

June 17, 2013

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Federal Aviation Administration
800 Independence Avenue
Washington, DC 20591

Dear Margaret:

Peggy

The Performance based operations Aviation Rulemaking Committee (PARC) is pleased to submit the attached executive summary, report and recommendations for improved processes and steps enabling safe continued airworthiness of aircraft and operations in environments with changing magnetic variation. The PARC MagVar Action Team was formed following FAA investigation into reported ILS approach anomalies at Anchorage, Alaska in 2012, that were the result of excessive differences in the magnetic variation used by aircraft guidance systems, ground NAVAIDS, and procedures. The PARC was asked to review current processes and requirements on the determination and use of magnetic variation data. A PARC action team was formed with representatives from AIRBUS, Alaska Airlines, Boeing, Honeywell, Jeppeson, Mitre, and the FAA. FAA participants were drawn from Aircraft Certification, Flight Standards, and Air Traffic Organization Aeronautical Navigation Products and Technical Operations. The group's evaluation focused on ILS procedures and the role of the inertial reference unit or system.

Among the specific recommendations made is one for updating the Anchorage and Fairbanks (common alternate) magnetic variation values this year and in the coming years. This is intended to maximize the compatibility with ILS operations for aircraft with current magnetic variation data. The recommendations also highlight the need for improved communication from the FAA on source data as well from aircraft OEMs to operators on maintaining aircraft databases. In addition, the dependency of autoflight performance on magnetic variation accuracy was identified.

Two areas for further investigation were proposed. One is to consider whether further coordination on the timing of magnetic variation source data application can be achieved such that the time between FAA procedure updates is lengthened. Another is to consider the use of true references at near-polar locations, such as in Northern Alaska, with significant dynamics in the earth's magnetic field.

The group also considered the solution of documenting procedures in true, also known as Idea Hub #5926. However, the group recommends retaining the responsibility for the application of magnetic variation data with the procedure developer instead of moving it to the chart maker.

PARC appreciates your continued support of our activities. Please call me if you have any questions or would like to discuss any aspect of the report or activity.

Sincerely,

A handwritten signature in black ink, appearing to read "Dave Nakamura". The signature is fluid and cursive, with a long horizontal stroke at the end.

Dave Nakamura
Chairman
Performance based operations Aviation
Rulemaking Committee

Cc: J. Hickey
B. DeCleene
R. Jennings
M. Steinbicker
B. Clark

Executive Summary: Magnetic Variation Review and Recommendations

Introduction

As a result of the reported ILS approach anomalies at Anchorage, Alaska in 2012, further magnetic variation updates to both Anchorage and Fairbanks were put on hold and certain aircraft were prohibited from using autoflight ILS approaches in low visibility. Excessive differences in the magnetic variation used by aircraft guidance systems, ground NAVAIDS, and procedures can result in unacceptable aircraft lateral guidance performance and/or an unsafe condition. Current processes and requirements on the determination and use of magnetic variation data were evaluated with a focus on ILS procedures and the role of the inertial reference unit or system.

Near-term Recommendations

The following recommendations are suggested for FAA consideration within the next few months. Recommendations related to magnetic variation updates at Anchorage and Fairbanks in out years are in the body of the report. Additional policy recommendations that are strictly editorial and for clarity are also excluded from this list, but retained in the document body.

- a) Require aircraft OEM documentation to address procedure compatibility with magnetic variation source data so operators can more easily determine the airplane qualification requirements for operations at a specific location and time
- b) Replace process requirements with a performance requirement in Order 8260.19E to achieve the legacy standard for magnetic variation accuracy of +/- 1 deg for CAT II/III ILS facilities
- c) Update Order 8260.19E to support autoflight to CAT I ILS facilities where needed by requiring +/- 1-2 degrees magnetic variation accuracy depending upon facility latitude
- d) Establish a standard way of providing database suppliers with the magnetic variation values used in procedure design that do not agree with the magnetic variation of record for the airport and clarify the magnetic variation of record for a location or airport
- e) Establish a standard way of providing runway magnetic bearings that allows its application consistent with the procedure updates

- f) Hold the Anchorage airport and ILSs magnetic variations at their current values of 19 degrees E until December 2014. Update the Fairbanks value to 20 degrees E as soon as possible in 2013.
- g) Support NOAA's sustained commitment to providing the World Magnetic Model (WMM) and periodically collaborate with NOAA to ensure that the WMM products continue to meet the needs of civil aviation users in terms of accuracy, availability, frequency of update, and geographic applicability
- h) Encourage RTCA SC-227 to review the recommendations and consider the safety and operational benefits of current magnetic variation data for incorporation into the MASPS and MOPS
- i) Retain the responsibility for the application of magnetic variation data with the developer instead of moving it to the chart maker (refer to Idea Hub # 5926 – Documenting Procedures in True)

Activities for Further Consideration

Two areas for further investigation should be considered:

- a) Investigate whether improved service provider and stakeholder coordination of the timing of magnetic variation source data application can be achieved such that the time between procedure updates can be lengthened; Determine if cost savings to service providers can be realized by trying to “stabilize/dampen the magnetic variation changes somewhat” versus the current practice of maintaining a reference that is “close to reality”
- b) Study the use of true references (instead of magnetic) at locations with a high rate of change in local magnetic variation or high magnetic inclination and determine if these airports should be documented in True North reference.

Magnetic Variation Review and Recommendations

1) Introduction

Excessive differences in the magnetic variation (MV) used by aircraft guidance systems, ground NAVAIDS, and procedures can result in unacceptable aircraft lateral guidance performance and/or an unsafe condition. The action team focused their efforts on ILS procedures and the role of the inertial reference unit or system. The action team evaluated current processes and requirements on the determination and use of MV data.

Highlights of current processes and practices are provided in Section 2) . Near term updates to FAA policy and guidance actions are given in Section 3) and intended to improve the coordination of changes in MV and support improved industry practices. In turn, this is expected to reduce or eliminate the potential for related unsafe conditions in the US NAS and to minimize temporary periods of lost operational capabilities for airlines when MV discrepancies occur. Activities which require further consideration are given in Section 4).

2) Current Processes and Policies on the Use of Magnetic Variation Information

2-a) *Government*

World Magnetic Model

The World Magnetic Model (WMM) is sponsored by the U. S. National Geospatial-Intelligence Agency (NGA) and the U. K. Defence Geographic Centre (DGC). It is produced by the U. S. National Oceanographic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC) and the British Geological Survey (BGS). It is a widely used standard model for navigation, attitude, and heading reference systems using the geomagnetic field. Data for the model were provided by institutes and agencies from 48 countries around the world.

The WMM models the so-called "main field" of the Earth's magnetic field as a function of date and location (from 1 km below the Earth's surface to 850 km above it). The WMM is documented, has source support, is assessed for accuracy, and meets a government performance standard. It is updated every five years. Internet "calculators" and source code are available. This model is used by FAA AeroNav Products, Boeing, Honeywell for some products, and is referenced in AC 20-138C.

Appendix 2 has a brief description of the Earth's magnetic field and the WMM.

Note: The International Geomagnetic Reference Field (IGRF) model also represents the main field and is periodically updated and released. It is produced by the International Association of Geomagnetism and Aeronomy (IAGA). IAGA is one of the eight Associations of the International Union of Geodesy and Geophysics, a non-governmental body funded through the subscriptions paid by its member countries. The IGRF model is considered academic research by some and is reportedly used widely in studies of the Earth's deep interior, crust, ionosphere and magnetosphere. It is also used in a number of applications (for example mobile phones, portable applications, mineral exploration and drilling), including some avionics (for example multiple Garmin products).

Airports and Procedures

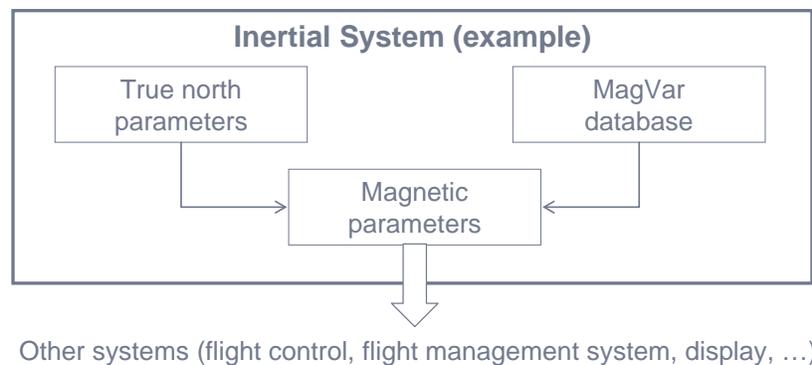
Order 8260.19E, *Flight Procedures and Airspace*, defines how magnetic variation is maintained and used for flight procedures within the National Airspace System. Chapter 2, Section 5 provides the procedures for implementing MV epoch year variation. This information is published as the Magnetic Variation of Record, and is normally used as the magnetic variation for RNAV instrument procedures, on airport NAVAIDS, including ILSs, the runway bearing and even the ATC RADAR alignment. The MV of record is not measured, but estimated using the WMM within its five year applicability timeframe. The model produces a MV for any day during this time for any location. For ILS facilities, values are currently computed twice a year for comparison to the MV of Record values and to use in planning MV changes. The most stringent MV requirements are for CAT II/III ILS facilities. Once the MV of record is assigned, it is a fixed value until a change is determined to be necessary to remain within the current policy limit for MV tolerance. A change to the MV of record necessitates that all the associated procedures be changed on the same cycle in order for the MV to match. (There are variations to this process sometimes as described in Section 3 below). The MV of record is available through government data sources and is on the 8260 forms for all instrument procedures.

