Satellite Data Assimilation within a Prototype Warn-on-Forecast System

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Warn-on-Forecast Project

- **Provide accurate, short range (0-3 h) probabilistic forecasts of severe convective storms is a key component of the Warn-on-Forecast project**
- **A regional, convection allowing ensemble model is essential to achieving this goal**
  - Requires hi-resolution observations of convection and the near storm environment
  - Robust methods to assimilate high resolution remote sensing observations from multiple platforms and sensors
- **Model-based probabilistic forecasts can aid in severe weather warning guidance and leading to significantly improved lead times**
- **Move from *observation based* warnings to a *mix of observations and probabilistic forecasts***

Satellite Data Assimilation

- **GOES-Imager observations are suitable for storm-scale DA**
  - High temporal and spatial resolution, low data latency
  - Supplements radar observations from WSR-88D Doppler radars
  - WSR-88D not as sensitive to non-precipitating clouds
    - Low-level stratus, cirrus outflow from storms
    - Developing convection during CI
  - *Clear-air reflectivity* is not the same as *cloud-free* radiances / retrievals
- **Future GOES-R data will provide additional and higher resolution cloud products**
  - Launches in November 2016
  - First useable data available Spring 2017
- **Important consideration: Assimilating satellite observations must be able to show skill in high impact weather forecasting compared to only assimilating radar data**

NSSL Experimental Warn-on-Forecast System for ensembles (NEWS-e)

- **WRF-ARW: v3.6.1**
  - Convection permitting horizontal resolution: 3 km, 51 vertical levels
- **36-member ensemble with physics diversity**
  - Cloud microphysics: Thompson
  - PBL: YSU, MYJ, MYNN2
  - Radiation (SW/LW): Dudhia/RRTM, RRTMG/RRTMG
- **RAP Land Surface Model, 9 soil levels**
- **IC/BCs** use members of an experimental HRRR ensemble generated by GSD run during the spring 2016.
- **Data assimilation (DA) procedure:**
  - DART parallel ensemble adjustment Kalman filter
  - Prior adaptive inflation applied to state
  - Gaspari and Cohn spatial vertical and horizontal localizations
  - Localization radius is a function of observation type

http://www.nssl.noaa.gov/projects/wof/news-e/

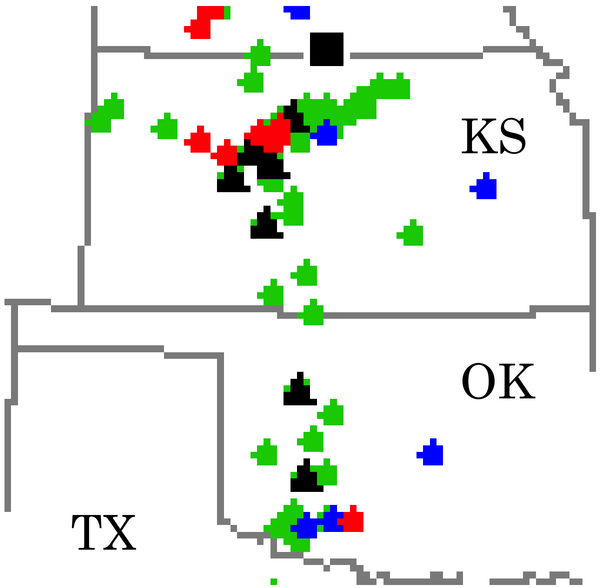
Storm-scale Data Assimilation

- **Assimilation of observations begins at 1800 UTC for each day**
  - Continues until 0300 UTC the next day
- **15 minute assimilation cycle with observations partitioned into ±2.5 minute windows**
- **Assimilated observations:**
  - WSR-88D Reflectivity from the MRMS product and Level 2 Doppler radial velocity from all radars in storm-scale domain
  - Liquid and Ice water path (LWP, IWP) retrievals from GOES Imager retrievals
  - All radar and satellite observations objectively analyzed to 6 km resolution (2 delta-X model grid)
  - Oklahoma mesonet observations (grid permitting)
- **Additive noise applied to prior state (T, T_D, u, v) where reflectivity observations indicate strong precipitation**
- **Two sets of experiments are conducted**
  - RADONLY: Assimilates only radar and mesonet observations
  - RADSAT: Assimilates radar, mesonet, and satellite observations

