WHAT ARE EARTH SYSTEM MODELS USED FOR?

CLIM 670 EARTH SYSTEM MODELING

SEPTEMBER 8, 2020

Cristiana Stan

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

CLASS STRUCTURE

- Lecture: 10:30am – 11:40am
- Hands-on activity: evaluate the forecast skill of the NOAA Unified Forecast System (UFS) prototype 2:

  noon – 1:00pm
- Discussion session: What did you learn from the practicum, issues that you encountered, other questions:
  - 1:00pm - 1:10pm

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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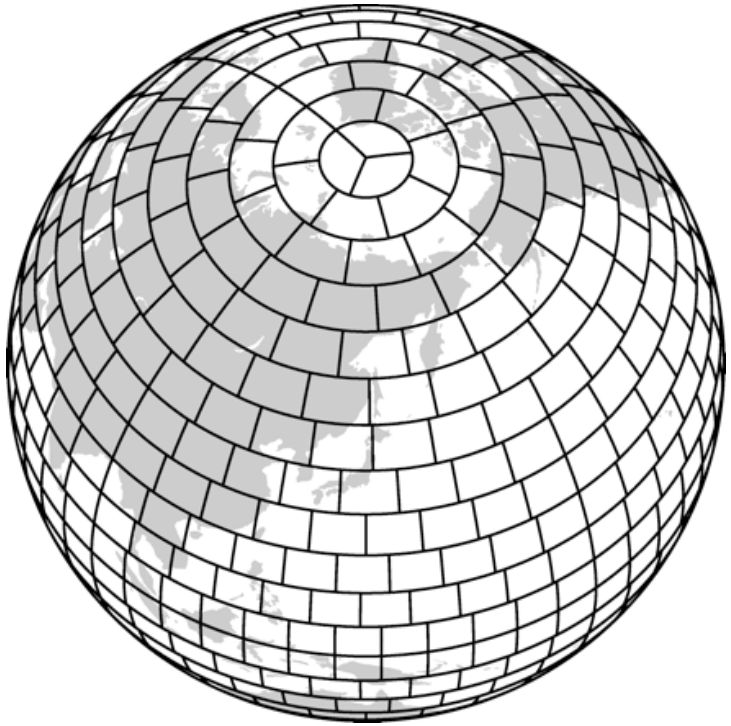
DRY DYNAMICAL CORE

- 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.

