SWARM SCARF Dedicated Ionospheric Field Inversion chain

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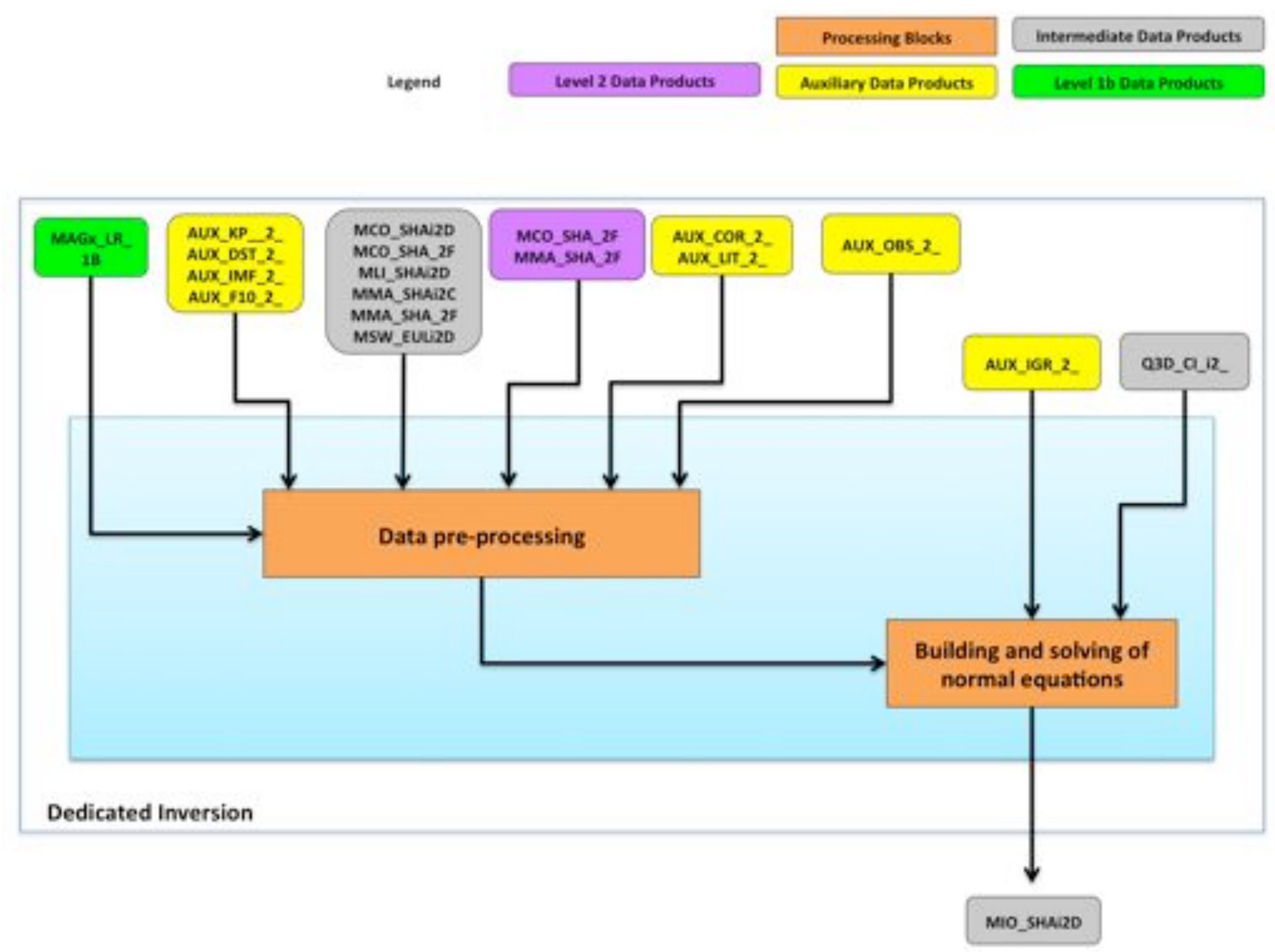
Abstract

