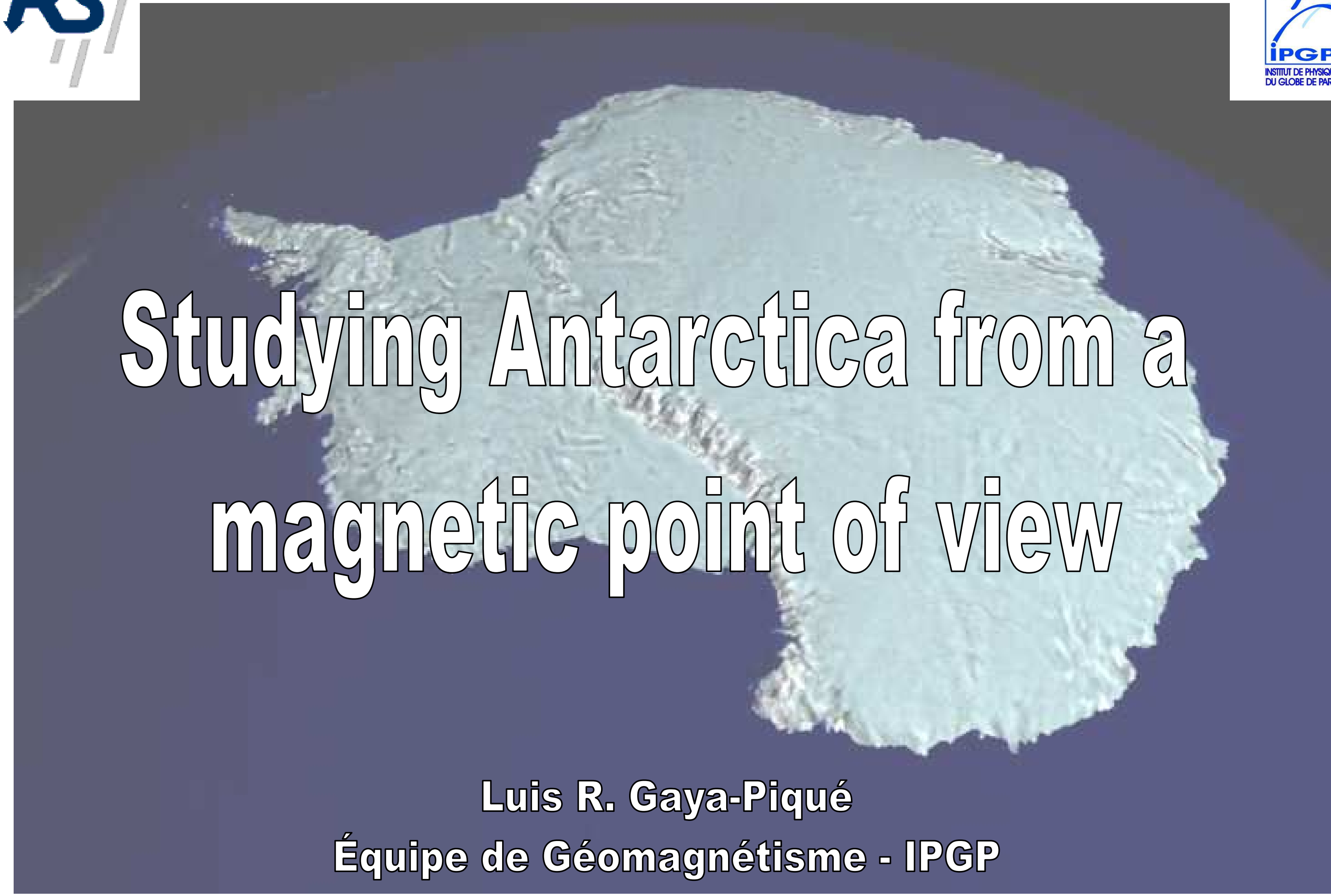
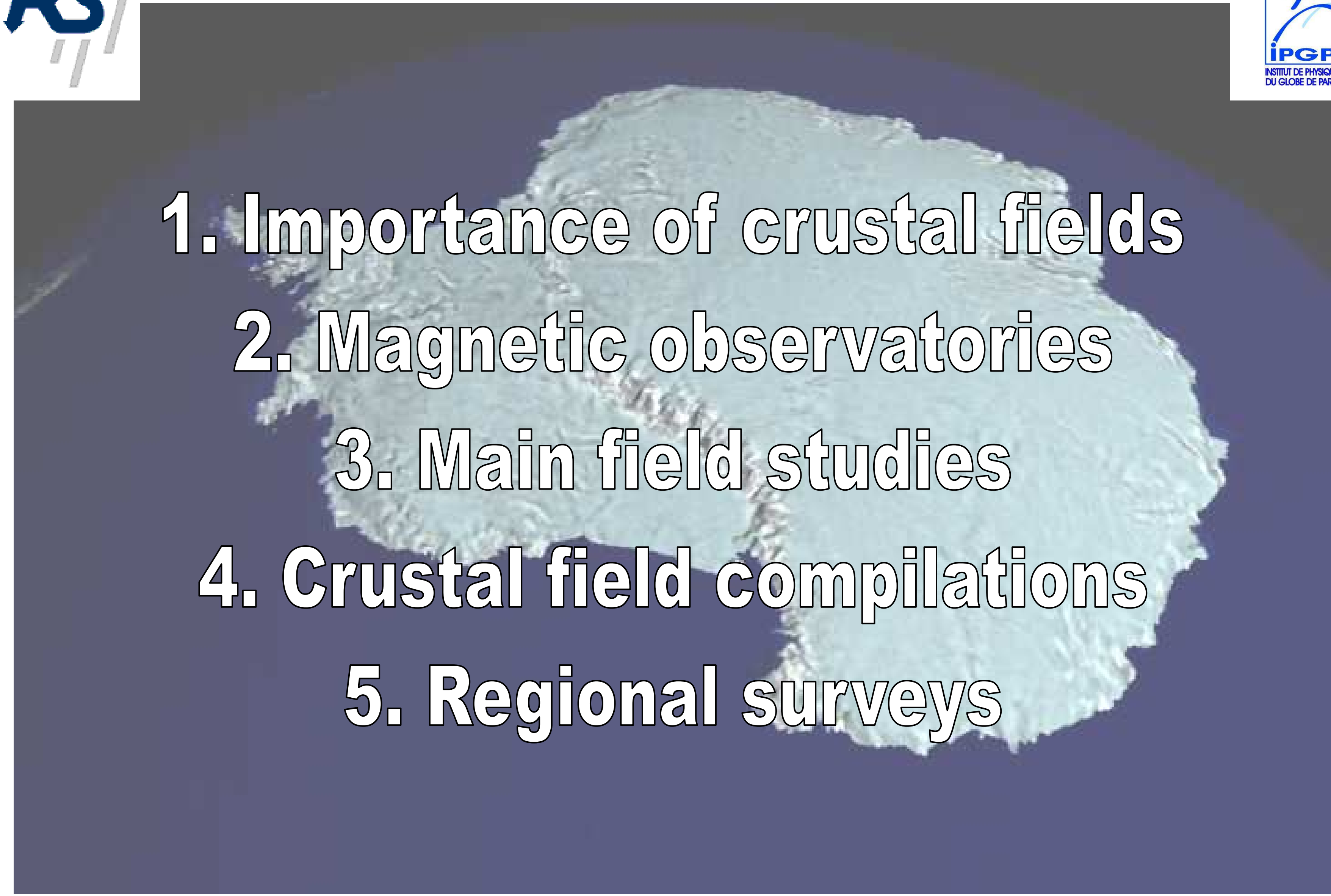


Studying Antarctica from a magnetic point of view

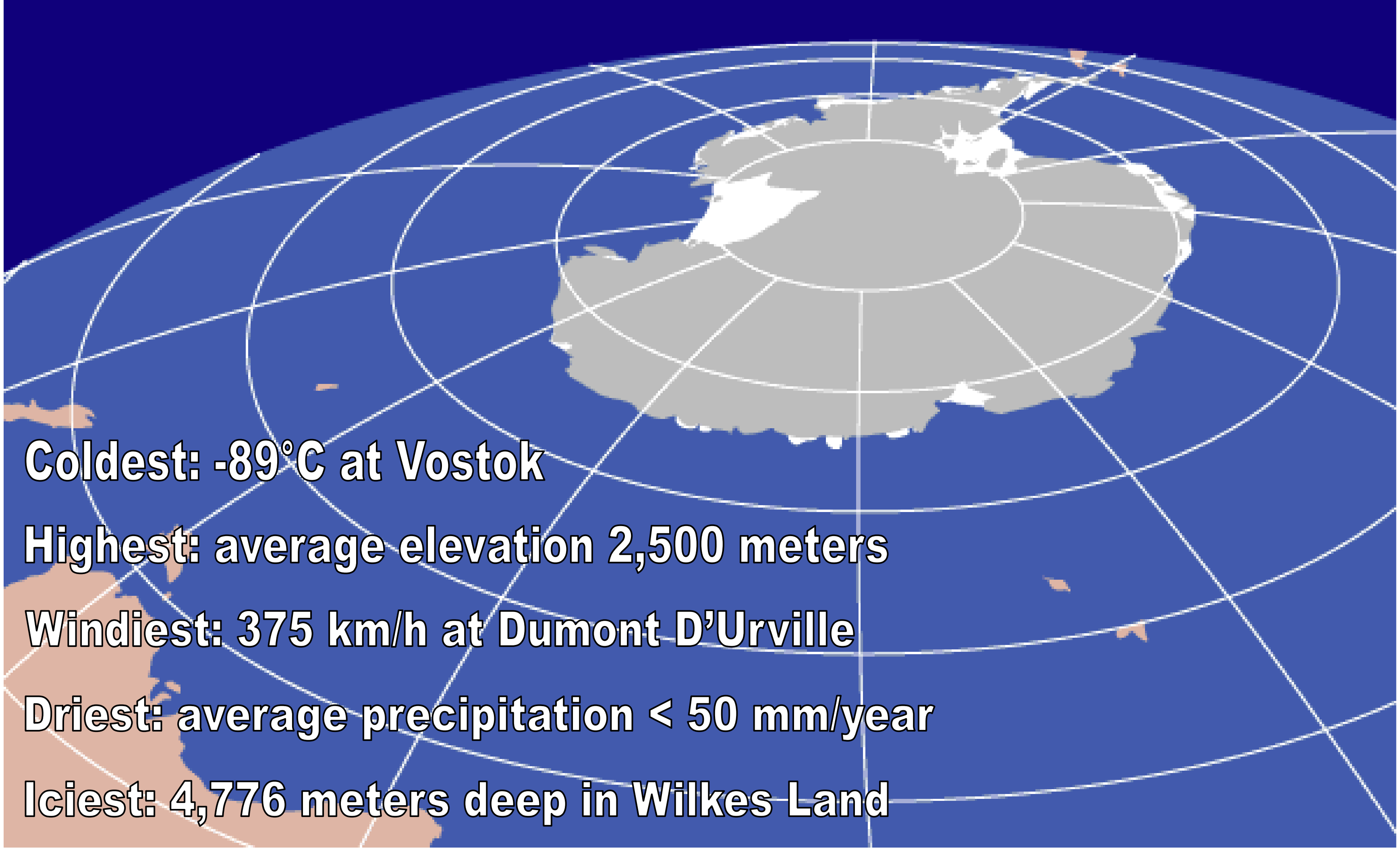
Luis R. Gaya-Piqué

Équipe de Géomagnétisme - IPGP

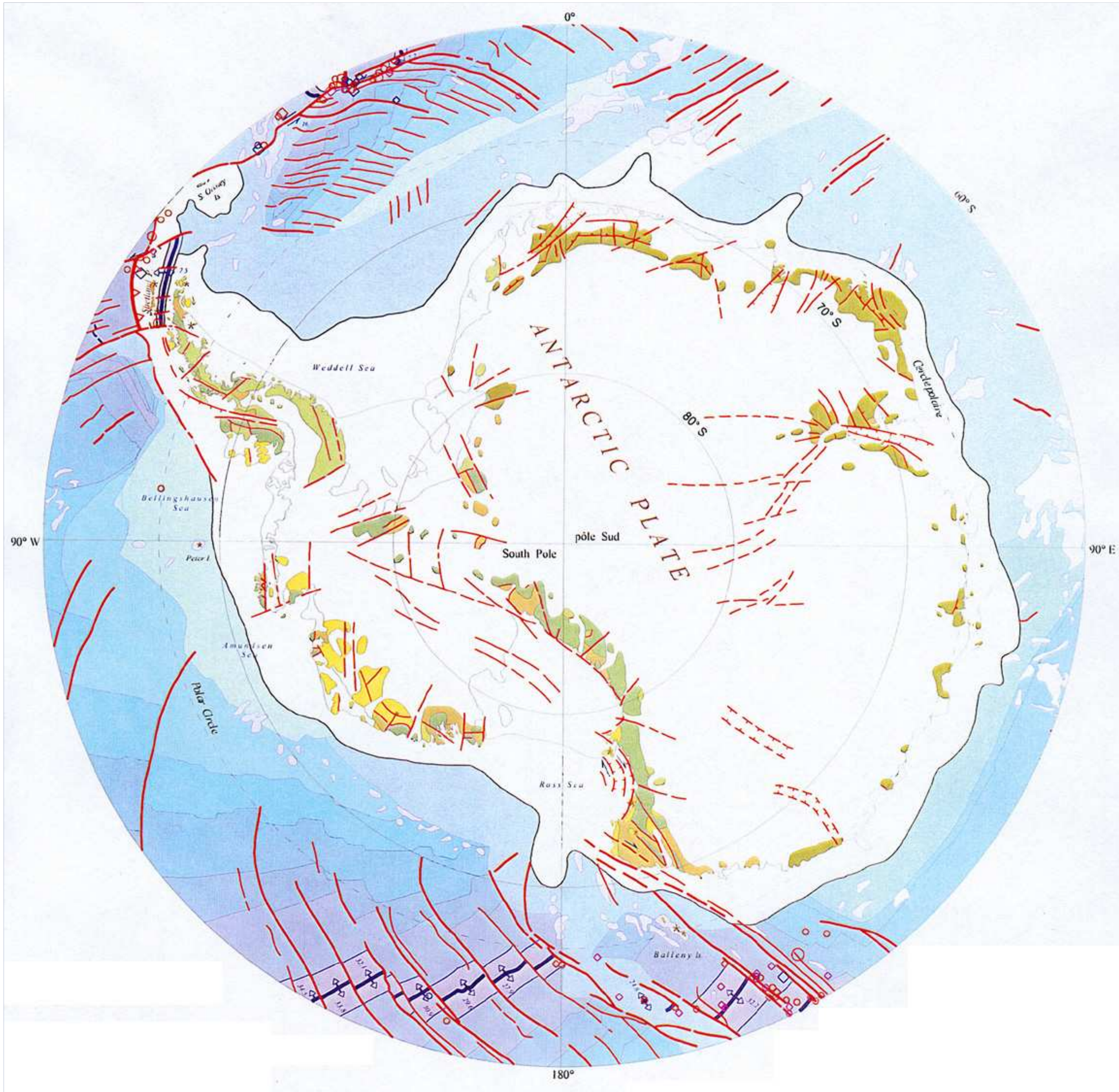


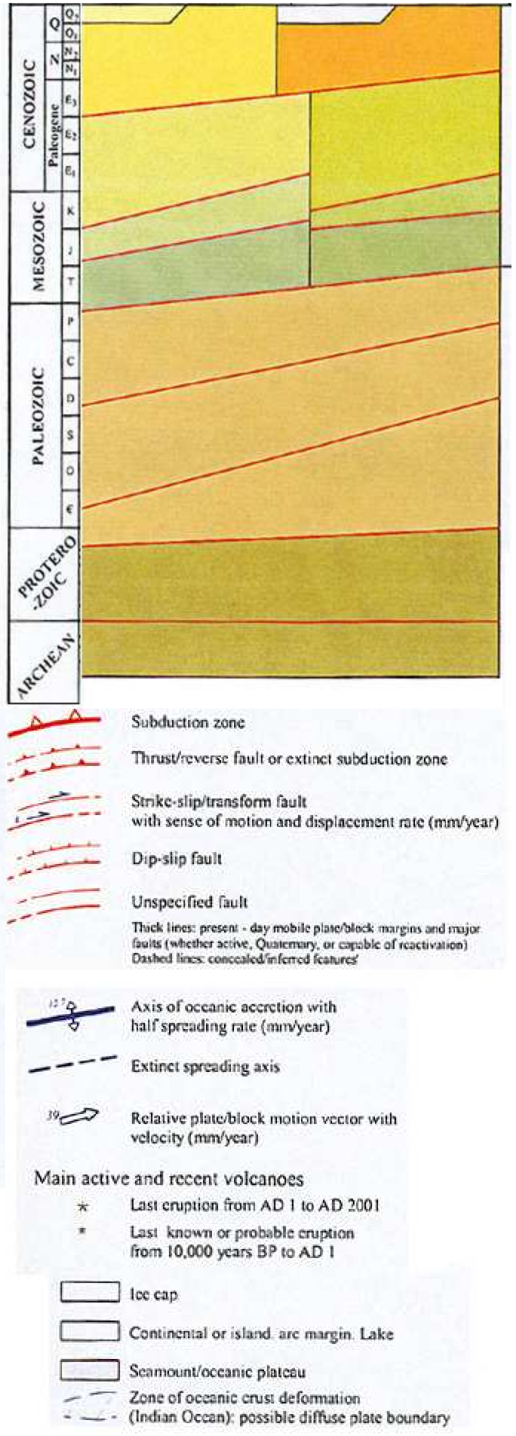
1. Importance of crustal fields
2. Magnetic observatories
3. Main field studies
4. Crustal field compilations
5. Regional surveys

