CHAPTER TEN

10. FIELD APPLICATION: 1D SOIL MOISTURE PROFILE ESTIMATION

The computationally efficient soil moisture model ABDOMEN, developed in Chapter 7, compared well with simulations from the one-dimensional Richards equation model PROXSIM1D for forecasting the soil moisture profile of a one-dimensional soil column. However, an evaluation of its ability to capture the dynamics of field soil moisture content as a result of rainfall and evaporation required a field application. Hence this chapter calibrates and evaluates the one-dimensional soil moisture model ABDOMEN1D for estimation of soil moisture profiles, using the soil moisture profile measurements made in the Nerrigundah catchment (Chapter 9). Moreover, this has evaluated the vertical redistribution component of ABDOMEN3D, which is applied in Chapter 11 for forecasting of the spatial distribution and temporal variation of soil moisture profiles. This chapter uses the original Kalman-filter algorithm (section 3.3.2) for updating of the soil moisture profile forecasting model, as this was not a computational constraint in the one-dimensional application.

10.1 CALIBRATION OF ABDOMEN1D

Soil moisture profile data collected at the weather station (see Figure 9.4) using the Virrib and connector TDR (soil moisture profile number 2) soil moisture sensors provide the necessary data for calibration of the one-dimensional soil moisture model ABDOMEN1D. This data is applicable to one-dimensional soil moisture modelling, as the weather station was situated in a level location in the upper reaches of the catchment, where effects of lateral redistribution should be negligible.

Data collected with the Virrib soil moisture sensors could not be used for calibration or evaluation of the soil moisture model until several months after installation, to allow for settling in of the sensors, as a result of soil disturbance. Furthermore, as there was missing data between Julian day 267 1997 and Julian day 270 1997 (see Table B.1 in Appendix B for a Julian day calender), it was desirable to perform the model calibration against soil moisture data collected prior to Julian day 267 1997, and model evaluation against soil moisture data collected subsequent to Julian day of year 270 1997.

A settling in time of 7 months was felt to be of sufficient length for the Virrib sensors. Moreover, this coincided with installation of the connector TDR soil moisture sensors. Thus, soil moisture data from Julian day 130 1997 to Julian day 267 1997 seemed appropriate for calibration of the ABDOMEN1D soil moisture model. Julian day 130 1997 was just prior to a final wetting up of the catchment for the winter months, which would allow for calibration to both infiltration and exfiltration events (see Figure B.2). However, Virrib soil moisture data suggested that during this wetting up period, more rainfall occurred than was recorded by the raingauges (see section 9.3.1.1.3). To eliminate this inconsistency between rainfall and soil moisture observations, calibration was performed on a 100 day dry down period from Julian day 167 1997 to Julian day 267 1997.

10.1.1 OBSERVED MODEL PARAMETERS

Several of the soil parameters could be defined directly from field observations and measurements. Apart from layer 1 in the soil moisture model, soil layer thicknesses were estimated commensurate with soil horizon thicknesses, using the proportion of total profile depth given in Figure 9.46. Layer 1 was set at a thickness of 1 cm to be commensurate with the typical near-surface soil moisture observation depth from remote sensing. The depression storage parameter was set at 5 mm, based on measurements of rms surface roughness made near the weather station (see Appendix D). Likewise, the saturated hydraulic conductivity was estimated from the Guelph permeameter and double ring infiltrometer measurements made near the weather station (see Table B.7). The porosity and residual soil moisture content for each of the model layers were estimated from an analysis of both Virrib and connector TDR soil moisture measurements made from Julian day 130 1997 to Julian day 274 1998. The soil porosity values were estimated from periods when the soil was saturated and the residual soil moisture values were estimated from periods when the soil was at its driest (during the summer of 1997/98).

10.1.2 CALIBRATED MODEL PARAMETERS

With the model parameters described above defined directly from field measurements and observations, the only parameters requiring calibration via the one-dimensional soil moisture model ABDOMEN1D were the van Genuchten parameter *n*, for relating hydraulic conductivity to saturated hydraulic conductivity, and *MGRAD*. Calibration of these parameters was performed with NLFIT, using the Virrib soil moisture measurements as observations of model layers 3, 4 and 5, and connector TDR soil moisture measurements of depth integrated soil moisture over model layers 1 to 3, 1 to 4, and 1 to 5. Calibrations were made to these two data sources individually and jointly.

In the model calibration and comparisons with Virrib soil moisture observations, soil moisture measurements from Virrib sensor #1 (depth range of 40 mm to 160 mm) were used as observations of the soil moisture content for model layer 3 (depth range of 55 mm to 113 mm); the average of soil moisture measurements from Virrib sensors #2 and #3 (depth range of 90 mm to 260 mm) were used as observations of the soil moisture content for model layer 4 (depth range 113 mm to 225 mm); and the average of soil moisture measurements from Virrib sensors #4 and #5 (depth range of 260 mm to 450 mm) were used for observations of the soil moisture content of model layer 5 (depth range of 225 mm to 450 mm). As a good fit to the data could not be obtained using the observations of layer 5, the calibration to Virrib data was only for model layers 3 and 4.

In the model calibration and comparisons with connector TDR soil moisture observations, the average of connector TDR soil moisture measurements for 10 cm and 15 cm probe lengths (ie. depth range of 0 to 125 mm) were used as observations of the average soil moisture content in model layers 1 to 3 (depth range 0 to 113 mm); the average of connector TDR measurements for 20 cm and 30 cm probe lengths (ie. depth range of 0 to 250 mm) were used as observations of the average soil moisture content in model layers 1 to 4 (depth range 0 to 225 mm); and the connector TDR measurement for the 40 cm probe length (ie depth range of 0 to 400 mm) were used as observations of the average soil moisture content in model layers 1 to 5 (depth range of 0 to 450 mm).

Since calibration commenced on Julian day 167 1997, being a time when the soil was saturated, initial soil moisture values were set to the soil porosity values. With the soil column being underlain by a layer of bedrock, a zero moisture flux boundary condition was applied to the base of the soil column. The surface soil moisture flux boundary condition was set at a fixed value for half hour increments (which may consist of several time steps). This surface soil moisture flux was taken as the average of 10 minute measurements of Penman-Monteith potential evapotranspiration rate, reduced by the soil moisture stress index (see section 9.4.3), except for periods when there was rainfall recorded. During these periods it was assumed that no evapotranspiration occurred and that the rainfall recorded had a uniform rainfall rate over the half hour period.

10.1.2.1 Calibration to Virrib Observations

The results from calibrating the ABDOMEN1D model parameters *MGRAD* and *n* to Virrib soil moisture data for model layers 3 and 4 are given in Table 10.1(a) and Figure 10.1. These calibrated parameter values gave a very good fit to the Virrib soil moisture data in model layers 3 and 4. However, the comparison with Virrib soil moisture data in model layer 5 was very poor from Julian day 200 to 260. It was felt that this poor agreement in model layer 5 was a

Table 10.1: Calibrated soil parameters for the simplified one-dimensional soil moisture model ABDOMEN1D, from Virrib and connector TDR soil moisture data collected at soil moisture profile number 2.

Layer	**Thickness (mm)**	**Horizon**	K_s (mm/h)	ϕ (%v/v)	θ_r (%v/v)	***n***	***MGRAD***
(a) Calibration to Virrib Observations							
1 2	10 45	A1	15	60	6	1.15	432
3	68	A2	15	46	8	2.42	384
4	112	B1	3	42	12	1.64	389
5	225	B2	0.4	48	18	2.25	32
(b) Calibration to Connector TDR Observations							
1 2	10 45	A1	15	60	6	2.18	23
3	68	A2	15	46	8	1.34	22
4	112	B1	3	42	12	2.19	50
5	225	B2	0.4	48	18	1.46	275
(c) Calibration to Virrib and Connector TDR Observations							
1 2	10 45	A1	15	50	6	1.16	108
3	68	A2	15	46	8	2.33	339
4	112	B1	3	42	12	1.80	238
5	225	B2	0.4	48	18	1.96	137

