Community AI at NSF NCAR

John Clyne

Manager, NSF NCAR's Intelligent Methods, Prediction, Analysis, and Community Tools (IMPACT) Section

**ECMWF workshop on high performance computing in meteorology**

September 17, 2025

NSF National Center for Atmospheric Research (NCAR)

NSF NCAR was established by the U.S. National Science Foundation in 1960 to provide the university community with world-class facilities and services that were beyond the reach of any individual institution.

The NSF NCAR Mission:

- To understand the behavior of the atmosphere and related Earth and geospace systems
- To support, enhance, and extend the capabilities of the university community and the broader scientific community, nationally and internationally
- To foster the transfer of knowledge and technology for the betterment of life on Earth
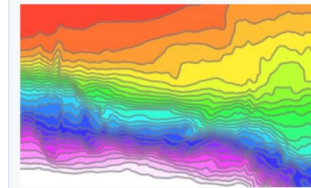
ATMOSPHERIC CHEMISTRY OBSERVATIONS & MODELING (ACOM)

ACOM research focuses on advancing understanding and predictive capability for atmospheric composition and related processes.
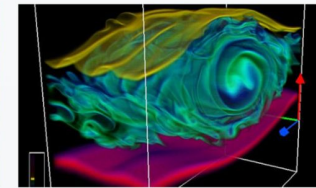
VISIT ACOM
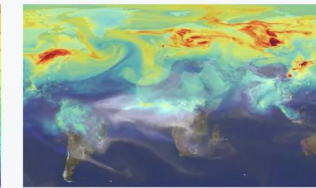
CLIMATE & GLOBAL DYNAMICS (CGD)

CGD develops understanding of the Earth system and is a leader of community-developed and community-owned models of the Earth system.

VISIT CGD

COMPUTATIONAL & INFORMATION SYSTEMS LABORATORY (CISL)

CISL is a world leader in supercomputing and cyberinfrastructure, providing services to NCAR, UCAR member universities, and the broader geosciences community.

VISIT CISL

EDUCATION, ENGAGEMENT & EARLY-CAREER DEVELOPMENT (EDEC)

EdEC is committed to inspiring, engaging and informing the public about the science going on at NCAR and in our broader scientific community.
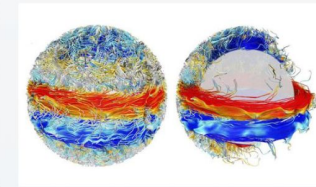
VISIT EDEC

EARTH OBSERVING LABORATORY (EOL)

EOL provides state-of-the-art atmospheric observing systems and support services to the university-based research community for climate, weather, and related Earth system research.
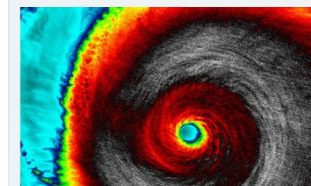
VISIT EOL

HIGH ALTITUDE OBSERVATORY (HAO)

HAO conducts fundamental and applied research in solar-terrestrial physics using observational, theoretical, and numerical methods. Research at HAO extends from the solar core to the surface of the Earth.

VISIT HAO

MESOSCALE & MICROSCALE METEOROLOGY (MMM)

MMM advances the understanding of regional and fine-scale aspects of weather and climate and applies this knowledge to benefit society.

VISIT MMM

RESEARCH APPLICATIONS LABORATORY (RAL)

RAL conducts directed research and engineering to discover solutions to problems relevant to society and facilitates the transfer of our information, expertise, and technology to the public and private sectors.

VISIT RAL

NSF NCAR's Computational Information Systems Lab (CISL)

- **Support for Earth System Modeling**: Computational & Data Infrastructure

- **Access to ESS data** Observed and reanalysis model outputs, integrated with NSF NCAR High Performance Compute services

- **Appropriate and easy-to-use/adapt tools:** Models, Analysis, Visualization, and AI

- **Data Assimilation Advancements** Methodologies, tools and software to enable data assimilation capabilities within ESS models

- **Machine Learning:** Research to improve our ability to apply rigorous, explainable, and quantifiable modeling to ESS
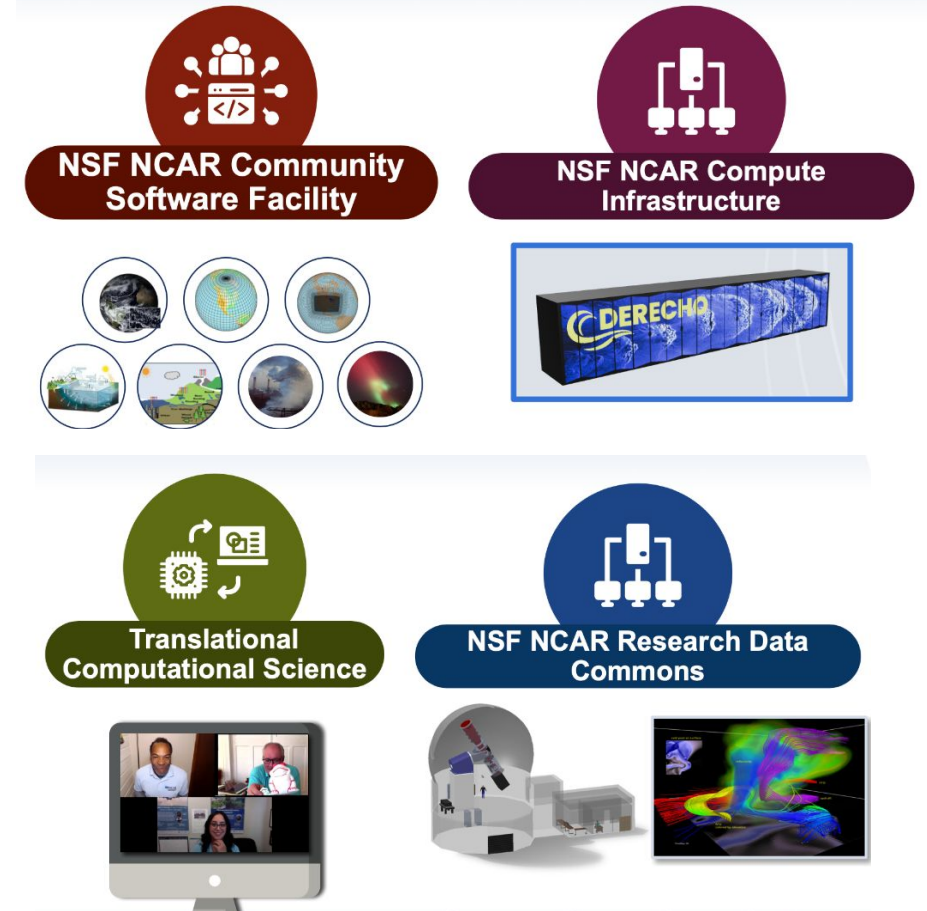
- **Enabling and supporting the community through a digital Earth System Science lab**
- **Democratizing Research Capabilities in support of Earth System Science**

