Advanced Geothermal Reservoir Evaluation

Sustainable System Research Laboratory, CRIEPI

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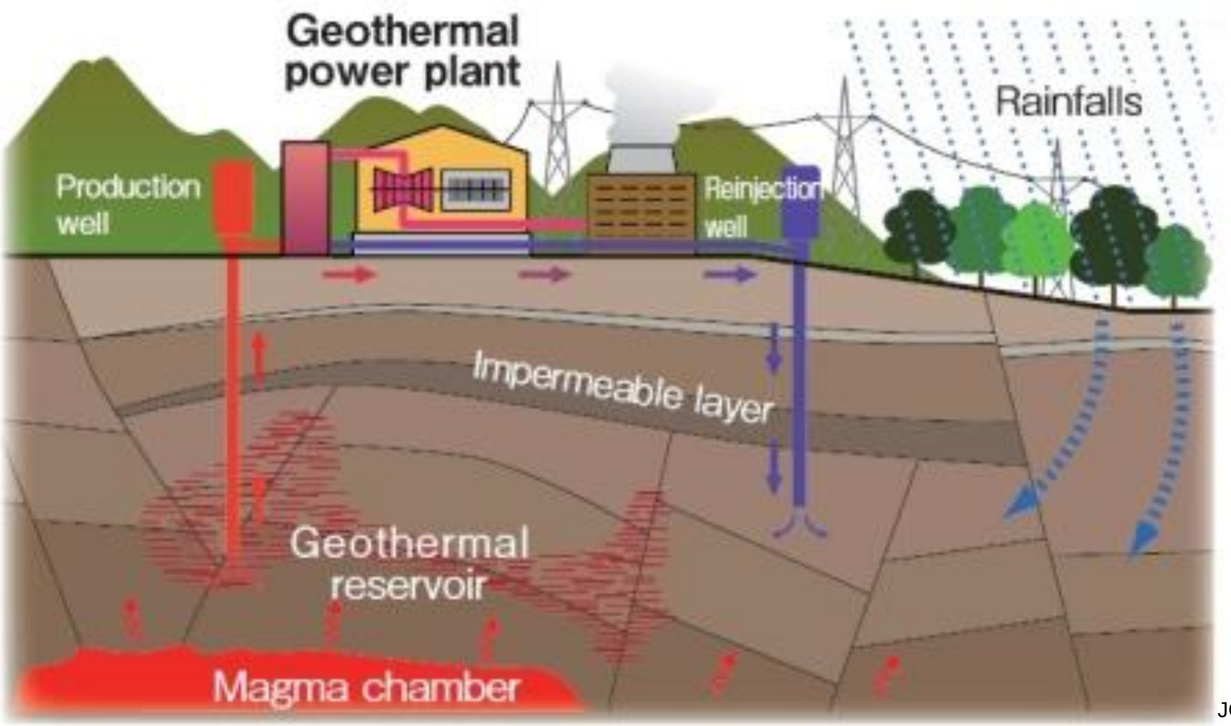
CRIEPI
Central Research Institute of Electric Power Industry

Outline

- Overview of geothermal energy
- The flow of reservoir evaluation
- New approach to evaluation using gravity

Geothermal energy



JOGMEC

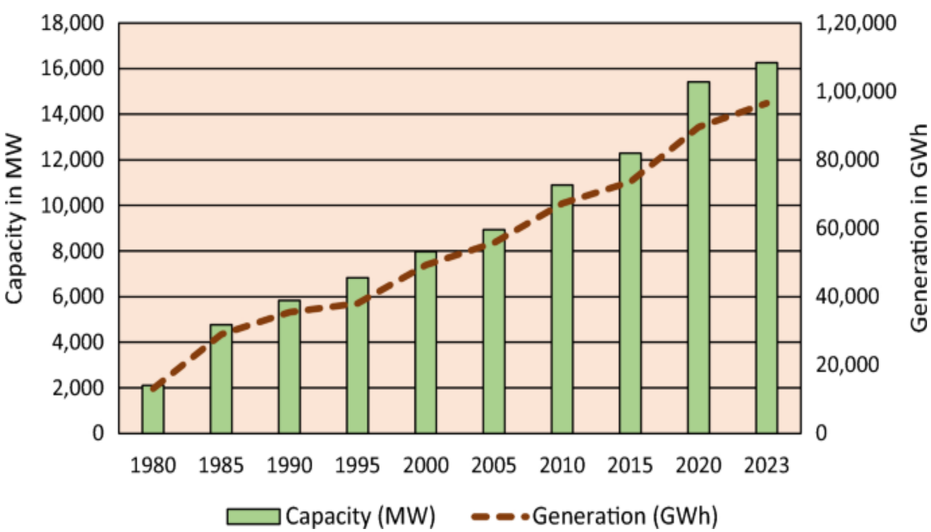
Renewable

Baseload

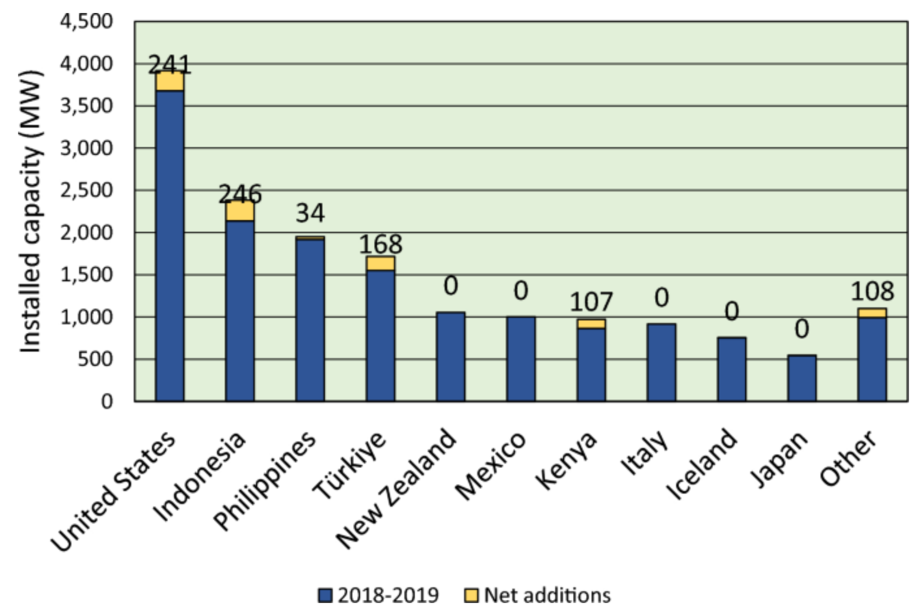
Domestic

JOGMEC:(https://www.jogmec.go.jp/english/geothermal/geothermal_10_000004.html)

Global Trends



World geothermal capacity and electric generation between 1980 and 2023*



Top ten countries with the highest geothermal installed capacity in 2020–2021, and net additions in MW over the last 3 years*

*Gutiérrez-Negrín, L.C.A. (2024). https://doi.org/10.1186/s40517-024-00290-w

Taiwan

The main geothermal power parameters for Taiwan in 2021(Gutiérrez-Negrín, 2024)

- Geothermal fields in operation:	3
- Production wells:	6 (estimated)
- Capacity (MW)	6.6
- Generation (GWh)	25.0
- Capacity factor (%)	43.3%
- Average production per well (MWh):	0.41

Geothermal power plants in Yilan

- Qingshui：4.2MW, 2021～
- Renze：0.84MW, 2023～

THINK GEOENERGY NEWS GEOTHERMAL PLANT MAP RESEARCH PUBLICATIONS EVENTS WEB

The event was also live-streamed and the recording can be accessed via this link.

Panel discussion at the 2024 Taiwan International Geothermal Conference (source: ThinkGeoEnergy)

During the opening of the event, Deputy Economy Minister Tseng Wen-sheng emphasized that geothermal energy is an essential component of the nation's Net Zero 2050 goals. The Minister also stated Taiwan's ambitious goals of building 20 MW of installed geothermal power capacity by 2025 and scaling this up to 200 MW by 2030 and 2 GW by 2040.

