Particle Precipitation Caused by Wave-particle Gyroresonant Interaction during NPM Experiment

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The 2nd International DEMETER Workshop

Outline

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2. **Wave-Particle Gyroresonant Interaction and Pitch Angle Diffusion**
3. **Ground-based VLF Transmitter(NPM) Induced Particle Precipitation**
4. **Conclusions and Further Discussion**

Motivation

- Resonant interactions between particle and wave is responsible for the acceleration and loss of radiation belt electrons.
  - If the wave amplitude is enough small, the interaction between wave and particle can be treated as a diffusive process.
  - Generally, the electrons are diffusing in energy as well as pitch angle, and which causes their change together.

- In the inner radiation belt , different types of waves (such as whistlers, VLF transmitters and so on) contribute to the process of pitch angle diffusion which plays an dominant role in electrons precipitation.

Pitch Angle Diffusion

Quasi-linear diffusion:

- Expand Vlasov equation for the particle distribution to second order in perturbed quantities
- Small scattering with small amplitude wave
- Gaussian spectrum
- Diffusion rate is proportional to wave power
- In inner radiation belt, pitch angle diffusion plays dominant role

Local Pitch angle Diffusion Coefficient:

$$D_{\alpha\alpha} \propto \frac{\Omega_e}{(E+1)^2}\left(\frac{B_\omega}{B_0}\right)^2 \sum_i \frac{\left(1-\frac{x_i \sin\alpha}{y_i \beta}\right)^2 \left|\frac{dx_i}{dy_i}\right|}{\delta x \left|\beta\cos\alpha - \frac{dx_i}{dy_i}\right|}$$

$$\times \exp\left[-\left(\frac{x_i - x_m}{\delta x}\right)^2\right]$$

$$x_i = \omega_i / \Omega_e \qquad y_i = ck_i / \Omega_e$$

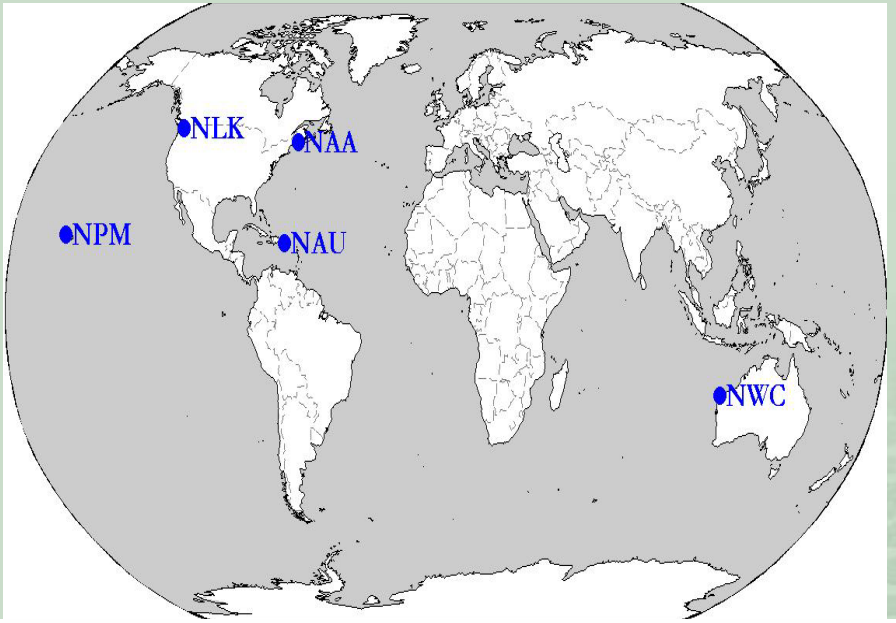
Bounce Averaged Diffusion Rate:

$$\left\langle D_{\alpha\alpha} \right\rangle = \frac{1}{S(\alpha_{eq})} \int_0^{\lambda_m} D_{\alpha\alpha} \frac{\cos(\alpha)\cos^7(\lambda)}{\cos^2(\alpha_{eq})} d\lambda$$

Pitch Angle Diffusion Equation:

$$\frac{\partial f}{\partial t} = \frac{1}{\sin\alpha} \frac{\partial}{\partial \alpha}\left[D_{\alpha\alpha} \sin\alpha \frac{\partial f}{\partial \alpha} \right]$$

