Wind and Thermodynamic Profiling for High-Impact Local Weather Nowcasting and Forecasting

Forecast indices derived from radiosonde soundings are traditionally used to forecast and nowcast local lightning, hail, rain, fog, gust fronts, turbulence, wind shear, air quality and icing risk. Highest accuracy is obtained by this method when radiosonde latency is low (an hour or so). Thereafter accuracy degrades, particularly during dynamic weather conditions. Traditional twice-daily radiosonde soundings are also routinely assimilated into models for numerical weather forecasting. However, it is widely recognized that more frequent boundary layer thermodynamic and wind soundings are required as a key ingredient to be able to provide accurate forecasts and nowcasts of high impact local weather. The US National Academy of Sciences recommends creation of a national thermodynamic and wind profiling network to address this requirement[1].

Thermodynamic Profiles

Microwave radiometer profilers provide continuous high-accuracy upper air thermodynamic soundings[2]. A comparison of simultaneous radiometer and radiosonde soundings from nearby locations is shown in Figure 1.

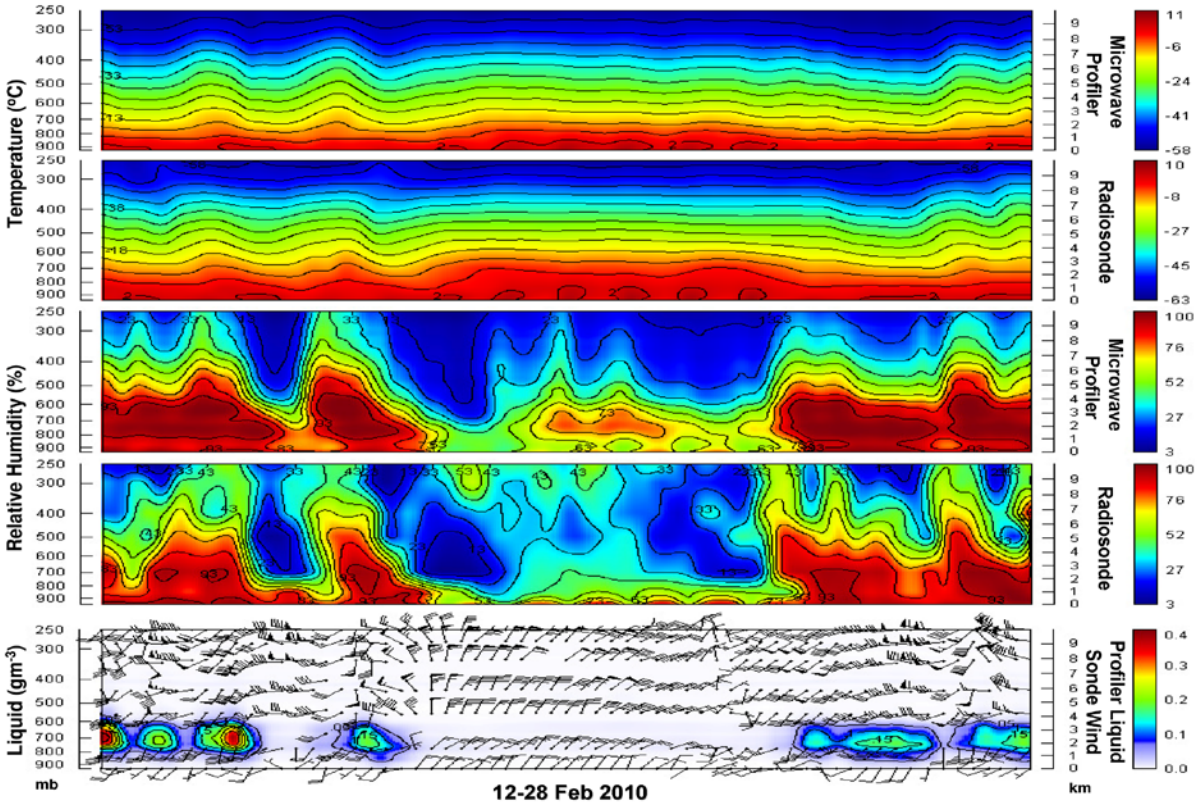

Figure 1. Microwave radiometer and radiosonde soundings during the 2010 Winter Olympics show good temperature and relative humidity agreement.[3] Wind direction correlation with cloud liquid and upper level thermodynamics is clearly evident.

[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; RAOB image (www.raob.com).

In Figure 1, 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. 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 cloud liquid. In general (as seen in Figure 1), liquid condensation releases latent heat, increases upper-level temperature and humidity, and generates precipitation. In contrast, northerly winds and clear non-precipitating conditions are seen 17-23 Feb.

