RO and the Two Weather Prediction Revolutions

Cliff Mass

University of Washington

Numerical Weather Prediction has experienced two revolutions during the past four decades

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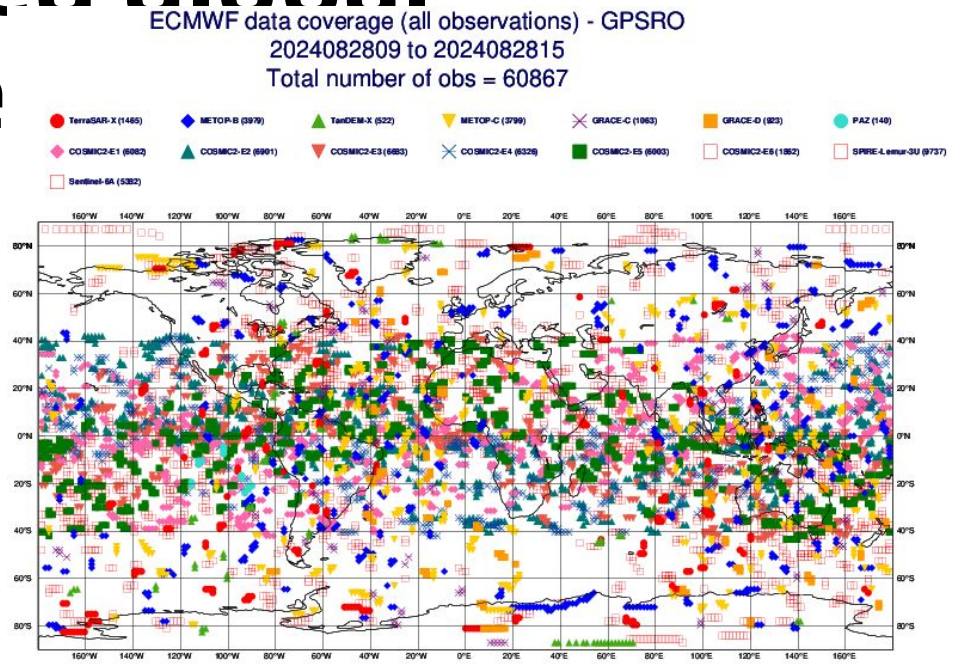
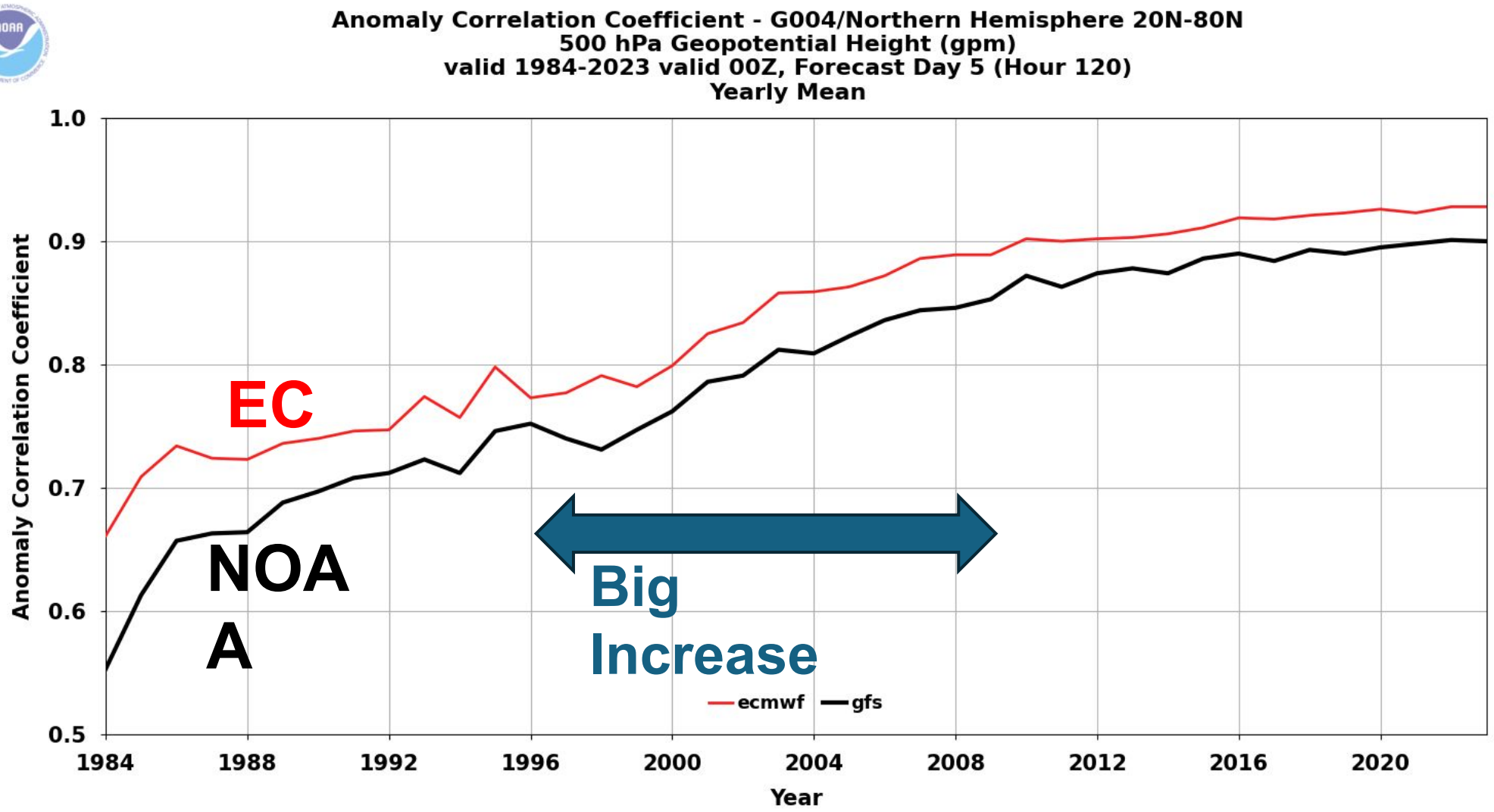
The RO Community Has Played a Major Role in One of the Revolutions

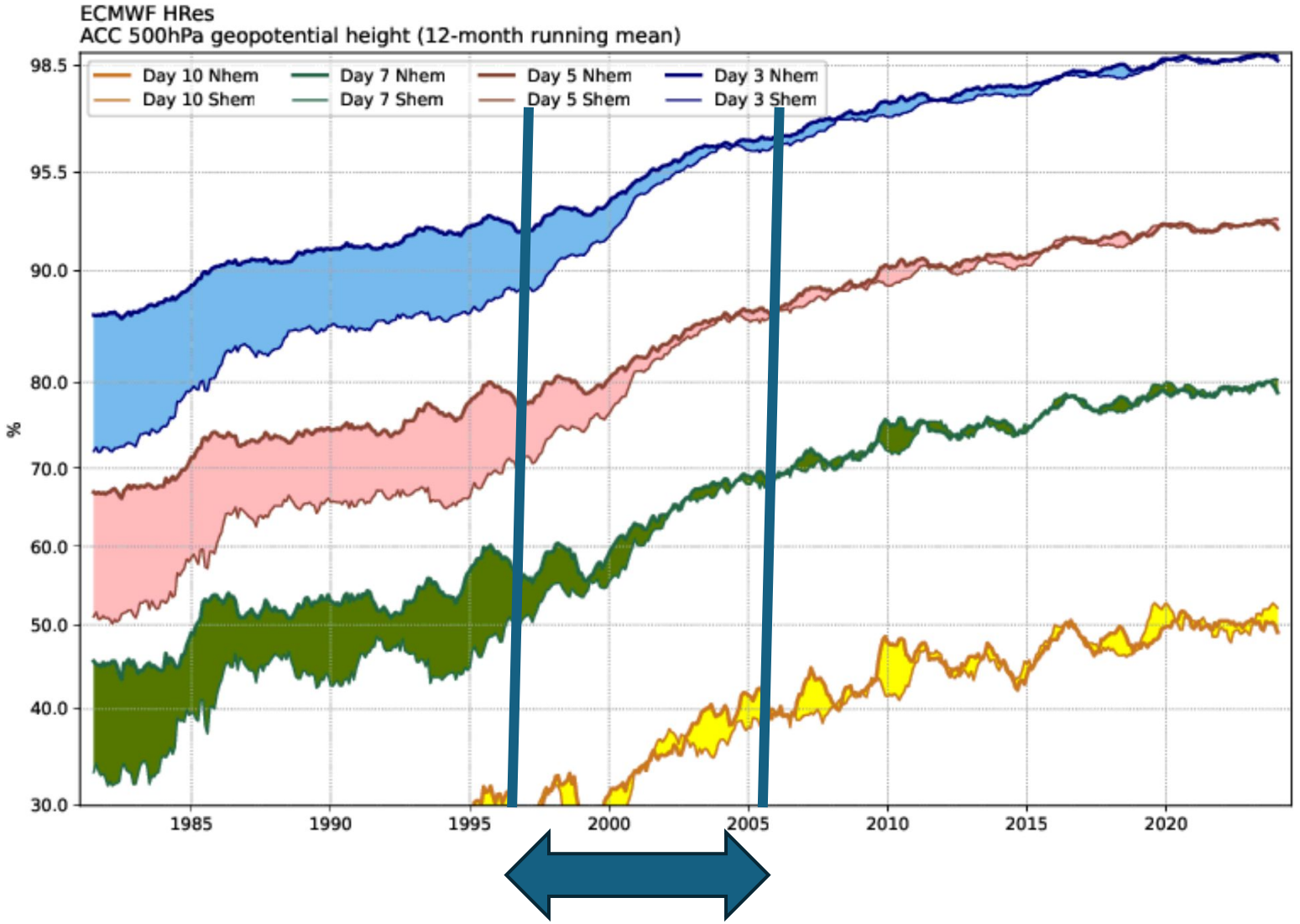
Providing massive amounts of weather data that has revolutionized global observation and global we



Large Satellite-Driven Increase in Global Forecast Skill from the mid-90s to ~2009

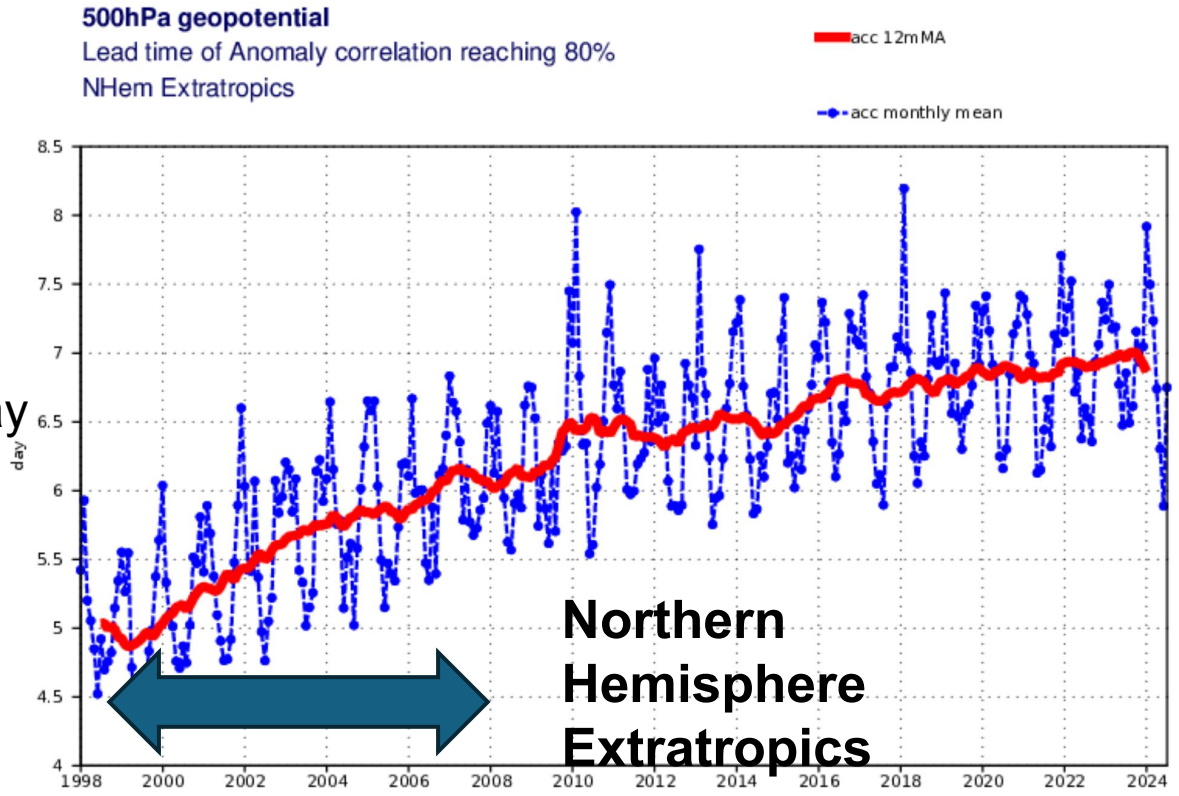


During the satellite-data revolution the SH became as skillful at the NH



Same Story Regarding Skillful Lead Time

Lead time of anomaly correlation coefficient scores (ACC) of 500 hPa height falls to 80%



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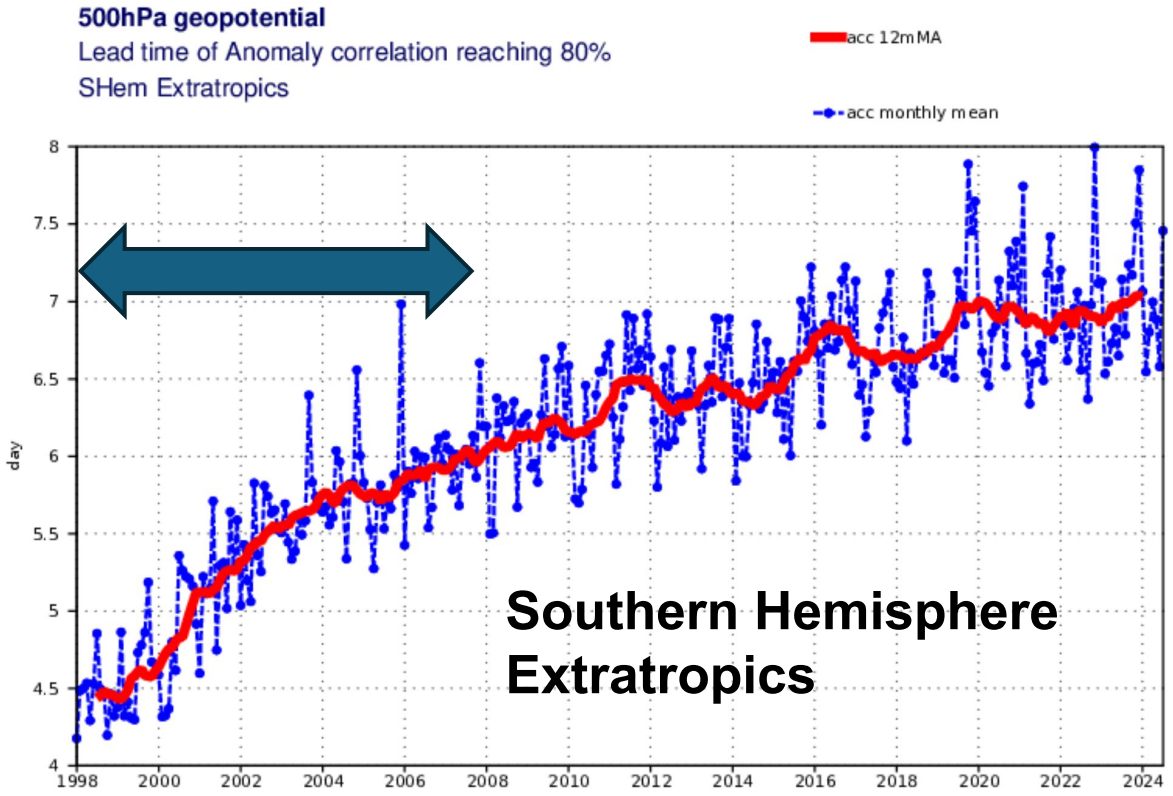
Created at 2024-08-26T21:10:14.753Z

ECMWF

Lead time of anomaly correlation coefficient scores (ACC) of 500 hPa height falls to 80%



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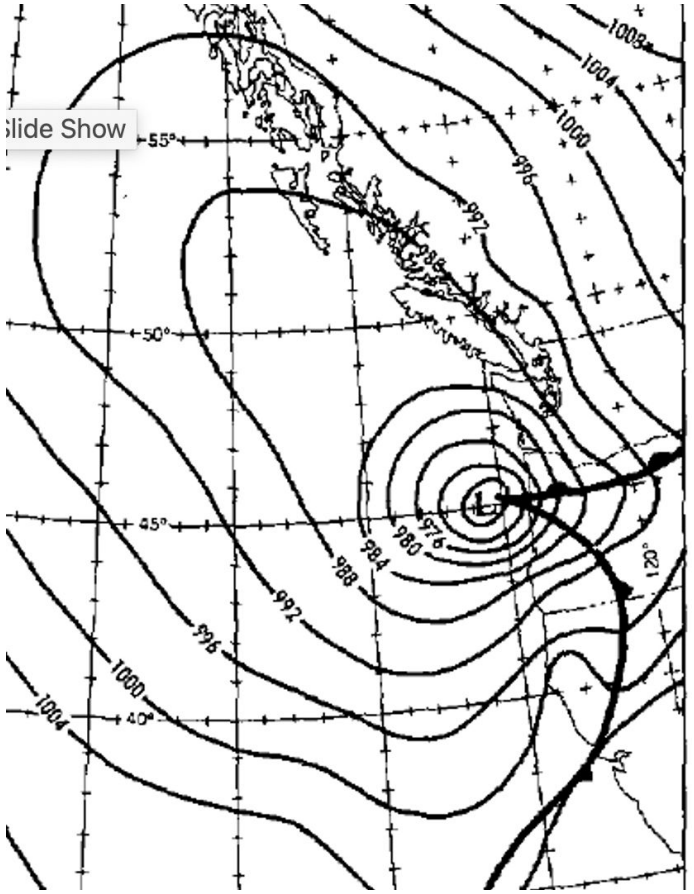
ECMWF

The Impacts of Improved Global Data and Its Effective Assimilation Were Evident for Major Storms

On the West Coast, every major landfalling cyclone was poorly forecast before ~ 1990



Columbus Day Storm, Oct. 12, 1962

955 hPa low

October 11th Forecast: No Major Storm on October 12th!

—A. P. wirephoto map.

The Seattle Times 51
Thursday, October 11, 1962

Wrangle Over State Capital Stirs Alaskans

(Wayne Jacobi, Times staff reporter, is with a Seattle Chamber of Commerce delegation attending the annual convention of the Alaska State Chamber o

Seattle Times

State Forecasts

Western Washington: Partly cloudy, with a few showers tonight and tomorrow. Snow on the mountain passes. High tomorrow, 46 to 54; low tonight, 35 to 45.

Mountain areas: Freezing level dropping to about 3,000 or 4,000 feet tonight and tomorrow, with rain changing to snow above 3,000 feet. Snow flurries on the east slopes of the Cascades.

Eastern Washington: Rain, beginning in the southwest, becoming general by tonight with increasing winds. Partly cloudy and cooler tomorrow, with snow flurries over the mountains. High tomorrow, 42 to 52; low tonight, 35 to 45.

Marine Warnings

Gale warnings were hoisted on the following waters:

Inland—southeast winds 30 to 45 knots, diminishing tonight.

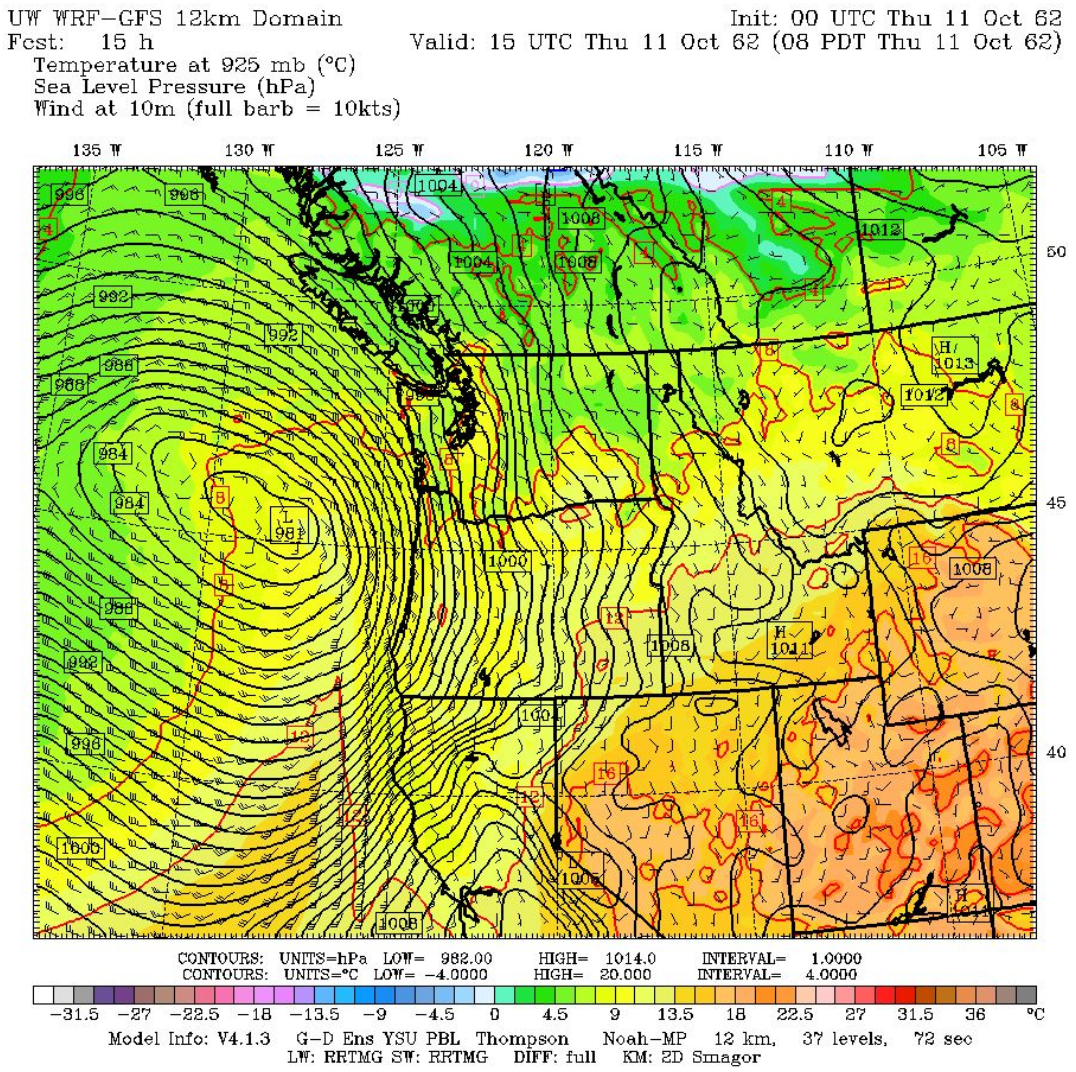
Strait—northeast winds 35 to 45 knots, shifting to southwest or west and diminishing tonight.

