High-temporal and Spatial Resolution Radar with AI Application

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Presentation at NCAR
March 10, 2026

Radar Signals

- Hydrometeors are randomly distributed in space.
- Radar echo is the sum of backscattered signals from a large number of randomly distributed hydrometers.
- Central limit theorem: The sum of many independent random radar signals is a Gaussian random variable.

Statistical Properties of Radar Signals

Radar signal: $X(t) = I(t) + iQ(t)$

X(t): represents voltage,

I(t) and Q(t) represent time series

I and Q are independent zero-mean Gaussian.

Power: $P = \langle I^2 \rangle + \langle Q^2 \rangle$ is exponentially distributed.

For one independent sample, power estimate has a relative error of 100%.

Prediction of Radar Signals Using AI

Rationale for Radar Signal Prediction

Radar detects a limited range of (i) mean velocities {500 discrete values} and (ii) Doppler spectrum widths {50 discrete values} width combinations in the atmosphere.

Population of radar signals (I and Q) is finite.

Radar time series is correlated in time.

Finite population and correlation of time series enable radar signal prediction.

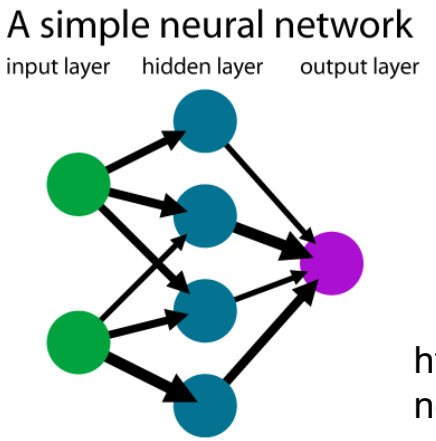
Artificial Intelligence (AI)

Neural networks is crucial component of AI:

consist of layers of neurons that learn by adjusting weights and biases through forward propagation and backpropagation.

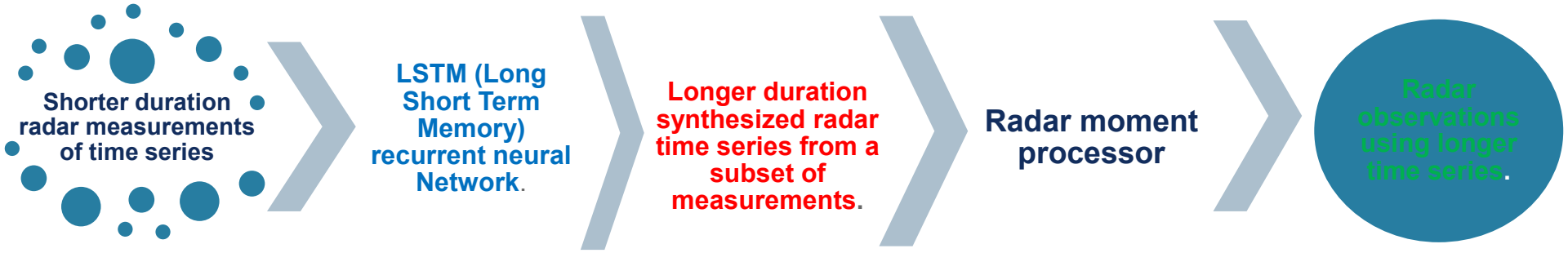
Recurrent neural network (RNN) architected to process timeseries.

LSTM (Long Short-Term Memory) network is a type of RNN.



