Radars detect most severe weather **threats,** but **see little of their cause,**
limiting radar-based NWP while making threat nowcasting easy.

Radar cannot do it alone:
Fundamental limits of covariance-based DA at storm scales

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The three-minute story

Fundamentally, **radars constrain** some precipitation features and **one** (v_{radial}) **of seven** ($u, v, w, P, T, e, q_{cloud}$) dynamical and thermodynamic **properties of relevance** to storms.

To fill the missing info, most **DA approaches rely on** the **covariance between errors.** But experience shows that it does not help much at convective scales. **Is it only us having these difficulties?**

We studied the analyses resulting from two state-of-the-art DA systems: the one used for the NSSL Spring Forecast Experiment, and the Japanese cycled assimilation of phased-array radars every 30 s.

Results: Ensemble spread of (thermo-)dynamic fields at storm scale exceeds ±70%, **limiting predictability**

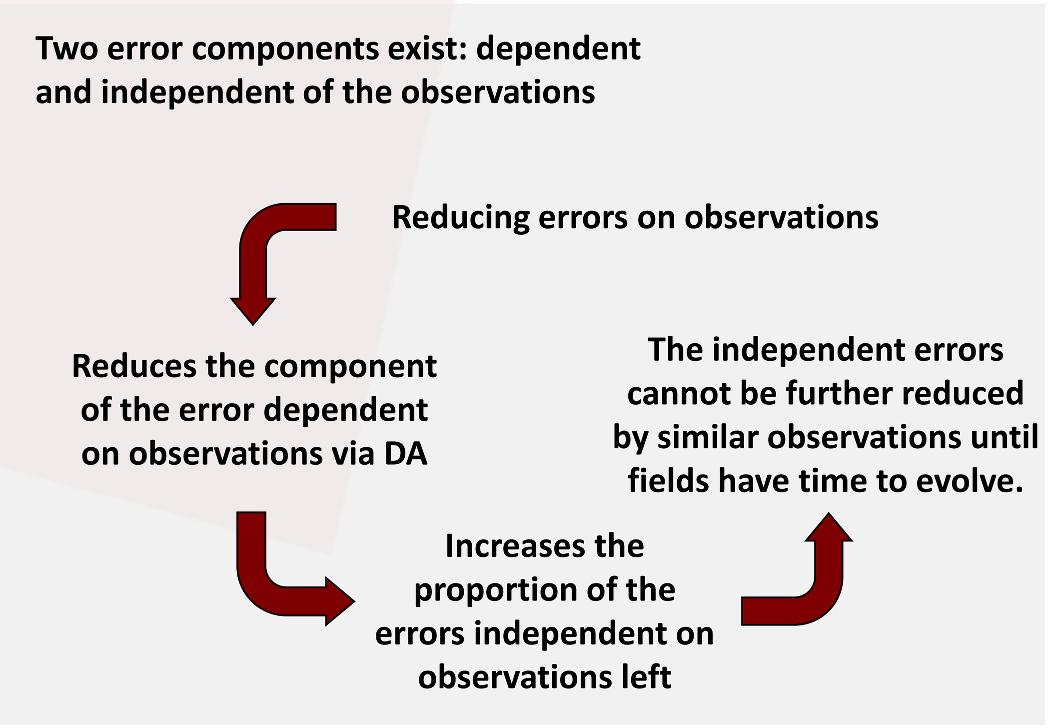
Why is this the case?

- Strong relationships between observations and model thermodynamics are needed. But convective **storms evolve too chaotically** for useful linear error relationships to arise;

→ **Error correlations are weak**, limiting radars' ability to correct unobserved properties;

→ Considerable **uncertainty remains** in key storm fields.

- Plus, every time **error covariances** are used by a DA machine, they **are "consumed"**, reducing their strength and their future usefulness at correcting remaining errors



We have **tried several new approaches** to improve radar data DA in order to fight this limitation, including:

- Multi-scale DA
- Grafting/Bogussing storms
- Assimilating trends / tendencies
- Assimilating future rainfall
- Momentum nudging

However, gains remain marginal as **storm dynamics remains misrepresented**.

