Introduction to Question 2

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Q2: Concerning NOAA's key mission element of understanding, predicting, and projecting changes in the Earth System, how can GFDL drive further advances in these areas, including extremes and environmental hazards, through scientific innovation based on observations, theory, and modeling? Where are the strengths, gaps, and new frontiers?

GFDL science & outlooks serve NOAA's mission

Societal relevance: GFDL advances **understanding, predictions, and projections** of the Earth System to support national health, safety, security, and prosperity, by **informing decisions** that protect and enhance lives, livelihoods, property, infrastructure, communities, and ecosystems.

Role in NOAA: Fundamental R&D to underpin science, models, and outlooks for decision support.

The nation relies on GFDL science and outlooks

GFDL effectively and efficiently generates **trusted world-leading science, tools, and outlooks** that are in demand and highly valued by stakeholders, and directly relevant to NOAA's mission in service of society.

GFDL continues to lead the way with **important, challenging, and pioneering** research and development that are vital to **predict, protect, manage, and mitigate** the environmental factors affecting the economy and our daily lives.

GFDL science yields abundant harvests

Use-inspired, science-based research & development

Fruits of past investments in GFDL:

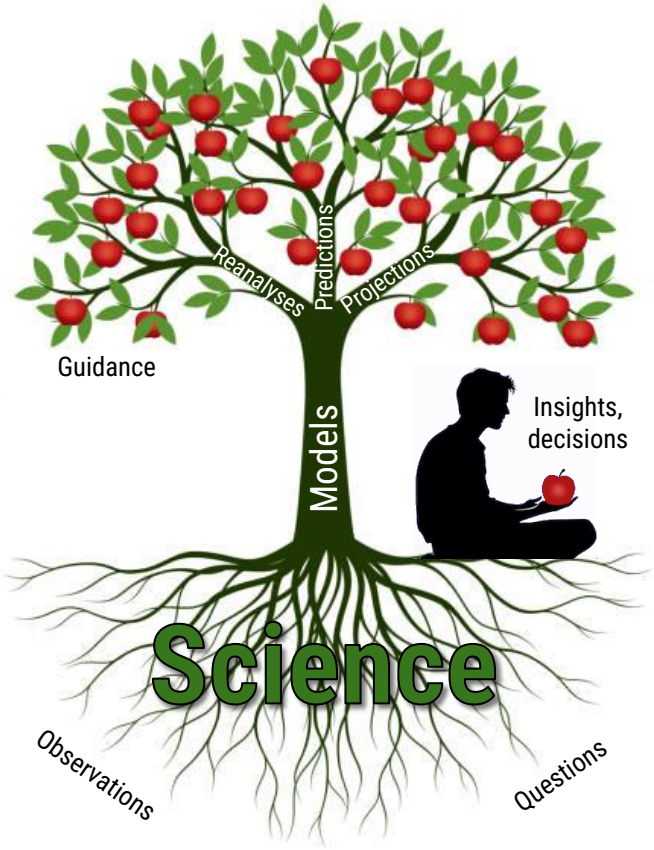
- **Highly-cited** research, reports, models, data, outlooks
- First coupled GCM; GFDL hurricane model; Nobel prizes
- R2O: FV3, MOM ⟶ **widely used** in operations & community
- SHiELD, SPEAR, CM4, ESM4.1
- Seasonal-to-decadal outlooks, ocean reanalyses
- Rapid-response & fisheries assessment tools

⇒ NMME, CMIP, WMO, WCRP, IPCC, NCA

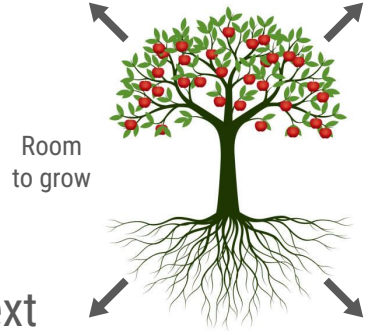
A **well-tended tree** sustains the harvest.

⟶ Better decisions that expand opportunities

⟶ A more secure nation that leads in the marketplace



GFDL's integrated approach grows the scientific roots and product branches



Comprehensive scope: Atmos, land, ocean, ice, chemistry, biology, forcings

Seamless tools illuminate **high-impact events** within their global context

Heat/cold, rain/snow, drought, ice, hurricanes, severe weather, fires, smoke, fog, pollution

Multi-scale interactions drive feedbacks & impacts (local to global, minutes to centuries)

Key to **improve models**, identify **sources & limits of predictability**

→ focused development → higher return on research investment

Key for **attribution** and risk assessment

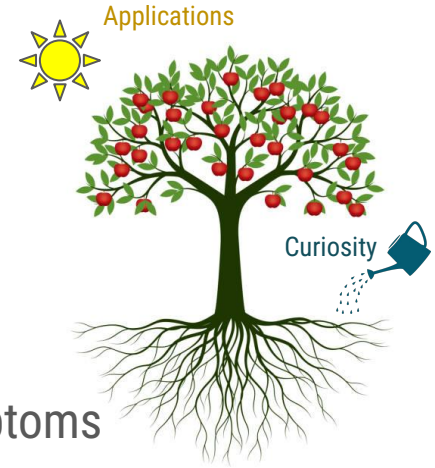
Understand *spectrum* of observed extremes & future sensitivities → better decisions

