WHAT ARE EARTH SYSTEM MODELS USED FOR?

CLIM 670 EARTH SYSTEM MODELING

FEBRUARY 6, 2020

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LEARNING OUTCOMES

- Understand the approaches used in the design of general circulation models and forecast systems
- Able to apply course information and skills to a real world situation

WHAT IS A GENERAL CIRCULATION MODEL (GCM)?
CLIMATE MODEL, COUPLED GCM (CGCM), ATMOSPHERIC GCM (AGCM)

- **Complex Definition**

A discrete form of the Navier-Stokes equations applied to the motion field of atmosphere, ocean, land surface, and ice in response to the solar energy and abide the fundamental physical principles such as the first law of thermodynamics, Stefan-Boltzman law, and Clausius-Clapeyron equation.

- **Simple Definition**

A collection of numerical methods that describe processes in the atmosphere, oceans, land surface, and ice, along with their interactions.

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ATMOSPHERIC MODEL
ATMOSPHERIC GENERAL CIRCULATION MODEL (AGCM)

1. A set of *numerical methods* describing only processes in which the atmospheric fluid does not undergo phase changes – **dry dynamical core.**

2. A set of *numerical methods* describing small-scale processes such as clouds, aerosol, turbulence, radiation, and their interactions – **model physics.**

3. A set of *properties* describing the interactions between the atmosphere and the other components of the climate model – **boundary conditions**.

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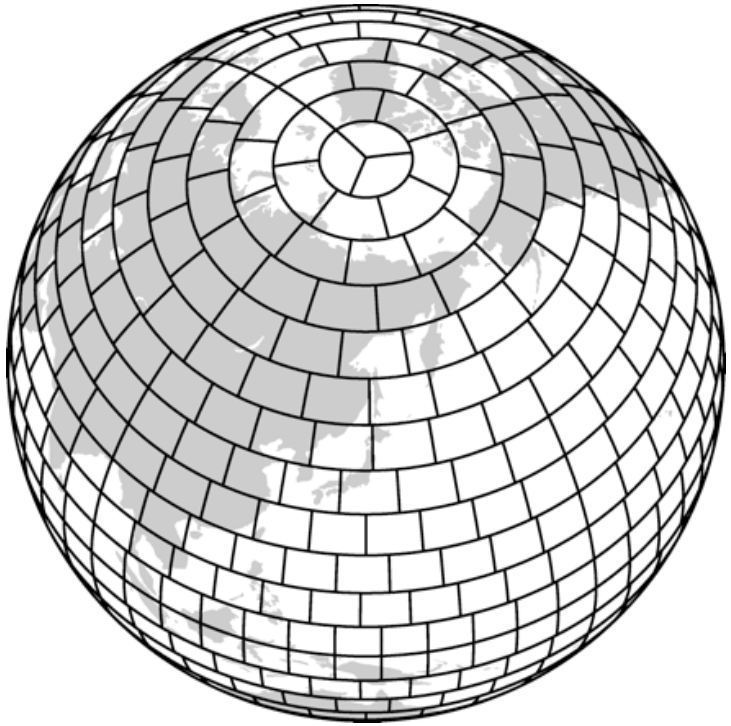
DRY DYNAMICAL CORE

- Grid that the model equations are discretized on.
- Conservative properties: dry mass, possibly energy and angular momentum.
- Requires a mix of numerical analysis, geophysical fluid dynamics, and computational science.