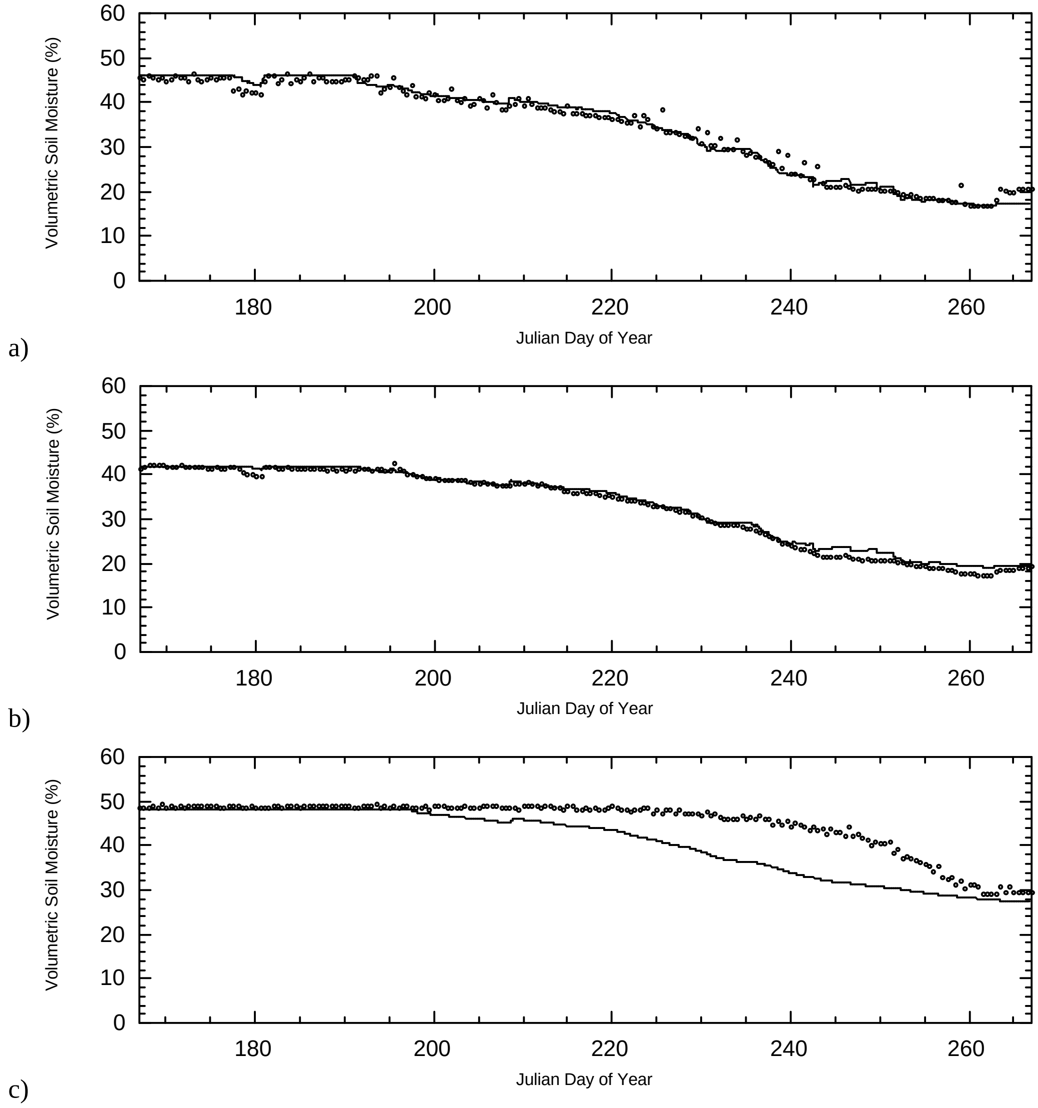

Figure 10.1: Calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) to Virrib soil moisture measurements (open circles) at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows soil moisture content in a) layer 3, b) layer 4 and c) layer 5. Note that the calibration used only layer 3 and layer 4. Layer 5 is provided for comparison purposes only.

result of poor quality soil moisture data in this layer, rather than a weakness of the ABDOMEN1D model. Some of the reasons for this have already been mentioned in Chapter 9 (section 9.3.1.1.3).

Installation of the Virrib soil moisture sensors required excavation and recompaction of the soil around the sensors. Hence, even after 7 months the soil may not have returned to its original state, particularly at greater depths. In addition, just prior to the calibration period, the Virrib soil moisture sensors over estimated the increase in soil moisture content relative to the amount of rainfall recorded. It was also shown in Chapter 9 that connector TDR soil moisture

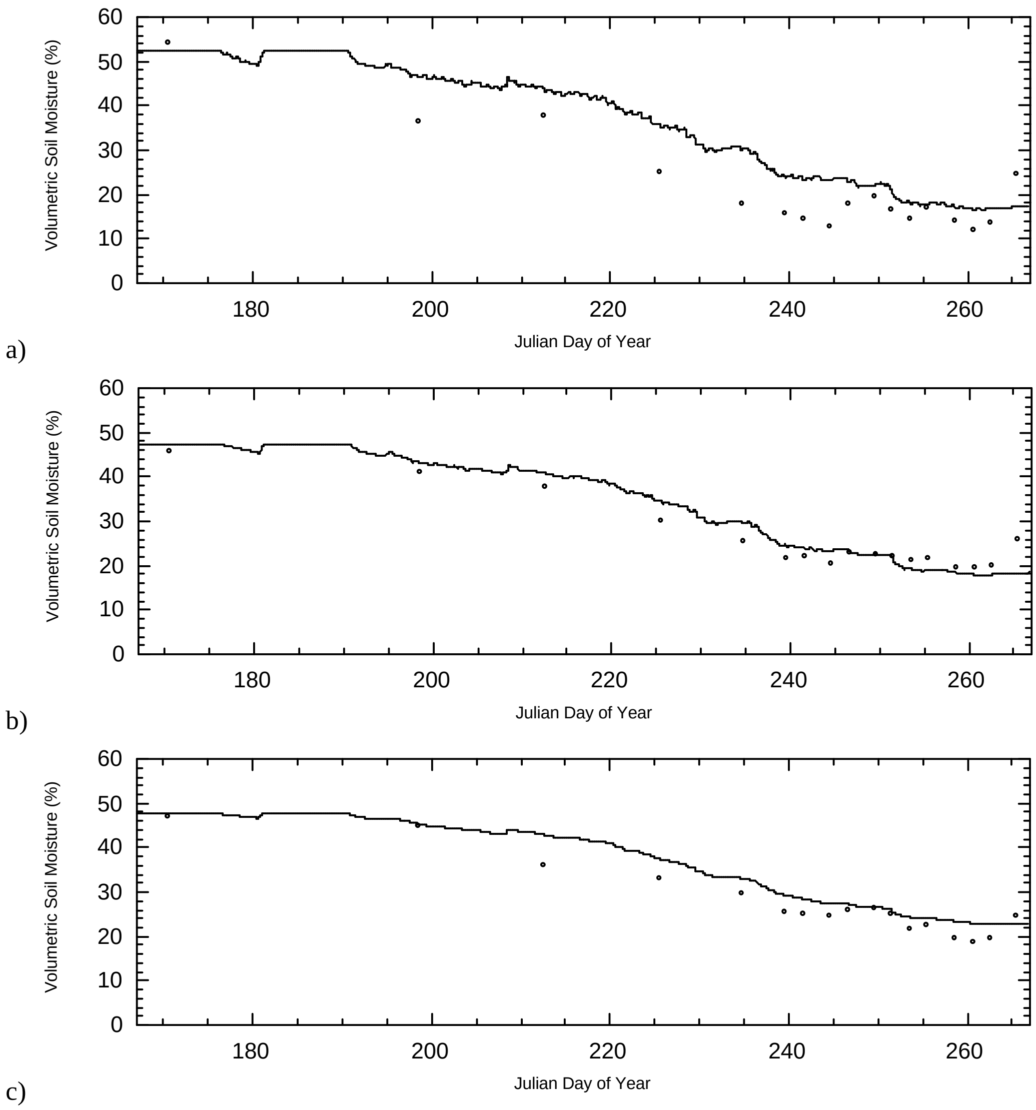

Figure 10.2: Comparison of connector TDR soil moisture measurements (open circles) with calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) to Virrib soil moisture measurements at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows average soil moisture content over a) layers 1 to 3, b) layers 1 to 4 and c) layers 1 to 5.

measurements did not agree well with the Virrib soil moisture measurements during this period, and that connector TDR soil moisture measurements agree better with soil moisture calculations using a simple bucket water balance model. An additional reason why the Virrib soil moisture measurements at depth may be of poor quality is that the soil profile contained quite a lot of rock and gravelly material in the deeper layers, which could be affecting the measurement technique.

Comparisons of connector TDR soil moisture measurements with the ABDOMEN1D model simulation using soil parameters from calibration to the

Virrib soil moisture measurements are given in Figure 10.2. This comparison showed a good agreement for the average soil moisture content of model layers 1 to 4 and model layers 1 to 5, but a rather poor agreement for the average soil moisture content of model layers 1 to 3. Furthermore, the model simulation did not respond to the wetting up towards the end of the calibration period, as indicated by the observed data.

10.1.2.2 Calibration to Connector TDR Observations

In an attempt to improve the ABDOMEN1D model comparison with connector TDR soil moisture measurements, a calibration run was made to the connector TDR soil moisture data. The results from this calibration are given in Table 10.1(b) and Figure 10.3. These calibrated parameter values gave a very good agreement with the connector TDR soil moisture data for model layers 1 to 3 and 1 to 4, an equally good agreement for model layers 1 to 5 as for the calibration to Virrib soil moisture data. The model simulation also responded to the wetting up at the end of the calibration period. In addition, the *MGRAD* values from calibration to the connector TDR data increased with depth, rather than decreased as with the calibration to Virrib soil moisture data. Increasing *MGRAD* values with depth agree better with intuition, as the clay content in the soil profile increases with depth, and hence the matric suction should be greater at deeper depths.

The consistent slight over-estimation of soil moisture storage for the entire soil profile as compared to the connector TDR measurements of soil moisture content may be a result of: (i) the no drainage boundary condition at the bottom of the soil profile, (ii) an incorrect estimate of rainfall and/or evapotranspiration, or (iii) a systematic error in the 40 cm TDR measurement.

A comparison of the model simulation, using the parameters in Table 10.1(b), is made with the Virrib soil moisture data in Figure 10.4. This comparison has shown a good agreement with model layer 3 and a better agreement in model layer 5 than for the calibration to Virrib soil moisture data itself. However, the comparison with model layer 4 is degraded somewhat. The good agreement in model layer 3 with Virrib soil moisture data indicated that Virrib sensor #1 observations of near-surface soil moisture content may be used

