Stuttgart, June 29, 2007

Project Digital Camera Calibration and Validation

Official notes from the project pilot centre

Comment 1

The project was focussed on the empirical testing of geometric accuracy of commercial large format digital cameras. **The project did not emphasize in the comparison of accuracy from different camera systems**, but in the definition and testing of sensor related self-calibration parameter sets, which then could be recommended for each different sensor type individually.

Comment 2

The distribution of the three empirical test flight data, i.e.

- Intergraph/ZI DMC test **Fredrikstad**, Oct 10, 2003,
- Leica Geosystems ADS40 test **Vaihingen/Enz**, Jun 26, 2004,
- Microsoft Imaging UltracamD test **Fredrikstad**, Sep 16, 2004

was officially reconfirmed by all three manufacturers.

Comment 3

All empirical results rely on those three flights only – **only one sample of flight data for each camera** has been used. The obtained accuracy has to be validated from results of additional similar flights. Such data have not been available for this EuroSDR project.

Comment 4

The empirical flight data was acquired in 2003 and 2004 already and thus **might not fully reflect the today's performance** of the tested three sensor systems due to continuous refinements in sensor development.

Comment 5

All three sensors were flown in two different flying heights resulting in **different ground sampling distances** (GSD) with **individual block geometries**. Flights were done in **two different test ranges**.

EuroSDR (formerly OEEPE) - Network "Digital Camera Calibration"
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Comment 6

Even though the frame sensor systems were both flown in the Fredrikstad test site with similar ground sampling distances

- DMC high flight,
  - flying height 1800m above ground
  - corresponding **GSD 0.18m**
- UCD low flight
  - flying height 1900m above ground
  - corresponding **GSD 0.17m**

their **results cannot be compared directly**. The UltracamD flight consists of 4 lines with 80% overlap, 60% sidelap including one cross strip (altogether 131 images). In contrary to this the DMC flight covers the same area but with standard 60% / 30% overlaps only, resulting in 3 flight lines with no cross strips (altogether 34 images). The **UltracamD block is of considerably stronger geometry than the DMC block**, which positively influences the accuracy of object point determination.

Comment 7

The most important results from this EuroSDR test are summarized like follows

- **Self-calibration is necessary** to improve quality of object point determination for all three tested camera systems.
- **Self-calibration is of larger influence for DMC and UltracamD compared to ADS40**.
- **Systematic corrections for UltracamD are more significant compared to DMC**.
- Besides self-calibration model the **a priori weighting is of larger influence**. In some case the choice of weighting factors even exceeds the influence of the applied self-calibration model.
- In some cases **specially designed self-calibration parameter sets adopted to sensor geometry are necessary**. The standard photogrammetric Ebner or Gruen parameters are not able to fully compensate for the systematic errors in all cases.

Comment 8

The detailed results of this extensive test will be part of the final report. This report is compiled in fall this year and publicly available through the project web site http://www.ifp.uni-stuttgart.de/eurosdr/index.html.
For this year's Photogrammetric Week a first paper including the most important findings will be published.

Stuttgart, June 29, 2007

EuroSDR project leader

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Results from the EuroSDR network on Digital Camera Calibration and Validation

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ISPRS Workshop

High Resolution Earth Imaging

May 29 – June 1, 2007

Leibniz Universität Hannover

Objectives

- *theoretical **PHASE 1** (finished end of 2004)*

  Collection of publicly available material to compile an extensive report documenting currently used calibration practice and methods
  - All network participants, i.e. camera producers and other experts contribute with their experiences
  - Common knowledge base for the formulation on future strategies
  - Helpful for system users to gain their knowledge in digital camera calibration
  - Report is open to system suppliers, users and customers

www.ifp.uni-stuttgart.de/EuroSDR/EuroSDR-Phase1-Report.pdf

Objectives

- *empirical **PHASE 2** (finished end of 2006)*

  Recommendation/development of commonly accepted procedure(s) for camera systems calibration and experimental testing

  - Focus on some of the technical aspects in a sequential order, i.e. starting with geometrical aspects and verification
  - Empirical testing should *not* lead to direct comparisons of cameras, but to **individual calibration recommendations for each digital camera** design

  Empirical phase 2 extended to **Phase 2b** (recently finished May 2007)

EuroSDR Network on Digital Camera Calibration and Validation

#	Group	Institutions / Systems	#
1	Camera manufacturers	ADS, DIMAC, DMC, DSS, UltracamD, Starimager, 3-DAS-1, DigiCAM	12
2	AT software developers	BLUH, ORIMA, inpho, dgap, CSIRO	5
3	Other companies	Vito, ISTAR, Geosys, OMC, stereocarto	5
4	Science	ETH, OSU, Glasgow, Stuttgart (2x), IdeG, Rostock, DLR (2x), Berlin, Nottingham, Aas, Pavia, Leon	29
5	NMCAs	ICC, USGS, OrdSurv, IGN, FGI, Lantmäteriet, Swisstopo, BEV, ICV, itacyl	13
		Σ representatives	64

Phase 2 / 2 b

Active Participants

#	Code	Institutions
1	ICC	Institute Cartographic Catalunya, Spain
2	LM	Lantmatäriet, Gävle, Sweden
3	itacyl	ITACYL, Valladolid, Spain
4	inpho	inpho, Stuttgart, Germany
5	CSIRO	CSIRO Information Sciences, Wembley, Australia
6	DLR-B	DLR, Berlin, Germany
7	HfT	University of Applied Science, Stuttgart, Germany
8	IPI	IPI, University of Hannover, Germany
9	ETH	ETH Zürich, Switzerland
10	UoP	University of Pavia, Italy
11	UoN	University of Nottingham, England
12	Ingr.ZI	Intergraph ZI, Aalen, Germany
13	Vexcel	Vexcel, Graz, Austria

Results from the EuroSDR network on

Digital Camera Calibration

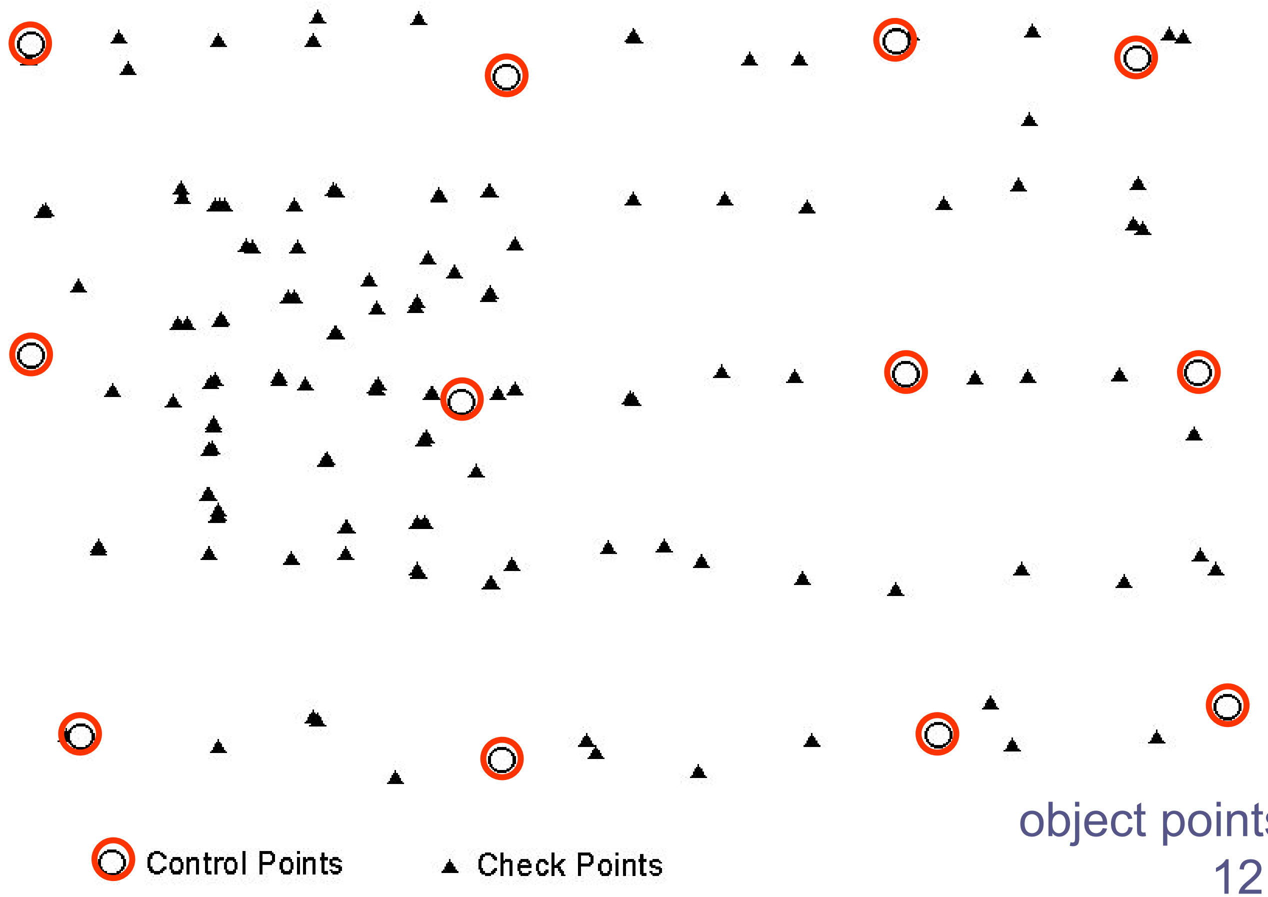
The empirical test flight data

Experimental Phase 2 data

#	Altitude [m]	GSD [m]	# strips long/cross	% overlap long/cross	# Images	Additional data
ADS Vaihingen/Enz, June 26, 2004						
low	1500	0.18	4 / 2	100 / 44	36	GPS/INS
high	2500	0.26	3 / 3	100 / 70	36	GPS/INS
DMC Fredrikstad, October 10, 2003						**Phase 2b**
low	950	0.10	5	60 / 30	115	n.a.
high	1800	0.18	3	60 / 30	34	n.a.
UltracamD Fredrikstad, September 16, 2004						
low	1900	0.17	4 / 1	80 / 60	131	GPS
high	3800	0.34	2	80 / 60	28	GPS

