GLOBAL SCALE EVALUATION OF WETLANDS USING THE ENVISAT RA-2

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ABSTRACT
In order to determine whether or not the EnviSat RA-2 can be used to monitor water levels within wetlands a study of four wetlands was conducted. The chosen wetlands were: the Okavango Delta, the Sudd marshes, the Vasyugan Swamp and Big Cypress. To enable precise measurements, accurate masks were derived of the surfaces within each wetland. Several parameters including Sigma0 and waveform analysis were employed in addition to geographic information to delineate the land from open waterbodies. Timeseries were obtained from a number of wetlands, both within wetlands themselves and externally from the inflow/outflow rivers, demonstrating the valuable potential contribution from the RA-2 to monitoring wetlands.

1. INTRODUCTION
With advances in the monitoring of inland water [1] the next logical step was to try and extend this work to cover an even more complex problem- that of wetlands. Due to the nature of Wetlands they are highly susceptible to change and any variations in the surrounding area can have a profound effect. They are incredibly fragile and a small alteration to the volume of water flowing into them can cause the wetlands to shrink dramatically or even disappear completely. Since these areas have not previously been extensively studied using this instrument it was unclear how well the RA-2 would be able to acquire Wetlands targets and if there were any circumstances that were either necessary for or could prevent any useful data return. In order to test the theory it was decided to study four different Wetlands from different parts of the globe. The target sites were chosen in an attempt to obtain data representative of as many different Wetlands as possible. The four chosen were as follows:

- **The Okavango Delta** – this wetland is situated in Botswana (Southern Africa). It is the world’s largest inland delta. The Okavango River flows into it; however due to the fact that it has no outflow all of the water must drain underground which provides a lot of the water for local wells.
- **The Sudd marshes** – these marshes are located in Southern Sudan. They are the largest inland wetland in the world. The Nile River flows into and out of the Sudd, losing a large portion of its water within the area. These were in fact the first wetlands to be studied using altimetry [2].
- **The Vasyugan swamp** – the swamp is located in Siberia, lying within the watershed of the Ob and Irtysh rivers. Approximately 2% of the total peat bogs are located in the area as well as large forested areas. Due to its Northern location surface water freezes during the winter and thaws in the spring, which may have an effect on the waveform retracking and subsequent height retrieval.
- **Big Cypress** – this coastal swamp is located in Southern Florida and joins up with the Everglades. This swamp was chosen because it has no major river flowing through it. Due to the location on the coast the water levels will be fluctuating with the tides.

Part of the reason that altimetry has such potential to be of use in the monitoring of Wetlands is because there are currently very few options available (they tend to be in inhospitable environments and so have poor access for humans) and other remote sensing techniques also encounter problems. For example, monitoring using visual images can be problematic because floating vegetation can mask the spatial extent of water bodies. However even for the altimeter there are going to be problems within the swamps. Firstly the exact extent of the Wetlands often varies at differing times of year which means that care must be taken in selection of waveforms to include in an analysis. Even when the spatial extent of the wetland is well-defined there is still the problem of the composition of the interior; the land and the water are so closely intermingled that it is frequently difficult to know exactly where the land finishes and the water begins.

The following sections provide a summary of the analyses of each wetland.

2. OKAVANGO DELTA
The first step in the analysis of the Okavango Delta was to determine the exact extent of the area to be looked at by the altimeter. In order to do this the GLCC mask [3] was used as a starting point (Fig. 1). However, this was far from ideal because it did not include the Okavango River that forms the delta. In an attempt to locate the path of this river the GLCC mask was fused with results from the ERS-1 Geodetic mission [4] using waveform

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analysis and Sigma0 derived from an expert system approach [5] to delineate the river courses (Fig. 2).

With this mask in place both Envisat [6] and ERS-2 waveforms were retracked using an expert system approach (ibid) and produced a number of timeseries of varying quality of the Okavango River. Fig.3 shows an example of a very good timeseries from upstream of the delta near the confluence of the two tributaries forming the Okavango River. A clear annual signature is visible with two main peaks obtained. Fig.4 shows an example where there is an outlier in the data; however the rest of the data appear good and can clearly be utilised to retrieve useful height information. This timeseries was obtained right at the mouth of the delta. Finally Fig.5 shows an example where an annual signature is produced; however there appears to be a problem at the maximum of the cycle, which reduces the quality of the data. It is likely that this is a consequence of off-ranging, where the altimeter is snagging on still pools of water and the current system has incompletely removed these contaminated echoes.

These results clearly show that the water flow into the Okavango can be measured by the RA-2, providing a very valuable contribution to measuring the changing volume of water within the wetland. The next step was to try and obtain data from within the wetland itself. In order to investigate the makeup of the interior, sigma0 profiles from multiple Envisat Ku-band tracks were analysed. Areas with high peaks were identified as still pools of water. By analysing 12 cycles (cycles 21 to 32) worth of data it was actually possible to see the water flowing down into the delta followed by the occurrence of still pools, then as the inflow reduces, after a short delay the water in the still pools decreases. Numerous still pools were identified for each of the tracks analysed.

