ICG-5, 2010, Trino

PNT Improvements supported by BeiDou

Yuanxi Yang

China National Administration of GNSS and Applications (CNAGA)

1. Background

Questions

- What is the limit of navigation satellites?
- How many satellite constellations do we need?
- How many frequencies are suitable?

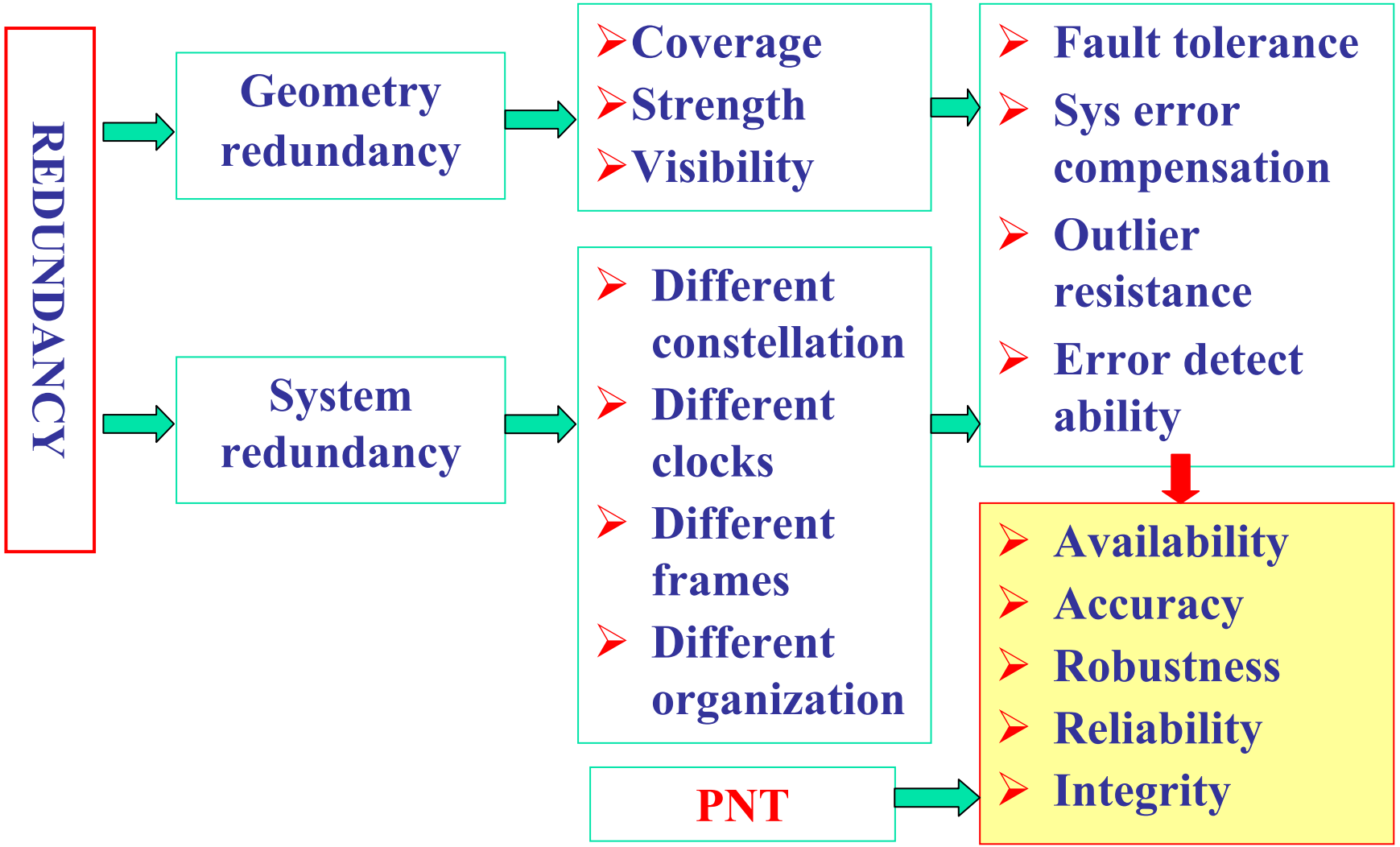
Answer

- Satellites---at least 4----any where, any time, any cut angle.
- Constellations---at least 3----for voting----spoofing identification.
- Frequencies---at least 2,----for error mitigation?