Microwave radiometers provide continuous high accuracy thermodynamic profiles in the boundary layer where thermodynamics plays a key role in initiation and development of convective storms[4]. At higher levels radiometer thermodynamic profiles gradually approach the climatology of the historical radiosondes used to prepare the profile retrieval algorithm. This key role is evident in radiometer-derived soundings, and indices derived from those soundings, that provide forecasters with information heretofore not available. Such information can be used to provide far better short-term predictions and forecasts of local high-impact convective and other hazardous weather as compared to traditional twice a day radiosonde derived soundings (Figure 2).

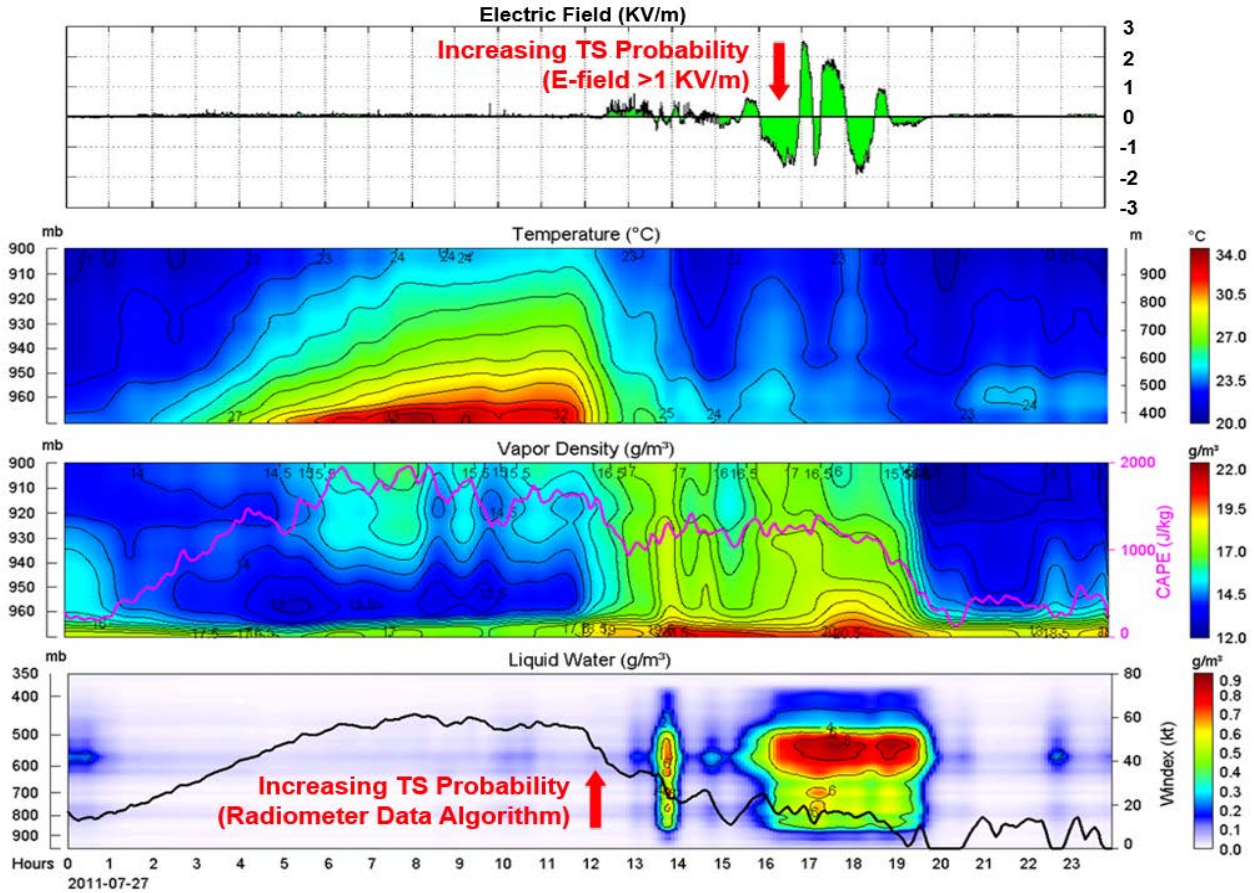

Figure 2. Increasing Severe Thunderstorm (TS) Probability advisories from electric field and thermodynamic measurements[5].

[4] Crook, 1996.

[5] Madhulatha et al, 2013; RAOB analysis and display (www.raob.com).

Radiometer soundings and derived forecast indices during severe weather that killed 22 persons and knocked out power for five days in Washington, D.C., are shown in Figure 3. An important point shown is that radiosonde derived CAPE value from 12Z on June 29th was near zero yet in just a couple of hours CAPE had grown to over 3,000 J/kg as evident in the radiometer data, providing significant instability for severe storms that may not have been known without the radiometer data.