Building towards this goal, there are currently 24 geothermal projects in operation or under development across Taiwan, mainly in the Datunshan District, Qingshui and Renze in Yilan, Ruisui in Hualien, and Hongye in Taitung.

https://www.taipower.com.tw/2764/2804/2805/60219/normalPost

https://www.thinkgeoenergy.com/setting-the-stage-for-taiwans-geothermal-sector-at-the-tigc-2024/

Development process

Site screening (5-300 km^2) → Survey (5-10 km^2) → Reservoir evaluation (3-4 km^2) → Permits/ licenses → Construction → Operation

Site screening (5-300 km^2)
- ◆Survey
  - Remote sensing
  - Geology
  - Geophysic
  - Geochemistry
  - Well test

Survey (5-10 km^2)
- ◆Survey
  - Geology
  - Geophysics
- ◆Drilling

Reservoir evaluation (3-4 km^2)
- ◆Simulation
- ◆Planning
  - Capacity
  - System
  - Production

Permits/ licenses
- ◆Environmental Assessment
- ◆Nature park
- ◆Site negotiation

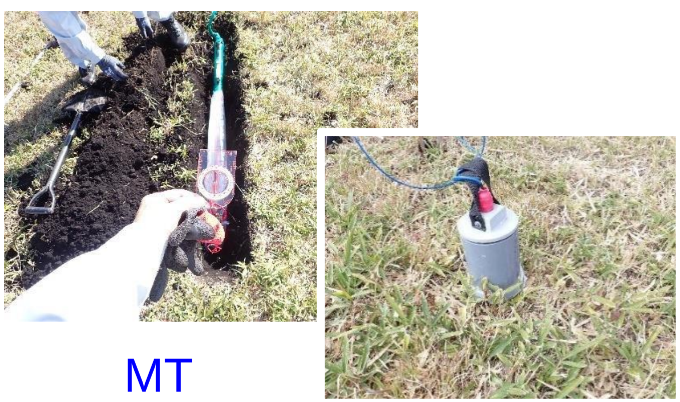
Construction
- ◆Road
- ◆Power plant

Operation
- ◆Production management
- ◆Monitoring
- ◆Make-up well

Survey

Main geophysical methods used for reservoir exploration

Method	Result	Estimated information
Electromagnetic	Resistivity structure	Heat source, cap rock
Gravity	Bouguer anomaly, density	Base structure, fault, fracture
Magnetic	Magnetic intensity	Geologic structure, temperature anomaly
Elastic wave	Velocity structure	Fault, fracture



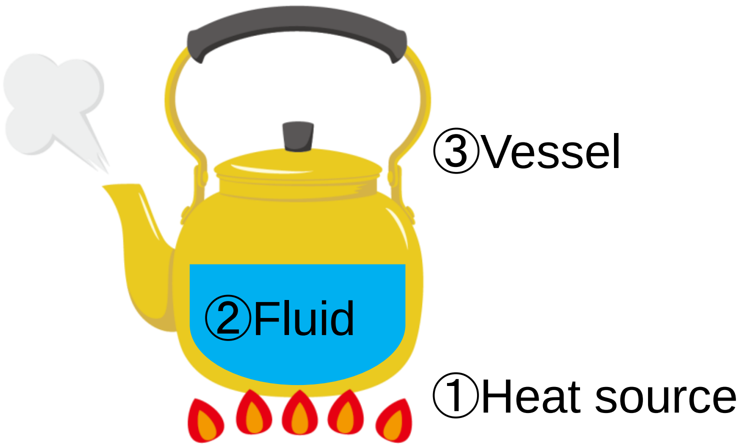
MT

JOGMEC

Airborne EM

Gravity

Geothermal system



Three components of a geothermal system

- Distribution and direction of the geothermal fluid cannot be determined only from geophysical surveys.
- Reservoir simulations are often performed based on a conceptual model obtained from the geophysical exploration data.

Reservoir evaluation

Survey results

↓

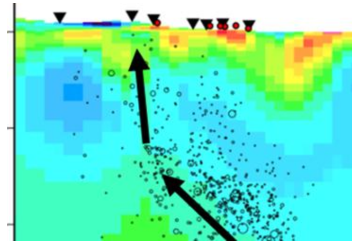
Conceptual models

↓

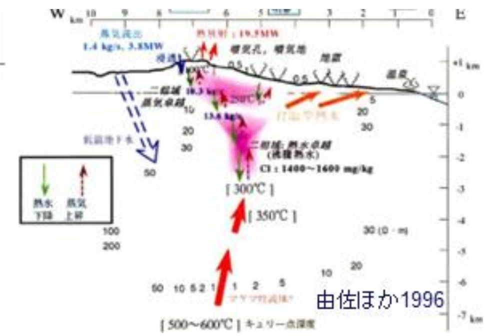
Reservoir simulation (Natural state)

↓

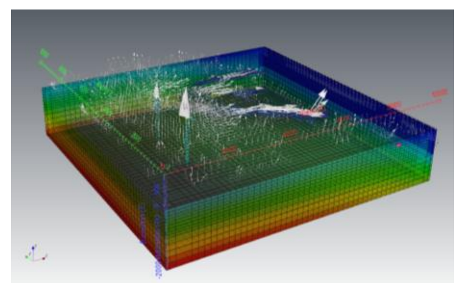
Validation



Survey results
(MT, Gravity, etc.)



Conceptual Models



Reservoir simulation

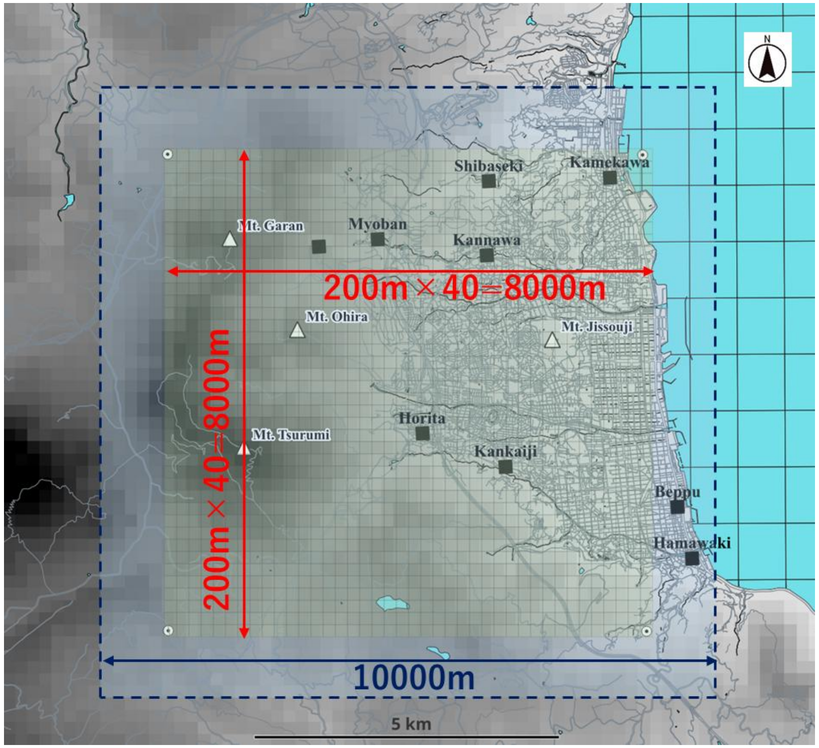
Simulator

Simulator	Characteristics
HYDOROTHERM2・3	● Hot water, steam, and supercritical water under a wide range of temperature and pressure conditions (0 to 1,200℃, 0.5 to 10,000 bar). ● Free. HT3 has a pre-post processor.
TOUGH2・3	● Specializes in multiphase flow analysis ● Multiple types of fluids, e.g., CO2, salt water, etc. ● Production reduction simulation is possible ● Charged. Pre-post processors such as PetraSim are available separately.
Volsung (Seequent)	● Developed based on TOUGH2. ● Complex well setups and even power plant tie-ins can be performed within Volsung. ● Modules are prepared for forward calculations such as gravity changes and settlements. ● Charged.

