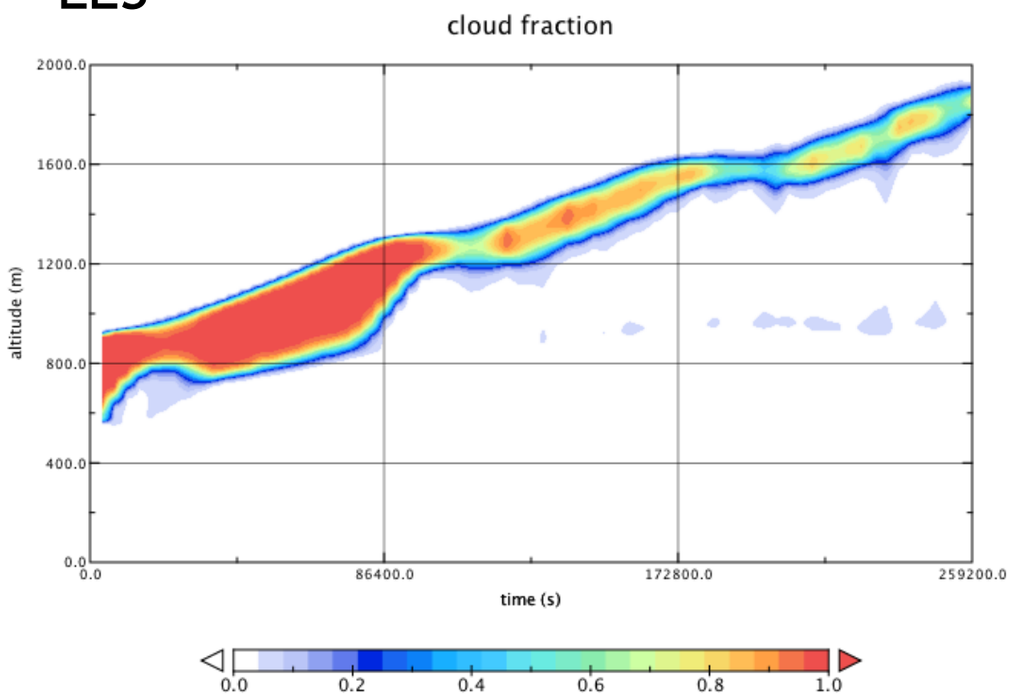
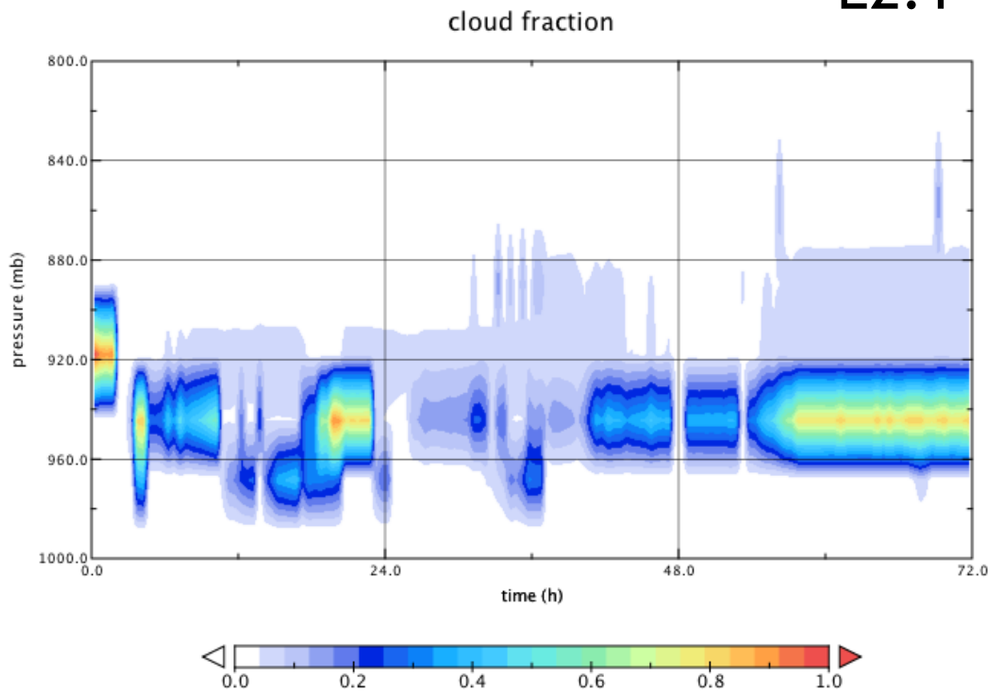
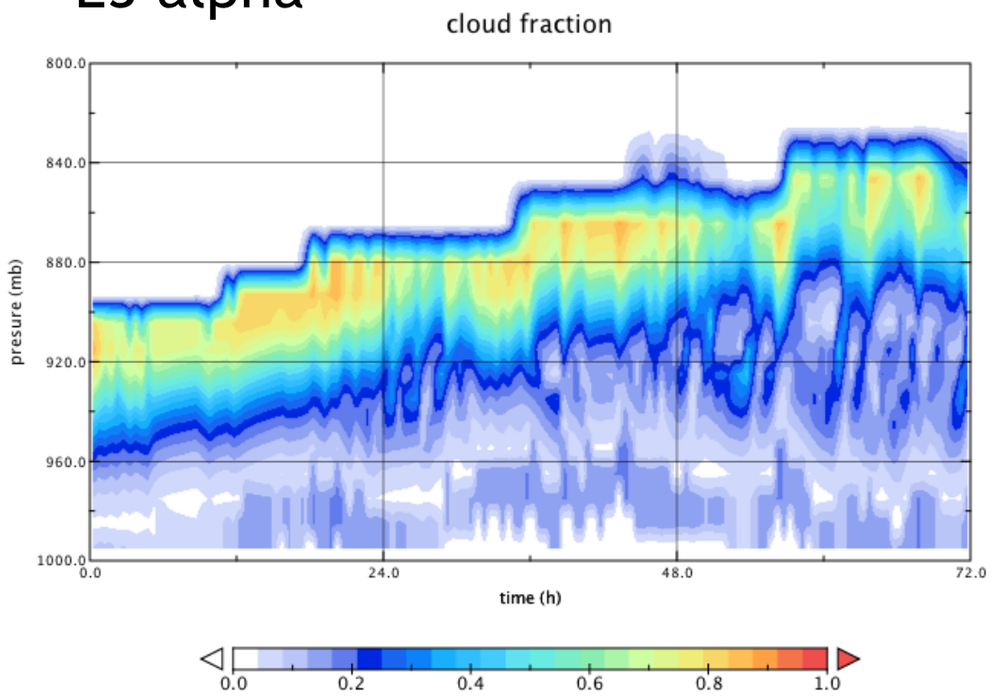
LES



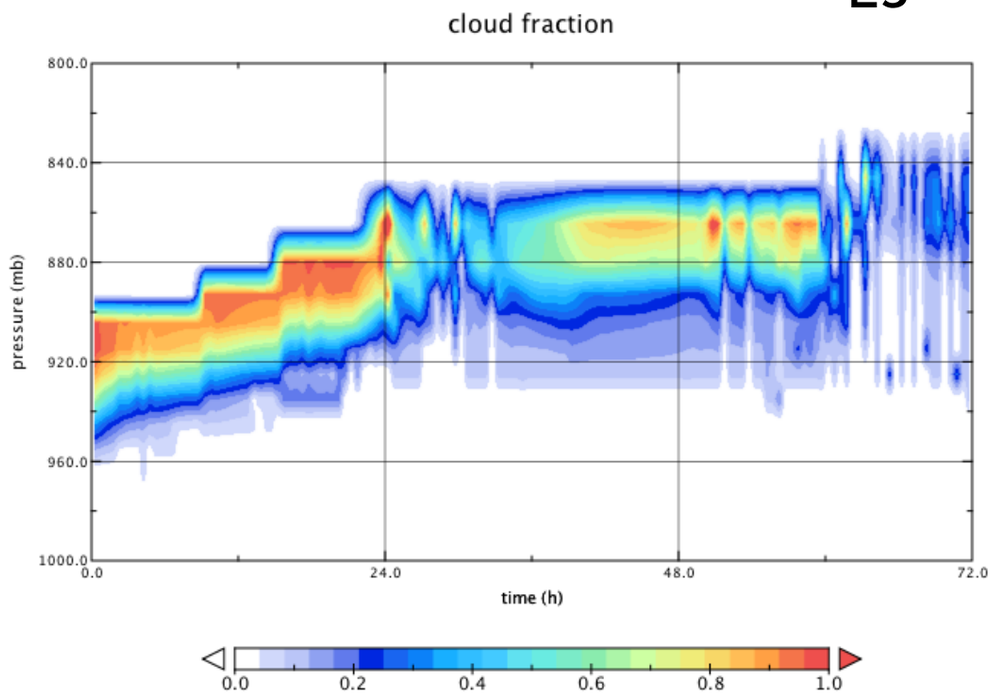
E2.1



E3 alpha



E3



Representation of Volcanic Forcings

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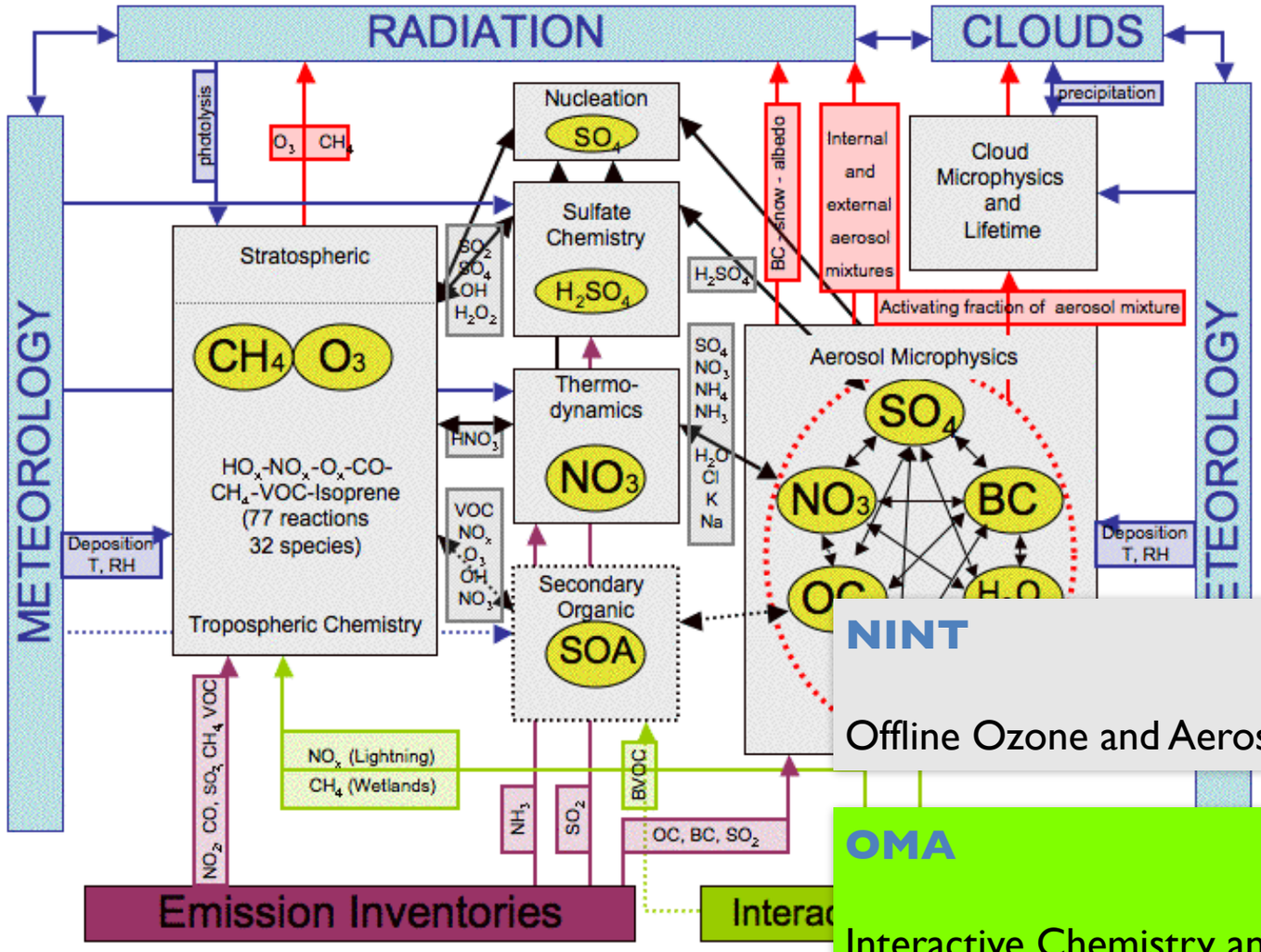

