1 Introduction

Atmospheric convection plays an important role in energy circulation of the atmosphere by transporting heat, momentum and moisture from boundary layer to the free atmosphere. The vertical transport of these fluxes (heat, momentum and moisture) determines the evolution of multi-scale convective phenomena such as thunderstorms, tornadoes etc (Lane, et. al., 2010, Shaw, et al, 2013). The temporal scale of these phenomena range from few minutes to hours and are associated with disastrous effects having socio-economic importance (Doswell, 1985). Therefore, a continuous monitoring of profiles of the atmosphere is important for their study. Conventionally, they are observed using radiosonde (/ GPS-sonde hereafter reffered as radiosonde) measurements. However, it is difficult to study the evolution of convection using them due to its limited availability of these observations, as operationally two radiosonde launches are scheduled at 0000 and 1200 UTC of everyday. Also, it is very expensive to launch radiosonde operationally on regular intervel of one hour. Therefore, it is difficult to monitor the convective systems which evolves during the interval in between these launches. Moreover, network of radiosonde observations is spatially course and many times convection may not occur in the way radiosonde is flying. Further, updrafts and downdrafts occuring during the convection cause either drift or burst of rubber baloon attached to radiosonde equipments. On the other hand, spaced based measurements of vertical profile of the atmosphere using radio and microwave RADARS / Radiometers on low earth orbiting satellites / sun syncronous satellites / geostationary satellites are useful to identify the convections, their movement and evolution. However, their re-visit time/frequency of the observations and limitted retrieval skill at lower portion of the atmosphere does not allow investigating the genesis and evolution convection in most of the cases.

In this situation, Multichannel Microwave Radiometers (MWR) has evolved as powerful tool for monitoring the genesis and evolution of the convection over a site (Chen, 2009). The MWR is a device which measures the vertical column profiles of temperature, humidity and cloud liquid water content. Therefore, the MWR enables continuous monitoring of the thermodynamic conditions of the atmosphere which are very important to study convective storms (Chen, 2009; Cimini et. al. 2011). Generally, it is a passive radiometer, continuously monitors brightness temperature in various wavelengths in microwave region of electromagnetic spectra. Tanner, 1998 discussed about the design details, radiometric stability and laboratory test results of MWR operating around 20 GHz. Shinder and Hazen (1998), descried the observations of water vapor and cloud liquid based on MWR operating on frequencies 20, 23, 31 and 90 GHz. They carried out measurements at several continental locations in the United States. They found that there is a significant differences in precipitable water vapor and cloud liquid in temparate and tropical region. d'Auria et al, 1998 used MWR observations to study cloud properties and generating database of cloud genera. Westwater et al, 1998 deployed scanning MWR operating in frequency 5 mm (60 GHz) radiometer over Flotting Instrument Platform over ocean to study the oceanic boundary layer and Southern Great Plains of Central Oklahoma. Their results showed the excellent agreement between atmospheric temperatures estimated by MWR and other measurements (Meteorological Towers and IR measurement). Bleisch and Campfer (2001) discussed about the technique of retrieval of water vapor profile using MWR operating in frequnecy 22 GHz and its application to retrive humidity profile in Upper Troposphere and Lower Stratospheric (UTLS) region. Cimini et. al. 2003, discussed the performance, calibration and achivable accuracy of a set of four MWR operating in the 20-30 GHz band for the Atmospheric Radiation Program field experiments. They found that, the brightness temperature measurements for two identical instruments differed less than 0.2 K over a period of 24 hours. Binco et. al., 2005 demonstrated synergetic use of microwave radiometer profiles and wind profiler RADAR to retrieve atmospheric humidity. They used wind profiler RADAR to estimate the potential refractivity gradient profiles and optimally combined them with MWR estimated potential temperatures in order to fully retrieve humidity gradient profile. Their results show the significant improvement in the spatial vertical resolution of the atmospheric humidity profilers. Iassaman et al 2009 used 12 frequency MWR to analyze the statistical distribution of tropospheric water vapor content in clear and cloudy conditions. They found that water vapor containt, vertically integrated water vapor containt is well fitted Weibull distribution and vertical profiles of clear and cloudy conditions are well described a function of temperature having same form as the Clausius-Clapeyron equation. Chen 2009, discussed the use of a MWR thermodynamic profiles for nowcasting of severe weather such as rainstorm using humidity profile and K index. They found that, the accumulation of water vapor and increase in the instability in the troposphere 1 hour prior to occurance of heavy rain is useful for its nowcasting.