https://computerhistory.org/blog/how-do-neural-network-systems-work/

Conceptual AI Radar

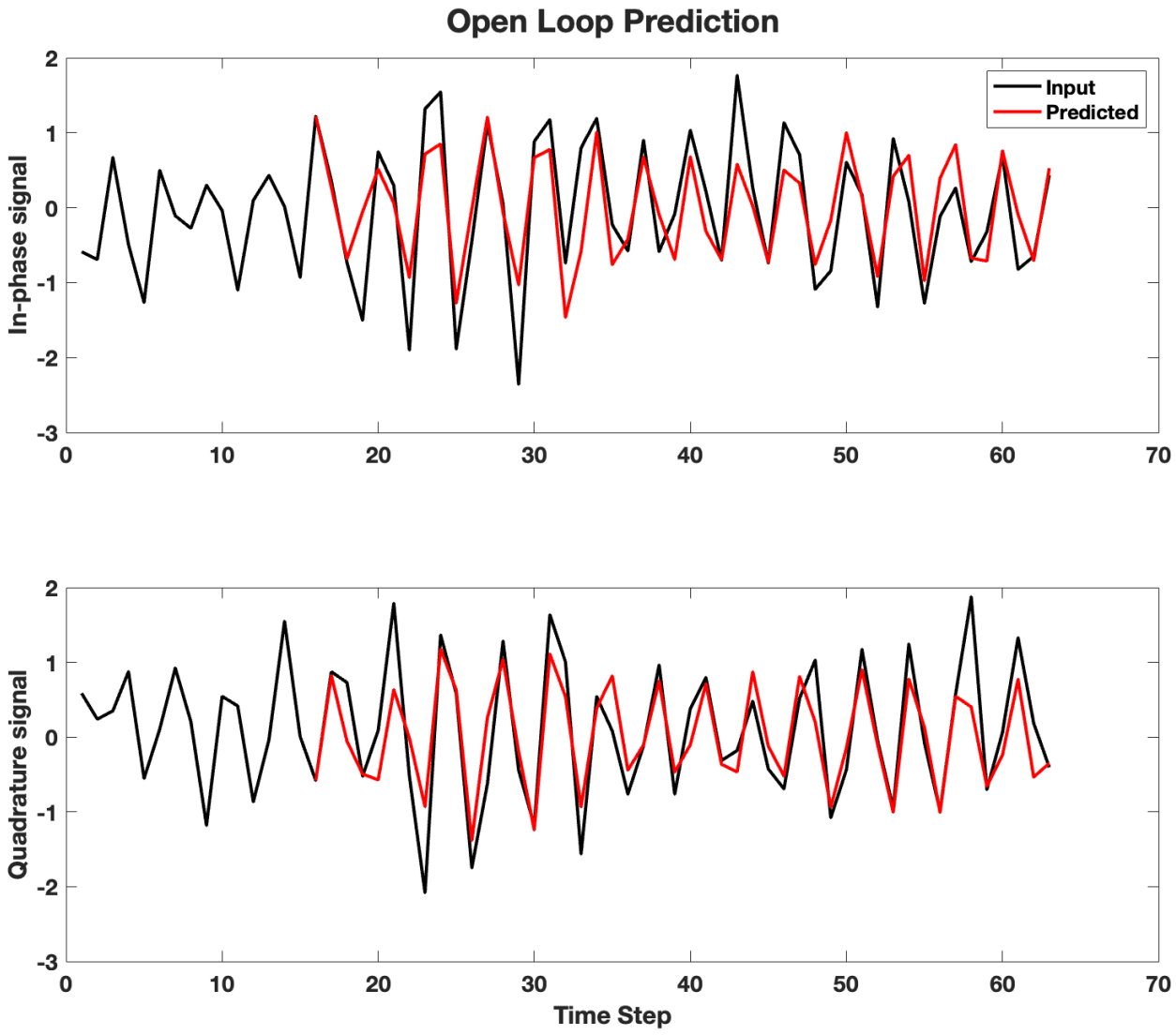


Existing radar **AI** **Enhanced radar time series**

Higher temporal and spatial resolution measurements

Original {64} vs Synthesized {16+48=64} series

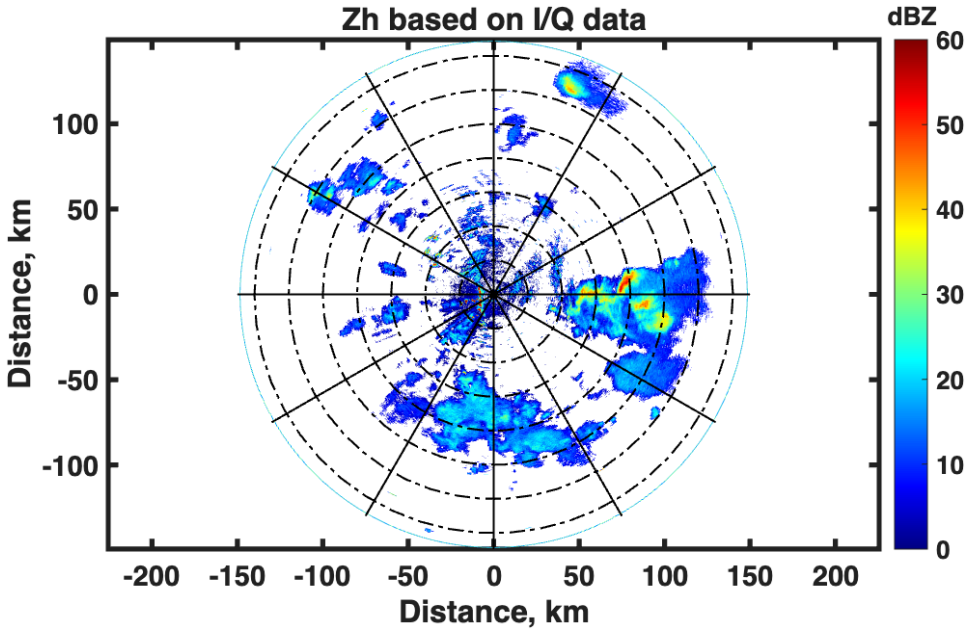
Mean velocity=14.6 [14.80] m/s and spectrum width =0.96 [1.35] m/s

