Continuous Temperature, Humidity & Liquid Profiling

Joint NCAR – UOP Seminar

25 September 2008

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(point to callouts at upper left of each slide for presentation notes)

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Presentation Summary

- Surface-based passive microwave & infrared remote sensing -- basic physics and method
- Continuous temperature and humidity profiling with accuracy equivalent to radiosondes
- Liquid profiles for precipitation forecasting and climate research
- Colorado tornado case study

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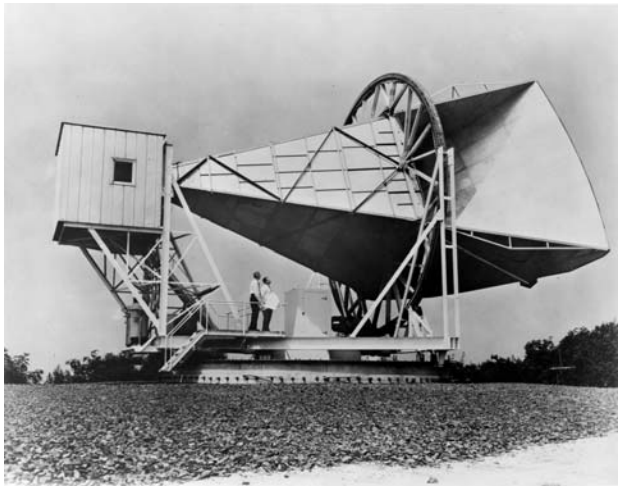
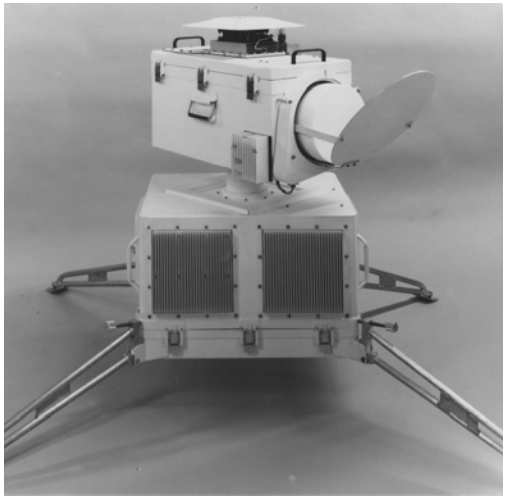


1963 Bell Labs

1978 NOAA Labs



1986 NASA JPL

1990 Radiometrics

2005 Radiometrics

2008 Radiometrics

Evolution of microwave radiometer technology for atmospheric remote sensing

Basic Physics and Retrieval Method

- Hyperspectral microwave observations are converted to brightness temperatures using the Planck Radiation Equation.
- Air temperature, humidity and liquid structures are linked to brightness temperatures by Radiative Transfer Equations.
- Neural Networks convert brightness temperatures to temperature, humidity and liquid profiles.

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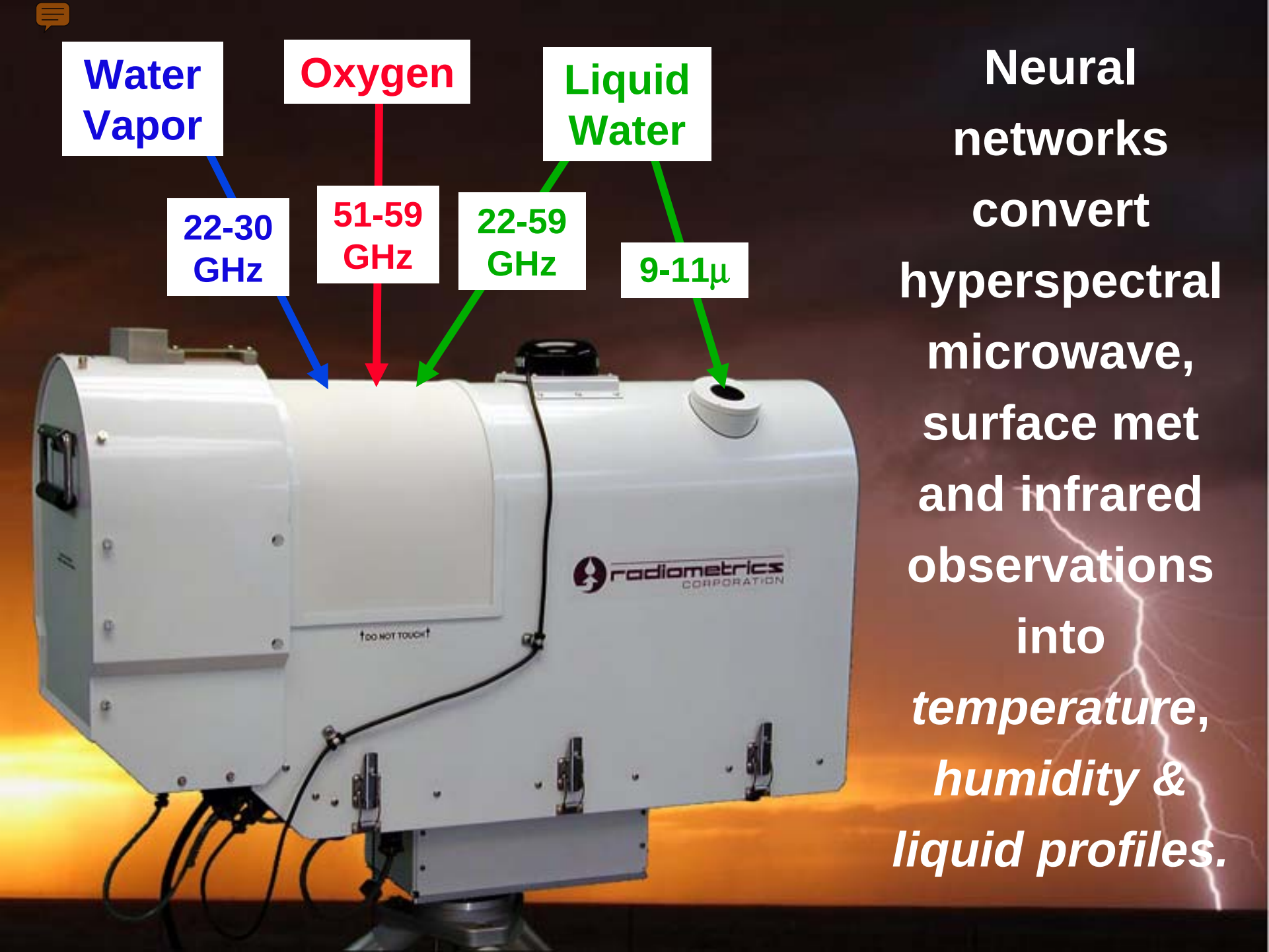
Planck Radiation Equation

$$B_\nu(T) = \frac{2h\nu^3}{c^2} \frac{1}{(\exp(h\nu/kT) - 1)}$$

Radiative Transfer Equation

$$B_\nu(T_b) = B_\nu(T_c)\exp(-\tau_\nu) + \int_0^\infty B_\nu(T(s))\,\alpha_\nu(s)\exp\left(-\int_0^s \alpha_\nu(s')ds'\right)ds$$

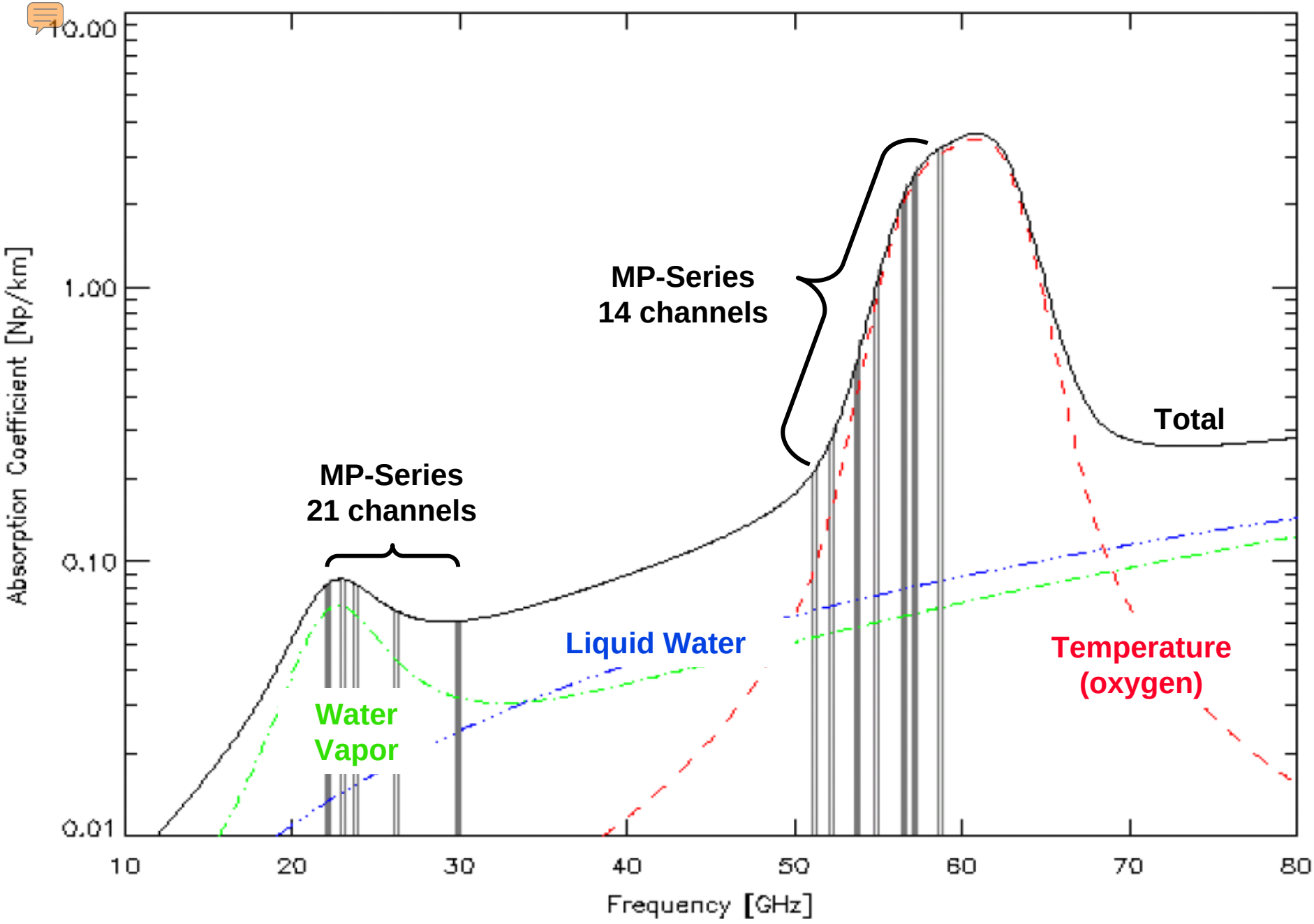
Westwater et al., Principles of Surface-based Microwave and Millimeter wave Radiometric Remote Sensing of the Troposphere, Quaderni Della Societa Italiana Elletromagnetismo, 2005 (http://radiometrics.com/Rad_rev_05.pdf).