Application areas for AI/ML in Earth System Sciences
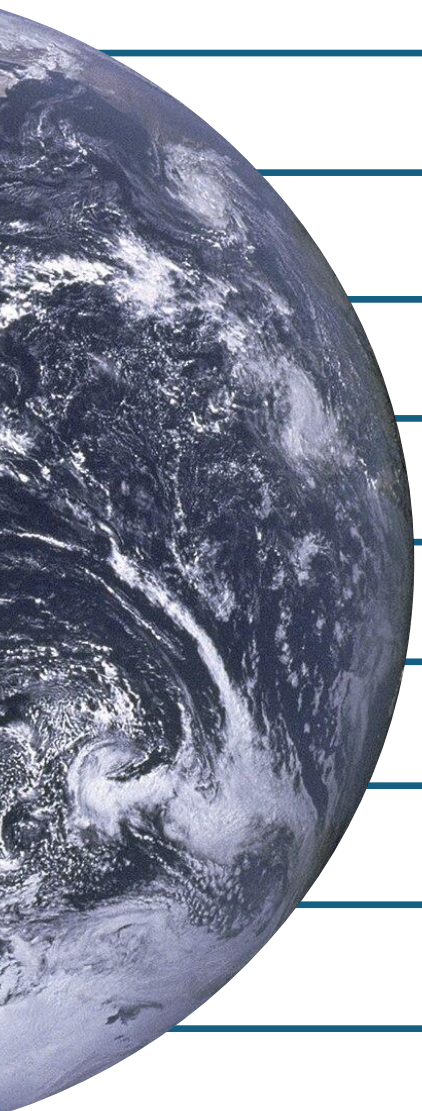
- Hybrid Earth system modeling: Physics-Informed AI/ML Models
- Extreme Event Prediction & Attribution
- Prediction Across Timescales (Nowcasting→S2S→S2D)
- Downscaling & Super Resolution
- AI-Enhanced Data Assimilation
- Observation Fusion, Gap Filling & Retrievals
- Impacts Assessments & "What-if" Scenarios
- Data-Driven Insights & Decision Support
- Data Processing and Analysis

Envisioned NSF NCAR AI Roadmap:

- A unified strategy that enables researchers to work smarter, faster, and together, adopting AI/ML to accelerate Earth System Science (ESS) breakthroughs.

- Democratize AI-enabled research across the ESS community.

- Coordinate workforce development with and for the community.

- Strengthens computational and data infrastructure to support AI-enabled research at scale.

The objectives around which we will construct a vision for the Roadmap are:
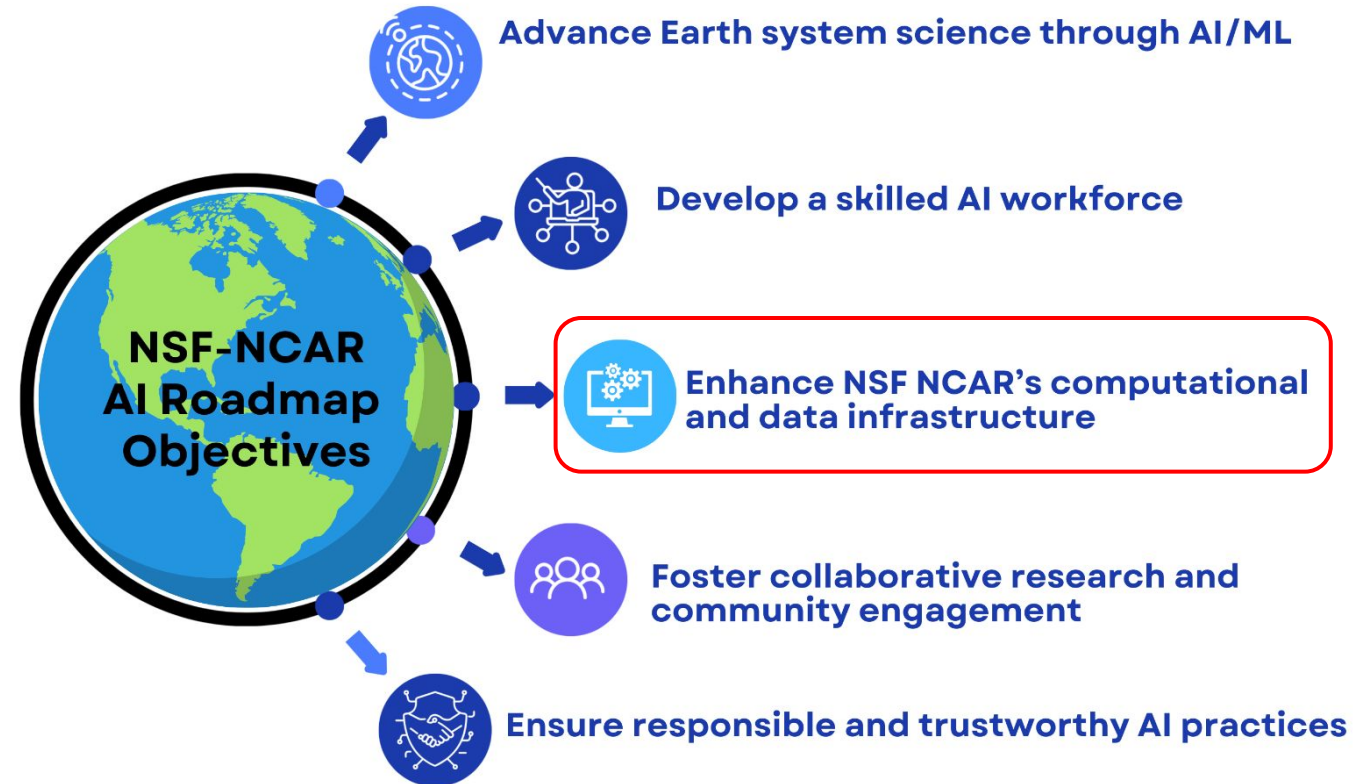
NSF-NCAR AI Roadmap Objectives

Advance Earth system science through AI/ML

Develop a skilled AI workforce

Enhance NSF NCAR's computational and data infrastructure

Foster collaborative research and community engagement

Ensure responsible and trustworthy AI practices

1. **Geoscience Data Exchange (GDEX)** - An integrated research data commons

2. **CREDIT Pilot Project**- Exploring transforming NCAR's experimental AIWP framework into community Open Source Ecosystem (OSE)