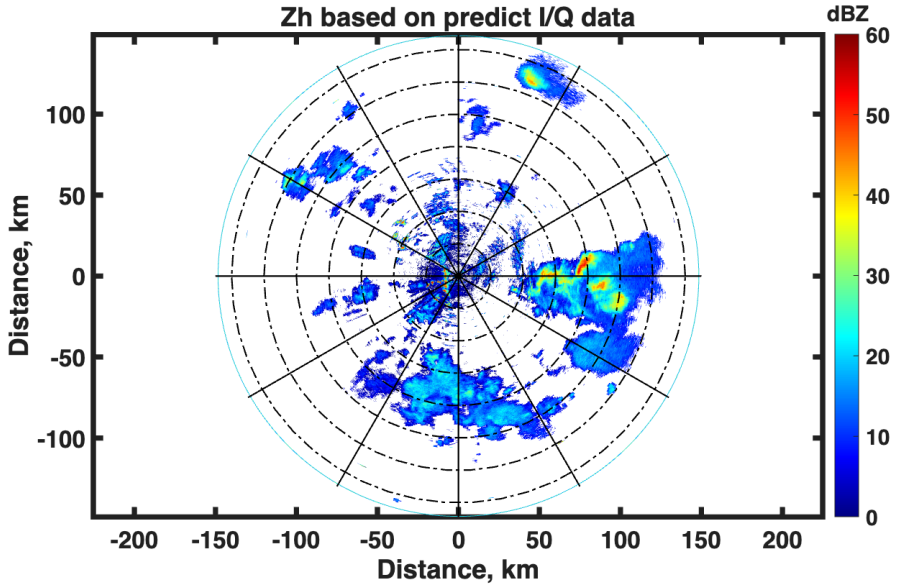


Application to S -Pol Measurements

Measurement {64} vs Synthesized {16+48=64} series

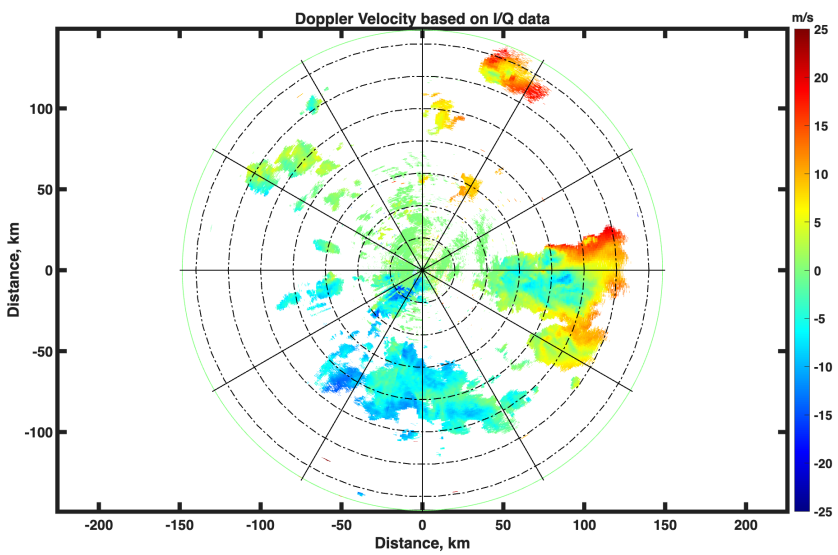
