GFDL Models

Where are we and

Where do we want to go?

WGCM24

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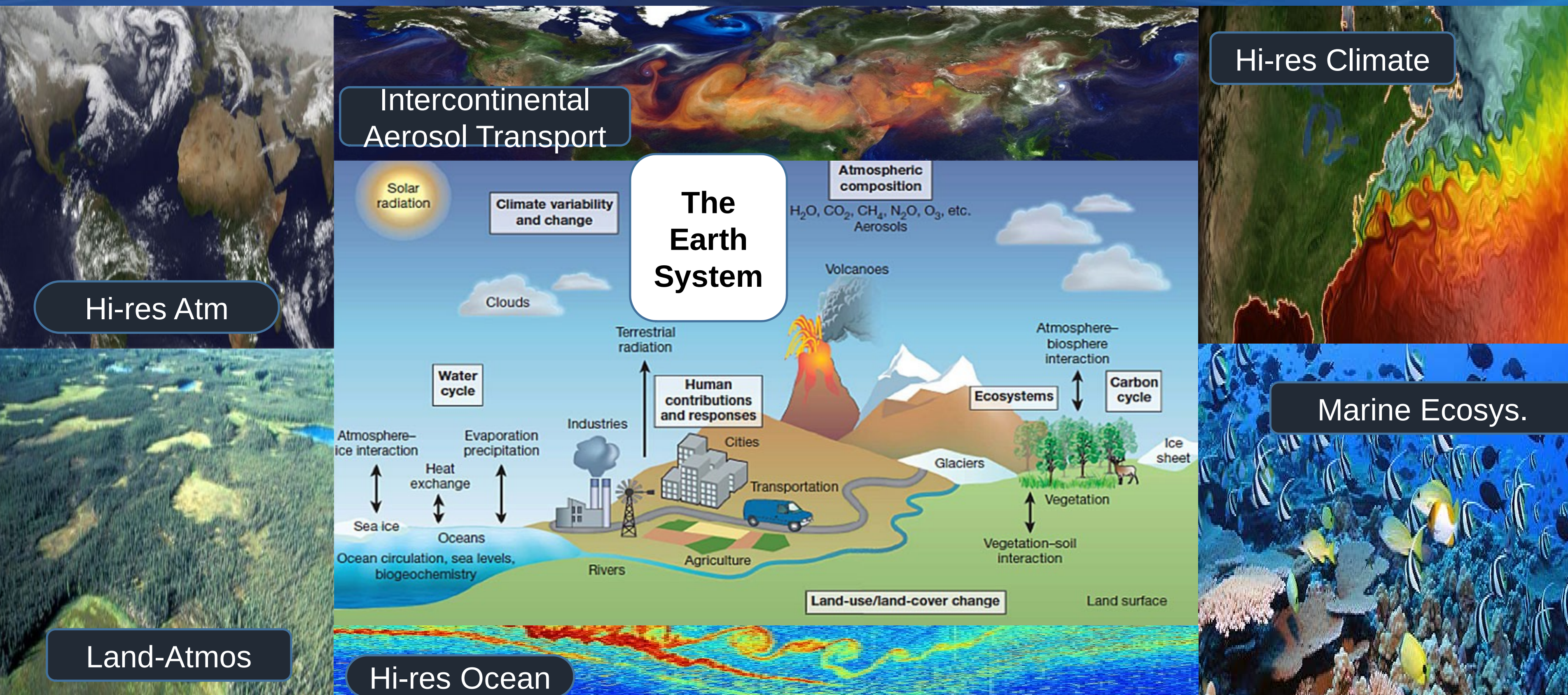
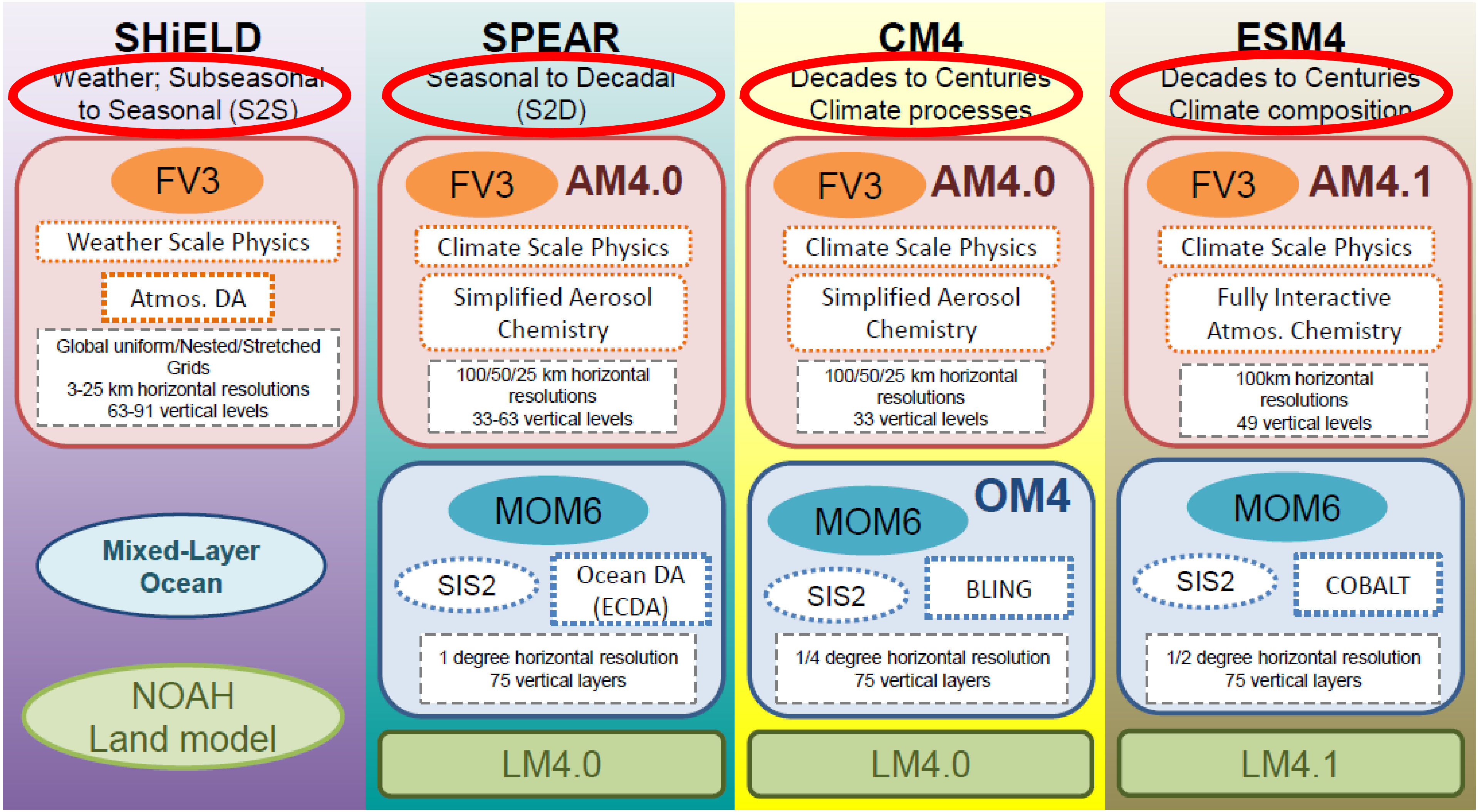
Modeling, Understanding and Predicting the Earth System