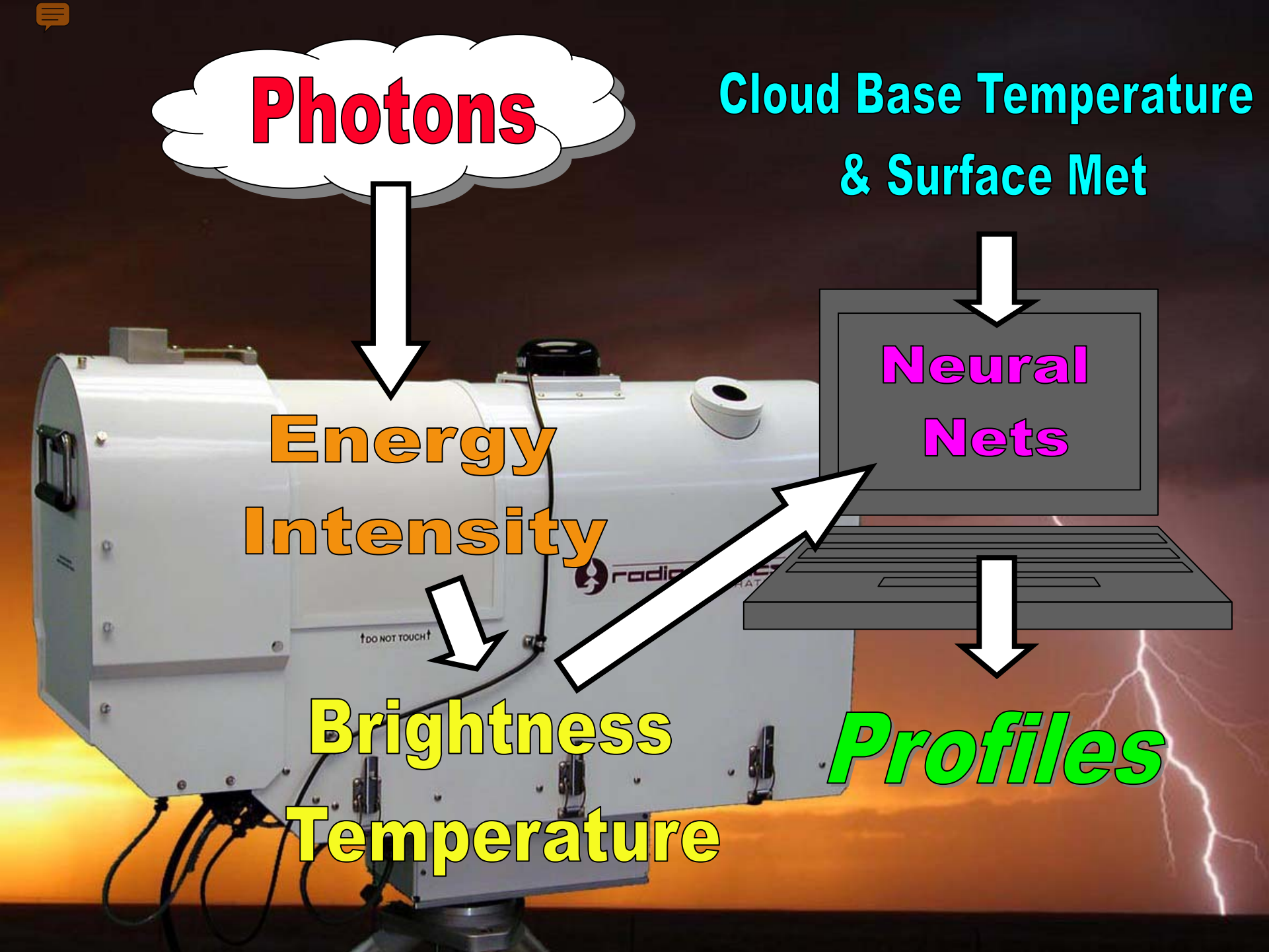
Neural networks convert hyperspectral microwave, surface met and infrared observations into *temperature, humidity & liquid profiles.*

Retrieving Atmospheric Profiles

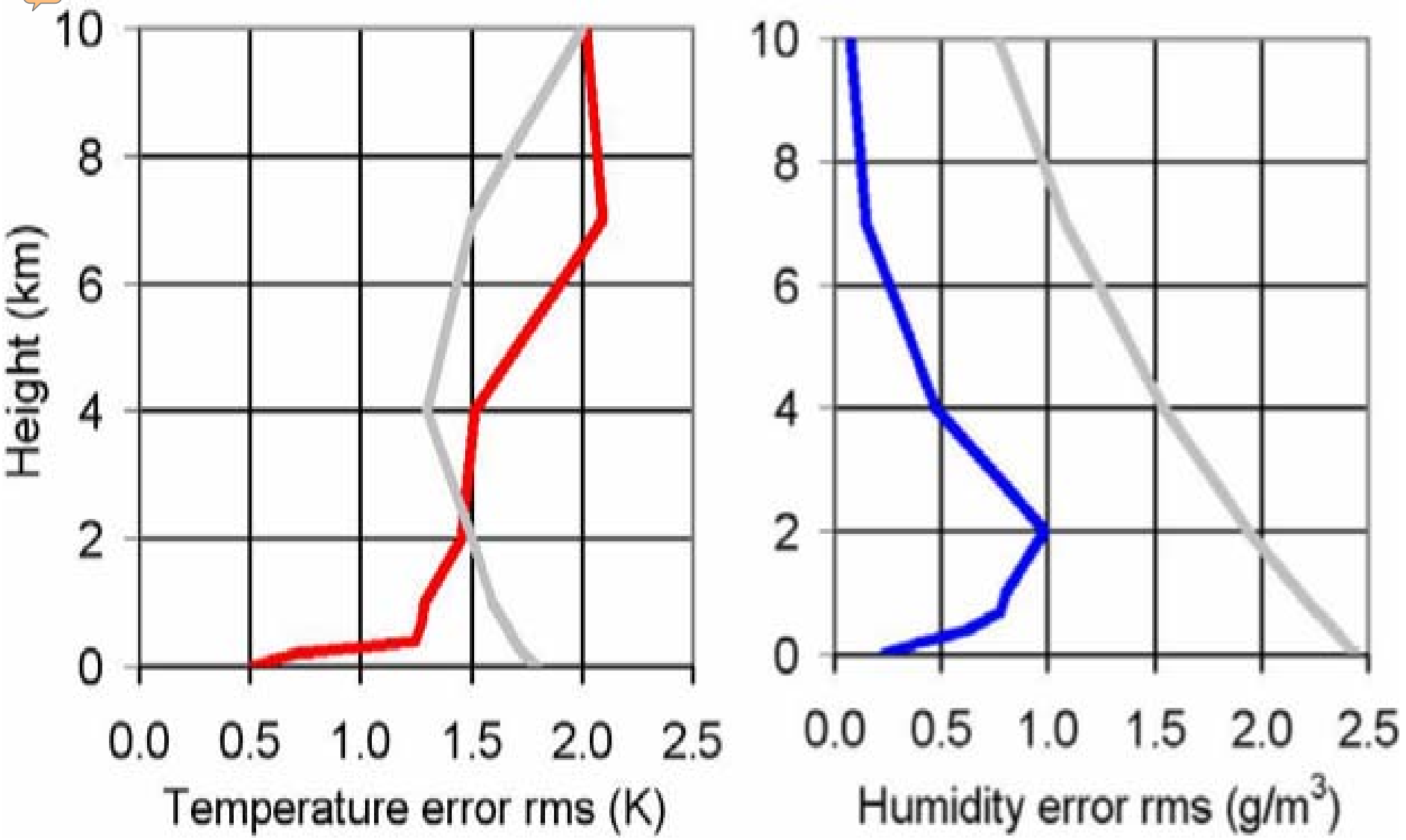
- A hyperspectral sensor receives a picowatt of microwave energy and converts it to brightness temperatures using Planck's Law
- Cloud base temperature is measured along with surface temperature, relative humidity and pressure
- Historical radiosonde data are forward modeled with radiative transfer equations for neural network training
- Neural network methods convert spectral microwave, infrared and surface observations to temperature, humidity and liquid profiles



Atmospheric Microwave Emission Spectrum


Photons
Cloud Base Temperature
& Surface Met
Energy
Intensity
Neural
Nets
Brightness
Temperature
Profiles

German Weather Service radiometer and 6-hr radiosonde comparisons since 1998 [Güldner and Spänkuch, **JAOT**, 2001]



Radiometer-radiosonde comparison statistics (red and blue), and radiosonde representativeness error (gray) [Güldner and Spänkuch, **JAOT**, 2003; Ware et al., **Rad. Sci.,** 2003].

DOE ARM radiometers calibrate radiosondes for climate research.

