Using initialized climate models for testing model physics and understanding model processes and biases


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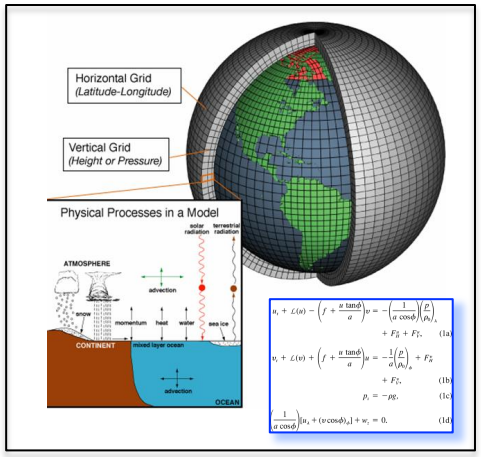
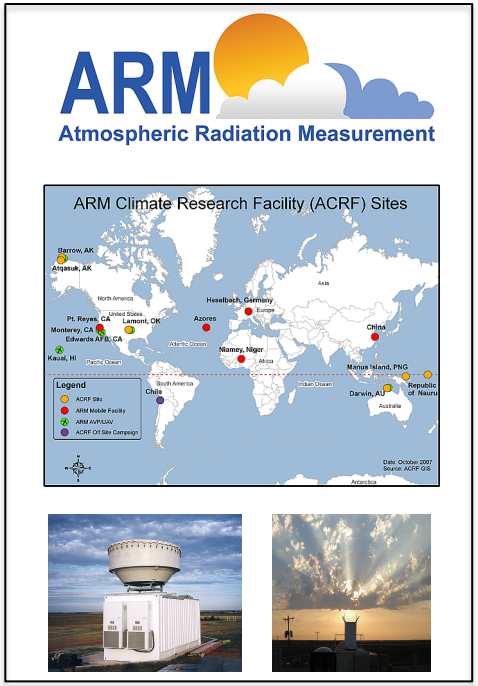
Outline

- DOE's interest in initialized climate models
- Origin and growth of initialized climate models as a diagnostic technique
- Typical procedures for initialized climate models
- The 5 questions
- Future directions

DOE's interest

- DOE's interest: long-term human climate change
- DOE supports the development of climate models (CESM, now ACME)
- DOE also collects ground-based point observations of radiation, cloud, aerosol and precipitation from fixed sites through the Atmospheric Radiation Measurement (ARM) program
  - These observations are collected so that representation of atmospheric physics in climate models can be improved
- In 2002, DOE organized a research effort bridging the modeling and observational programs





Origin and Growth

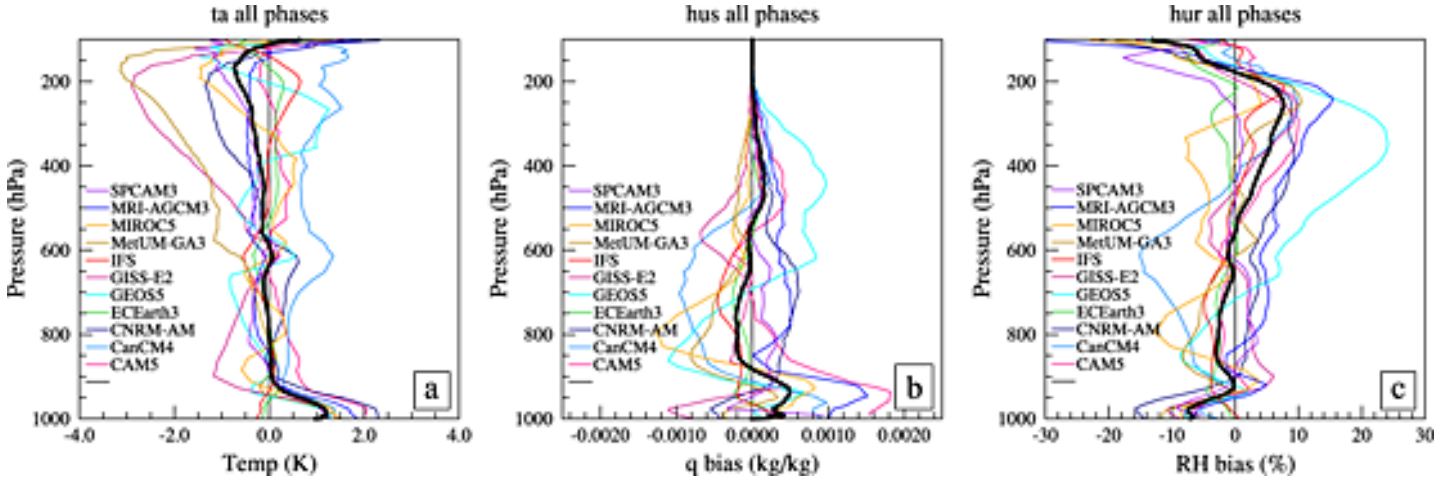
- Solution: Initialize atmospheric climate models to simulate the weather over the ARM sites facilitating a comparison physical parameterizations to ARM data
- In 2003, the CCPP-ARM Parameterization Testbed (CAPT*) was founded working primarily with the Community Atmosphere Model
- Since then, much of the climate modeling community has used initialized atmospheric (+land) models for occasional diagnostic studies
- Modeling intercomparison hindcast projects examples:
  - Transpose-AMIP II (~7 CMIP5 climate models)
  - MJO model intercomparison project (~10 climate models)

*CAPT now stands for the Cloud-Associated Parameterization Testbed

Widespread adoption

- Transpose-AMIP II
  - Williams et al. 2013
  - Ma et al. 2014
  - Barton et al. 2014
  - See also:
    - Demoto et al. (MIROC5, GRL '13),
    - Kamae & Watanabe (MIROC5, ClimDyn '13),
    - Klocke & Rodwell (IFS, QJ '14),
    - Fermepin & Bony (IPSL CM5A, JAMES '14),
    - Pearson et al. (UKMO, QJ '14)
- MJO Project Papers
  - Klingaman et al. 2015 (overview)
  - Klingaman et al. 2015 (20-day)
  - Xavier et al. 2015 (2-day)
  - See also Jiang et al. 2015 (20-year)

