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

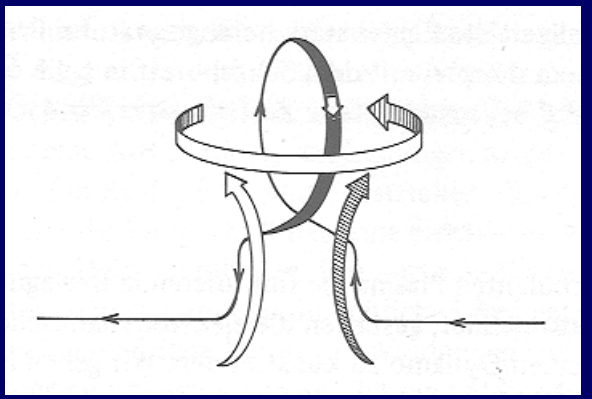
~3% of the magnetic field strength measured at the Earth's surface

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

fuzzy numbers



perfectly conducting plasma:
magnetic field is "frozen-in"

Figure after Parker (1970)

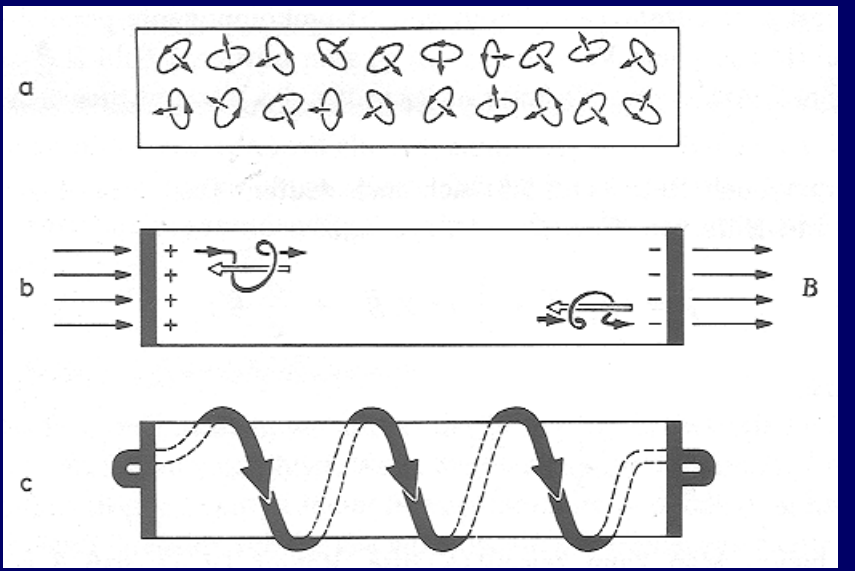


Figure after Krause & Rädler (1971)

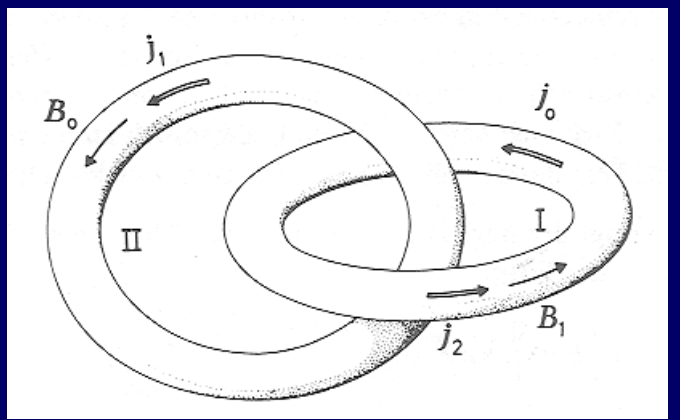


Figure from Kippenhahn & Moellenhoff, "Elementary plasma physics" (1975)

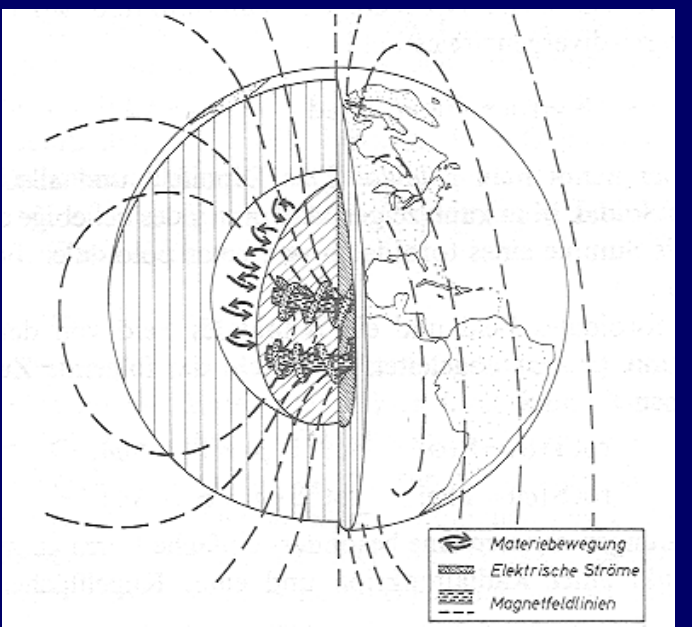
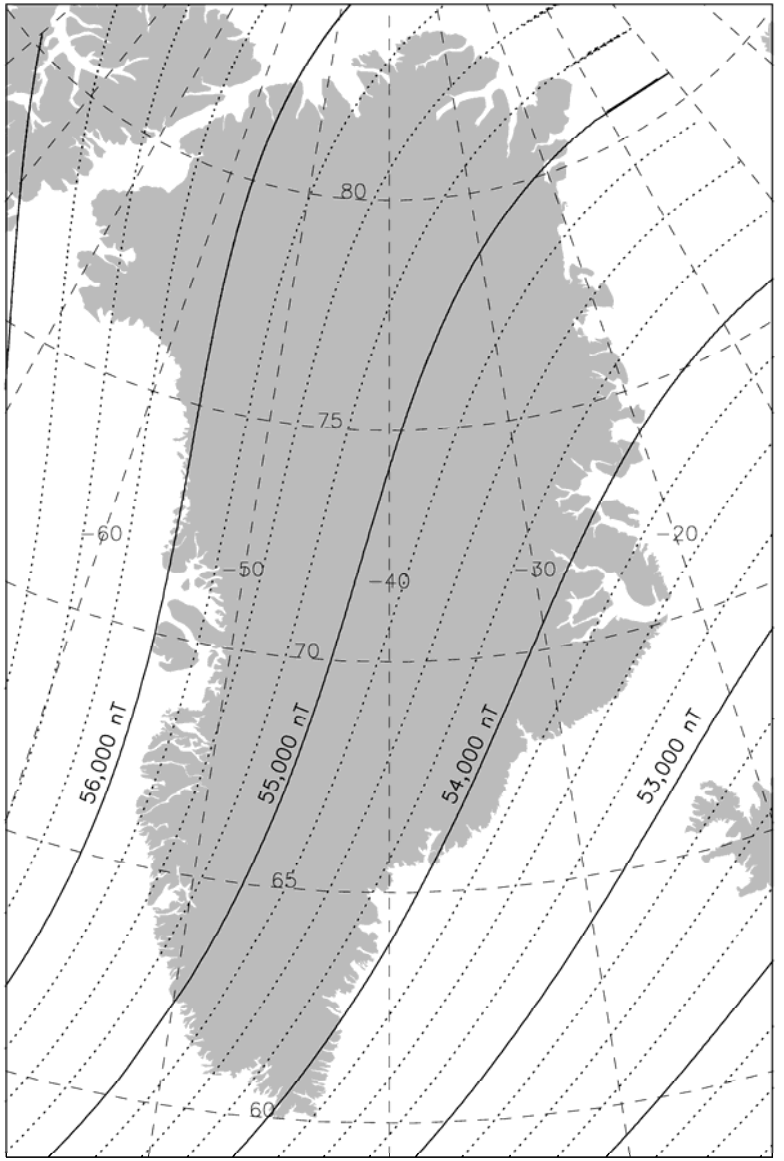


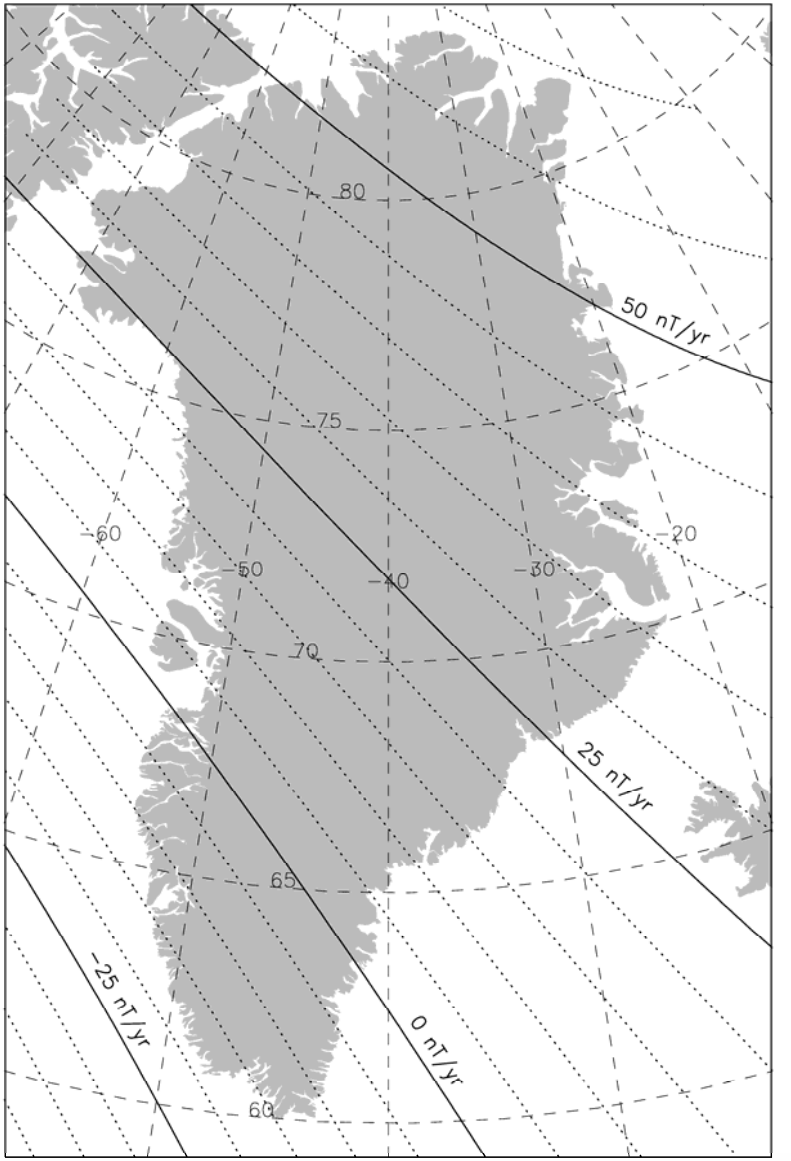
Figure after W. Elsasser (1958)

