Steps towards ingesting radar-estimated refractivity into numerical weather prediction models

Ya-Chien Feng* and Frédéric Fabry
Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, Québec, Canada
*ya-chien.feng@mail.mcgill.ca

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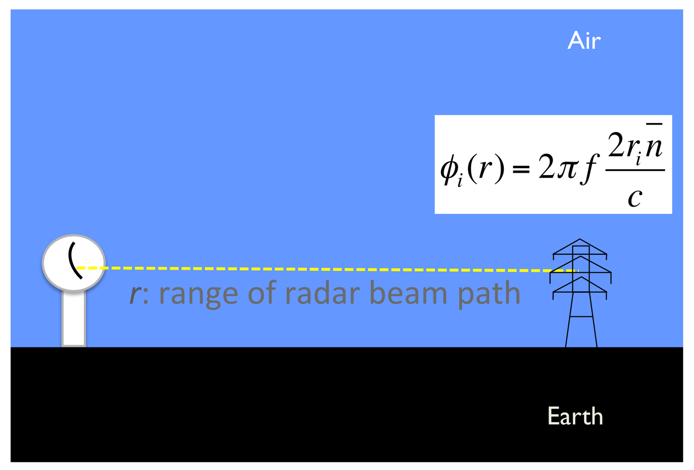
Why ingest radar-derived refractivity (N) into NWP models?

- Convection initiation and quantitative precipitation forecasting are sensitive to the low-level moisture variation.
- The radar-estimated refractivity provides insights on high-resolution near-surface moisture.
  When T = 18°C, ΔT = 1°C → ΔN = 1, ΔT_{dew} = 1°C → ΔN = 5.
- The phase ϕ of a fixed ground target changes with the refractive index of air (n), as a proxy of low-level moisture.

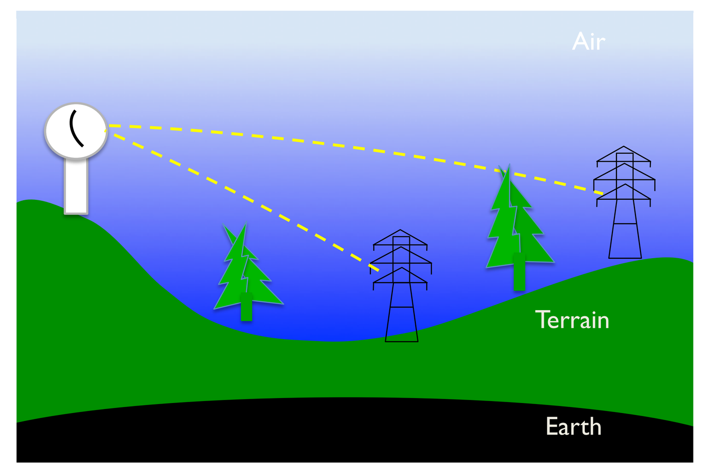
Concept of radar N estimation (Fabry et al, 1997)

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

P: pressure, T: temperature, e: water vapor pressure
f: radar transmitter frequency, c: speed of light in vacuum