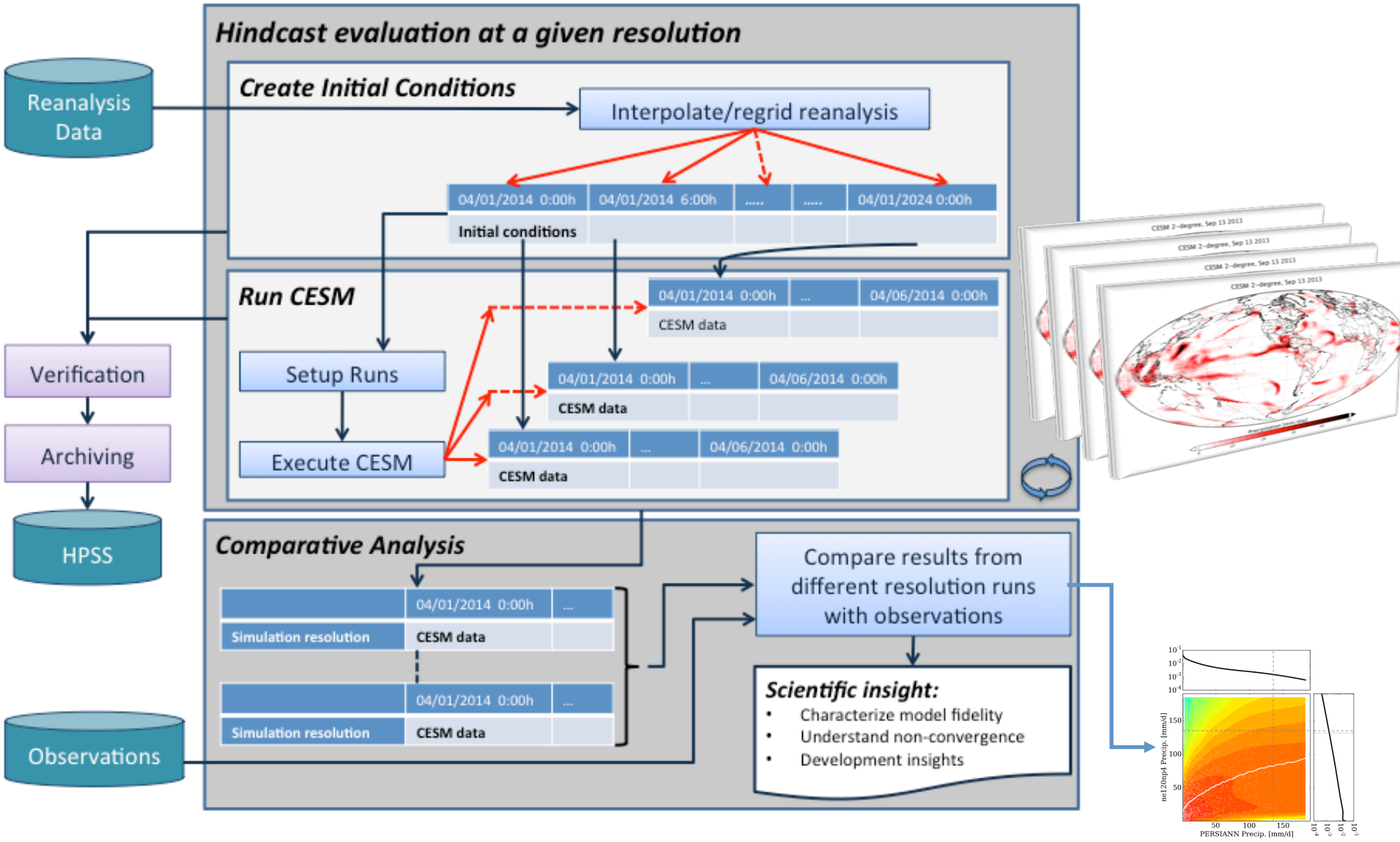
Hour 12-36 Biases in During 2 YOTC MJOs @ Indian Ocean



Xavier et al. (2015)

Typical Procedures

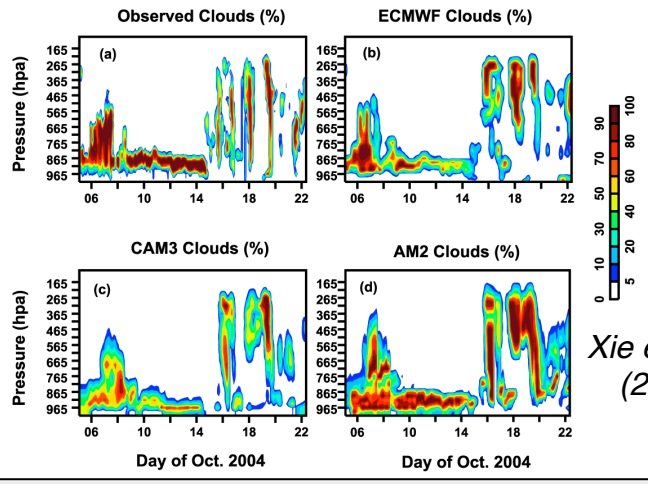
- Integrate atmospheric portion of climate model at its native resolution
- For models without data-assimilation, create initial conditions for the atmosphere model by interpolating NWP analysis data (*u,v,T,q)* to climate model grid *(carefully – using techniques from ECMWF)*
- Various levels of sophistication to the initialization of other atmospheric variables (e.g. aerosols) and land-model variables
  - Ocean and sea-ice model initialization (for initialized coupled integrations) has been developed at climate modeling centers (e.g., ocean data assimilations)
- Conventional forecast measures (e.g. Z*500) are respectable


Hindcast evaluation at a given resolution
Reanalysis Data
Create Initial Conditions
Interpolate/regrid reanalysis
04/01/2014 0:00h
04/01/2014 6:00h
.....
.....
04/01/2024 0:00h
Initial conditions
Run CESM
04/01/2014 0:00h
...
04/06/2014 0:00h
CESM data
Setup Runs
Execute CESM
Verification
Archiving
HPSS
Comparative Analysis
Simulation resolution
CESM data
Observations
Compare results from different resolution runs with observations
Scientific insight:
Characterize model fidelity
Understand non-convergence
Development insights
PERSIANN Precip. [mm/d]

Question 1: *Are initialized simulations effective for comparing to point observations?*

