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The *-Virtual-* 10th Swarm Data Quality Workshop

Summary and Recommendations Report

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1 CONTEXT AND MEETING SCOPE

The Swarm Data Quality Workshop (SDQW) is a yearly event organized by ESA and Swarm data quality team with the participation of multidisciplinary scientists and instruments' experts that focusses on innovative ideas for future Swarm-based activities and products, targeting new processing algorithms, correction improvements, emerging applications and multi-mission synergies. The SDQW#10 was held virtually from 5th to 9th October 2020 due to the Covid-19 pandemic situation, with the participation of more than 160 attendees.

The scope of this document - based on contributions from SDQW#10 session chairs- is to summarize the main points discussed during this workshop and compile key user recommendations and feedback, which should be translated into future Swarm-based product evolutions, services, and scientific activities.

Technical sessions cover Swarm data quality status and algorithm improvements for plasma, magnet and orbit/accelerometer data products. Besides that, the SDQW#10 offers unique opportunities to further discuss with the Swarm community on key technical challenges and science topics related to Internal/external field variations and applications in the areas of Near-Earth Space Sciences and Space Weather. Based on these interactions, key objectives of the workshop are to compile recommendations (see **Section 3** of this report): in view of reshaping the content of the Swarm data product portfolio, in identifying new services based on an enhanced synergy with other satellite missions and ground-based observations. The workshop is also instrumental in demonstrating the growing importance of Swarm-based virtual research environment used in support to innovating data processing approaches as well as in collecting inputs for the optimization of the orbital constellation.

To achieve these goals, the SDQW#10 was structured in 8 sessions including large time slots for discussions and brainstorming (see detailed agenda in **Appendix I**):

- Session 1: Mission overview
- Session 2: Magnetic field measurements
- Session 3: Electric field measurements
- Session 4: GPSR and accelerometer measurements
- Session 5: Advance products for Internal Fields
- Session 6: Advance products for External Fields
- Session 7: Swarm-CSES joined meeting
- Session 8: Summaries, Recommendations and Future

2 SESSION SUMMARY

2.1 Introduction

Session 1 presented an overview of the Swarm Mission illustrating the Mission Status, a brief overview of Swarm data quality and characteristics, and the meeting objectives. After 7 years in space, the three satellites are in excellent shape, being able to address new scientific challenges and operational applications and are ready for collecting data for several more years. Moreover, the Mission Extension by ESA' s Member states has been approved through 2022. The status of the mission remains green, regarding both Platforms, Payload systems, data quality and PDGS infrastructures, despite the issues introduced by the COVID-19 pandemic. To enable full exploitation of the Swarm constellation, the processing algorithms as well as the ground and flight operating segments are constantly improved, taking advantage of experience gained by ESA and the Swarm user community in the past years. Thanks to these joint efforts, the Swarm mission has already achieved remarkable scientific results also opening the door for many innovative applications beyond its original scope. This is particularly true in the area of Near-Earth Space physics where Swarm data exploitation should benefit of new opportunities of synergies with other ESA science missions. The combination of Swarm with complementary satellites is indeed promising as it increases the scientific value of the mission, enhancing temporal and spatial coverage. In this respect the status of current CSES and Swarm-Echo mission as well as potential future satellites (Macau and ESA SCOUT NanoMagSat) were also presented as part of the Swarm mission overview session.

2.2 Magnetic Field Measurements

Session 2 of the Swarm DQW#10 was dedicated to the data quality status of the Magnetic package instruments on-board the Swarm spacecraft, i.e., the Vector Field Magnetometer (VFM), the Absolute Scalar Magnetometer (ASM) and the Star Tracker (STR). During this session, the excellent performance of all above-mentioned instruments was reported. In addition, the main improvements in the L1B data processing chain were also presented, i.e.: (i) the generation of 1 Hz ASM data when the ASM instruments operate in Burst mode (i.e., 250 Hz rate) and (ii) improved the combination of the three STR attitude quaternions into the combined attitude solution. The Level 1B operational processor containing such improvements has been successfully deployed into operations on 10 Feb. 2020.

Overall, the quality of Swarm L1B Magnetic field products, currently with product baseline and file counter number 0506, remains excellent.

Concerning the STR, the IBA (Inter Boresight Angles) correction model introduced in Sept. 2018 into the computation of the attitude of the STR Common Reference Frame (CRF) in order to remove the variation of the CHU boresight with temperature continue to perform very well. After in-depth investigation performed on-ground by an industrial consortium led by AIRBUS aimed at understanding the root cause of temperature-dependent CHU boresight variations, such root cause remains unknown.

Concerning the VFM instrument, the dB_Sun correction model, currently used in operations, is performing very well. For Swarm Alpha and Charlie, the VFM scaling that changes with time has been slightly adjusted starting from 2018-01-01 onward. Such adjustment was introduced in the Swarm L1B processing chain in Feb. 2020 and a regeneration of Swarm Alpha and Charlie MAGNET data for 2018-01-01 to 2020-02-07 was performed.

The on-ground test campaign showed that the sun-induced disturbance field might be due to the thermoelectric currents created by temperature difference between MLI rivet. The cross-satellite comparisons of ASM scalar measurements showed that ASM instruments are also affected from such disturbance. These findings, combined with elements of previously developed correction models, allowed to develop a new model parameterized by a few physical parameters, i.e., the so-called physical correction model. This model is mainly applied to ASM data due to geometry complexity. This allows to separate the sun-induced disturbances between the ASM and VFM. Nevertheless, further (combined) analyses are needed in order to confirm their correctness (i.e., ASM correction model to be tested during non-nominal flight periods). Another investigation linked to this activity is simulating the magnetic field induced by the thermal blanket configuration at the ASM and VFM locations by considering the properties and geometry of the thermal blanket and grounding wiring configuration. The study on ASM confirmed that there is a preferred direction (Y) for the magnetic field disturbance. For the VFM instead, the simulations confirm the MLI (Multi-Layer Insulator) and the rivets are responsible for the disturbances of same order of magnitude of the ones registered during on-ground campaign. These simulations also confirmed that only the outer MLI is responsible for such disturbances while the inner one is not contributing at all.

Following the growing interest from the Swarm community on the ASM Burst mode sessions (i.e., scalar measurements at 250 Hz frequency rate), instruments on-board Swarm Alpha and Bravo have been operated in Burst mode regularly during the last year, with 1-week/month cadence. All corresponding ASM 250 Hz science data have been processed by IPGP and Leti on an experimental basis. A good example of new results obtained by the analysis of 250 Hz ASM data is the Whistlers waves detection. Whistlers waves that are excited by the lightning activity on the Earth surface can propagate deeply into the Earth ionosphere. It is found that higher number of Whistlers waves is detected when Swarm spacecraft are in local time (LT) from 18 to 22. However, still some LT are uncovered. In the coming months more burst sessions will be performed in order to complete all the LT sectors. Please note that very soon the full ASM 250 Hz Burst mode science data will be distributed by ESA to a broader community.

During this session it was also reported on the Swarm Echo MGF instrument performance and data processing and quality. The MGF instrument is performing nominally. Moreover, the combination of improved attitude data and the use of a new reference model (CHAOS-7) have improved the quality of MGF data. A first test set of 1 Hz and 160 Hz data for January to March 2019 in CDF format has been made available to all community for feedback. On this activity, Swarm DISC continue to give a significant support.

2.3 Electric Field Instruments

Session 3 was dedicated to the Electric Field Instrument (EFI) status and performance. The EFI is composed of two instruments: two Langmuir Probes (LPs), and the Thermal Ion Imager (TII). It follows from SDQW presentations that both instruments are performing very well.

