Assimilating cloud water path as a function of WRF cloud microphysics option

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Objectives:

- Assimilate satellite derived cloud properties in hi-resolution NWP models
- Validate that assimilating satellite data improves storm-scale analysis fields
- Investigate differences in model analysis as a function of model cloud microphysics
- Use results as basis for developing procedures for assimilating the array of satellite products to be generated by the GOES-R staring in 2015-16.

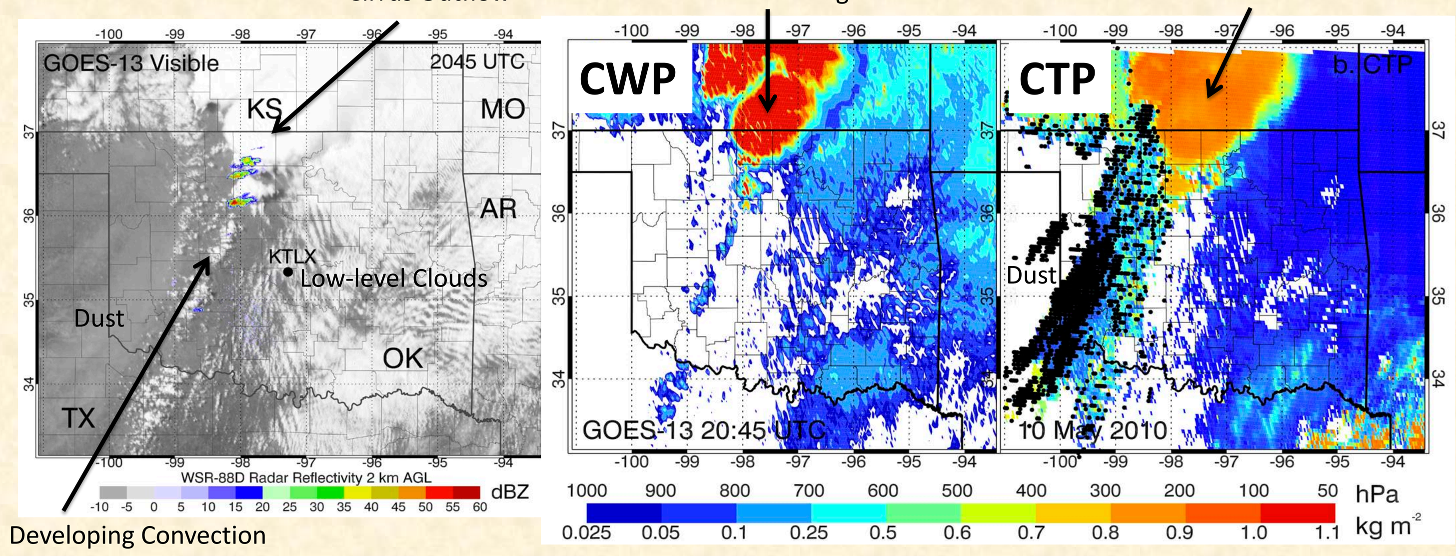
Satellite Data:

- GOES-13 (East) 4 km resolution cloud property retrievals from algorithms developed at the NASA Langley Research Center.
- Retrieved properties include:
  - Cloud Top Pressure (CTP)
  - Cloud Base Pressure (CBP)
  - Cloud Phase
  - Cloud liquid water (and ice) path (CLWP, CIWP)
- Uncertainty in CTP / CBP is approximately ±1 km
- Uncertainty in CLWP / CIWP is 10%
- Cloud phase is a binary classification, multi-phase clouds are not properly defined
- To account for this, total cloud water path (CWP) is defined as the summation of CLWP and CIWP, thus the total water content of a cloud no matter the phase is contained within a single variable

Case Study Characteristics:

