Microsoft Research Faculty Summit 2014

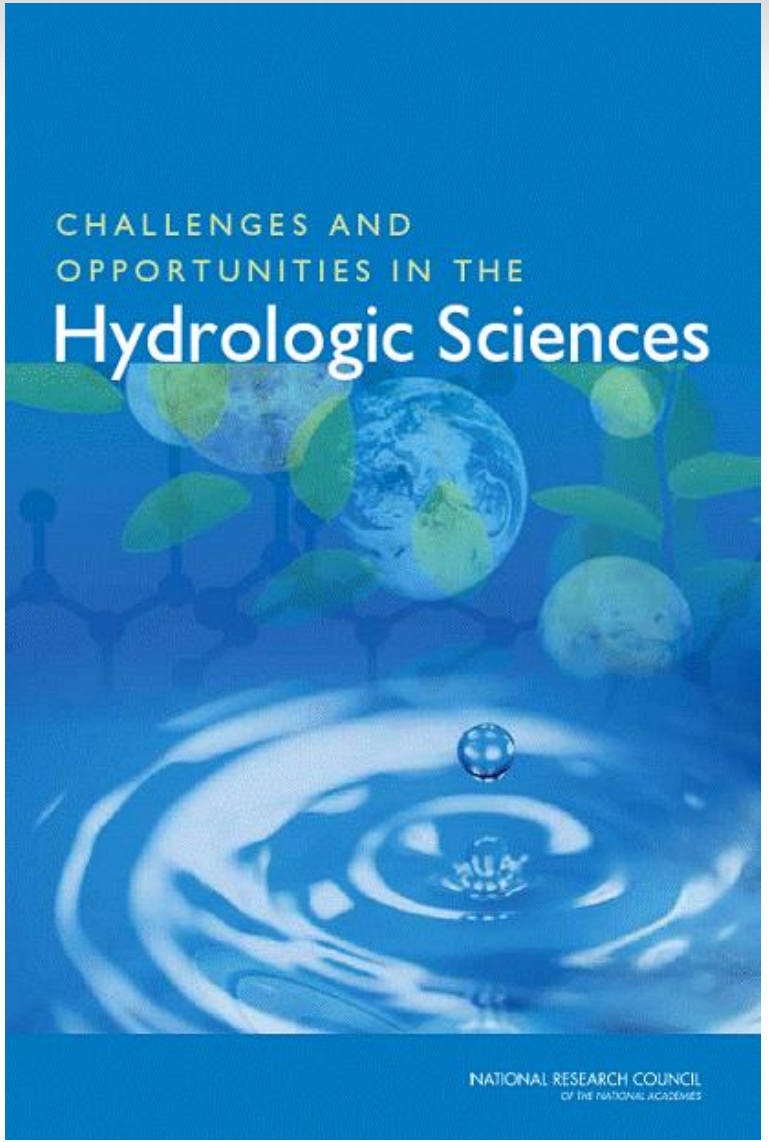
15TH ANNUAL

Numerical Modeling of Ecohydrological Processes and Contaminant Transport Using Microsoft Azure Cloud

Chunmiao Zheng
Center for Water Research
Peking University
(http://hydro.pku.edu.cn)

Three Grand Challenges in Hydrological Sciences

- Water Cycle:
  An Agent of Change
- Water and Life
- Clean Water for People
  and Ecosystems



– National Research Council (2012)


China Water Crisis:
Water Scarcity & Water Pollution
Water Pollution Control Action Plan
~2 Trillion RMB

LETTERS

edited by Jennifer Sills

China's "Love Canal" Moment?

IN FEBRUARY 2013, A POSTING IN CHINA'S BURGEONING BLOGOSPHERE ACCUSED BUSINESS owners in Shandong Province of disposing waste water through injection wells and contaminating shallow groundwater (*1*). This seemingly innocuous message, describing a practice that is not uncommon, ignited a firestorm on the Internet (*2*). The outburst of condemnation and concern caught many observers by surprise and reached the uppermost echelon of the Chinese government (*3*). Du Ying, Vice Chair of the powerful National Development and Reform Commission, declared that "China needs a law specifically designed for groundwater protection" (*4*).

Call to action. A child protests in the Love Canal neighborhood in 1978.

Groundwater provides about 20% of total water supplies for China, and 50 to 80% of water in water-scarce north and northwest regions of the country (*5*). However, the outlook for groundwater quality is bleak. According to the latest round of water well sampling in 2011 in more than 200 cities and administrative regions by China's Ministry of Land and Resources, fully 55% of more than 4700 samples indicated groundwater of category IV or V [on a scale of I to V from the best to poorest quality (*6*)]. Still, no one knows the true extent and severity of groundwater pollution in China.

It is imperative that the Chinese government move aggressively and assertively to combat groundwater pollution. The challenges and action of the United States and other developed countries should serve as an example. The United States alone has spent hundreds of billions of dollars on detecting, monitoring, assessing, and remediating contaminated groundwater since the 1970s (*7*), when groundwater

6. China Ministry of Environmental Protection, "National Quality Standard for Ground Water (GB/T 14848-93)" (1994).
7. National Research Council, "Alternatives for managing the nation's complex contaminated groundwater sites" (National Academies Press, Washington, DC, 2012).

The True Challenge of Giant Marine Reserves

THE NEWS FOCUS STORY "GIANT MARINE reserves pose vast challenges" (C. Pala, 8 February, p. 640) discusses the potential role of large marine reserves in conserving pelagic species. We highlight three points that are misrepresented in the article.

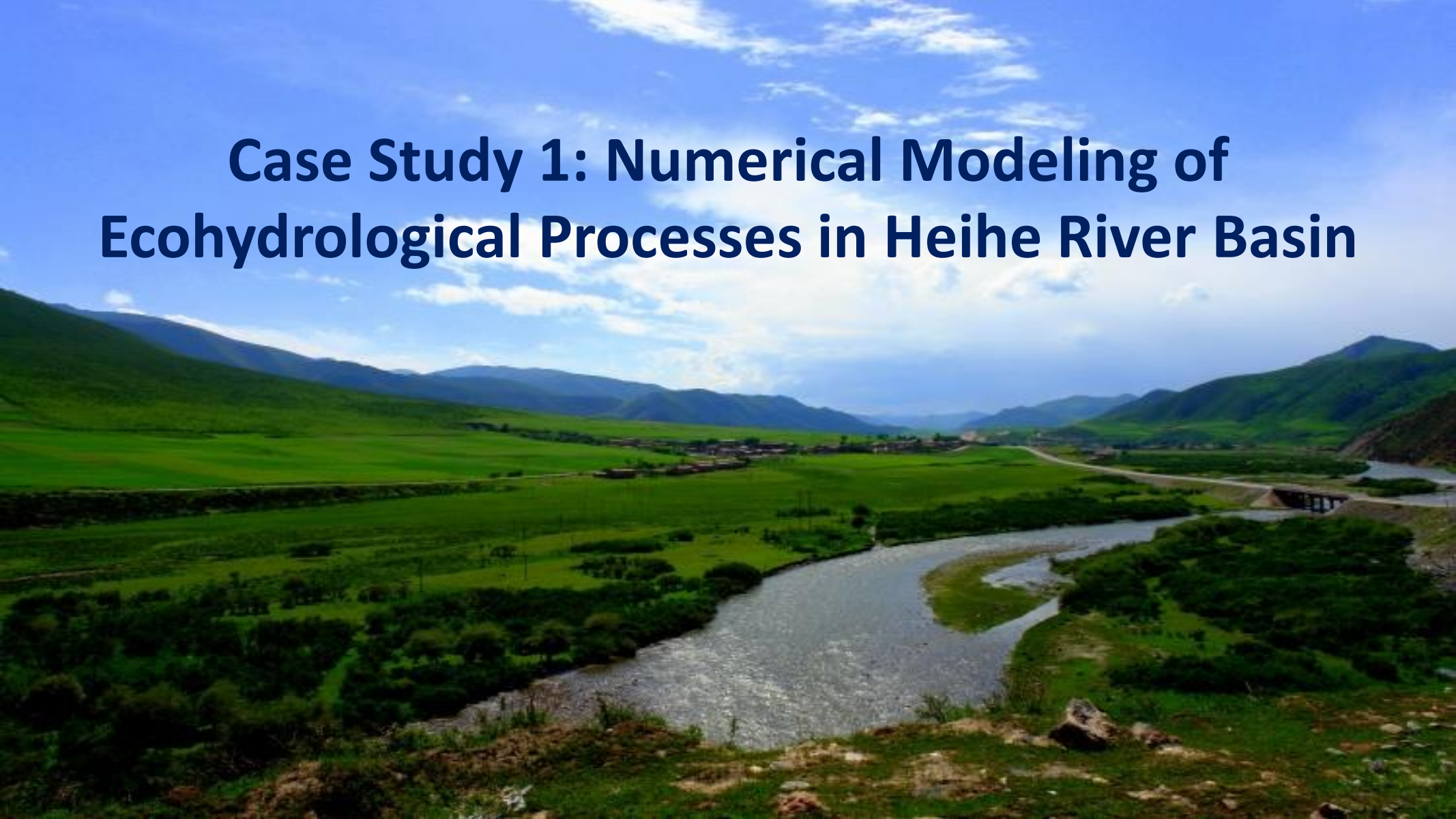
First, the story describes tropical tuna stocks in the Indian Ocean as "depleted," implying that they are severely overexploited (*1*). Fishery overcapacity is certainly worrisome, but these stocks are not currently overexploited (*2*). This clarification by no means precludes appropriate use of area-based management, but stock status is central to weighing different management options.

Second, the article claims that "mainstream marine biologists are more optimistic" about the efficacy of the Chagos Islands reserve because "tuna there don't necessarily swim vast distances." We disagree. Juvenile

Science 340
May 17, 2013

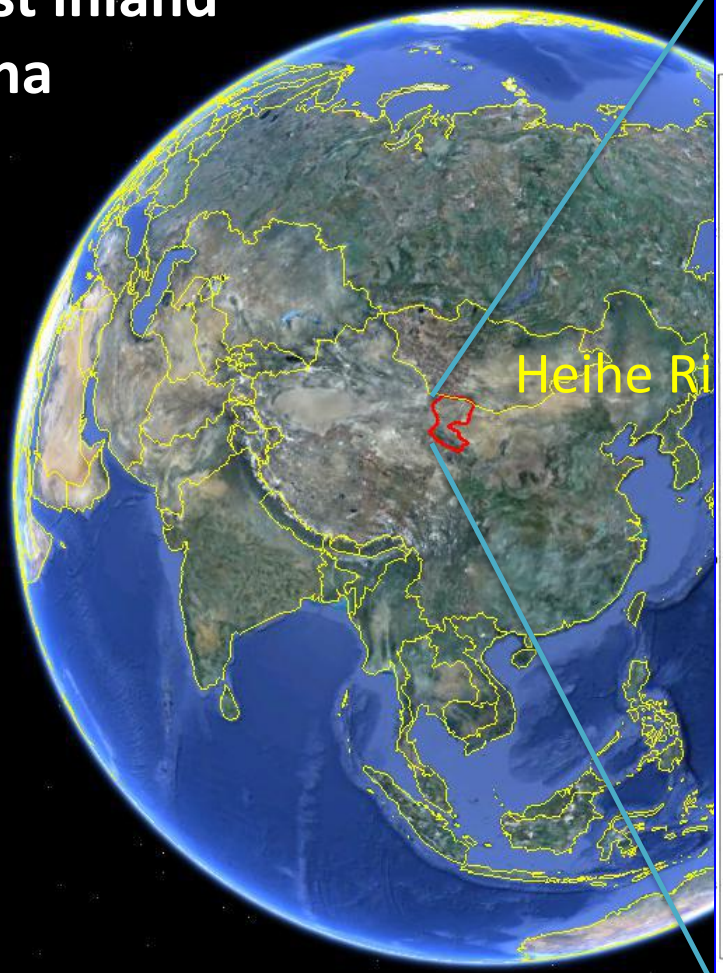
C. Zheng & J. Liu

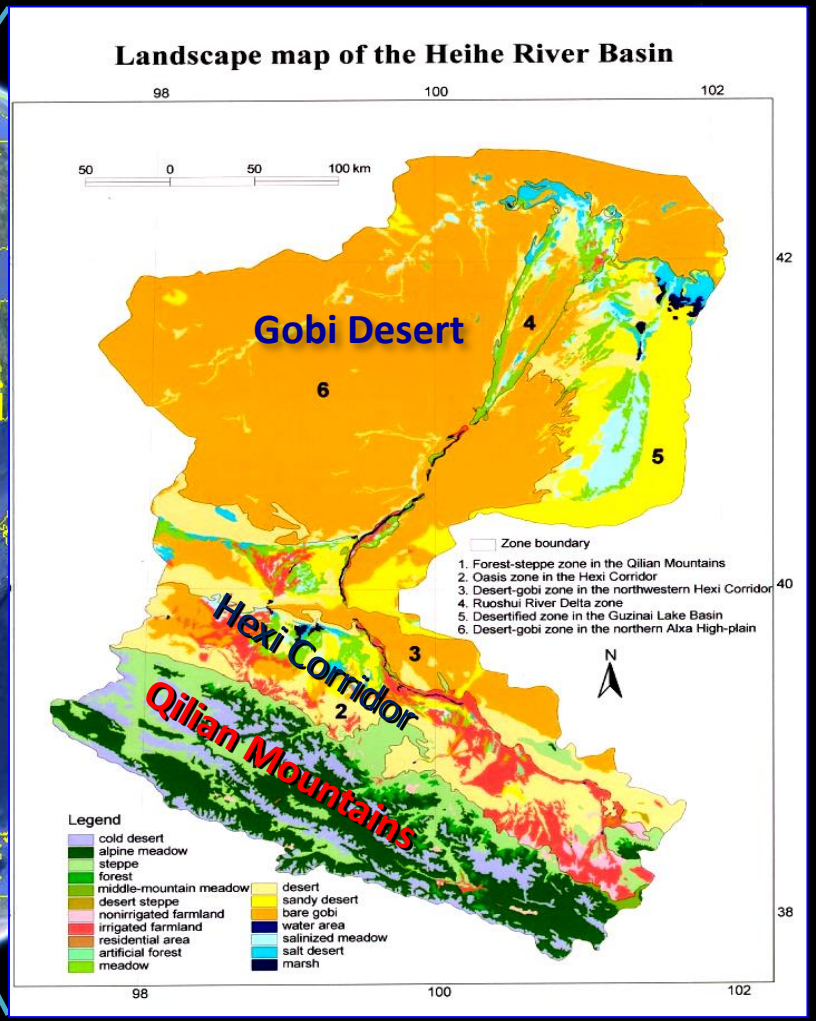
Case Study 1: Numerical Modeling of Ecohydrological Processes in Heihe River Basin

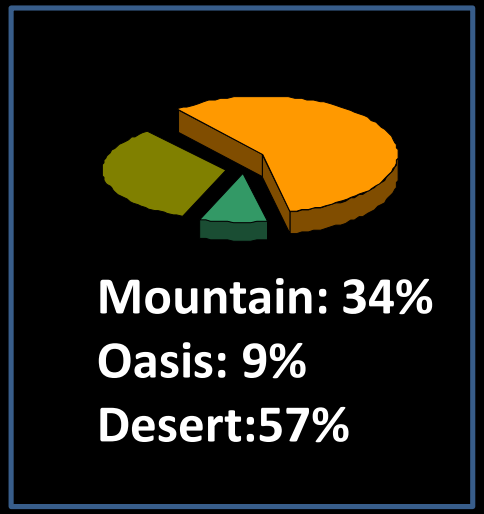


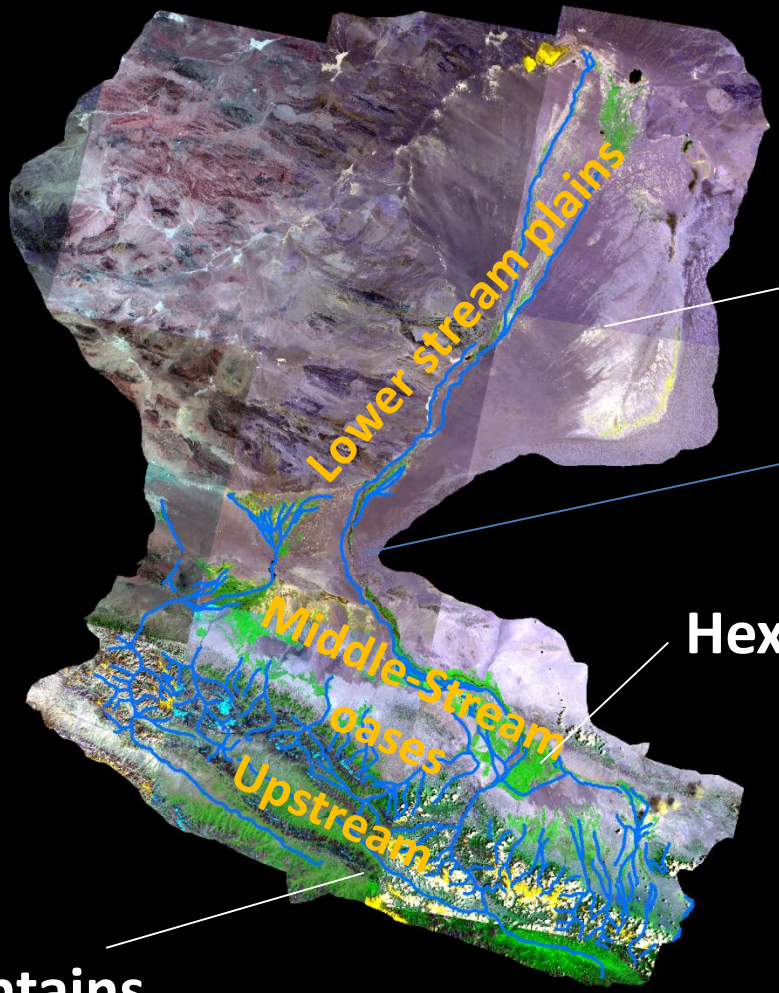
The second largest inland river basin In China

