

# SCARF - THE SWARM SATELLITE CONSTELLATION APPLICATION AND RESEARCH FACILITY

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**Abstract:** In order to take advantage of the unique constellation aspect of the Swarm mission, considerably advanced data analysis tools will need to be developed. Scientific use of data from the Swarm mission will also benefit significantly from derived products, the so-called Level-2 products, that take into account the features of the constellation. For this reason ESA has established a "Satellite Constellation Application and Research Facility" (SCARF), in the form of a consortium of several research institutions.

A number of Level-2 data products will be offered by this consortium, including various models of the core and lithospheric field, as well as of the ionospheric and magnetospheric field. In addition, derived parameters like mantle conductivity, thermospheric mass density and winds, field-aligned currents, an ionospheric plasma bubble index, the ionospheric total electron content and the dayside equatorial zonal electrical field will be calculated. Following the end of the currently running 30-month development phase, this service is expected to be operational for a period of 5 years after the launch of the Swarm Mission, which is scheduled for summer 2012.

All of the derived products will be available through the Swarm Payload Data Ground Segment (PDGS), located at ESRIN, the ESA Centre for Earth Observation in Frascati, Italy.

## The Level-2 Data Products

### Cat-1 Products

Complex algorithms to derive Level-2 products describing specific sources of the Earth's magnetic field. Product derived by SCARF since scientific experience is required to derive these products.

Science Objective	Name	Description
All Needed for L1b processing	MSW_EUL_2	Euler angles describing transformation from STR-CRF to VFM frame for satellites A, B, and C
O1: Core Field	MCO_SHA_2	Spherical harmonic model of the main (core) field and its temporal variation
O2: Lithospheric Field	MLI_SHA_2	Spherical harmonic model of the lithospheric field
O3: Mantle Conductivity	MIN_1DM_2	1D model of mantle conductivity
	MIN_3DM_2	3D model of mantle conductivity
	MCR_1DM_2	1D C-response maps
	MCR_3DM_2	3D C-response maps
O4: External Current Systems	MMA_SHA_2	Spherical harmonic model of the large-scale magnetospheric field and its Earth-induced counterpart
	MIO_SHA_2	Spherical harmonic model of the daily geomagnetic variation at middle latitudes (Sq and low latitudes (EEL))
Precise Orbit Determination	SP3xCOM_2	time series of position and velocity of the center of mass of each satellite
	ACCxCAL_2	Accelerometer calibration parameters from the POD process
	ACCxPOD_2	Time series of non-gravitational accelerations estimated by POD
O5: Magnetic Forcing of the Upper Atmosphere	ACCx_AE_2	Time series of calibrated and pre-processed accelerometer observations and of aerodynamic accelerations from Satellite x. (x=A,B or C)
	DNSxWIND_2	time series of neutral thermospheric density and wind speed

### Cat-2 Products

Algorithms leading to Level-2 products with minimum delay, e.g. for space weather applications. Near real-time capability. All Cat-2 products are provided in CDF format. Algorithms designed by SCARF, data processed by PDGS

Science Objective	Name	Description
O4: External Current Systems	IBIXTMS_2F	CAT-2: Ionospheric bubble index
	TECXTMS_2F	CAT-2: Time series of the ionospheric total electron content
	FAC_TMS_2F	CAT-2: Time series of field-aligned currents
	EEFX_TMS_2F	CAT-2: Time series of field-aligned currents
	EEFX_TMS_2	CAT-2: Equatorial Electric Field

