Climate Modeling at GFDL

2nd US Climate Modeling Summit
Washington, DC
March 9-10, 2016

Geophysical Fluid Dynamics Laboratory

Model configurations

AM4 primarily being developed at 1 deg and 1/2 deg

With 2 vertical resolutions/physics packages:
32 level with fast chemistry
48 levels with full tropospheric and stratospheric chemistry

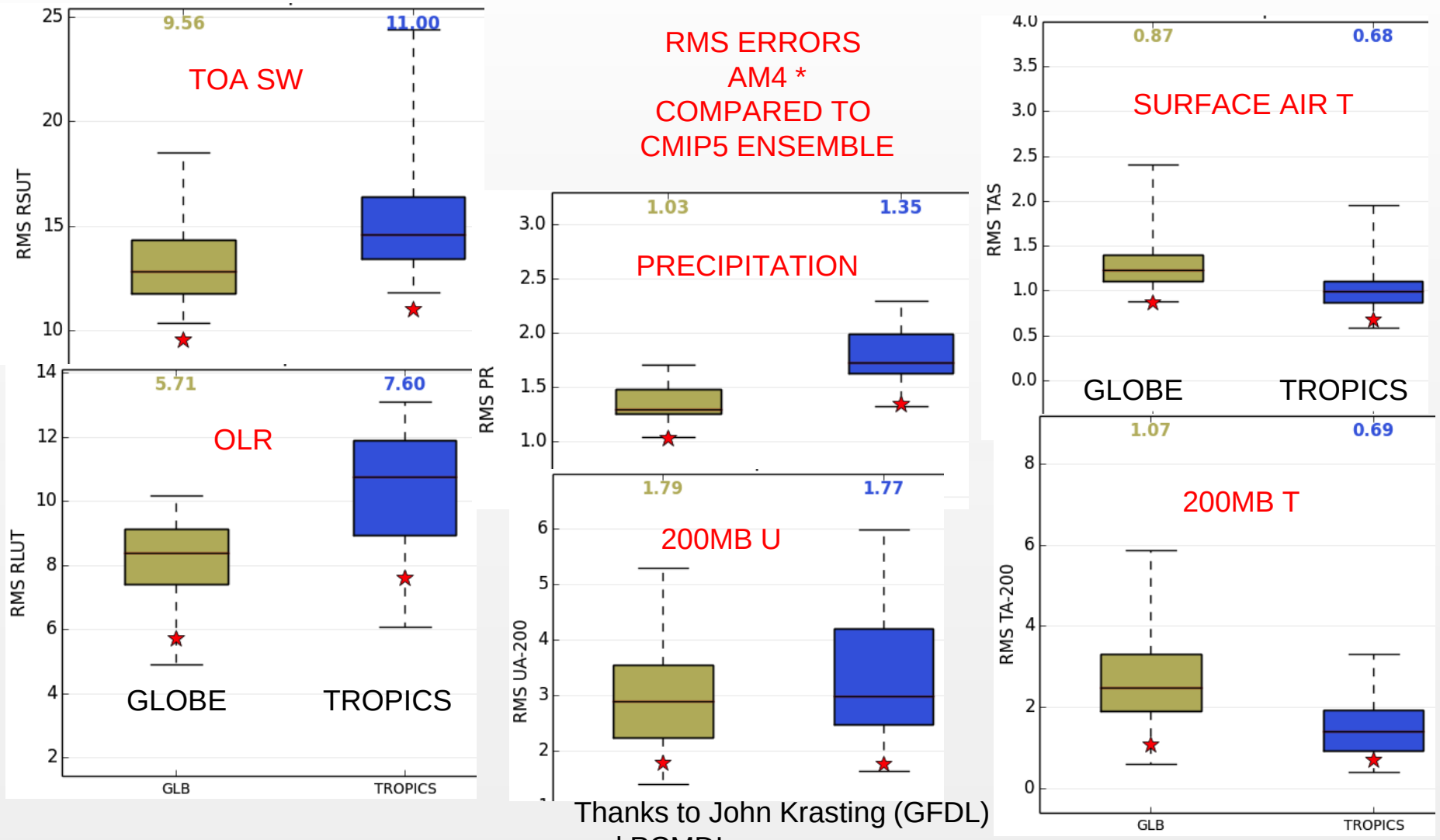
Ocean (MOM6) primarily being developed at 1/2 deg and 1/4 deg

2 target configurations for CMIP6:

ESM4: 1 deg, 48 level, full chemistry atmosphere plus land biology
1/2 degree ocean with biogeochemistry (COBALT)

CM4: 1/2 degree, 32 level, fast/chemistry atmosphere
1/4 degree ocean

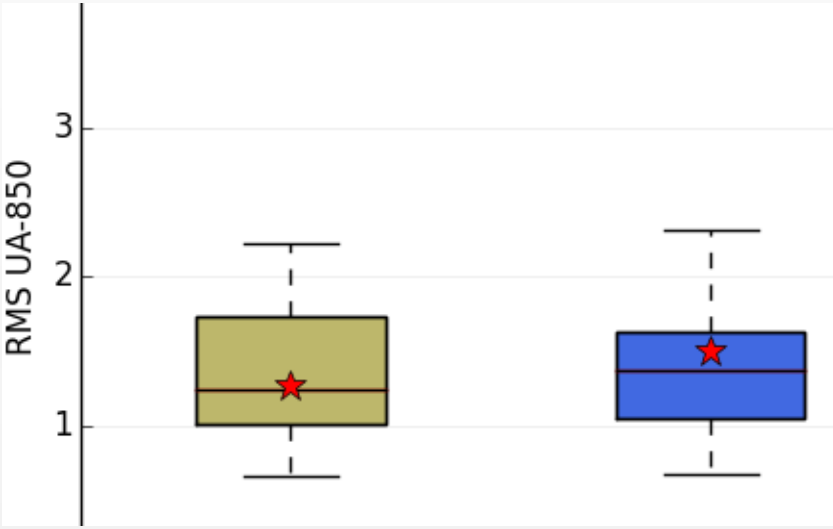
THE QUALITY OF THE ANNUAL MEAN ATMOSPHERE: AM4g7 AMIP vs CMIP5 AMIPs



Thanks to John Krasting (GFDL) and PCMDI

THE QUALITY OF THE ANNUAL MEAN ATMOSPHERE: AM4g7 AMIP vs CMIP5 AMIPs

850mb U: a less satisfactory field
(trade winds exceptionally strong)



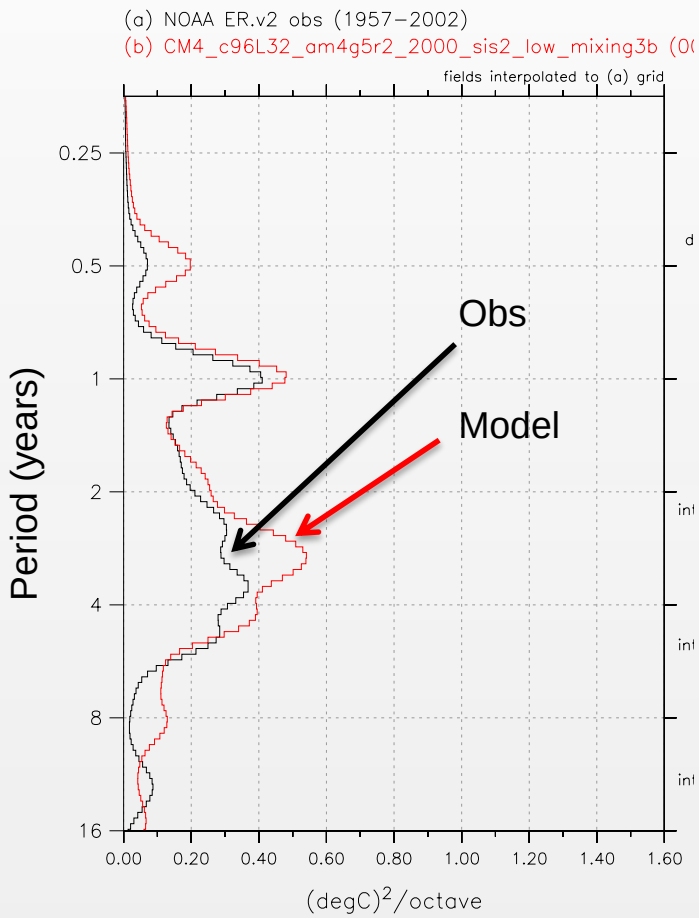
GLOBE TROPICS

RMS ERRORS
AM4 *
COMPARED TO
CMIP5
ENSEMBLE

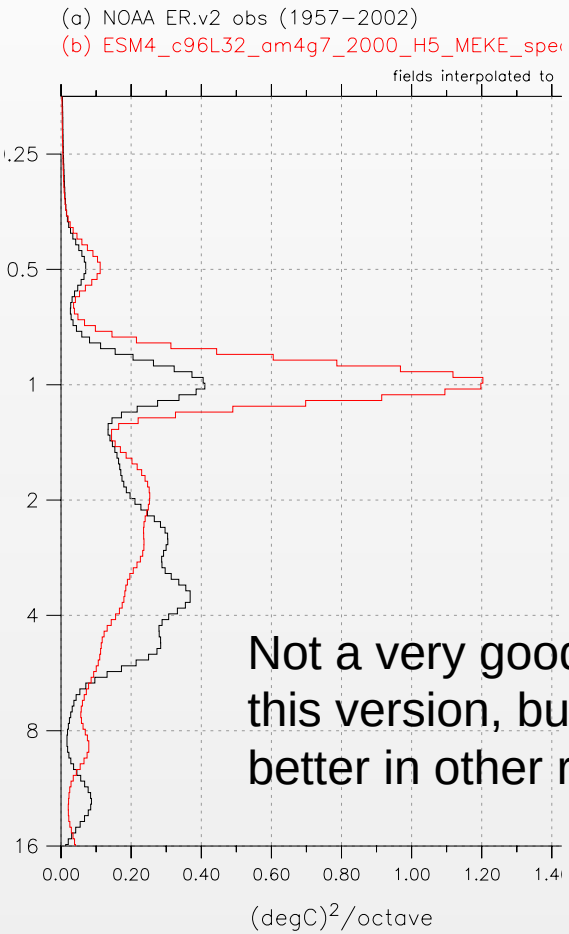
Thanks to John Krasting (GFDL)
and PCMDI

CM4 ENSO delicate

Spectrum of NINO3.4



OUR BEST VERSION



Not a very good ENSO in this version, but better in other respects

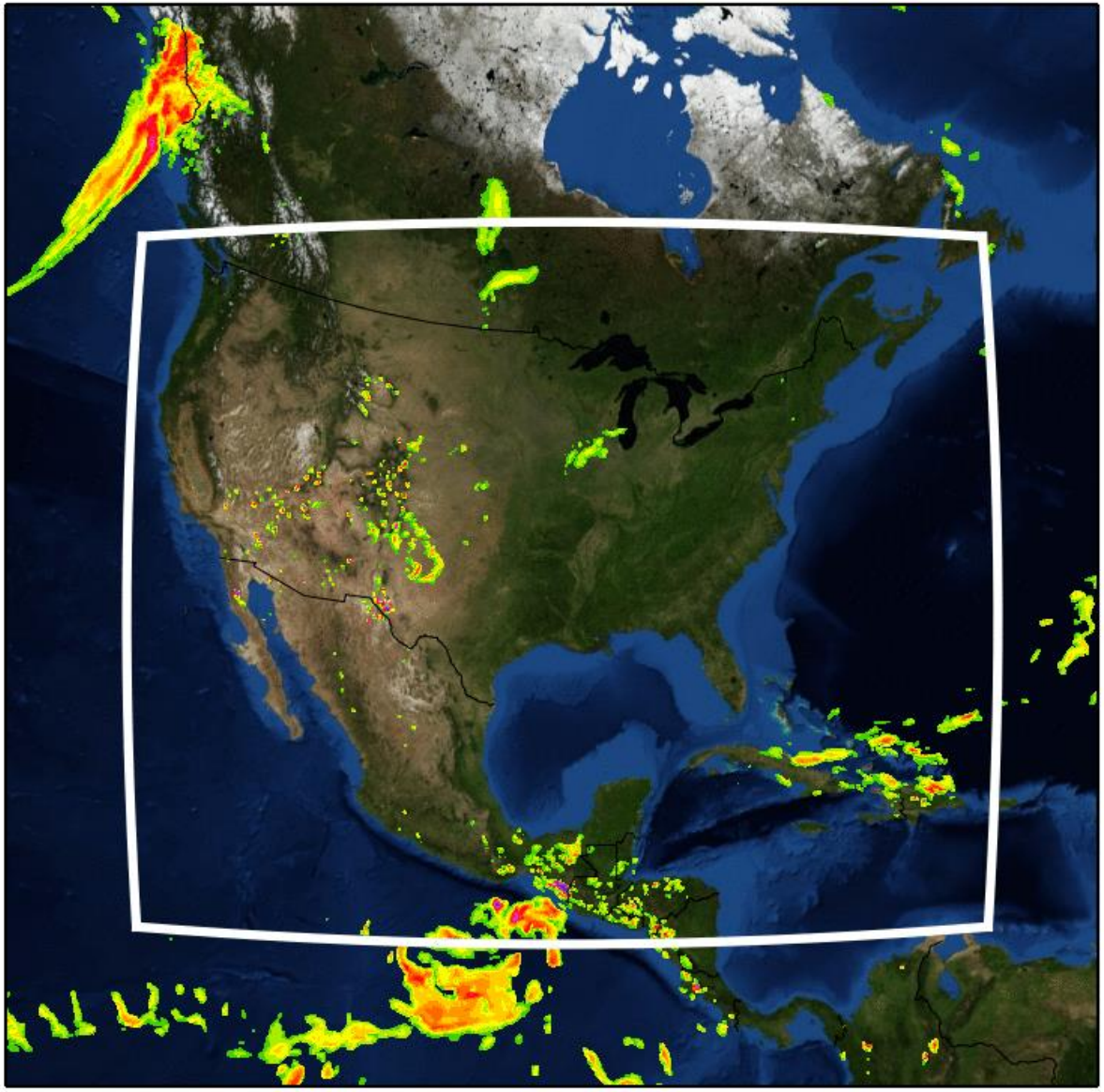
High-Resolution Atmospheric Modeling System for Weather & climate Predictions

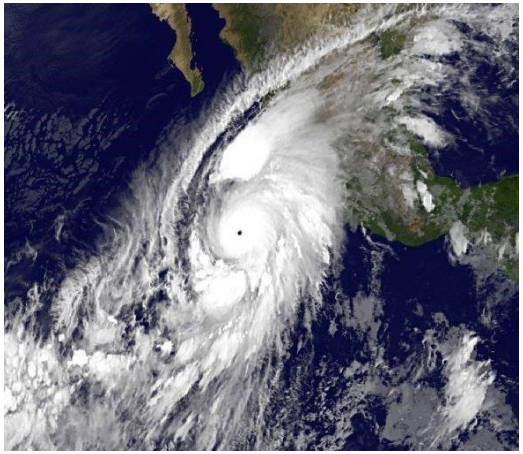
Weather ⟷ **Climate**

1. Brute-force, ultra-high-resolution, global “cloud-resolving” approach
2. Zoom-in, variable resolution, seamless regional-global approach

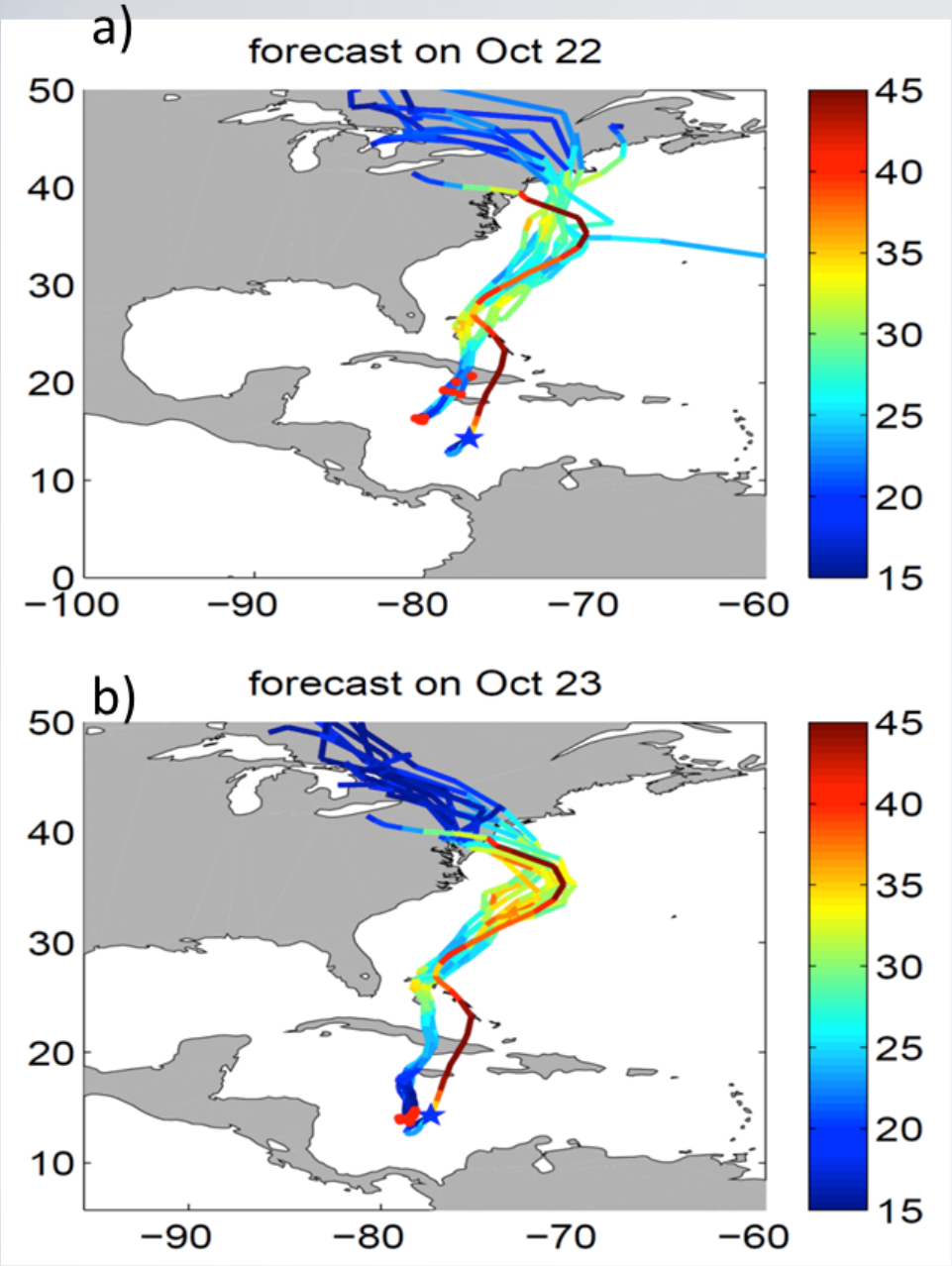
Integrated regional-global prediction with a 3-km nest hurricane Patricia (2015)

2015-10-21 01:00:00





Hurricane Patricia was the most intense tropical cyclone on record in the Western Hemisphere. It intensified from a tropical storm to a cat-5 hurricane in 24 hours.

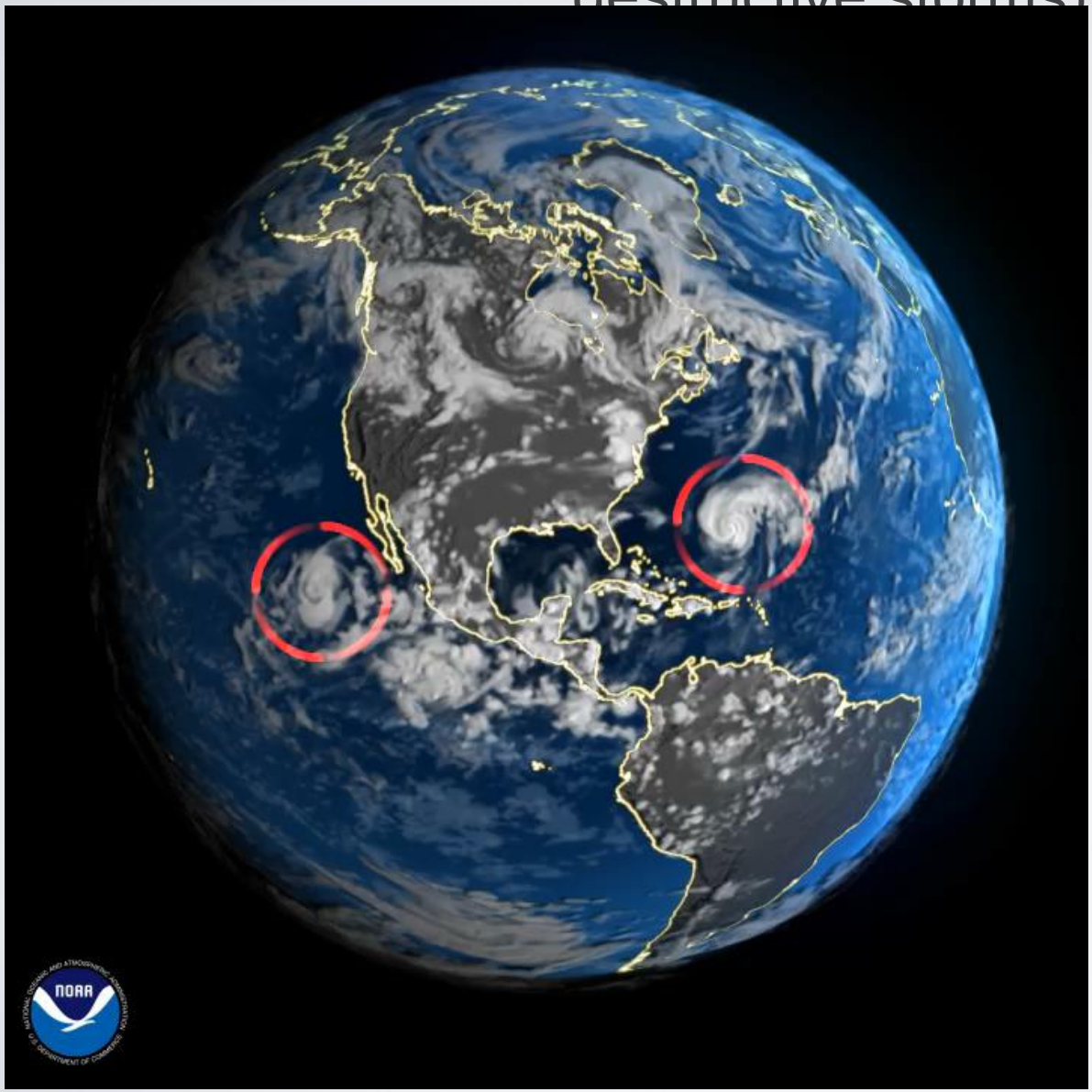


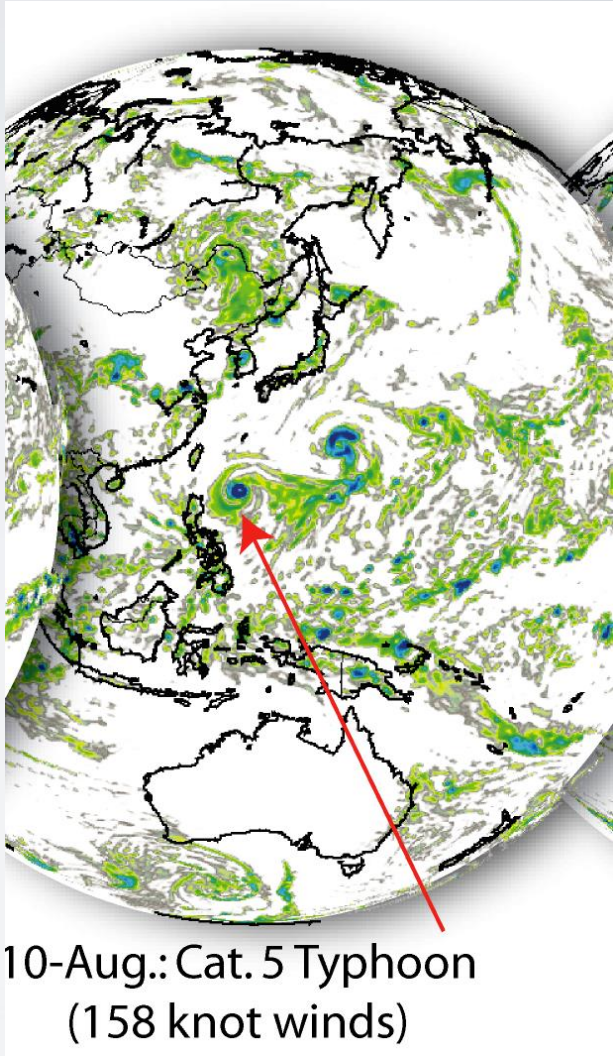
Seamless predictions: weather forecasts of Sandy with a version of FLOR

Xiang et al. (2015, MWR)

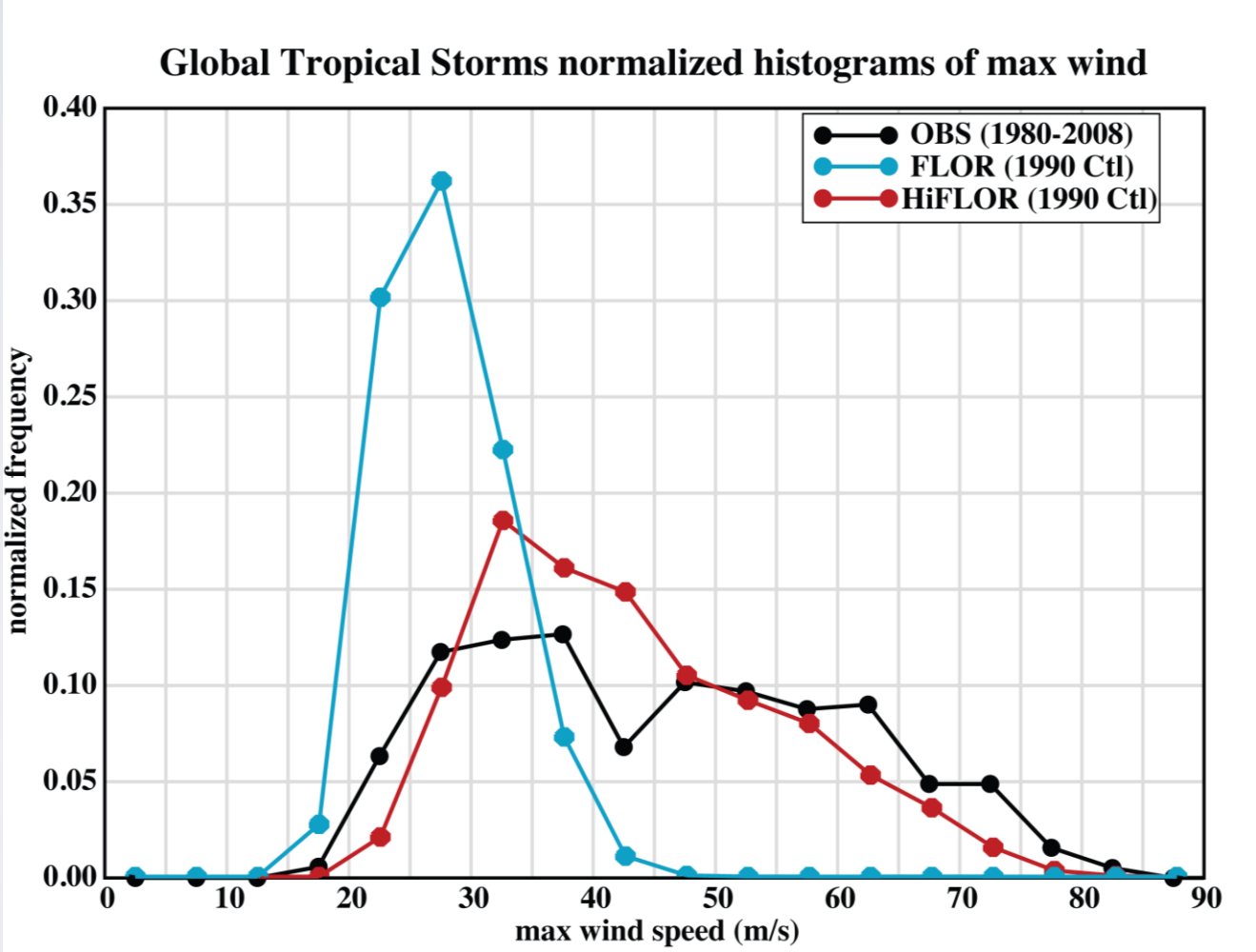
Forecasts initialized 7 & 8 days before landfall capture track

HiFLOR: FV-3 based doubling atmospheric resolution of FLOR (cost 6x) allows us model to simulate Cat. 4-5 TCs (most destructive storms)





Most impactful hurricanes tend to be strongest. Need prediction models that can capture them. New prototype model ("GFDL-HiFLOR", first run May 2014) able to simulate Cat. 4-5s



(25km FV3 atmosphere coupled to 1° MOM5)

Murakami et al. (2015, J. Clim)

GFDL HPC Status (Oakridge facility)

- FY15 90% of the allocation of 128K Cores (split on two partitions C1 & C2)
- FY16 Transitioning to new partition, C3. C1 & C2 are retired.
- C3 has 48K cores which are performing at nearly twice that of C1 & C2.
- GFDL's allocation on C3 is 80% of the machine, which equates to a 40% drop in effective computing.
- Additional HPC capacity is expected this fall (how much is still undetermined).