Antarctica



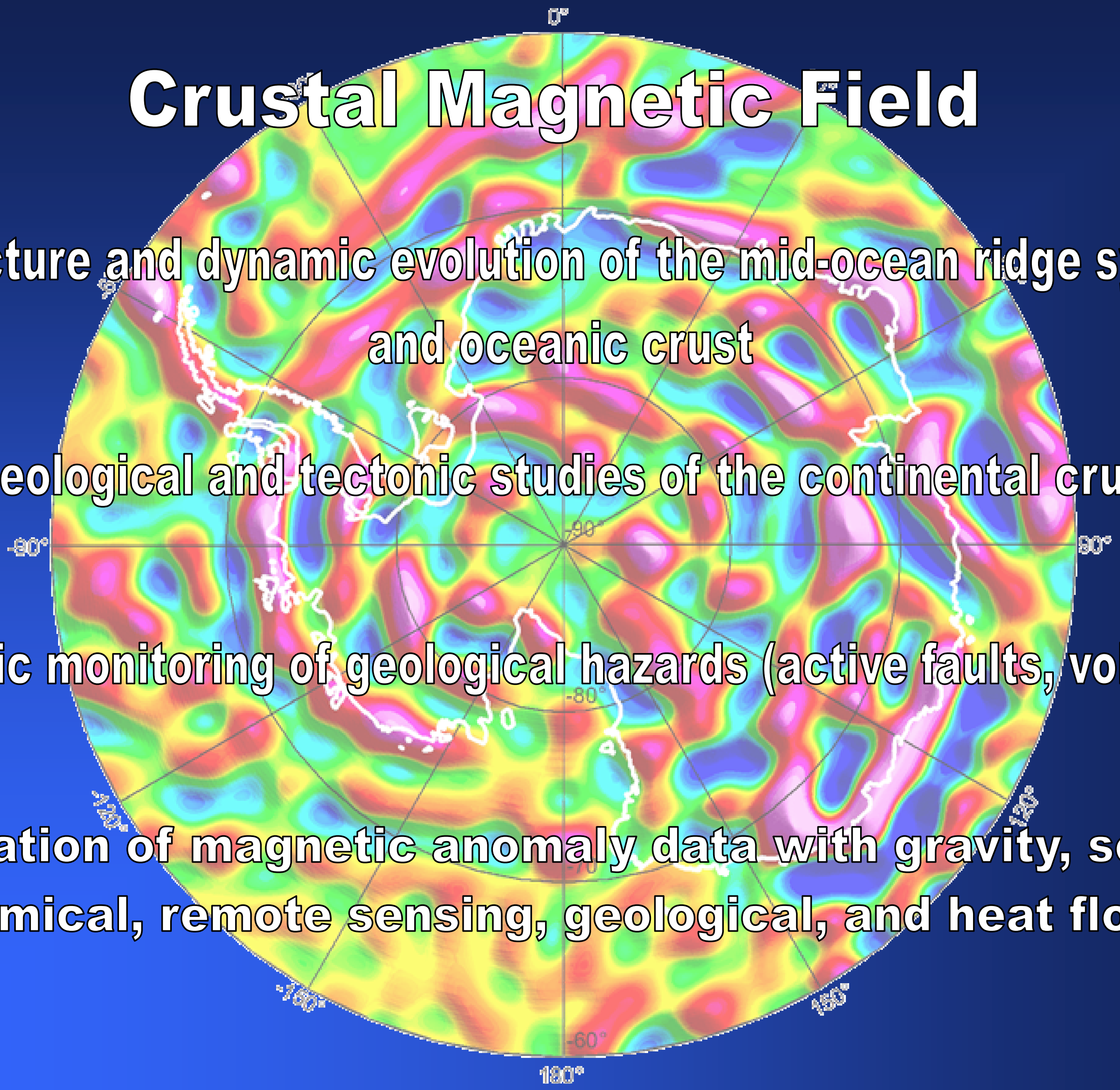
- Coldest: -89°C at Vostok
- Highest: average elevation 2,500 meters
- Windiest: 375 km/h at Dumont D'Urville
- Driest: average precipitation < 50 mm/year
- Iciest: 4,776 meters deep in Wilkes Land





Haghipour, UNESCO, 2001

Crustal Magnetic Field

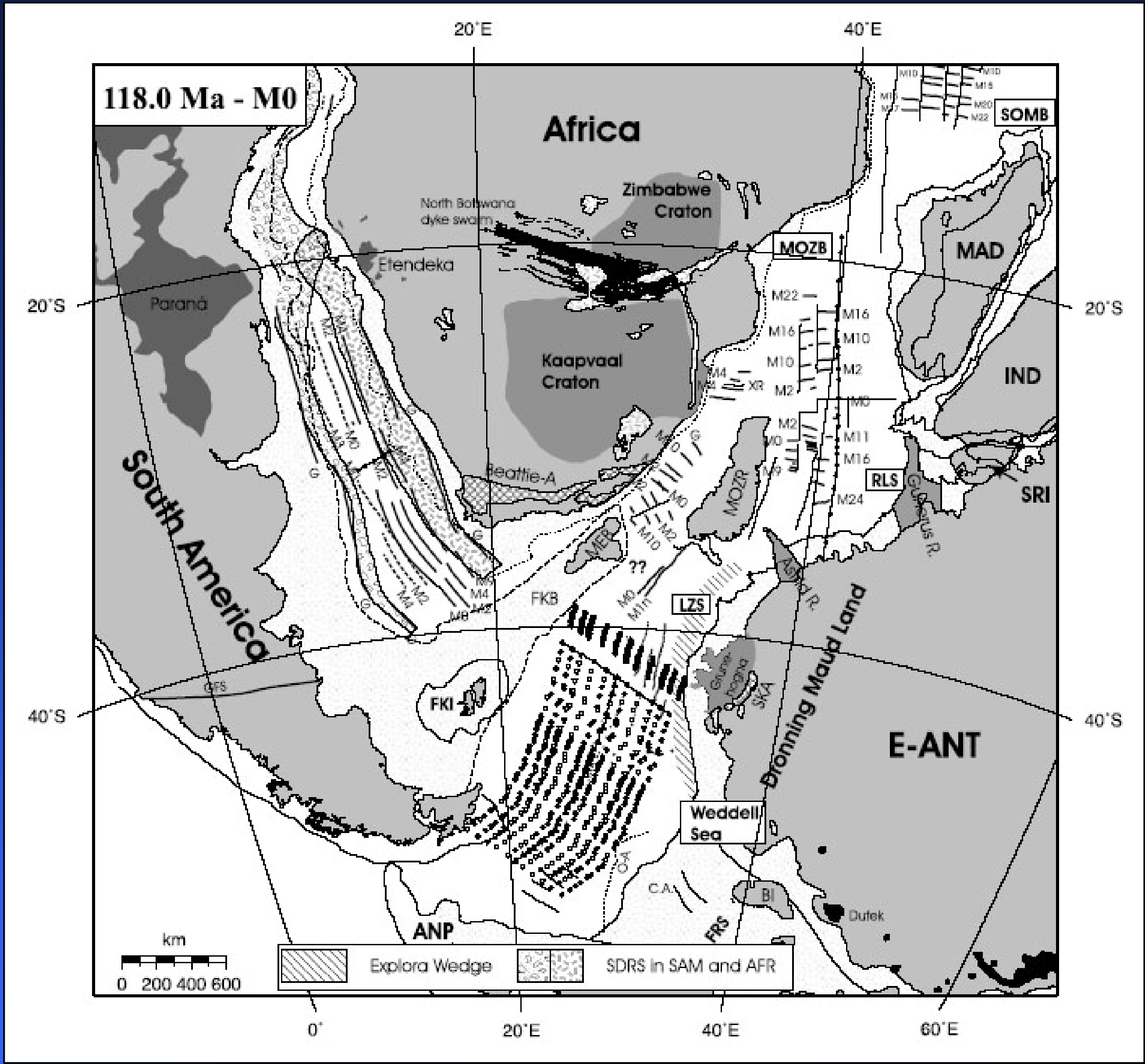


Structure and dynamic evolution of the mid-ocean ridge system and oceanic crust

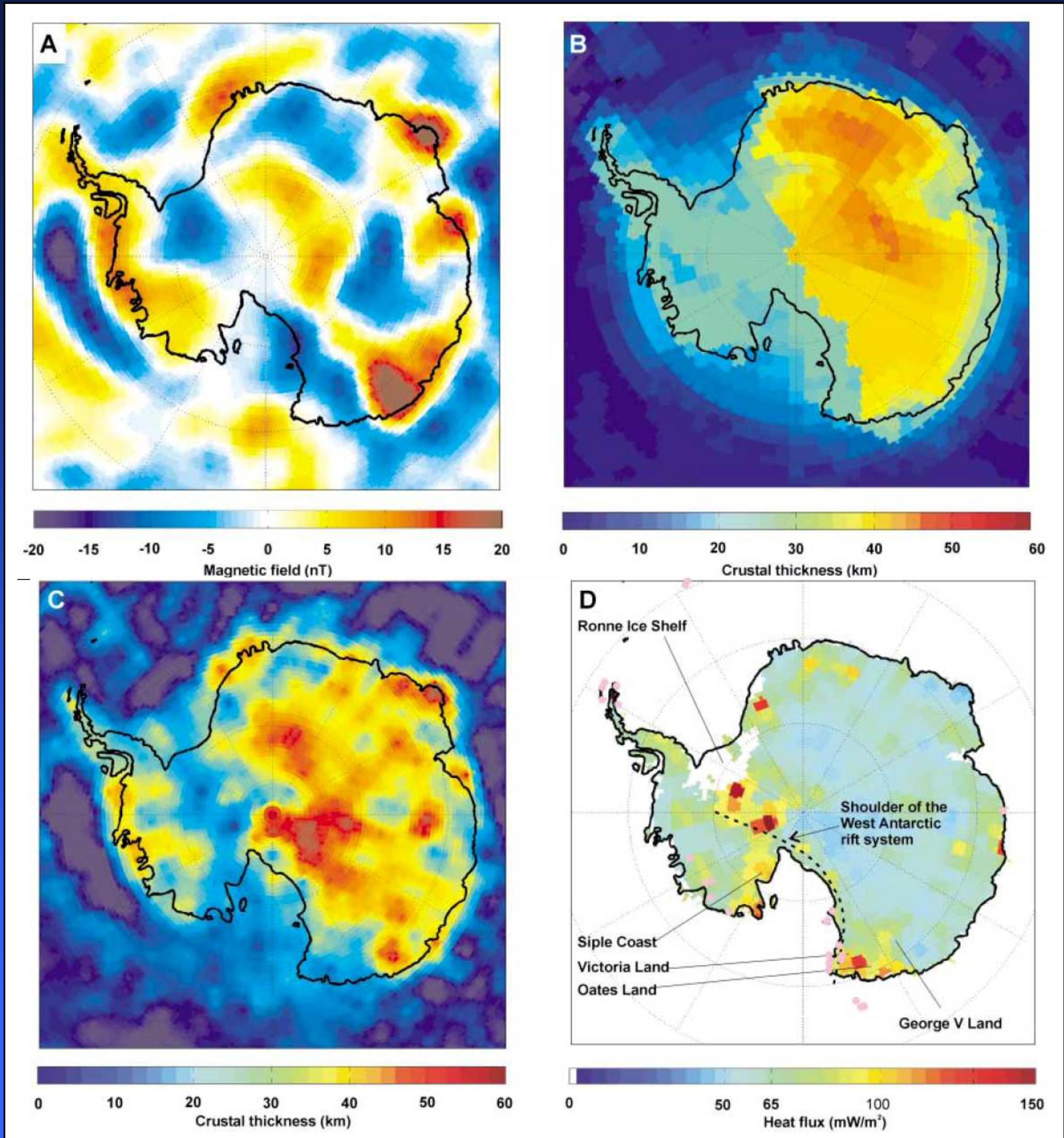
Geological and tectonic studies of the continental crust

Magnetic monitoring of geological hazards (active faults, volcanoes)

Integration of magnetic anomaly data with gravity, seismic, geochemical, remote sensing, geological, and heat flow data

