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Reference Frame in Practice

Manila, Philippines 21-22 June 2013

Japanese Hybrid Geoid Model "GSIGEO2011" and its application for height determination

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Sponsors :

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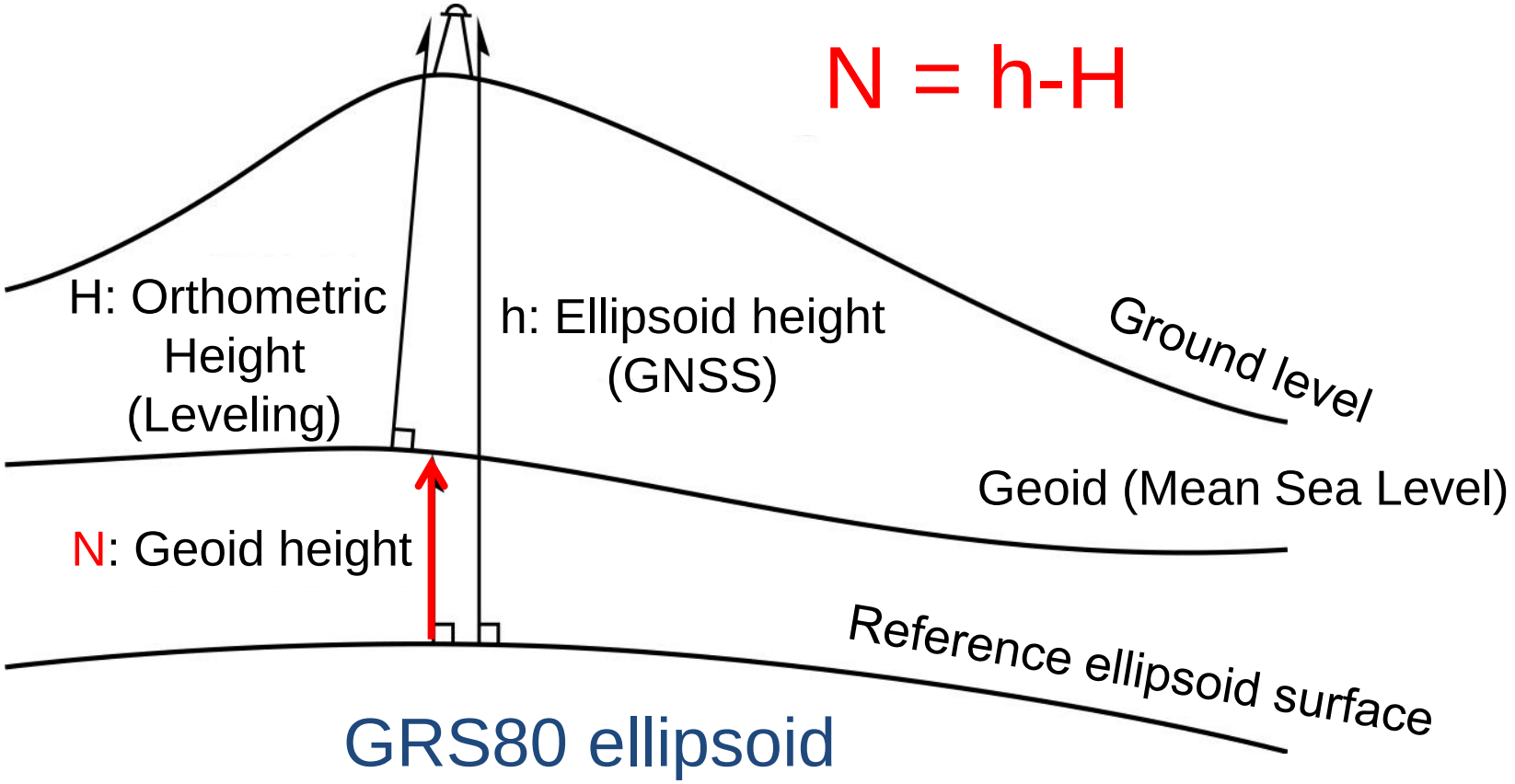
Purpose

- Orthometric heights in Japan are determined by leveling survey.
- However, leveling survey takes time and expensive.
- Height determination by GNSS survey with geoid model is less expensive.

→ Goal is to establish enough accurate geoid model for applying to orthometric height determination in Japan.

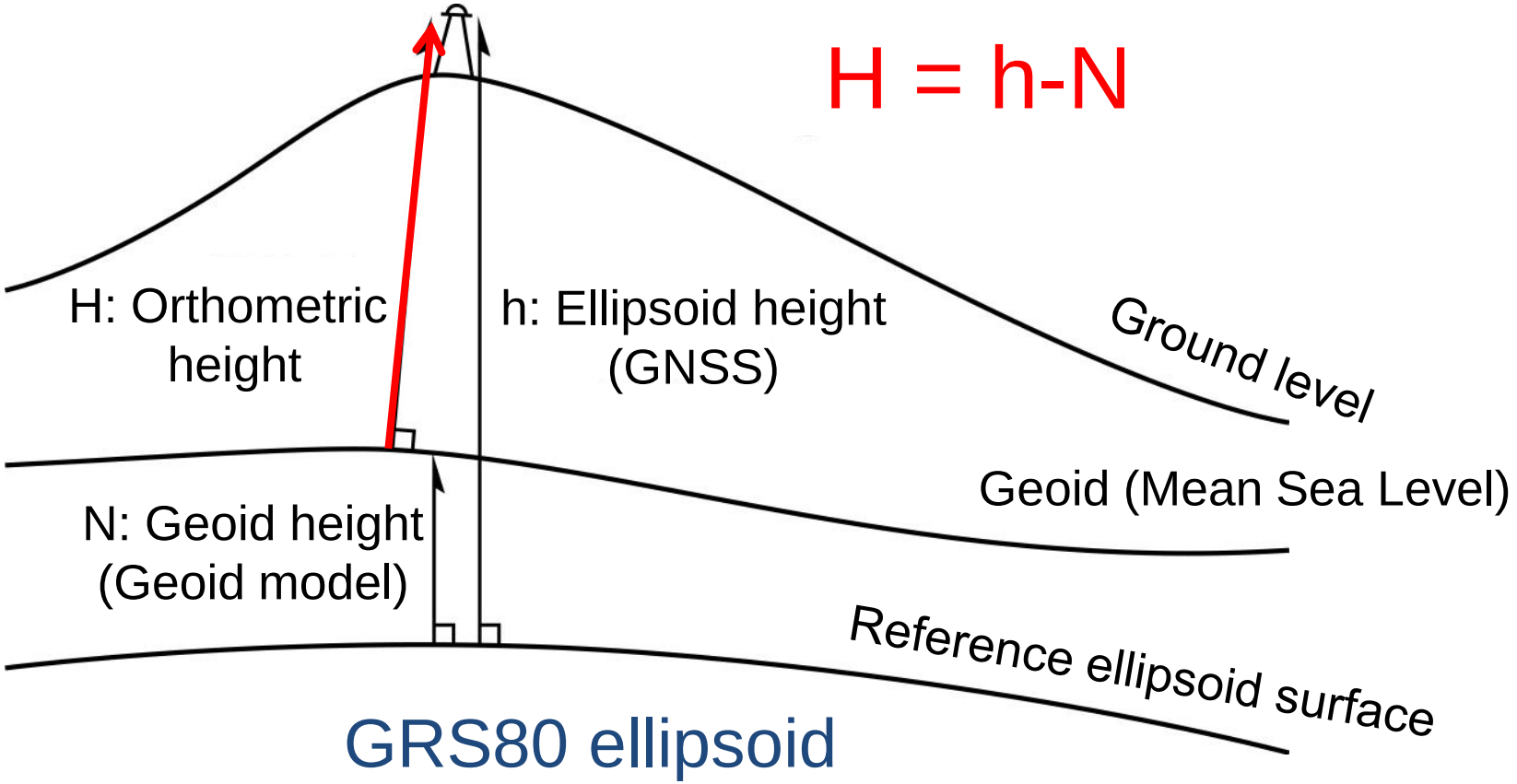
Geoid height

Geoid height can be determined from ellipsoid height (GNSS) and orthometric height (leveling survey)



Orthometric height

If geoid model is accurate enough, orthometric height can be determined from ellipsoid height (GNSS) and geoid height (Model)



Geoid Model

○ Geoid Model is a height model which describes shape of surface of geopotential zero.

