Volume Scanning Microwave Radiometry for Convection Forecasting

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The Challenge

- At the mesoscale, errors in initial conditions of 1°C in temperature or 1 g/kg in humidity lead to drastically different outcomes (Crook 1996).

We are not there yet, and need better than that.
The Challenge

- Humidity has considerable small-scale structure that both influences and results from convection.

Left: Mesoscale simulation of humidity at 1 km and vertical velocity at 2 km altitude of humidity (top) and vertical velocity (bottom) over a 456*356 km domain of an event that occurred near Montreal.

Images courtesy of Dominik Jacques, McGill
A workshop sponsored by NSF and NWS pushed for the deployment of a network of thermodynamic profilers to measure temperature and humidity profiles at ~100 km resolution and the assimilation of that data.
The Proposed Response

Open questions:
- No single technology can do the job all the time → The report remains silent on what should be deployed;
- The choice for instrument spacing was dictated more by what authors thought we could get, not what is needed.
Illustration of a 100-km Profiling Network in a Mesoscale Context: A Radar Animation

5-hr radar animation courtesy of NASA and its Applied Meteorology Unit at the Kennedy Space Center
Can We Get the Needed Accuracy?

If we had (non-existing) perfect profilers spaced every ~100 km, would it achieve the needed accuracy?

A simulation:
- Take the variability and covariances of $T$ and $e$ from the Rapid Refresh model analysis fields around Montreal in July 2012, as a priori knowledge and its uncertainty;
- Assume perfect knowledge of temperature and humidity at all heights over the instruments;
- Evaluate how well could we estimate temperature and humidity if we had a network of perfect profilers.

Target: 0.5°C and 0.5 g/kg accuracy over 15-km wide columns.
Perfect Profiler Experiment: Results

If we had (non-existing) perfect profilers spaced every ~100 km, would it achieve the needed accuracy?

Temperature: No
Perfect Profiler Experiment: Results

If we had (non-existing) perfect profilers spaced every ~100 km, would it achieve the needed accuracy?

Humidity: No, not even at 25 km spacing
(1 g/kg achieved at ~ 70 km spacing)
Perfect Profilers Fail. Why?

The spatial variability of humidity and temperature is large enough that constraints every 100+ km are insufficient.

→ Need for constraints with tighter horizontal spacing.

In fact, we need much much tighter spacing, if we ever want to succeed where perfect profilers every 25 km fail.

→ Scanning sensors are hence unavoidable to constrain temperature and humidity to accuracies needed for mesoscale forecasting (not as the whole solution, but as part of the mix).
Scanning Instrument Approach: A “Mesoscale Radiometer”

How would a realistic (imperfect) scanning instrument do to constrain mesoscale (temperature and) humidity fields?

Here, a narrow-beam scanning microwave radiometer (K-band) is being considered.
A “Mesoscale Radiometer”

5.0 deg. PPI
Retrieved parameters
McGill mesoradiometer
2009/08/19 16:27
Scanning Measurement Approach: Performance Simulation

- Take the same problem as before;
- Assume we have brightness temperature measurements with 0.5 K\(^+\) accuracy from a scanning radiometer taking measurements at 15 elevations and 26* frequencies at K-band;
- Try to constrain \(T\) & \(e\) fields.

\* Radiometric resolution of HATPRO at K-Band: 0.1 K RMS @ 1 s integration;

\* Determined by the capabilities of the current prototype; subsequent tests revealed that beyond 8 frequencies, gains are extremely limited.
Accuracy of Retrievals from a Single Mesoscale Radiometer

Temperature: Not impressive, but not unexpected given the use of K-band;

Humidity: Better than 1 g/kg within 60 km.
Accuracy of Retrievals from a Network of Mesoscale Radiometers

- One instrument per 135 km → Diminishes humidity uncertainty from climatological down to ~0.8 g/kg at worst, a feat not achieved with the perfect profilers at the same instrument density;

- Add V-band radiometer: Helps a bit with temperature (better than 1K below 5 km altitude).

→ The density of constraints that naturally arises with scanning permits considerable uncertainty reductions.

DFS of humidity: ~600 for one instrument (50-level context)
DFS for temperature: ~60, half of which from K-band
Conclusions

- If the target accuracy is 1°C and 1 g/kg accuracy at low levels at O(10 km) resolution, scanning radiometers at K- and V-band every ~100 km seem to achieve this result, while perfect profilers at the same resolution do not.

→ Narrow-beam scanning radiometers could have considerable value for mesoscale research and forecasting.

- If the target accuracy is 0.5°C and 0.5 g/kg accuracy, a simple and single instrument such as a radiometer is insufficient to get us to the target. Instrument synergy remains the key.
Partial surprise: K-band radiometers can provide some temperature information at very low elevations, as path-integrated opacity exceeds 90% at 22 GHz.

If a V-band is added, new information primarily comes over the instrument as the 1/e penetration distance at low elevations is short.