Innovative Application of GSHP in the Asian Region - Lessons learnt from ERIA geothermal project -

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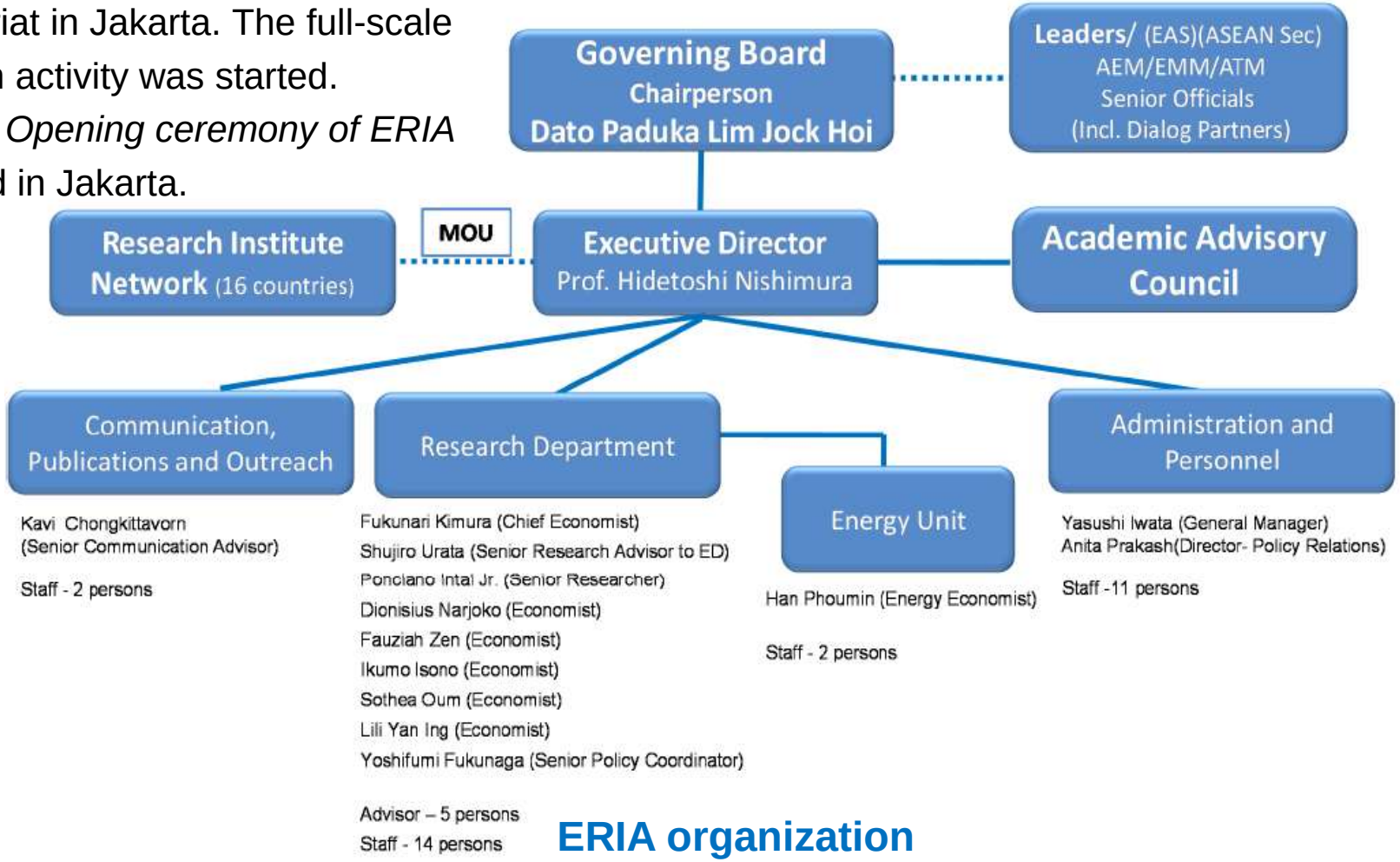
Short introduction of ERIA

History of **Economic Research Institute for ASEAN and East Asia (ERIA)**

- 2006/04 *Global Economic Strategy* was announced.
- 2006/08 Japan proposed the *establishment of ERIA* at the *13th ASEAN-Japan Economic Ministers Meeting* on August 23.
- 2008/06 *The inaugural ERIA Governor Board Meeting* was held at the ASEAN Secretariat in Jakarta. The full-scale research activity was started.
- 2008/09 *Opening ceremony of ERIA* was held in Jakarta.



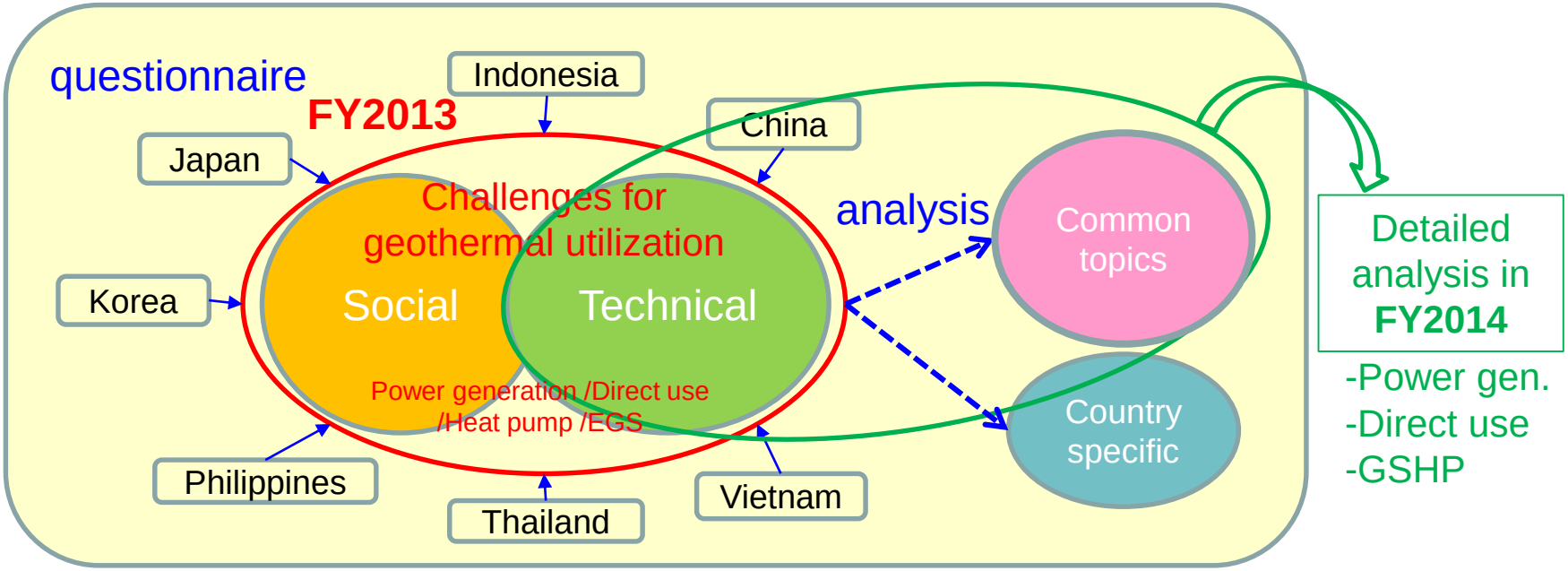
ERIA organization

"Sustainability Assessment of Utilizing Conventional and New-Type Geothermal Resources in East Asia"

Sustainability is the key to improve the reliability of geothermal energy.

Project Results

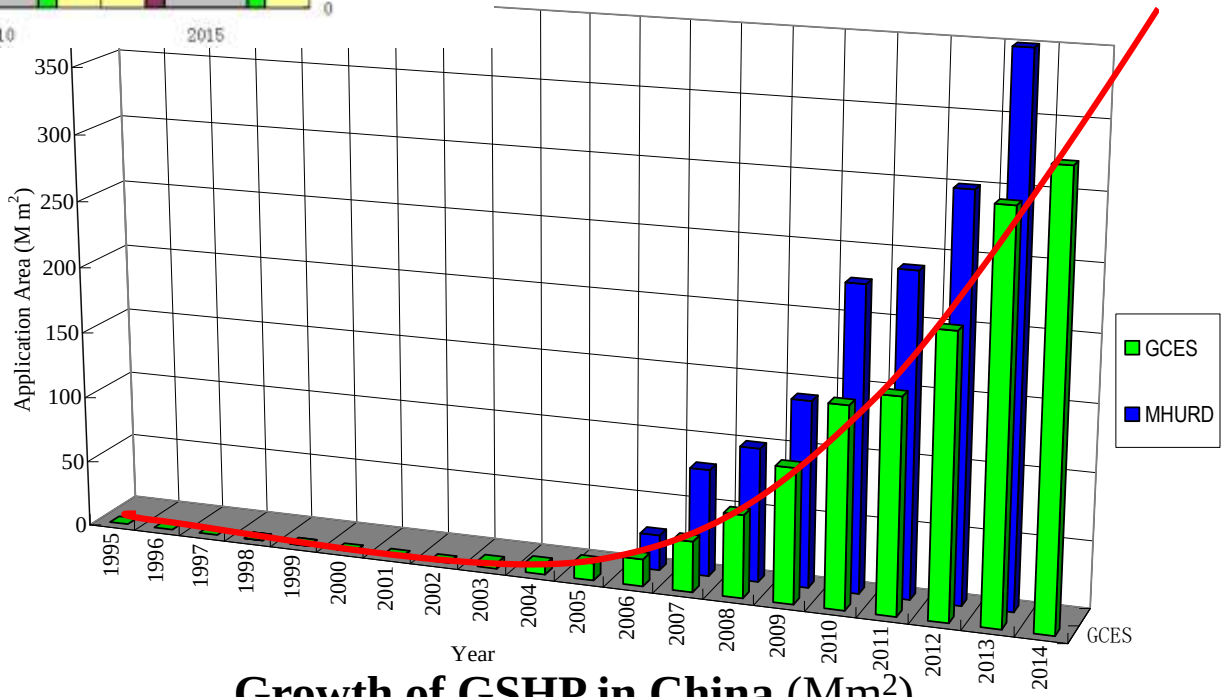
In FY2013, technical and social challenges for geothermal utilization (power generation, direct use, GSHP and EGS) in each member countries are summarized. In FY2014, common technical problems on sustainable use of geothermal energy are picked up and a guideline for these problems was made by analyzing collection of case studies from member countries.