3. **AI Factory Proof of Concept** - ESS model training as a service

4. **IMPACT** - NSF NCAR's new AI-focused R&D section

Siloed Data Systems
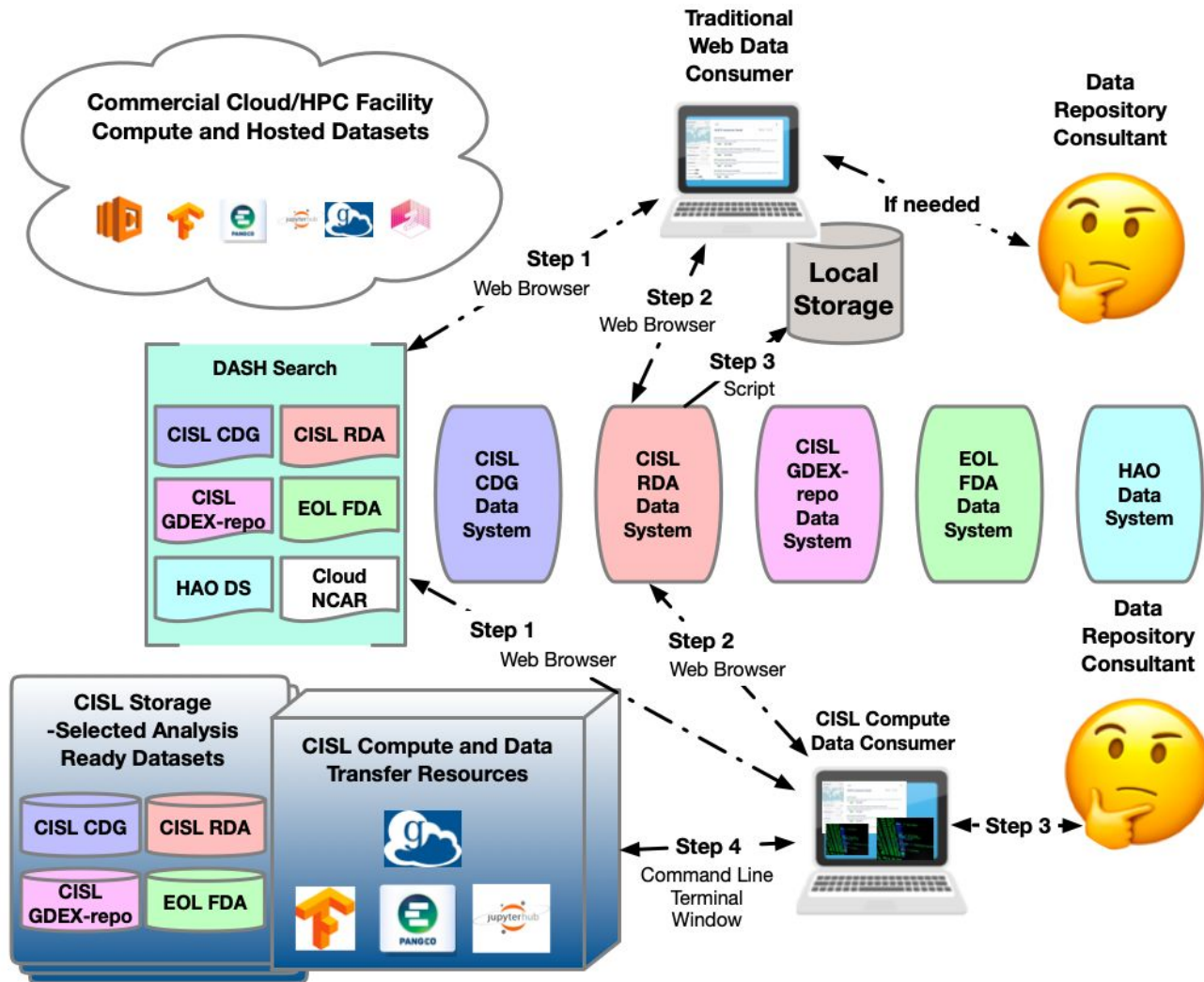
NCAR's data services have decades of trusted data stewardship in the research community

Silos created fragmentation in access and governance

Data Commons unifies NSF NCAR data curation and access

Vision:

Accessible to All
Provide intuitive entry points and a consistent experience for researchers at every level—from novice to expert.

Integrated for Insight
Connect tools for data exploration, analysis, assimilation, **and AI/ML workflows** into a cohesive, interoperable environment.

Built for Community Leadership
Position NSF NCAR to lead and support next-generation community cyberinfrastructure (CI) initiatives, advancing open science and collaboration.

Unifying Scientific Data for Seamless Access and Insight
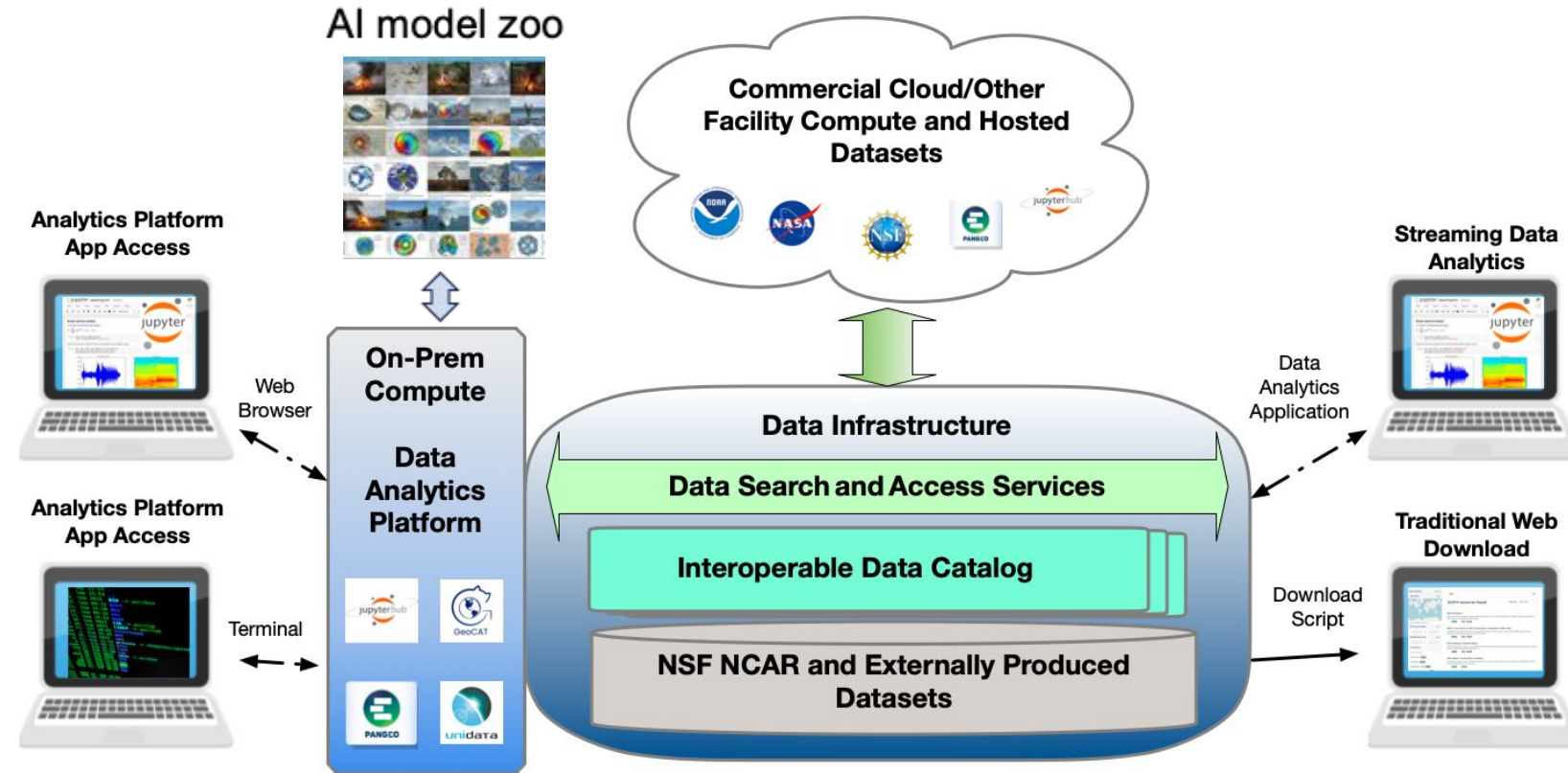
A unified data infrastructure enables seamless access to scientific data—accelerating insight through both traditional and next-generation workflows.

