Development of a method to analyze the error factor of GNSS-A system using SGO-A data

#Yusuke Yokota[1], Tadashi Ishikawa[2] , Shun-ichi Watanabe[2], Yuto Nakamura[2]
1：Institute of Industrial Science, University of Tokyo
2： Hydrographic and Oceanographic Department, Japan Coast Guard

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東京大学
THE UNIVERSITY OF TOKYO

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Error source of GNSS-A

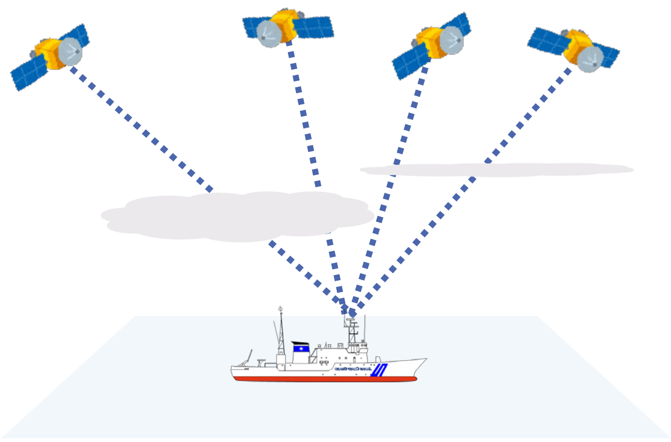
- GNSS error (atmospheric delay)
- Bias due to instrumental error of observation equipment
- Survey line-stations positional relationship

- **Disturbance of underwater sound speed structure**

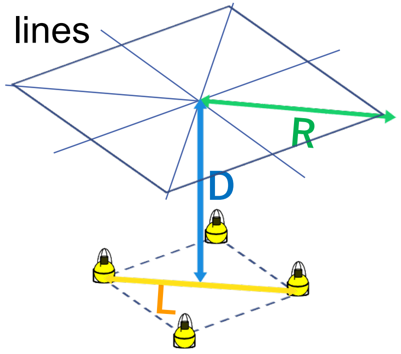
Physical validation →

- ➢ Validity of modeling
- ➢ Bias error detection
- ➢ Oceanographic interpretation

GNSS



Survey line-stations positional relationship



Station array

Nakamura et al. 2021, FES

Error source of GNSS-A

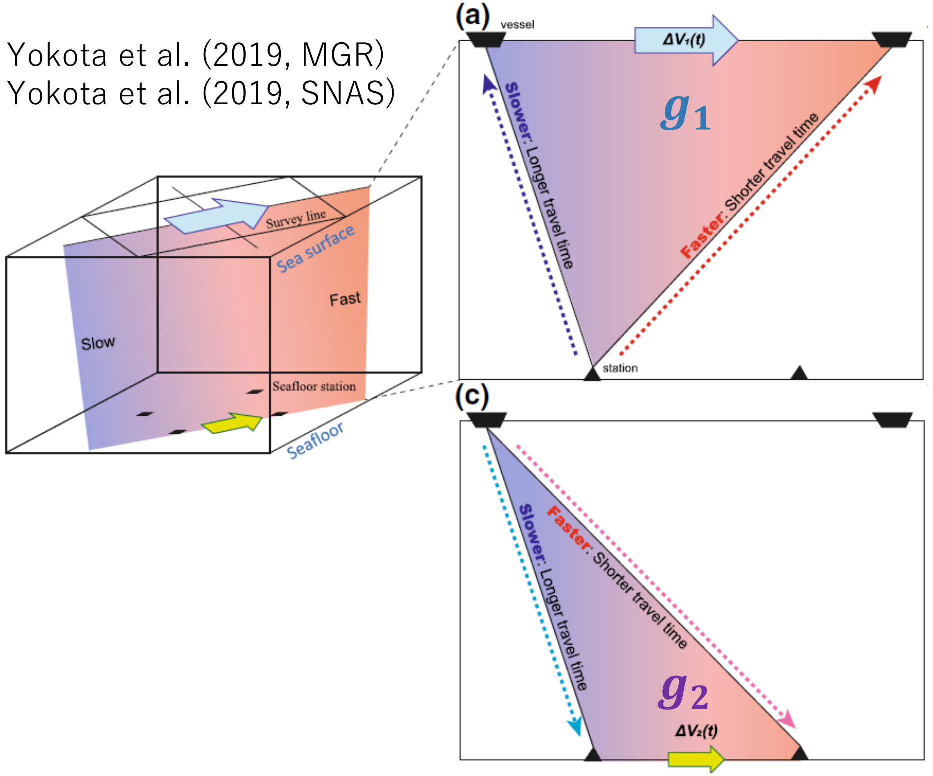
Latest open source method
GARPOS（Watanabe et al. 2020, FES）

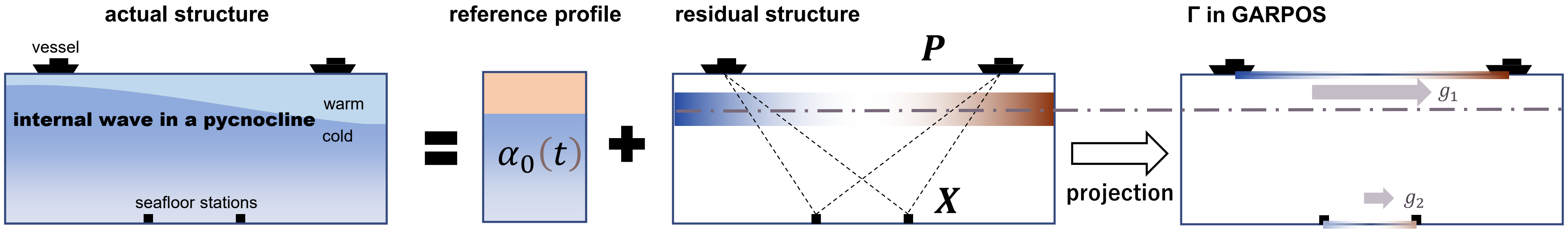
GARPOS
Positioning for 70% of our planet

- Simultaneously estimate the seafloor station position and the underwater sound speed field by empirical Bayes.
- Underwater sound speed field is represented by a Γ function model.

In GARPOS, the deviation from the reference profile (disturbance field) is extracted as two sonic disturbance parameters (g_1, g_2) projected on the sea surface and the seafloor.