Global Main VLF Transmitters

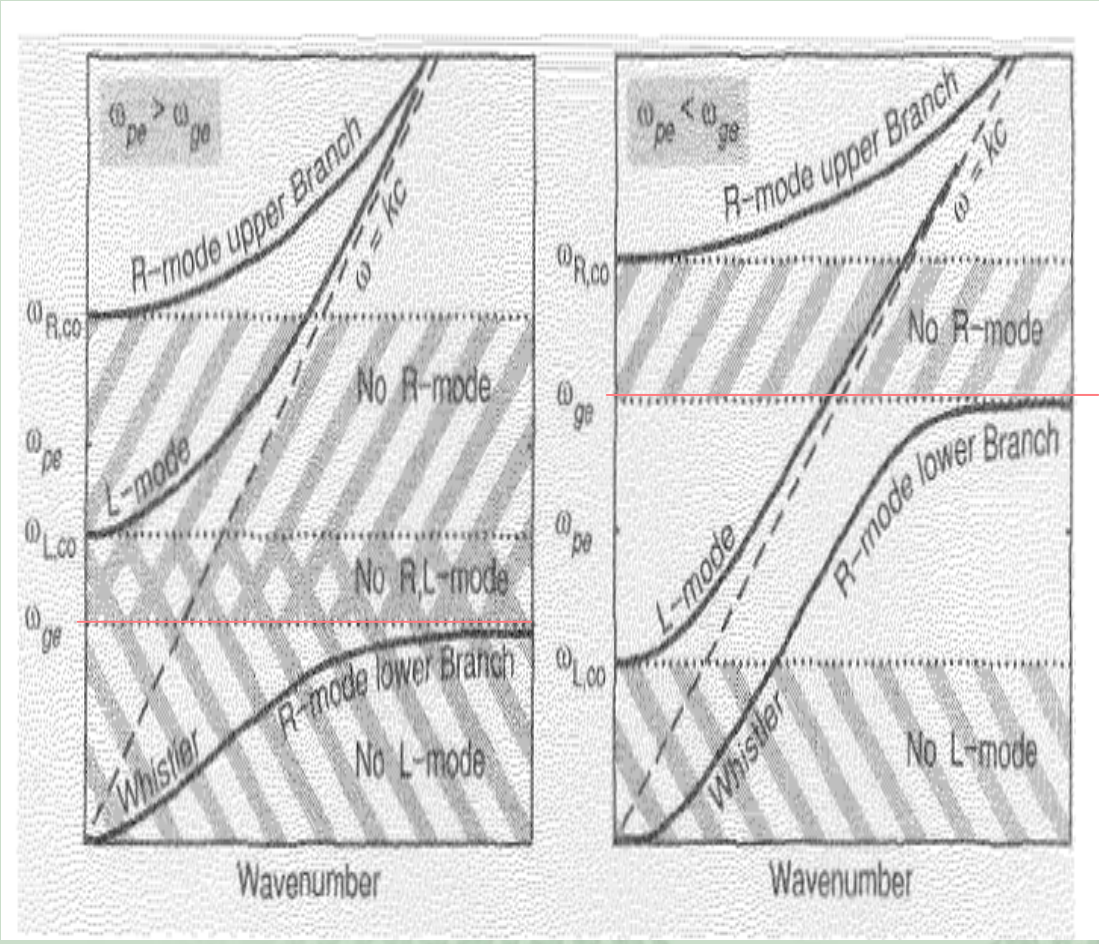


List of VLF Transmitters

Transmitter	Latitude (deg)	Power (kW)	Frequency (kHz)
NAA (Cutler, Maine)	54.6 N	1000	24.0
NLK (Jim Creek, Washington)	52.9 N	192	24.8
NAU (Aguadilla, Puerto Rico)	28.6 N	100	40.75
NPM (Lualualei, Hawaii)	21.4 N	424	21.4
NWC (N. W. Cape, Australia)	31.7 S	1000	19.8

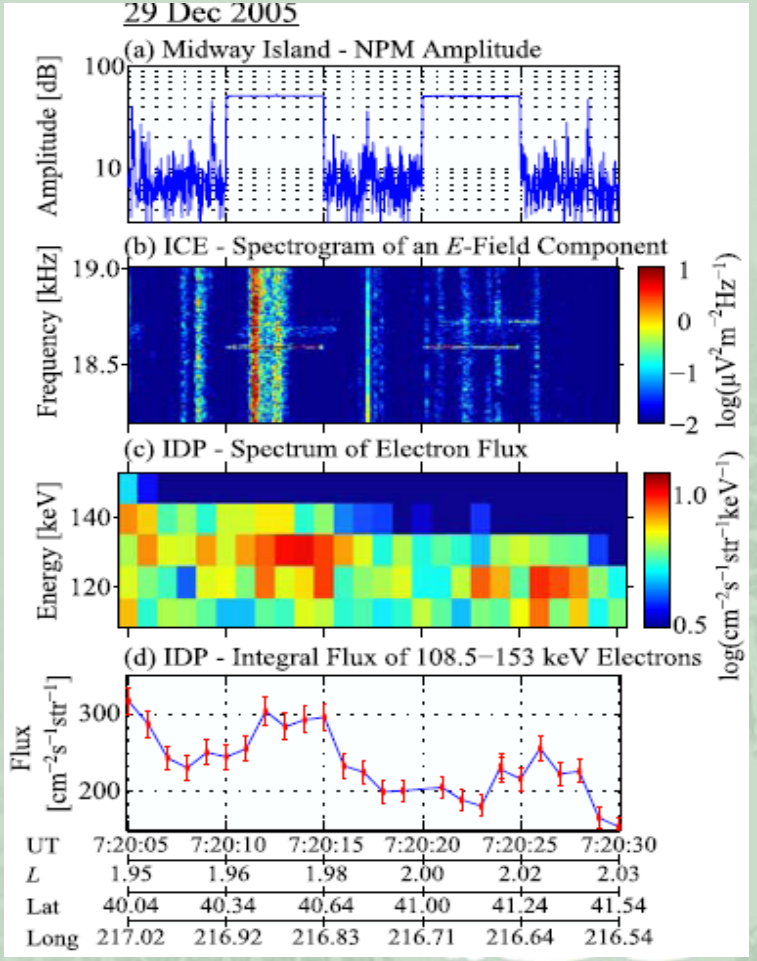
Dispersion Relation for Parallel Propagation

- For ground transmitters, VLF wave can propagate upward with field-aligned transverse R-mode, whose lower frequency band is whistler
- Pitch angle diffusion occurs when electrons encounter waves along the field line



NPM Experiment

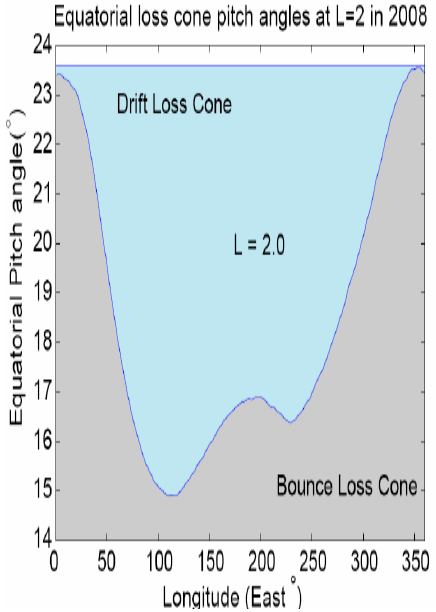
- NPM transmitted in a 5-sec ON/5-sec OFF format
- Two bursts of particle flux closely following NPM ON operation are observed near loss cone
- The center energy are approximately130 keV and120 keV, respectively
- No more than two bursts are observed