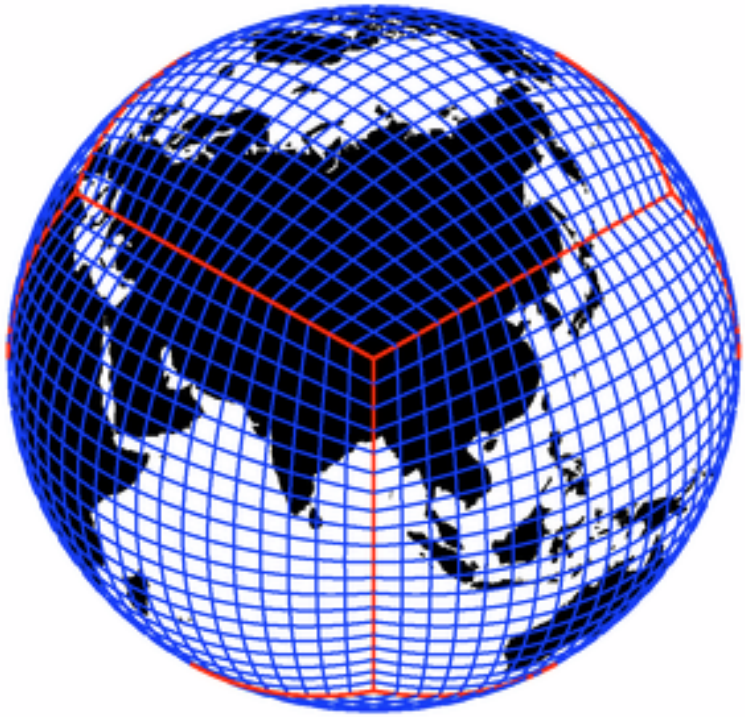
DRY DYNAMICAL CORE EXAMPLES

Gaussian

Reduced Gaussian

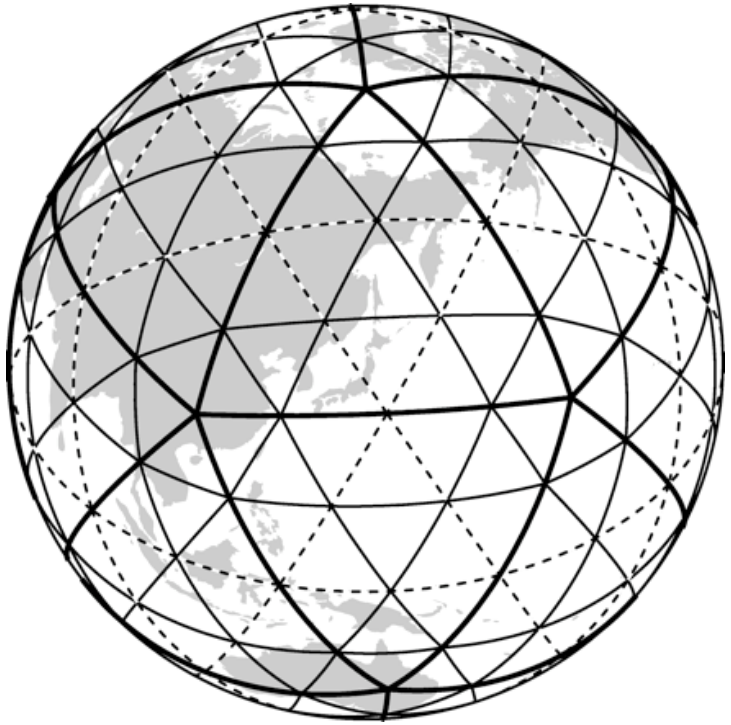


Cubed Sphere

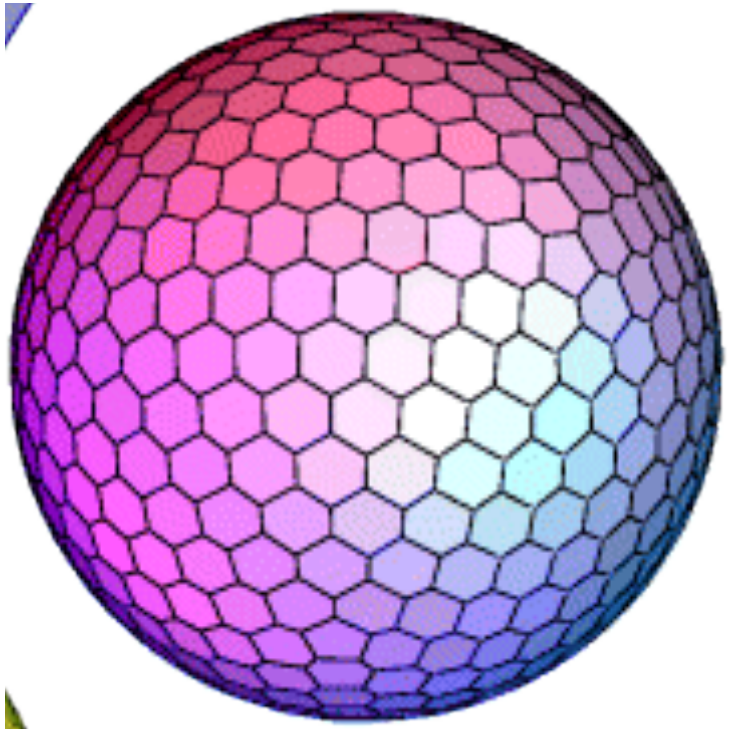


DRY DYNAMICAL CORE EXAMPLES

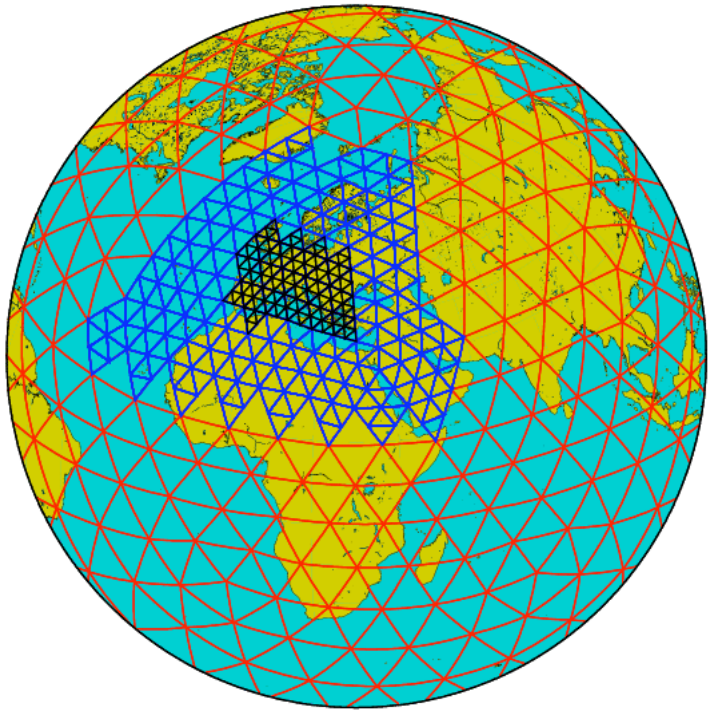
Triangular



Hexagonal

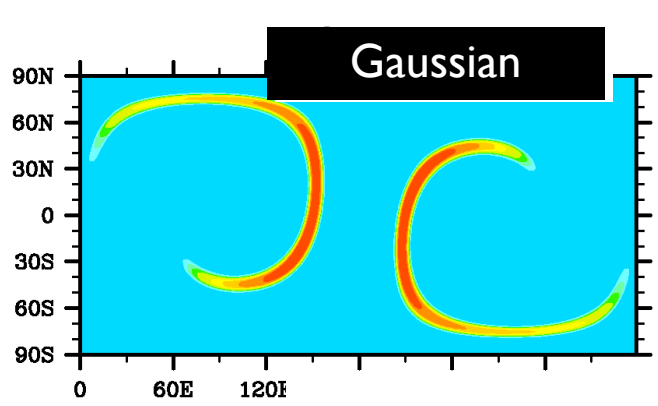


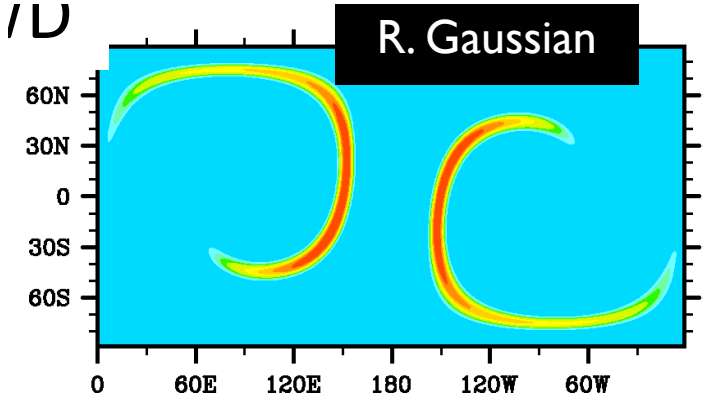
Variable Resolution

