GOCE External Calibration

Calibration of GOCE gradiometer data in the MBW using ground data

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Abbreviations and Acronyms

AD	Applicable Document
ADD	Architectural Design Document
ADIR	Architectural Design and Interface Review
ADP	Auxiliary Data Provider
AIT	Acceptance, Integration, Test
ANX	Ascending Equator Crossing Node
AO	Announcement of Opportunity
AR	Acceptance Review
AS	Anti-Spoofing
ATP	Authorisation To Proceed
ATR	Algorithm Test Review
CAB	Change Appeal Board
CBCP	Current Baseline Cost Plan
CCN	Contract Change Notice
CDAF	Command and Data Acquisition Facility
CDP	Configuration and Documentation management Plan
CDR	Critical Design Review
CFI	Customer Furnished Item
CHAMP	CHAllenging Minisatellite Payload for geophysical research and application
CMF	Calibration and Monitoring Facility
CNL	Contract change Notices status List
COP	Commissioning Operations Phase
COS	Consortium Organisation Structure
CPF	Central Processing Facility
CPR	Cycle Per Revolution
CPS	Company Project Structure
CR	Change Request
CRB	Change Review Board
DCN	Document Change Notice
DDP	Design and Development Plan
DFACS	Drag-Free and Attitude Control System
DPA	Data Processing Archive
DPM	Detailed Processing Model
DSAT	Development Site Acceptance Test
DTL	Documentation Tree and status List
E2E	End-to-End Simulator
ECMWF	European Centre for Medium-range Weather Forecast
ECP	External Calibration Products
ECSS	European Cooperation for Space Standardization
EFRF	Earth Fixed Reference Frame
EGG	Electrostatic Gravity Gradiometer
EGG-C	European GOCE Gravity Consortium
EM	Engineering Model
EME2000	Equinox and Mean Equator of J2000.0
EO	Earth Observation
EOEP	Earth Observation Envelope Programme
EPAR	Extended mission Product Acceptance Review
ESA	European Space Agency
FM	Flight Model
FOCC	Flight Operations Control Centre
FOS	Flight Operations Segment
GLONASS	GLObal NAvigation Satellite System
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GRF	Gradiometer Reference Frame
GS	Ground Segment
GSOV	Ground Segment Overall Validation
GSRR	Ground Segment Readiness Review
HK	House-Keeping
HOP	Hibernation Operations Phase
HPF	High level Processing Facility
HW	Hardware
ICD	Interface Control Document
IGS	International GPS Service
ILRS	International Laser Ranging Service
IPF1	Instrument Processing Facility level 1
ISP	Instrument Source Packet
ITT	Invitation To Tender
L	Level, L-band frequency
LAN	Local Area Network
LEOP	Launch and Early Orbit Phase
LORF	Local Orbital Reference Frame
LRR	Laser Retro-Reflector
LTA	Long-Term Archive
MBW	Measurement BandWidth
MOP	Measurement Operational Phase
MPS	Mission Planning System
NA	Not Applicable
NRT	Near-Real Time
OBCP	On-Board Control Procedures
OBT	On-Board Time

ORR	Operational Readiness Review
OSAT	On-Site Acceptance Test
PAR	Product Acceptance Review
PCD	Product Confidence Data
PDD	Product Definition Document
PDS	Payload Data Segment
PF	Processing Facility
PI	Principal Investigator
POD	Precise Orbit Determination
PSD	Packet Structure Definition; Power Spectral Density
QL	Quick-Look
QLP	Quick-Look Products
RD	Reference Document
RERF	Radial Earth-pointing Reference Frame
RFQ	Request For Quotation
RMS	Root-Mean Square
RPF	Reference Planning Facility
RSS	Root-Sum Square
S/C	Space-Craft
SCP	Secure Copy (remote file copy program)
SDE	Software Development Environment
SFTP	Secure File Transfer Program
SGG	Satellite Gravity Gradiometer
SLR	Satellite Laser Ranging
SMF	Software Maintenance Facility
SOW	Statement Of Work
SPC	Satellite Prime Contractor
SPF	Sub-Processing Facility
SPR	Software Problem Report
SPRL	Software PRoblems status List
SRD	System Requirements Document
SRR	System Requirements Review
SST	Satellite-to-Satellite Tracking
SSTI	Satellite-to-Satellite Tracking Instrument
SSTR	Sub-System Test Review
STP	Software Test Plan
SVT	System Validation Test
SW	SoftWare
SWRD	SoftWare Requirements Document
TBC	To Be Confirmed
TBD	To Be Defined
TC	TeleCommand
TM	TeleMetry
TP	Test Plan
TR	Test Report
USF	User Services Facility
UTC	Universal Time Coordinated
V0/1/2	Version 0/1/2
VC	Virtual Channel
WAN	Wide Area Network
WBS	Work Breakdown Structure
WP	Work Package
XML	eXtensible Markup Language

Table of Contents

Abstract

The GOCE gravity gradients are contaminated by coloured noise outside the measurement band-width (MBW). This noise is within HPF WP3000 removed and the data inside the MBW are calibrated using global gravity field models. The successful calibration is verified by comparing the calibrated values with values computed using ground gravity data. This is done in regions with high quality and smoothly varying gravity anomalies. The computation of the gravity gradients along the GOCE orbit is performed using Least-Squares Collocation (LSC).

1. INTRODUCTION

1.1 PURPOSE

The GOCE satellite will produce gravity gradient data which are contaminated by coloured noise. If the noise is stationary and the noise-variance has a magnitude which is less than the signal variance for anomalous quantities, then Least-Squares Collocation (LSC) may be used for the calibration of the gradiometer, i.e. determination of bias, drift and scale-factor parameters as described e.g. in [RD-1].

The results will especially be good if an area with a smooth gravity field is used. Four such areas were used, Canadian Plains (ca), Central Scandinavia (sk), Australia (au) and central Norway (no).

However in these cases the noise variance may dominate the signal, and it is problematic to use LSC. The noise in the MWB is however expected to be small, in the order of 10 mE for 4 of the 6 gradients. SRON (see Table 1-1), which is responsible for the calibration, has therefore developed a calibration procedure using the data in the MBW.

In this report we will demonstrate how we are able to use ground data in the form of gravity anomalies for the verification of the global calibration. Initially we will use global calibration for the verification and subsequently focus on the regional calibration. We have used data prepared for the HPF acceptance review 1 and 2.

1.2 APPLICABILITY

This document is part of the Deliverable Items List [AD-3] and classifies for review by the Agency. The document applies to the development phase and to the actual implementation and operational phases of the HPF.

1.3 DEFINITIONS

EGG-C is composed by 10 European institutions. Institutions and team members contributing to the HPF project are defined in Table 1-1.

Table 1-1: EGG-C Team Members in Alphabetical Order

Acronym	Institution	Function	Team Members
AIUB	Astronomical Institute, University of Bern, Switzerland	WP4000 Partner	G. Beutler U. Hugentobler
CNES	Centre National d'Etudes Spatiales, Groupe de Recherche de Géodésie Spatiale, Toulouse, France	WP5000 Manager	G. Balmino S. Bruinsma
FAE/A&S	Faculty of Aerospace Engineering, Astrodynamics & Satellite systems, Delft University of Technology, Delft, The Netherlands	WP 4000 Manager WP 3000 Partner WP 8000 Partner WP 6000 Consultant	P. Visser
GFZ	GeoForschungsZentrum Potsdam, Department 1 Geodesy and Remote Sensing, Potsdam, Germany	WP 5000 Partner	Ch. Reigber P. Schwintzer
IAPG	Institute of Astronomical and Physical Geodesy, Technical University Munich, Germany	Principal Investigator Management WP 3000 Partner WP 4000 Partner WP 6000 Partner WP 8000 Manager	R. Rummel Th. Gruber J. Flury
ITG	Institute of Theoretical Geodesy, University Bonn, Germany	WP 6000 Partner	W.D. Schuh
POLIMI	DIIAR – Sezione Rilevamento, Politecnico di Milano, Italy	WP 7000 Manager	F. Sanso F. Migliaccio
SRON	SRON National Institute for Space Research , Utrecht, The Netherlands	Management WP3000 Manager	R. Koop J. Bouman
TUG	Institute of Navigation and Satellite Geodesy, Graz University of Technology	WP 6000 Manager	H. Sünkel R. Pail G. Plank
UCPH	Department of Geophysics, University of Copenhagen, Denmark	WP 3000 Partner WP 7000 Partner	Ch. Tscherning

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1 APPLICABLE DOCUMENTS

[AD-1] GO-SW-ESA-GS-0079: GOCE High Level processing Facility, Statement of Work, Issue 1.0, 5. December 2003
[AD-2] GO-RS-ESA-GS-0080: GOCE High Level processing Facility, Statement of Work Appendix 1, Management Requirements, Issue 1.0, 5. December 2003
[AD-3] GO-LI-ESA-GS-0081: GOCE High Level Processing Facility, Statement of Work Appendix 2, Deliverable Items List, Issue 1.0, 5. December 2003
[AD-4] GO-RS-ESA-GS-0082: GOCE High Level Processing Facility, Statement of Work Appendix 3, Technical Requirements Specification, Issue 1.0, 5. December 2003
[AD-5] GO-LI-ESA-GS-0087: GOCE High Level Processing Facility, Statement of Work Appendix 4, List of CFI, Issue 1.0, 5. December 2003
[AD-6] GO-TN-ESA-GS-0085: GOCE High Level Processing Facility, Statement of Work Appendix 5, Tailoring of ECSS Standards, Issue 1.0, 5. December 2003
[AD-7] ECSS-E-40B: Space Engineering, Software Standards, Draft Issue, 28. July 2000
[AD-8] ECSS-Q-80B: Space Product Assurance, Software Product Assurance, Issue 3. April 2000
[AD-9] PE-TN-ESA-GS-0001: Earth Explorer Ground Segment File Format Standard
[AD-10] GO-ID-ACS-GS-0109: PDS Product Specification Document
[AD-11] GO-IC-AI-0009: End-to-End Simulator Post-Processing
[AD-12] GO-PL-HPF-GS-0055: HPF Test Plan and Procedures
[AD-13] GO-PL-HPF-GS-0054: CPF Sub System Acceptance Test Plan and Procedures
[AD-14] GO-PL-HPF-GS-0048: WP3000 Sub System Acceptance Test Plan and Procedures
[AD-15] GO-PL-HPF-GS-0050: WP4000 Sub System Acceptance Test Plan and Procedures
[AD-16] GO-PL-HPF-GS-0043: WP5000 Sub System Acceptance Test Plan and Procedures
[AD-17] GO-PL-HPF-GS-0051: WP6000 Sub System Acceptance Test Plan and Procedures
[AD-18] GO-PL-HPF-GS-0052: WP7000 Sub System Acceptance Test Plan and Procedures
[AD-19] GO-PL-HPF-GS-0053: WP8000 Sub System Acceptance Test Plan and Procedures

As a general rule it holds that the latest approved issue of the document is applicable, except if the issue number and the document date is specified.