USGCRP and other national priority-relevant

- Weather–Climate nexus

  Seasonal prediction (NMME)

  Decadal predictability

  NGGPS Phase II tests for NWS' next-gen dy-core

  Research on subseasonal timescale phenomena and predictability

USGCRP and other national priority-relevant

- Hydrologic cycle

Stretched grid AGCM (very high res. – 10 km) over CONUS to explore interactive climate, land use and urban changes

1 km CONUS land model to explore wet and dry extremes and implications for water, snow, and carbon storage

ESM to explore vulnerability of water management systems (irrigation and impoundment) under changing climate

CPTs

- Process understanding to improve climate models

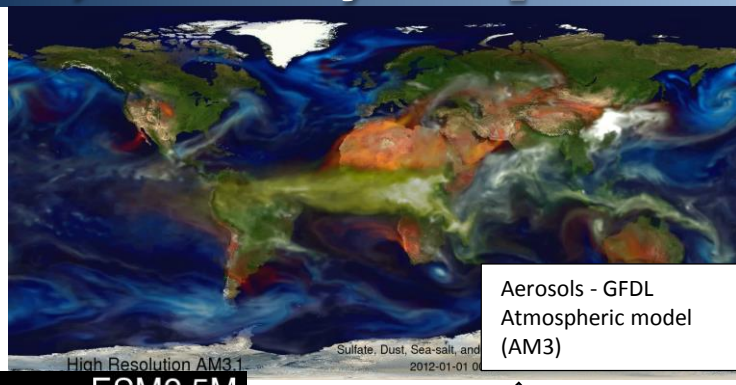
CLIVAR Workshop [October, 2015]

“Grand Challenge” topics

- “COP-21” aftermath
- Carbon and other biogeochemical cycles (e.g., Nitrogen), and interactions with the physical climate system
- Air and water quality
- Carbon (CO2, CH4): wetlands, permafrost, leaks, blue carbon
- Arctic: ESM with prognostic ecosystems including wetlands and GHG emissions

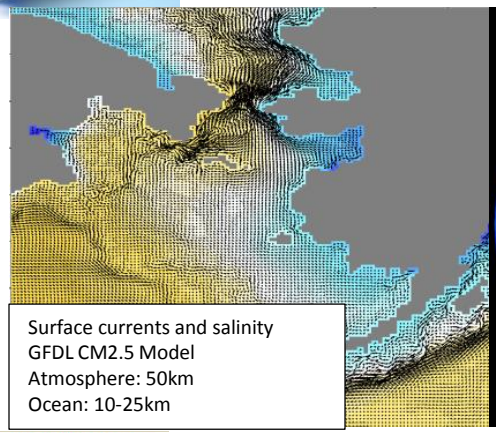
Mission-requirements-driven scientific research
[*IPCC AR5, National Assessment, and beyond*]

GFDL HiRAM Global climate model
12.5 km resolution

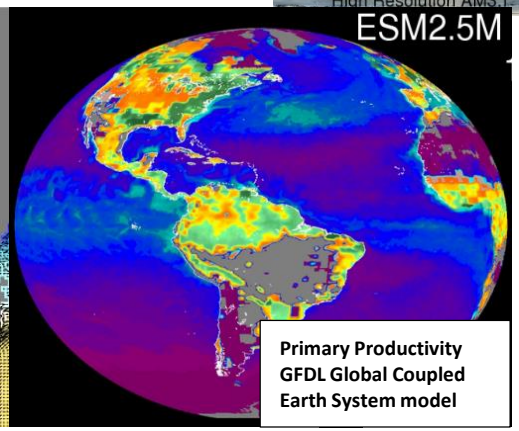


Aerosols - GFDL Atmospheric model (AM3)

Resolution

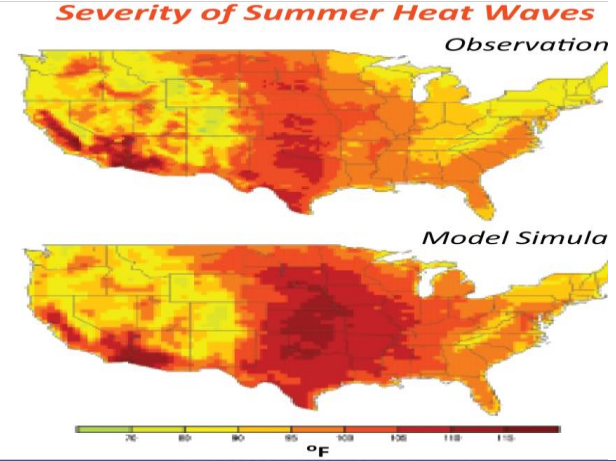


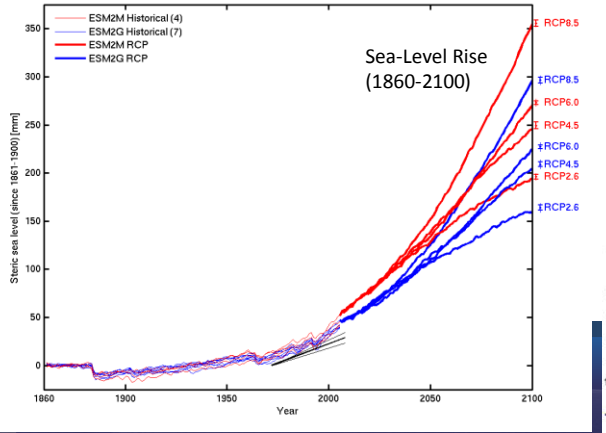
Surface currents and salinity
GFDL CM2.5 Model
Atmosphere: 50km
Ocean: 10-25km

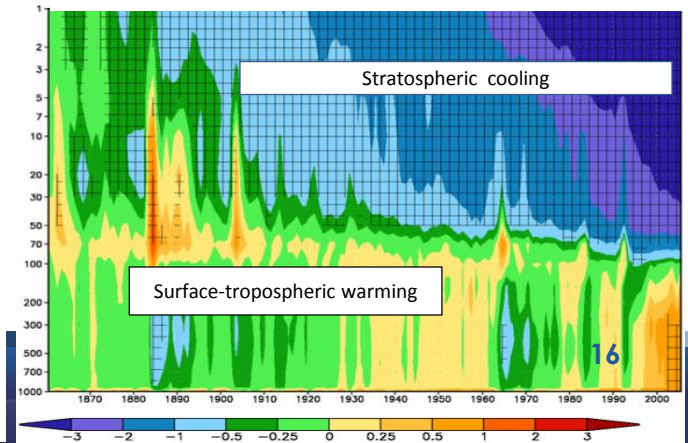


Primary Productivity
GFDL Global Coupled Earth System model

Earth System Complexity





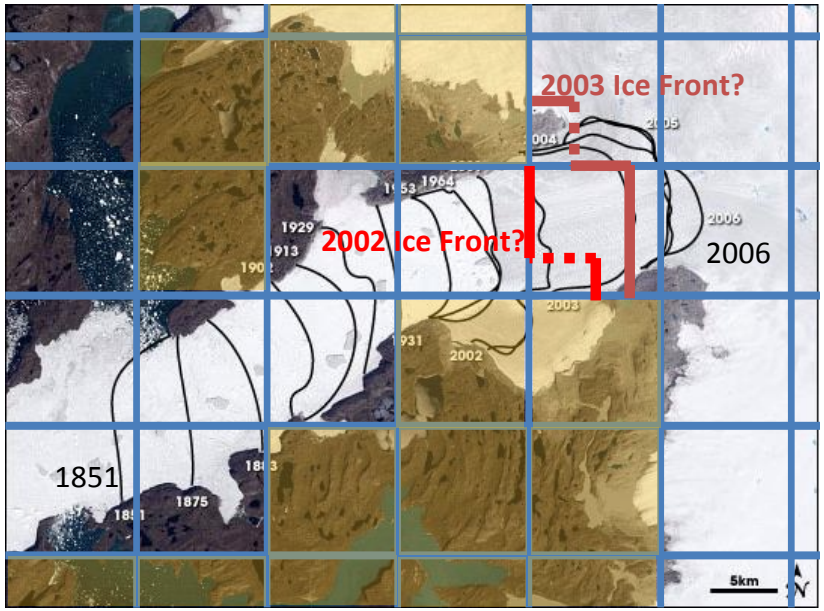


Ocean Working Group: Objectives

- **Eddying-resolution** (¼°) ocean component
  - Admit **large eddies** and **internal ocean variability**
  - Interior mixing mechanisms
  - Scale-aware param.
  - Better **resolve boundary regimes**
  - Allow dynamic **sub-ice shelf cavities**
  - Strategy:
    - z*-coordinate first
    - Hybrid coordinates later

- **Address biases** of previous models
  - **Heat uptake/sea level**
  - Processes/coupled interact$^{\underline{ns}}$: **overflows, cryosphere**

Jakobshavn & ¼° Mercator grid



GFDL family of land models (LM#)

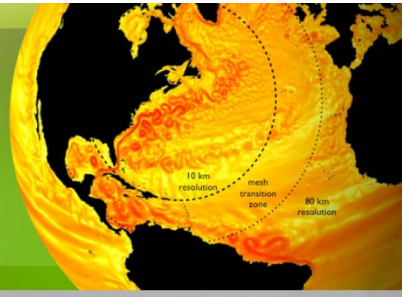
- LM2 – soil bucket with a constant stomata by biome type (Milly & Shmakin, 2002)
- LM3 – new ecosystems and hydrology
  - Dynamic vegetation, land use, C cycle (Shevliakova et al. 2009)
  - Liquid and frozen, rivers & lakes, dynamic water table (Milly et al 2014)
- Coupled C-N in veg, soils,& rivers (Gerber et al 2010, Lee et al 2014)
- Ongoing development of LM4 for CM4/ESM4
  - *Comprehensive* biogeochemistry: N, CH4, BVOCs, P …
  - Prognostic aerosols: dust, biomass burning, …
  - Sub-grid hill-slope *heterogeneity*
  - New age-height vegetation succession model LM3-PPA
  - Land-use management: fertilizers, water quality,…
  - Model-data fusion

A lot of problems ripe for S2S research!

Possible topics to investigate

- Stratospheric-tropospheric coupling - NAO/AO predictability, links with tropical forcing, etc.
- MJO and associated impacts (blocking, atmospheric rivers, tropical cyclones, etc.)
- Predictability and processes of atmospheric blocking
- Subseasonal predictions of Arctic sea ice
- Subseasonal tropical cyclone predictability/forecasting
- Predictability of tracers*, ecosystems, diseases and disease vectors
- Role of radiatively active species on S2S predictability
- Role of the ocean in predictability**

ACME
Accelerated Climate Model for Energy



ACME Update for USCMS 2016

David C. Bader
ACME Council Chair

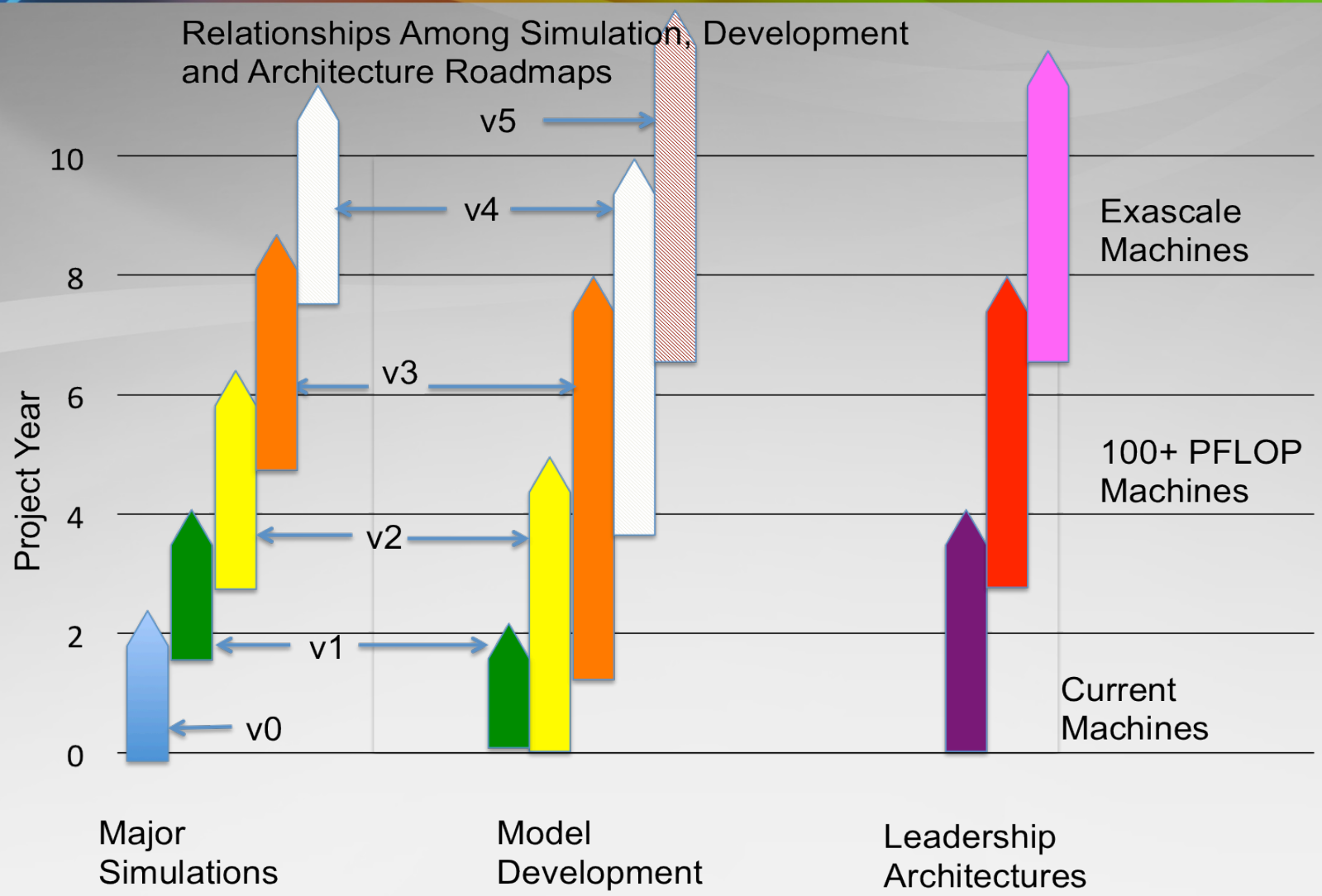
March 9, 2016

Why ACME?

The Accelerated Climate Modeling for Energy Project is an ongoing, state-of-the-science Earth system modeling, simulation, and prediction project that optimizes the use of DOE laboratory resources to meet the science needs of the nation and the mission needs of DOE.

A DOE Model for the DOE Mission on DOE computers.

ACME Roadmap

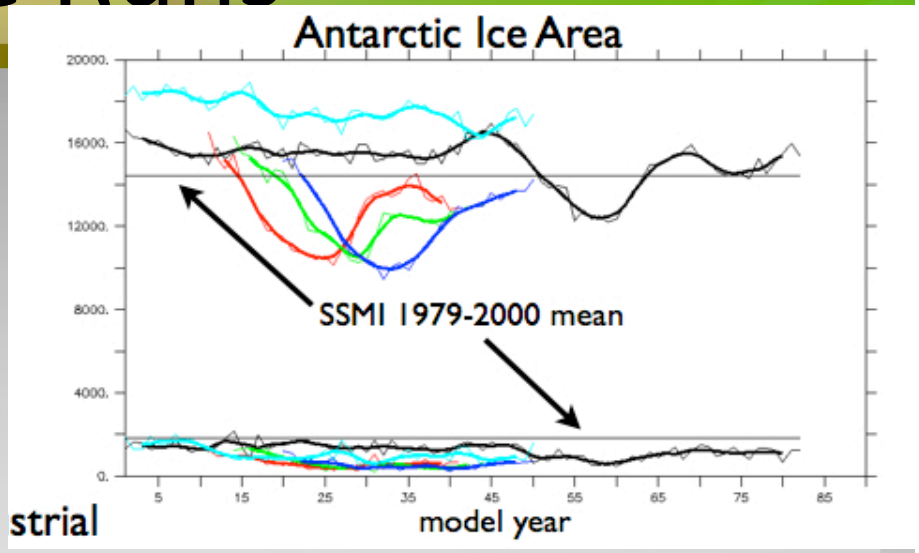


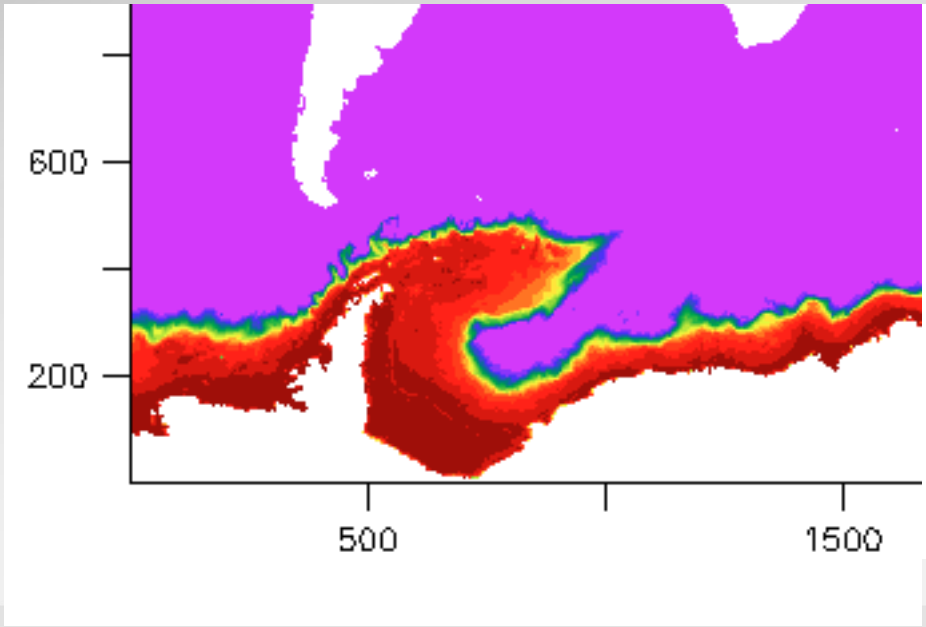
Changes Since Last Year

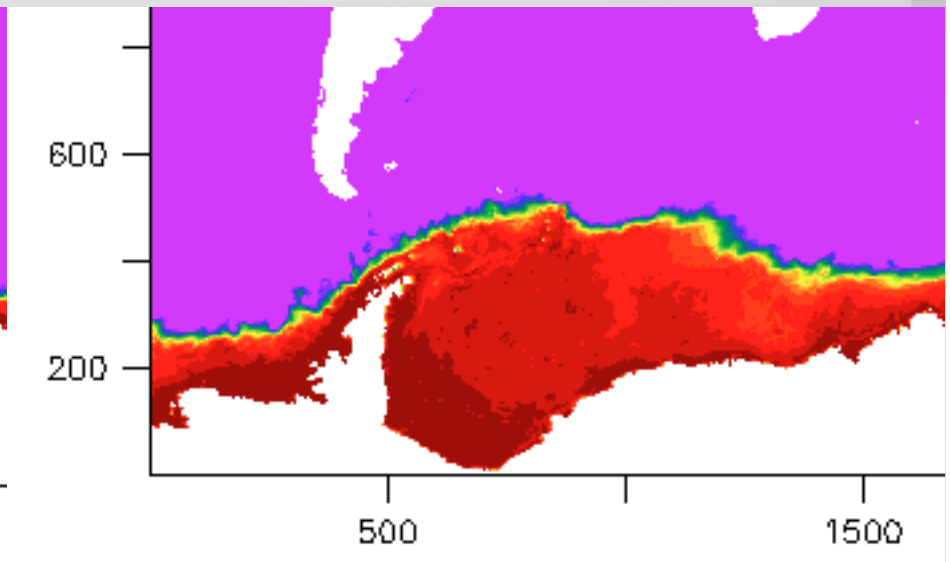
- Bill Collins Accepted a Division Leader Appointment at LBNL and Stepped Down as Chief Scientist
- Ruby Leung is New Chief Scientist
- Several Changes in Group Leaders
- 2 Successful “All-hands” project meetings

Baseline Runs

- Completed 97+ years of 1850 high resolution coupled simulation
- Completed 3 member ensemble using approximate present day forcing

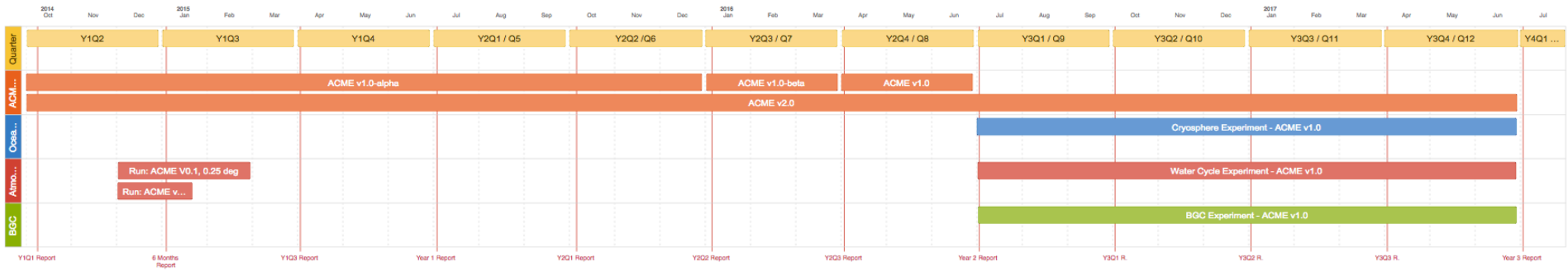






3-year Roadmap Main Points

- **Complete construction of v1-alpha** EOY 2015
  - 1 configuration, 2 resolutions, 2 levels of BGC activation
- **Coupled system tuning** Jun 2016
- **Start major experiments with ACME v1.0 code base** Jul 2016
  - The 3 experiments need not activate same functionality
  - But they should all share the same code base, with active functionality controlled by run-time switches
- **All major 3 year experiments completed** Jul 2017

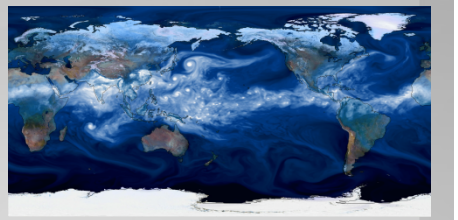


ACME
Accelerated Climate Model for Energy

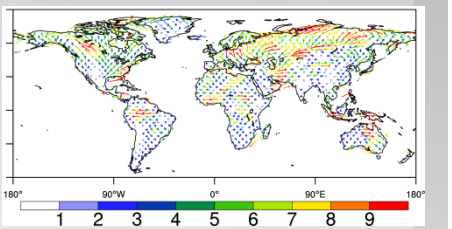
Questions?

Climate Science Drivers

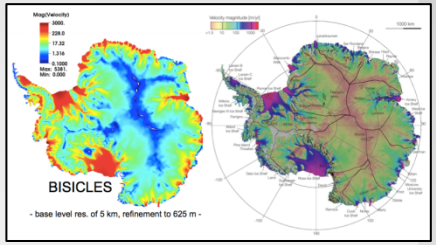
Water cycle: How do the hydrological cycle and water resources interact with the climate system on local to global scales?



Biogeochemistry: How do biogeochemical cycles interact with global climate change?

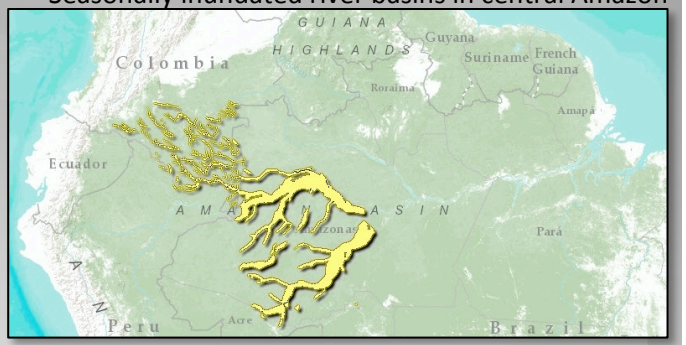


Cryosphere: How do rapid changes in cryospheric systems interact with the climate system?

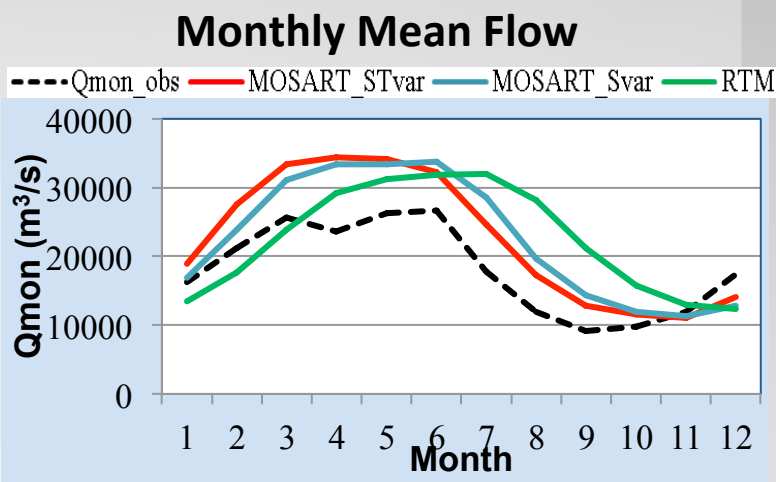


Water Cycle Experiment Strategy

Seasonally inundated river basins in central Amazon

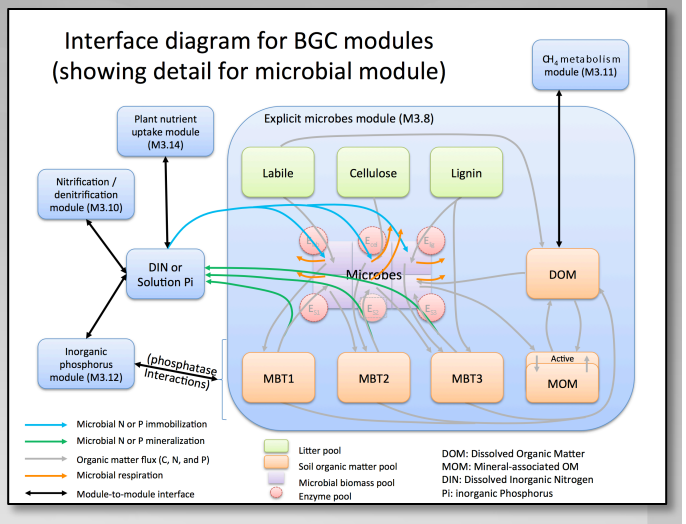


- **Explore the role of physical processes and parameterization in climate models influencing river flow and fresh water supply.**
- **Produce accurate simulation of river flow for major river basins: Mississippi, Amazon, Ganges**
- **These basins represent very different:**
  - Climatic and hydrologic regimes
  - Large-scale ocean-atmosphere interactions
  - Regional land-atmosphere interactions
  - Local human activities

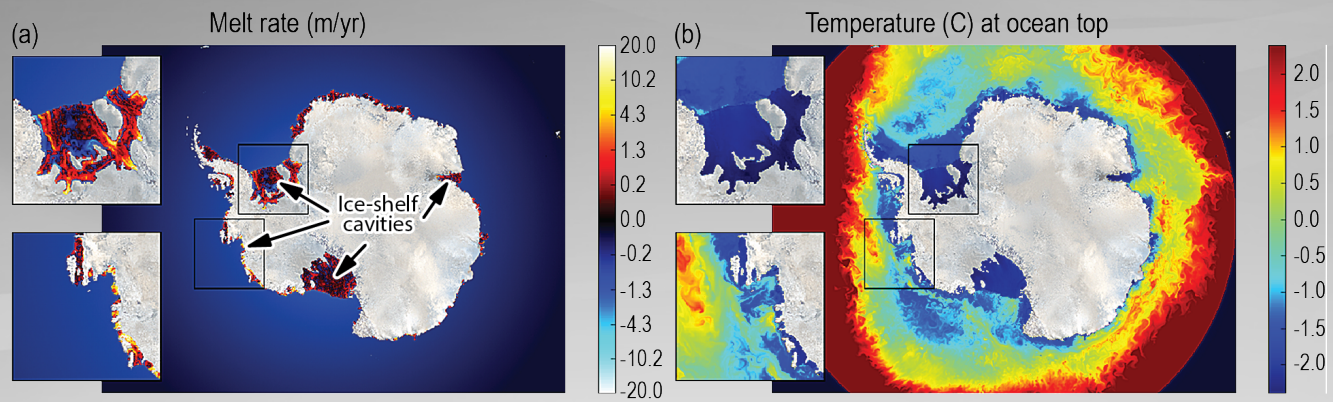


Land BGC 3-year Experiment

- **Evaluate role of nutrients on constraining ecosystem processes.**
- **Define two basic model structures to be used:**
  - Case 1: Based on CLM4-CNP
  - Case 2: CLM4.5-BGC
- **Begin model development for Case 1 and Case 2**
- **Define simulation scenarios (e.g., C4MIP, C, CN, CNP)**
  - Evaluate computational needs for coupled experiments
- **Benchmarking approaches**
  - Collaborative with the Land Benchmarking team



Cryospheric Experiments



Near-term: Could a dynamical instability in the Antarctic Ice Sheet be triggered within the next 40 years?

