Relationship between amplitude of geomagnetic sudden commencement and solar wind dynamic pressure variation

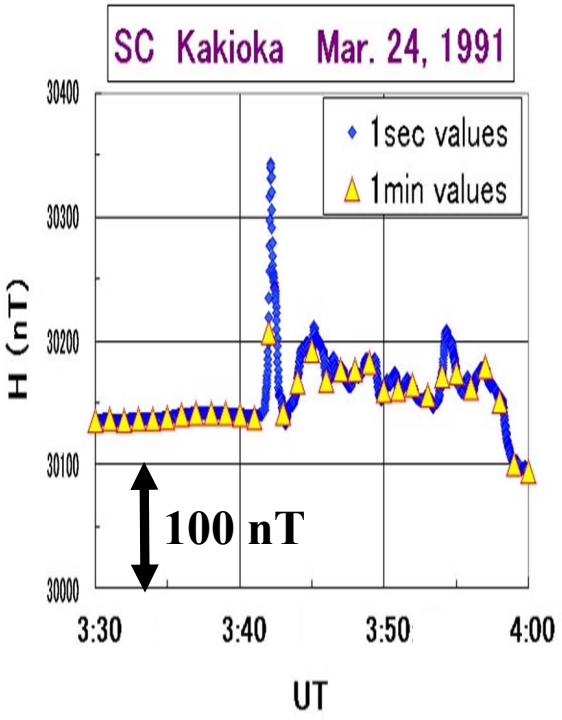
Tohru Araki

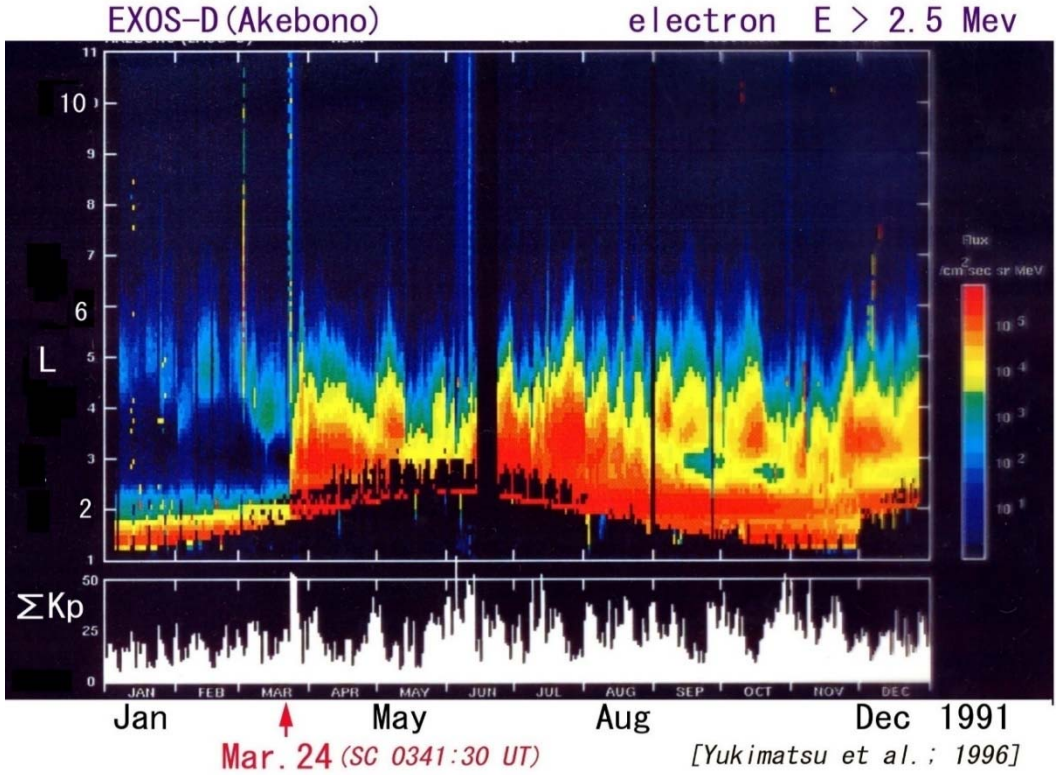
「太陽地球環境データ解析に基づく超高層大気の空間・時間変動の解明」 2015.2.19-20　京大理セミナーハウス

