GNSS Related Activities to Ionospheric and Tropospheric Studies in Cyprus

Website: http://cyirg.frederick.ac.cy/

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Cyprus

United Nations/Finland Workshop on the Applications of Global Navigation Satellite Systems
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Frederick University At a glance

- Campuses in 2 cities: Nicosia and Limassol
- 50+ Years of education experience
- 5 Schools
- 80+ Accredited and fully recognized Programs of Study
  Covering a wide spectrum of academic domains, including engineering, sciences, the arts, education, humanities, health sciences and architecture
- 45+ Students from countries
- 25+ years of Research Experience
- One of the most reputable Universities of the region
School of Engineering

Undergraduate
- Architect Engineer (5 year Diploma – Integrated Master)
- Civil Engineering
- Electrical Engineering
- Computer Science
- Computer Engineering
- Mechanical Engineering
- Automotive Engineering

Postgraduate
- Structural Engineering
- Electrical Engineering
- Web and Smart Systems
- Manufacturing Engineering Design
- Conservation & Restoration of Historical Structures & Monuments
- Energy Engineering
- Marine Engineering and Management

PhD
- Electrical Engineering
- Computer Engineering
- Computer Science
- Mechanical Engineering
- Civil Engineering
- Architecture

School of Business and Law

Undergraduate
- Business Administration
- Accounting and Finance
- Maritime Studies
- Law

Postgraduate
- Master of Business Administration (MBA)
- International Trade and Shipping Management
- Maritime Law & Shipping Management
- Health Management*
- Public Law

PhD
- Management
- Law

School of Arts, Communication and Cultural Studies

Undergraduate
- Visual Communication
- Interior Design
- Fashion and Image Design
- Journalism and Media
- Communication*

Postgraduate
- Visual Arts

PhD
- Art and Design Practices

School of Education and Social Sciences

Undergraduate
- Physical Education and Sport Sciences*
- Primary Education*
- Pre-Primary Education*
- Psychology*
- Social Work*

Postgraduate
- Education for Sustainable Development and Social Change
- Educational Studies: Curriculum & Instruction
- Educational Administration and Leadership*
- Adult Education*
- Social Work and Social Administration*

PhD
- Education*
- Social Work, Social Policy and Administration*

School of Health Sciences

Undergraduate
- Nursing*
- Pharmacy (5 years – Integrated Master)*

Postgraduate
- Advanced Health Care*
- Health Management*
- Advanced Cosmetic Science and Natural Health Products

PhD
- Health Sciences*
- Pharmacy

Distance Learning Programs

Undergraduate
- Business Administration*

Postgraduate
- Adult Education*
- Special Education*
- Educational Administration and Leadership*
- Educational Studies: Curriculum & Instruction*
- Education for Sustainable Development and Social Change
- Health Management*
- Community Health Care*
- MBA
- MBA with Specialisation in Public Policy and Management*
- International Trade and Shipping Management
- Maritime Law and Shipping Management
- European Law*
- Web and Smart Systems
- Intercultural Studies and Greek as a 2nd Language*
- Conservation & Restoration of Historical Structures & Monuments

*This program of study is offered in Greek
Research & Innovation

**Links with**
- **680** Universities
- **250** Research Centers
- **728** Companies
- **796** Public Authorities & NGOs

**200+ RDI projects in the last 10 years**
- **40+** Research Units

**50+** new RDI projects running in 2021/22
- **44+** Successful Projects implemented
- **€12 Million Total Budget**
- **25+** Years Of Research Experience

Active in research areas:
- Arts, Education & Culture
- Civil Engineering & Architecture
- Electrical and Electronics Engineering
- Energy, Environment & Sustainable Development
- Health Sciences & Biotechnology
- Information & Communication Technologies
- Mechanical Engineering
- Social Sciences & Economics

Frederick University
The research activity of the Cyprus Ionospheric Research group lies in the context of the study and mitigation of ionospheric effects on radio systems.

It is in the position to pursue this aim by means of its infrastructure that facilitates continuous remote sensing of the state of the ionosphere, within various parts of the electromagnetic spectrum.

