Ground-Based Remote Sensing Techniques for Space Launch Decision Support

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Abstract. Space launches are becoming increasingly more frequent. Launch safety and efficiency requires timely and accurate wind and thermodynamic profiles from the surface to 20 km or more in height as well as identification of launch hazards such as the risk of triggered and natural lightning. Ground-based remote sensing techniques including radar wind profilers (RWP) and microwave thermodynamic profilers (MTP) can provide continuous and accurate representation of the atmosphere along the launch trajectory in both clear and cloudy conditions. Reliably reaching 20 km in altitude is challenging especially for the MTP technology. However, when blended with model analyses such as the Rapid Refresh (RAP) model, profiles can be extended to 20 km and beyond. In this paper we explore an innovative decision support system that combines thermodynamics from MTP instruments, Doppler wind radar profiles and RAP soundings to produce continuous radiosonde-like observations. This information also has the potential to support launch operations by providing the decision support team with continuous Launch Commit Criteria parameters.

Launch Processing and Weather

Space launch activities can be divided into two broad categories – ground processing and launch processing. Launch processing, especially Day of Launch (DOL) activities, dominate. However, when considering overall costs and schedules, ground processing activities are significant. Many of these activities, such as vehicle assembly and testing, and propellant loading, are vulnerable to weather conditions. Daily quantification and accurate timing of threats from lightning, heavy precipitation and high winds are important for scheduling, as well as personnel and resource protection. Figure 1 shows Eastern Range weather impact statistics.

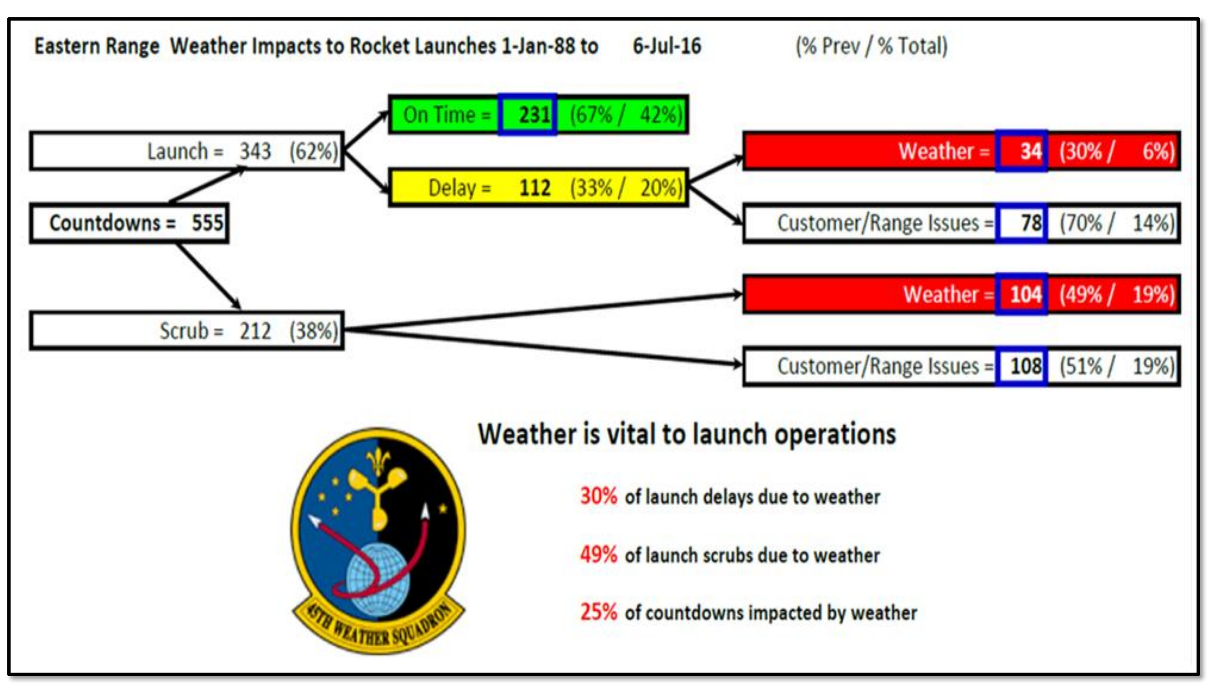

Figure 1. Weather impacts to DOL activities at the Eastern Range. Compiled by the 45th Weather Squadron, Patrick AFB.