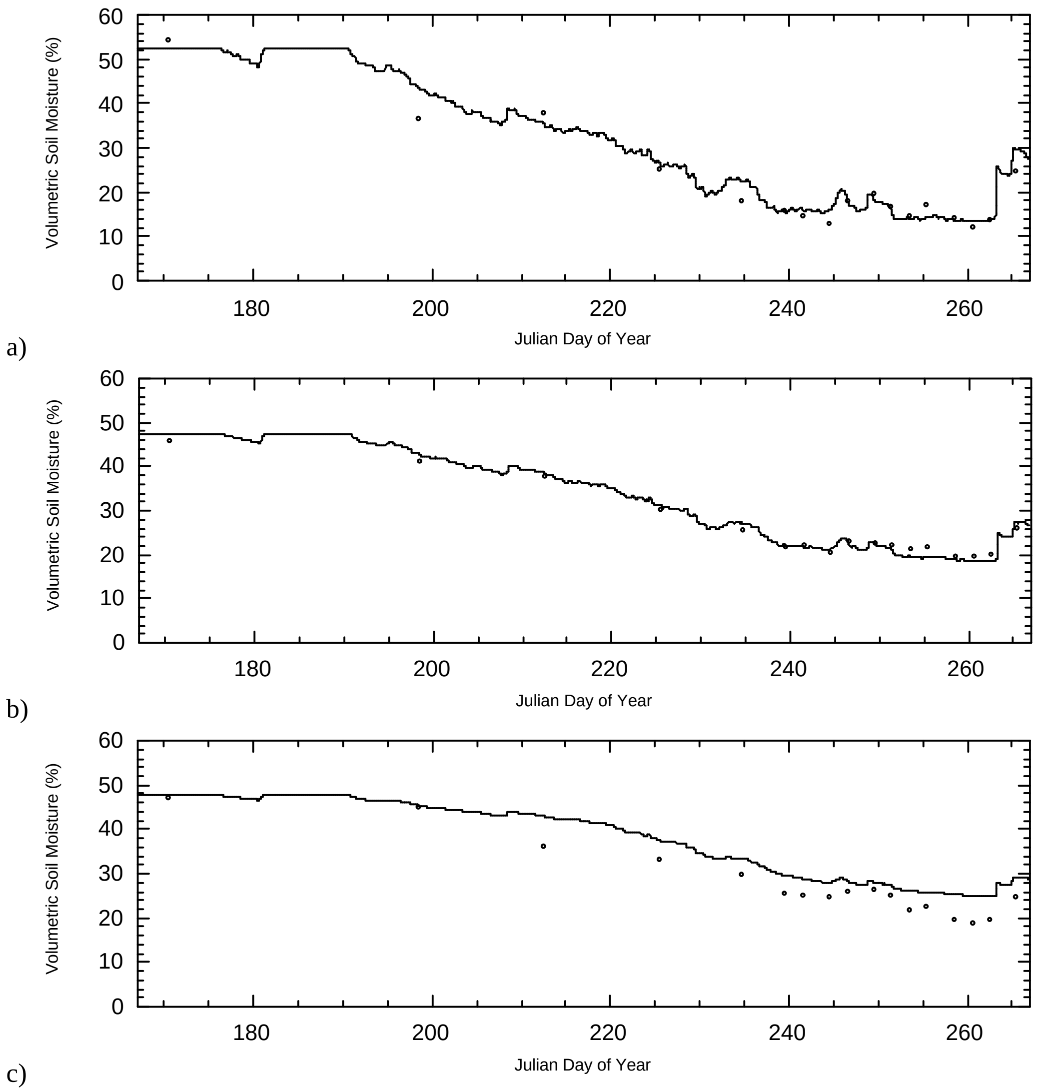

Figure 10.3: Calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) to connector TDR soil moisture measurements (open circles) at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows average soil moisture content over a) layers 1 to 3, b) layers 1 to 4 and c) layers 1 to 5.

for updating of the one-dimensional soil moisture forecasting model ABDOMEN1D.

10.1.2.3 Calibration to Virrib and Connector TDR Observations

As a final attempt to improve the calibration of ABDOMEN1D to both Virrib and connector TDR soil moisture data, ABDOMEN1D was calibrated jointly to both the connector TDR data, and Virrib data for model layers 3 and 4. The results from this calibration are given in Table 10.1(c), with a comparison to Virrib soil moisture data in Figure 10.5 and connector TDR soil moisture data in

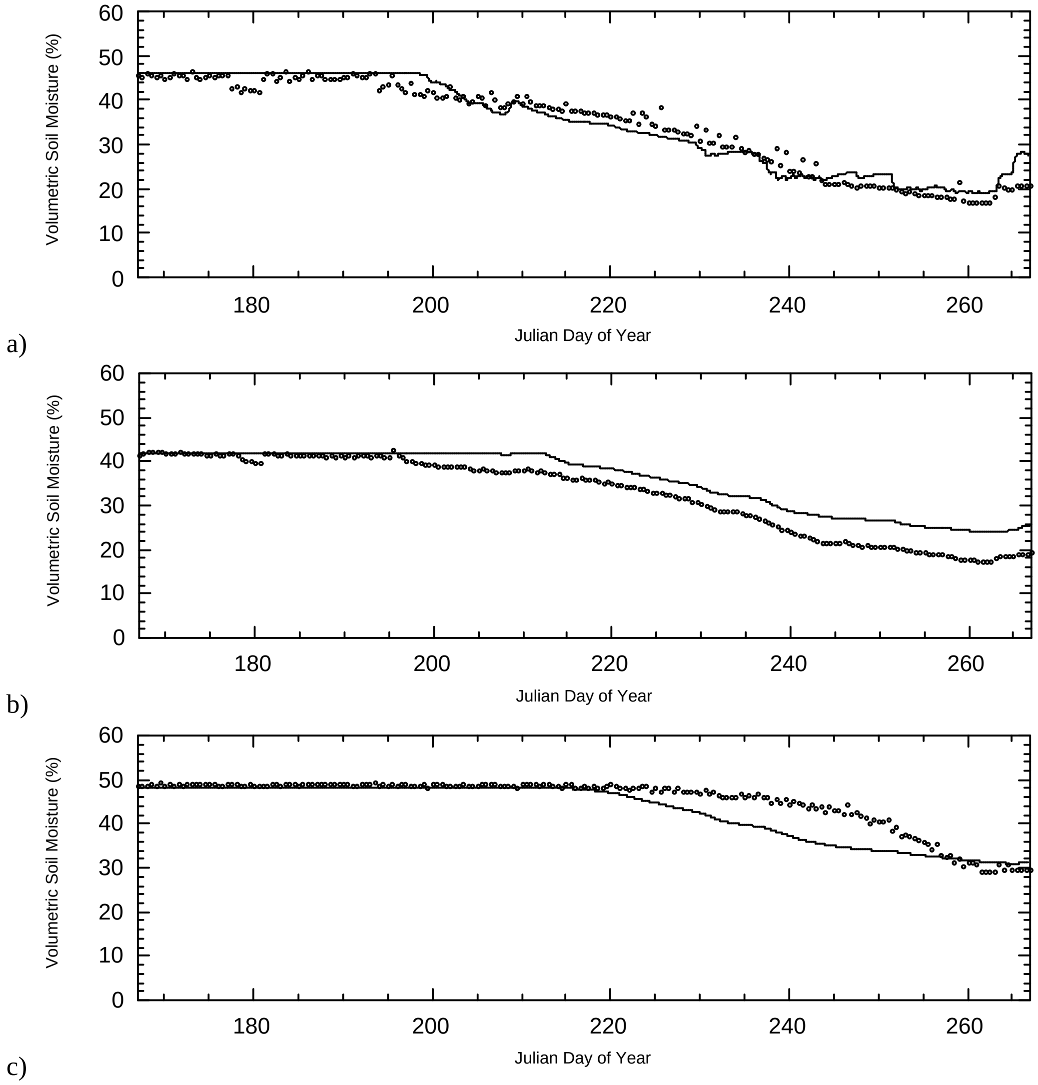

Figure 10.4: Comparison of Virrib soil moisture measurements (open circles) with calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) to connector TDR soil moisture measurements at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows soil moisture content in a) layer 3, b) layer 4 and c) layer 5.

Figure 10.6. In order to improve the comparison with connector TDR soil moisture data for model layers 1 to 3 in Figure 10.2, the soil porosity for soil horizon A1 was also calibrated. The philosophy for this was that a reduced soil porosity of the near surface layers would improve the comparison with near-surface soil moisture observations.

The *MGRAD* parameter from this calibration again decreased with depth, and the comparisons were not much different to those from calibration to the Virrib soil moisture data alone. This may have been a result of fitting to more Virrib soil moisture data points than connector TDR soil moisture data points.

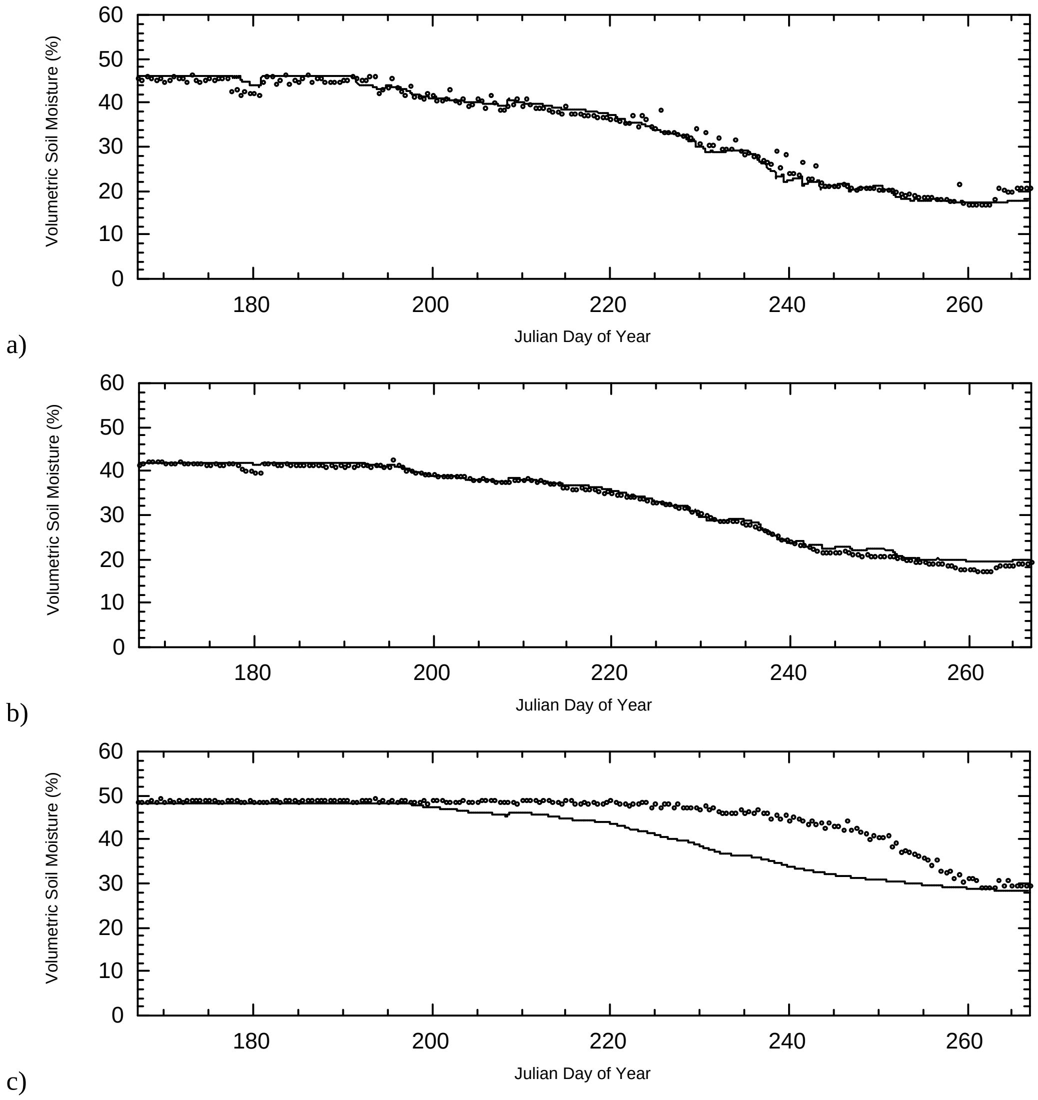

Figure 10.5: Calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) jointly to Virrib (open circles) and connector TDR soil moisture measurements at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows soil moisture content in a) layer 3, b) layer 4 and c) layer 5.