### Example of MCO core field model

```

Product name
SW_TEST_MCO_SHA_2R_19980101T000000_20030101T000000_0001.DBL

# Input core field model for generation of core field part of TDC-1 data set.
# n_mix = 1, n_max = 20.
# 51 Snap-shots derived from order-isog=6 spline models. There are isog=2 snap-shots
# per node-interval, plus one at each node i.e. every isog=5 snap-shot corresponds
# to a spline node.
# Gauss coefficient format F11.6
1 20 51 6 5
1 1998.00 1998.10 1998.20 1998.30 1998.40 ...
1 0 -29576.796430 -29575.710728 -29574.634241 -29573.565540 -29572.502687 ...
1 1 -1693.946980 -1693.838403 -1693.727136 -1693.611818 -1693.500903 ...
1 -1 -5122.038131 5111.921493 5117.796579 5115.670116 5113.536484 ...
2 0 -2309.793580 -2311.180751 -2312.556466 -2313.920616 -2315.277000 ...
2 1 3058.875059 3051.410796 3057.940221 3057.463661 3056.981523 ...
2 -1 -2548.622966 -2551.872138 -2553.120633 -2553.368075 -2557.614122 ...
2 2 1661.519141 1661.263484 1661.057810 1660.841342 1660.623302 ...
2 -2 -492.677420 -493.890273 -495.107699 -496.328271 -497.550457 ...
3 0 1334.483767 1334.478280 1334.480542 1334.480123 1334.506292 ...
3 1 -2296.508319 -2296.303216 -2297.151739 -2297.482789 -2297.808748 ...
3 -1 -209.483862 -208.913432 -208.340820 -207.764238 -207.183928 ...
3 2 1247.909872 1247.812538 1247.717822 1247.625034 1247.533335 ...
3 -2 278.291831 277.810544 277.325647 276.837327 276.345760 ...
3 3 690.119217 690.275988 690.530698 691.727961 696.918823 ...
3 -3 -513.031082 -513.626410 -514.209373 -514.780763 -515.341350 ...
4 0 925.304661 925.304685 924.807330 924.562662 924.320544 ...
4 1 793.136676 793.614932 793.614932 793.614932 794.093111 ...
4 -1 279.222843 279.335146 279.650497 279.868796 280.089920 ...
4 2 226.556805 225.188496 225.018553 224.246895 223.473365 ...
    
```

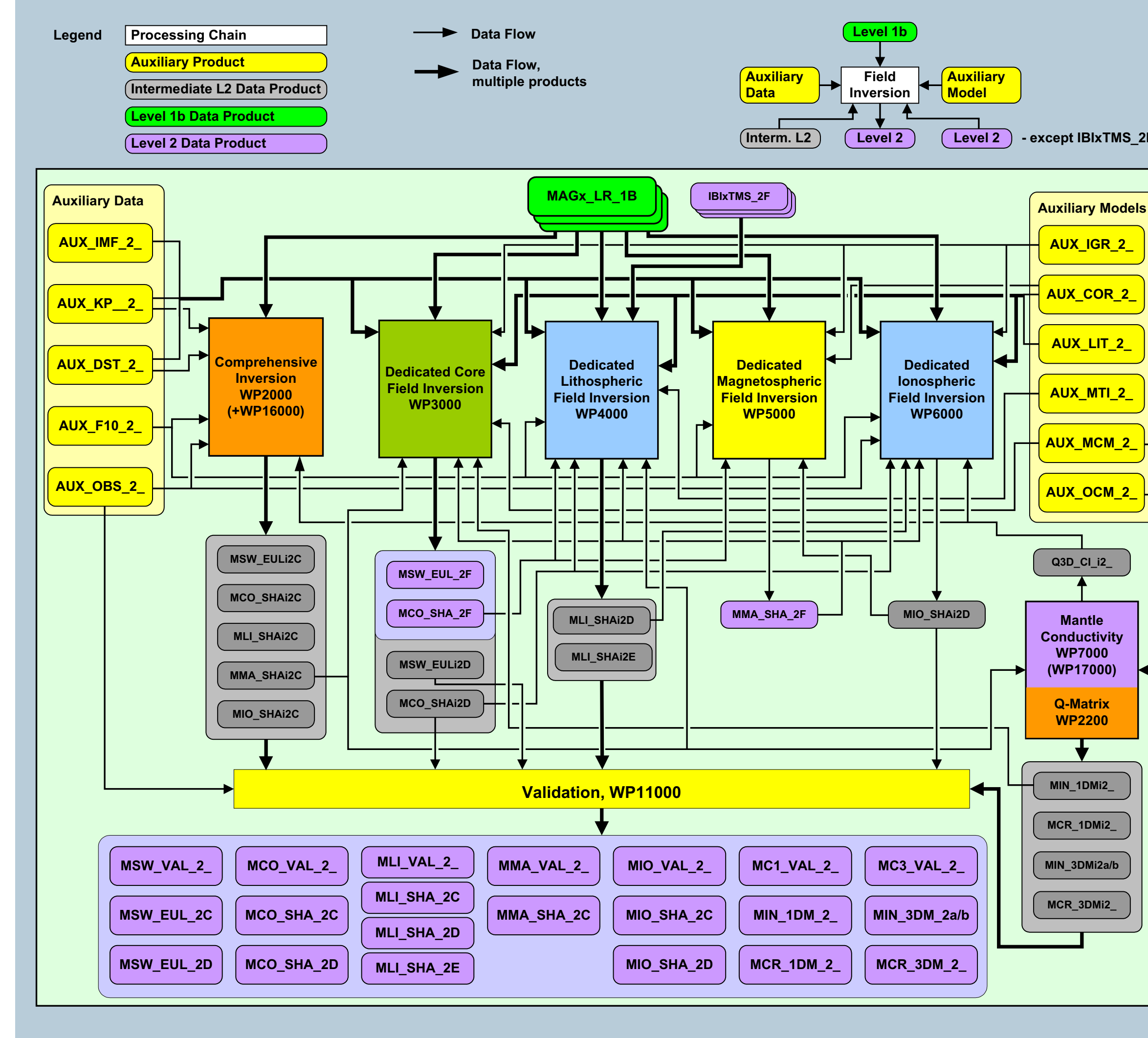
### Example of ionospheric total electron content (TEC)

