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An integrated information system for snowmelt flood early-warning based on internet of things

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Abstract Floods and water resource management are major challenges for human in present and the near future, and snowmelt floods which usually break out in arid or semi-arid regions often cause tremendous social and economic losses, and integrated information system (IIS) is valuable to scientific and public decision-making. This paper presents an integrated approach to snowmelt floods early-warning based on geoinformatics (i.e. remote sensing (RS), geographical information systems (GIS) and global positioning systems (GPS)), Internet of Things (IoT) and cloud services. It consists of main components such as infrastructure and devices in IoT, cloud information warehouse, management tools, applications and services, the results from a case study shows that the effectiveness of flood prediction and decision-making can be improved by using the IIS. The prototype system implemented in this paper is valuable to the acquisition, management and sharing of multi-source information in snowmelt flood early-warning even in other tasks of water resource management. The contribution of this work includes developing a prototype IIS for snowmelt flood early-warning in water resource management with the combination of IoT, Geoinformatics and Cloud Service, with the IIS, everyone could be a sensor of IoT and a contributor of the information warehouse, professional users and public are both servers and clients for information management and services. Furthermore, the IIS provides a preliminary framework of e-Science in resources management and environment science. This study highlights the crucial significance of a systematic approach toward IISs for effective resource and environment management.

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1 Introduction

Natural disasters have been increasing apparently in recent years (Su et al. 2011), and flood disaster is one of the frequent and the biggest natural disasters in the world especially in China (Zou et al. 2012), which causes 75 % of the population death and 40 % of economic loss in many kinds of natural disaster (Zhang et al. 2000; Huang et al. 2010), about two-thirds of China is under threat of floods, and the northwest of China is frequently attacked by snowmelt flood (Zhao et al. 2009). With the climate change and the development of the economy, the loss which is caused by the flood disaster would be more and more serious. Accurate monitoring and forecasting of snow cover and flood process are very important for the flood disasters prevention and mitigation (Cloke and Pappenberger 2009; Fang et al. 2013), and one of the key non-project measures is to establish a real-time, highly effective, reliable information system for disasters (Winz et al. 2009). The availability of several global ensemble weather prediction systems through the "THORPEX Interactive Grand Global Ensemble" (TIGGE) archive provides an opportunity to explore new dimensions in early flood forecasting and warning (Pappenberger et al. 2008). The European Flood Alert System (EFAS) research project started in 2003 with the development of a prototype at the European Commission Joint Research Centre (JRC), in close collaboration with the national hydrological and meteorological services (Thielen et al. 2009). Flood warning lead-times of 3–10 days are achieved through the incorporation of medium-range weather forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF), comprising a full set of 51 probabilistic forecasts from the Ensemble Prediction System (EPS) provided by ECMWF (Roulin 2007). It is critical to have accurate snowmelt runoff estimates for both irrigated agriculture and flood warning (Horne and Kavvas 1997). Accurate prediction of available water supply from snowmelt is needed if the myriad of human, environmental, agricultural, and industrial demands for water are to be satisfied, especially given legislatively imposed conditions on its allocation (Simpson et al. 2004). A new method of stand-alone short-term spring snowmelt river flood forecasting was developed based on wavelet and cross-wavelet analysis. Wavelet and cross-wavelet analysis were used to decompose flow and meteorological time series data and to develop wavelet based constituent components which were then used to forecast floods 1, 2, and 6 days ahead (Adamowski 2008). Seasonal snow accumulation and melt dominate the seasonal pattern of stream flow in many regions of the world, and a substantial amount of effort has focused on the development of models for predicting snowmelt runoff (Jost et al. 2012). Many approaches include observations, modeling, assessment techniques that engage stakeholders in a participatory process, economic impact assessment and decision analysis have been discussed for creating plausible scenarios to investigate some of the most challenging and important topics about climate change (Moss et al. 2010). Prototype spatial decision support systems (SDSSs), which are developed for integrated real-time river basin flood control in multipurpose and multi-reservoir systems, were implemented in past decades. Decision support systems for flooding usually combine the wireless sensor network for data acquisition and software agent technology for legacy system integration (Luo et al. 2007). Geoinformatics including Geographical Information Systems (GIS), Remote Sensing (RS) and Global Positioning Systems (GPS) have been widely used in the simulation and prediction of snowmelt runoff (Wang and Li 2001; Nagler et al. 2008).

Integrated information systems (IISs) approach and types of information integration tools have been widely used in practices involving ecosystem assessment and resources management in environmental research, Enterprise Information Systems (EIS) are key platforms and main patterns for the next generation information systems for resources and environment management (Xu 2011a; Guo et al. 2012; Duan and Xu 2012), core technologies of IIS or EIS and their future trends have been discussed in many works (Panetto and Cecil 2013). There are numerous literatures on the applications of IISs in different areas within the framework of Industrial Information Integration Engineering (IIIE), which is a set of foundational concepts and techniques that facilitate the industrial information integration process and comprise methods for solving complex problems when developing integrated information systems (Xu 2011a; Ulmer et al. 2013). The applications of IIIE have covered areas such as business analytics (Duan and Xu 2012), information architecture for supply chain management (Xu 2011b; Gao et al. 2013), integrated medical supply systems (Xu E et al. 2011), enterprise management (Xu et al. 2006), automated assembly planning system (Xu et al. 2012a), service workflow management (Viriyasitavat et al. 2012; Xu et al. 2012b; Monakova and Leymann 2013), human-machine system design (Yin et al. 2012), and decision support systems (Xu et al. 2007). Web services were also used to create accessible interfaces for the National Water Information System (NWIS) and manage the integrated data sets including situ observations, remote sensing data and simulation model outputs. These provide an online repository of historical and real-time runoff, water quality, and ground water level observations maintained by the United States Geological Survey (USGS) (Goodall et al. 2008). System dynamics has also been used to address complex dynamic water resources management issues (Winz et al. 2009). Furthermore, integrated models have been implemented for supporting sustainable water resources planning and management (Liu et al. 2008).

