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Steps towards ingesting radar retrieved refractivity into numerical models

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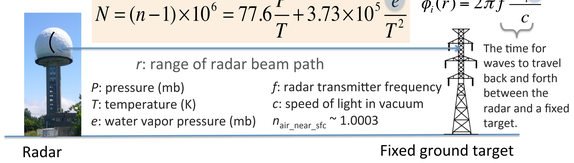
What is radar retrieved refractivity (*N*)?

- The phase ϕ of a fixed ground target changes with the refractivity *N* of air, a proxy of low-level moisture (Fabry et al., 1997). See image at right.

- **Radar refractivity is sensitive to the moisture variation**:
  T = 18°C, ΔT = 1°C → ΔN = 1
  Δq = 0.2g/kg → ΔN = 1

$$N = (n-1)\times 10^6 = 77.6\frac{P}{T} + 3.73\times 10^5 \frac{e}{T^2}$$

$$\phi_t(r) = 2\pi f \frac{2r\bar{n}}{c}$$



- The radar refractivity retrieval provides insights on **high-resolution near-surface moisture**, which is important to understanding convection initiation and evolution as well as boundary layer processes.

Quantifying the observation errors for variational methods

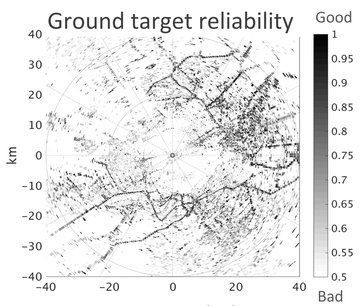
- **The characteristics of errors are critical for data assimilation, or radar refractivity networks implementation.**
- Radar *N* fields have been assimilated to improve the initial condition of low-level moisture for a better quantitative precipitation forecasting result, but with assumed observational errors and representative height.

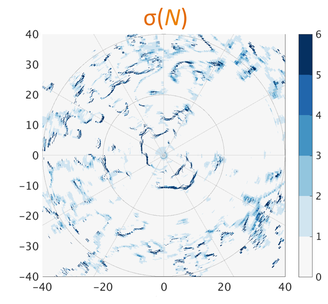
- The error variance (σ^2) of *N* is affected by the measured phase (ϕ) of a single target and retrieval method:
  $\sigma^2(N) = \sigma^2$ [retrieval method ($\sigma^2(\phi)$)]

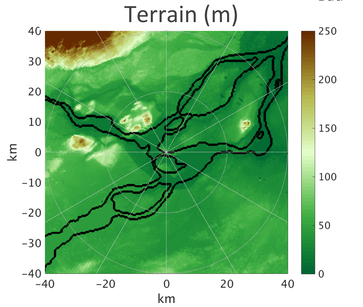
$\sigma^2(\phi)$ = σ^2 (Radar transmitter frequency, hardware)
+ σ^2 (Antenna phase pattern, refractivity profile *dN/dz*)
+ σ^2 (Refractivity profile *dN/dz*, target heights)
+ σ^2 (Atmospheric scintillation)
+ σ^2 (Target movement)
+ σ^2 (complexity of targets: point/extended)

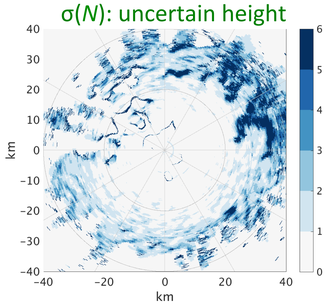
Bias: Systematic. Can be corrected. (Feng et al. 2016)