Total Area: 130,000 km²









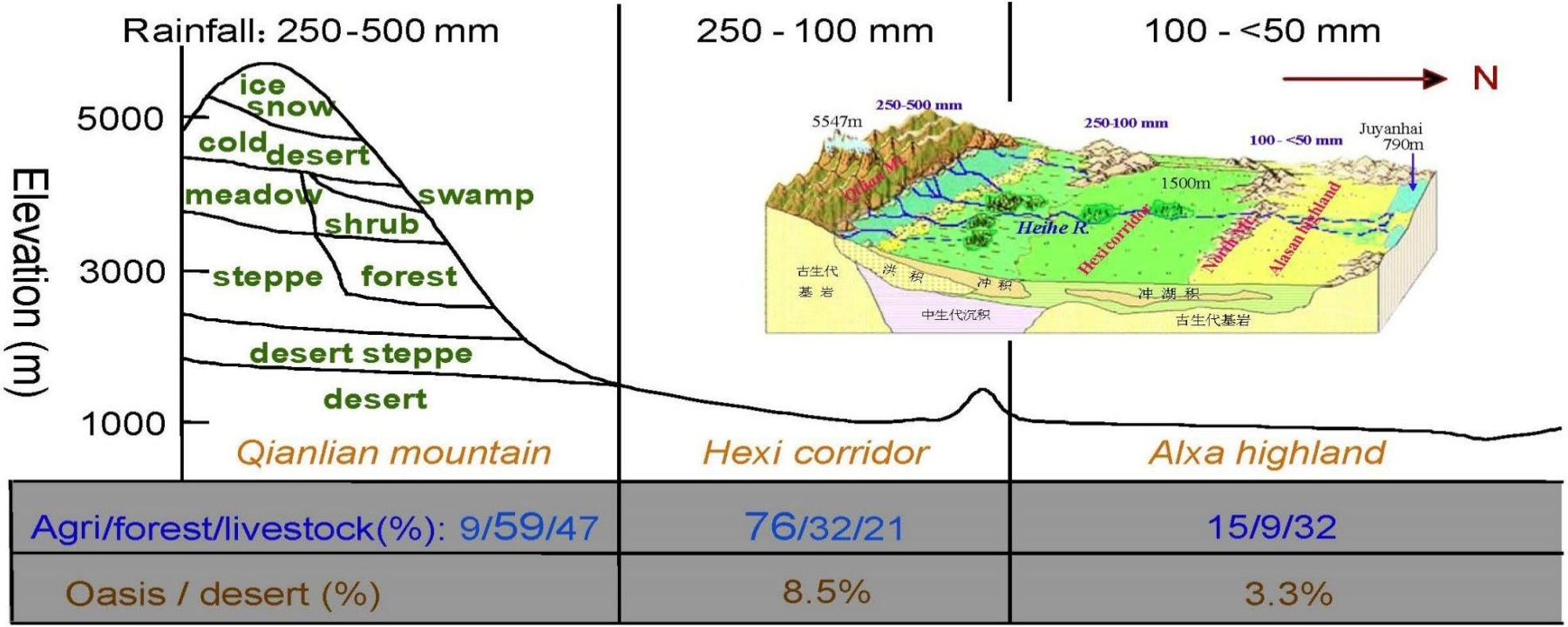
Gobi Desert

Main River Channel

Hexi Corridor Oases

Qilian Mountains

Landscape of Heihe River Basin



Agri/forest/livestock(%): 9/59/47	76/32/21	15/9/32
Oasis / desert (%)	8.5%	3.3%

Vertical profile in the mountains


Ejina Basin
Field
Study
Terminal Lake

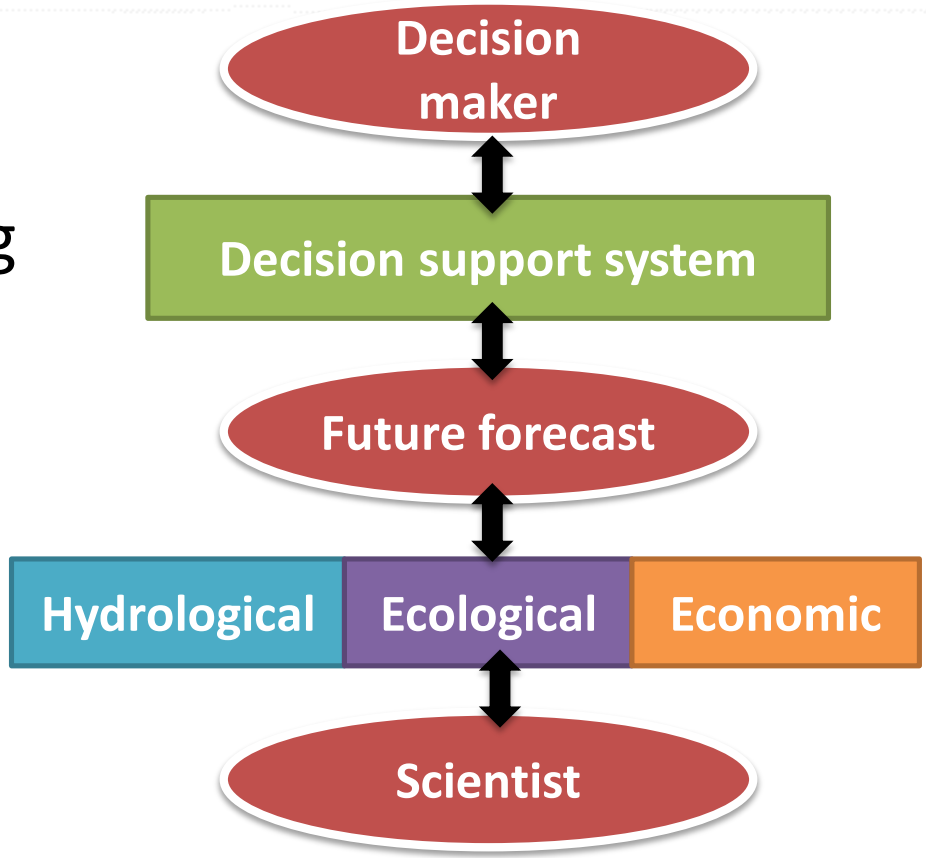
Heihe Research Program

- An on-going major research programme of National Natural Science Foundation of China (2011-2018)
- Conduct an integrative study of ecological and hydrologic processes in Heihe River Basin toward more sustainable water resources management
- Led by Prof. Cheng Guodong of Chinese Academy of Sciences and advised by an expert panel of multidisciplinary scientists
- 200 million RMB core funding (~32 million USD)

Overall Objectives

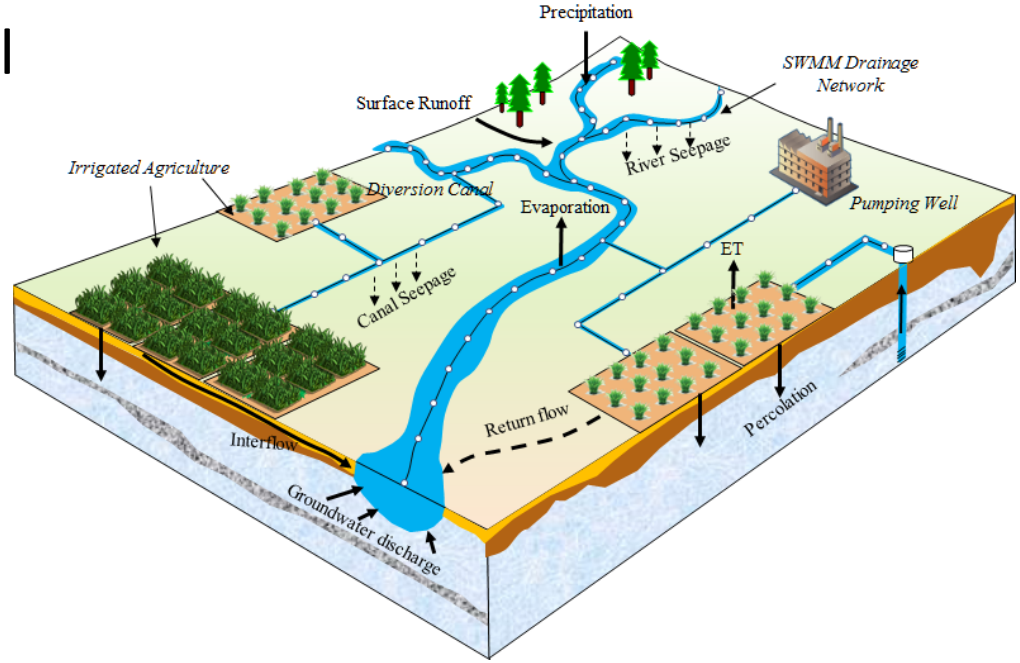
- Integrate observation, experimentation, and modeling
- Improve predictive capability
- Increase water use efficiency

Toward more sustainable water resources in arid ecosystems

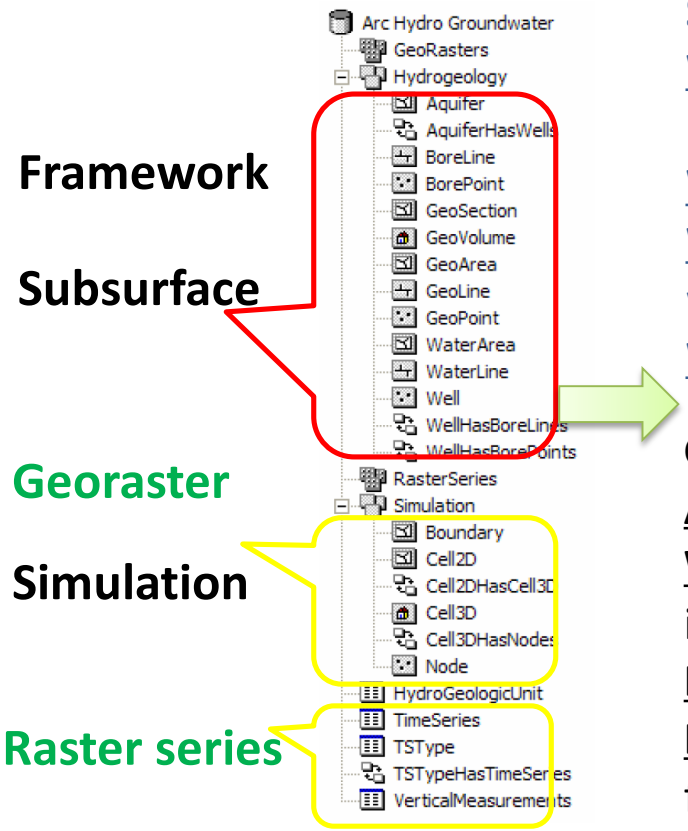


HEIFLOW (Hydrological-Ecological Integrated watershed-scale FLOW model)

- Physically-based distributed-parameter 3D numerical model
- Include all key components of the hydrological cycle
- 2D overland flow and river channel hydrodynamics
- Saturated/unsaturated zones
- 3D solute and heat transport
- Modules for agricultural crops and desert vegetation



Heihe River Basin Geodatabase



Surface water :(2-D)

Waterbody (Polygon feature class): lake, ponds, (swamps)

Waterline (Line feature class): streams, rivers

WaterPoint (Point feature class): springs, water withdrawal/discharge locations

Watershed (Polygen feature class): drainage areas

Groundwater: (2-D , 3-D)

