Impact of Radiosonde Measurement Accuracy on Precipitation Type and Convective Weather Forecast

Raisa Lehtinen[1), Petteri Survo[1), Johanna Lentonen[1), Mona Kurppa[2)

1) Vaisala Oyj 2) University of Helsinki

Radiosonde Measurement Accuracy

Radiosondes serve as the fundamental method for retrieving detailed vertical profiles of the atmosphere. This information is central input to Numerical Weather Prediction (NWP) models. Radiosondes also have an important role in forecasting, model validation, climatology, and validation of remote sensing instruments. These applications demand high accuracy and consistency of the measurement. The sensors must work reliably throughout the harsh environment of the upper atmosphere and properly identify atmospheric features, such as temperature inversions, cloud layers, humid and dry layers, and ice formation. This study evaluates and quantifies the impact of small measurement inaccuracies on the assessment and forecast of weather, with particular focus on convective weather and winter precipitation.

Key Findings

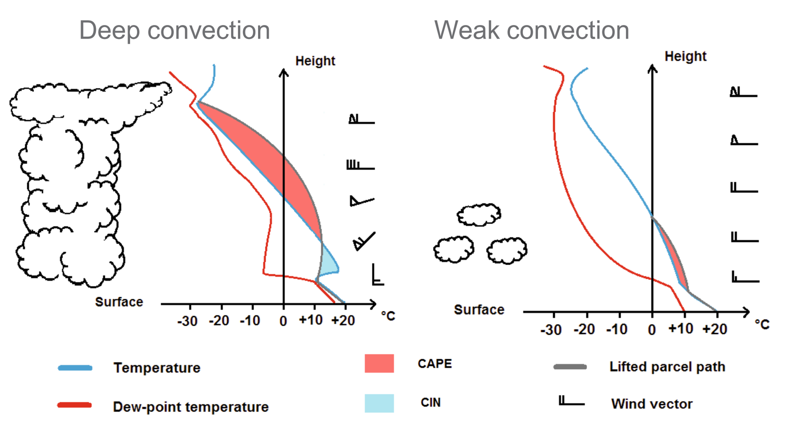
The results demonstrate that small errors in vertical profile measurements can potentially lead to significant forecast errors during high-impact weather events.

- The analysis of 56 radiosonde profiles preceding severe convective weather showed a 5 - 29 % mean relative change in key meteorological indices from a constant -4 % RH offset in humidity. The sensitivity to measurement error was even more significant in the 19 borderline cases where the evolution of severe convection was more uncertain.
- A case study exploring forecasting winter precipitation type demonstrates that a wet-bulb error or small offsets of -4 % RH and +0.3 °C in the profile can change the forecasted precipitation type on the ground between ice pellets, freezing rain, and light rain.

Convective Weather

Forecasting Convection from Radiosonde Profiles

During convection, warm air near the ground starts rising, potentially leading to thunderstorms. Convection is still poorly represented in the NWP models. High-quality radiosonde profiles show the characteristic features that predict the strength of the convection, including temperature inversions, wind shear, and cloud layers. Meteorological indices, such as CAPE and CIN, can be calculated from the profile.

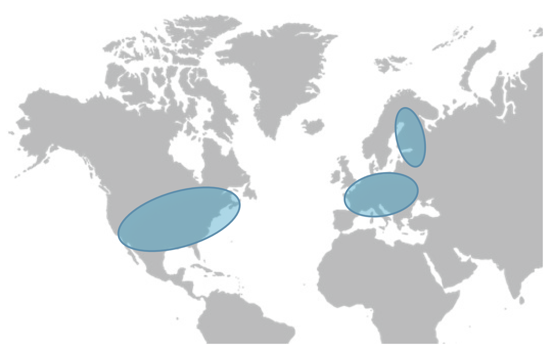


Model profiles predicting various types of convection.

Experimental Setup

The impact of measurement accuracy was studied by modifying radiosonde profiles with small artificial errors and studying the changes in meteorological indices, using the original profiles as the reference.

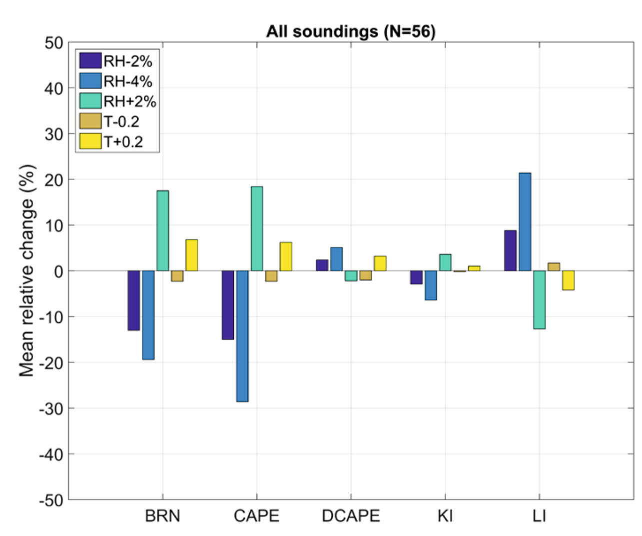
- 56 soundings with Vaisala Radiosonde RS92 or RS41
- Three geographical areas in conditions that resulted in severe convective weather
- Applied offsets: -4, -2, +2 % RH and ±0.2 °C
- Analysis software: RAOB 6.3



