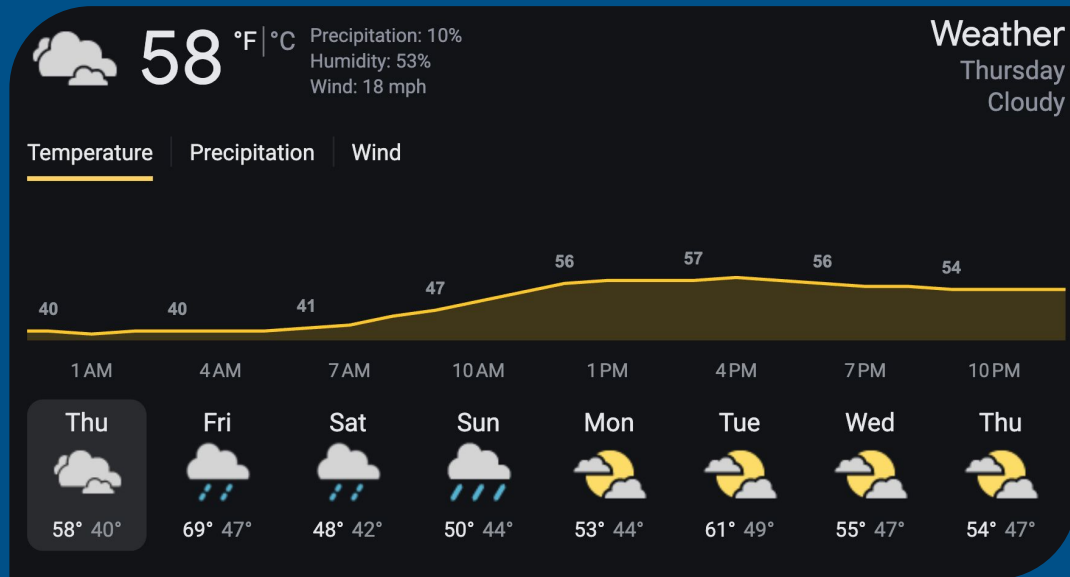


# HPC in Weather Prediction

–Sabyasachi Behera



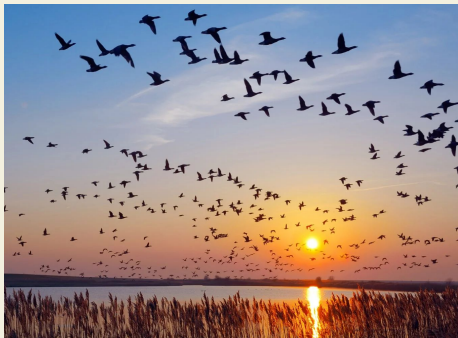
# Introduction

## Impact of Weather Forecast

✈️ DEPARTURES				
TIME	DESTINATION	FLIGHT	GATE	REMARKS
12:39	LONDON	BA 903	31	CANCELLED
12:57	SYDNEY	QF5723	27	CANCELLED
13:08	TORONTO	AC5984	22	CANCELLED
13:21	TOKYO	JL 608	41	DELAYED
13:37	HONG KONG	CX5471	29	CANCELLED
13:48	MADRID	IB3941	30	DELAYED



## Evolution of Weather forecasting Techniques



### QG OMEGA EQUATION:

$$\left( \sigma \nabla^2 + f_0 \frac{\partial^2}{\partial p^2} \right) \omega = f_0 \frac{\partial}{\partial p} \left[ \vec{V}_s \cdot \nabla (\zeta_s + f) \right] + \nabla^2 \left[ \vec{V}_s \cdot \nabla \left( -\frac{\partial \phi}{\partial p} \right) \right]$$

### EXPAND THE ADVECTION TERMS:

$$\sigma \left( \nabla^2 + \frac{f_0}{\sigma} \frac{\partial^2}{\partial p^2} \right) \omega = f_0 \frac{\partial}{\partial p} \left[ u_s \frac{\partial (\zeta_s + f)}{\partial x} + v_s \frac{\partial (\zeta_s + f)}{\partial y} \right] + \nabla^2 \left[ -u_s \frac{\partial^2 \phi}{\partial x \partial p} - v_s \frac{\partial^2 \phi}{\partial y \partial p} \right]$$

