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The 9th Swarm Data Quality Workshop

Summary and Recommendations Report

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WORKSHOP HIGHLIGTHS

- The 9th Swarm Data Quality Workshop (SDQW#9) held in the Faculty of Civil Engineering of the Czech Technical University of Prague, from 16th to 20th September 2019
- The Swarm DQW#9 was successful, with more than 130 EU and non-EU participants, 110 talks, 11 sessions and numerous discussions.
- The workshop has allowed to:
  - Provide an overview of Swarm Mission Status and future plans
  - Discuss on Swarm data quality status, correction improvements (e.g. new ASM and VFM dB_Sun models) and evolutions
  - Present progress in Swarm-based visualization tools and data processing approaches from virtual research environment
  - Discuss with the Swarm community on the future of the satellite constellation regarding the counter rotating orbit configuration in 2021
- The Swarm DQW#9 was an occasion to discuss synergetic benefits obtained from other sensor systems through future cooperation with the ESA Science Directorate and partner agencies.
- A dedicated session on Swarm / Chinese CSES mission synergies was organized for the second time to further structure future joint Cal-Val activities and scientific cooperation.
- The Swarm DQW#9 has allowed to consolidate/update 40 recommendations from the SDQW#8 as well as to identify 23 new SDQW#9 recommendations
- These 63 DQW commendations will be used to refine the roadmap for future Swarm product evolutions, services, ESA/DISC ITTs and science activities.
- The next Swarm DQW should held in NOA (Athens, Greece) from 05th to 09th October 2020.

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1 CONTEXT AND MEETING SCOPE

ESA and the Swarm Data quality team organize once a year a meeting inviting Swarm multi-disciplinary scientists and instruments' experts (see **Appendix I**) with the objective to listen their view and collect innovative ideas for future Swarm-based activities and products, targeting new processing algorithms, correction improvements, emerging applications and multi-mission synergy. The SDQW#9 was hosted by the Faculty of Civil Engineering of the Czech Technical University of Prague, from 16th (start at 1pm) to 20th (finish at 1pm) September.

The scope of this document - mainly based on contributions from SDQW#9 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#9 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 in view of reshaping the content of the Swarm data product portfolio, in identifying new services potentially based on an enhanced synergy with other satellite mission. 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#9 was structured in 11 sessions including large time slots for discussions and brainstorming (see detailed agenda in **Appendix II**):

- Session 01: Mission overview
- Session 02: Magnetic field measurements
- Session 03: Electric field measurements
- Session 04: GPSR and accelerometer measurements
- Session 05: Advance products for Internal Fields
- Session 06: Advance products for External Fields
- Session 07: Swarm products for Space Weather/ Space Physics
- Session 08: Multi-mission Synergies
- Session 09: Highlights on Swarm-CSES synergies
- Session 10: Data processing Analysis and Visualization
- Session 11: Summary and Conclusions

All the SDQW#9 presentations are available at:
https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/activities/conferences/9th-data-quality-workshop

2 SESSION SUMMARY

2.1 Introduction

During the mission overview session, Swarm ESA and DISC teams introduced first the Mission Status, the meeting objectives and provided a brief overview of Swarm data portfolio and characteristics, allowing to address a growing number of scientific challenges and operational applications. After 6 years in space, the satellites are in excellent shape and are ready for a continuation of several more years. The status of the mission remains green, regarding both Platforms, Payload systems, data quality and PDGS infrastructures. To enable full exploitation of the Swarm constellation, the processing algorithms as well as the ground and flight operating segments are constantly being improved, taking advantage of experience gained by ESA and the Swarm user community as the mission progresses. Thanks to these joint efforts, the Swarm mission has already achieved remarkable scientific results and has opened 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-Echos 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#9 was dedicated to the data quality status of the Magnetic package instruments on-board the Swarm spacecrafts, 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. During the last year, no change was introduced in the L1B data processing chain, which continues to produce magnetic field data with the product baseline and file counter number 0505. This version is being used to generate reference magnetic field models of internal and external origin (i.e. Swarm L2 products and other models) confirming the excellent health of Magnetic package instruments and the very high quality of associated L1B magnetic data.

Concerning the STR, an increase of frequency from 1 Hz to 2 Hz was introduced for Swarm Alpha on 12/12/2018, for Swarm Bravo on 17/10/2018 and for Swarm Charlie on 18/12/2018. Tests performed on-ground show an improved performance of 2Hz STR pointing measurements. An update of STR_q_CHU was therefore introduced in L1B processing chain in order to bring the CHU frames after the switch to 2Hz into the CHU frames before the switch (i.e. no Euler Angle update was needed). The IBA (Inter Boresight Angles) correction model was also introduced 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. A test campaign was performed by an industrial consortium led by AIRBUS to understand the root cause of temperature-dependent CHU boresight variations and to check if in-orbit distortions are caused by supporting structure or appendences (e.g. harness etc). However further investigations are needed as the tests were unable to reproduce the in-orbit values. Moreover, since March 2018, the STR instruments on-board the three Swarm spacecraft operate as particle detector (through counting of hotspots). The first results are very promising, showing a clear day/night and east/west flux differences. As soon as a consolidated processing procedure is established, the generation of particle flux will be implemented in the operational L1B data processing chain.

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, i.e., s_t, needs to be slightly adjusted. As soon as this update will be introduced in operations, a regeneration of MAG data for the affected period is recommended. On sun-induced disturbance field, it is known from on-ground tests, that thermoelectric currents in the pigtail grounding-wires are the most probable cause for the disturbance observed in-flight. From the same tests it appears that not only the VFM instrument is affected by such disturbance but also probably the ASM.

An expert group is working to build a physical-based correction model for the ASM instrument, considering all the outcomes coming from these ground tests and also taking advantage of some periods when Swarm spacecraft was flying not in the nominal direction (i.e., during manoeuvres). As reported during this session, we now have a better understanding of ASM blanket configuration. Moreover, the different teams involved in this investigation have performed independent simulations and the outcomes are consistent. Linked to this activity, there is another investigation on-going in order to simulate the magnetic field induced by the thermal blanket configuration at the ASM location by considering the properties and geometry of the thermal blanket and grounding wiring configuration. The first outcome of this study confirms that there is a preferred direction for the magnetic field disturbance at the ASM location in the Y-direction.