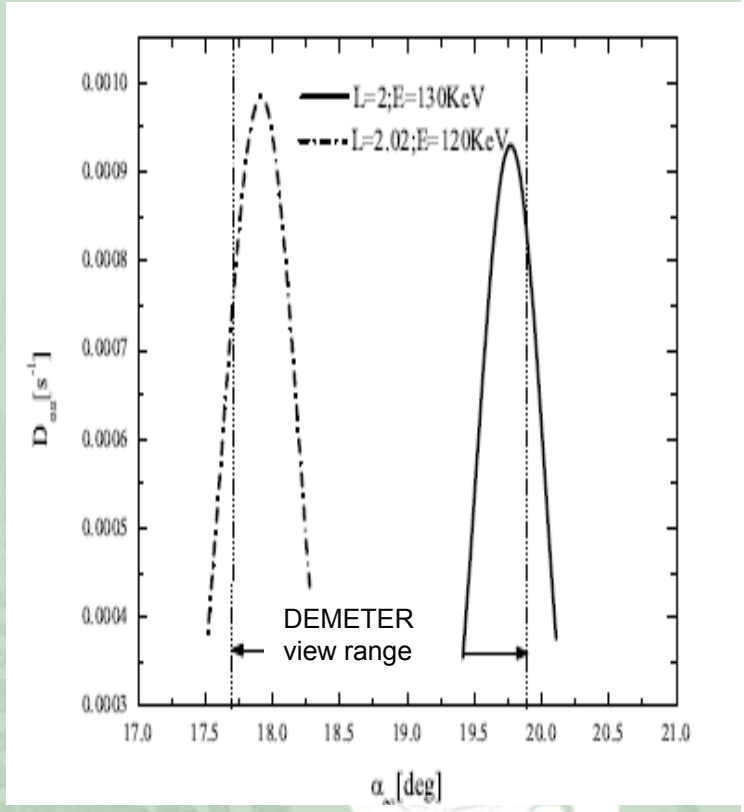
K. L. Graf et al., 2009

Pitch Angle Diffusion Rate for Electrons with increasing L

- Local and averaged diffusion rate for electron in this case have negligible difference
- Pitch angle diffusion occurs within or nearby IDP view range
- Generally, as satellite move to higher L, pitch angle diffusion happens more and more away from IDP view range.
- Because electrons pitch angle always firstly are scattered into neighborhood in diffusion process ,so the possible reason for no more than two bursts are observed is just because other diffusion occurs far more away from IDP view range

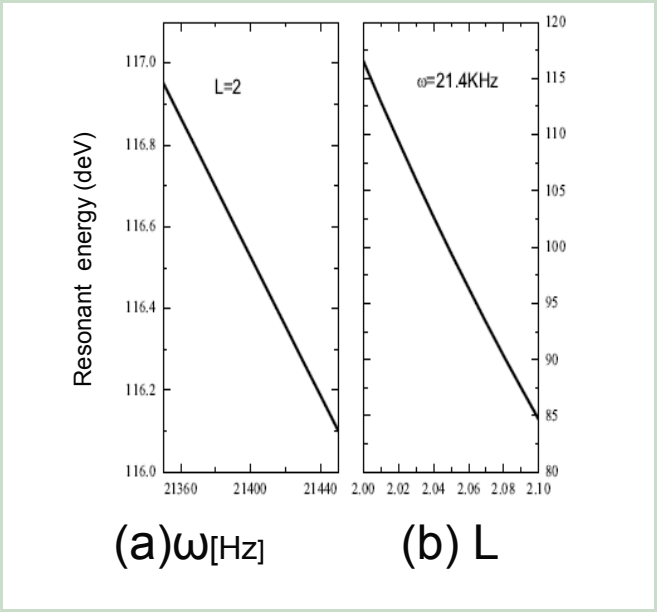


Local Diffusion Coefficient

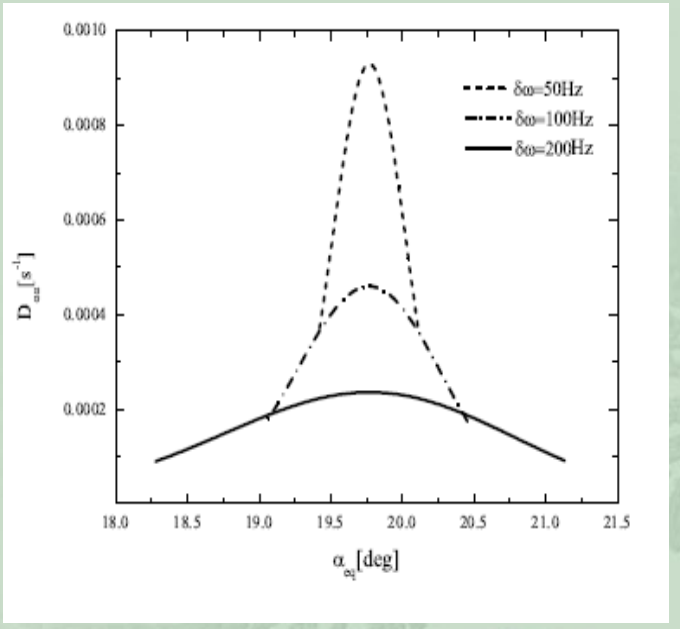


Electrons which fall into loss cone will precipitate during next bounce or drift period

Resonant Energy and Diffusion Coefficient for Different Parameters



Resonant energy for different wave frequency with fixed L (a) and for different L with fixed wave frequency (b)



Diffusion coefficients for different semibandwidth

Different Plasma Density Models

Although different plasma density models maybe give different diffusion coefficients, the previous statement that possible reason for no more than two bursts are observed is just because other diffusion occurs far more away from IDP view range is still exist

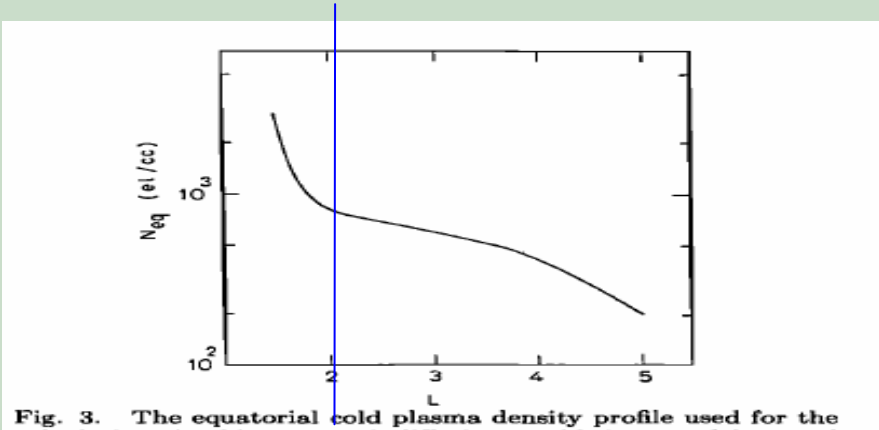
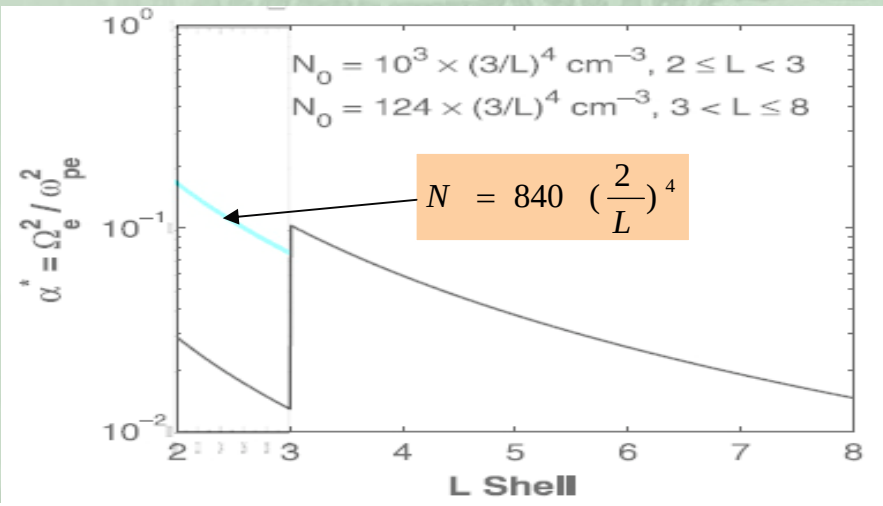


Fig. 3. The equatorial cold plasma density profile used for the calculations in this paper. A diffusive equilibrium model is used for the variation of the density along the field lines.

