Verification of Magnetic Declinations computed by World Magnetic Model

For the

FAA Target Generation Facility

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August 2002

1 Introduction

The World Magnetic Model (WMM) predicts the magnetic declination at specific latitudes and longitudes for specific dates. The original implementation of the WMM in C from the United States Geological Survey (USGS), was re-implemented in Java by Jim Mauroff and Mike Ross at the Target Generation Facility (TGF) at the FAA Technical Center. To verify the accuracy of these implementations of the WMM, a program, TestWMM, was written that compared the magnetic declinations predicted by both C and java implementations of the WMM with data reported for 19,720 airports by the National Flight Data Center (NFDC).

The tests show that the C and Java implementations give nearly identical results, but these results disagree substantially with the magnetic declination data reported in the NFDC data set.

The purpose of this paper is to explain whether this disagreement is due to a problem with the WMM model or with the accuracy of the NFDC magnetic declination data.

The conclusion is that the problem lies with the NFDC data and that the output of WMM algorithms is suitable for use in TGF simulations.

2 Magnetic Declination and the World Magnetic Models

Magnetic declination is the difference between true North and the direction of the local magnetic field (horizontal component) at a given location. Also called variation, this difference changes over time because the location of the magnetic poles is changing.

The causes for this change are not completely understood, so mathematical models of the earth's magnetic field are re-calibrated every 5 years.

The Defense Mapping Agency (DMA) produces the WMM (World Magnetic Model) Series of Models[1]. These models are updated every 5 years on January 1st of years divisible by 5, e.g., 1980, 1985, 1990, 1995, 2000 by the U.S. Naval Oceanographic Office in cooperation with the British Geological Survey (BGS). The models are based on Geomagnetic Survey measurements from aircraft, satellite, and geomagnetic observatories

The WMM models are composed of two parts: a Main Field Model, which is valid at the base epoch of the current model, and a Secular Variation Model, which accounts for changes in magnetic declination based the movement of the magnetic poles during the epoch.

The WMM models compute the geomagnetic field potential at a location, elevation, and date by summing spherical harmonic factors with coefficients appropriate to the epoch

[1] See http://www.seaspace.com/service/support/TeraScan_Docs/doc/man5/magnetic_model.html

year of the model. The coefficients represent a best fit of field measurements of magnetic field readings to the spherical harmonic equations modeling geomagnetic field.

The coefficient files include spherical harmonic coefficients up to degree and order 12, which experience has shown, describes magnetic field potential due to movement of the Earth's core (long wavelength spatial magnetic fluctuations), also called the Main Field. If the coefficients included higher order (than 12) values, the model would also account for the more minor sources of magnetic field potential from the Earth's mantle and crust (intermediate and short wavelength spatial magnetic fluctuations). Specifically, the WMM model does not account for isolated anomalies in magnetic declination due to iron deposits, etc., and cannot predict nonsecular temporal fluctuations of geomagnetic field due to changes in the magnetosphere or ionosphere.

In general, the accuracy of the WMM is estimated to be < 0.5 degrees as long as the location is further than 15 degrees latitude from the poles.

The sets of geomagnetic coefficient representing the main field for a particular epoch are issued every 5 years and are called the International Geomagnetic Reference Field (IGRF)[2]. If a previous IGRF is modified using new data not available at the time of its production, the result is called a Definitive Geomagnetic Reference Field (DGRF).

The WMM program (geomag) converts the location inputs from geodetic coordinates (latitude, longitude, altitude) to spherical coordinates (r, θ, φ). It then computes unnormalized associated Legendre polynomials and derivatives via recursion relations using coefficient data for the epoch year. In the spherical coordinate space, the model accumulates terms from the spherical harmonic expansions to compute the magnetic field potential for the translated location and elevation. The Secular Change model assumes a linear (1st degree approximation) rate of change and applies an offset to the magnetic field potential based on input date. Finally, the program rotates the magnetic field components from spherical back to geodetic coordinates.

3 TestWMM

TestWMM is a java program that reads a large file of airport information from the NFDC and compares the reported magnetic declination with that computed using WMM algorithms. The NFDC data describes 19,720 airports by airport ID, latitude, longitude, altitude, and reported magnetic declination.

TestWMM computes the magnetic declination for each airport by supplying the latitude, longitude, altitude, and date to a sub-program. The differences between reported and computed magnetic declinations are squared, totaled, etc., to compute a standard deviation between the two sets of magnetic declination data.

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[2] See http://www.ngdc.noaa.gov/IAGA/wg8/igrf.html

Using NFDC data for June 13, 2002, the standard deviation between reported and computed magnetic deviation is 0.732.