Waveform analysis of the local area was performed; this showed quite clearly where the altimeter started to pick up the present of water with numerous quasi-specular echoes and a definite body of still open water. With all of these results a clear picture is formed about the Okavango Delta; the inflow can be measured and it is should be possible to generate data over the swamp. The main requirement in order to achieve this however is that an accurate mask must be derived for the bodies of both non-seasonal and seasonal water to avoid land contamination reducing the quality of the data.

3. THE SUDD MARSHES

The Sudd marshes required a slightly different approach to the Okavango Delta, because both inflow and outflow occur. The GLCC mask has an accurate delineation of the Nile River as it makes its way through the Sudd marshes. Waveform retracking was carried out for the
whole area using both ERS-2 and Envisat Ku-band data. A number of timeseries were obtained from both altimeters and it was discovered that not only could data from the inflow be obtained (Fig.6 & Fig.7) and the outflow (Fig.8) but also that timeseries could be generated from within the Sudd itself (Fig.9).

While these results allow monitoring of the level of the river as it runs through the Sudd it does not permit the identification of water in the marsh separate from the river. In order to locate bodies of still water within the marshes an analysis of 1 year’s worth (cycles 20-30) of Envisat Ku-band backscatter was performed. This analysis was able to locate a number of water bodies that are covered in water year round which manifest as spikes in sigma0 such as that on the far left of Fig.10. However because the data were for a full year a number of seasonal pools were identified. These are the points where there is a high maximum for certain cycles whereas the majority of cycles showed a much lower and more correlated response; numerous examples of this are located on the left of Fig.10.

Finally to complete this initial study of the Sudd an analysis of the Orthometric height was performed. As Wetlands are made up of numerous relatively still pools of water it was expected that the plot should show a large flat area encompassing the wetland. Plotting both ascending (pass 8312) and descending track (pass 8420) together with a second ascending track (pass 8083) gave the results graphed in Fig.11. When plotted the three show very consistent correlation (Fig.12), however they also show a large slope (approximately 50m). If this slope did exist then all of the water would drain straight out of the Sudd. After analysis it was determined that the geoid model was causing this error, which also occurs over many lakes. With the release of the new geoid model (EGM07) it is hoped that this problem will be greatly reduced.
From using all these results it is clear that altimetry can make a valuable contribution to the monitoring of the Sudd. It is possible to monitor the water both entering and leaving the marshes thus potentially enabling a direct estimate of the amount of water remaining within the wetland. As with the Okavango it is important to utilise or construct an accurate surface water map to optimise the quality of the altimeter retracked measurements.

4. BIG CYPRESS

As there is no river that feeds the Big Cypress swamp it was obviously impossible to utilise the approach adopted in the previous two examples. However the analysis technique for finding still pools remains a viable option. As before 1 years worth of data (cycles 25 to 35) were analysed to see if any pools could be found. When plotted (Fig.13) it became clear that this time it was not possible to definitely locate any permanent pools of water. The high Sigma0 values indicate that almost all of the swamp is under water at one time or another however the water also recedes just as quickly. There are some cycles (e.g. cycle 30) were the whole area appears waterlogged.

This means that unfortunately the altimeter is going to be of limited use over this Wetland; this is an expected result since the altimeter only overpasses the area every 35 days and the swamp water level is affected by tidal flooding.

5. THE VASYUGAN SWAMP

The Vasyugan covers a large area in Siberia and is a mixture of peat bogs, marshes and forested wetland making it an excellent test case. Due to the cold weather in the winter a large amount of the water within the wetlands freezes and thaws again in the spring. The existing GLCC map of the area already had a large number of potential targets within it and was used to delineate the test area. Using waveform retracking a number of viable targets were identified and a group of timeseries produced from around the centre of the wetland. Figures 14, 15 and 16 show timeseries containing clear annual signals. It is apparent that there are a number of locations which show a rapid change within a period of 35 days, apparent as a rapid reduction in surface water, occurring when the water freezes. Conversely the subsequent large increase correlates with the ice thawing. It is therefore clear that, whilst the current retracking of these data is non-optimal there is a strong signal apparent, and with further improvements to the retracking algorithms much better results could be obtained. This work is now ongoing.

![Figure 12 Orthometric heights over the Sudd](image)

![Figure 13 1 year’s worth of Sigma0 over Big Cypress](image)

![Figure 14 Timeseries from Vasyugan swamp](image)

![Figure 15 Timeseries within Vasyugan](image)
6. CONCLUSIONS

The results from this study demonstrate that radar altimetry from ERS-1/2 and the EnviSat RA-2 certainly can make a valuable contribution to the monitoring of many wetlands. Direct measurement can be made within the wetlands themselves, as long as they contain pools of water large enough to be visible to the altimeter. Just as importantly, we can now measure inflow and outflow for several of the wetlands in this study; applying the selection criteria determined from this initial study will now facilitate identification of those wetlands where the inflow/outflow may be successfully measured by the RA-2. There are however cases where the contribution of the altimeter will be limited, especially in coastal wetlands.

In order to obtain the clearest possible data it is vital that an accurate mask of the surfaces of the wetland is available. Due to the rapidly varying nature of wetlands coupled with environmental factors the echoes returned from wetlands are incredibly complex. In order to deal with these data effectively, sophisticated retracking is vital to identify and retrack that part of these complex echoes returned by the inland water.

7. REFERENCES


