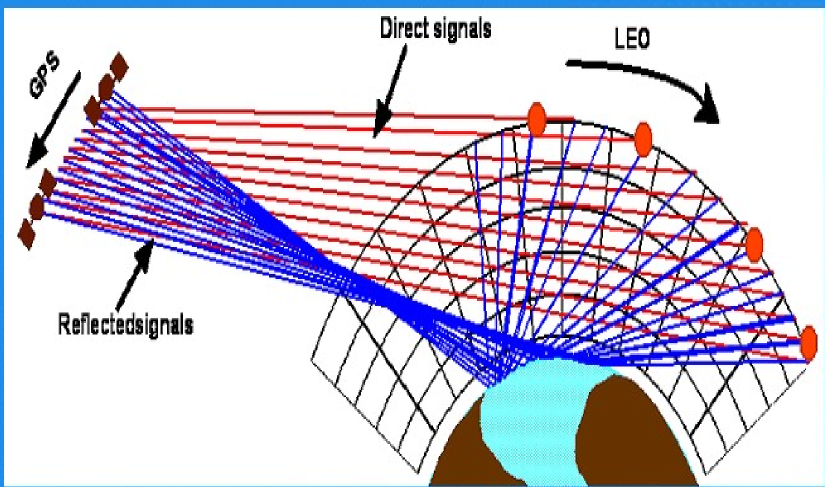
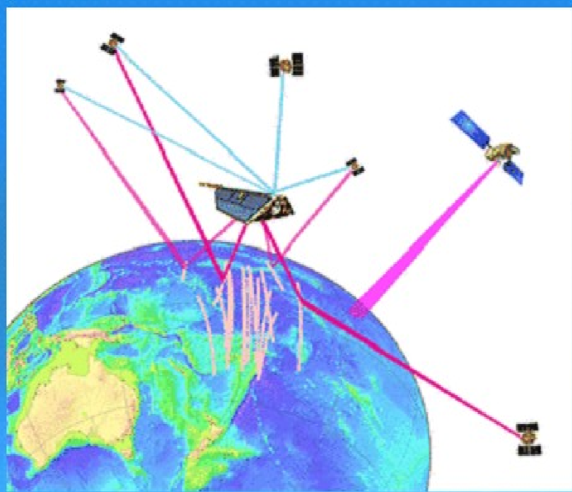
International workshop on GNSS Remote Sensing for Future Missions & Sciences

August 7-9, 2011, Shanghai, China

http://www.shao.ac.cn/GNSS





Venue: 3rd floor of Astronomical Building

Shanghai Astronomical Observatory, Chinese Acad. of Sciences

International workshop on

GNSS Remote Sensing for Future Missions and Sciences

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Emergency Phone: 13167075822
Policeman: 110; Ambulance: 120

Venue: 3rd floor, Astronomical Building
Shanghai Astronomical Observatory, Chinese Academy of Sciences
80 Nandan Road, Shanghai 200030, China

Available WIFI at the workshop with the password at conference hall doors

Sponsors

- International Association of Geodesy (IAG) SG 4.1 "GNSS Remote Sensing & Applications"
- IEEE Geoscience & Remote Sensing Society (IEEE-GRSS)
- Shanghai International Culture Association
- Asia-Pacific Space Geodynamics (APSG), Shanghai, China
- Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences

The Global Navigation Satellite System (GNSS) has been widely used in navigation, positioning and geoscience applications. Recently, the versatile refracted, reflected and scattered signals of GNSS have been successfully demonstrated to sound the atmosphere and ionosphere, ocean, land surfaces (including soil moisture) and the cryosphere as a new remote sensing tool. With the further improvement of the next generation multi-frequency GNSS systems and receivers and new space-based instruments utilizing GNSS reflections and refractions, new scientific applications of GNSS are expected in various environment remote sensing fields in the near future.

The international workshop on "GNSS Remote Sensing for Future Missions and Sciences" will be a forum for assessing current ability and presenting recent results and future developments as well as looking for new collaboration opportunities, joint nanosatellite experiments and missions using GNSS refractometry, reflectometry and scatterometry, e.g., atmospheric and ionospheric sounding using ground and space-borne GPS measurements (CHAMP, GRACE, COSMIC, MetOp, TerraSAR-X, OceanSat-2...), GNSS reflectometry (GNSS-R) in ocean altimetry, and soil moisture and ice/snow status as well as geohazards monitoring/warning (e.g., Hurricane, Typhoon, Tsunami and Earthquake...).

On behalf of the Organizing Committee, we are pleased to invite you to attend the International workshop on GNSS Remote Sensing for Future Missions and Sciences August 7-9, 2011, Shanghai, China. For any questions, please feel free to contact LOC at http://www.shao.ac.cn/gnss

Sincerely yours

Prof. Shuanggen Jin
Chair of GNSS-RS Workshop

Honor Chair:

- Shuhua Ye (Academician, SHAO, China)

Scientific Organizing Committee (SOC)

- Shuanggen Jin (SHAO, China) (Chair)
- Antonio Rius (IEEC, Spain)
- Chris Rizos (UNSW, Australia)
- Christopher Buck (ESA, Holland)
- Naser El-Sheimy (UCalgary, Canada)
- Alain Geiger (ETHZ, Switzerland)
- Farzad Kamalabadi (Uni. IL, USA)
- Yuei-An Liou (NCU, Taiwan)
- Stephen T. Lowe (JPL, USA)
- Yueqiang Sun (CSSAR, China)
- Jens Wickert (GFZ, Germany)

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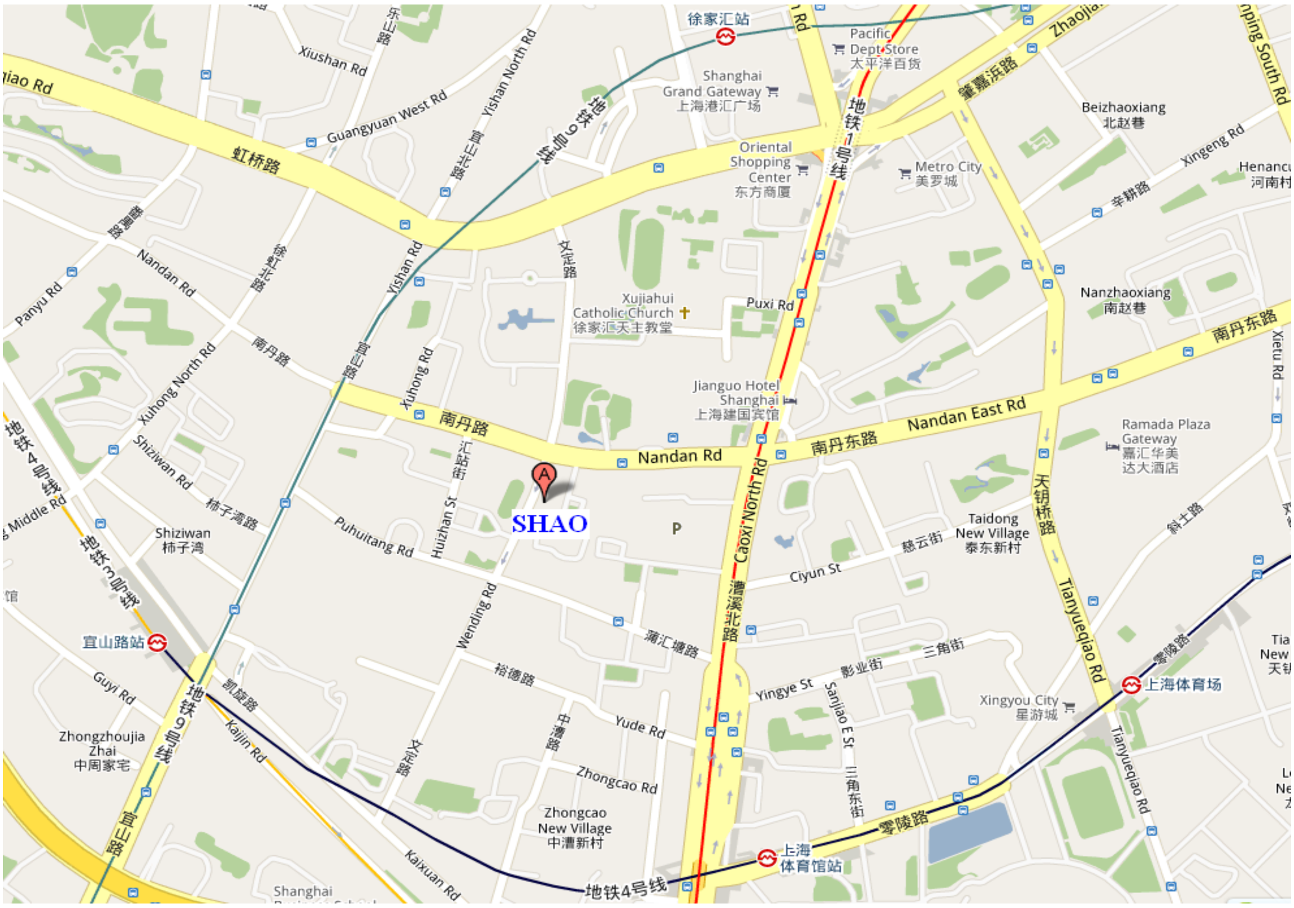
- Xiaotao Chang (SBSM)
- Wenli Dong (SHAO)
- Guiping Feng (SHAO)
- Xiong Hu (CSSAR)
- Shuanggen Jin (SHAO) (Chair)
- Dongkai Yang (BUAA)
- Liangjing Zhang (SHAO)
- Ruixian Zhou (SHAO)

Topics

- Next Generation GNSS and Emerging Applications
- GNSS-R Receiver, Signals and Simulations
- Atmospheric Sensing/Modelling using GNSS
- GNSS Ionosphere & Space Weather/Earthquake
- Ocean Remote Sensing using GNSS-R
- GNSS Seismometer & Tsunami Warning Sensing
- Soil/Vegetable/Ice/Snow Sensing & GNSS Multipath
- Remote Sensing using GNSS and multi-sensor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南丹东路
Nandan East Rd
虹桥路
Guangyuan West Rd
Xiushan Rd
Yishan North Rd
Yishan Rd
宜山路
Xuhong Rd
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Panyu Rd
Puhuitang Rd
Huizhan St
汇站街
Wending Rd
Shiziwan Rd
Shiziwan
柿子湾
Caoxi North Rd
漕溪北路
Puxi Rd
Ciyun St
Yingye St
Sanjiao St
Yude Rd
Zhongcao Rd
Zhongcao New Village
中漕新村
Kaixuan Rd
Kaijin Rd
Guyi Rd
Zhongzhoujia Zhai
中周家宅
宜山路站
徐家汇站
上海体育场
上海体育馆站
地铁4号线
地铁9号线
地铁1号线
零陵路
Tianyueqiao Rd
天钥桥路
Xujiahui Catholic Church
徐家汇天主教堂
Jianguo Hotel Shanghai
上海建国宾馆
Shanghai Grand Gateway
上海港汇广场
Oriental Shopping Center
东方商厦
Pacific Dept Store
太平洋百货
Metro City
美罗城
Beizhaoxiang
北赵巷
Nanzhaoxiang
南赵巷
Xingeng Rd
Ramada Plaza Gateway
嘉汇华美达大酒店
Taidong New Village
泰东新村
Xingyou City
星游城
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Zhaojiabang Rd
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罗店镇
Changxingxiang
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Lujiazhen
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Huaqiaozhen
花桥镇
Gaoqiaozhen
高桥镇
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上海高东海上救助机场
Hengshaxiang
横沙乡
Putuo
普陀区
Zhabei
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Yangpu
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Changning
Pudong Xinqu
浦东新区
Heqingzhen
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Shanghai Hongqiao International Airport
上海虹桥国际机场
Xuhui
徐汇区
Qingpu
青浦区
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Sijingzhen
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Pujiangzhen
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Tinglinzhen
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朱行镇
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奉新镇
Zhangyanzhen
张堰镇
Guangchenzhen
Jinshan
G2 Jinghu Expy
S5 Hujia Expy
G50沪渝高速
S32 Shenjiahu Expy
G15 Shenhai Expy
S19 Xinwei Expy
S2 Hulu Expy
S4沪金高速
S36亭枫高速
大亭公路
S2沪芦高速
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东海大桥
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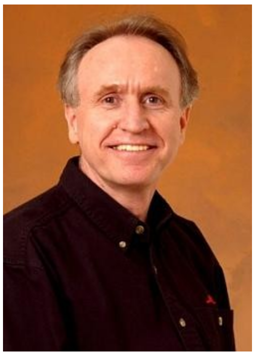
Astronomical Building of Shanghai Astronomical Observatory, CAS

25m radio telescope, 1.56m reflector, SLR, GPS etc. at SHAO

Shuhua Ye, female and Astronomer, was an Academician of Chinese Academy of Sciences. She was Director of Shanghai Astronomical Observatory in 1981-1993 and the vice president of the International Astronomical Union in 1988-1994. She is vice-president of the Chinese Association for Science and Technology, and member of the Standing Committee of the National Congress of P.R.China. In the 1990's, she has been the chief scientist for a major state basic research project "Investigation on Recent Crustal Motion and Geodynamics". As an extension of this project, in 1994, she initiated an international project, entitled "Asia-Pacific Space Geodynamics" as chairperson of the Management Board, which was endorsed by the International Association of Geodesy.



Thomas P. Yunck, Founder and President of GeoOptics, Inc., was a manager and researcher at NASA's Jet Propulsion Laboratory for 30 years, where he developed space remote sensing techniques for Earth science applications. He is also a past president of the Federation of Earth Science Information Partners. In 1988 he co-wrote the first proposal for exploiting GPS radio signals to sound the Earth's atmosphere for weather and climate applications. In 1992 he proposed the concept for the Gravity Recovery and Climate Experiment (GRACE), which is now in its ninth year of operation. Yunck holds the basic patent on the "state space" approach to wide area differential GPS positioning. Dr. Yunck is currently principal investigator for NASA's Climate Virtual Observatory (CVO), an online system to integrate observational data from space sensors for environmental studies. He holds a Ph.D. in Systems and Information Science from Yale University.

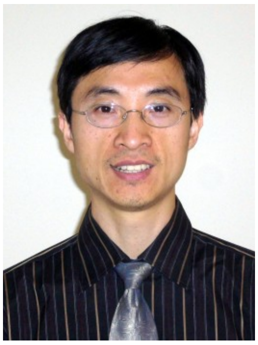
Chris Rizos is currently Professor and Head of the School of Surveying and Spatial Information Systems, University of New South Wales, Australia. He has been researching the technology and high precision applications of GPS since 1985, and has published over 400 journal and conference papers. He is a Fellow of the Australian Institute of Navigation and a Fellow of the International Association of Geodesy (IAG). He is currently the President of the International Association of Geodesy (IAG) and a member of the Executive and Governing Board of the International GNSS Service (IGS).

Antonio Rius received the Ph.D. degree in astrophysics from Barcelona University, Barcelona, Spain, in 1974. From 1975 to 1985, he was a Member of the Technical Staff at NASA's Deep Space Communications Complex, Madrid, Spain, where he was responsible for the radio astronomical activities. Since 1986, he has been with the Spanish Consejo Superior de Investigaciones Cientı´ficas, Barcelona. He is currently responsible for the research group on Earth Observation at the Institut d'Estudis Espacials de Catalunya (IEEC). His current research interests include applications to Earth Science of the Global Navigation Satellite Systems, particularly GNSS Reflectometry (GNSS-R).

Alain Geiger is Professor at the Geodesy and Geodynamics Lab of the Institute of Geodesy and Photogrammetry, Eidgenössische Technische Hochschule Zürich (ETH Zürich), Switzerland. He received an M.S. degree in physics and a Ph.D. in geodesy and geodynamics, both from ETH Zurich. He was National Correspondent of International Association of Geodesy (IAG) (2003-2007). His main interesting is GPS meteorology and GPS water vapor tomography.

Gottfried Kirchengast is currently the Director of Wegener Center for Climate and Global Change (WEGC) at the University of Graz and of its Climate and Environmental Change Research and Monitoring Program. He is also Head of the Atmospheric Remote Sensing and Climate Systems (ARSCliSys) Research Group and Head of Geophysics & Meteorology at the Institute of Geophysics, Astrophysics and Meteorology (IGAM)/Institute of Physics University of Graz. His main interesting is atmospheric remote sensing from space and its applications for climate research. He has received several prestigious research awards, including Austria's most prestigious and best endowed discretionary research funding awards, the START and Wittgenstein prizes.

Urs Hugentobler is Professor at the Institute for Astronomical and Physical Geodesy, Technical University Munich and head of the Forschungseinrichtung Satellitengeodäsie that contributes to research and operations at the German geodetic observatory in Wettzell. He is currently the Chair of the Governing Board of the International GNSS Service (IGS). For 1999-2006, he has been Head of the GPS research group at the Astronomical Institute of the University of Bern, responsible for the CODE (Center for Orbit Determination in Europe) Analysis Center of the International GNSS Service (IGS) and the developments of the Bernese GPS Software.



