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Long-term Trends in the Upper atmosphere using the observations of Incoherent Scatter Radar at Arecibo Observatory

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Abstract

Several studies on long-term trend using the ion temperature in ionospheric F-region are made in high-latitude stations using Incoherent Scatter Radar (ISR) measurements. Those observed trends indicate the upper atmospheric cooling. Those studies reported that those have strong dependency on magnetic latitude for the altitudes above ~275 km. Given the advantage of high sensitivity of Arecibo Observatory's ISR and its location at geomagnetic latitude (29°N), it is very much interesting to examine the long-term trends of the ion temperatures (T_i) for the altitudes above ~275 km. We have analyzed T_i data sets of ISR from 1985 to 2015, to examine the long-term trends of the ion temperature as function of altitude from ~122 km to ~700 km over Arecibo (18.3°N). These long-term trends are examined in relation to solar flux of $F_{10.7}$ (flux at 10.7 cm) and A_p index for the understanding of influence of solar flux and geomagnetic activity on temperature trends of the F-region. These results will be discussed to understand the effects of solar activity and geomagnetic activity.

1 Introduction

High sensitivity ISR radars have been highly used for estimating the plasma parameters from earth's ionosphere. Especially, its capable in observing the topside ionosphere. One of the plasma parameter from ISR measurement is ion temperature (T_i) which is highly used in long-term trend studies. Since the least contribution in error to the energy balance by T_i when T_n is estimated from T_i upto ~400 km [1, 2, 3, 4]. In this way, ISR's T_i offer a direct estimate of the thermal status of the upper atmosphere/ionosphere [4]. Long-term trends could be examined in the (Ti) at ionospheric F-region by the close coupling between neutrals and ions.

Studies on effect of the increasing green house gases on upper atmosphere/ionosphere has been accelarated after the theoretical modeling by [5]. Few of those studies interms of long–trend, could find the thermospheric cooling [6, 7] which support the effect of green house gases on the upper atmosphere/ionosphere. Observed cooling trend is larger than modeled, it drives many questions. One of which is speculated to be a cooling gravity wave which was studid by [8]. [8] suggested that increasing cooling could be by gravity waves. Divers of the cooling in the upper atmosphere/ionosphere yet to be unterstood.

We made an attempt to understand the observed long–term cooling in the upper atmosphere/ionosphere by the influence of solar flux at wavelength of 10.7 cm, geomagnetic activity via A_p index, and also wave coupling (under progress).

2 Data Analysis

Ion temperature from AO-ISR is analyzed and binned into 16 altitude bins with altitude resolution of 36 km. Observations of all elevations are used in this study since AO-ISR could see off-zenith angles within ±20 only. Daily values of $F_{10.7}$ and A_p index are used. $F_{10.7}$ and A_p index removed if those are more than 300 and 80, respectively, for further calculations [4]. Corresponding T_i to those removable $F_{10.7}$ and A_p index are also removed for further calculations. T_i data are binned into altitude and monthly bin for constructing a T_i model. To asses the difference between day and night, T_is are corresponding to local mid-noon and midnight are taken with ±3 hour of them. Figure 1 shows the monthly median of T_i (black dot) at various altitudes along with corresponding $F_{10.7}$ and A_p index. T_i values are for ±3 hour of local noon (night values are not presented here but those also have similar features with $F_{10.7}$ and A_p index). Red line indicates the yearly averages. Monthly and yearly medians of ISR observed T_i are having similar trend as $F_{10.7}$ and A_p index. It means that influence of $F_{10.7}$ and A_p index are in T_i which are need to be removed in order to get the trend residual as a function of time (year). It can be mentioned that continuous observations of T_i are not available for all the the day and night. So that there are data gaps, especially above ~620 km in day and below ~200 km in night (not shown here). Those altitude ranges are included instead of removing, to have a consistancy in altitude range in day and night.

For a given altitude, T_i variations are modeled for each time bin based on a least square fitting using monthly median of ISR observed T_i, monthly median of solar flux at 10.7 cm and monthly median of A_p index as suggested by [4, 9, 10, 11] while taking into account the annual-, semi-annual oscillations also. Variation of Ti is modeled based on the equation given by [4], as shown in equation

(1):

$$T_i = T_b + t(y - \bar{y}) + \sum_{n=1}^{2} [a_n \sin(2\pi nd/365) + b_n \cos(2\pi nd/365)] + f_1(F_{10.7} - \overline{F_{10.7}}) + f_2(F_{10.7} - \overline{F_{10.7}})^2 + a(Ap - \overline{Ap}) + R \quad (1)$$

where, y-floating-point year, y-mean floating year, t-long-term trend, d-day number of the year, F10.7 and F10.7-solar flux in sfu, A_p and A_p –A_p index, R-fitting residual. t, T_b , f_1, f_2, a are estimated via least square fitting.

