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Evaluating the impact of assimilating cloud-affected infrared radiances from GOES-16 ABI on the forecast of a severe storm in the Midwest U.S.

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Background on funding/motivation

Prediction and Assimilation for Clouds (PANDA-C); project funded by the U.S. Air Force, led by Chris Snyder and Jake Liu

Goal: global rapid-update cloud forecasting (CF) system

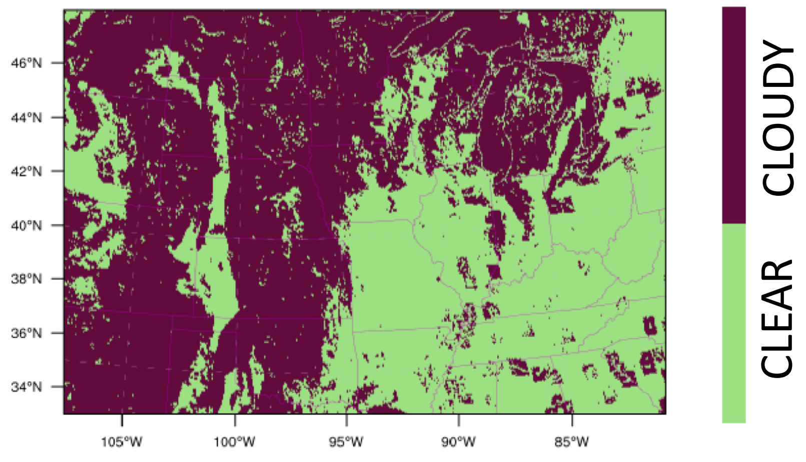
Multiple top-level aspects:

1. Exploratory research to determine key factors to producing credible/effective CF with regional NWP
2. Develop objective cloud verification methods for 4D location and phase
3. Incorporate developed tools/techniques into global rapid-update system (currently targeted at JCSDA's JEDI framework)

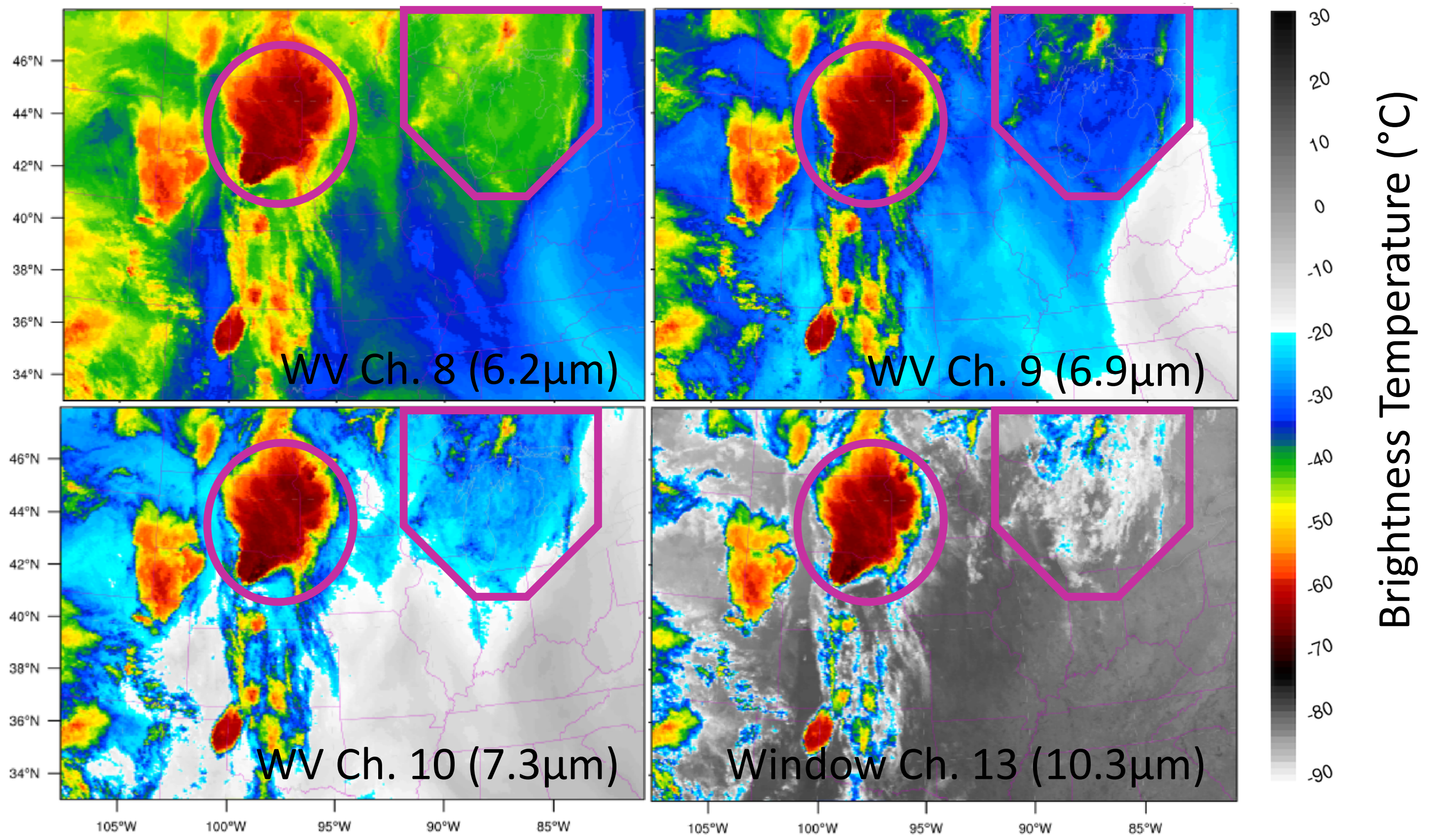
GOES-ABI channel selection for DA experiments