Therefore, MWR is becoming useful tool for nowcasting of intese convective weather. Thus, high frequency and accurate measurement of radiometric profiles are very important to understand mesoscale processes and physical mechanisms involved in preconditioning and triggering of small scale convections such as thunderstorms, tornados, etc and also for understanding of their evolution. There are very limitted efforts to understand it especially over the tropical region because of unavailability of high frequency observations over this region eventhough it is very important to understand it to study global energy transport.

Recent developments in the retrieval algorithms and computational techniques are adaptive and devise a model (Gaffard Tim Hewison, 2003) which improves the performance and accuracy of radiometer retrievals. Many nonlinear statistical / evolutionary algorithms are being developed for retrieving the profiles of atmosphere using MWR (Solheim, 1998). These includes ANN, Newtonian iteration of statistically retrieved profiles, Bayesian most probabale retrieval, etc. Artificial Neural Networks (ANNs) is widely used for different types of infrared and microwave sounding instruments (Frate and Schiavon, 1998; Binco et. al., 2005). Frate and Schiavon, 1998 presented an inversion technique to retrive profiles of temperature and water vapor using MWR. Their techniques combined a profile over a complete set of orthrogonal function with ANN which performs the estimate of coefficient of the expansion itself. Their analysis shows that this technique is flexible and robust. Kottayil et al 2010 used a new nonliner techique ANFIS to improve the first guess using simulated infrared brightness temperature for GOES-12 sounder channels. They found results of ANFIS retrieval are robust and reduces root mean squared error by 20% compared to regression fiting. They also argued that as ANFIS use Fuzzy Information System (FIS) for the classification of input, the classification of traning dataset is not needed as it is required for regression techniques. In the present work, we have developed a ANFIS model based retrieval of atmospheric parameters using MWR observations at NARL, India. The objective of this algorithm development is to improve the accuracy of retrieval of temperature and humidity profiles of MWR especially over lower atmosphere.

The paper is organized as follows. The next section 2 of this paper describe the details of data used for this study. The details of method used and ANFIS algorithum is described in section 3.

The experimental results are discussed in section 4 and conclusions obtained from this work are presented in section 5.