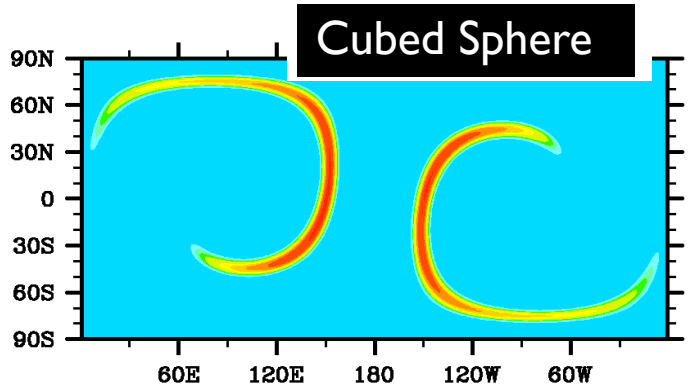


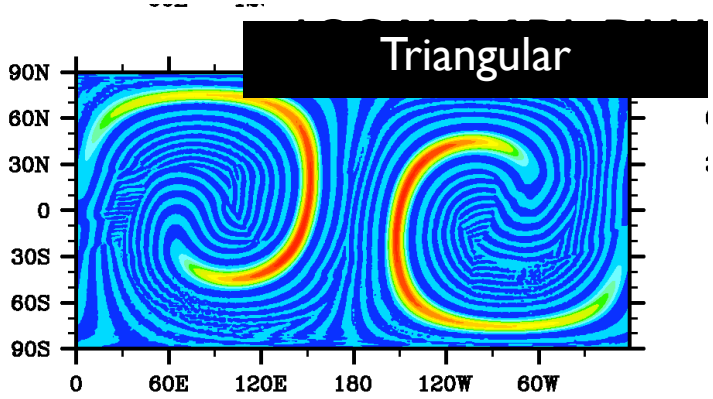
New generation

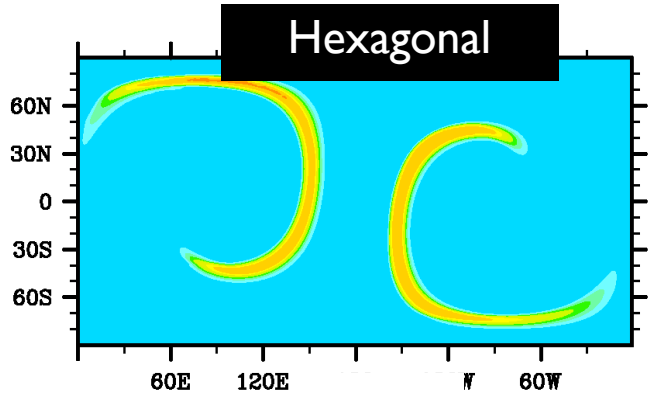
HOW DO THE GRIDS COMPARE?











Test of correlated tracers: http://earthsystemcog.org/projects/dcmip-2012

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MODEL PHYSICS/CLOUDS REPRESENTATION

1. **Conventional Parameterizations**: statistical effects of small-scale processes on the large scales are represented in terms of the atmospheric state on scales on the order of the grid box size.

2. **Stochastic Parameterizations:** extension of conventional parameterizations to include a stochastic process.

3. **Global cloud resolving models**: models with the grid box size that allows representation of small-scale processes by making direct use of equations that govern them.

