Accuracy Assessment of Some Potential GNSS Positioning Techniques for Ellipsoidally Referenced Hydrographic Surveys

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:: OUTLINE ::

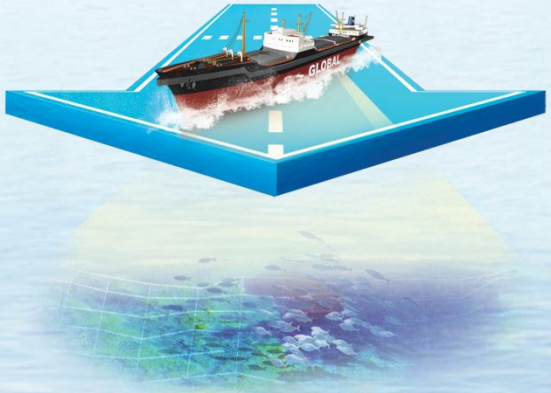
I INTRODUCTION

II GNSS DATA AND METHODOLOGY

III RESULTS AND DISCUSSION

III CONCLUDING REMARKS

I INTRODUCTION



Vertical Datum (Height System)

- A one-dimensional coordinate system
- Used to define the metric distance of some point **from reference surface along a well-defined path** (i.e., the height of the point)

Component	**Datum Surface + Path that the distance is measured over**

Classification	
	Not related to Gravity using straight-line path
	Related to Gravity using curved path (e.g., plumbline)

Which Class of the System is Natural and Physically Meaningful?

- Water **must** flow **downhill** from a higher to a lower height
- The Earth's gravitational force governs water flow

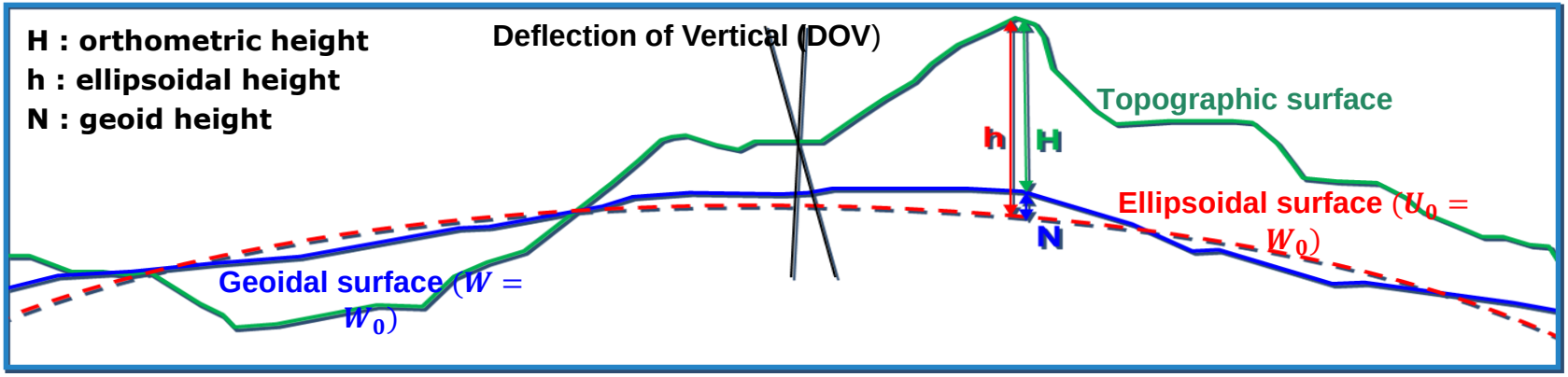
Category of Vertical Datum (1/2)

Geodetic Vertical Datum

- Geoid is the reference surface of the geodetic datum from a theoretical standpoint.
- Equipotential surface of the Earth's gravity field which best fits (global) mean sea level in a least squares sense.
- Topographic data are often referenced to a local datum, such as Local MSL.

Reference Ellipsoid

- Simple mathematical surface of the Earth which closely approximates the geoid.
- GNSS heights are determined relative to this surface.
- **Orthometric Height (H) = Ellipsodial Height (h) – Geoidal Height (N)**



Category of Vertical Datum (2/2)

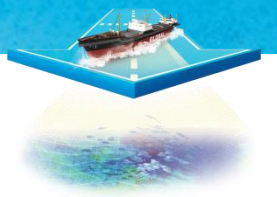


Chart Datum (CD)

- Used on nautical charts to reference water depths.
- Bathymetric data displayed on charts is reference to a low water tidal vertical datum (e.g., Lowest Astronomical Tide – LAT).
- Chart datums are only fully valid at the location where the tides are observed.
- Challenge in traditional hydrography is establishing relationship between the instantaneous water surface (IWS) and CD away from gauge locations.
- Uncertainty in the relationship between IWS and CD at the survey site is a significant component of the overall depth uncertainty.

- **MLW** Mean Low Water
- **MLLWLT** Mean Lower Low Water Large Tide
- **MLLW** Mean Lower Low Water
- **LNT** Lowest Normal Tide
- **LLWLT** Lower Low Water Large Tide
- **LAT** Lowest Astronomic Tide (atmospheric & oceanographic effects minimized)

ELLIPSOIDALLY REFERENCED SURVEY

ONE OF THE MOST SIGNIFICANT ISSUES IN HYDROGRAPHY TODAY IS TO USE THE ELLIPSOID AS THE REFERENCE FOR MEASURING WATER DEPTH.

- Hydrographic survey has traditionally been performed for establishing nautical charts for safety of navigation, **but has now a vital role in costal zone management.**
- Costal zone encompasses a wide belt along the shoreline including the land and sea.
- **Integration of hydrographic and topographic data is essential for the analysis of coastal processes and sound management decision.**
- **GPS derived-heights on land and seas can be readily related to one another by GEOID, HYDRODYNAMIC & TSS MODELS.**
- The ellipsoid is convenient surface for field surveying, but it has only geometrical meaning.
- **The ellipsoidally referenced spatial information should be transformed to geodetic or chart datum.**

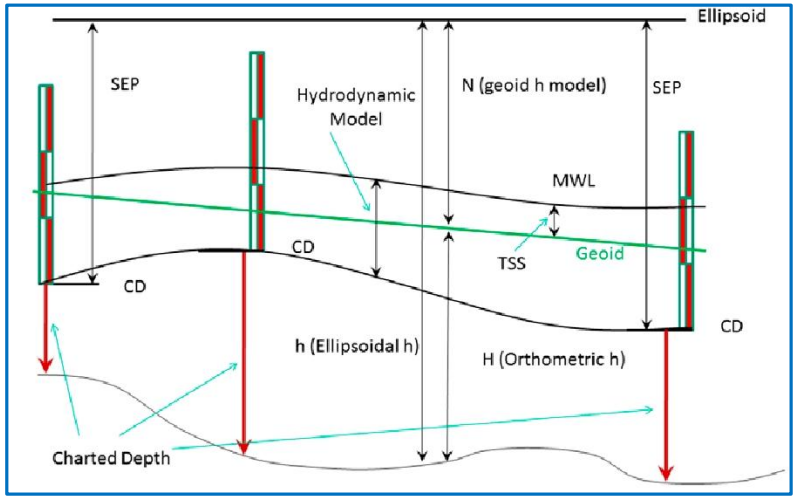


FIG (2014) Ellipsoidally reference surveying for hydrography, Publication No. 62, 62pp.