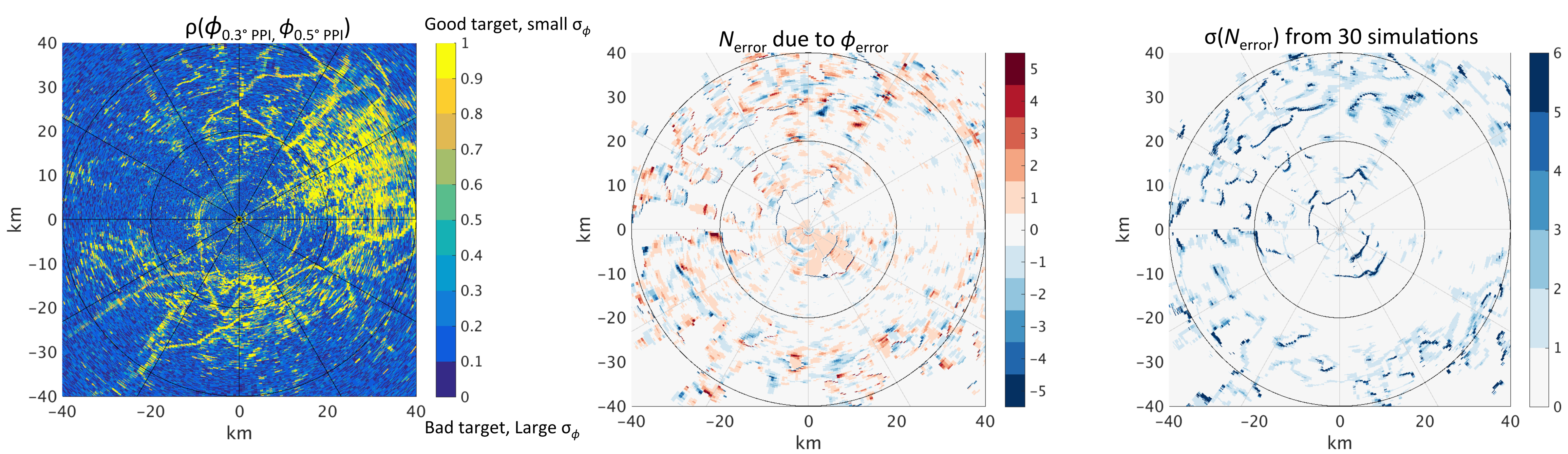


In reality, the data quality of phases (and radar-estimated N) is affected by radar hardware, propagations condition of air, and ground targets (Feng et al., 2016).

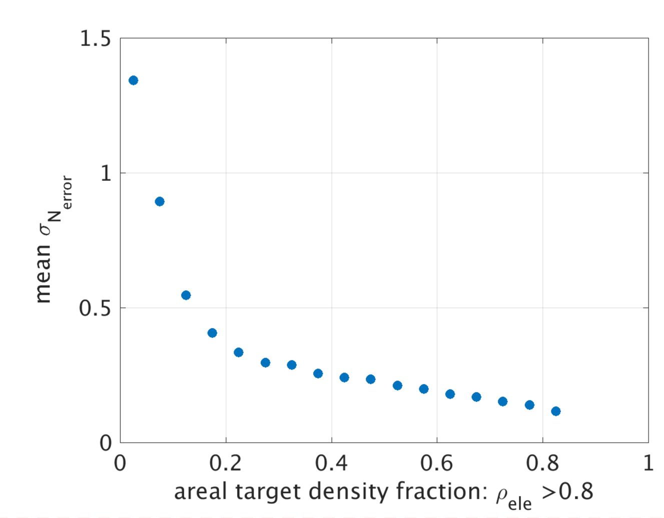


How large are the observational errors of N?

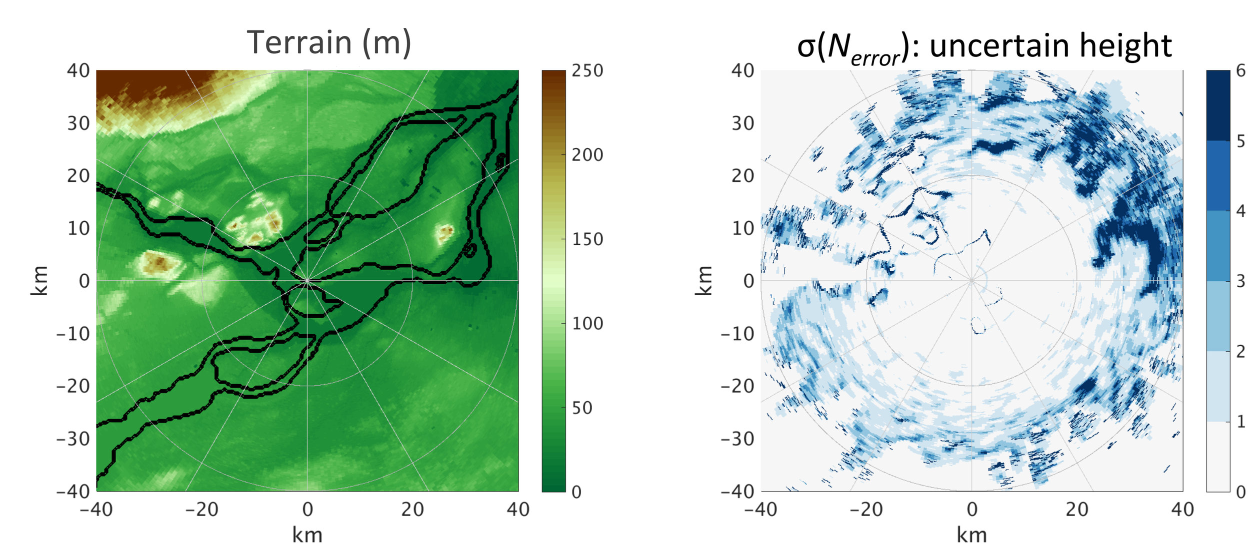
- The quality of N depends on the uncertainties of measured ϕ, which can be classified into:
  Bias is systematic and correctable, e.g. ϕ uncertainties caused by the radar hardware and the combination effect of atmospheric propagation conditions and target heights.
  Error can NOT be corrected, but can be estimated. The error variance of ϕ (σ_ϕ^2) is related to targets properties.