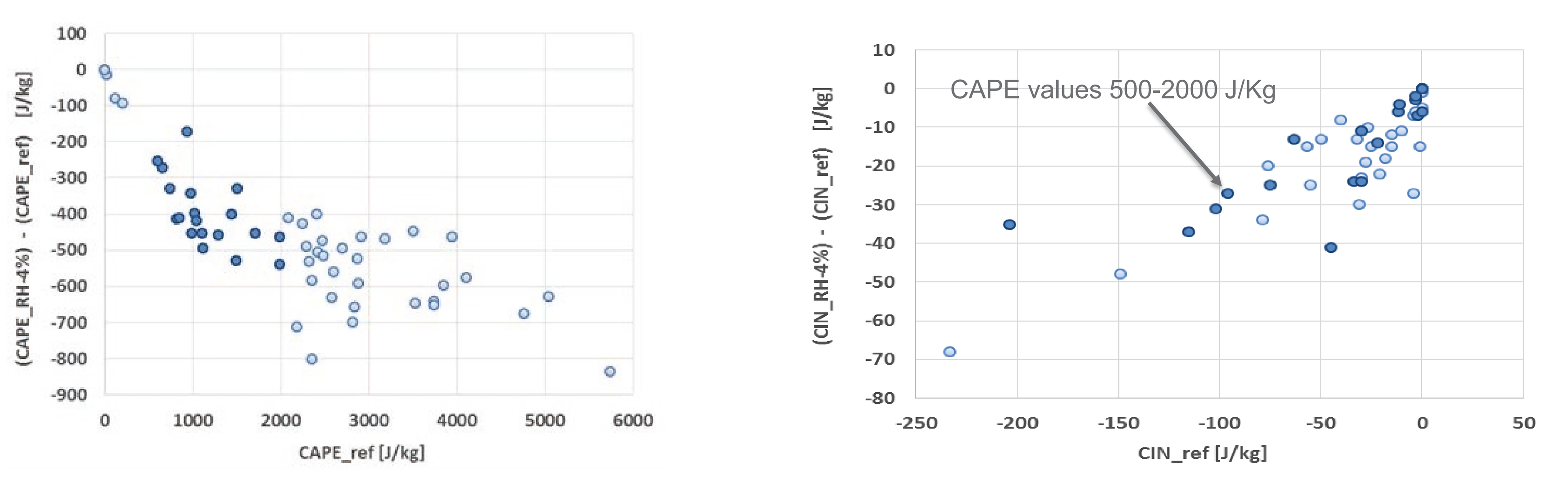
Impact of Accuracy on Meteorological Indices

The results suggest that the prediction of severe convective weather is sensitive to relatively small humidity errors: a constant -4 % RH offset in humidity results in a 5 - 29 % mean relative change in key meteorological indices. A ±0.2 °C temperature offset causes changes of up to 7 % in all indices.

The impact was more significant in borderline situations indicating less potential for convection, as typical shifts of -500… -250 J/kg in CAPE and associated decreased CIN values could lead to a serious underestimation of convection.



Relative changes in five meteorological indices due to small humidity and temperature offsets.

