Aspects of Main-Field and Secular Variation Models Derived from Ørsted and Contemporary Ground-Based Data

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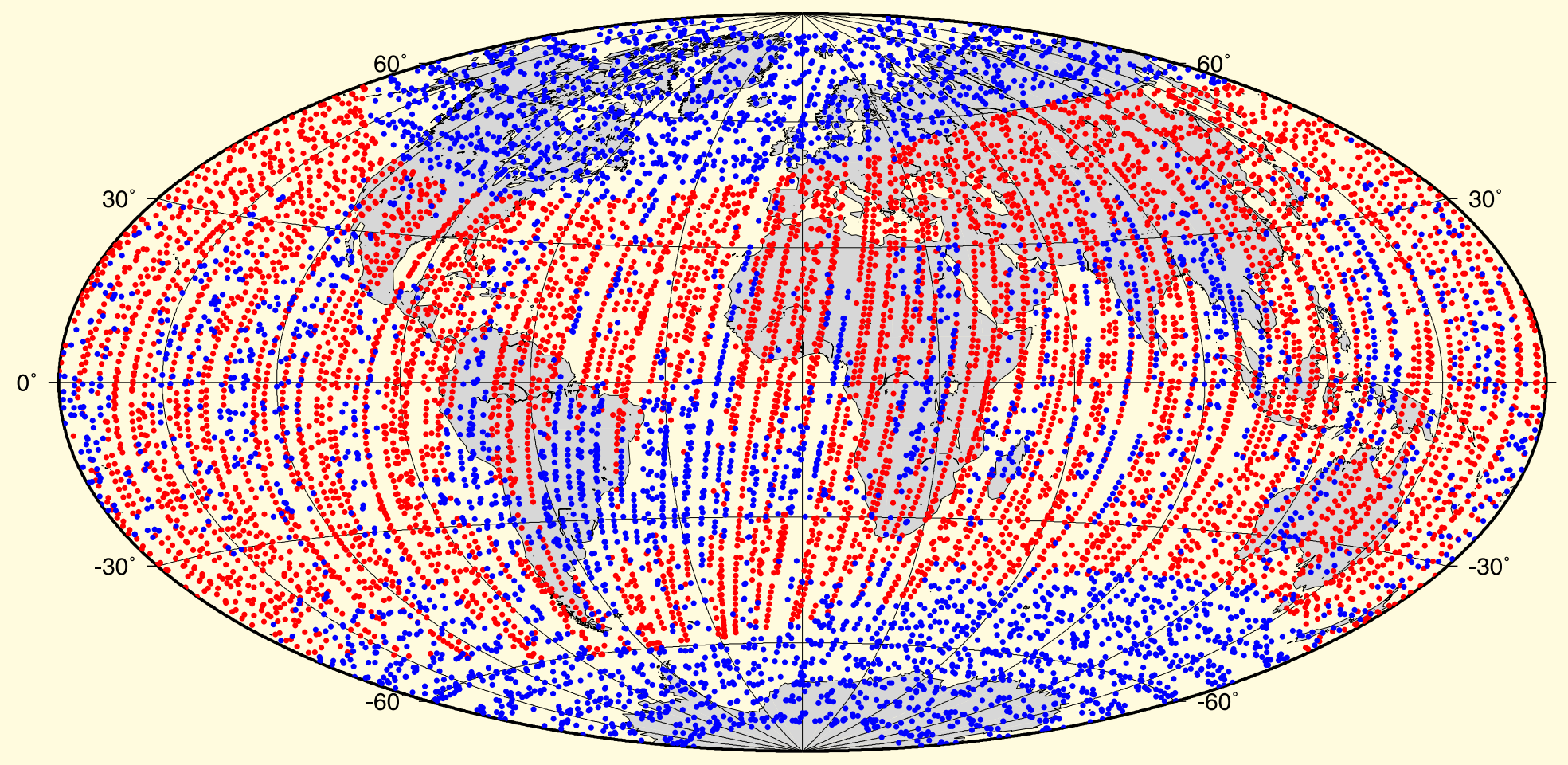
Ground-based data that are contemporary with the Ørsted mission are valuable as an independent data source for main field and secular variation modelling. We consider the potential contribution of both types of data to geomagnetic models from the perspective of quality and distribution in space and time. Seasonal and local time effects in Ørsted-based models are noted. Estimates of apparent crustal biases at world-wide observatories are compared with equivalent values for the Magsat era.

Below Left:	Data selection issues and the significance of geographical and local time variations
Below Centre:	Secular variation observed in Ørsted and ground data and also changes in SV between Ørsted (2000) and Magsat (1980)
Below Right:	Estimates of dayside ionospheric field disturbance profiles (99/00)
Top Right:	A comparison of crustal biases at the Magsat and Ørsted eras