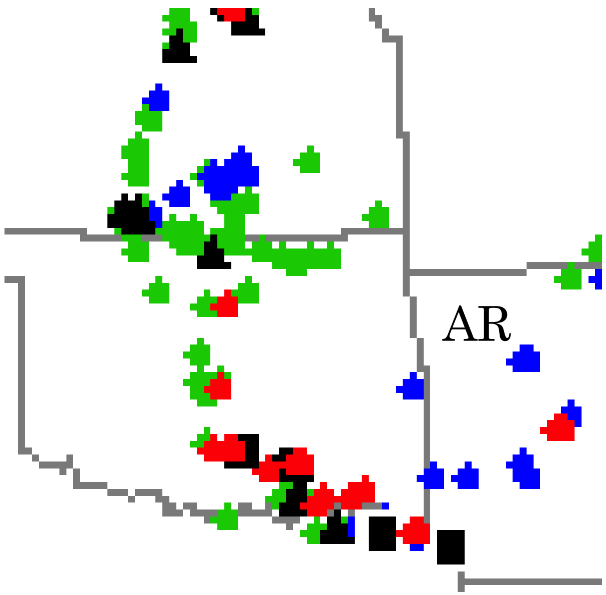
Example Cases: 8, 9 May 2016

Severe Weather Reports

8 May



9 May

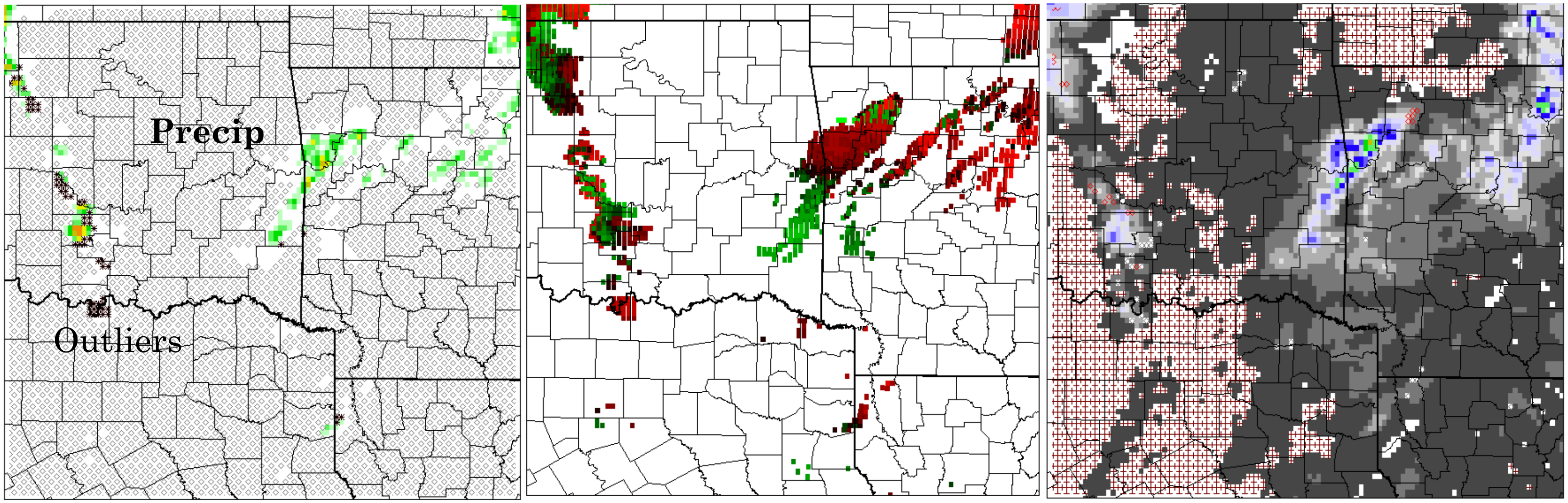


- Multiple severe storms in western OK and KS.
- OK storms are mostly hail threats, both left and right movers persist

- Eastward shift of severe convection compared to 8 May
- Several tornados in central and southeast OK
  - One anti-cyclonic tornado

