GNS Geothermal Workshop by JOGMEC

温泉との共生のための研究
For co-existence of geothermal business and local hot spring business

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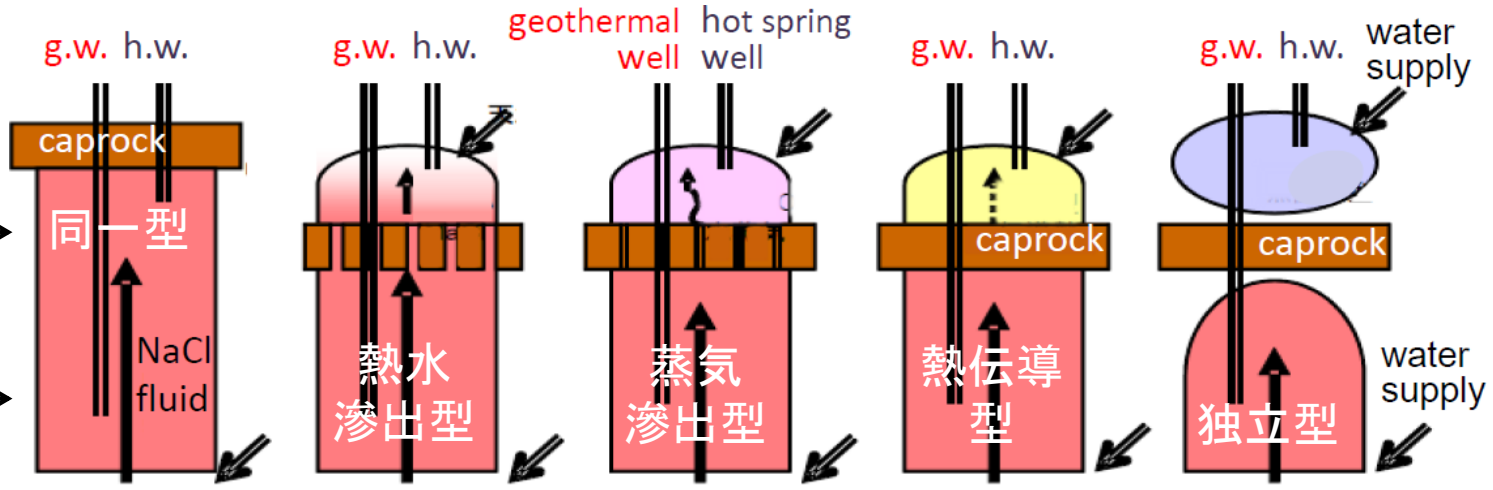
Topics 本日の内容

- “Harmonious geothermal reservoir management system with hot springs”
  温泉共生型地熱貯留層管理システム
- “Advanced Software for harmonious reservoir management system with hot springs”
  温泉共生貯留層管理システム用アドバンスド・ソフトウェア
- Related current researches by AIST Geothermal Team (hot spring monitoring sensor, etc.)
  産総研地熱チームによる現行の関連研究（温泉モニタ用センサー、ほか）

Background of the study

- For developments of new GPPs, agreement with local society is essential. Interference to nearby hydraulic system should be avoided (in Japan, special care for *commercialized hot springs* is needed).
- Logically there should not be a problem if;
  - **Natural heat & fluid recharges and utilization are well balanced, or**
  - **A caprock exists between hot spring aquifer(s) and a geothermal reservoir.**
- A three-year research project **"Development of an advanced geothermal reservoir management system for harmonious utilization with hot spring resources"**(2010-2012) was conducted to indicate a way to exploit geothermal energy without negative impacts on nearby hot springs, sponsored by **Ministry of Environment**.

Possible relation between geothermal reservoir and hot spring aquifer

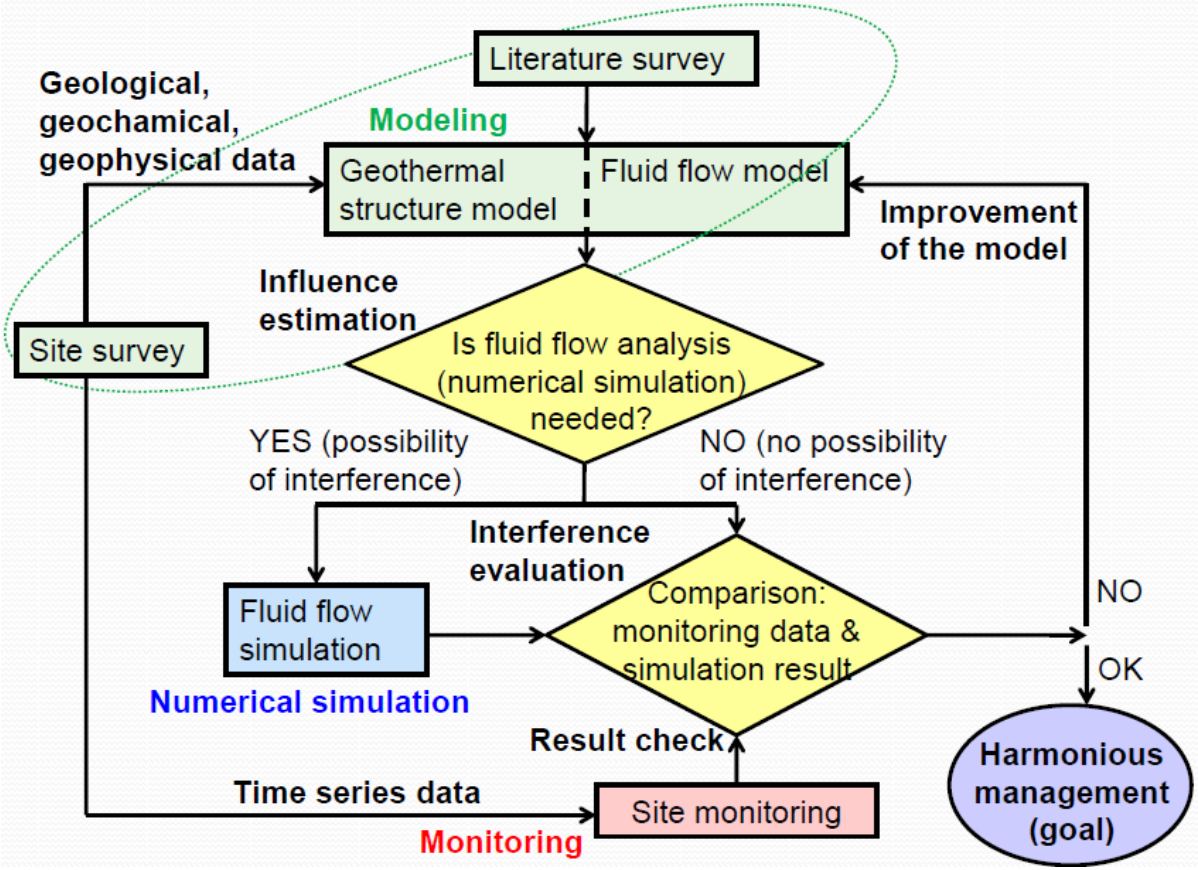


Possibility and type of influence	large F.R., T	medium F.R., T, Che	small Che, T	very small T	none -

T: Temperature, F.R.: Flow Rate, Che: Chemical component

Based on geothermal system modeling, type of relation and possible influence(s) will be identified. **Monitoring parameters will be chosen based on the type**.

Flow chart of "Harmonious Geothermal Reservoir Management System with Hot Springs"



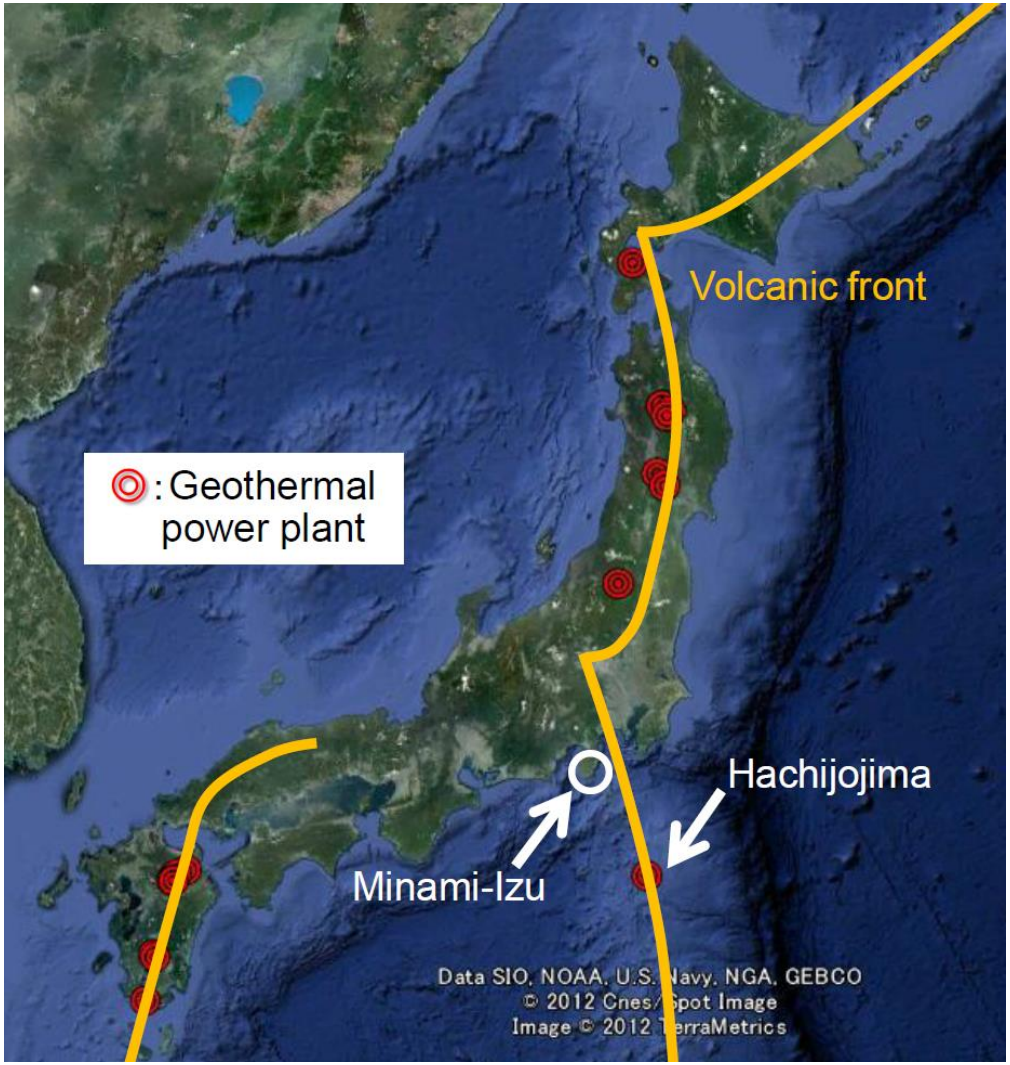
Basic technical components:

- •Geothermal modeling
- •Numerical simulation
- •Monitoring

are the same as normal geothermal exploration.