2.2 REFERENCE DOCUMENTS

[RD-1] Tscherning, C.C., M.Veicherts and D.Arabelos: Calibration of GOCE gravity gradient data using smooth ground gravity. Proceedings GOCINA workshop, Cahiers du

Centre Europeen de Geodynamique et de Seismologie, Vol. 2, 5, pp. 63-67, Luxenbourg, 2006.

[RD-2] Arabelos, D. & C.C.Tscherning: Calibration of satellite gradiometer data aided by ground gravity data. Journal of Geodesy, Vol. 12, no. 11, pp. 617 - 625, 1998.

[RD-3] Arabelos, D. and C.C.Tscherning: External calibration of GOCE SGG data with terrestrial gravity data. GO-TN-HPF-GS-0070, GOCE HPF Report, 2006.

[RD-4] Bouman, J.: EGG_NOM_2. E-mail dated May 31, 2006.

[RD-5] ESA-SP-1233(1): Gravity Field and Steady-State Ocean Circulation Mission

[RD-6] GO-RS-ESA-SY-0001: GOCE Mission requirements Document

[RD-7] GO-SP-AI-0004: GPS Receiver Ground Processing Algorithms Specification

[RD-8] GO-SP-AI-0003: Gradiometer Ground Processing Algorithms Specification

[RD-9] GO-TN-AI-0067: Gradiometer Ground Processing Algorithms Documentation

[RD-10] GO-TN-AI-0068: Gradiometer Ground processing Analysis

[RD-11] GO-PL-AI-0039: Gradiometer Calibration Plan

[RD-12] GO-TN-AI-0069: Gradiometer On-Orbit Calibration Procedure Analysis

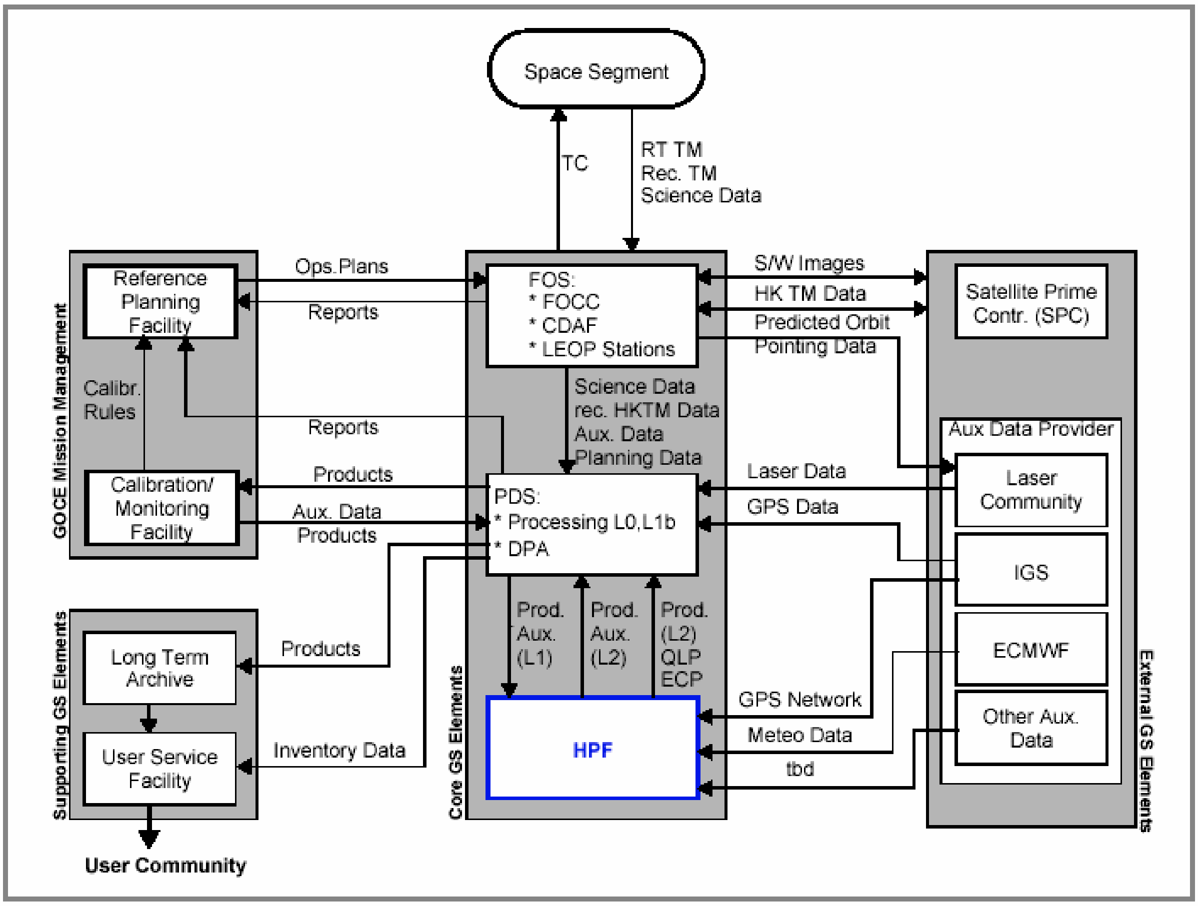
[RD-13] CS-MA-DMS-GS-0001: Earth Explorer Mission Conventions Document

3. GOCE GROUND SEGMENT

3.1 OVERVIEW GOCE GROUND SEGMENT

The GOCE ground segment concept and architecture is described in [RD-3]. The following gives a brief summary of all ground segment elements, depicted in Figure 3-1.

Figure 3-1: GOCE Ground System



3.2 HIGH-LEVEL PROCESSING FACILITY

Within the GOCE GS the HPF is one of the Core GS Elements (ESA-controlled), and it is charged with the generation of L2 products and acquisition of the external (auxiliary) data needed to generate these products, the delivery of these products (auxiliary, intermediate and final) to the PDS/DPA and/or the LTA and the generation of QLP and ECP for the purpose of the activities of the CMF.

4. FILTERING

The MBW is here defined as the gravity gradient values filtered time-wise using a filter which removes wavelengths corresponding to frequencies below 0.005 - 0.01 Hz and above 0.2 Hz. (Other boundaries may also be used). This corresponds to flight distances between 1600 km and 35 km. (Other filters could also have been used).

In the original proposed method for calibration using ground data (e.g. Arabelos and Tscherning, 1998 [RD-2]) gravity anomalies on the ground were used to compute bias, drift and scale-factor parameters for gravity gradients at the satellite position on the tracks crossing the areas where the ground data were located.

Now, ground data may be used to calculate LSC estimates of the gradients at the satellite tracks with a high precision in areas with a smooth gravity field (Arabelos and Tscherning, 2006 [RD-3]). For the areas used, the estimated error is below 5 mE (1 mE=10^{-12} s^{-2}). The areas used have an extend of maximally 12 degrees, corresponding to about 1300 km. Therefore it is difficult to apply a filter corresponding to the MBW on these predicted values.

Also a similar filter can not be applied on the randomly scattered gravity anomaly ground data.
However, a time series of control or reference data may be generated using a spherical harmonic model enhanced with improved values in the above mentioned four areas computed using ground data. This time series $\overline{V}_{ij}(P)$ as well as the HPF delivered time series $V_{ij}(P)$ can then be filtered, so for both time-series the part in the MBW and the part outside are computed.

$$V_{ij}(P) = V_{ij}^{o}(P) + V_{ij}^{mbw}(P), \text{ for HPF test data and}$$
$$\overline{V}_{ij}(P) = \overline{V}_{ij}^{o}(P) + \overline{V}_{ij}^{mbw}(P), \text{ for Model/reference data}$$

The subscript ij refer to the derivatives in the GRF (x: 1, y: 2, and z: 3).
Here we must realize, that the data are not periodic, and the simple filter used will not be correct close to the start and the end points. Consequently the colored noise will not be eliminated at the start and at the end of the time interval used for the Fourier analysis. (In order to deal with this situation various kinds of tampering may be used).

Instead of working with the "full" potential $\overline{V}_{ij}(P)$ and $V_{ij}(P)$ it is of advantage to work with anomalous quantities, $\overline{T}_{ij}(P)$ and $T_{ij}(P)$ in order to eliminate most of the frequencies which are related to the revolution of the satellite around the Earth. We have here subtracted values computed using the normal potential associated with GRS80.

The two functions in the MBW are compared, and a least-squares adjustment is used to estimate calibration parameters. Again, since influence of bias and drift as an effect of the filtering is removed, only a scale-factor is left to be estimated.

The program **http://cct.gfy.ku.dk/ftrans.f** has been used (for this purpose in mode=5). The discrete Fourier transformation (DFT) was used on anomalous quantities.

The Fourier coefficients were computed using

$$\begin{Bmatrix} a_k \\ b_k \end{Bmatrix}_{ij} = \frac{2}{M} \sum_{l=1}^{[M/2]} T_{ij}(l) \cdot \begin{Bmatrix} \cos(k \cdot (l-0.5) \cdot 2\pi / M) \\ \sin(k \cdot (l-0.5) \cdot 2\pi / M) \end{Bmatrix}, \quad k = 1, \ldots, [M/2]$$

The equivalent function in the MWB is then computed by summing the coefficients multiplied with cosine or sine, respectively, to an integer J, corresponding to a wave-number equivalent to the frequencies 0.005 or 0.01 Hz.

$$T_{ij}^{mwb}(k) = \sum_{l=M-J+1}^{M} (a_l \cdot \cos(l \cdot (k-0.5) \cdot 2\pi / M) + b_l \cdot \sin(l \cdot (k-0.5) \cdot 2\pi / M)).$$

The power-spectrum is computed by

$$\sigma_k^2 = a_k^2 + b_k^2$$

with the covariance function

$$\operatorname{cov}(t) = \sum_{k=1}^{K} o_k^2 \cos(k).$$

The frequencies above 0.2 Hz are here removed in two ways. One by simply only considering 5 s data and the other by using mean values over 5 s intervals.

