

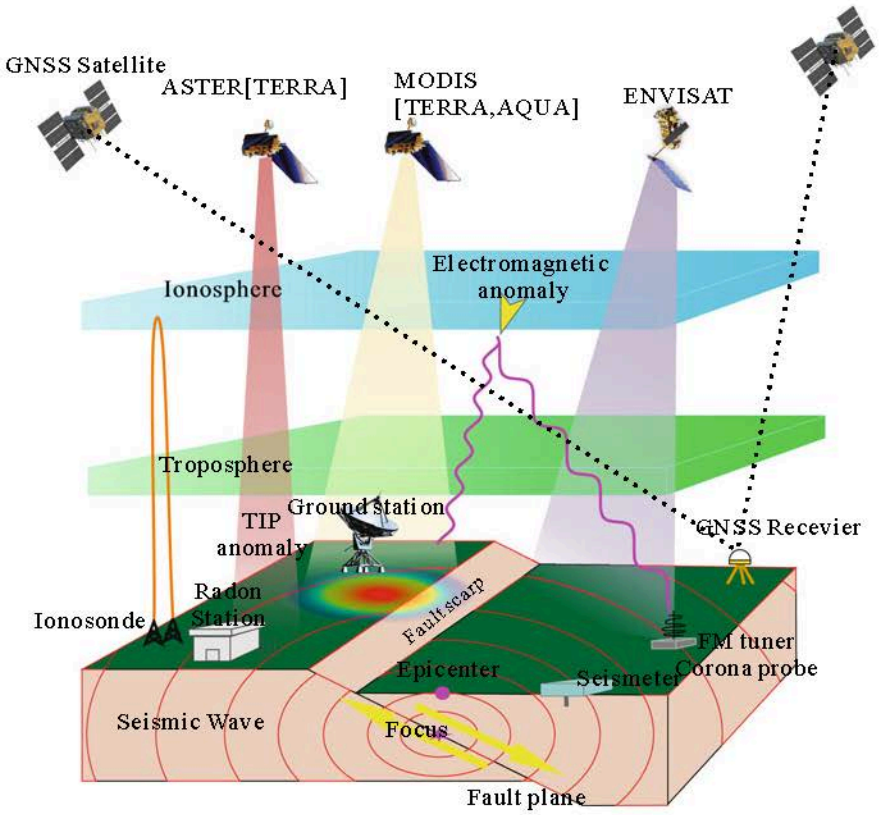
Shuanggen Jin · R. Jin · X. Liu

GNSS Atmospheric Seismology

Theory, Observations and Modeling

 Springer

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Preface

The earthquake is a very complex and broad topic, which is related to various scales motions of the Earth's surface mass and interior as well as the microscopic processes, such as the generation of electric charge and chemical reactions. Also, earthquakes often occur and result in civilian casualties and huge damages as well as secondary disasters, such as tsunami and landslide. Therefore, monitoring and understanding of earthquakes are still a major objective for many countries. The worldwide seismometers could estimate rapidly the location, the magnitude, and the focal mechanism of earthquakes, but the detailed rupture and pre-seismic anomalies are still not clear due to the lack of dense near-field observations and limited observations. Global Navigation Satellite Systems (GNSS), Interferometric Synthetic Aperture (InSAR), seismometer, and gravity measurements could provide unique insights on the size and rupture of the earthquake. However, understanding and prediction of earthquakes are still challenging or difficultly confirmed from traditional technique observations. Nowadays, seismic atmospheric disturbance observations may help us to get a more comprehensive and profound knowledge on the Earth's atmospheric response to the earthquake, volcano, tsunami, and solid Earth/ionosphere coupling, e.g., ionospheric or electromagnet observations.

GNSS is a powerful tool not only for the crust deformation but also the seismic atmospheric-ionospheric variations, especially for regions with dense GNSS continuous operating stations. The neutral atmospheric parameters and ionospheric Total Electron Content (TEC) can be precisely estimated from ground-based GNSS and spaceborne GNSS Radio Occultation, which can be used to investigate the seismic atmospheric-ionospheric disturbances and may provide insights on the earthquake. Recently, several significant seismic ionospheric disturbances were observed from continuous GPS measurements with acoustic waves, Rayleigh wave, and gravity waves, e.g., the 2011 $M_w = 9.1$ Japan earthquake. The seismic ionospheric disturbances are probably driven by the ground-coupled airwaves from ground vertical motion of seismic waves propagating. Some mechanism on atmospheric/ionospheric anomalies and coupling processes between the atmosphere and solid Earth were also discussed. Furthermore, some pre-seismic atmospheric and ionospheric anomalies with several hours to several days before the main shock

onset were also observed in the temperature, TEC, and NmF2 time series. Therefore, GNSS may provide us a new perspective to monitor and understand the earthquake with seismic atmospheric–ionospheric disturbances.

