Supplement 1 to TN: WP2420 Mission Architecture Definition/Supervision

5. COMPARISON OF POLAR AND SSO INLINE-FORMATIONS AND PENDULUM AND THEIR COMBINATIONS (BENDER-DESIGN)

It was shown in section 4.6 that the sensitivity can be increased by combining (different) formations on different orbits. The largest improvement can be achieved if formation flights with complementary information are combined. In section 4.6 only combinations of inline-formations and combinations of polar inline-formations and SSO-pendulums/cartwheels are investigated. In this section further combinations of polar and SSO inline- and pendulum-formations are investigated (except the combination of polar pendulum and SSO-inline due to the relatively low accuracy of higher orders for the inline-formations). Cartwheel-formations are not considered since they can not be implemented with sufficient accuracy at present state, as showed in [RD-3] and [RD-4], and also their realisation at low orbit height, e.g. h ≈ 350 km, seems to be problematic due to high power consumption. For simulations including a polar pendulum a repeat mode of $(\beta/\alpha) = 463/30$ with an orbit height oh h ≈ 417 km was assumed since a lower orbit height also seems to be not feasible due to an enhanced propulsion consumption [RD-3]. For all the other formations the repeat modes and orbit heights (@ h ≈ 335-350 km) originally suggested for the simulations were used. **Figure 5-1** and **Figure 5-2** show the results for various combinations of polar and SSO inline-/pendulum-formations as well as of the basic single formations. The formations and formation-combinations tested are:

- polar inline ($(\beta/\alpha) = 503/32$, h ≈ 335 km)
- polar pendulum ($(\beta/\alpha) = 463/30$, h ≈ 417 km)
- SSO-pendulum ($(\beta/\alpha) = 503/32$, h ≈ 348 km, $\alpha = 45°$)
- inline-Bender (polar inline + SSO-inline)
- inline-Bender (polar inline + (I = 63°)-inline)
- polar inline + SSO-pendulum ($\alpha = 67°$)
- polar inline + polar pendulum ($\alpha = 67°$)
- polar pendulum ($\alpha = 23°$) + SSO-pendulum ($\alpha = 45°$)

For all formations an average intersatellite distance of $\rho = 75$ km and white range-acceleration noise of psd = 10^{-10} [m/s²/sqrt(Hz)] is used. For the SSO-pendulums the constellation with the left satellite as a leader was used since the constellation with a right leader is less sensitive, as showed in section 4.6.

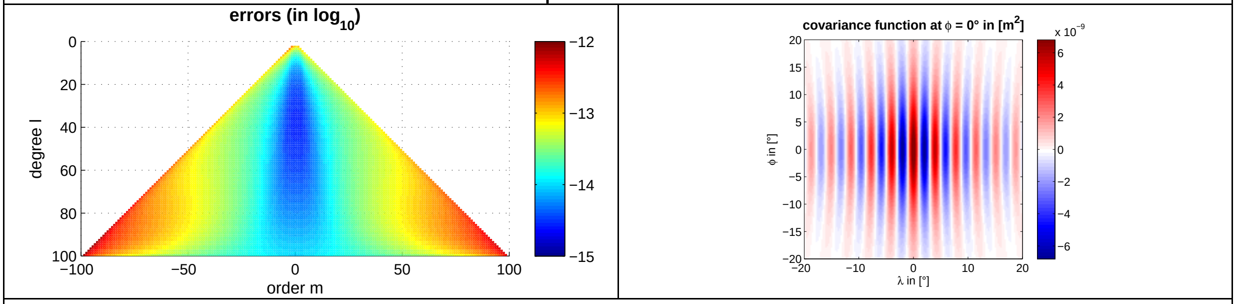
As it can be seen in **Figure 5-1** and **Figure 5-2** the best results for the formation combinations concerning accuracy and isotropy can be obtained for the combinations using the SSO-pendulum. This is because the SSO-pendulum offers both, a large isotropy compared to inline formations and an improved accuracy for higher degrees compared to the polar pendulum due to the lower orbit. Here the combination of polar inline + SSO-pendulum (mixed-Bender) outperforms the combination of polar pendulum + SSO-pendulum (pendulum-Bender) since the polar inline shows higher accuracy for the low order coefficients than the polar pendulum.