Historically largest geomagnetic sudden commencement (SC) since 1868

T. Araki

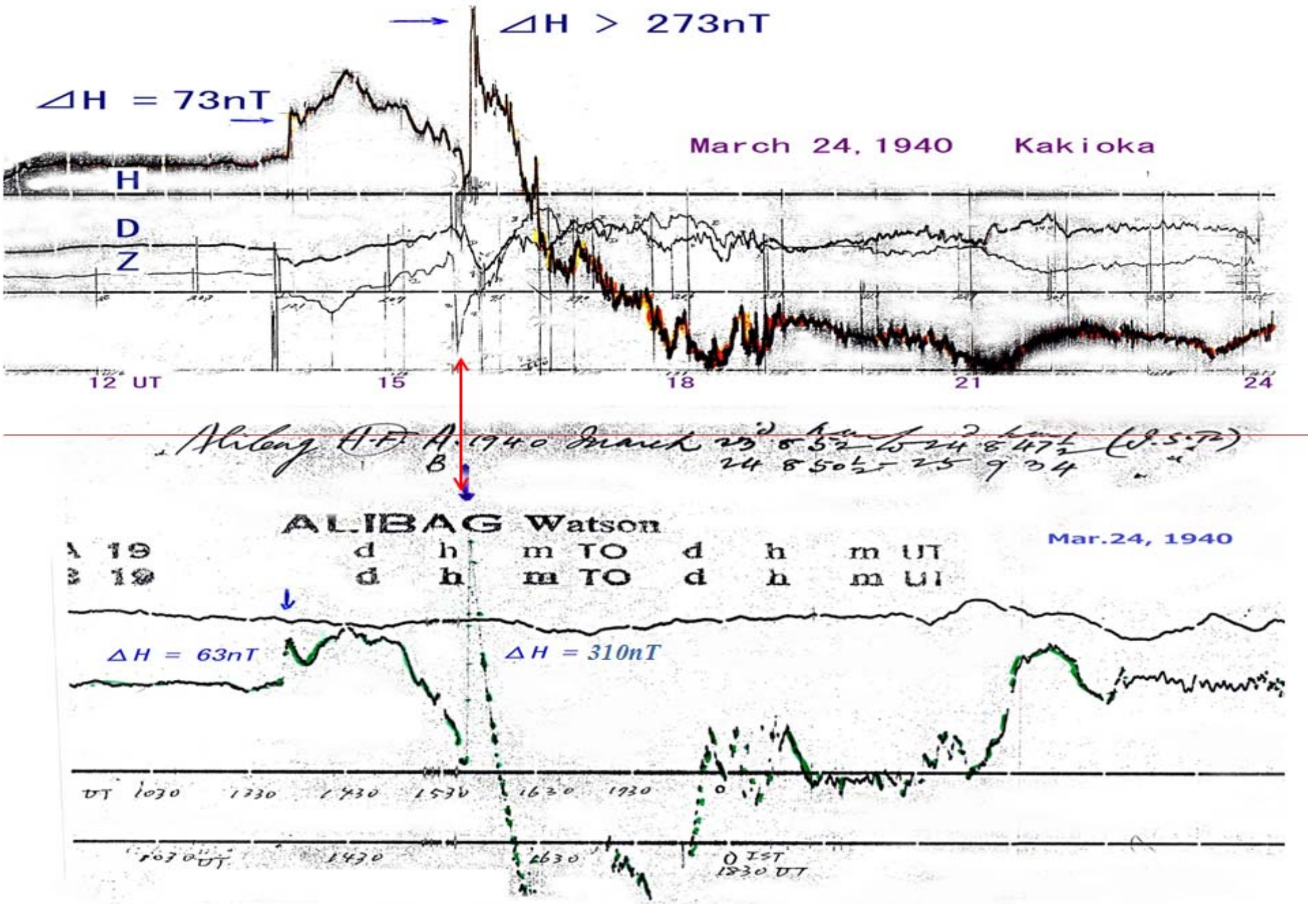
Earth, Planets and Space, 66, 2014





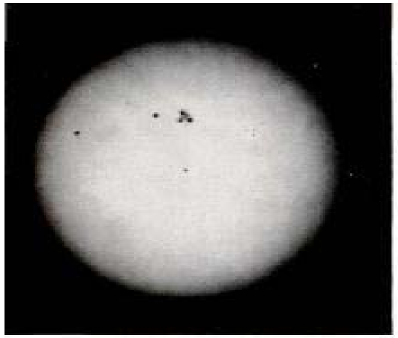
ΔH (amplitude) = 202 nT
ΔT (rise time) = 28 sec
ΔTw (pulse width) = 88 sec

How large is the largest SC?


⊿H > 273nT
⊿H = 73nT
March 24, 1940 Kakioka
H
D
Z
12 UT
15
18
21
24
ALIBAG Watson
Mar.24, 1940
⊿H = 63nT
⊿H = 310nT
UT 1030 1330 1430 1530 1630 1930
1430
1630
0 IST
1830 UT

LIFE

Space Weather Event (1940.3.25)



SUNSPOTS GREW TO THIS SIZE BY MARCH 25

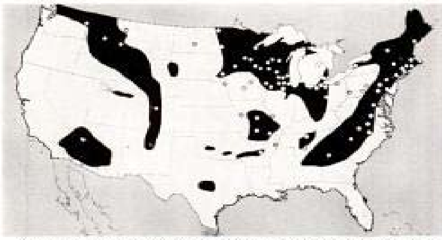
MARCH 26. SPOTS MOVE SLOWLY ACROSS THE SUN'S FACE

MARCH 27. BIGGEST GROUP IS 33,000 MILES ACROSS

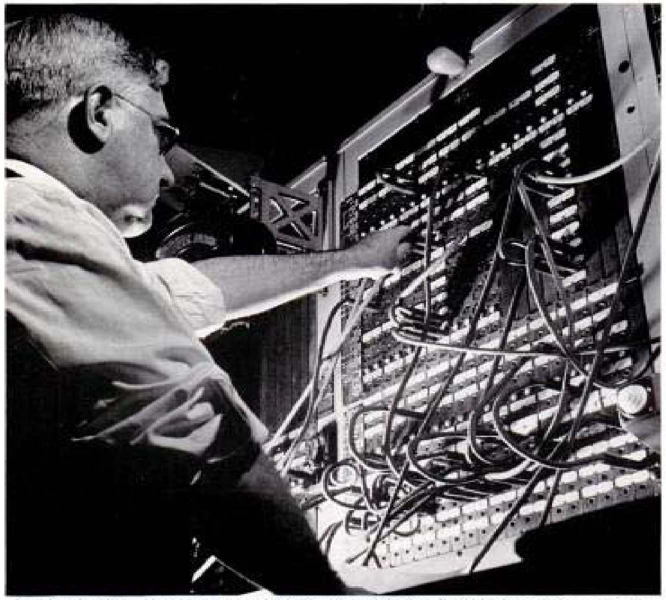
SPOTS ON THE FACE OF THE SUN MESS UP EARTH'S COMMUNICATIONS

Last week the earth's magnetic field had a bad attack of spring fever. Well-behaved landlines of A. T. and T. turned taciturn. The ionosphere, the super-stratospheric layer of the earth's atmosphere, which radio companies use for a cushion to bounce their signals like billiard balls across the ocean, suddenly went porous. Wirephotos showed black streaks and teletype machines went to work on their own to click off analphabetic rhapsodies like the one below.

Moving across the face of the sun could be seen the villains of the piece—a series of sunspots, volcanic whirlwinds of gas which so upset the earth's magnetic field that forces as high as 790 volts were induced in power and communications lines. Counting up at the end of the week, the world found a debit that no one cared to estimate in disrupted communications and fused wires. On the credit side were several spectacular displays of northern lights.



MAP OF U. S. AREAS WHERE "EARTH CURRENTS" WERE STRONGEST



WESTERN UNION SET UP EMERGENCY CIRCUITS TO RE-ROUTE MESSAGES AS REGULAR LINES WENT DEAD

AT THE HEIGHT OF THE MAGNETIC STORM, TELETYPE AND OTHER AUTOMATIC TELEGRAPH MACHINES WENT HAYWIRE, PRINTED OUT MESSAGES LIKE THIS ON THEIR OWN HOOK

