Riding the Winds and Currents to Understand and Predict the Climate System

NOAA Environmental Leadership Seminar
July 13, 2021

V. Ramaswamy

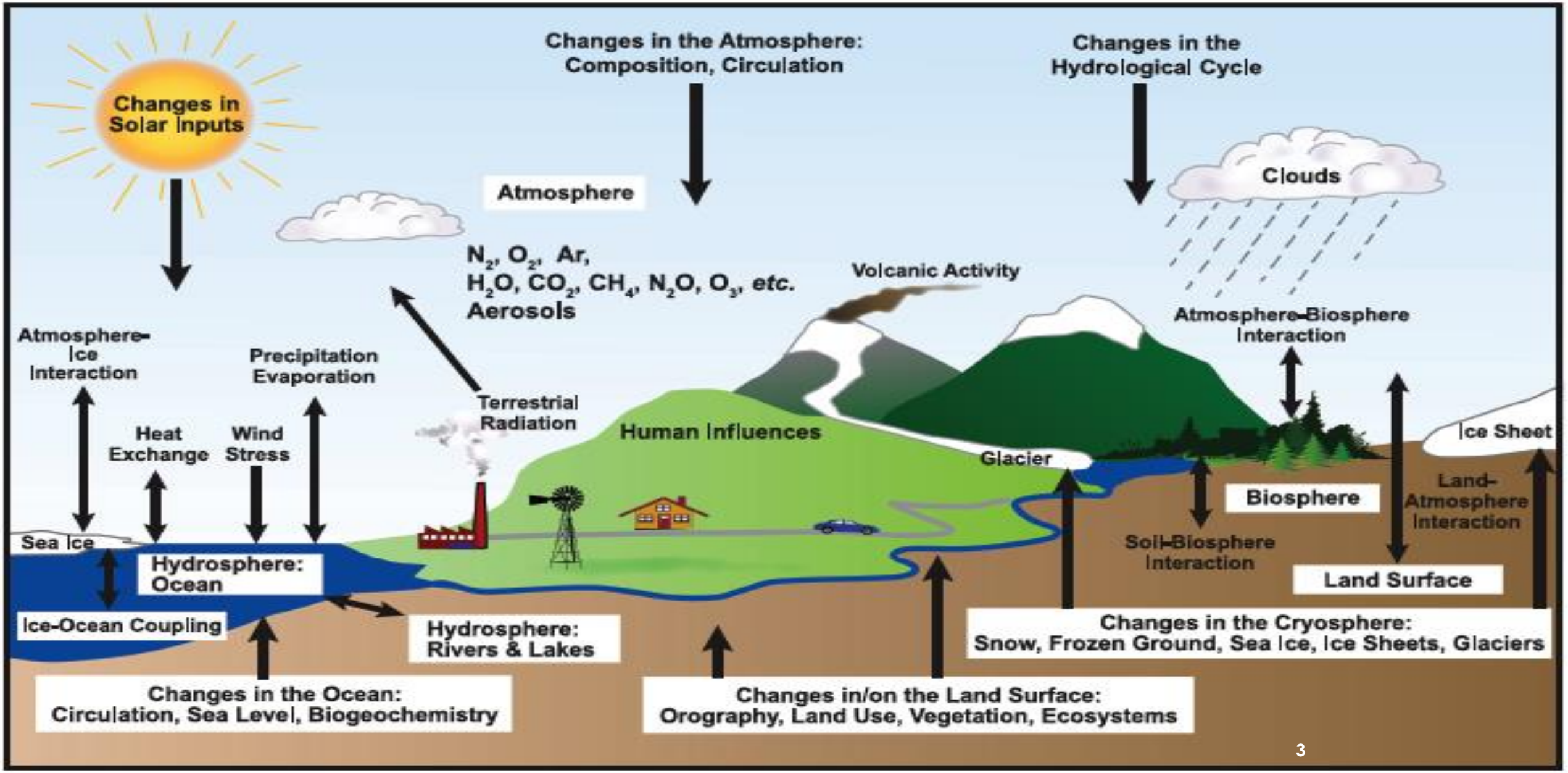
Geophysical Fluid Dynamics Laboratory

DOC Strategic Objective
NOAA - Alignment of Strategy

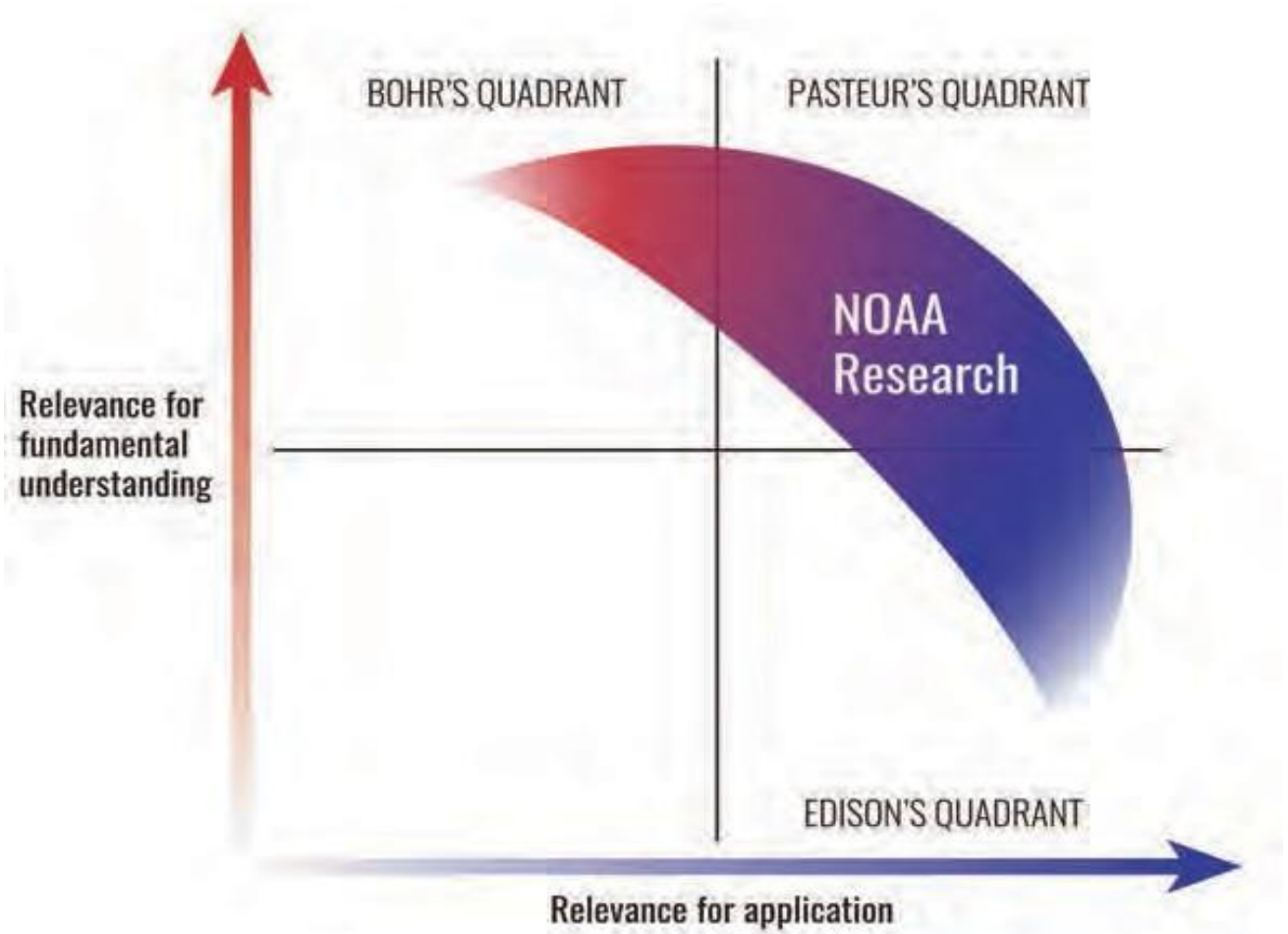
OAR MISSION

Conduct research to understand and predict the Earth's oceans, weather and climate, to advance NOAA science, service and stewardship and transition the results so they are useful to society.

The Earth System
(Atmosphere, Oceans, Biosphere, Cryosphere, Ecosystems)



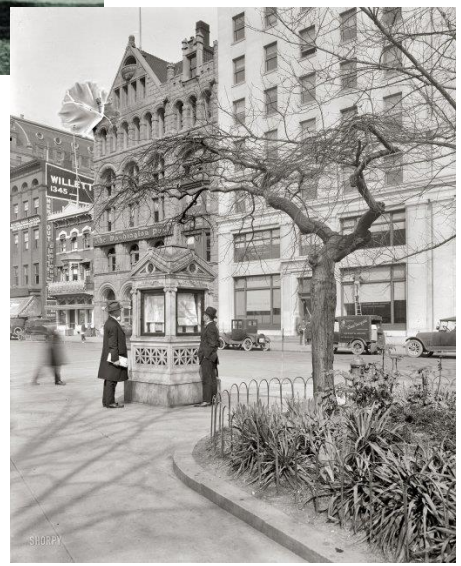
NOAA Strategic Research [NOAA Chief Scientist Report, 2016]



Adapted from Donald Stokes (Princeton Univ.): "*Pasteur's Quadrant: Basic Science and Technological Innovation" (1997)*

1955 – Geophysical Fluid Dynamics Lab

U.S Weather Bureau, Washington, DC, 1912



Weather Bureau Kiosk on Pennsylvania Avenue in 1920

The forerunner to the Geophysical Fluid Dynamics Laboratory (GFDL) was created as a section of the Office of Meteorological Research under the U.S. Weather Bureau in Washington, DC. The unit was called the GCRS or General Circulation Research Service.

In October, 1955, Dr. Joseph Smagorinsky was installed as the head of the new unit to continue his research into developing accurate numerical models of the laws that govern the circulation of the atmosphere – better known as general circulation modeling. The unit was soon renamed to the Geophysical Fluid Dynamics Laboratory, better reflecting the scope of its activities.

