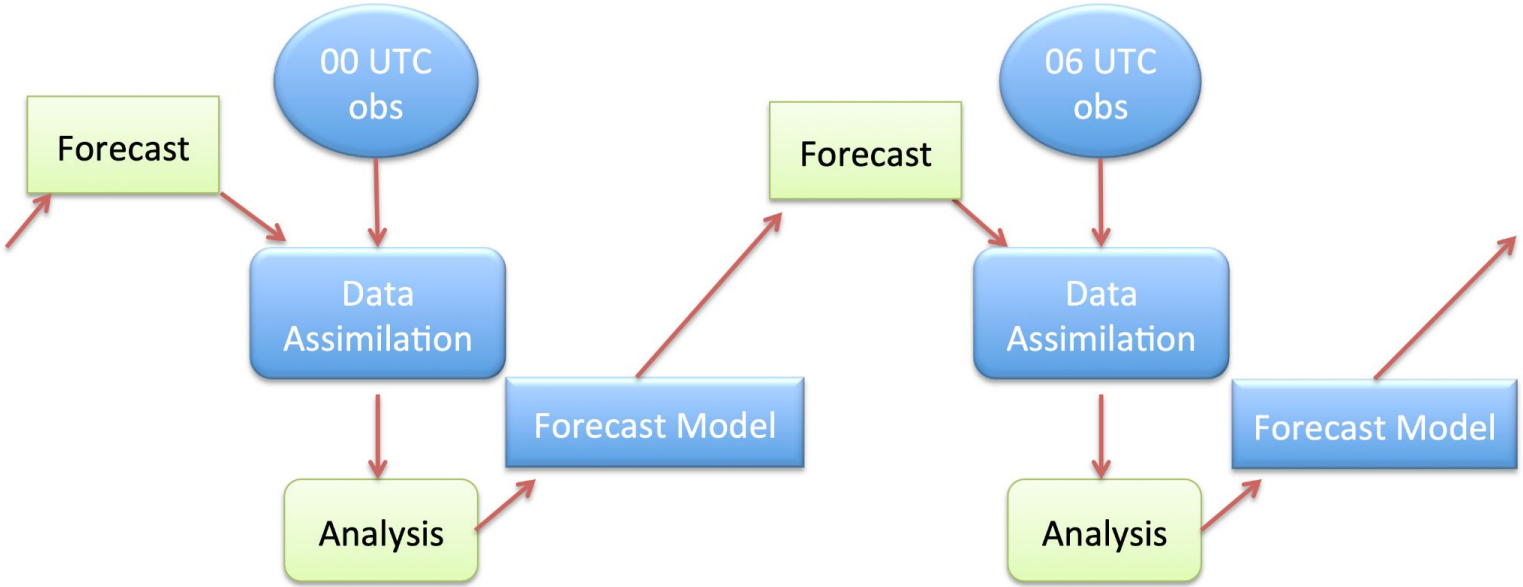
R2O in NOAA

How it works now, and how to incorporate emerging AI methods

Jeff Whitaker
NOAA Physical Sciences Laboratory

<jeffrey.s.whitaker@noaa.gov>

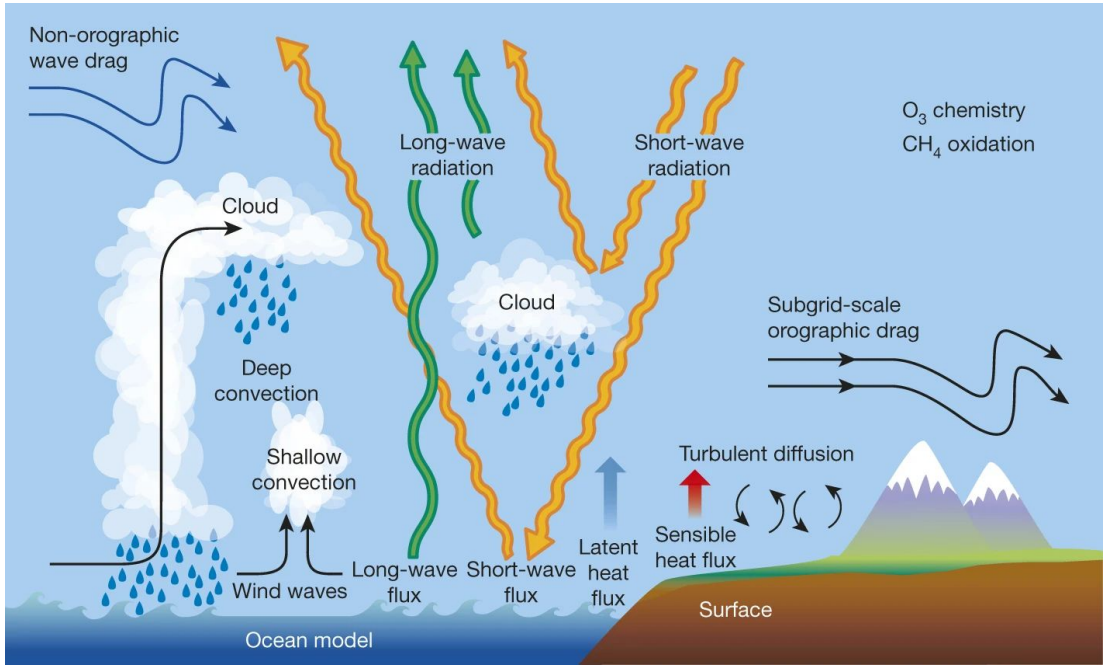
The NWP process



Analyses and forecasts become more accurate when observations, forecast model and/or data assimilation components improve.

Note: forecast model carries information from past observations.