- Method: (1) Calculating the correlation of phases at two elevations (ρ) of each target. Estimating the σ_ϕ by $\rho \approx exp(-(\sigma_\phi/57.3)^2)$. (2) Processing the simulated uncertain ϕ through the original N estimation method.
- N is reliable in the dense area of good targets and its $\sigma(N_{error})$ is within ±1 N-unit. Larger observational errors in the less dense target area are quantified.



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



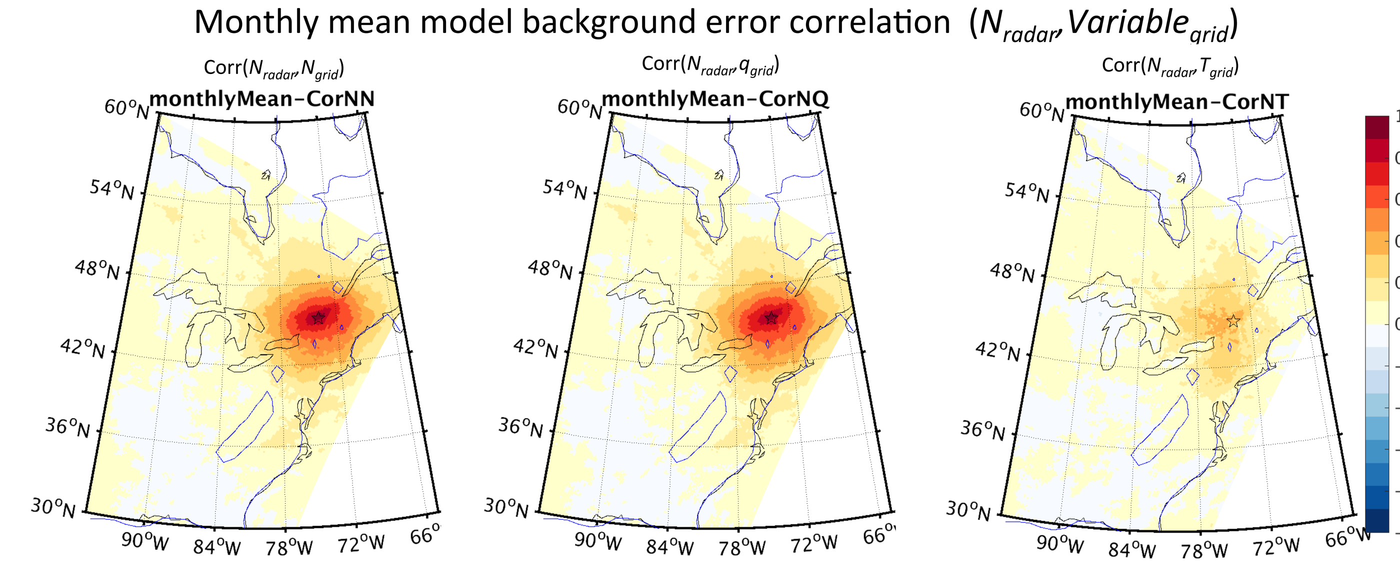
New paths of refractivity applications in NWP models