Ørsted Data Selection: Local Time, Season & Spatial Distribution

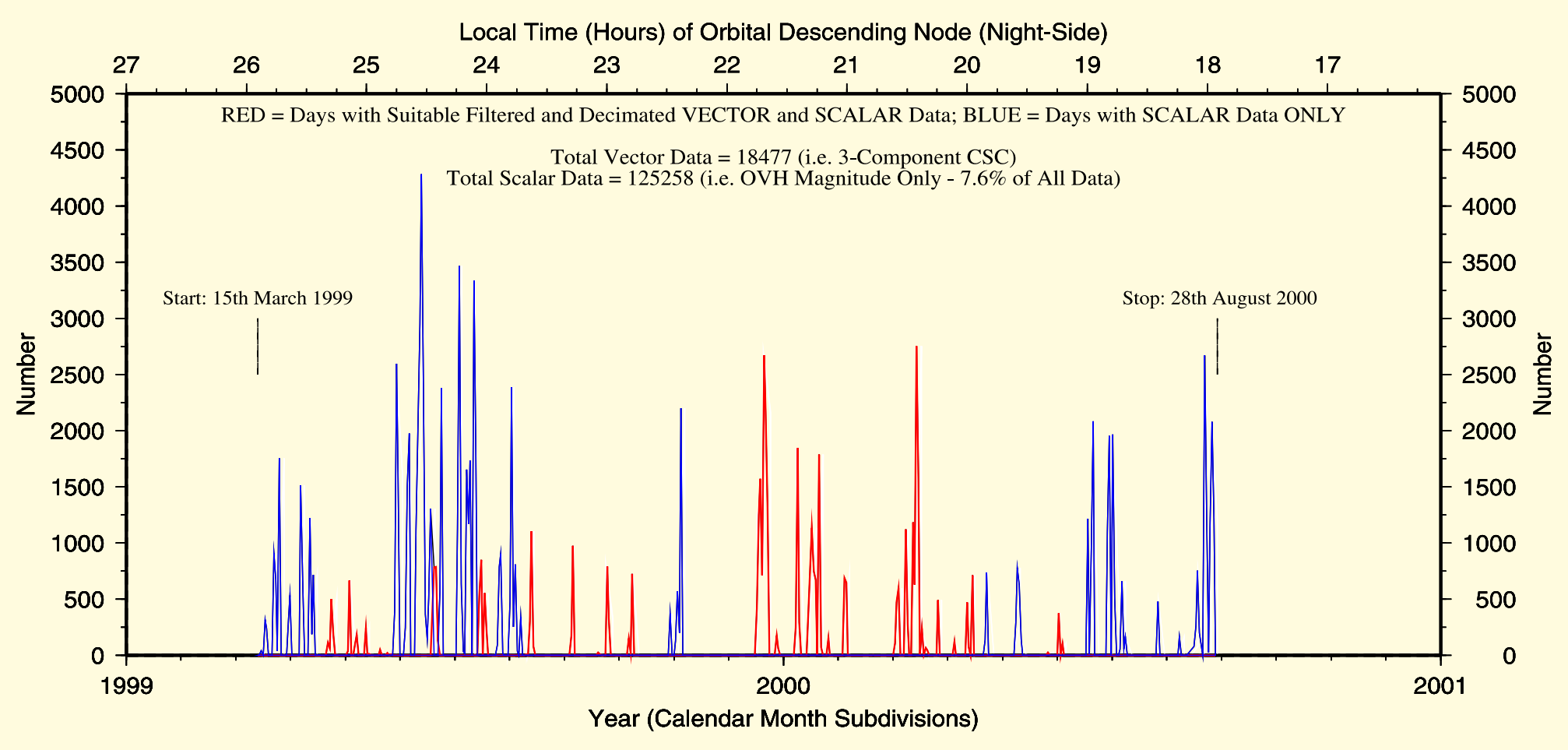
Ørsted Vector and Scalar Data Available for Modelling

- Filtered Data Set (By Activity Level, Local Night-Time, Data Quality, Equal-Area Tessera) -



Vector (CSC) and Scalar (OVH) [Red], Scalar OVH Only [Blue]

Quiet-Time Ørsted Data for Geomagnetic Main-Field Modelling



FILTERS

Kp(now) < 1+; Kp(3hr ago) < 2o; |Dst(now)| < 20 nT; |Dst(1hr ago)| < 25 nT

IMF |Bz| < 4 nT; |By| < 4 nT; |Bx| < 5 nT; Vsw < 425 km/s

|Preliminary Ørsted Model - Measured| < 25 nT; NO High-Latitude Solar Zenith Angle Filter

ALL LOCAL TIMES; Decimation = Every 20th Data Point; Vector Data Within 50 Degrees of Geomagnetic Equator

Method:

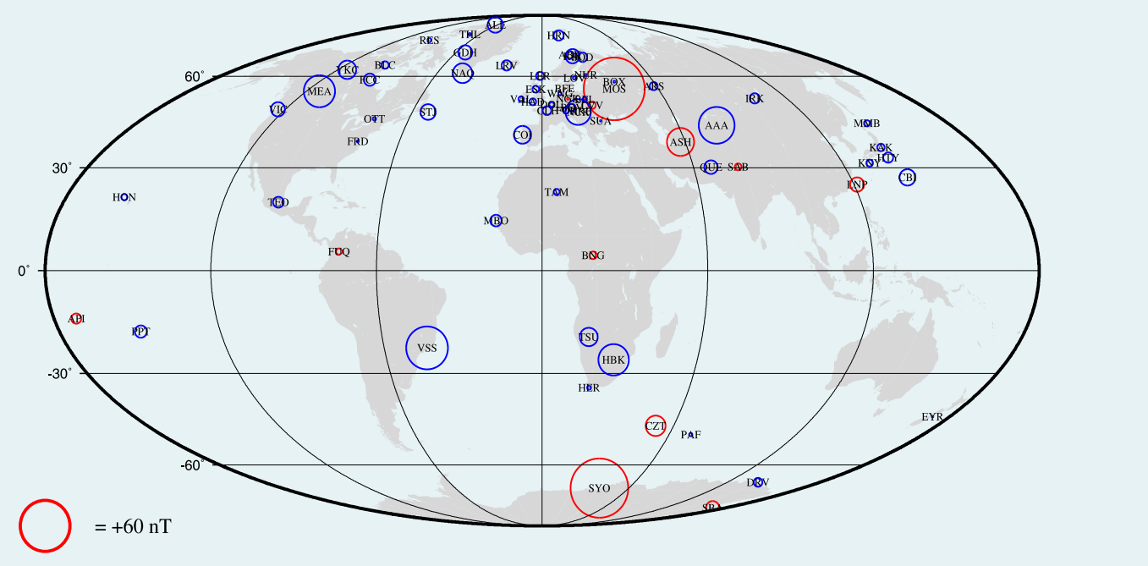
Shown left is a typical geographical distribution of data under quiet external field conditions where only night-side (quiet ionosphere) data are required. Solar wind (*ACE* spacecraft) and solar zenith angle are also used as filters. Vector and scalar data within 50 degrees of the geomagnetic equator are used and only scalar data otherwise. Data decimation is every 20th sample, to reduce along-track correlations. The data are binned in equal-area tesserae (equivalent to 5 degrees by 5 degrees at the equator) and we select the seven quietest external field data per bin. Main-field models up to degree 18 internal and degree two external (together with a *Dst* dependence for the external dipole) have been calculated from such distributions. The Holme method (*EPS*, 2000) of treating anisotropic errors in Ørsted vector data has not yet been implemented - but we plan to do so. Even so, the r.m.s. fit of model to data is typically 5.2 nT for a complete year of data. Below left is a plot of the temporal distribution of suitable Ørsted data ('suitable' defined by the data filters given in the caption below the figure). We show all local times here. Currently only scalar data are available after July 2000.

