RETRACKING ERS-1 ALTIMETER WAVEFORMS OVER LAND FOR TOPOGRAPHIC HEIGHT DETERMINATION: AN EXPERT SYSTEMS APPROACH.

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ABSTRACT

The behaviour of altimeter echoes over land from the ERS-1 geodetic mission has been investigated. Highly complex altimeter echoes are observed over much of the terrain not sampled by previous altimeters due to loss of lock. Investigation into the effects of off-ranging has shown that for low to moderate slopes this effect is not observed as significant over validation areas; accurate height data can be determined. Attention has therefore been focussed on improving retracking performance and an expert system has been developed to retrack individual waveforms using a range of retrackers specifically configured to interpret echoes over land. Results are presented indicating the value of an expert system approach to land altimetry retracking.

1. INTRODUCTION

The ERS-1 mission resulted in the acquisition of large volumes of echoes over non-ocean surfaces. Whilst returns over ice have been the focus of considerable research, the land altimetry dataset has been much less studied.

Detailed study of data from the 35 day repeat mission demonstrated the potential for accurate height generation from ERS-1 altimeter data over land [1,2,3] with recovery of good height data found to be essentially independent of altitude, dependant primarily on the severity of the terrain relief. Subsequent retracking of the entire geodetic mission WAP dataset, and analysis of the results including series of comparisons with ground truth, confirmed this initial finding and indicated that very good agreement between ground truth and retracked altimeter data could be obtained [4, 5]. An investigation into the error budget for land altimetry was therefore carried out.

2. ERROR BUDGET
2.1 GLOBE analysis

The primary source of error for altimeter data over topographic surfaces occurs when the altimeter receives a strong return from an off-nadir sloping surface within the illuminated footprint [4].

Following initial evaluation with one cycle of 35 day data over the Rift Valley, Kenya [12] which showed less evidence of off-ranging than had been expected, a test area in the central USA was selected for a study into the effects of slope induced error on altimeter derived height estimates over land. A brief summary of the results is included here.

Figure 2.11 shows a series of sample profiles of altimeter derived 1 km mean heights plotted against the GLOBE GDEM values for the corresponding 1km pixels; overlaid on these graphs is the along track slope calculated from the GLOBE dataset. Note that these estimates refer to mean slopes over 1km pixels; these values will therefore tend to under-represent the actual slopes present in the terrain. Analysis of all profiles considered shows that for mean slopes of less than 0.8 degrees, no systematic effects of off-ranging are detected. For higher slopes, a characteristic lateral displacement of feature is occasionally observed. However, even when present, the vertical errors are lower by a factor of 2 or 3 than would be expected from a simple calculation for off-ranging from a uniform slope [4] , as are the horizontal displacements. This is a not unexpected finding, as slopes over land are not generally well characterised by a single mean value for a region, but typically comprise an aggregate of areas of differing extent and slope. A more realistic model for this effect is currently being addressed. Results from crossover analyses over Zimbabwe and the USA test areas [8,10,13] also confirm the internal consistency of the altimeter measurements.

