Daily monitoring of the Kuroshio over the Izu Ridge using ferry-onboard GNSS

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1. Introduction

- The Kuroshio, western boundary current of the North Pacific, sometime takes a significant meandering path.
- The Izu Ridge south of Japan is considered to affect the path selections.
- But we do not have frequent observations over the Izu Ridge (even with satellite altimeters) to cover rapid path changes.

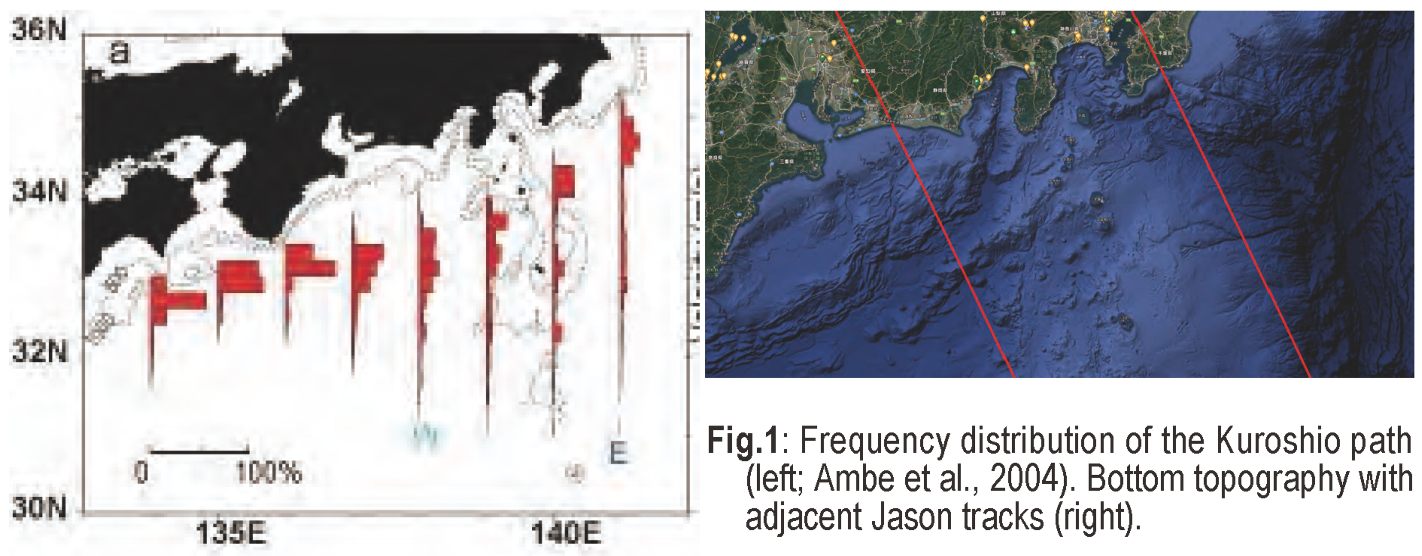

Fig.1: Frequency distribution of the Kuroshio path (left; Ambe et al., 2004). Bottom topography with adjacent Jason tracks (right).