China: Investigation, evaluation, and monitoring

Data source: Geothermal Council of China Energy Society (GCES), Ministry of Housing and Urban-Rural Development (MHURD)

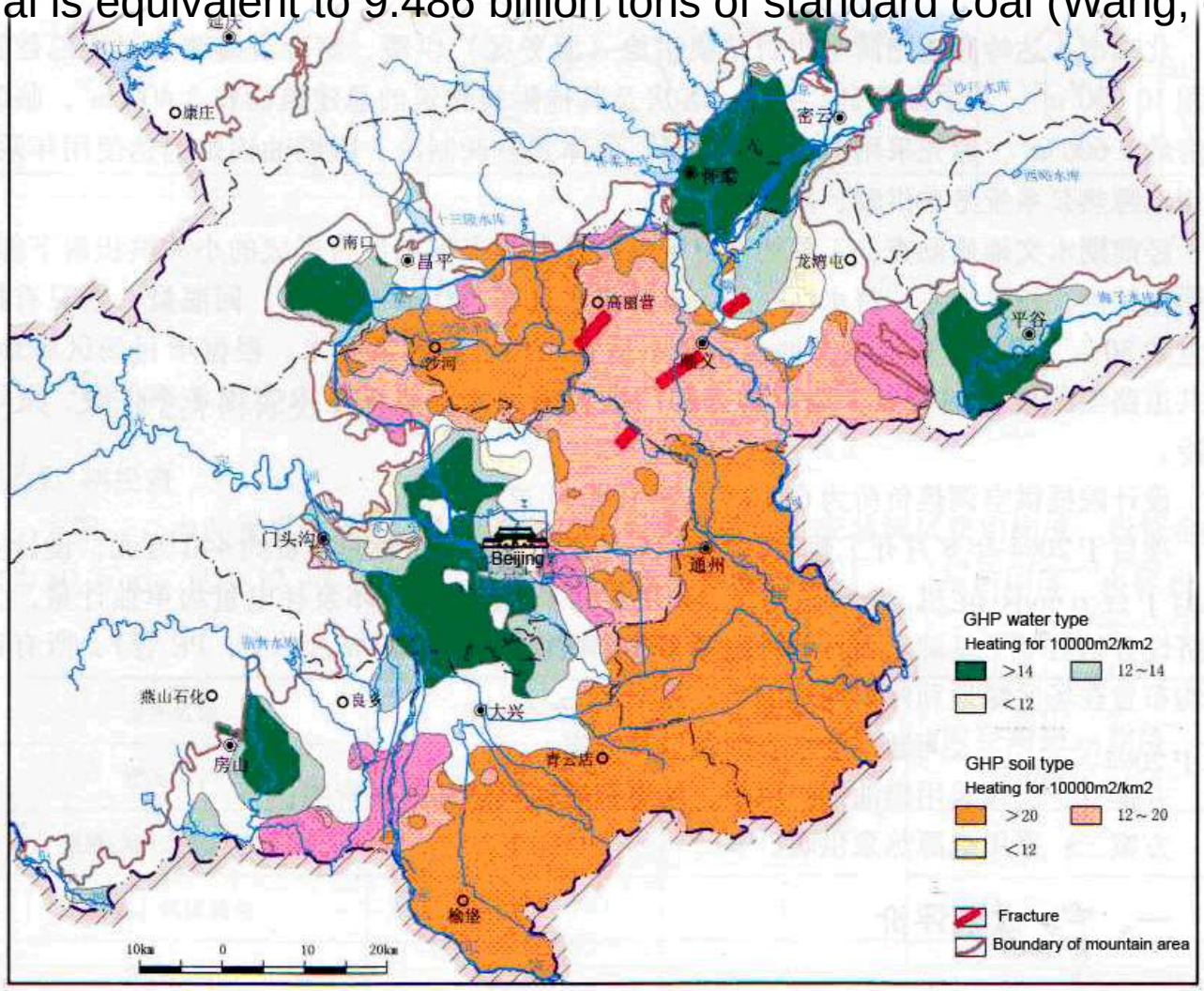
Growth of Geothermal Utilisation in China



Growth of GSHP in China (Mm^2)

China: Investigation, evaluation, and monitoring

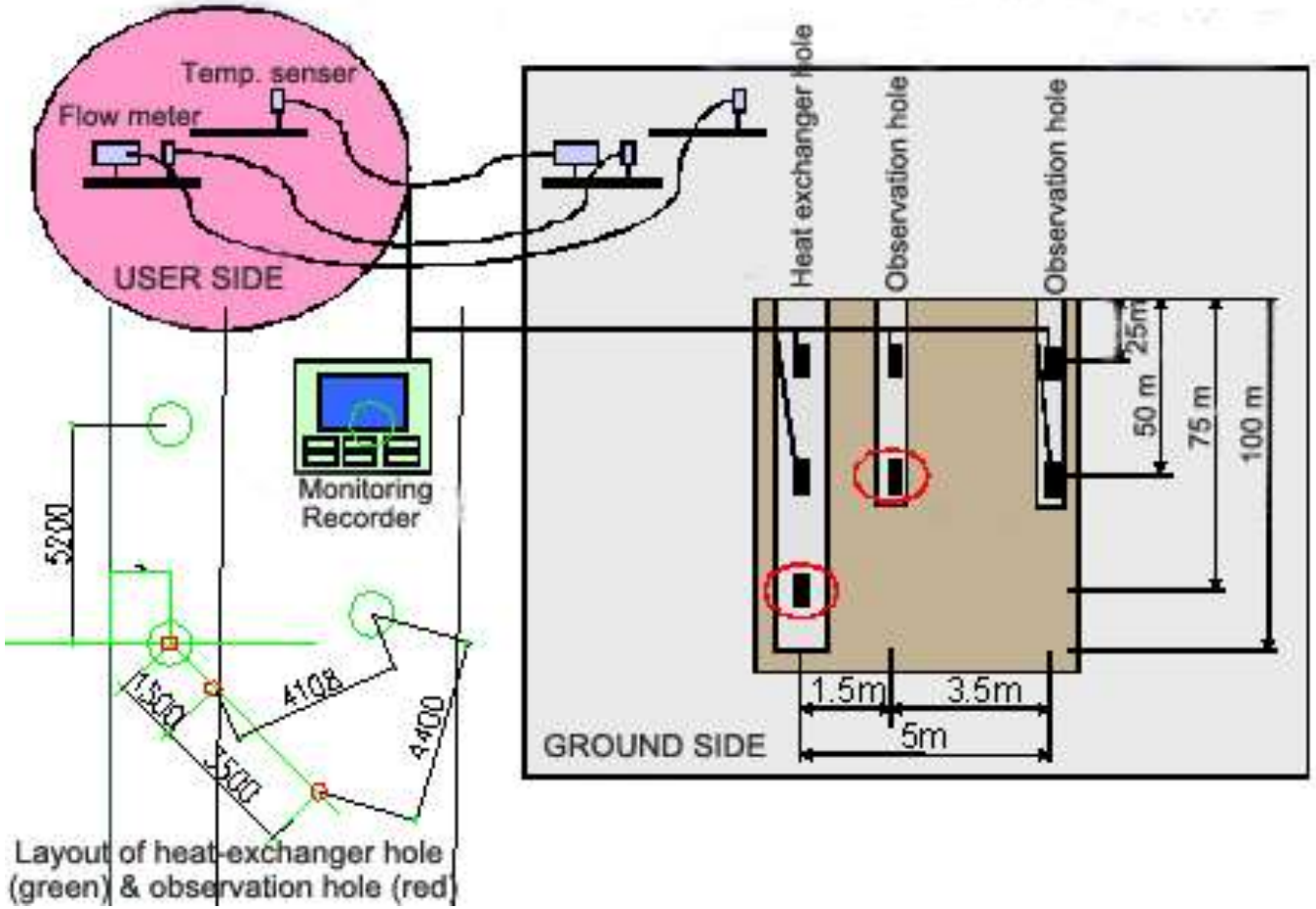
The national project of investigation and evaluation of shallow geothermal energy has shown great potential. It provides heat capacity for GSHP use. The total potential is equivalent to 9.486 billion tons of standard coal (Wang, et al., 2013).



Map Showing Shallow Geothermal Energy Conditions in Beijing

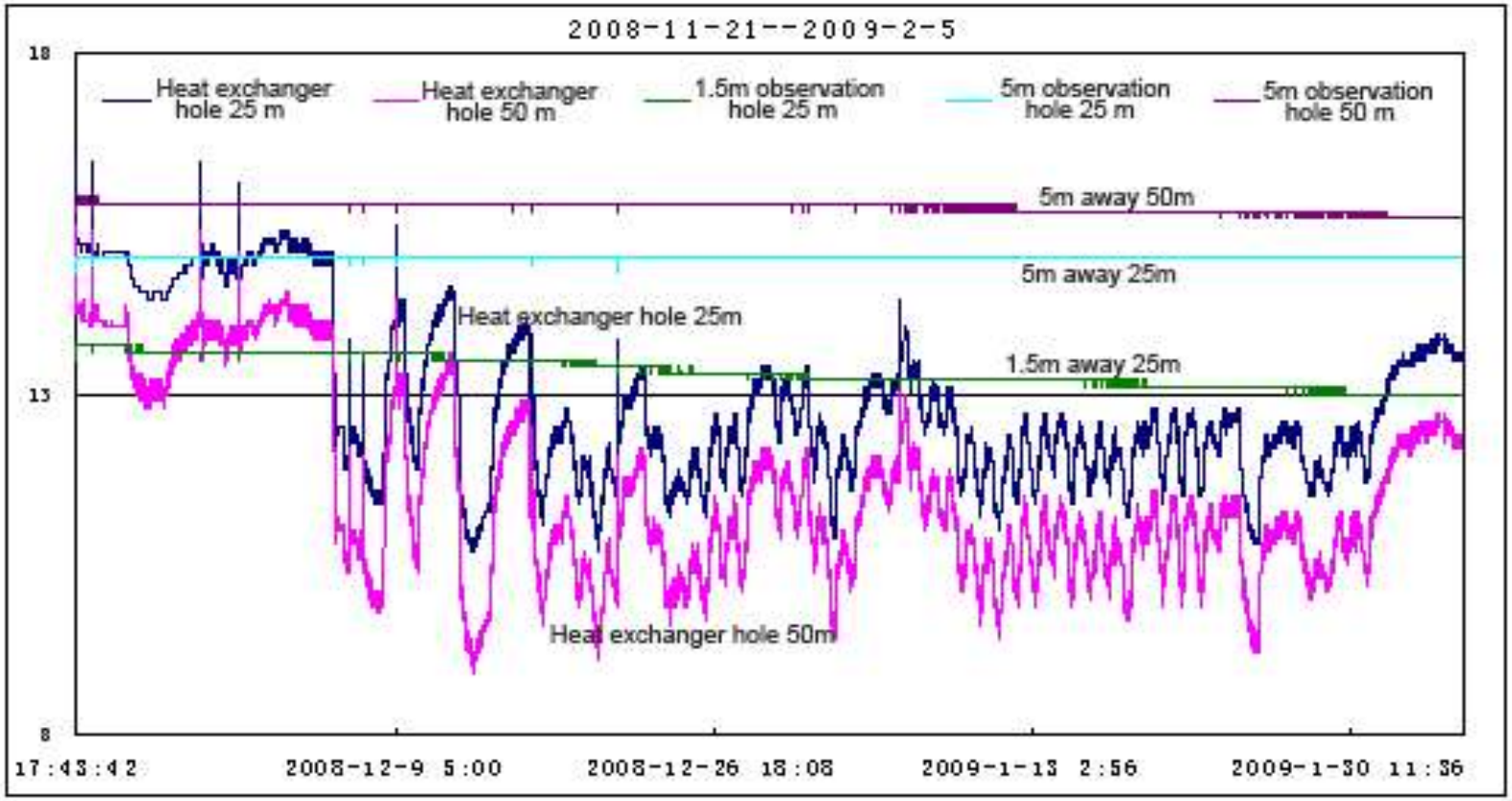
China: Investigation, evaluation, and monitoring

Concerning the balance of heating and cooling, long-term monitoring has been conducted in typical projects for more than 10 years. Long-term monitoring of ground temperature and HP system has shown positive results for 20 or more projects in Beijing. (see next slide)



Installation of Monitoring Tools for GSHP System

China: Investigation, evaluation, and monitoring



Temperature Curves Measured in Different Monitoring Holes

Lessons learned

- Mapping shallow geothermal energy conditions, such as water type and soil type, is important to perform proper design of GSHP systems.
- Monitoring of ground temperature is important to monitor thermal recovery of the ground and to assure the balance of heating and cooling.

Korea: Importance of monitoring and its data analysis

The government building complex of Sejong Metropolitan City

- The total building area: 607,555 m^2.
- Total GSHP installed capacity >20 MW_t, covering 38 % or more heating and cooling load.
- 70 % of heat is from borehole heat exchangers (BHEs) through 1,190 boreholes of 200 m deep (total length of holes: 238 km).
- 30 % of heat is from ground water wells of around 400 m deep.
- Zone 1 of the building complex started operation in 2012,
- Zone 2 in 2013, and Zone 3 was completed in 2014.
- GSHP for other public buildings including City Hall and the Educational District Buildings are continuously being installed.