NINT

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]

Second Challenge

Evaluation of the emergent properties of the simulations

Big improvements in representation of MJO

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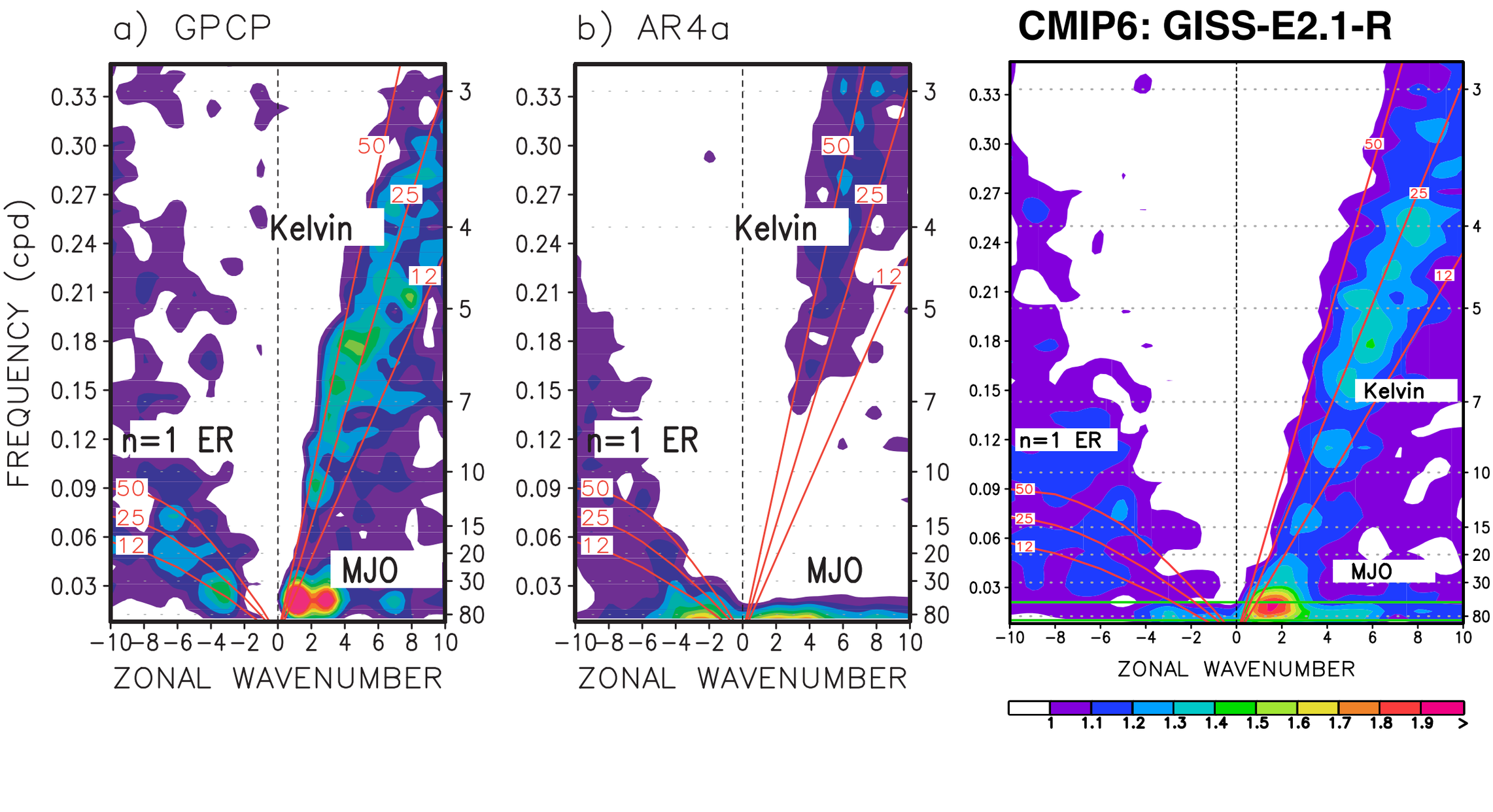

(Wheeler-Kiladis diagrams extended from Kim et al, 2012)

Low cloud increases in marine stratus regions

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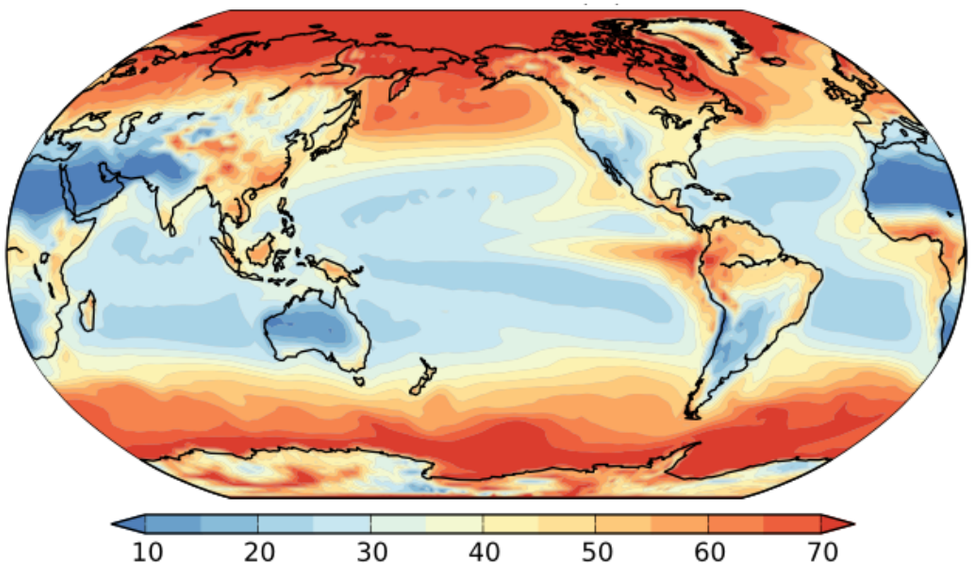
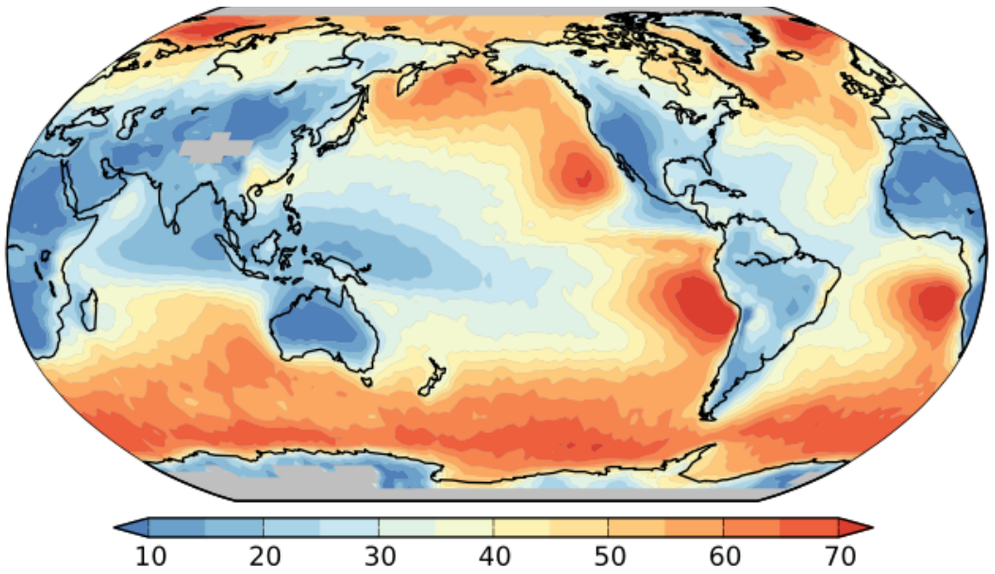
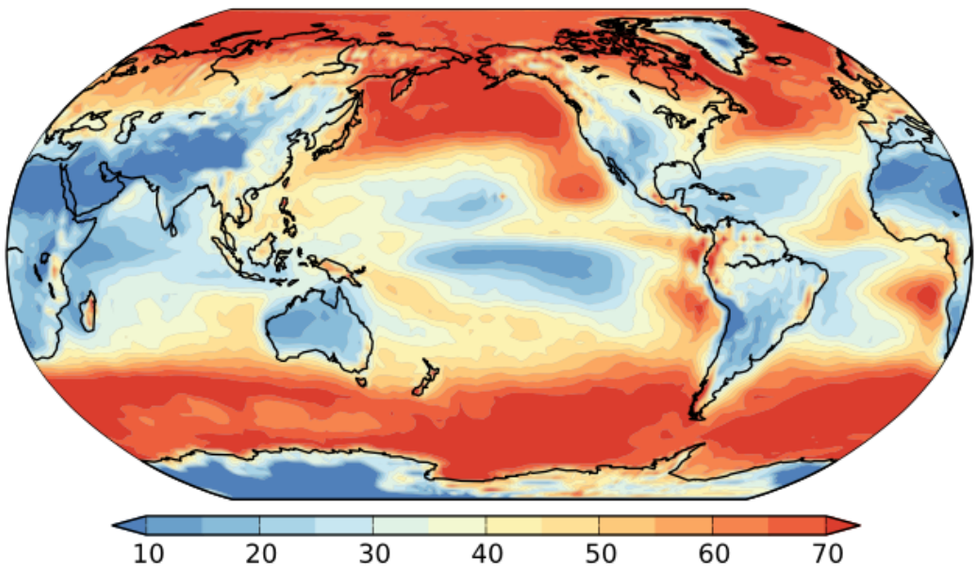
GISS-E2.1 (AMIP L40)



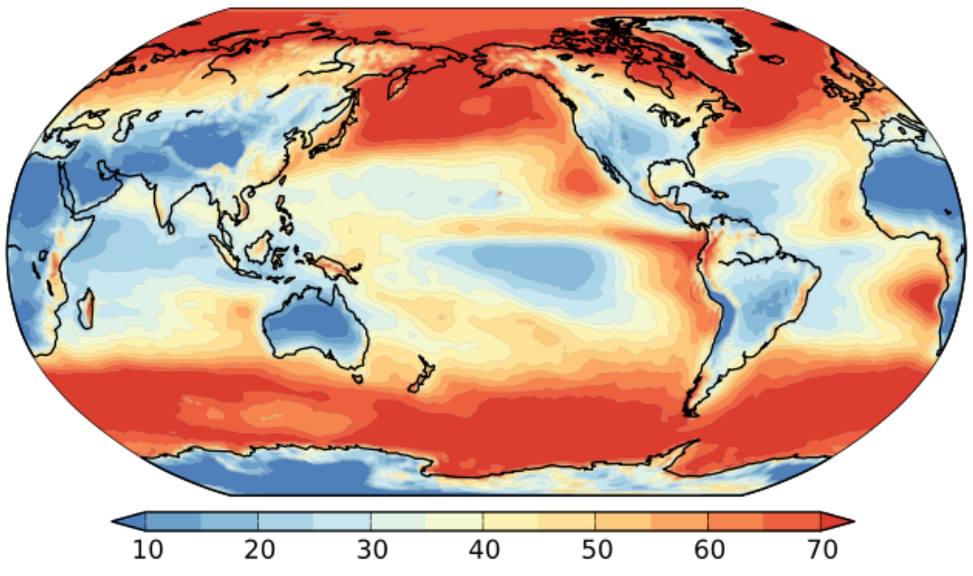
CALIPSO Observations



GISS-E3 (lat/lon L104)



GISS-E3 (Cubed sphere L104)



The process-based diagnostic challenge

Imagine....