2. Methods

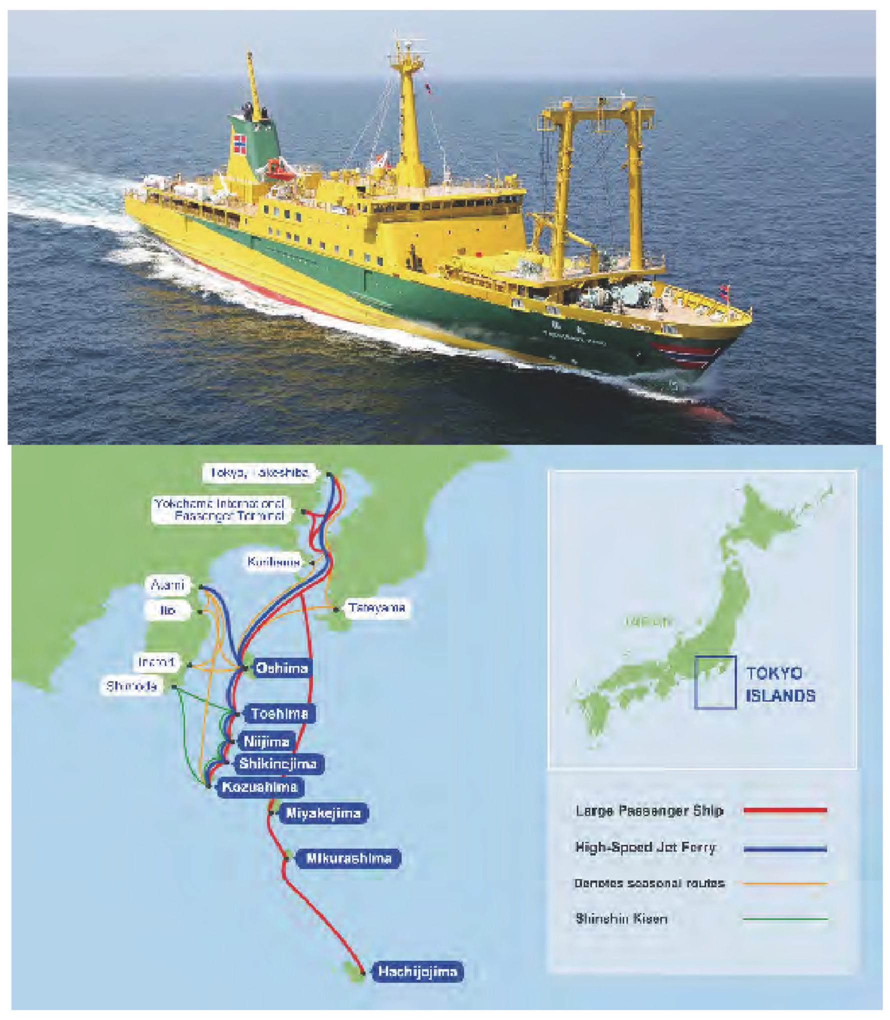

Fig.2: *Tachibana Maru* (118 m, 5700 tons) and her ship route to Hachijo island via Miyakejima and Mikurashima islands.

- We have started SSH measurements by GNSS (Global Navigation Satellite System) on ***Tachibana Maru*** (Tokai Kisen Co. Ltd.) that crosses the Kuroshio over the Izu Ridge twice a day.
- SSH (*Hs*) is determined by the antenna height (***Ha***) from a reference surface, with correction of the distance (*h*) between the antenna and the sea surface (Fig. 3).
- The distance *h* can be determined by GNSS Reflectometry (GNSS-R) that uses GNSS signals reflected at the sea surface which are always delayed from the direct signals (Ichikawa et al., 2019).
  - Since the GNSS-R method is too sensitive to waves, long-term smoothing is necessary. Fortunately, actual draft changes of a large vessel are expected small and slow.

