Parameterization of Hydrological Models: The Contribution of Remote Sensing to Water Resources Management

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Abstract Distributed hydrological models are a key issue in water resources management. They serve as tools for applied hydrological decision making. Since they are based to a large amount on areal data, remote sensing data is a powerful technique to supply models with actual areal input. The number of hydrologically important parameters derived from remote sensing data is manifold and ranges from precipitation estimates, evapotranspiration over land use and Digital Terrain Models (DTMs) to soil moisture and vegetation parameters. Especially in remote areas like most parts of rural Africa with lack of field measurements of components of the hydrological cycle, remote sensing data is the only way to provide areal input. Major drawback of all these high resolution satellite systems in the hydrological sense is the limited time resolution. The requests of hydrological systems analyses to data derived from remote sensing and the possibilities of remote sensing for the parameterization of hydrological models (MMS/PRMS, ACRU) are the major objectives. It is realized within the methodological chain of optical, microwave backscatter, microwave phase (interferometry) and multifrequent and multipolarimetric SAR data evaluation. These methods are applied to examples from different climatic zones and different relief energy: Thuringia (Germany), Sardinia (Italy) and Southern Africa (South Africa, Swaziland, Zimbabwe). Integration of the data into a GIS and connection with a DBMS inside a decision support system called IWRMS (Integrated Water Resources Management System) in Southern Africa are shown, as well as the role of remote sensing data for the validation of simulation results. The use of remote sensing data though enables the extrapolation and regionalisation of hydrologic models.

1. INTRODUCTION

Remote sensing is an important areal and actual input for applied hydrological modelling [Meijerink et al. 1994, Baumgartner et al. 1997]. The number of hydrologically important parameters derived from remote sensing data is manifold and ranges from precipitation estimates, evapotranspiration over land use and Digital Terrain Models (DTMs) to soil moisture and vegetation parameters [Engman and Guerney 1991, Rango and Ritchie 1996]. Especially in remote areas like most parts of rural Africa with lack of field measurements of components of the hydrological cycle, remote sensing data is the only way to provide areal input. Major drawback of all these high resolution satellite systems in the hydrological sense is the limited time resolution [Mauser et al. 1997]. The requests of hydrological systems analyses to data derived from remote sensing and the possibilities of remote sensing for the parameterization of hydrological models (MMS/PRMS, ACRU) are the major objectives. It is realized within the methodological chain of optical, microwave backscatter, microwave phase (interferometry) and multifrequent and multipolarimetric SAR data evaluation. These methods are applied to examples from different climatic zones and different relief energy: Thuringia (Germany), Sardinia (Italy) and Southern Africa (South Africa, Swaziland, Zimbabwe). Integration of the data into a GIS and connection with a DBMS inside a decision support system called IWRMS (Integrated Water Resources Management System) in Southern Africa are shown, as well as the role of remote sensing data for the validation of simulation results. The use of remote sensing data though enables the extrapolation and regionalisation of hydrologic models.

2. PARAMETERIZATION WITH REMOTE SENSING DATA

Components of the hydrological cycle could be distinguished into structural elements, processes and storage elements [ESA 1997]. The task of remote sensing is to detect these structural elements like topography and drainage network, soil types and geology, climate or land cover. But also hydrological processes like precipitation, interception, infiltration, evapotranspiration, runoff, erosion and sedimentation, soil moisture fluxes, groundwater movement or storage elements like snow cover, surface water, soil moisture or groundwater.