Since the beginning of the mission, the ASM instruments have simultaneously produced vector data (ASM-V) that are independent from the core L1b VFM data. An improved ASM-V dataset was generated and now ready to be distributed through ESA ftp server to all the Swarm users. It is worth noticing that there is a growing interest on having the ASM instruments on-board Swarm Alpha and Bravo set in Burst mode more frequently, i.e., scalar measurements at 250 Hz frequency rate. To this aim, few ASM Burst sessions of 1-week were performed over the last year. All corresponding ASM 250 Hz science data have been processed and will be distributed by ESA to all the Swarm users.

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. While the combination of improved attitude data and the use of a new reference model have improved quality of MGF data. In parallel, the Swarm DISC have tried to improve the calibration of the MGF data (year 2018 as first TDS) and obtained positive results. It was agreed to implement the same calibration procedure in the Swarm Echo magnetic data processing chain.

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 well albeit still with restricted orbital coverage. The discussions during this session were very fruitful, leading to several recommendations and to the definition of an action plan for further improving the quality of the Swarm EFI-based data.

Since December 2018, the LPs gain mode has been swapped. The Probe 1 is operating in high-gain mode, and Probe 2 is operating in low-gain mode. The status of the LP instrument is nominal. Currently, we are in the minimum of the solar activity, thus the measured electron density is lower and the electron temperature is higher. Due to the lower density, the occurrence of non-physical negative values increases, as shown in a statistical analysis correlated with the F10 index. Therefore, the EFI-LP team is trying to improve the computation of this variable by better considering the influence of the solar activity. Also, since the beginning of the mission, the LP measured very high values of the electron temperature, exceeding ten thousand Kelvin. Investigations are ongoing to understand the nature of these extreme values. From a preliminary statistical analysis, there are evidences that the distribution of extreme events is well structured and can be partially due to physical features. Kinetic simulations have been performed to characterize the non-ideal conditions that would introduce uncertainties in the LP data. The results are promising and the simulations can be used also for validation of potential new LP-based products as the effective ion mass.

The quality of the TII data is continuously improved. Since the beginning of the mission 77 Anomaly Review Board (ARB) meetings took place to investigate instrumental issues and set-up "Scrubbing" techniques to prepare the instrument for the scientific measurements. The constant improvements of these techniques lead to an increased coverage and quality of TII data. Furthermore, the TII team has improved the algorithm to compute the cross- and along-track ion velocity. The methods have been validated by comparing the datasets both with the semi-empirical model (Weimer 2005) as well as with DMSP and SuperDarn measurements. The datasets will be delivered soon to the Swarm user community.

Also, the Swarm Echo team is currently working hardly to reprocess e-PoP dataset and improve its quality and consistency with regards to Swarm. Joint Cal/Val activities have been scheduled and numerous scientific results have been published or submitted in peer-review journals.

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, STR and RRI data processing.

Regarding the accelerometer data processing, the time series of Swarm C along-track accelerations covers now from February 2014 to April 2019. It was necessary to correct not only for steps, but also for spikes, which is a new feature in the processing. In order to explore which accelerometer data to process in addition to Swarm C along-track accelerations, two sample datasets of calibrated Swarm C cross-track and Swarm A along-track accelerations are under investigation. For the first time, the calibration procedure needs to be changed. The calibrated Swarm A along-track accelerations showed a very good agreement to those of Swarm C, though the noise level appears to be twice as high. The advances of the aerodynamic and gas-surface interactions modelling in order to improve the Swarm thermosphere data have been discussed. The improvements encompass a high-fidelity geometry model of the satellite and an improved model for gas-surface interactions based on the SPARTA software. The analysis of yaw manoeuvres in 2014 suggests that the energy accommodation coefficient should be reduced from 0.93 to approximately 0.85, which will be implemented in future baselines. Furthermore, the new Swarm thermosphere datasets, which were disseminated in the month before the workshop, introduces improvements in the radiation pressure modelling. The thermosphere density data that is based on accelerometer and GPS receiver data will be disseminated shortly after the workshop. This dataset is more accurate and will be assimilated also in the DTM2019 model.

An assessment of bias products by GRG (CNES/CLS), COD (test dataset), and ESA (test dataset) on Swarm ambiguity fixed orbits produced by POSITIM, has been presented. It was found that the POD results are equivalent for all three bias products. First results of correcting carrier phase observations of the GPS receiver based on the recently provided information on the tracking loops have also been discussed. The corrected carrier phase observations show a reduced standard deviation and the "magnetic equator" artefact in the gravity field solutions is significantly reduced. It is concluded that the "magnetic equator" artefact can be explained by the behaviour of the GPS receiver tracking loops. Also, in the DISC project four different gravity field solutions from four different processing centres are combined to a final solution, which is more accurate than the individual solutions. Thus, the "analyst noise" is reduced in the combination.

The development of a new calibrated STEC data product based on CASSIOPE's GAP-O has been presented. New products for ionosphere density, topside vertical TEC, and perturbation TEC are being developed. The relative attitude biases of the attitude determination using CASSIOPE star sensor attitude data were corrected. The new attitude product is found to be much more accurate than the existing one. The attitude data was used as part of the precise orbit and attitude determination using CASSIOPE GAP-A data for the year 2018. There is a notable overall improvement of orbit accuracy compared to receiver navigation solution and the reference orbit as available in the standard CASSIOPE ephemeris data product, which showed errors at 10 km level errors in early 2018. The new orbit has peak overlap errors of less than 5cm for 60% of all days, but more than 1 m for 10% of all days. The attitude determination using GAP-A data was demonstrated at an accuracy of 0.10 – 0.30. Also, the activities related to the CASSIOPE radio receiver instrument, including a comparison to SuperDARN data, have been presented.

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.
An application of the virtual observatory concept to Swarm data, within the framework of the Swarm DISC GVO project, has been presented. This approach complements the traditional models based on the spherical harmonic expansion. Its ability to provide spatially localized error estimates will be useful for future assimilations into physical geodynamo models. Also, an application of the VO data obtained by the CryoSat platform magnetometers, as well as a new derivation of local field gradient component GVOs, has been discussed. The option of co-estimation of the vector magnetometer calibration parameters with a main field model was presented as an alternative to the use of an a-priori field model for magnetometer calibration. A similar technique was also presented in other sessions demonstrating the suitability of vector data from the ASM-V instrument for main field modelling. Two additional models leading to IGRF candidates have been introduced; one with sequential assimilation approach allowing the inclusion of statistical information derived from physical geodynamo models; and the other investigating the possibility of using gradient only data to derive main field models, finding that this was not sufficiently stable. Also, the recent developments and applications of the WMM model have been presented.