20180501_04Z

WRFDA ABI Cloud Mask



Uses IR-only portions of ABI Cloud Mask with some modifications from Zhuge and Zou, 2016

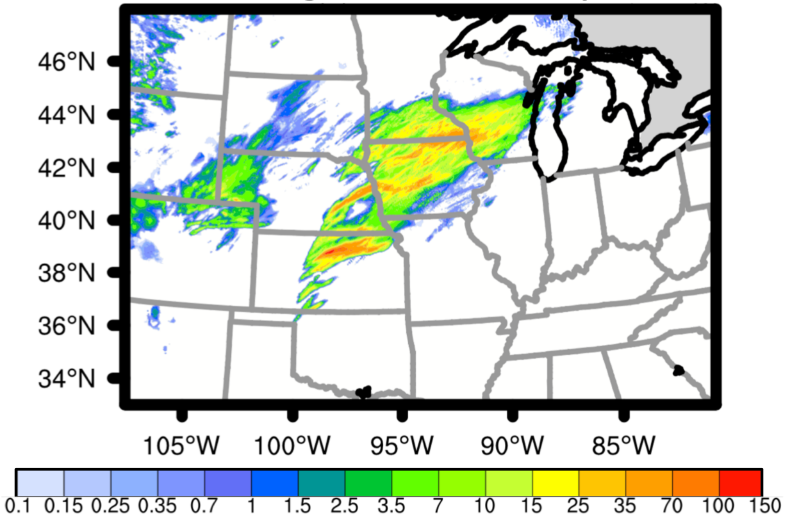


WV channels sensitive to the WRF moisture prognostic variable in clear scenes and above low clouds – added value in forecasts [assimilation+verification]

Window channels sensitive to surface emissivity and temperature – not included as WRFDA control variables and prone to error [cloud verification]

01 May 2018 Midwest Severe Storm

NCEP Stage IV Precipitation

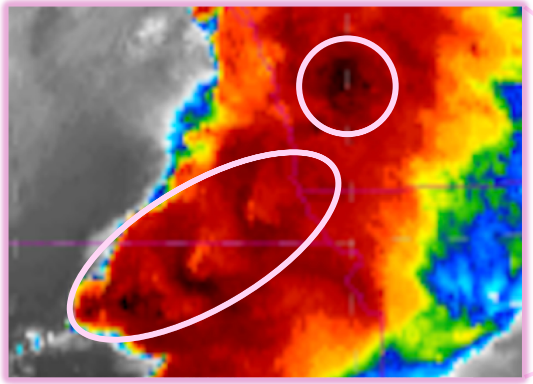


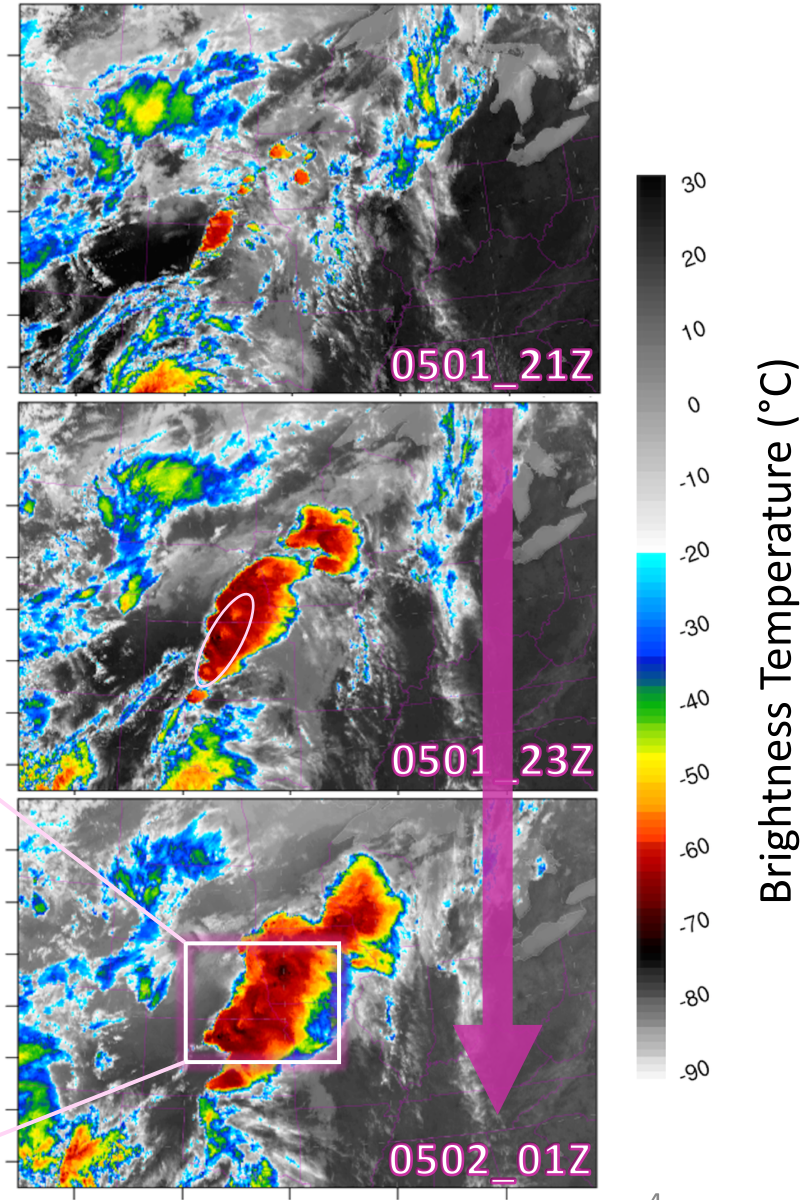
Accumulated Rainfall (mm)
20180501_18Z to 20180502_05Z