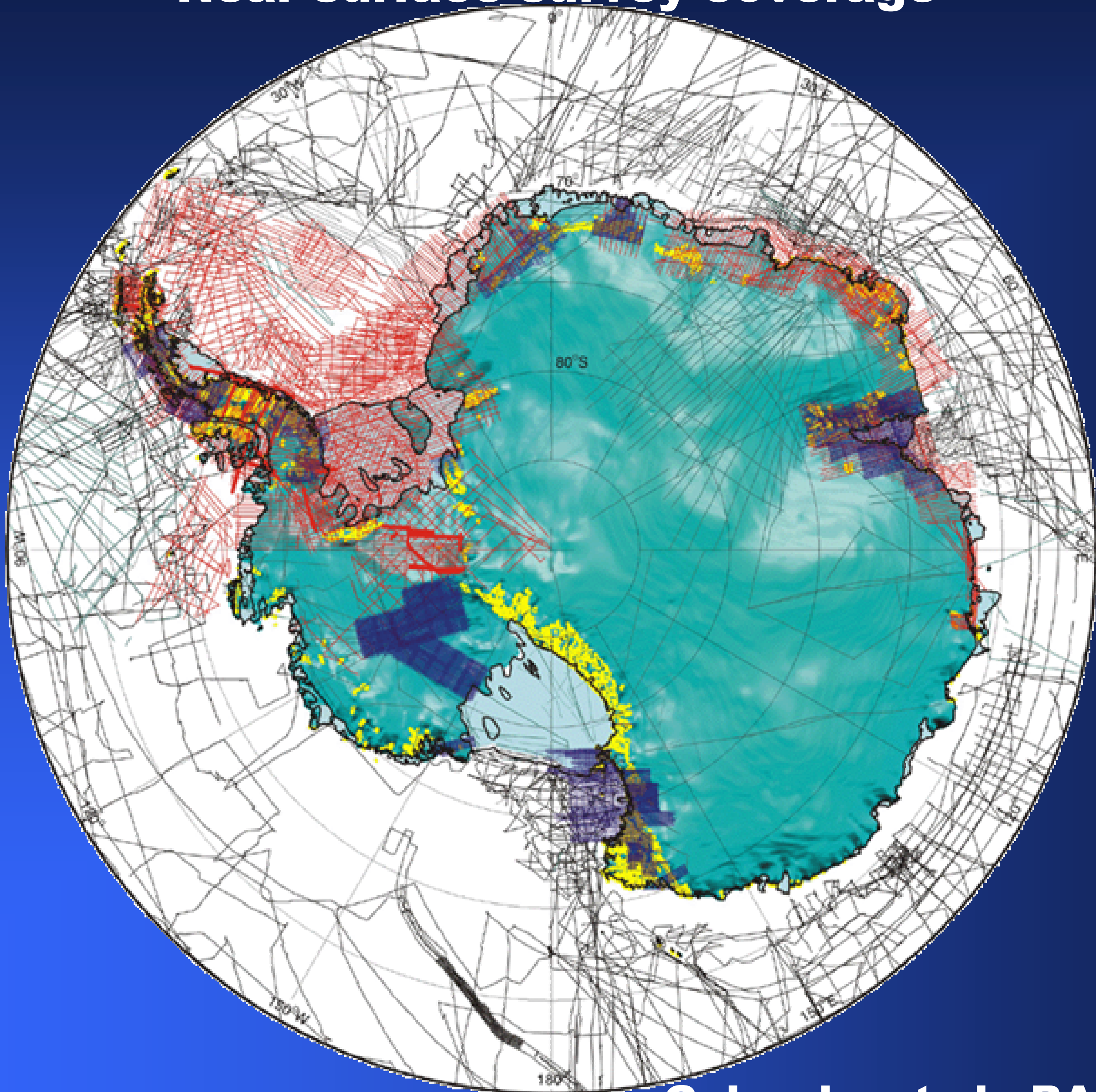


König and Jokat, JGR, 2006



Fox-Maule et al., Science, 2005

Antarctic Digital Magnetic Anomaly Project
Near-surface survey coverage



Golynsky et al., BAS pub., 2001

Components of the Magnetic Field

Constituent Field	Location of Source	Mean Intensity (Maximum)
Main	Outer core	50,000 nT (70,000 nT)
Local	Crust (upper mantle?)	100 nT (10^5 nT)
Regular Storm	Magnetosphere	150 nT (500 nT)
Irregular storm	Ionosphere and magnetosphere	100 nT (200 nT)
Diurnal Variation	Ionosphere	50 nT (200 nT)
Induced	Crust, upper mantle, and oceans	½ of above three fields

How to combine all these surveys?

$$\vec{B}(\vec{r},t) = \vec{B}_m(\vec{r},t) + \vec{A}(\vec{r}) + \vec{D}(\vec{r},t) + \vec{e}(t)$$

Main Field

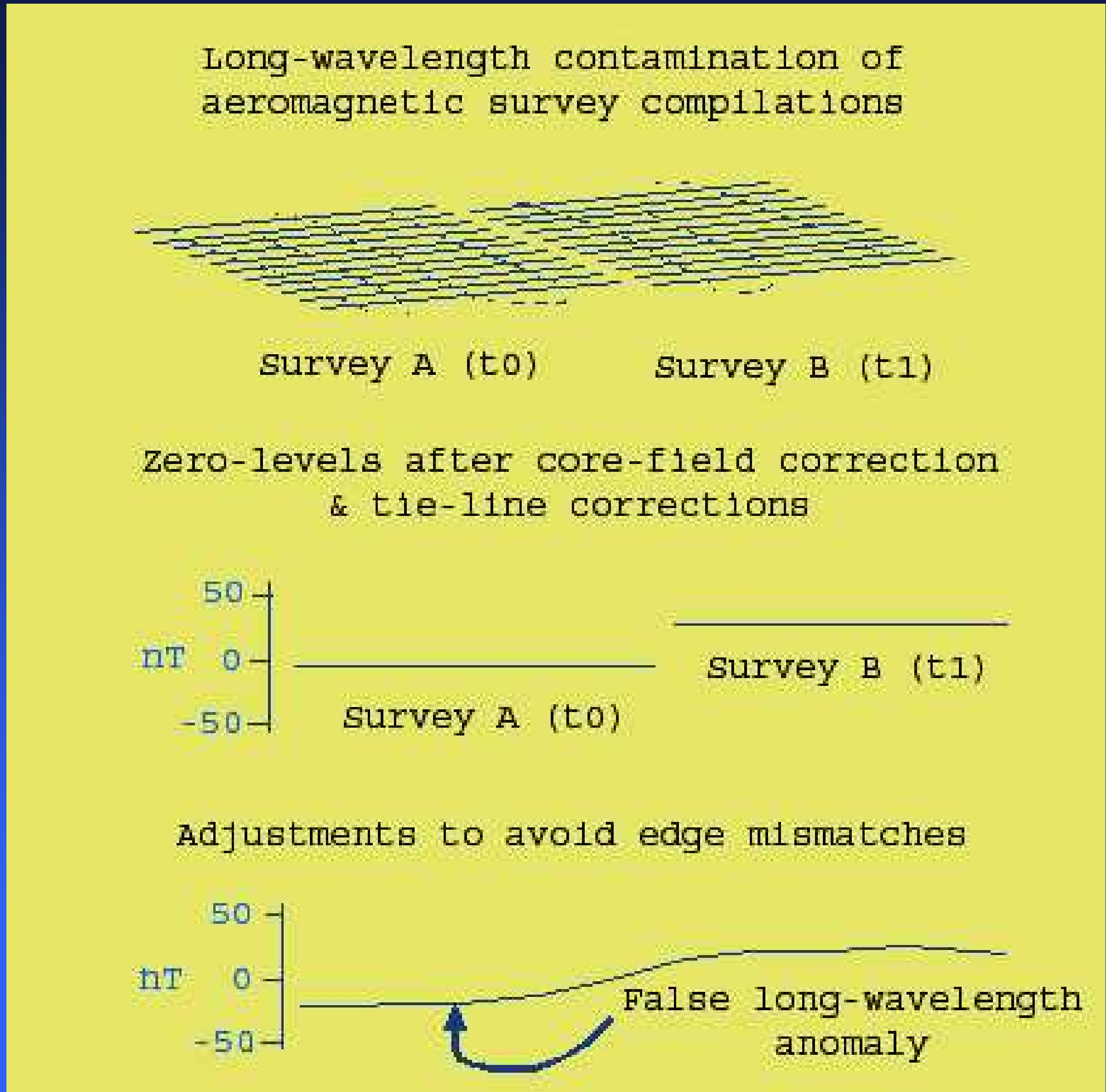
Crustal Field

Measurement error

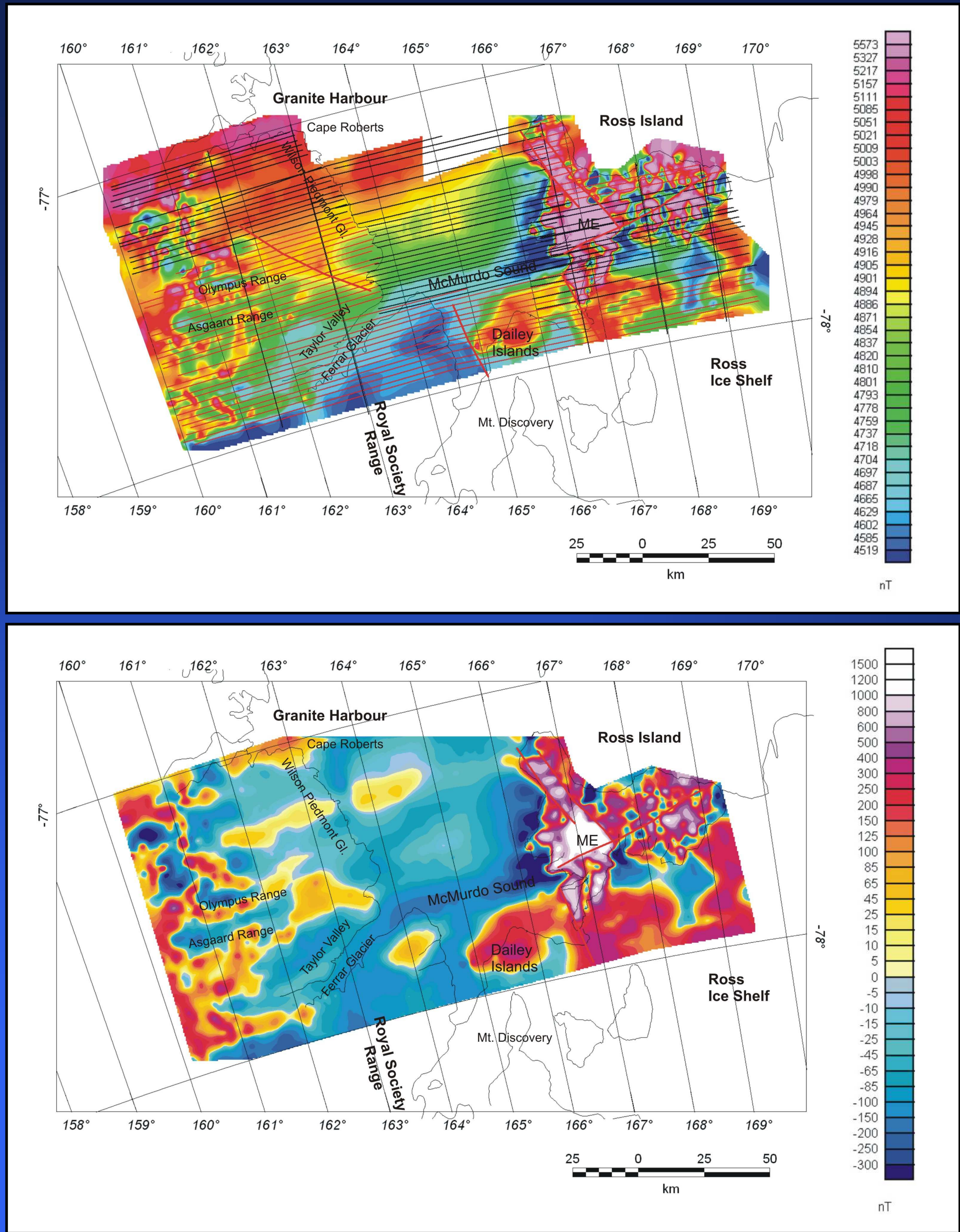
Magnetospheric, ionospheric, and induced Fields

International Geomagnetic Reference Field

... sometimes it does not work



Ravat et al., The Leading Edge, 2003

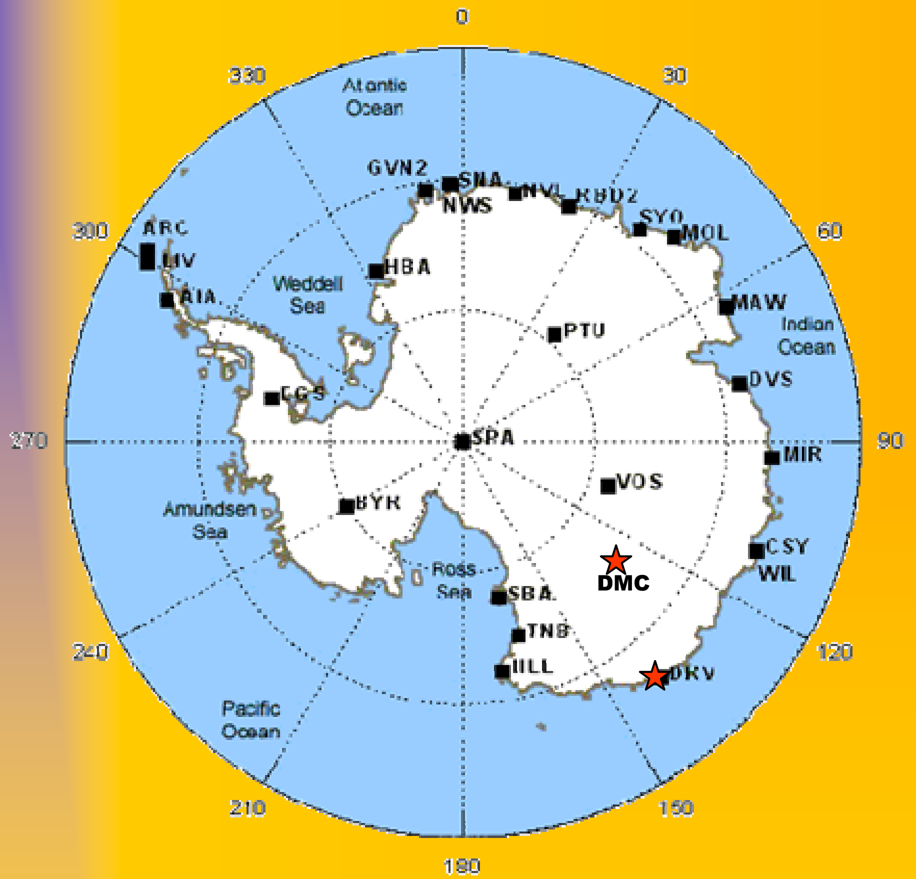


Chiappini et al., Tectonophysics, 2002

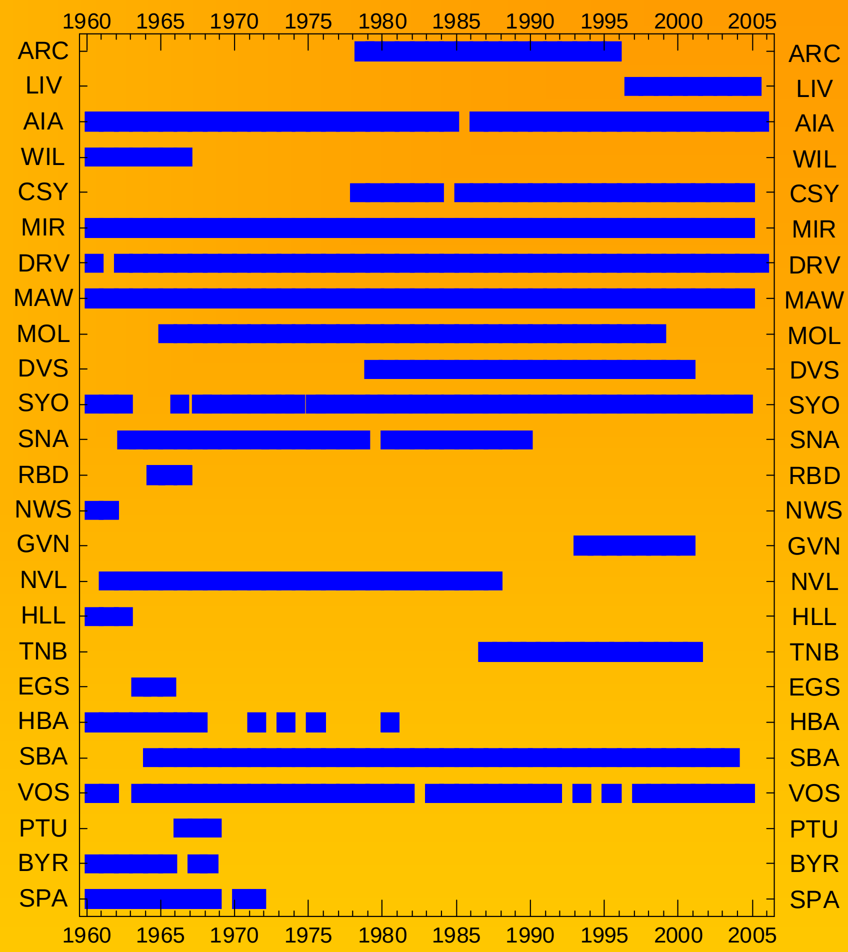
 An improved main field reference model for Antarctica is needed