Simulations: Simulation plan focuses on

1. Rigorous testing of the ice sheet and its interactions with the atmosphere, underlying continent, ocean, and sea ice
2. Transient fully coupled simulation from 1970 to 2050.

NASA'S GMAO - UPDATES

Steven Pawson

US Climate Modeling Summit: March 9, 2016

NASA's observations in Earth System models, spanning timescales of days to decades

GMAO Themes

- Weather Analysis and Prediction
- Seasonal-to-Decadal Analysis and Prediction
- Reanalysis
- Global Mesoscale Modeling
- Observing System Science

- These (non-orthogonal) themes span GMAO's main focus areas
- Strong emphasis on NASA's Earth Observations (use, support, planning)
- GEOS-5 research uses the same systems as used for product generation
- GEOS-5 is a modular system, encompassing many Earth System components

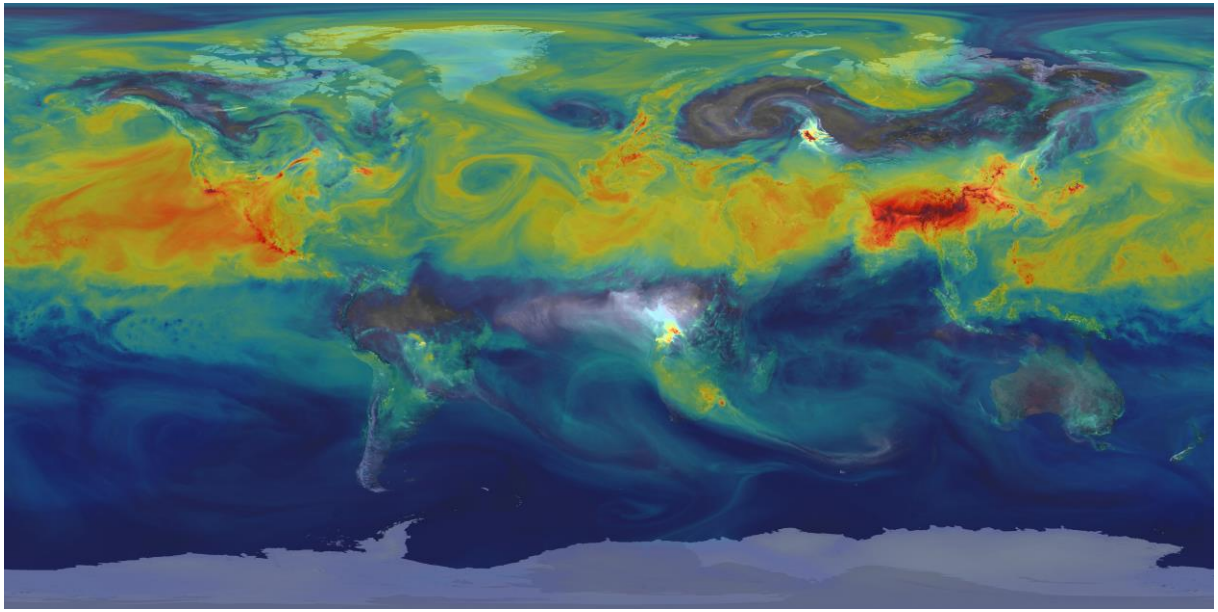
Seamlessness

- Modular model structure:
  - Timescales: sub-diurnal to seasons and decades
  - Space scales: “few kilometer” to about 100-km grids, global
- Complexity spans many Earth System processes:
  - Atmospheric “weather” system includes aerosols, ocean skin layer
  - Coupled “Seasonal system” – investigations of aerosol, chemistry, land interactions (driven by NASA observations)
  - Chemistry-climate studies include ocean feedbacks
- Seamless requirements:
  - Ensemble-based weather analysis system
  - Emergence of sub-seasonal component alongside seasonal

Global Mesoscale Modeling

- Pushing the frontiers:
  - 7-km GEOS-5 Nature Run (7-km G5NR) completed in 2014
  - More than 4Petabytes of data distributed via DataPortal at NCCS
  - Major documentation/evaluation completed
- More than the weather:
  - 7km-G5NR includes aerosols and carbon: great resource
  - Planning high-resolution simulations with full chemistry
  - Plans for higher resolution and more complexity
- The one-day-per-day standard:
  - The simulation that fills the computer and runs at one day per day is the target operational resolution for circa 10 years down the road!

Global CO_2 field from the 7km-G5NR (June 21, 2006)

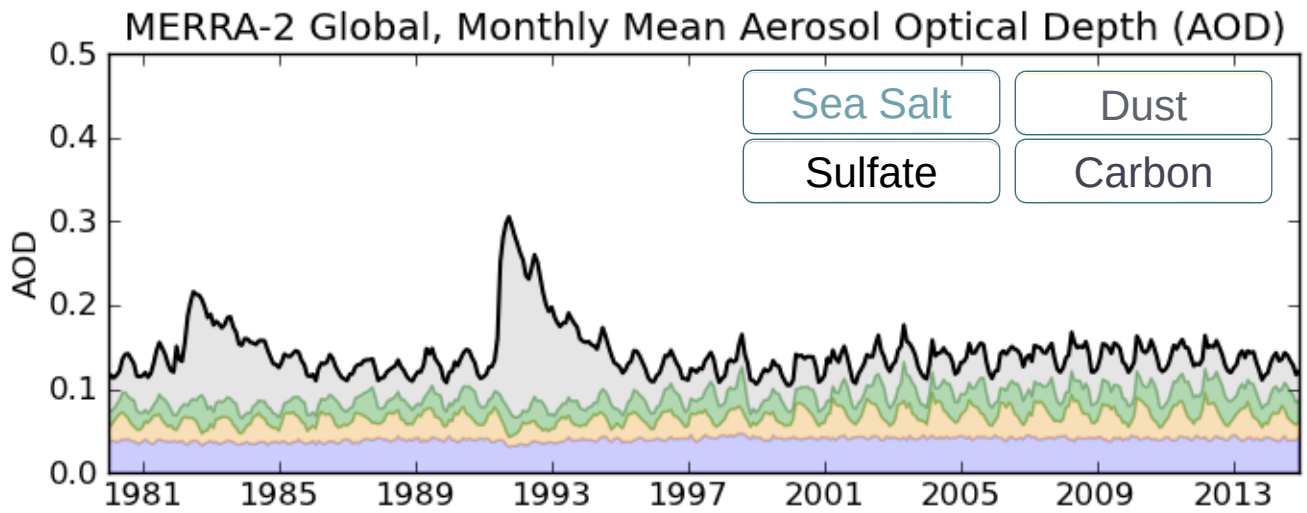


- Demonstrates fidelity for constituent simulation alongside meteorology
- Opens pathways towards non-meteorological OSSEs, including studies for active CO_2 sensors
- Pathway towards high-resolution air-quality modeling (GEOS-Chem)

Reanalysis with GEOS-5

- MERRA-2 was released in late 2015:
  - Replaces MERRA
  - File specs and evaluation documents released
  - Evaluation documents are close
- Innovative Earth System Aspects of MERRA-2:
  - MERRA-2 includes a coupled aerosol analysis
  - Enhanced representations of cryospheric processes
  - Representation of the middle atmosphere
- Pathways for the future:
  - 10-15km resolution atmospheric/land product, focused on Earth system, for the post-2000 period (~2018 timeframe) [NASA EOS]
  - ~25-km coupled product, 1980-2020 (~2020 timeframe) [climate]

MERRA-2: on the Path to Earth System Reanalysis



As well as using new meteorological data types and an updated GEOS-5 system, MERRA-2:

- Includes a coupled aerosol analysis
- Has a more realistic middle atmosphere
- Improves the representation of polar climate

Meaningful relationships

- NASA Agency level:
  - Close relationship with NCCS
  - Strategic collaborations with GISS (e.g., MATRIX aerosols)
  - Mature and emerging links to NASA's data teams
- Other agencies:
  - NOAA NCEP: GSI assimilation methodology
  - NOAA GFDL: MOMx oceans, FV3 core
  - DoE: CICE sea ice model
- Results of competed projects from NASA (MAP):
  - NCAR: two-moment microphysics
  - NCAR/DoE: Dynamic vegentation/phenology
  - PNNL/university: MAM aerosol option

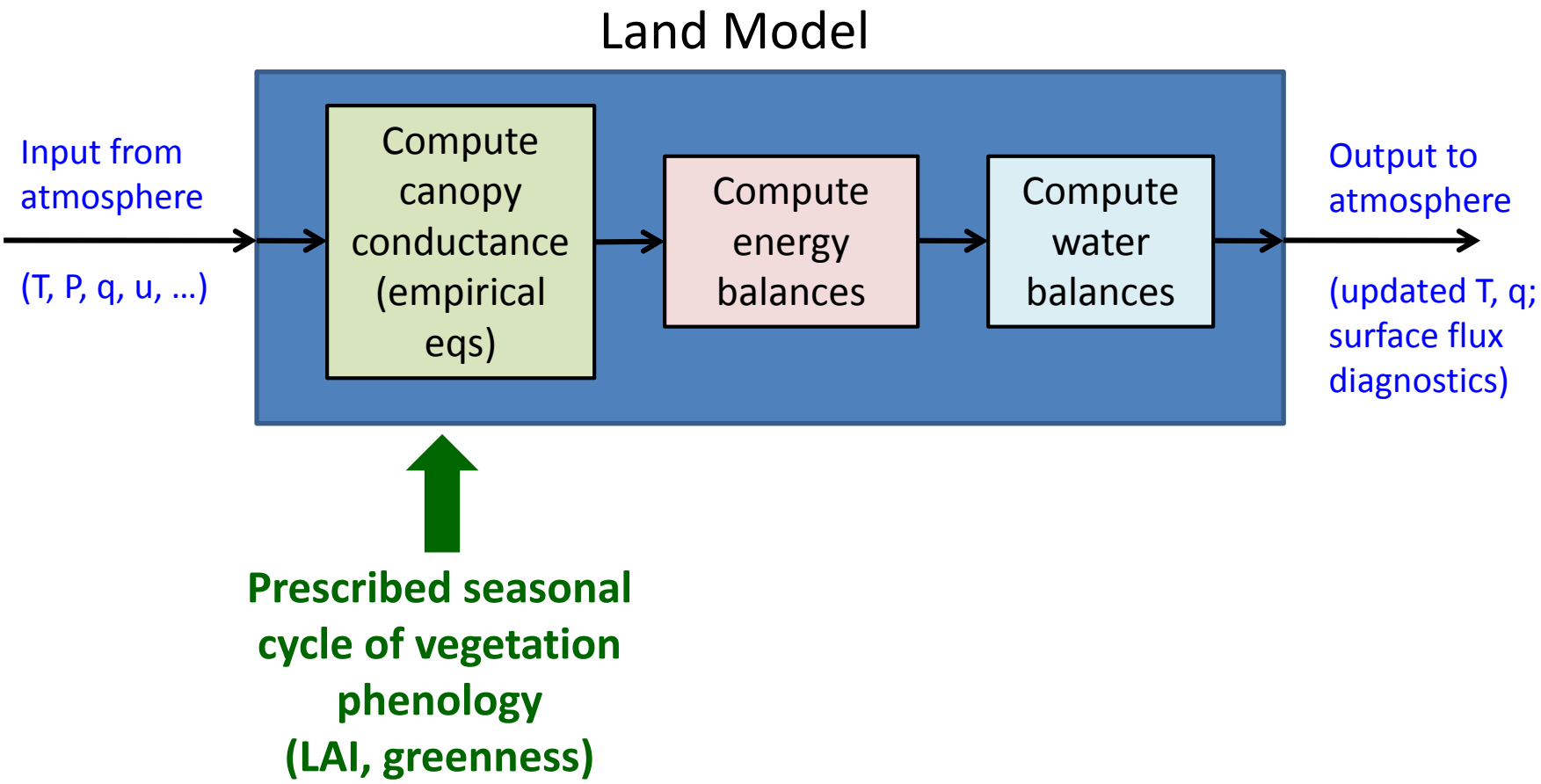
Will GMAO contribute to CMIP-6 using GEOS-5?

- Possibly!
- Coupled GEOS-5 configurations:
  - Current: MERRA-driven, 1° atmosphere, 0.5° MOM-4L40 ocean
  - 2016: MERRA-2-driven, 0.5° atmosphere, 0.5°L40 MOM-5 ocean
  - 2018-2020: 0.25° atmosphere, 0.25° MOM-6L50 ocean: ensemble-based analysis with coupling
- This latter coupled system would be suited for CMIP-6:
  - Thorough evaluation of coupled model used for reanalysis
  - Part of CMIP-6 deck is required for our own evaluations
  - Supplements NASA's role in national climate activities
  - Provides NASA with a viable tool for climate-mission planning

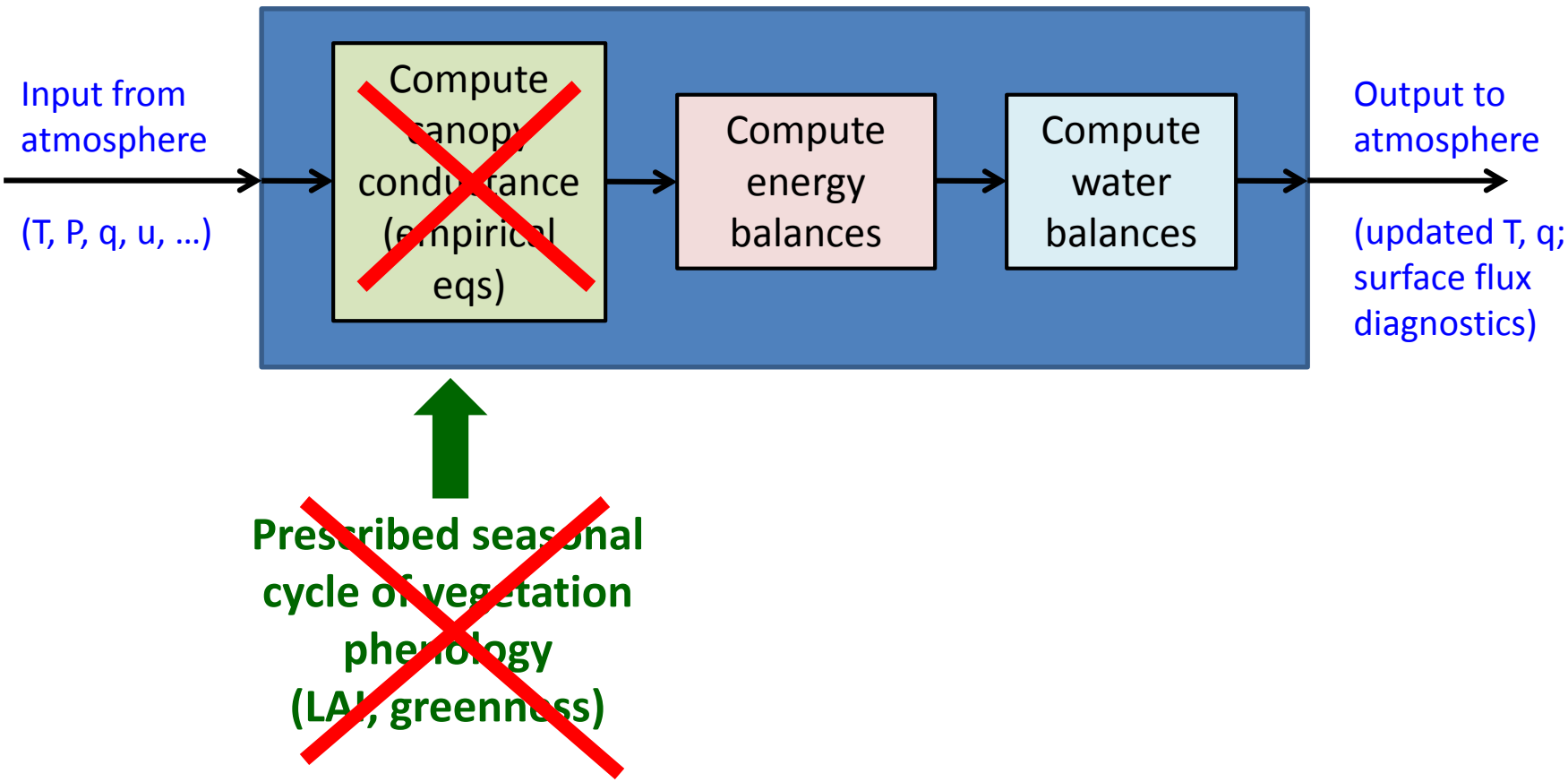
Linking the Carbon, Water, and Energy Cycles at the Land Surface: Some Recent GEOS-5 Efforts

Randal Koster

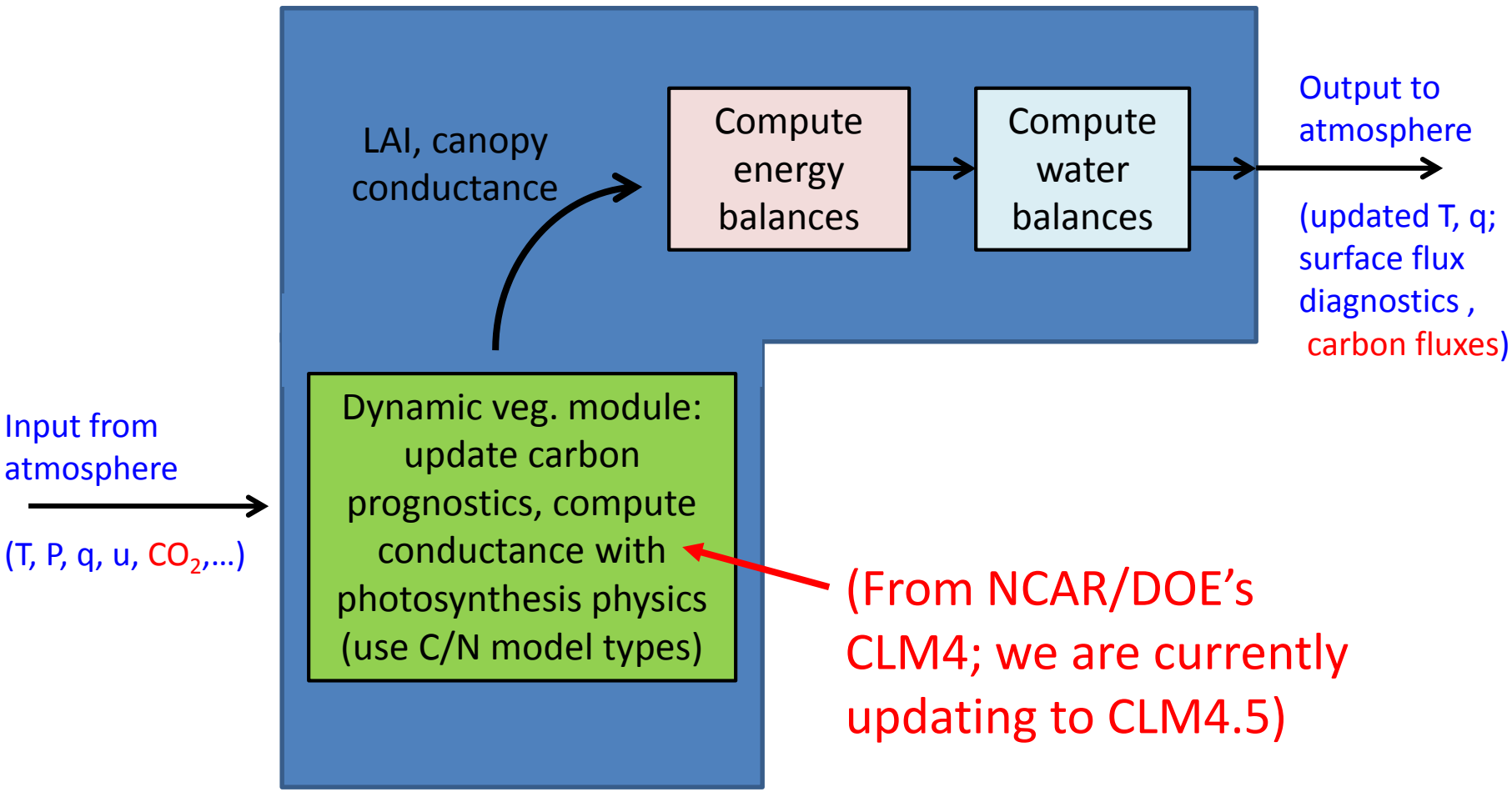
Original model set-up (MERRA, GEOS-5)



Land Model

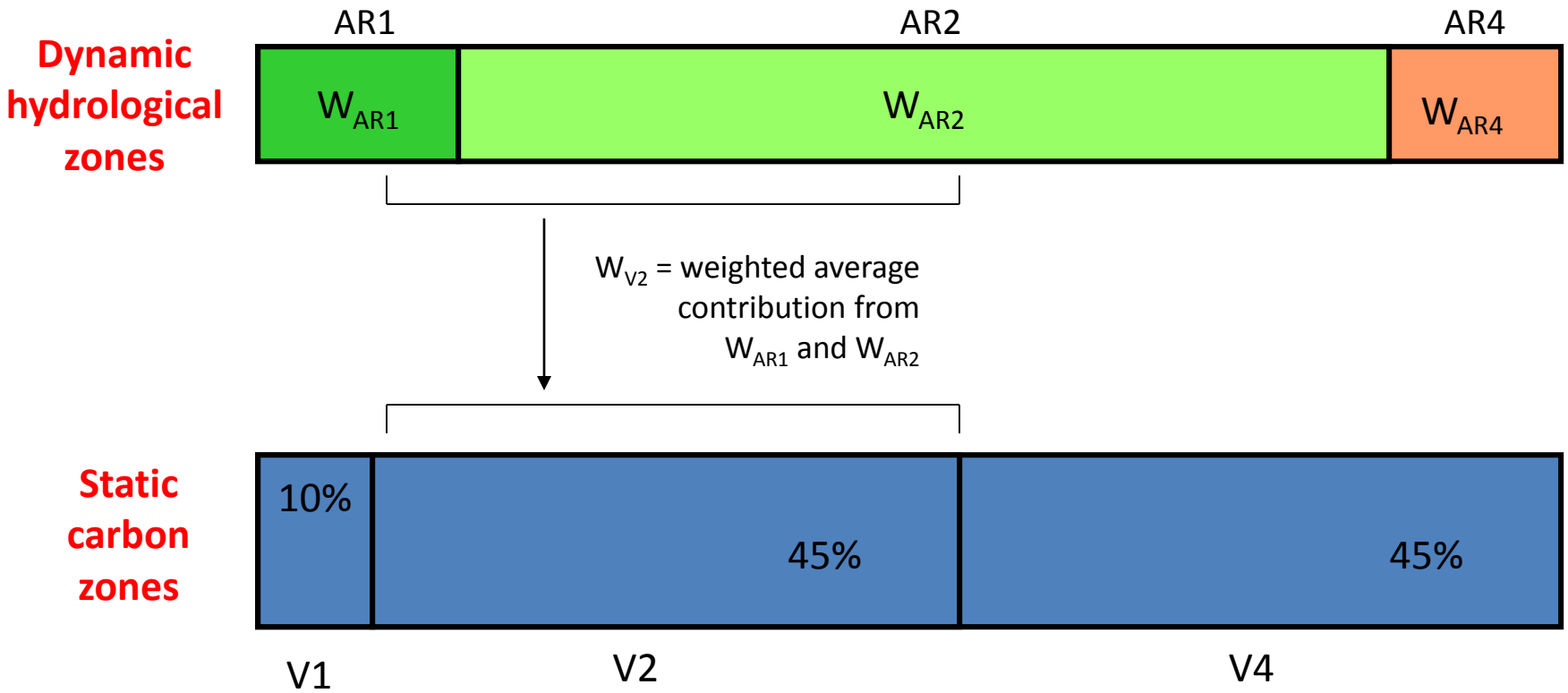

Input from atmosphere
(T, P, q, u, …)
Compute canopy conductance (empirical eqs)
Compute energy balances
Compute water balances
Output to atmosphere
(updated T, q; surface flux diagnostics)
Prescribed seasonal cycle of vegetation phenology (LAI, greenness)

Land Model


LAI, canopy conductance
Compute energy balances
Compute water balances
Output to atmosphere
(updated T, q; surface flux diagnostics , carbon fluxes)
Input from atmosphere
(T, P, q, u, CO_2,…)
Dynamic veg. module: update carbon prognostics, compute conductance with photosynthesis physics (use C/N model types)
(From NCAR/DOE's CLM4; we are currently updating to CLM4.5)

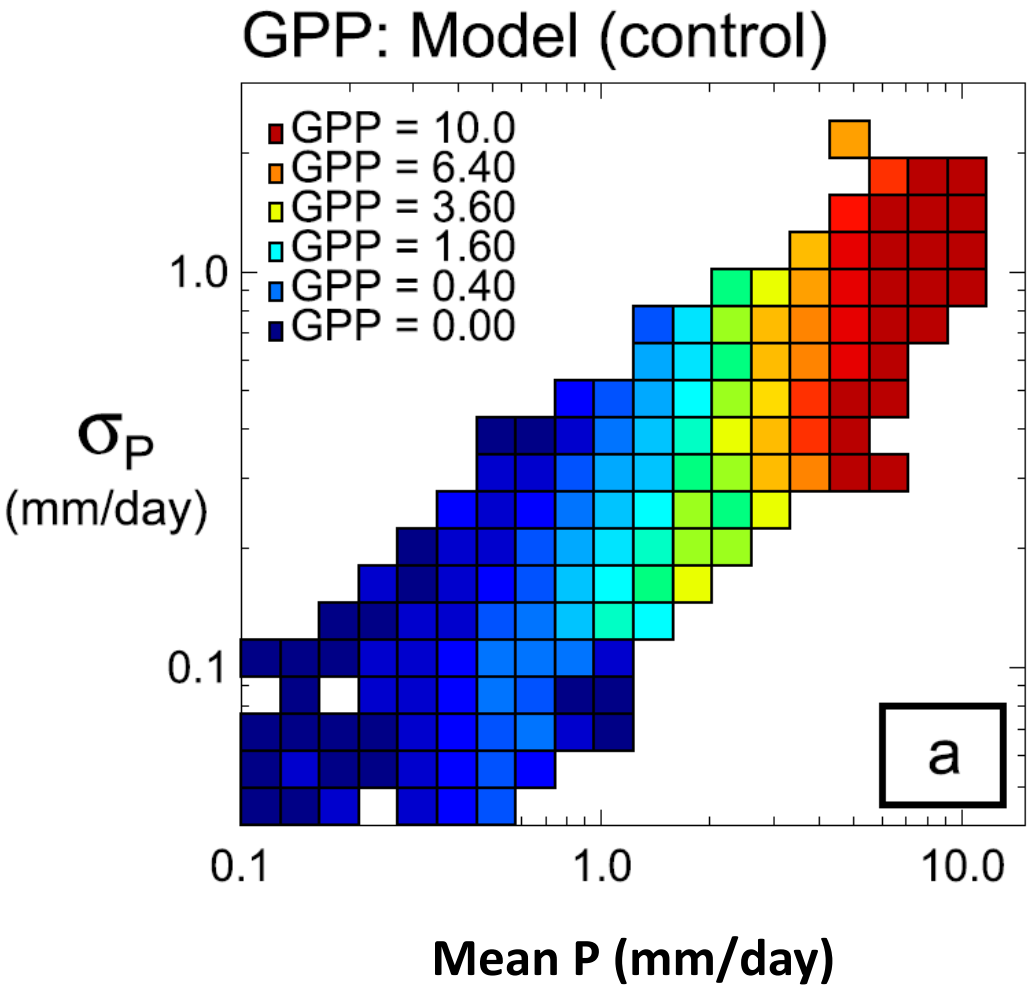
Additional feature in our implementation:

Catchment is separated into three non-dynamic sub-areas (10%, 45%, 45%); independent carbon states are saved in each.