Observable from ABI:

- Quickly developing storm system
- Overshooting updrafts
- Cold/Warm Thermal Couplets
- Enhanced-V Structures

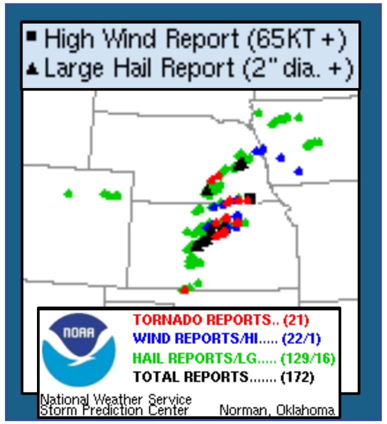
Window IR (ch. 13)





NOAA SPC Storm Reports

https://www.spc.noaa.gov/exper/archive/event.php?date=20180501

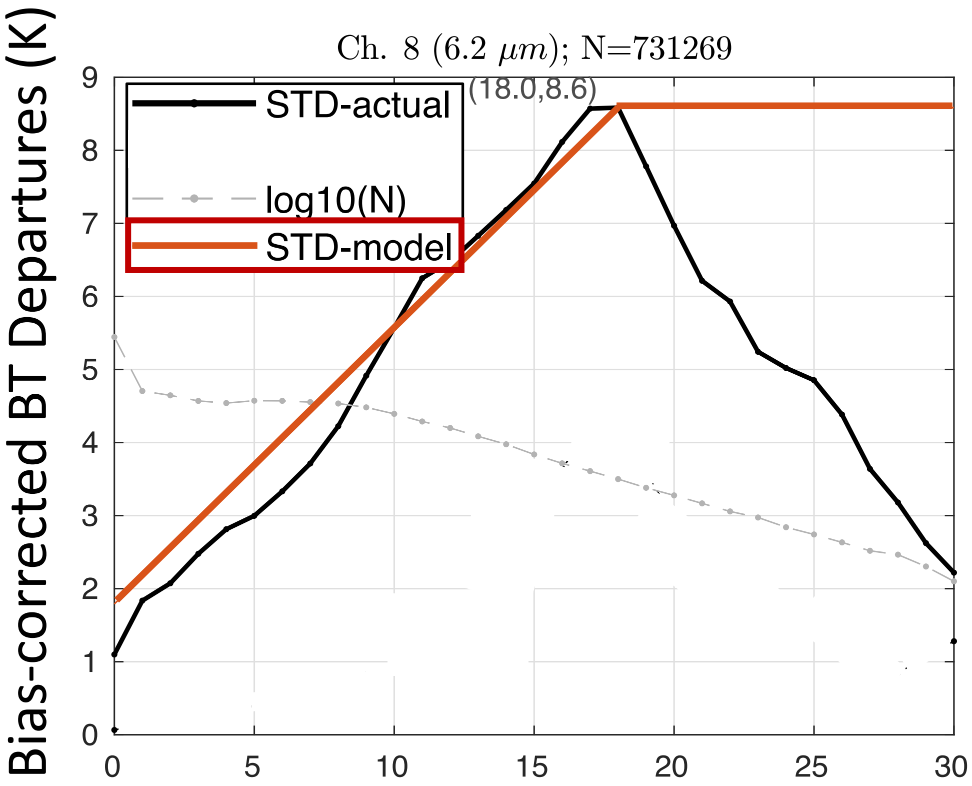


Experimental setup

- 4 experiments:
  - **CONV_VAR**: Univariate 3D-Var assimilating GTS+GNSS-RO observations
  - **CONV_HYB**: Hybrid 3DEnVar, 33% ensemble **B**, 6-12 hour forecasts from N=20 NCEP GEFS
  - **CLRSKY_WV_HYB**: +ABI WV channels in clear scenes (thinned to 18km)
  - **ALLSKY_WV_HYB**: +ABI WV channels in cloudy scenes
- 24 hourly cycles from 20180501_00Z to 20180501_23Z
- 11 hour forecast from 20180501_18Z encompassing the severe storm event