Detrimental ionospheric effects on radio systems usually have their origin on the disturbed state or natural variability of the Sun and therefore the group has a genuine research interest on Space Weather and its subsequent impact on the Upper Atmosphere.
Permanent Cyprus Ionospheric Research Group researchers
Cyprus Ionospheric Research Group Post-doctoral researchers

Dr. Arun Kumar Singh
Cyprus Ionospheric Research
Group Post-doctoral researcher

Dr. Christos Giannaras
Cyprus Ionospheric Research
Group Post-doctoral researcher

Dr. Antonios Constantinides
Cyprus Ionospheric Research
Group Post-doctoral researcher

Dr. Krishnendu Paul
Cyprus Ionospheric Research
Group Post-doctoral researcher

Dr. Md Colam Mostafa
Cyprus Ionospheric Research
Group Post-doctoral researcher
More than 15 ground-based ionosondes are currently available covering European ionosphere. The recently started Nicosia DPS-4D ionosonde station is expected to introduce new opportunities for real-time ground based ionospheric operations in the Mediterranean area.
Specific Scientific and Technological Objectives:
✓ Explore techniques to improve and optimize the Galileo single frequency users’ positioning algorithm in a context of assisted GNSS driven by a regional and therefore more accurate ionospheric representation

Basic idea
✓ On a long-term scale this improvement is achieved through updating of the long-term median ionospheric characteristics (in the form of 12 files)
✓ On a short-term scale this improvement is enhanced by driving the NeQuick-G algorithm with a more accurate estimation of the ionisation level obtained with a GNSS receiver in Cyprus on a local scale as opposed to a less accurate global scale estimation which is applied in the context of Galileo

Measure sTEC  
Optimise $Az(\mu)$  
Run NeQuick
SERVice for ImproviNg Galileo operation over Cyprus (SERVING)

Galileo Single Frequency Iono algorithm

- Observe slant TEC in Sensor Stations for 24 hours
- Optimise effective ionisation parameter for NeQuick to match observations
- Transmit effective ionisation parameter in Navigation message
  \[ \Delta z = a_0 + a_1 \cdot \mu + a_2 \cdot \mu^2 \]
- Calculate slant TEC using NeQuick with broadcast ionisation parameter. Correct for ionospheric delay at frequency in question.

Difference of Vertical TEC & NEQUICK TEC 2001

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

Month of the Year

00:00 06:00 12:00 18:00 00:00
time

-50 -40 -30 -20 -10 0 10 20 30 40 50

Temperature
Service for Improving Galileo operation over Cyprus (SERVING)

Get all ionograms from previous day → Autoscale ionograms → Extract foF2 and M(3000)F2 values

Estimate calibrated VTEC from local GNSS receiver from previous day RINEX file → Run NeQuick-G to determine optimum ionization level Az

Determine Short CCIR files using \( \chi^2 \) minimisation

Use optimized Az and CCIR to run NeQuick-G next day
We can apply the SERVING concept over Europe with good ionosonde coverage
We can apply the SERVING concept in any part of the world that operates an ionospheric sounder (within a radius of 1000 km).
Potential Enhancements in Ionospheric Monitoring under SSA (PEIMSSA ESA PECS activity)

(a) Position of F3/C RO EDP NmF2/hmF2 (Red) and corresponding topside EDP Ne (Blue) nearest to Nicosia ionosonde (b) F3/C RO EDP ground projection with respect to latitude and longitude around Nicosia.
Potential Enhancements in Ionospheric Monitoring under SSA (PEIMSSA ESA PECS activity)

(a) Topside and (b) Bottomside scatter plots of ionosonde vs F3/C plasma frequency for all European stations.

RO-Digisondes topside-bottomside difference investigation
Potential Enhancements in Ionospheric Monitoring under SSA (PEIMSSA ESA PECS activity)

(a) Topside and (b) Bottomside plasma frequency relative difference from colocated ionosonde and F3/C RO EDPs over all stations.
Potential Enhancements in Ionospheric Monitoring under SSA (PEIMSSA ESA PECS activity)

Collocated EDPs in space and time from COSMIC and Digisondes and Swarm Ne
Potential Enhancements in Ionospheric Monitoring under SSA (PEIMSSA ESA PECS activity)

Colocated EDPs in space and time from COSMIC and Digisondes and Swarm Ne
Latitude variation of the ratios of Swarm AC Ne to F3/C Ne at 460 km and their variation w.r.t. (a) Year and (b) Local Time over the European region for years 2014-2018.
Ionospheric topside studies (IRENE ESA PECS activity)
DRAWING maps indicating MSTID activity during every spread F event over Cyprus (indicated with a circle on the top left) during Summer of 2014 (high solar activity)
Co-seismic ionospheric signatures
Tectonic setting and seismicity caused by the 2023 Kahramanmaraş Earthquake Sequence
(Luca Dal Zilio & Jean-Paul Ampuero Communications Earth & Environment 2023)
GPS and GLONASS IPP tracks