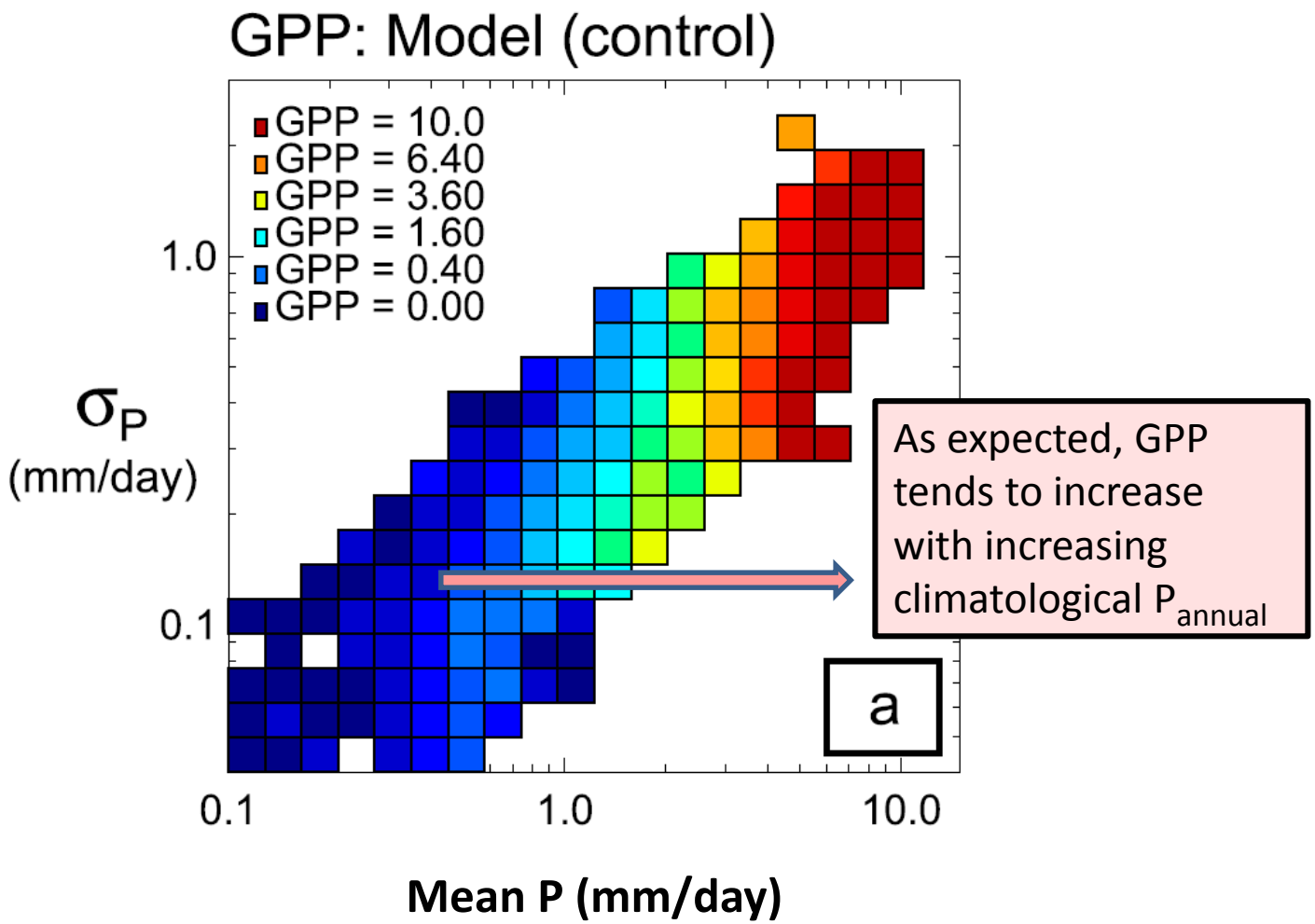


This breakdown allows the modeling of topographical impacts on vegetation.

One (offline) global study: Impact of precipitation means and variability on GPP



One (offline) global study: Impact of precipitation means and variability on gross primary productivity (GPP)



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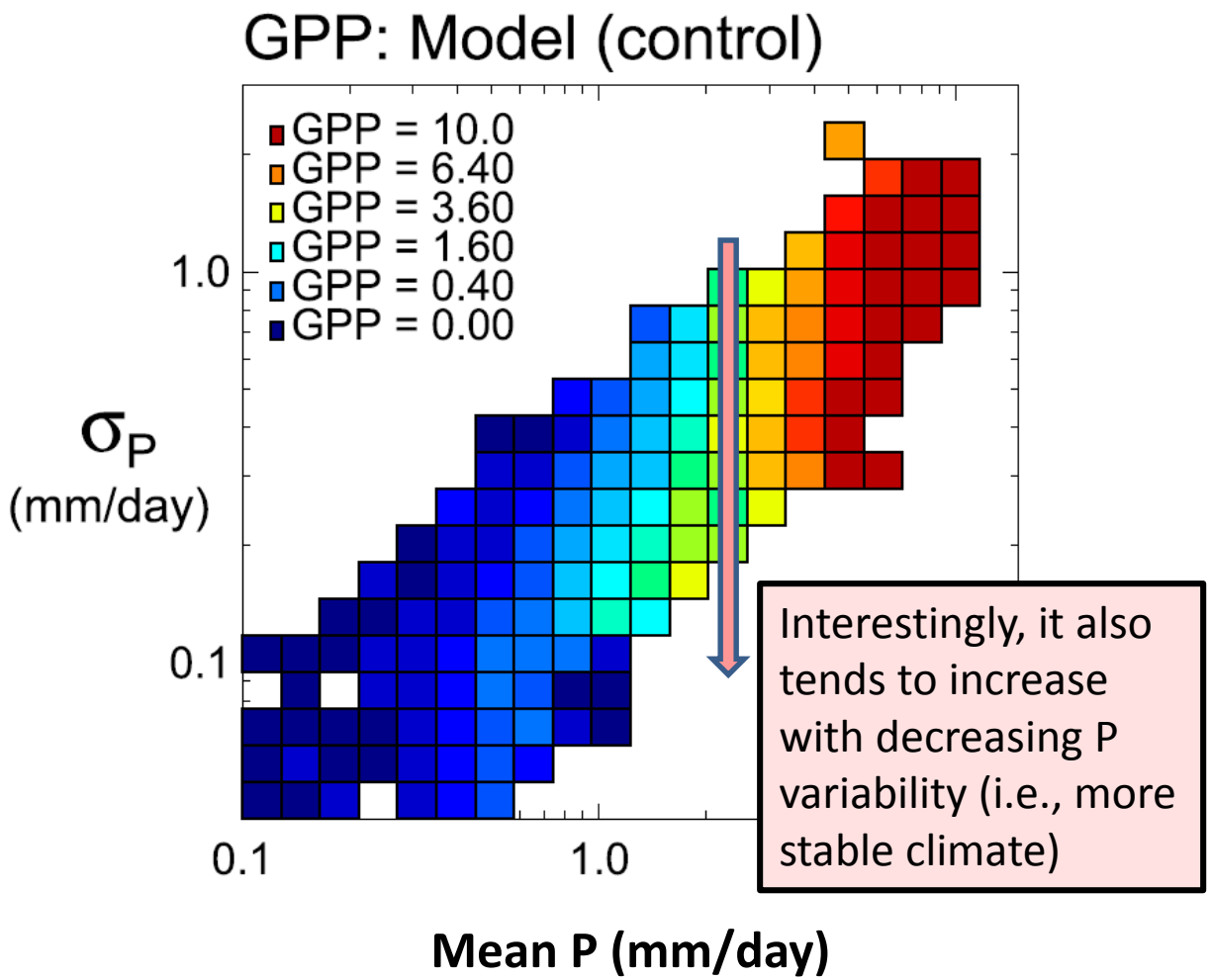

Potential Sources of Monthly Forecast Skill

Source	Time scale	Utilized in NASA GEOS-5 system?
Atmospheric quantities	Days - weeks	✔
Ocean heat content	Months - decades	✔
Soil moisture	Weeks - months	✔
Vegetation phenology	Weeks – years?	Not yet; explored here

*Also snow, soil heat content, stratospheric state, sea ice…

Experiment Design

Three suites of monthly, 21-member forecasts covering May, June, July and August of 1979-2010. AGCM: 2.5°×2°, with persisted SST and sea ice anomalies:

- **Experiment OA**: "Ocean-Atmosphere". Initial atmospheric and ocean conditions differed between forecasts, whereas soil moisture and vegetation prognostic variables were maintained at (seasonally-varying) climatological values determined from an offline simulation.

  Predictability and skill derived only from atmosphere and ocean initial conditions (ICs)

- **Experiment OAW**: "Ocean-Atmosphere-Soil Moisture". Same as Experiment OA, but with soil moisture no longer prescribed, and with its initial conditions set to observations-based values from the offline simulation discussed above.

  Predictability and skill derived from atmosphere, ocean, and soil moisture ICs

- **Experiment OAWV**: "Ocean-Atmosphere-Soil Moisture-Vegetation". Same as experiment OA, but with both soil moisture and vegetation state no longer prescribed, and with both sets of initial conditions set to observations-based values from the offline simulation.

  Predictability and skill derived from atmosphere, ocean, soil moisture, and vegetation ICs

Experiment Design

Three suites of monthly, 21-member forecasts covering May, June, July and August of 1979-2010. AGCM: 2.5°×2°, with persisted SST and sea ice anomalies:

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Compute skill from each experiment; subtract to isolate impact of soil moisture ICs on skill.

Predictability and skill derived only from atmosphere and ocean initial conditions (ICs)

Predictability and skill derived from atmosphere, ocean, and soil moisture ICs

Predictability and skill derived from atmosphere, ocean, soil moisture, and vegetation ICs

Experiment Design

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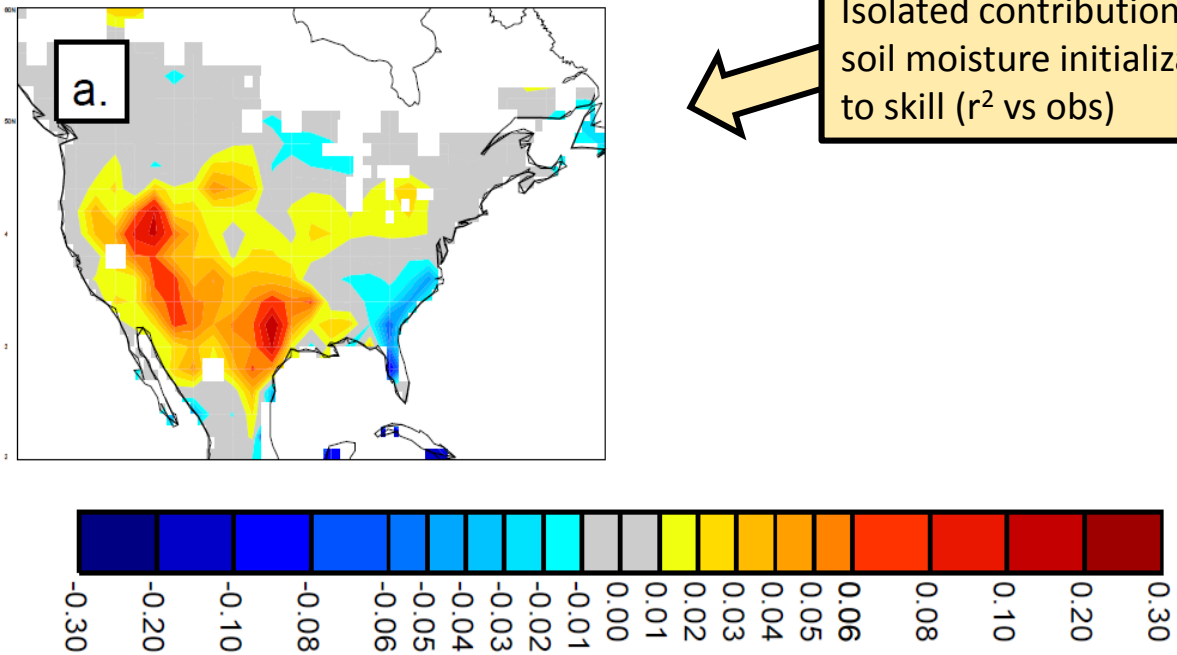
Predictability and skill derived <u>only</u> from atmosphere and ocean initial conditions (ICs)

Predictability and skill derived from atmosphere, ocean, and soil moisture ICs

Predictability and skill derived from atmosphere, ocean, soil moisture, and vegetation ICs

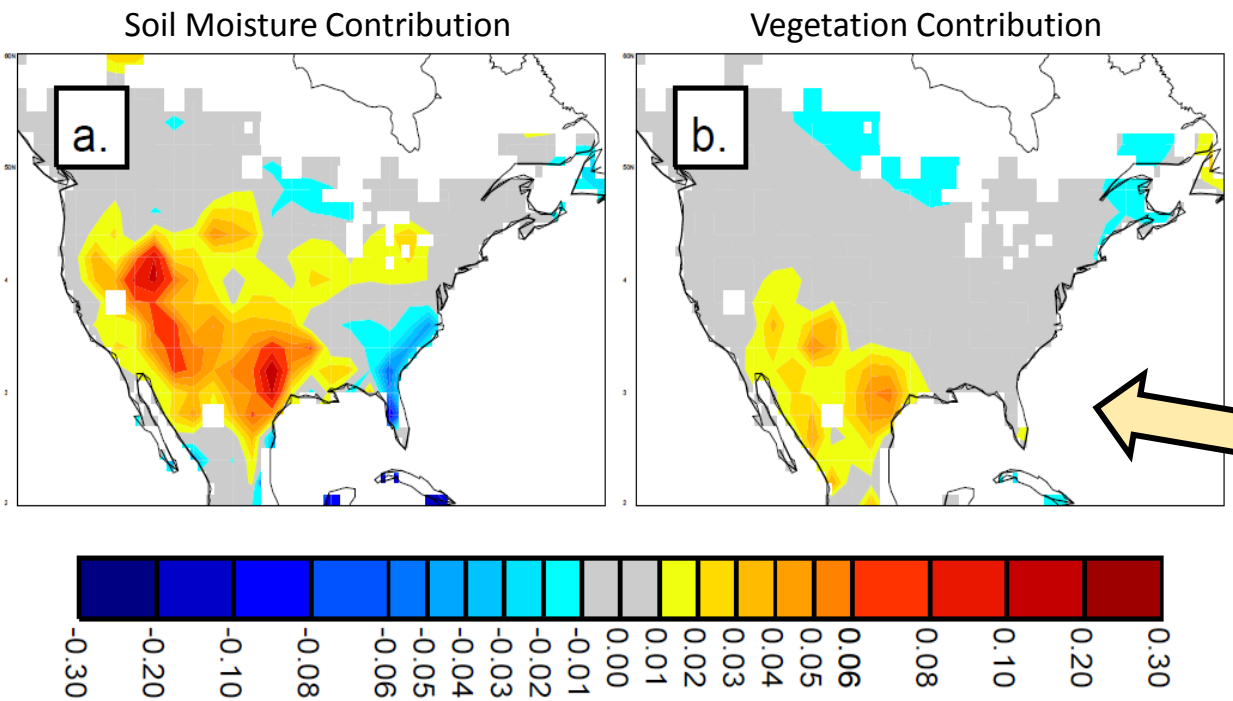
Results: Forecast of Monthly 2-m Air Temperature

Soil Moisture Contribution



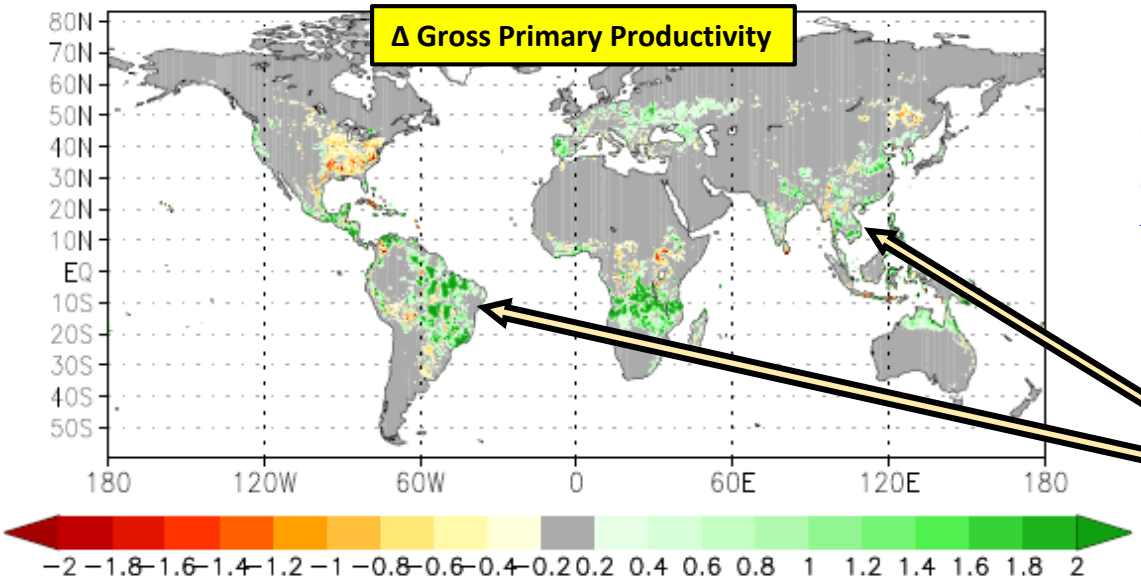
Isolated contribution of soil moisture initialization to skill (r^2 vs obs)

Results: Forecast of Monthly 2-m Air Temperature



Corresponding contribution of vegetation dynamics/ initialization

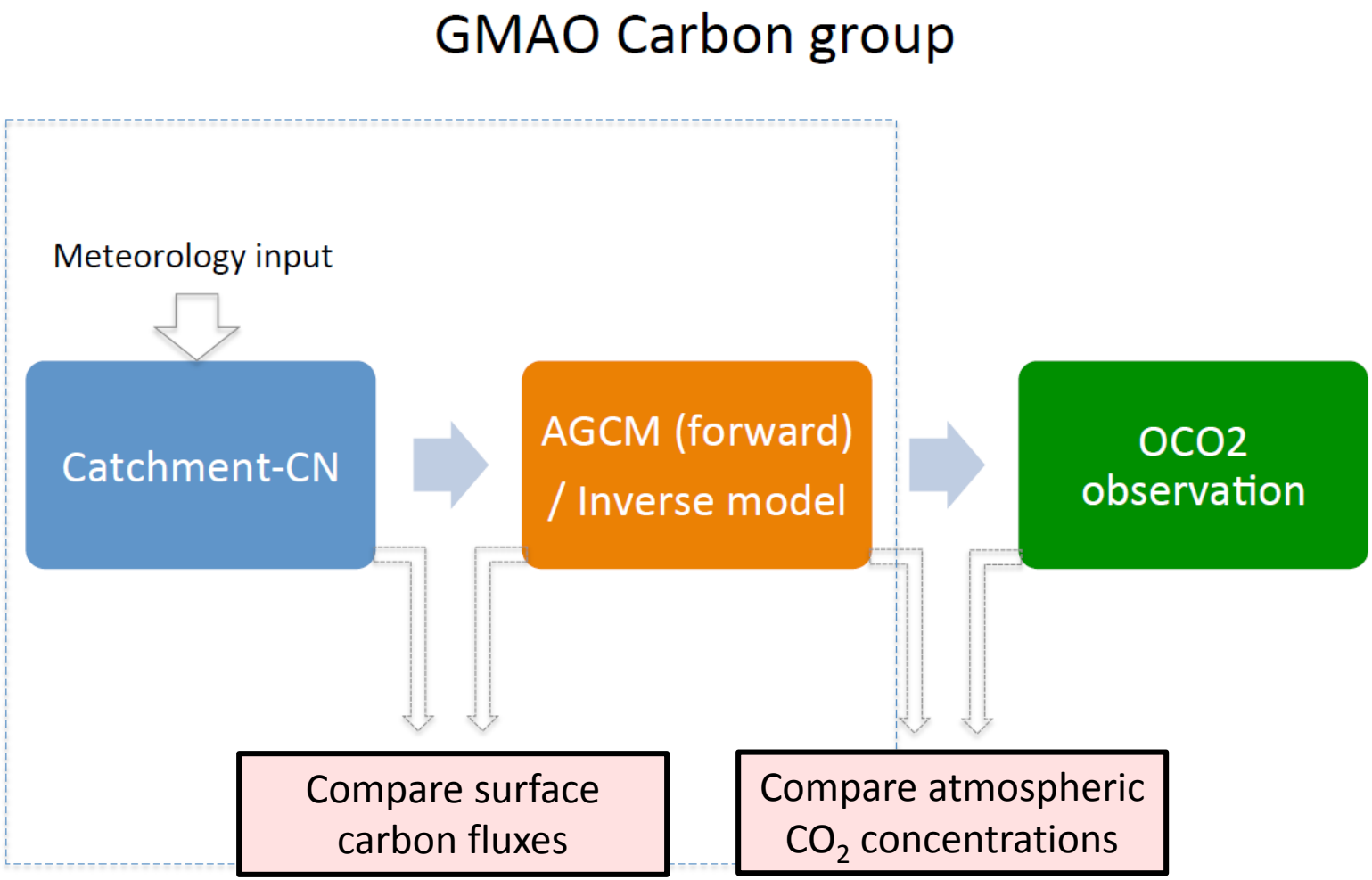
Another study:
Using SMAP soil moisture data to "correct" GPP estimates



Sample simulation results: Changes in GPP induced by correcting soil moisture levels with a satellite-based product

In this exercise, GPP is clearly sensitive to the correction of soil moisture levels in many areas

Future work also includes linking land surface and atmospheric carbon budgets…



(from Eunjee Lee)

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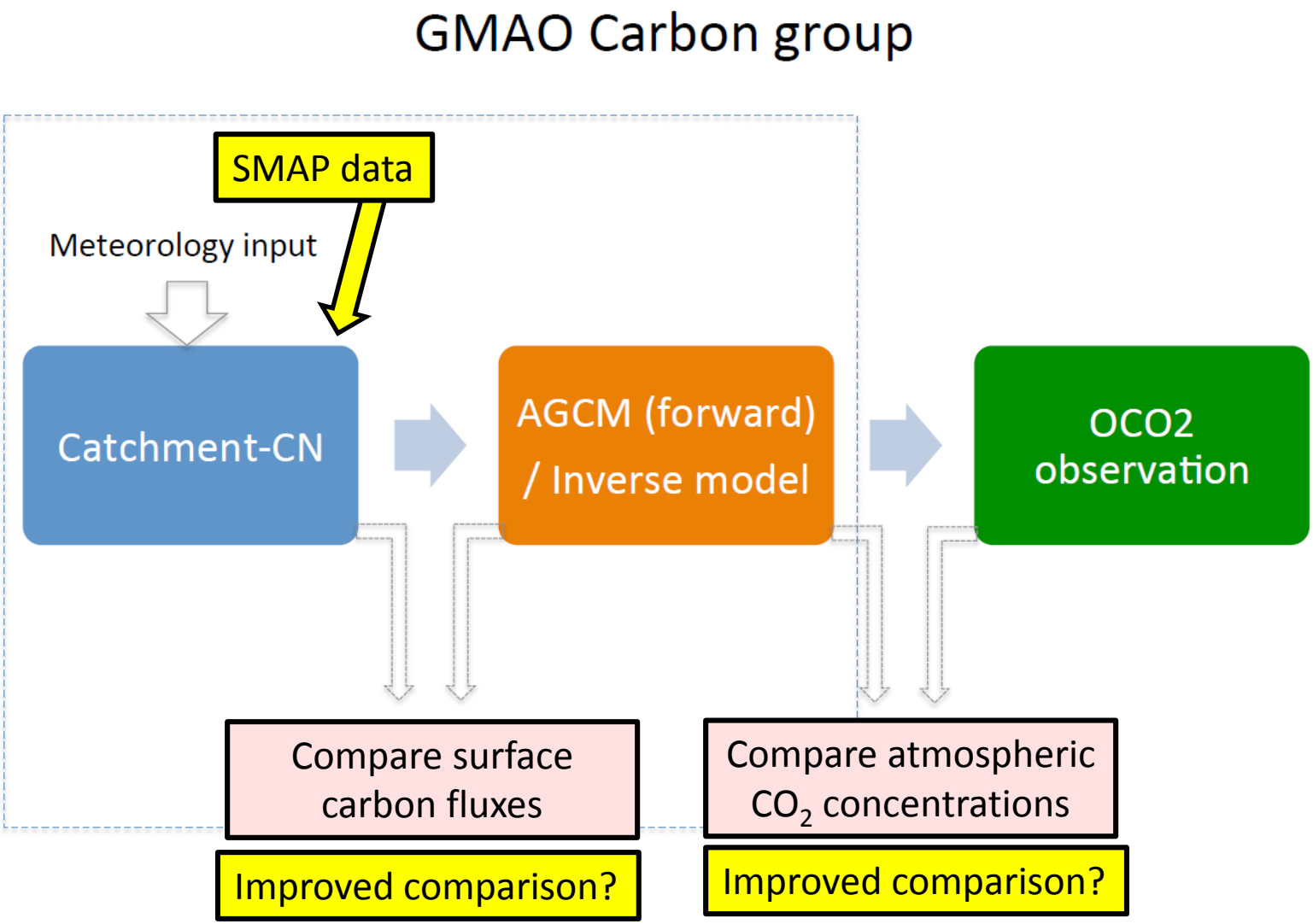


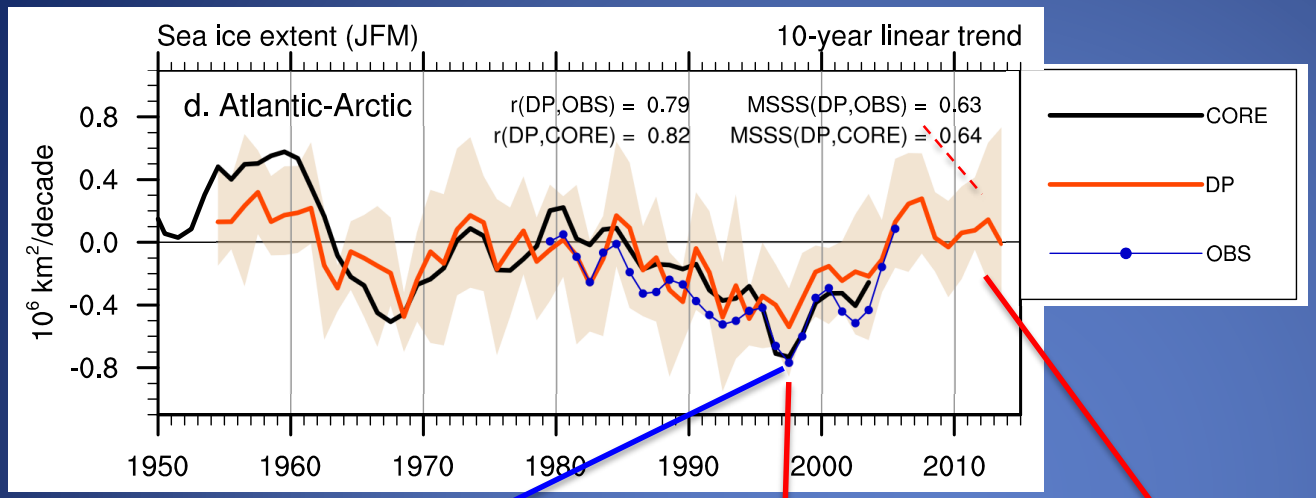
(from Eunjee Lee)

Center Update for Community Earth System Model

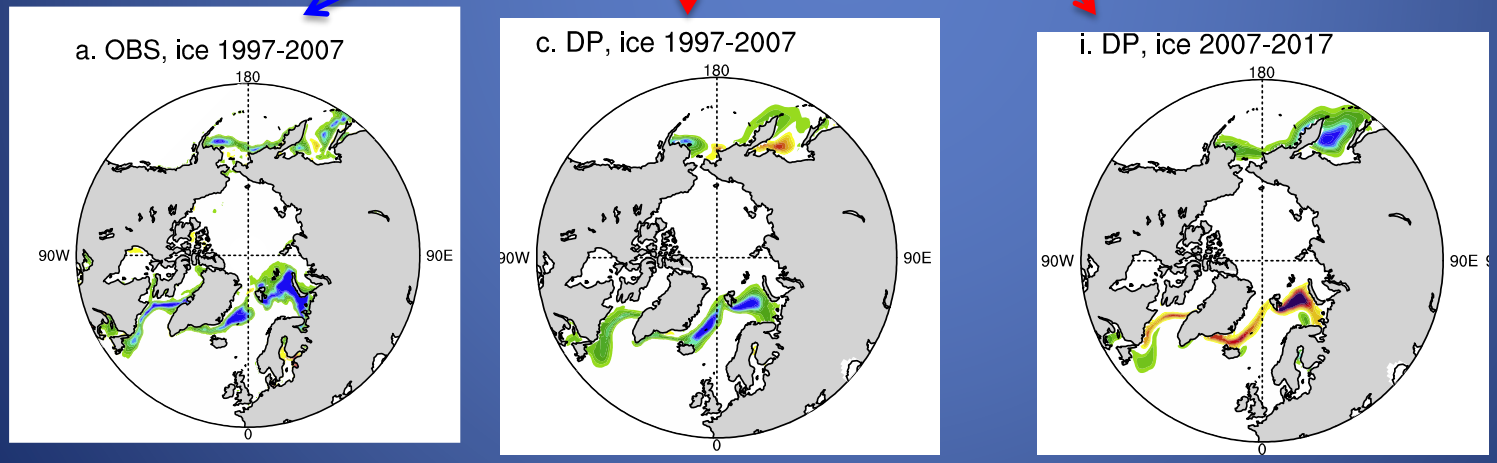
2016 US Climate Modeling Summit
March 9 2016

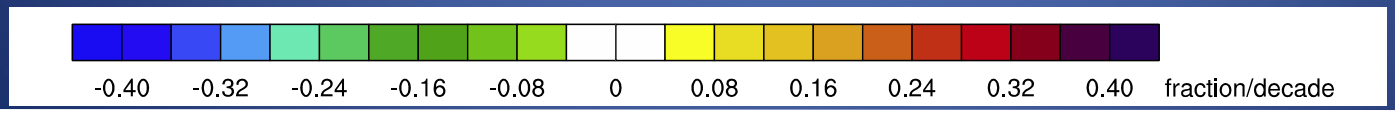
Jean-François Lamarque
CESM Chief Scientist
Atmospheric Chemistry Observations and Modeling
and Climate and Global Dynamics Laboratories
NCAR

Example of Climate Predictability: Reversal of Atlantic sector sea ice loss



- CESM1 decadal prediction simulations can skillfully predict decadal changes in the rate of Arctic winter sea ice loss in the Atlantic sector.