4. **Super-parameterization:** bridges the gap between the conventional and stochastic parameterizations and global cloud resolving models.

5. Machine Learning Parametrizations: emulation of observed or simulated cloud parameters using data driven AI techniques.

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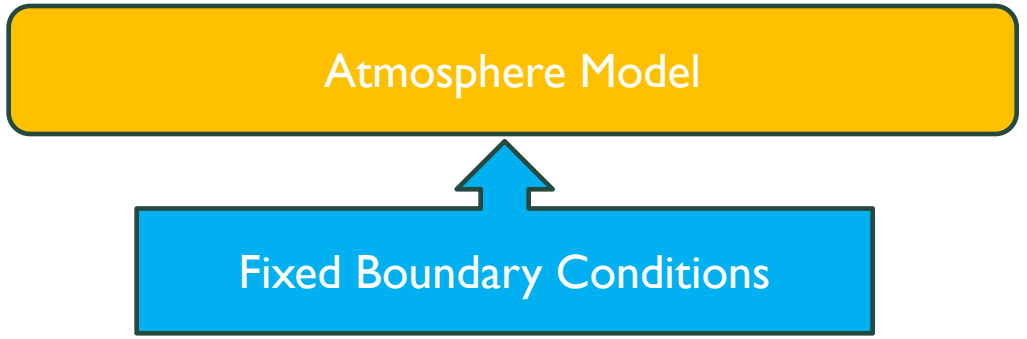
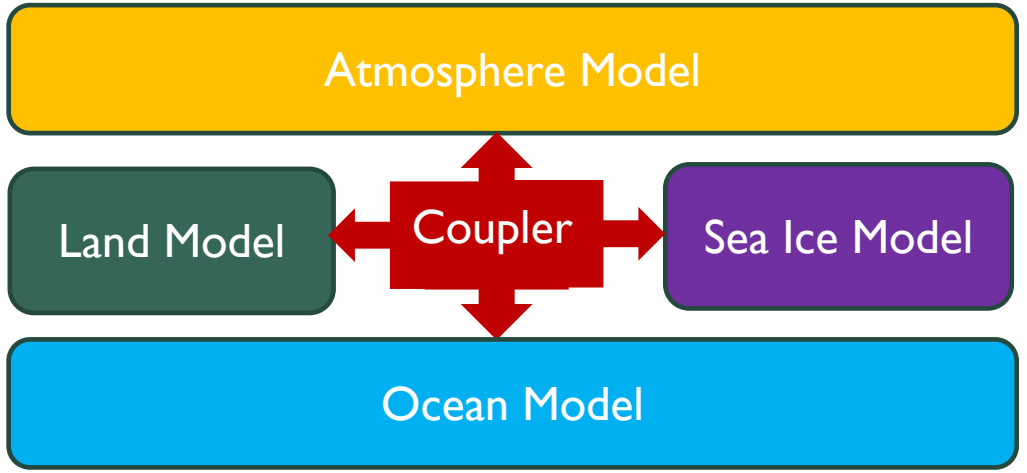
BOUNDARY CONDITIONS

- **Fixed:** uncoupled GCM
  - Observed climatology
  - Time varying observations