Lindenberg Meteorological Observatory - Richard-Aßmann-Observatory

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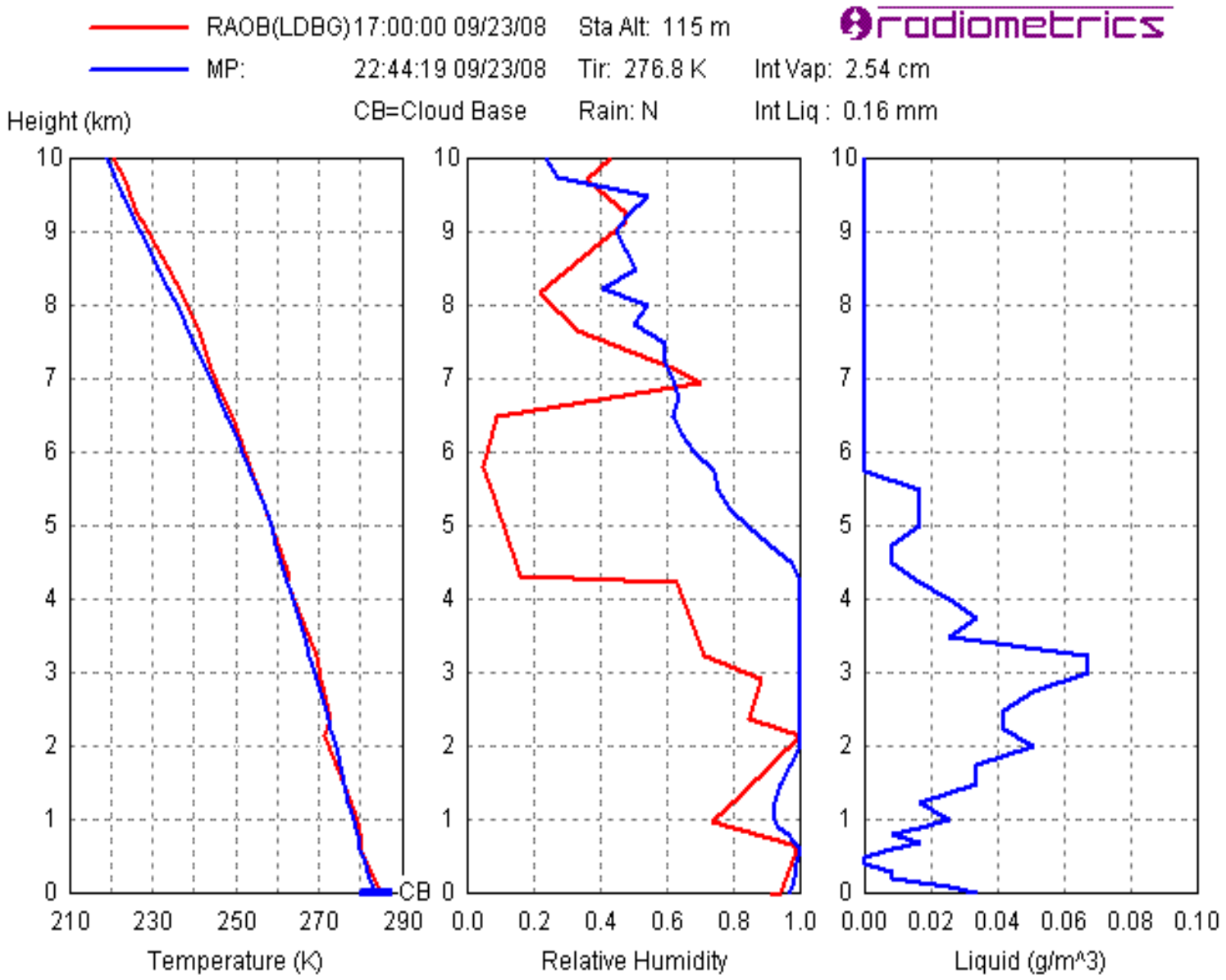

Radiometer (above) and radiosonde (below) temperature and humidity profiles, with ceilometer (asterisks), to 6 km height.

Lindenberg Meteorological Observatory - Richard-Aßmann-Observatory

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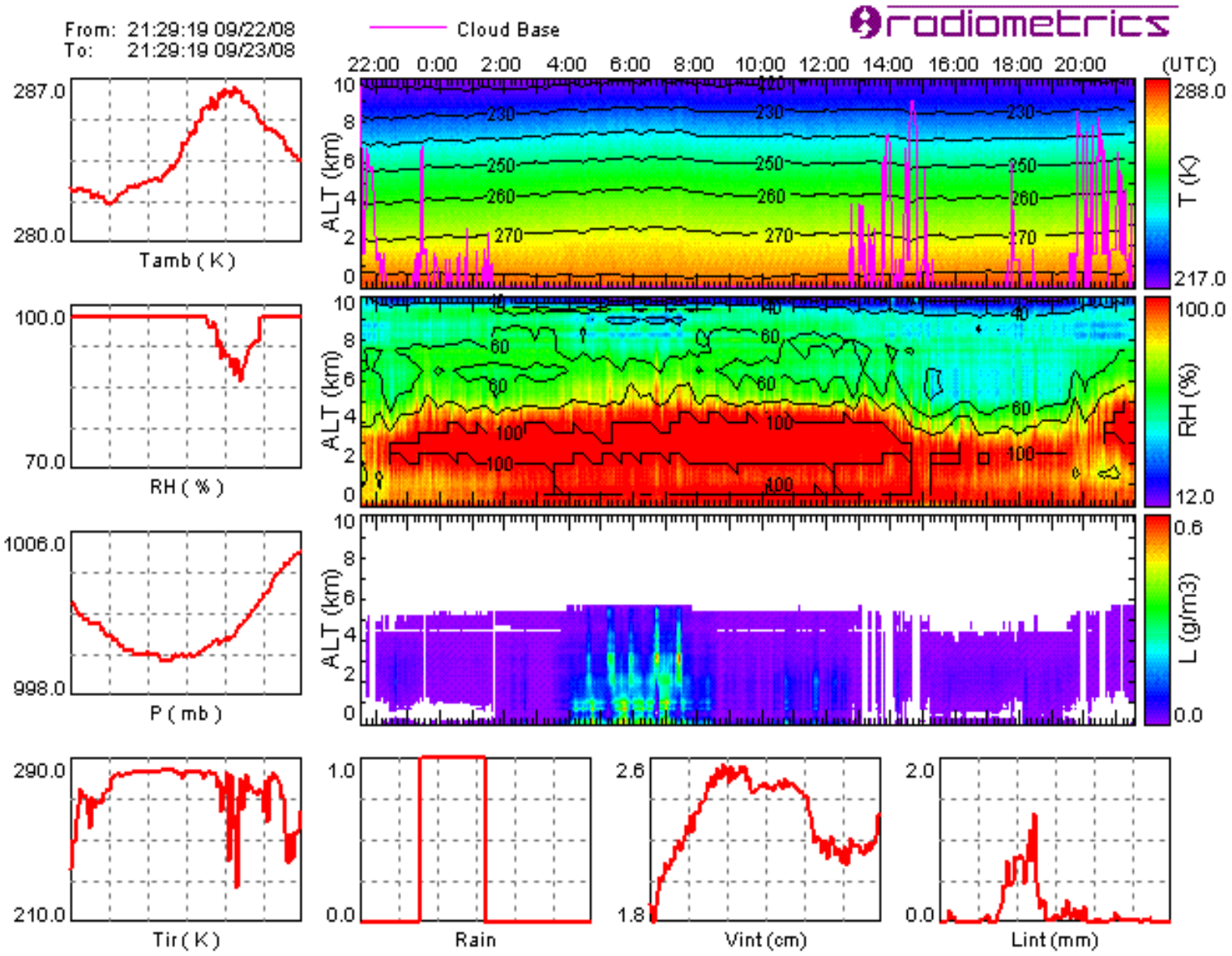

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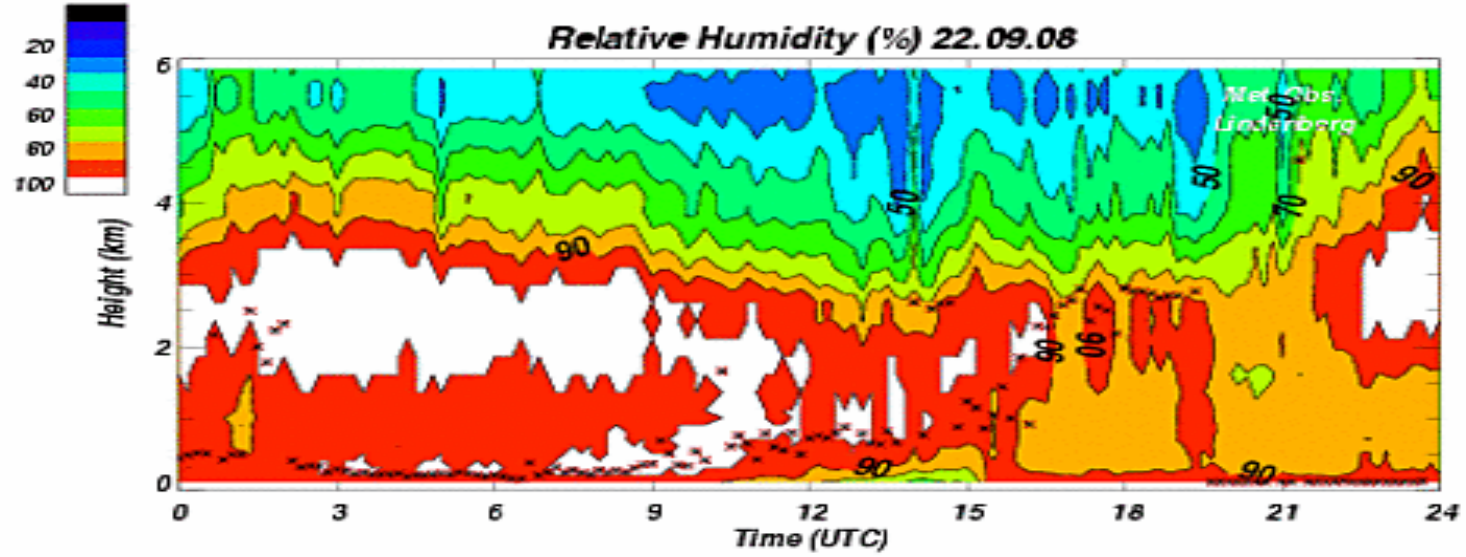

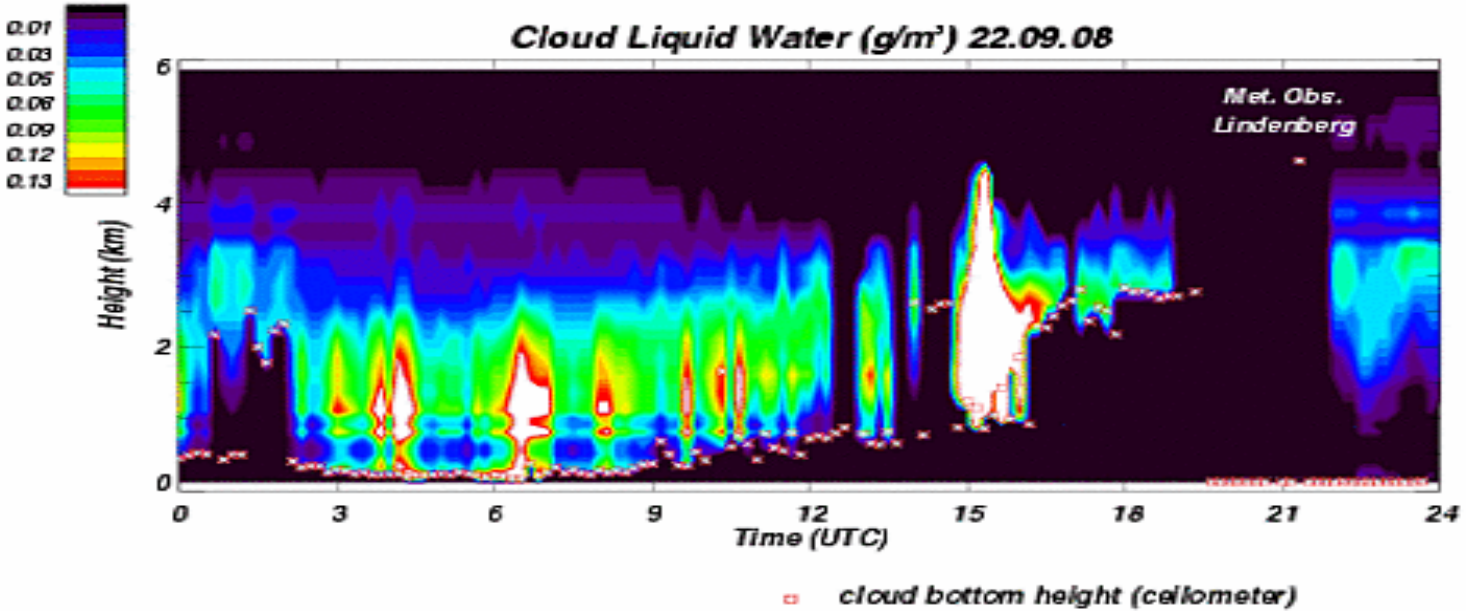

Radiometer RH and liquid density profiles and laser ceilometer cloud base height.

