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Agenda item [[2]](#footnote-2) (from agenda)

Workplan Task Number / Technical Domain 2 2018 - 2022 / Task 2.2.7

Working Group WG1

Author(s) / Submitter(s) China MSA

Dual-mode transformation of maritime RBN-DGPS stations in China

1. SuMMary

Since 2014, China has launched the technical exploration and experiment of the dual-mode transformation of maritime RBN-DGPS. The main objective is to transmit the DGPS&DBDS information simultaneously on the existing RBN-DGPS stations, in order to improve the availability of RBN differential signal, and improve the positioning accuracy of ship users. There are two technical schemes: one is to broadcast DBDS information through the station sub-carrier frequency, and the original DGPS information transmission link does not be affected; The other scheme is to transmit DBDS & DGPS information on the same radio beacon frequency. Due to the limitation of frequency resource, DGPS & DBDS information transmitted on the same radio-pointing carrier frequency is demonstrated to be more feasible and reasonable, as the effect of time delay on the system performance is within the acceptable range (up to 8 seconds).This scheme has been adopted in 22 RBN-DGPS stations in China's coastal areas since 2015.

* 1. Purpose of the document

The proposal introduces the exploration, relevant technical scheme and test results of the dual-mode transformation of maritime RBN-DGPS stations in China, it provides a reference for IALA developing guidelines on “DGNSS service provision, upgrades and future uses” and other countries building and uparading RBN-DGNSS . It also introduces the research and exploration based on RBN-DGNSS station, and provides some practical experiences for IALA to formulate the future development direction of RBN-DGNSS.

* 1. Related documents

1. R-150 DGNSS service provision, upgrades and future uses

2. IALA workshop on the future of marine radio beacon DGPS/DGNSS report 27 to 31 January 2020

1. BackgrounD

With the development of technology, the single point positioning accuracy of satellite navigation system is getting higher and higher, and the satellite based augmentation system is more and more favored by the navigation users because of its wide area coverage. Some countries are considering shutting down the RBN-DGPS system , no longer providing related services, and then using Wass, EGNOS and other satellite-based augmentation systems as an alternative, because RBN-DGPS equipment aging and maintenance cost increasing is bcoming more and more prominent. IALA's attitude about it is that these countries need to ensure the integrity of their waters when considering alternatives. As the same frequency band of Satellite Navigation Systems and their satellite-based augmentation systems are , their signals are vulnerable to interference and camouflage, furthermore, the existing satellite-based augmentation system receiver automatic integrity monitoring (RAIM) is not as effective as the reference station Integrity Monitoring (RSIM) for maritime applications, so in the short term, RBN differential enhancement system is still an effective and reliable way to provide high-precision positioning service for ships entering and leaving ports.

1. DiscussioN

Due to the need of autonomous navigation of unmanned vessels and pilotage of large ships, the positioning accuracy of RBN-DGPS system has no obvious advantages compared with other means. Therefore, upgrading the existing RBN-DGPS system to achieve the compatibility of multi-satellite navigation system constellations can increase the number of observable satellites in a specific region, the user selects the optimal satellite correction information through the software for the multi-satellite system fusion solution, which can theoretically improve the positioning accuracy and signal availability of the system. The test of signal receiving and positioning after the dual-mode reconstruction in the Chinese coastal area also verified this point.

* 1. Principle of transformation
     1. The original DGPS usershould not be affected

Since most of the domestic and international ship user terminals are RBN-DGPS equipments, the broadcast signal format and radio characteristics of the reformed system should not be changed and need to be received and located normally by the existing RBN-DGPS equipments, existing users will not be required to replace equipment or upgrade related software, and the system characteristics shall comply with the relevant requirements of the global radio navigation system as set out in IMO Resolution A. 1046(27) .

* + 1. Using BDS/GPS/GLONASS integrated equipment

The Reference Station and Integrity Monitoring Station should adopt BDS/GPS/GLONASS integrated equipment to support multi-satellite system, multi-frequency, multi-channel, and ensure the system performance while leaving the possibility for further upgrading and compatibility.