Example Observations

3 km AGL Reflectivity | Radial Velocity | Liquid Water/Ice Path

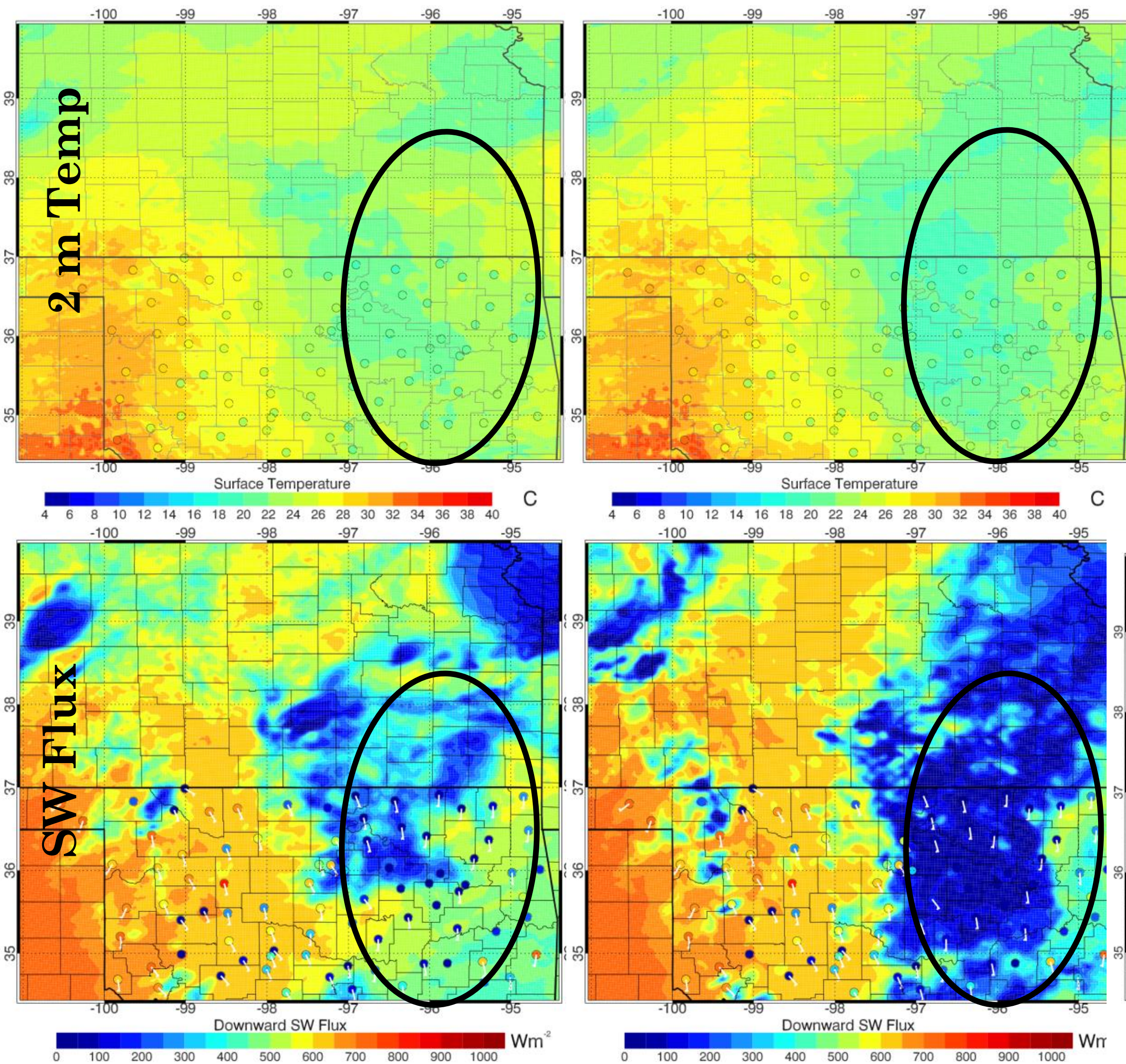


Clear-air: 0 dBZ | Clear sky (CWP=0) | Clouds

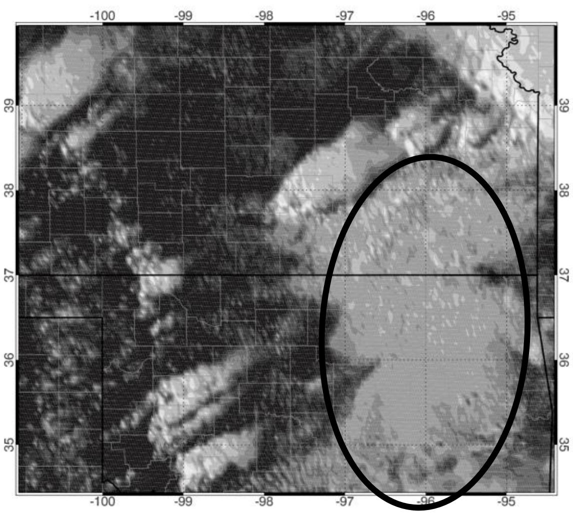
- Radar reflectivity, radial velocity, and satellite LWP and IWP assimilated at a single cycle at 2100 UTC 9 May
- Note the large area of clouds indicated by the satellite observations where no precipitation is detected from the radar
- Total number of observations > 50000