Aircraft Regulatory

Although a considerable body of current regulatory and policy guidance exists to address magnetic variation issues, only the very recently published AC 20-138C, *Airworthiness Approval of Positioning and Navigation Systems*, directly addresses currency of avionics magnetic variation databases. This particular text is only now beginning to be used and applied. It does not address ILS avionics or integrations.

2-b) Aircraft

Airplanes navigate using a blend of true and magnetic references. Generally, the best airborne heading references are provided by inertial navigation systems. Most transport category airplanes (with onboard inertial reference systems) provide true-referenced data; calculate corresponding magnetic data; and use or output data in either or both reference frames. These airplane systems do not need magnetic sensor data because of the onboard inertial systems (such as IRS, IRU, ADIRU). These inertial systems contain magnetic variation coefficient databases, and derive magnetic values from these databases to support displays and other airplane systems requirements.



In other types of airplanes, less expensive, smaller, and less accurate heading reference systems depend on other implementations, which may use the Earth's magnetic field (via a flux valve or flux gate) coupled to a gyroscope or a sub-inertial gyroscope to maintain a three-axis reference (such as in a compass coupler, magnetic heading reference system (MHRS) or airplane heading reference system (AHRS)).

Airplanes' area navigation systems perform their calculations based on true references, but require the ability to navigate in both true and magnetic reference frames because most charts, runways, facility references and ground-based NAVAIDS use magnetic references. In addition, instrument approach procedures, charts and airports use magnetic references. All of these elements (airborne, ground, and flight procedures) must be updated as the Earth's magnetic field moves.

On airplanes with inertial systems, magnetic variation data is contained in a "Magvar Table," which is a 2-D database of magnetic variation as a function of latitude and longitude. (Refer to Appendix 1 for an overview of MV accuracy

requirements within inertial systems.) Magnetic reference information is calculated as a sum of True minus Magnetic Variation and becomes an output of the inertial system. MV tables are stored in the inertial system and area navigation system (typically a flight management computer). These MV tables are intended to be valid generally for at least 10 years, and are accurate enough for a much longer period at many locations. These data tables are embedded or loadable; are based on a magnetic field model for a given Epoch, and are usually updated every 5 or 10 years, depending on the design. The majority of fielded inertial systems require a return to the factory or a service center with appropriate capability in order to have their tables updated.

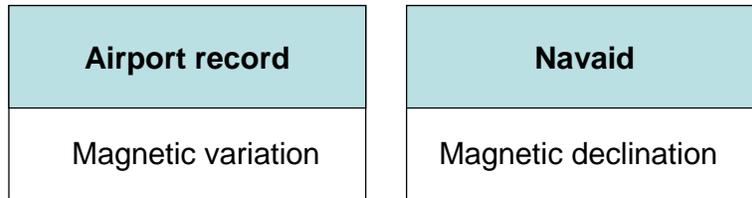
Area navigation (RNAV) systems also use MV data contained in onboard navigation databases (NDB). Some terminal area procedures are designed with magnetic course-based leg types which require a magnetic variation to compute repeatable tracks over the ground. When MV data relative to a specific leg is provided in the NDB, most RNAV systems will utilize the MV data to compute the true ground track. Others use an internal model of magnetic variation. The NDB magnetic variation information originates from the States. The data suppliers (or “data houses”) may provide an interpretation of multiple State sources, but they do not *originate* data.

The NDB MV data elements are based on the route or procedure type. For RNAV it is one thing, for ILS it is something different, for VOR and non-directional beacons it is something different again. (See for example ICAO Document 8168 Volume II Section 1.11.1.1 Application of magnetic variation [for procedure promulgation].)

For RNAV terminal procedures, the NDB MV data is the MV of record for the airport or the station declination associated with a NAVAID that establishes the basis of a procedure. Historically the station declination of the recommended NAVAID for the procedure was used. (In general in the US, a NAVAID on the airport should have the same magnetic variation as the MV of record for the airport; see FAA Order 8260.19E. However in a quick survey of 81 VORs on airports, 43 had a different station declination value than the magnetic variation of record for the airport.) With the advent of RNAV procedures, the MV of record for the airport has been used in lieu of the procedure NAVAID declination.

As an example, in the NDB airport record, the magnetic variation is given as the difference in degrees between the measured values of true north and magnetic north at that location. The field labeled “Station Declination” in the record for a VOR differs in that it is the angular difference between true north and the zero

degree radial of the NAVAID the last time the site was updated. See figure below. The capability to provide source (State) provided Procedure Design Magnetic Variation (PDMV) embedded into the procedure data has been added to ARINC 424. This new capability allows for its potential use by avionics, replacing other forms of magnetic variation data such as NAVAID magnetic variation.



Magvar related fields in navigation database

A significant portion of the reported MV issues associated with RNAV systems have been associated with the display of magnetic courses for airways on the (M)CDU versus that depicted on the airway chart. Though the actual RNAV path over the ground is correct (because it is point to point), pilots become disconcerted that the displayed course on the (M)CDU is different than the chart. Though both the chart and the FMS are computing tracks in true, and converting to magnetic for display, different MV values are being used to perform the conversion.

When updating MV data tables is infeasible, OEMs generally manage MV related operational restrictions through airplane flight manual (AFM) and OEM documentation updates.

2-c) Avionics

As noted in the previous section, in transport category airplanes, MV data tables are typically stored in the inertial system and area navigation system (typically a flight management computer). Avionics manufacturers process NOAA (or IGRF) MV data, which is released every five years, to build a data table containing a grid of MV data points to use in an area navigation system or inertial system. The grid uses latitude/longitude coordinates and assures adequate agreement with the model to support magnetic heading based operations over the entire earth. MV data tables are analyzed and adjusted by the avionics OEM so that the values in the table are optimized for an additional period of time, typically five additional years. Thus, these MV data tables are generally intended to be valid for at least 10 years, and are accurate enough for a

much longer period of time at most locations. These data tables are contained in embedded or loadable software; are based on a magnetic field model for a given Epoch, and are usually updated every 5 or 10 years, depending on the design.

A similar process is assumed for similar avionics applications in other classes of aircraft. As was previously noted, not all avionics uses the NOAA WMM as the MV source.

When MV maps for inertial or area navigation systems are updated, the new tables are made available to operators through an aircraft or avionics OEM service bulletin. Avionics OEM service bulletins address the avionics and do not address all of the operational or aircraft level functional issues associated with implementing or not implementing the service bulletin.

2-d) Operator

Operators generally rely upon the aircraft OEM to provide guidance and instructions regarding maintenance and operation of their fleets, including magnetic variation operational requirements. Generally, OEM guidance and instructions for operators falls into three primary categories:

- Information only (information-only bulletins affecting airplane configuration or airplane operations but which do not require specific operator action)
- Instructions (several categories):
 - Aircraft changes (mandatory or non-mandatory changes/service bulletins/notices)
 - Operational procedure changes (usually mandatory)
 - Maintenance manuals, troubleshooting instructions (effective almost as much as if mandatory)
 - Minimum equipment list (MEL) requirements (mandatory)
- Airplane Flight Manual (AFM).

When operational restrictions exist due to MV, OEMs will typically document these in the AFM or supplemental documents, and/or issue information-only bulletins as necessary to alert operators regarding the changes. The degree of necessity the OEM specifies for making MV changes appears to vary significantly among OEMs. That is, one OEM may be highly prescriptive in prohibiting specified operations at specified locations with older-than-authorized MV tables, whereas another OEM may simply make MV table updates available on a

scheduled cycle, without identifying (in the corresponding communication) the operational effect of using older MV tables.

Not all operators choose to install inertial system MV map (a.k.a. database) updates when the OEM makes them available through an aircraft change/service bulletin. In some combinations of location, aircraft type and operation, this may be acceptable. The world-wide rates of change for MV values depend on the specific location. In some parts of the world, the rate of MV change is slow enough that an epoch difference between the static inertial system MV data table and actual MV value would not present an operational impact in those areas. Experience has also shown that some operators inappropriately fail to update their MV data tables frequently enough to ensure accuracy that is commensurate with MV changes in their operating areas, their operations and avionics architecture.

For fleets with avionics that cannot be updated on-board or without equipment removal, implementing new MV data tables can be a multi-year process.

3) Recommendations

3-a) Aircraft OEM documentation to address procedure compatibility with magnetic variation source data

The aircraft OEM communication with operators must be specific enough for the operator to determine the airplane qualification requirements for operations during some reasonable period of time.

An update to AC 120-29A, *Criteria for Approval of Category I and Category II Weather Minima for Approach*, (or equivalent such as AC 120-xLS currently in development) should be made to include requirements to address the aircraft system magnetic variation requirements for compatibility with flight procedures. It is proposed that a new section in Section 5 be included which embodies topical “airborne system requirements.” A proposed section is provided below. This addition to AC 120-29A becomes applicable as well to AC 120-28D, *Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout*, by reference.

Section 5.TBD. Magnetic Variation Data and Onboard Database.

