Swarm satellite A and C Field Aligned Currents in a rotated frame

Code Documentation

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Overview

The program was created with Matlab as a part of a summer job employment for ionosphere physics research unit in the University of Oulu. Its main purpose is to calculate Field Aligned Currents (FAC) in a coordinate frame that has been rotated by an angle θ from the North-South axis. The program is capable of this with either low resolution (LR, 1 Hz) or high resolution (HR, 50 Hz) data. To fully utilize the program, two main scripts, `remove_CHAOS.m` and `rotated_FAC.m`, and their respective subscripts are required.

remove_CHAOS.m

The purpose of this script is to remove the CHAOS field model from the satellite's magnetometer data. The code can also limit the data to include only the period in which the user is interested in.

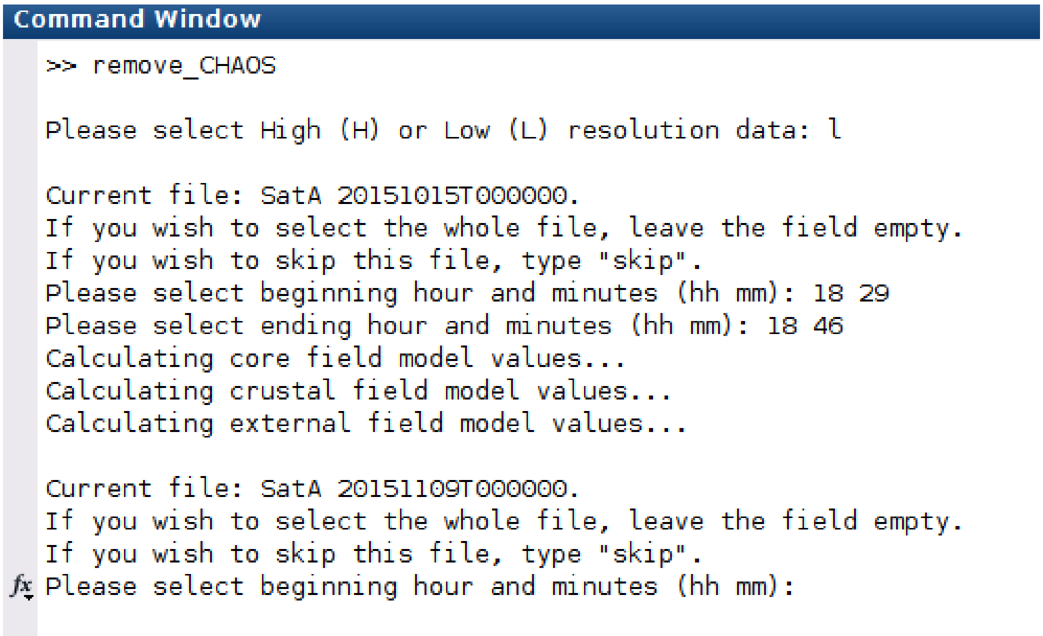

Figure 1: Example of a typical execution of remove_CHAOS.m.

The first script requires .cdf files from ESA, which include the necessary magnetometer data (low or high resolution) for satellites A and/or C. These files can be found in `ftp://swarm-diss.eo.esa.int/Level1b/Latest_baselines/`. Please note; a registered account is required to access the site.

Once the files are downloaded and found in a subfolder `cdfData/`, the script can be run. It goes through all of the .cdf files in the aforementioned folder and the user can process or skip each file individually. The key input when running the code is the selection between low or high resolution data. When one is chosen, the program ignores the other completely for that runtime. After this, the user may choose the time window one is interested in. As each .cdf file includes data only from a single day, the inputs required are hours and minutes, separated by a space. For example, inputs "21 22" and "23 01" would limit the data calculations between 21:22 and 23:10. It is possible to run the program for all of one day's data. This, however, is not recommended as the CHAOS field removal is highly taxing mathematically and longer data will results in greatly increased runtimes. After the CHAOS field for a file has been removed, the values are stored in a file with a format of `swarmMag_*.mat`, where the symbol "*" is replaced with the resolution in question, satellite name and the event date, e.g. *swarmMag_HRSatA20151109T000000*.