Redundancy is needed!

1. Background

Redundancy



2. Contribution of BeiDou to PNT users

Multi constellation and multi frequency are helpful

- to improve DOP values (Increasing the number of satellites always reduces GDOP—Yarlagadda et al 2000).
- to weaken the influence of multi-path and interference (different spectrums).
- to weaken the effects of ionosphere and troposphere (multi frequency),
- to weaken the restriction of distance from the reference stations.
- to fix ambiguity and shorten initial positioning time.

2. Contribution of BeiDou to PNT users

- to identify outliers, to make the state estimates robust and reliable
- to compensate colored and systematic errors
- to improve time scale estimates and accuracy
- to resist random error effects
- to improve availability and integrity (satellite visibility)
- to improve reliability of coordinate reference systems (different satellite products and wide distributed tracking stations).

3. Simulation Analysis for Visibility and DOP Values

- A simulated example is given by using STK software.
- The J2 perturbation was considered in the satellite position computation.
- The time period covered 24 hours, i.e. 12 o'clock, July 1 to 12 o'clock, July 2, 2009. The sampling interval was 300s.
- The circle orbits for Galileo and BeiDou were employed.
- 9 satellites were even distributed in 3 orbit surfaces for Galileo.
- The 27 MEO satellites for BeiDou were also distributed in 3 orbits.
- For GPS and GLONASS satellites, the orbit parameters were obtained by using their broadcast ephemeris. In the period 31 GPS and 21 GLONASS satellites were involved.

3.1 Simulation explanation

- **Basic orbit parameters for Galileo:**
  - Major axis a=29993.707km;
  - Inclination angle i=56°;
  - Orbit flattening e=0;
  - Argument of perigee ω = 0°;
  - Right ascension of ascending node Ω=60°, 180°, 300° (3 orbit);
  - Mean anomaly M0=0° (Start time of the 1st sat. in each orbit M0=0°, others plus 40° each).

- **Basic orbit parameters for BeiDou MEO:**
  - Major axis a=27878.1km;
  - Inclination angle i=55°;
  - Orbit flattening e=0;
  - Argument of perigee ω =0°;
  - Right ascension of ascending node Ω=0°, 120°, 240° for 3 orbits;
  - Mean anomaly M0=0°, 15°, 30° (Start time of the 1st sat. in each orbit. Others plus 45° each. The reserve sat. with mean anomaly of 10°, 55°, 105°)

3.1 Simulation explanation

Computation schemes for Visibility and DOP

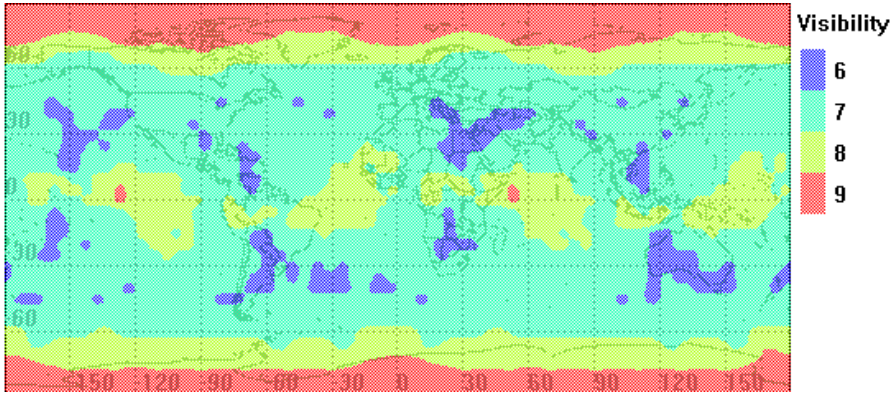
- Scheme 1: Single GPS constellation
- Scheme 2: GPS+BeiDou
- Scheme 3: GPS+GLONASS
- Scheme 4: GPS+GLONASS+ BeiDou
- Scheme 5: GPS+ GLONASS+GALILEO
- Scheme 6: GPS +GLONASS+GALILEO+BeiDou