Reanalysis: find mid-latitude storms

Satellites: Create composite

Models: Create composite

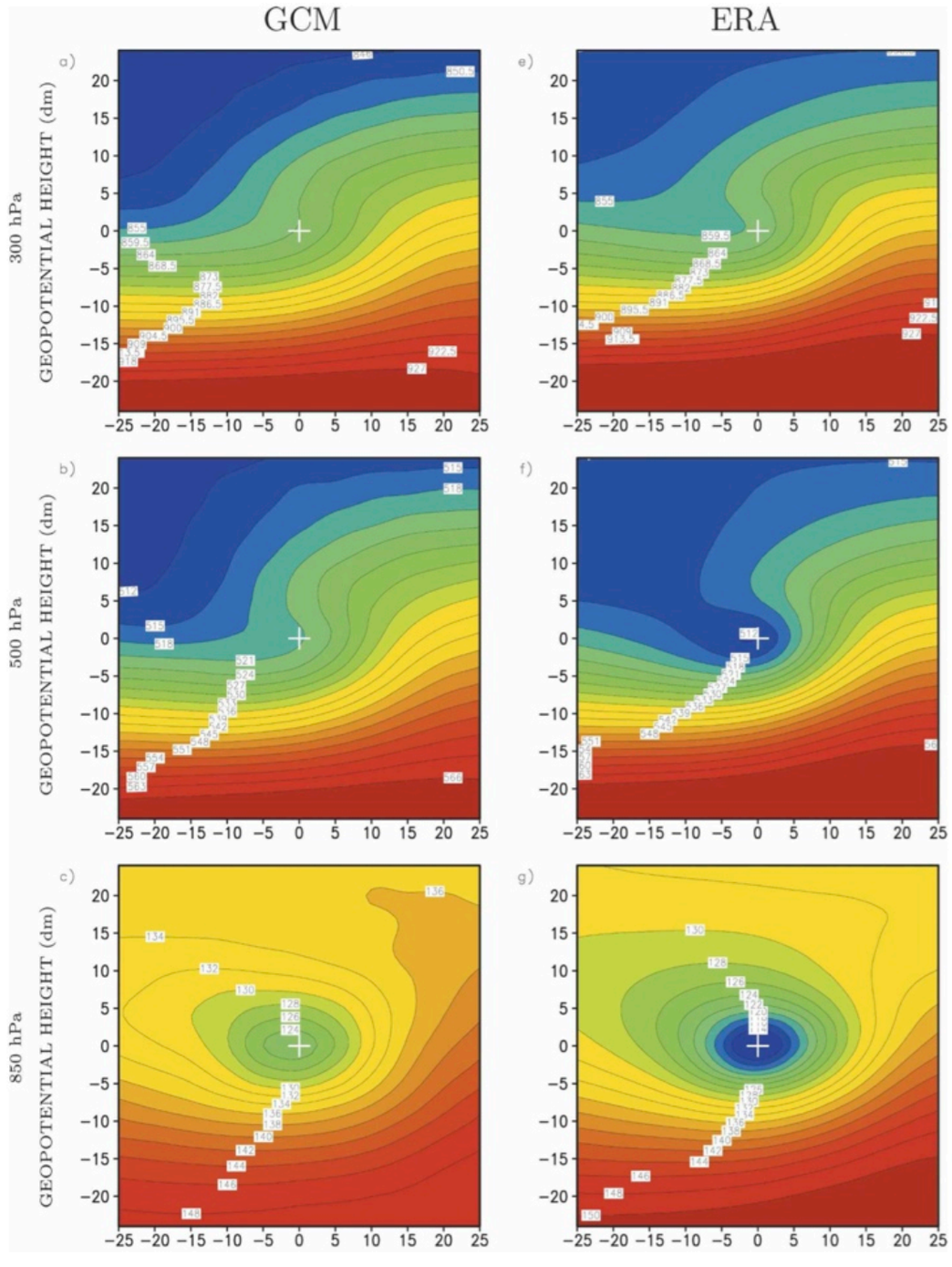
Models: Create pseudo-satellite views

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

Third Challenge

Climate model tuning:

How do we calibrate the overall model?

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GCM Parameterization Tuning: incorporating knowledge of observational uncertainty

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

***Observational bias ≠ retrieval product uncertainty estimates.**

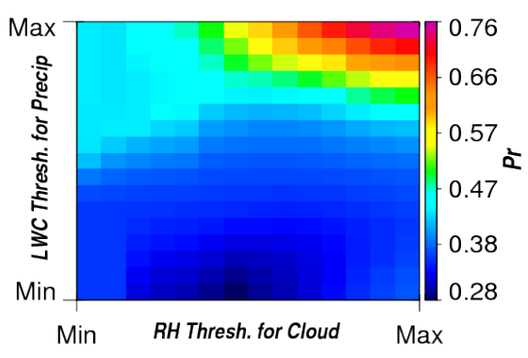
$$E^2 = \frac{1}{W}\sum_i \sum_j \sum_t w_{i,j,t}(F_{i,j,t} - R_{i,j,t})^2$$

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

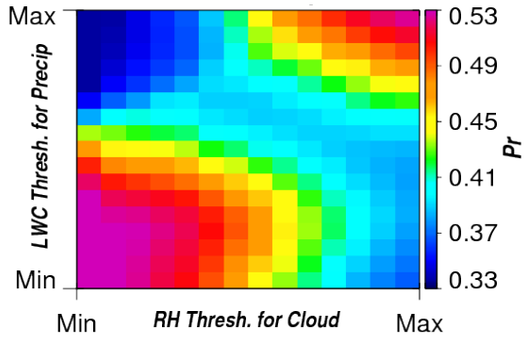
Incorporate obs. bias into '*W*'

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

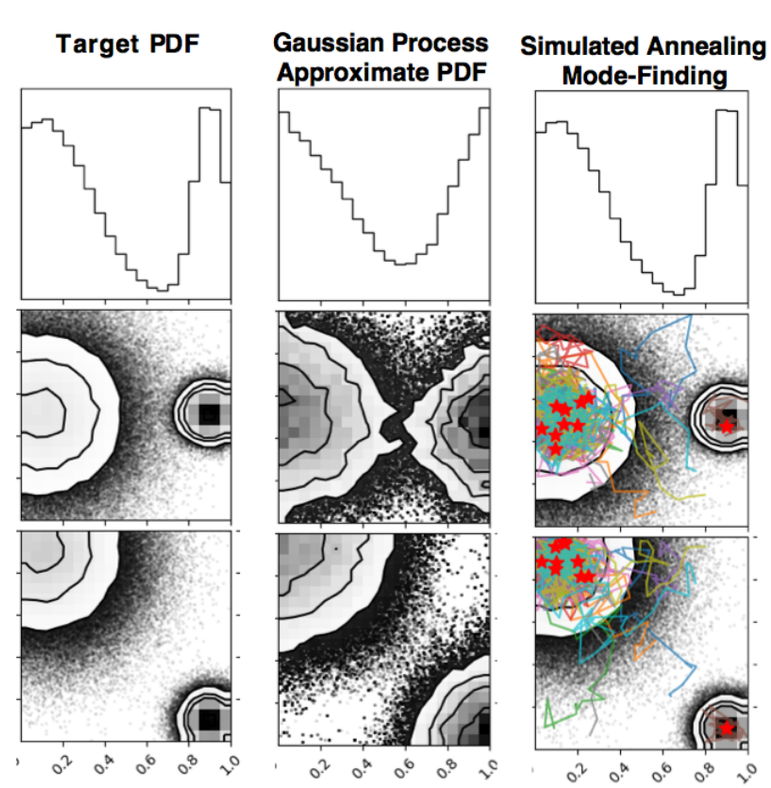
No Observational Bias



With Observational Bias



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



Elsaesser et al (in prep)

“If we had observations of the future, we obviously would trust them more than models, but unfortunately…

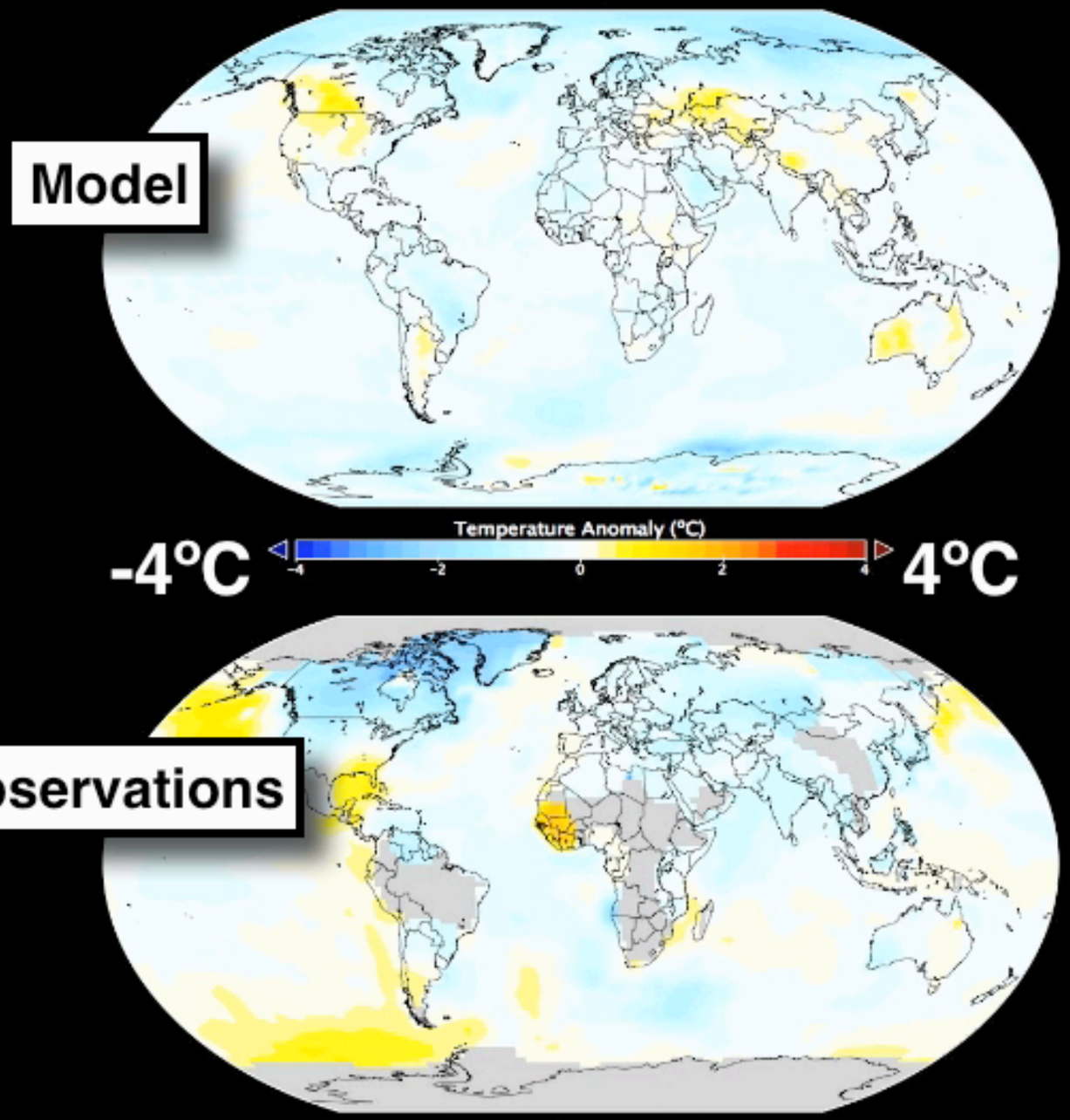
… observations of the future are not available at this time.”