S-Pol

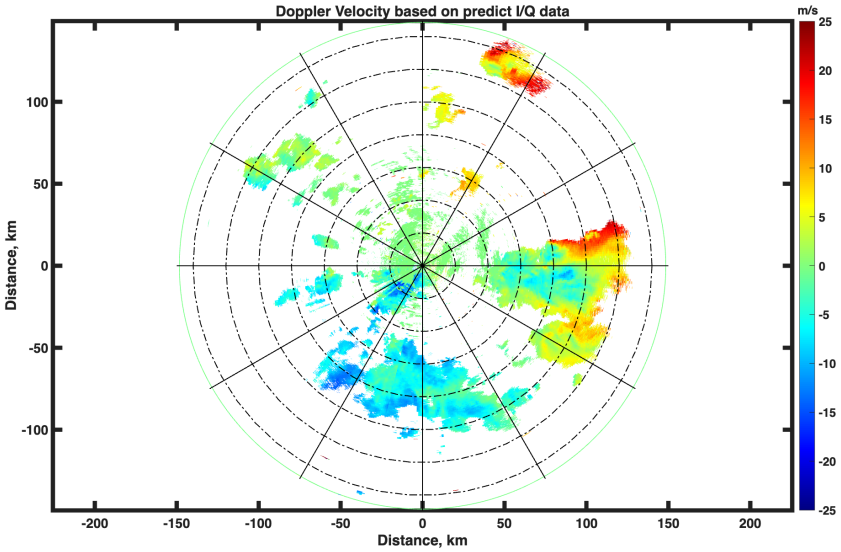




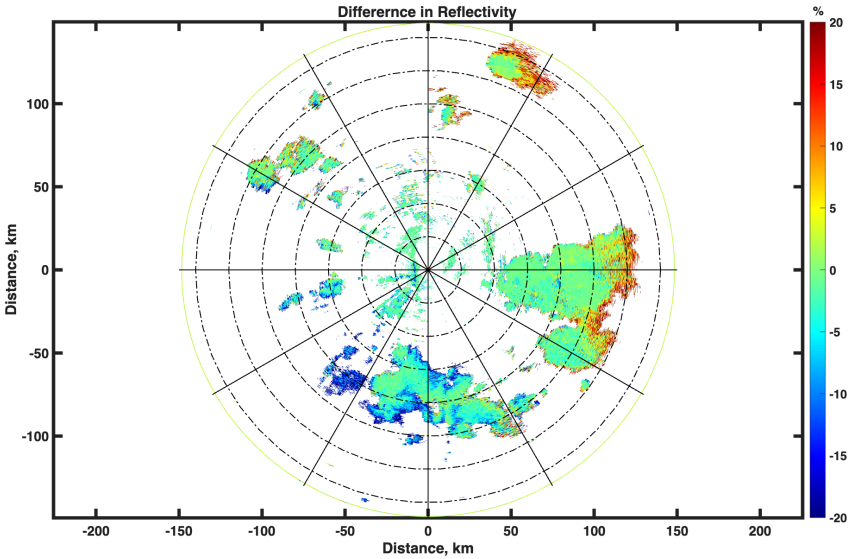
Measurement {64} vs Synthesized {16+48=64} series