The Vaihingen/Enz test range

Vaihingen/Enz (ADS)



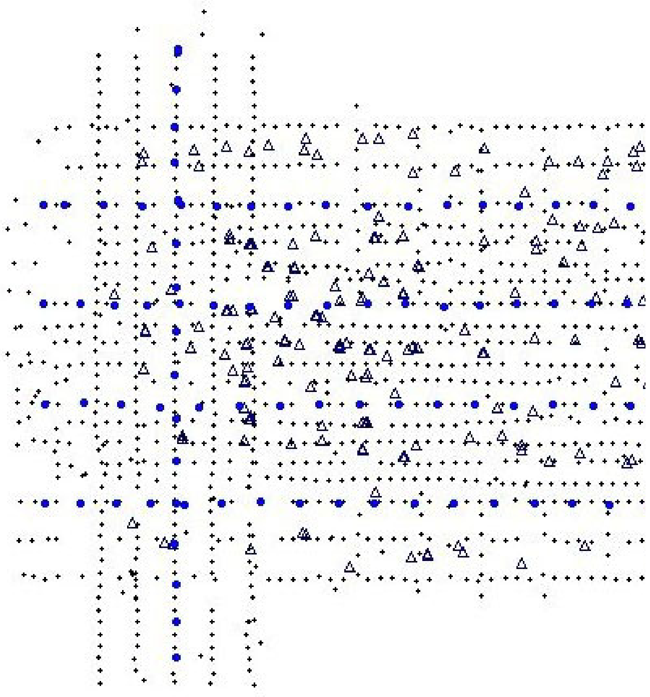
object points

12 control points

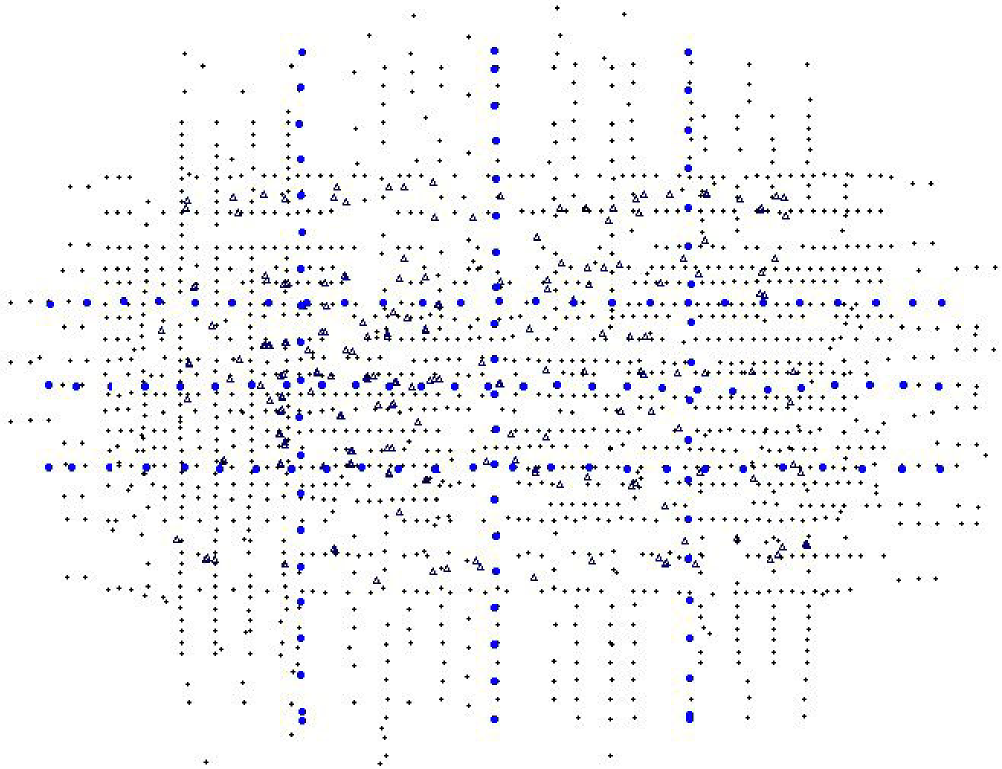
>200 check points

ADS40 image block geometry

ADS Vaihingen/Enz, June 26, 2004



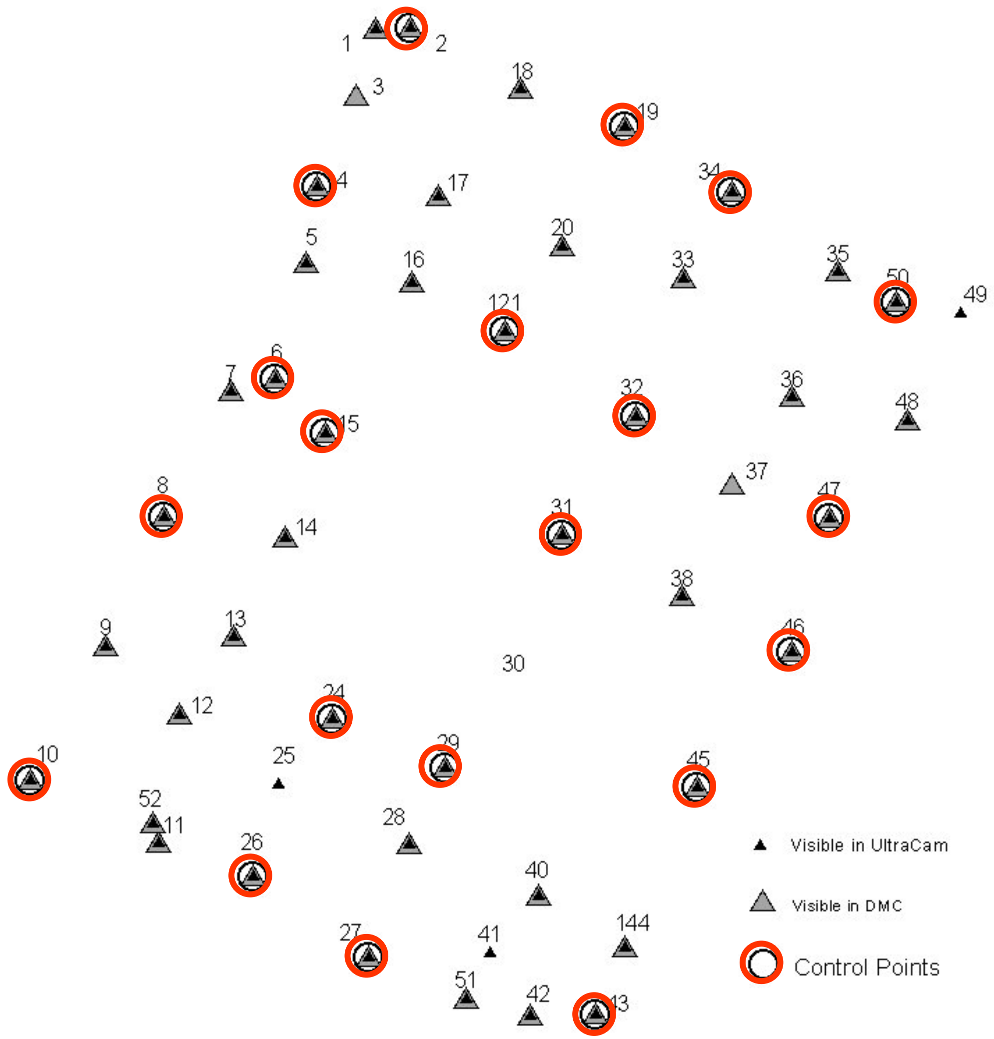
Low (GSD 18cm, h=1500m)
non-staggered



High (GSD 26cm, h=2500m)
non-staggered

The Fredrikstad test range

DMC and UCD flights



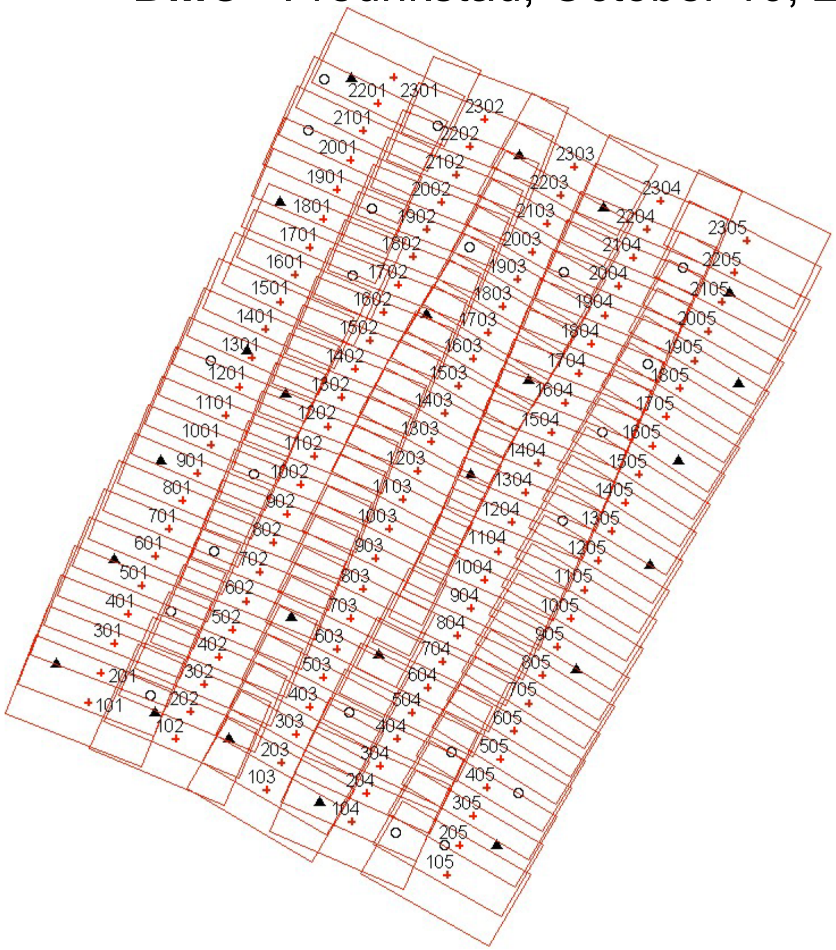