* + 1. Support for remote monitoring

The Reference Station Server, Integrity Monitoring Station server and console can be connected to the network remotely. The real-time operation parameters and various reports of the station can be monitored and displayed locally and remotely.

* 1. technical solution

The station transformation is carried out on the basis of RBN-DGPS station, using the existing power supply and lightning protection facilities, adding 2 sets of DGNSS reference stations, 2 sets of DGNSS integrity monitoring stations, routers and other network equipment to a single station, and replace the console, I/O converter, transmitter, automatic antenna tuner and other equipment, the original DGPS reference, DGPS integrity monitoring equipment as a backup system. The operating frequency, identification number and transmitting power of the retrofitted station remain unchanged. Key components such as reference station, Integrity Monitoring Station and transmitter power amplifier unit can be switched automatically and manually by double-click hot backup to ensure continuous and stable operation of the system.

The improved RBN-DGNSS dual-mode station is shown in figure 1. In the dotted frame is the original RBN-DGPS equipment, as a backup system, outside the dotted frame, for upgrading the new RBN-DGNSS equipment.

*Figture 1 Composition of RBN-DGNSS station after transformation*

The differential messages are encoded by a combination of DGPS and DBDS, and both of which are encoded by a group of three satellites in RTCM format (see Appendix A: The Beidou differential message data format) , and are transmitted alternately. Integrity monitoring uses the reference station integrity monitoring standard (RSIM) V1.2. Message broadcasted as explained in the Table 1:

|  |  |  |
| --- | --- | --- |
| **Messeage type** | **Broadcasting frequency** | **instructions** |
| 9 （Differential correction of partial GPS satellite） | Continuously | Broadcasting corrections by a group of three GPS satellites circularly,of which elevation is more than 7.5゜. |
| 42（Differential correction of partial BDS satellite） | Continuously | Broadcasting corrections by a group of three GPS satellites circularly,of which elevation is more than 7.5゜. |
| 16（Station text information） | When necessary | Message type 16 shall not be transmitted for at least 90 seconds before or after message type .3, 5, 7, 27 |
| 3（GNSS RS parameters） | The 15th and 45th minute after the hour | Broadcasting when necessary. |
| 5（GPS constellation health status） | The 5th minutes after the hour, then broadcasting every 15 minutes | Broadcasting when an unavailable GPS satellite can be used in RBN-DGNSS system. |
| 7（Transmitter information） | The 7th minutes after the hour, then broadcasting every 10 minutes | When the status of the transmitter station changes, the message type 7 should be modified and broadcast within 2 minutes from the 7th minute of the next hour. |
| 27（Extended Transmitter information） | The 9th minutes after the hour, then broadcasting every 10 minutes | When the status of the transmitter station changes, the message type 27 should be modified and broadcast within 2 minutes from the 9th minute of the next hour. |
| 43（BDS constellation health status） | The 6th minutes after the hour, then broadcasting every 15 minutes | Broadcasting when an unavailable BDS satellite can be used in RBN-DGNSS system. |

*Table 1 Messeage broadcasting instructions*

* 1. test results

The technical verification of the station's dual-mode transformation is carried out at Beitang station in Tianjin. The equipment of the reference station, integrity monitoring station and transmitting station are replaced, and relevant software configuration is carried out. The transmitting antenna adopts the existing antenna ground network of the station, and the signals broadcast by the station are tested at fixed points on land and dynamically at sea.

* + 1. fixed-points test

Six land static test points are selected within the coverage of Beitang station. The distance and distribution between the test points and the reference station are shown in Figure 2.