Antarctic Observatory Data

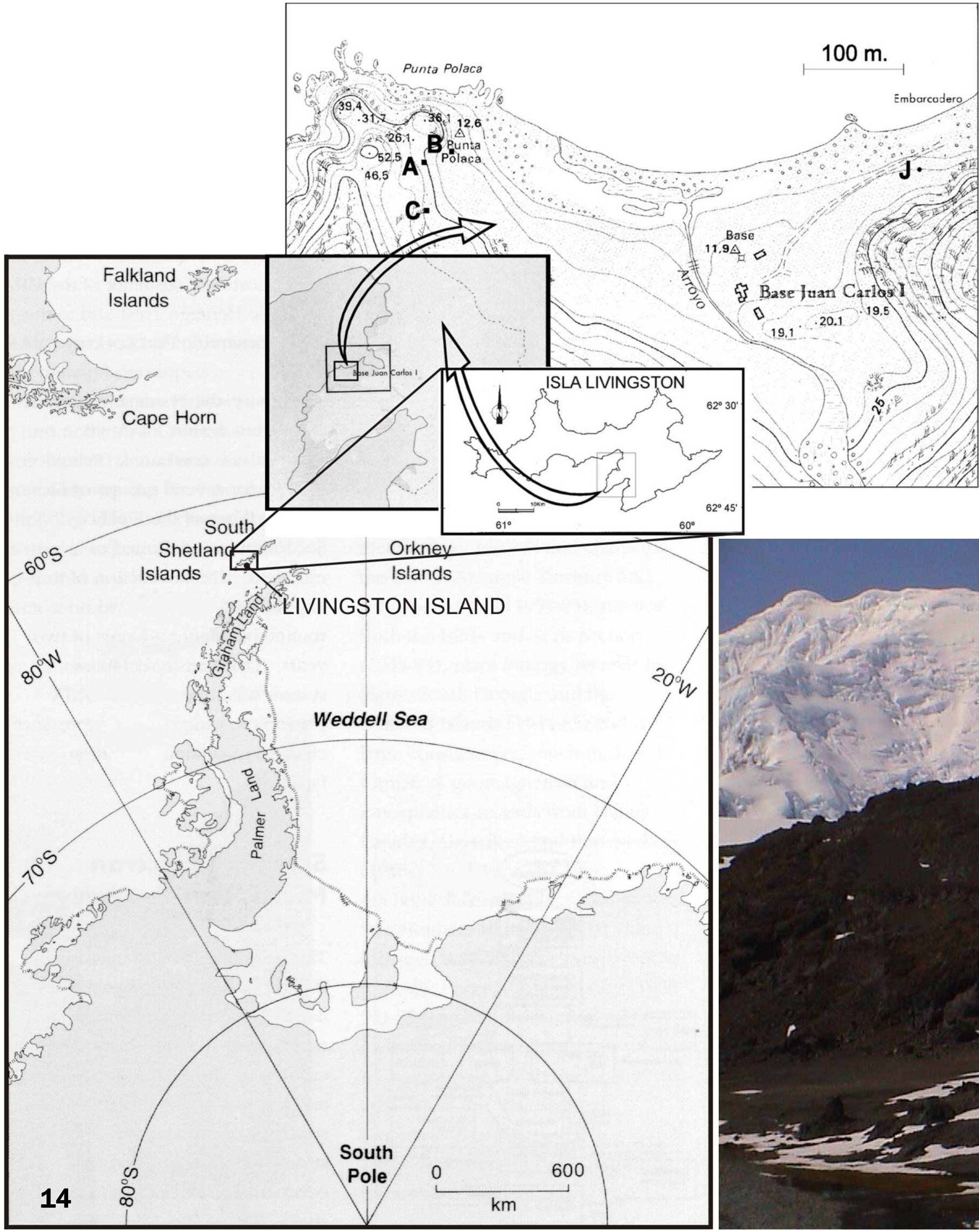
Spatial Distribution



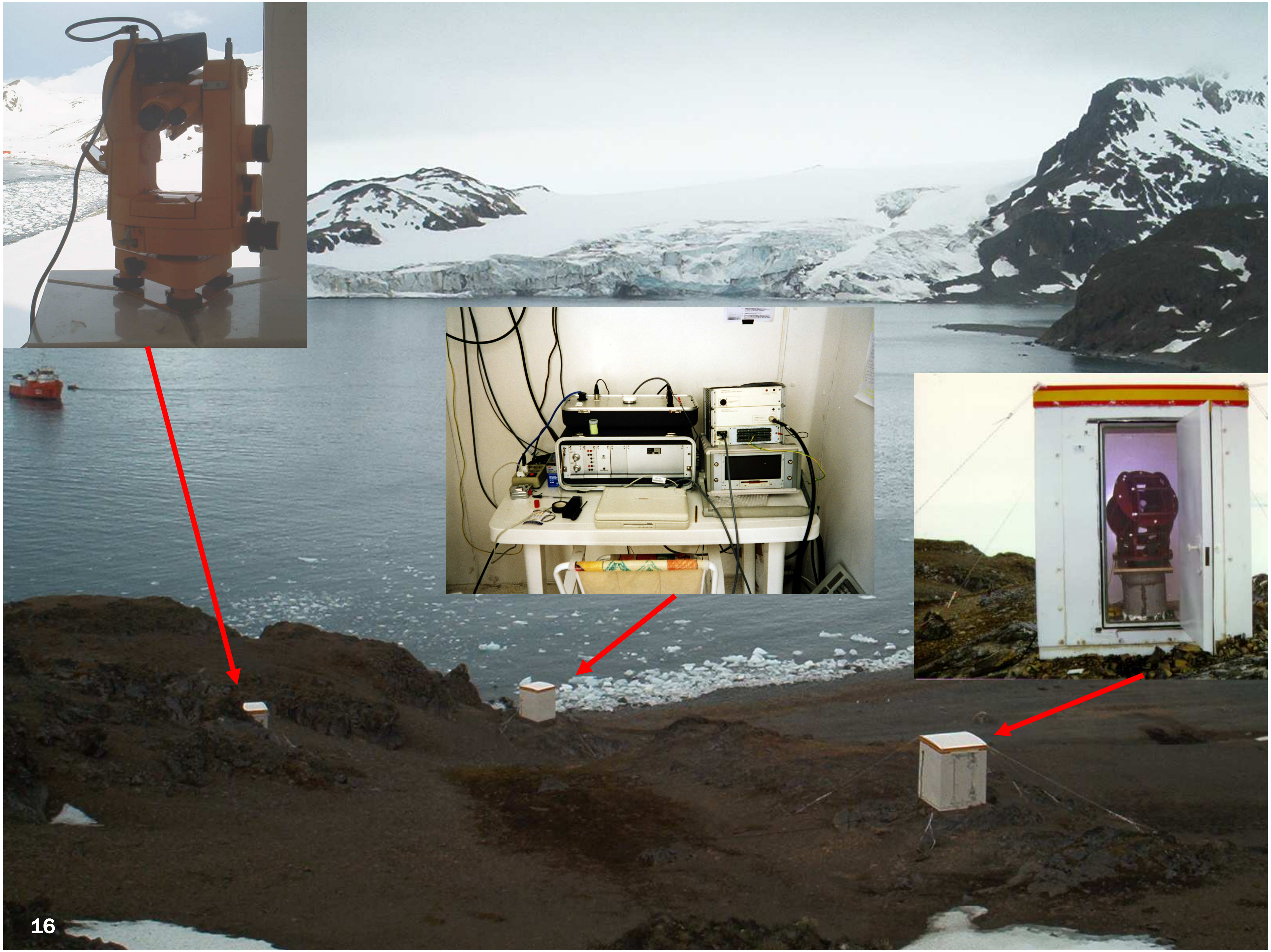
Temporal Distribution



Annual means from the WDC for Geomagnetism in Edinburgh, march 2007



OBSERVATORI DE L'EBRE EN LA B.A.E. JUAN CARLOS I - ANTARTIDA -



Variometer

• GEOMAG SM90R Overhauser magnetometer at the center of a pair of dual axis Helmholtz coils (BGS)
• Minute values, recording continuously since December 1996

Absolute Measurements

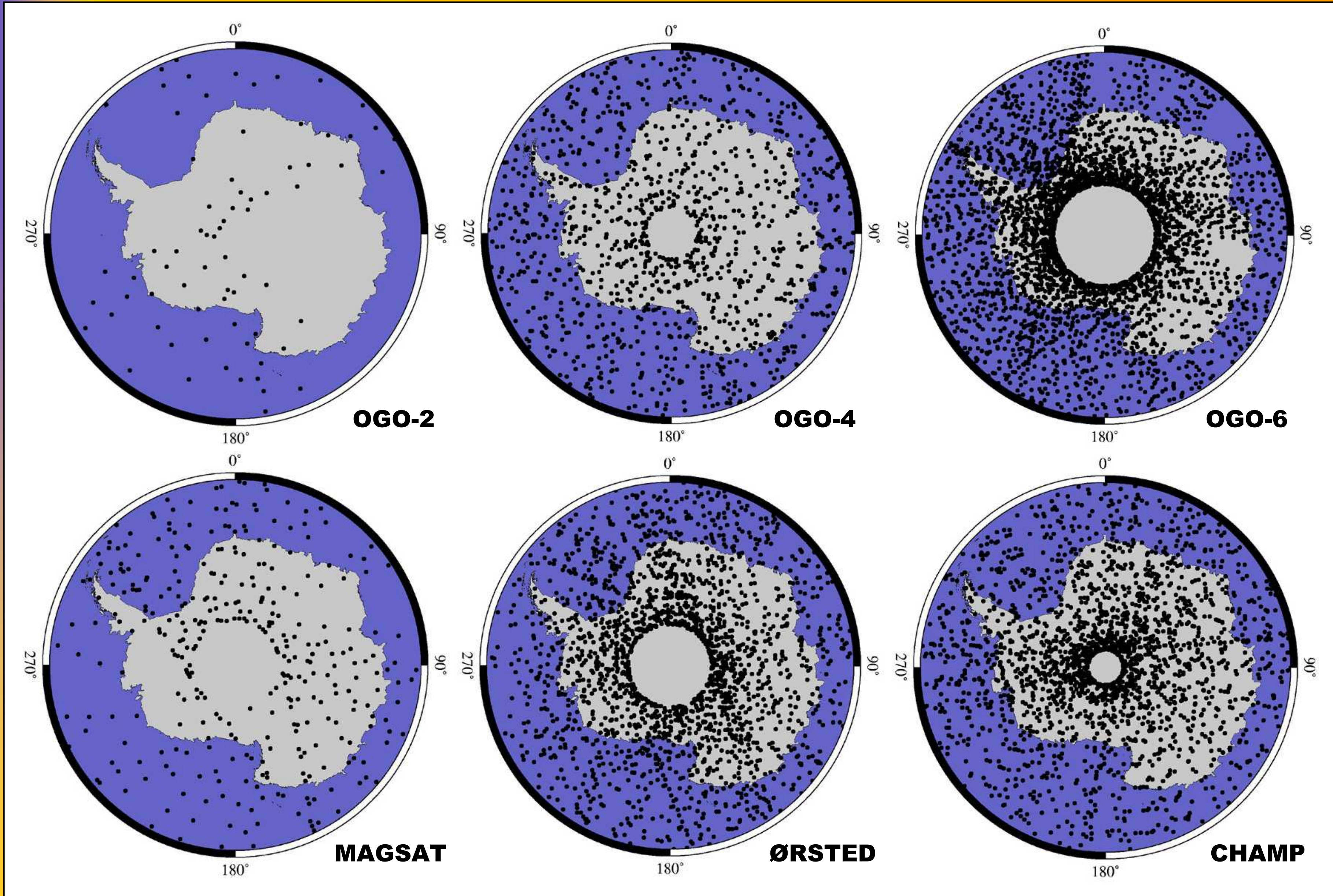
• Elsec 810A D/I-fluxgate on a Zeiss 015B amagnetic theodolite
• Null-field procedure
• Elsec 820A proton precession magnetometer for F
• Observations limited to Austral summer

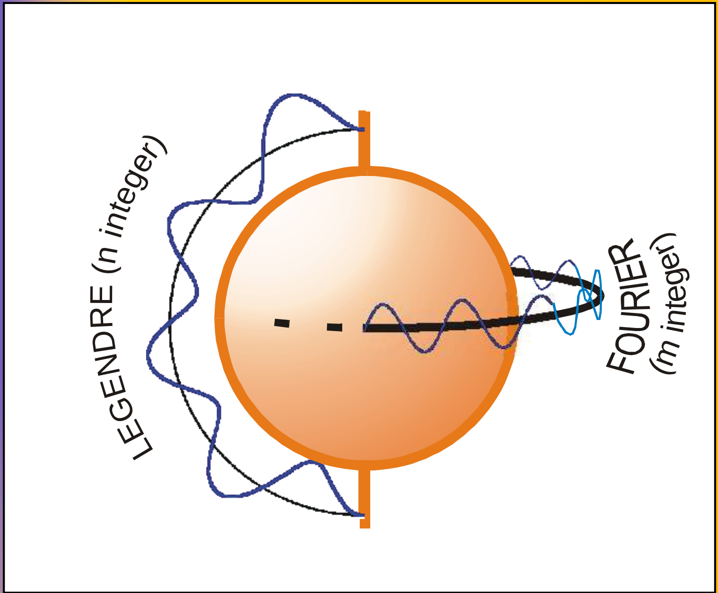

EDINBURGH
EBRE
North Atlantic Ocean
South Atlantic Ocean
LIVINGSTON I.
Meteosat

Magnetic Satellite Missions

Satellite	Date	Altitude (km)	Inclination	Local Time	Instrumentation
OGO-2	Oct 1965 to Sep 1967	413 – 1510	87°	All local times	Rubidium (scalar)
OGO-4	Jul 1967 to Jan 1969	412 – 908	86°	All local times	Rubidium (scalar)
OGO-6	Jun 1969 to Jul 1971	397 – 1098	82°	All local times	Rubidium (scalar)
Magsat	Nov 1979 to May 1980	325 –550	97°	06:00 / 18:00	Fluxgate (vector) and Cesium (scalar)
Ørsted	Feb 1999 to present	620 – 850	96°	All local times	Fluxgate (vector) and Overhauser (scalar)
Champ	Jul 2000 to present	300 – 460	87°	All local times	Fluxgate (vector) and Overhauser (scalar)

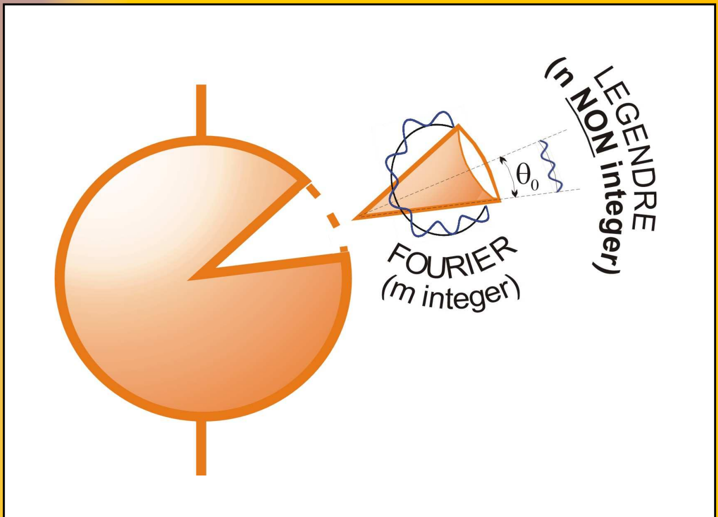
Quiet-time Satellite Data over Antarctica





Geomagnetic potential over the Sphere
SPHERICAL HARMONIC ANALYSIS

Spherical Harmonic analysis of the Earth's magnetic field by means of Legendre Polynomials and Fourier series.