However, there're some challenges for the development and application of traditional information systems, the most concerned is that we're entered an era named "Big Data" (Kusnetzky 2010; Lohr 2012; Snijders et al. 2012), which is a collection of data sets so large and complex that it becomes difficult to process using on-hand database management tools or traditional data processing applications (Jacobs 2009). Data are flooding in at rates never seen before (Bughin et al. 2010), which will grow exponentially with Moore's Law by widespread information-sensing mobile devices, aerial sensory technologies (such as remote sensing), software logs, cameras, microphones, radio-frequency identification readers, and wireless sensor networks (Hellerstein 2008). Data sets will grow more explosively with the rapid development and widely application of Internet of Things (IoT) (Atzori et al. 2010; López et al. 2011; He et al. 2013) and Cloud services (Marston et al. 2011) in the future. The term Internet of Things was first used by Kevin Ashton in 1999 (Ashton 2009) and became popular through the Auto-ID Center and related market analysts publications (Chaouchi 2010). Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones are often seen as prerequisites for the Internet of Things (Atzori et al. 2010). The Internet of Things has great promise, yet business, policy, and technical challenges must be tackled before these systems are widely embraced (Chui et al. 2010). When we are moving towards the IoT, millions of devices will be interconnected, providing and consuming mass information with different scales and different structures on various networks, for the interoperation of these devices, the service-oriented approach seems to be a promising solution, the IoT infrastructure will be strongly integrated with the environment, and its integration with the enterprise systems will break the boundaries between the business IT systems and the real world, also change the way we design and use devices and services (Spiess et al. 2009; Pang et al. 2013). Application fields of IoT include smart product management, waste management, intelligent shopping, urban planning, continuous care, sustainable urban environment, smart meters, emergency response, smart events, home automation and so on (Presser et al. 2012; Han et al. 2012; Liu et al. 2012; Pang et al. 2012; Zhang and Zhang 2012). Furthermore, some technologies which have been widely used in resource management and environmental science are professional components of IoTs, such as remote sensing, GIS, GPS and etc.

There were remarkable achievements in real-time flood forecasting with the application of geoinformatics and DSSs, and it will continue to move toward to integrated information systems with the rapid development and widely application of IoT. There have been a series of research work on the snowmelt process and forecasting, however, there is no work on IIS or EIS for snowmelt flooding available. In this article, we focus our work on the integration of key technologies of information system for "big data" based on geoinformatics and IoT, and have a specific study on the snowmelt flood early-warning. The purpose of the study is to establish a formal paradigm of integrated information system (IIS) for resources management and environmental research. The study is of great significance to initiate a new perspective of research on resources management and environmental sciences. In addition, the study is also of some significance for further development and application of IoT in scientific tasks.

The remaining sections of this article will be organized as follows. In Section 2, describes the architecture of the integrated information system for snowmelt flood early-warning based on IoT and geoinformatics, main components were discussed in this section. In Section 3, introduces the management of knowledge and models in the IIS, they are foundations of the process of snowmelt flood early-warning. In Section 4, describes a prototype based on these technologies. The last section of the article provides concluding remarks and avenues for future research.

2 System architecture

There're many important progress in both flood warning (including snowmelt flood early-warning) and IIS, however, Big Data represents a new era in data exploration and utilization, which are very important for scientific and engineering disciplines, businesses, and government endeavors, more studies on the next generation IISs are still in demand to focus on the integration of IIS and IoT, which are basic approaches or platforms for both scientific works and businesses.

In the past decades, system theory and information technologies have laid the foundation for integrative information architecture. In the area of integrated resources management and environmental sciences, GIS, RS, GPS, DSS and EIS are widely used in various IISs (Fang et al. 2013). However, IISs for snowmelt flood early-warning in water resource management that integrates these technologies are almost non-existing. Based on the key technologies and components of geoinformatics and IoT, the system architecture of the integrated information system for snowmelt flood early-warning developed in this study is shown in Fig. 1, the overall architecture of the system consisting of four main components, which are infrastructure & devices, cloud information warehouse, management tools and applications & services.

2.1 Infrastructure & devices

The basic infrastructure and devices of the integrated information system for snowmelt flood early-warning include 4 parts, which are information acquisition facilities, information storage facilities, computing & analysis facilities and network & software.

1) *Information acquisition facilities:* the information acquisition facilities (see in Fig. 2) mainly consist of remote

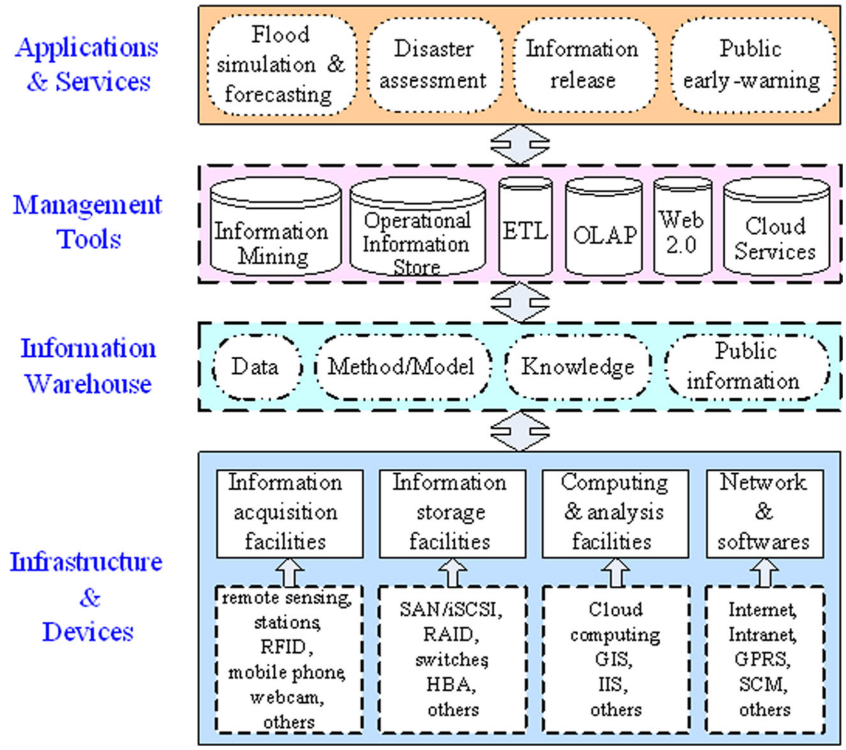

Fig. 1 System architecture of the integrated information system for snowmelt flood early-warning