Special feature is that all modeling, numerical simulation and monitoring **include** hot spring well(s) and hot spring aquifer(s).

Two Model Fields of the project



Hachijojima Island

- Hachijojima GPP (3MW) has been in operation since 1999.
- Case study with full data set from GPP

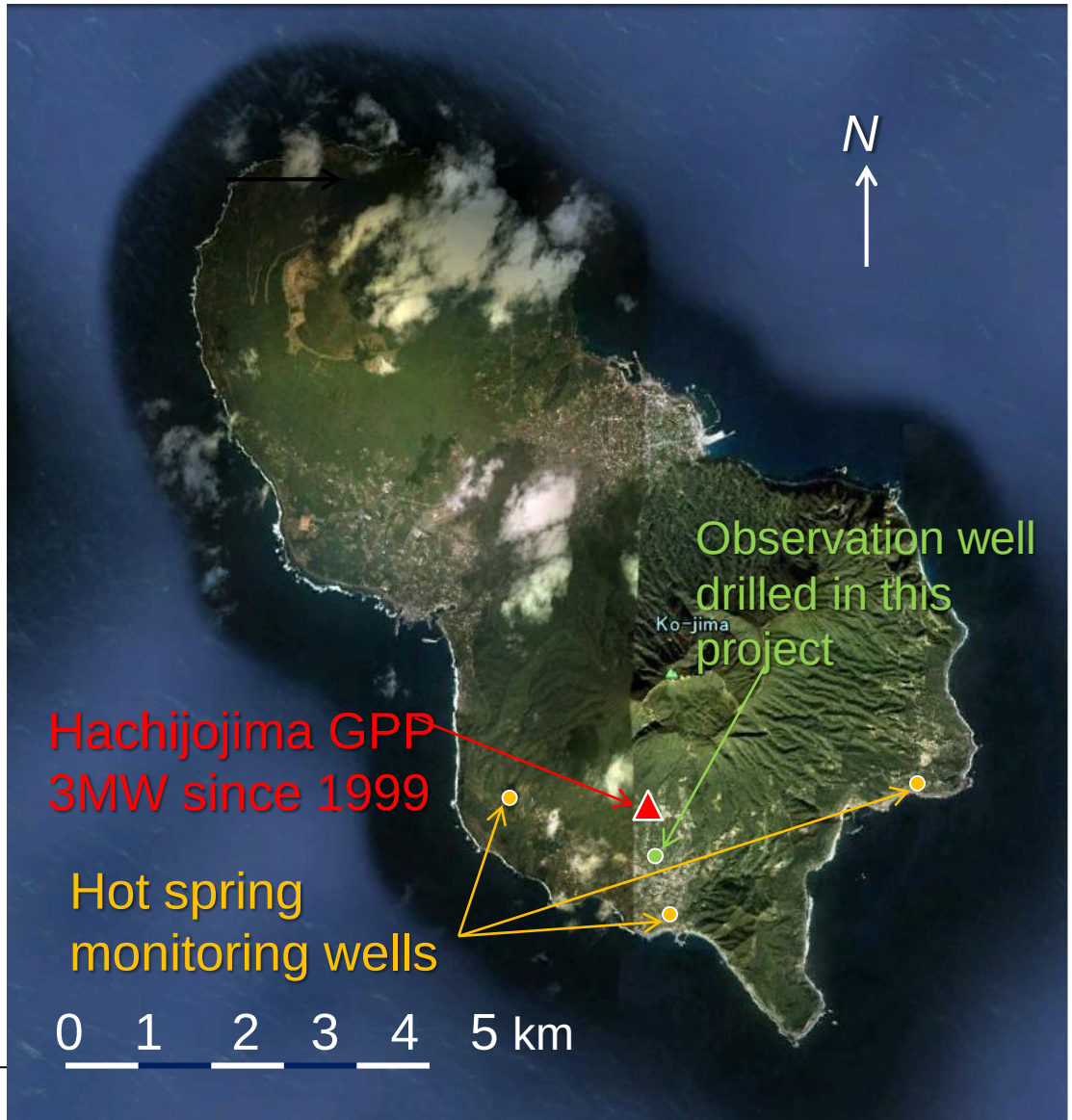
Minami-Izu

- No GPP, but many hot spring wells exist in the area.

(No development plan yet)

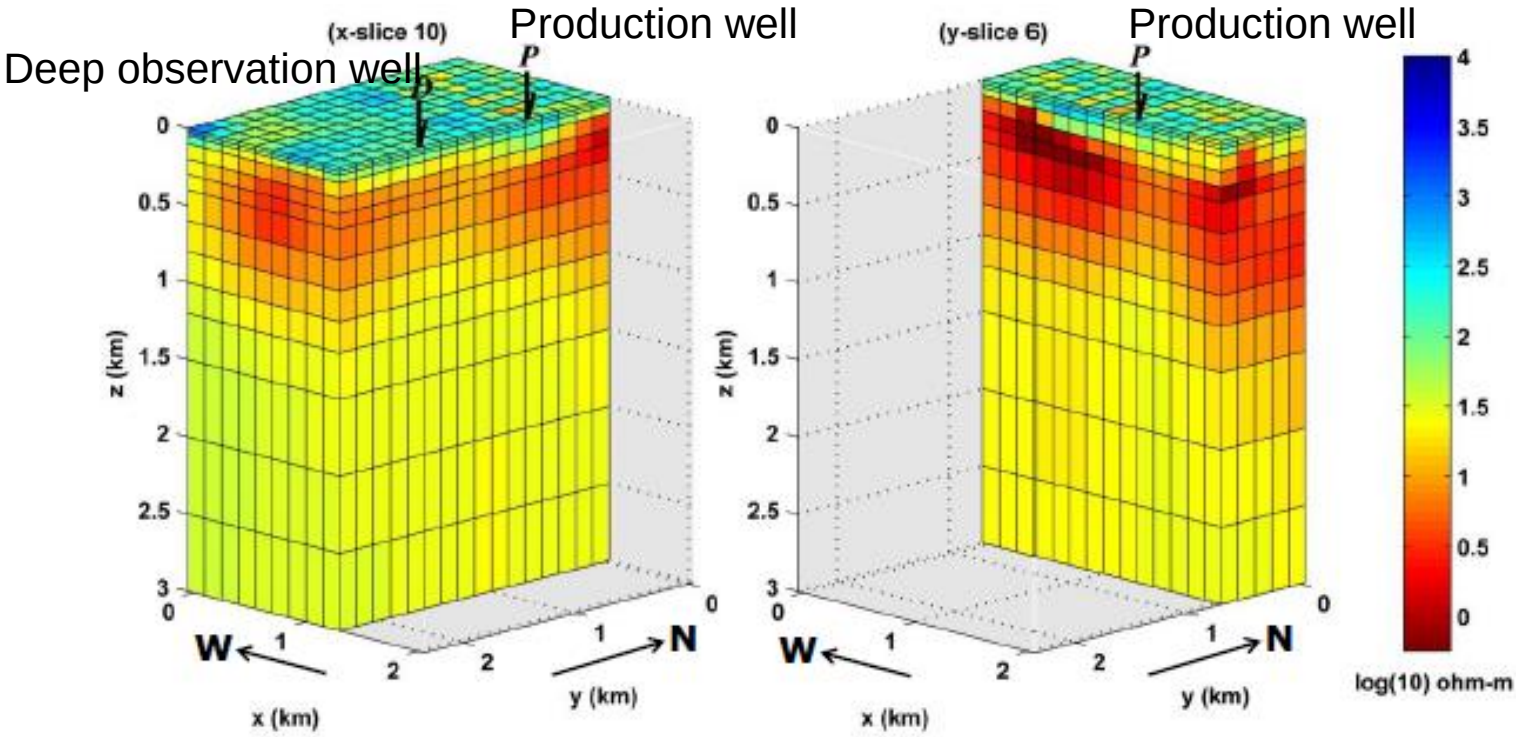
- Case study with limited data

Studies at Hachijojima



- Volcanic island
- Operational data of the GPP are available.
- Detailed numerical simulation had been done for power production.
- Additional geological, geochemical and geophysical study has been done to extend numerical model to cover hot spring aquifers.

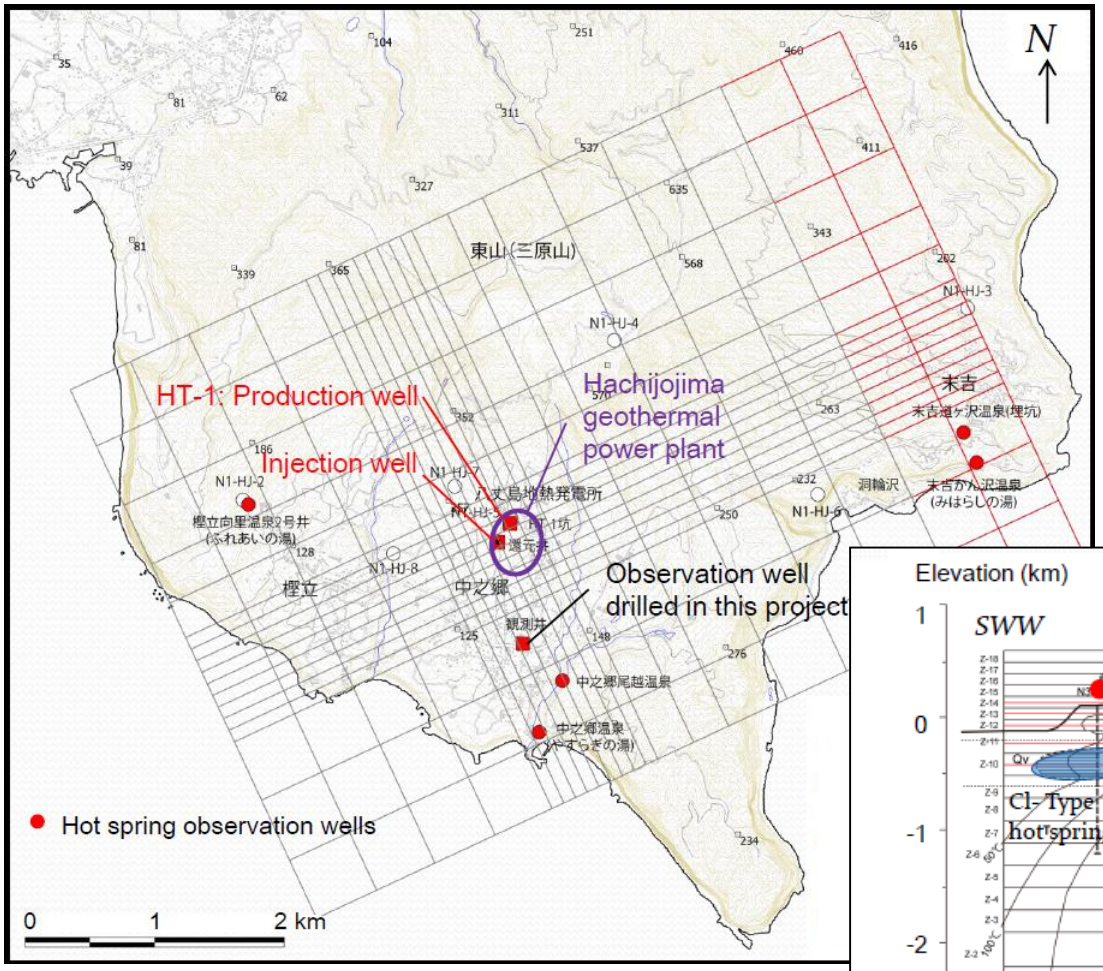
Studies at Hachijojima



3D Resistivity model of Hachijojima area as a result of 2D inversion of MT and AMT data

