Equatorial MU Radar (EMU)
under
“Study of Coupling Processes in the Solar-Terrestrial System”
+
New beacon satellite project
TBEx and COSMIC-2

Mamoru Yamamoto
(RISH, Kyoto Univ.)
Quo Vadis as Japanese MANGA

Authors: SAEKI Kayono
       SHINTANI Kaoru

Period: 2007-now
Volume: 1-18
Quo Vadis as video game


Machine: SEGA Saturn PLAYSTATION
1. Equator: Develop Equatorial MU Radar (EMU) at the EAR site
2. Polar region: Develop EISCAT_3D radar in Europe
Inter-university Upper Atmosphere Global Observation NETwork (IUGONET) (2009 - )

PROBLEM: Various kind, huge amount of data spread over institutes and universities

SOLUTION: Create a metadata database for cross-search of these distributed data

Promote new types of upper atmospheric research by analysis of multi-disciplinary data

Strengthen collaboration among universities

Researchers in other institutes/universities in Japan and overseas

Finally to other Earth and planetary science fields...

Expand this system to satellite and simulation data

Create a metadata database of upper atmospheric data for cross-search

Develop an integrated data analysis tool to handle data from the IUGONET institutes

ICSWSE, Kyushu Univ.

PPARC, Tohoku Univ.

National Institute of Polar Research

WDS for Geomag., Kyoto Univ.

ISEE, Nagoya Univ.

Kwasan & Hida Observatories, Kyoto Univ.

Virtual Information Center for upper atmospheric sci.

Obs. Database + Analysis Tool

Metadata DB

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Virtual Information Center for upper atmospheric sci.
**Plasma Fountain:** Energy exchange by dynamical and electro-magneto-dynamical coupling processes and perturbations of electron density

**Fountain of the Middle Atmosphere:** upward transport of tropospheric air through the equatorial tropopause and global distribution by the general circulation

**Driving Force of Fountain:** Generation, propagation and dissipation of atmospheric waves and production of turbulence

**Origin of Fountain Materials:** Emission of materials from land and ocean surface and transport and mixing in the troposphere
MU radar (Shigaraki, Japan)
(Completed in 1984, Multi-purpose MST/IS radar)

Frequency: 46.5MHz, Output power: 1MW
Antenna: 103m Φ (475 crossed Yagis)

IEEE awarded milestone to Kyoto Univ. and Mitsubishi Electric Co. for MU radar as first MST radar with 2D active-phased array antenna system.
(Award in May 2015)
Equatorial Atmosphere Radar (EAR)  
(Installed in 2001, long-time experiment)

Antenna View: 560 Yagi-antenna arrays (110m diameter)  
Peak Power: 100 kW

Kototabang, West Sumatra, INDONESIA  
(0.20S, 100.32E)

EAR long-time continuous observation since 2001.  
(Gray: Atmosphere, Black: Atmosphere + FAI)
The system construction was completed. PANSY is now working with full power.
## Comparison of MU Radar, EAR, and PANSY

<table>
<thead>
<tr>
<th></th>
<th>MU radar</th>
<th>EAR</th>
<th>PANSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo</td>
<td><img src="image1.png" alt="MU radar photo" /></td>
<td><img src="image2.png" alt="EAR photo" /></td>
<td><img src="image3.png" alt="PANSY photo" /></td>
</tr>
<tr>
<td>Lon, Lat</td>
<td>34.85N, 136.11E</td>
<td>0.20S, 100.32E</td>
<td>69.00S, 39.59E</td>
</tr>
<tr>
<td>Number of antenna</td>
<td>475</td>
<td>560</td>
<td>1045</td>
</tr>
<tr>
<td>Number of RX channel</td>
<td>25 ch</td>
<td>1 ch</td>
<td>55 ch</td>
</tr>
<tr>
<td>Antenna aperture</td>
<td>8,300 m² (103 m diameter)</td>
<td>9,500 m² (110 m diameter)</td>
<td>20,000 m² (160 m diameter)</td>
</tr>
<tr>
<td>TX module output</td>
<td>2.2 kW</td>
<td>200 W</td>
<td>500 W</td>
</tr>
<tr>
<td>Peak output power</td>
<td>1 MW</td>
<td>100 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>Antenna aperture × Output power</td>
<td>1.0 (standard)</td>
<td>0.11</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Equatorial MU Radar (EMU)

- **EMU System**
  - Frequency: 47MHz
  - Antenna: Active-phased array
    - (163m diameter, Total 1045 Yagis)
  - Output power: 500kW PEP