Shuanggen Jin is Professor and Group Head at the Shanghai Astronomical Observatory, Chinese Academy of Sciences. His main research areas include Satellite Navigation & Positioning, Remote Sensing & Climate Change, and Space/Planetary Geomatics & Dynamics. He has over 70 peer-reviewed journal papers as the lead author in JGR, EPSL, GJI, IEEE, J. Geodesy etc., 10 books/chapters and more than 100 proceeding papers. He has been President of the IAG Sub-Commission 2.6 (2011-2015), Chair of the IAG SG 4.1 (2007-2011), Editor-in-Chief of Int. J. Geosci. (2010-), Editor of J. Geod. Sci. (2010-), Guest Editor of Adv. Space Res. (2009-2011). He has received several awards/honors including Special Prize of the Korea Astronomy and Space Science Institute (2006), One-Hundred Talents Program of the Chinese Academy of Sciences (2010) and Fellow of International Association of Geodesy (IAG) (2011).

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1. Program Schedule

	Saturday 6th August 2011
14:00-17:00	**Registration (Third floor of SHAO)**
	Sunday 7th August 2011
08:00-12:00	**Registration (Third floor of SHAO)**
09:00-09:10	**Opening Ceremony** **Chair: Shuanggen Jin**
09:10-10:10	**Keynote (Room A)** **Chair: Danan Dong, Farzad Kamalabadi**
09:10-09:40	CICERO: Community Initiative for Continuing Earth Radio Occultation Thomas P. Yunck (President), GeOptic Inc., USA
09:40-10:10	GNSS radio occultation and LEO-LEO occultation for meteorology and climate: What's achieved & what's next Gottfried Kirchengast, Uni-Graz, Austria
	Take photo at first floor & Coffee Break
10:30-12:40	**Plenary Session (Room A)** **Chair: Chris Rizos, Xuhui Shen**
10:30-10:50	GNSS as an Atmosphere & Sea Surface Observing Technology: Prospects, Plans, Promises & Challenges Chris Rizos (IAG President), University of New Wales, Australia
10:50-11:10	Aircraft GNSS-R Interferometry Experiment in the Gulf of Finland Antonio Rius, IEEC, Spain
11:10-11:30	New Satellite Systems and New Signals Urs Hugentobler (IGS Chair), Technische Universitaet Muenche, Germany
11:30-11:50	The 1st China Seismo-Electromagnetic Satellite and its GNSS & Three-frequency Transmitter onboard Xuhui Shen, Institute of Earthquake Science, CEA, China
11:50-12:40	**Panel discussion** **(Thomas Yunck, Gottfried Kirchengast, Antonio Rius, Chris Rizos, Urs Hugentobler, Xuhui Shen)**
	Lunch (Cafeteria, 2nd floor of Active Center Building)
13:30-15:35	**Session 1: Next generation GNSS system and Applications (Room A)** **Chair: Urs Hugentobler, Yang Fu**
13:30-13:50	Next generation of European iniaturized space receivers compatible with new GNSS signals Josep Rosell, ESA/ESTEC, Netherlands
13:50-14:05	The development of the third generation GNSS receiver Lei Huang, Unicore Communication Inc., China
14:05-14:20	Determination of refractivity variations with GNSS and ultra-stable frequency standards Markus Vennebusch, Leibniz-Universität Hannover, Germany
14:20-14:35	Detecting Tsunami Genesis and Scales Directly from Coastal GPS Stations Y. Tony Song, NASA Jet Propulsion Laboratory, USA

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<tr><td>14:50-15:05</td><td colspan="2">Observing Earth-dynamics using GNSS: Perspective of the CMONOC Network
Junping Chen, Shanghai Astronomical Observatory, CAS, China</td></tr>
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<tr><td></td><td colspan="2">Coffee Break</td></tr>
<tr><td>15:45-17:30</td><td>Session 2A: GNSS Atmospheric Sounding & Effects (Room A)
Chair:Giovanni Occhipinti,Chunmin Wang</td><td>Session 2B: Round table on international collaboration (Room B)
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<tr><td>15:45-16:00</td><td>Long-term variation of total electron contents over Daejeon measured from Global Positioning System between 2000 and 2010
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Some specific suggestions
1) Status of COSMIC-2.
2) CICERO, how could we join and support the international CICERO program with about 100 satellites?
3) Radio Occultation Science On Iridium NEXT
4) The 1st China Seismo-Electromagnetic Satellite
5) GNSS-R share and discussion, e.g. experiments, data share or collaboration
6) Other joint small satellite with GNSS-R?
7) New small gravity missions with GNSS.
8) Join program in Pacific Rim with ocean and tectonics hazards?
….</td></tr>
<tr><td>16:00-16:15</td><td>An evaluation of solar radio emission power level as a potential threat of GPS/GLONASS performance
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<tr><td>16:45-17:00</td><td>Reconstruction of water vapor tomography based on ground-based GPS measurements and its validation: A test case in South Korea
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Debao Wen, Changsha University of Science & Technology, China</td></tr>
<tr><td>17:15-17:30</td><td>Assimilation of GPS/TEC Data in Global and Regional Ionospheric Models
Yiyan Zhou, Institute of Seismology, China Earthquake Administration, China</td></tr>
<tr><td>18:30-21:00</td><td colspan="2">Banquet (2nd floor, Sports Hotel) (Addressed by Shuhua Ye)</td></tr>
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	Monday 8th August 2011	
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08:15-08:30	Impact of a priori tropospheric zenith delay on temporal and spatial variability of GPS based PWV M.S.M. Vijayan, CSIR Centre for Math. Modelling & Computer Simulation (C-MMACS), INDIA	
08:30-08:45	Using ground-based GPS data to estimate long term trends in the atmospheric water vapour content Tong Ning, Chalmers University of Technology, Sweden	
08:45-09:00	Wet Refractivity tomographic reconstruction over small areas using an ad-hoc GPS receivers network Riccardo Notarpietro, Politecnico di Torino, Italy	
09:00-10:15	**Session 4: GNSS Ionosphere Sounding & Space Weather (Room A)** **Chair: Riccardo Notarpietro, Xiong Hu**	
09:00-09:15	Ionospheric Imaging and Tomography using GNSS Kunitsyn V.E. M.Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia	
09:15-09:30	Estimation of Ionospheric Total Electron Content based on GPS Carrier Phase Measurements Chang-Moon Lee, Inha University, Korea	
09:30-09:45	A Potential Broadcast Ionosphere Model for Future Single-Frequency User of COMPASS Yunbin Yuan, WHIGG, China	
09:45-10:00	Ionospheric super-bubble effects on the GPS positioning V. V. Demyanov, Institute of Solar and Terrestrial Physics SB RAS, Russia	
10:00-10:15	GAIM Development to Serve Space Weather Applications and Research Xiaoqing Pi, JPL, USA	
	Coffee Break	
10:25-12:40	**Session 5A: GNSS Radio Occultation and Applications (Room A)** **Chair: Gottfried Kirchengast, Sridevi Jade**	**Session 5B: GNSS Seismometer & Tsunami Warning Sensing (Room B)** **Chair: Y. Tony Song, Xiaotong Chao**
10:25-10:40	Study of global stratospheric gravity waves with COSMIC data Rui Wang, Shanghai Astronomical Observatory, CAS, China	Three-dimensional numerical modeling of tsunami-related internal gravity waves in the Hawaiian atmosphere Giovanni Occhipinti, IPGP, France
10:40-10:55	Integration of ground and space-based GNSS observations for severe weather monitoring Witold Rohm, WROC, Poland	Co-seismic slip and rupture of the 2011 Mw 9.1 Tohoku Earthquake from GPS observations Zhicai Li, Geodesy Department, National Geomatics Center of China
10:55-11:10	A modified sliding spectral method for GPS radio occultation Xiansheng Xu, Shanghai Astronomical Observatory, CAS, China	Comparison of tsunami arrival times along the west coast of India using different GIS techniques & the Tsunami N2 model for a source in Makran region. Kirti Srivastava, National Geophysical Research Institute (CSIR), India.

11:10-11:25	Research of Tropopause Temperature and Height Variation with COSMIC Data Xiaoyong Du, Beijing Institute of Applied Meteorology, China	GNSS Seismology – Real – Time Monitoring of Co-Seismic Motion During the Great Eastern Japan Earthquake Masayuki Kanzaki, Hitachi Zosen Corp., Japan
11:25-11:40	Non-spherically symmetric inversion of ionospheric radio occultation data Guo Peng, Shanghai Astron. Observatory, CAS	First Real-Time Detection and Warning of Tsunami Waves with GPS Ocean Buoys Masayuki Kanzaki, Hitachi Zosen Corp, Japan
11:40-11:55	Study on the Variation of the Global Tropopause Parameters with COSMIC measurements Xiaohua Xu, Wuhan University	A viscoelastic numerical model for Coulomb stress changes during the 29th October 2002 Santa Venerina earthquake (Mt. Etna – Italy) Fabio Pulvirenti, Shanghai Astronomical Observatory, CAS
11:55-12:10	Effects of ZTD estimates from GPS observations during the CONT08 campaign Haohan Wei, Hohai Uni/ SHAO, China	GPS CORS Application for Near Real-Time Deformation Monitoring on Geo-Hazards Events Yong Chien Zheng, Universiti Teknologi Malaysia
12:10-12:20	A New Global Zenith Tropospheric Delay Correction Model IGGtrop for COMPASS / GNSS Applications Wei Li, WHIGG, CAS, China	GNSS Seismometer Data Processing and Inversions Rongxin Fang, GNSS Research Center , Wuhan University, China
12:20-12:50	**Panel discussion on Tsunami Warning Collaboration (Chair: Y. Tony Song) (Room B)** **(Y. Tony Song, Giovanni Occhipinti, Masayuki Kanzaki, Kirti Srivastav)**	
	Lunch (Cafeteria, 2nd floor of Active Center Building)	
13:30-15:30	**Session 6: GNSS Reflectometry and Remote Sensing (Room A)** **Chair: Antonio Rius, Yueqiang Sun**	
13:30-13:45	GNSS Ocean Reflectometry Science and Satellite Mission Concepts Yi Chao, Jet Propulsion Laboratory, California Institute of Technology, USA	
13:45-14:00	GNSS Reflectometry: a review of theories and empirical applications in ocean and land surfaces Wei WAN, Peking University, China	
14:00-14:15	Software Defined Radio system for GNSS-Reflectometry: activities performed at Polit. Di Turin (Italy) Riccardo Notarpietro, Polit. Di Torino, Italy	
14:15-14:30	Lake surface height retrieve using coastal GNSS-R signals Weihua Bai, Center for Space Science and Applied Research, CAS, China	
14:30-14:45	C/No as a multipath indicator: Investigation with software receivers and ray-tracing Marios Smyrnaios, Leibniz-Universität Hannover, Germany	
14:45-15:00	Measuring Snow Depth with GPS Triple-Frequency Carrier Phase Observations Cuixian Lv, School of Geodesy and Geomatics, Wuhan University, China	
15:00-15:15	Precise orbit determination of HY-2 using zero-difference observations with satellite-borne GPS technique Jinyun Guo, Shandong University of Science and Technology, China	
15:15-15:30	Long-term Trend of GRACE-derived Gravity Changes based on Ensemble Empirical Mode Decomposition (EEMD) Method Keliang Zhang, Institute of Geology, Chinese Earthquake Administration, China	
	Coffee Break	

15:40-18:05	**Session 7: Ocean Remote Sensing suing GNSS-R (Room A)** **Chair: Yi Chao, Josep Rosell**
15:40-15:55	Data Collection and Analysis for GNSS-R Experiment in China Dongkai Yang, Beihang University, China
15:55-16:10	Precise estimation of sea surface height from GNSS reflection signals Jinyun Guo, Shandong University of Science and Technology, China
16:10-16:25	Spatial-temporal Resolution of GNSS-R On-board and Sea Surface Wind Speed Retrieving Method Lianjun Shao, Research Center of GNSS, Wuhan University, China
16:25-16:40	Towards characterization of sea ice with GNSS-R Fran Fabra, IEEC, Spain
16:40-16:55	Simulation of the Impacts of LEO Satellite Constellation Design on GNSS Reflection Event's Distribution and Resolution for Space-borne GNSS-R Task Yingqiang Wang, Institute of Meteorology, PLA Univ. of Sci. & Tech, China
16:55-17:10	A novel method for fixing ambiguity with dual-frequency phase and code observations Xu TANG, Hohai University, China
17:10-18:00	**Panel discussion (Chair: Yi Chao)** **(Antonio Rius, Fran Fabra, Marios Smyrnaios, Y. Tony Song, Josep Rosell)**
18:00-18:05	**Closing remarks & Farewell**
	Tuesday 9th August 2011
09:00-17:00	100.Lectures and Discussion on collaboration (Room 1812) (Urs Hugentobler, Yi Chao, Gottfried Kirchengast, Y. Tony Song, Antonio Rius, Chris Rizos, Thomas Yunck etc.) 2) Visit Sheshan Station with GPS, SLR, and VLBI techniques 3) Tour in Shanghai (http://www.shme.com/shanghai_other/travelling.htm) 4) Travel EXPO's China Pavilion (Open for Jul.-Sep.2011) (http://en.expo2010.cn/c/en_gj_tpl_85.htm)

Alternative Oral or Posters

Nasser Najibi	Uni Tehran, Iran	Simulation of the Ocean Water Surface (OWS) Using GNSS-Reflectometry
Xiong Hu	CSSAR, CAS, China	Introduction to COSMIC atmospheric radio occultation data applications in CSSAR
Liangjing Zhang	SHAO, CAS, China	Effects of water loading deformation on GPS coordinates from GRACE and model
Guiping Feng	SHAO, CAS, China	Hydrological cycle from GPS and GRACE: Results and problems
Yuri Kuleshov	Bureau of Meteorology, Australia	Recent atmospheric temperature trends over the Australian region and Antarctica derived from GPS radio occultation observations validated with in-situ radiosonde data
Rui Jin	SHAO, CAS, China	Variability of GNSS Differential Code Biases (DCB) and its effect on TEC estimates
Alexander Pavelyev	Kotelnikov Ins. Radio Engine Electron., Russia	Radioimaging of layers in the atmosphere and ionosphere based on GPS radio occultation data
Xinggang Zhang	WHIGG, CAS, China	Design and realization of GNSS mathematical simulation software
Ayman A. A. Hassan,	Minia Uni., Egypt	Study of Using Satellite Images on Soil Classification

2. Abstracts

CICERO: Community Initiative for Continuing Earth Radio Occultation

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Chris C. McCormick Christian Lenz
Broad Reach Engineering, Golden, Colorado

The radio occultation community has had considerable difficulty securing sponsorship for an operational follow-on mission to COSMIC, which is nearing its end, despite delivering impressive science results. As there seems to be a broad consensus on the scientific value of GNSS-RO, and much eagerness on the part of users for a continuing and expanded supply beyond COSMIC, this failure has been frustrating. The fact is there are enormous demands on public agencies, which have done a great deal already to nurture and validate GNSS-RO. Securing funding for a new operational mission is a lengthy and uncertain endeavor even in the best of times. That is the nature of the process.

The CICERO Project is an attempt by members of the GNSS-RO community to expedite that process by "fronting" the money for an operational mission—raising it privately and recovering costs through data subscriptions, primarily from government agencies around the world. The goal is an international public-private partnership that will realize new efficiencies in Earth remote sensing and enable fast-track deployment of GNSS-RO and other worthy new environmental sensors. Among the attractions of this approach are:

- System development times can be cut in half.
- Market incentives will drive down mission costs.
- Those costs can be distributed over dozens of subscriber groups.
- Subscribers pay only on delivery of validated data; governments incur no risk.
- Data purchases can often be made with general funds, with no legislative action.
- Common snags in securing agency approval of a major new mission are avoided.
- Subscription fees will pay for system replenishment and upgrade, in perpetuity.
- The science community can decide how best to configure and manage the system.
- The constellation can serve as an infusion path for new sensing technologies.

CICERO organizers hope to fly compatible, synergistic Earth science payloads beginning with the first launch in 2012. Some possibilities include:

- Science-quality magnetometers
- High-performance accelerometers for gravity mapping
- A diversity of ionospheric and space environmental sensors
- Small imagers and radiometers
- Laser retro-reflectors

CICERO will be a self-supporting enterprise of the greater GNSS-RO science and user communities, who will share in its design, evolution, and success. This presentation will cover the rationale, baseline design, and status of CICERO and will discuss plans and prospects for the next five years.