- Evaluate satellite data assimilation on a severe weather outbreak from **10 May 2010**
- This event produced multiple reports of severe wind, hail, and tornadoes during the late afternoon in Oklahoma (OK) and Kansas (KS)
- Supercells developed ahead of an eastward progressing dryline around 2000 UTC
- Convection moved eastward at speeds of approximately 25 ms^{-1}
- Supercells present in N. OK and S. KS by 2045 UTC with convection developing southward

2045 UTC



Model Characteristics:

- Advanced Weather Research Forecast (WRF-ARW) forecast model version 3.3.1
- MYJ boundary layer physics, Noah LSM, RRTMG SW and LW radiation
- Use Ensemble Kalman Filter (EnKF) data assimilation approach: 40 members
- Assimilate traditional observations (surface, marine, aircraft, and radiosondes) into 15 km resolution mesoscale run at hourly intervals between 1200 - 2100 UTC 10 May 2010
- Assimilate conventional and cloud variables at 15 minute intervals starting at 1800 UTC in nested 3 km domain using mesoscale analyses as boundary conditions
- Horizontal localization half radius = 100 km for conventional observations and 20 km for satellite retrievals
- Conventional and conventional + CWP data assimilation experiments performed for 5 separate cloud microphysics options

Acknowledgements:

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Cloud Water Path Forward Operator:

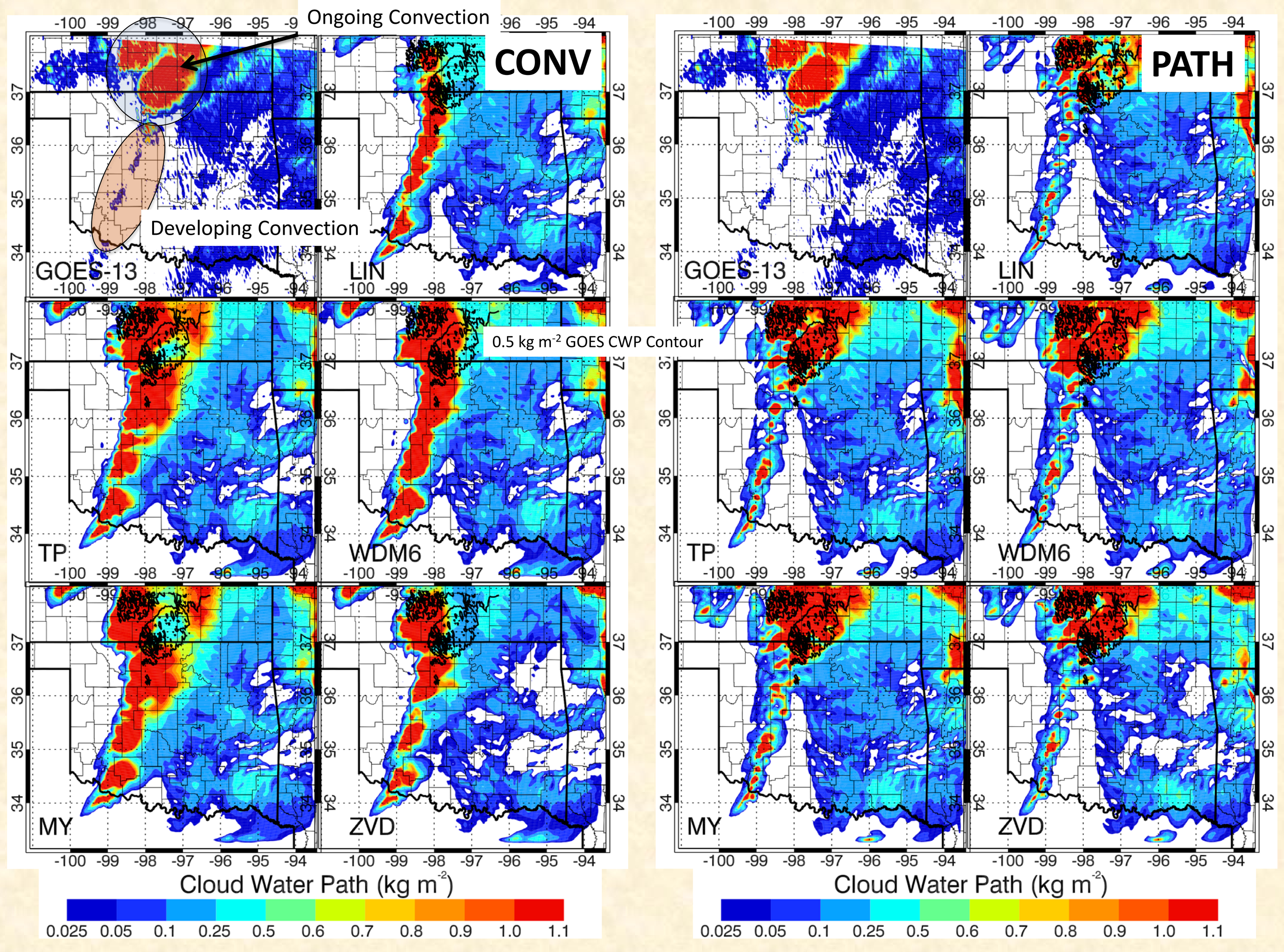
- Assimilating satellite derived cloud properties requires the development of a new forward operator within DART
- The challenge is to relate WRF output to satellite retrieved cloud properties
- WRF CWP is defined as the summation of the mixing ratios of cloud water (QCLOUD), cloud ice (QICE), graupel (QGRAUPEL), cloud rain (QRAIN), snow (QSNOW), and sometimes hail (QHAIL)
- The forward operator sums these mixing ratios for model levels in between the satellite derived CBP and CTP pressure. (Single cloud layer assumed)
- When no clouds are detected, the WRF CWP is summed over all model layers
- The resulting WRF CWP value are then compared with the satellite retrievals and the appropriate adjustments to the model analysis are made
- Where clouds exist, the model CWP is adjusted to better match the satellite retrieval
- Where no clouds exist, the model CWP is adjusted closer to zero