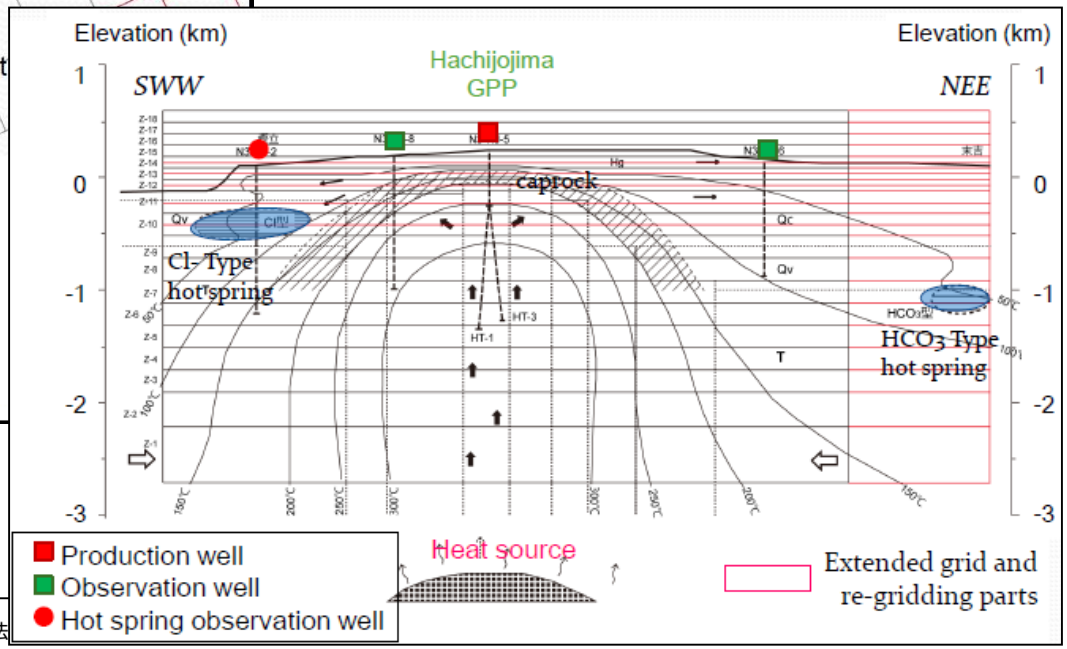
- Shallow part is re-constructed with higher resolution.
- Low resistivity zone is corresponding to caprock.

Studies at Hachijojima



Hachijojima 3D reservoir model was:

- Extended to cover hot spring aquifers, and
- Re-gridded to re-construct shallow aquifer level.

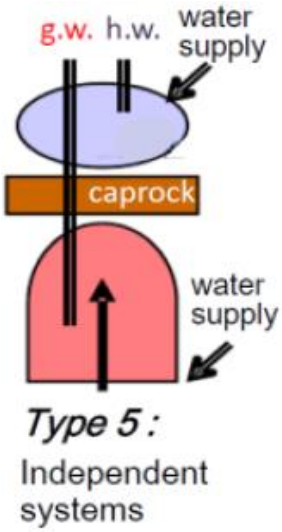


Numerical simulation

Studies at Hachijojima

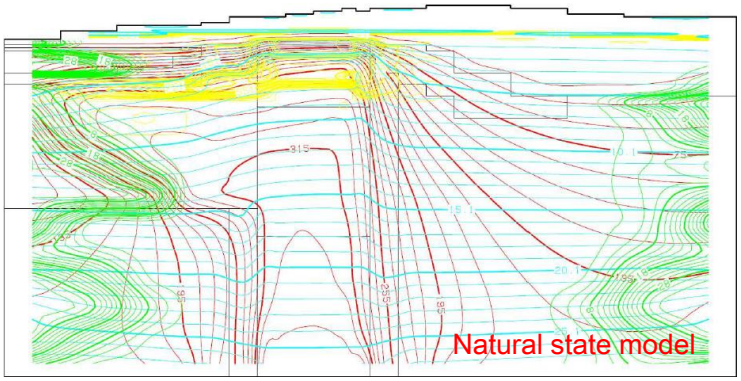
Simulation result shows

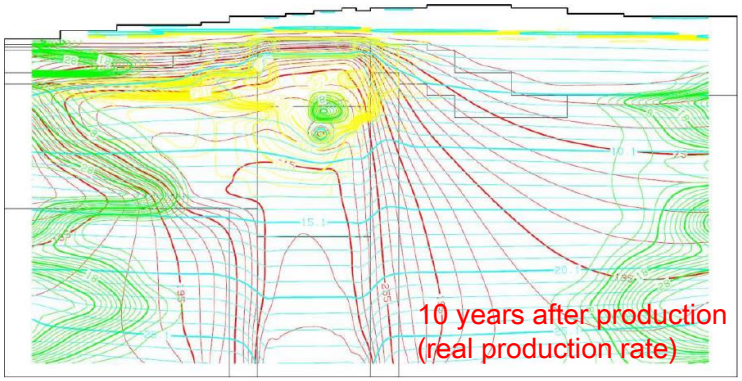
- Even 10 times bigger production than real production does not affect on shallow aquifer.

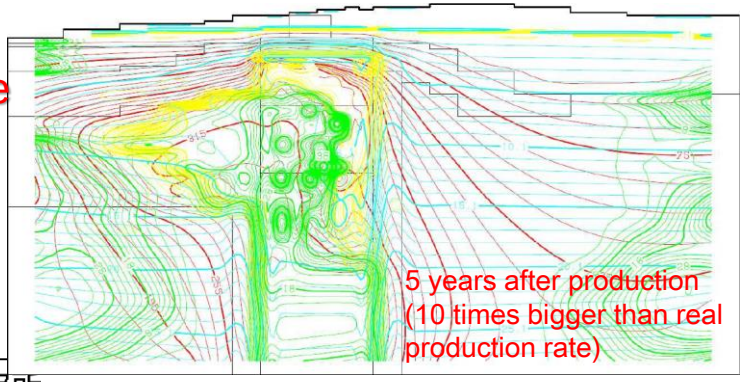


Type 5 :
Independent systems

It is consistent with Geothermal Modeling result, suggesting this system is Type 5. (independent systems)





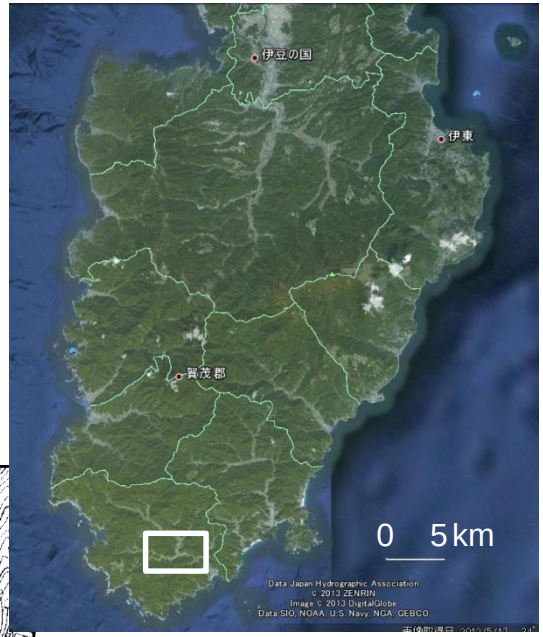


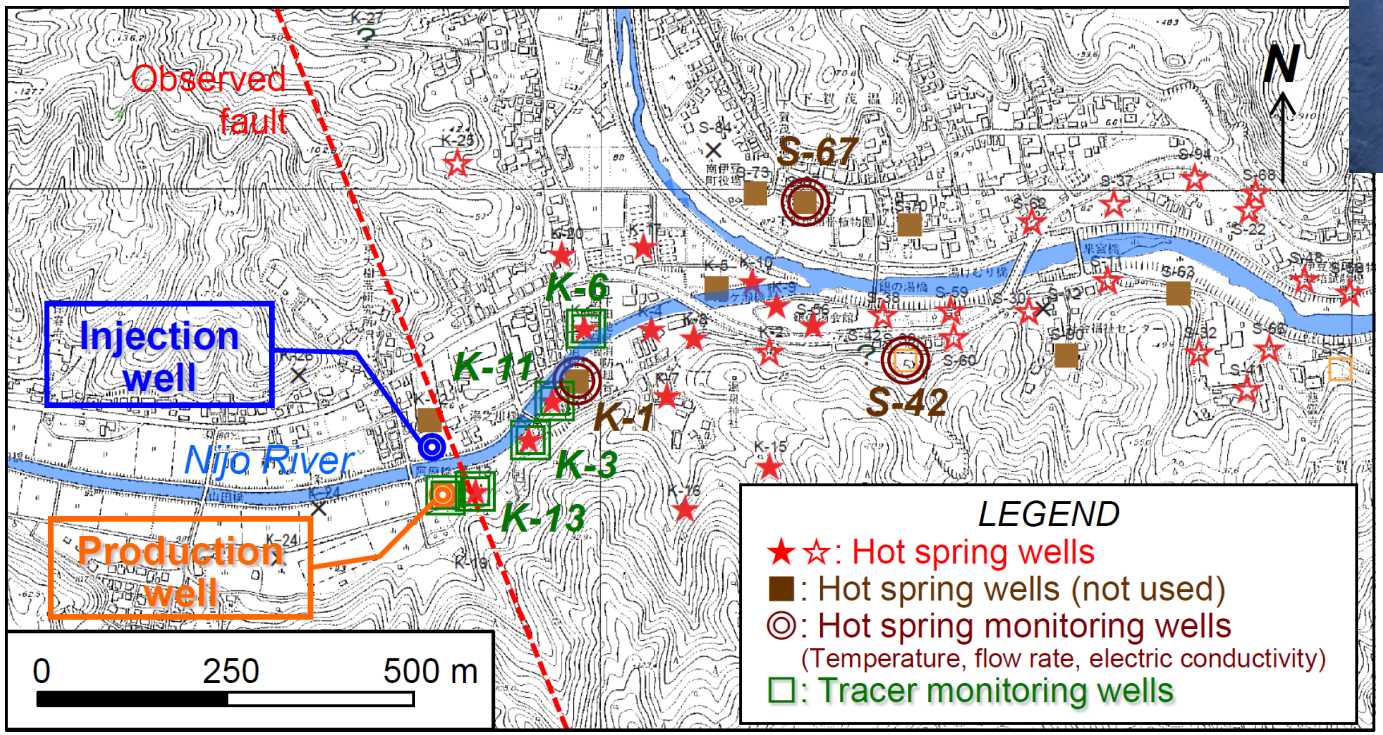
Red: temperature
blue: pressure,
green: salinity
yellow: steam saturation