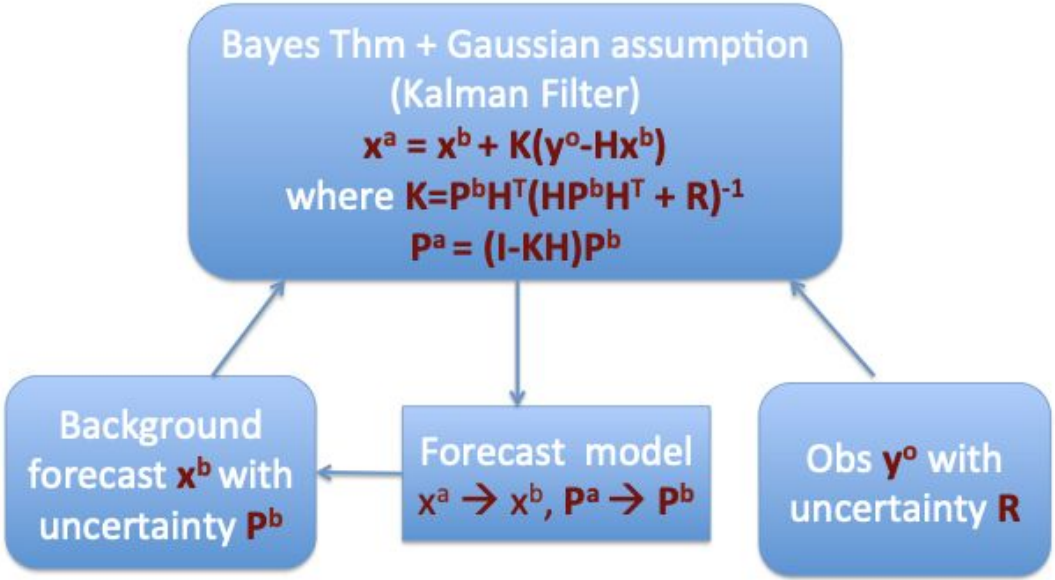
Improving numerical weather prediction models



From **"The quiet revolution of numerical weather prediction"** https://doi.org/10.1038/nature14956

Improvements in resolution and numerical methods for solving PDEs, ensemble modelling and the representation of unresolved (parameterized) processes have led to improved forecasts.

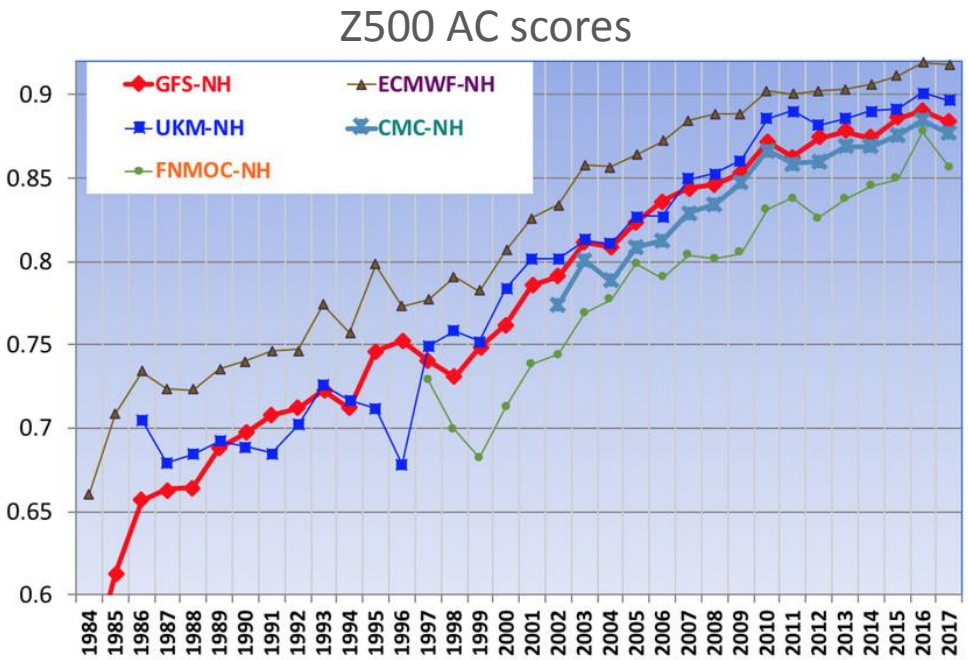
Improvements in data assimilation (model initialization)



