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Continuous thermodynamic and wind profiling for improved short-term weather forecasting

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ABSTRACT

Skill levels of 1-12 hour weather forecasting are notoriously poor. Reasonably accurate forecasts can be obtained during the first hour by assuming no change in weather. However, forecast skill rapidly degrades until initialization with new radiosonde observations typically 12 hours later. This situation can be improved using thermodynamic and wind profiling, and slant GPS observations. Wind profiling is widely used in weather research and operational forecasting. Thermodynamic profiling of temperature, humidity and cloud liquid is a mature research technology that is moving toward operational use. Local profile observations can be extended to regional scale using slant GPS observations. We compare local forecasts and radiosondes with thermodynamic and wind soundings. We summarize the latest slant GPS research results and their potential impact on regional three-dimensional wind and moisture analysis. Applications for improved short-term forecasting include boundary layer dispersion, airport operations, agriculture, construction, and outdoor events.

Keywords: microwave radiometer, wind profiler, short-term forecasting, dispersion, slant GPS

1. CONTINUOUS THERMODYNAMIC AND WIND PROFILING

Thermodynamic and wind profiling are mature technologies with applications in high-resolution weather modeling and forecasting. Examples of mobile boundary layer wind, temperature, humidity and cloud liquid profilers are shown in Figure 1.

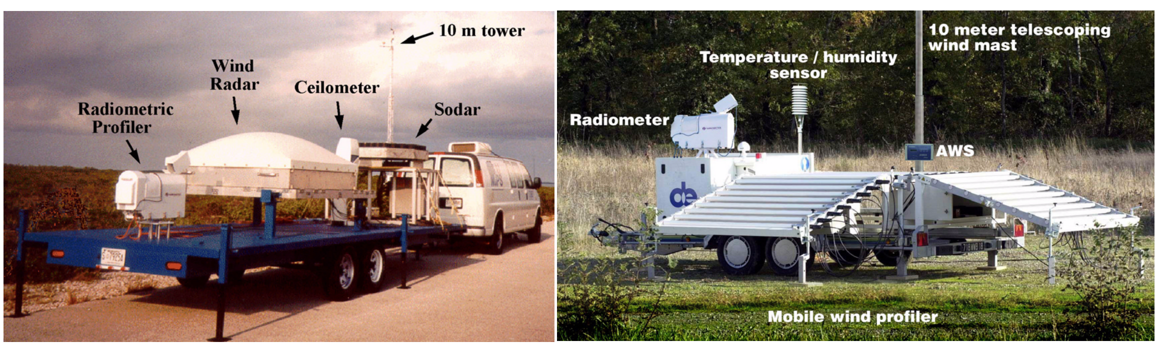

Figure 1. Mobile wind radar and radiometric profilers designed for research (http://vortex.nsstc.uah.edu/mips) and commercial applications (http://www.meteo.degreane.fr).

Thermodynamic and wind soundings can improve high-resolution dispersion and short-term precipitation modeling and forecasting (Nehrkorn et al., 2001). Example soundings obtained from stationary radar and radiometric profilers are shown in Figure 2. Also shown for comparison are radiosonde and 24-hr forecast (MM5) profiles. The combined wind and thermodynamic profile observations improved the calculated accuracy of long-range (30 km) artillery miss distances to 93 m, compared to 219 m for corrections based on 24-hr forecasts (Ware and Solheim, 2002). Larger improvements are expected in more remote and topographically complex locations where forecasts are likely to be less accurate.

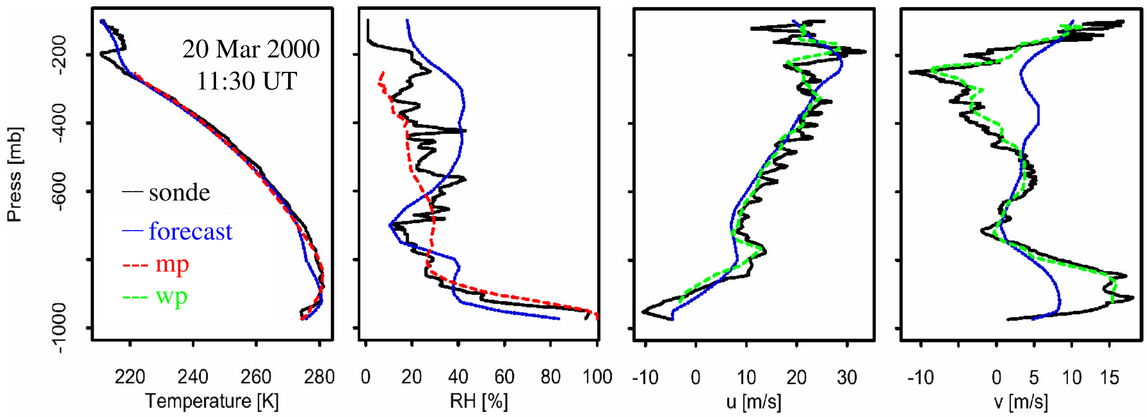

Figure 2. Example thermodynamic (microwave profiler - mp) and wind profiler (wp) observations compared with radiosonde and forecast (MM5) profiles at Lamont, Oklahoma.