- **Subsystems**:
  - TR module at each Yagi-antenna
  - Multi-channel receivers
  - Radar controller / Data processor

1-group = 19 Yagis
Array consists of 55 groups
(19 Yagis x 55 = 1045)
EMUは屋外のアクティブ・フェーズド・アレイ・アンテナ及び送受信モジュールと、屋内のデータ処理装置及び変調装置から構成されます。多チャンネルの高速デジタル信号処理により、EMUの観測性能を極限まで高めています。

The EMU comprises antenna and TR Module unit, data processing unit, modulator unit, and demodulator unit. Multi-channel digital signal processing brings out the full measurement capability of the EMU.
New observations with EMU

– Troposphere and lower stratosphere
  • Good data up to ~20km height.

– Mesosphere experiment
  • 60-80km height, daytime echoes
  • Atmospheric tides and gravity waves

– IS (incoherent scatter) experiment
  • Ionosphere plasma density, drift, and temperature measurement.

– Radar interferometry with multi-channel receivers
  • Radar imaging observations.
  • Meteor-echo observations.
Summary (1)

• Evaluation of big scientific projects in Japan.
  – Ministry of Education, Culture, Sports, Science and Technology (MEXT) sets Roadmap after Masterplan(?)

• History of our project “Coupling process of Sun-Earth”
  – Failed SCJ Masterplan 2010.
    • Different name project. EMU only.
  – On SCJ Masterplan 2011. (1/200)
    • Same name project. EMU + Solar-C satellite.
  – On SCJ Masterplan 2014 as important project. (1/27)
    • Current shape. EMU + EISCAT_3D + Obs. net.
  – On MEXT Roadmap 2014. (1 of 11 new projects)
    • Kyoto Univ. requests ~30M USD (EMU HW cost) to MEXT.
  – Applying SCJ Masterplan 2017.
    • Keep the same shape/name.
Summary (2)

• EMU project status
  – The radar can be installed within one year after funding.
    • Radar design is almost fixed.
    • Detailed design improvements are underway. (Yagi antenna construction, Clutter mitigation, etc)
    • Location is next to EAR (West Sumatra, Indonesia)

• Preparation tasks
  – Visited RISTEK Minister of Indonesia for 2 times.
  – LAPAN was officially allocated as counterpart for EMU.
  – RISH-LAPAN LoI signed in 2014.
    • Location is secured by LAPAN. Construction permission is already obtained after environment assessment process.
    • 15th Anniversary of EAR will be held in Jakarta on August 4, 2016 (at RISTEK auditorium).
  – We now submit the project paper to Radio Science
Study of equatorial ionospheric disturbances using radio beacons on TBEx and FORMOSAT-7/COSMIC-2 satellites and a dense ground network

Mamoru Yamamoto (RISH, Kyoto University)
Roland Tsunoda (SRI International)
Richard Doe (SRI International)
Mayumi Matsunaga (Ehime University)
Tung-Yuan Hsiao (Hsing Wu University)
TBEx: Tandem Beacon Experiment by SRI International (PI: R. Tsunoda)

- Funded by NASA: Low-Cost Access to Space (LCAS) Program
- Two CubeSats: Identical tri-frequency (150, 400, 1067 MHz) radio beacons
- To be launched in tandem into near-identical (~28 deg inclination) orbits (Piggyback with COSMIC-2!!)
- TBEx objective: Capture space-time description of equatorial plasma bubbles (EPBs)
- Overall science question: Does causal relationship exist between tropospheric weather, large-scale wave structure (LSWS), and EPBs?
Causal Link: Convective Activity to EPBs?

- **Input, Stage 1**: Outgoing longwave radiation (OLR) can be used to map distribution of convectively active regions.
- **Output, Stage 1 (or Input, Stage 2)**: Large-scale wave structure (LSWS) can be measured as TEC variations using TBEx & cluster of ground receivers.
- **Output, Stage 2**: Equatorial plasma bubbles (EPBs) can be measured with ground-based radar & COSMIC-2 in situ sensors.
- **Partitioning** link into two stages allows clear evaluation of roles played by contributing sources and processes.
Relationship between plasma bubble and weather

Ogawa et al, Earth Planets Space, Vol. 61, pp. 397-10, 2009

- Correlation between
  - Daily variation of nighttime GPS S4 index at the EAR site (Indonesia)
  - Daily variation of Tbb as cloud-top temperature
- Maximum correlation was ~0.4. Enhanced region is shifted west of S4 measurement location.
## TBEx and COSMIC-2 beacon signals