Inan,et.al.,1984



Conclusions and Further Discussion

Conclusions:

Pitch angle diffusion plays an essential role in inner radiation belt electrons precipitation and loss, from which we present a possible reason to explain two electron correlated bursts structure, however this can not account for why so few two correlated bursts happen. Further study is still needed.

	Number of Occurrences in Precipitation Region	Number of Occurrences in Conjugate Region
2 Correlated bursts	3	2
1 Correlated burst	9	13
No bursts detected	73	82
1 Uncorrelated burst	5	6
2 Uncorrelated bursts	1	0
Total number of passes	91	103

K. L. Graf et al., 2009

Further Discussion

Since pitch angle diffusion plays so important role in process of electron precipitation and loss, pitch angle measurement became more and more important. In order to observe more phenomena of electron precipitation more large view range detector is needed. Beside that another factor decide the range of pitch angle measurement is the choice of place where particle detector is fixed relative to satellite.

Different Placement for Different Mission

DEMETER	perpendicular
ELEKTRON	perpendicular
ARINA	perpendicular
GAMMA	zenith
NINA	zenith
SAMPEX	zenith
NOAA	zenith

For an imaginary example

Satellite parameter: 97 °inclination orbit
500km altitude
Detector parameter: ±37° View range

◆We list the figures according to different Geo-latitude and Geo-longitude.

◆Different symbols in each figure represent the value of the angle θ between detector and Earth's local magnetic field.

◆The range of pitch angle viewed by detector is represented by error bar $\theta \pm 37^0$

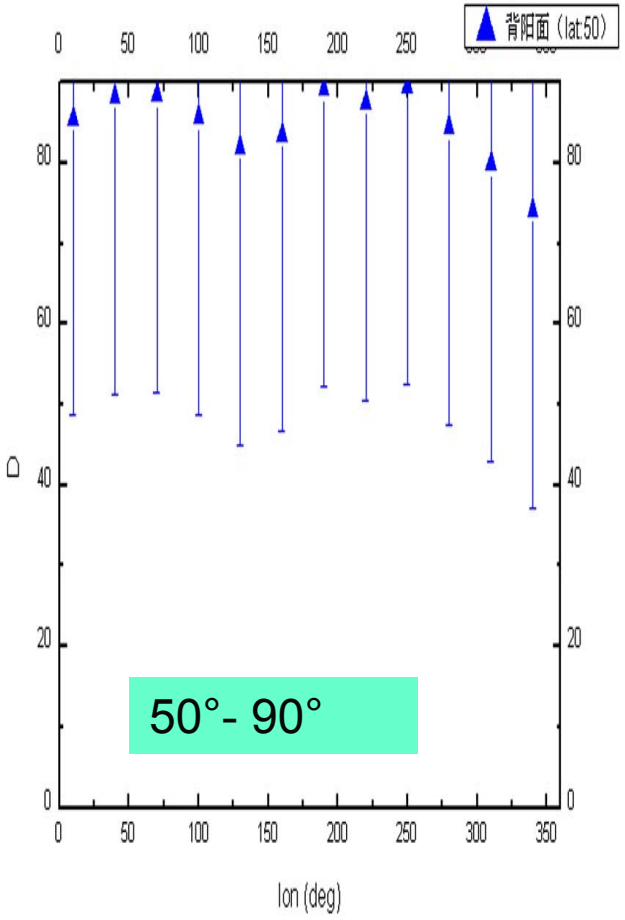
Note: Opposite direction has the same pitch angle measurement

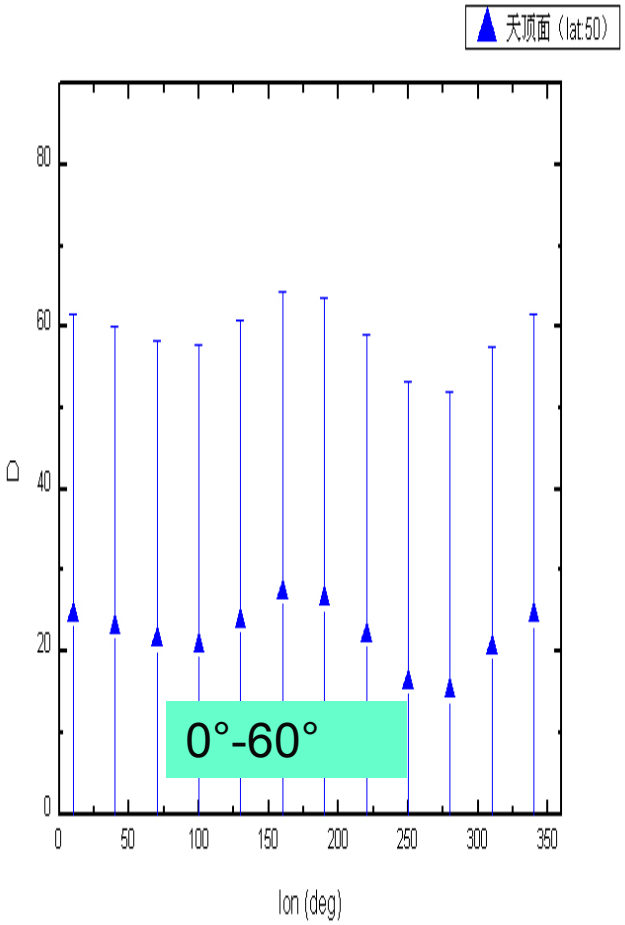
Compare for Different Situation-Latitude=50°