A 1-D mantle conductivity model and its conversion into a temperature profile, that are based on an independent processing of Level 1B vector data, have been presented, showing the recent results of the 3-D time-domain chain and the development of a new approach to parameterizing field sources based on current loops. The contribution from Session 8 is also relevant here, as it was presented during that session on the improvements of the squared coherency between the external and internal field coefficients for two dominant ring current spatial modes by inclusion of Cryosat data.

Three presentations were dedicated to the modelling of lithospheric field. The first showing an improved model based on CHAMP, Swarm, as well as marine and airborne data grids from the WDMAM. The second presenting a model of time-dependent component of the lithospheric field, providing new maps of vertically integrated magnetic susceptibility and models of remnant magnetization. The third, introducing a scheme to suppress the noise in modelling the lithospheric field in the auroral areas by first pre-processing to grid data sequentially in both geographic and QD latitude-MLT coordinates.

2.6 Advanced products for External fields

Session 6 illustrated several projects that use Swarm data to investigate or to model the fields of external origin, focussing on high latitude ionospheric currents, middle and low latitude currents, plasma irregularities and plasma waves.

For the high latitude region, a new DISC project developed a global empirical model of Field Aligned Currents (FAC) based on Champ and Swarm FAC data, which has been recently updated including the more recent Swarm measurements, and it is now based on more than 23 million Swarm and CHAMP data samples in addition to the solar wind velocity, the interplanetary magnetic field orientation, the Earth's dipole tilt and the F10.7 index. Another DISC project is developing a new Swarm product that defines the boundaries of auroral oval through the small scale FAC, and the profiles of auroral electrojet using two different methods: spherical elementary current system and linear currents method. Another study computed the cross correlation between single spacecraft FAC estimates from Swarm A and C, and determined the orientation of the current sheet. It is found that current sheets are well aligned with the auroral oval boundary for both regions 1 and 2, with a larger variability for region 1 around the local noon. Higher ordering of orientations is found in the dawn-dusk regions.

For the low latitude region, a new baseline of Swarm equatorial electric field product (EEF) is now available, covering the period from the beginning of the mission to 15 August 2019. The validation of EEF with observations from JULIA radar data showed a very good agreement. Another high-level product provides the Solar quiet (Sq) and Equatorial Electrojet currents (EEJ) computed from Swarm Magnetic field measurements with a time-varying solar harmonic representation called Dedicated Ionosphere Field Inversion (DIFI). DIFI has been recently extended to pre-Swarm data measured by other satellites, and this highlighted a detectable climatological change in Sq and EEJ currents over the years 2001 – 2018, which cannot be explained by the variation of F10.7 in these years. Further studies will focus on the origin of this trend. Moreover, a new statistical study focussed on the inter-hemispheric FACs behaviour analysing 5 years of FAC and radial current dual spacecraft product. This study highlighted a number of unexpected features in IHFACs, which will be also further investigated.

Plasma structures or irregularities in the ionosphere can have a significant impact on GPS data, causing an increase of errors in the estimated position, or even loss of lock for the larger structures. A new Swarm DISC project has developed a new Swarm index, proportional to the GPS scintillations, for plasma irregularities detected in various regions of the ionosphere, such as polar cap patches and equatorial plasma bubbles.

Another study is focussing on a subclass of plasma structures observed in the equatorial region and characterized by pressure balance, where the plasma pressure variation is compensated by the magnetic pressure. Data measured inside these structures would also allow to validate Swarm electron temperature data, by using magnetic field measurements. A further investigation is studying the small-scale perturbation of electron density measured by Swarm, detected at middle and low latitudes in the dayside ionosphere. Further investigations are needed to verify if these perturbations are due to propagating structures, or rather, to some instrumental issues.

Swarm data allow also a detailed investigation of waves in the ionosphere, which play an important role for energy transfer and particle energization. In particular, a recent project analysed the ultralow frequency (ULF) waves in the Pc-3 and Pc-1 bands, using low resolution (1Hz) and high-resolution magnetic field data (50 Hz) respectively. Moreover, a new project is studying the burst mode magnetic field data (250 Hz), identifying several Whistler mode waves with a clear dispersion relation. It has been found that each of these Whistler waves is produced by a lightning in the atmosphere, whose location can be precisely identified in the World ELF Radiolocation Array (WERA) data. From the characteristics of the dispersion relation of these Whistler waves it is possible to obtain a remote sensing of the ionosphere below Swarm spacecraft, providing a validation of IRI model where no other measurements are available.

The final discussion focussed on possible impact of the various projects presented in this session for Swarm data quality. Two projects in particular, one about small density fluctuations and the other about pressure balance structures, reported observations that could be very valuable for data quality, reporting features in electron density and temperature that are potentially caused by instrumental issues. The results obtained by these two projects will be used in future, in dedicated investigations about LP probes data.

2.7 Swarm products for space physics/ weather

The session 7 highlighted the significant contribution of Swarm data for understanding various physical processes in the Ionosphere, at different temporal and spatial scales.

In the context of Ionosphere-thermosphere coupling studies, by comparing the energy pointing flux obtained from Swarm magnetic and electric field data, with the vertical velocity measured by Swarm and/or incoherent scatter radars, it is possible to study the ion up/out flow processes. Moreover, the analysis of electron density and zonal electric field measured by Swarm confirmed the presence of large amplitude lunar tides during the Sudden Stratospheric Warming events (SSWs), already highlighted in previous studies. The Swarm currents products (Field Aligned and radial currents) will allow to assess the response of ionospheric currents to SSWs events.

Swarm allows also to study in detail the ionospheric irregularities, their origin assessing their potential impact on GPS tracking. The characteristics of scaling features of electron density measured by Swarm highlighted the presence of two different families of plasma irregularities that seem to be associated with different physical properties. Moreover, the analysis of the intermittent fluctuations in the high time resolution magnetic field data measured by Swarm (50 Hz) allows to separate the compressional component, observed near the dip equator in the post sunset local times, from the transverse fluctuations, observed along the auroral oval.