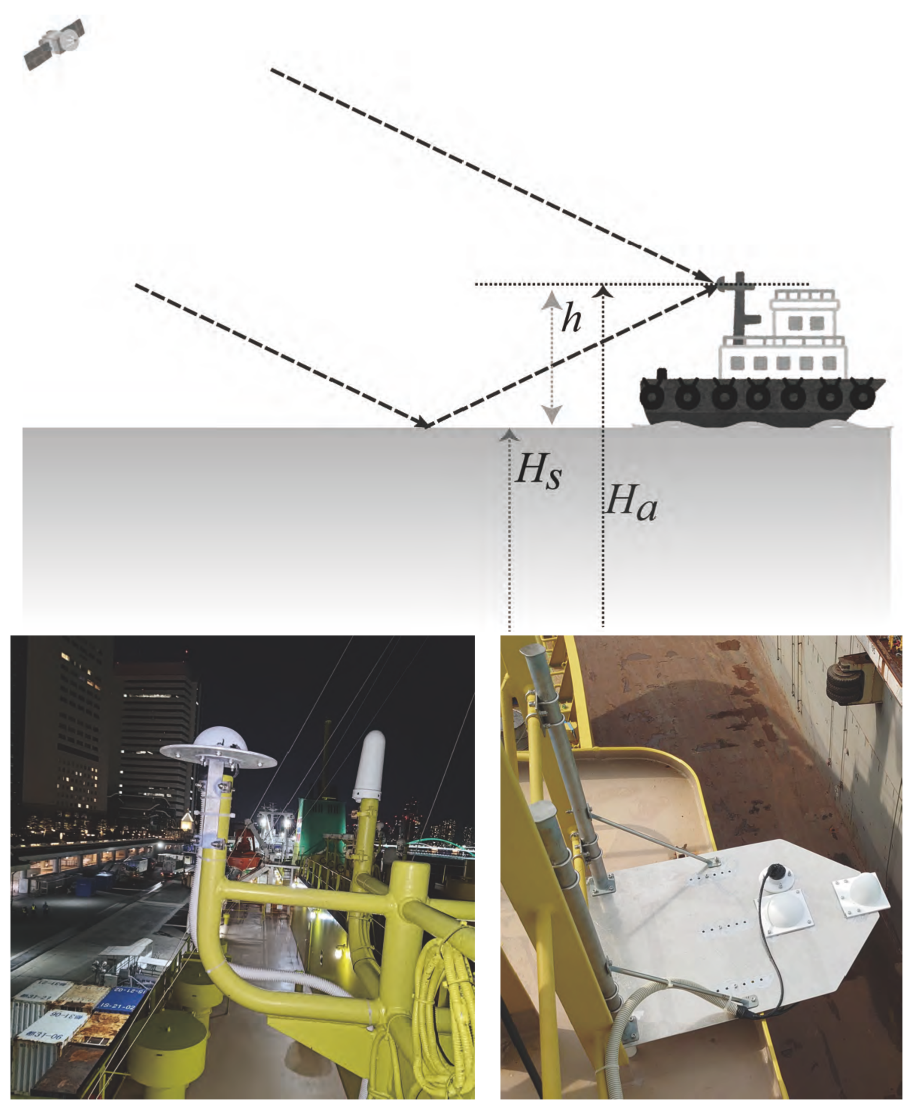

Fig.3: Schematic plot of GNSS measurements (top), and GNSS antennas for *Ha* (left) and *h* (right) for 1 Hz observations.

3. Results and Discussions

3.1 Unfixed Ship Routes

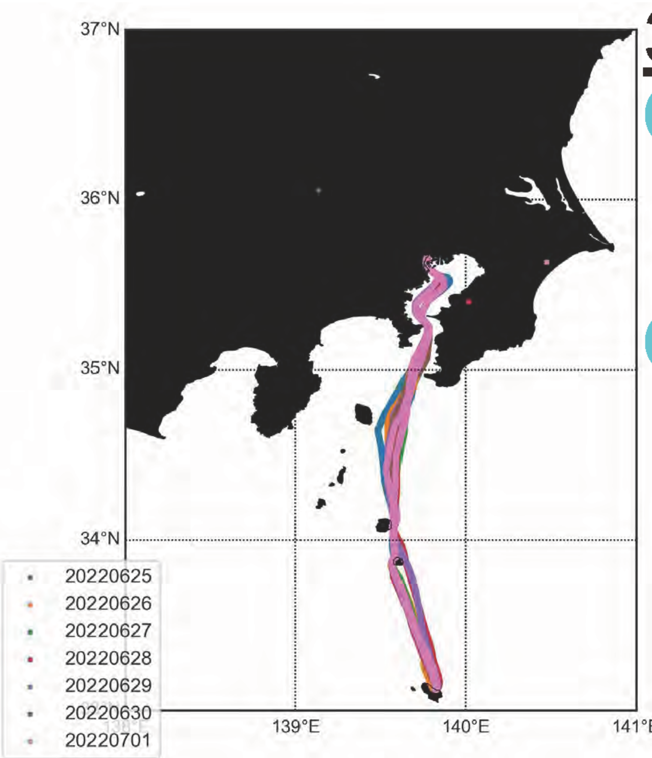

Fig.4: Ship routes in a week (2022/06/25-07/01)

