Impact of Data Assimilation Variations on 1-km Forecasts of 24 May 2011 Tornadic Supercells

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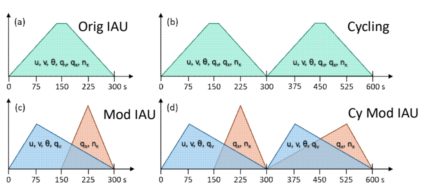
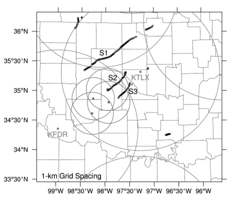
Introduction

- Data assimilation techniques are designed to produce accurate initial model fields by minimizing deviations from observations while also limiting imbalances that can lead to, for example, spurious gravity waves.
- One such technique is incremental analysis updating (IAU; Bloom et al. 1996).
- IAU acts to minimize the "shock" to the model state by gradually updating the model fields during the data assimilation window.
- Brewster et al. (2015) and Brewster and Stratman (2016) expand on the original IAU method by allowing for variable-dependent, temporally-weighted distributions of the increments of the model state variables.
- Both studies determine that introducing the majority of the hydrometeor increments after the temperature, water vapor, and wind increments results in stronger vertical velocities and preserves larger graupel and hail mixing ratios.
- Another data assimilation technique used by real-time forecast systems is a cycled analysis-forecast strategy with multiple periods of data insertion.
- Test case: 1-km forecasts of 24 May 2011 tornadic supercells, which devastated parts of Oklahoma.

Experiment Design

- 5 data assimilation techniques tested:
  - **OrigIAU** – increments added every 20 s using the original IAU technique (a)
  - **Cycling** – two 5-min original IAU windows (b)
  - **ModIAU** – increments added every 26 s using the modified IAU technique with variable-dependent increment distributions (c)
  - **CyModIAU** – two 5-min modified IAU windows (d)
  - **NoIAU** – no IAU window or cycling
- After the IAU/cycling process, simulations integrated forward for 120 min.
- Assimilated observational data using 3DVAR and complex cloud analysis:
  - NWS METAR and Oklahoma Mesonet data
  - WSR-88D radar data (KTLX, KFDR, KVNX, KICT, KDDC, KFWS, and KINX)
  - Collaborative Adaptive Sensing of the Atmosphere (CASA) IP-1 radar data (KCYR, KSAO, KWE, and KRSP; McLaughlin et al. 2009)
- Some model details:
  - Advanced Regional Prediction System (ARPS), developed at CAPS
  - 323 × 353 grid-point domain with 53 vertical levels
  - 1-km horizontal grid spacing
  - Minimum vertical grid spacing of 20 m
  - dt_{big} = 2.0 s and dt_{sml} = 0.5 s
  - 12-km NAM model output used for background fields and lateral BCs
  - Milbrandt and Yau double-moment bulk microphysics (Milbrandt and Yau 2005a,b)



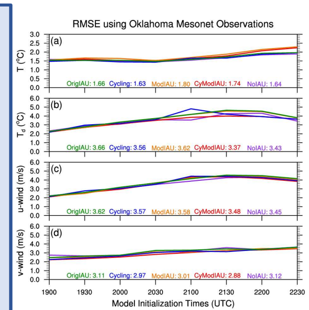


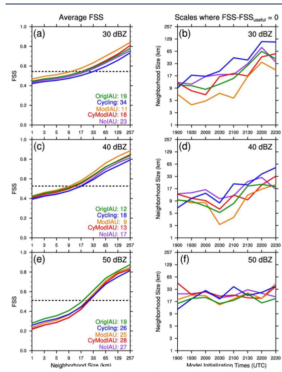
Verification Techniques

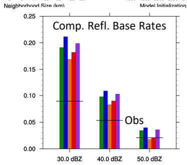
- **RMSE** computed and averaged using Oklahoma Mesonet data.
- Fractions skill score (**FSS**) computed and averaged for composite reflectivity at three thresholds using the neighborhood technique with several window sizes (i.e., scales).
- An **object-based verification** technique is used to verify simulated 0–1-km UH (0-1UH) centers with estimated tornado locations for three storms of interest by computing **same-time (ST) and any-time (AT) distance and timing errors**.
  - A search radius of 4 km is used to isolate 1–6-km (0–1-km) UH maxima that are greater than or equal to 300 $m^2 s^{-2}$ (15 $m^2 s^{-2}$) and their surrounding grid point values. A max UH value is considered a UH-center candidate if 4 out of 8 (1 out of 8) of the adjacent grid point values equals or exceeds 150 $m^2 s^{-2}$ (10 $m^2 s^{-2}$). The UH-weighted center is then computed using a radius of 3 km (2 km) extending from the grid point with the max UH value. The 0–1-km UH-weighted centers are filtered by requiring a 1–6-km UH-weighted center to concurrently exist within 5 km.

RMSE Results

- Relative to the **OrigIAU** runs, the modified IAU technique yields larger temperature errors, while cycling tends to produce slightly smaller temperature errors.
- Cycling and modified IAU techniques contribute to a small reduction in dewpoint temperature errors. However, the **NoIAU** runs had smaller errors than the other runs, except for the **CyModIAU** runs.
- Even though the **NoIAU** runs generally have the smallest u-wind errors, the cycling and modified IAU techniques both contribute to reduced u- and v-wind errors relative to the **OrigIAU** runs.