Major advancements in weather and climate science have come about with

- **Improvements in theory & observations;**
- **Improved understanding of processes; and**
- **Advances in computational modeling**

Oceans, Atmosphere, Biosphere, Cryosphere, Ecosystems

Mathematical Modeling

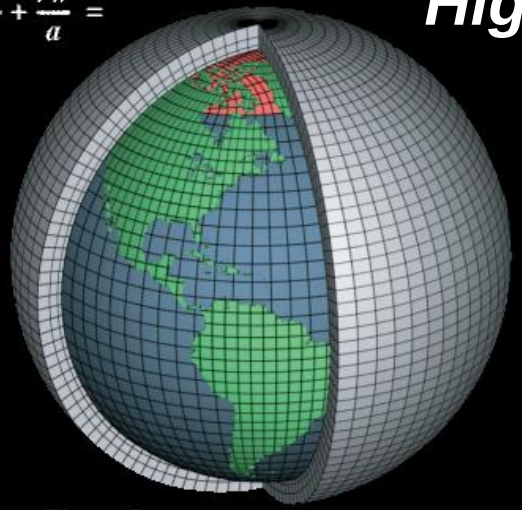
$$\frac{\partial v}{\partial t} + \frac{u}{a\cos\phi}\frac{\partial v}{\partial \lambda} + \frac{v}{a}\frac{\partial v}{\partial \phi} + w\frac{\partial v}{\partial z} + \frac{u^2\tan\phi}{a} + \frac{vw}{a} = -\frac{1}{\rho_0 a}\frac{\partial p}{\partial \phi} - fu + F^{\phi}$$

$$f = 2\Omega\sin\phi$$

$$p(z) = \int_{z}^{0} \rho g\, dz + p_s$$

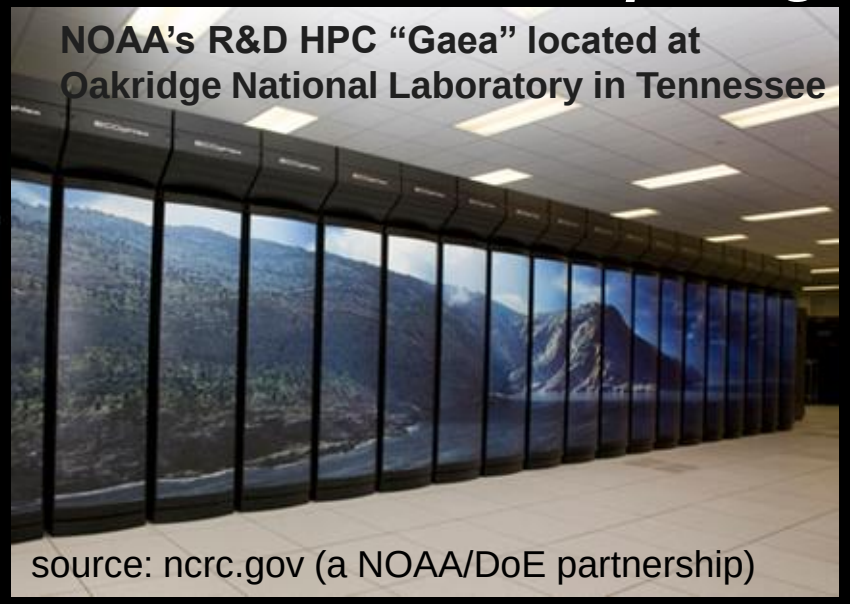
$$\frac{1}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{1}{a}\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{dT}{dt} = \frac{u}{a\cos\phi}\frac{\partial T}{\partial \lambda} + \frac{v}{a}\frac{\partial T}{\partial \phi} + w\frac{\partial T}{\partial z} + D^{T\lambda} + D^{T\phi} + D^{Tz}$$



original image source: NOAA-GFDL

High-Performance Computing

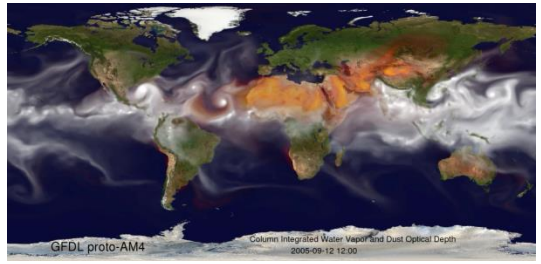


source: ncrc.gov (a NOAA/DoE partnership)

Recent fundamental advances

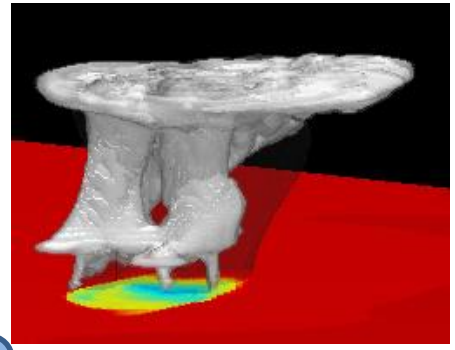
Geophysical Fluid Dynamics Laboratory

Seamless Weather-Climate Prediction System



50-km GFDL-AM4

Global ⟷ GFDL FV3 ⟷ Regional



1-km GFDL "Super HiRAM"

NOAA Research: Transformative Atmospheric Model

Goals:

- Develop a **unified** modeling system for Weather and Climate simulations
- Unify regional (convective-scale) and global modeling systems

July 2016 - NOAA selected **FV3** (Finite-volume core on the Cubed-Sphere) for NGGPS (Next Generation Global Prediction System).

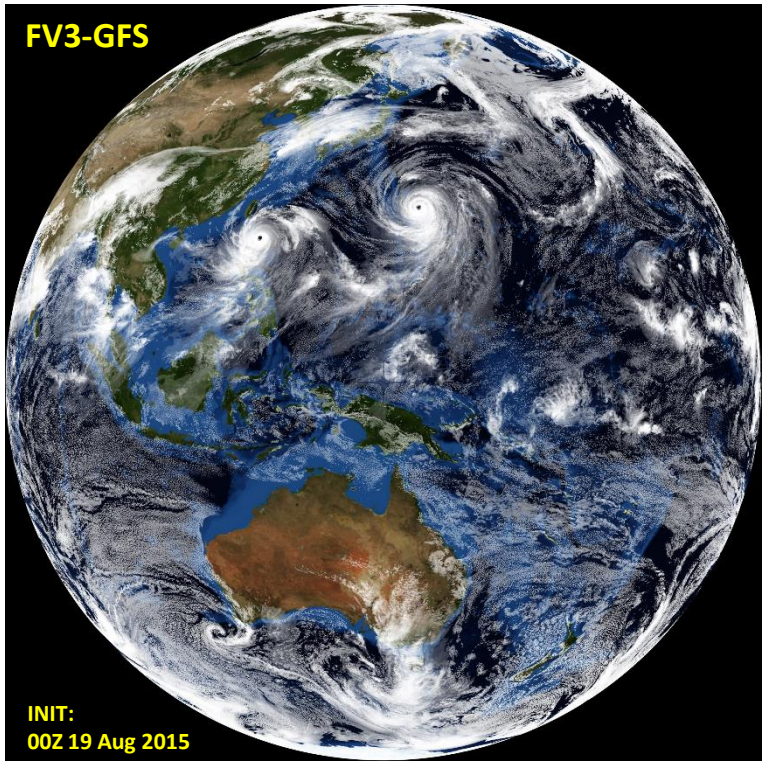
2017-18-19: Transition to NWS and Operations.

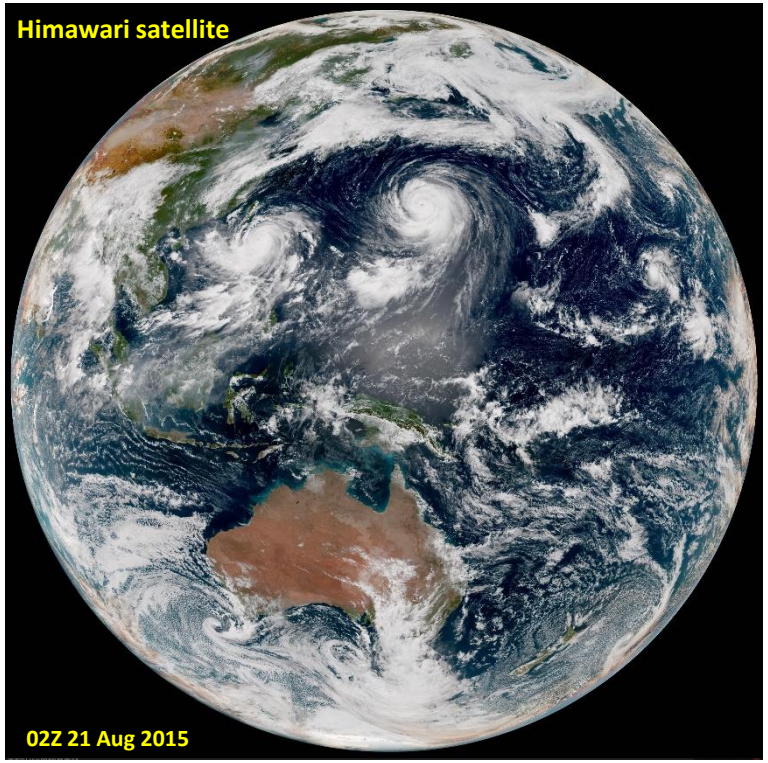
Predictions: **2017-2021 hurricanes**; **2018-2021 Midwestern spring storms**.