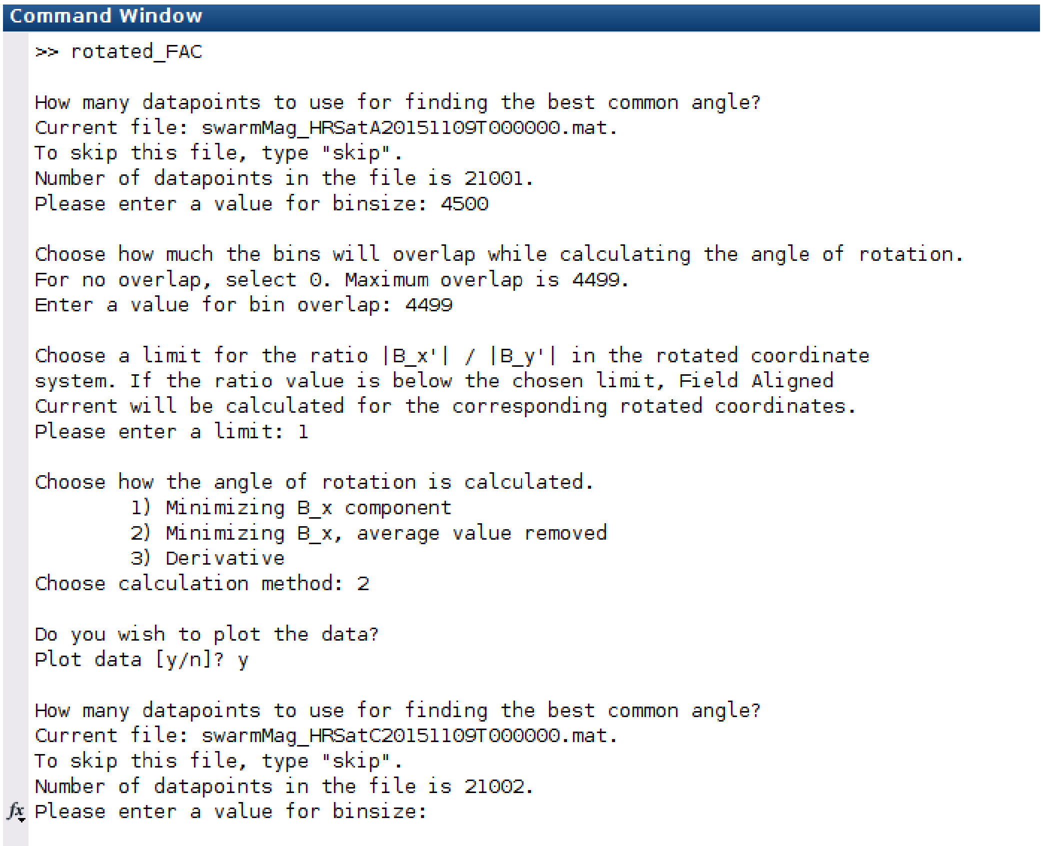

Figure 2: Example of a typical execution of rotated_FAC.m.

It should also be mentioned that all of the user inputs in this script and also in `rotated_FAC.m` have error checks to prevent unwanted values and resulting crashes, so no need to be alarmed if a typo or two slips in.

rotated_FAC.m

The purpose of this script is to find the best common angle of rotation θ and calculate field aligned currents in a coordinate frame rotated by that angle.

To run this script, a .mat file created by `remove_CHAOS.m` is necessary. The script will run through all of the .mat files with the right format and the user can process or skip them one by one, similar to `remove_CHAOS.m`.
First required user input is selecting the number of datapoints to use for finding the best common angle θ, ie. binsize. Binsize has the greatest im-