object points

~ 20 control points

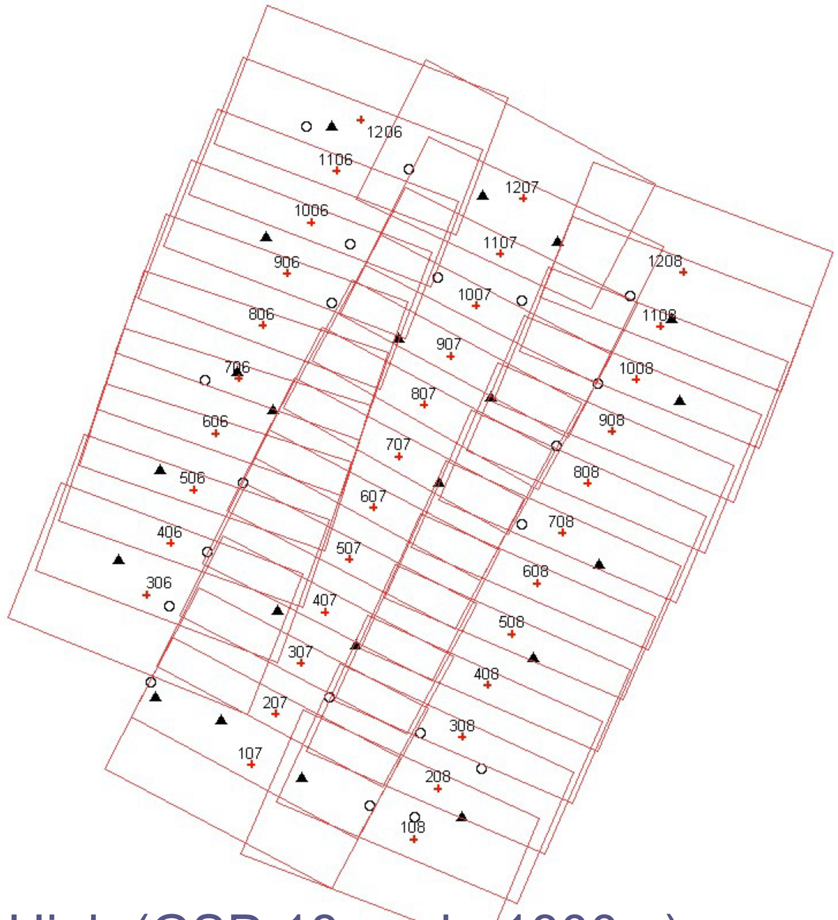
~ 25 check points

DMC image block geometry

DMC Fredrikstad, October 10, 2003



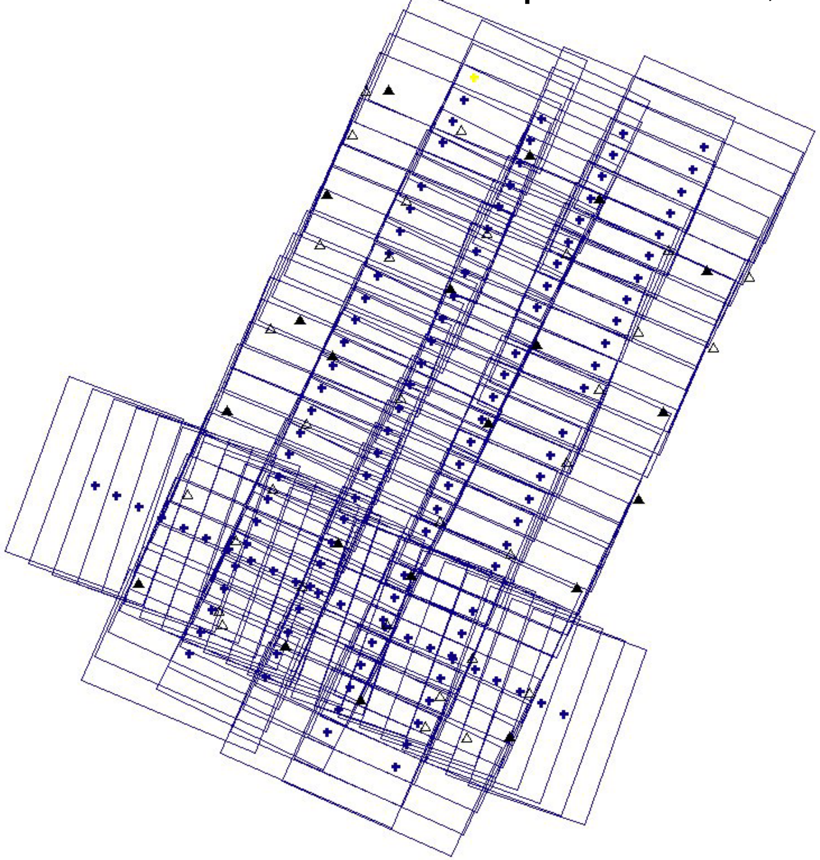
Low (GSD 10cm, h=950m)



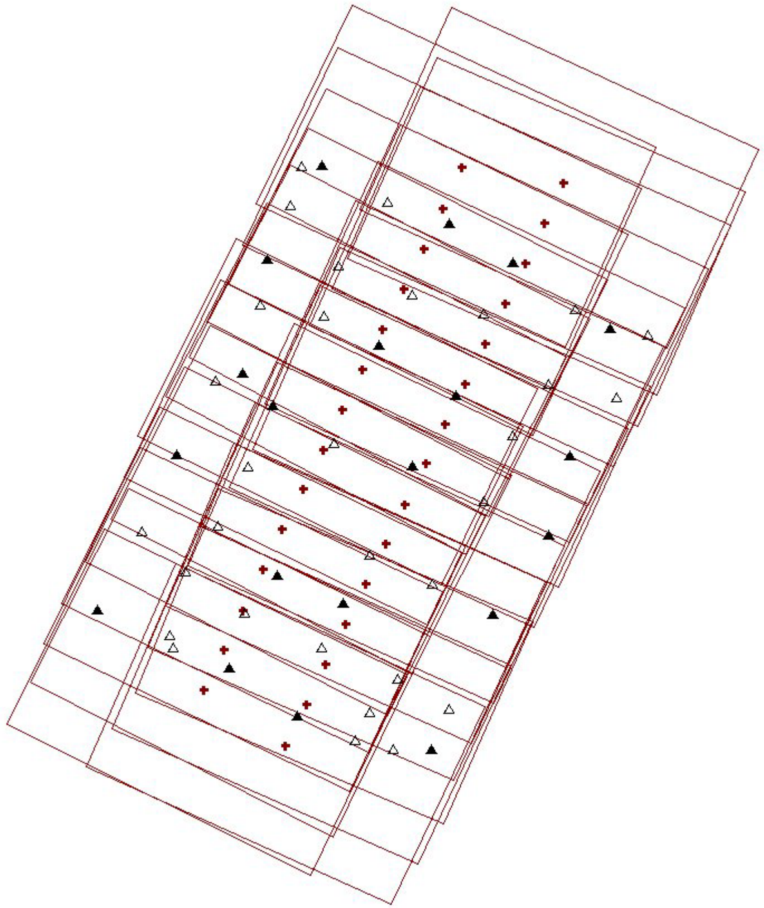
High (GSD 18cm, h=1800m)

UCD image block geometry

UCD Fredrikstad, September 16, 2004



Low (GSD 17cm, h=1900m)

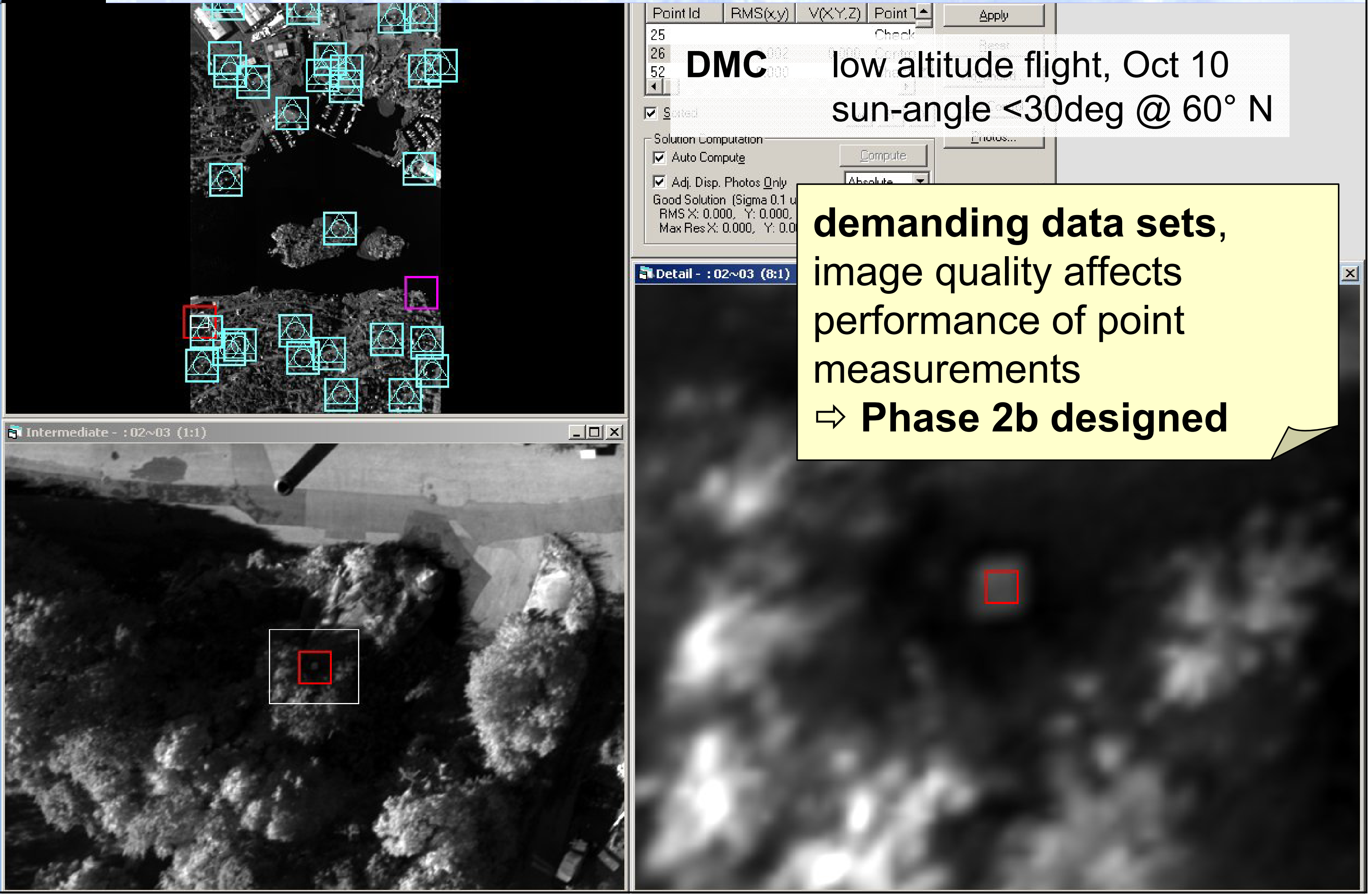


High (GSD 34cm, h=3800m)