Whole-gale warnings were displayed on the coast from Tatoosh to Astoria for southeast winds 50 to 60 knots, diminishing to 34 to 46 tonight and 23 to 34 tomorrow.

Attempts to simulate with modern models and data assimilation failed

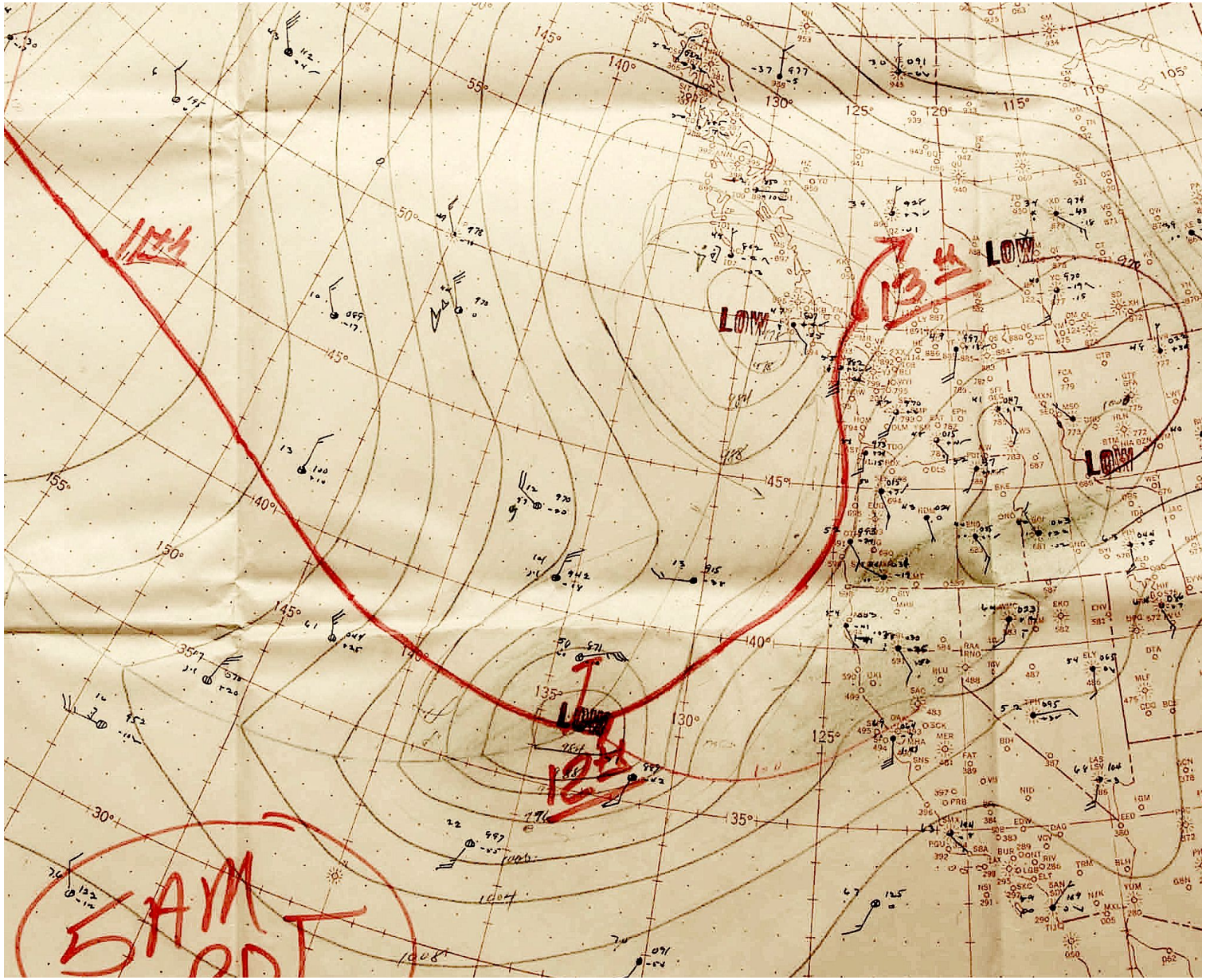
Clearly there was a problem with the initial state over the Pacific (and other oceans) before the satellite era.

Observations were inadequate



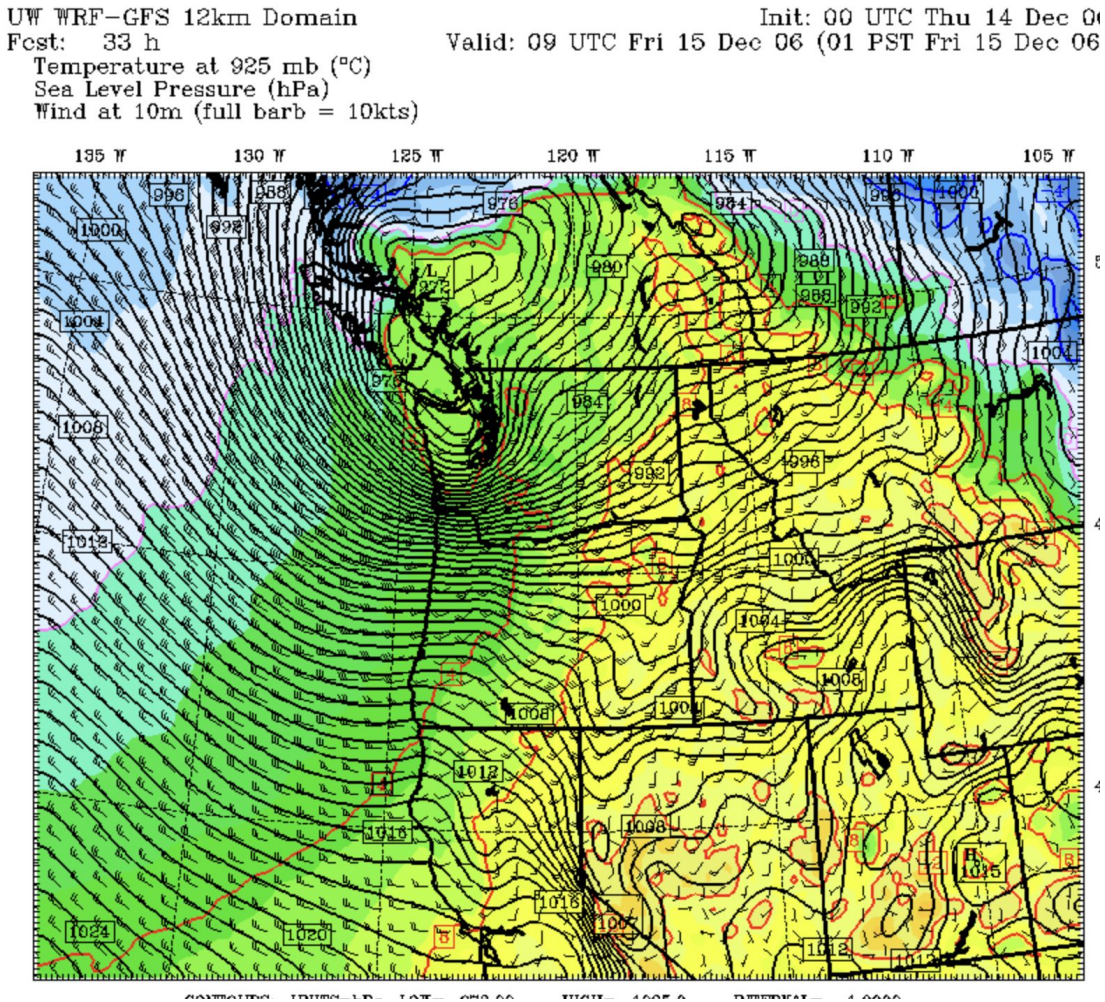
Not deep enough, too far offshore

Only some ships and island stations offshore

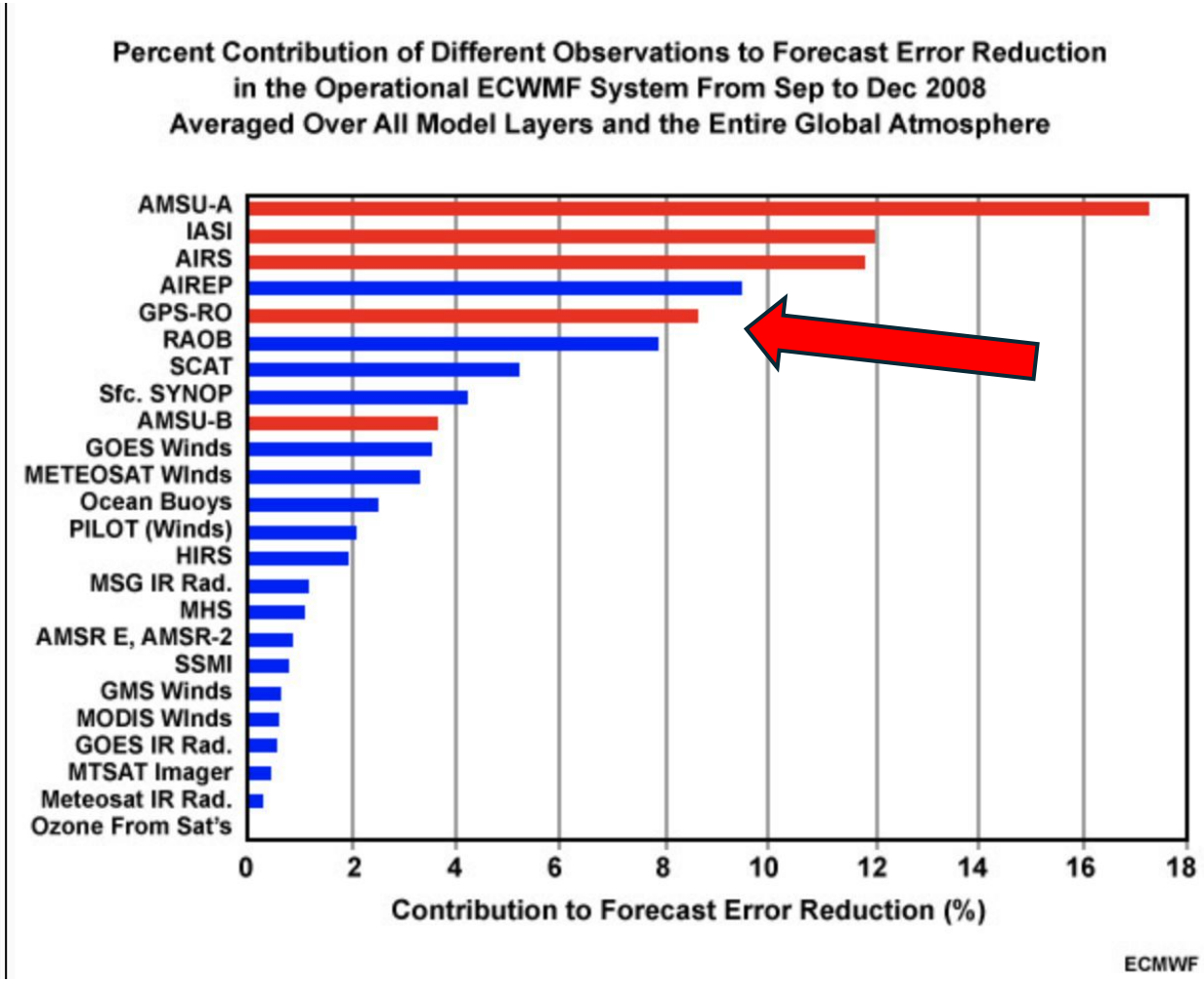


After ~1995 With Satellite Observations All Major Storms Were Predicted Skillfully for Days 1-3

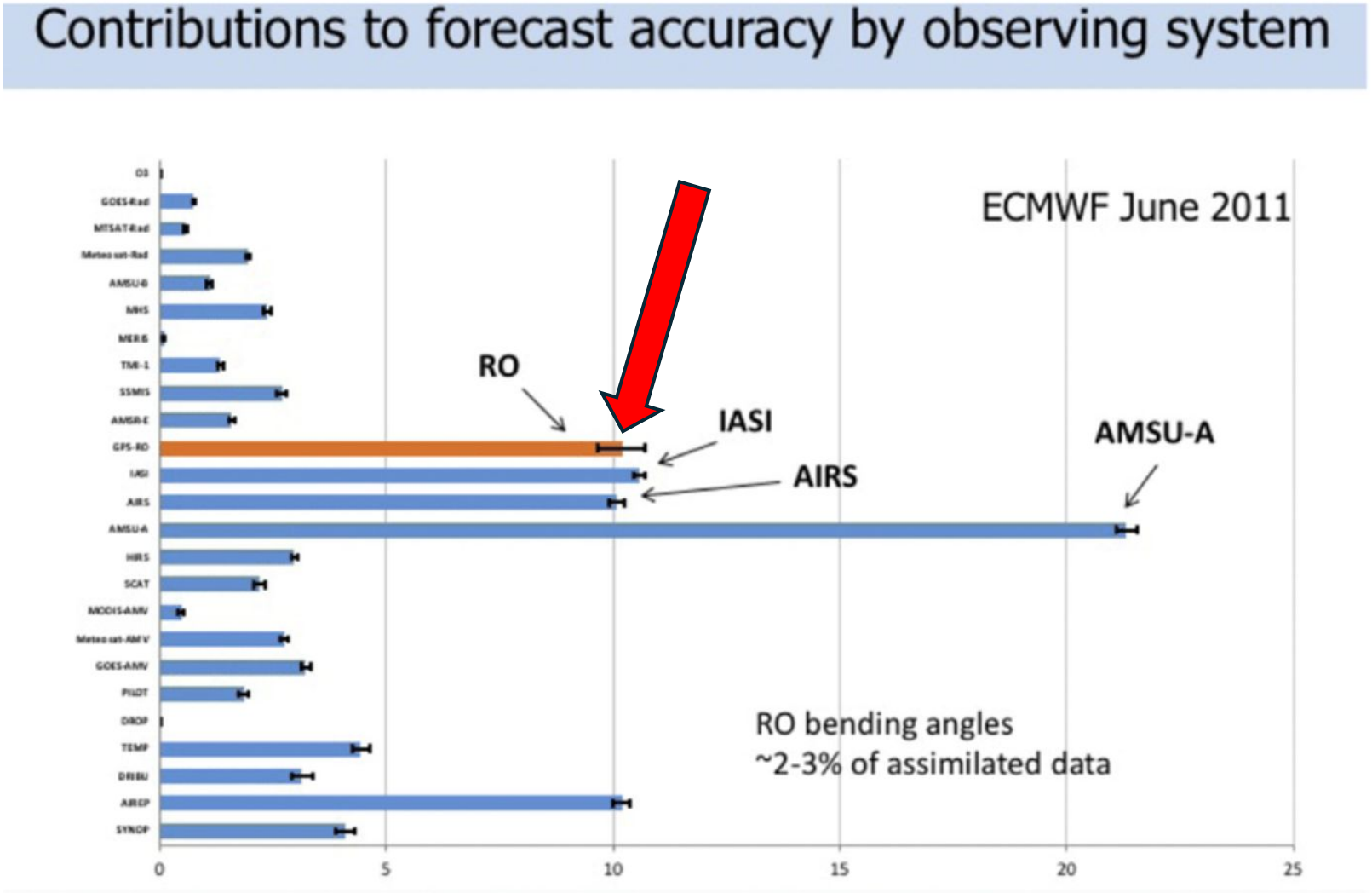
Chanukah Eve Storm: 18-h forecast for 10 PM December 14, 2006



RO Satellites Played A Critical Role in This Revolution After ~2007



RO Satellites Played A Critical Role



The Improvement of NWP by RO Data is Documented in Many Papers and Reports

Journal of Geophysical Research: Atmospheres / Volume 129, Issue 14 / e2024JD041709

Research Article

Impact of Varying Number of Radio Occultation Observations on Regional Weather Prediction Over India During the Summer Monsoon Season

Randhir Singh, Satya P. Ojha, Richard Anthes

First published: 11 July 2024

Geophysical Research Letters / Volume 50, Issue 5 / e2021GL096750

Research Letter | Open Access

Potential Impacts of Radio Occultation Data Assimilation on Forecast Skill of Tropical Cyclone Formation in the Western North Pacific

Hsu-Feng Teng, Ying-Hwa Kuo, James M. Done

Contract Report to the European Space Agency

Final Technical Note of "Impact assessment of commercial GNSS-RO data"

Katrin Lonitz*, Christian Marquardt$, Neill Bowler+ and Sean Healy*
* ECMWF $ EUMETSAT + UK Met Office

November 15, 2021

Even AI Concurs

Does RO data improve weather forecasts?

Show drafts

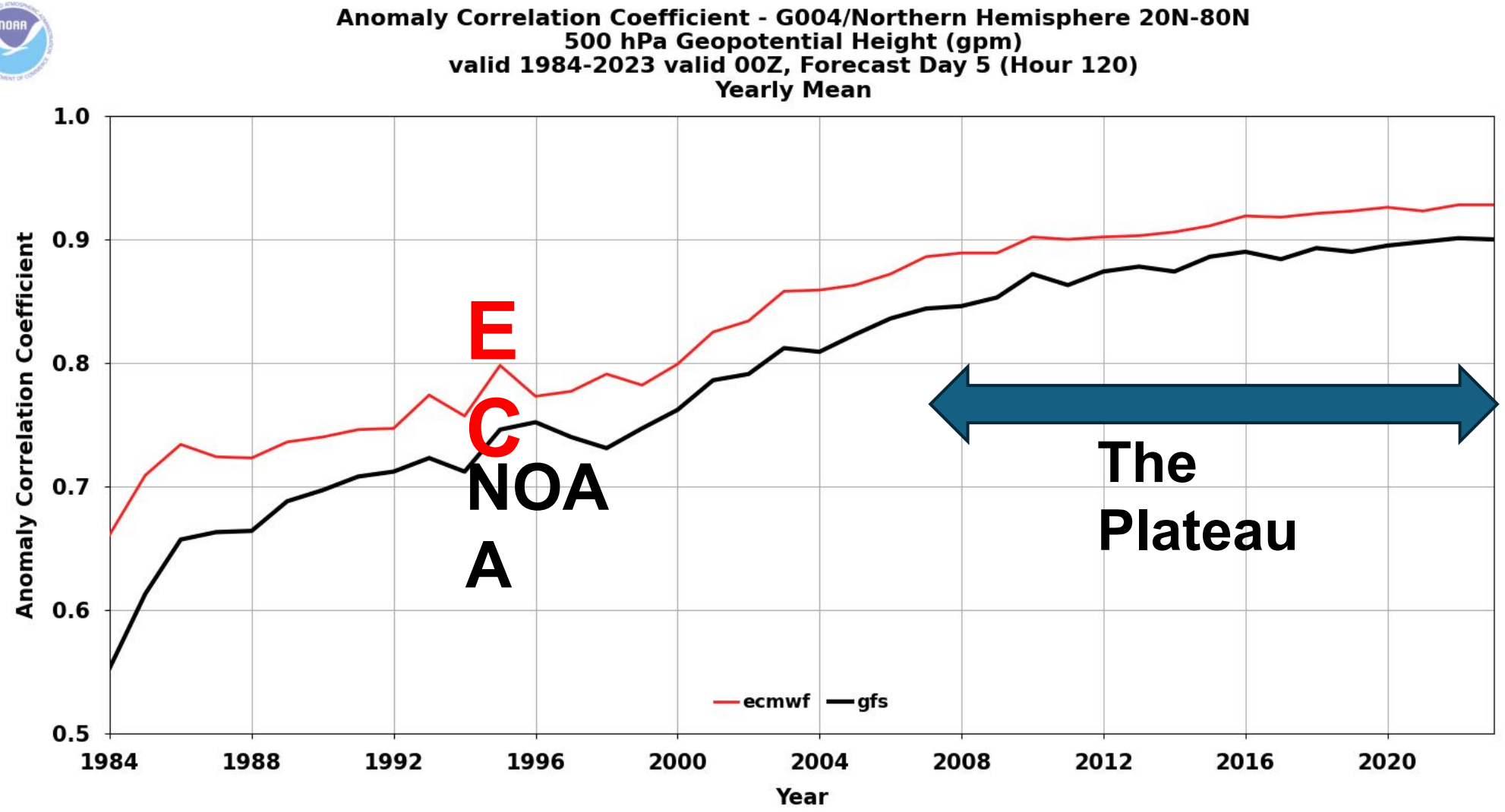
Yes, Radio Occultation (RO) data significantly improves weather forecasts.

RO data provides high-resolution vertical profiles of atmospheric temperature, pressure, and humidity. These profiles are crucial for accurate weather prediction models. Here's why:

- **Improved understanding of atmospheric structure:** RO data helps meteorologists better understand the vertical structure of the atmosphere, including the boundary layer, troposphere, stratosphere, and mesosphere.
- **Enhanced tropical cyclone forecasts:** RO data has been shown to improve forecasts of tropical cyclone intensity and track.
- **Better prediction of extreme weather events:** By providing more accurate atmospheric data, RO can help improve predictions of severe weather events like hurricanes, thunderstorms, and heavy rainfall.
- **Real-time monitoring of atmospheric conditions:** RO data can be collected in real-time, providing meteorologists with up-to-date information for making timely weather forecasts and warnings.

In essence, RO data offers a valuable tool for improving weather prediction capabilities and ensuring public safety.

Major improvement (1995-2008) following by the great plateau in large-scale forecast skill



Does the “great plateau” mean that actual forecast skill has stagnated?