June 12, 2019 ➔ NOAA/NWS operational forecasts with the "FV3GFS"

Courtesy: S-J. Lin and L. Harris

FV3-powered unified system for regional-global predictions down at 3-km scale

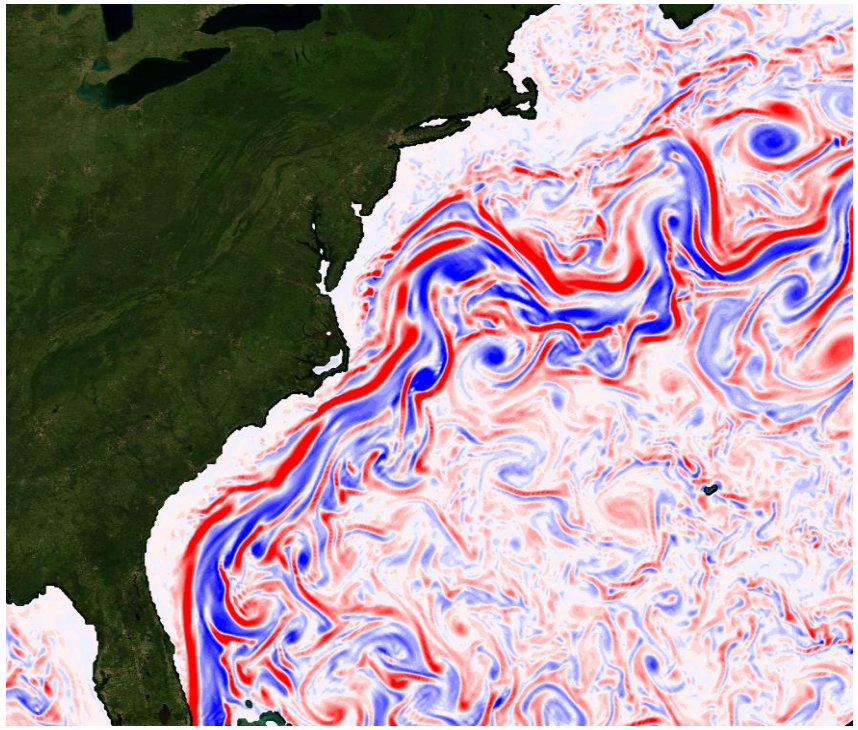




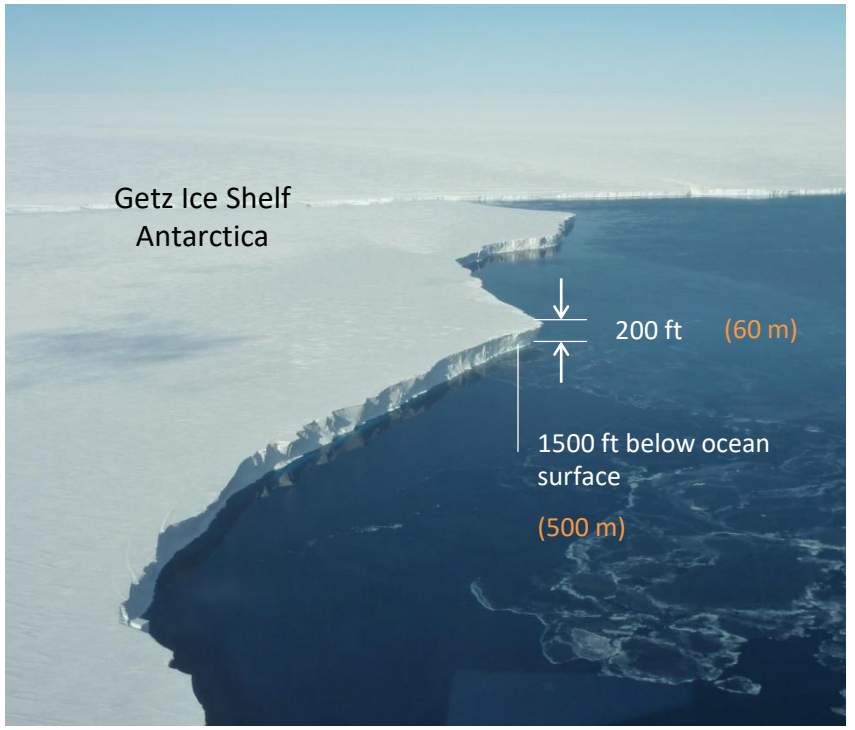
Courtesy: L. Harris

Frontiers in ocean/ice-sheet modeling: Ocean Model (MOM6)

Role of ocean eddies in climate/earth system

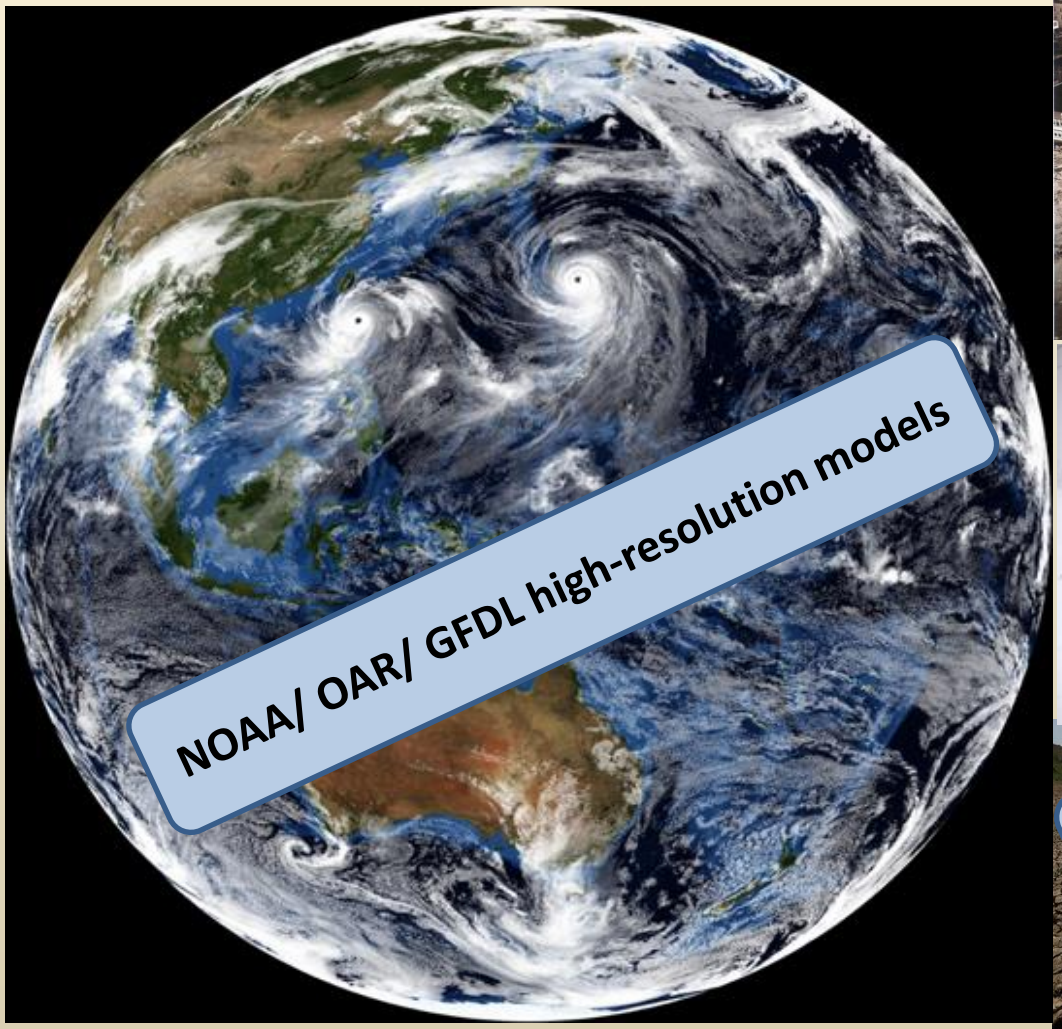


Sea-level rise and ice-sheet/ocean interaction



Courtesy: A. Adcroft, S. Griffies, R. Hallberg

NOAA's "seamless" high-resolution modeling system for understanding and predicting weather and climate extremes



Climate and Earth System Modeling

(Understanding and Prediction)

- Seamless across timescales → Weather-to-Climate
- High-resolution simulations → Capturing regional events
- Weather extremes in Climate → Information on Risks

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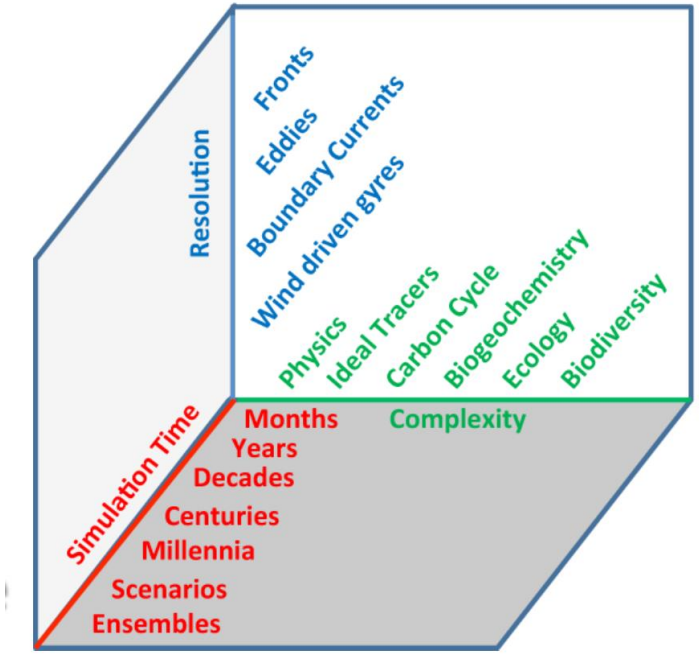
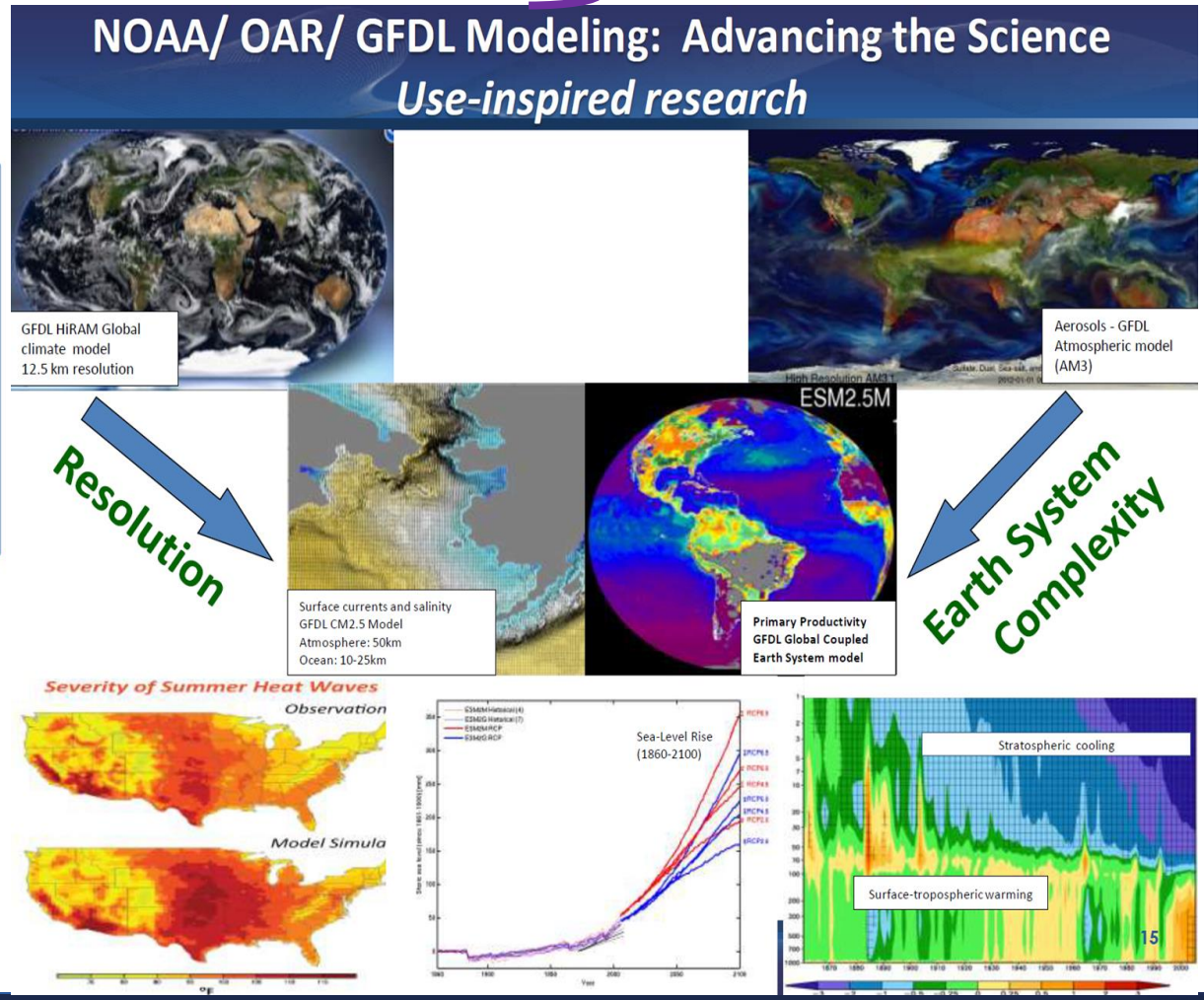
Factors in Earth System Modeling