ifp

DMC and UCD flights

Image quality and point measurements

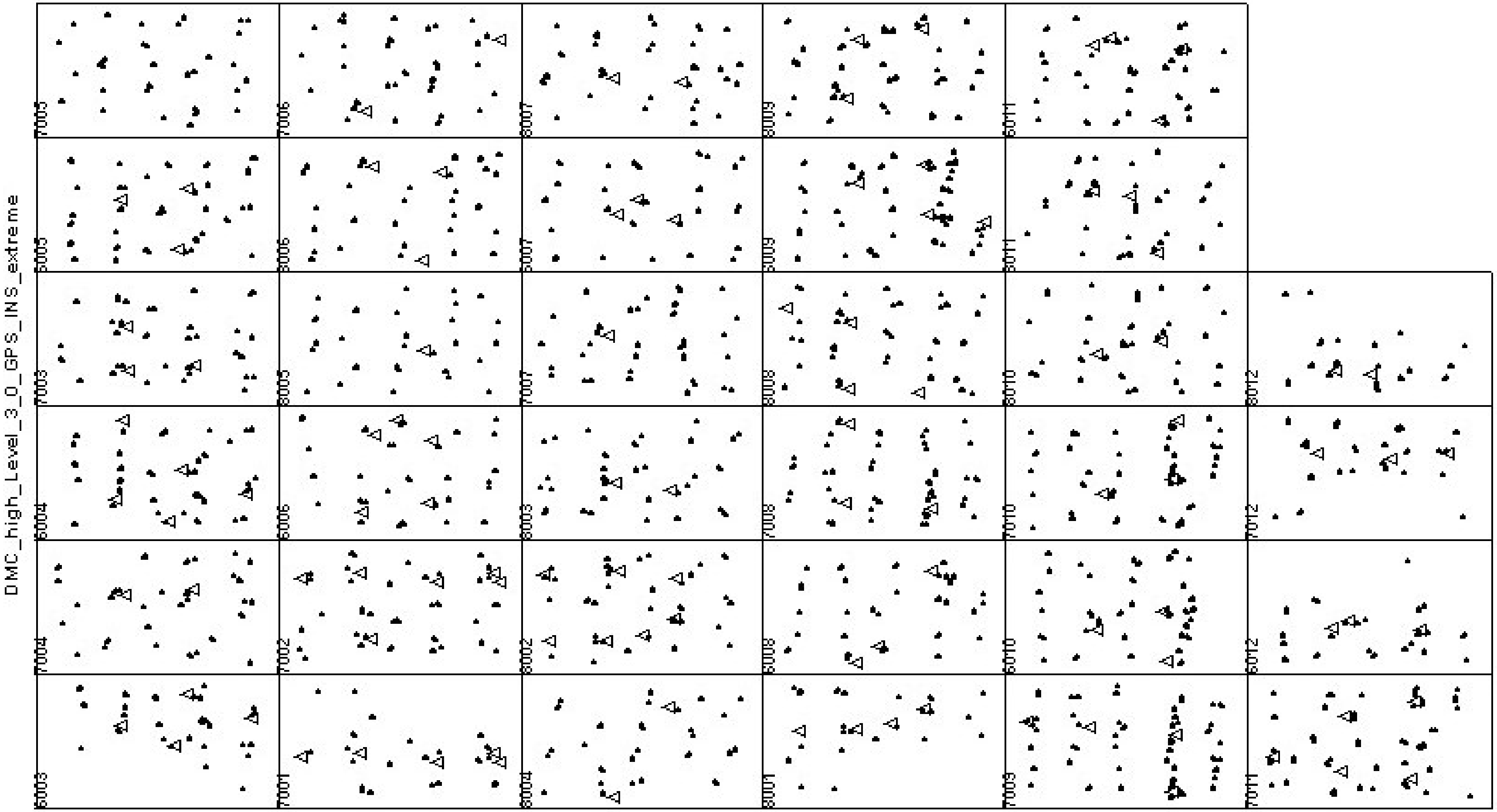


DMC low altitude flight, Oct 10
sun-angle <30deg @ 60° N

demanding data sets, image quality affects performance of point measurements
⇨ **Phase 2b designed**

Image coordinates by Pilot Centre

Phase 2b, DMC and UCD flights



Example: DMC high block - measured points / image

Results from the EuroSDR network on

Digital Camera Calibration

The results

Phase 2 / 2b

Evaluated data sets

Phase 2 Data Set	# Results	Participants
ADS	3	UoP, DLR-B, ETH
DMC	6	ICC, IPI, inpho, HfT, LM, Ingr.ZI
UltracamD	5	UoN, IPI, itacyl, inpho, CSIRO

77 different versions (Phase 2) evaluated

Phase 2b Data Set	# Results	Participants
DMC	5	ICC, IPI, CSIRO, ETH, Ingr.ZI
UltracamD	4	IPI, CSIRO, ETH, Vexcel

80 different versions (Phase 2b) evaluated

General remarks on data processing (1/2)

- typically the two different flight heights processed independently, only few participants used both heights for common adjustment
- standard and proprietary software packages used

Process step	Software
Matching and point measurement (only for Phase 2)	Manual, MATCH-AT, LPS, ISAT, Gpro, PhotoMod, others
Bundle adjustment	Match-AT, ORIMA, InBlock, BLUH, PhotoMod, ACX-Geotex, IS-PhotoT, others

General remarks on data processing (2/2)

- Self-calibration was applied in general,
- but additionally almost each participant also provided solution w/o use of additional SC
- some participants used modified SC approaches taking the specific image geometry of large format DMC / UCD imagery into account

Data set	Self-calibration parameter set (if applied)
DMC	Ebner, Grün, Polynom, BLUH parameters Ebner / Grün per quadrant, BLUH DMC specific
UCD	Brown, Grün, BLUH parameters Ebner / Grün per image patch, BLUH UCD specific
ADS	Brown (with some extensions)

EuroSDR

Results from the EuroSDR network on

Digital Camera Calibration

The ADS results

Phase 2 – ADS

ifp solution

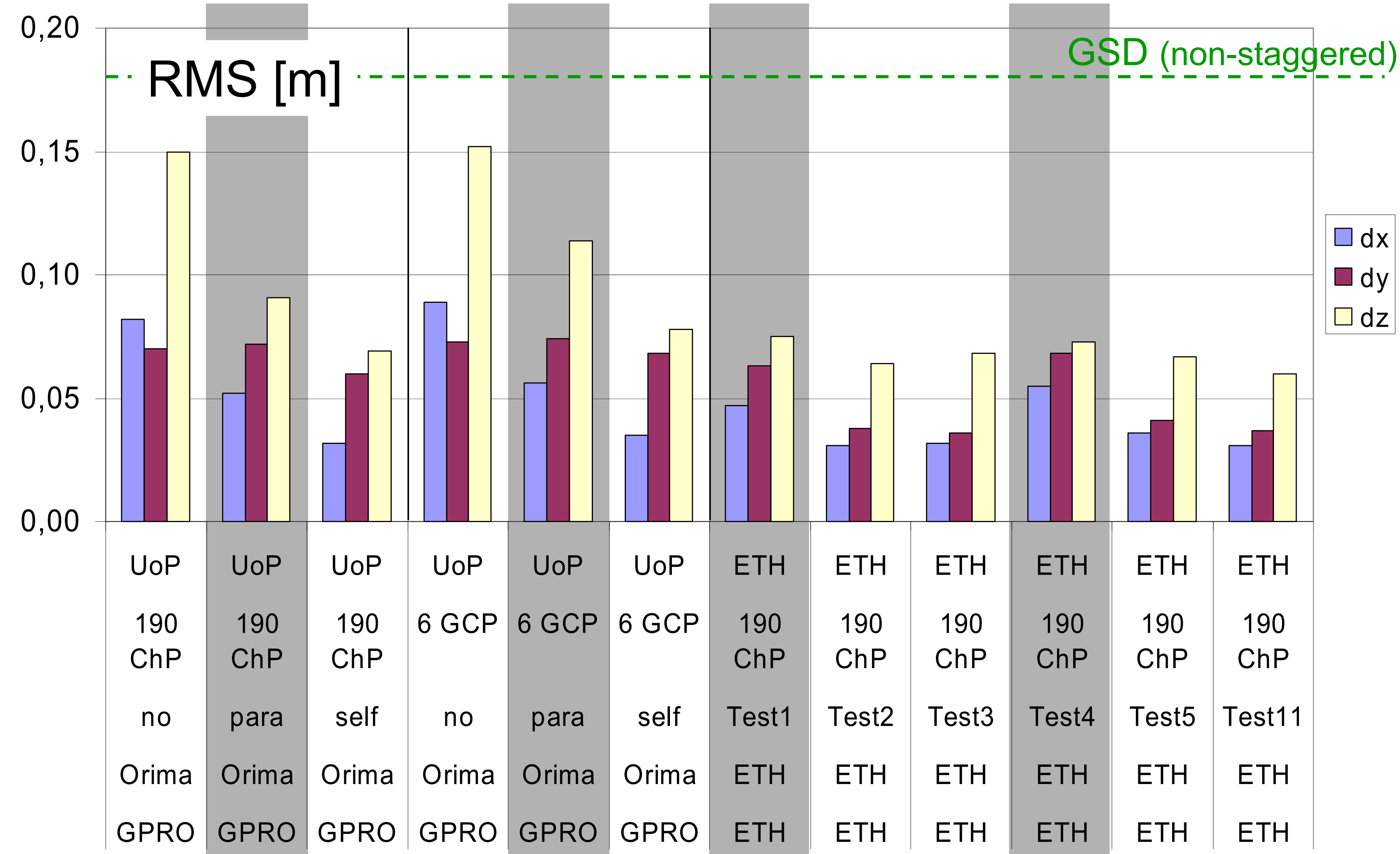
Flight	H [m]	GSD [m] *non-stag.*	RMS		
			X [m]	Y [m]	Z [m]
ADS low	1500 **no SC**	0.18	0.052	0.054	0.077
ADS low	1500 **with SC**	0.18	0.031	0.040	0.057
ADS high	2500 **no SC**	0.26	0.066	0.060	0.100
ADS high	2500 **with SC**	0.26	0.064	0.059	0.087