Aquifer (Polygon feature class):confined and unconfined

Well (Point feature class): monitoring, water supply, and irrigation wells

Borehole (Boreholelog Table): vertical data

Boreline and BorePoint: 3D (z-enbled) line and point feature class

GeoArea, GeoPoint

“Digital Heihe” Datasets

DIGITAL RIVER BASIN

http://westdc.westgis.ac.cn/

Foundation data

DEM， Topographic, Hydrological map

Earth observation data

Landsat, ASTER, QuickBird——

Thematic data

Geology, Hydrology, Vegetation——

Observation data

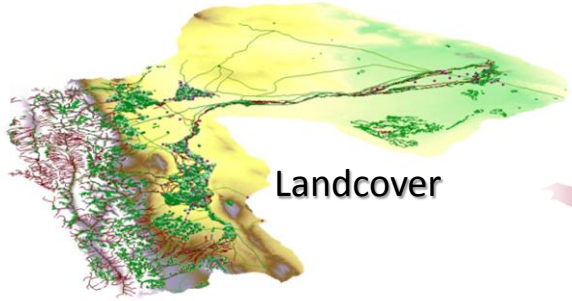
Meteorology、Hydrology、Groundwater——

Experimental data

Field Survey, test——

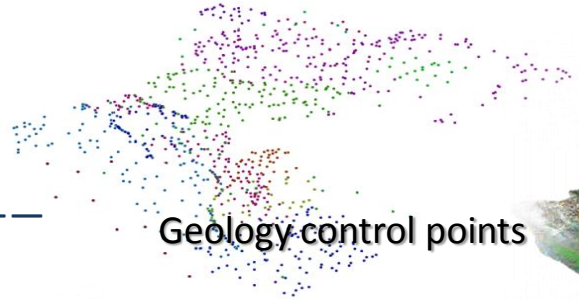
Model data

Radiation， Land assimilation， SWAT——

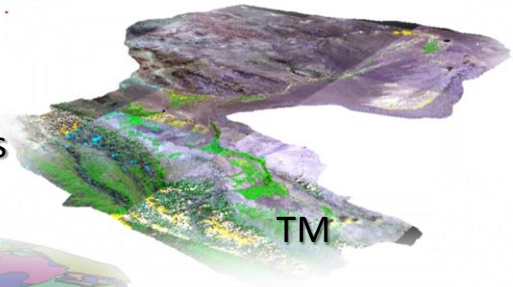


Landcover

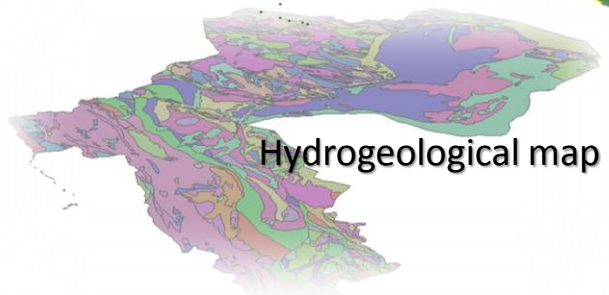
Aquifer



Geology control points

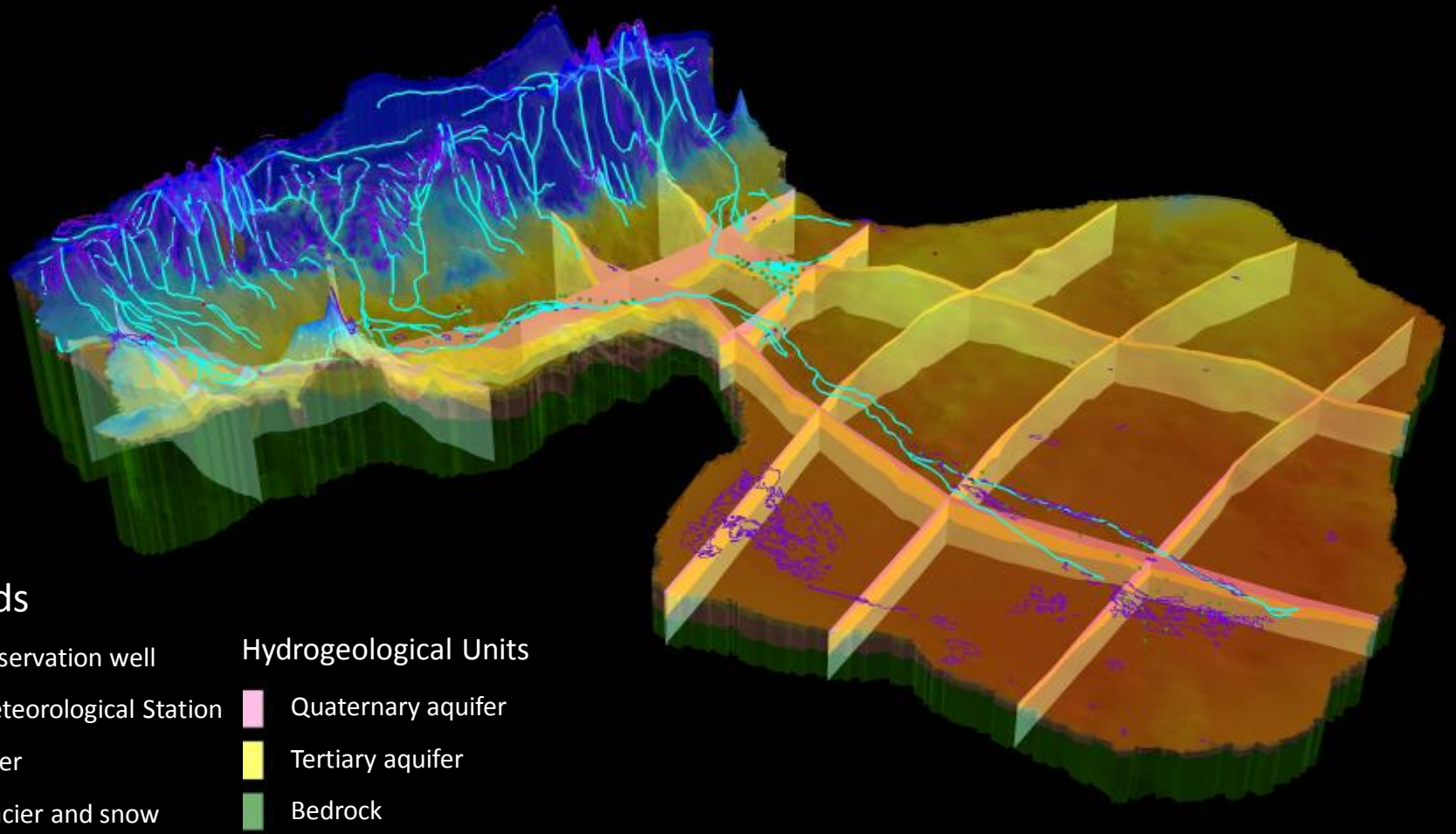


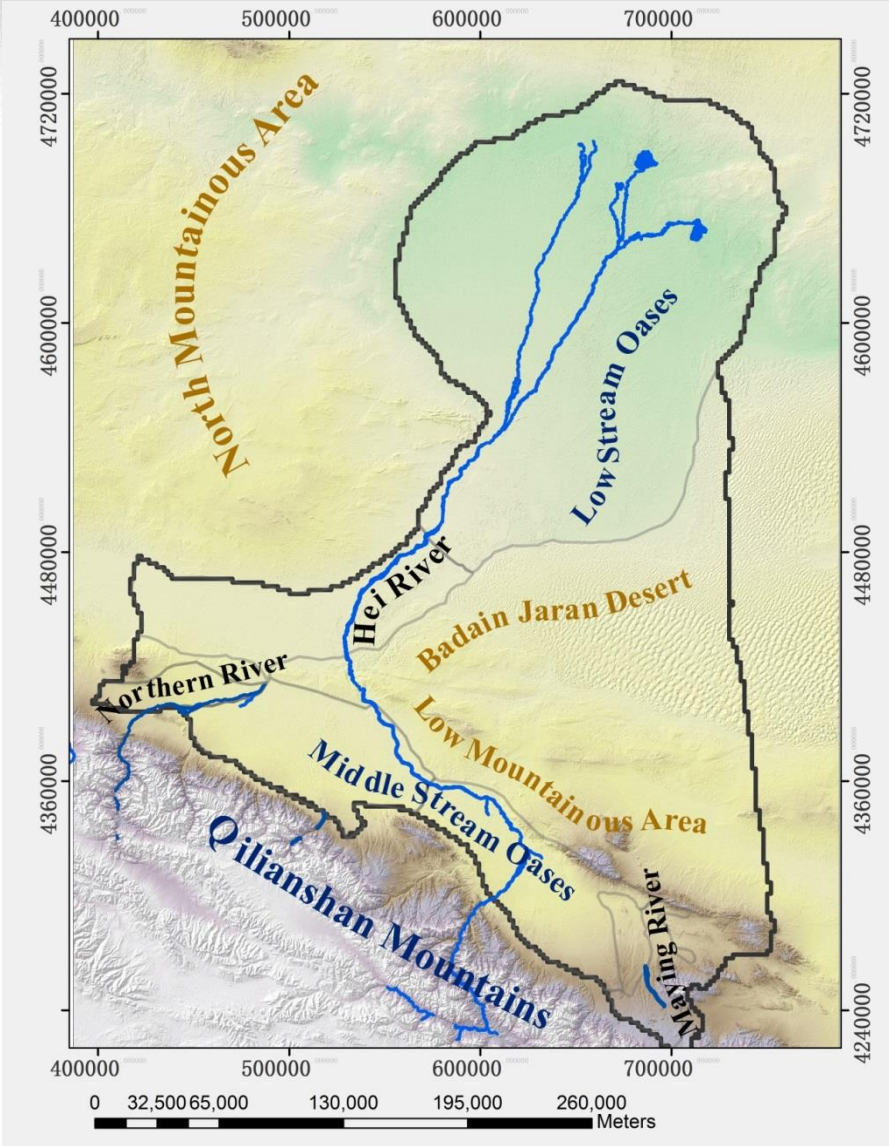
TM



Hydrogeological map

3D View of Subsurface with Cross Sections

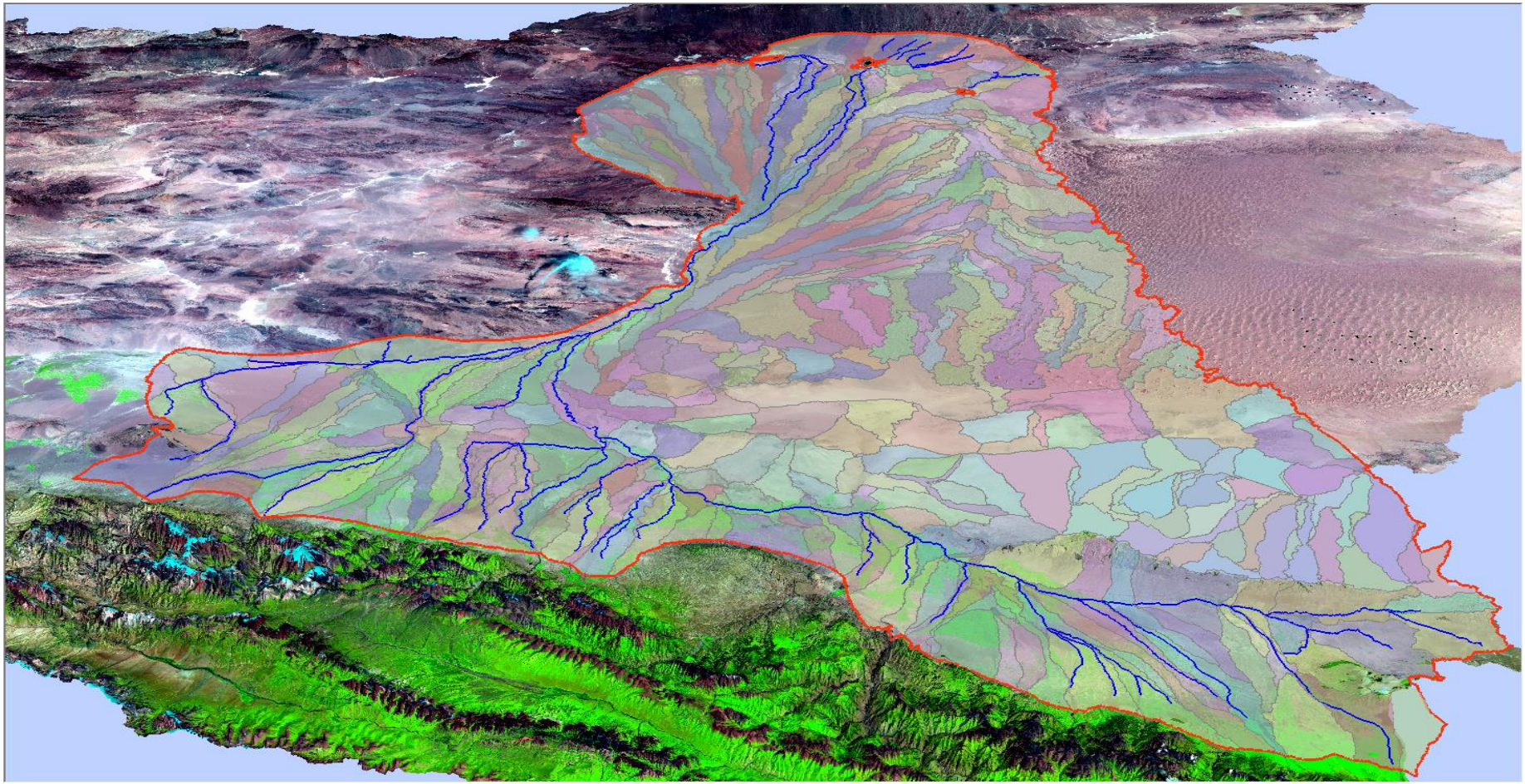




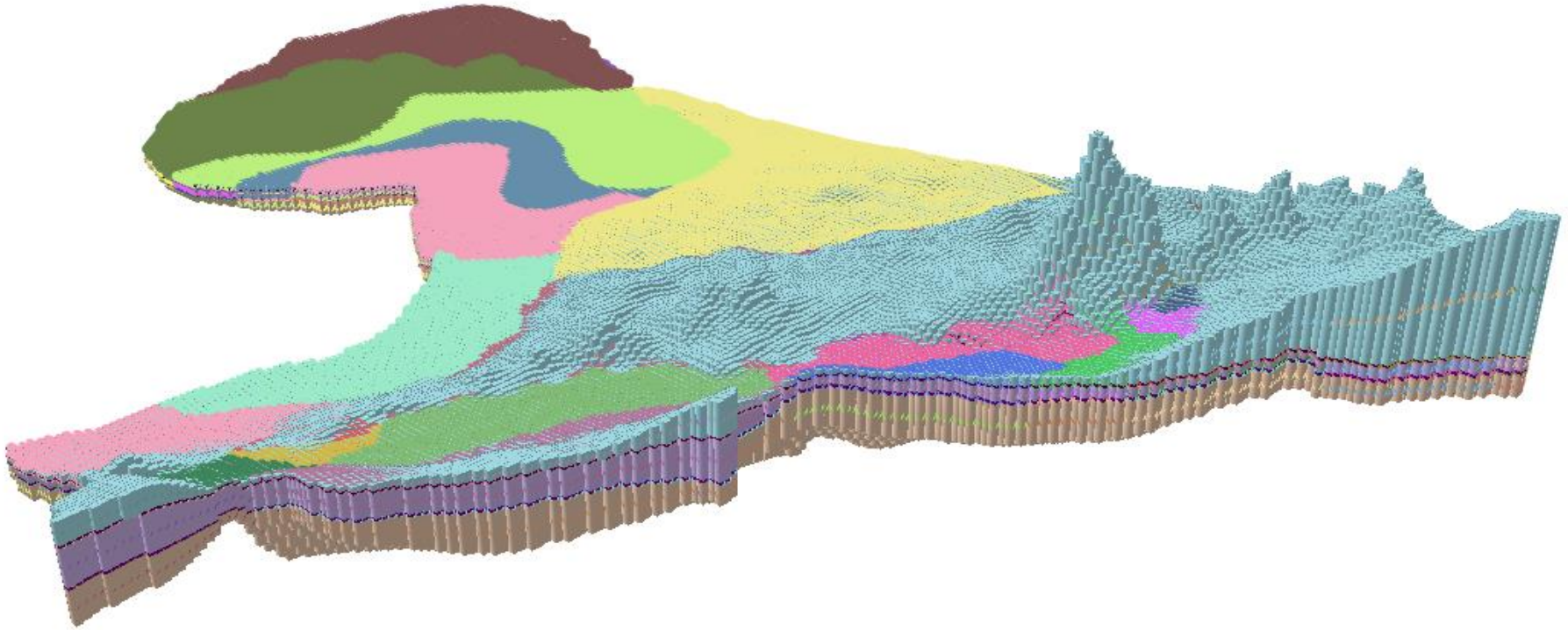
Middle & Lower Heihe River Basin Model Domain: ~100,000 km^2

Grid spacing:
1 km by 1 km
Rows: 548
Columns: 404
Layers: 5

Surface Water Model for Middle/Lower Heihe

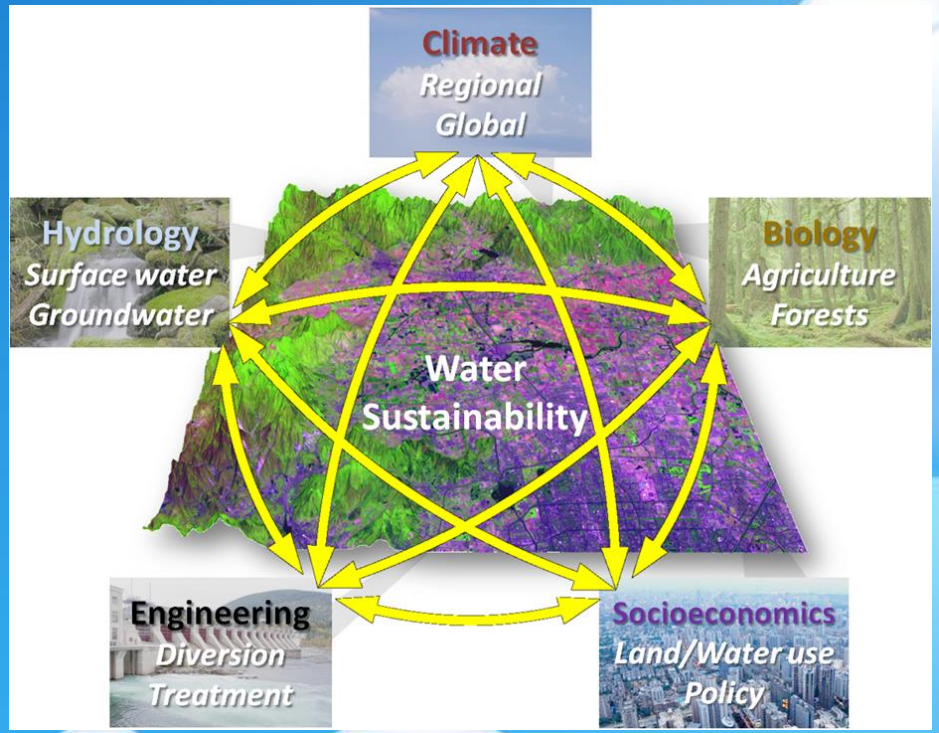


Discretization and Parameter Zonation for Subsurface Model



Layer 1	2	3	4	5
Unconfined aquifer	Aquitard 1	Shallow confined	Aquitard 2	Deep confined