WRF Microphysics Options:

Microphysics	Moments	QCLOUD	QICE	QGRAUPEL	QHAIL	QRAIN	QSNOW	QNCLOUD	QNICE	QNGRAUPEL	QNHAIL	QNRAIN	QNSNOW
Lin	Single	Y	Y	Y	N	Y	Y	N	N	N	N	N	N
Thompson	Single-Double	Y	Y	Y	N	Y	Y	N	Y	N	N	Y	N
WDM6	Double	Y	Y	Y	N	Y	Y	Y[1]	N	N	N	Y	N
Milbrandt and Yau	Double	Y	Y	Y	Y	Y	Y	Y	Y	Y	y	Y	Y
ZVD	Double	Y	Y	Y	Y	Y	Y	Y	Y	Y	y	Y	Y

- **Notes:**

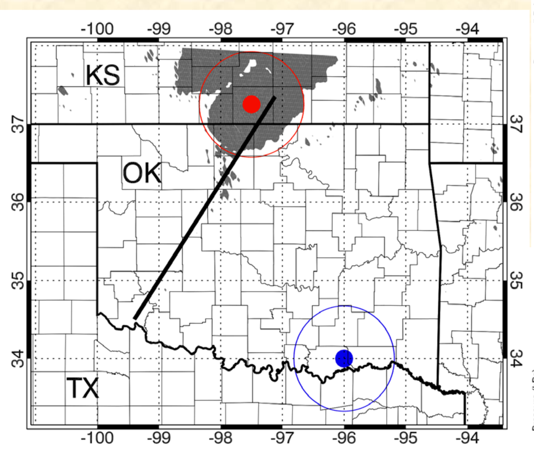
  ZVD = Ziegler Variable Density, NSSL double moment microphysics
- Ten separate experiments are generated, using five different microphysics options
  - One set does not assimilate CWP (**CONV**) while the other set does (**PATH**)
- Both single and double moment microphysics used
- Single moment schemes do not forecast number concentrations (QN*) while double moment schemes do
- All microphysics options used here forecast liquid and frozen hydrometeor concentrations for five variables: QCLOUD, QICE, QGRAUPEL, QRAIN, QSNOW, and QHAIL
- Milbrandt & Yau and ZVD also explicitly forecast QHAIL and corresponding number concentrations