Yokota et al. (2019, MGR)
Yokota et al. (2019, SNAS)





$$\Gamma(t,\boldsymbol{P},\boldsymbol{X}) \equiv \alpha_0(t) + \boldsymbol{\alpha}_1(t)\cdot\frac{\boldsymbol{P}}{L^*} + \boldsymbol{\alpha}_2(t)\cdot\frac{\boldsymbol{X}}{L^*}$$

$$\begin{cases} g_1 = \alpha_1 V_0 \\ g_2 = \alpha_2 V_0 \end{cases}$$

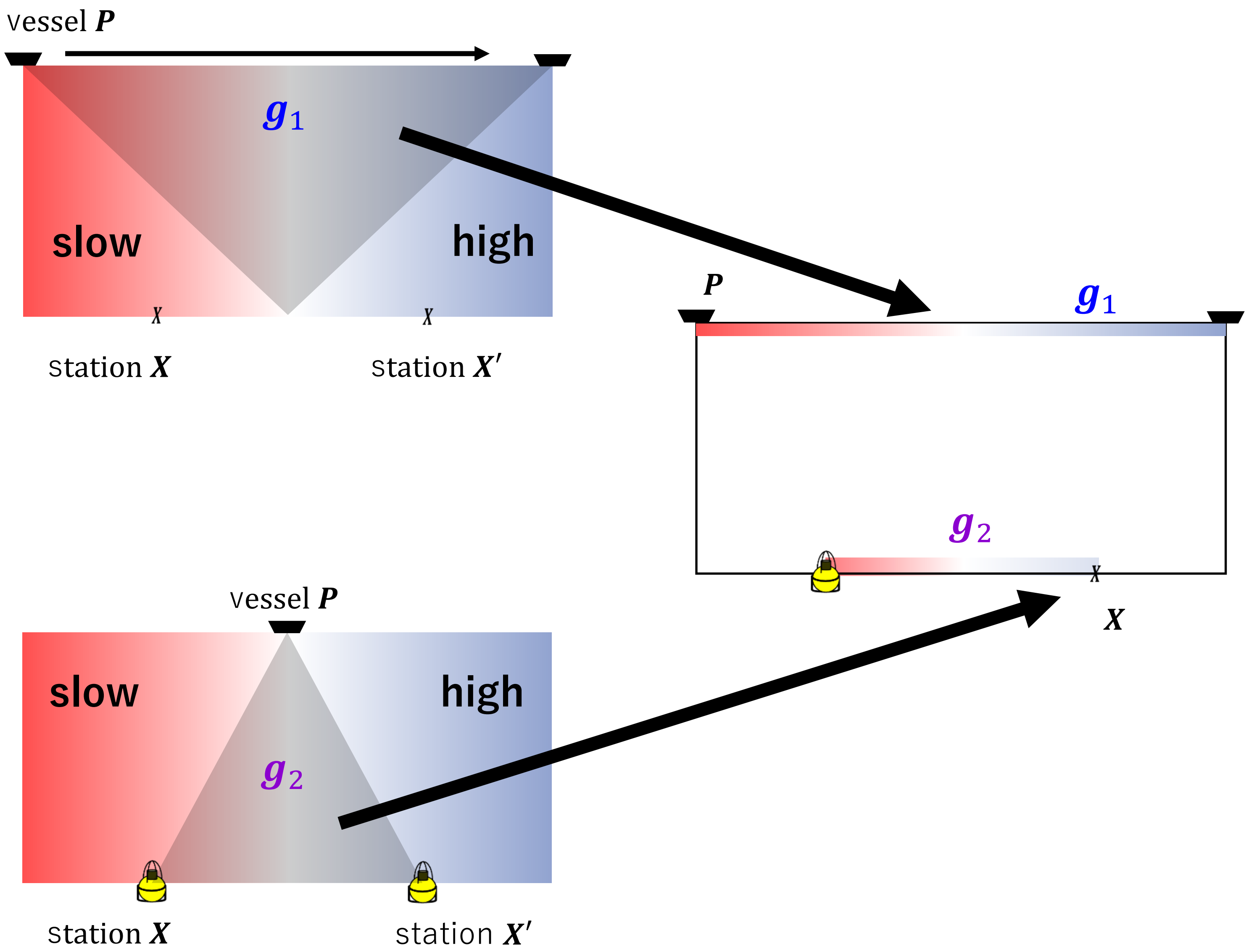
Sound speed structure model in GARPOS

$\boldsymbol{g}_1$: **Correction of sound speed depending on the position**

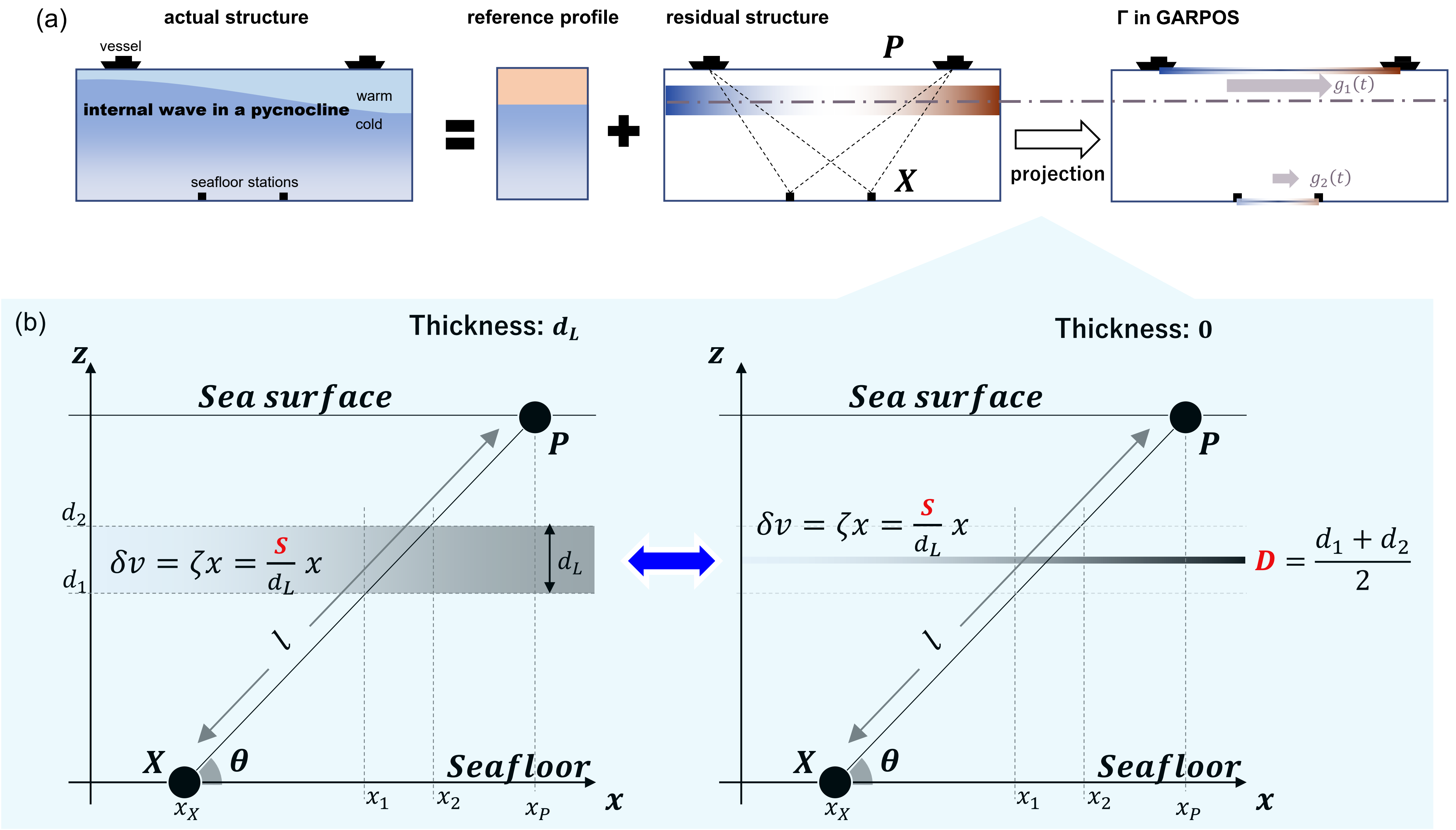
⇒$\boldsymbol{g}_1$ reflects a relatively upper horizontal gradient.