ESA's Swarm mission, to be launched in fall 2013, is an optimized constellation of three low-Earth orbiting satellites providing measurements of the geomagnetic field with unprecedented precision. Over the last two and a half years, a consortium of research institutions has teamed up with ESA to set up the Swarm "Satellite Constellation Application and Research Facility (SCARF)", a distributed processing facility that will produce level-2 data products during the Swarm mission. As a member of the consortium, the IPGP developed the "Dedicated Ionospheric Field Inversion chain" (DIFI). The DIFI algorithm produces global, spherical harmonic and time varying models of the geomagnetic Sq field, i.e., the magnetic field generated by electrical currents flowing in the conducting layers of the ionosphere, on the dayside of the Earth. It takes into account seasonal effects as well as solar cycle variability. It separates the observed Sq field in two parts: the primary field originating in the ionosphere, and the secondary field induced in the electrical conducting mantle. The obtained models are valid both on the ground and at satellite altitude, and at all latitudes within +/-55°. The DIFI algorithm was thoroughly tested during the development phase of the L2PS, using synthetic Swarm data. A first model based upon real Swarm data will be delivered about 6 months after the end of the Swarm commissioning phase.

DIFI algorithm



The first block of the DIFI algorithm reads all level 1b Swarm magnetic field data available during the considered time interval (typically 1yr), selects data at magnetically quiet times, and corrects these data for the core, lithospheric and magnetospheric fields, using other dedicated and comprehensive SCARF models (see posters in the same session).

The second block inverts for the ionospheric field, relying on the same parameterizations as the comprehensive models (e.g., Sabaka et al., 2002, 2013):

- Daily and seasonal (annual and semi-annual) variations are described by Fourier series of complex spherical harmonic coefficients until degree 45 and order 5 in quasi-dipole coordinates (Richmond, 1995);
- The primary and secondary (induced) fields are separated using a Q-matrix calculated from a 1D or a 3D model of the electrical mantle conductivity (to be determined during the mission);
- The solar cycle variability is assumed to be linearly related to the F10.7 index, using a Wolf ratio determined by Olsen et al. (1993).

DIFI models will be distributed as Fourier series of real spherical harmonic coefficients, in geomagnetic coordinates.

Test results

Two types of tests were performed during the preparation phase:

- an inversion directly from a 1-yr set of synthetic ionospheric data (AR1 test),
- the application of the full DIFI chain to a synthetic dataset (TDS-1) including all sources (core, lithospheric, magnetospheric and ionospheric) and some modeled instrumental noise (AR2 test).

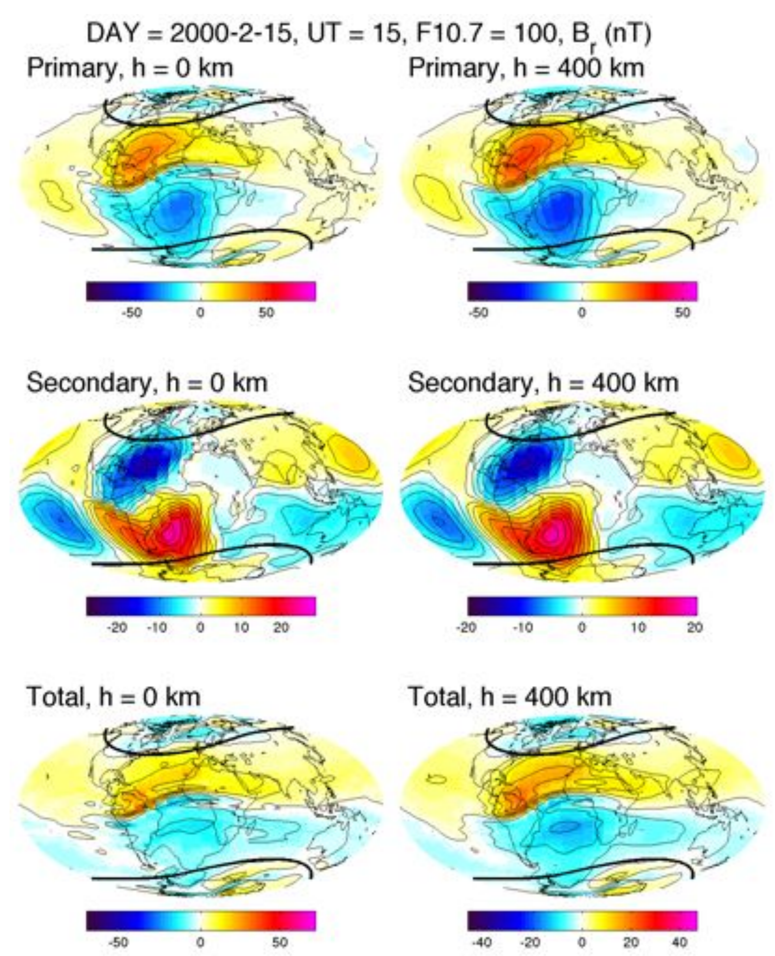
Performances are defined as the standard deviation of the field differences at ground with respect to the reference ionospheric field model, divided by the maximum field value. For the AR1 test, performances are less than 2%, ie, well below the threshold requirement of 10%. Performances for the AR2 test are below or slightly above the threshold requirement, depending on the component (see Table).

