



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

The Ionosphere and its Effects on GNSS Systems

MITRE Presentations

14 to 16 April 2008
Santiago, Chile

Dr. M. Bakry El-Arini
Ing. Roland O. Lejeune
Dr. S. Vincent Massimini



Sobre MITRE – Nota Informativa

MITRE, una de las organizaciones más grandes en ingeniería de sistemas de Estados Unidos, es una institución de investigación no comercial, sin fines de lucro, dedicada a servir al interés público. Localizada en Washington, D.C. y Bedford, Massachusetts, cuenta con una planta de más de 6500 profesionales, en su mayoría ingenieros. Su Centro para el Desarrollo de Sistemas Avanzados de Aviación es la organización de investigación y desarrollo de ingeniería de sistemas aeroportuarios y de control de tráfico aéreo más grande de Estados Unidos. Muchos de los procedimientos aeronáuticos de la aviación civil internacional y los algoritmos de componentes electrónicos a bordo de aeronaves a nivel internacional fueron desarrollados por MITRE durante su medio siglo de existencia. MITRE ha colaborado con cerca de 50 naciones. Los orígenes de MITRE se remontan a años previos a 1958, cuando MITRE formaba parte del sistema de laboratorios del Massachusetts Institute of Technology (MIT), luego de lo cual pasó a convertirse en un laboratorio independiente de interés nacional.



Contacto con MITRE

Para información y contacto con MITRE, escribir al Dr. Bernardo Lisker, Director Internacional, Internet bernard@mitre.org o llamar al teléfono +1 703 983 6970 (Estados Unidos) (español o inglés)



Table of Contents

1 of 3

-
- **Principal Acronyms and Abbreviations** 7
 - **Overview of GNSS Navigation Sources, Augmentation Systems, and Applications** 12
 - **Ionospheric Effects on GNSS** 92
 - **Description of a Real-Time Algorithm for Detecting Ionospheric Depletions for SBAS and the Statistics of Depletions in South America During the Peak of the Current Solar Cycle** 125



Table of Contents

2 of 3

-
- **Tropospheric Effects on GNSS** **145**
 - **Ionospheric Corrections for GNSS** **166**
 - **Tropospheric Corrections Model for GNSS Receivers** **179**
 - **General Description of MITRE's Service Volume Models** **194**
 - **Modeling Effects of Ionospheric Delay on GNSS Availability** **210**



Table of Contents

3 of 3

-
- **Modeling Scintillation Effects on L1/L5 SBAS Availability in North and South America** 232
 - **Performance Estimates for Current and Future GNSS Systems and Augmented GNSS Systems (SBAS/GBAS/GRAS)** 266
 - **Short and Long-Term Planning Considerations** 291
 - **Recommendations for GNSS Data Collection, Planning, and Implementation** 297



Principal Acronyms and Abbreviations

1 of 5

A&K	Altshuler and Kalaghan Model
A/A/C	Accuracy, Availability and Continuity
ABAS	Aircraft-Based Augmentation System
ADS-B	Automatic Dependent Surveillance - Broadcast mode
APV	Approach with Vertical Guidance
ATC	Air Traffic Control
B&E	Black and Eisner Model
C/A	Coarse/Acquisition
CAT	Category
CDU	Control Display Unit
CMC	Code-Minus-Carrier
DF	Dual Frequency
DME	Distance Measuring Equipment
DoD	Department of Defense
DOP	Dilution of Precision
EGNOS	European Geostationary Navigation Overlay Service
FAA	Federal Aviation Administration
FDE	Fault Detection and Exclusion
FMS	Flight Management System



Principal Acronyms and Abbreviations

2 of 5

FTE	Flight Technical Error
GA	General Aviation
GAGAN	Indian Geo Aided GPS Augmented Navigation
GATOM	GNSS Air Traffic Operations Model
GBAS	Ground-Based Augmentation System
GDOP	Geometric Dilution of Precision
GISM	Global Ionospheric Scintillation Model
GIVE	Grid Ionospheric Vertical Error
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GRAS	Ground-Based Regional Augmentation System
HAL	Horizontal Alert Limit
HPE	Horizontal Position Error
HPL	Horizontal Protection Level
ICAO	International Civil Aviation Organization
IFOR	Interagency Forum on Operational Requirements
IFR	Instrument Flight Rules
IGP	Ionospheric Grid Points



Principal Acronyms and Abbreviations

3 of 5

ILS	Instrument Landing System
INS	Inertial Navigation System
IPP	Ionospheric Pierce Point
IRS	Inertial Reference System
ITU	International Telecommunication Union
LAAS	Local Area Augmentation System
LNAV	Lateral Navigation
LORAN	Long Range Navigation
LOS	Line of Sight
LPV	Localizer Performance with Vertical Guidance
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Standard
MSAS	MTSAT Satellite-based Augmentation System (Japan)
MTSAT	Multi-function Transport Satellite (Japan)
NAS	National Airspace System
NAVAID	Navigational Aid
NDB	Non-Directional Beacon
NM	Nautical Miles
NPA	Non-Precision Approach



Principal Acronyms and Abbreviations

4 of 5

NWRA	North West Research Associates,
PIM	Parameterized Ionosphere Model
PPS	Precise Positioning Service
PRN	Pseudo Random
RAIM	Receiver Autonomous Integrity Monitoring
RDM	Range Domain Monitor
RNAV	Area Navigation
RNP	Required Navigation Performance
S/A	Selective Availability
SAAAR	Special Aircrew and Aircraft Authorization Required
SARPS	Standards and Recommended Practices
SBAS	Satellite-Based Augmentation System
SCM	Service Continuity Model
SF	Single Frequency
SID	Standard Instrument Departure
SPS	Standard Positioning Service
SSN	Sun Spot Number
STAR	Standard Terminal Arrival
SV	Satellite Vehicle



Principal Acronyms and Abbreviations

5 of 5

SWAT	SBAS Worldwide Availability Tool
TAWS	Terrain Awareness Warning System
TEC	Total Electron Content
TSO	Technical Standard Order
UDRE	User Differential Range Error
URA	User Range Accuracy
USAF	United States Air Force
VNAV	Vertical Navigation
VORTAC	Very High Frequency Omnidirectional Range Collocated with Tactical Air Navigation Station
VPE	Vertical Position Error
VPL	Vertical Protection Level
WAAS	Wide Area Augmentation System
WATUSI	WAAS Analysis Testbed for Unavailability-of-Service Investigations
WBMOD	WideBand Model
WRS	WAAS Reference Station