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Energetic Electron Diffusion and Precipitation Driven by Ducted Hiss Waves in High Density Irregular Region

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Abstract

Plasmaspheric hiss plays an important role in the electron precipitation and the slot formation in radiation belts. Recent studies show the whistler-mode waves can be guided in the density irregularities, performing parallel propagation. Therefore, the resonance between ducted waves and energetic electrons can expand to higher latitudes, and then drive strong energetic electron scattering. In this study, we report a conjugate observation using data from Van Allen Probe A and POES. Through the analysis of observation and the quantification of quasi-linear diffusion coefficients, the results show the ducted hiss can effectively scatter the energetic electrons and drive enhanced electron flux at low altitude region. We suggest the ducted hiss is important for electron loss process in radiation belts.

Conjugate Observation

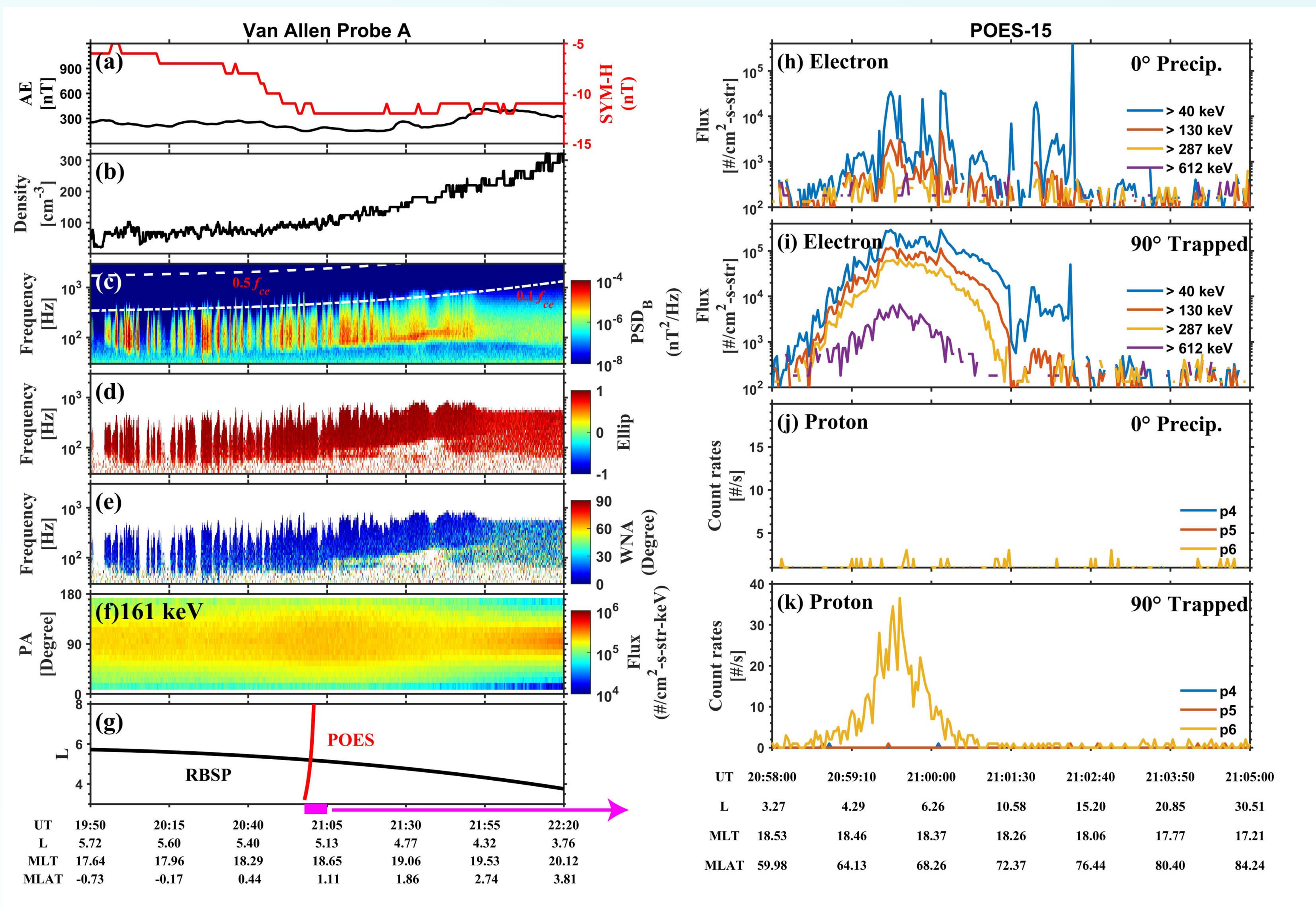

Figure 1. The overview of the conjugate observation between Van Allen Probe A (left panels) during 19:50 UT-22:20 UT and POES-15 (right panels) during 20:58 UT-21:05 UT on 23 May 2017. (a) AE and SYM-H index. (b)-(e) Total electron number density, frequency-time spectrogram of magnetic spectral density, corresponding