Grossman, R.L. Ten lessons for data sharing with a data commons. *Sci Data* 10, 120 (2023). https://doi.org/10.1038/s41597-023-02029-x

GDEX Implementation Timeline and Phases

The Data Commons implementation is transitioning legacy GDEX-repository and CDG into a modernized RDA, to be relaunched as GDEX Integrated Research Data Commons reinforcing NSF NCAR's data infrastructure. This work is being carried out in six phases across FY25 and FY26.
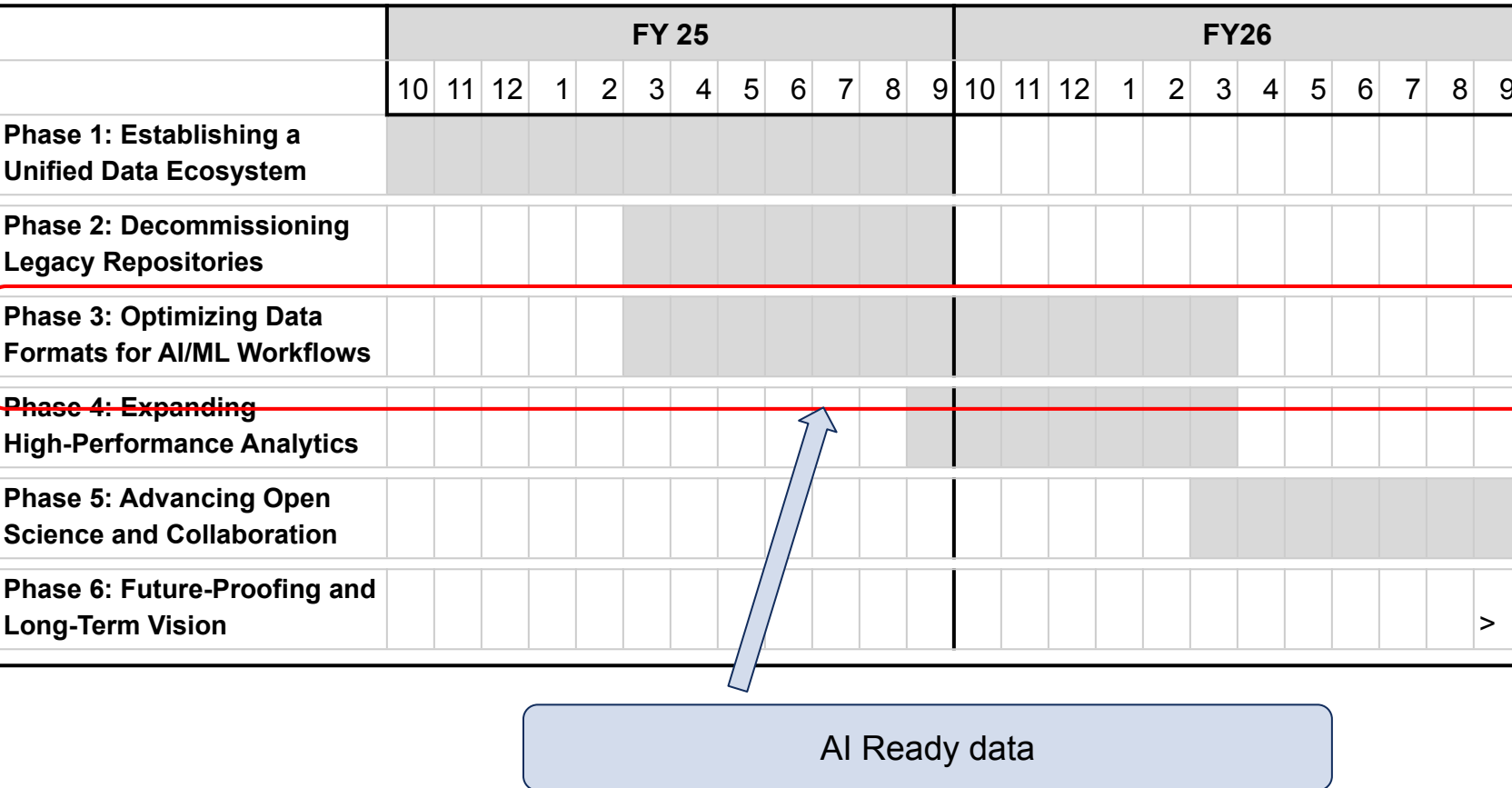
	FY 25												FY26											
	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Phase 1: Establishing a Unified Data Ecosystem																								
Phase 2: Decommissioning Legacy Repositories																								
Phase 3: Optimizing Data Formats for AI/ML Workflows																								
Phase 4: Expanding High-Performance Analytics																								
Phase 5: Advancing Open Science and Collaboration																								
Phase 6: Future-Proofing and Long-Term Vision																							>

FY 25 Goals:

- Engage users and manage the transition process
- Restructure legacy data into Analysis/AI-Ready formats
- Update RDA catalog to improve search and usability
- Merge CDG and GDEX into RDA
- Redirect all traffic to the unified rda.ucar.edu site
- Sunset CDG and GDEX platforms
- Relaunch RDA as the new GDEX

FY 26 Goals:

- Launch a Virtual Research Environment (VRE) "Science Gateway" Prototype
- Continue user engagement and feedback
- Support ongoing user consulting and dataset deposits