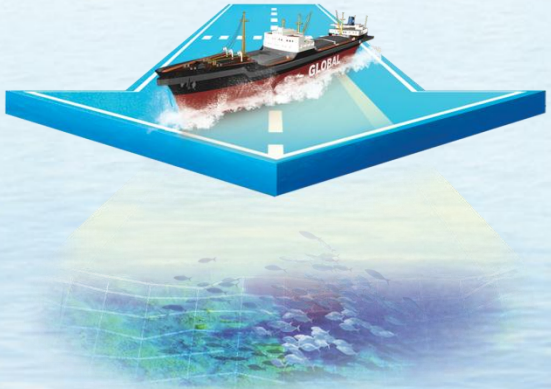
TECHNICAL ISSUES IN ERS

I	**Data acquisition of high accuracy of GNNS**
II	**GNSS data processing scheme and its accuracy (uncertainty)**
III	**Vertical separation model (SEP) development and application**
IV	**Quality control of vertical offset, GNSS, motion, SEP.**
V	**Uncertainty associated with offset, GNSS, motion and SEP**
VI	**Data archive reference**

FIG (2014) Ellipsoidally reference surveying for hydrography, Publication No. 62, 62pp.

- This presentation focuses on the first and second issue.
- GNSS data collected **in static and kinematic mode** has processed by two different strategies and software.
- **Accuracy of GNSS-derived ellipsoidal height is mainly discussed.**

Ⅱ GNSS Data & Methodology



GNSS Measurement Equations

1 Pseudo-Range (PR)

$$R_i^s = \rho_i^s + d\rho_i^s + c(dt^s - dT_i) + di_i^s + dr_i^s + dm_{i,R}^s + \varepsilon_{i,R}^s$$

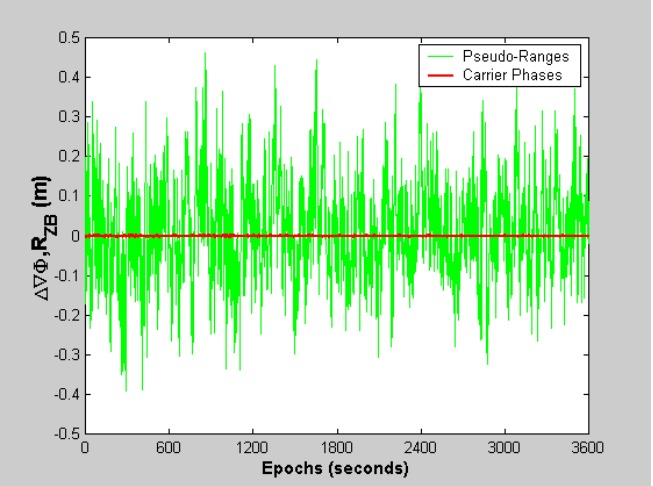
2 Carrier-Phase (CPH)

$$\lambda_G \cdot \phi_i^s = \rho_i^s + d\rho_i^s + c(dt^s - dT_i) + \lambda_G \cdot N_i^s - di_i^s + dr_i^s + dm_{i,\phi}^s + \varepsilon_{i,\phi}^s$$

Data processing schemes depend upon

- Type of measurements used for estimation of coordinates (PR Vs. CPH);
- Method how errors boxed in the equations are handled (Point Vs. Relative).

To maximize positioning accuracy, CPH should be used for estimation process.



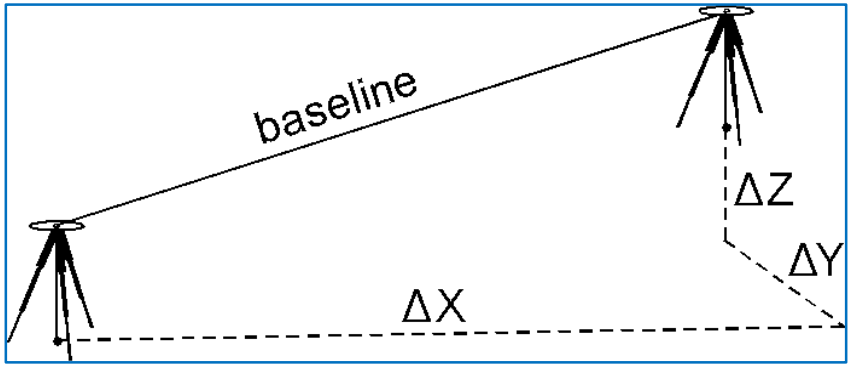
Comparison of noise level of PR and CPH

PRECISE RELATIVE POSITIONING (PPK)

With two GNSS receivers tracking the same satellite signal at the same epoch, differencing technique is applied for the measurements to:

1. Eliminate satellite clock bias (and SA when it was on).
2. Reduce the effect of satellite ephemeris bias.*
3. Reduce the effect of reference station coordinate bias.*
4. Reduce the effect of ionospheric bias.*
5. Reduce the effect of tropospheric bias.*

***Degree of reduction depends on baseline length ...**



PRECISE RELATIVE POSITIONING (PPK)

DOUBLE-DIFFERENCING (DD) TECHNIQUE IS COMMONLY USED FOR CPH PROCESSING

1 Short Baseline (< 20km)

$$\lambda \cdot \Delta\nabla\phi_{ij}^{st} = \Delta\nabla\rho_{ij}^{st} + \lambda \cdot \Delta\nabla N_{ij}^{st} + \Delta\nabla\varepsilon_{ij,\phi}^{st}$$

2 Medium-Baseline (20km < 1,000km)

$$\lambda \cdot \Delta\nabla\phi_{ij}^{st} = \Delta\nabla\rho_{ij}^{st} + \lambda \cdot \Delta\nabla N_{ij}^{st} - \Delta\nabla di_{ij}^{st} + \Delta\nabla dr_{ij}^{st} + \Delta\nabla\varepsilon_{ij,\phi}^{st}$$

*For 'high productivity' techniques **reliable ambiguity estimation & resolution** is crucial.*

*Residual **ionosphere & troposphere** biases are fundamental limit to GPS accuracy.*

- Precise satellite ephemeris should be used.
- Residual ionosphere & troposphere biases should be estimated together with coordinates using a filter and/or smoother.