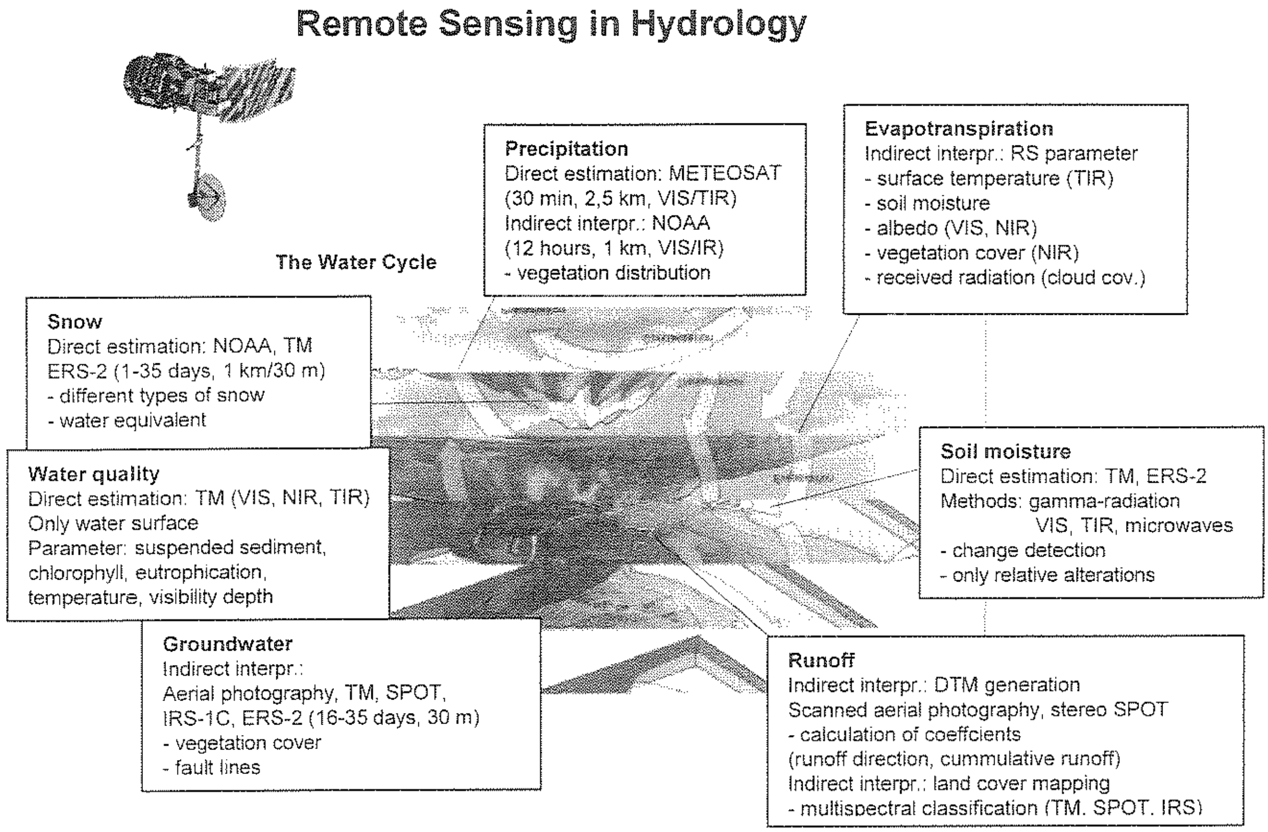

Figure 1: Remote sensing possibilities to determine hydrological components.

The methods of remote sensing enable direct estimations of single processes (precipitation) as well as indirect interpretations of single parameters (evapotranspiration, Fig. 1).

Convective rainfall could be derived from METEOSAT data from the surface temperature of clouds. An indirect interpretation of precipitation could be made from vegetation distributions in semi arid climatic zones from NOAA data. Evapotranspiration is indirectly interpreted from remote sensing parameters: The surface temperature could be derived from Thermal Infrared (TIR), the soil moisture from microwave data, the albedo and the vegetation cover from optical sensors and the received radiation could be modelled through the cloud coverage from weather satellites.

The runoff could not be derived directly, but important information could be gained from Digital Terrain Models (DTM) like runoff direction or cummulative runoff generated from remote sensing data (scanned aerial photography, stereo SPOT or interferometry). Land use mapping through multispectral classifications provides runoff relevant information of different land cover types.

Storage elements like the snow cover could be directly estimated with NOAA, TM or microwave data (i.e. ERS-2). It is possible to distinguish between different types of snow and to derive the water equivalent. The soil moisture could be estimated with several methods ranging from gamma radiation sensing to microwave evaluations. Up to now only relative alterations are possible to detect with change detection algorithmns, but future multifrequent and multipolarized systems might be able to derive also absolute moisture values. Groundwater information is only indirectly interpretable from conditions of the vegetation cover or fault lines.

The water quality could be directly estimated through optical sensors like TM (VIS, NIR, TIR), although they are touching only the water surface. So derived parameters like suspended sediment, chlorophyll or temperature are only applicable for the water surface and not for the whole water body.

