External Magnetic Field Variations and Aeromagnetic Surveys
Experiences, Problems, Potential Solutions

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The Origin of the Geomagnetic Field
The ground geomagnetic field is composed of

the "main field" (also "core field")
- dynamo in the Earth's fluid outer core
- approximated by a dipole ~700 km off the Earth's centre of gravity
- ~95% of the field strength measured at the Earth's surface

the "crustal field"
- magnetized solid rocks
- partially remanent, partially induced
- ~3% of the magnetic field strength measured at the Earth's surface

the "external field"
- electric currents in the ionosphere and magnetosphere
- geomagnetically induced currents (GIC) in the upper mantle and the crust
- ~2% of the magnetic field strength measured at the Earth's surface
perfectly conducting plasma: magnetic field is "frozen-in"

Figure after Parker (1970)

Figure after Kippenhahn & Moellenhoff, "Elementary plasma physics" (1975)

Figure after W. Elsasser (1958)
Examples of the origins of crustal magnetisation

Figure from E.P. Metzger after NSTA/FEMA
Sea-floor spreading  (mid-Atlantic ridge)

Figures from V.J. Vine, "Sea-Floor Spreading" (1972)
"Solar quiet" (Sq) ionospheric currents systems
right: solar tides only; left: tides + convection

Figure from "Handbook of Geophysics and the Space Environment, chapter 4" (AFRL 1985)
Magnetosphere-ionosphere large-scale current system under steady southward IMF conditions

Figure from M.C. Kelley
"The Earth's Ionosphere" (1989)
Solar quiet variations

⇐ deep polar cap

⇐ polar cap

⇐ auroral zone

⇐ subauroral zone
External disturbance field

Provisional hourly AE (AU & AL) and final Dst indices during the Bastille storm month

Figure courtesy of World Data Center for Geomagnetism, Kyoto
Aeromagnetic Surveys in Greenland

characteristics and conditions
# Greenland survey flight parameters (2001)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td>Cessna 208 Caravan</td>
</tr>
<tr>
<td><strong>Flight altitude:</strong></td>
<td>60 – 300 m</td>
</tr>
<tr>
<td><strong>Flight speed:</strong></td>
<td>~250 km/h</td>
</tr>
<tr>
<td><strong>N-S survey line separation:</strong></td>
<td>100 – 500 m</td>
</tr>
<tr>
<td><strong>E-W tie line separation:</strong></td>
<td>1000 – 5000 m</td>
</tr>
<tr>
<td><strong>Magnetometer sampling rate:</strong></td>
<td>0.1 s ($\approx$ 7 m flight distance)</td>
</tr>
<tr>
<td><strong>GPS sampling rate:</strong></td>
<td>1 s</td>
</tr>
<tr>
<td><strong>Barometer+radar sampling rate:</strong></td>
<td>0.5 s</td>
</tr>
<tr>
<td><strong>Data rejection criterion:</strong></td>
<td>Variations at base station exceed 10 nT within a chord of 1 minute</td>
</tr>
</tbody>
</table>
Magnetic anomaly map compiled from 2001 aeromagnetic survey data

Figure courtesy of T. Rasmussen, GEUS
Magnetic storm period 29/30 May 2003 (Dst = -131 nT)
Breakdown of aeromagnetic survey schedule deviations coastal area of south-west Greenland, 1998+1999+2001
### 1998 + 1999 + 2001 surveys (total 331 survey days)

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number of Days</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight survey production affected by technical problems</td>
<td>14</td>
<td>4.2 %</td>
</tr>
<tr>
<td>Flight delayed because of adverse weather conditions</td>
<td>11</td>
<td>3.3 %</td>
</tr>
<tr>
<td>Flight delayed because of excessive geomagnetic activity</td>
<td>35</td>
<td>10.6 %</td>
</tr>
<tr>
<td>Flight delayed because of both bad weather and geomagnetic activity</td>
<td>8</td>
<td>2.4 %</td>
</tr>
<tr>
<td>Flight canceled because of adverse weather conditions</td>
<td>94</td>
<td>28.4 %</td>
</tr>
<tr>
<td>Flight canceled because of excessive geomagnetic activity</td>
<td>7</td>
<td>2.1 %</td>
</tr>
<tr>
<td>Flight canceled because of both bad weather and geomagnetic activity</td>
<td>19</td>
<td>5.7 %</td>
</tr>
<tr>
<td>Flight cut short because of adverse weather conditions</td>
<td>35</td>
<td>10.6 %</td>
</tr>
<tr>
<td>Flight cut short because of excessive geomagnetic activity</td>
<td>6</td>
<td>1.8 %</td>
</tr>
<tr>
<td>Flight cut short because of both bad weather and geomagnetic activity</td>
<td>5</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Relight of previously flown survey lines</td>
<td>14</td>
<td>4.2 %</td>
</tr>
</tbody>
</table>

*Survey log book data kindly provided by Sander Geophysics Ltd.*
How to reduce the risk that external field fluctuations perturb survey data and reduce their quality?