Yeager et al., 2015, GRL

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Update on CESM2

- Currently CESM1.5 (new or significantly updated components)
  - > CAM5.5 (WACCM and chemistry)
  - > CLM5 (incl. MOSART)
  - > CICE5
  - > CISM2
  - > POP2 with extended BGC
  - > Uses CIME for coupling infrastructure
  - > Improved workflow for CMIP6 (parallelization)
- Significant optimization to get ≈20 sim. years per day for 1° CESM1.5.
- Coupled simulations started in November 2015
- Preliminary evaluation at the CESM WG meetings in Feb. 2016
- CESM Release in Dec. 2016

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Existing (CESM1) paradigm – everything in *restricted* developer repository

Infrastructure and all model components
Restricted Subversion Repository -

<u>Prognostic Components (CAM, CLM, CICE, etc.)</u>
Data Models (DATM, DLND, DICE, etc.)
Stub Models (SATM, SLND, SICE, etc.)
CPL Test Models (XATM, XLND, XICE, etc.)
Driver-Coupler Code
Share Code
Scripts
System and Unit Testing Mapping Utilities
New Post-Processing and Workflow Tools`

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New paradigm – all infrastructure is ***Open Source***

Separate repository for prognostic components (CESM example)

Common Infrastructure for Modeling the Earth

Infrastructure
PUBLIC Open Source Github Repository

Driver-Coupler
Share Code
Scripts
Mapping Utilities
System/Unit Testing
All Data Models
All Stub Models
All cpl-test Models
New Post Processing and Workflow Tools
Shared Optimized math and communication utilities

Only prognostic components
Restricted Subversion Repository

CAM
CLM
CICE
POP
RTM MOSART
CISM
WW3

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Why CIME?

- Facilitates infrastructure modernization as a collaborative project
- Eliminates duplication of efforts across modeling centers

➢ Accelerated by NCAR Software Engineers in response to February 2015 Climate Modeling Summit, now regular discussions and planning with collaborators from ACME and ESPC & ESMF (C. DeLuca)

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CIME Infrastructure can be used to facilitate releases and external collaborations

Infrastructure
PUBLIC Open Source Github Repository

Collaborator model code
Restricted or Public Repositories

ESMF/NUOPC and ACME Collaborations
Driver-Coupler
Share Code
Scripts
System/Unit testing
Mapping Utilities
All Data Models
All Stub Models
All cpl-test Models

Examples:

Model Components:
CESM or
ACME or
NUOPC-NEMS

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CMIP Analysis Platform

- Idea was originally discussed at the 2015 CMS
- ➢ New NCAR service to address the CMIP Big Data storage and analysis problems.
  - Funded by NSF for the university community
- Available to any researcher who is eligible for a university Small or Educational allocation.
  - Researcher supported by an NSF award in an eligible domain.
  - A grad student or post-doc conducting their dissertation project or postdoctoral research project.
- Currently prototyping with CMIP5 data sets and preparing to scale up for CMIP6.
- Tutorial planned for late summer 2016

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Highlights of USGCRP priority-relevant current activities

- What are USGCRP priority activities? Do they overlap with priorities of NCAR strategic imperatives?

  --Discovery-oriented research into climate system behaviors

  --Develop a process level understanding

  --Discover inherent predictability limits

  --Pursue interdisciplinary projects

  --Accelerate advances in community models

  --Multiscale modeling systems to span from minutes to decades

  --Adapt to emerging supercomputing architectures

  --Improve efficiencies in Big Data capabilities

  --Integrate physical and social sciences; communicate risk

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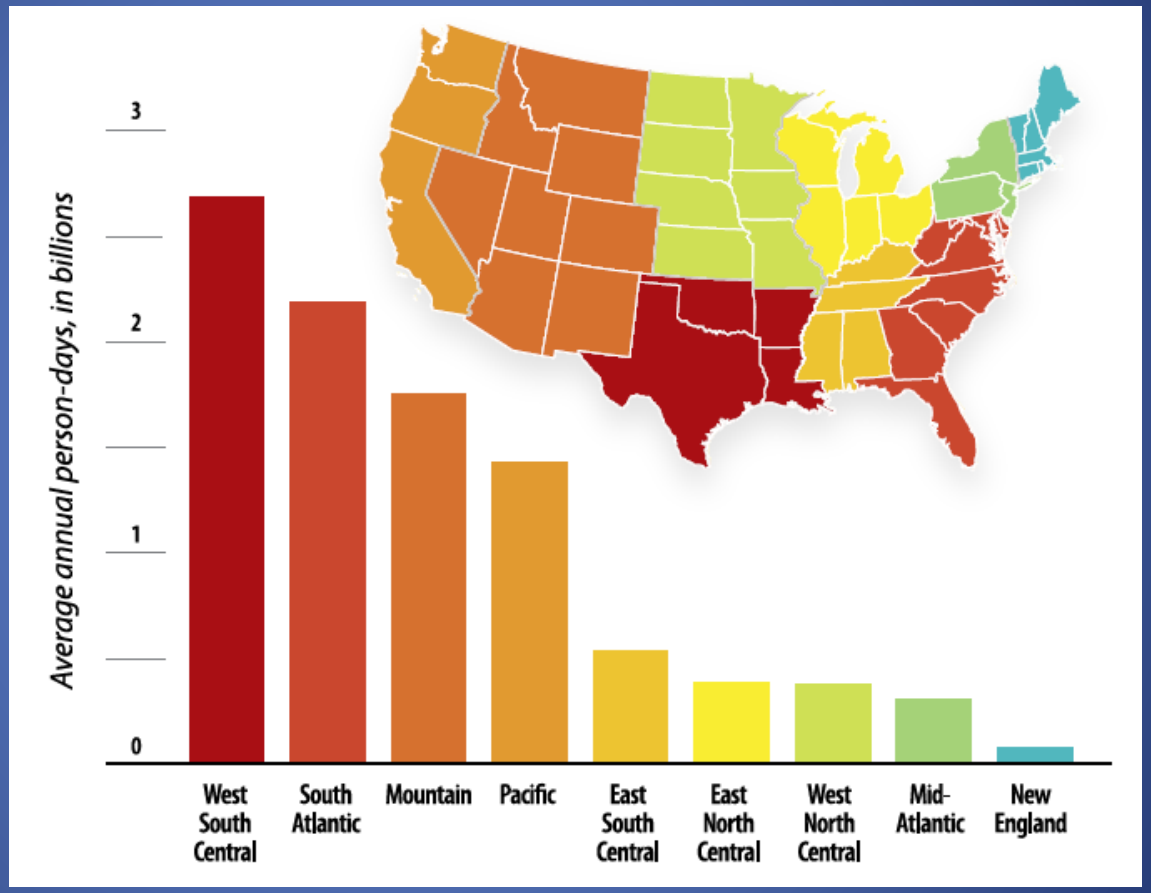
Impacts on Human Systems: combining climate and demography projections

Exposure to Extreme Heat is on the Rise :

1971—2000 vs. 2041—2070



Jones, O'Neill, McDaniel, McGinnis, Mearns, Tebaldi. 2015. Nature Climate Change.

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CESM Grand Challenges

- Avoided impacts
- High-resolution and scale-aware parameterizations
- Biogeochemical cycles and process representation
- Cloud-aerosol interactions, with an emphasis on natural aerosols
- Whole-atmosphere coupling

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Interest in CMIP/CPTs/high res.

- CMIP
  - 1-degree model (incl. expanded WACCM) will be CMIP workhorse
- CPTs
  - Successful participation in CLUBB, CVMix, …
- High resolution
  - Present focus on ¼-degree atm. and 1-degree or 0.1-degree ocean
  - Limited by computer time availability

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What does "Seamless Prediction of Weather and Climate" mean? Raising some points from Shukla (2009)

- Confusion between seamless prediction, unified framework , seamless framework (others use "unified approach"). Which is it?
- A single prediction from an initial state to produce 1-5 day, seasonal – interannual -- decadal forecasts : seems impractical until there is more computing ("International Center for Climate Prediction")
- Seasonal and longer become boundary value problems, unlike NWP (SST, sea ice conditions, land use, top of model). When does anthropogenic forcing enter the problem and change the rules?
- Arguments for feasibility of following NWP are based on -5/3 and -3 spectra and are specious for "peaked" phenomena such and ENSO, MJO and other modes of climate variability (AMOC, PDO, SAM)
- Assumes data & its assimilation are similar across boundaries. Is the methodology and impacts of coupled data assimilation seamless?

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Questions?

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GISS ModelE Progress and Plans

USCMS 2016

Gavin Schmidt and team

Goddard Institute for
Space Studies

Recent Progress

- Improvements to CMIP5 model (all components) --> GISS-E2.1
  - MJO, QBO variability, improved mesoscale ocean parameterisations
- Testing/development of next-generation of models --> GISS-E3, GISS-E4
  - Cubed sphere atmosphere/ocean, cloud+aerosol microphysics
- Applications

Newly resolved modes I: MJO

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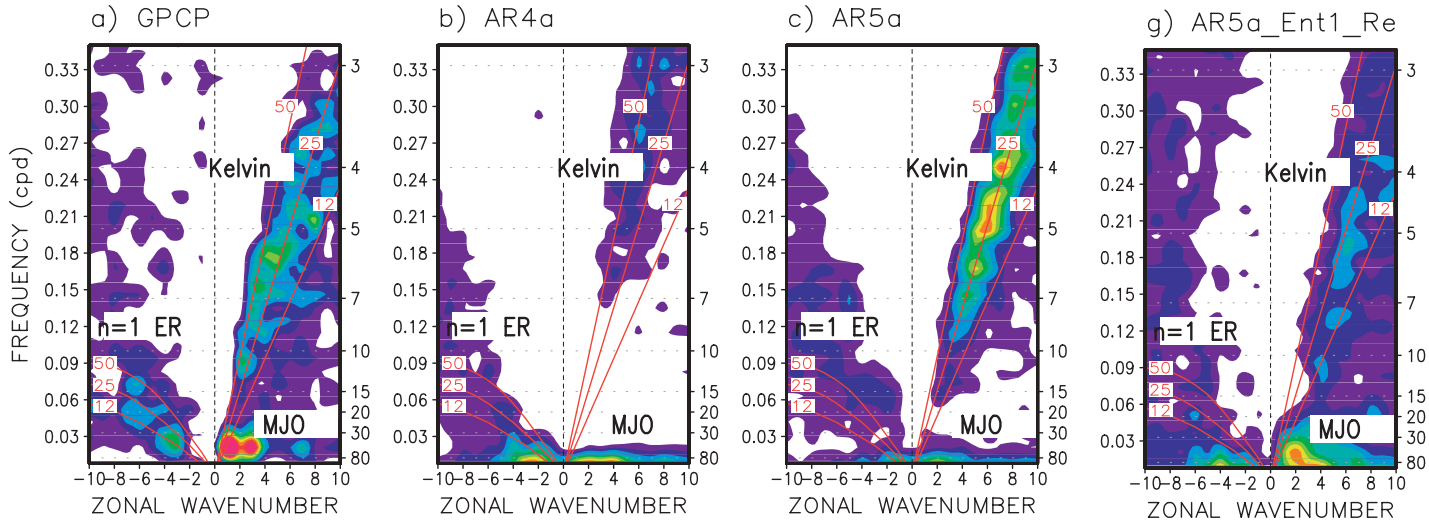

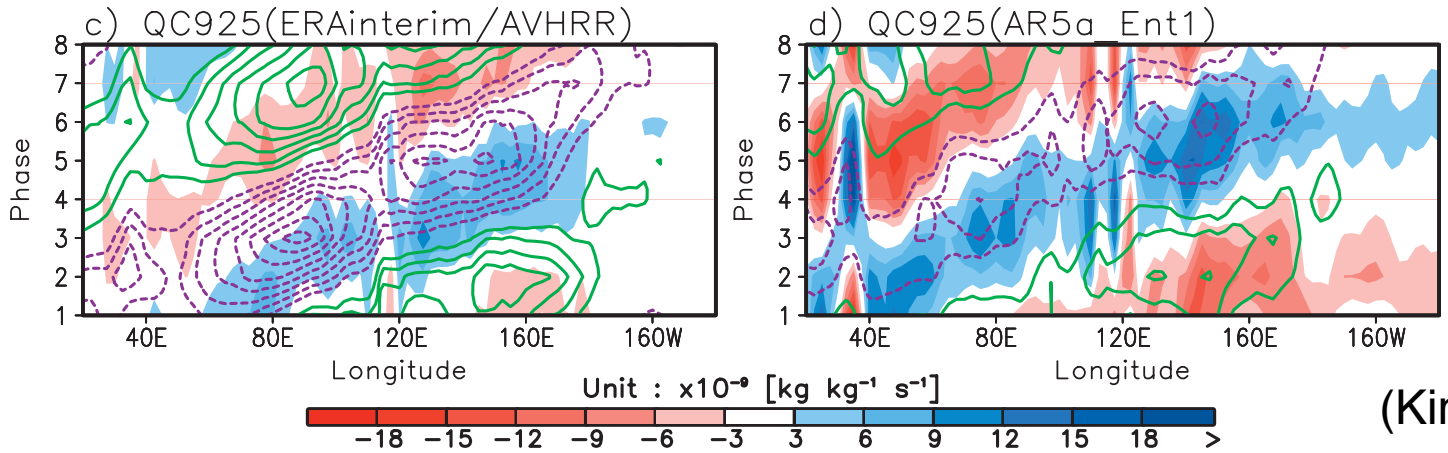

(Kim et al, 2012)

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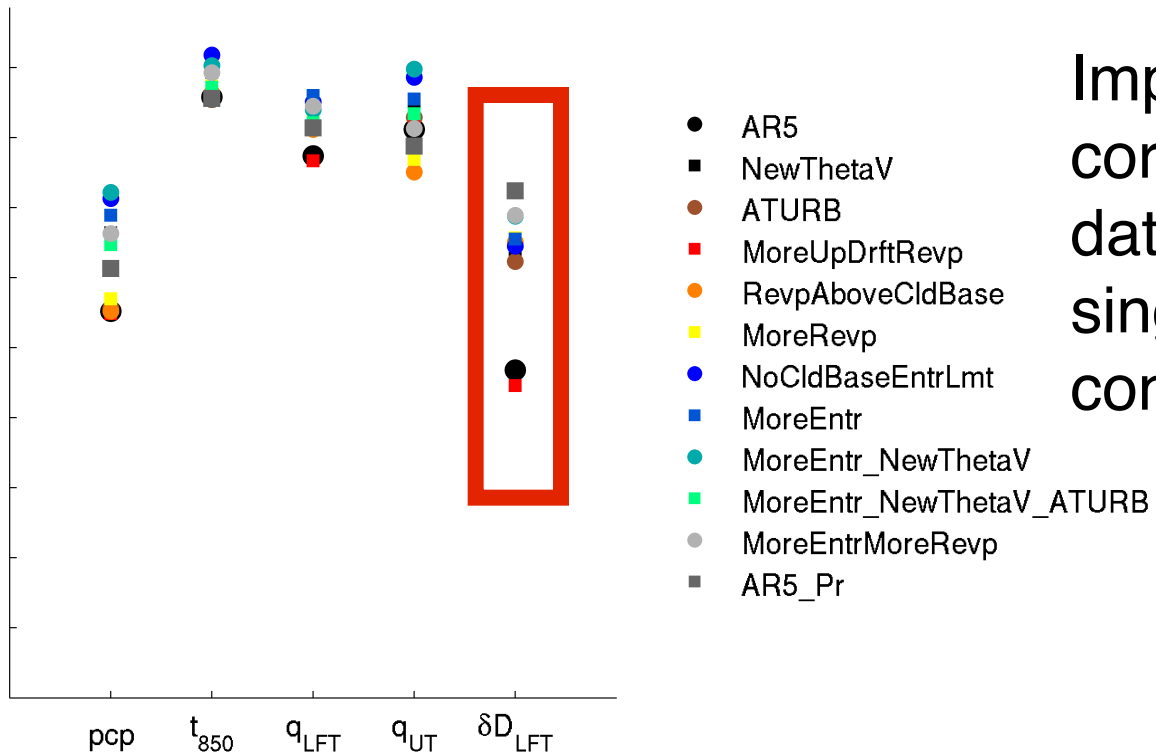
Water isotopes are better discriminants of convection



Improvement in pattern correlations to satellite data as function of single changes in convection

Field et al, 2014

...as are CO profiles

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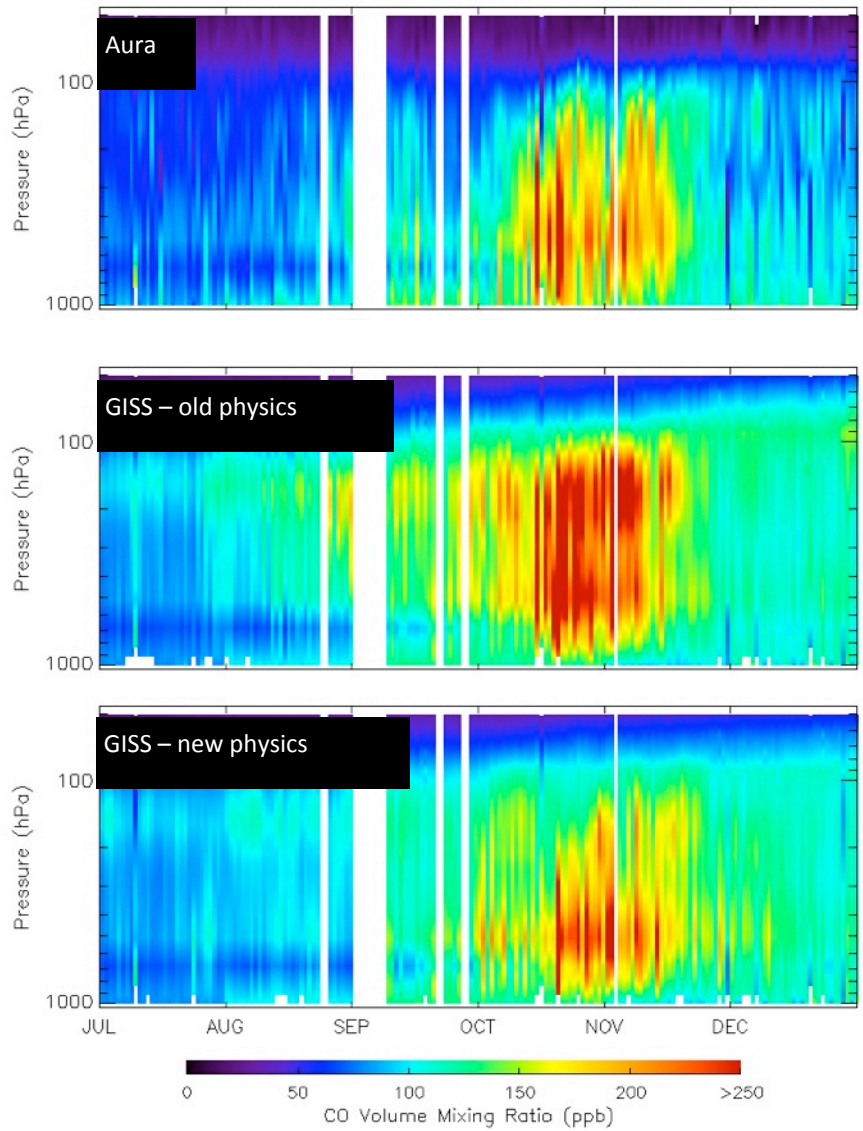
New CO profiles retrieved from Aura TES and MLS provide **an independent check** on new convection physics that led to the successful simulation of an MJO in GISS E2.1.

Upper tropospheric CO during late 2006 over Indonesia was amongst the highest during the MLS period[3] due to uncontrolled peat burning.

With the old (AR5) convection physics, upper tropospheric CO was unrealistically high.

With the new convection physics, the vertical distribution of CO is in better agreement with Aura because of changes in the timing and depth of convection.

CO over Western Indonesia, Jul-Dec 2006



Field et al, 2015

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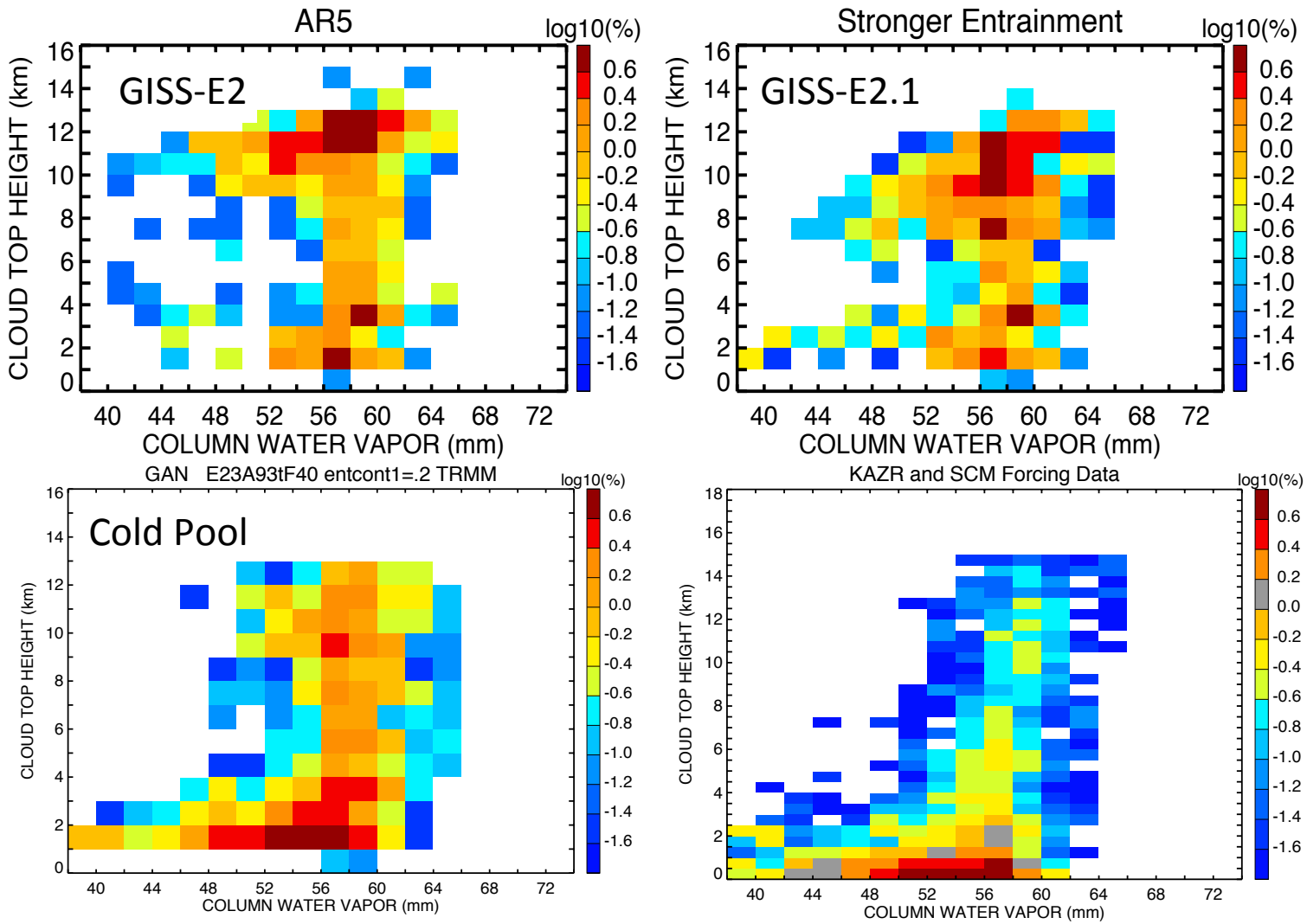
Cold pool parameterization:

Formed from downdrafts, used to restrict occurrence of weakly entraining plumes



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MJO Hindcasts: YOTC

	20 day hindcast	Last 10 days
GISS-E2	0.22	
GISS-E2.1	0.48	0.35
GISS-E2.1+Cold Pools	0.63	0.60
TRMM/PR	0.7	

