SuperDARN 概要と近況

SuperDARN overview and recent issues

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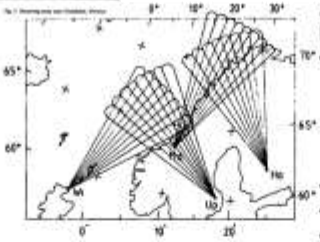
NIPR/SOKENDAI

STARE radar (VHF radar)

(Scandinavian Twin Auroral Radar Experiment)

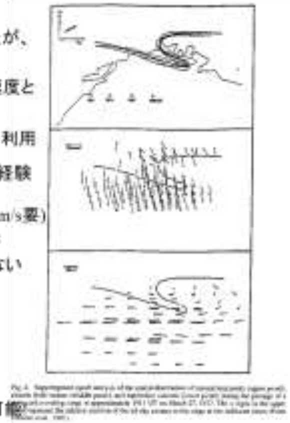


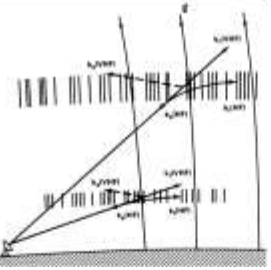
oherent radars in northern Europe. The German radar operates from Hankasalmi (Ha) and Malvik (Ma), the British one from Uppsala (Up) and Wiik (Wi). (After E. Nielsen and J. D. Whitehead, *Advances in Space Research* 2, 131, 1983)

広域E層観測で多くの成果をあげ成功したが、

【shortcomings(欠点)...】

- E層FAIのdrift速度は、E層プラズマ速度と考えてよい？
  - ・V: saturate@ion-acoustic vol.
  - ・E層電場とion-acoustic速度の関係を利用し、E層plasma速度をより正確に求める経験式
- Vの下限の存在(FAI生成にVe>=300m/s要)
- E層Doppler速度の物理解釈の困難さ
- VHF帯では極域F層磁場との直交しない(F層観測不可)





極域(高緯度)では、、

- VHF帯レーダーでは、F層で磁場と直交不可。
- HF帯レーダーなら電離層での屈折の為、可能且つより広大な領域を探査可能
- F層ならNeも大きく、FAIも豊富に存在か?
- F層なら、vの複雑な制限もなさそうで、この為、vとEの関係も単純な筈
- ⇒HFレーダーへ！

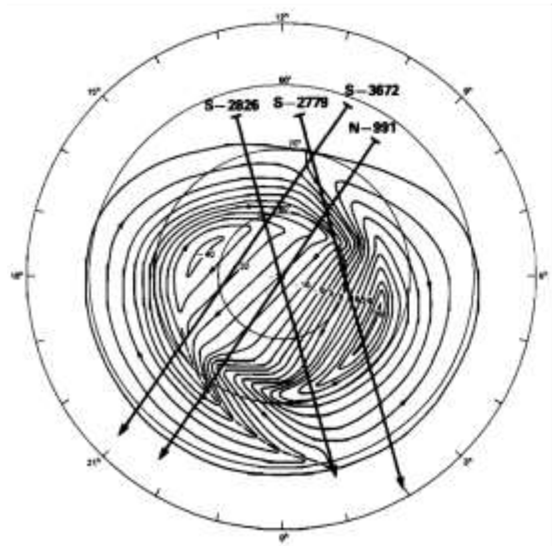
$$\mathbf{E} = -\mathbf{v} \times \mathbf{B} \quad \text{@ F層}$$

E: 電場vector

v:プラズマ(ion, electron)速度vector

B: 磁場vector

極域電離圏プラズマ対流
人工衛星電場観測による統計研究



Model BC

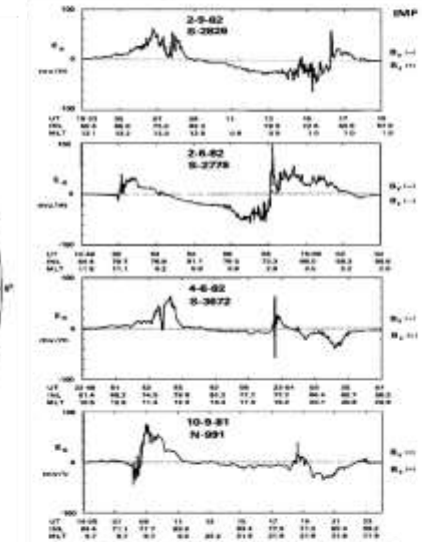
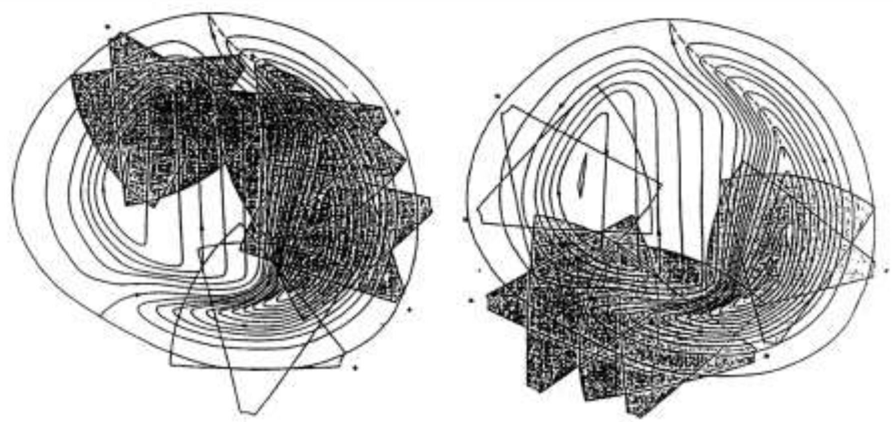


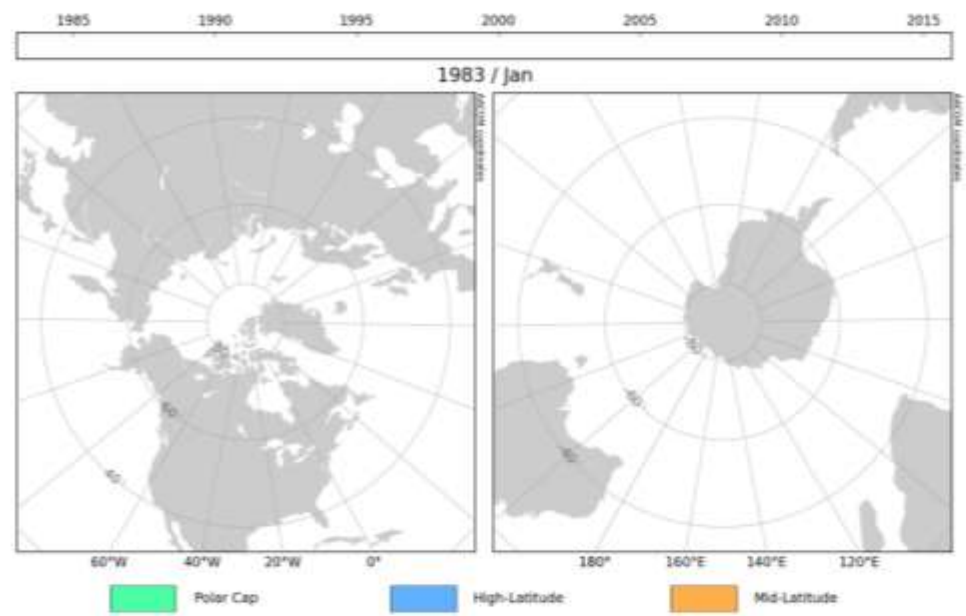
Fig. 6. Examples related to model BC: northern hemisphere with +Y IMF and southern hemisphere with −Y IMF. Simultaneous Kp values (top to bottom) are 2+, 4−, 3, and 3−. E_y is positive in the direction of orbital motion.