5. ESTIMATION OF BIAS, DRIFT AND SCALE FACTORS

We have the observation equations:

$$T_{ij}^{mwb}(t) - \overline{T}_{ij}^{mwb}(t) = \mathrm{a} + \mathrm{b}(\mathrm{t} - \mathrm{t}_0)$$

for bias a and drift b, and t_0 start time,

and with s scale factor - 1,

$$(T_{ij}^{mwb}(t) - \overline{T}_{ij}^{mwb}(t)) = \mathrm{s} \cdot \overline{T}_{ij}^{mwb}(t)$$

A least-squares adjustment can then be made for the whole data-set or for segments of the tracks passing through a calibration area.

$$s_{ij} = \sum_{k=k_1}^{k_2} \nu^2 (T_{ij}^{mwb}(k) - \overline{T}_{ij}^{mwb}(k)) / \sum_{k=k_1}^{k_2} \overline{T}_{ij}^{mwb}(k), \quad o_s^2 = \sum_{k=k_1}^{k_2} \nu^2 / \sum_{k=k_1}^{k_2} \overline{T}_{ij}^{mwb}(k), \text{ where}$$

k_1 and k_2 are the interval end-point indices, ν the noise standard-deviation and σ_s^2 the error-estimate.

6. DATA USED

Three data-sets have been available. Two used during the AR1 test and one used during the AR2 test. The AR1 test data have been calibrated by SRON and are denoted New_Vij4 and New_Vij5. For the "New_Vij5" data-set, the data in the MWB (as defined by SRON) have been multiplied by 1.01. For these two data-sets the part outside the MWB has been replaced by the contribution calculated from EIGEN, see Appendix 1.

The AR2 data set is denoted POS_NOV.dat. Here the data in the MWB have been calibrated, and the file contains the sum of the calibrated values and the part outside the SRON defined MWB. For this data-set we should therefore expect to find a calibration scale very close to 1.

All the data-sets were thinned from 1 s data to 5 s data by picking out each fifth data point. These files are denoted pos_new_vij4_5.dat, pos_new_vij5_5.dat and POS_NOV_5.dat. From the AR2 dataset an additional data set was produced by taking the mean value of blocks of 5 data. This data set was denoted POS_NOV_FIL_5.dat.

The AR1 dataset consisted of 483840 values and the AR2 dataset of 1002240 values. Corresponding data-sets were produced using EGM96 to degree 360.

The data up to M = 482400 were used, corresponding to 450 revolutions. 0.01 Hz and 0.005 Hz then corresponds to J = 24120, and J = 12060.

7. GLOBAL RESULTS

In the results below we also list the correlation as well as the standard deviation of each quantity (σ) and of the difference. Results are for two data-sets. One, for all the data, and the other corresponding to the elimination of 25000 values at the beginning and at the end of the data-set. Mean values are not shown, since they in all cases are zero, due to the filtering of all long-wavelengths.

7.1 AR1 RESULTS

A reference data-set /home/cct/param/ar1/pos_ggt_true_ano.dat, $\overline{V}_{ij}$, was computed using http://cct.gfy.ku.dk/geocol17.f, using EGM96 to deg. 360 and the rotation matrix in the file /home/mave/ar2/param/GRF2ENZ_iag_a.dat. The job-file is egm96_360_all.job. The corresponding normal potential values was also produced (file pos_ggt_true_abs.dat, abs_vij4.job was used) and subtracted from the full values using the program http://cct.gfy.ku.dk/fc2.f, to produce the file pos_ggt_true_ano.dat. This is the data-set denoted $\overline{T}_{ij}$. The same normal potential values were also subtracted from the "observations" , file /home/mave/param/out/pos_new_vij4_5.dat to produce T_{ij} , resulting file named vij4_abs.dat.

	All data	Subset	All data	Subset	All data	Subset
ij	11	11	22	22	33	33
Correlation	0.973	0.873	0.440	0.442	0.904	0.905
Scalefactor	1.00428	1.00399	1.01641	1.0171	1.00113	1.00088
σ diff.	0.025	0.025	0.025	0.025	0.025	0.025
σ obs	0.051	0.051	0.028	0.028	0.058	0.058
σ ref	0.044	0.044	0.012	0.012	0.052	0.052

Table 7-1 Results for dataset /home/mave/param/out/pos_new_vij4_5.dat.

The filtered data-set is based on a file where the values of the normal potential has been subtracted as described above. The filtered data T^{o}_{ij} and T^{mbw}_{ij} are stored together in files named /home/cct/param/ar1/pos_vIJabs_filt.dat, where IJ=1,1, 2,2, 3,3 etc. The corresponding filtered reference data values are stored in pos_vIJano_filt.dat.
Note in the table that the standard deviation of "obs", for I,J=2,2, T^{mwb}_{22} is much larger than the standard deviation of the reference data, $\overline{T}^{mwb}_{22}$. The correlation between the two data-set is also considerable smaller than for the data related to the two other diagonal terms.

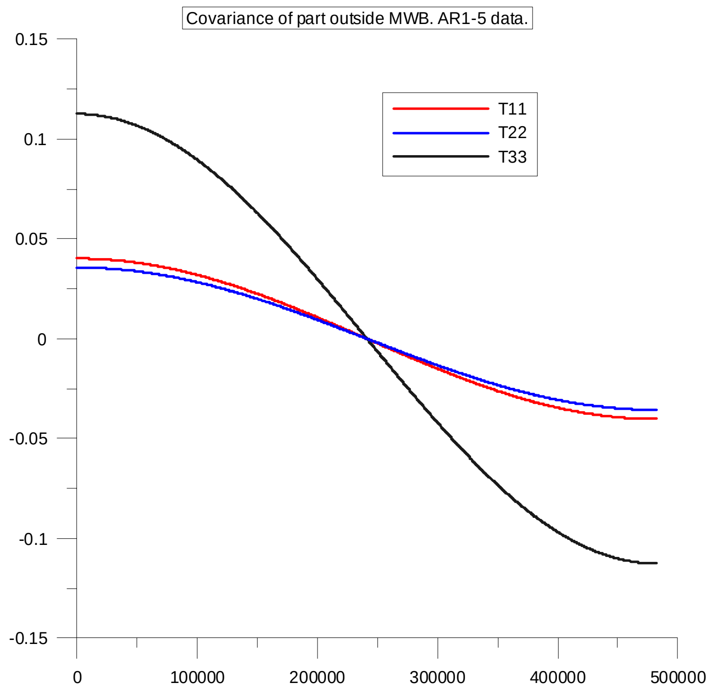


Figure 7-1 Covariance functions of the diagonal components for the part outside the MBW. Note the small variances. Units E^2.

The program http://cct.gfy.ku.dk/**scale.f** was then used with the data in the MBW to produce the values in the table. Results are given for 482410 5 s values and for a subset where 25000 have been cut off at the start and the beginning.

The same procedure was used on data-set received from SRON, where the values in the MBW deliberately have been multiplied by 1.01.

	All data	Subset	All data	Subset	All data	Subset
ij	11	11	22	22	33	33
Correlation	0.873	0.873	0.440	0.442	0.905	0.904
Scalefactor	1.0143	1.0140	1.0267	1.0274	1.0109	1.0111
σ diff.	0.025	0.025	0.025	0.025	0.025	0.025
σ obs	0.051	0.051	0.028	0.028	0.058	0.058
σ ref	0.044	0.044	0.012	0.012	0.052	0.052

Table 7-2 dataset /home/mave/param/out/pos_new_vij5_5.dat.

The result in Table Table 7-2 are for filtered data-sets denoted /home/cct/param/ar1/pos_vIJ5abs_filt.dat. Here the table shows that we have been able to recover the 1.01 factor for components (1,1) and (3,3). There is something wrong with the (2,2) components as also indicated by the low correlation of 0.44 compared to 0.87 and 0.90 for the components (1,1) and (3,3).

7.2 AR2 RESULTS

The same procedure as used for the AR1 data was used for the AR2 data. The original data-set, /data/mave/data/ar2/POS_NOV_5.DAT is the data denoted V_{ij} . From this was subtracted normal potential values, file POS_NOV_true_abs.dat, in order to obtain T_{ij} , file POS_NOV_abs.dat . This was also done for the data set made from mean values.
The filtered data are stored in files named pos_vIJabs_filt.dat (T_{ij}^{o} and T_{ij}^{mbw}) and pos_vIJano_filt.dat ($\overline{T}_{ij}^{o}$ and $\overline{T}_{ij}^{mbw}$) .
The filtered data were then used to compute the values in Table 7-3 using the program scale.f. Both the full data-set and data-sets from which head and tail of the file have been cut off were used.

The standard-deviation of the estimated scale factors are in general below 0.001. So, if we only regard the “inner” part of the data, we see that the scale factor is not significantly different from 1.0.

	wavenumber/ cut-off freq.	Grad	482400 data points (450 rev)		Subset1 2x12500		Subset2 2x25000	
			Scale factor	Corre-lation	Scale factor	Corre-lation	Scale factor	Corre-lation
POS_NOV_A BS_FIL_5.dat	12060/0.005Hz	11	1.02291	0.227	0.99997	0.998	0.99997	0.999
		22	1.50835	0.022	1.00062	0.737	1.00089	0.831
		33	0.92890	0.086	1.00023	0.990	1.00022	0.995
	24120/0.01Hz	11	1.02200	0.182	0.99995	0.998	0.99979	0.999
		22	1.55110	0.011	0.99637	0.591	1.00484	0.710
		33	0.93537	0.062	1.00015	0.990	1.00034	0.994
POS_NOV_A BS_5.dat	12060/0.005Hz	11	1.02137	0.228	1.00000	0.996	1.00006	0.997
		22	1.4644	0.021	1.0004	0.734	1.00005	0.826
		33	0.93430	0.183	1.00038	0.989	1.00038	0.993
	24120/0.01Hz	11	1.01575	0.182	0.99981	0.991	0.99972	0.992
		22	1.44062	0.010	0.99573	0.577	1.00346	0.684
		33	0.95209	0.064	1.00019	0.985	1.00021	0.990

Table 7-3 SF results from POS_NOV_abs.dat and POS_NOV_abs_fil.dat.

It is obvious that the gradients - especially the yy component - are better correlated to the model values and closer to 1 when using the wider MBW, and also removal of the errorneous data using only a subset of the avaliable data gives a clear improvement of the SF. However it seems that taking mean values of the gradients before applying the filter does not add significant value to the results.

The problems with the non periodicity of the gradient functions are shown in Figure 7-2.