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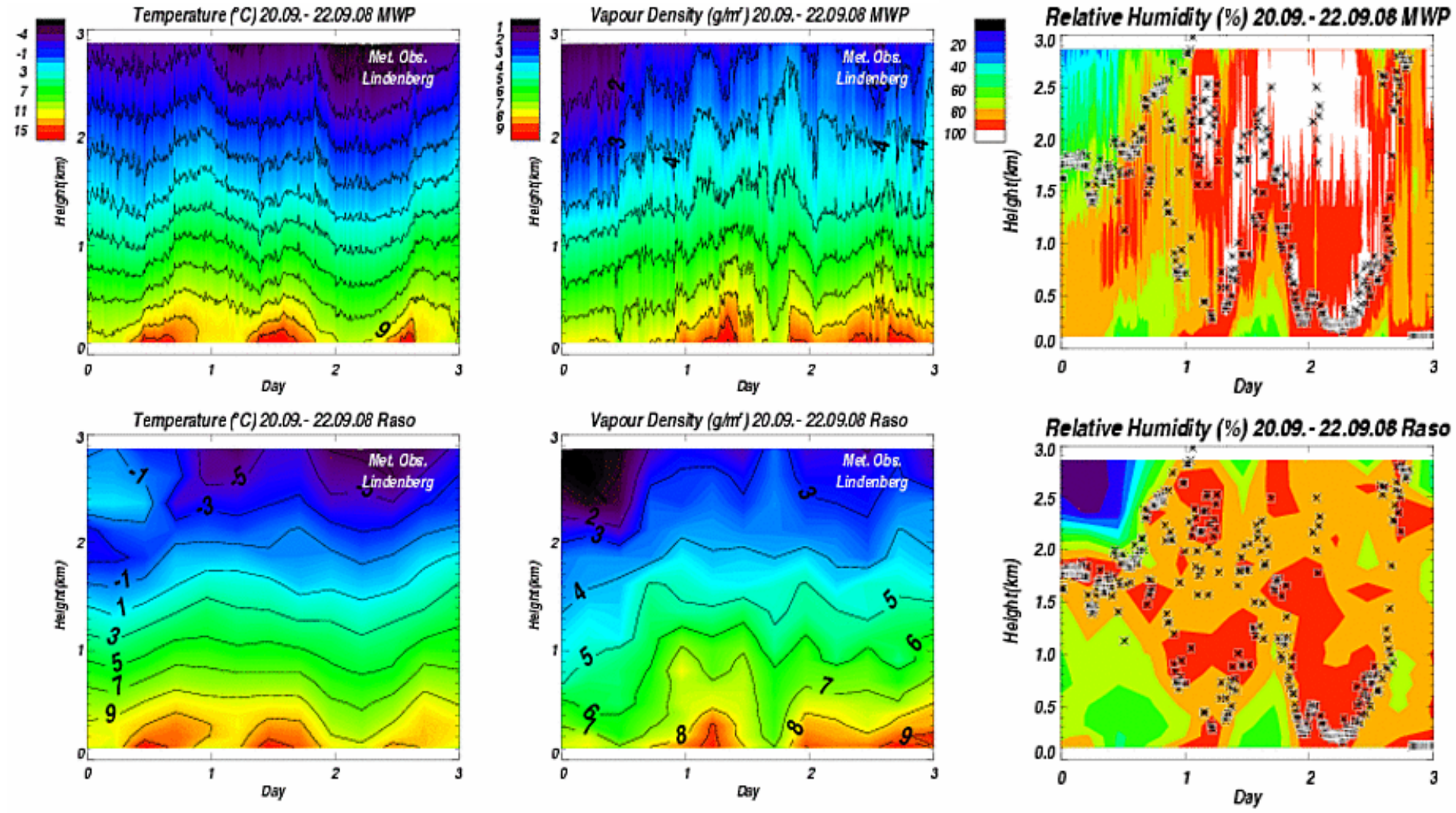
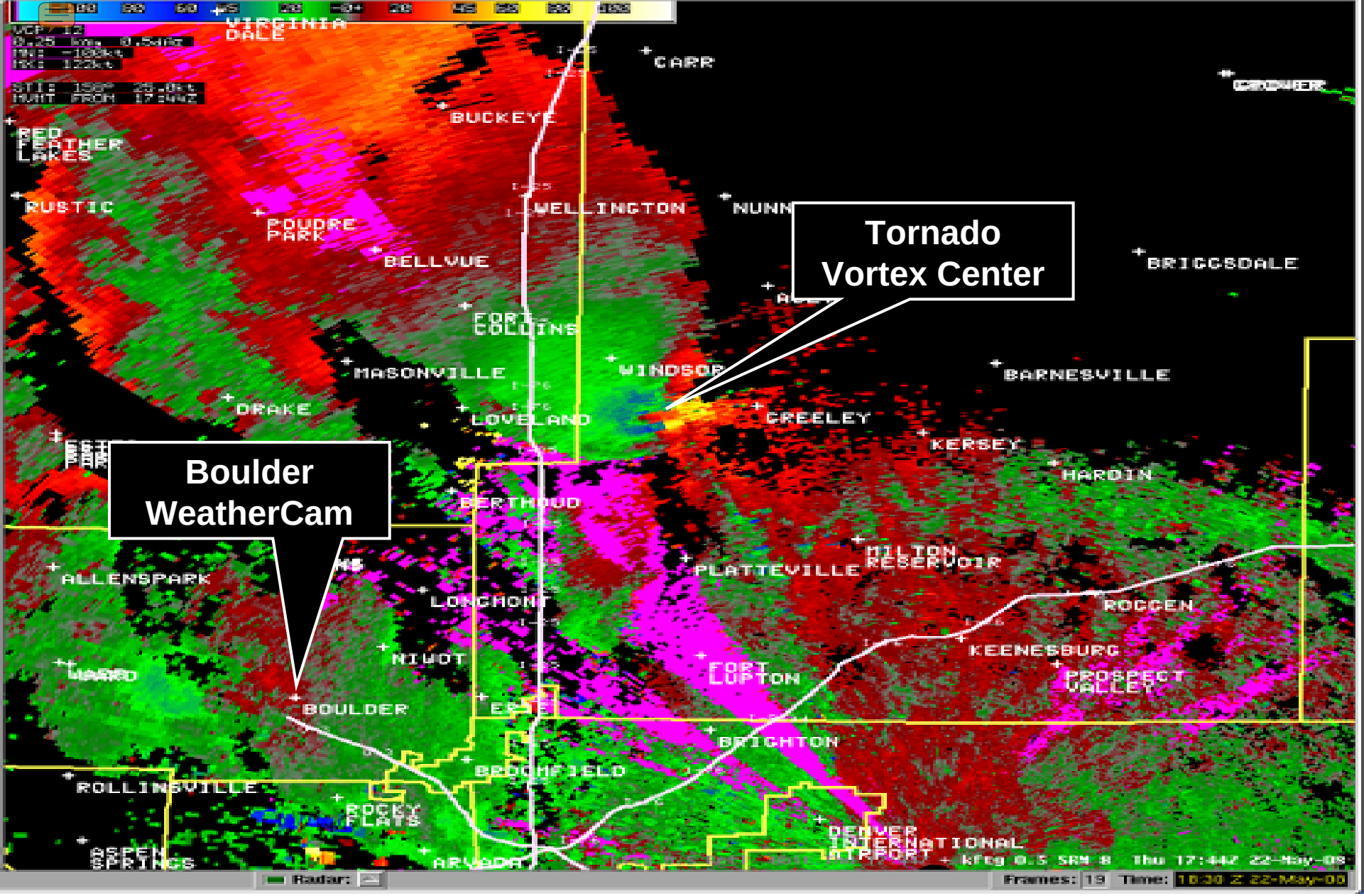


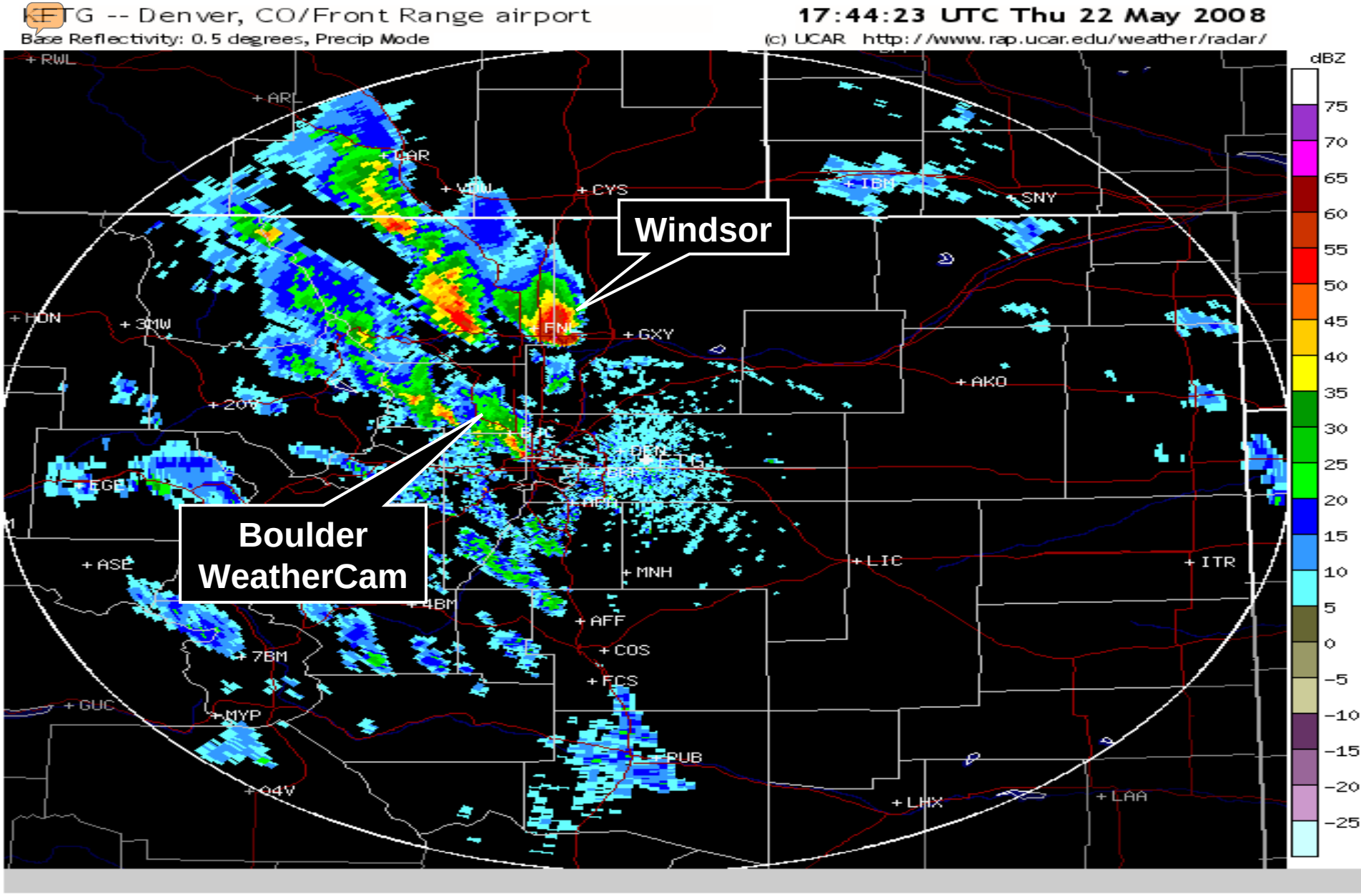
Deutscher Wetterdienst radiometer (top) and radiosonde (below) temperature, vapor density and relative humidity to 3 km height.