Every vehicle design has physical limits that restrict acceptable launch conditions. As a vehicle accelerates after launch, dynamic pressures peak at an altitude where atmospheric density and vehicle speed produce maximum dynamic pressures usually at 10-12 km in altitude. Thus, part of the launch decision process must consider the vehicle steering program, the DOL wind profile, and atmospheric density profile. In addition to vehicle loads analyses, some weather conditions must be evaluated before launch to protect the vehicle from triggered and natural lightning.

Balloon Borne Measurements

Currently, most space launch programs rely exclusively on balloon borne thermodynamic and wind soundings on day of launch (DOL). The balloon soundings are then used to model vehicle atmospheric stress and to help characterize lightning risk. However, balloon based soundings have some limitations. In addition to being manpower intensive, the balloons take an hour or more to reach altitude, and drift with the wind (Figure 2).

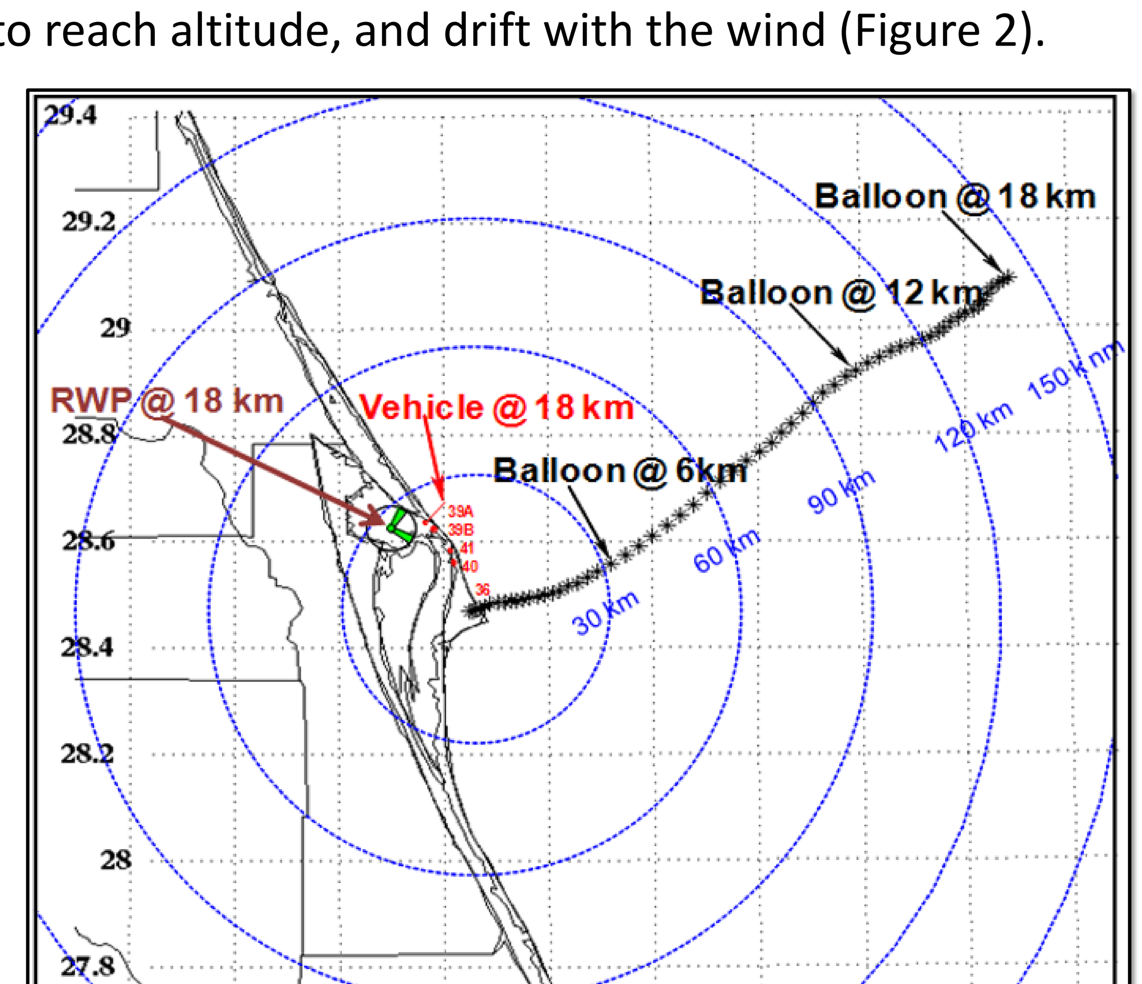

Figure 2. Example weather balloon and vehicle trajectories. Compiled by the 45th Weather Squadron, Patrick AFB.