PRECISE POINT POSITIONING (PPP)

Precise Point Positioning (PPP) refer to

- **Centimeter-level** positioning accuracy of **a single static receiver** using a long observation series,
- **Sub-decimeter-level** accuracy of **a single moving receiver** using **ionospheric-free** pseudo-range and carrier phase measurements.

1 All known error correction must be applied to PR and CPH.

- **Precise satellite ephemeris (e.g., IGS, CODE)**
- **Satellite clock correction (e.g., IGS, CDE)**
- **Tropospheric delay model (e.g., Hopfield, Saastamoinen model)**

2 Forming ionospheric-free combination to eliminate ionospheric effects

$$R^s_{i,free} = \rho^s_i - c \cdot dt_i + dr^s_i + \varepsilon^s_{R,i}$$

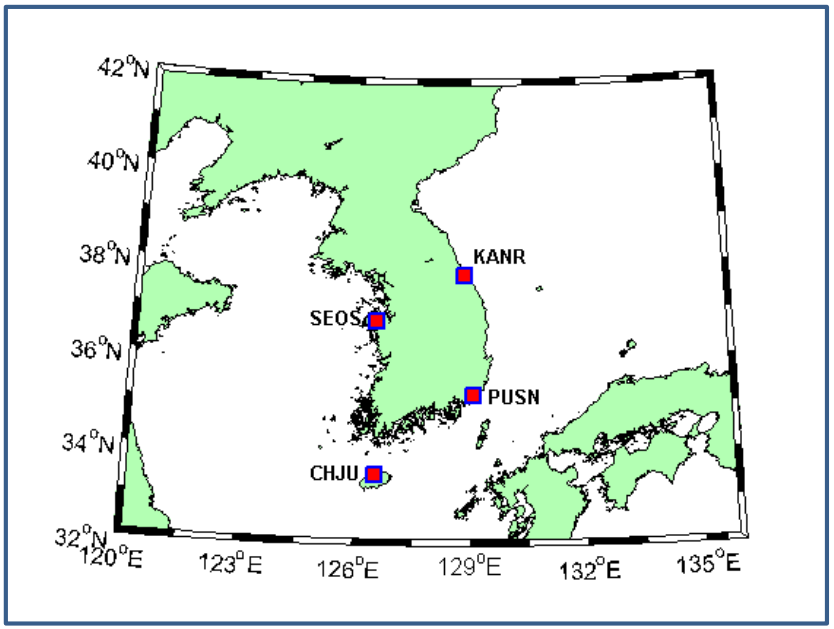
$$\lambda\phi^s_{i,free} = \rho^s_i - c \cdot dt_i + \lambda N^s_i + dr^s_i + \varepsilon^s_{\phi,i}$$

The receiver clock bias and the residual troposphere are estimated together with the receiver coordinates in the processing.

GNSS DATA

Static Case

- Five CORS stations in Korea
- 24 hours GPS data
- Over 250km of Baseline length



Kinematic Cases

Turn-table Test

- Sokkia GRS2600 (dual-frequency)
- 1Hz sampling rate
- 70 min. including 10 min. static session

Survey Vessel Test

- Three of Sokkia GRX1 (dual-frequency)
- 1Hz sampling rate for 2 hours
- Two hours kinematic session

Precise satellite orbit and clock (5 sec. sampling) were included in GNSS data processing.

GNSS Software & Processing

Software#1 (WS-1)

- An open source program package for GNSS positioning
- Standard and precise positioning algorithms with **GPS, GLONASS, SBAS, QZSS**
- Positioning mode for **real-time and post-processing: Single, SBAS, DGPS, RTK, PPP**
- Support many formats/protocols & receivers

Software#2 (WS-2)

- Commercial post-processing software by Novatel
- Highly configurable processing engine that allows for **the best possible static or kinematic accuracy.**
- Differential and PPP processing
- Support multiple reference station
- Support for GPS L1/L2/L2C, GLONASS, BeiDou

Evaluation of achievable accuracy of ellipsoidal height estimated by medium-range PPK and PPP

Medium-Range Baseline PPK

- ✓ CODE precise satellite orbit
- ✓ Estimation of Iono. & trop.
- ✓ Ambiguity float solutions
- ✓ Combination of forward & backward processing

Short Baseline PPK

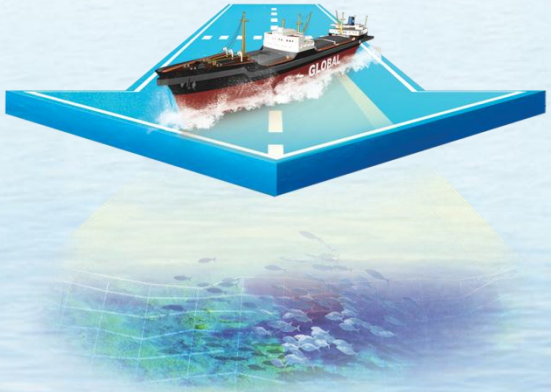
- ✓ Generation of reference for accuracy evaluation
- ✓ Ambiguity fixed solutions
- ✓ Usage of the nearest base station (e.g., shorter than 3km)

PPP - Kinematic

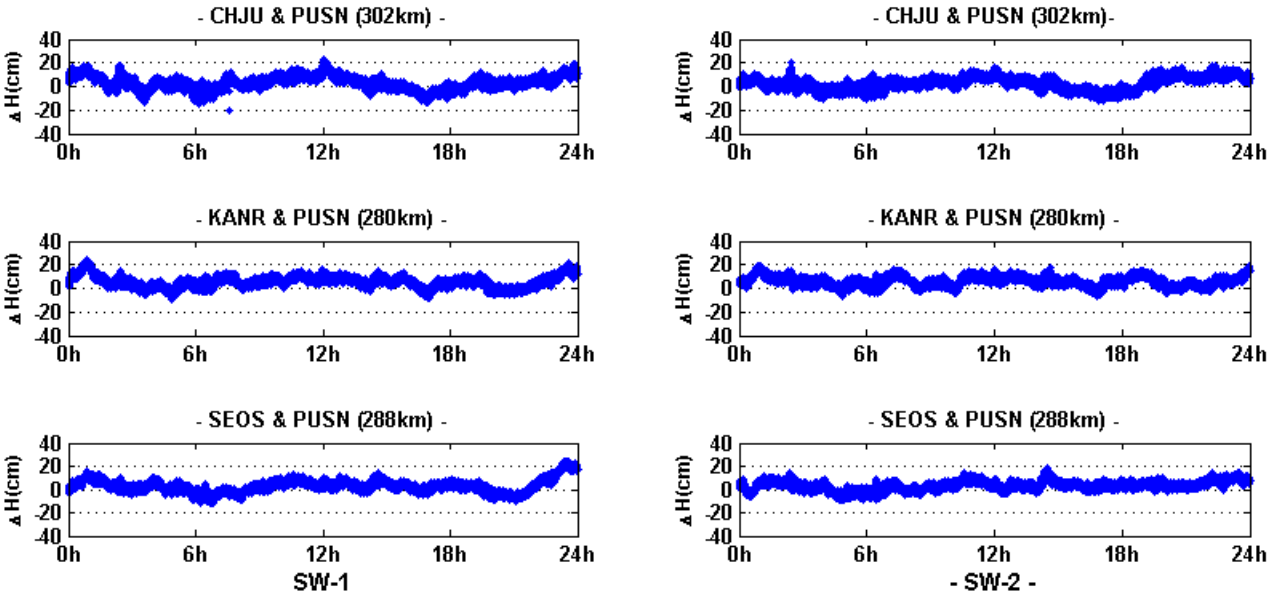
- ✓ CODE precise satellite orbit
- ✓ CODE 5 sec. satellite clock
- ✓ Ambiguity float solutions
- ✓ Combination of forward & backward processing