NOAA/OAR/GFDL: *An Integrative Modeling Strategy*



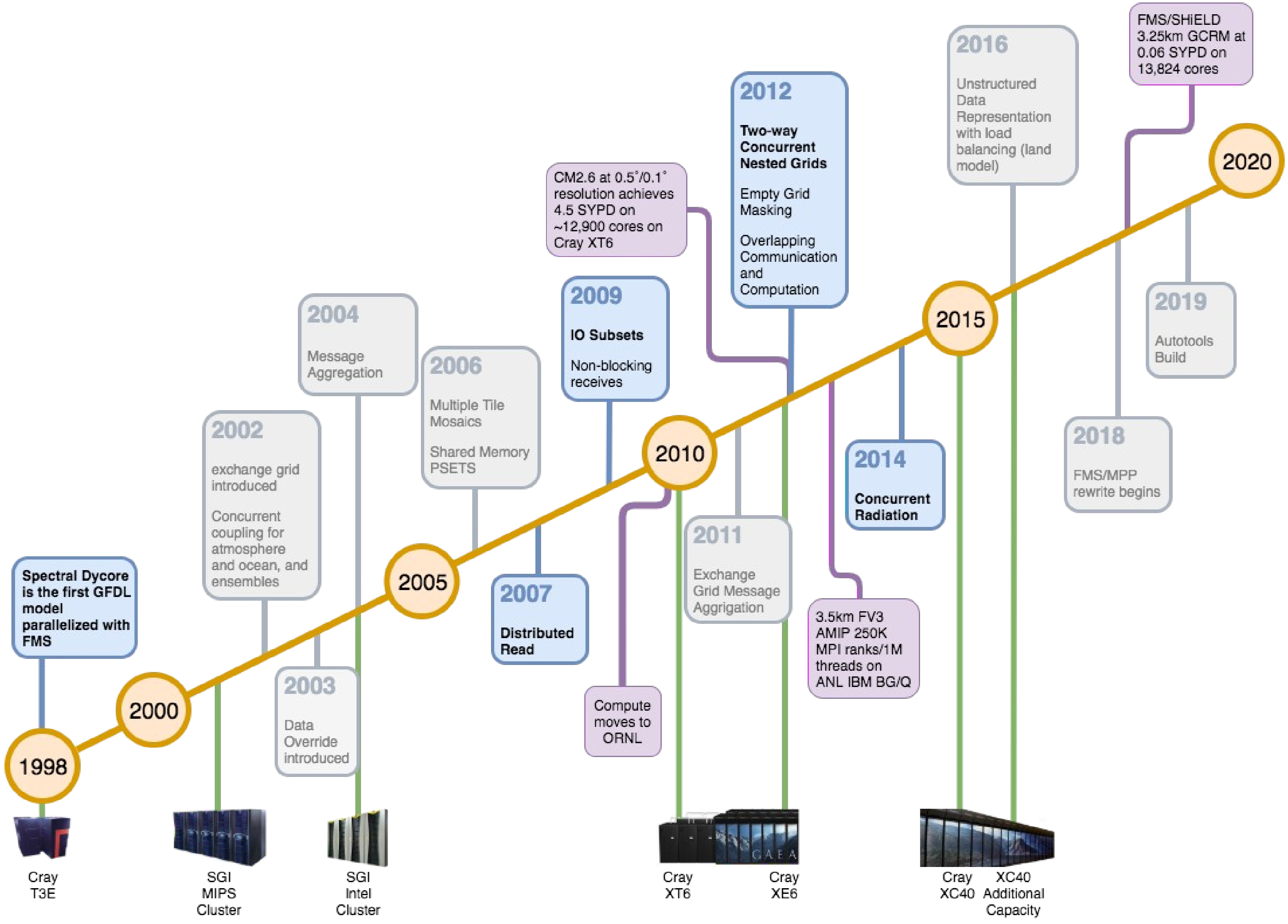
Interactions leading to Changes, Variations, Extremes