Bird's-eye View of Zones 1 and 2 of the Government Building Complex, Sejong Metropolitan City

Monitoring

The GSHP system in Sejong City is readily equipped with automated monitoring systems and the monitored data are automatically collected at each site.

But there is no systematic regulation or organisation for checking and analysing the monitoring data. It is very important not only to monitor the geothermal system, but to analyse the data.

Regulations or organisations are needed for making advice on the sustainable use of GSHP systems based on the analysis of results.


drilling of borehole for BHE


trench line of heat exchanger pipes into building

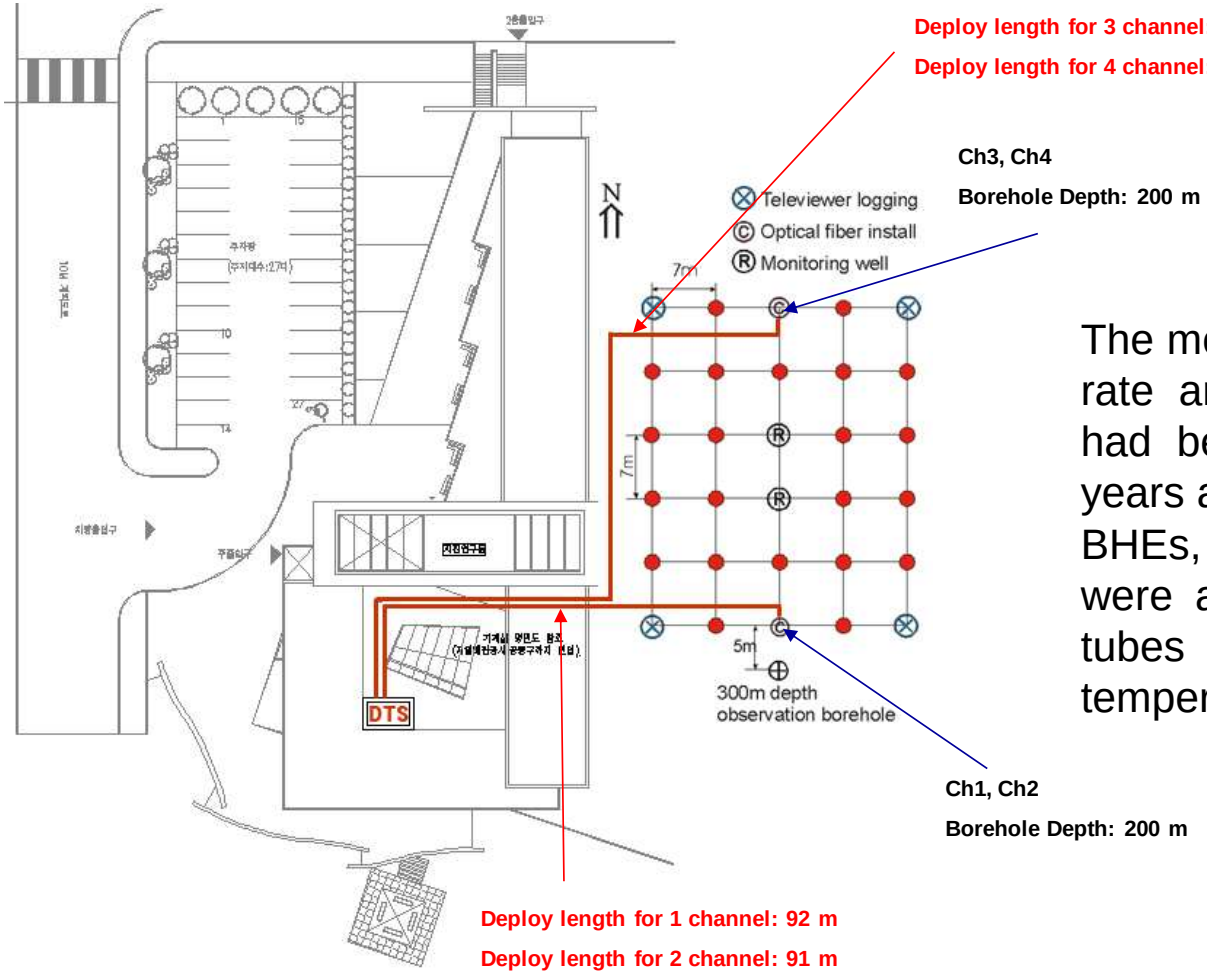

heat pumps in the basement floor of building

Long-term temperature monitoring in Earthquake Research Center, KIGAM

- A long-term monitoring case of ground temperature variation according to GSHP operation can be found at the Earthquake Research Center (ERC) building in KIGAM.
- The building is three storeys high with an area of 700–900 m^2 each, 2,435.4 m^2 in total, constructed in 2005.
- The heating and cooling load is 400 kW.
- 28 boreholes with a diameter of 165 mm, a depth of 200 m, and 7 m apart were drilled to be installed with double U-tube type borehole heat exchangers (BHE).

ERC building in KIGAM during the Installation of BHEs (left) and after Covering BHEs with Green Grasses (right)

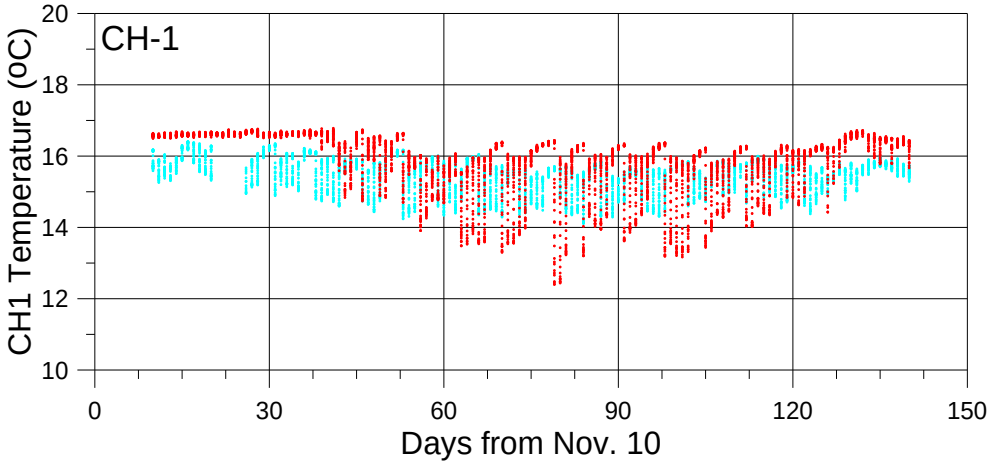
Long-term temperature monitoring in Earthquake Research Center, KIGAM

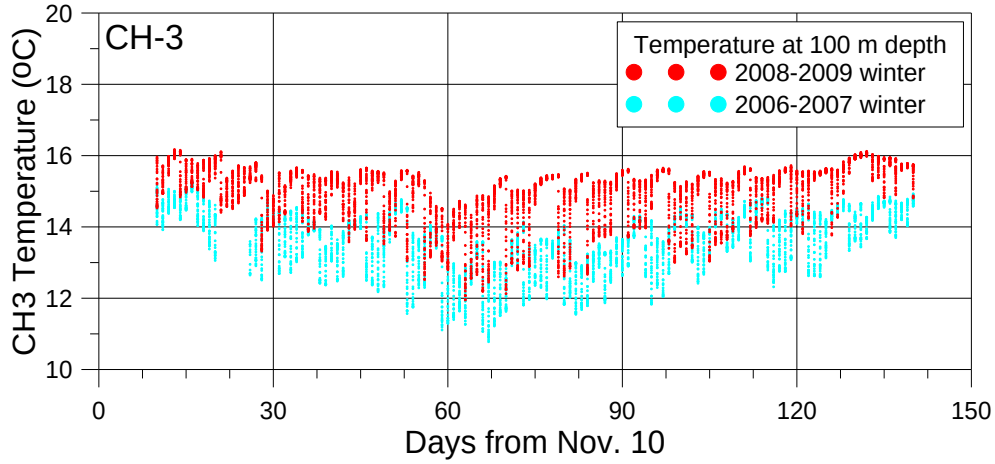


The monitoring of the inlet/outlet flow rate and temperature of the BHEs had been performed for about 3.5 years after the installation. Among 28 BHEs, in addition, fibre optic cables were attached to the outside of U-tubes of two BHEs to monitor the temperature variation with depth.

Layout of BHEs and the Monitoring System for the ERC Building at KIGAM

Long-term temperature monitoring in Earthquake Research Center, KIGAM





The subsurface temperature beneath the borehole field was getting higher with the GSHP operations and we can see 0.5–1°C of temperature increase per year at 100 m depth.

The increase of subsurface temperature was caused by unbalanced seasonal variation of load (cooling load is bigger than heating in the building), which may lead to performance degradation as GSHP operation continues year after year.

This result is a good example showing that accurate monitoring of the subsurface is important for sustainable use of geothermal energy in heating and cooling applications.

- **Comparison of Temperature Variations at 100 metre Depth between the Winter Seasons of 2006–2007 and 2008–2009**

Korea: Importance of monitoring and its data analysis

Problem

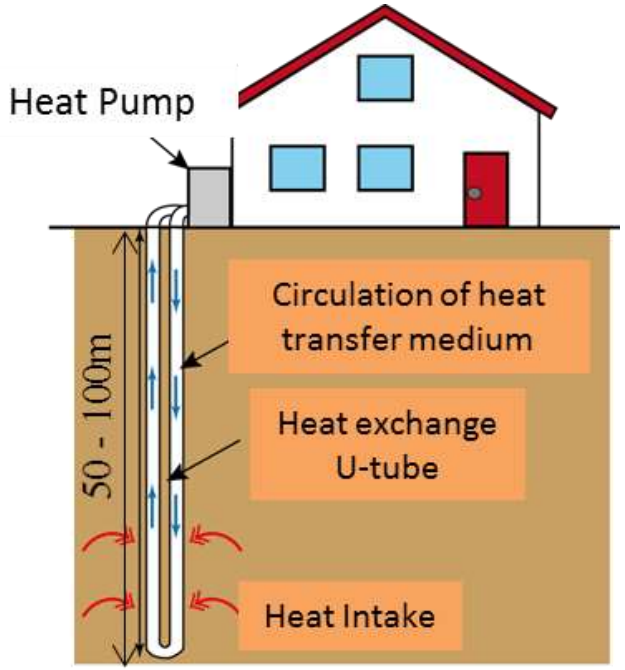
In South Korea, by law, all GSHP systems are subject to be monitored in terms of inlet and outlet temperature and flow rates during operation. All these data are collected by the authorised ministry. However, no analysis has been made for these data so that the actual coefficient of performance (COP) has not been calculated, although the COP is the key to understand the effectiveness of GSHP in terms of saving energy, heat extraction, and sustainability.

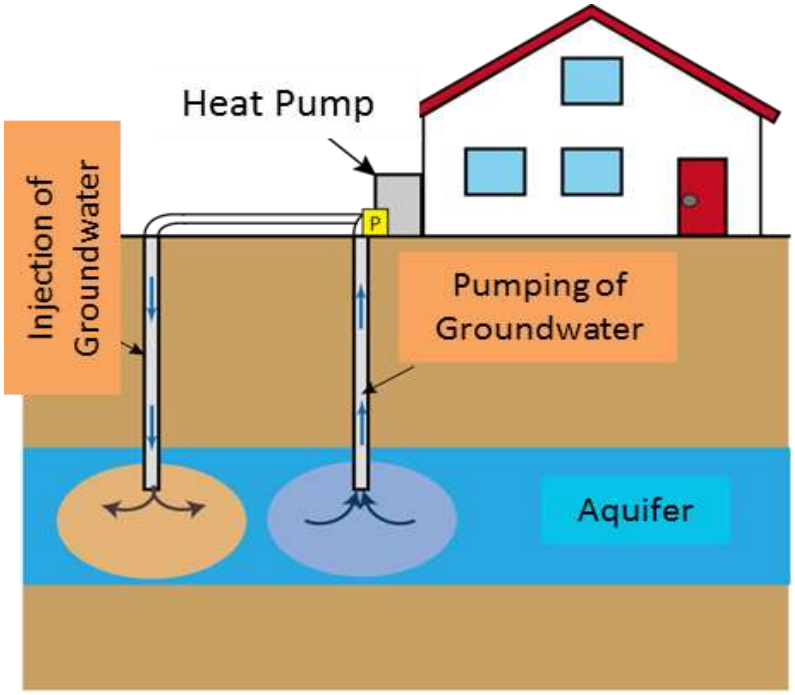
Lessons learned

- For long-term sustainability, monitoring of the system is important. The monitoring is mandated by law in case of South Korea, but the problem is that the monitoring data has not been properly analysed in many cases.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored.
- The flow rate and temperature of the primary and secondary fluids and electricity consumption of the heat pump and circulation pump should be monitored to calculate actual COP and long-term performance including extracted heat, amongst others.