Concerning the single formations, the best performance is achieved by the SSO-pendulum, if the polar data-gap is disregarded. But even the polar pendulum, which is flying in a higher orbit is able to improve the accuracy compared to the inline-formation (see **Figure 5-2**).

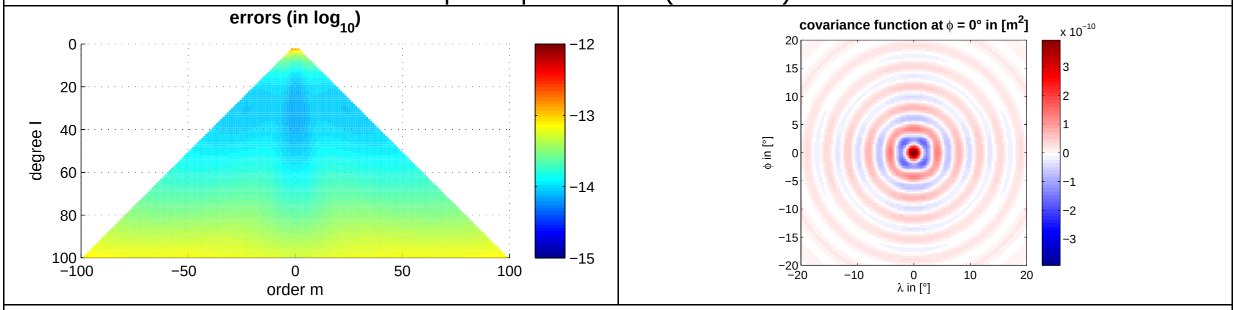
The degree-RMS-curve in **Figure 5-2** shows that the SSO-pendulum, inline-Bender (inline, polar + (I = 63°)), pendulum-Bender (pendulum, polar + SSO) and the combination polar-inline + polar-pendulum lead to similar results. In this case the mission options with lower cost/risk/complexity levels should be favoured, i.e. inline-Bender or the SSO-pendulum.

The most promising option seems to be the mixed Bender-combination of a polar-inline-formation and a SSO-pendulum. Such a constellation has the advantage that each of the formations forming this combination is a valuable mission on its own. This means that such a constellation can be realized by two independent agencies, e.g. ESA and NASA, where each agency is responsible for one formation.