Tom Knutson and Robert Tuleya

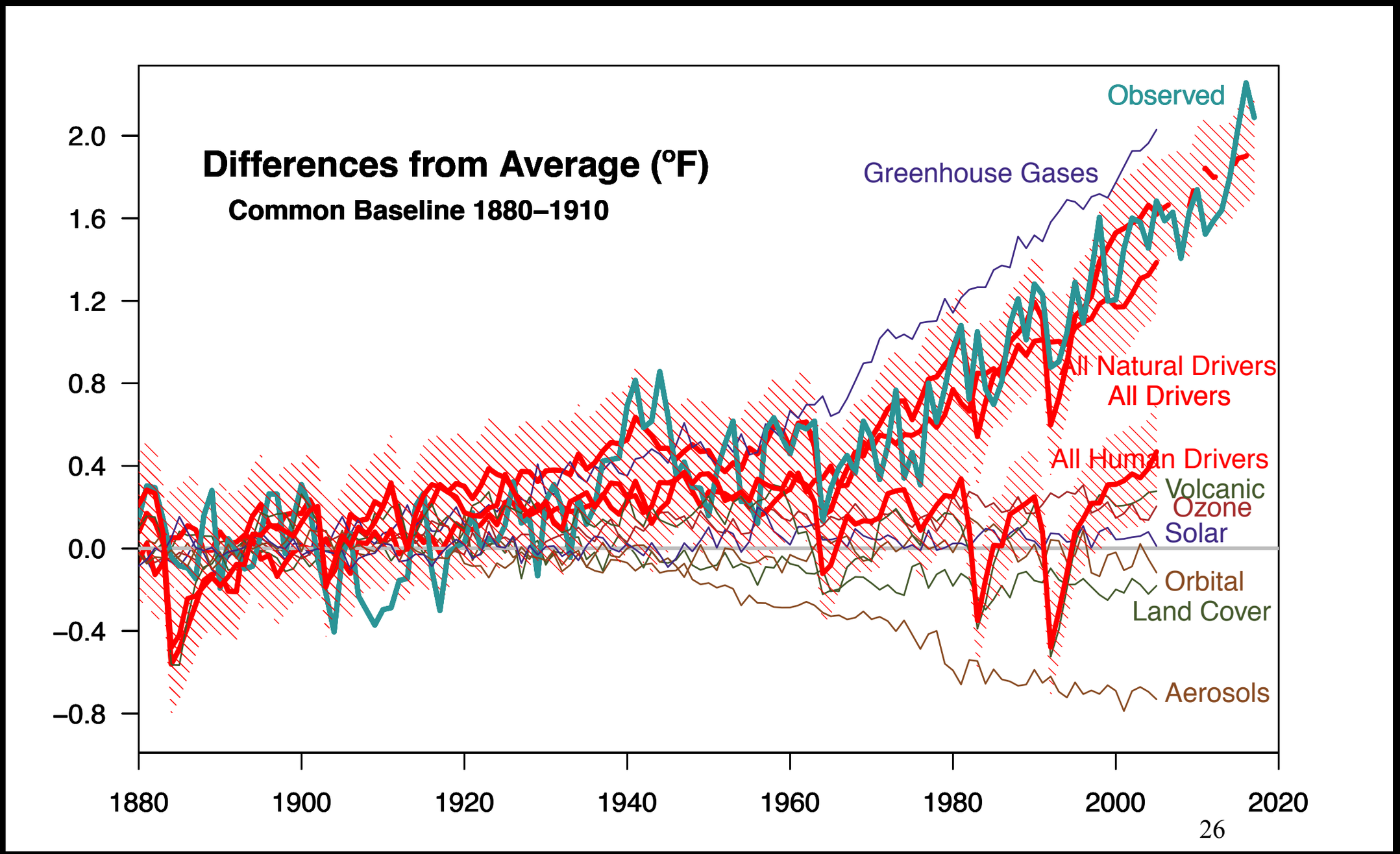
Fourth Challenge

How do we evaluate predictive skill?

20th Century Surface Temperature changes



Natural drivers are inadequate



NASA GISS

Fifth Challenge

How do we deal with the multi-model ensemble?

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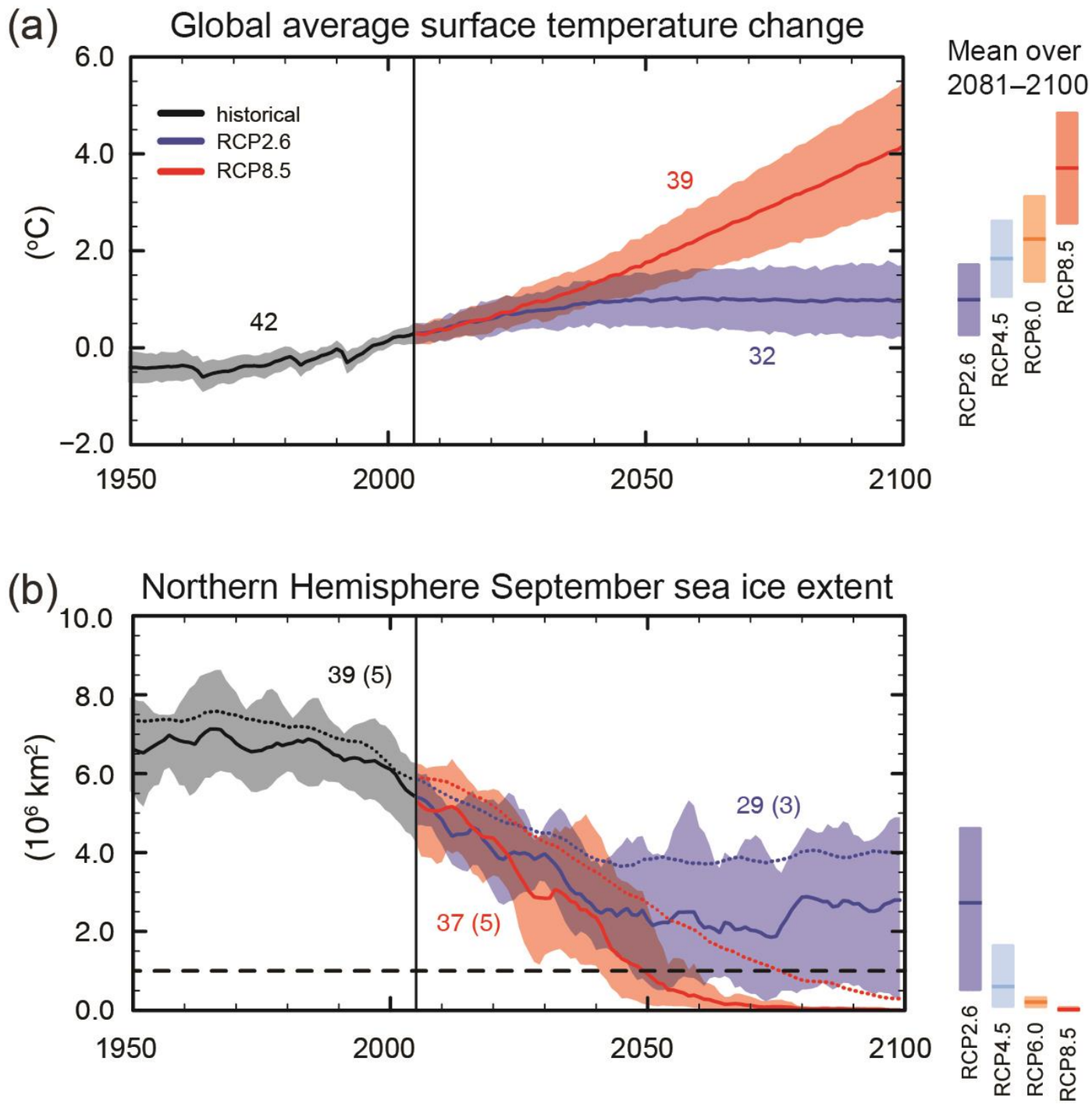
Structural Uncertainty across models leads to a range of predictions



IPCC AR5
Fig. SPM.7

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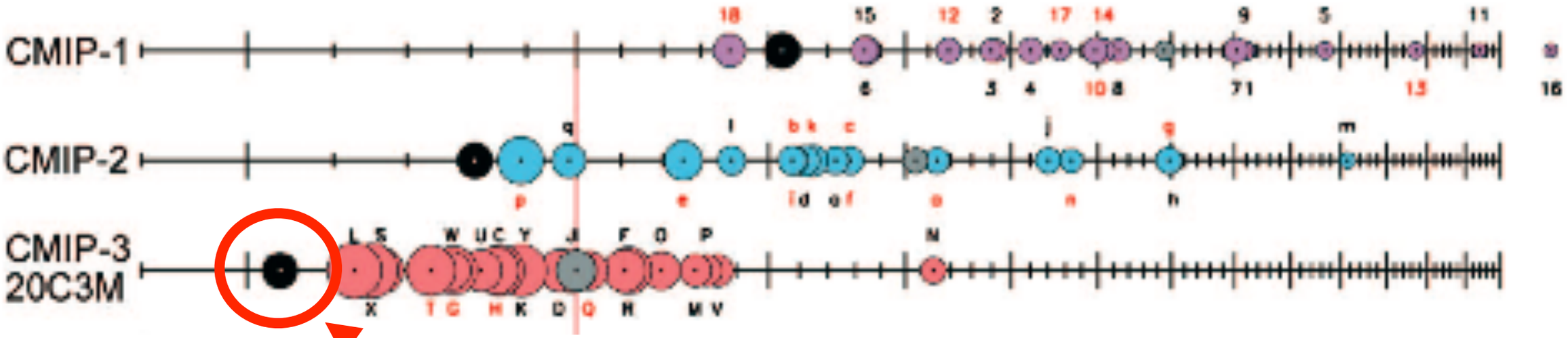
Model skill is improving