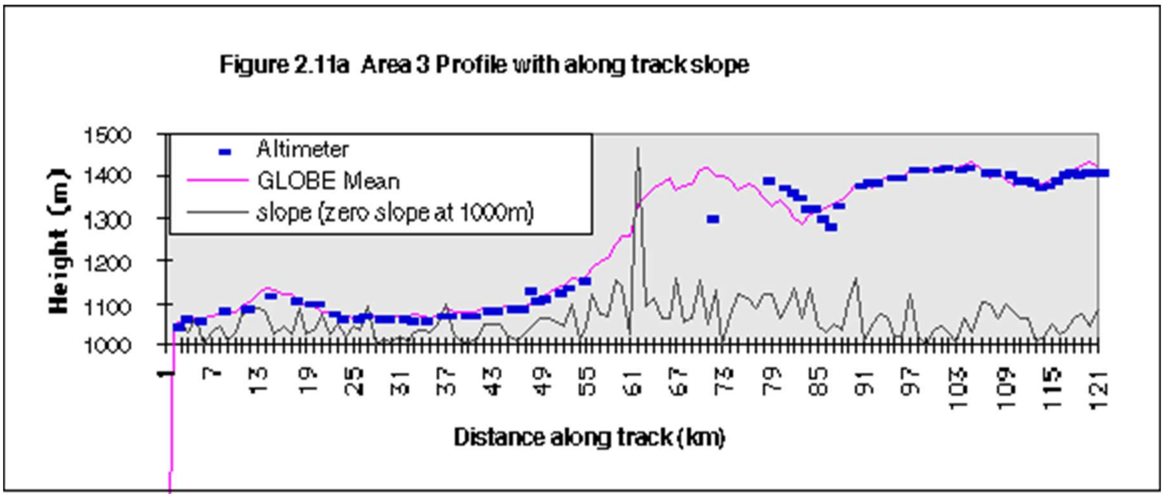

Figure 2.11a Area 3 Profile with along track slope

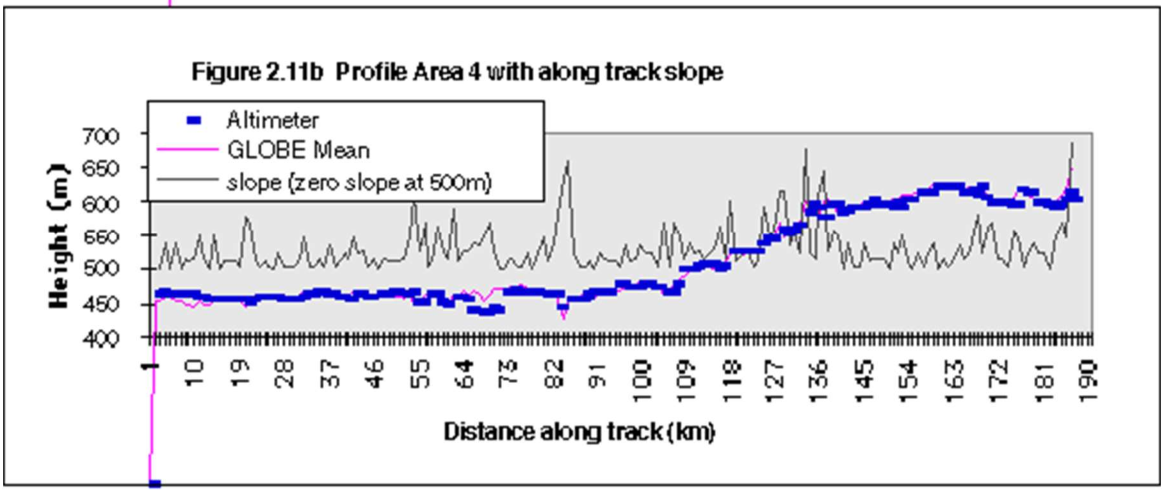

Figure 2.11b Profile Area 4 with along track slope

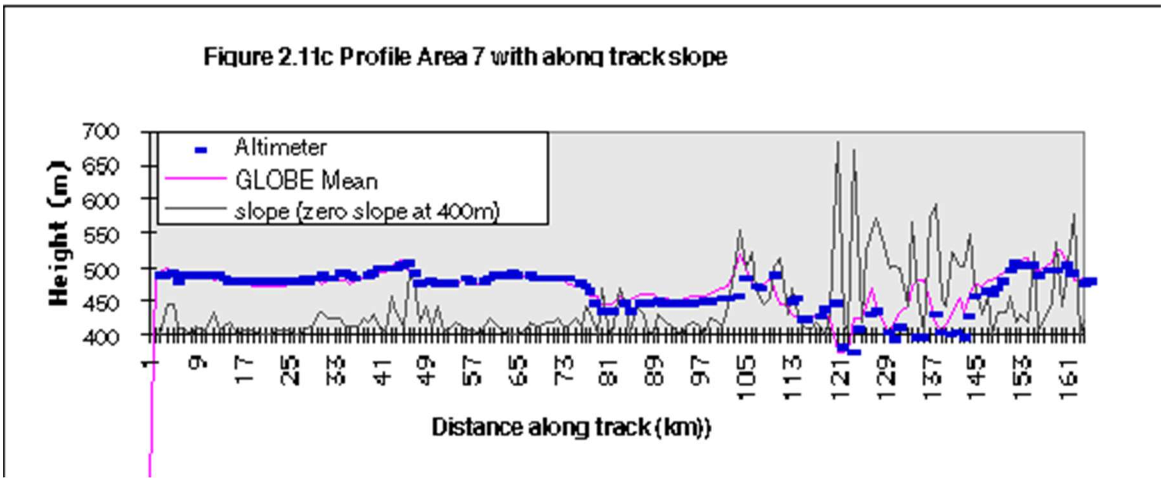

Figure 2.11c Profile Area 7 with along track slope

Note: in the above profiles the scaling of the along track slope is such that 1 degree corresponds to 100 metres on the height scale. The origin of the slope scale is marked on each figure.

The results over the test areas indicate that for a large proportion of data, slope induced error is not a significant error factor. This offers the possibility of obtaining orthometric height data from much of the ERS-1 geodetic mission data. However, this research also confirmed that highly complex and variable altimeter echoes are observed in this dataset, primarily over terrain not sampled by previous altimeters due to loss of lock. Initial research indicated that simple retracking techniques such as threshold retracking were not adequate to derive accurate height estimates from these complex waveforms [2,3,6,9]. To optimise the accuracy of data derived from this unique dataset, an expert system has therefore been developed to retrack individual waveforms using a range of retrackers specifically configured to interpret these echoes.

3. EXPERT SYSTEM

The expert system works within a processing chain to process data from ERS-1. From the input WAP datastream the raw altimetry data is abstracted and processed through a series of algorithms prior to input to the expert system. These algorithms include checks to exclude obviously erroneous data, or data for which vital auxiliary information is missing, but may still include 'unusable' waveforms, for example where the leading edge is missing.