sensing, stations, RFID, mobile phones, webcam and other sensors, and all of these sensors are generalized facilities of IoT. Datasets for snowmelt flood simulation and prediction mostly contain snow information (including snow coverage map, snow depth map, and snow density map), meteorological data (observed and prediction), hydrological data (runoff, evapotranspiration and etc.), basic geographical data (DEM, topography, land use and land cover, and etc.), socio-economic data (population, GDP, transportation network, public facilities, and etc.). Snow information usually comes from two parts, one is picked up by remote sensing

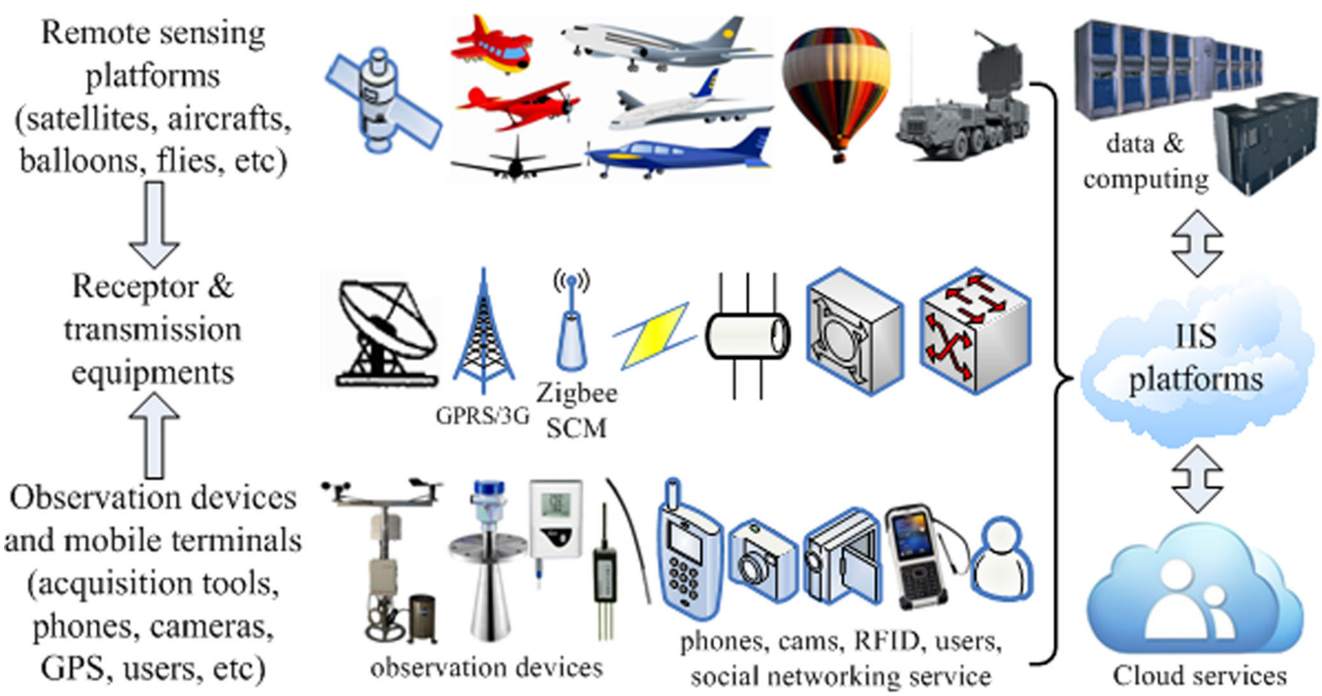

Fig. 2 Information acquisition facilities in the integrated information system for snowmelt flood early-warning

data such as MODIS and ENVISAT-ASAR, which are operating on a daily time step and at a hundred meters spatial resolution, remote sensing data are convenient for the observation of snow information on regional scale or big basins (>100 km^2), however, the spatial and temporal resolution of these data are not enough for the details of the snowmelt process, both the real-time simulation and prediction of the snowmelt process need input data with higher spatial and temporal resolution, so the other source of the data sets is from users and public, usually by mobile terminals, webcams and web services, such as handheld GPS terminals, cell phones, cameras, SCM (Single-Chip Microcomputer), online social networking service (such as Facebook, Twitter, QQ, Weibo, and etc.), PCs, and etc. Everyone in the network can play the role as a sensor, a broadcaster and a user, as well as a contributor to the information warehouse. The weather prediction data are also from two parts. One is the Numerical Forecasting Production from Weather Research and Forecasting Model (WRF), with a forecasting time step of 3 to 24 h. The other part is the ground-based observation data from the meteorological stations and automatic weather instruments, including some SCMs have been erected in typical sites. The weather data sets include air temperature, land surface temperature, air humidity, wind speed, wind direction, net radiation, soil temperature, soil moisture, ground flux, which are basic input data for the snowmelt flood simulation/forecasting models. The hydrological data (runoff and evapotranspiration) is mainly collected by ground-based observation including artificial observations and automatic monitoring. The basic geography data such as DEM, the slope, the gradient, the basin division, water system or drainage network, road network, distribution of population and public facilities, etc., are picked up by GIS and EIS which are integrated in the e-science platform.

