Radar Uncertainties in Cell-based TITAN Analyses

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Abstract

Radar uncertainties are analysed through the use of error analysis in numerical radar data obtained by **TITAN** (**T**hunderstorm **I**dentification **T**racking **A**nd **N**owcasting) in clouds and rainfall over Texas. The estimation of uncertainties in repeatable measurements is discussed due to the fact that repeated measurements cannot be obtained when dealing with clouds. Every cloud is a unique and unrepeatable process, and therefore, the actual estimation involves radar uncertainties plus natural variability. Although usually meteorologists and hydrologists do not bother to consider uncertainties in every day measurements, these uncertainties are very important to validate the radar as a tool in the measure of hydro-meteorological quantities and in the evaluation of potential increases in applied weather modification projects.

Key Words: Radar, TITAN, cells, clouds, precipitation, uncertainties

Introduction

Water districts and the State of Texas decided to introduce TITAN software in 1997. This introduction had as main purpose to help meteorologists and managers in dealing with radar data during and after cloud seeding operations. TITAN is software for personal computer that runs on Linux systems and processes volume-scan radar data producing useful pictures of radar echoes (Dixon and Wiener, 1993). However, we soon learnt that the software is more than just beautiful pictures since it is capable of producing numerical data files for every tracked unit, and these files can be used to obtain statistical evaluations of performance in cloud seeding operations (Ruiz-Columbie et al, 2003). These files contain information of sixteen variables, scan by scan, and they can be easily formatted in like-excel files (g-numeric files when using a gnome Linux distribution) for posterior calculations. Precisely, the numerical files for cell entities allow the users to develop like-climatological studies, recognize patterns of behaviour, and build empirical models. Together with trends, the users may study the uncertainties of the variables in use.

Radar uncertainties in weather data have received poor attention in literature. Perhaps because there is no need for great accuracy in nowcasting tasks, or maybe because of our natural underestimation of weather radars as tools, these uncertainties have being missed in many papers and books (see an exception in Rinehart, 1997). However, the increasing use of radars in water management (see for instance Henderson et al, 2000) and the need to study precipitation-water vapour correlations (atmospheric water closure) suggest that we will need to approach soon the analysis of radar uncertainties in weather data. This paper is our first attempt.

Background

Weather radars are used to detect the presence, type, and range of weather systems from the receivers. This is done by emitting an electromagnetic wave and then observing the signal scattered back toward the radar by the targets encountered. The ranges are obtained from the time delays of the backscattered signal, whereas the types or sizes of targets are obtained from its strength. The weather systems are composed mainly of large number of precipitation particles which are stochastically located in space, move with a random speed distribution, and have a random size distribution. Moreover, the received signal is passed through a complex electronic system where is processed before the results are shown on the radar screen. The high complexity of the whole process would make the detailed analysis of uncertainties an almost impossible task, but since the backscattered signal from a single precipitation particle depends on the size of the particle and the distance from the particle to the radar, early scientists and engineers were capable to give us radar equations in which the radar reflectivity factor (Z) of a weather target is independent of the particular radar in use, and then, it is a genuine property of the target. The advent of the digital era brought also the possibility of dealing with numerical data which allow us to analyse uncertainties using the classical error analysis.

According to the latter, all measurements are subject to some uncertainties (Taylor, 1982). Error analysis is precisely the study and estimation of these uncertainties, which constitutes an important part of any scientific or engineering report. However, many measurements involve uncertainties that are really hard to estimate from a single reading and therefore, repeatable measurements are advised, leading then error analysis to the realm of statistics. Here an additional problem appears when dealing with weather systems: repeated measurements are always done on different stages of a given target, which is unique and unrepeatable as a process. The extension of error analysis to weather data breaks the axiom about that the quantity measured must be the same quantity each time since the rapid evolution of weather systems forbids this assumption.