ellipticity, and wave normal angle observed by Van Allen Probe A. (f) Differential electron fluxes as function of pitch angle in energy of 161 keV. (g) L shells of Van Allen Probe A and POES satellites. (h) Fluxes of energetic electrons in four energy channels detected by the 0° detector of POES-15. (i) Similar to (h), but detected by 90° detector. (j) Count rates of protons in three energy channels detected by 0° detector of POES-15. (k) Similar to (j), but detected by 90° detector.

1. As shown in left hand of Figure 1, Van Allen Probe A observed the intensified hiss waves in high density irregular region at magnetic equator, they show the characteristics of spatial segregation.
2. The anisotropic electron differential flux may provide the free energy for wave growth.
3. At ~21:00 UT, POSE-15 satellite orbited the similar field lines with Van Allen Probe A at low altitude region as shown in Figure 2, the difference in longitude is < 7 degrees.

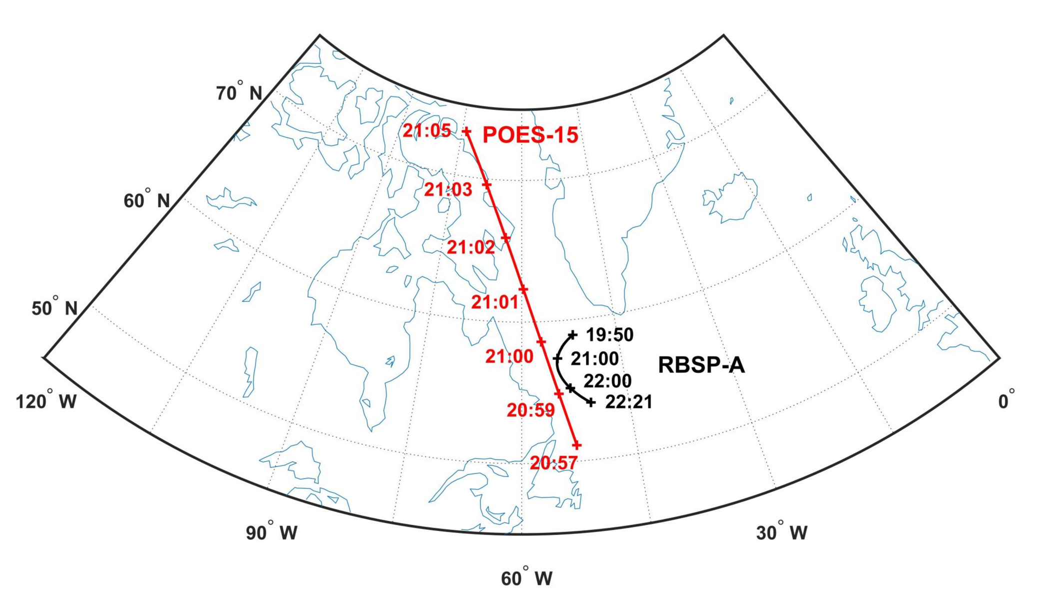

Figure 2. The footprints of Van Allen A (black curve line) and POES-15 (red curve line) satellites.

4. As shown in right hand of Figure 1. At the conjugate time, POES satellite observed the enhanced flux in trapped and precipitating electrons, trapped relativistic electrons (P6). Considering the closing distances between two probes, the enhancements in fluxes may be driven by ducted hiss waves.