Scan QR code for details

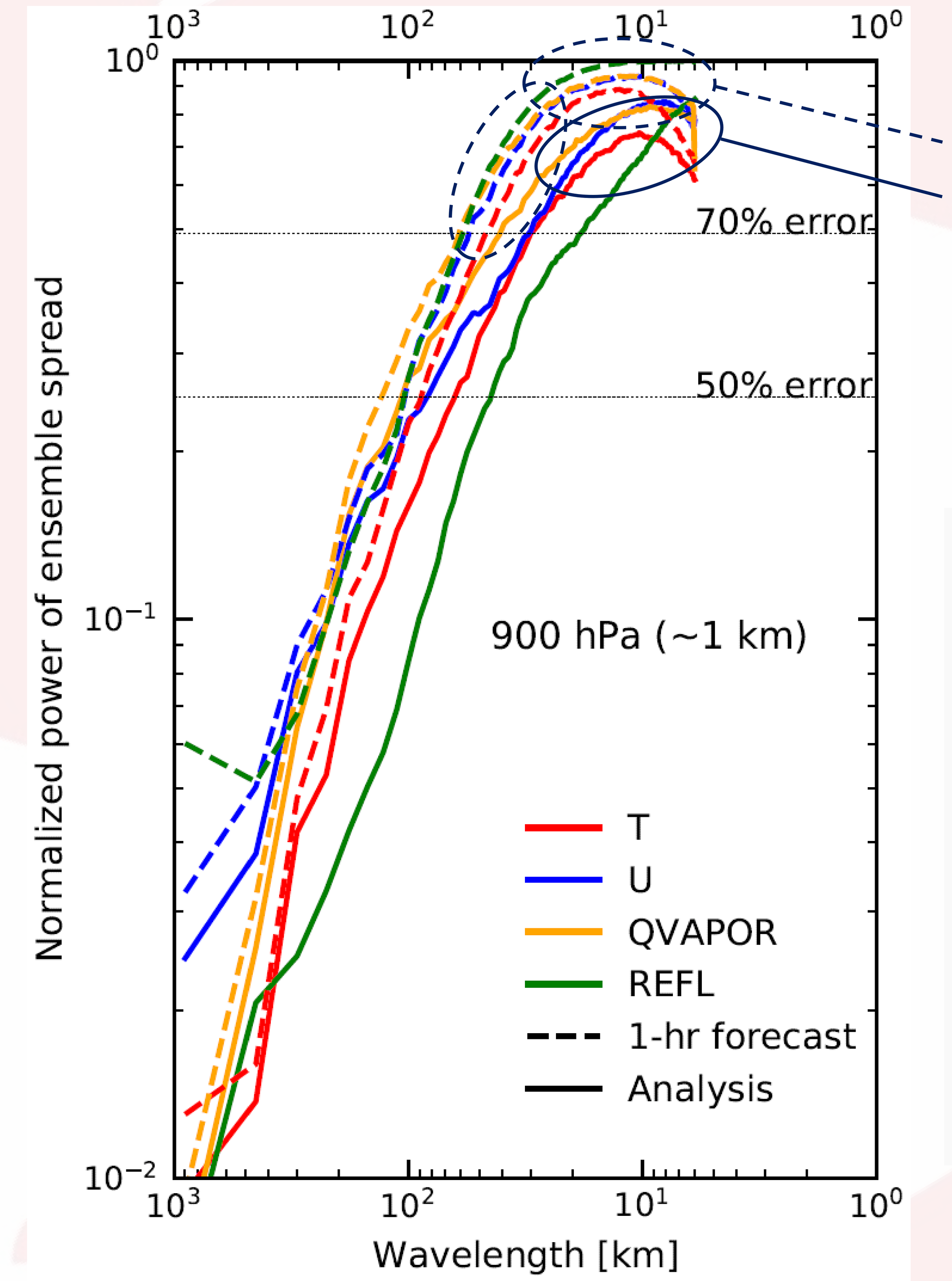
Sobering conclusions:

1) **Radar-dominated DA struggles** at constraining supporting fields needed by NWP;
2) However, **radars detecting most threats** (heavy rain, hail, strong winds…), rule-based **nowcasting** (imposed or learned) can more easily **take advantage of time continuity** and clear **pattern-based associations** (e.g., weak echo regions, kidney signatures, VIL, …).