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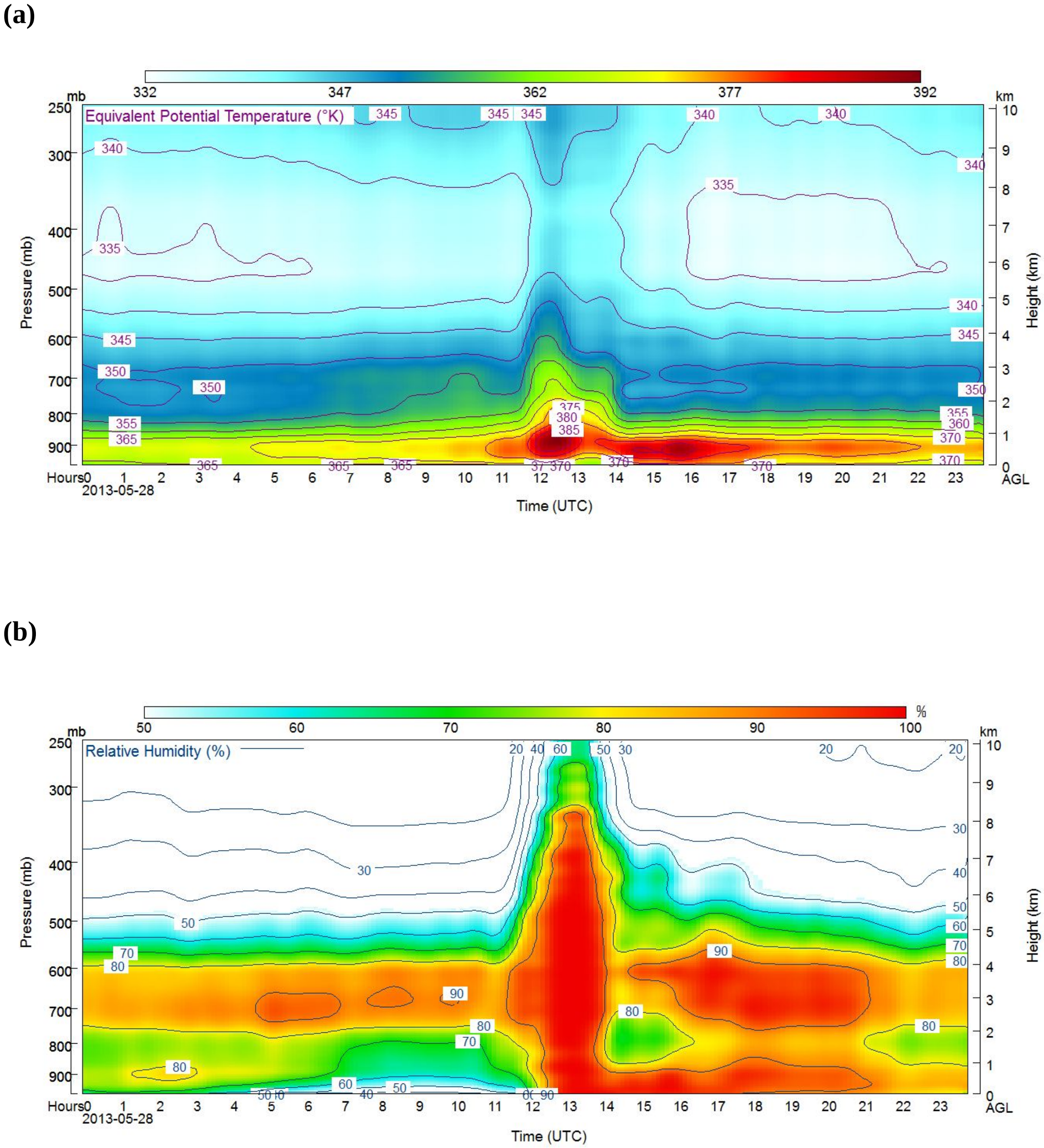
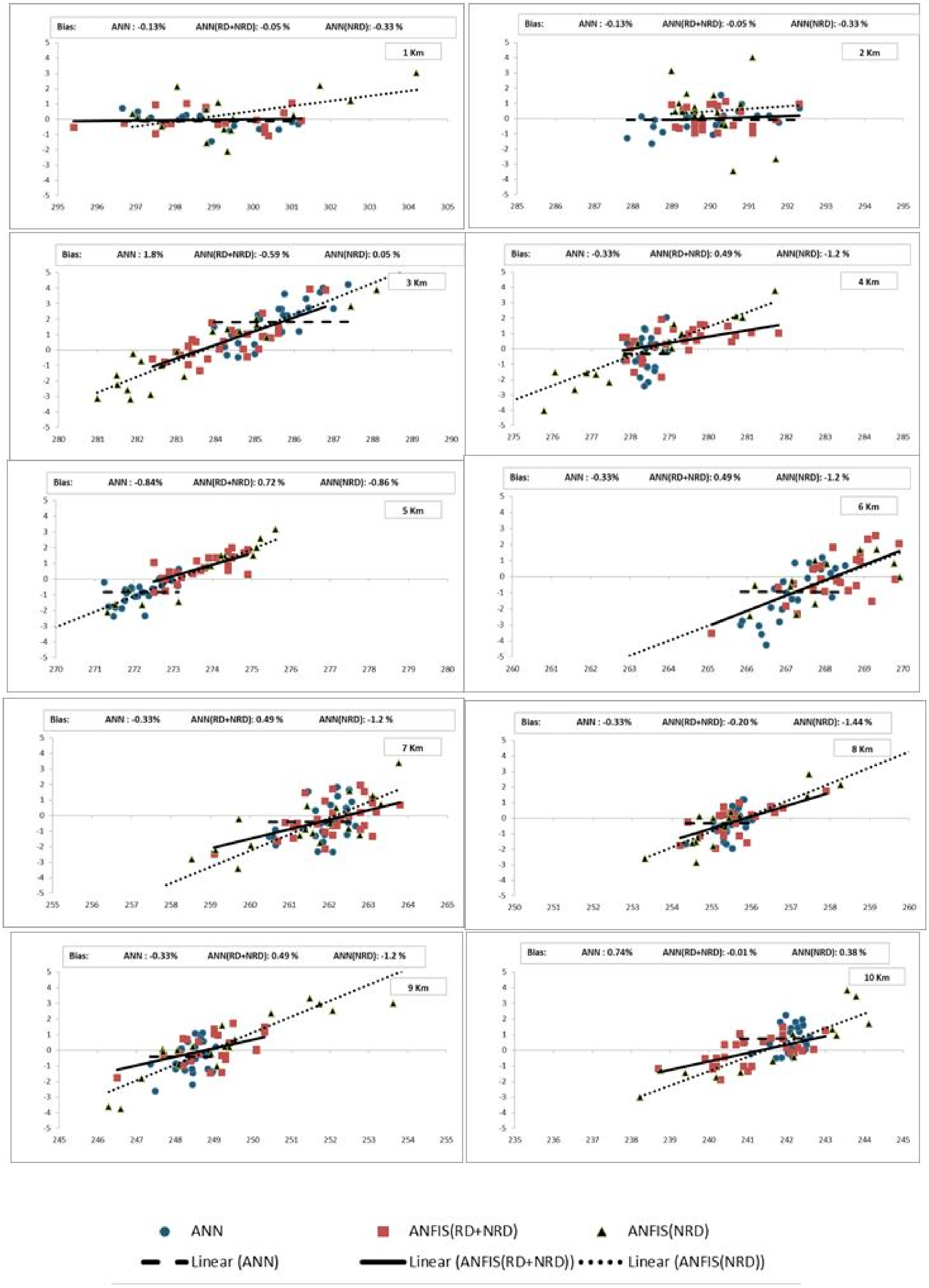


