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Thermodynamic and Wind Surveillance for Local High-Impact Weather Forecasting

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Abstract

It is widely recognized that more comprehensive boundary layer thermodynamic and wind data are needed to improve local weather modeling and high-impact nowcasting (1-3 hr) and forecasting. Public and private networks on international, regional and local scales are collecting these data using various commercial products. We present thermodynamic and wind observation examples, and describe emerging, existing and planned networks and applications.

Traditional Methods

Forecast indices derived from radiosonde soundings are traditionally used for local lightning, hail, rain, fog, gust front, turbulence, wind shear, air quality and icing risk short-term forecasting (nowcasting). Highest accuracy is obtained when radiosonde latency is low (less than one hour). Thereafter accuracy degrades, particularly during dynamic weather conditions. Traditional twice-daily radiosonde soundings are also routinely assimilated into models for numerical weather forecasting. However, more frequent boundary layer

thermodynamic and wind soundings are essential for accurate high impact local weather forecasting and nowcasting. The US National Academy of Sciences recommends creation of a national thermodynamic and wind profiling network to address this requirement¹.

Thermodynamic and Liquid Profiling

Microwave radiometer profilers provide continuous boundary layer thermodynamic soundings with radiosonde-equivalent observation accuracy². A comparison of radiometer and radiosonde soundings from nearby locations is shown in Figure 1.



Figure 1. Radiometer and radiosonde soundings during the 2010 Winter Olympics show good temperature and relative humidity agreement.³ Wind direction correlation with cloud liquid and upper level thermodynamics is clearly evident.

Sixteen days of 6-hr radiosonde and radiometer profiles show good agreement (top four panels) in spite of their 4 km horizontal and 170 m vertical separation (Figure 1). Wind (radiosonde) and liquid (radiometer) correlation is evident 12-17 and 23-28 Feb (bottom panel) when southwest wind advects moist maritime air up-valley where it condenses into

¹ US National Academy of Sciences 2008, 2010, 2012.

² Radiometrics MP-3000 (Güldner and Spänkuch 2001; WMO Guide, 2010).

³ Ware et al, 2013.

cloud liquid. Liquid condensation releases latent heat, increases upper-level temperature and humidity (evident in Figure 1, upper four panels), and generates precipitation. In contrast, northerly winds create the clear non-precipitating 17-23 Feb conditions.



Figure 2. Early stage convection is evident in radiometer data several hours before traditional detection in electric field gradient data⁴.

Microwave radiometers provide continuous high accuracy thermodynamic profiles in the boundary layer where thermodynamics plays a key role in initiation and development of convective storms⁵. At higher levels radiometer thermodynamic profile accuracy is to the error assigned to radiosondes when they are assimilated in numerical weather models. This key role is evident in radiometer-derived soundings, and in forecast indices derived from those soundings, that provide forecasters with continuous information heretofore unavailable. Such information can be used to provide far better short-term predictions and forecasts of local high-impact convection and other hazardous weather as compared to traditional twice a day radiosonde derived soundings (Figure 2).

⁴ Madhulatha et al, 2013.

⁵ Crook, 1996.

Radiometer soundings and derived forecast indices during severe weather that killed 22 and knocked out power for five days in Washington, D.C., are shown in Figure 3. Radiosonde derived CAPE at 12Z on June 29th was near zero yet several hours later it had grown to nearly 5,000 J/kg as evident in the radiometer data, indicating highly unstable conditions that fueled the destructive severe weather that followed.



Figure 3. Radiometer profiles and forecast indices, and radiosonde-derived forecast indices (stars).

Wind Profiling

Frequent boundary layer wind and thermodynamic soundings are required for accurate high impact local weather forecasting⁶. Wind radars can be combined with radiometers to satisfy this requirement⁷. Example wind and thermodynamic soundings with derived forecast indices and tools at Los Angeles International Airport (LAX) are shown in Figure 4. Continuous wind and thermodynamic sounding systems provide fog, wind shear and turbulence alerts at international airports, lightning risk assessment⁸ at space launch facilities, and for fire weather and electric load forecasting (Figure 5).

