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中文题名	水流泥沙数学模型的数据同化与参数反演
英文题名	Data assimilation and parameters inversion of water-sediment numerical model
中文关键词	水流泥沙,数学模型,集合卡尔曼滤波,变分同化,参数反演
英文关键词	water-sediment, numerical model, ensemble Kalman filter, variational data assimilation, inversion of parameter
中文文摘	提高水流泥沙预测精度对防洪规划、灾情评估、防汛、工程施工等方面有重要意义。水沙数学模型和原型观测资料是河道水流泥沙可以获取的两类信息来源。水沙数学模型以水沙动力学理论为基础，是对水流泥沙输移过程的物理概化和数学描述，存在一定的模型结构误差。原型观测数据由于观测设备、观测手段和数据处理等方面的原因，也存在一定的误差。随着原型观测技术和信息通信技术的发展，有必要开展水沙数学模型的数据同化方面的研究，融合模型计算值和原型观测值，提高模型预测精度，将既有的水沙数学模型发展为实时校正的水沙数学模型。建立了河道水沙数学模型的集合卡尔曼滤波数据同化系统。在一维水沙输移方程的基础上，将水位、流量、含沙量和糙率参数作为控制变量，以控制理论为基础，构造了这些参变量的输入输出方程和观测方程。分析了这些参变量的误差分布规律，利用集合卡尔曼滤波方法，建立了水位、流量、含沙量和糙率参数的集合卡尔曼滤波同化系统。建立了悬移质泥沙输移的变分同化系统。构造了模型预测含沙量和原型观测含沙量之间差值的代价函数，并将悬移质泥沙输移方程作为代价函数的约束条件。推导了带约束条件代价函数的伴随方程，及其对恢复饱和系数、挟沙力参数 k 和指数 m 的梯度。分析了集合卡尔曼滤波和变分同化算法的优缺点，建立了河道水流泥沙的耦合数据同化机制。耦合同化机制中，集合卡尔曼滤波优化水位流量并反演糙率参数，卡尔曼滤波逼近得到的模型误差作为变分优化的初始条件，再利用变分同化方法优化含沙量并反演泥沙输移参数。水沙集合卡尔曼滤波系统应用黄河下游 2011 年调水调沙案例，分析了模拟水位、流量和含沙量的精度，分析了反演糙率参数与水位等变量的相关关系。含沙量变分同化系统应用于黄河下游 2009 年调水调沙案例，分析了模拟含沙量的精度，以及反演泥沙参数的合理性，分析了变分同化系统对没有观测资料区域的影响。水沙耦合数据同化系统应用于黄河下游 2013 年调水调沙案例，分析了耦合数据同化机制的可行性。
外文文摘	Improving the predicted accuration of water level, discharge, sediment concentration is import to the application on flood risk analyses. Water-sediment numerical model and field observation are the two main data sources to investigate the real river. On the one hand, water-sediment numerical models are based on the theory of dynamics and are the form of mathematical description from the real physical phenomenon. So the water-sediment numerical models have structural errors. On the other hand, the field observations have errors attributing to the instrument, observed thechnics and data preprocess. With the technical development of field observation and information communication, it is necessary to research a data assimilation system for water-sediment numerical model. In the data assimilation system, the observations and numerical results are integrated and mixed together for more accurate predictions. The practice of the data assimilation system can develop the existing water-sediment numerical model to a real-time model in which the predited values of flow and sediment concentration are optimized dynamiclly. An ensemble Kalman filter system for water-sediment numerical model is built up. One dimensional numerical model is used to model the transport of water and sediment and the Preissmann four implicit scheme is adopted to solve the equations. The state-space equations of the variables (water level, discharge, sediment concentration, roughness) are constructed based on the theory of control system. A variational data assimilation system of suspended load is built up. A cost function which measures the difference between the observations and the numerical result is introduced first. The transport equation of suspended load is taken as a constraint of the cost function. The adjoint equations for the cost function are deduced and the gradients of the transport parameters including saturation recovery and sediment carrying capacity are constructed. A coupled data assimilation system of water-sediment

	numerical model is built up based on the advantage and disadvantage of the two assimilation method. In the coupled data assimilation system, the values of water level and discharge are calculated using ensemble Kalman filter and the value of suspended sediment concentration is calculated based on the variational method. Forthmore, the background error of the coupled assimilation system is estimated by ensemble Kalman filter and the parameters of water-sediment model are calculated in a way of inverse problem. The ensemble Kalman filter system is tested using historical flood data in 2011 of the lower Yellow River. The variational data assimilation system of suspended load is applicated using historical flood in 2009 of the lower Yellow River. The performace of the assimilation system is tested and the effect of the assimilation system to the area without observations is analyzed. The coupled data assimilation system is applied in the lower Yellow River using the flood data in 2013.
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