Cloud Water Path Analysis at 2045 UTC

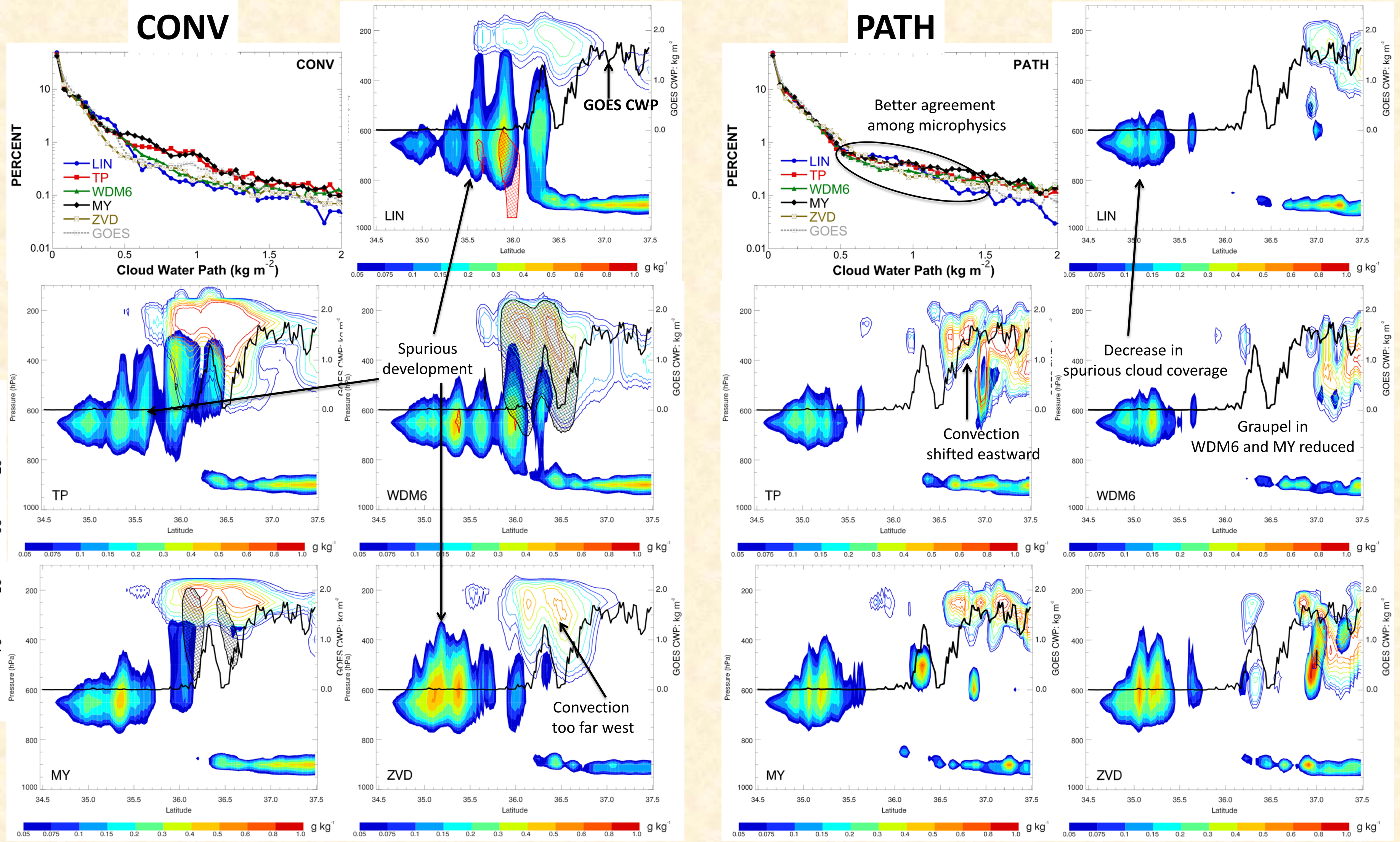
- For all microphysics schemes, CONV develop convection too quickly in central and southern OK
- Ongoing convection in KS is also misplaced
- LIN generates the lowest CWP values owing to lower cloud ice concentrations
- Thompson, WDM6, and Milbrant & Yau all show similar characteristics
- ZVD generally has lower CWP values than other double moment schemes
  - Especially in stratiform cloud areas in eastern OK
- For the PATH experiments, developing convection in central and southern OK is suppressed
- The location of the KS convection is also portrayed better in all schemes except LIN
- Visually,