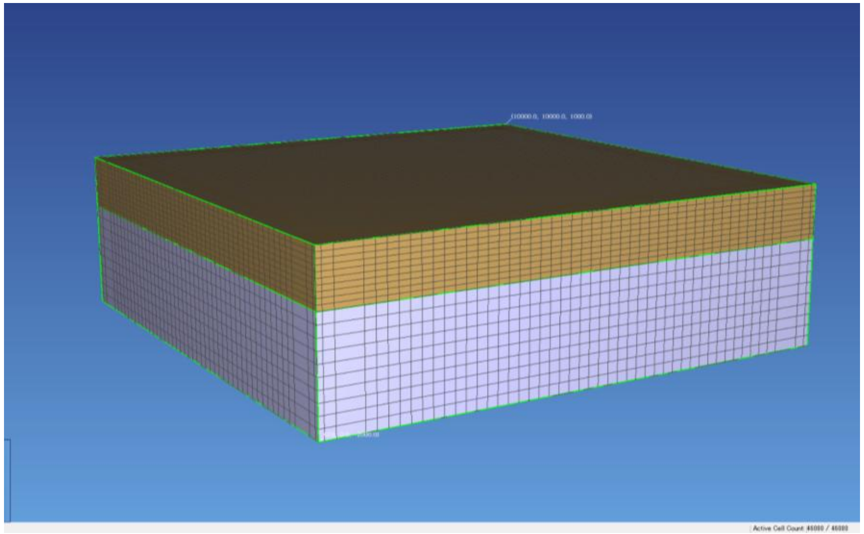
Beppu geothermal field

Phots by Beppu city (https://photobeppucity.tumblr.com/)

Simulation

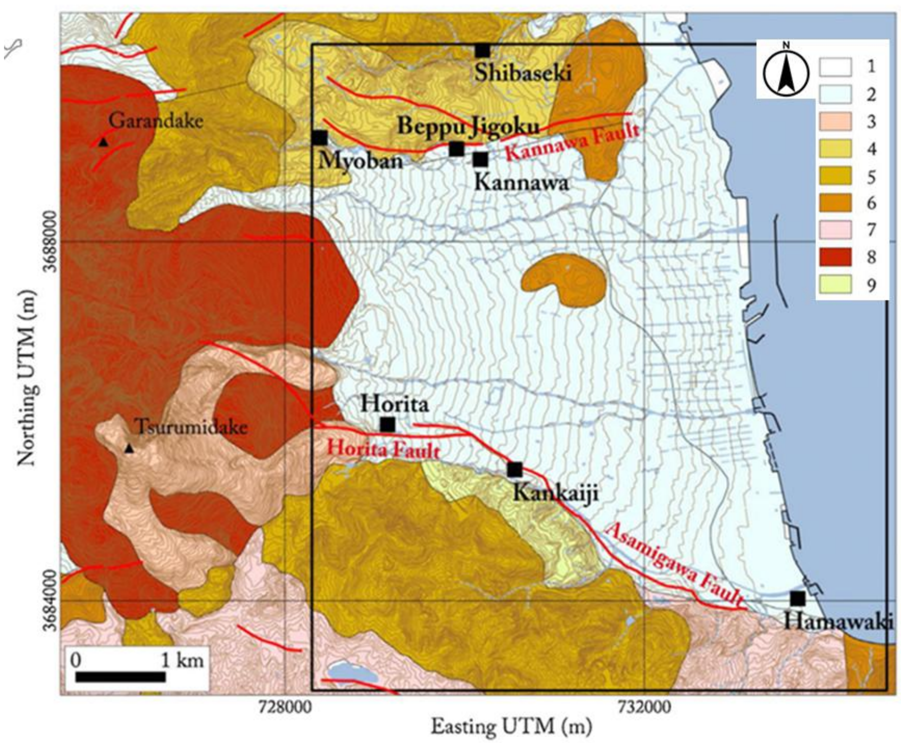


Area of reservoir simulation

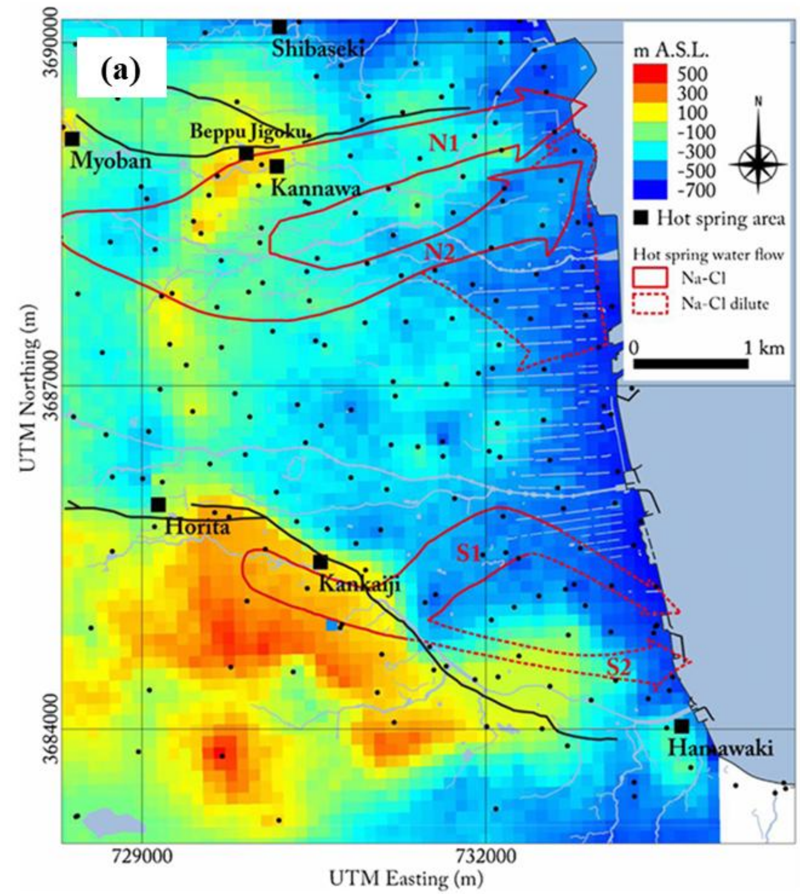


Grid

Example of input data



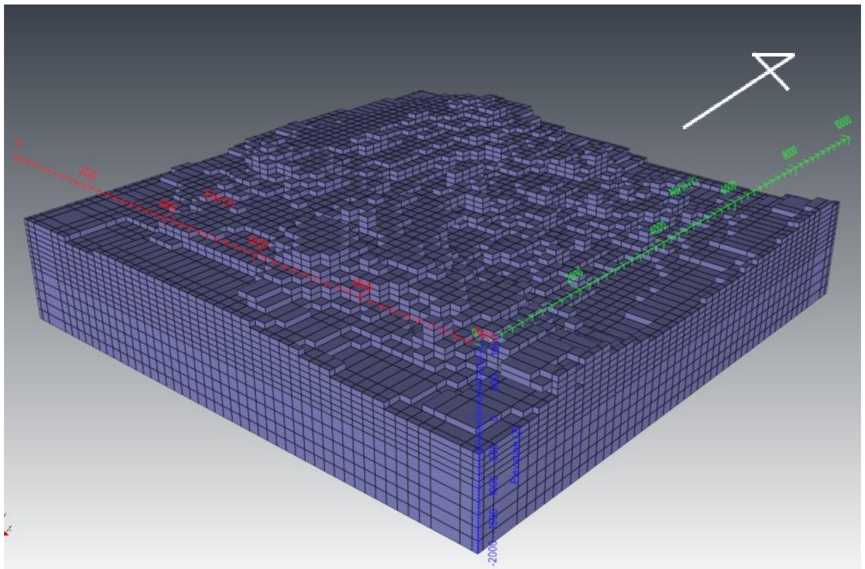
1: Reclaimed land, 2: Fan Deposit, 3/8/9: Andesite,
4: Debris Avalanche Deposit, 5/6: Lava, 7: Pyroclastic Flow Deposit