SuperDARN計画



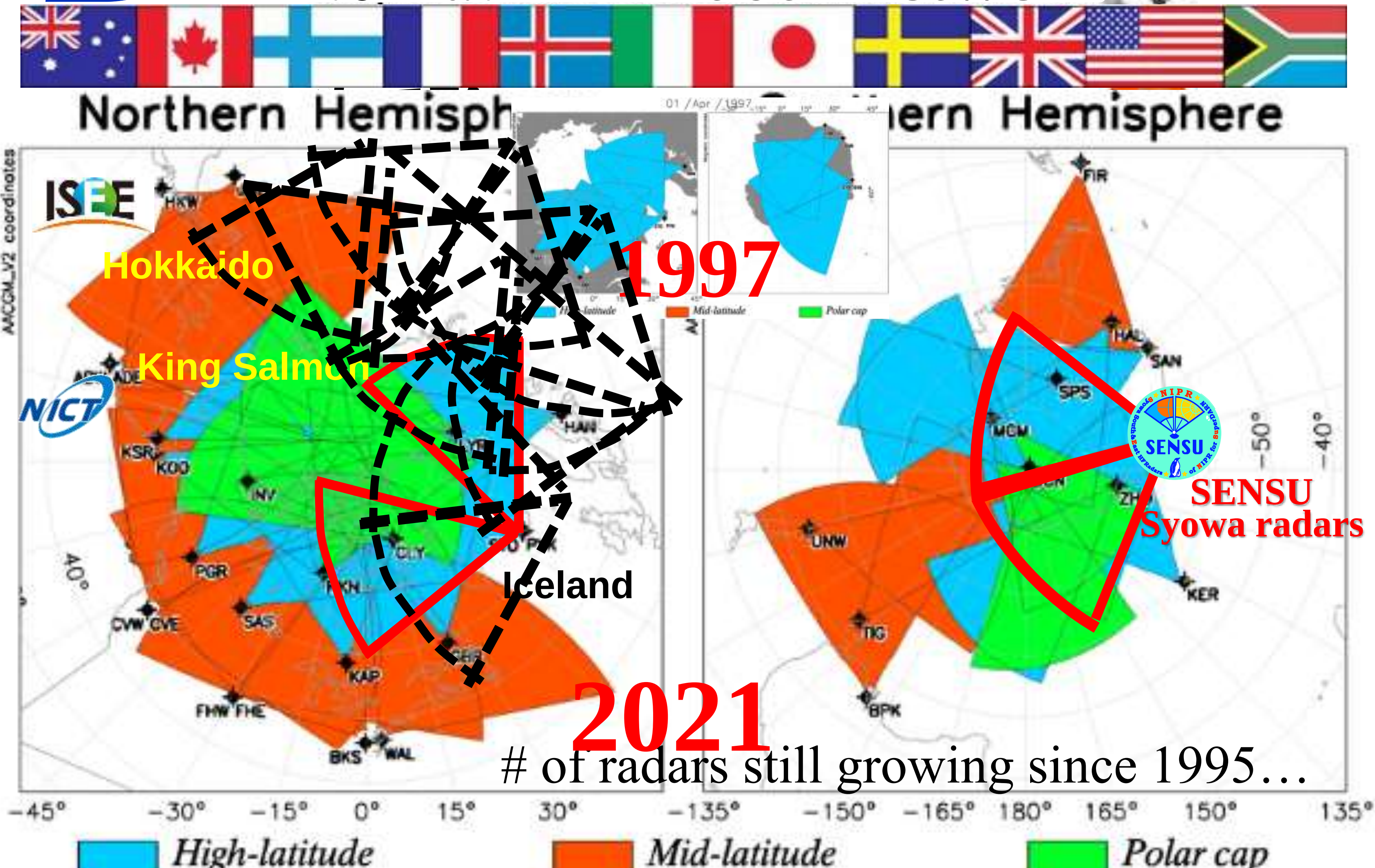
- レーダー視野で極域の広い領域をカバー
- 過渡的現象も含めた時々刻々の電離圏プラズマ対流と電場ポテンシャルを観測

More data-more radars/FOVs



SuperDARN

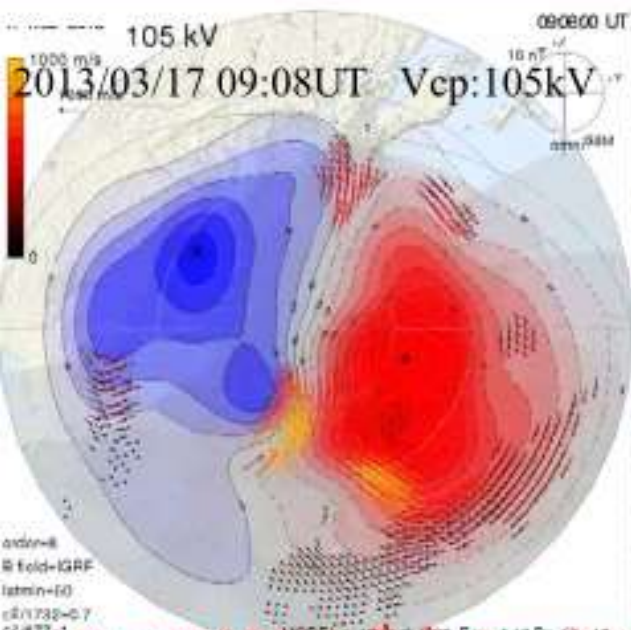
Internat'l HF radar network



# of radars still growing since 1995…

SuperDARN

太陽風変動とSD宇宙天気図



SupeDARNの基本データは多くの科学

Doppler radar transmitting HF radio band pulses obliquely to the (E-/F-region) ionosphere, originally designed to obtain coherent backscatter from FAIs up to horizontally over 3000km distance

SuperDARN HF radar

Tx freq.: 8~20 MHz
Tx power: 9.6 kW (600Wx16)
Ant. beams: fan beam by 16 log-periodic phased-array ant.
beam directions: 16 (3.3 deg. beam width each) (=> ~50deg. FOV)
pulse length: 300 usec (45km) (100, 200 usec possible, no pulse coding)
pulse sequence: unevenly spaced 7 pulses / sequence (min. lag=2.4msec, ~90 msec / sequence)
Interferometer: exists (for most radars)
norm operation: frang=180km, rsep=45km, nrang=75, intt=3~7sec, simple beam scan

SuperDARN観測の意義

- 「宇宙天気図」を時々刻々得られる唯一の手段。
- 太陽/太陽風変動に対する超高層大気(地球規模の南北高~中緯度)の応答を初めて可視化。
- 地磁気嵐やオーロラ(嵐)の解明に貢献。
- 「宇宙災害」ともいわれる通信障害や電力送電網事故、測位誤差、宇宙飛行士の安全にも繋がる宇宙天気研究・予報に貢献。
- 他観測との協調による、海洋・下層大気から宇宙空間迄の(上下結合を含む)一貫した理解をして初めて長期気候変動の正確な予測も可能となる筈。
特に、長期太陽活動変動等、宇宙からの地球環境変動への影響は未解明、定量的評価が今後の予想の為にも重要。長期継続観測の必要性。

Number of SuperDARN papers & citations

No of Papers 1991 - 2020.6 No of Citations 1994 - 2020.6

936 publications 16148 citations
h-index (of the full list of pubs) = 46
(as a way to asses the impact of the SD network)

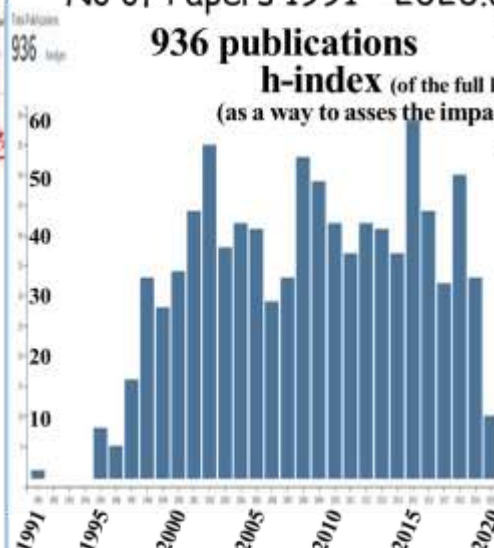


Figure 1a. Number of SuperDARN papers published on an annual basis since 1991, including 2019. The data query of the Web of Science database was performed on 2nd June, 2020.

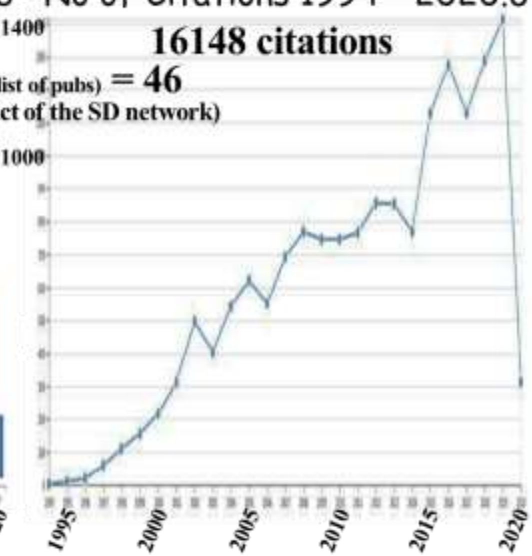


Figure 1b. Number of citations for SuperDARN papers on an annual basis derived from the query of the Web of Science database.

SuperDARN data – widely used in science and applications

SuperDARN観測原理

SuperDARNレーダー観測手法（マルチパルスACF観測法）

パルスレーダーによる遠距離(>3000km,OTH)電離層FAI
Bragg散乱coherentエコーのDoppler観測の必要条件

- ●電離圏FAI coherentエコーの相関時間　(IPP<)数msec～数十msec(typically)
- ●長距離(>300km)(E/)F層エコーの受信　r=3000km ⇔ τ=20msec
- ●高速なF層プラズマ運動速度の検出　v≦3000m/s⇔IPP≦2.5msec
- ●極域電離圏の様々な時間規模の変動
  - ●太陽風変動への応答　数分以内の応答時間(?)
  - ●オーロラ　数秒～数十分(?)
  - ●波動現象（Pc3～Pc5）　数秒のsampling必要
  - ●磁気圏境界面現象（FTE/TCV等）　数分周期等