- Answer: *Yes*, of course
- Helps with comparing to unique ARM observations for assessing model physics
  - vertical cloud profile from cloud radars
  - diabatic heating estimates from radiosonde balloon networks
- Complementary to Single Column Modeling approaches, but without the need to develop a large-scale forcing dataset

Time-Height Cloud Fraction During M-PACE @ NSA

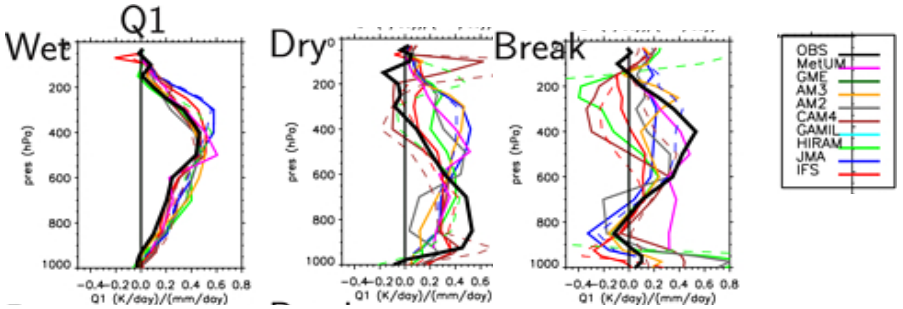


Xie et al. (2008)

Field Campaigns Examined

ARM CAP-MBL (2009-2010)
ASCOS (2009)
ARM NSA ISDAC (2008)
ARM TWP-ICE (2006)
ARM NSA M-PACE (2004)
ARM SGP AEROSOL IOP (2003)
EPIC (2000)
ARM SGP SCM IOP (April 1997)
ARM SGP SCM IOP (June 1997)
TOGA-COARE (1991-92)

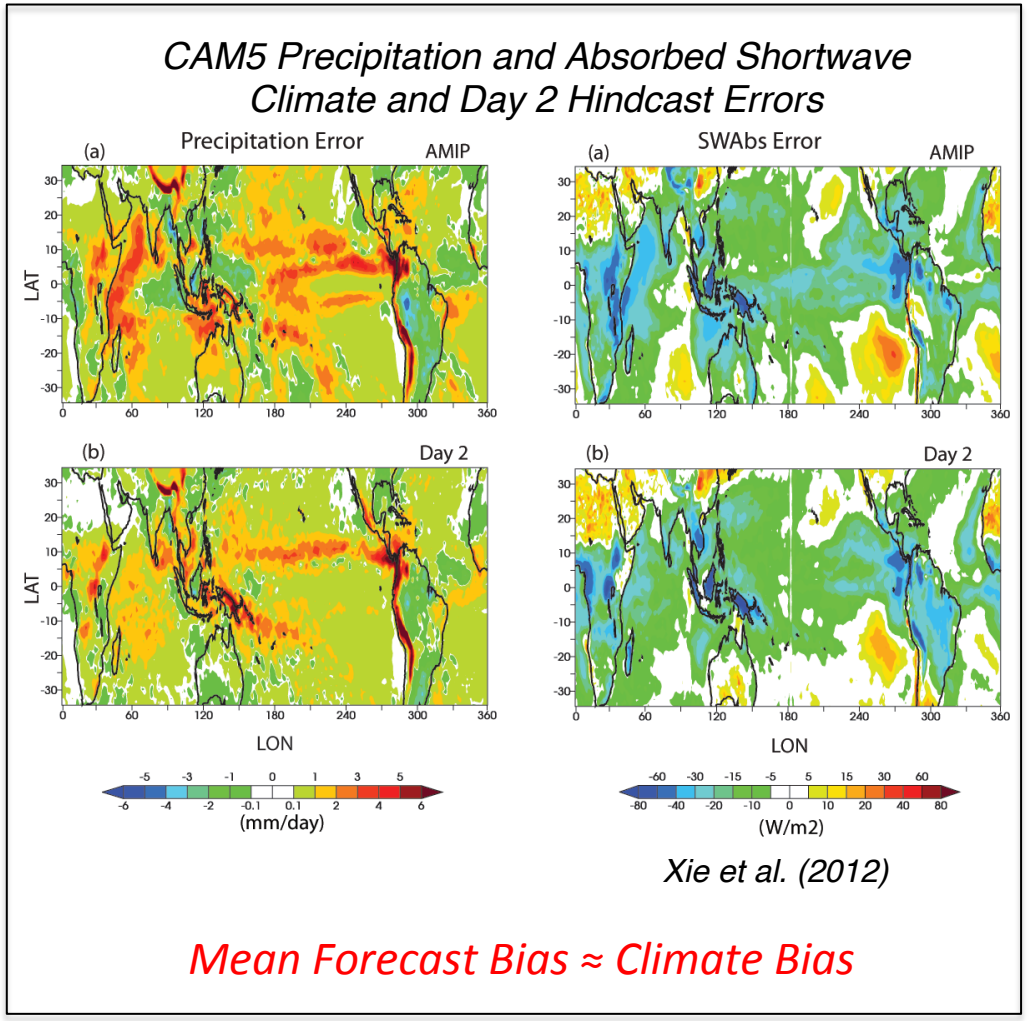
Diabatic Heating for 3 Monsoon Phases During TWP-ICE @ Darwin



Lin et al. (2012)