OAR/GFDL: Seamless Modeling of the Earth System



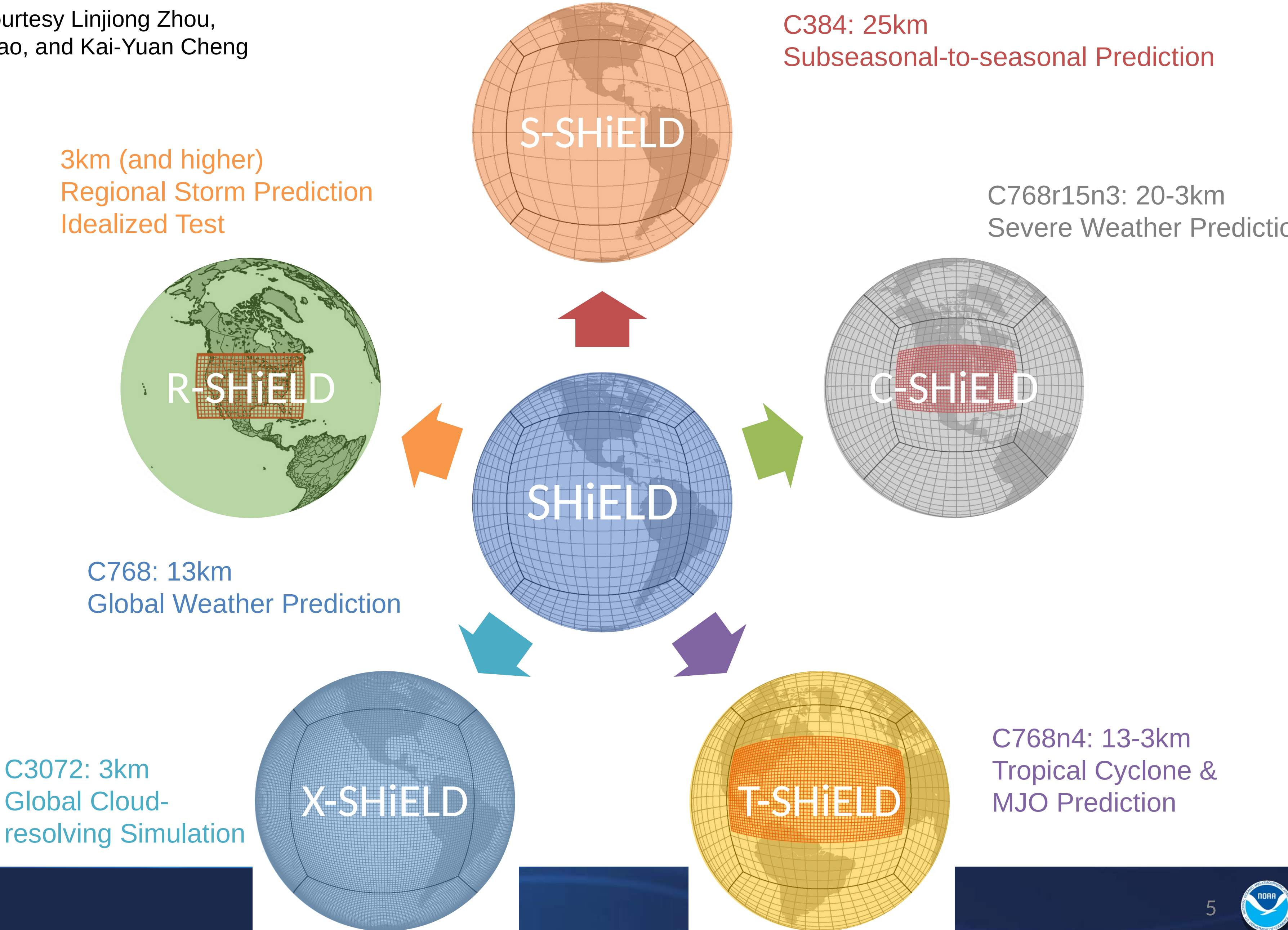
Understanding, Applications, Predictions & Projections