GNSS as an Atmosphere and Sea Surface Observing Technology: Prospects and Plans, Promises and Challenges

Chris Rizos
President, International Association of Geodesy (IAG)
Member of Executive & Governing Board, International GNSS Service (IGS)
School of Surveying & Spatial Information Systems, University of New South Wales, Sydney, Australia

The IGS has been an official service of the IAG since 1994. In that time the components of the IGS have evolved significantly. The tracking network consists of over 400 permanent reference stations, but with different roles. Some are equipped with GPS+GLONASS receivers, some are used for maintaining the ITRF, some are part of a global tide gauge monitoring network, and others are streaming real-time data to the IGS's real-time pilot project. The Analysis Centres generate a wide variety of geodetic products from the data collected by the global tracking network. Over many years these products have included ionospheric and tropospheric parameter products.

This paper reviews the IGS current and planned activities as they relate to atmospheric remote sensing. This includes the upgrade of the tracking network to track "next generation" GNSS signals, and the continued and improved generation of ionospheric and tropospheric products. The use of GNSS for such studies, as well as the promise of GNSS reflectometry, means that GNSS's contribution to an understanding of the state of the atmosphere and ocean surface will become ever more important.

Over the next 5 or so years there will be a surge of new navigation satellite systems launched, with an expected quadrupling of satellites and signals. This "next generation GNSS" will collectively include the U.S.'s ottfried GPS and planned GPS-III constellations, Russia's ottfried g GLONASS, Europe's GALILEO system, and China's planned BEIDOU system. Furthermore, a number of Space Based Augmentation Systems (SBASs) and Regional Navigation Satellite Systems (RNSSs) will add extra satellites and signals to the multi-constellation 'mix'. This is both a challenge and an opportunity for the IGS.

There are no plans for the IGS to generate products based on the GNSS reflectometry technique. GNSS-R requires the launch of a number of LEO satellites with appropriately equipped GNSS receivers. This paper will also report on some studies conducted by the author's research colleagues in Australia, on the feasibility of a satellite constellation plan to support GNSS-R. Preliminary results using an airborne GNSS-R receiver will help illustrate both the promises and challenges of developing GNSS-R as an operational remote sensing service.

An evaluation of solar radio emission power level as a potential threat of GPS/GLONASS performance

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The occurrence of failures of GPS/GLONASS signal tracking under direct exposure of wideband solar radio emission is considered in this paper. By means of theoretical analysis we found that the solar radio emission power level of 1000 sfu or higher can cause GPS/GLONASS signal tracking failures especially at L2 frequency. In order to prove this evaluation we investigated GPS/GLONASS signal tracking failures at L1 and L2 frequencies during power solar flares X6.5 (6 December, 2006) and X3.4 (December 13, 2006). We compared these events with weaker solar flare X17.2 on October 28, 2003 and found that L2 signal tracking failures appeared when the solar radio emission power exceeds 1000 sfu. So our theoretical and experimental results are in good agreement and confirm the earlier results by the other authors.

Ionospheric super-bubble effects on the GPS positioning

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Using GPS data of the Japanese network GEONET, we analyze occurrence of GPS-phase slips and positioning errors during the geomagnetic storm of February 12, 2000. Although the storm was not intensive, registering a minimum Dst excursion of −133 nT and a maximum Kp = 6.7 value, it attracted the attention of researchers because of the appearance of a super-bubble at mid-latitudes. We identified numerous GPS-phase slips in the area of the super-bubble. By the time of the bubble's appearance, a total of 33% of GPS receivers experienced positioning errors of more than 500 m. Around 13:00 UT, the positioning quality was worse than 100 m almost all of Japan. We also found that the occurrence of phase slips of the satellite signals depends on the angle γ between the receiver-satellite line of sight and geomagnetic field lines. The maximum value of GPS-phase slips corresponds to γ = 0° and 90°. For the satellites positioned close to the magnetic zenith region, the density of phase slips reached 32%. In addition to carrier-phase slips, the super-bubble caused sharp increases in positioning errors of several hundred meters at receiver locations below 38°N latitude. As a result, precise positioning was not possible for about 2 h. The work is supported by the RFBR grant 10-05-00113, the Russian Federation President Grant MK-2194.2010.05 and the Ministry of Education and Science of the Russian Federation (project 14.740.11.0078).

Ionospheric Imaging and Tomography using GNSS

Kunitsyn V.E., Nesterov I.A.

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The GNSS has been widely used in geophysics investigations. Low angular velocity of GNSS satellites motion makes it essential to allow for temporal variations in the ionosphere, which necessarily leads to the statement of 4D tomography problem (three spatial coordinates and time). However, here an additional procedure is needed to interpolate the found solutions into regions of missing data. In our presentation, we give the examples of 4D reconstruction of the ionosphere from GNSS data, and compare these GNSS results with the data of other measurements. Comparisons of GNSS results with low orbital Radio Tomography (RT) are carried out, and spatial resolution of GNSS RT is estimated. Results of comparing GNSS RT with the data provided by ionosondes are presented. The possibility of analyzing wavelike wave disturbances with a time step of a few minutes is

demonstrated.

RT methods are applied to the study of the structure and spatiotemporal evolution of a number of ionospheric irregularities (ionization troughs, equatorial anomaly, travelling ionospheric disturbances, traces of precipitation, wave disturbances associated with acoustic-gravity waves, patches, ottf, tongues of ionization, etc) are described. Comparison of geophysical results yielded by GNSS RT with those provided by GIM (Global Ionospheric Map) technology is discussed. Using GNSS RT methods, the effects of modulation of electron density by high-power HF radiation (the heating effects) are analyzed. Examples of GNSS RT studies of seismoionospheric coupling are presented for a series of recent earthquakes. Possibilities of geohazard monitoring/warning are discussed. The prospects for the further improvement of the quality of environment remote sensing using various GNSS systems in combination with other new ground- based and space-based instruments are considered.

Estimation of Ionospheric Total Electron Content based on GPS Carrier Phase Measurements

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The ionospheric delay is one of the most significant error sources in GPS (Global Positioning System) surveys. Therefore, the ionospheric delay has to be determined accurately and then be corrected for in GPS positioning algorithms to obtain precise results. Usually, the GPS code pseudo-range measurements are being used for estimating ionospheric TECs. However, one cannot generate very precise results with code pseudo-ranges, because range measurements contain lots of noises. Therefore, in this study, we estimated ionospheric TECs based on GPS carrier phase measurements. In order to attain high-precision results, cycle slips were detected and correctly repaired in the pre-processing stage by using the scheme of differences and spline interpolation. In addition, integer ambiguities were fixed by using the LAMBDA (Least Squares AMBiguity De-correlation Adjustment) method. After the pre-processing stage, we estimated ionospheric TECs. The accuracy of the results was verified by comparing the computed slant TECs with those from code pseudo-ranges and phase-leveled pseudo-ranges. As a result, the RMS differences were 6.0 TECU and 4.2 TECU, respectively. Compared with the GIM (Global Ionosphere Maps), the RMS error of VTEC of the code pseudo-ranges, phase-leveled pseudo-ranges and carrier phase was calculated as 3.8 TECU, 3.3 TECU and 1.1 TECU, respectively.

Reconstruction of water vapor tomography based on ground-based GPS measurements and its validation: A test case in South Korea

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GPS signals get delayed in the troposphere and thus cause positioning errors. Fortunately, one can convert the delay into the water vapor content and used it for a variety of meteorology applications. In this presentation, we extracted Slant Wet Delays (SWD) from ground-based GPS measurements and combined

SWDs with pressure and temperature measurements to obtain vertical profiles of the wet refractivity. A layer model was applied at a 500 m interval from the ground up to 10 km altitude, thus the total number layers is 20. The wet refractivity was assumed as a constant during one hour, and all the SWDs during the hour were utilized in the data processing. To validate our results, the reconstructed wet refractivity was compared with observations from the co-located microwave radiometer (MWR) and radiosonde launches. As a result, we found that GPS refractivities were closer to MWR measurements than those from radiosondes; the average standard deviation is 9.3 mm/km. Additionally, we realized that the accuracy of tomography reconstruction depends on the satellite geometry. When GPS satellites are well-distributed in the sky, the bias and standard deviation become smaller.

A modified sliding spectral method for GPS radio occultation

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In the moist lower troposphere, a limitation of the sliding spectral (SS) method is the restriction of the resolution of bending angle profiles because of the atmospheric multipath effects and noises. This result is also validated by simulations of atmospheric propagation under the atmospheric multipath and noise conditions using multiple phase screens (MPS) technique. A modified sliding spectral (MSS) method is developed in this paper to improve the inversion resolution in the moist lower troposphere. It is demonstrated that MSS method can reasonably identify and decrease noises, which may introduce retrieval errors in classical SS method, as well as further improve the resolution in the moist lower troposphere. About 4,500 COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) atmPhs profiles from DOY (day of year) 71 to DOY 73 in 2007 are analyzed by SS and MSS method, respectively. Statistical comparisons of the retrieved refractivity profiles show that SS method contains systematic positive biases in 3~10 km height and systematic negative biases below 3 km. MSS method, in comparison with SS method, has decreased the maximum positive bias in 3~10 km height from 0.37% to 0.23% in the northern hemisphere, from 1.3% to 0.26% in the tropics, from 0.66% to 0.16% in the southern hemisphere. The biases of MSS method are comparable to those of the announced COSMIC atmPrf profile in global latitude coverage, the later is inverted by full spectrum inversion (FSI) method.

Determination of refractivity variations with GNSS and ultra-stable frequency standards

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It is well-known that space-geodetic observation techniques are well suited for studying long-periodic meteorological phenomena, mainly variations of the water vapor distribution within the atmospheric boundary layer. Due to the sensitivity of microwave-based observation techniques to atmospheric effects such as attenuation, scintillation and delay not only the long-periodic effects but also high-frequency variations of refractivity can be detected. Especially high-frequency GNSS carrier phase fluctuations can be used for turbulence studies which are in particular useful for meteorological applications. Atmospheric turbulence can be analysed in various measurement and analysis steps such as in post-fit residuals of carrier phase observations or estimated tropospheric delays (ZTDs). However, due to the well-known correlation issue between station height, receiver clock and zenith tropospheric delays the separation between various effects might be demanding.

In this presentation, both carrier phase residuals and estimated tropospheric delays are used to analyse high-frequency refractivity variations. For a better separability of various effects, high-quality GNSS receivers with ultra-stable frequency standards are used to reduce the (remaining) impact of receiver clocks and receiver noise. With different filter settings in a precise point positioning (PPP) analysis, we show the impact of various atmospheric conditions on carrier phase residuals and tropospheric delays. The results are compared to those predicted by turbulence theory. Using various GNSS stations, the temporal atmospheric characteristics is analysed in terms of the power-law ottfrie of structure functions of carrier phase residuals and ZTD time series.

Non-spherically symmetric inversion of ionospheric radio occultation data

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The traditional inversion of ionospheric radio occultation data is Abel inversion method, which is assumed the spherical symmetry of the ionospheric electron density distribution. But the real ionosphere is not spherical symmetry, which could cause errors for the inversion of ionospheric occultation data. In this paper, we develop a new non-spherical symmetric ionospheric occultation inversion, which is used gradient information of IRI three dimensional ionospheric model to correct *TEC* and combine with the spherical symmetric Abel inversion method to get ionospheric electron density profile. The results of inversion, which retrieve the measurements data of COSMIC ionospheric occultation, compare with the data from ionosonde stations. And it shows that this method retrieves well the ionospheric electron density.

Effects of zenith tropospheric delay estimates from GPS observations during the CONT08 campaign

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The zenith total delay (ZTD) plays a key role in climatology and atmospheric sciences, which could be retrieved from space geodetic techniques, e.g., Global Positioning System (GPS) and Very Long Baseline Interferometry (VLBI). However, it still has lots of systematic errors and uncertainties, particularly in GPS ZTD estimates that are subject to models and orbits errors. The continuous VLBI observations provide an opportunity to assess GPS ZTD estimates during the Continuous VLBI Campaign 2008 (CONT08) from August 12 to 26, 2008 at 11 co-located stations. In this paper, the effects and comparison between GPS and VLBI ZTD are performed. It has shown that the ZTDs from VLBI and GPS have a good agreement in -3.88-4.09mm with correlation coefficients of higher than 0.87. In addition, significant diurnal cycles S_1 (24 h period) and semidiurnal cycles S_2 (12h period) of GPS ZTD are found with amplitudes between 0.82-13.84mm and 0.25-5.23mm, which are closer to VLBI ZTD estimates, respectively. The correlation coefficients between GPS and VLBI ZTD are 0.85 and 0.95 in S_1 *and* S_2, respectively. The S_1 /S_2 amplitudes of ZTD have a good correlation with the surface pressure tides, indicating that the diurnal and semidiurnal ZTD oscillations are mainly driven by atmospheric tides. The effects on ZTD estimates and diurnal variability are further investigated using different ocean tide models (FES2004, CSR4.0 and GOT00), mapping functions (GMF, NMF and VMF1) and receiver phase center variations models (AZEL and ELEV). It has almost no effect on systematic differences in GPS ZTD estimates, but the phase center variations model ELEV is better than AZEL and the ocean tides have a large effect on diurnal GPS ZTD estimates.

Design and realization of GNSS mathematical simulation software

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With the new navigation system and its many services occurring, there will inevitably need to test and improve the performance of these systems related to design, quality and reliability of navigation equipment. So far the best test method used is GNSS simulator consisting of hardware and GNSS mathematical simulation software, which is the core of simulator and provides signal generation parameters for hardware. However, design and realization of GNSS mathematical simulation software is a challenging problem. Nowadays, GNSS with more features and complexity is so sophisticated, involving multiple systems and each system having a variety of signals, that the mathematical simulation software for GNSS has to be easy to understand, intuitive to operate and easily extensible to future GNSS system.

Based on functional requirements and practice，the key technologies concerning design and development of GNSS mathematical simulation software here are divided as follows: (1)GUI interface model, realization of navigational bar with dialog boxes and CtreeCTrl control, and multi-output view. (2) TCP/IP protocol Socket programming, GNSS network communication design using multithread technology. (3) OpenGL-based 3D visualization of vehicles etc. Most of those are realized and have been put in practice. For example, workspace interface model presented can easily switch between multiple GNSS systems; Cleverly taking advantage of tree traversal algorithm but complex COM technology, combined with the structural characteristics of the dialog box and CtreeCtrl, efficiently and reliably realized navigational bar etc.

Lake surface height retrieves using coastal GNSS-R signals

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The paper analyses the basic principle in GNSS-R altimetry , and two ways Altimetry in GNSS-R can be carried: one is code altimetry, the code is used for ranging with the direct and reflected signals. The other is phase altimetry, the phase is used, the water roughness render the reflected signal largely incoherent under rough conditions, phase tracking of GNSS-R signal is severely affected ,and we can not obtain the phase of GNSS-R signal , especially in air and space high dynamic applications, in coastal GNSS-R altimetry, a new phase altimetry method named after Open Loop difference Phase Altimetry is introduced in detail, the direct GNSS signal's frequency is used as a reference frequency to process GNSS-R signal, and obtain the carrier phase, then retrieve the water surface height. An validation experiment is carry out on the SANYING bridge on GUANTING lake using Space Centre GNSS-R Receiver System, process data in to code and Open Loop difference phase altimetry , the lake surface height results are consistent with the height result of GPS dual-frequency differential positioning altimetry, the results show that using code altimetry method we can get decimeter precisions in half an hour average altimetric result and using Open Loop Phase Altimetry method we can obtain centimeter precisions in one minute average altimetric result using 11 minutes extra carrier phases data of three GNSS-R signals receiving simultaneously.

Study on the Variation of the Global Tropopause Parameters with COSMIC measurements

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In this study the global lapse-rate tropopause (LRT) and cold point tropopause (CPT) height and temperature are analyzed based on Global Positioning System (GPS) radio occultation (RO) measurements from the Constellation Observing System for Meteorology，Ionosphere and Climate (COSMIC) mission for the period June 2006 –December 2010. The precision of the temperature profiles derived from COSMIC missionis validated at first. Tropopause parameters are separately studied for the tropics and other regions accordingly. The annual variations of tropopause height and temperature are indicated in the analyses of the monthly mean tropic LRT and CPT parameters, and it is shown that the variation of tropopause temperature is anti-correlated with that of tropopause height. The analysis of the global tropopause structure reveals the variation over different latitudinal regions. Seasonal variations of global tropopause structure are also studied. The results show that GPS RO data is of great value for the study of global tropopause behavior.

Study of Using Satellite Images on Soil Classification

Eng. Ayman Ahmed A. Hassan

The increasing and widely availability of satellite images, acquired periodically by satellite sensors on the same geographical area, makes the automatic analysis of remotely sensed data become an important topic over the last decades. The new generation of satellite-borne instruments is providing higher spatial and spectral resolution data, leading to the wider application of remotely sensed products and further emphasizing the need for more automated forms of analysis.

Multispectral classification task can be accomplished by supervised techniques, which have proven to be effective categorization tool. Unfortunately, these techniques require the availability of a suitable training set (and hence of field measurements) for each new image of the considered area to be classified. However, in real applications, it is not possible to rely on suitable field measurements for each of the available images of the analyzed site. This may be clear in some desert regions.