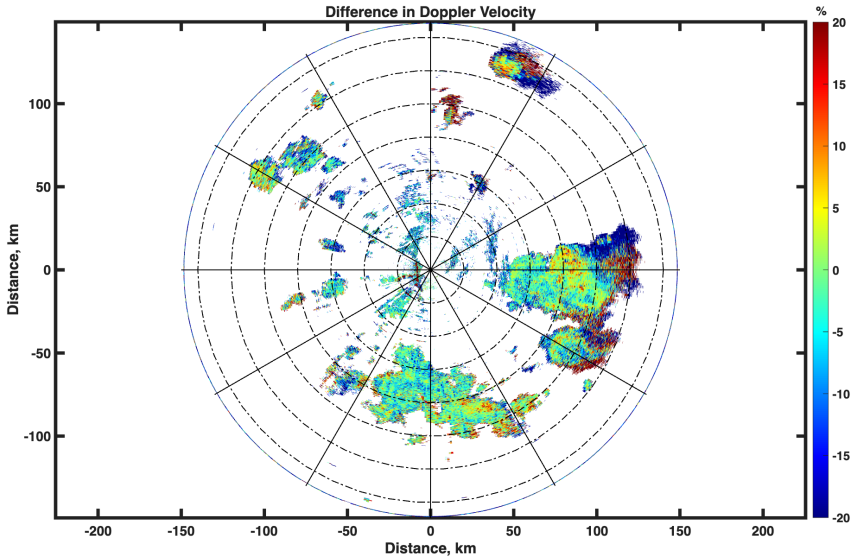
S-Pol



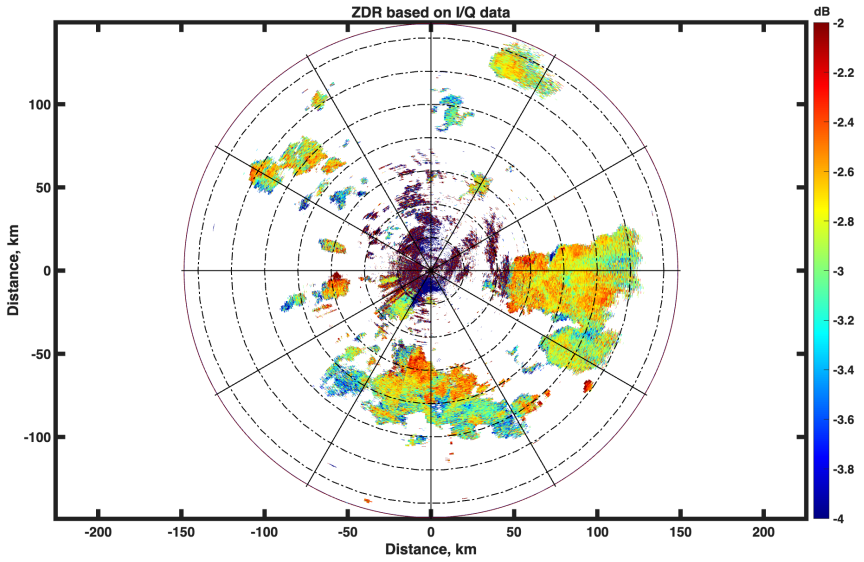


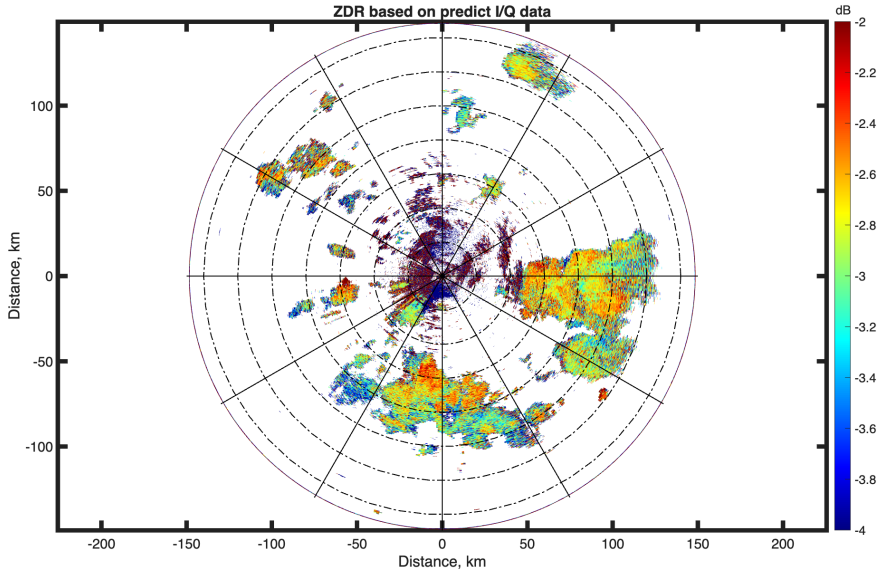
Differences in measurements





Measurement {64} vs Synthesized {16+48=64} series