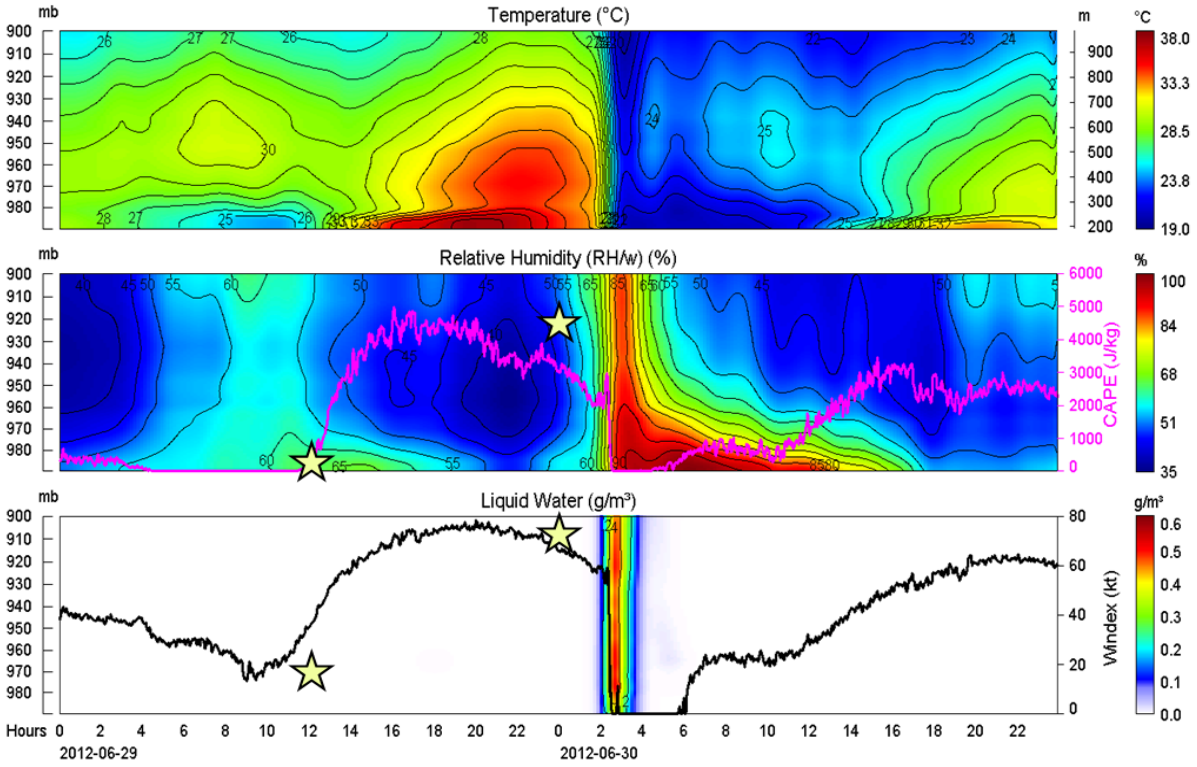

Figure 3. Radiometer profiles with radiometer and radiosonde (stars) derived forecast indices[6].

Radiometer + Gridded Analysis

Boundary layer thermodynamics in numerical weather models is notoriously poor, particularly during dynamic conditions, due to inadequate observational data. However, high thermodynamic accuracy can be obtained in the boundary layer and above by combining radiometer and model gridded analysis using one-dimensional variational analysis (1DVAR)[7]. *Sigma Soundings* that automatically combine radiometer with gridded analysis, providing continuous high accuracy tropospheric thermodynamic and wind profiles are now available[8]. Continuously updated traditional forecast tools and indices derived from these profiles can be used by forecasters and mesoscale modeling systems to generate more accurate and timely high-impact local weather predictions and alerts[7]. An example *Sigma Sounding* at a time when tornadoes occurred nearby is shown in Figure 4. Radiometer observations and analysis in the vicinity of other tornadoes have been reported[9].

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[6] RAOB image.
[7] Hewison, 2006; Cimini 2010, 2011, 2014; Araki et al, 2014.
[8] www.radiometrics.com
[9] Araki et al 2014; and Koch et al, 2014.