Swarm data are also very useful to characterize the behaviour of the ionosphere during geomagnetic active conditions. The 50 Hz magnetic field data can monitor the presence of Pc1 waves, which are also observed in 16 Hz cross track velocity. During geomagnetic storms, these Pc1 waves are detected by Swarm in correspondence to the dropouts of ultra- relativistic electrons from the radiation belts (measured from Van Allen Probes data, and models). This confirms the important role of Pc1 waves for the scattering of high energetic particles. Moreover, the low resolution (1 Hz) magnetic field data can be processed in order to obtain a new dst-like index that monitors the integral intensity of symmetrical magnetospheric ring current. This new Swarm Dst-like has a much higher time resolution (1 Hz) with respect to standard ground-based ones (1 hour for standard Dst, 1 minute for SYM-H). Finally, the Swarm Field Aligned current (FAC) products analysed in combination to the orientation of the Interplanetary Magnetic Field (IMF) measured in the Lagrangian point L1, can provide the time response of the magnetosphere- ionosphere system.

The final discussion focussed on possible impact of the various researches and projects presented in this session for Swarm data quality. In particular, the project 'Swarm as a platform for ion outflow studies' could be particularly useful to improve Swarm data quality. Indeed, this project collected several Swarm overflights on EISCAT radars, with the purpose of comparing the vertical velocity inferred from EISCAT with the one measured by Swarm. The Swarm TII team is now working to a new calibration of Swarm cross track velocity, and the vertical velocity measured by EISCAT can be very useful to validate the vertical component of the velocity obtained with the new algorithm. We added a new recommendation, to facilitate the collaboration between the team of this project and the TII team, and use these overflights for a validation purpose.

2.8 Multi-Missions Synergies

The Session 8 discussed scientific results that are gained from synergies between Swarm data and data from other satellites. The benefit lies in the combination of multiple missions, e.g., to increase the amount of data, and to enhanced temporal coverage, both in lengths of time span and in local time. Also, the spatial expansion, such as in longitude and altitude is important. Many of the applications presented are in support to the Swarm mission, and others have been enabled by the expertise and effort of the Swarm team. The presentations in session 8 discussed the exploitation of geomagnetic observations and of GPS observables derived from multiple satellites. They covered areas in solid Earth geophysics, space physics and space weather, as well as gravity.

A calibration strategy of data from the non-dedicated platform magnetometers on board the Cryosat-2 satellites has been showed. These magnetometer data have been applied for an enhanced modelling of the global geomagnetic main field when high precision geomagnetic observations from the CHAMP or Swarm missions have not been available between 2010 and 2013. Also, the Cryosat-2 data have been used to infer ocean tides and the magnetospheric ring current index. These results showed similar quality to those derived from Swarm or ground observatories.

A a co-estimation of calibration parameters and core field parameters in one inversion step based on CHAMP, Swarm, DMSP and Cryosat-2 magnetic data has been presented. It has been demonstrated that a robust secular variation of the main magnetic field up to degree 6 can be derived for the gap period between CHAMP and Swarm. The combination of the magnetospheric ring current signatures derived from Swarm and Cryosat-2 helped to improve the recovery (separation) of external (inducing) and internal (induced) signals of magnetospheric origin up to 10%. The improvement was mainly attributed to the enhanced local time coverage by the combination of multi-mission observations.

Furthermore, the US-American MagQuest challenge calling for ideas to increase the efficiency, reliability, and sustainability of geomagnetic data collection for continuous main field modelling. This challenge concerns new satellite mission and ground observation concepts.

It has been proposed an optimal exploitation of the combined analysis of Cluster, Swarm and ground-based magnetic observations to better characterize mechanisms for magnetospheric Bursty Bulk Flows.

New optical observations are expected from the future SMILE mission, that focuses on even enhanced investigations the solar wind-magnetosphere-ionosphere coupling.Also, GPS observables have been applied to derive Total Electron Content (TEC), and to develop a model of the local plasmasphere. Differencing these model estimates to the Swarm TEC observations allows to access the ionospheric part of the Swarm readings. It has been emphasized that the time variability of the satellite-based GPS receiver biases have much shorter temporal scales than one day, as was often assumed.

Results of the COST-G action to derive time-varying gravity field from Swarm, especially to fill the gap between GRACE and GRACE-FO, have been shown. A combined solution of Swarm-derived gravity fields from different processing centers outperforms the single solutions in accuracy.

2.9 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 set of presentations dealt with the magnetometry capacity of the CSES mission. First presentation provided an update of the general status of the High Precision Magnetometry (HPM) payload, which includes two Flux Gate Magnetometers (FGM providing vector relative measurements) and a Coupled Dark State Magnetometer (CDSM), used to provide reference absolute scalar magnetic data to the CSES mission. Perturbations from satellite operations were highlighted, some of which have been mitigated. The general health of the payload is good. The status of the CDSM was also presented. The instrument is working very well, and is in good shape after 18 months is space. Overall (very conservative) uncertainty has been estimated to be of less than +/- 1nT, with occasional jumps of up to that order (but usually less) when the instruments changes from one of its measurement principle to the other (which occurs a couple of times every orbits). Comparisons with Swarm Bravo scalar data (using a geomagnetic field model for correcting for known magnetic sources) show very good agreement between the two missions with a bias of order 0.4 nT in the Northern Hemisphere, but somewhat higher (2.2 nT) in the Southern Hemisphere, revealing a possible issue with CSES, to be investigated. Current efforts of the CSES team towards improving vector magnetic field data calibration (i.e., calibration of the Flux Gate Magnetometers) were independently reported. Significant progress has been done, but a number of issues are still open. Room for further improvements seems within reach. Finally, successful joint efforts of the Swarm and CSES scientists towards building an IGRF 2020 candidate model for IGRF-13 were also presented. These efforts 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. Despite these limitations, a model could be built.

A second set of presentations next focussed on Plasma measurements. The effects that could possibly affect Langmuir Probe (LP) measurements on both Swarm and the CSES -which do not agree well in terms of electron density measurements - were discussed. This is a very good example of the benefit of a joint CSES/Swarm analysis of such data. Further comparisons of CSES and Swarm electron density measurements were shown, also discussing comparisons with other previous missions, in the context of various geophysical conditions, again leading to some discussion about the relative sensitivity of the LP on Swarm and CSES. Finally the point of view of Swarm experts were also presented, carrying similar comparisons, but now also with respect to the IRI reference model. They again concluded that LP data on CSES disagree in terms of magnitude with respect to the Swarm LP data, but also with respect to IRI. They nevertheless highlighted the capacity of CSES LP to detect useful geophysical signals. The cause of the disagreements between the two missions is still an open question.