AI Ready data

3 day Z500 RMSE Skill Score vs Publication Time
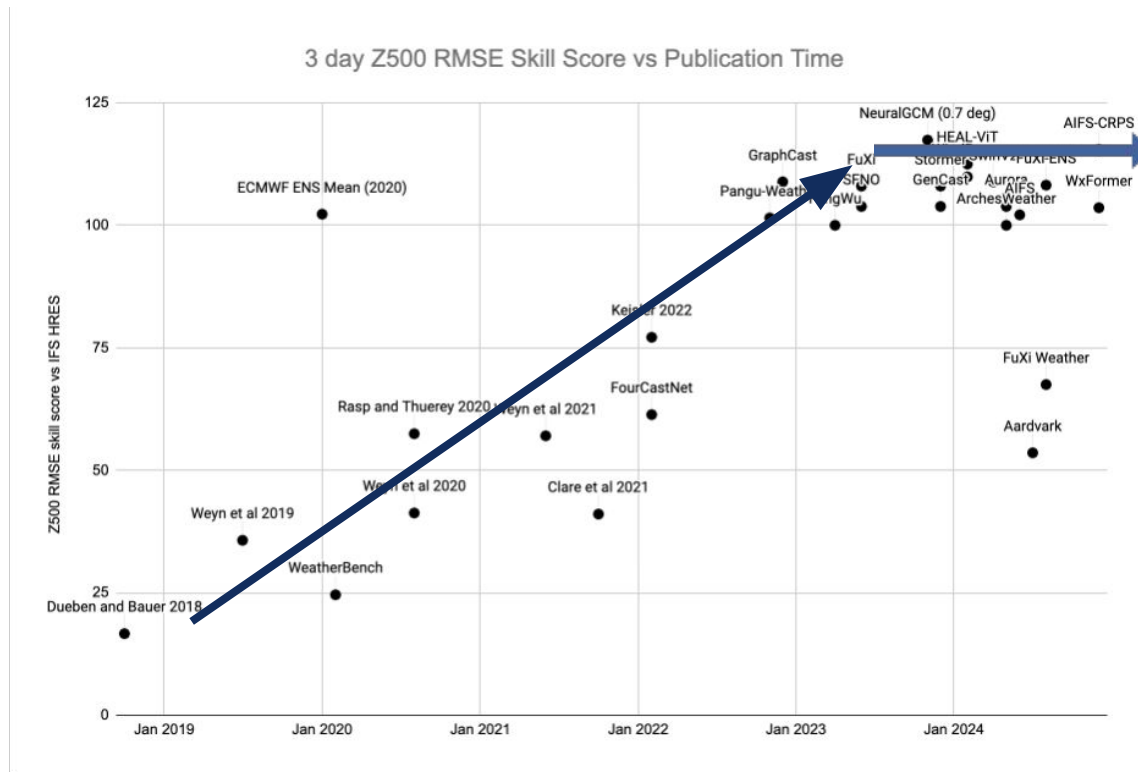
After 4 years of rapid advancement in accuracy, further advancements in AI weather modeling have shown diminishing returns in improving global metrics.

- Past 3 years have produced a growing zoo of AI weather prediction models, so why are more needed?
- What if you need
  - Higher frequency model output than 6-hourly
  - Precipitation, clouds, aerosols
  - Processes not included in IFS/ERA5
  - Higher resolution
  - Physics conservation constraints
  - Changing architectures
  - Calibrated Ensembles
- Requires training or fine-tuning AI models

CREDIT: Community Research Earth Digital Intelligence Twin

What is CREDIT?

An open foundational **platform** for developing and deploying AI weather and Earth system prediction models.
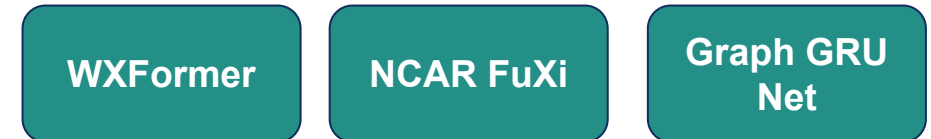
CREDIT enables users to build custom data and modeling pipelines to load data, train configurable AI forward models, and deploy them for real-time forecasting, hindcasting, or scenario projections.

CREDIT offers both scientifically validated model configurations and endless customization for any use case.
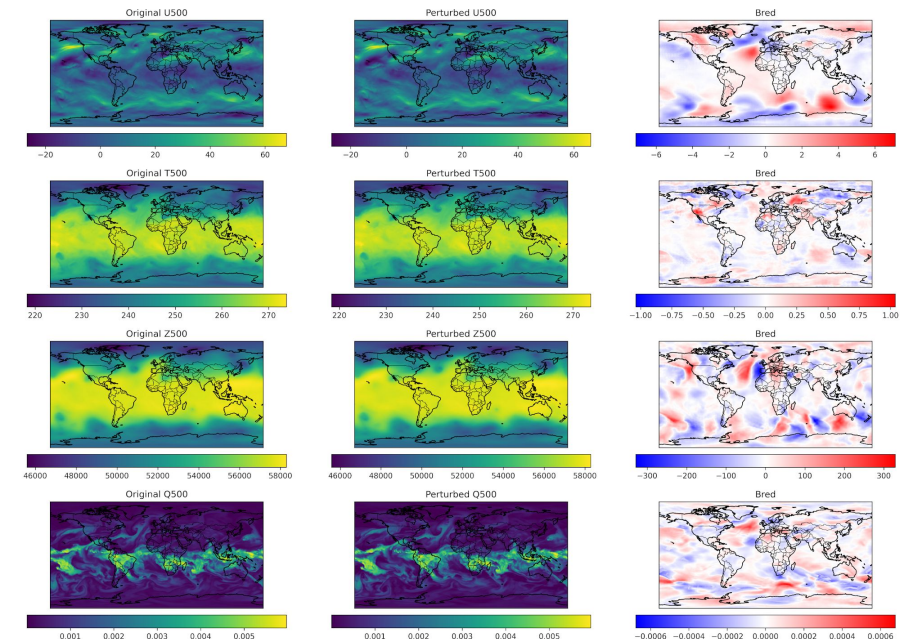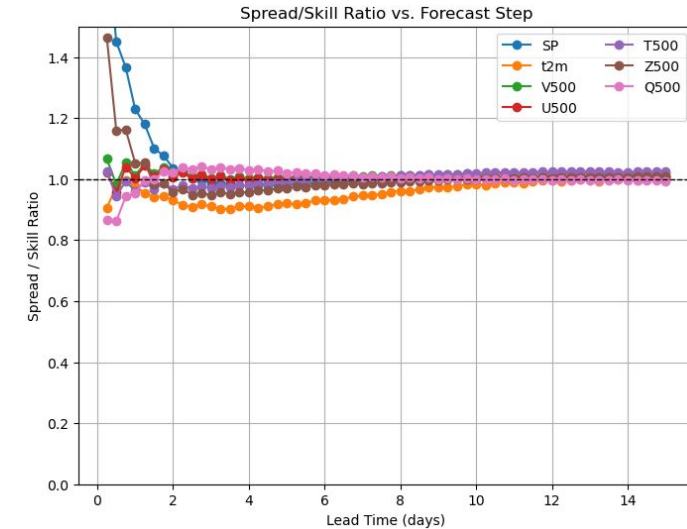
Datasets