The Answer is No

Why? Because of ANOTHER NWP revolution that occurred as the great plateau become evident

RO and Satellite Observations

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A Revolution That Would Allow Mesoscale/Local Forecast Skill to Increase Even as Large-Scale Skill Stagnated

RO and Satellite Observations

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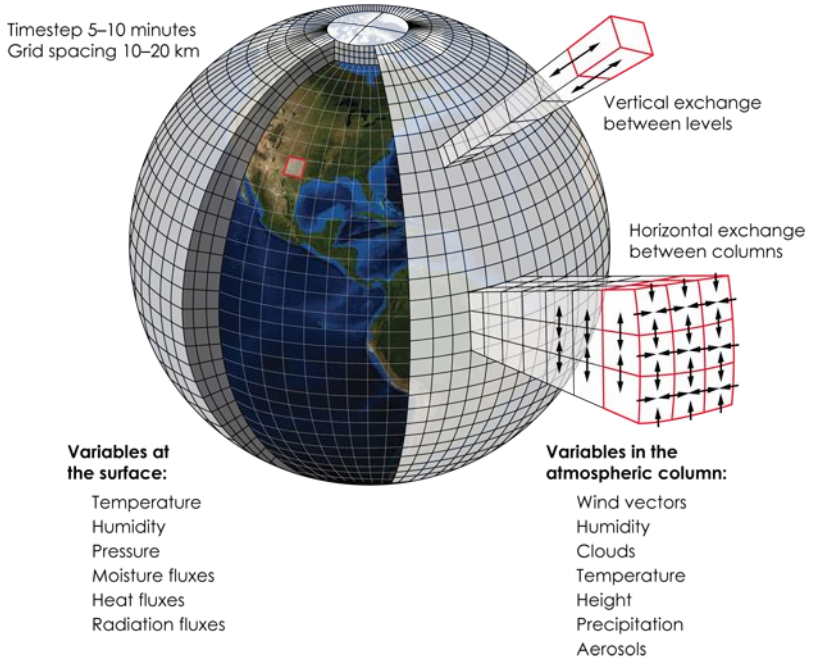
Hint: Bill Kuo and Rick Anthes Played a Major Role in Both Revolutions

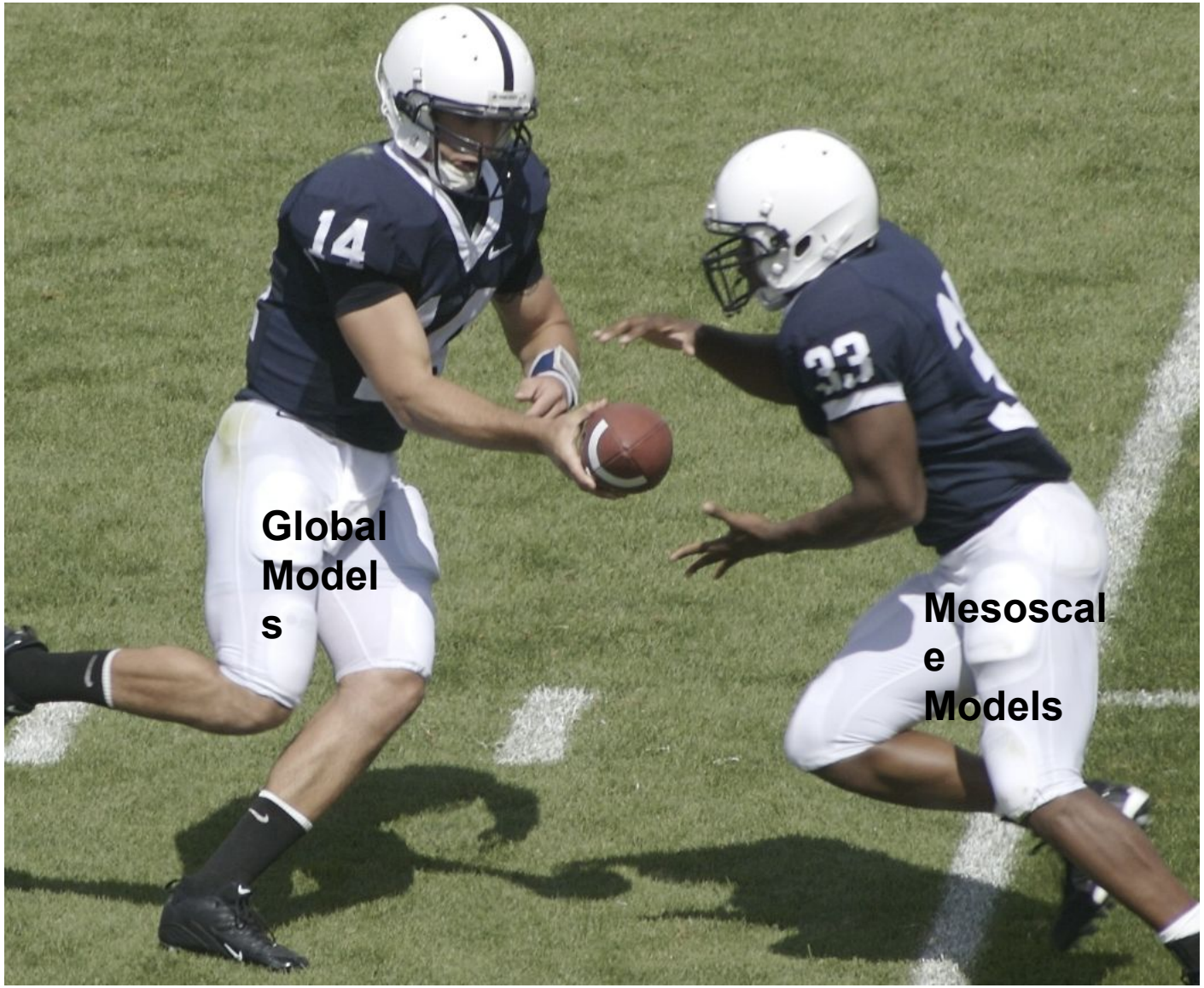
The High-Resolution Prediction Revolution

- During the past two decades, model resolution and physics improved substantially, allowing more accurate simulation of critical mesoscale features.
- In the U.S., global models went from ~ 100 km grid spacing in 1995 to 13 km in ~2020. National and regional models went from ~50 to ~4 km during the same period.

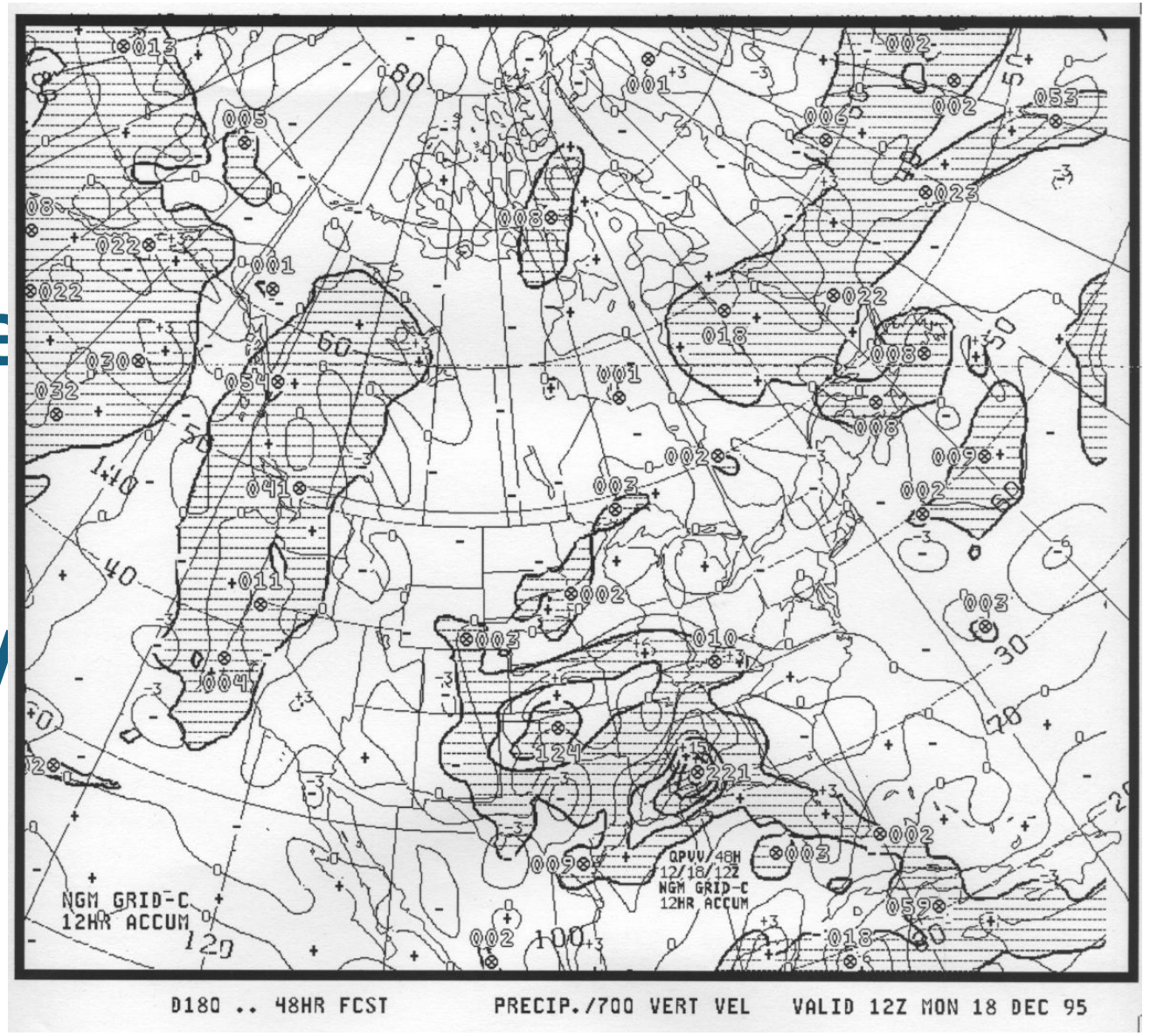


The Hand Off

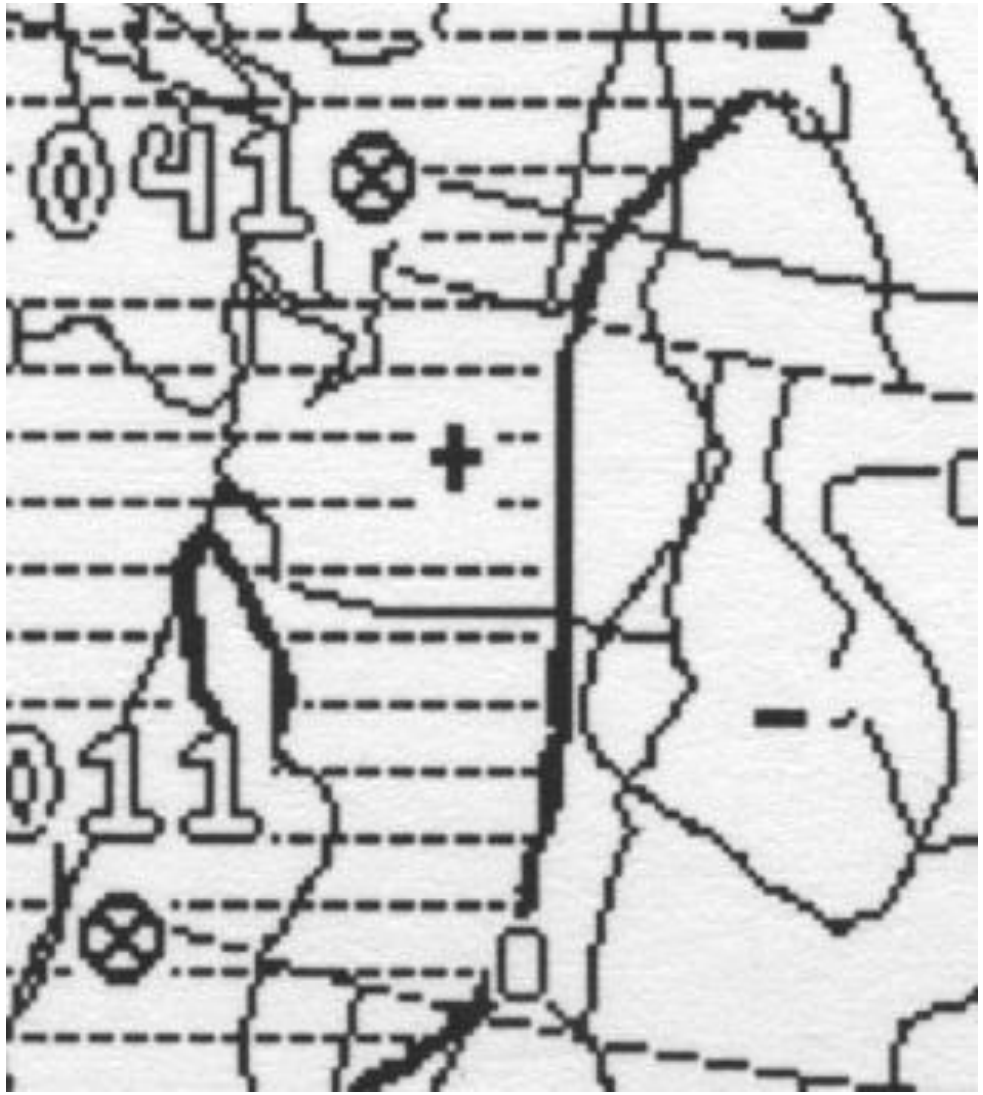
Using improve global data assimilation and prediction as a starting point, high resolution prediction provided increasingly skillful downscaling of global forecasts.

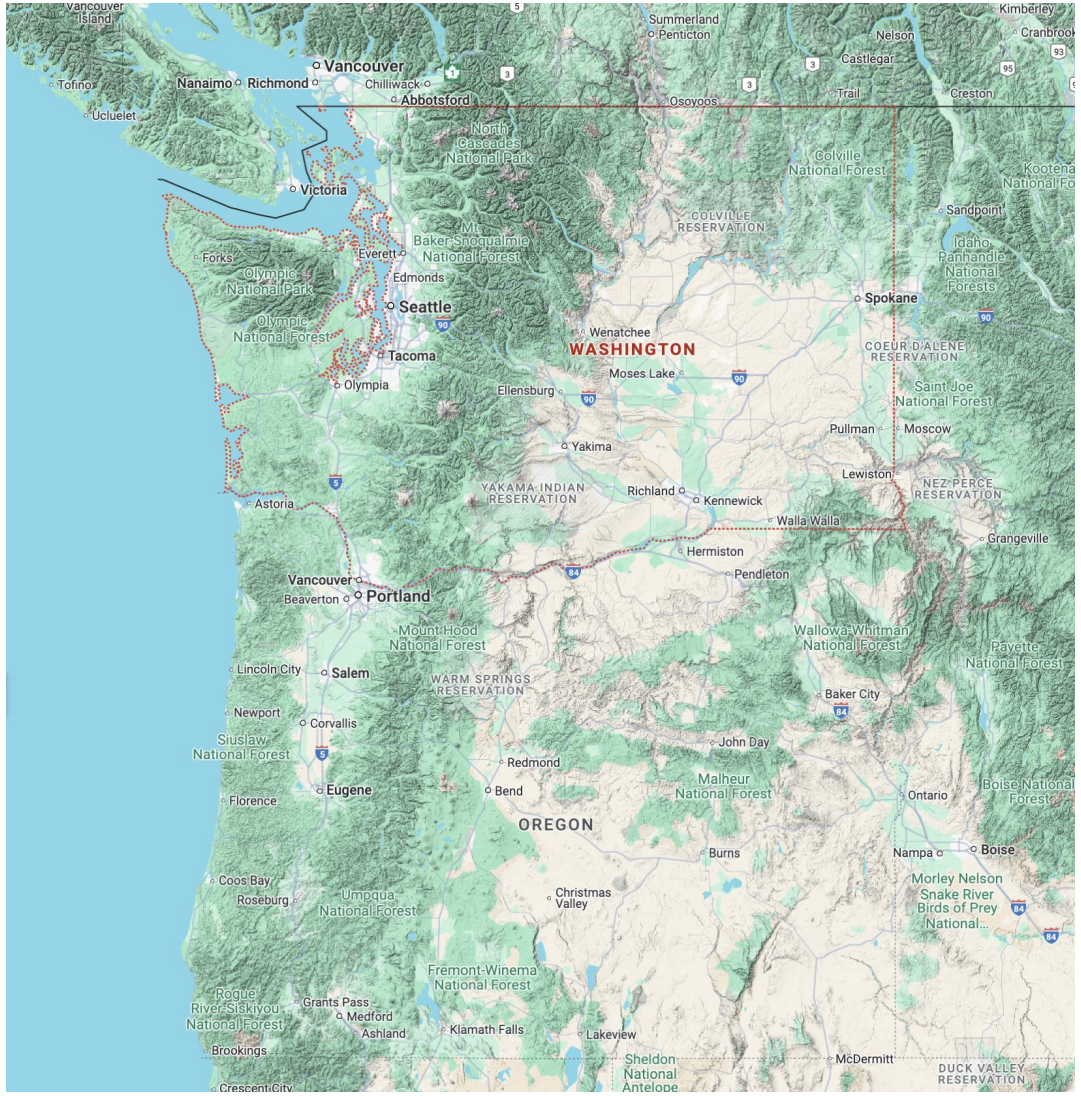


1995 State of the Art Operational Prediction: the NOAA/NWS NGM Model

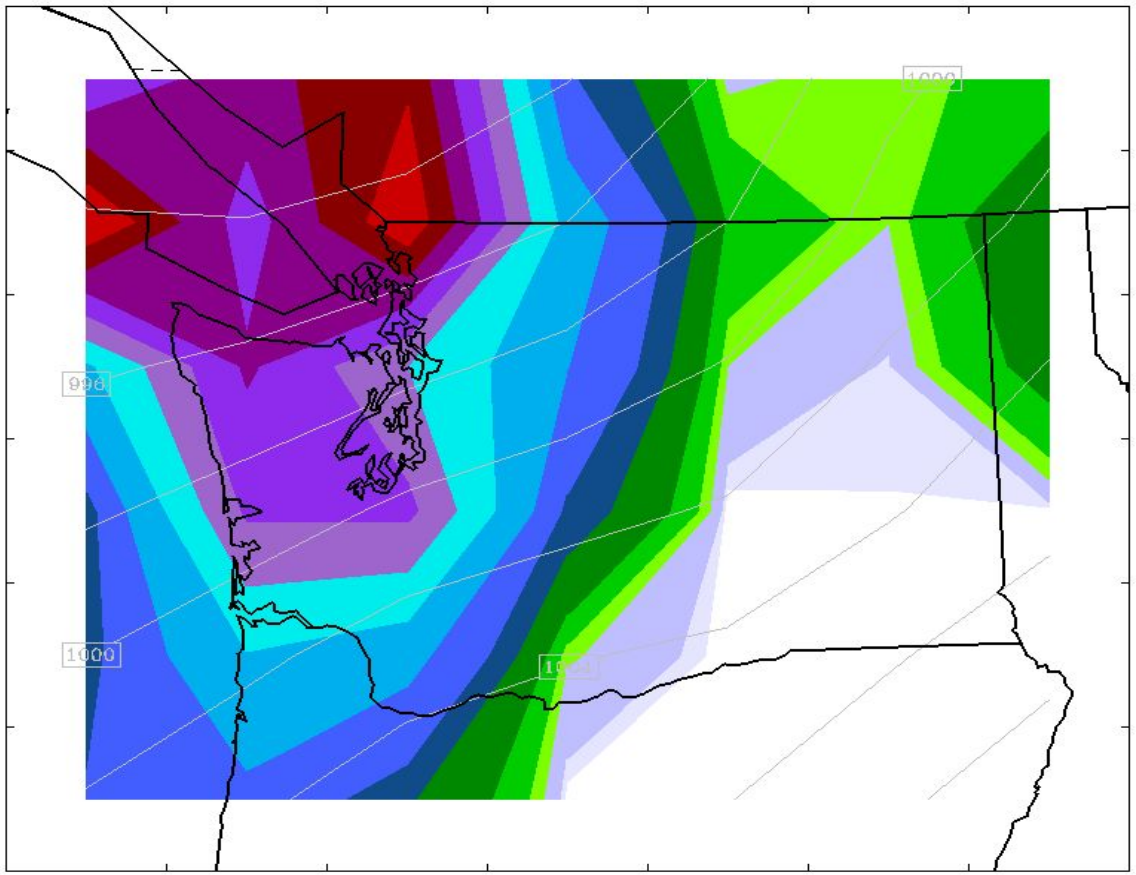


No Mesoscale Structures

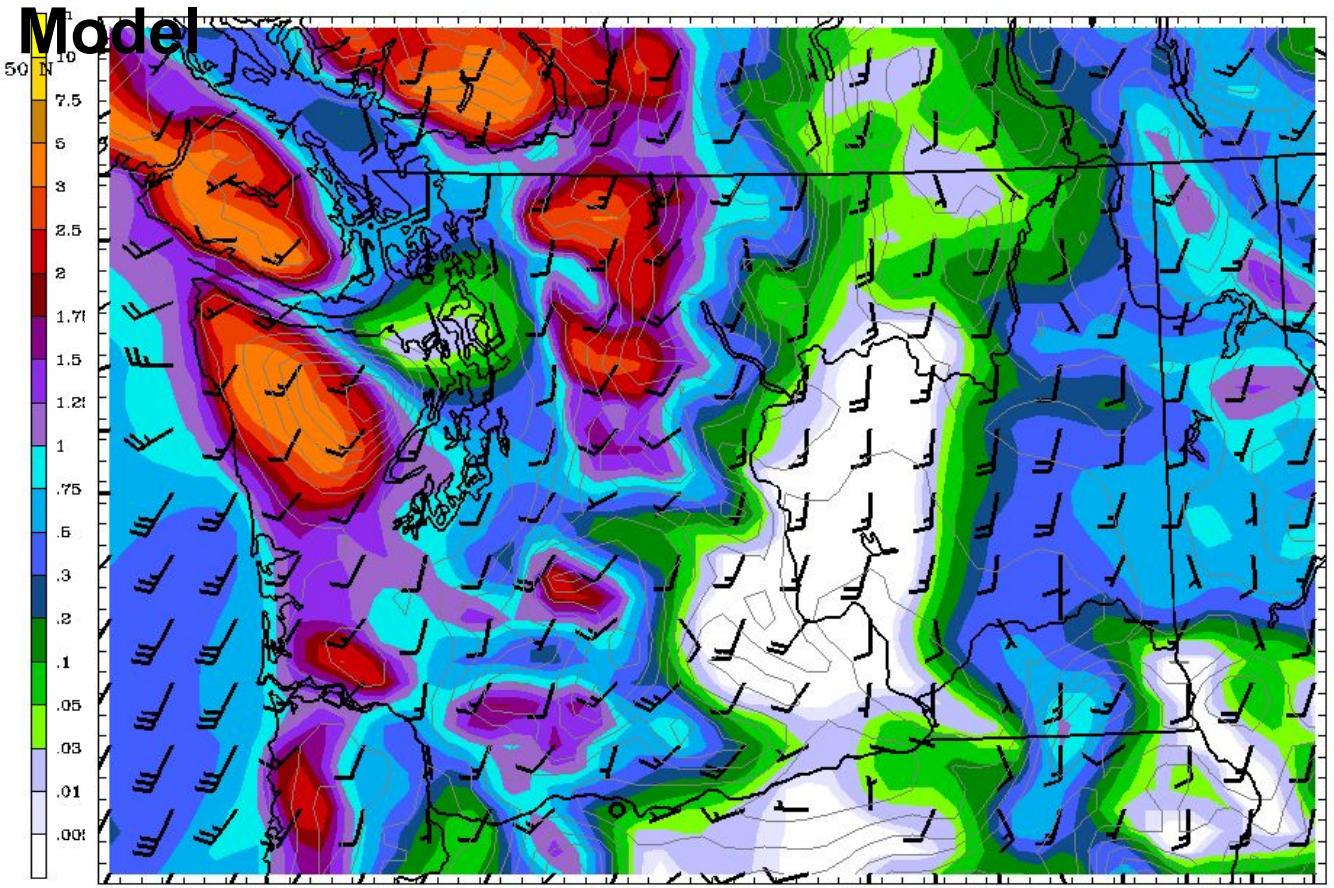




When grid spacings declined to ~15 km amazing things happened. Example: mesoscale terrain effects