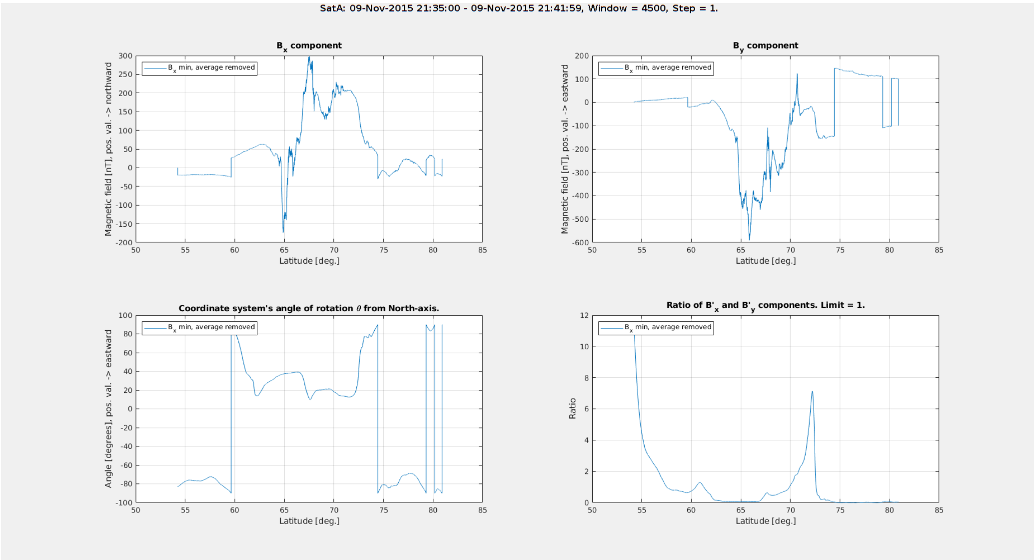

Figure 3: Example of a multiplot.

pact of all the inputs on the final result so the user should try multiple values to find the best result. However, there are optimal value ranges for both LR and HR data. See section analysis.m for more details. Binsize defines the range of datapoints inside which the best common angle is defined. Due to the nature of the data, values calculated at the beginning and end of the *entire* datarange are not as accurate as the rest, so choosing a range of times slightly larger than necessary with `remove_CHAOS` is highly advised.

Next input asks how much the bins should overlap one another when calculating the angles. Another way of understanding this is that this value defines how much the bin will "jump" after finding the best common angle for any range. For example, if the binsize is 250 and overlap is 245, best common angle will be calculated at every $250 - 245 = 5$ points. This, however, does not mean that there will be empty datapoints between every 5th point. Instead, the angle will have the same value for every segment of 5 corresponding datapoints. In theory, choosing the maximum value of overlap should give the best results. Maximum value is always shown to the user while the program asks for overlap input.

The third input is selecting a limit for the ratio $\mid B'_x \mid / \mid B'_y \mid$. For each point, if this ratio is above the chosen limit, Field Aligned Current (in rotated and non-rotated frame) will not be included in the final data. This is to exclude the situations where the B'_x component is too large, which causes unreliable results when calculating the currents.

The fourth input asks the user what method of calculation should be used for finding the best common angle: 1) minimization of the B_x component, 2) minimizing the B_x component and removing the average value $\langle B_x \rangle$ or 3) derivative. The end results can vary substantially based on the method chosen. See section analysis.m for more detailed view of the differences between these methods.
Last input determines whether the data is plotted at the end of calculations or not. If the user selects "y" ie. "yes", 3 plots are generated: multiplot (see Figure 3) including B_x and B_y components, angle of rotation and the ratio $| B'_x | / | B'_y |$. On the other two plots are the Field Aligned Currents in a non-rotated frame and FACs in the rotated frame. All of these plots are as functions of latitude.
After the calculations have been completed, the results are saved in a .mat file in the format of `swarm_bdot_*.mat`, regardless if the data was plotted or not.
If the user wishes to skip the input processes and create, for example, a loop of his/her own, the actual calculations are done in the files `calc_field_rot.m` and `calc_field_rot_1step.m` (for when maximum overlap is used) and in their subscripts.

analysis.m

The purpose of this script is to test different values of window size to find the optimal value ranges.

This program automatically loops through different artificial datafiles created by Heikki Vanhamäki (university of Oulu) to test the `rotated_FAC.m` script and to find the optimal binsize values for both LR and HR data with all of the 3 calculation methods. The datafiles include the true values of the artificial Field Aligned Currents and their angles or rotation, which can be used to compare the results found by the script. The comparison is done so that for each datapoint the absolute values of the remainders of the two angles are summed over the whole dataset. The smaller the resulting number is, the more accurate the calculation has been. The results of this analysis can be seen in Tables 1 and 2.

In actual data, the electrojet phenomenon is always present and it affects the magnetic field, which in turn distorts the FAC calculations. For this reason the $B_x - \langle B_x \rangle$ calculation method was included and as can be seen from the results, it is the most accurate method in files where electrojet is simulated. If ejet can somehow be neglected due to its effect being

LR simulation data	B_x min	$B_x - \langle B_x \rangle$	Derivative
FAC ideal	**2**	22	16
FAC noisy1	**72**	72	160
FAC noisy2	**85**	94	160
FAC noisy3	**118**	150	120
FAC noisy4	**124**	158	160
FAC+Ejet ideal	98	**88**	46
FAC+Ejet noisy1	96	**50**	22
FAC+Ejet noisy2	100	**44**	88
FAC+Ejet noisy3	96	92	**36**
FAC+Ejet noisy4	68	94	**58**

Table 1: Results of LR analysis. Binsizes are between 2-160 with an increase of 2 every loop. Best method of calculation for each file has been bolded.