$\boldsymbol{g}_2$: **Correction of sound speed depending on the stations**

⇒$\boldsymbol{g}_2$ reflects a relatively deeper horizontal gradient.



Sound speed structure model in GARPOS



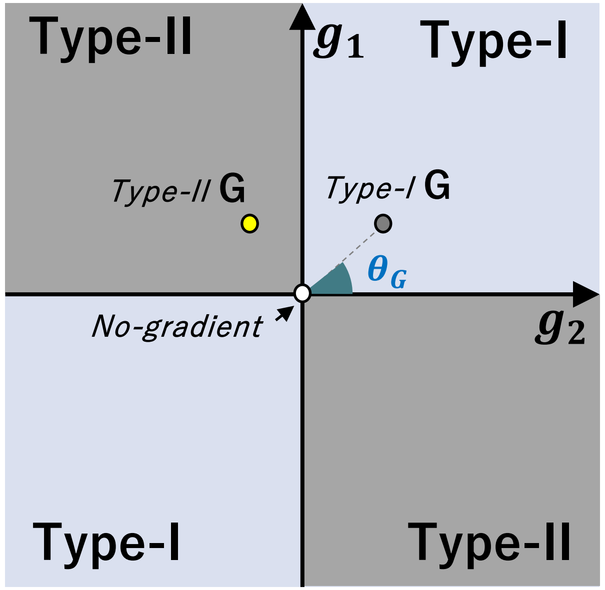
G-plane

- Vertical $\boldsymbol{g_1}$, Horizontal $\boldsymbol{g}_2$
- $\mathrm{sgn}(\boldsymbol{g_1})=\mathrm{sgn}(\boldsymbol{g_2})$, a state that can be interpreted by a one-layer model with a thickness of 0

→Type-I

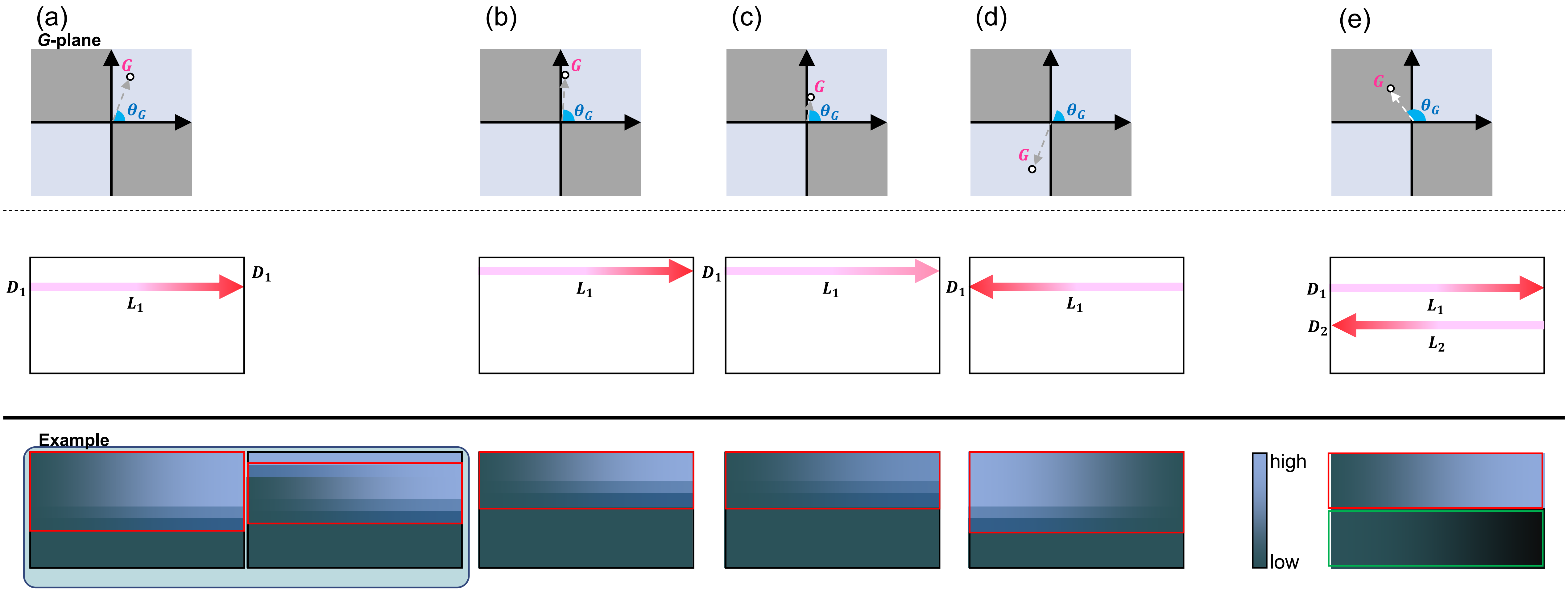
- $\mathrm{sgn}(\boldsymbol{g_1}) \neq \mathrm{sgn}(\boldsymbol{g_2})$, a state that must be interpreted by a two-layers model with a thickness of 0

→Type-II



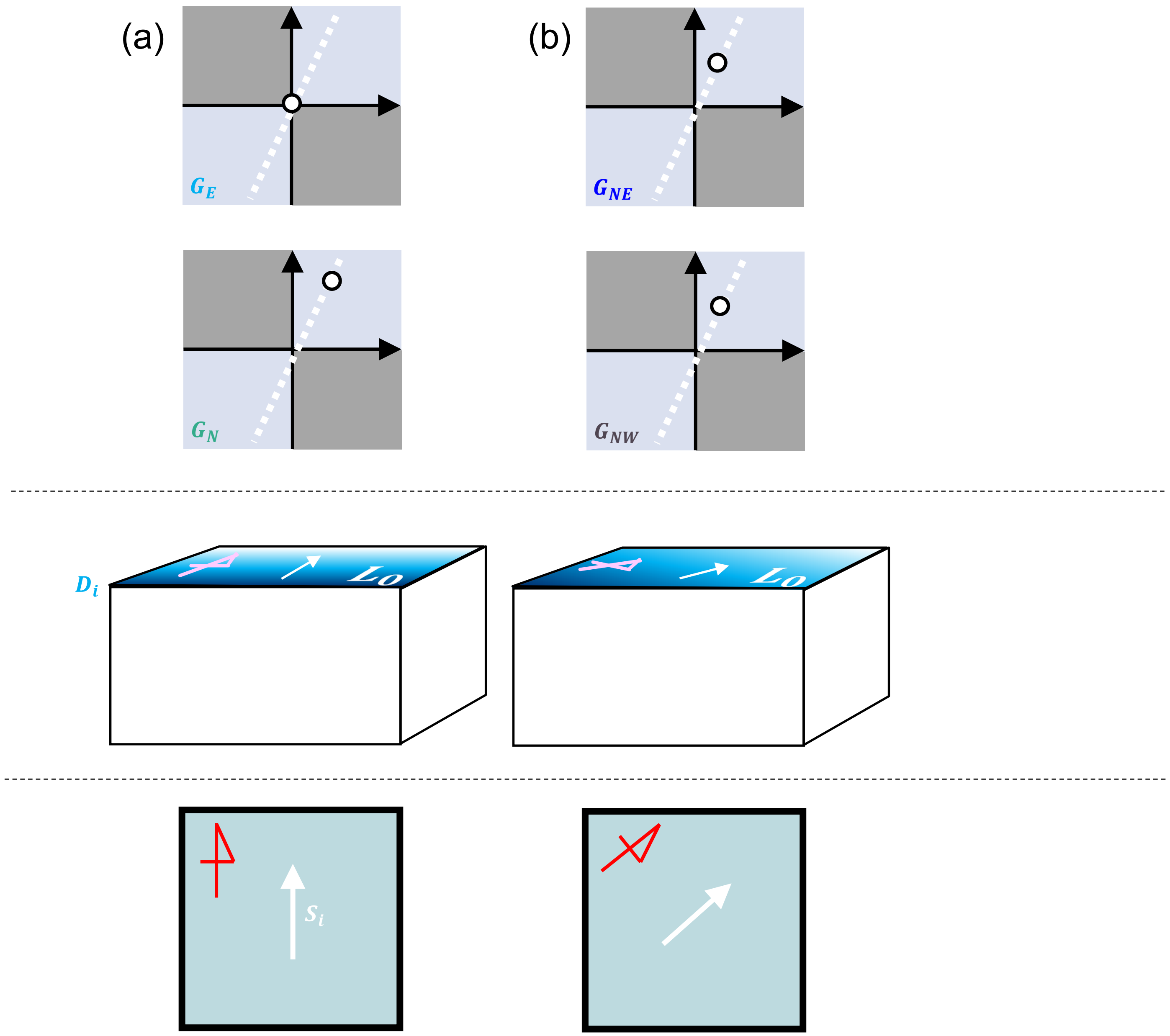
Conversion of G to an ocean field model based on this assumption