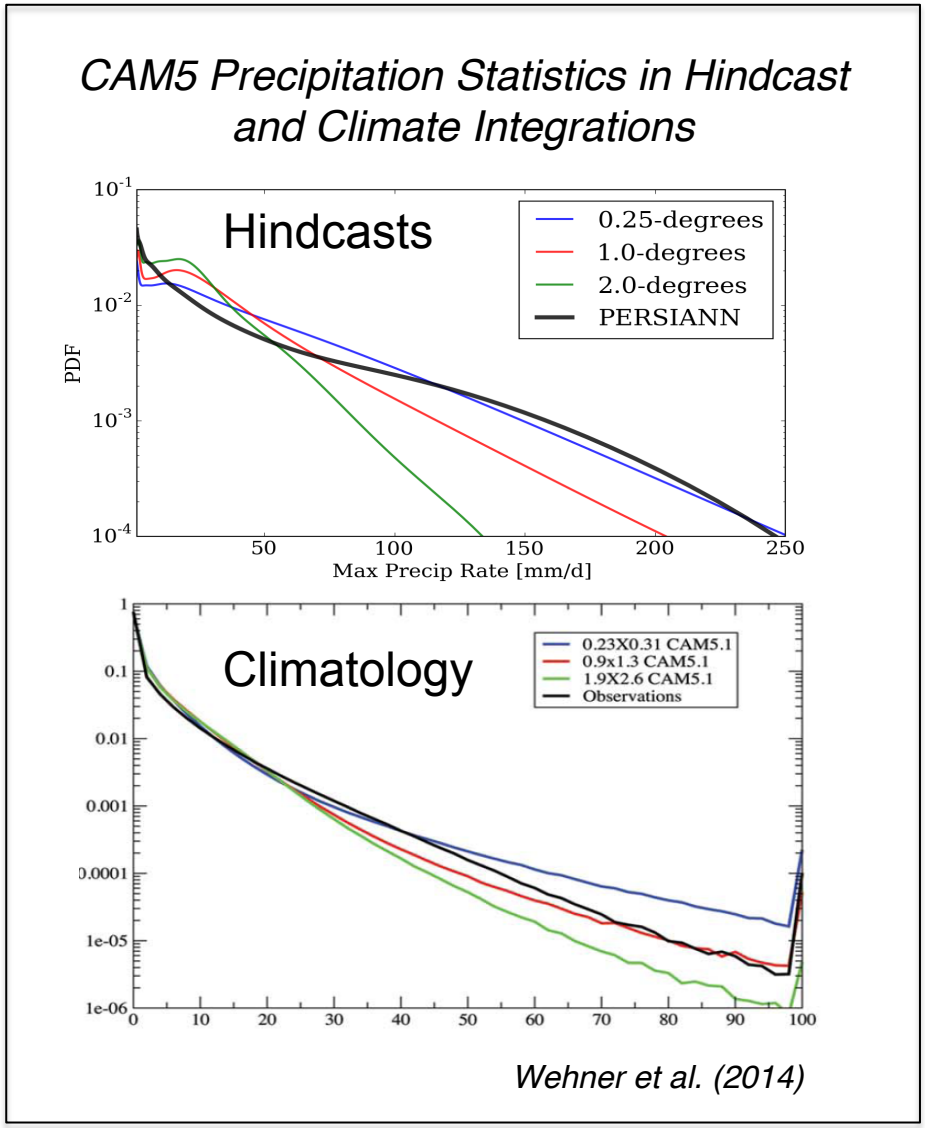
Question 2a: *Are hindcast biases climate biases?*

- Answer: *Yes* for fast (~hours to days) atmospheric physical processes:
  - clouds
  - radiation
  - precipitation
- Even some dynamical quantities
- Exceptions: Double-ITCZ
- Multi-model conformation from Transpose AMIP II confirmation (Ma et al. 2014)



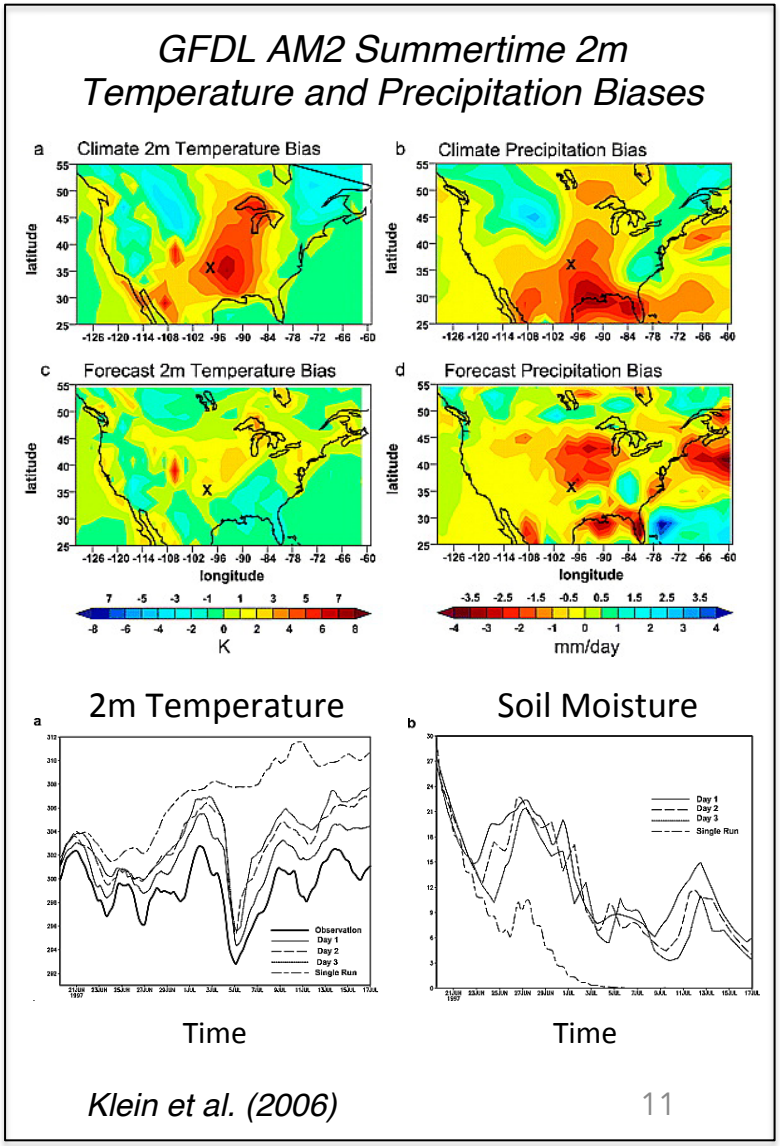
Question 2b: *Are hindcast statistics climate statistics?*

- Answer: *Maybe* for precipitation
- Further analysis needed for other climate variables



Question 3: *Do initialized simulations help you understand the growth of climate biases?*