- a. Some avionics convert true heading references to magnetic heading references by using worldwide magnetic variation data contained in an on-board magnetic variation database and a set of software algorithms. The algorithms convert the data into a specific magnetic heading reference

for a specific geographic reference point. However, since the Earth's magnetic fields constantly change, magnetic variation databases need periodic updates to provide accurate magnetic heading references. The National Oceanic and Atmospheric Administration (NOAA) offers a World Magnetic Model available at <http://www.ngdc.noaa.gov/geomag/geomag.shtml>, and this product is one acceptable source for updating an aircraft magnetic variation database.

b. Aircraft design approval holders should identify any operating limitations of their aircraft associated with application of the magnetic variation data to ensure sufficiently accurate magnetic heading references are presented and used in the aircraft. Consider at least the following in determining the operating limitations: the error characteristics of magnetic heading references, especially where local magnetic anomalies occur or in regions of high magnetic field inclination or high secular rates of change; intended operation (ILS approach, automatic landing, enroute navigation, display of course/track to the pilot, etc.); errors in the magnetic reference of any radio navigation aid used, and/or the accuracy of the magnetic reference of the procedure. Operational limitations need to be re-evaluated commensurate with the intended use and the dynamics of error associated with the magnetic heading reference. Conditions under which operations do not meet the intended function must be clearly identified.

c. The aircraft design approval holders' continuing airworthiness requirements must define the conditions under which the magnetic variation database and, if applicable, conversion algorithms or hardware, must be updated. This could be contained in a periodic aircraft flight manual update or other OEM documentation. These requirements should also define the maintenance procedures necessary to update the on-board magnetic variation database for their avionics.

This recommended update is intended to address the operator's need to know when and how to update their magnetic variation databases in order to maintain their suite of intended functions. It is intended to supplement, not replace, the guidance contained in AC 20-138, *Airworthiness Approval of Positioning and Navigation Systems*.

3-b) Update of Order 8260.19E to achieve legacy standard of +/- 1 deg for CAT II/III ILS facilities

The current order writes the requirement in terms of a process of checking annually to see if the MV of Record is within 1 degree of the “actual airport magnetic variation”. (As mentioned above in Section 2-a)ii) the term actual magnetic variation means the estimated magnetic variation calculated from the NOAA WMM.) The checking process actually allows the MV of Record to be greater than 1 degree off for a period of time (less than a year). The action team was briefed that the intent of the current Order was to require the MV of Record to be within +/- 1 deg of actual (again interpreted as the current estimate from the WMM) for CAT II/III ILS facilities.

Aircraft manufacturers’ current, typical allocations for NAVAIDS used to support automatic approach, landing, and/or rollout correspond to standards found in documents such as RTCA DO-201A, *Standards for Aeronautical Information*. This document gives an accuracy of +/- 1 deg for the magnetic variation of navigation aids. However, accuracy is not defined and the commentary in Section 2.2.4 says that MV is “often determined by local magnetic survey”. Although the numerical values of the standard agree with the Order, it is not apparent that they are meant to convey the same thing. At many (if not most) terrestrial locations, the difference between a local magnetic survey and the WMM may be insignificant. At other locations, differences of a degree would not be unexpected.

It is recommended that the order be updated to reflect the intended requirement, instead of a process or means to meet it. Since the actual values are obtained from a model which provides valid values over a five year timeframe, the MV of Record values can be planned in advance to meet the desired tolerance.

The middle of Order 8260.19E Section 2 Paragraph 2-18 (a) could be changed to read:

However, for CAT II/III ILS facilities, the intent is to keep these facilities closely aligned with the actual (as predicted by the current WMM) magnetic variation at the airport. Maintain the assigned magnetic variation value (MV of Record) for these facilities within +/-1 degree of the current airport magnetic variation.

In addition, it is recommended that the following informational note be added after this paragraph. This suggestion is editorial and the note duplicates information in later paragraphs of the order.

Note: At airports that have CAT II/III instrument procedures, the one degree tolerance effectively applies to the airport MV, the MV for all facilities on the airport, and the MV for all RNAV procedures required to use the aerodrome MV as indicated in sections (b), (d), and (f) below.

3-c) Update Order 8260.19E to support autoflight to CAT I ILS facilities

The current international industry standard effectively allocates magnetic variation error between the procedures and the aircraft. Procedures are updated periodically to make sure they reflect both the desired ground track and the appropriate magnetic bearings. The standard for magnetic variation for CAT II/III ILS facilities is more stringent than others in order to support automatic approach and landing. However, aircraft automatic flight control systems do not change their performance based on the visibility or minima. Airworthiness approvals link the performance of ground facilities and aircraft without regard to visibility, whereas operational approvals take visibility into account.

Any ILS facility intended to routinely support automatic approach, landing, and/or roll-out with large, modern, air transport aircraft should meet the more stringent requirements of Order 8260.19E for “CAT II/III ILS facilities.” Facilities maintained to the lesser standard may support automatic flight for some aircraft, under some conditions when errors do not stack up unfavorably. However, since at mid-latitudes magnetic headings are more accurate (due to lower field inclination values and more stable local MV whether directly sensed or synthesized from inertial-derived true heading and a MV database) and operations on CAT I facilities generally do have a satisfactory visual segment during which the pilot can verify alignment, some relaxation of the facility MV accuracy allocation is possible at mid-latitudes.

It is recommended to append the following text to the end of Order 8260.19E Section 2 Paragraph 2-18 (a) in order to support routine, autopilot coupled flight of these aircraft with CAT I ILS facilities:

For non Cat II/III ILS airports (ie, all other Cat I ILS airports), maintain the assigned magnetic variation value (MV of Record) for ILS CAT I facilities within +/- 1 degree of current airport magnetic variation for regions exceeding latitudes of N50 and S50 degrees. For non Cat II/III ILS airports within the range of N50 and S50 degrees latitude, maintain the assigned magnetic variation value (MV of Record) for ILS CAT I facilities within +/- 2 degrees of the current magnetic variation.

Additional qualifying criteria (for example whether the airport is a Part 139 airport) should be considered to verify that this provision provides an appropriate cost/benefit trade-off for a specific airport and their operators. Given the large number of airports potentially affected by such a change, some consideration needs to be given to airport facility implementation considerations (runway numbering and signage) as well as the relative priority of this capability versus other procedure development tasks and the resources required to accomplish it.

3-d) Provision of airport magnetic variation

The MV value on airport diagrams is updated on a different cycle than the MV of record and does not match the value used in the development of procedures for the airport, since it is published to the hundredth of a degree, rather than as whole degrees, even in cases where it would agree otherwise. ARINC databases provide an airport MV value that indicates the angular difference between True North and Magnetic North at the location defined in the ARINC record. Database providers determine the MV to be populated from official government data sources and geographical magnetic variation source. Experience with Anchorage has shown that “special means” of providing the airport magnetic variation (by a remark in the National Flight Data Database) is an unreliable means to affect the data which ultimately is hosted in aircraft navigation databases. The three data base suppliers did not provide uniform data as a result of this unusual FAA action.

It is recommended that a standard way of providing database suppliers with the MV values used in procedure design that do not agree with the magnetic variation of record be established and that the MV of record for a location or airport be clarified.

3-e) Provision of runway magnetic bearings

Runway true bearings are provided. For example, see <https://nfdc.faa.gov/xwiki/bin/view/NFDC/WebHome>. The magnetic variation of record of the airport is used to determine the runway magnetic variation.

It is recommended that a standard way of providing runway magnetic bearings be established that allows its application consistent with the procedure updates.

3-f) Editorial clarifications to Order 8260.19E

The PARC Magvar AT recommends the following editorial clarifications to Order 8260.19E (Change 2) Chapter 2 Section 5:

- The NOAA model estimates MV at any location and day within the five year validity window of the model. For example, the World Magnetic Model for 2000 provided MV values at locations for January 1, 2000 through December 31, 2004. Clarify that when the model is used to provide “the next/nearest future epoch year MV,” the value on the last day of validity is used.
- Add a reference in the section 2-17 (a)(12) Navigational aids NOT supporting en route structure as indicated by the underlined text:

(a) Initiate implementation of the nearest future Epoch Year MV in accordance with paragraph 2-18a, whenever any instrument procedure is established or amended. The nearest future Epoch Year MV will become effective concurrent with publication of the amendment [see paragraphs 8-57n and 8-57o].

3-g) Anchorage and Fairbanks Magnetic Variation Updates

As a result of the recent reported ILS approach anomalies at Anchorage, Alaska (PANC), further MV updates to both PANC and Fairbanks were put on hold. Action team members assessed the expected magnetic variation at both airports. Charts below show the NOAA estimated magnetic variation at PANC (Anchorage) and PAFA (Fairbanks) from 2010 to 2012 with projected magnetic variation from 2013 to 2020 using the most current model. Past ILS declination values are shown and recommended future ILS declination changes for the period from 2013 to 2020. The recommended future values are also tabulated below. The table provides two scenarios for updates to Anchorage, although only one is depicted in the figure. These recommendations are not intended to replace the use of the magnetic variation values from the WMM 2015 NOAA model for years 2015-2020 when available.

Table 1 Recommended Future Values for Select Alaska Airports’ Magnetic Variation in Degrees East

Effective Date	Anchorage	Fairbanks
ASAP 2013	18* ¹	20
Mar, 2015* ²		18* ²

June, 2016*2	16*2	
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*Note 1: If a change is needed in 2013 to meet FAA or other requirements, change to 18 degrees E. Otherwise, the current airport and ILS magvar and magdec values can be maintained at 19 degrees E until December 2014 when the value can change to 17 degrees E.

*Note 2: The exact timing of this change needs to be established when the WMM 2015 is available (in December 2014). These values also assume no policy changes will be implemented in the intervening years (which may or may not be the case).

Note that at the time of the last update depicted (17 E, February 2012) for Anchorage, Order 8260.19E contained a flawed process for selecting the MV. If the process was followed, it could result in setting the MV for airports with CAT II/III ILS facilities to values greater than 1 deg away from the current MV by favoring the use of the next upcoming epoch year value (as estimated by the current model), and which may still exist in other States. This deficiency was identified and corrected in March 2012 with Change 2 to the order.

For some procedures at Anchorage, the MV was set back to 19 E in May 2012, resulting in a mix of MV references being used at the airport. The mismatch with RNAV procedures already published and/or developed with 17 deg E is considered tolerable.