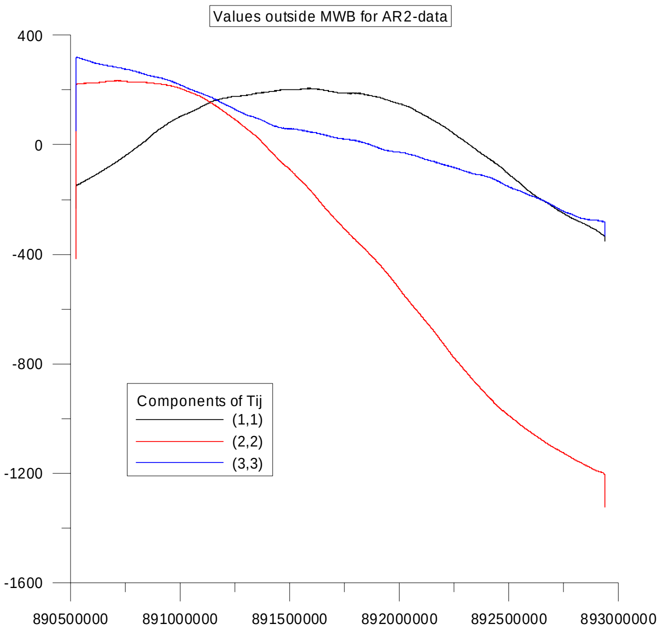


Figure 7-2 Part of data outside MBW (T_{ij}^{o}) with (i,j)=(1,1), (2,2) and (3,3). Note the non-stationary behavior of the functions and the spikes at the end-points. Units E.

Ongoing work is being done to investigate the influence of cosine tapering, linearisation and extraction of a spline model to improve the filtering technique and results.

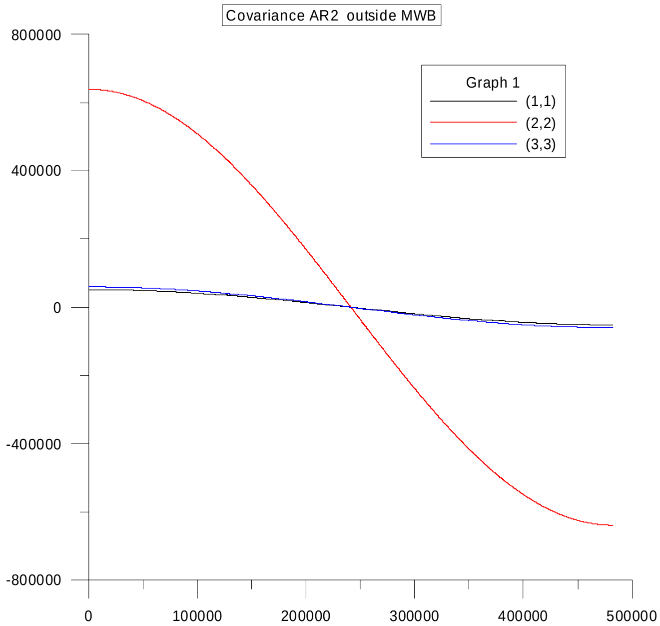


Figure 7-3 Covariance of diagonal components (T_{ij}^{o}) outside MWB. Units E.

From the covariance function of the diagonal components Figure 7-3 note the large variances, despite the fact that the normal potential contribution has been subtracted. Also the (2,2) component has a much larger variance than the two other components.

8. REGIONAL RESULTS

Scale parameters have been determined for each track-segment passing the calibration areas using the program scale.f, but now with an internal parameter "larea" set true, so that only data within given boundaries would be used in the scale-factor estimation. The local gravity data were set equal to the EGM96 values, but were not used, since they would not have changed the reference values. Consequently the noise in the MWB was set equal to 10 mE for all points on all tracks. The regions used are confined geographically as described in Table 8-1.

Region	Latitude		Longitude	
	S	N	E	W
Australia	-33.0°	-23.0°	124.0°	136.0°
Canada	56.0°	66.0°	-122.0°	-112.0°
Scandinavia	54.0°	64.0°	18.0°	30.0°
Norway	57.0°	67.0°	0.0°	18.0°

Table 8-1 Geographical boundaries of regions, unit degrees.

8.1 AR1 RESULTS

The results are found in Appendix 2 for tracks with more than 9 points. Here we show the results for the (1,1) component for all tracks. The figures based on the New_Vij4 data-set.

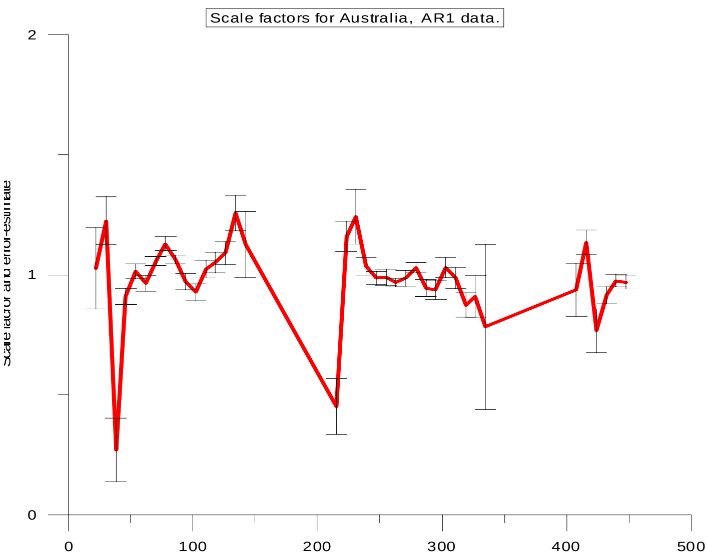


Figure 8-1 Australian region, Vxx.

The regional results are stored in /home/cct/ar1/scaleIJ_area.dat, with IJ the components and area sk, no, au or ca as mentioned above.

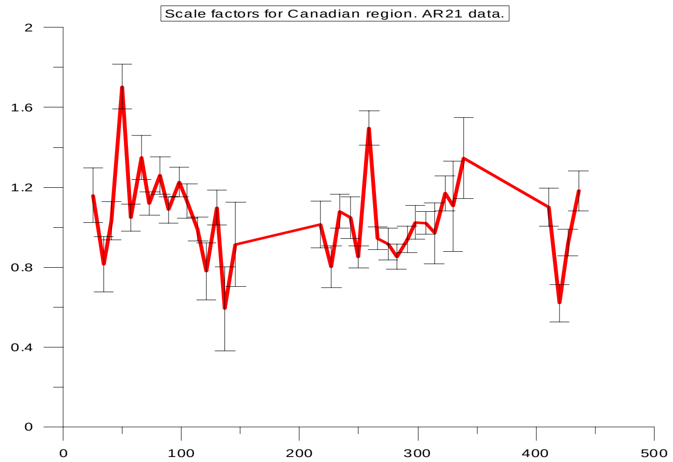


Figure 8-2 Canadian region, Vxx.

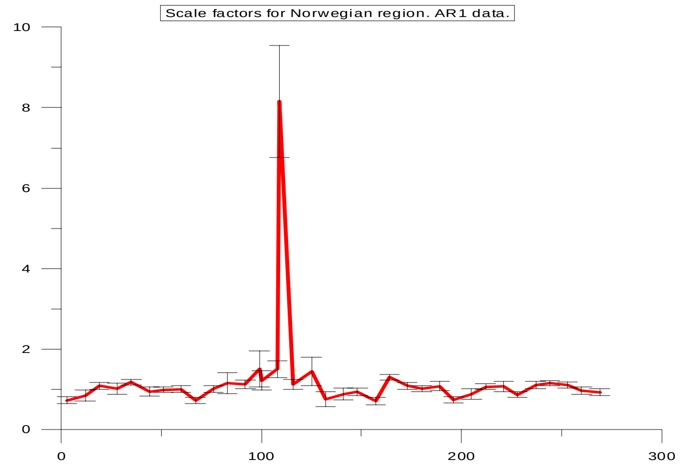


Figure 8-3 Central Norwegian region, Vxx.

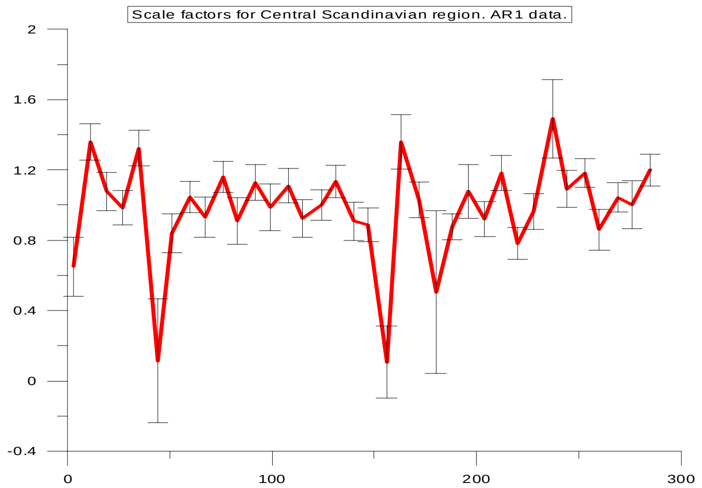


Figure 8-4 Central Scandinavia.

8.2 AR2 RESULTS

The results are found in Appendix 2 for tracks with more than 9 points. Here we only show results for the (1,1) component for the different regions as Figures 8 – 11.