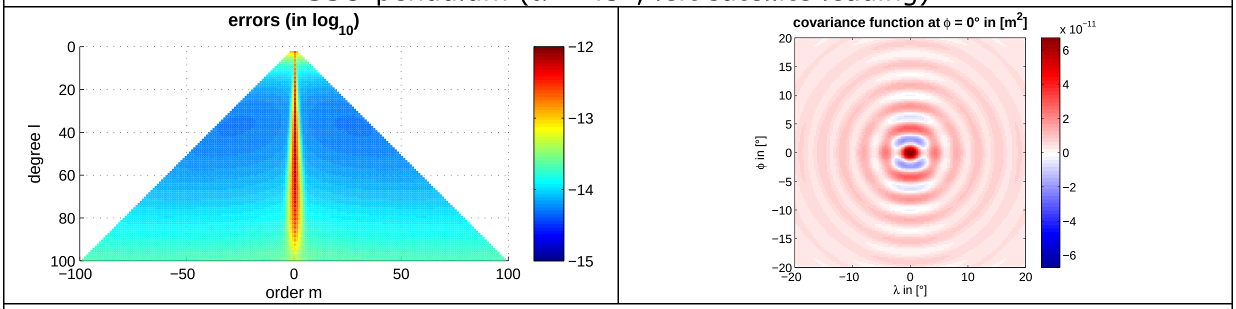
polar inline



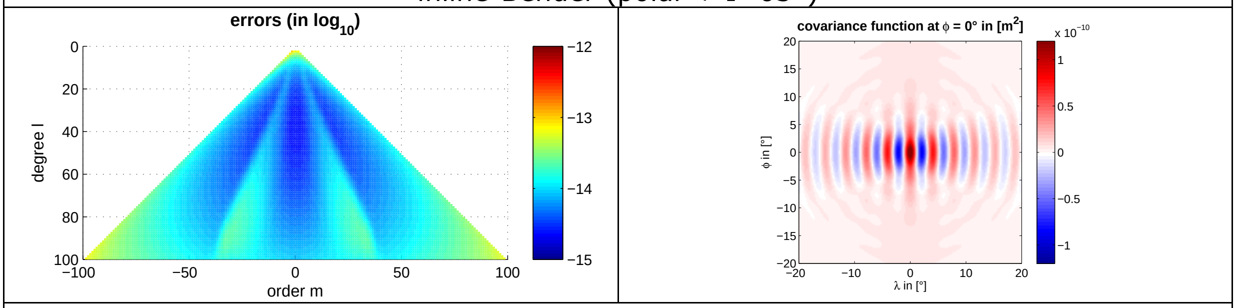
polar pendulum (α = 45°)



SSO-pendulum (α = 45°, left satellite leading)



inline-Bender (polar + I=63°)



inline-Bender (polar + SSO)