Accordingly, the expert system has been developed following an interpretation system design. The method of knowledge representation within this altimetry system is the procedural knowledge representation. Input waveforms are analysed by specific rules. Following the analysis a decision is made about which retracker will be used and in which way the output will be built. Following the rule-based system the inference engine of this expert system is based on the forward chaining technique.

3.1 RULE-BASED EXPERT SYSTEM

A rule-based expert system is a computer program that processes problem-specific information contained in the working memory with a set of rules contained in the knowledge base, using an inference engine to infer new information.

The rule-based expert system is shown by the following model (Figure 3.11):

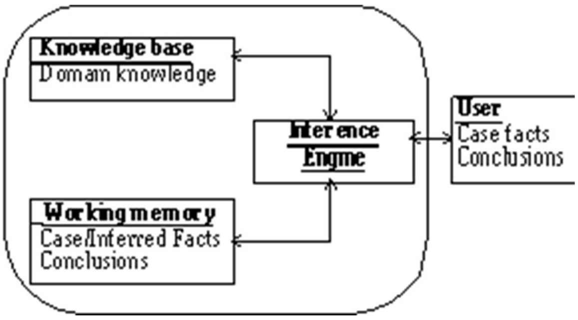

Figure 3.11 Rule-based expert system

In the rule-based system used, the rules contained in the knowledge base represent the productions contained in the long-term memory (waveform specification) and the facts contained in the working memory represent the situations in the short-term memory (altimetry data). The inference engine acts as the reasoning module of the production system model and compares the facts with the rules. Those rules that fire have their conclusions added to the working memory (using flags) and the process continues. Rule-based expert systems like this are not necessarily an exact match for human problem solving, but they provide a reasonable model for replicating this behaviour with a computer.