*Figture 2 Distance and distribution between test point and Beitang reference station*

After two hours of continuous static acquisition and observation at the sampling rate of 1 second, the plane / elevation results of six fixed-point tests are shown in Tables 2 and 3:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **fixed-point** | **Distance to Beitang（km）** | **BDS（m）** | **GPS（m）** | **BDS+GPS（m）** |
| Huanghua Port | 66.2 | 1.08 | 0.79 | 0.69 |
| Caofeidian Port | 91.3 | 0.87 | 1.68 | 0.92 |
| Dongying Port | 154.7 | 1.40 | 1.20 | 0.62 |
| Changdao | 292.3 | 1.24 | 1.37 | 1.03 |
| Laotieshan | 315.7 | 2.53 | 1.55 | 1.68 |
| Yantai Mountain | 368.7 | 2.36 | 2.03 | 1.78 |

*Table 2 statistical error of plane static test (confidence level 95%)*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **fixed-point** | **Distance to Beitang（km）** | **BDS（m）** | **GPS（m）** | **BDS+GPS（m）** |
| Huanghua Port | 66.2 | 2.94 | 1.12 | 1.37 |
| Caofeidian Port | 91.3 | 1.38 | 2.21 | 1.30 |
| Dongying Port | 154.7 | 2.03 | 1.29 | 1.29 |
| Changdao | 292.3 | 2.64 | 2.14 | 1.42 |
| Laotieshan | 315.7 | 2.99 | 2.91 | 1.76 |
| Yantai Mountain | 368.7 | 4.21 | 2.51 | 3.13 |

*Table 3 statistical error of elevation static test (confidence level 95%)*

Based on the above results, we can see that:

(1) The results show that the plane positioning accuracy of the dual-mode differential system is about 1 m (95%), and the elevation accuracy is about 2 m (95%); the positioning accuracy of BDS, GPS and BDS + GPS becomes better in turn.

(2) The coverage of the receiving reference station outside 300 km (Laotieshan and Yantai mountain) is weakened, the plane positioning accuracy is about 2 m (95%), the elevation accuracy is basically around 3 m (95%), and the positioning accuracy of BDS, GPS and BDS+GPS becomes better in turn.

* + 1. Marine dynamic test

In the coverage area of Beitang station, Tianjin Port - Lushun Port and Dalian Port - Yantai port are selected for the sea dynamic test. In the continuous observation mode, the data are collected continuously at the sampling rate of 1 second. There are three different modes of GPS, BDS and BDS + GPS on each test path. The motion trajectory of marine dynamic test is shown in Figure 3.



*Figure 3 Schematic diagram of marine dynamic test track*

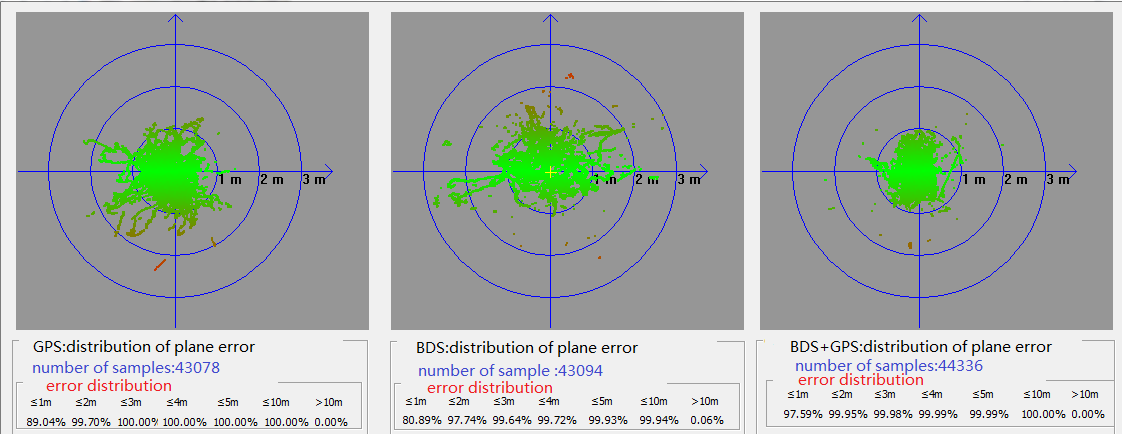
The dynamic statistical results of positioning accuracy and two-dimensional error distribution are as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **route** | **Distance to Beitang（km）** | **BDS(m)** | **GPS (m)** | **BDS+GPS(m)** |
| Tianjin Port—Lvshun Port | 40-310 | 1.55 | 1.31 | 0.87 |
| Dalian Port—Yantai Port | 360-360 | 1.77 | 3.11 | 2.44 |