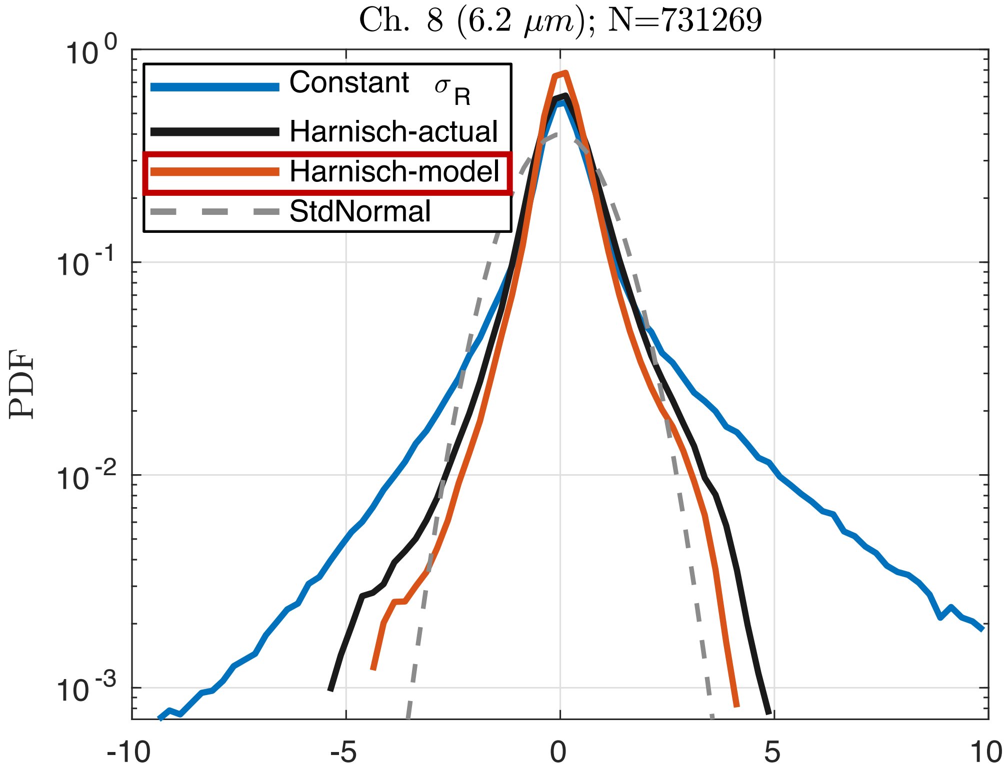
- CRTM version 2.3.0 + fixed VarBC coefficients derived from clear-sky pixels
- WRF/WRFDA V4.1.2; Thompson Microphysics (TMP) w/ 5 hydrometeor phases
- Nested domain (15km over N.A. and 3km Eastern CONUS)

Error inflation for cloudy pixels (ch. 8)



$$C_a = \frac{C_{OBS} + C_{MODEL}}{2}$$

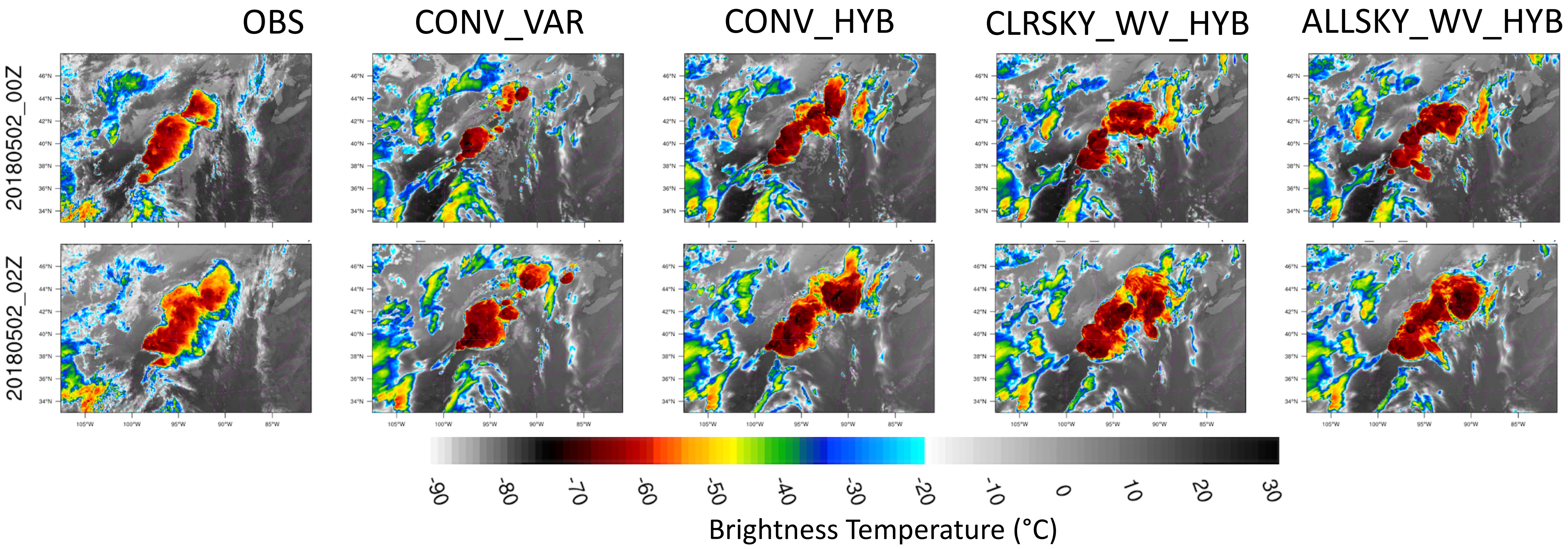
Symmetric cloud impact from Harnisch et al., 2016