Filename SW\_TEST\_TECATMS\_2F\_20081119T000000\_20081119T235959\_0001.DBL

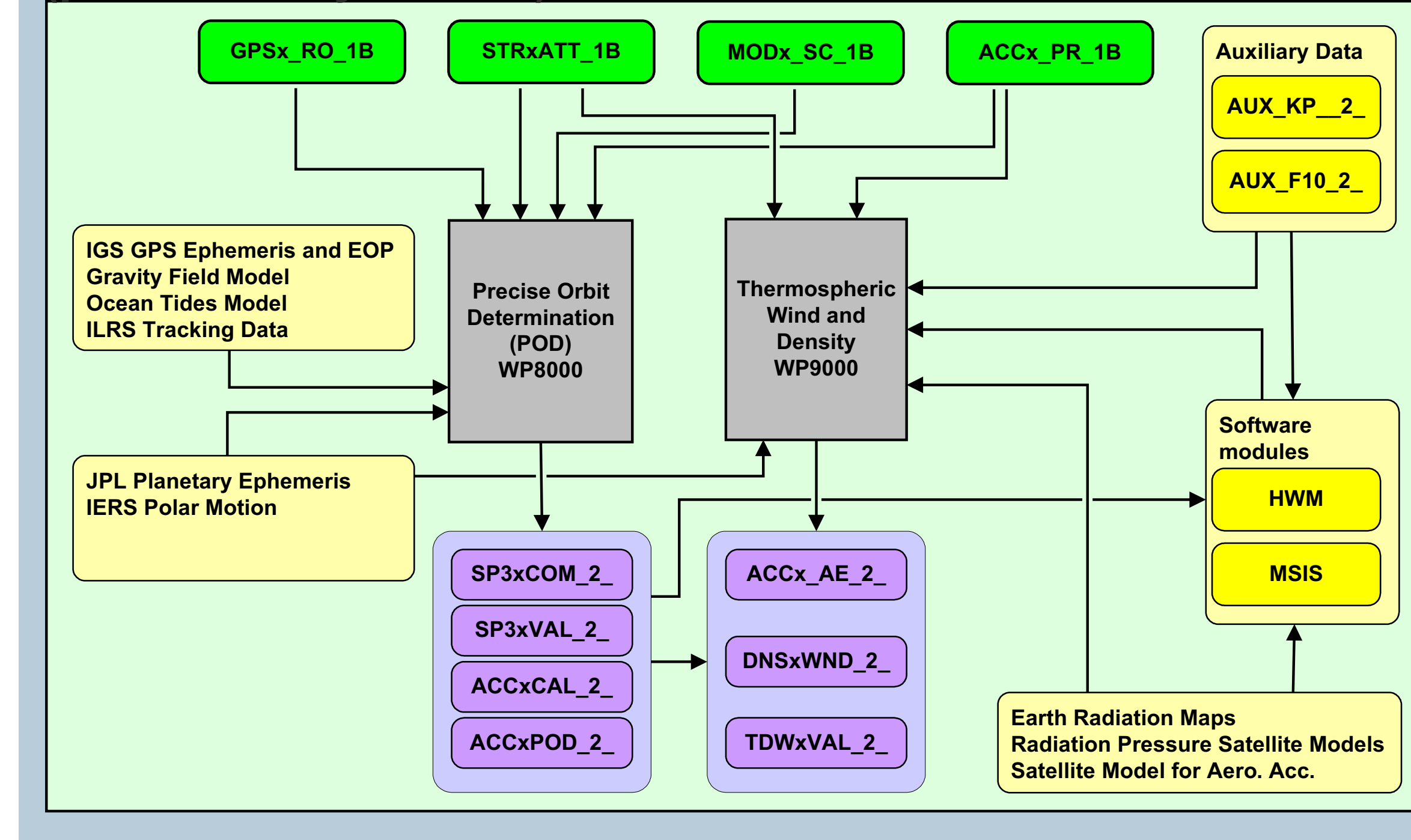
Each processed GPS-Swarm satellite link is uniquely defined by one row of 18 variable arrays, provided in CDF format