*Table 4 Statistics of plane accuracy of marine dynamic test (confidence level 95%)*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **route** | **Distance to Beitang（km）** | **BDS(m)** | **GPS(m)** | **BDS+GPS(m)** |
| Tianjin Port—Lvshun Port | 40-310km | 2.55 | 2.01 | 1.69 |
| Dalian Port—Yantai Port | 360-360km | 2.85 | 4.45 | 4.29 |

*Table 5 Statistics of elevation error in marine dynamic test (confidence level is 95%)*



*Figure 4 two dimensional plane error distribution of of marine dynamic test (GPS / BDS / BDS + GPS)*

From the above statistical results, it can be seen that the accuracy of dual-mode differential system is greatly improved compared with single DBDs and DGPS, and the plane accuracy is improved more. At the same time, the analysis of signal availability shows that the percentage of epochs with pseudo range differential failure in the total epochs is maintained at a very low level, DBDs and DGPS single system are maintained at about 2%, while BDS + GPS combined differential system is less than 1%, which indicates that the dual-mode differential system is more robust and has better performances.

* 1. Overall transformation

There are 22 RBN differential stations in China's coastal areas, which will be transformed in phases since 2015. In 2016, the 14 stations of Qinhuangdao, Laotieshan, Chengshanjiao, Beitang, Haozhigang, Dinghai,Shitang,Lingkun,Tiandashan,Zhenhaijiao,Sanya,Baohujiao,Luyu,Naozhoudao were transformed . In 2017, the 7 stations of Yingkou, Wangjiamai, Dasanshan, Yanweigang,Yangpu,Sanzao,Fangchenggang were transformed. In 2018, Dajishan stations was transformed, all the 22 stations transformation was completely by then.

In addition, in 2016, three sea level remote centralized monitoring centers and nine remote integrity monitoring stations were built in the North China Sea, the East China Sea and the South China Sea. In 2017, four integrity monitoring stations were built. Remote integrity monitoring of station broadcast signals and centralized monitoring management realized.

* 1. Technical parameters and system performance after transformation
     1. Working frequency

The working frequency of the transformed station is the same as that of the original RBN-DGPS station (see Appendix B technical parameters of China maritime RBN-DGNSS station), which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA. It is the frequency range of maritime radio (283.5 -325.0 Khz) divided by the International Telecommunication Union, and adopts single frequency transmission to produce and broadcast differential correction information.

* + 1. Identification code

The identification code of each station is the same as that of the original RBN-DGPS station (see Annex 2 technical parameters of China maritime RBN-DGNSS station), which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

* + 1. Transmitting power

200 WATTS, which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

* + 1. Single station signal range

When the receiving field strength is 75 V / m, the operating distance is 300 km.

* + 1. Modulation mode and broadcast category

The minimum shift- frequency keying (MSK) modulation mode is adopted, and the broadcast type is phase modulation single channel data transmission (g1d).

* + 1. Signal format and message type

The signal format adopts RTCM sc-104 signal format standard v2.3, GPS Differential message type is 9-3, and Beidou differential message types are 41 and 42 (see Annex 1 Beidou differential message data format).

* + 1. Differential data transmission rate

200 bits/s, which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

* + 1. Coordinate system

The coordinate system of reference station is CGCS2000.