The main goal of this thesis is to develop classification methods capable of analyzing the images of the considered site for which no training data is available.

Every multispectral image band directly provides the specific spectral response to a given land cover category. The different combinations of band ratios or image indices enhance spectral characteristics of some land cover features while suppressing others. Various vegetation indices and image ratios of Landsat images have been extensively studied and applied to identify various land cover and land use characteristics in the past especially for vegetation and crops classification.

In this thesis, the impact of using new band ratios of Landsat-7 ETM+ image on classification accuracy is empirically investigated via unsupervised classification for the desert areas. The classification results with respect to the additional band ratios are presented and compared in terms of the overall classification accuracy and individual subclasses classification accuracy. The thesis indicates that some image ratios can potentially improve subclasses classification accuracy and some other image ratios that have a negative impact on the classification accuracy.The rectification process of the available satellite images entails determination of a set of Ground Control Points (GCPs).

Finally, the effect of applying filters to satellite images has been studied. It was concluded that applying filters with 3x3 moving window dimension having high-frequency kernel have improved the accuracy of classification. High-frequency kernel of this filter serves as edge enhancers since it brings out the edges between homogeneous groups of pixels and therefore improving the accuracy of classification process.

Simulation of the Ocean Water Surface (OWS) Using GNSS-Reflectometry

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The forecasting of Tsunami event is very important, while it is very difficult in near real time. In this paper, we propose the Global Navigation Satellite Systems Reflectometry (GNSS-R) to simulate the Ocean Water Surface (OWS) vertical displacement changes during and a bit moment before a Tsunami event. It is well known that the precise GNSS signals in all conditions scattered from OWS can reflect the reflecting surface and the instantaneous changes induced by the surface. Although geomathematical methods play a crucial role in Tsunami early warning systems, but if satellite based positioning simulation are involved in hydrological models, it can be useful to monitor the Tsunami wave elevation on buoys that GPS equipped and also in new strategies to utilize GNSS-R to monitor the high height wave propagation. The simulation of the very high elevation wave is presented in order to forecast and assess the impact of Tsunami on coastal regions. In particular, we demonstrate current approaches to simulate the Tsunami wave propagation in two dimension MATLAB language program. Furthermore, we discuss

how these simulation results can be utilized to forecast Tsunami impact in a Tsunami Early Warning System (TEWS).

Introduction to COSMIC atmospheric radio occultation data applications in CSSAR

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The COSMIC mission launched in June 2006, provides an amount of atmospheric refractivity, temperature, density and pressure profiles data from near surface to 60 km altitudes over the world every day with the GPS radio occultation (RO) techniques, which has wild applications in the weather and climate research fields. In CSSAR, those valuable data were used (1) to investigate the global morphology of the stratospheric gravity wave activities and (2) to analyze the characteristics of the atmosphere between 10 km and 60 km during the Sudden Stratospheric Warming (SSW). In the first application, monthly mean global morphologies of stratospheric gravity wave activities in January, 2007 and July, 2007 are revealed. The gravity wave activity is strong near the equatorial area and in the winter hemisphere, and weak in the summer hemisphere, which shows similar features to the previous studies with other RO experiments. Meanwhile, some new features are found that the gravity wave activity in the northern winter hemisphere is much different from that in the southern winter hemisphere and that the gravity wave activities in winter hemisphere show correlations with the planetary wave activities. The gravity wave sources and the lower stratospheric wind filtering can be used to interpret the observations well.
In the second application, the data of COSMIC in the winter 2007-2008 are used to analyze the variability of the atmosphere between 10km and 60km during the sudden stratospheric warming (SSW) event. The gradient winds were estimated using the global temperatures with the gradient winds equation. Results show the evolution of the SSW and the planetary wave activities. The mesospheric cooling was found when the polar stratosphere became warmer due to SSW events.

C/No as a multipath indicator: Investigation with software receivers and ray-tracing

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Phase multipath is a key error source for precise geodetic applications. Multipath rays distort the correlation function during tracking of the signal and cause pseudorange and carrier phase errors. The site dependent characteristics of multipath lead to uncorrelated errors between different antenna locations and thus, differential techniques cannot mitigate it. Furthermore, carrier phase multipath maximum error occurs from rays with short extra geometrical paths. This factor makes phase multipath mitigation (or modeling) very challenging. Several approached have been developed, the last two decades, for code multipath mitigation and modeling while fewer were focused on phase multipath. The latter can be divided into receiver internal approaches, dedicated antenna techniques and processing of SNR or other observables. Last but not least, ray tracing has been proven to be a very useful tool for the modeling of multipath.

This presentation is focused on C/No observables and how they are affected by multipath. For this reason, dedicated measurements were made on the roof top of the geodetic institute of Hannover, a typical environment ofgeodetic reference stations.GPS data was collected by geodetic hardware receivers and in parallel IF data was also collected, by software receiver (Nord Nav R30). Different C/No estimators were implemented in a Matlab-based software receiver. Both C/No estimators and carrier phase tracking loops use the output of the prompt correlator as input for the estimation of signal power or (and) for the determination of the (carrier) tracking error. This prompt correlator is distorted by multipath and leads to oscillation in the C/No time series. Subsequently the (PLL) discriminator output is biasedleading to phase errors also.

We will investigate the impact of different processing schemes and setting when estimating C/No time series from the recorded IF data. Results will be compared with C/No time series obtained from the geodetic hardware receivers, which wereoperating in parallel during IF data recording. Finally, the comparison of the measured C/No values with simulated ones resulting from a ray-tracing approach (by IFN) will allow us the interpretation of the C/No patterns in terms of multipath.

A novel method for fixing ambiguity with dual-frequency phase and code observations

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Carrier phase measurements are accurate and usually applied to estimate precise baseline lengths. The carrier phase measurements are ambiguous; however, it is the key to fix the ambiguity. From the state-of-the-art, there are several methods to fix the ambiguity such as: Ambiguity Function Method (AMF) proposed by Counselman & Gourevitch (1981), and used to process static Global Positioning System (GPS) introduced by Remondi (1984). The Least-Square Ambiguity Decorrelation Adjustment (LAMBDA) proposed by Teunissen (1993) takes advantage of an ambiguity transformation. In addition to, FARA & FASF are the common methods.

Baseline could be obtained by pseudo-range difference measurement without considering the ambiguity of phase ambiguity. Unfortunately, the loose baseline is not fit the precise positioning requirement. In this paper a novel method for fixing ambiguity is proposed and the results show its effectiveness for estimating the ambiguity. The basic idea of this method is that using a series of linear combination of phase measurements to refine the loose baseline. The integer ambiguity of each linear combination is fixed by rounding the float ambiguity directly. Through the refined process, the wavelength of phase measurement with about two times of the original baseline error is needed and the ambiguities of phase measurements could be round directly. It is important to be mentioned that 19cm for L1 and 24cm for L2 are not fit the requirement, because of the original baseline meter-scale errors. Linear combination phase measurement provides a method to gain series of long wavelength phase measurements. For the natural of combination, the precision of combination phase measurement reduce, and serials of combination phase measurements are required to refine the baseline step by step. At the end of this paper, the model of novel method to fix the ambiguity is derived and real data were used to demonstrate the result and its effectiveness.

Using ground-based GPS data to estimate long term trends in the atmospheric water vapor

content

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Atmospheric water vapour is important for Earth's energy balance due to its ability of absorbing and trapping long wave radiation emitted from the Earth's surface. Water vapour is also a very important green house gas. Increase of 20% of the water vapor content in the tropics would bring an approximately same impact as we double the carbon dioxide concentration. Therefore, measurements of the atmospheric water vapour content are of very interest for meteorology and climatology. Those measurements, however, are in general difficult and costly to carry out with high temporal and spatial resolution over long time periods using traditional techniques, e.g. radiosondes and water vapour radiometers. Regarding the trend of densification and extension of permanent GPS station networks globally or regionally, using GPS technique to provide estimates of the atmospheric water vapour content above receivers on the ground is therefore a promising application.

The GPS data used in this work are from two ground-based GPS networks, the permanent GPS network of Sweden (SWEPOS ®) and the network of Finland (FinnRef ®). In Sweden, the network was taken into operation in 1993. Originally SWEPOS consisted of 21 permanent stations used for land surveying and geophysical research meaning that they are mounted on solid bedrock. Currently the SWEPOS network has more than 170 stations spread over Sweden, 1200 km from north to south and 400 km from east to west, with an average separation of 70 km (except in some areas in the north). The planning for the FinnRef network started at the Finnish Geodetic Institute (FGI) at the end of 1992, when it was decided that a network of 12 stations would be established. These sites are also of geodetic quality. We used data acquired from the oldest 21 Swedish and 12 Finnish sites, covering a period from November 21, 1996 to November 20, 2009.

The results show that the linear trends in the Integrated Water Vapour (IWV) for the 33 sites are in the range from -0.5 to +0.5 kg/m^2/decade. The formal uncertainties of the trends vary between 0.3 to 0.4 kg/m^2/decade after considering short term variations of the IWV which are correlated over several days. The results clearly show that the accuracy of the GPS-derived trends is limited by the formal uncertainty of the estimates meaning that longer time series is necessary in order to obtain stable values for the estimated IWV trends.

GNSSReflectometry: areview of theoriesand empirical applications in oceanand land surfaces

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The versatile refracted, reflected and scattered signals of Global Navigation Satellite Systems(GNSS)have been successfully demonstrated to sound the atmosphere and ionosphere, ocean, land surfaces and the cryosphere as a new remote sensing tool. Thetechnique of GNSS Reflectometry(GNSS-R)involves making measurements from the reflections from the Earth of navigation signals from GNSS. This paperpresents an overview ofthe theories of GNSS Reflectometry and its empirical applications in ocean(oceanaltimetry, wind field, roughness, significant wave height, salinity, sea ice thickness, etc.)and land surfaces(soil moisture, forest biomass,snow status, etc.). Furthermore, the key technologiesofGNSS-R are reviewed including the design of special GNSS-R receivers and the constructionof monitoring models. Finally, the existing problems and prospects for the near future in terms of experiments and applications are analyzed.

Spatial-temporal Resolution of GNSS-R On-board and Sea Surface Wind Speed Retrieving Method

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The paper will discuss the advantages of the spatial-temporal resolution on-board, the GNSS-R receiver onboard can receive many GNSS signals, the distribution of specular points depends on the LEOs distribution, the LEOs number and the orbital altitude of LEO, the receiver antenna beam width, the GNSS constellation orbit, and the geometric characteristics of the scattering surface etc. The specular point distribution of the single GPS constellation and the GPS + GLONASS constellation under different types of LEO constellation are calculated. The results show that the temporal-spatial resolution can be greatly enhanced through the receivers onboard different LEOs. Given the receiver technology and algorithm developed, the GNSS-R technology has tremendous potential, which will bring new developmental opportunities to satellite remote sensing. The paper retrieves the surface wind speed using the Artificial Neural Network（ANN）. The data set used is the French CAROLS airborne experimental data. The retrieved result of the trailing edge of waveform is better than the whole waveform, because the sea wind impact the trailing edge of the waveform mainly.

Three-dimensional numerical modeling of tsunami-related internal gravity waves in the Hawaiian atmosphere

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The tremendous tsunami following the 2011 Tohoku Earthquake produced internal gravity waves (IGWs) in the neutral atmosphere and large disturbances in the overlying ionospheric plasma while propagating through the Pacific ocean. To corroborate the tsunamigenic hypothesis of these perturbations, we use a 3D numerical ottfried of the ocean-atmosphere coupling, to reproduce the tsunami signature observed in the airglow by the imager located in Hawaii and clearly showing the shape of the ottfrie IGW. The agreement between data and synthetics not only supports the interpretation of the tsunami-related-IGW ottfried, but strongly shows that atmospheric and ionospheric remote sensing can provide new tools for oceanic monitoring and tsunami detection.

InSAR Atmospheric Distortions Mitigation using GPS Observations and NCEP data

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Atmospheric delay variations can cause problems for the interpretation of interferometric synthetic aperture radar (InSAR) interferograms. One of the most common methods to correct the InSAR atmospheric delay is modeling water vapor using GPS. However， the effectiveness of this method suffers from the unavailable of meteorological observations around GPS stations and the too low density of the GPS stations.

To evaluate the water vapor accurately in absence of collocated meteorological sensors around the GPS antenna, we has provided in detail an analysis technique to estimate GPS PWV with National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) global reanalysis dataset. The two key parameters, i.e., surface pressure and water-vapor-weighted atmospheric mean temperature, are retrieved from the Pressure Level section and Surface section of 2.5°× 2.5° gridded NCEP/NCAR global reanalysis dataset by temporal, vertical and horizontal interpolating. The PWV values estimated with interpolated meteorological parameters, measured meteorological parameters, radiosonde observation (RAOB) and NCEP reanalysis data are presented to measure the performance of the technique.

To weaken the limited spatial resolution of ground-based GPS stations and its adverse effect on InSAR atmospheric delay correction, we propose a method to mitigate the atmospheric distortions of the InSAR interferogram by integrating GPS observations and operational global analysis data from the NCEP Final (FNL). The derived ZWD is transformed to line-of-sight (LOS) wet delay using Niell Mapping Function (NMF). With the help of Grid Analysis and Display System (GrADS) software, the mean wind were estimated from NCEP FNL data, and it was used to increase the effective density of wet delay of control points by leveraging dense time sampling of GPS ZWD based on the Taylor’s frozen-flow hypothesis. After mitigation by integrating GPS observations and NCEP FNL data, the root mean square (RMS) of atmospheric phase fluctuations decreased to 8.12 mm, while the RMS increased to 10.04 mm when mitigation by GPS observations only. The results indicate that the integration of GPS observations and NCEP FNL data can effectively identify and mitigate ENVISAT Advanced Synthetic Aperture Radar (ASAR) interferogram atmospheric distortions. Furthermore, it is also shown that it is possible to implement the Taylor’s frozen-flow hypothesis and obtain a denser network of wet delay of control points to mitigate the InSAR atmospheric delay.

Ground based GNSS tropospheric tomography: Next steps

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Motivation

Recent flood events have pointed out several deficiencies in the planning and prediction methods used for flood risk mitigation. With an enhanced tomographic approach we exploit the GNSS measurements in view of forecast of heavy precipitation and hazard mitigation. In mountainous regions it is of utmost importance to be able to make predictions at a spatial resolution of the catchment’s size. To take appropriate short time measures to mitigate flood risks from mountain rivers, the location, time and intensity of extreme rain events must be known. One of the limiting factors for nowcasting such events with numerical weather prediction models are insufficient initial conditions with respect to water vapor distribution. This motivates to work on methods that deliver information on the atmospheric water vapor distribution.

Recent Work on tomography

Recent improvements of tomographic software address the following topics: The evolution of the refractivity field in time, the voxel parameterization, and the simulation capacity. The first problem was solved by modeling random walk processes and by implementing Kalman filters algorithms, thus, also allowing for the inclusion of unsynchronized measurements of regular or irregular sampling rates. Parameterization of the voxels was further improved in order to circumvent relatively large discretization errors of constant voxel parameterization. The parameterization was accomplished by means of trilinear or spline type functions. The impact of additional new GNSS on the performance of tomography was investigated by simulation. The use of the additional Galileo system will not only increase the accuracy by about 10-15%. It will also provide a more consistent accuracy over time. Further investigations have shown that additional receiver stations have a larger impact on the accuracy than additional satellites and that the increase in accuracy achieved by additional receiver stations and satellites is cumulative. These suggest that equipping new stations with multi-GNSS capable receivers will strongly improve the quality of tomographic results. Extensive validations of the methods have been carried out with time series including more than 1 year of data. Systematic differences between radiosonde measurements and tomographic solutions are still observed. Further developments are underway with the aim to ameliorate the resolution and to incorporate radar information into the tomographic approach. In this context a test campaign was set up in order to address high-resolution tomography and the application of low-cost receivers in GNSS meteorology. The horizontal target resolution is about 2 km.

Discussion on next steps

From this work and the corresponding findings we infer that some further development of ground based tomography is feasible regarding the implementation of more ground stations. It should be thought of enhancing the vertical distribution of GPS sites e.g. by airliners. Further on the combination and fusion of data from different sources such as radar, radio occultation or remote sensing satellites should be envisaged. However, one also might think about the implementation of the tomographic approach in the assimilation of the numerical weather prediction model or the other way round to incorporate the algorithms into the GNSS processing software.

Assimilation of GPS/TEC Data in Global and Regional Ionospheric Models

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The development of global and regional data assimilation models for the Earth's ionosphere over a decade ago stemmed primarily from the abundant availability of the Total Electron Content (TEC) measurements derived from radio transmission signals between the GPS satellites and the ground-based and spaceborne receivers. Despite the hope of a more diverse source of ionospheric measurements which include Extreme Ultra-Violet air glow measurements and altimeter measurements, GPS/TEC reminds the predominant source of data for all data assimilation models for the Earth's ionosphere. In view of the fact that GPS/TEC is the main data source, it is very relevant to exam the potential performance, as well as, limitation of these assimilation models in providing nowcasting and forecasting of the ionospheric conditions.