Variable	Description	Unit	Example
Timestamp	Time stamp in UTC (cdepoch)	UTC	19-Nov-2008 00:00:06
Latitude	Geographic latitude	degree	-16.3335
Longitude	Geographic longitude	degree	-18.7664
Radius	Geographic radius	m	6697840.4999
GPS_Position	X-,Y-,Z-coordinates (WGS84) of the GPS satellite	m	[26162272.8492; -5620247.17084; 44794.0304]
LEO_Position	X-,Y-,Z-coordinates (WGS84) of the LEO satellite	m	[5697840.4999; -2067805.7800; 1883619.9080]
PRN	GPS satellite PRN	-	4
L1	GPS L1 carrier phase observation	m	-1893872.6910
L2	GPS L2 carrier phase observation	m	-1893875.5805
P1	GPS P1 code phase observation	m	20508459.0015
P2	GPS P2 code phase observation	m	20508461.8378
S1	GPS signal-to-noise ratio or raw signal strength on L1	-	300
S2	GPS signal-to-noise ratio or raw signal strength on L2	-	501
Absolute STEC	Absolute slant TEC	TECU	8.0119
Relative STEC	Relative slant TEC	TECU	27.5071
STEC_RMS	Root mean square error of relative slant TEC	TECU	0.3190
DCB	GPS receiver differential code bias	TECU	-14.6977
DCB_Error	Error of the GPS receiver differential code bias	TECU	0.8100