2) *Information storage facilities*: the information storage facilities in this study include two parts (see in Fig. 3), offline storage and online storage, and the former is also called client-side storage, which has been widely used in the past works and still popular in some areas for several reasons, for example, the client can make app work when the user is offline; it's fast and efficient for app works; and it's a performance booster; furthermore, it's an easier mode with no server infrastructure required. The offline storage part in this work was mainly for data apply, download and upload, and for applications and services, as well as some basic functions for observation works. The other (online storage) is widely used in cloud storage and e-Science, which is used in this study; it's a mode of networked enterprise storage where data is stored not only in users' computer, but also stored in virtualized pools of storage which are generally hosted by other users or third parties. Hosting companies or professional platforms operate large data centers and provide information services, and people who require their data buy or lease storage capacity from them. The hosts operate and manage the resources according to the requirements of the customer and expose them as storage pools, which the customers can themselves use to store files or data objects, especially for their special products and shared datasets, and they also have authorities for sharing and spread of their data, that's mean, the customers are also hosts in the cloud storage. The cloud storage used in this work is mainly

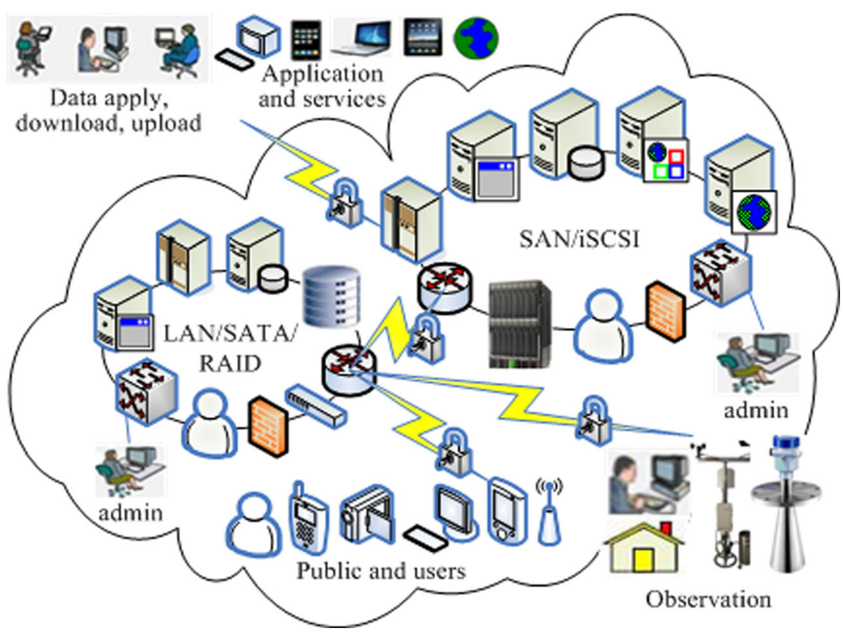

Fig. 3 Information storage facilities in the integrated information system for snowmelt flood early-warning

consists two parts, one is established in LAN (local area network), SATA and RAID are basic facilities of them, and the other is based on SAN (storage area network) or iSCSI (Internet Small Computer System Interface), public and users in cloud connect to LAN or SAN by internet or intranet.

3) *Computing & analysis facilities:* one of the most concerned challenge in sciences and enterprises now is how to handle and analysis Big Data, the waves of information generated and stored in the cloud, cloud computing and e-Science are best choices for sciences and enterprises in the Big Data era, which are also used for data computing and information analysis in this work. Computing and analysis facilities in this work are consist of cloud computing facilities, GIS and IIS, and cloud computing facilities in this study are mainly from the basic parts of e-Science, which include IaaS (Infrastructure as a Service), DaaS (Data as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service), key technologies or basic components of each part of e-Science were shown in Fig. 4.
4) *Network & software:* network and software are very important in cloud computing and e-Science, they are key bridges and links between the infrastructures or users in cloud services and e-Science, NaaS (Network as a Service) and SaaS (Software as a Service) are common styles in cloud services and e-Science, which are also used in this work. VPN (Virtual Private Network) was used as the NaaS Service Model in this study, which extends a private network and the resources contained in the network across public networks like the Internet, and it enables a host computer to send and receive data across shared or public networks. SaaS is referred to as "on-demand software" and is usually priced on a pay-per-use basis, and the initial setup cost for SaaS is typically lower than the equivalent enterprise software, furthermore, some software used for scientific research are open access or discount, so SaaS in e-Science is popular and has a good prospects in the future.

2.2 Cloud information warehouse

The typical and traditional styles of storage and management of information (including data, method/model, knowledge and others) are relational database, data warehousing and transaction database; however, they're not enough in IoT and e-Science because it's difficult to access, store, process, search and service big data, which is usually up to Petabyte (PB), Exabyte (EB) and it would be more and more in the future. Both the business world and scientific works are moving towards the cloud for many enterprise or e-Science applications, but there're different between business and science, for most companies, security and other concerns may prevent them from adopting cloud infrastructure for information warehousing, it's reasonable that make money and keep business secrets are basic principles for enterprises. However, cloud infrastructure for information warehousing is much easier to achieve for e-Science, because sciences are much more open, freedom and public.

Cloud information warehouse is a new pattern of storage, management, application and services of information, it's a combination of databases and database management tools and it could be defined as the new generation of information warehouse for information management and information services based on cloud environment. The cloud information warehouse has the abilities to create both materialized and non-materialized views of shared information, to support the