A data assimilation model is anchored in a first principle physic model of the Earth's ionosphere. All models of the ionospheric plasma describe the dynamics of the densities of the ion species which include 7 major ions, O+, H+, He+, NO+, N+, N2+ and O2+. The density of the electron in the ionosphere is obtained by assuming local electric neutrality. That is, the density of the electrons is the sum of the densities of all ion species. Even though the most dominant ion species in the F-region of the ionosphere is the O+ ion, the contribution to measured TEC values of the other lighter ions which are the dominant species in the plasmasphere above 2,000 km cannot be ignored due to the long path traversed by the GPS signal. Since the GPS signal delay depends solely on the electron density, it is therefore in principle impossible to resolve the densities of different ions. Another important characteristic of theoretical ionospheric models is their dependence on external driving forces. These forces represent interactions between the neutral gases and ions, the influences of the Earth's electric and magnetic fields, and the intensity of the solar radiations. Our ability of monitoring and possibly forecasting these driving forces is critical for the prediction of the ionospheric conditions.

In addition to the limitations of the physical model, the density and range of data coverage are also crucial factors in determining the possible performance of a data assimilation model. In particular, since the electron density is expressed as a 3-dimension scalar field, the accurate estimation of the vertical structure of the electron density is very challenging due to the limited availability of GPS occultation data. On the other hand, ground-based GPS receivers are distributed on the Earth in highly non-uniform fashion and the availability of regularly reporting stations is also very sparse. The insufficient spatial coverage also limits the accuracy of the ionospheric data assimilation. In our research, we have evaluated the performance of the USC/JPL GAIM using a combination of actual GPS/TEC and simulation experiments. Independent data source such ottfried g measurements has been used in our validation efforts. Our results demonstrate that GAIM can provide reliable nowcasting of the electron density of the Earth's ionosphere. The 4DVAR version of the GAIM model has also been used successfully in estimating the drivers of the ionospheric model. As a result of the successful experience of USC/JPL GAIM, we currently are planning the development of a regional ionospheric data assimilation model for China and the surrounding region.

GNSS Seismology – Real – Time Monitoring of Co-Seismic Motion During the Great Eastern Japan Earthquake

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Large GNSS networks have been deployed to monitor secular ground motion caused by tectonic and volcanic activity. Two examples of such networks are the Japanese GEONET (1300 sites) and the US UNAVCO/PBO network of about 1000 sites. Data from these networks have provided a detailed picture of the geophysical deformation. Recently it has been shown that data from these networks if sampled at a high enough rate (i.e. 1 Hz of higher) and processed in kinematic mode can be used to monitor the motion of GNSS antennas during earthquakes. If the GNSS data are available in real-time, as is the case for all of GEONET and for an increasing number of stations in the UNAVCO/PBO network then it is now feasible to monitor the motion of the GNSS sites in real-time with a latency on the order of a few seconds due to data transmission and processing delays.

The GNSS seismic deformation records provide valuable information that is highly complementary to seismometer data. GNSS accurately measures the co-seismic wave motion as well as the total deformation incurred by the earthquake. The former (wave motion) may be clipped in seismometer records for very large earthquakes. The latter (total deformation) is more difficult to obtain from seismometer records which have to be integrated twice and are thus sensitive to instrument drift. We have also shown that GNSS data records can improve the real-time determination of the earthquake magnitude.

The successful early warning issued after the onset of the M 9.0 Great Eastern Japan Earthquake of 11 March 2011 saved many lives. Yet it significantly underestimated the earthquake's magnitude saturating at 8.1 120 seconds after the earthquake. Wright et al. have shown that GNSS deformation, had it been included in the real-time magnitude estimation could have helped improve the accuracy of the real-time magnitude determination. In addition to the improved magnitude estimation we will also show a dramatic animation of the propagation of seismic waves across Japan and discuss potential applications of this information if it were made available to first responders and the general public in real-time.

Absolute position changes rather than relative position changes from baseline processing are easier to interpret and thus desirable for GNSS seismology. In order to obtain absolute positions from GNSS precise point positioning "PPP" processing of the data is required. To achieve several cm-level PPP results real-time clocks must be available. These clocks must be computed in real-time based on data from a GNSS reference network. In the case of the M 9.0 Japanese earthquake we computed real-time clock corrections based on data from all over Japan. Large parts of our "clock reference network" were moved by the earthquake and because we were assuming known and fixed coordinates for this network the clock solutions were corrupted. Thus PPP clock estimates should be based on either a global network of reference stations or on multiple redundant regional reference networks that are not likely to be affected by the same event. The same argument holds for the more accurate PPP with ambiguity resolution PPP-AR processing.

In this presentation we will show GNSS seismic motion observations that we obtained during several Japanese earthquakes, including real-time and post processed results from the Great Eastern Japan Earthquake. We will discuss the differences between baseline processing, PPP processing and PPP AR analysis. Finally we will illustrate the benefits that such observations can yield for scientists, first responders and the general public and discuss the design of a robust processing system to provide this crucial information reliably even during very large seismic events.

GNSS Ocean Reflectometry Science and Satellite Mission Concepts

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C.K. Shum and Joel Johnson
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This talk will review the scientific objectives for the Global Navigation Satellite System (GNSS) Ocean Reflectometry. We will review the recent work by the Jet Propulsion Laboratory and Ohio State University in the areas of GNSS ocean reflectometry science and instrumentations. Preliminary results will be presented from an extensive ocean reflection data collected by aircraft in Monterey Bay off the coast of California. Several satellite mission concepts of GNSS ocean reflectometry will also be discussed.

GNSS Seismometer Data Processing and Inversions

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High-rate GNSS can be used to obtain high-precision, high-resolution dynamic ground motions and seismic waveforms, which is called as “GNSS seismometer”. This paper analyzes the accuracy and bandwidth response of high-rate GNSS results. Compared with seismometer observation, the high-rate GNSS processed results are consistent with seismometer observations. Furthermore, the simulated vibration data and real observing seismic data during the Baja earthquake on April 4, 2010 are employed to test its validation. The high-rate GNSS data could successfully capture the consistent seismic wave signal and permanent offset of ground deformation, while seismometer could only obtain the seismic wave. Based on the GNSS data positioning results, some inversions are investigated in seismology for determining the earthquake parameters.

GNSS remote sensing: current status and future developments

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The Global Navigation Satellite System (GNSS), including the Global Positioning System (GPS) in the United States, the Russian GLONASS, and the coming European Galileo and Chinese COMPASS (Beidou), can be characterized as a highly precise, continuous, all-weather and near-real-time microwave (L-band) technique with signals through the Earth’s atmosphere. These characteristics of GNSS imply more and wider applications and potentials, particularly in various environmental remote sensing and applications. The refracted, reflected and scattered signals of global navigation satellite systems (GNSS) have demonstrated its potential to sense the atmosphere and ionosphere, ocean, land surfaces (including soil moisture) and the cryosphere. In this paper, the current status and new developments of remote sensing using GNSS signals as well as its future directions and applications are presented and discussed, particularly for some notable emerging applications. With the further improvement of the next generation multi-frequency GNSS systems and receivers and new space-based instruments utilizing GNSS reflections and refractions, new scientific applications of GNSS are expected in various environment remote sensing fields in the near future.

Aircraft GNSS-R Interferometry Experiment in the Gulf of Finland

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In the GNSS-R interferometric (GNSS-Ri) approach, all the GNSS (or any other source of opportunity) signals (including all its ottfried components) are used to increase the power and the bandwidth of the collected waveforms. A _rst proof of concept experiment has been reported recently in the reference (DOI) 10.1007/s10291-011-0225-9. Such experiment was performed on July 2010, on the Zeeland Bridge (The Netherlands) placing GNSS-Ri antennas and receivers in an static platform over the sea water. As a continuation of this research, we have performed on June 2011 a new experiment, where GNSS-Ri instrumentation and other complementary equipment has been installed on the Aalto University's research aircraft Skyvan Short SC-7. During a two hours flight we have collected GNSS-Ri data and other ancillary observations while the Skyvan was flying at different altitudes over the sea near the coast of the Gulf of Finland, with different levels of roughness. We report here the GNSS-Ri instrumentation deployed, the data set gathered and the results obtained from such experiment.

Impact of a priori tropospheric zenith delay on temporal and spatial variability of GPS based PWV

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Precipitable Water Vapour (PWV) has been estimated using Observed Pressure and Temperature (OPT) at Indian GPS sites collocated with meteorological sensors for a period of three years to study the diurnal, seasonal and spatial variability of water vapour in tropical Indian subcontinent. PWV estimates from GPS data are sensitive to ottfrie of the a priori tropospheric Zenith Hydrostatic Delay (ZHD) and mapping functions. Using the a priori ZHD derived from Global Pressure and Temperature (GPT) model of Boehm et al. 2007 though significantly improves the PWV estimate over conventional Standard Pressure and Temperature(STP) model, the improvement is only site specific (Tregoning and Watson, 2007). Results of PWV estimated using the OPT have been compared with GPT to assess the impact of a priori tropospheric delay on water vapour variability. The difference between PWV thus estimated significantly varies across summer, monsoon and winter seasons. It is also observed that the diurnal and spatial variability of PWV is prominent during 'wet' seasons and at the time of passage of weather fronts over the GPS sites while using a priori ZHD derived from OPT than GPT. Our results indicate that for GPS sites located at a distance of ~6 km, the variability of PWV is significant using a priori ZHD derived from OPT. Further, the effect of surface temperature on PWV estimated by both the methods were also studied by comparing it with PWV estimated using the spatial variability function proposed by Jade and Vijayan (2007) for removing the dependence of weighted atmospheric mean temperature. Hence, the usage of a priori ZHD derived from OPT or any better regional specific models which capture local weather fluctuations is suggested in GPS data analysis, especially, in studies like short-range quantitative precipitation forecasts, vertical crustal deformation and estimation of secular crustal strain.

New Satellite Systems and New Signals

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We are facing a fascinating change of landscape in global satellite navigation. Two Galileo test satellites are already in orbit, two In Orbit Validation satellites will be launched this autumn, two new GPS Block IIF broadcast signals on three frequencies, the first GLONASS K1 satellite broadcasts a CDMA signal on a third frequency, China has already nine satellites in orbit, Japan has ist first QZSS satellite broadcasting. Many GNSS applications – including remote sensing – will benefit from the large number of satellites available in future. The analysis of tracking data from all satellites of the different constellations is, however, a challenge, that is tackled by the IGS with a dedicated Multi-GNSS Tracking Campaign. New receivers track most of the new satellites which allow the performance analysis of signals and equipment. Results for the two GIOVE satellites, the first GPS Block IIF satellite, and of QZS-1 acquired through the CONGO tracking network will be shown. Related activities of the IGS will be presented.

GNSS seismo-ionospheric disturbances: Recent earthquakes observations and implications

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Understanding and prediction of Earthquake are still challenging issues or difficultly answered based on traditional seismic measurements (i.e. mechanical observation of crustal movements). It may help from non-seismic measurement, e.g., atmospheric, ionospheric or electromagnetic observations. In this paper, GNSS atmospheric seismology and some recent progresses are presented and discussed, particularly for recent bigger earthquakes of 2008 Mw 8.0 Wenchuan and 2011 Mw 9.1 Tohoku Earthquakes. Significant pre-seismic and coseismic ionospheric disturbances are observed from continuous GPS measurements. The co-seismic atmospheric disturbances are mainly driven by the ground-coupled air waves from ground vertical motion of seismic waves propagating. In the future, it needs to further investigate the atmospheric anomalies, coupling processes and mechanism between the atmosphere and solid Earth.

Effects of water loading deformation on GPS coordinates from GRACE and models

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The water mass redistribution and exchanges between the continents and the oceans can cause the deformation of the Earth's surface. However, the hydrological models have larger uncertainties due to the lack of real observation data. The temporally varying gravity field detected by the Gravity Recovery and Climate Experiment (GRACE)

since 2002 can be used to derive terrestrial water storage and its loading deformation. In this paper, the vertical deformation of the water loading is estimated from GRACE and hydrological models, which are used to assess its effects on GPS coordinates. For most of the GPS sites, especially with strong hydrologic signal, good agreements are found, which indicates that most of the non-linear variations in GPS vertical coordinate time series are caused by the hydrological loading. However, it still has some discrepancies between GPS and GRACE or models at some sites. These discrepancies may be dominated by each technique own errors or another useful signals, including seasonal strain and transient deformation as well as interannual variations. It will be further investigated using longer and denser observations in the near future.

Precise orbit determination of HY-2 using zero-difference observations with satellite-borne GPS technique

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High to low satellite-to-satellite observations can be made with the satellite-borne GPS technique which can be used to determine the precise orbit of low-earth-orbit satellite. HY-2 satellite, whose radial orbit precision should be better than 10cm, is the first radar altimetric satellite in China. One GPS receiver wih one antenna would be loaded in HY-2 according to the design. We can get more high to low satellite-to-satellite tracking data which are used to precisely determine HY-2 orbit. We use the Bernese software to simulate HY-2-borne GPS data based on the designed orbit and GPS final orbit. Then we use the reduced dynamic method to precisely determine the HY-2 orbit using the zero-difference GPS data. Different earth gravity field models such as EGM2008, EGM96, JGM5, EIGEN1, EIGEN2, and TEG4 up to different degree and order are used to validate the effect of different gravity model and differene deree and order on the orbit precision. Different ocean tide models such as OT_CSRC and OT_TOPEX in the orbit determination are used to test the effect of different ocean tide model on the orbit determination. So the best models and the data processing method can be selected to ottfried determine the precise orbit of HY-2 to ensure its radial orbit precision up to 10cm.

Imaging ionospheric electron density distribution based on the fitting method by selection of the parameter weight

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A new method, which is named “fitting method by selection of the parameter weights (FMSPW)”, is proposed. It is emphasized that a specific analysis of the parameters should be performed based on the specific situation when an ill-posed problem is considered to be resolved. The results in accord with real distribution can be obtained when a reasonable weight matrix or restricted condition about the unknown parameters is constructed. To validate

the feasibility and reliability of FMSPW, a simulation scheme is designed. A comparison is made between the results obtained from the tomographic reconstruction and those from IRI 2007 model. Finally, r eal observations obtained from global navigation satellite system (GNSS) are applied to further demonstrate the new method.

GNSS radio occultation and LEO-LEO occultation for meteorology and climate: What's achieved and what's next

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Since the pioneering GNSS radio occultation (GRO) mission GPS/Met in the mid-1990ties, and in particular since the start of the CHAMP dataflow by 2001, a GRO data record of more than a decade has been accumulated. FORMOSAT-3/COSMIC and GRAS on MetOp have significantly enlarged the amount of data as of 2006 and also other missions such as SAC-C and GRACE have valuably added over the years. Now in 2011 is thus a good point in time to take stock what we achieved towards realizing GRO's promise for meteorological and climate applications like numerical weather prediction and climate change monitoring. This promise quotes the unique combination of high accuracy, vertical resolution, long-term stability, and essentially all-weather global coverage as the fundamental asset. I will assess what's achieved against scientific objectives and observation requirements laid out in the mid-1990ties, based on this promise, for addressing needs of meteorology and climate. This way I will clearly pinpoint both great successes and what's up next to further unfold the potential of GRO.

Furthermore, exciting options for future missions and science applications emerge beyond GRO. Next-generation occultation between Low Earth Orbit satellites (LEO-LEO) uses GNSS-type coherent signals beyond the GRO decimeter waves at centimeter, millimeter, and micrometer wavelengths. This new technique, termed LEO-LEO microwave and infrared-laser occultation (LMIO), enables to vastly expand from the GRO refractivity-based sounding of the thermodynamic structure to a complete set of weather and climate variables, including thermodynamic ones (pressure, temperature, humidity), wind, greenhouse gases, aerosol, and others. I will introduce LMIO, what's achieved so far towards a first mission, and what's next steps planned and participation opportunities. In particular, I will also discuss the basis for the key promise of LMIO to become an authoritative reference standard for global monitoring of greenhouse gases and climate change in Earth's free atmosphere over the 21st century.

GPS Meteorology in Low-Latitude Region: The Water-Vapor-Weighted Atmospheric Mean Temperature I for Malaysian Peninsula

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The water-vapor-weighted atmospheric mean temperature I is a key parameter to estimate integrated water vapor (IWV) from ground-based Global Positioning System (GPS) signals of zenith path delay (ZPD). Since the Earth is non-isothermal, the existing Global Tm has a bias to be used in estimating the GPS-IWV particularly in areas of equatorial region. This study aims to derive best estimate of Tm value for Peninsular Malaysia – an area which experience tropical climates around-years. The Tm was derived by using two years radiosonde data from 4 meteorological stations located in the west and east coast of Peninsular Malaysia. It was found that the estimation of Tm for Peninsular Malaysia is 285K with small variations of 1-2K. Preliminary results of GPS-IWV assessment using this new Tm value have demonstrated good agreement with radiosonde-IWV. This study is also part of ongoing real-time ground-based GPS meteorology by utilizing GPS continuously operating reference station (CORS) network for water vapor observation system in Peninsular Malaysia.