Figure 1: Composite of vertical profiles of equivalent potential temperature (a) and relative humidity (b) retrieved during convection event on May 28, 2013 over NARL Gadanki using MWR (ANN algorithm). The time resolution of these profiles is 4 minutes. (c) sensitivity of 31

microwave brightness channels measured by MWR (not shown in supplementary material to improve the quality of figure)

(The detailed structure of ANFIS model will be added to revised manuscript not shown in supplimentary material.)

Figure 2: Structure of ANFIS Model.


Bias: ANN : -0.13% ANN(RD+NRD): -0.05 % ANN(NRD): -0.33 %
1 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
295 296 297 298 299 300 301 302 303 304 305
Bias: ANN : -0.13% ANN(RD+NRD): -0.05 % ANN(NRD): -0.33 %
2 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
285 286 287 288 289 290 291 292 293 294 295
Bias: ANN : 1.8% ANN(RD+NRD): -0.59 % ANN(NRD): 0.05 %
3 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
280 281 282 283 284 285 286 287 288 289 290
Bias: ANN : -0.33% ANN(RD+NRD): 0.49 % ANN(NRD): -1.2 %
4 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
275 276 277 278 279 280 281 282 283 284 285
Bias: ANN : -0.84% ANN(RD+NRD): 0.72 % ANN(NRD): -0.86 %
5 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
270 271 272 273 274 275 276 277 278 279 280
Bias: ANN : -0.33% ANN(RD+NRD): 0.49 % ANN(NRD): -1.2 %
6 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
260 261 262 263 264 265 266 267 268 269 270
Bias: ANN : -0.33% ANN(RD+NRD): 0.49 % ANN(NRD): -1.2 %
7 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
255 256 257 258 259 260 261 262 263 264 265
Bias: ANN : -0.33% ANN(RD+NRD): -0.20 % ANN(NRD): -1.44 %
8 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
250 251 252 253 254 255 256 257 258 259 260
Bias: ANN : -0.33% ANN(RD+NRD): 0.49 % ANN(NRD): -1.2 %
9 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
245 246 247 248 249 250 251 252 253 254 255
Bias: ANN : 0.74% ANN(RD+NRD): -0.01 % ANN(NRD): 0.38 %
10 Km
5 4 3 2 1 0 -1 -2 -3 -4 -5
235 236 237 238 239 240 241 242 243 244 245
● ANN
■ ANFIS(RD+NRD)
▲ ANFIS(NRD)
Linear (ANN)
Linear (ANFIS(RD+NRD))
Linear (ANFIS(NRD))