⁶ US National Academy of Sciences 2008, 2010, 2012.

⁷ Beran, 1998; Clifford, 1994; Benjamin, 2004.

⁸ Ratnam et al, 2013; Madhulatha et al, 2013; Cimini et al, 2014; Koch et al, 2016.



Figure 4. Wind and thermodynamic soundings at LAX, 00Z 3 Mar 2016.



Figure 5. Mobile Radar Wind and Thermodynamic Profiling System operated by San Diego Gas & Electric for fire weather and electric load forecasting.⁹

⁹ ABC 10 News, <u>SDG&E Unveils High Wind Warning System</u>, 2015.

Aviation Weather

An Aviation Weather Decision Support System¹⁰ at the Dubai International Airport derives automated nowcasts, alerts and warnings for fog, low-level wind-shear, squalls, microbursts, inversions, gust fronts and sea breeze fronts from radiometer and wind radar observations.¹¹ Specifically, radiometer temperature and humidity data were used to reduce fog forecast false alarms by 50%, in particular during conditions locally called *too humid for fog*. On numerous occasions, the radiometer detected a saturated layer more than a thousand feet deep that reduced nocturnal radiative cooling and prevented fog formation. The radiometer also provides liquid profiles, identifying stratus clouds that modulate radiative cooling. Similar aviation weather decision support systems are operational at an increasing number of international airports.



Figure 6. Storm Character and Category tools (left panel) derived from combined radiometer, wind radar and gridded analysis identified strong storm and multicell risk hours before multiple local tornadoes touched down.

Combining Profiles with Gridded Analysis

Radiometer, wind radar and numerical weather model gridded analysis can be combined using variational methods to optimize thermodynamic and wind profile accuracy¹². Continuously updated traditional forecast tools and indices derived from variational analysis can improve high-impact local weather forecasting. For example, wind and thermodynamic

¹⁰ Barrere et al, 2008.

¹¹ Thomas, 2008.

¹² <u>http://radiometrics.com/live-data</u>

soundings combined with gridded analysis are shown in Figure 6 hours before multiple tornadoes touched down in Denver, Colorado. Additional radiometer observations and analyses in the vicinity of tornadoes have been reported¹³.

Thermodynamic and Wind Profiling Networks

Thermodynamic and wind profiling networks are emerging in Asia, Europe¹⁴ and the Americas. For example, the New York State Mesonet (NYSM)¹⁵ includes 125 state-of-theart environmental monitoring stations serving as the foundation for a statewide early warning severe weather detection system. It measures low level temperature, humidity and wind, soil moisture and temperature, solar radiation, and rain and snow precipitation amounts. Seventeen of the NYSM stations are enhanced with remote sensing instrumentation to capture vertical profiles of temperature, relative humidity, three-dimensional wind speed, boundary layer height and cloud base height (Figure 7).



Figure 7. NYSM includes 17 wind and thermodynamic profilers.

The NYSM thermodynamic and wind soundings will be used to generate continuously updated forecast indices and tools and will also be assimilated in high-resolution models to improve high-impact weather forecasting.

¹³ Araki et al, 2014; Koch et al, 2016.

¹⁴ Cimini et al, 2014.

¹⁵ <u>http://www.nysmesonet.org</u>

Summary

Continuous thermodynamic and wind soundings can be combined with model gridded analysis using variational methods to obtain continuous high accuracy radiosonde-like soundings of the entire troposphere and above. Time series of traditional forecast indices derived from the resulting variational soundings are powerful new tools for local high impact weather forecasting and nowcasting. Alternatively, the thermodynamic and wind soundings can be assimilated into numerical weather models¹⁶.

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¹⁶ Shaw et al, 2008.

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