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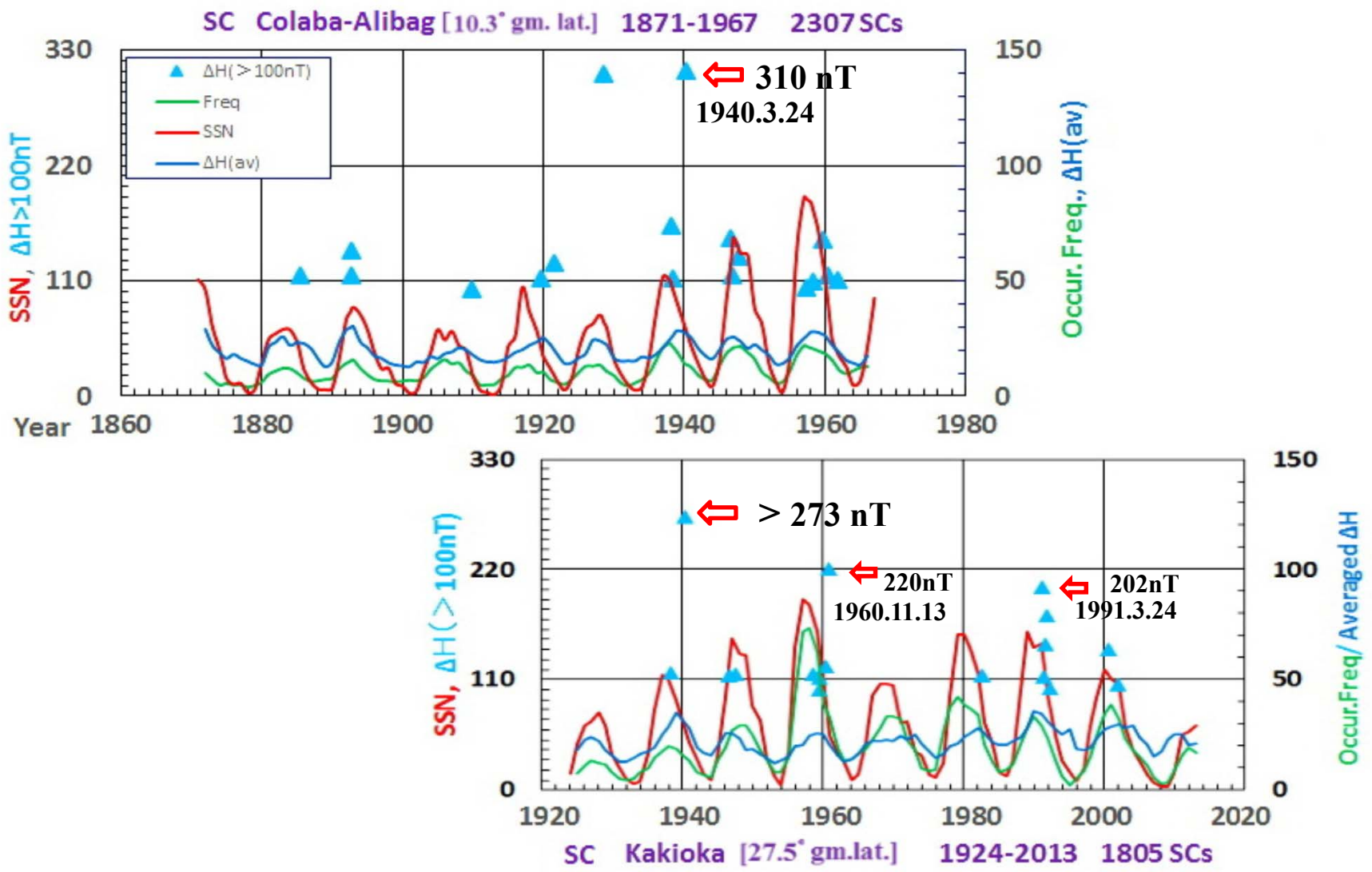
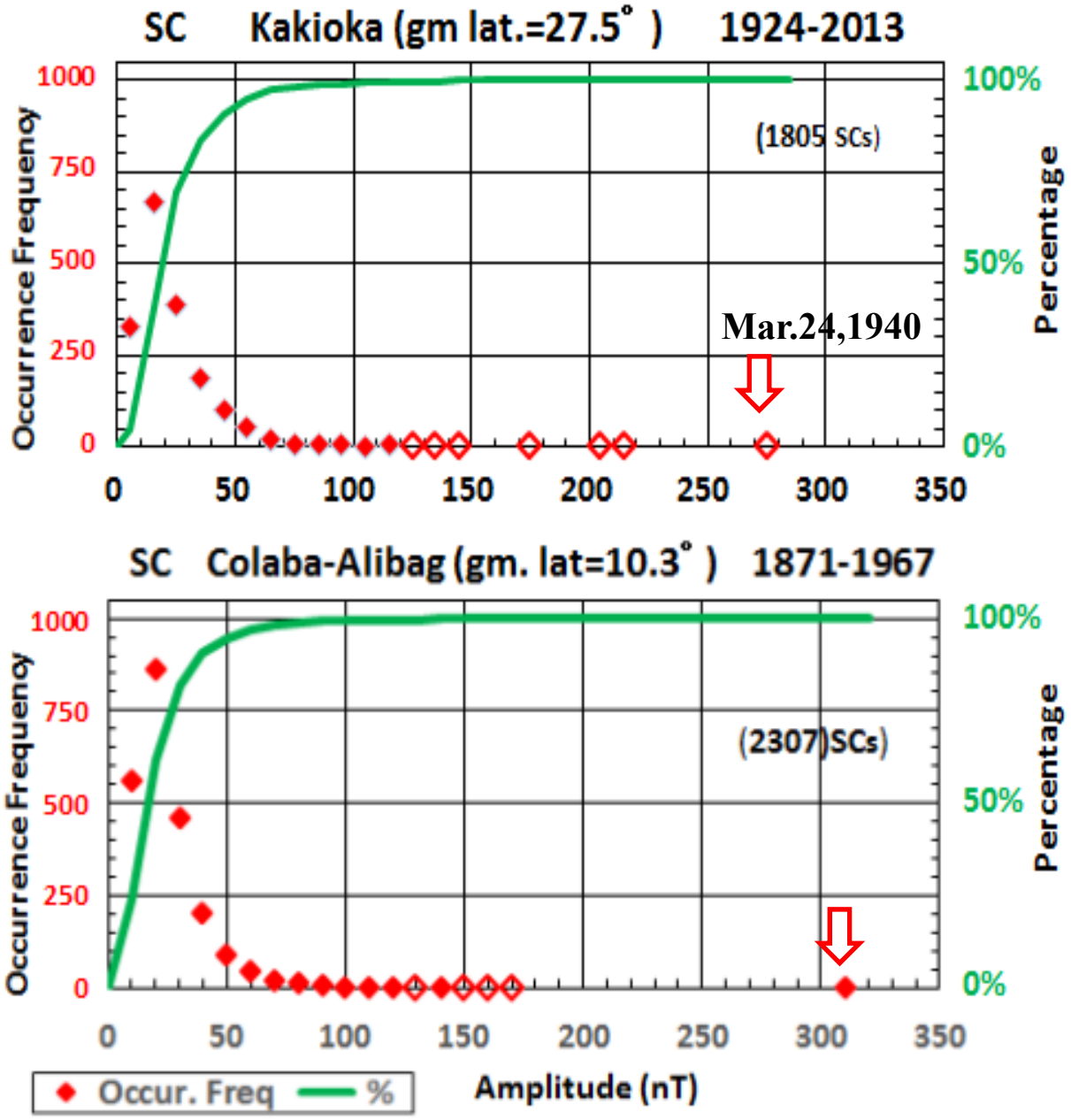
IAGA Bulletin No.33, 1973 **Mayaud, P.N., A hundred year series of geomagnetic data** 1868-1967