Geomagnetic potential over a Spherical Cap
SPHERICAL CAP HARMONIC ANALYSIS

Regionalization of the global model for spherical cap by means of non integer Legendre polynomials and Fourier series

SPHERICAL HARMONIC ANALYSIS

$$\nabla^2 V = 0 \qquad V_i(r,\theta,\phi) = a\sum_{n=1}^{\infty}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^{n+1}\left\{g_n^m \cos m\phi + h_n^m \sin m\phi\right\}P_n^m(\cos\theta)$$

$$X \equiv -B_\theta = \frac{1}{r}\frac{\partial V}{\partial\theta} \qquad Y \equiv B_\phi = \left(-\frac{1}{r\sin\theta}\right)\frac{\partial V}{\partial\phi} \qquad Z \equiv -B_r = \frac{\partial V}{\partial r}$$

SPHERICAL CAP HARMONIC ANALYSIS

$$V(r,\theta,\phi,t) = a\sum_{k=0}^{K}\sum_{m=0}^{k}\left(\frac{a}{r}\right)^{n_k(m)+1} P_{n_k}^m(\cos\theta)\cdot\sum_{l=0}^{L}(g_{k,l}^m \cos m\phi + h_{k,l}^m \sin m\phi)\cdot t^l$$

K , *L :* maximum index and degree of spatial and temporal expansions

$g_{k,l}^m, h_{k,l}^m$: coefficients of the model

$P_{n_k(m)}^m(\cos\theta)$: associated Legendre functions of integral order *m* but usually nonintegral degree $n_k(m)$, determined to satisfy alternatively the following boundary conditions:

$$\left.\frac{dP_{n_k(m)}^m(\cos\theta)}{d\theta}\right|_{\theta=\theta_0} = 0,\ k-m = even \qquad P_{n_k(m)}^m(\cos\theta_0) = 0,\ k-m = odd$$

Fit to Observatory Data

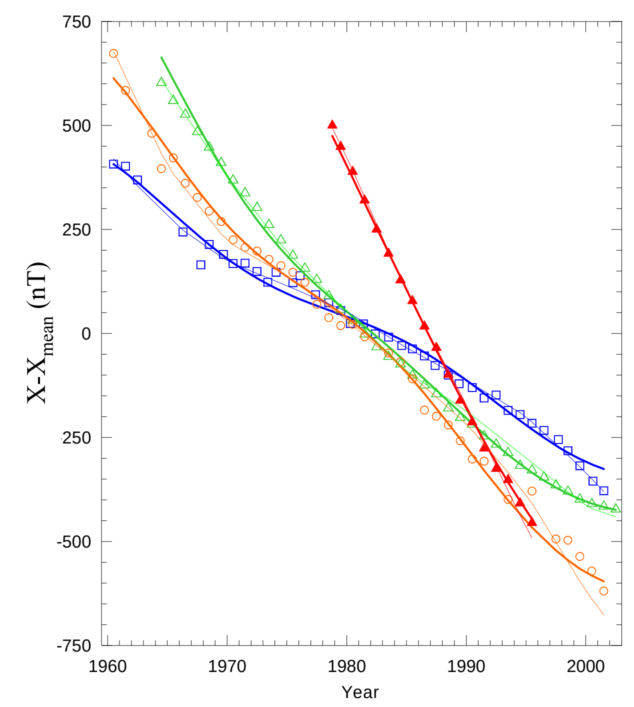
Model	X	Y	Z	F
ARM	678	612	1359	1399
IGRF-9	694	600	1372	1411
$CM4_{internal}$	690	611	1365	1403

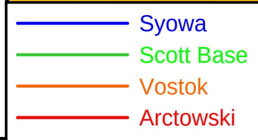
Fit to Satellite Data

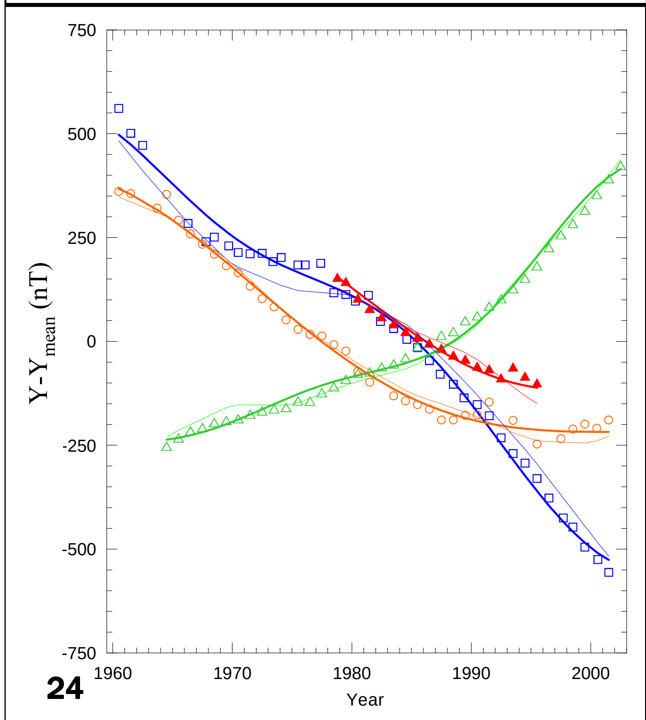
Model	OGO-2	OGO-4	OGO-6	Magsat	Champ	Ørsted
ARM	22.9	13.4	11.4	13.2	9.8	9.4
IGRF-9	21.9	21.7	22.5	14.7	19.0	19.7
$CM4_{internal}$	16.6	22.3	22.2	21.4	24.8	24.5
$CM4_{int+ext}$	6.3	5.8	5.3	3.7	4.6	3.3

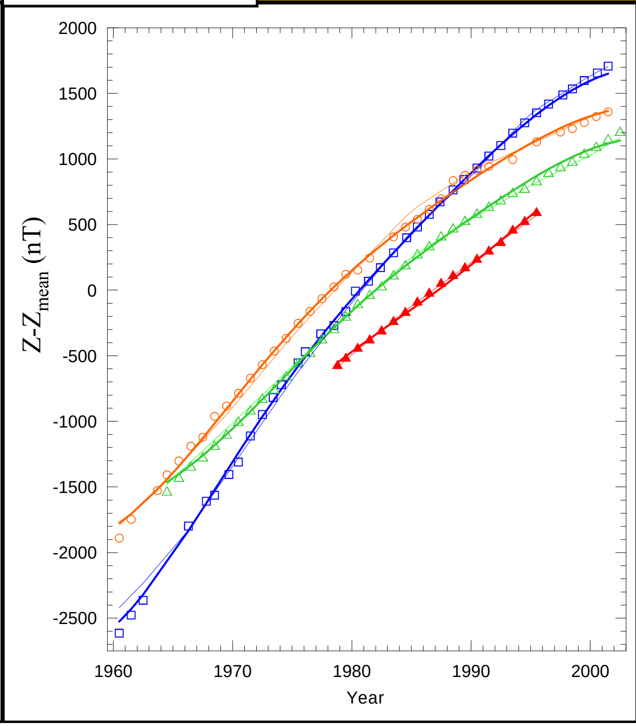
Fit to Secular Variation

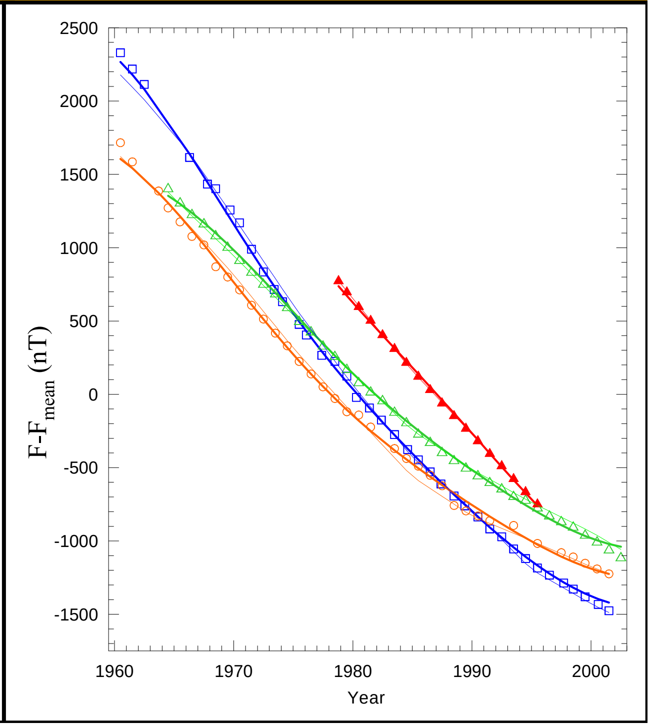
Model	RMS X (nT/year)	RMS Y (nT/year)	RMS Z (nT/year)	RMS F (nT/year)
IGRF-9	36.1	38.1	49.6	51.6
CM4	31.3	34.7	43.8	45.5
ARM	28.2	32.6	35.3	35.4





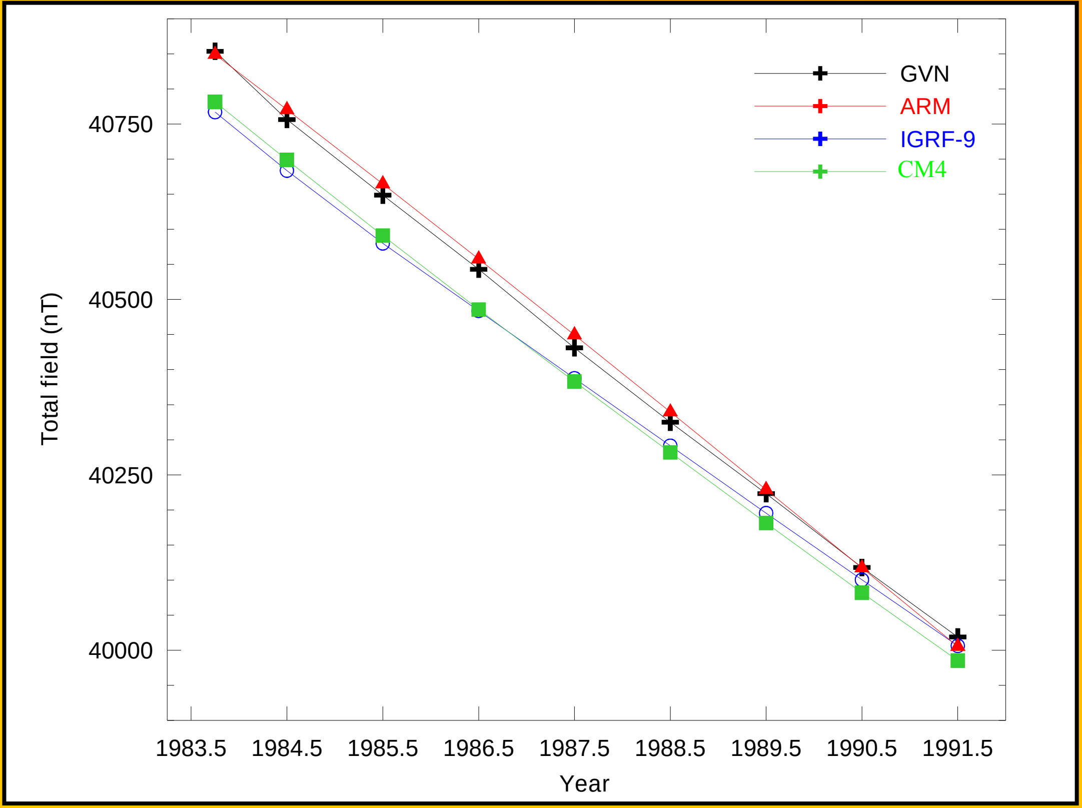






Fit to Ground Data not used in the model

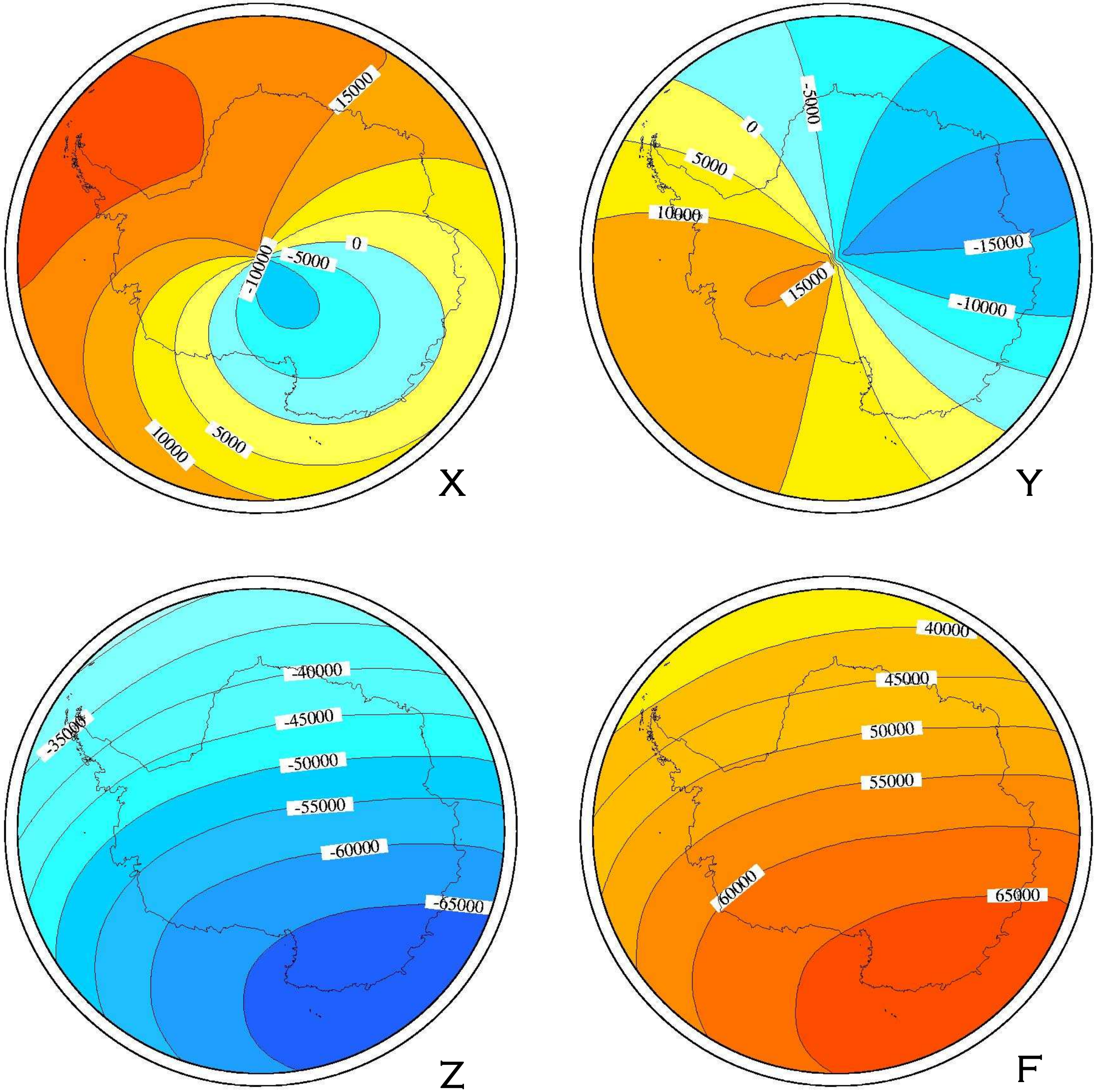
Georg von Neumayer Observatory (-70.617°S, 351.633°E)