A statistical comparison between LP measurements and the Incoherent Scatter Radars (ISRs) located at equatorial, low, and middle latitudes has been performed in the past. This study demonstrates that the LP are under-estimating the density of about 20%, and over-estimating the electron temperature of about 400 K, on average. Recently, these correction factors have been computed for the entire EFI-LP dataset, considering the geographical constraints related to the ISRs location. A TEST dataset of EFI-LP data containing the calibration factors (as separate variables) has been delivered to the Swarm users before the SDQW#10, with the aim of studying the variation of scientific results by including the LP calibration. The feedback has been positive, mainly because the calibration has a strong scientific valence. However, this method can be applied only for certain latitudes, thus the community will study how to improve the LP calibration by also considering higher latitudes. The calibration factors for the LP variables will be included in the L1B data products with the transfer to operation of the next operational processor.

In general, the LP data have very good quality. Some differences on the number of flagged values (ACD overflows, negative densities, etc…) are observed by comparing the measurements during high and low solar activity. The plasma densities can be computed at negative or positive bias (obtaining ion and electron density respectively), or obtained from the faceplate (part of TII) instrument. The three methods sometimes disagree, thus the EFI team is investigating a method to harmonize the density measurements.

The LP electron temperature frequently shows very high measurements. The values exceeding the 20k K will be flagged as “extreme” in the reviewed flag tables, which will be delivered with the next L1B operational processor. Some of these extreme values are related to an instrumental disturbance due to the particular incidence of the Sun on the solar panels. This issue has been investigated in detail, resulting in a correlation of almost perpendicular sun orientation with respect to the normal of the solar panel, and electron temperature train-spike observations. Further analysis will involve the HK data to study some current induction.

The quality and time coverage of the TII data is continuously improved. Since the beginning of the mission 87 Anomaly Review Board (ARB) meetings took place to investigate instrumental issues and set-up “Scrubbing” techniques to prepare the instrument for the scientific measurements. Recently, an updated version of the TII cross-track ion flow dataset v0301 has been released. The dataset is available at 2Hz and 16Hz for all the three spacecraft covering a time interval from December 2013 to June 2020. This release fixed some bugs registered in the previous TIICT dataset v0201, resulting in too large ion drift and electric field magnitudes by approximately 35% for measurements made prior to mid-September 2018. The TIICT received very good feedback from the scientific community. During the meeting it was agreed to implement the TIICT dataset in the ViRes platform.

Many scientific papers based on Swarm EFI and/or ePoP plasma data have been published in peer-reviewed journals during 2020. Part of these recent results have been discussed during the session 3, demonstrating the scientific value of joint Swarm and ePoP plasma observations. Also, plasma irregularities have been statistically investigated at different scales, in particular by analysing the high-cadence plasma current and the ion time-of-flight measurements from ePOP. This analysis will be compared with the results obtained from Swarm.

The Swarm-EFI team is working to further improve the quality of the Swarm EFI-based data and to define a road map for future evolutions.

2.4 GPS and ACC instruments

Session 4 focused on Swarm A/B/C accelerometry and density processing, precise orbit determination, and gravity field models, as well as CASSIOPE GAP data processing.

The overview presentation of the accelerometer and GPS receiver clarified which mass density data product serves which application. Further, the result of an investigation of the accelerometer spikes suggested that these could be caused by thermo-mechanical stress release of the solar arrays caused by the temperature variations of the solar array temperature. The accelerometer data processing was advanced on several points. The POD-only total acceleration was replaced by the sum of the POD-only aerodynamic acceleration and modelled radiation pressure acceleration within the calibration of the accelerometer measurements. Further, new corrections for spikes and voltage jitter were implemented in the calibrated accelerometer data product. An analysis of the corrected steps showed that much less steps occur when the satellite is in dawn/dusk orbital orbital configuration, i.e. when the onboard temperature variations are very small. Finally, the coupling between accelerometer axes is sometimes critical, though difficult to model. It was decided to spend spare time on the processing of Swarm A accelerometer data in 2014, which appears to be better than in later years.

The POD processing is progressing nominally. The plans for improvement in orbit processing include the implementation of integer ambiguity fixing, generation of covariance matrices for the kinematic orbits, and screening for ionospheric scintillations. The plans for improving the density processing encompass the usage of an improved energy accommodation coefficient and the usage of more advanced geometry and surface properties within the radiation pressure modelling. The assessment of mass densities revealed a potential issue with the concentration of Helium as derived from a thermosphere model. This could lead to a bias in the effective aerodynamic coefficient, which translates into a bias in the mass density observations. This needs further investigation.

An empirical correction for an artefact in L2 phase observations of the GPS receiver was developed. The correction significantly reduces the artefact, though it does not completely remove it. It was noted that the L2 PLL bandwidth modification of GPS receiver was an effective way of mitigating the artefact at the source. There is an interest from other groups to process the corrected RINEX observation files and precise kinematic orbits that were corrected for the artefact.

The operational CASSIOPE GAP data processing has significantly advanced, partly because of software upgrades. The processing of atmospheric profiling needs further improvement to reach the required position accuracy of decimetre level. The GAP data availability has drastically improved by means of an automatic onboard procedure. The TEC processing is working well and several experiments were carried out in the period from fall 2019 to summer 2020.

The Swarm gravity field model processing as part of a Swarm DISC project is proceeding well. All groups contribute actively with their gravity field solutions and the combination gives high-quality GPS-only Swarm gravity field models.

2.5 Advanced products for Internal fields

Session 5 introduced the recent advances in the areas of main field and lithospheric field modelling, and mantle conductivity recovery.

The Geomagnetic Virtual Observatory (GVO) data product, the outcome of a Swarm DISC project, was presented. This provides time series of the vector magnetic field at four monthly and one monthly cadence on an equal area grid at satellite altitude, coming in a version containing all field sources (observed field) and a version processed to isolate as best as possible the core field. Validation was carried out by comparison to ground observatory records. The Swarm GVO scalar field secular variations (computed by annual differences) agree with benchmark ground observatories to a level 1.2 nT/yr (four monthly product) and 1.8nT/yr (one monthly product). Operational product on the GVO product will begin in November 2020. The was also a presentation of an application of the GVO product in deriving core flows, as part of the 4D Deep Earth: Core consortium. Annual external field signal remains in the GVO core field series, especially at high latitude. There was discussion of the point that furthers are needed to better isolate non-core signals at monthly and longer periods.

A presentation was given of a new approach to time-dependent field modelling based on sequential three-monthly inversions within a Kalman filter framework. The results generally agree well with more traditional field modelling schemes but allows fast field changes to be retrieved at high spherical harmonic degree. After smooth it was possible to retrieve the field acceleration at the core-mantle boundary up to spherical harmonic degree 12. The origin of fast variations in the zonal terms required further investigations and the next step is to include better prior information for the external part of the model.

A study of the use of MMA products for deriving mantle conductivity studies was presented. It was shown that for long periods, greater than 100 days, a simple axisymmetric (P10) ring current transfer function cannot be explained with a 1-D mantle conductivity model. It was pointed out that there is a discrepancy between the non-P10 terms in the Q-matrix estimated with ground and satellite data. Further work is needed to clarify the reason for this, but it may be related to ionospheric currents at auroral latitudes being seen differently on ground and in Swarm data. It was shown that the signal to noise ratio for Q-matrix elements other than P10 generally remains small and there was a discussion of the need to better characterize the high latitude ionospheric field. There was also discussion of the opportunity to obtain a better description of the local time dependence of magnetospheric sources using platform magnetometer data.

Regarding the lithospheric field products, there was a presentation about the successful release of a new extended lithospheric field model from joint inversions from six years of Swarm vector and scalar data and gradients, along with CHAMP data and near surface data (a subset of the WDMAM-2 grid). This extended lithospheric field model is provided to degree 300. It was shown that the regional models from which the global spherical harmonic model are constructed contain further information. There was a discussion on the need to apply band limiting functions to the near surface data before combining them Swarm and CHAMP data.