A final set of presentations discussed results related to Search Coil Magnetometer (SCM) and Electric Field Detector (EFD) on board CSES, which give access to high frequency magnetic and electric signals, and provide the possibility of investigating waves. It was in particular highlighted the possibility of investigating ELF/VLF rising tone quasi-periodic waves associated with energetic electron precipitations in the high latitude ionosphere (note that no similar data are available on Swarm). EMIC fluctuations observed by CSES and Swarm during magnetic storms from multi-instrument analysis (CSM, EFD, but also FGM, allowing some comparison with Swarm) also demonstrate interesting possible synergy of the two missions for such studies.

Altogether, this session clearly showed the value of joint CSES and Swarm analysis, and of close collaborations of the scientists involved in both missions.

2.10 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.

2.11 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 SDQW9 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 Eearth. 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 around the next DQW.

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

The following table provides an update (at time of DQW#9) on **40 recommendations** expressed by the **Swarm DQW#8** participants and compile **23 new recommendations from the DQW#9**. All these recommendations will be regularly updated and documented via the ESA ARTS tracking system.

TOPICS	RECOMMENDATIONS	STATUS	MAIN UPDATES AT DQW#9
Magnetic Field	[DQW8_Rec 1.]Adapt the L1BOP in order to be able to process L1B MAG data with ASMxBUR_0_ data as input	Ongoing	Action almost completed. GMV delivered on 22/08/2019 an updated version of the L1BOP (v.03.22) in which this functionality is implemented. Verification process ongoing.
	[DQW8_Rec 2.]Run ASM on Swarm Alpha and Swarm Bravo in Burst mode more frequently (two weeks sessions).	Ongoing	We have had different sessions (1-week duration) with ASM on-board Swarm Alpha or Swarm Bravo commanded in Burst mode. Agreed to have from now on one of the two ASM's in burst mode 1-week per month.
	[DQW8_Rec 3.]Generate new Swarm Product from ASM 250 Hz Burst mode science data.	Ongoing	A first TDS (one day, 25/07/2018 for Swarm Alpha) was produced by IPGP (in collaboration with Leti) and delivered to DISC for a first verification. IPGP have processed all the available Burst mode data and will make them available to all the Swarm community very soon.
	[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	Ongoing	Action on DTU. Activity ongoing.
	[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).	Ongoing	Action on IPGP and DTU. Activity ongoing. a. Agree on the new correction to be introduced in MAG data processing (action on PB+GH+LTC) b. Test this correction (action led by DTU) c. Implement the correction in L1B data processing chain
	[DQW9_Rec 1.] In case of reprocessing POD data to be used as input for magnetic data processing	**Open**	
	[DQW9_Rec 2.] Move MGF comparison model to CHAOS	**Open**	
	[DQW9_Rec 3.] Create a Level 1b product of Cassiope spacecraft house - keeping data to aid with MGF calibration	**Open**	
	[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.	**Open**	
Electric Field	[DQW8_Rec 8.] Implement a new firmware to adopt an updated version of the TII automatic gain control, and to download TII images at higher 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.	Ongoing	Tests on the AGC functioning and firmware are ongoing. Frequent updates on these activities during the TII-ARBs.

	[DQW8_Rec 9.]	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.]	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.	Ongoing	e-POP IRM data will be reprocessed and delivered to the EFI community for joint Cal/Val activities
	[DQW9_Rec 5.]	Release new cross-track velocity dataset TIICT 0201 with latest improved calibration	Ongoing	Yaw and pitch tests have been requested in order to update the calibration coefficients
	[DQW9_Rec 6.]	Release of the new dataset TIIVI 0101 (3D flows) with quality info in the Flags.	Ongoing	The dataset have been already validated via comparison with DMSP data and Weimer 2005 model.
	[DQW9_Rec 7.]	Improve the computation of the electron density.	Ongoing	Results show underestimation of Ne and overestimation of Te of about 10% (Lomidze et al., 2018). Furthermore, Ne is often negative during low density when computed from the ion current, while it shows spikes when computed from the electron current.
	[DQW9_Rec 8.]	Make a complete statistical analysis from BOM to characterize the evolution of the EFI L1B data quality and related anomalies to identify possible improvements.	Ongoing	Te extreme events, % of flagged values and outliers, small scale disturbances etc.
GPS **ACC**	[DQW8_Rec 11.]	Release to users the Swarm C along-track accelerations	Done	

and ACC	**data**		covering the period from May to November 2016		
		[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).	**Ongoing**	Swarm C along-track processing is current now. Analysis whether to continue with Swarm A along-track or Swarm C cross-track is in progress
		[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.	**Open**	Nothing has happened wrt. this recommendation.
		[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	**Open**	
	A/B/C	[DQW8_Rec 15.]	Exploit integer ambiguity fixing	**Open**	This is still on our list of future improvements.

	GPS	when determining the non-gravitational acceleration from GPS receiver data.		
	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.	Ongoing	We should check how the data availability evolved since DQW#8. We did have a lot of exchanges with the CASSIOPE team and understand now that there are limitations in the on-board data handling that cannot be solved. Reducing the data rate of the GPS is not helping to get more data.
		[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)	Ongoing	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).	Ongoing	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	Done	Work completed by O. Montenbruck, A. Hauschild, and R. Langley. Submitted a paper recently to GPS Solutions.

		groups performing precise orbit determination for Swarm E.		
	[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. Feasibility of thermosphere mass density not assessed.
	[DQW9_Rec 10.]	Make the new CASSIOPE orbit and attitude data available on Swarm dissemination server	**Ongoing**	
	[DQW9_Rec 11.]	Place technical note on CASSIOPE attitude determination on Swarm webpage	**Ongoing**	
Internal Fields	[DQW8_Rec 23.]	Generate and distribute Swarm-based VO products	**Ongoing**	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	**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” in preparation

	on sub-decadal timescale.		
	~~[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	
External Fields	[DQW8_Rec 26.] Update the Swarm cross-track velocity data archive with a quality flag characterizing the intensity of along-track velocities	Ongoing	The possible implementation of this quality flag, which would be very useful to assess the errors in electric field measured by Swarm, is related to the possibility to estimate the along track velocity from TII or LP data. This is currently under investigation. Therefore this quality flag will be possibly implemented in future, in new data release by UoC.
	[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 extension. Adrian Blagau presented the first tools part of this toolbox
Space physics	**[DQW9_Rec 13.]** Further analyse and investigate LP based Te and Ne features	Open	Discussed in DQW#9 session7. But this recommendation is more related to the E-field instrument (i.e. DQW#9 session 3).