### USE THE EXPRESSIONS FOR THE GEOSTROPHIC WIND AND GEOSTROPHIC VORTICITY:

$$u_s = -\frac{1}{f} \frac{\partial \phi}{\partial y} \quad v_s = \frac{1}{f} \frac{\partial \phi}{\partial x} \quad \zeta_s = -\frac{1}{f_0} \nabla^2 \phi$$

### To Get:

$$\sigma \left( \nabla^2 + \frac{f_0}{\sigma} \frac{\partial^2}{\partial p^2} \right) \omega = f_0 \frac{\partial}{\partial p} \left[ -\frac{1}{f} \frac{\partial \phi}{\partial y} \frac{\partial}{\partial x} \left( \frac{1}{f_0} \nabla^2 \phi + f \right) + \frac{1}{f} \frac{\partial \phi}{\partial x} \frac{\partial}{\partial y} \left( \frac{1}{f_0} \nabla^2 \phi + f \right) \right] + \frac{1}{f} \nabla^2 \left[ \frac{\partial \phi}{\partial y} \frac{\partial^2 \phi}{\partial x \partial p} + \frac{\partial \phi}{\partial x} \frac{\partial^2 \phi}{\partial y \partial p} \right]$$



# Evolution of Weather Forecasting



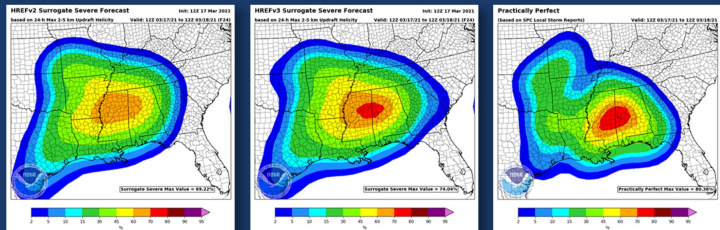
Famously summarised turbulence in rhyming verse in Weather Prediction by Numerical Process:

*Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity.*



## High Resolution Ensemble Forecast

March 17, 2021 severe weather outbreak comparison

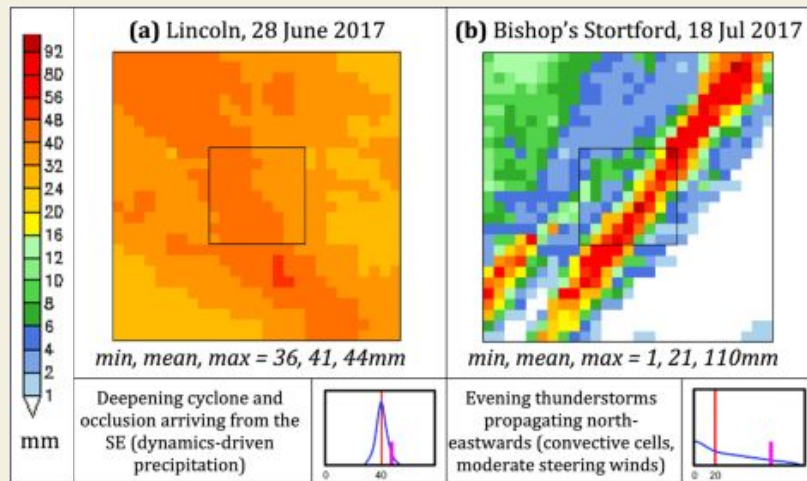


Current HREF system forecast

Upgraded HREF system forecast

Actual conditions observed

Credit: NOAA/EMC and SPC



# Architecture Evolution

Single Computer  
Single processor

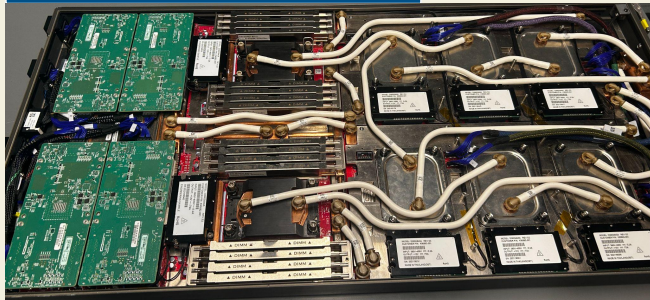


Single Computer  
Multiple processors  
(Parallel Computing)