A presentation was given covering applications of platform magnetometer data to assist internal field studies. It was pointed out that CryoSat-2, GRACE-FO and now also GRACE data are available. CryoSat-2 and GRACE data have already been used in field modelling studies. Further efforts with GRACE data using house-keeping data, following experience from CryoSat-2 was recommended.

There was a presentation of simulation studies for the proposed Daedalus mission. This involves highly elliptical orbits, part of which come to very low altitudes. It was demonstrated that the low altitude data could be very valuable for lithospheric field studies. Following a discussion, it was recommended the Swarm community strongly support Daedalus as an Earth observation mission that can contribute to our knowledge of the lithosphere.

There was finally a presentation illustrating the application of the ViRES platform for visualizing Swarm data and internal field models. The ability to compare models and look for differences was presented. An update was given on the status of the Virtual Research Environment (VRE), and example jupyter notebooks were demonstrated. It was discussed that VRE-based dashboards for observatory data and field model diagnostics and comparisons would be useful.

2.6 Advanced products for External fields

Session 6 compiled contributions from new, advanced data products or developments of recently implemented products and services enhancing the description of the Earth's space environment. Special emphasis was taken on concerted approaches by multi-parameter analyses and the exploitation of multi-mission constellations in support for the Swarm science objectives in exploiting the space environment and towards Space Weather. All presentations showed results from individual projects supported by DISC.

Within the AEBS project, magnetic field observation on board Swarm are used to derive the location and strength of the auroral electrojet including an estimate of its equatorward and poleward boundaries. These products have been derived from two different and independent approaches. The cross-comparison of their results showed a general good agreement between them that confirm the robustness and quality of the products, although some differences were also identified. AEBS also includes an estimate of the auroral boundaries determined from small scale field aligned currents. Independent magnetic field and particle precipitation data from the DMSP satellites revealed that the peak of field-aligned current density shows systematic differences to peak particle precipitation which opens new ways to investigate the complex ionosphere/magnetosphere.

The PRISM project developed an index of the plasma pause location and of the mid-latitude trough considering small scale field-aligned currents, electron density and temperature, and Total Electron Content from Swarm. These parameters are important indicators for space weather, since the plasmasphere is highly sensitive to the geomagnetic disturbance level. The study could show that the midlatitude trough is near-linearity related to the Kp index and to local time.

The IPIR project presents a collection of irregularity indices including the rate of change of electron density (RODI) and the rate of change of TEC (ROTI) along the Swarm orbits. Together with other irregularity parameters, an index to characterise the global ionospheric disturbance has been made available, that represents the multitude of ionospheric irregularity types from equator to pole.

Ion temperature is one of the key parameters that provide insight into the thermal balance of the coupled ionosphere-thermosphere system. Within the SITE project, estimations of ion temperature along the orbits of Swarm are developed using observational and model data. To this aim, plasma drift observations from the Swarm TII is used as input whenever reliably available, and the drift is replaced by empirical model results elsewhere. The so far performed validation and error analysis indicate that the proposed method shows reasonable results.

Total electron content and electron density observations from the CHAMP, GRACE, and GRACE-FO missions are derived within the TIRO project. Together with Swarm, this activity will lead to an observational coverage of these parameters at altitudes of 400-500 km over almost two solar cycles. Cross-comparisons during conjunction events of simultaneous missions, such as Swarm and GRACE-FO revealed an already high integrity of the so far preliminary products. Also calibrated magnetic field data of the GRACE-FO mission have been presented, that were derived within a DISC effort of exploiting platform magnetometer data. Using the dual satellite aspect of GRACE-FO and the availability of magnetic and plasma parameters during selected magnetic storm events, it was shown that GRACE-FO has the potential for a space environment mission, to even enhance the perspectives of the Swarm activities.

There was finally a presentation illustrating the application of the ViRES platform for visualizing Swarm data for external field products. The ability to compare different parameters was presented. The final discussion recognised the expanding number of valuable products for space science and space weather derived from Swarm observations. System level approaches are achieved with the combination of different parameters and the use of multi-missions. It was revealed that a Swarm data delivery on faster track than currently implemented will further enhance the applicability of the new products for Space Weather characterisation in near real time. This may be through empirical models developed from Swarm or direct application of Swarm data in near real time, e.g., in combination with other data globally distributed.

2.7 Swarm-CSES synergies

This session was an opportunity to update the Swarm community with the present status of the Chinese CSES mission, and to discuss results from this mission, with emphasis on the benefit of the collaboration established between Swarm and CSES scientists.

A first overview presentation by Z. Zhima and X. Shen (National Institute of Natural Hazards, Ministry of Emergency Management of China, NINH MEMC) on behalf of the CSES Chinese team provided the current status of the mission, an overview of the Swarm/CSES cooperation activities, some outcomes of this cooperation, and some proposal for next-step bilateral cooperation.

It was first reported that the current mission is the first (CSES-01) of a series of several missions. It should soon be followed by CSES-02 (a copy of CSES-01 with an Ionospheric Photometer added as an additional payload) already approved and which passed PDR in March 2020 for a tentative launch in 2022. CSES-02 is to be launched on the same orbit as CSES-01, but phased 180° (antipodal) along the orbit. An additional mission is already in the planning (CSES-03), now to be built as “a constellation with more probes”. No further details were provided. This series of satellites (collectively known as Zhanheng) is to focus on Electromagnetism. Also in the planning (proposal stage), however, is a gravity satellite (Zhanheng-02).

The CSES Scientific Payload was reported to be healthy, though the Electric Field Detector (EFD) was noted to suffer from high noise in the HF band, while the Plasma Analyser Package (PAP) suffers from contamination of still unknown origin. The Tri-Band Beacon (TBB) was also noted to still have problems in the 400 MHz band. It was said that all data are to be shared through http://leos.ac.cn (a link that is temporarily not operational, though, due to transfer of ownership).

Swarm/CSES cooperation activities in 2019 and 2020 consisted in joint participations to a number of meetings in China (2) and Europe (1) and the setting up of an International Science team within ISSI-BJ. It was also reported that a proposal between CSES team and Swarm related institutes (GFZ, INGV, INFN) was successfully included in the Dragon-5 project, approved in June 2020 and kicked-off in July 2020.

Outcomes of the Swarm/CSES cooperation were briefly reviewed (some of which were next detailed in following presentations, see below). These include: successful cooperation on validation and data quality control of the high precision magnetometry payload (HPM), leading to 3 joint publications; successful cooperation on validation and data quality control of the Electric Field Detector and Search Coil Magnetometer (EFD/SCM) payload, providing material for 4 joint publications; successful cooperation on validation and data quality control of the Plasma Analyser Package (PAP), Langmuir Probe (LAP) and GNSS Occultation Receiver (GOR), leading to an additional 4 joint publications; and finally, a successful cooperation (mainly with the Italian contributors to the CSES payload) on cross-validation of the Chinese (HEPP) and Italian (HEPD) High Energy Particle Detectors, leading to 3 additional papers. A list of 13 papers resulting from these cooperations was provided. The presentation concluded with some considerations on the envisioned next steps for ensuring continuity of these cooperations: more data validation, more science exploitation, targeting ionospheric environment, geomagnetic field modelling, studies of natural disaster events, and exploring Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) mechanism and coupling (the main target of the mission).

The second presentation, by G. Hulot (IPGP) and colleagues (from both Europe and China), more specifically illustrated an example of successful Swarm/CSES collaboration using HPM data, in the context of the so-called joint magnetometry CAL/VAL core team. This collaboration led to the CSES CGGM IGRF-13 candidate model, entirely based on CSES HPM data, and an associated publication. It also led to the identification of a number of issues with the vector data, related in particular to the stability of the mechanical link between the HPM payload (on a boom) and the Star Trackers (STR, on the body of the satellite) used to provide attitude restitution. It finally also highlighted the benefit of also making HPM data (at least scalar data) available at high latitude (above 65° absolute latitudes) for such global geomagnetic field modelling efforts. More generally, this collaboration also made it clear that key to success is fast reactivity of the CSES team to ensure easy and fast access (including from outside China) to well-documented data and the possibility for members of the collaboration to spend significant joint working time in a common location (either in Europe or in China). More such efforts should be done to further improve the quality of the HPM data.