HEIFLOW on the Cloud



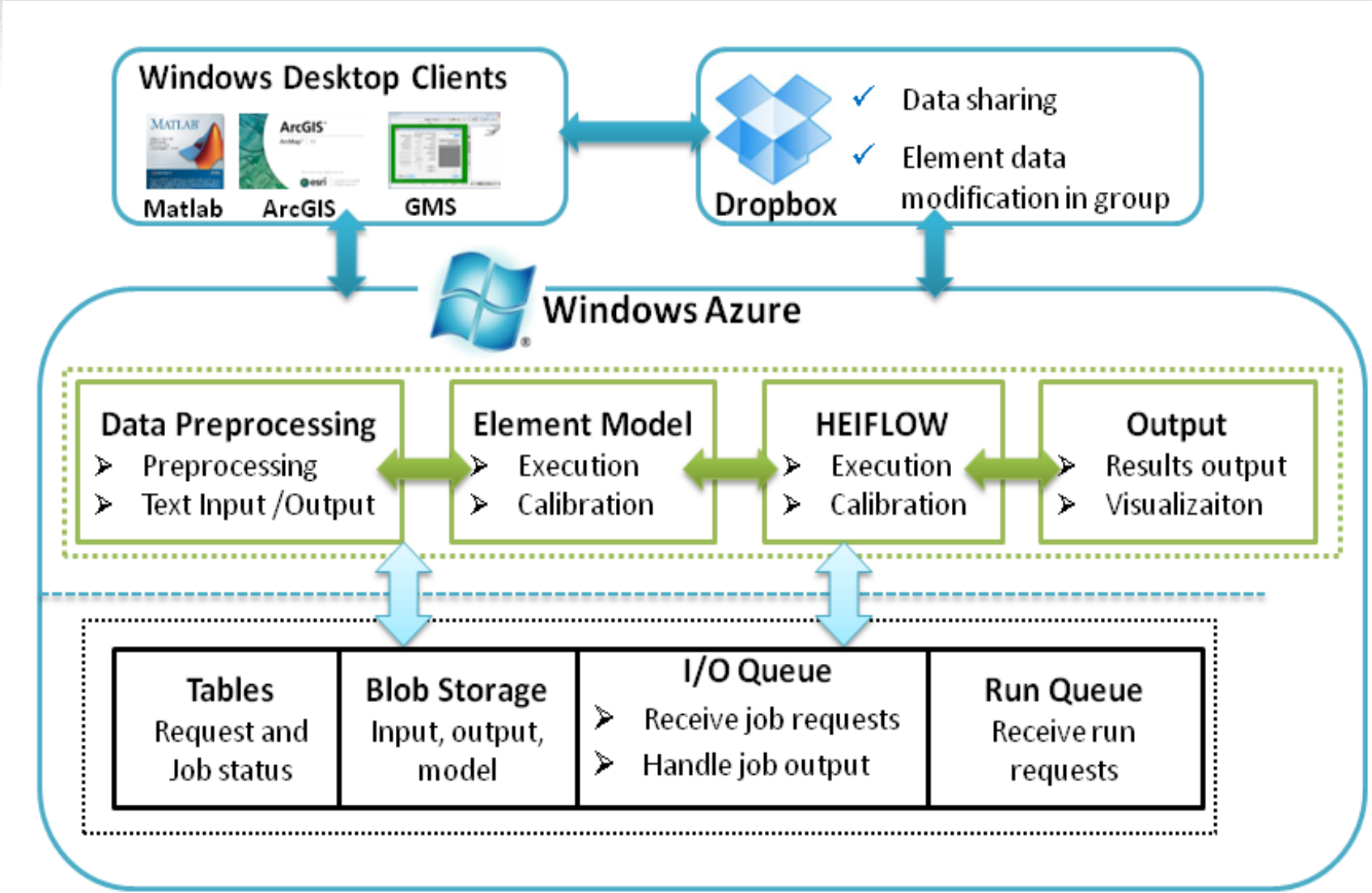
Conceptual Model

Model Execution

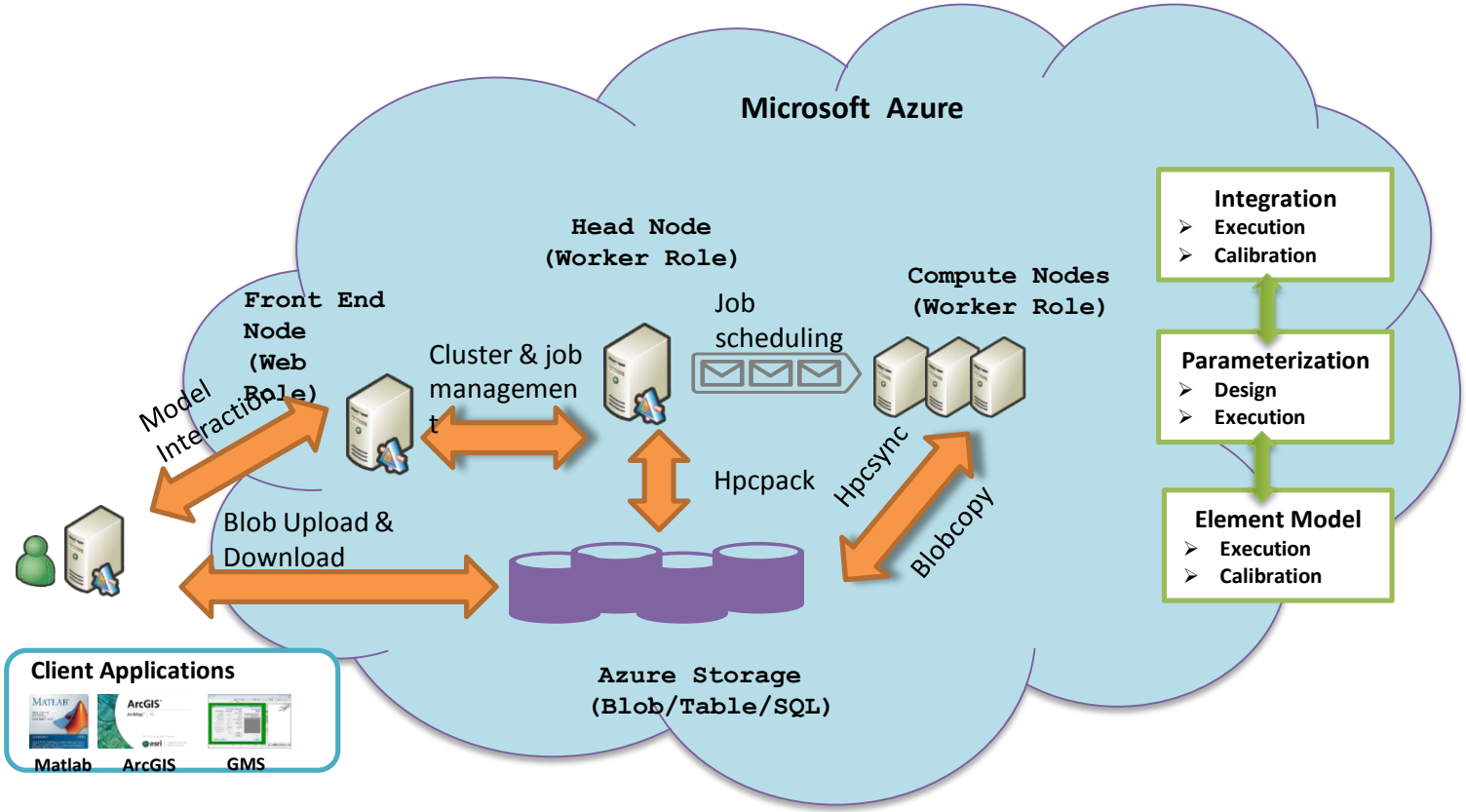
Model Calibration

Uncertainty Analysis

Optimized Decision

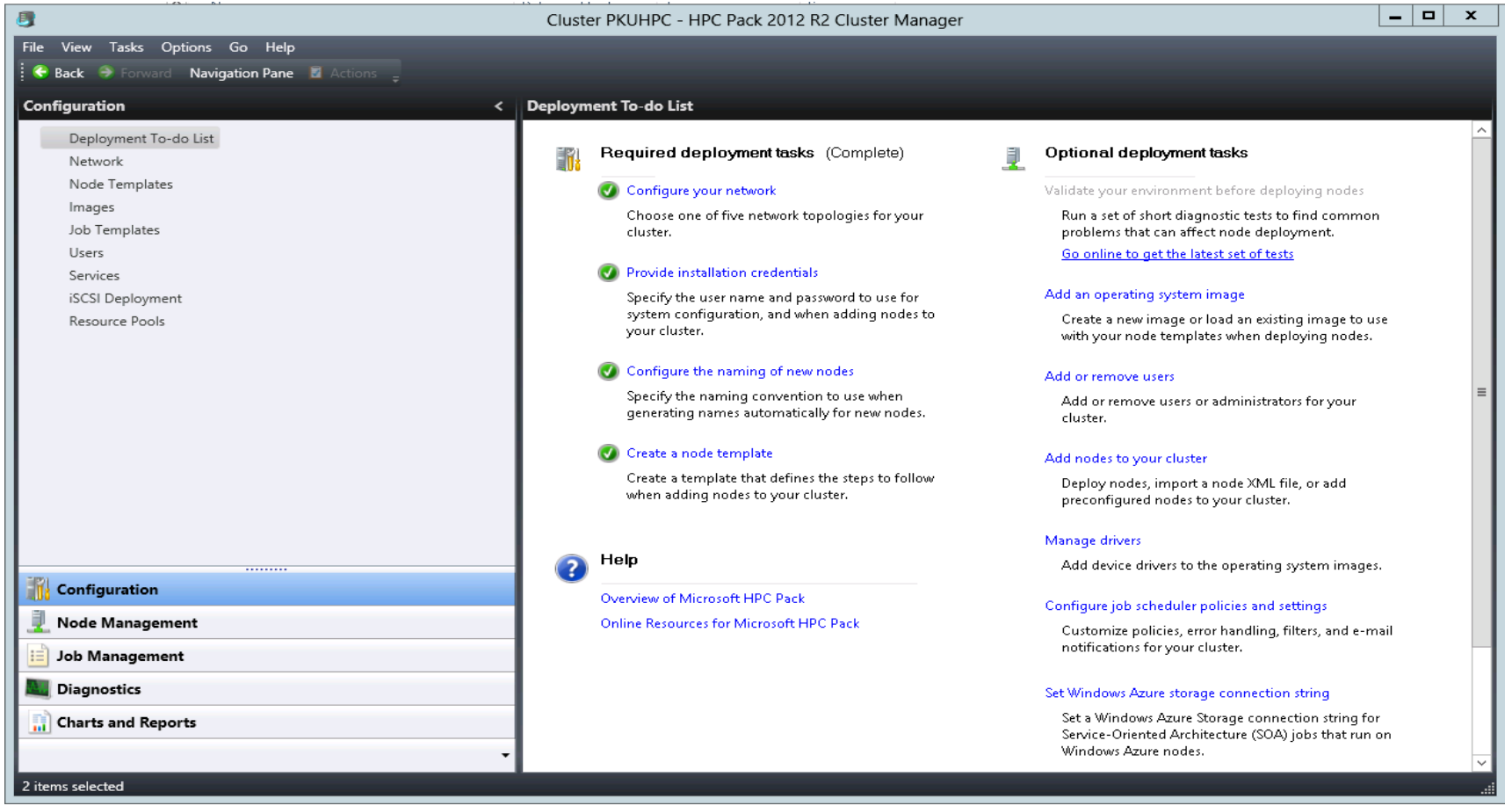

Windows Desktop Clients
Matlab
ArcGIS
GMS
Dropbox
Data sharing
Element data modification in group
Windows Azure
Data Preprocessing
Preprocessing
Text Input /Output
Element Model
Execution
Calibration
HEIFLOW
Execution
Calibration
Output
Results output
Visualizaiton
Tables
Request and Job status
Blob Storage
Input, output, model
I/O Queue
Receive job requests
Handle job output
Run Queue
Receive run requests

HPC on Microsoft Azure for ecohydrological modeling



Deployment of HPC on Azure for ecohydrological modeling

Installing HPC → Managing Nodes → Uploading Model → Verification → Application



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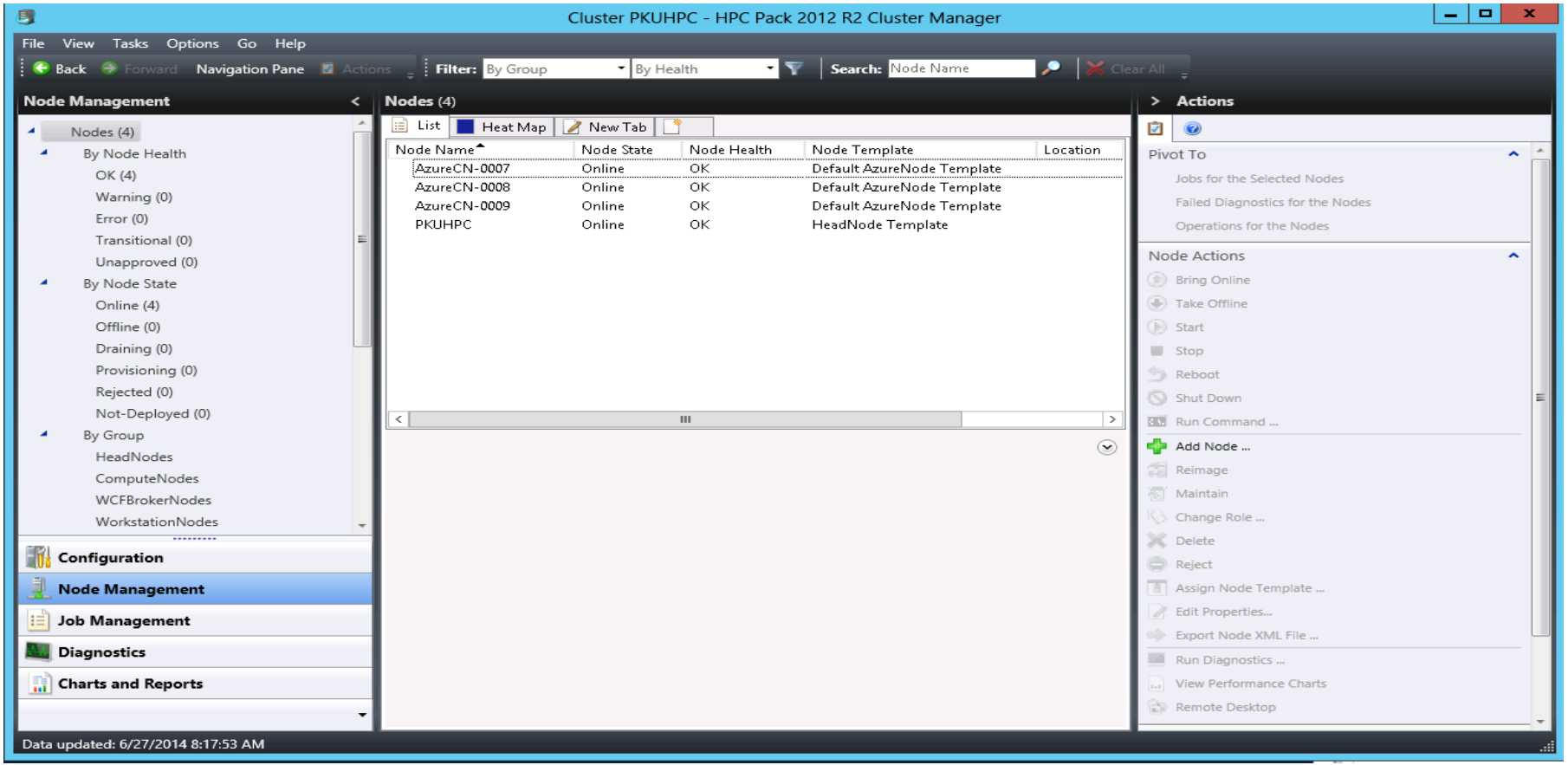

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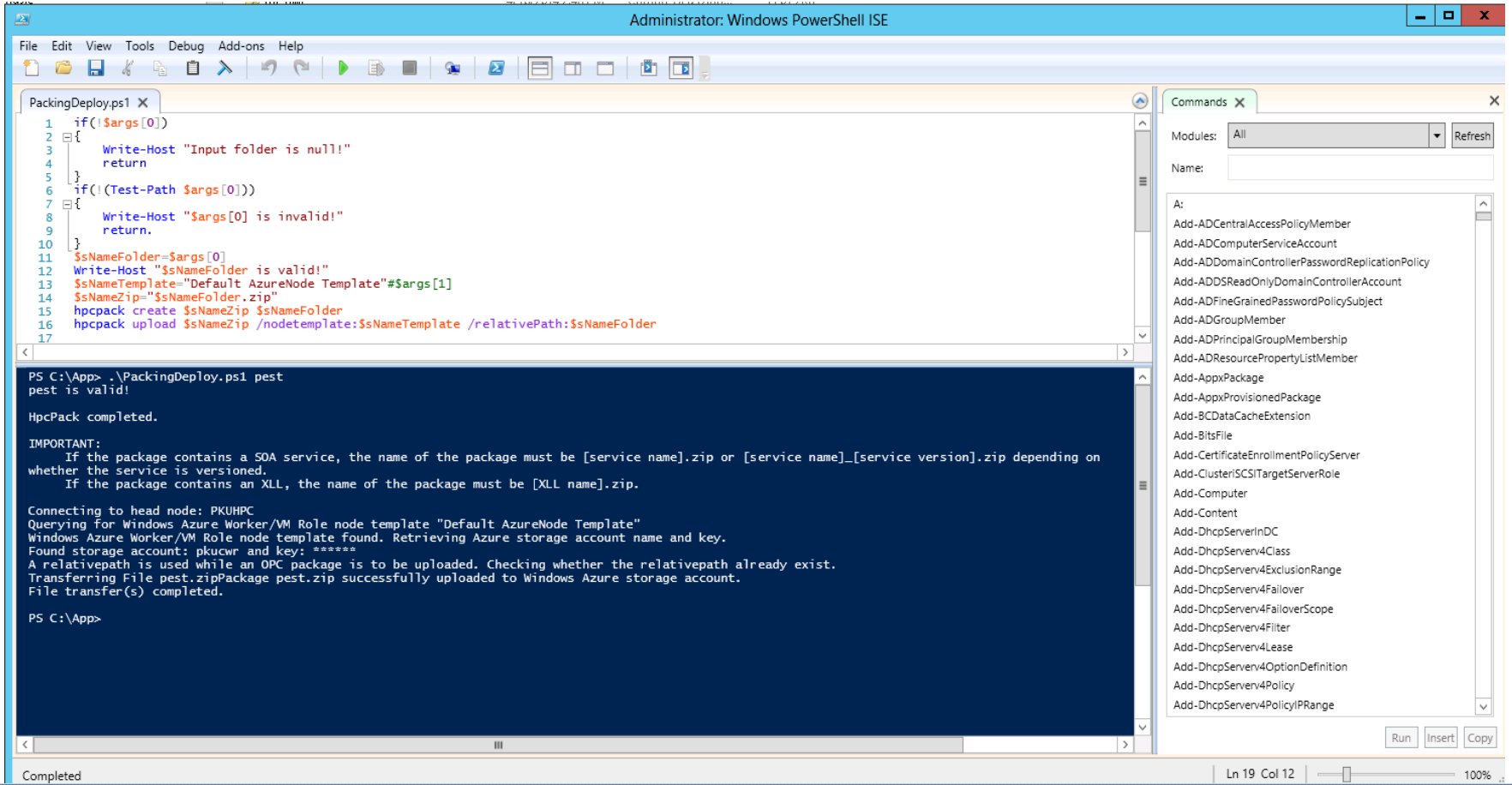