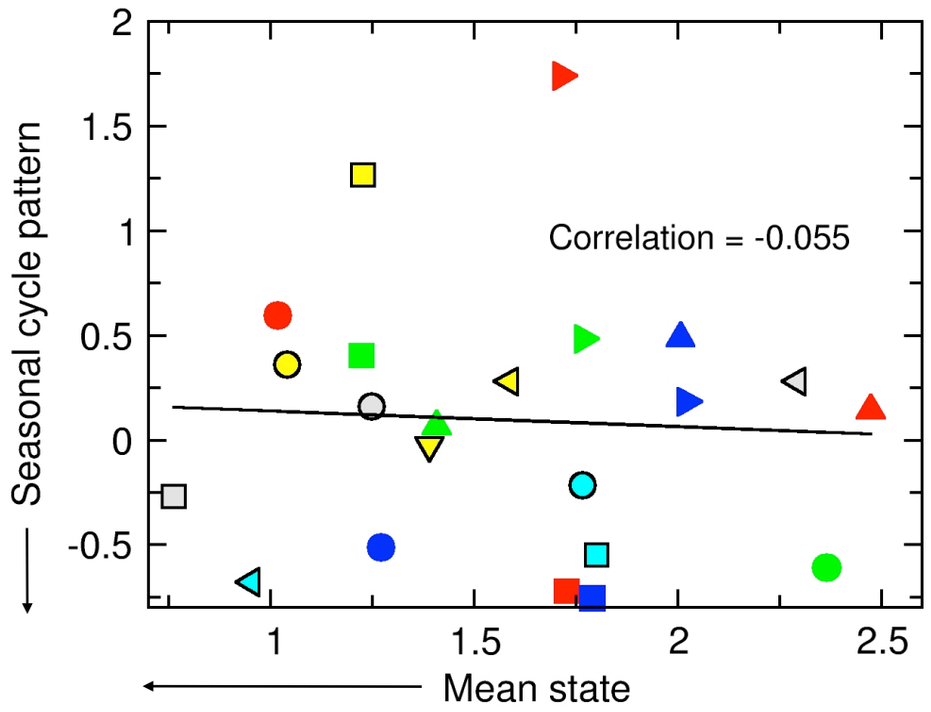
"Better"

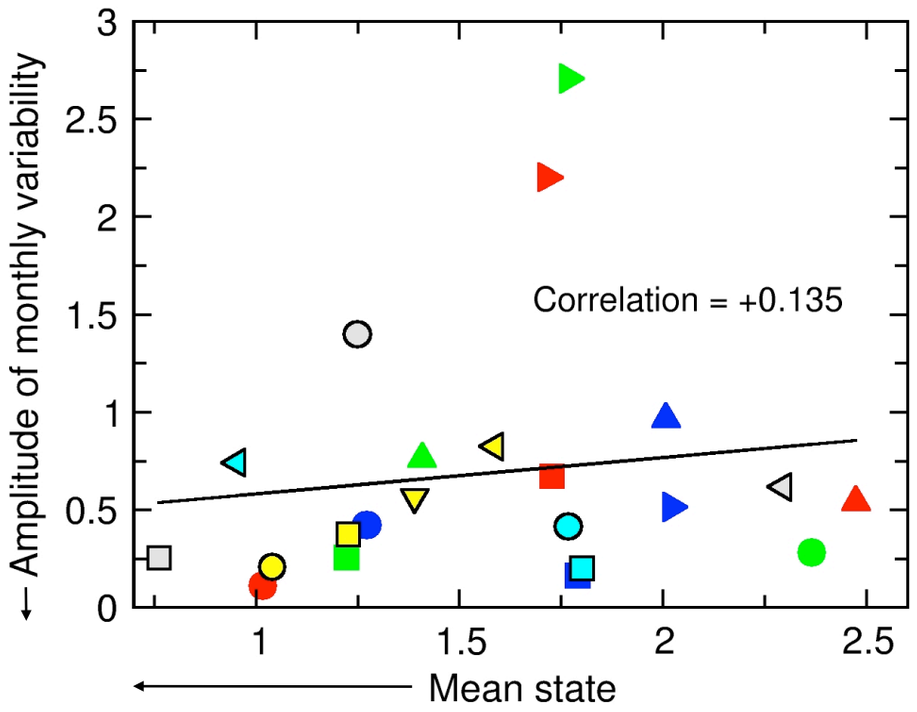
"Worse"

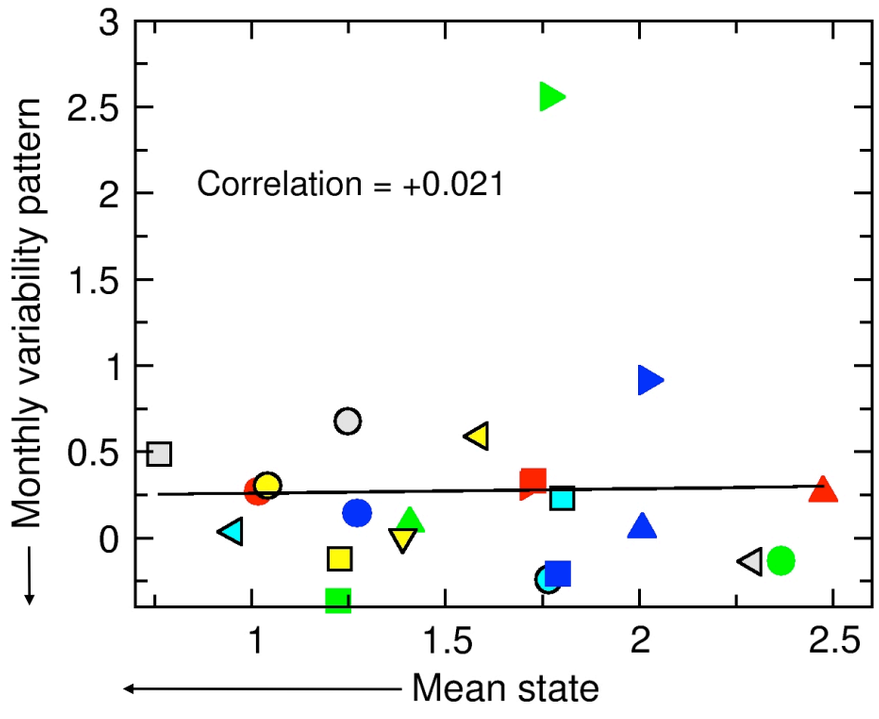
"Best" is almost always the multi-model mean!

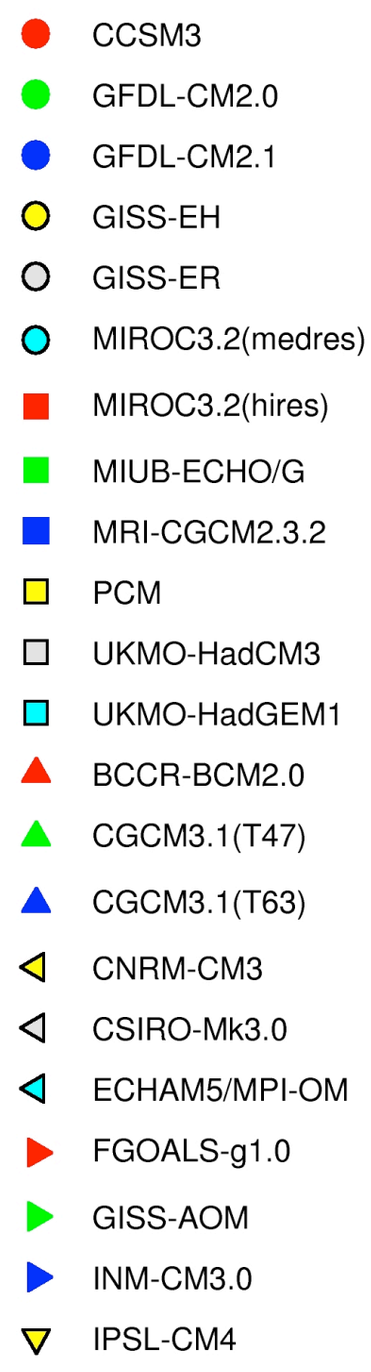
Reichler and Kim (2008)

Relationship between different measures of present-day model skill









Santer et al, 2012

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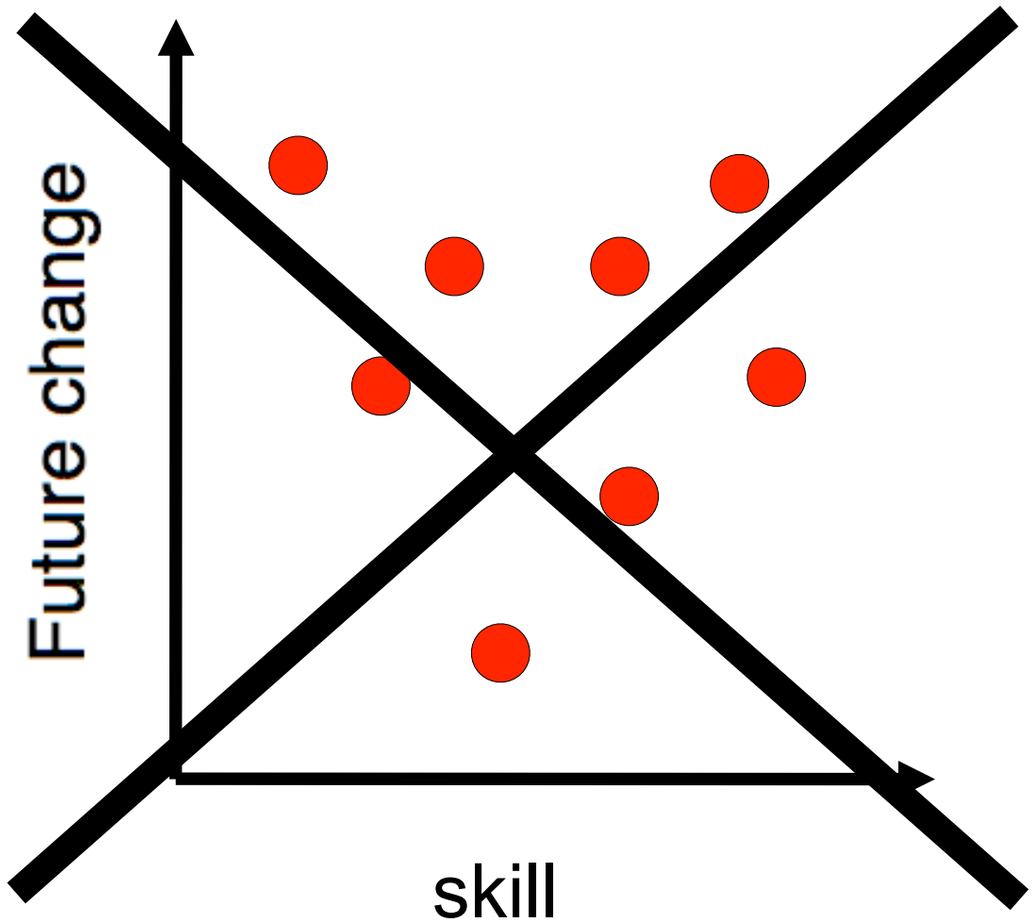
Need correlations of skill scores with future projections...

i.e. does a good simulation/fit to a prior event give any information about future events?