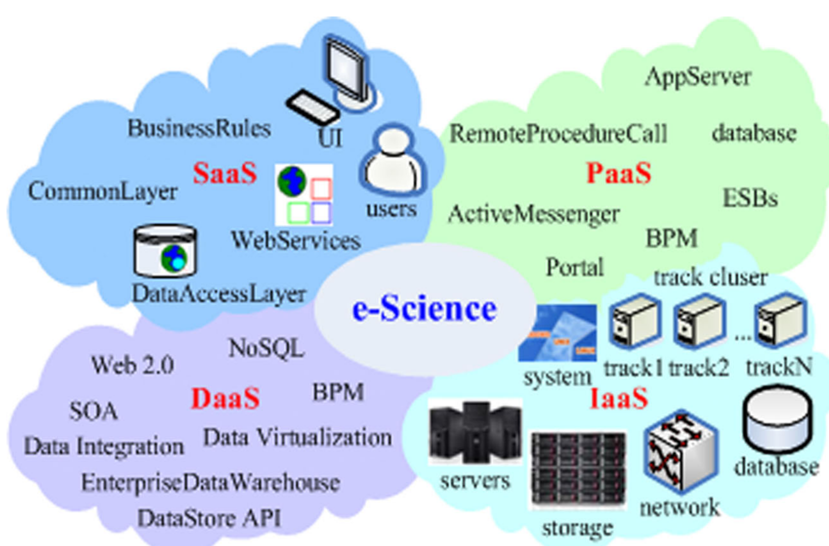

Fig. 4 main functions of e-Science

linking of external data via load, link, index to accelerate associative value, to keep updated, to support mixed operation systems, to accelerate linearly with addition of resources in both the delivery of throughput and the reductions in analytic latency, and to exploit analyst natural language such as SQL, ETL, Hadoop, MapReduce or other programming languages.

2.3 Management tools

Management tools include information mining, ETL (Extraction-Transformation-Loading), operational data store, OLAP (Online transaction processing system), GIS and cloud service. The task of information mining is to collect, collate and analyze large quantities of information (i.e., data, models and knowledge) automatically or semi-automatically, spatial data mining and sensor data mining are two special functions in this system. Operational data store is used to integrate kinds of information (i.e. data, models and knowledge) from multiple sources for further operations, and Oracle is used in this work. The main function of ETL is to extract, transform and load the demand information from EIS operational information source to analytical information in the information warehouse. The two main tasks of ETL in this study are: 1) since information comes from different sources, ETL is expected to integrate them and 2) ETL is expected to transform the original information structure to subject-oriented structure. OLAP is an approach to swiftly answer multi-dimensional analytical (MDA) queries and is part of the broader category of business intelligence. Once the needed information is extracted and transformed to the required format, OLAP is realized through relational OLAP (ROLAP) that is based on snowflake schema. Measures are derived from the records in "fact tables" and dimensions are derived from "dimension tables", and each measure has a set of labels and a dimension is what describes these labels. This system supports standard OLAP operations including slicing, dicing, roll up, drill-down, and pivoting. The results can be displayed in a variety of formats such as figures, tables, charts or other forms of graphical outputs. Furthermore, GIS is used for temporal analysis of datasets in this work.

2.4 Applications & services

The top level of the integrated information system is applications and services, including flood simulation and forecasting, disaster assessment, information release, public early-warning, and etc. Scientists, public and policy-makers load the system with Internet/Intranet or mobile Internet, to communicate with each other through tools like web services, chat rooms, NetSend (a network messaging tool) and NetDDE (Network Dynamic Data Exchange) technologies. JSP/Servlets of J2EE and Web Application are applied to implement the system interface, and JDBC of Java (Java Data Base Connectivity) is used to connect with the Oracle Database, for the accomplishment of the data I/O. In this IIS, it can carry out policy-making functions of snowmelt flood early-warning like transformation of flood models, spatial analysis of GIS data, simulation and forecasting snowmelt flood as well as to establish the decision programs, manage and disseminate the information.

3 Management of knowledge and models

3.1 Knowledge base in the IIS

Knowledge base is used to store and organize the knowledge of entities. According to the characteristics of the knowledge and its expression of the snowmelt flood early-warning IIS, how to organize the storage architectures and experience is the focus of the study. The knowledge must be organized in a convenient way to store, expanse and the inferential machine is applied. In order to effectively store variety of knowledge, methods and examples in the process of snow flood early-warning, techniques and methods of object-oriented were used to build knowledge representation models and knowledge base. Object-oriented models were mapped to relational database for storing, organizing knowledge base with the form of database, and OOP (Object Oriented Programming) was used to establish the knowledge base of snowmelt flood early-warning IIS.

3.2 Model base system in the IIS

In the IIS, one of the core tasks is the simulation and prediction of snowmelt runoff, so there're kinds of models, such as distributed snowmelt runoff models, spatial analysis models, interpolation models, statistical analysis models, error analysis models, and etc., and there would be more and more models implemented and introduced into the system by different users and various tasks, so an efficient model base management is important for the IIS.

1) *Construction and management of the models*: In addition to the snowmelt flood early-warning models such as distributed grid snowmelt models, distributed grid runoff models and distributed grid conflux models, a large number of other universal models were also included in the model base, and with the gradual increasing of various models, the management of models became more difficult. Model Base System have these basic features: Accession, modification, amputation, classification, enquiry and browsing of models; Management of the dictionary of model parameters, such as increasing, modifying, deleting, querying, browsing, and other conventional operations of the parameters in the dictionary of models; Administration of file formats of the parameters in models. The type of file format will provide

accessing form for parameters in models, and that's very important for the running of various models and parameters; Prescribing parameters for each model in the DSS when the parameters were not initialized. Since the parameters and their descriptive documents would be more than one, it's necessary to establish their relationships to ensure that every parameter of every model is understandable to every user.