- Actual ship routes are not fixed, so that variations of geoid are included
- Remove geoid to obtain dynamic height (SSDH)
  - Unfortunately, marine areas are out of coverage of the latest local geoid model provided by Geospatial Informatoin Autority (GIA) of Japan
  - Use EGM08 instead

3.2 Dependency on positioning methods

- Determination of *Ha* strongly depends on the positioning methods
  - Standalone single positioning include unrealistic 2-m order undurations
  - Precise Point Positioning (PPP) is less variable, but includes a large gap at Mikurashima Island, and an increasing trend toward north
  - Post processed kinematic (PPK) referring to the stationary Miyakejima station (by GIA) provides most reasonable SSDH variations

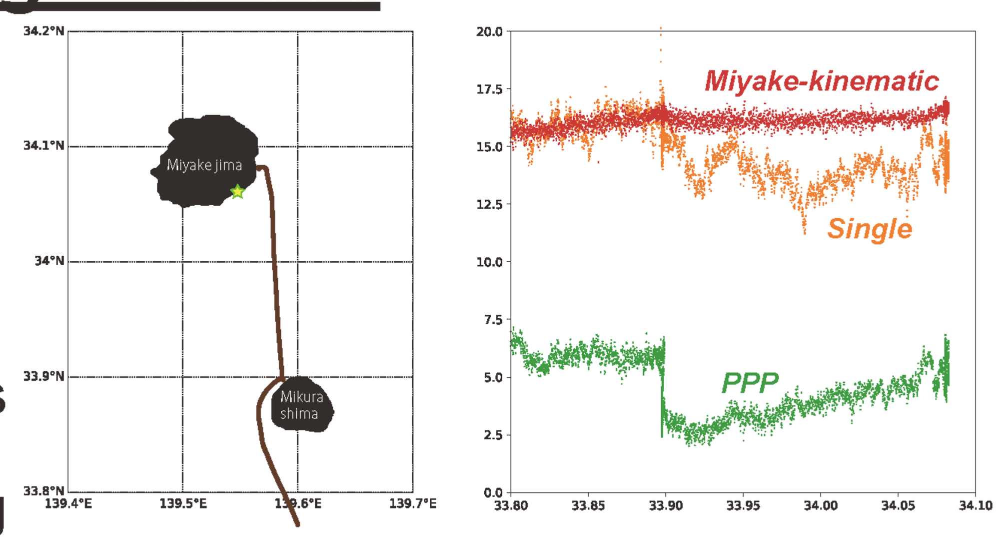

Fig.5: Ship route on 2022/06/30 (left) and estimated SSDH by various methods in RTKlib (Takasu, 2009) ver 2.4.3 (right).