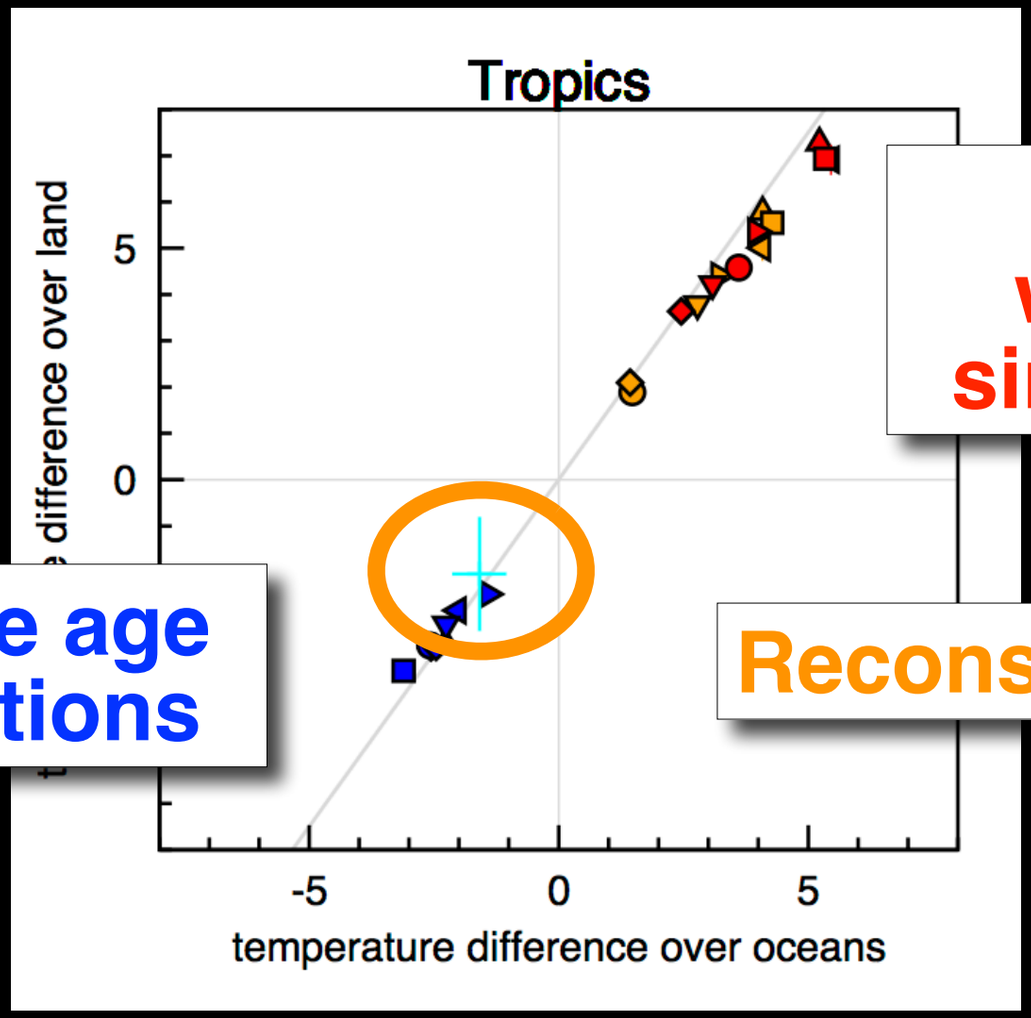


This needs to be demonstrated, not just assumed!

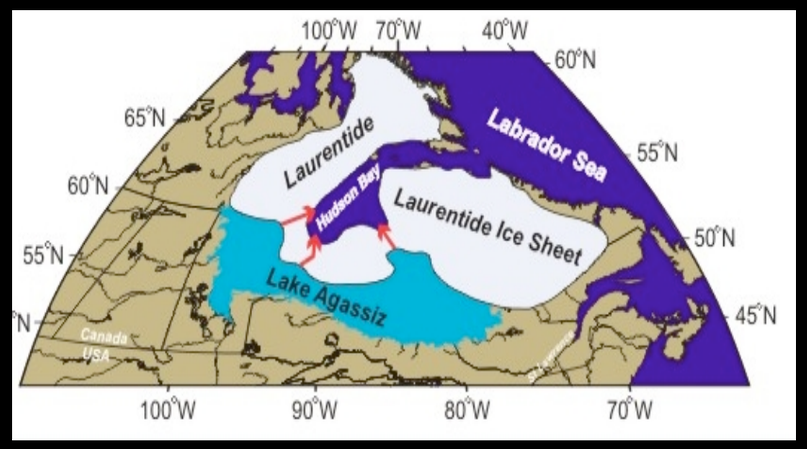
“… from what has actually been, we have data for concluding with regard to that which is to happen thereafter.”

James Hutton (1788)

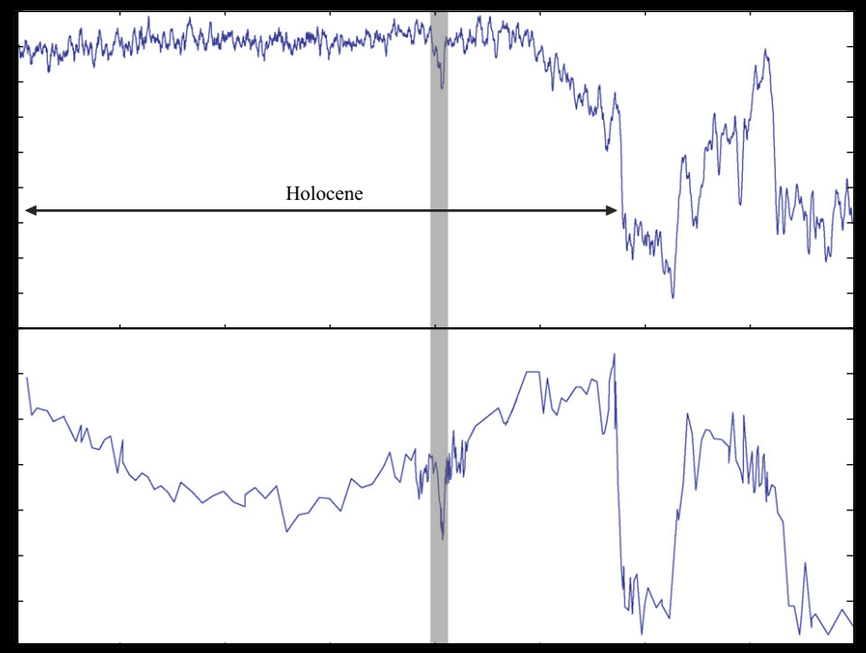
Land-Ocean contrasts are robust in past and future



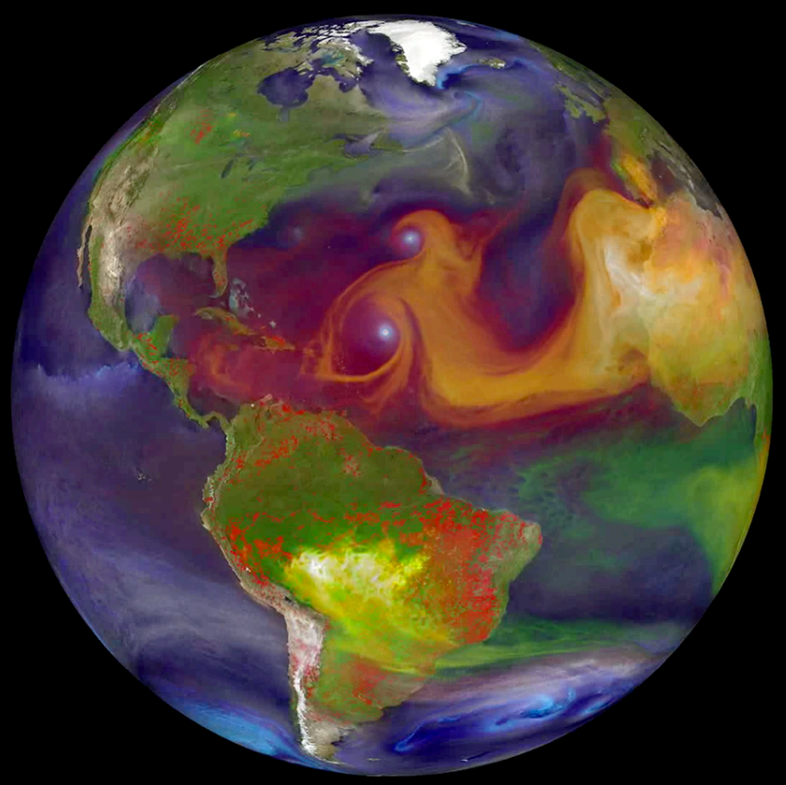
Masa Kageyama (Schmidt et al, 2014)



A lake burst 8000 years ago...



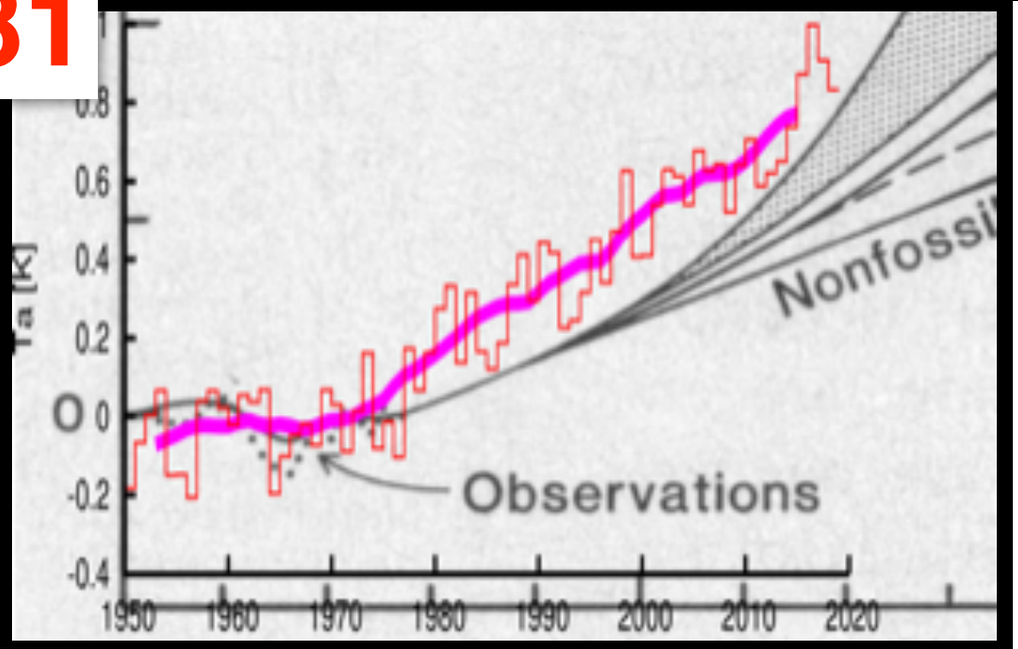
...changed ocean circulation and left traces in Greenland ice...