and weather applications		potentially impacted by instrumental issues.		
	[DQW9_Rec 14.]	Investigate the potential use of vertical velocity measured by EISCAT radars for the calibration of Swarm TII data.	**Open**	Discussed in DQW#9 session7. But this recommendation is more related to the E-field instrument (i.e. DQW#9 session 3).
Swarm - CSES Synergies	[DQW8_Rec 29.]	Foster collaboration between CSES and Swarm experts team for cross-calibration and validation activities.	**Ongoing**	Dedicated magnet and plasma cal/val core teams have been established following the DQW#8. Joint work was initiated for the magnet cal/val core team during a visit of Yanyan Yang (from CEA) at IPGP and DTU during four weeks in early 2019. This kicked off work to make progress on calibration and start building a CSES based candidate IGRF 2020 model for IGRF-13. These efforts led to a successful submission of such a model (deadline October 1, 2019), finally used as one of the models that contributed to the official IGRF 2020 model (released on December 19, 2019). Joint work was initiated for the magnet cal/val plasma team through telecom meetings on 15.02. and 21.03.2019, allowing preliminary analysis. Results of both groups have been presented at the CSES/ESA meeting in Changsha, China (April 23-26, 2019) and at the Living Planet Symposium, in Milan (May 2019). A dedicated session was organized at DQW#9. Swarm scientists were invited to join the 4th CSES International Workshop in Changsha (17-21 October, 2019). An ISSI-BJ International Team, with members of both core teams, has been put together ("The electromagnetic data validation and scientific application research based on CSES satellite"), with a first one-week session organized (21-25 October 2019).

	[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 share specific level data according to specific calibration tasks and scientific interests for Swarm-CSES synergies. Work on IGRF led to efforts to also make (non-nominal) magnetic intensity data available at high latitudes. More data are to be shared in the context of the ISSI-BJ International Team.
	[DQW9_Rec 15.] Organise a joint CSES-Swarm Data Quality or Science workshop	**Open**	Coordination of timing of the next opportunities (5th International Workshop of CSES, probably in May 2020; Swarm DQW#10 in Fall 2020) is under way.
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.
	[DQW8_Rec 32.] Coordinate Swarm Echo and Swarm A/B/C activities regarding data cross-calibration and scientific validation	**Open**	Will commence once Swarm-E self-calibrations are complete.
	[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, Germany. 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 analyzed 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.	Open	Topics may potentially be addressed in 4D-ionosphere and/or new DISC ideas. Evaluation pending.
	[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, …), 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.	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) Peer-reviewed article to be submitted to EPS special issue is in preparation. First results on the use of GOCE, GRACE, CryoSat-2 calibrated and consistently aligned with Swarm and CHAMP data presented at IUGG in July 2019 and at Swarm DQW #9 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. GRACE magnetic data quality has been found not being high enough for high level products (noisy, cut at 50knT). GRACE-FO data available since summer 2019.
	[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.]

	[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	
	[DQW9_Rec 23.] Investigate new funding schemes enabling consistent calibrations of multimission data.	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 and facilitate collaborations via the development of VRE	Ongoing	Initial version of Swarm VRE will be open at Swarm QWG #9
	[DQW8_Rec 40.] Redesign and improve the	Ongoing	The Swarm DISC team is intensively working on improvements

	content of the Swarm website to make it fully align with the scientific community expectations		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 is not known yet and therefore main changes/updates will be introduced and designed later.

APPENDIX I - SWARM DQW#9 REGISTRED PARTICIPANTS

Last name	First name	Organization
Alken	Patrick	University of Colorado
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Brauer	Peter	DTU Space
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Brown	William	British Geological Survey
Buchert	Stephan	Swedish Institute of Space Physics
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Coco	Igino	INGV
Coïsson	Pierdavide	IPGP
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Wenkel	Mike	Perspecta
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Zhang	Yiteng	National Space Science Center
Zhou	Bin	Nation Space Science Center, CAS

APPENDIX 2 - SWARM DQW#9 AGENDA

Day 1	Monday 16/09/2019		
		Location: Room B-286	
12:30	14:00	Registration	
		Session 1: Mission overview	**Chairs:Anja Stromme & Jerome Bouffard**
14:00	14:10	Welcome by LOC and logistic information	Aleš Bezděk/Josef Sebera
14:10	14:25	Swarm - status overview and plans for the extended mission	Anja Stromme
14:25	14:40	Swarm Data Quality Status and DQW objectives	Jerome Bouffard
14:40	14:55	Opportunity of synergies between Swarm and other ESA science missions	Rune Floberghagen
14:55	15:10	Swarm after (almost) six years in space - Towards the second half of a Solar Cycle	Nils Olsen
15:10	15:25	Magnetic package instruments and processors	Enkelejda Qamili
15:25	15:40	Electric field instrument and processors	Filomena Catapano
15:40	15:55	GPS and Accelerometer instruments and processors	Christian Siemes
15:55	16:15	Coffee break	
16:15	16:30	Flight Operations Segment Status	Ignacio Clerigo
16:30	16:45	Constellation status of the Swarm mission	Detlef Sieg
16:45	17:00	Cassiope (Swarm-E) Status and Operational Overview	Andrew Howarth
17:00	17:15	Swarm PDGS Status & Outlook	Antonio de la Fuente
17:15	17:30	e-POP Data Access Updates	Andrew White
17:30	17:45	VirES for Swarm - Data Visualization Platform and Virtual Research Environment - Status	Martin Paces
17:45	18:00	Status of the NanoMagSat project	Gauthier Hulot
18:00	18:15	Macau Satellite Project	Keke Zhang

18:15-19.30 Ice Breaker with welcome speech by IAGA president
Location: Atrium at the entrance to Faculty of Civil Engineering

