Introduction to E-region studies using radio and optical techniques at Arecibo

The unique instrument clusters at Arecibo Observatory is well suited to study the complex interactions occurring in the Space Atmosphere Interaction Region (SAIR). The E-region of the Earth's atmosphere, which encompasses upper mesosphere and a part of the lower thermosphere (MLT), is known for a wide variety of interesting phenomena. These include Sporadic-E, influence through meteor activity, occurrence of metallic layers, deposition of energy and momentum by gravity waves that effects the mean flow, neutral instabilities, etc. Additionally, the coupling from the lower atmosphere by gravity waves and solar input from the upper region adds complexity to this part of the SAIR region.

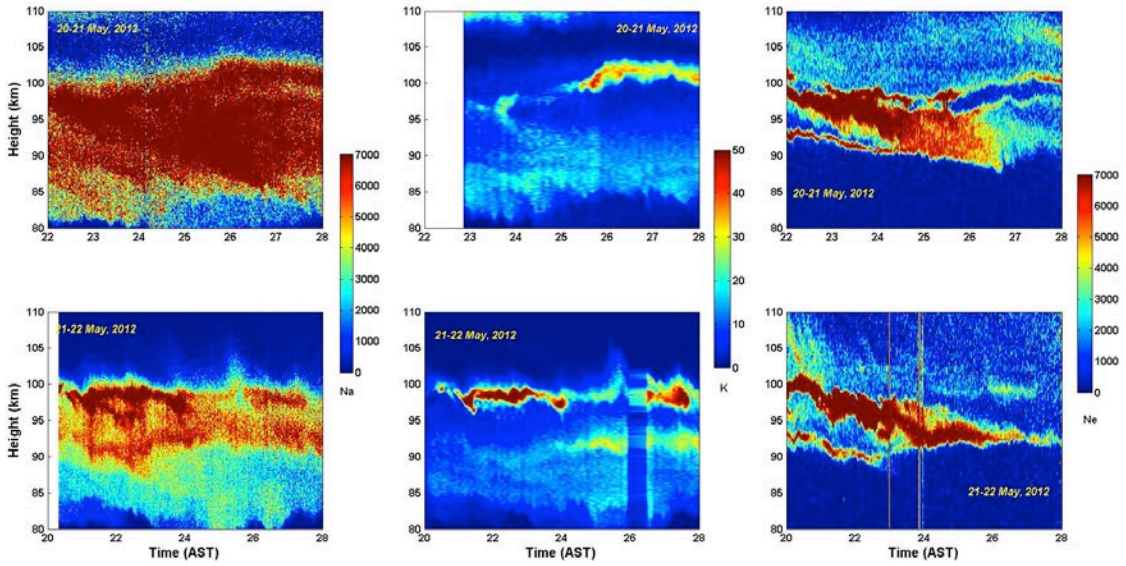
The powerful instrumentation existing at Arecibo comprises Incoherent Scatter Radar along with a variety of new optical systems that range from resonance lidars, imagers, photometers, and spectrometers. These provide excellent opportunity to investigate ion-neutral-electron coupling, dynamics, energetics, space weather effects, quasi-periodic echoes, plasma trails as observed in both radio and optical instruments.

Several significant studies at AO involving both radio and optical instruments have contributed to our knowledge pertaining to the MLT region. One of the examples was the Arecibo Initiative in Dynamics of the Atmosphere (AIDA-89) campaign. This effort led to exciting research that demonstrated the need of instrument clusters at Arecibo and also led to the future developments. The topics featured study of ion-layer trajectories [*Mathews et al., 1993*], GWs characteristics using airglow/lidar [*Hecht et al., 1993; Kane et al, 1993, Senft et al. 1993, Wang et al. 1993, Wien et al. 1993*], influence of geomagnetic storm on the E-region tidal ion layers [*Morton and Mathews, 1993*], insights about sporadic E layers [*Zhou et al., 1993*].

The importance of continuing measurements from Arecibo can be realized from the long-term studies to investigate the influence of solar cycle on the F region neutral winds [*Tepley et al., 2011; Santos et al., 2011; Brum et al., 2012*]. Such studies need to be extended to E-region in the future. Other research activities have shed light on ion-neutral interactions [*Collins et al., 2002; Raizada and Tepley 2002, Friedman et al., 2003, Tepley et al., 2003, Zhou et al., 2005*], topside thermospheric metal layers [*Höffner and Friedman, 2004, 2005; Friedman et al., 2013*], differences in sporadic neutral activity in different metals and ions [*Raizada et al., 2004, Zhou et al., 2008; Raizada et al., 2011, Raizada et al., 2012*], interplay of chemistry and dynamics in influencing metal layers [*Raizada et al., 2012; Delgado et al., 2012; Yue et al., 2013*], quasi periodic waves and echoes [*Livneh et al., 2007, Larsen et al., 2007*], implications of instabilities on neutral and ion distributions [*Hysell et al., 2012, Sarkhel et al., 2012*].

The above studies have successfully demonstrated the scientific motivation for optical observations, there are several reasons for making multi-metal observations, which coupled with electron density from Incoherent Scatter Radar and airglow data make this facility a unique place. An example of simultaneous observations of Na (left panel), K

(middle panel) and electron concentration (right panel) obtained using ISR and resonance lidars at Arecibo for two adjacent nights are shown in the figure below. The night of 21-22 May 2012 (lower panels) display finger like projections with similarities to Quasi-periodic (QP) echoes in both the neutral and electrons. The reason(s) for these structures needs to be further investigated. This investigation is currently in progress.



Such multi-instrument approach sheds new light on the influence of dynamics, transport and chemistry in the SAIR of the earth's atmosphere, which is part of the *CEDAR: The New Dimension* paradigm. Even though lot of progress has been made in the ionospheric studies, there are still several unanswered questions that demand more investigation using multi-instrument approach. For example, the summer time maxima in Sporadic E still cannot be explained just by wind-shear theory. This coupled with neutral metal layers can help to delineate the effects of meteors, chemistry and dynamics and help us to resolve such issues. The relative role of meteor input and chemistry in explaining the deficiency of neutral calcium is also not understood completely. The dependence of neutral layers on geomagnetic activity needs to be understood. The relationship of high altitude metal layers to tidal ion layers is still unexplained and needs coupled optical and radar observations. Questions like what factors drive the quasi-periodic waves and variability of quasi-periodic echoes in the ionosphere along with their relationship to the neutrals require more investigation. Some of our users like Prof. John Mathews, Prof. Q. Zhou, Prof. X. Chu, plan to actively use the capabilities at AO and have been instrumental in many optical upgrades recently.

The new upcoming Heating Facility at AO offers exciting opportunities that will be extremely beneficial to E-region studies, when operated at 5 MHz. Sporadic E can often reach these frequencies and cause non-linear plasma interactions that can be studied by combining both optical and radar instruments.

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