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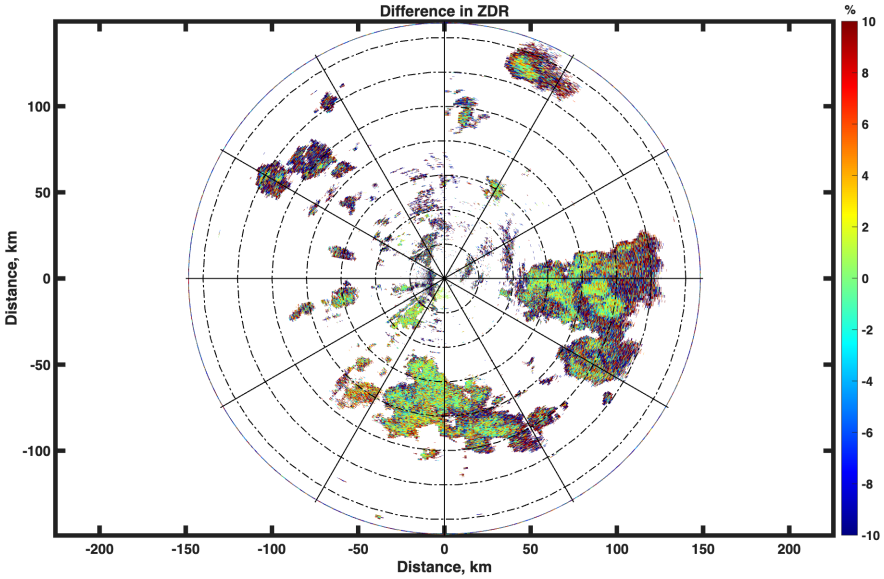
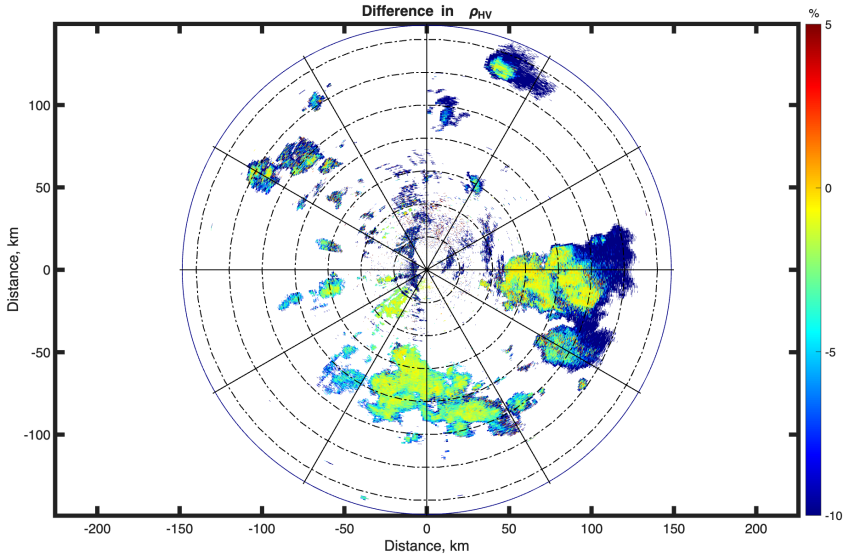
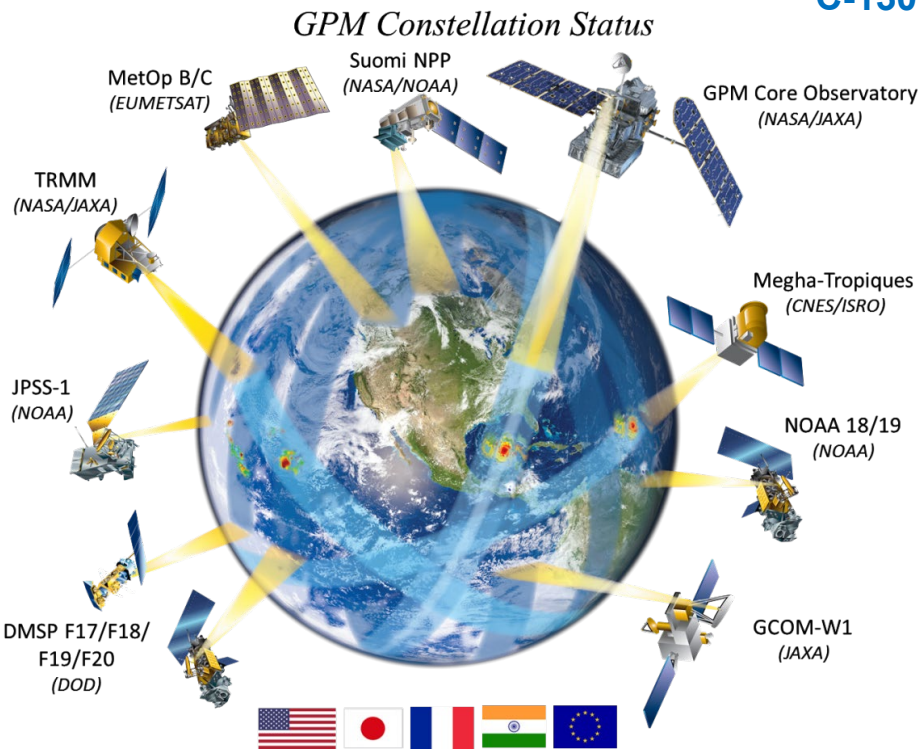