Day 2	Tuesday 17/09/2019		
		Location: Room B-286	
		Session 2: Magnetic field measurements (splinter session)	**Chair: Enkelejda Qamili**
08:30	08:45	The Vector Field Magnetometer stability and status on the three Swarm satellites	Jose M. G. Merajo
08:45	09:05	Latest Results on dB_Sun Characterisation	Lars Toffner Clausen
09:05	09:25	Modified thermoelectric model of the ASM blanket with uncovered nadir rivet	Peter Brauer
09:25	09:45	Towards correcting ASM data for the Sun-related thermoelectric effect	Pierre Vigneron
09:45	10:05	Simulations of magnetic field disturbance at the ASM location	Gabriela Blaga
10:05	***10:30***	***Discussion and Recommendations***	
10:30	11:00	Coffee break with VirES/VRE Demo [Part1/2]- Hall	Martin Paces
11:00	11:15	Status of the ASM-V and ASM Burst mode data	Rémi Madelon
11:15	11:30	Solidity and performance of the thermal model and its future ramifications	Matija Herceg
11:30	11:45	Results of the radiation monitor and the implications for the associated drift shells	John Leif Jørgensen
11:45	12:00	Improved Swarm-Echo Magnetic Field Data Products	David Miles / Robert Broadfoot
12:00	12:15	More about ePOP calibration	Martin Rother
12:15	***13:00***	***Discussion and Recommendations***	
13:00	14:00	Lunch	
		Session 3: Electric field measurements (splinter session)	**Chair: Filomena Catapano**
14:00	14:15	LP overview and status	Stephan Buchert
14:15	14:30	Swarm electron temperature analysis over four years: statistical occurrence of "bad data" as a function of latitude, local time and orbits	Igino Coco
14:30	14:45	Kinetic Simulations of the Swarm Langmuir Probes in non ideal conditions	Pedro Alberto Resendiz Lira
14:45	15:00	Effective Ion Mass and Bulk Flow Velocity from EFI/LP	Matthias Foerster
15:00	15:15	Recent science from Swarm EFI and ePOP SEI	David Knudsen
15:15	***15:45***	***Discussion and Recommendations***	
15:45	16:15	Coffee break with VirES/VRE Demo [Part2/2]- Hall	Martin Paces
16:15	16:30	EFI TII drift dataset	Johnathan Burchill
16:30	16:45	Assessment of Swarm EFI vertical ion drifts at high latitudes	Alexei Kouznetsov
16:45	17:00	High latitude ion and neutral composition in the context of Swarm data analysis	Andrew Yau
17:00	17:15	Assessment of a technique to validate / optimize the electric field and conductance on multiple Swarm events	Ivan Ionut Madalin
17:15	17:30	Cassiope Fast Auroral Imager New Data Product	Andrew Howarth
17:30	**18:00**	***Discussion and Recommendations***	
18:00	***18:30***	***Open discussion on future Swarm constellation***	***Detlef Sieg and All***

Day 2	**Tuesday 17/09/2019**		
		Location: Room C-202	
		Session 4: GPSR and accelerometer (splinter session)	**Chair: Christian Siemes**
08:30	08:45	Swarm accelerometer 2013-2018 data quality and processing	Sergiy Svitlov
08:45	09:00	Update on aerodynamic and gas-surface interactions modelling for the Swarm L2 density product	Günther March
09:00	09:15	Swarm L2 thermospheric density products: last update and current status	Elisabetta Iorfida
09:15	09:30	Swarm GPS densities rapid evaluation	Christian Siemes
09:30	09:45	Ambiguity-fixed SWARM orbits based on different bias products	Heike Peter
09:45	10:00	Investigation of artifacts in carrier phase observations	Lucas Schreiter
10:00	10:15	Multi-approach gravity field models from Swarm GPS data	Pieter Vissser
10:15	***10:30***	***Discussion and Recommendations***	
10:30	11:00	Coffee break with VirES/VRE Demo [Part1/2] - Hall	Martin Paces
11:00	11:15	Current status of Swarm-E GAP data products and science applications	Chris Watson
11:15	11:30	CASSIOPE star sensor data combination	Christian Siemes
11:30	11:45	CASSIOPE orbit and attitude determination	Oliver Montenbruck
11:45	12:00	Radio Receiver Instrument on e-POP (Swarm-E) Business	Gordon James
12:00	***12:30***	***Discussion and Recommendations***	
12:30	14:00	Lunch	
14:00	**15:45**	**VirES & VRE Individual Training and Practice /Room C-202**	**Martin Paces**
15:45	16:15	Coffee break with VirES/VRE Demo [Part2/2]- Hall	Martin Paces

Day 3	Wednesday 18/09/2019		
		Location: Room B-286	
		Session 5: Advanced products for internal fields	**Chairs: Jakub Velímský & Chris Finlay**
08:30	08:45	Geomagnetic Virtual Observatories: Monitoring long-term field variations with Swarm data	Chris Finlay
08:45	09:00	An assessment of Cryosat platform magnetometer data using geomagnetic virtual observatory data series	Magnus Danel Hammer
09:00	09:15	Using secular variation gradient data to infer core surface flows	Kathy Whaler
09:15	09:30	Extending Geomagnetic Field Modelling to Include Co-estimation of Calibration Parameters of Vector Field Data	Clemens Kloss
09:30	09:45	Core field modeling using ASM-V data	Pierre Vigneron
09:45	10:00	Sequential modelling of the Earth core magnetic field: a candidate to the IGRF-13	Guillaume Ropp
10:00	10:15	The GFZ Mag.num field model as a parent model for an IGRF candidate	Martin Rother
10:15	10:45	Coffee break	
10:45	11:00	Use of Swarm data in the development, validation and assessment of the World Magnetic Model	Arnaud Chulliat
11:00	11:15	World Magnetic Model 2020	Michael Paniccia
11:15	11:30	Mantle conductivity time-domain chain: Progress report after 5 years	Jakub Velímský
11:30	11:45	A 1D electrical conductivity and temperature profil of the Earth's mantle	Erwan Thebault
11:45	12:00	An extended lithospheric magnetic field model based on Swarm, CHAMP and WDMAM data	Erwan Thebault
12:00	12:15	Models of the lithospheric time variation and corrections to satellite data	Eldar Baykiev
12:15	12:30	Removing the Auroral Oval 'Noise' from the Crustal Field 'Signal' in Satellite Magnetic Data Using an Equal-Area Grid	Ashley Smith
12:30	***13:00***	***Discussion and Recommendations***	
13:00	14:00	Lunch	
		Session 6: Advanced products for external fields	**Chairs: Karl M. Laundal & Lorenzo Trenchi**
14:00	14:15	Overview of new Swarm DISC projects	Line Drube
14:15	14:30	Time-scale dependence of the Average Magnetic field and Polar current System (AMPS) model	Karl M. Laundal
14:30	14:45	New Swarm products: Auroral oval and electrojet boundaries	Kirsti Kauristie
14:45	15:00	Ionospheric currents at mid- and low-latitudes derived from 5 Years of Swarm observations	Guram Kervalishvili
15:00	15:15	Advances on the Level-2 equatorial electrojet product	Patrick Alken
15:15	15:30	Extended climatological model of non-polar geomagnetic daily variations: preliminary results	Arnaud Chulliat
15:30	15:45	Recent results and status on the Ionospheric Plasma IRregularities (IPIR) data product	Yaqi Jin
15:45	16:15	Coffee break	