8 May Surface Analysis: 2200 UTC

RADONLY **RADSAT**



- Assimilating CWP increases cloud cover in the model analysis
- Surface temperature lowered
- Better matches observations

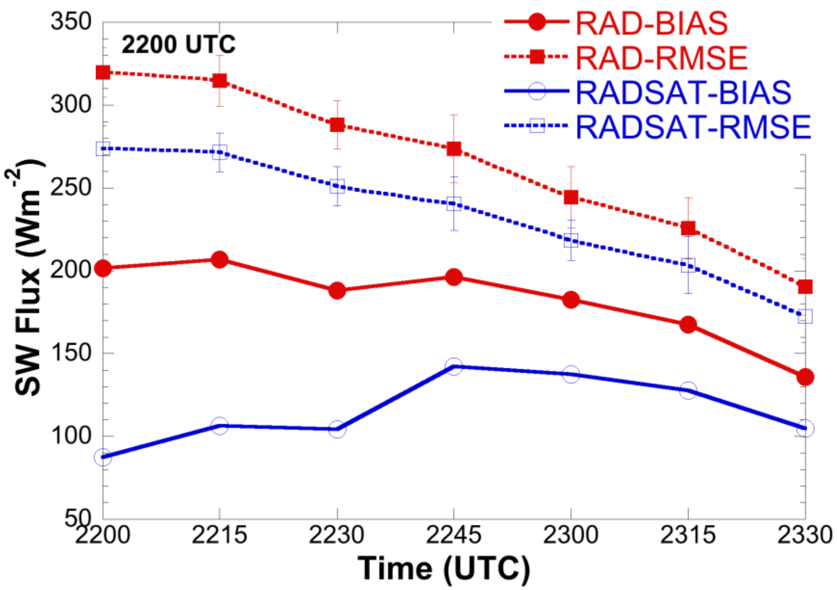


GOES-13 Visible

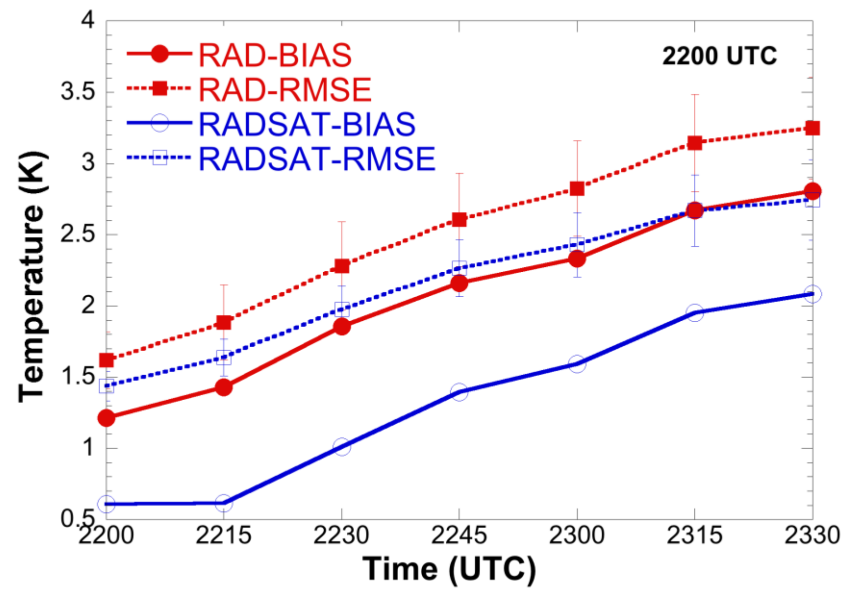
8 May Forecast Statistics: 2200 UTC

90-minute forecast verified against OK mesonet observations

Downward SW Flux



2-m Temperature