| ERA5 | Community Atmosphere Model | GFS | CONUS 404 |

Models

| WXFormer | NCAR FuXi | Graph GRU Net |

Physics

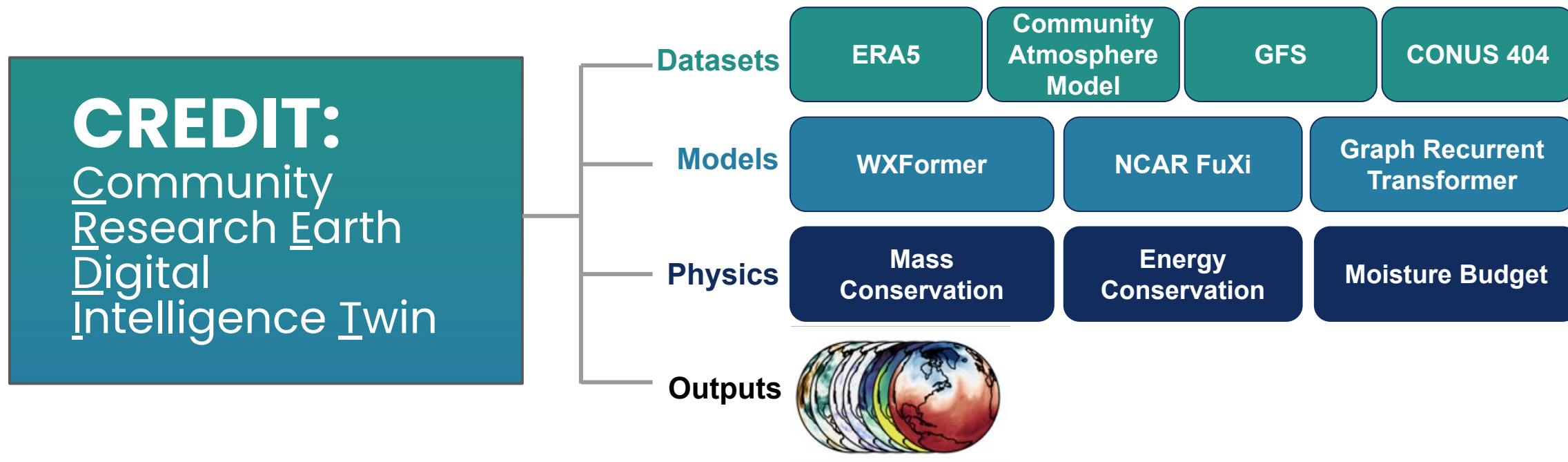| Mass Conservation | Energy Conservation | Moisture Budget |

- CREDIT is supporting the investigation of multiple ensemble perturbation techniques for AIWP
  - **Tuned latent space perturbations**
  - Bred Vectors
  - Initial condition ensembles (GEFS ICs)
  - SKEBS
  - Diffusion
- Ongoing validation work to determine which method produces the optimal balance of spread and skill

CREDIT: From Research Platform to Community Digital Twin

CREDIT:
Community
Research Earth
Digital
Intelligence Twin

Datasets

| ERA5 | Community Atmosphere Model | GFS | CONUS 404 |

Models

| WXFormer | NCAR FuXi | Graph Recurrent Transformer |

Physics

| Mass Conservation | Energy Conservation | Moisture Budget |

Outputs

TODAY: A "lab code" for AI experts

- To explore best practices in AI atmospheric prediction
- To deliver novel AI architectures integrated with critical physical constraints
- To provide a flexible, scalable toolkit for AI training, AI inference, and analysis

TOMORROW: A Community code for domain scientists???

- An intelligent digital twin community ecosystem
- Democratized access to cutting-edge, physics-informed AI for the ESS community from a supercomputer to your laptop
- Integrated ESS AI enabled modeling capabilities

Phase 1: Provide access to **pre-trained** models

- Interactive web interface
  - Access previously run forecasts
  - Run a custom forecast or hindcast
- Command line and programmatic interfaces
  - Documentation, on-boarding, examples
  - Portability
- Make strides toward an production-ready code
  - Robust, maintainable, documented code
  - Software engineering best practices (version control, testing, CI/CD pipelines)

Phase 2: **Facilitate** training of new models

- New training data sets
- Portability and scalability
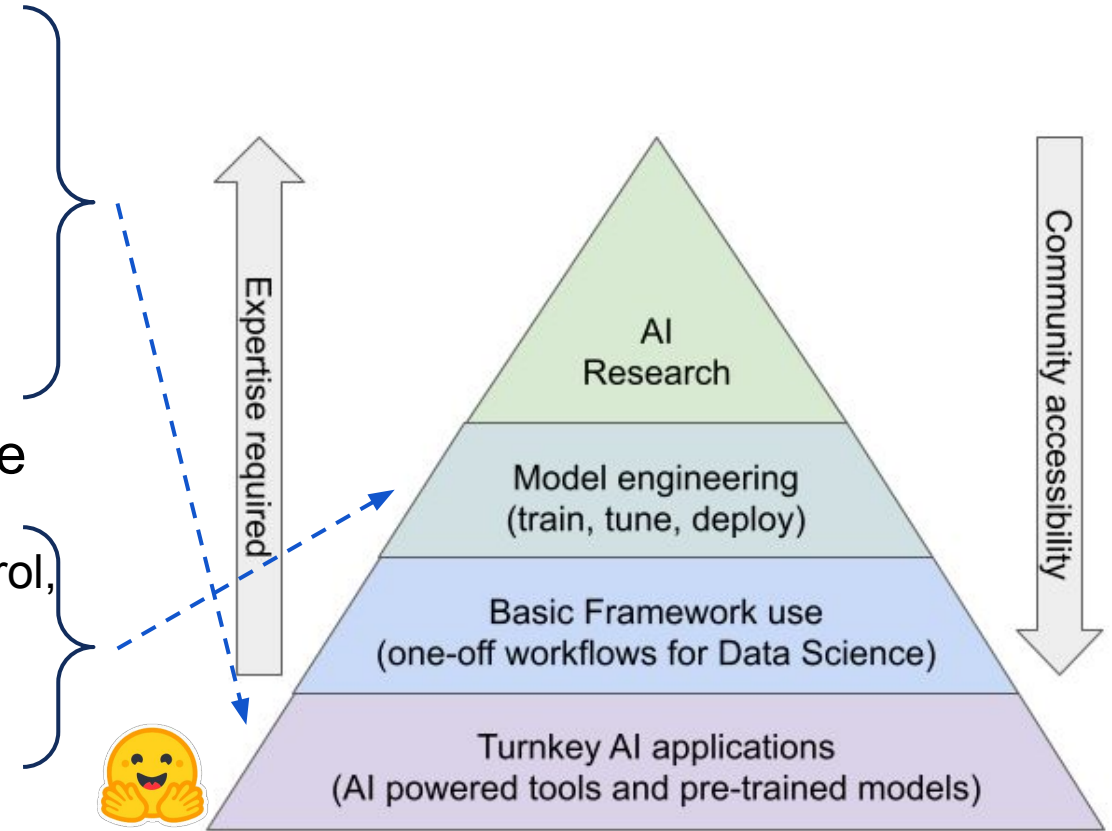
CREDIT pilot anticipated outcomes