Greenland – total magnetic induction



JFW – 30/10/2008 IGRF10 epoch 2008.5

Greenland – secular variation



JFW – 30/10/2008 IGRF10 epoch 2008.5

Examples of the origins of crustal magnetisation

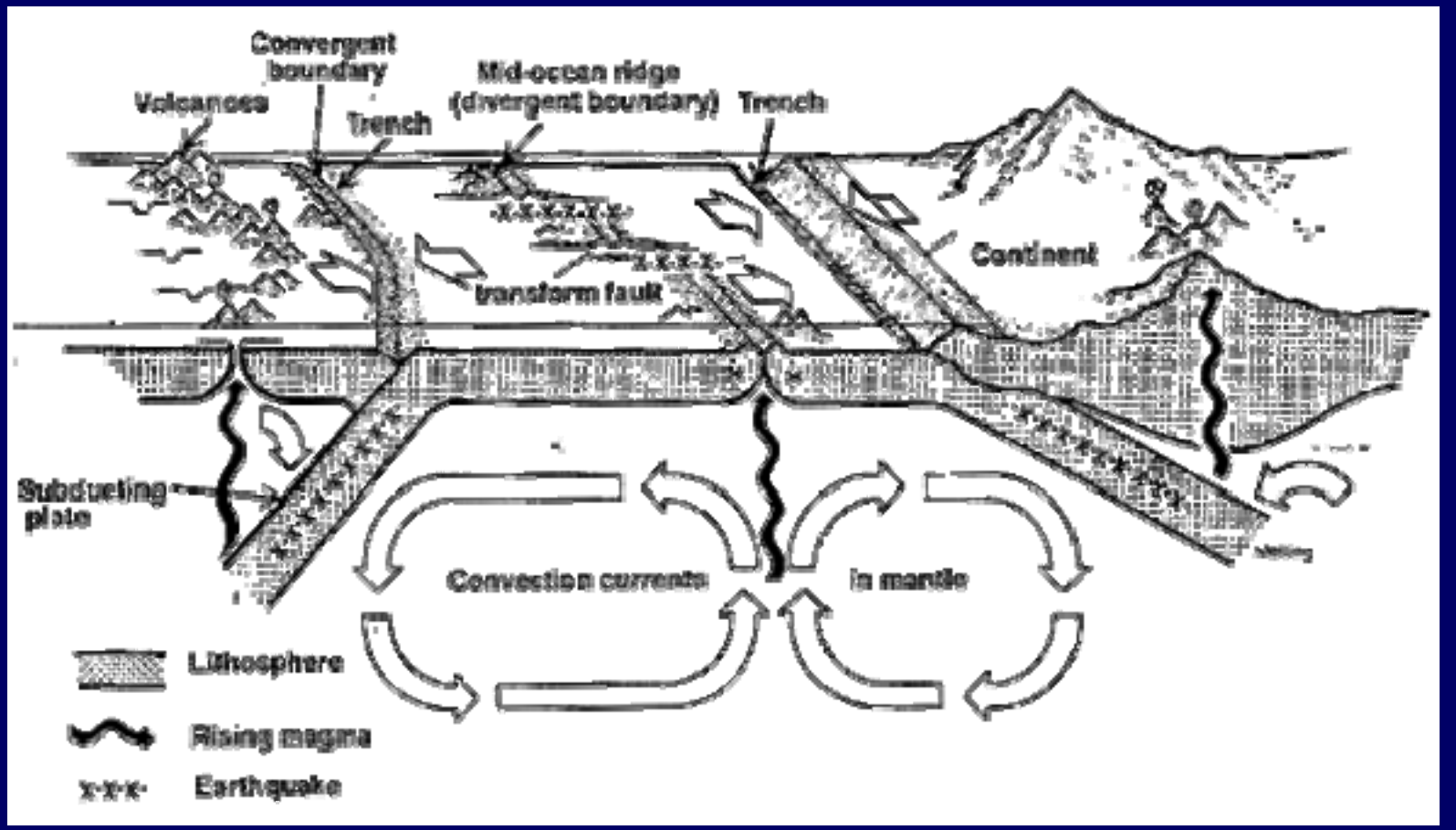
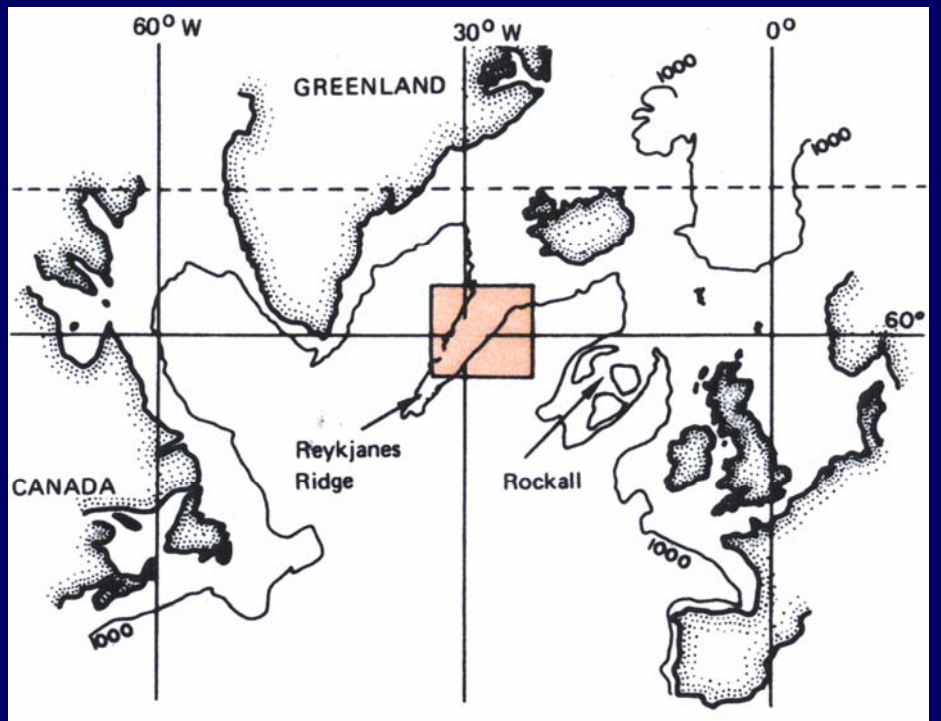
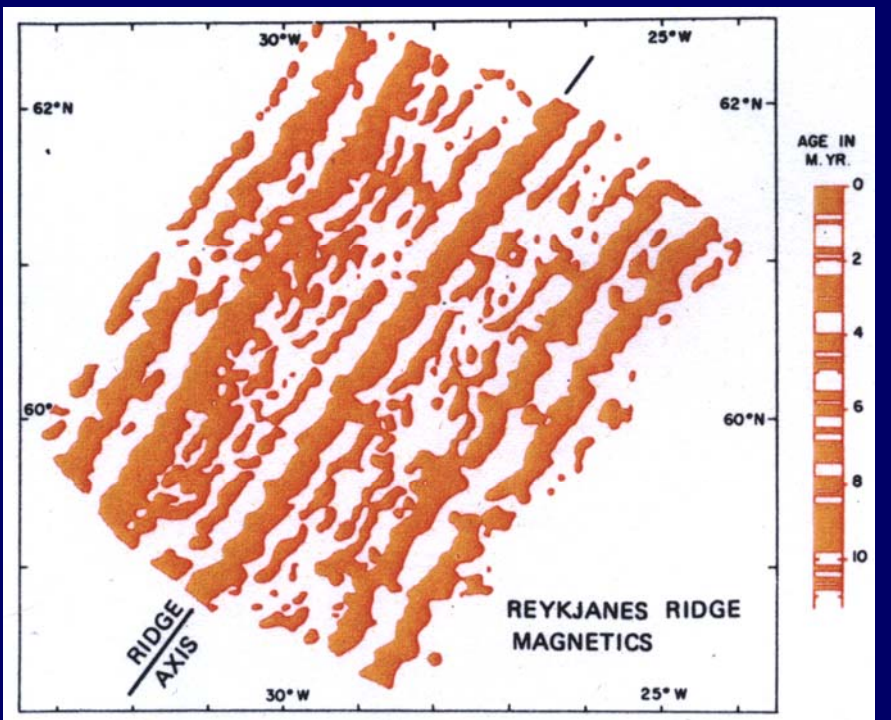