The parameterization, the so called quantification of model parameters (measured constants or variables) describing the initial status of the system, is done with different remote sensing sensors, so that the simulation of the

Precipitation	Temperature	Radiation	Interception	Snow dynamics	Evapotranspiration	Groundwater	Soils Interflow	Runoff	Catchment Topography
Percentage of rain per month	Index of Temp.-Station	Cloud coverage	Summertime vegetation density	Snow akkumulation	Begin of Transpiration	Base flow	Soil moisture	Runoff contributing area	Catchment size
Advection/ Convection	Temp.-Station of HRU	Radiation on summer days	Wintertime vegetation density	Snow melt	Surface temperature	Deep percolation	Field capacity	Max interception storage	HRU size
Adjustment factor for rain	Adjusted monthly Tmax	Radiation on winter days	Land use	Albedo of snow covered areas	Soil moisture	Storage capacity of aquifer	Soil type	Runoff contributing soil water	HRU elevation
Adjustment factor for snow	Temperature decrease with elevation	Radiation plane HRU	Snow interception	Snow density	Albedo	Index of GW-reservoir	Initial storage of soil water	Non linear surface runoff	Slope
Threshold for rain	Adjusted energy balance	Aspect	Interception storage	Water equivalent	Vegetation cover	Index of GW-storage	GW-recharge	Water quality	Percentage of imperviousness
Threshold for snow	Station elevation	Slope	Winter-time interception storage	Convection/Condensation energy	Radiation gain		Surface roughness		

Figure 2: From remote sensing data derived parameters of the MMS/PRMS model.

dynamical system is based on realistic assumptions. Figure 2 is showing hydrological processes and the connected parameters as simulated with the MMS/PRMS model. Grey are the parameter which could be detected with remote sensing, dark grey are the parameters which had been derived from remote sensing for this study. This means, that i.e. for the interception the vegetation density and the land use have been derived from remote sensing, meanwhile for the evapotranspiration the surface temperature, the albedo and the vegetation cover hav been derived from TM data, the soil moisture is derived from ERS data.

3. INFORMATION GAIN USING DIFFERENT SENSORS

The evaluation of optical data is done by standard image processing methods. Preprocessing includes contrast stretching, filtering, atmospheric correction and geocoding. If DTMs are available, they could be used for Topographic Normalization of optical data or orthorectification of SAR data. The Topographic Normalization reduces the illumination dependent impact of the relief and enables therefore enhanced classifications. Within the classification methods, the use of parametric classifiers (Maximm Likelihood Classifier) has been approved, because it considers the statistics, even with derivations of the normal distribution.

The land cover classifications have been enhanced in hydrological terms, which means to distinguish between planted alien and indigenous forests, to distiguish settlements according to their imperviousness instead of classes of income or to assess agricultural areas according to their site preparation and their above surface layers (litter, mulch, etc., Schulze & Hohls 1993).

The addition of microwave data (SAR intensity) enables a further discrimination due to physical characteristics like surface roughness, moisture or dielectricial constant. So induced alterations become visible through the creation of multisensoral and multitemporal composites. Further hydrological relavant information (separation between forest and non-forest, height variations due to ploughing or swelling clay minerals) could be gained through evaluations of interferometric data (SAR phase).

The hydrologically important soil moisture distribution is derived reliable only by using multifrequent and multipolarimetric SAR data. Although these data are available only airborne at the moment, there will be spaceborne systems (LightSAR) in the near future. Especially the L-Band (23 cm wavelength) is sensitive to soil moisture (HH- and VV-polarisation), meanwhile the L-Band cross-polarization yields biomass information. This clarifies, that the addition of