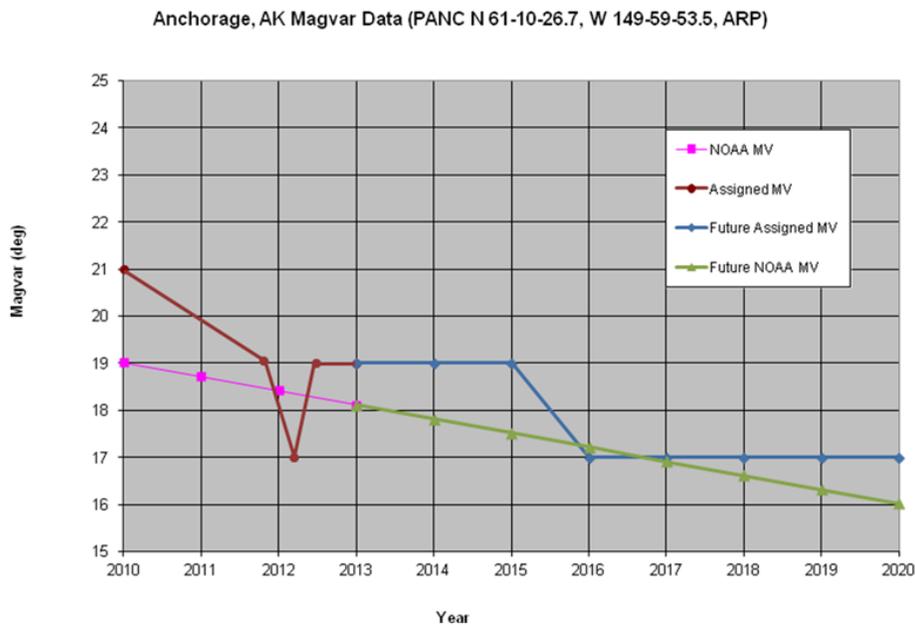


Figure 1 Anchorage Alaska Historical and Future Airport Magnetic Variation

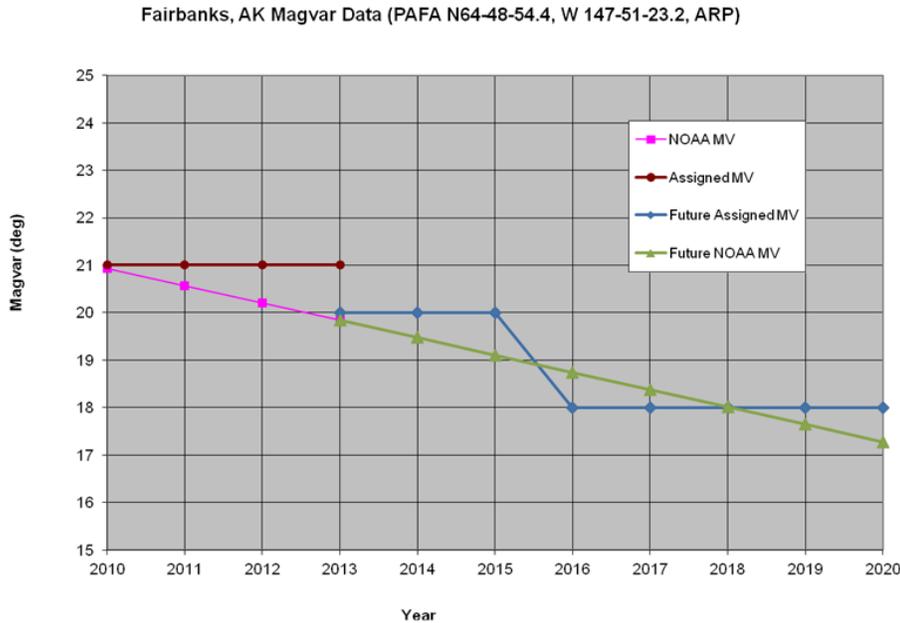


Figure 2 Fairbanks Alaska Historical and Future Airport Magnetic Variation

3-h) *Interagency support for the World Magnetic Model*

Because the stabilization of the NAS routes and procedures is achieved through consistency with the World Magnetic Model, support for its continued development is required. Current products satisfy aviation needs in terms of accuracy, availability, frequency of update, and geographic applicability. However, the model must be updated every five years with data generated from observations made around world as well as from satellites. Sustained commitment of resources is required from NOAA. Both NOAA and the FAA need to be aware of aviation’s dependence on the model and underlying measurements. The infrastructure afforded by the existence of the model cannot be replicated by the FAA. Therefore, NOAA and the FAA should establish an agreement to collaborate periodically to ensure that the WMM continues to meet the needs of civil aviation users.

3-i) *RTCA SC-227*

DO-236B, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*, and DO-283A, *Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation*, are currently being revised to incorporate operational experience not reflected in the current standards and to address the interim recommendations on trajectory operations.

Each of the existing versions of the documents address MV and specify requirements for the application and use of MV for navigation operations. The documents also recommend that the magnetic data should be updated “periodically” and updated consistent with other systems. However, neither document specifies a recommended update cycle or period. It is certainly recognized that a prescriptive requirement, in either the RNP MASPS or MOPS, which specifies the frequency and coordination of the respective aircraft systems’ MV table updates would be difficult. Nonetheless, it is recommended that SC-227 review this working group’s set of recommendations and consider the safety and operational benefits of current MV data for incorporation into the MASPS and MOPS.

3-j) Idea Hub # 5926 – Documenting Procedures in True

After due consideration, the suggestion to move the magnetic variation from the developer to the chart maker has some merit. However, those merits do not outweigh the possible errors introduced into the National Airspace System when there are multiple chart makers and an error is made in the application of the magnetic variation to apply. It would create more confusion than is acceptable to have one chart maker charting one magnetic course on procedures at an airport while other chart makers chart a different magnetic course for the same procedures. The NOTAMs and/or safety alerts required to make the necessary corrections to incorrectly charted procedures would cause confusion for aircrews, and could result in crews improperly altering charts which are correct.

However, an evaluation of whether some procedures should be true referenced instead of magnetic referenced is recommended in Section 4-b).

4) Activities for Further Consideration

4-a) Potential for service provider and stakeholder coordination of the timing of magnetic variation source data (“lock-step” method)

From a service provider perspective, the most demanding aircraft in terms of MV tolerances for ILS approach and landing operations are the autoland aircraft which use a synthetic magnetic heading and/or track derived from an inertial reference and a MV database. Although the procedures are maintained with regard to actual MV at the airport, it is the excessive differences between the MV values used by the procedure designer and those within the IRU database installed on aircraft that can cause lateral tracking discrepancies in some aircraft

types as they seek, and follow, the localizer beam. As such, there is a potential to minimize the difference and maximize the performance by the procedure designer using the same values as the aircraft.¹

With the current strategy, it is possible for a procedure at a given airport to be updated multiple times while all along the aircraft are applying the same fixed value for that airport. A new strategy may be feasible that focuses on lengthening the time between procedure updates and better matching the aircraft values. The new strategy would not be able to disregard the accuracy of the resulting magnetic headings since some aircraft use actual magnetic heading measurements to fly the approaches. However, the accuracy requirements for these aircraft are less demanding than the allocation that is currently applied to the ILS facilities for MV.

It recommended that this idea be further developed, demonstrated, and evaluated. The cost to service providers of maintaining the NAS magnetic reference “close to reality” is larger than to simply “stabilize/dampen the magnetic variation changes somewhat”.

4-b) Use of true references at locations with high rate of change or high magnetic inclination

A simple magnetic compass aligns with the horizontal component of the Earth’s magnetic field. When the inclination of the magnetic field is high (approaching the magnetic poles), the field is mostly oriented vertically with respect to the surface of the Earth and measurements made with predominantly the horizontal component of the field will be unreliable. [The secular variation of the magnetic declination (aka variation) also increases as you approach the magnetic poles. Secular variation is the change over periods of time on the order of a year.] In such instances, navigation with regard to a true reference or grid navigation is

¹ Since the difference in the MV is what is important for approach/landing for these aircraft, it is important for users to know what values the FAA uses and intends to use over time. In addition, since the FAA does not attempt to match “actual” magnetic variation but instead estimates it based on a model, increased fidelity on the part of users with regard to selecting MV values more closely aligned with the actual MV at a location doesn’t necessarily mean increased performance.

magnetic variation values. The tolerances for changing an airport facility's magnetic variation values are set by standards defined by FAA orders. To change at a more frequent interval is impractical and expensive to maintain ground based facilities and airborne systems within requirements.

Currently all documentation used for aviation navigation are documented with values of magnetic variation. The airport facilities values are maintained by the FAA which provides the values to display on aviation procedure charts. The study should research and review the industry application of considering changing an airport facility to be True North referenced when the an airport's local magnetic variation has a rate of change higher than approximately 0.4 degrees per year. The impact to current aviation standards should be assessed as well as the number of airports impacted and the ability of local users to operate in true

Large Inclination of Local Magnetic Field

The Earth's magnetism is measured in direction and intensity. For the purposes described here only the direction components are used. The two direction components are variation and inclination and are both measured in degrees. The magnetic variation is the horizontal component of the angle between magnetic north and true north. The magnetic inclination is the angle between the horizontal plane and the total field vector from 0 to 90 degrees with positive values pointing into the Earth. The study should research the local magnetic inclination and if it is above 72 degrees, the facility could be identified as a candidate for conversion to True North referenced. The study can further research the need for a requirement that if the local magnetic inclination is above 80 degrees, the facility must be converted to True North referenced.

Something to be considered during the study is the impact to aircraft of different industry standards. Not all airplanes have inertial systems as described in this paper. It is important to consider that gyro stabilized magnetic heading systems compliant with TSO/ETSO-C6d and its referenced SAE Aerospace Standard AS 8013, are allowed degraded performance/accuracy at field inclinations above 72 degrees and have no required/assured performance at field inclinations above 80 degrees.