2) *Combination and running of models*: There are many models participating in the simulation of the snowmelt flood, so manipulability of the models and simulation process is important. The following specific features are included: Establishment of simulation process and detailed steps, providing models for every step and selecting the files of the parameters of the models; Management of the simulation process and every step of the way. Here you can arbitrarily increase or decrease models and parameters, and can also change the order, which ensures that users can choose different combinations to take simulation firstly and then choose suitable models according to the simulation results; Administration of the initial value of parameters and results of the simulation with different models.
3) *Management of download, upload and conversion of the parameters files in the models*: Conversion management of the parameters documents. Documents were recorded in the form of required data format in the database, and you can convert them into text files or convert data from text files; Upload and download of parameters documents. Parameters documents in the form of text files could be downloaded by the client, and text files could be also uploaded to the server and internet; The realization of the model base system in the snowmelt flood early warning DSS was completely based on Web mode and cross-platform technologies, with Oracle9i relational database to manage the model base system in client services, J2EE technologies to take material development, and JDBC technologies to visit and operate model base, parameters data, parameters dictionary and so on.
4) *Distributed snowmelt runoff model:* A model based on geoinformatics including the grid snowmelt model based on the energy balance, the grid flow model based on the water volume balance and the distributed grid runoff model has been developed with explicit physical conception. The snowmelt model is the core part of the whole distributed snowmelt runoff model. An energy balance snowmelt model was used to calculate the snowmelt in this work. The energy budget of snowpack is:

$$Q_M + Q_I = Q_{NR} + Q_S + Q_L + Q_G \tag{1}$$

Where: Q_M, Q_I, Q_{NR}, Q_S, Q_L and Q_G are net energy flux for snowmelt, changes of storage energy in the snowpack, net radiation flux, turbulent sensible heat flux, turbulent latent heat flux heat and conductive exchange of sensible with the ground.

$$Q_{NR} = Q(1-\alpha) + L\downarrow - L\uparrow \tag{2}$$

Where Q stands for the solar Radiation, α is the albedo of snow surface, $L\downarrow$ is the atmospheric downward longwave radiation, $L\uparrow$ is the atmospheric upward longwave radiation.

$$Q = Q_{dir} + Q_{diff} \tag{3}$$

Where: Q_{dir} and Q_{diff} stand for the direct solar radiation and the diffuse solar radiation.

$$Q_{dir} = Q^0_{dir} \times \cos Incident/\sin A_s \tag{4}$$

$$Q_{diff} = Q^0_{diff} \times \frac{1+\cos A_0}{2} \tag{5}$$

$$\begin{aligned} \cos Incident = {} & \cos A_S \times \sin A_0 \times \cos(Z_S - Z_0) \\ & + \sin A_S \times \cos A_0 \end{aligned} \tag{6}$$

Where $Q_{dir}{}^0$ and $Q_{diff}{}^0$ are the direct solar radiation and the diffuse solar radiation in the noon of 1 day, cos*Incident* is the cosine of the solar incidence anglel, A_S and Z_S are solar elevation angle and azimuth in the noon, A_0 and Z_0 stand for the slope and aspect of DEM.

$$\begin{aligned} \alpha = {} & 0.3973\alpha_1 + 0.2382\alpha_2 + 0.3489\alpha_3 - 0.2655\alpha_4 \\ & + 0.1604\alpha_5 - 0.0138\alpha_6 + 0.0682\alpha_7 + 0.0036 \end{aligned} \tag{7}$$

Where α_i stands for the corresponding narrowband albedo of MODIS imagines (i=1 to 7).

$$L\downarrow = \left(1 + 0.0035c^2\right)\left[1 - a\exp\left(-b\frac{e}{T_a}\right)\right] \times \sigma T_a{}^4 \tag{8}$$

Where c stands for the cloudiness (eighth made), a=0.35, b=10.0, T_a is the air temperature (k), e is the vapor pressure (hpa), σ is the Stefan-Boltzman constant ($5.67\times 10^{-8}\ \mathrm{W{\cdot}m^{-2}{\cdot}K^{-4}}$).

$$L\uparrow = \varepsilon\sigma T_0{}^4 \tag{9}$$

Where ε stands for the emissivity of snow, T_0 is the surface temperature of snowpack (k).

$$\begin{aligned} T_0 = {} & C + \left(A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2}\right) \times \frac{T_{31}+T_{32}}{2} + \\ & \left(B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2}\right) \times \frac{T_{31}-T_{32}}{2} \end{aligned} \tag{10}$$

$$\varepsilon = (\varepsilon_{31} + \varepsilon_{32})/2 \tag{11}$$

$$\Delta\varepsilon = \varepsilon_{31} - \varepsilon_{32} \quad (12)$$

Where T_{31} and T_{32} are brightness temperature of band 31 and band 32 of MODIS imagines, ε_{31}=0.98818, ε_{32}=0.97115, $C, A_1, A_2, A_3, B_1, B_2$ and B_3 are coefficients.

$$Q_S = \rho C_P (T_a - T_0)/r \quad (13)$$

$$r = \frac{\ln\left(\frac{x+z_m}{z_m}\right)\ln\left(\frac{x+z_h}{z_h}\right)}{k^2\mu} \quad (14)$$

Where (ρCp) is the air volumetric heat capacity (1205 W·S/(m^3·K)), r is the aerodynamic resistance, x= 1.5 m, μ is the wind speed, z_m and z_h are dynamic resistance coefficient and heat and moisture resistance coefficient (z_m=0.001 and z_h=0.0002 for the snowpack surface in this work), k is Von Karman constant (k=0.41 in this work).

$$Q_L = \frac{Q_S}{C_B P \frac{T_0 - T_a}{e_0 - e}} \quad (15)$$

$$P = [(288 - 0.0065H)/288]^{5.256} \times P_0 \quad (16)$$

Where C_B is the Bowen constant (C_B=6.1×10^{-4}), P is the atmospheric pressure (hPa), e_0 is the vapor pressure of the snowpack surface, P_0 is the sea-level atmospheric pressure (1013 hPa), H is the elevation.

Furthermore, Q_I is usually negligible for its small value and Q_G could be valued by meteorological observation. When Q_M has been calculated with forward equations based on data sets from RS, meteorological observation and cloud services, the distributed snowmelt amount of the whole study area could be calculated based on GIS tools such as ArcGIS.