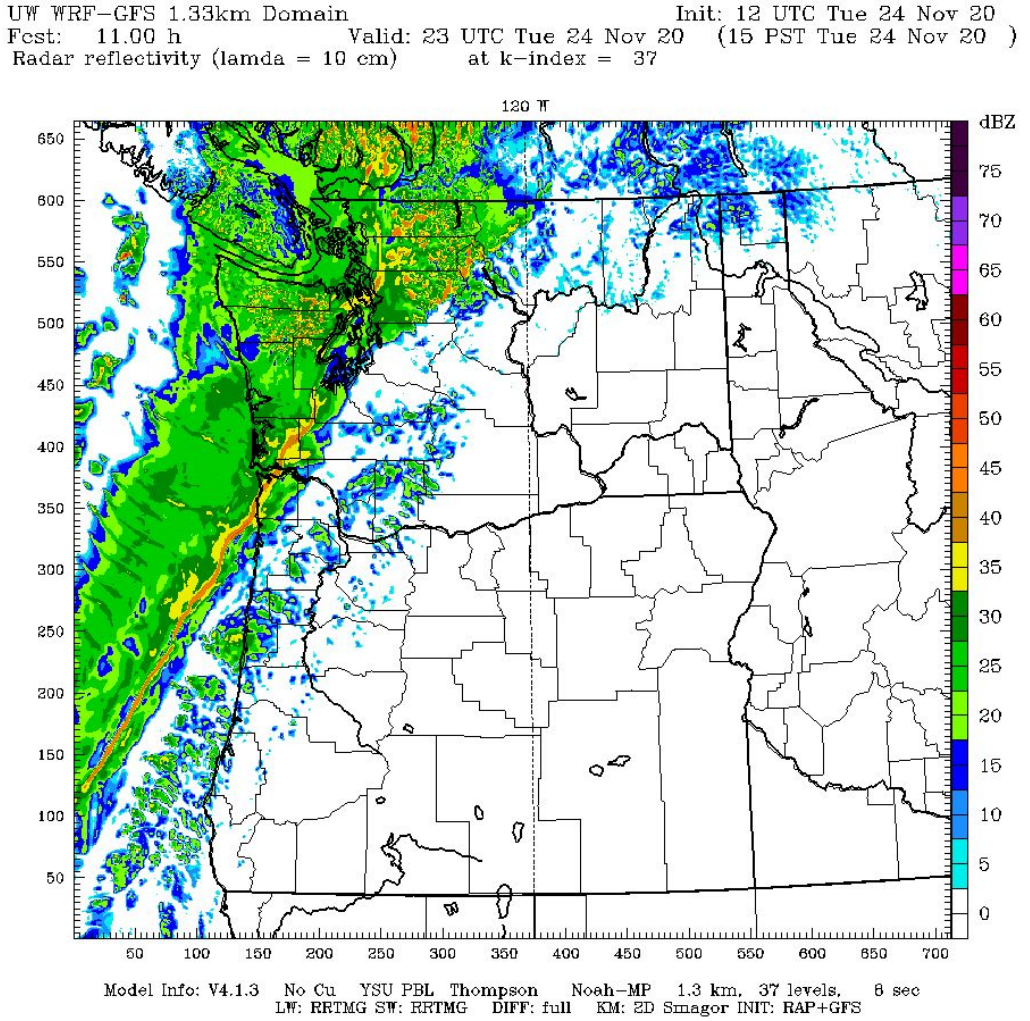
100-km Grid Spacing



12-km Grid Spacing

But it was more than that.. At higher resolution…

- Frontal collapse and frontal circulations become resolved
- Downslope windstorms were simulated
- Convection increasingly resolved
- Diurnal circulations were simulated
- And much more…



Cold Front and Narrow Cold Frontal Rainbands

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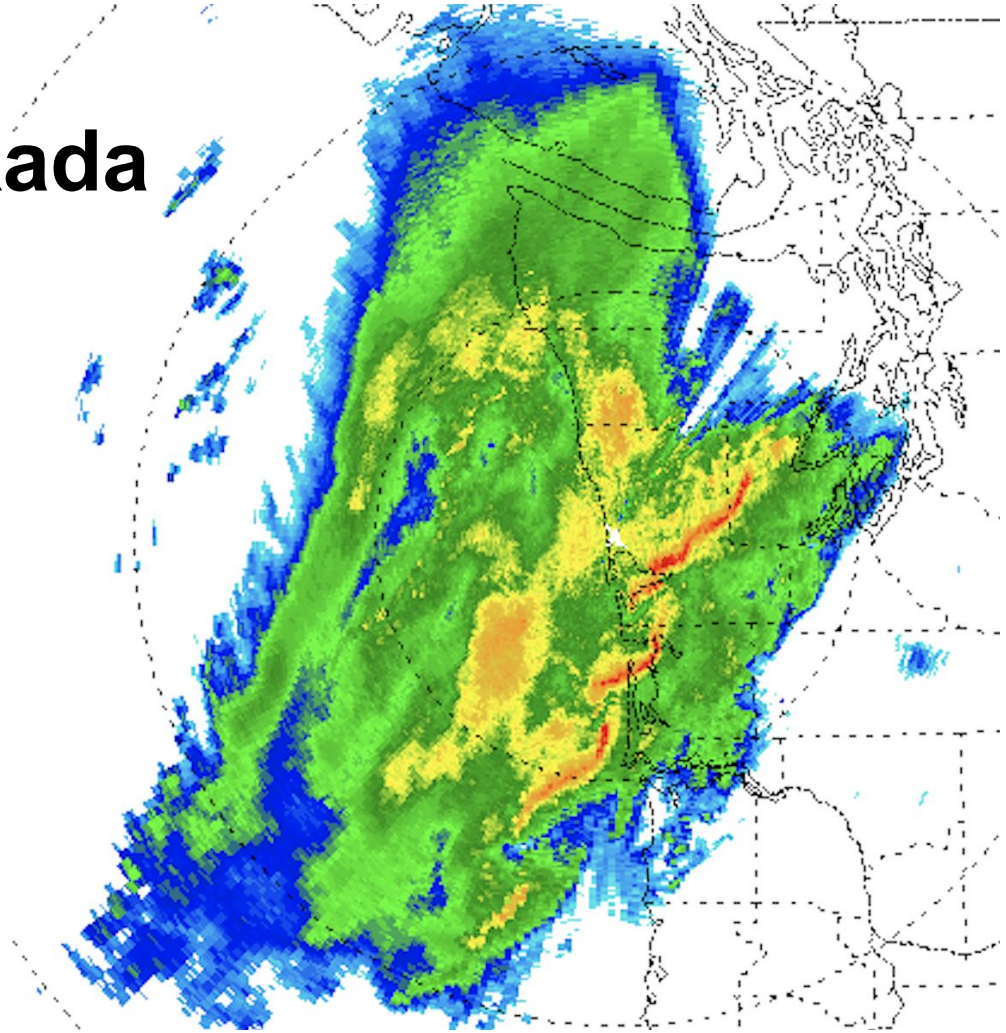
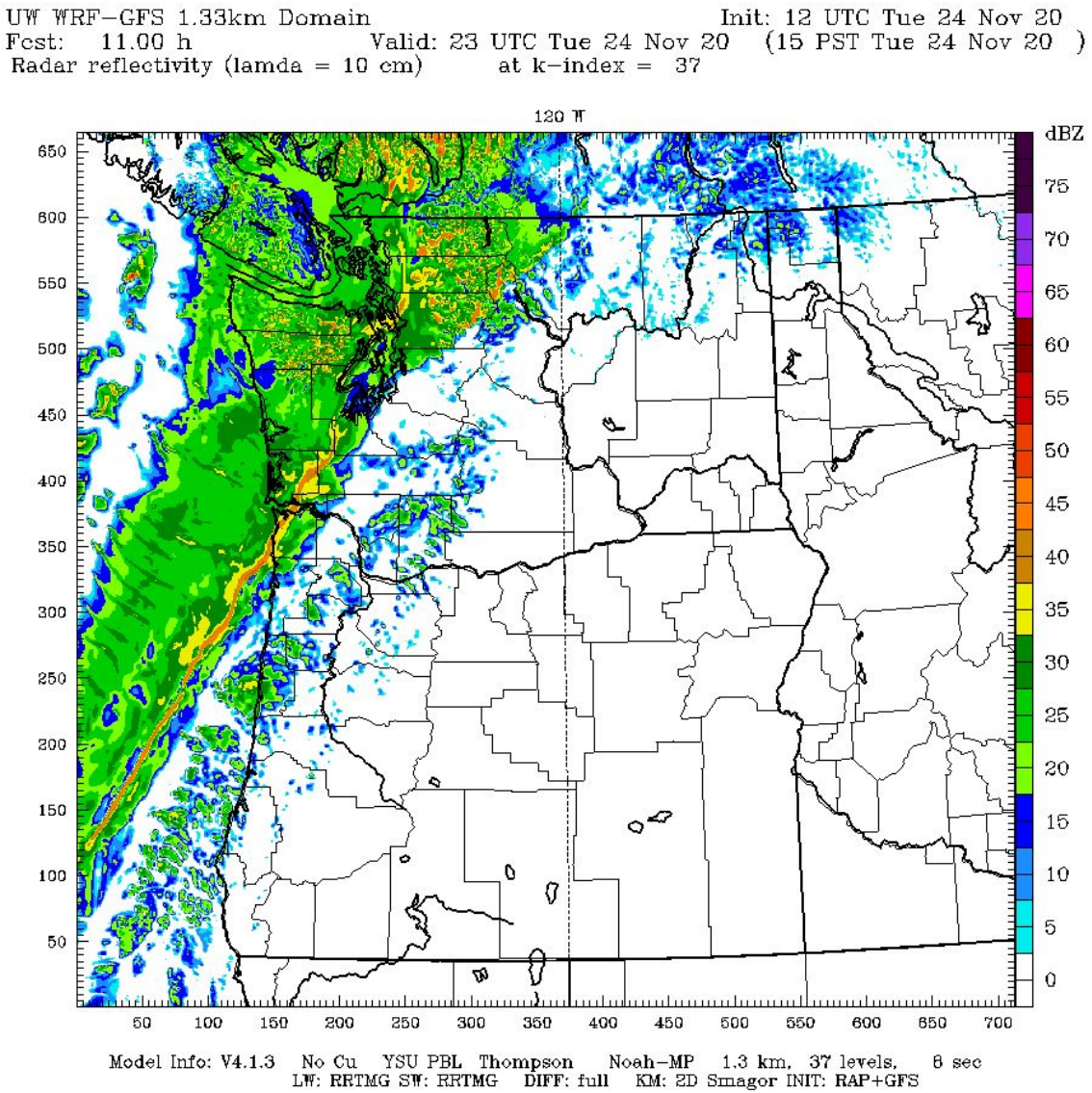
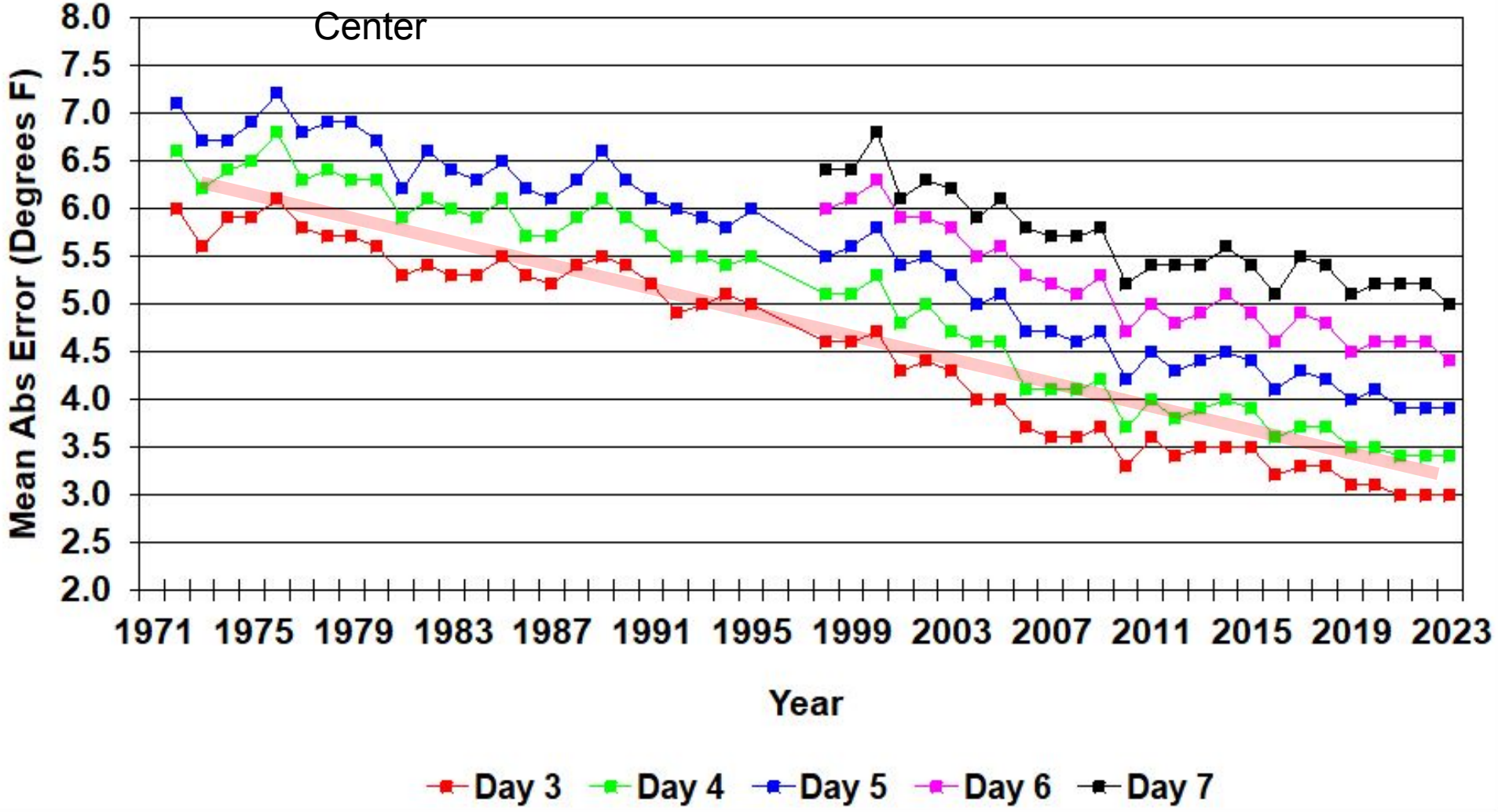




Objective Verification of the Second Revolution

Annual WPC Mean Absolute Errors
Maximum Temperatures

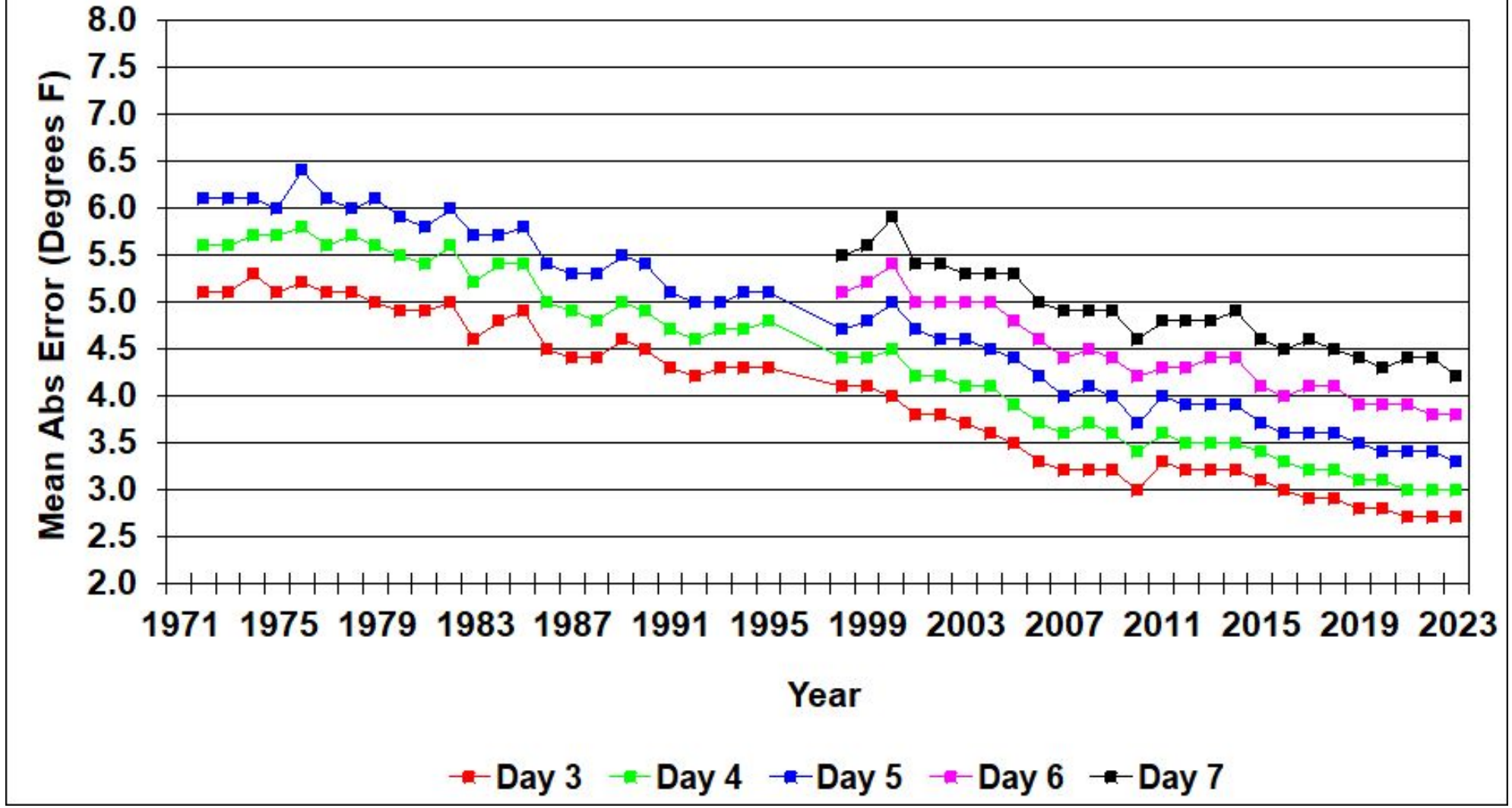
WPC is the NOAA/NWS Weather Prediction Center