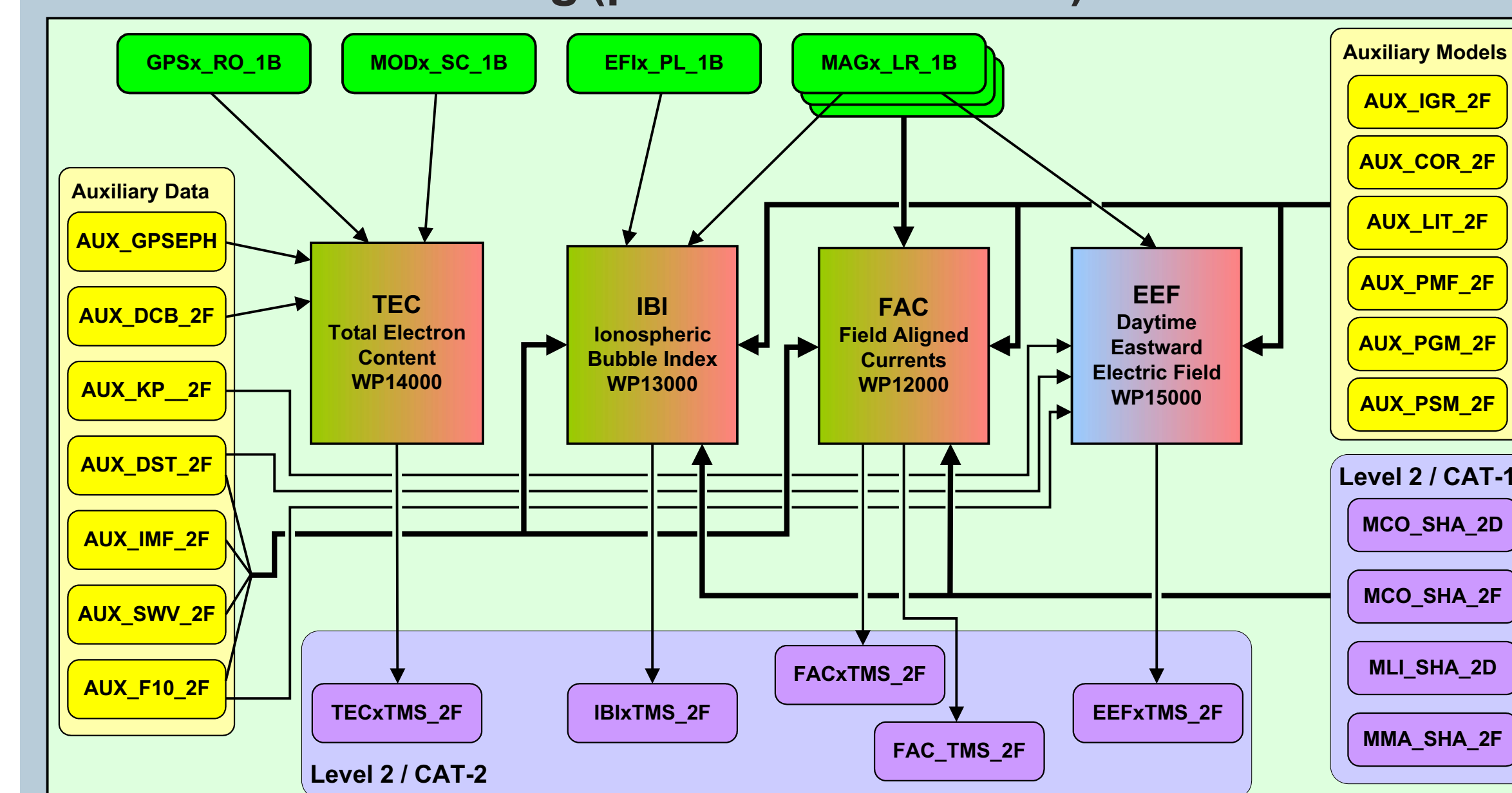
## Cat-1 Magnetic Data Processing (performed by SCARF)