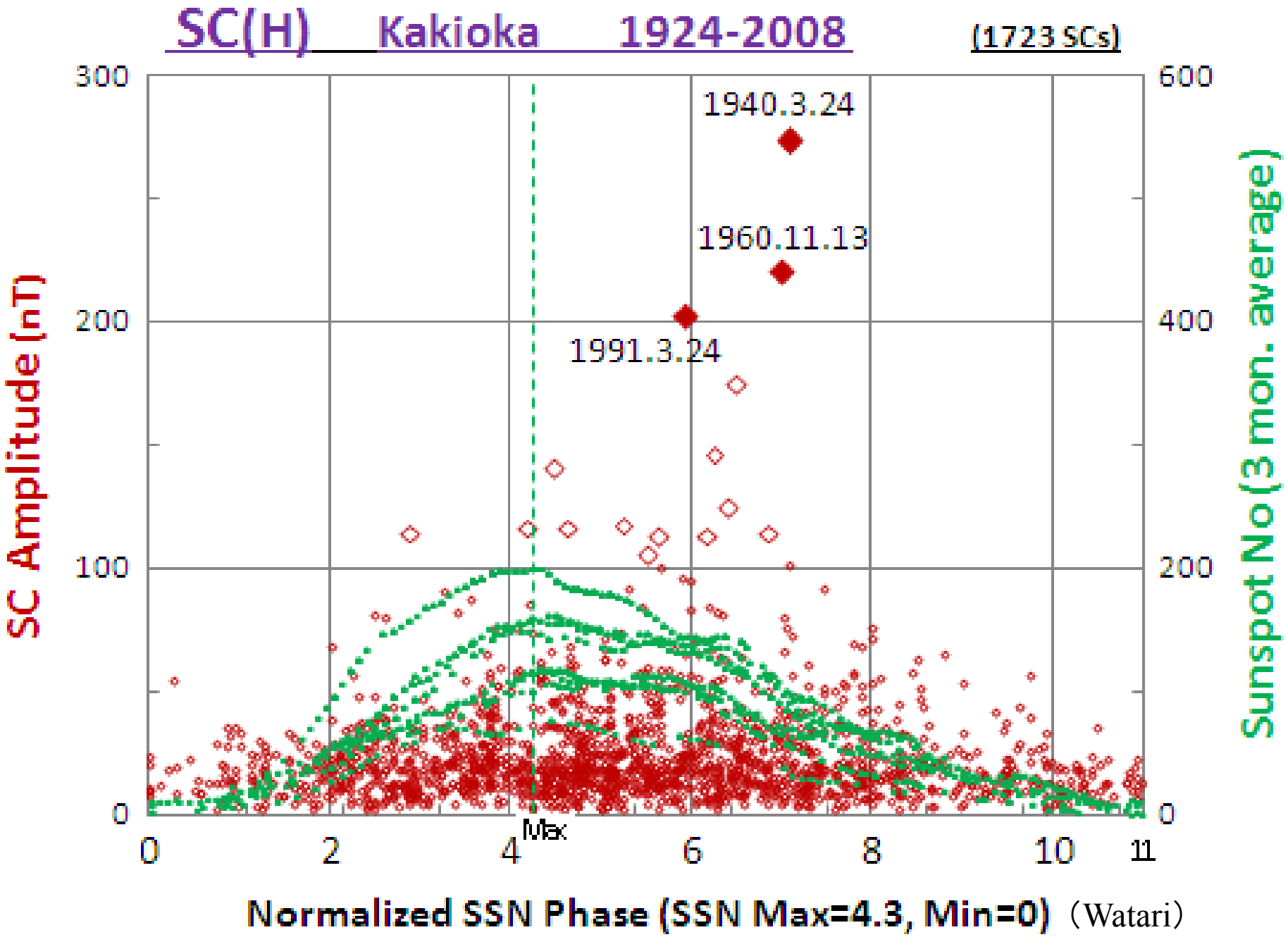


List of Geomag. Storm, Kaioka 1924-2014



ΔH > 50nT
less than 5%

ΔH > 100nT
less than 1%


SC(H) Kakioka 1924-2008
(1723 SCs)
1940.3.24
1960.11.13
1991.3.24
SC Amplitude (nT)
Sunspot No (3 mon. average)
Max
Normalized SSN Phase (SSN Max=4.3, Min=0) (Watari)

$$\Delta H = \alpha \cdot \Delta (P_d)^{0.5} = f \cdot a \cdot k \cdot [(P_{d2})^{0.5} - (P_{d1})^{0.5}]$$

f : induction effect of the earth (1.5)
a : solar wind-magnetosphere interaction (1-2)
k : experimentally determined linear coefficient

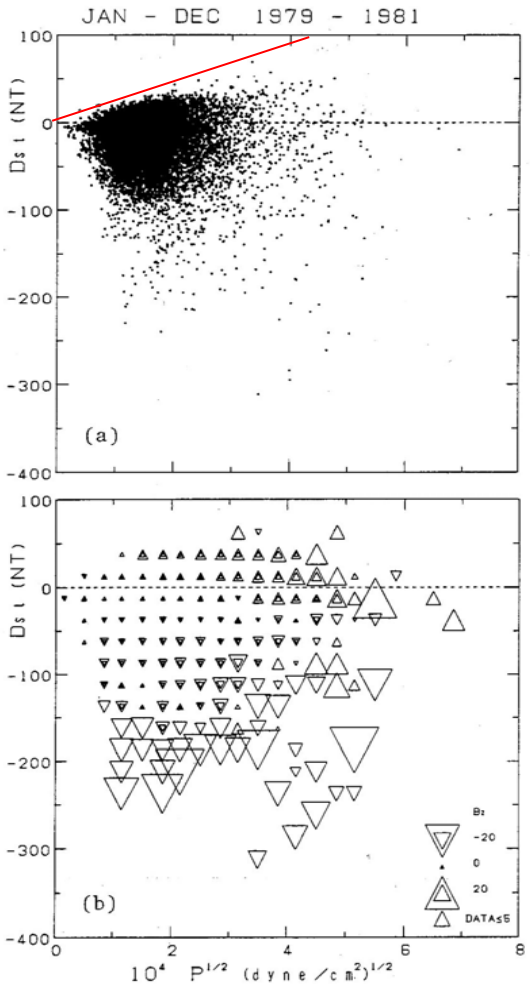
[Siscoe et al, 1968]

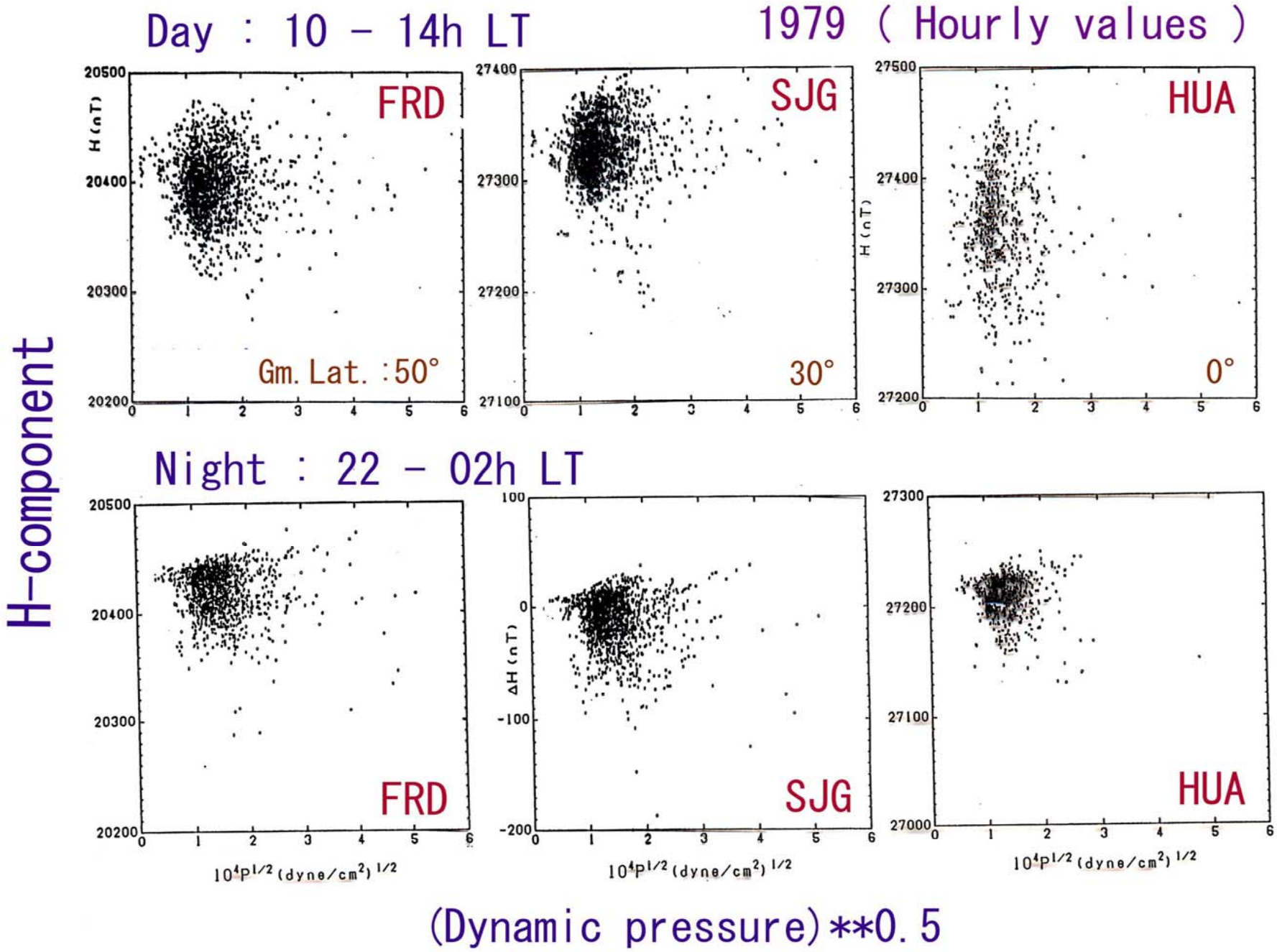
$$\alpha = f \cdot a \cdot k = 1.5k \sim 15$$