Normalized bias-corrected BT Departures (K)

Similar error characterization is applied to all three WV channels

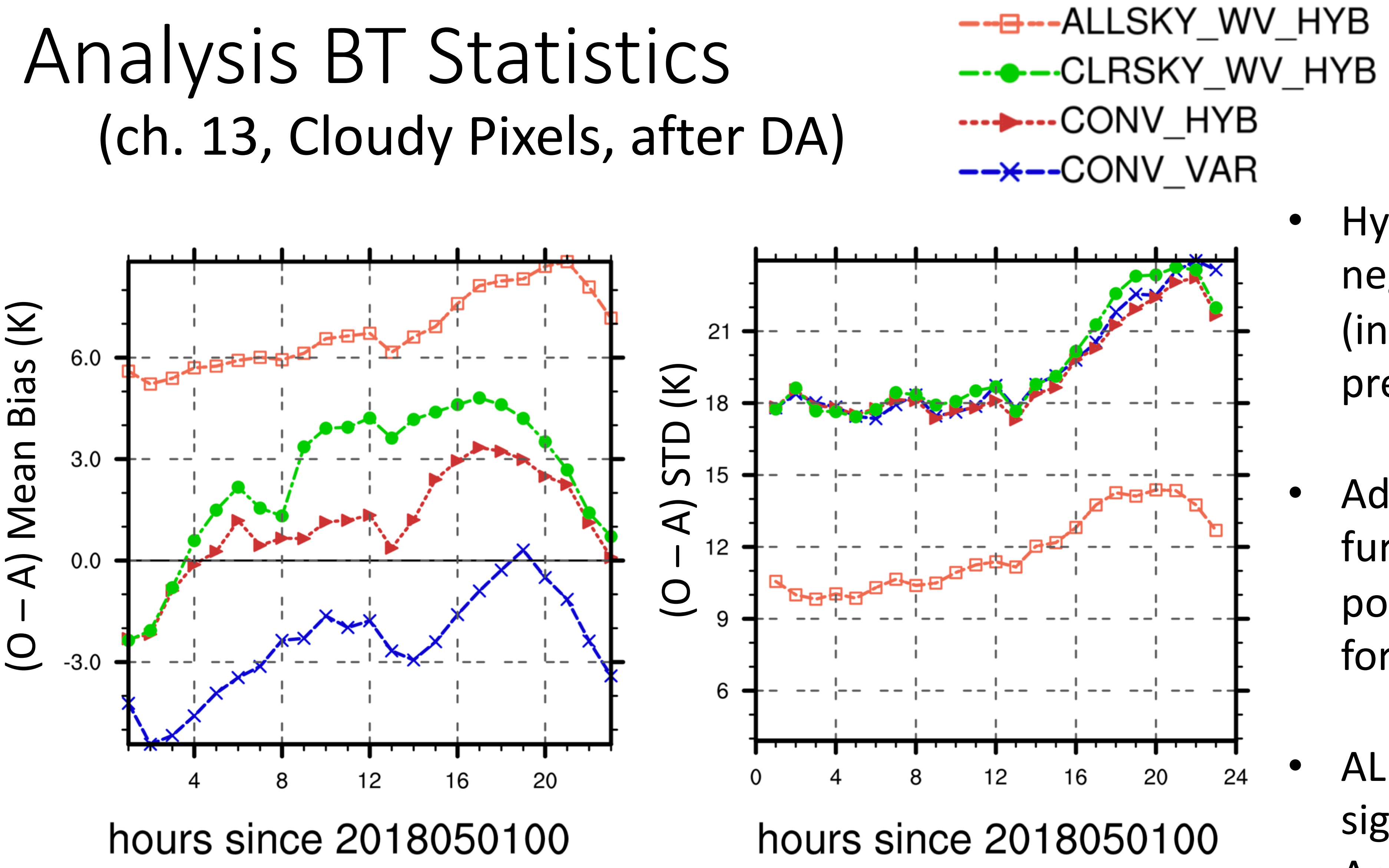
Forecast BT’s (i.e., 6+8-hr forecasted ch. 13)



- In general, WRF is colder than OBS both in updrafts and across the storm anvil
- HYB produces more realistic storm cloud spatial pattern than VAR