Colorado Tornadoes

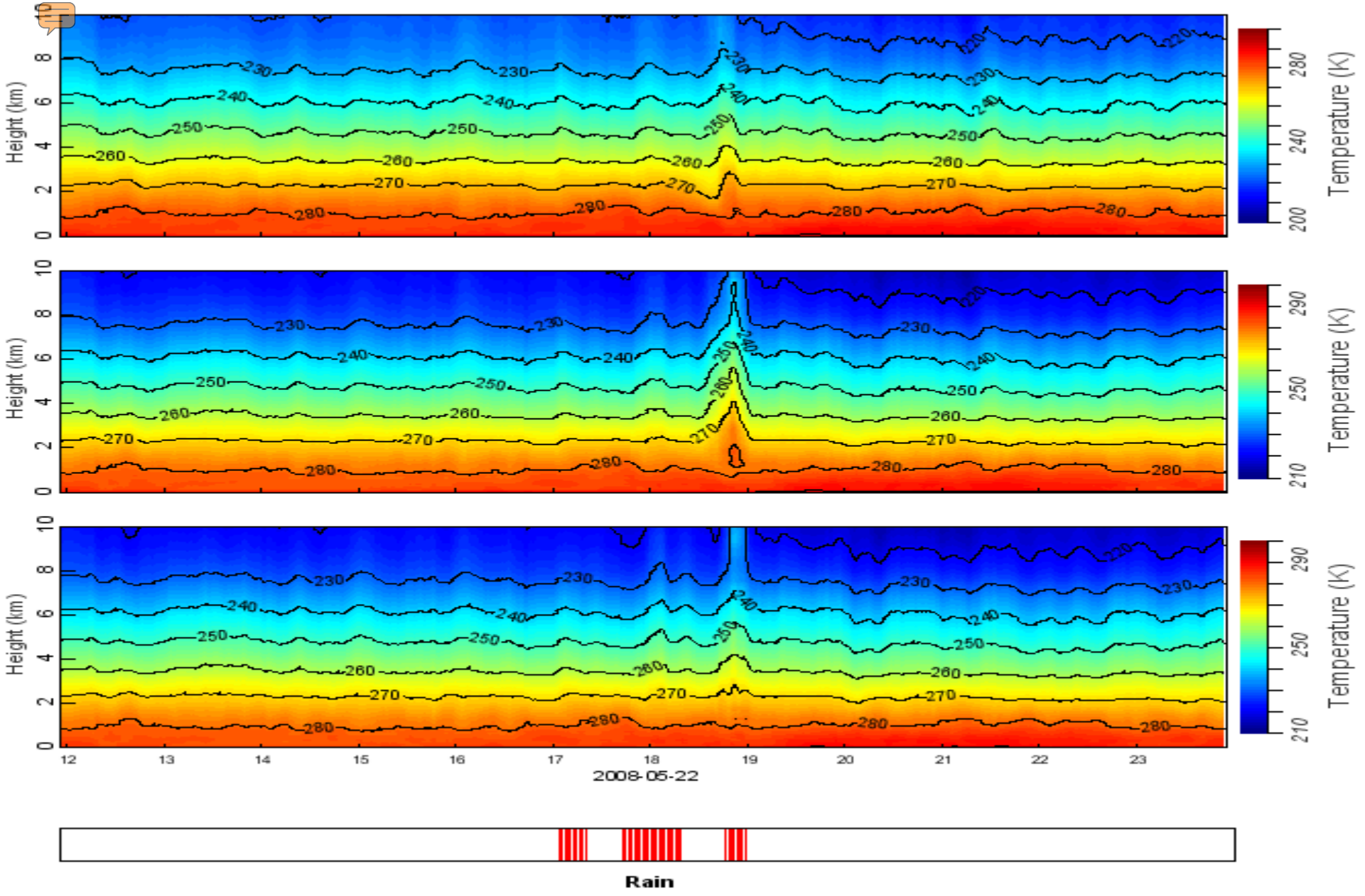
- A cluster of tornadoes swept through Northern Colorado on May 22, 2008.
- Radar, radiosonde and microwave radiometer (WeatherCam) observations are presented.
- WeatherCam provides continuous 3D thermodynamic and liquid structure.



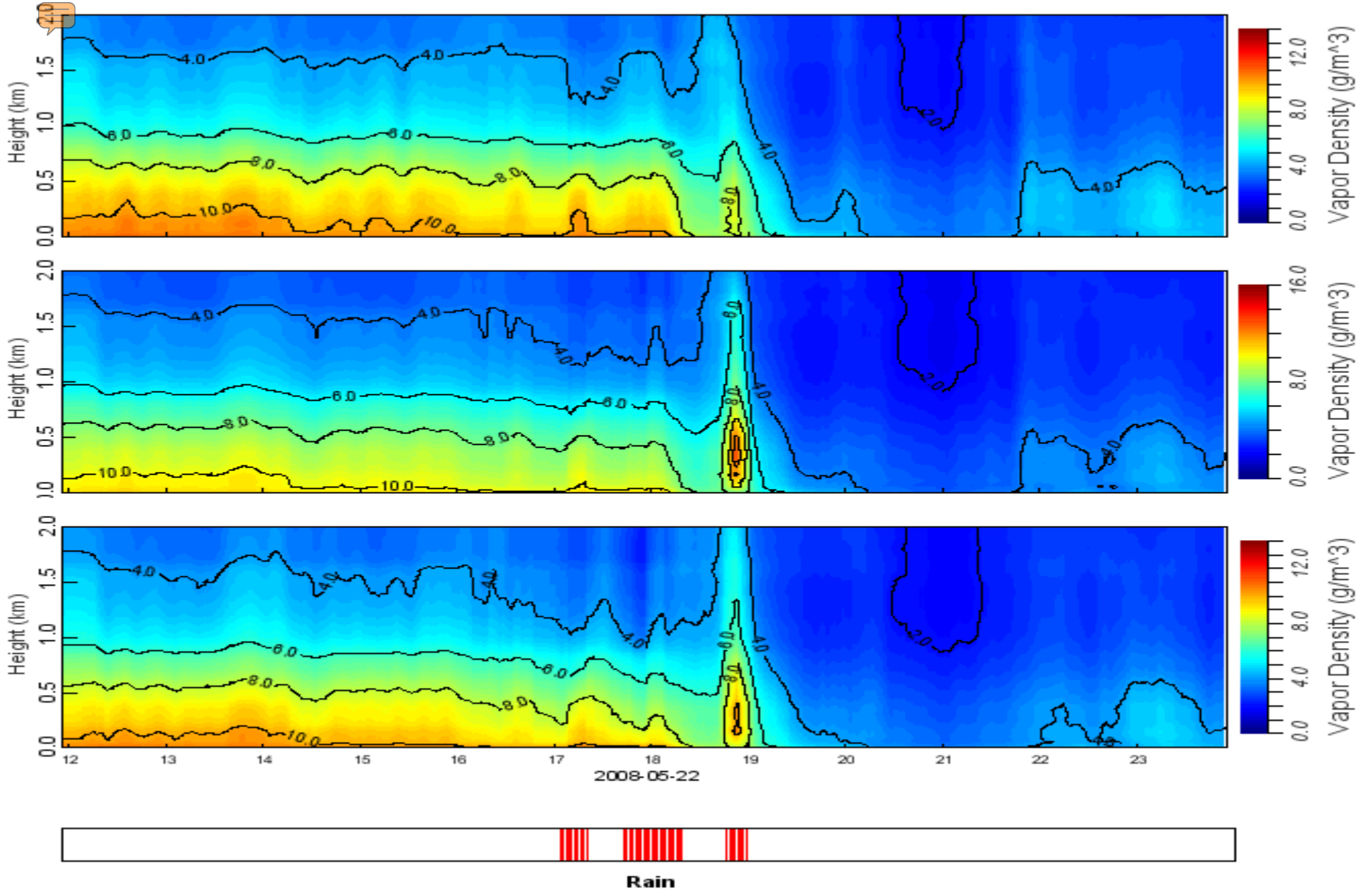
Denver radar showing 80 m/s (180 mph) winds near Windsor, Colorado, at 17:44 UT (11:44 local time) 5-22-08.