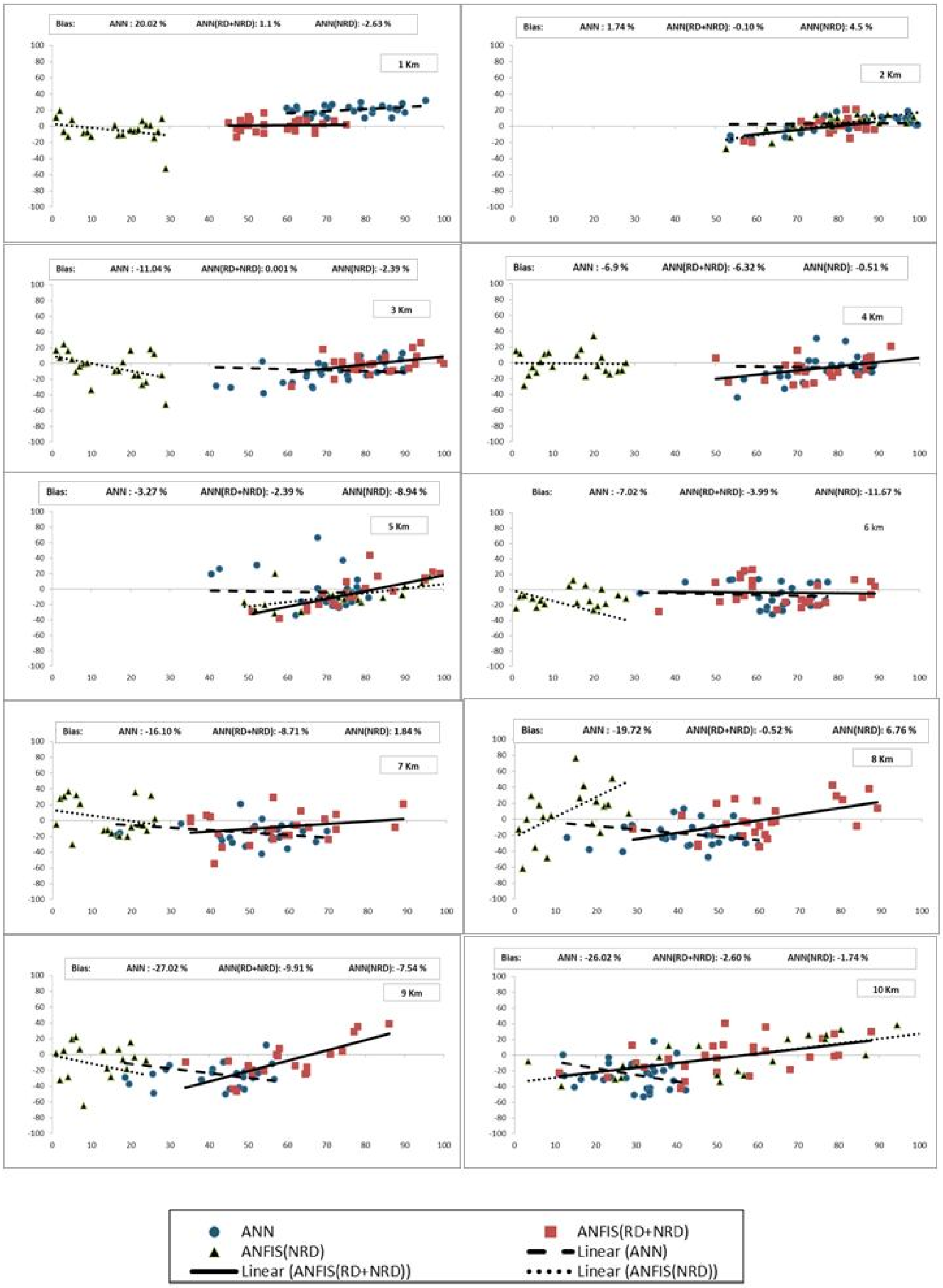


Figure 3: Scatter plot of difference between retrieved values using ANN / ANFIS(RD+NRD) / ANFIS(NRD) technique with radiosonde observations versus the retrieved values using these techniques respectively for (a) temperature retrieval (b) retrieval of relative humidity