Numerical simulation

Studies at Minami-Izu

- Several hot spring wells (150–200 m deep, 100°C) exist in the east of a fault.
- No information is available for deeper part.
- A test production well (695m) and an injection well (200m) are drilled in this project to investigate connection between deeper and shallower parts.

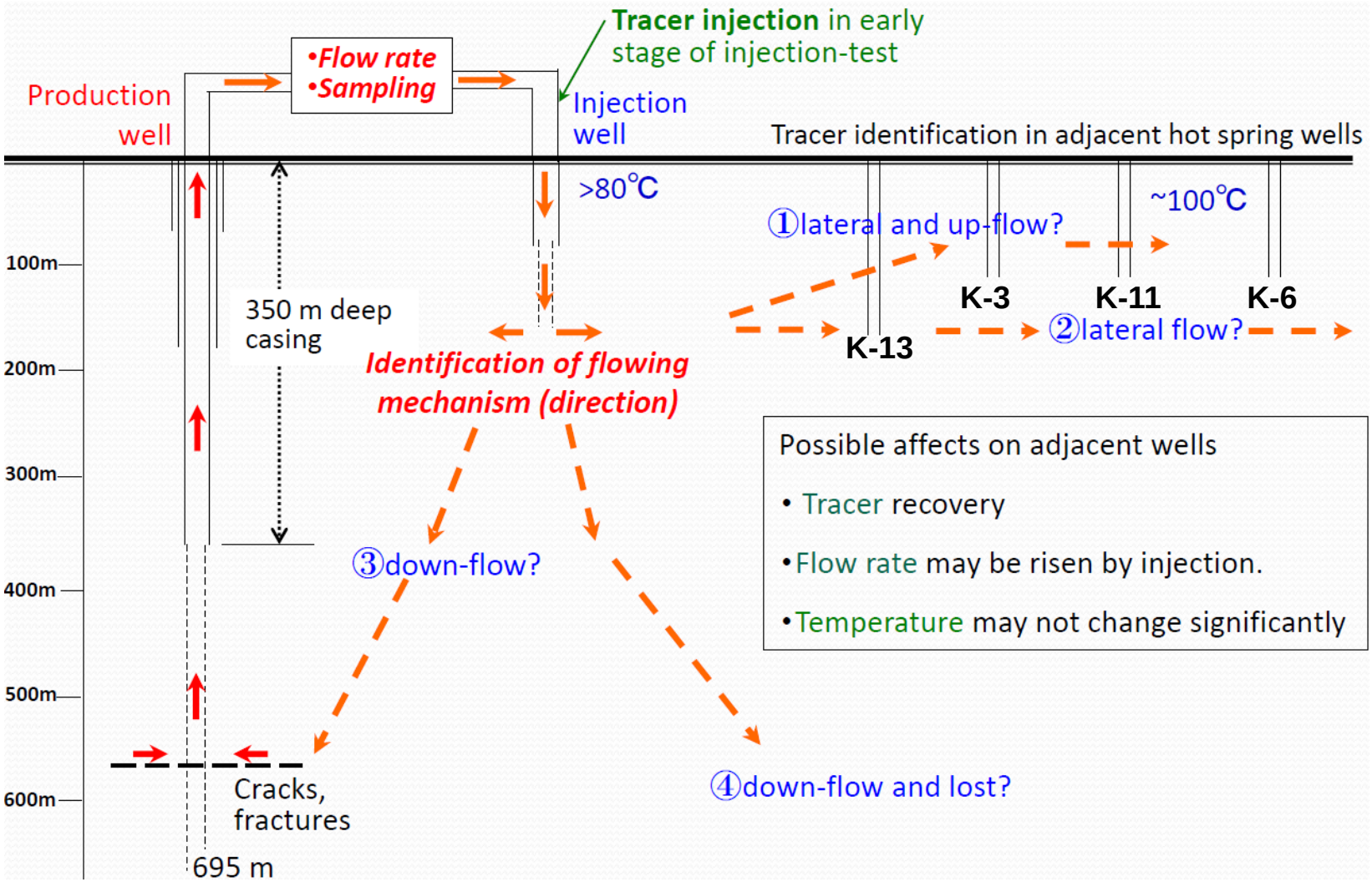




Location of wells in Minami-Izu

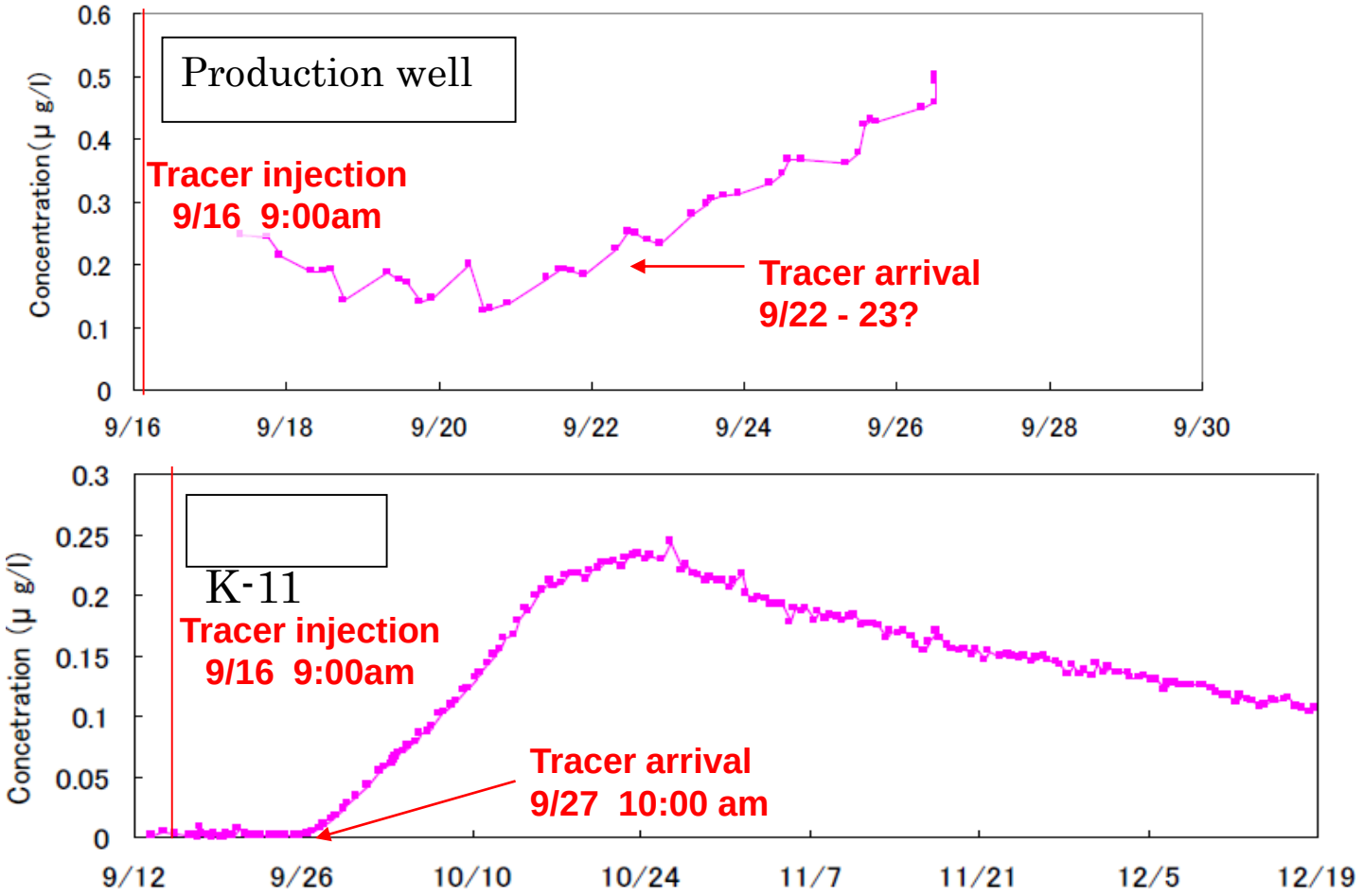
- No hot-spring-monitoring has been done in this area.
- So we monitored a hot spring well to identify its natural fluctuation in temperature, water level and electric conductivity.