等

⇒ シングルパルス観測では実現困難

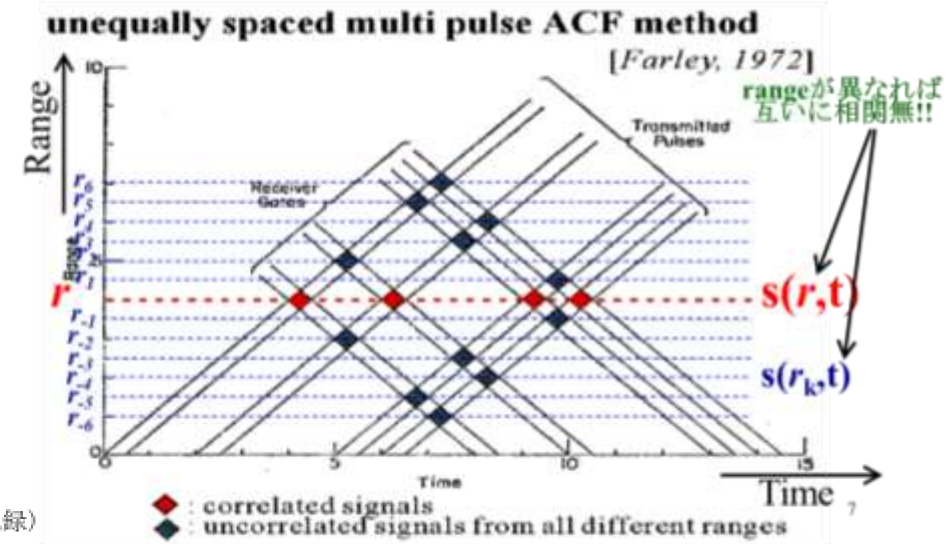
⇒ マルチパルスACF取得によるDopplerスペクトル観測が必要（IPP≦2.5msec）

⇒ SuperDARNではACF観測に特化した観測法を採用
（ACF計算後、生時系列データを記録せず、ACF及びfittingされた物理量のみ記録）

SuperDARN観測原理

不等間隔Multi-Pulse法によるACF(Dopplerスペクトル)観測

不等間隔Multi-Pulse法 [D.T. Farley, 1972]

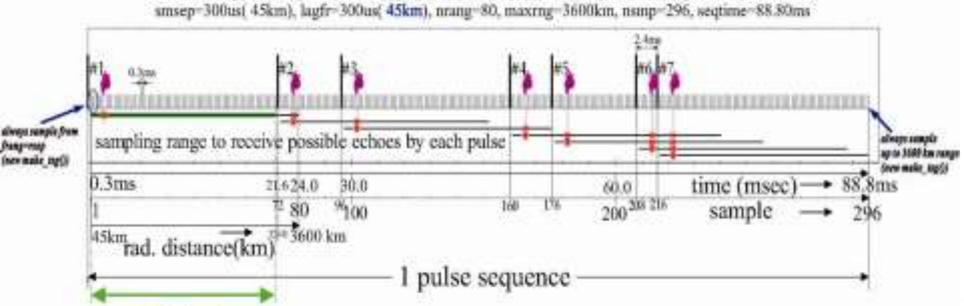


SuperDARN観測原理

最近のSuperDARN multi-pulse

SuperDARN pulse sequence and sampling points

mppul=7, mpinc=2400us, pput[7]={0,9,12,20,22,26,27}, txpl=300us (rsep=45km)
smsep=300us(45km), lagfr=300us(45km), nrang=80, maxrng=3600km, nsmp=296, seqtime=88.80ms

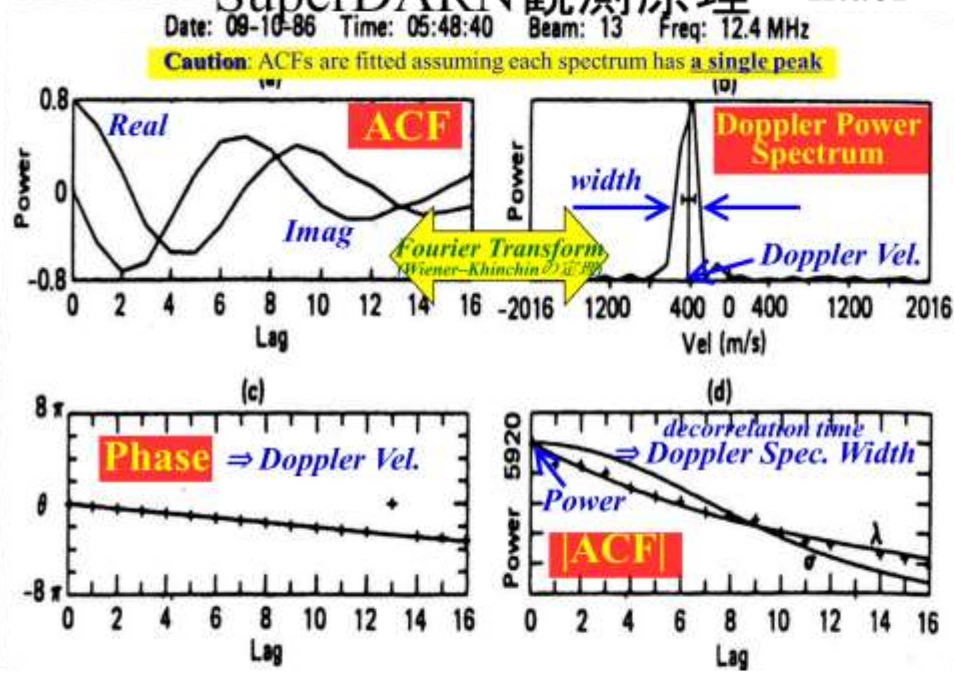


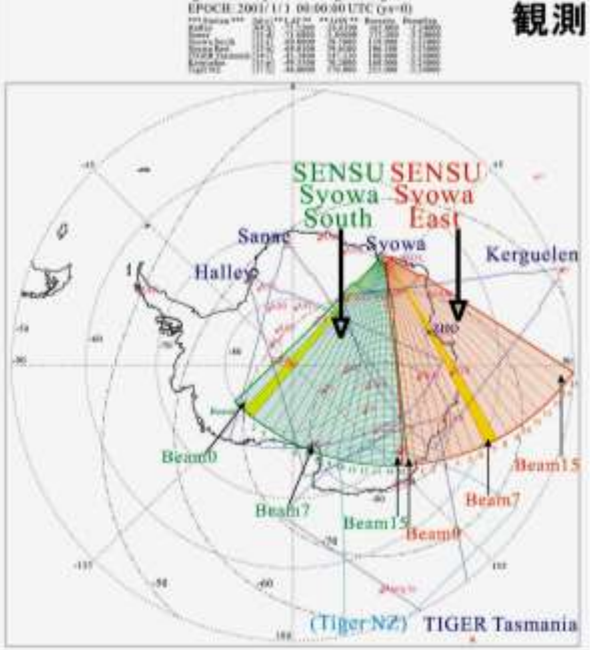
just a "single-pulse" observation!!

i.e., at least ~10 Hz sampling raw time series analysis are always possible! (for 45~3195 km ranges in this case)
(though 10 Hz is not enough for most studies due to freq-aliasing)

: 7samples for 270 km range (range #6) as an example.
All of these except the 1st sample can be a mixture of echoes from the range in question (range #6) and from other ranges by prev. pulses.

SuperDARN観測原理　fitacf





観測で得られる主要変数:

iqdata:
sampled raw I/Q values..

ACF:
raw ACF (constructed from main array IQ samples) to deduce physical params

XCF:
raw XCF between main array and interferometer Rx output (constructed from main and interf. Rx IQ samples) to deduce AOA elevation angle

Power:
echo power (SNR) [dB]
Lambda fit, sigma fit

VEL(Vlos):
Line of sight Doppler velocity[m/s]

Spectral width:
spectral width [m/s]

elev.
AOA elevation angle(到来仰角) [deg]

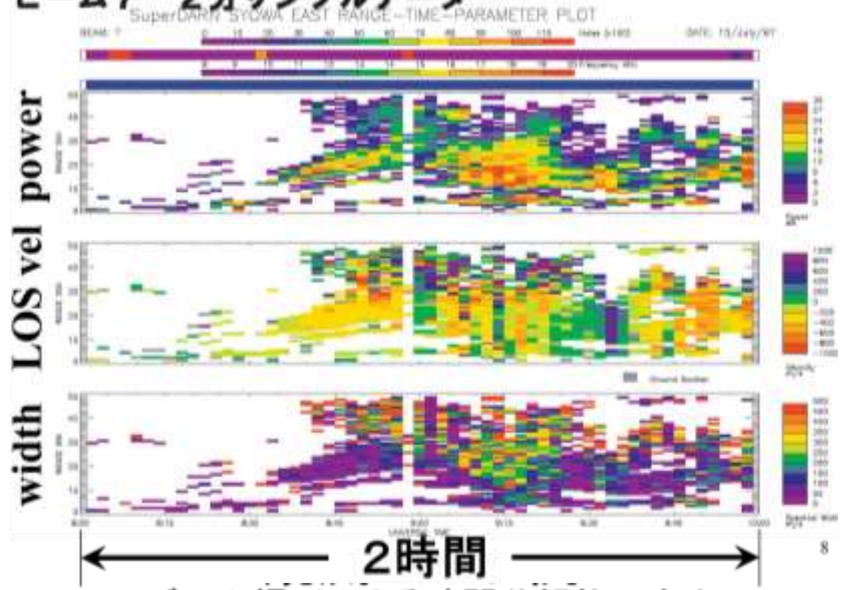
noise:
noise level [A/D units^2]
determined during Rx only mode
(various) **errors:**
estimated error for each fitted parameters
・・・