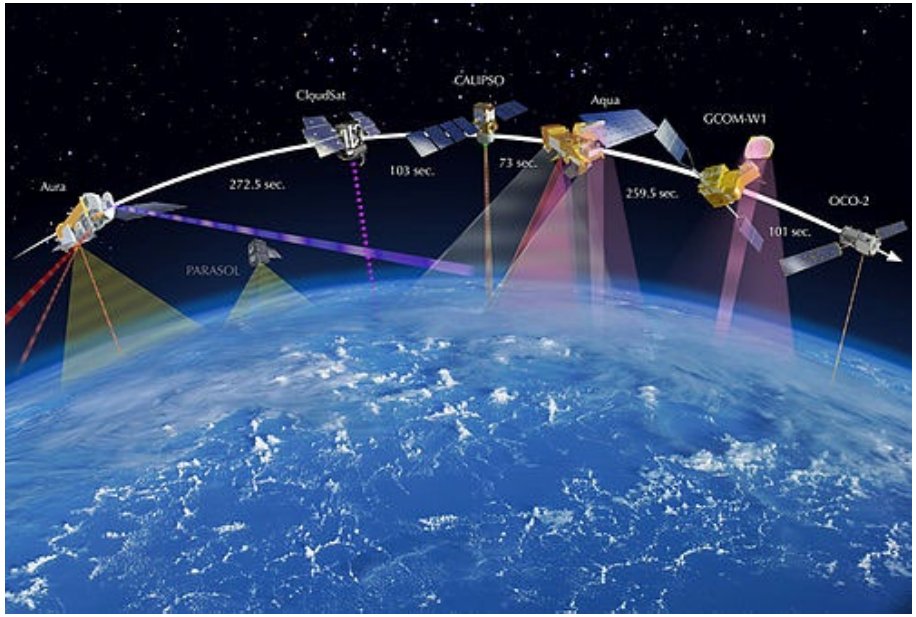


Satellite Constellations

Satellite velocity 7000 m/s

C-130 aircraft velocity 120 m/s





https://gpm.nasa.gov/education/images/gpm-constellation-satellites

https://en.wikipedia.org/wiki/Earth_observation_satellite

Summary

- AI has the potential to predict radar signals using a sub -set of measurements.
- The proposed radar signal prediction uses LSTM neural network.
- Application to radar measurements show promising results.
- Possibility of improving spatial or temporal resolution of radars and wind profilers by a factor of four.
- The signal prediction technique is applicable to instruments on ground, airborne and spaceborne platforms.