Model	RMS F (nT)
IGRF-9	53.0
CM4	51.1
ARM	12.7

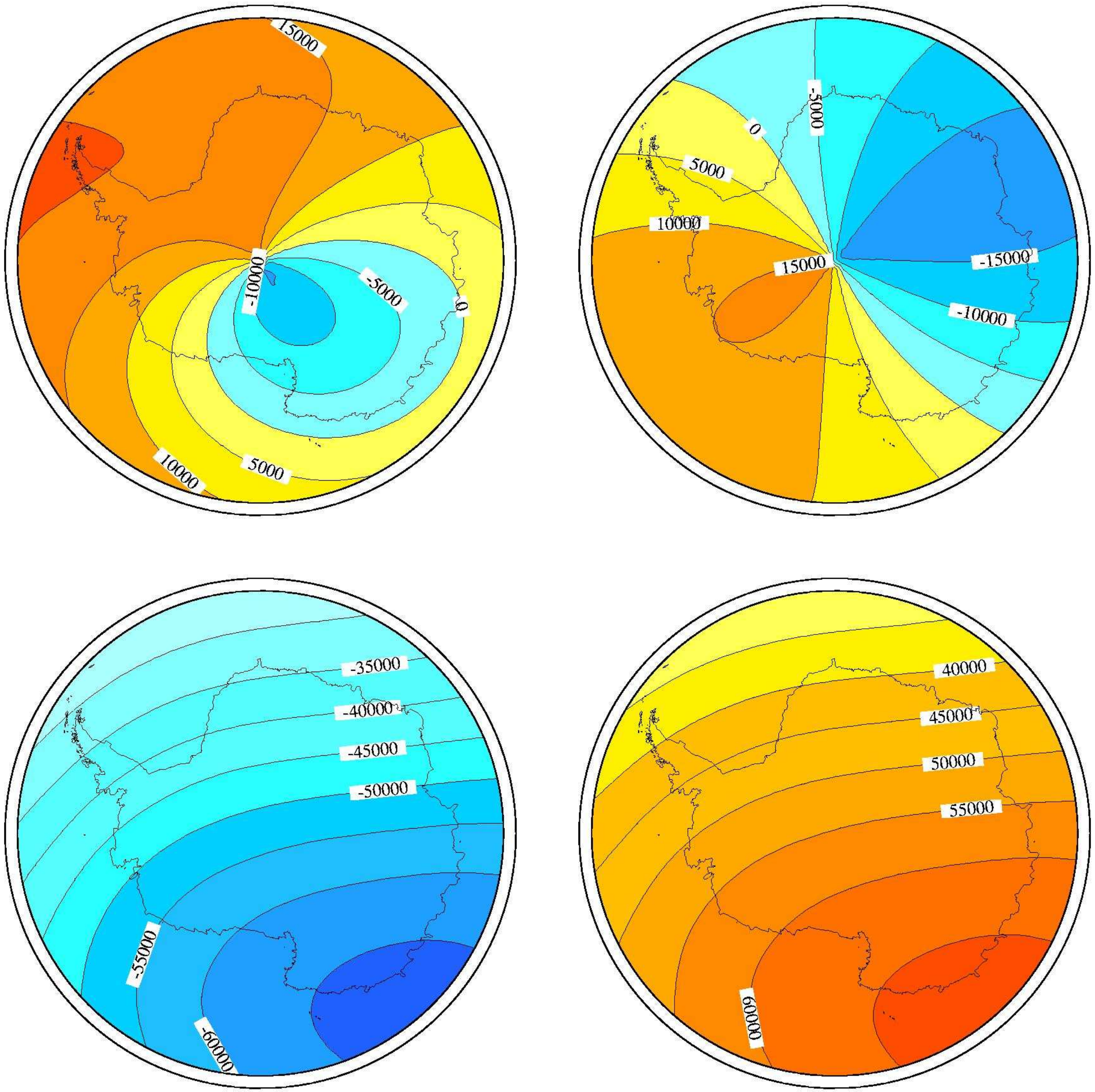
Mean Secular Variation (nT/year)	
Real	-107.1
IGRF-9	-97.5
CM4	-102.6
ARM	-108.9

ARM Magnetic Field Maps



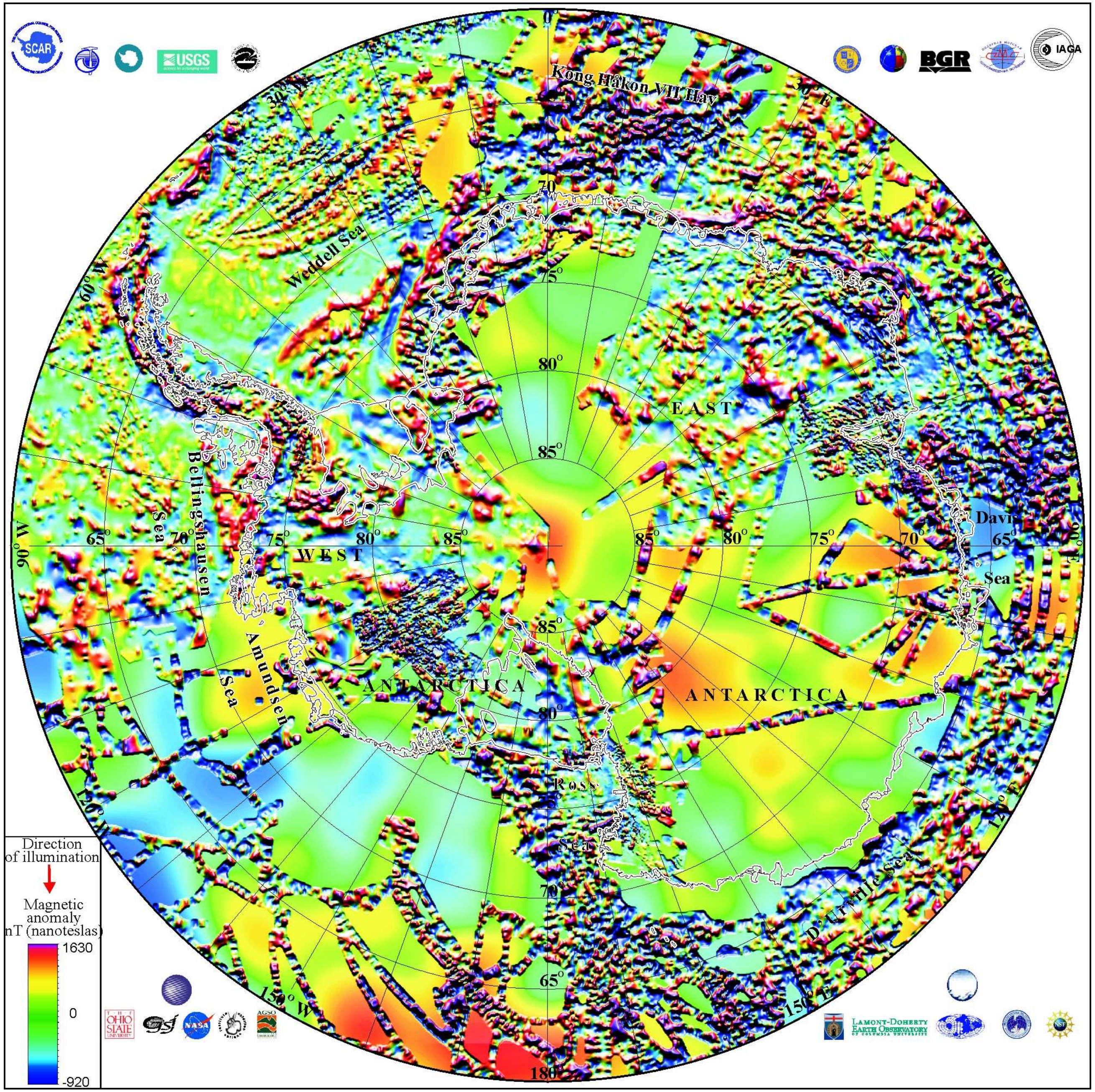
1960.0

ARM Magnetic Field Maps



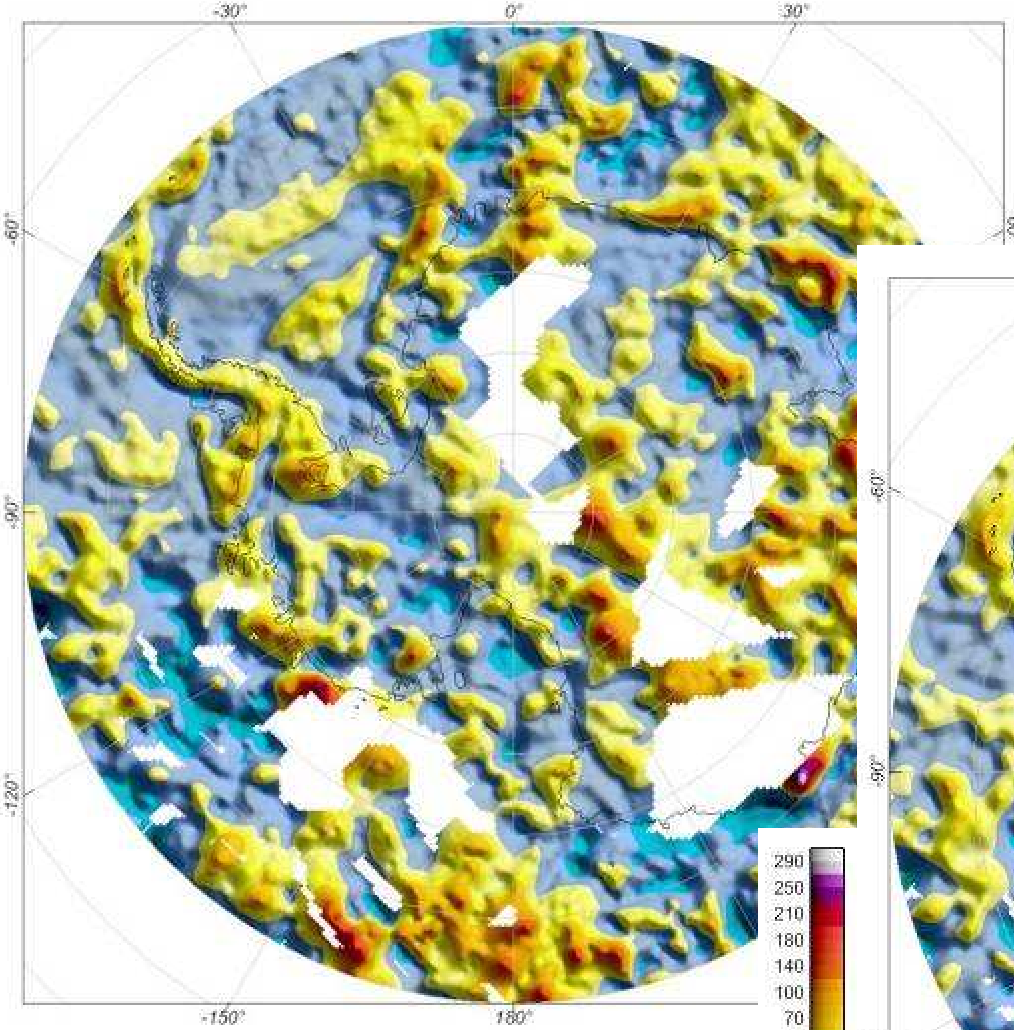
2005.0

ADMAP Magnetic Anomaly Map

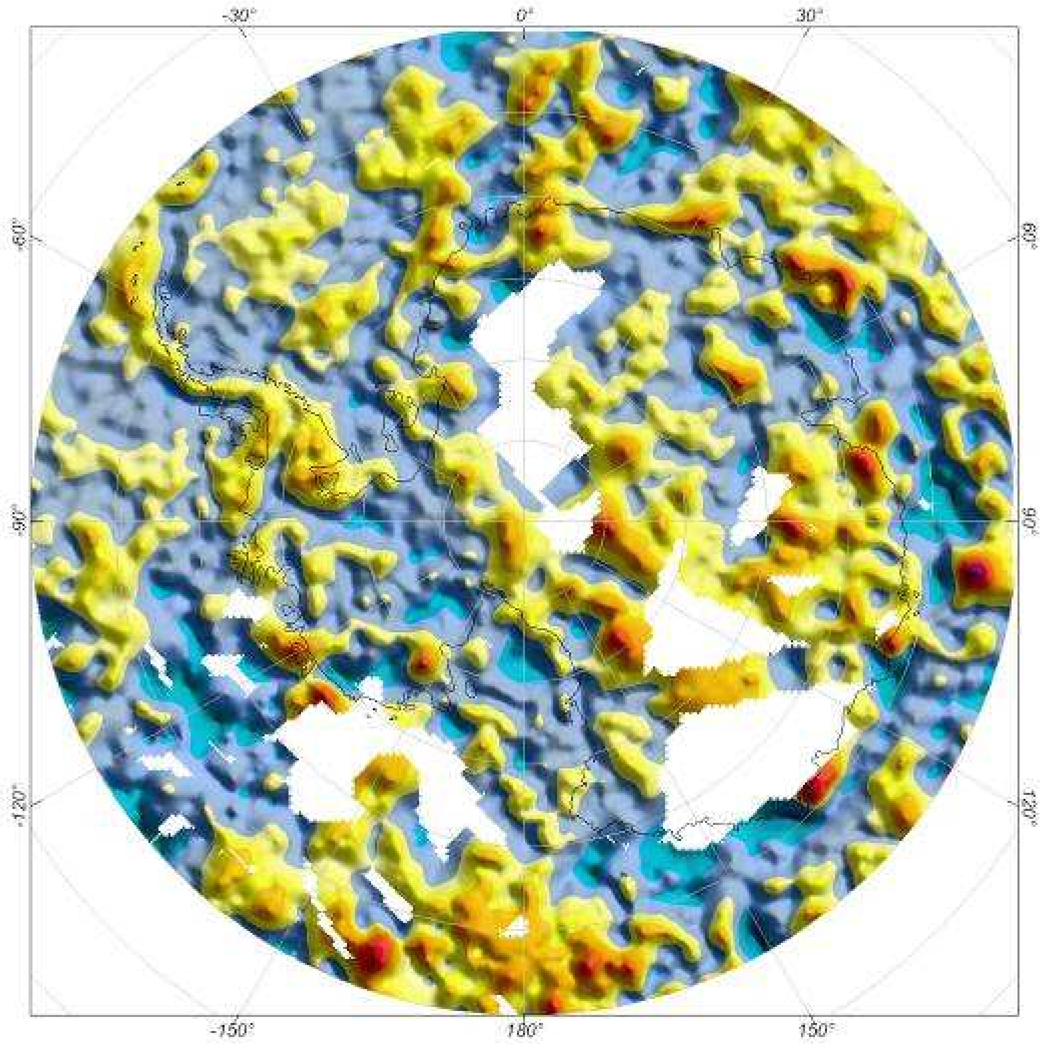


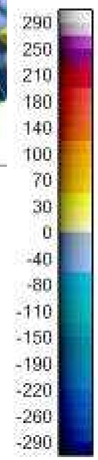
Altitude 50 km , grid interval 50 km
Amplitude range ± 300 nT