The third presentation, by Y. Yang (NINH, MEMC) and colleagues (from both China and Europe), presented the CSES HPM data products, specifying the way Level 2 data files are defined, produced and organized, also highlighting all known issues, identified using flags. The purpose of this talk was to let future CSES HPM data users be aware of how to best take advantage of these data for advanced science investigations. To illustrate such use, an example study of an intense geomagnetic storm was also presented. A paper describing the material presented is reported in a joint publication currently under revision for JGR Space Physics.

The fourth presentation, by Chao Xiong (GFZ) and colleagues from both Europe and China, reported on the activity of the so-called Plasma CAL/VAL core team. This activity was also very fruitful, leading to the identification of two issues in the CSES LAP data: lower electron density than expected when compared to analogous Swarm data; existence of sudden jumps and small-scale fluctuations. No final conclusion has yet been reached about the cause of the lower values of the CSES electron density data. In contrast, sudden jumps are found to be coincident with sudden drops in the potentials, which mostly happens when the satellite is within certain solar zenith angles. By applying an appropriate filter, both jumps and small-scale fluctuations can be removed. It is concluded that CSES LAP data, once corrected, are quite reliable for event and statistical studies. Four joint studies have already been published.

The final presentation, by J. Wang (NINH MEMC) and colleagues (from both China and Europe), provided yet another illustration of science application of the CSES HPM data products, now only using scalar data (from the CDSM instrument). These data, free of the issues affecting the vector data mentioned above (see second presentation), were successfully used to produce a initial map of the large scale lithospheric magnetic anomalies in China and surrounding regions, providing evidence of the potential usefulness of such data also for such studies. This work also led to a joint publication.

Altogether, this session clearly showed the value of joint CSES and Swarm analysis, and of close collaborations of the scientists involved in both missions. It also showed the path to further improve the quality of the CSES data and better take advantage of those combined with Swarm data.

2.8 Swarm Analysis and Visualization

This session addresses advanced approaches for data processing as well as new data visualisation tools and services. In continuation of the presentation and practical demonstrations of the Swarm VirES visualisation tool (available at www.vires.services) given during the first days of the meeting, the viresclient, a Python "add-on" software package to access the VirES API, has been presented. The software allows to interact with the background VirES machinery, access and download Swarm observations and model values with just a few lines of code. A practical demonstration of the tool showed its capability e.g., for easy extraction and processing of lithospheric signatures in Swarm magnetic data.

The Python package for determination of FAC density from Swarm magnetic observations has been showed. The underlying algorithms have been developed as part of the ESA-funded SIFACIT project. In its final form the presented Python package will consist of Jupyter notebooks for estimation of FAC and their associated quality indicators using single-satellite, dual-satellite, and triple-satellite magnetic data.

Also, a machine learning approach for automated detection of ULF waves has been presented. The algorithm is based on a previously developed time-frequency analysis wavelet tool for detection of pulsations in magnetic and electric field data, the output of which is used for the detection and classification of ULF wave activity and pulsations.

During the following discussion, many participants expressed interest of the scientific community in easily accessible software tools and services for Swarm data analysis, which would be a welcomed complement to the present Swarm data product portfolio.

2.9 Future on Swarm Constellation

The current constellation of the satellites was presented in session#1 while the future orbit evolutions have been extensively discussed during dedicated brainstorming session between ESA and SDQW10 participants.

Today, the Swarm-B is orbiting at 510km and the lower pair satellites at about 440km altitude decaying 2.5km/year due to the air drag. The yearly fuel consumption is less than 1kg per year and 60kg of fuel are remaining. Due to the non-spherical gravity field of the earth the orbital planes continue to rotate at a rate providing 24h local time coverage about every 9 months. The Swarm-B orbital plane rotates slightly faster and reaches 180 deg relative to the lower pair in October 2021. Thus Swarm-B will then orbit in the opposite direction. Shortly after the SDQW the presented inclination change manoeuvres were successfully executed. Now the lower pair node crossing difference reduces continuously and crosses through zero also in October 2021.

The open discussion on the future Swarm constellation focused on the counter rotating orbit configuration in 2021. Swarm-B passes over the lower pair 30 times per day. Due to the inclination of the orbits the overfly points are always separated at least 600km across track close to the poles. But overfly points with much smaller cross track separation are present at lower latitudes. This latitude varies between +/-40 deg while the local time of the ascending node evolves from 2h to 14h between August and December 2021.

The scientists proposed and discussed three different potential lower pair along track configurations: A relatively small separation of some seconds, a large separation in the order of 1000km and a variable separation where the along track separation is synchronised with the evolution of the node crossing difference such that both satellites can observe the same geophysical phenomena that corotate with the Earth. Each configuration would have to be present for several months to cover different local times.

Fuel consumption-wise all these formations are feasible as an along track orbit shift is relatively cheap (half a kilo of propellant would be required to achieve 1000km along track separation within less than a month). Whether more than one configuration can be implemented depends on the required duration for local time coverage and needs to be decided during the SDQW#10.

Further future milestones are the orbit raise, which is expected to be required in 2022 but with large uncertainty due to the not yet known start and intensity of solar cycle 25, and the decision on when to stop the orbital plane rotation of the lower pair satellites after the counter rotation phase in 2021.

3 RECOMMENDATIONS

TOPICS	RECOMMENDATIONS	STATUS	MAIN UPDATES AT DQW#10
Magnetic Field	[DQW8_Rec 1.] Adapt the L1BOP in order to be able to process L1B MAG data with ASMxBUR_0_ data as input	Done	Action completed. Improved version of L1BOP deployed in operations in Feb. 2020. Activity completed.
	[DQW8_Rec 2.] Run ASM on Swarm Alpha and Swarm Bravo in Burst mode more frequently (two weeks sessions).	Done	On-going regular monthly 1-week burst sessions since August 2019 and bi-monthly 1-week sessions from July 2020.
	[DQW8_Rec 3.] Generate new Swarm Product from ASM 250 Hz Burst mode science data.	Ongoing	IPGP have processed all the available Burst mode data and made them available to ESA and DISC for further validation. Soon such dataset will be made available to all the Swarm community.
	[DQW8_Rec 4.] Produce a new Swarm STR L1B “particle flux” product	Ongoing	Action on DTU-MI. A paper containing the description of the “Particle flux” product is currently under preparation. As soon as it is finished with be shared with ESA.
	[DQW8_Rec 5.] Implement a Time-jitter correction in the MAGNET processor to remove systematic spikes in ASM power spectrum	On-hold	Action on DTU. Activity put on hold.
	[DQW8_Rec 6.] Test the improvement that can be obtained by the use of POD rather than MODx_SC_1B as input positions for MAGx_.._1B	Done	Action completed. C. Siemes perform such investigation. By replacing the MOD with POD a difference of max 10-20 cm in the position was obtained. I.e., no improvement in mag data is expected. Action closed.
	[DQW8_Rec 7.] Use the ASM correction model to investigate impacts on field modelling (external fields).	Done	DTU performed this investigation and confirmed the new ASM correction model do not have any impact on core field, on data misfit, on quite time magnetospheric estimations. This model instead slightly impacts the Euler angles.
	[DQW9_Rec 1.] In case of reprocessing POD data to be used as input for magnetic data processing	Ongoing	L1B MAGNET processor adapted to read as input, when available, POD (SP3_COM) files. Implementation currently under validation. This functionality will be used during the upcoming 2nd Swarm L1B data full reprocessing campaign.
	[DQW9_Rec 2.] Move MGF comparison model to CHAOS	Done	The MGF comparison wrt Chaos-7 model has been implemented. Such change has reduced drastically the residuals.
	[DQW9_Rec 3.] Create a Level 1b product of Cassiope spacecraft house -keeping data to aid with MGF calibration	Done	The L1B Cassiope products have been created as Swarm-like product. The consistency has been tested using the ingestion on Vires.
	[DQW9_Rec 4.] MGF output products to be in a CDF format similar to Swarm A/B/C products. Consider having daily files for both 1 Hz and 160 Hz products.	Ongoing	Activity on track via the MGF team meeting.
	[DQW10_Rec1.] IPGP to validate the dB_Sun_ASM correction model proposed by DTU	Ongoing	
	[DQW10_Rec2.] DTU to consolidate the new dB_Sun correction model and transfer it into operations.	Ongoing	
Electric Field	[DQW8_Rec 8.] To implement a new firmware to adopt an updated version of the TII automatic gain control, and to download TII images at higher	Ongoing	Tests on the AGC functioning and firmware are ongoing. Frequent updates on these activities during the TII-ARBs. We are working to get the EFI engineering qualification model shipped to Calgary to support TII testing and software