- RMS values from 190 check point differences
- Results obtained from standard Leica processing software
  - ORIMA bundle adjustment, 12 GCPs used
  - self calibration (if applied) based on Brown parameters

ADS low

h_g 1500m, GSD 0.18m non-staggered

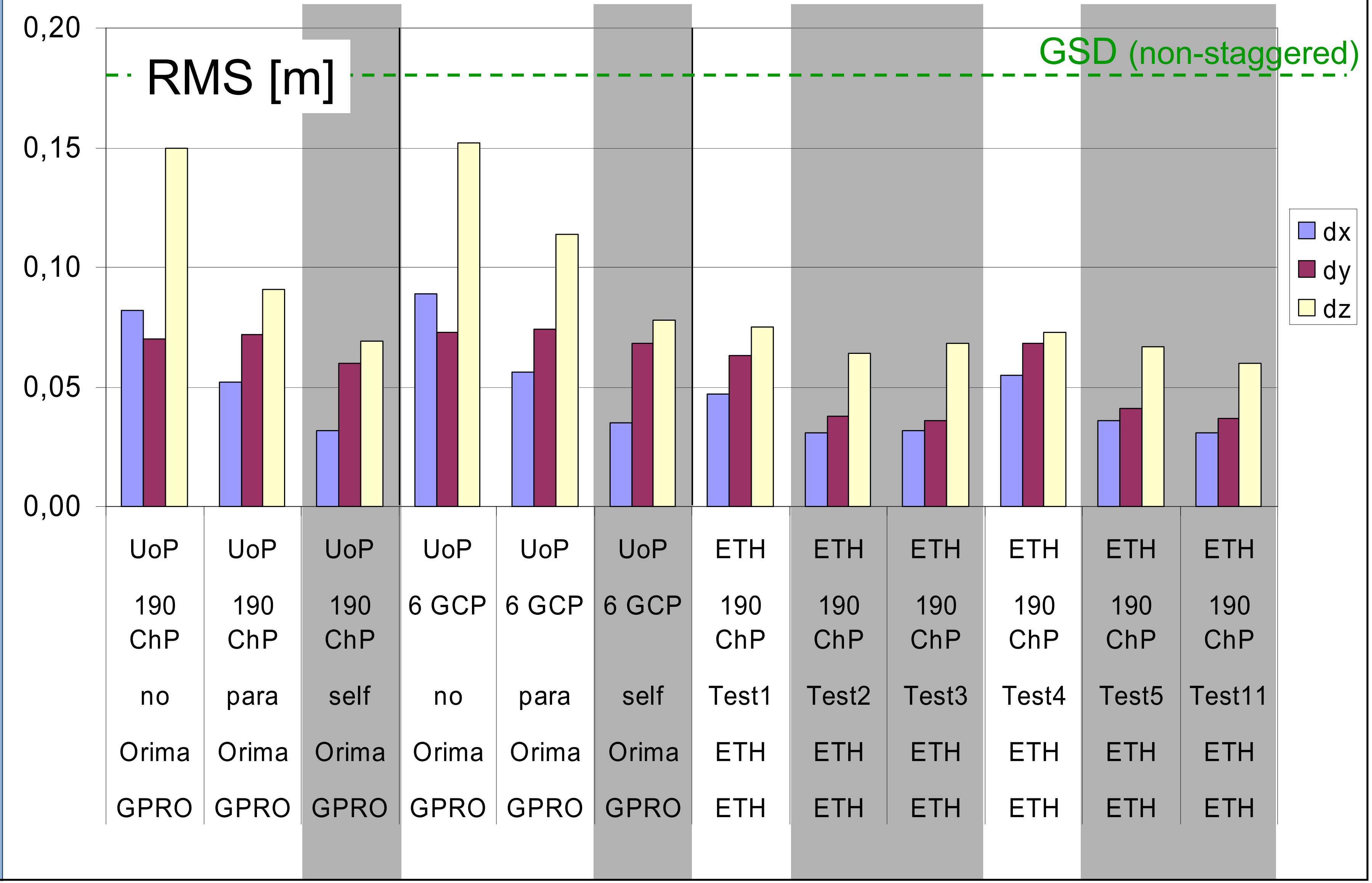
No SC



ADS low

h_g 1500m, GSD 0.18m non-staggered

with SC



Remarks to the reader

ETH versions

Test1	DGR (direct georeferencing) trajectory model, no self-calibration applied, only 4 GCP
Test2	DGR trajectory model, 18 params in SC, only 4 GCP
	6 for camera lens : 1 focal length, 3 radial & 2 tangential distortions
	for each of the three lines: 2 principal point, 1 scan line inclination, 1 affinity across flight direction
Test3	DGR trajectory model, 12 params in SC, only 4 GCP
	like above, but without x0 forward + nadir, y0 nadir, sy nadir, phi nadir
Test4	LIM (lagrange interpolation model) trajectory model, no SC, only 4 GCP
Test5	LIM trajectory model, 18 params in SC, only 4 GCP
Test11	DGR trajectory model, 18 params in SC, 12 GCP

UoP version (only A lines used)

basic	no additional parameters estimated (no self-calibration, no IMU misalignment, drift, datum)
para	no SC, but additional parameters like IMU misalignment, datum transform, drift
self	additional SC besides the para additional parameters above

all UoP versions calculated with all 12 GCP and a reduced number of 6 GCP only

Results from the EuroSDR network on

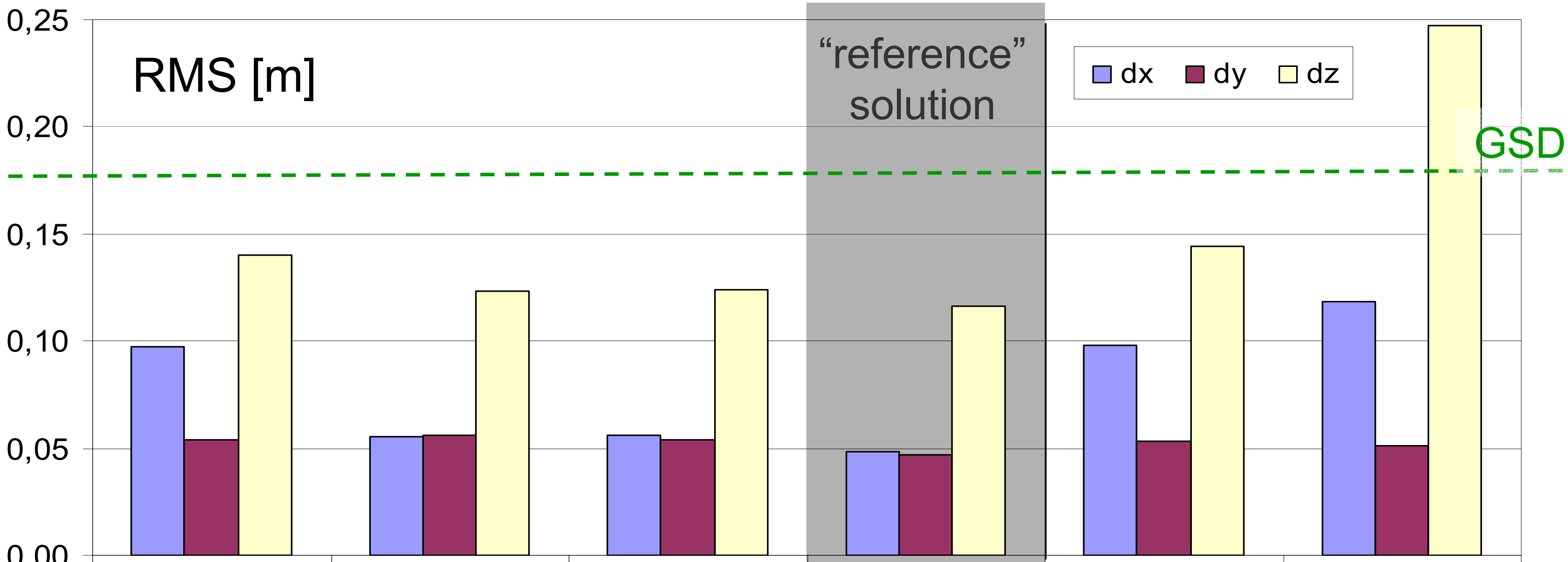
Digital Camera Calibration

The DMC & UCD results

(Phase 2b only)

Phase 2b – DMC high, GSD 0.18m

ifp solutions



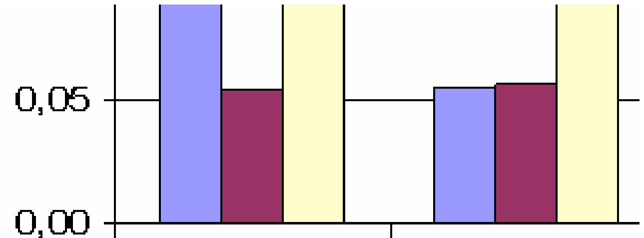
	ifp	ifp	ifp	ifp	ifp	ifp
	no	p44	p44 sign	p44 all cp	no	no
	dgap	dgap	dgap	dgap	patb	patb
STD [m] GCPs.	0.02	0.02	0.02	0.02	0.02	0.01
	0.02	0.02	0.02	0.02	0.02	0.01
STD [um] Image pts.	3	3	3	3	3	3,6
	3	3	3	3	3	1,2