SCHA-Modeling of ADMAP



30º Spherical Cap
λ_{min} = 221 km

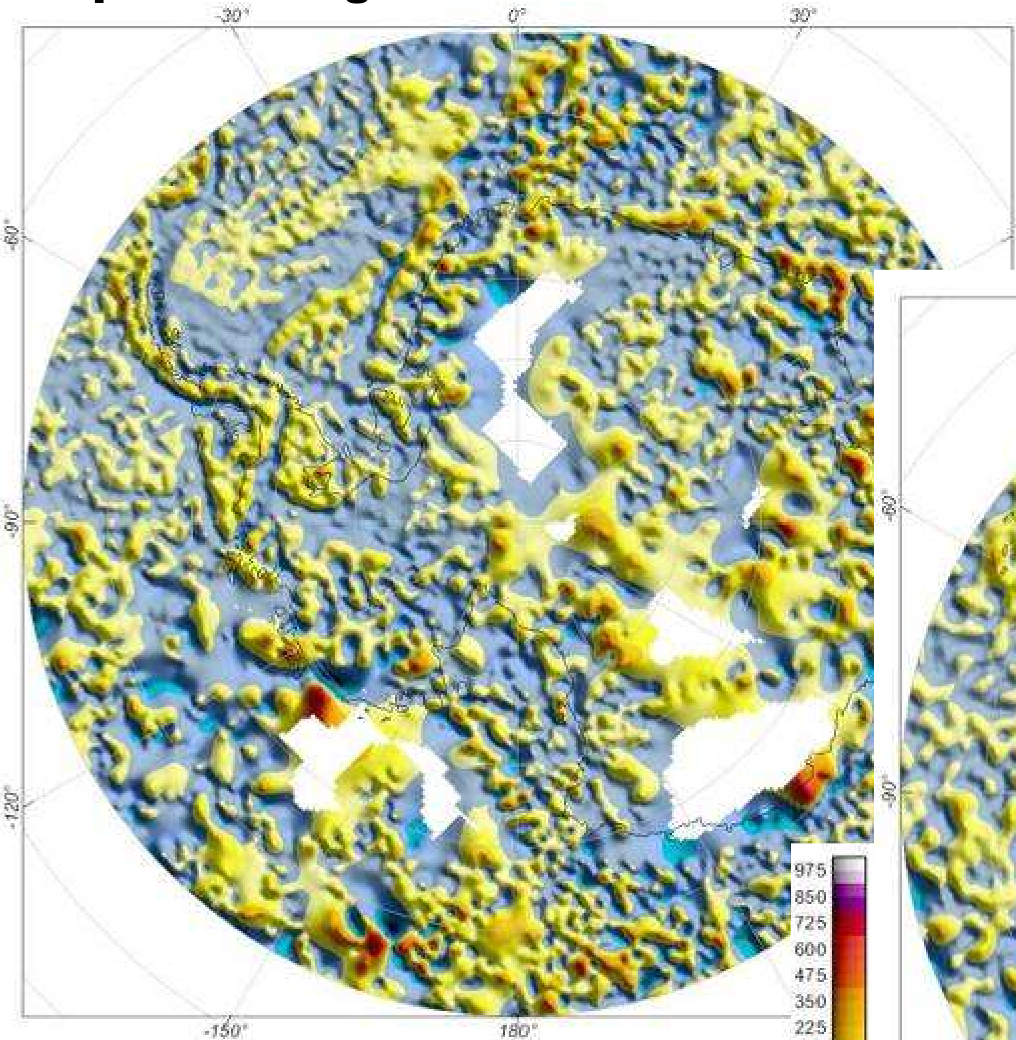




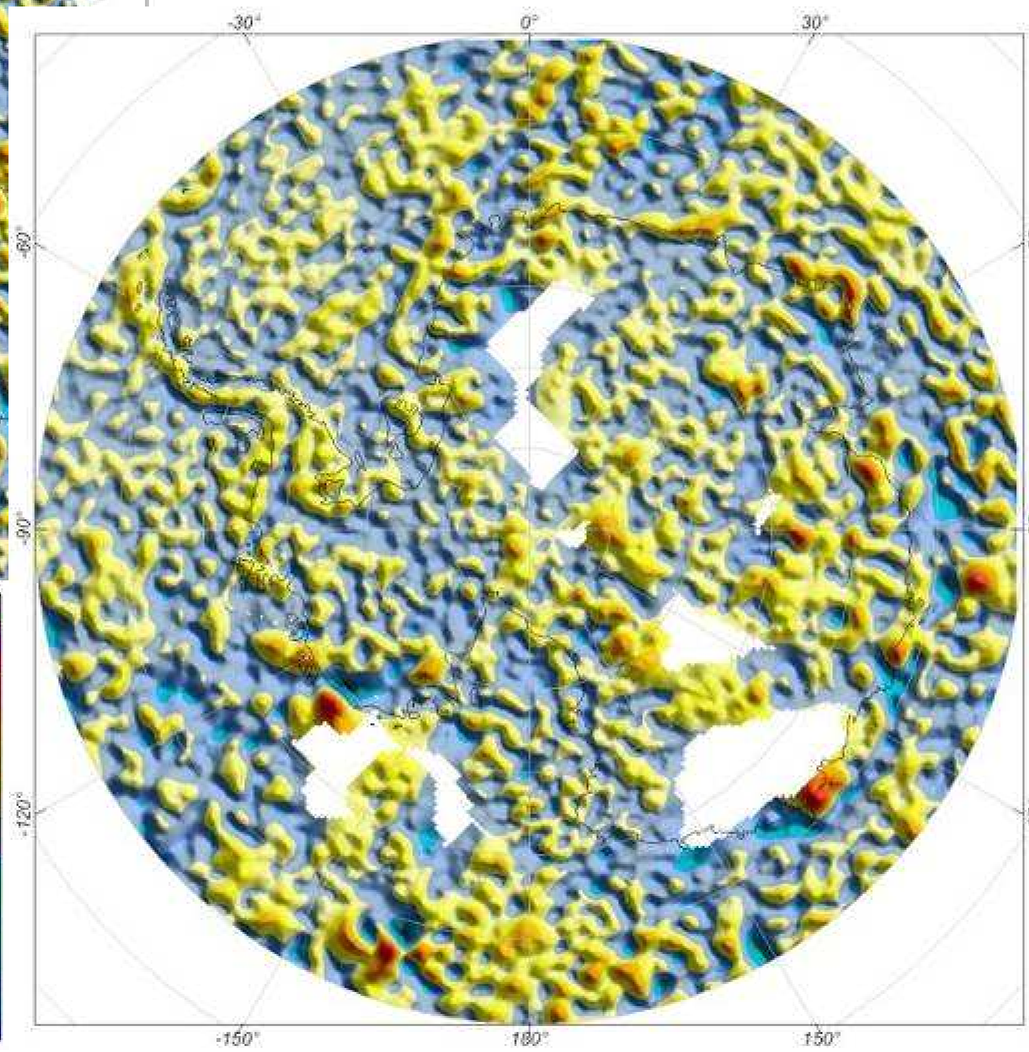
Mean difference 9.2 nT
σ = 8.8 nT
Δ_{max} = 84.5 nT
ρ = 0.95

SCHA-Modeling of ADMAP

Altitude 5 km , grid interval 50 km
Amplitude range ± 1000 nT

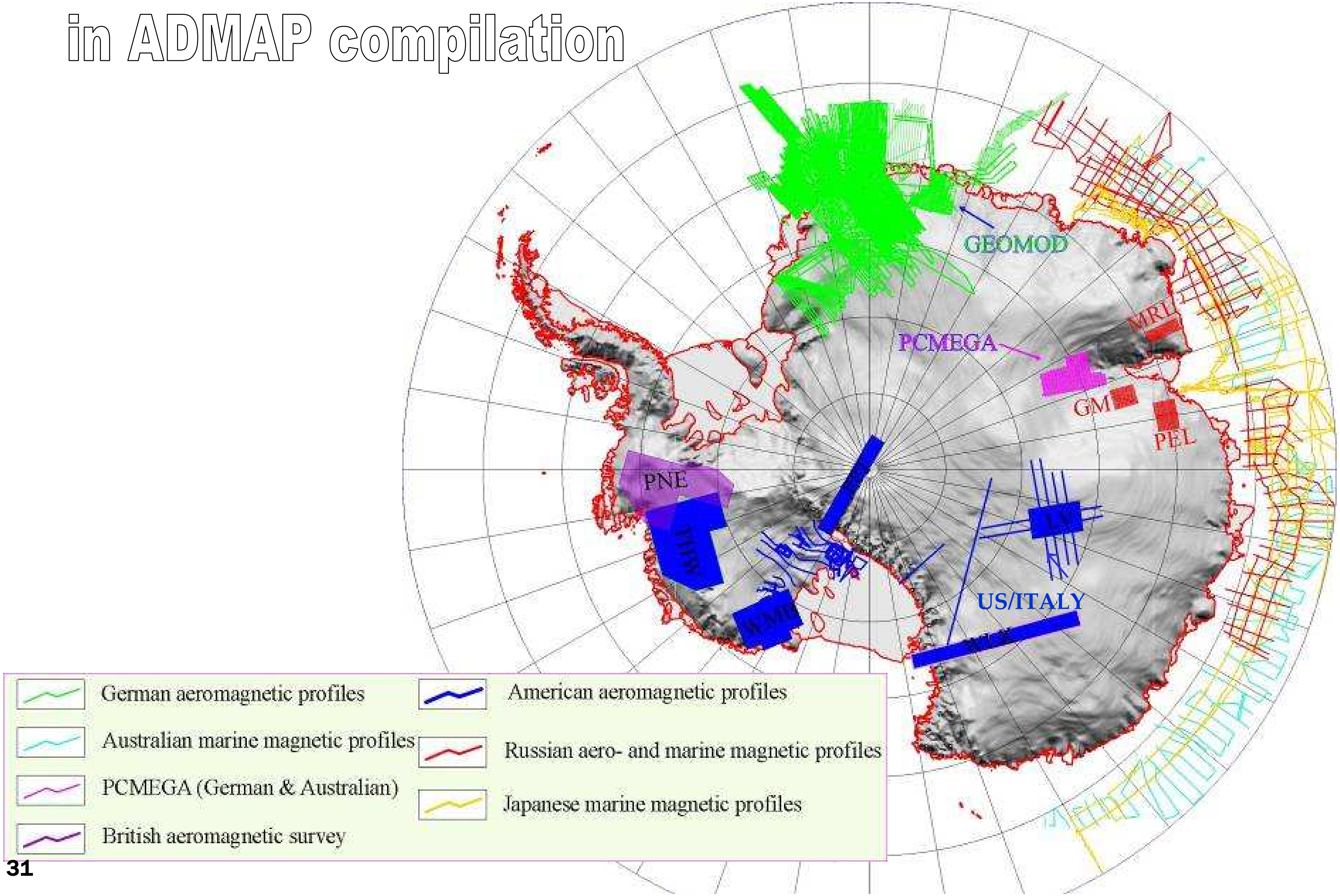


30º Spherical Cap
λ_{min} = 111 km



Mean difference 43 nT
σ = 42 nT
Δ_{max} = 540 nT
ρ = 0.85

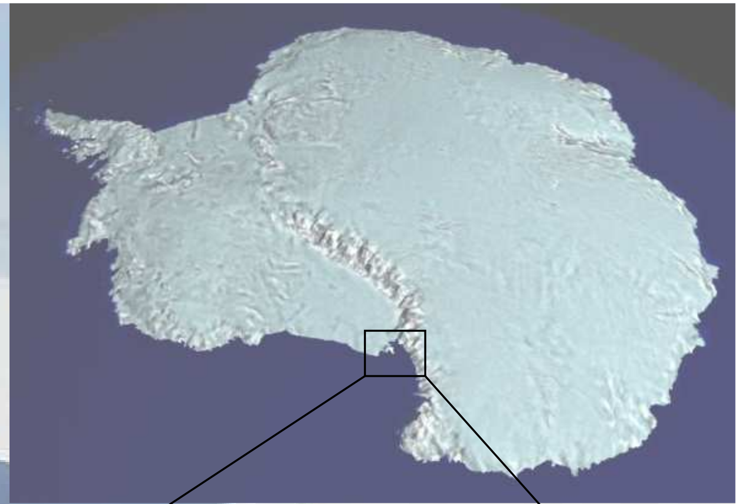
Magnetic anomaly data not in ADMAP compilation

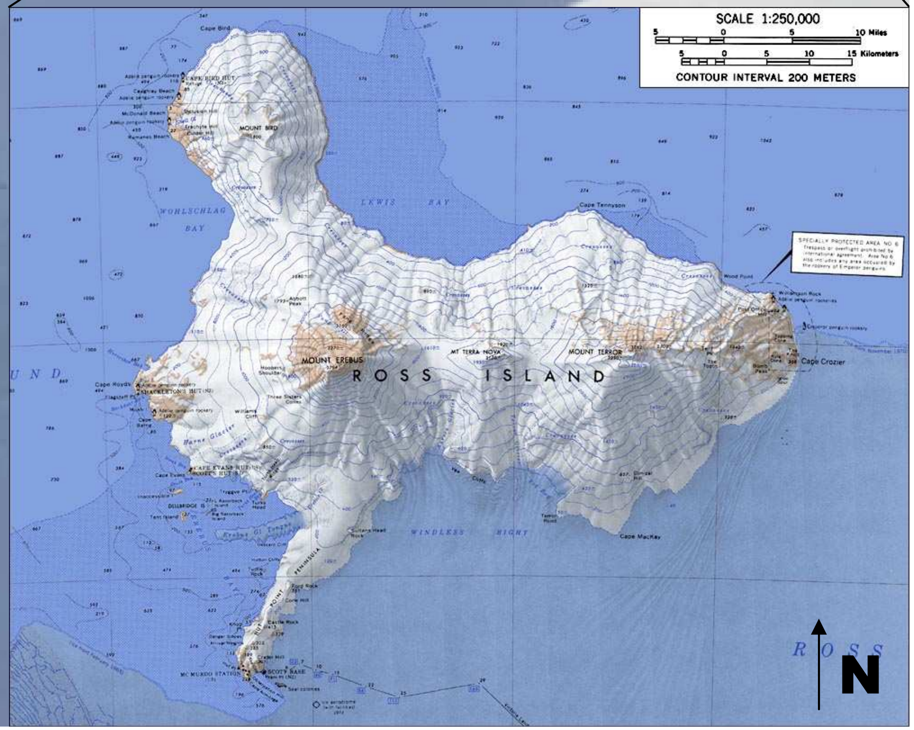


GEOIMAG survey

2003/2004 campaign

1. **To characterize from a magnetic point of view the Northern part of the Terror Rift (Ross Island, Erebus volcano, and associated volcanic structures)**
2. **To develop a high-resolution aeromagnetic survey over the McMurdo Sound related to the ANDRILL international project**





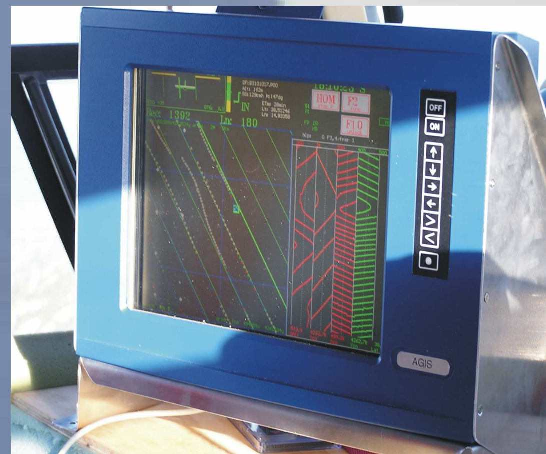
INGV AIRBORNE GEOPHYSICAL EQUIPMENT

Optically pumped Cesium Magnetometer

AGIS acquisition system: Magnetic Field data + GPS + laser altimeter + Pilot Guidance Unit + video recording system