Domain Map Showing cross-section location and vertical profile locations



2045 UTC 10 May 2010

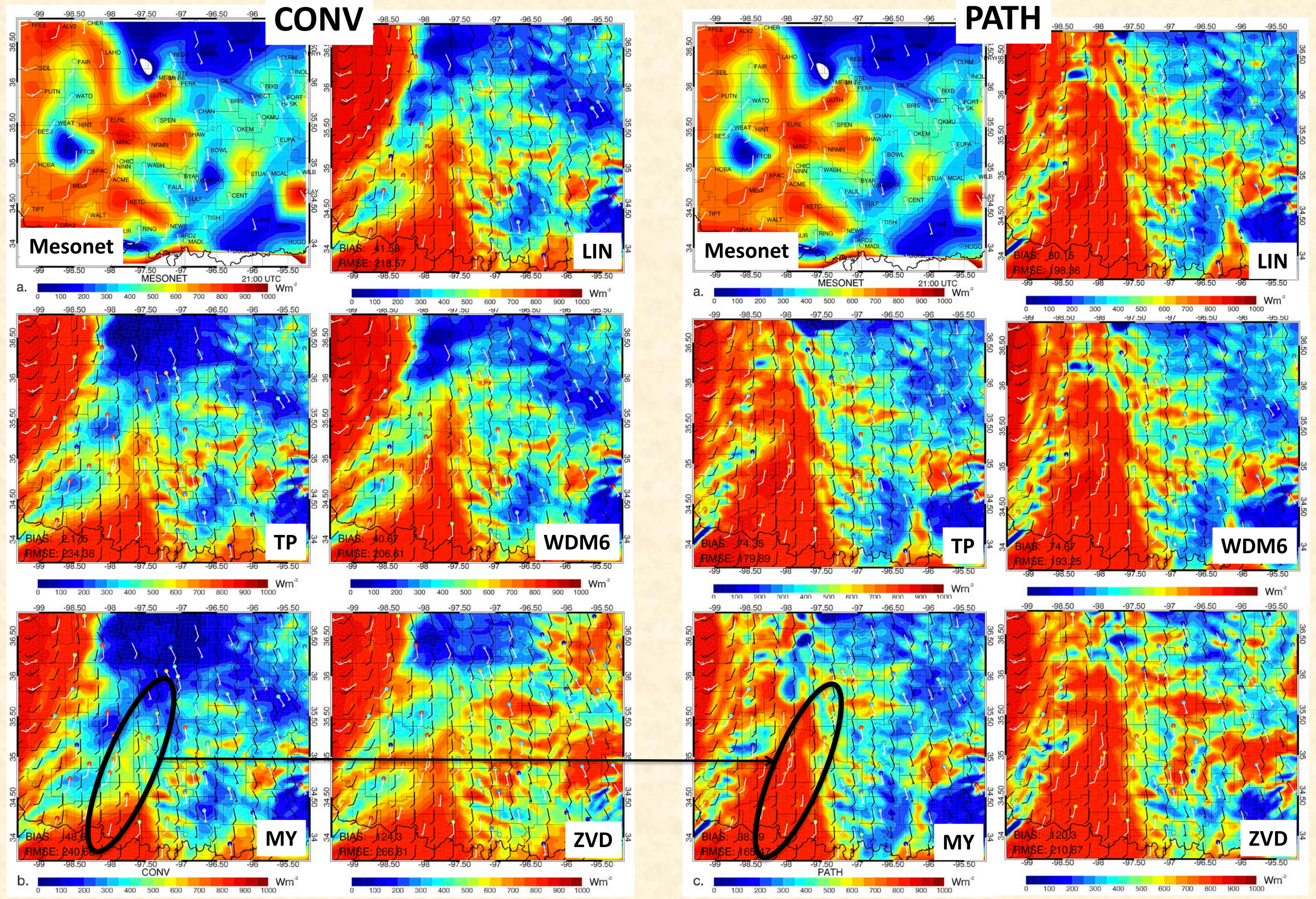
Liquid and Frozen Cloud Water Mixing Ratio Cross-Sections at 2045 UTC