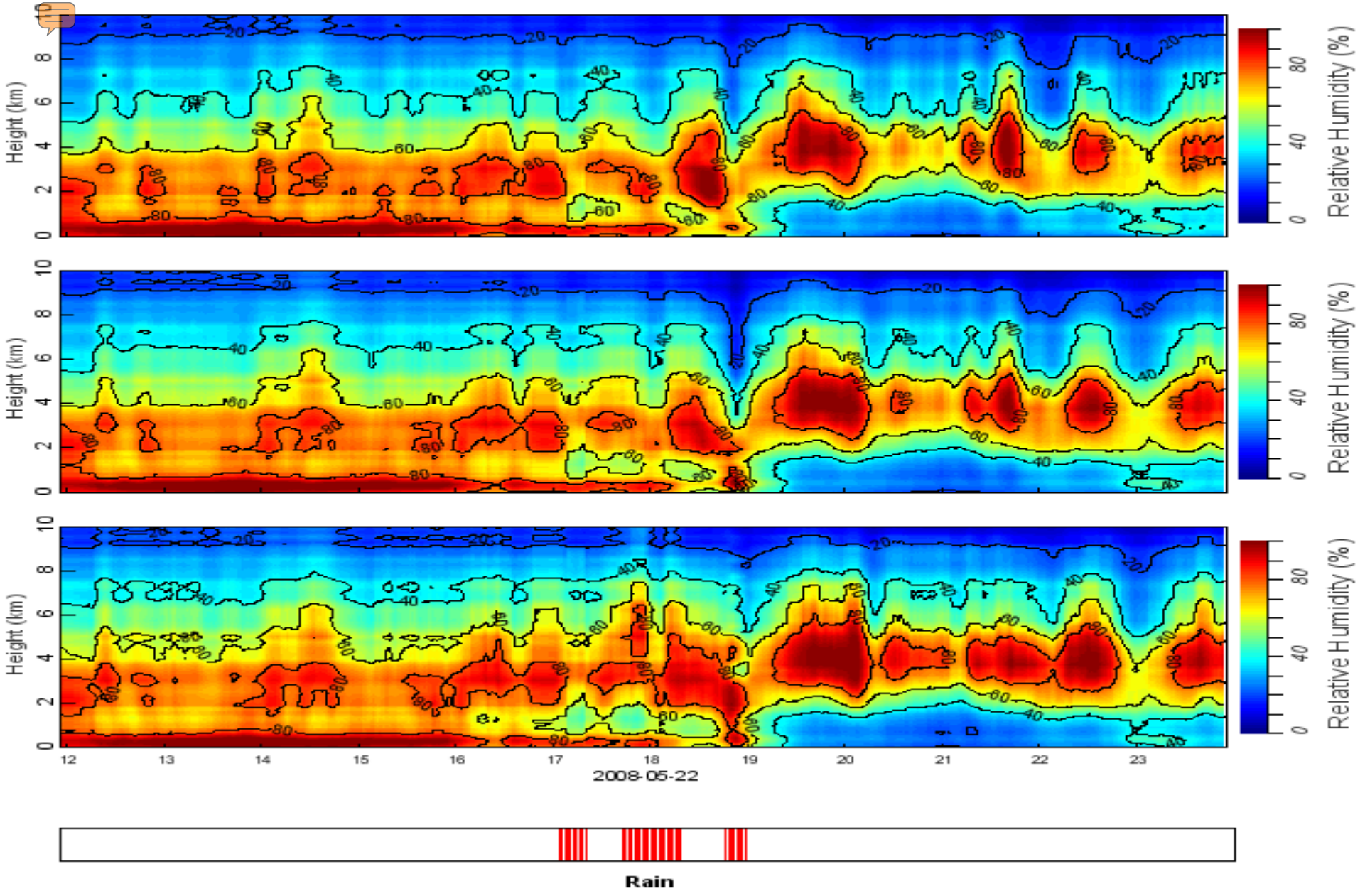
Strong radar reflectivities at Windsor and near Boulder at 17:44 UT (11:44 local time) 5-22-08.



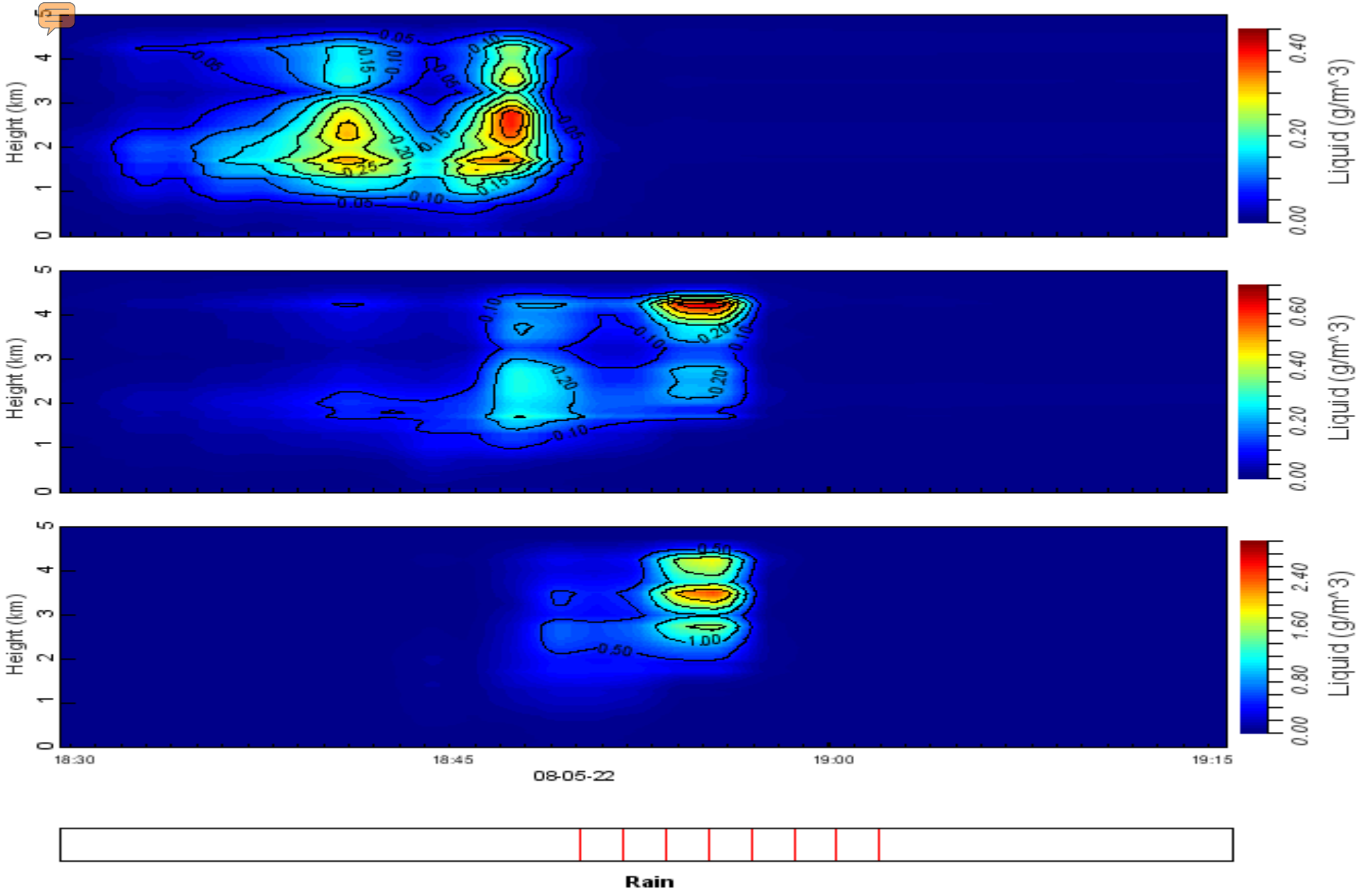
South, zenith and north (top to bottom) temperature profiles to 10 km height were strongly disturbed by local convection.



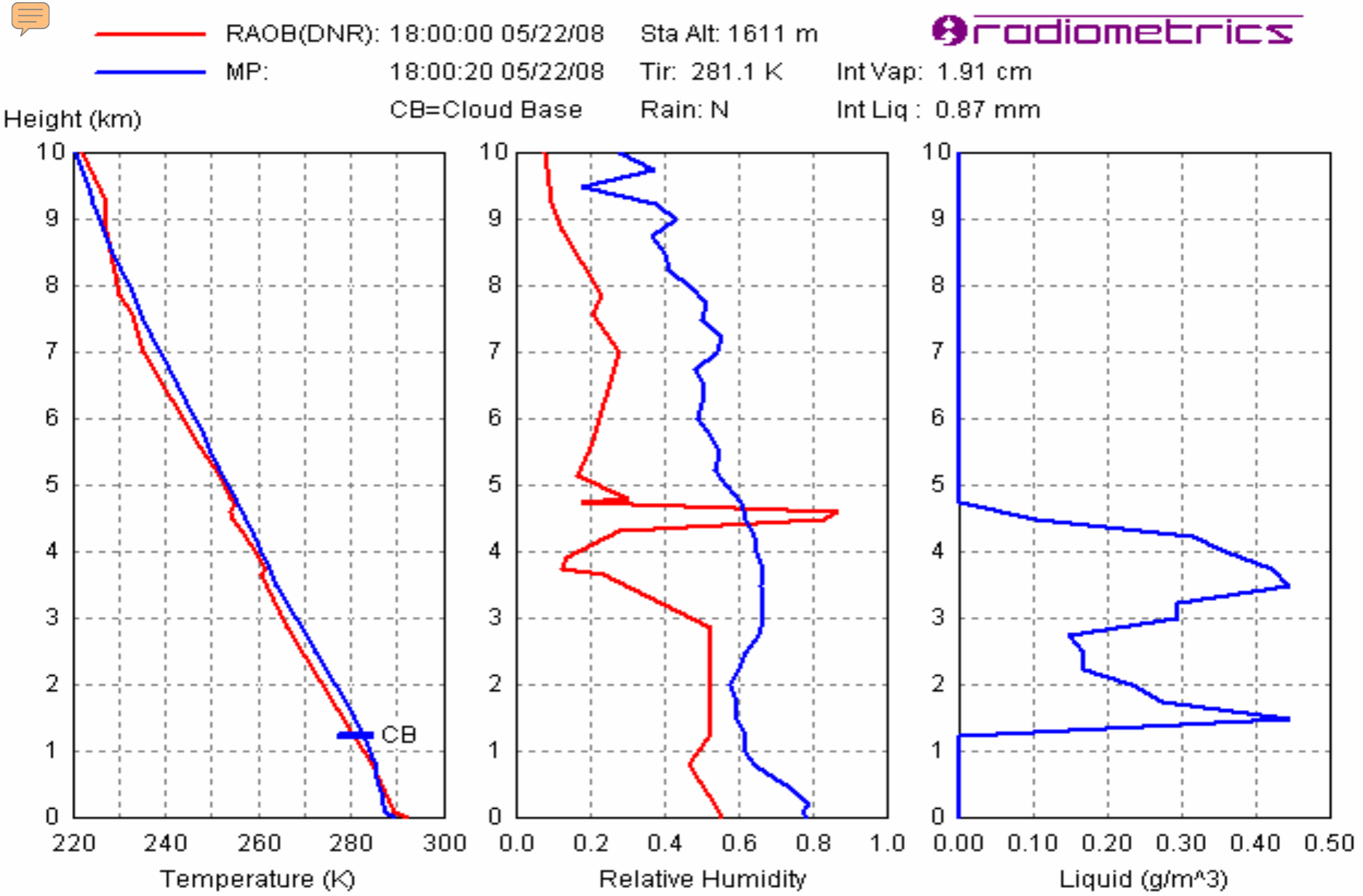
South, zenith and north vapor density profiles to 2 km height show high variability during local convection.