The NFDC issues a CD of a variety of Aviation Data every 56 days and so gives the impression that the data, including magnetic declination, is re-measured every 56 days.

The large size of the standard deviation is the specific reason for concern about using the WMM algorithms for TGF simulations.

4 Analysis

4.1 Best Fit in Time

On the suspicion that the NFDC data might not all be current, the TestWMM code was slightly modified ("MyTestWMM") to compare the 6/13/2002 NFDC magnetic declination data to computed magnetic declination for earlier dates. If the NFDC data is current, one would expect that this experiment would produce larger standard deviations.

However, magnetic declinations predicted by the WMM algorithm for earlier dates were better fits to the NFDC magnetic declination data of 6/13/2002. In fact, they were uniformly better (lower standard deviation) as dates were reduced. Summary outputs of MyTestWMM in Appendix A show that this improvement continues for trials back to 1/13/1990.

4.2 Specific Airports with High Variation

The output of TestWMM was sorted to identify the airports with the highest variation between the reported NFDC magnetic declination and the computed magnetic declination. A large number of airports at the top of this sorted data are in Alaska with a scattershot of other locations Pennsylvania, Illinois, Florida, and Wisconsin. The lack of any systematic geographic pattern in these other airports suggest that the problem is in the NFDC data; if instead, there were many airports in the Pacific Northwest (close to Alaska), and fewer as distance increased from Alaska, the WMM model might have come under greater suspicion.

To test this theory further, an independent source of magnetic declination data was needed.

The Internet site www.airnav.com reports airport latitude, longitude and magnetic declination, with a note documenting when the magnetic declination was measured. This permitted a comparison with computed magnetic declination using on-line WMM models at the USGS site, gldpsp.cr.usgs.gov/geomag/geomagAWT.html. There is very good agreement between the reported magnetic declination and computed magnetic declination when the year of the reported data is used in the WMM models.

However, when the WMM models computed magnetic declination for 6/13/2002 at the locations of the airports in the www.airnav.com sites, the results were different than the reported magnetic declination, in just the same magnitude and direction from that discovered in TestWMM trials.

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For Alaskan airports, this difference in magnetic declination between 2002 and 1985 is as much as 4 degrees. (The www.airnav.com site reports magnetic declination of many Alaska airports for the year 1985).

4.3 New and older NFDC data

To further test the hypothesis that NFDC data was out of date, a data set of NFDC data for 12/30/1999 was compared to the NFDC data for 6/13/2002. One germane fact emerged: the precision of the magnetic declination data was limited to degrees only, whereas the magnetic declination computed by WMM algorithms has a much higher precision. For example, a typical NFDC magnetic declination is 11.0 or –8.0, whereas the WMM algorithms produces a magnetic declination like –12.313046270139704.

The two sets of data had 18,167 locations in common and of these, 133 airports reported different magnetic declinations for the two dates. The magnitude of the differences were mostly 1 degree, but 33 of the 133 airports had differences larger than 1, 6 had differences larger than 6, and 2 had differences of 10 degrees!

Incidentally, the two NFDC data sets also showed that 1332 airports changed IDs between 12/20/1999 and 6/13/2002.

The WMM model was run to see how large the change "should" be for the 19,720 airports of the 6/13/2002 NFDC data. In other words, the model was run with the 6/13/2002 date and again with the date 1/13/2000 and the magnetic declinations for each airport compared. The largest magnitude of change was less than 0.3 degrees for any airport.

The magnetic declination values from the WMM model were rounded to the nearest integer and results compared between the 6/13/2002 and 1/13/2000 trials. With this rounding of magnetic declination, 4,810 of the 19,720 airports changed magnetic declination values, all by 1.

This suggests that if measurements were actually made for the 18,167 airports on 12/30/1999 and again on 6/13/2002, there should be many more reported changes than the 133 airports that actually changed in the data. This, and the fact that for 33 airports, the reported change in magnetic declination was greater than 1, suggests that the NFDC data does not actually represent a re-measurement of magnetic declination every time a new data set is issued.

The analysis of the NFDC data for 12/30/1999 and 6/13/2002 concludes that the reported magnetic declination data changes too slowly for it to represent actual measurements at airports on the respective dates, and that the data includes a small incidence of clerical errors.

5 NFDC Magnetic Declination Epoch Year

A closer examination of the airport information file, apt.txt, on a FAA National Airspace System Resource Aeronautical Data CD, showed that the data includes a "magnetic declination epoch year" field after the "magnetic variation" field. The magnetic declination (variation) in the NFDC data is qualified by a year in which the data was measured. The airport information file from the CD of April 18, 2002, has the following distribution of epoch years:

1965	31
1975	15
1980	353
1984	64
1985	13848
1986	87
1987	1
1990	1997
1995	2084
1999	1
2000	791

This substantiates the hypothesis that the NFDC data is older than suggested by the release date of the distribution CD and that a substantial number of measurements of magnetic declination were made in 1985.