10.1.2.4 Summary of Calibration Results

The best calibration results for the ABDOMEN1D model to soil moisture data at soil moisture profile number 2 was that to the connector TDR soil moisture data alone given in Table 10.1(b). This is fortuitous, as connector TDR soil moisture data are the only soil moisture profile data available for calibration of the catchment scale version of this simplified soil moisture model in Chapter 11.

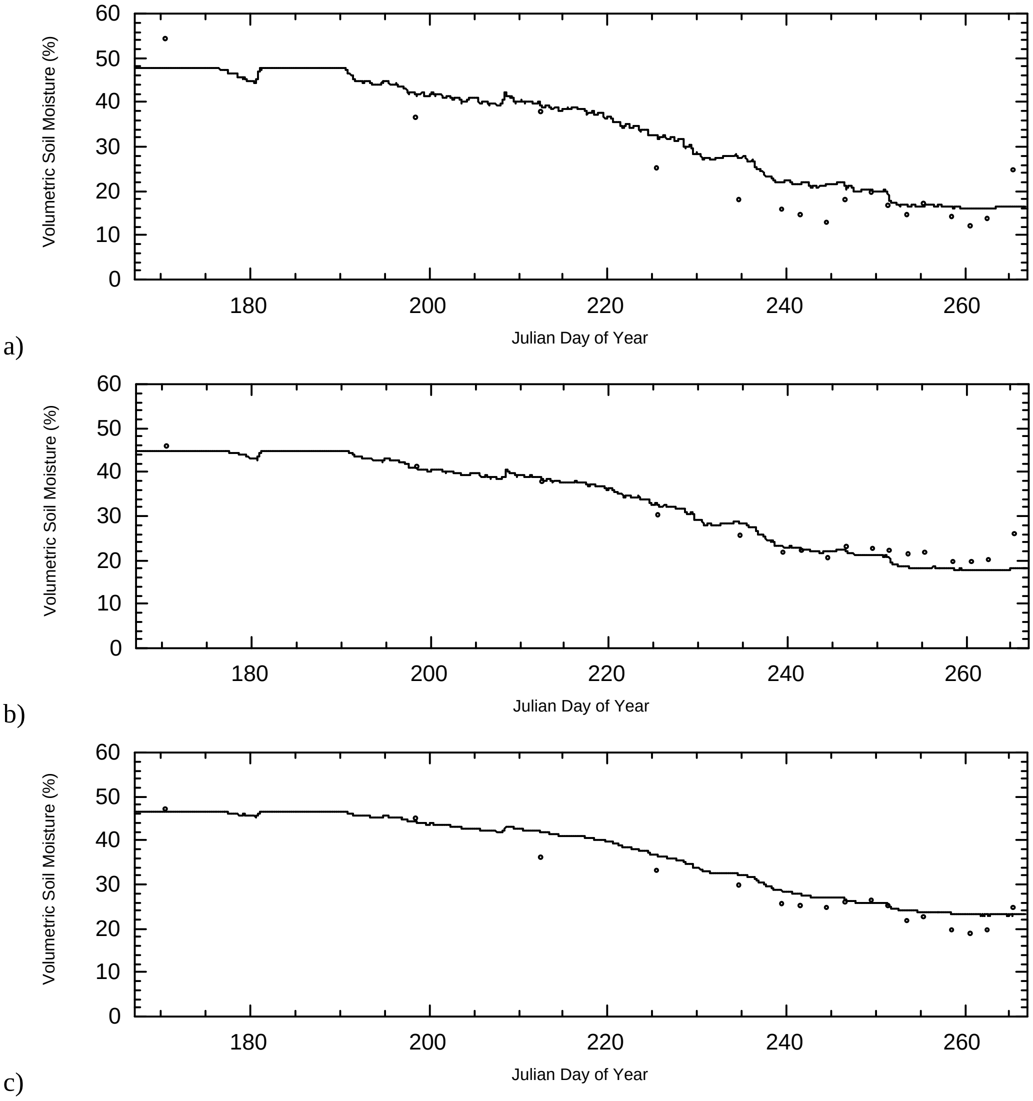

Figure 10.6: Calibration of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) jointly to Virrib and connector TDR (open circles) soil moisture measurements at soil moisture profile number 2 from Julian day 167 to 267, 1997. The figure shows the average soil moisture content over a) layers 1 to 3, b) layers 1 to 4 and c) layers 1 to 5.

10.2 EVALUATION OF ABDOMEN1D CALIBRATION

Using the calibrated parameters for ABDOMEN1D from section 10.1 that gave the best agreement with observed soil moisture data, Table 10.1(b), calibration to connector TDR observations), ABDOMEN1D was evaluated for the period from Julian day 130 1997 to Julian day 274 1998. This was an independent set of soil moisture observations to those used in the calibration.

The simulation results from this evaluation are given in Figure 10.7, where there was a good agreement with observed soil moisture data for the top 123 mm (layers 1 to 3) for the entire simulation period. The comparison with observed soil

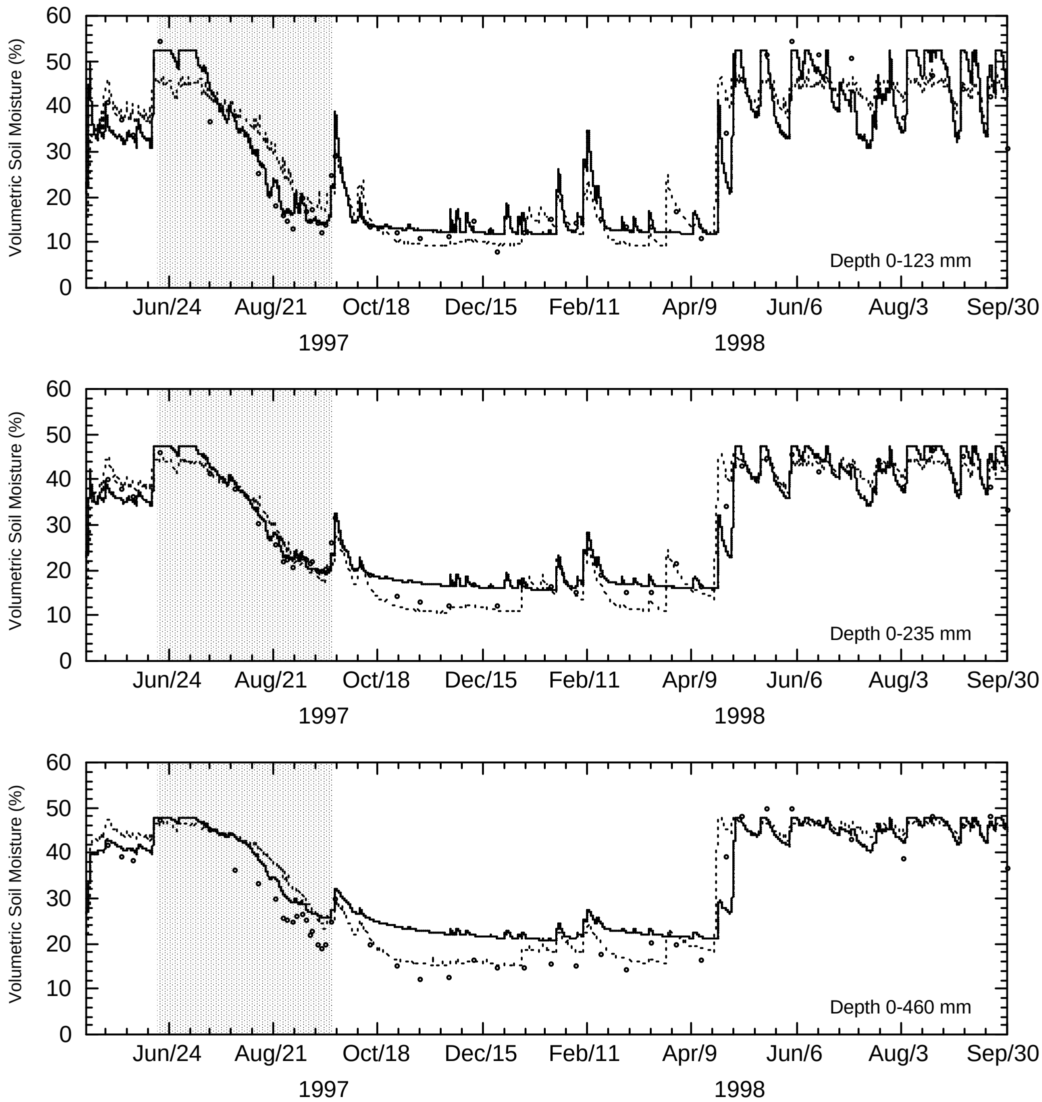

Figure 10.7: Evaluation of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) from Julian day 130 1997 to Julian day 274 1998 against Virrib (dashed line) and connector TDR (open circles) soil moisture measurements. The shaded region indicates the period of calibration with connector TDR soil moisture measurements. Zero moisture flux at base of soil column.

moisture data for the top 235 mm (layers 1 to 4) was also quite good, apart from a slight over-estimation (5% v/v) of soil moisture content during the summer period. This over-estimation of soil moisture during the summer period was greatest for the comparison with total profile soil moisture storage, with a maximum over-estimation of about 10% v/v. This is consistent with the calibration results, where the total soil moisture storage was over-estimated by approximately 5% v/v.

