Measurement Group Discussion

- *Attendees:* Bukovcic, S. Chen, Gao, Kirkstetter, McFarquhar, Nai, E. Smith, Reinhart , Ryzhkov, Schuur, D. Stechman, P. Zhang, J. Zhang, G. Zhang, Zrnic, F. Zhang, Homeyer, N. Lis
- *Note taken by:* J. Carlin

- Use the questions from the agenda as guideline, many aspects of measurement uncertainty were discussed,
- Model deficiency and connecting model with observation were also discussed, more important issue
- While trying to answer the questions, but more questions were raised

Question h)

What are current ways of using radar data?

- Severe weather detection through observations, derived products and other tools such as machine learning (Reinhart)
- Winter precipitation observations and the products (E. Smith)
- Classification, microphysics retrieval (Terry)
- QPE: MRMS products (J. Zhang),
- QPF through DA: successful in using radial velocity due to robustness of measurements and linearity with model variables, Reflectivity in an EnKF scheme, variational scheme, cloud analyses (Jidong)
- Nowcasting for operational forecasters (J. Zhang)

Question i)-1:

What are limitations of the current usage?

- 3D-Cartesian array of polarimetric radar data generated not for general use (for NOAA partners currently) due to the difficulty in combining polarimetric data and KDP issues (Ryzhkov,J. Zhang, Reinhart, Bukovcic)
- No model state parameters produced from radar data yet, but, W, N_t, D_m can be generated/provided for rain (Ryzhkov)
- Direct estimation/retrieval, not optimal, somewhat empirical
- Statistical approaches (Bayesian, VAR, EnKF…) can be used for obs.-based retrieval, and uncertainty needed to be taken into account (confidence vector was used, and can be done further)
- Need better estimation, representation and documentation of uncertainty in both observations and derived products. Lack of full understanding and accurate representation of cloud physics
- Model deficiencies! Especially microphysics. Size sorting, melting, etc. cannot be rigorously treated in single-moment (or even double-moment) microphysics (Reinhart; Ryzhkov). Improving model and model microphysics through direct comparison with real radar observation (Ryzhkov)

Question i)-2:

What would be the optimal/efficient way of using radar data (direct use or derived products)?

- Ideally, directly assimilation of radar data to NWP model is the optimal way (operational centers and DA scientists want raw data: J. Zhang; Reinhart), but reality is not
- It is only true for *fully understanding and utilizing information and idea,* meaning perfect model, accurate operator, and correct error representation that we don't have yet
- Before above issues are fully resolved, derived products have values to users including modelers. Different group want different things. Sometimes, derived products are more reliable.
- If we could even provide perfect PSDs at every grid point, what is the long-term (e.g., few hours) impact of that? Would microphysics schemes just retreat back to their own climatologies? (Carlin) What is the use for adding hydrometeor when there is no water vapor?
- How can we use model output and talk about the uncertainty when we aren't even including/representing these processes? If we're off by two orders of magnitude, what kind of uncertainties are we dealing with? There's something much more fundamentally wrong (Ryzhkov).

Question i)-3:

What needs to be done to achieve a better usage of radar data?

- Improve understanding of cloud physics
- Improve (and develop new) model microphysical parameterization (Ryzhkov)
- Develop more efficient and simpler (but still accurate) forward operators (Gao) that are *key* for informing modelers of existing deficiencies (Ryzhkov)
- Accurately characterize uncertainty/error in models, measurements, and operators (J. Zhang, Kirkstetter)
- Include other datasets/information
- Better communication/collaboration among modelers, radar engineers/meteorologists and DA experts, learn from each other

Question j)

What are the uncertainties in radar-derived (or other data-derived) products? How to constrain the uncertainties

- The uncertainties in radar-derived products are mostly understood, but need better documentation and communications with users
- Questions raised as how to estimate and represent uncertainties?
  - Statistical analysis not good enough (Physical reasons and time-dependence (J. Zhang).
  - Error bar, **bias**&std, or PDF ? (J. Zhang, Kirkstetter Reinhart)
- To constrain the uncertainties, we need
  - Better model and model microphysics, forward operators should contain information from model background (J. Gao), or used as sanity checks, more users of existing data like WSR-88D (Ryzhkov).
  - Better QC, consistence check, and error documentation/awareness (Bukovcic, Ryzhkov)
  - Better algorithms (i.e., reductions in IWC retrievals from 1000% to 20%; Ryzhkov)
  - More observations/in-situ data, satellite data to validate the products

Question k)

What steps need to be taken to further refine uncertainties in in-situ measurements?
What are the best ways of establishing how those uncertainties affect either the remote retrieval of cloud quantities?

- Small ice crystals still present a large amount of uncertainty, especially in some types of clouds like tropical clouds (low Z, high IWC) (McFarquhar)
- Address uncertainties in processing of in-situ measurements. Lots of discrepancies exist in the community. We need to standardize the product or at least the understanding of existing uncertainties. (McFarquhar)
- Better probes and better characterization of the uncertainties associated with probes (McFarquhar).
  - Partnership with private industry (e.g., IBHS) through SBIR? (Reinhart, E. Smith)
  - Ground-based effort using aircraft probes? Mountain-tops to get requisite flow? (McFarquhar)
  - Balloon-borne probes? (Zrnic)
  - Vertically-pointing cloud radars are underutilized – in combination with weather radars? E.g., what is at Stony Brook (Zrnic)

Question I)

What are the best ways of communicating uncertainties in measurements?

- Quantitative data about standard deviations, etc. are trivial to me – I can tell by looking at spread of a scatterplot about uncertainty (Fuqing)
- Natural variability can exceed measurement errors (McFarquhar)
- Modelers can figure out the spread of observed data on their own, but they need information from scientists about hardware reliability, measurement error, etc.
- Different levels (std, bias, PDF) of representing measurement uncertainties are useful for different groups.

Question m)

Are more data needed? If so, what type of data? What types of analysis can be done with the data that we already have?

- Need more in-situ data for in-cloud convection studies (McFarquhar) – is new NCAR aircraft able to fly?
- Videosondes (i.e., Sean Waugh's work) … *relatively* cheap, reusable…
- Coordinated multi-wavelength campaign using existing network (e.g., ARM) to have more info about clouds
- Satellite all-sky radiances are widely used for large-scale NWP but has yet to be fully studied at the storm-scale (F. Zhang).
- boundary layer information (E. Smith), pre-storm environments, ascent of PBL during the morning from Bragg scattering (Ryzhkov) can be derived from radar. Moisture information? at what extend? Need to investigate the scanning strategies
- Satellite all-sky radiances are widely used for large-scale NWP but has yet to be fully studied at the storm-scale (F. Zhang).
- OSSEs are idealistic and optimistic but still useful for determining a best-case scenario. (Fuqing). However, real data presents a much more complicated case, especially when operational concerns are included.

Answers to General Questions

- What is hindering progress on improving atmospheric predictability?

Model deficiencies; gaps among modeling, observation and DA; and coordination are needed, meaning common projects & $$$

- What are the key sources of uncertainty, and how can they be reduced or minimized?

Full understanding and representation of model microphysics, through looking into the parameterization schemes (every process) and comparing with real polarimetric radar observations

- What additional tools, models, observations and resources are needed to address these challenges?

Statistical methods, machine learning, water vapor and cloud measurements,