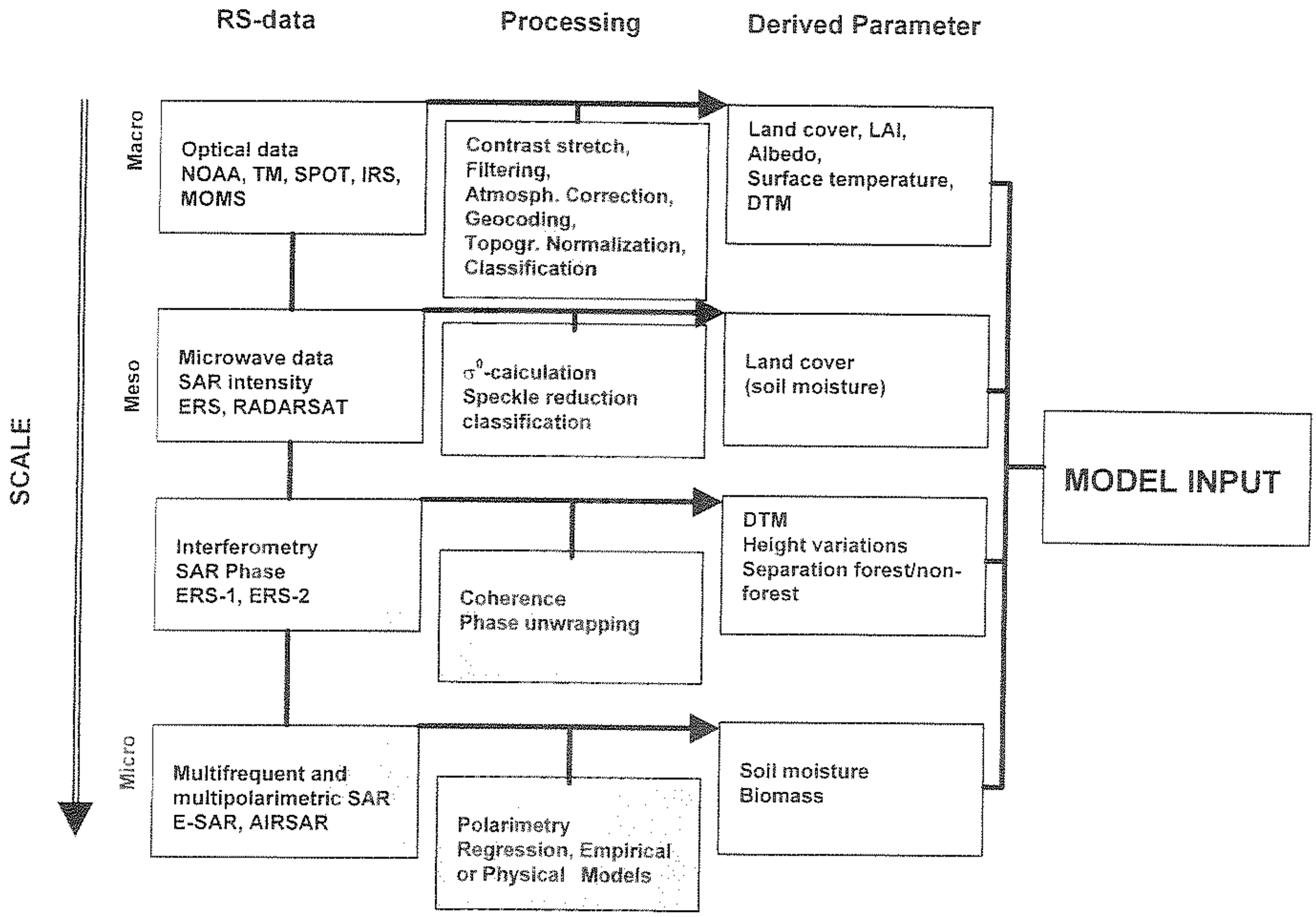

Figure 3: Hydrological information gain with the use of different remote sensing sensors.

several sensors enables the areal derivation of more hydrological relevant parameters (weather satellites – precipitation; optical data – land cover, LAI, Albedo; SAR intensity – enhanced land cover due to different physical characteristics; SAR phase – forest/non-forest separation; multifrequent and multipolarized SAR – soil moisture, biomass.

4. REMOTE SENSING EVALUATIONS

4.1 Mesoscale land cover classification

Land cover controls the hydrological storage and it has an impact on above ground processes like interception or evapotranspiration, ground processes like erosion or infiltration as well as below ground processes like the water consumption of plant roots. A fourth level might be the type of management. It must be realised that land use changes affect every event in which precipitation is transformed into the measurable products of a catchment, i.e. water, sediment or vegetation growth [Schulze 1980].

At the moment a lot of efforts are undertaken to derive land cover information as accurate and as actual as possible from optical and microwave data. Hydrological models work with 5 to 9 classes of a lot more possible land cover classes (sometimes 22 or more). But they have to be selected according the above mentioned criteria, so land cover seems to be a critical issue for any hydrological model. Therefore a nine class classification legend is used at the moment for modelling in Southern Africa: it contains natural forest, planted forest, bushland, grassland, dryland, wetland, urban, river channels and dams/irrigation. Modifications are due to climatological zoning.

4.2 Identification of gully erosion

The task to be solved here is identification of the main erosional features (source areas of sediment transport). This is done by multitemporal interpretation of large scale aerial photography in combination with high resolution DTMs in order to evaluate the amount of soil losses, it means the volume of sediments reaching the fluvial system from the most degraded slopes.