Japan: Suitability mapping for both closed & open systems

In sedimentary basins and plains in monsoon Asia, sustainable heat exchange rate and preferred drilling depth of a closed loop system varies with local hydrogeological settings due to the variation of effective heat conductivity caused by groundwater flow. Therefore, suitability mapping for closed loop system is important in such regions.





Suitability index parameters for closed loop system

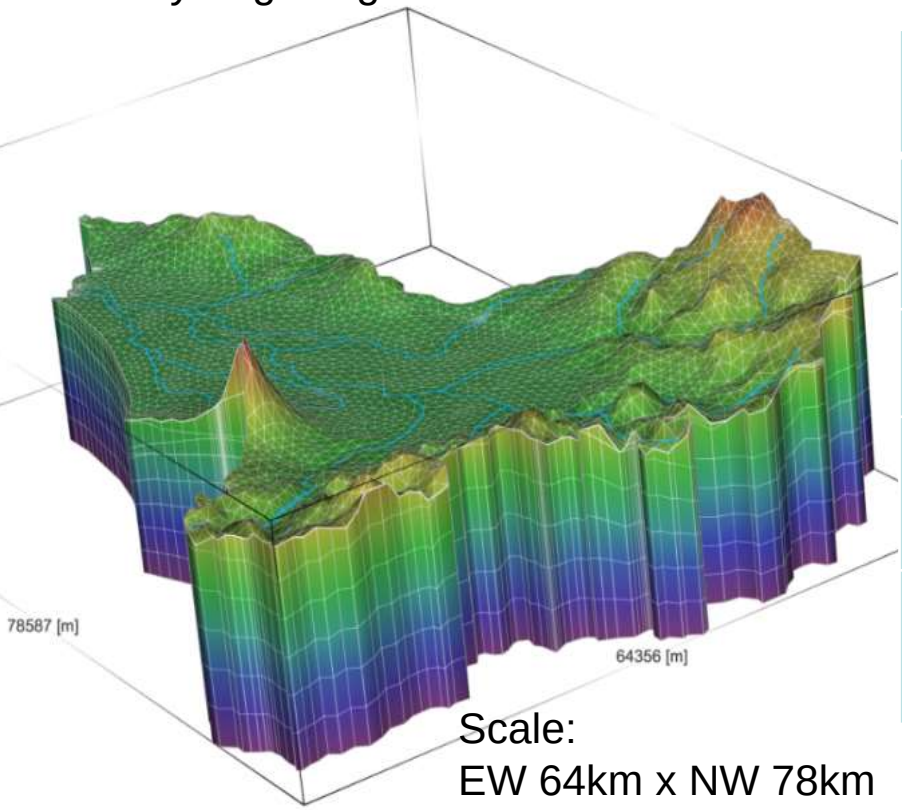
- Effective heat conductivity (or equivalent overlaid parameters: see the following page)

Suitability index parameters for open loop system:

- Economical availability (accessibility) of aquifer
- Injectivity of the aquifer
- Productivity of the aquifer

Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system in the Tsugaru Plain

The objective of this study is to assess the installation suitability of a closed-loop GSHP system by developing 'suitability' maps. The term suitability is mainly related to heat exchange with the subsurface, which depends on geology, groundwater flow system, and subsurface temperature distribution. Hence, suitability assessment should be done based on hydrogeological and thermal information.



Scale:
EW 64km x NW 78km

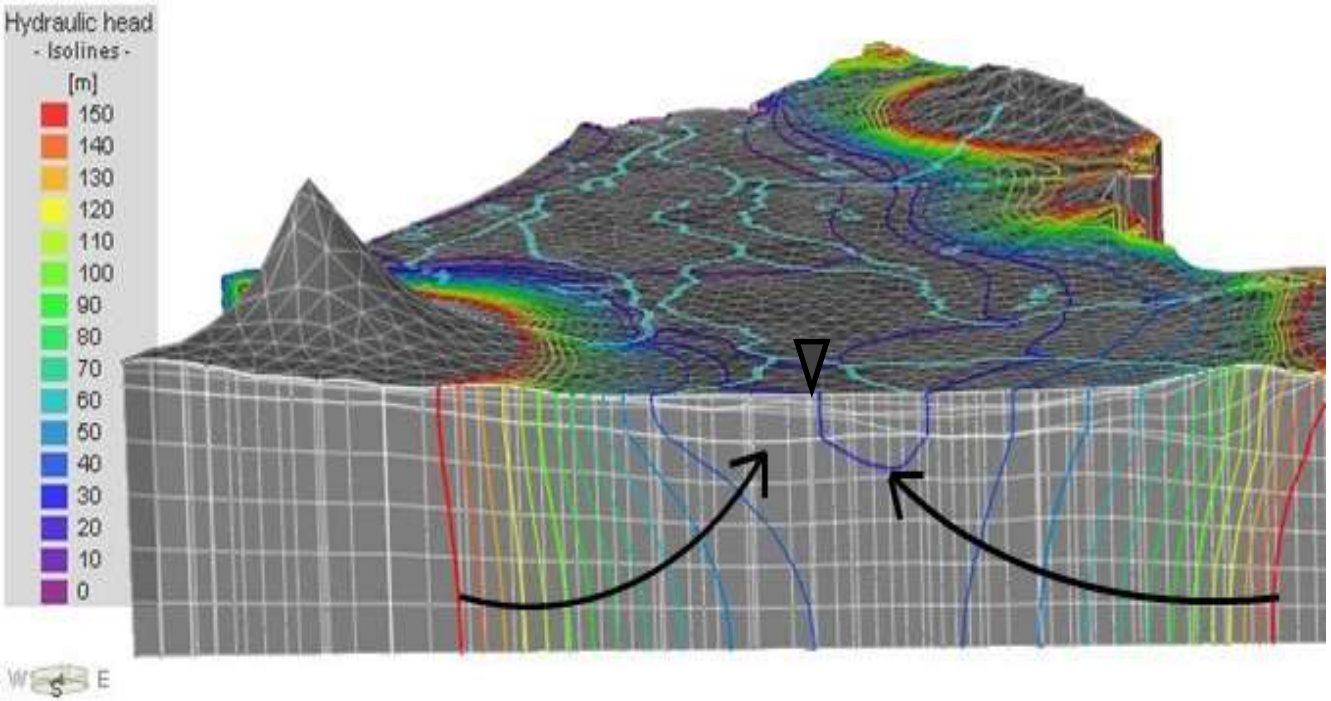
	Quaternary System	Tertiary System	
		Neogene	Paleogene
Hydraulic Conductivity (m/s)	5×10^{-5}	3.4×10^{-6}	2.4×10^{-7}
Porosity (-)	0.4	0.1	0.1
Heat Capacity (J/m^3K)	2.6×10^{6}	2.6×10^{6}	2.6×10^{6}
Thermal Conductivity (W/mK)	1.2	1.5	1.5

Regional scale analysis model and its input parameters (Shrestha, et al., 2015).

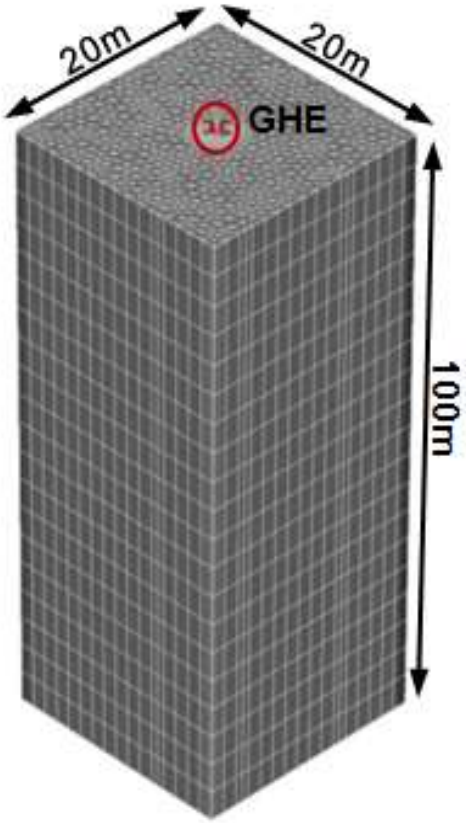
Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system in the Tsugaru Plain

Normally simulation results of the regional model is compared with observed temperature profiles in observation wells. But since there is no observation wells in this plain, results of TRT at several sites are compared with calculation results of single GHE model using boundary conditions obtained by regional model.

Thus the model parameters are adjusted.



Groundwater Upflow at Tomita Spring (Shrestha, et al., 2015).

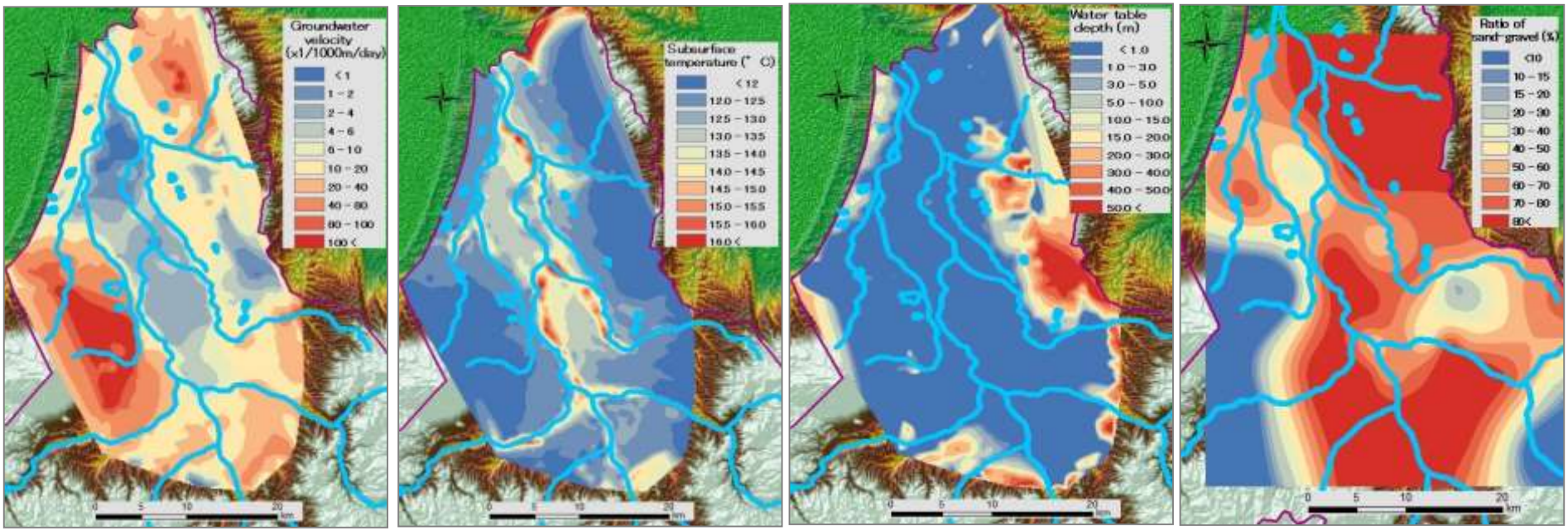


Single Ground Heat Exchanger Model

Japan: Suitability mapping for both closed & open systems

Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system in the Tsugaru Plain

Then “Thematic Maps,” to be overlaid into a suitability map, are made using simulation results of regional model.