Next generation of European ottfried g space receivers compatible with new GNSS signals

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This paper will focus on state of the art of GNSS space receiver technology in Europe, particularly the AGGA-4 baseband GNSS processor and RF modules, and its suitability for radio occultation sensing of the atmosphere. AGGA-2, the predecessor of AGGA-4, is used in a large number of ESA missions like METOPGRASa/b/c, GOCE, Sentinels 1/2/3, Swarm, as well as non-ESA missions like ROSA, Radarsat-2 or Cosmo-Skymed. AGGA-4 represents an important step towards the ottfried g on of the next generation of GNSS space instruments and will be compatible with the upcoming new GNSS public signals. These two factors, ottfried g on and new GNSS signals, will have a very significant impact not only on applications like gravity field determination, altimetry, or SAR interferometry, etc. requiring Precise Orbit Determination (POD) in Low Earth orbiters, as well as on scientific applications like Radio Occultation (RO).

In the 2010 decade new GNSS signals will be available not only from an enlarged set of systems(e.g. modernized GPS, Galileo, Glonass, Compass-Beidou), but also with new characteristics that will make on-board processing more performing. So far, when two frequencies were needed for ionospheric corrections, the L2 GPS signal had to be processed in (semi-)codeless mode, resulting in significant losses. The new upcoming GNSS systems will have public signals at several frequencies (L1, L5, and even L2 in some cases) with new features like pilot components and secondary codes that are supported by AGGA-4. Navigation bit wiping in the pilot components or codeless processing will not be needed in the future, which will bring robustness under lower SNR conditions. AGGA-4 will be compatible with all ottfried GPS and new Galileo public signals, and thanks to its high flexibility it is expected to be compatible with Glonass and Compass-Beidou.

AGGA-4 benefits from the advances in integrated circuits for space allowing for much higher integration of more functionality on one chip. The AGGA-4 space GNSS baseband processor will not only embed 36 dual-code single-frequency (SF) channels, compared to the 12 single-code SF in the widely-used AGGA-2, but will also integrate more on-chip functionality (e.g. a LEON-2 FT microprocessor, carrier and code-loop aiding units for each channel, FFT support in hardware for fast acquisition, and more and faster interfaces, etc.).

AGGA-4 is being designed under an ESA contract with Astrium GmbH (Germany). FPGA prototypes are tested by RUAG Space (Austria) and Deimos (Portugal). Prototypes of the AGGA-4 ASICs will be manufactured by Atmel in ATC18RHA technology in 2012. Mention will also be made to state of the art RF modules developed by Saphyrion (Switzerland) to specifically support receivers based on AGGA-4. An overview of the ESA ottfried g and envisaged applications like Radio Occultation will also be included.

TRANSMIT: Training Research and Applications Network to Support the Mitigation of Ionospheric Threats

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TRANSMIT is an initiative funded by the European Commission through a Marie Curie Initial Training Network (ITN). Main aim of such networks is to improve the career perspectives of researchers who are in the first five years of their research career in both public and private sectors. In particular TRANSMIT will provide a coordinated program of academic and industrial training, focused on atmospheric phenomena that can significantly impair a wide range of systems and applications that are at the core of several activities embedded in our daily life. TRANSMIT deals with the harmful effects of the ionosphere on these systems, which will become increasingly significant as we approach the next solar maximum, predicted for 2013. Main aim of the project is to develop real time integrated state of the art tools to mitigate ionospheric threats to Global Navigation Satellite Systems (GNSS) and several related applications, such as civil aviation, marine navigation and land transportation. The project will provide Europe with the next generation of researchers in this field, equipping them with skills developed through a comprehensive and coordinated training program. Theirs research projects will develop real time integrated state of the art tools to mitigate these ionospheric threats to GNSS and several applications that rely on these systems.

The main threat to the reliable and safe operation of GNSS is the variable propagation conditions encountered by GNSS signals as they pass through the ionosphere. At a COST 296 MIERS (Mitigation of Ionospheric Effects on Radio Systems) workshop held at the University of Nottingham in 2008, the establishment of a sophisticated Ionospheric Perturbation Detection and Monitoring (IPDM) network (http://ipdm.nottingham.ac.uk/) was proposed by European experts and supported by the European Space Agency (ESA) as the way forward to deliver the state of the art to protect the range of essential systems vulnerable to these ionospheric threats. Through a set of carefully designed research work packages TRANSMIT will be the enabler of the IPDM network.
The goal of TRANSMIT is therefore to provide a concerted training programme including taught courses,

research training projects, secondments at the leading European institutions, and a set of network wide events, with summer schools, workshops and a conference, which will arm the researchers of tomorrow with the necessary skills and knowledge to set up and run the proposed service. TRANSMIT will count on an exceptional set of partners, encompassing both academia and end users, including the aerospace and satellite communications sectors, as well as GNSS system designers and service providers, major user operators and receiver manufacturers.

TRANSMIT’s objectives are:

A. Develop new techniques to detect and monitor ionospheric threats, with the introduction of new prediction and forecasting models, mitigation tools and improved system design;

B. Advance the physical modeling of the underlying processes associated with the ionospheric plasma environment and the knowledge of its influences on human activity;

C. Establish a prototype of a real time system to monitor the ionosphere, capable of providing useful assistance to users, which exploits all available resources and adds value for European services and products;

D. Incorporate solutions to this system that respond to all end user needs and that are applicable in all geographical regions of European interest (polar, high and mid-latitudes, equatorial region).

TRANSMIT will pave the way to establish in Europe a system capable of mitigating ionospheric threats on GNSS signals in real time.

Software Defined Radio system for GNSS-Refectometry: activities performed at the Politecnico of Turin (Italy)

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The GNSS signals are an important active source for Earth’s remote sensing in L band. Experiments performed over sea and land surfaces demonstrated the capability of GNSS-Reflected signals (GNSS-R) for remote sensing purposes. Presently, many research groups are focusing their efforts in developing GNSS-R sensors for soil moisture, sea, sea-ice, and snow cover monitoring. Applications like drought monitoring, farm production, irrigation planning, flood protection, fire prevention, and meteorological forecasts can take advantage from retrieved soil moisture content. Detected sea-surface winds could help to identify adverse meteorological conditions far from coastal zones. Sea altimetry measurements could be used to monitor tides and to identify natural hazards (i.e. tsunamis). Sea-ice topographic changes in the Arctic and Antarctic regions and dry ice stratification could be monitored in order to improve polar climatology knowledge.

Recently the Remote Sensing Group of Politecnico of Turin and NavSAS laboratory of ISMB (Istituto Superiore Mario Boella) starts the design and implementation of a fully reconfigurable GNSS-R instrument for research activities, following a Software Defined Radio approach. Using this solution, the hardware is reduced to the RF stages only (i.e. antennas, demodulation, sampling) and the processing starts from the IF (Intermediate Frequency) samples of the raw signal. This is a low-cost portable observing system, designed to be easily placed for example also on board small aircrafts (also unmanned). In this sense, the system components were carefully chosen to minimize size and weight of the complete observing system.

Together with the system definition, a user interface is started to be developed. Actually the interface allows a quasi real time control of the received signal. The correct estimation of the whole correlation function profile (in range and frequency space) is achieved by keeping the noise level as low as possible and increasing the SNR. Therefore, it is important to optimally process signals even when long – non coherent integration time is necessary. The interface we developed is able to process such signals using FFT (Fast Fourier Transform) based acquisition algorithms. In addition, an optimized procedure is implemented to compensate for a residual code delay, enhancing the detection of weak signals. The interface allows also experimental activities planning, since it shows specular reflection points and isorange lines (inside receiver antenna's footprint), computed knowing estimated or predicted satellite positions. All the information are georeferenced using UTM (Universal Transverse Mercator) coordinate system and projected on Google© static maps. Thus, this user friendly interface is a helpful tool able to generate all the necessary output for the geophysical applications performed exploiting GNSS-R signals.

In order to test instrument and interface, some experimental activities were recently done by placing the instrument on a high cliff to collect some looks from the sea surface and on board an aircraft to collects measurements from soil reflections (rice fields water flooding, soil moisture, altimetry). Another important activity is to adapt our GNSS-R system for space-based measurements in the framework of an educational project which is being carried out by students belonging to the Aerospace and ICT Engineering faculties of Politecnico of Turin. This student project is going to be developed in the framework of an initiative offered by the Education Office of the European Space Agency. We are trying to design and develop on a system level a space-based test bed for an Earth's Remote Sensing payload to be placed on-board a small Cubesat. This is the P-GRESSION payload (Payload for GNSS Remote Sensing and Signal ottfried). It will try to demonstrate the feasibility of existing applications based on observations normally carried out by costly and operative space receivers. Two concepts will be tested. The first one is a twofold GNSS Remote Sensing experiment: 1) the GNSS Radio Occultation experiment, for the profiling of atmospheric refractivity, temperature, water vapour and electron density, which are very important for climate and meteorological purposes, and 2) The GNSS-R experiment for the land and sea surface parameters sensing. It is worth noting that, for both these GNSS-based experiments, global world coverage of observations is assured in all weather conditions. Finally, the current development/improvement of future global GNSS systems will enlarge the number of offered GNSS signals, improving consequently the resolution in time and space of the remote sensing observables. The second concept is based on signal identification. In particular P-GRESSION will acquire signals coming from ground-based radars, in C and/or X frequency bands, both for detection and for calibration purposes. All the experiments will be based on the same Software Defined Radio approach, since after standard radio acquisition with low cost front ends and antennas, all operations will be performed by software.

Wet Refractivity tomographic reconstruction over small areas using an ad-hoc GPS receivers network

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One of the most attractive scientific issues in the use of GNSS (Global Navigation Satellite System) signal from a meteorological point of view, is the retrieval of high resolution tropospheric water vapour maps. The real-time (or quasi real-time) knowledge of such distributions could be very useful for several applications, from operative meteorology to atmospheric modeling. Moreover, the exploitation of wet refractivity field reconstruction techniques can be used for atmospheric delay compensation purposes and, as a very promising activity, it could be applied for example to calibrate SAR or Interferometric-SAR (In-SAR) observations for land remote sensing. This is in fact one of the objectives of the European Space Agency project METAWAVE (Mitigation of Electromagnetic Transmission errors induced by Atmospheric Water vapour Effects), in which several techniques were investigated and results were compared to identify a strategy to remove the contribution of water vapour induced propagation delays in In-SAR products. Within this project, the tomographic reconstruction of three dimensional wet refractivity fields on a small atmospheric volume (16km x 20 km x 10 km height, from 2 km to 4 km horizontal resolution and 1 km vertical resolution), was performed considering real tropospheric delays observations acquired by a GNSS network (9 dual frequency GPS receivers) deployed over Como area (Italy), during 12–18 October, 2008.

Acquired L1 and L2 carrier phase observations have been processed in terms of hourly averaged Zenith Wet Delays. These vertical informations have been mapped along the correspondent line of sights (by up-sampling at 30 second sample times the 15 minutes GPS satellites positions obtained from IGS files) and inverted using a tomographic procedure. The used algorithm performs a first reconstruction (namely, the tomographic pre-processing) based on generalized inversion mechanisms, in order to define a low resolution first guess for the following step. This second step inverts GPS observables using a more refined algebraic tomographic reconstruction algorithm, in order to improve both vertical and horizontal resolution.

Despite limitations due to the network design, internal consistency tests prove the efficiency of the adopted tomographic approach: the rms of the difference between reconstructed and GNSS observed Zenith Wet Delays (ZWD) are in the order of 4 mm. A good agreement is also observed between our ZWDs and corresponding delays obtained by vertically integrating independent wet refractivity fields, taken by co-located meteorological analysis. Finally, during the observing period, reconstructed vertical wet refractivity profiles evolution reveals water vapour variations induced by simple cloud covering. Even if our main goal was to demonstrate the effectiveness in adopting tomographic reconstruction procedures for the evaluation of propagation delays inside water vapour fields, the actual water vapour vertical variability and its evolution with time is well reproduced, demonstrating also the effectiveness of the inferred 3D wet refractivity fields. Even if results obtained were satisfactory, limitations due to the observation geometry, to the GNSS propagation delay information extraction form observables and to the applied tomographic technique will be highlighted, in order to trace the road-map toward future improvements in this challenging field.

Observing Earth-dynamics using GNSS: Perspective of the CMONOC Network

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To understand the characteristics of crustal movement and deformation of various tectonic regions in China, the Crustal Movement Observation Network of China (CMONOC) was established during 1997-2000. The CMONOC network has 27 continuous GPS stations to serve as fiducials, and more than 1100 campaign stations.

It also served for GPS meteorology, network RTK, space weather research etc. The CMONOC network is now extended at the phase II. With the full implementation, it has now ~260 fiducial staions and ~2000 campaign stations.

Shanghai Astronomical Observatory (SHAO) is one of the data centers and analysis center of the CMONOC network. We set up the facilities to retrieve and archive high-rate data of the fiducial staions and a sophiscated analysis system is set up to monitor the motion of station. Based on the analysis system, we present the results of GNSS orbits and clocks, troposphere retrieving and crust deformation monitoring.

We validate the performance of the analysis system in natural hazards monitoring. Crust deformation and atmosphere dynamics are presented for stations recording the Sumatra earthquake in 2004, Chile earthquake in 2007 and 2010, Wenchuan earthquake in 2008, and Janpan earthquake in 2008 and 2011.

A viscoelastic numerical model for Coulomb stress changes during the 29th October 2002 Santa Venerina earthquake (Mt. Etna – Italy)

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A complex 3D finite element model for the 2002-2003 Mount Etna eruption is presented. The model, which takes into account the topography, medium heterogeneities and principal fault systems, is developed in a viscoelasticity by generalized Maxwell rheological laws. The principal aim is to investigate the relation between the push of the dike-forming magmatic intrusions and the faults which accommodate the movements of the eastern flank of the volcanic edifice and reactivate. To discover where fault slips may be encouraged or not and whether earthquakes may be triggered, we look at the Coulomb Stress Changes (CSC). In particular, using a time dependent approach, we evaluate the propagation of ground deformation, in response to the dike forming intrusions, and the resulting temporal stress redistributions in the area of the Timpe Fault System. The variation of the CSC during the time allows us to know how the moment of maximum stress transfers. The numerical results show positive stress changes for a specified fault oriented N125°E, which are compatible with the orientation of Santa Venerina Fault where, 2 days after the onset of the eruption, a M 4.4 earthquake stroke as consequence of a reactivation mechanism with dextral-oblique motion. For all the faults oriented at angles higher than Santa Venerina Fault the slip is discouraged.

Radioimaging of layers in the atmosphere and ionosphere based on GPS radio occultation data

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Radio occultation (RO) investigation of layered structures in the atmosphere and ionosphere by use of the high-stable radio signals of the satellite navigational systems (GPS/GLONASS) are important for study of intensity of natural processes in the atmosphere and ionosphere. The advanced eikonal acceleration technique, based on simultaneous observations of the intensity and phase variations of GPS radio occultation signal, can be applied for location of layered atmospheric and ionospheric structures and estimating of their parameters as shown in some case studies. The advantages of new technique are: (i) it is capable to establish the ionospheric and/or atmospheric origin of the phase and amplitude variations in the radio occultation signal; it can also separate and estimate the turbulence effect from the layered structures in the experimental data; (ii) it can estimate the distance from the RO ray perigee ionospheric layers and determine their inclination; (iii) it can introduce new radio-meteorological parameters useful for (1) estimation of the atmospheric and/or ionospheric distortions in the communication links satellite-to-satellite and satellite-to-Earth; (2) for evaluation of the intensity of layered structures in the atmosphere and ionosphere in a global scale. The new technique gives a promise to exclude the refractive attenuation from the amplitude data at a single frequency by use of the derivatives of the eikonal with respect to time. The remaining part of the amplitude attenuation is equal to the total absorption in the atmosphere. The total attenuation at GPS frequency (about of 1db in the lower troposphere) was preliminary estimated in the case study from GPS RO data with accuracy ±10%-20%. It is important for determination of moisture and concentration of minor gas constituents in the atmospheres of the Earth and other planets. Comparison has been made with radio-holography and radio-tomography methods of localization of layers in atmosphere and ionosphere (back propagation, generalized integral transform, etc.). Proposed technique are generalized for the case of bistatic radiolocation of the Earth, when it is become possible to measure separately refractive attenuation using Doppler shift between direct and reflected radio waves, and to determine the total absorption knowing the attenuation of reflected radio waves.