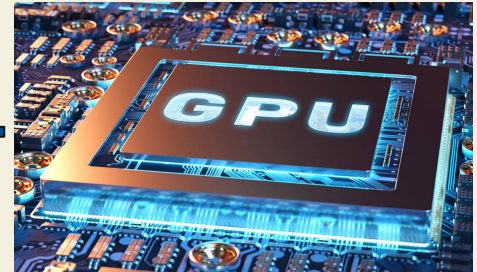
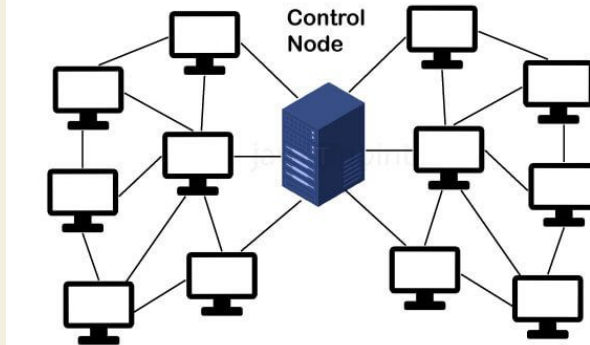


Vectorisation (Loop unrolling)

Massively parallel  
supercomputers  
(Thousands of  
Processors)