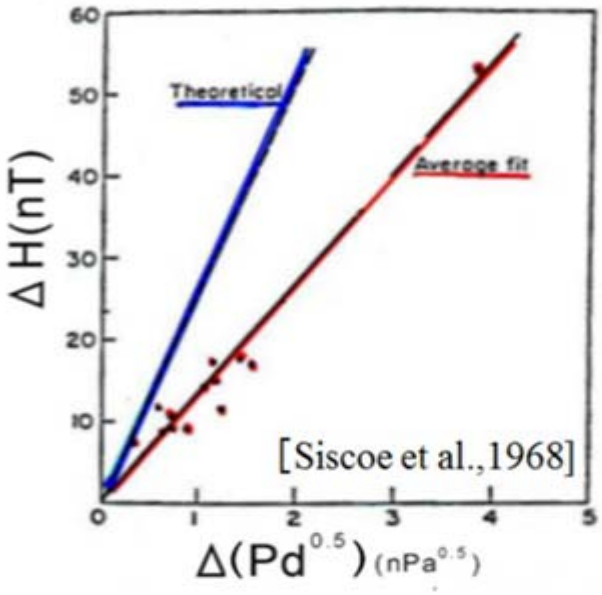
Table 1 Values of k [$\times 10^4 nT/dyne^{0.5}/cm$]

Present analysis [Araki et al., 1993]				
D_{st}	:1979-81			11.8
nighttime (22-02LT) H				
Fredericksburg	:1979-80			11.6
San Juan	:1979-81			10.7
Memambetsu	:1979-81			11.1
Past Analyses				
Mead	[1964]	theory(elastic interaction)		17.4
Siscoe et al.	[1968]	13 SIs		9.0 ± 2.0
		12 quiet days nighttime average		8.9 ± 2.9
Ogilvie et al.	[1968]	9 SCs		11.4 ± 1.5
Verzariu et al.	[1972]	19 hourly D_{st}		18.4
Su and Konradi	[1975]	36 hourly D_{st}		22.6
Burton et al.	[1975]	3 SCs		10.5
Smith et al.	[1986]	22 SCs		14
Lepping et al.	[1987]	9 SCs		8.5
Russell et al.	[1992]	18 SIs at 4 stations	average	11.0
			noon	12.0
			midnight	8.0

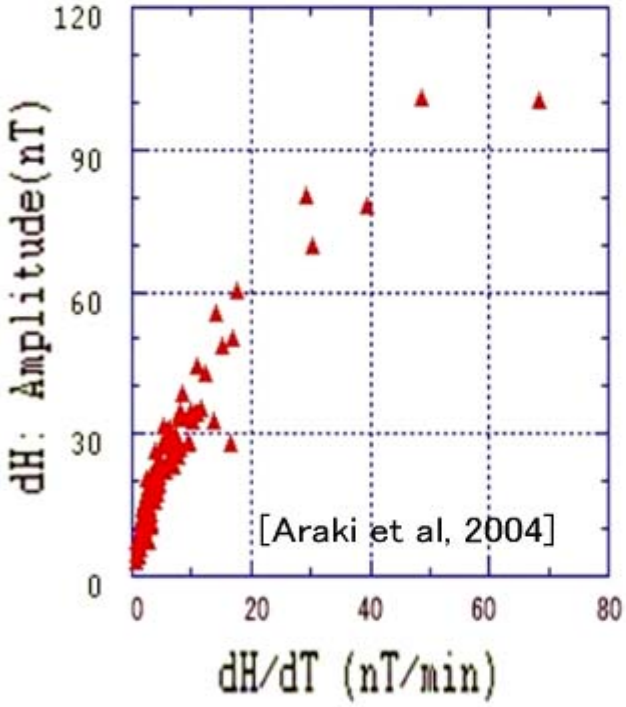
[Araki et al.; 1993]




Day : 10 - 14h LT
1979 (Hourly values)
FRD
SJG
HUA
Gm.Lat.:50°
30°
0°
H(nT)
Night : 22 - 02h LT
ΔH(nT)
H-component
10⁴P^1/2 (dyne/cm²)^1/2
(Dynamic pressure)**0.5



SC Guam 20-04h LT 1957-1975



$$\Delta H_{SC} = \alpha\, \Delta(P_d^{0.5}) \qquad \alpha = k f \sigma$$

k: proportionality constant

f: solar wind-magnetosphere interaction ($f=1$)

σ: effect of currents induced in the Earth ($\sigma = 1.5$)

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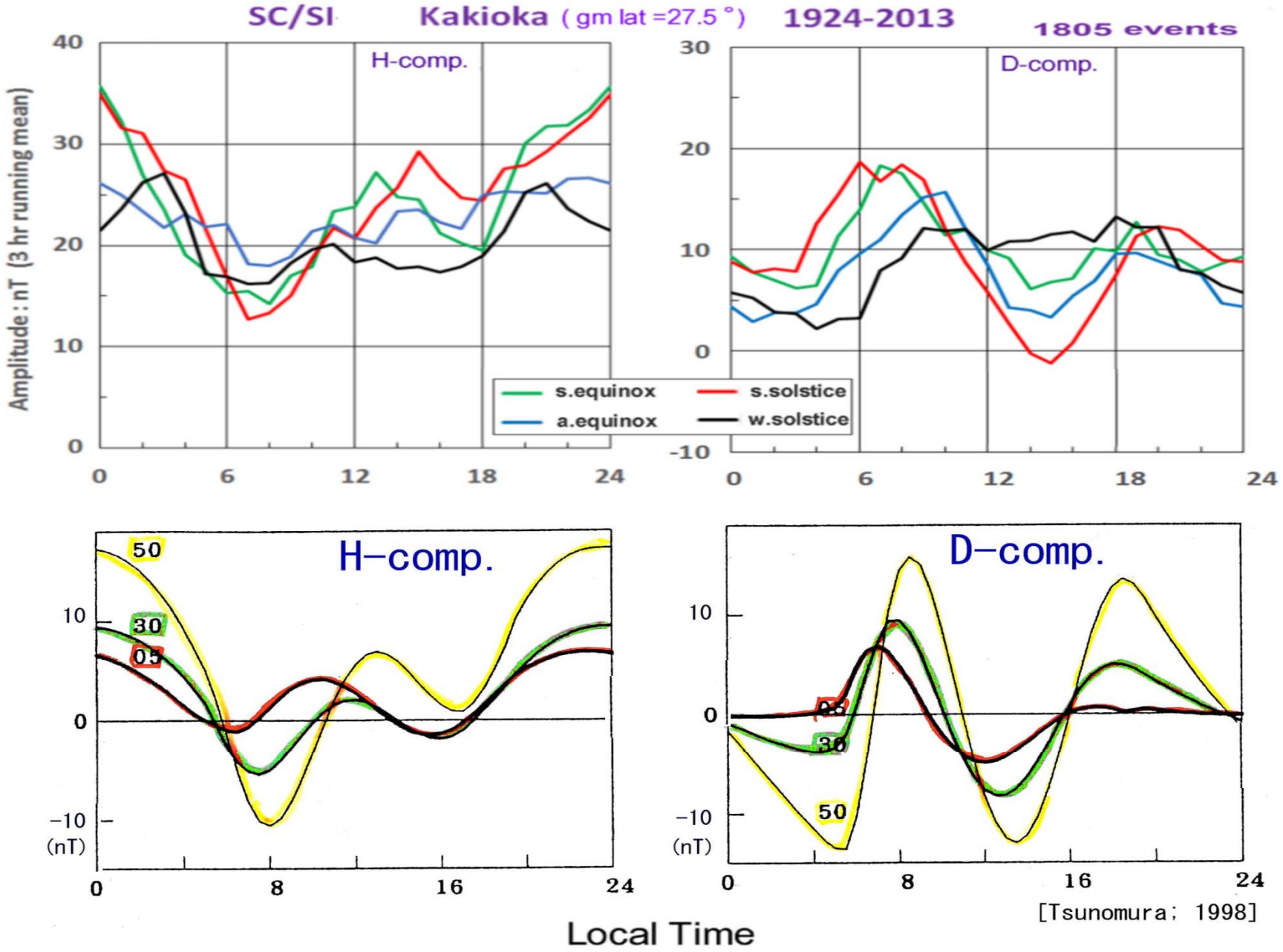
if $Pd1 = 2$ nPa and $\Delta H = 300$ nT,