		frequencies (16 Hz). During such high frequency TII acquisitions, the number of pixels can be reduced to 32, instead of 64, in order to limit telemetry problems.		development. The higher-rate imagery modifications are not going to be implemented soon, as the software changes will be substantial.
		[DQW8_Rec 9.] To implement new tests for LP bias, with higher voltages (+5V).	Done	Sweep cycle mode tests have been performed together with other tests (FP bias, Ne computed via electron current). Data are currently on IRF database, TBD if they will disseminate those via ESA's dissemination server.
		[DQW8_Rec 10.] To define a new e-POP science mode in order to collect data during conjunctions with Swarm that would allow cross-calibration of cross track plasma velocity between the two spacecraft.	Done	e-POP IRM data will be reprocessed and delivered to the EFI community for joint Cal/Val activities. A first meeting between Swarm/e-PoP teams took place and it was agreed to share the list of spacecraft conjunctions, but it is too early to plan further joint activities.
		[DQW9_Rec 5.] To release new cross-track velocity dataset TIICT 0201 with latest improved calibration	Done	After the yaw and pitch tests, the calibration coefficients have been updated and the new TIICT 0301 dataset has been delivered for all the Swarm spacecraft, covering from Dec 2013 to June 2020 at 2 Hz and 16Hz .
		[DQW9_Rec 6.] Release of the new dataset TIIVI 0101 (3D flows) with quality info in the Flags.	Done	The dataset has been already validated via comparison with DMSP data and Weimer 2005 model. Action completed as a revision on the cross-track flow dataset, which is now at revision 0302, and covers 10 December 2013 through 11 September 2020 for all three satellites. Quality flags have been revised and extended to include more information about the quality of the data processing. The next step will be to keep providing 0302 data at regular intervals (1 week to 1 month, say). Then we would like to have feedback and recommendations from users on the TII ion drift data quality.
		[DQW9_Rec 7.] To improve the computation of the electron density.	Ongoing	Since the DQW#9, 6 meetings took place to discuss these and other LP anomalies. SB showed comparison of different method to estimate the Ne density. The faster way to have better results is to compare the EFIx_LP_1B data with the Faceplate dataset. This suggestion has been passed to the user with a note on the data quality page. Further investigations are on-going.
		[DQW9_Rec 8.] To make a complete statistical analysis from BOM to characterize the evolution of the EFI L1B data quality and related anomalies to identify possible improvements.	Done	The Review of the Swarm L1B data quality has been published. The document describes the past issues, recent achievements, and future objectives.
		[DQW10_Rec3.] To include the TIICT dataset in the ViRes platform	Open	To contact the ViRes Team and check the info that they need in order to include the TIICT dataset in the ViRes platform.
		[DQW10_Rec4.] To analyse the data as outcome of the LP bias setting tests (See [DQW8_Rec9].)	Open	The dataset is currently stored in the IRFU server. Action on IRF to perform that analysis.
GPS and ACC	ACC data	[DQW8_Rec 11.] Release to users the Swarm C along-track accelerations covering the period from May to November 2016	Done	
		[DQW8_Rec 12.] Continue to correct Swarm C along-track accelerometer data. Focus next on Swarm C cross-track accelerometer data of the second half of 2014 (motivations: large signals at beginning of mission; no large manoeuvres; Swarm C at lower altitude; 1 Hz GPS receiver data available).	Done	Swarm C along-track processing is current now and focus will remain on this. Experimental dataset of calibrated Swarm C cross-track accelerations was produced and published. Swarm A along-track acceleration data was calibrated and compared to Swarm C. Since the signal content appears to be identical and the noise level as well as the artefacts are twice as worse compared to Swarm C, the additional value of Swarm A accelerometer data is being able to distinguish better between signals and artefacts features in Swarm C acceleration data.

		[DQW8_Rec 13.] Improve the flagging and daily quality index of the ACCxCAL data products.	Ongoing	Some improvements were implemented after the discussions at DQW#8. However, this should be considered a standing recommendation.
		[DQW8_Rec 14.] Implement geophysical meaningful sanity checks based on presence of gravity waves (statistics with respect to latitude, local time, solar and geomagnetic activity, season, plasma bubbles, day/night side, etc.) that help to assess the quality of ACCxCAL data products before release.	Ongoing	Prototype for sanity check at eclipse transitions based on model radiation pressure signal (ACCx_FMi2 product) was implemented. Transition to operations is pending,
		[DQW9_Rec 9.] Release as much calibrated Swarm accelerometer data as possible, i.e. also fractions of days when part of the day is judged to be not usable	Done	Implemented in the disseminations since DQW#9.
		[DQW10_Rec 5] Check cut-off in mass density variations	Open	The assessment of mass density data showed that variations appear to be truncated at a threshold. This needs to be cross-checked independently.
		[DQW10_Rec 6] Investigate dependency of density observations on errors in the concentration of Helium in thermosphere models.	Open	Observations of mass density rely on the atmospheric composition derived from density models. Often NRLMSISE is used, which overestimates density during solar minimum conditions. Thus, there could be bias in the composition, which leads to a bias in the mass density observations. In particular the concentration of Helium could be important as it may change the effective aerodynamic coefficient.
	A/B/C GPS	[DQW8_Rec 15.] Exploit integer ambiguity fixing when determining the non-gravitational acceleration from GPS receiver data.	Open	This is still on our list of future improvements. For the precise orbit, the activity was initiated.
		[DQW10_Rec 7] Make RINEX observation and precise orbit (SP3) files of AIUB with an empirical correction for L2 phase observations available in a dedicated folder on the Swarm ftp.	Open	The Astronomical Institute of the University of Bern (AIUB) produced RINEX observation files, which are corrected for an artefact resulting from the L2 PLL. Further, improved precise kinematic orbits were produced. The files should be distributed to other users, in particular all groups producing precise orbits and gravity field models, via the Swarm ftp in a dedicated folder.
		[DQW10_Rec 8] Distribute all files needed for generating mass density observations in near real-time and develop a near real-time mass density observations product, to be distributed also in near real-time.	Open	Operational orbit prediction is expected to benefit from near real-time mass density observations, which can be assimilated in density models. All required input files need to be made available in near real-time. A near real-time mass density product needs to be developed.
	E GAP	[DQW8_Rec 16.] Maximize the duty cycle of the GAP-A instrument; noting that one receiver at a 0.1 Hz data rate is sufficient.	Done	CASSIOPE team implemented onboard procedure to maximize the duty cycle.
		[DQW8_Rec 17.] Make star tracker data available and try to collect star tracker data when GAP data is collected, noting accurate spacecraft attitude data is needed for macro models (radiation pressure modelling, etc.).	Done	See technical note ESA-EOPSM-SWRM-TN-3487 (the tech note should be placed on the Swarm webpage when we decided to make available the data)
		[DQW8_Rec 18.] Collect GAP-A data once per orbit, preferably at low altitudes (high drag signal) and also some at apogee (constrains orbit)	Done	Satisfied with the improved GAP duty cycle.