Time-Longitude rain anomaly pattern correlation with TRMM TMI

Convective Ice Parameterization

Based on Field campaign data

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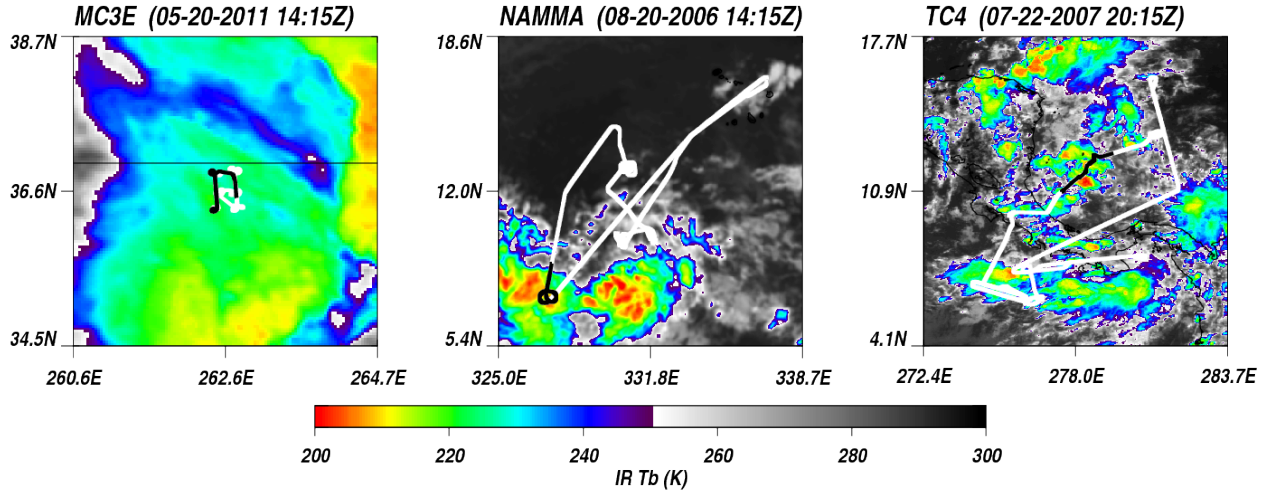
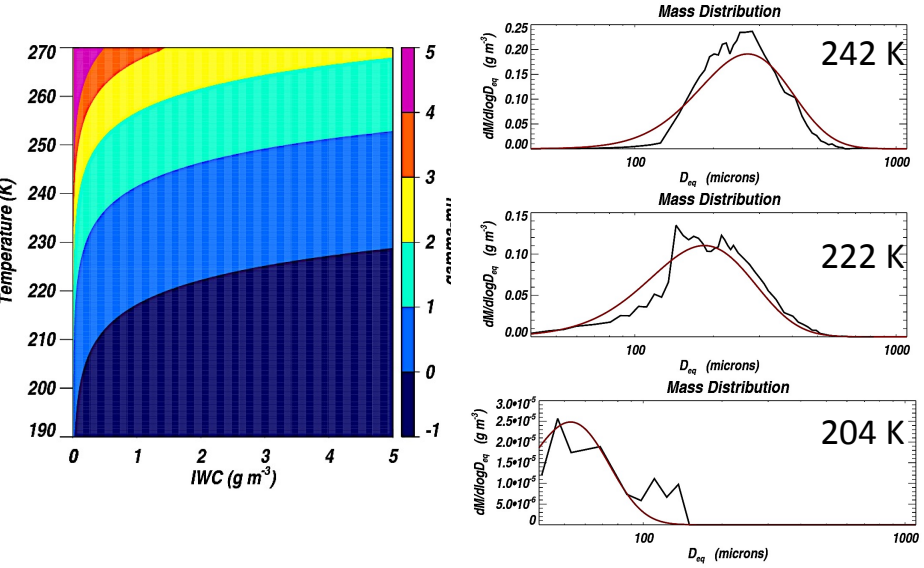
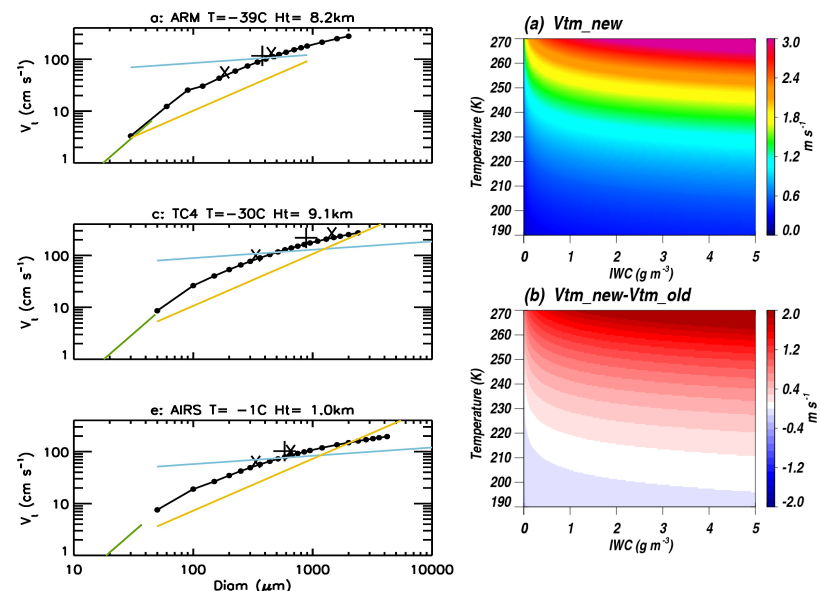


Gamma distribution fits to PSDs



Heymsfield formulations for particle $V_{fall}(D)$



Ice Water Content improvements

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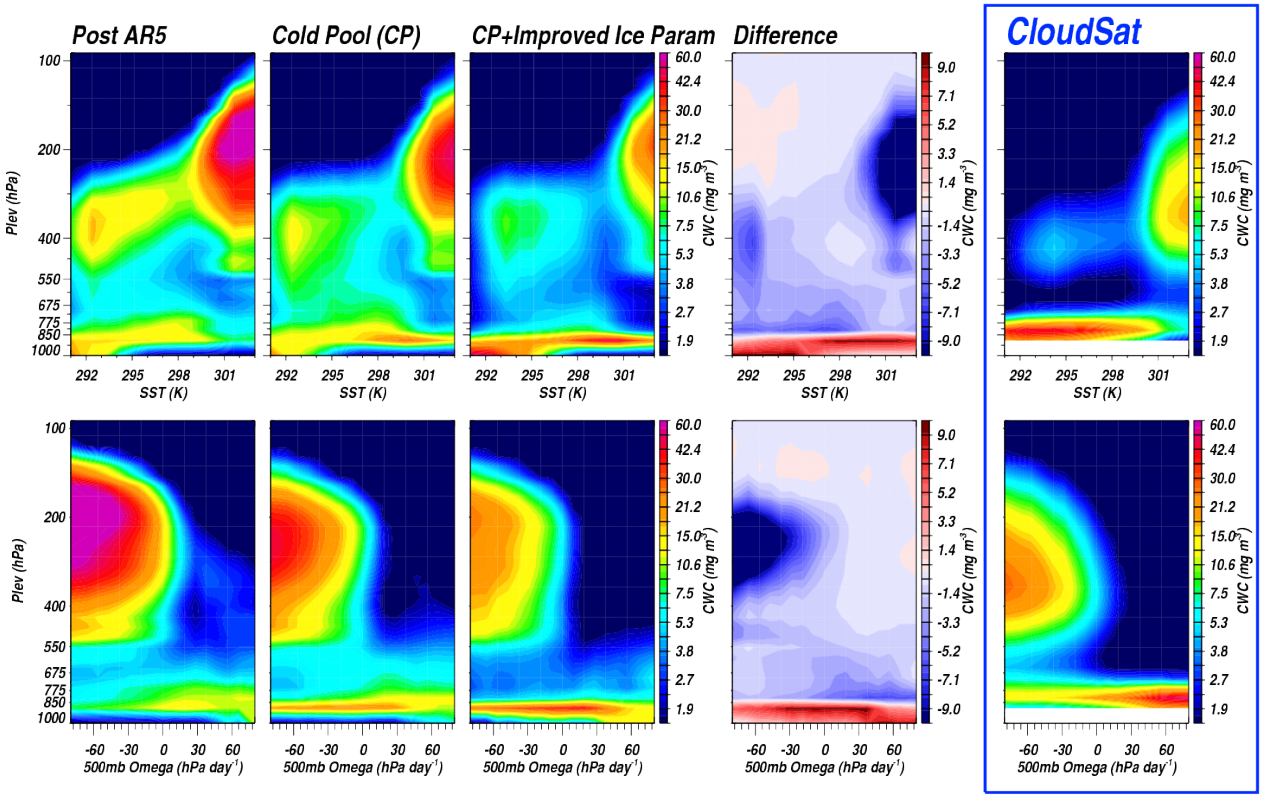

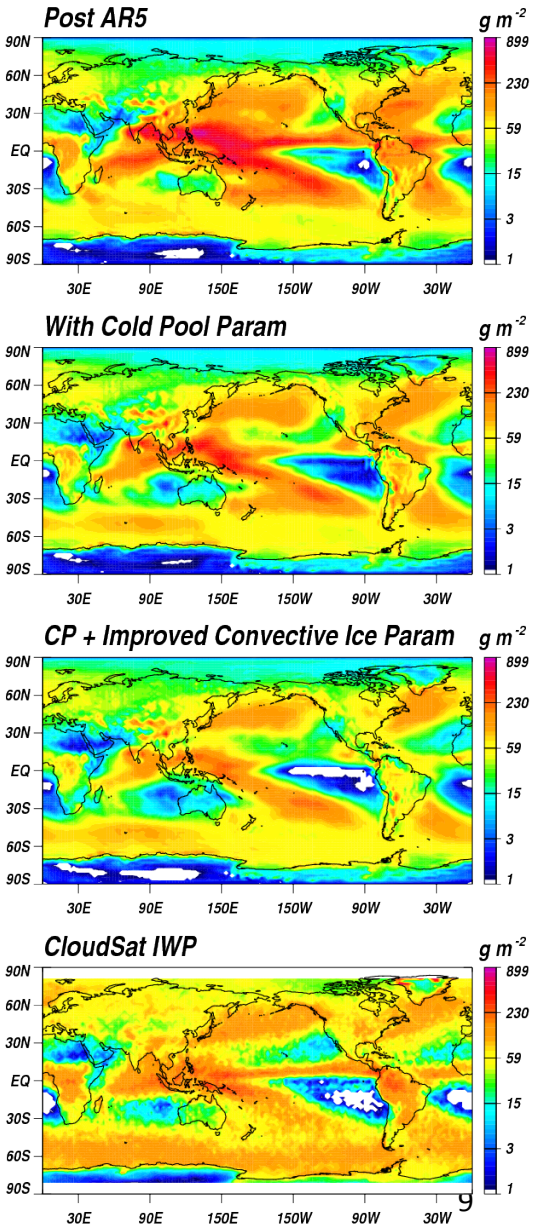

Improvements in GCM physics decrease IWP: GISS-E2.1: 103 g/m^2, Cold Pool: 70 g/m^2, CP+ Improved Convective Ice: 54 g/m^2 (right)

Regime-sorting of IWC(p) (top): Largest decreases in IWP are due to upper-trop. IWC in deep convection regions (high SST, upward ω_{500}).

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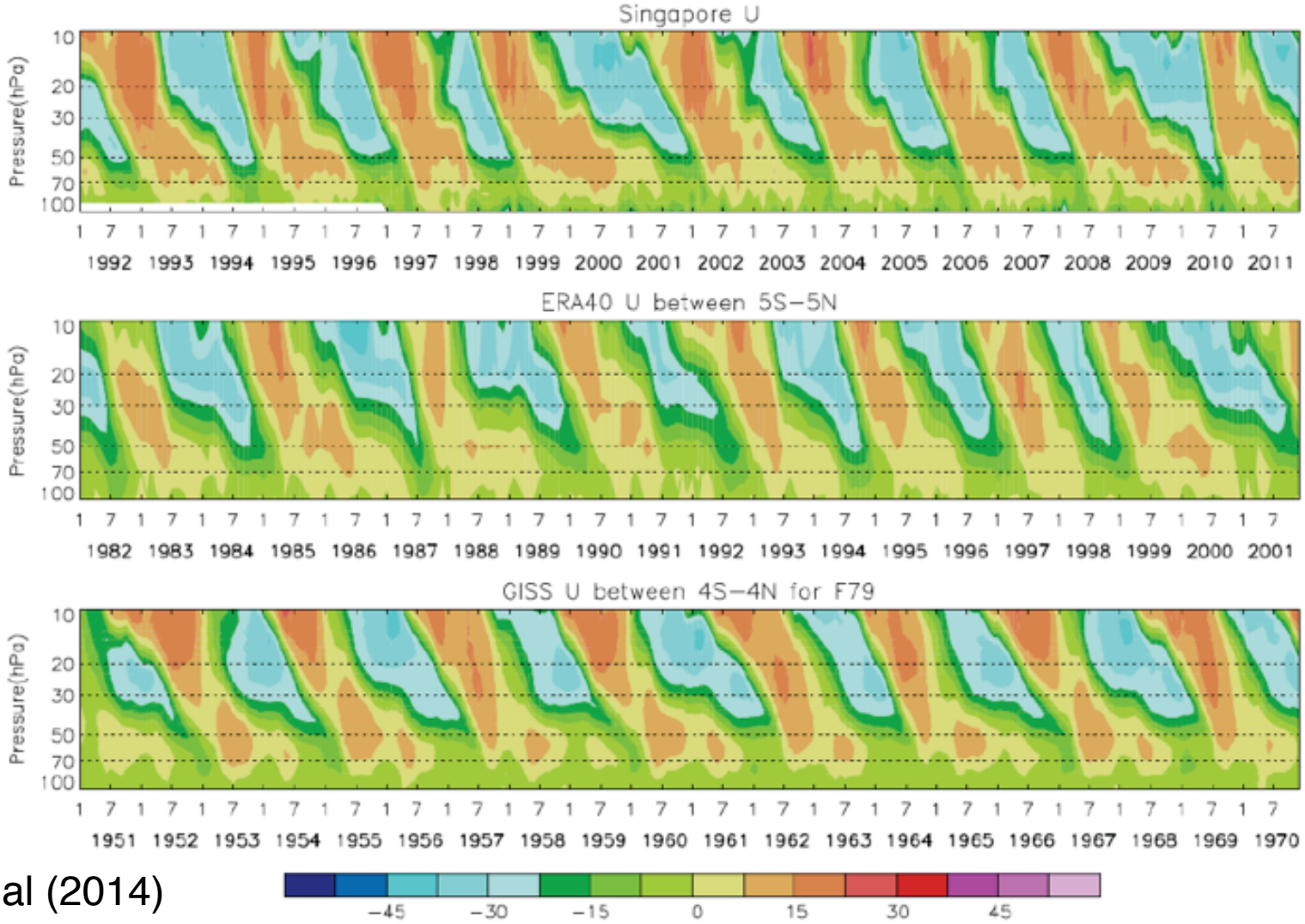
Self-generated stratospheric QBO

Tropical zonal mean winds



Rind et al (2014)

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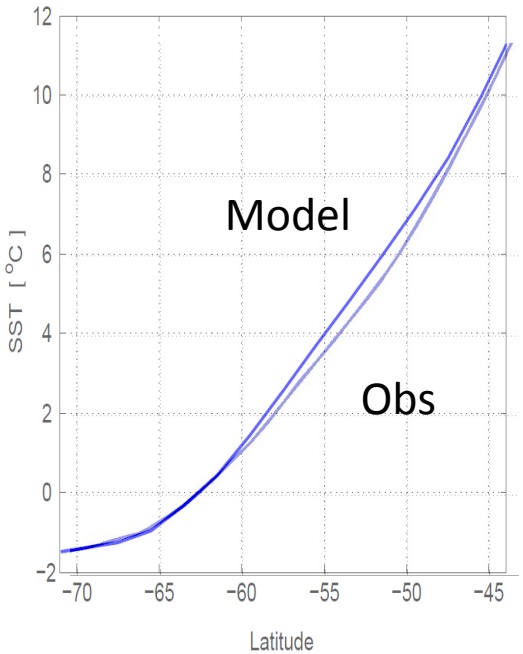
Ocean model improvements

Reformulation of GM eddy parameterisation

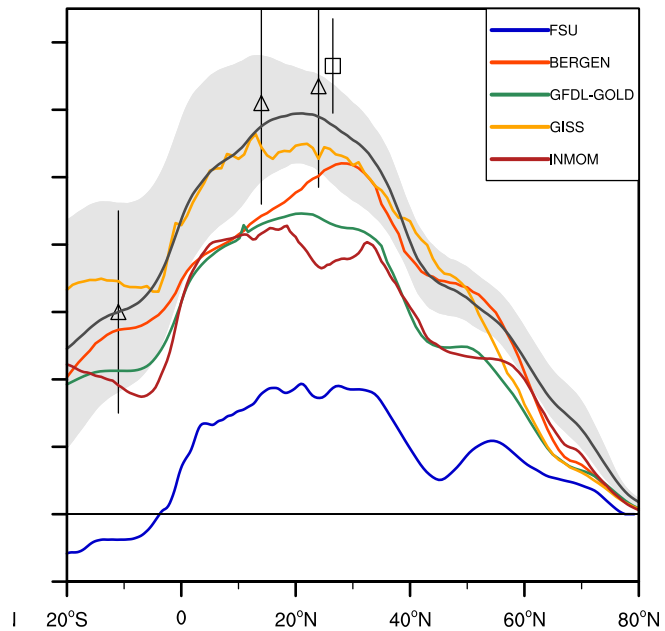
GISS-Vertical Mixing Scheme

Inclusion of GM vertical dependence

Evaluation with stand-alone ocean CORE-I/II protocol



Zonal mean SST gradients
Southern Ocean



AMOC Heat flux 26ºN
CORE II: Danabasoglu et al (2014)

GISS Ocean 2 (GO2) Model

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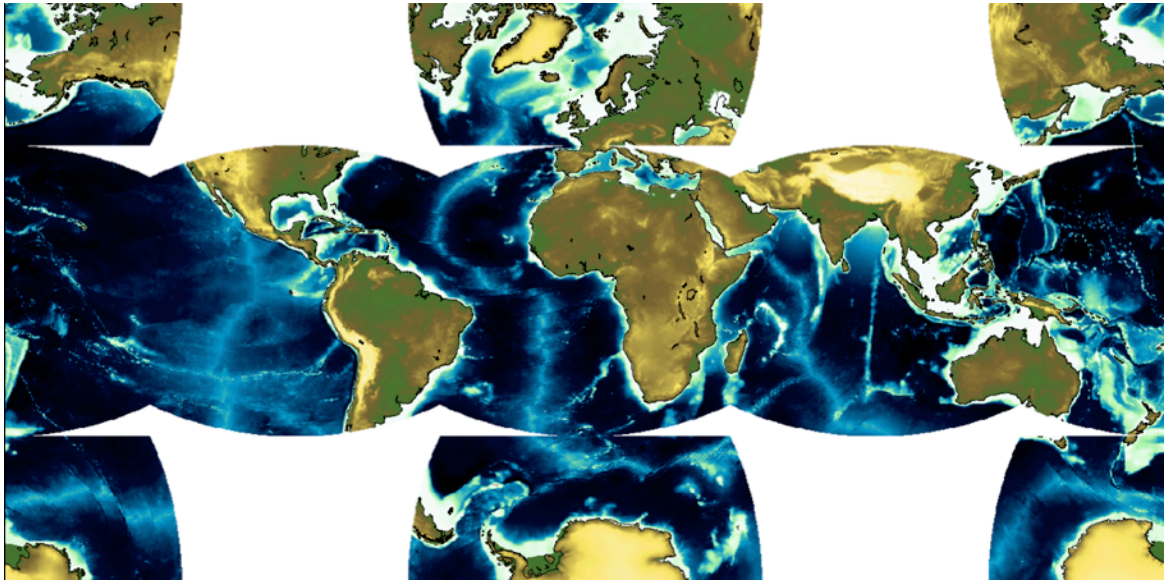
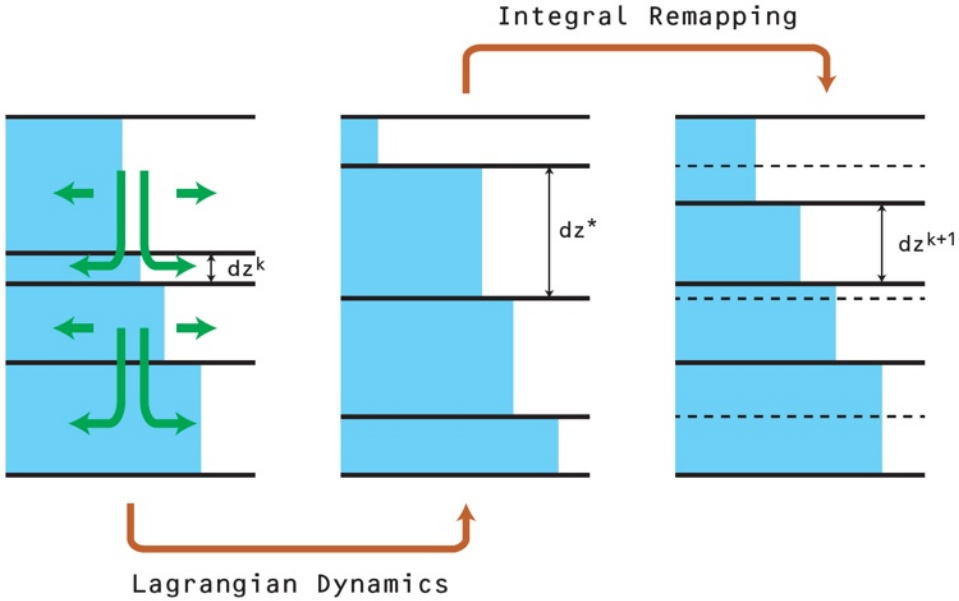
Orthogonal Cubed-Sphere grid
C720 goal (1/8º)



Arbitrary Lagrangian Eulerian (ALE) vertical coordinate



GISS Ocean 2 (GO2) Model

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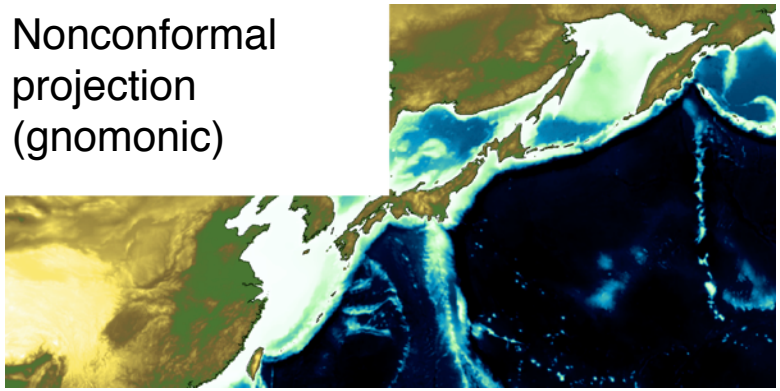
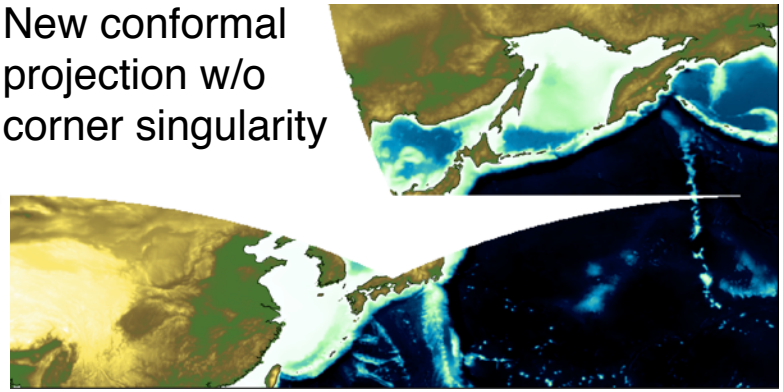
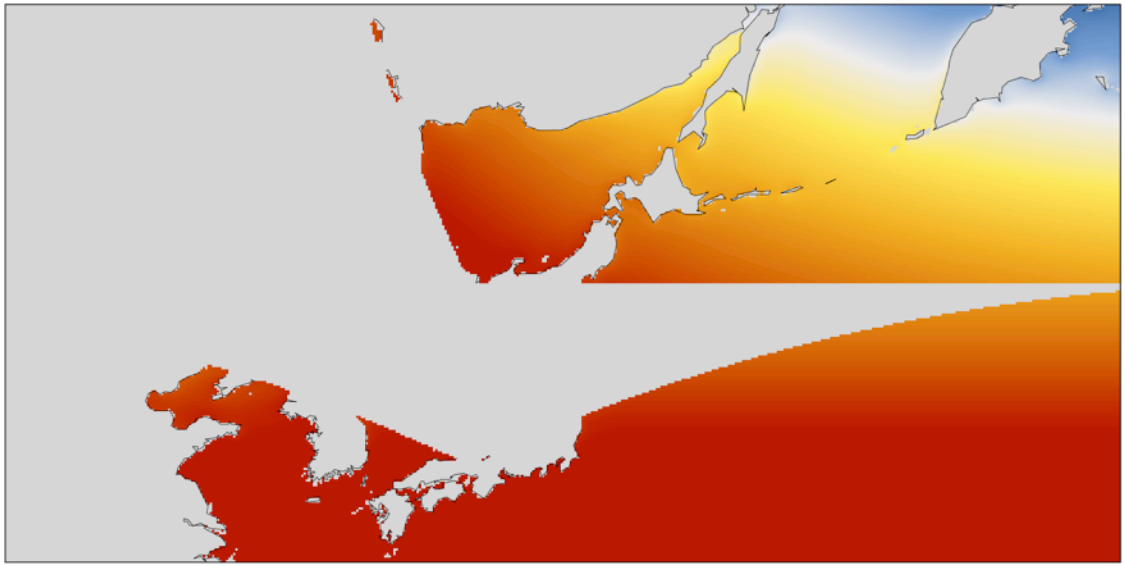
Nonconformal projection (gnomonic)



New conformal projection w/o corner singularity



Numerical techniques to handle cube edges and programming to efficiently deploy MPI parallelism now complete. --> 3D



Mineral Composition of Soil Dust Aerosols

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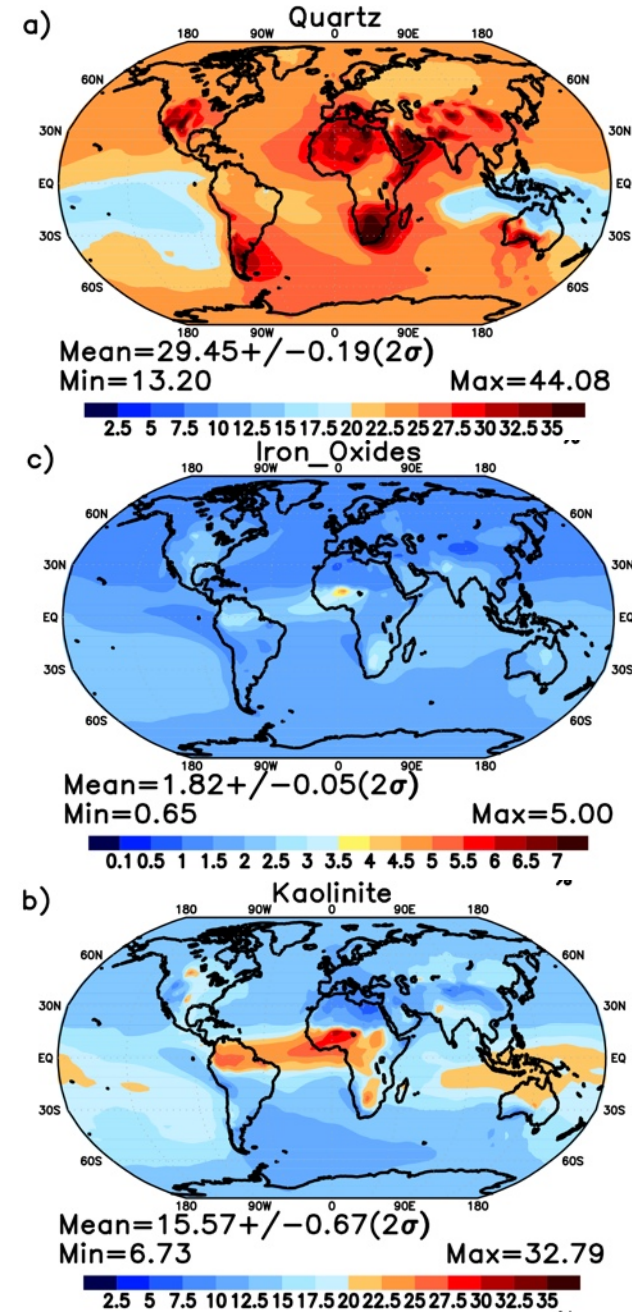
- Aerosol mineral content is important for dust radiative forcing, cloud droplet and ice nucleation, heterogeneous aerosol chemistry and delivery of iron to catalyze marine photosynthesis (and draw down atmospheric CO_2).
- Models typically treat dust aerosol composition as globally uniform, neglecting regional variations of soil mineral content.

Previous Work: Claquin et al. (1999) estimate mineral composition of wet-sieved soil using a global atlas of arid soil type.

- **Our extensions**
- Relate *soil* mineral composition to *aerosol* mineral composition by accounting for wet-sieving and mobilization.
- Consider *mixtures* of minerals (important for transport of iron oxides that are the primary shortwave absorber in dust: pure iron oxide is dense and falls out near the source; far-travelled iron oxides are mainly small impurities on the surface of other mineral grains).
- Compile observations and evaluate (no comprehensive comparison until now).