Figure from E.P. Metzger after NSTA/FEMA

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

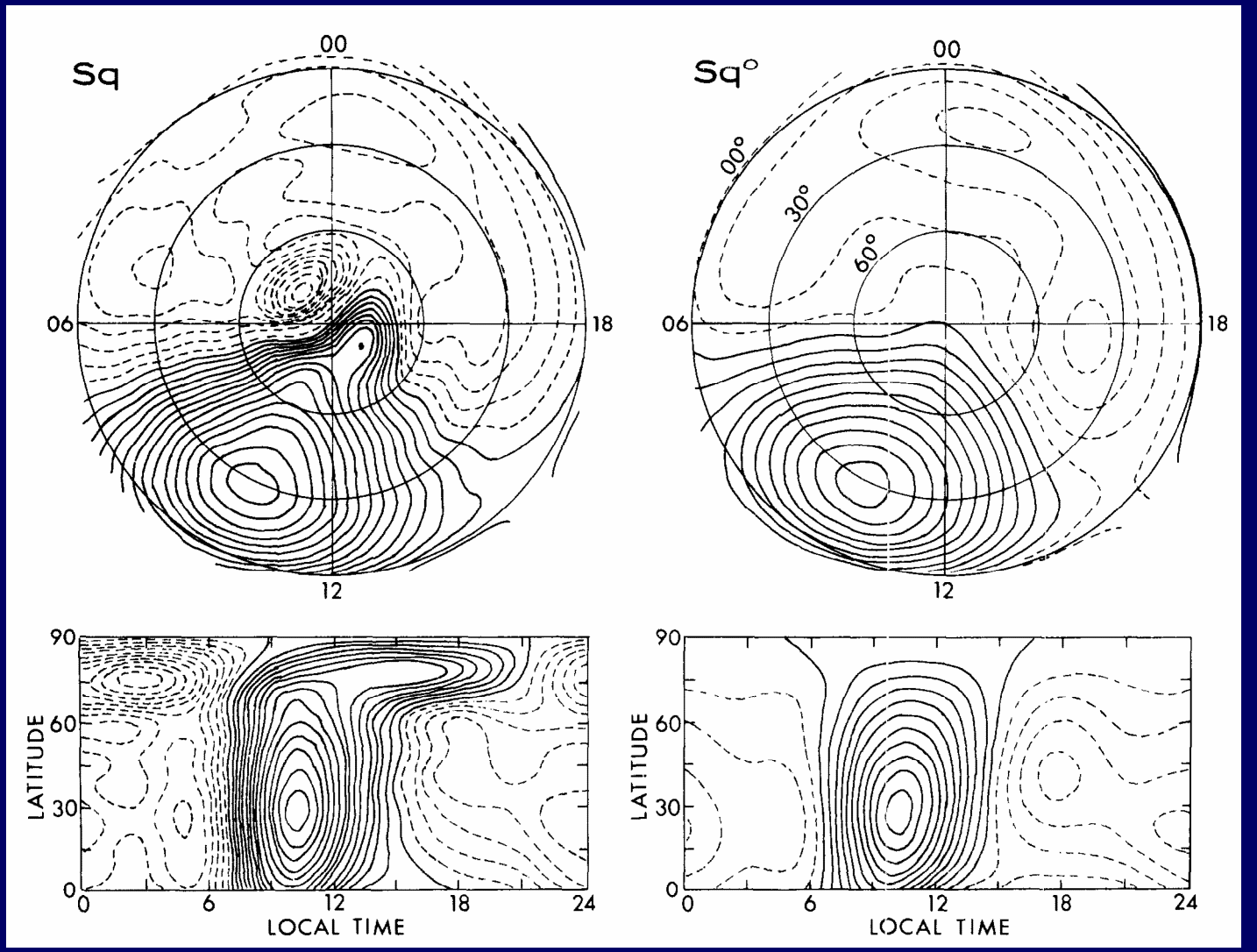
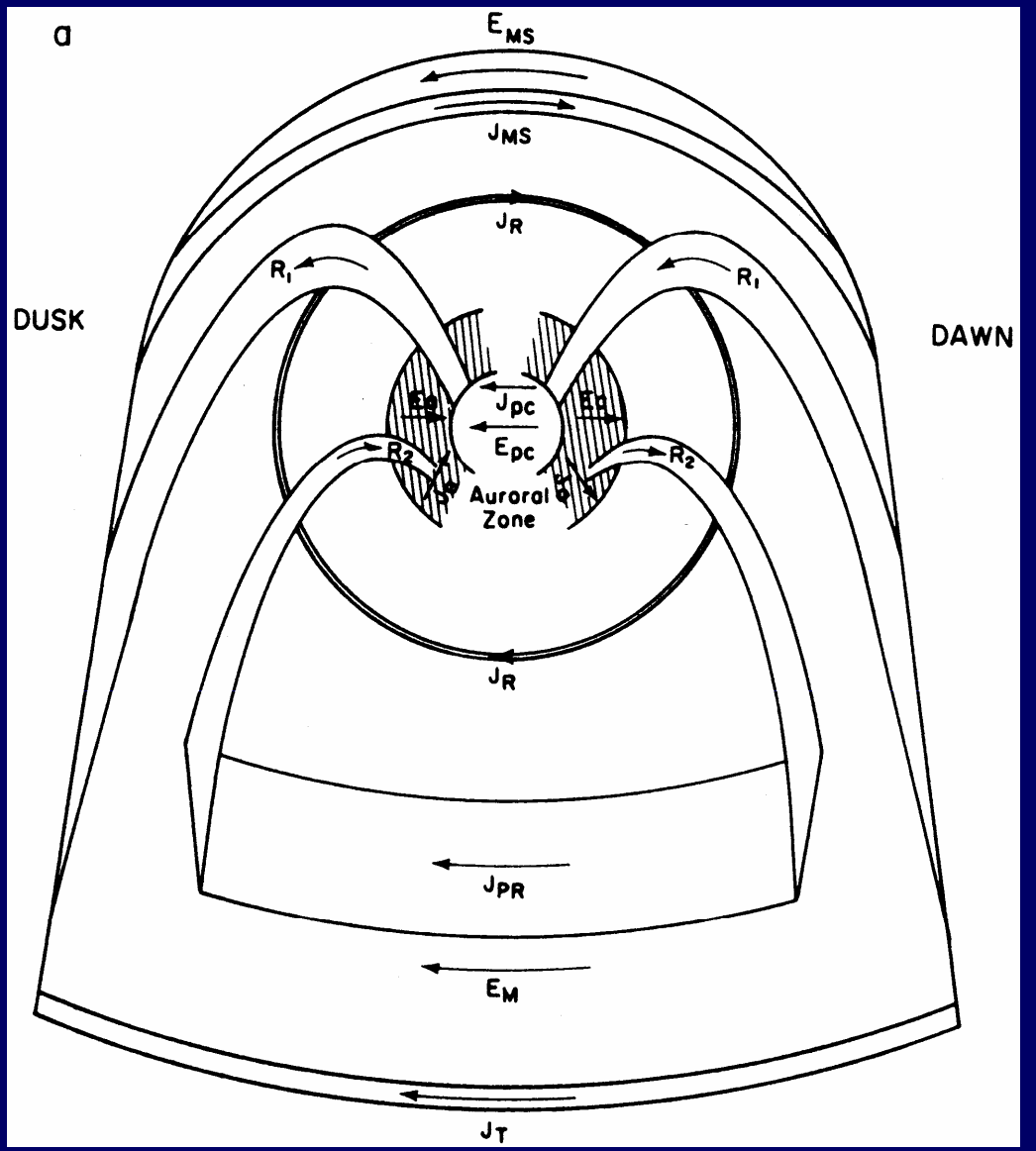


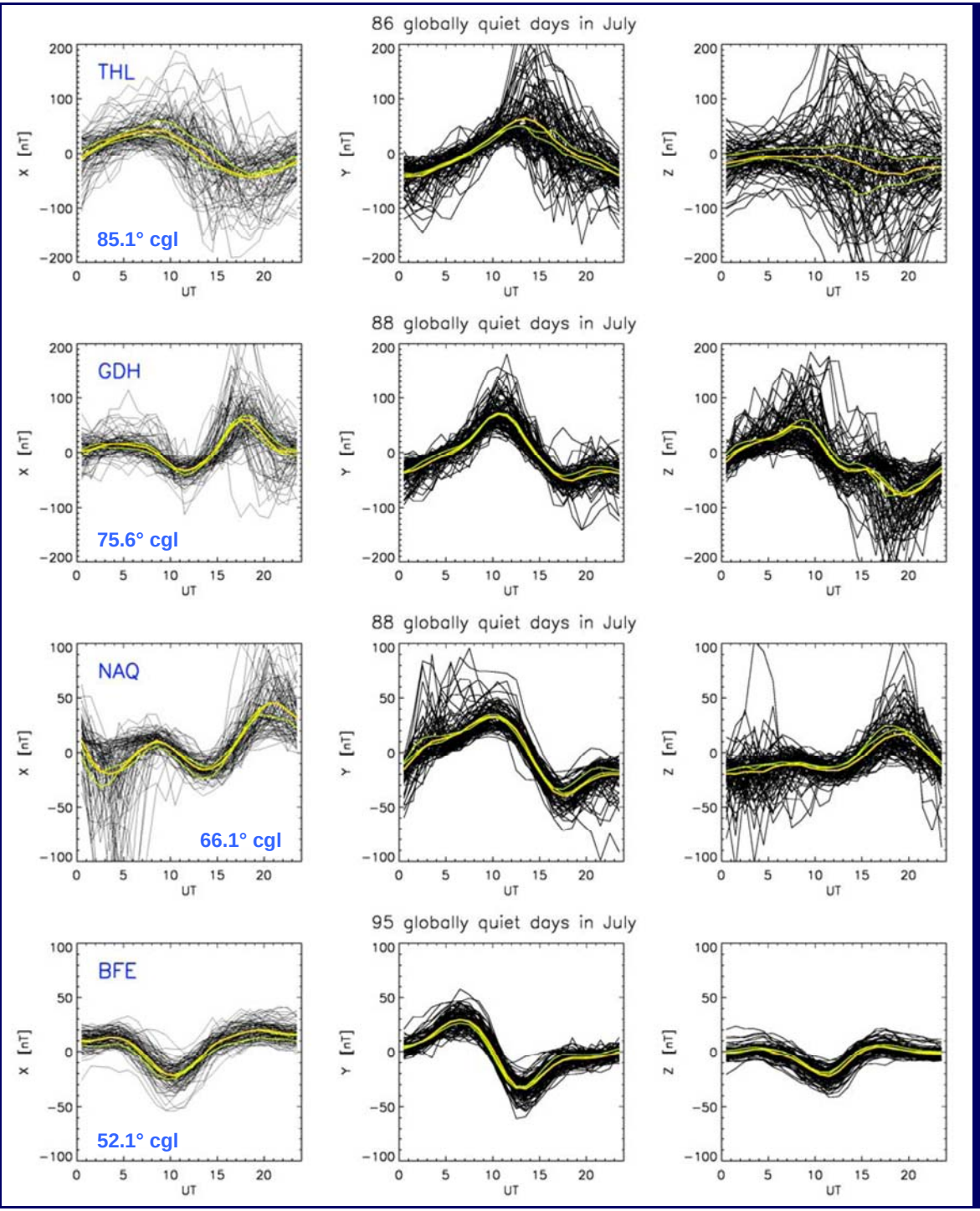
Figure from "Handbook of Geophysics and the Space Environment, chapter 4" (AFRL 1985)