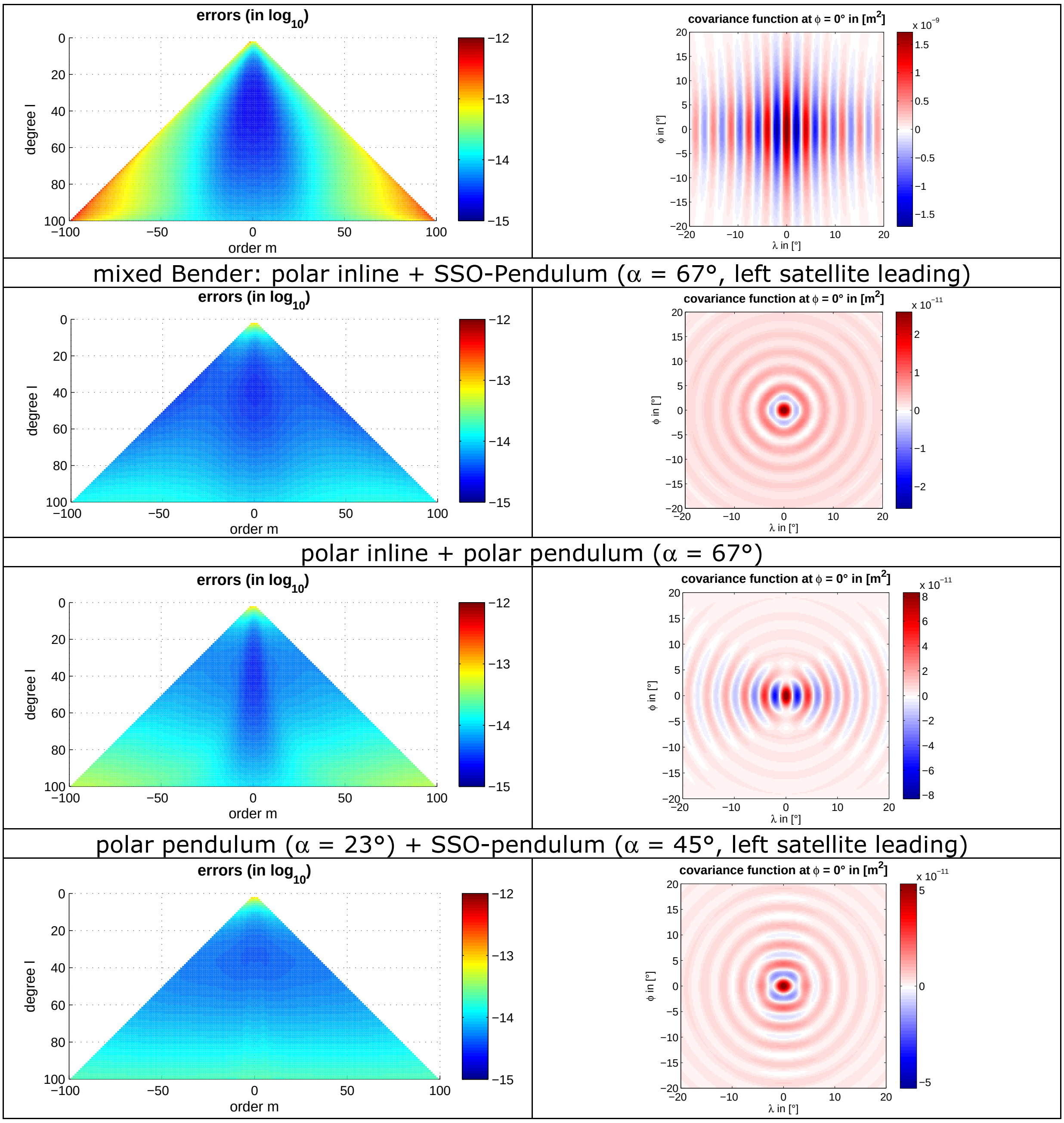


Figure 5-1: comparison of polar and SSO inline-formations and pendulums and combinations of them (Bender-design) in terms of formal coefficient errors and covariance functions. The orbits used are: polar inline: $(\beta/\alpha) = 503/32$, $h \approx 335$ km; polar pendulum: $(\beta/\alpha) = 463/30$, $h \approx 417$ km; SSO-orbits: $(\beta/\alpha) = 503/32$, $h \approx 348$ km.

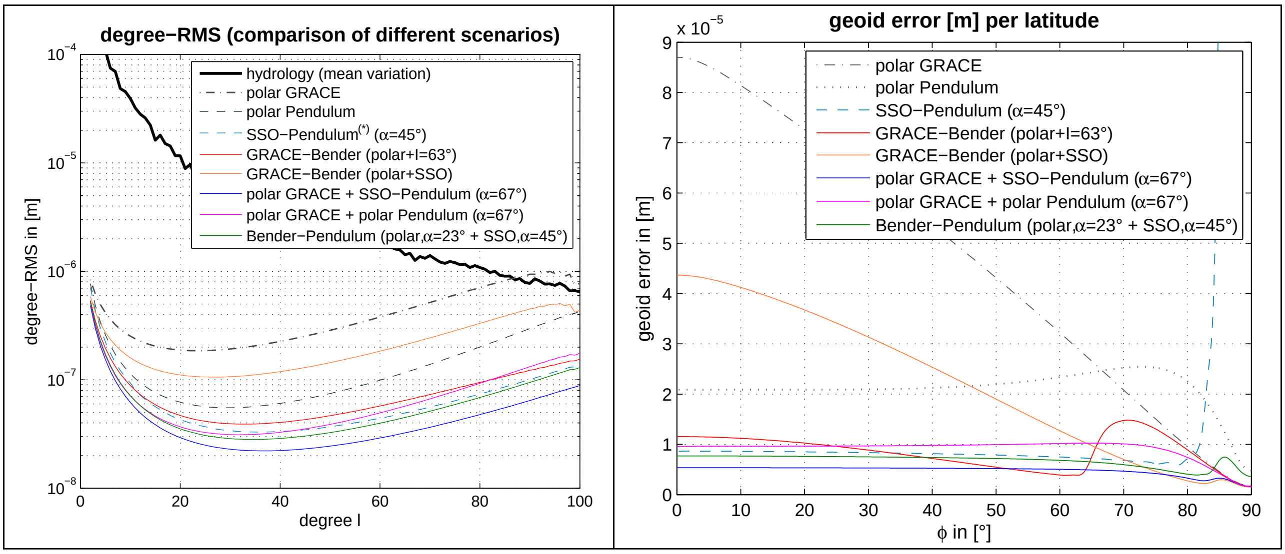


Figure 5-2: comparison of polar and SSO inline-formations and pendulums and combinations of them (Bender-design) in terms of degree-RMS and geoid errors per latitude.