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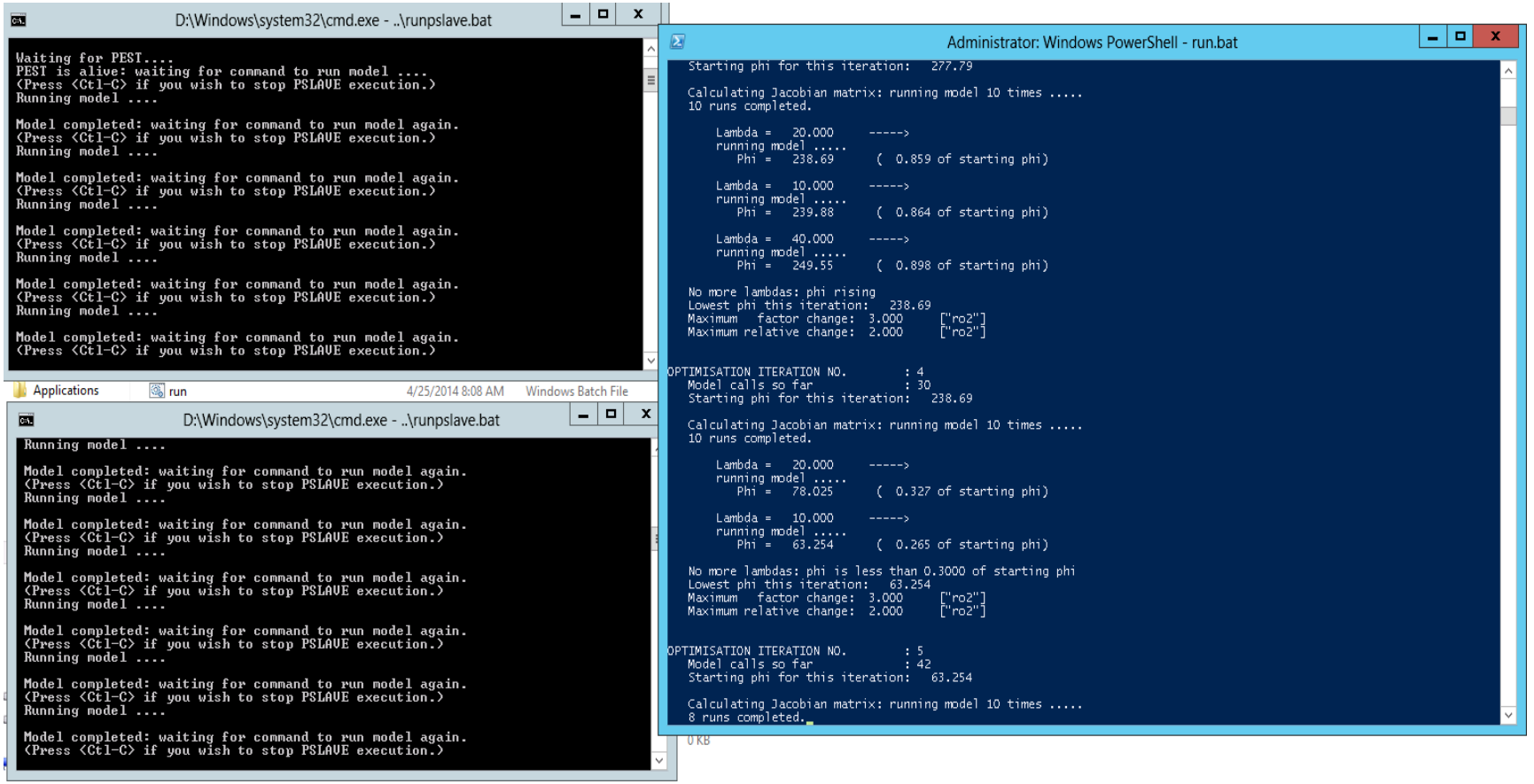

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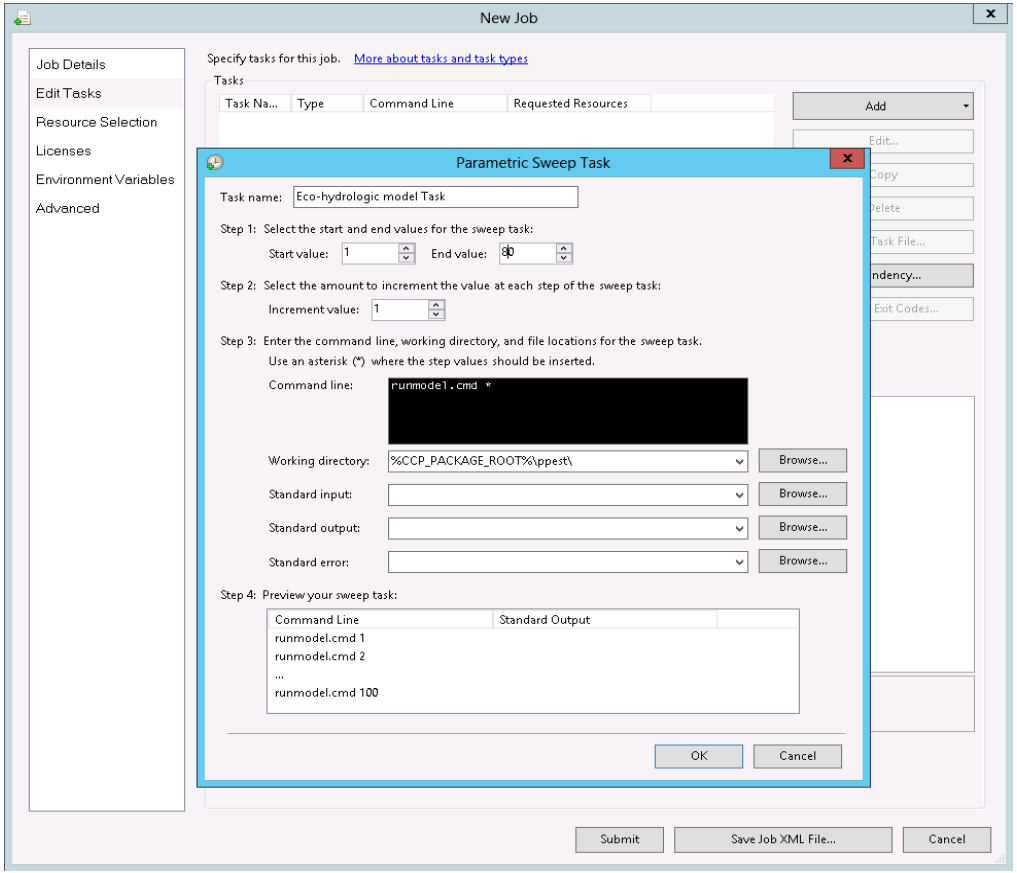
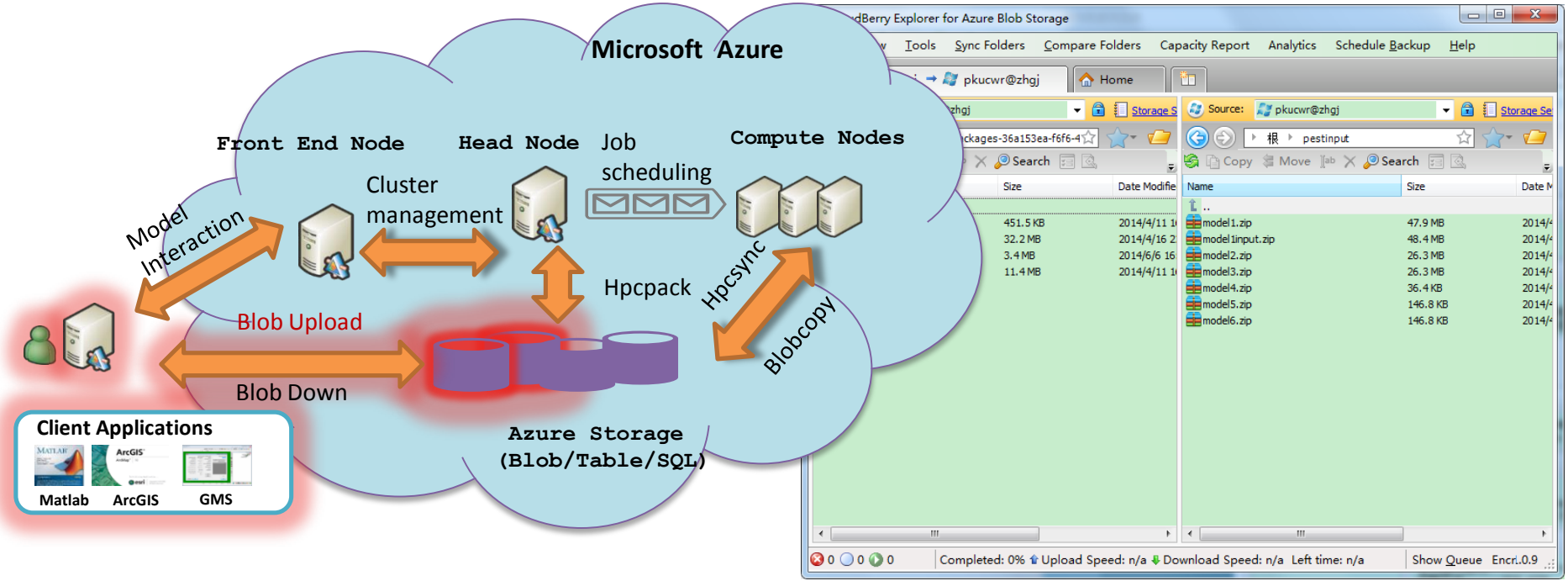


Ecohydrological model execution in HPC on Azure

Data Preparing & Uploading → **Job Submitting** → **Status Monitoring** → **Result Getting**



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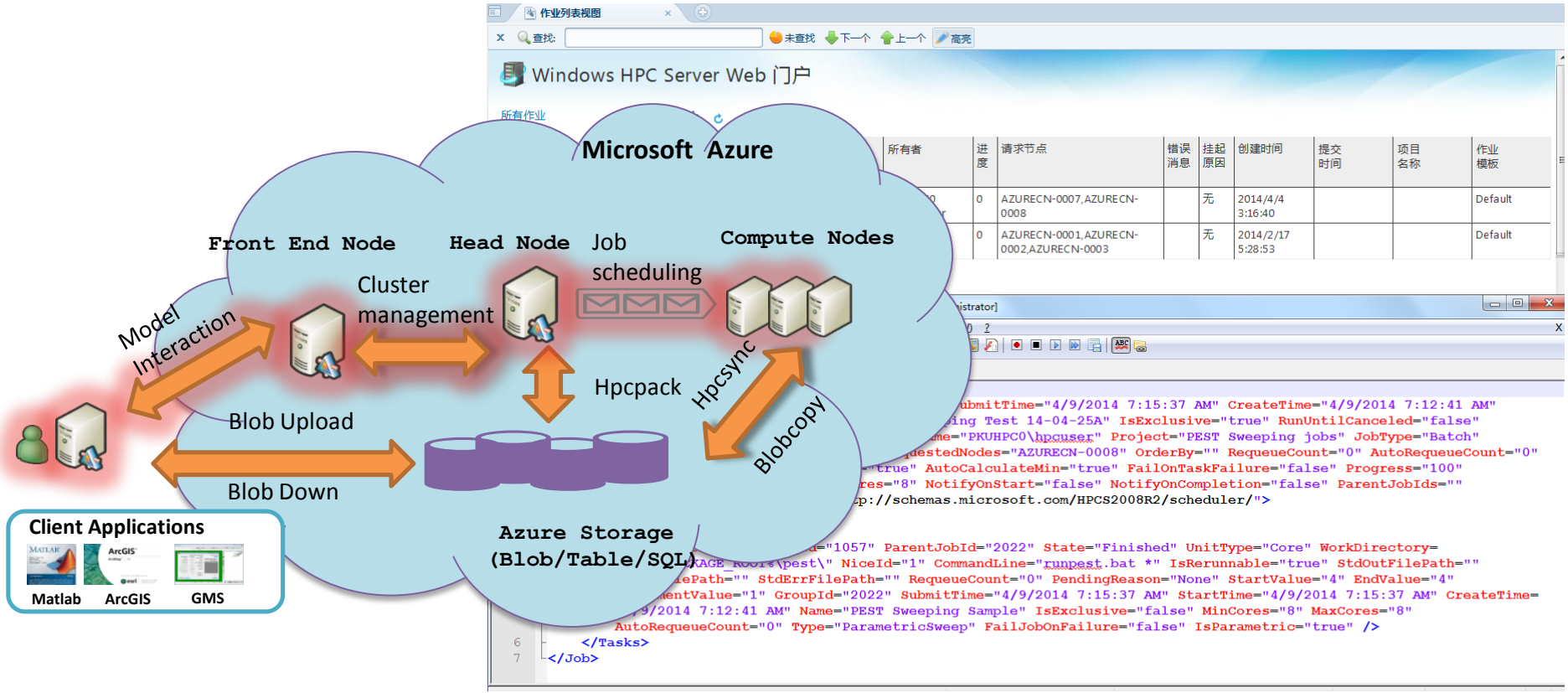

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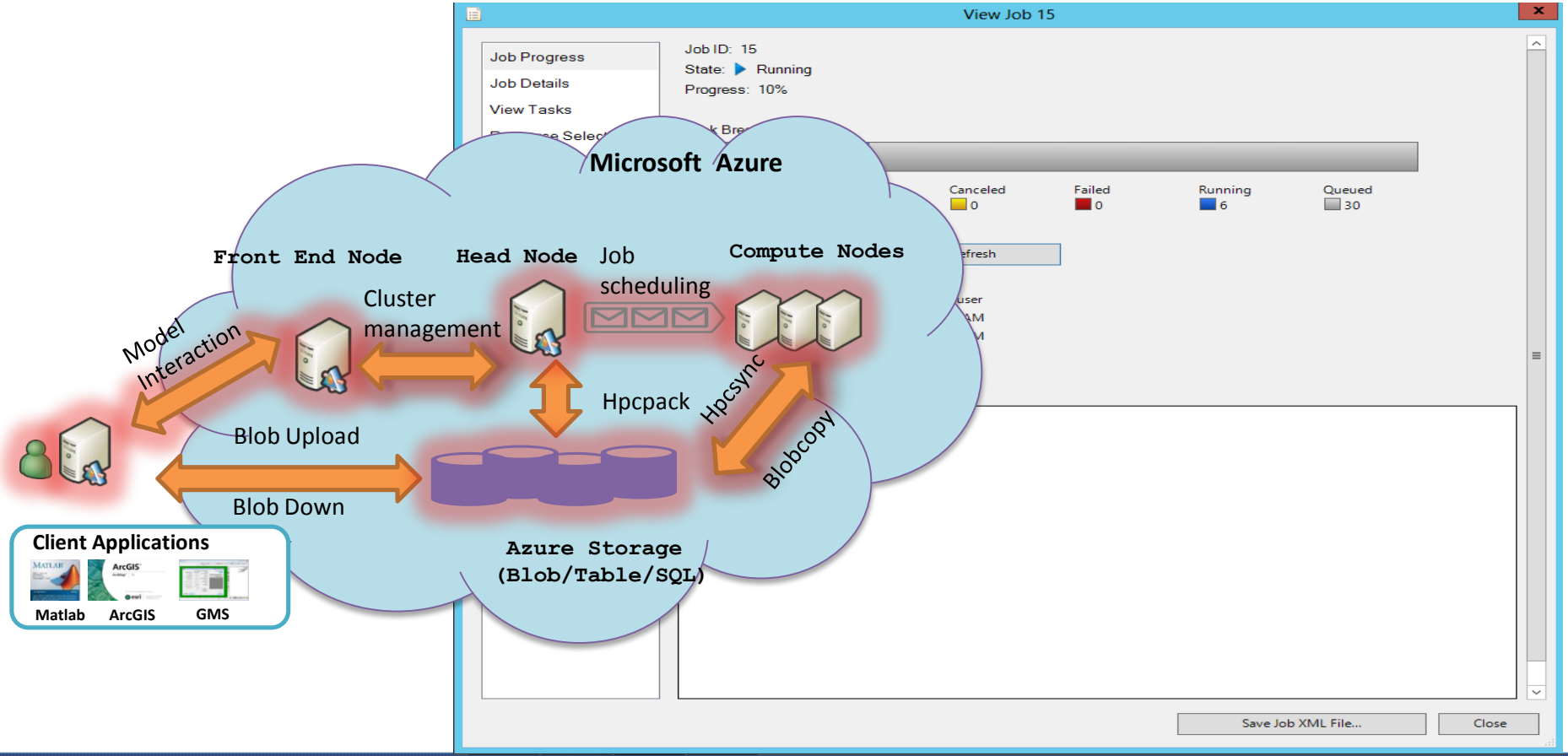