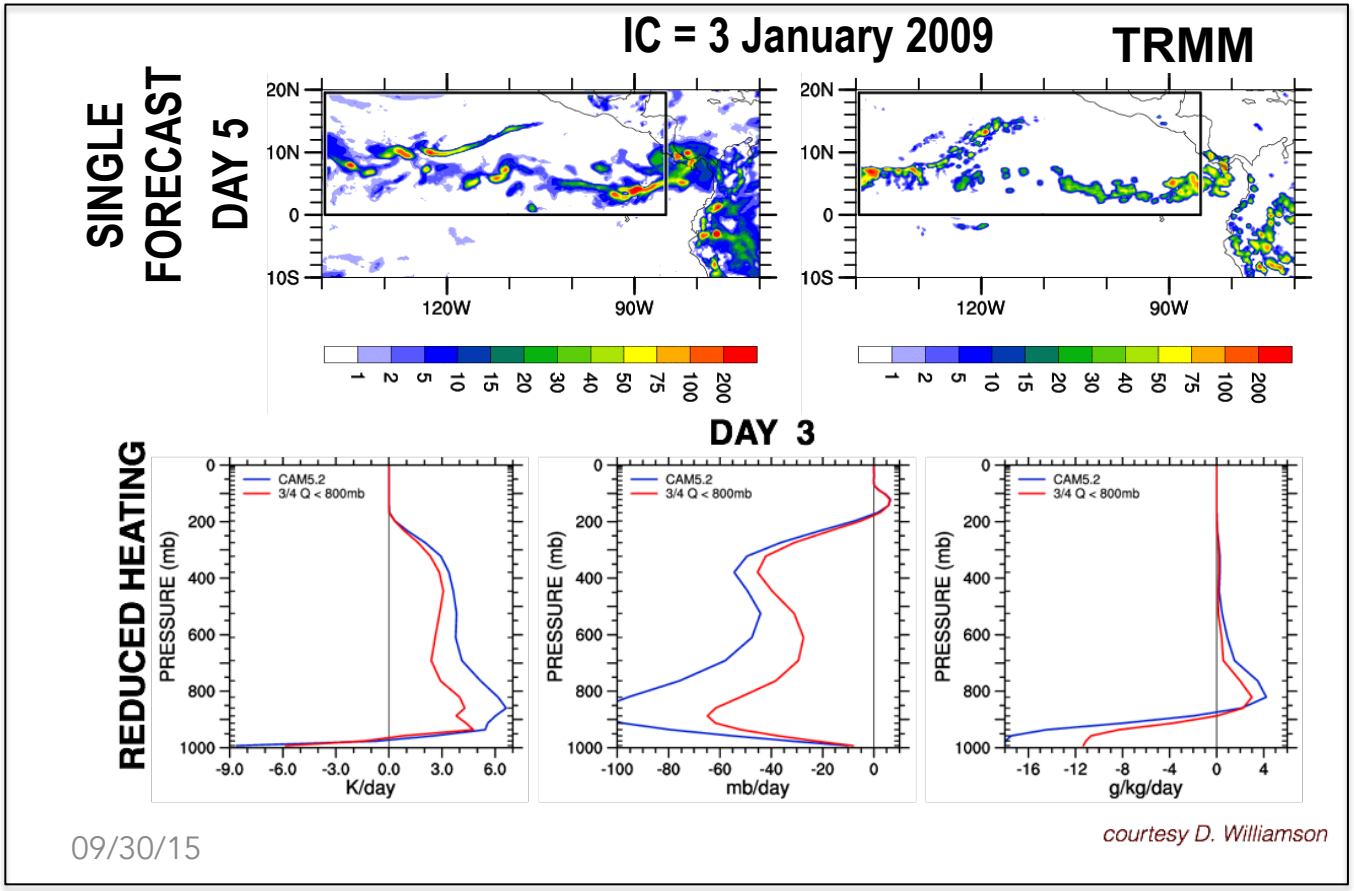
- Answer: *Yes* at least in some cases where feedbacks amplify biases
- *Example:* Continental warm bias in summertime surface air temperature
- *Explanation:* Lack of precipitation (i.e., mesoscale convective systems) drives land-surface to a dry state whereby radiative input can only be balanced by sensible heat loss through an increased surface temperature
- Motivation for new GASS hindcast multi-model intercomparison project entitled "CAUSES" (van Weverberg et al. 2015)



GASS GEWEX WCRP Global Atmospheric System Studies

Question 4: *Do initialized simulations show the impact of physical parameterizations?*

- Answer: *Yes,* for fast physical processes (e.g. cloud processes ~ hours), so look at hindcasts after the first few hours



Parameterizations Tested by CAPT

DEEP CONVECTION
- Unified Convection (UNICON)
- Mapes-Neale Convective Organization
- Neale Entrainment Limiter
- G. Zhang (2005) Convective Closure
- Zhang-McFarlane selected settings
- Xie-Zhang Convective Trigger

CLOUD MICROPHYSICS
- Morrison and Gettelman Version 2
- G.Zhang MG microphysics in convection
- Gettelman ice/mixed-phase cloud physics
- Liu ice cloud physics
- Phillips ice nucleation
- Bergeron Process / Rain-freezing temperatures
- Cloud Droplet Nucleation Parameterizations (4)
- Autoconversion Parameterizations (5)

OTHER
- Cloud-Layers Unified By Binormals (CLUBB)
- RRTMG Radiation Code
- U. Washington PBL/ShCu

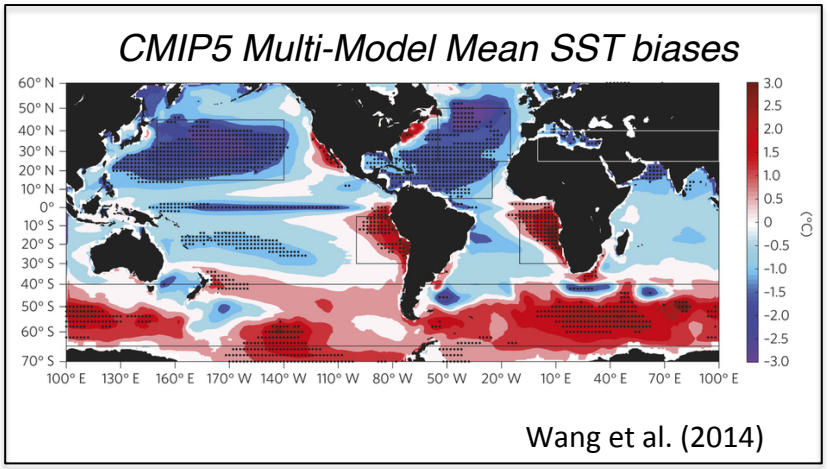
0.25° CAM5 rains too much in E. Pac., traced to feedback between dynamics and physics that is activated because UW shallow convection places heating too low. Artificially raising the heating reduces the bias by removing the feedback.