In the previous comparisons in **Figure 5-1** and **Figure 5-2** the best formations and combinations of formations of each type of formation/combination have been compared. **Figure 5-3** to **Figure 5-7** shows the results of different designs of each type of formation/combination.

In **Figure 5-3** the various designs of SSO-pendulums using different line-of-sight angles α are compared. It can be seen that the SSO-pendulum with α = 45° seems to be the most promising option.

In **Figure 5-4** different designs of the combination polar inline + SSO-pendulum using different line-of-sight angles α are tested. The most promising option is the combination with a pendulum with α = 67°. However, the improvement in contrast to a single SSO-pendulum is only a factor of 1.5-2, if the polar data-gap is disregarded.

In **Figure 5-5** different designs of the combination polar inline + polar pendulum with different line-of-sight angles α are investigated. The most promising option seems to be the combination with a pendulum with α = 67°.

In **Figure 5-6** different implementations of pendulum-Bender missions (polar pendulum + SSO-pendulum) with different line-of-sight angles α are investigated. In the first row the combinations with a polar pendulum with α = 23° are tested. The best options seems to be the combination of a polar pendulum (α = 23°) + SSO-pendulum (α = 45°). In the second row the combinations with a polar pendulum with α = 45° are investigated. The best option seems to be the combination of a polar pendulum (α = 45°) + SSO-pendulum (α = 45°). In the third row the combinations with a polar pendulum with α = 67° are analyzed. The best option seems to be the combination of a polar pendulum (α = 67°) + SSO-pendulum (α = 45°). These best three options are compared in **Figure 5-7**. It shows that in principle all three options with a SSO-pendulum with α = 45° are quite similar, with only slight advantages of the combination polar pendulum (α = 23°) + SSO-pendulum (α = 45°) at near-polar areas.

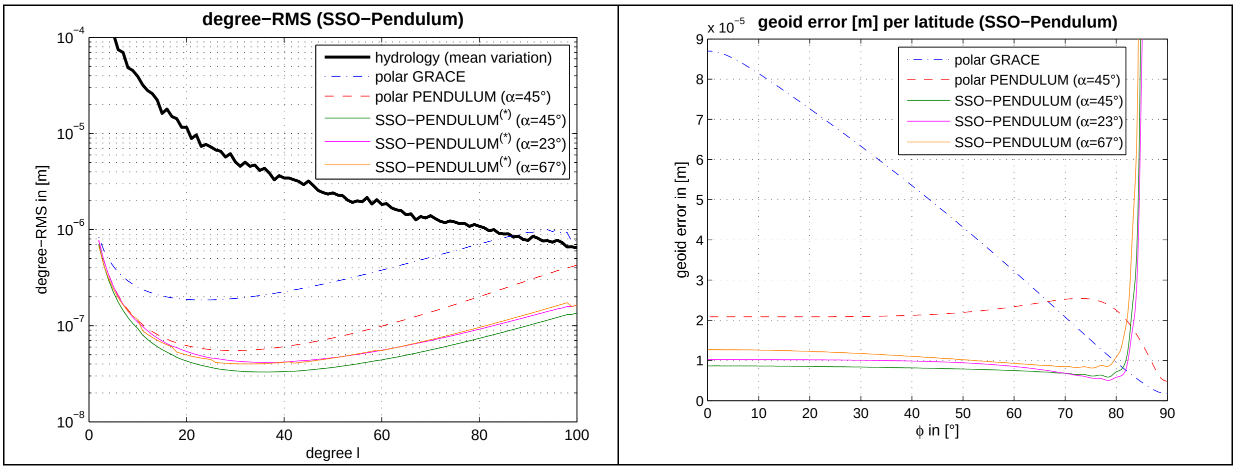


Figure 5-3: comparison of single formations: polar inline/pendulum and SSO-pendulums with different yaw angles α.