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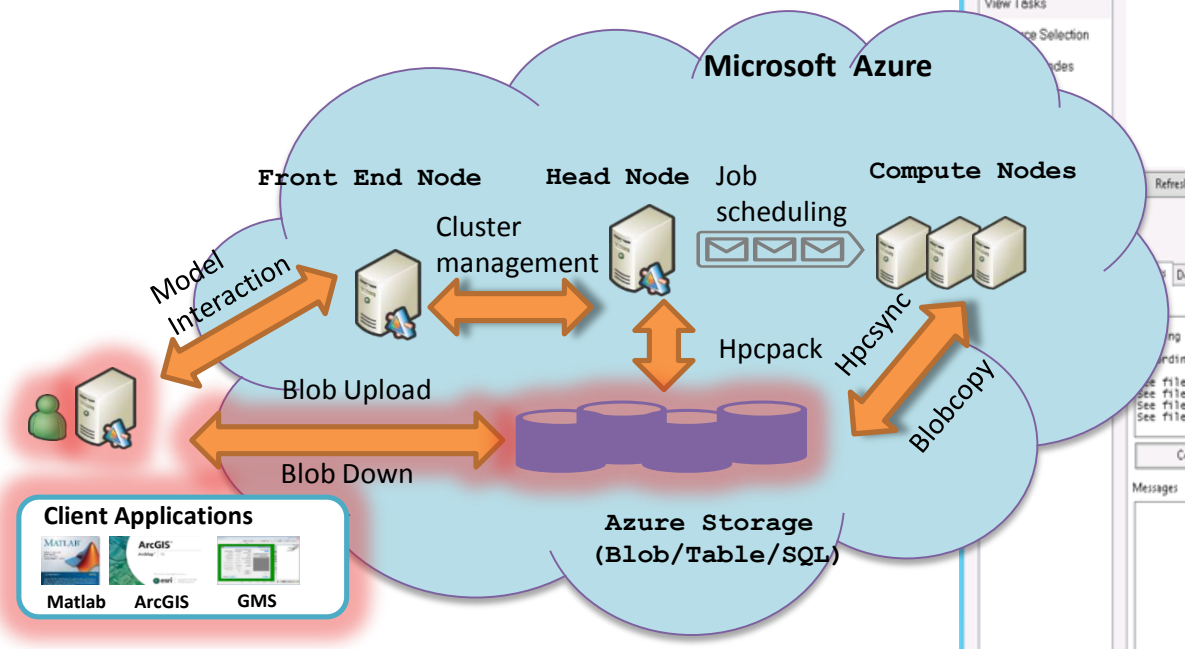
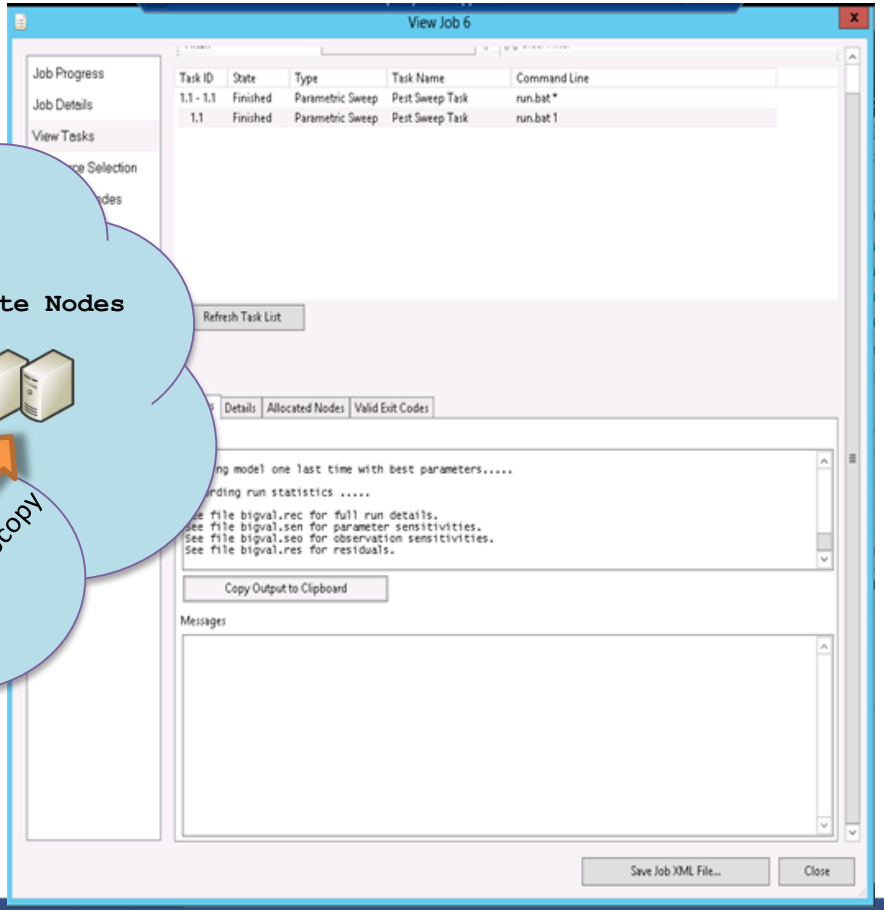
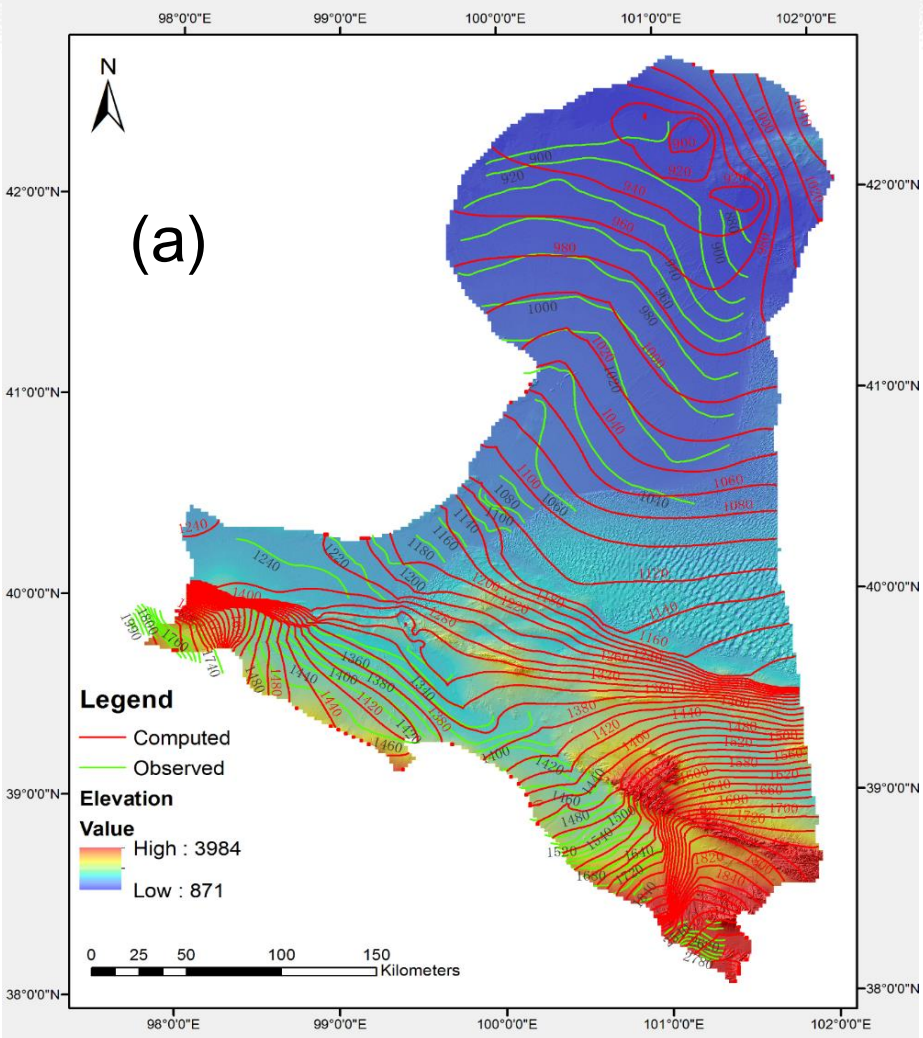
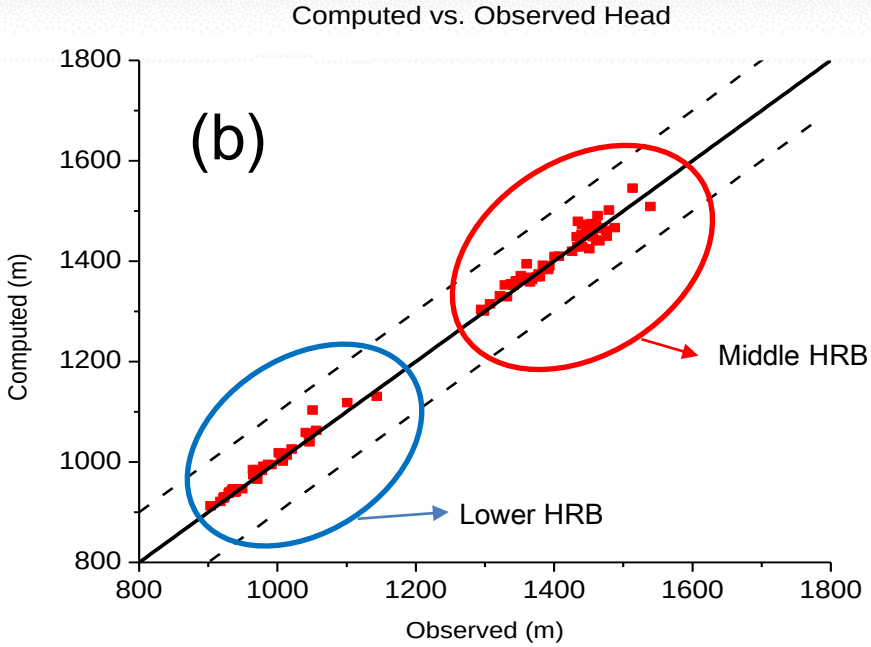






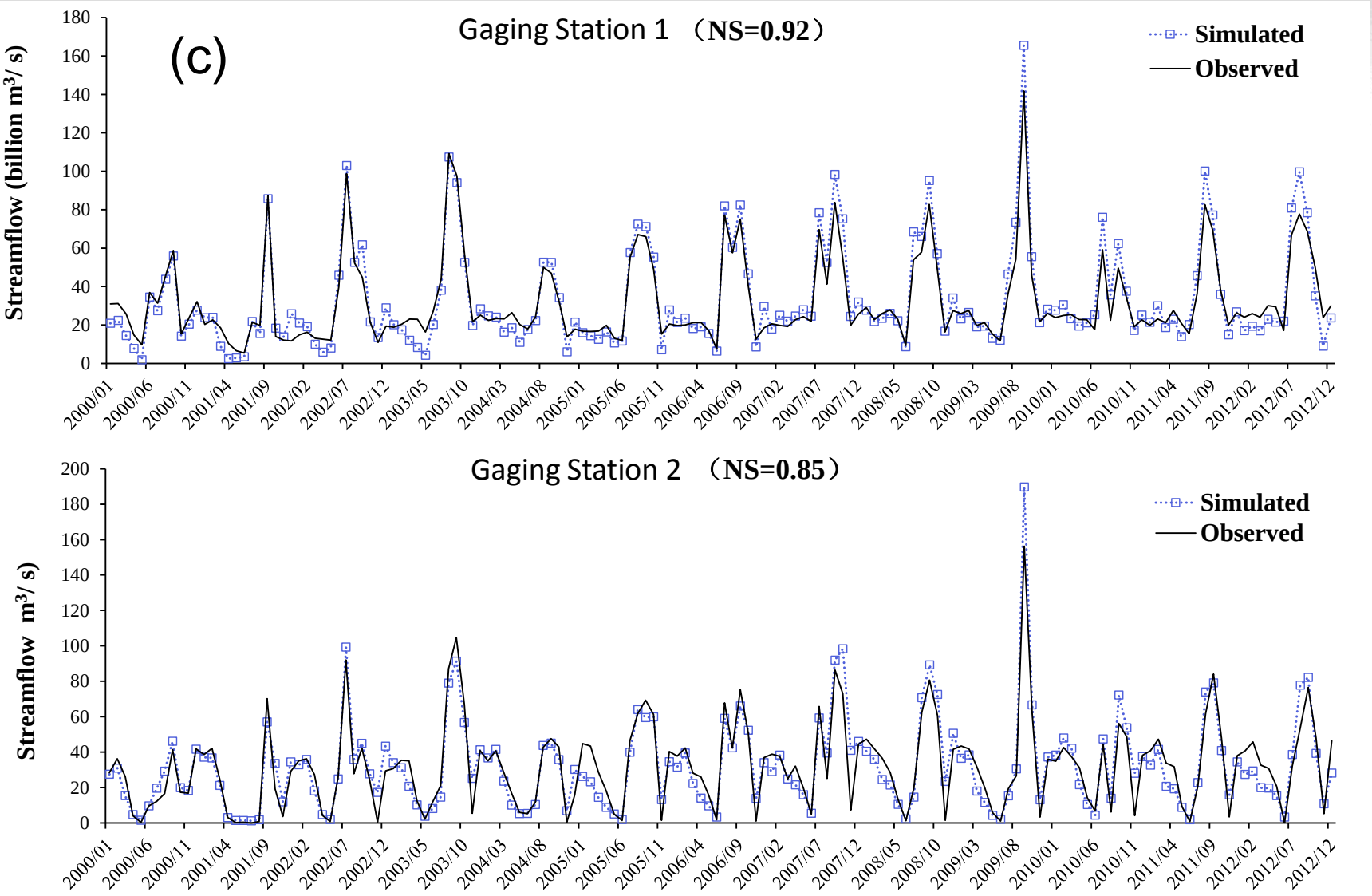


Model Calibration:

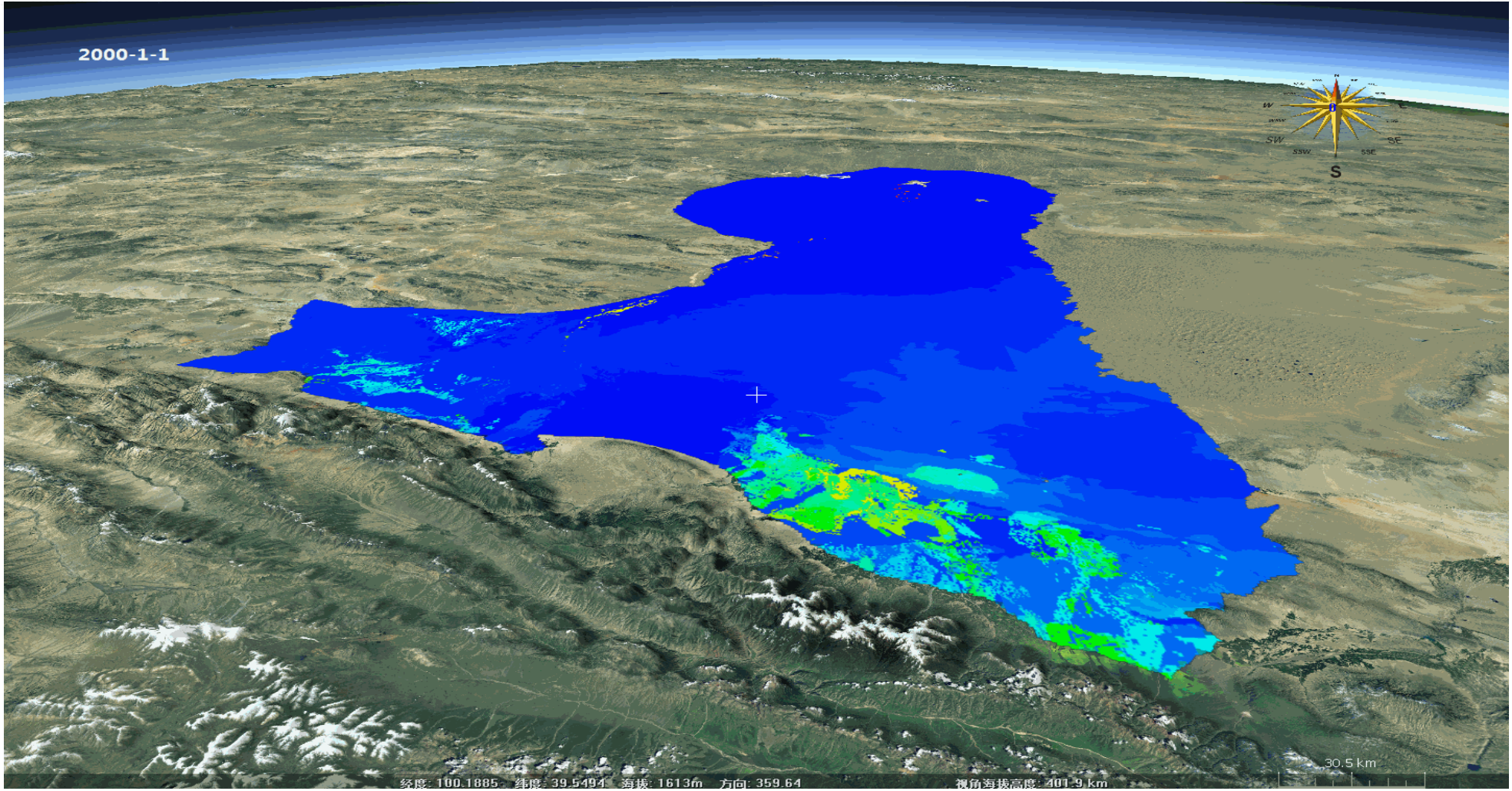
(a) Comparison between contour maps of computed and observed groundwater levels;

(b) Comparison between computed and observed heads at monitoring wells;

(c) Comparison of computed and observed streamflows and evapotranspiration


(c)
Gaging Station 1 （NS=0.92）
Simulated
Observed
Streamflow (billion m³/ s)
Gaging Station 2 （NS=0.85）
Simulated
Observed
Streamflow m³/ s)

Simulated Evapotranspiration Dynamic Patterns (2000)