Remarks to the reader

ifp versions

No SC	like participants, only based on 21 GCPs
P44	Gruen parameters from 21 GCPs, like participants
P44 sign	like P44 variant but only significant parameters used
P44 all cp	Gruen parameters estimated from all ground points (GCP + ChP), only significant terms corrected, this control point data data was not accessible to participants

The different numbers at the bottom of each table have to be interpreted like follows:



ifp	ifp	participant
no	p44	approach
dgap	dgap	bundle SW
0.02	0.02	vertical std.dev. GCP [m]
0.02	0.02	horizontal std.dev. GCP [m]
3	3	manual image points std.dev. [um]
3	3	automatic tie points std.dev. [um]

Phase 2b – DMC & UCD

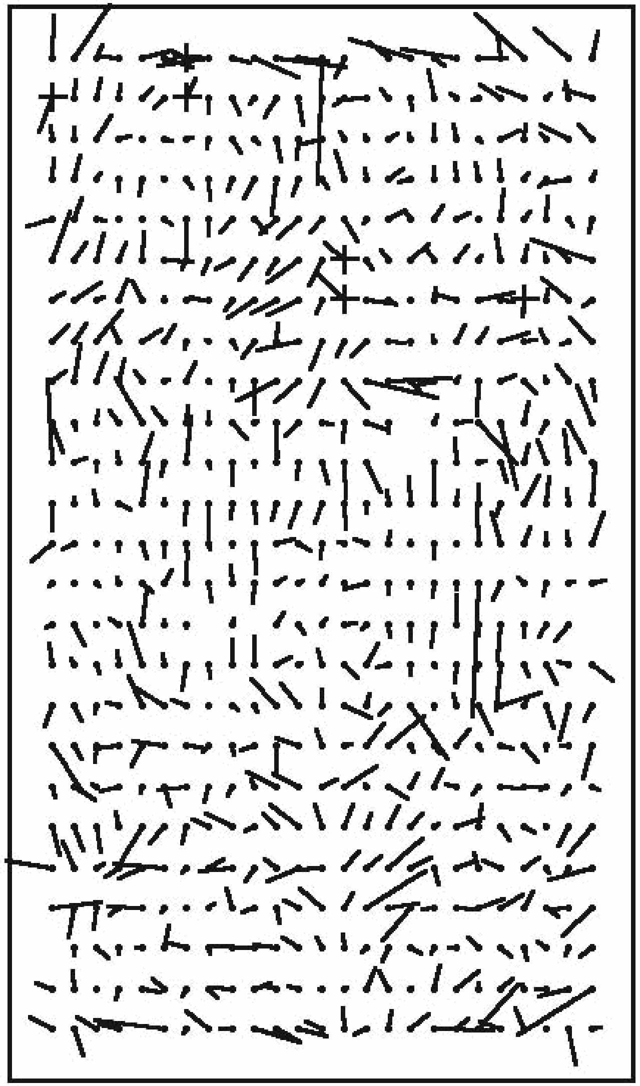
ifp "reference" solutions

Flight	H [m]	GSD [m]	RMS		
			X [m]	Y [m]	Z [m]
DMC	950	0.10	0.040	0.048	0.132
DMC	1800	0.18	0.048	0.047	0.116
UCD	1900	0.17	0.076	0.060	0.059
UCD	3800	0.34	0.048	0.068	0.103

- RMS values from check point differences
- in all cases **44 significant Gruen parameters** introduced, from all available ground points (GCPs and ChPs)
- Input std.dev. used for weighting:
  - image points 3um
  - GCPs 2cm

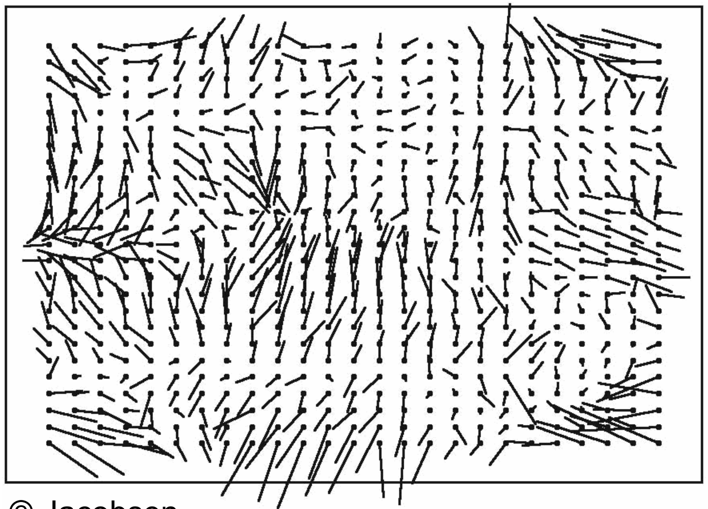
Image coordinate residuals
AT without add. params

DMC



© Jacobsen

3.0



© Jacobsen

UCD

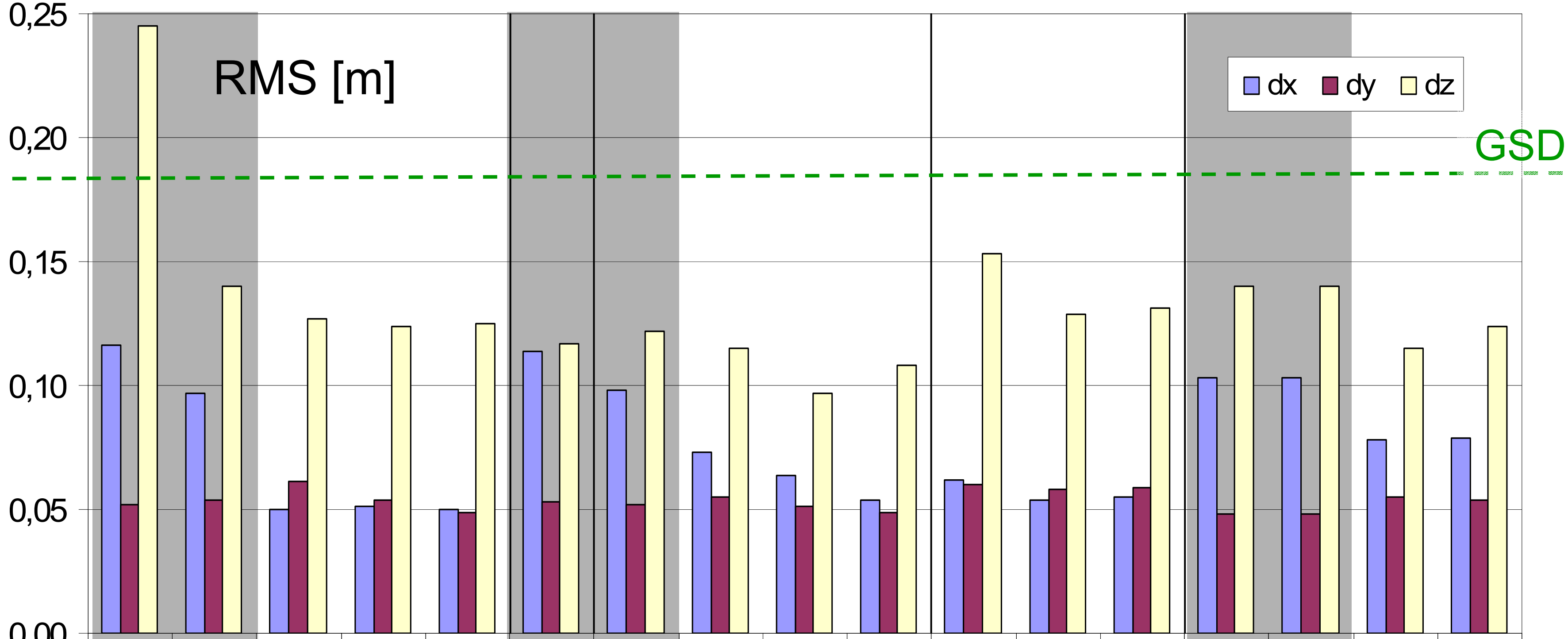
3.0

Overlay of residuals from both flying heights (low & high)

