Vehicles as Mobile Weather Observation Systems

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Anyone who has recently purchased a new car or truck knows that vehicles are now very sophisticated and full of computer-controlled systems and advanced consumer electronics. What many people do not realize is that modern passenger vehicles contain data-management systems that monitor nearly every operation, from controlling engine performance to recording seat belt use, headlamp status, door positions, and hundreds of other parameters. Most vehicles also measure air temperature and pressure, and an increasing number have solar and rain sensors. Can these data be accessed, processed, and utilized by the transportation and weather enterprise to improve weather diagnostics and predictions? The authors not only believe they can, but they are actively engaged in research, development, and outreach programs to make this a reality.

High-resolution spatial and temporal observations are crucial to advance our understanding of meso- and microscale meteorology, improve weather forecasts and products, and ultimately protect life and property. Over the last few decades, significant strides have been made to increase the quality and quantity of weather observations. Recently, the National Research Council (NRC) report, "Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks," focused attention on the U.S. national needs and progress toward development of a nationwide "network of networks" observational system. Arguably, one of the most promising possibilities envisioned in the NRC report is the potential of utilizing passenger and fleet vehicles as weather-observation systems. With 230 million vehicles on the nation's roads logging 3 trillion miles driven annually, vehicles represent an unparalleled opportunity to increase the nation's surface-observation network, particularly with respect to the roadway environment. In the near future, many of these vehicles will anonymously measure, record, and disseminate direct (e.g., temperature, pressure) and indirect (e.g., wiper status, antilock brake, and vehicle stability control system status) measurements of the road and atmospheric conditions.

The NRC is not the only organization that recognizes the enormous opportunity of vehicle-based weather observations. The AMS's Board on Enterprise Planning (BEP) also began the process of reviewing the national mesoscale-observing network. In 2006, through the Annual Partnership Topic (APT) process, the BEP established a Mesoscale Observing Networks Topic Committee. This BEP committee has finished its work, and the AMS Commission on the Climate and Weather Enterprise has continued the effort by creating a Committee on Network of Networks that will continue and expand the discussion of mesonets and the potential contributions of various sensing systems to the national network.

The National Oceanic and Atmospheric Administration (NOAA) has taken action to transition its Meteorological Assimilation Data Ingest System (MADIS) into an operational environment. MADIS currently resides in a research environment under NOAA's Office of Oceanic and Atmospheric Research (OAR), and its transition will take it to the National Weather Service (NWS). MADIS collects, quality-checks, and archives observations from across the nation from both public and privately operated mesonetworks. The culmination of the transition plan moves the nation a step closer to realizing the establishment of a truly national-scale mesonetwork of observations.

These activities clearly demonstrate that there is a strong national interest in establishing and maintaining a robust surface-observing network and exploring unique opportunities to expand the network.

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A quickly approaching opportunity to expand the network is the pending availability of measurements from passenger vehicles and commercial car and truck fleets. Imagine a capability where millions of privately owned automobiles are equipped with transceivers that are able to transmit data captured from their onboard sensors and safety systems to a nationwide infrastructure connected by high-speed data hubs. Even the most common components of the passenger vehicle can begin to tell a story about the near-surface (driver level) atmospheric and pavement conditions through the intelligent utilization of vehicle data elements such as windshield wiper state, external air temperature, headlamps, atmospheric pressure, sun sensors, vehicle stability control, and the status of an antilock braking system.

Today, a U.S. Department of Transportation (USDOT) initiative called IntelliDrive℠ (previously known as the Vehicle Infrastructure Integration Initiative; www.intellidriveusa.org) is moving toward developing these capabilities. Automobile companies are working with USDOT and other stakeholders on equipment that can send and receive messages via wireless communication. In addition, USDOT, state and local governments, and the private sector are looking at a wide range of strategies for utilizing the data to improve transportation safety and mobility. Using IntelliDrive℠ data for improving road weather services represents only a small fraction of the envisioned benefits. IntelliDrive℠ technologies are viewed as the key enabler in a wide suite of transportation safety, mobility, and environmental applications. The IntelliDrive℠ architecture is currently being developed to assure anonymity and untraceability, as data privacy is paramount to this initiative. For instance, drivers will have opportunities to "opt in" or "opt out" of certain aspects of data transmission.