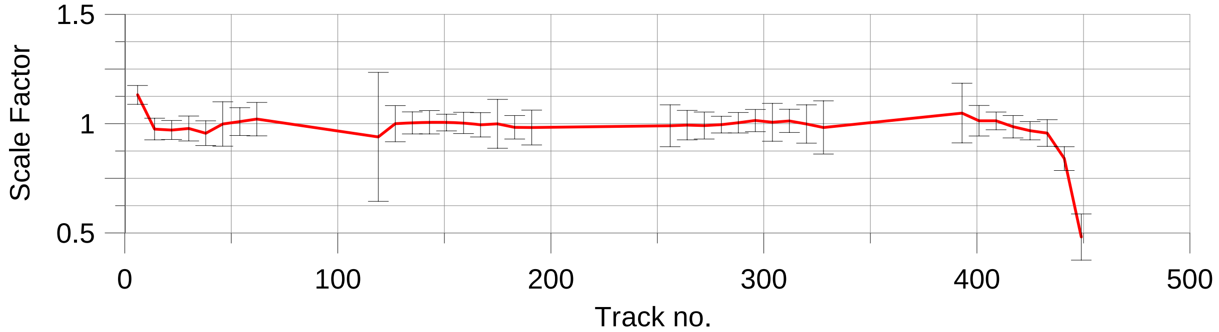


Figure 8-5 Australian region, Vxx

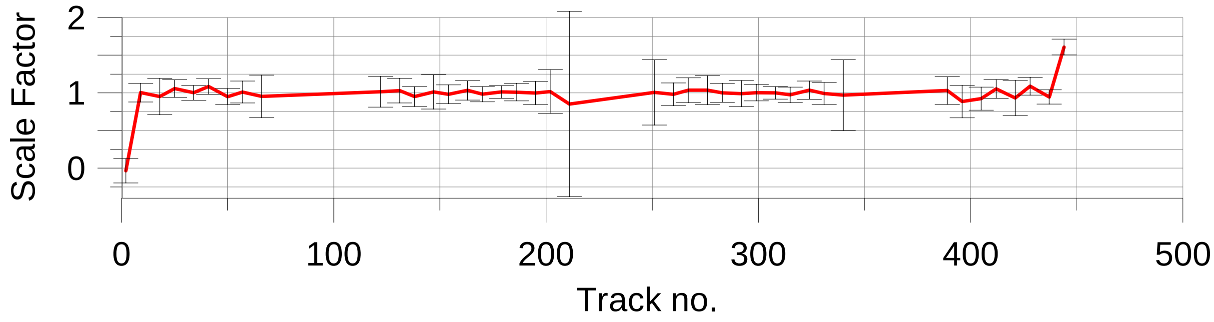


Figure 8-6 Canadian region, Vxx

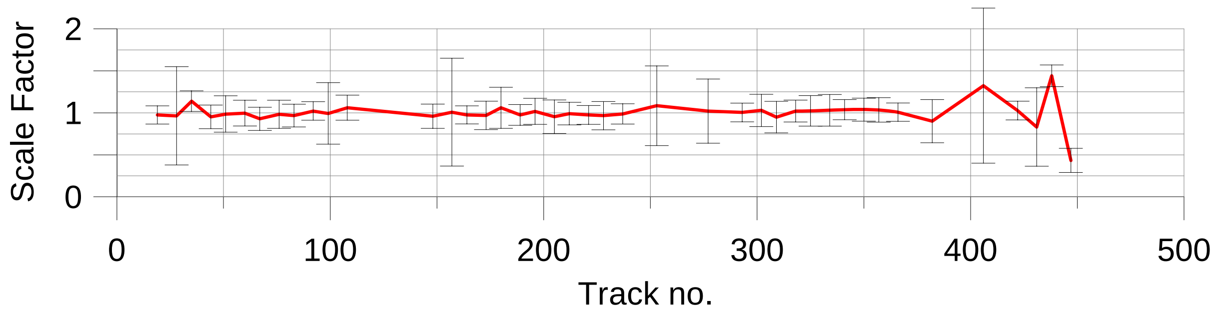


Figure 8-7 Central Scandinavian Region, Vxx

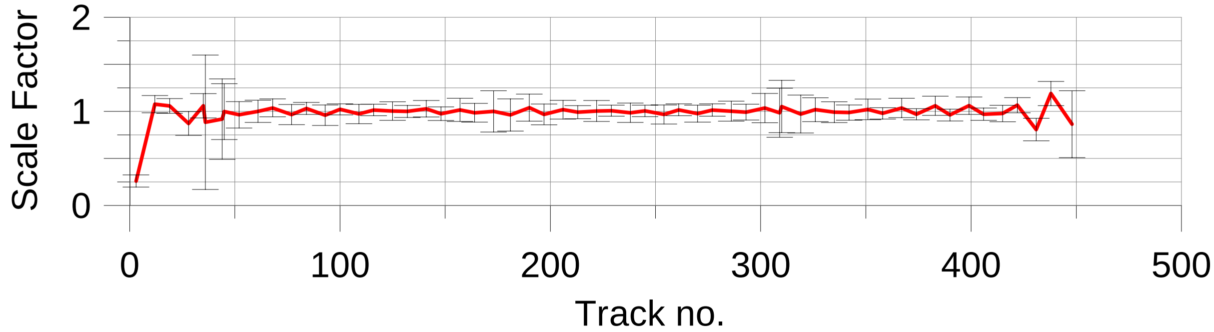


Figure 8-8 Central Norwegian Region, Vxx

The tracks with a large noise are (as expected) found at the beginning and the end of the time period used and for tracks with only 1 or 2 data-points. Depending on the area there are for "good" tracks between 10 and 20 points.

The regional results are stored in /home/cct/ar2/scaleIJ_area.dat, with ij the components and area sk, no, au or ca as mentioned above.

9. CONTROL USING LAPLACE EQUATION

We can use the Laplace equation for a control of the scale-factor estimation, in the sense that after the application of the scale factor, the Laplace equation should be better fulfilled than before. This was, however not the case, probably because of the problems with the (2,2) component.

It should here be mentioned that the reference data in the MWB fulfilled the Laplace equation at the 1 mE level.

No. of data 482400			Std. dev.			
			All data		Subset 2*12500	
	Data	MBW [Hz]	SF = 1	SFs = est.	SF = 1	SF = est.
Mean	EGM96	0.005	0.00022			
	EGG_NOV		4.52345	3.62825	0.05932	0.05929
		0.01	3.18867	2.51393	0.02987	0.02994
5 sec	EGM96	0.005	0.00050			
	EGG_NOV		4.52345	3.67906	0.06017	0.06015
		0.01	3.18870	2.60070	0.03148	0.03156

Figure 9-1 Laplace equation results. Only standard deviations are shown. All mean values = 0.0000. With SF = est(imated), it means that scale factors from above tables are used.

We see again a large improvement when using subsets of the data, while the pre-filtering gives only a marginal, - however constant - improvement. In general there is a quite large deviation of the trace sum from zero as seen from the standard deviation.

10. CONCLUSION

The procedure with the use of the data in the MWB has been successfully used despite the obvious non-stationarity of the long-periodic “noise”.

The global results are good for the (1,1) and (3,3) components for both AR-1 and AR-2 data, if we consider a sub-interval.

The tests with ground data also give good results, considering the noise and number of data on each track. No scale-factors (including those which are expected to be 1.01) are significantly different from 1 at the 3-σ level when we use the value of 10 mE for the data noise.

The selection of the proper time-interval and wave-number interval which defines the MBW requires more investigation, however. For this purpose, the fulfillment of the Laplace-equation could be used.

The 'weakest' component seems to be the (2,2) = (yy) component, and this component is also benefitting the most of using an extended MBW.

The MWB method can be used operationally, if data are received as a time-series without gaps.

The LSC method used in earlier investigations will work even if data has gaps, and the method (LSC with parameters) may possibly also be used to remove the part outside the MBW. The observation equation to be used is the one found in Section 2, relating the Fourier coefficients and the observations.

Acknowledgement. Thanks to Johannes Bouman for providing the test data and for valuable advice.