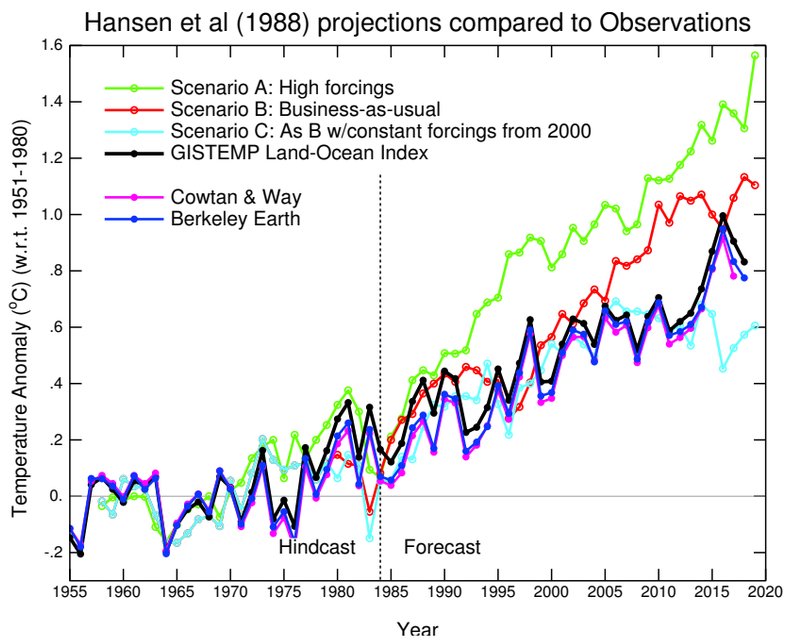
... providing an out-of-sample test for the same models that predict ocean, dust and CH_4 changes in the future.

How are old model predictions doing?