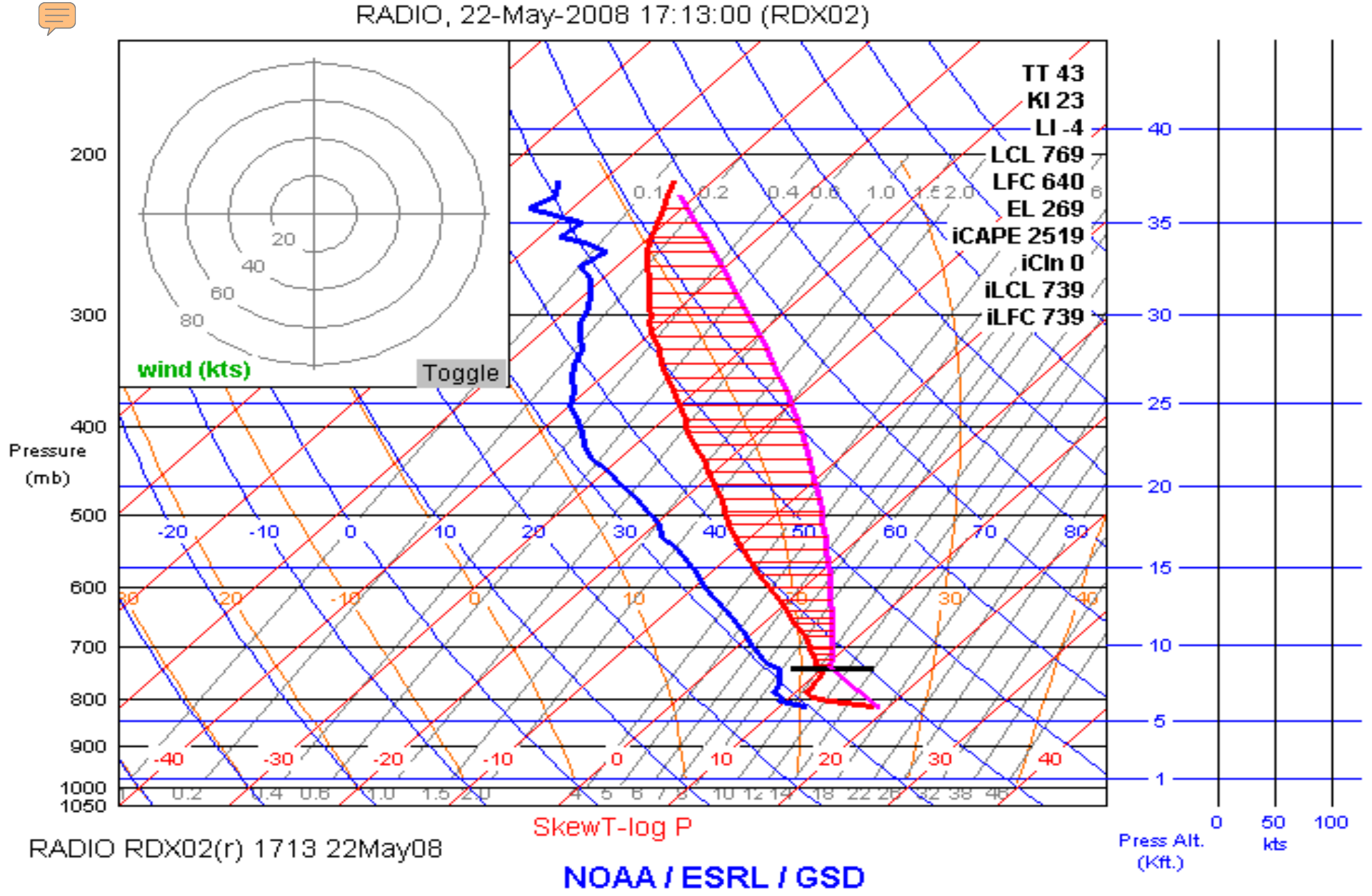
South, zenith and north relative humidity profiles to 10 km height show subsidence of dry air.



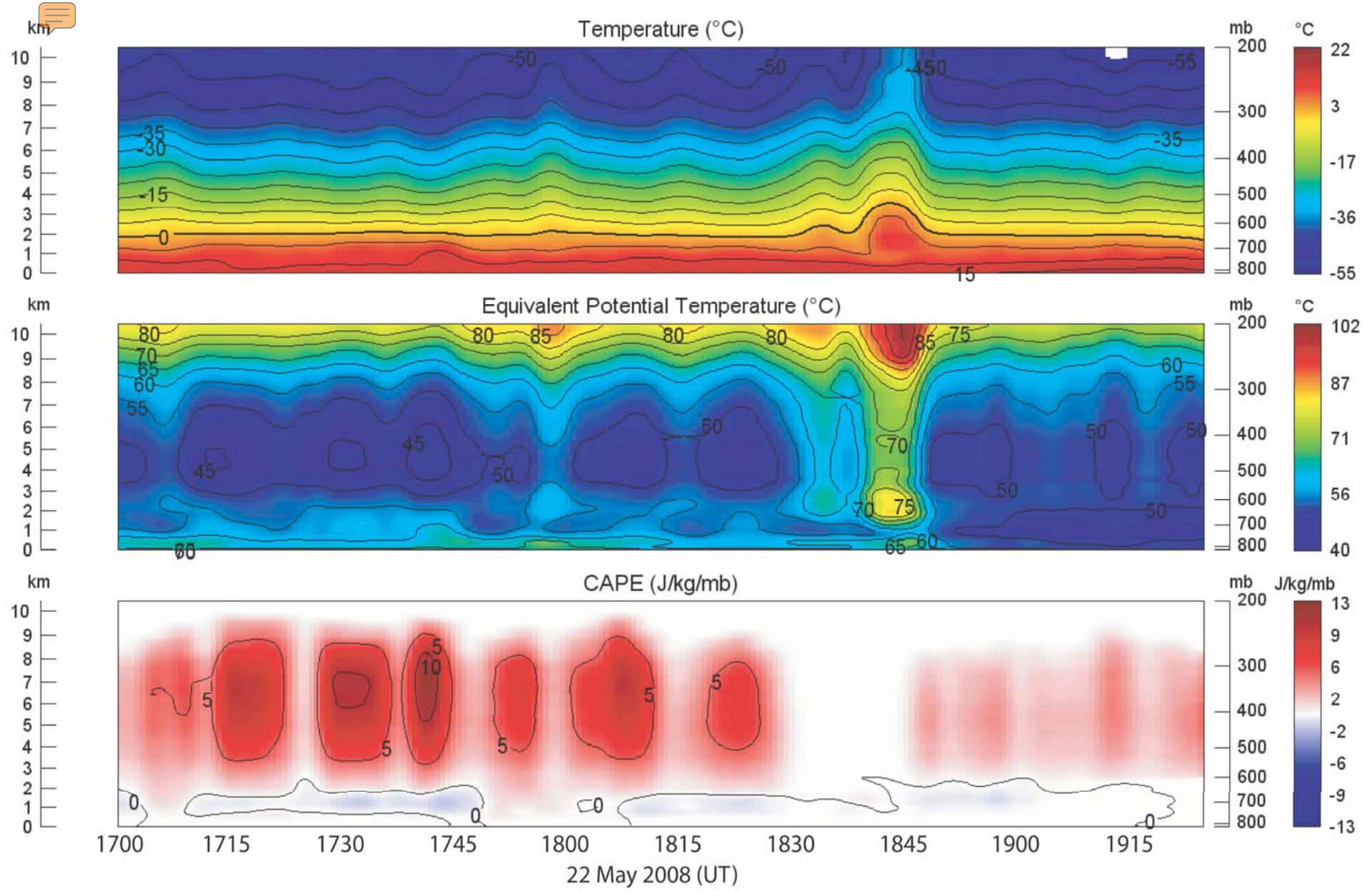
South, zenith and north liquid density profiles to 5 km height, 1830-1915 UT (1230-1315 local time).



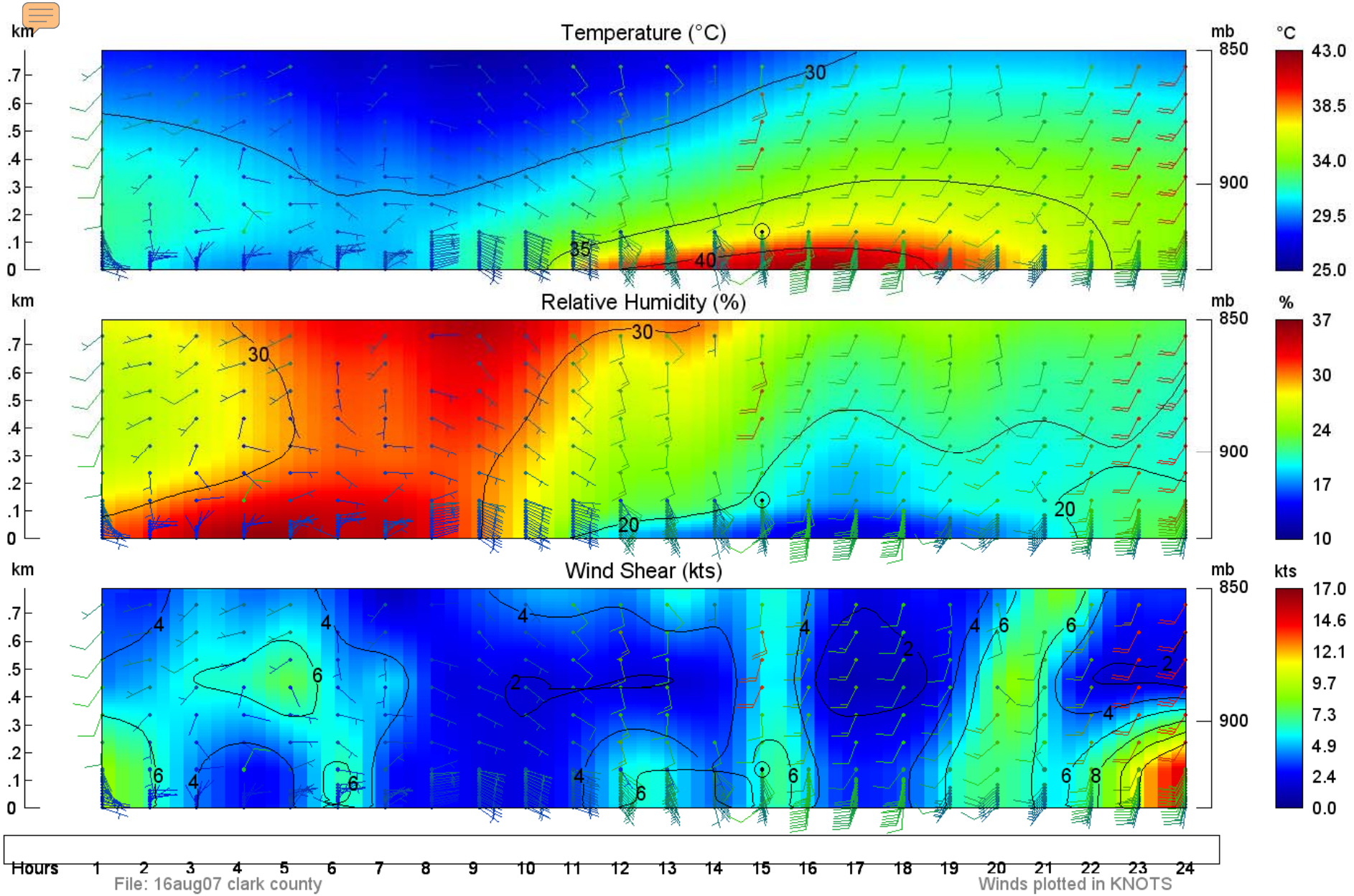
Denver radiosonde and Boulder WeatherCam temperature, relative humidity and liquid, 18:00 UT (12:00 local time) 5-22-08.