Grid and Cluster Computing



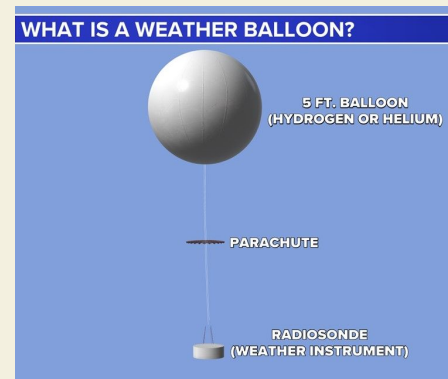
# Supercomputers in Weather Forecasting



Satellites



Radar



Weather Balloon

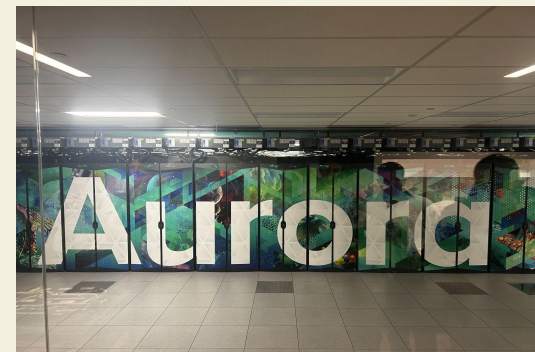


Ocean Sensor



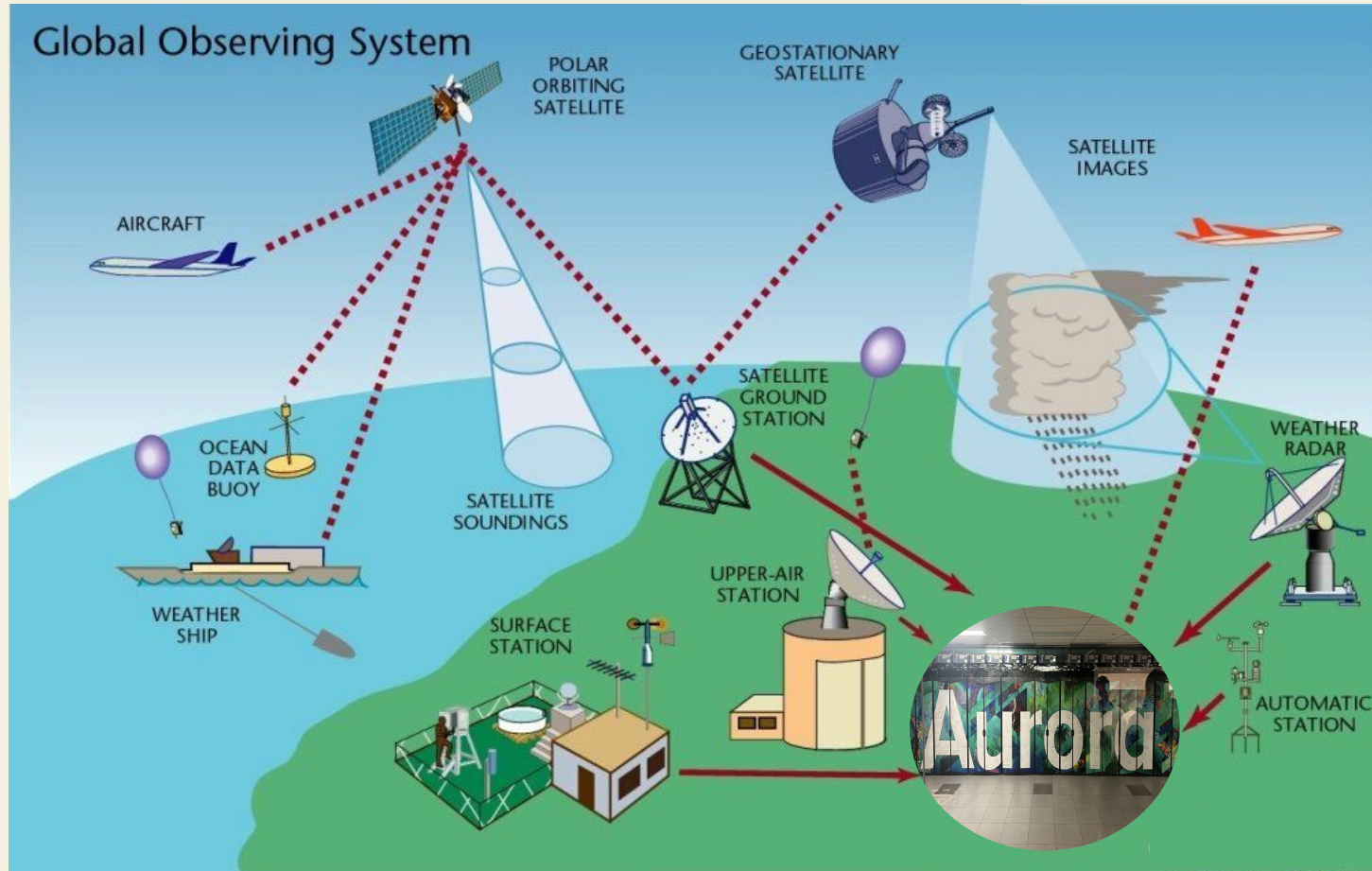
Hundreds of  
Terabytes of  
Data per day