(a)Groundwater velocity (b)Subsurface temperature (c)Water table depth (d)Sand-gravel ratio (Shrestha, et al., 2015).

Japan: Suitability mapping for both closed & open systems

Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system in the Tsugaru Plain

Then “Thematic Maps” are reclassified to be overlaid into a suitability map.

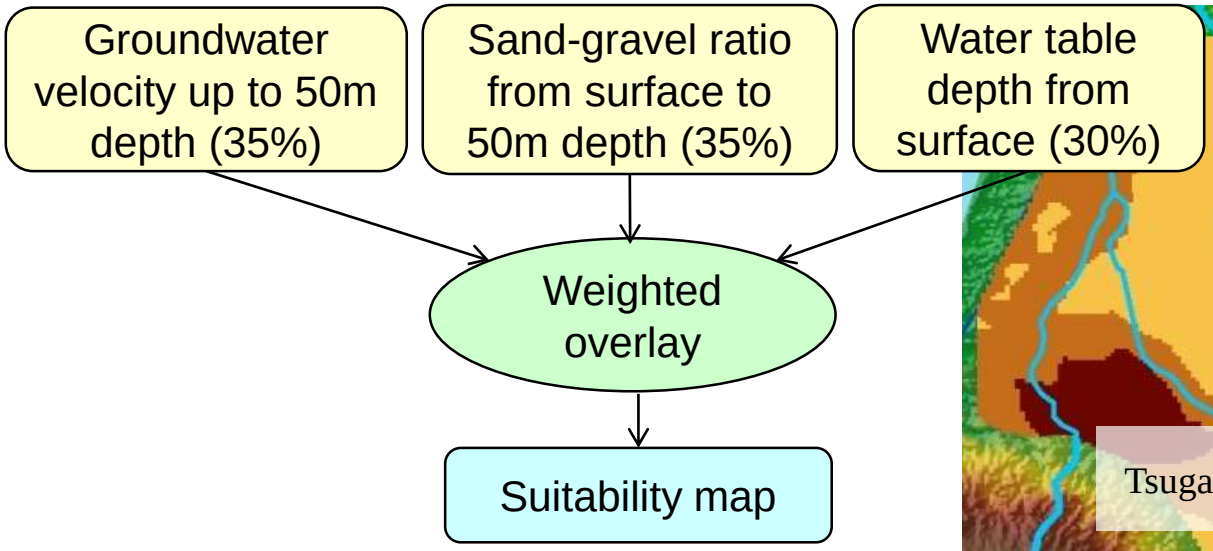
Groundwater velocity Index class ($x10^{-3}$m/day)	Sand-gravel ratio Index class (%)	Water table depth from surface Index class (m)	Grade
< 1	<10	50 <	1
1 – 2	10 – 15	40 - 50	2
2 – 4	15 – 20	30 - 40	3
4 – 6	20 – 30	20 - 30	4
6 – 10	30 – 40	15 - 20	5
10 – 20	40 – 50	10 - 15	6
20 – 40	50 – 60	5 - 10	7
40 – 80	60 – 70	3 - 5	8
80 – 100	70 – 80	1 - 3	9
100 <	80 <	< 1	10

Reclassification of Thematic Maps(Shrestha, et al., 2015).

Japan: Suitability mapping for both closed & open systems

Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system in the Tsugaru Plain

Then “Thematic Maps” are overlaid into a suitability map.



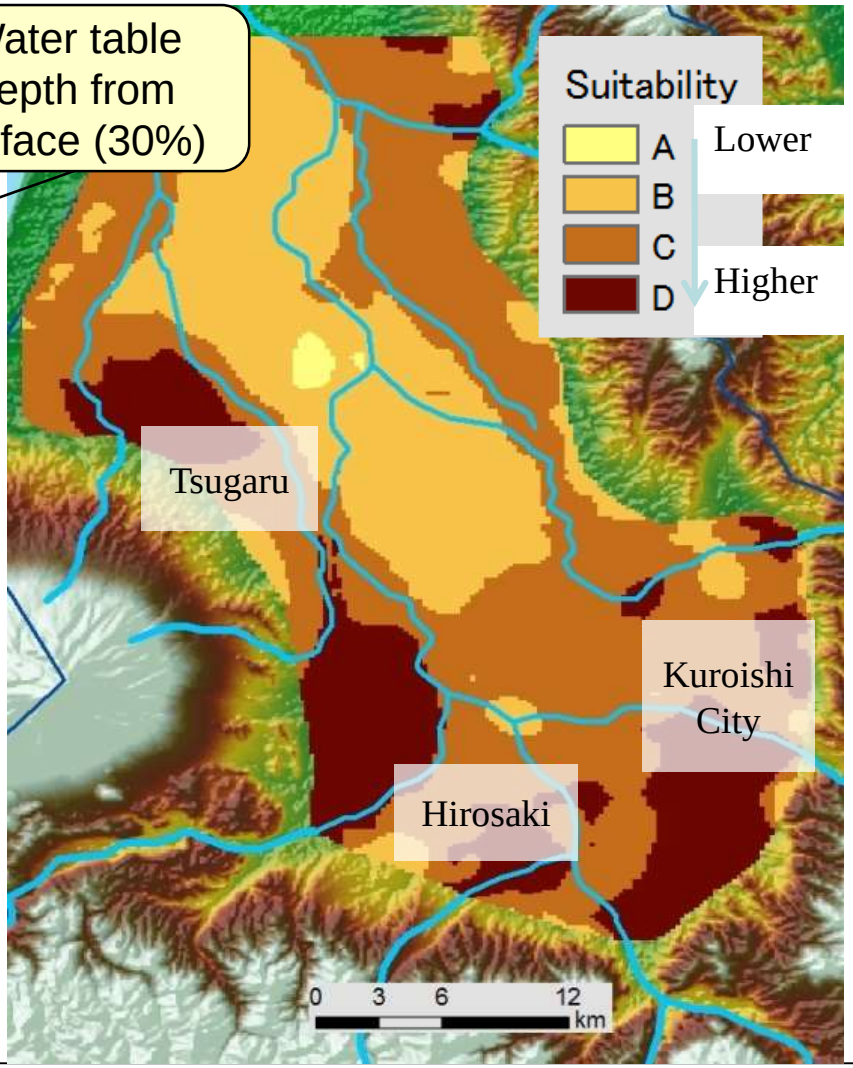
Weighted Overlay Model for Space Heating and Cooling

(Shrestha, et al., 2015).

For the case of heating purpose only, Subsurface temperature is also overlaid.

Suitability Map

(Shrestha, et al., 2014)



Lessons learned

- For sustainable use of GSHP systems, system design suitable for the subsurface condition of the location as well as GSHP application purpose is needed.
- Heat exchange rate and preferred drilling depth of a GSHP system varies with local subsurface conditions.
- In this context, a hydrogeological survey is very important for places in sedimentary basins and plains, while only rock properties are important for places with near surface hard rocks.
- To compile suitability maps of GSHP systems for sedimentary regions, groundwater and geological surveys are needed to perform numerical simulations on groundwater flow and local heat exchange rate.
- The design of a GSHP system can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.

Japan: Suitability mapping for both closed & open systems

Lessons learned (continued)

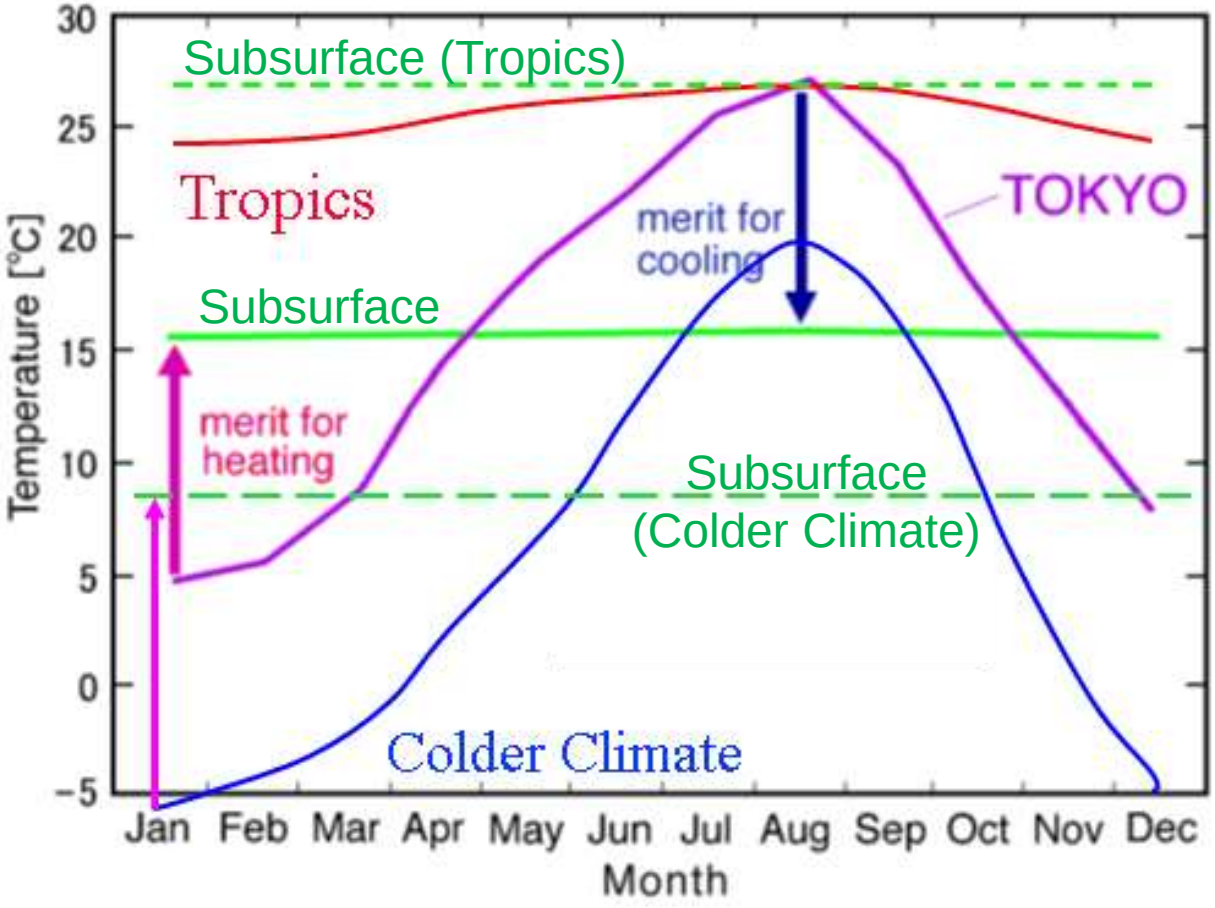
- A suitability map can be made in the following order of procedures:

1. Groundwater and geological survey
2. Regional groundwater flow simulation
3. Heat exchange simulation of the site
4. Making suitability map
   - Weighted overlay method may be used for making suitability map.
   - For closed-loop system, groundwater velocity, sand-gravel ratio, and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used.
   - Space heating suitability map needs subsurface temperature data additionally.