Comparison! **Comparison!**

III Results and Discussion

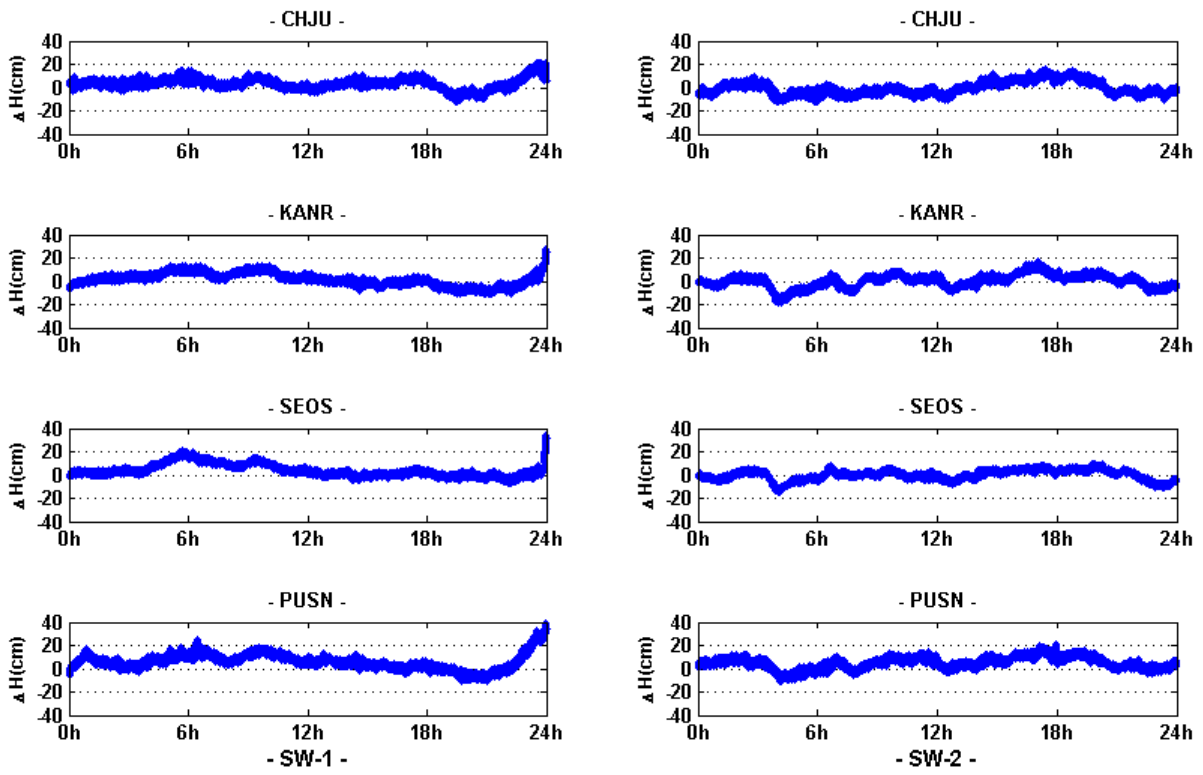


STATIC TEST - PPK



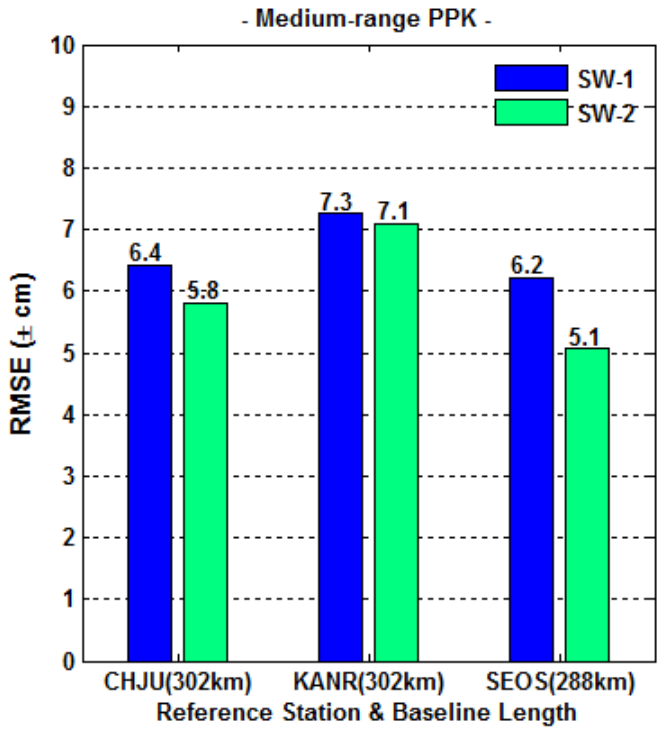
- ✓ Three baseline solutions were generated by each software.
- ✓ Time-series of coordinate differences between PPK-derived and published height.
- ✓ Graphs in left column: solutions from SW-1
- ✓ Graphs in right column: solutions from SW-2