Question 5: *How well should initialization be done?*

- Answer: *It depends.* *For:*
  - Physical parameterization and resolution comparisons: *Interpolating NWP analysis is generally OK*
  - Exploring systematic (large) long-term biases from fast processes: *Interpolating NWP analysis is generally OK*
  - Studies involving fields not (currently) available from NWP analysis (e.g. compatible aerosols and land-surface): *Attention is needed*
  - Quantitatively assessing forecast skill of a model, would want to minimize IC error: *Sophistication is necessary*
  - Coupled model integrations: ???
- What you want: Size of model error >> Size of error introduced by using a foreign analysis
- Don't want to have to do fancy initialization is part of the point
- Testing alternate NWP analysis can be used to show robustness

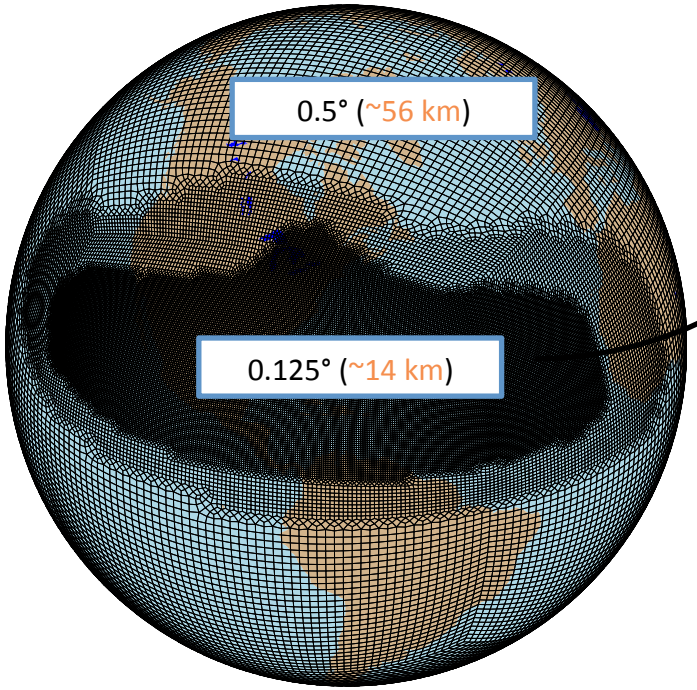
Future (1): *Initialized coupled-model simulations*

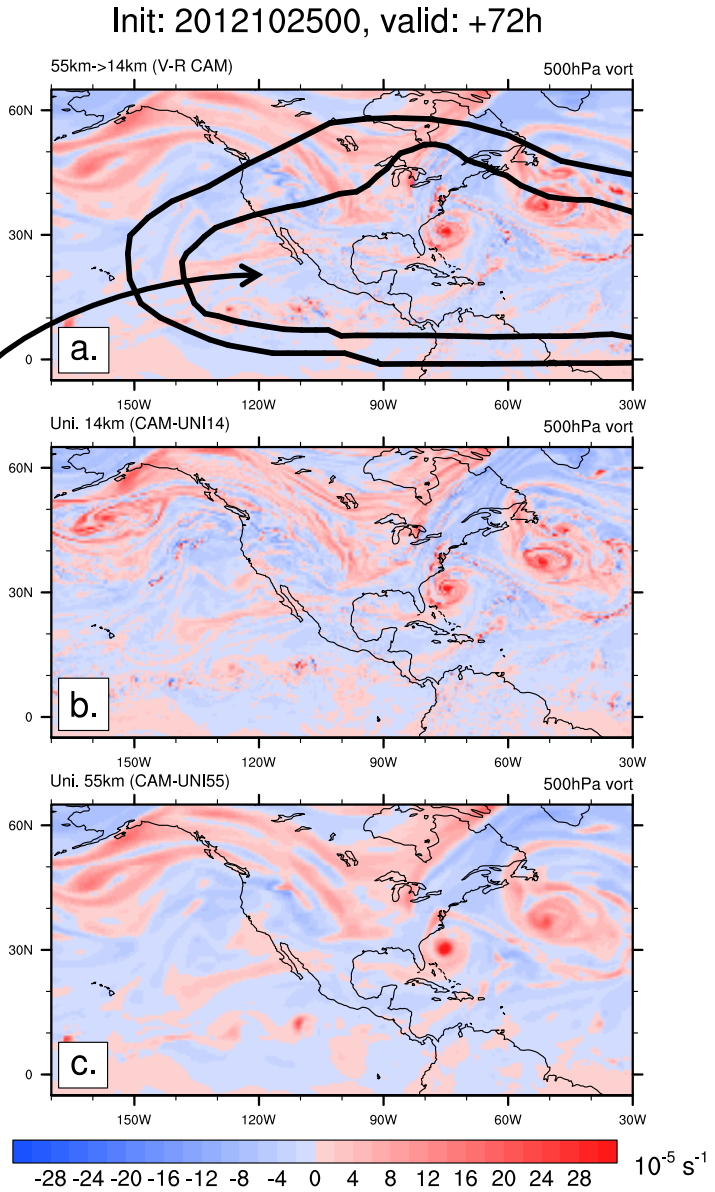
- The growth of biases in initialized coupled models is understudied
- Hypothesis: Many climate biases (e.g. SST) represent the average effects of biases in fast processes (e.g. clouds, precipitation, wind stress) and are visible within simulations of a few months
- How much are due to atmospheric errors, oceanic errors, or coupled ocean-atmospheric interactions errors?
- Over what time-scales do biases develop?
- Prior Studies (w/ CMIP5 decadal hindcasts)
  - Tropical Pacific (Vanniere et al. 2013, 2014)
  - Tropical South Atlantic (Toniazzo and Woolnough 2014, Voldoire et al. 2014)
  - Double ITCZ (Liu et al. 2012, Zhang and Wang 2006)



- Would coordinated multi-model intercomparisons be useful?
  - Eventually but perhaps not right now (WGNE Transpose CMIP white paper 2015): WGSIP?
  - Issues with starting from a common ocean initial condition
  - How to separate model error from initialization error from shock