	Gravity Geoid Model	Hybrid Geoid Model
Input Data	•Global Gravity Potential Model （GGM） •Gravity Data（Land 240,000~, Marine 570,000~） •Topographic Data (DEM)	•Gravity Geoid Model •Geoid Height （GNSS/Leveling）
Advantage	•Spatial Coverage with high resolution •High accuracy in short wave-length	•Fitting Gravity Geoid Model to GNSS/Leveling Geoid Height •Consistent with Vertical Datum in Japan
Issue	Error in long and middle wave-length components	
Example	JGEOID2000、JGEOID2008	GSIGEO2000, GSIGEO2011

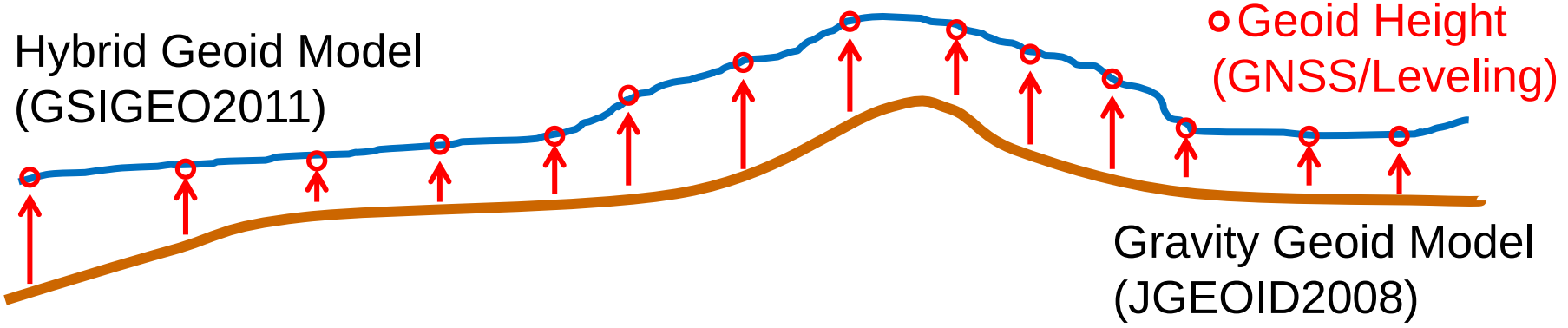
Geoid Model

- Purpose of GSI hybrid geoid model is to give consistent orthometric heights with Japanese vertical datum which is established by leveling survey.
- Base geoid model is Japanese gravity geoid model “JGEOID2008”.

→ Hybrid geoid model “GSIGEO2011” is established by fitting JGEOID2008 to geoid height determined from GNSS/Leveling.

Geoid Model

- Gravity geoid model is established from gravity observation on both land and marine.
- Geoid heights are determined by GNSS/Leveling on benchmarks and stainless steel survey markers at GEONET stations.
- Hybrid geoid model is established by fitting gravity geoid to GNSS/Leveling geoid heights.



Geoid Model

Hybrid Geoid Model Establishment in Japan

Gravity Geoid Model

- ✓Full Spatial Coverage
- ✓High Resolution
- ✓High Accuracy in short wave-length
- ➢NOT consistent with Japanese Vertical Datum

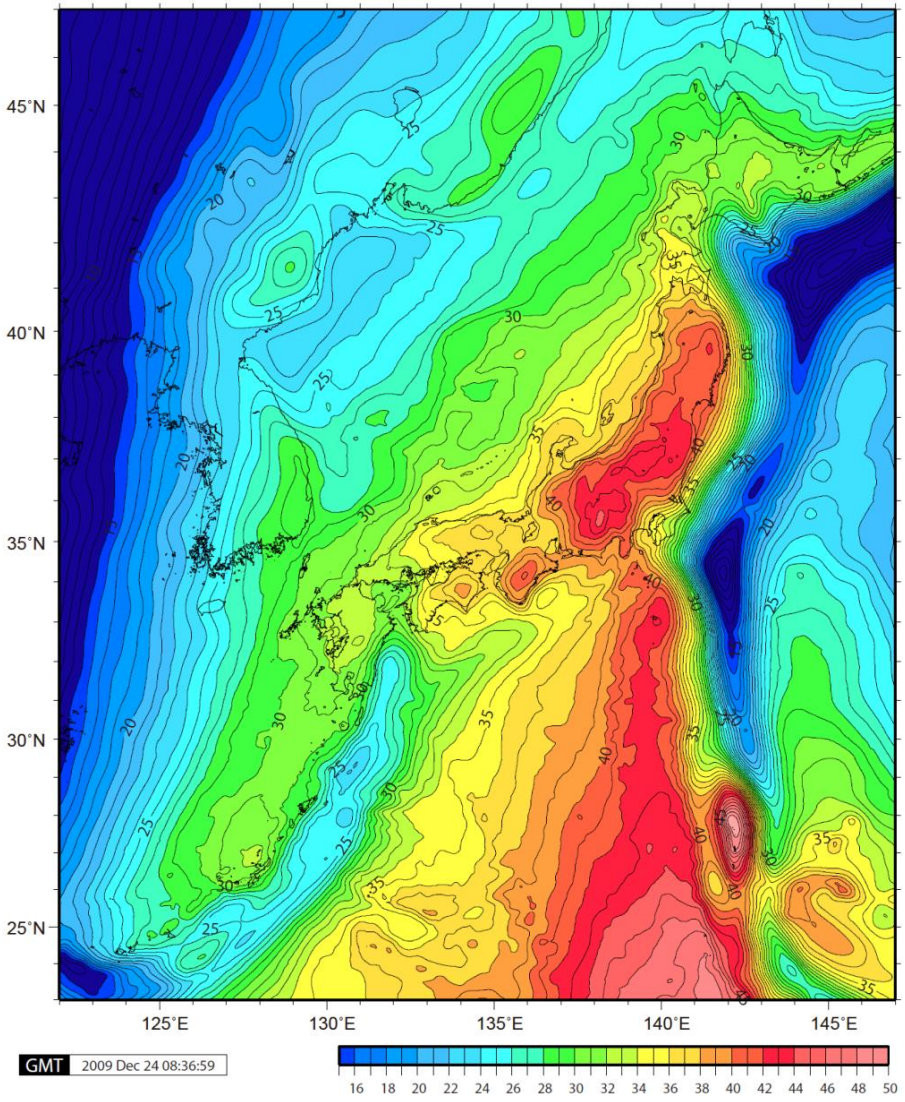
Geoid Height Data

- ✓Determined by GNSS/Leveling
- ✓Consistent with Japanese Vertical Datum
- ➢Discrete Distribution (Only on Benchmarks or stainless steel survey markers at GEONET stations)

Fitting Gravity Geoid Model to Japanese Vertical Datum by GNSS/Leveling Geoid Height Data

Hybrid Geoid Model

Gravity Geoid Model



- JGEOID2008 is the latest gravity geoid model by GSI for Japan.
- Combining
  - GGM02C: GRACE-based global geopotential model
  - surface(land and ship-borne) gravity measurements
  - KMS2002: altimetry-derived marine gravity model
- 1×1.5 arc-minute grid
- SD: 8.44cm
  Max Dif.: -20.22cm
  (Compared with GNSS/Leveling geoid height on benchmarks)

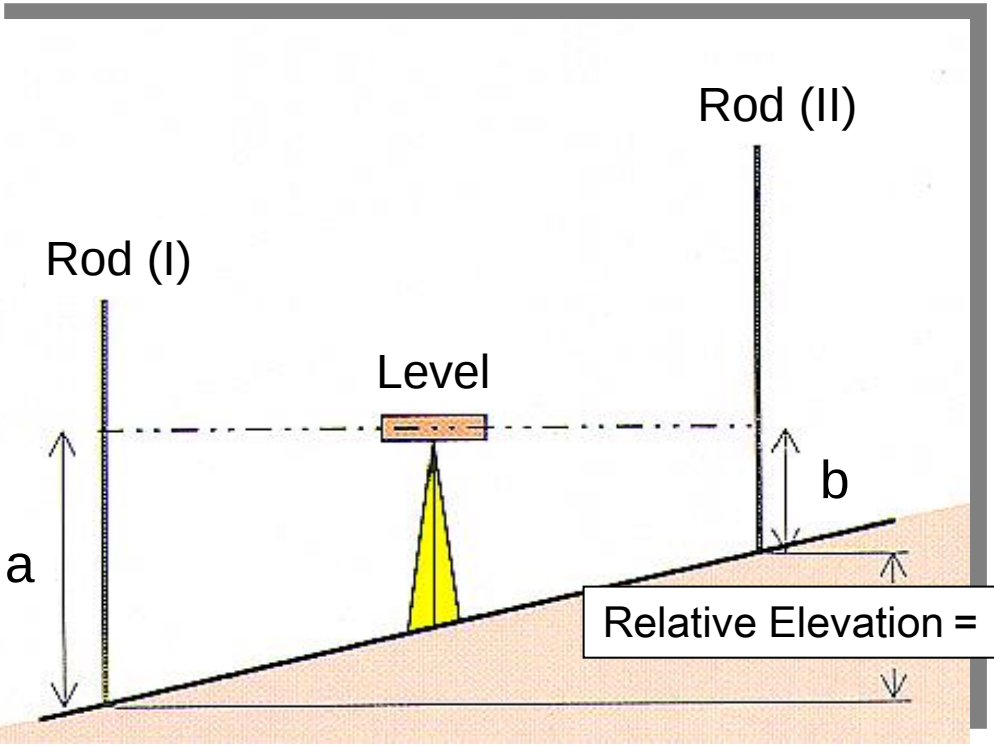
Kuroishi (2009) : Improved geoid model determination for Japan from GRACE and a regional gravity field model

JGEOID2008

	JGEOID2008
Universal gravity model	GGM02C/EGM96 (GGM02C complete to degree and order 200, merged with EGM96 from degrees 201 to 360)
Land Gravity Data	267,805 pt.
Marine Gravity Data	579,186 pt. (Bureau Gravimetrique International) KMS2002 (combined with ship-bone gravity data by the semidiscrete wavelet analysis/reconstruction method with two-dimensional Halo wavelets)
Land Elevation model	250m mesh Digital Elevation Model (GSI)
Calculation method	Spherical 1-D FFT to Stokes' integral in remove-restore manner
Output datum set	1′×1.5′grid (Ellipsoid : GRS80)
Comparison with GNSS/Leveling geoid	SD: 8.44cm Max Dif.:-20.22cm Planer fit (Tilt: 0.18ppm Azimuth: 97 SD: 5.99cm)

GNSS/Leveling (Leveling)

Orthometric heights are determined by leveling survey between standard datum of leveling and benchmarks or stainless steel survey markers at GEONET stations.