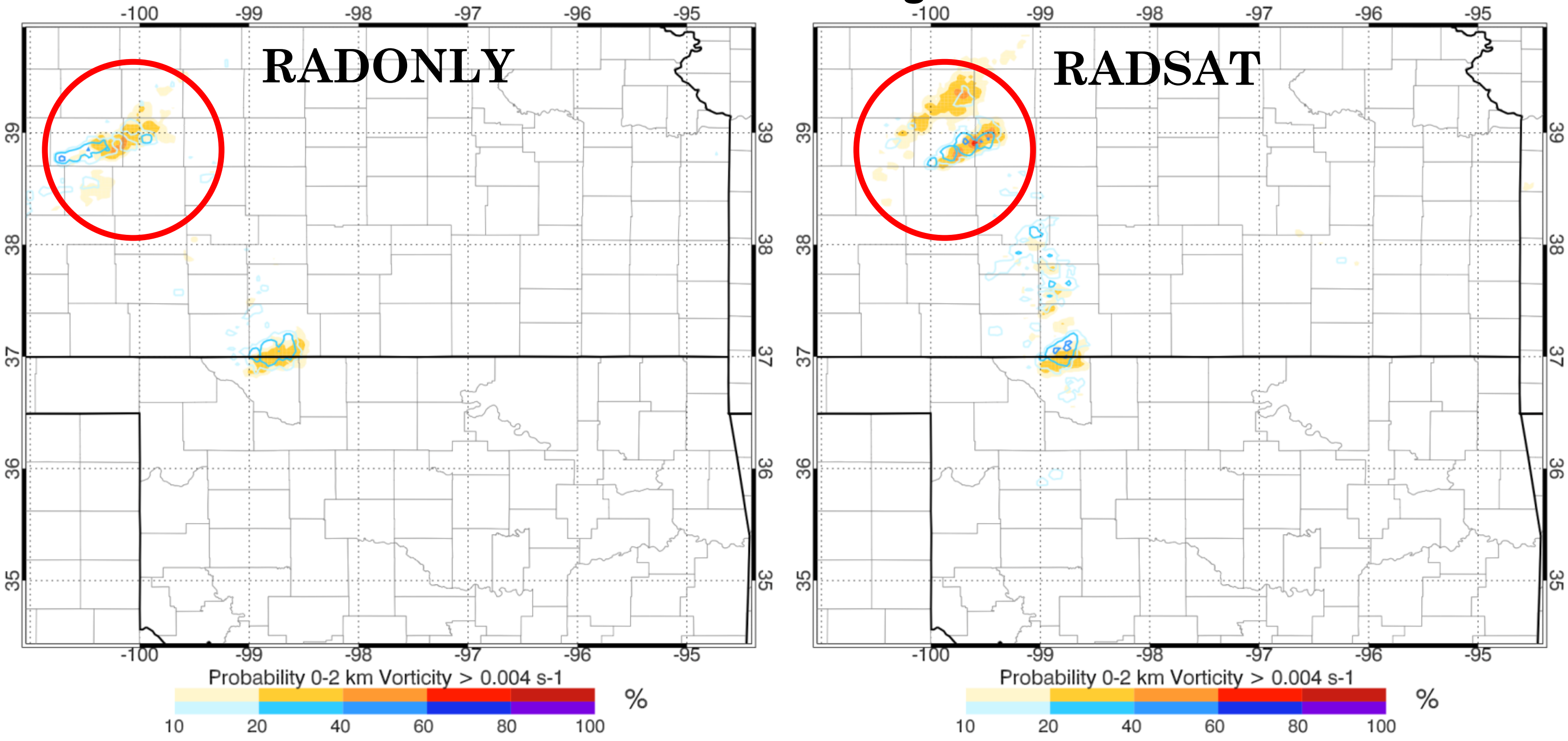


Bias (Model – Ob) and RMSE calculated for each ensemble member and mean values plotted. Error bars for RMSE represent the standard deviation of RMSE over all ensemble members.

- Both experiments have a high (warm) bias in solar radiation and surface temperature.
- RADSAT substantially reduces this bias at the analysis time with the impact persisting throughout the forecast period