6 Conclusion

The disagreement between the results of the WMM algorithm and the magnetic declination reported by the NFDC is the result of the NFDC data being out of date. This is demonstrated by the fact that the agreement between NFDC magnetic declination for an airport and the that computed by the WMM algorithm improves for increasingly older dates – see Appendix A. Further, the very small number of changes in reported magnetic declination between the 6/13/2002 NFDC data set and the 12/30/1999 NFDC data set suggests that values from one set are often carried forward into the next data set.

Furthermore, the WMM algorithm produces magnetic declination values that do agree with values at www.airnav.com, which provides a basis for trusting the WMM algorithms. In particular, comparisons of values from Alaska airports, where magnetic declination changes significantly with time, provides a strong basis for confidence in the WMM algorithms.

Appendix A: Results of "Best fit in Time"

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[Fri Aug  2 09:37:37]$
[Fri Aug  2 09:37:39]$
[Fri Aug  2 09:37:39]$
[Fri Aug  2 09:37:39]$ tmymf
 Aces to Java Standard Deviation: 0.7320682563258165   6/13/2002
 Aces to Java Standard Deviation: 0.7295256511070447   5/13/2002
 Aces to Java Standard Deviation: 0.7270754862732507   4/13/2002
 Aces to Java Standard Deviation: 0.7245545293605143   3/13/2002
 Aces to Java Standard Deviation: 0.7222871363967186   2/13/2002
 Aces to Java Standard Deviation: 0.7197875452577187   1/13/2002
 Aces to Java Standard Deviation: 0.7172993511586946   12/13/2001
 Aces to Java Standard Deviation: 0.7149023851518336   11/13/2001
 Aces to Java Standard Deviation: 0.7124369665743467   10/13/2001
 Aces to Java Standard Deviation: 0.7100622677606402   9/13/2001
 Aces to Java Standard Deviation: 0.7076200946333852   8/13/2001
 Aces to Java Standard Deviation: 0.7051899175409304   7/13/2001
 Aces to Java Standard Deviation: 0.7028496724545862   6/13/2001
 Aces to Java Standard Deviation: 0.7004434653772006   5/13/2001
 Aces to Java Standard Deviation: 0.6981266535832527   4/13/2001
 Aces to Java Standard Deviation: 0.6957449073803266   3/13/2001
 Aces to Java Standard Deviation: 0.6936044977694306   2/13/2001
 Aces to Java Standard Deviation: 0.6912468852059525   1/13/2001
 Aces to Java Standard Deviation: 0.6889058522389268   12/13/2000
 Aces to Java Standard Deviation: 0.6866552540729954   11/13/2000
 Aces to Java Standard Deviation: 0.6843424853359295   10/13/2000
 Aces to Java Standard Deviation: 0.6821168808248181   9/13/2000
 Aces to Java Standard Deviation: 0.6798301973442317   8/13/2000
 Aces to Java Standard Deviation: 0.6775569701775789   7/13/2000
 Aces to Java Standard Deviation: 0.6753700132540366   6/13/2000
 Aces to Java Standard Deviation: 0.673123662819416   5/13/2000
 Aces to Java Standard Deviation: 0.6709629732896129   4/13/2000
 Aces to Java Standard Deviation: 0.6687440339658566   3/13/2000
 Aces to Java Standard Deviation: 0.666681047985583   2/13/2000
 Aces to Java Standard Deviation: 0.6644895989485075   1/13/2000
[Fri Aug  2 09:52:02]$