☆**中性風速**も導出可能だが今回射程外。

観測モード例：

ビーム掃引による時間分解能の向上

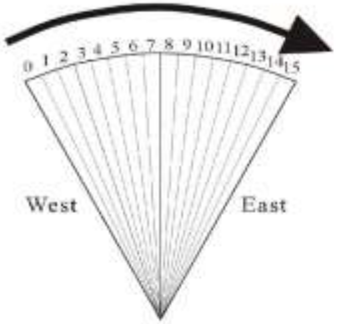
ビーム７　２分サンプルデータ



normal_scan / fast_scan

normal_scan

beam sequence



0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

beam integration time： intt = 7 seconds

1 beam scan = 7 sec/beam × 16 beams/scan = 112 sec+ α

global convection : every 2 min

each beam sampling period : 2 min

in case of another Common Time program,

"**fast_scan**":

intt = 3 sec

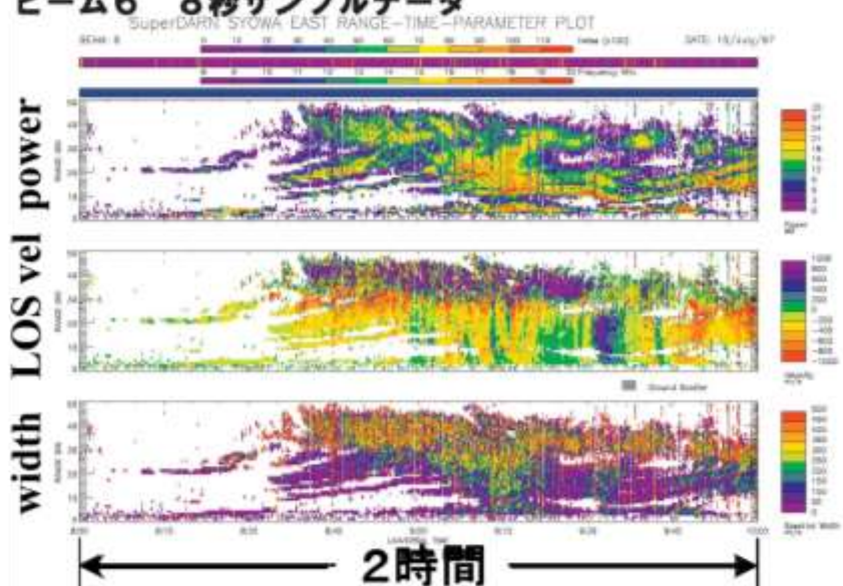
global convection: every 1 min

each beam sampling period: 2min

std. multi-pulse params.
(mppul=7or8 etc.)
frang=180km
rsep=45km
(i.e., txpl=smsep=300us)
nrang=70 or 75 (or even larger)
intt=7 sec (normalscan) or
3 sec (fast_scan: current std.)
beam seq: 0,1,2,3, ...,14,15 or
15,14,13,.....,1,0
beam scan: 2min or 1min

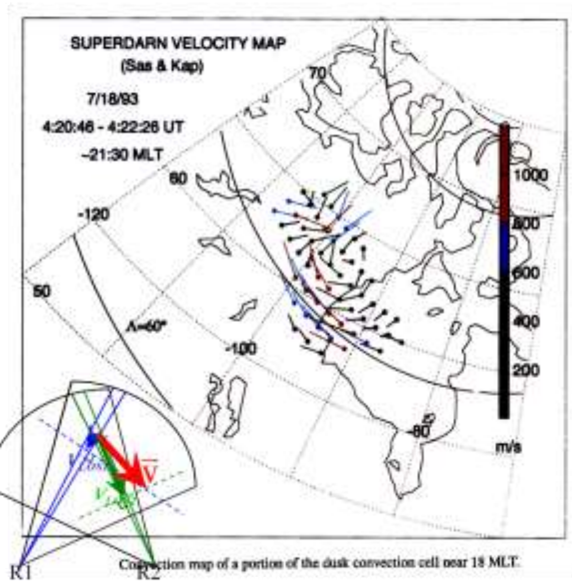
ビーム掃引による時間分解能の向上

ビーム６　８秒サンプルデータ



解析手法：直接2次元電場導出:merge

共通視野を持つ2レーダーを用いた2次元plasma速度導出



Convection map of a portion of the dusk convection cell near 18 MLT.

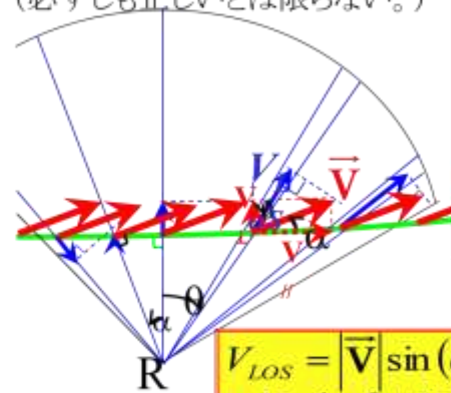
2レーダーの共通視野の領域であり、且つ、同時刻に同じ領域でエコーがないと、ベクトル合成できない。案外厳しい条件。

解析手法：L-shell fitting

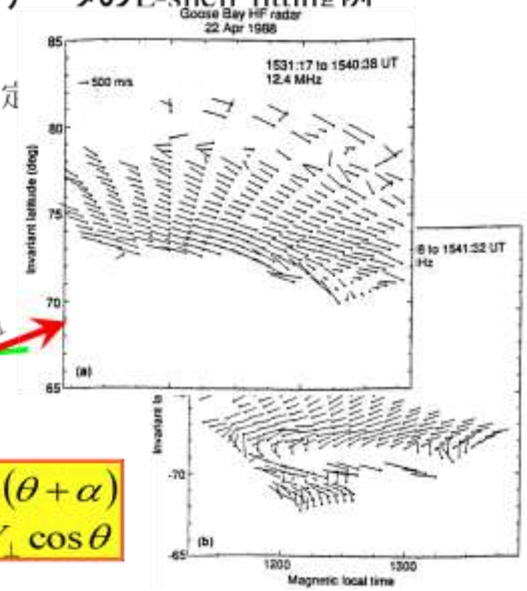
1レーダーのデータのみから2次元plasma速度を推測

南北共役レーダーデータのL-shell fitting例

L-shell（等地磁気緯度）沿いにplasma flowは一定であると仮定（必ずしも正しいとは限らない。）



$$V_{LOS} = \left|\vec{\mathbf{V}}\right| \sin(\theta+\alpha) = V_{//} \sin\theta + V_{\perp} \cos\theta$$



解析手法：球面調和関数fitting

複数レーダーから大域電離圏対流パターンの導出(map_potential)

- 電場potentialの球面調和関数展開によるfittingをすればよい。

$$E = -\nabla\Phi$$

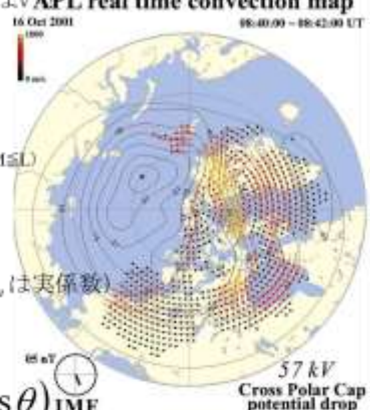
$$\vec{V} = \frac{\vec{E}\times\vec{B}}{B^2}, \quad \left(\vec{E} = -\vec{V}\times\vec{B}\right)$$

- 静電電場potentialΦを球面調和関数Y_{lm}展開（係数A_{lm}は複素数, M≦L）

$$\Phi(\theta,\phi) = \sum_{l=0}^{L}\sum_{m=-M}^{M} A_{lm} Y_{lm}(\theta,\phi)$$

- Φは実scalarなので、Legendre関数P_l^0展開に（係数$A_{lm}B_{lm}$は実係数）

$$\Phi(\theta,\phi) = \sum_{l=0}^{L} A_{l0} P_l^0(\cos\theta) + \sum_{m=1}^{l}\left(A_{lm}\cos m\phi + B_{lm}\sin m\phi\right)P_l^m(\cos\theta)$$



- N点の観測データV_{LOS}（値W_i, 不確かさs_i）を上記Φで最小二乗近似。
次のc^2を最小にすることになる。(V[i]はfitされたV, kはbeam方向)

$$\chi^2 = \sum_{i=1}^{N}\frac{1}{\sigma_i^2}\left(\vec{V}[i]\cdot\vec{k}[i] - W_i\right)^2$$

- real-time Convection map Web 公開。
- Space Weatherへの貢献。

SuperDARN scheduling

・3種類のcategoryに分けられる。

Common Time(CT)：

全radarが基本観測modeで観測。月の50%以上。
基本的に、PIとcontactの上、誰でも使える。
normal scan、近年では、fast scan/fast sound mode。
更に、(元々STで実施していた)THEMIS衛星との特別観測(themisscan mode)を、CT枠で実施している。

Special Time(ST):

全radarが特別な科学目的の為に特別なmodeで観測。
月の20%以下。
一定期間は観測提唱者にdata使用のpriority有。

Discretionary Time(DT):

各PIの裁量で観測可能な期間。
1~数レーダーによる特別観測やレーダー保守もこのcategory。月の30%以下。
一定期間は、各PIにdata使用のpriority有。

・2ヶ月前までにSD scheduling WGに計画と割当要求を提出し、SD scheduling WGがSD PI Groupの承認を経て1ヶ月前までにschedule決定。最小要求単位は、2時間。
・stereo radarの場合、chBは、radar保有PIの自由裁量。
・CT/ST/DTは、cpid（program ID）で区別できる（筈だが混乱も有）。

some very basic SuperDARN references

HF radar, multi-pulse technique, fitacf （基礎を知りたい方は是非一読を）:

・**Greenwald**, R.A., K.B.Baker, R.A. Hutchins, and C. Hanuise, "An HF phased-array radar for studying small-scale structure in the high-latitude ionosphere", Radio Sci., **20**, 63-79, **1985**.