Assess demand for climate and weather emulator framework

- Assess the demand from NSF NCAR and universities for an OSE framework for experimentation with climate and weather model emulation
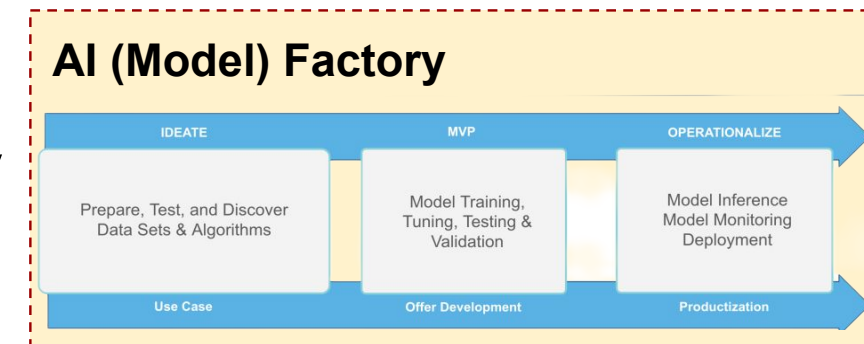
Experience with sharing pre-trained models

- Develop guidelines for sharing pre-trained model weights, leveraging platforms like HuggingFace

Workforce development

- Gain experience with building, deploying, and supporting AI based community tools

AI Factory guidance

- Help guide and inform decisions about CISL's AI Factory

AI (Model) Factory

IDEATE	MVP	OPERATIONALIZE
Prepare, Test, and Discover Data Sets & Algorithms	Model Training, Tuning, Testing & Validation	Model Inference Model Monitoring Deployment
Use Case	Offer Development	Productization

Typical AI/ML Training workflow in ESS

Data

Data Ingestion & Preprocessing

Training & Validation

Trained Model

Zarr

netCDF

COG

HDF

Challenges:
- Massive data volume & data movement
- Computational cost and complexity
- Model lifecycle management
- Reproducibility
- Software complexity
- Trust and ethical use
- …

GPU

Model Inference

Slide credit: Negin Sobhani
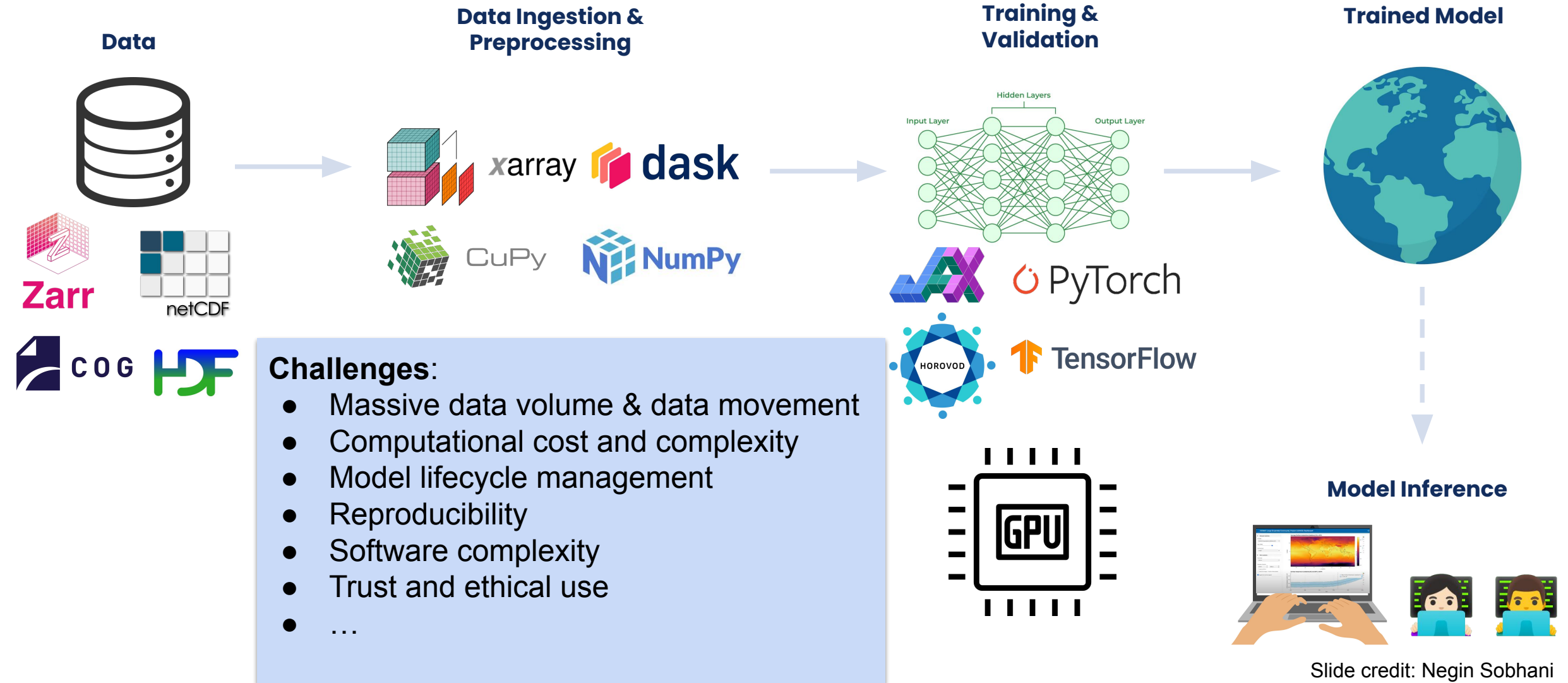
An **AI Factory** is a systematic, automated infrastructure and process framework that transforms data into reproducible AI models at scale.

Key Components:

Not the EC definition!

- **Data Pipeline:** Automated ingestion, preprocessing, and quality management systems
- **Model Development:** Training, validation, and optimization workflows
- **Deployment Infrastructure:** Scalable computing resources (HPC or cloud platforms with AI accelerators)
- **MLOps Framework:** Continuous integration, deployment, and monitoring approaches
- **Automation Tools:** Orchestration, scheduling, and workflow management capabilities

The **AI Factory represents a critical piece within NCAR's AI Ecosystem.** It formalizes repeatable efficiencies and automations that can scale as institutional capacity and infrastructure evolve.