Element Model - **Calibration**

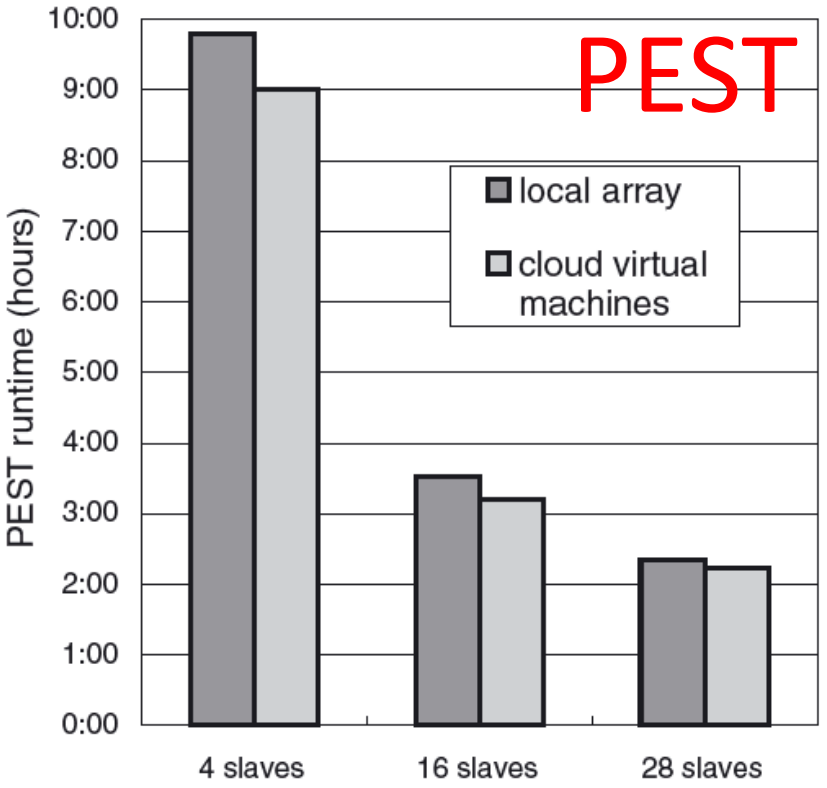
Table 1
Comparison of Runtimes of One Model Run

Computer	Time (s)
Q6700 Core 2 Quad (2.66 GHz)	85
GoGrid Cloud virtual machine	81
Xeon (3.0 GHz)	73
Q9650 Core 2 Quad (3.0 GHz)	71
i7 (3.33 GHz)	58

ground water
Rapid Communication/

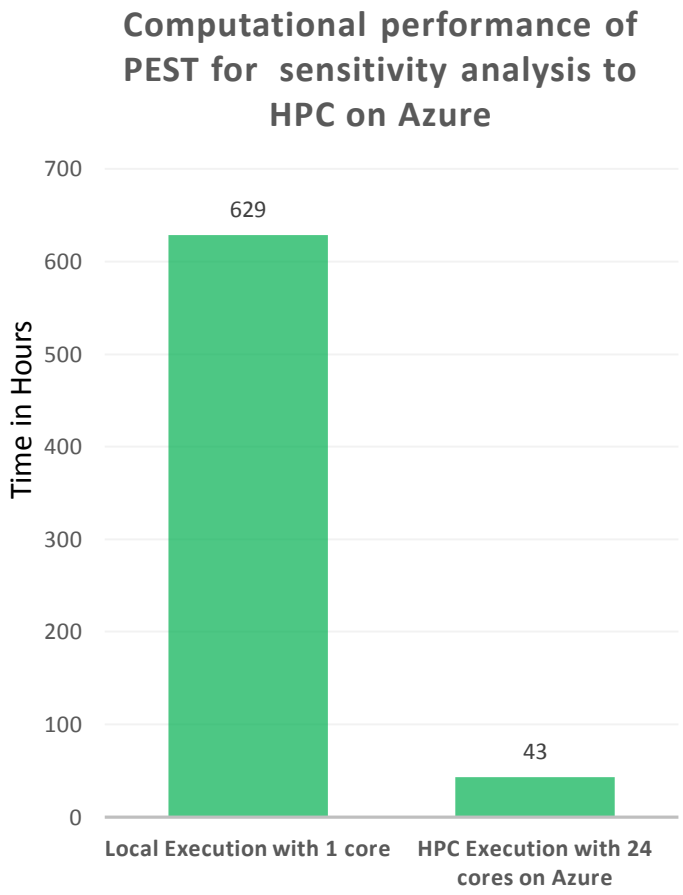
Using a Cloud to Replenish Parched Groundwater Modeling Efforts

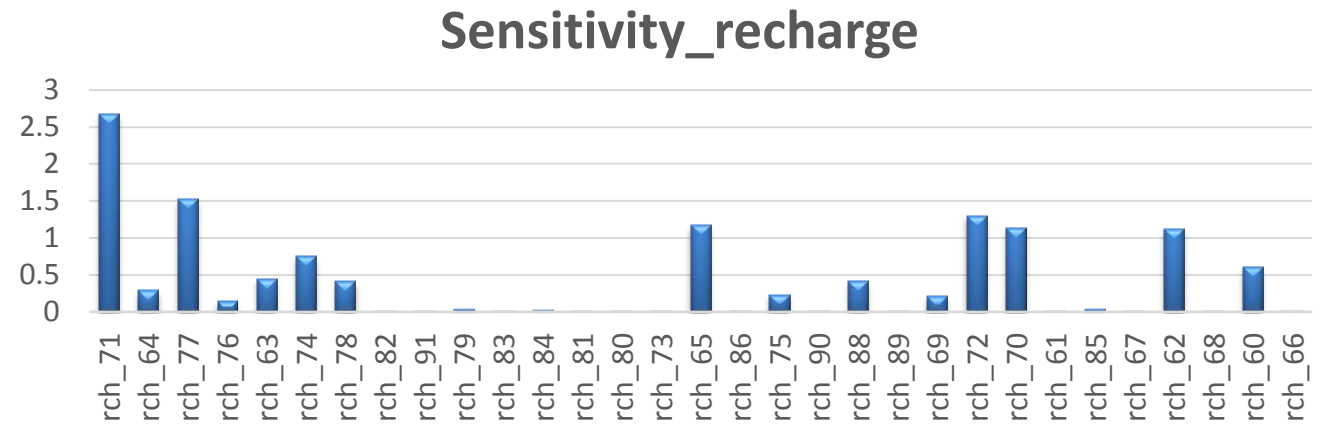
by Randall J. Hunt[1], Joseph Luchette[2], Willem A. Schreuder[3], James O. Rumbaugh[4], John Doherty[5,6], Matthew J. Tonkin[7], and Douglas B. Rumbaugh[4]

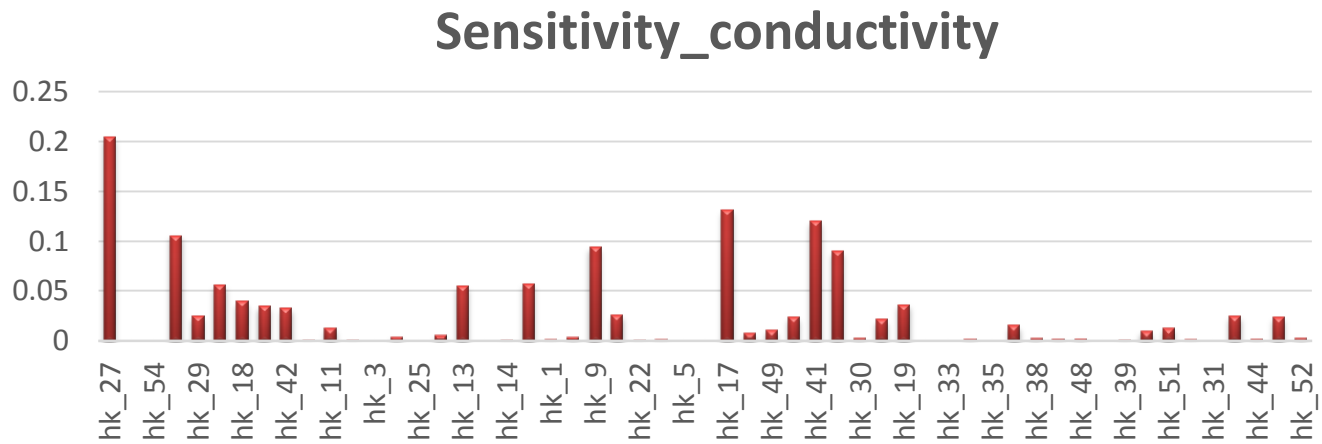


Comparison of parameter estimation runtimes obtained from a dedicated local desktop array and virtual machines run on the cloud

Results of sensitivity analysis on Cloud

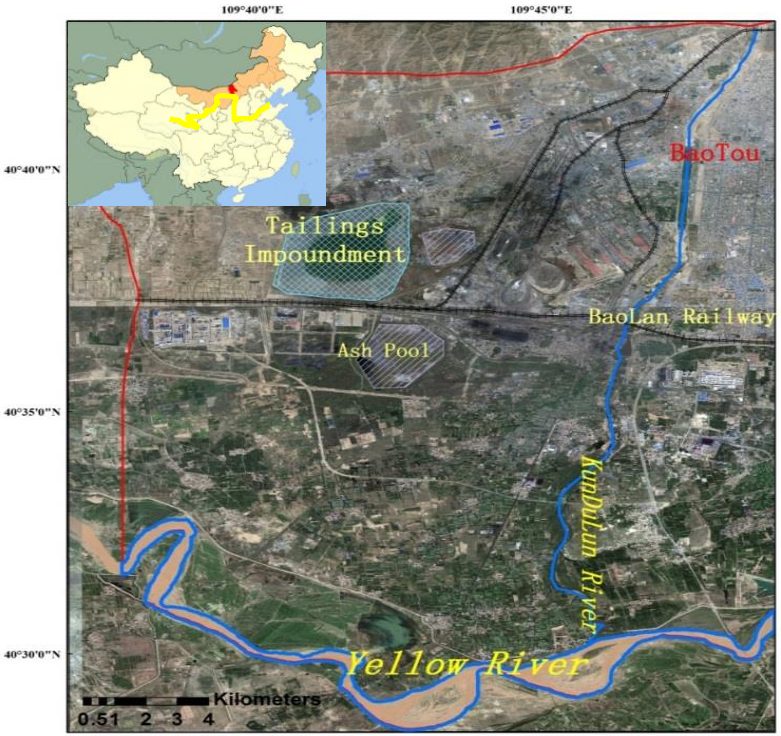




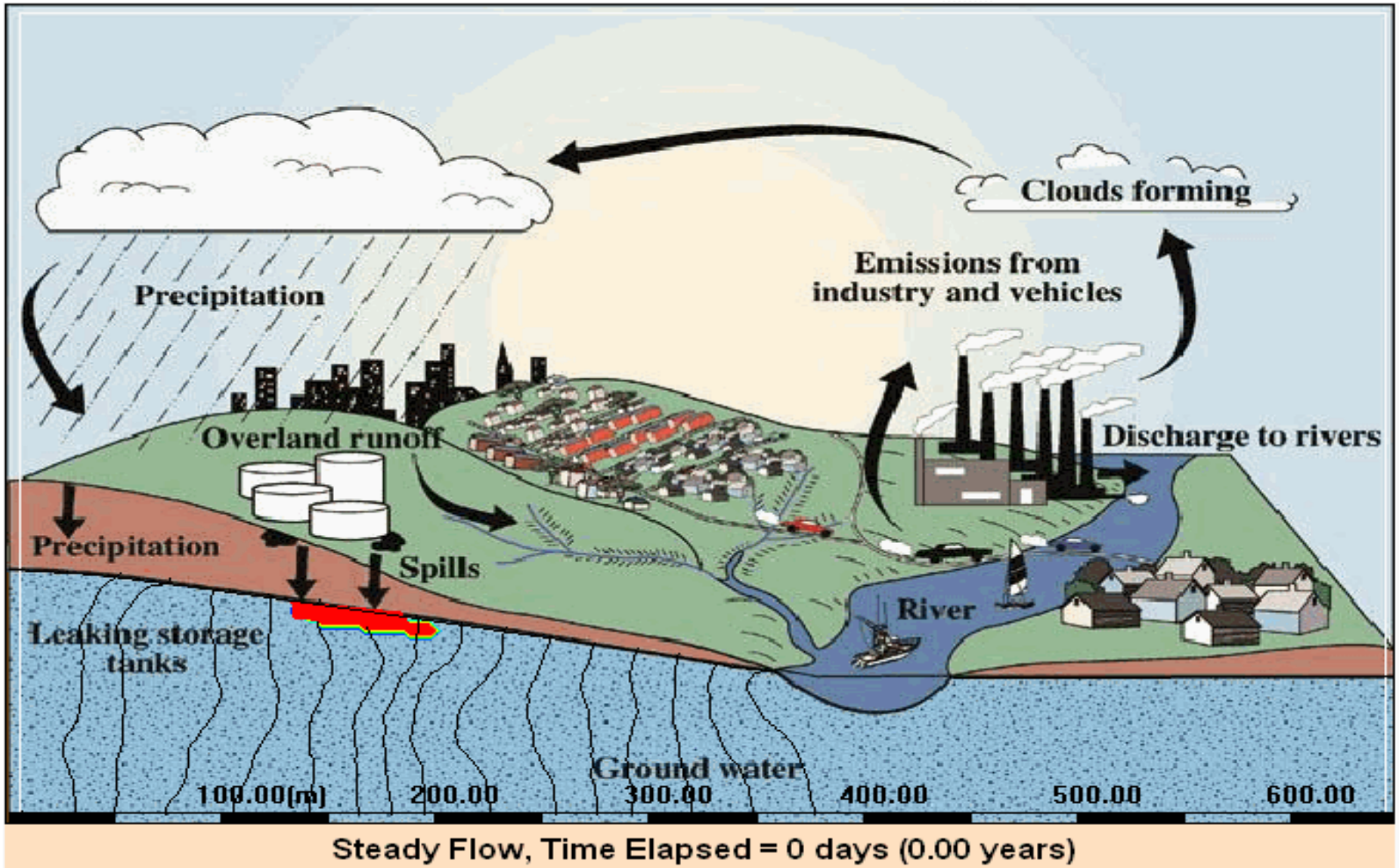


Case Study 2:
Thorium Reactive Transport Modeling

- Baotou tailings pond, one of the largest tailings in China piled above ground surfaces.
- Most productive “secondary mines”, approximately 11 floors high!
- Of greatest concern is the potential for radioactive pollution of the Yellow River nearby which is the primary water source for 150 million people.



Modeling Contaminant Transport and Remediation



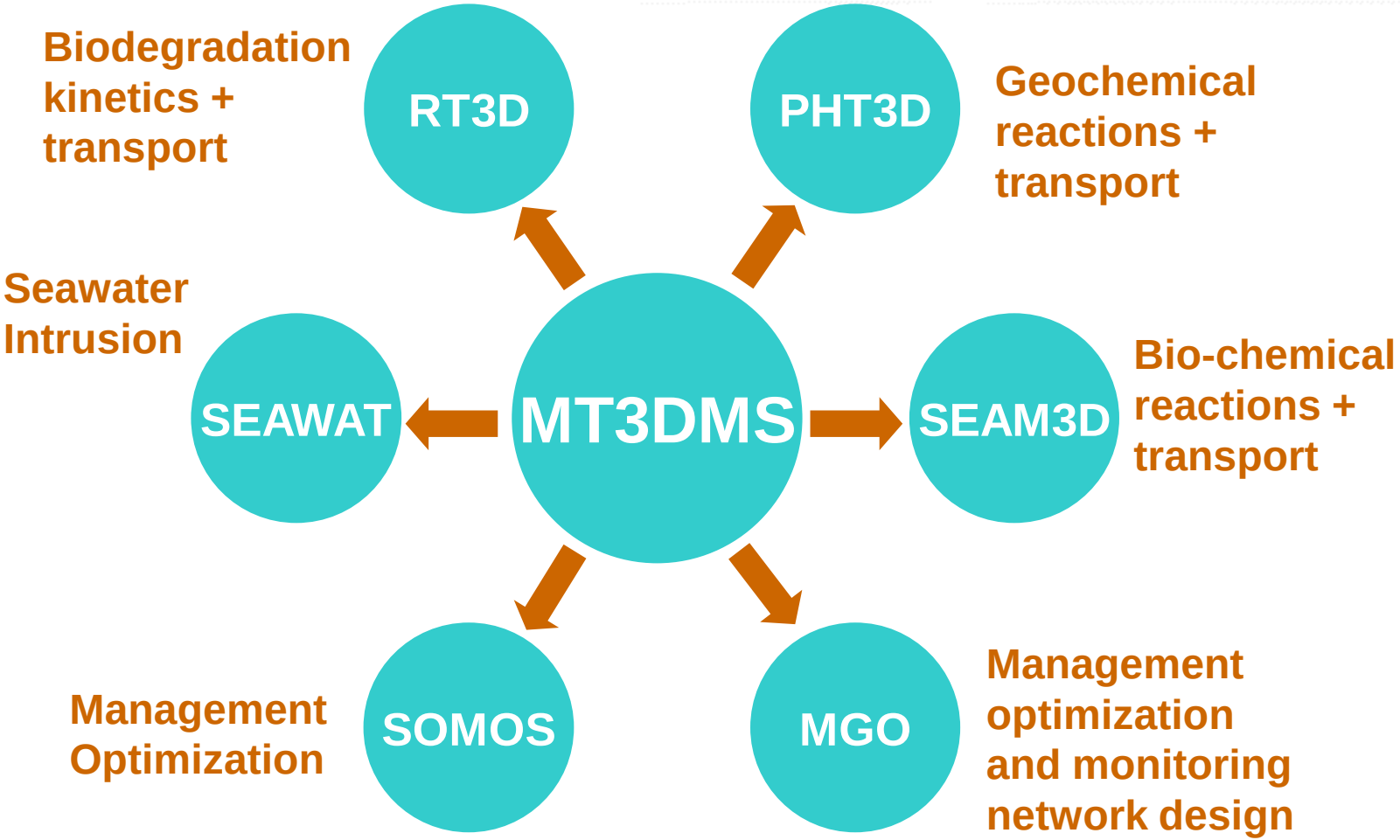
Zheng 1990
Zheng and Wang 1999
Zheng 2010
Zheng et al. 2013