Methodology

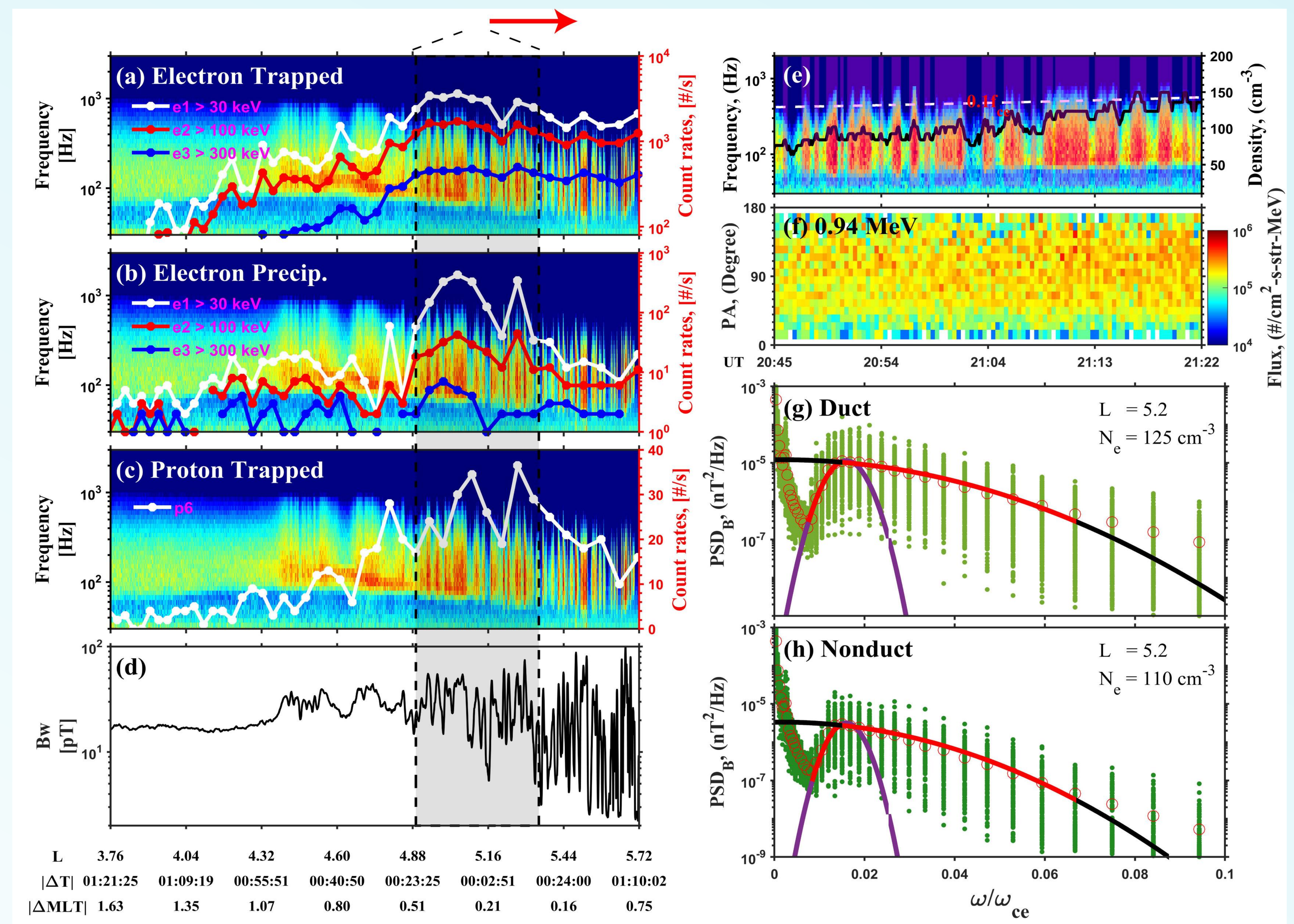

Figure 3. Comparison of count rates and amplitudes (and power spectrum density (PSD)) of hiss based on L shells (left) in the conjugate region. (a)-(b) Count rates of electrons in three energy channels detected by 0° and 90° detector of POES-15. (c) Count rates of protons in P6 channel detected by 90° detector of POES-15. The background colors in above panels indicate the magnetic PSD. (d) Amplitudes of hiss waves. (e) Electron number density and PSD of waves. (f) Electron Differential flux observed by Van Allen Probe A (g)-(h) Observed (green solid circles) and averaged (red hollow circles) PSD as a function of normalized frequency, black and purple curve lines are fitted two Gaussian functions, red curve lines are fitting part to calculate diffusion coefficients. Gray shades box in (a)-(d) is our interesting region.