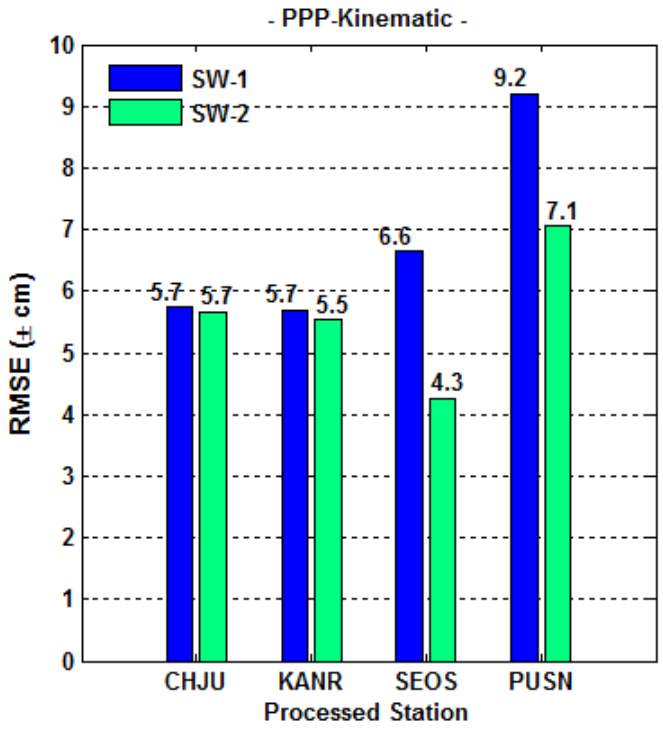
STATIC TEST - PPP



- ✓ Solutions were generated with respect to each station.
- ✓ Time-series of coordinate differences between PPP-derived and published height.

STATIC TEST - RMSE

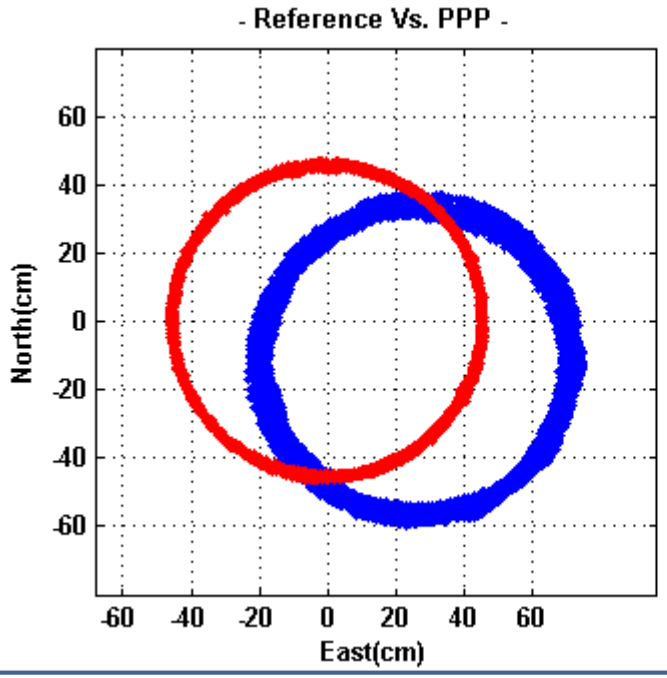


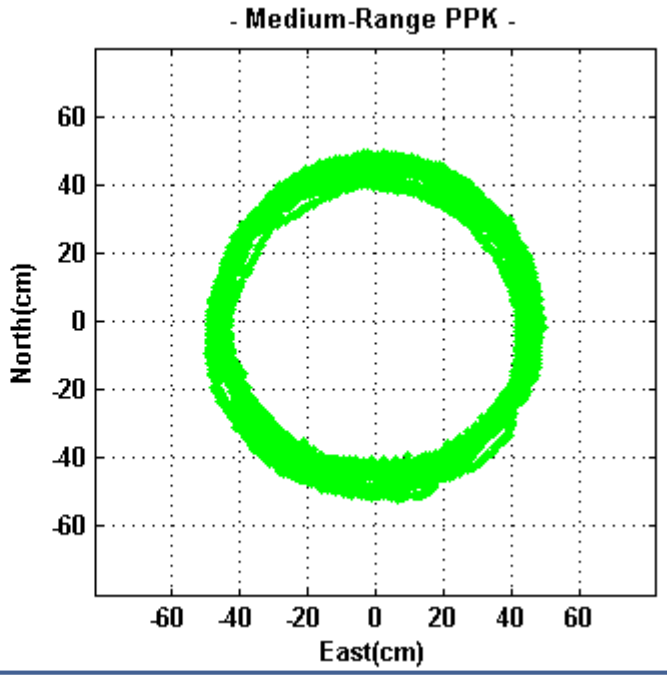


- ✓ Accuracy of PPK and PPP is almost equivalent (PPK: ±5 - ±7cm, PPP: ±4 – 7cm except for PPP at PUSN).
- ✓ Solutions from SW-2 are slightly more accurate than those of SW-1.