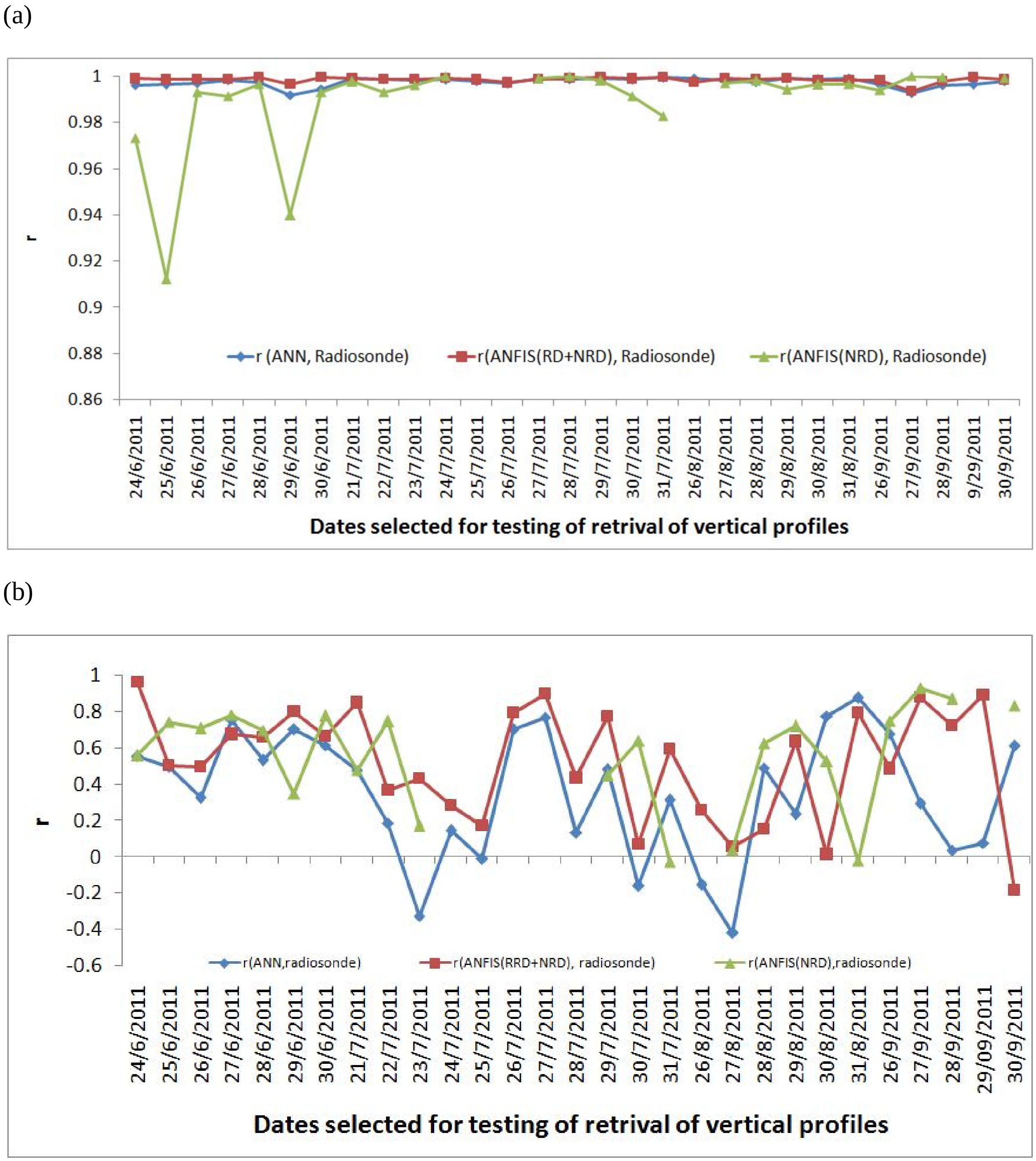


Figure 4: Pearson product movement correlation coefficient (r) between radiosonde temperature (a) and humidity (b) profiles and retrived profiles using ANN and ANFIS