able to perform over a quintillion calculations  
per second



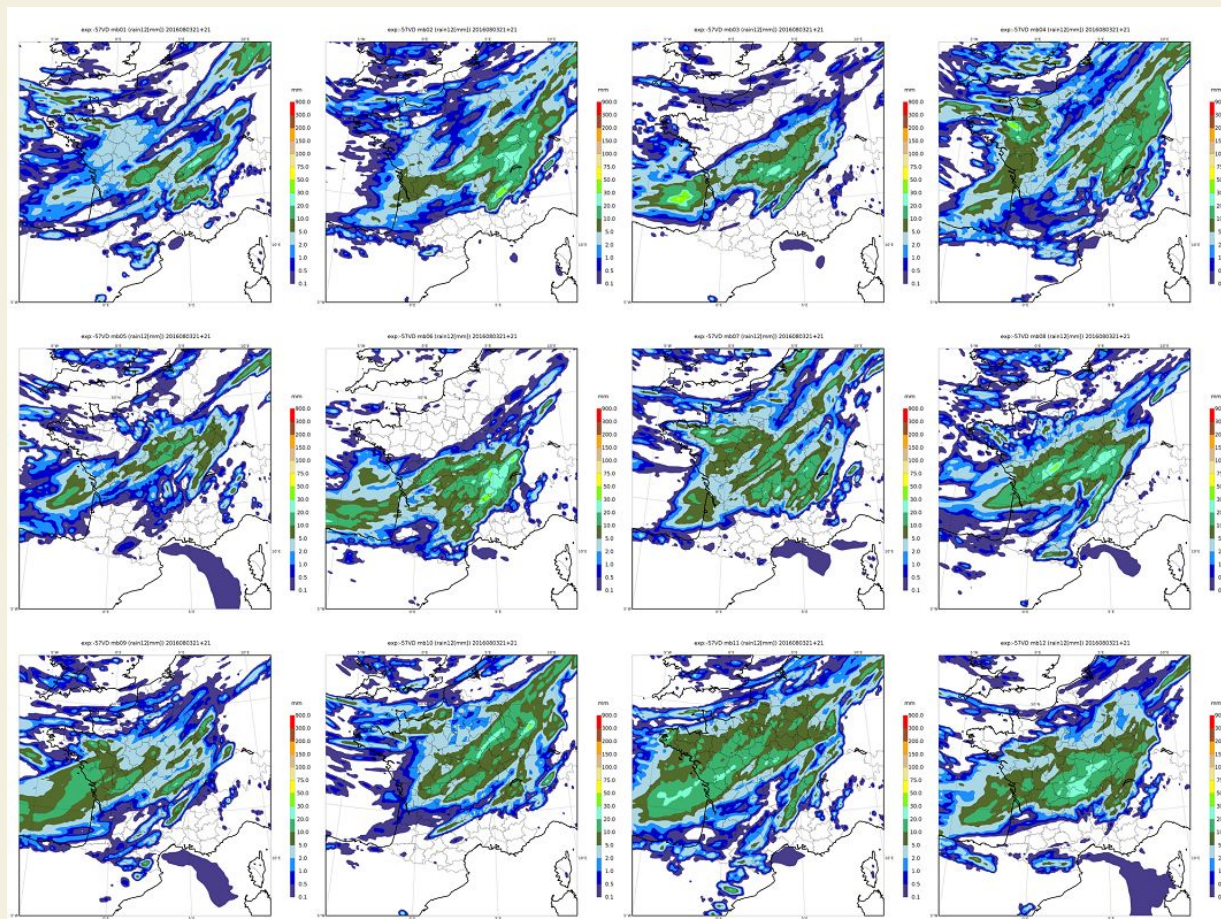
Exascale Computing

# Data Assimilation

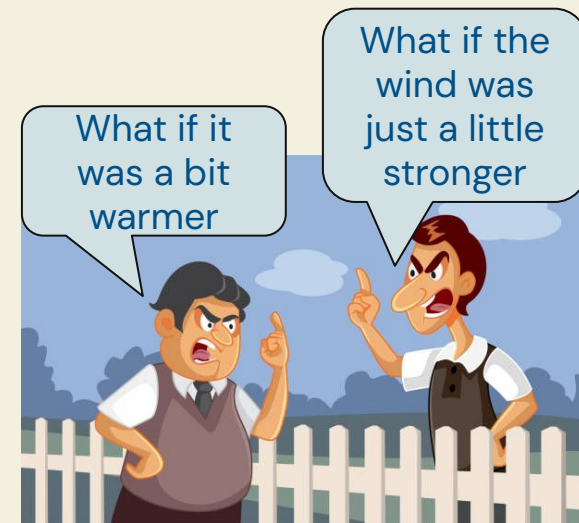


It's the process of updating the model with real-time observations so it stays on track.