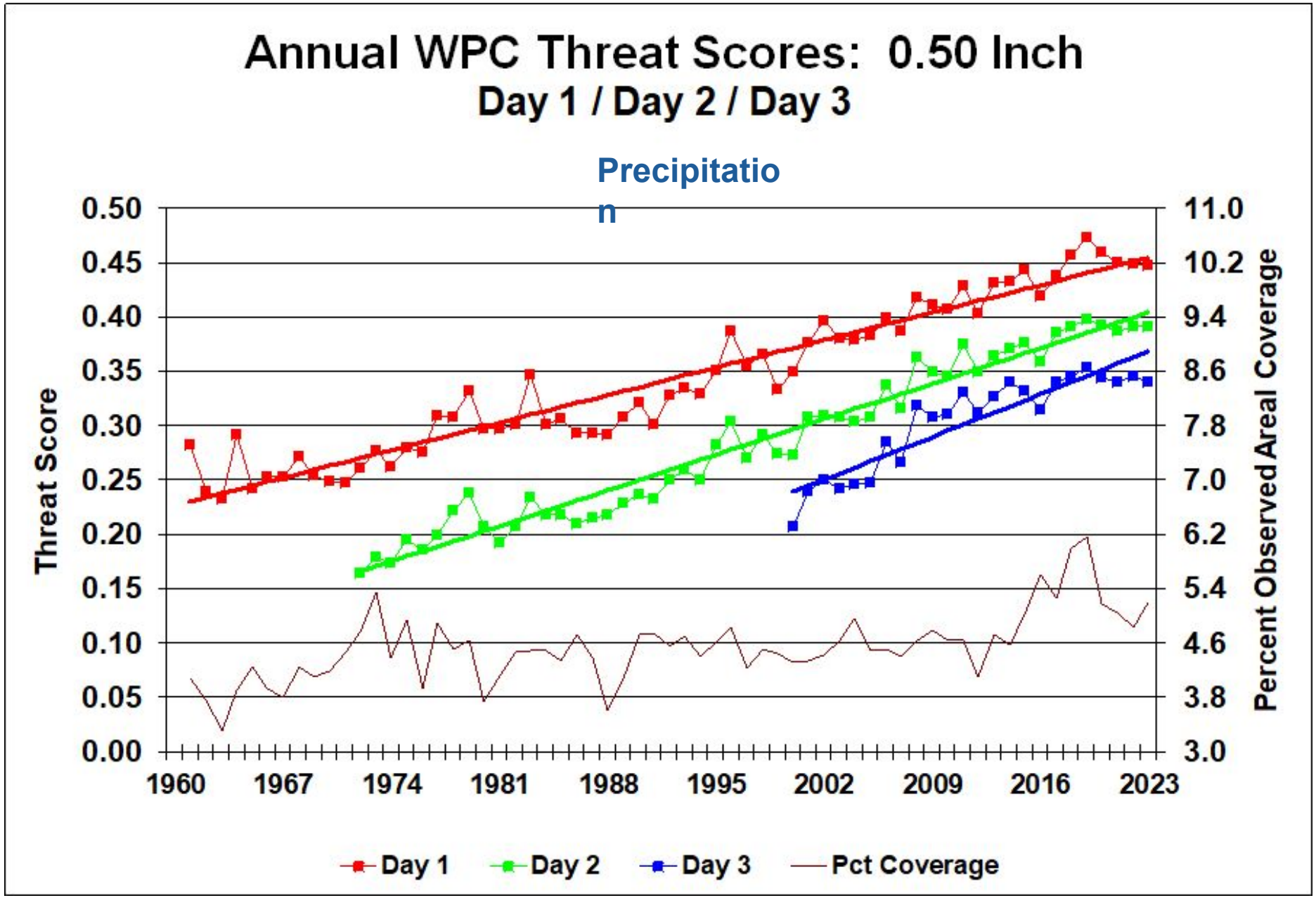


Skill trend Maintained

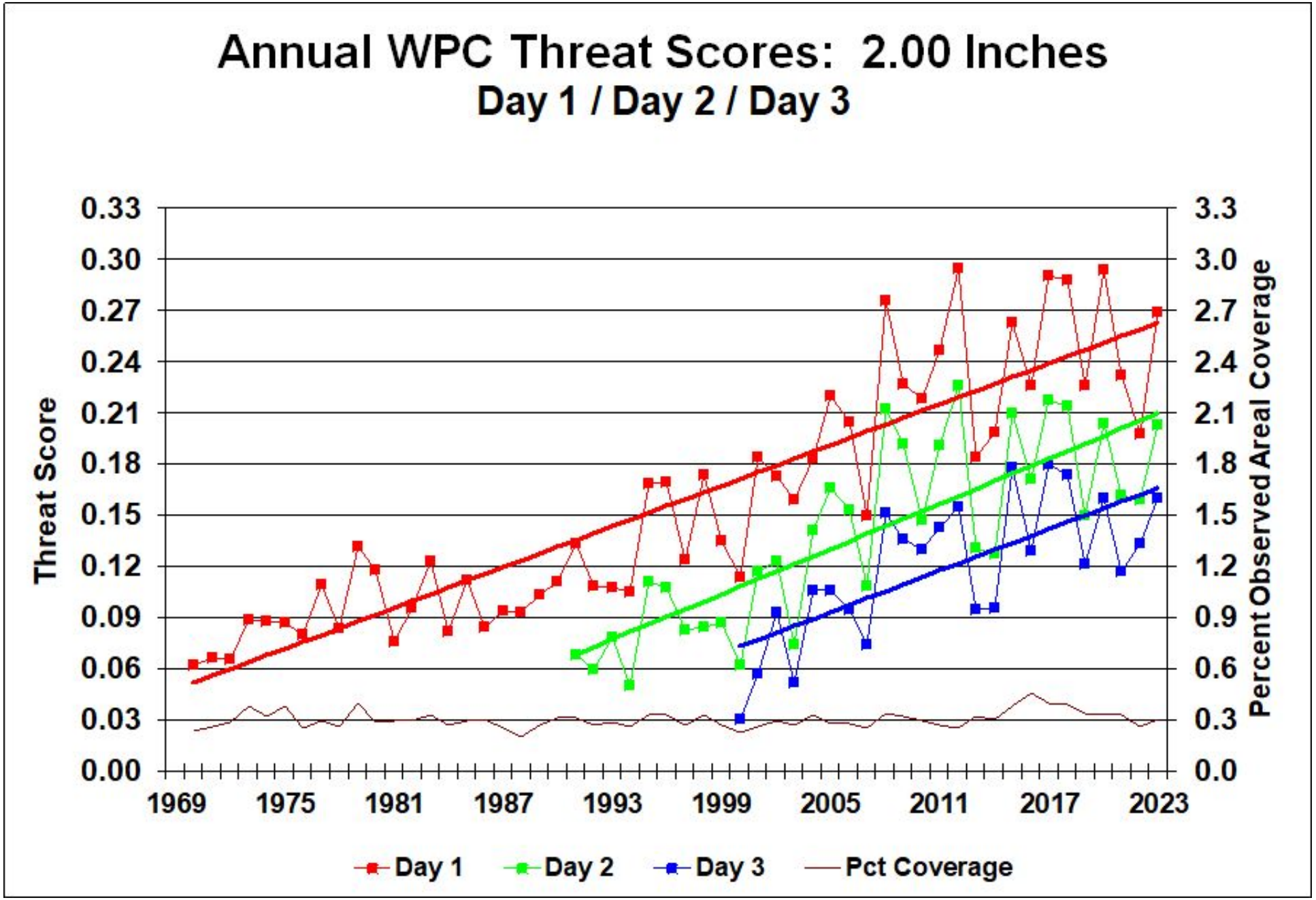
No Plateau

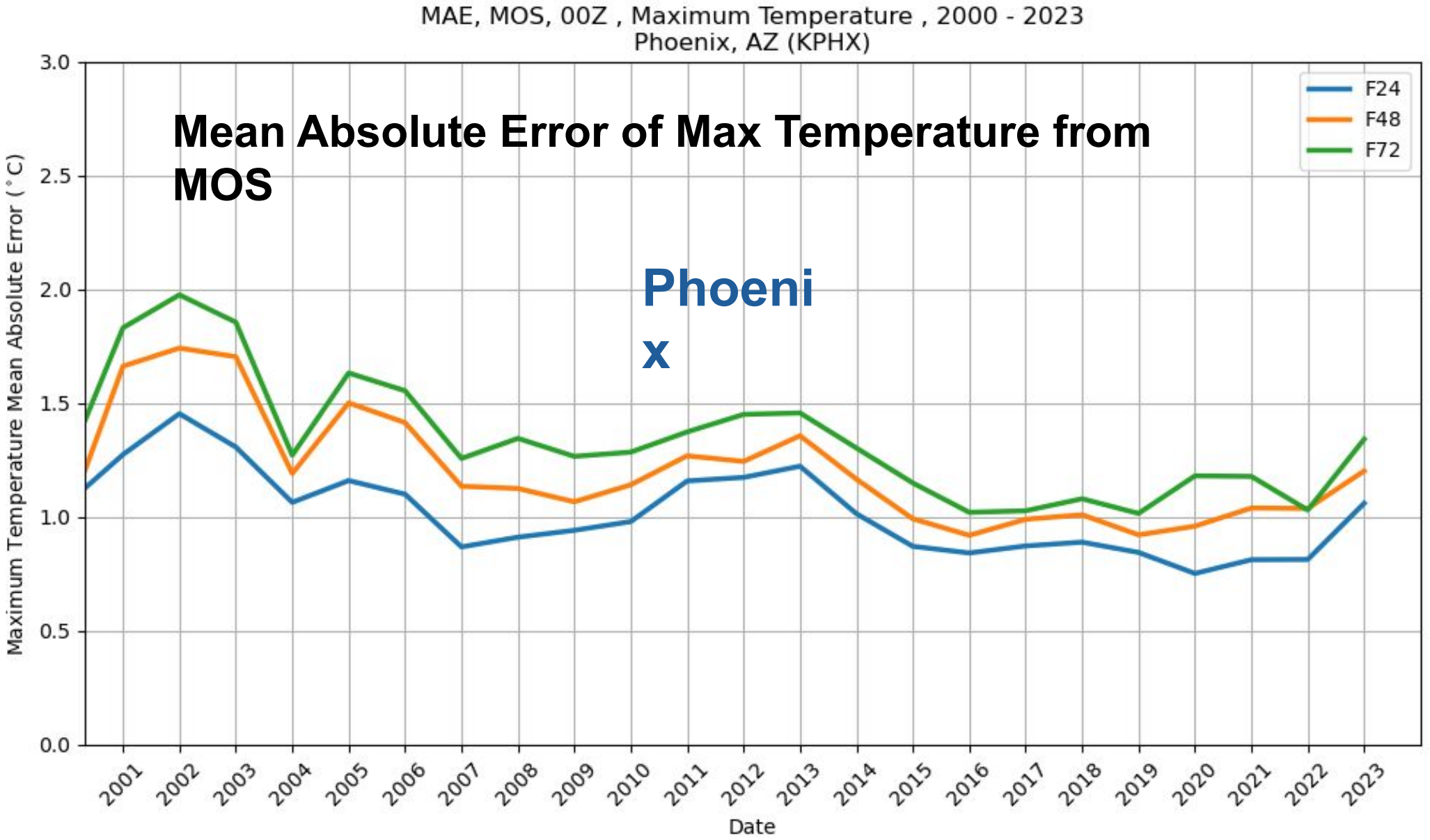
Annual WPC Mean Absolute Errors
Minimum Temperatures




Annual WPC Threat Scores: 0.50 Inch
Day 1 / Day 2 / Day 3
Precipitation
Threat Score
Percent Observed Areal Coverage
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
11.0
10.2
9.4
8.6
7.8
7.0
6.2
5.4
4.6
3.8
3.0
1960
1967
1974
1981
1988
1995
2002
2009
2016
2023
Day 1
Day 2
Day 3
Pct Coverage

Heavy Precipitation




MAE, MOS, 00Z , Maximum Temperature , 2000 - 2023
Phoenix, AZ (KPHX)
Mean Absolute Error of Max Temperature from MOS
Phoeni
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F24
F48
F72
Maximum Temperature Mean Absolute Error (°C)
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2.5
2.0
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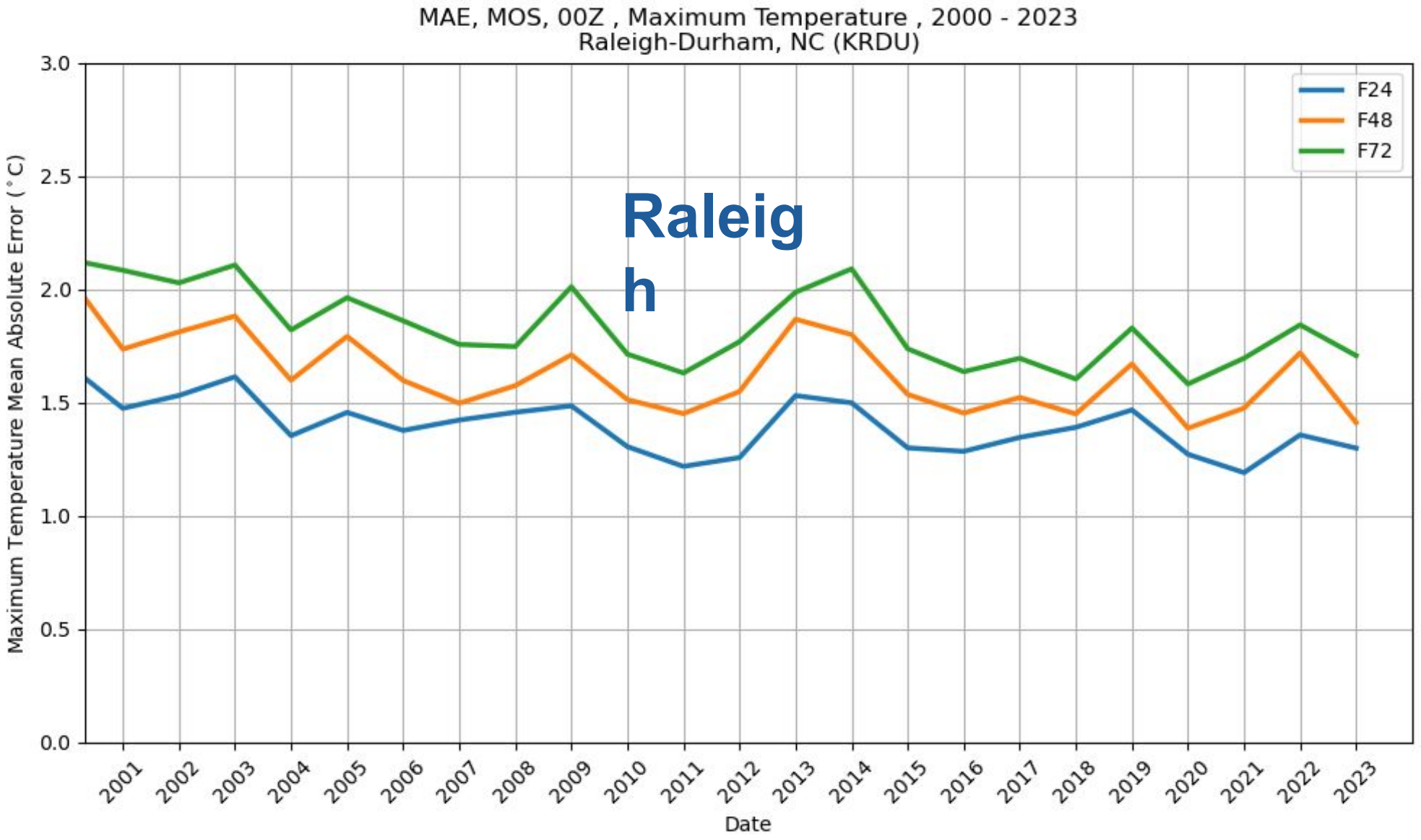
MAE, MOS, 00Z , Maximum Temperature , 2000 - 2023
Raleigh-Durham, NC (KRDU)
Maximum Temperature Mean Absolute Error (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
F24
F48
F72
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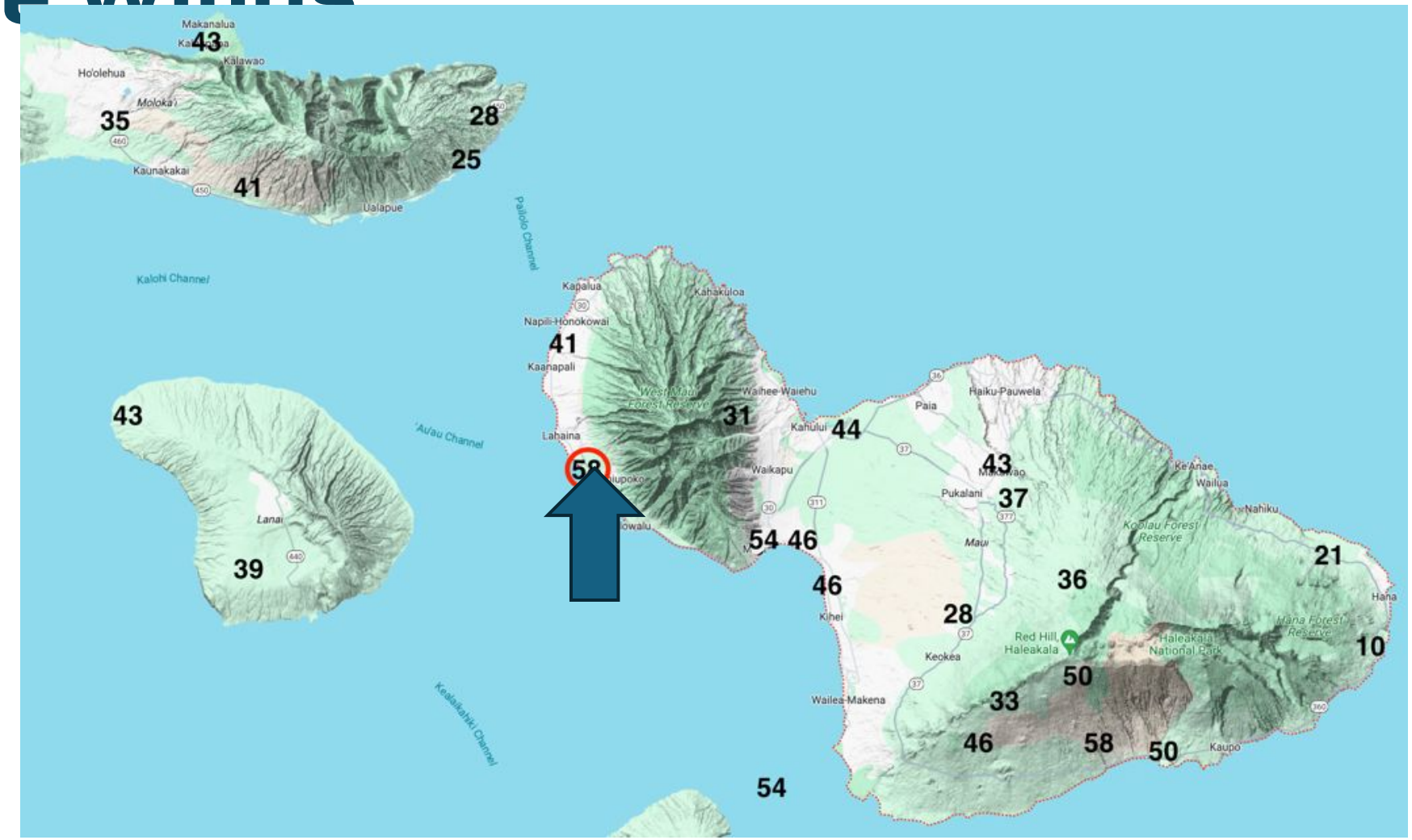
2022
2023
Date

A Stunning Example of Progress

On August 8, 2023, large wildfires hit western and central Maui, killing at least 100 people and resulting in 3-6 billion dollars of damage

The Maui Wildfire Event Was Associated with Very Strong Downslope Winds

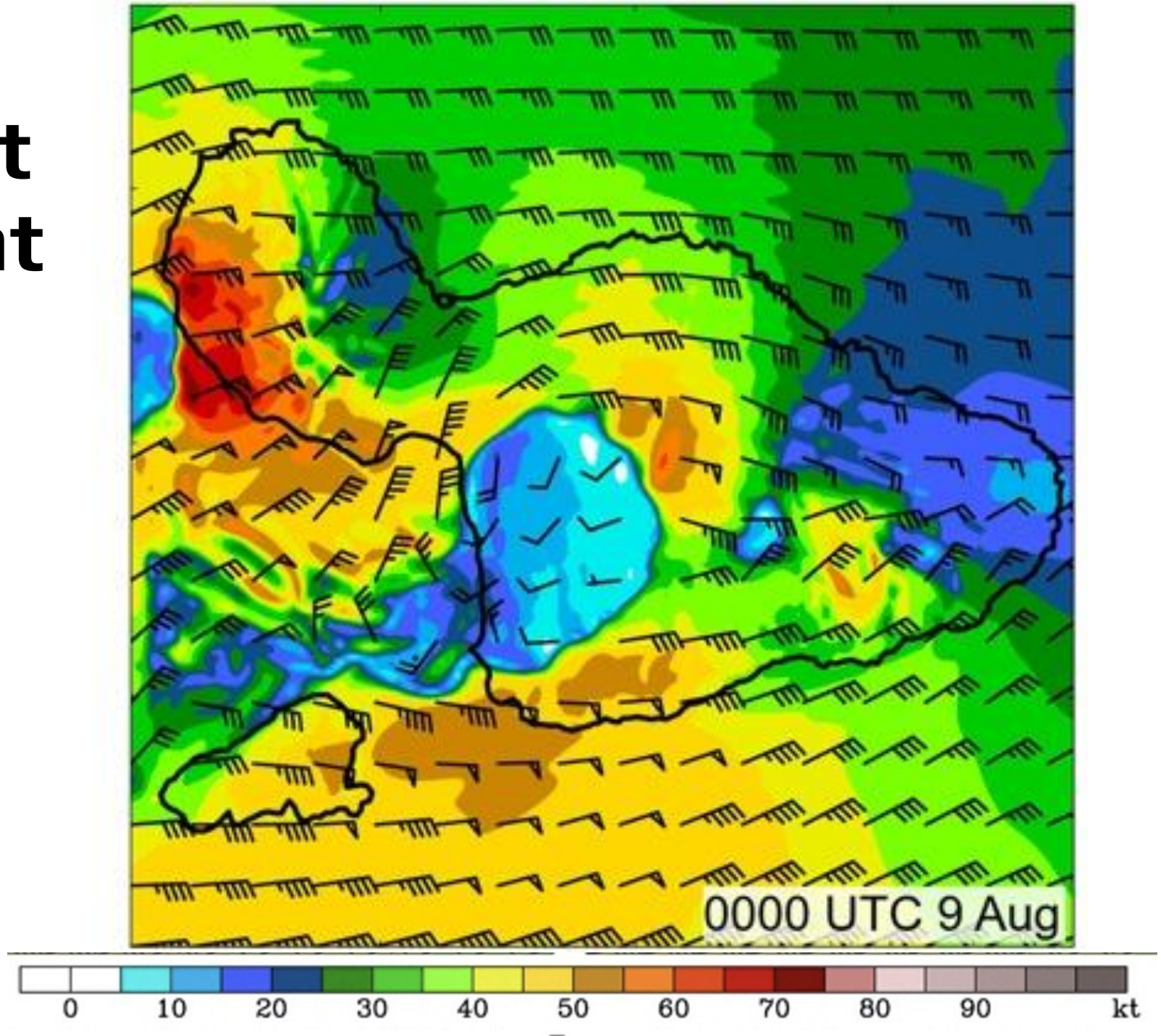
Based on damage and limited wind observations, estimated **winds gusted to 60-80 kt in and east of Lahaina**