GISS Dust group: Ron Miller, Carlos Pérez García-Pando, Jan Perlwitz

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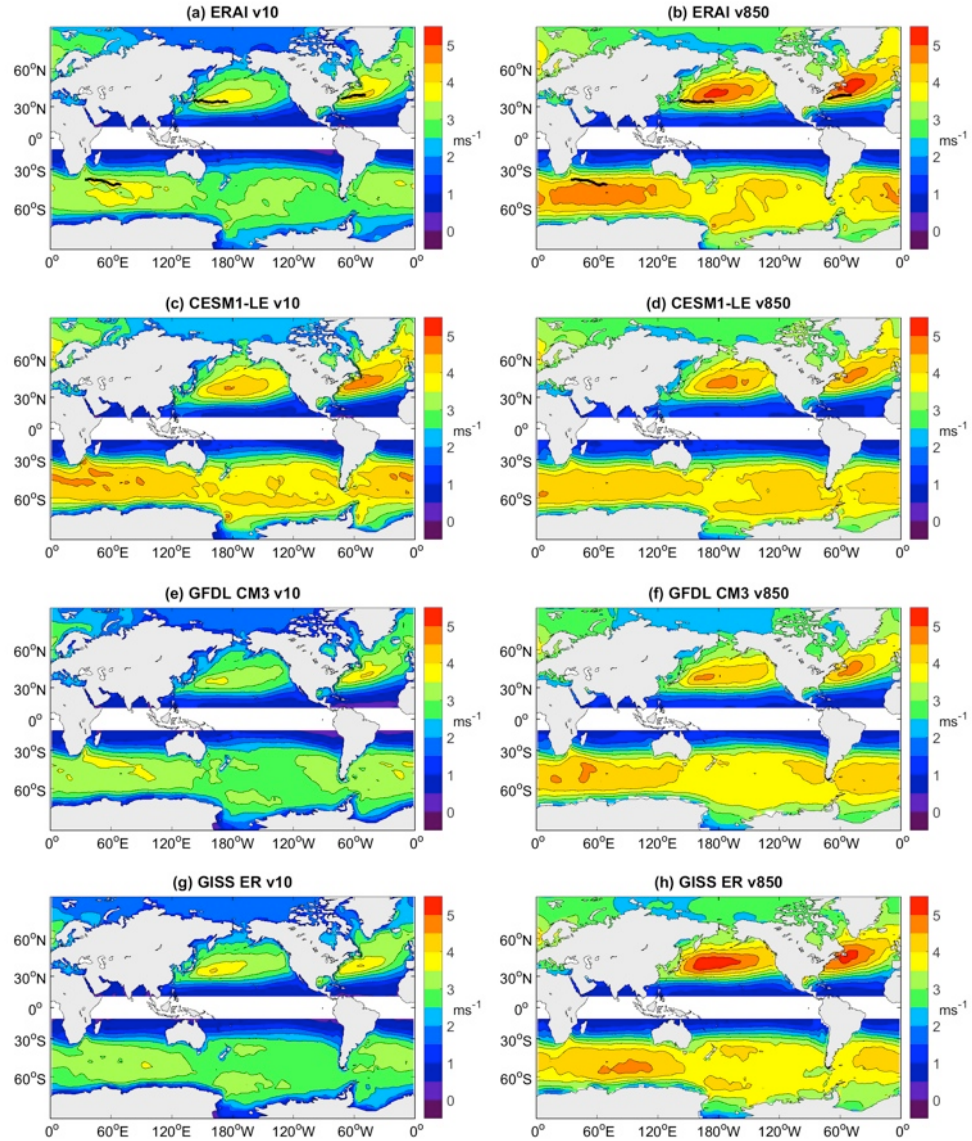
Surface & 850-hPa storm tracks in US models



NH shows DJF and SH shows JJA.

Storm tracks defined here as the standard deviation of meridional winds that have been filtered in time to isolate 2-6 day variability.

<u>Surface Storm Track Location</u>
the surface storm track maxima is close to the ocean Western Boundary Currents rather an being co-located with 850-hPa maxima.

<u>Surface Storm Track Strength</u>
CESM1-LE surface storm track is too strong compared to reanalysis.

GISS and GFDL differ by basin and details relate to boundary layer coupling and SST biases.

<u>850 hPa Storm Track Strength</u>
CESM1-LE and GFDL CM3 are biased weak, GISS modelE2-R does well in the NH.

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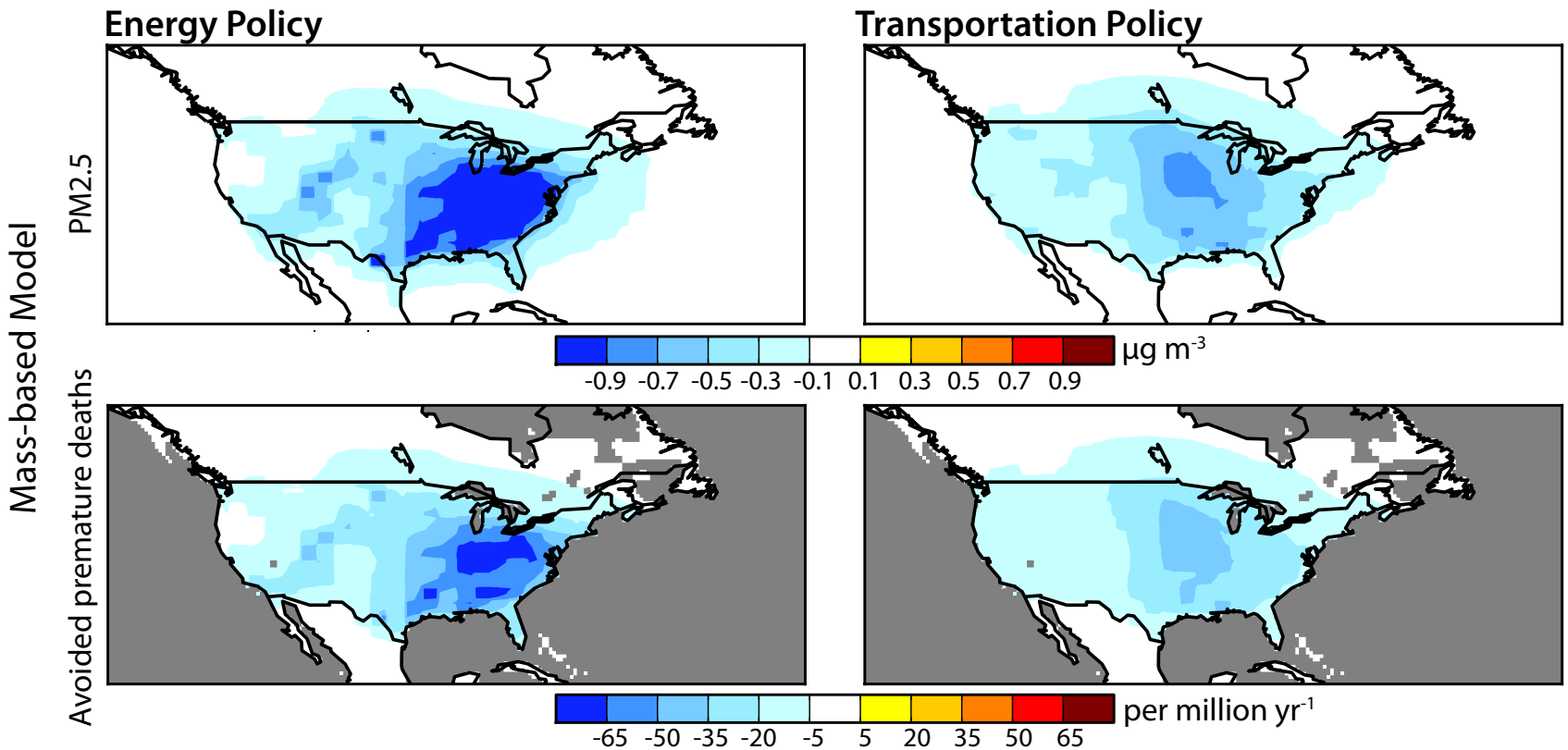
Avoidable premature deaths via policy action



Clean Energy: Avoids ~175,000 premature deaths by 2030 (-50%/+450%; ~80% $PM_{2.5}$, 20% O_3)

Clean Transportation: ~120,000 lives by 2030 (-36%/+360%; ~66% PM2.5, 33% O3)

Shindell et al (2016)

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Alignment w/USGCRP priorities

1) Predictions:

   Climate projections RCPs/SSPs/Alt. Scenarios; MJO

2) Water Cycle:

   Convection, IWP, water isotopes/tracers as discriminants, improved soil + groundwater, river flows

3) Arctic Research:

   Improvements in ocean/sea ice components, radiative transfer, mixed phase clouds

4) Actionable science:

   Combining climate/air quality/public health --> SCAR (Social Cost of Atmospheric Release)

GISS Planning for CMIP6

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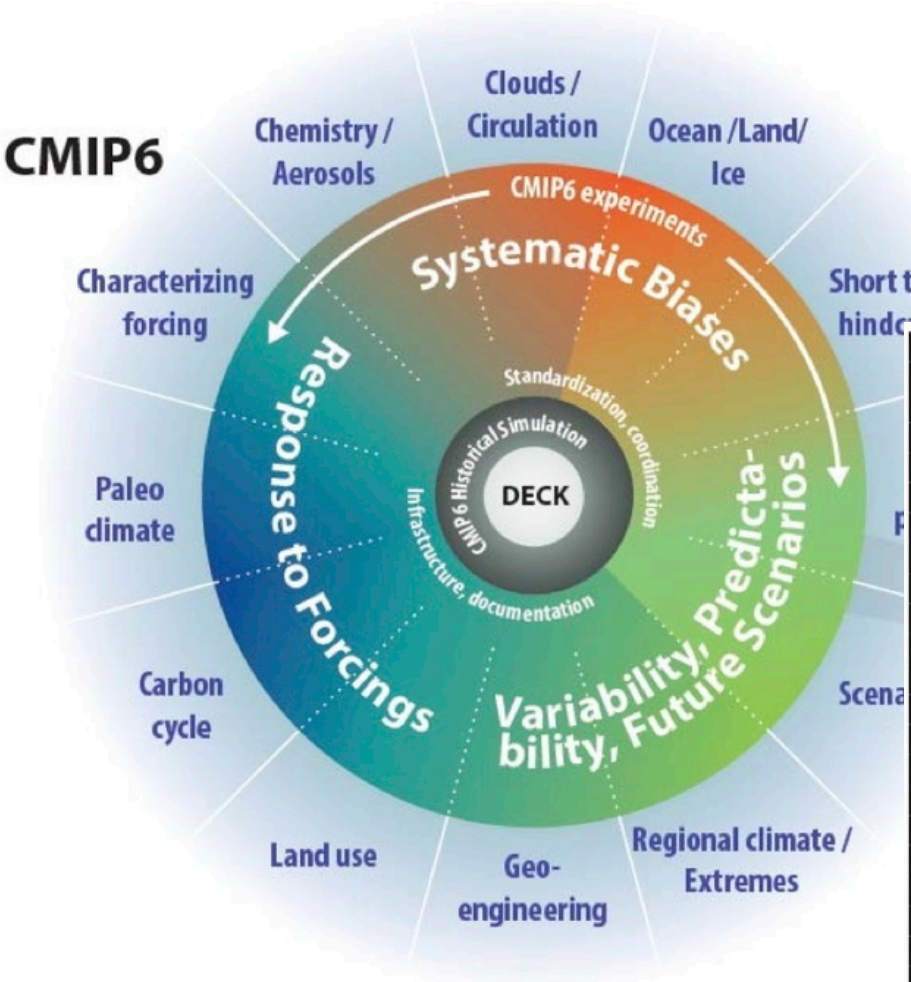

	Short Name of MIP	Long Name of MIP
1	AerChemMIP	Aerosols and Chemistry Model Intercomparison Project
2	C4MIP	Coupled Climate Carbon Cycle Model Intercomparison Project
3	CFMIP	Cloud Feedback Model Intercomparison Project
4	DAMIP	Detection and Attribution Model Intercomparison Project
5	DCPP	Decadal Climate Prediction Project
6	ENSOMIP	ENSO Model Intercomparison Project
7	FAFMIP	Flux-Anomaly-Forced Model Intercomparison Project
8	GDDEX	Global Dynamical Downscaling Experiment
9	GeoMIP	Geoengineering Model Intercomparison Project
10	GMMIP	Global Monsoons Model Intercomparison Project
11	HighResMIP	High Resolution Model Intercomparison Project
12	ISMIP6	Ice Sheet Model Intercomparison Project for CMIP6
13	LS3MIP	Land Surface, Snow and Soil Moisture
14	LUMIP	Land-Use Model Intercomparison Project
15	nonlinMIP	Non-linear Model Intercomparison Project
16	OCMIP6	Ocean Carbon Cycle Model Intercomparison Project, Phase 6
17	OMIP	Ocean Model Intercomparison Project
18	PDRMIP	Precipitation Driver and Response Model Intercomparison Project
19	PMIP	Palaeoclimate Modelling Intercomparison Project
20	RFMIP	Radiative Forcing Model Intercomparison Project
21	ScenarioMIP	Scenario Model Intercomparison Project
22	SensMIP	Sensitivity Model Intercomparison Project
23	SolarMIP	Solar Model Intercomparison Project
24	VolMIP	Volcanic Forcings Model Intercomparison Project

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Planned GISS CMIP6 Configurations

Multiple configurations w/variations for DECK runs:

1) GISS-E2.1 (ready)

   Vars: OMA vs MATRIX; R vs H ocean; L40 vs L96

2) GISS-E3 (mid-2016)

   C90+L96 (optional ext. to mesopause), same oceans; QBO, MATRIX aerosols, cloud microphysics, cold pool convection

3) GISS-E4 (2017-2018?)

   C180+L96, GO2 (GISS Ocean 2)

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MIP foci

1) DAMIP - single forcing ensembles (SolarMIP/ VolMIP/LUMIP)

2) RFMIP - Essential complement to understanding responses

3) AerChemMIP

4) CFMIP

5) PMIP - ‘out-of-sample’ evaluations

Use of single forcing ensembles

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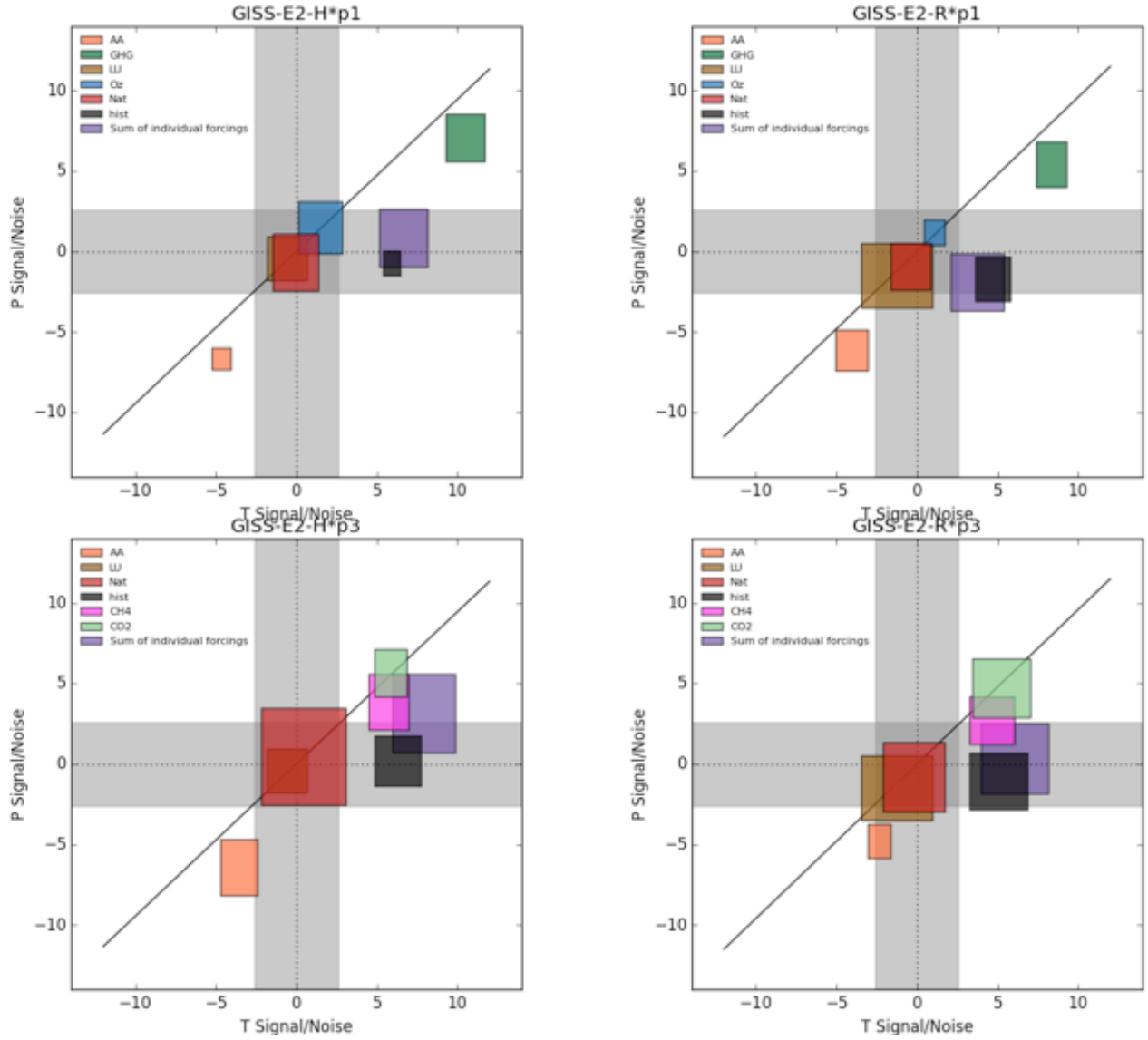
By concentration

By emissions



Different oceans

Marvel et al (2015)

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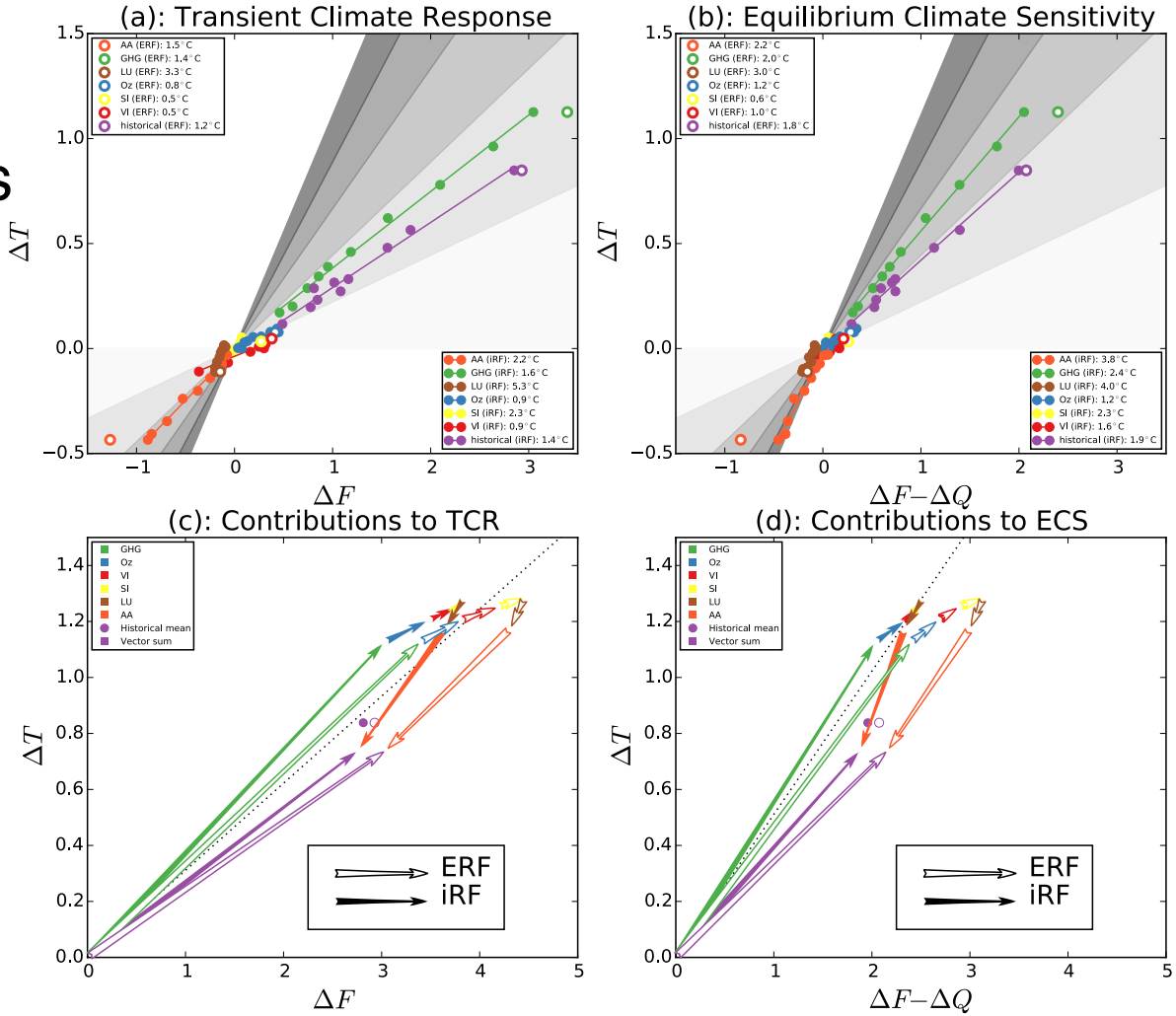
Efficacy of forcings in transient runs

Use historicalMisc runs + forcing calculations to assess predictability of TCR+ECS from historical transients

Historical runs ***underpredict*** sensitivity



Marvel et al, 2016

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Forcing improvements

Irrigation (water added to land surface, either from rivers or groundwater)

Greater differentiation in LU (crops, pasture etc.)

Volcanic forcing by emission

Solar forcing uncertainty

Aerosol forcing - uncertain pre-cursor emissions and atm. processing

Urban fractions

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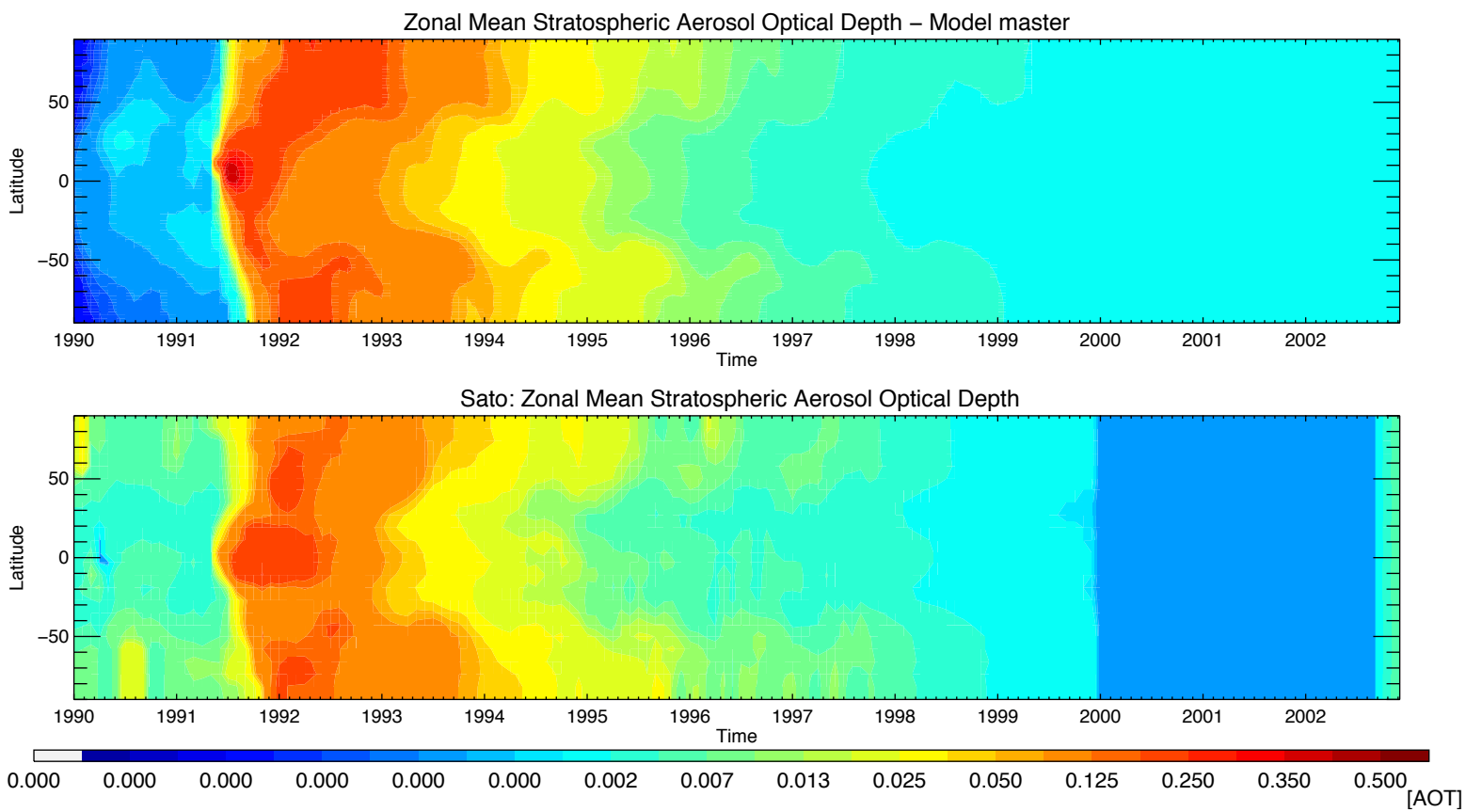
Interactive simulation of explosive volcanoes

Pinatubo AOD via GISS E2.1 + MATRIX



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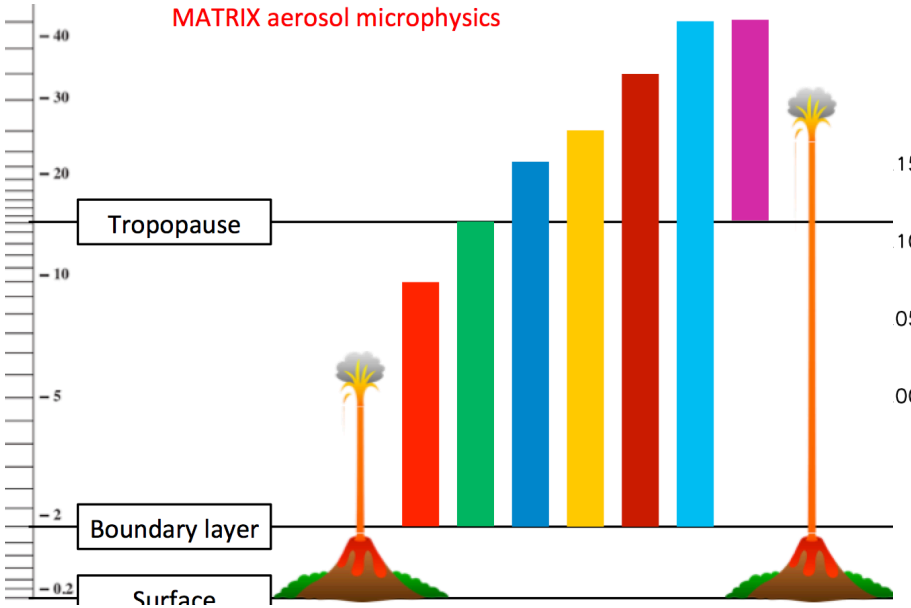
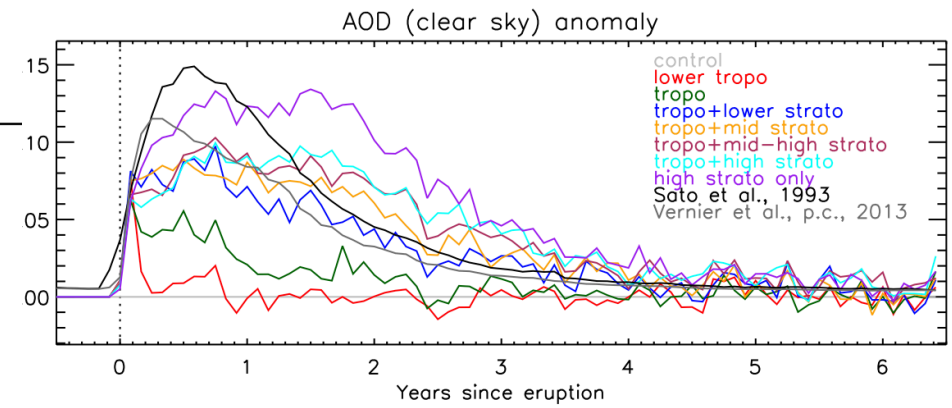
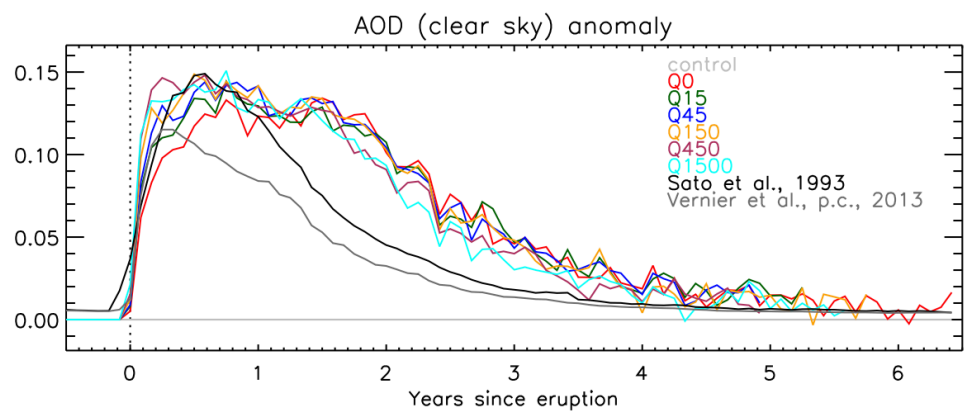
Importance of water injection as well as SO2?





