Variations of 0.7-6.0 MeV Electrons at Geosynchronous Orbit as a Function of Solar Wind

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Abstract. The variations of MeV electron flux at geosynchronous orbit are predictable based on solar wind measurements. Using a model based on the standard radial diffusion equation applied for the years 1995-1999, a prediction efficiency of 64.4% and a linear correlation of 0.81 were achieved for the logarithm of average daily flux of 0.7-1.8 MeV electrons. The same model with different parameters gave a prediction efficiency of 70.2% and 72.4% and a linear correlation of 0.84 and 0.85, respectively, for 1.8-3.5 MeV and 3.5-6.0 MeV electrons during the same time period. The radial diffusion coefficient in the model is a function of location, solar wind velocity, interplanetary magnetic field, season, and solar cycle. The average lifetime of the electrons is a function of the radial distance and solar cycle. The radial diffusion equation is solved with given boundary conditions. These results suggest that MeV electrons at geosynchronous orbit, extending over a wide energy range, have a systematic response to the solar wind variations. This model has been updated and is making real-time forecasts of daily averaged >2 MeV electron fluxes at geosynchronous orbit.

Introduction

As part of the International Solar Terrestrial Program, the solar wind has been monitored almost continuously since Dec. 1994 by the Wind [Acuna et al., 1995] and Advanced Composition Explorer (ACE, launched in 1998) [Stone et al., 1998] spacecraft. Solar activity in the form of solar flares, coronal mass injections (CMEs), and recurrent high speed streams influence Earth's space weather by increasing ionization in the ionosphere and by producing magnetic storms and their associated electrical currents, energetic charged particle injections, and aurora. These phenomena can have a deleterious impact on man-made systems. Energetic particles, which can lead to satellite failure through radiation damage, are of increasing concern as mankind relies more on satellite systems. Of special concern is the radiation environment at geosynchronous orbit where the largest number of satellites is located.

As early as in 1966, it was realized [Williams, 1966] that the variations of radiation belt electron fluxes correlated with the solar wind velocity. Paulikas and Blake [1979] showed in a more quantitative way that the MeV electron flux at geosynchronous orbit would enhance 1-2 days following a passage of a high speed solar wind stream. This correlation was used by Baker et al. [1990] to develop a linear filter model to predict MeV electrons at geosynchronous orbit. The linear filter model was developed from limited intervals of continuous solar wind and MeV electron flux measurements. The linear prediction filter method achieved a prediction efficiency (PE) [Baker et al., 1990] of 52% in their three-month sample period.

The physical mechanisms behind the correlation have been pursued by many researchers. The current prevailing argument is that solar wind variations perturb the magnetosphere and generate ultra low frequency (ULF) waves [Engebretson et al., 1998; Vennerstrom, 1999], which are important in driving radial diffusion [Rostoker et al., 1998; Baker et al., 1998; Mathie and Mann, 2000; Li et al., 2001a; Mathie and Mann, 2001; Obrien et al., 2003]. and thus energize electrons. Magnetohydrodynamic simulations and test-particle tracing have shown a direct response of radiation belt electrons to such magnetospheric fluctuations [Hudson et al., 1999; Elkington et al., 1999].

Recently, Li et al. [2001a] have developed a radial diffusion model to predict 0.7-1.8 MeV electron at geosynchronous orbit based on solar wind measurements. They concluded: (1) the approximate 1-2 day delay between the peak in the solar wind velocity and the peak in the MeV electron flux can be explained as the time for the electrons to diffuse inward to geosynchronous orbit in response to changes in the solar wind; (2) the solar wind velocity is the most important parameter governing relativistic electron fluxes at geosynchronous orbit; (3) the interplanetary magnetic field (IMF) orientation has significant effect on the electron flux only when the IMF polarity is southward for a long time. (4) A small variation in the diffusion coefficient can produce a larger variation in the electron flux because of competition between inward diffusion and loss, the response of the MeV electron flux at geosynchronous orbit is not linear to solar wind variations.