* + 1. Positioning accuracy

After fixed-point and marine dynamic test, the positioning accuracy of meter level receiver is better than 5 meters (95%) and that of sub meter level receiver is better than 2 meters (95%) in the sea area 300 km away from the reference station, which is better than that of single RBN-DGPS system.

1. Exploration of other related applications on rbn-dgnss station

The exploration and other related application on RBN-DGNSS station in China are as follows:

(1) Broadcast differential Loran information. The positioning accuracy of Loran system has been greatly improved by broadcasting differential Loran information through RTCM data format on the radio beacon carrier frequency, Loran and the differential Loran are considered as land-based backup systems.

(2) Forward the differential information of satellite based augmentation system. At present, China is building a BDS satellite based augmentation system, and studying the technical scheme of usingRBN-DGNSS stations to forward BDS satellite based augmentation information, so that existing ship users can enjoy differential augmentation service without upgrading shipborne terminals.

(3) MF R-mode. In addition to the R-mode of AIS and VDES, China has carried out the application research of R-mode based on radio beacon MF signal to explore its feasibility and positioning effect, and also takes it as a possible land-based backup system.

1. References

None.

1. QEQUEST

The committee is requested to review the proposal and focus on China's actions in the future development of RBN-DGNSS stations.

Appendix A: The Beidou differential message data format

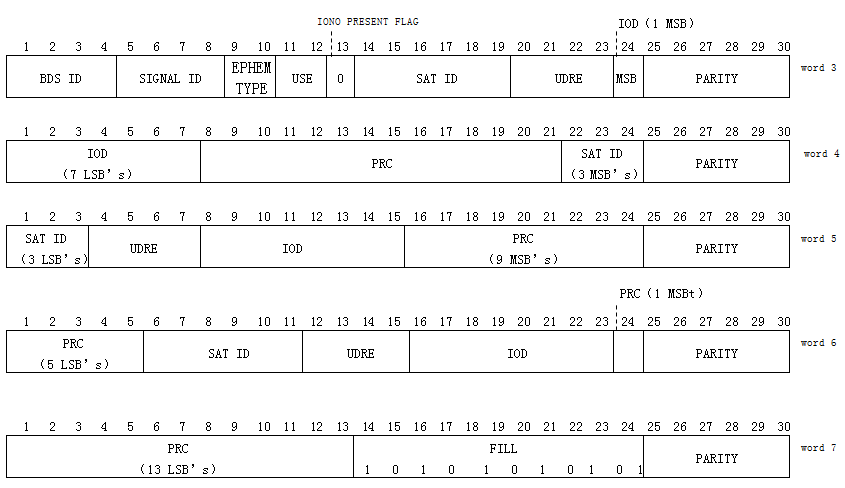
Appendix B: Technical parameters of China maritime RBN-DGNSS station

Appendix

## Appendix A: The BDS differential message data format

1. message type 41

The data format of differential message adopts RTCM (v2.3) standard, and the two words in the header are general data structure. BDS pseudo range correction message is type 41 message. See Figure 1 for format and table 1 for content.



*Figure 1 message type 41 format*

|  |  |  |  |
| --- | --- | --- | --- |
| PARAMETER | NUMBER OF BITS | UNITS | RANGE |
| BDS ID | 4 | 1 | BDS:0110 |
| BDS SIGNAL ID | 4 | 1 | 0～15，as shown in table 2 |
| EPHEMERIS ID | 2 | 1 | 0～3，as shown in table 3 |
| USE flag | 2 | 1 | 0～3，as shown in table 4 |
| IONO PRESENT | 1 | — | 0：IONOSPHERIC DELAY not present in the messeage |
| SAT ID | 6 | 1 | BDS SAT ID: 1～63，corresponding to BDS satellite PRN code, satellite ID "0" is not available |
| UDRE | 4 | as shown in table 5 | 16 states |
| IOD | 8 | 1 | — |
| PRC | 14 | 0.02m | ±163.84 |
| FILL | The remainder of the total count divided by 24 | — | Fill in the last part of the message alternately with 1 and 0 |
| PARITY | 6×N | — |  |