Examples



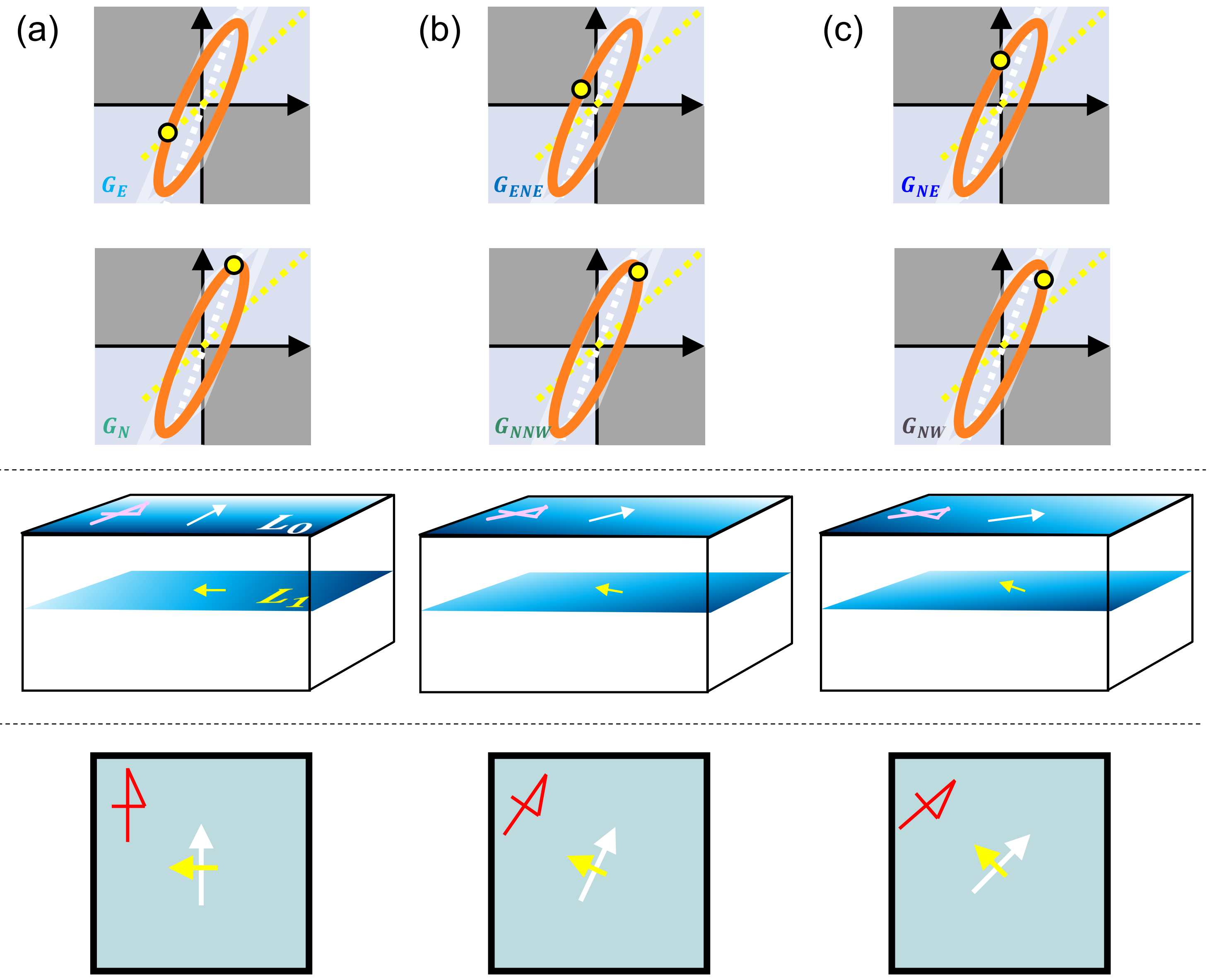
3D case

Two G planes can be obtained in two axial directions.
When only the orientation is different and the gradient depth/strength is the same,
$G_{E/N}$ values are located on the same straight line through the origin.