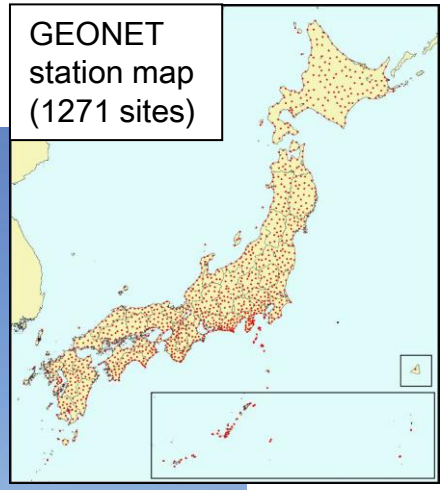


Standard Datum of Leveling

GNSS/Leveling (Leveling)

GEONET station

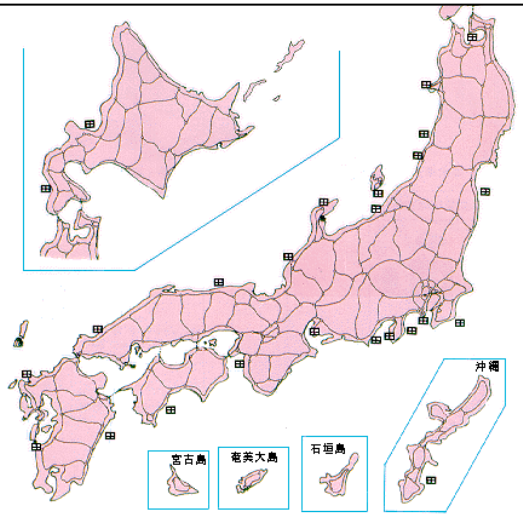
GEONET station map (1271 sites)



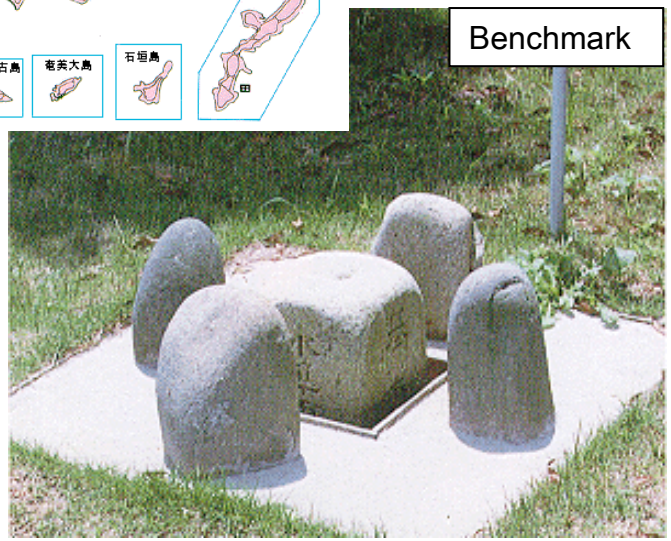
Stainless steel survey marker

Benchmark

First order leveling route (20,000km)



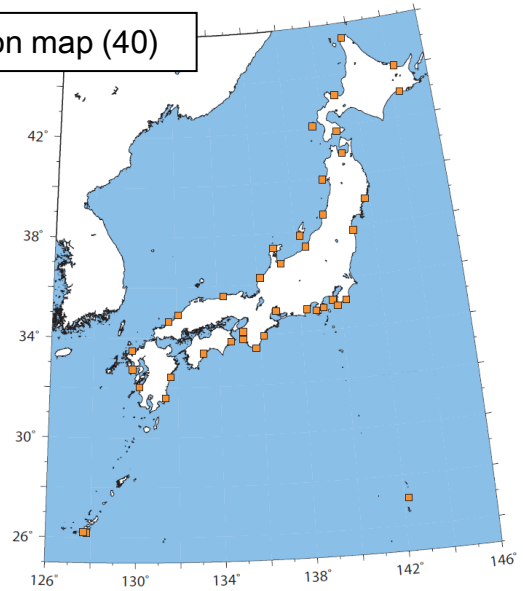
Benchmark



GNSS/Leveling (Leveling)

Tidal gauge station

Station map (40)



Benchmark

Tidal station with continuous GNSS observation

GNSS/Leveling (GNSS)

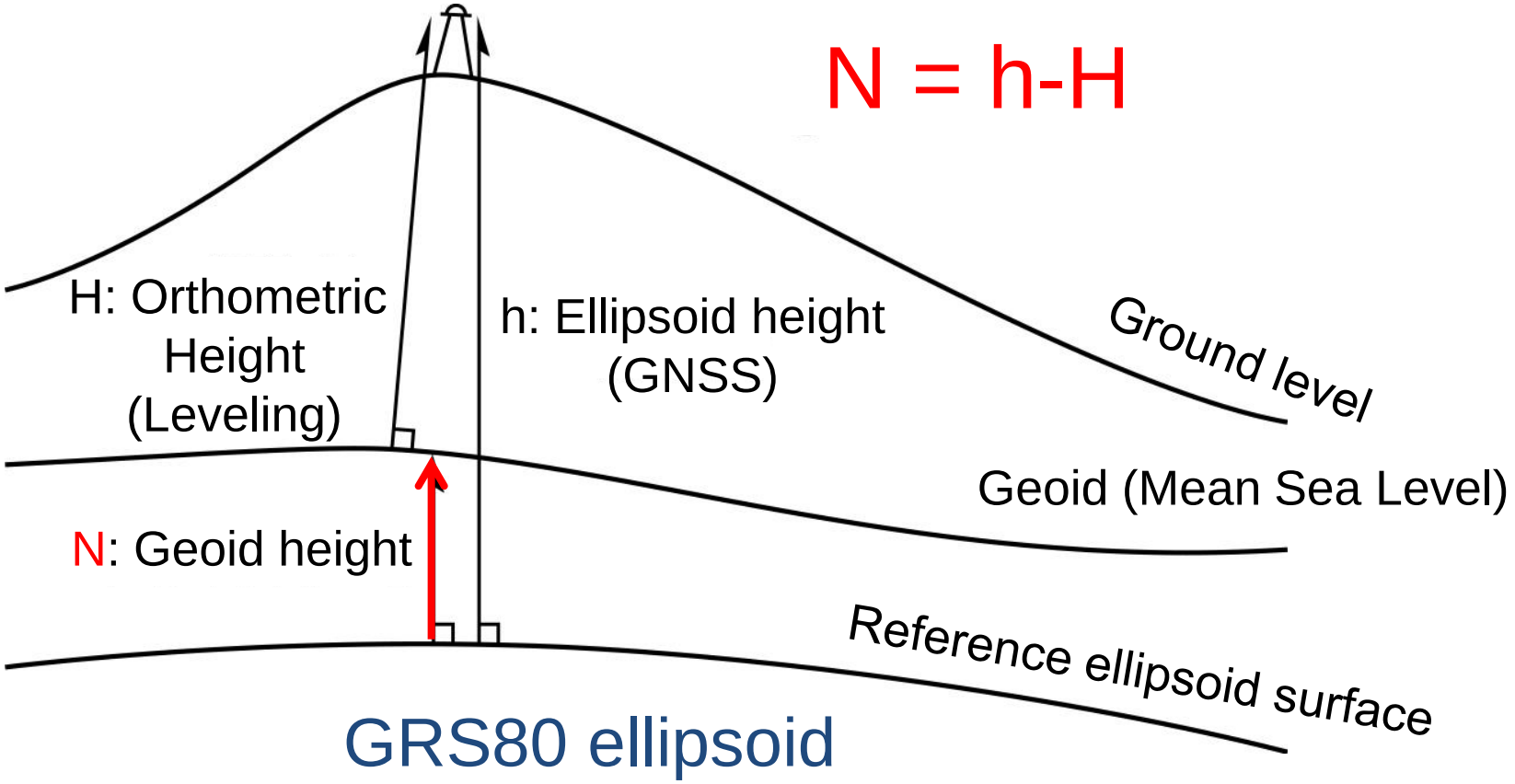
Ellipsoid heights are determined by GNSS continuous observation at GEONET stations or GNSS survey on benchmarks.

GNSS survey on a benchmark

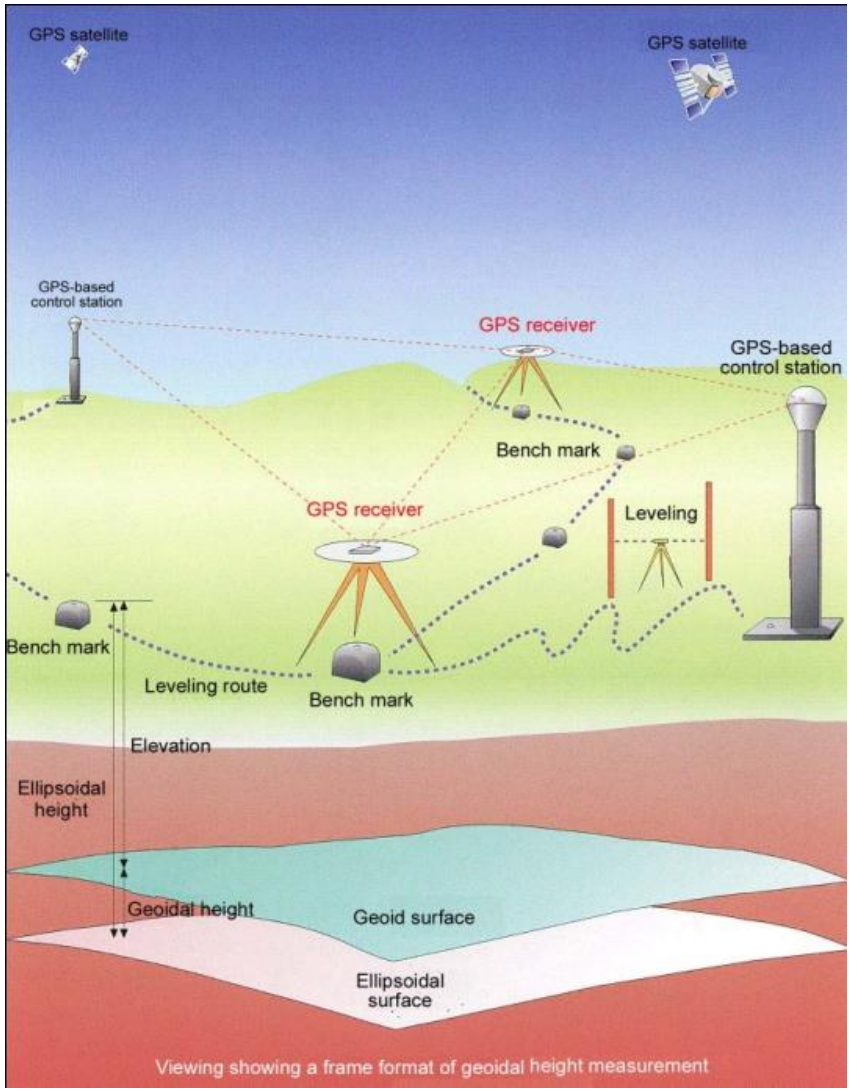
GEONET station (at GSI)