3.2 DESIGN OF EXPERT SYSTEM

The expert system fits within the existing processing chain (Figure 3.21), inputting and preprocessing one orbit of data at a time. The waveforms are then analysed and retracked individually. If no preference is given a decision is made according to the analysis results and the expert system rules. When the retracking of one waveform is completed, the output is generated. The process of decisions, retracking and outputting repeats for all data in the orbit file. All or a combination of the existing retrackers can also be run over all data for comparison purposes.

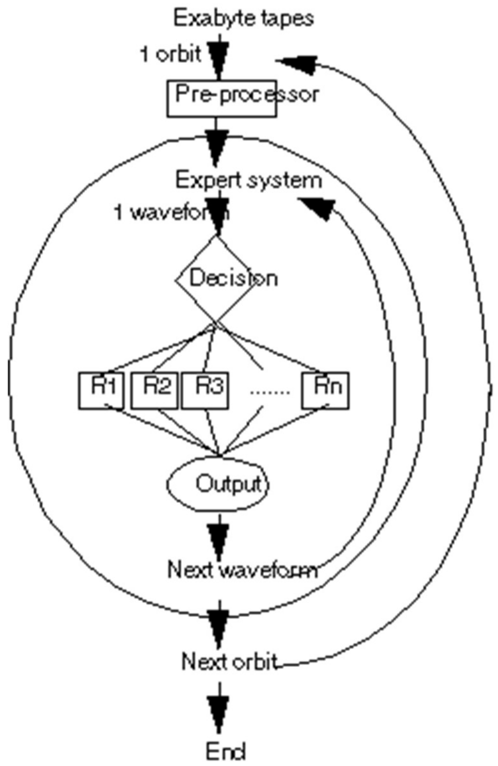

Figure 3.21 Expert System Overview

3.3 CHARACTERISTICS OF RULE-BASED SYSTEMS

A few notes on the advantages of rule-base systems are summarised for completeness in this section:

- Natural Expression: Because humans naturally express their problem-solving knowledge in IF...THEN type statements, it is easy to capture knowledge in a rule making the rule-based approach an easy to understand approach for the design of an expert system.

- Separation of control from knowledge: This feature is not unique to rule-based systems but is a trademark of all expert systems. This valuable feature permits a change to be made in the system's knowledge or control separately.

- Modularity of knowledge: A rule is an independent chunk of knowledge; thus its correctness can easily be reviewed and verified.

- Ease of expansion: The separation of the system's knowledge from its control permits additional rules to be included easily, allowing for a graceful expansion of the system's knowledge.

- Proportional growth of intelligence: Even one rule can be a valuable piece of knowledge. As the number of rules increases, the system's level of intelligence about the problem likewise increases.

- Use of relevant knowledge: The system will use only the rules that are relevant to the problem.

- Consistency checking: The rigid structure of the rule also allows for consistency checking of the system to ensure that the same situations do not lead to different actions.

- Utilisation of heuristic knowledge: Rule-based systems are well suited for working with this heuristic knowledge. Most heuristic rules that work in a common-sense fashion draw conclusions or efficiently control the search of the knowledge base.

4. RESULTS
4.1 Initial evaluation

An analysis of typical waveform shapes over Zimbabwe [8,10,13] indicated that many waveforms were 'pre-peaked', with a significant peak appearing prior to the main peak. Under these circumstances, the performance of threshold retracking was not found to be in agreement with other retrackers used (although such differences were found to be generally fairly small, on the order of a few metres). Additionally, significant numbers of waveforms demonstrated an elongated leading edge with multiple peaks; high differences between retracker results and known GPS ground points were observed for these waveforms, often of many tens of metres. A new retracker was developed to deal with these waveforms. Following this analysis, four retrackers and a set of rules were programmed into the expert system and the data over the test area were processed.