4.3 Multisensoral analysis of river channels

The combination of optical (Landsat TM) and microwave (ERS-1) sensors provided an estimation of the extent of the active floodplain of the Limpopo river (Southern Africa) because the ERS-1 image was acquired before (18.12.95) the floods in the beginning of 1996 meanwhile the TM scene was acquired immediatly after the floods (12.03.96). It therefore provides an estimation of the extent of the active floodplain which is needed for the determination of the shallow aquifers.

4.4 DTM Generation

Official DTMs with a grid size of 400 and 200 m have not a sufficient accuracy for detailed hydrological modelling and process studies. So the Digital Terrain Models generated from different remote sensing sources. On the subcatchment scale they were derived either from stereo SPOT imagery or with interferometry from microwave data and on the more detailed process study scale from scanned aerial photography using digital photogrammetric software [HOCHSCHILD 1998]. The achieved accuracy varies between 10 m for SPOT and 1 m for the aerial photography. The DTMs are used to create Hydrological Response Units [FLUEGEL 1996] and to derive important intermediate products for hydrological modelling like runoff direction or cumulative runoff.

4.5 Detection of rural settlements

In order to extract the settlements from remotely sensed images two sensor fusion approaches are used. The first one is the ARSIS concept [RANCHIN et al. 1998]. This method allows, in a set of images with different spatial and spectral resolutions, the improvement of the spatial resolution of multispectral images up to the best spatial resolution available, with respect to their original spectral content. This method was demonstrated as the most efficient method according to this aim. This allows to obtain a multispectral set of data and to obtain a better classification of features for example in urban areas. The second one was defined in order to extract, target points from SAR images and to combine them with optical data to provide them an understandable context for their detection [MANGOLINI et al., 1993].

These two methods will be used for the mapping of rural settlements in the catchments. The results will be integrated in hydrological models in order to assess their impact on water quality or water demand.

4.6 Derivation of Leaf Area Index

The Leaf Area Index (LAI) is important for the modelling of the interception as well as for the energy balance (transmission). It could be derived from the Normalized Dense Vegetation Index (NOAA, TM) with the following formula:

$$LAI = 4.147 * NDVI - 0.276 \qquad (1)$$

Problems are encountered since this LAI is dependent on the photoactive vital vegetation, meanwhile also dead vegetation has a hydrological impact on the soil surface.

4.7 Coherence images

Land cover information was extracted from training sites of the dominant land cover types in German midmountain range catchments (agricultural fields, improved grassland, unimproved grassland, rural settlements and forests). The large amount of volume scattering and the unstable geometry of trees (for C-Band wavelength) is leading to the typically low coherence values of the forested areas. It is therefore obvious, that the coherence information can be used for precise forest/non-forest discriminations, at least during times of no snow. Snow covered forests have also a high coherence.

4.8 Multifrequent and –polarimetric E-SAR

Analysis of multifrequent and multipolarimetric airborne E-SAR (Experimental SAR) data was carried out for a 3 * 10 km strip in Germany. The data has had a spatial resolution of 2.5 m in X-HH, C-HH, L-VV, L-HH and L-HV. It enabled the derivation of a high resolution land cover classification similar to an optical one (although it included a two step classification process: multispectral for the grassland/agri-cultural areas, textural for settlements/forests) and the derivation of an areal soil moisture. Since there are several spaceborne systems coming up in the near future (LightSAR or ALOS), this seems to be a promising new possibility to derive soil moisture from remote sensing data.

5. CONCLUSION

Catchment-based integrated water resources management can be described as decision making based on physiographical data of the catchment (obtainable through remote sensing), socio-economic conditions (also partly available by earth observation techniques), hydrological knowlegde (implemented in hydrological models and rule-based expert systems, defining the constraints for the models) and "What-If" scenarios (analysed by hydrological models) [LAM 1997].

Water quantity and quality at a certain location and time can be assessed by means of hydrological models. However, if one wants to describe hydrological processes at a detailed level, a sound physically based hydrological model is necessary [FLUEGEL 1996]. Such complex models require many physiographical up-to-date data, such as soil properties, landuse, vegetation cover and topography, normally hardly available, particularly in developing countries. The only way therefore is to use routine job data delivered from satellites.

6. ACKNOWLEDGEMENTS

The results presented in this paper are subject to different projects supported by the German Research Association (DFG) as well as the INCO-DC and the Environment and Climate Program of the EU.

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