Boulder WeatherCam maximum CAPE = 2,519 J/kg
at 17:13 UT (11:13 pm, local time) 5-22-08.



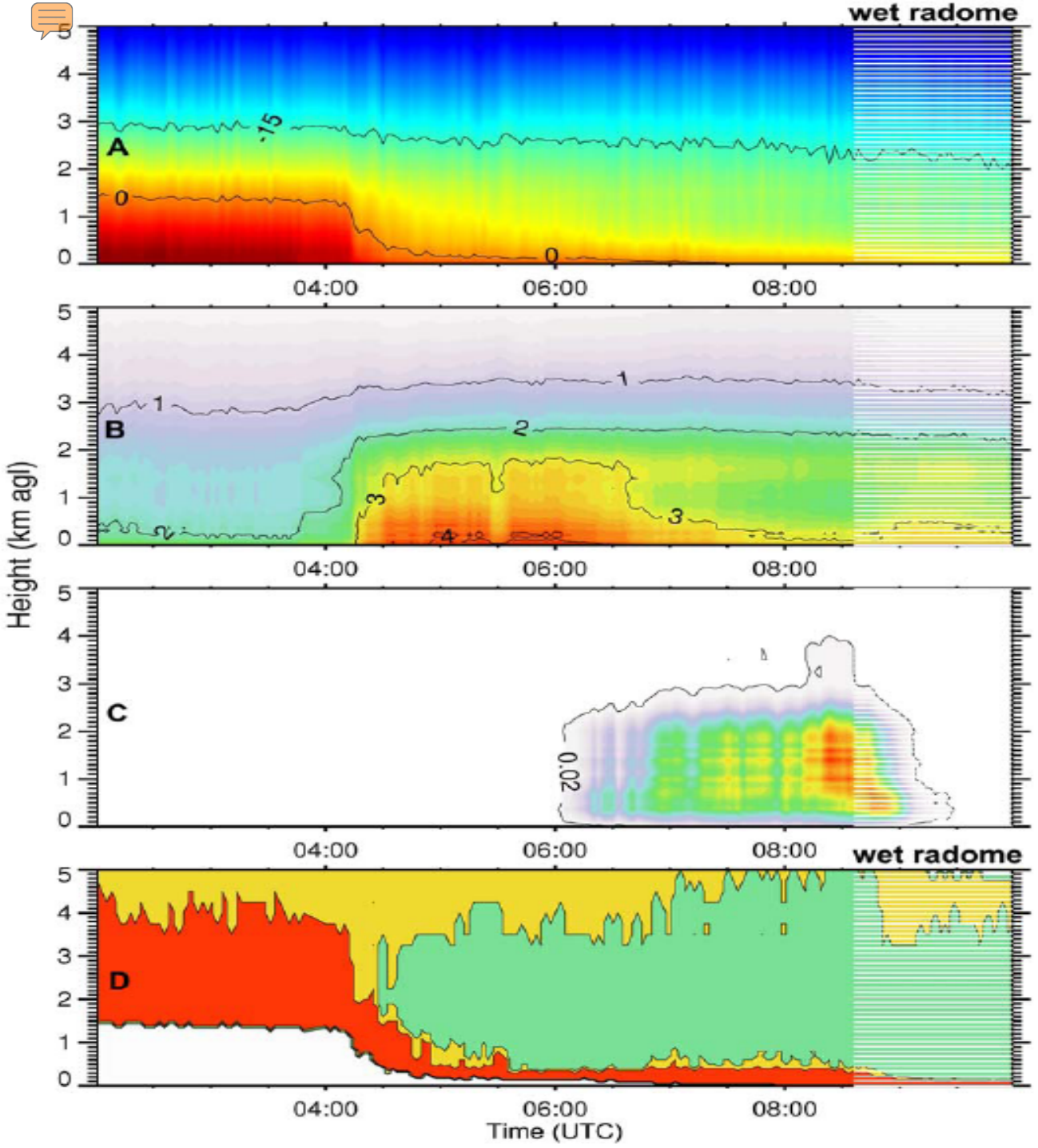
Temperature, equivalent potential temperature and CAPE (maximum CAPE just before 17:45 UT Windsor Tornado).



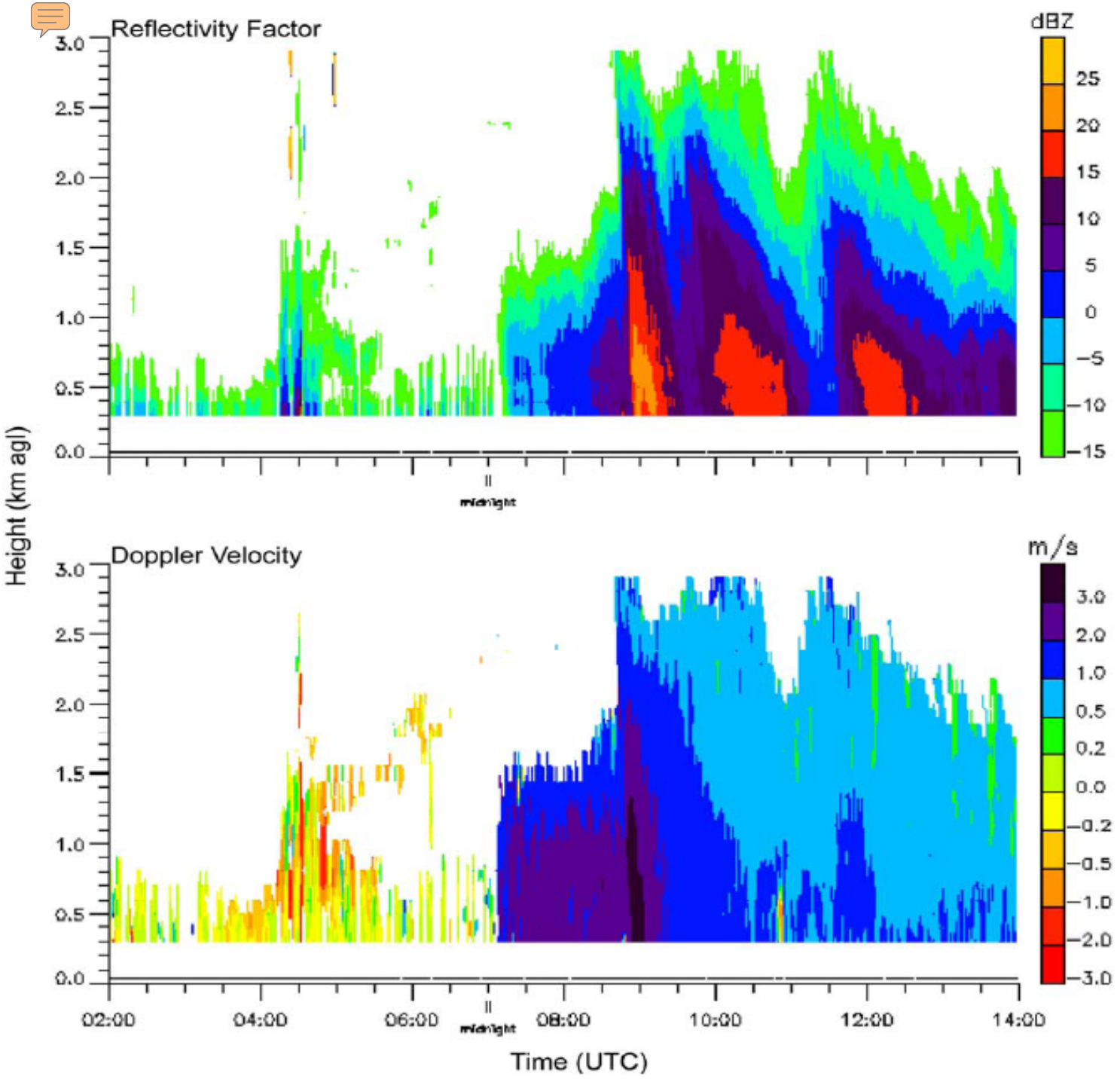
Real time boundary layer temperature, relative humidity and wind shear contour plots with wind barbs.

Meteorological Value of Ground-Based Passive Microwave Observations

- Microwave profiling delivers a continuous flow of temperature, humidity, and cloud liquid profile data
- Fresh radiometer data can feed weather forecast tools and indices developed for radiosondes
- Radiometers deliver unique cloud liquid profiles needed to initialize and update weather models, to monitor and forecast fog and aircraft icing hazard, and to identify opportunity for weather modification
- Microwave profiling provides automated upper air observations with very little human intervention



WeatherCam temperature, vapor and liquid profiles, showing genesis of powder snow via the Wegener-Bergeron-Findeisen process.



NCAR Wind Profiler observations of reflectivity and Doppler velocity during the 14 Feb 2008 upslope powder snowstorm at Boulder, Colorado

Ongoing Research

- A case study of the 22 May 08 Colorado tornadoes including assimilation of Radiometer, Wind Profiler and Doppler Radar data into high resolution models.
- Models include WRF, the Space and Time Mesoscale Analysis System (STMAS) and water vapor tomography.
- Other upper air data could include: CHILL radar, COSMIC, slant GPS (SuomiNet and GPS Solutions).
- Collaborators: NCAR MMM (Rizvi and Moncrieff) and RAL (Vivekanandan), ESRL (Xie and MacDonald), Vaisala (Frederick).

radiometrics

WeatherCam pencil beam (1º) radiometers can detect early stage convection at distances of 100 km or more.

radiometrics

U.S. DOE ARM Program
Barrow, Alaska

Dubai International Airport
United Arab Emirates

German Weather Service
Lindenberg

Met Service Canada
Vancouver Winter
Olympics

Hong Kong
Chek Lap Kok
International Airport

Chinese Meteorological
Administration
Beijing Olympics