5) Action Team Members

The members of the action team were:

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Belloir, Frederic	AIRBUS
Call, Curt	Honeywell
Chism, Linda	Alaska Airlines
Clark, Barbara	FAA, Aircraft Certification, Avionic Systems Branch
Courtney, Dale	FAA, Air Traffic Organization, National Resource Engineer for Navigation
Fisher, Blaney	Boeing
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Kasten, John	Jeppesen
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Rush, Brad	FAA, Manager, Quality Assurance Regulatory Support, Aeronautical Navigation Products
Shaver, Tim	FAA, Manager, Avionics Maintenance Branch
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Appendix 1 - Underlying IRU magnetic variation requirements to support aircraft operations

Requirements for magnetic variation vary depending upon the operation and on the specific aircraft implementation, making them hard to uniquely define. Differences in Flight Management Systems, autopilot/auto-flight systems, path steering algorithms, display systems, and the myriad of data formats used make general statements difficult. However, there are two general high level requirements for the magnetic variation databases internal to inertial reference units. The first is derived from the basic magnetic heading accuracy requirement. EASA has documented² the general consensus requirements for magnetic heading as a function of latitude as given below in Table A1. Other requirements are considered by applicant request. The second high level MV constraint is derived from aircraft automatic control requirements. It can be stated in terms of the difference (“delta”) between what the aircraft thinks is the MV versus the MV value the state used in defining the intended path. Aircraft OEMs fairly consistently define a “delta” MV limit of 3 degrees, with larger values yielding degraded aircraft behavior or fault annunciation during alignment or path capture. This 3 degree difference is also considered the generic limit for meeting certification criteria for automatic landing and/or roll-out.

Table A2 EASA Guidance on Magnetic Heading Accuracy Derived from True and Magnetic Variation Databases

Acceptable Accuracy Values	Latitude Range
2 degrees	between 50°S and 50°N
3 degrees	between 50°N and 73°N
3 degrees	between 50°S and 60°S
5 degrees	between 73°N and 79°N
8 degrees	between 79°N and 82°N

Notes:

1. For magnetic heading indications obtained via geographic (true) heading, the accuracy of the heading indication should account for the accuracy of the magnetic variation data based on geographic position. This variation may change over time.
2. In areas of known magnetic unreliability (e.g. the magnetic poles), the magnetic variation error can be very large, so the magnetic heading indications (if output) should not be relied upon.

² *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes*, European Aviation Safety Agency, CS-25 Amendment 12, 13 July 2012.

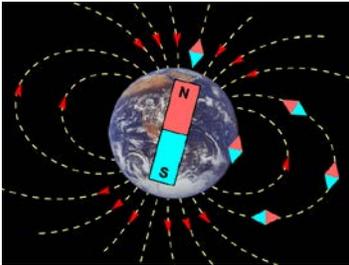
3. For geographic (true) heading indications (such as those provided by Inertial Reference Units), the accuracy should be better or equal to 1°.

In summary, the internal IRU MV database must try to replicate the actual magnetic field of the Earth to meet the intended magnetic heading accuracy, but it cannot deviate too far from individual procedure definitions of MV, which, by virtue of having discrete updates to static procedures, cannot perfectly represent the local magnetic field. Note that the IRU database depends on the aircraft location and has no knowledge of what procedure is being flown. Specific MV tolerances as well as how MV is used in aircraft integrations are generally proprietary.

Appendix 2 – Primer on Magnetic Variation

The Earth has a magnetic field within and around it. The earth's magnetic field is what a simple needle compass is responding to when it "points North." Compasses have been used by man for direction finding for about a millennium. The Earth's magnetic field has been measured, studied, predicted, and modeled to varying degrees for over a century. Aviators have relied upon it nearly since human flight began. A magnetic compass is required as a basic instrument for flight (14 CFR 91.205) and aeronautical charts reference it.

The Earth's magnetic field is sometimes described as similar to a dipole magnet (straight bar with two poles) that is oriented roughly 10 degrees off from the rotational axis of the Earth. One can picture a field with predominant direction and intensity at various locations on and around our planet. But, the field is not stationary – it changes over time. In fact, how it changes (called secular variation) also changes over time.



Key points for aviation:

- Direction references in the US NAS (and most of the world's airspace) are generally defined with regard to the magnetic field.
- At some locations, the changes in the magnetic field over the period of a few years are significant.
- The earth's magnetic field has both horizontal and vertical components. A magnetic compass is designed to indicate direction over the earth's surface by aligning with the horizontal component of the field, but in fact it actually aligns with both the horizontal and vertical components. At some locations, particularly those relatively close to the earth's magnetic poles, the standard aviation magnetic compass is unusable because it aligns mainly to the vertical component of the field and/or because the horizontal component of the field is very small by comparison. In addition, as one approaches the north magnetic pole, significant daily fluctuations in the field are normal. Other options exist for navigation in these areas.
- On some aircraft, magnetic compasses are used for navigation; on some they aren't (except as a back-up) – but "synthetic" magnetic headings are displayed (and/or used) routinely that rely on true heading (referenced to True north), which is mathematically converted to magnetic heading

using a simplified model of the Earth's magnetic field that needs to be updated every now and then.

- The magnetic field can change rapidly during a geomagnetic storm (associated with solar flares and coronal mass ejections) and magnetic compasses will respond. For example, on 30 October 2003, compass north temporarily changed by five degrees in only six minutes. Systems that use "synthetic" magnetic heading, as described above, are not affected by these rapid temporary changes in the earth's magnetic field.

The following brief tour of the Earth's magnetic field and the description of the World Magnetic Model (WMM) were compiled from extracts of the following report (with a bit of editing for our purposes):

Maus, S., S. Macmillan, S. McLean, B. Hamilton, A. Thomson, M. Nair, and C. Rollins, 2010, *The US/UK World Magnetic Model for 2010-2015*, NOAA Technical Report NESDIS/NGDC.

The complete report can be found on the Web at:

<http://www.ngdc.noaa.gov/geomag/WMM/>.

The Earth's magnetic field is a composite of fields from multiple sources. The three primary ones of "internal origin" are: the core field generated by the fluid outer core, the crustal field generated by magnetic minerals in the Earth's crust and mantle, and that induced by the flow of conducting sea water through the ambient magnetic field. In addition there is a "disturbance field" from both electrical currents in the upper atmosphere and the magnetosphere (near-Earth space), which induce currents in the sea and ground. The so-called main field includes components of the three primary fields of internal origin and accounts for approximately 95% of the composite field strength at the Earth's surface. The main field varies in location and time. The crustal field varies spatially, but is considered constant over a period of years. The disturbance field varies by location and rapidly in time.

The main field is the only field represented by the WMM. The mathematical method of the model is an expansion of the magnetic potential into spherical harmonic functions to degree and order 12. The model includes only those internal magnetic fields that are not part of the disturbance field and have spatial wavelengths exceeding 30° in arc-length. This works out to be almost the entire core field and the long-wavelength portion of the crustal and oceanic fields. The core field changes perceptibly from year to year. This effect, called secular variation (SV), is accounted for in the WMM by a linear SV model. (Specifically, a

straight line is used as the model of the time-dependence of each coefficient of the spherical harmonic representation of the magnetic potential.). Due to unpredictable non-linear changes in the core field, the values of the WMM coefficients have to be updated every five years.

The model is accurate on its release date and deteriorates until a new model (with new coefficients) is released. The following chart (Figure 4) was provided by NOAA to illustrate this concept. It plots the estimated grid variation error from the WMM as a function of time. Grid variation is related to the magnetic variation and the convergence of meridians. See the full NOAA report for the technical definition of terms. Also illustrated is the standard the WMM is designed to meet. Note that SWARM is a three-spacecraft European Space Agency satellite mission to measure the magnetic field with more detail than ever before. The saw-tooth pattern clearly illustrates this pattern of model update every five years and degradation during the period of validity (as NOAA calls it).

Note also that the MIL-SPEC requirement may be more stringent than required by some civil aviation users. Aviation MV accuracy requirements may vary among OEMs depending on specific equipment installations, or between aircraft and flight procedure development applications.