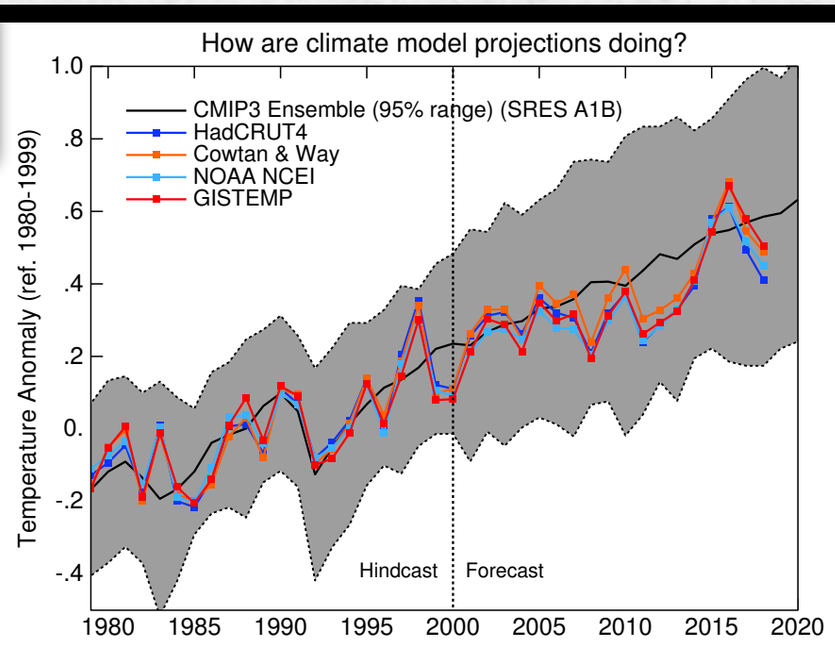
1981



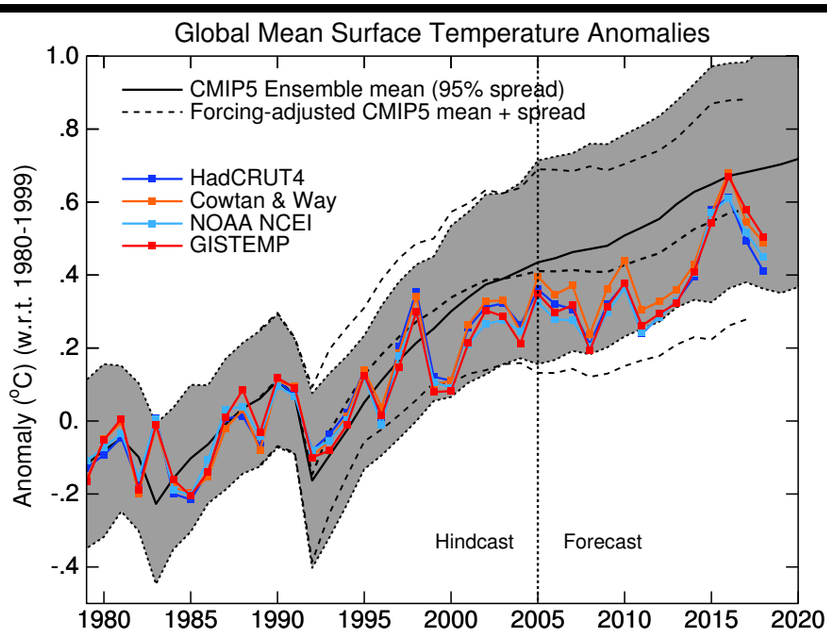
1984



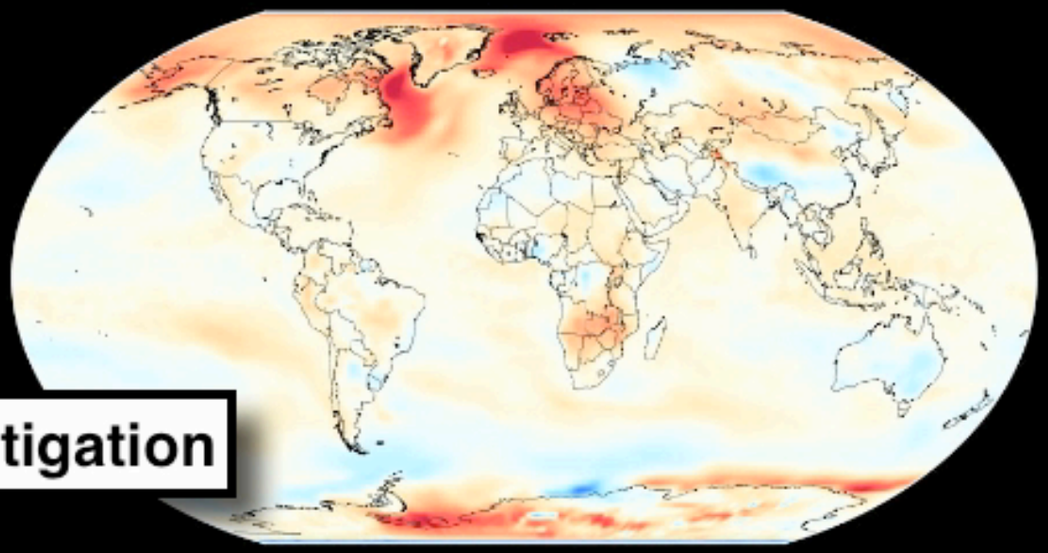
2000



2005



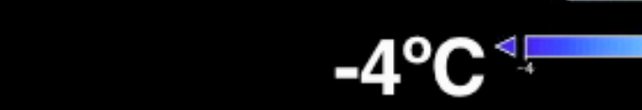
21st Century projections



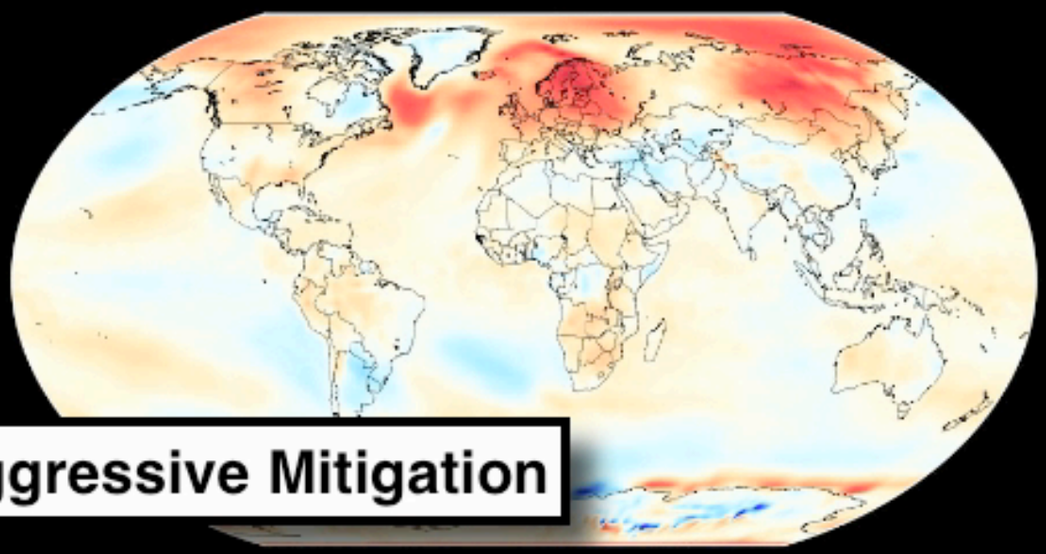
Serious Mitigation

Years: 2006

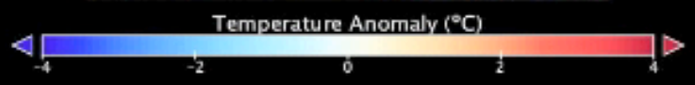
-4°C

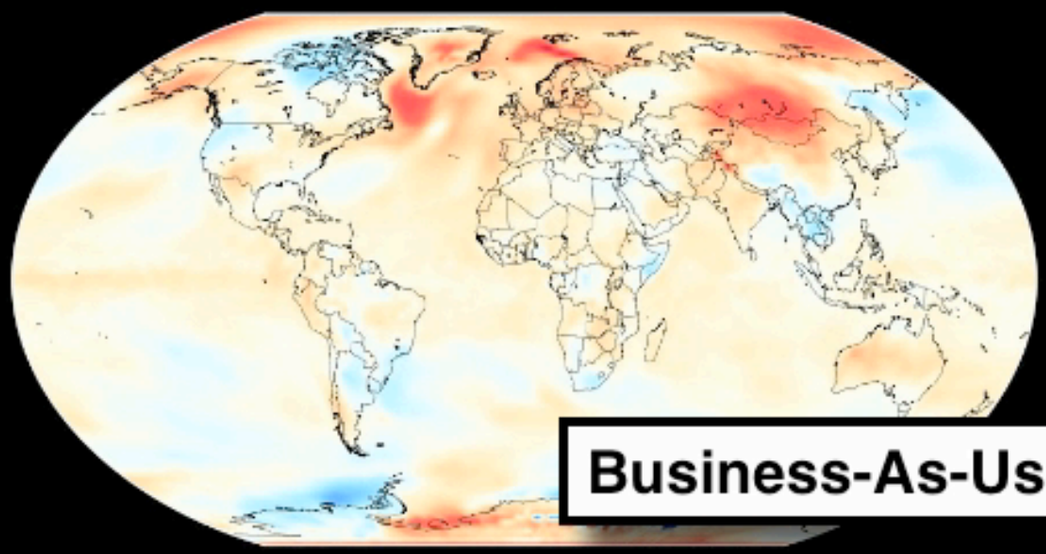


4°C

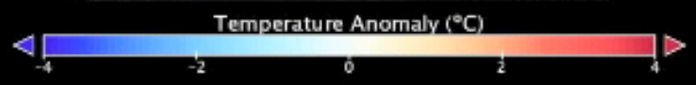


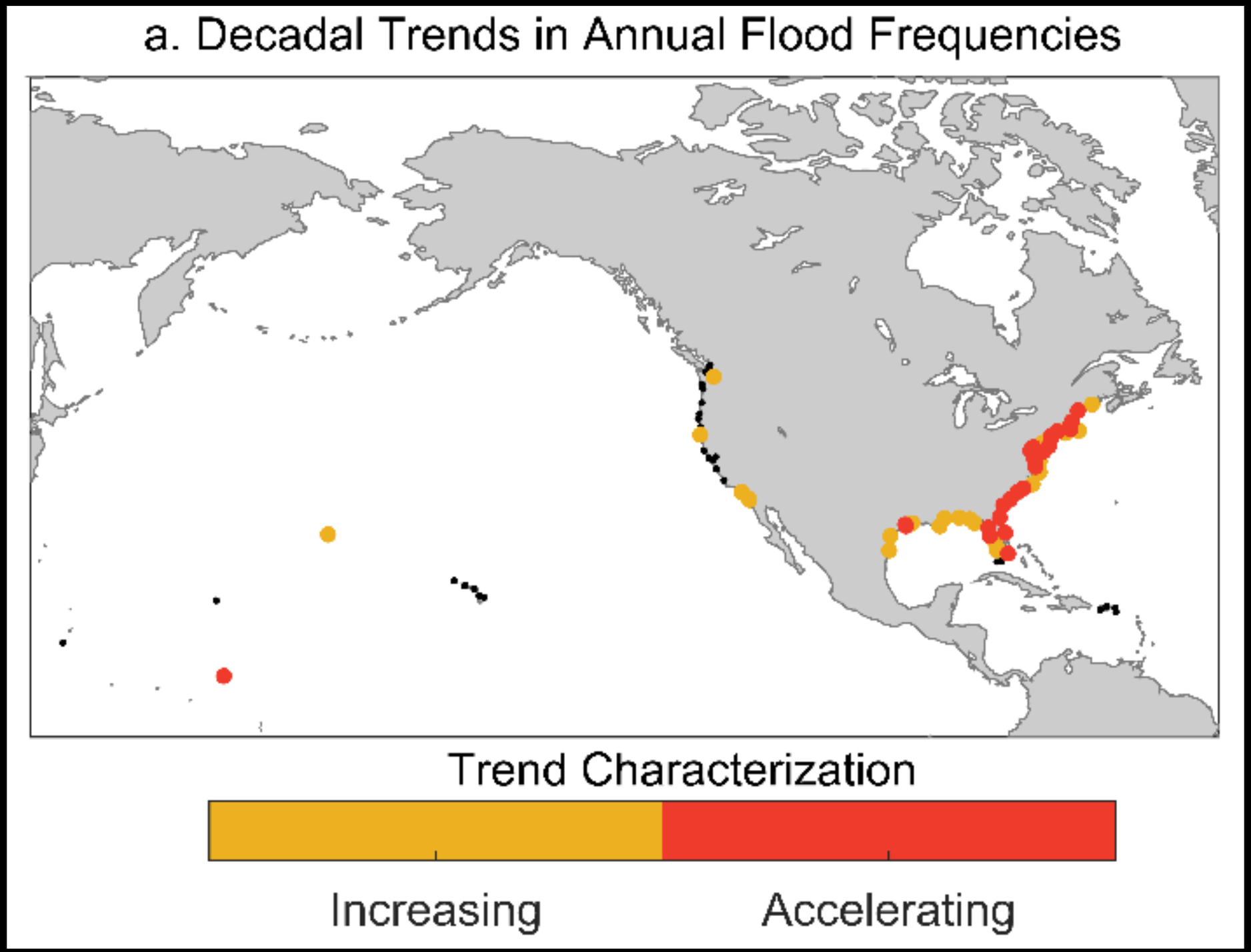
Aggressive Mitigation



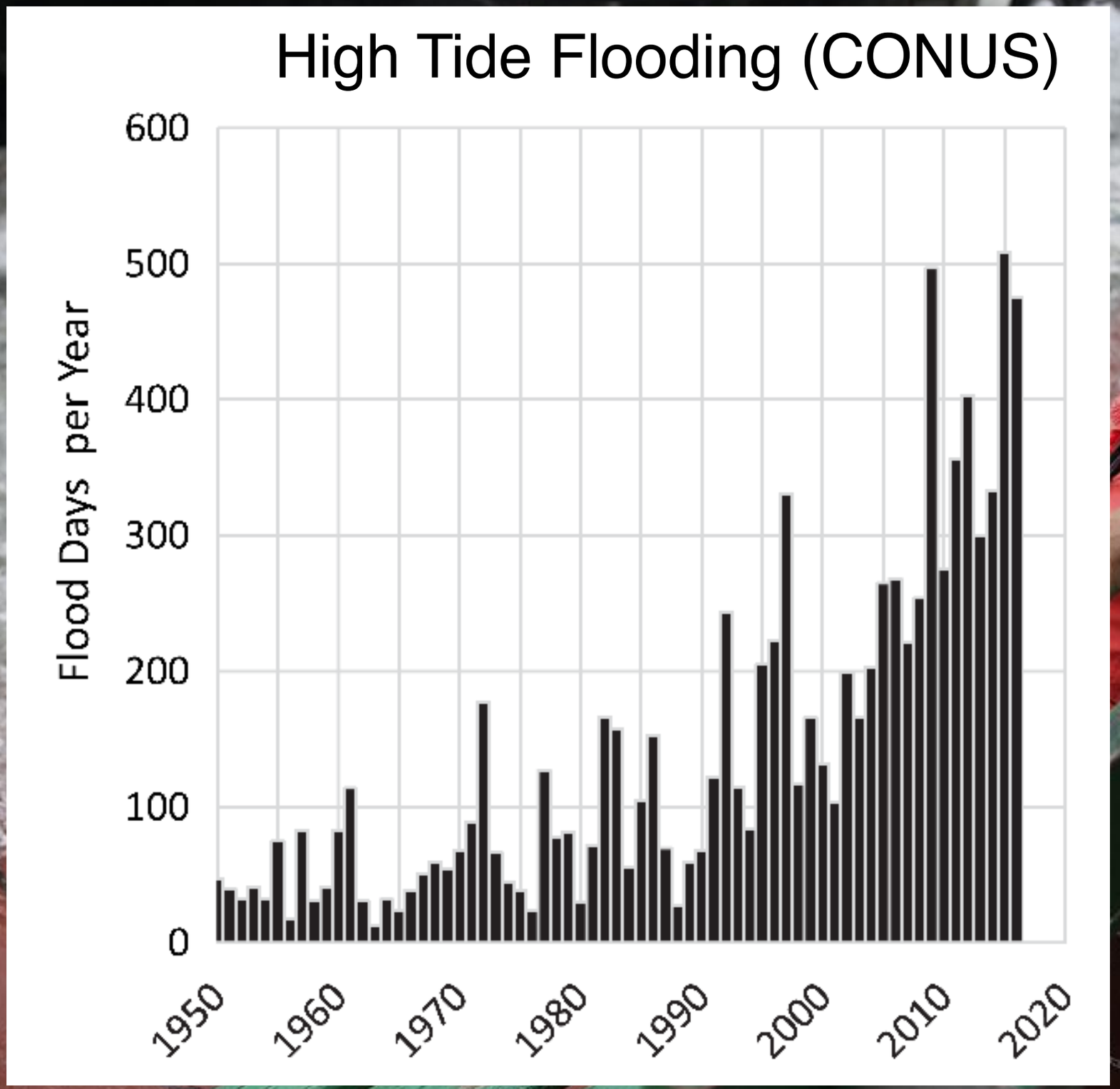


Business-As-Usual





Sweet et al (201



Miami, 2015

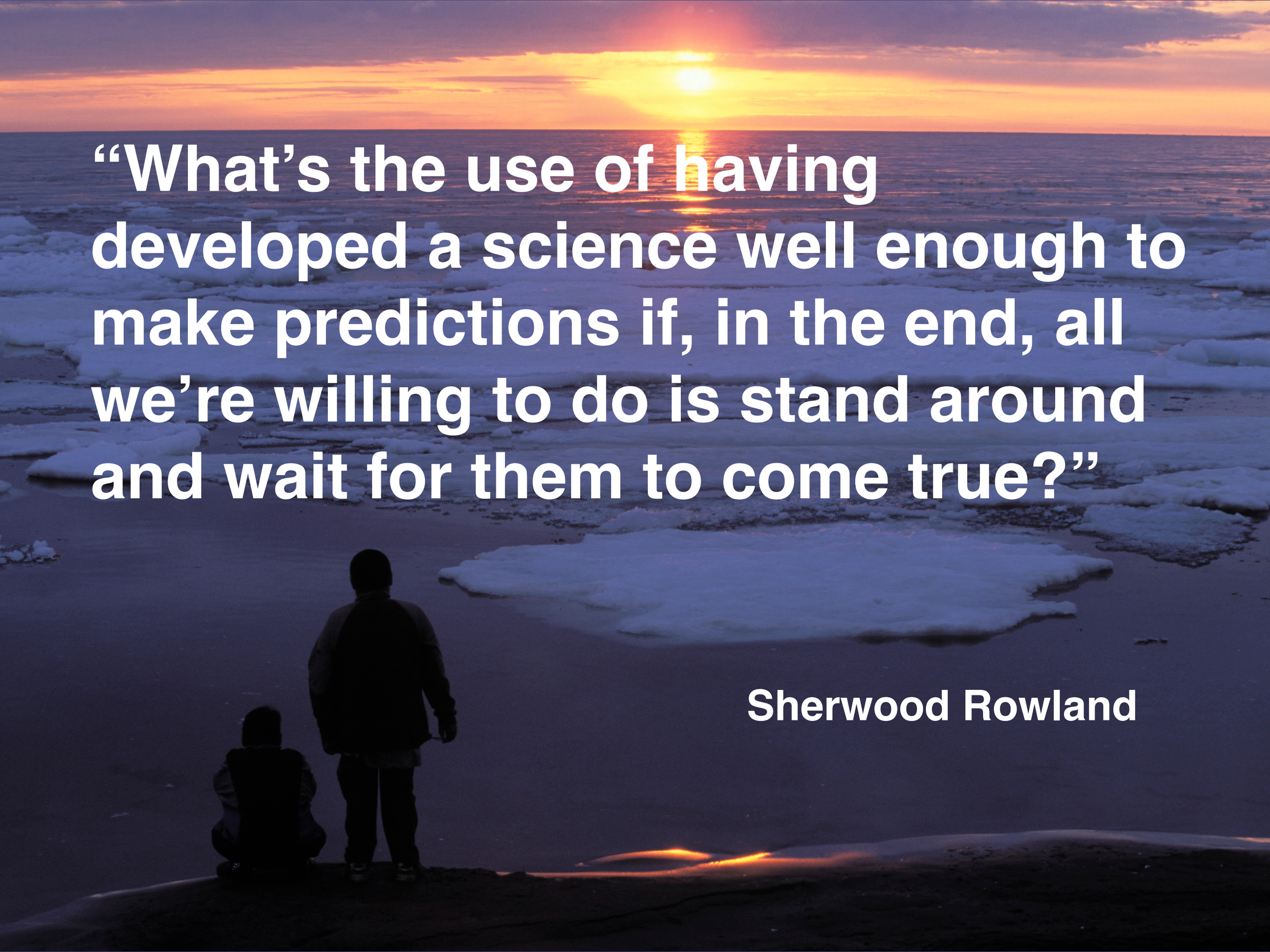
Joe Raedle/Getty

Sixth Challenge

How do we communicate effectively what we've found?

Current global scale policies are not consistent with a stable climate

But future balance between mitigation, adaptation and suffering is still TBD…


“What’s the use of having developed a science well enough to make predictions if, in the end, all we’re willing to do is stand around and wait for them to come true?”
Sherwood Rowland