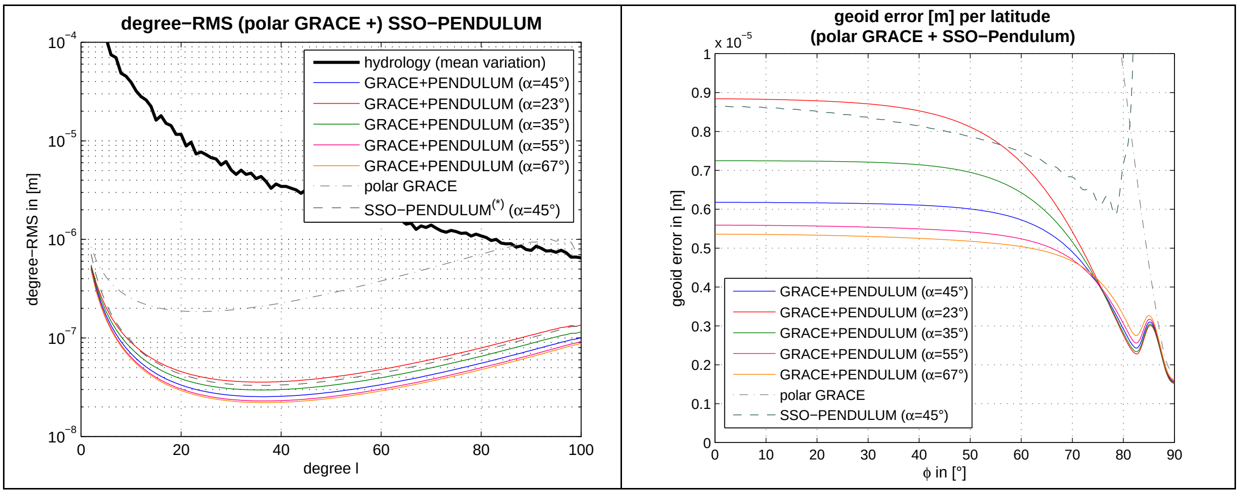


Figure 5-4: comparison of combinations of polar inline formation with SSO-pendulums with different yaw angles α.