To evaluate if this over-estimation of total soil moisture storage was a result of assuming no gravity drainage from the bottom of the soil profile, the

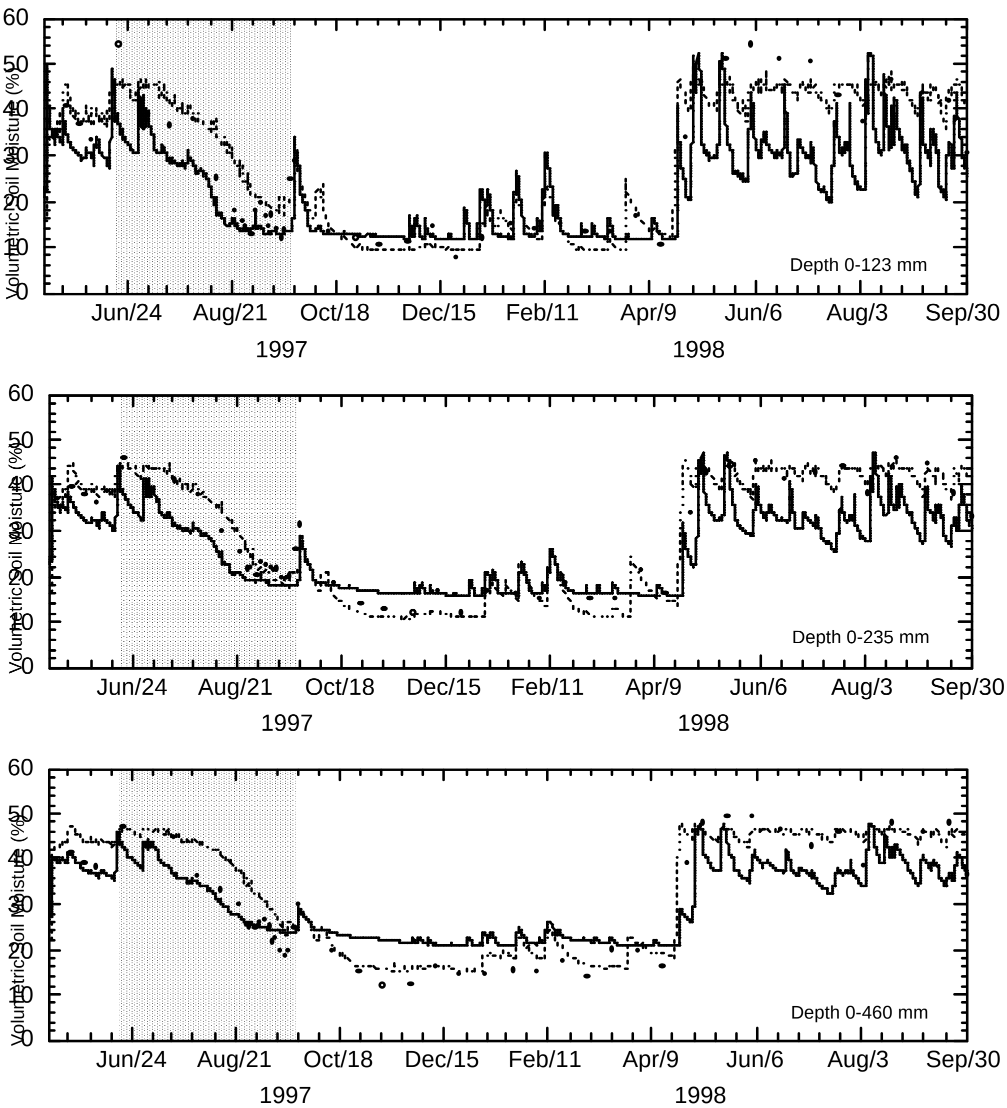

Figure 10.8: Evaluation of the simplified one-dimensional soil moisture model ABDOMEN1D (solid line) from Julian day 130 1997 to Julian day 274 1998 against Virrib (dashed line) and connector TDR (open circles) soil moisture measurements, with gravity drainage. Shaded region indicates the period of calibration with connector TDR soil moisture measurements without gravity drainage.

gravity drainage boundary condition was applied for the previously calibrated model parameters. The results from this simulation, given in Figure 10.8, indicated a degradation of soil moisture profile simulation results during wetter periods and no improvement during drier periods. These results agree with intuition, as gravity drainage has its maximum influence when soil moisture content is high, as a result of a higher rate of hydraulic conductivity. Hence, it would appear from this crude assessment that the zero flux boundary condition imposed at the base of the soil column was not the reason for the poor comparison with total soil moisture storage observations.

Another possible reason for the poor comparison of the model simulation of total soil moisture storage with soil moisture observations is the assumption of no lateral redistribution at the weather station. However, as with gravity drainage, the effects of lateral redistribution are greatest during periods of high soil moisture content. Thus, the most likely reason for the poor comparison during dry periods was the estimation and/or application of evapotranspiration in the model.

In ABDOMEN1D, all evapotranspiration, estimated from the Penman-Monteith potential evapotranspiration equation and a soil moisture stress index (see section 9.4.1), was subtracted directly from the near-surface soil layer. When the surface layer(s) approach the residual soil moisture content, the extraction of evapotranspiration was limited by the amount of available soil moisture in the surface layer and the rate of upward transport from deeper layers. Hence, during the summer when near-surface soil moisture content approached the residual soil moisture content, evapotranspiration from the model profile was less than it should be, resulting in an over-estimation of the total soil moisture profile storage. In order to overcome this, it would be necessary to include a root water uptake term in the soil moisture model. This extension was not made as it was beyond the scope of this thesis.

10.3 SOIL MOISTURE PROFILE ESTIMATION

The ability to accurately estimate the soil moisture profile from near-surface soil moisture observations under field conditions using the original Kalman-filter assimilation scheme was evaluated from Julian day 270 1997 to Julian day 274 1998. In applying the Kalman-filter, initial soil moisture states were given a standard deviation of 50% v/v and zero correlation between model layers for generating the initial system state covariance matrix. The system noise matrix was given a value of 5% of the system states per half an hour of simulation time for diagonal elements and zero for off diagonal elements. The observation covariance matrix consisted of a single value, being the variance of the near-surface soil moisture observation, having a value of 2% of the observation.

10.3.1 UPDATING ONCE EVERY DAY

For the first run with the soil moisture profile estimation algorithm using the Kalman-filter assimilation scheme, the initial soil moisture profile was estimated from the Virrib #1 soil moisture measurements, and applied as being uniform over the entire soil profile. The ABDOMEN1D soil moisture profile forecasting model was then run, subject to the surface forcing data (Figure B.2 and Figure B.3), and updated once every day with Virrib #1 soil moisture measurements, taken as being "observations" of the top 10 mm soil layer (model layer 1). The results from this simulation are compared with the open loop simulation (no updating of the soil moisture model), Virrib soil moisture data and connector TDR soil moisture data in Figure 10.9. This simulation shows a very poor estimation of the soil moisture profile using the Kalman-filter and a fairly good comparison between observed soil moisture data and the open loop simulation.

The poor estimation of the soil moisture profile using the Kalman-filter assimilation scheme was a result of near-surface soil moisture "observations" that were not commensurate with the observation depth over which they were applied. As the soil moisture observations were actually made for a depth of 40 mm to 160 mm, which is a much deeper layer than the 10 mm for which they were applied, the soil moisture observations during the summer were always wetter than what they would be for a much thinner near-surface soil layer. Hence, the Kalman-filter estimate of the soil moisture profile was wetter than it should be during the summer. During the winter, when the soil profile was wetter and the correlation between the soil moisture content of a thin near-surface soil layer and that of a thicker soil layer was high, the Kalman-filter was able to estimate the soil moisture profile adequately.

The open loop simulation was able to track the observed soil moisture profile quite closely in this simulation, as the initial soil moisture values were close to the correct values for near-surface layers, and slightly less than the correct values for deeper layers. The effect of this was to offset the influence of no root water uptake, as seen in Figure 10.7.