$\alpha = 10 \rightarrow Pd2 = 985$ nPa

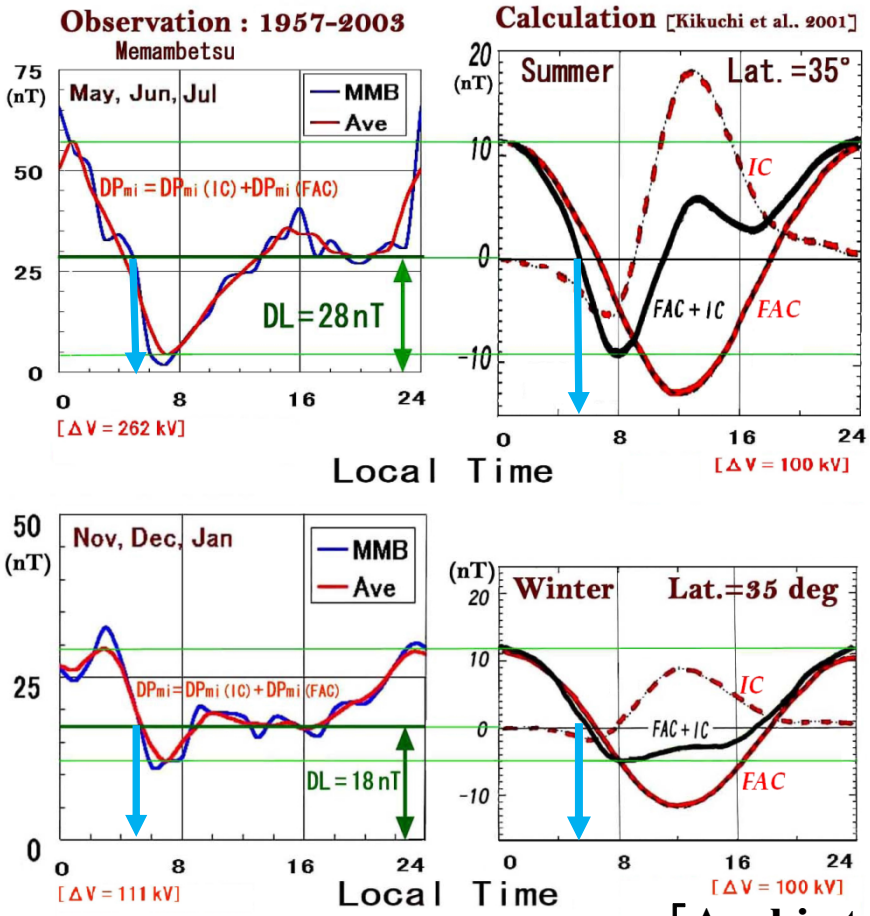
$\alpha = 15 \rightarrow Pd2 = 458$ nPa

$\alpha = 20 \rightarrow Pd2 = 269$ nPa

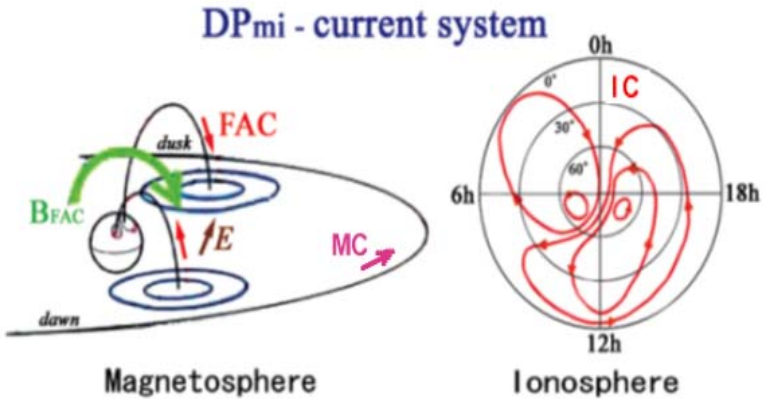
Non-linear effect → larger Pd2
Induction current effect
→ smaller Pd2
(large amplitude SC → short rise time
→ high time variation rate
→ large induction current)


SC/SI
Kakioka (gm lat =27.5 °)
1924-2013
1805 events
H-comp.
D-comp.
Amplitude : nT (3 hr running mean)
s.equinox
s.solstice
a.equinox
w.solstice
H−comp.
D−comp.
50
30
05
(nT)
Local Time
[Tsunomura; 1998]

LT Variation of SC Amplitude (H-comp.)



[Araki et al., 2009]



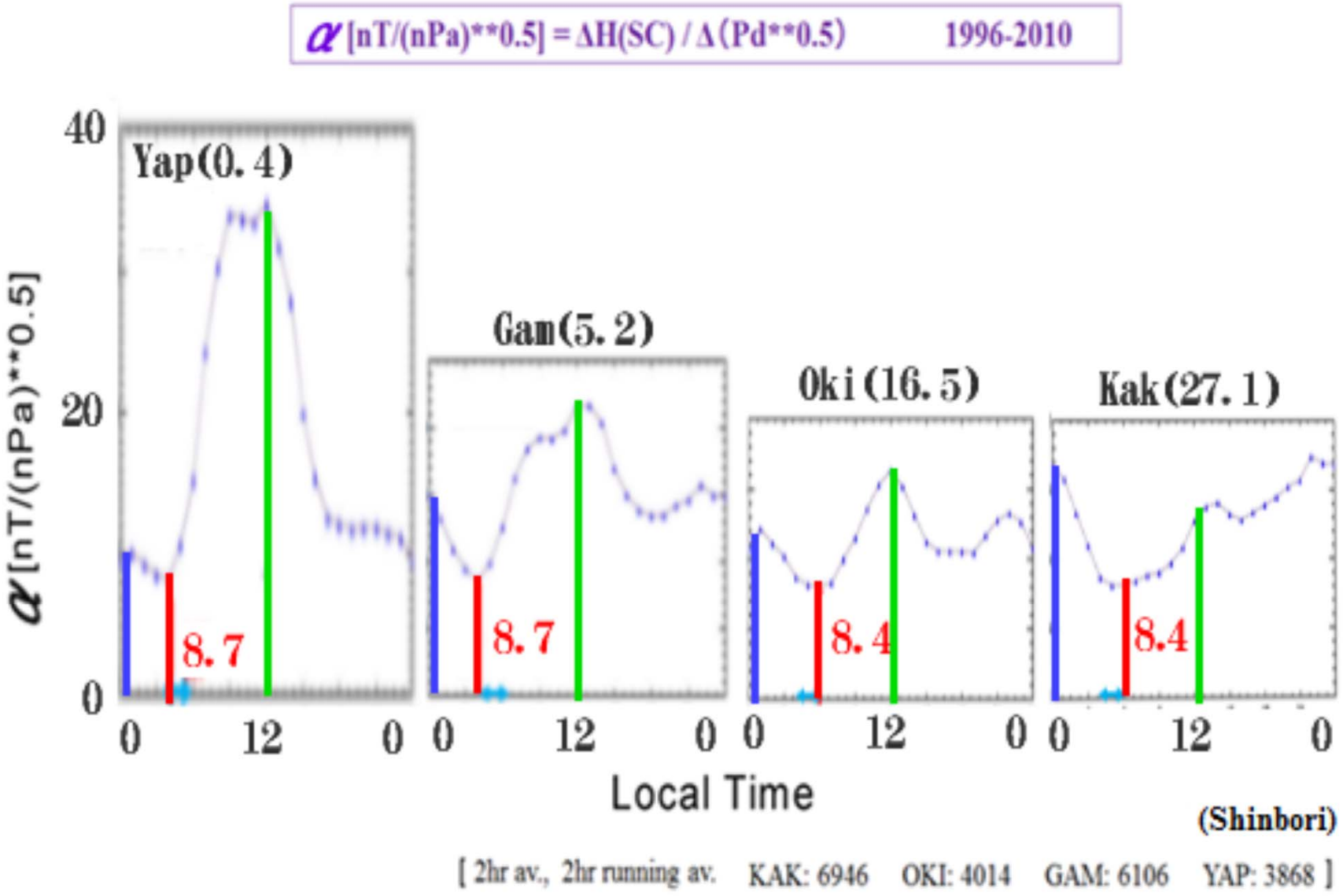
[large seasonal/LT variation]