For a given component (year trend/$F_{10.7}$/A_p index), residuals are obtained for various components by removing other two components [4, 9, 10, 11].

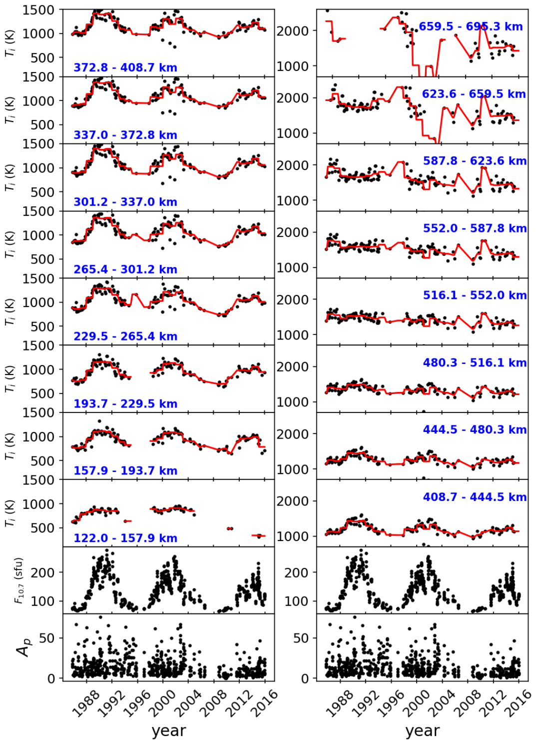

Figure 1. Monthly median of ion temperature (black dot) at various altitudes along with corresponding $F_{10.7}$ and A_p index. T_i values are for ±3 hour of local noon, represents day. Red line indicates the yearly medians.

3 Results

3.1 Results

T_i residual is presented in Figure 2. The T_i residual is calculated by separating the modeled T_i (for the component of year to estimate T_i trend) from ISR measured T_i to remove the influence of $F_{10.7}$ and A_p. In Figure 2, T_i residuals (monthly median-black and yearly median-red) are shown for various altitudes along with trend line (green) and its slope (m), its standard error (Err), and correlation coefficient (r) between T_i and floating year. T_i residuals are spreaded around the trend line which means those residuals are origin of geophysical rather than statistical noise. Upper heights having more error. Those T_i trends corresponding to large error (Err>2) are removed for further analysis. T_i trends of $F_{10.7}$ and A_p for each altitude are estimated but not shown here.

Estimated T_i trends for components of year, $F_{10.7}$ and A_p index are shown in Figure **??**. These T_i variations for day and night are presented as function of altitude in Figure 3, (a) Ti trend (K/year), (b) δTi / δf10.7 (K/sfu), and (c) δTi / δAp (K/ap).

Estimated T_i trends are varying from -0.63 K/year to -13.5 K/year, indicating the cooling trend overall ionosphere during day and night.

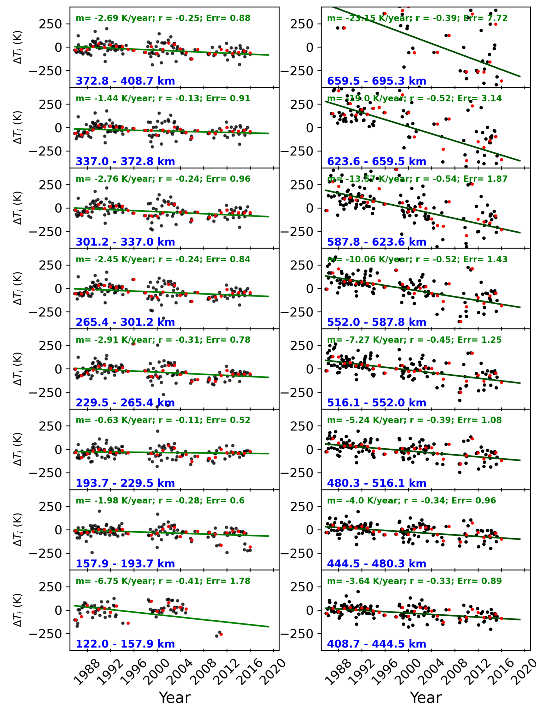

Figure 2. T_i residuals for various altitudes along with trend line (green) and its slope (m), its standard error (Err), and correlation coefficient (r) between T_i and floating year. Monthly medians are in black and yearly medians are in red.