Studies at Minami-Izu



Production-injection test and tracer test in Minami-Izu

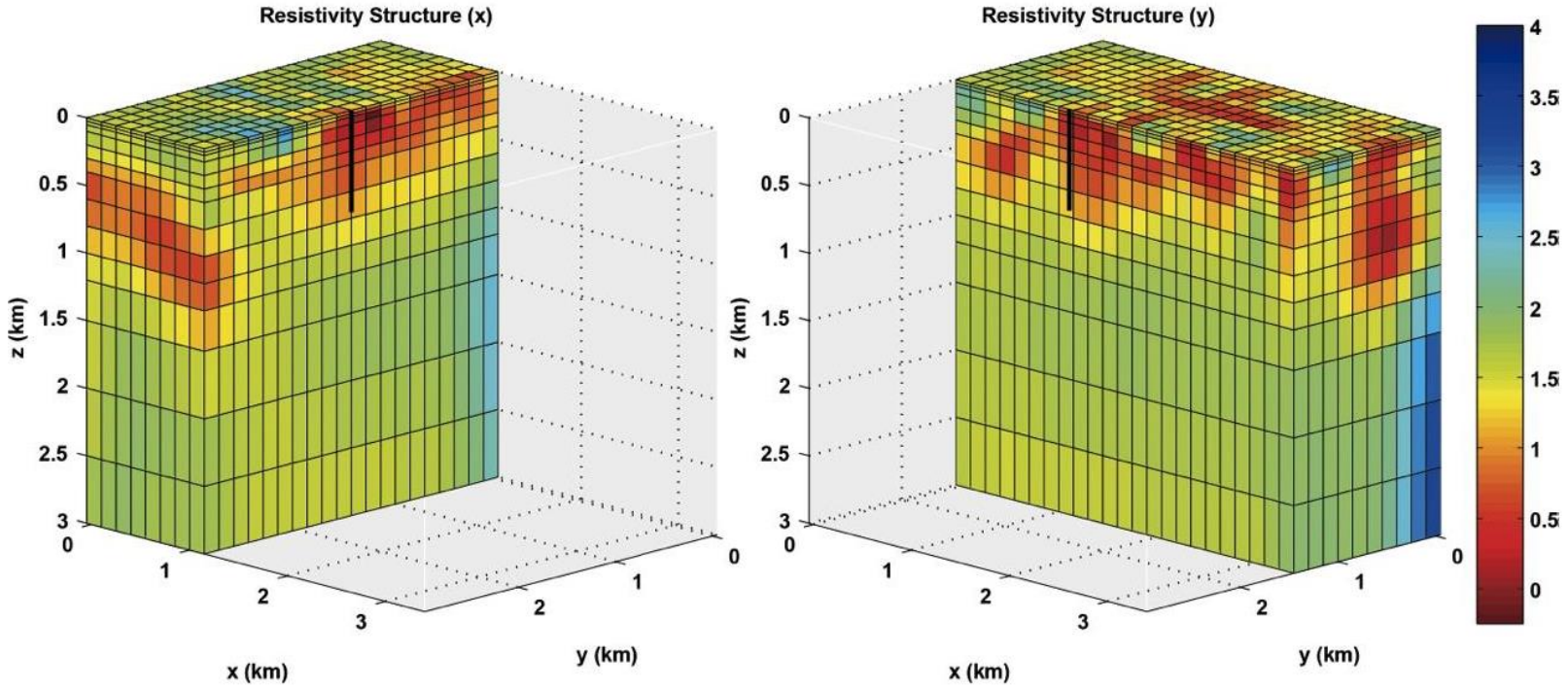
Studies at Minami-Izu



Tracer recoveries

Tracer from shallow injection well reaches to deep production well earlier than shallow K-11, suggesting vertical hydraulic connection.

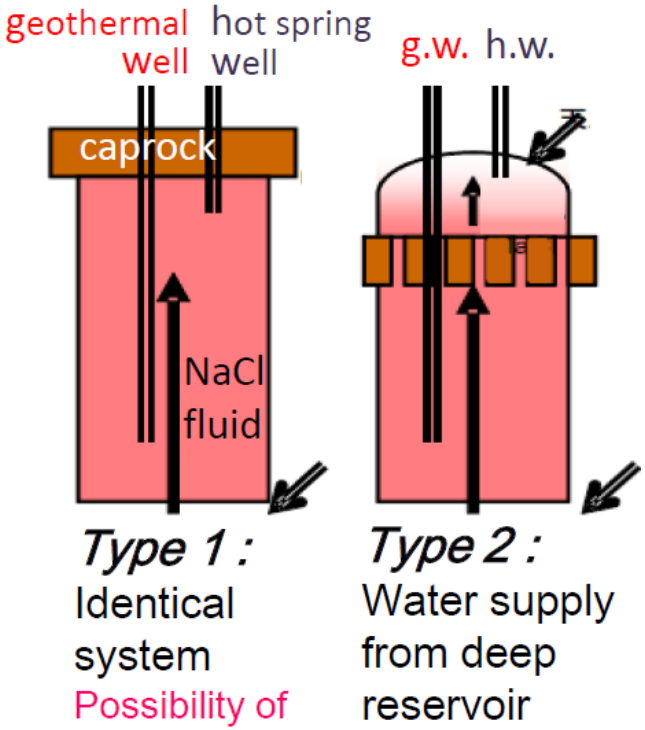
Studies at Minami-Izu



3D Resistivity model of Minami-Izu area as result of 2D inversion of MT and AMT data

- Shallow part is re-constructed with higher resolution.
- Low resistivity zone is corresponding to reservoir.
- No caprock exists between hot spring aquifer and deeper part =suggesting vertical hydraulic connection.

Studies at Minami-Izu



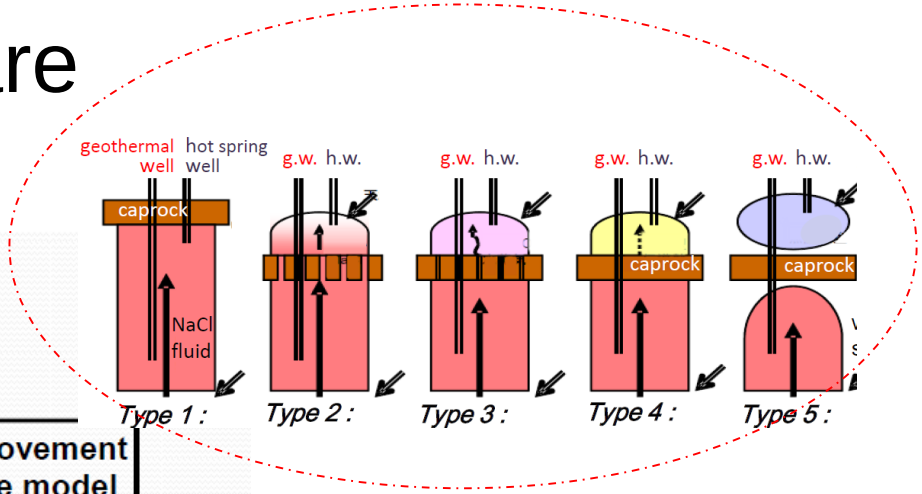
Another result

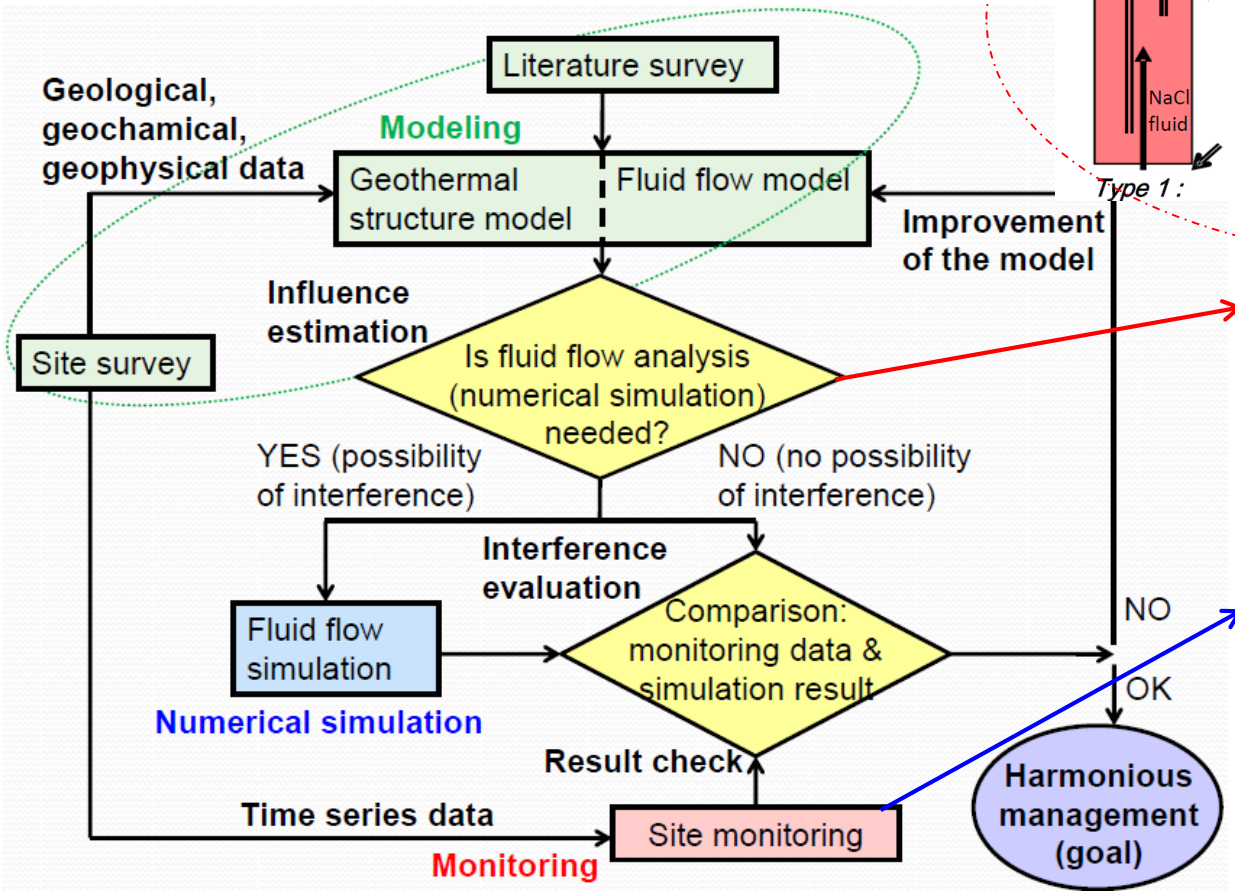
- The hot-spring-monitoring result shows fluctuation in water level and temperature due to pumping, precipitation, seasonal change, etc.
- Importance of long term monitoring should be emphasized to detect impact of any external causes.

Tracer test, resistivity survey, etc. suggest strong hydraulic connection of shallower and deeper parts.

•This system is Type 1 or 2 at least to the depth of 700 m.
•In case of geothermal development, careful monitoring of discharge and recharge balance is needed.

System support software (proto-type software)





Function 1: タイプ判別
Simplified type analysis by hot spring chemistry

Function 2: 干渉の評価
Interference evaluation by time series analysis

*Both Functions use hot spring data only (no geothermal data).