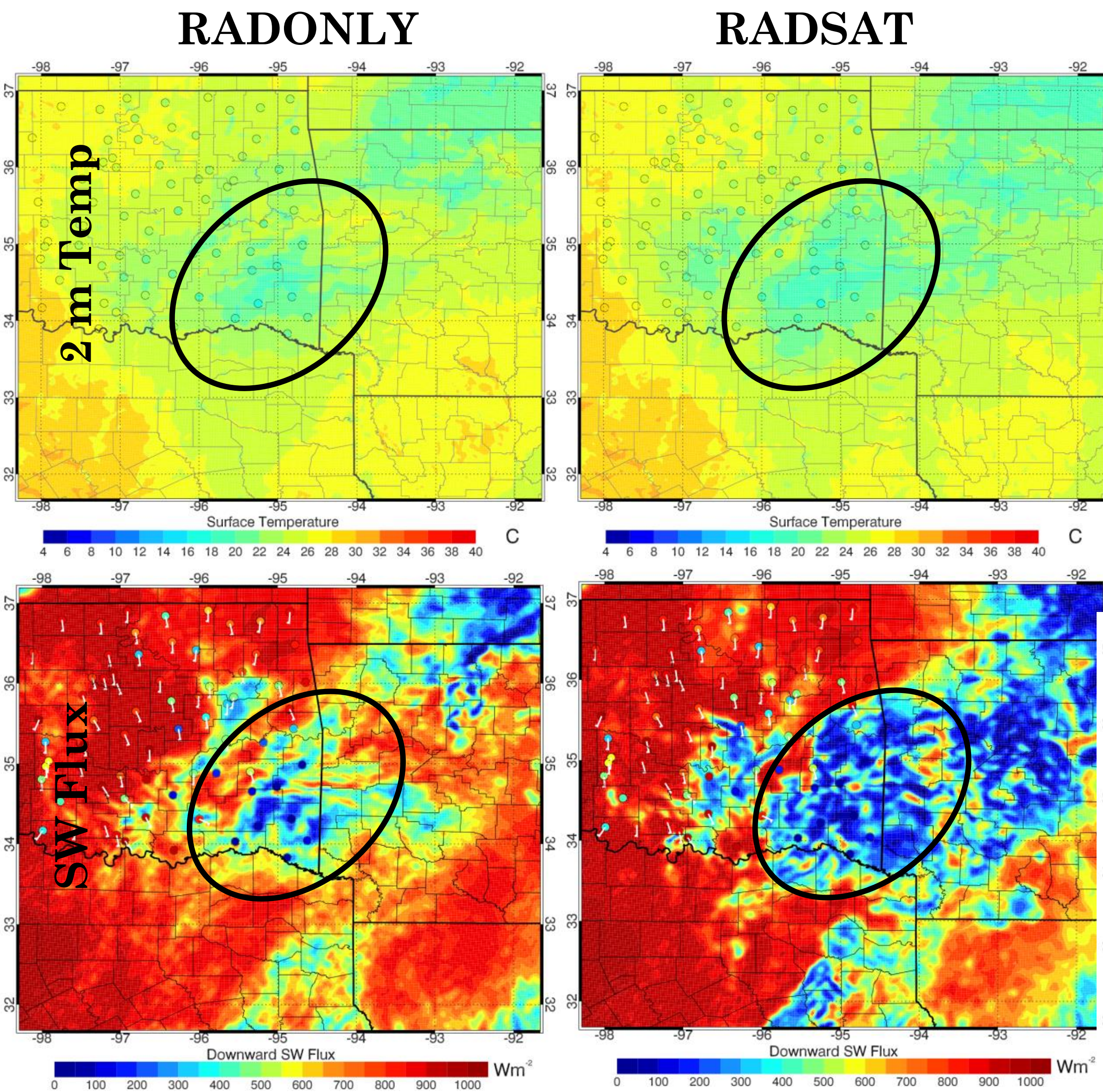
8 May Low-level Vorticity Forecasts

Probability of 0-2 km vertical vorticity > 0.004 s^{-1}
90 minute forecast starting at 2200 UTC

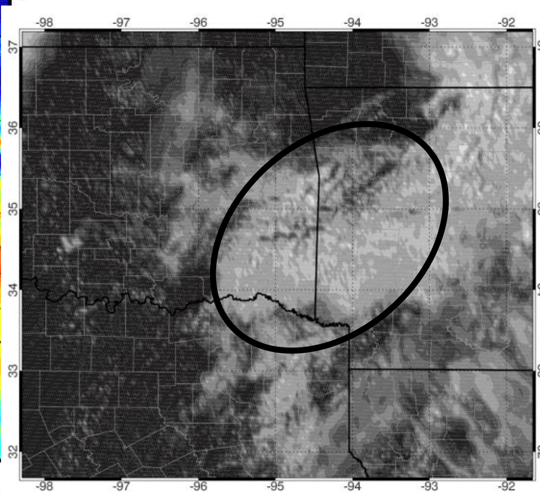


- RADSAT generates higher vorticity probability swathes in northern KS associated with the multiple tornado reports in this region