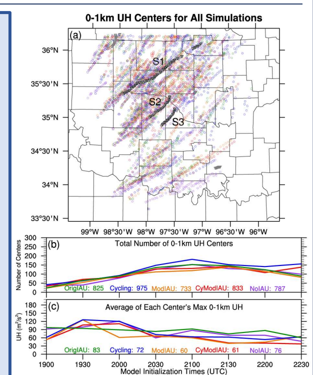


FSS Results

- At 30 dBZ, the **ModIAU** runs exhibit the best skill at all scales, while the **Cycling** runs exhibit the worst skill at all scales. This finding is consistent for most model initialization times.
- At 40 dBZ, the findings are mostly the same as at the 30-dBZ threshold, but the differences among the runs are smaller. The **ModIAU** runs substantially outperform the other runs at the 2030 and 2100 UTC model initialization times.
- At 50 dBZ, the **OrigIAU** runs exhibit the best skill at all scales, while the **CyModIAU** (**Cycling**) runs perform the worst at the smaller (larger) scales. The **OrigIAU** and **ModIAU** runs perform similarly for most model initialization times.
- Some of the successes and failures can be attributed to the amount of overforecasting the areal coverages of reflectivity.
- For example, the **ModIAU** runs overforecasted the least at the 30- and 40-dBZ thresholds, aiding in better skill scores.
- Conversely, the **Cycling** runs overforecasted the most at all thresholds, contributing to mostly poor skill scores, esp. at 30 and 40 dBZ.

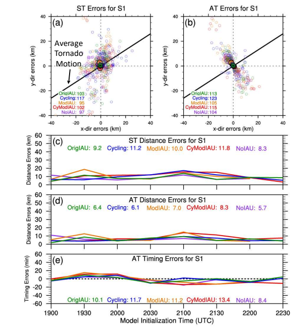
0-1UH Centers Results

- High density of 0-1UH centers near S1's tornado locations, especially for the first two tornadoes.
- A dense coverage of 0-1UH centers generally exists along and north of S2's tornado locations.
- The number of 0-1UH centers near S3's tornado locations is substantially lacking.
- Cycling leads to a larger number of 0-1UH centers for the **Cycling** and **CyModIAU** runs.
- Conversely, the modified IAU technique results in a reduction in the number of 0-1UH centers.
- Even though a goal of the modified IAU technique is to better retain updrafts, the **ModIAU** and **CyModIAU** runs generally yield weaker 0-1UH centers as compared to the other runs.



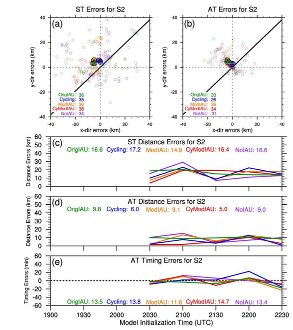
Object Based Verification: Storm 1

- Excellent forecast by all. All of the runs depict *same-time* distance errors less than 12 km and *any-time* distance and timing errors less than 9 km and 14 min, respectively.
- The **Cycling** runs have the most number of 0-1UH centers near S1, while the **ModIAU** runs have the fewest.
- All of the runs have a fairly even north-south distribution of *any-time* 0-1UH centers, except for the **ModIAU** runs, which tend to be a little too far north.
- The **NoIAU** runs yield the smallest *same-time* and *any-time* distance and timing errors but by very small margins.



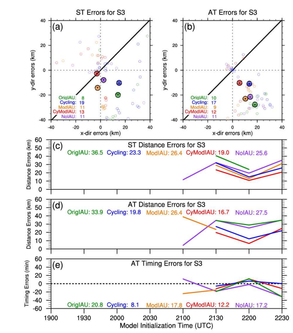
Object Based Verification: Storm 2

- Good results for all, with *any-time* distance errors mostly less than 10 km and **CyModIAU** runs performing the best.
- The **ModIAU** runs yield the smallest *any-time* timing errors, but all of the runs mostly have errors less than 15 min.
- All of the runs produce a similar number of *same-time* 0-1UH centers near S2 with a tendency for the centers to be too far north.
- The *any-time* 0-1UH centers also depict this northward-bias. The **Cycling** runs result in the fewest centers.
- On average, the **ModIAU** runs have the smallest *same-time* distance errors.



Object Based Verification: Storm 3

- Complex storm interactions yield less success in forecasting Storm 3. The **CyModIAU** runs mostly yield the smallest *same-time* and *any-time* distance errors, though produce a smaller number of 0-1 UH centers than **Cycling**.
- The **Cycling** runs result in the smallest *any-time* timing errors with errors less than 10 min.
- All of the runs tend to produce *any-time* 0-1UH centers too far south. However, this result is due to the simulations picking up a non-tornadic supercell that existed ~30 km to the south of S3 in reality.
- Note, several runs fail to predict anything for S3 when tornadoes are occurring.



Conclusions and Future Work

- The choice of data assimilation technique has some impact to 1-km forecasts of surface variables, composite reflectivity, and location and timing of low-level circulations.
- The **Cycling**, **ModIAU**, and **CyModIAU** runs all show signs of improving forecasts of convection-related variables, especially low-level circulations.
- In many of the RMSE and object-based metrics, the **NoIAU** runs performed better than the **OrigIAU** runs, but differences among methods are very small.
- Additional work needs to be done in fully understanding these results by looking closer at adjustments happening during and soon after the assimilation windows.

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