- CONV experiments overestimate QCLOUD and QICE in cloud free regions
- Underestimates where strong convection is ongoing
- LIN has lower QICE concentrations compared to double moment schemes
- WDM6 and Milbrandt & Yau have high graupel concentrations (black shading = QGRAUP > 0.75 g kg^{-1}) corresponding to analyzed convection
- ZVD has highest QCLOUD concentrations in the southern region, but the lowest further north under the analyzed ice fields.

- PATH experiments reduce QCLOUD and QICE where no convection is ongoing
  - None completely eliminate it
- Significant increase in QICE concentrations associated with the location of ongoing convection
- Height and magnitude of changes differ among cloud microphysics

Downward Shortwave Flux Comparison

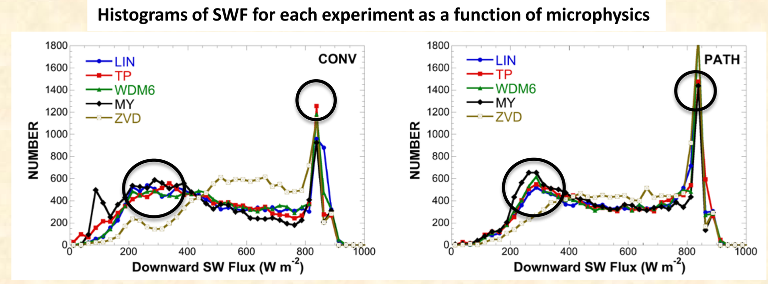


- Model SWF differs as a function of microphysics
- All underestimate SWF in western OK due to early development of convection
- ZVD generates higher SWF in stratiform areas
  - Has highest initial RMSD and bias
- WDM6 has lowest RMSD followed by LIN

	CONV		PATH	
Microphysics	BIAS	RMSD	BIAS	RMSD
Lin	41.6	*218.6*	80.2	198.4
Thompson	*2.2*	234.4	*74.4*	179.9
WDM6	40.7	206.6	74.7	193.2
Milbrandt and Yau	-48.7	240.7	39.0	*165.5*
ZVD	124.4	266.8	120.4	210.9

- Differences in SWF as a function of microphysics remain
  - They are smaller compared to the CONV experiment
- All increase SWF in western OK by suppressing convection
- RMSD errors reduced for all microphysics
  - Largest impact seen for MY: reduces RMSD by 75 Wm^{-2}
  - Smallest for WDM6, which was the best performer prior assimilating CWP
- Biases become positive due to reduction in cloud cover in PATH experiments