Ingesting continental-scale radar refractivity data into regional models

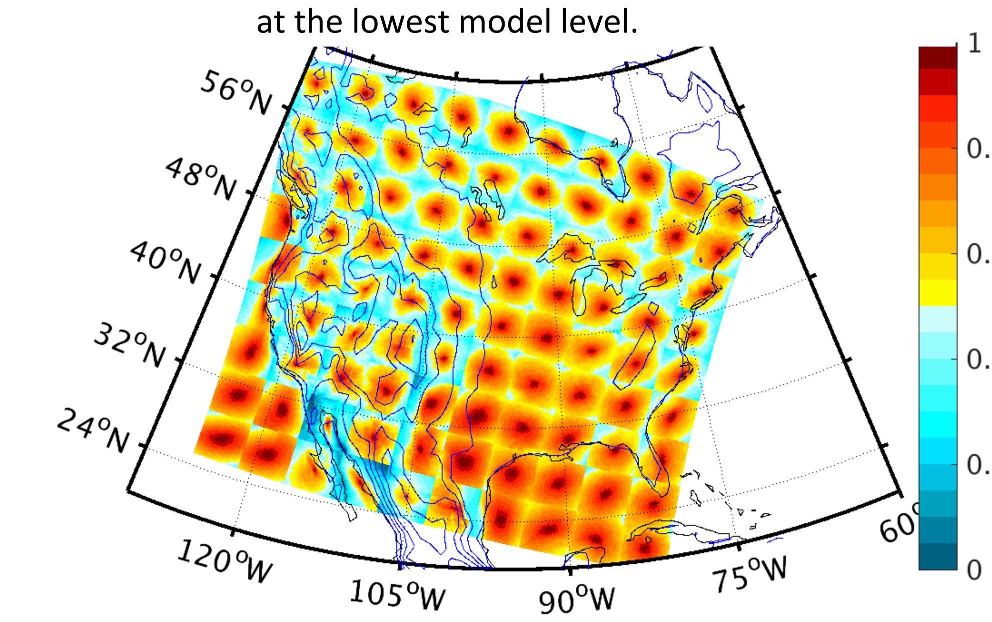
- Application of radar N has been focused on improving the highly-variable moisture field at mesoscale.
- The average radar N over a region with a 30 km radius can be more representative than the surface point observations. Can radar N from the national radar network provide a low-level thermodynamic constraint at regional scales?
- The decorrelation lengths of the model background error of N and specific humidity (q) as well as the autocorrelation of N are about 300 km. This implies the information of N can be propagated over a substantial area at regional scale.

Data: Environment Canada regional model, 15 km resolution, forecasting 12hr, 20 ensemble

Monthly mean model background error correlation (N_{radar}, $Variable_{grid}$)

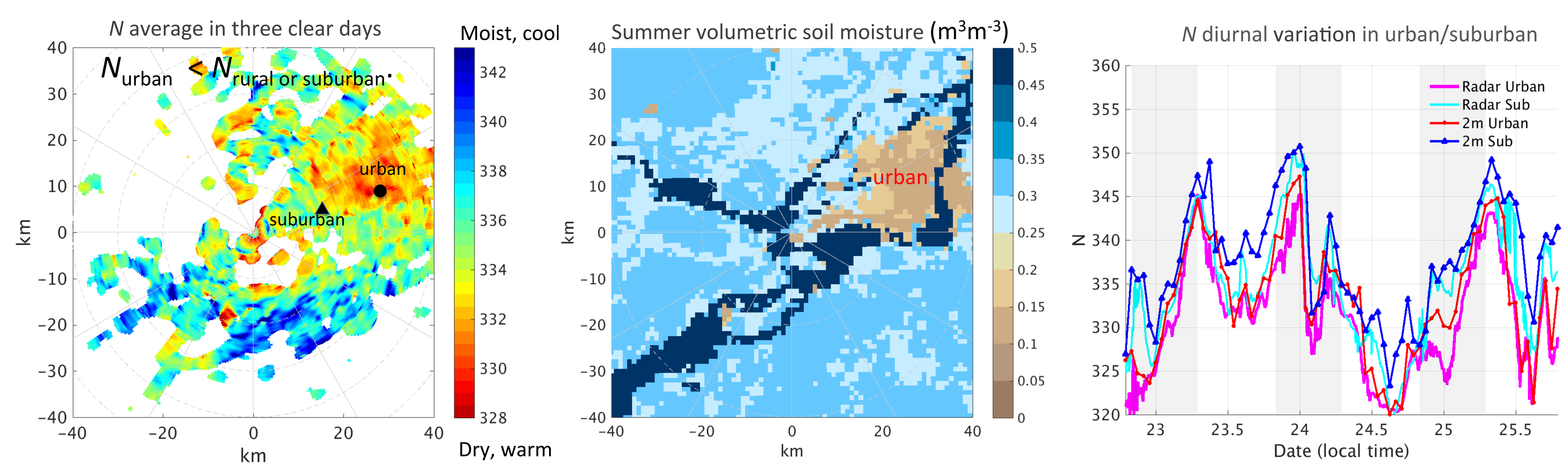


Horizontal auto-correlation of N field at the center of each rectangle grid (450 x 450 km^2) at the lowest model level.



Model output verification / land-surface atmospheric interaction study

- N map shows the near-surface air thermodynamic spatial contrast between urban and suburban areas in Montreal (Canada). N map is consistent with the climatology of summer volumetric soil moisture.
  The representative height of radar N is at about 20 m above the terrain, which is close the lowest level of model.
- High spatial-temporal resolution of N could help (1) study land-surface atmospheric interaction over a heterogeneous land surface (2) verify the model output.



Summary: What can radar refractivity do for you?

- Radar refractivity provides valuable high-resolution low-level thermodynamic fields for studying the land-surface atmospheric interaction, 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 of radar refractivity for variational methods, 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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