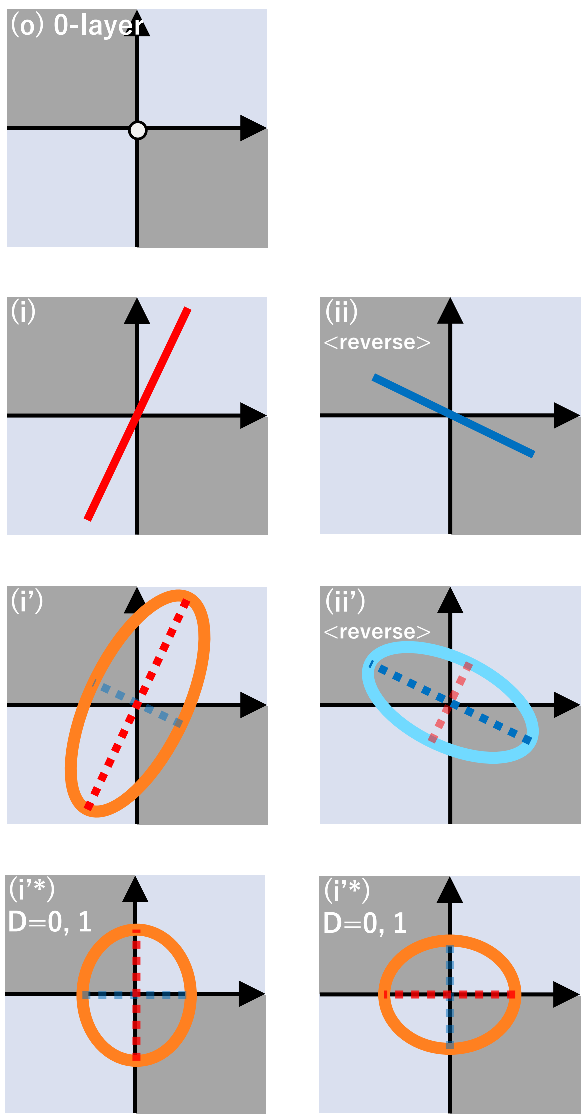


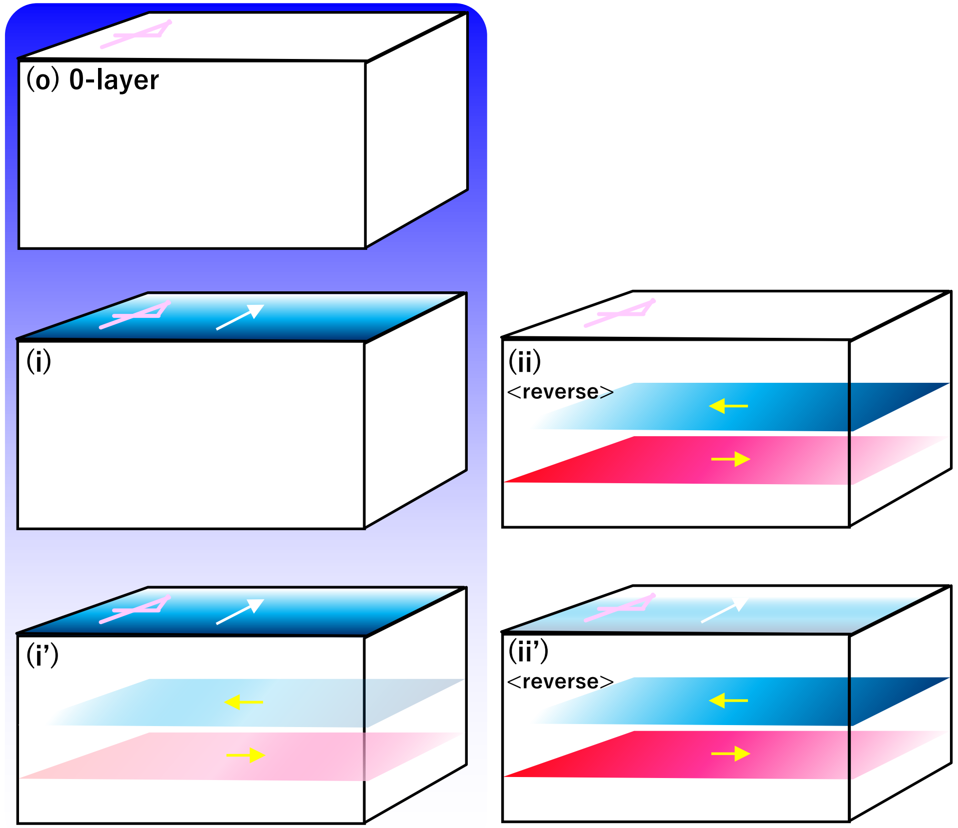
3D case（When need more than one layer）

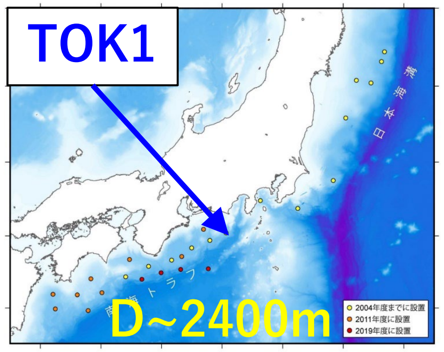
When $\mathbf{G}_{E/N}$ are not on the same straight line through the origin
→ Changing the directions, it turns over an ellipse centered on the origin.
→ No matter which direction **G** are facing, it cannot be interpreted with a single-layer gradient.