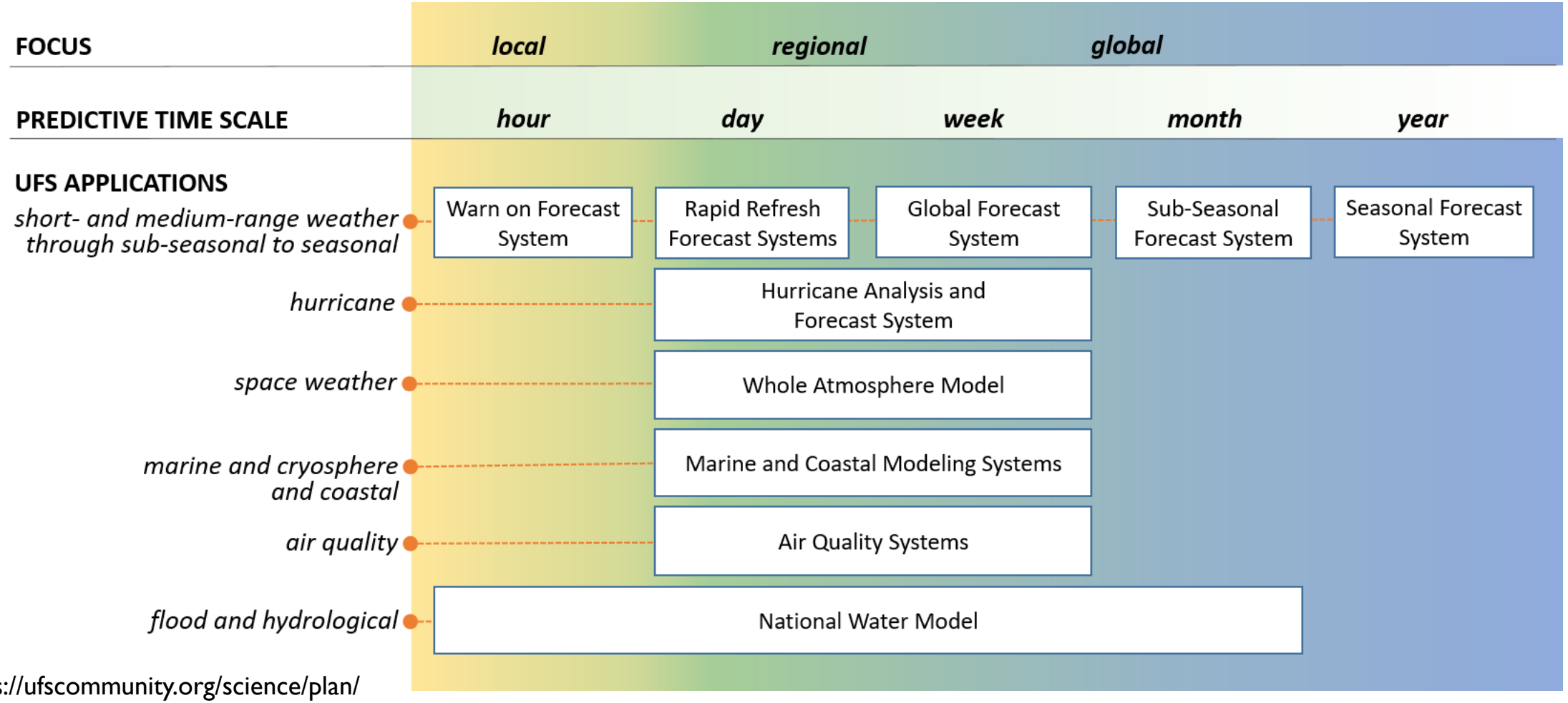
- **Dynamical Models:** coupled GCM
  - Land model
  - Ocean model
  - Sea-ice model



WHAT ARE GENERAL CIRCULATION MODELS USED FOR?

1. Design numerical experiments to help us understand how the climate system varies on time scales from a few weeks to multi-decadal, and how human activity is affecting the Earth's climate.
   - **Read the two articles**:
     - Mrinmoy Majumder, 2010: Introduction to Climate Change and Climate Models in "Impact of Climate Change on Natural Resource Management", B.K. Jana and M. Majumder (eds.).DOI 10.1007/978-90-481-3581-3_23, © Springer Science+Business Media B.V. 2010
     - Antonello Provenzale, 2014: Climate Models, Rend. Fis. Acc. Lincei, 25:49–58. DOI 10.1007/s12210-013-0268-7
2. Weather and climate forecasts
   - Need to know the current state or initial conditions
   - Forecast system = Data Assimilation System (DA) + Numerical Model (GCM)

UNIFIED FORECAST SYSTEM (UFS)



From: https://ufscommunity.org/science/plan/

UNIFIED FORECAST SYSTEM (UFS)