E.g. future AMOC La Niña hurricane wind/rain/inundation impacts

Compound events can amplify impacts:

E.g. hot + dry + windy → fires → smoke & dust + pollution → urban air quality impact

Insights stem from a freedom to experiment



Inspired top-down by **applications**, and bottom-up by **curiosity**

Long-lead high-reward research

- Embraces short-term risk (like investing in stocks, not CDs)
- Seek **deep integrated scientific basis**, to yield quantum leaps
- Identify & treat underlying *causes* of model biases, not just symptoms
- Discover Earth System **sensitivities** and **predictive signals**

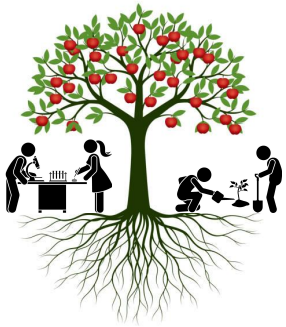
Innovative use of models of **varying complexity** with targeted strengths

- Tailor the *tool* to the *problem*: "As simple as possible, no simpler."
- Aided by **shared, flexible code framework**, variable resolution & comprehensiveness

Comprehensive + detailed + integrated + robust + tested → **compute-intensive**

processes *resolution* *coupling* *ensembles* *experiments*

Exceptional scientists → strong performance



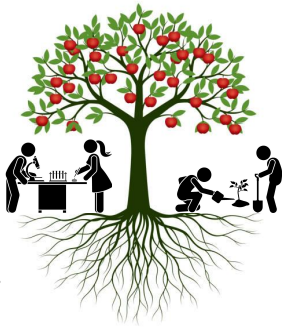
Interdisciplinary award-winning R&D teams
- Federal scientists, contractors, postdocs, students
- Strong GFDL/**Princeton** connection (internal + external funding)

Unique and hard-to-find expertise, under one roof
- Meteorology, oceanography, hydrology, physics, fluid dynamics, chemistry, biology, applied math, statistics, numerical analysis, software engineering

Coordinated, open, engaged & **leading** in the scientific community

Collaborations across NOAA, academia, national, international
- Fills gaps in GFDL expertise, broadens impact, accelerates R2O

GFDL science divisions are cohesive & interactive



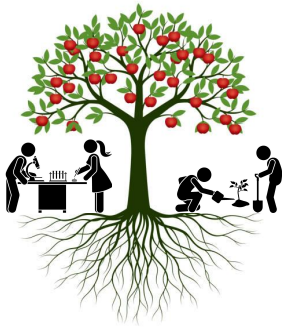
Groups streamline management, resources, communication.

Collaboration encouraged; many projects & models cross divisions.

GFDL **Science Board** and **Research Council** aid coordination.

Weather & Climate Dynamics	**Oceans & Cryosphere**	**Earth System Processes & Interactions**
Atmospheric Physics	**Seasonal to Decadal Variability & Predictability**	**Marine Ecosystems & Downscaling**
Modeling Systems		*Management Services*

Collaborative culture sustains high performance



Effective and efficient research & development
- Critical mass of **deep and integrative** expertise & skills
- **Open communication** and collaboration — leaders in the scientific community
- Tailor flexible modeling & analysis tools to the scientific question
- Outsized & lasting impact → **enthusiastic feedback** from stakeholders
  - **Milestones** and goals are met or exceeded
  - Data products and outlooks are provided on time

Continually improving **reliability, applicability, efficiency** of research & products
- Identify *sources* of predictive skill & bias → focuses efforts
- Saves money & time → greater returns on research investments

Science actions following the 2019 GFDL Lab Review

*R1 & R3: "Strengthen **Princeton** connection; and leverage **outside entities** to fill gaps"*

Princeton: symposia, summer schools, interns, tutorials, Stellar, onboarding
Joint collaborations, papers, proposals (CPO, DOE, ASCE, …), Fair Use Policy, ERB initiative
Testbeds & task forces (Hazardous Weather, rapid response), Global Nest, US CMS
CPTs (atmos, ocean, land); OAR labs, industry, philanthropic/nonprofit, international partners

*R4: "Engage with other **NOAA** efforts"*

OAR/NOAA collabs; embedded EMC/NMFS scientists at GFDL; GFDL scientist at NESDIS
R2O: FV3, MOM6, cloud microphysics → EMC, NWS, UFS, EPIC
Coastal ecosystem modeling (CEFI, NMFS); weather & coastal inundation (NOS)
Joint workshops (AOML, GSL); NOAA ERB & ATLAS-15 projects
Multi-model assessments (CMIP, WMO, NCA); Climate Impacts Initiative
SPEAR → NMME; real-time attribution (PSL, CPC, NCEI)

⇒ More co-development of science & products with partners & stakeholders (Q3).