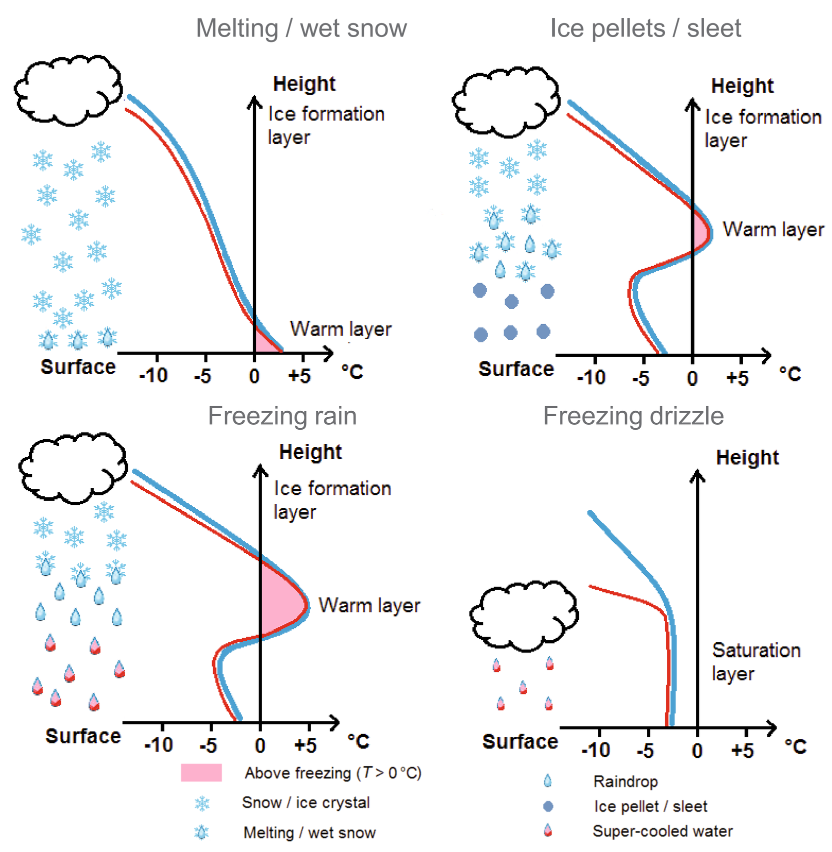


Absolute changes in CAPE (left) and CIN indices due to -4 % RH humidity offset as a function of the original index values.

Winter Precipitation Type

Forecasting Precipitation Type from Radiosonde Profiles

Precipitation type is one of the focus areas in winter forecasting. NWP models have difficulty representing small-scale surface phenomena and shallow air layers. Radiosonde observations capture all the important features, serve as important NWP input, and complement NWP models when they are likely to be incorrect and misleading in predicting the precipitation type.

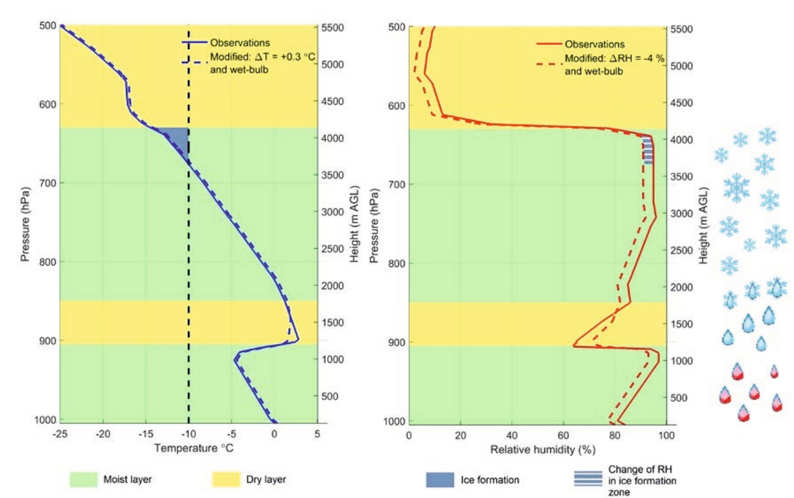


Model profiles predicting various types of winter precipitation.

Experimental Setup

A sounding profile during a long-lasting freezing rain event was modified in a case study.

- RS92 sounding
- Applied offsets and errors: -4 % RH and +0.3 °C, and a wet-bulb error, as shown in the graphs
- The precipitation types on the ground for the original and modified profiles were estimated from significant atmospheric layers, using the reported weather observation as the reference



Temperature and relative humidity profiles for a sounding in Zagreb, Croatia, 2014-02-05, showing original and modified observations.

Impact of Accuracy on Precipitation Type

As shown by the reasoning in the table below, the original sounding profile indicates freezing rain, which corresponds to the observed weather. However, this is a borderline case. A wet-bulb type error would decrease the level of melting in the elevated warm layer and thus increase the probability of forecasting ice pellets instead of freezing rain. On the other hand, an offset of -4 % RH would decrease the efficiency of ice formation in the shallow ice formation layer. Combined with a temperature offset of +0.3 °C, the forecasted precipitation type changes towards liquid precipitation. In this case even small temperature and humidity offsets can change the forecast towards either solid or liquid precipitation.

Sounding profile	Modified sounding: wet-bulb error	Original sounding	Modified sounding: ΔT = +0.3 °C, ΔRH = -4 %
Ice formation	Shallow layer T < -10 °C → Probable ice formation	Shallow layer T < -10 °C → Probable ice formation	Shallow layer T < -10 °C → Less probable due to lower humidity
Elevated warm layer	T_{max} = 1.9 °C → Partial melting of ice → Solid and liquid can occur	T_{max} = 2.8 °C → Partial melting of ice → Rain more probable, also sleet can occur	T_{max} > 3 °C → Complete melting of ice → Rain
Surface	$T_{surface}$ < 0 °C → Rain will freeze on the ground → Ice accumulation / sleet	$T_{surface}$ < 0 °C → Rain will freeze on the ground → Ice accumulation / sleet	$T_{surface}$ > 0 °C → No freezing on the ground
Forecast	Ice pellets (more probable) or freezing rain or mix	Light freezing rain (more probable) or ice pellets	Light rain or no rain
Observed weather	Light freezing rain		

More information: Accuracy Matters in Radiosonde Measurements White Paper
www.vaisala.com