Beginning in 2008 and continuing beyond 2013, a series of demonstrations will take place to address a number of scientific and technical issues. During 2008, a proof-of-concept test for IntelliDrive℠ was conducted near Detroit, Michigan. Similar test beds are in use in northern California and New York, and other test beds are envisioned by various stakeholder groups. The Federal Highway Administration (FHWA) and the USDOT Research and Innovative Technology Administration (RITA) are conducting research to evaluate and validate the viability of using vehicle-based sensor data to generate potentially millions of new weather and pavement condition observations. In 2007, a FHWA report prepared by the National Center for Atmospheric Research (NCAR) described how vehicle data could be used to improve weather and road condition applications and services.

For this initiative to be successful and move forward toward national implementation, all sectors of the weather enterprise (e.g., public, private, and academic) must become involved to help define, shape, and support the effort to bring these data to bear on the weather and transportation communities. The potential availability of millions of surface observations from passenger vehicles and fleets represents a huge opportunity for the weather community. Whether this opportunity is seized or missed (at least initially) will depend greatly on the weather community's technical understanding and adoption of these unique datasets and its level of participation within the IntelliDrive℠ community. The AMS recognized the need to engage the weather enterprise on this topic and in 2009, through the APT process, established the Committee on Mobile Observations. Bringing this topic forward as an APT provides an opportunity for a deliberate discussion among stakeholders about its potential, technical challenges, research needs, implementation strategy, and other issues. This committee plans to complete its work on this topic in 2011.

RESEARCH AND DEVELOPMENT EFFORTS. Advances in wireless vehicle technologies are being driven by numerous organizations and economic sectors. At the federal level, RITA is overseeing the IntelliDrive℠ program. The IntelliDrive℠ initiative represents a suite of technologies, communication standards, sensor location analysis, and applications that use wireless connectivity with and between vehicles, between vehicles and the roadway, and with devices (such as consumer electronics) in the vehicle to achieve transformational improvements in safety, mobility, and environmental quality.

With funding and support from RITA and direction from the FHWA Road Weather Management Program (http://ops.fhwa.dot.gov/Weather), NCAR is conducting research under the IntelliDrive℠ initiative to develop a prototype Vehicle Data Translator (VDT), which collects, quality-checks, and disseminates vehicle-based weather and road condition data (www.rap.ucar.edu/projects/intellidrive). In addition, the VDT incorporates vehicle-based measurements of the road and surrounding atmosphere with other more traditional weather data sources, and creates prototype road and atmospheric hazard products.

These quality-controlled observations will eventually be provided to the meteorological community and other users through USDOT or NOAA via systems like Clarus (www.clarusinitiative.org) or MADIS.

NOAA is also involved in funding mobile observation research and development. In late 2009, the NWS began funding of a project to build a Mobile Platform Environmental Data observation network (MoPED). The objective of MoPED is to demonstrate that vehicle data can support surface transportation weather applications, and, if successful, these data will be included as part of the national mesonet system.

At the state level, the Michigan DOT has been funding a Data Use Analysis and Processing (DUAP) project to examine the opportunities and benefits to MDOT of acquiring and using vehicle data in managing traffic and MDOT's transportation system assets. The DUAP project builds on previous work to investigate how the availability of vehicle data currently available throughout the road network may change the way transportation agencies do business. This project focuses specifically on data uses and benefits in responding to safety concerns, managing traffic, and managing MDOT's transportation system assets. Weather is not a focus of this project, but MDOT has made the vehicle data available to the FHWA Road Weather Management Program for analysis.

VEHICLE DATA. Several studies describe weather-related data elements that are already, or will soon be, available from mobile platforms. Table 1 lists the most common elements, categorized as either "input" or "observed." The "observed" category includes direct observations of specific atmospheric variables (e.g., barometric pressure, temperature) that should benefit the weather community as input for weather models and as data at high spatial and temporal resolution data for improved situational awareness. The "input" category includes both logistical information (e.g., date, time, location) and vehicle system status observations (e.g., windshield wiper state, traction control, stability control), which can be used in conjunction with other datasets to infer weather and road conditions. For example, the prototype VDT includes a "road precipitation" algorithm that blends vehicle data elements (e.g., wiper status distribution, air temperature) with radar data, nearby weather station data, and weather model and satellite data. The end result is an indication of whether a road segment is experiencing "rain," "frozen precipitation," "mix," "road splash," or "none/virga." The road splash category occurs when precipitation is no longer falling, but the vehicles are still reporting significant wiper activity. On the other hand, the VDT classifies a "none/virga" condition even in the presence of radar returns if the precipitation is evaporating before it hits the ground because information is known about wiper usage. This type of derived data can provide critical information to the meteorological community that is not currently available in the traditional observational network.