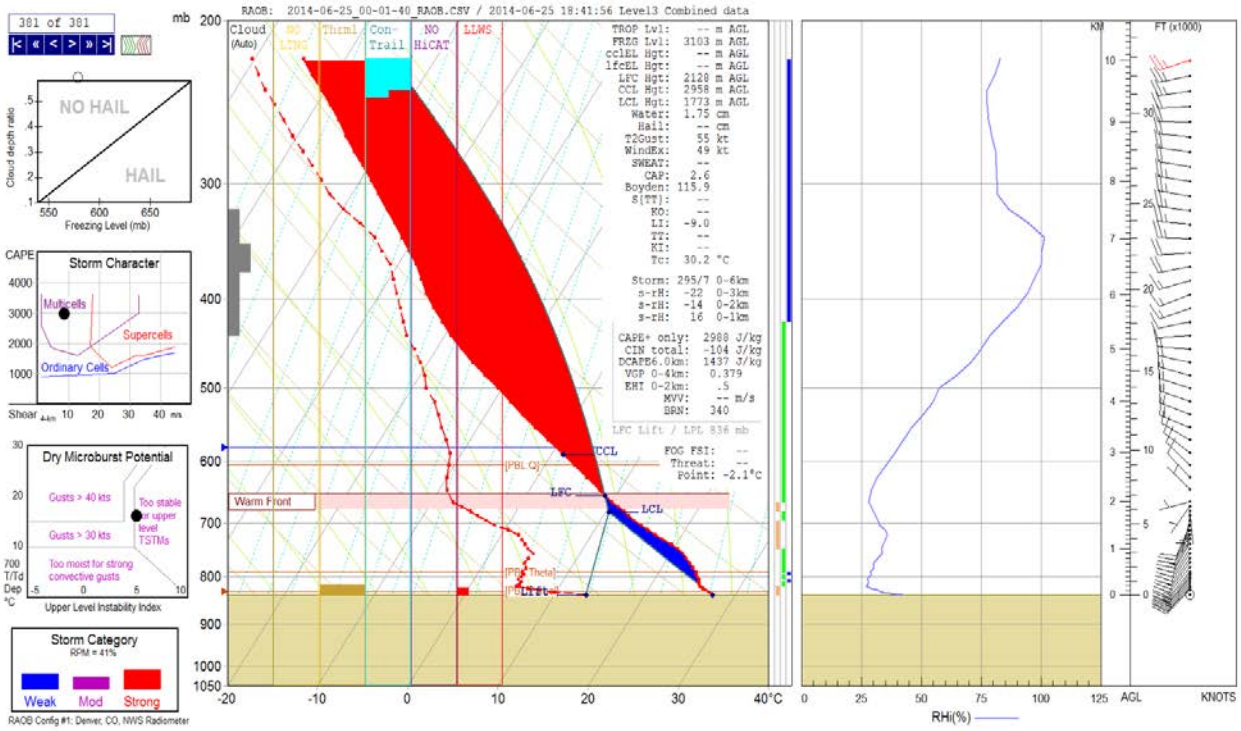

Figure 4. *Sigma Sounding* from a US National Weather Service radiometer at Denver, Colorado[10], several hours before multiple tornadoes were reported nearby.

Wind Profiles

More frequent boundary layer thermodynamic and wind soundings are required for accurate high impact local weather forecasting[11]. Wind profiling radars satisfy this requirement, by providing continuous high-accuracy upper air wind soundings of the boundary layer, or in larger configurations up to 18 km height[12]. They can operate in fixed locations or on mobile trailer platforms (Figure 5). Continuous wind and thermodynamic sounding systems are in use at international airports to provide fog, wind shear and turbulence alerts, at space launch facilities for lightning risk assessment[13], and for other high impact local weather applications.

Aviation Weather

The Aviation Weather Decision Support System (AWDSS)[14] operated by the Dubai International Airport uses radiometer and wind radar observations to provide "automated real-time nowcasts in the form of alerts and warnings for fog, low-level wind-shear, squalls, microbursts, inversions, gust fronts and sea breeze fronts".[15] Specifically, radiometer measurements of boundary layer temperature and humidity were used to reduce fog forecast false alarms by 50%, in particular during conditions

[10] Real time display: http://173.164.54.41/denver.htm (RAOB software).
[11] US National Academy of Sciences 2008, 2010, 2012.
[12] Beran, 1998; Clifford, 1994; Benjamin, 2004.
[13] Ratnam et al, 2013; Madhulatha et al, 2013; Cimini et al, 2014; Koch et al, 2014.
[14] Barrere et al, 2008.
[15] Thomas, 2008.

locally called ‘too humid for fog’. On numerous occasions, the radiometer detected a humid boundary layer more than a thousand feet deep that reduced nocturnal radiative cooling and prevented fog formation. The radiometer also provides accurate liquid profiles[16] identifying stratus clouds that further limit radiative cooling[14].

Figure 5. Mobile Radar Wind and Thermodynamic Profiler (RWTP)[17].

Summary

Continuous thermodynamic and wind remote soundings are emerging as powerful new tools for high-impact local weather nowcasting and forecasting. These soundings can be combined with model gridded analysis to obtain the full suite of continuously updated traditional forecast tools and indices. Alternatively, the soundings can be assimilated into models for numerical forecasting[18].

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