Science actions following the 2019 GFDL Lab Review

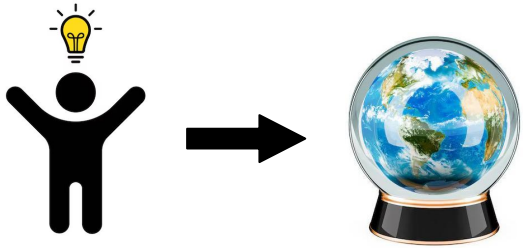
*R6: "Use additional **observations** to improve GFDL models"*

Leveraged new obs: Clouds, precip, radiation, chemistry, lightning, aerosols, water vapor, SST
Cloud-Climate Initiative; SHiELD/SPEAR/BGC assimilation; MDTF & ENSO metrics
Process-oriented diags: clouds, ABL, convection, precip, radiation, OML heat budget
Obs constraints & targeting: (BGC-)Argo, (B-)SOSE, TAO, TPOS/TEPEX, nudging, FA
NOAA, NASA, USGS

*R7: "**AI/ML** collaborations with private sector"*

M^2LInES, Vulcan→AI2; AI-enhanced & AI-emulator models

Plan for this session



Organized by GFDL's **science divisions**
(though many projects span divisions)
Overview & highlights from GFDL's portfolio: past 5 years + plans
More details in prerequisite slides & online materials, or ask in Discussions

Spotlight on **high-impact events**, in context of climate variations
Responsible for outsized impacts across scales
Showcase GFDL's comprehensive, seamless, interdisciplinary approach
New science → new capabilities → societal impact

Emphasize **relevance, quality, performance** of results, and new **opportunities**
Slide title gives the take-home point of each slide

Overview of Q2 presentations: Skill, predictability, utility

Extreme weather events: TCs, precip, thunderstorms, winter storms, drought, heat waves (SHiELD)

Subseasonal-to-decadal variations in risks & extremes (SPEAR, AM4VR; downscaling)

- **Heat/cold**; **precip** (TCs, ARs, MCS, droughts, snow); **storms** & blocking; **wind** energy
- **Sea level** (inundation, TCs, AMOC); climate modes (e.g. **MJO**, **ENSO, AMOC, PDV, SO**)
- **Sea ice** & ice shelves; **ocean circulation**, **BGC, marine resources** → downscaling
- **Air quality** (dust, smoke, ozone, urban pollution)

Regional & global changes in climate and extremes (CM4, ESM4.1)

- **Internal vs. forced variations**: monitoring; mitigation; reversibility; geoengineering
  - Reducing uncertainties in climate forcings, feedbacks, and projections
- **Detection, attribution, impacts** of changes; warming commitment; tipping points
  - TCs, heat/cold, precip, drought, storms, ENSO; ocean circulation & heat uptake, BGC
  - Carbon cycle; pollution (air/land/rivers/coasts), fires/smoke, dust, air quality

Common themes from Q2 presentations

GFDL delivers world-class science & outlooks to assess climate, extremes & hazards.

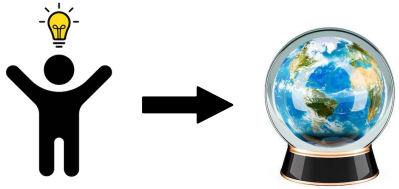
Seamless across scales (regional to global, hours to decades)

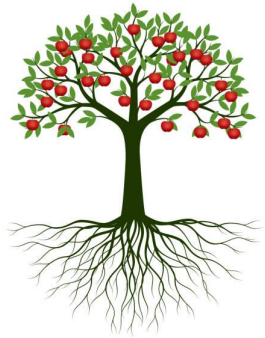
- Pioneering experimental **forecasts** → skillful/useful **products** → R2O (see also Q3)
- **Rapid attribution** of observed events & changes → understand causes → better decisions
- **High-res** to capture extremes, interactions, sensitivities; **ensembles** to assess skill & risks
  - → Strong case for investing in additional compute

Process understanding improves models & outlooks → societal relevance

- **Multiscale feedbacks** & **compound events**, sources & limits of **predictability**
  - E.g. ENSO, TCs, storm-driven inundation, fire, pollution, and future changes
- Utilizes & guides **observations** and **theory**; provides **metrics** for models
  - → Better simulations, outlooks, understanding of **sensitivities & risks**
- **AI/ML** to learn model corrections, find predictive signals, attribute observed changes

Seeds for Discussion





Challenges

- Computing, hiring, funding stability: required for **high-reward deep-dive** projects
- Maintain focus & core strengths, given **increasing complexity** & user demands
- Balance between model diversity & **consolidation**, comprehensiveness & **interpretability**

New frontiers

- Extend research & products to **new scales, phenomena, interactions, impacts**
- **Large ensembles** to assess robustness, risks, extremes
- Further improve **skill** of models & outlooks
  - New observational constraints, theory, and process diagnostics
  - Resolution, parameterizations, initialization, scenarios, bias correction
- Further leverage **AI/ML**