- Also, depends on softwares

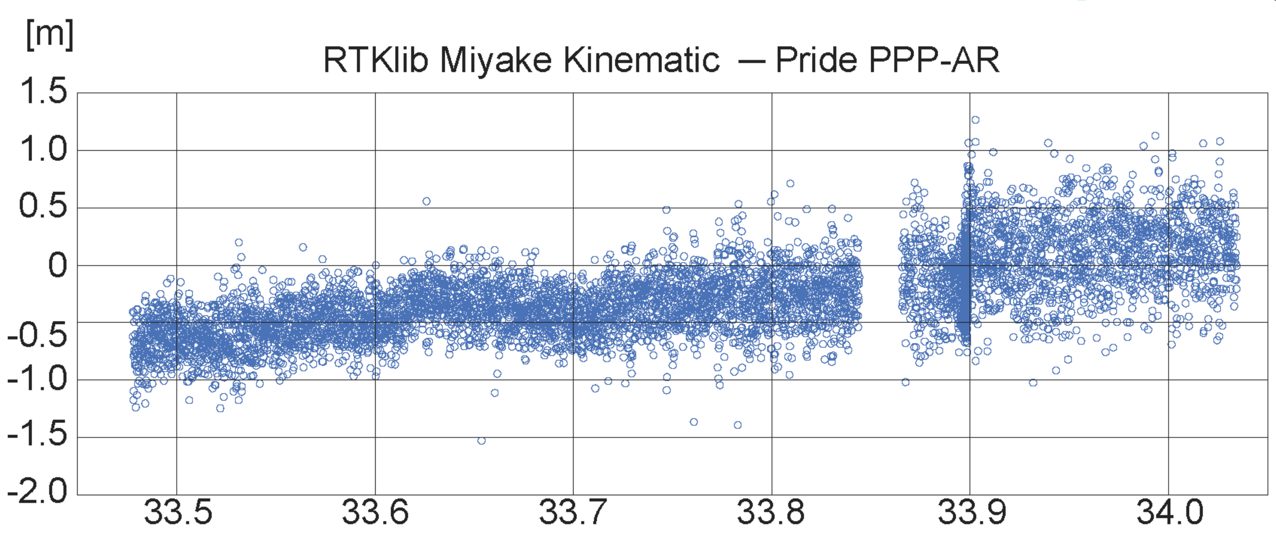

Fig.6: Difference between RTKlib kinematic solutions and Pride PPP-AR solutions.

- PPP solution by Pride PPP-AR (Geng et al., 2019) is much closer to PPK solution in Fig. 5 than RTKlib PPP.
- Difference between PPK and PPP (Fig 6) are less than 1 m, but still there are an unexplained trend.

3.3 SSDH Samples

- 12-h SSDH (Fig.7) shows
  - Large tidal variations within Tokyo Bay (north of 35.2ºN)
  - Lower SSDH between 33.5ºN and 34.2º (south of Miyakejima island)
  - Strong westward and eastward flows at 34.9ºN and 35ºN, respectively
- In situ velocity obs (Fig.8) shows
  - Northern branch of the Kuroshio at 35ºN, downstream of Oshima island
  - Southward meander of the Kuroshio at 139ºE