Component	AR1 test	AR2 test
R	0.00 +/- 0.15	0.01 +/- 1.78
THETA	0.00 +/- 0.10	-0.01 +/- 2.75
PHI	-0.01 +/- 0.10	0.00 +/- 2.04

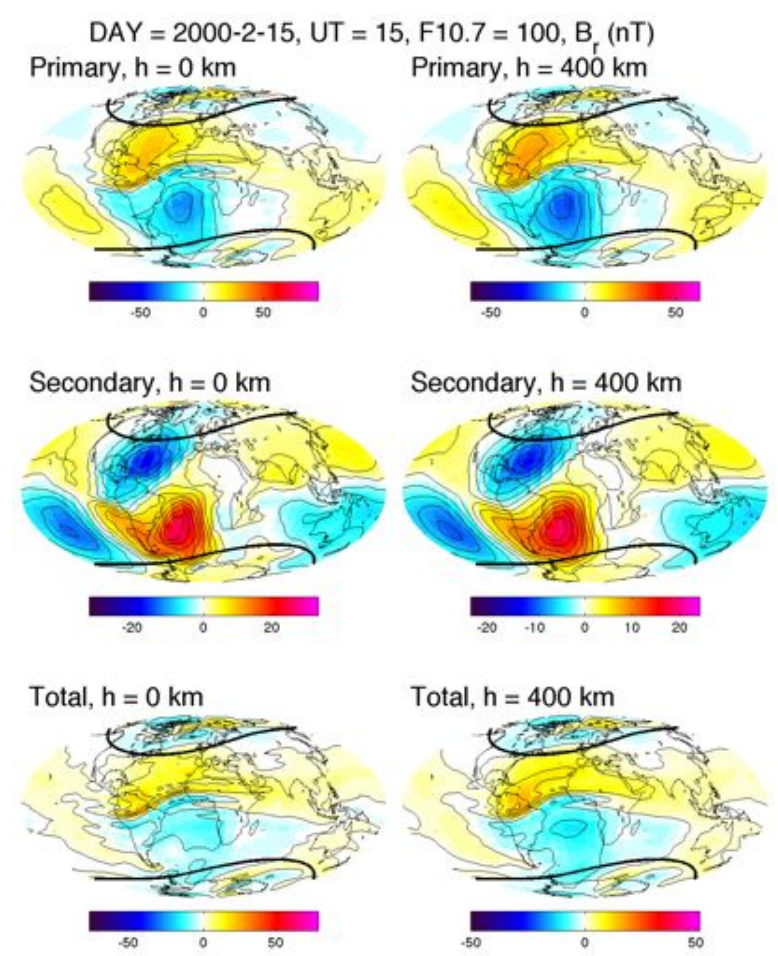
Residual statistics

Component	AR1 test	AR2 test
R	0.75 %	8.93 %
THETA	1.56 %	10.4 %
PHI	1.90 %	14.6 %