9 May Surface Analysis: 2000 UTC



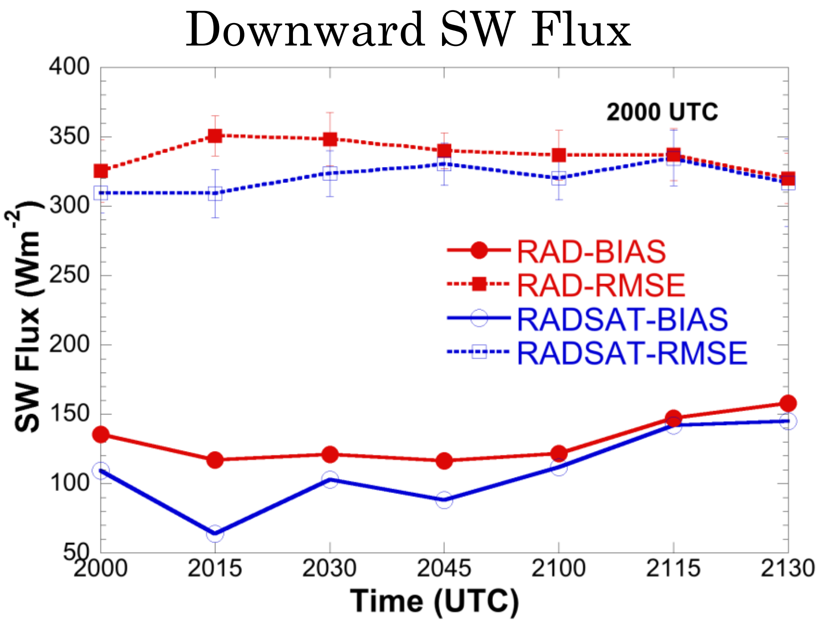
- Assimilating CWP again increases cloud cover and reduces surface temperature compared to RADONLY