4 Summary

- Estimated T_i trends are varying from -0.63 K/year to -13.5 K/year, indicating the cooling trend overall ionosphere during day and night.
- Over all trends indicate four different layers. During day, those layers are in altitude range of ~122-230

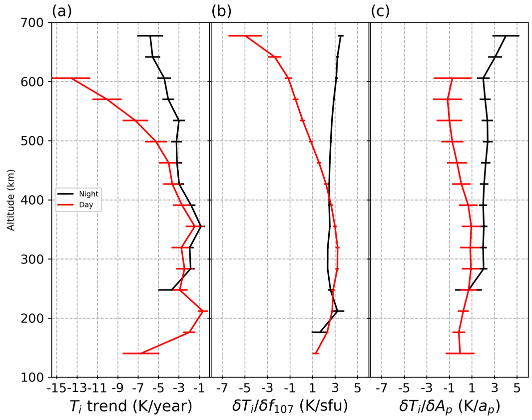

Figure 3. T_i trend variations for day (red) and night (black) as function of altitude (a) T_i trend (K/year), (b) δT_i / $\delta f_{10.7}$ (K/sfu), and (c) $\delta T_i / \delta A_p (K/a_p)$.

km (day-layer1), ~230-373 km (day-layer2), ~373-480 km (day-layer3), ~480-624 km (day-layer4). During nigh, those layers are in altitude range of ~230-373 km (night-layer1), ~373-409 km (night-layer2), ~409-552 km (night-layer3), ~552-700 km (night-layer4).

- Lower layer is cooling than the top layer in the altitude range of 122–230 km, where T_i trend increase from -6.5 K/year to -0.63 K/year. It can be noted that -6.5 K/year is estimated highly from 2 solar cycle data sets along with error of 1.78 K/year.
- High cooling trends are seen in day-layer4 and night-layer4, those are above ~500 km. It can be metioned that continuous cooling trends are above 500 km.
- Variation of the trends are similar during day and night in the altitude ragne of ~230-480 km.

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References

[1] Alcaydé, D., J. Fontanari, and P. Bauer (1982), “High latitude neutral atmosphere temperature and concentration measurements from the first EISCAT incoherent scatter observations, ” *Ann. Geophys.*, **38**, 473–479, 1982.

[2] Bauer, P., P. Waldteufel, and D. Alcaydé, “Diurnal variations of the atomic oxygen density determined from incoherent scatter measurements in the ionospheric F-region, ” *J. Geophys. Res.*, **75**, 4825–4832, 1970.

[3] Buonsanto, M. J., and L. M. Pohlman, “Climatology of neutral exospheric temperature above Millstone Hill,” *J. Geophys. Res.*, 103, 23,381–23, **392**, 1998.

[4] J.M. Holt and S.R. Zhang, “Long-term temperature trends in the ionosphere above Millstone Hill,” *Geophysical Research Letters*, **35**, L05813, 2008, doi:10.1029/2007GL031148.

[5] Roble, R. G., and R. E. Dickinson, “How will changes in carbon dioxide and methane modify the mean structure of the mesosphere and thermosphere?,” *Geophys. Res. Lett.*, **16**, 1441–1444, 1989.

[6] Emmert, J. T., J. M. Picone, J. L. Lean, and S. H. Knowles, “Global change in the thermosphere: Compelling evidence of a secular decrease in density, ” *J. Geophys. Res.*, **109**, A02301, 2004, doi:10.1029/2003JA010176.

[7] Keating, G. M., R. H. Tolson, and M. S. Bradford, “Evidence of long term global decline in the EarthâĂŹs thermospheric densities apparently related to anthropogenic effects,” *Geophys. Res. Lett.*, **27**, 2000, 1523–1526.

[8] Oliver, W. L., S.-R. Zhang, and L. P. Goncharenko, “Is thermospheric global cooling caused by gravity waves?,” *J. Geophys. Res. Space Physics*, **118**, 3898–3908, 2013, doi:10.1002/jgra.50370.

[9] Zhang, S.-R., J. M. Holt, and J. Kurdzo, “Millstone Hill ISR observations of upper atmospheric long–term changes: Height dependency, ” *J. Geophys. Res.*, **116**, A00H05, 2011, doi:10.1029/2010JA016414.

[10] Zhang, S.-R., and J. M. Holt, “Long-term ionospheric cooling: Dependency on local time, season, solar activity, and geomagnetic activity, ” *J. Geophys. Res. Space Physics*, **118**, 3719–3730, 2013, doi:10.1002/jgra.50306.

[11] Zhang, S.-R., J. M. Holt, P. J. Erickson, L. P. Goncharenko, M. J. Nicolls, M. McCready, and J. Kelly, “Ionospheric ion temperature climate and upper atmospheric long-term cooling, ” *J. Geophys. Res. Space Physics*, **121**, 8951–8968, 2016, doi:10.1002/2016JA022971.