Magnetosphere-ionosphere large-scale current system under steady southward IMF conditions

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

Solar quiet variations



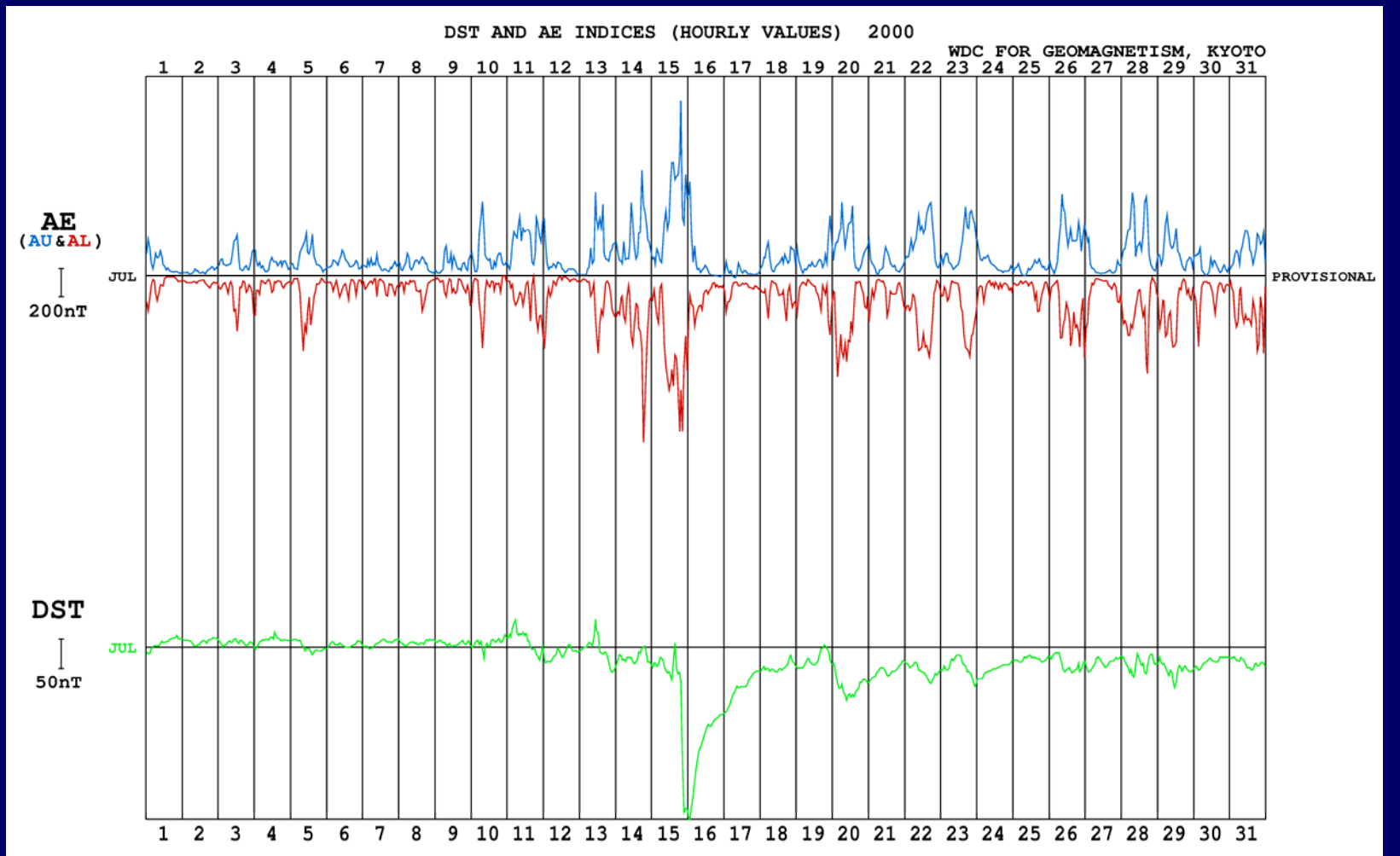
⇐ deep polar cap

⇐ polar cap

⇐ auroral zone

⇐ subauroral zone

External disturbance field



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

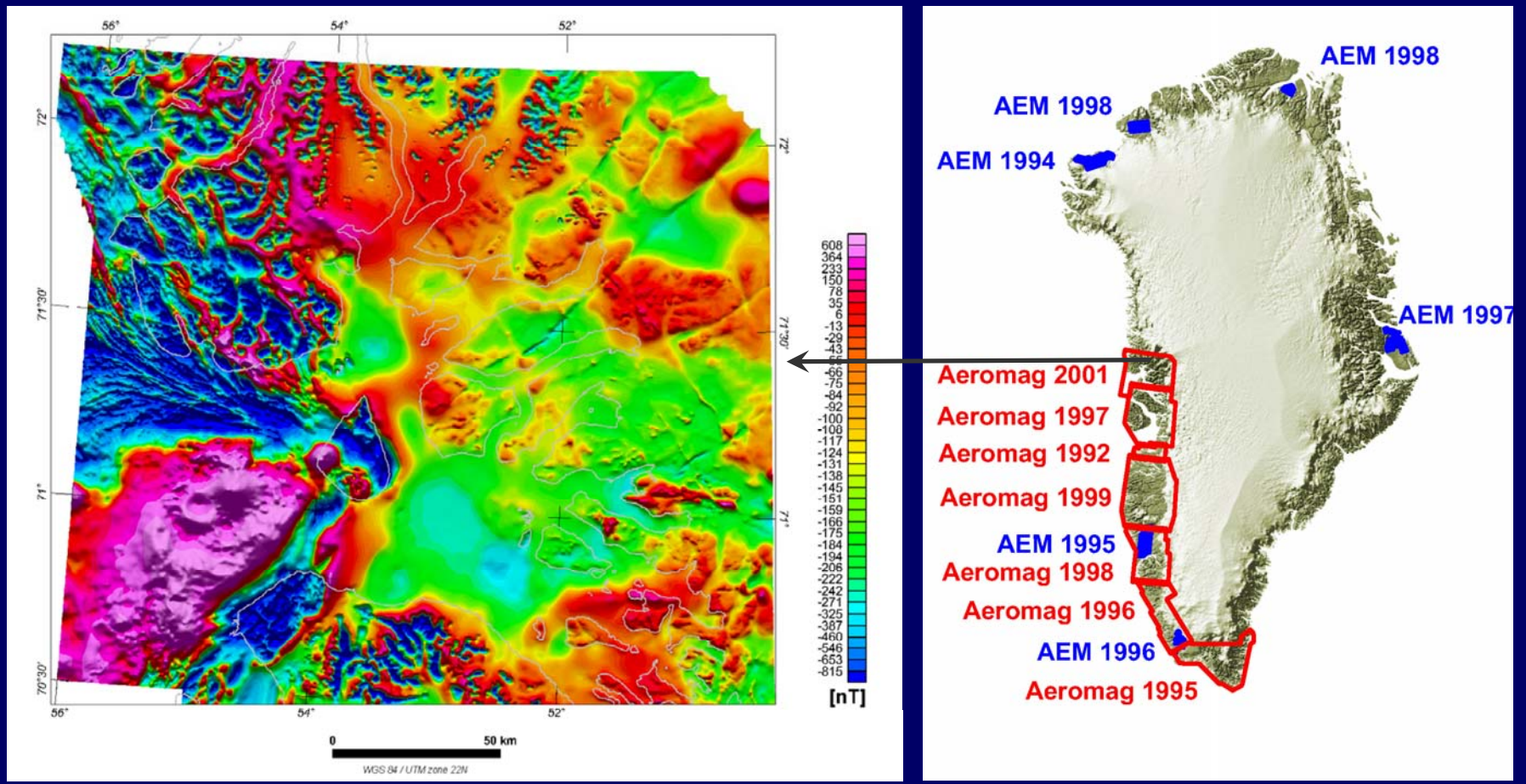
Figure courtesy of World Data Center for Geomagnetism, Kyoto

Aeromagnetic Surveys in Greenland

characteristics and conditions

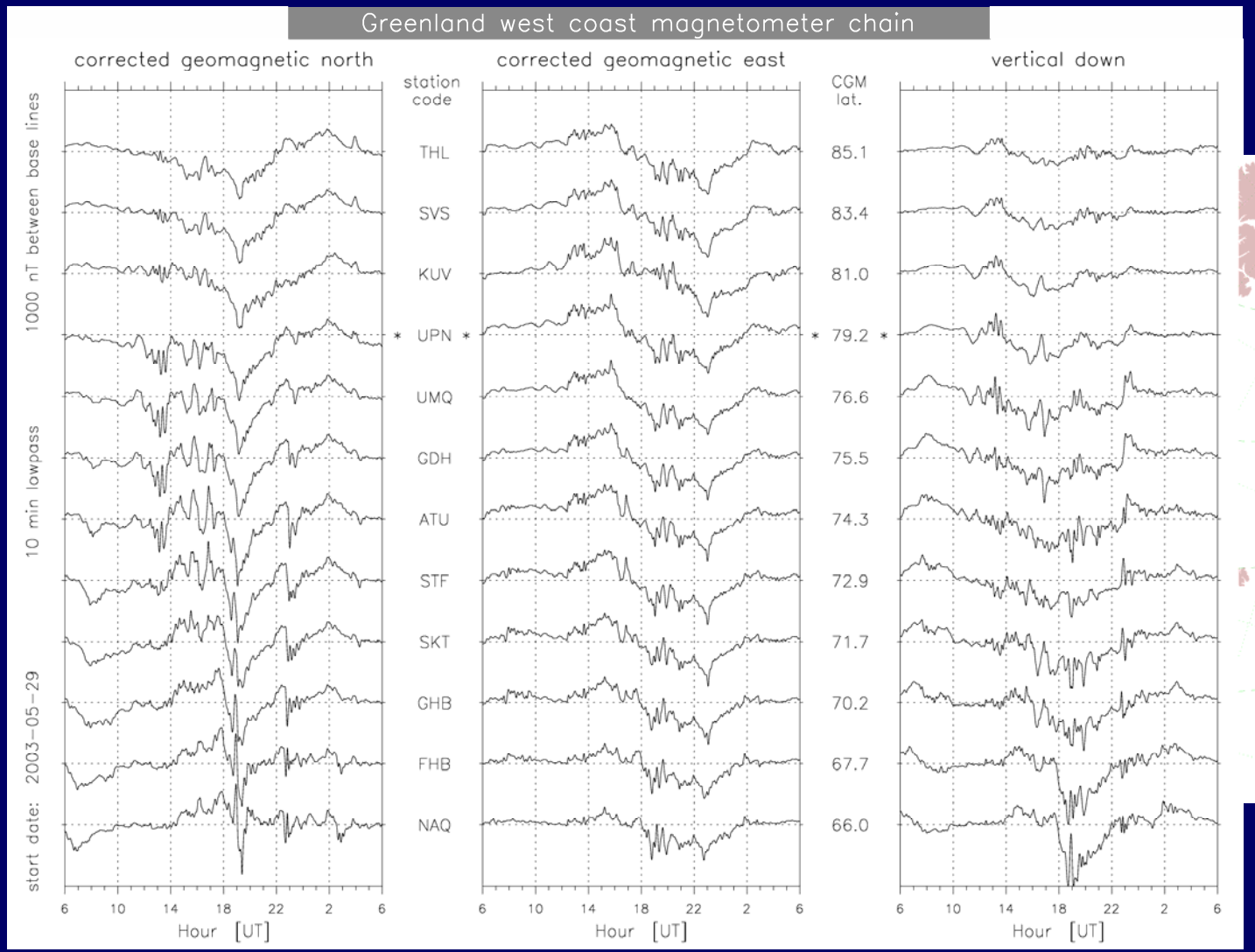
Greenland survey flight parameters (2001)