In this paper, we extend the work of Li et al. [2001a] by including predictions of higher energy electrons and including the contribution of seasonal variations and solar cycle variations to the prediction. We will also discuss the phase space density variation of the relativistic electrons. In addition, we will introduce our forecast model based on radial diffusion, which operates in real-time and forecasts the daily variation of >2 MeV electrons at geosynchronous orbit 1-2 days in advance. Before we discuss the results, we first briefly describe the data source and the model.

Data Sources

Figure 1 shows nearly half of a solar cycle of solar wind velocity (x-component) and the five-day window-averaged z-component (in GSM coordinates) of IMF. These five years include the late part of the descending phase of the last sunspot cycle (1993-1995) when recurrent high speed solar wind streams emanating from persistent trans-equatorial coronal holes were a characteristic feature of the solar wind, the sunspot minimum (1996-1997) when the solar activity was generally quiet and the ascending phase toward the maximum of the solar cycle (1998-1999) when solar flares and CMEs occur more frequently.

The solar wind data are primarily from the Wind satellite, with the solar wind velocity and density from the 3D/plasma and energetic particle instrument [Lin et al., 1995] and the IMF from the magnetometer [Lepping et al., 1995]. Wind was in the solar wind almost continuously except for a few passes through the magnetosphere. We interpolated the solar wind data during these gaps before ACE data were available in 1998 and then used ACE data from the SWEPAM and MAG instruments [McComas et al., 1998; Smith e al., 1999] to fill most of the gaps. The rest of the gaps are interpolated to assure the model with a continuous input. ACE has been in a halo-parking orbit near the L1 point, about 240 earth radii upstream in the solar wind from the Earth.

The MeV electron data at geosynchronous orbit are from the Los Alamos National Laboratory (LANL) sensors on geosynchronous satellites. These sensors are identically designed and record electron fluxes in the energy ranges of 0.7-1.8 MeV, 1.8-3.5 MeV, and 3.5-6.0 MeV. The long-term average of the LANL data gives an e-folding energy of 0.47 MeV if fitted by an exponential. Hourly averaged electron fluxes from LANL sensors on all available satellites (maximum 5), positioned at different longitudes, were mathematically averaged to form daily averaged fluxes. Data gaps (no data from any of the LANL sensors over a day) still exist, which are visible from Figure 2-4, and these data gaps are excluded in the comparisons with the model results.

For real-time forecast, we use real-time data from ACE and GOES-10 to forecast daily averaged $>$2 MeV electrons at geosynchronous orbit up to 48 hours in advance.

Model Description

The description of the model here is mainly based on Li et al. [2001a].

The MeV electron prediction model for geosynchronous orbit is based on the standard radial diffusion equation [Schulz and Lanzerotti, 1974]:

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}\right) - \frac{f}{\tau}, \tag{1}$$

where f is the electron phase space density. It is related to the differential flux j by

$$f = j/p^2, \tag{2}$$

where p is the momentum of the electron. If Earth's field is approximated as a dipole field, L corresponds to the radial distance in units of R_E at the equator. D_{LL} and τ are the diffusion coefficient and the average life time of the electrons, and in our model both are steep functions of L: $D_{LL} = D_0(L/6.6)^{10}$ and $\tau = \tau_0(6.6/L)^{9.9}$. The unique feature of our model is that the diffusion coefficient is directly linked to solar wind parameters.

The inner and outer boundary are set at $L = 4.5$ and $L = 11$, though these values can be adjusted. Since we have so far used the model to determine the MeV electron flux at geosynchronous orbit only, the exact values of the inner and outer boundary do not significantly affect our results. We have run model with the outer boundary at L=10 and 10.5, and changed the other model parameters parameters accordingly and obtained similar results. Since we do not have continuous measurements of the electrons beyond geosynchronous orbit, the exact outer boundary condition remains uncertain. This uncertainty should also be kept in mind for interpreting the implication of the model results (see further discussions later).