*Table 1 message type 41 content*

The parameters of message type 41 are described as follows:

a) BDS ID and BDS SAT ID: BDS ID is used to indicate the Beidou satellite navigation system, and BDS SAT ID is used to indicate the BDS satellite number.

b) BDS SIGNAL ID: BDS SIGNAL ID is used to indicate the type of observation value of differential message correction number, and the code is shown in Table 2.

| SIGNAL ID | SIGNAL |
| --- | --- |
| 0 | RESVERD |
| 1 | B1 I |
| 2 | B1 Q |
| 3 | B2 I |
| 4 | B2 Q |
| 5 | B3 I |
| 6 | B3 Q |
| 7～15 | RESVERD |

*Table2 BDS ID*

c) Satellite ephemeris type: the satellite ephemeris type identifies the resources and methods for calculating the satellite position in the message, and uses the ephemeris type and IOD to compare the satellite ephemeris used by the user, so as to ensure that the user and the station use the same satellite ephemeris. The types of satellite ephemeris are shown in Table 3.

|  |  |  |  |
| --- | --- | --- | --- |
| Ephemeris type | Satellite position calculation | IOD | reference |
| 0 | NAV | — | BDS-SIS-ICD-2.1 |
| 1～2 | — | — | BDS-SIS-ICD-2.1 |

*Table 3 Ephemeris type*

d) USE Flag: use flag indicates the maximum correction period used in t0 and t periods. When the time domain of the indicator is exceeded, the corresponding correction number should be stopped. See Table 4 for the contents of satellite use identification.

|  |  |
| --- | --- |
| USE Flag（binary） | Use maximum correction（s） |
| 00 | 15s |
| 01 | 30s |
| 10 | 60s |
| 11 | 120s |

*Tabel 4 Satellite USE Flag*

e) UDRE: the final UDRE value is obtained from the UDRE scale factor of the health status information of some stations in the message header and the UDRE bit value of the satellite. GNSS UDRE is shown in Table 5.

Example 1: if UDRE scale factor of message header is 0.30 and UDRE bit value of satellite is 0, then 0.0m ≤ UDRE ≤ 0.012m;

Example 2: if UDRE scale factor of message header is 0.75 and UDRE bit value of satellite is 6, then 0.268m ≤ UDRE ≤ 0.416m;

Example 3: if UDRE scale factor of message header is 1.00 and UDRE bit value of satellite is 15, UDRE > 18.480 M.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| UDRE Unit | 1.00 | 0.75 | 0.50 | 0.30 | 0.20 | 0.10 |
| UDRE（bit） | UDRE（m） | UDRE（m） | UDRE（m） | UDRE（m） | UDRE（m） | UDRE（m） |
| 0 | 0.040 | 0.030 | 0.020 | 0.012 | 0.008 | 0.004 |
| 1 | 0.062 | 0.047 | 0.031 | 0.019 | 0.012 | 0.006 |
| 2 | 0.096 | 0.072 | 0.048 | 0.029 | 0.019 | 0.010 |
| 3 | 0.149 | 0.112 | 0.074 | 0.045 | 0.030 | 0.015 |
| 4 | 0.231 | 0.173 | 0.115 | 0.069 | 0.046 | 0.023 |
| 5 | 0.358 | 0.268 | 0.179 | 0.107 | 0.072 | 0.036 |
| 6 | 0.555 | 0.416 | 0.277 | 0.166 | 0.111 | 0.055 |
| 7 | 0.860 | 0.645 | 0.430 | 0.258 | 0.172 | 0.086 |
| 8 | 1.333 | 0.999 | 0.666 | 0.400 | 0.267 | 0.133 |
| 9 | 2.066 | 1.549 | 1.033 | 0.620 | 0.413 | 0.207 |
| 10 | 3.202 | 2.401 | 1.601 | 0.961 | 0.640 | 0.320 |
| 11 | 4.963 | 3.722 | 2.481 | 1.489 | 0.993 | 0.496 |
| 12 | 7.692 | 5.769 | 3.846 | 2.308 | 1.538 | 0.769 |
| 13 | 11.923 | 8.942 | 5.961 | 3.577 | 2.835 | 1.192 |
| 14 | 18.480 | 13.860 | 9.240 | 3.544 | 3.696 | 1.848 |
| 15 | ＞18.480 | ＞13.860 | ＞9.240 | ＞3.544 | ＞3.696 | ＞1.848 |

