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Humidity Mapping and High-Impact Local Weather Prediction

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Abstract

Early stage convection can be predicted using continuous Forecast Indices derived from microwave radiometer thermodynamic soundings. Prediction can be extended to regional scale using three-dimensional humidity mapping via combined GNSS[1] and radiometer observations. We present radiometer observations preceding a catastrophic convective storm that struck Washington, D.C., a radiometer method for lightning prediction two-hours in advance, and radiometer observations of strong tornadogenesis. Finally, we discuss GNSS and radiometer networks that present opportunity for humidity mapping and improved local high-impact weather prediction.

Convective Storms

Convection is initiated when humid air is lofted by converging winds, thermals, or wind passage over rising terrain. Expansion and cooling of the lofted air induces liquid condensation. Latent heat released during condensation creates buoyancy and draws underlying humid air upward, inducing additional condensation and

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[1] Global Navigation Satellite System

heating. During typical convection, ten cubic meters of air releases roughly the amount of energy in a cubic centimeter of gasoline, generating the familiar mushroom-shaped convective storm cloud. Total thirty minute energy release during a typical convective storm is tens of kilotons of TNT (similar to nanosecond energy release by historical atomic bombs).

Thermodynamic and Wind Profiling

Radiosondes traditionally provide twice-daily temperature, humidity and wind soundings. These soundings are routinely assimilated into numerical weather models and are also used to generate Forecast Indices for local weather forecasting. However, radiosonde temporal and spatial sampling are typically inadequate to forecast convection and other local high impact weather events that develop on time scales of hours.

Boundary Layer Measurements

It is widely recognized that more frequent boundary layer thermodynamic and wind observations are needed to improve local high impact weather forecasting. The U.S. National Research Council recommends a 400-site boundary layer thermodynamic and wind monitoring network in the continental U.S.[2] () to reduce the >$100 billion per year local severe weather impact on the U.S. economy[3].

Severe Thunderstorm

A severe thunderstorm produced torrential rains and wind gusts approaching 150 km/hr in Washington, D.C., on the evening of June 29, 2012, causing 22 deaths and widespread damage that left millions without power for nearly a week. Thermodynamic observations from a nearby private radiometer network[4] show extremely unstable conditions (CAPE=5,000 J/kg) and high wind (Windex=80kt=100 mph) potential more than six hours before severe weather onset (**Figure** 1). Also shown are CAPE and Windex derived from radiosonde soundings at Dulles, VA, 20-km from Washington D.C. (stars). Radiosonde and radiometer CAPE and Windex values show good agreement. The six hour advance indication of severe weather risk is clearly evident, illustrating the value of continuous thermodynamic

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[2] U.S. National Research Council, 2008.

[3] Lazo et al, 2011.

[4] http://earthnetworks.com/Products/BoundaryLayerNetwork.aspx

measurements for local high impact weather forecasting.