Equation (1) is solved by setting f 10^4 times larger at the outer boundary than the inner boundary [Li et al., 1997b]) and by making D_0 a function of the solar wind parameters as

$$D_0 = C(v/v_0)^{\gamma_1} \cdot [1+((v_x b_z + |v_x b_z|)/\alpha)^2]^{\gamma_2} \cdot [(\frac{\triangle v^2}{\triangle t})^2/\beta]^{\gamma_3}. \tag{3}$$

The first term is a function of the solar wind velocity divided by its nominal value, 425 km/s; the second term is a function of the y-component of solar wind electric field, which contributes only when b_z, the z-component of the IMF in GSM coordinates, is negative since v_x is always negative; and the third term is a function of solar wind velocity fluctuations. The term $\frac{\triangle v^2}{\triangle t}$ is directly calculated from the solar velocity using data at a rate of one measurement every 10 minutes and window-averaged over about 1.5 hours, and β is the average of $(\frac{\triangle v^2}{\triangle t})^2$ over the two years 1995-1996, which has a value of 9000 km^4/min^6. The velocity fluctuation is an approximation of 2v*dv/dt, a combination of solar wind velocity and velocity fluctuation.

We also explore whether the prediction would be improved by including a seasonal and solar cycle factor in the D_0 and τ_0,

$$D_0 = D_0 * D_{sea} * D_{sol} \tag{4}$$

$$\tau_0 = \tau_0 * \tau_{sea} * \tau_{sol} \tag{5}$$

where

$$D_{sea} = 1. - F_{sea} * \cos(2\pi(TT - T0_{sea})/T_{sea}) \tag{6}$$

$$D_{sol} = 1. - F_{sol} * \cos(2\pi(TT - T0_{sol})/T_{sol}) \tag{7}$$

$$\tau_{sea} = 1/[1. + E_{sea} * \cos(2\pi(TT - T0_{sea})/T_{sea})] \tag{8}$$

$$\tau_{sol} = 1/[1. + E_{sol} * \cos(2\pi(TT - T0_{sol})/T_{sol})] \tag{9}$$

where $T0_{sea}$ and $T0_{sol}$ are initial phase values, T_{sea} and T_{sol} are the corresponding periods of the variations. For the results of this paper, $T0_{sea} = 76, T0_{sol} = -(365*3.7+1), T_{sea} =$

$182.625, T_{sol} = 11 * 365 + 2$ in units of days. TT is the time variable and starts on day 1 of 1995 (TT=0 for 1/1/1995), all are in unit of day. $F_{sea}, F_{sol}, E_{sea}$, and E_{sol} are coefficients determining the significance of the variations. When they are equal to zero, then there are no contribution from these variations.

Furthermore, we included two decoupled processes, the Dst effect and a dynamic pressure effect, to adjust f and then plotted the data and the simulated results. The Dst effect is a measure of the adiabatic response of electrons to magnetic field changes [Li et al., 1997a; Kim and Chan, 1997]. We implement this effect in an *ad hoc* way by adjusting f at all points,

$$f = f * exp[\frac{(Dst(t + \triangle t) - Dst(t))}{Dst_n}], \tag{10}$$

where Dst_n is a parameter. This makes f at a given position decrease as Dst decreases and increase as Dst increases. Dst is directly calculated from solar wind parameters using a new Dst prediction model using solar wind velocity, density, and magnetic field [Temerin and Li, 2002].

The dynamic pressure effect is implemented by adjusting f in the following way

$$f = f * exp(-(p/p_n)^{0.6}) \tag{11}$$

where $p = \rho v^2$ in units of nPa (nano-Pascal), ρ is solar wind mass density, and the p_n is a parameter. The above equation indicates that f decreases when the solar wind dynamic pressure increases. One possible explanation is that electrons with large pitch angles starting on the night side will drift farther out on the dayside along the contour of constant magnetic field at their mirror points. An enhancement in the solar wind dynamic pressure will push the magnetopause inward and enhance the magnetic field on the dayside such that more electrons will be lost by reaching the magnetopause. Another possible reason is that enhanced solar wind pressure is usually associated with enhanced electron precipitation.