MT3DMS

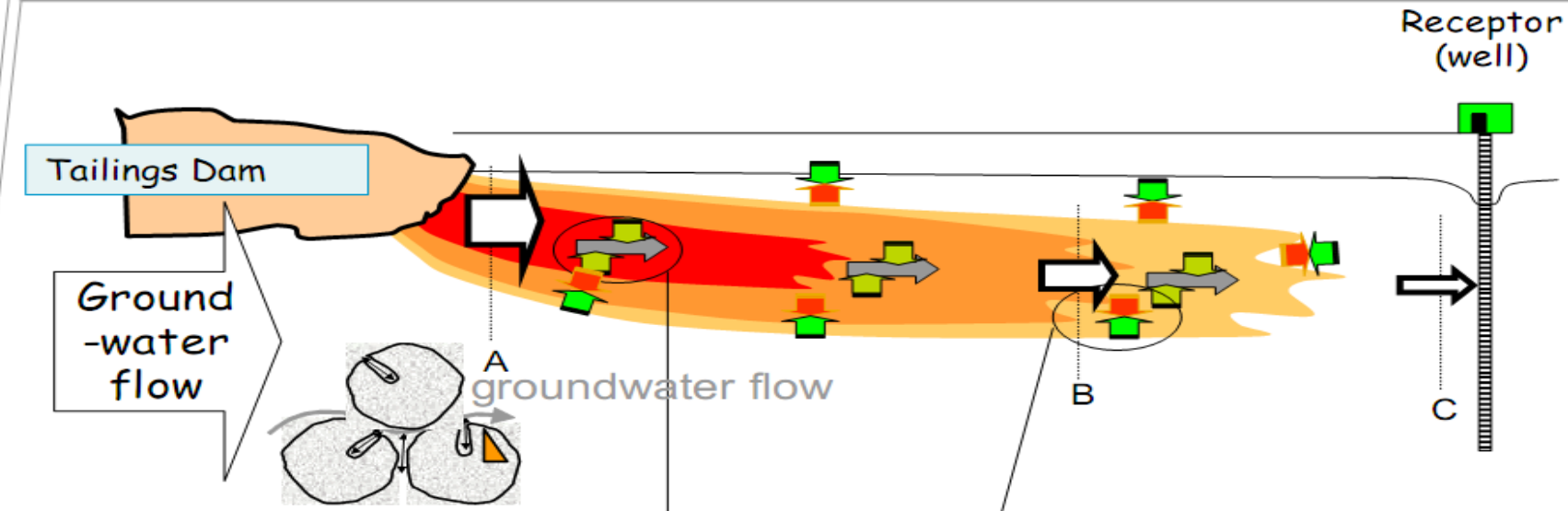
A Modular 3-D Multi-Species Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems

A reactive multicomponent transport model for saturated porous media

MT3DMS-Based Transport Modeling Tools



Conceptual model for acidic leachate attenuation



Plume core:

Mineral dissolution/precipitation,

Sorption, Ion exchange

Plume fringe:

Transverse mixing

Two major attenuation mechanisms:
Dilution and Reaction

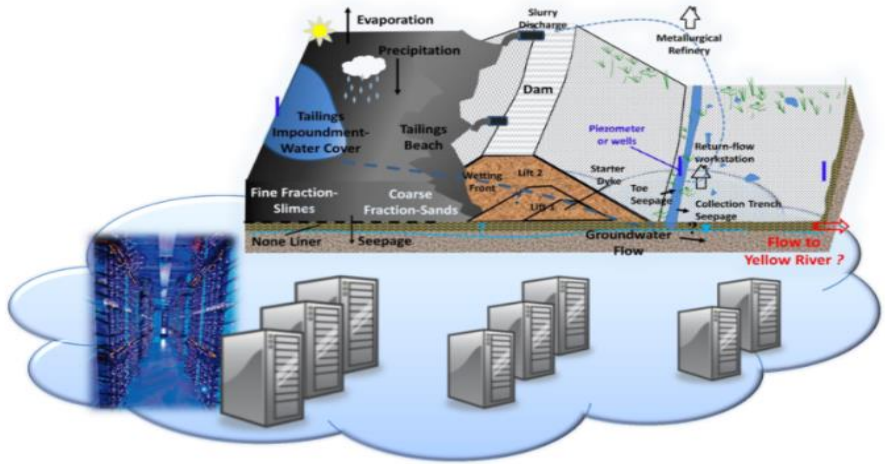
(Henning Prommer, 2013)

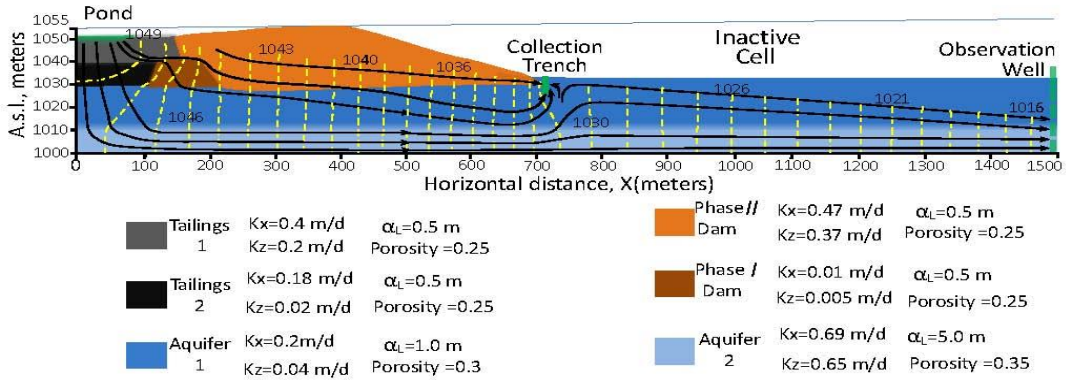
Numerical model

- Transported chemical undergoes surface complexation, with mineral dissolution/precipitation.
- Governing equation:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}(D_{ij}\frac{\partial C}{\partial x_j}) - \frac{\partial}{\partial x_i}(v_i C) - \boldsymbol{R}$$

- Single species transport model in MT3DMS with advection, multiple species reactive modeling in PHREEQC.





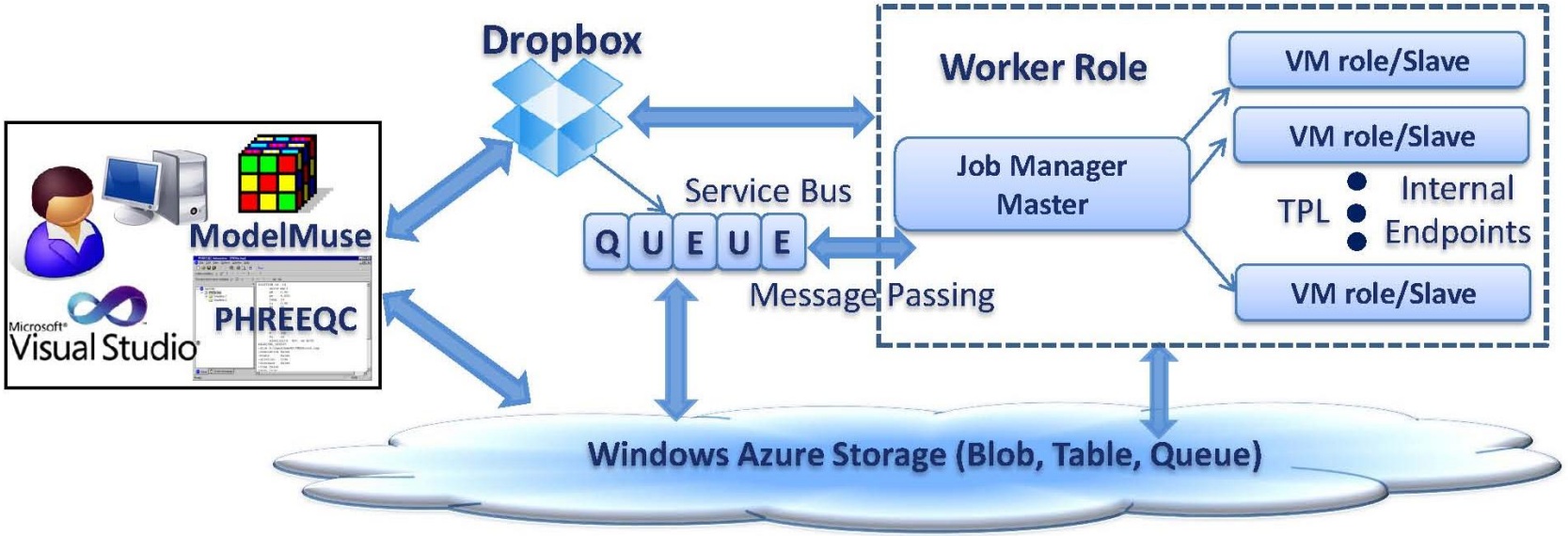
Architecture of Modeling Application on Azure

Job manager

- Communicate between Web portal and request queue.
- Coordinating computation workloads.
- Monitoring the execution status.

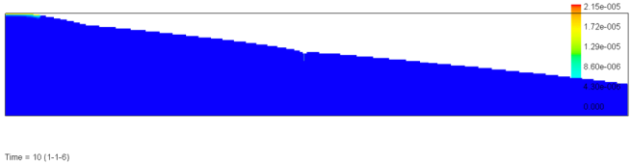
Task queue

- Communicate among Job manager, Slave VMs and Dropbox/GUIs.
- Releasing computation-input/-output queues according to bat files.

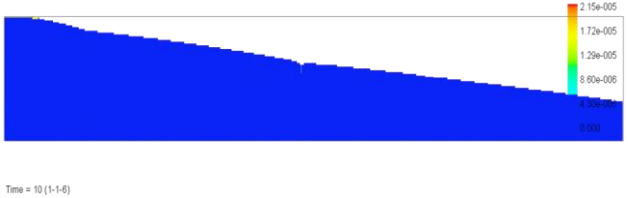


Simulation Results

Conservative transport plumes

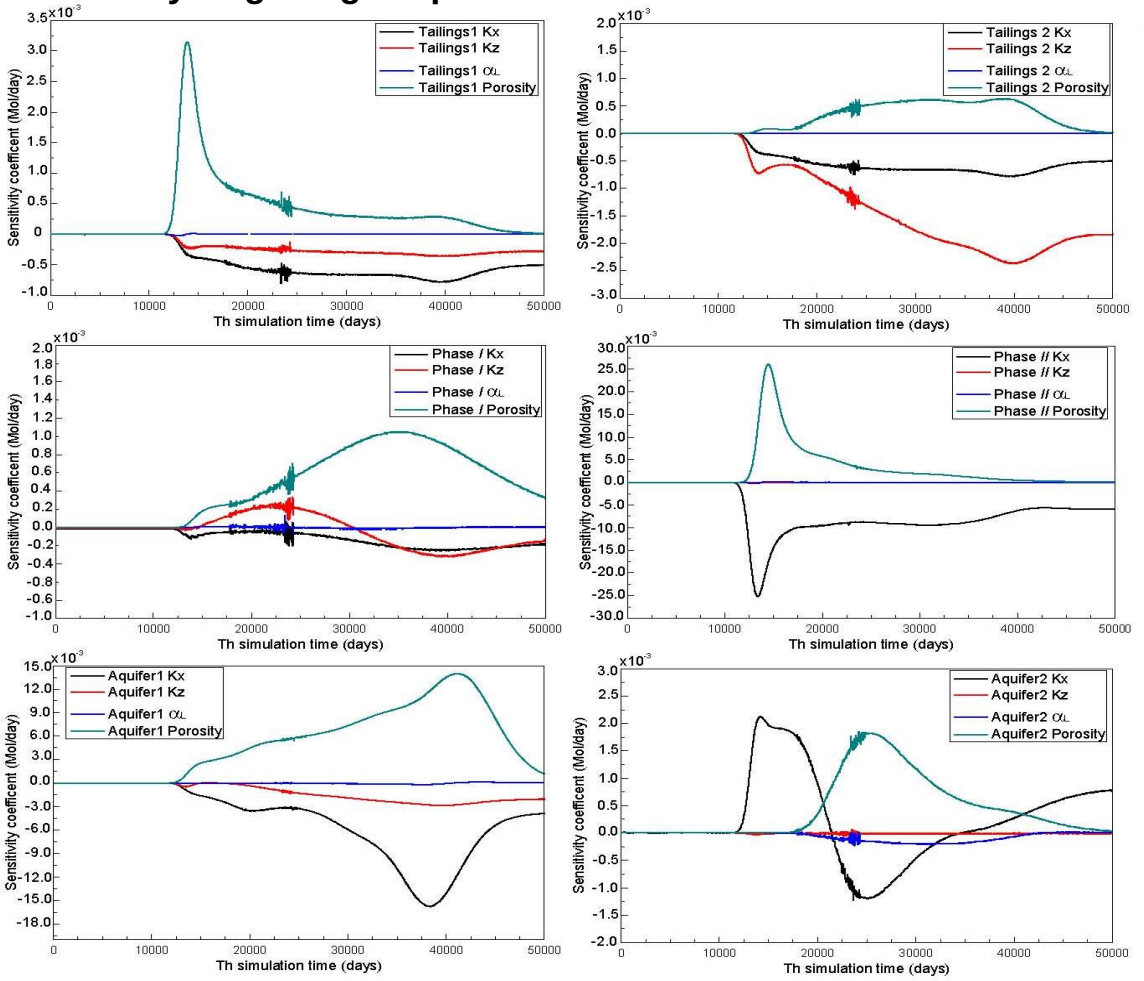


Thorium reactive transport plumes

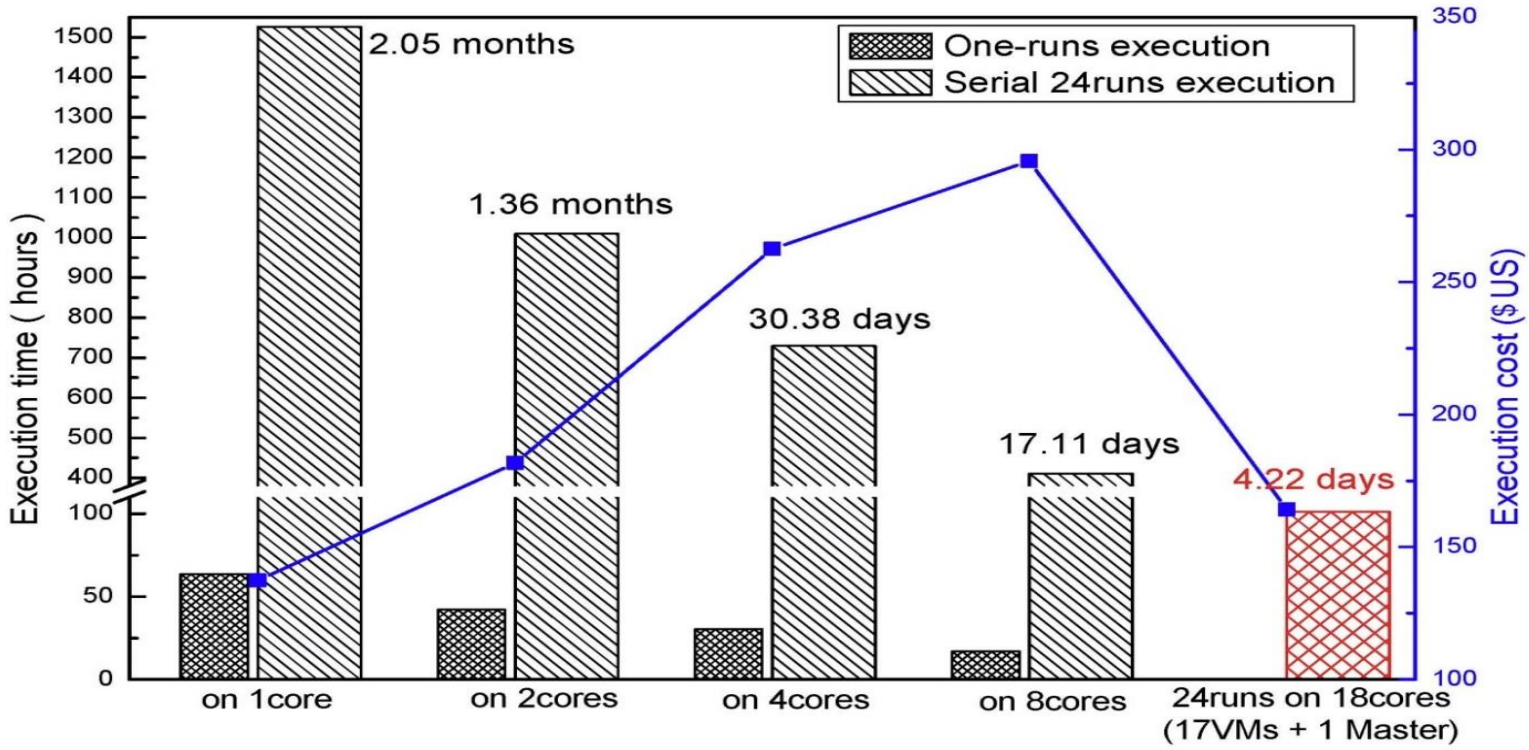


- FD, TVD, split-operator algorithm
- 72 layers, 745 columns

Sensitivities of thorium mass-fluxes into collection-trench to 24 hydrogeological parameters



Execution Time and Costs



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Microsoft Resxearch Asia: Lily Sun; Xin Ma


Thank You!

Save the planet and return
your name badge before you
leave (on Tuesday)