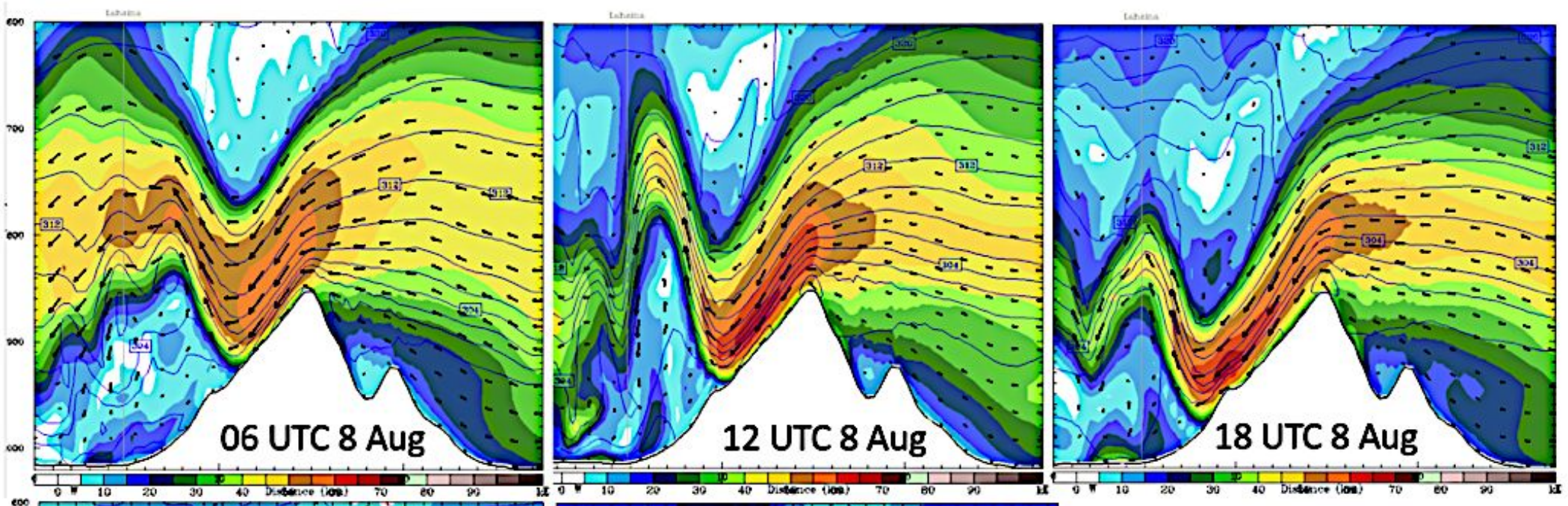


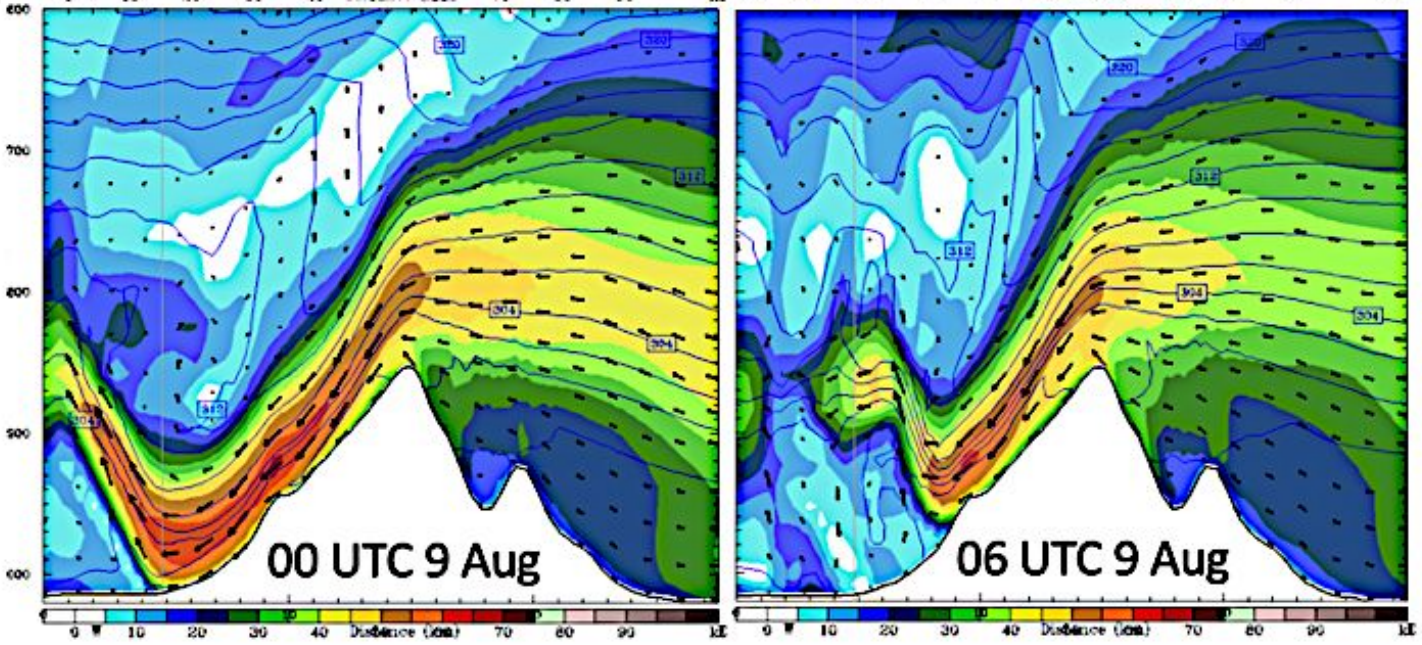
24-h forecast was excellent

WRF Model Forecast Wind Gusts (kt)

Initialized 0000 UTC 8 August



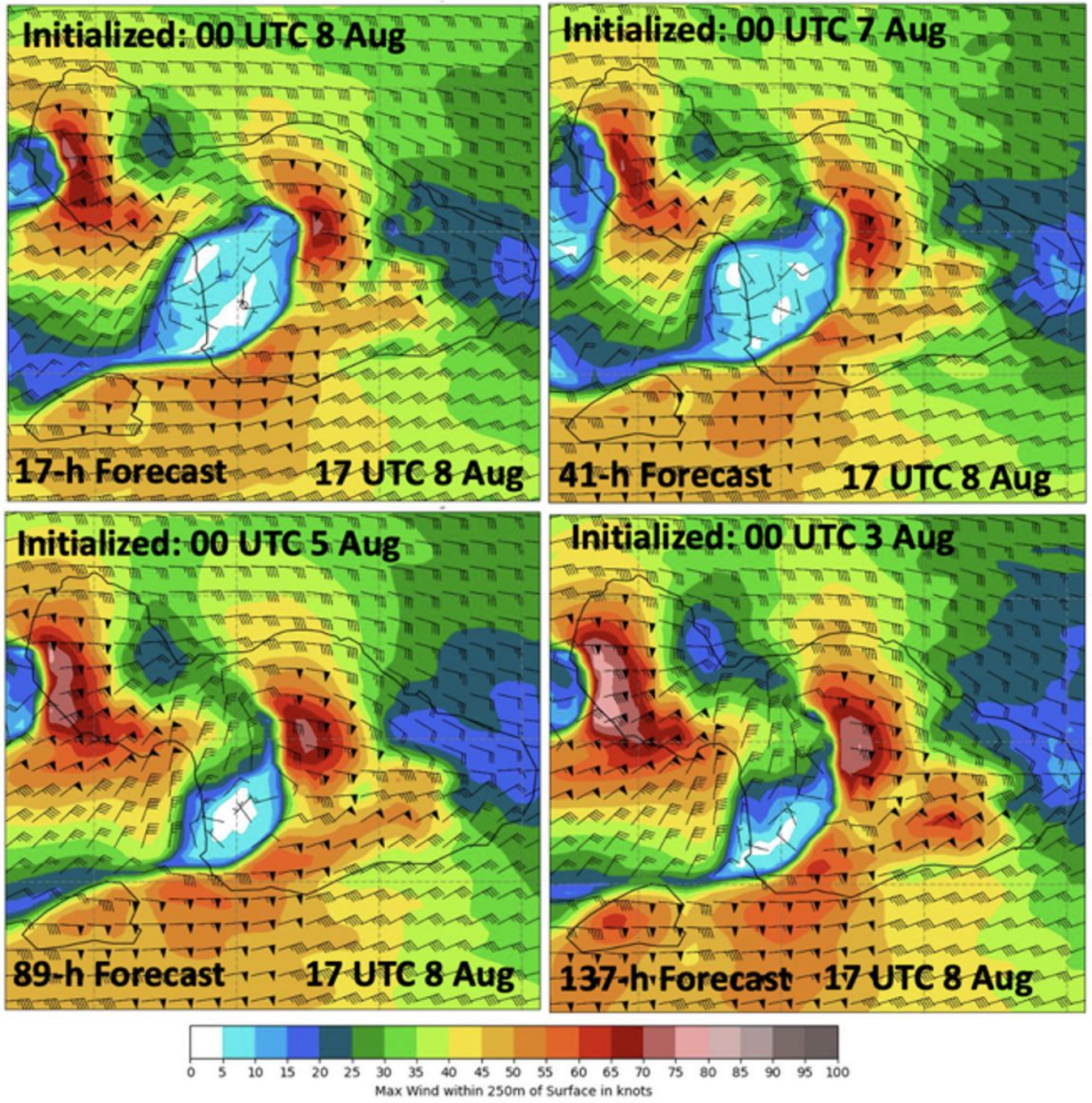




Potential Temperature
Wind Speed (shaded)
Wind Vector in Cross Section

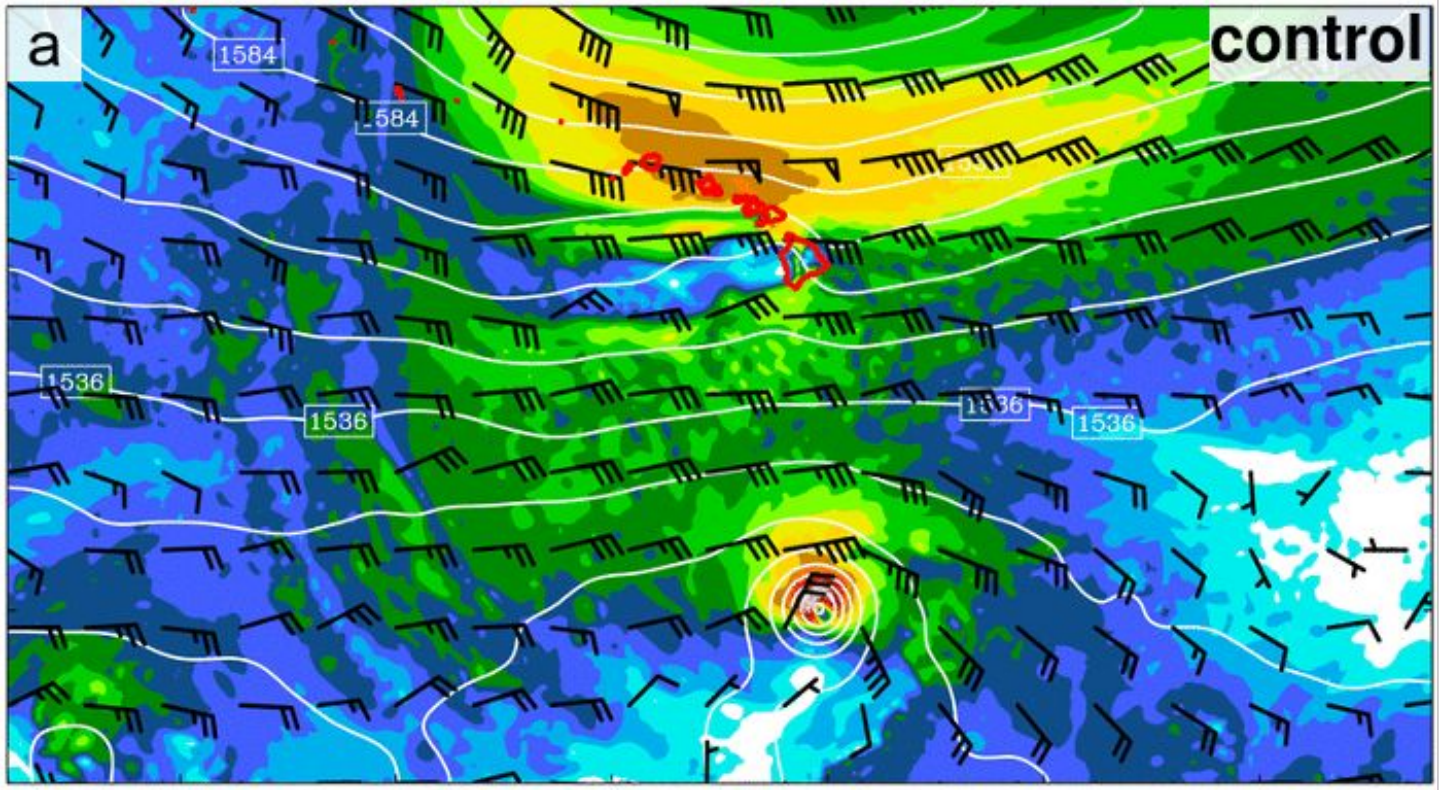
High Amplitude Mountain Wave and Downslope Windstorm

Almost no loss of skill through 137 h (nearly 6 days!)



The Two Revolutions Made This Happen

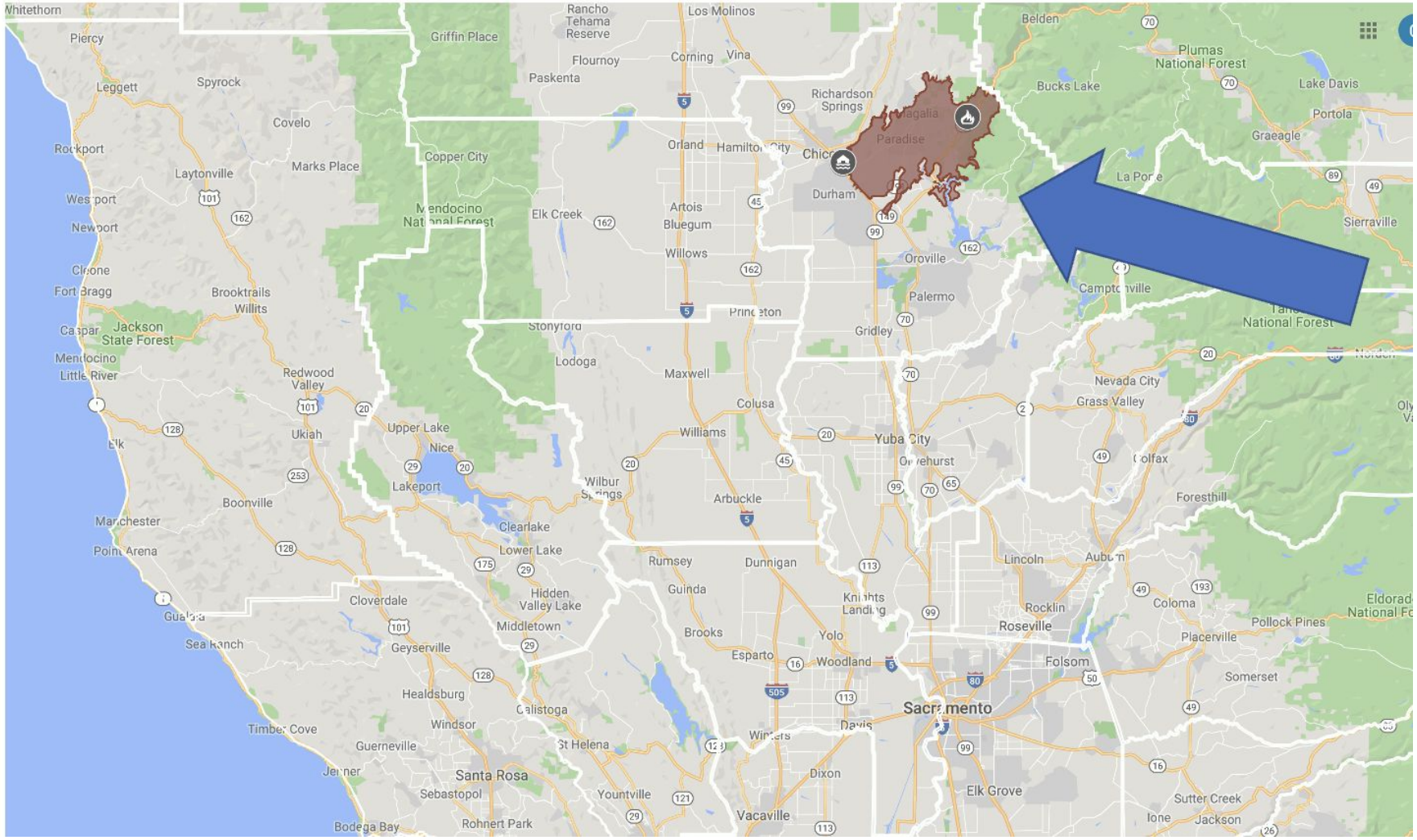
- **Excellent large-scale initialization over the vast Pacific from satellite assets**
- Excellent downscaling to the mesoscale by high-resolution NWP models, such as WRF.



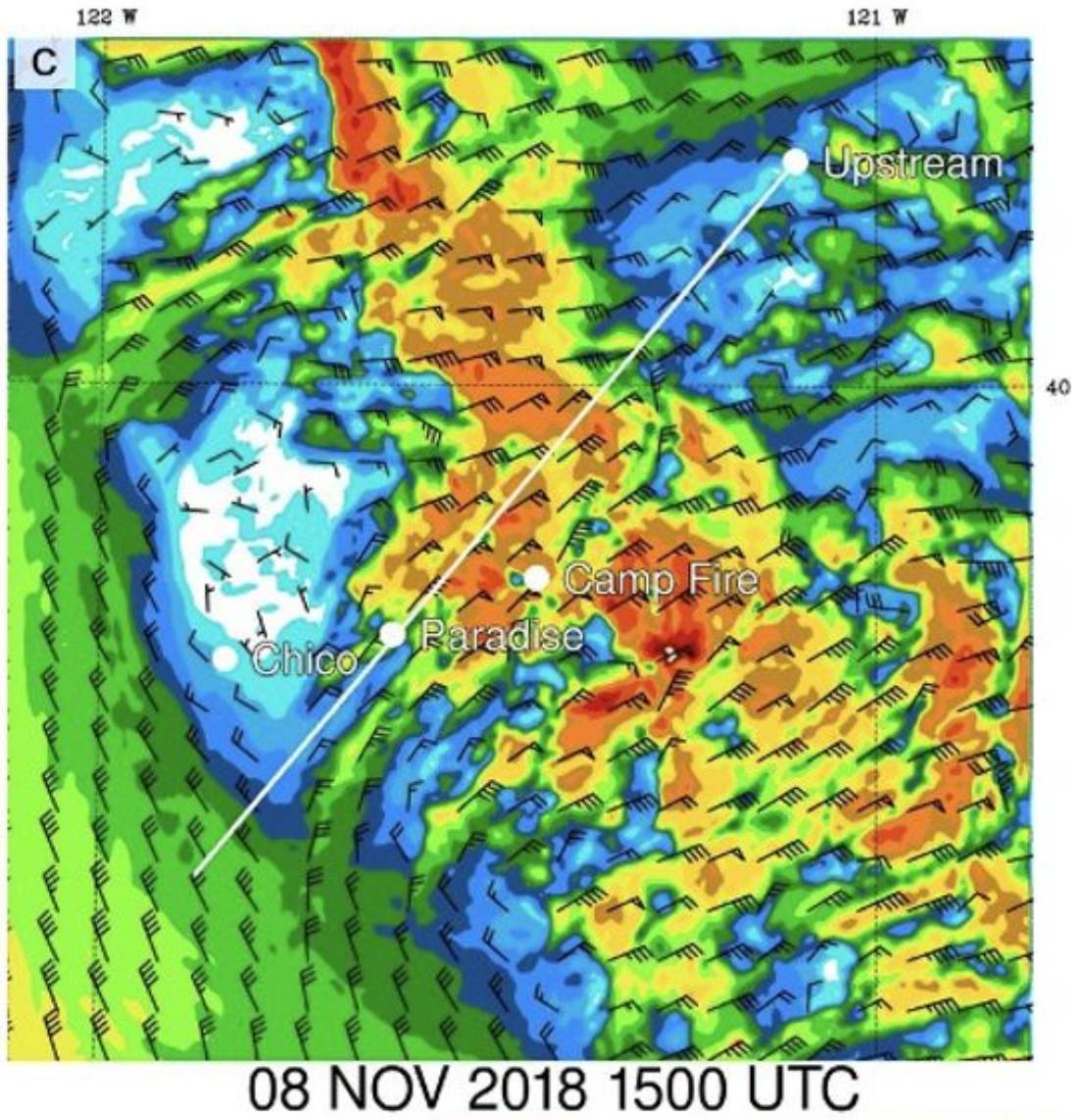
850 hPa Heights and Wind Anomalies

This case was not exceptional: similarly skillful forecasts have occurred time and time again

Camp Fire Location



Near Perfect Forecasts of the Event



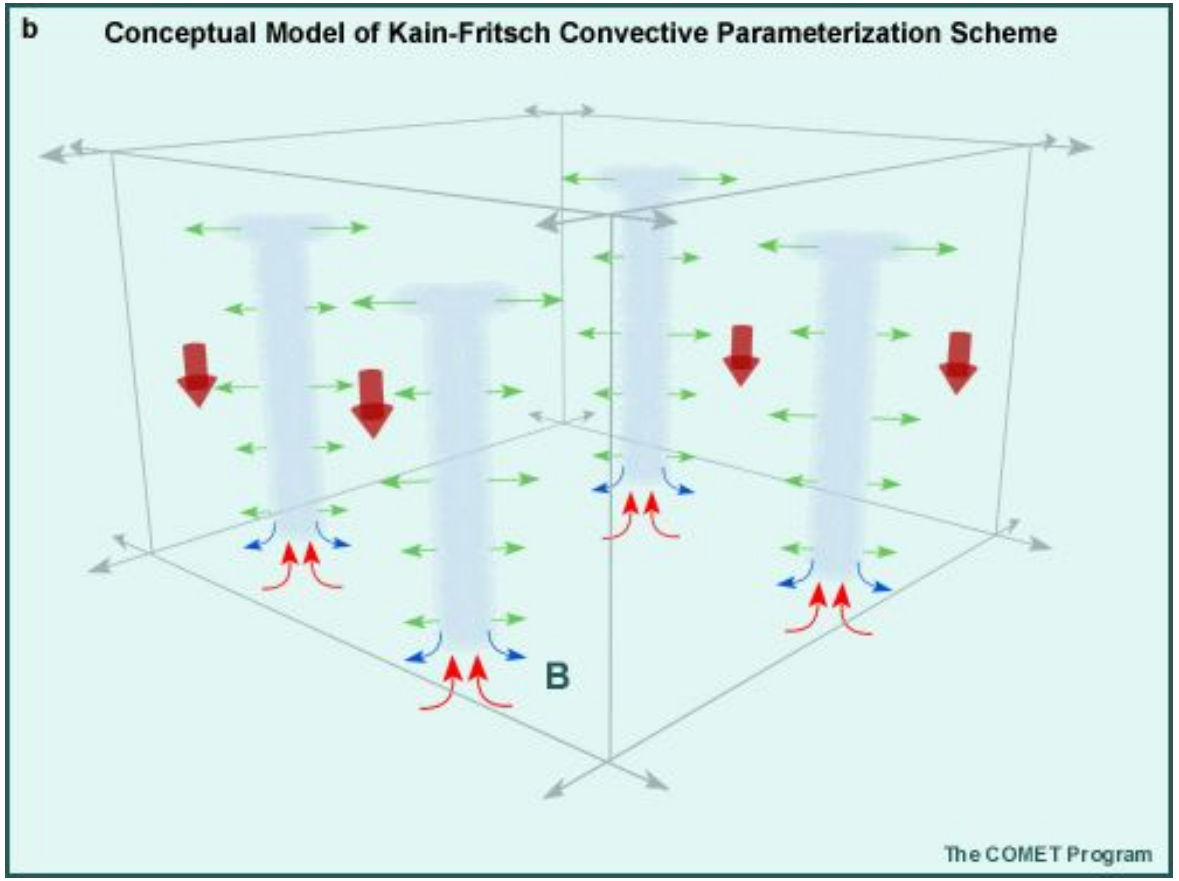
Looking into the Future

The NWP modeling community has not caught up with the improved global analyses and data assimilation made possible by the RO community and others.