GNSS/Leveling(Geoid Determination)

Geoid heights are determined by orthometric heights(leveling) and ellipsoid heights(GNSS).



GNSS/Leveling (Geoid Determination)

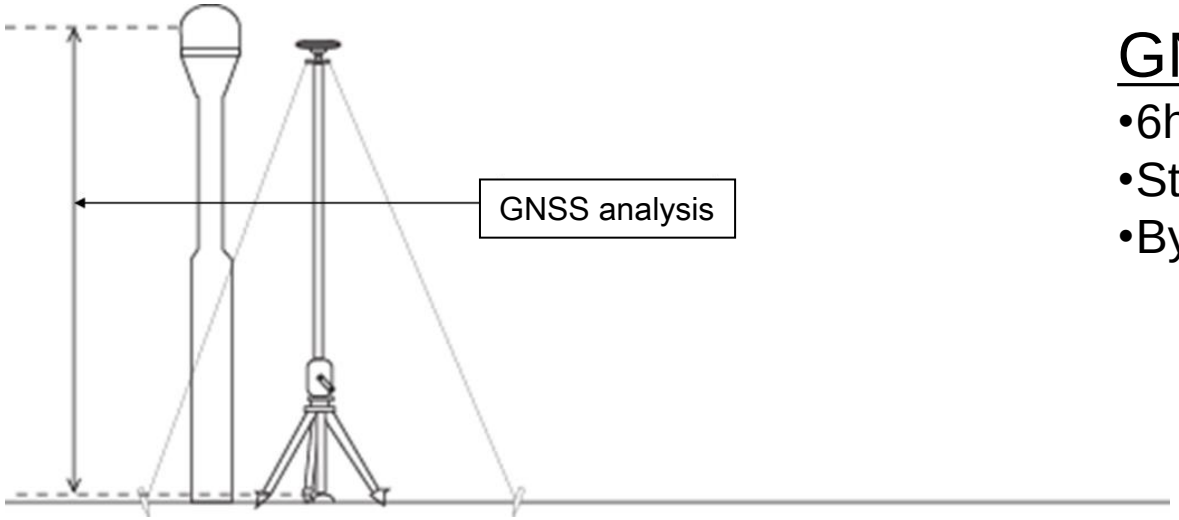


Geoid Height =
Orthometric height - Ellipsoidal heights

	Ellipsoid Height	Orthometric Height
Benchmarks	GNSS Survey	Leveling
GEONET Stations	GNSS continuous observation	Height measurements between stainless steel survey markers（GNSS or TS）
Brass markers at GEONET Stations	Height measurements between antenna（GNSS or TS）	Leveling

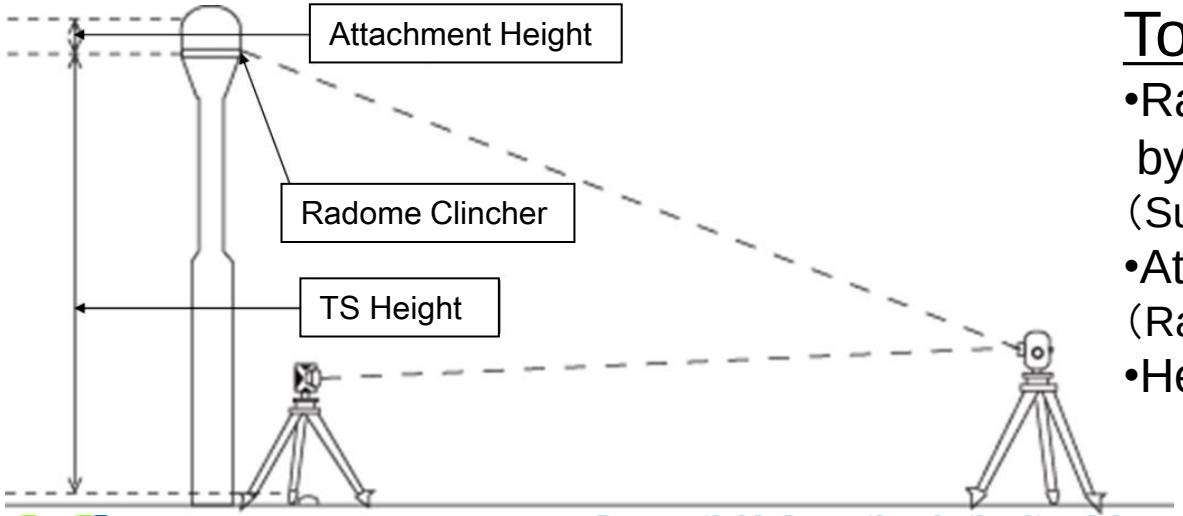
GNSS/Leveling(Height Measurements)

Height measurements between an antenna and a survey marker.



GNSS survey (2004~)

- 6h GNSS observation
- Static analysis between the station
- By GAMIT software



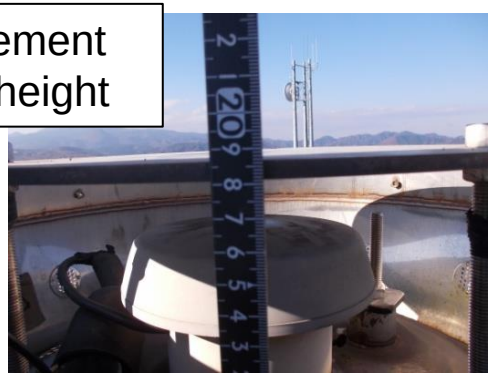
Total Station（2008～）

- Ranging and angle measurement by Total Station
（Survey marker ~ Radome clincher ）
- Attachment height
（Radome clincher ~ Bottom of antenna）
- Height = Attachment Height + TS Height

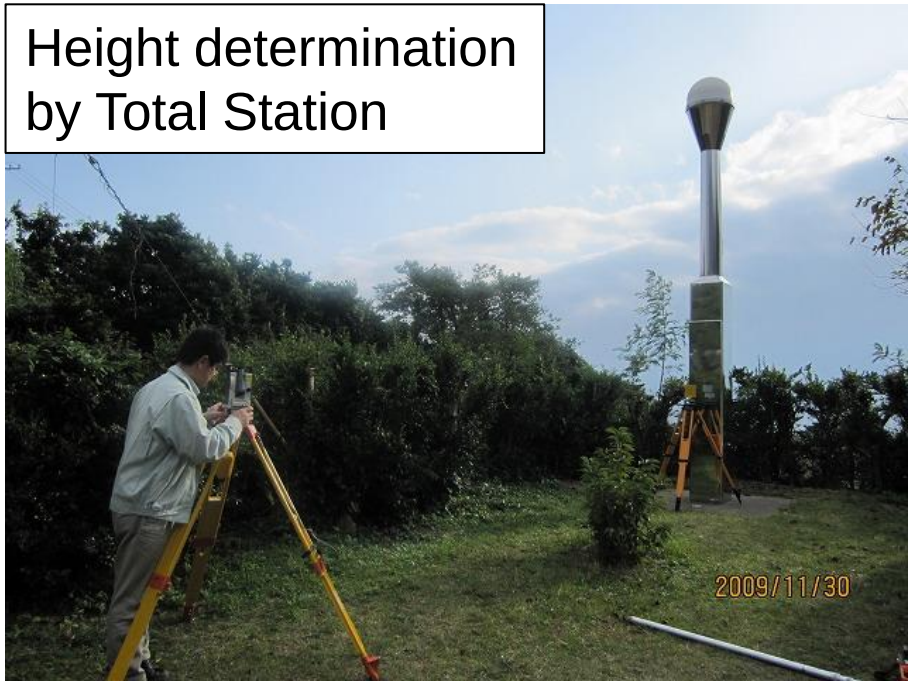
GNSS/Leveling(Height Measurements)