Nicosia 10:30 UT (NI135) (a)

Nicosia 10:35 UT (NI135) (b)

Epicenter

Nicosia station
Ionospheric signatures Cyprus GNSS network

Kahramanmaras earthquake sequence

6 Feb 23, 1:17 UTC
M 7.8

6 Feb 23, 1:28 UTC
M 6.7

6 Feb 23, 10:24 UTC
M 7.5
Ionospheric scintillations over Cyprus
CYprus Radar for Ionospheric Space Situational Awareness

CYRISSA
Strong equatorward plasma convection on 17 March 2015 (left plot) and Travelling Ionospheric Disturbances (right plot) as shown on Total Electron Content DRAWING maps
Enhancing Space Awareness in Cyprus through Space Weather Studies (ESA PECS activity)

The Sun and Us
Space weather exhibition

-ESA funded project
Enhancing Space Awareness in Cyprus through Space Weather Studies (ESA PECS activity)
**Extreme precipitation weather disasters**

- **Daniel** 2023
  - >11,000 deaths in Greece & Libya
- **1998 - 2017**
  - 500,000 deaths & €3.47 trillion loss globally
- **2019**
  - €300 billion loss in USA
- **2021**
  - €10 billion in Central Europe

Frequency and intensity of extreme rainfall events is predicted to increase by a factor of 5-50 between 2025 and 2075.
Severe LOCAL weather events in Cyprus

- **Dec 2018** 4 deaths from flood
- **Jan 2023** Rare floods in Ayia Napa
- **Aug 2023** Extreme lighting activity & rainfall – Unusual storm trajectory not predicted by NWP models
- **Sept 2015** > 90 people in hospital (Breathing difficulty) from dust storm in EM
- **1966 - now** 6 deaths from Tornadoes 126 cases of tornadoes

Flood, January 2023, Ayia Napa, Cyprus

Lightning over Nicosia, August 2023

Dust storm, September 2015, Cyprus

Tornadoes in Cyprus
Radio signals transmitted on two L-band frequencies from GNSS satellites are delayed by the neutral part of atmosphere (whose lowest portion is troposphere) before being received on earth surface by GNSS antennas.

This zenith tropospheric delay (ZTD) consists of the hydrostatic (dry) component which is caused by dry air gases in the atmosphere and accounts for the greatest part of delay and of the wet component which is caused by the water vapor of the atmosphere:

\[ ZTD = ZHD + ZWD \]

\[ ZHD = (0.0022768 \pm 0.0000005 \ P_{\text{GNSS}} f(\varphi(h)) \]

with \( f(\varphi, h) = 1 - 0.0026 \cos 2\varphi - 0.00028 \ h \), where \( \varphi \) is the latitude and \( h \) is the height (km)

\[ Q = 10^{-6} \rho \frac{R_0}{M_w} \left( k_2^{'T_m} + \frac{k_3}{T_m} \right) \]

where \( \rho \) is the density of liquid water, \( R_0 \) is the universal gas constant, \( M_w \) is the molar mass of water vapor and \( T_m \) is the weighted mean temperature of the atmosphere in [K]. The physical constants \( k_2^{'} = 17 \ \text{Kmb}^{-1} \) and \( k_3 = 3.776 \times 10^5 \ \text{Kmb}^{-1} \).
• **15 new GNSS stations** were installed in Bulgaria (12), Cyprus (1) and Greece (2) (red lines)
• **25 new Meteorological stations** were installed in Bulgaria (3), Cyprus (8) and Greece (14) (blue lines)
Permanent GNSS stations located in Greece, Bulgaria and Cyprus used at BeRTISSL
EUMETNET Programme E-GVAP:
The GNSS water vapour programme was set up, in April 2005, to provide its EUMETNET (European National Meteorological Services) GNSS delay and water vapour estimates for operational meteorology in near real-time
http://egvap.dmi.dk
BalkanMed real time severe weather service

BeRTISS

• Low spatial resolution of geodetic GNSS networks (~ 80 km)

• Low temporal resolution of real time Water Vapor data (hourly)