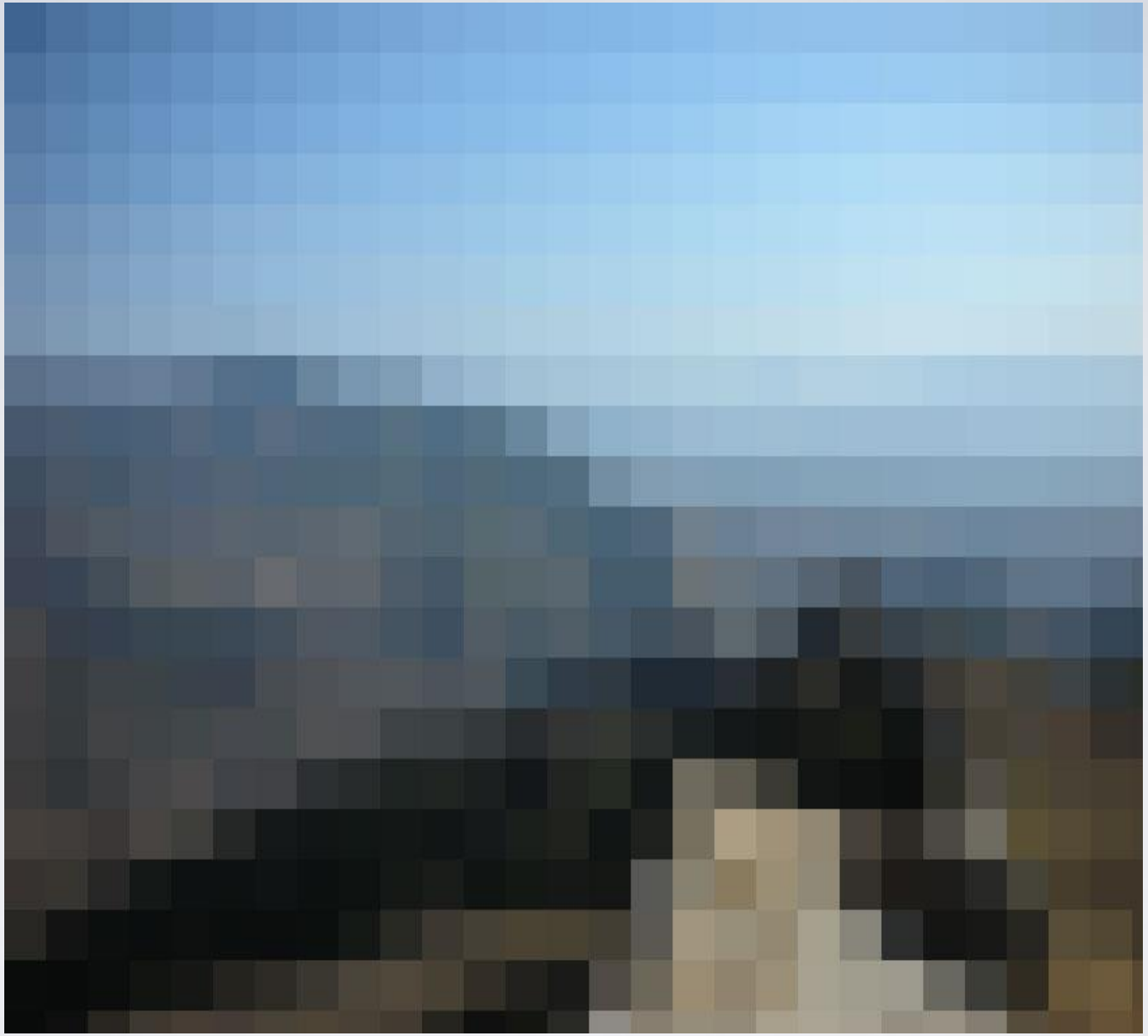
- **Resolution, Complexity, Simulation time**
- **Efficiency & Realism**

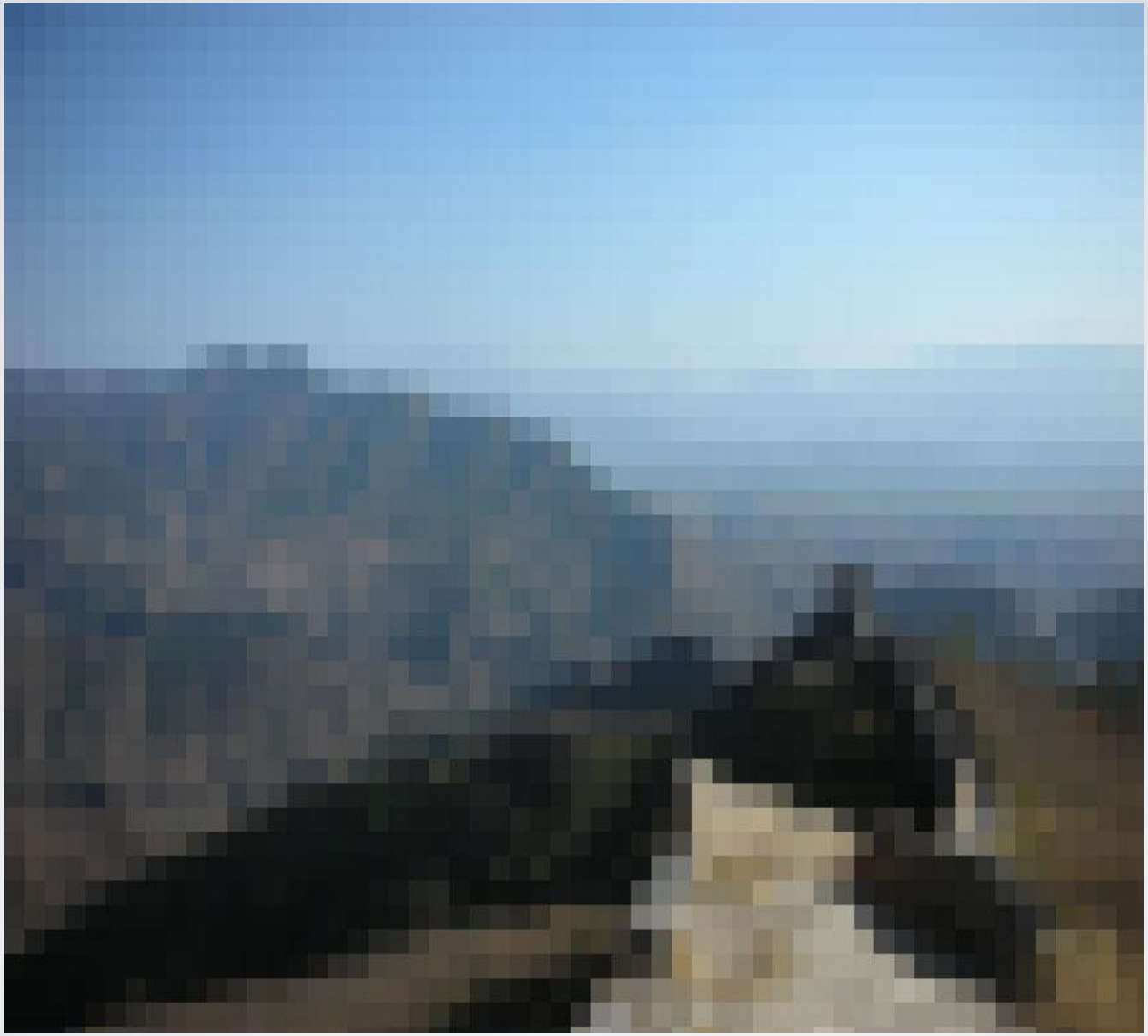
Integrated & Optimized Earth System Models