DATA QUANTITY AND QUALITY. In comparison with fixed sensors, mobile observations provide both advantages and disadvantages. By their

Table 1. Weather-related vehicle data observations.

Observed data elements	
Barometric pressure	Rain (rain sensor)
Ambient air temperature	Sun (sun sensor)
Relative humidity	Pavement temperature
Input data elements	
Date (year, month, day)	Brake status
Time (hour, minute, second)	Brake boost
Location (lat/lon)	Accelerometer (lateral, longitudinal)
Elevation	Yaw rate
Vehicle heading	Headlight status
Vehicle velocity	Traction control
Hours of operation	Stability control
Wiper status	Rate of change of steering
Anti-lock braking system status	Impact sensor
Adaptive cruise control radar	Ambient noise level
Short-range wide beam radar	Camera imagery

very nature, mobile sensors offer the opportunity to collect information over a considerably larger territory than fixed sensors, and as mentioned previously, with millions of vehicles there is the potential to collect considerably more data from mobile as opposed to fixed sensors. However, the volume and anonymity of vehicle-based observations pose several challenges with respect to data integrity that must be addressed before these data will be broadly usable and acceptable. In a fully realized mobile observation network, the sheer volume of the observations will present challenges in data handling.

One solution for this issue is to statistically process and generate derived observations, which are valid along a given length of roadway. In the prototype VDT, these derived observations consist of all observations of one parameter (e.g., temperature, pressure) aggregated on a road segment over a designated period. In other words, the derived observations provide synthesized atmospheric and road conditions for a specific area and time. The default setting for the road segment length is 1 mile, and the default setting for the period is 5 minutes, but these settings are configurable. In terms of anonymity, metadata on fixed sensors usually provide instrument type and tolerances, and time-series information can be used to help diagnose problematic data. In the mobile world, the anonymity requirements preclude vehicles from sending identifying information. This could lead to problems in quality control. Therefore, a key component of using mobile observation data is to develop rigorous data filtering and quality-checking (QCh) routines. In the prototype VDT, some of the QCh routines are similar to those used at fixed weather-sensing stations. For example, the Sensor Range Test (SRT) and Climatological Range Test (CRT) are mobile versions of the tests run for the Clarus system. Nevertheless, vehicle data also pose additional QCh challenges. Outside air temperature measurements from vehicles may not be representative of the true ambient conditions if the vehicle speed is less than 25 mph or if measurements are collected from inside tunnels or other confined locations. As part of its QCh process, the VDT can filter out these observations. Additionally, the VDT QCh process determines whether an observation is similar to nearby vehicles and fixed weather stations, and evaluates the vehicle measurements with fine-resolution weather model and satellite data. Evaluating the quality of vehicle data and addressing quality issues as they arise will require an ongoing research and development effort across the weather community.

DISCUSSION AND SUMMARY. The potential use of vehicle data in weather-related applications and products for the surface transportation is being discussed within the weather and transportation communities. The availability of millions of vehicle observations would almost certainly lead to improvements in the diagnosis and prediction of adverse weather and road conditions. Moreover, technological improvements in the automotive industry will likely result in additional environmental and road-related data elements becoming available in the future.

One of the most important aspects of this discussion is that a significant amount of research will be required to understand the feasibility of using vehicle-based data, as the characteristics of the data will vary greatly between vehicle manufacturers, vehicle models of the same manufacturer, and sensor types and models. It is unlikely that any single vehicle-based data element will be able to stand alone as truth, as there will be too many uncertainties about their quality. Vehicle data will need to be processed in a statistical manner to address data outliers and to raise the overall confidence in data quality. The weather community has substantial experience combining multiple disparate datasets to derive products. Vehicle data will have to be treated in a similar manner. Additionally, issues of communication costs and data volume are not fully resolved. However, even with those caveats and concerns, we anticipate that vehicle data will contribute in a positive manner to the generation of improved weather and road condition products because of the large volume of data, distribution of observations, and frequent updates. The weather community is encouraged to participate in this exciting endeavor.

FOR FURTHER READING

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