GNSS survey on stainless steel survey marker at GEONET station

Direct measurement of attachment height

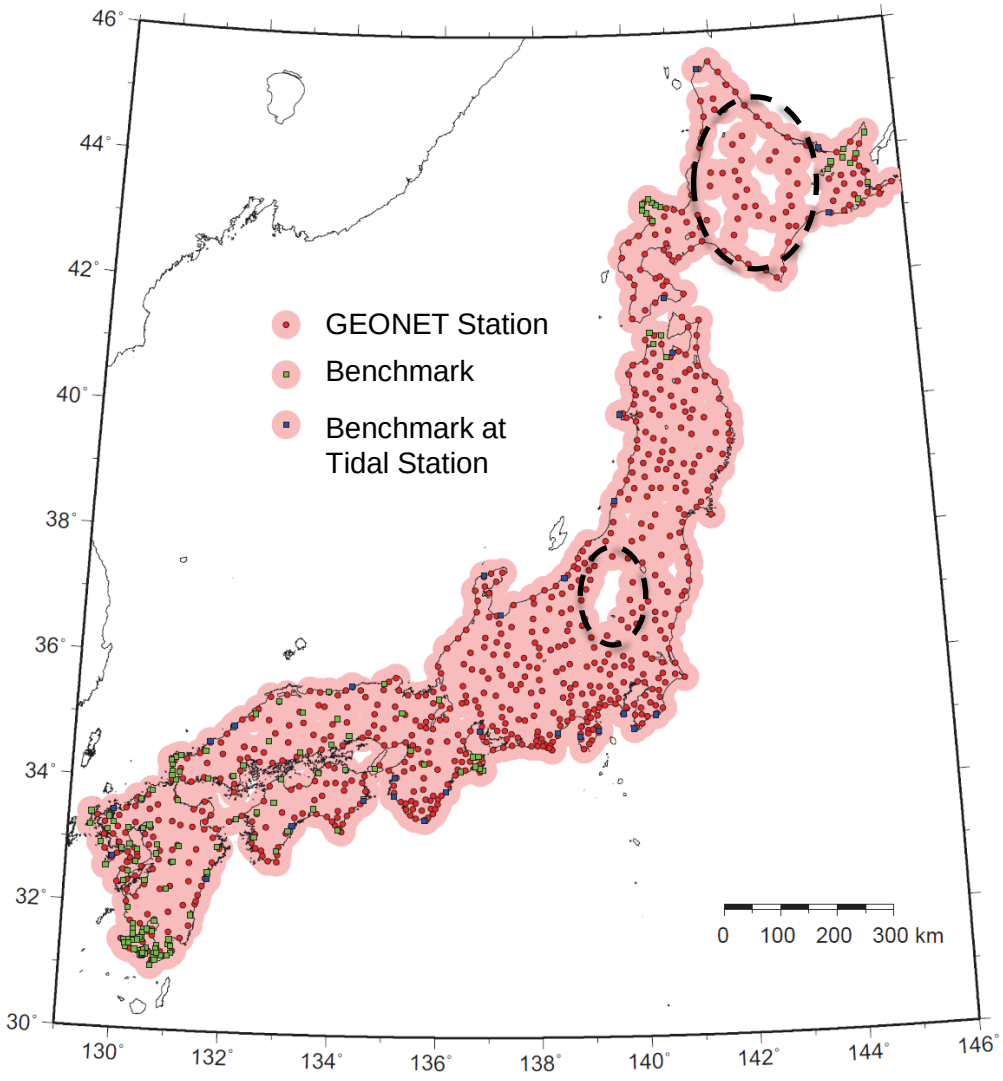


Height determination by Total Station



Radome Clincher

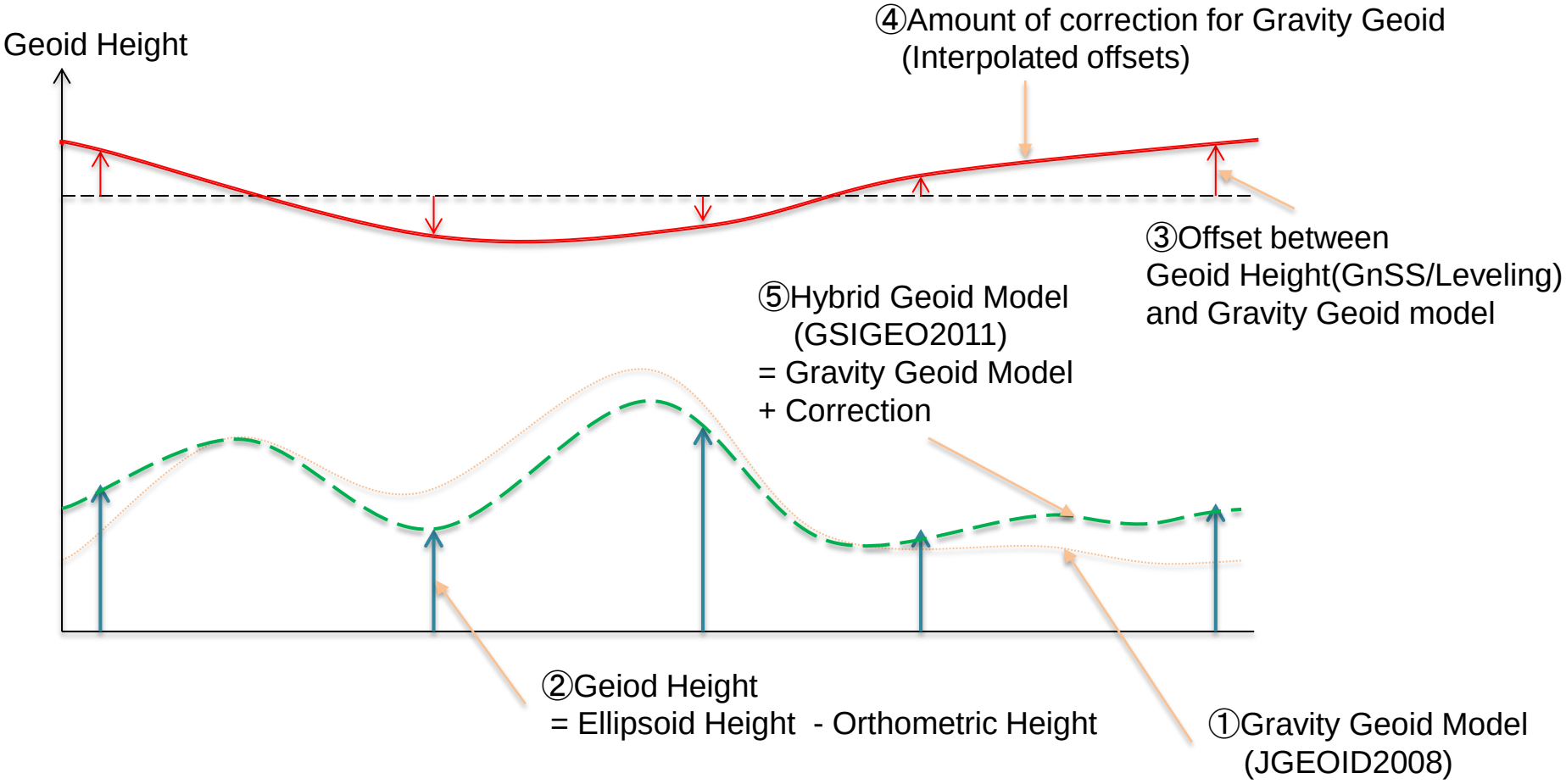
GNSS/Leveling



- Leveling survey on stainless steel survey markers at GEONET station: 775
- GNSS survey on benchmarks : 142 (spatially complement GEONET stations)
- Leveling survey on benchmarks at tidal stations: 29
- Additional leveling survey is in operation on 35 stainless steel survey markers at GEONET station in data lacking areas.

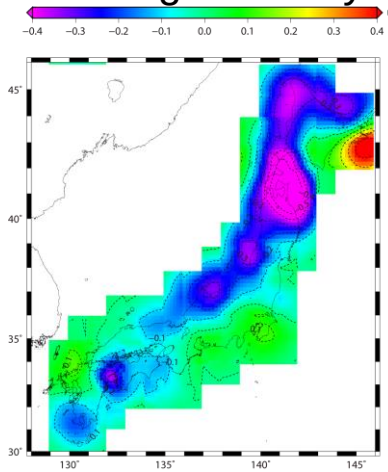
Hybrid Geoid Model

Fitting gravity geoid model to GNSS/Leveling geoid heights.