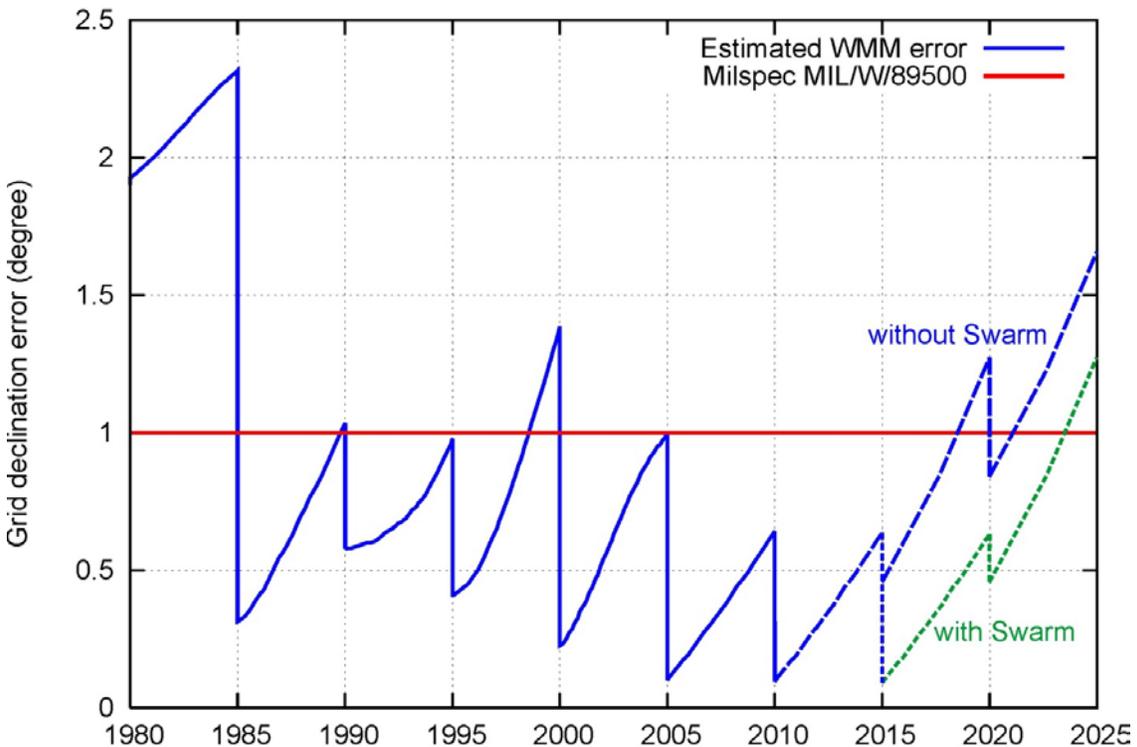


Figure 4 Accuracy of the World Magnetic Model Over Time

Although the WMM characterizes the “majority” of the Earth’s internal magnetic field, the remaining field contributors are not insignificant. As was said, the portions of the geomagnetic field generated by the Earth’s crust and upper mantle, and by the ionosphere and magnetosphere, are largely unrepresented in the WMM. Consequently, a magnetic sensor such as a compass or magnetometer may observe spatial and temporal magnetic anomalies when referenced to the WMM. In particular, certain local, regional, and temporal magnetic declination anomalies can exceed 10 degrees. Anomalies of this magnitude are uncommon but they do exist. Declination anomalies on the order of 3 or 4 degrees are not uncommon but are usually of small spatial extent.

The expected total error of the WMM2010 can be calculated as the root of the sum of the squares of the terms from the average error budget at the Earth’s surface (see table below). The expected difference between the observed and modeled declination in 2010 (solar minimum conditions) is 1.7 degrees while the worst-case scenario for the magnetic declination during an extreme magnetic storm in 2015 is 3.24 degrees.

Table 3 Estimated RMS Contributions to the Observed Magnetic Field at the Earth’s Surface after subtracting the WMM2010.

Row		Inclination** I (deg)	Declination** D (deg)
1	WMM2010 inaccuracy in 2010.0	0.01	0.08
2	in 2015.0	0.12	0.25
3	Crustal magnetization*	0.37	1.67
4	Disturbance field, solar minimum	0.03	0.28
5	solar maximum	0.06	0.43
6	moderate magnetic storm	0.14	0.87
7	extreme magnetic storm	0.35	2.76

* Estimated from land-based observations. Expected to be lower at sea.

** See Figure 2 for the definition of these terms.

NOAA’s NDGC also develops a higher resolution model of the Earth’s field. This model, the Enhanced Magnetic Model (EMM), includes the large scale crustal magnetic field variation. The EMM extends to degree and order 720, resolving magnetic anomalies down to 56 km wavelength (see comparison in the figure below). It is available on the same schedule as the WMM.

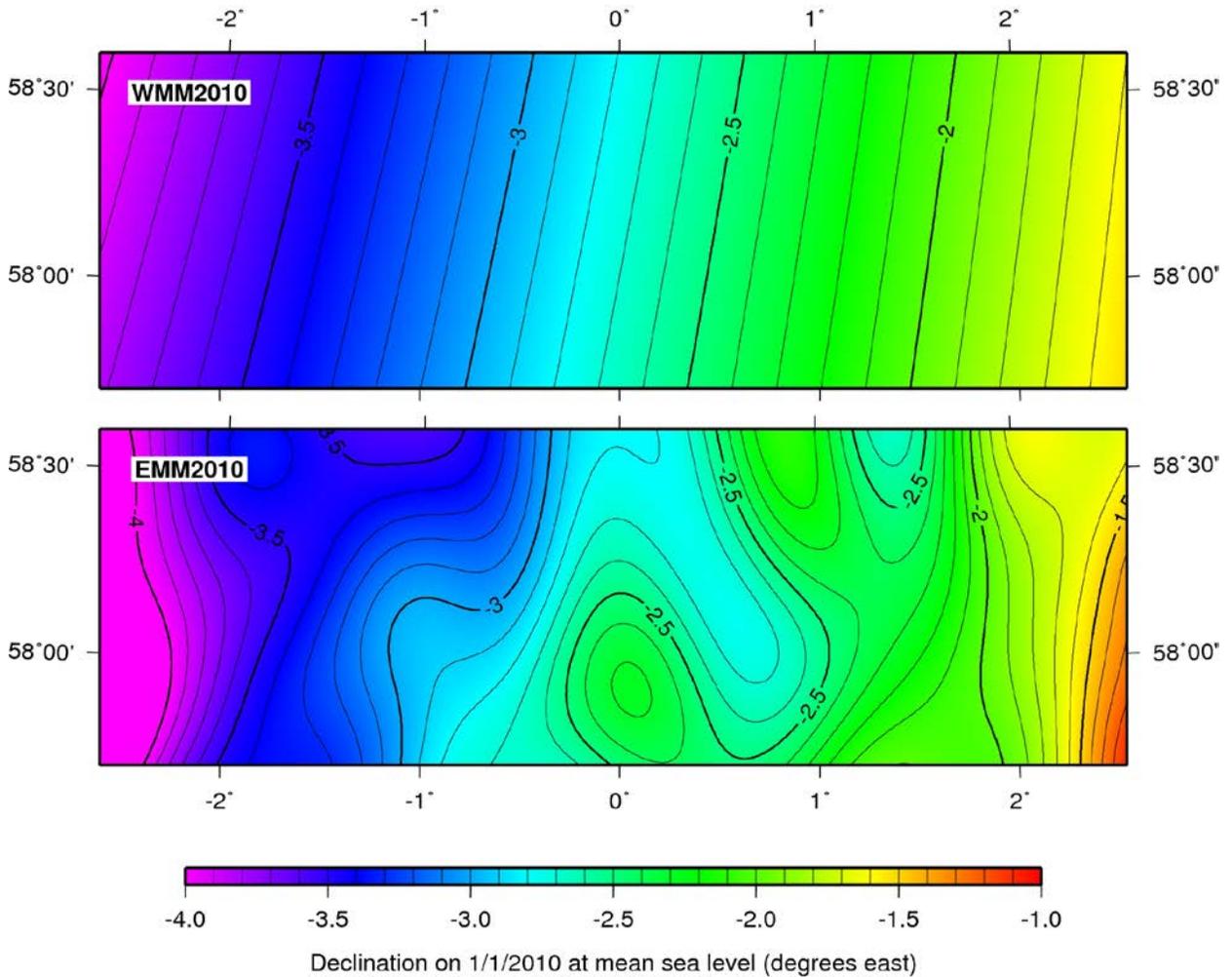


Figure 5 Comparison of the World Magnetic Model and the Enhanced Magnetic Model

NDGC has yet a third even higher fidelity model updated yearly called the High Definition Geomagnetic Model that is used by equipment requiring extremely high MV accuracy such as directional drillers used in the oil industry. Unlike the other models, this one is for purchase.

At a given location and time, the Earth's magnetic field can be described. (See figure below.) The descriptions used here are the convention used in the World Magnetic Model. The three components of intensity (northerly intensity X , easterly intensity Y , and the vertical intensity Z – positive downwards) are reported in nano-Teslas (nT). Other quantities used to describe the field are the horizontal intensity (H), the total intensity (F), the inclination angle (I), and the declination angle (D). The inclination angle is also called the dip angle and is measured from the horizontal plane to the field vector, positive downwards. The declination angle is also called the magnetic variation and is measured clockwise from true north to the horizontal component of the field vector. In these

definitions, the vertical direction is perpendicular to the WGS-84 ellipsoid model of the Earth, the horizontal plane is perpendicular to the vertical direction, and the rotational directions clockwise and counter-clockwise are determined from a view from above.

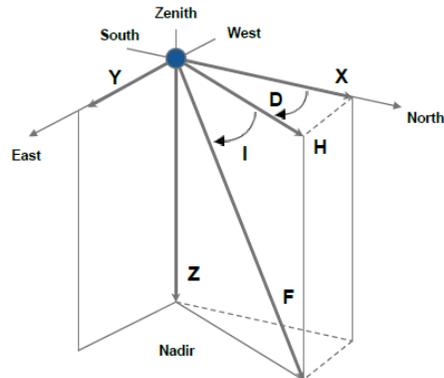


Figure 6 Definition of Geomagnetic Field Vector Elements at Arbitrary Point in Space

The following pages present the quantities of most interest for broadly understanding magnetic variation for aviation. The plots are from the WMM 2010.

The main field declination (magnetic variation) is illustrated below. Figure 7 is a Mercator projection. The contour interval is 2 degrees. Red contours are positive (east) and blue are negative (west). The green contours are the (agonic) zero line. Figure 8 is a north polar stereographic projection. The contour interval is 2 degrees. Red contours are positive (east) and blue are negative (west). The green contours are the (agonic) zero line.