Conclusions:

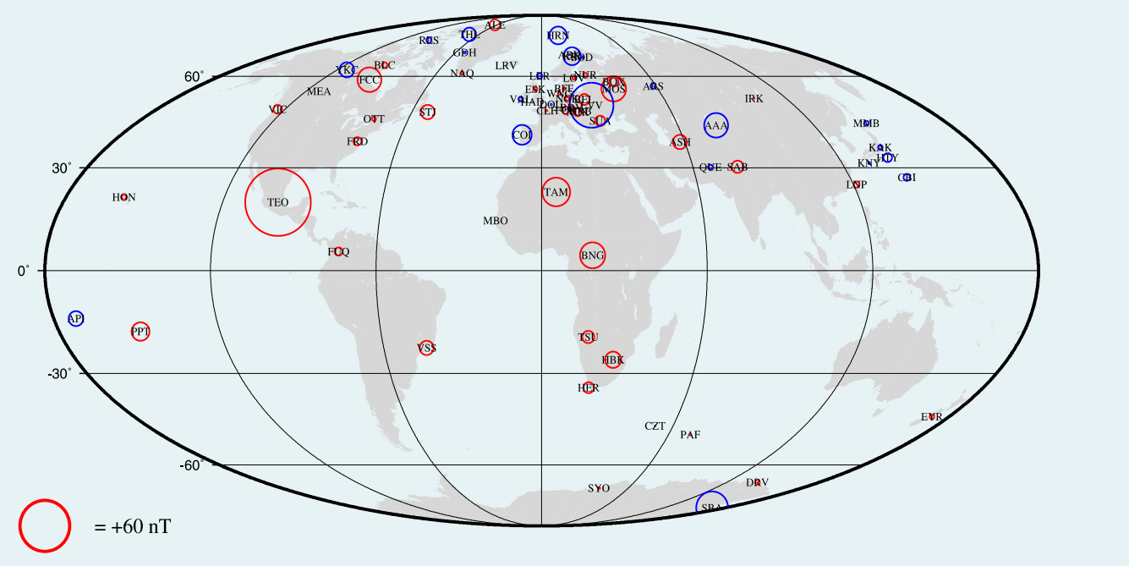
(1) An even geographical distribution of data is readily achievable although the lack of vector data in the South Atlantic Anomaly may yet be significant in terms of the 'Backus Effect'.
(2) Though we have not shown it here it is possible to realise adequate geographical distributions of data from time spans as short as around 2-3 months. However as can be seen on the left, some months in the last year or so have little or no useful data, particularly vector data.
(3) It is clear from the Figure on the left that data selections of less than one year pick out particular local times. That is local time and seasonal effects are inter-twined. Seasonal effects were noted in the Ørsted Initial Field Model (epoch 2000.0) of Olsen *et al* (*GRL,* 2000).

Crustal Biases at Worldwide Observatories: 1980 and 1999 Compared

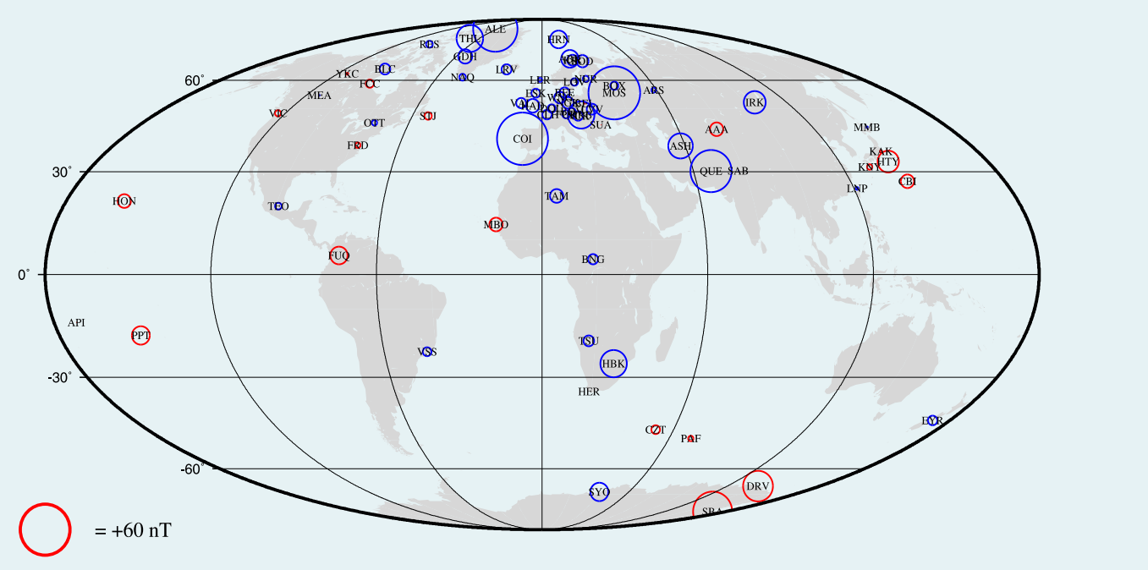
(NOTE: 'Missing' data in this Figure are off-scale and not zero)



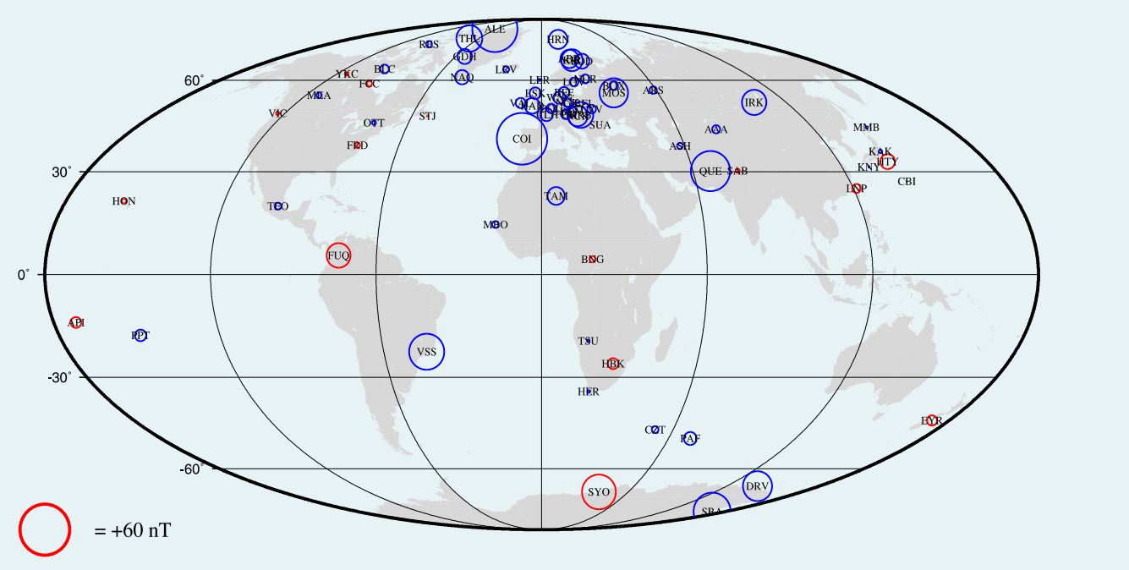
Changes in observatory X crustal biases in sense Oersted-based estimate at 1999.5 - Magsat-based estimate at 1980.0.