	Atm	Land	Ocean	Sea Ice	Aerosol	Ionosphere	Storm Surge	Wave
Medium-Range Weather	●	●						●
S2S	●	●	●	●	●			
Hurricane	●	●	●					●
Short-Range Weather	●	●						
Space Weather	●	●				●		
Coastal							●	●
Air Quality	●	●			●			

Adapted from: https://ufscommunity.org/science/aboutapps/

NAVY EARTH SYSTEM PREDICTION CAPABILITY (NAVY-ESPC)

- ESCP is the new global coupled atmosphere-ocean-sea ice prediction system developed at the Naval Research Laboratory (NRL) for operational forecasting for timescales of days to subseasonal.

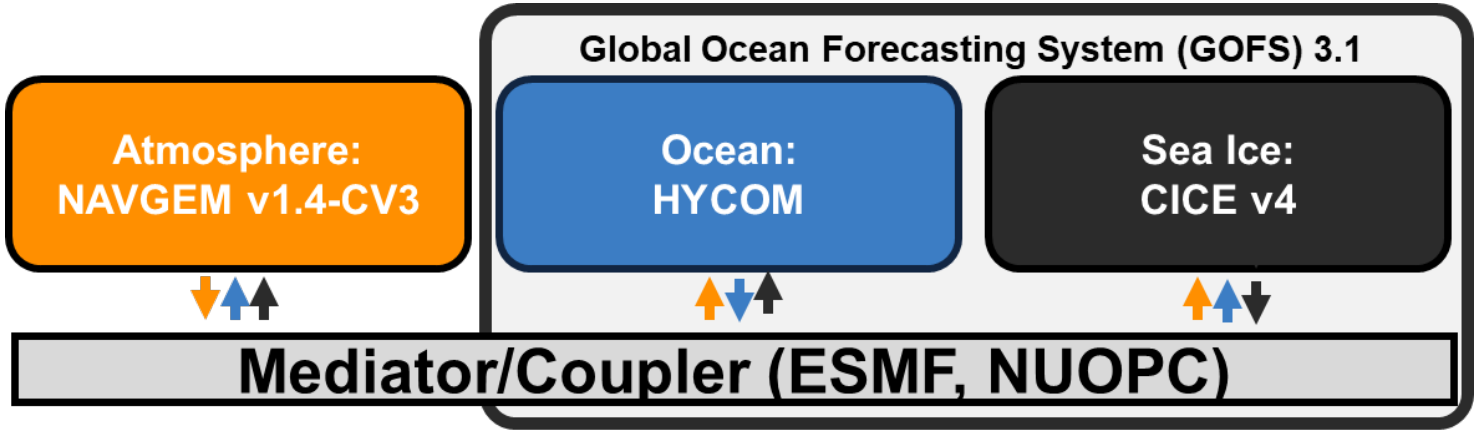


Figure 1: Schematic of the Navy-ESPC coupled system that will be used for Initial Operational Capability (IOC). The colored arrows represent variables being passed to and from each component (e.g., NAVGEM, HYCOM, CICE) to and from the mediator. The mediator uses the NUOPC standards on top of the ESMF tools. NAVGEM v1.4-CV3 is NAVGEM v1.4 with changes described in section 2.1.3. The GOFS 3.1 model is HYCOM and CICE coupled without NAVGEM.

EARTH SYSTEM MODELS IN THE U.S.

- The NCAR Community Earth System Model (**CESM**) is a fully-coupled, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states.
- The DOE Energy Exascale Earth System Model (**E3SM**) is a state-of-the-science Earth system model development and simulation project to investigate energy-relevant science using code optimized for DOE's advanced computers
- The GFDL Earth System Model (**ESM4**)
- The NASA Goddard Earth Observing System (**GEOS**) model consists of a group of model components that can be connected in a flexible manner in order to address questions related to different aspects of Earth Science.
- The NASA Goddard Institute for Space Studies (**GISS**) GCM is primarily used to study the human impact on the climate as well as the effects of a changing climate on society and the environment.