H2O adds OH and speeds processing of SO2

No big impact on RF



US Climate Modeling Summit 2016

NOAA NCEP contributions

Hendrik L. Tolman
Director, Environmental Modeling Center

HendrikTolman@NOAA.gov

March 9, 9:30 am

Seamless Weather-Climate Science and Prediction panel

NWS / NCEP

Developments since last year:

- UMAC* review of modeling suite, some major recommendations
  - Simplify model suite
  - Unified modeling across scales
- Starting development of a unified modeling plan
- NGGPS projects
  - Selection of new global dycore for the future
    - NH, capable of running CAM globally
    - Two candidates remaining ; MPAS and FV3
  - Physics group
    - Need to unify physics, HOW ???? (link to CPO projects)
    - Meso physics features needed globally
  - Coupled demonstration projects (from CFS, Arctic workshop)
- Community modeling

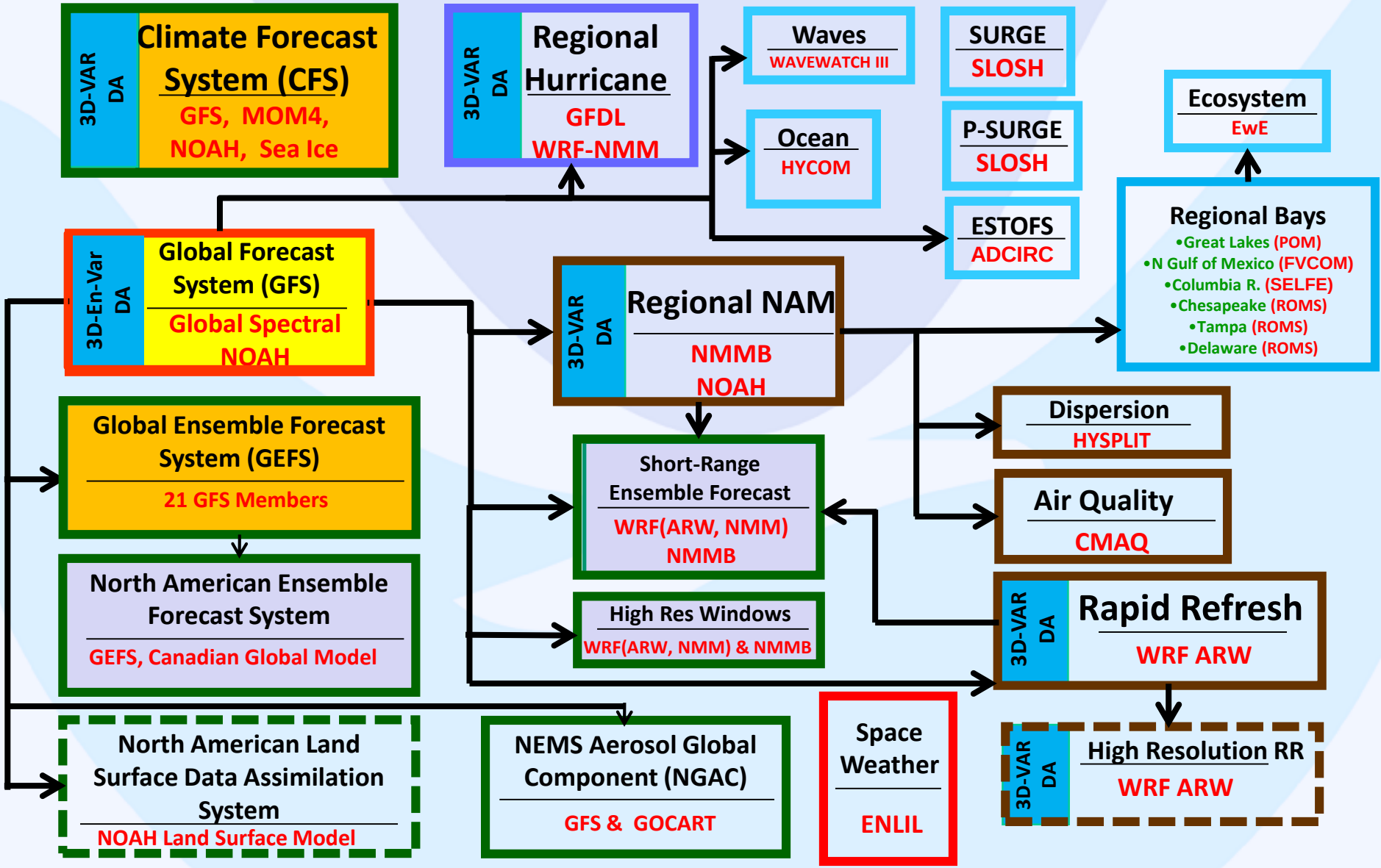
* UCACN Model Advisory Committee

https://www.earthsystemcog.org/projects/umac_model_advisory

March 9, 2:00 pm

Center Updates

Past: Production suite ca. January 2014



Unify: atmosphere

Start with weather side:

- We are NWS !

Starting with products:

- What forecast time ranges
- which reasonably imply
  - Run cadences
  - Update cycle.
- Not so clear:
  - Resolutions
  - Data Assimilation
  - Reforecast / reanalysis / retrospectives
- Need to map requirements to forecast ranges

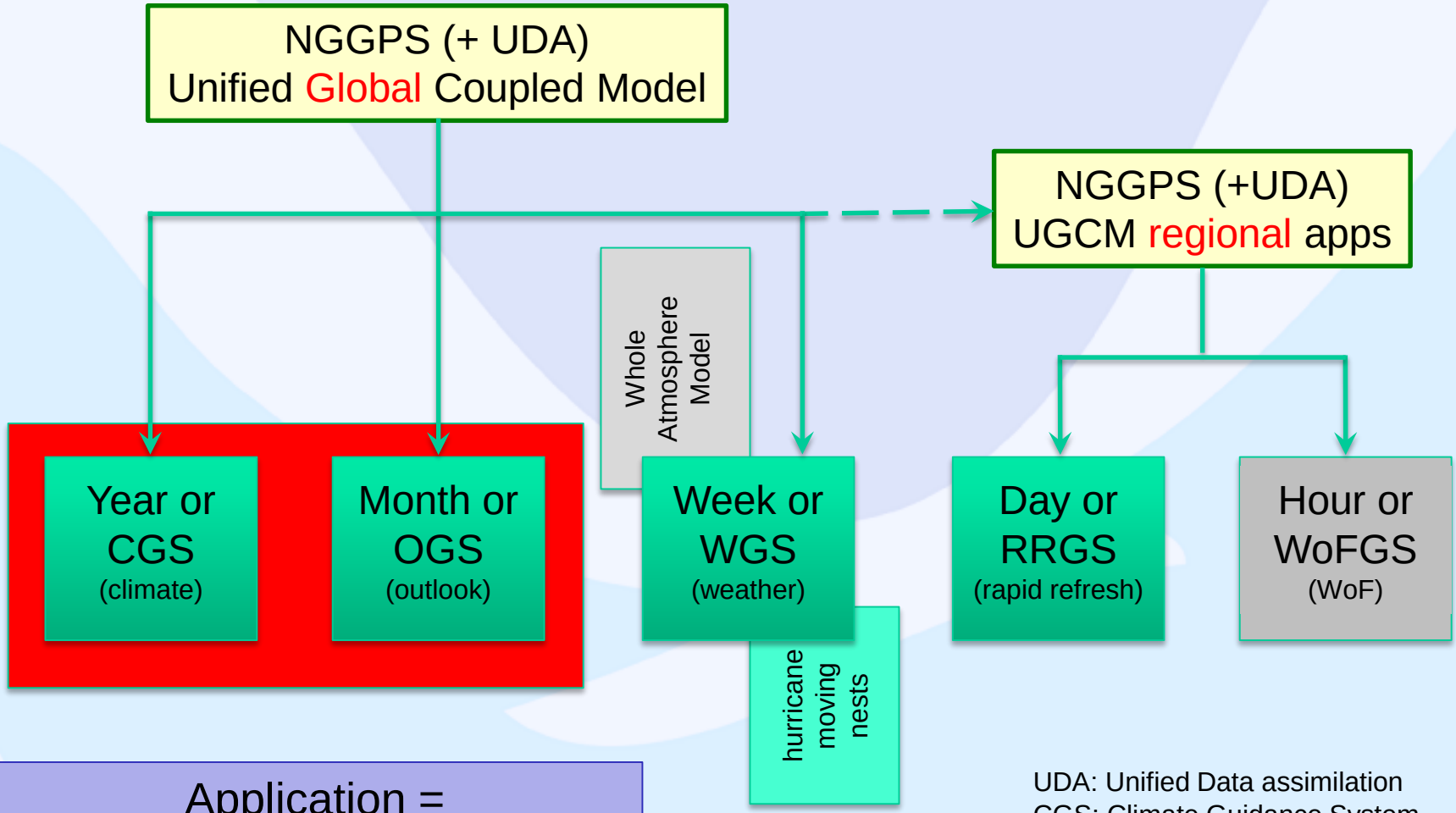
Possible Approach			
Range	Target	Cadence	Means
year	Seasonal	?	9-15mo
month	S2S	6-24h	35-45d
week	Actionable weather	6h	3-16d
day	Convection resolving	1h	18-36h
hour	Warn On Forecast *	5-15 ‘	3-6h
now	Analyses **	?	now

* FACETs

** Separating from DA for models

Tentatively vetted at the Dec. 2015 NCEP Production Suite Review

Future: Unified design (high level goal)



Application =
Coupled Ensemble
+ Reanalysis + Reforecast

UDA: Unified Data assimilation
CGS: Climate Guidance System
OGS: Outlook Guidance System
WGS: Weather Guidance System
RRGS: Rapid Refresh Guidance System
WoFGS; WoF Guidance System

Tentatively vetted at the Dec. 2015 NCEP Production Suite Review

Year:

Tentative layout:

- 50km resolution, 9-15 month forecasts, full ensemble, updating weekly. Assuming DA mostly from hourly range, coupled

Present status:

- Corresponds to present CFS, but will only include longest runs

Key science questions

- Predictability; what to focus on for products
- Advanced coupling
- Physics suitable for severe weather outlook

Implementation issues:

- Dropping 45 day runs of present CFS requires “month” solution to be in place, otherwise “trivial”.

Month:

Tentative layout:

- Extend present weather scale ensembles out to week 3-4.
- 35km resolution (constant for forecast), coupling (ocean, ice, ?), increased ensemble size, DA from week range ?

Present status:

- Extend range of GEFS without stepping down resolution
- Could be uncoupled baseline IOC, but coupling preferred

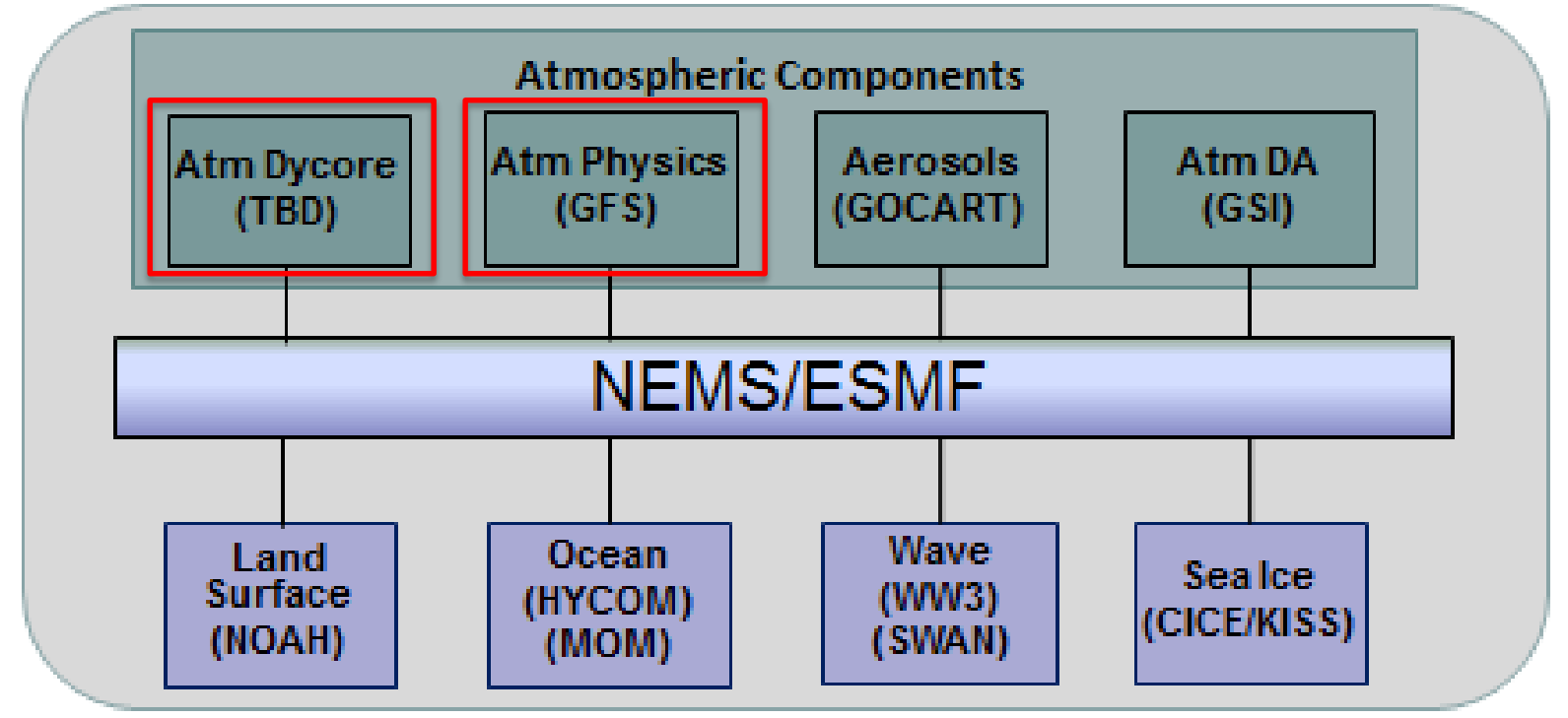
Key science questions:

- Predictability, target products
- Need / payback for coupling
- Physics improvements (severe weather outlook)

Implementation issues:

- Slot can be filled by natural extension of GEFS

NGGPS/UGCM and NEMS / ESMF



Modular modeling, using ESMF to modularize elements
in fully coupled unified global model
(+ *NWM, ionosphere , ecosystems , ……*)

NGGPS physics

Scale aware
Stochastic
"Unified"

Atmosphere Model including Dynamics

Dynamical equations, advection, horizontal mixing, diffusion.

standard interface for model physics

Δt, u, v, w, T, θ, p, z, q_x, c_x, a_x
destaggered

Tendencies
and Updates

Atmospheric Physics Driver

(init, run, finalize modes)

Modified Kalnay Rules Layer

Radiation | Deep and Shallow Cumulus | Surface Layer | PBL and Vertical Mixing | Micro-physics

Initialize Physics Tables and Databases

Init Mode

Finalize Mode.

Output Diagnostics
- fields
- rates
- budgets
- others

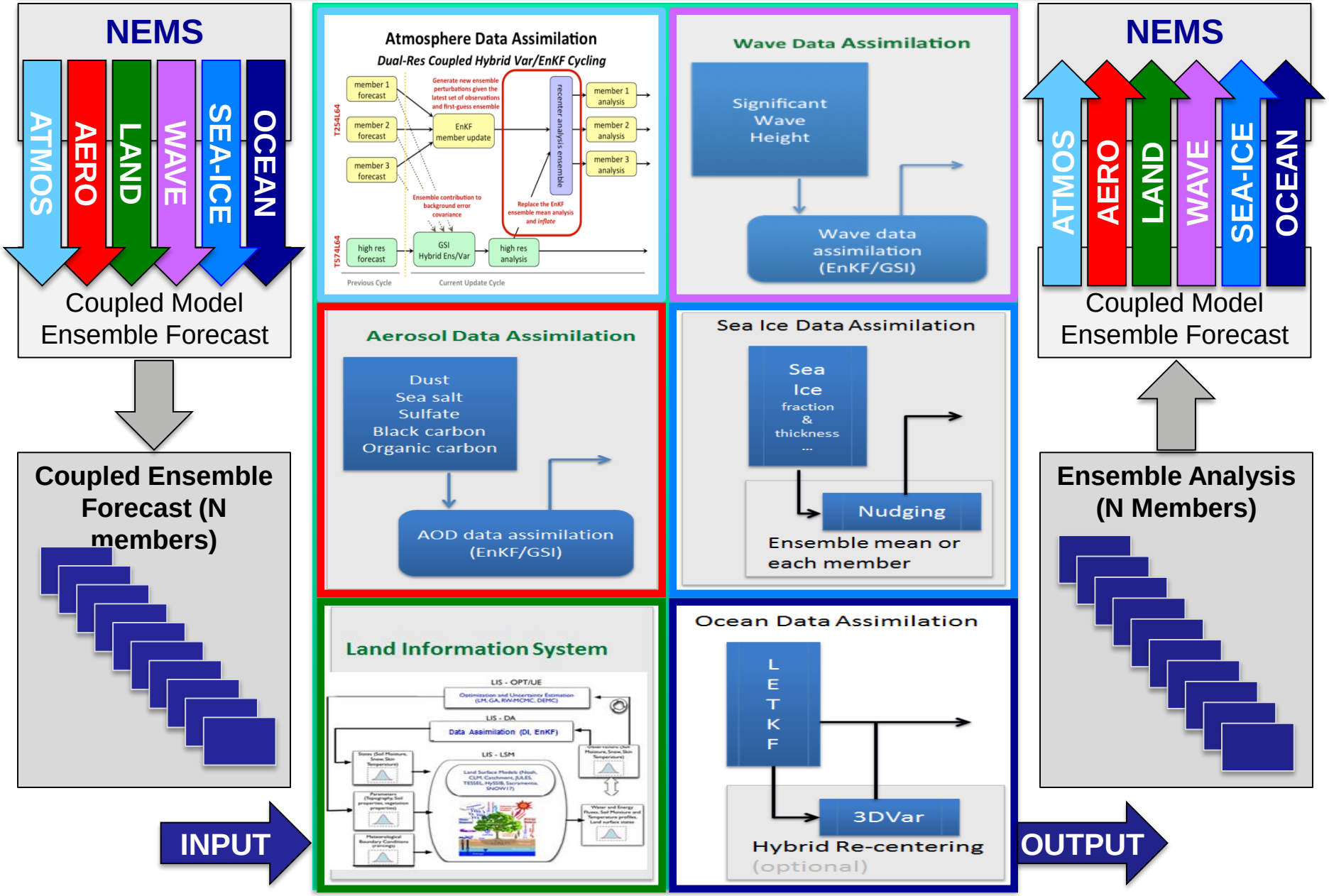
NUOPC Physics Driver Schematic
Extend to coupling!

DTC support as CCPP

Coupled DA Proof of Concept

- Coupling models and coupled DA.
  - Atmosphere: Hybrid 4D-EnVAR approach using a 80-member coupled forecast and analysis ensemble, with Semi-lagrangian dynamics, and 128 levels in the vertical hybrid sigma/pressure coordinates.
  - Ocean/Seaice: GFDL MOM5.1/MOM6 and/or HYCOM for the ocean and sea-ice coupling, using the NEMS coupler.
  - Aerosols: Inline GOCART for aerosol coupling.
  - Waves: Inline WAVEWATCH III for wave coupling.
  - Land: Inline Noah Land Model for land coupling.

NCEP Coupled Hybrid Data Assimilation and Forecast System



Backup slides

Models: atmosphere

Range	Year	Month	Week	Day	Hour	Now
Target	Seasonal outlook	S2S outlook	Actionable weather	Convection resolving	Warn On Forecast	Analyses / nowcast
Present models	CFS	CFS (GEFS extension)	GFS, GEFS, NAM, SREF, RAP, hurricane	HRRR, NAM nest, HiresW		RTMA, URMA, blend
Cadence	? (is 6h)	24h (is 6h)	6h	1h	5-15'	?
Range	9-15mo global	35-45d global	3-16d global (?)	18-36h regional (?)	3-6h ? regional	0 regional (?)
Updates	4y	2y	1y	1y	1y	6 mo
Reanal.	1979-now	20-25y	3y	?	?	
Where	?	WCOSS	WCOSS	WCOSS	?	WCOSS

- Ensemble based DA for all ranges (day and hour TBD), except possibly for the now range
- All global applications from single unified modeling system.
- Global / regional unification ?

- Present NPS elements not fitting in this layout:
  - Space weather (WAM-IPE / Geospace).
  - Hurricane models (GFDL / HWRF).

Basic approach : coupling

This is not just a science problem

- Requirements for additional, traditionally downstream products
- ‘”One-way” model coupling versus downstream model:
  - Increases forcing resolution of downstream models while reducing I/O needed to force models
  - Creates a better integrated test environment for holistic evaluation of model upgrades
  - Less implementations
  - Creates environment for investigating benefits of two-way coupling. Enables two-way coupling if science proves benefit

Negative aspects of coupling:

- More complex implementations
- Less flexibility to tailor product.
- Produce “too much” compared to tailored products (forecast range)

Basic approach : coupling

Many potentially coupled model components already have products in the production suite :

- Where no products exists, science suggests benefit of coupling
- For the hourly forecast range, all still TBD
- DA is also moving (internationally) to coupling
- Space weather making its way into operations
- Ecosystems (marine) being considered (not in table)

Subsystem	Year	Month	Week	Day	Hour
Land / hydro	Y	Y	Y	S	?
Ocean / coast	Y	Y	Y	S/R	?
Ice	Y	Y	S	?	?
Waves	S	Y	Y	Y	?
Aerosols	S	S	Y	Y	?
Space weather	?	?	Y	?	?

Y: present product
S: science benefit
R: unmet requirement
?: TBD

Basic approach : coupling “now”

	Influencing						
	Atmos.	Land / hydro	Ocean / coast	ice	waves	Aerosols	Space W.
Atmos.		yes	yes	yes	yes	yes	yes
Land/hydro	yes		inflow	yes	inundation		
Ocean/coast	yes	inundation		yes	WCI	climate	
Ice	yes		yes		yes		
Waves	fluxes		WCI	yes			
Aerosols	climate						yes
Space W.	yes					yes	

Green boxes: light: tradition 1-wy downstream coupling
dark: two-way coupling in selected operations.
Grey boxes: fixed data, not dynamic coupling
Black text: presently in place.
Red text: science has shown impact

Basic approach : DA

Unifying on GSI and ensemble hybrid 4DVAR.

Global focus:

- Is a single DA system for all global models feasible?
  - Freeze or update DA for climate applications
- Where do we go with coupling
- Issues:
  - Scaling of GSI
  - Resolution of underlying ensemble

Regional focus:

- We do want to unify, but how feasible is this?
- Great progress with convection resolving, but
- not yet at the science level achieved at global scales
  - Ensemble based convection resolving DA ….
  - Hourly WoF, many efforts, no real link to production suite yet

Estimating compute costs

Going on with the memo / spreadsheet from previous Part.

- Low, med, high estimate; high-2 represents aggressive resolution

Starting from costs of present systems (PFlop)

Identifying factors that drive costs:

- Resolution, cadence, forecast range, ensemble size, DA, other

Go from actual PFlop per model, to required computer peak performance

- “Missing” part of NPS in analysis
- New requirements (NWC etc)
- Peak performance versus actual usage

Need same analysis for disk, tape, communications

Estimating element costs

	resolution	levels	length	cadence	members	phys / num	coupling	DA	cost
	km	-	h	per day	-	X	X	X	Pflops
Year ("CFS")	100	64	6480	4	1				0.009
low	50	128	6480	0.14	28	1.3	1.1	1	0.126
med	50	128	8640	0.14	28	1.5	1.1	1	0.194
high	50	128	10800	0.14	56	1.7	1.1	1	0.550
high (res)	35	128	10800	0.14	56	1.7	1.1	1	1.604
Month ("GEFS")	35	64	277	4	21				0.020
wave ensemble	55	1440	240	4	21				0.006
low	35	64	840	4	21	1.3	1.5	1	0.119
med	35	90	960	4	31	1.5	1.5	1	0.326
high	35	128	1080	4	41	1.7	1.5	1	0.782
high (res)	18	128	1080	4	21	1.7	1.5	1	2.944
Week ("GFS")	13	64	256	4	1				0.028
SREF	16	40	84	4	26				0.029
RAP	13	50	18	4	1				0.004
wave multi_1/2	54-18-7	1440	180	4	1				0.005
RTOFS Global	13	64	192	1	1				0.003
low	11	128	144	4	15	1.3	1.3	2	2.644
med	11	128	168	4	21	1.5	1.3	2	4.982
high	11	128	192	4	26	1.7	1.3	2	7.990
high (res)	9	128	192	4	31	1.7	1.3	2	17.393
Day ("HRRR")	3	64	15	24	1				0.025
NAM parent and nest	4	60	60	4					0.014
HiResWin	3	45	48	2					0.010
low	3	64	18	24	21	1	1.3	3	5.063
med	3	90	21	24	26	1	1.3	3	9.173
high	3	128	24	24	31	1	1.3	3	16.160
high (res)	2	128	24	24	31	1	1.3	3	54.541
Hour (WoF from HRRR)	data taken directly from previous "day" block								
low	1	64	4	96	26	1	1	3	56.300
med	1	90	3	144	26	1	1	3	89.068
high	1	128	2	288	26	1	1	3	168.900
high (res)	0.5	128	2	288	26	1	1	3	1351.200

Resulting compute needs (ops)

Cost in PFlop

	year	month	week	day	hour	total
low	0.32	0.30	6.6	12.7	141	161
med	0.49	0.81	12.5	22.9	223	259
high	1.38	1.95	20.0	40.4	422	486
high-2	4.01	7.36	43.5	136.4	3378	3569

Overall costs per element uncertain, but clearly different with respect to NPS element:

- Hour / WoF very expensive
- Other elements feasible in next 5-10 years at “med” level

Moving from equal split between global (year-week) and meso (day-hour) modeling to compute focus on meso.

Percentage of NPS without hour element

	year	month	week	day
low	1.6%	1.5%	33.2%	63.7%
med	1.3%	2.2%	34.0%	62.5%
high	2.2%	3.1%	31.4%	63.4%
high-2	2.1%	3.8%	22.7%	71.3%

Compute needs beyond operations

More elements that operational machine only

- Backup machine of same size
- T2O needs for NCEP and partners to fully support ops
- R&D needs “higher up in the funnel” (tentative)
  - ➤ Outside NPS represents balanced one-NOAA HPC approach
- Separate resources for Reforecast / Reanalysis (RR)

PFlop with hour element, feasible ?

	ops	backup	T2O	R&D	RR	total
low	161	161	321	1071	120	1834
med	259	259	519	1729	195	2961
high	486	486	972	3240	364	5548
high-2	3569	3569	7138	23795	2677	40748

PFlop without hour element, feasible !

	ops	backup	T2O	R&D	RR	total
low	20	20	40	133	15	227
med	37	37	73	245	28	419
high	64	64	127	425	48	727
high-2	191	191	382	1275	143	2183