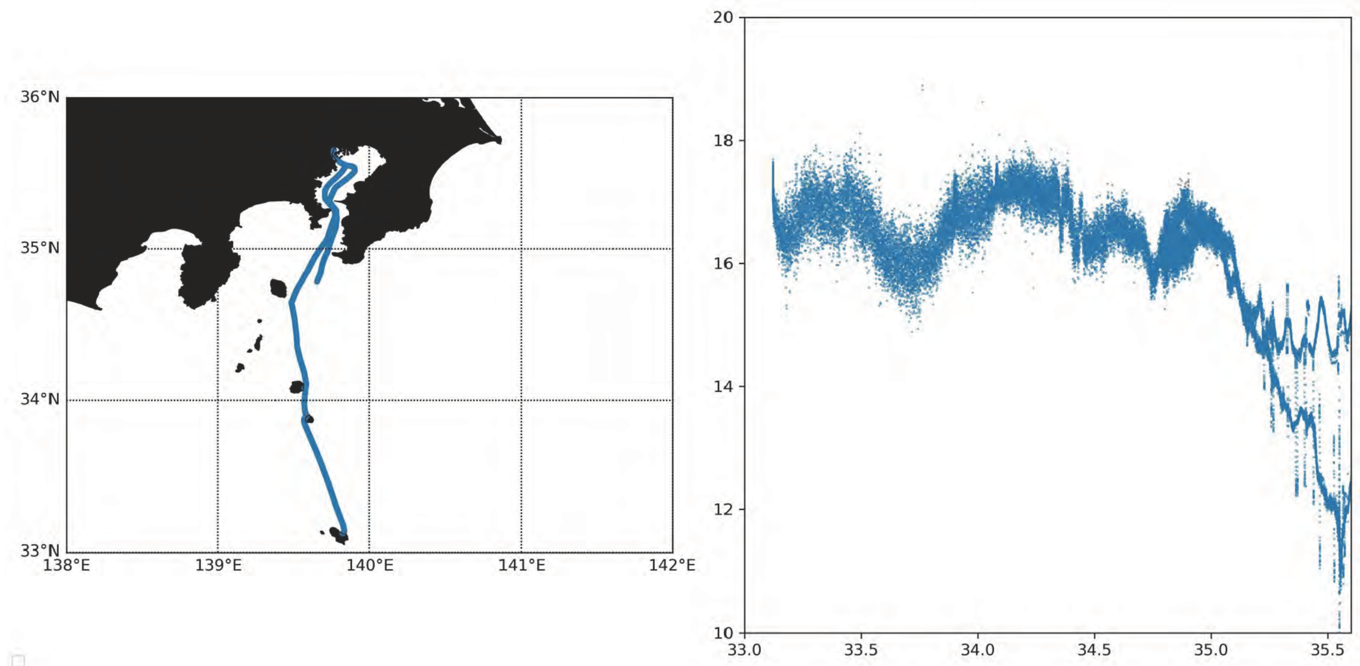

Fig.7: 12-h SSDH on 2022/06/30 estimated by PPK (right) and ship tracks (left)

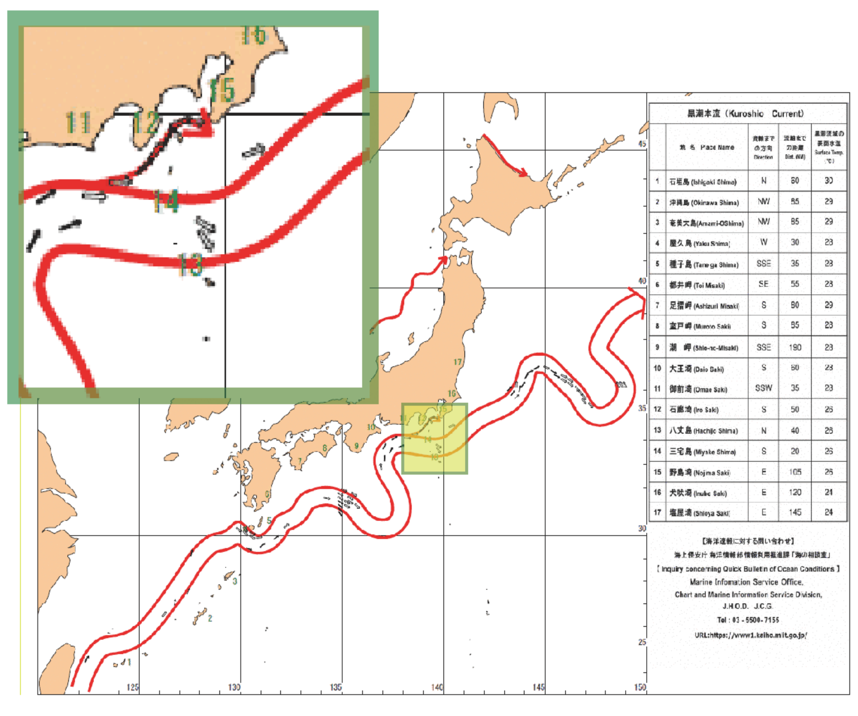

Fig.8: Quck bulletin of Ocean Conditions on 2022/06/30 from Japan Coast Guard. Enlarged figure at the top left corner.

4. Conclusions

- SSDH over the Izu Ridge can be obtained by GNSS on a ferryboat
- More cal/val are necessary for reliable estimates

References

Ambe *et al.* (2004) *J.Oceanogr.*, 60, 375-382.
Geng *et al.* (2019) *GPS Solutions*, 23, 91
Ichikawa *et al.* (2019) *Sensors*, 19, 998, doi:10.3390/s19050998
Takasu (2009) *FOSS4G*