$$Dmi = DL(MC) + DPmi(FAC) + DPmi(IC)$$

$$\Downarrow$$

$$0$$

4h - 6h LT


α [nT/(nPa)**0.5] = ΔH(SC) / Δ(Pd**0.5) 1996-2010
Yap(0.4)
Gam(5.2)
Oki(16.5)
Kak(27.1)
8.7
8.7
8.4
8.4
α [nT/(nPa)**0.5]
40
20
0
0
12
0
Local Time
(Shinbori)
[2hr av., 2hr running av. KAK: 6946 OKI: 4014 GAM: 6106 YAP: 3868]

Normalized amplitude at 6h LT

40.3.24

ΔH>273nT

↓

163nT

91.3.24

ΔH=202nT

↓

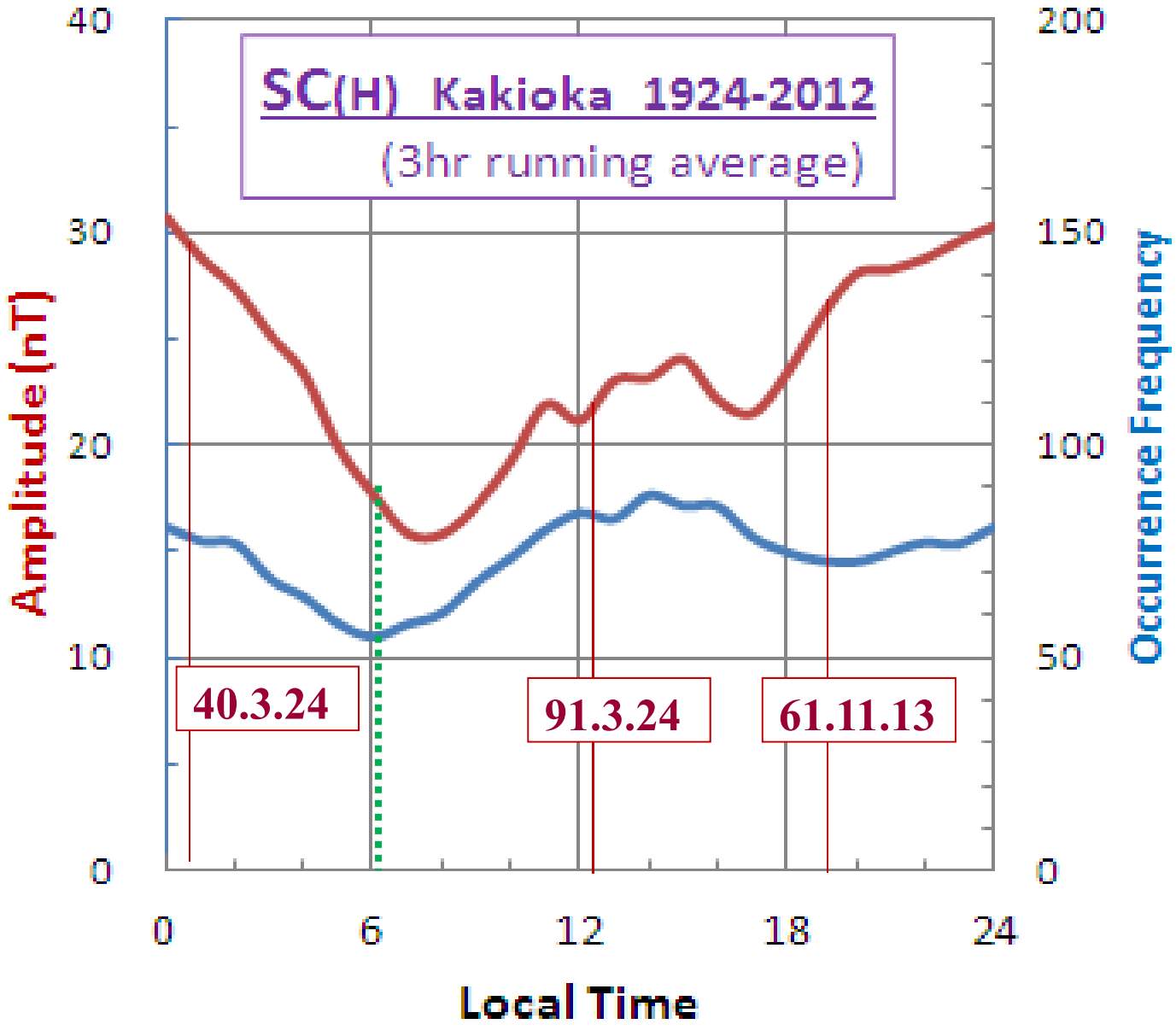
162nT

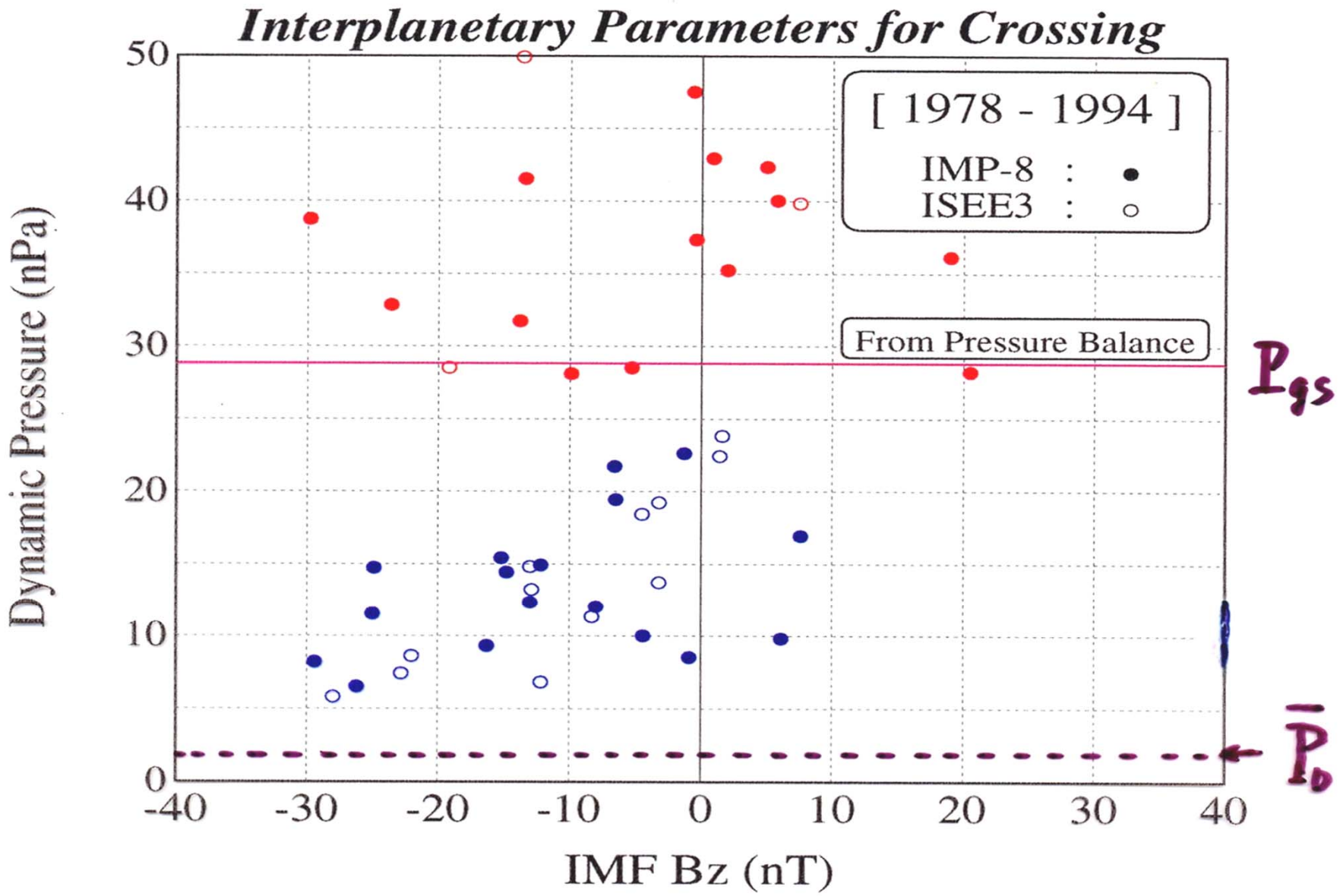
61.11.13

ΔH=220nT

↓

145nT





$$\Delta H = \alpha \cdot \Delta (P_d)^{0.5} = \alpha \, [30^{0.5} - 2^{0.5}] \sim 60nT$$

まとめ

