# A Deployable Modular Profiling Network (MPN) for Lower Atmospheric Applications

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**ABSTRACT**

The National Center for Atmospheric Research (NCAR) / Earth Observing Lab (EOL) and the University of Oklahoma's Atmospheric Radar Research Center (ARRC) in collaboration with engineers from NOAA/ESRL, and with Howard University's Beltsville Lidar Team, are proposing the development of the Modular Profiling Network (MPN; Fig. 1). The MPN will consist of up to six stations, each with a new wind profiler of modular design, surface flux towers, mini-Doppler lidars, GPS receivers for water vapor measurement, and other sensors. The system aims to meet the need in the NCAR user community for atmospheric profile measurements with improved range, spatial and temporal resolution, areal extent, flexibility, and ease of deployment. The modular design of the new wind profiler allows the deployment of radars of varying sizes, depending on the needs of a particular experiment.

*Figure 1: Three components of the MPN stations, a prototype antenna module for the wind profiler (top), a surface flux tower (lower left), and mini-Doppler lidar (lower right, e.g. HALO-Photonics).*

## 1. BACKGROUND

NCAR/EOL currently deploys Integrated Sounding Systems (ISS) [1] consisting of boundary layer wind profilers, radiosondes, and surface meteorology stations. The ISS have been involved in more than 30 projects including TOGA-COARE, FASTEX, ACE, CASES, IMPROVE, NAME, IHOP, VTMX, and T-REX, to study surface-atmosphere exchange, precipitation, boundary layer evolution, air quality, airflow in complex terrain and many other topics.

Currently the ISS use three DBS (Doppler Beam Swinging) boundary layer 915 MHz profilers of the classic NOAA Aeronomy Lab design [2]. These systems are very capable for boundary layer studies; however, they require a clutter screen, and have limited range (typically up to 3–4 km) and time resolution (winds every 15 – 30 min).

The ISS does have one advanced 915 MHz wind profiler, MAPR (Multiple Antenna Profiler Radar) [3] developed at NCAR/EOL. MAPR uses spaced antennas to make fast wind measurements (1-5 min), but otherwise has similar performance to the older systems (i.e. an altitude range of 3 or 4 km).

A variety of technological advances enable the development of much more capable wind profilers that will allow a greater range of deployment strategies and better meet needs of a diverse range of experiments. For example, some projects could benefit from a wind profiler capable of penetrating deep into the troposphere, whereas others could use a wider network of small boundary layer capable systems.

There are also advances that could improve the near surface observations from the ISS. The lowest sampling height of the wind profilers is typically 150–250 m; currently this data gap is filled using a mini sodar.

The MPN design extends the capabilities and fills these gaps in the present system, as described below.

## 2. DESIGN OVERVIEW

The proposed MPN stations consist of three key components:

- 449 MHz Modular Wind Profilers
- Mini Doppler Lidars
- Surface Energy Balance Stations

### 2.1 Modular Wind Profiler

A key feature of the proposed wind profiler system is modularity. The system would consist of a number of modules, each of which is largely self-contained with a transmitter, receiver, antenna, and data acquisition and processing unit. These modules would be assembled together to produce wind profilers of varying sizes. The module and possible configurations are

*© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2*
*Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna*

illustrated in Fig. 2. This modularity and other key features of the radar bring together design elements from a number of very successful atmospheric radars.

Modularity: A modular antenna and distributed receiver concept has been used in AMISR (Advanced Modular Incoherent Scatter Radar), a very large radar used for ionospheric research, and in the University of Massachusetts Turbulent Eddy Profiler (TEP) [4]. This would allow the systems to be readily reconfigured depending on the application. Each panel would be ~2 m across, include a transmitter and receiver and could operate independently or together with other panels.

449 MHz (67-cm wavelength): Profilers in this frequency band are used by the National Weather Service (NWS) in the NOAA Profiler Network and by NOAA Earth System Research Laboratory (ESRL) for their superior range and high sensitivity.

Multiple Receivers: MAPR and TEP, as well as the Australian Bureau of Meteorology wind profilers incorporate multiple receiver spaced antenna techniques in order to measure the wind much more rapidly than traditional Doppler Beam Swinging wind profilers.

Hexagonal Antenna Modules: This shape is used in VHF radars such as the large MU radar in Japan, and in UHF radars such as the wind profiler on NOAAs *R/V Ronald H Brown* [5]. The panels can be fitted together as in a honeycomb (Fig. 2), yet retain the basic uniform outline producing an even antenna pattern with reduced sidelobes (Fig. 3).

Solid-state transmitter units: Each module would use solid-state transmitter units. Similar transmitters are used behind each antenna element in AMISR, and are also used in the NOAA/ESRL “quarter-scale” 449-MHz radars.