Changes in observatory Y crustal biases in sense Oersted-based estimate at 1999.5 - Magsat-based estimate at 1980.0



Changes in observatory Z crustal biases in sense Oersted-based estimate at 1999.5 - Magsat-based estimate at 1980.0



Changes in observatory F crustal biases in sense Oersted-based estimate at 1999.5 - Magsat-based estimate at 1980.0

Method:

By subtracting a main-field and external field model from observatory annual means we can estimate the crustal bias for each observatory and for each component of the field. Shown left are biases determined for 69 observatories for which we have means for 1979, 1980 and 1999 (more 1999 data will become available in the future). Any site discontinuities between 1980 and 1999 have been accounted for. Also shown are Magsat-derived biases computed from GSFC12/83 (see Langel *et al, JGR*, 1985). The Ørsted model used is a degree 13 internal and degree 1 external with *Dst* dependence of the external dipole and is based on one year of data at epoch 1999.5 (described in box on lower-left of poster). Shown above, for each component of the field, are the changes in crustal bias portrayed geographically.

Conclusions:

(1) The histogram (left) suggests little change in crustal biases in nearly 20 years. The differences are:
Mean (RMS) X, Y, Z, F = -6.2 (20.1) 2.9 (17.6) -7.4 (20.7) -10.3 (20.3) (N=69 common observatories)
(2) However the geographical distribution (above) as well as the magnitude of the r.m.s. differences between Magsat and Ørsted suggests that external fields may be significant. Alternatively, the differences may be real and reflect the induced magnetisation. Further study is suggested.

Secular Variation at 1980 and 2000 and the Significance of Ground Observations

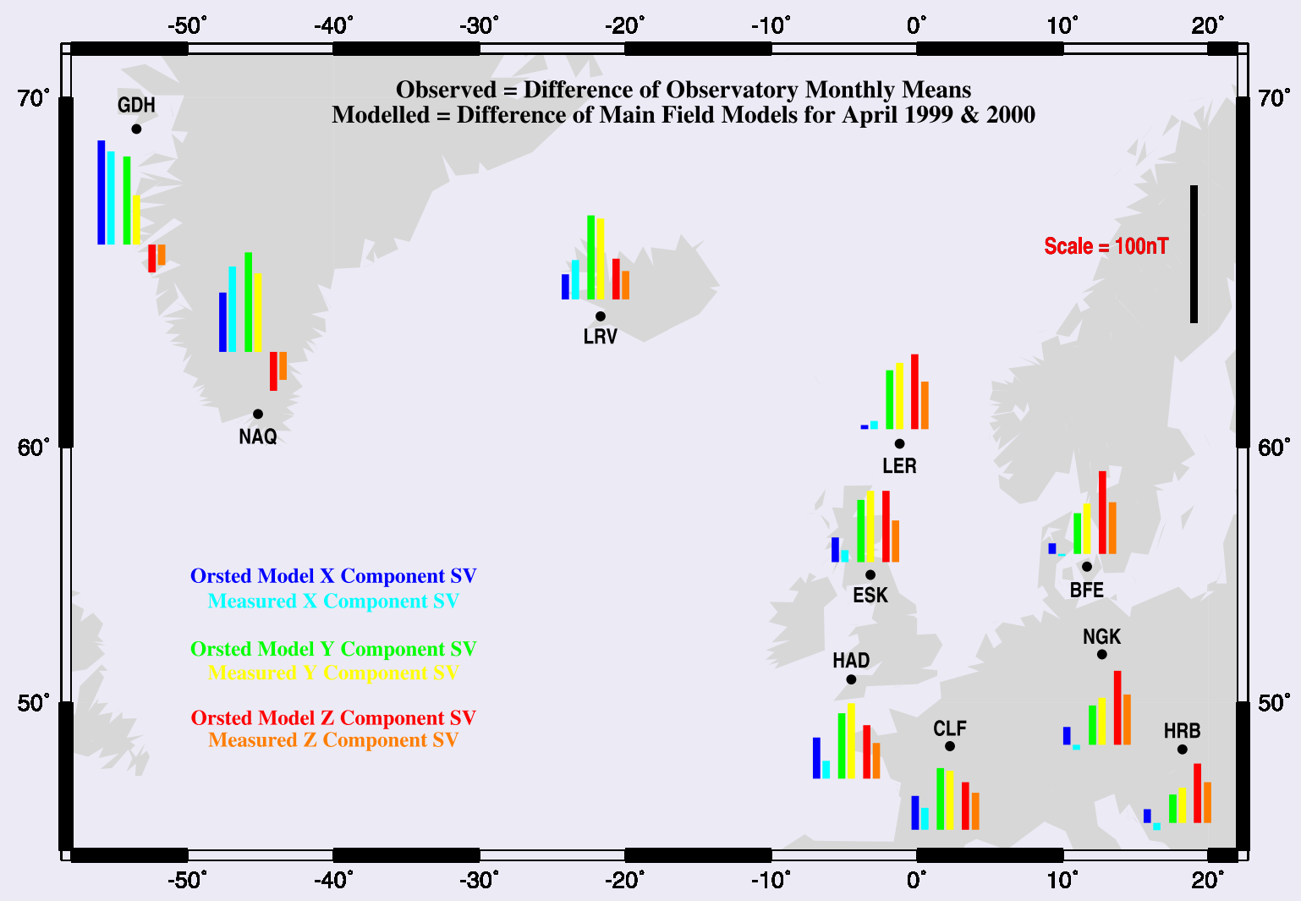
Method:

Below we show observed annual SV at 10 northern hemisphere observatories estimated by differencing monthly means for April 1999 and 2000. We also show a difference of Ørsted main-field models for the same periods. The Ørsted models are D&O=13 internal and D&O=2 external, with a *Dst* dependence of the external dipole. Only quiet-time night side data are used with, in particular, |*Dst*| < 30nT, *Kp*<2+, to produce an acceptable data distribution. The Ørsted models were derived from data from the three months centered on April of each year. On the right are comparisons of annual SV (truncated at D&O=8) at 2000.0 for thepurely Ørsted model (top), a combination model of Ørsted, POGS (1991-1993) and surface data (1997-2000) (centre) and also SV at 1980 from the Magsat model GSFC 12/83 (Langel *et al., JGR,* 1985) (bottom). The data distribution for the combination model is shown bottom left and is typical of BGS models of SV: we rely on satellite data to 'fill' the ocean areas.