Choice of overlaid parameters and their weight

Thailand: Comparison of groundwater and atmosphere

Is GSHP applicable everywhere? Not really in tropics…



Monthly mean atmospheric and subsurface temperature

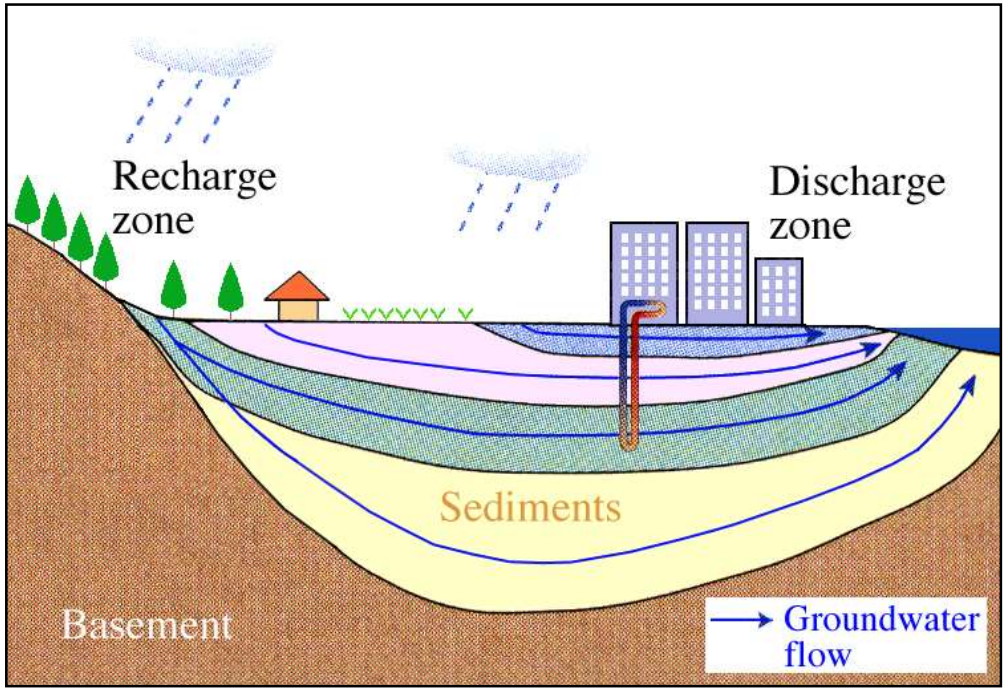
(Yasukawa et al., 2009)

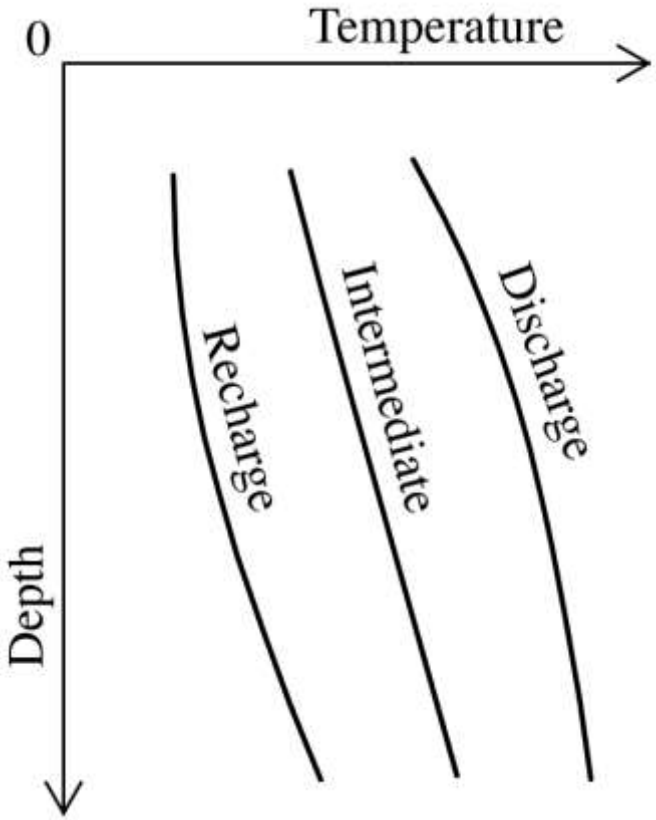
Can we use GSHP System in tropics?

- In East-Asia, where significant economical growth in this century is expected, energy saving and environmental protection are major matters of importance
- Promotion of GSHP may contribute to energy (electricity) savings and protection of the environment
- However, in tropics where space-cooling is needed, subsurface temperature is generally higher throughout a year and the underground is not suitable for heat exchange
- Nevertheless in tropical regions, underground may be used as a cold source, if there exist seasonal and areal variation in atmospheric temperature, and subsurface temperature is rather low

Shallow subsurface temperature affected by groundwater flow

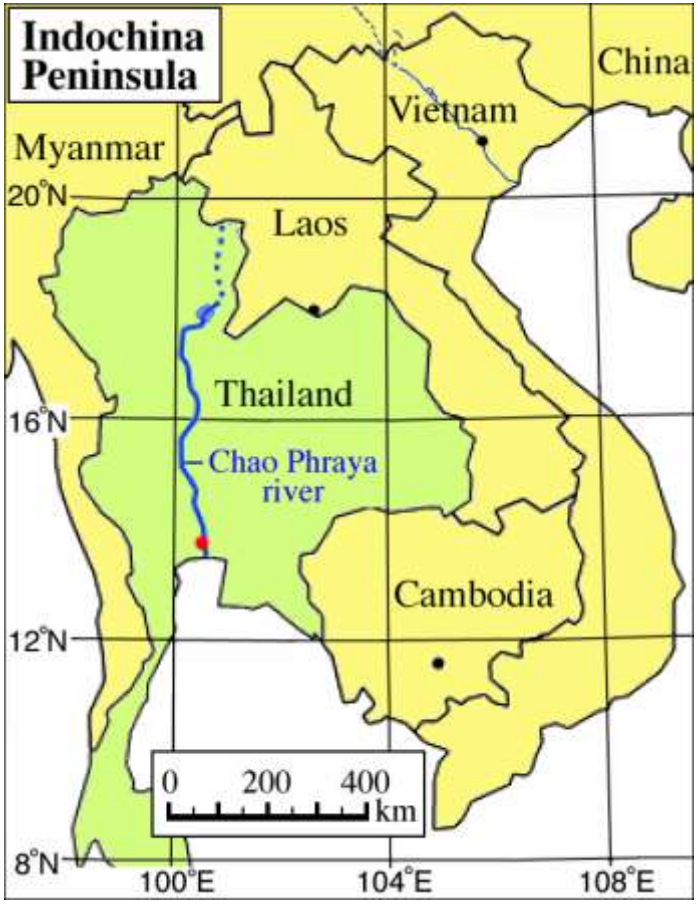
- At recharge zones (high elevation), shallow temperature is lower, while it is higher at discharge zones
- At recharge zones, underground may be used as cold source in tropics