# Ensemble Forecasting = "what if" scenarios



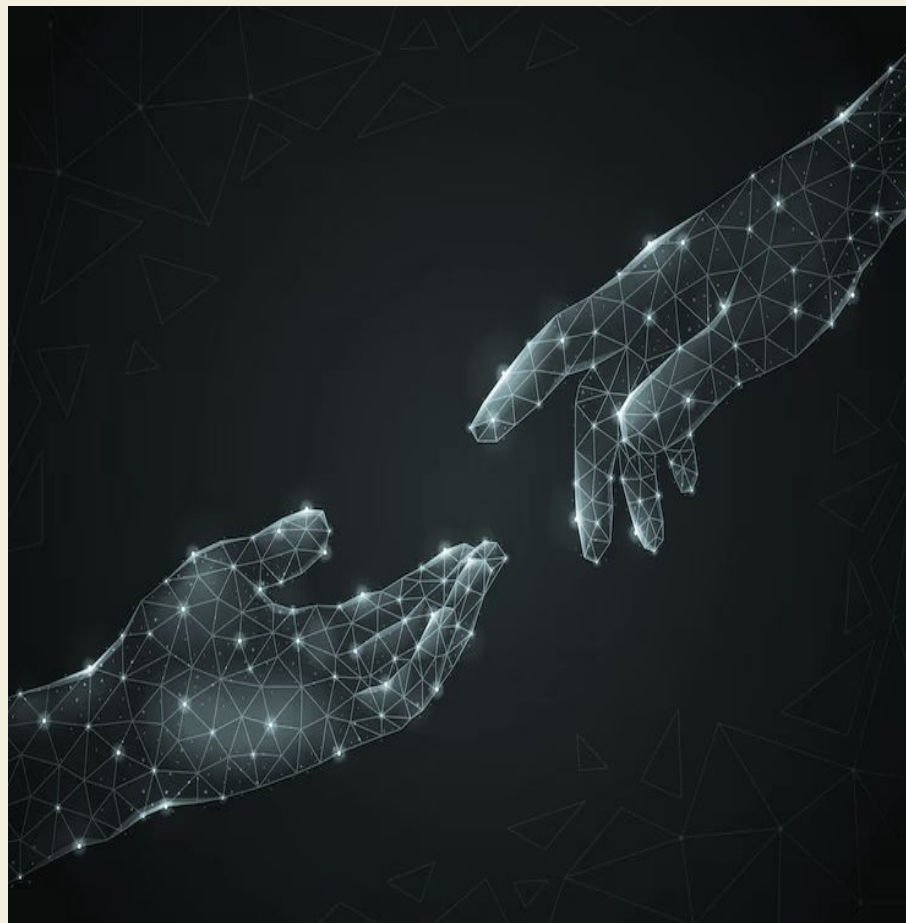
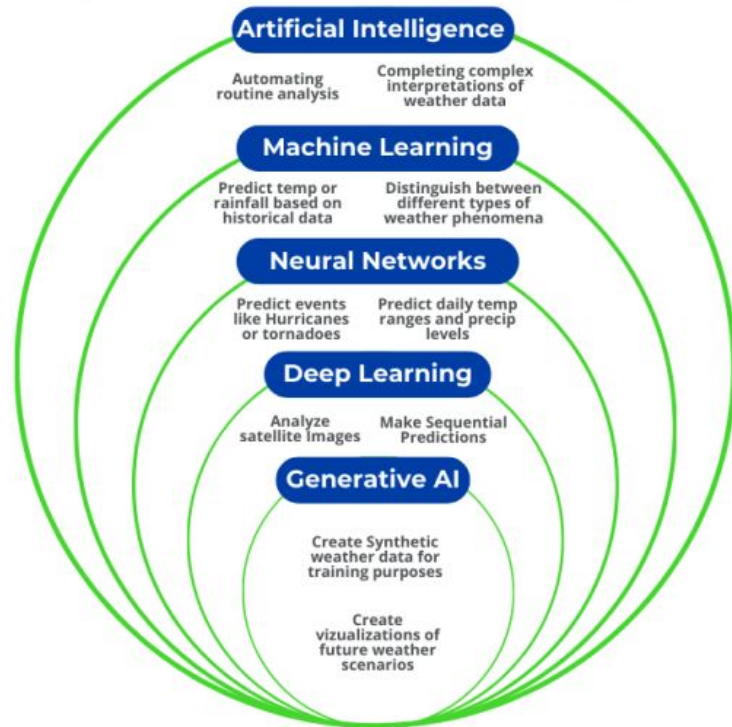
run  
the same model a bunch  
of times, each with  
slightly different starting  
conditions



# AI and Deep Learning Integration

## AI Systems for Weather

Examples of how these systems can be applied for weather prediction



# Thank you

Questions?