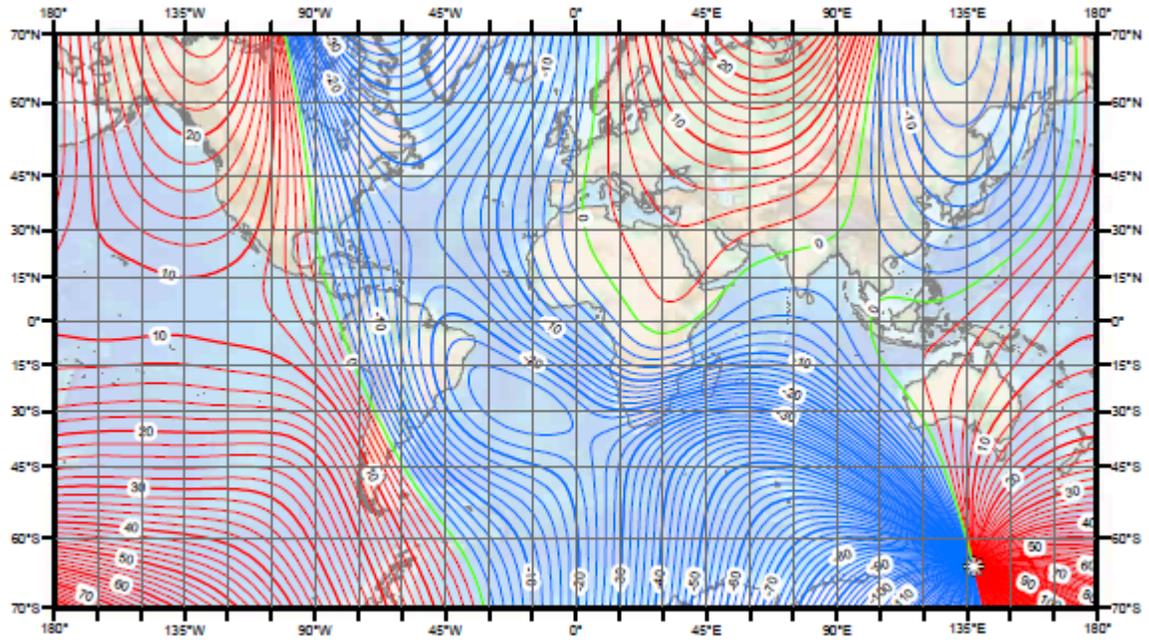


Figure 7 Main Field Declination, Mercator Projection

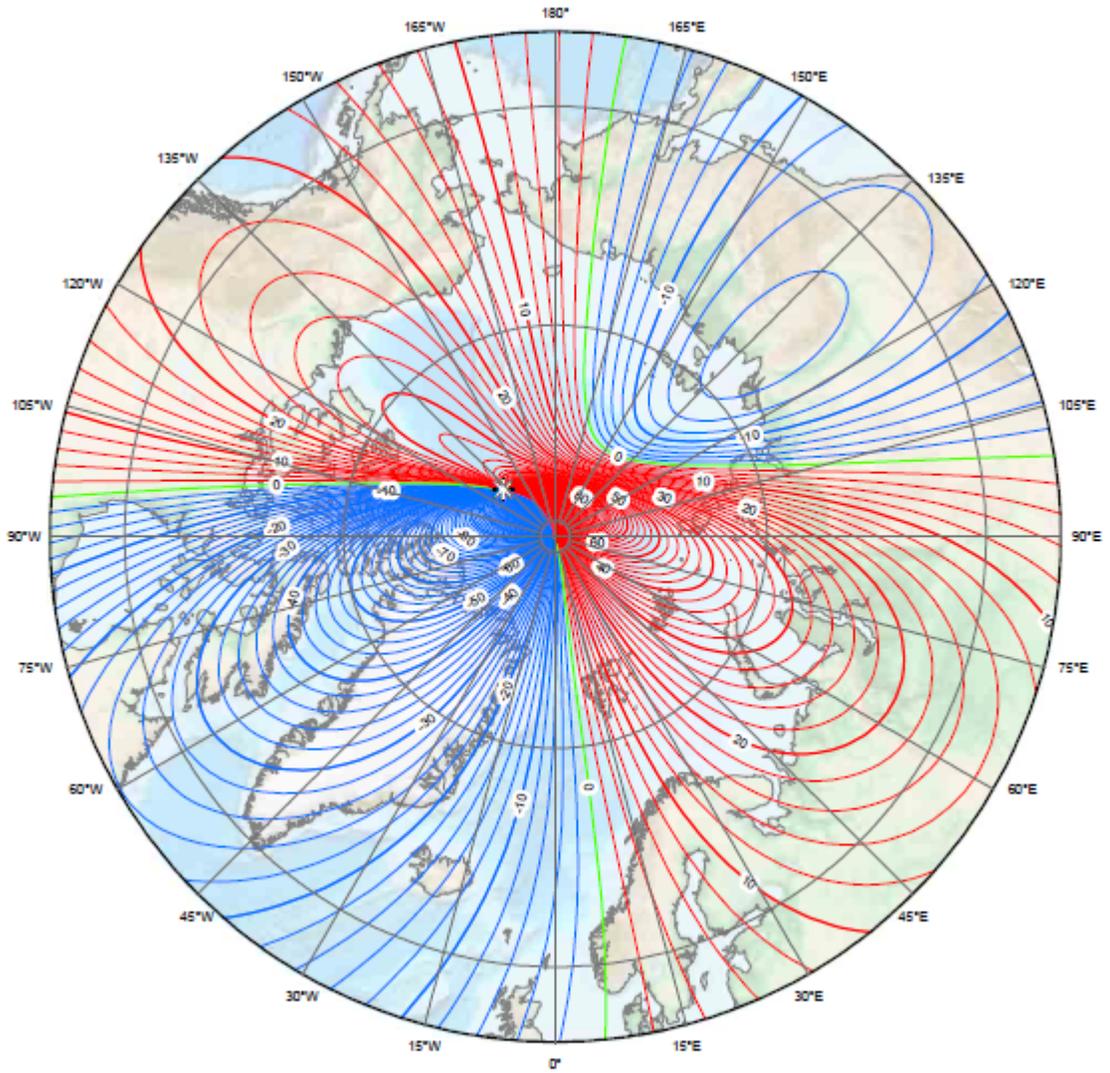


Figure 8 Main field declination (D), North Polar Stereographic Projection

The main field inclination (dip) is illustrated below. Figure 9 is a Mercator projection. The contour interval is 2 degrees. Red contours are positive (down) and blue are negative (up). The green is the zero line. Figure 10 is a north polar stereographic projection. The contour interval is 2 degrees.