Conclusions:

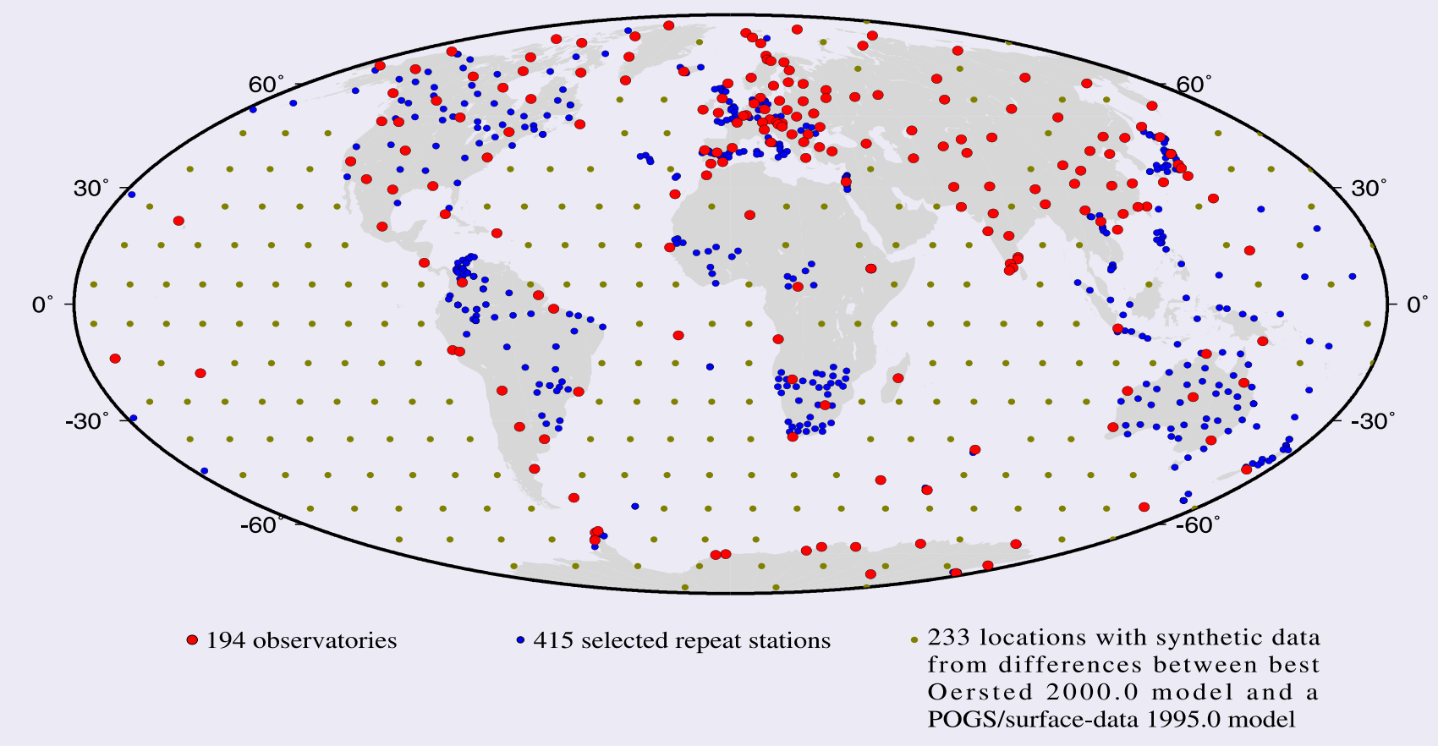
(1) Spot values of Ørsted models (e.g. below) are most accurate in the *Y* component and least accurate in *Z.* However observatory monthly (and annual) means include active field data whereas here we model with only quiet external fields.
(2) Ørsted SV models (e.g. right) demonstrate the same features as SV maps produced in more 'traditional' ways. However we feel that surface data remain essential in building SV models.
(3) Consistent features can be seen in the SV at 1980 and 2000. However a significant drift South-West of the SV focus in the Indian Ocean/South-East Asia can be clearly seen, as well as a developing feature in the central Pacific.

Observed and Modelled Annual SV (April 1999 - April 2000)