(1) Select times statistically known to be less disturbed
Diurnal and seasonal distributions of the 2‰ magnetically most perturbed days (1985-2003)

Figure compiled by H. Gleisner, DMI
Greenland aeromagnetic survey 2001
(area north of the GDH magnetic observatory)

Best survey time from a geomagnetic point of view
• December-January 15 LT – 24 LT (19 UT – 04 UT)
  (winter afternoon-evening hours)

Flight scheduling restrictions
• airport opening hours (8 – 16 LT Mon through Sat)
• terrestrial weather conditions
• visibility
How to reduce the risk that external field fluctuations perturb survey data and reduce their quality?

(1) Select times statistically known to be less disturbed

(2) Do not fly when conditions are not optimal – wait
Greenland aeromagnetic surveys

Flight delay possible
  • long daylight hours (Arctic summer)

  downside
  • extra fees for take-off or landing after 16 LT

Flight cancelation possible
  downside
  • each survey day costs around 8 k€
    (*lost if not used otherwise*)
How to reduce the risk that external field fluctuations perturbe survey data and reduce their quality?

(1) Select times statistically known to be less disturbed
(2) Do not fly when conditions are not optimal – wait
(3) Fly anyway and re-fly *a-posteriori* rejected legs
Canada – acceptance rate vs. geomagnetic latitude and rejection threshold

Figure 1: Location of Canadian Magnetic Observatories.

Figure 2: Comparison of yearly rejection rates for the different observatories in 2001 and different tolerances as maximum per chord length in minutes.

*Figures from "Correlation between aeromagnetic diurnal rejection and geomagnetic indices" M.A. Vallée (Fugro Airborne Surveys), L. Newitt, R. Dumont, P. Keating (Geological Survey of Canada)*
Greenland aeromagnetic surveys

Re-flight possible
downside
  • survey day costs + fuel + aircraft wear and tear
How to reduce the risk that external field fluctuations perturbe survey data and reduce their quality?

(1) Select times statistically known to be less disturbed
(2) Do not fly when conditions are not optimal – wait
(3) Fly anyway and re-fly \textit{a-posteriori} rejected legs
(4) Correct survey data with help of base station data
Greenland Aeromag 2001 survey
(polar cap latitudes)

Temporal magnetic field perturbations can be
- spatially uniform \textit{ideal but rare}
- spatially non-uniform \textit{typical}
- moving (traveling) \textit{frequent}

Interpolation between neighboring base stations
- possible
- limited by site spacing
  \textit{but partially offset by field integration effect}
  \text{field continuation: } B_{\text{ground}} = B_{\text{ionosphere}} \cdot e^{-kh}
2001 survey area north of Uummannaq (Greenland west coast)
How to reduce the risk that external field fluctuations perturbe survey data and reduce their quality?

(1) Select times statistically known to be less disturbed
(2) Do not fly when conditions are not optimal – wait
(3) Fly anyway and re-fly *a-posteriori* rejected legs
(4) Correct survey data with help of base station data
(5) Attempt to predict excessive geomagnetic activity
GAFS – Geomagnetic Activity Forecast Service for Denmark and West Greenland

SDA supported by ESA through SWAPP
DK & GL observatories – activity thresholds (alert levels)

Time intervals considered: 0–3 hrs, 3–12 hrs, 12–48 hrs

<table>
<thead>
<tr>
<th>Observatory</th>
<th>Time Interval</th>
<th>Predicted Field Element</th>
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</thead>
<tbody>
<tr>
<td>THL</td>
<td>0–3 hrs</td>
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<td>GDH</td>
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<td>0–3 hrs</td>
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<td>12–48 hrs</td>
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<td>BFE</td>
<td>0–3 hrs</td>
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</tr>
</tbody>
</table>

*green* – quiet: predicted field element < threshold with 80% probability

*yellow* – active: predicted field element > threshold with 67% probability

*red* – disturbed: predicted field element > threshold with 67% probability
Jan – Dec 2004
false alarm and miss rates

Method:
06 UT: note alert level
09–18 UT: record magnetic field
later: compare alert level with peak disturbance (5-min average)

solid: GAFS forecast
hatched: random forecast
yellow: active
red: disturbed
Jan – Dec 2004
false alarm and miss rates

Method:
06 UT: note alert level
18–06 UT (two days later): record magnetic field
later: compare alert level with peak disturbance (5-min average)

solid: GAFS forecast
hatched: random forecast
yellow: active
red: disturbed
Cancelation of plans for real world survey

Simulation of aeromagnetic survey (Oct 10 – Dec 20, 2005)

Method:

06 LT  
  survey manager examines GAFS web site (nowcast + forecast)
  survey manager decides  "no fly" / "fly" / "wait"

"no fly"  
  plane stays grounded for the day

"fly"  
  plane takes off at 08 LT, returns at 14 LT

"wait"  
  survey team prepares plane but does not take off

09.30 LT  
  manager re-examines GAFS web site, decides  "no fly" / "fly"

"no fly"  
  plane stays grounded for the day

"fly"  
  plane takes off at 10 LT, returns at 16 LT before airport closure
relative occurrence rate of days on which the difference between two successive 1-min samples exceeded 10 nT less than the number of times indicated by the numbers on the horizontal axis.
Conclusion and Outlook

"no-flight" decision is based on intensity of short-term variations
Assumption: large temporal scale $\approx$ large spatial scale

Interpolation between reference sites requires spatial correlation
Assumption: characteristic spatial scale $>$ site spacing

Necessary

Study of the
spatial scale and its relation to the
temporal scale of
magnetic field fluctuations in
regions of interest (specified by GML–MLT)