Appendix 1 : E-mail from Johannes Bouman, dated Apr. 26, 2006.

```
I've prepared two sets of calibrated and filtered gradients. Here is what
I've done:
1) I've calibrated EGG_GGT_2C using EIGEN model gradients. I used
calibration windows of 1 week and estimated a GG scale factor and bias
2a) I've high-pass filtered these gradients to keep all signal in and above
the MBW and I've added the complementary part below the MBW from the model
gradients. This should have removed the large systematic effects. Details:
I've used a 4th-order high-pass Butterworth filter in forward and reverse
direction to remove all phase distortion. So in effect it is an 8th-order
filter.
2b) I've multiplied the gradients from 1) with 1.01. So there is a scale
factor error of 1%. Then I've used the same filter procedure as in 2a).

So both filtered sets 2a and 2b have the full signal content and should
contain no, or very small, long wavelength errors.

You can get both sets, NewVij4 and NewVij5, by using anonymous ftp:
ftp.sron.nl and go to pub/johannes
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Appendix 2.

Tables of AR1 regional results. Only tracks with more than 9 points shown.

Calibration results for Australian area. Nov_Vij4, AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
38	30	0.271	0.132	1.362	0.119	1.222	0.088
46	30	0.910	0.034	2.094	0.345	0.972	0.031
54	30	1.015	0.031	0.864	0.153	1.100	0.027
62	30	0.965	0.032	0.676	0.172	0.981	0.029
70	30	1.057	0.017	1.140	0.084	0.976	0.014
78	30	1.129	0.030	1.365	0.153	1.066	0.025
86	30	1.064	0.019	1.082	0.104	1.032	0.016
94	30	0.971	0.033	1.153	0.223	0.897	0.029

102	30	0.927	0.036	0.154	0.245	0.936	0.039
110	30	1.023	0.038	1.093	0.118	0.972	0.030
118	30	1.051	0.044	0.701	0.187	1.078	0.041
126	30	1.091	0.047	1.294	0.167	1.051	0.039
134	10	1.258	0.073	1.079	0.643	1.097	0.081
231	30	1.242	0.113	0.997	0.124	1.237	0.108
239	30	1.037	0.036	1.483	0.382	0.911	0.034
247	30	0.986	0.027	1.211	0.144	0.931	0.023
255	30	0.991	0.034	0.757	0.185	1.019	0.030
263	30	0.967	0.017	1.066	0.075	1.021	0.014
271	30	0.986	0.032	0.853	0.159	0.977	0.028
279	30	1.030	0.021	1.257	0.133	1.024	0.019
287	30	0.945	0.036	1.007	0.265	0.914	0.032
295	30	0.938	0.041	1.601	0.294	0.960	0.042
303	30	1.031	0.040	1.092	0.119	0.905	0.032
311	30	0.986	0.043	1.139	0.186	0.954	0.040
319	30	0.874	0.051	0.846	0.209	0.961	0.042
408	11	0.937	0.111	0.440	0.226	0.829	0.075
416	13	1.135	0.050	1.119	0.287	1.016	0.044
424	30	0.768	0.091	1.410	0.156	0.884	0.108
432	30	0.915	0.036	0.385	0.272	0.991	0.034
440	30	0.975	0.026	1.004	0.154	1.012	0.023
448	30	0.970	0.029	0.587	0.178	0.959	0.025

Calibration results for Canadian area. New_Vij4 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
41	19	1.033	0.096	1.801	0.276	0.950	0.077
50	11	1.703	0.111	0.628	0.327	1.216	0.106
57	28	1.049	0.067	0.469	0.244	1.131	0.055
66	21	1.349	0.111	-1.456	0.774	1.004	0.118
73	31	1.119	0.059	1.054	0.242	0.816	0.049
82	30	1.259	0.093	1.045	0.268	0.700	0.078
89	31	1.087	0.066	0.544	0.232	1.051	0.052
98	31	1.225	0.074	1.518	0.158	1.049	0.053
105	26	1.132	0.086	1.038	0.372	1.106	0.072
114	31	0.991	0.059	1.127	0.093	0.936	0.037
121	15	0.780	0.143	2.513	0.602	1.235	0.184
130	23	1.099	0.088	0.828	0.142	1.084	0.055
146	13	0.914	0.210	0.457	0.231	1.278	0.115
218	10	1.014	0.118	-3.024	1.569	1.073	0.111
234	21	1.080	0.084	0.552	0.225	0.699	0.065
243	12	1.048	0.104	1.263	0.318	0.708	0.101
250	30	0.853	0.056	1.251	0.218	1.089	0.046
259	23	1.498	0.086	0.068	0.545	1.067	0.085
266	31	0.944	0.057	1.460	0.230	1.122	0.047
275	31	0.915	0.080	0.837	0.203	0.863	0.064
282	31	0.853	0.063	1.251	0.199	0.915	0.048
291	31	0.940	0.065	1.135	0.133	0.980	0.045
298	24	1.024	0.085	0.246	0.493	1.059	0.075
307	30	1.022	0.057	0.963	0.084	1.061	0.035
314	13	0.970	0.152	0.635	0.446	0.794	0.220
323	21	1.170	0.088	0.596	0.145	1.133	0.056
339	11	1.346	0.202	1.764	0.197	1.144	0.103
411	12	1.100	0.095	2.350	1.008	0.927	0.089
427	22	0.924	0.066	1.038	0.185	1.197	0.051
436	13	1.182	0.100	0.499	0.318	1.067	0.105
443	31	0.987	0.046	0.943	0.199	0.967	0.038

Calibration results for Norwegian area. New_Vij4 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	31	0.732	0.079	1.564	0.487	1.023	0.080
12	31	0.848	0.143	0.507	0.412	1.231	0.134
19	30	1.087	0.079	0.379	0.217	0.925	0.069
28	31	1.012	0.139	0.103	0.247	0.696	0.133
35	31	1.179	0.073	0.651	0.309	1.025	0.064
44	31	0.947	0.111	-0.341	0.342	0.629	0.113
51	31	0.994	0.067	1.295	0.144	0.901	0.046
60	31	1.005	0.082	0.782	0.272	1.075	0.064
67	26	0.722	0.080	0.886	0.207	0.990	0.058
76	25	1.011	0.086	2.923	0.420	0.817	0.074
83	15	1.155	0.267	0.348	0.235	0.920	0.212
92	17	1.124	0.102	1.262	0.454	0.904	0.122
116	13	1.123	0.120	1.270	0.186	0.983	0.074
125	10	1.450	0.356	1.710	0.314	0.585	0.269
132	22	0.754	0.181	1.145	0.329	0.766	0.144
141	20	0.883	0.144	1.486	0.238	0.914	0.091
148	30	0.940	0.087	0.775	0.580	1.339	0.082
157	30	0.710	0.088	0.349	0.208	1.061	0.062
164	31	1.302	0.070	1.443	0.190	1.021	0.053
173	30	1.089	0.083	0.787	0.177	0.795	0.057
180	31	1.015	0.076	0.337	0.313	1.020	0.071
189	31	1.082	0.113	-0.387	0.356	1.273	0.095
196	31	0.743	0.079	0.779	0.460	1.023	0.079
205	31	0.884	0.134	1.133	0.336	0.904	0.124
212	31	1.067	0.072	0.903	0.194	0.731	0.063
221	31	1.073	0.126	0.787	0.207	1.004	0.114
228	31	0.869	0.069	0.248	0.350	0.889	0.060
237	31	1.107	0.097	0.711	0.361	1.101	0.097
244	30	1.157	0.067	0.866	0.131	1.022	0.045
253	30	1.105	0.076	0.689	0.235	1.087	0.059
260	24	0.972	0.090	0.214	0.234	1.064	0.067
269	24	0.930	0.079	4.181	0.469	0.986	0.071
276	13	0.673	0.353	1.021	0.202	0.995	0.201
285	15	1.293	0.095	2.516	0.504	0.850	0.114
309	14	1.075	0.124	1.093	0.181	0.956	0.075
318	12	1.187	0.277	1.403	0.309	0.564	0.209
325	23	0.872	0.169	0.670	0.374	1.513	0.147
334	22	1.196	0.118	1.553	0.200	1.186	0.075
341	30	1.197	0.079	-0.545	0.539	1.001	0.071
350	30	0.983	0.079	1.198	0.195	0.932	0.056
357	31	0.740	0.066	1.138	0.172	1.105	0.050
366	31	1.004	0.078	0.244	0.166	0.912	0.054
373	31	1.052	0.073	0.975	0.324	1.222	0.072
382	31	0.960	0.108	1.431	0.443	1.018	0.096
389	31	0.849	0.072	0.814	0.376	1.410	0.070
398	31	0.781	0.124	0.772	0.280	1.106	0.115
405	31	1.081	0.066	1.043	0.175	0.766	0.056
414	31	1.310	0.114	1.069	0.182	1.100	0.103
421	31	1.004	0.063	1.346	0.288	0.953	0.052
430	30	0.853	0.090	0.861	0.424	1.104	0.087
437	30	1.042	0.063	0.757	0.114	0.999	0.041
446	31	0.920	0.069	0.711	0.206	0.799	0.053

Calibration results for Scandinavian area. New_Vij4 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	13	0.650	0.168	1.803	0.483	1.451	0.191
11	15	1.358	0.103	0.524	0.187	0.875	0.069
19	16	1.078	0.108	0.995	0.268	0.956	0.079
35	16	1.323	0.102	0.723	0.303	1.069	0.078
51	15	0.839	0.111	1.246	0.206	0.982	0.073
60	16	1.048	0.088	1.147	0.307	0.975	0.070
67	15	0.932	0.113	0.392	0.408	0.990	0.089
76	15	1.162	0.088	1.723	0.329	0.992	0.076
83	15	0.909	0.132	-0.764	0.533	0.879	0.165
92	15	1.128	0.101	0.570	0.414	0.783	0.120
99	15	0.986	0.134	0.960	0.363	1.188	0.178
108	15	1.111	0.098	0.745	0.655	0.796	0.113
115	15	0.926	0.106	1.011	0.297	0.954	0.094
124	15	1.000	0.086	0.781	0.405	1.153	0.073
131	15	1.134	0.092	0.005	0.291	1.123	0.075
140	15	0.908	0.109	0.826	0.320	0.673	0.082
147	15	0.888	0.095	1.296	0.407	1.191	0.081
156	15	0.107	0.205	1.527	0.527	1.285	0.168
172	15	1.028	0.102	1.931	0.252	1.267	0.073
188	15	0.877	0.073	1.047	0.103	1.014	0.043
196	15	1.078	0.153	0.699	0.489	1.111	0.159
204	15	0.920	0.100	1.441	0.201	0.819	0.069
212	15	1.181	0.099	1.335	0.241	0.930	0.072
228	15	0.963	0.100	0.891	0.335	0.947	0.078
244	16	1.091	0.105	1.040	0.187	1.084	0.068
253	16	1.183	0.082	0.950	0.255	1.033	0.064
260	16	0.860	0.115	1.794	0.511	1.144	0.094
269	15	1.044	0.081	1.781	0.312	1.059	0.072
276	16	1.002	0.137	2.448	0.415	1.120	0.186
285	15	1.199	0.091	1.045	0.422	0.868	0.110
292	15	1.075	0.131	2.125	0.330	0.899	0.156
301	15	1.038	0.086	1.815	0.711	0.979	0.095