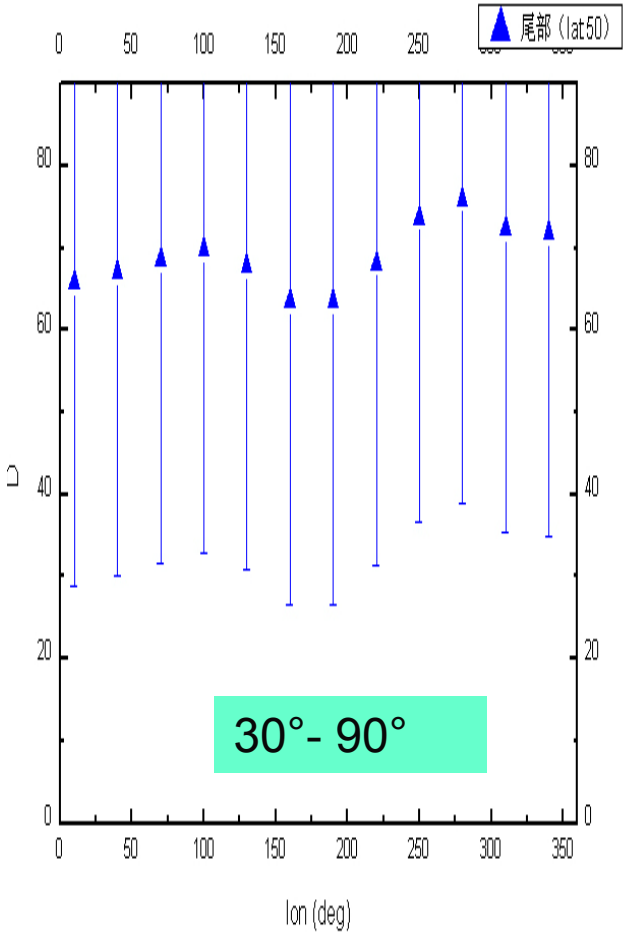
Perpendicular

Zenith

Rear





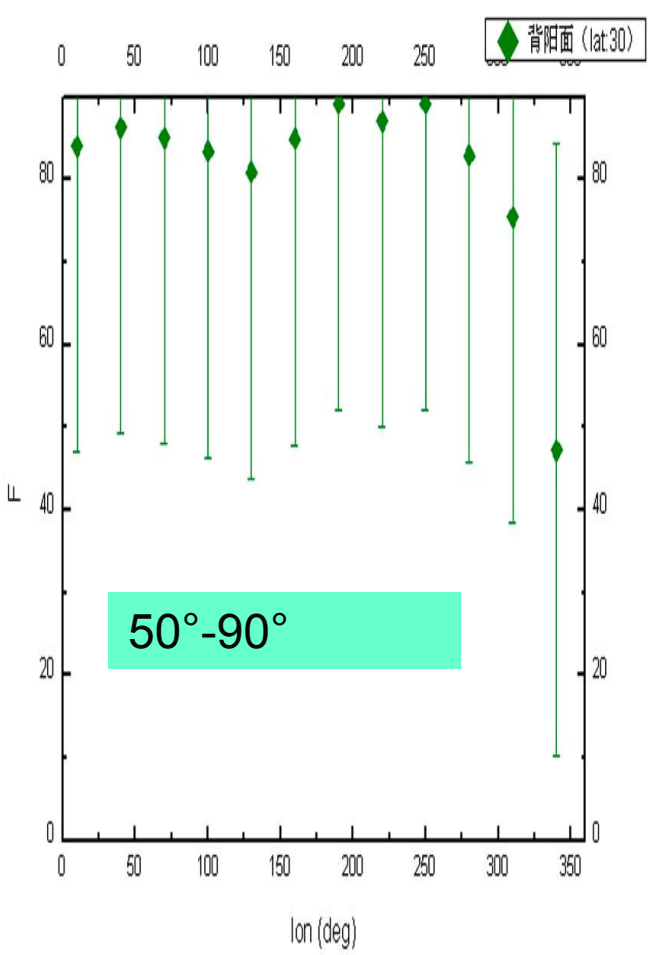


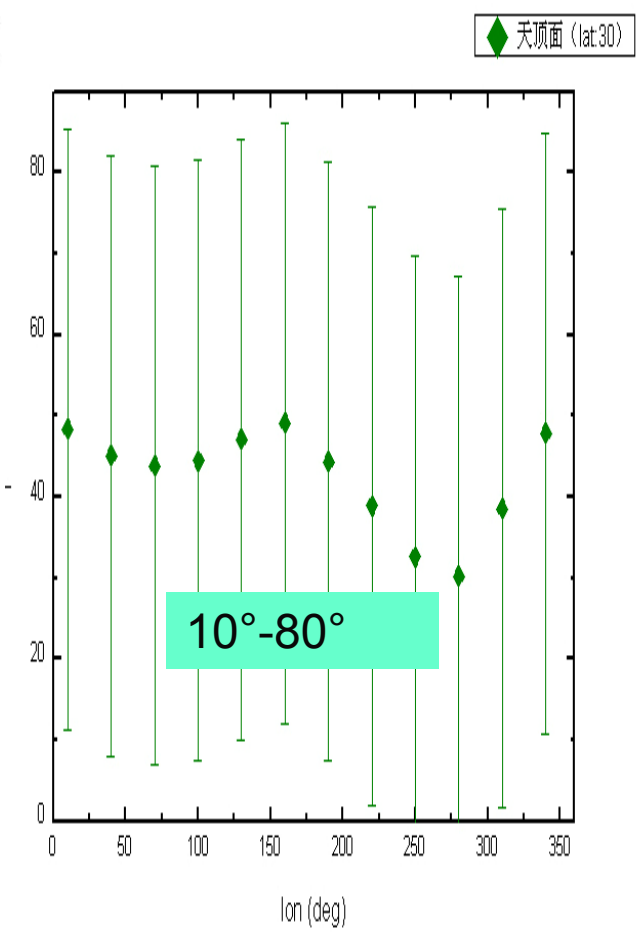
Compare for Different Situation-Latitude=30°