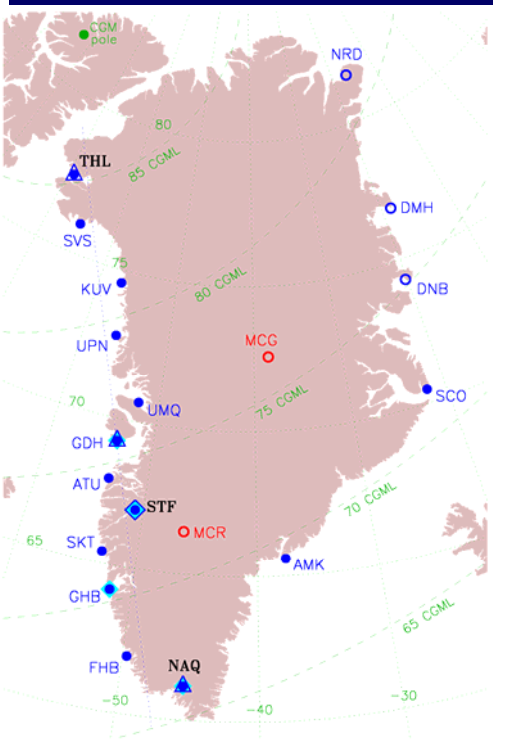
Equipment:	Cessna 208 Caravan
Flight altitude:	60 – 300 m
Flight speed:	~250 km/h
N-S survey line separation:	100 – 500 m
E-W tie line separation:	1000 – 5000 m
Magnetometer sampling rate:	0.1 s (≅ 7 m flight distance)
GPS sampling rate:	1 s
Barometer+radar sampling rate:	0.5 s
Data rejection criterion:	Variations at base station exceed 10 nT within a chord of 1 minute



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

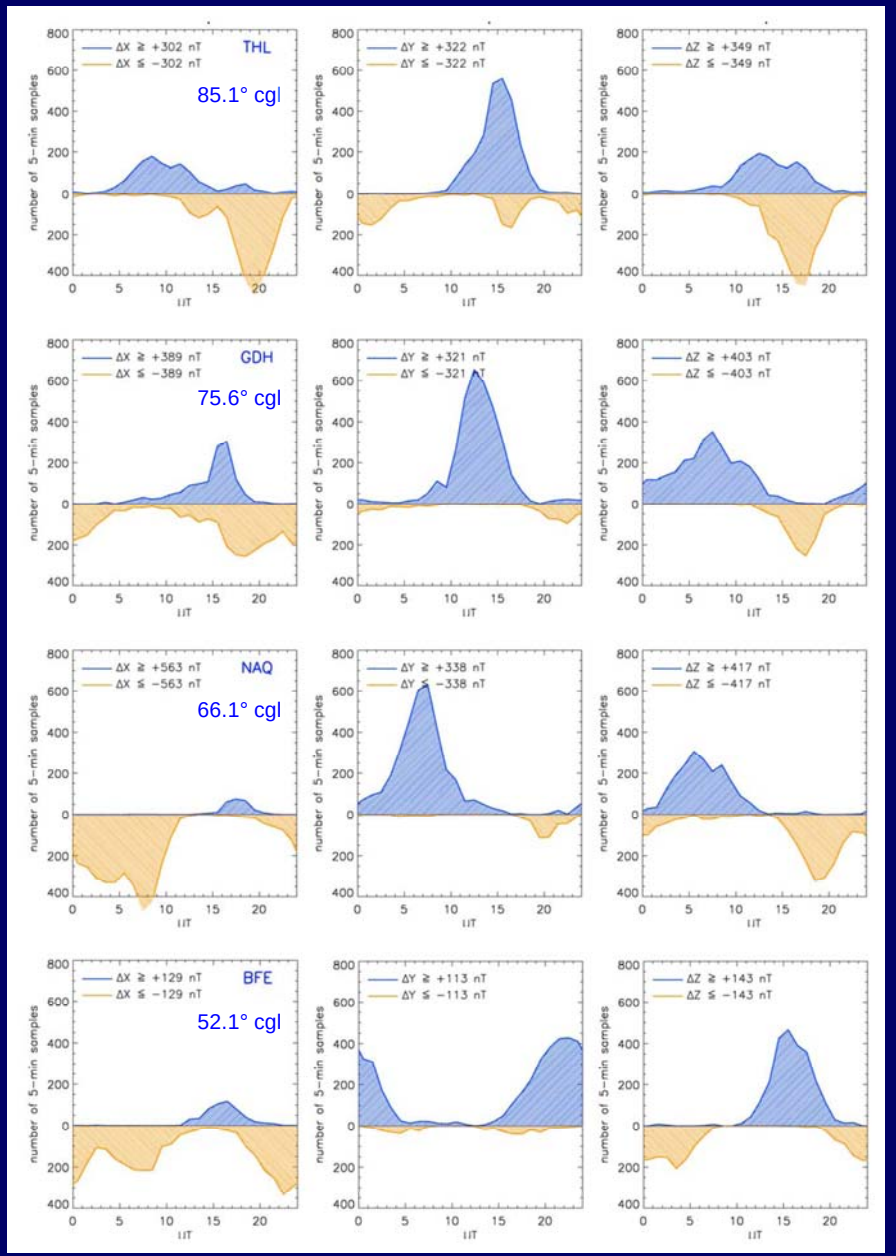
1998 + 1999 + 2001 surveys (total 331 survey days)

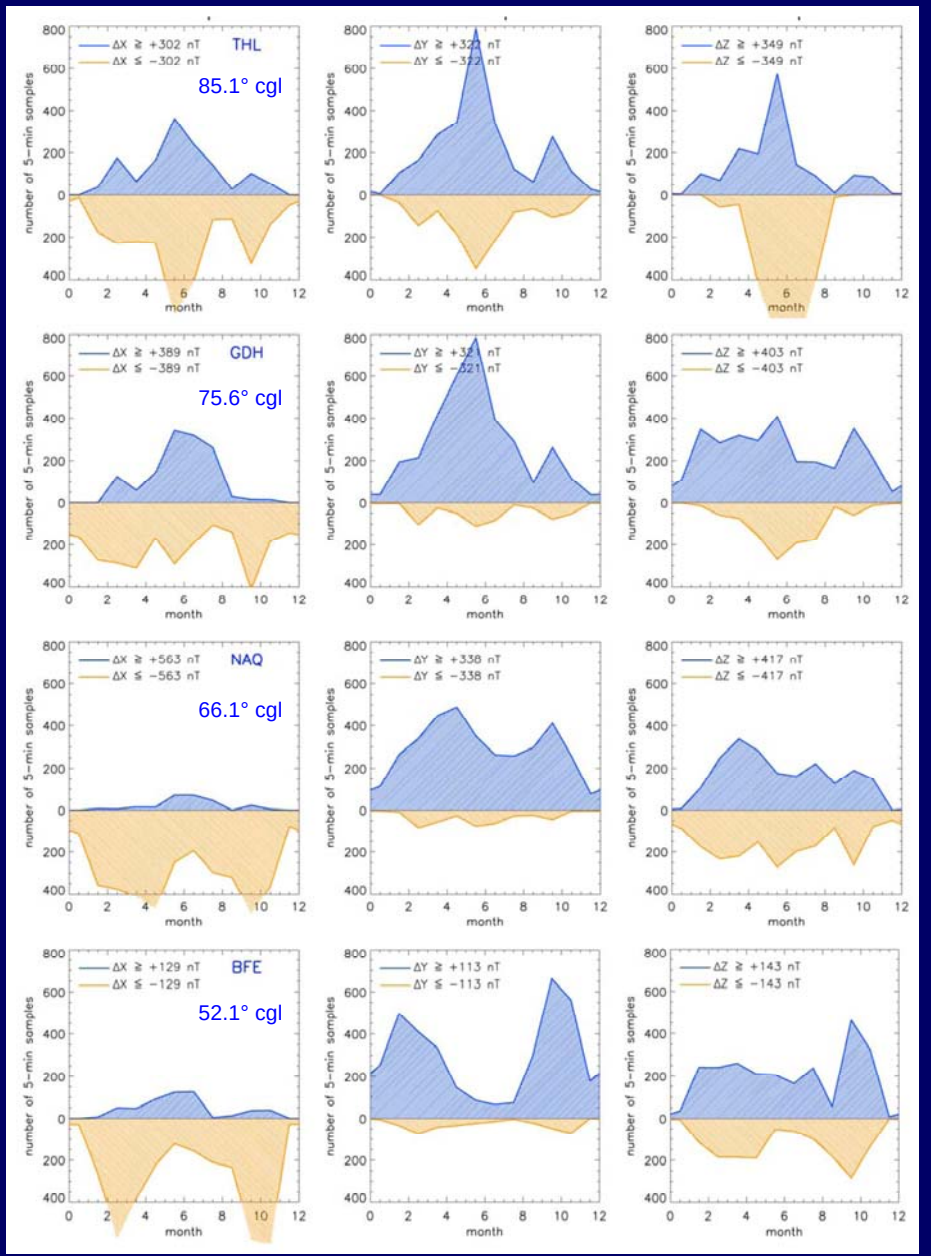
	number of days	
flight survey production affected by technical problems	14	4.2 %
flight delayed because of adverse weather conditions	11	3.3 %
flight delayed because of excessive geomagnetic activity	35	10.6 %
flight delayed because of both bad weather and geomagnetic activity	8	2.4 %
flight canceled because of adverse weather conditions	94	28.4 %
flight canceled because of excessive geomagnetic activity	7	2.1 %
flight canceled because of a both bad weather and geomagnetic activity	19	5.7 %
flight cut short because of adverse weather conditions	35	10.6 %
flight cut short because of excessive geomagnetic activity	6	1.8 %
flight cut short because of both bad weather and geomagnetic activity	5	1.5 %
reflight of previously flown survey lines	14	4.2 %

Survey log book data kindly provided by Sander Geophysics Ltd.