Radar Wind Profiler

At the Kennedy Space Center on the Eastern Range, wind profiles to 20 km height are provided close to the vehicle trajectory by a 48 MHz Radar Wind Profiler (RWP) (Figure 3). Further, the RWP operates unattended providing wind soundings every 5 minutes.

Figure 3. NASA radar wind profiler at Cape Kennedy.

Microwave Thermodynamic Profiler

The MTP (Figure 4) uses neural networks (NN) to retrieve temperature, humidity and liquid profiles in clear and cloudy conditions. The NN are typically trained using five years of historical radiosonde soundings. Molecular emission and radiative transfer equations are applied to each radiosonde sounding to estimate the microwave brightness temperatures that would be observed at ground level by each of the 35 MTP frequency channels. Planck's law is applied to convert microwave energy to brightness temperature (Figure 4).

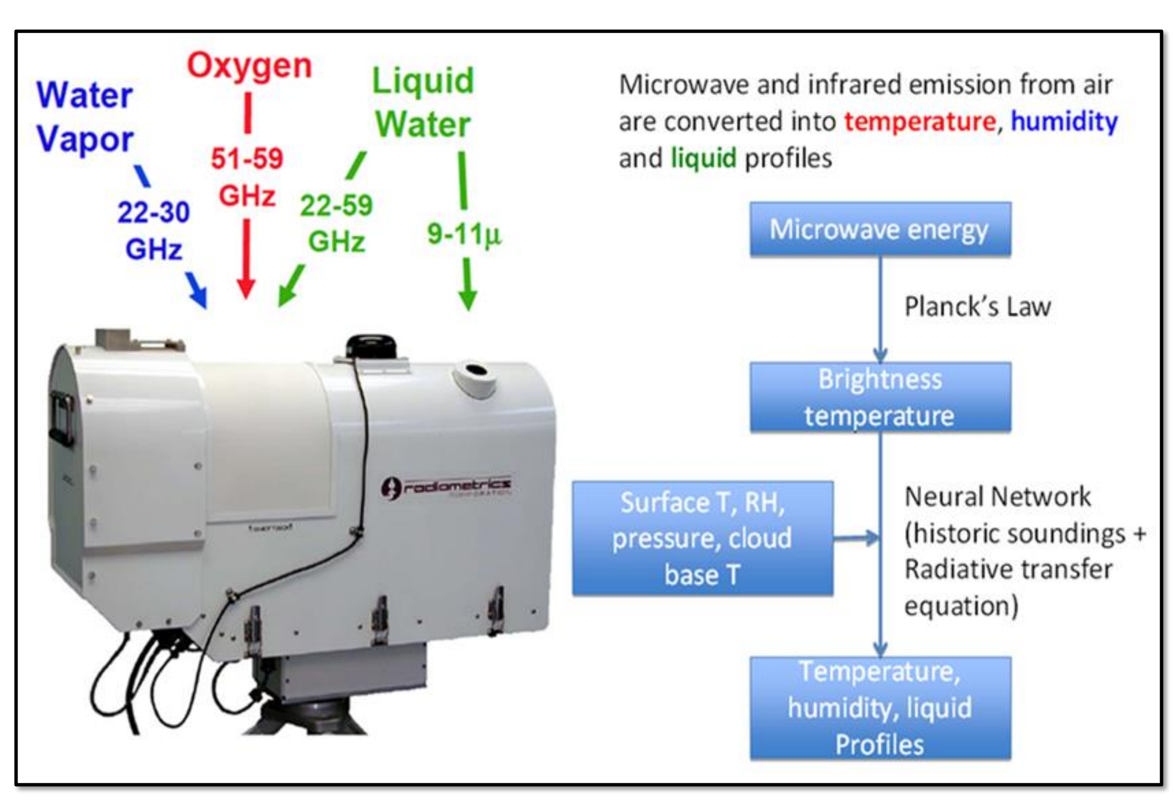

Figure 4. Microwave profiler retrieval schematic.

Example MTP soundings at Frisco, Texas, on 5 Dec 2016 are shown in Figure 5. Liquid profiles seen in the bottom panel extending to ground level from 21 to 2230Z are consistent with the occurrence of rain showers. Patented MTP rain effect mitigation methods optimize retrieval accuracy during precipitation.