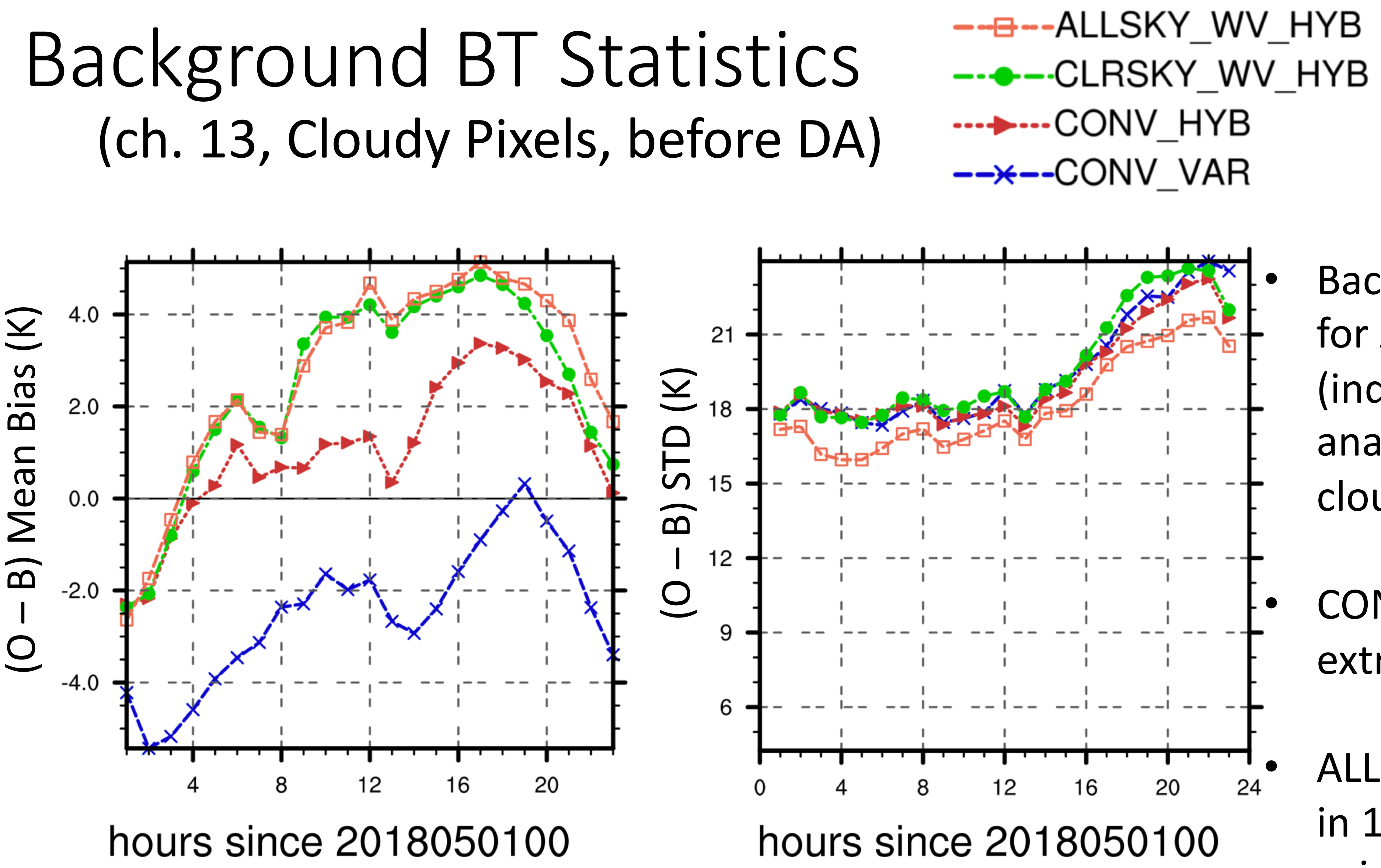
Analysis BT Statistics

(ch. 13, Cloudy Pixels, after DA)