Digital Receivers with Software Defined Radio (SDR): These FPGA (Field Programmable Gate Array) receivers are used in a number of radars (e.g., Applied Technologies 449-MHz Aerostat profilers) for their superior signal processing capabilities.

Other features being investigated are Range IMaging (RIM) [6], [7] to improve the range resolution of the radars; adaptive clutter mitigation using spatial filtering with additional wide field-of-view antenna modules [8]; and RASS (Radio Acoustic Sounding System) for virtual temperature profiling.

Table 1 presents the expected performance in each of the principle configurations (the right-most column is the current 915 MHz DBS profiler capability). The proposed full-troposphere configuration should have altitude coverage comparable to the large U.S. National Profiler Network (NPN) operational systems [9], and the Mid-Troposphere configuration should have altitude coverage similar to the NOAA quarter-scale profiler [10]. All options will have much better time and altitude resolution and will be easily deployable for research programs.

### 2.2 Mini Doppler Lidar

The MPN proposes to use a mini Doppler lidar to provide winds from the surface up through the boundary layer. The lidar being considered is an off-the-shelf scanning eye-safe system operating at 1.5 microns (e.g. Fig. 1). In addition to providing low-level winds, these systems are capable of measuring turbulence, and tracing features such as thermals, boundaries, gusts, and boundary layer top. An evaluation study of the lidar is being proposed for the Beltsville Research Site of Howard University.

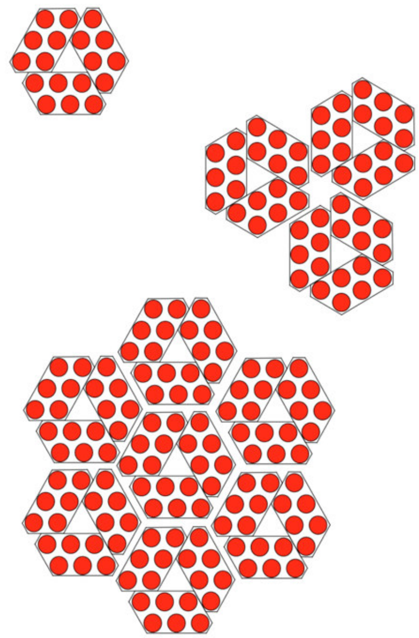

*Figure 2: The antenna module (upper left) and layouts for boundary layer operations (3-modules, upper right) and mid-troposphere operations (7-modules, lower left).*

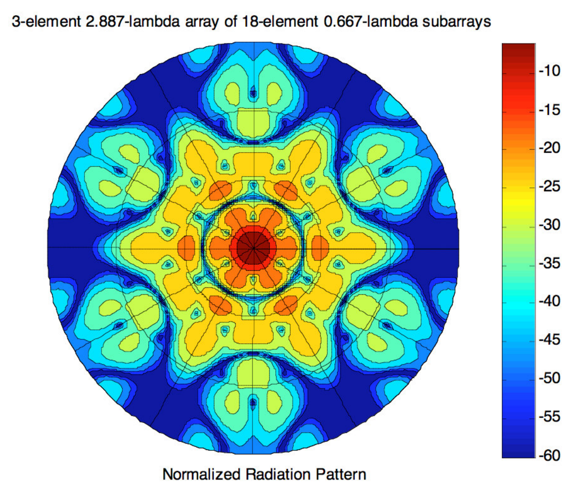


*Figure 3: Theoretical antenna pattern for the 3-module boundary layer configuration. Spacing of individual modules is 2.887 wavelengths; spacing of antenna elements is 0.667 wavelengths.*

### 2.3 Surface Energy Balance

Three surface stations will be deployed with each MPN station to measure all components of the surface energy balance. These include eddy-correlation measurements of the fluxes of temperature, moisture, momentum, four-component radiation, and soil heat flux and moisture.

### 2.4 Additional Components

The stations will be deployed with GPS receivers for water vapor measurements and will also be capable of hosting radiosondes systems and additional user supplied instruments.

## 3. CURRENT STATUS

An initial design study has been conducted and is being revised based on component testing. Three prototype test antennas have been manufactured (see Fig. 1). It was connected to the electronics of a NOAA / ESRL 449-MHz radar for two days in Boulder, Colorado. Observations of snow are shown in Fig. 4, along with observations from a collocated 915 MHz wind profiler. Neither radar used a ground clutter screen. The difference in reflectivity between the 915-MHz and 449-MHz observations is close to the theoretically expected 11 dB. Signals from the prototype antenna were very clean and showed none of the ground clutter seen by the near-by 915-MHz system.