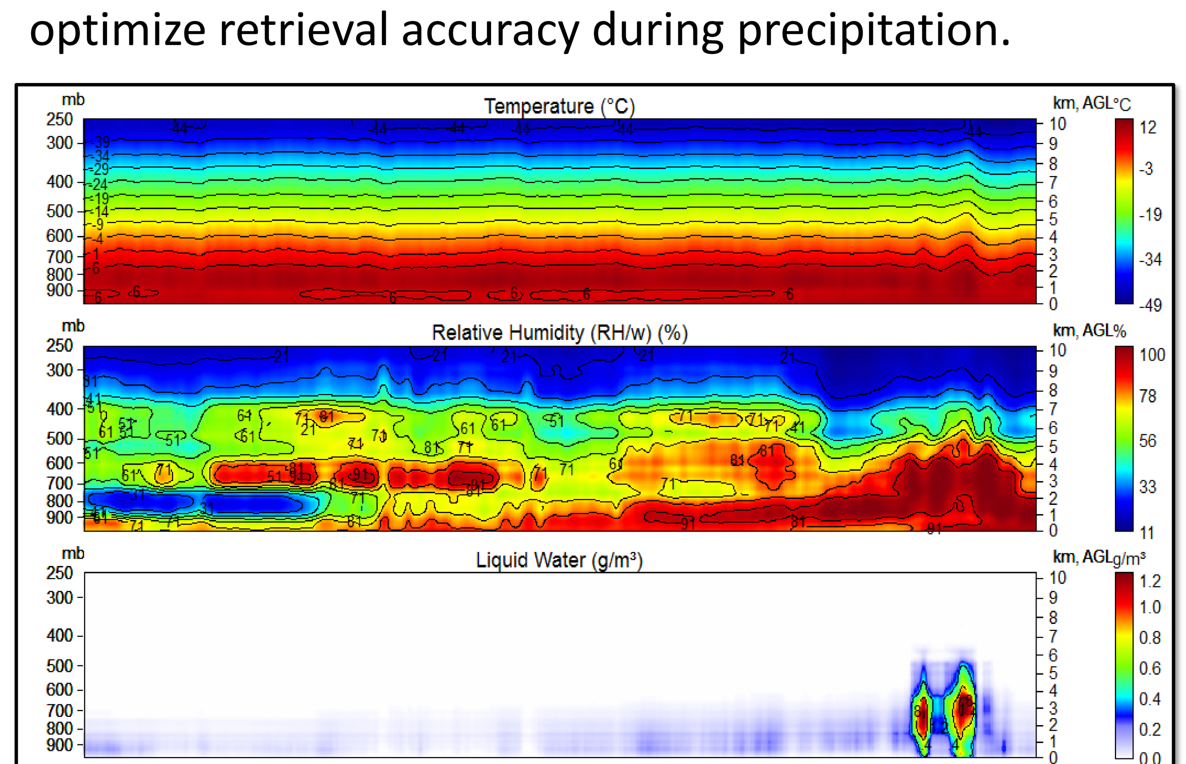

Figure 5. Microwave profiler soundings at Frisco, TX, 5 Dec 2016.

Integrating Profiles & Gridded Analysis

Radiometer, wind radar and numerical weather model gridded analysis can be combined using variational methods to optimize thermodynamic and wind profile accuracy. Continuously updated traditional forecast tools and indices derived from these profiles can improve high-impact local weather forecasting. For example, wind and thermodynamic soundings combined with gridded analysis are shown in Figure 6 hours before multiple tornadoes touched down in Denver, Colorado.