Some improvements are needed for practical use. -> It'll be explained in the next section, "**Advanced Software for harmonious reservoir management system with hot springs**.

Summary of "Harmonious geothermal reservoir management system with hot springs"
"温泉共生型地熱貯留層管理システム"のまとめ

- An integrated geothermal reservoir operation system (scenario) for adequately controlled utilization was developed to conduct geothermal development without interference to nearby hot springs.
- The system consists of three parts: Geothermal modeling, Numerical simulation and Monitoring.
- The system was applied to two model fields. The results showed that the Minami-Izu field is Type 1 or 2 (identical system or water supply from deep reservoir) while the Hachijojima field is Type 5 (independent type).
- Importance of long term hot-spring-monitoring is emphasized to detect impact of external causes including geothermal production.
- A proto-type system support software, which helps "type analysis" and "time series analysis" is developed, which should be improved.

➢ *Acknowledge: this project was sponsored by Ministry of Environment.*

Advanced software for harmonious reservoir management system with hot springs
温泉共生貯留層管理システム用アドバンスド・ソフトウェア

1. Introduction
2. Function 1 : Type analysis
   - Type of relationship between hot spring aquifer and geothermal reservoir
3. Function 2 : Time series analysis
   - Correlation analysis with any other data
   - Student T-test
4. Discussion and Summary

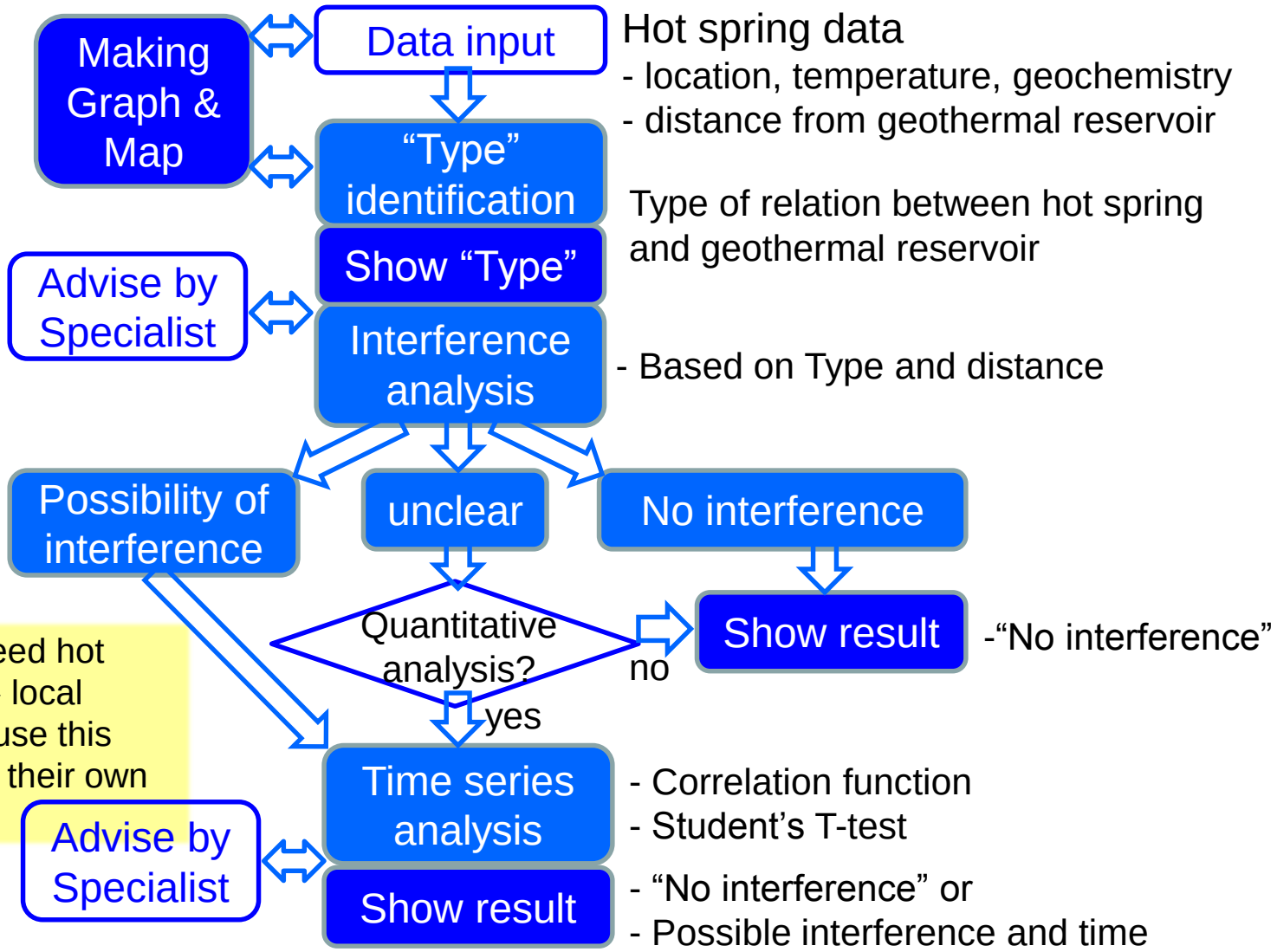
Introduction: Concept of the Advanced Software
for harmonious reservoir management system with hot springs

- For management of hot spring system, monitoring of 1) *flow rate*/water level, 2) *temperature*, and/or 3) *chemical component* is needed.
- Among many causes of hot spring fluctuation in above three items, internal cause (ex., pumping of hot spring itself, interference of hot spring wells) are most likely causes. Geothermal development is **one of** external causes.
- Interference of geothermal development on hot springs;
  - is controlled by *hydrological shielding ability of geological formation between them* and *balance of fluid and heat recharge and extraction*.
  - should be assessed in duration of few months to few years.
- *Hydrological shielding ability* may be identified by 3D positioning of hot spring and geothermal reservoir and formation mechanism of hot spring.
- If the shielding ability is identified to be insufficient, interference should be predicted by time series analysis of monitoring data.

Introduction: Flow chart of the Advanced Software
for harmonious reservoir management system with hot springs

Function 1
Type analysis
(interference prediction)

Function 2
Time series analysis
of interference



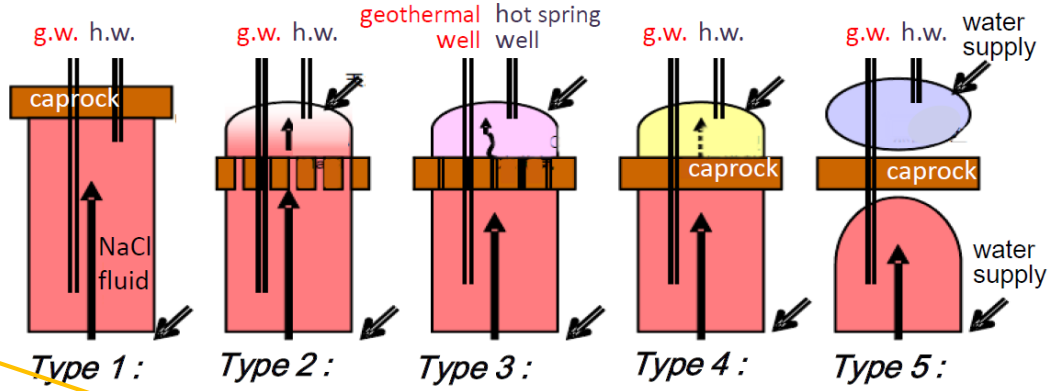
*Basic functions need hot spring data only → local communities may use this software to protect their own hot springs.

Function 1 *Type analysis* (interference prediction)

Proto-type software

- Type is **roughly** identified by the characteristic of hot spring.

Threshold shown in GRSJ (2010), based on 4,536 hot spring data in GSJ (2005)