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Units</th>
<th>Inclination</th>
<th>Beacon frequency</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORMOSAT-7/ COSMIC-2 (USA,Taiwan)</td>
<td>6</td>
<td>24°</td>
<td>383 MHz, 400 MHz, 965 MHz, 2200 MHz</td>
<td>383 MHz modulated, Others are CW.</td>
</tr>
<tr>
<td>TBEx (USA)</td>
<td>2</td>
<td>28.5°</td>
<td>150 MHz, 400 MHz, 1067 MHz</td>
<td>Decided launch with COSMIC-2.</td>
</tr>
</tbody>
</table>

- Satellites for 150/400MHz beacon are getting old. **C/NOFS** stopped.
- **COSMIC-2** and TBEx will be launched in 2017 1Q. They fly in the low-latitude region with triple-band beacon TXs.
- We develop a new GRBR system that covers 150/400/965/1067MHz signals for these satellites.
Development of new GRBR Antenna part by Prof. Matsunaga at Ehime Univ.

**CONCEPT**

- 150MHz, 400MHz, 965MHz and 1067MHz Right-Hand Circular polarization
- Single feed (One port)
- Maximum size: 320mm x 320mm
- Getting good antenna gain with a cavity back
Overall concept of observation & study

COSMIC-2
6 Satellites
750 km @24°
UHF
L- Band
S-Band

TBEx
2 Satellites
700 X 300 km @28°
VHF
UHF
L-Band

Ionospheric F Layer

Communication & Navigation Assets

Ionospheric Disturbance

GPS Navigation for Air Traffic Control

Ground network of GRBR and radar(s)

eTBEx orbit & frequency diversity enhances awareness of impending RF disturbances
Summary

• What we want to do ...
  – Plasma bubble study
    • How LSWS affects/works for onset of bubbles.
    • Find source of LSWS (comparison with low-atmosphere signals).
  – TBEx (2 units of 3U-cubesat) launch by COSMIC-2 piggyback (2017 1Q).

• COSMIC-2 beacon is very important.

• We now develop new GRBR for TBEx + COSMIC-2 beacon signals.
  – Patch antenna + digital receiver.
  – 1 set cost will be 5000 USD (hope 4000 USD range).
EMU will be next to EAR

- Equatorial MU Radar (EMU) will be installed next to the existing Equatorial Atmosphere Radar (EAR) at Kototabang, West Sumatra.
- EMU will be operated under collaboration with LAPAN based on success of RISH-LAPAN collaboration on the EAR.
- Detailed local survey was conducted in March 2012. Now design and installation plan of the EMU is precise and complete. We are ready to realize the new radar as soon as the funding would decided.
EMUでは、アンテナの大径化（直径約160m）と尖頭送信出力の増大（500 kW）により、EARと比較して10倍以上感度が向上します。また、19本×55群のサブアレイを用いたレーダーイメージング観測が可能となります。

The large-sized antenna array of 160-m diameter and 500 kW peak output power enables the EMU to have 10-times higher sensitivity than the EAR. For radar imaging measurements, the 1045 Yagi elements can be divided into 55 sub-arrays, each of which is composed of 19 Yagi elements.
LEO satellite beacon and GRBR

- VHF(150MHz)/UHF(400MHz) beacon signals from LEO satellite are used for ionospheric TEC measurement for long time.
- GRBR (GNU Radio Beacon Receiver) was developed with GNU Radio and USRP-1 board at cost of 2000-3000 USD/system.
- Network of about 30 GRBRs already exist over Japan, southeast Asia, Pacific, etc., and used for studies.
Envisioned Coordinated Measurements for eTBEx

- LSWS from TEC variations from TBEx (bottom panel)
- EPBs from PAR-50 and COSMIC-2 in situ data (center panel)
- Convective activity from OLR maps (not shown here)
- Partitioning of scintillation regions with TBEx and COSMIC-2 beacons
- Joint PAR-50 and ALTAIR measurements, if possible (field campaigns)
Space-Weather Relevance

- Physical insight into LSWS generation of EPBs will greatly improve ionospheric forecasts, comm/nav system robustness, and storm time transmission capacity.
- Increased awareness of EPBs and associated scintillation regions requires multi-angle beacon imaging and frequent bubble revisit times.
- Only a dense constellation of beacons with altitude and aspect diversity can mutually address problems associated with imaging and low revisit times (eTBEx concept).