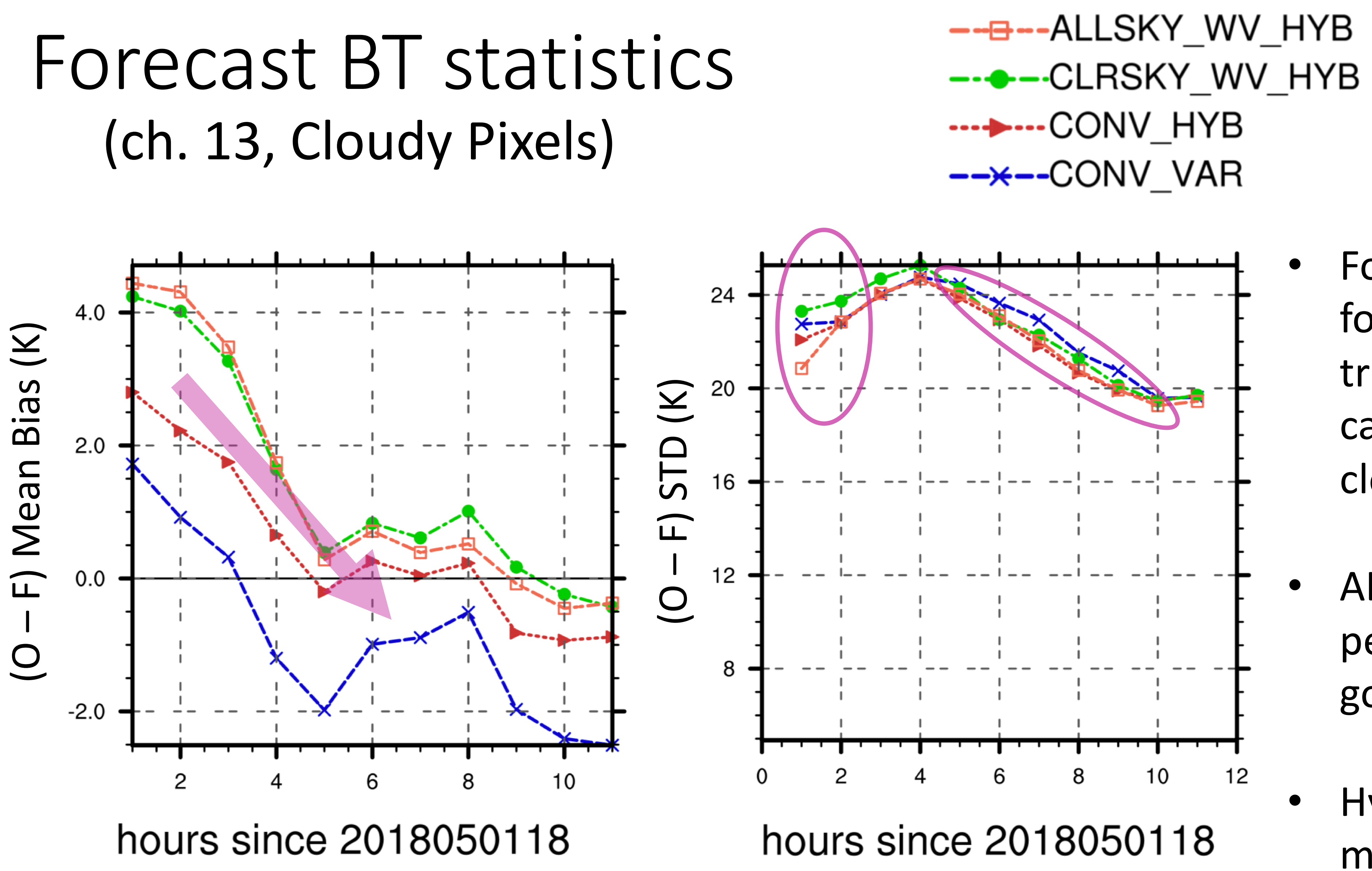
- Hybrid EnVar corrects negative (O-A) bias (increases cloud prevalence)
- Adding ABI radiances further increases posterior bias (more-so for ALLSKY)
- ALLSKY radiances significantly reduce Analysis STD in cloudy pixels (as expected)

Background BT Statistics
(ch. 13, Cloudy Pixels, before DA)



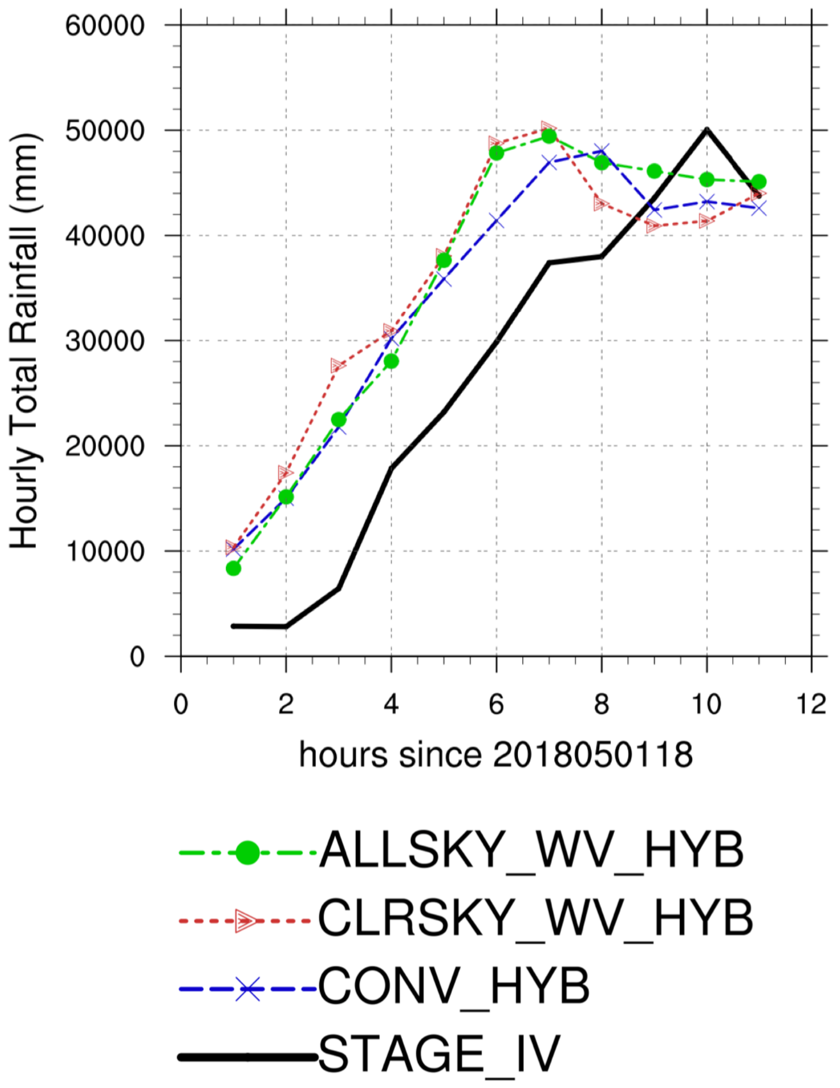
- Background has lower bias for ALLSKY than analysis (indicates unbiased analysis increment, adding clouds, not removing)
- CONV_HYB has least extreme bias
- ALLSKY still improves STD in 1hr forecast, but large gains from analysis dissipate