Improvements in DA have come from better error estimation ($\mathbf{P^b}$ and **R**), forward modeling of observations (**H**), better observation QC, and relaxation of linearity assumptions.

Impacts of computing advances

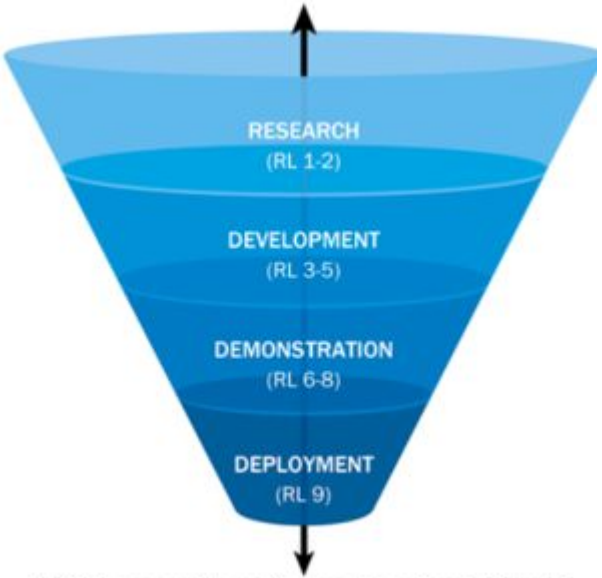
- Progress in modeling and DA has always been limited by the availability of compute resources and the time constraints imposed by operational NWP.
- Improvements in NWP have largely tracked Moore's law (systems do not utilize GPUs well) - one day lead time per decade.



From "100 Years of Progress in Forecasting and NWP Applications"
https://doi.org/10.1175/AMSMONOGRAPHS-D-18-0020.1

The current R2O process in NOAA

- NOAA uses the concept of an R2O “funnel” to fund and track the progression of R&D projects along the spectrum of readiness levels through ‘Operational Transition’ (Deployment).
- Lower Readiness-Level (RL) activities funded through NOFOs at universities.
- Higher RL activities funded mainly at labs and testbeds.
- The “UFS-R2O project” (now in its fourth year) is an attempt to streamline this process by bringing the efforts from RL-6 downward under one collaborative framework.



NOAA's research transition readiness levels "funnel" connecting research with application.

UFSR2O

Medium-Range Weather/Subseasonal to Seasonal Integrated Application Team

Short-Range Weather/Convective Allowing Models Integrated Application Team

Hurricane Integrated Application Team

- Atmospheric Composition
- Marine Components
- Atmospheric Physics and Dynamics, (including stochastic physics & land)
- Data Assimilation, Reanalysis & Reforecast
- Modeling Infrastructure
- Verification & Post-Processing Infrastructure

How to fit AI into this process?