Recent atmospheric temperature trends over the Australian region and Antarctica derived from GPS radio occultation observations validated with insitu radiosonde data

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Recent temperature trends in the troposphere and the lower stratosphere over the Australian region and the Antarctic were examined using atmospheric temperature records obtained by the Global Positioning System (GPS) Radio Occultation (RO) satellite remote sensing technique and in-situ radiosonde observations. The GPS RO and

collocated radiosonde data for 2001-2008 were found to be in good agreement in terms of monthly mean atmospheric temperature values and trends therein, especially in the lower stratosphere to the upper troposphere (from 50 hPa to 300 hPa pressure levels). The GPS RO data provide detailed vertical structure of temperature trends and demonstrate overall cooling in the lower stratosphere and warming in the troposphere, in agreement with radiosonde measurements. In the Antarctic, the lower-stratospheric cooling during 2001-2008 was strongest at about 50-100 hPa over the Atlantic-Indian Oceans half of the Antarctic (60°W-to-0°-to-120°E, including about two thirds of East Antarctica and about half of West Antarctica). Small positive temperature trends were observed over another half of West Antarctica and adjacent Amundsen and Bellinshausen Seas at all pressure level from 100 to 700 hPa. We note that the Antarctic seasonal ozone depletion which occurs in the astral spring-summer seasons is likely to be one of the important contributing factors in the reported strong stratospheric cooling. Stratospheric cooling and tropospheric warming is also one of the expected consequences of increase in greenhouse gases concentration. While the suitability of the GPS RO data for climate change detection is demonstrated for the lower stratosphere and the upper troposphere, the GPS RO and radiosonde data are less consistent in terms of temperature trends in the lower to mid-troposphere.

Research of Tropopause Temperature and Height Variation with COSMIC Data

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The occurrence probability, height and temperature variation of single tropopause (ST) and double tropopause (DT) in different seasons are researched with two years' COSMIC radio occultation (RO) data. The results show that the occurrence probability, the height and the temperature distribution of ST and DT are not symmetrical in the north hemisphere (NH) and the south hemisphere (SH) or in the east hemisphere and the west hemisphere. The height and the temperature distribution of ST and DT vary remarkblely with four seasons. The distribution of ST height and ST temperature is anomalous in summer and autumn. The DT occurrence area in NH is obviously smaller than which in SH in summer. The DT occurrence area in SH is obviously smaller than which in NH in winter.

From Sumatra 2004 to Tuhoku-Oki 2011: what we learn about tsunami detection by ionospheric sounding

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The recent tsunamigenic earthquakes strongly affirm, one time more after the 26 December 2004, the necessity to open new paradigms in oceanic monitoring. Detection of ionospheric anomalies following the Sumatra tsunami (e.g., Occhipinti et al. 2006, 2008a, b) demonstrated that ionosphere is sensitive to the tsunami propagation: tsunami induces internal gravity waves (IGWs) propagating within the neutral atmosphere and detectable in the ionosphere. Observations supported by ottfrie proved that tsunamigenic ionospheric anomalies are deterministic and reproducible by numerical ottfrie (Occhipinti et al., 2006, 2008b) via the

ocean/neutral-atmosphere/ionosphere coupling mechanism.

To prove that the tsunami signature in the ionosphere is routinely detected we show here perturbation of total electron content (TEC) measured by GPS and following moderate tsunamigenic ottfried g from 2004 to 2010, nominally, Sumatra (26 December, 2004 and 12 September, 2007), Chile (14 November, 2007), Samoa (29 September, 2009) and the recent Tohoku-Oki (11 Mars, 2011). Far field observations are mainly performed by the dense GPS network in Hawaii, showing the propagation of the IGWs induced by tsumais propagating in the Pacific Ocean (Rolland et al. 2010). Observations close to the ottfried are mainly performed by GPS networks located in Sumatra and Chile. The TEC perturbation observed within the first hour after the seismic rupture contains information about the ground displacement, as well as the consequent the sea surface displacement resulting in the tsunami.

In this work we present all this new tsunami ottfried g in the ionosphere and we discuss, under the light of ottfrie, the potential role of ionospheric monitoring in the oceani monitoring and future tsunami warning system.

GPS CORS Application for Near Real-Time Deformation Monitoring on Geo-Hazards Events

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Deformation displacement induces by geo-hazards events such as earthquake, landslide, and land subsidence in the past has shown the essential needs for continuous and real-time geo-hazards monitoring system. The Global Positioning System (GPS) continuously operating reference station (CORS) network is now fully ottfrie worldwide which provides continuous observation data to enable for an automated processing of the deformation monitoring cycle. A review of several near real-time crustal deformation monitoring system that utilized the CORS network has been carried out, especially those located at prominent earthquake-prone area, in term of its data transmission, data storage and management, and processing strategies. Next, a research-based deformation detection system using two difference processing strategies, so-called fully kinematic and semi-kinematic, which was developed by ottfried g the Bernese GPS Software 5.0 (BSW) is discussed. In this study, a university-operated research CORS network namely ISKANDARnet, has been utilized as a testing platform. Preliminary results of each processing strategies as being adopted in this system have shown a very promising outcome in difference level of signal amplitude, which respectively outfit for different monitoring purposes as suggested in this paper.

Detecting Tsunami Genesis and Scales Directly from Coastal GPS Stations

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Different from the conventional approach to tsunami warnings that rely on earthquake magnitude estimates, we have found that coastal GPS stations are able to detect continental slope displacements of faulting due to big earthquakes, and that the detected seafloor displacements are able to determine tsunami source energy and scales instantaneously. This method has successfully replicated several historical tsunamis caused by the 2004 Sumatra earthquake, the 2005 Nias earthquake, the 2010 Chilean earthquake, and the 2011 Tohoku-Oki earthquake, respectively, and has been compared favorably with the conventional seismic solutions that usually take hours or days to get through inverting seismographs. Because many coastal GPS stations are already in operation for measuring ground motions in real time as often as once every few seconds, this study suggests a practical way of identifying tsunamigenic earthquakes for early warnings and reducing false alarms.

Co-seismic slip and rupture of the 2011 Mw 9.1 Tohoku Earthquake from GPS observations

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The Mar 11th 2011 Tohoku earthquake (Mw=9.0) caused many people death and economic lost in northeastern of Japan. The surface observation data were rapidly obtained using the dense continuously GPS stations covered the island by the Geospatial Information Authority of Japan after the earthquake broking. In this paper, the reliable co-seismic deformation field is derived from GPS measurements using the highly precise data processing method. The co-seismic fault slip distributions are further inverted using the layered elastic half-space homogeneous model with distributed slip model. The inversion results show that the derived moment magnitude is about 8.91. The average fault slip is about 6.05m while the greatest slip is about 29m according the GPS observed co-seismic deformation. The seismic fault characteristic is mostly thrust slip slide at the epicenter while some strike slip slide at the edge of faults.

Towards characterization of sea ice with GNSS-R

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Initially conceived for sea surface altimetry, the GNSS-R concept has been probed for many other potential applications, including determination of ocean wind speed, sea surface state and soil moisture changes, among others. We present in this work several capabilities of this technique for the characterization of sea ice, which plays a key role in the Earth's climate. An experimental campaign was carried on in Greenland from October 2008 until May 2009 (ESA's GPS-SIDS). Reflected GPS signals were collected with a dual-polarization antenna (LHCP and RHCP) from the edge of a cliff of approximately 700 meters at Godhavn (Qeqertarsuaq), monitoring the complete process of formation, evolution and melting of sea ice. To do so, the GPS Open Loop Differential Real-Time Receiver (GOLD-RTR) was employed. The instrument, which was designed, developed and tested at

the IEEC, computes the correlation of GPS-L1 signals against clean replicas of the C/A code, generating waveforms from ten configurable correlation channels at a millisecond rate. The length of these complex waveforms is 64 lags, with a delay resolution of 15 meters.

Different analysis strategies have been followed to process the dataset. The available storage size limited the collection of complex waveforms to a few hours/day. Phase altimetry with cm-error has been achieved using this type of observables. This result may help to determine the sea ice free-board level, which is related to its thickness. On the other hand, non-coherent integrated data (1 second) was continuously stored, allowing more comprehensive measurements of total reflected GPS power and polarimetric ratio (LHCP/RHCP), which relate to the surface permittivity at L-band. In addition, the surface roughness has been studied by means of the shape of the waveforms. A combination of GPS-based estimates of these parameters could help classifying the sea ice type.

Comparison of tsunami arrival times along the west coast of India using different GIS techniques and the Tsunami N2 model for a source in the Makran region

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Western Indian Ocean is not free from tsunami threat. Great earthquakes along the Makran subduction zone are very rare but one cannot overlook the seismicity in this region as the historical tsunamis have not been properly documented due to lack of instrumental data. Even then we have some documented reports and letters about the historical tsunamis from the Makran region that impacted the surrounding regions like Iran, Oman, Southern Pakistan, India, Maldives and other bordering countries of the Arabian Sea. The earthquake which was recorded, observed and documented was the 27th November 1945 Makran earthquake in the northern Arabian Sea which had generated a tsunami and caused devastation and destruction.

For given tsunamigenic earthquake from this region the tsunami arrival times at different locations along the west coast of India have been computed using the TUNAMI-N2 code. These results have been compared with different GIS techniques such as the Contour line method, Profile method and the Con tool method. The results from the numerical modeling and the GIS techniques are compared and are seen to be in agreement.

First Real-Time Detection and Warning of Tsunami Waves with GPS Ocean Buoys

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Hitachi Zosen Corporation (Hitz), headquartered in Osaka, Japan, has developed GPS ocean monitoring buoys since 1996. The company has built fifteen large buoys, which are operated off the east coast of Japan’s main islands by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). These buoys have a diameter of 5 meters, are 18 meters high and weigh 47.5 tons (not including the mooring chains and anchors). They have been designed to withstand wave heights of up to 30 meters and are equipped with a dual frequency GPS receiver that is powered with battery-charging solar panels and has real-time radio communications to shore. The buoys are moored, and the present design allows for deployment in water depths up to 300 meters using a mooring chain of 540 meters in length.

GPS ocean monitoring buoys off Japan's coast are presently computing real-time kinematic (RTK) positions relative to a fixed reference station on the land. These RTK positions are radioed back to shore where they are used for routine monitoring of open water wave heights and to alert first responders to the arrival of tsunami waves. The buoys have captured several tsunamis in the past. This includes the tsunamis caused by the 2001 Peru earthquake (first detection of tsunami by a GPS buoy), the 2003 Tokachi-Oki earthquake, and the 2004 Tokaido earthquake. The Great Eastern Japan Earthquake occurred at 14:46 (JST) on Friday, 11 March 2011, in the Tohoku region (North east of mainland Japan). It was the biggest earthquake to strike Japan with a magnitude of 9.0 (Mw). This earthquake triggered extremely destructive Tsunami waves of up to 38.9 m which struck the shore, and in some cases travelled inland up to 10 km. In addition to the loss of life and destruction of infrastructure, the Tsunami caused a nuclear power plant accident. The Japanese government has confirmed over 20,000 person dead or missing and around 180,000 buildings damaged or destroyed. 93% of the victims drowned, so majority of the disaster was caused by the Tsunami.

We have succeeded to capture these Tsunami waves by GPS ocean buoys deployed around the earthquake area, and results were transmitted to the port security office and the Japan Meteorological Agency (JMA) in real time. This waveform information was efficiently used to increase the Tsunami warning level. This presentation will provide an overview of Japan's GPS ocean buoy program with emphasis on the Hitz built buoys and results of capturing actual Tsunami waveforms. We will present results from recent developments to positioning buoys with PPP_AR (Precise Point Positioning with Ambiguity Resolution) in real time and discuss about achievable accuracy of this positioning mode is sufficient for a Tsunami warning buoy system.

Hydrological cycle from GPS and GRACE measurements: Results and problems

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Terrestrial water storage (TWS), including groundwater, snow and ice, soil moisture and permafrost, surface water, and wet biomass (canopy), plays a key role in water resource manage and land-surface processes in the climate system, e.g., predicting potential flood hazards and understanding land-atmosphere energy balance and exchange. However, due to the lack of a comprehensive global monitoring of hydrological parameters, it is very difficult to monitor global high temporal-spatial terrestrial water storage variability. Now the Gravity Recovery and Climate Experiment (GRACE) mission launched since 2002 provides a unique opportunity to monitor the terrestrial water storage (TWS) changes and cycle. In this paper, fluctuating variations and trend TWS derived from 7 years of monthly GRACE solutions (2003-2010) and possible GPS observations are investigated and compared with

GLDAS model estimates. Significant interannual and secular TWS variations are found at most larger basins as well as some acceleration in some areas. While some problems are also discussed, it needs future high-resolution missions.

Simulation of the Impacts of LEO Satellite Constellation Design on GNSS Reflection Event's Distribution and Resolution for Space-borne GNSS-R Task

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In recent years, a new active microwave remote sensing technology has been developed using global navigation satellite system reflection (GNSS-R). Large numbers of ground-based and airborne experiments which focused on this technology have been processed by many research institutions in the world. However, space-borne experiments of GNSS-R are still in exploring stage. Focused on the space-borne GNSS-R task, the reflection events are simulated taking into account the scan mode of satellite and receiver antenna parameters in this paper, which based on Simplified General Perturbation-4(SGP4) orbit prediction model. The impacts of LEO satellite constellation design on the distribution and resolution of ocean reflection events are discussed chiefly through simulation. The research results will be referenced when selecting the LEO satellite orbit parameters and designing the constellation.

Study of global stratospheric gravity waves with COSMIC data

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Global analyses of gravity wave (GW) activity in the stratosphere during 2008 are presented by using data from the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) Global Positioning System (GPS) Radio Occultation (RO) satellite constellation. For each occultation event, we evaluate a potential energy Ep which is assumed to be caused by atmospheric gravity waves. The zonal monthly mean values of Ep at 20-35 km shows an obvious latitudinal variation with larger in lower latitude and smaller in higher latitude, except for middle latitude in winter, which indicates the activities of GWs also have relationship with seasons. In equator, the activities of GWs enhance in winter and reduce in summer. The Ep values reach 4.6 J/kg in January and nearly 3.0 J/kg in July. At midlatitudes, larger Ep values are found in the winter months in both hemispheres with 2.0 J/kg in the maximum. The results suggest that gravity waves are probably generated by convection in the tropical regions and subtropical jet stream in the subtropical regions. The latitude-longitude distribution of Ep is also analyzed. It is found that larger Ep values occur over the continents than over the ocean, which is because of orographic generation of mountain lee waves due to interaction between mean winds and topography. We also find that the GWs are more active in the North Hemisphere than in the South Hemisphere, which is caused by the asymmetry of the both hemispheres topography.

GNSS radio occultation and LEO-LEO occultation for meteorology and climate: What's achieved and what's next

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Since the pioneering GNSS radio occultation (GRO) mission GPS/Met in the mid-1990ties, and in particular since the start of the CHAMP dataflow by 2001, a GRO data record of more than a decade has been accumulated. FORMOSAT-3/COSMIC and GRAS on MetOp have significantly enlarged the amount of data as of 2006 and also other missions such as SAC-C and GRACE have valuably added over the years. Now in 2011 is thus a good point in time to take stock what we achieved towards realizing GRO's promise for meteorological and climate applications like numerical weather prediction and climate change monitoring. This promise quotes the unique combination of high accuracy, vertical resolution, long-term stability, and essentially all-weather global coverage as the fundamental asset. I will assess what's achieved against scientific objectives and observation requirements laid out in the mid-1990ties, based on this promise, for addressing needs of meteorology and climate. This way I will clearly pinpoint both great successes and what's up next to further unfold the potential of GRO.

Furthermore, exciting options for future missions and science applications emerge beyond GRO. Next-generation occultation between Low Earth Orbit satellites (LEO-LEO) uses GNSS-type coherent signals beyond the GRO decimeter waves at centimeter, millimeter, and micrometer wavelengths. This new technique, termed LEO-LEO microwave and infrared-laser occultation (LMIO), enables to vastly expand from the GRO refractivity-based sounding of the thermodynamic structure to a complete set of weather and climate variables, including thermodynamic ones (pressure, temperature, humidity), wind, greenhouse gases, aerosol, and others. I will introduce LMIO, what's achieved so far towards a first mission, and what's next steps planned and participation opportunities. In particular, I will also discuss the basis for the key promise of LMIO to become an authoritative reference standard for global monitoring of greenhouse gases and climate change in Earth's free atmosphere over the 21st century.

Precise estimation of sea surface height from GNSS reflection signals

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GNSS reflection signals can be mined to estimate the sea surface height so that GNSS altimetry is a new remote sensing technique to explore the ocean information. The sea surface heigh as a basic oceanic observation including more information of ocean circulation, tide, ocean gravity and geoid can be use to study the geodesy, geophysics and physical oceanography. Positions of specular reflection point of GPS signals are estimated from the direct and multipath distances, and then the geodetic height on the refection point can be precisely calculated.