3.3 Early-warning model and disaster prevention measures

Assessment of disasters often include disaster risk imputation and risk assessment, when estimating the absolute losses caused by disaster, the imputation of the disaster situation is a difficult task because on the one hand the many direct economic losses are incalculable; on the other hand, the estimating process is hard to handle. In this study of the warning of snowmelt flood, the possibility of snowmelt flood has been associated with the local societal and economic conditions, striving to pre-evaluate the uncertainty of the possible flood damage succinctly. Firstly the main factors as a whole which can reflect the snowmelt flood farthest were selected, and then they were divided into various indicators factors. The appropriate quantitative

Table 1 Early-warning *i*ndexes (R) of snowmelt flood grades

R	Grades	Signification	Warning level
0–0.30	General	Infrequent feasibility of snowmelt flood, even occurred, the disaster small can be easily controlled, or biggish flood but without losses	Blue (IV)
0.30–0.50	Heavier	Which has basic terms of snowmelt flood, relevant departments should be reminded, but the possibility of flood occurred is smaller, should strengthen the monitoring of temperature, radiation and other meteorological elements, to prevent the mutations occurred	Yellow (III)
0.50–0.80	Serious	Should make preparations for flood prevention and disaster relief, to inform related departments to initiate flood defense plans, flood will spread fleetly, the affected area will be significant, to transfer staves and important materials in danger area	Orange (II)
0.80–1.00	Particularly	Snowmelt flood is a foregone conclusion, and the impact will be lumping, to submit conditions to the higher authorities early, warnings should be carefully put out, to avoid panic and big fluctuations of public order	Red (I)

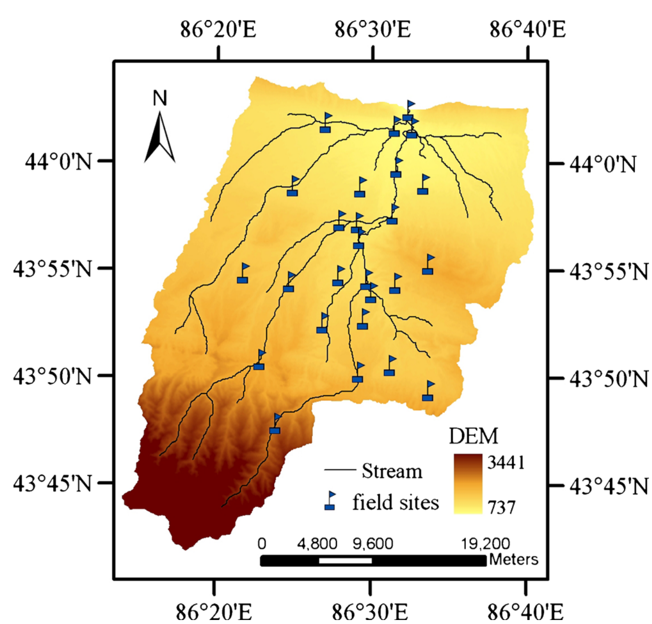

Fig. 5 the study area (Quergou River Basin, Xinjiang, China)

exponents were used to synthetically quantify the risk of snowmelt flood, as the measurable indicators of snowmelt flood after that promulgating the alert of corresponding levels. Finally basis for decision making for warning in regional snowmelt flood in spring were provided.

According to the disaster impacts on survival and development objectives of human, losses of floods can be divided into economic loss and non-economic loss. With the features of the development of time, economic losses of floods can be divided into direct and indirect economic losses. Common classification methods all involve economic loss and non-economic losses, and researchers have also put forward a concept named “potential loss”, which means the losses caused by disaster can be make up without taking any measures, but the definition is not accurate for ignoring the social condition attacked by the flood.

The level of the early-warning index is to be confirmed based on a combination of economic losses and social losses, and before it, we pre-evaluate the possible disasters, with fully consideration of natural factors, and to offset part estimated loss with capacity of flood control of the community. The following four categories have been picked up of our initial selection; they were natural factors, economic factors, population factors and flood control facilities’ contribution factors. After quantitative treatment of all factors to be the corresponding indexes, they were natural factors indexes (N), economic factors indexes (E), population factors indexes (P) and flood control facilities factors indexes (F). And a measurement index named Early-warning Index (R) for sizing of snowmelt flood disasters was constructed after simple combination of the four factors indexes (N, E, P & F), as formula 1.

$$R = \sqrt[3]{N \times E \times P} \times F \tag{17}$$

According to the calculated early-warning indexes, referring to the hazard rating of grassland fire danger, the risk profile of the indexes can be classified into four grades. According to the seriousness of disasters and emergency degrees, meteorological

Fig. 6 the web interface of the IIS

disasters were generally divided into four classes (IV, III, II and Class I). Combining the promulgation of warning signals of those disasters, colors followed by blue, yellow, orange and red, with logo in both Chinese and English, representing the general (IV), heavier (III), serious (II) and particularly (I) (Table 1).

This paper carried out a verification with snowmelt flood data of these years in the typical study area, Quergou River Basin, located in Hutubi County, Xinjiang, China, compared with the actual situation, all reflecting the size of snowmelt flood disaster basically without in 2000 and 2006.

4 Prototype implementation

The IIS developed in this work has been tested and applied with a case study in the Quergou River Basin, which is located in the middle part of the north-Tianshan Mountains in Xinjiang, China. Figure 5 shows some details of the study area, with the statistic and analysis by GIS, the elevation of the headstream is about 3440 m, and the mainly parts ranging from 1000 m to 1500 m, and the average elevation is about 1503 m. The area of this basin is about 833.57 km^2, and the average annual runoff of this basin is about 3.89×10^8 m^3. This basin has some obvious hydrological characters of the arid area rivers; the snowmelt flood of past years in the basin is representative.

Figure 6 shows the web interface of the IIS, both scientists and public users could load the IIS for different applications or services. Figure 7 shows the brief steps of snowmelt flood early-warning based on the IIS, the first step is data collection by sensors in IoT, then the next step is data transmission and management with net/web, and the last step is further analysis or services in the IIS.