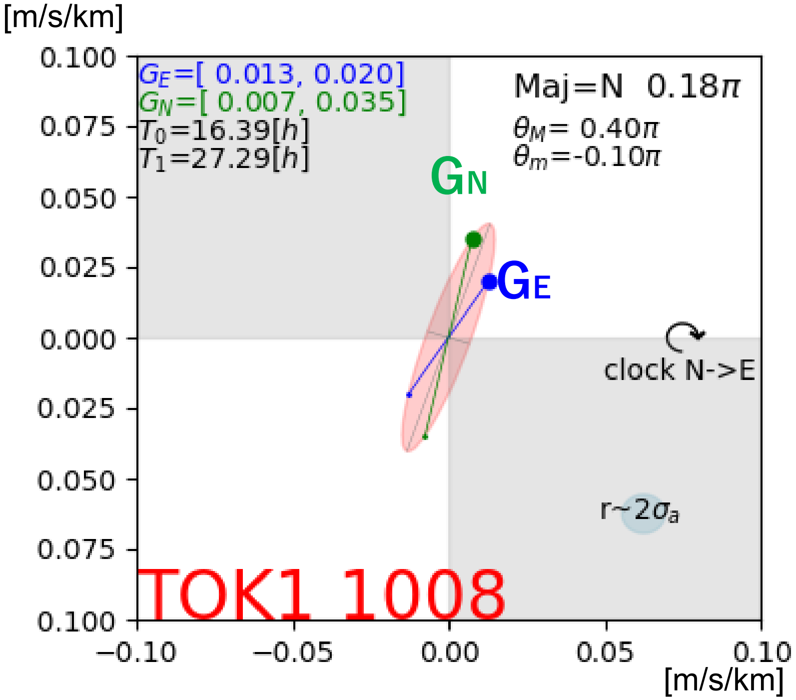


Features of G orbital ellipse in 3D





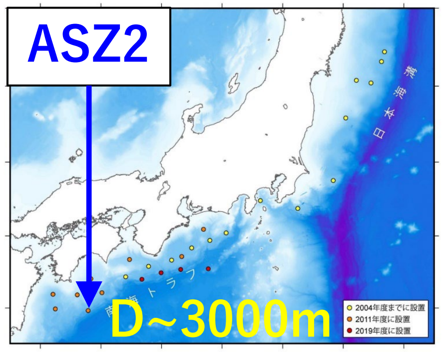




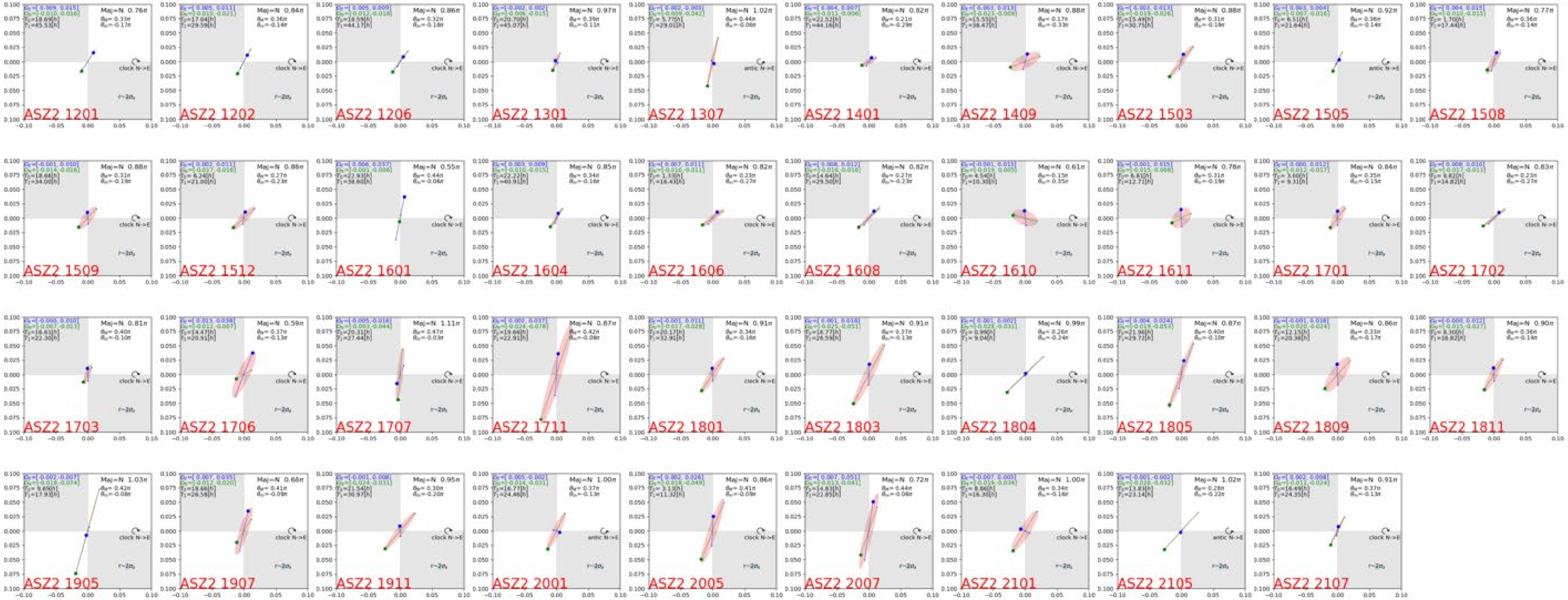
(Discussion)
We feel that the closer it is to (o) and (i), the more appropriate it is. ....

Detection of variation in G estimation and correction by constraint (ASZ2)

(a)



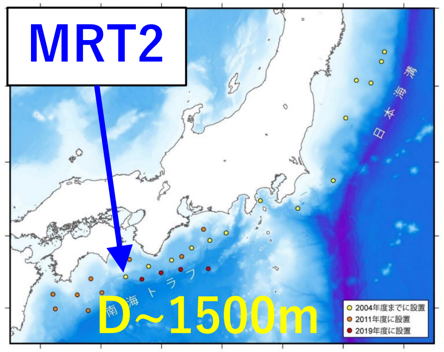
(b) **G** results by no-constraint basic GARPOS [Watanabe et al., 2021, FES]

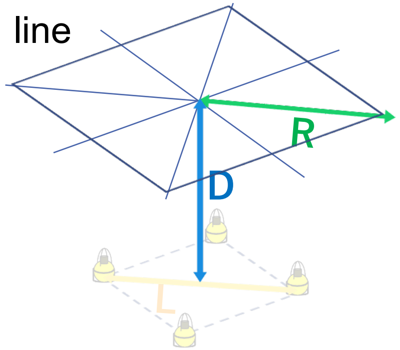


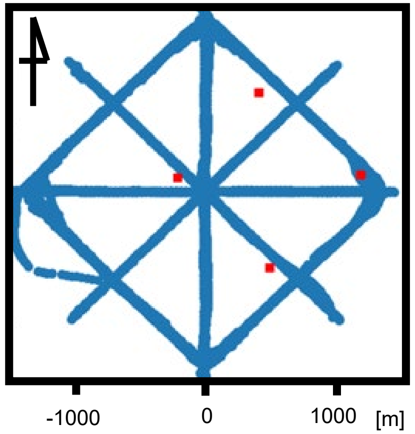
・ Most are close to (i) (i')
・ There are variations in the angle and the length of the major axis (there are differences in the gradient depth and strength).
・ It is easier to obtain an appropriate solution by constraining to one straight line through the origin (Watanabe et al. (in prep)).

Application to bias error detection and correction (1): Survey line bias (MRT2)

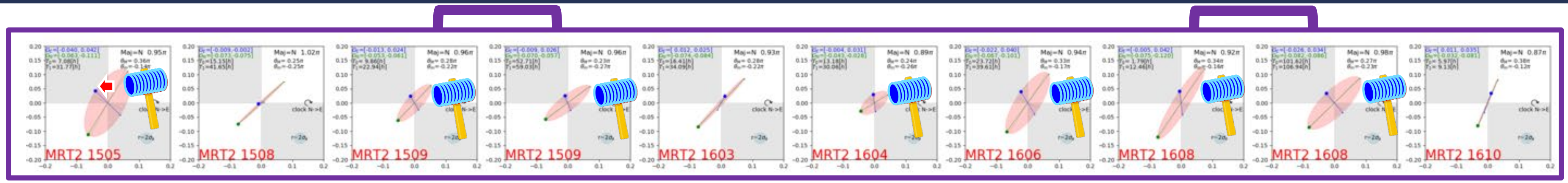
(a)



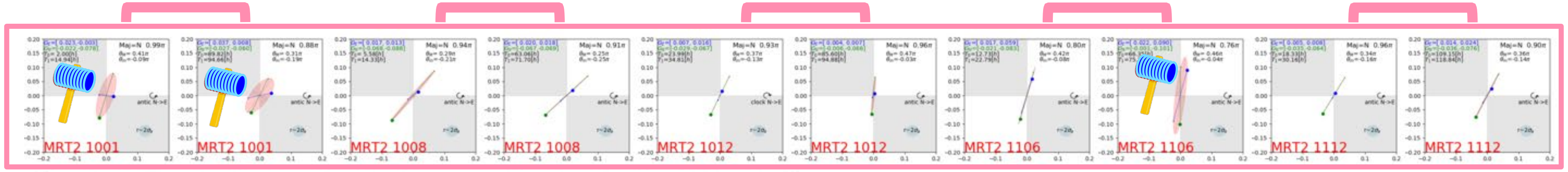




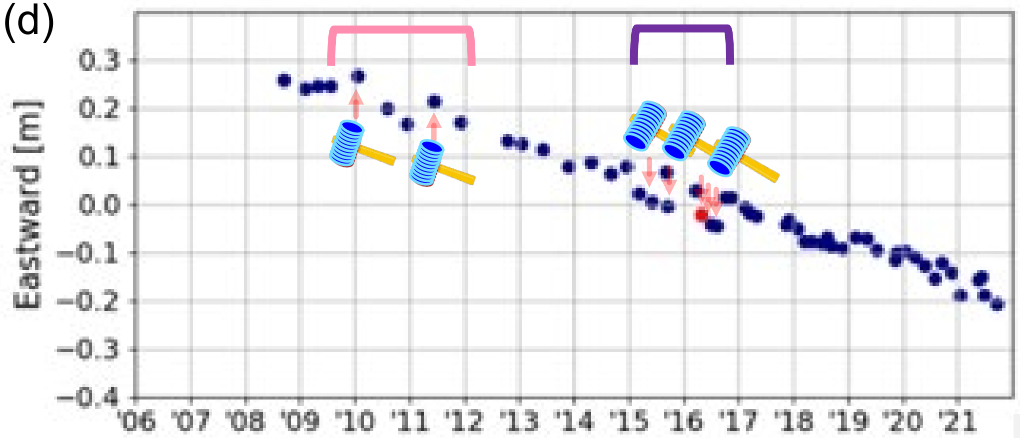
(b)