Error: Uncertainty. Can not be corrected, but can be simulated





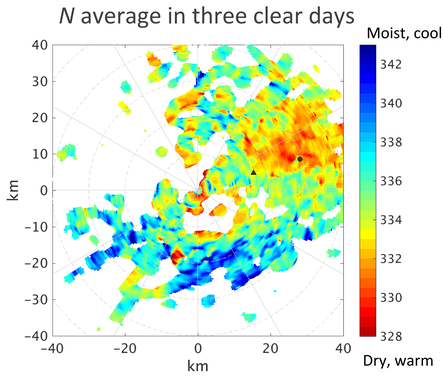




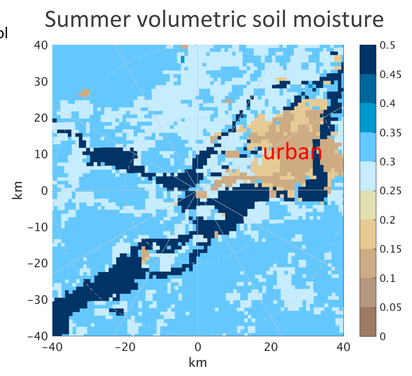
- $\sigma^2(\phi)$ can be estimated by ground target reliability.
- **$\sigma(N)$ is NOT randomly distributed.** *N* is reliable in the dense good targets area. $\sigma(N)$ is within ±1 N-unit.
- Larger observational errors in the less dense target area is quantified.

- Even though the target heights can be estimated from terrain, there are still some uncertainties.
- The $\sigma(N)$ is larger for steeper terrain slopes under the most extreme *dN/dz* conditions; in Montreal, such conditions are rare.

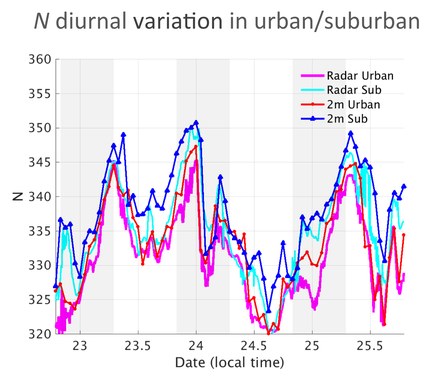
Refractivity map to study land-surface atmospheric interaction



- **The *N* map shows the near-surface air thermodynamic spatial contrast between urban and suburban areas in Montreal (Canada).**
  - $N_{urban} < N_{rural\ or\ suburban}$
  - The local variation of water vapor is affected both by horizontal moisture advection and by evaporation from the land surface.



- **The *N* map shows consistency with the climatology of summer volumetric soil moisture** (m^3m^{-3}) from U.S. Geological Survey land-use database.
  - High spatial-temporal resolution of *N* might help study land-surface atmospheric interaction over a heterogeneous land surface.

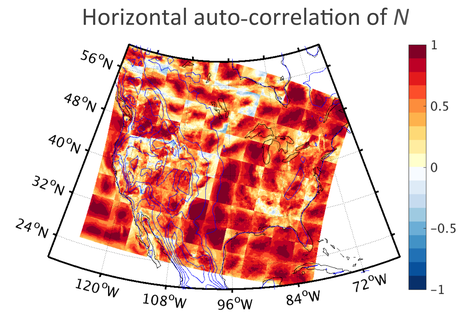


- **The radar retrieved *N* shows consistent trends with the *N* of the surface stations.**
  - Radar *N* at ~20 m above terrain, close the lowest level of model.
  - The difference in *N* is largely due to the refractivity profiles (*dN/dz*) and height difference.

Refractivity in the operational radar network for a regional model

- Can radar refractivity from the national radar network provide a low-level thermodynamic constraint for the model at regional scales?
  - Horizontal auto-correlation of refractivity field at the center of each square grid at the lowest model level suggests *N* information would propagate. (Environment Canada regional model, 15 km resolution, forecasting 12hr, 20 ensembles though more are needed)

- We believe the average refractivity over a small region (~30 km radius) can be very precise and would be more representative than point observations.



Summary: What can radar refractivity do for you?

- Radar refractivity provides valuable high-resolution low-level thermodynamic fields to study the land-surface atmospheric interaction, and help model evaluation and data assimilation in mesoscale and regional numerical weather prediction models.
- A better understanding of the biases and quantification of errors provides solid data characteristics for variational method, such as data assimilation and synergizing with other boundary layer instruments.
- Radars and ground targets are there in the national radar network. *Why not make refractivity operational?*

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