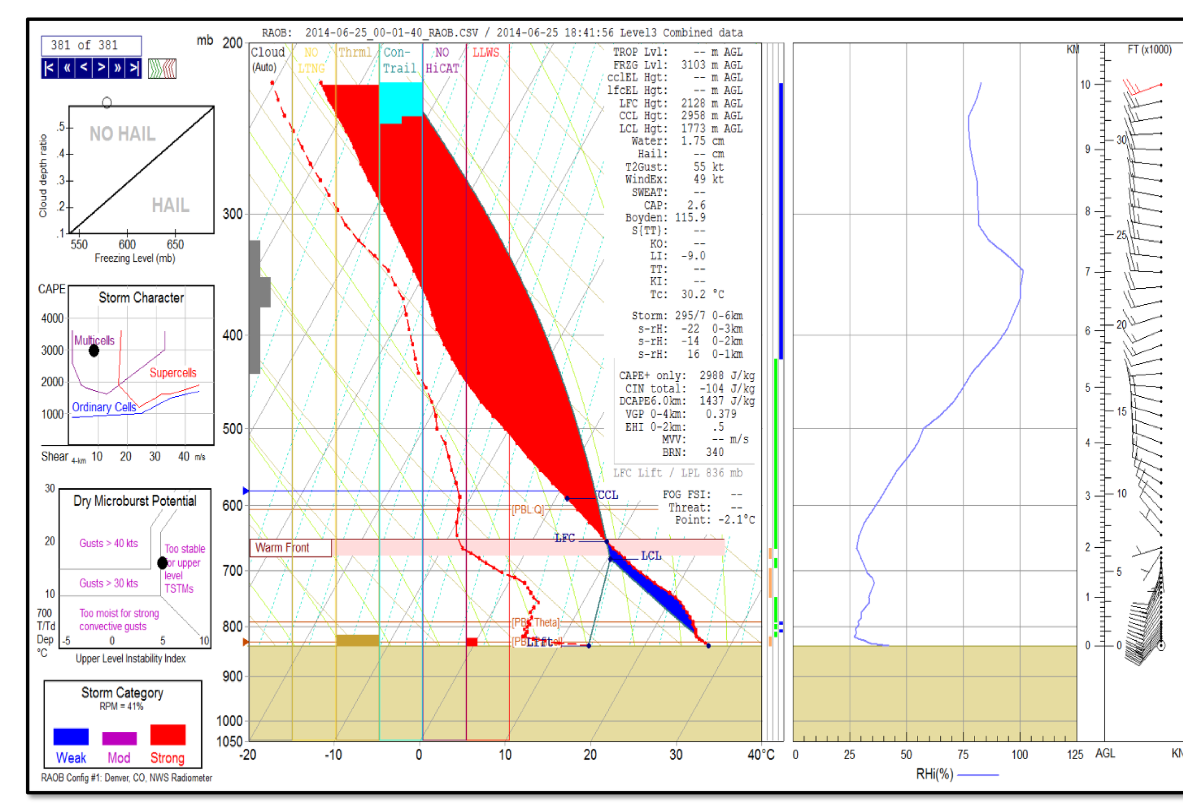

Figure 6. Combined radiometer, wind radar and gridded analysis identified strong storm and multicell risk hours before an outbreak of local tornadoes.

MTP temperature and humidity profile accuracies can be determined by comparison with radiosondes. One-dimensional variational retrievals (MTP 1DVAR) combining MTP and model gridded analysis are compared with the Ft. Worth RS in Figure 7 (a).