## Cat-1 Processing of POD and Thermospheric Winds (performed by SCARF)



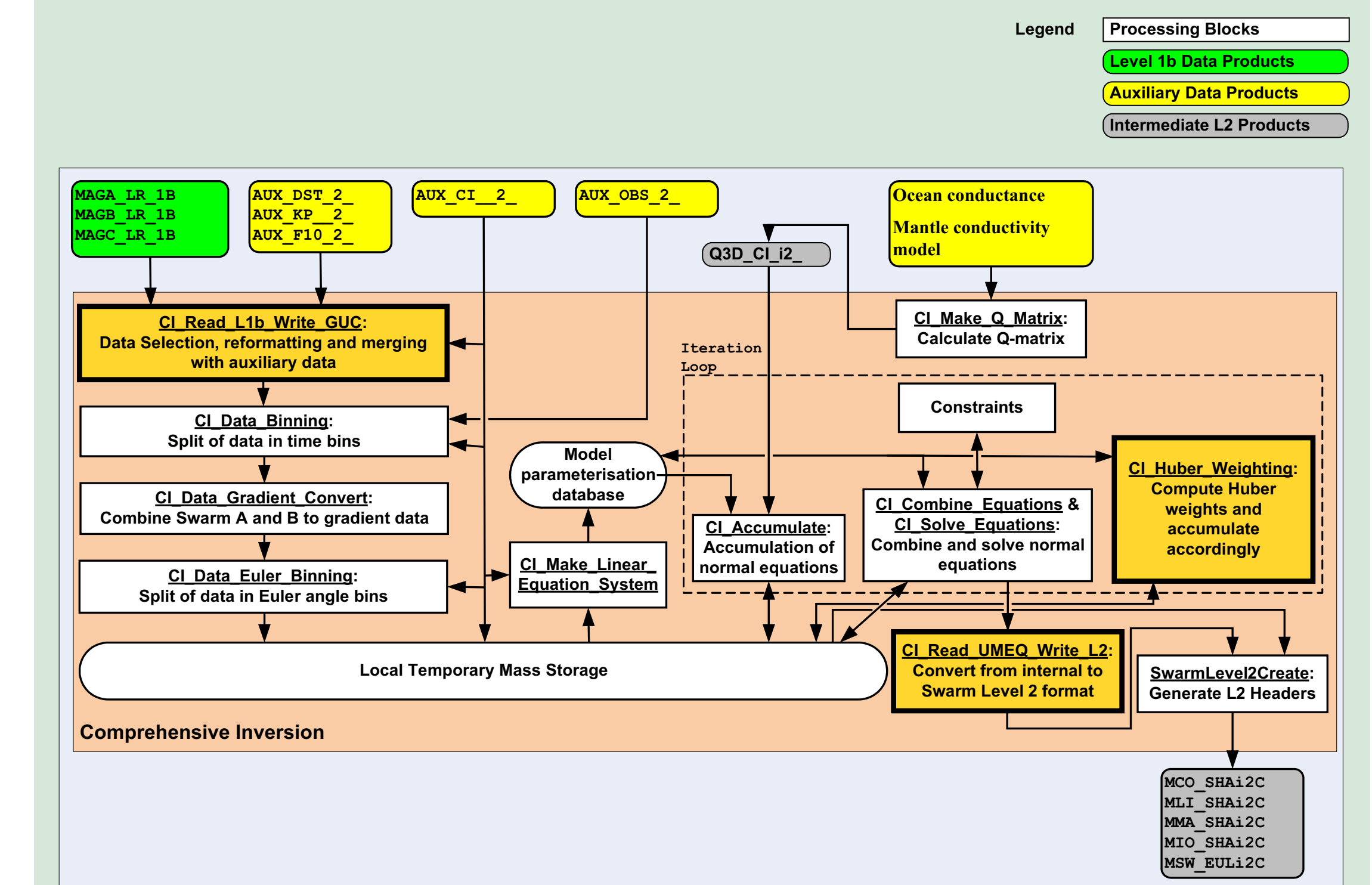
## Cat-2 Data Processing (performed at PDGS)



## The Comprehensive Inversion Chain

The Comprehensive Inversion takes Level-1b data (time series of magnetic field measurements) and estimates simultaneously the following L2 products:

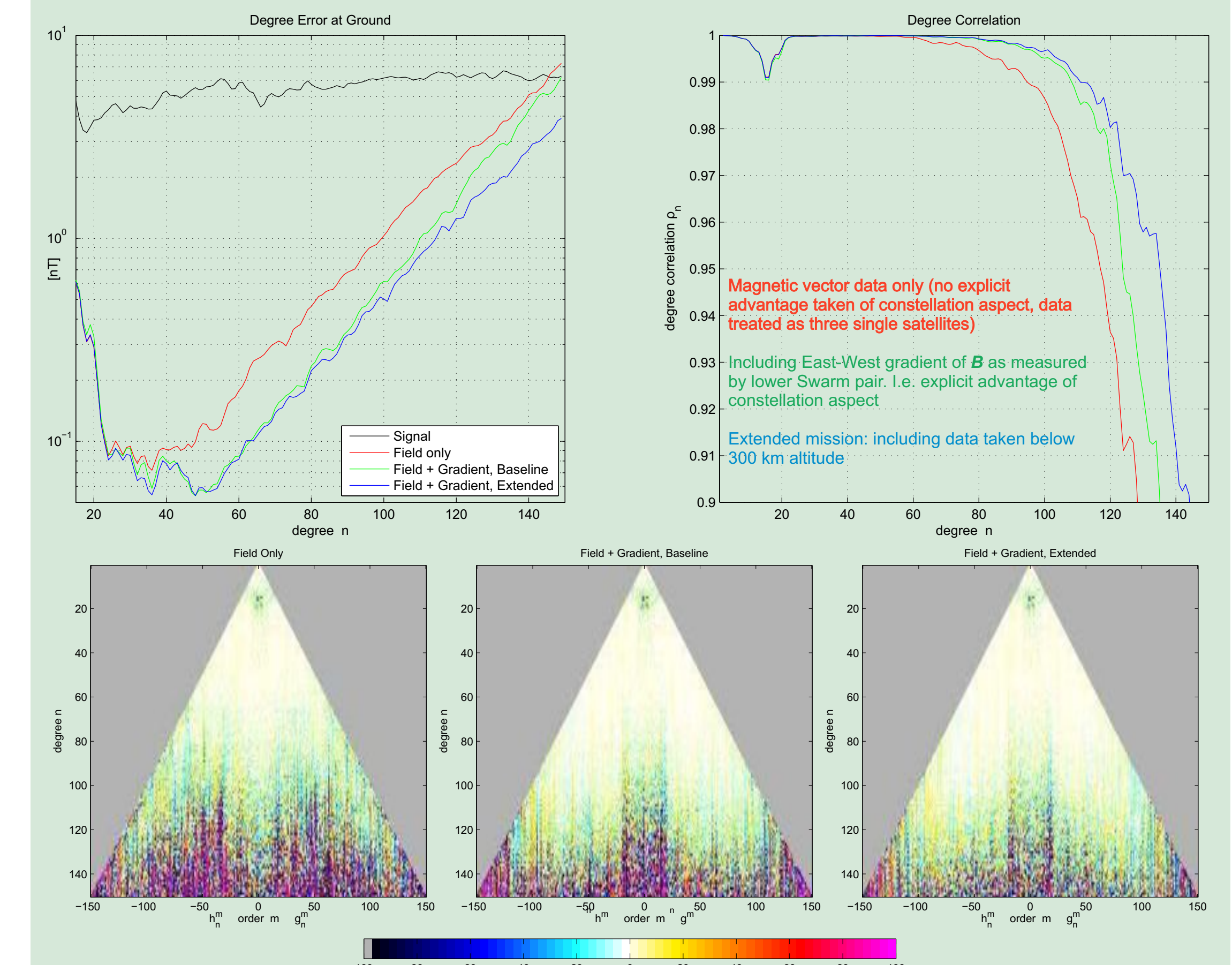
- MCO: Core field up to degree  $n = 20$ , temporal resolution order-5 splines, 6 months knot separation
- MLI: Lithospheric field up to  $n = 150$
- MMI: Ionospheric field in quasi-dipole frame, up to  $n = 60$ ;  $m = 12$ , semi-annual and quarter-daily periodicity; induced contributions accounted for by pre-defined conductivity of 3D mantle + oceans
- MMA: Magnetospheric field up to  $n = 3$ ;  $m = 1$ , 1 hour bins; induced field up to  $n, m = 6, 6$  hour bins
- MSW: Instrument alignment parameters (Euler angles), 30 days bins