・**Baker**, K.B., R.A. Greenwald, J.P. Villain, and S. Wing, "Spectral characteristics of high frequency (HF) backscatter from high latitude ionospheric irregularities: Preliminary analysis of statistical properties", *Interim Rep*., **RADC-TR-87-284**, Rome Air Dev. Cent., Griffis Air Force Base, N.Y., **1988.**

・**Farley**, D.T., "Multi-pulse incoherent scatter correlation function measurements", Radio Sci., **7**, 661-666, **1972**.

SuperDARN review (有用なreferences多数引用。研究分野の拡がりを知るにもお薦め度花丸◎!!!!):

・**Greenwald**, R.A., K.B. Baker, J.R. Dudeney, M. Pinnock, T.B. Jones, E.C. Thomas, J.-P. Villain, J.-C. Cerisier, C. Senior, C. Hanuise, R.D. Hunsucker, G. Sofko, J. Koehler, E. Nielsen. R. Pellinen, A.D.M. Walker, N. Sato and H. Yamagishi, "DARN/SUPERDARN - A Global View of the Dynamics of High-Latitude Convection", **Space Sci. Rev.**, **71**, 761-796, **1995**.

・**Chisham**, G., M. Lester, S.E. Milan, M.P. Freeman, W.A. Bristow, A. Grocott, K.A. McWilliams, J.M. Ruohoniemi, T.K. Yeoman, P.L. Dyson, R.A. Greenwald, T. Kikuchi, M. Pinnock, J.P.S. Rash, N. Sato, G.J. Sofko, J.-P. Villain, and A.D.M. Walker, A decade of the Super Dual Auroral Radar Network (SuperDARN): scientific achievements, new techniques and future directions, **Surv. Geophys.**, 28, 33-109, doi:10.1007/s10712-007-9017-8, **2007**.

・**Nishitani, N.**, et al., Review of the accomplishments of mid-latitude Super Dual Auroral Radar Network (SuperDARN) HF radars, PEPS, doi:10.1186/s40645-019-0270-5, 2019.

AACGM座標系:

・**Baker**, K.B., and S. Wing, "A new magnetic coordinate system for conjugate studies of high latitudes", J. Geophys. Res., **94**, 9139-9143, **1989**.

merge: http://www.ion.le.ac.uk/cutlass/merge/merge.html

map_potential:

・**Ruohoniemi**, J.M. and K.B. Baker, "Large-scale imaging of high-latitude convection with Super Dual Auroral Radar Network HF radar observations", J. Geophys. Res., **103**, 20797-20811, **1998**.

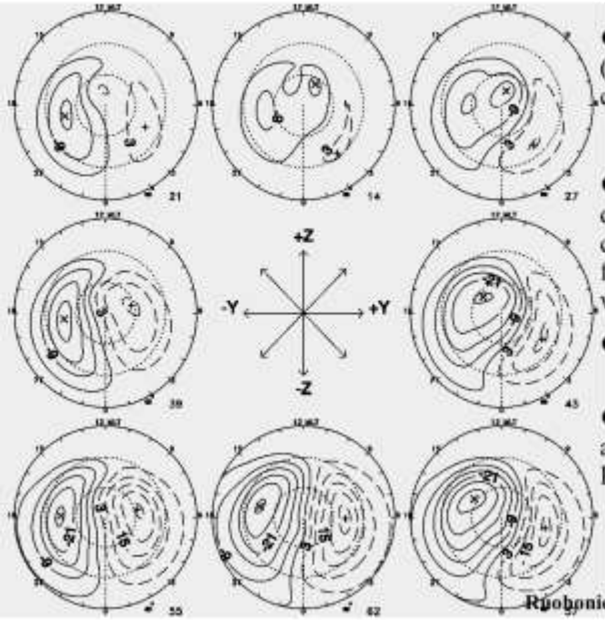
・ http://www.ion.le.ac.uk/~gp3/map_potential.html

・ http://www.ion.le.ac.uk/~ag27/map_potential/advanced/manual.pdf

map_potential:

・http://polaris.nipr.ac.jp/~SD/sdjapan/ ・http://vt.superdarn.org/ ….

statistical global convection model

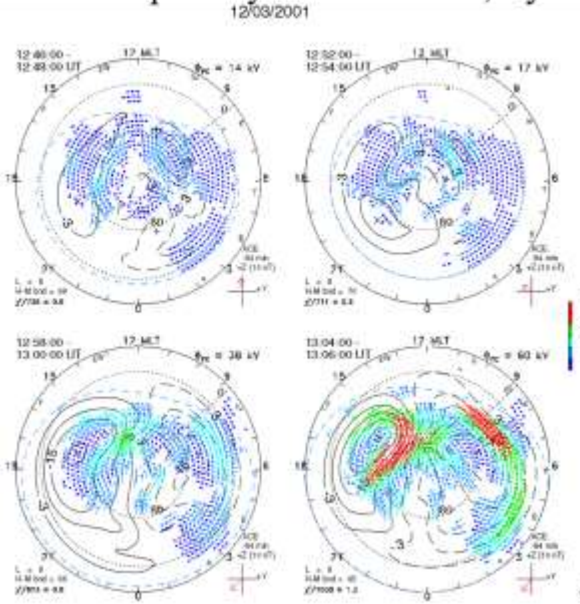


- global convection pattern (spherical harmonic fit) classified by IMF condition
- IMF Bz>0 (NBz), |By|~0: dayside high lat.: 2 cell reverse convections (sunward flow) form 4 call pattern together with lower lat 2 cell
- Bz<0 :2 cell pattern, larger Φ_{PC}
- 2 cell pattern dawn-dusk asynmetry : reverse for reverse By sign

Ruohoniemi & Greenwald, JGR, 1996 & 2005

dynamics of global convection

especially when IMF Bz, By drastically changes

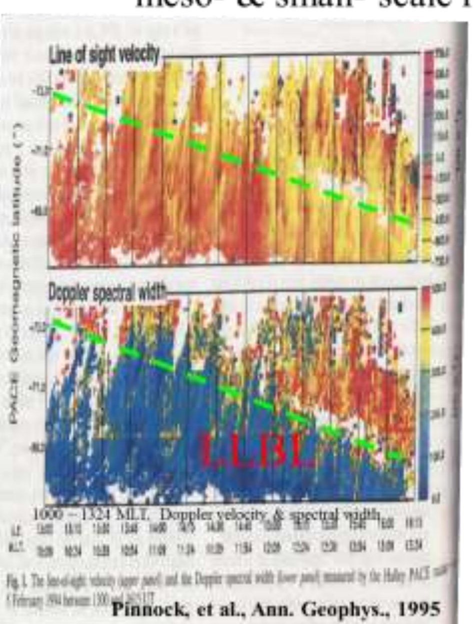


- ~12:56 : IMF Bz>0 stable condition
  4 cell pattern @ 12:46
  3 cell pattern @ 12:52
- 12:56 : abrupt Bz<0 change happened!
- ~2min later aft Bz change : reconfiguration from Bz>0 pattern to Bz<0 pattern within 2-4 min.
- ~10 min later : enhance & strengthen Bz<0 pattern

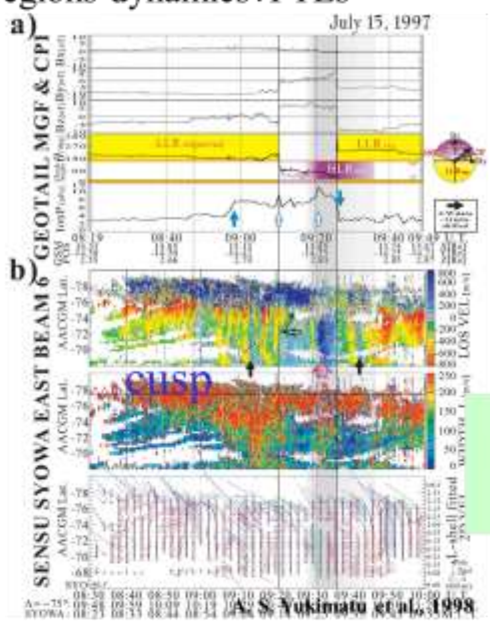
Chisham, et al., Surv. in Geophys., 2007

dynamics of FTEs related to IMF changes

meso- & small- scale regions dynamics : FTEs



Pinnock, et al., Ann. Geophys., 1995

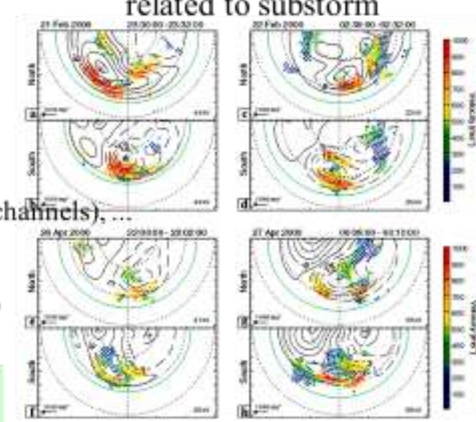


A. S. Yukimatu et al., 1998

meso-&small- scale convection dynamics

- FTEs (Flux Transfer Events)
- TCVs (Traveling Convection Vortices)
- SAPS (sub-auroral polarization stream)
  - PJs (polarization jets)
  - SAIDs (sub-auroral ion drifts),
  - SARAS,
  - AWFCs (auroral westward flow channels), ...
- substorm related convection transients
- storm time related phenomena (SED, ...)
- ....