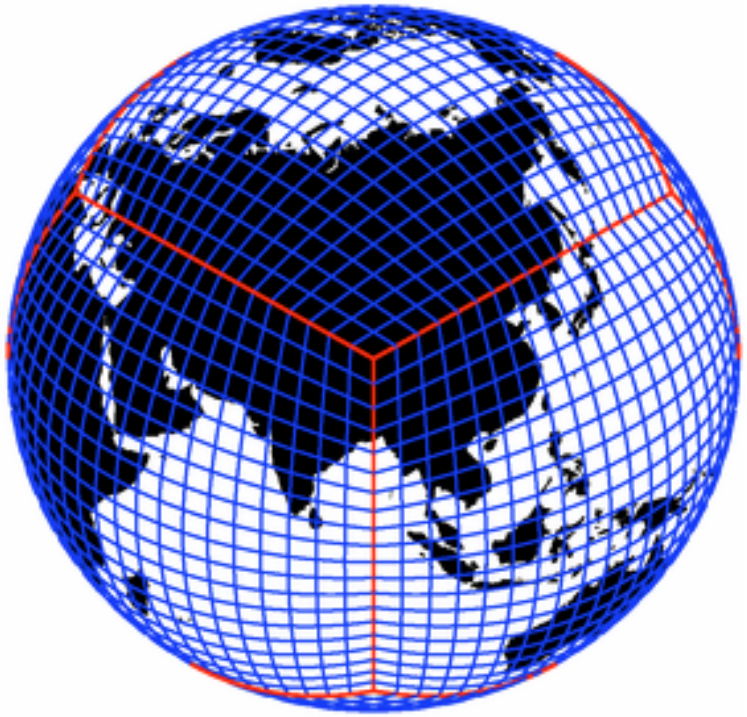
DRY DYNAMICAL CORE EXAMPLES

Gaussian

Reduced Gaussian

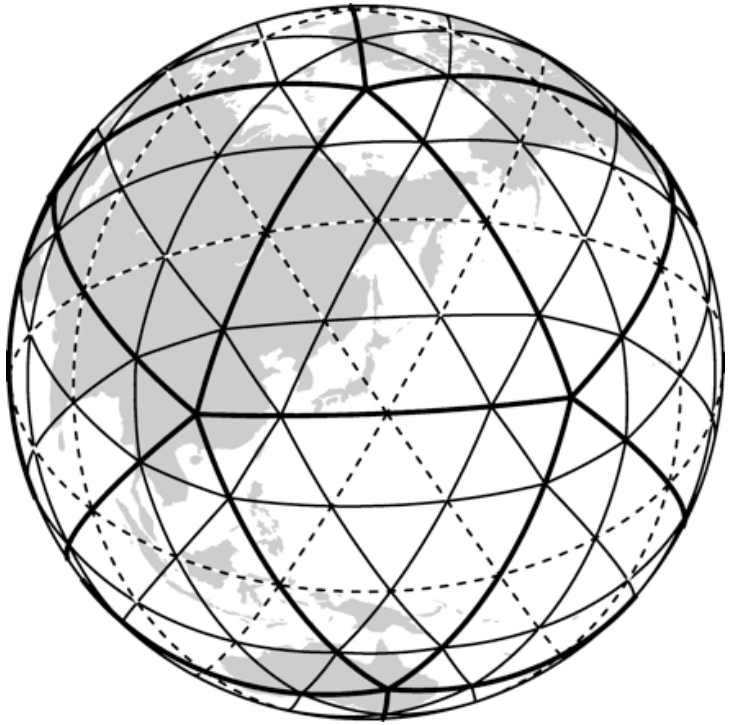


Cubed Sphere

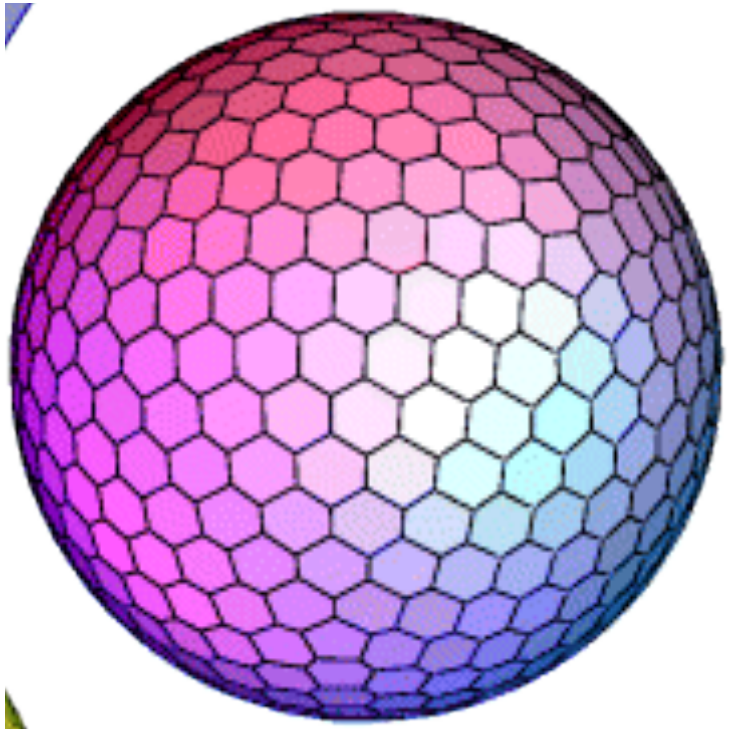


DRY DYNAMICAL CORE EXAMPLES

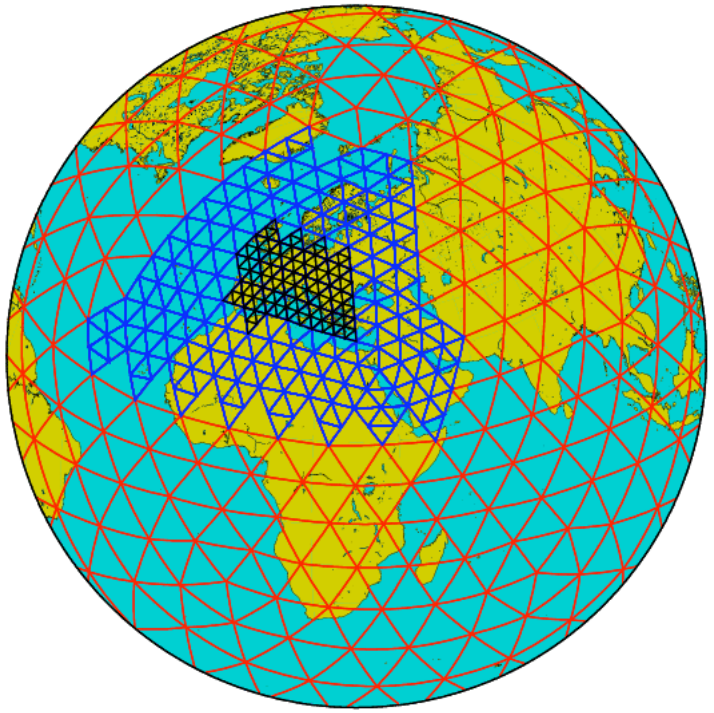