Advanced Machine Learning/ Artificial Intelligence Techniques



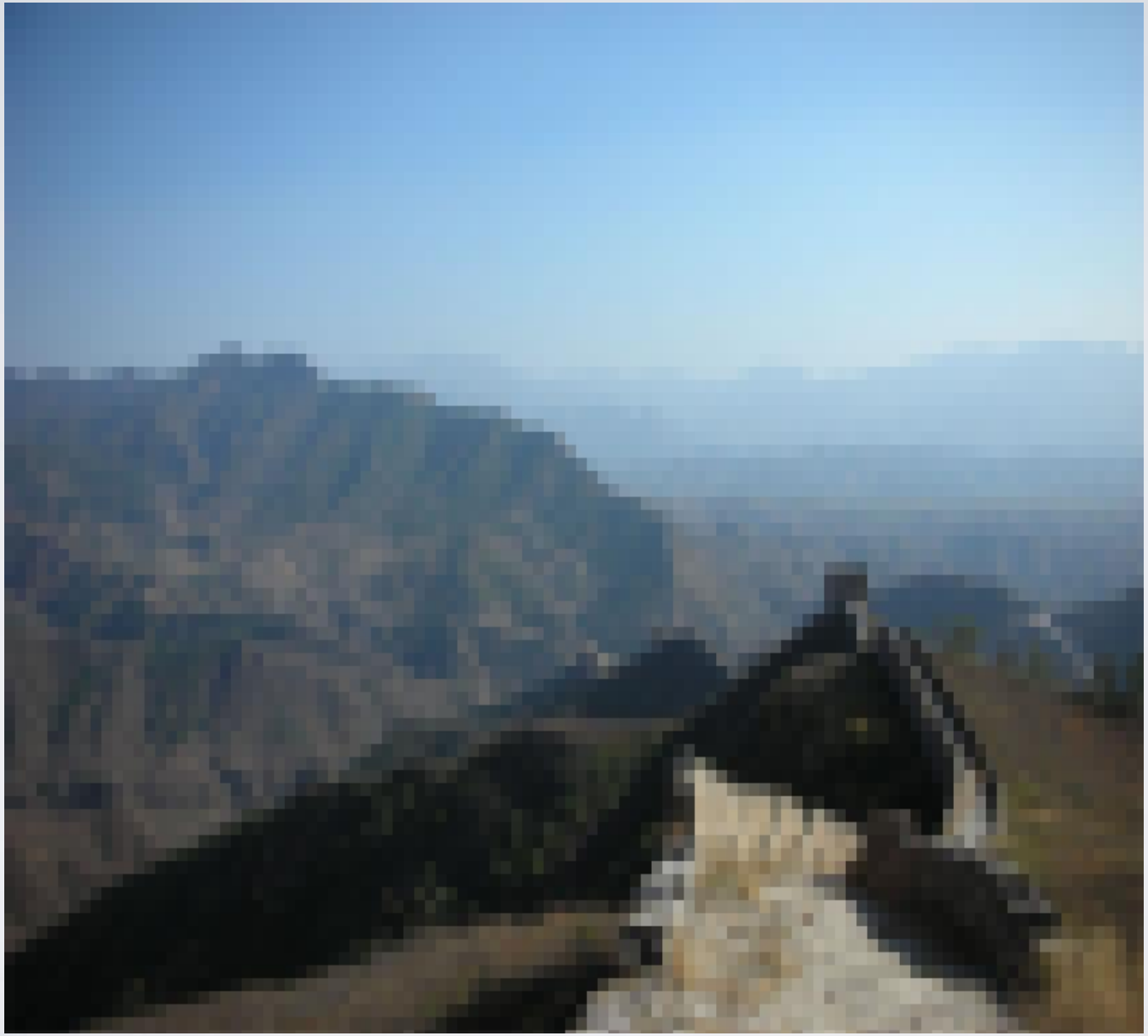




x2

Poll Question:

What are we looking at?

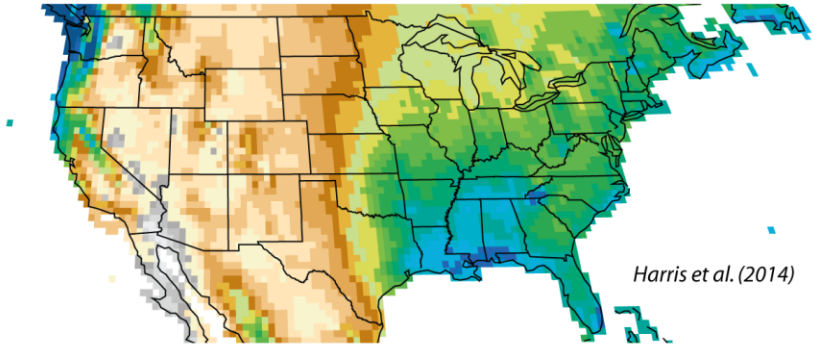


x4

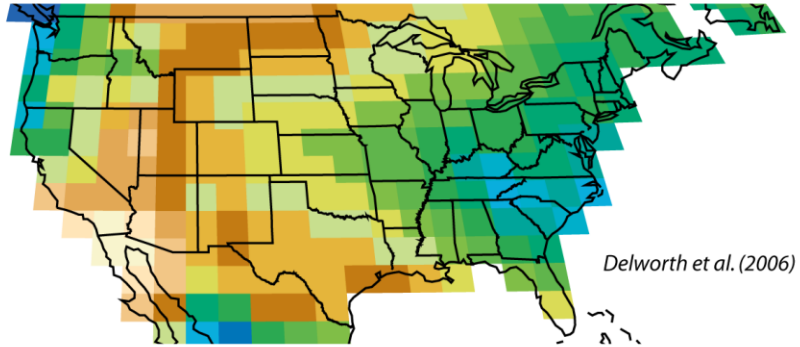
x16

Improved simulation of rainfall over land in North America in FV3-powered coupled model

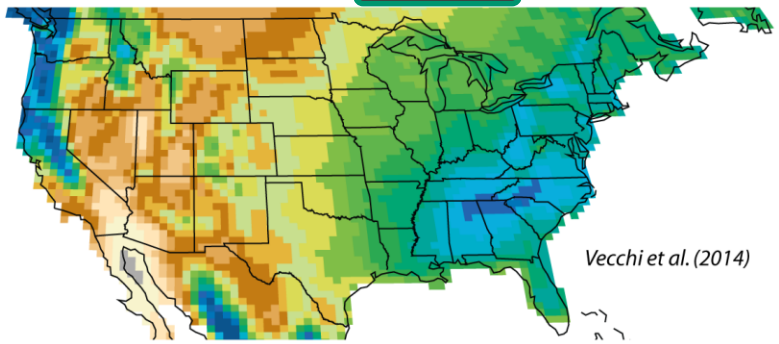
Rain gauge estimates : **Observed**
(U. East Anglia CRU 3.22)



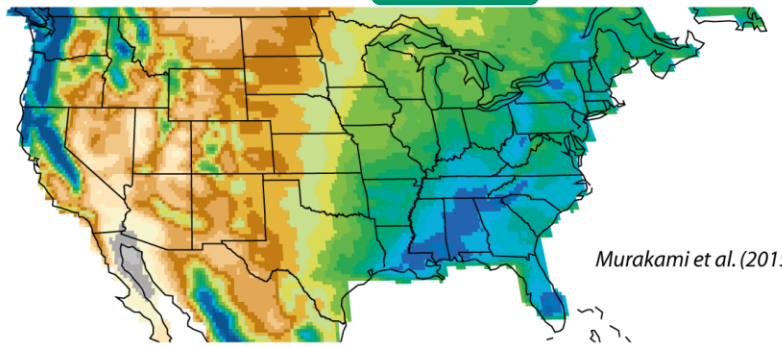
Real-time seasonal prediction model
160-mile "tiles": CM2.1 **2006**



Real-time seasonal prediction model
30-mile "tiles": FLOR **2014**



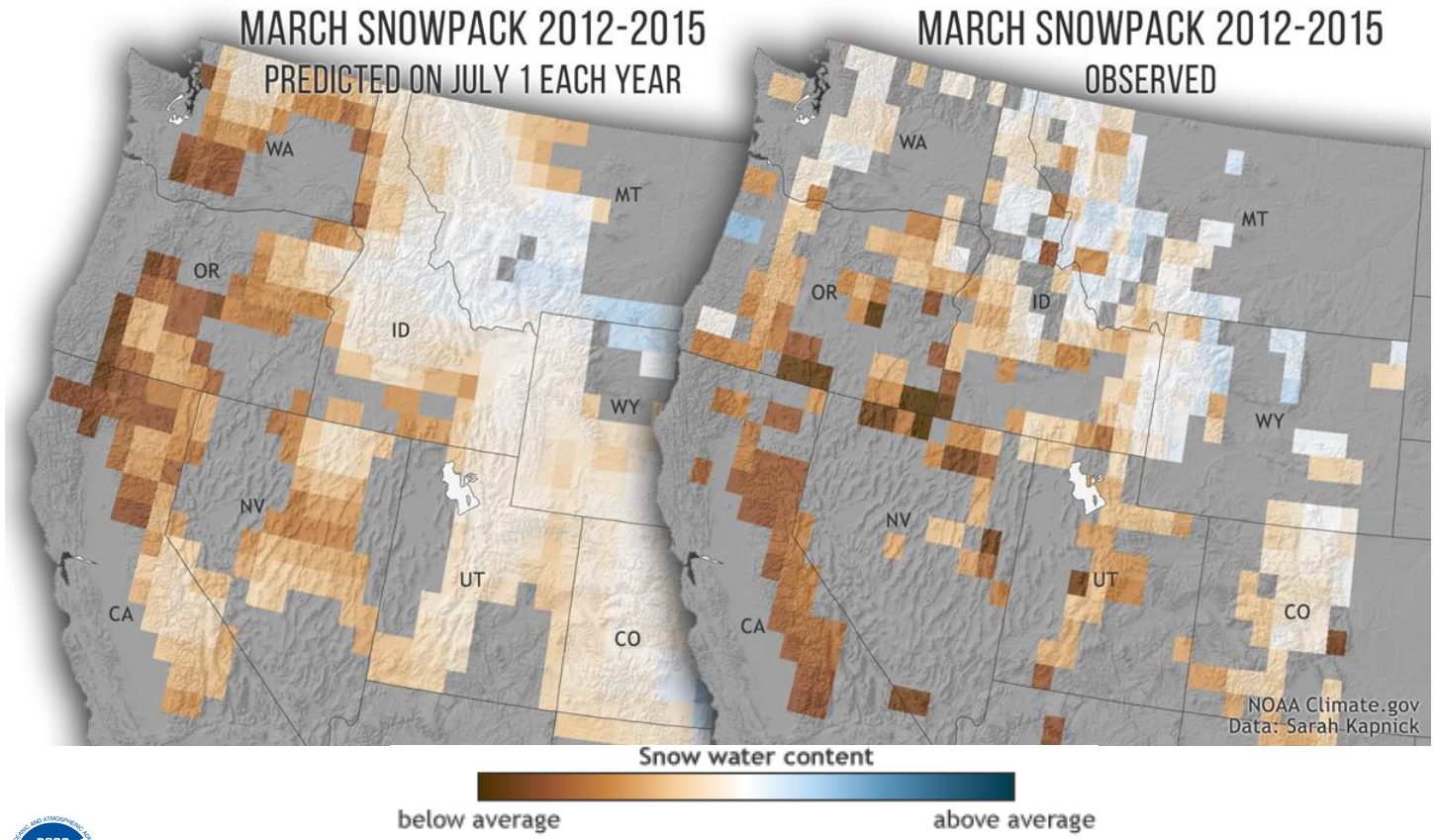
Prototype seasonal prediction model
16-mile "tiles": HiFLOR **2015**