→ This **explains why** "simplistic" **rule-based nowcasting** generally **outperforms** technically-superior **physically-based NWP** in predicting **storm threats** at short lead times. This may be where the future of threat nowcasting is!

→ Unless we can find a way to constrain <u>many</u> more of $u, v, w, P, T, e, q_{cloud}$ <u>at storm scales</u> observationally or otherwise, this will remain so for a long time: **Radar-dominated DA cannot do it alone**.

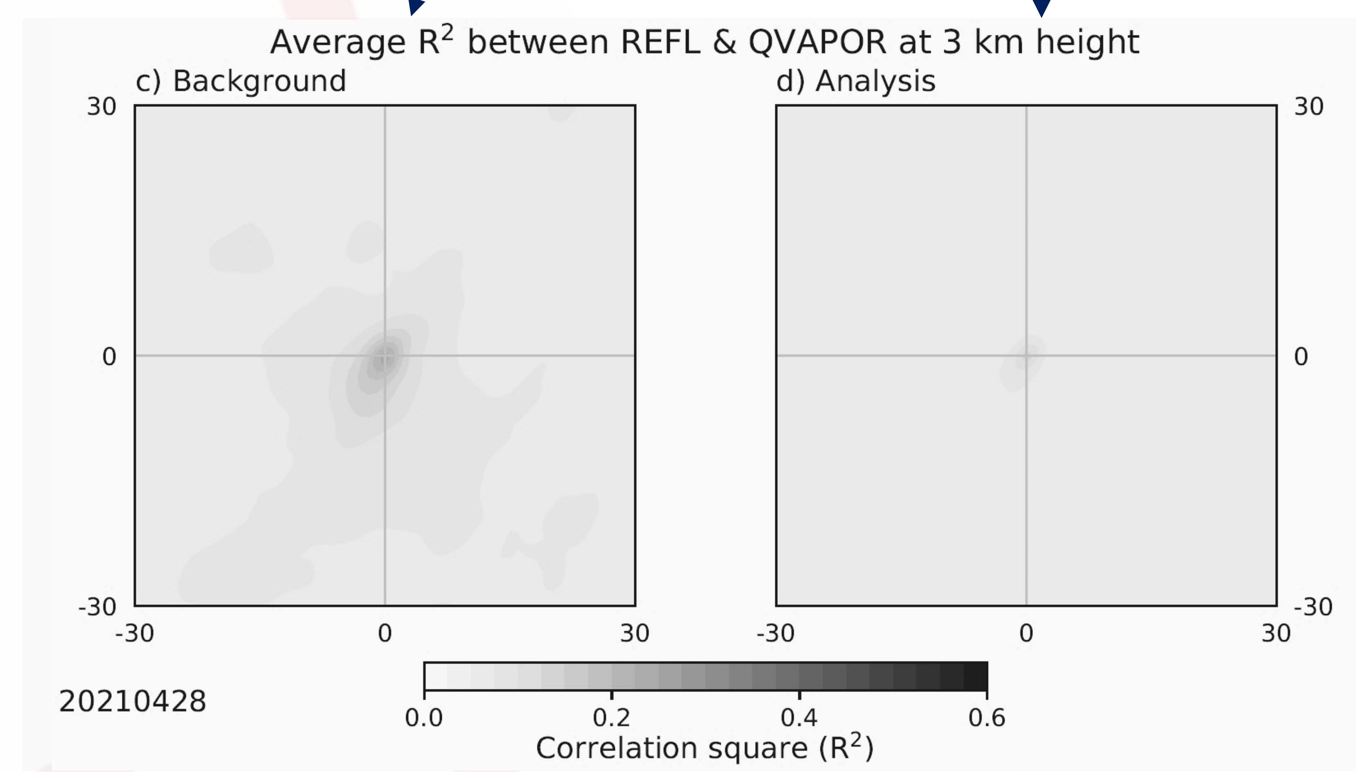
Supporting material



NSSL Spring Forecast Experiment (2020-21):

Large ensemble spreads for 1-hr forecasts below 50-km scale result from large spread at analysis time below 30-km scale.