Future (2): *Initialized high-resolution model simulations*



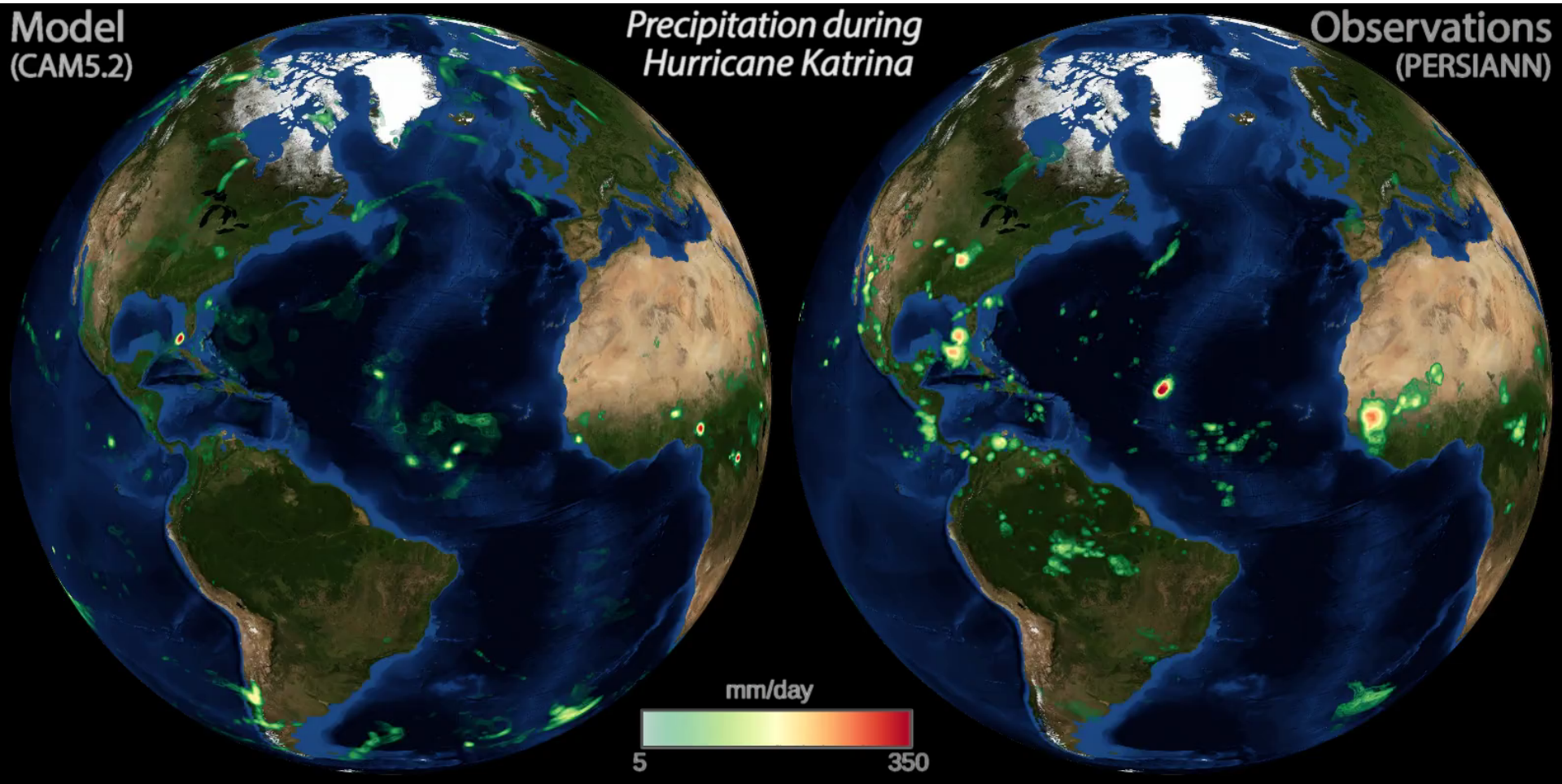


Variable-resolution CAM-SE
Hurricane Sandy 500 hPa vorticity
INIT 00Z 10/25/12
VALID 00Z 10/28/12

Zarzycki and Jablonowski, MWR, 2015

Future (2): *Initialized high-resolution model simulations*

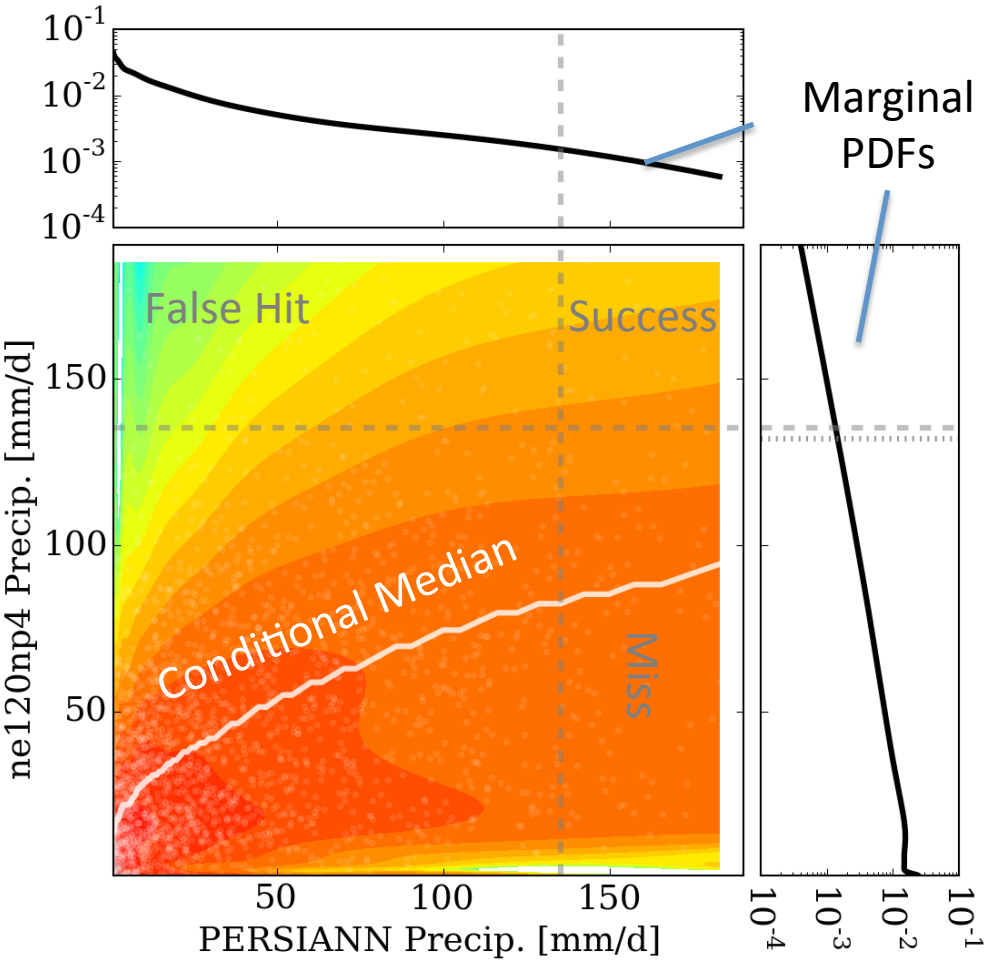
Global CAM5.2 @ 0.25-degree for Hurricane Katrina