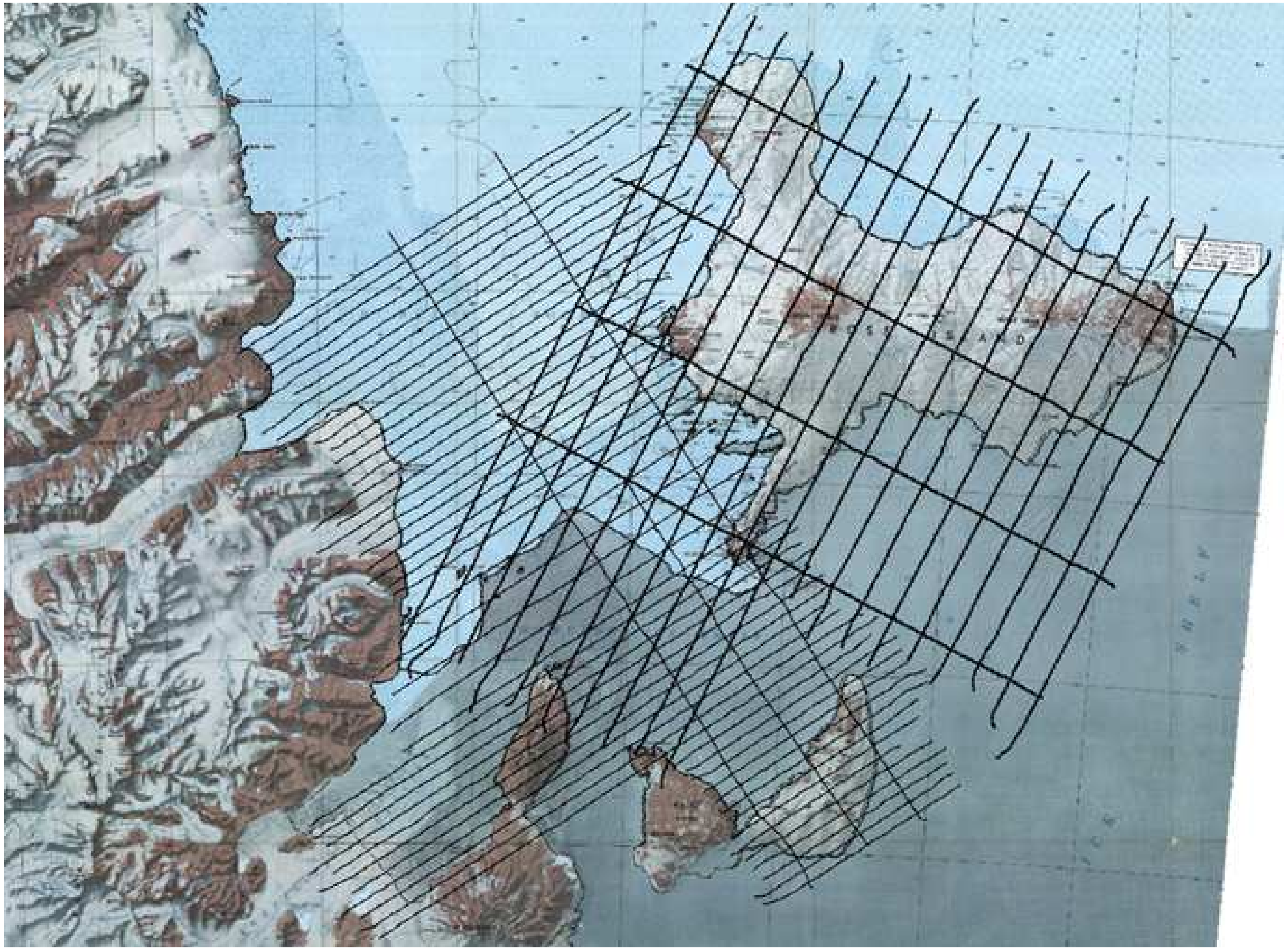
Also: DGPS + magnetometric base station + radar altimeter

Aerodinamical bird (left) containing the cesium magnetometer (right)



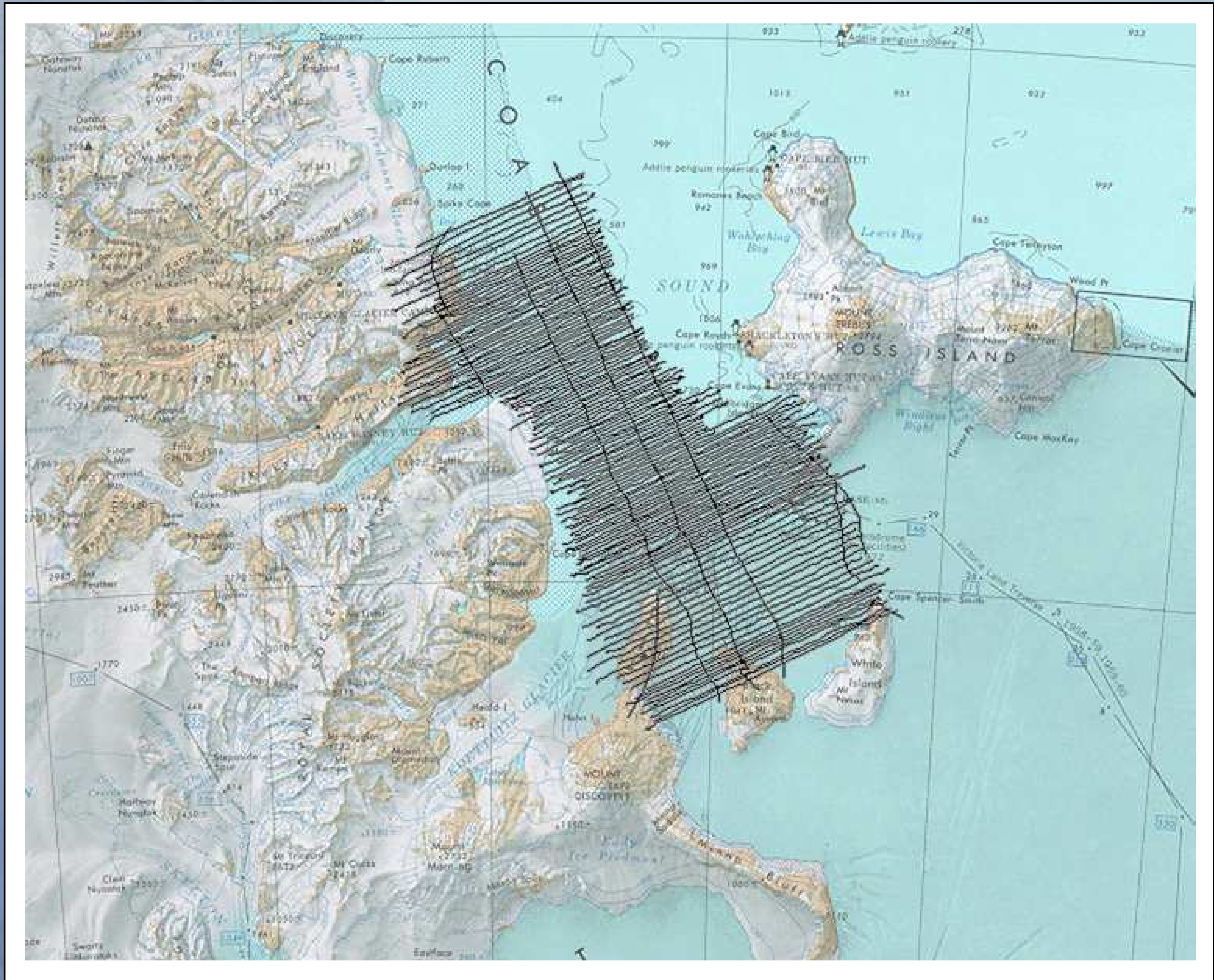
AGIS acquisition system

High-altitude surveys over Ross Island and McMurdo Sound

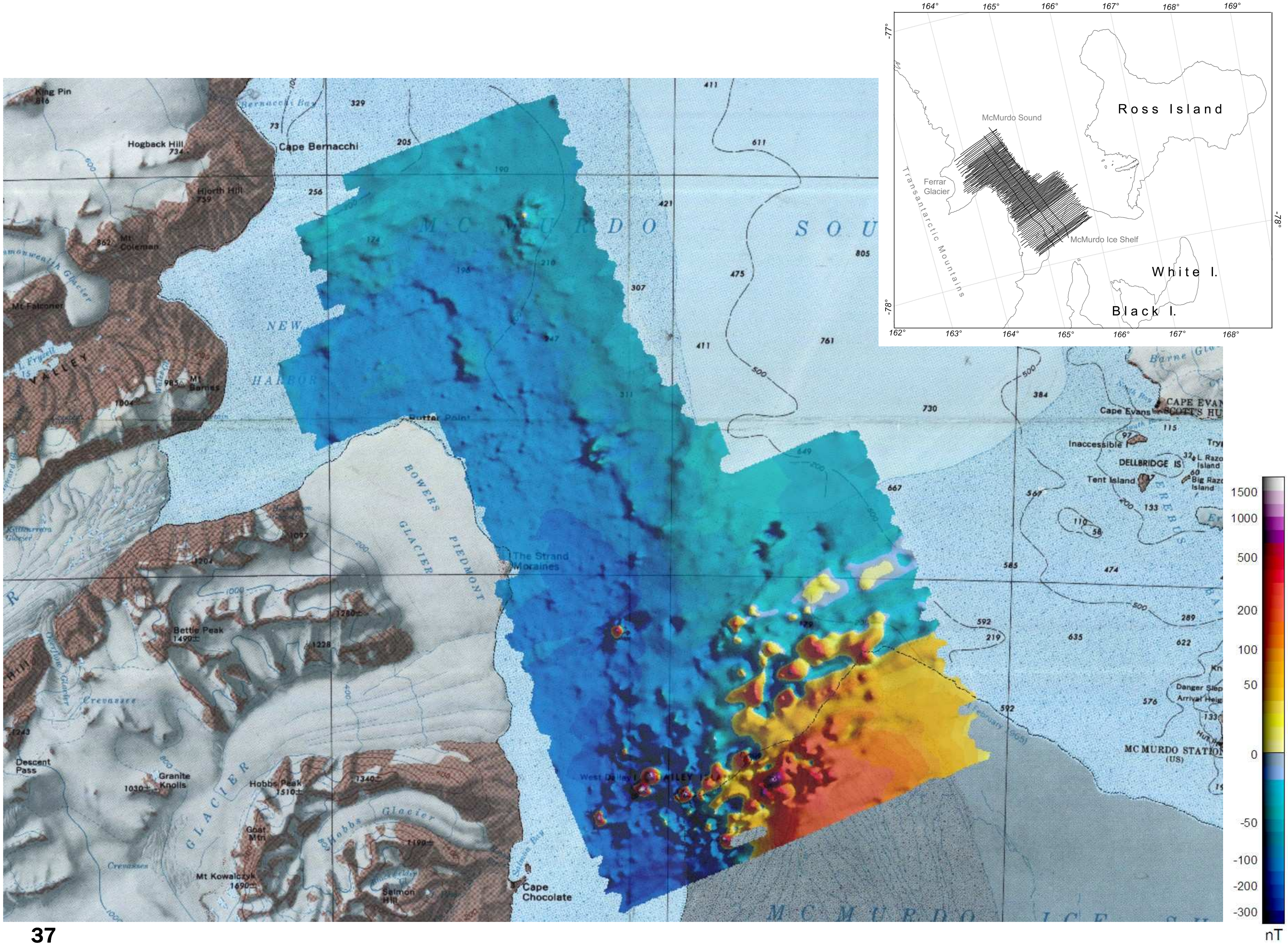


Twin Otter aircraft, 30 hours, 1500 - 5000 m

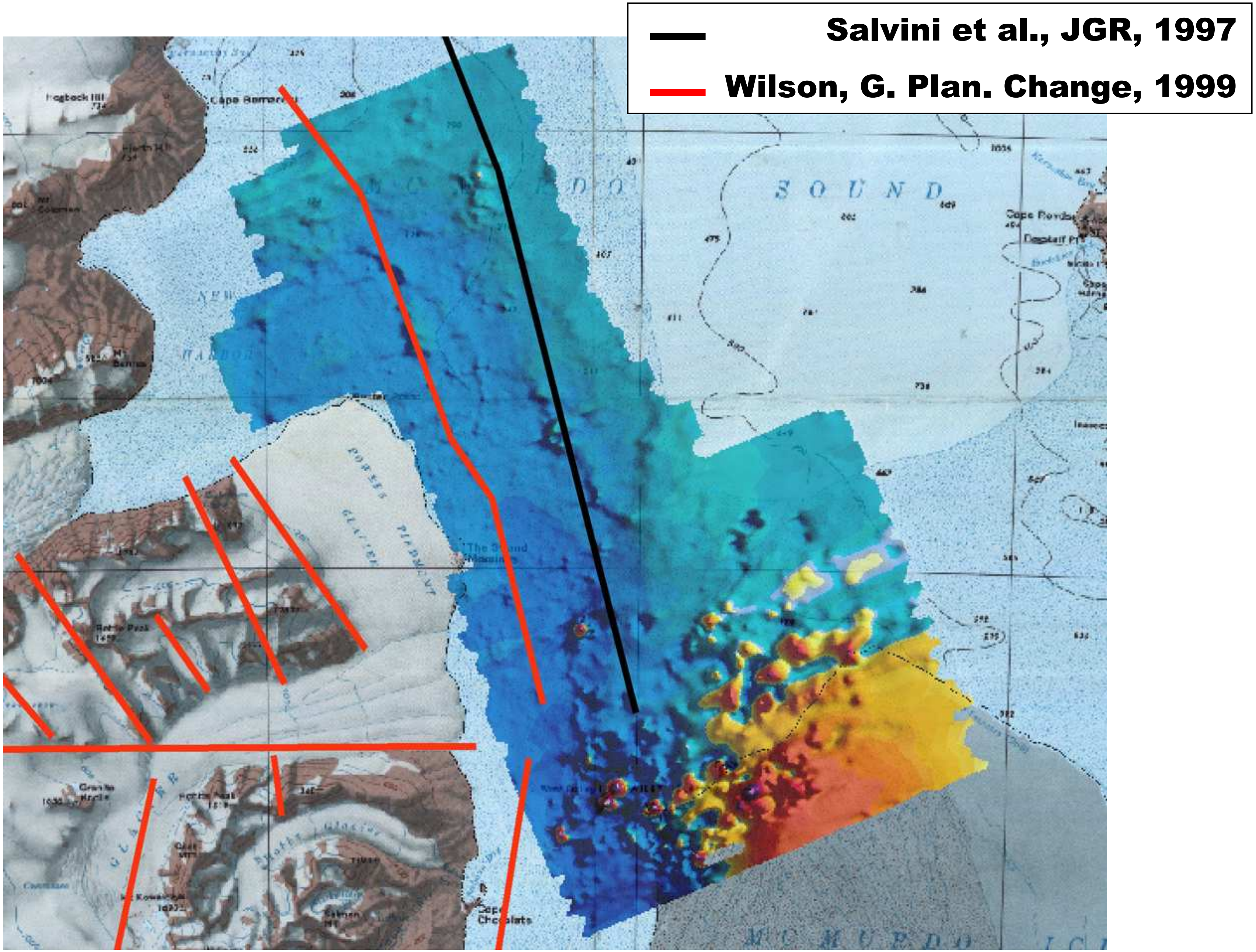
High-resolution, low-altitude survey over McMurdo Sound



Squirrel helicopter, 22 hours, 100 m



Ross Island
McMurdo Sound
Ferrar Glacier
Transantarctic Mountains
McMurdo Ice Shelf
White I.
Black I.
King Pin
Hogback Hill
Cape Bernacchi
Hjorth Hill
Mt Coleman
Mt Falconer
Mt Barnes
Butter Point
BOWERS PIEDMONT GLACIER
The Strand Moraines
Bettle Peak
Descent Pass
Granite Knolls
Hobbs Peak
Goat Mtn
Mt Kowalczyk
Salmon Hill
Cape Chocolate
Hobbs Glacier
CAPE EVANS
Cape Evans
Inaccessible I
DELLBRIDGE IS
Tent Island
MC MURDO STATION (US)
1500
1000
500
200
100
50
0
-50
-100
-200
-300
nT



Salvini et al., JGR, 1997
Wilson, G. Plan. Change, 1999
S O U N D

The study of the crustal field at all scales:

- Local (observatories)

- Regional (surveys)

- Continental (compilations)

constitutes a powerful tool to improve our knowledge of the geology and tectonic history of our planet