$$\Delta H = \alpha \cdot \Delta (P_d)^{0.5} = \beta \cdot \gamma \cdot k \cdot [(P_{d2})^{0.5} - (P_{d1})^{0.5}]$$

適用の条件

1. 非線形効果の評価

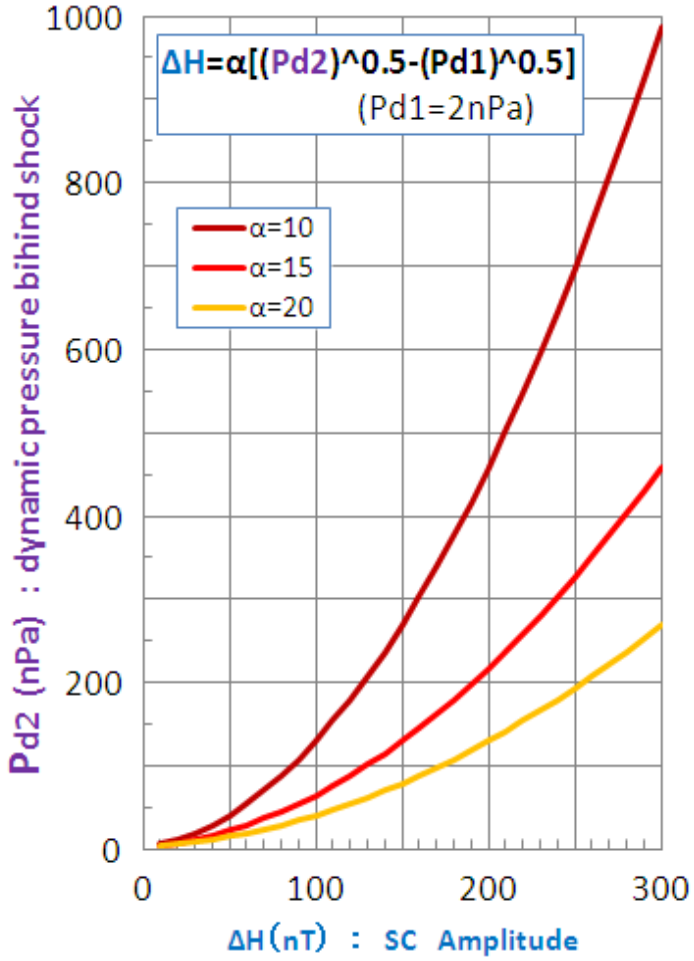
   非線形効果 ←→ 誘導電流効果 ： 競合的

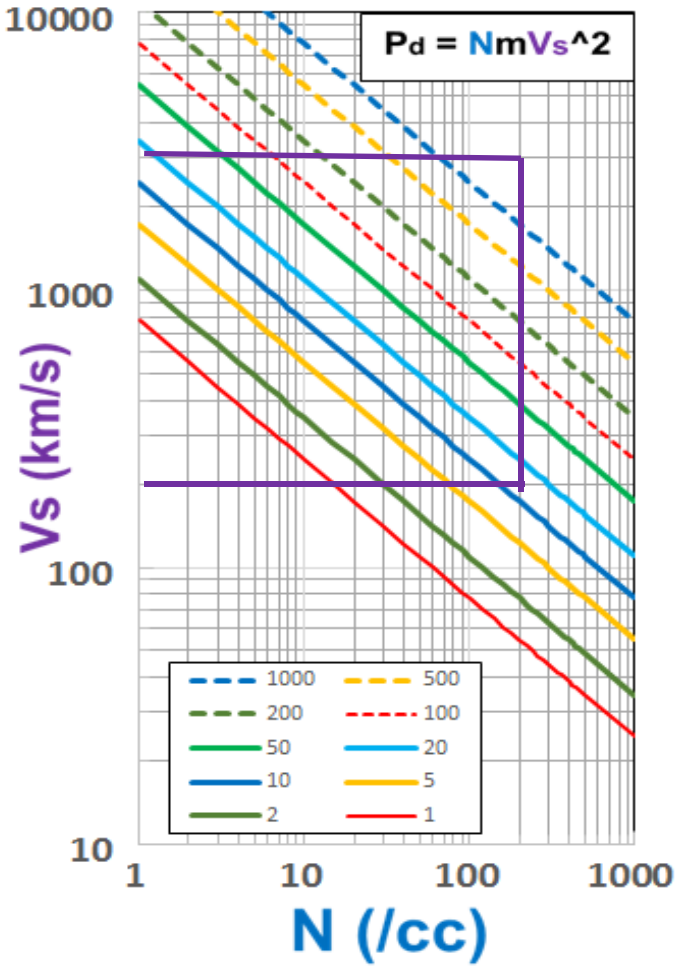
   (→大Pd) (→小Pd)

2. ΔH日変化の考慮

   Field Aligned CurrentとIonospheric Currentの磁場を最小にするLTの選択 ⟹ 4-6h LT

3. 大振幅SCのΔH日変化は？ 要調査


ΔH=α[(Pd2)^0.5-(Pd1)^0.5]
(Pd1=2nPa)
α=10
α=15
α=20
Pd2 (nPa) : dynamic pressure bihind shock
1000
800
600
400
200
0
0
100
200
300
ΔH(nT) : SC Amplitude


Pd = NmVs^2
10000
1000
100
10
Vs (km/s)
1
10
100
1000
N (/cc)
1000
500
200
100
50
20
10
5
2
1