Phase 2b – DMC high

GSD 0.18m, h_g 1800m

No SC

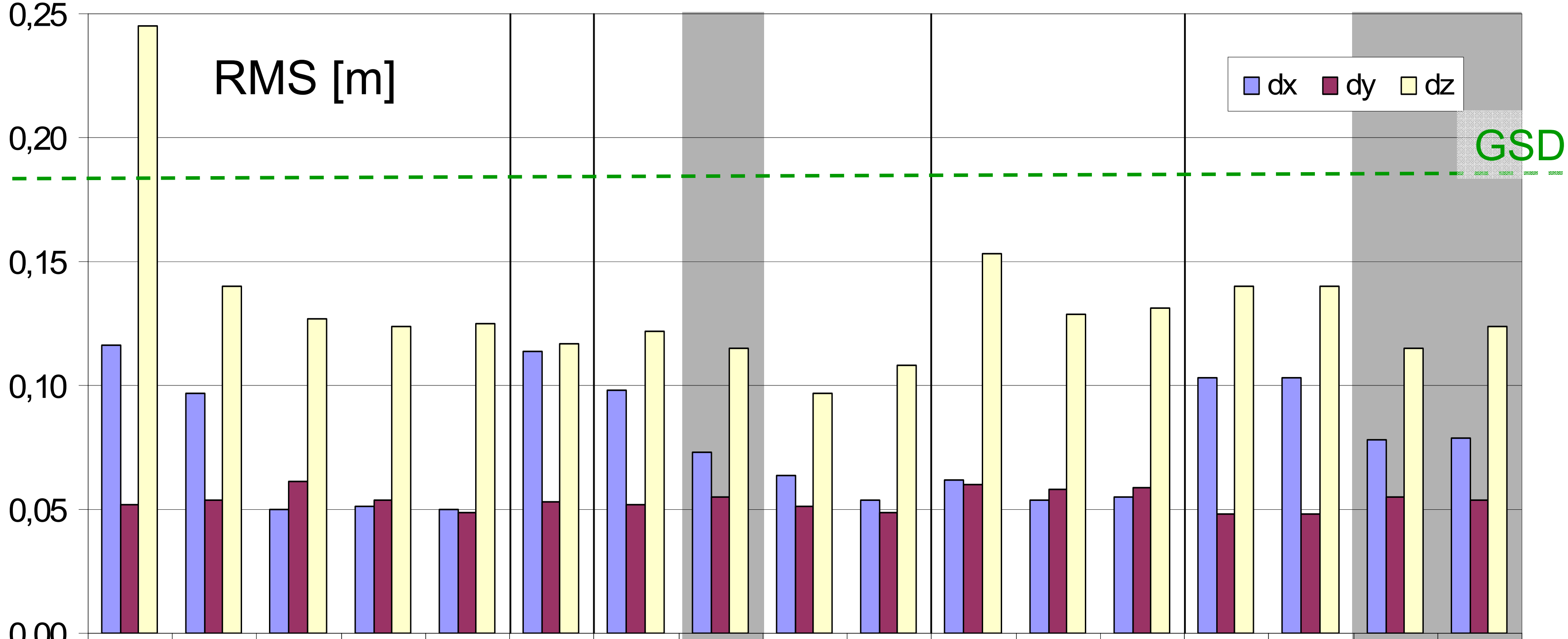


	ETH	ETH	ETH	ETH	ETH	CSIRO	IPI	IPI	IPI	IPI	ICC	ICC	ICC	IngrZI	IngrZI	IngrZI	IngrZI
	no	no	Ebner V0	Ebner V4	Gruen V0	no	no	par1-12	par1-12, 79-80	par1-12,30-	12 per quad.	12 per quad.	12 per quad.	no	no	Ebner	Ebner
	ETH	ETH	ETH	ETH	ETH	CSIRO	BLUH	BLUH	BLUH	BLUH	ACX	ACX	ACX	IngrZI	IngrZI	IngrZI	IngrZI
STD [m]	0.01	0.02	0.02	0.02	0.02		0.04	0.04	0.04	0.04	0.05	0.025	0.025	0.1	0.08	0.1	0.08
GCPs.	0.01	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.1	0.06	0.1	0.06
STD [um]	3,6	3	3	3	3		3	3	3	3	6	2,5	5	5	3	5	3
Image pts.	1,2	3	3	3	3		3	3	3	3	2	2	5	5	3	5	3

Phase 2b – DMC high

GSD 0.18m, h_g 1800m

Standard params



	ETH	ETH	ETH	ETH	ETH	CSIRO	IPI	IPI	IPI	IPI	ICC	ICC	ICC	IngrZI	IngrZI	IngrZI	IngrZI
	no	no	Ebner V0	Ebner V4	Gruen V0	no	no	par1-12	par1-12, 79-80	par1-12,30-	12 per quad.	12 per quad.	12 per quad.	no	no	Ebner	Ebner
	ETH	ETH	ETH	ETH	ETH	CSIRO	BLUH	BLUH	BLUH	BLUH	ACX	ACX	ACX	IngrZI	IngrZI	IngrZI	IngrZI
STD [m] GCPs.	0.01	0.02	0.02	0.02	0.02		0.04	0.04	0.04	0.04	0.05	0.025	0.025	0.1	0.08	0.1	0.08
	0.01	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.1	0.06	0.1	0.06
STD [um] Image pts.	3,6	3	3	3	3		3	3	3	3	6	2,5	5	5	3	5	3
	1,2	3	3	3	3		3	3	3	3	2	2	5	5	3	5	3

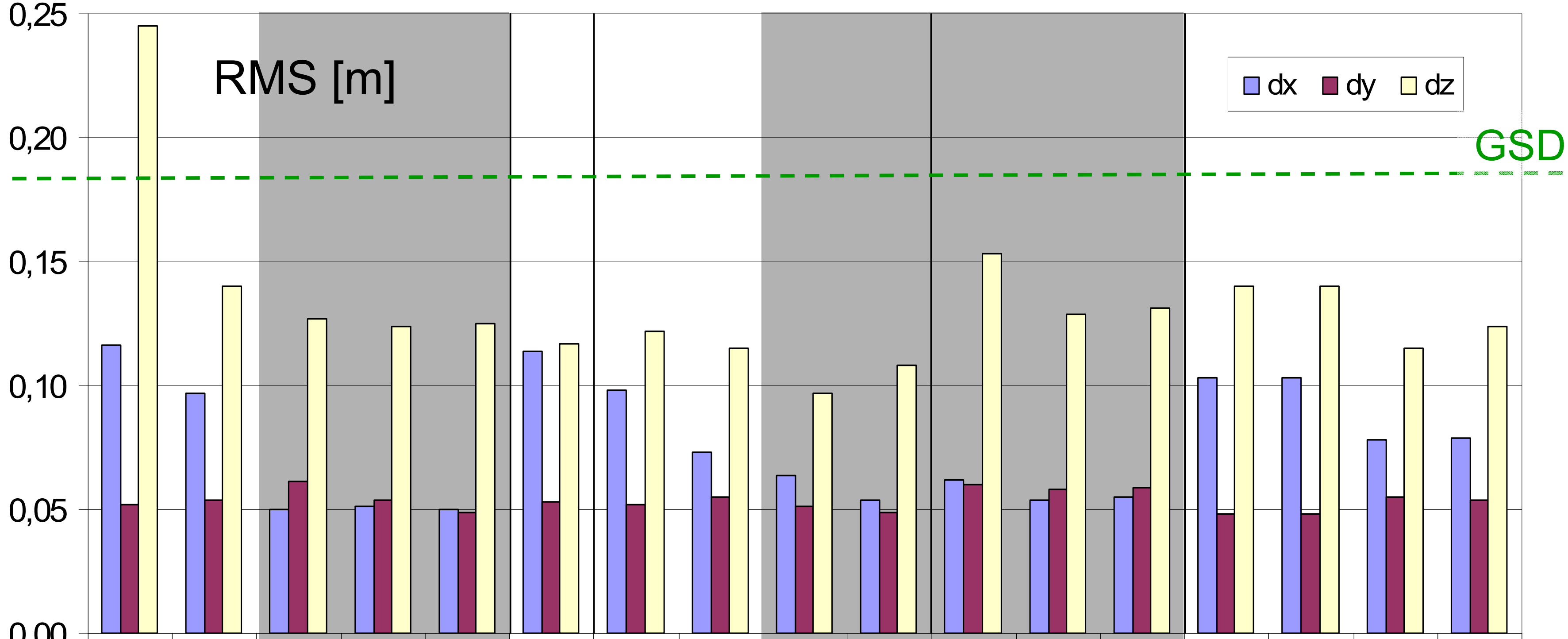
Phase 2b – DMC high

GSD 0.18m, h_g 1800m

DMC params

The test flight results

ersität Stuttgart



	ETH	ETH	ETH	ETH	ETH	CSIRO	IPI	IPI	IPI	IPI	ICC	ICC	ICC	IngrZI	IngrZI	IngrZI	IngrZI
	no	no	Ebner V0	Ebner V4	Gruen V0	no	no	par1-12	par1-12, 79-80	par1-12,30-	12 per quad.	12 per quad.	12 per quad.	no	no	Ebner	Ebner
	ETH	ETH	ETH	ETH	ETH	CSIRO	BLUH	BLUH	BLUH	BLUH	ACX	ACX	ACX	IngrZI	IngrZI	IngrZI	IngrZI
STD [m] GCPs.	0.01	0.02	0.02	0.02	0.02		0.04	0.04	0.04	0.04	0.05	0.025	0.025	0.1	0.08	0.1	0.08
	0.01	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.1	0.06	0.1	0.06
STD [um] Image pts.	3,6	3	3	3	3		3	3	3	3	6	2,5	5	5	3	5	3
	1,2	3	3	3	3		3	3	3	3	2	2	5	5	3	5	3

Remarks to the reader

ETH versions

no	no SC, notice different weighting of a priori observations
Ebner V0/V4	12 Ebner parameters estimated for 4 image patches / quadrants
Gruen V0	44 Gruen parameters estimated for 4 image patches / quadrants

CSIRO version

no	no SC, no values given for a priori weights

IPI versions

no	no SC parameters used
par1-12	12 standard BLUH parameters
par1-12, 78-80	12 standard BLUH params plus two additional params (view angle (78) and rad. distortion (80) for all heads together)
par1-12, 30-41, 74-77	12 standard BLUH params plus additional params describing individual DMC sub-image geometry

ICC versions

12/quadr.	12 Ebner parameters used for each quadrant of the virtual image, note different weights

Ingr.ZI versions

no	no additional SC parameters estimated (no self-calibration, no IMU misalignment, drift, datum)
Ebner	12 Ebner parameters used for the image, note different weightings