Model performances



Ionospheric field from the AR1 test (nT)



Ionospheric field from the AR2 test (nT)

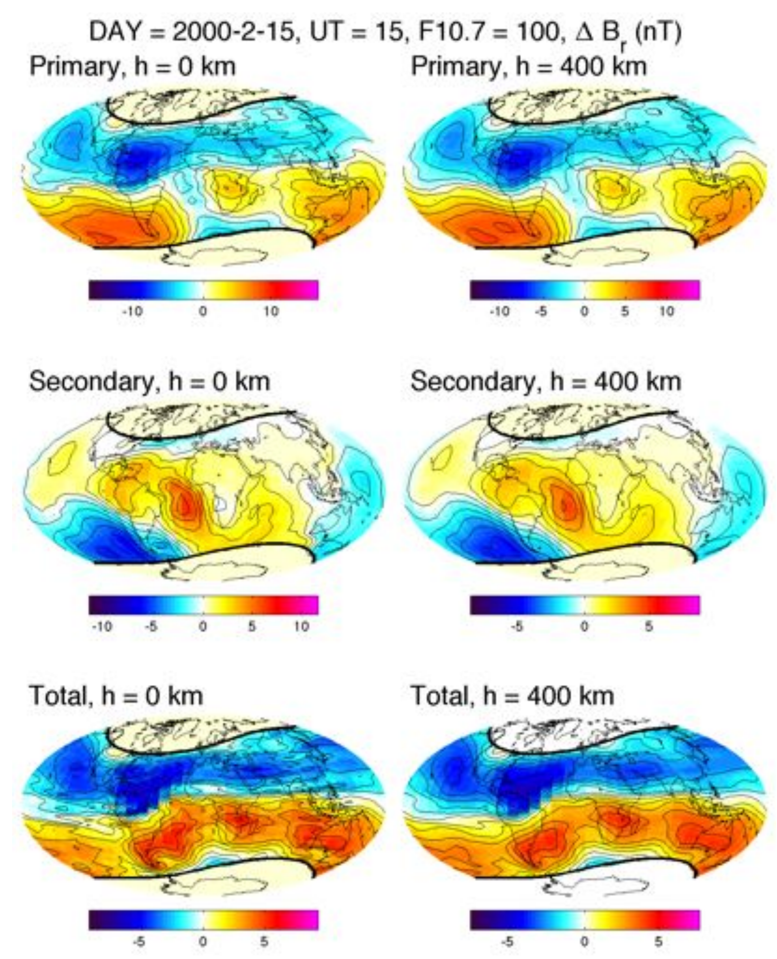
Maps of the AR1 field are indistinguishable from maps of the reference field. Field differences between the AR2 and reference fields are caused by imperfect corrections of the core and magnetospheric fields by other SCARF models.

Several **failure cases** were tested:

(a) Lack of magnetic vector data from Swarm C satellite
(b) Intermittent random bias (300 pT amplitude) on magnetic vector measurements from all three satellites
(c) Total failure of Swarm C satellite

Component	Failure (a)	Failure (b)	Failure (c)
R	15.7 %	8.42 %	15.7 %
THETA	19.4 %	10.2 %	19.3 %
PHI	29.5 %	14.4 %	29.2 %

Model performances (failure cases)