*Table 5 GNSS UDRE*

f) IOD: data issue number IOD identifies BDS navigation data. There is no IOD parameter in BDS navigation message. According to BDS-SIS-ICD-2.1, the BDS IOD parameter of this message is generated based on TOC, that is, BDS IOD = (TOC / 720)% 240, with a length of 8 bits.

1. message type 42

Message type 42 provides the pseudo range differential correction number of some BDS satellite groups. Three satellites form a group, and less than three satellites form a group. Its format and content are the same as message type 41. Maritime RBN-DGNSS stations in China use this message format to broadcast differential BDS information.

## Appendix B: Technical parameters of China maritime RBN-DGNSS station

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sea area | Serial | Station | Location | | Identification Code | | | Frequency  (kHz) |
| North latitude | East longitude | RS1 | RS2 | Transmitter |
| North  China Sea | 1 | Dasanshan | 38°52’ | 121°50’ | 602 | 603 | 601 | 301.5 |
| 2 | Laotieshan | 38°44’ | 121°08’ | 604 | 605 | 602 | 307.5 |
| 3 | Qinghuangdao | 39°55’ | 119°37’ | 606 | 607 | 603 | 287.5 |
| 4 | Beitang | 38°50’ | 117°30’ | 608 | 609 | 604 | 310.5 |
| 5 | Yingkou | 40°17’ | 122°06’ | 610 | 611 | 605 | 291.5 |
| 6 | Chengshanjiao | 37°24’ | 122°41’ | 612 | 613 | 606 | 317.0 |
| 7 | Wangjiamai | 36°04’ | 120°26’ | 614 | 615 | 607 | 313.5 |
| East  China Sea | 8 | Yanweigang | 34°29’ | 119°47’ | 620 | 621 | 610 | 291.0 |
| 9 | Haozhigang | 32°01’ | 121°43’ | 622 | 623 | 611 | 304.0 |
| 10 | Dajishan | 30°49’ | 122°10’ | 624 | 625 | 612 | 307.5 |
| 11 | Dinghai | 30°01’ | 122°04’ | 626 | 627 | 613 | 310.0 |
| 12 | Shitang | 28°16’ | 121°37’ | 628 | 629 | 614 | 295.0 |
| 13 | Tiandashan | 25°28’ | 119°42’ | 630 | 631 | 615 | 313.0 |
| 14 | Zhenhaijiao | 24°16’ | 118°08’ | 632 | 633 | 616 | 320.0 |
| 15 | Lingkun | 27°58’ | 120°54’ | 634 | 635 | 617 | 286.5 |
| South  China Sea | 16 | Dezhoudao | 23°20’ | 116°45’ | 640 | 641 | 620 | 317.0 |
| 17 | Sanzaodao | 22°00’ | 113°24’ | 642 | 643 | 621 | 291.0 |
| 18 | Naozhoudao | 20°54’ | 110°36’ | 644 | 645 | 622 | 301.0 |
| 19 | Fangchenggang | 21°35’ | 108°19’ | 646 | 647 | 623 | 287.0 |
| 20 | Baohujiao | 20°00’ | 110°55’ | 652 | 653 | 626 | 310.5 |
| 21 | Sanya | 18°17’ | 109°21’ | 654 | 655 | 627 | 295.0 |
| 22 | Yangpugang | 19°43 | 109°12 | 656 | 657 | 628 | 313.0 |

1. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)