GDOP Changes

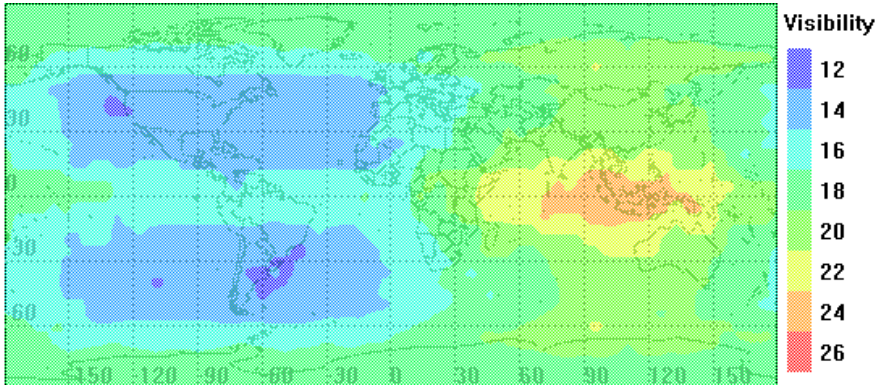
$$\Delta D = DOP_o - DOP_n = tr\{N_o^{-1} A_n^T (A_n N_o^{-1} A_n^T + P^{-1})^{-1} A_n N_o^{-1}\}$$

3.2 Satellite Visibility Analysis

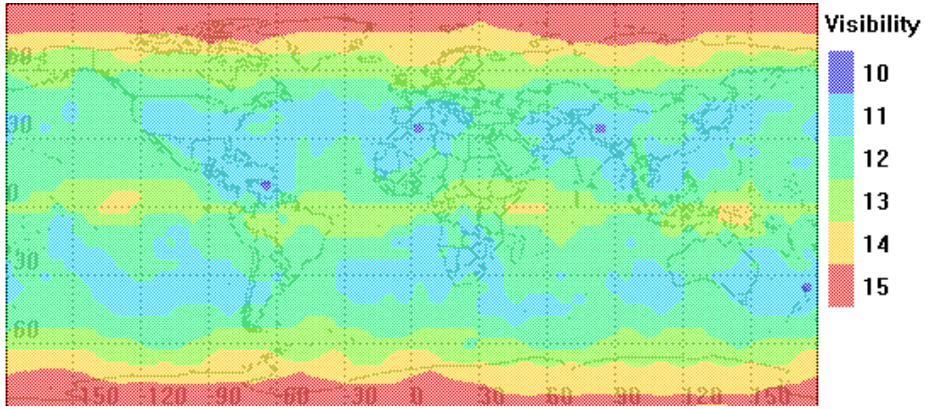
Visibility (Global)