Triangular



Hexagonal

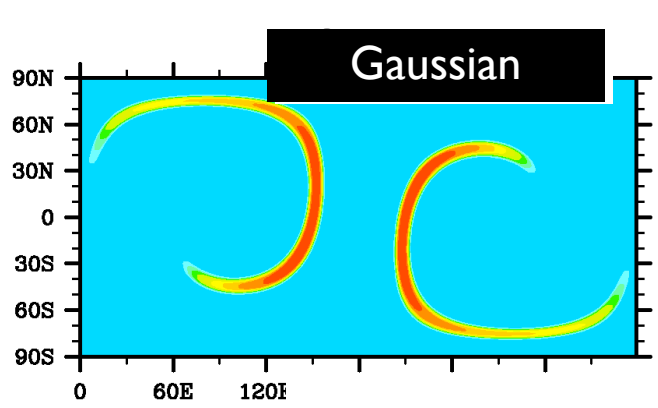


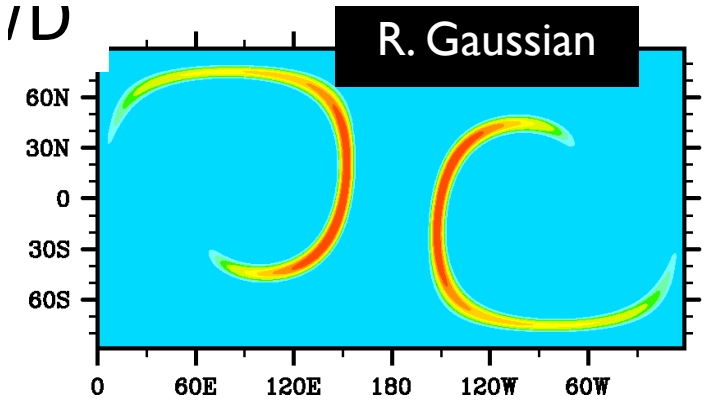
Variable Resolution

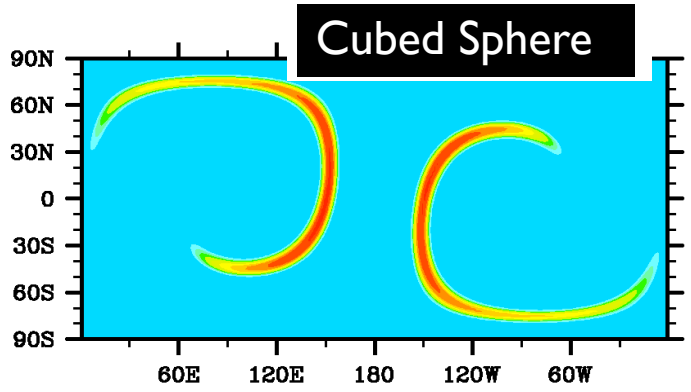


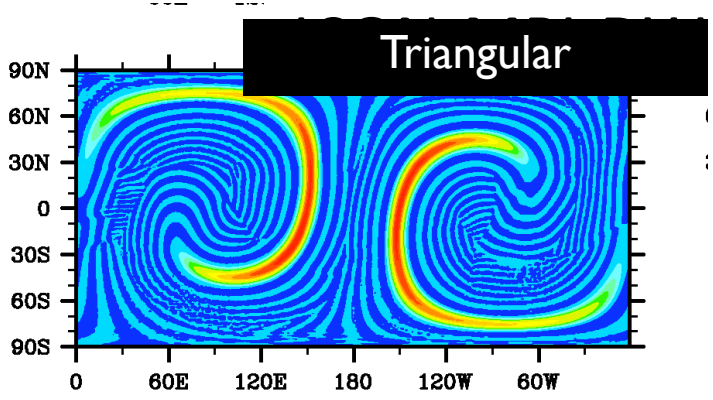
New generation

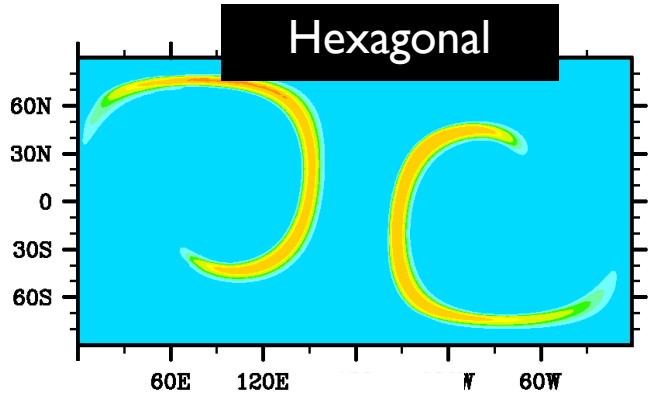