• Expensive existing geodetic GNSS receivers > 10,000 €

BeRTISS: real time severe weather service

BeRTISS: 15 new GNSS geodetic & 25 AWS stations

http://app.bertiss.eu/home

Project Coordinated by Frederick University, Cyprus (2017 - 2020)
CyMETEO infrastructure – GNSS network

- **PREcipitable WAtter vapour Monitor**
  - Developed by Cloudwater Ltd

- ‘PREWAM’
  - Low-cost GNSS receiver for near-real time estimation of PWV with high-resolution
  - Takes fully advantage of all GNSS satellite systems: GPS, GALILEO, GLONASS and BeiDou
  - Constructed by 3D Printing technology
  - Can be embedded to AWS stations (Campbell, Vaisala, Davis, etc)

- Transmit the IWV data directly to users (or through Atmospheric Weather Stations, AWS)

- GNSS network components:
  - GPS, Galileo, BeiDou

- Ground GNSS station

- Co-located meteo data (Atm. Pressure & Temperature)
  - Real-time co-located meteo data
  - ERAS reanalysis data
  - Calculate IWV

- SP3 orbits

- PREWAM
  - Estimate ZTD
  - Calculate ZTD based on:
    - Real-time co-located meteo data (Atm. Pressure & Temperature)
    - ERAS reanalysis data
  - Calculate IWV
Comparison BeRTISS (Geodetic Leica receiver) – CLOUDWATER (Low-cost PREWAM receiver)

High-grade geodetic receiver **LeicaGR30** and low-cost **PREWAM** receiver used for **PWV estimation**

**Period of study:** October 2022 – December 2022
Comparison BeRTISS (Geodetic Leica receiver) – CLOUDWATER (Low-cost PREWAM receiver)

- Leica GR30 geodetic receiver KLIR
- PREWAM low-cost receiver KLIC

**ZTD**
- Correlation Coefficient $R = 0.96$
- Correlation Coefficient $R = 0.95$

- October 2022
- November 2022
- December 2022

**PWV**
- PREWAM using ERA (KLIC station)
- High-grade LEICA using GPT2 (KLIR station)

**Using empirical blind model GPT2w**
- PREWAM low-cost receiver – KLIC
  Using ERA5 empirical model for P,T estimation

**First Potential Clients International**
- 12 Letters of Interest
Project Objective - proposed Solution

CyMETEO infrastructure & service

Existing Meteo system

- 2 Weather RADAR (Humidity)
- 1 Radiosonde (Humidity)
- 500 Meteo stations

5 Lighting detectors network

Radar wind profiler RWP

Microwave Radiometer MWR

Water Vapor profiles

GNSS network

Densification

Integrated Water vapor

Observational Component

Modelling Component

CyMETEO Web-portal

Observational Component

Data Assimilation (DA)

In NWP model (first time in Cyprus)

Modelling Component

‘WRF’ NWP model used by Cyprus Dep of Meteorology

New supercomputer for DA
CyMETEO infrastructure – GNSS network densification

**Precipitable Water Vapor PWV**
- Deliver high, spatial & temporal, resolution of PWV, Slant & Zenith Tropospheric Delay (STD & ZTD)
- PWV data Assimilation into NWP model
- Research on PWV climatology (long-term)

**NEW Equipment**

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<thead>
<tr>
<th>GNSS receivers</th>
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<tbody>
<tr>
<td>9 low-cost PREWAM GNSS receivers</td>
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<td>(Nicosia district Hyper-dense GNSS network)</td>
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<tr>
<td>3 geodetic Leica GR30 GNSS receivers</td>
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<tr>
<td>(with AR20 Choke Ring antennas)</td>
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**Existing Equipment**

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<th>GNSS receivers</th>
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<td>7 CYPOS system of the Dep. of Lands and Surveys (DLS) GNSS stations</td>
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<td>4 low-cost PREWAM GNSS receivers of Cloudwater Ltd partner</td>
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Area of ~25 km²

Nicosia district Hyper-dense GNSS network (9 receivers)
CyMETEO Further Expansion Opportunities

Dense GNSS network for Ionospheric space weather monitoring

- Expand system with:
  a) Tropospheric weather monitoring
  b) Ionospheric weather monitoring

Near-real time detection of TIDs: Travelling Ionospheric Disturbances

Use Multi-Purpose GNSS receiver: MGR (by Cloudwater Ltd)
Thank You!

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