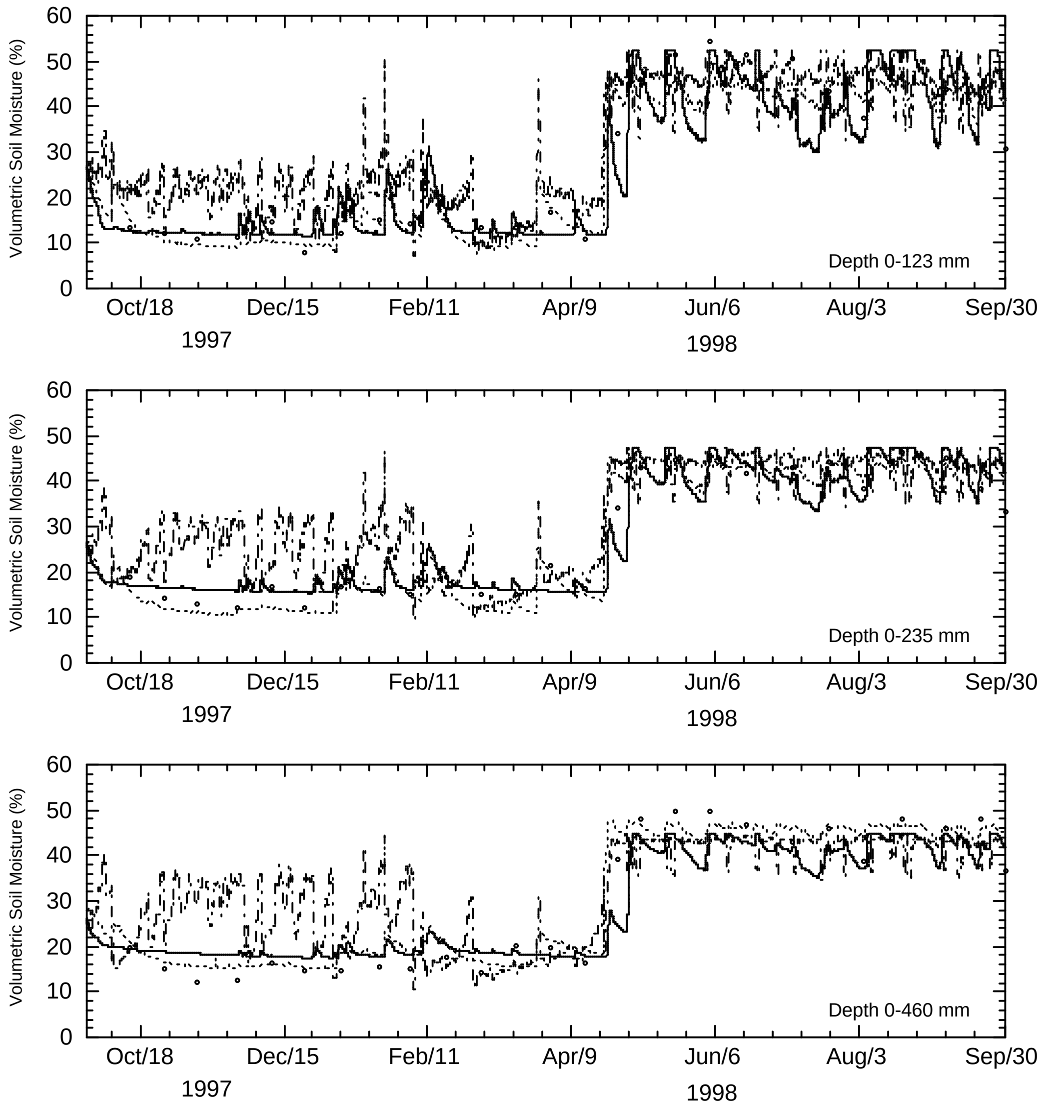

Figure 10.9: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 10 mm against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements, and the open loop simulation (solid line). The simulations were initiated with a uniform soil moisture profile of 26.6% v/v from the near-surface soil moisture measurement; the soil moisture profile was updated once per day.

To overcome the problem of near-surface soil moisture observations being for a much deeper soil layer than 10 mm, the soil moisture observations were applied over an observation depth of 123 mm (layers 1 to 3), being the approximate depth of the near-surface soil moisture observations.

The simulation results from updating over a depth of 123 mm are given in Figure 10.10, where the Kalman-filter makes a good estimation of the measured soil moisture profile to a depth of 235 mm. The estimation of soil moisture content in the top 123 mm of the profile follows the Virrib soil moisture measurements almost exactly, as expected, while estimation of soil moisture

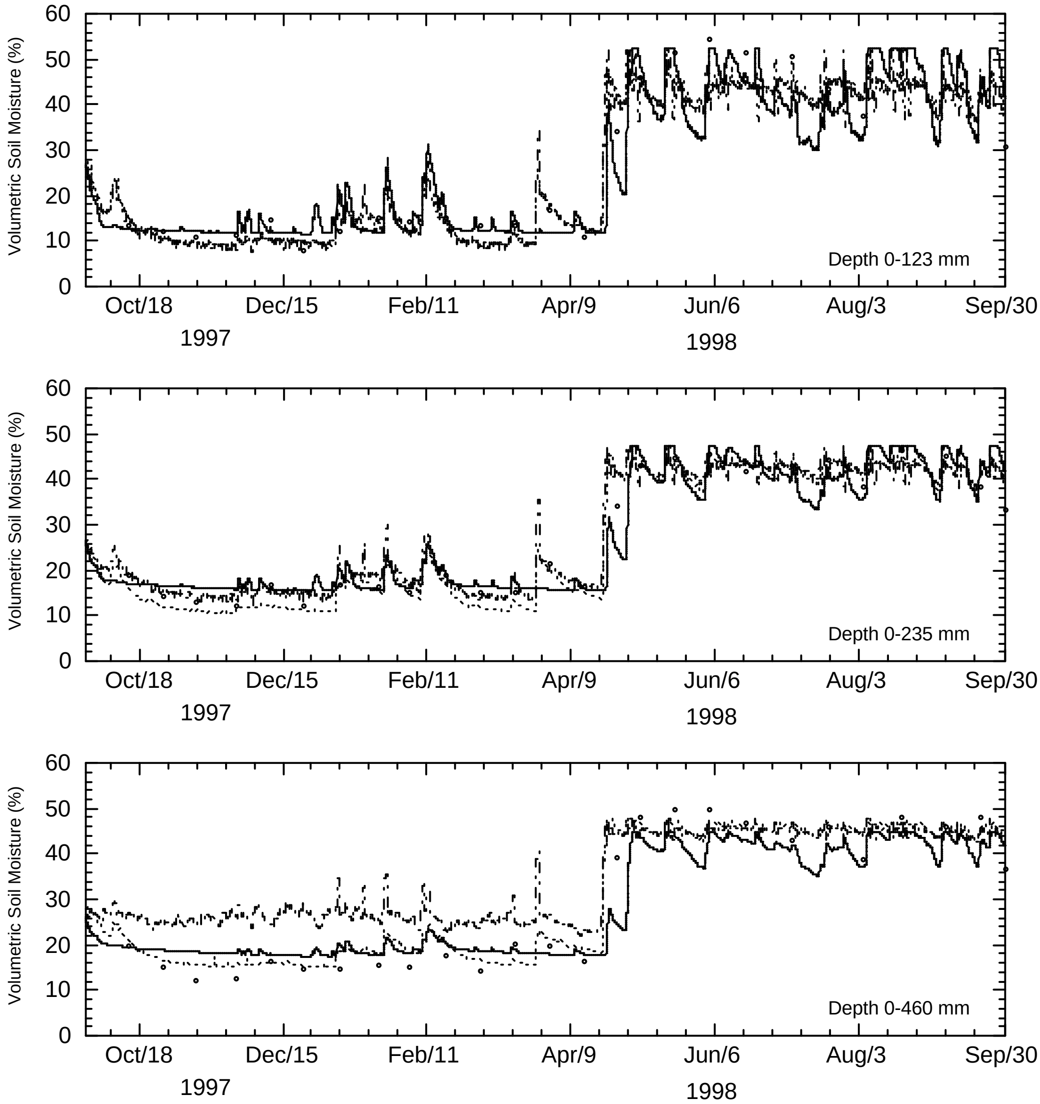

Figure 10.10: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 123 mm soil layer against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements, and the open loop simulation (solid line). The simulations were initiated with a uniform soil moisture profile of 26.6% v/v from the near-surface measurement,; the soil moisture profile was updated once per day.

content in the top 235 mm follows both the Virrib and connector TDR soil moisture measurements very closely. However, during the dry summer period, the estimated soil moisture content for the entire soil profile was greater than the measured soil moisture content.

The reason for this over-estimation of the total soil moisture storage was that the correct soil moisture profile was retrieved very early in the simulation. Once the forecasting model had come on track, the near-surface observations and model predictions of soil moisture content in the near-surface layer had a good agreement for the remainder of the simulation. Hence, without any discrepancy between the near-surface observations and the model predictions, the Kalman-filter had no indication that there was a discrepancy at deeper depths, and could not make any adjustment to the soil moisture profile to correct it.

This scenario was also seen in Chapter 8, where the near-surface soil layer became decoupled from the deep soil layers. However, the reason for the poor estimation of the soil moisture profile in this simulation was a result of a systematic error in the forecasting model, rather than a decoupling of the soil moisture content in deeper soil layers from the near-surface soil moisture content. If this systematic error did not exist in the forecasting model, then the simulation of the soil moisture profile would have continued to track the measured soil moisture profile correctly, once the measured soil moisture profile was retrieved.

The reason for the forecasting model ABDOMEN1D simulating the near-surface soil moisture content correctly yet over-predicting the total soil moisture storage is evident from Figure 10.7. During the dry summer period, ABDOMEN1D simulates the near-surface soil moisture content accurately but over-estimates the total soil moisture profile storage. Hence, the Kalman-filter estimation of the soil moisture profile is only as good as the model prediction of the soil moisture profile for a given near-surface soil moisture content. This scenario was also seen in Figure 7.14.