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





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
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

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

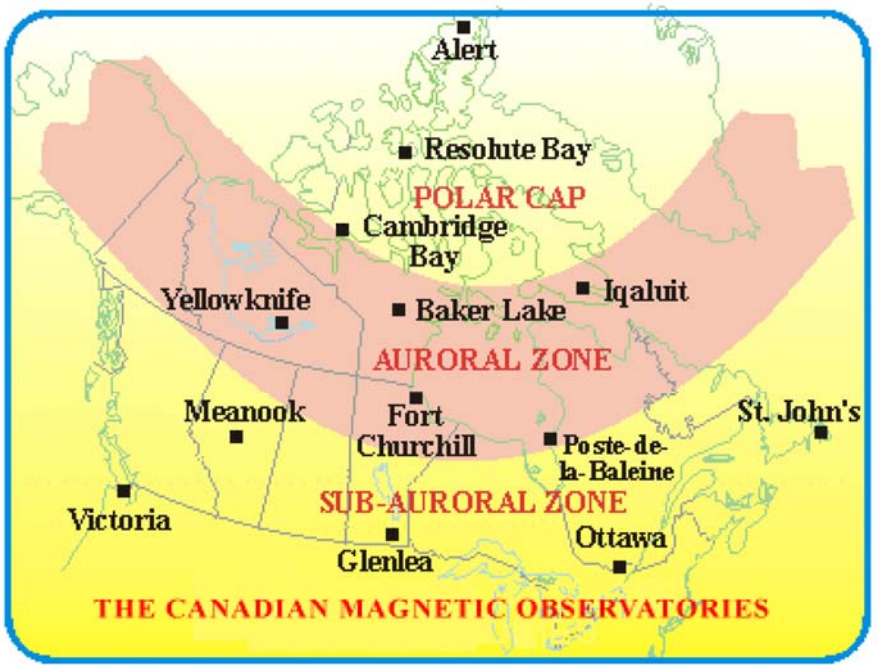


Figure 1: Location of Canadian Magnetic Observatories.

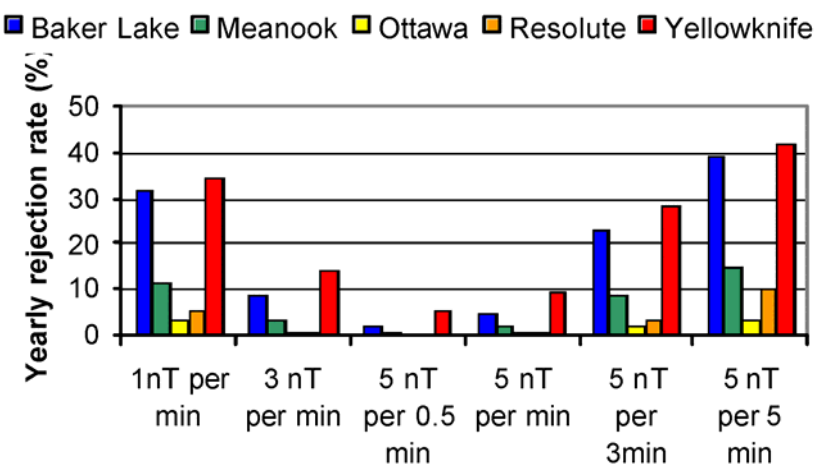


Figure 2: Comparison of yearly rejection rates for the different observatories in 2001 and different tolerances as maximum per chord length in minutes.

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 *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 *ideal but rare*
- spatially non-uniform *typical*
- moving (traveling) *frequent*