TURN TABLE TEST - TRACE

Example of SW-2 Results

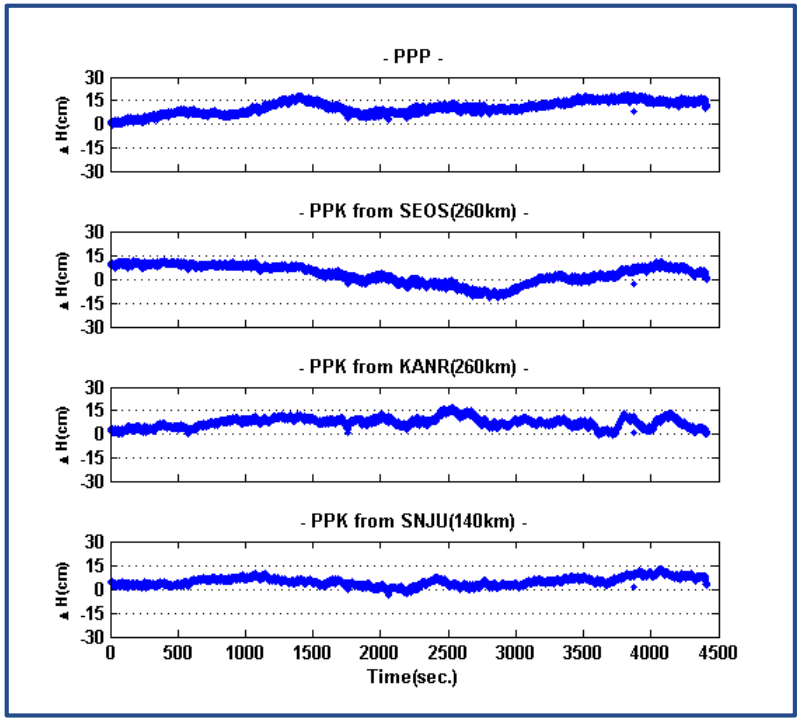




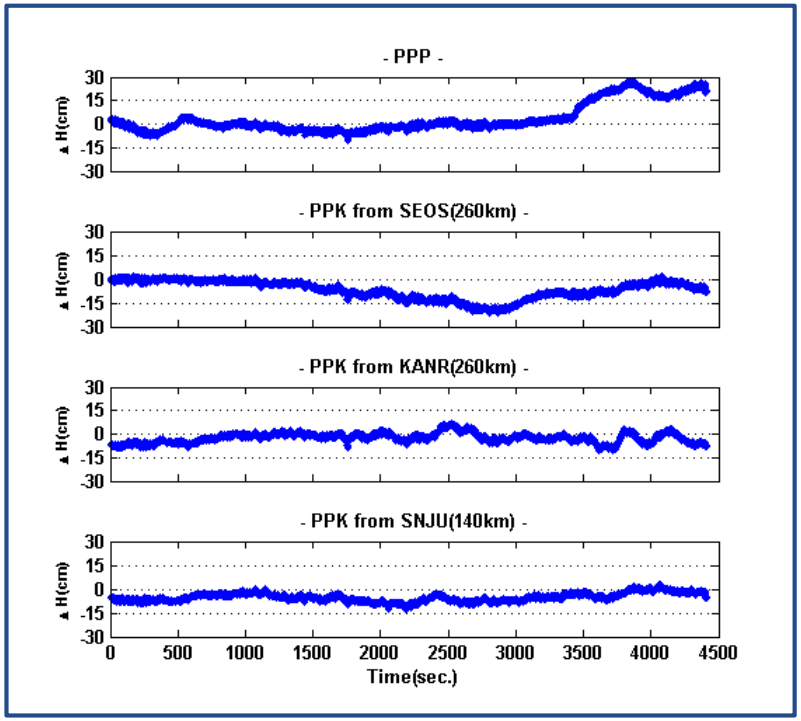
- Example of results given by SW-1 solutions
- PPK solution is obtained from baseline processing of SEOS & Turn Table (260km).
- Bias between reference and PPP is caused by different epoch of solution (i.e., KGD2002 to which the published coordinates is referenced is aligned to epoch 2002.0).

TURN TABLE TEST – HEIGHT

SW-2: PPP Vs. PPK

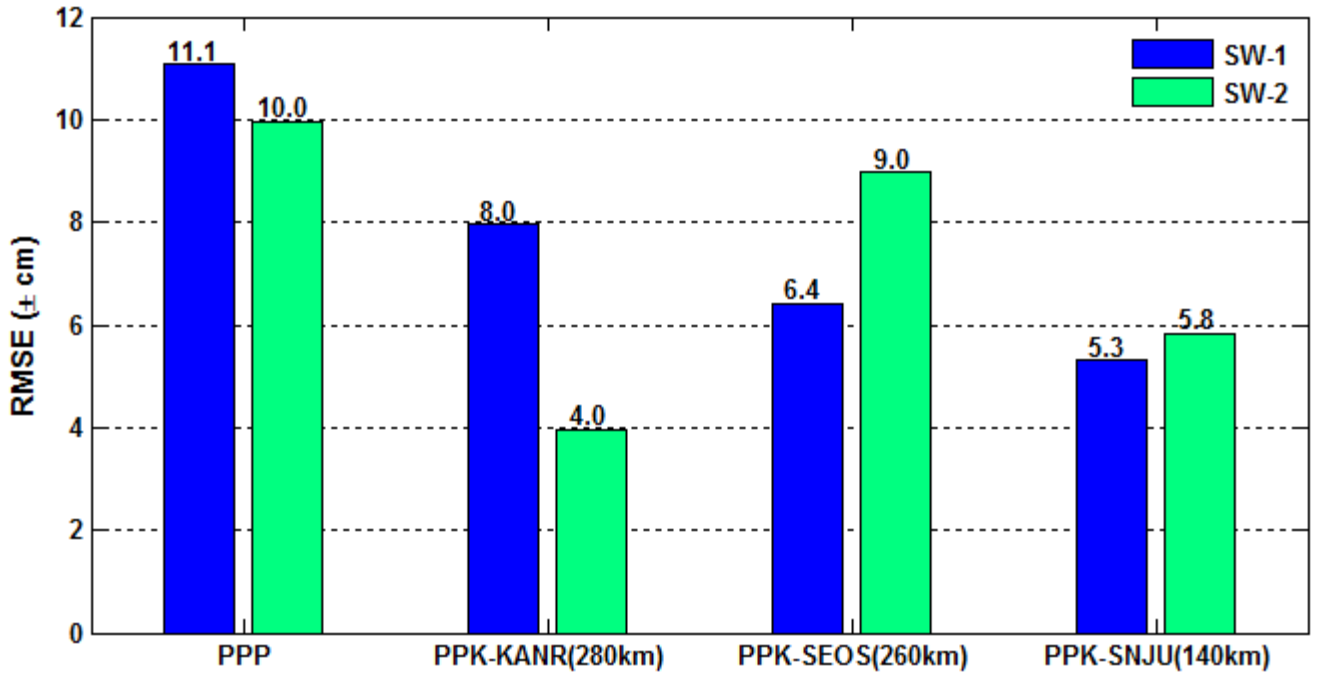


SW-2: PPP Vs. PPK



- Comparing solutions given by two S/W, variation pattern is similar, but different level of bias is observed.
- It seems to be caused by different modeling schemes of ionosphere and troposphere have been implemented in the software.

TURN TABLE TEST – RMSE



- PPK solutions are slightly more accurate than that of PPP.
- Accuracy of PPP is around ±10cm while that of PPK is better than ±10 cm
- Accuracy of PPK-KANR from SW-2 is superior to that of SW-1, but in other two cases SW-1 is a little bit better.
- Note that filter initialization is required for few tens of minutes.