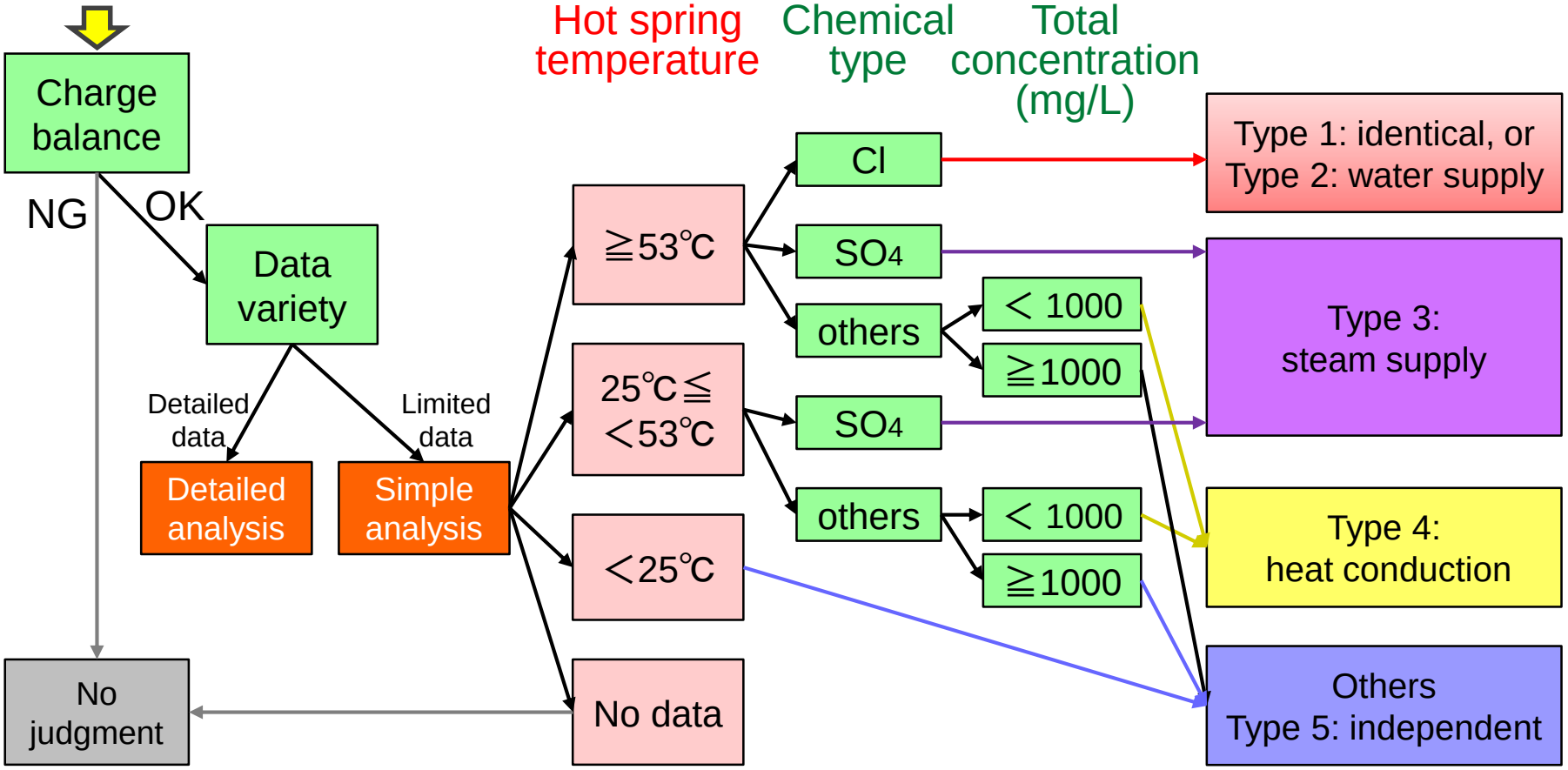


Type	Relation: hot spring & geothermal reservoir	Possibility of Interference	Characteristics of hot spring	Required monitoring (Possible interference)
Type 1	Identical system	High	Cl^- /total anion >80% Temperature >53°C	Flow rate (Temperature)
Type 2	Water supply from deep reservoir	Medium	Cl^- type Temperature >53°C	Flow rate (Temperature) (Electric conductivity)
Type 3	Steam supply from deep reservoir	Low	SO_4^- type Temperature >53°C	Chemical Component (Temperature)
Type 4	Heat conduction	Very low	Total ions < 1000 mg/L Temperature >25°C	(Temperature)
Type 5	Independent system	None	No particular type	No

Function 1 *Type analysis* (interference prediction)

Proto-type software: Flow chart of Function 1

Simplified type analysis by hot spring chemistry

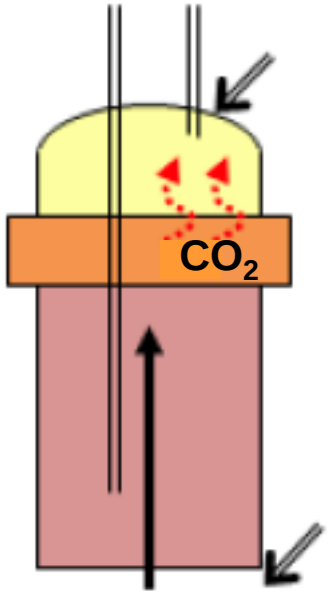


Problem: wrong judgment for hot springs with “dominant CO_2“ or with “volcanic gas.

Function 1 *Type analysis* (interference prediction)

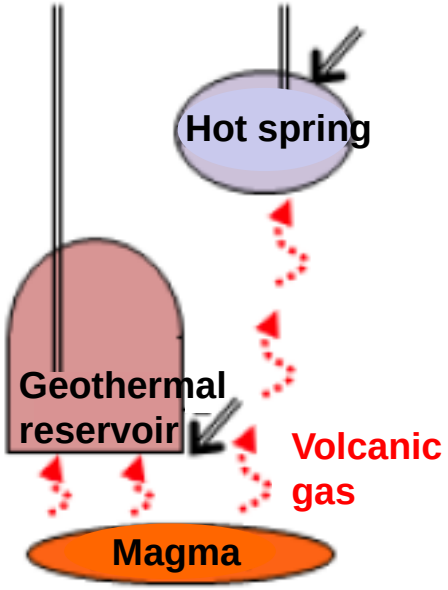
Improvements in the advanced software

- Two types are newly added for a better type analysis.



CO_2 supply (from rock)

- HCO_3^- is so dominant that ratio of Cl^- and SO_4^- cannot be evaluated.
- Interference Type is not predictable. (It could by any of Type 1-5)

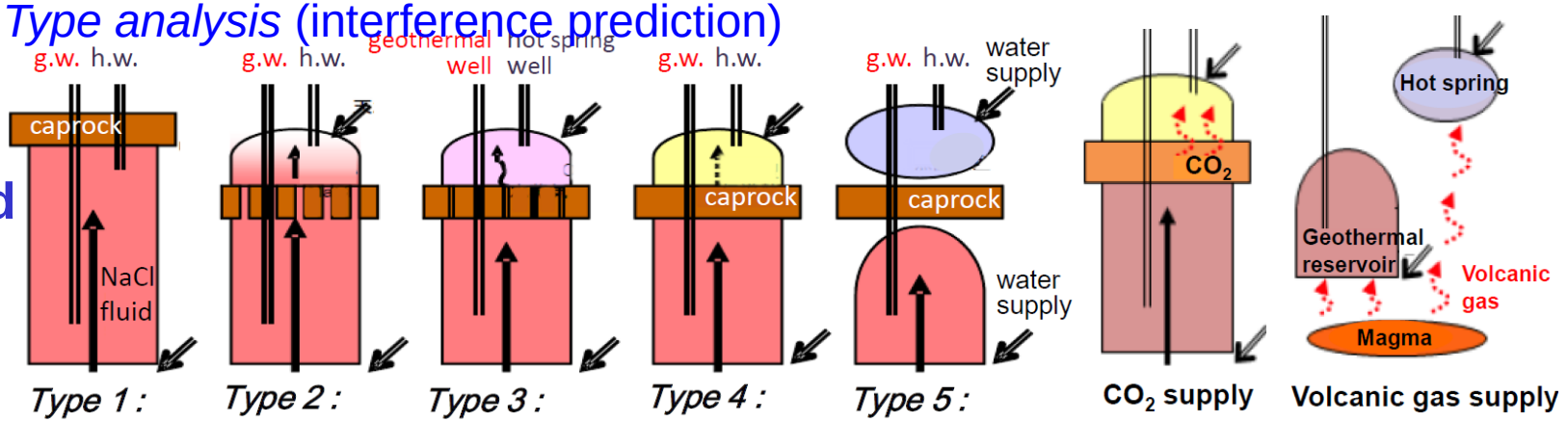


Volcanic gas supply

- $Cl^- > SO_4^-$, but not Type 1 or 2.
- Identified by low pH.
- No interference (Type 5).

Function 1 *Type analysis* (interference prediction)

Advanced software



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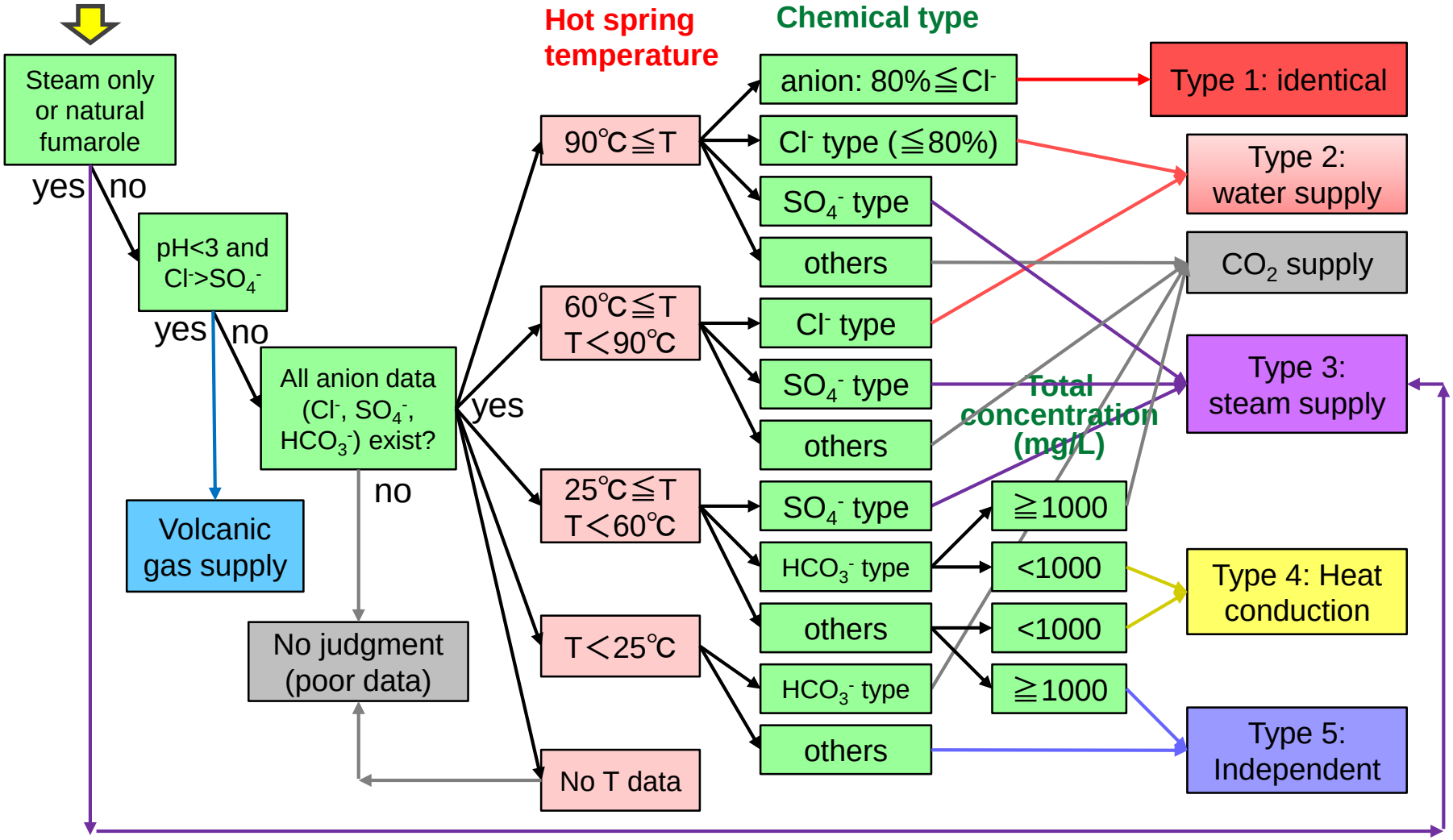
Type 3	Steam supply from deep reservoir	Low	SO_4^- type	Chemical Component (Temperature)
	CO_2 supply	unpredictable	HCO_3^- type	All
Type 4	Heat conduction	Very low	Total ions < 1000 mg/L Temperature >25°C	(Temperature)
Type 5	Independent system	None	No particular type	No
	Volcanic gas supply (independent)	None	pH<3 and Cl^->SO_4^-	No

Function 1 *Type analysis* (interference prediction)