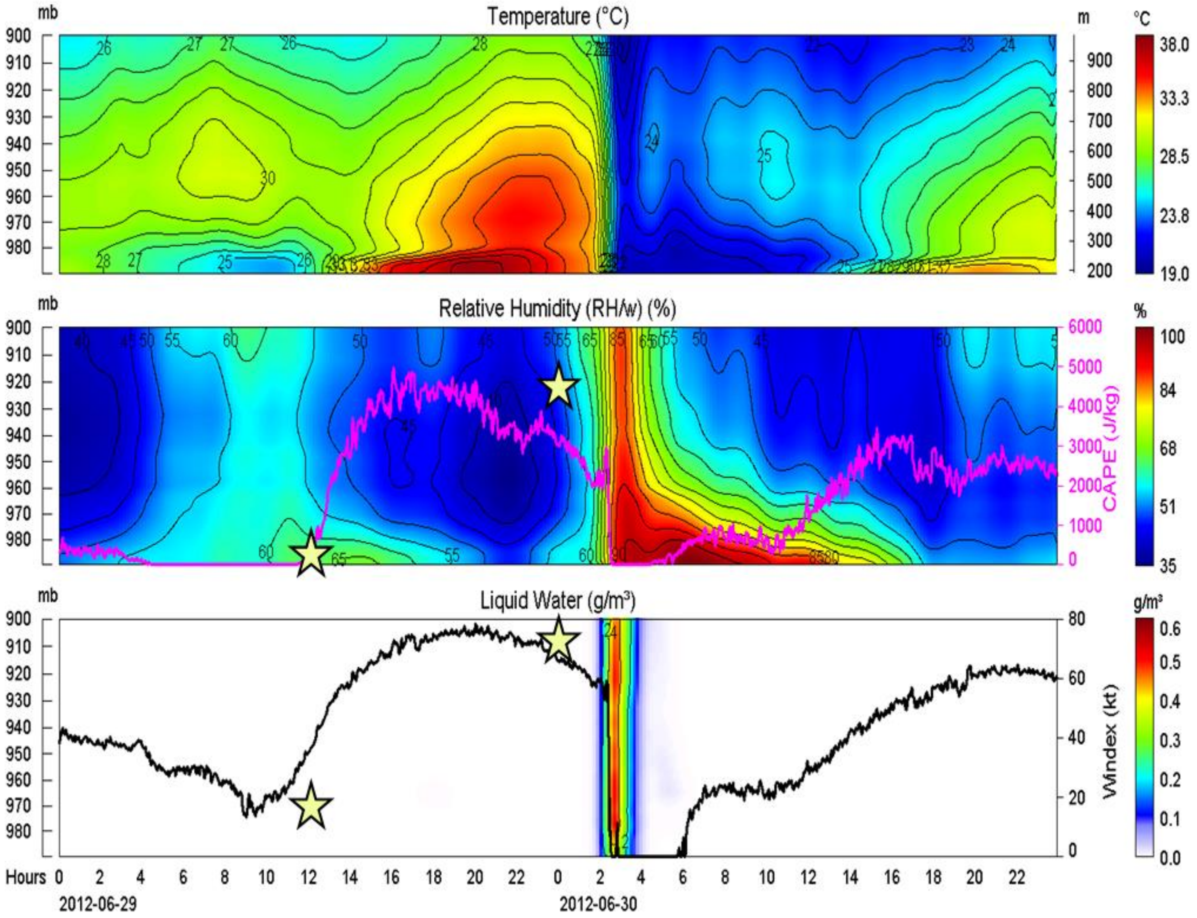

Figure 1. Radiometer profiles and radiometer and radiosonde (star) CAPE and Windex.

Forecast indices derived from nearby radiosonde and radiometer soundings[5] are shown in Table 1.

Table 1. Radiosonde and radiometer derived Forecast Indices.

Date Time	Sensor	CAPE[6] (J/kg)	Windex[7] (kt)
29Jun12 12Z	Radiometer	0	26
	Radiosonde	125	18
30Jun12 00Z	Radiometer	3,465	62
	Radiosonde	4,409	71

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[5] Radiosonde and radiometer locations are <30 km from Washington, D.C.

[6] Moncrieff and Miller, 1976.

[7] McCann, 1994.

Lightning Prediction Hours in Advance

Electric field mill measurements are widely used at space launch facilities for lightning risk assessment[8]. The India Space Research Organization (ISRO) compared radiosonde and radiometer-derived stability indices and reported good agreement[9]. They collected side-by-side electric field mill and radiometer data during more than two dozen convective lightning storms and developed a lightning risk algorithm based on radiometer-derived stability indices.