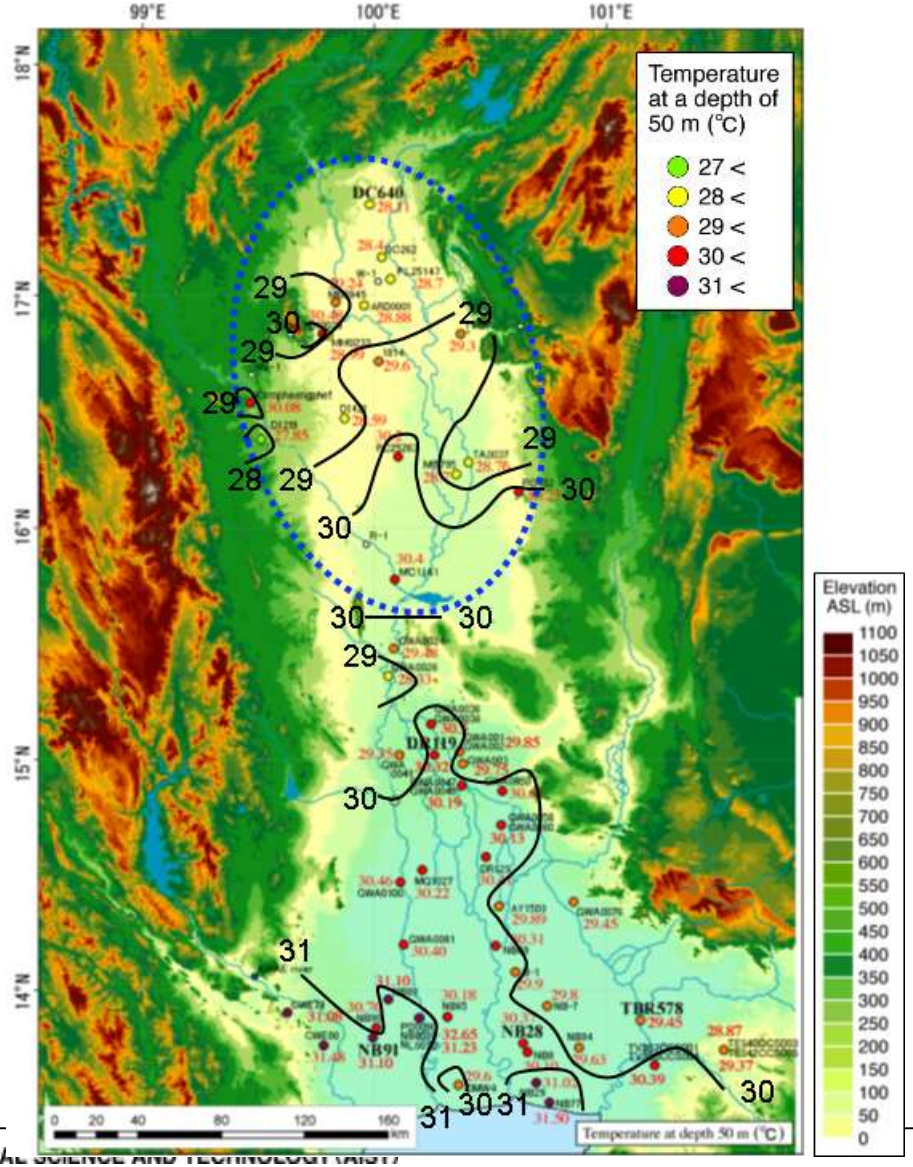




Subsurface temperature profile with groundwater flow

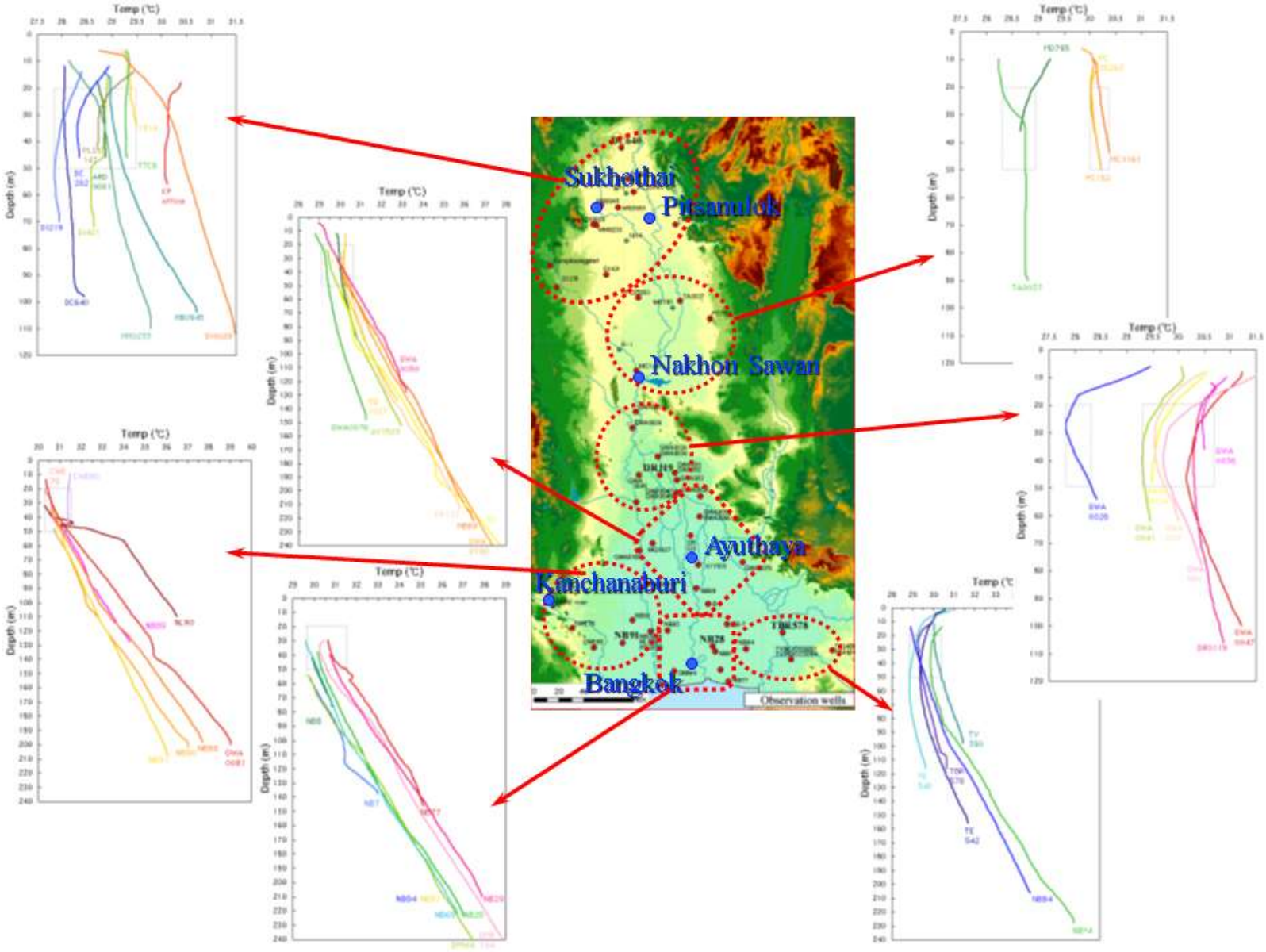
Temperature measurements in Thailand





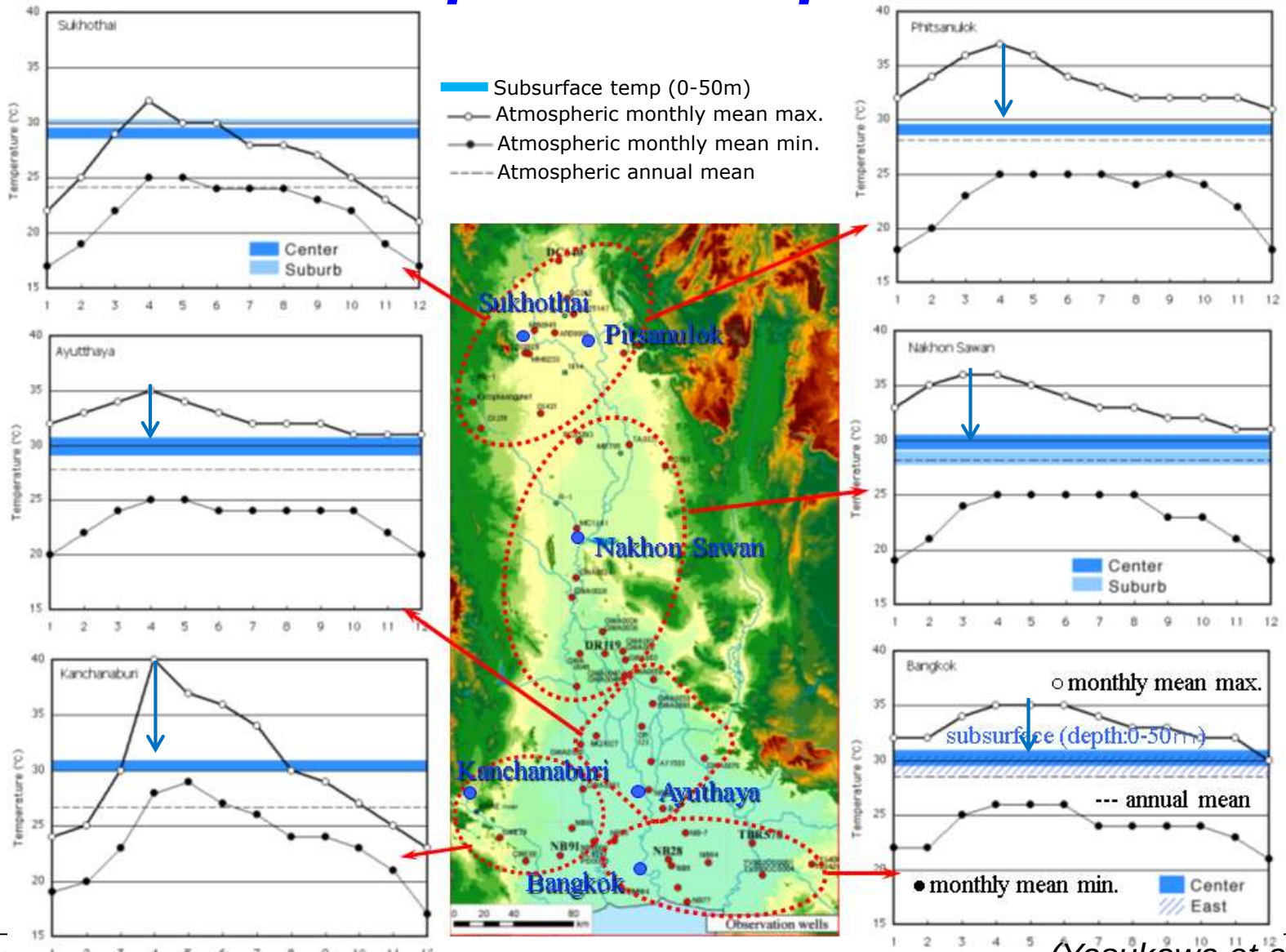
DGR: Department of Groundwater Resources of Thailand

Subsurface Temperature Profiles



(Yasukawa et al., 2009)

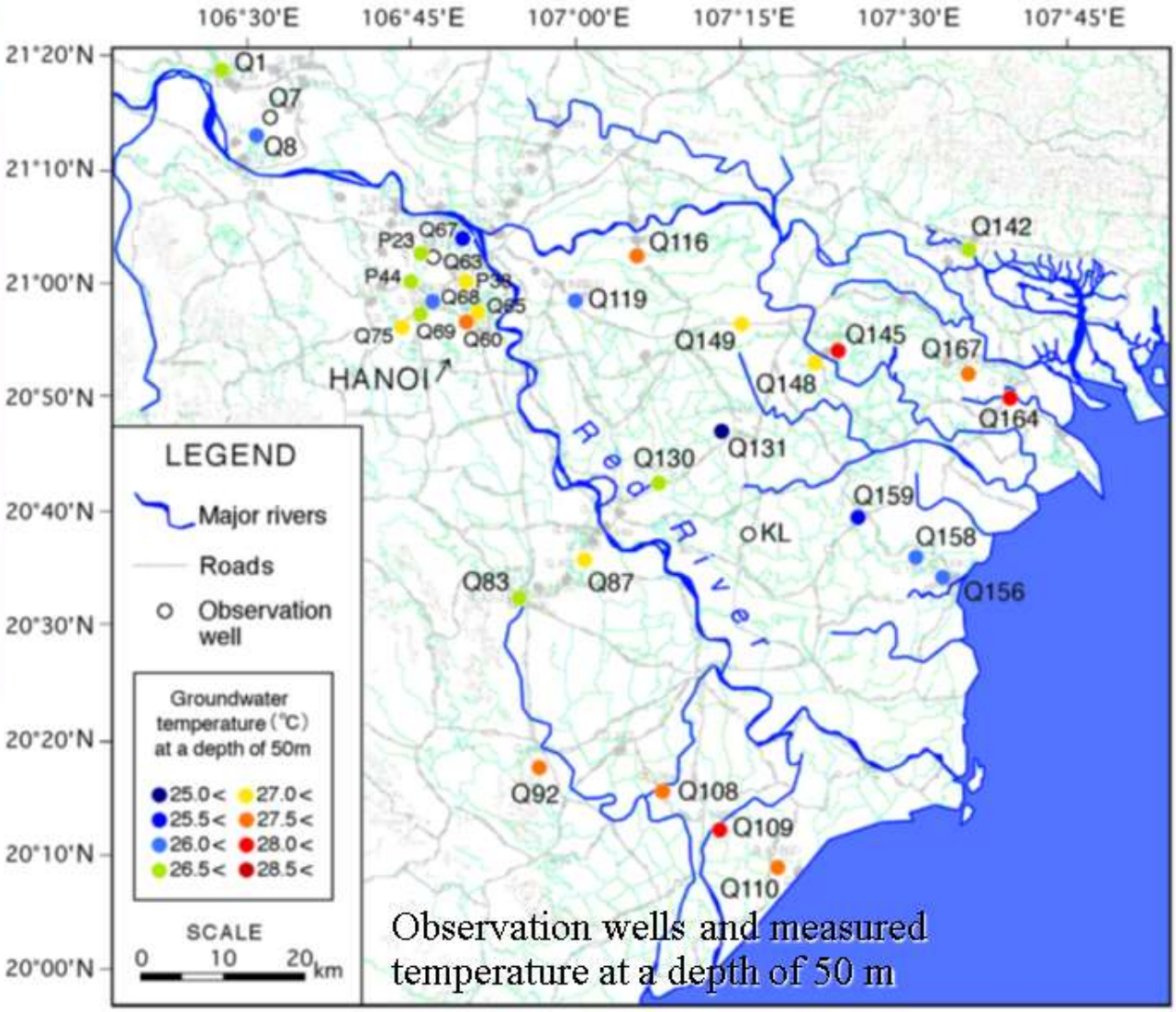
Comparison between subsurface and atmospheric temperature



(Yasukawa et al., 2009)

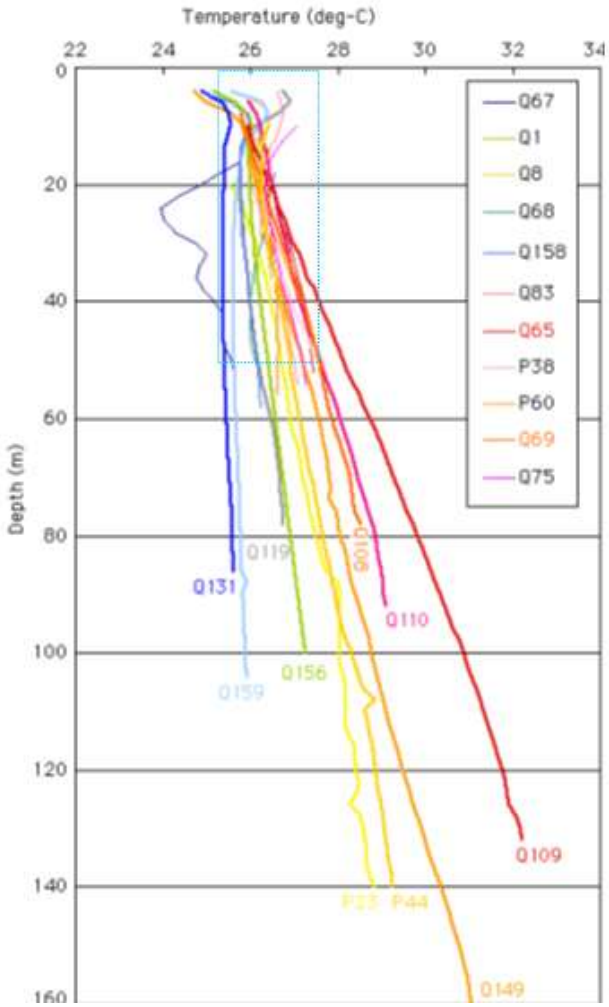
Vietnam: Comparison of groundwater and atmosphere