nightside convection dynamics related to substorm

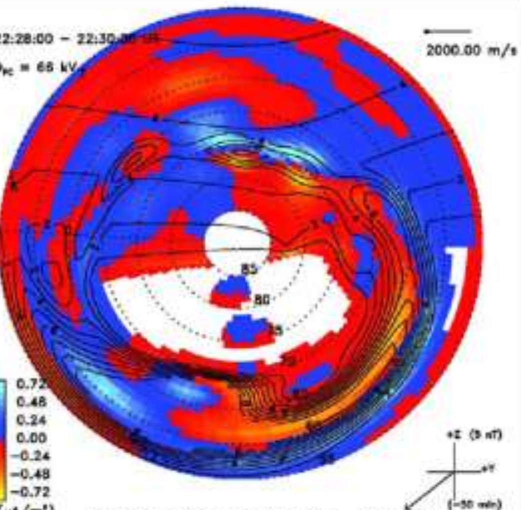


Grocott et al., Ann. Geophys., 2005

Transient phenomena
Region identification
(I-M mapping)

Especially during storm/substorms
comparison with MHD simulation..

deduction of global FAC system



Bristow and Lummerzheim, JGR, 2001

- From Polar UVI image auroral luminosity, particles precipitation into ionosphere can be inferred, which can then be combined with model for photo-ionization etc and Pedersen、Hall conductivity（Σ_P, Σ_H）at whole polar region can be deduced. (possible problems on reliability at low luminosity regions)
- By combining the deduced Σ_P, Σ_H & SD 2-D global E fileds, $J_\perp$ can be obtained and FAC, $J_{//}$ can then be inferred (by $\nabla\cdot J_\perp$).
- up(red)/down(blue) ward FAC、& Σ_P (contour)
- extensive validation with satellite magnetometer data etc requied

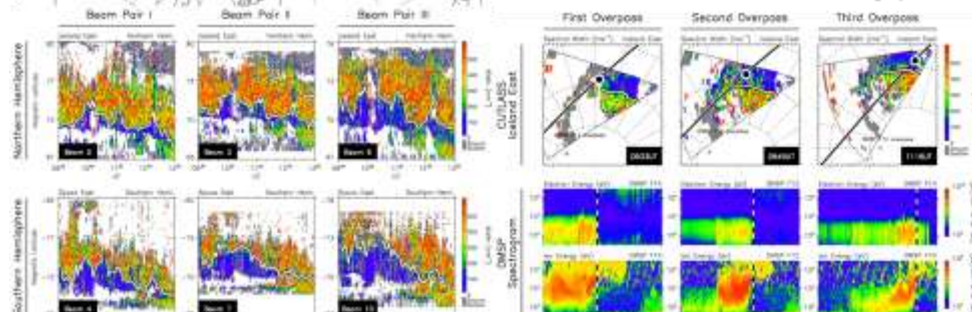
昼間側は太陽紫外線の影響がdominantで∇∑は小さく、∇xVによるFACの評価でもよいが、夜側は、aurora活動による∇∑が大きく、∇xVからFACの評価は困難であることもわかる。

SWB/OCB/FTE/Reconnection

Spectral Width Boundary(SWB) as proxy of OCB?

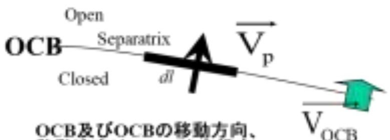
- Doppler Spectral Width sharply changes around Convection Flow Reversal (polar: higher width)
- Can Spectral Width Boundary (SWB) be a proxy of OCB (open/closed field line boundary)?

Hosokawa et al., Ann. Geophys., 2003



Hosokawa et al., Ann. Geophys., 2003

estimate of Reconnection Rate



OCB及びOCBの移動方向、移動速度は、SWBから推定。

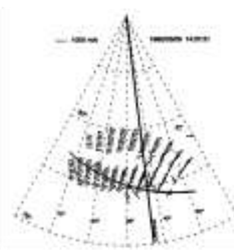
OCB上長さdlの境界線を超えて単位時間あたりに輸送される磁束Fは、、

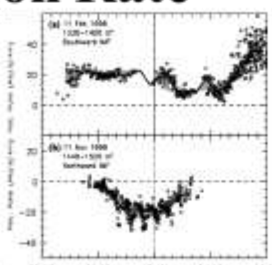
$$dF/dt = \vec{B}\times\vec{V}\cdot\vec{dl}$$

$$\vec{V} = \vec{V_p} - \vec{V_{OCB}}$$

Testing Reconnection theories

- antiparallel reconnection hypothesis
  places where antiparallel happen
- component reconnection hypothesis
  subsolar point
  high sheath B strength & sheath flow stagnate

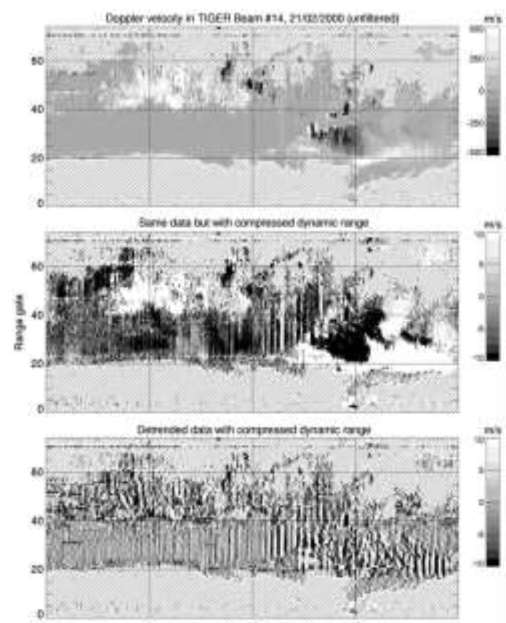




（OCBの静止系からみたplasma速度）

Baker et al., JGR, 1997
Pinnock et al., Ann. Geophys., 2003,
Chisham et al., Ann. Geophys., 2004b
Coleman et al., JGR, 2001

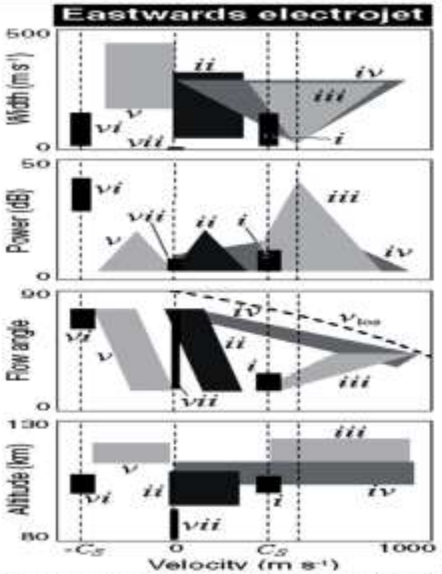
MHD waves with SuperDARN



- Pc3~Pc5 detectable w/ SD
- ULF waves also found in ground scatter echoes
- ionospheric heater visualizes natural ULF waves
- waves with different period/m-number between S-N beam (Finland) & E-W beam (Iceland East) simultaneously co-exist
- but low-m low freq waves only observed at ground mag. data.
- low-m & low-freq wave: basic FLR（field line resonance）. high-m & high-freq wave: 2nd harmonics of low-freq wave, triggered by high energy particles in ring current inside magnetosphere

Panomarenko et al., GRL, 2003

studies on E-region FAIs @HF



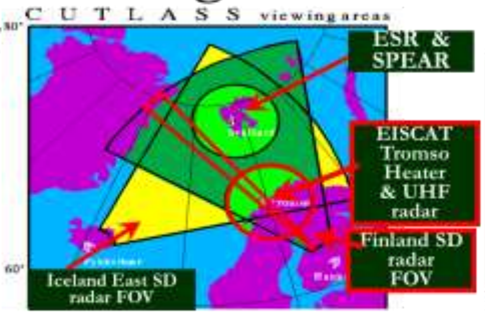
Villain et al., JGR, 1987, 1990, Hanuise et al., Ann. Geophys., 1991, St-Maurice et al., JGR, 1994, Milan and Lester, Adv. Space Res., 1999, Milan and Lester, Ann. Geophys., 2001a,b, Milan et al., Ann. Geophys., 2004, and so on...