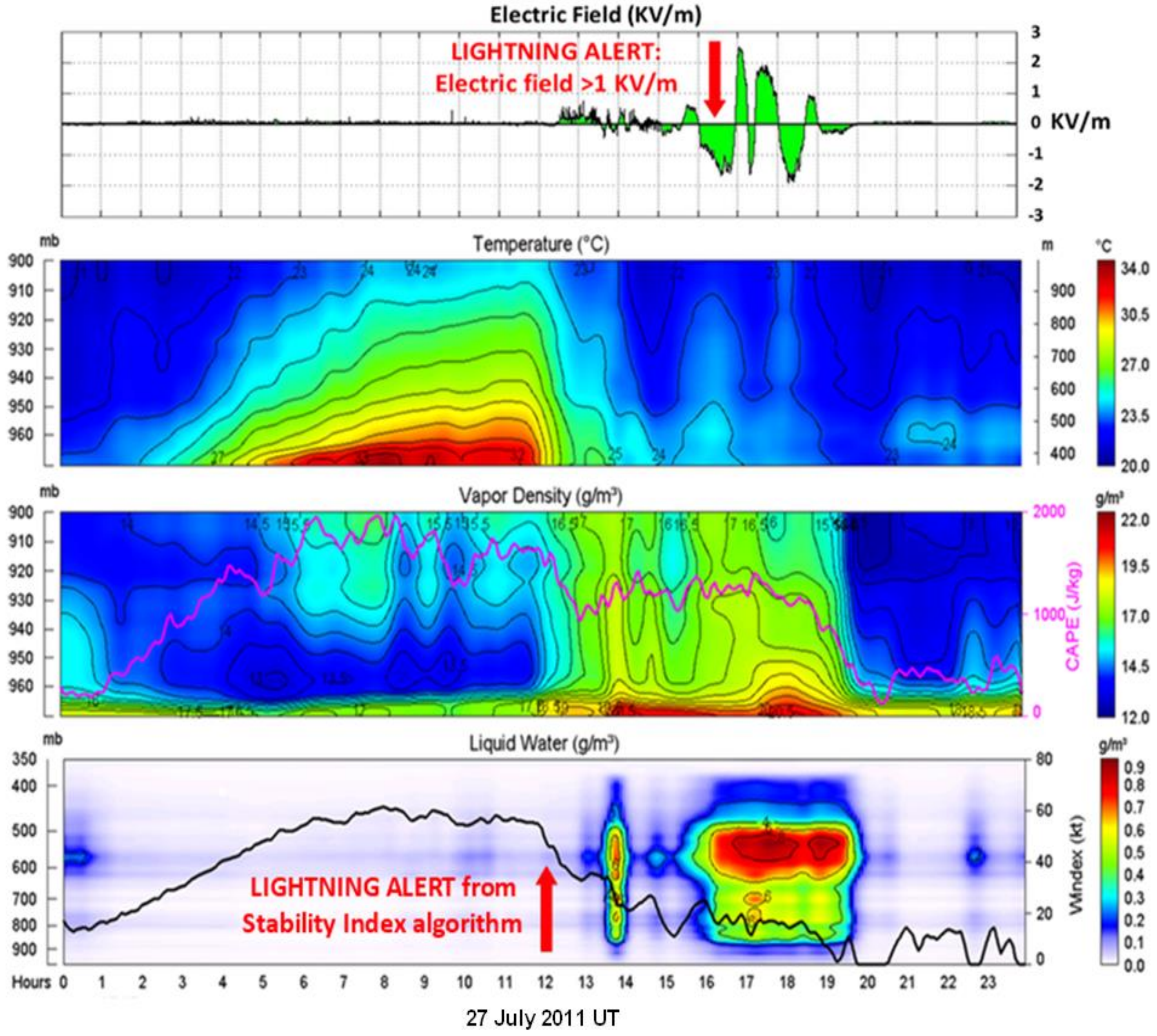

Figure 2. Lightning alerts from electric field and thermodynamic measurements.

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[8] Evans and Velkoff, 1972.

[9] Ratnam et al, 2013.

ISRO applied the algorithm to nine independent storm cases and demonstrated lightning risk prediction more than two hours in advance[10]. ISRO now operates a radiometer for lightning risk assessment at its Sriharikota Rocket Launch Range. Electric field mill data are shown in Figure 2, along with collocated boundary layer thermodynamic measurements. At 1615 UT the electric field exceeded 1 kV/m, a threshold that mandates a scrub decision for India space launch operations. CAPE and Windex are superimposed on the contour plots in the bottom two panels. These indices fall by nearly 40% from 1200 to 1300 UT, accompanied by large boundary layer temperature and vapor density changes, preceding the electric field gradient alert by more than three hours.