Diagnosing extremes at high resolution

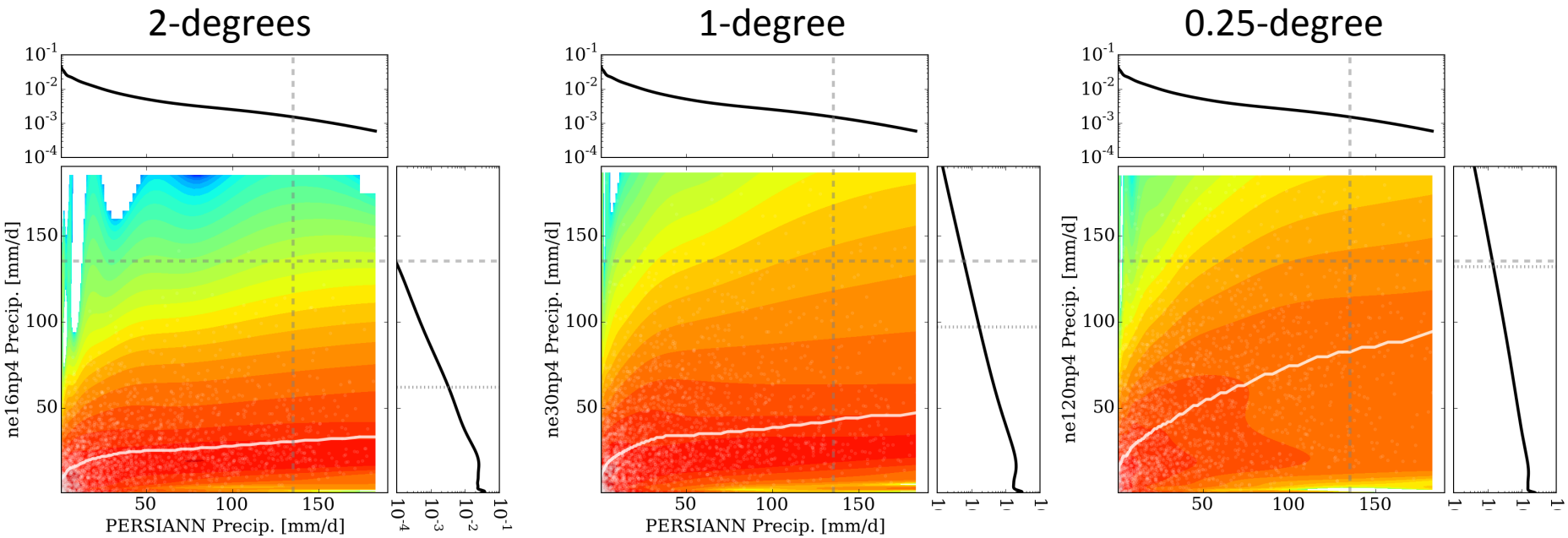
The probability of max precip (within a 5x5-degree box) in CAM at 0.25-degree res, ***conditioned on max precip*** in PERSIANN observations (in the same box at the same time).

This is from 1-year of 5-day hindcasts for each day in 2005. 2005—2009 have been completed and will be publicly available soon.

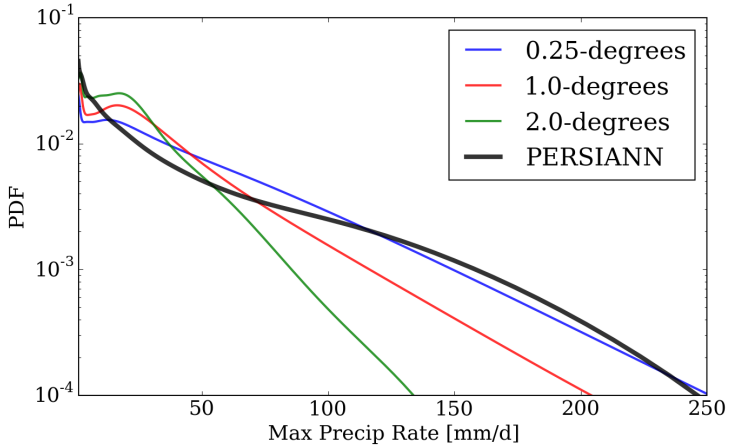


PDF Estimated using fastKDE:
http://bitbucket.org/lbl-cascade/fastkde

Diagnosing extremes at high resolution



Notice that the precip PDF approaches observations at high resolution (right), but that the model systematically produces too little precip in conditions that produce the most extreme events in reality.



Summary (1)

- Initialized simulations with climate models are now a well-established diagnostic tool available to climate model developers
  - Quasi- 'seamless' modeling approach

Summary (2)

- Initialized simulations are a computationally efficient framework to learn about the behavior of physical components (e.g. clouds, precipitation) aiding in:
  - Comparison to observations that are limited in space or time
  - Testing model's parameterization and resolution sensitivities
  - Diagnosing the growth of systematic biases involving feedbacks between faster (e.g. hours-days/clouds, precipitation) and slower (e.g. days-weeks/MJO, soil moisture) components of the climate system

Summary (3)

- Ongoing and future works involving extending the diagnosis of physical processes in initialized climate simulations to:
  - Coupled ocean-atmosphere simulations
  - Higher horizontal resolution simulations (efficient for high-resolution model testing of physics)

Session 3 Topics

- How does the simulation of small-scale processes change with model resolution?
- What can be learned about model physical processes and the growth of climate biases from initialized coupled model simulations?