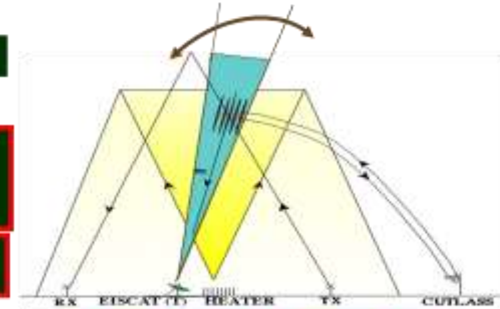
- Re-classification of E region FAIs in HF band.
- Not only type I&II, but also more types (not rare) identified
- Some has Vlos sense opposite to ExB drift direction
- FAI generation mechanism
- found high aspect angle echoes from E-region FAIs (HAIR) @HF

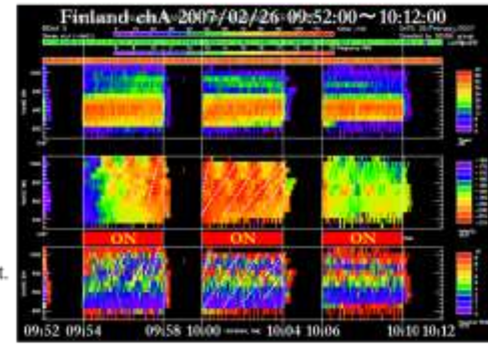
HAIR

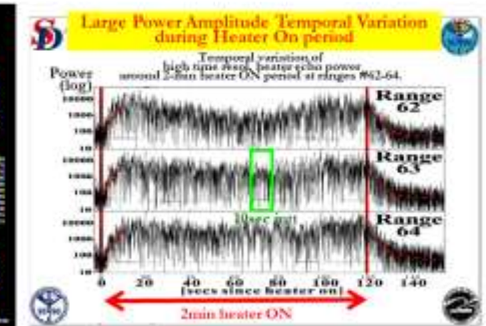
- Found in nearest ranges in electrojets
- **Very large aspect angle ~30deg**
- **Aspect sensitivity is 0.5~1 db/deg (normally ~10dB/deg)**
- Generation mechanism proposed but not clear yet. [Robinson & Schlegel, Ann. Geophys., 2000, St-Maurice et al., 200x, etc]

F-region FAIs with heater & SD







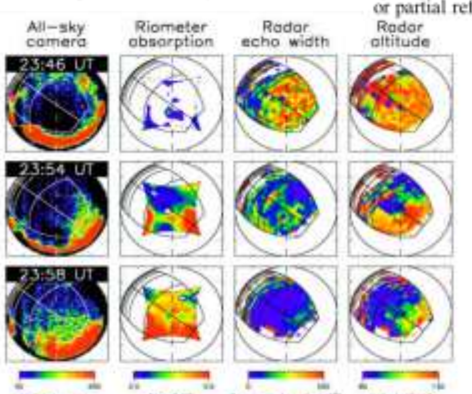


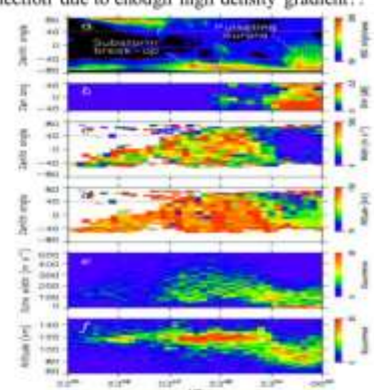
studies on mesosphere/D-region echoes

- Meteor echoes [Hall et al., JGR, 1997]
- PMSE [Ogawa, et al., GRL, 2002, Ann. Geophys., 2003]
- 3rd assoc. w/ energetic particle precip. CNA & pulsating aurora [Milan et al., Ann. Geophys., 2001, 2008]

height: 80-100km, Vlos<100m/s, spectral width: <20m/s very low (<< E region ~100m/s)
⇒related to ambipolar diffusion?

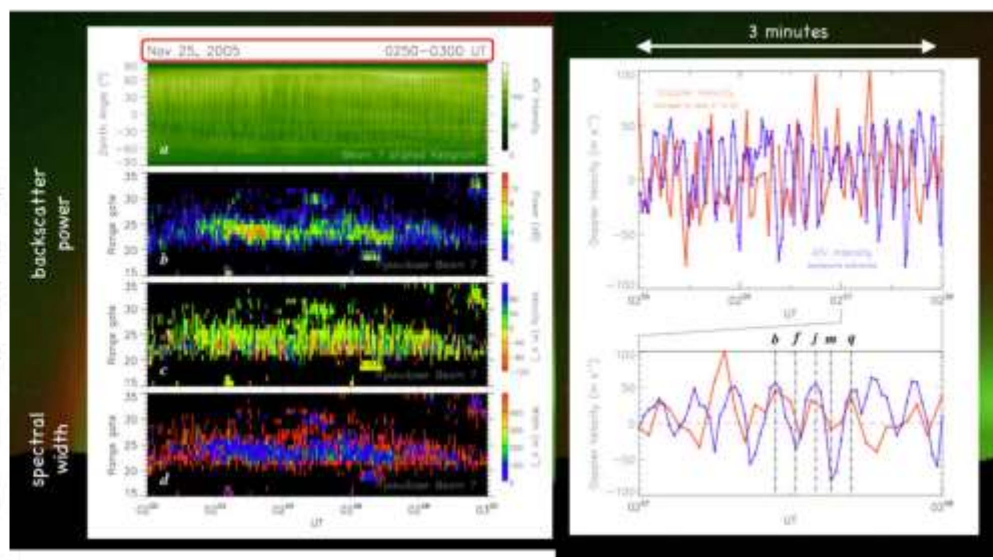
non-aspect sensitive again! $\alpha \sim 25^\circ$!! ⇒precipitation spatial scale $\sim\lambda\sim$10m if coherent?? or partial reflection due to enough high density gradient??





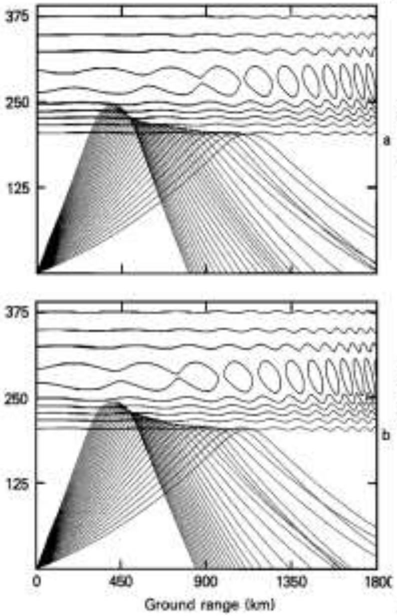
studies on echoes ass.w/ aurora

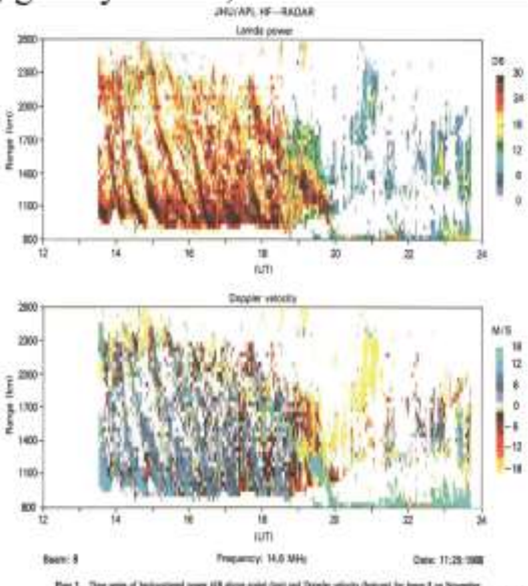
- PsA [Hosokawa et al., SD2008]



Atmospheric waves - ground scatters

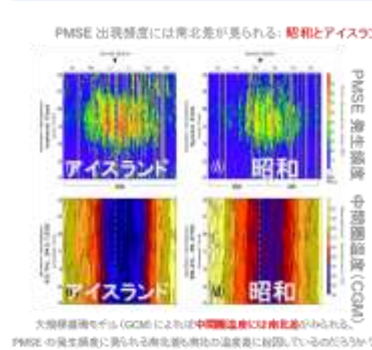
TIDs, tides, gravity waves, ...



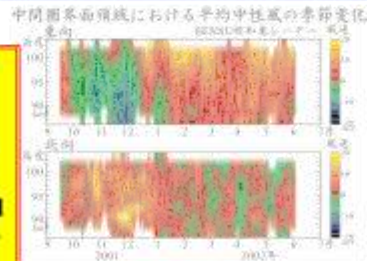


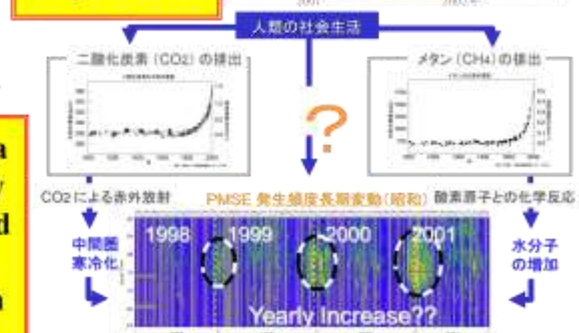
Sansom et al., JGR, 1990

Precise neutral wind and PMSEs observation



SuperDARN-first-ever precise neutral wind altitude profile obtained at Syowa radar

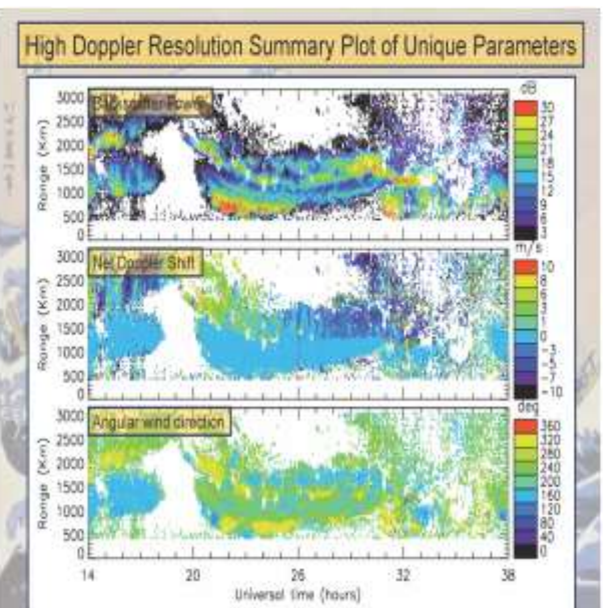




PMSEs detected at Syowa SuperDARN radar firstly obtained in SD radars and its yearly variation – possible relationship with global warming?