FMS provides the basis for 20 years of Unified Modeling

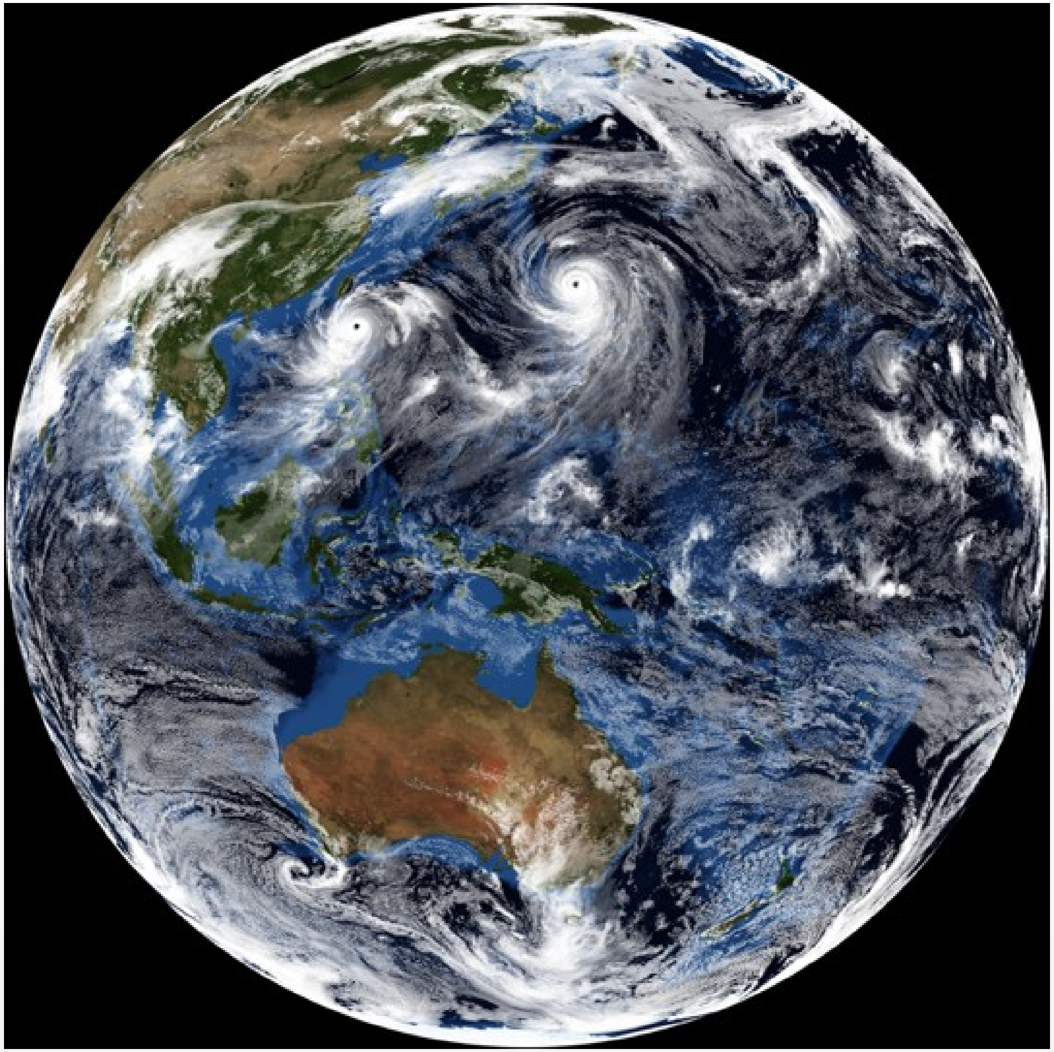


SHiELD System for High-resolution prediction on Earth-to-Local Domains

Plot courtesy Linjiong Zhou, Kun Gao, and Kai-Yuan Cheng



Global Cloud-Resolving Modeling



3.3-km GFDL X-SHiELD GCRM: Great realism, way expensive
Seamlessly integrated with all other UFS models

FV3-based GCRMs at GFDL and NASA have led US efforts since 2007.

GFDL X-SHiELD a powerful tool for weather prediction, climate modeling, and basic science. Leverages UFS advances
(cf. TKE-EDMF improvements to Stratocumulus)

Use case: Vulcan and UW use ML *emulation* of GCRM in a cheap climate model to reduce biases.

VULCAN

GFDL

Heterogeneous Computing

GFDL: fastest nonhydro model in DYAMOND but still too expensive.

NASA Goddard: 30x GPU speedup in FV3-based GEOS in early 2010s. (This takes a lot of work!!)

GridTools DSL: *performance portability* between CPUs, GPUs, ARMs, etc.

- Swiss/German COSMO and German ICON already ported
- ECMWF plan to port **soon**

Public-Private-University partnership working **now** to port FV3 and the UFS into GridTools.

Goal: Accelerate to global 1 km

Model	Nodes	CPU Cores	SDPD
ARPEGE-NH	300	7200	2.6
FV3	384	13,824	19
GEOS	512	20,480	6.2
ICON	540	12,960	6.1
IFS	360	12,960	124
MPAS	256	9216	3.5
NICAM	640	2560	2.6
SAM	128	4608	6.0
UM	340	12,240	6.0

Table 5 from Bjorn Stevens et al., 2019, PEPS
All models except ARPEGE-NH and ICON at same or coarser Δx

GridTools

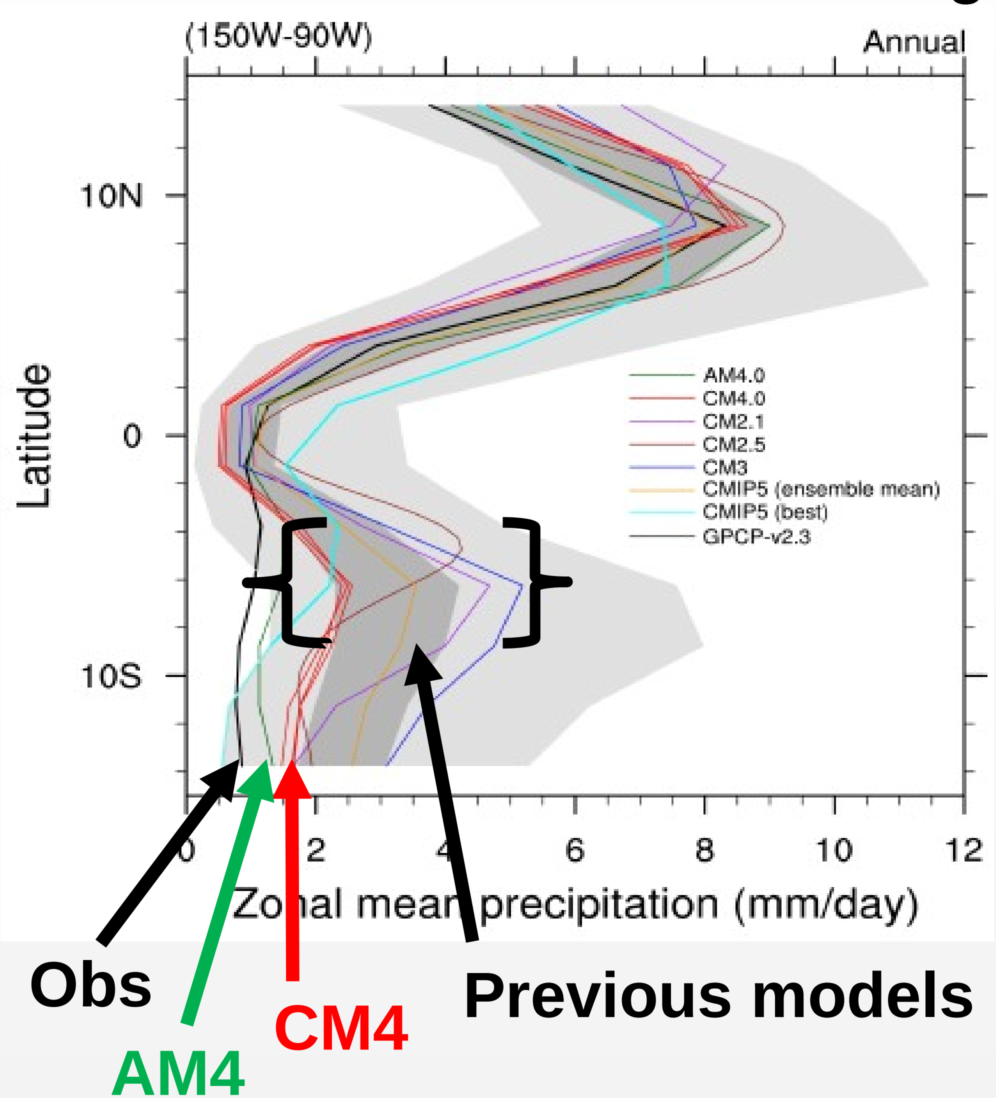
GFDL VULCAN UNIVERSITY OF WASHINGTON 1861 NASA