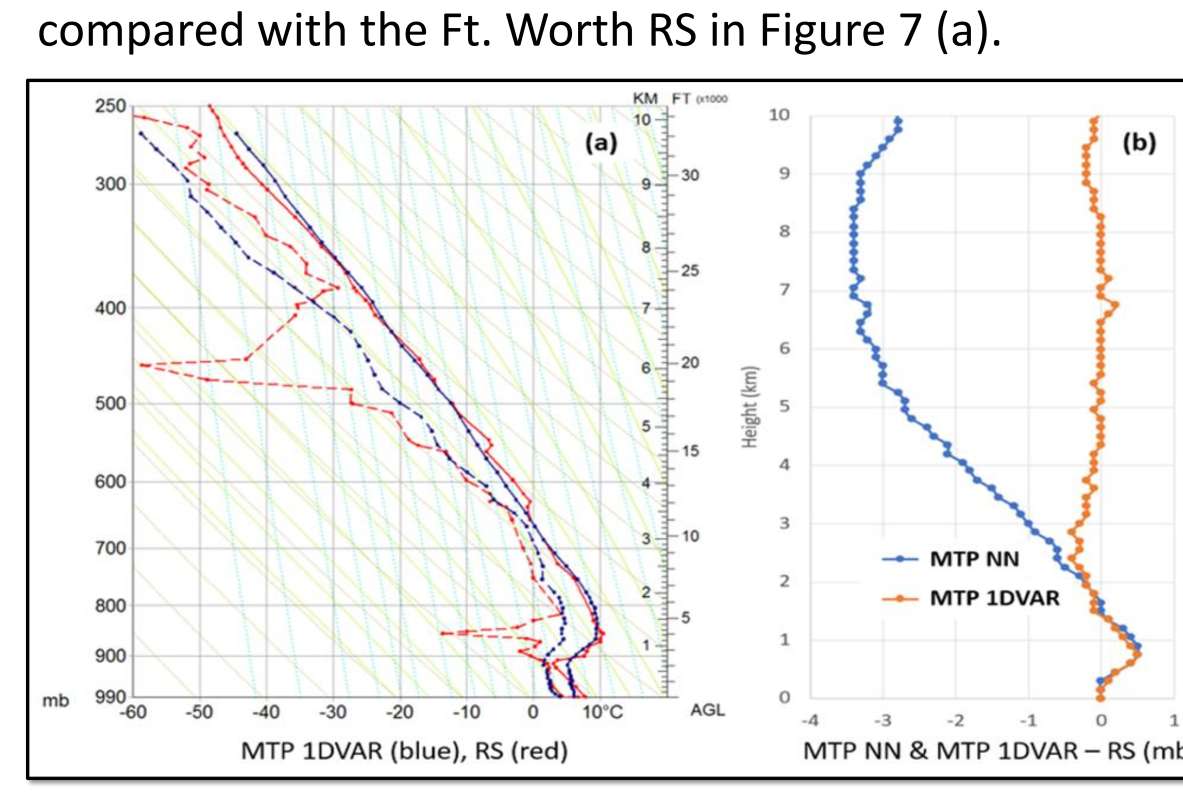

Figure 7. MTP 1DVAR and radiosonde profiles (left); MTP neural net and 1DVAR minus radiosonde pressure profiles (right).

The India Space Research Organization (ISRO) demonstrated MTP observations can be used to identify lightning risk more than two hours in advance of traditional methods using electric field mill lightning alerts (Figure 8).

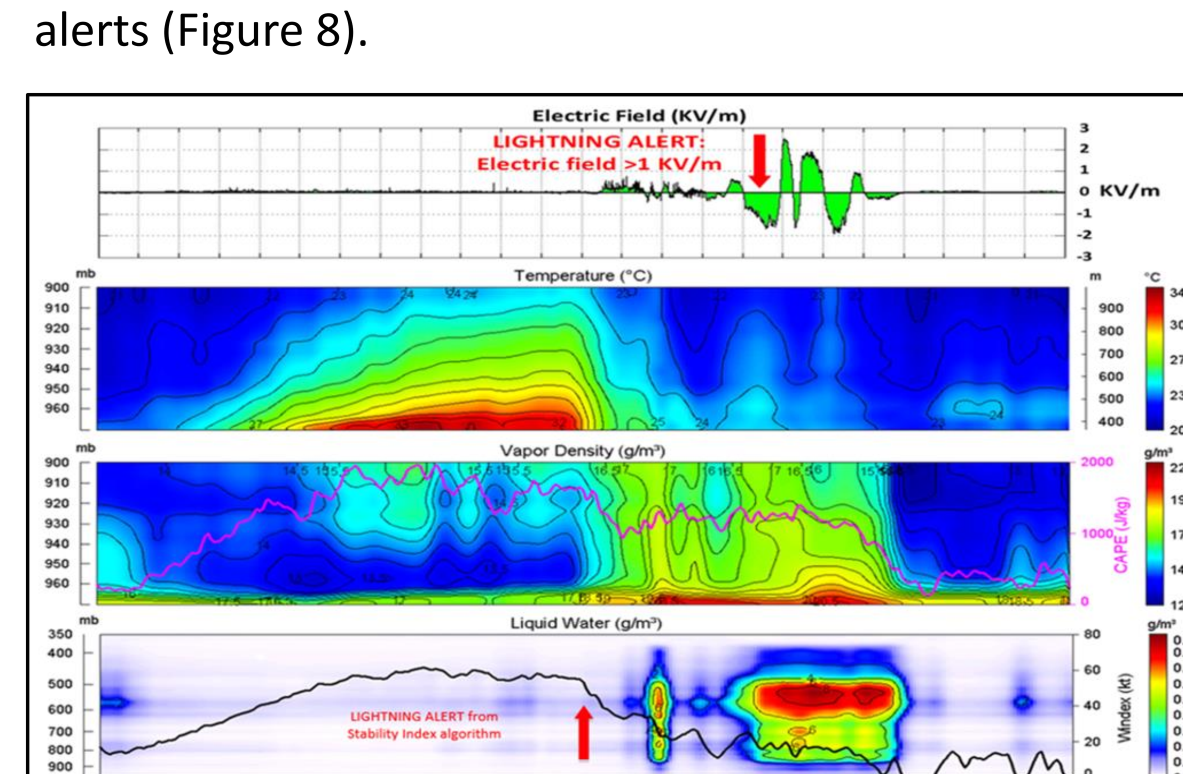

Figure 8. Lightning risk identification >2-hr in advance.