308	15	0.793	0.099	0.301	0.268	0.973	0.083
317	15	1.116	0.079	1.470	0.298	0.946	0.064
324	15	0.758	0.088	1.699	0.295	0.999	0.072
333	15	1.165	0.111	1.582	0.359	0.859	0.085
340	15	0.975	0.093	0.907	0.291	0.850	0.076
349	15	0.266	0.184	0.668	0.430	0.966	0.140
365	15	0.901	0.089	0.815	0.197	0.932	0.062
381	15	0.868	0.072	0.906	0.097	0.963	0.042
389	15	1.066	0.125	-0.120	0.544	0.773	0.122
397	15	1.217	0.096	1.608	0.214	0.863	0.068
405	15	0.970	0.087	1.431	0.211	0.778	0.063
421	15	1.089	0.092	0.956	0.315	0.901	0.072
437	15	0.992	0.101	0.811	0.178	0.851	0.066
446	15	0.872	0.078	0.384	0.236	1.001	0.060

Calibration results for Australian area. New_Vij5 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
41	19	1.049	0.096	1.824	0.276	0.965	0.077
50	11	1.723	0.111	0.633	0.327	1.229	0.106
57	28	1.059	0.067	0.474	0.244	1.141	0.055
66	21	1.357	0.111	-1.498	0.774	1.006	0.118
73	31	1.129	0.059	1.056	0.242	0.825	0.049
82	30	1.274	0.093	1.058	0.268	0.707	0.078
89	31	1.095	0.066	0.555	0.232	1.061	0.052
98	31	1.239	0.074	1.537	0.158	1.062	0.053
105	26	1.148	0.086	1.020	0.372	1.123	0.072
114	31	0.999	0.059	1.145	0.093	0.947	0.037
121	15	0.784	0.143	2.539	0.602	1.252	0.184
130	23	1.102	0.088	0.839	0.142	1.093	0.055
146	13	0.923	0.210	0.463	0.231	1.291	0.115
218	10	1.027	0.118	-3.089	1.569	1.084	0.111
234	21	1.092	0.084	0.561	0.225	0.705	0.065
243	12	1.056	0.104	1.268	0.318	0.720	0.101
250	30	0.861	0.056	1.274	0.218	1.100	0.046
259	23	1.512	0.086	0.037	0.545	1.077	0.085
266	31	0.951	0.057	1.462	0.230	1.131	0.047
275	31	0.929	0.080	0.846	0.203	0.873	0.064
282	31	0.865	0.063	1.270	0.199	0.925	0.048
291	31	0.949	0.065	1.141	0.133	0.989	0.045
298	24	1.031	0.085	0.265	0.493	1.070	0.075
307	30	1.033	0.057	0.975	0.084	1.072	0.035
314	13	0.977	0.152	0.628	0.446	0.809	0.220
323	21	1.185	0.088	0.597	0.145	1.142	0.056
339	11	1.361	0.202	1.785	0.197	1.151	0.103
411	12	1.108	0.095	2.355	1.008	0.932	0.089
427	22	0.931	0.066	1.050	0.185	1.209	0.051
436	13	1.194	0.100	0.504	0.318	1.083	0.105
443	31	0.996	0.046	0.941	0.199	0.977	0.038

Calibration results for Canadian area. New_Vij5 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
41	19	1.049	0.096	1.824	0.276	0.965	0.077
50	11	1.723	0.111	0.633	0.327	1.229	0.106
57	28	1.059	0.067	0.474	0.244	1.141	0.055
66	21	1.357	0.111	-1.498	0.774	1.006	0.118
73	31	1.129	0.059	1.056	0.242	0.825	0.049
82	30	1.274	0.093	1.058	0.268	0.707	0.078
89	31	1.095	0.066	0.555	0.232	1.061	0.052
98	31	1.239	0.074	1.537	0.158	1.062	0.053
105	26	1.148	0.086	1.020	0.372	1.123	0.072
114	31	0.999	0.059	1.145	0.093	0.947	0.037
121	15	0.784	0.143	2.539	0.602	1.252	0.184
130	23	1.102	0.088	0.839	0.142	1.093	0.055
146	13	0.923	0.210	0.463	0.231	1.291	0.115
218	10	1.027	0.118	-3.089	1.569	1.084	0.111
234	21	1.092	0.084	0.561	0.225	0.705	0.065
243	12	1.056	0.104	1.268	0.318	0.720	0.101
250	30	0.861	0.056	1.274	0.218	1.100	0.046
259	23	1.512	0.086	0.037	0.545	1.077	0.085
266	31	0.951	0.057	1.462	0.230	1.131	0.047
275	31	0.929	0.080	0.846	0.203	0.873	0.064
282	31	0.865	0.063	1.270	0.199	0.925	0.048
291	31	0.949	0.065	1.141	0.133	0.989	0.045
298	24	1.031	0.085	0.265	0.493	1.070	0.075
307	30	1.033	0.057	0.975	0.084	1.072	0.035
314	13	0.977	0.152	0.628	0.446	0.809	0.220
323	21	1.185	0.088	0.597	0.145	1.142	0.056
339	11	1.361	0.202	1.785	0.197	1.151	0.103
411	12	1.108	0.095	2.355	1.008	0.932	0.089
427	22	0.931	0.066	1.050	0.185	1.209	0.051
436	13	1.194	0.100	0.504	0.318	1.083	0.105
443	31	0.996	0.046	0.941	0.199	0.977	0.038

Calibration results for Norwegian area. New_Vij5 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	31	0.734	0.079	1.621	0.487	1.031	0.080
12	31	0.857	0.143	0.527	0.412	1.240	0.134
19	30	1.096	0.079	0.400	0.217	0.930	0.069
28	31	1.013	0.139	0.091	0.247	0.705	0.133
35	31	1.187	0.073	0.637	0.309	1.031	0.064
44	31	0.956	0.111	-0.369	0.342	0.635	0.113
51	31	1.004	0.067	1.295	0.144	0.911	0.046
60	31	1.014	0.082	0.793	0.272	1.089	0.064
67	26	0.733	0.080	0.883	0.207	0.999	0.058
76	25	1.022	0.086	2.969	0.420	0.823	0.074
83	15	1.169	0.267	0.348	0.235	0.918	0.212
92	17	1.135	0.102	1.276	0.454	0.908	0.122
116	13	1.128	0.120	1.270	0.186	0.991	0.074
125	10	1.456	0.356	1.723	0.314	0.585	0.269
132	22	0.758	0.181	1.155	0.329	0.768	0.144
141	20	0.893	0.144	1.492	0.238	0.922	0.091
148	30	0.946	0.087	0.791	0.580	1.355	0.082
157	30	0.715	0.088	0.346	0.208	1.070	0.062
164	31	1.315	0.070	1.455	0.190	1.033	0.053
173	30	1.103	0.083	0.792	0.177	0.804	0.057
180	31	1.020	0.076	0.339	0.313	1.028	0.071
189	31	1.090	0.113	-0.384	0.356	1.286	0.095
196	31	0.751	0.079	0.770	0.460	1.029	0.079
205	31	0.900	0.134	1.156	0.336	0.919	0.124
212	31	1.078	0.072	0.918	0.194	0.736	0.063
221	31	1.084	0.126	0.790	0.207	1.011	0.114
228	31	0.876	0.069	0.238	0.350	0.900	0.060
237	31	1.113	0.097	0.704	0.361	1.116	0.097
244	30	1.168	0.067	0.876	0.131	1.030	0.045
253	30	1.116	0.076	0.692	0.235	1.097	0.059
260	24	0.984	0.090	0.217	0.234	1.075	0.067
269	24	0.937	0.079	4.222	0.469	0.994	0.071
276	13	0.675	0.353	1.025	0.202	1.004	0.201
285	15	1.305	0.095	2.555	0.504	0.858	0.114
309	14	1.094	0.124	1.100	0.181	0.963	0.075
318	12	1.207	0.277	1.439	0.309	0.566	0.209
325	23	0.883	0.169	0.664	0.374	1.534	0.147
334	22	1.208	0.118	1.574	0.200	1.200	0.075
341	30	1.210	0.079	-0.579	0.539	1.011	0.071
350	30	0.989	0.079	1.191	0.195	0.938	0.056
357	31	0.747	0.066	1.147	0.172	1.113	0.050
366	31	1.015	0.078	0.246	0.166	0.921	0.054
373	31	1.060	0.073	0.986	0.324	1.237	0.072
382	31	0.972	0.108	1.457	0.443	1.024	0.096
389	31	0.859	0.072	0.823	0.376	1.423	0.070
398	31	0.791	0.124	0.776	0.280	1.117	0.115
405	31	1.095	0.066	1.038	0.175	0.776	0.056
414	31	1.322	0.114	1.071	0.182	1.112	0.103
421	31	1.015	0.063	1.370	0.288	0.966	0.052
430	30	0.860	0.090	0.888	0.424	1.112	0.087
437	30	1.055	0.063	0.766	0.114	1.008	0.041
446	31	0.928	0.069	0.723	0.206	0.806	0.053

Calibration results for Scandinavian area. New_Vij5 AR1 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	13	0.652	0.168	1.850	0.483	1.459	0.191
11	15	1.374	0.103	0.520	0.187	0.880	0.069
19	16	1.086	0.108	1.015	0.268	0.963	0.079
35	16	1.339	0.102	0.725	0.303	1.077	0.078
51	15	0.845	0.111	1.251	0.206	0.990	0.073
60	16	1.058	0.088	1.158	0.307	0.987	0.070
67	15	0.948	0.113	0.406	0.408	0.998	0.089
76	15	1.174	0.088	1.738	0.329	1.001	0.076
83	15	0.919	0.132	-0.794	0.533	0.890	0.165
92	15	1.142	0.101	0.581	0.414	0.791	0.120
99	15	1.000	0.134	0.957	0.363	1.186	0.178
108	15	1.121	0.098	0.760	0.655	0.803	0.113
115	15	0.938	0.106	1.017	0.297	0.961	0.094
124	15	1.008	0.086	0.796	0.405	1.162	0.073
131	15	1.146	0.092	-0.001	0.291	1.134	0.075
140	15	0.919	0.109	0.839	0.320	0.679	0.082
147	15	0.897	0.095	1.302	0.407	1.204	0.081
156	15	0.110	0.205	1.551	0.527	1.298	0.168
172	15	1.040	0.102	1.976	0.252	1.279	0.073
188	15	0.885	0.073	1.061	0.103	1.021	0.043
196	15	1.092	0.153	0.689	0.489	1.119	0.159
204	15	0.927	0.100	1.457	0.201	0.828	0.069
212	15	1.195	0.099	1.361	0.241	0.937	0.072
228	15	0.971	0.100	0.892	0.335	0.959	0.078
244	16	1.103	0.105	1.050	0.187	1.092	0.068
253	16	1.193	0.082	0.953	0.255	1.043	0.064
260	16	0.870	0.115	1.827	0.511	1.155	0.094
269	15	1.053	0.081	1.789	0.312	1.070	0.072
276	16	1.009	0.137	2.479	0.415	1.136	0.186
285	15	1.210	0.091	1.029	0.422	0.880	0.110
292	15	1.084	0.131	2.144	0.330	0.913	0.156
301	15	1.048	0.086	1.851	0.711	0.988	0.095
308	15	0.805	0.099	0.302	0.268	0.981	0.083
317	15	1.133	0.079	1.472	0.298	0.953	0.064
324	15	0.765	0.088	1.709	0.295	1.011	0.072
333	15	1.171	0.111	1.589	0.359	0.867	0.085
340	15	0.986	0.093	0.917	0.291	0.859	0.076
349	15	0.262	0.184	0.660	0.430	0.980	0.140
365	15	0.907	0.089	0.834	0.197	0.942	0.062
381	15	0.878	0.072	0.918	0.097	0.971	0.042
389	15	1.074	0.125	-0.091	0.544	0.783	0.122
397	15	1.231	0.096	1.620	0.214	0.868	0.068
405	15	0.983	0.087	1.434	0.211	0.788	0.063
421	15	1.102	0.092	0.947	0.315	0.912	0.072
437	15	1.003	0.101	0.828	0.178	0.861	0.066