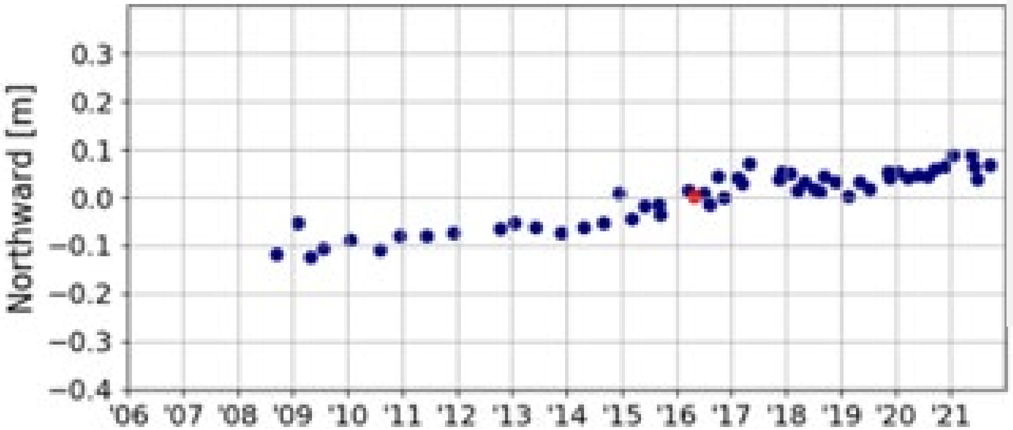


(c)



(d)

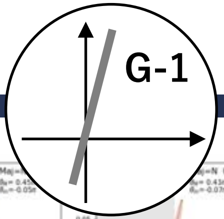




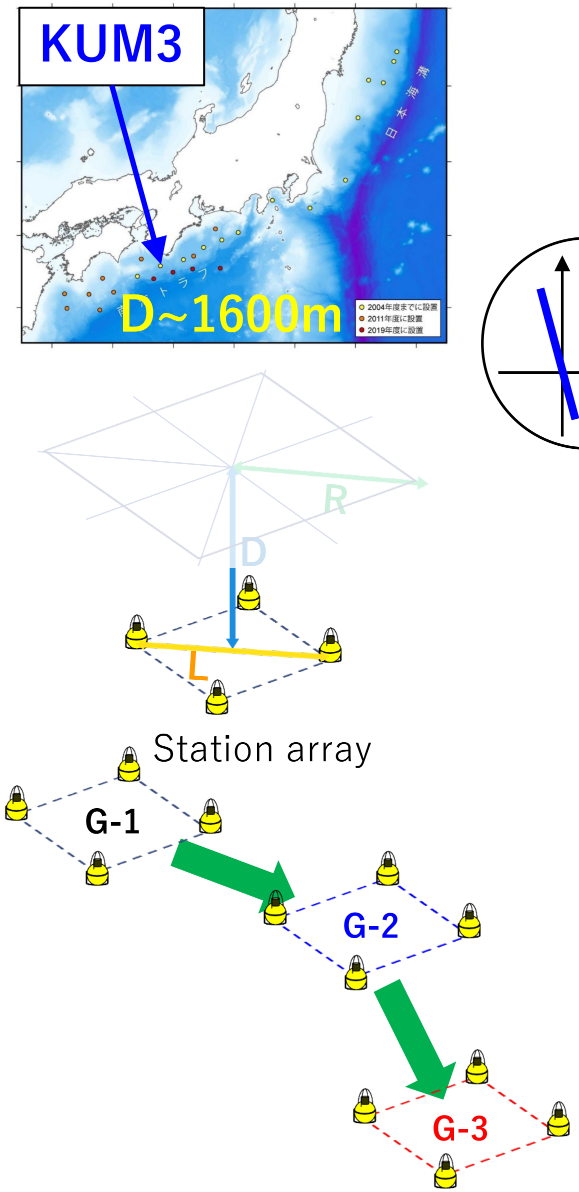
・ The G bias (deviation) on the G-plane and the deviation of the station position (Eastward direction) is consistent.

・ It suggests that the analysis should be constrained to the angle in the direction in which the correct G is considered to be obtained.

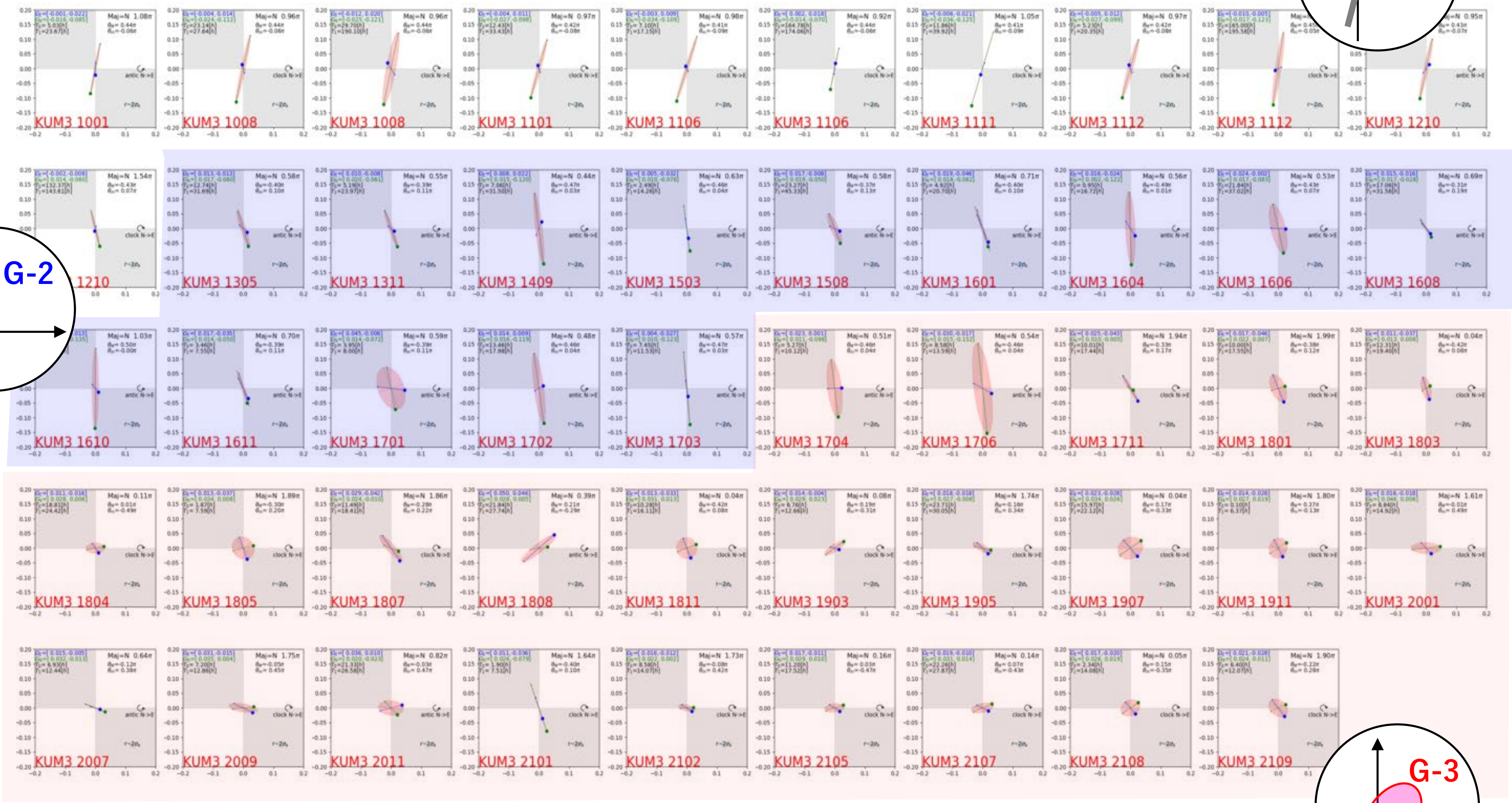
Application to bias error detection and correction (2): Array bias (KUM3)