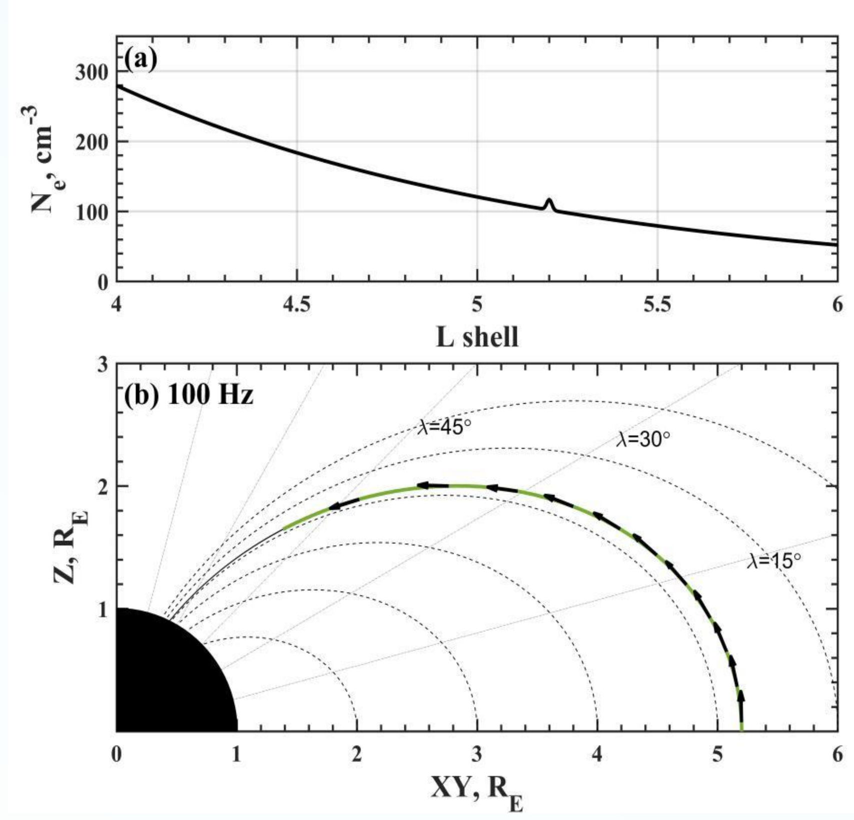

Figure 4. Ray tracing simulation for ducted hiss.

1. To study if the enhanced fluxes driven by ducted hiss waves based on field lines as previous studies, we perform the count rates detected by POES-15 and PSD of hiss waves based on L shells as shown in left hand in Figure 3a-3d.
2. In the conjugate region (black box), where the difference in UT is smaller than 15 minutes, there are two peaks in all exhibited flux, and the two peaks are correlated well with PSD and amplitudes of hiss waves.
3. As shown in Figure 3e, the hiss waves are in the small-scale density irregulars.
4. To infer the enhanced flux is driven by ducted hiss waves, we select the observed parameters to calculate diffusion coefficients.
5. Ray tracing simulation also shows the hiss waves can indeed be guided in density duct and performing parellel propagation.

Results

1. The simulation results are shown in Figure 5. Figures 5a-5d display the bounce averaged pitch angle (<Dαα >) and momentum (<Dpp>) diffusion coefficients as functions of equatorial pitch angle and energy (10keV-10 MeV) for both ducted (Figures 4a and 4b) and nonducted hiss (Figures 4c and 4d).
2. Compared to nonducted hiss, the ducted hiss drives stronger <Dαα >, especially for electron energy >200 keV and those with pitch angle near loss cone.
3. As shown in Figure 4i, for both ducted and nonducted hiss, the <Dαα>|LC are more closed to strong diffusion for electron energies from 20 to 100 keV (particularly for few tens of keV), indicating they are more prone to precipitation, this result is also related to the observed precipitating electrons in the energy of >30 keV.