Why are modelers behind you?

One Reason: Most global models parameterize convection

- Convective parameterizations are **all** problematic and inadequate
- There is **extensive evidence** that convective-allowing resolution in global models, with convection simulated explicitly, is MUCH more skillful.



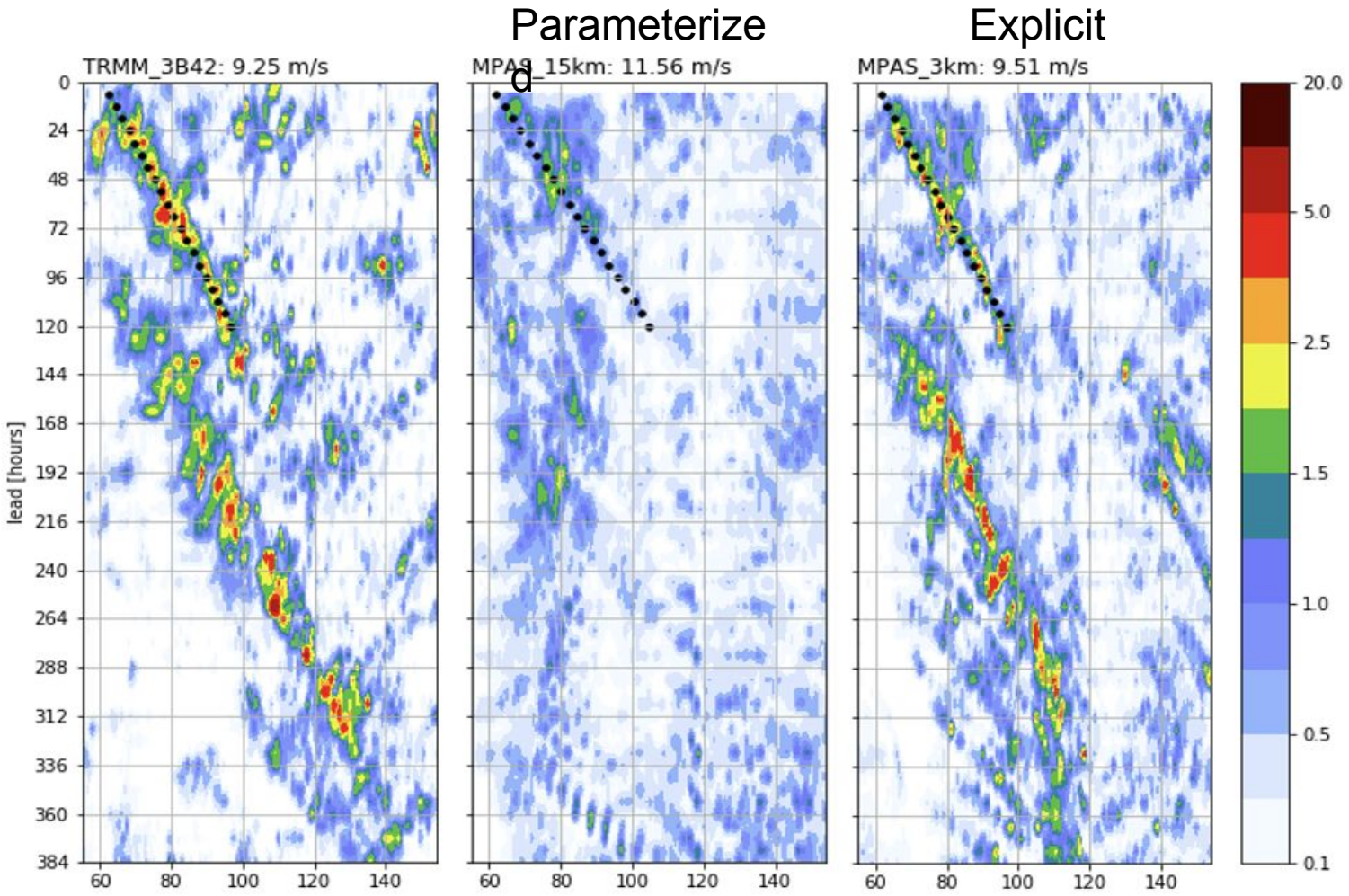
Convection Permitting Global Prediction: Evaluation for Operational Application

Cliff Mass

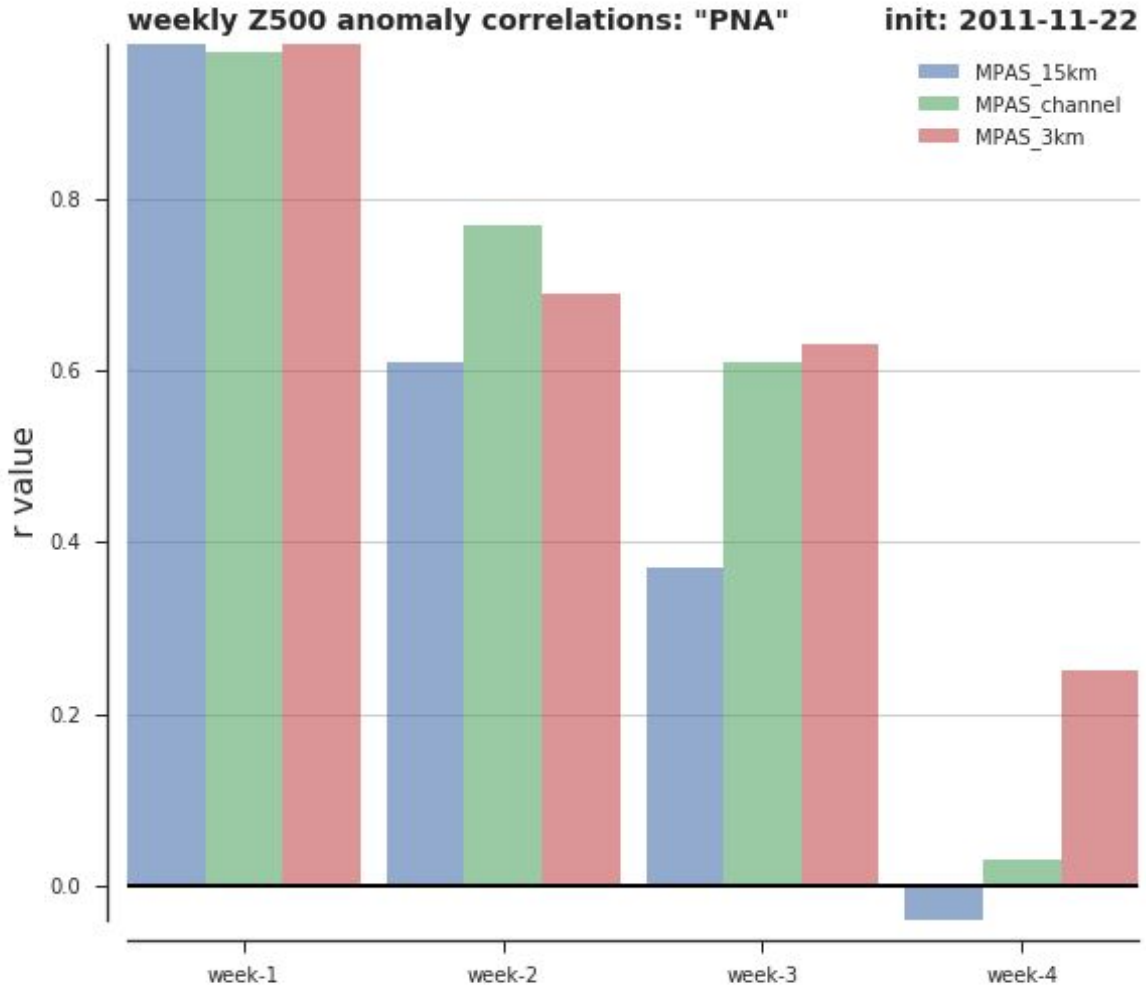
Nick Weber

One-month global forecasts at 3-km grid spacing (MPAS)

Major Improvements in Tropical Convective Wave Propagation (MJO propagation)



Major Increases in Week 3-4 Forecast Skill
With Explicit Convection



Only a matter of time before all global NWP models are run at convection-allowing resolution with explicitly modeled convection

Forecast skill will increase, with better use of the potential of satellite-based data

But there is something else……

More proof that current models are not taking advantage of all the potential skill in current analyses/initializations

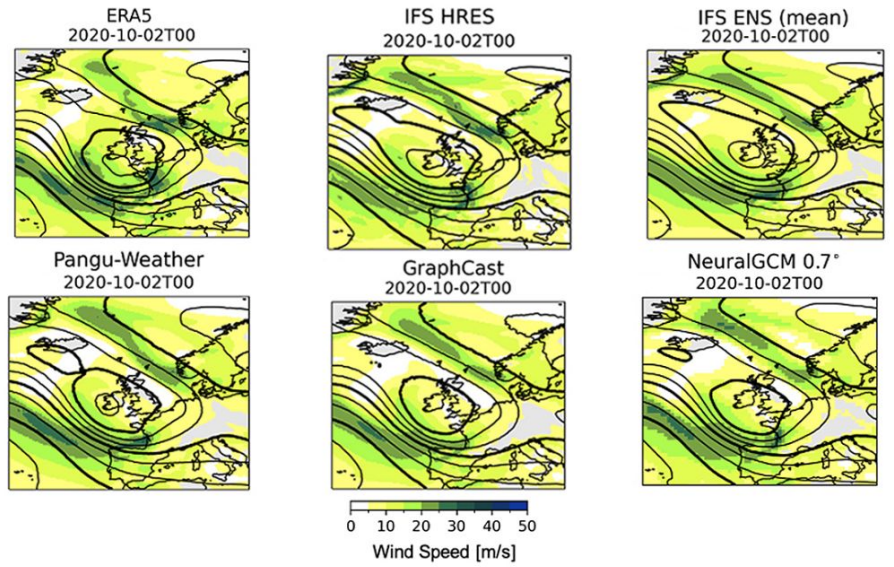
The Implications of Machine Learning NWP

Machine Learning Masters Weather Prediction

Community datasets and evaluation standards are needed to further advance machine learning for weather prediction.

By **Hannah Christensen**

10 July 2024

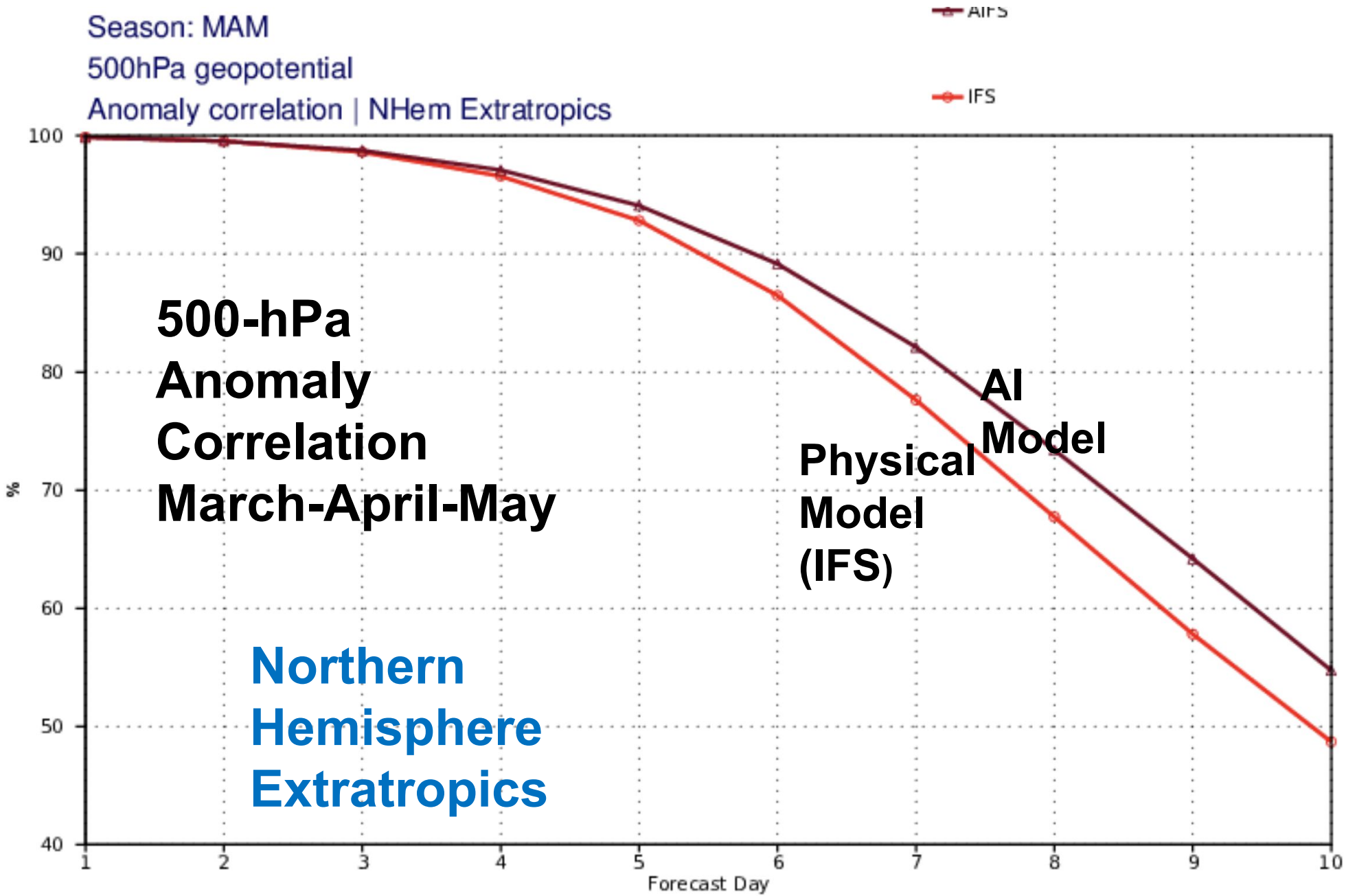


Machine Learning Appears to be More Skillful than Traditional Global NWP Models

Implications:

- There is a a lot more skill that be squeezed out of our current initial conditions!
- Today's physical global models have deficiencies that have prevented them from deriving maximum skill from improved descriptions of the initial state

EC


Season: MAM
500hPa geopotential
Anomaly correlation | NHem Extratropics
AIFS
IFS
100
90
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6
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9
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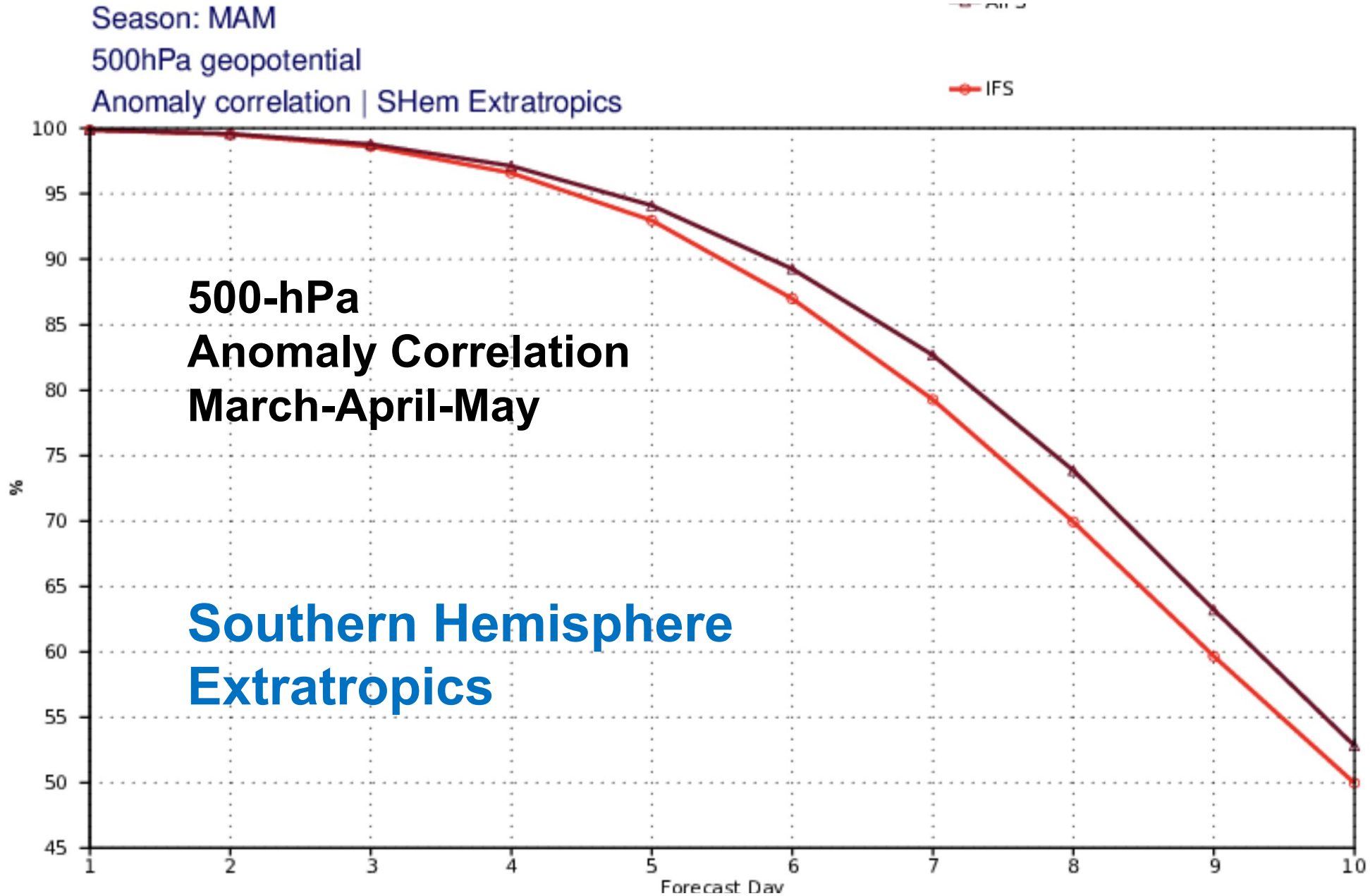
Forecast Day
500-hPa
Anomaly
Correlation
March-April-May
Northern
Hemisphere
Extratropics
AI
Model
Physical
Model
(IFS)