		[DQW8_Rec 19.] Avoid too much segmentation of GAP-A data (ambiguity fixing, etc.) and data gaps longer than one orbit (accuracy gets much worse for long interpolations).	Done	Satisfied with the improved GAP duty cycle.
		[DQW8_Rec 20.] Determine the GPS antenna phase center location with respect to the spacecraft CoM (from documentation, verify with in-flight data), which should be used conventionally by all groups performing precise orbit determination for Swarm E.	Done	Work completed by O. Montenbruck, A. Hauschild, and R. Langley. Submitted a paper recently to GPS Solutions.
		[DQW8_Rec 21.] Determine GPS antenna phase center variations with respect to the antenna phase center location for Swarm E, potentially supported by dedicated campaigns GPS antenna calibration.	Done	Work completed by O. Montenbruck, A. Hauschild, and R. Langley. Submitted a paper recently to GPS Solutions.
		[DQW8_Rec 22.] Focus first on precise orbit determination for Swarm E and assess the feasibility of the determination of neutral density at a later stage.	Ongoing	Precise orbits are available for 2018 and 2019. CASSIOPE team is implemented precise orbit determination. Feasibility of thermosphere mass density not assessed.
		[DQW9_Rec 10.] Make the new CASSIOPE orbit and attitude data available on Swarm dissemination server	Done	POD Cassiope product available for the year 2019 in the Swarm dissemination server.
		[DQW9_Rec 11.] Place technical note on CASSIOPE attitude determination on Swarm webpage	Done	TN has been published in the Swarm webpage (see here)
		[DQW9_Rec 12.] Extension of [DQW8_Rec 23.] and [DQW8_Rec 24.] towards the use of platform magnetometer data.	Ongoing	GVO dataset to be released.
Internal Fields		[DQW8_Rec 23.] Generate and distribute Swarm-based VO products	Done	Geomagnetic Virtual Observatories (GVO) DISC project started in June 2019 to derive monthly and 4-monthly magnetic field values at satellite altitude on an equally spaced grid of 300 points. First GVO data products will be published in June 2020.
		[DQW8_Rec 24.] Develop new data processing/ modelling approaches using Swarm data to get better mantle conductivity models and understanding of core dynamics on sub-decadal timescale.	Ongoing	ESA STSE Project "4D core" has been kicked off Swarm DISC ITT on "Internal strength of magnetic field in core from quasi-geostrophic model of core dynamic" was opened. This recommendation was extended into DQW9_Rec 12.
		[DQW8_Rec 25.] Justify rationale for 3D Earth approach using Swarm data	Done	Irrelevant recommendation.
		[DQW9_Rec 12.] Extension of [DQW8_Rec 23.] and [DQW8_Rec 24.] towards the use of platform magnetometer data.	Ongoing	The Swarm DISC GVO project was successfully completed in June 2020, GVO products are now operational. No bid was accepted for the DISC ITT on ""Internal strength of magnetic field in core from quasi-geostrophic model of core dynamics". 4D core project is beginning to use GVO products for core flow determination and work on core dynamics models is ongoing. CryoSat-2 and Grace data have been used for internal field studies, but further calibration efforts needed on Grace.
		[DQW10_Rec9] Investigate annual signals in GVO series	Open	
		[DQW10_Rec 10] Explore more realistic prior information for	Open	

	external fields, to be used in field modelling for example in the MCM model of Lesur and co-workers		
	[DQW10_Rec 11] Further studies of merging satellite and near-surface data, exploring band-limiting of near-surface data, in the extended dedicated crustal field product	Open	
	[DQW10_Rec 12] Clarify difference between ground and satellite Q-matrix in induction studies for mantle conductivity	Open	
	[DQW10_Rec 13] Continue efforts to calibrate platform magnetometers, using house-keeping data if possible (e.g. GRACE), to aid induction studies	Open	
	[DQW10_Rec 14] VRE-based dashboards for exploring ground observatory data and magnetic field models	Open	
External Fields	[DQW8_Rec 26.] Update the Swarm cross-track velocity data archive with a quality flag characterizing the intensity of along-track velocities	Done	The quality Flag of the TIICT have been reviewed and updated in agreement with this Rec (see related TN).
	[DQW8_Rec 27.] Improve the description on the linkage of electron density and TEC fluctuation rates to GNSS phase and amplitude scintillations to further enhance the use of Swarm for space weather applications	Done	See presentations by L. Schreiter at DQW#9.
	[DQW8_Rec 28.] Develop a well-documented toolbox to facilitate wider usage of innovative methods for Swarm-based FAC determinations.	Ongoing	Python Jupyter notebook version swarmpyfac of Swarm L2 FAC single processor developed by DISC. Available on github (https://github.com/Swarm-DISC/SwarmPyFAC) and on Swarm VRE Another Python package for FAC calculation is under development by ISS, in the context of SIFACIT project. The first toolbox for computing the FAC with three s/c method is completed, and the team is now working on the second package to automatically identify the conjunctions at auroral latitude among the three s/c.
	[DQW10_Rec 15] Expand the number of products for space science and space weather. e.g., by combination of different parameters (B, Ne, E, TEC, …) and multi-mission approach	Ongoing	
Space physics and weather applications	[DQW9_Rec 13.] Further analyse and investigate LP based Te and Ne features potentially impacted by instrumental issues.	Ongoing	Discussed in DQW#9 session7. But this recommendation is more related to the E-field instrument (i.e. DQW#9 session 3).
	[DQW9_Rec 14.] Investigate the potential use of vertical velocity measured by EISCAT radars for the calibration of Swarm TII data.	Done	This activity consisted on the identification of 15 conjunction events among EISCAT radar and Swarm Alpha when TII was measuring good quality science data. Among these events, after the verification of good velocity data measured by EISCAT, a subset of 12 events have been selected, delivered to TII team, and illustrated to them in a number of dedicated meetings. The TII team will consider these events when they will focus on calibration of vertical cross track velocity component.

	[DQW10_Rec 16] Investigate the potential of Swarm for Space Weather research and application	Open	
	[DQW10_Rec 17] Evaluate the potential of fast access of Swarm data with respect to reduced processing time and/or more frequent download	Open	A table of specific requirements is prepared at https://docs.google.com/spreadsheets/d/1-fr5z_DA_5-vRDqRrKAtWaqHqRjKSwqjaigGGA7IhXc/edit#gid=0
Swarm - CSES Synergies	[DQW8_Rec 29.] Foster collaboration between CSES and Swarm expert teams for cross-calibration and validation activities.	Ongoing	Dedicated magnet and plasma cal/val core teams have been established, resulting in already three dedicated joint papers published with the magnet cal/val core team (Yang et al., EPS, 2020; Yang et al., JGR Space Physics, in revision; Wang et al., Science China Technological Sciences, 2020) and already three papers published with the plasma cal/val core team (Huang et al. JGR-Space Physics, 2020; Yan et al., et al. JGR-Space Physics, 2020; Piersanti et al., Advances in Space Research, 2020). Results of both groups have progressively been presented at the 3rd CSES workshop in Beijing (November 2018), at a joint CNSA-ESA Earth Observation Workgroup Meeting in Changsha (April 2019), at the Living Planet Symposium in Milan (May 2019), at the 9th Swarm Data Quality Meeting in Prague (September 2019) and at the 4th International Workshop of CSES mission in Changsha October 2019) and at this SDQW#10 (5-9 October 2020). In addition, an ISSI-BJ Team on "The electromagnetic data validation and scientific research based on CSES satellite", has been set-up, which already met once in November 2019 in Beijing, and an independent proposal was successfully included in the Dragon-5 project, approved in June 2020 and kicked-off in July 2020.
	[DQW8_Rec 30.] Make available appropriate level of CSES data to Swarm experts for starting such activities to as soon as possible.	Ongoing	Two sides initially shared specific level data according to specific calibration tasks and scientific interests for Swarm-CSES synergies. Efforts have recently (after SQW#10) resumed and is ongoing to ensure transfer of all CSES HPM Level-2 data files currently available to an ESA ftp site easily accessible to the ESA partners.
	[DQW9_Rec 15.] Organise a joint CSES-Swarm Data Quality or Science workshop	Ongoing	As stated above, several sessions have been organized, and an ISSI-BJ science team set-up. A new meeting of this ISSI-BJ science team is to be organized.
	[DQW10_Rec 18] CSES-Swarm collaboration: Coordinate activities of Swarm DISC, ISSI-BJ science team and proposal included in the Dragon-5 project (also clarifying what can be funded by the Dragon-5 program), to ensure full advantage is taken of both tools (also ensuring possibility of mixed "physical" and "remote" attendance). Collaborate further on improving data CAL/VAL. Ensure the possibility of long-enough cross-visits for spending significant joint working time in same location, for allowing quick exchange of practical (hence critical) information.	Open	
	[DQW10_Rec 19] CSES data: Streamline CSES data access to make all of them (not only HPM FGM2 data, but data from all payloads) accessible from outside China, including auxiliary data, by e.g. using ESA ftp site (as is currently done for HPM data). Provide relevant	Open	