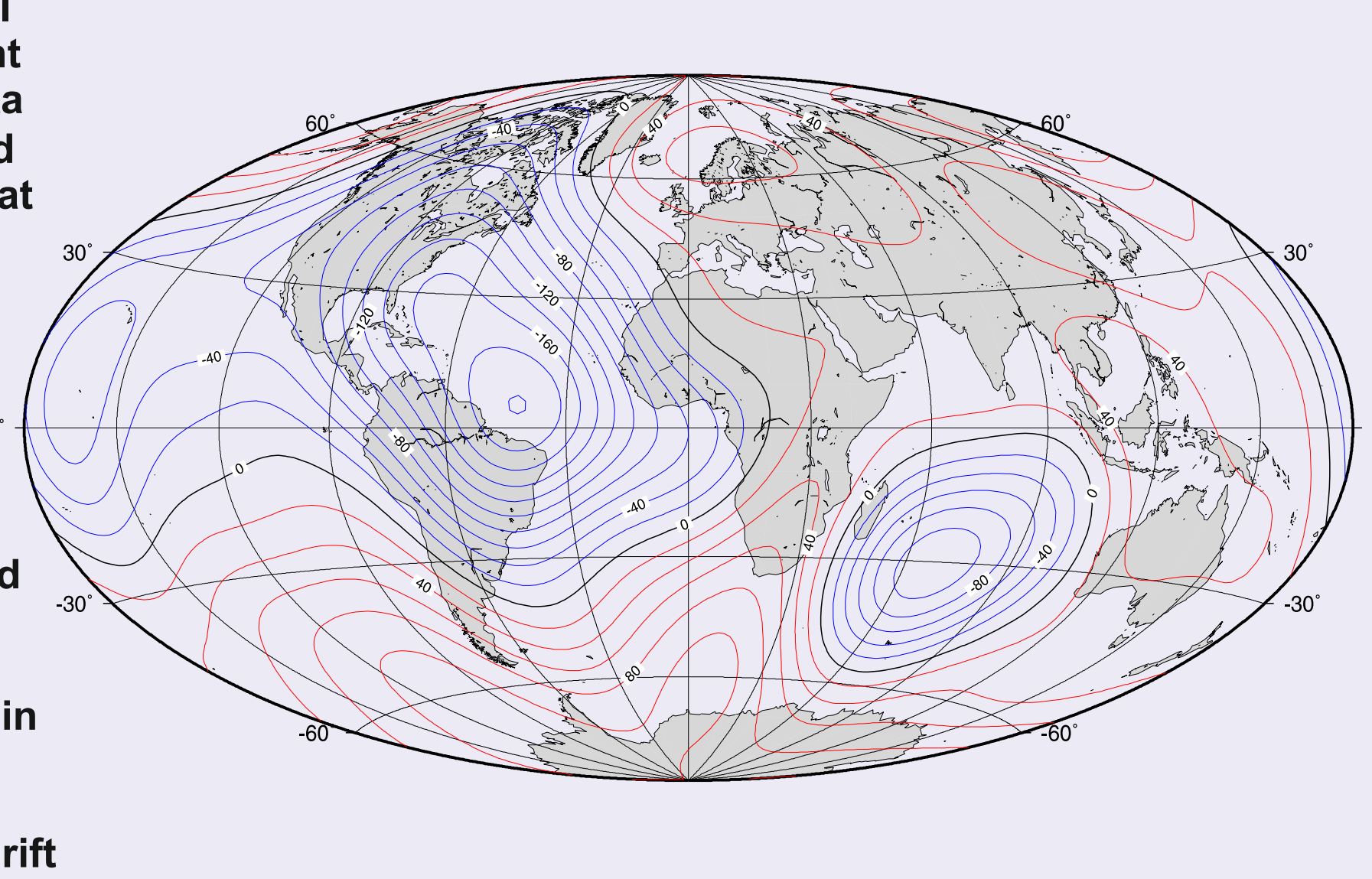


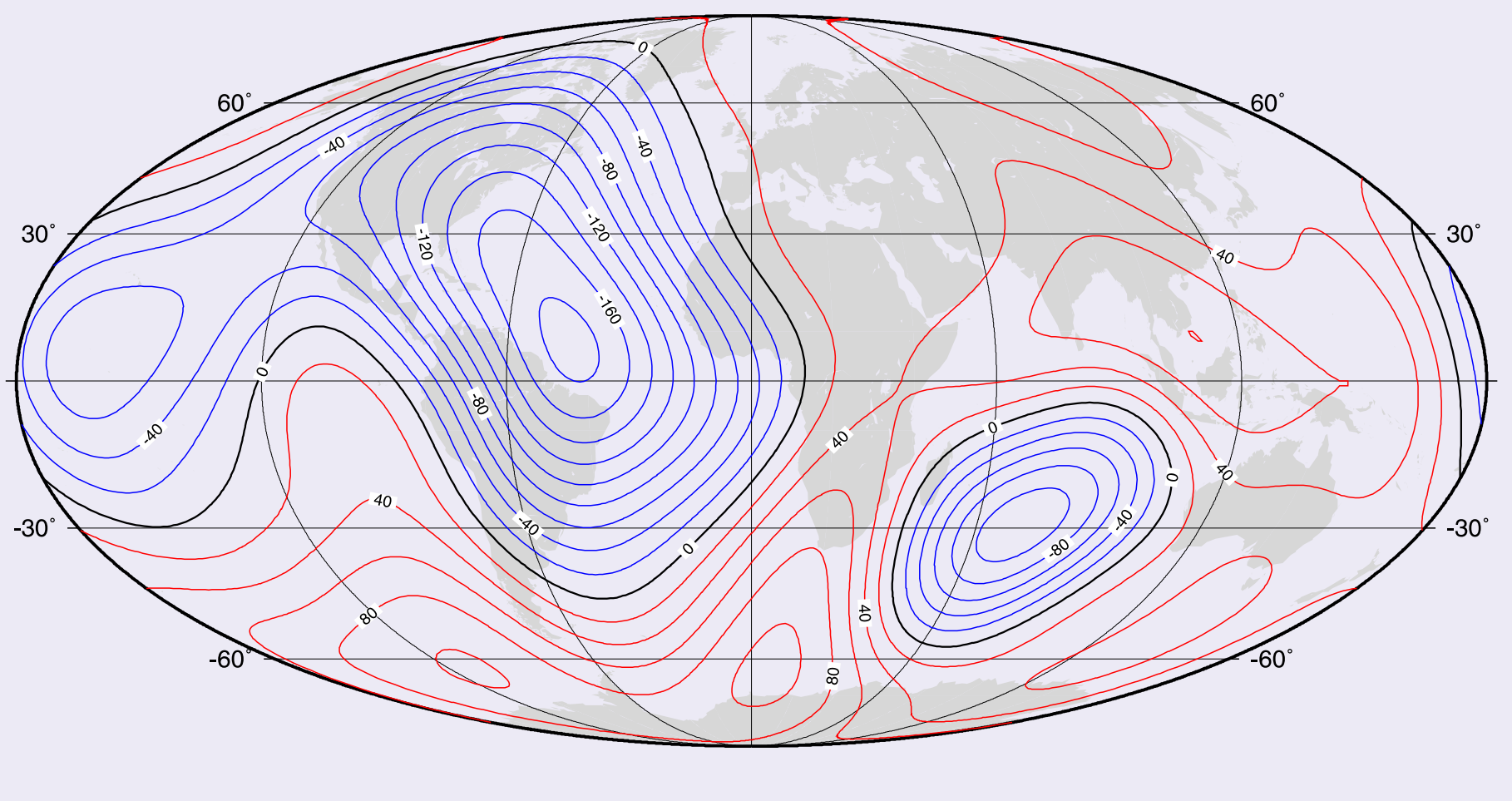
Mean (RMS) Model-Observed Differences:
X = 5.2 (12.6) nT Y = 1.0 (11.3) nT Z = 11.2 (15.1) nT