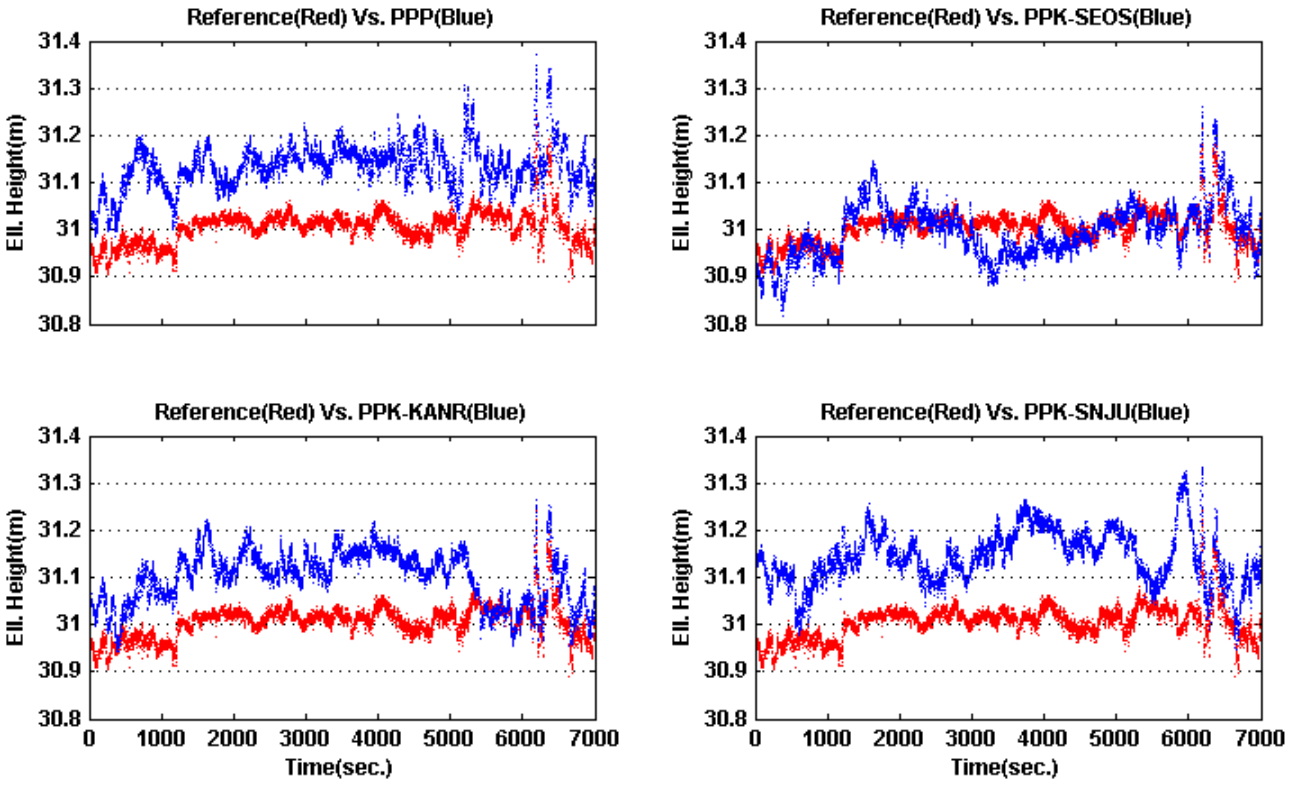
Survey Vessel Test

Trajectory and location of reference stations

- ✓ The experiment was conducted around West Nakdong River in Busan, Korea.
- ✓ GPS observation was made for approximate 2 hours by 3 rover receivers

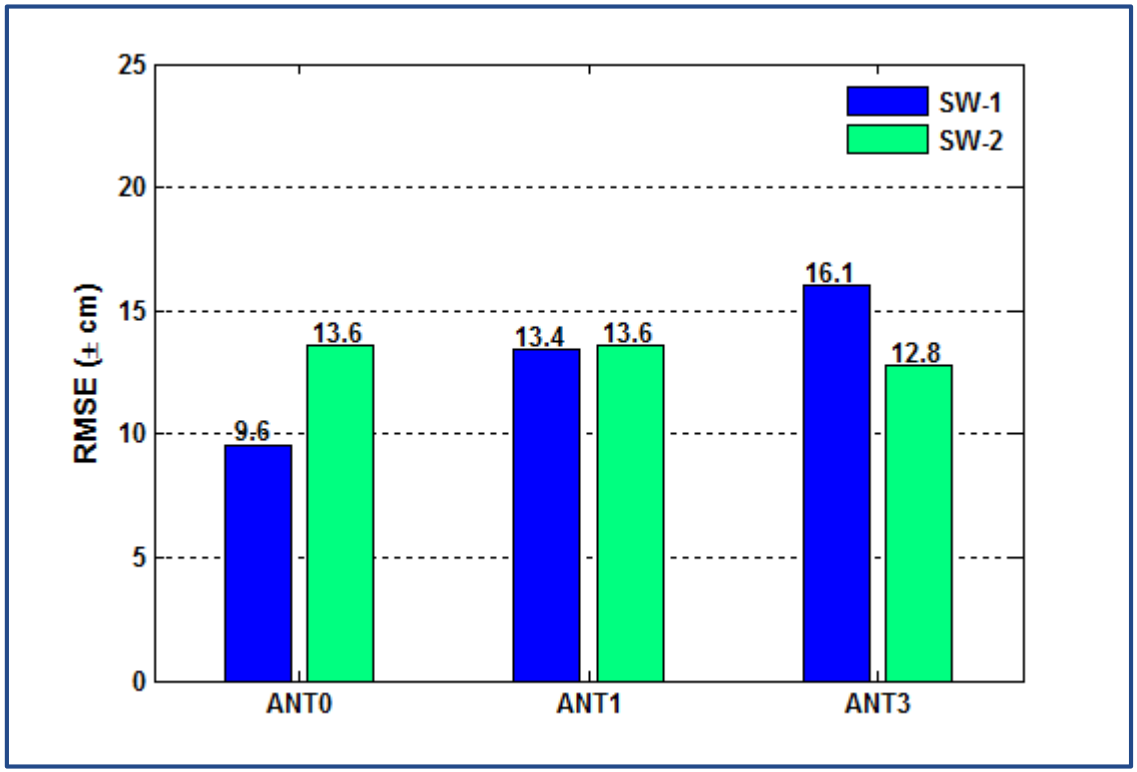
SURVEY VESSEL TEST - EXAMPLE

- Comparison with the reference trajectory (example of ANT0)



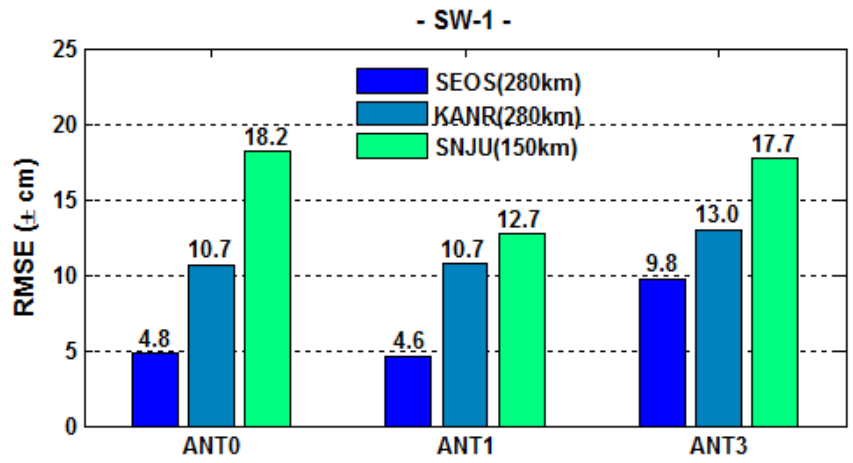
- ✓ Bias is clearly in the results, expect for PPK-SEOS.
- ✓ Considering characteristics of errors in measurement models, it seems to be induced by residual troposphere