CSCS Centro Svizzero di Calcolo Scientifico Swiss National Supercomputing Centre

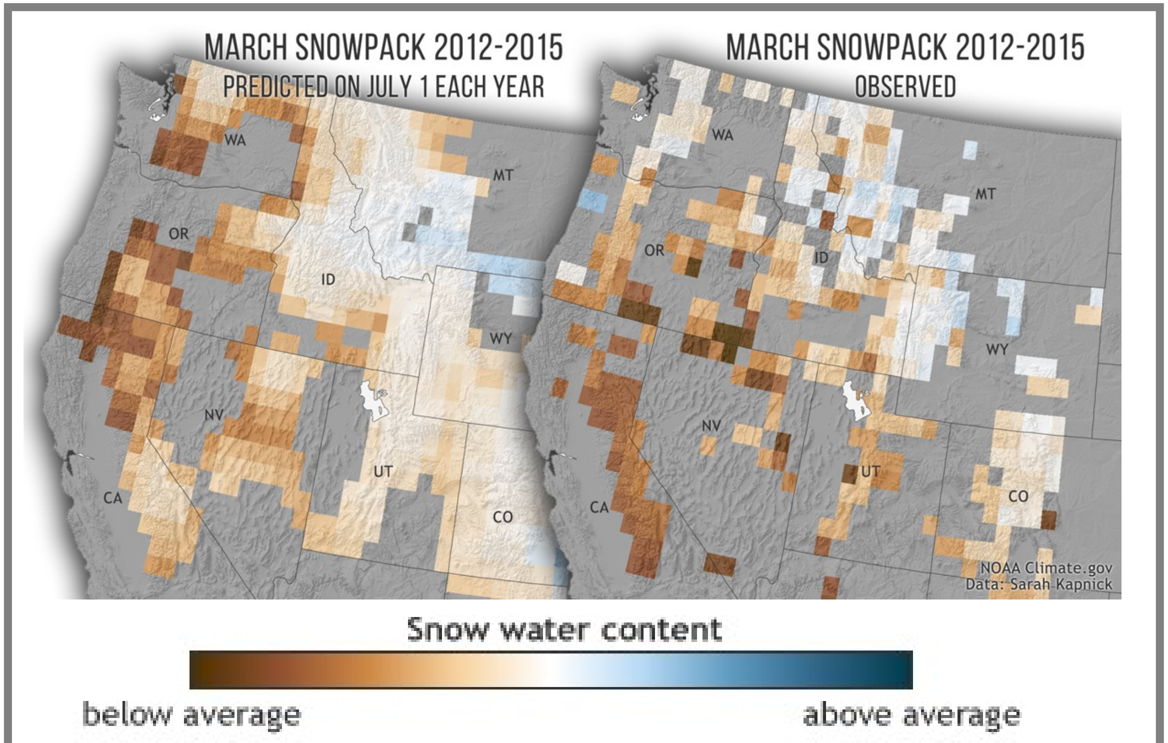
ETH zürich

Strongly Improved Regional Precipitation

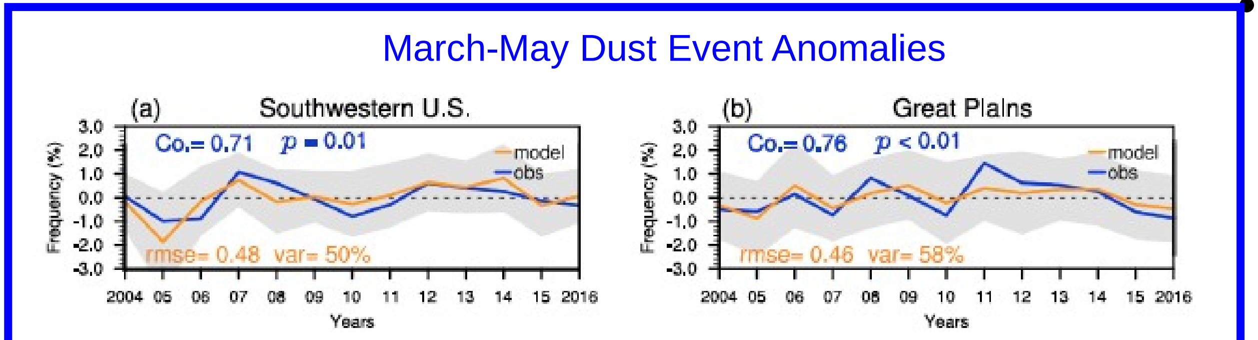
Pacific Double ITCZ Challenge



Prediction Skill: New Skill Identified



Source: Climate.gov image adapted from Kapnick et al., Proc. Natl. Acad. Sci. 2018