A comparison of forecast and radiometric profiles at Boulder, Colorado, during an upslope weather condition including dense fog is shown in Figure 3 (Ware et al., 2002). The 10-km MM5 (http://rain.mmm.ucar.edu/mm5) analysis and forecast missed the fog event.

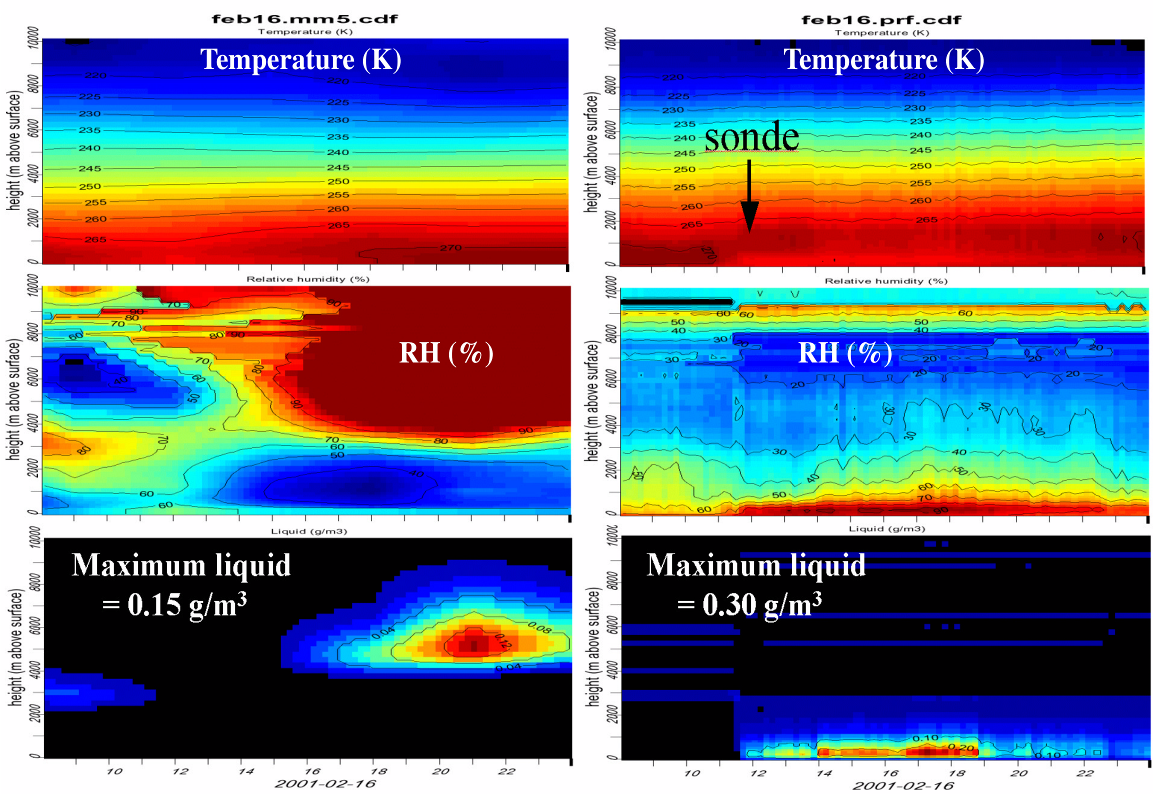

Figure 3. Forecast (MM5 - left) and radiometric profiles at Boulder, Colorado on 16 February 2001. Dense fog was observed by the radiometer that was not forecast. A radiosonde observation at Denver, Colorado (~50 km southeast of Boulder) at the time indicated in the upper right plot is shown in the following figure.

A radiosonde sounding from Denver (50 km southeast of Boulder) observed saturation from ground-level up to ~500 m height consistent with fog (Figure 4). This event caused the diversion of flights from Denver International Airport for 18 hours. We expect local short-term forecast improvements (including fog and precipitation) with proper assimilation of radiometric soundings.

Thermodynamic soundings provide accurate, continuous data (Güldner and Spänkuch, 2001) needed to improve local high-resolution modeling and forecasting. Complementary measurements that have the potential to extend forecast improvements to regional scales are provided by low elevation angle GPS observations. "Slant GPS" observations close to zero degrees elevation extend more than one hundred km in the boundary layer (Figure 5).

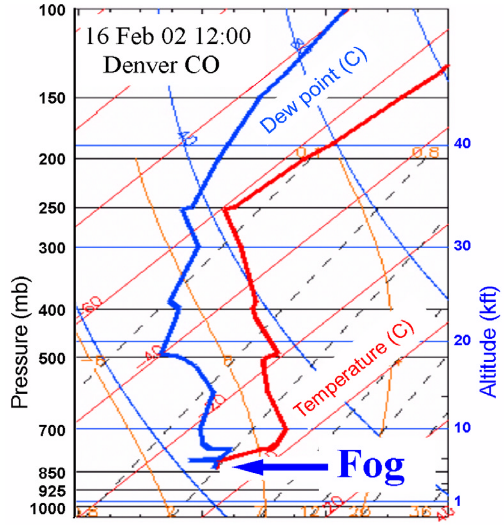

Figure 4. Radiosonde observation at Denver, Colorado on 16 February 2001 showing saturation from dense fog, consistent with radiometer observations of fog shown in the previous figure.