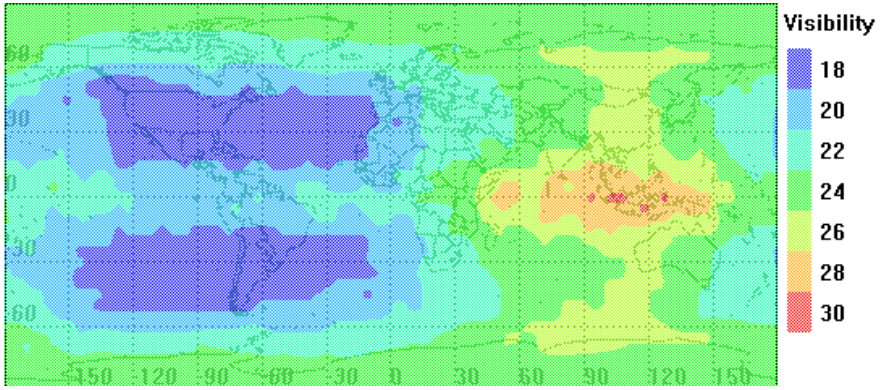
GPS Visibility



GPS+BeiDou Visibility



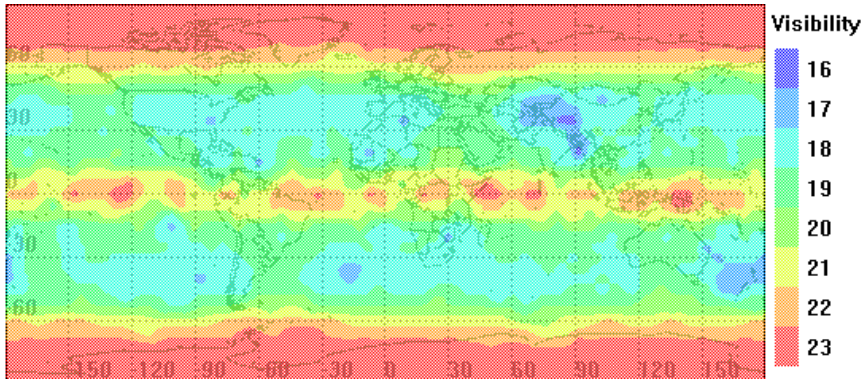
GPS+GLONASS Visibility



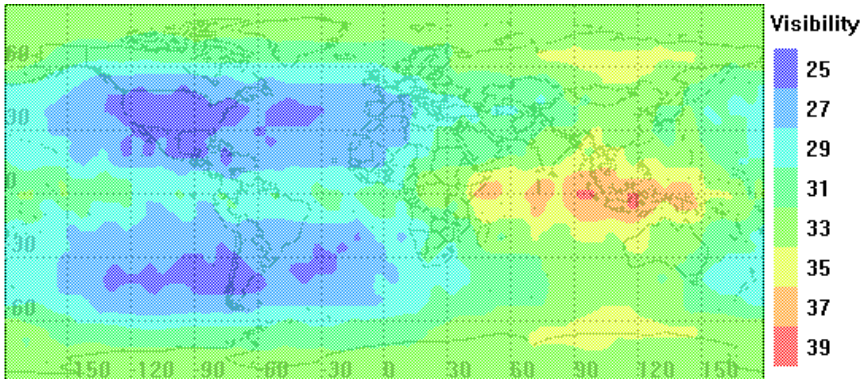
GPS+GLONASS+BeiDou Visibility

3.2 Satellite Visibility Analysis

Visibility (Global)