Annual Average Precipitation (mm/day)

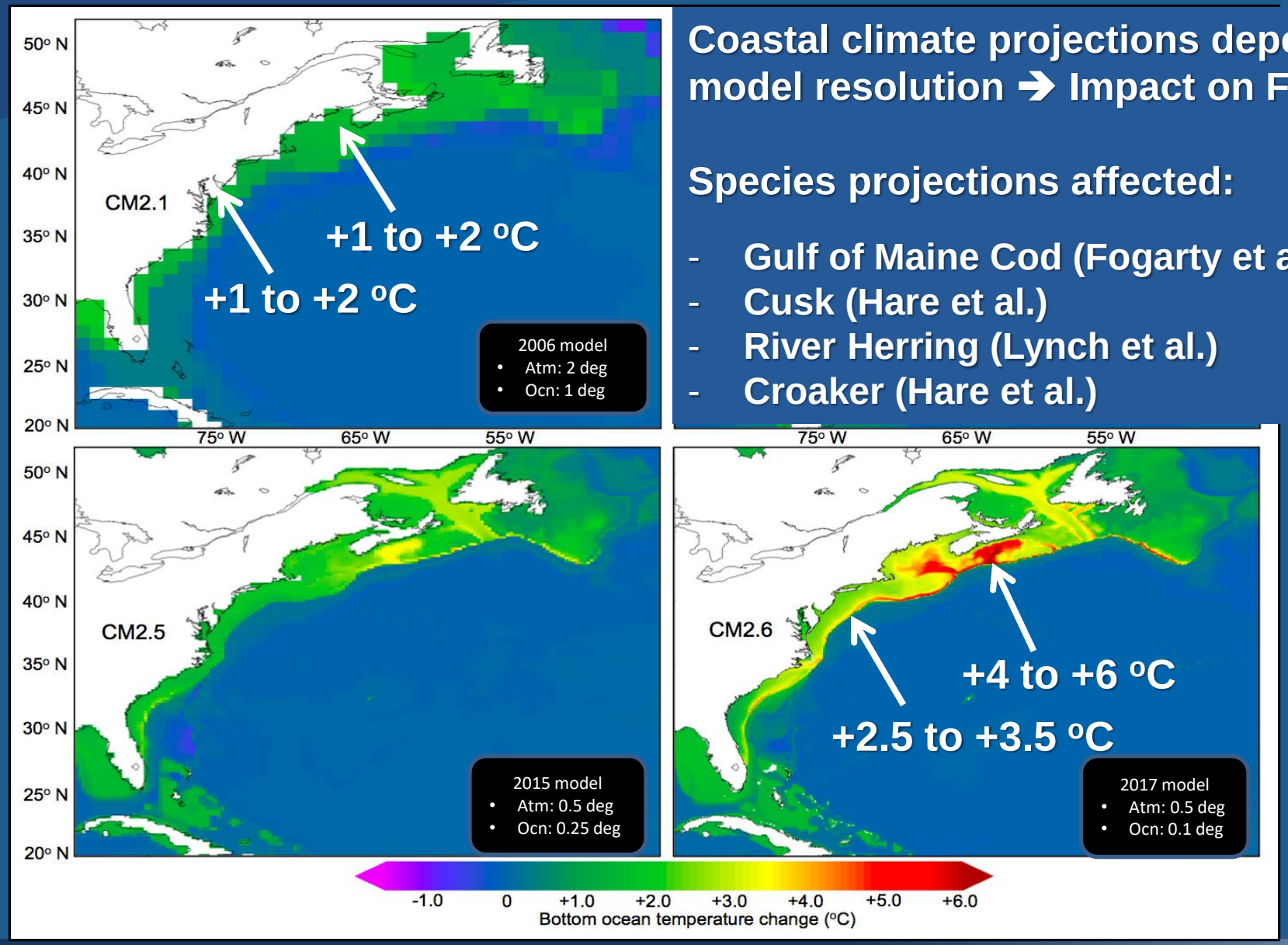
Courtesy:
G. Vecchi

Low March snowpack case study: 2012-15
Yearly predictions made July 1 (50 km model) vs. observed



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

Multidecadal: Northwest Atlantic 2xCO_2 Projection



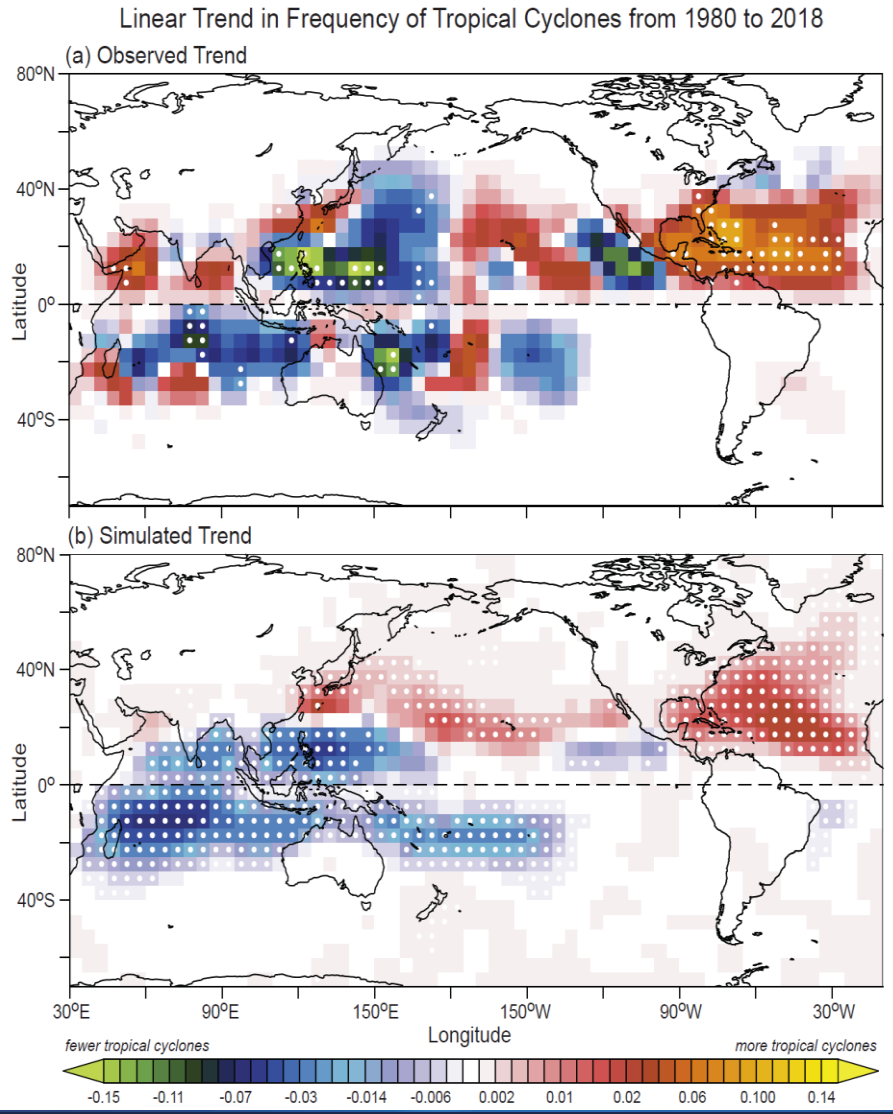
Coastal climate projections depend on model resolution ➔ Impact on Fisheries

Species projections affected:

- Gulf of Maine Cod (Fogarty et al.)
- Cusk (Hare et al.)
- River Herring (Lynch et al.)
- Croaker (Hare et al.)

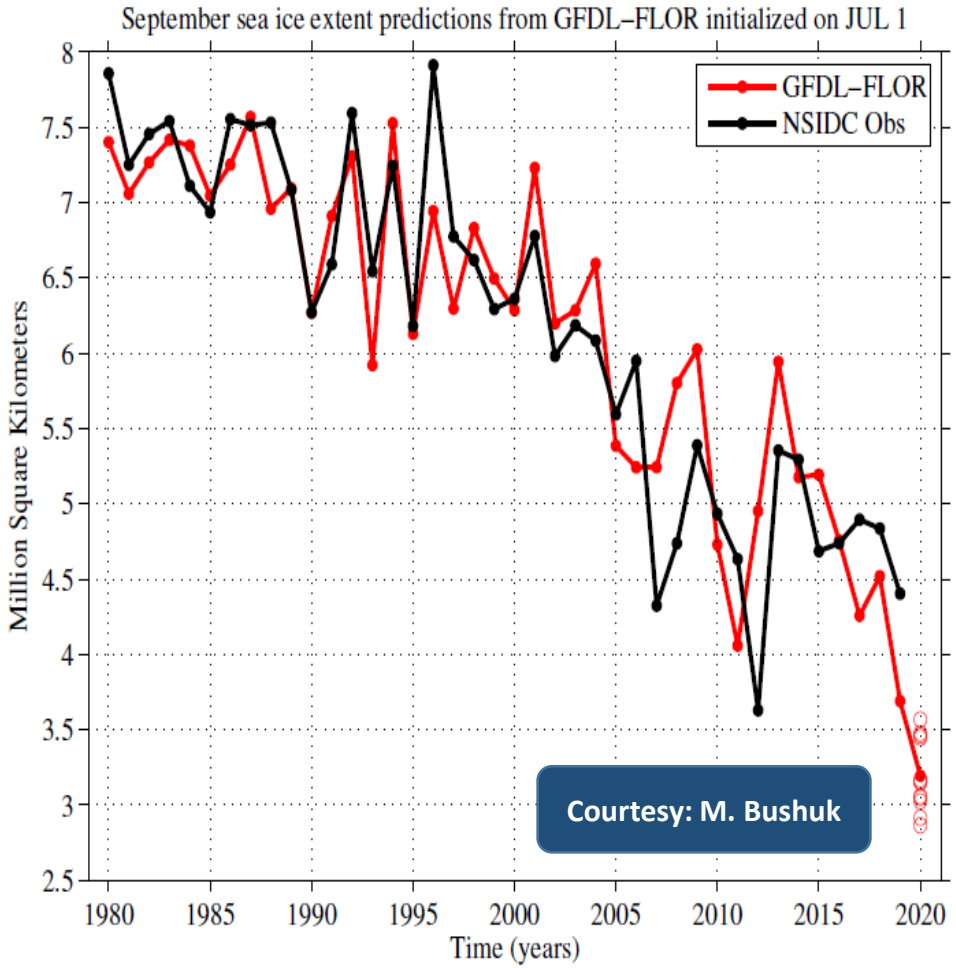
Saba et al. (J. Geophys. Res., 2017)