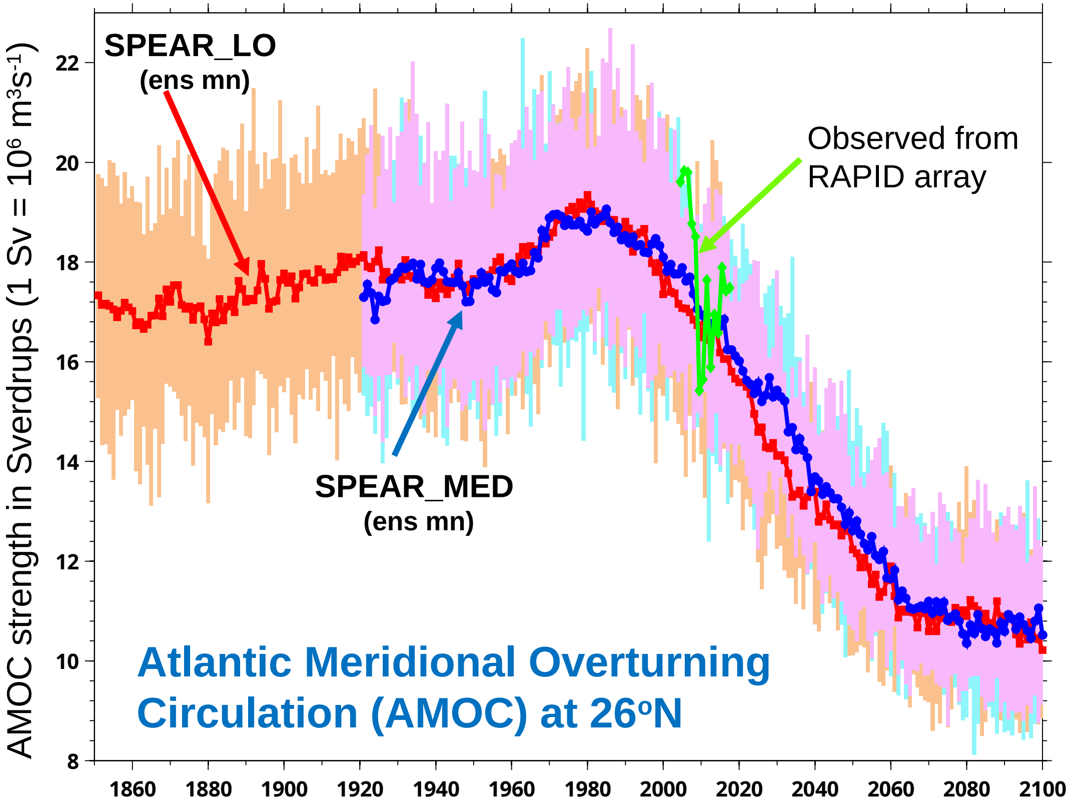


- We are successively looking at more complex prediction problems
  - Start with precipitation & temperature (Jia et al. *J Clim*, 2015, 2016, 2017; Zhang & Delworth, *Nature Comm*, 2018)
  - Extratropical storm tracks (Yang et al., *J Clim*, 2015)
  - Snowpack (Kapnick et al., *PNAS*, 2018)
  - Dustiness (Pu et al, *GRL* 2019)
- Improvements in prediction systems push the limit of prediction for phenomena, regional scope, & lead time

SPEAR Large Ensembles

Seasonal/Decadal prediction model is used to generate 30-member ensembles of projections for 1851-2100.

- 1851-2010: Use observed atmospheric composition
- 2011-2100: Use projected atmospheric composition from SSP5-85



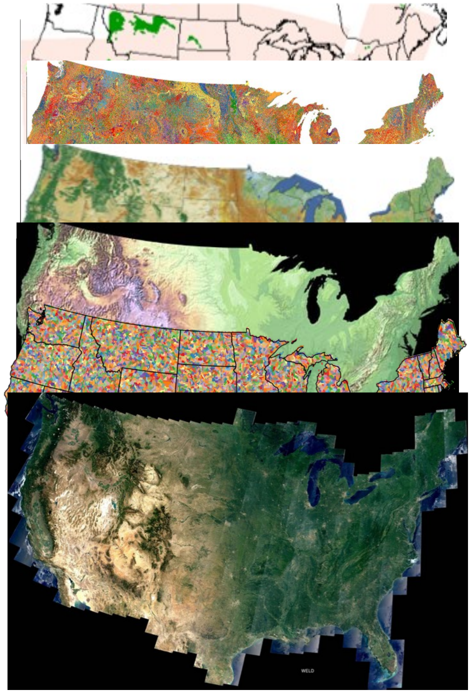
30-member ensembles using both SPEAR_LO (100 km atmosphere) and SPEAR_MED (50 km atmosphere)

Observations from RAPID array fall within model spread.