[david@localhost magneticField]$ tmymf95
 Aces to Java Standard Deviation: 0.6629221645174677   12/13/1999
 Aces to Java Standard Deviation: 0.660894416102333   11/13/1999
 Aces to Java Standard Deviation: 0.6588087481267555   10/13/1999
 Aces to Java Standard Deviation: 0.6567998026787462   9/13/1999
 Aces to Java Standard Deviation: 0.6547337372786685   8/13/1999
 Aces to Java Standard Deviation: 0.6526777674764745   7/13/1999
 Aces to Java Standard Deviation: 0.6506978172930779   6/13/1999
 Aces to Java Standard Deviation: 0.648661979209375   5/13/1999
 Aces to Java Standard Deviation: 0.6467016835736678   4/13/1999
 Aces to Java Standard Deviation: 0.644686334440395   3/13/1999
 Aces to Java Standard Deviation: 0.6428750852371221   2/13/1999
 Aces to Java Standard Deviation: 0.64087989786463   1/13/1999
 Aces to Java Standard Deviation: 0.6388954412805026   12/13/1998
 Aces to Java Standard Deviation: 0.6369853064492099   11/13/1998
 Aces to Java Standard Deviation: 0.6350222445424056   10/13/1998
 Aces to Java Standard Deviation: 0.6331329947858431   9/13/1998
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 Aces to Java Standard Deviation: 0.6311917018865274   8/13/1998
 Aces to Java Standard Deviation: 0.6292616168928189   7/13/1998
 Aces to Java Standard Deviation: 0.6274045568964095   6/13/1998
 Aces to Java Standard Deviation: 0.6254968143394701   5/13/1998
 Aces to Java Standard Deviation: 0.6236615622437643   4/13/1998
 Aces to Java Standard Deviation: 0.6217765480316274   3/13/1998
 Aces to Java Standard Deviation: 0.6200840079474504   2/13/1998
 Aces to Java Standard Deviation: 0.6182213481506983   1/13/1998
 Aces to Java Standard Deviation: 0.6163705815121432   12/13/1997
 Aces to Java Standard Deviation: 0.614590937337529   11/13/1997
 Aces to Java Standard Deviation: 0.6127638728498749   10/13/1997
 Aces to Java Standard Deviation: 0.6110073595330666   9/13/1997
 Aces to Java Standard Deviation: 0.6092043976425916   8/13/1997
 Aces to Java Standard Deviation: 0.60741383929547   7/13/1997
 Aces to Java Standard Deviation: 0.6056929494992709   6/13/1997
 Aces to Java Standard Deviation: 0.6039271047846662   5/13/1997
 Aces to Java Standard Deviation: 0.6022303291580205   4/13/1997
 Aces to Java Standard Deviation: 0.6004896076014901   3/13/1997
 Aces to Java Standard Deviation: 0.598928449741347   2/13/1997
 Aces to Java Standard Deviation: 0.5972124202709225   1/13/1997
 Aces to Java Standard Deviation: 0.5955122113955088   12/13/1996
 Aces to Java Standard Deviation: 0.5938812769784112   11/13/1996
 Aces to Java Standard Deviation: 0.5922090336813554   10/13/1996
 Aces to Java Standard Deviation: 0.5906034683053522   9/13/1996
 Aces to Java Standard Deviation: 0.5889576480611779   8/13/1996
 Aces to Java Standard Deviation: 0.5873254161374011   7/13/1996
 Aces to Java Standard Deviation: 0.585758876774352   6/13/1996
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 Aces to Java Standard Deviation: 0.5810358448859276   3/13/1996
 Aces to Java Standard Deviation: 0.5795727163457656   2/13/1996
 Aces to Java Standard Deviation: 0.5780224530304127   1/13/1996
 Aces to Java Standard Deviation: 0.5764840945503608   12/13/1995
 Aces to Java Standard Deviation: 0.5750074740529341   11/13/1995
 Aces to Java Standard Deviation: 0.5734960306273651   10/13/1995
 Aces to Java Standard Deviation: 0.5720473797346373   9/13/1995
 Aces to Java Standard Deviation: 0.570565052253635   8/13/1995
 Aces to Java Standard Deviation: 0.5690976854478234   7/13/1995
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 Aces to Java Standard Deviation: 0.5662543962840562   5/13/1995
 Aces to Java Standard Deviation: 0.5648777207362096   4/13/1995
 Aces to Java Standard Deviation: 0.5634703039871957   3/13/1995
 Aces to Java Standard Deviation: 0.5622124128701962   2/13/1995
 Aces to Java Standard Deviation: 0.5608346005038574   1/13/1995
[david@localhost magneticField]$

[david@localhost magneticField]$
[david@localhost magneticField]$ tmymf90
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 Aces to Java Standard Deviation: 0.5310393030727357   7/13/1994
 Aces to Java Standard Deviation: 0.530469050287822   6/13/1994
 Aces to Java Standard Deviation: 0.5298867302978217   5/13/1994
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 Aces to Java Standard Deviation: 0.5250667873272041   8/13/1993
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 Aces to Java Standard Deviation: 0.511296655441998   7/13/1990
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 Aces to Java Standard Deviation: 0.5108418487330102   5/13/1990
 Aces to Java Standard Deviation: 0.510629410954191   4/13/1990
 Aces to Java Standard Deviation: 0.5104176897153543   3/13/1990
 Aces to Java Standard Deviation: 0.510233278307332   2/13/1990
 Aces to Java Standard Deviation: 0.5100366691234609   1/13/1990
[david@localhost magneticField]$
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