Interpolation between neighboring base stations

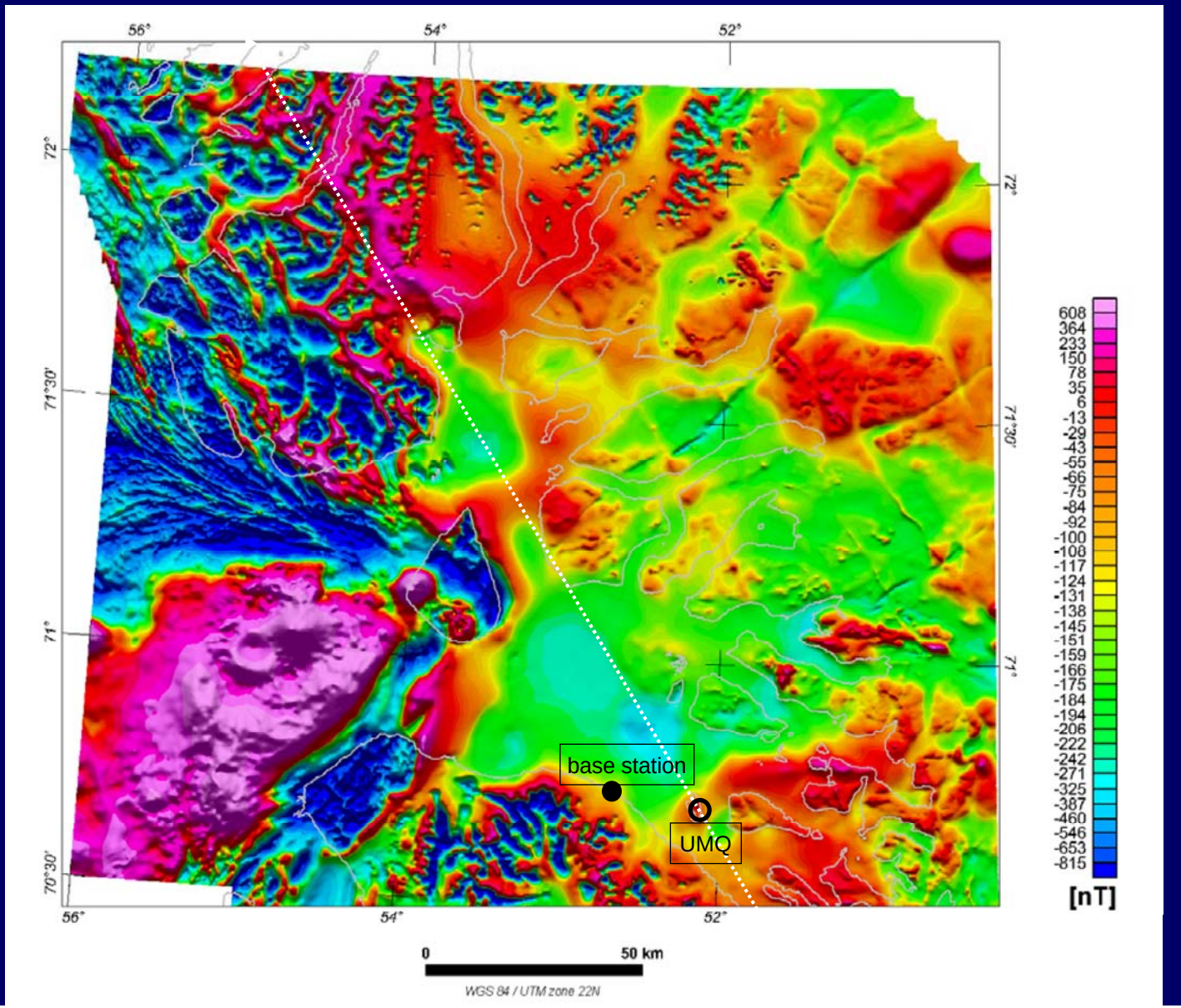
- possible
- limited by site spacing

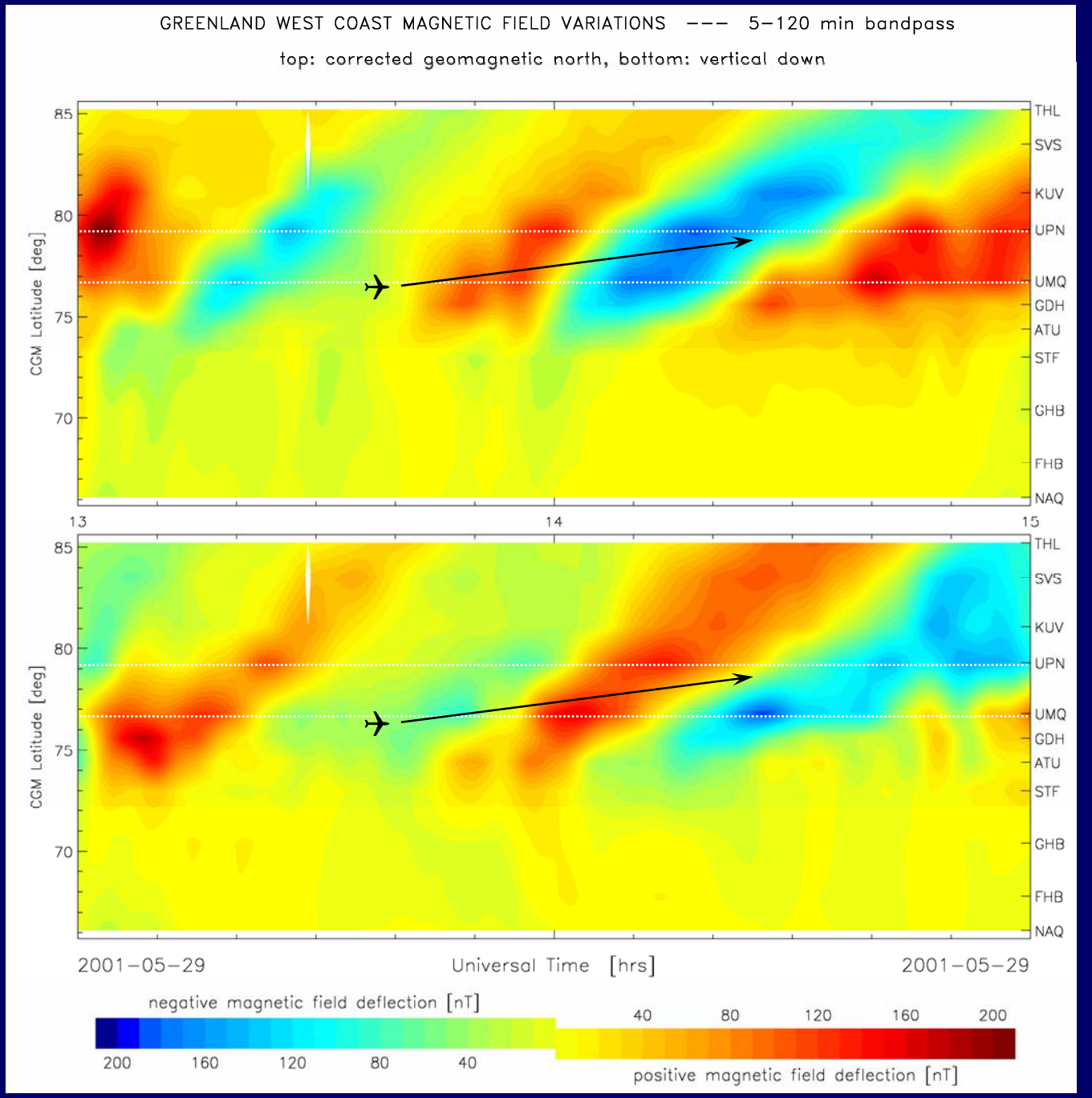
  but partially offset by field integration effect

  field continuation: $\underline{B}_{ground} = \underline{B}_{ionosphere} \cdot e^{-kh}$

UPN

2001 survey area north of Uummannaq (Greenland west coast)




GREENLAND WEST COAST MAGNETIC FIELD VARIATIONS --- 5-120 min bandpass
top: corrected geomagnetic north, bottom: vertical down
CGM Latitude [deg]
85
80
75
70
THL
SVS
KUV
UPN
UMQ
GDH
ATU
STF
GHB
FHB
NAQ
13
14
15
2001-05-29
Universal Time [hrs]
2001-05-29
negative magnetic field deflection [nT]
200
160
120
80
40
40
80
120
160
200
positive magnetic field deflection [nT]

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

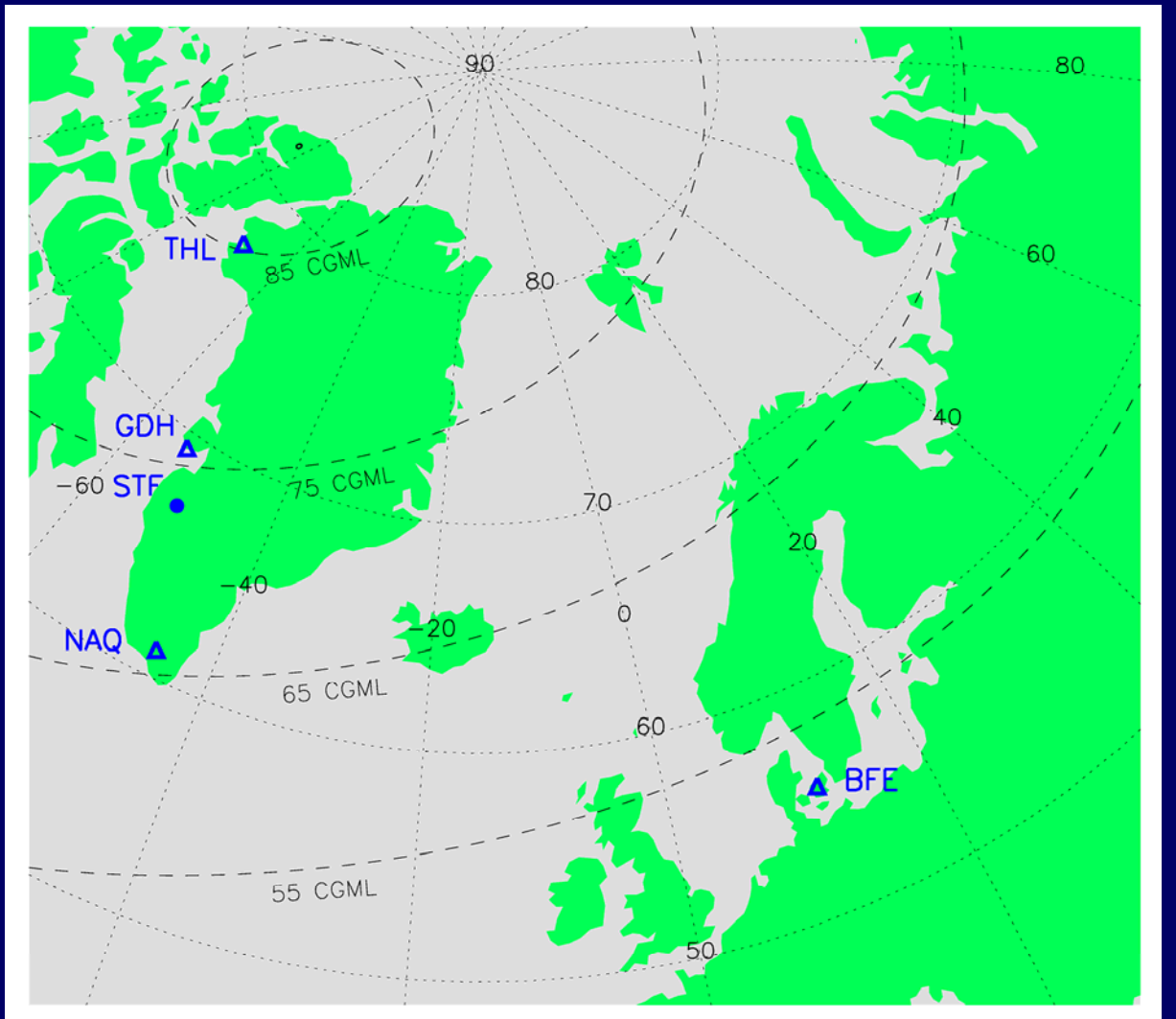
(2) Do not fly when conditions are not optimal – wait

(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



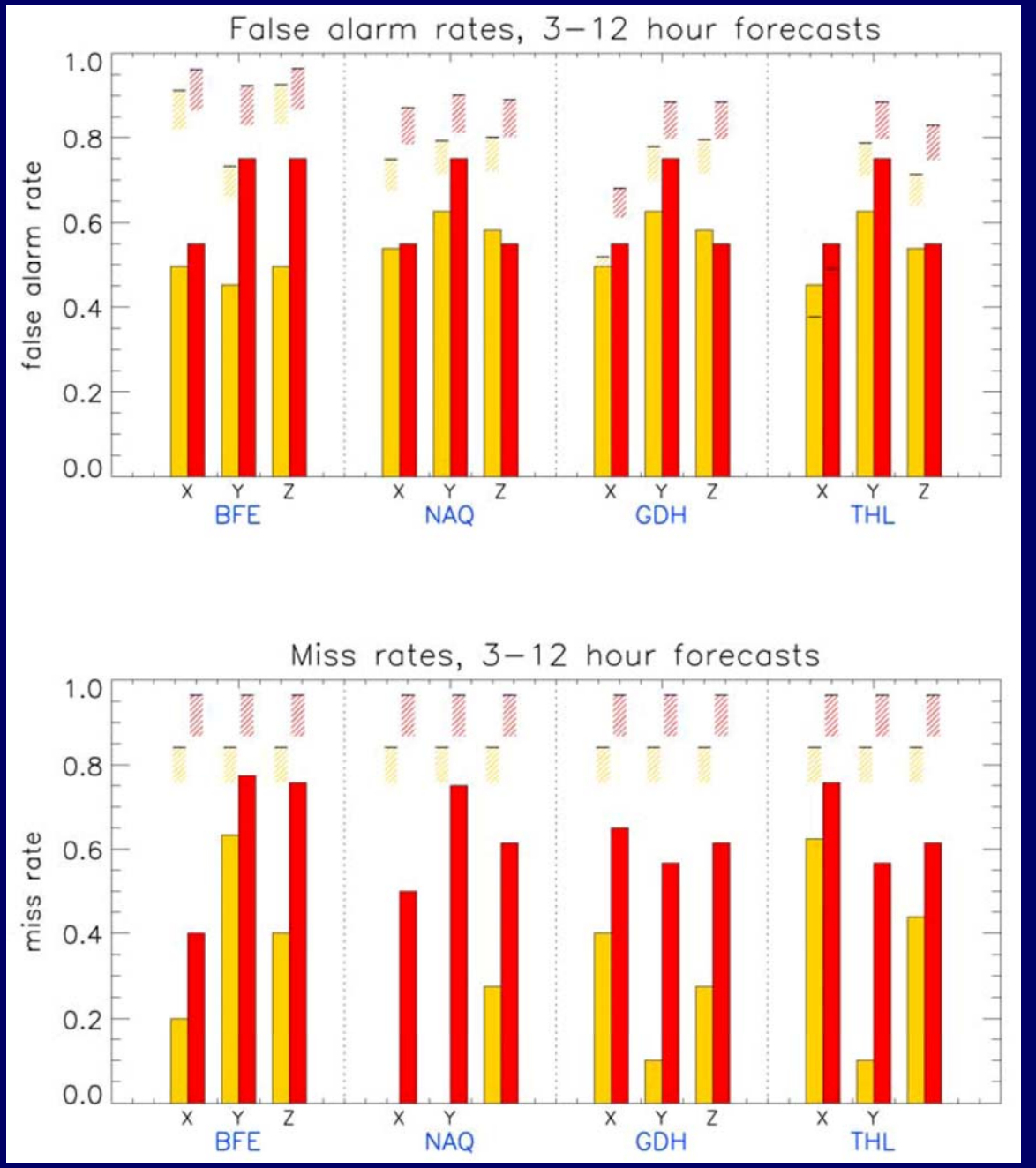
SDA supported by ESA through SWAPP

DK & GL observatories – activity thresholds (alert levels)