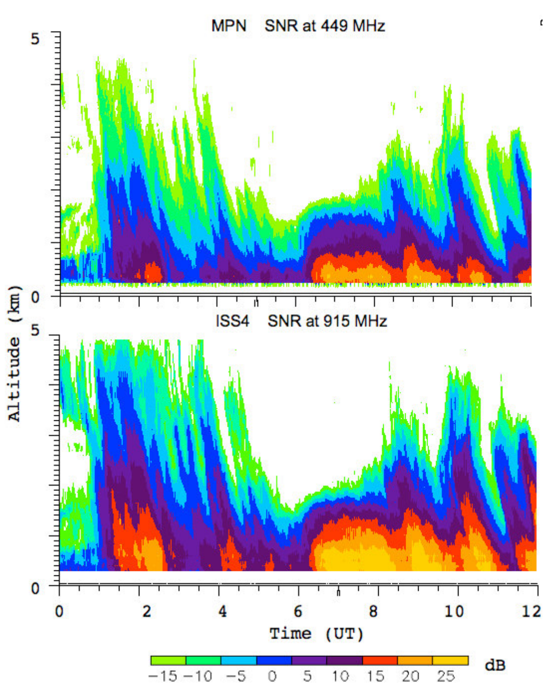


*Figure 4: Observations of snow made in Boulder, Colorado, at 449 MHz (upper panel) using a prototype MPN antenna, and at 915 MHz (lower panel) with a standard wind profiler.*

The radiation pattern of the prototype antenna was also measured at the Marshall antenna test range just south of Boulder. Results from these tests are shown in Fig. 5. The measured one-way antenna pattern at the horizon is around 40–50 dB below the main lobe, which is close to that predicted by theory. The antenna performs very well and it appears that the profiler will indeed be able to be deployed without a clutter screen. A total of 7 prototype antennas are under construction to test the performance of a modest modular profiler. Future plans include further testing of distributed transmitter and receiver designs.

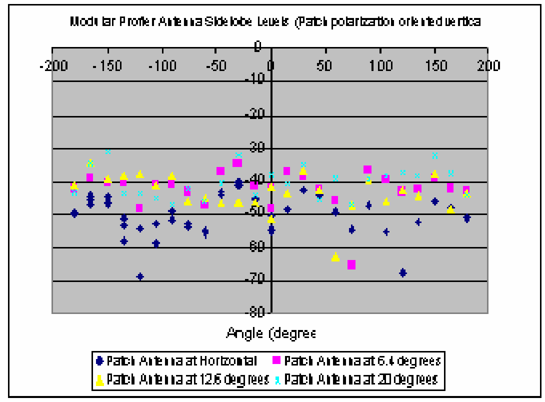


*Figure 5: Preliminary antenna test range measurements of the beam pattern of a prototype single antenna module (pointed vertically) showing one-way signal at, or near, the horizon as a function of azimuth angle.*

## 4. SAMPLE CONFIGURATIONS

We envision this network to be applicable to a wide variety of atmospheric observations. As a 6 station boundary-layer network it might be used to study spatial flows within an urban environment (e.g. megacity) or a mountain basin; or in a picket line to capture frontal changes over a mountain range; or in a loop to measure divergence. As a 2 station mid-tropospheric network it would penetrate higher than our current ISS profilers to study mountain waves and rotors, or elevated jets, or storm inflow regions. As a single station full-tropospheric site it would study the lower UTLS region and complement aircraft observations from NCAR's G-V, the Global Hawk UAS, and others.

The lidar and surface flux components expand capabilities in the boundary layer. GPS receivers, optional radiosondes, and hosted additional instruments further add to capabilities.

As the study of atmospheric interfaces increases in importance, the MPN could add observations at the land-atmosphere interface, at the boundary layer top, and at the troposphere-stratosphere level.

Comments and/or expressions of interest from the community are welcomed.

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*TABLE 1: Proposed performance targets and modes of operation for the MPN stations.*

| | **Configuration-1 Boundary Layer** | **Configuration-2 Mid-Troposphere** | **Configuration-3 Full-Troposphere** | **Current 915 MHz BL Profiler (DBS)** |
|---|---|---|---|---|
| Number of Stations[1] | 6 | 2 | 1 | 3 |
| Modules per station | 3 | 7 | 19 | |
| Expected Altitudes[2] | 0.15 to 4 km | 0.20 to 7 km | 0.30 to 15 km | 0.15 to 4 km |
| Altitude Resolution[3] | 30-m | 30-m to 200-m | 100-m to 200-m | 60-m to 100-m |
| Time resolution | ~1-min | ~1-min | ~5-min | 30-min |
| $T_V$ coverage (RASS)[4] | ~1 km | ~2 km | ~4 km | ~1 km |

[1] Proposed number of wind profilers that NCAR/EOL will be able to deploy

[2] A Doppler lidar will fill in winds down to 30-m AGL with good time resolution

[3] High-resolution is achieved in the boundary layer through the RIM technique, with lower resolution required at higher altitudes.

[4] Radio Acoustic Sounding System (RASS) is an add-on to wind profilers which measures virtual temperature through radar measurement of the speed-of-sound.