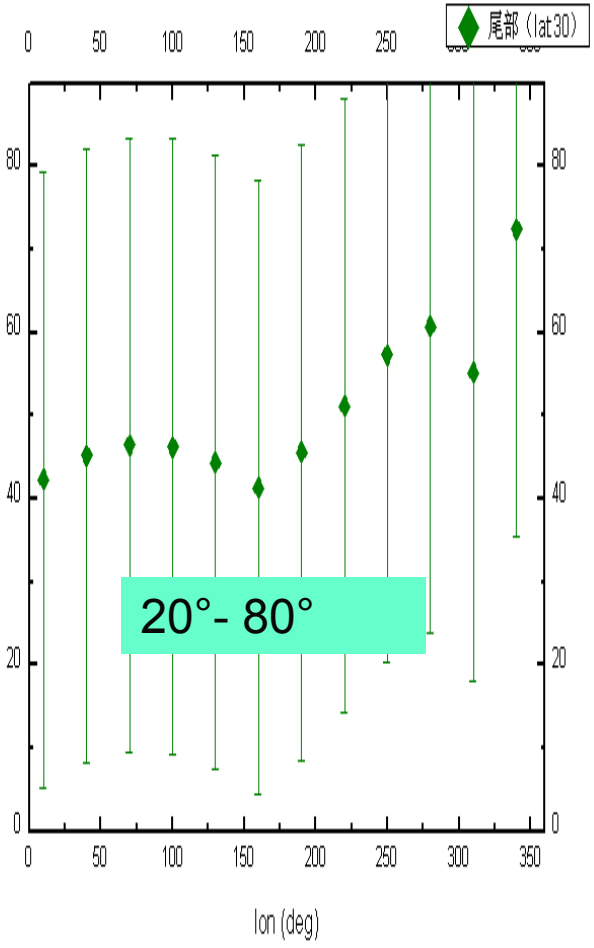
Perpendicular

Zenith

Rear





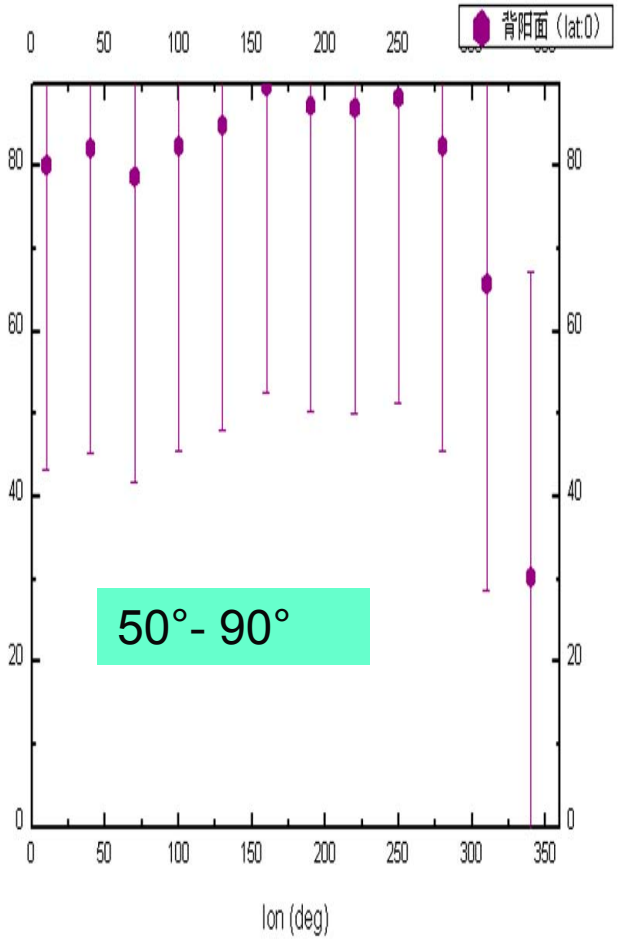


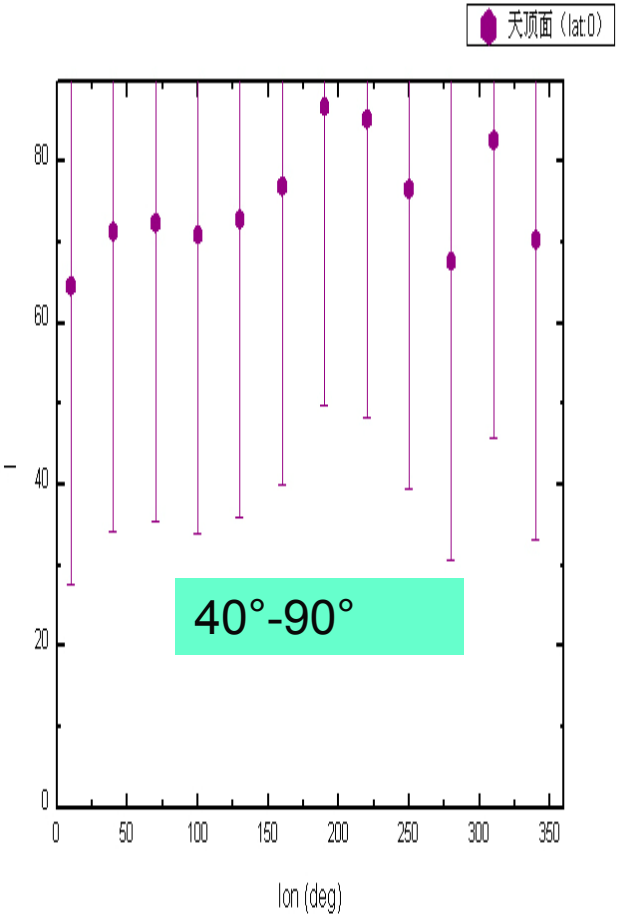
Compare for Different Situation- Latitude=0°