Figure 10.10 has shown how the Kalman-filter assimilation scheme performs under the situation where model initialisation is close to the correct initial soil moisture profile values. For comparison, the Kalman-filter assimilation scheme has been run for the situation where the model was initialised with a poor estimate of the soil moisture profile, being the soil porosity values for each model layer (Figure 10.11). Figure 10.11 has shown once more that the soil moisture profile estimation algorithm using the Kalman-filter assimilation scheme quickly brings the soil model on track to a depth of 235 mm. However, the total soil moisture profile storage is still over-predicted, as expected. It should be noted however, that in this instance the open loop simulation yielded a poorer estimate of the soil moisture profile than Figure 10.10, particularly for total soil moisture profile storage. However, towards the end of the dry summer period, the open loop simulation had come on track, and continued to simulate the soil moisture

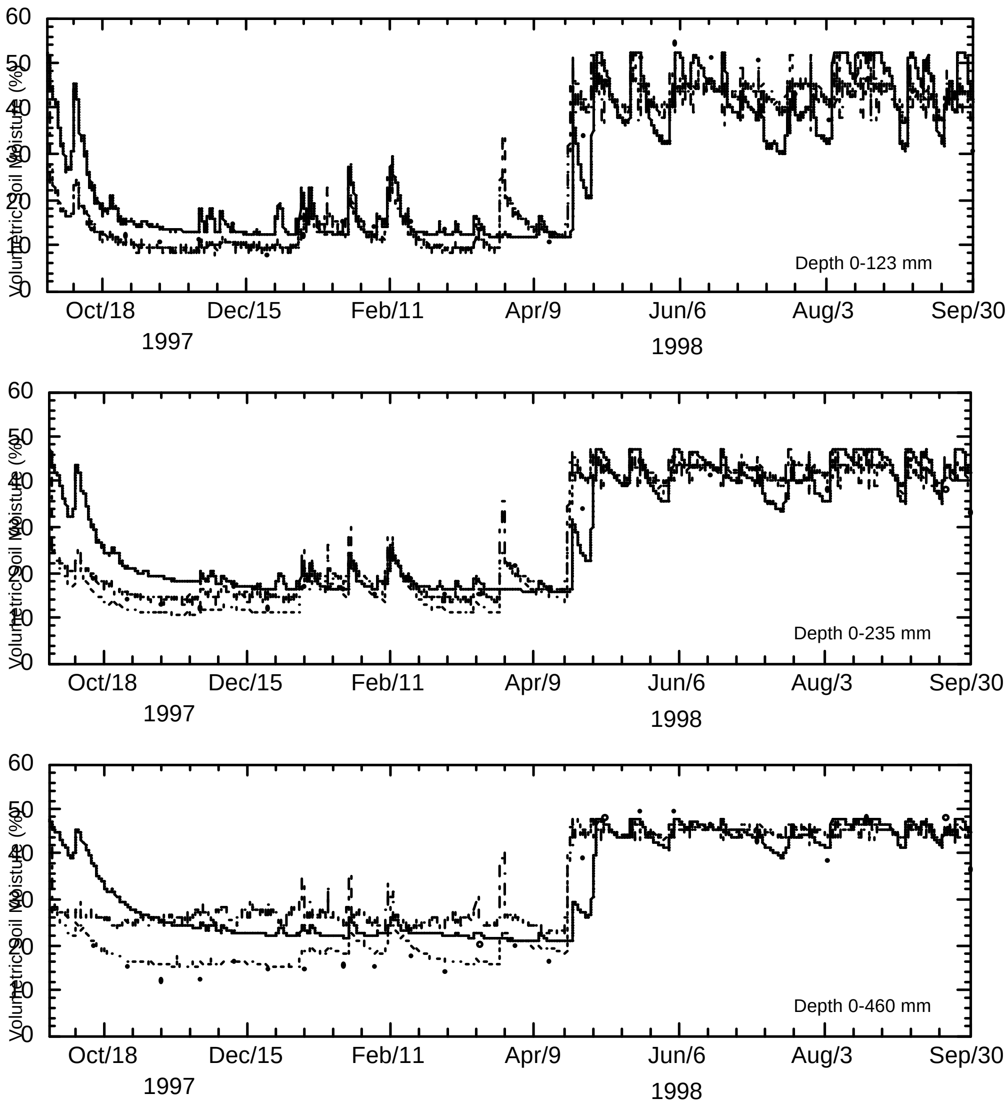

Figure 10.11: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 123 mm soil layer against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements and the open loop simulation (solid line). The simulations were initiated with a poor initial guess of the soil moisture profile, being the soil porosity; the soil moisture profile was updated once per day.

profile storage correctly through into the wet winter months. This suggests that profile soil moisture may be simulated correctly during sustained dry periods and sustained wet periods, without assimilation of near-surface observations. This means that the forecasting model resets itself whenever it hits a state boundary (ie. dry or saturated). However, during dynamic wetting/drying periods, assimilation of near-surface soil moisture observations is important for correct simulation of the soil moisture profile.

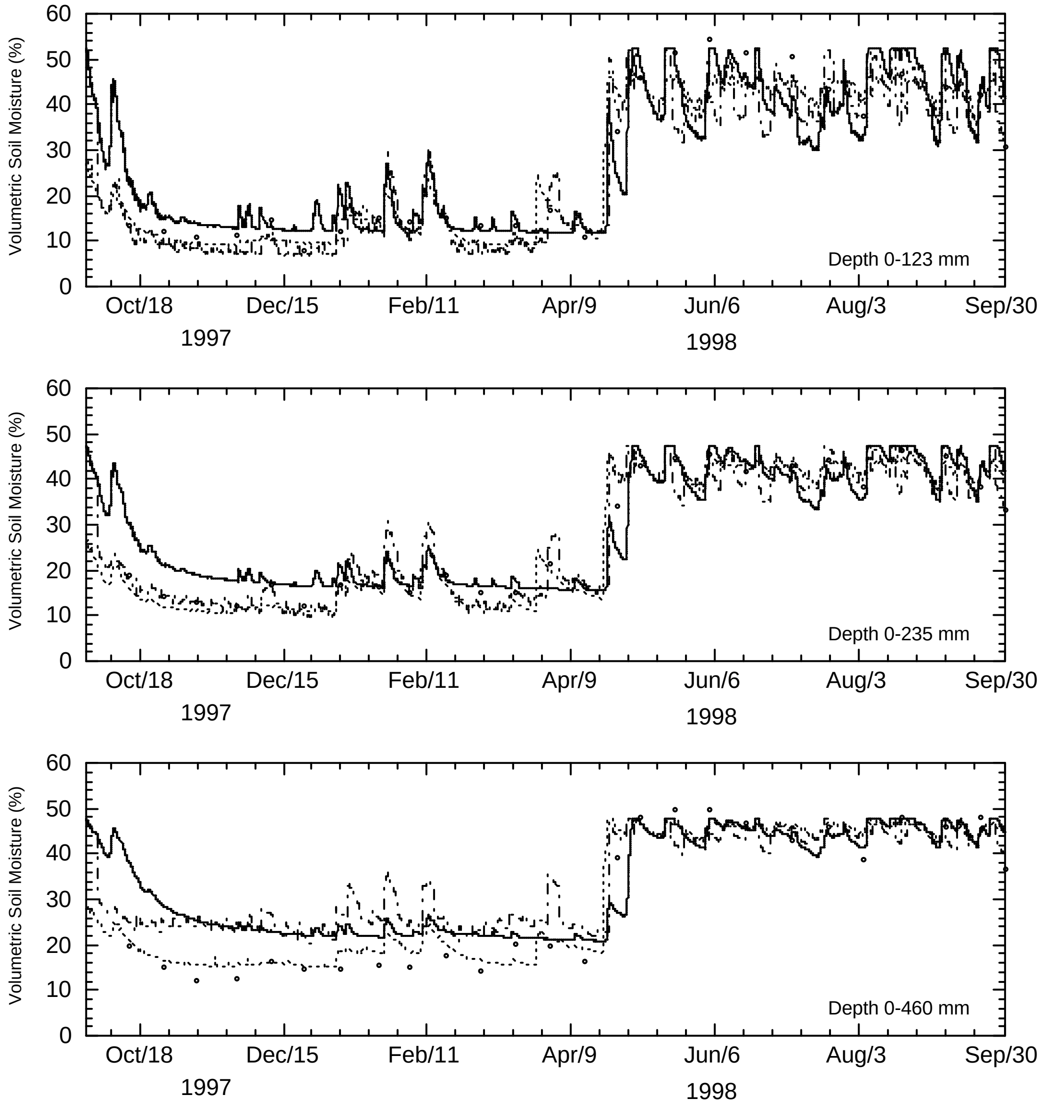

Figure 10.12: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 123 mm soil layer against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements, and the open loop simulation (solid line). The simulations were initiated with a poor initial guess of the soil moisture profile, being the soil porosity; the soil moisture profile was updated once every 5 days.

10.3.2 UPDATING AT LOW TEMPORAL RESOLUTIONS

While updating with near-surface soil moisture observations once per day may be feasible for some low spatial resolution satellites, such as passive microwave sensors (in the near future), updating with high spatial resolution observations, such as those from active microwave sensors, requires updating on a much coarser temporal resolution. In addressing the effects from less frequent updating, simulations have been run with the forecasting model updated once