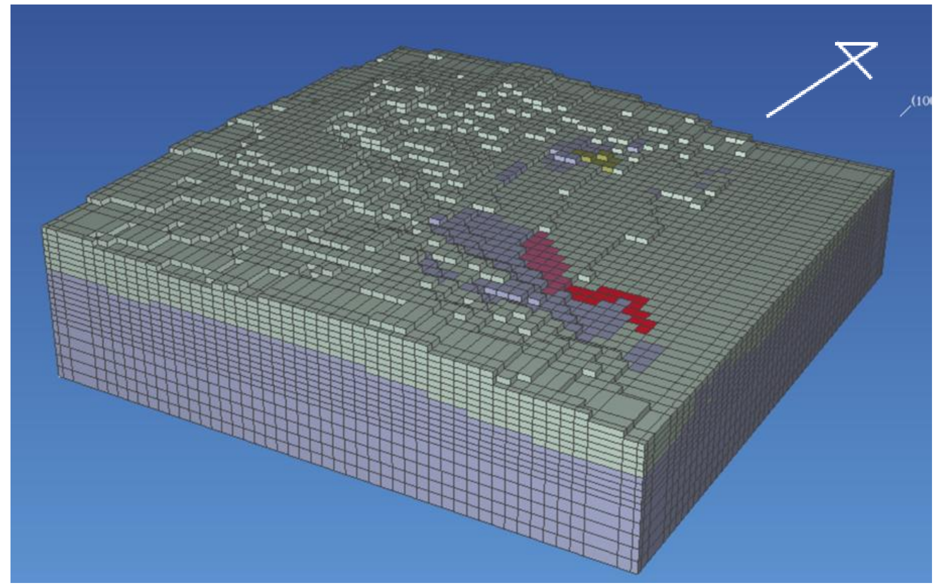
Geology map
(Geological Survey of Japan, 2014)

Gravity basement
(Nishijima & Naritomi, 2017)

Block model



Gravity basement



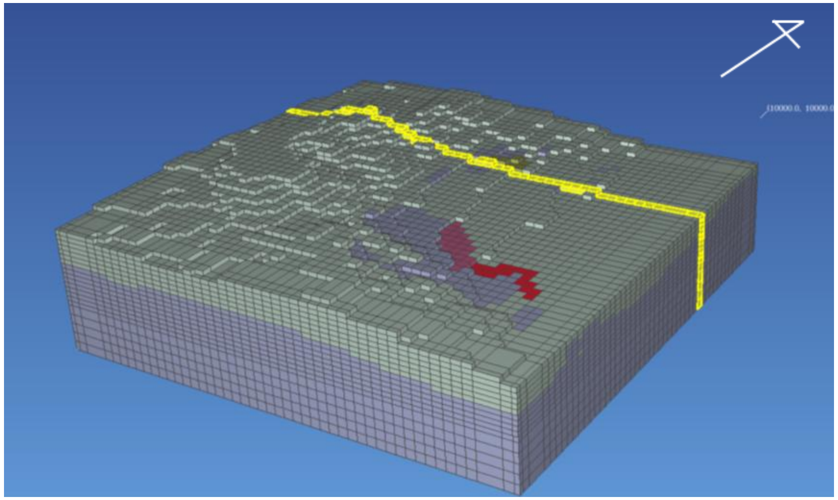
Entire

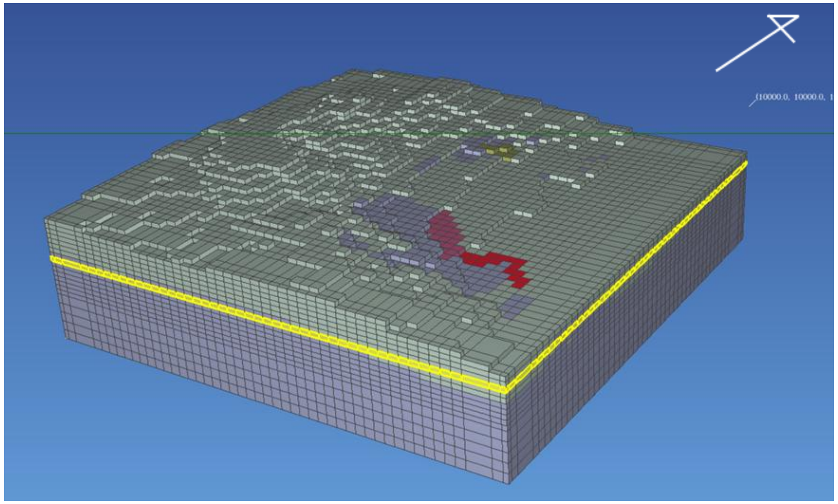
Materials	ϕ	Heat cond [W/m･K]	Density [kg/m^3]	Specific Heat [J/kg･K]	Permeability [m^2]
Fan deposit	0.15	1.8	1900	1000	10^{-14}
Cap rock	0.15	1.8	1900	1000	10^{-17}
Fracture	0.09	2.1	2100	1000	10^{-13}
Fracture in Andesite	0.02	2.4	2100	1000	10^{-15}
Andesite(Base)	0.02	2.4	2300	1000	10^{-16}

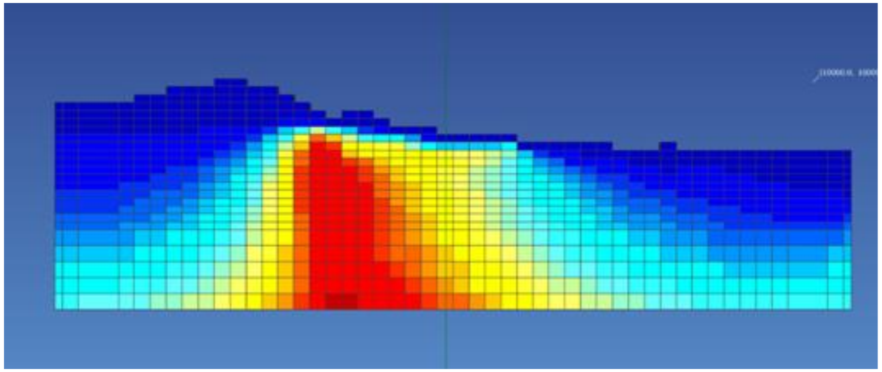
Simulation time	50000 years
Initial Condition	Hydrostatic pressure, Geothermal gradient
Boundary condition	East : Permeable
Source	Heat : 0.250 W/m² from bottom Mass rate: 300 degree Celsius, 23kg/s from two locations