However, the detailed pattern, evolution, and mechanism of the seismic ionospheric disturbance are not clear together with earthquake sources. The relationship between the earthquake and the atmospheric–ionospheric variation is not understood comprehensively up to now. The earthquake threshold and pre-seismic ionospheric disturbances following earthquakes with different magnitudes, focal mechanism, depth, and external conditions are still challenging as well as the mechanism of solid Earth/ocean–atmosphere–ionosphere coupling, which needs to be improved for more cases and be verified with more GNSS measurements. This book presents GNSS atmospheric seismology with some recent progresses.

GNSS Atmospheric Seismology: Methods, Observations and Modelling, has been written as a monograph and textbook that guides the reader through the theory and practice of seismic atmospheric disturbances sounding as well as possible applications. This book includes Chap. 1: Introduction, Chap. 2: Atmospheric Changes and Observations, Chap. 3: GNSS Tropospheric Sounding, Chap. 4: GNSS Ionospheric Sounding, Chap. 5: Detection Methods for Ionospheric Disturbances, Chap. 6: Seismic Lower Atmospheric Anomalies, Chap. 7: Pre-seismic Ionospheric Anomalies, Chap. 8: Co-/Post-seismic Ionospheric Disturbances, Chap. 9: Two-Mode Seismo-ionospheric Disturbances, Chap. 10: Seismo-ionospheric Rayleigh Waves, Chap. 11: Epicenter from Ionospheric Disturbances, Chap. 12: Tsunami Ionospheric Disturbances, Chap. 13: Volcano Atmospheric Disturbances, Chap. 14: Volcanic Plumes Detection from GNSS SNR, and Chap. 15: Summary and Prospective. Chapters 1–4, 6–10 and 12–15 were contributed from Prof. Shuanggen Jin, Chaps. 5 and 11 and part of Chaps. 8 and 10 were contributed from R. Jin, Chaps. 12 and 13 were contributed from X. Liu, Chap. 14 was contributed from Qinyun Zhang, and part of Chap. 10 was contribute from Yuhan Liu as well as part of Chaps. 6 and 7 from Munawar Shah.

This book presents the theory, methods, results, and modeling of GNSS atmospheric seismology for scientists and users who have basic background and experiences in GNSS and seismology. Furthermore, it is also useful for the increasing number of next generation multi-GNSS scientists, engineers, and users' community as well as hazards mitigation and reduction. We would like to thank Assistant Editor's help and Springer-Verlag for their cordial collaboration and help during the process of publishing this book.

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Abbreviations

ABL	Atmospheric Boundary Layer
AGW	Acoustic Gravity Wave
ART	Algebraic Reconstruction Technique
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVO	Alaska Volcano Observatory
BDS	BeiDou Navigation Satellite System
BPR	Bottom Pressure Records
C/A	Coarse/Acquisition
CAS	Chinese Academy of Sciences
CDMA	Code Division Multiple Access
CEA	China Earthquake Administration
CHAMP	Challenging Mini-satellite Payload
CID	Co-seismic Ionospheric Disturbances
CIT	Computerized Ionospheric Tomography
CMONOC	Crustal Movement Observation Network of China
CMT	Centroid Moment Tensor
CODE	Center for Orbit Determination in Europe
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CYGNSS	CYclon GNSS
DART	Deep-ocean Assessment and Reporting of Tsunamis
DCB	Differential Code Biases
DD	Double Difference
DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DGPS	Differential GPS
DOT	Department of Transportation
DOY	Day of Year