4 Components of the AI Factory

1. **Data Pipeline:** A semi-automated, systematic process for gathering, cleaning, integrating, and securing company data

2. **Algorithm Development:** Algorithms that transform data into action insights to help you anticipate trends

3. **Software Infrastructure:** Foundational architecture that supports your AI factory's data pipeline and algorithm

4. **Experimentation Platform:** Where you can test, refine, and optimize AI models and predict outcomes based on different conditions

Harvard Business School Online

AI Factories powered by NVIDIA
Manufacturing enterprise intelligence at scale
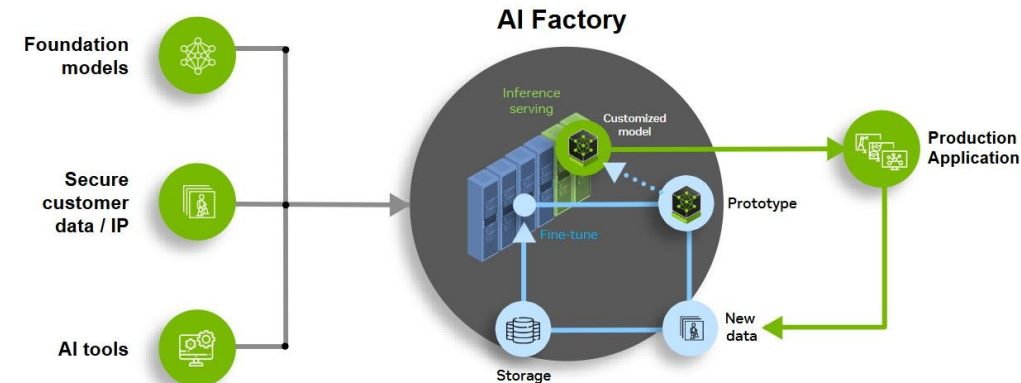
Intelligent Methods, Prediction, Analysis, and Community Tools (IMPACT)

Mission: Empower the Earth sciences by harnessing the full potential of AI/ML combined with NSF NCAR's **expertise**, **computing** and **data** resources.

- Conduct **applied** research in Artificial Intelligence (AI) and Machine Learning (ML)

- Develop robust, scalable, **easy-to-use** tools tailored to the needs of ESS workflows and applications

- Evaluate emerging technologies for trustworthiness, performance, and relevance.

*A core focus of IMPACT's work is making AI more **accessible**—simplifying complex methods, designing intuitive interfaces, and delivering capabilities that Earth scientists can readily adopt and apply to real-world challenges. Through this integrated approach, IMPACT aims to enable accelerated discovery, improve predictive understanding, and help support informed decision-making in the study of our planet.*

AI/ML Opportunities form LLMs in Data Analytics and Visualization
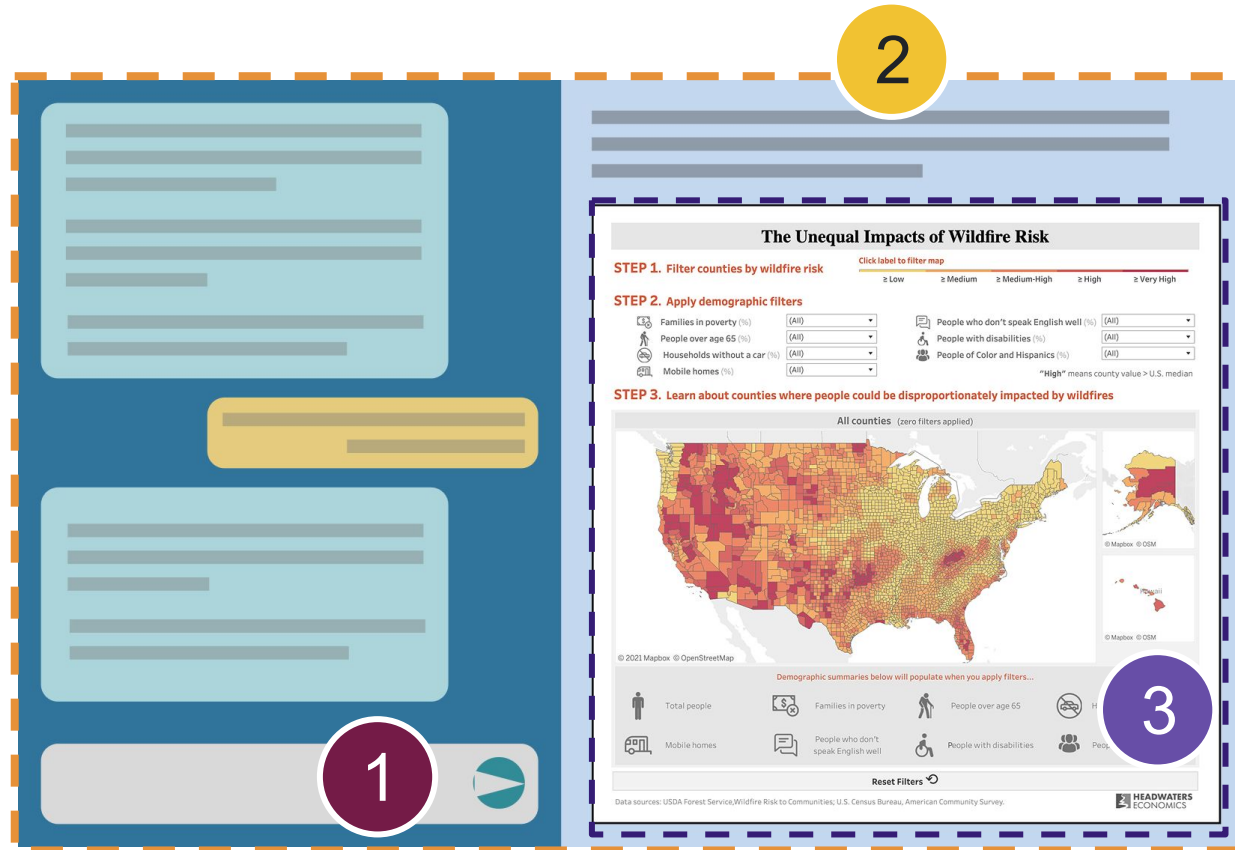
1 Conversational Interfaces

2 Ad-Hoc Dashboards and visualization code generation

3 Visual analytics leveraging semantic information

Unlocking novel paradigms for *Human-In-The-Loop* data exploration.

Summary

NSF NCAR AI Roadmap: Envisions a future where AI and ML are integral to Earth system research, accelerating scientific discovery and improving our ability to understand and predict complex Earth system processes

NCAR's Computational Information Systems Lab (CISL) has launched several initiatives in alignment with the evolving NCAR AI Roadmap

- CREDIT Pilot Project will explore the development of a community emulator framework to support ESS research goals

- Geoscience Data Exchange (GDEX) is being refactored to support AI/ML training needs

- AI Factory Proof of Concept: Can we offer model training as a service?

- IMPACT: NCAR's new AI-focused R&D section

Interested in any of these topics or have experiences to share? email: clyne@ucar.edu

Questions?

clyne@ucar.edu