	documentation (file format, data content, etc...) in English.		
	[DQW10_Rec 20] CSES data: Produce and provide high-latitude (above 65° latitudes) HPM scalar data (at least).	Open	
Swarm - Echo	[DQW8_Rec 31.] Update data format of new MAG and GAP Swarm Echo products to better match with Swarm L1b and L2 data product formats	Ongoing	MAG data products has been improved using enhanced attitude information provided by Ch. Siemes. Results for 2018 are currently exploited. See also [DQW9_Rec 3.][DQW9_Rec 4.]
	[DQW8_Rec 32.] Coordinate Swarm Echo and Swarm A/B/C activities regarding data cross-calibration and scientific validation	Ongoing	. See also [DQW9_Rec 3.][DQW9_Rec 4.]
	[DQW9_Rec 16.] e-POP related data quality status should be now reported into Swarm L1B data sessions.	Done	As full member of Swarm family, presentation and discussion on e-POP data quality already was done in session 1, 2 and 3 of Swarm DQW#9.
Swarm and Multi-mission Synergies	[DQW8_Rec 33.] Structure a "Magnetometer calibration expert group" and organise a workshop on "Multi-mission data calibration and application" (about 6 month after the SDQW#8) for identification and coordination of the multi-mission potential and corresponding formulation of needs and procedures.	Done	A dedicated workshop has been conducted on May 21-23, 2019 in Potsdam. A special issue is open in EPS: https://www.springeropen.com/collections/leo
	[DQW8_Rec 34.] Foster cooperation and exchange experience between ACC data processing experts from GRACE-FO & Swarm missions	Done	C. Siemes analysed a sample dataset from GRACE-FO and provided feedback in form of a document to the GRACE-FO team.
	[DQW8_Rec 35.] Develop multi-mission, consistent, reliable, and well-calibrate multi-mission datasets to address key scientific challenges related to upper atmosphere "climate" trend analysis, studies of longer-term secular variation vs solar cycle effects, quantification of energy transports by waves and other phenomena.	Ongoing	Multi-mission ionospheric data (TEC and Ne of CHAMP, GRACE, GRACE-FO) currently developed in DISC TIRO. New DISC call open for generation of thermospheric data of GRACE or similar missions. GOCE TEC data is openly published at http://eo-virtual-archive1.esa.int/GOCE-Thermosphere.html, first results were presented at DQW#8. Synergies between Swarm and Sentinel's TEC presented at Swarm DQW #9.
	[DQW9_Rec 17.] The Swarm DQW#8 Rec.34 to Rec.39 have been replaced by the new Rec i.e., [DQW9_Rec 18.] - [DQW9_Rec 23.], here below	Done	
	[DQW9_Rec 18.] Exploit needs and new research opportunities from multi-mission approaches in the areas of core field evolution, mantle conductivity, ionosphere-atmosphere, ionosphere-magnetosphere, and thermosphere-atmosphere coupling, climate trends, geodesy, and gravity, among others.	Ongoing	
	[DQW9_Rec 19.] Prepare and provide calibrated data of (platform) satellite magnetometers in support for Swarm. These data may include those from ESA missions (Aeolus, Cryosat-2, GOCE, e-POP, Sentinels, …), new missions (Daedalus, SMILE, Macao, NanoMagSat, …),	Ongoing	Fully calibrated Cryosat-2 magnetic data for August 2010 to December 2018 available as daily CDF files at Swarm PDGS (ftp://swarm-diss.eo.esa.int/%23CryoSat-2) Fully calibrated GRACE-FO magnetic data available from the start of the mission until October 2020 and continuously updated at ftp://isdcftp.gfz-potsdam.de/grace-fo/MAGNETIC_FIELD/0201/

	none-ESA scientific missions (DMSP, GRACE, GRACE-FO, …), and commercial missions (AMPERE, SPIRE, …). It is aimed that these data are provided in daily CDF files (time, position, calibrated B_FGM, STR data, B_NEC, flags, …) and available to the scientific community.		Peer-reviewed papers collected in a special issue at EPS: https://www.springeropen.com/collections/leo
	[DQW9_Rec 20.] Continue effort in expert group for "Multi-mission data calibration and application": Compile a peer-review publication describing data products and calibration process, and several publications on the multi-mission potential and applications in a special issue.	Ongoing	An article describing data product and calibration processes of magnetic LEO data is expected to be a contribution of the special issue with submission deadline in 2020: https://www.springeropen.com/collections/leo
	[DQW9_Rec 21.] Further investigate new data sources (e.g., platform magnetometers) to fill the gap between CHAMP and Swarm	Ongoing	See [DQW9_Rec 19.] Several articles collected in https://www.springeropen.com/collections/leo
	[DQW9_Rec 22.] Enhance the potential synergy of thermosphere – ionosphere data of Swarm and other satellite missions, such as GRACE(-FO), Sentinels, e-POP, SPIRE, …).	Ongoing	Multi-mission ionspheric data (TEC and Ne of CHAMP, GRACE, GRACE-FO) currently developped in DISC TIRO. New DISC call open for generation of thermospheric data of GRACE or simiar missions. GOCE TEC data is available at http://eo-virtual-archive1.esa.int/GOCE-Thermosphere.html, first results were presented at DQW#8. Synergies between Swarm and Sentinel's TEC presented at Swarm DQW #9.
	[DQW9_Rec 23.] Investigate new funding schemes enabling consistent calibrations of multimission data.	Open	
	[DQW10_Rec 21] Combine magnetic observations from LEO satellites (dedicated and platform) distributed at different local times to characterise the asymmetry of the magnetospheric ring current signal, and for induction studies.	Ongoing	
	[DQW#10_Rec22] Express strong support for exciting contribution Daedalus mission can make to lithospheric studies	Open	
Swarm SPACE4.0I, Data Visualization and Analysis	[DQW8_Rec 36.] Provide lessons learned from the Swarm community to the Daedalus MAG	Ongoing	
	[DQW8_Rec 37.] Investigate whether the science objectives of Daedalus could be broadened to Swarm areas of science	Ongoing	
	[DQW8_Rec 38.] Enhance the use of Machine Learning / AI methods applied to emerging Swarm Data applications	Ongoing	The Machine Learning approach has been adopted recently by Papadimitriou for automatic detection of ULF waves in Swarm data. Moreover, Yaxin Bi adopted a Deep Learning approach for Anomaly detection. In addition, in ESRIN Phi-Lab is applying a supervised Machine Learning approach to investigate the possible relation of some magnetic perturbation measured by Swarm with Earthquake activity on Earth. This study is currently ongoing.
	[DQW8_Rec 39.] Make easier the access / manipulation of Swarm data	Ongoing	Initial version of Swarm VRE will be open at Swarm DQW#9

	and facilitate collaborations via the development of VRE		
	[DQW8_Rec 40.] Redesign and improve the content of the Swarm website to make it fully align with the scientific community expectations	Ongoing	The Swarm DISC team is intensively working on improvements and extension of scientific information provided for the Swarm mission. In parallel the Swarm DISC team working in close collaboration with ESA EO web team on the design and content of the new ESA EO website (will be updated for all missions). The launch of the new website occurred in April 2020. However, many other changes/updates will be introduced later in time, as already agreed with the ESA EO team.