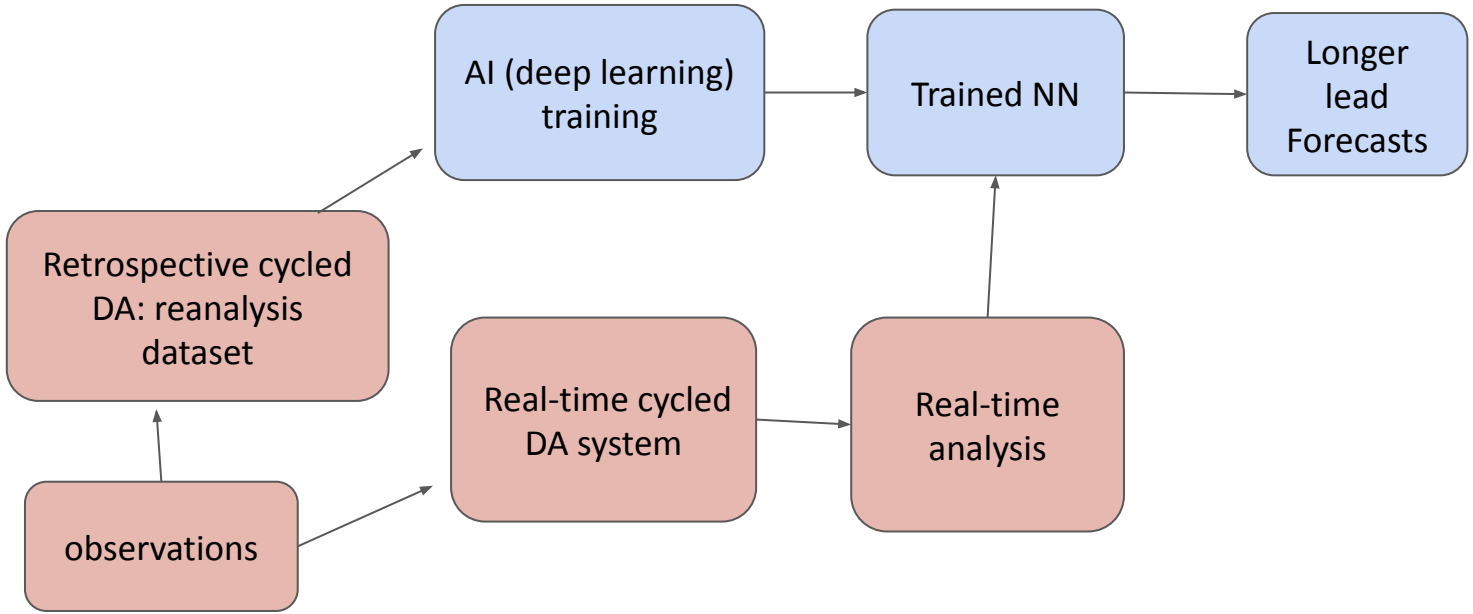
Up till now, improvements in NWP forecasts have come from

- Improvements in ***forecast model resolution and physics*** (by increasing compute power and utilizing observations to improve process understanding, translating to better representation in models).
- Improvements in ***observation networks, DA algorithms*** to better initialize the models.

Recent rapid improvements in AI forecasts have come from

- Better utilization of ***training datasets*** (reanalyses).
- Better, more efficient ***deep learning methods***.
- Efficient workflows for training that leverage the power of ***GPU***s.

Re-envisioning the NWP process (strawman - how would this impact the R2O process?)



Red boxes are things we do now, blue boxes are new AI additions to the pipeline

Re-envisioning the NWP and R2O process

AI/ML could also be integrated in different ways, for example

- Hybrid physics-based NWP/AI models (e.g.”Neural GCMS” https://arxiv.org/pdf/2311.07222.pdf)
  - AI/ML augments, corrects or replaces traditional physics parameterizations.
- Forward observation, balance, covariance, TLM/adjoint operators for DA.
- Ensemble perturbation emulators for efficient large ensemble generation.
  - Development needed since current generation emulators focused on deterministic prediction, not uncertainty estimation.

Potential questions/discussion topics

- Recent rapid advances mainly for global atmospheric prediction problem, using global reanalyses for training. How to apply to other applications? (convective-scale, hurricane, etc)
  - Do we need to focus more on development of reanalysis datasets for other applications?
  - What are the AI training requirements for reanalysis datasets?
- How to entrain the needed AI/ML expertise into our R2O pipeline?
  - Such a fast moving field - how to speed up R2O process? How to gauge RL of AI/ML methods?
- What are the implications (if any) for the development of physics-based NWP models?
  - Our current physics-based modeling approach will not go away!
- Does the NWP development cycle need to change?
  - Example: should the operational forecast dev cycle be tied directly to the dev cycle for training datasets (reanalyses)?

backup

R2O In Detail

Initial Development

- Map user requirements to possible solutions
- Develop requirements of the system
- Engage Modeling community (Academia, OAR)
- Begin system development

Prototypes

- Establish metrics and benchmarks
- Hierarchical Testing
- Development and Operational communities interface
- Engage operational forecasters
- Transition plans

Tested in Operational-like System

- Integrate Testing and Evaluation in Testbeds
- Engage operational forecasters
- Engage users and stakeholders
- Refine and iterate

Operations

- Rollout plan
- Public notices and feedback period
- NCEP acceptance
- Service change notice
- Operational integration
- Production

Courtesy Kevin Garrett NWS/OSTI