Locations of SV data for 2000.0 epoch

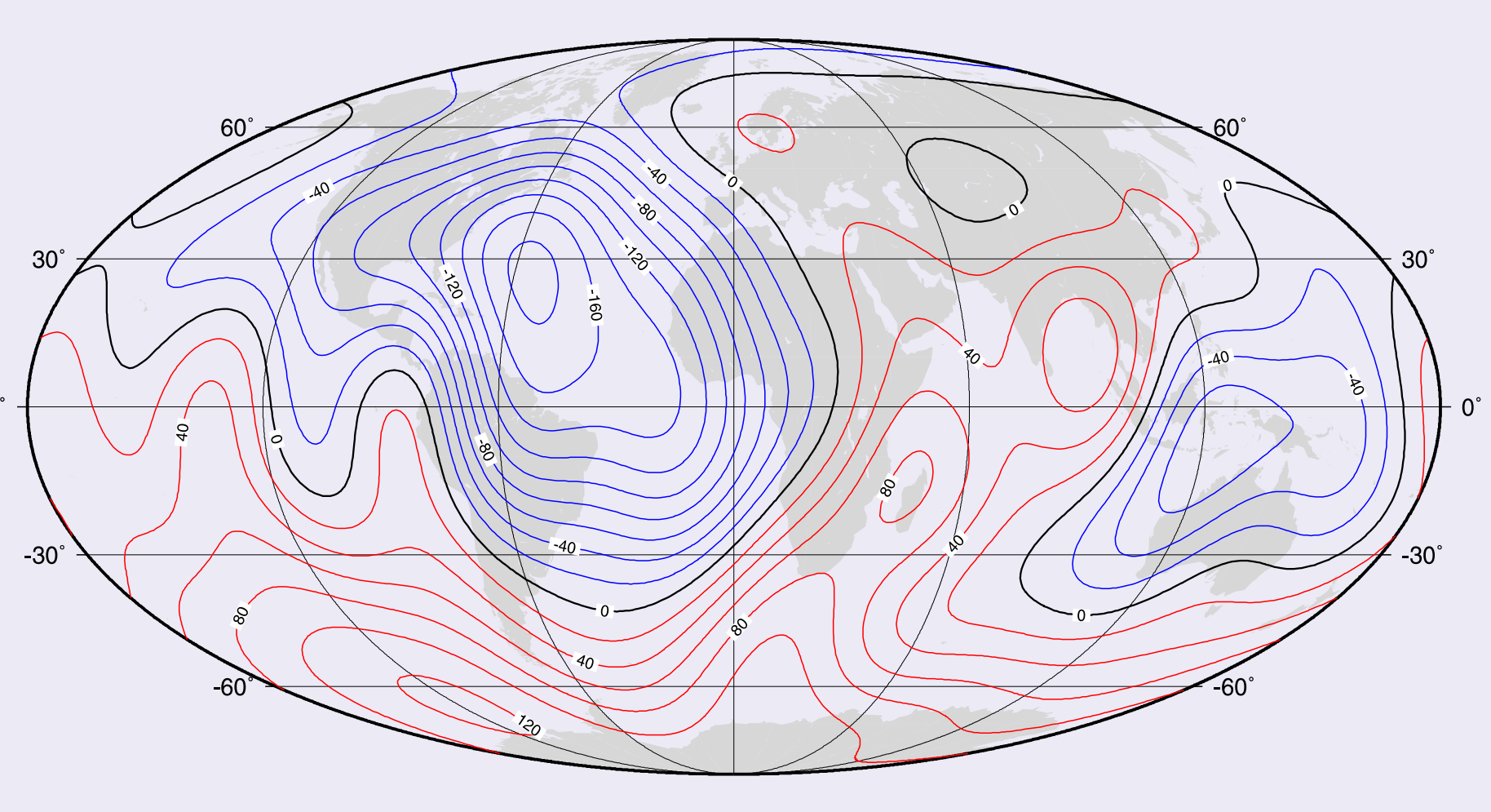


Ørsted SV in Z Component, April 1999-2000 (D&O 8; Units: nT/year, Geodetic Co-ordinates)





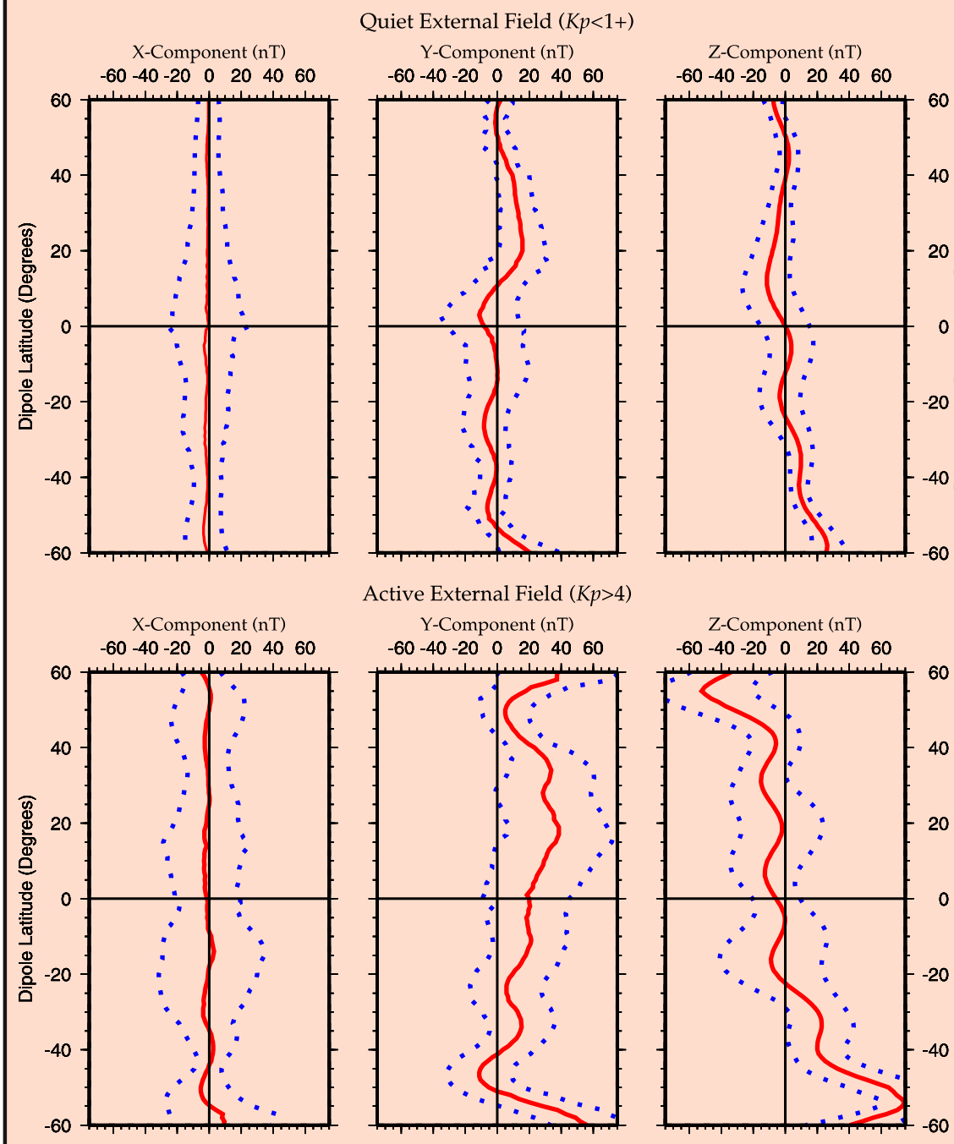
Secular variation in Z (nT/year) at 2000.0 from annual model derived by BGS in November 2000 incorporating data from observatories, repeat stations, POGS and Oersted satellites.