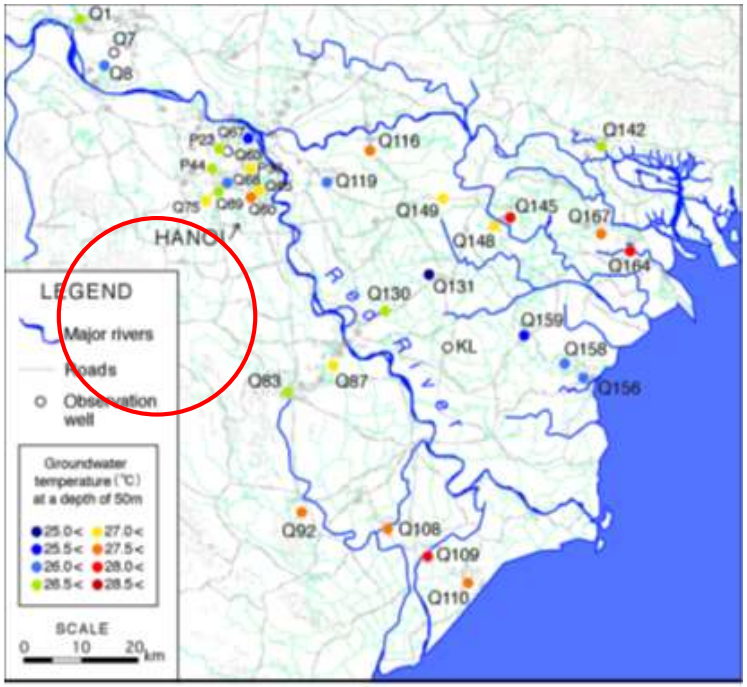
Temperature measurements in the Red River Plain (Hanoi region)

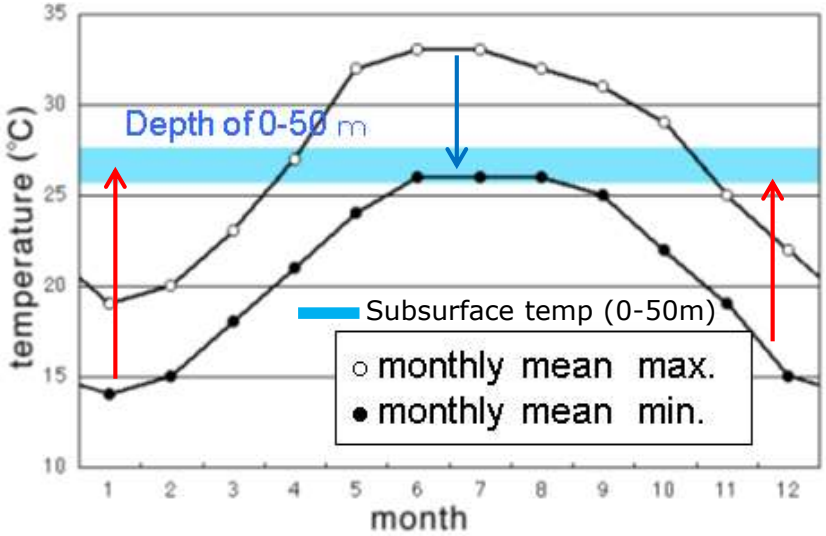


(Yasukawa et al., 2009)

Comparison between subsurface and atmospheric temperature in Hanoi



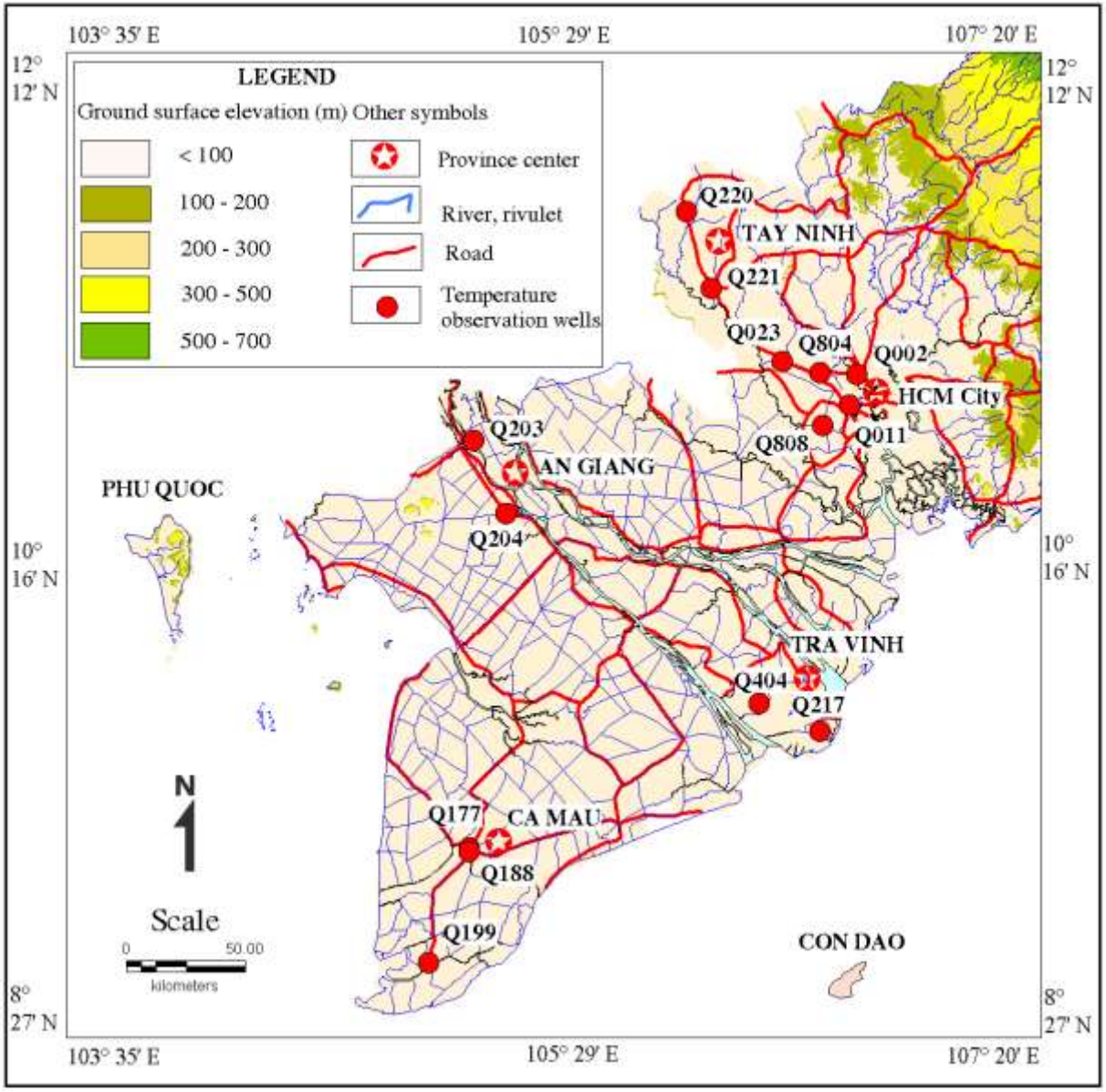




(Yasukawa et al., 2009)

Vietnam: Comparison of groundwater and atmosphere

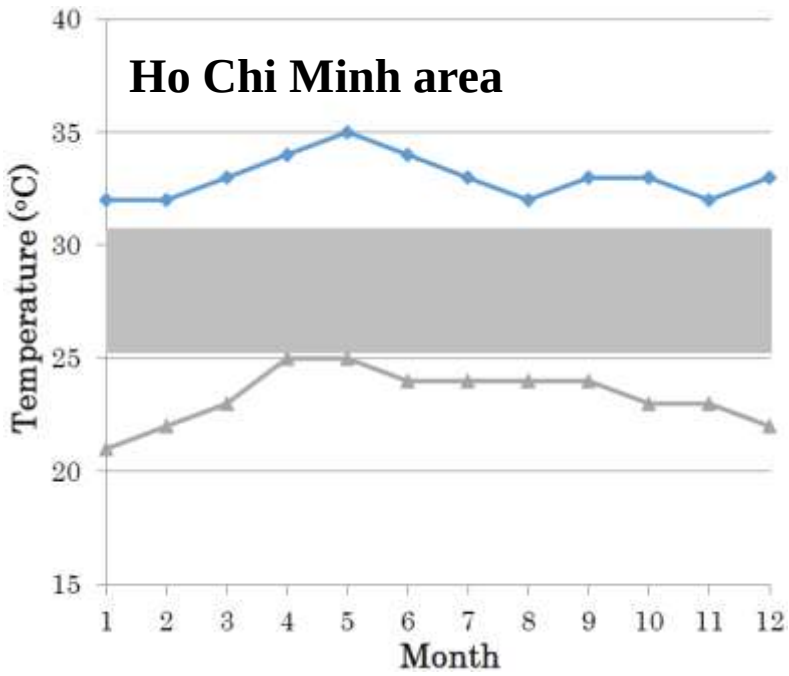
Temperature measurements in the South Plain (Ho Chi Minh region)

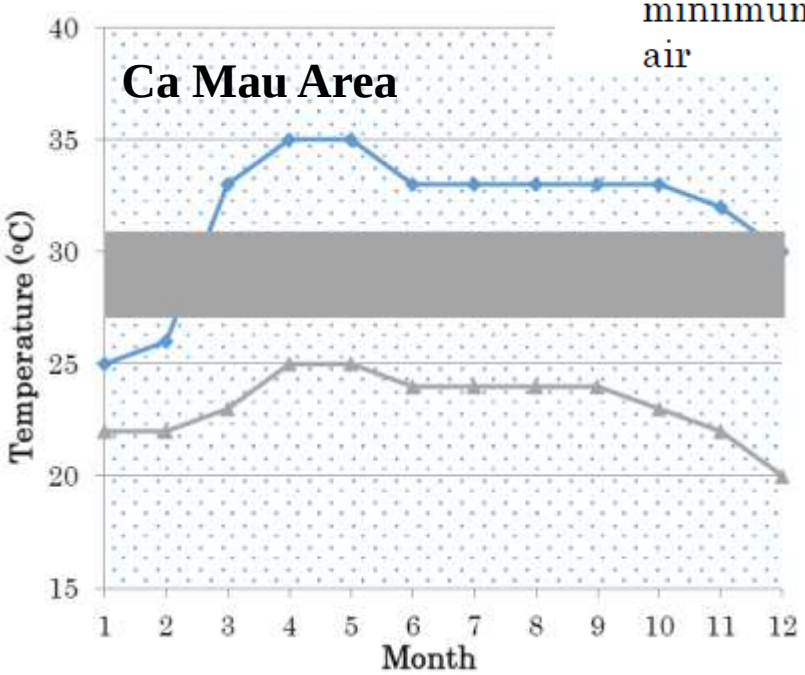


NDWRPI (2011).

Vietnam: Comparison of groundwater and atmosphere

Comparison of Atmospheric and Groundwater Temperatures





Monthly mean maximum of air

Monthly mean of ground water

Monthly mean miniimum of air

In this case, groundwater temperatures are observed at 1m below the water level. Temperature profiles of the wells are not obtained in this region.

Edited by ERIA project authors

Vietnam: Comparison of groundwater and atmosphere

Lessons learned and recommendation

- For GSHP application in tropical regions where only space cooling is needed, the underground temperature should be measured first to ensure the applicability of the GSHP system.
- If the underground temperature is lower than the atmosphere at least in daytime, GSHP may be effective. Thus temperature survey results shows the applicability of a GSHP system in many cities in Thailand and Vietnam.

- The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated.
- To extract the suitable areas for GSHP systems, more detailed investigations including suitability mapping based on hydrogeological data should be conducted.
- As for areas where the GSHP can be applied, a pilot system installation and operation including subsurface temperature monitoring is recommended before distribution of the systems.

Conclusions

- As a result of ERIA Geothermal Project, following matters are emphasized for sustainable use of GSHP systems:
  - **Investigation, evaluation, and monitoring (China)**
  - **Importance of monitoring and its data analysis (Korea)**
  - **Suitability mapping for both closed & open systems (Japan)**
  - **Comparison of groundwater and atmospheric temperatures: Thailand and Vietnam**
- The report of the whole project will be posted on;

  http://www.eria.org