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

THL 85.1° cgl	$\lvert X\rvert < 130$ nT $\lvert Y\rvert < 140$ nT $\lvert Z\rvert < 140$ nT	$\lvert X\rvert > 130$ nT $\lvert Y\rvert > 140$ nT $\lvert Z\rvert > 140$ nT	$\lvert X\rvert > 200$ nT $\lvert Y\rvert > 220$ nT $\lvert Z\rvert > 230$ nT
GDH 75.6° cgl	$\lvert X\rvert < 150$ nT $\lvert Y\rvert < 120$ nT $\lvert Z\rvert < 170$ nT	$\lvert X\rvert > 150$ nT $\lvert Y\rvert > 120$ nT $\lvert Z\rvert > 170$ nT	$\lvert X\rvert > 250$ nT $\lvert Y\rvert > 200$ nT $\lvert Z\rvert > 270$ nT
NAQ 66.1° cgl	$\lvert X\rvert < 220$ nT $\lvert Y\rvert < 120$ nT $\lvert Z\rvert < 150$ nT	$\lvert X\rvert > 220$ nT $\lvert Y\rvert > 120$ nT $\lvert Z\rvert > 150$ nT	$\lvert X\rvert > 370$ nT $\lvert Y\rvert > 210$ nT $\lvert Z\rvert > 270$ nT
BFE 52.1° cgl	$\lvert F\rvert < 100$ nT $\lvert D\rvert < 17'$ $\lvert I\rvert < 7'$	$\lvert F\rvert > 100$ nT $\lvert D\rvert > 17'$ $\lvert I\rvert > 7'$	$\lvert F\rvert > 150$ nT $\lvert D\rvert > 23'$ $\lvert I\rvert > 9'$

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

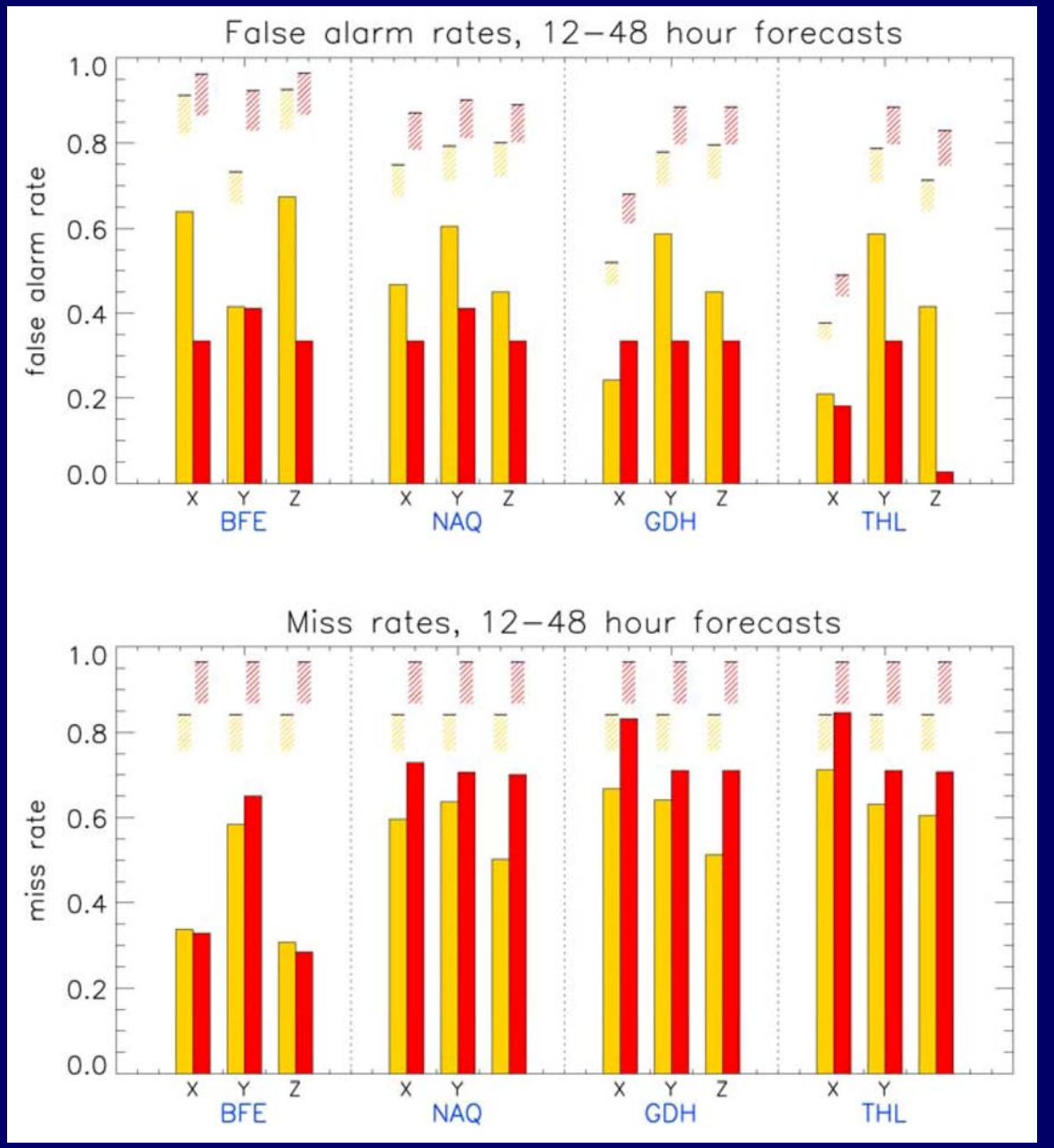
later: compare alert level with peak disturbance (5-min average)

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

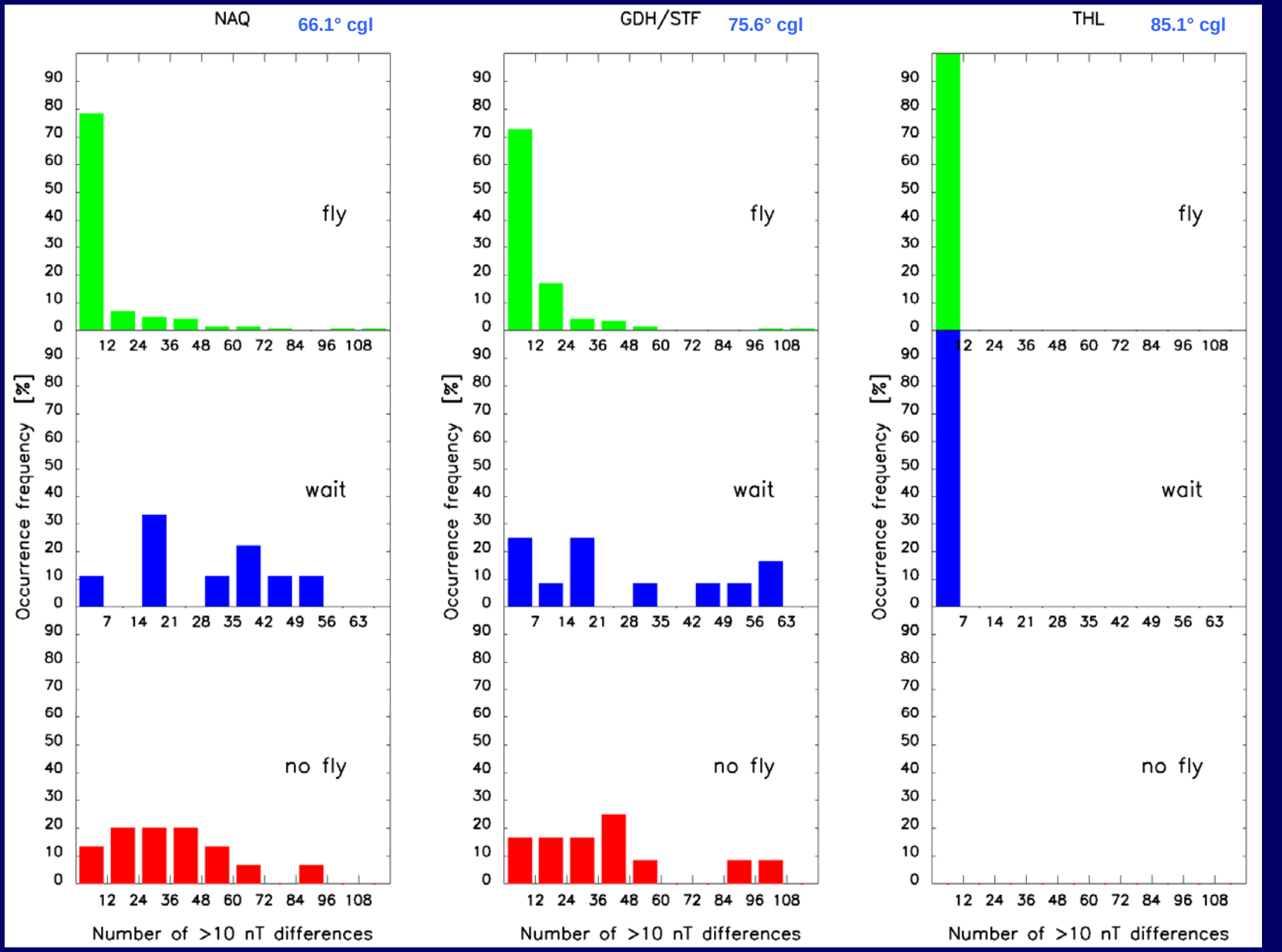
⇓

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 oin 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 $\cong$ 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)