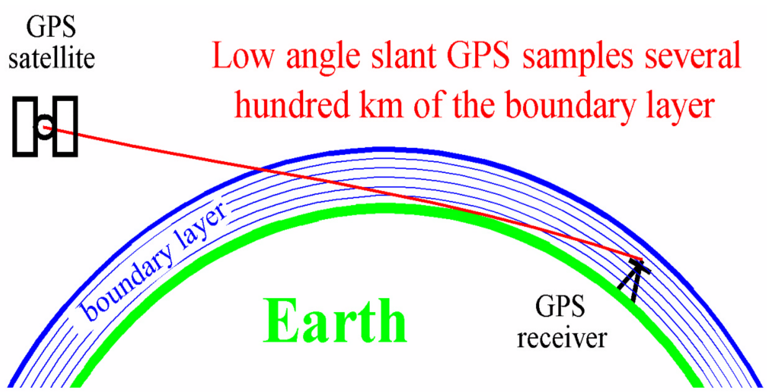

Figure 5. Slant GPS methods provide accurate regional measurements of boundary layer refractivity. These measurements have the potential to extend local thermodynamic and wind profile observations to regional scales.

Slant GPS measurements are particularly sensitive to the moisture field (MacDonald et al., 2002), but they also contain information on temperature and wind fields (MacDonald et al., 2001). Slant GPS measurements of integrated water vapor are accurate to 1.4 mm above 10 degrees elevation, as determined by comparison with pointed radiometers (Braun et al., 2001; 2002). Below 2 degrees elevation slant GPS observation error is less than 1% (Pany, 2002).

Example slant GPS measurements are shown in Figure 6 (http://www.gst.ucar.edu/gpsrg/realtime). Satellite ground tracks as low as 4 degrees elevation are shown as smooth green curves, plotted vs. elevation (zenith at center, horizon at circumference) and azimuth angles. Unmodeled residuals are shown (blue - more water vapor, red - less water vapor). Sky plots are divided into 8 three hour intervals per day. The fourth interval (9-12 UT) is shown in this plot for days 112 and 113. Day to day variability in temporal-spatial water vapor distribution is evident. Sky plots of residual GPS slant delay are also available via http://www-gpsg.mit.edu/~tah/cont98g/cont98.html.

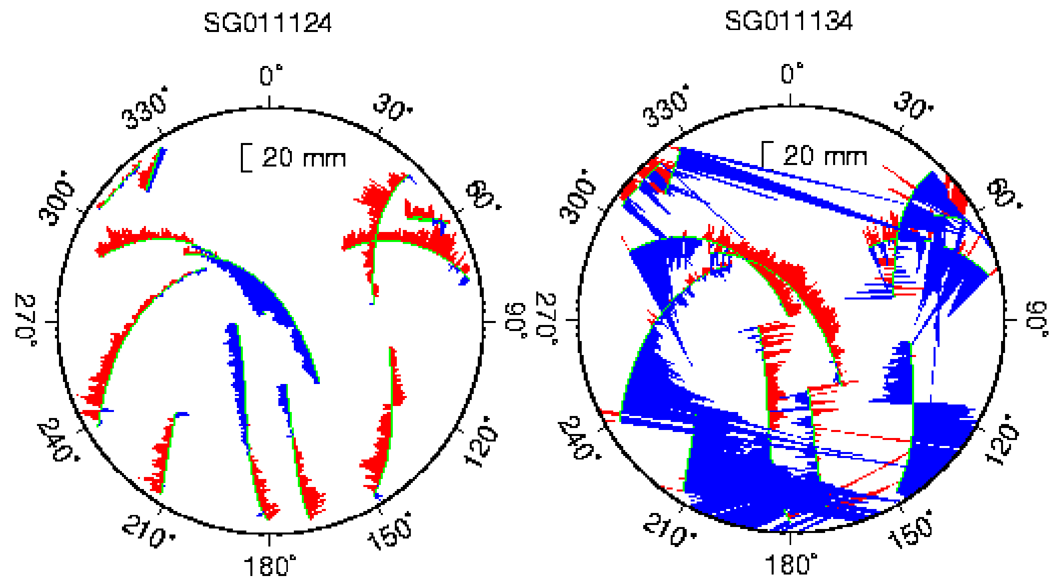

Figure 6. Example "sky plots" of residual GPS slant delay measurements near Lamont, Oklahoma, on 22-23 April, 2002. Weather conditions were stable and clear (left), and active with clouds and convection (right).

2. CONCLUSIONS

Radar and GPS (active) and radiometric (passive) ground-based microwave remote sensing can be used to improve short-term modeling and forecasting. In particular, thermodynamic and wind profiler soundings can improve local dispersion and short term precipitation forecasting. By including slant GPS observations, local forecast improvements can be extended to regional scale.

3. ACKNOWLEDGEMENTS

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