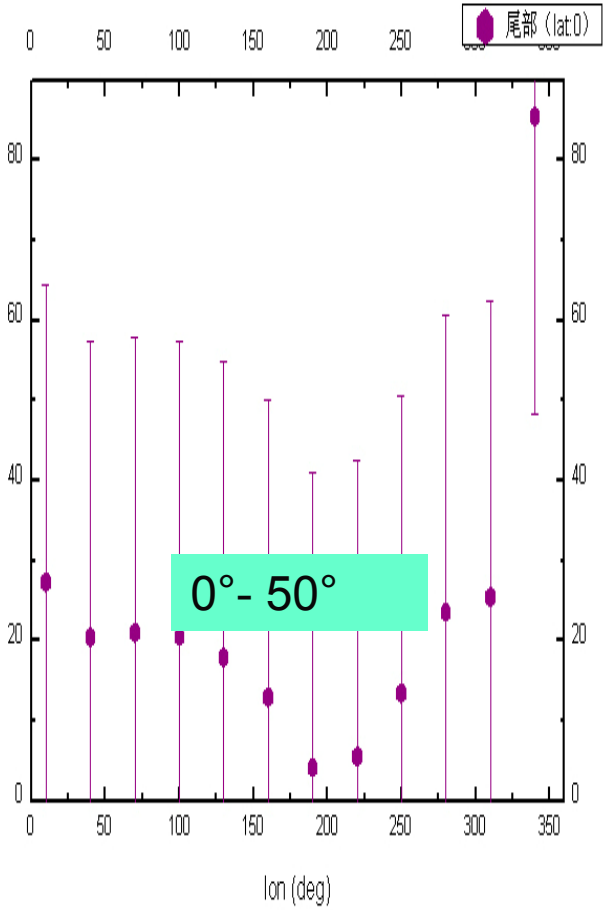
Perpendicular

Zenith

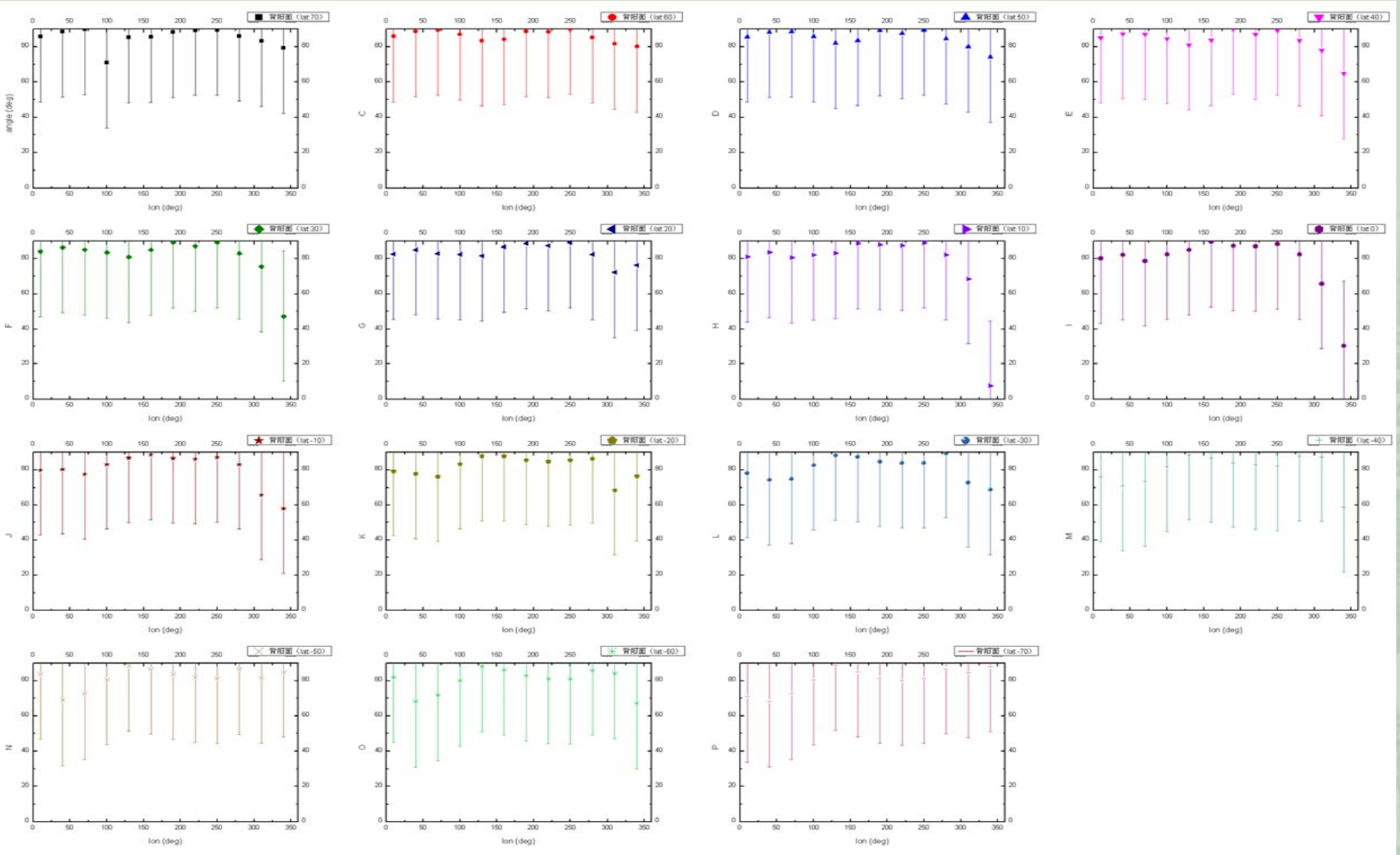
Rear



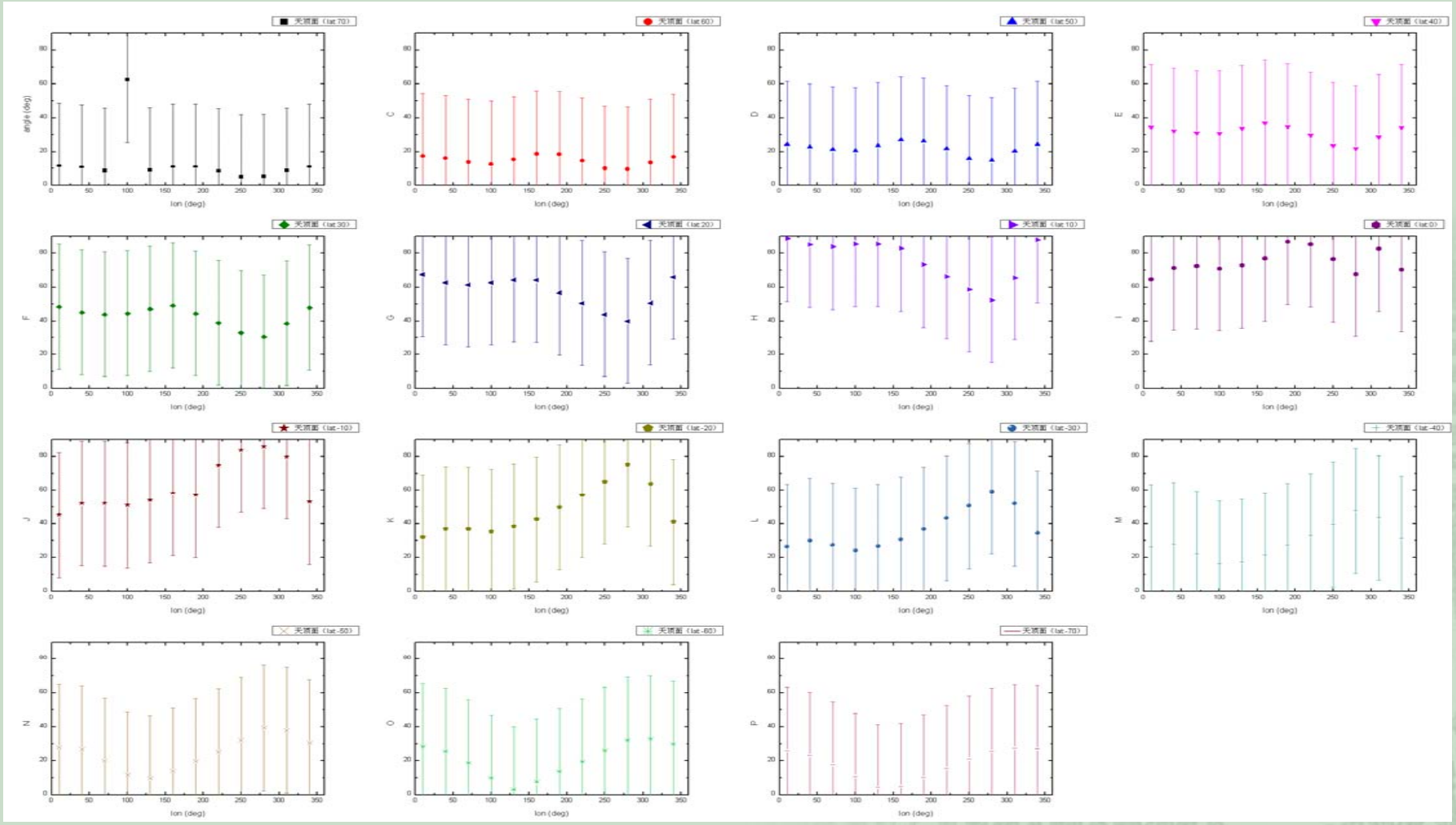




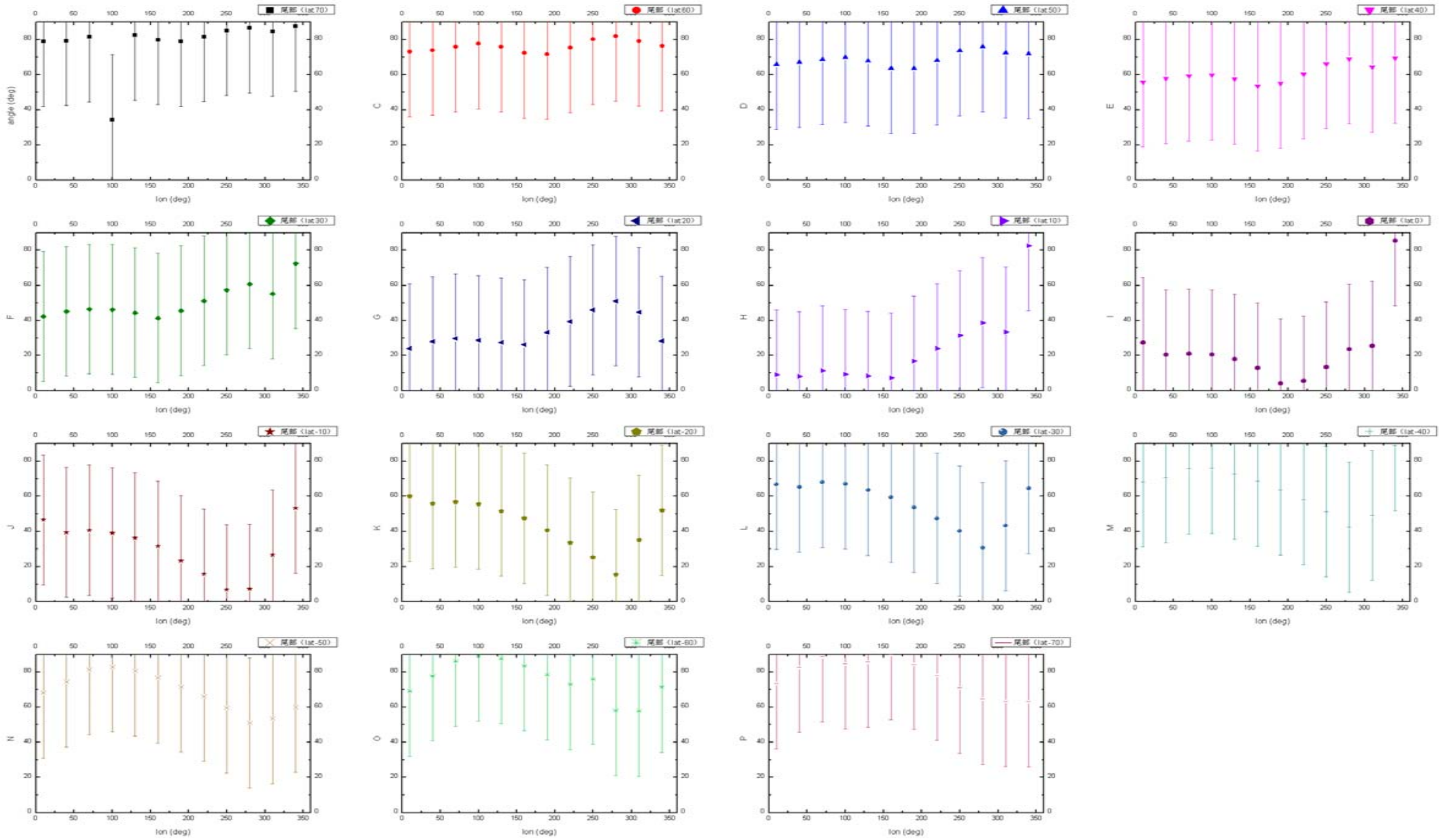
Perpendicular(like IDP)



Zenith


天顶面（lat 70）
天顶面（lat 60）
天顶面（lat 50）
天顶面（lat 40）
天顶面（lat 30）
天顶面（lat 20）
天顶面（lat 10）
天顶面（lat 0）
天顶面（lat -10）
天顶面（lat -20）
天顶面（lat -30）
天顶面（lat -40）
天顶面（lat -50）
天顶面（lat -60）
天顶面（lat -70）
angle (deg)
lon (deg)

Rear



尾部（lat70）
尾部（lat60）
尾部（lat50）
尾部（lat40）
尾部（lat30）
尾部（lat20）
尾部（lat10）
尾部（lat0）
尾部（lat-10）
尾部（lat-20）
尾部（lat-30）
尾部（lat-40）
尾部（lat-50）
尾部（lat-60）
尾部（lat-70）
angle (deg)
lon (deg)
C
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Further Discussion

If only consider pitch angle measurement, is rear a better choice?

Thank you!