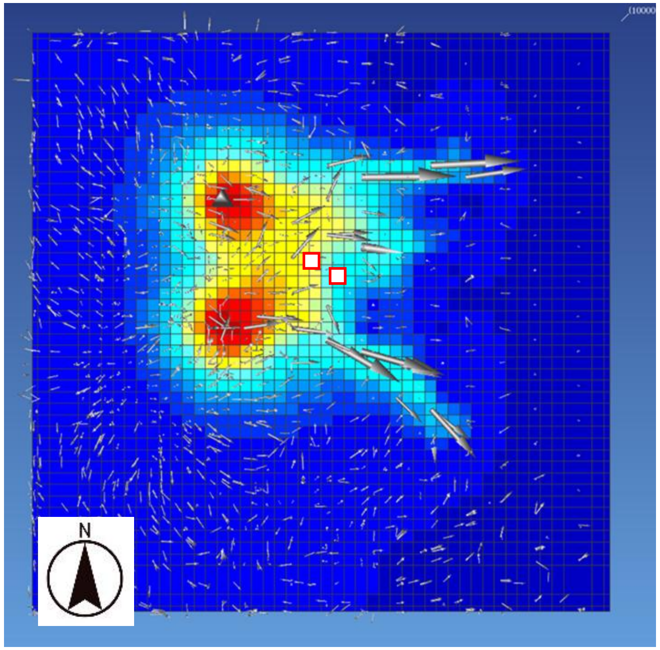
Morifuji et al., 2024

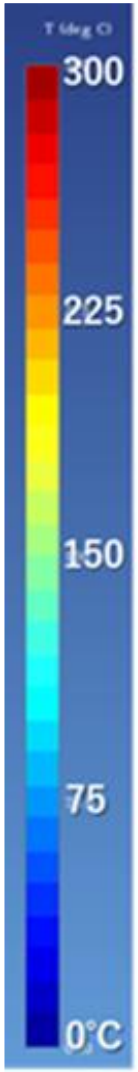
Natural state











Morifuji et al., 2024

Reservoir evaluation

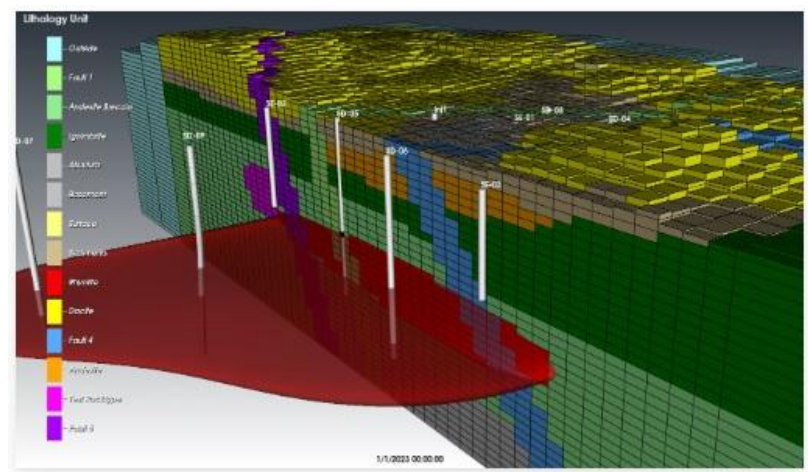
Survey results

Conceptual models

Reservoir simulation (Natural state)

Validation

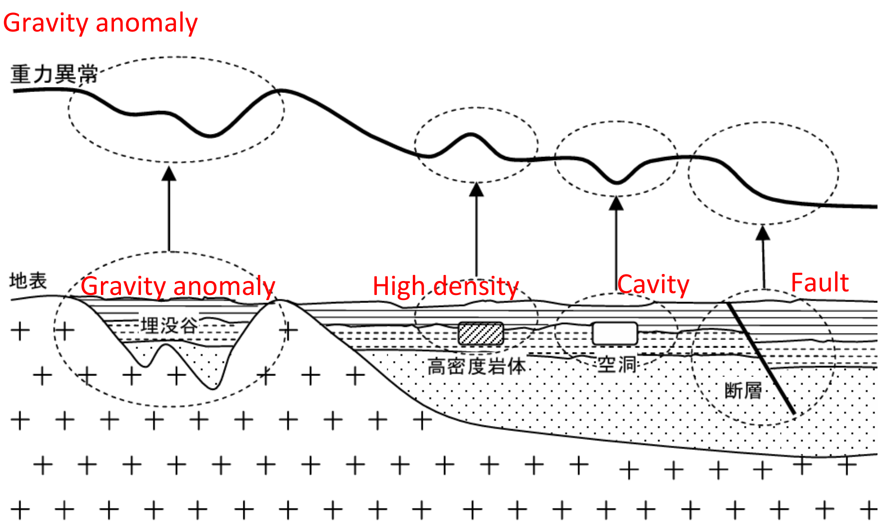
Production simulation

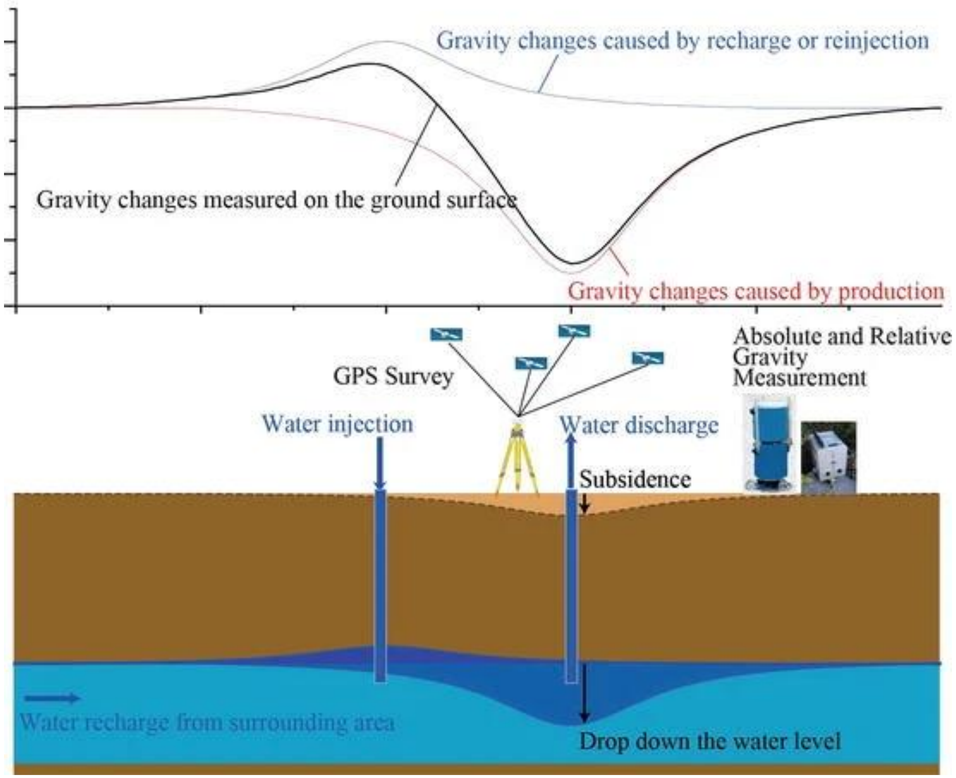


Production simulation*

*Volsing(Seequent)