4.2 Waveform and statistical results over test areas

For results presented here, the Delta implementation of the expert system has been used. This development version incorporates rules and retrackers based on results from the comparison of 35 day data with regional DEMs, the initial retracking analysis of the geodetic mission data and detailed analyses of these data over test areas including comparison with regional DEM and point ground truth [9,10,11,12,13].

A statistical breakdown of the retrackers called by the expert system for all valid data points over two test areas is given in Figure 4.21. A key is given in Table 4.22, together with brief notes. Note the high number of specular returns over Zimbabwe, attributed to data acquired during the rainy season.

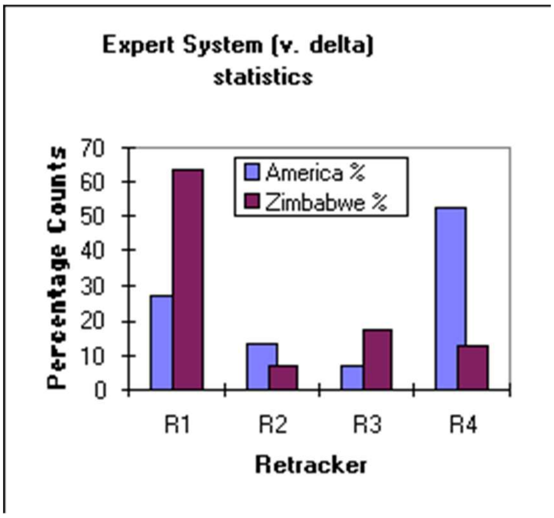

Figure 4.21 Expert System Output Statistics

<u>ID Retracker</u> <u>Notes</u>

R1 Threshold The default retracker (set at 50%)

R2 Specular Retracks specular waveforms separately

R3 Spline Default for pre-peaked waveforms

R4 BOR Selects complex waveform shapes

Table 4.22 Retracker Key

Typical results for a 1% sample of data where the BOR retracker was used are given in Figure 4.23. Detailed analysis of expert system retracked altimeter data is presented elsewhere [12,13].

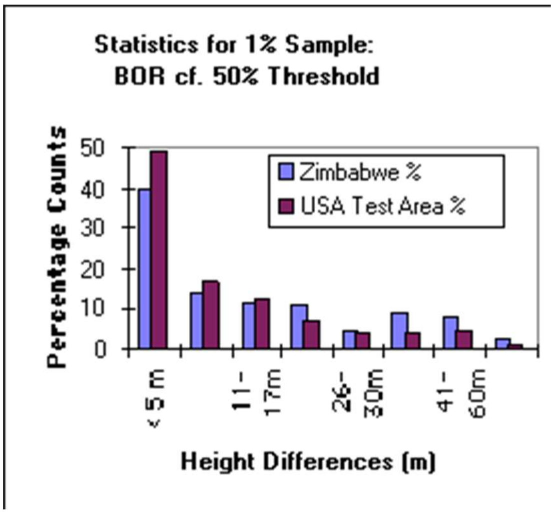

Figure 4.23 Comparison of retracker outputs for 1% sample

5. DISCUSSION

The results obtained using the expert system are currently being evaluated and the rules tuned using comparison with ground truth. However, it is already clear that each new rule increases the terrain related information returned by the expert system. Gains on well-behaved waveforms (near vertical leading edge with low retrack correction) are minimal; on more complex waveforms differences of 40m between retracker outputs are not uncommon. Examination of slope-induced error shows that the altimeter is preferentially ranging to low slope areas close to nadir; thus many returns where the mean slope is in excess of 0.5 degrees can still be retracked. However, waveforms obtained from surfaces of significant mean slope tend to have complex shapes, and threshold retracking is not found to perform well. For regions of appreciable topographic relief the advantage of an expert system approach to land altimeter retracking becomes apparent.

6. ACKNOWLEDGMENTS

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