Three Dimensional Humidity Mapping

Humidity convergence during early stage convection can be detected in radiometer and GNSS data before it generates lightning hydrometeors detectable by radar[11]. Integrated water vapor along receiver-satellite lines-of-sight (slant water vapor) can be estimated from ground-based GNSS receiver and surface meteorological data[12]. Water vapor tomography methods combine GNSS and radiometer observations for three-dimensional humidity mapping and detection of early stage convection[13].

Tornadic Supercell Analysis

A supercell tornado passed within 14 km of a radiometer at Tateno, Japan, on 6 May 2012. Doppler radar and radiometer 1DVAR[14] hydrometeor density (rainwater, snow and graupel) analysis are shown in Figure 3. Ten forecast indices were derived from 1DVAR soundings for this study. Ninety minutes before the tornado, the convective available potential energy increased significantly. At the time of minimum distance to the supercell, low-level vertical wind shear and some composite parameters were consistent with supercell activity. Hook echoes are evident in the radar and 1DVAR hydrometeor analysis. High resolution humidity field analysis from a 17-km grid GNSS network[15] shows a pattern similar to the

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[10] Madhulatha et al, 2013.

[11] MacDonald et al, 2002; Liu and Xue, 2006; Bauer et al, 2011.

[12] Ware et al, 1997, 2000.

[13] MacDonald et al, 2002.

[14] Hewison, 2006; Cimini et al, 2011, 2015; Ishimoto, 2014.

[15] Shoji et al, 2014.

hydrometeor density analysis in Figure 3(b). This case study demonstrates realistic tornado analysis when continuous radiometer data are assimilated, with promise for further improvement if GNSS-derived humidity maps are included.

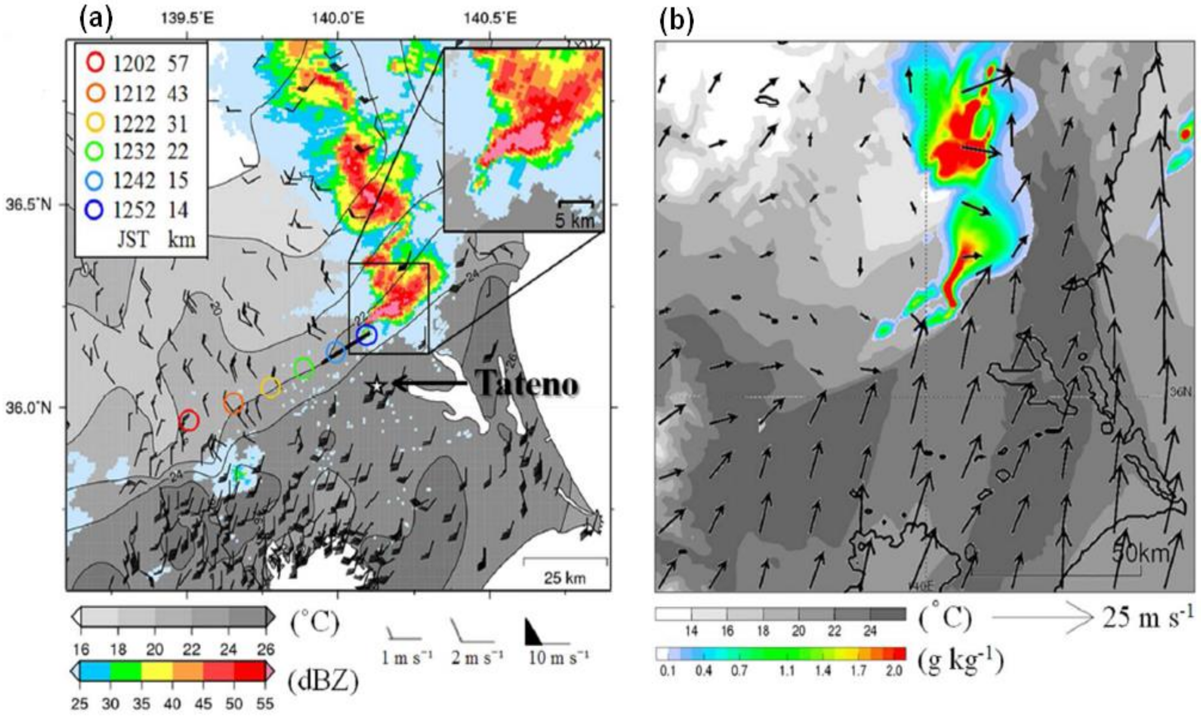

Figure 3. Radar observations (a), and analysis (b) including radiometer data. Hook echoes are evident in (a) with time and distance from Tateno indicated by colored circles, and in (b) at 12:45 JST[16].