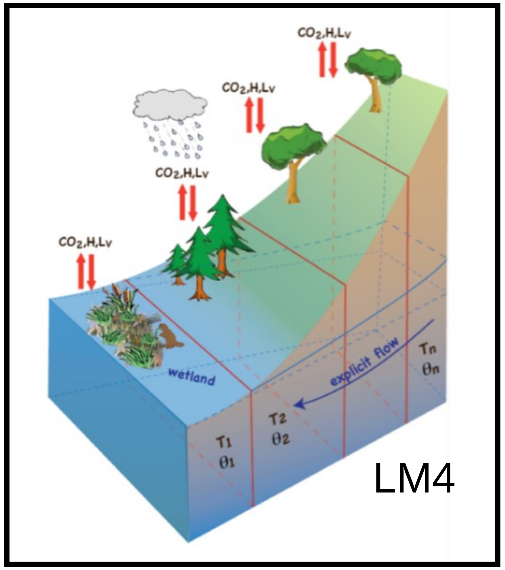
Large ensembles help to separate the signal of climate change from the noise of climate variability

Where we are: Land model prototype capturing 30m-scale water heterogeneity

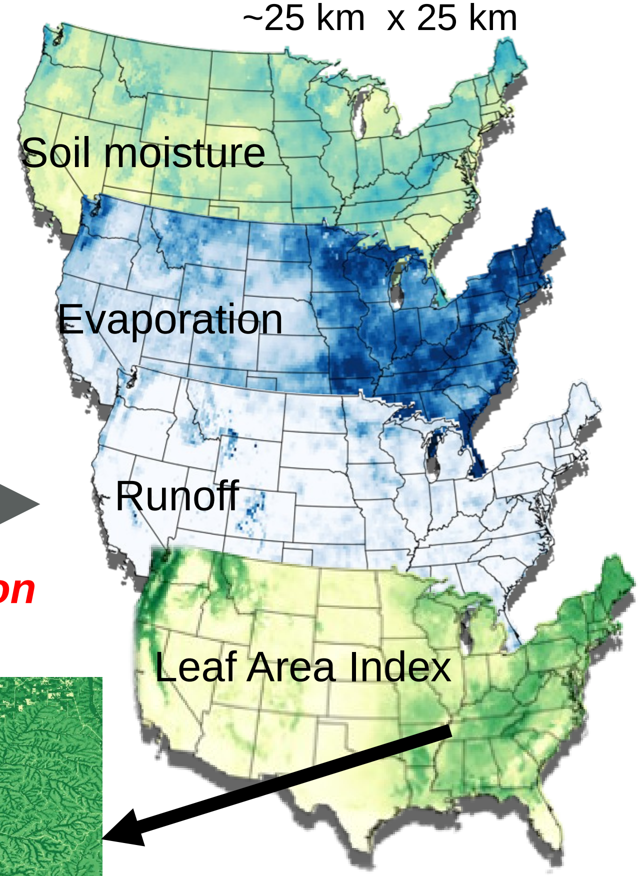
Environmental data



Hydro-blocks



Simulations

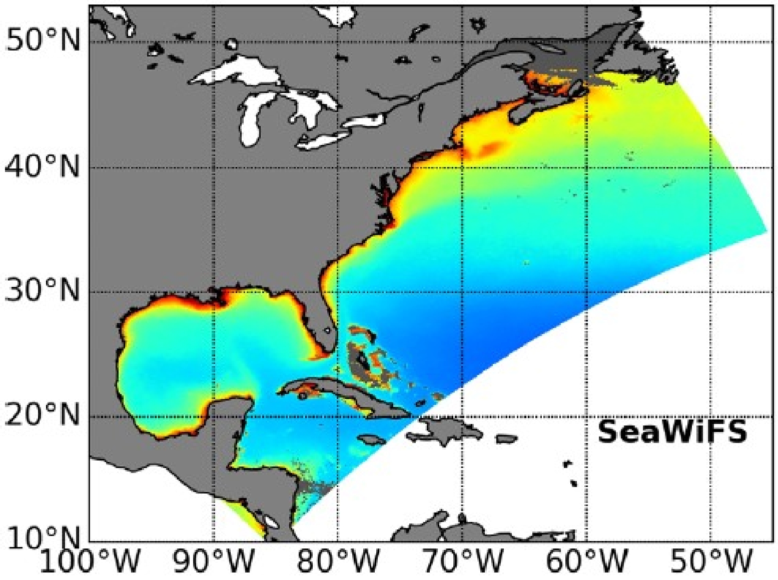


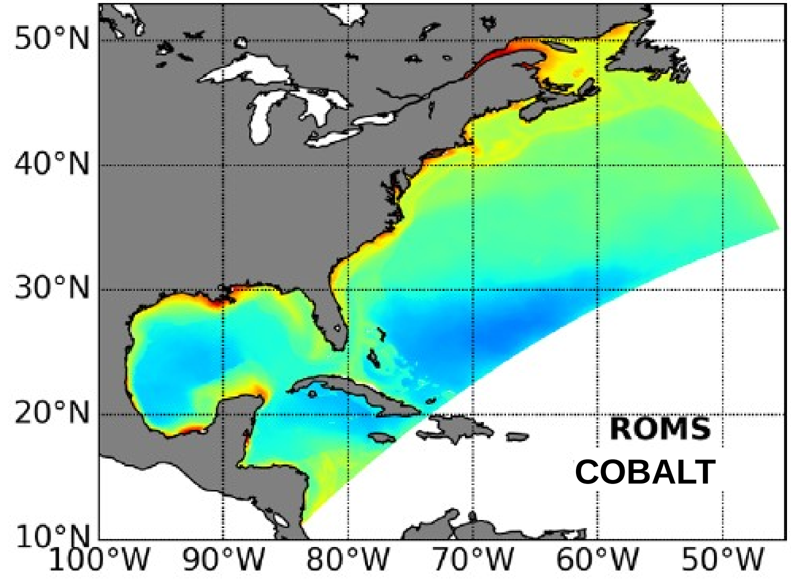
Modeling ecosystem information at the forest plot or farm scale!