Season: MAM
500hPa geopotential
Anomaly correlation | SHem Extratropics
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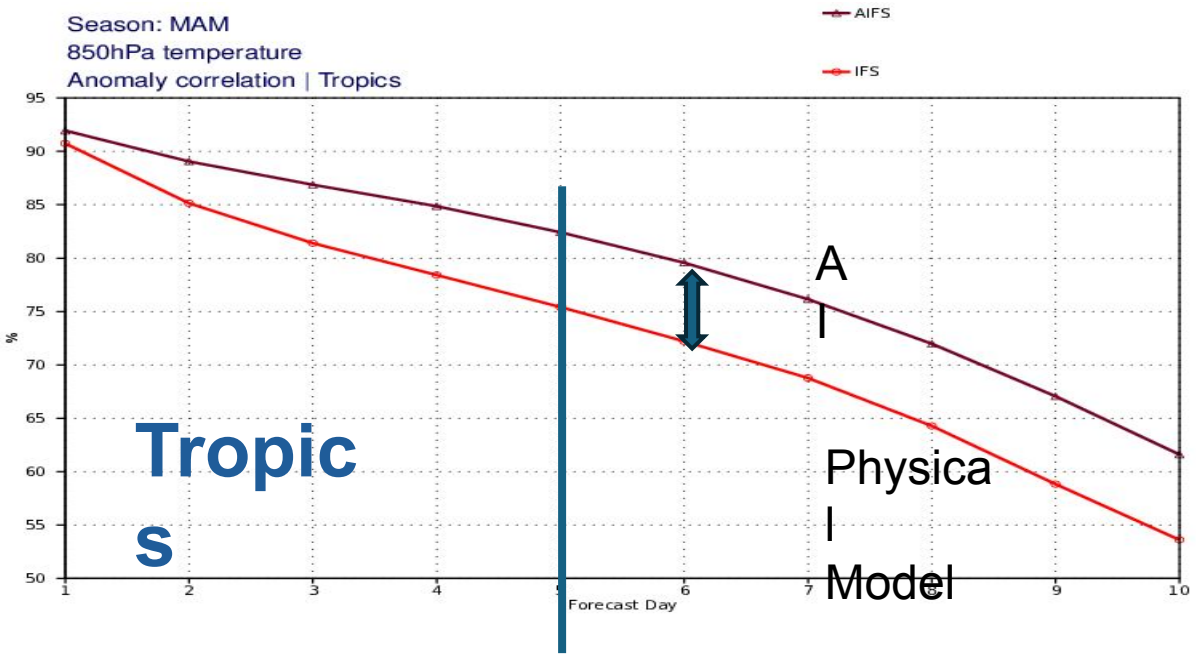
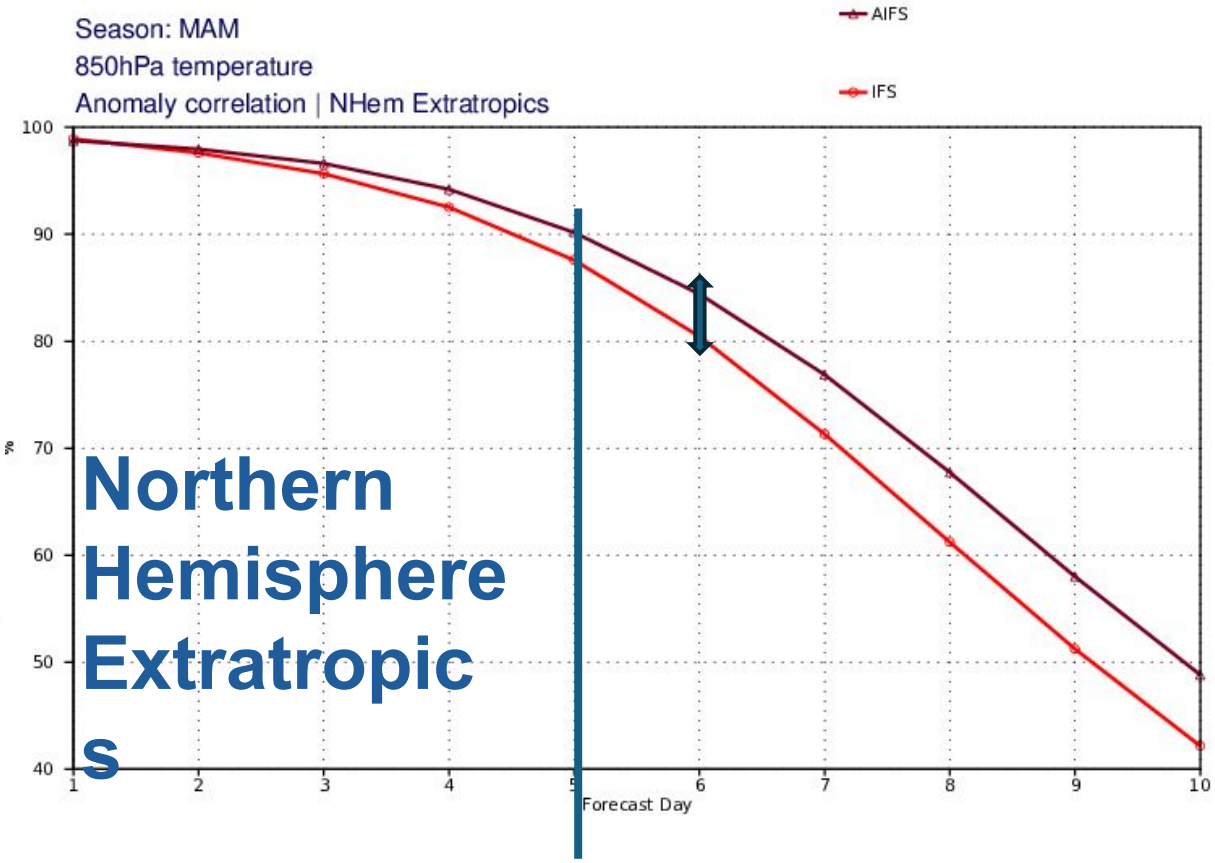
Forecast Day
500-hPa
Anomaly Correlation
March-April-May
Southern Hemisphere
Extratropics

The Tropics Versus Northern Hemisphere:

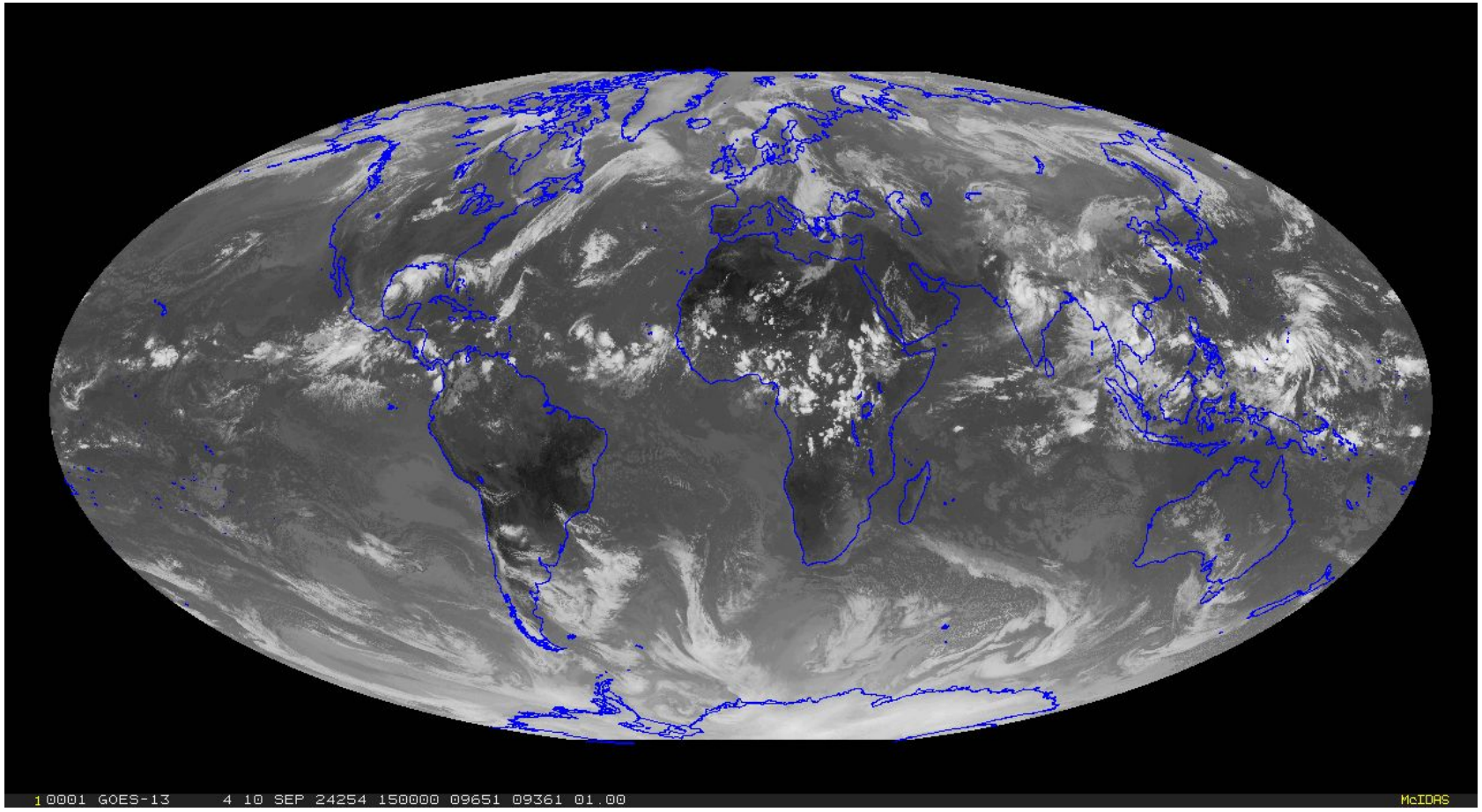
850 hPa temperature





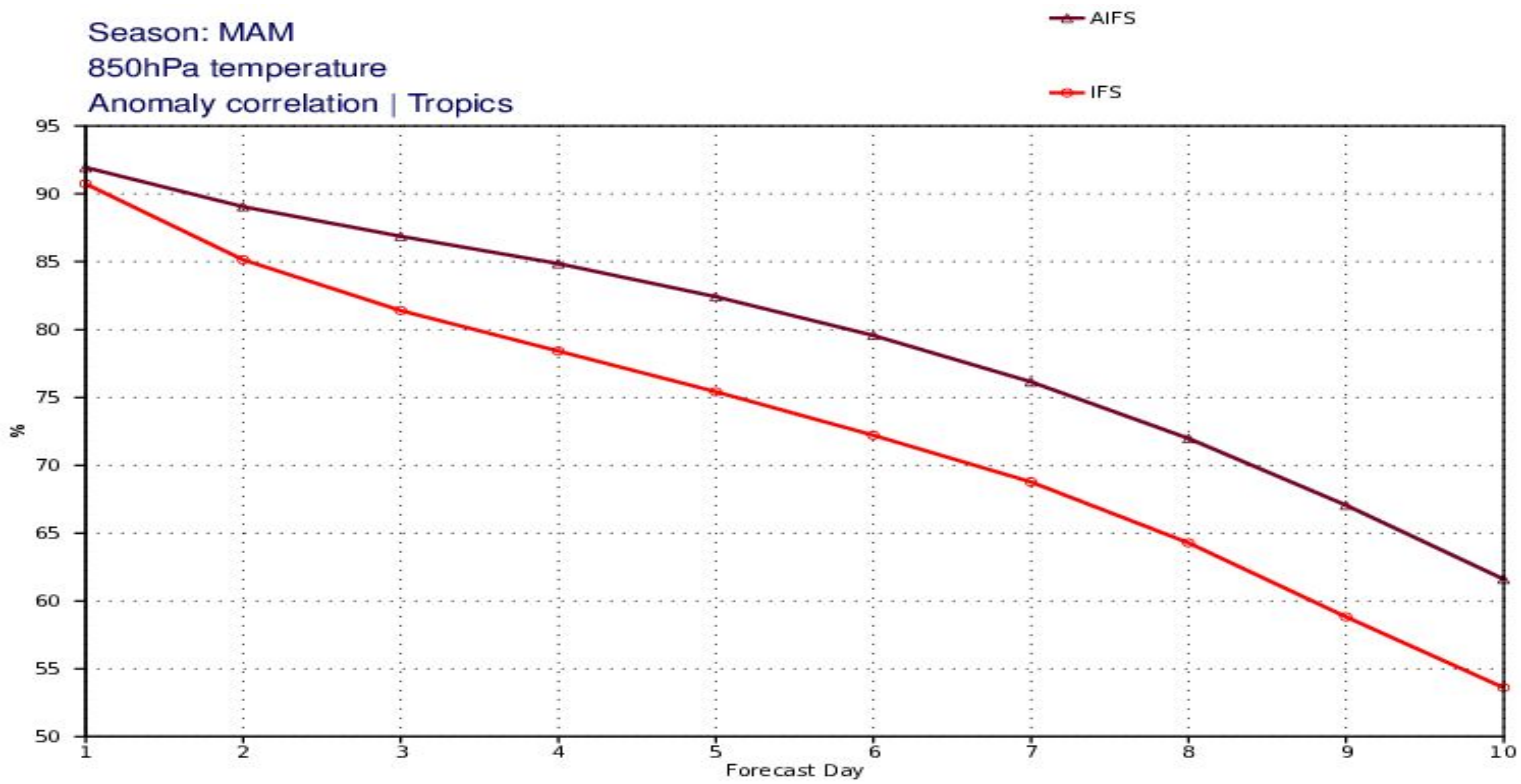
AI NWP is relatively far more skillful in tropics compared to traditional models.

Could this be true because convection is far more important in the tropics?



Possible implication: AI is doing better with the aggregate effects of convection

Tropics

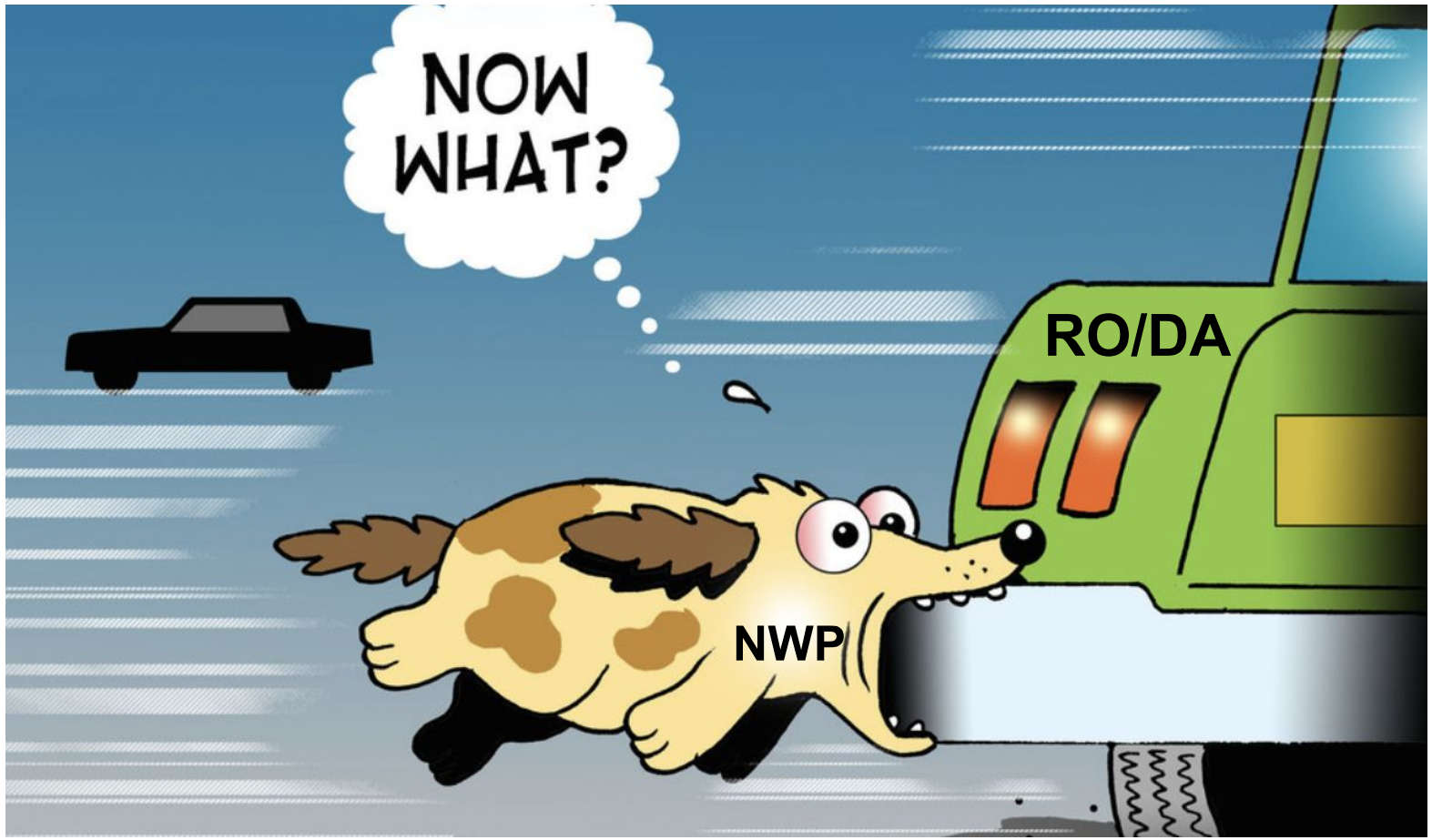


Important Point

Either convection-allowing global physical models or AI models will allow global NWP to make better use of the improved initial state that the RO and satellite community are providing

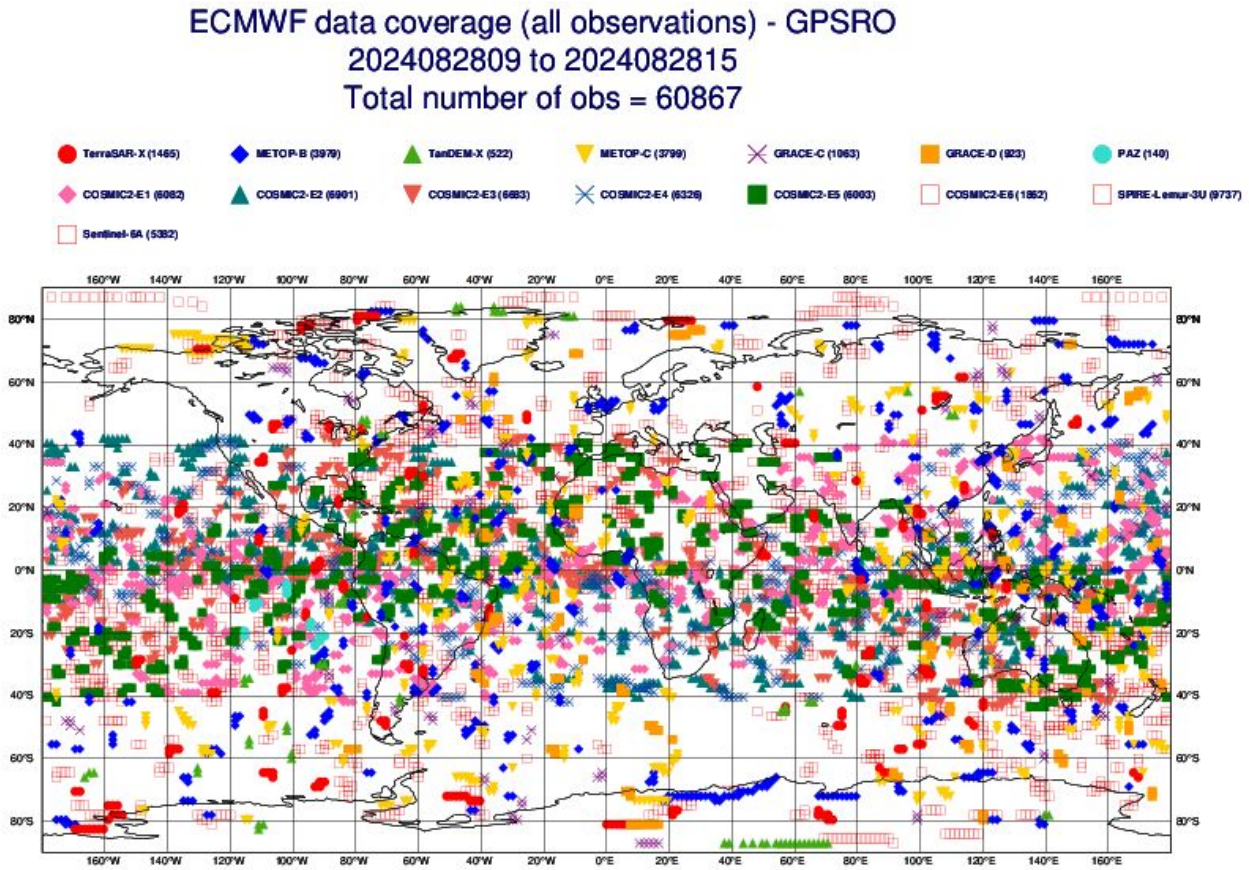
There is substantial room for improvement

Eventually, the modeling community will catch up to you….so the RO and DA communities need to keep ahead



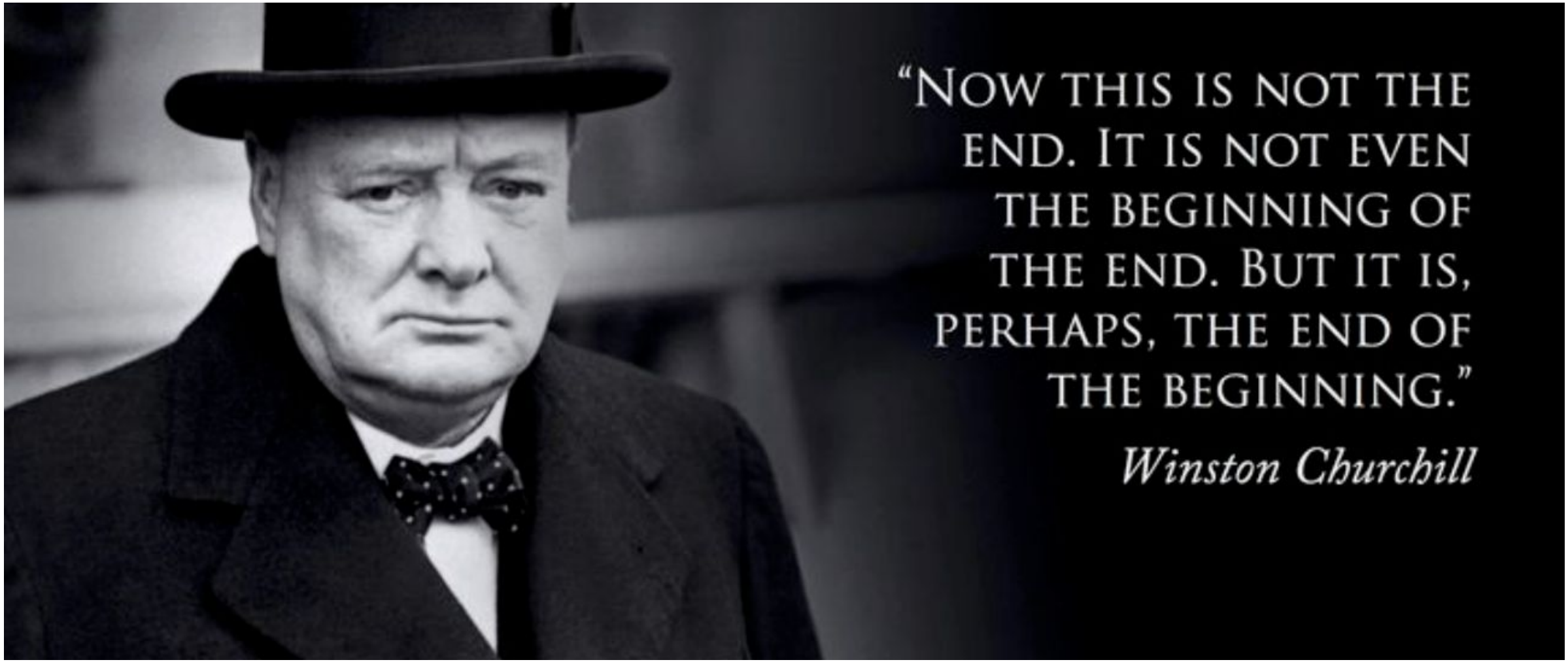
One final note

- Current AI NWP is trained on analyses, such as ERA-5
- If observations are dense enough from RO and other satellite sensors, could AI-NWP be trained directly on observations or gridded versions of observations?



Summary

- Increased satellite assets, such as RO, have led to a rapid increase in large-scale forecast skill in NWP during approximately 1995-2008, followed by a subsequent leveling off
- Mesoscale forecasting skill continued to increase rapidly due to increasing resolution and improved physics.
- Operational NWP has not not caught up to the potential of current global analyses.
- Convection-allowing global modeling and AI NWP are two approaches to “catch up” and greatly improve forecast skill.


"Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning."
Winston Churchill