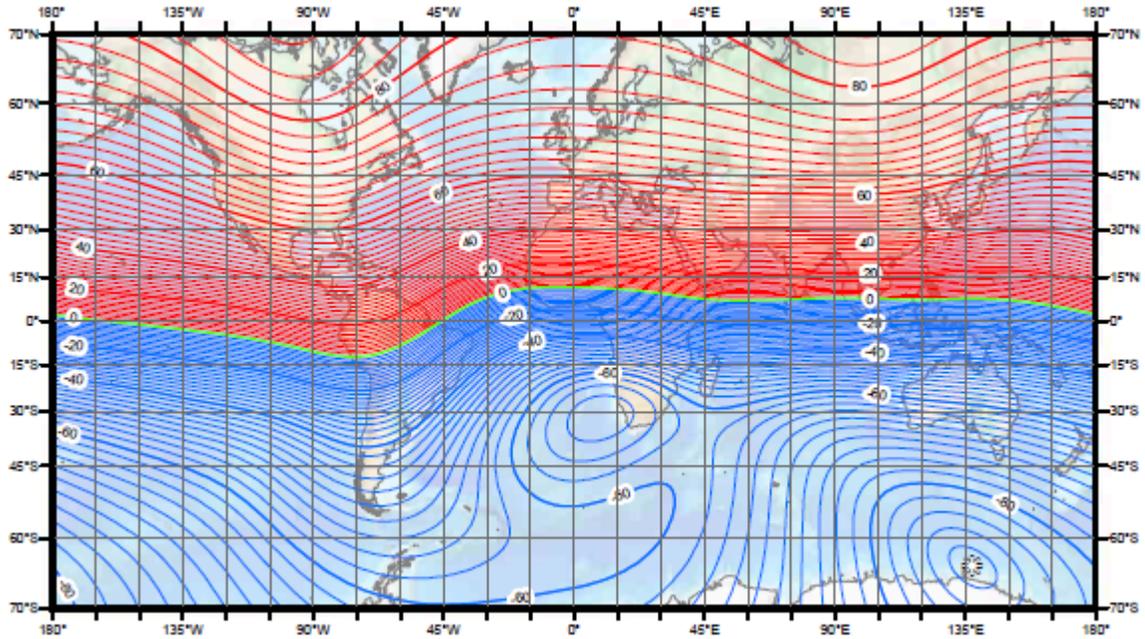


Figure 9 Main Field Inclination Mercator Projection

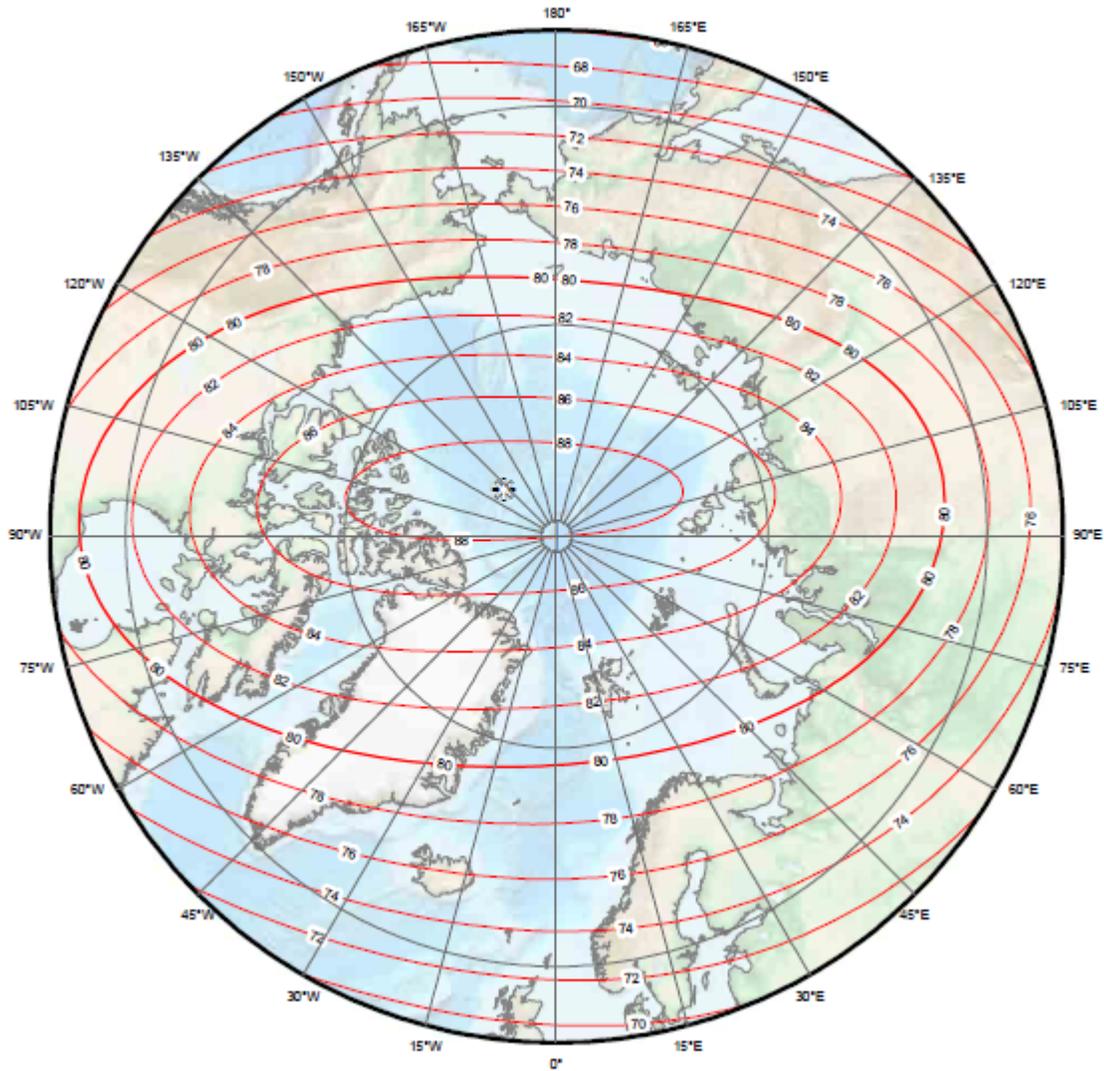


Figure 10 Main Field Inclination North Polar Stereographic Projection

The secular variation (or annual change) of the main field declination (magnetic variation) is illustrated below. Figure 11 is a Mercator projection. The contour interval is 2 arc-minutes / year. Red contours are positive (clockwise) and blue are negative (counter-clockwise). The green contours are the zero change line. Figure 12 is a north polar stereographic projection. The contour interval is 2 arc-minutes / year. Red contours are positive (clockwise) and blue are negative (counter-clockwise). The green contours are the zero change line.

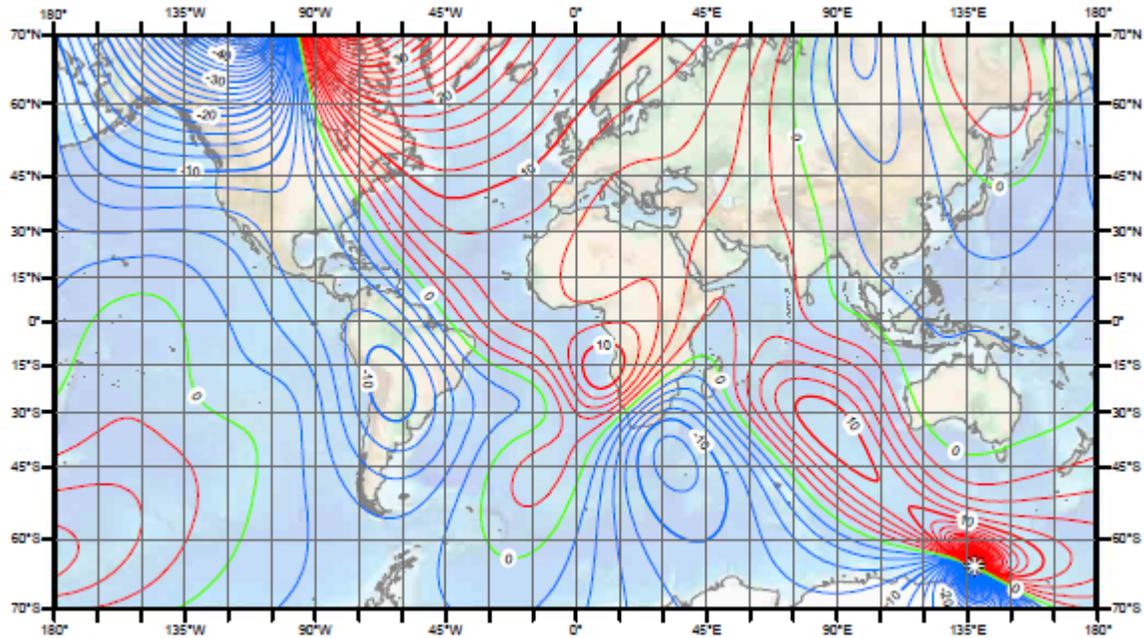


Figure 11 Annual Change of the Main Field Declination, Mercator Projection

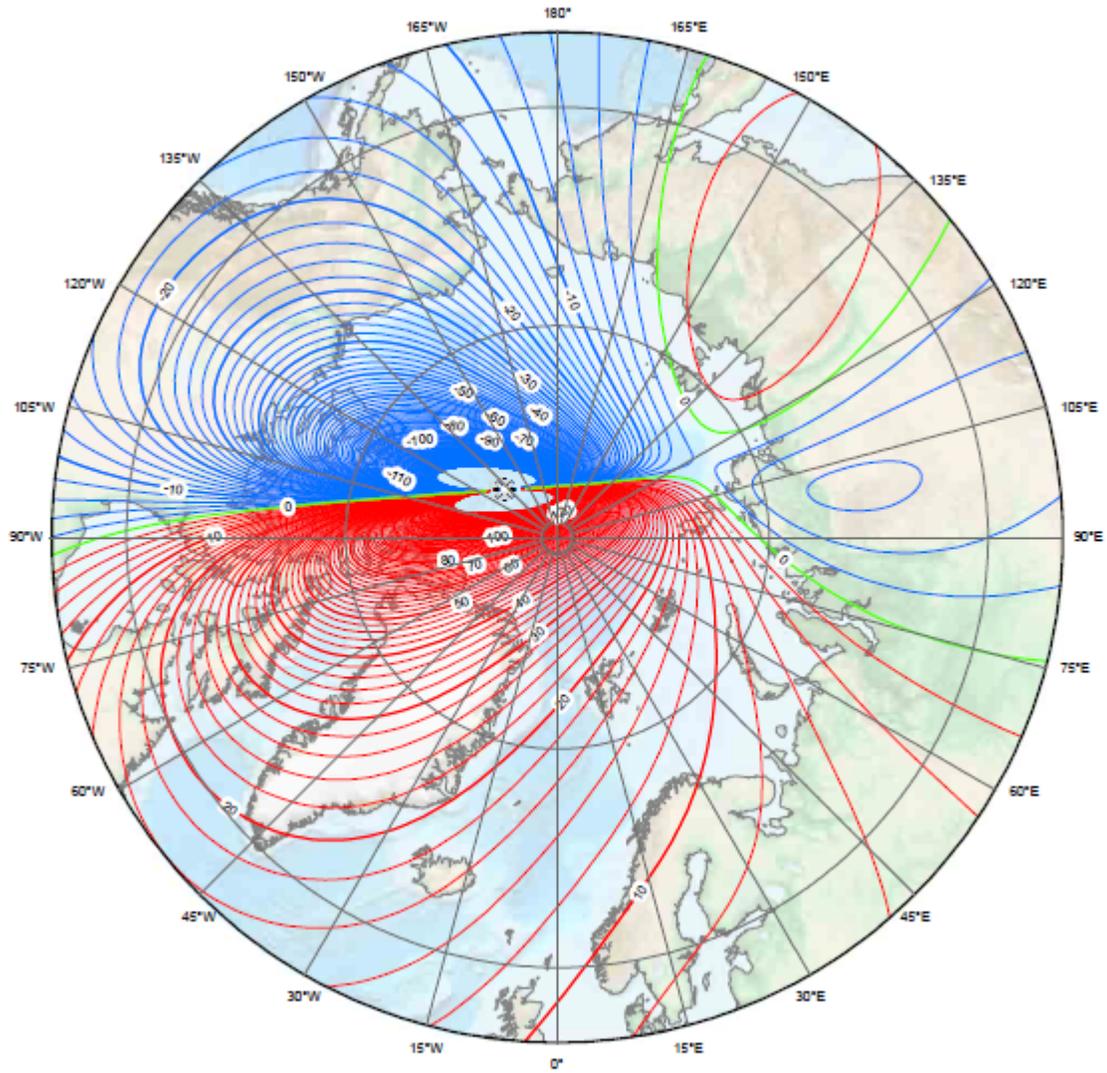


Figure 12 Annual Change of the Main Field Declination, North Stereographic Projection