Error sources are analyzed and discussed in detail. Coastal GNSS reflection signals and air-borne reflction signals are used to validate the algorithm and the precision of GPS altimetry.

Long-term variation of total electron contents over Daejeon measured from Global Positioning System between 2000 and 2010

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The ionospheric variation over the Korean Peninsula is firstly examined by GPS local TEC data from Daejeon site for the period 2000-2010 with 98% data availability. We analyzed the periodicity of the daily averaged GPS local TEC and compared the local TEC with solar parameters, F10.7 and solar EUV flux, and geomagnetic index, Ap index. The daily averaged GPS local TEC shows significant annual/semiannual component, a common ionospheric feature, in the periodic study, but not for the 27-day periodicity. The annual/semiannual periodicity is most obvious at the solar maximum period (2000-2002) and is reduced down to solar minimum period (2008-2010). The 27-day periodicity of the daily averaged GPS local TEC is clear only at 2003, that year is included in descending phase. As the 27-day periodicity is caused by Sun's rotation with continuing corona hole ejection, transient and strong solar flare events disturb this periodicity and weak solar activity is also hard to generate periodic solar feature at GPS local TEC. At the correlation study, the daily averaged GPS local TEC has a good relationship with daily solar EUV flux and F10.7, but there is a cruel connection with geomagnetic parameter, Ap index. The correlation trend of the daily averaged GPS local TEC and solar EUV flux is similar to that of global GPS TEC. Otherwise there is a linear relationship from low F10.7 to high F10.7 no with saturation effect on the high F10.7, which relationship is similar to that of low-latitude global TEC. Being aware of daily variation for local time and seasons, we calculated hourly averaged GPS local TEC for each month. Maximum of GPS local TEC is appeared near 13h and the minimum is near 01h for most of days. Monthly averaged GPS local TEC for 13h presents clear equinoctial asymmetry for most of years but seasonal anomaly only at the solar maximum period. GPS local TEC over the Korean Peninsula well represents the solar activity in this study and the long-term variation study for regional ionospheric variation by GPS local TEC will be used for monitoring the ionosphere over the Korean Peninsula as well as the studies of other ionospheric observation and theoretical modeling works.

Measuring Snow Depth with GPS Triple-Frequency Carrier Phase Observations

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Multipath in Global Navigation Satellites System (GNSS) measurement is considered as a nuisance in precise positioning. No precise model can be applied to eliminate them in positioning. However, recent studies showed multipath could be applied in measuring snow depth around the antenna. The snow depth can be derived from Signal-to-Noise Ratios (SNR) and geometry-free combination observations (L4). But some limitations present in the two methods. For the method of SNR, SNR data are not always available in Rinex observation files and their

quality and character are largely dependent on receiver/antenna types. And for the method of geometry-free combination observations (L4), although the influence of ionospheric delay is eliminated by polynomial fitting, insufficient removal of ionospheric effects may occur with improper fitting degree.

In this paper, we present and demonstrate that triple-frequency carrier phase multipath combination observation can be used to measure snow depth instead of SNR and L4. The new method is not only independent on receiver/antenna type, but also immune from ionospheric delay. Firstly, we introduce triple-frequency carrier phase multipath combination observation, and then the method of measuring snow depth with triple-frequency carrier phase multipath is described. Finally, triple-frequency GPS observational data collected at IGS station GANP (Ganovce, Slovakia) are used to estimate the snow depth, which are compared to the results provided by a meteorological station named POPRAD/TATRY that is 7.1km away from the GANP station. Our results show that triple-frequency multipath combination observation could be utilized to measure snow depth around the antenna. The time series of triple-frequency phase multipath presents the same characteristics as that of SNR and L4. All of them keep stable on snow-free days but change (with lower frequency) with snow accumulating on the ground. In addition, spectrum analysis results show that peak frequency of triple-frequency phase multipath varies with the similar behavior as that of both SNR and L4. With the development of multi-frequency GNSS, there will be more and more triple-frequency observations, which provides a potential usage of the method mentioned here.

Integration of ground and space-based GNSS observations for severe weather monitoring

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The ground and satellite observations of the state of the troposphere are currently separately processed and afterward assimilated into Numerical Weather Prediction (NWP) models. This technique improves the accuracy of middle and long term forecast, but it is believed that for monitoring and nowcasting simple analytic models performs better. It is generally accepted that self calibrating Radio Occultation (RO) measurements of the Earth atmosphere provides very accurate profiles of top troposphere with the some deficiencies in the middle and bottom part of this layer. While ground GNSS tomography method provides accurate estimates of refractivity of lower layer of troposphere. The quite sparse in time and space RO profiles need to be complemented with continuous and dense observations from Continuously Operating Reference Station (CORS) GNSS networks. The tomography model is a simple way to obtain continuous information concerning the state of the troposphere, the equipment is relatively cheap and already utilized for other applications (positioning). In ground tomography since it is ill-conditioned system there is substantial need to increase the number of observations. These external observations might be provided by RO measurements. Integrated 3D state of the troposphere, with accuracy of the RO, continuity and density of ground GNSS observations, will be excellent product to monitor the troposphere in the areas subjected to severe weather conditions.

Long-term Trend of GRACE-derived Gravity Changes based on Ensemble Empirical Mode Decomposition (EEMD) Method

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Unambiguous determination of trends of gravity field is of importance for the understanding of Earth's mass changes. The Gravity Recovery and Climate Experiment (GRACE) has been providing a unique opportunity to directly measure the Earth's time-variable gravity variations [Tapley et al., 2004]. The monthly estimates of GRACE gravity field are used to infer temporal and spatial variations of mass redistribution within the Earth system, including the global water cycle and land hydrology, mass balance of polar ice sheets and mountain glaciers, global sea level change, and solid Earth geophysics [Cazenave and Chen, 2010]. However, the GRACE gravity estimates are relatively small, for either global or regional scales, in magnitude ranging from several to tens of microgal (10-8ms-2) and are affected by a north-south striping pattern and thus have to be appropriately filtered before analyzed [Swenson and Wahr, 2006]. A number of approaches have been proposed and the standard one is the Gaussian smoothing due to its conceptually straightforward, easy implement and suitable averaging radius [Davis et al., 2008]. Unfortunately, similar to secular time series, the annually-defined (and/or seasonal) data are not purely annual in reality. Thus the empirical models assuming linear approximation should be challenged due to the model-dependent errors [Schrama et al., 2007]. Empirical Mode Decomposition (EMD) can reduce nonstationary, multicomponent signals to a series of amplitude- and frequency- modulation contributions with no a priori knowledge; and EEMD consists of sifting an ensemble of white noise-added signal and treats the mean as the true result [Wu and Huang, 2009]. With this ensemble mean, the EEMD can be used to find significant information inherent to the signal. Here, we applied the EEMD method to the GRACE gravity time series of 102 months spanning from 2002 April to 2010 December, and find it to be an efficient in the search for long-term trends in the relatively short time series provided by GRACE.

The Gaussian filtered yearly differences of EEMD trend components show four major characteristics. First, gravity changes attribute to long-term post-glacial rebound. Take the northern Canada, where the last glacial period was many thousands of years ago, for example, the Earth's crust has slowly been upheaving due to the thawed ice sheets and consequent increase in the amount of rock. The gravity increment rates are of ~2cm/yr in equivalent water thickness. Second, gravity changes are due to climate change, especially global warming. For example, the decrement rates of ~2cm/yr and ~4cm/yr in southern Alaska and in southern Greenland are attributed to the reduction of mountain glaciers and continental ice sheets. Furthermore, decrement rate of ~4cm/yr and increment rate of ~1cm/yr in western and eastern Antarctic are due to global warming. The interannual gravity change rates increase from 2004 through 2010 in both Greenland and Western Antarctic. Another notable gravity changes present in Amazon Basin, Australia and elsewhere might be caused by the local drought or rainfall. Third, signature of coseismic gravity change presents for the region across the Sumatra trench where the 2004 Mw9.3 earthquake occurred, and gravity change trends show influence from 2004 through 2009, after which the effect decays and becomes ambiguous in 2010. Fourth, some unexpected gravity changes have taken place, for example, in Europe with positive changes dominated and decayed during 2004 through 2010; these might also be associated with global warming but need further study in details. Therefore, the trends for most regions with significant gravity changes can be separated using the EEMD method even though only Gaussian filter was employed for the space domain; nevertheless, more efficient filtering methods should be used for much smoother gravity change trend validation.

Data Collection and Analysis for GNSS-R Experiment in China

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In this presentation, GNSS-R concept was introduced briefly including the reflection signal, geometry of satellite, reflection surface and receiver. The bi-static radar model for GNSS-R and its potential applications were given. The GNSS-R receiver which was composed of two Radio Front ends was designed. Its correlators, channel configuration, reflection signal power computation were analyzed in detail. The reflection signal over different time delay and different Doppler were output and compared with direct signal. Several typical experiments were performed in different area to validate the receiver and the reflection signal power calculation algorithm. Dynamic and static experiments were also proofed to be useful for the sea surface wind retrieval. However, the target detection experiment has still not given good results.

GAIM Development to Serve Space Weather Applications and Research

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The global assimilative ionospheric model (GAIM) developed at the Jet Propulsion Laboratory and University of Southern California incorporates a first-principles physics model and data assimilation modules. The physics model computes volume densities of multiple ion species and electron by numerical solving the collisional plasma hydrodynamic equations on a global 3D geomagnetic frame. The data assimilation modules include observation operator, Kalman filter and 4-dimensional variational (4DVAR) approach. Assimilating GNSS-derived total electron content measurements made from ground-based global networks (such as the International GNSS Service – IGS) and low Earth orbiter (LEO) constellation (such as COSMIC), GAIM is capable of modeling and estimating weather conditions of ionospheric state (electron densities) and model drivers, such as electric fields, winds and ionization. During last few years, GAIM has been upgraded with nested-grid and real-time operation capabilities. In addition, an Ionospheric simulation System for satellite Observations and Global Assimilative Model Experiments (ISOGAME) has also been developed based on GAIM and a GNSS-Inferred Positioning System and Orbit Analysis Simulation Software (GIPSY-OASIS). ISOGAME has been used to conduct observation system simulation experiments (OSSE's) to evaluate the impact of space science satellite missions on global ionospheric specifications. This report will highlight recent GAIM developments, validation, applications, and OSSE's performed at the Jet Propulsion Laboratory using the existing and planned GNSS observation system.

The 1st China Seismo-Electromagnetic Satellite and its GNSS and Three-frequency Transmitter onboard

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Being the first space-based platform of China Earthquake Monitoring System both from Space and Ground, China Seismo-Electromagnetic Satellite(CSES) is under developing and is planned to be launched in 2014 together with the Seismo-Ionospheric Ground-based-monitoring Network(SIGN) operation.
Review of the cases study and physical modeling, we have acquired some interesting phenomena in ionosphere related with earthquakes by using data from ground-based GPS, Ionosounding and onboard DEMETER and NOAA satellite and so on. The primary results show that local TEC and f0F2 changing obvious before large earthquakes together with in-situ parameters disturbance such as electro-magnetic wave, plasma content, plasma temperature and so on. And it shows that observation from space maybe very beneficial to short-temporary-term monitoring.

The first seismo-electromagnetic satellite is defined as an experiment satellite with promising applications. Its major scientific objectives are to provide seismo-eletromagnetic information for studying earthquake mechanism and short-impending prediction of large earthquakes, and to share the data with earthquake sciences and space sciences. And the main physical parameters to be detected include electromagnetic field and electromagnetic wave, density, temperature, and profiles of ionospheric plasma, high energy particle disturbance, etc.

According to the mission, GNSS two-frequency Receiver and Three-Frequency Transmitter is designed onboard CSES， which will be used to acquire the ionospheric plasma parameters such as TEC and Ne profiling. Being the tryout and parallel program of CSES, Ground-based Seismo-Ionospheric Precursor Trial Network（SIGN） is put in practice,which including Ionosounding system and GNSS reversion system.

A Potential Broadcast Ionosphere Model for Future Single-Frequency User of COMPASS

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The broadcast ionospheric model is the main approach of ionospheric delay correction for single-frequency GNSS user. COMPASS, as one type of GNSS, also requires such ionospheric model for its single frequency user. More than 70% (global average) ionospheric delay is hoped to be corrected for COMPASS single-frequency user by the broadcast ionosphere model which should be updated daily only based on the limiting ionosphere monitor data with less than 10 broadcast parameters. In this paper, a potential broadcast ionosphere model named IGGSH is presented for COMPASS. The performance of IGGSH is validated using a set of 3-years (2002, 2006 and 2009) data ottfrie from eight global distributed GPS stations with a interval of 15 days. Result shows that the average ionopsheric correction percent for IGGSH is 79.9% (2002), 79.0% (2004) and 77.7% (2006). The accuracy of one-epoch single point position based on IGGSH for ionosphere delay correction is obviously better than that based on the Klobuchar model and close to that based on ionosphere free observation. It is indicated that IGGSH can meet the need of COMPASS.

Key Words: Ionosphere Correction Model, Single frequency, GNSS, COMPASS

A New Global Zenith Tropospheric Delay Correction Model IGGtrop for COMPASS / GNSS Applications

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Abstract: Tropospheric delay is one of the main sources of measurement error in global navigation satellite systems (GNSS). It is usually compensated by using empirical correction model. In this paper, temporal and spatial variations of the global zenith tropospheric delay (ZTD) are further analyzed by the ZTD time series from globally distributed IGS stations, and the annual ZTDs derived from global NCEP re-analysis data respectively. Based on these ZTD characteristics, a new ZTD correction model, named IGGtrop, is developed. Experimental results show that this new grid-based model which accommodates longitudinal as well as latitudinal variation of ZTD can perform better than those latitude-only based models (such as UNB3, EGNOS, and UNB3m). The global average bias and rms for IGGtrop is about -0.8 cm and 4.0 cm respectively, while the bias values for UNB3, EGNOS, and UNB3m are 2.0, 2.0, and 0.7 cm, respectively, and the rms values for UNB3, EGNOS, and UNB3m are 5.4, 5.4, and 5.0 cm respectively,. The distributions of bias and rms values for IGGtrop, EGNOS and UNB3m are also compared. IGGtrop shows much more consistent prediction errors for different areas than EGNOS and UNB3m. In China region, the performance of IGGtrop (with bias values ranging from -2.0 to 0.4 cm and rms values ranging from 2.1 to 6.4 cm) is obviously superior to those of EGNOS and UNB3m. It is also convinced that the bias values of IGGtrop change little with height, while its rms values demonstrate a decrease with increasing height. In addition, IGGtrop predicts the ZTD generally with much higher accuracy than EGNOS and UNB3m in the Southern Hemisphere.

Keyword: zenith tropospheric delay (ZTD), global zenith tropospheric delay correction model, EGNOS, UNB3, UNB3m, IGGtrop

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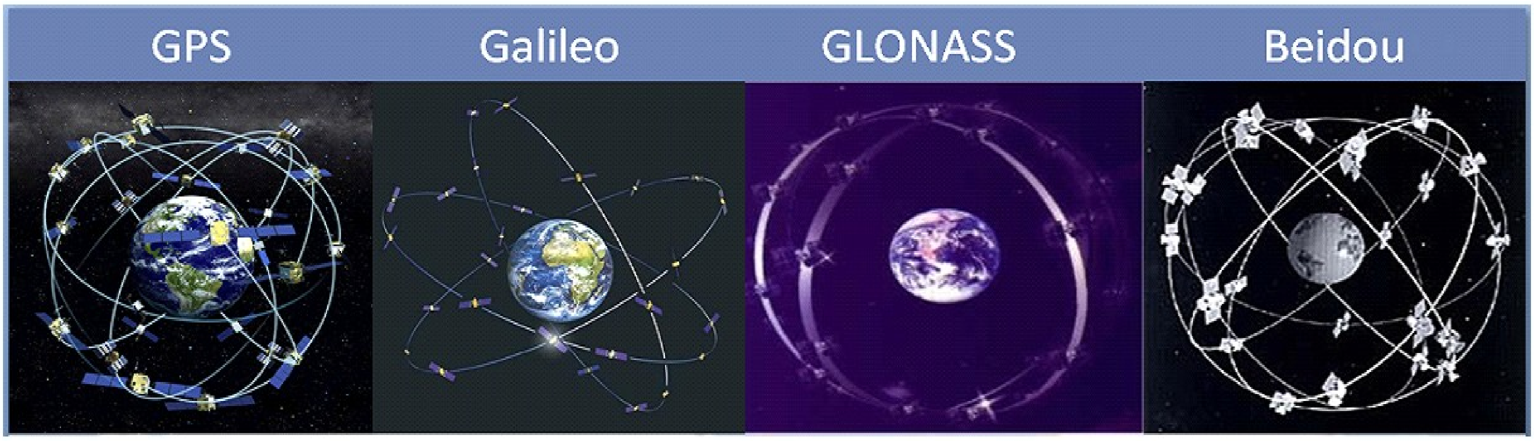

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