GPS+GLONASS+Galileo Visibility



GPS+GLONASS+Galileo+BeiDou Visibility

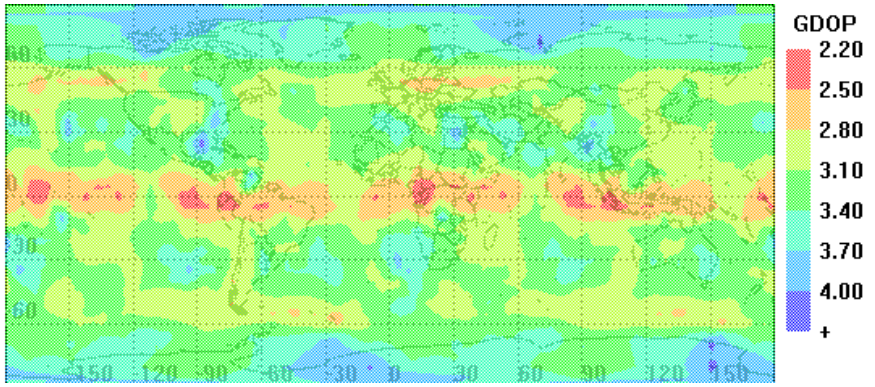
3.2 Satellite Visibility Analysis

- **Average visibility in different cut angles**

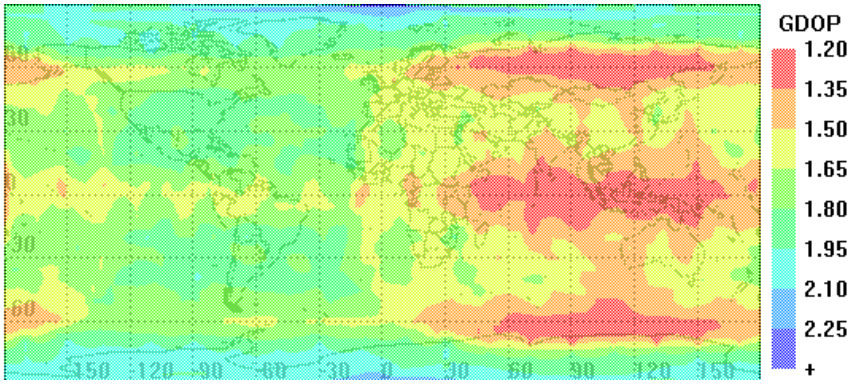
	10° (95%>)		20° (90%>)		30° (90%>)		40° (90%>)	
Schemes	min	mean	min	mean	min	mean	min	mean
1	6	7.2	4	5.3	3	3.6	1	2.1
2	12	17.8	10	13.2	7	9.4	3	5.9
3	10	12.1	8	9.2	4	6.4	2	3.8
4	18	22.5	13	17.1	8	12.2	5	7.9
5	16	19.8	14	15.3	8	10.8	5	6.8
6	25	30.8	20	23.4	12	16.6	7	10.1

3.3 DOP Value Comparison

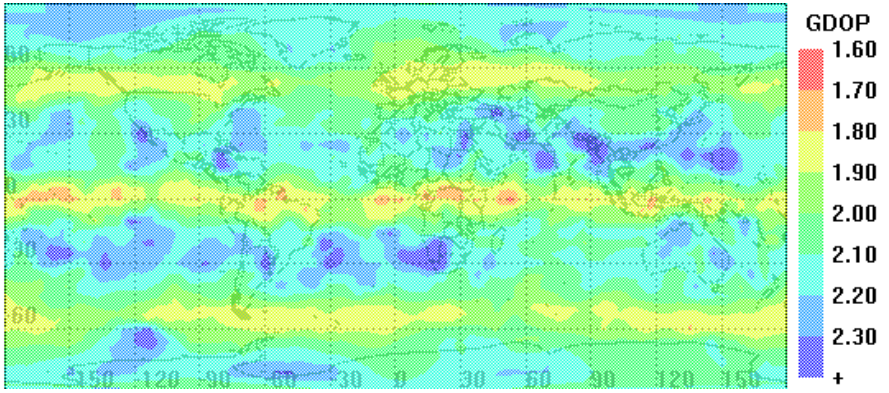
- GDOP Improvement (Global)



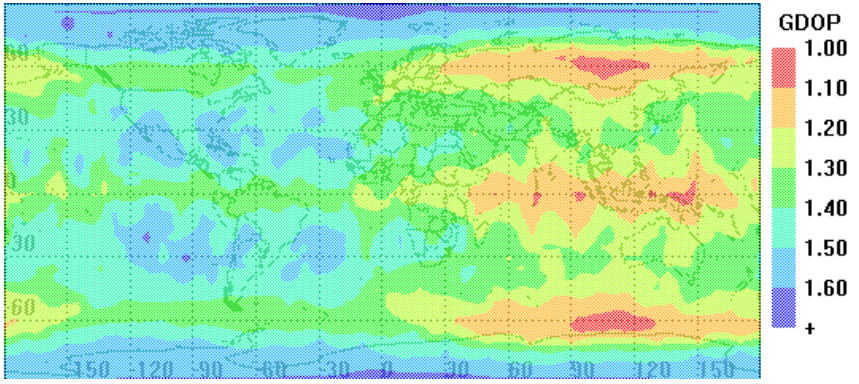
GDOP of GPS (G)



GDOP of GPS(G)+BeiDou(B)



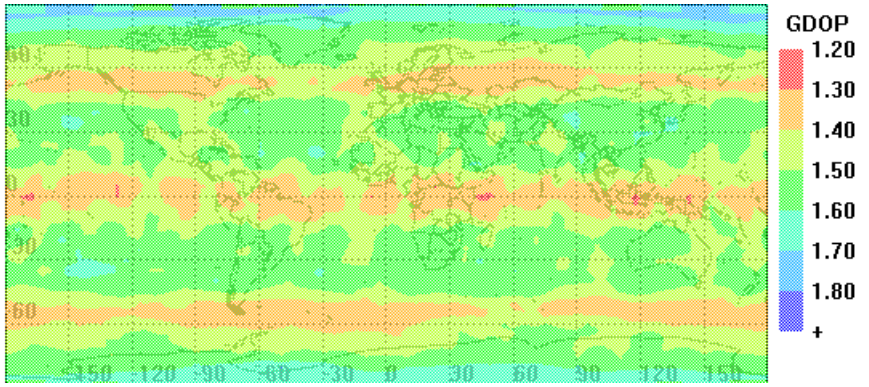
GDOP of GPS(G)+GLONASS(G_R)