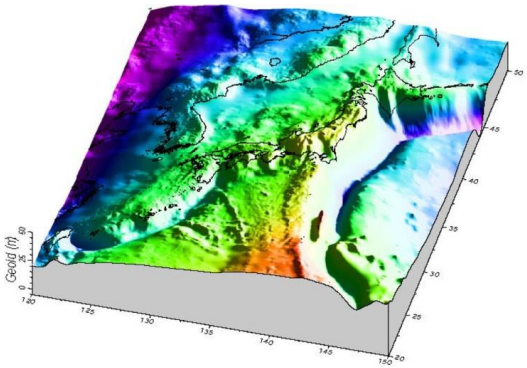


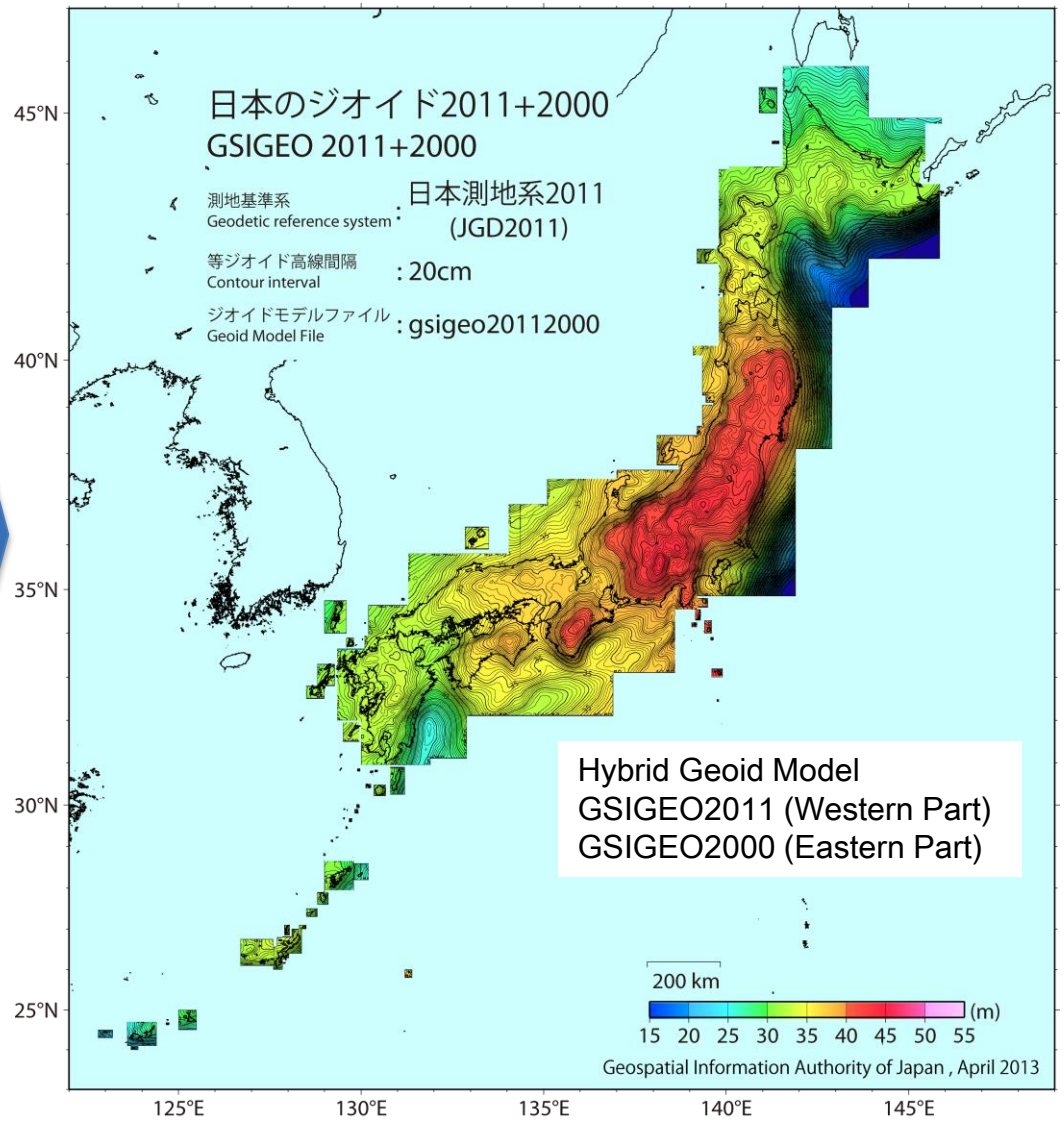
Hybrid Geoid Model

Geoid Correction Model
(GNSS/Leveling – Gravity Geoid)



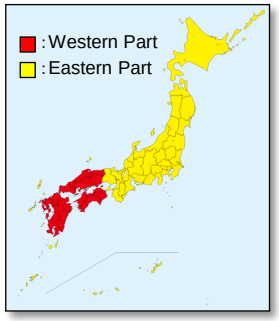
Gravity Geoid Model
JGEOID2008 (Western part)
JGEOID2000 (Eastern part)





History and Schedule
Geoid model in GSI

Hybrid geoid model “GSIGEO2011” for western part of Japan established April 2013, and GSIGEO2011 for eastern part will be established by the end of March 2013 after additional geoid height data will be obtained .



Gravity model

JGEOID93

JGEOID98

JGEOID2000

JGEOID2004

JGEOID2008

GSIGEO96

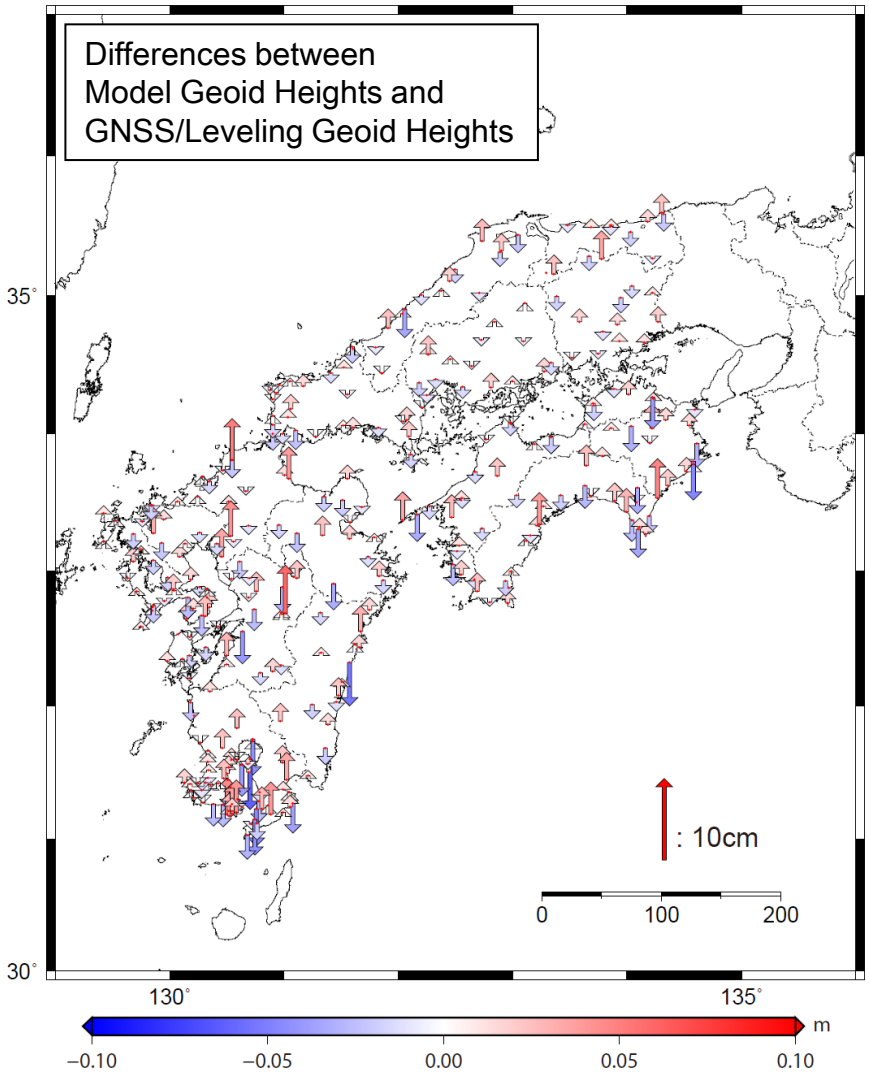
GSIGEO2000

GSIGEO2011(Western part)

GSIGEO2011(Eastern part)

Hybrid model

Evaluation of GSIGEO2011



- Geoid heights of GSIGEO2011 are compared with geoid heights determined by GNSS/Leveling to evaluate the consistency of the model with Japanese vertical datum.

	GSIGEO2011 – GNSS/Leveling
Average	-0.2mm
SD	20.8mm
Max Dif.	-66mm (65mm)

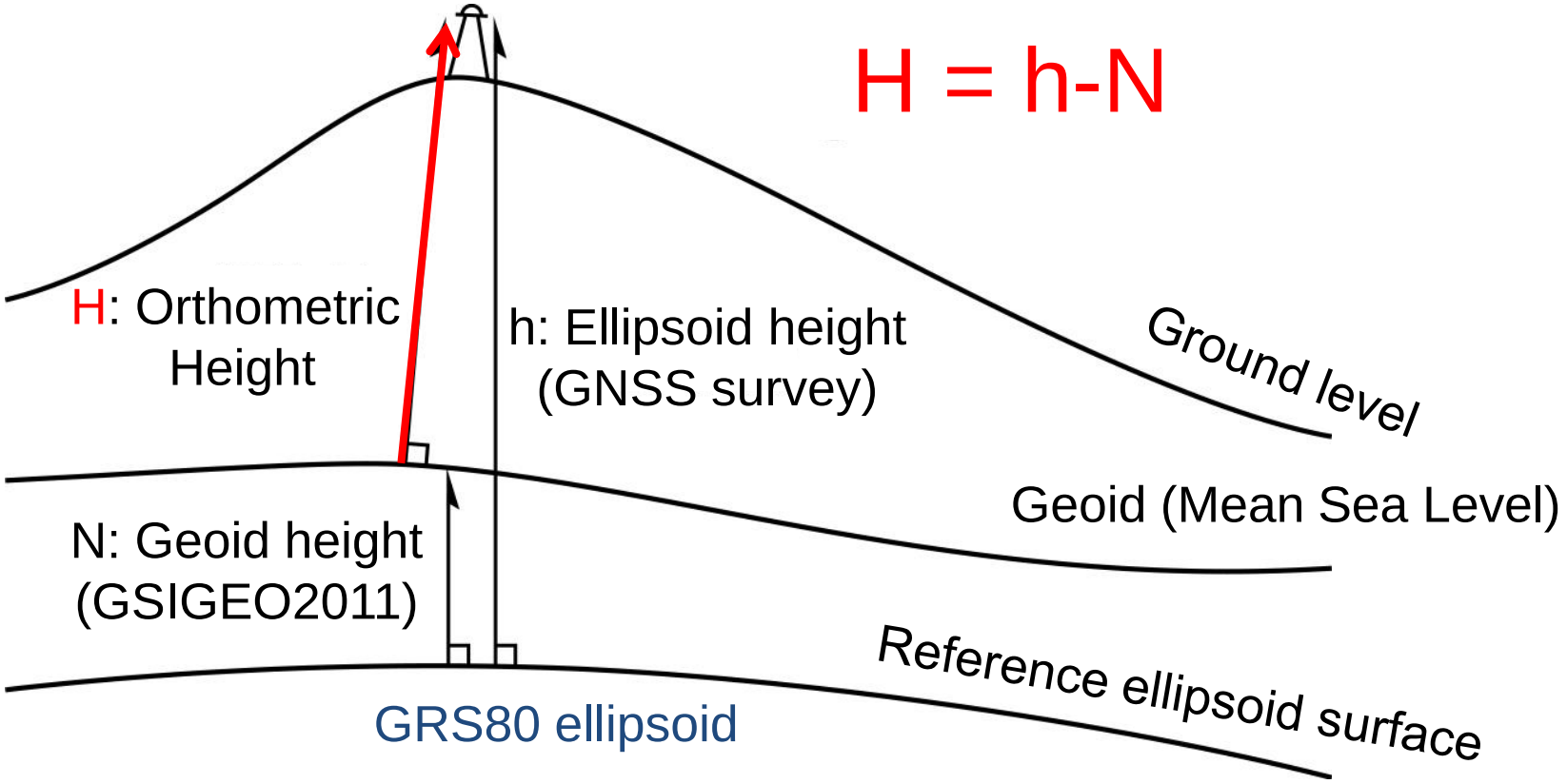
Orthometirc Height Determination by GNSS Survey with GSIGEO2011