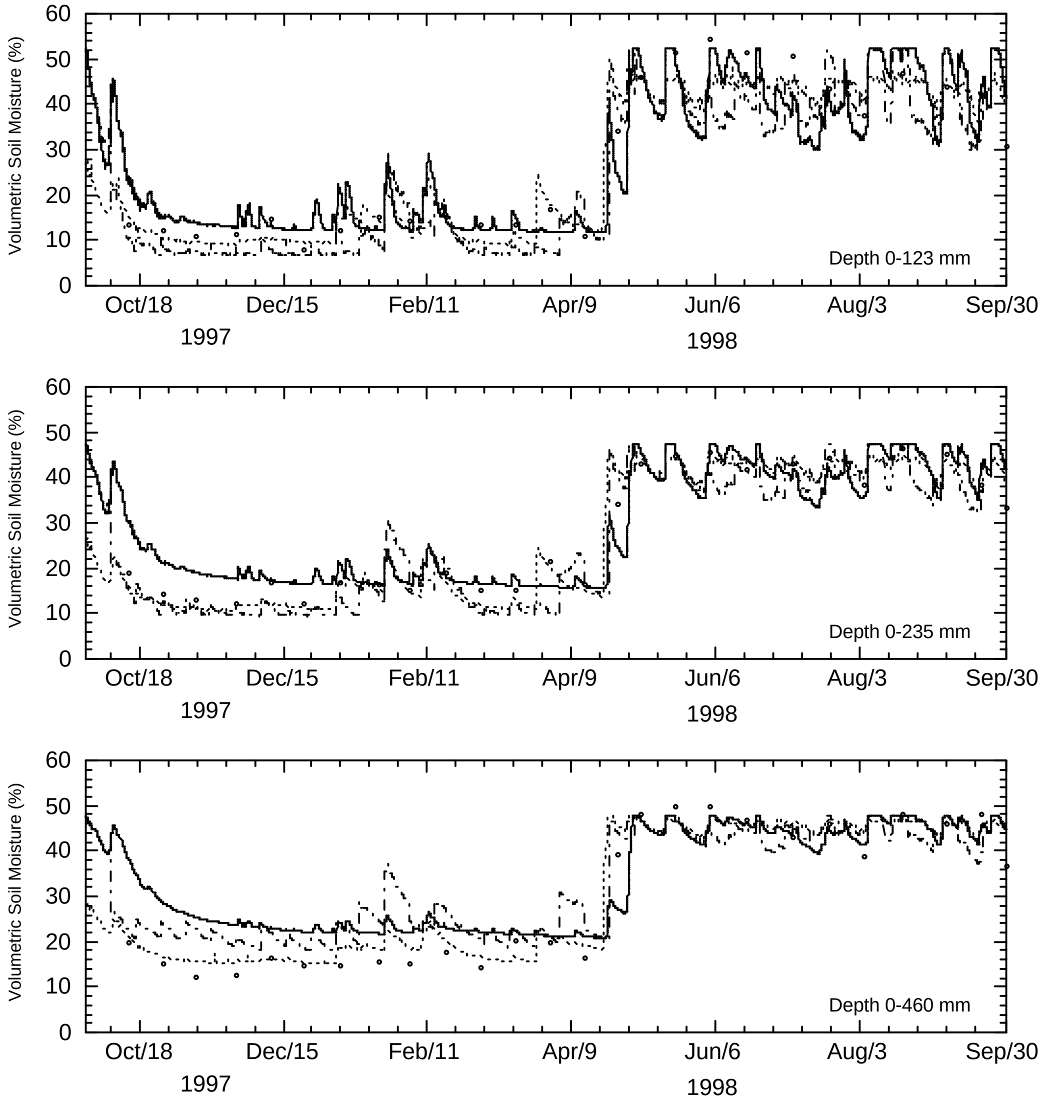

Figure 10.13: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 123 mm soil layer against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements and the open loop simulation (solid line). The simulations were initiated with a poor initial guess of the soil moisture profile, being the soil porosity; the soil profile was updated once every 10 days.

every 5, 10 and 20 days. These simulation results are given in Figure 10.12, Figure 10.13 and Figure 10.14 respectively.

Simulation results from less frequent updating suggest that total soil moisture profile storage is simulated more accurately as the update frequency is reduced, while near-surface soil moisture is modelled more poorly. The reason for this is evident from Figure 10.14, where it can be seen that the forecast near-surface soil moisture content went to the observed near-surface soil moisture content at each update step, with a corresponding increase in the soil moisture content of the deeper soil layers.

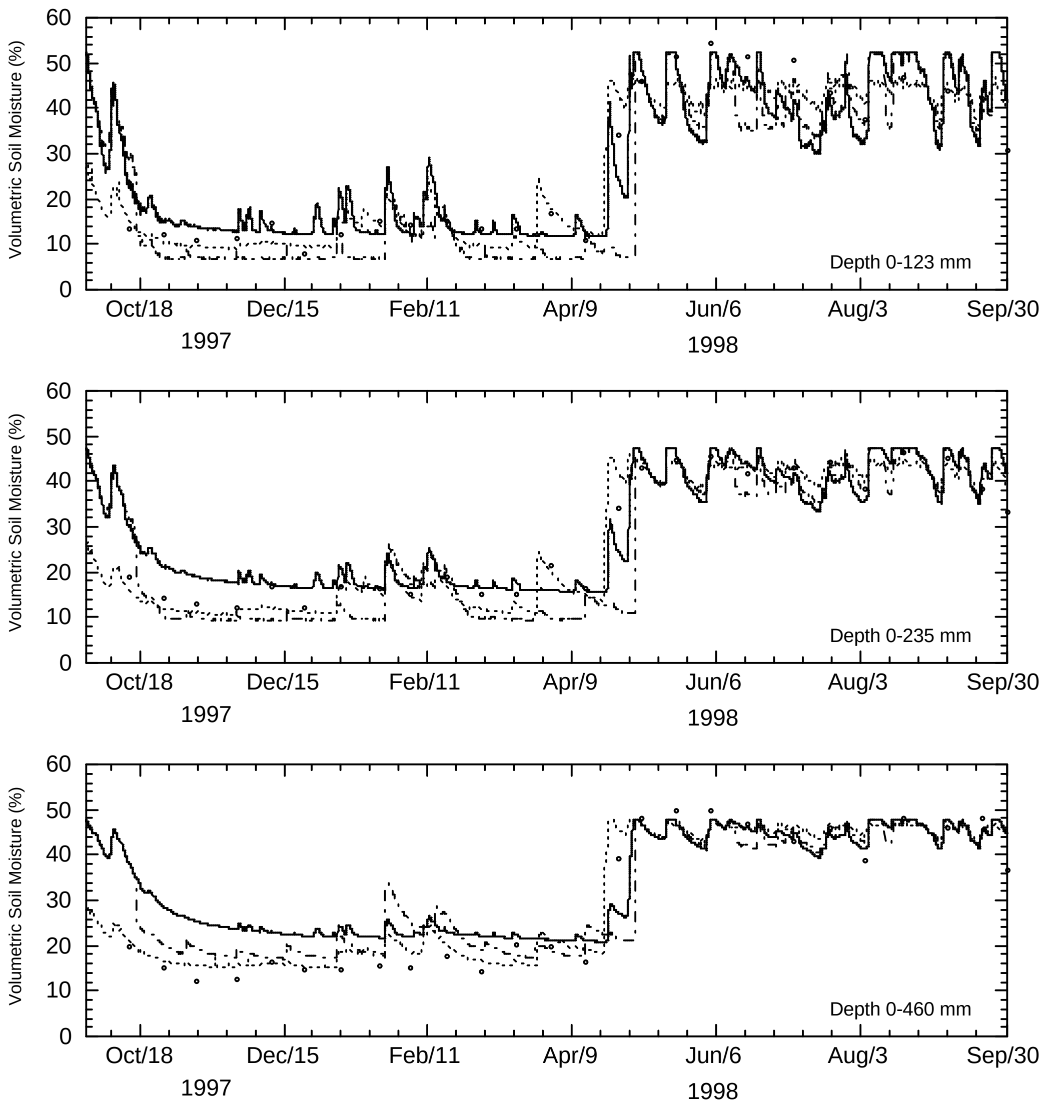

Figure 10.14: Comparison of the estimated soil moisture profile (dash dot line) from updating with Virrib #1 soil moisture measurements in the top 123 mm soil layer against Virrib (dotted line) and connector TDR (open circle) soil moisture measurements and the open loop simulation (solid line). The simulations were initiated with poor initial guess of the soil moisture profile, being the soil porosity; the soil moisture profile was updated once every 20 days.

During the inter-observation period, the forecasting model predicted a dry-down of the entire soil profile, with near-surface soil moisture content estimates being less than the observed near-surface soil moisture content, and the total soil moisture profile storage estimate approaching the observed total soil moisture profile storage. When the forecast model was updated more frequently, as in Figure 10.12 and Figure 10.13, the model was forced to estimate the near-surface soil moisture content more closely. The effect of this was a poorer estimation of the total soil moisture storage as a result of a systematic error in the soil moisture forecasting model, and insufficient time for the forecasting model dynamics to make significant changes to the soil moisture profile estimation.

The systematic error observed in the forecasting model was that for a given near-surface soil moisture content, greater than the residual soil moisture content, the model predicted a greater total soil moisture storage than observed in the field. This characteristic of the ABDOMEN1D model was already observed in Figure 10.7, and is a result of the forecasting model not having a root water uptake term. By adding a root water uptake term to the soil moisture model, a drier total soil moisture profile storage would be predicted for a given near-surface soil moisture content, meaning that the Kalman-filter would be able to better estimate the soil moisture profile from observations of the near-surface soil moisture content.

These simulations would suggest that estimation of the correct soil moisture profile using the Kalman-filter assimilation scheme is more dependent on the forecasting model being able to adequately forecast the soil moisture profile dynamics, than it is on the frequency of updating information.

10.4 CHAPTER SUMMARY

It has been shown in this chapter that although the simplified soil moisture model ABDOMEN1D was a good approximation to the Richards equation, a root water uptake term should be added in order to simulate field measured soil moisture accurately. Without the root water uptake term or calibration to extreme drying events, the model over-predicts the soil moisture of deeper soil layers during extreme drying events.

Simulation results have also shown that the Kalman-filter is likely to perform poorly for estimation of the soil moisture profile if the near-surface soil moisture observation depth is not commensurate with the depth over which the near-surface observations are applied in the forecasting model. This is particularly important when there is a soil moisture gradient in the near-surface layers of the soil profile. The significance of this is that in order for remote sensing observations of near surface soil moisture to be of use in updating of hydrologic models for estimation of the soil moisture profile, the remote sensing observation depth must be adequately estimated.

It has been found that soil porosity and residual soil moisture content are the most important soil parameters for correct estimation of the soil moisture profile. A residual soil moisture content that is too high or a soil porosity value that is too low will restrain the forecasting model from ever reaching the correct soil moisture content during extreme wet or extreme dry periods, even with an assimilation scheme. Furthermore, simulation results have indicated that providing these two soil parameters have been identified correctly, the soil moisture profile may be modelled correctly during sustained dry and sustained wet periods, without assimilation of near-surface soil moisture observations, meaning that the forecasting model resets itself whenever it hits a state boundary. However, during dynamic wetting and drying periods, assimilation of near-surface soil moisture observations is important for correct simulation of the soil moisture profile.

Simulation results have also shown that estimation of the soil moisture profile with the Kalman-filter assimilation scheme is only as good as the model representation of the dominant soil physical processes and its calibration. When the model over-predicts or under-predicts the soil moisture profile for a given near-surface soil moisture content, then the estimated soil moisture profile is likely to be poor. Moreover, estimation of the soil moisture profile using the Kalman-filter assimilation scheme has been shown to be more dependent on the adequacy of the forecasting model to correctly predict the soil moisture profile dynamics than it is on the temporal resolution of near-surface soil moisture measurements.