Secular variation in Z (nT/year) at 1980.0 from model derived by GSFC in December 1983 incorporating data from observatories and Magsat satellite.

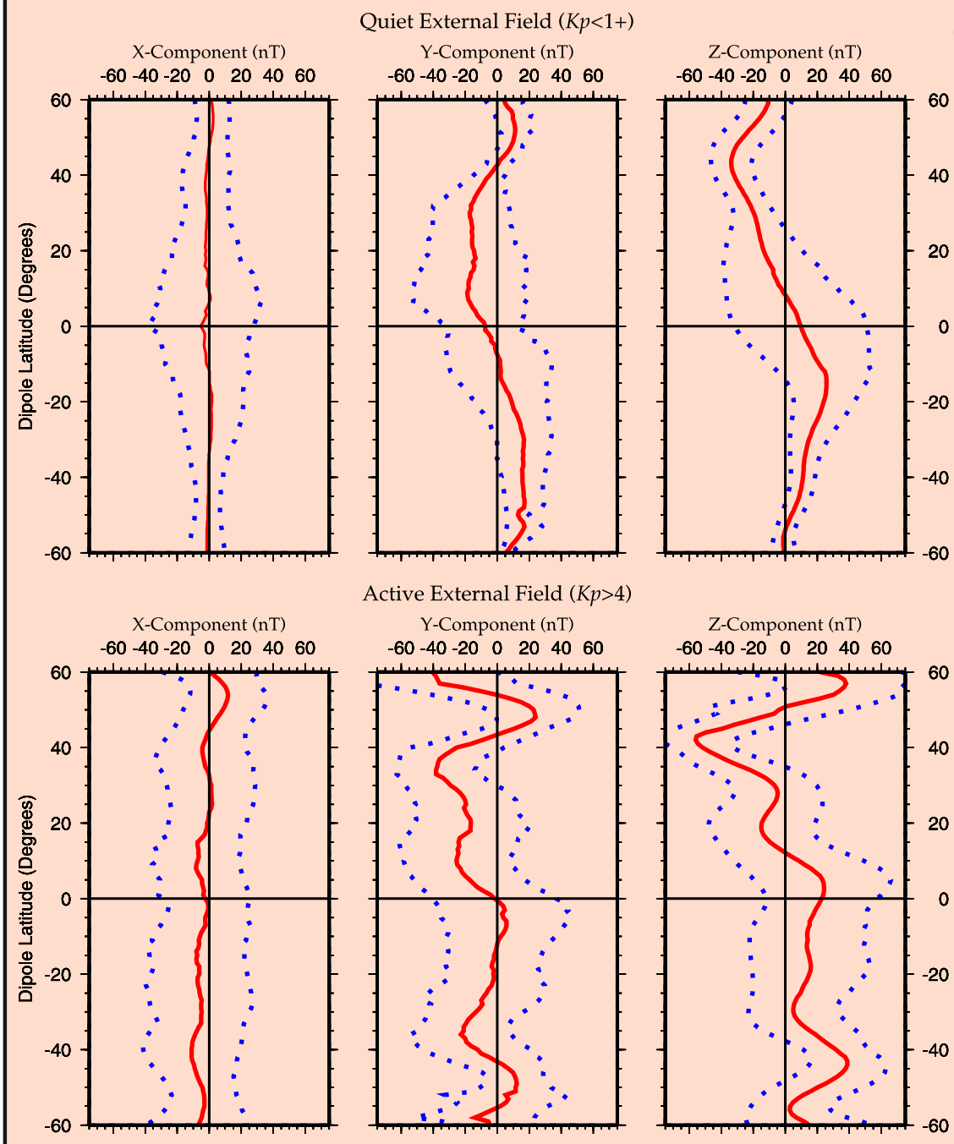
Mean Ionospheric Fields on the Dayside

Mean Ionospheric Fields: 0900 Local Time (±1.5 hours)



Northern Winter/Southern Summer (November 1999 - March 2000)
Mean ±1 Standard Deviation, Geomagnetic Dipole Co-ordinates

Mean Ionospheric Fields: 1200 Local Time (±1.5 hours)



Northern Summer/Southern Winter (May 1999 - August 1999)
Mean ±1 Standard Deviation, Geomagnetic Dipole Co-ordinates

Method:

Yanagisawa and Kono (*JGR*, 1985) describe the computation of 'mean ionospheric fields' for the dawn and dusk sectors, derived from Magsat data by subtracting a main-field model from selected Magsat passes followed by averaging. These fields are then used in 'cleaning-up' data for crustal modelling.
Here we have constructed mean fields for sectors of local time each three hours wide, centred on 0900 and 1200. We calculate spherical harmonic models of degree 13 internal and degree 1 external for each dayside LT interval. We then subtract similarly constructed models from corresponding satellite passes on the nightside. By averaging over all longitudes at each latitude we derive the maps shown on the left (dotted lines indicate one standard deviation). If we have adequately determined the internal, long-wavelength crustal and the magnetospheric sources by the spherical harmonic procedure we should be left with purely ionospheric fields. The maps show the field perturbation at the Earth's surface. As will be seen we have calculated mean fields for quiet and active (*Kp*) external field conditions.

Conclusions:

(1)The maps are clearly not identical at different activity levels. This may be due to the 'activation' of the ionosphere by magnetospheric currents or may be a result of poor characterisation of external fields.
(2) Each map at low *Kp* is probably an average of the *Sq* field - there is no clear evidence of an equatorial electrojet.
(4) Each LT sector occurs at different seasons, e.g. 1200 LT at the equator occurred around Northern Summer 1999. This may account for the 'displacement' North of the centre of the *Sq* system.
(5) Recently collected data will allow comparisons with the Yanagisawa & Kono dawn/dusk models.

Acknowledgements
Provision of magnetic data by the Ørsted Science Team and by worldwide observatories and institutes is greatly appreciated.