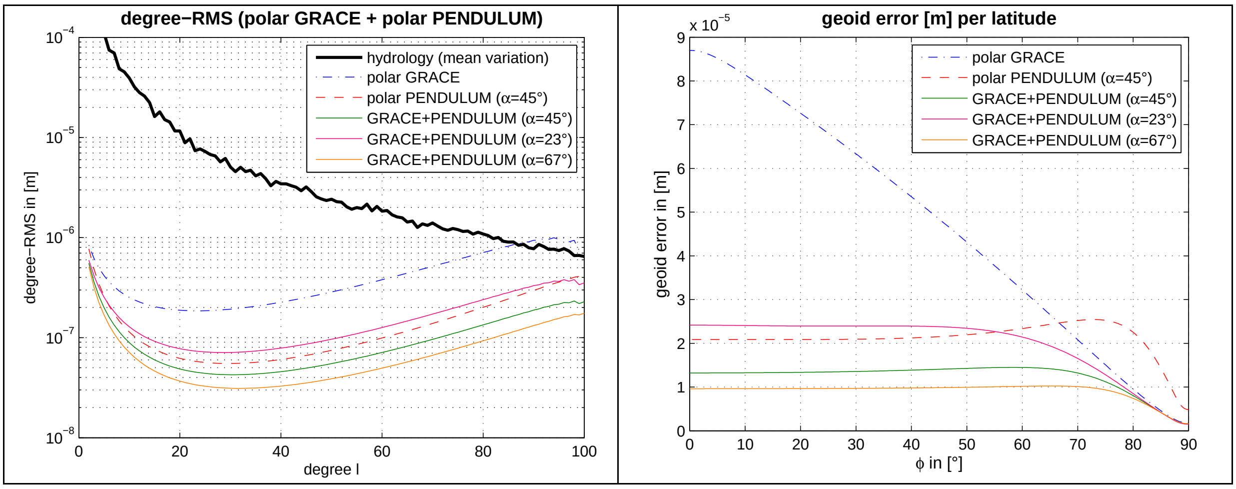


Figure 5-5: comparison of combinations of polar inline formation with polar pendulums with different yaw angles α.