Results and Discussions

We compared the predicted results with the MeV electron measurements of a given energy range by minimizing χ^2:

$$\chi^2 = \frac{1}{N} \sum_{i}^{N} [log_{10}(j_i) - log_{10}(j_i^l)]^2, \tag{12}$$

where j_i is the modeled result and j_i^l is from LANL data for the particular energy range. We adjusted the parameters $C, \alpha, \gamma_1, \gamma_2, \gamma_3, \tau_0, F_{sea}, F_{sol}, E_{sea}, E_{sol}$ and the parameters associated with Dst and dynamic pressure effects for the years 1995-1999 to achieve the minimum χ^2. The prediction efficiency (PE) is defined as

$$PE = (1 - \frac{\chi^2}{\Lambda^2}) \times 100\%,$$

where $\Lambda^2 = \frac{1}{N} \sum_i^N [log_{10}(j_i^l) - < log_{10}(j^l) >]^2$ and $< log_{10}(j^l) >= \frac{1}{N} \sum_i^N log_{10}({j_i}^l)$. The data and the prediction are plotted in Figure 2-4 for electron energy ranges: 0.7-1.8, 1.8-3.5, 3.5-6.0 MeV, respectively. The model parameters for these figures are listed in Table 1 where the energy channels correspond to the energy ranges: 0.7-1.8, 1.8-3.5, 3.5-6.0 MeV, respectively. The seasonal and solar cycle variation coefficients are $F_{sea} = 0.32, 0., 0., F_{sol} = 0.135, 0.08, 0., E_{sea} = 0., 0., 0., E_{sol}$=0., 0.05, 0.10, for the three respective energy ranges.

MeV Electron's Response to the Solar Wind

Figure 2-4 shows that the variations of MeV electrons at geosynchronous orbit are well reproduced by the model, which uses solar wind measurements as the only input. Both the shorter time scale and the longer seasonal effects, such as the overall reduction in the electron fluxes in the middle of 1996 for all the energy ranges are reproduced by the model. This means that the variations of the MeV electrons in general are driven by the solar wind variations, or the MeV electrons have a systematic way to respond to variations of solar wind. Comparing with Figure 1, it is also evident that the solar wind velocity is the most important parameter in driving the variation of MeV electrons for all energy ranges. We also studied the response of lower energy electrons to the solar wind. For the daily averaged electron fluxes, we found that the solar wind velocity is still the most important parameter for electrons down to 300 keV at geosynchronous orbit.

Phase Space Density Analysis

The radial diffusion equation (1) is solved by setting f 10^4 times larger at the outer boundary (L=11) than the inner boundary (L=4.5). Due to the radial gradient, f will diffuse inward. How fast it diffuses inward is governed by the diffusion coefficient, which in turn is a function of the solar wind parameters as described by equation (3). The upper panel of Figure 5 shows f as a function of L and time for first half year of 1995. The intensity of f is color-coded in logarithmic scale. At a given L, we convert f into differential flux, using equation (2), to compare with measurements. Since we have so far used the model to determine the electron flux at a specific radial distance, geosynchronous orbit, the exact values of the inner and outer boundary do not significantly affect our results.