Hazardous Weather Testbed

The NOAA Hazardous Weather Testbed[17] evaluates the operational utility of new science, technology and products. A principal experimental objective is improved understanding of convective initiation[18]. Radiometer and GNSS data are being collected in the Dallas-Ft. Worth region during spring 2015 (Figure 4). Network station density is roughly 50 km, adequate for three-dimensional humidity mapping and detection of moisture convergence associated with early stage convection[19].

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[16] Araki et al, 2014.

[17] http://hwt.nssl.noaa.gov/spring_experiment

[18] Kain et al, 2013.

[19] MacDonald et al, 2002.

Evaluation of two and three dimensional humidity mapping derived from GNSS and radiometer observations is underway.

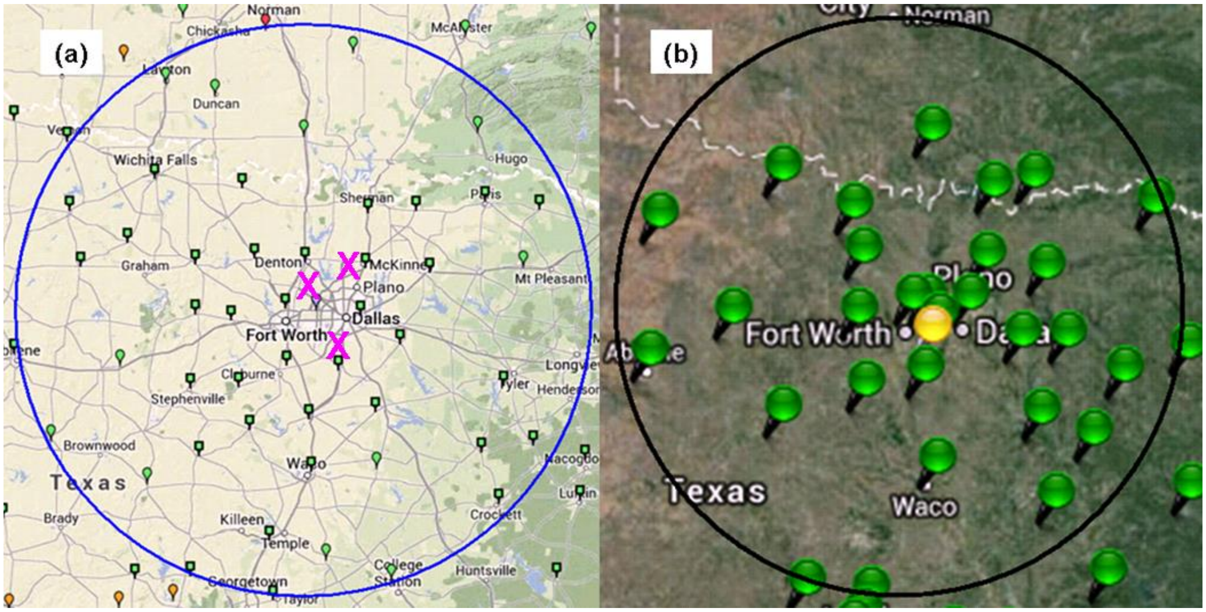

Figure 4. Public (a) and private (b) GNSS stations and private radiometer stations (X) within 250 km of Dallas-Ft. Worth.

Summary

Detection of early stage convection using radiometer and GNSS slant water vapor observations shows promise. We presented radiometer thermodynamic data associated with early stage convection, radiometer-derived lightning prediction hours in advance of electric field gradient methods, and combined radar and radiometer observations of a supercell tornado, and described ongoing experiments seeking convective initiation signatures in radiometer and slant GNSS data.

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