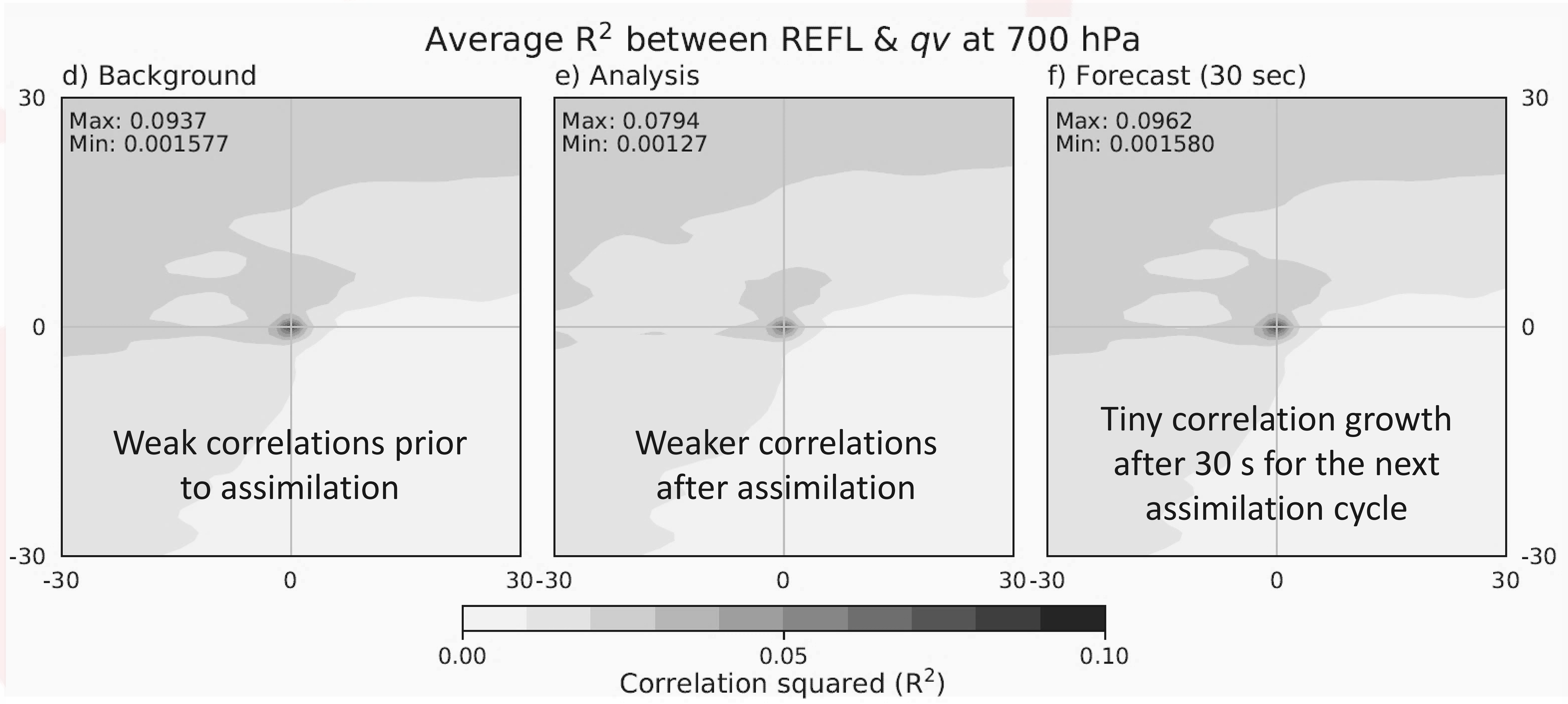
Reason #1: The correlations R between reflectivity (or radial velocity) at a grid point and other variables at or near this grid point are <u>weak prior to assimilation</u>, and <u>even weaker after</u>.



Reason #2: Other observations are too sparse to help much.

30-s assimilation cycle of phased-array radar data (Ruiz et al. 2021):

Frequent assimilation collapses error correlations R, reducing their ability to correct unobserved fields.
Context: A <u>perfect</u> observation (ha!) reduces the error on an unobserved quantity by $1-\sqrt{1-R^2}$:
A correlation of ±0.5 leads to a 13% error reduction; a 50% error reduction requires a correlation of ±0.87.



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