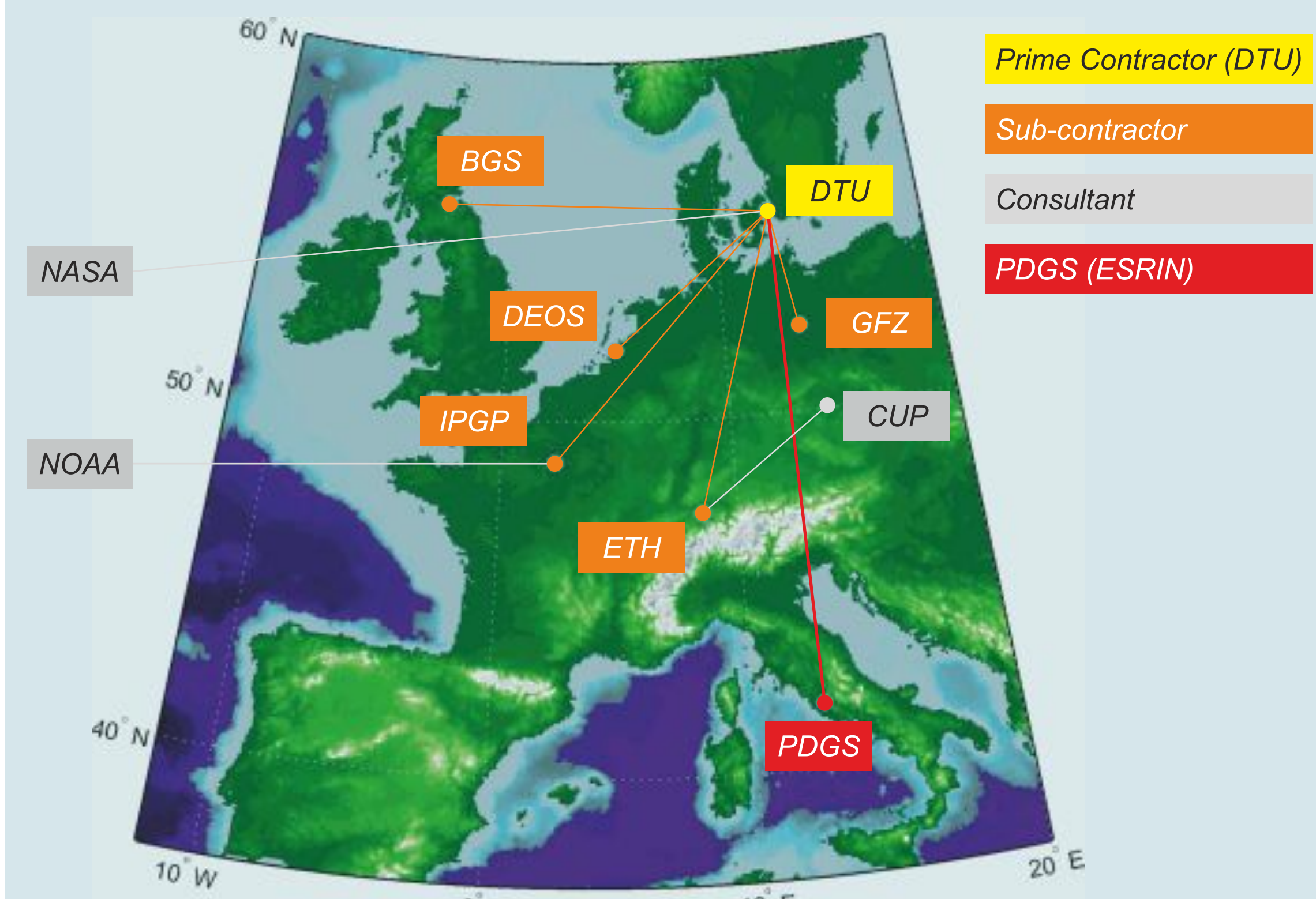
## Test of the Comprehensive Inversion Chain

Simulation of the magnetic measurements of a full Swarm Mission by generation of synthetic L1b data using sophisticated input models (of the core, lithosphere, ionosphere, magnetosphere plus induced contributions). The resulting L1b time series are subsequently inverted using the Comprehensive Inversion scheme and the estimated models are compared to the input models.

## Assessment of the lithospheric field



## The Partners of SCARF



SCARF Development Phase: October 2010 - March 2013  
 SCARF Exploitation Phase: 2013 - 2018 (5 years)

Scheduled Swarm launch: July 2012

## Milestones of SCARF Development Phase