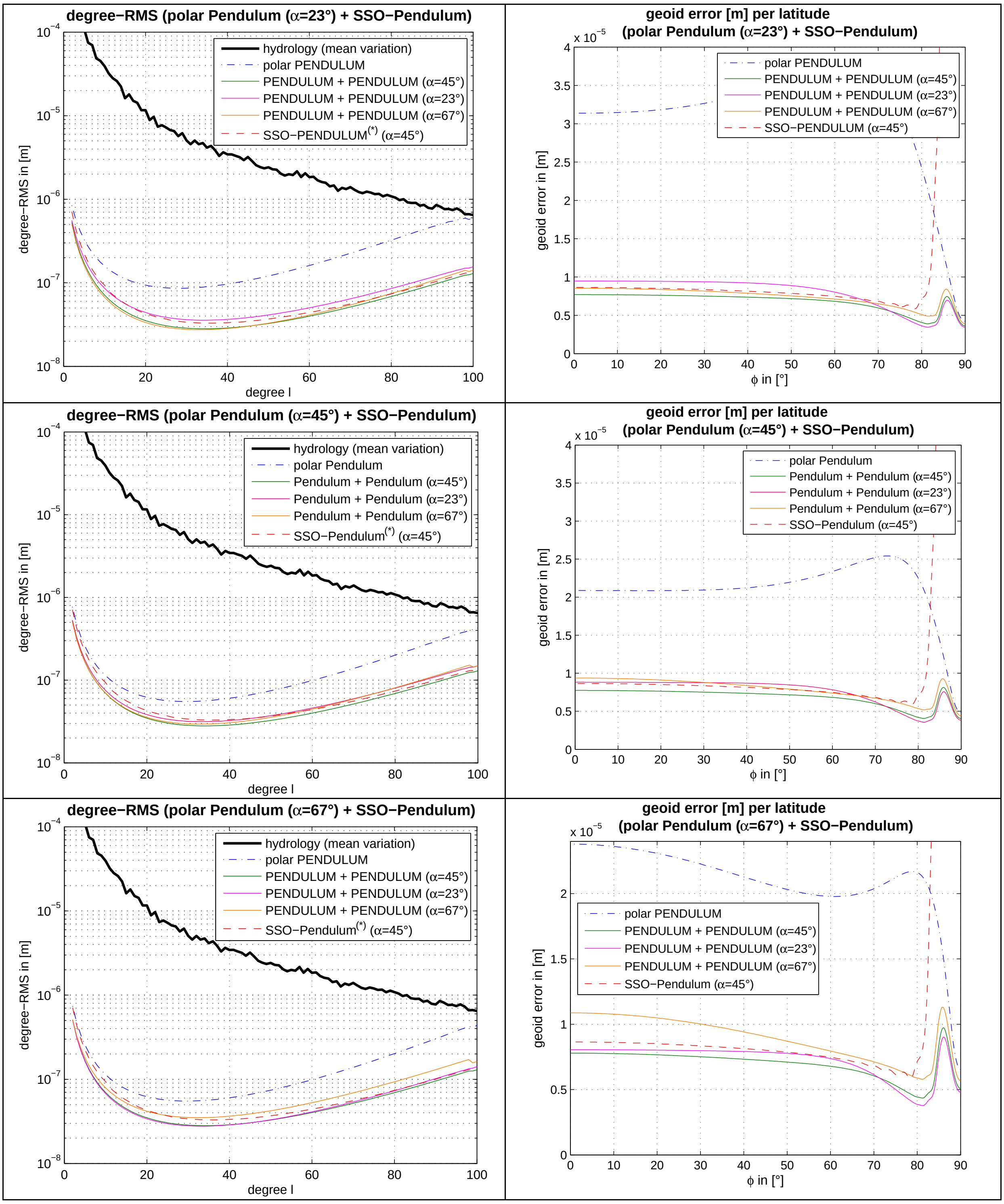


Figure 5-6: comparison of combinations of polar pendulums and SSO-pendulums with different yaw angles α); first row: combinations of polar pendulum with α = 23°, second row: combinations of polar pendulum with α = 45°; third row: combinations of polar pendulum with α = 67°.

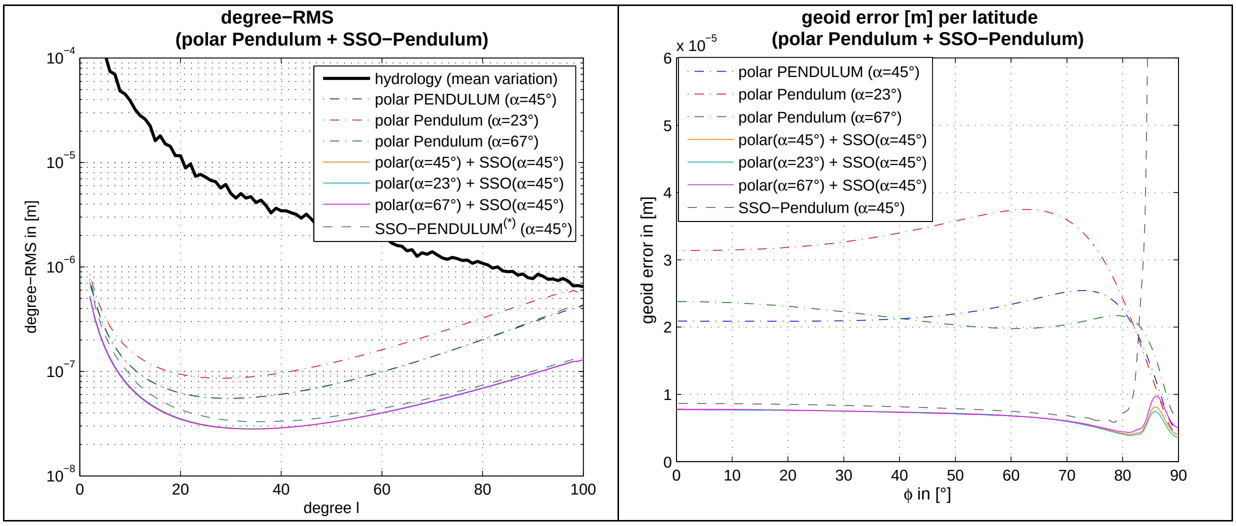


Figure 5-7: comparison of combinations of polar pendulums with different yaw angles α and SSO-pendulums with a yaw angle of α = 45° (best of each row of Figure 4-36).

Reference Documents

[RD-3] Anselmi, A (2010) TN6: Mission Architecture outlines. Technical Note of the ESA-Contract 22643/09/NL/AF "Assessment of a Next Generation Gravity Mission for Monitoring the Variations of Earth's Gravity Field".

[RD-4] Visser PNAM, Ditmar PG, Teixeira da Encarnacao (2010) WP2330 Backward Module. Technical Note of the ESA-Contract 22643/09/NL/AF "Assessment of a Next Generation Gravity Mission for Monitoring the Variations of Earth's Gravity Field".