16:15	16:30	BGS development of enhanced Fast-track Magnetosphere Model	William Brown
16:30	16:45	New ULF wave indices derived from Swarm observations to investigate magnetosphere-ionosphere coupling	Georgios Balasis
16:45	17:00	Assessment of the balance between plasma and magnetic pressure across equatorial plasma depletions	Juan Rodriguez-Zuluaga
17:00	17:15	ELF whistlers analysis for ionospheric modelling: Initial results of the ILGEW project	Pierdavide Coïsson
17:15	17:30	Analysis of field-aligned currents compared to ground and other space measurements	Malcolm Dunlop
17:30	17:45	Small scale perturbations of plasma density on the edges of equatorial anomaly	Ewa Slominska
17:45	***18:15***	***Discussion and Recommendations***	

19:30 - 23:00 Social dinner at the Original Prague Brewery

Day 4	Thursday 19/09/2019		
		Location: Room B-286	
		Session 7: Swarm products for space physics/ weather applications	**Chair: Lorenzo Trenchi**
08:30	08:45	Distributed Spacecraft Autonomy: Reactive, Coordinated Science with Cross-Linked Satellites	Daniel Cellucci
08:45	09:00	Investigating dynamical complexity using a Swarm-derived Dst index and information-theoretic measures	Georgios Balasis
09:00	09:15	Swarm as a platform for ion outflow studies	Spencer Hatch
09:15	09:30	Timescales of Birkeland currents driven by the IMF	John Coxon
09:30	09:45	On the RODI and Ionospheric Electron Density Spectral Features During Geomagnetic Storms	Paola de Michelis
09:45	10:00	Observations of intense mid-latitude Pc1 waves during geomagnetic storms: Towards the use of Swarm for radiation belt science	Ivan Pakhotin
10:00	10:15	New space weather information exploited from the Swam observations: Introduction of the EPHEMERIS project	Balázs Heilig
10:15	10:30	VERA: Vertical Coupling in the Earth's Atmosphere at Mid and High Latitudes	Yosuke Yamazaki
10:30	***10:45***	***Discussion and Recommendations***	
10:45	11:00	Coffee break	
		Session 8: Multi-mission synergies - Part 1	**Chair: Claudia Stolle**
11:00	11:15	Towards a real swarm of magnetic satellites - recent progress in exploitation of platform magnetometer satellite data	Nils Olsen
11:15	11:30	Towards better description of spatio-temporal structure of magnetospheric ring current using LEO sat. platform magnetometers	Alexey Kuvshinov
11:30	11:45	Co-estimation of core field and fluxgate calibration parameters	Patrick Alken
11:45	12:00	Topside ionosphere and plasmasphere derived from SWARM and Sentinel GPS data	Lucas Schreiter
12:00	12:15	Introduction of the PRODEX project "MAGnetosphere dynamics and coupling to Ionosphere as observed by Cluster and Swarm - MAGICS"	Octav Marghitu
12:15	12:30	SMILE (Solar wind-Magnetosphere-Ionosphere Link Explorer) mission status	Eric Donovan
12:30	12:45	COST-G combination of Swarm gravity fields from different analysis centers	Ulrich Meyer
12:45	13:00	MagQuest Results: A $1.2 million competition to advance how we measure Earth's magnetic field.	Angelique Garcia
13:00	14:00	Lunch	
14:00	14:15	**Discussion and Recommendations**	
		Session 9: Multi-mission synergies - Part 2: Highlights on CSES joint analyses	**Chairs: Gauthier Hulot & Zeren Zhima**
14:15	14:30	Correct the instability of vector magnetic field linear parameters	Bin Zhou
14:30	14:45	In-orbit results of the Coupled Dark State Magnetometer aboard the China Seismo-Electromagnetic Satellite	Andreas Pollinger
14:45	15:00	On the possibility of building an IGRF candidate using CSES magnetic data	Gauthier Hulot
15:00	15:15	Instrumental considerations for the understanding of Swarm/ CSES ratio in plasma density measurements.	Piero Diego

15:15	15:30	The Langmiur Probe on CSES, Swarm, DEMETER and other satelites	Xuemin Zhang
15:30	15:45	The equatorial plasma bubble observed by CSES and Swarm	Chao Xiong
15:45	16:00	Coffee break	
16:00	16:15	The quasiperiodic waves recorded by CSES satellite	Zeren Zhima
16:15	16:30	HPM operation status in orbit	Bingjun Cheng
16:30	16:45	EMIC fluctuations observed by CSES and SWARM satellites during magnetic storms	Yiteng Zhang
16:45	17:00	The precipitation of energetic particles caused by NWC	Wei Chu
17:00	***17:15***	***Discussion and Recommendations***	
		Session 10: data processing analysis and data visualization	**Chair: Nils Olsen**
17:15	17:30	viresclient: Programmatic access to Swarm for rapid and reusable research	Ashley Smith
17:30	17:45	Python package for FAC density estimations with Swarm	Adrien Blagau
17:45	18:00	A machine learning approach for automated ULF wave recognition	Constantinos Papadimitriou
18:00	18:15	Anomaly Detection for Swarm Electromagnetic data using a Deep Learning Approach	Yaxin Bi
18:15	***18:30***	***Discussion and Recommendations***	

Day 5	Friday 20/09/2019		
		Location: Room B-286	
		Session 11: Summaries , Recommendations & Future	**Chair: Jerome Bouffard**
09:00	09:15	Summary & Recommendation session 2	Enkelejda Qamili
09:15	09:30	Summary & Recommendations session 3	Filomena Catapano
09:30	09:45	Summary & Recommendations on session 4	Christian Siemes
09:45	10:00	Summary & Recommendations on session 5	Jakub Velímský and Chris Finlay
10:00	10:15	Summary & Recommendations on session 6	Karl M. Laundal and Lorenzo Trenchi
10:15	10:45	Coffee break	
10:45	11:00	Summary & Recommendations on session 7	Lorenzo Trenchi
11:00	11:15	Summary & Recommendations on session 8	Claudia Stolle
11:15	11:30	Summary & Recommendations on session 9	Gauthier Hulot and Zeren Zhima
11:30	11:45	Summary & Recommendations on session 10	Nils Olsen
11:45	12:00	Open discussion for the next Swarm DQW format/content	All
12:00	12:05	Meeting Conlusions	Jerome Bouffard and Anja Stromme

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