APPENDIX- I : SDQW#10 AGENDA

Day 1	**Monday 05/10/2020**		
		Session 1: Mission overview	**Chairs: Anja Stromme & Jerome Bouffard**
10:00	10:20	Swarm status overview and plans for the extended mission	Anja Stromme
10:20	10:40	Swarm Data Quality Status and DQW objectives	Jerome Bouffard
10:40	11:00	Swarm after almost seven years in space	Nils Olsen
11:00	11:30	Coffee break	
11:30	11:50	Flight Operations Segment Status	Ignacio Clerigo
11:50	12:10	PDGS status update	Antonio de la Fuente
12:10	12:30	Constellation status of the Swarm mission	Detlef Sieg
12:30	13:00	**Discussion**	
13:00	**14:00**	**Lunch**	
		Session 2: Magnetic field measurements	**Chair: Enkelejda Qamili**
14:00	14:30	Magnetic package instruments and processors	Enkelejda Qamili
14:30	15:00	Simulations of magnetic field disturbance at the ASM and VFM locations	Gabriela Blaga
15:00	15:30	Testing Models of dB_Sun for ASM and VFM	Lars Toffner-Clausen
15:30	16:00	Coffee break	
16:00	16:30	ASM 250 Hz burst science data	Pierdavide Coïsson
16:30	17:00	ASM burst data whistlers characterisation	Pierdavide Coïsson
17:00	17:30	Updates on the Swarm-Echo Magnetic Field Data product	David Miles & Martin Rother
17:30	18:00	***Discussion and Recommendations***	

Day 2	**Tuesday 06/10/2020**		
10:00	12:00	**Webinar on VirES + VRE status** **https://hackmd.io/@swarm/vre-webinar/%2F%40swarm%2Fvre-webinar-plan**	Martin Paces & Ashley Smith
		Lunch	
		Session 3: Electric field measurements	**Chair: Filomena Catapano**
14:00	14:30	Electric field instrument and processor	Filomena Catapano
14:30	15:00	The Swarm LPs, status, data, and developments	Stephan Buchert
15:00	15:30	Te spike-trains in Swarm LP data: Results of the statistical study	Matthias Forster
15:30	16:00	Coffee break	
16:00	16:30	Calibration and validation of EFI TII cross-track flow data	Johnathan Burchill
16:30	17:00	Recent insights into high-latitude electrodynamics from Swarm EFI and ePOP SEI	David Knudsen
17:00	17:30	High-Cadence Plasma Current and Ion Time-of-Flight Data from Swarm-E IRM for Plasma Irregularities and Magnetosphere-Ionosphere Coupling Studies	Andrew Yau
17:30	18:00	***Discussion and Recommendations***	

Day 3	**Wednesday 07/10/2020**		
		No session in the morning	
		Lunch	
		Session 4: GPSR and accelerometer	**Chair: Christian Siemes**
14:00	14:30	GPS and accelerometer instrument and data status	Christian Siemes
14:30	15:00	Accelerometer data processing	Sergiy Svitlov
15:00	15:30	Swarm precise orbits and density	Jose van den Ijssel
15:30	16:00	Evaluation of Swarm densities	Sean Bruinsma
16:00	16:30	Coffee break	
16:30	17:00	L2 bandwidth correction for the Swarm Satellites	Lucas Schreiter
17:00	17:30	Precise orbit determination, medium accuracy orbit determination, topside TEC, and small-scale ionospheric scintillation (Swarm-E GAP)	Andrew Howarth
17:30	18:00	Multi-approach gravity field models from Swarm GPS data	João Encarnação
18:00	18:30	***Discussion and Recommendations***	

Day 4	**Thursday 08/10/2020**		
		Session 5: Advanced products: Internal field	**Chair: Chris Finlay**
10:00	10:15	Geomagnetic Virtual Observatory data product	Chris Finlay
10:15	10:30	4D Earth: Probing core dynamics with Swarm data	Nicolas Gillet
10:30	10.45	Sequential modelling of the Earth's core magnetic field	Vincent Lesur/ Guillaume Ropp
10:45	11:00	Evaluation of the dedicated magnetospheric field product (MMA_SHA) for mantle induction studies	Alexander Grayver
11:00	11:30	Coffee break	
11:30	11:50	Merging satellite and near surface lithospheric field datasets	Erwan Thébault
11:50	12:10	Satellites in support of "Internal Field" Swarm Science - GRACE platform magnetometer data and lithospheric fieldmodelling using proposed EOP Daedalus satellite	Nils Olsen
12:10	12:30	VirES and VRE status: Demo on Internal Field	Martin Paces / Ashley Smith
12:30	**14:00**	**Lunch**	
		Session 6: Advanced products: External field	**Chair: Claudia Stolle**
14:00	14:20	Auroral Electrojet and auroral Boundaries estimated from Swarm observations (AEBS data products)	Kirsti Kauristie
14:20	15:40	Plasmapause Related boundaries in the topside Ionosphere as derived from Swarm Measurements (PRISM data products)	Balázs Heilig
15:40	15:00	Swarm Ion Temperature Estimation (SITE data products)	Levan Lomidze
15:00	15:30	Coffee break	
15:30	15:50	Ionospheric Plasma IRregularities (IPIR data products)	Wojciech Miloch
15:50	16:10	Exploring Earth's magnetic environment with GRACE-FO and Topside Ionosphere Radio Observations from multiple LEO-missions (TIRO)	Claudia Stolle
16:10	16:30	VirES and VRE: Demo on External Field	Ashley Smith / Martin Paces
16:30	17:00	***Discussion and Recommendations***	

Day 5	Friday 09/10/2020		
		Session 7: Swarm CSES joined meeting	**Chairs: G. Hulot & Z. Zhima**
10:00	10:20	The latest results and status of CSES mission	Zeren Zhima
10:20	10:40	Swarm - CSES joined activities on MAGNET	Gauthier Hulot
10:40	11:00	CSES High Precision Magnetometer Data Products and Example Study of an Intense Geomagnetic Storm	Yanyan Yang
11:00	11:20	Coffee break	
11:20	11:40	Swarm - CSES joined activities on PLASMA	Chao Xiong
11:40	12:00	The regional lithospheric magnetic anomaly	Jie Wang
12:00	12:30	***Discussion and Recommendations***	
12:30	**14:00**	**Lunch**	
		Session 8: Summaries, Recommendations & Future	**Chair: Jerome Bouffard**
14:00	14:30	Open discussion on Swarm constellation evolution	Detlef Sieg
14:30	14:40	Summary & Recommendation session 2	Enkelejda Qamili
14:40	14:50	Summary & Recommendations session 3	Filomena Catapano
14:50	15:00	Summary & Recommendations session 4	Christian Siemes
15:00	15:10	Summary & Recommendations session 5	Chris Finlay
15:10	15:20	Summary & Recommendations session 6	Claudia Stolle
15:20	15:30	Summary & Recommendations session 7	Gauthier Hulot & Zeren Zhima
15:30	16:00	**Swarm DQW#10 summary & conclusions**	Anja Stromme & Jerome Bouffard