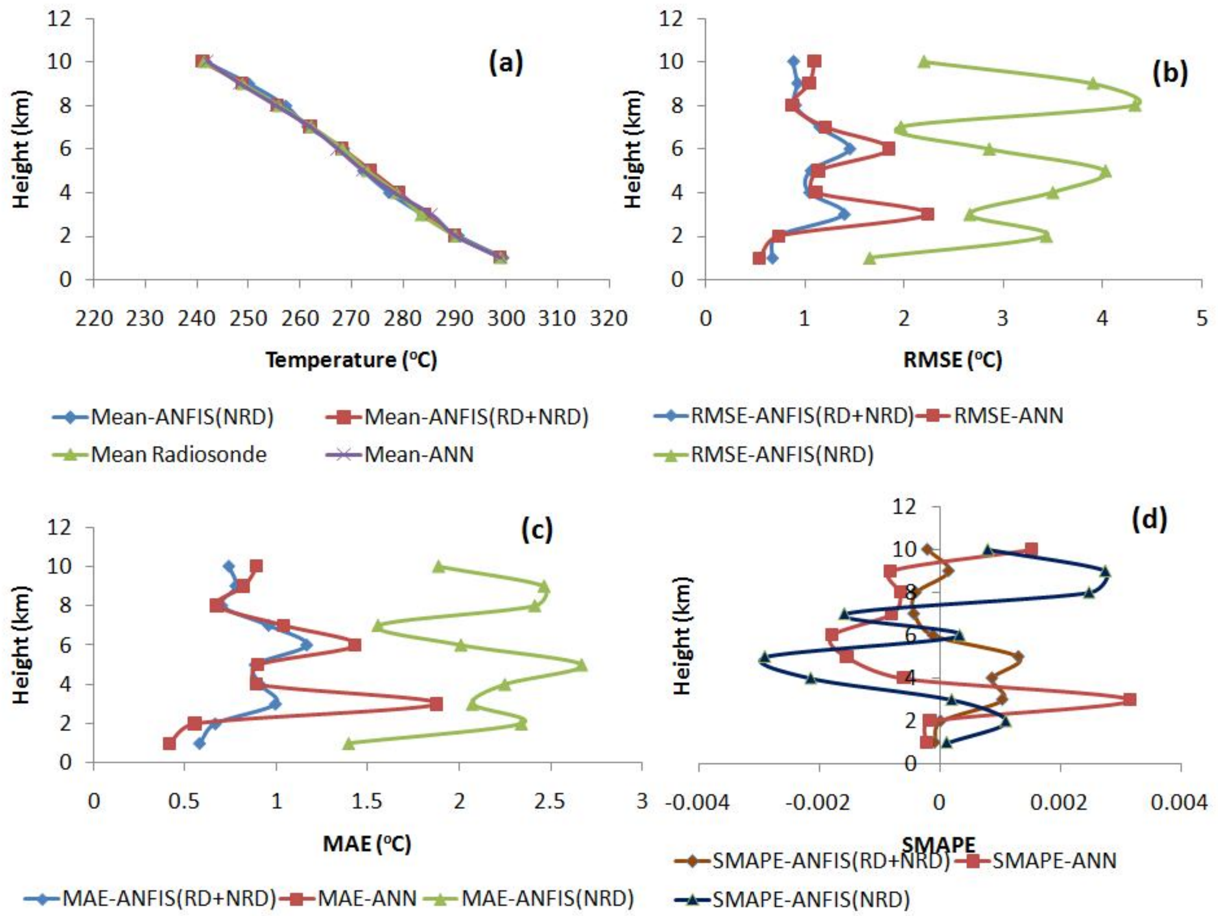


Figure 5**:** Comparison of vertical profiles of (a) temperatures from radiosonde and profiles retrived from ANN and ANFIS and (b) RMSE (c) MAE (d) SMAPE retrived from ANN and ANFIS with respect to temperature profiles from radiosonde observations.