Gravity





【Structure survey】

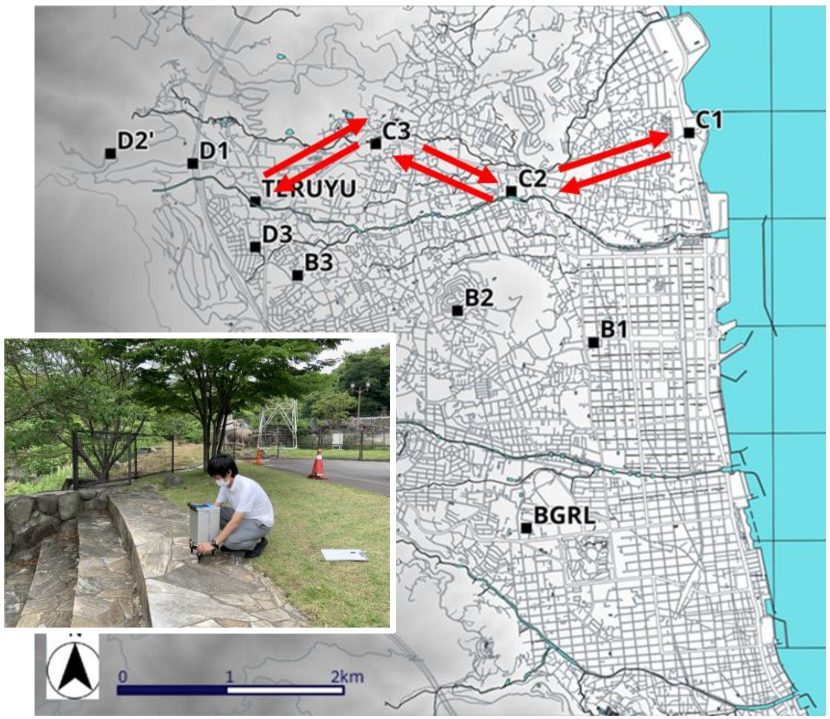
Required accuracy : mgal

【Reservoir monitoring】

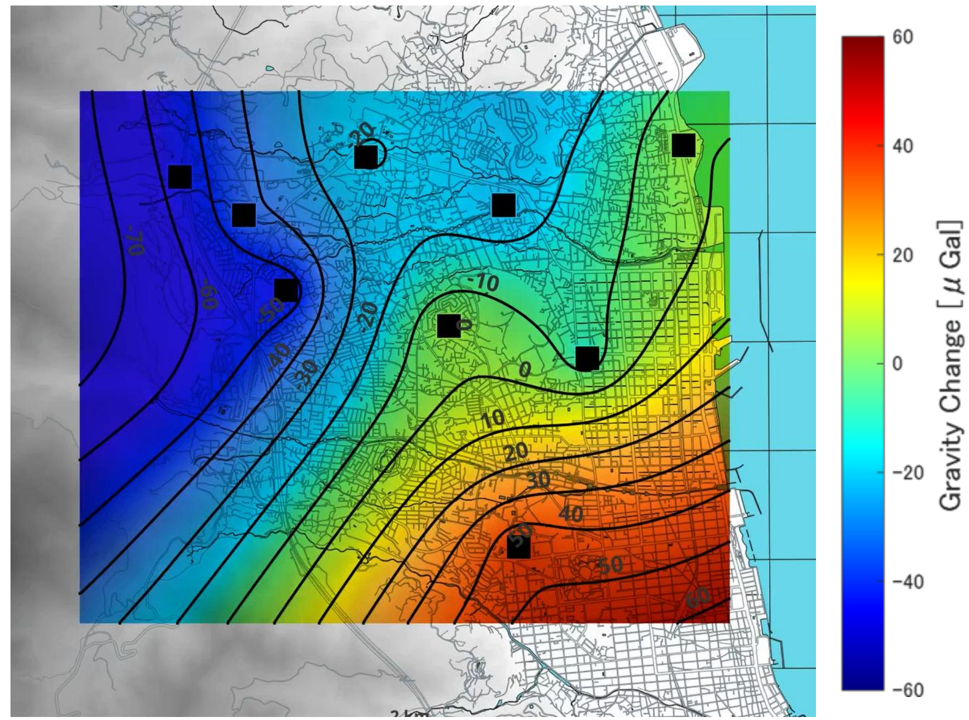
Required accuracy : 10μgal

SEGJ, 2008

Gravity measurement



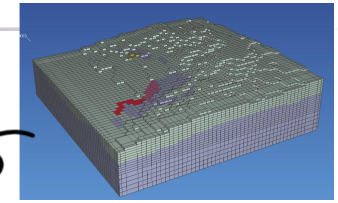
Measurement points



Gravity change from 2015 to 2023

Morifuji et al., 2024

Gravity Forward Calculation

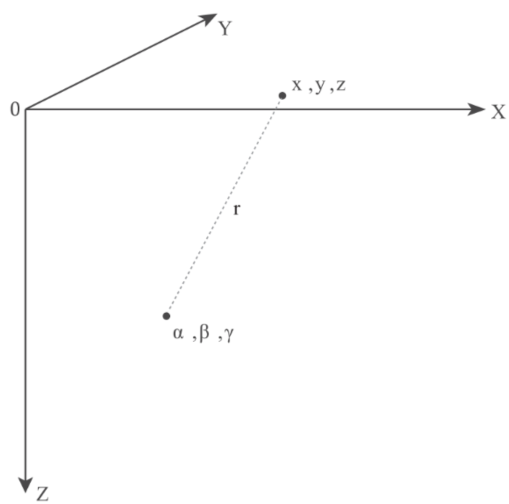


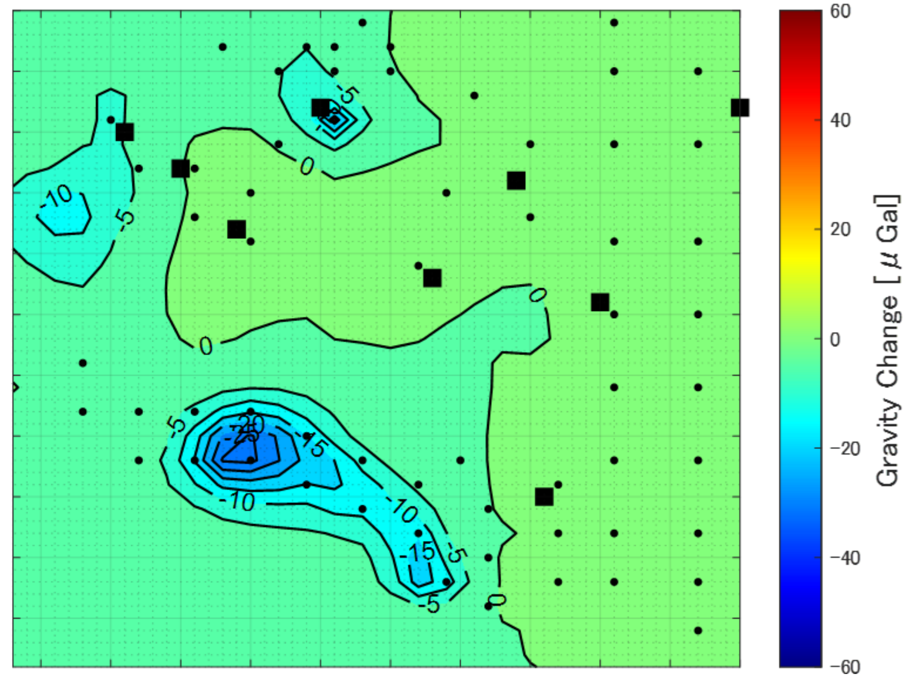
Natural state model

Gravity at point i on the earth's surface

$$\boldsymbol{g_i} = -G\emptyset\rho \int \frac{\boldsymbol{r_i} - \boldsymbol{r}}{|\boldsymbol{r_i} - \boldsymbol{r}|^3} dV$$

G : gravity constant, $\emptyset$: porosity, $\boldsymbol{r}$: (x, y, z)
ρ : Fluid density $(DG * SG + DW * SW)$





▪ Well

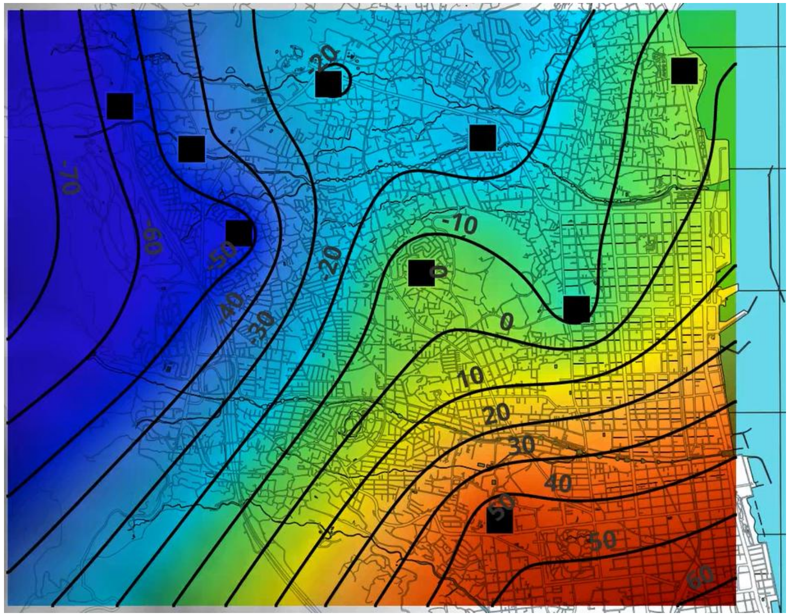
Simulated gravity change cased by production
(2015 → 2023)