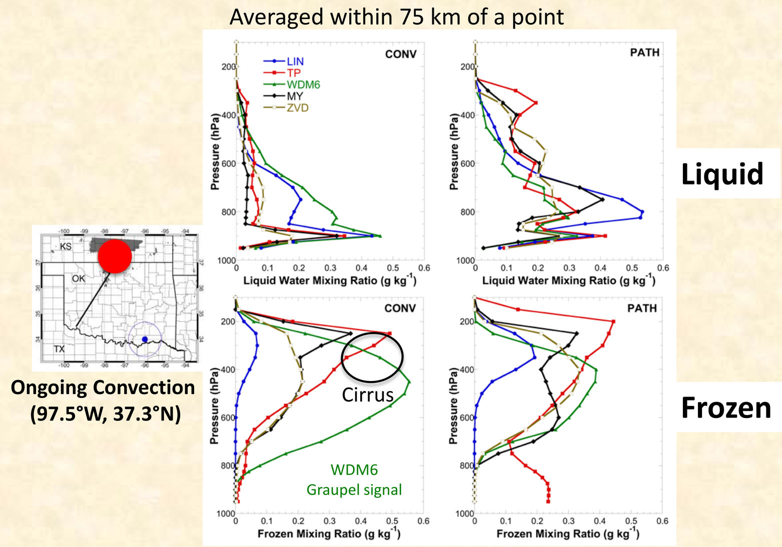
Histograms of SWF for each experiment as a function of microphysics



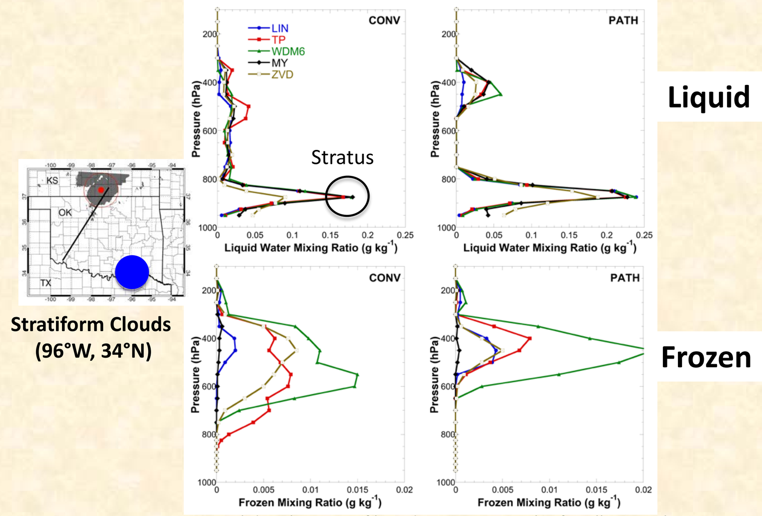
- Peak number near 825 Wm^{-2} corresponding to clear-sky areas for both experiments
- Smaller peak around 300 Wm^{-2}
- Distribution for ZVD differs significantly from other microphysics
  - Biased towards higher SWF values
- Assimilation of CWP brings all experiments into closer agreement
  - Clear and cloudy-sky peaks both increase
  - ZVD much closer to other microphysics schemes

Vertical Profiles of Liquid and Frozen Cloud Water Mixing Ratios

Averaged within 75 km of a point



- Large differences in both liquid and frozen hydrometeor variables
- Liquid peak near 900 hPa in CONV, increasing to 800 hPa in PATH
- Frozen hydrometeor concentrations small for LIN, larger for others
  - Peak near 300 hPa for LIN, MY, and TP, lower for WDM6 and ZVD
- PATH increases frozen hydrometeor concentrations except for WDM6
  - Consistent with increase in CWP and decrease in SWF over this area



- Vertical distributions of liquid water are similar for all microphysics
  - ZVD has somewhat lower values
- PATH experiment redistributes liquid water into low-level (850 hPa) and upper level (450 hPa) peaks, while reducing it in between
- Frozen hydrometeor concentrations are very small (< 0.02 g kg^{-1})
  - WDM6 has slightly higher frozen concentrations (due to graupel)
  - Mostly low level stratus present

Conclusions:

- *Model cloud microphysics has significant impact on how CWP is assimilated*
- *Assimilating CWP reduces RMSD and closes differences between microphysics schemes*
- *Further understanding of changes in liquid vs. frozen hydrometeor concentrations is required and is being assessed*