- GSIGEO2011 is consistent with GNSS/Leveling geoid heights with 21mm in SD and can give geoid heights consistent with Japanese vertical datum.
- Orthometric heights consistent with Japanese vertical datum can be determined by GNSS survey with GSIGEO2011.
- According to field survey experiments, expected error range in GNSS ellipsoid height determination is 29mm in SD up to 30km baseline length.
- Considering error in GSIGEO2011, expected error range in orthometric height by GNSS with GSIGEO2011 is 36mm.

Error in GSIGEO2011	Error in GNSS survey	Error in orthometric height
21mm	29mm	36mm

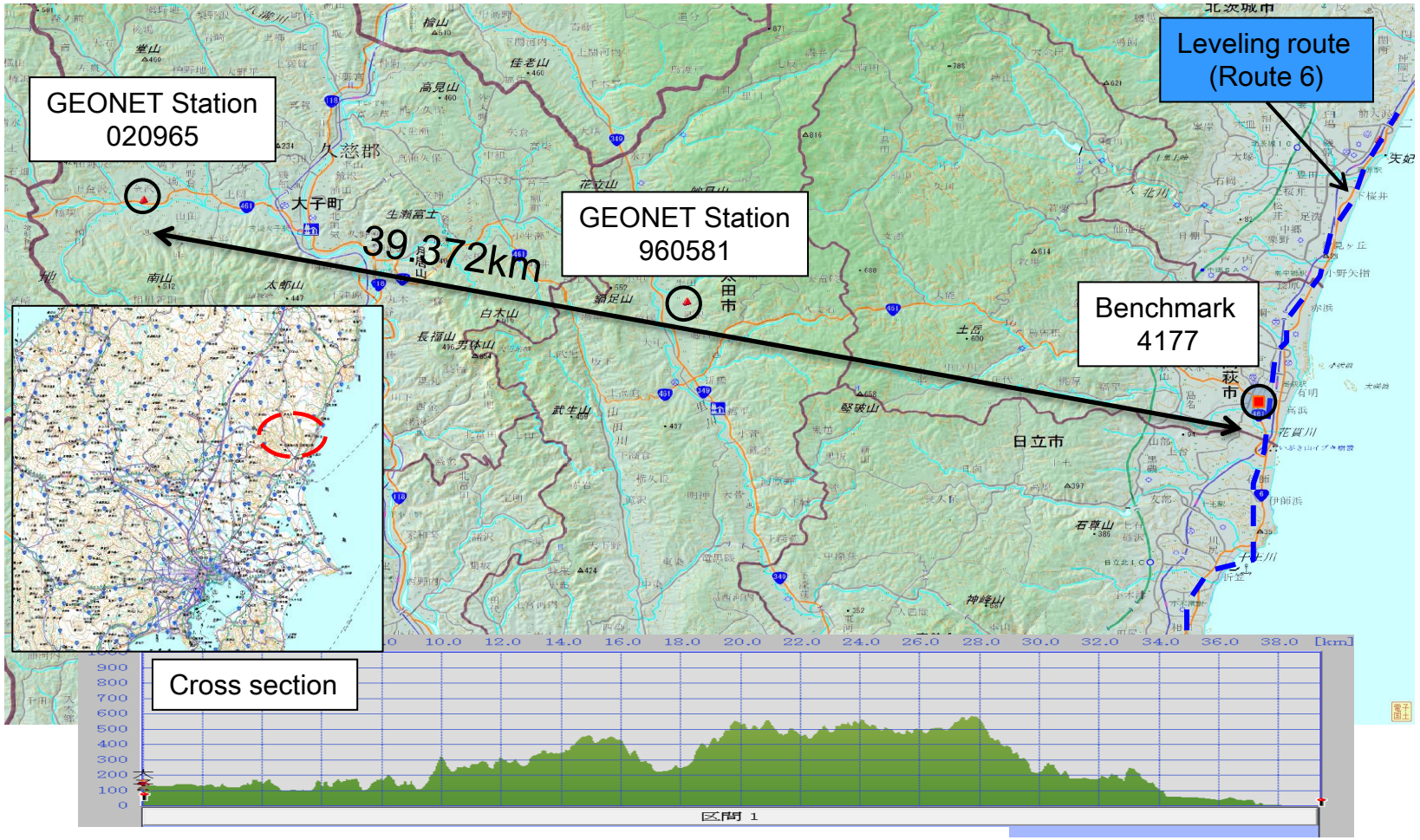
Orthometirc Height Determination by GNSS Survey with GSIGEO2011

GNSS survey on new benchmarks → Ellipsoid heights



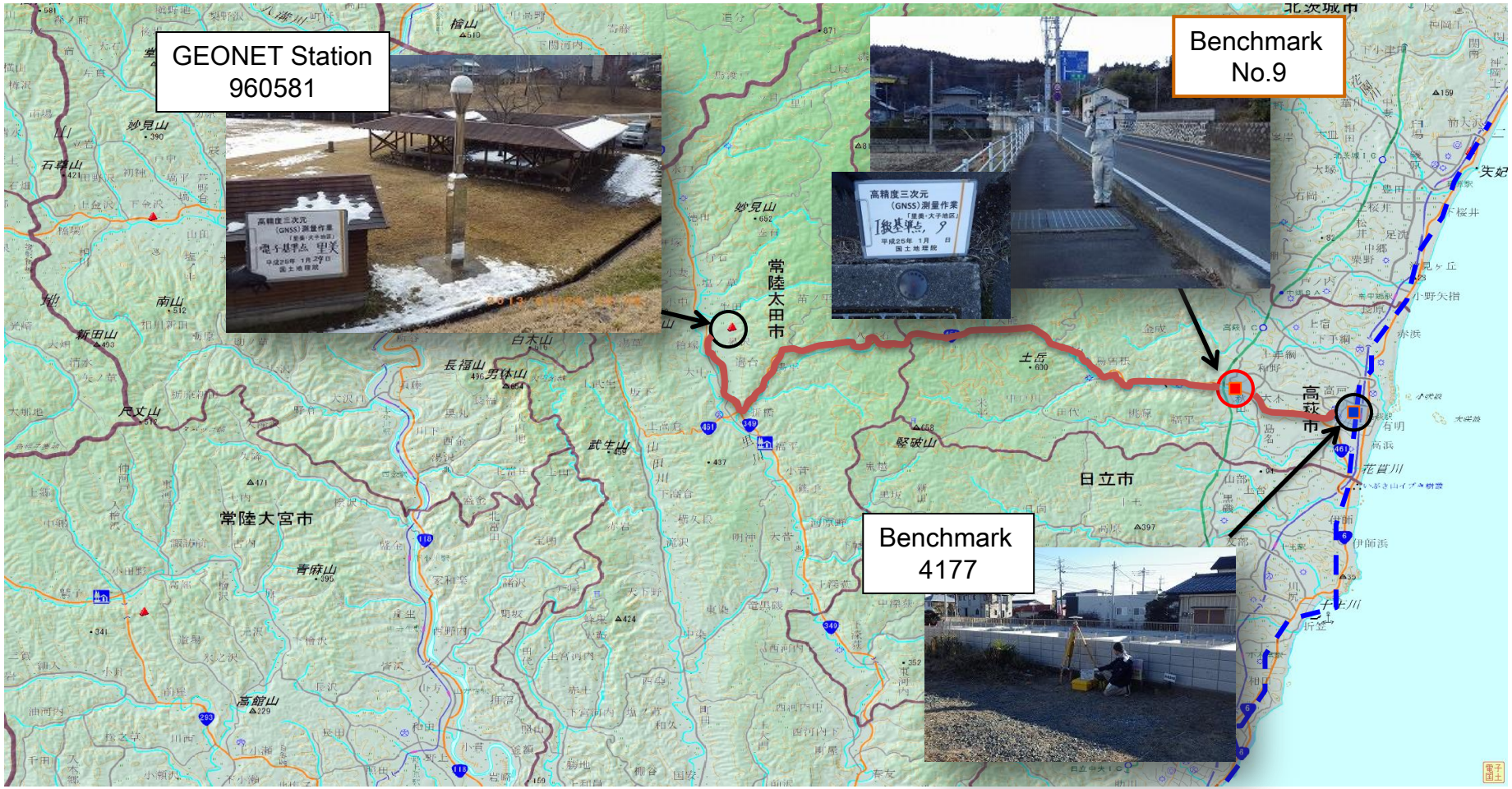
Experimental Survey

Field experimental survey of height determination by GNSS with hybrid geoid model “GSIGEO2011”