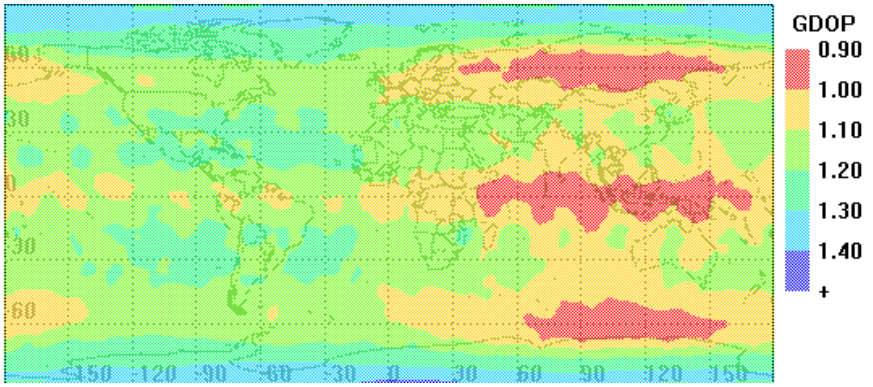
GDOP of G+G_R+B

3.3 DOP Value Comparison

- GDOP Improvement (Global)



GDOP of G+G_R+Galileo(G_E)



GDOP of G+G_R+G_E+B

DOP Improvement percentage by BeiDou with cut angle of 10° (Do not consider any time systematic parameter)

Scheme	GDOP	PDOP	HDOP	VDOP
G	50.1%	49.5%	46.3%	50.1%
$G+G_R$	32.7%	32.3%	31.0%	32.8%
$G+G_E$	29.5%	29.0%	28.1%	29.5%
$G+G_R+G_E$	22.6%	22.2%	22.5%	22.5%

DOP Improvement percentage by BeiDou with cut angle of 10° (Considering the time systematic parameter of BeiDou)

Scheme	GDOP	PDOP	HDOP	VDOP
G	46.1%	48.5%	45.3%	49.1%
$G+G_R$	27.5%	31.1%	29.9%	31.6%
$G+G_E$	23.8%	27.7%	27.3%	28.0%
$G+G_R+G_E$	16.2%	21.0%	21.7%	21.2%

4. Analysis

- The average visibility of satellites (AVS) increased from about 7 with GPS constellation to 17 with cutting angle of 10 deg;
- AVS increases from 12 with GPS+GLONASS to 22 with BeiDou added (85%);
- AVS increases from 21 with GPS+GLONASS+ GALILEO to 31 with BeiDou added in whole word.

It will improve the continuity, availability and integrity as well as the robustness of PNT.

4. Analysis

- The DOP value is decreased nearly 49% with GPS+BeiDou based on GPS only;
- The DOP is decreased about 32% and 28% by BeiDou based on GPS+GLONASS and GPS+Galileo respectively;
- The DOP value of GPS+GLONASS+Galileo is still improved 22.6% by BeiDou.

The decreases of DOP values will improve the precision of PNT.

5. Future works and conclusions

- For the masking area, multiple constellations will not only improve the visibility of satellites, but also improve the geometry strength.
- When the cut angle is 40 deg, a single constellation can only provide 2 satellites or less, but the two constellations will averagely provide more than 4 satellites and four constellations will provide 10 satellites. In this case there will not be any blind area for the users in the world.
- Thus the interoperability of multiple satellite navigation systems will significantly reduce the blind area and improve the availability of PNT.

5. Conclusions and future works

- BeiDou improves the visibility of satellites greatly.
- BeiDou will also improve the users' PNT geometry distribution.
- The integrity and continuity of PNT will be improved by multiple satellite constellations.
- The accuracy and reliability of PNT will be improved by integrating the multiple satellite systems.
- If the compatibility parameters are considered, the changes of DOP values should be changed. Thus the compatibility is very important.

Thanks for your attention!