HOW DO THE GRIDS COMPARE?











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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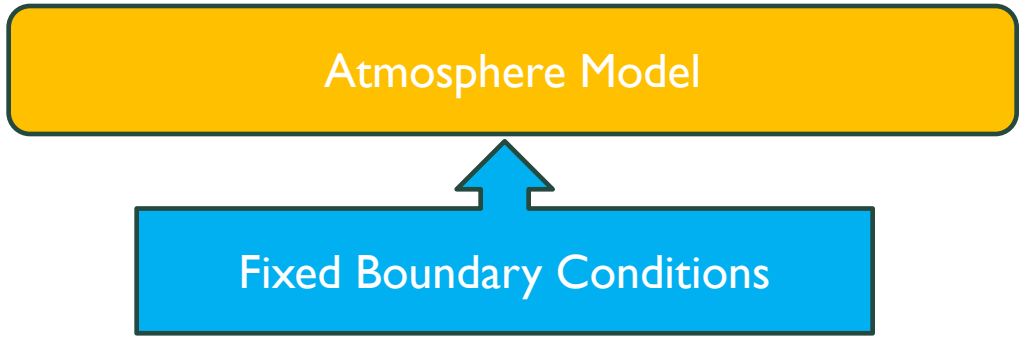
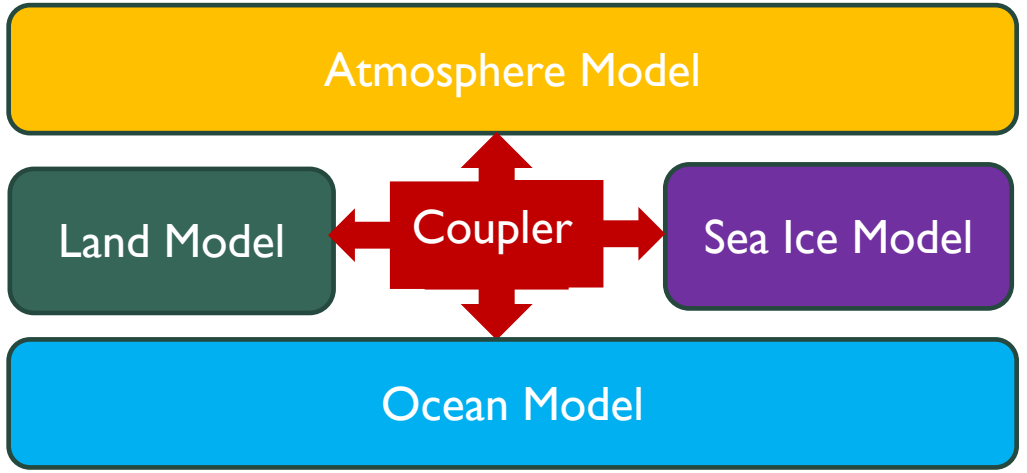
BOUNDARY CONDITIONS