HR simulation data	B_x min	$B_x - \langle B_x \rangle$	Derivative
FAC ideal	**20**	1070	770
FAC noisy1	**3620**	3770	6470
FAC noisy2	**3620**	4220	6470
FAC noisy3	6470	**6470**	5720
FAC noisy4	**4370**	6470	6470
FAC+Ejet ideal	4970	**4520**	2120
FAC+Ejet noisy1	4820	**4370**	3470
FAC+Ejet noisy2	4820	**4670**	2120
FAC+Ejet noisy3	3620	**4820**	2270
FAC+Ejet noisy4	3620	**4970**	2270

Table 2: Results of HR analysis. Binsizes between 20-6500 with and increase of 150 every loop. Best method of calculation for each file has been bolded.

insignificant, the minimization of the B_x component method is the best method. Derivative does not seem to be a noteworthy option with its values being far less accurate than the other two methods' in almost all situations.

From the tables we can also estimate the optimal binsizes, which are roughly **80-100 for LR data** and **4500-5000 for HR data**. These, however, are merely guidelines, because actual data can and will differ from the simu-

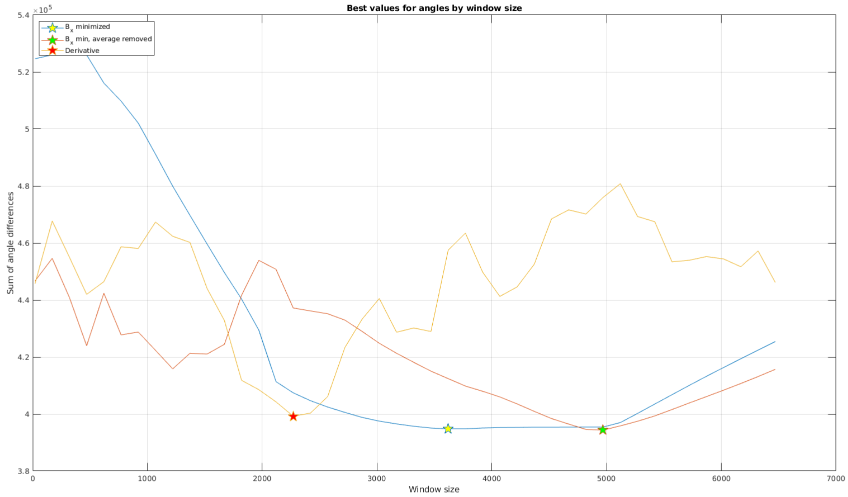

Figure 4: Example of a analysis plot for HR FAC + Ejet noisy4 datafile. The minimum values for each method of calculation are marked with a star symbol.

lations. It is ultimately up to the user to find window size values which give sufficiently accurate results for each event .

Code requirements

Here are listed all of the files and subscripts required to run the main programs.

remove_CHAOS.m

- `CHAOS6_AB.m`
- `sub_ReadMagData_HResolution.m`
- `sub_ReadMagData_LResolution.m`
- `aacgm_v2` script package
- `CHAOS_6` script package
- ESA .cdf file(s) in `/cdfData` folder

rotated_FAC.m

- `calc_FAC.m`
- `calc_field_rot.m`
- `calc_field_rot_1step.m`
- `find_theta.m`
- `swarmplot.m`
- Datafile(s) in the format `swarm_bdot_*.mat`

Notes

- If there are any unexpected problems with the calculation/data and a program error is assumed to be the culprit, best bet is to delete the `swarmMag_*.mat` and `swarm_bdot_*.mat` files and start the process fresh with `remove_CHAOS.m`.
- If you interrupt the program with ctrl+C, use of "clear all" command is recommended after.
- When processing HR data, the programs *will* take a long time to run due to the massive increase in the number of datapoints when compared to LR data.
- I have avoided going into too great a detail about the code in this documentation, because the code itself is sufficiently commentated for those interested.
- Even though I have tested these scripts extensively, I cannot guarantee that a bug or two has not slipped in, as one sometimes is blinded to one's own mistakes. Major bugs should be squashed at least.