446	15	0.880	0.078	0.404	0.236	1.010	0.060

Tables of AR2 regional results. Only tracks with more than 9 points shown.

Calibration results for Australian area. AR2 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
6	30	0.976	0.024	-5.916	0.152	1.125	0.022
14	30	1.076	0.024	4.920	0.119	0.759	0.020
22	30	1.026	0.017	1.619	0.074	0.917	0.014
30	30	1.003	0.025	0.243	0.184	0.987	0.023
38	29	0.919	0.039	3.164	0.334	1.116	0.040
46	30	0.988	0.032	1.229	0.087	0.993	0.025
54	22	0.966	0.043	-0.565	0.302	1.158	0.041
62	14	0.964	0.093	1.005	0.905	1.162	0.091
119	14	0.999	0.119	0.375	0.172	1.166	0.072
127	23	1.008	0.031	0.463	0.232	1.045	0.028
135	30	0.980	0.034	1.221	0.189	1.043	0.033
143	30	1.007	0.025	0.556	0.129	1.022	0.021
151	30	1.005	0.016	1.223	0.068	0.993	0.013
159	30	0.992	0.025	1.168	0.131	0.997	0.021
167	30	0.978	0.028	0.258	0.215	0.977	0.028
175	30	1.013	0.030	1.232	0.092	0.998	0.024
183	30	1.012	0.040	1.497	0.187	1.013	0.037
191	24	1.023	0.053	1.584	0.237	0.962	0.045
256	10	1.022	0.044	1.533	0.238	0.974	0.038
264	30	0.949	0.068	0.536	0.147	0.882	0.088
272	30	1.005	0.027	1.437	0.134	0.990	0.025
280	29	0.999	0.018	0.735	0.102	1.025	0.015
288	30	0.975	0.024	0.840	0.120	1.024	0.021
296	30	1.004	0.020	1.393	0.127	1.000	0.018
304	30	0.990	0.028	0.537	0.126	1.021	0.024
312	30	1.046	0.042	0.721	0.243	0.992	0.039
320	30	1.019	0.039	0.887	0.128	0.996	0.032
393	26	0.963	0.146	1.834	0.111	0.709	0.077
401	30	0.982	0.027	-1.528	0.260	1.056	0.026
409	30	1.011	0.022	0.912	0.151	0.971	0.020
417	30	1.041	0.025	2.905	0.123	0.873	0.021
425	30	1.017	0.016	1.528	0.074	0.947	0.013
433	30	1.004	0.027	0.005	0.204	0.965	0.025
441	29	0.866	0.038	10.164	0.337	1.355	0.038
449	30	6.390	0.035	0.530	0.087	0.461	0.027

Calibration results for Canadian area. AR2 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
2	14	-1.261	0.111	-8.279	0.287	8.884	0.112
9	29	1.229	0.053	-1.038	0.213	0.566	0.045
18	30	1.047	0.084	-3.639	0.198	1.247	0.073
25	30	0.925	0.054	-1.312	0.158	1.213	0.040
34	31	1.067	0.069	0.990	0.136	0.940	0.048
41	25	1.043	0.078	1.736	0.421	0.891	0.069
50	26	1.007	0.073	1.468	0.094	0.939	0.042
57	10	1.074	0.174	-0.300	0.356	0.975	0.311
66	13	1.099	0.261	0.949	0.183	1.047	0.110
122	13	0.972	0.088	-0.783	0.587	1.083	0.078
131	10	1.045	0.109	0.487	0.246	0.901	0.094
138	26	1.002	0.059	1.738	0.179	0.978	0.048
147	25	0.926	0.099	1.963	0.289	1.076	0.097
154	30	0.974	0.053	0.735	0.193	1.001	0.043
163	30	1.005	0.082	0.483	0.173	1.032	0.059
170	30	0.945	0.065	0.338	0.205	1.083	0.051
179	29	0.992	0.061	1.153	0.082	0.999	0.036
186	14	1.081	0.139	0.546	0.439	0.892	0.200
195	17	1.126	0.139	1.328	0.170	0.879	0.079
267	22	0.967	0.069	0.681	0.167	1.073	0.052
276	19	1.020	0.157	-0.419	0.392	0.633	0.238
283	31	1.054	0.049	1.547	0.217	1.013	0.042
292	31	0.945	0.086	1.700	0.186	0.905	0.067
299	31	1.014	0.056	1.366	0.151	0.960	0.042
308	31	0.955	0.060	0.704	0.092	1.028	0.038
315	19	0.970	0.102	2.704	1.069	1.200	0.111
324	21	0.947	0.090	0.886	0.125	1.050	0.053
396	18	1.032	0.082	2.389	0.239	0.824	0.066
405	14	0.959	0.120	1.506	0.282	1.431	0.126
412	30	1.026	0.049	-0.096	0.207	0.939	0.042
421	30	1.049	0.082	-2.169	0.205	1.184	0.072
428	31	0.889	0.051	-1.602	0.153	1.322	0.039
437	31	0.907	0.066	-0.635	0.132	1.140	0.046
444	25	0.788	0.075	-5.844	0.407	1.568	0.067

Calibration results for Norwegian area. AR2 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	31	1.991	0.053	16.674	0.103	-1.186	0.036
12	29	0.743	0.068	-5.341	0.199	1.720	0.052
19	21	0.965	0.100	1.586	0.303	1.143	0.078
28	17	1.071	0.091	-2.682	0.523	0.684	0.104
52	16	0.966	0.117	0.421	0.163	1.136	0.071
61	19	1.125	0.120	2.249	0.212	0.708	0.080
68	28	0.936	0.083	3.801	0.449	1.074	0.079
77	30	1.028	0.082	0.187	0.187	1.101	0.058
84	30	1.005	0.068	1.460	0.172	1.012	0.054
93	31	0.934	0.105	1.445	0.227	0.970	0.079
100	31	1.037	0.072	-0.686	0.316	0.964	0.076
109	31	0.998	0.125	1.149	0.262	0.948	0.101
116	31	1.015	0.060	1.667	0.153	0.950	0.051
125	31	1.077	0.111	0.892	0.206	0.933	0.103
132	31	0.952	0.054	0.981	0.143	1.019	0.040
141	31	1.041	0.070	1.099	0.193	1.006	0.052
148	25	1.006	0.068	1.578	0.168	0.926	0.049
157	20	0.999	0.083	1.931	0.560	1.027	0.085
164	10	1.236	0.383	1.200	0.161	0.823	0.125
181	12	1.023	0.110	1.341	0.156	1.009	0.066
190	15	0.973	0.191	1.416	0.264	0.923	0.136
197	25	1.058	0.117	-0.122	0.538	1.082	0.113
206	31	0.992	0.083	1.420	0.179	0.948	0.057
213	31	0.995	0.069	0.225	0.220	1.035	0.055
222	31	0.978	0.089	0.436	0.171	0.977	0.062
229	31	0.958	0.075	2.147	0.331	1.068	0.080
238	31	0.959	0.119	0.004	0.391	0.994	0.104
245	31	1.034	0.063	0.586	0.185	0.954	0.055
254	31	0.915	0.119	1.412	0.179	1.026	0.096
261	31	0.981	0.058	1.557	0.275	0.997	0.049
270	31	1.076	0.078	1.656	0.319	0.956	0.064
277	30	0.957	0.056	0.849	0.108	1.039	0.037
286	24	1.045	0.075	1.708	0.416	0.944	0.066
293	15	1.098	0.187	0.937	0.214	1.111	0.118
302	12	1.047	0.115	2.163	0.658	1.093	0.139
319	11	1.094	0.313	0.386	0.200	1.083	0.190
326	21	1.069	0.151	1.826	0.255	0.856	0.120
335	25	0.934	0.091	0.400	0.165	1.096	0.059
342	31	1.057	0.074	1.328	0.451	0.902	0.065
351	30	0.978	0.083	1.664	0.168	0.933	0.057
358	31	0.963	0.074	0.167	0.238	1.012	0.066
367	31	1.056	0.114	3.001	0.525	0.864	0.102
374	30	0.917	0.070	2.409	0.309	0.985	0.068
383	31	0.983	0.119	0.739	0.192	0.911	0.094
390	31	0.922	0.059	0.092	0.185	1.197	0.051
399	31	1.050	0.091	-0.607	0.329	1.027	0.087
406	31	1.049	0.053	1.980	0.101	0.833	0.035
415	29	0.899	0.068	-1.096	0.201	1.247	0.052
422	20	0.859	0.106	1.434	0.318	1.225	0.083
431	17	1.097	0.084	-2.995	0.525	0.637	0.094

Calibration results for Scandinavian area. AR2 data.

Track	number of points	(1,1) scale factor	error	(2,2) scale factor	error	(3,3) scale factor	error
3	15	1.907	0.083	16.753	0.142	-1.096	0.053
12	16	0.697	0.072	-2.934	0.213	1.659	0.055
19	15	0.961	0.100	5.391	0.734	1.107	0.091
28	15	1.118	0.086	-2.513	0.488	0.466	0.096
35	16	0.924	0.169	2.149	0.260	0.659	0.260
44	15	0.988	0.094	0.350	0.573	1.152	0.104
51	15	1.022	0.093	0.455	0.205	0.945	0.072
60	15	0.925	0.090	0.606	0.292	1.045	0.069
67	15	0.917	0.086	-0.687	0.468	1.198	0.076
76	16	0.989	0.210	-0.638	0.365	1.113	0.159
92	15	1.101	0.093	1.602	0.123	0.895	0.054
100	12	1.010	0.110	0.024	0.350	1.064	0.125
108	15	1.075	0.089	1.527	0.210	0.880	0.064
116	15	1.093	0.074	1.802	0.193	0.909	0.056
132	15	0.908	0.081	0.420	0.179	1.080	0.057
141	16	1.061	0.077	0.869	0.222	1.006	0.058
148	15	0.998	0.090	2.154	0.317	0.929	0.071
157	15	1.045	0.078	1.849	0.396	1.032	0.077
164	15	1.006	0.155	1.709	0.288	1.032	0.242
173	15	0.969	0.096	-0.205	0.453	0.831	0.119
180	15	1.053	0.116	1.200	0.205	0.929	0.094
189	15	0.953	0.086	0.252	0.310	1.039	0.069
196	15	1.036	0.084	0.687	0.331	0.998	0.071
205	16	1.007	0.161	0.295	0.534	1.186	0.146
212	11	1.098	0.123	0.594	0.229	1.114	0.082
221	16	0.975	0.112	0.729	0.199	1.074	0.073
237	15	1.009	0.096	1.284	0.133	1.006	0.060
245	15	0.992	0.081	0.511	0.273	0.993	0.065
261	15	1.059	0.080	1.838	0.282	0.931	0.063
270	14	1.069	0.087	1.453	0.379	0.959	0.071
277	16	0.899	0.080	0.539	0.169	1.052	0.055
286	15	1.022	0.072	0.782	0.297	0.966	0.063
293	15	1.078	0.125	-0.407	0.444	0.829	0.144
302	15	0.994	0.093	2.296	0.525	1.207	0.113
309	15	0.837	0.138	0.854	0.233	1.090	0.127
318	15	1.008	0.085	2.748	0.546	0.909	0.079
325	15	0.994	0.086	1.456	0.232	1.047	0.068
334	15	0.917	0.110	1.384	0.422	0.995	0.088
341	15	1.025	0.096	1.293	0.233	0.922	0.079
350	15	1.195	0.166	1.679	0.323	0.905	0.110
366	15	1.017	0.087	0.640	0.098	1.050	0.048
374	16	0.975	0.094	1.847	0.413	0.900	0.093
382	10	0.993	0.092	0.419	0.201	1.121	0.063
390	15	0.925	0.075	0.134	0.207	1.182	0.057
406	15	1.044	0.081	2.306	0.145	0.789	0.053
415	15	0.857	0.073	0.199	0.214	1.235	0.056
422	15	0.930	0.104	5.402	0.768	1.084	0.096
431	15	1.193	0.083	-2.883	0.494	0.406	0.091
438	16	0.645	0.163	7.393	0.270	0.263	0.234
447	15	1.420	0.092	0.164	0.572	-0.094	0.105