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

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



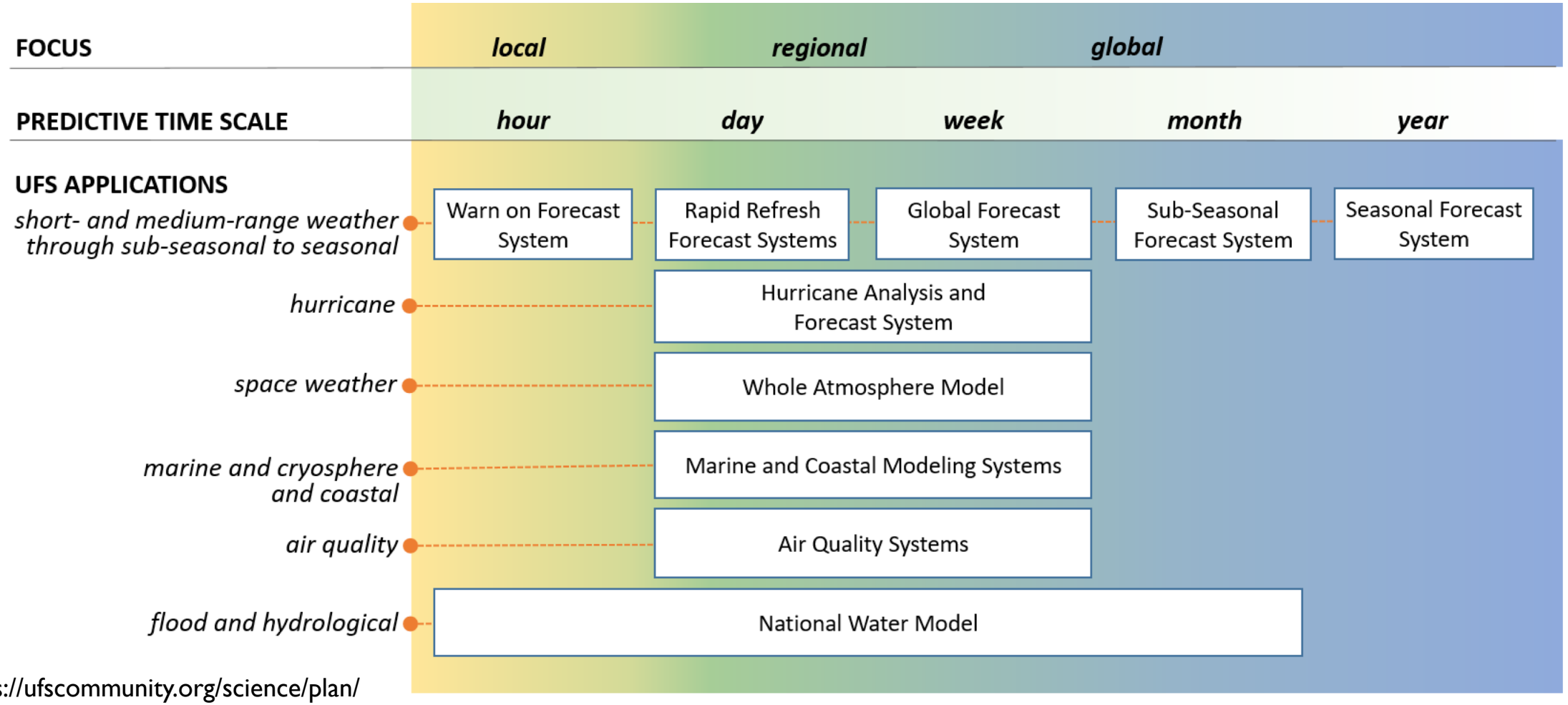


WHAT ARE GENERAL CIRCULATION MODELS USED FOR?

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 BAMS article**: Taylor, K. E., R. J. Stouffer, & G. A. Meehl, 2012: An overview of CMIP 5 and the experiment design. *Bulletin of the American Meteorological Society*, 93, 485-498.

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/

UNIFIED FORECAST SYSTEM (UFS)/S2S APPLICATION PROTOTYPE 2

Dynamical Core	Finite Volume version 3 (FV3): 28 km horizontal resolution; 64 levels
Physics	Radiation, Deep and Shallow Convection, Turbulent Transport, Cloud Microphysics, Gravity Wave Drag, Ozone, Land-Surface model
Ocean	Modular Ocean Model version 6 (MOM6): 0.25 deg horizontal resolution; 70 levels
Sea Ice	Community Ice CodE version 5 (CICE5): 0.25 deg horizontal resolution
Initial Conditions	ATM & Sea Ice: CFS Reanalysis; Ocean: CPC 3DVAR
Forecasts	Reforecasts: 2011-2107 initialized on 1st and 15th of every month
Forecast length	35 days
Ensemble members	1

EVALUATION OF UFS FORECAST ERRORS

Model Variable	Daily precipitation
Verification	Climate Prediction Center Unified (CPCU) daily precipitation
Analysis	root mean square (rms) error for each season (DJF, MAM, JJA, SON)
	rms error for week 1, week 2, week 3, and week 4

Assignment Due: September 22; Upload your code and figures or the path to your Jupyter Notebook to MS Teams