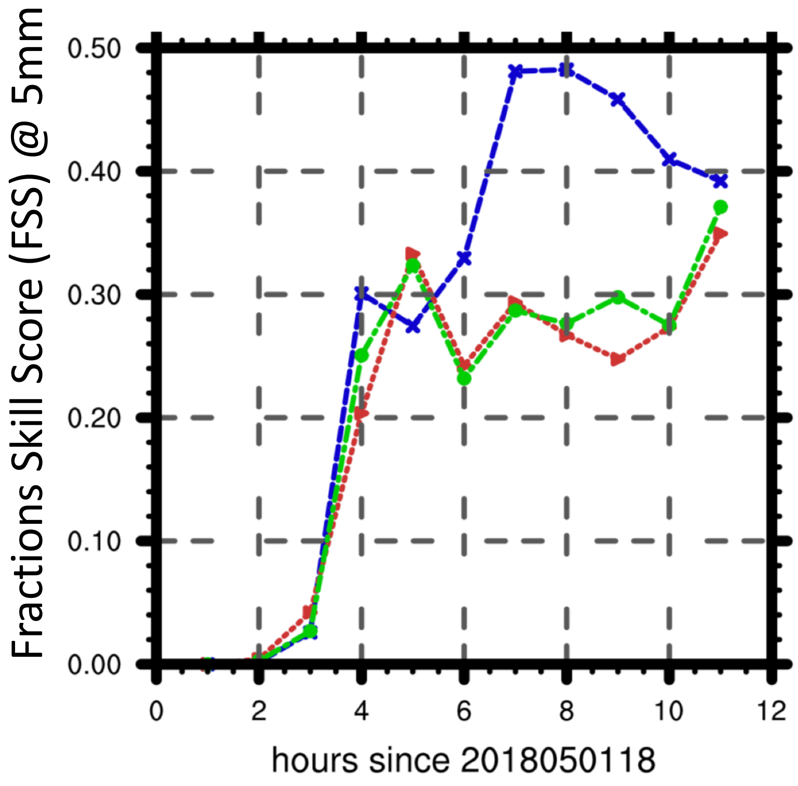
Forecast BT statistics
(ch. 13, Cloudy Pixels)



- Forecast decreases bias for all experiments as true storm catches/surpasses model cloud prevalence
- ALLSKY STD benefit persists for 1 hour but gone within 2 hours
- Hybrid EnVar produces marginally better cloud forecast than univariate 3D-Var

Precipitation Verification against NCEP STAGE IV





- All hybrid experiments precede the observed storm, but storm peak rain is correct
- ABI radiances cause earlier precipitation and degrades spatial positioning

Note: **CONV_VAR** not included

Conclusions

- Hybrid Covariance initiates earlier/stronger convection, probably due to large ensemble spread at 6-12 hr. forecast
- CLRSKY/ALLKY radiances strengthen convection
- ALLSKY radiances improves up to 1-hr cloud forecast
- Precipitation forecasts degraded by CLRSKY/ALLSKY radiances, but may be caused by ensemble **B**, as evidenced by early rain in CONV_HYB forecast

Discussion/Next Steps

- ALLSKY experiment is better at adding clouds than removing clouds; opposite behavior from literature using pure EnKF (e.g., Minamide and Zhang, 2018)
  - Caused by shallow Jacobian for IR bands in deep model clouds?
- Correlation between WV channels is non-zero, but not accounted for in WRFDA
- Background Covariance
  - 1hr forecasts instead of 6-12 hr
  - Localization tuning
  - Hydrometeor error distribution is non-Gaussian
- How can we make storm anvil BT's more realistic? More vertical levels? Fix dynamics/microphysics interactions?

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References

(1) Zhuge, X. & Zou, X. (2016): Test of a modified infrared-only ABI cloud mask algorithm for AHI radiance observations. Journal of Applied Meteorology and Climatology, 55(11), 2529-2546.

(2) Harnisch, F., Weissmann M., and Perianez A. (2016): Error model for the assimilation of cloud-affected infrared satellite observations in an ensemble data assimilation system. Q. J. R. Meteorol. Soc. 142: 1797–1808.