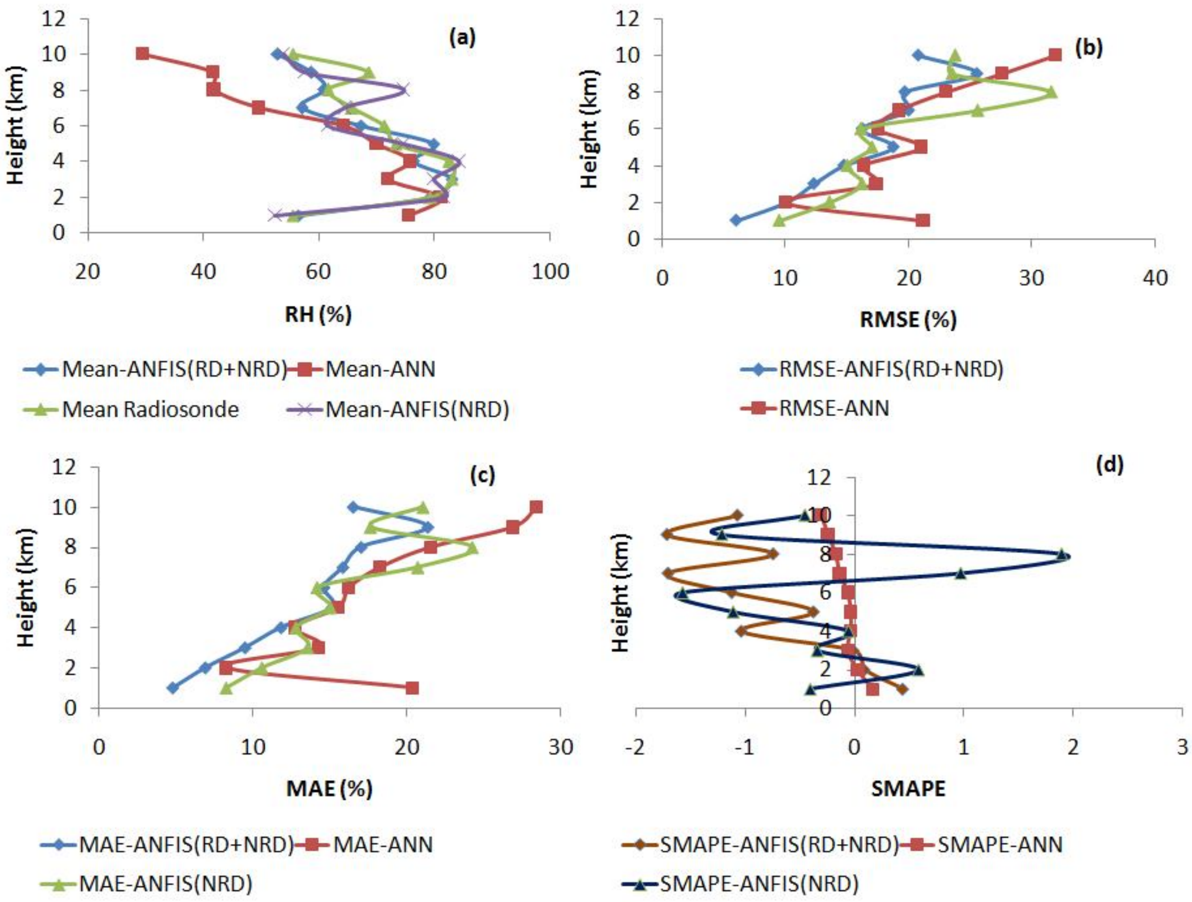


Figure 6**:** Comparison of vertical profiles of (a) RH from radiosonde and profiles retrived from ANN and ANFIS and (b) RMSE (c) MAE (d) SMAPE retrived from ANN and ANFIS with respect to RH profiles from radiosonde observations.