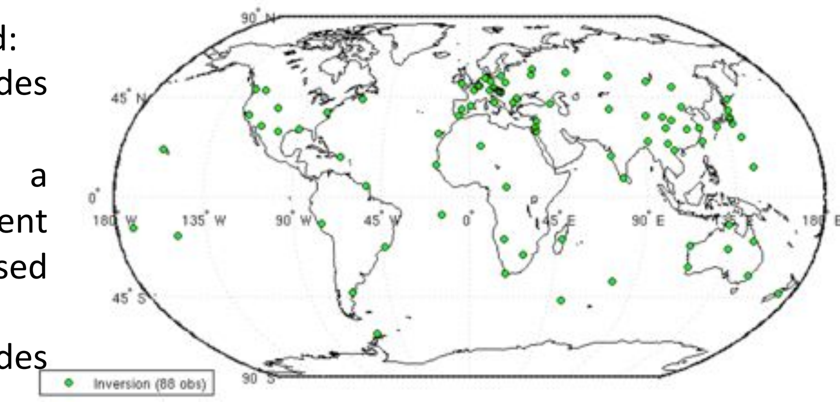
Field differences from the AR2 test (nT)

Improvements

The failure case analysis showed that any major failure at one satellite (either the vector magnetometer or the whole satellite) would severely deteriorate the overall performances of the DIFI chain (see table in test results). In order to mitigate this risk, and also possibly improve the performances of the chain in the nominal scenario, the DIFI chain was upgraded so that it could also ingest geomagnetic observatory data.

Various observatory distributions were used:

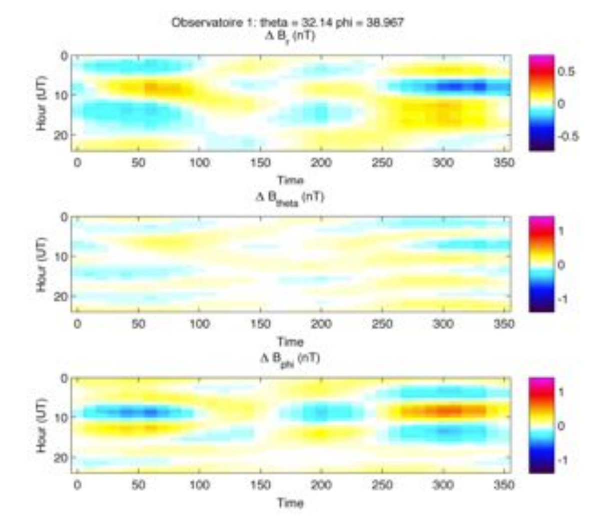
- 88 observatories at mid-to-low latitudes (AR1-like and AR2-like (A) runs)
- 90 observatories at all latitudes, using a more realistic distribution, including recent observatories, not including recently closed ones (AR2-like (B) run)
- 59 observatories at mid-to-low latitudes (AR2-like (C) run)
- 29 observatories at mid-to-low latitudes, with no significant loss of geographical coverage (AR2-like (D) run)



Observatory geographical distribution (AR1-like, AR2-like (A) runs)

Performances for the AR1 test were improved for all components, and most significantly for THETA and PHI).

Performances for the AR2 test were significantly improved on the PHI component, but only marginally on THETA and even slightly degraded on R. The actual geographical distribution of observatories has some effect on the result, but this effect is small if the distribution remains geographically homogeneous.



Observatory data residuals, AR1-like run

Component	AR1-like	AR2-like (A)	AR2-like (B)	AR2-like (C)	AR2-like (D)
R	0.62 %	10.9 %	11.5 %	11.3 %	10.7 %
THETA	0.90 %	9.33 %	9.75 %	9.59 %	9.37 %
PHI	0.85 %	5.04 %	4.79 %	4.51 %	5.50 %

Model performances (with observatory data)

Conclusions

1. Closed-loop tests (AR1 tests) using synthetic data showed that the DIFI algorithm is able to reproduce the original primary and induced ionospheric fields to a very high accuracy, at ground and satellite altitudes.
2. Tests relying on other SCARF models for data correction (AR2 tests) revealed that the pre-processing block is very sensitive to the quality of correcting models. However, the inversion block is stable and produces meaningful results despite imperfect data corrections.
3. Any major failure (vector magnetometer or the whole satellite) at one of the two satellites used by the DIFI chain would severely deteriorate the performances of the DIFI chain.
4. The use of observatory data improves the performance of the modeling for AR1-like tests, less so for AR-2 tests; its effect will have to be tested with real data.

References

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