Seasonal-to-Decadal Seamless Model: Hindcasts & Predictions



Change in the global distribution of tropical cyclones.
Simulation versus Observation [Murakami, PNAS, 2020]

Arctic Sea-ice prediction: Variability and Trend



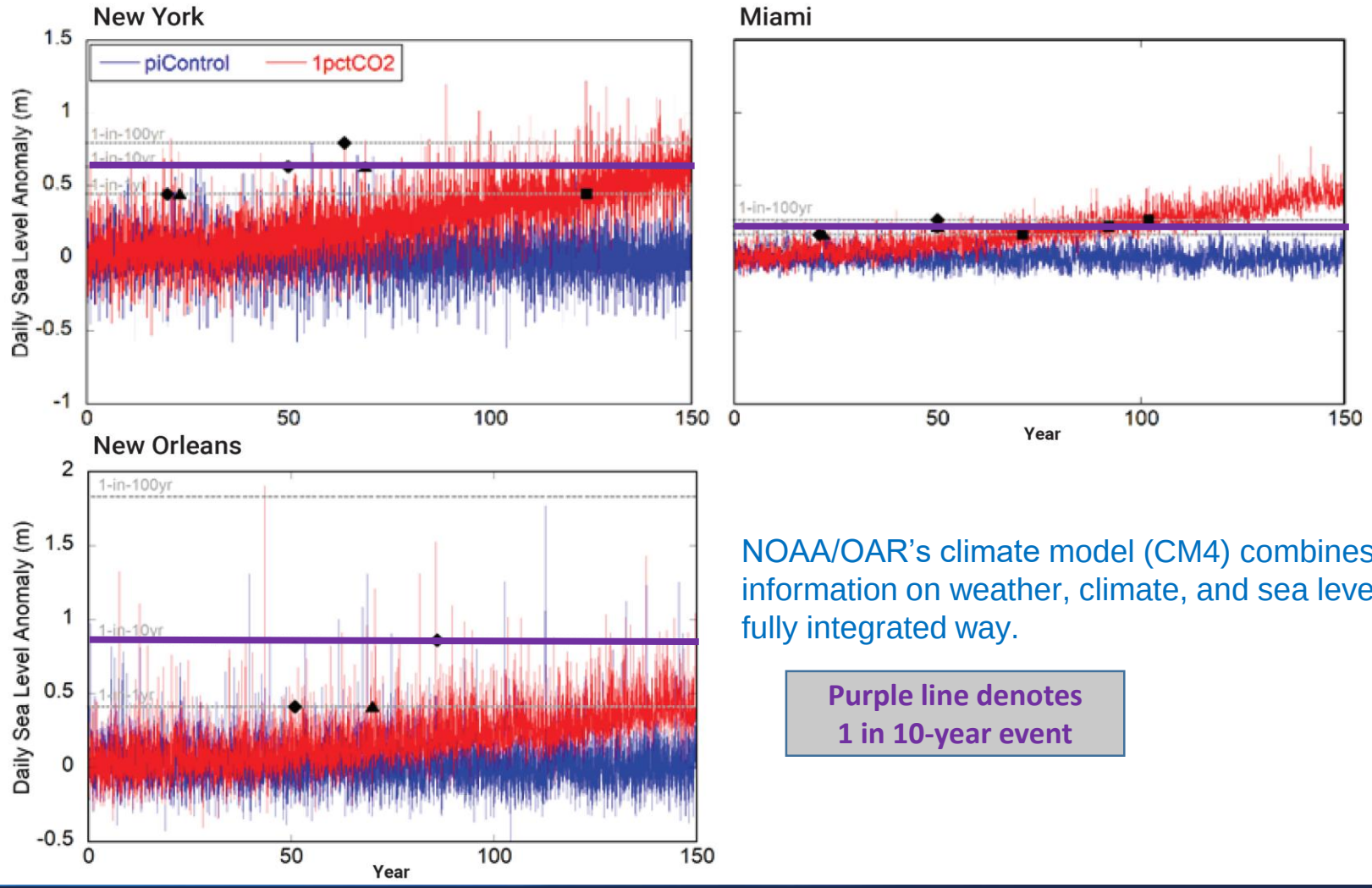
Courtesy: M. Bushuk

Other phenomena/events predicted:

US hydroclimate, atmospheric 'rivers', western US snowpack, winter storms, droughts, dust storms

Storm-Related Extreme Sea Level Along the U.S. Coast to Combined Weather and Climate Forcing

Time of emergence of the anthropogenic signal in storm related extreme sea level for New York, Miami, and New Orleans ➔ Significance for Coastal Resiliency

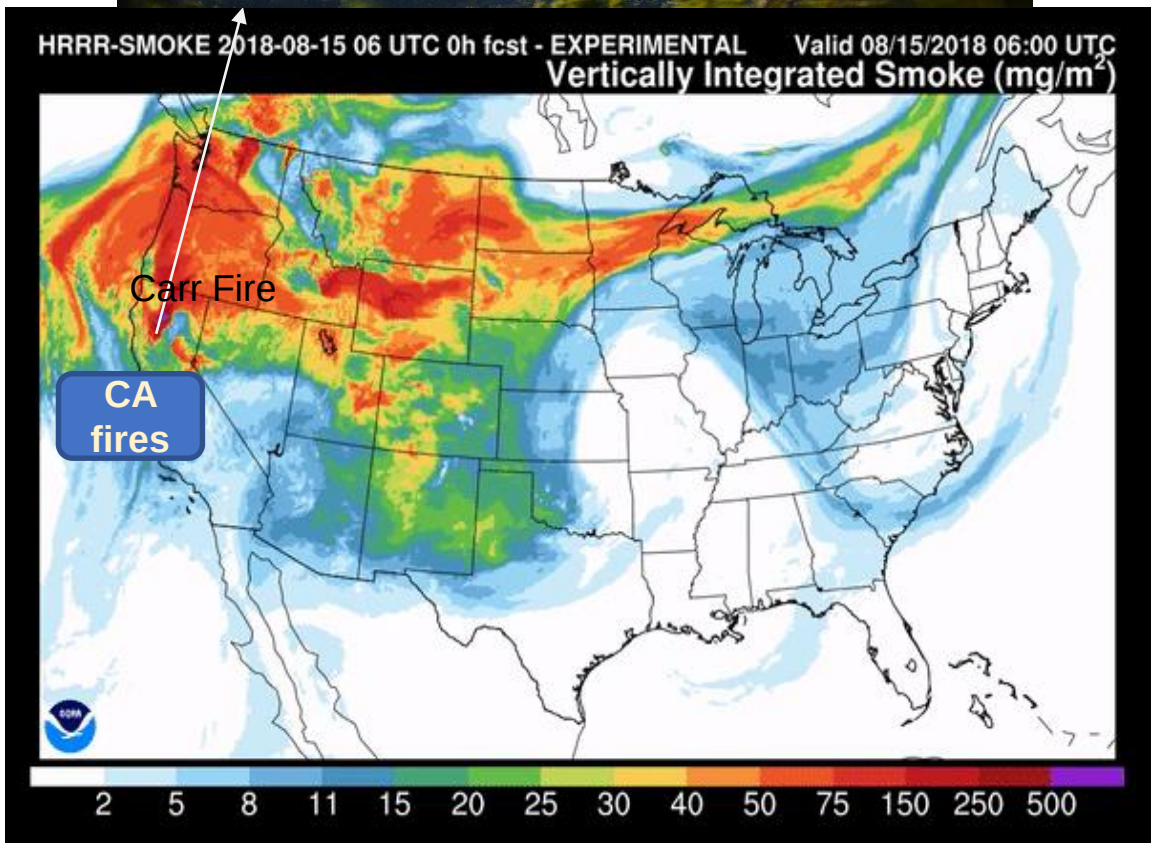


NOAA/OAR's climate model (CM4) combines information on weather, climate, and sea level in a fully integrated way.