Advanced Software: Flow chart of Function 1

Simplified type analysis by hot spring chemistry



Function 2 *Time series analysis* of interference

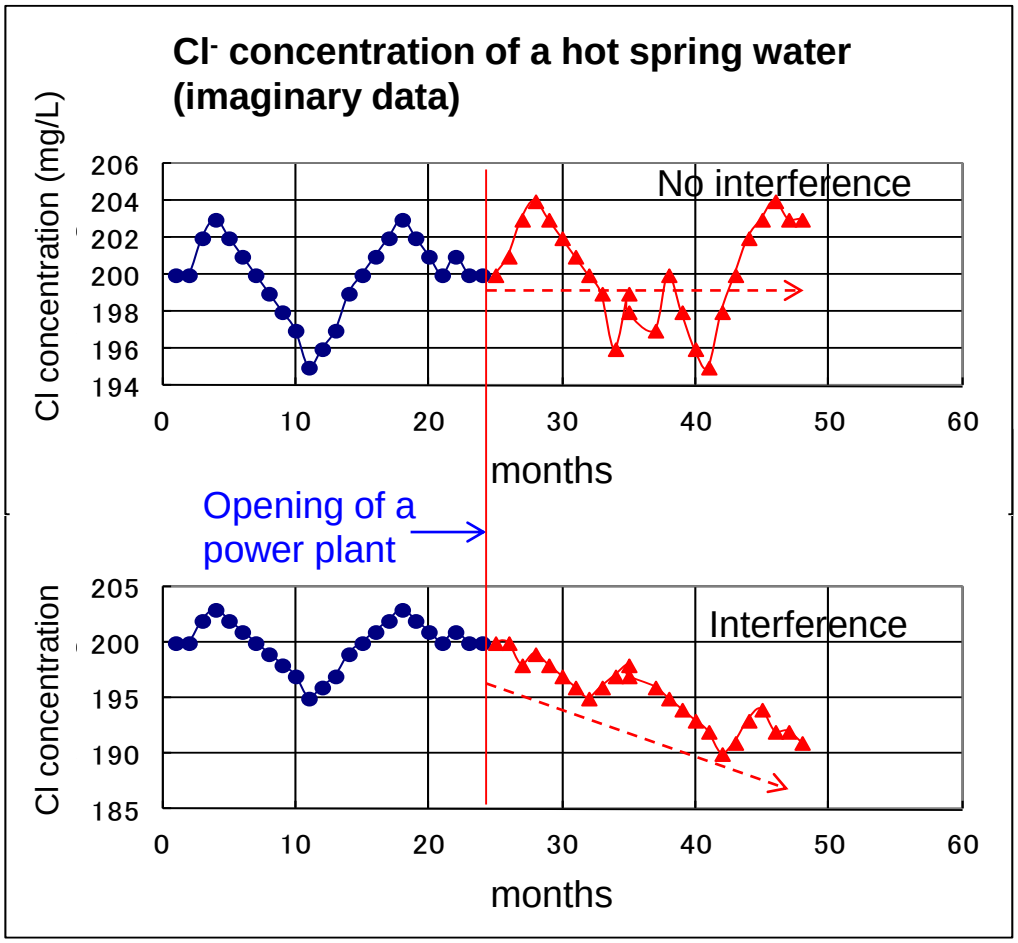
Time series analysis

- Correlation function with any time series data, such as meteoric or geothermal reservoir data (if available) can be calculated.
- Influence of geothermal development or any other cause can by analyzed by *Student's T-test*, by calculating the change of fluctuation amplitude after a specific time line.

Improvements in the *advanced software* is done mainly for the user interface of data input.

Function 2 *Time series analysis* of interference

Student's T-test



Time series analysis
Student's *T*-test

	t-value	judgment
Upper figure	-0.365	Within natural perturbation
Lower figure	6.202	Out of natural perturbation

If within natural perturbation,
$-2.013 \leqq t \leqq 2.013$.

Lower figure is considered to have interference.

Discussion: cautions for using the software

- Flow rate (water level) of **a hot spring** may mislead the result. Total flow rate of **hot springs** from the same aquifer should be monitored.
- If a trend change is observed in a time-series of hot spring data, mutual interaction of hot springs should be investigated first.
- Then if mutual interaction cannot explain the observed data, external causes including geothermal operation should be investigated.
- Possibility of interaction by geothermal reservoir operation may generally be indicated by Cl^- ion concentration.
- If a sudden pressure drop or continuous pressure decline of the geothermal reservoir is observed, monitoring of nearby hot spring should be carefully done.

Summary of “Advanced Software”

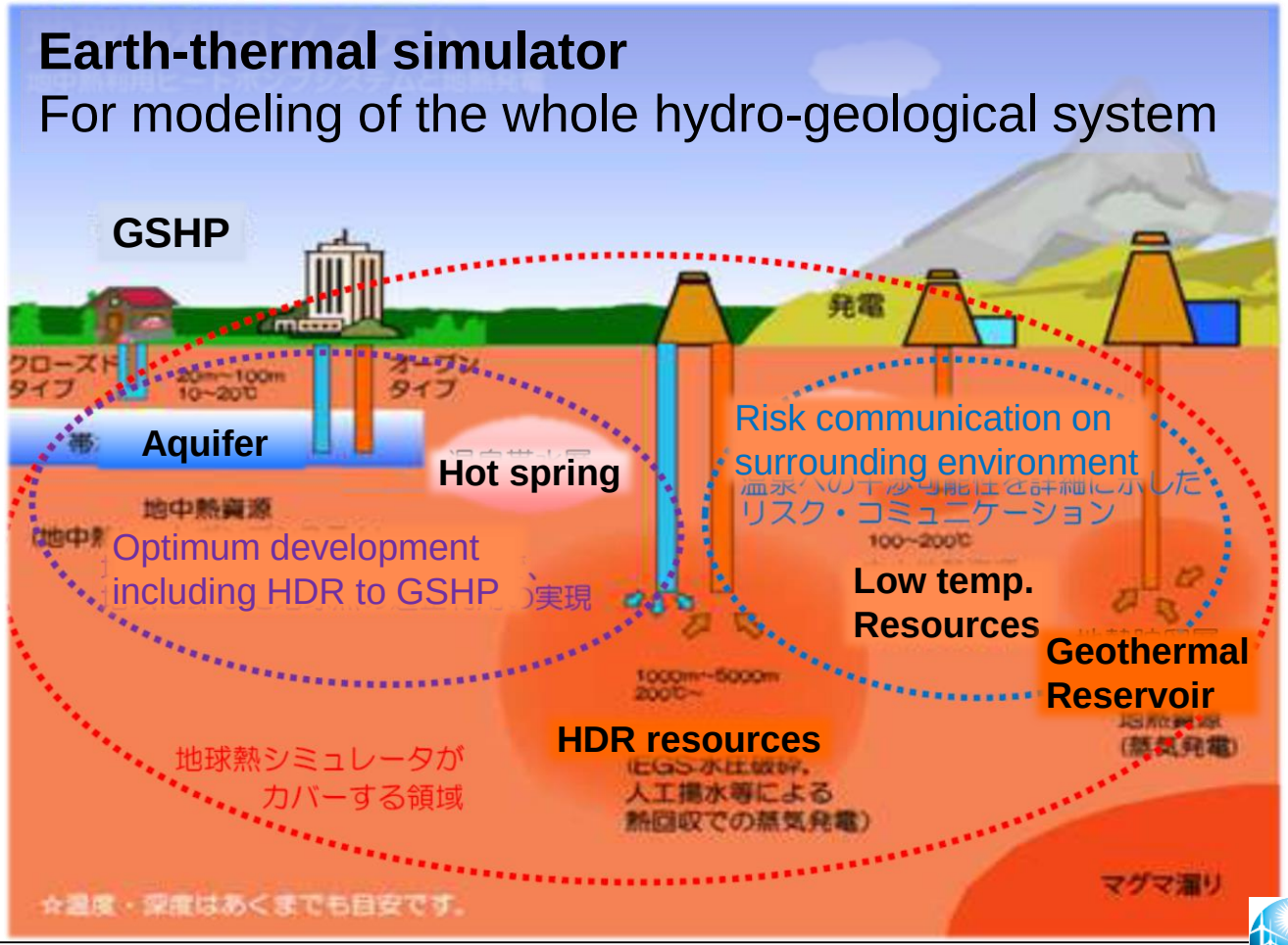
- The newly developed “Advanced Software” analyzes the possibility and type of interference of geothermal development onto near-by hot springs based on geochemistry of the hot springs only.
- The major improvement from the proto-type software is consideration of volcanic-gas-supply type and CO_2-supply type.
- Time series analysis of hot spring data can also be done to detect the trend change in the data series.
- Special feature of the software is that basic functions require hot spring data only so that local communities may use it to protect their own hot springs.
- Authors hope the software encourages geothermal development by supporting understanding of local community.

Related current researches by AIST Geothermal Team (hot spring monitoring sensor, etc.)
産総研地熱チームによる現行の関連研究（温泉モニタ用センサー、ほか）

- Earth-thermal simulator
- Development of a sensor for hot spring monitoring
- Simulated hot spring water generator

Development of Earth-thermal simulator （地球熱シミュレータの開発）

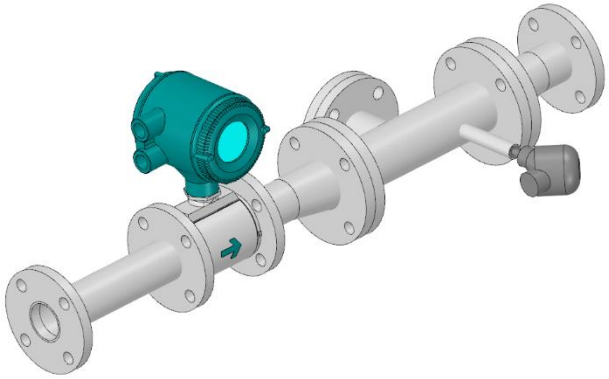
By numerically simulating various phenomenon which occur during geothermal development, **sustainable and optimum development scenario**, and **possible interference onto nearby hot springs** may be clarified.
It would help to find a development scenario with less impact to environment.



Searching for Optimal and Sustainable Geothermal Development Methods with Less Environmental Impact, …

Development of a sensor for hot spring monitoring
（温泉モニタリングセンサの開発）

sponsored by NEDO



- Flow rate
- Temperature
- Electric conductivity

➢ Target is a reasonable and compact system.

➢ A proto-type sensor is under test at a real hot spring (Obama, Nagasaki).

Simulated hot spring water generator
（温泉システム模擬装置）

Hot spring water of various spring qualities can be simulated.
It may be used for the evaluation of a hot spring monitoring sensor, experimentation of a hot spring power generation, etc.