Recently Titheridge (2000) considered a number of nighttime ionization mechanisms including 911-1026 Å starlight, geocorona and interplanetary background H/He resonant-scattering, and F-region recombination photon sources to model the nighttime E-region ionosphere. While his effort is laudable, we do not agree with his assertion that meteoric input and metallic ions play little role in affecting the mean value of the nighttime E-region peak concentration and altitude. His claim, at least for the temperate zone, does not appear to be supported by the Arecibo incoherent scatter radar observations. Additionally, the argument he used to reach his conclusion is flawed. We hope the following discussion will help clarify understanding of the nocturnal ionization mechanisms.

We start the discussion by quoting a paragraph from the Titheridge paper: "Ablation of meteors leaves metallic ions, largely Mg++, at heights of 80-120 km (e.g. Whitehead, 1989), and the effect of wind shears on these long-lived ions was often supposed to be the source of Es layers. However an extensive study by Baggaley and Steel (1984) found no correlation of Es with meteor showers. Nighttime data collected at Arecibo from 1987-1995 show an increase in densities in the height range 97-114 km, in the hours after midnight (Zhou et al., 1999). Solar radiation was ruled out as a cause, since increases did not occur at other heights, and ionisation was attributed to the increase number of meteors at dawn. However, this argument ignores the large contributions from starlight, interplanetary and F-region sources, and the effects of the changing atmospheric composition. It is shown in Section 5.1 that the observed E-layer density at Arecibo, at midnight, is in close agreement with that calculated in the present work. Thus while precipitating particles, wind shears or heavy ions may increase the variability of the low density ionisation above and below the night E-layer, there seems little evidence that they add significantly to mean values of NmE on quiet nights."

By quoting Baggaley and Steel (1984), Titheridge casts doubt on either the metallic ion composition of Es or its formation by windshear mechanism, or both. We note that the lack of correlation between Es layers and meteor showers does not necessarily have any logical bearing on either Es composition or the windshear mechanism. The reason for this is that the mass flux of shower meters, although visually spectacular, may only be a small fraction of that of background sporadic meteors (Hughes, 1978). This was pointed out by Zhou et al. (1999), which Titheridge also quoted in the above paragraph. The paper by Whitehead (1989) contains many references supporting the accumulation of metallic ions into Es layers by the windshear mechanism. (In addition, the in-situ observation by Earle et al. (2000) clearly demonstrates that the total metallic ion abundance in the lower E-region can far exceed the molecular ion abundance.) The more persistent Es layers, essentially always present at Arecibo, are formed by tidal winds and are termed tidal ion layers (TIL) by Mathews et al. (1993). The downward phase speed of the tidal wind system is typically small, around 1 km/hr, which allows the long lifetime ions in the E-region to be accumulated into the convergence null and move downward as a thin layer. The metallic ions are "dumped" at about 90 km for dynamical reasons and because increasing ion-neutral collision frequency facilitates recombination rates via clustering reactions. The motion of TILs and the "dumping" effect can be seen almost every night as observed by the Arecibo incoherent scatter radar—many examples can be found in Mathews et al. (1993) and Mathews (1998). Because of the high concentration of Es layers and its dynamic nature, any modeling of nighttime ionization, especially peak electron density and height, is incomplete without considering metallic ions and their downward motion.
All the TIL features discussed above are most clearly seen in Figure 1 (Mathews et al., 2000), which is rather
typical of nighttime incoherent scatter results and shows all factors discussed above. Specifically, at sundown
(just before 1800 hrs) the D-region and daytime E-region are seen to give way to the typical slowly-descending
TIL in which a significant Es event occurs with peak concentration near 1930 hrs. Important to this discussion
is the background diffuse E-region ionization around 100 km, which is seen after 2200 hrs once the TIL has
descended through it. This layer is the photochemical E-region ionization that Titheridge discusses. We note,
however, that the photochemical layer is very weak when compared with the TIL layer—this is essentially
always the case. In fact, less sensitive observations with the Arecibo incoherent scatter radar would make it
hardly noticeable. In addition, the photochemical E-region is centered at or just below 100 km—not the 105 km
assumed by Titheridge—and because of the short lifetime of molecular ions, is little affected by the ion
convergence zones just below and just above it. The presence of micrometeors—much smaller than those seen
by classical meteor radars (Mathews et al., 1997; Janches et al., 2000)—is seen in the vertical lines near 100 km
as explained in the caption. The micrometeor flux increases dramatically from midnight to dawn as the
atmosphere above the observatory faces progressively nearer to the apex of earth's orbit thus sweeping in more
micrometeoroids. The observed diurnal meteoric flux rate is given in Zhou et al. (1995).

Regarding the observational data found in Zhou et al. (1999), Titheridge criticized our meteoric input
explanation for the increase in ionization after midnight in the 97-114 km altitude range in not considering the
effect of starlight, interplanetary and F-region sources. While he is correct in pointing out our failure in
considering these mechanisms, it is hard to believe that scattering from starlight and interplanetary background
will create significant local time variation in ionization after the data have been averaged over nearly ten years.
In any case, the nighttime photoionization sources should be largely symmetric about local midnight and thus
would not affect our results or conclusions. Presumably, the E-region photoionization source due to O+ radiative recombination in the F-region can have a local time variation. However, the effect of such a process
on the E-region ionization has not been ascertained and Strobel et al.'s (1980) model, which is also the basis of
Titheridge's model, suggests that this process is less important than starlight and resonantly scattered Ly-α/β,
etc. Thus, although the nighttime ionization mechanisms considered by Titheridge may account for part of our
observations, this cannot be seen from the paper by Titheridge. In order for the other mechanisms to be as
viable as the meteoric input, they must also explain the observed increasing ionization after midnight in the 97-
114 km altitude range with no increases in adjacent altitude ranges. Model results displayed in a manner similar
to those shown in Figure 1 in Zhou et al. (1999) can help delineate the various nocturnal ionization mechanisms.
References


Figure Caption:

Figure 1. Logarithmic display of ISR electron concentration observations (gray-scale intensity) plotted versus altitude and time with basic resolutions of 150 m and 10 s, respectively. Except for some interference removal, removal of the noise-base, and conversion to electron concentration these results are in no way smoothed or otherwise distorted. A long-lived Tidal Ion Layer (TIL) is seen between 98-110 km over the whole time period and a true sporadic-E event occurs within the TIL over about 18-22 hrs. An intermediate-TIL (ITIL) descends from the F-region base at 18 hrs. The vertical lines near 100 km altitude are unsuccessfully decoded meteor returns while those at higher altitudes are orbital objects. Note that the daytime D- and E-region disappear at sunset—about 18 hrs—and that the photochemical nighttime E-region is seen just above the 95 km TIL as the TIL descends through the night. This result is typical for Arecibo. The geomagnetic activity for this period is very low (Kp for 14-17, 17-20, 20-23, 23-26 AST is 0+, 1-, 2-, 2, respectively.)