

# **Geodätisch-geophysikalische Arbeiten in der Schweiz**

(Fortsetzung der Publikationsreihe  
«Astronomisch-geodätische Arbeiten in der Schweiz»)

herausgegeben von der

**Schweizerischen Geodätischen Kommission**  
(Organ der Akademie der Naturwissenschaften Schweiz)

**Fünfundsiebziger Band**  
**Volume 75**

**Mutual Validation of Satellite-  
Geodetic Techniques and its Impact  
on GNSS Orbit Modeling**

Claudia Flohrer

2008

# Contents

<b>Contents</b>	i
<b>List of Figures</b>	v
<b>List of Tables</b>	xi
<b>List of Acronyms</b>	xiii
<b>1. Introduction and Motivation</b>	1
<b>2. Modeling the Observables in Satellite Geodesy</b>	5
2.1 The Dynamic Orbit Model for Artificial Satellites . . . . .	5
2.1.1 Orbital Elements . . . . .	6
2.1.2 Equations of Motion of an Artificial Earth Satellite . . . . .	7
2.1.3 Perturbing Forces Acting on a Satellite . . . . .	8
2.1.4 Variational Equations . . . . .	15
2.2 Station Coordinates . . . . .	17
2.3 Reference Systems . . . . .	18
2.3.1 The Terrestrial Reference System . . . . .	19
2.3.2 The Celestial Reference Systems . . . . .	19
2.3.3 Earth Orientation Parameters . . . . .	21
2.4 Parameter Estimation . . . . .	22
2.4.1 Method of Least Squares . . . . .	22
2.4.2 Observation Equations . . . . .	24

<b>3. Observing GNSS Satellites</b>	<b>31</b>
3.1 Characteristics of the Global Navigation Satellite Systems (GNSS) . . . . .	31
3.1.1 GNSS Overview . . . . .	31
3.1.2 GNSS Satellite Attitude . . . . .	38
3.1.3 GNSS Solar Radiation Pressure Modeling . . . . .	43
3.2 GNSS Orbit Determination Based on Microwave Observations . . . . .	48
3.2.1 The IGS Orbit Products . . . . .	49
3.2.2 GNSS Orbit Determination at CODE . . . . .	49
3.2.3 GNSS Orbit Accuracy . . . . .	51
3.3 Astrometric CCD Observations of GNSS Satellites . . . . .	52
3.4 SLR Observations of GNSS Satellites . . . . .	56
<b>4. Mutual Validation of the Different Satellite-Geodetic Techniques</b>	<b>61</b>
4.1 Validating the Astrometric Observation Technique . . . . .	61
4.1.1 Validation Procedure for Astrometric Observations . . . . .	62
4.1.2 Validation Results for Astrometric Observations Using Microwave-based GNSS Orbits . . . . .	65
4.1.3 Validation Results for Astrometric Observations Using SLR-based Orbits	75
4.2 Validating Microwave-based GNSS Orbits Using SLR Observations . . . . .	79
4.2.1 SLR Validation Procedure . . . . .	80
4.2.2 SLR Validation Results . . . . .	82
<b>5. Improvement of the GNSS Orbit Model</b>	<b>89</b>
5.1 Different Solar Radiation Pressure Models . . . . .	90
5.2 Assessing the Quality of the Orbit Model . . . . .	94
5.2.1 ... by Analyzing SLR Residuals . . . . .	94
5.2.2 ... by Analyzing Orbit Differences . . . . .	98
5.2.3 ... by Analyzing Orbit Predictions . . . . .	102
5.2.4 ... by Analyzing Orbit Overlap Errors of One-day and Three-day Arcs	107
5.2.5 ... by Analyzing the Geocenter Coordinates . . . . .	129
5.3 Estimating Different Sets of Dynamic Orbit Parameters . . . . .	130
5.4 Conclusions . . . . .	133

<b>6. Improving GNSS Orbits with SLR</b>	<b>137</b>
6.1 GNSS Orbit Determination Based on Combined Microwave and SLR Data Analysis . . . . .	137
6.1.1 Combination Strategy . . . . .	138
6.1.2 Combined Analysis of Microwave and SLR Observations . . . . .	138
6.1.3 Variance-Covariance Studies for the Combined Analysis of Microwave and SLR Observations of GPS and GLONASS Satellites . . . . .	152
6.1.4 Variance-Covariance Studies for the Combined Analysis of Microwave and SLR Observations of the GIOVE-A Satellite . . . . .	156
6.2 GIOVE-A Orbit Determination Based on SLR Observations . . . . .	159
<b>7. Conclusions and Recommendations</b>	<b>163</b>
<b>A. Observing GNSS Satellites</b>	<b>167</b>
A.1 GNSS Satellite Information . . . . .	167
A.2 SLR Sites . . . . .	172
<b>B. Mutual Validation of the Different Satellite-Geodetic Techniques</b>	<b>173</b>
B.1 SLR Residuals . . . . .	173
<b>C. Improvement of the GNSS Orbit Model</b>	<b>175</b>
C.1 Accelerations Due to Different Solar Radiation Pressure Models . . . . .	175
C.2 Overlap Errors of One-day and Three-day Arcs . . . . .	178