Morifuji et al., 2024

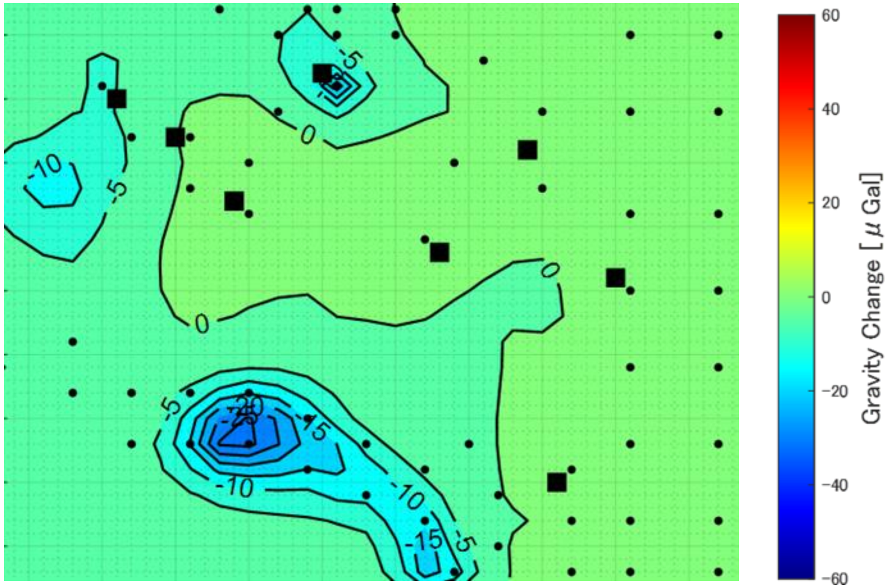
Comparison of observed and values

- The decrease in gravity mainly in the western region, but there were some areas where the gravity change could not be reproduced.

➢ The results suggest that it is difficult to construct an elaborate geothermal reservoir model based on well observations alone. A review of parameters (permeability and porosity) in the area should explain the gravity values measured.



Measurement data
(2015→2023)

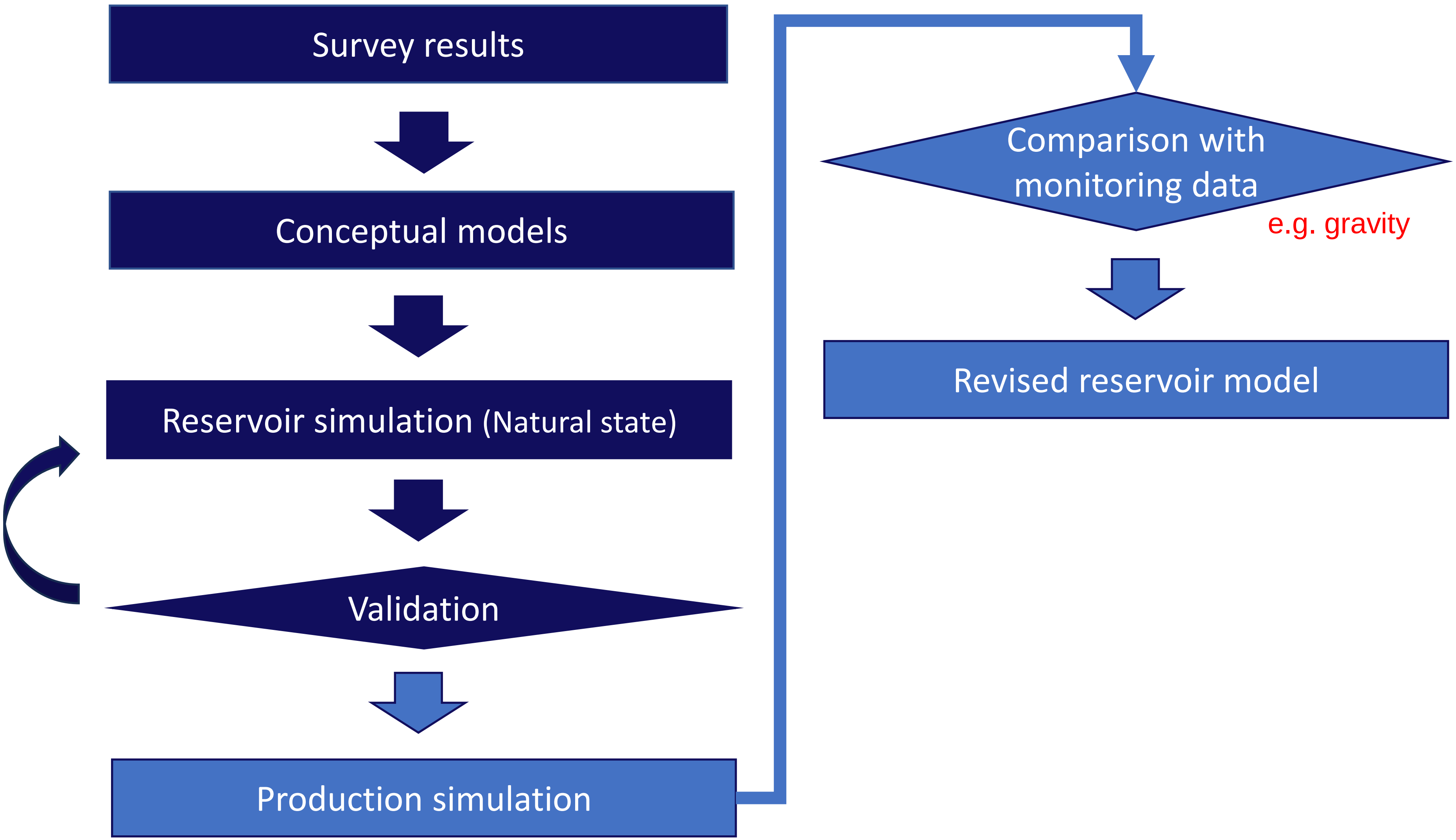


・Well

Forward calculation
(2015→2023)

Morifuji et al., 2024

New approach to reservoir evaluation



Summary

- Comparison of gravity changes based on simulation results with actual gravity changes enables upgrading of reservoir models from an areal perspective

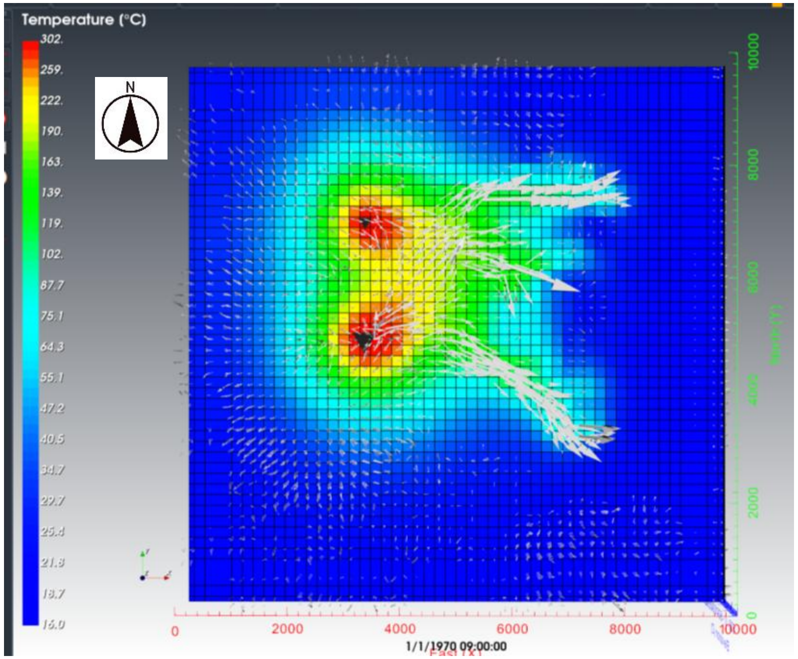
- Gravity measurements can be performed without drilling wells at any point, so that areal information can be obtained at low cost for the reservoir extent of each power plant. The information contributes to upgrade the reservoir model.