Dst	Disturbance storm time
ECMWF	European Centre for Medium-Range Weather Forecasts
EIA	Equatorial Ionization Anomaly
EISCAT	European Incoherent Scatter Scientific Association
ENVISAT	ENVironmental SATellite
ESA	European Space Agency
EST	Equivalent Slab Thickness
EU	European Union
FDMA	Frequency Division Multiple Access
FDSN	International Federation of Digital Seismograph Networks
FDTD	Finite Difference Time Domain
FFT	Fast Fourier Transform
GAGAN	GPS-Aided Geo Augmented Navigation
Galileo	Galileo Navigation Satellite System
GAMIT	GPS analysis software by Massachusetts Institute of Technology
GBAS	Ground-Based Augmentation Systems
GDOP	Geometric Dilution of Precision
GEO	Geostationary Earth Orbit
GEONET	GPS Earth Observation Network in Japan
GFZ	GeoForschungsZentrum Potsdam
GIM	Global Ionospheric Map
GPSY-OASIS	GNSS-Inferred Positioning System and Orbit Analysis
GLONASS	GLOnass NAVigation Satellite System of Russia
GMF	Global Mapping Function
GNSS	Global Navigation Satellite Systems
GNSS-R	GNSS-Reflectometry
GO	Geometric Optics
GOCE	Gravity Field and Steady-State Ocean Circulation Explorer
GPS	Global Positioning System
GPS/MET	GPS/Meteorology
GRACE	Gravity Recovery and Climate Experiment
GSI	Geographical Survey Institute in Japan
GSN	Global Seismographic Network
GTS	Global Telecommunication System
HFI	Hardy Function Interpolation
IAG	International Association of Geodesy
IERS	International Earth Rotation and Reference System Service
IGS	International GNSS Service
IGW	Internal Gravity Wave
InSAR	Interferometric Synthetic Aperture Radar
IPP	Ionosphere Pierce Point
IRI	International Reference Ionospheric
IRIS	Incorporated Research Institutions for Seismology
IRNSS	India's Regional Navigation Satellite Systems
ISR	Ionospheric Scatter Radar

ITRF	IERS Terrestrial Reference Frame
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory
LAAS	Local Area Augmentation System
LC	Linear Combination
LEO	Low Earth Orbit (satellite)
LiDAR	Light Detection And Ranging
LOS	Line of Sight
LS	Least Squares (adjustment)
LST	Land surface temperature
LT	Local Time
MART	Multiplicative Algebraic Reconstruction Technique
MDA	Maximum Disturbance Azimuth
MDD	Maximum Disturbance Distance
MDP	Maximum Disturbance Point
MEO	Medium Earth Orbit
mHz	milli-Hertz
MIT	Massachusetts Institute of Technology
MODIS	MODerate-resolution Imaging Spectroradiometer
MSS	Mean of the Square Slopes
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NGDC	US National Geophysical Data Center
NMF	Niell Mapping Function
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OBSIP	Ocean Bottom Seismograph Instrument Pool
OLR	Outgoing Long-wave Radiation
OMI	Aura/Ozone Monitoring Instrument
PASSCAL	Portable Array Seismic Studies of the Continental Lithosphere
PBO	Plate Boundary Observatory
PNT	Positioning, Navigation and Timing
POD	Precise Orbit Determination
PPP	Precise Point Positioning
PRN	Pseudo-Random Noise
PWV	Precipitable Water Vapor
QOA	Quasi-Optimum Algorithm
QZSS	Quasi-Zenith Satellite System
RINEX	Receiver Independent Exchange
RMS	Root Mean Square
RO	Radio Occultation
RTK	Real-Time Kinematic
SAC-C	Satellite de Aplicaciones Cientificas-C
SD	Single Difference
SHAO	Shanghai Astronomical Observatory

SID	Seismic Ionospheric Disturbance
SIP	Sub-ionospheric Pierce Points
SLM	Single Layer Model
SNR	Signal-to-Noise Ratio
SPIDR	Space Physics Interactive Data Resource
STD	Slant Tropospheric Delay
STEC	Slant Total Electron Content
SVD	Singular Value Decomposition
TEC	Total Electron Content
TECU	Total Electron Content Unit
TID	Traveling Ionospheric Disturbances
TIE-GCM	Thermosphere–Ionosphere–Electrodynamics General Circulation Model
UHF	Ultra High Frequency
UNAVCO	University NAVSTAR Consortium
USGS	US Geological Survey
UT	Universal Time
UTC	Coordinated Universal Time
VEI	Volcanic Explosivity Index
VHF	Very High Frequency
VMF	Vienna Mapping Functions
WGS	World Geodetic System
WVR	Water Vapor Radiometry
ZHD	Zenith Hydrostatic Delay
ZTD	Zenith Tropospheric Delay
ZWD	Zenith Wet Delay