Figure 8 displays a typical snowmelt flood process with the contrast of forecasted and observed runoff with the IIS from a browser interface, and Fig. 9 shows the dissemination and management of early-warning information with the IIS. The

Fig. 7 brief steps of snowmelt flood early-warning based on the IIS

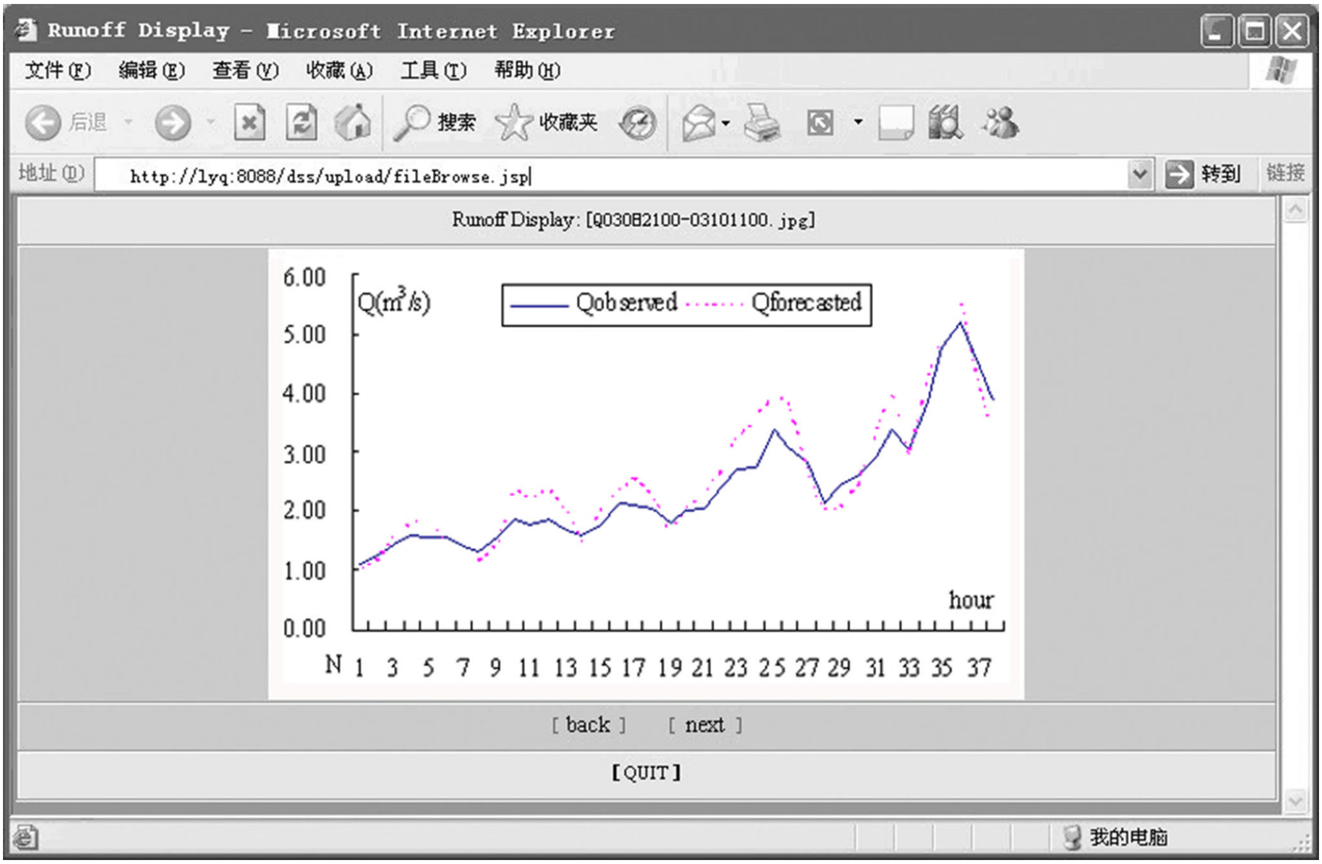

Fig. 8 Results display from browser interface

results showed that the precision of forecasting is very good, and the effectiveness of decision-making can be improved by using such an IIS.

5 Conclusion

This paper was motivated to address the gap in the development and application of integrated information system for snowmelt flood early-warning in water resource management. It presents an initial effort to develop an IIS that has the potential to provide basic functions and services to users or tasks. The proposed integrative system combines IoT, Geoinformatics (RS, GIS and GPS) and Cloud Service for snowmelt flood early-warning with a case study in Xinjiang, China. The results showed that the process of snowmelt flood simulation and early-warning are greatly benefited by such an integrated system in detailed works, and the effectiveness of decision-making

预警管理								
序号	预警指数	预警等级	预警颜色	预警名称	预警地区	预警日期	修改	删除恢复
1	0.18	低(IV)	蓝 色	2006年3月6日三工河干沟春季融雪洪水	新疆阜康三工河干沟地区	2006-12-05	修改	删除
2	0.52	高(II)	橙 色	2005年3月24日伊犁霍城县融雪洪水	新疆伊犁霍城县	2006-12-05	修改	删除
3	0.65	高(II)	橙 色	2006年2月14日查布查尔县融雪洪水	新疆伊犁查布查尔县	2006-12-05	修改	删除
4	0.41	中(III)	黄 色	2005年3月8日呼图壁军塘湖融雪洪水	新疆呼图壁军塘湖地区	2006-12-05	修改	删除
共 4 条记录 前页 后页 [1/1] 1								
新预警指数计算								

Fig. 9 dissemination and management of early-warning information

can be improved by using such an IIS. The prototype system implemented in this paper is valuable for the acquisition, management and sharing of multi-source information in snowmelt flood early-warning even in other tasks of water resource management.

The contribution of this work includes developing a prototype IIS for snowmelt flood early-warning in water resource management with the combination of IoT, Geoinformatics (i.e. RS, GIS and GPS) and Cloud Service, with the IIS, everyone could be a sensor of IoT and a contributor of the information warehouse, professional users and public are both servers and clients for information (i.e. data, models, knowledge, etc.). Furthermore, the IIS provides a preliminary framework of e-Science in resources management and environment science.

However, there are also several issues that need to be addressed in future works. A number of challenges limit the implementation of fully fledged IISs, such as standardization and operational of IoT, data formats and data standards, big data management, and information system compatibility, which are topics of further works in the near future.

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