- Land model run on a 1/4 degree grid over CONUS
- ~100 tiles per 1/4 degree grid cell (~13000 cells)
  - ~1.5 million different tiles over CONUS
  - Each 30 meter grid cell belongs to a tile
- Simulations between 2002 and 2014 (Spin-up 1974-2001)

Chaney et al, 2018

Where we want to go: Incorporation of fine scale local information for decision-relevant Earth System Model Predictions

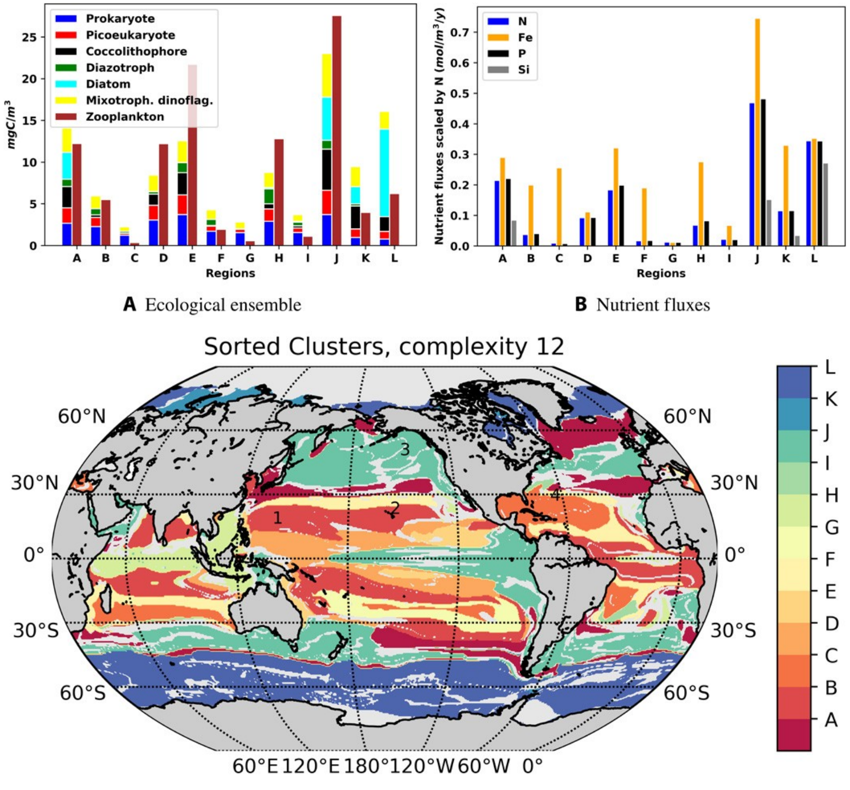




ROMS-COBALT developed through in collaboration with Rutgers University (Enrique Curchitser and Rafael Dussin); Simulations on east coast and Gulf of Mexico (Zhang et al., 2018; 2019); California Current (Dussin et al., 2019; van Oostende et al., 2018); Gulf of Alaska (Hauri et al., 2020) and Hawaii (Friedrichs et al., submitted)

Where we want to go: Regional MOM6 capacity to address these marine resource challenges within a unified framework

ML: combining theory and observations



A Ecological ensemble **B** Nutrient fluxes

C Global provinces

- From Sonnewald et al, *Science Advances* (2020), highlighted in Eos, How Machine Learning Redraws the Map of Ocean Ecosystems.
- Tracking such features of dynamics and ecology in historical simulations and model projections (ongoing and future work).

Other examples from GFDL: Muhling et al (2018) , Muhling et al (2017), Ross and Stock (2019), Chaney et al (2018)

Multiple weather-climate phenomena
Variability, extremes, and change

National Research Council (2012) Recommendation:
"Unified" modeling approaches

Internal Variability and External Forcings

Tornadoes
Snowstorms
Hurricanes
Typhoons

Heat Waves
Storm Track Variations
Madden-Julian Oscillation

El Niño-Southern Oscillation
Precipitation extreme
Intra- & Inter-season Variation
Changes in the Arctic

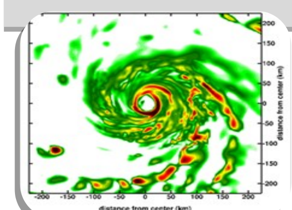
Decadal to Multi-decadal Variability
Cryospheric
Solar Variability

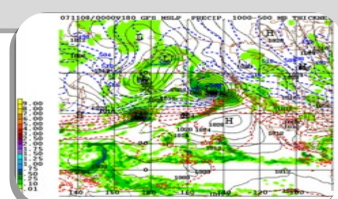
Ocean: Circulation, SLR, Heat Content
Greenhouse Gases and Aerosols

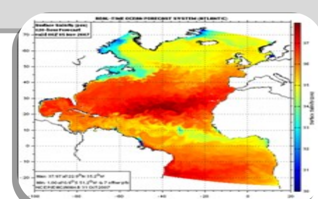
1 DAY | 30 DAYS | 1 SEASON | 3 YEARS | 10 YEARS | 30 YEARS | 100 YEARS

WEATHER | SHORT-TERM | INTERANNUAL | DECADE-TO-CENTURY

Sub-seasonal-to - Seasonal | Seasonal-to-Interannual | Interannual-to-Decadal | Decadal-to-Multidecadal







Weather to Climate is "Seamless"