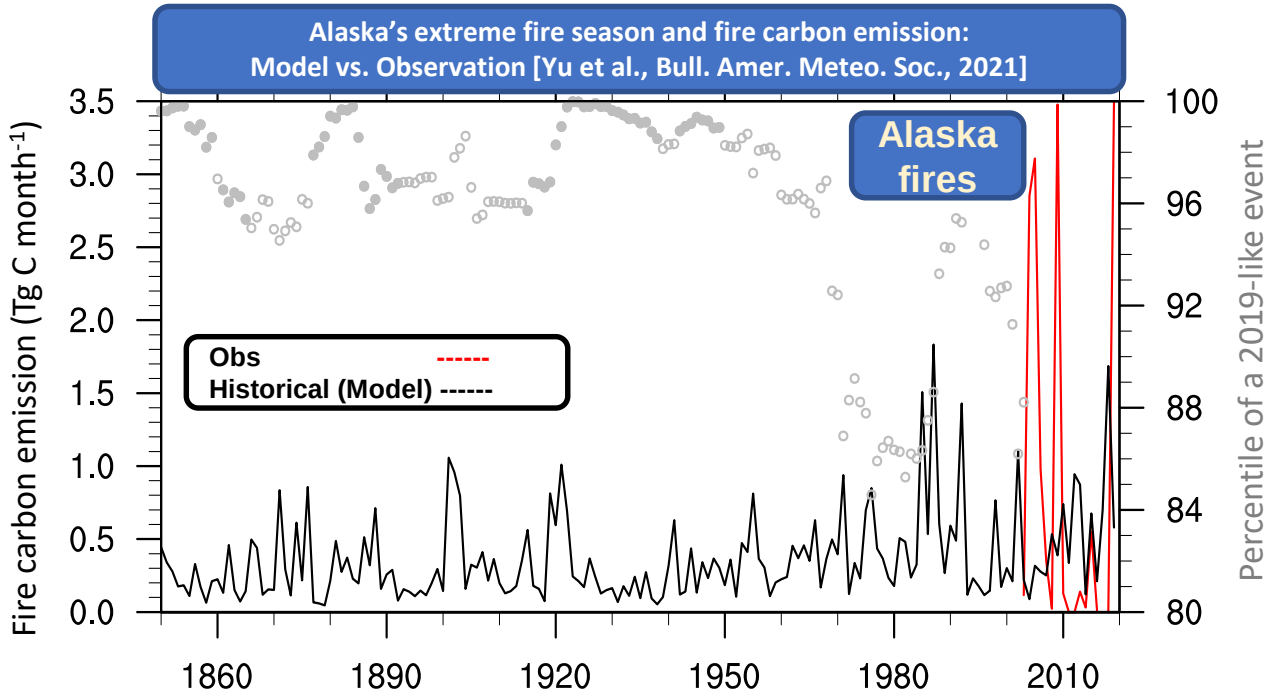
Purple line denotes 1 in 10-year event

Yin et al. (J. Climate, 2020)

FIRE – Air Quality: Weather, Climate, and Earth System

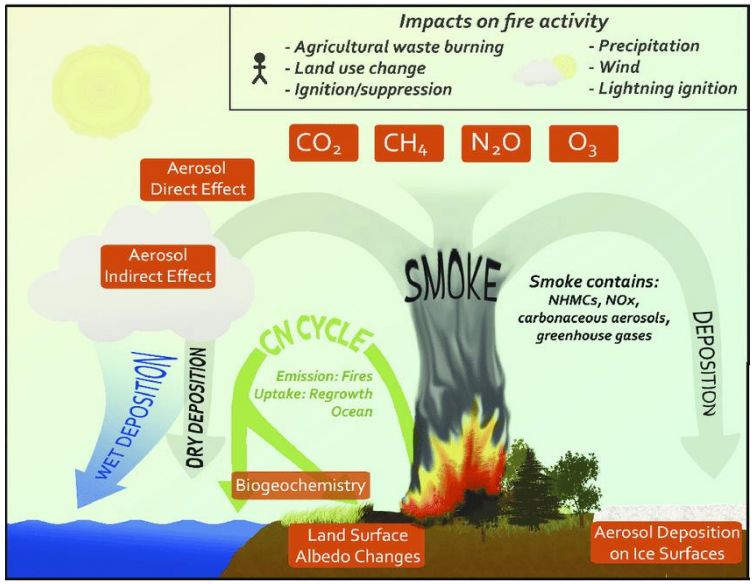


HRRR simulation of wildfire smoke and spread

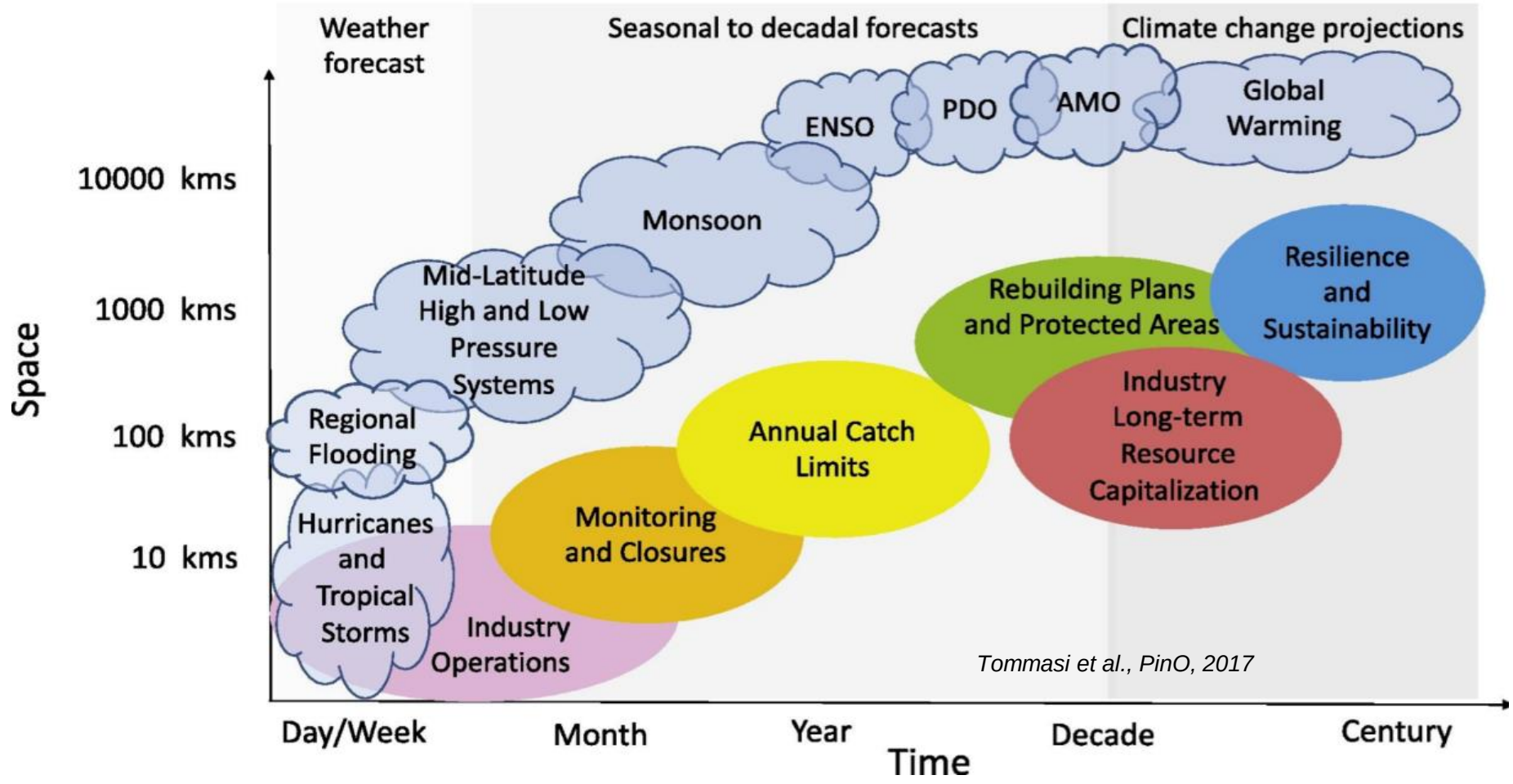


NOAA research:

- Field and laboratory studies
- Fire Weather models for operations
- Climate ➔ Fires (climate state, vegetation, fuel content, atmospheric chemistry and impacts)
- Fires ➔ Radiation Budget, Weather & Climate



Linking Physical System to Marine Ecosystems ➔ Risk, Resiliency, Investment



NOAA Modeling Picture:
Predictions and Projections of Extremes and Change

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

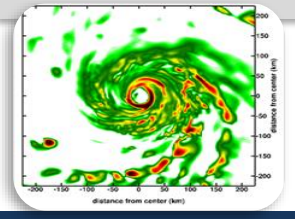
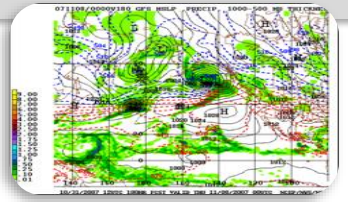
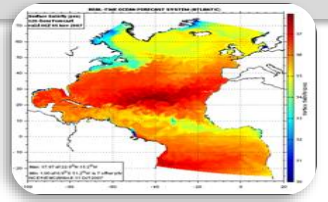
Decadal to Multi-decadal Variability
Cryospheric
Solar Variability

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

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

WEATHER → **CENTENNIAL**

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

Weather to Climate is “Seamless”

NOAA Modeling Picture:
Predictions and Projections of Extremes and Change

Internal Variability and External Forcings

Tornadoes
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Heat Waves

El Niño-Southern Oscillation

Decadal to Multi-decadal

Ocean: Circulation, SLR, Heat Content

Greenhouse Gases and Aerosols

1 DAY

WEATHER

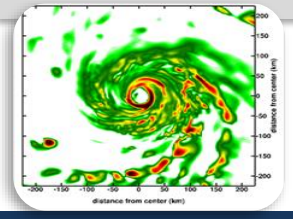
Seamless Modeling System
(Understanding and Prediction)

- ➔ Science-based, keying off fundamental advances
- ➔ Weather in the context of Climate & Climate Change
- ➔ Information, especially on Extremes
- ➔ Realism, and managing expectations
- ➔ Climate Risk assessments and Resiliency

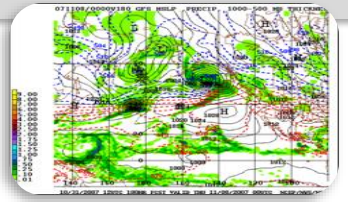
100 YEARS

CENTENNIAL

Sub-seasonal-to - Seasonal

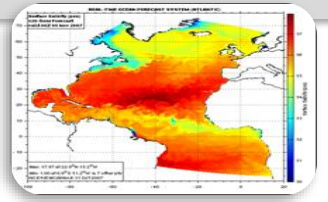


Seasonal-to-Interannual



Interannual-to-Decadal

Decadal-to-Multidecadal



Weather to Climate is "Seamless"

Thank you for your attention!

Acknowledgements

Thanks to all the GFDL Staff and other NOAA colleagues for making this presentation possible.

For additional information,

- **Contact: v.ramaswamy@noaa.gov**
- **Visit NOAA/OAR/GFDL website: www.gfdl.noaa.gov**
- **Publications: www.gfdl.noaa.gov/bibliography**