Because of the boundary condition, there is usually a positive gradient in f (larger f at larger L). However, because of the faster loss of the electrons at larger L, which is empirically determined to produce best PE, there are sometimes local peaks in f as a result of competition between diffusion and the loss. The lower panel of Figure 5 show such an example, which also says that a local peak in phase space density can be created by radial diffusion with a L-dependent loss. The previous simulation results by Selesnick and Blake [2000] drew the same conclusion. The electron phase space density or flux at any position always varies, due to the diffusion and loss in response to solar wind variation, which is the dynamic feature of the model. It should be pointed out that another possible way to create a local peak in f is by heating electrons with high frequency waves, which violates the first adiabatic invariant of the electron [Temerin et al., 1994; Summers et al., 1998; Horne and Thorne, 1998; Meredith et al., 2001; Meredith et al., 2002; Albert, 2002]. Recent analysis of electron measurements from the Polar spacecraft [Selesnick and Blake, 2000; Green and Kivelson, 2003] shows that local peaks in f can be due to electron heating inside geosynchronous orbit.

Variations Among Different Energy Electrons

The model parameters are different for different energy electrons, as shown in Table 1. These parameters are determined by producing the best PE. It is not clear why and how the model parameters differ for different energy. However, some trends are discernible from Table 1. It seems that higher energy electrons diffuse slower (with a smaller C), since C is directly proportional to the diffusion coefficient. The lifetime of higher energy electrons at geosynchronous orbit seems somewhat longer and the Dst effect seems to play a less significant role on the higher energy electrons.

Seasonal and Solar Cycle Effects

Li et al. [2001b] has used long term measurements to show that the radiation belt electron intensity peaks during the declining phase of the solar cycle, when the solar wind is dominated by recurrent high speed streams, and also peaks near equinoxes for a given year. These variations are discernible in the LANL measurements of MeV electrons at geosynchronous orbit even just for 1995-1999, as shown in Figures 2-5. In Figure 1, the solar wind velocity for all five years seems to be higher near equinoxes (more obvious for 1996-1997) in addition to the solar cycle variation. In our diffusion model, the solar wind velocity is a direct input, so is the IMF in GSM coordinates. Thus, the solar cycle and seasonal variation in the solar wind velocity and the different coupling efficiency due to the Russell-McPherron effect [Russell and McPherron, 1973] have been included in the model. So the model results without any additional seasonal and solar cycle effects are already reasonably good, see Table 1.

On the other hand, other known effects on seasonal variation, such as the equinoctial effect (orientation of the Earth's dipole axis relative to solar wind flow) [Cliver et al., 2000], are not included in the model. Also, the ionosphere expands during solar maximum due to enhanced UV radiation from the Sun. This might affect the fluctuations of magnetic fields in space and the lifetime of radiation belt electrons. Therefore, we would like to explore whether adding some seasonal and solar cycle effects will improve the model prediction.

The last two rows in Table 1 show the PE and linear correlation coefficient (LC) for different energy ranges of electrons without any additional seasonal and solar cycle effects included, i.e., $F_{sea} = F_{sol} = E_{sea} = E_{sol} = 0$.

We found that including E_{sea} did not improve the PE for any energy range (thus E_{sea} is set to zero throughout) and including other three factors, $F_{sea}, F_{sol}, E_{sol}$, did improve the PE for all the energy ranges, but in different ways, as illustrated in Table 2. Table 2 was produced in the following way: we first included E_{sol}, then F_{sol}, then F_{sea}. 'No improve' means that the PE was improved by less than 0.5% when one of the three factors was included.

The purpose of including the seasonal and solar cycle effects is to assess how important these factors are. It seems that there is a significant improvement of PE for 0.7-1.8 MeV electrons. The PE increased from 59.6% to 64.4%, an increase of 8%, while there is only about a 1% increase of PE for 3.5-6.0 MeV electrons.

It is unclear at this moment why including the additional solar cycle effect improves the PE for 0.7-1.8 so significantly but not for higher energy electrons. One possibility is that the solar cycle variation of the ionospheric density, which is caused by increased solar ultraviolet (UV) radiation as the Sun approaches solar maximum. The increased conductivity of the ionosphere may affect the ULF waves for given solar wind conditions, which in turn will have a greater affect on the radial diffusion of lower energy electrons. Another possibility is that solar wind properties change with solar cycle, and that is not captured in equation (3).