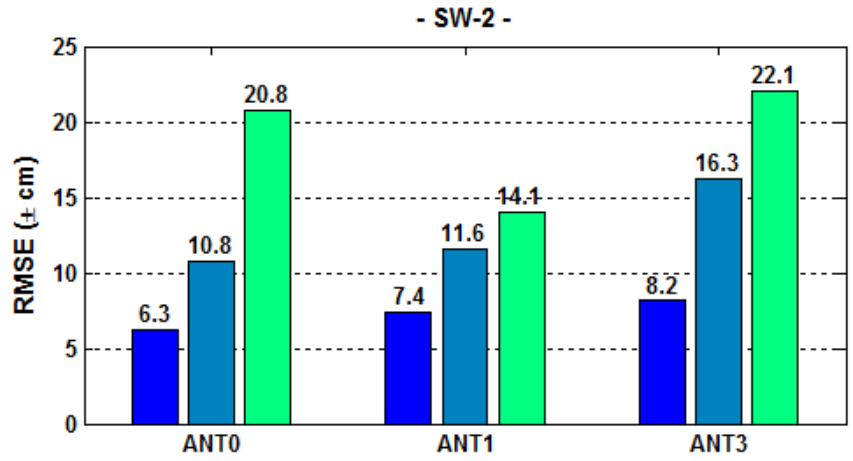
SURVEY VESSEL TEST - PPP



- ✓ S/W does not much impact into accuracy, but SW-2 provides more stable solutions.
- ✓ GNSS-derived height accuracy by PPP ranges from about ±10cm to 15 cm.

Survey Vessel Test - PPK



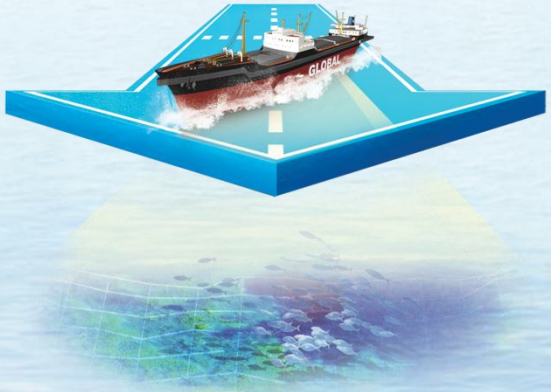


- ✓ Accuracy highly depends on selection of reference station.
- ✓ Baseline distance is not coupled with accuracy.
- ✓ The solutions are less stable than PPP.
- ✓ This might be caused by residual relative troposphere due to different **meteorological condition**.

Some parameter during the test

Site	Temp. (°C)	Humid. (%)
KANR	25 - 26	68 – 75
SEOS	28 - 29	84 – 90
SNJU	31 - 32	59 – 61
Testing Area	27- 30	79 - 86

Ⅳ Concluding Remarks

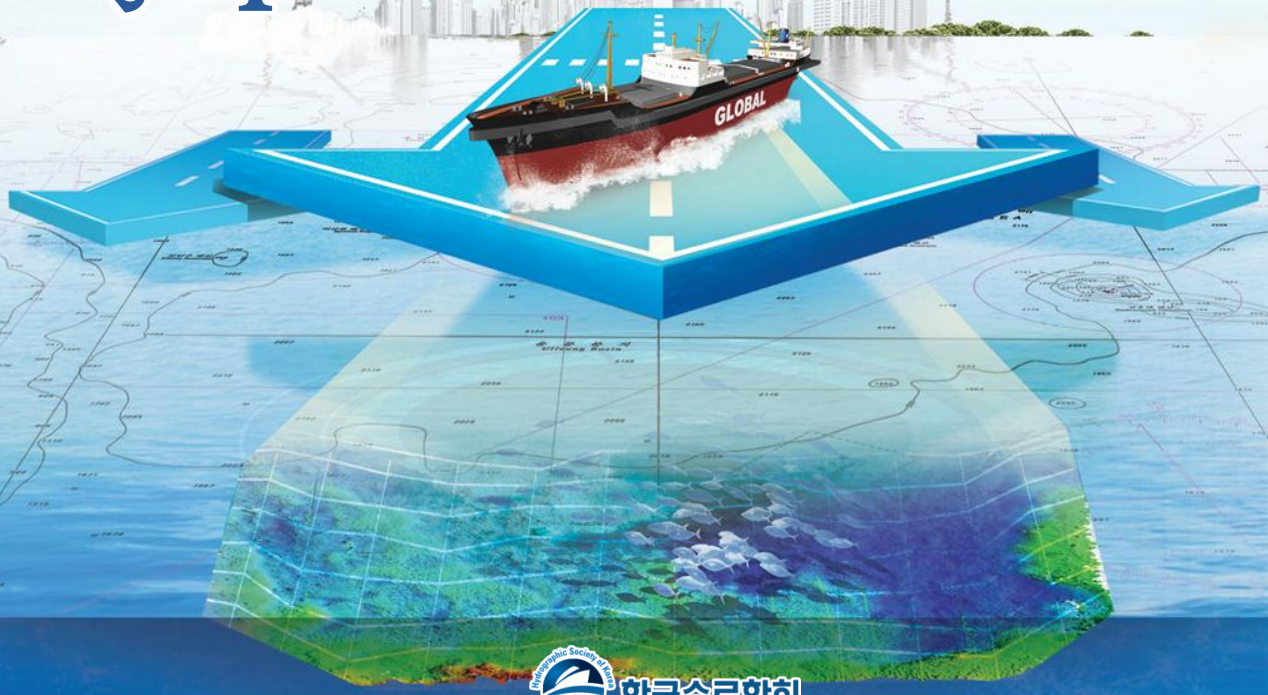


Concluding Remarks

- Concept and background of ERS has been reviewed with a view to integrating hydrographic and topographic data for costal management.
- Some potential GNSS data processing schemes have been discussed with emphasis on their features.
- Results of three experiments were presented to demonstrate achievable accuracy of GNSS height estimation:
  - ***Accuracy of GNSS PPP and medium-range PPK ranges from about 5cm to 20cm.***
  - ***Accuracy of PPP is compatible with that of PPK in height component estimation, but it is dependent on selectin of base station;***
  - ***Two types of software provide almost equivalent results.***
  - ***Further investigation is required to look into impact of residual troposphere to GNSS-estimation.***

Thanks for your attention!

Any question or comment?



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