ifp

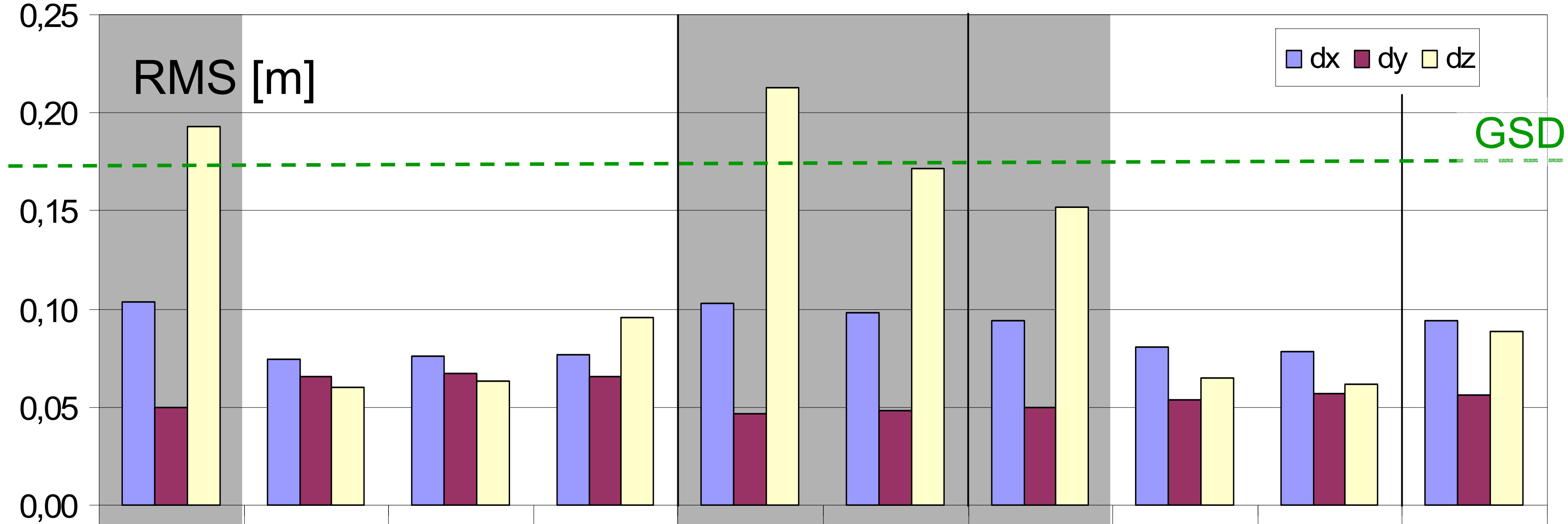
Phase 2b – UCD low

GSD 0.17m, h_g 1900m

No SC

The test flight results

Universität Stuttgart



	ETH	ETH	ETH	ETH	CSIRO	CSIRO	IPI	IPI	IPI	Vexcel
	no	gruen	ebner v0	gruen v0	Conf.B	Conf.C	no	par1-12	par1-	
	ETH	ETH	ETH	ETH	In House	In House	BLUH	BLUH	BLUH	BINGO
STD [m] GCPs.	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
STD [um] Image pts.	3	3	3	3			2	2	2	
	3	3	3	3			2	2	2	

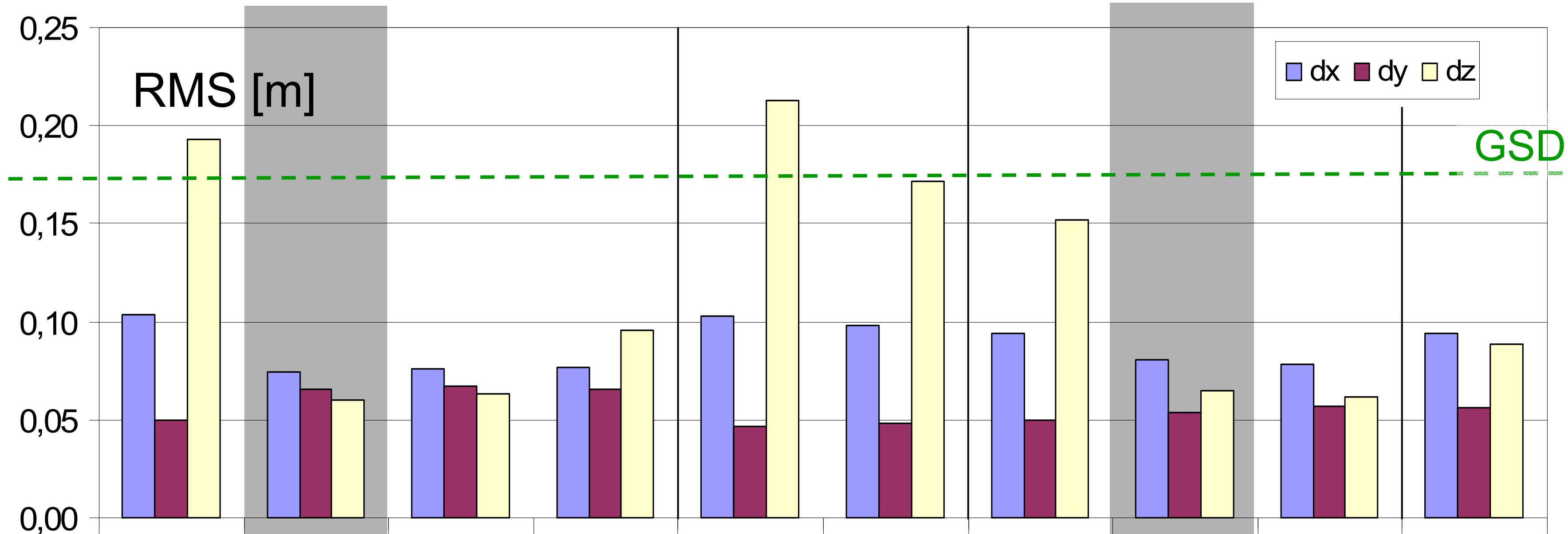
Phase 2b – UCD low

GSD 0.17m, h_g 1900m

Standard params

The test flight results

Universität Stuttgart

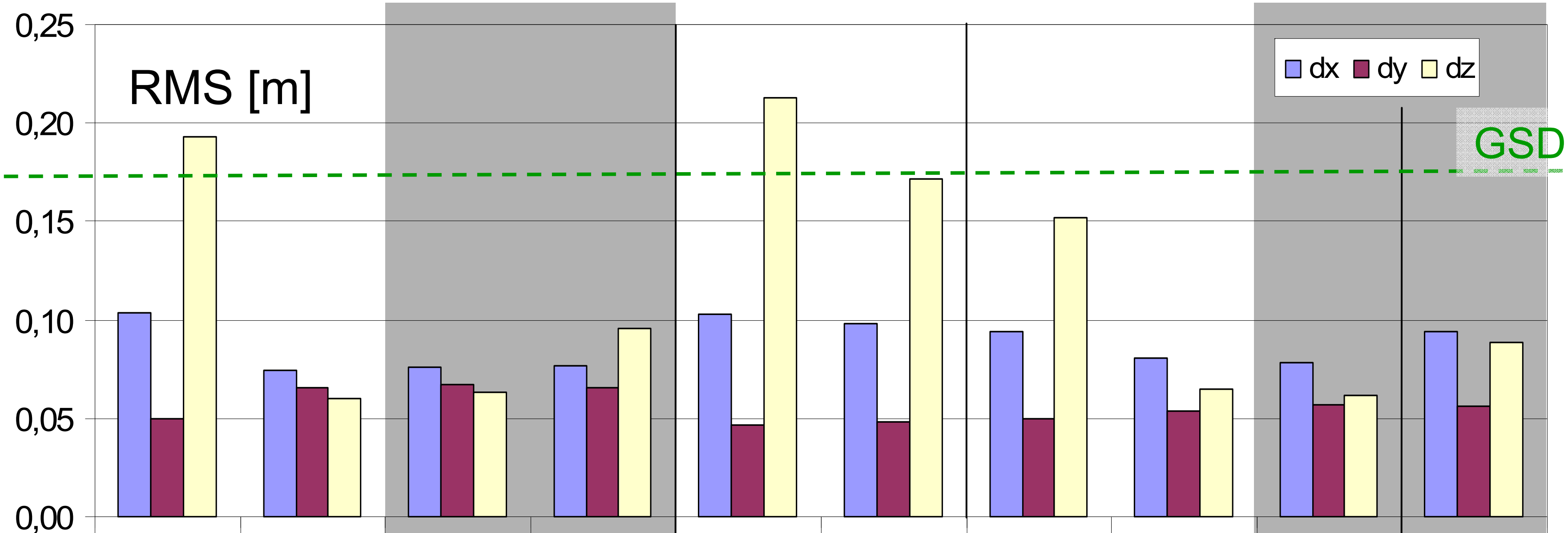


	ETH	ETH	ETH	ETH	CSIRO	CSIRO	IPI	IPI	IPI	Vexcel
	no	gruen	ebner v0	gruen v0	Conf.B	Conf.C	no	par1-12	par1-	
	ETH	ETH	ETH	ETH	In House	In House	BLUH	BLUH	BLUH	BINGO
STD [m] GCPs.	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
STD [um] Image pts.	3	3	3	3			2	2	2	
	3	3	3	3			2	2	2	

Phase 2b – UCD low

GSD 0.17m, h_g 1900m

UCD params



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STD [m] GCPs.	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
STD [um] Image pts.	3	3	3	3			2	2	2	
	3	3	3	3			2	2	2	

Remarks to the reader

ETH versions

no	no SC, notice different weighting of a priori observations
Gruen	44 Gruen parameters for the virtual image
Ebner V0	12 Ebner parameters estimated for 9 image patches, 15pix buffer between patches
Gruen V0	44 Gruen parameters estimated for 9 image patches, 15pix buffer between patches

CSIRO version

Conf.B	no SC, only use of the 4 long strips, no values given for a priori weights given
Conf.C	no SC, using all flight lines (4 long strips and 1 cross strip), no values for a priori weights given

IPI versions

no	no SC parameters used
par1-12	12 standard BLUH parameters
par1-12, 42-73	12 standard BLUH params plus additional params describing individual UCD sub-CCD patch geometry

ifp

Results from the EuroSDR network on

Digital Camera Calibration

Conclusions and outlook

Conclusions

- **self calibration seems to be necessary to improve object space accuracy for all three tested camera types**
  - Self-calibration is of larger influence for DMC and UCD compared to ADS
  - systematic corrections for UCD are more significant compared to DMC
- **a priori weightings** are also of influence (phase 2b), in some cases choice of weighting factors exceeds effect of additional parameter set
- in some cases **special parameter sets** adopted to sensor geometry seem to be necessary; **standard parameters** like Ebner or Gruen in some cases are not able to fully compensate the systematic errors
- **a priori recommendation of optimal additional parameter set is difficult or even not possible**

Outlook

- **Project now finalized,** final report pending, expected in fall this year

- Two **new EuroSDR projects** currently in their design phase, follow-ups of Camera Calibration Network
  - **Performance of Medium Format Digital Airborne Cameras**
    Project leader: Dr. G. Grenzdörffer, Universität Rostock
  - **Radiometric Aspects of Digital Airborne Imagery**
    Project leader: tbd

- New EuroSDR initiative in **European Digital Airborne Camera Certification (EuroDAC²)**

⇨ **Invitation to actively participate !**

More information, contact & links

EuroSDR

www.ifp.uni-stuttgart.de/eurosdr

- this **power point presentation** (next week)
- **final project report** (fall this year)
- some **more details** on calibration network

- New **follow-up projects** on medium format cameras and radiometry (as soon their design is completed)

- **EuroDAC² - European initiative on Digital Airborne Camera Calibration**