Variation of Energy Spectrum

The five-year average of the LANL daily averaged fluxes gives an e-folding energy of 0.47 MeV if fitted by an exponential. It is evident from comparing Figures 2-4 that the energy spectrum varies over a wide range, which means that the enhancements and decays of the electron fluxes are different. For example, around day 101 of 1995, the energy spectrum has an e-folding energy of about 0.66 MeV if fitted by an exponential, while the prediction gives an e-folding energy of 0.43 MeV for the same time. This indicates that though the MeV electrons have a systematic response to the external perturbation, the model is missing some aspects of the response.

Real-Time Forecast

Based on the model described above, we constructed a real-time model to forecast the $>$2 MeV electron flux at geosynchronous orbit up to 48 hours in advance using real-time solar wind data from ACE and real-time electron data from GOES-10. This forecast model has been automated and is running in real-time. The results are updated every two hours on the website: lasp.colorado.edu/∼lix (click Real Time Forecast ...). Figure 6 shows the comparison of daily averages of the MeV electron flux measured by GOES-10 at geosynchronous orbit with the forecast results. The green and purple crosses are the forecasts one and two days in advance, respectively.

In the real-time forecast we predict the next two day’s electron fluxes based on current solar wind conditions and electron data. To do this, we assume that the future solar wind velocity and velocity fluctuation remain the same as the average of the last two hours. This is reasonable because the solar wind speed typically changes slowly and the electrons typically take one or two days to respond to changes in the solar wind velocity. We do not include the two decoupled processes, the Dst effect and the dynamic pressure effect, to adjust f because assuming that they remain the same leads to no change in the electron flux and we do not yet try to predict changes in these parameters. The z-component of the IMF is simply taken as -2 nT, which is the approximate average of the negative z-component (since the positive z-components do not make a contribution, see equation (3)). On the other hand, we can make use of today's electron measurement to normalize our forecast for tomorrow and beyond. This is an advantage.

The biggest uncertainties associated with the current forecast model are due to assuming the same solar wind velocity for the next two days and using an averaged z-component of the IMF. This is unrealistic. However, the forecast results still look fairly good, e.g., see Fig. 6. This may be due to the fact that the enhancement of MeV electrons at geosynchronous orbit is delayed by 1-2 days following solar wind velocity enhancement and the diffusion coefficient is much larger at larger L, so the inward transport of the electrons is dominated by the current solar wind condition and the corresponding enhancement shows up 1-2 days later at geosynchronous orbit.

For example, we re-ran the forecast model using the actual solar wind velocity (assuming that we know exactly the solar wind velocity two days in advance) for one year, Nov. of 2000-Nov. of 2001, the PE for one-day 'forecast' is improved from 0.613 to 0.628, a 2.5% increase and the PE for two-day 'forecast' is improved from 0.168 to 0.184, a 9.5% increase. It is not surprising to see that two-day 'forecast' is improved much more.

Please note that in the real-time forecast, we compare our model results with the daily averaged electron flux from only one spacecraft (GOES-10), while in the prediction results shown in Figure 2-4, we compare with the daily averaged electron flux from four LANL spacecraft, the latter reflects a better averaged electron fluxes at geosynchronous orbit.

Implication of the model and its results

The main emphasis of this paper is to demonstrate the electron prediction model's operational usefulness. The diffusion model works as well as it does because it gives two essential elements of the physics of relativistic electrons: the time delay of their response to the solar input and the time constant of their decay. However, one may wish to know more about its physical basis.