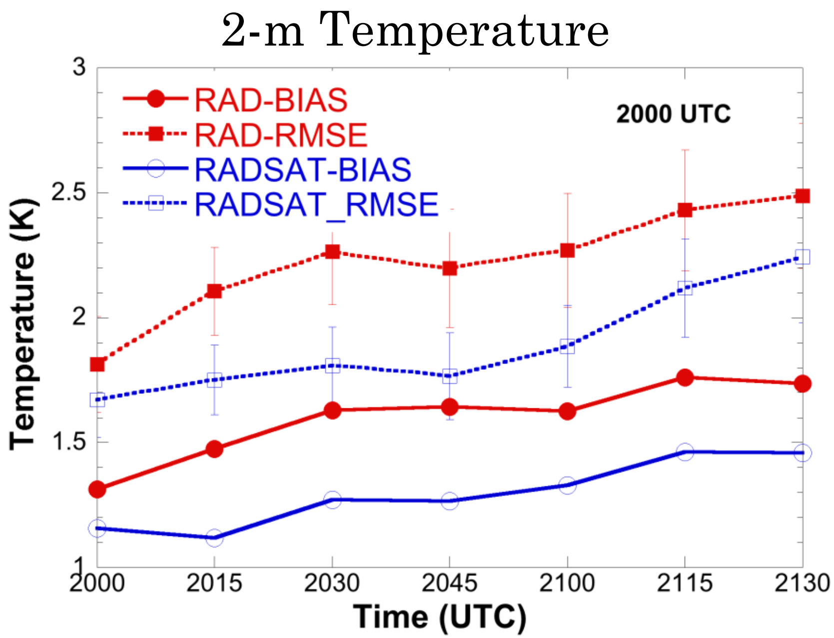


GOES-13 Visible

9 May Forecast Statistics: 2000 UTC

90-minute forecasts verified against OK mesonet observations



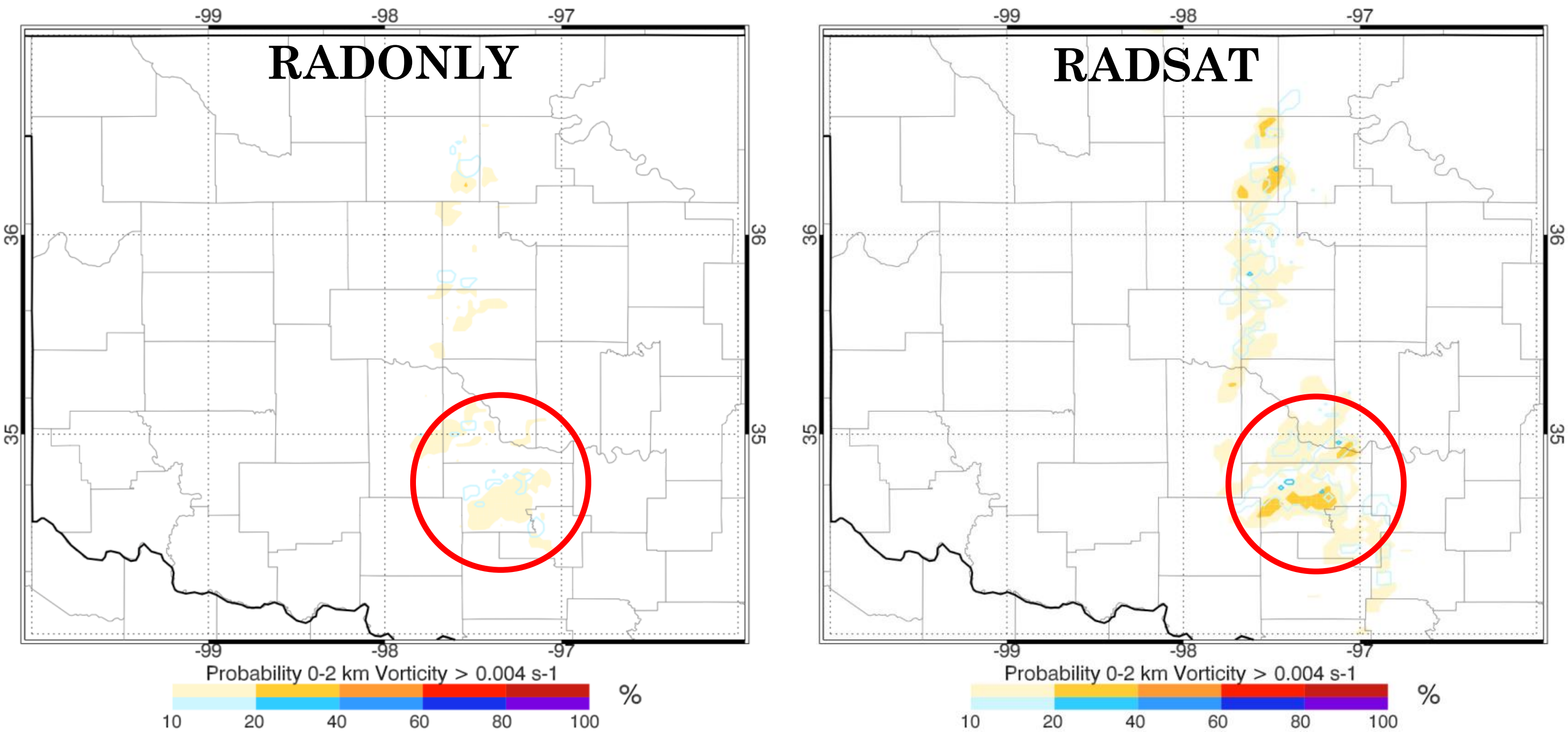


Bias (Model – Ob) and RMSE calculated for each ensemble member and mean values plotted. Error bars for RMSE represent the standard deviation of RMSE over all ensemble members.

- RADSAT lowers bias and errors with respect to RADONLY experiments, but the magnitude of the difference is not as great as in the 8 May case.
- Note that differences in Arkansas are not included in theses statistics due to lack of observations

9 May Low-level Vorticity Forecasts

Probability of 0-2 km vertical vorticity > 0.004 s^{-1}
90 minute forecast starting at 2000 UTC



- RADSAT again generates somewhat higher vorticity probabilities than RADONLY associated with southern Oklahoma tornadoes

Summary

- **The Good:**
  - Assimilating CWP improved surface thermodynamic conditions for several experiments
  - This improvement generally corresponded to better forecasts of low-level vorticity
- **The Bad:**
  - Using non-thinned radar and satellite observations, some evidence of storm cores weakening
  - Assimilating satellite observations also introduces noise in the dynamical fields in some cases.
- **Fixing the Bad:**
  - Further analyze model configuration, specifically radar and satellite forward operators
  - Determine the optimal combination of satellite and radar data to assimilate.
  - Dumping everything into the model without considering the relationship between radar and satellite observations is certainty not optimal – work on adaptive data thinning techniques

Future Considerations

- **Challenges:**
  - Assimilating combined radar and satellite observation data remains challenging
  - Further research in forward operators, data thinning techniques and new observation types (radiances, polarimetric radar) will be required going forward
  - In addition to clouds, rapid updates of aerosol concentrations will also have to be considered
- **Plans:**
  - Transition ensemble data assimilation system to GSI-EnKF
  - Take advantage of all the satellite QC options
  - Integrate GOES-R water vapor radiances and atmospheric motion vector into data assimilation system.
- **Perform experiments for other event types such as land-falling tropical cyclones and winter weather**

Questions

- If you are interesting in participating in this and similar projects, please contact me: Thomas.Jones@noaa.gov
- CIMMS post-doc jobs available: http://cimms.ou.edu/index.php/careers/