Thank you

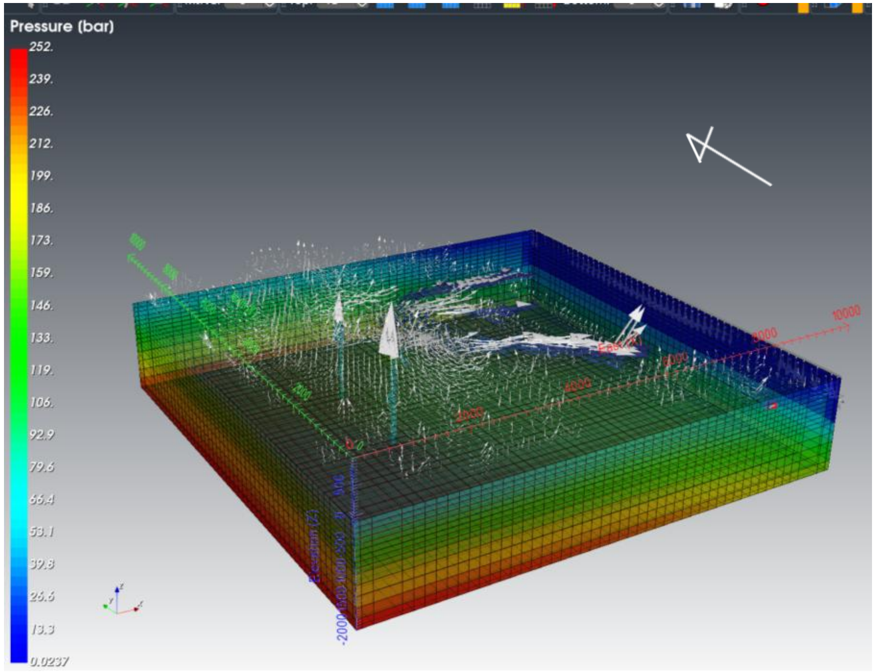
APPENDIX

Volsung

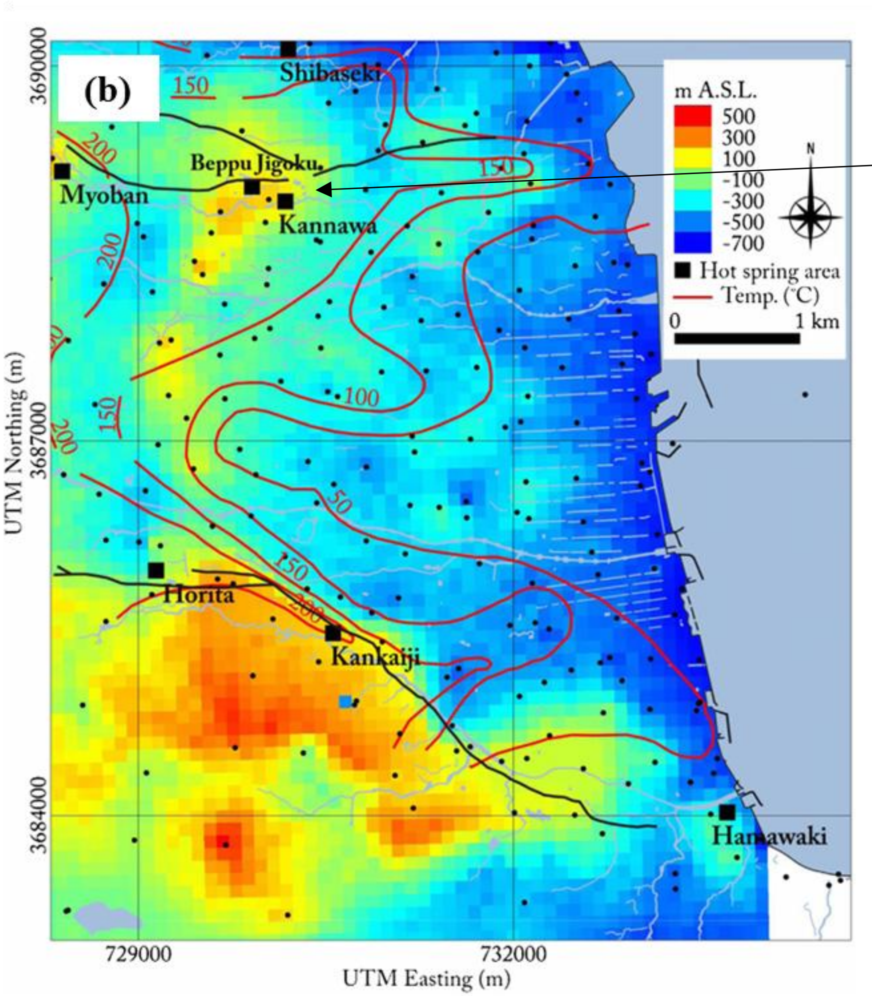
- A new simulation package integrating geothermal reservoir modelling, wellbores and surface networks.
- The geothermal reservoir modeling is developed based on TOUGH2.
- EOS of pure water allowed P=0 to 1000 bar, T=0 to 800 ℃
- Modules are available for forward calculation such as gravity change and settlement using the results of reservoir simulation.



Beppu natural state model

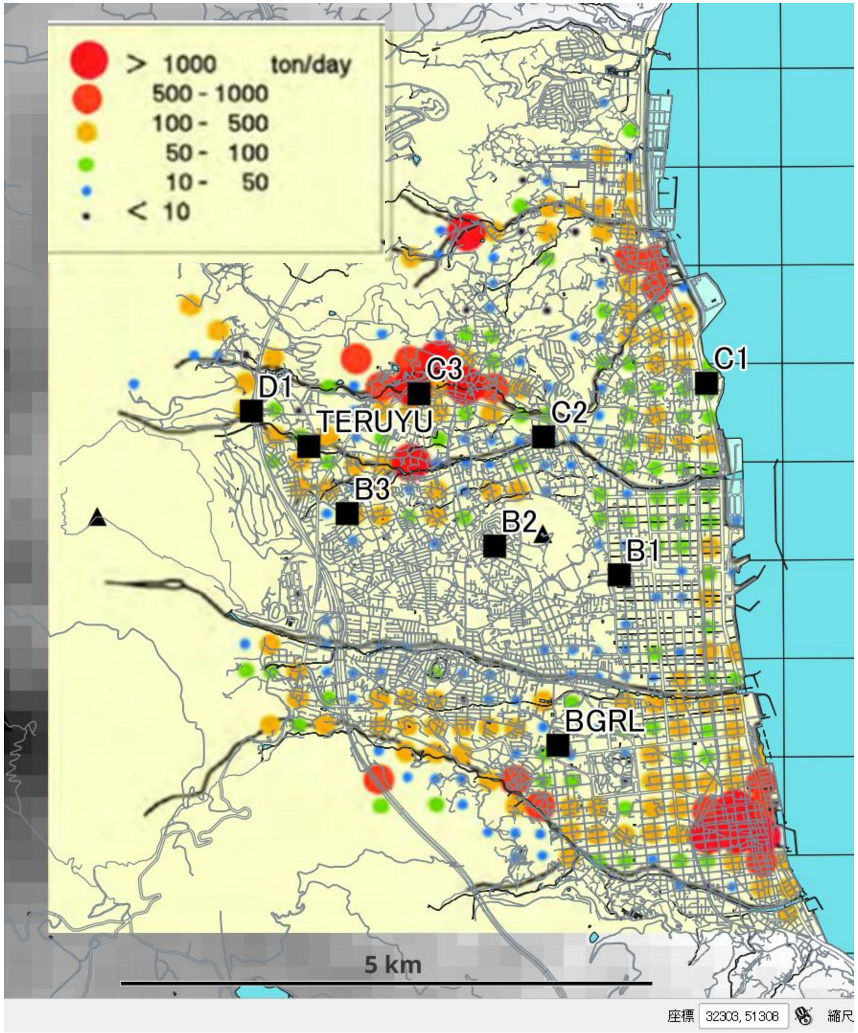


Beppu natural state model
From southwest



Comparison between the gravity basement and hot spring data (Nishijima & Naritomi, 2017) (a) The gravity basement and the subsurface flows of the Na-Cl type hot spring water, modified from Ohsawa et al. (1994) and Osawa and Yusa (1996). (b) The gravity basement and the isotherm at 100 m below sea level, modified from Allis and Yusa (1989).

Actual wells distribution and production rate



Wells distribution and production rate
(Yusa, 2008)