In brief, we use the general expression **Best Estimate ± Uncertainty** to report uncertainties of any variable. The best estimate can be any measure of central trend but we prefer the mean value since after long averaging any data will approach a normal trend, whereas the uncertainty is the standard deviation of the mean (called also standard error). The expression for this standard error is:

$$\sigma_{<x>} = \sigma_x / N^{0.5}$$

where <x> is the mean of x, σ_x its standard deviation, and N is the number of cases. The fractional expression of the error (relative error) is also used:

$$\textbf{relative error} = \sigma_{<x>} / <x>$$

The precedent mathematical considerations are well-supported through the Central Limit Theorem, which assumes the measurements to be independent, identically distributed random variables with finite second moment (standard deviation). The theorem assures that in a long-average process the mean approaches a normal distribution. Radar measurements must be done to accomplish the premises (Sauvageout, 1992)

One more comment is pertinent. Rainfall quantities are estimated in TITAN using Marshall-Palmer relationships (Marshall and Palmer, 1948). Uncertainty calculations could be made using the uncertainty corresponding to the radar reflectivity factor and later propagating the uncertainty through the analytical mathematical expression. Nevertheless, we prefer the statistical approach because we already have numerical files for different variables, and we believe it is more informative than the method of error propagation.

Facilities, Data, Results

The data used in this analysis were provided by the WSR-74C radar network in use during the Texas cloud seeding season 2002. At that time the network had ten 5-cm weather radars in operations which covered about 55 million acres. TITAN was capable to identify 897 seeded clouds although only 599 of them received proper unseeded control clouds to obtain a contrastive evaluation (Ruiz-Columbié et al, op.cit). The software assigned track numbers to the seeded and control entities following the criterion that maximum reflectivity were at least 32 dBz for an area greater or equal to 15 km^2, which assured rainfall intensity to overcome the evaporation. Table 1 shows the results obtained after the application of error analysis to both samples (the seeded and the unseeded). It is easy to note that minimal uncertainties were detected in Lifetime, Reflectivity and Heights, whereas the maximal uncertainties occurred in supercooled volume and in Precipitation Mass, the latter a variable derived from Z-R relationship. These uncertainties contain the instrumental uncertainties plus the uncertainties associated to the natural variability of cells under study (Chumchean, S., et al, 2003). However, we are interested in their superposition. It is important to notice that the uncertainties are significant smaller than their corresponding mean values, giving validation to the radars as proper tools. Radars are not perfect but they offer substantial information. Furthermore, the differences between uncertainties for the seeded and unseeded samples are really small if any, probably indicating that the seeding operations did not affect them, at least for these particular samples.

Conclusions

Two points should be noticed:

First, the uncertainties obtained by repeating measurements are called random errors. Here we have reported random uncertainties associated to mean values but nothing has being said about systematic errors. They are within the data although for the initial purpose of the analyses they do not matter since in Weather Modification we deal with comparison between seeded and unseeded samples (contrastive knowledge) and in the comparison any systematic error vanished. Systematic errors are very difficult to evaluate and probably the only way to diminish them is through careful calibration and using the state of art equipment. We are planning to utilize NEXRAD data in future cloud seeding operations and its evaluation, and also in water management tasks.

Second, these random uncertainties offer confident intervals for our estimation. In a normal approximation, about 70 % of the values are within the interval

Best Estimate ± Uncertainty

These confidence intervals will play an important role in the future coordination among radar data, ground-based GPS water vapour data, and rain gauge data.

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Appendix A

Table 1: Mean values and uncertainties for different radar variables corresponding to seeded and unseeded samples in Texas 2002 (599 couples)

	Mean		**Uncertainty**		**Relative Uncertainty in %**	
Variable	Seeded	Unseeded	Seeded	Unseeded	Seeded	Unseeded
Lifetime (min)	85	60	5	5	6	8
Area (km^2)	58	47	5	4	9	9
Volume (km^3)	193	140	19	14	10	10
Top Height (km)	8.0	7.5	0.2	0.2	3	3
SC-Volume above 6 km (km^3)	55	35	11	7	20	20
Max. Reflectivity (dBz)	47.3	45.6	0.9	0.9	2	2
Top Height of Max. Reflectivity (km)	4.2	4.3	0.1	0.1	2	2
Precipitation Flux (m^3/s)	289	191	29	19	10	10
Precipitation Mass (kton)	1439	667	230	100	16	15
Radar Cell Mass (kton)	120	80	14	10	12	13

Note: SC- Volume means supercooled volume, the part of clouds with temperature below 0 °C.