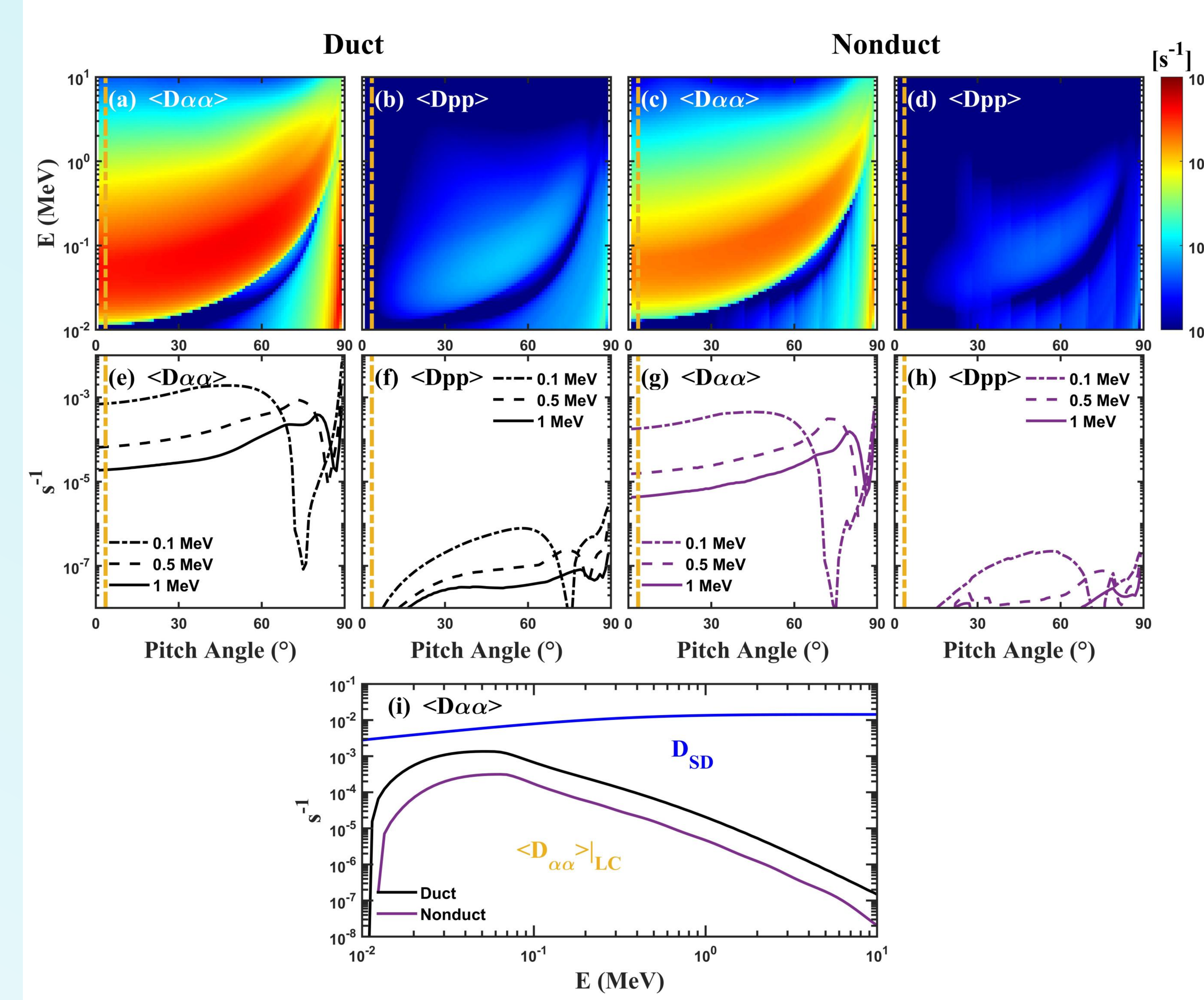

Figure 5. Overview of quasi-linear diffusion coefficients. (a)-(b) The equatorial pitch angle and momentum diffusion coefficients for ducted hiss. (e)-(f) Three energy levels of diffusion coefficients for ducted hiss. (c)-(d) and (g)-(h) are similar as (a)-(b) and (e)-(f), but for nonducted hiss. (i) The comparison of pitch angle diffusion coefficients (<Dαα>|LC) near the loss cone for both types of hiss waves with strong diffusion limit (blue line).

Conclusion

In this study, we report a conjugate observation between Van Allen Probe A and POES satellites. During the conjugate region, we observed the modulated hiss waves located in the equatorial plasmasphere, with the enhanced electron flux detected at low altitudes, including both precipitating and trapped electrons. By comparing the spatial distribution of hiss waves and the electron count rates, we infer that this enhancement of the electron flux at low altitudes is likely caused by the ducting propagation of hiss modulated by density irregularities. To quantify the efficiency of electron scattering and compare effects of ducted and nonducted hiss, we calculate the quasi-linear diffusion coefficients. The results show that the diffusion coefficients driven by ducted hiss are about half an order of magnitude higher than those driven by nonducted hiss. These results suggest that the observed electron scattering is predominantly driven by pitch angle diffusion caused by ducted hiss. And we find that the energies of electrons subject to efficient precipitation are mainly in the range of 20–100 keV, which is consistent with observation.