There are different ways to physically interpret the diffusion model. Equation (1) is written explicitly so as to look like the usual form of the radial diffusion equation and it has been the default position to physically interpret equation (1) in terms of radial diffusion but one could remove the L^2 factors in the equation and then change the 'L' dependence of the diffusion 'constant' D_{LL} and get the same operational prediction of the relativistic electron flux. If one were to consider only a single energy range at a single radial distance, L, one could then substitute 'E' (now representing particle's energy) for 'L' in this diffusion equation. One could then re-interpret the boundary conditions as a large phase space density of electrons at a low energy (instead of at a large L) and a low phase space density of electrons at a high energy (instead of at a small L). Such an interpretation would represent heating of the lower energy electrons at a constant L to produce the higher energy relativistic electrons being modeled. The operational result would again be the same. Here, on this basis, we can not decide which interpretation is better because, though we address different energies, we do not address different radial distances. It is likely that both radial diffusion and local heating at a constant radial distance play a role in creating relativistic electrons. However, the relative importance of these two mechanisms is of yet an open question and the answer as to which mechanism is most important may perhaps not be simple since the relative importance of the two mechanisms may be a function of energy, radial distance, and solar wind conditions.

Most of the physics that can be extracted from the model relates to the interaction of the solar wind with the magnetosphere rather than to any detail of the radial diffusion or heating process. The diffusion coefficient in the model is a function of the solar wind. We have found [Li et al., 2001a] that velocity of the solar wind is the most important parameter but that the z-component of the IMF also plays an important role and that other parameters are of less importance.

Conclusion

The variations of the daily averaged electrons in the energy range of 0.7-6.0 MeV are well reproduced by the radial diffusion model [Li et al., 2001a], which uses the solar wind measurements as the only input. This indicates that relativistic electrons, extending over a wide energy range, respond in a systematic way to the variations of the solar wind. While it is still a point of debate about the physical processes behind this systematic response, the model with the given boundary condition, nonetheless captures most of the variations, and also misses some aspects of the electrons' response, such as the energy spectrum. We analyzed the electron phase space density as a function of L and time and found that local peaks in phase space density can be produced by the radial diffusion equation with a L-dependent loss. We also found that adding additional seasonal and solar cycle effects into the model can significantly improve the prediction efficiency for 0.7-1.8 MeV electrons, but not much for the 3.5-6.0 MeV electrons, for which the physical reason is still unclear.

Finally, the model has been updated to make real-time forecasts of $>$2 MeV electrons at geosynchronous orbit up to 48 hours in advance using real-time data from ACE and GOES-10. The forecast results are updated very two hours at the website: lasp.colorado.edu/$\sim$lix.

Figure Caption

Figure 1. The x-component of solar wind velocity (every 10 minutes), and the z-component of interplanetary magnetic field (5-day window-averaged from 10 minute resolution data) for the five years of interest.

Figure 2. A comparison of five years of daily averages of 0.7-1.8 MeV electron flux measured at geosynchronous orbit with the predicted results based solely on measurements of the solar wind. The red line shows electron flux measured at geosynchronous orbit, data gaps are not plotted and are excluded in the calculation of PE and linear correlation coefficient. The green line shows predicted results. The Horizontal axis shows the day of the year.

Figure 3. The same as Figure 2, but for 1.8-3.5 MeV electrons.

Figure 4. The same as Figure 2, but for 3.5-6.0 MeV electrons.

Figure 5. Phase space density of the electrons in the model (at constant mu) as a function of L and time. The intensity is in unit of (c/cm MeV)^3 and color-coded in logarithmic scale

indicated by the color bar (in relative magnitude). Only the variations of phase space density are important in the model. The Dst effect and dynamic pressure effect are not included.

Figure 6. A comparison of daily averages of the MeV electron flux measured by GOES-10 at geosynchronous orbit with the real-time forecast results for June-July of 2003. The green and purple crosses are the forecasts one and two days in advance, respectively.

Table 1. Model parameters for Figures 1, 2, and 3. Energy channels, CH1, CH2, and CH3, correspond to the energy ranges: 0.7-1.8, 1.8-3.5, 3.5-6.0 MeV, respectively.

Table 2. Seasonal and solar cycle effects on prediction efficiency (PE) and linear correlation coefficient (LC) for different energy channels.

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