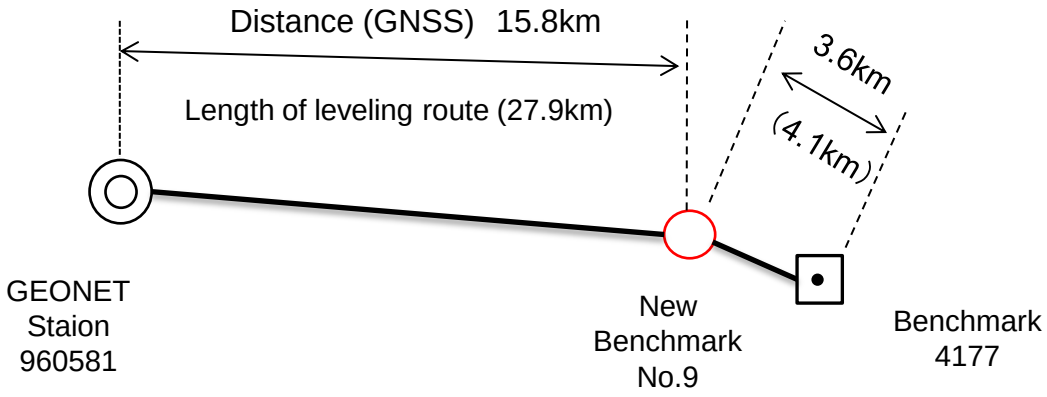
Experimental Survey

Height determination of new benchmark “No.9” by GNSS survey with hybrid geoid model “GSIGEO2011”



Experimental Survey

Difference between relative elevation by two survey methods is 14mm.

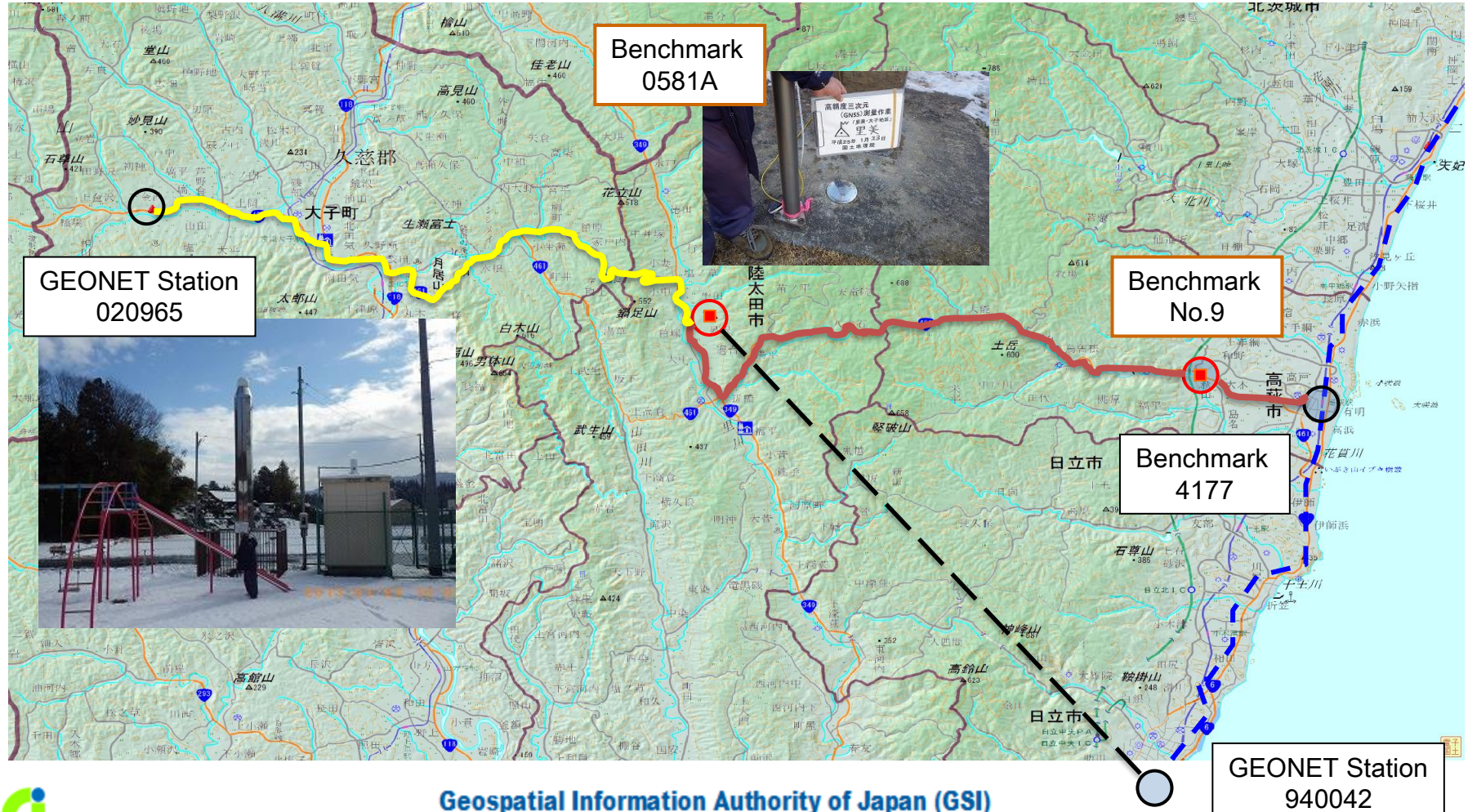


Test hybrid geoid model for

	①Relative elevation (GNSS survey with geoid model)	②Relative elevation (Leveling survey)	① - ② Difference	Acceptable Error range
NO.9	79.985 (m)	78.971 (m)	+14 mm	±44mm

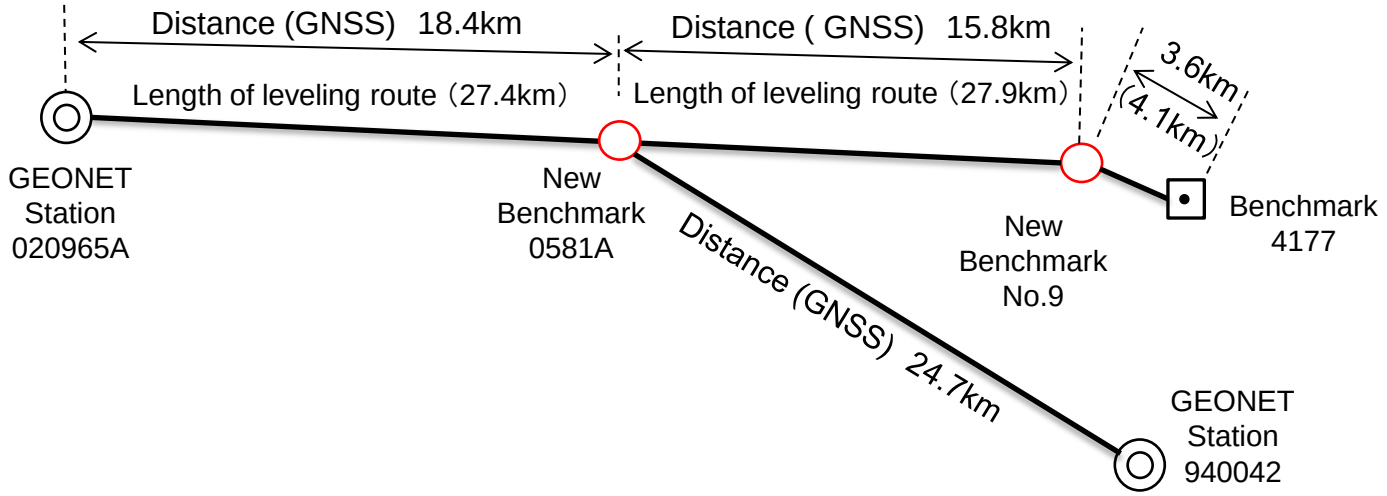
Experimental Survey

Height determination of two new benchmarks by GNSS survey with hybrid geoid model “GSIGEO2011”



Experimental Survey

Difference between relative elevation by two survey methods is 24~25mm.



	①Relative elevation (GNSS survey with geoid model)	②Relative elevation (Leveling survey)	① - ② Difference	Acceptable Error range
0581A	265.031(m)	265.006(m)	+25 mm	±61mm
NO.9	79.995(m)	78.971(m)	+24 mm	±61mm

Summary

- Orthometirc heights consistent with Japanese vertical datum can be determined by GNSS survey with hybrid geoid model.
- Hybrid geoid model “GSIGEO2011”for western part of Japan established by combining gravity geoid model “JGEOID2008” and GNSS/Leveling geoid data. (GSIGEO2011 for eastern part of Japan will be established by the end of March 2013)
- Difference between GSIGEO2011 and GNSS/Leveling is 21mm in SD, and max. difference is 66mm.
- According to experimental survey, relative elevations determined by GNSS survey with GSIGEO2011 are within acceptable error range.

Thank you for your attention.

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Geospatial Information Authority of Japan

Hybrid Geoid Model

Schematic Flow Chart of Model Establishment