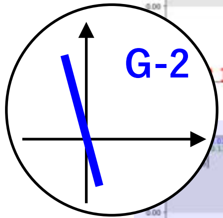


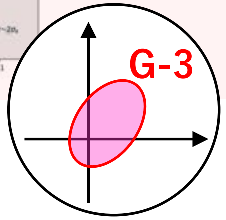
(a)



(b)



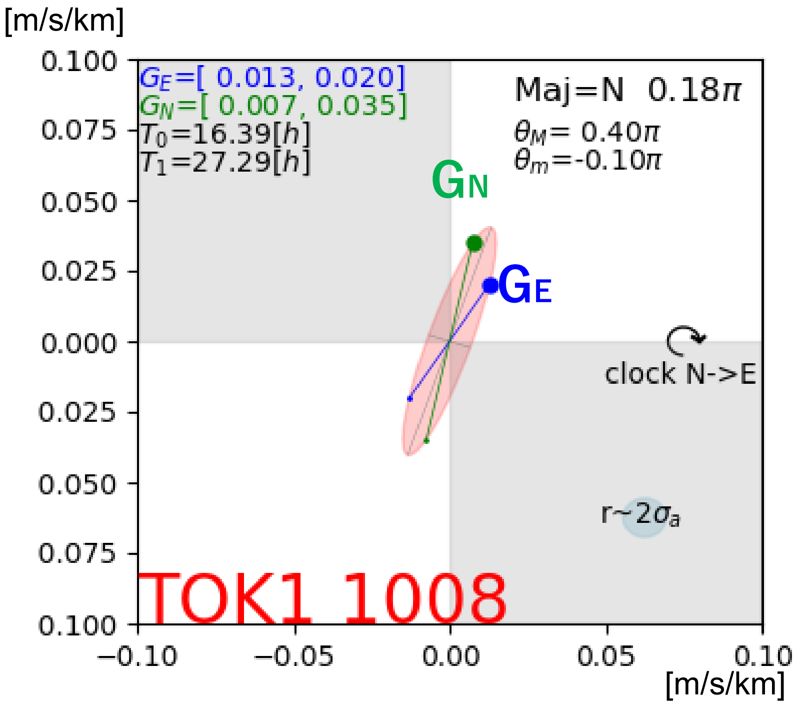


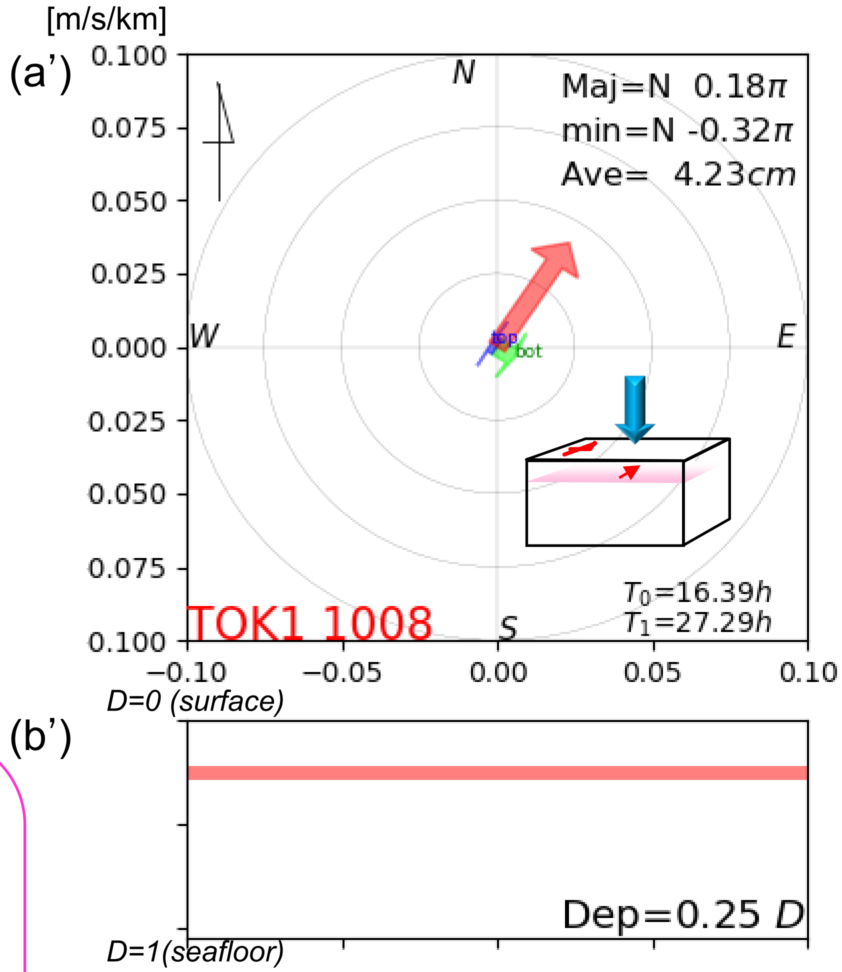


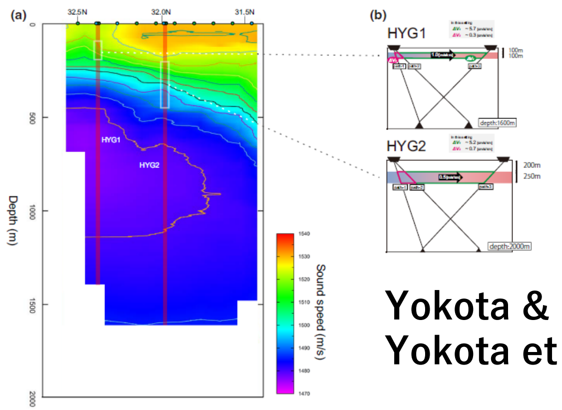
- The shape of the G ellipse changes every time the array is replaced.
- G ellipse after G-2 is unnatural (case of (ii)/(ii') increases rapidly)

→ The correct array has not been obtained

Quantitative oceanographic interpretation







Yokota & Ishikawa, SNAS 2019
Yokota et al., FES 2020

So far, qualitative discussions have been the main focus.

・ Only the characteristic grad direction, strength, and depth that can be known from GNSS-A oceanography can be obtained.
・ It is also expected that it will be possible to extract time changes to some extent (time scale) in the future.

Summary

We show:

- Physical verification of the validity of the underwater sound speed field estimation
- Representation of gradient structure in GARPOS Γ function model
- State classification method and quantification method in the case of 2D / 3D
- How to determine the bias error by this method
- It is possible to discuss the basic interpretation method for GNSS-A oceanography and the quantitative structure using it.

* It is necessary to understand the time-varying field for bias error detection and oceanographic understanding of observation points on the Japan Trench side where time-varying is predominant.