增加傾向にあるかどうかを確かめるにはさらに長期にわたる観測データの蓄積が必要。

Sea scatter (sea surface wave) (TMS application)

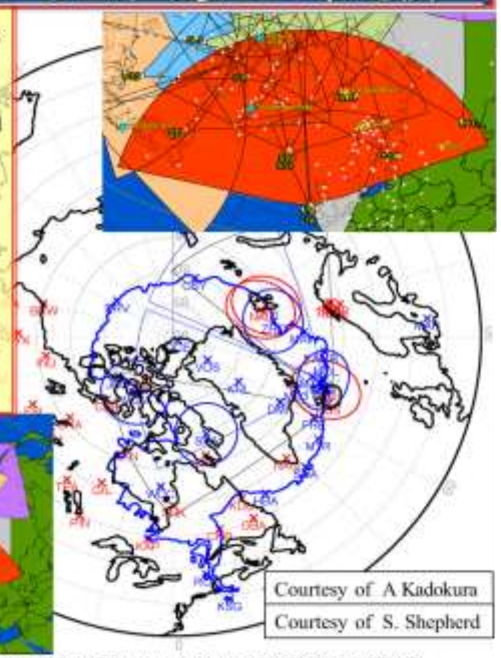


- SuperDARN as ocean radar : "Ground Scatter" can be sea scatter
- Bragg scatter at sea surface by surface sea waves ⇒ sea surface wave velocity etc can be investigated
- Very low Doppler Vel requires higher resolution Doppler spectra. Raw IQ time series analysis method (TMS) can be applied

Greenwood, et al., SD2007&2008

広域共役点観測～点から面、更に地球規模へ

- **Syowa-Iceland pair (so far mainly)**
  - Limited area – fine comparison between 2 points but large daily/seasonal/secure variation.
- **Syowa East +Zhongshan pair and Iceland East – Svalbard pair**
  - Comprehensive G.B. facilities in Svarbard and Zhongshan
  - Syowa : comprehensive GB facilities like Many opt. inst., MST/IS/MF radar, Lidar etc.
    But no SD radars so far whose FOV covers over Syowa (and Iceland widely) though Tjornes on Iceland covered by Iceland East – many optical simultaneous researches.
- **However,... SD is still grouwing...**
  - Iceland will be covered by new Ireland radars possibly (hopefully) soon (2017??)
  - Many potential research targets including auroral, subauroral and inner magnetospheric studies...
    (proposal by Simon Shepherd, USA)



Courtesy of A Kadokura

Courtesy of S. Shepherd

Station FOV(el>10.0) in Geomagnetic Map on 20150101-000000(UT)

SuperDARN

Scientific objectives

1) dynamics of **large scale convection**
2) dynamics of **meso-/small-scale convection**
inc. transient phenomena
e.g., FTEs/TCVs/OCB/aurora/patches
3) **substorm/storm/sub-auroral**
studies **SAPS**
4) **reconnection**/reconnection rates
5) **Field Aligned Currents**
6) **MHD waves**
7) hemispheric **Conjugacy/non-CJG**
7) **Inner magnentosphere**
8) D/E/F region **irregularities (FAIs)**
(radar aurora)
9) **atmospheric waves**
(TIDs, tides, gravity waves)
10) **neutral winds**
11) **PMSE/MSE/PMWE…**
12) **Sea** surface waves 13)...

Obtainable physical parameters

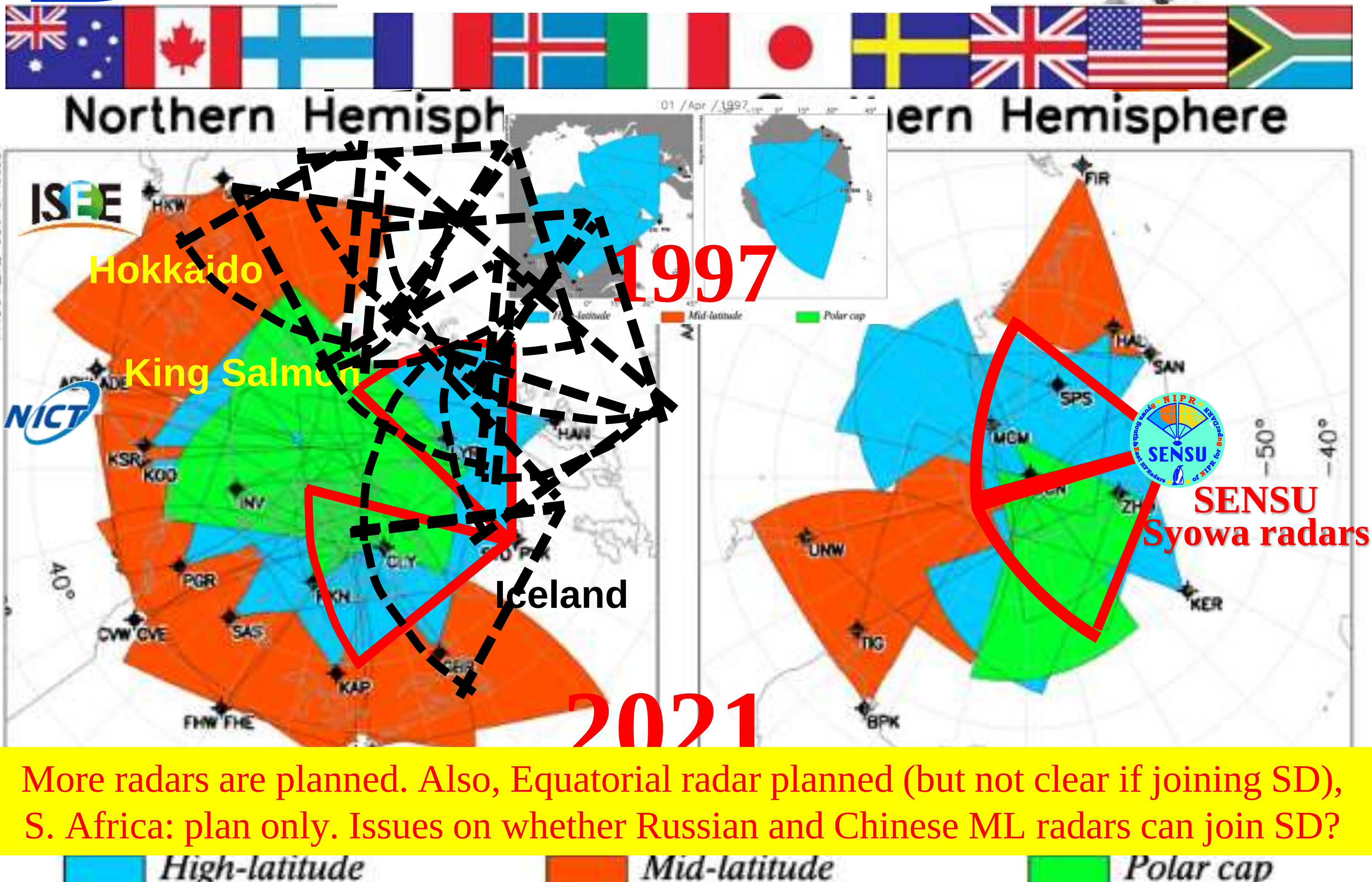
0) **Line-of-Sight Doppler Spectrum**
1) V_{LOS} in global 2-D in 1-2min resol.
⇒ E (in F),Φ, Φ_{PC} , Reconnection Rate.
⇒ MHD waves, **neutral wind velocity**
2) **echo power**
3) Doppler **Spectral Width (ΔV)**
decorrelation time, FAIs, regional identification
4) Dynamic Doppler. Spectrum
multi-peaks? wave influences? **–FAI/plasma insta.** info
5) elevation angle (AOA) by interferometer
⇒**echo height**
6) Ground scatter (low V_{LOS} and low width)
⇒(skip dist./foF_2, MHD waves, TIDs, Sea state
7) **MHD waves**
⇒no spatial integ. (v.s. ground mag.)
8) **FAC**s *(if combined w/ other info.)*
9) D/E/F region **irregularities (FAIs)**
10) **atmospheric waves** (TIDs, tides, GWs…)
11) **neutral winds in MLT region**
12) **Sea** surface waves, sea flows...
13) ...

Recent SD related issues

- More data! (data coverage): more radars&FOVs, mid&polarDARN, Siberian, Chinese, & equatorial radars to SD? Radars looking over Syowa and Iceland?!
- Older radar maintenance issues: refurbishment, license, budget, man power, Halley issue!
- Hardware variability and common software issues:
- RST 4.x released, Algorithm to fit ACFs: fitacf3
- Geolocation, Interferometer, range offset issues: NR meteor, D,E-F region
- E field, Velocity validation (Why artificial FAIs & sye no underestimate?)
- More reliable space weather potential maps (& real time product issues)
- Satellite collaboration and scheduling issues: VAP/ERG/THEMIS/e-POP/SWARM/…
- Plasma instabilities, FAIs, heating..., global and meso-scale comparison or meso-scale in global context Conjugacy Long-term changes...
- Other physical parameters – I-M mapping @ ionosphere
- SD Japan activities, SD WG activities
- More papers: citation >1000/year!
- Individual radar issues… SENSU:aged Tx & antenna w/ non-flat ground plane and sensitivity, imaging, interference, radio authority license issue, etc…

More data-more SD radars/FOVs?

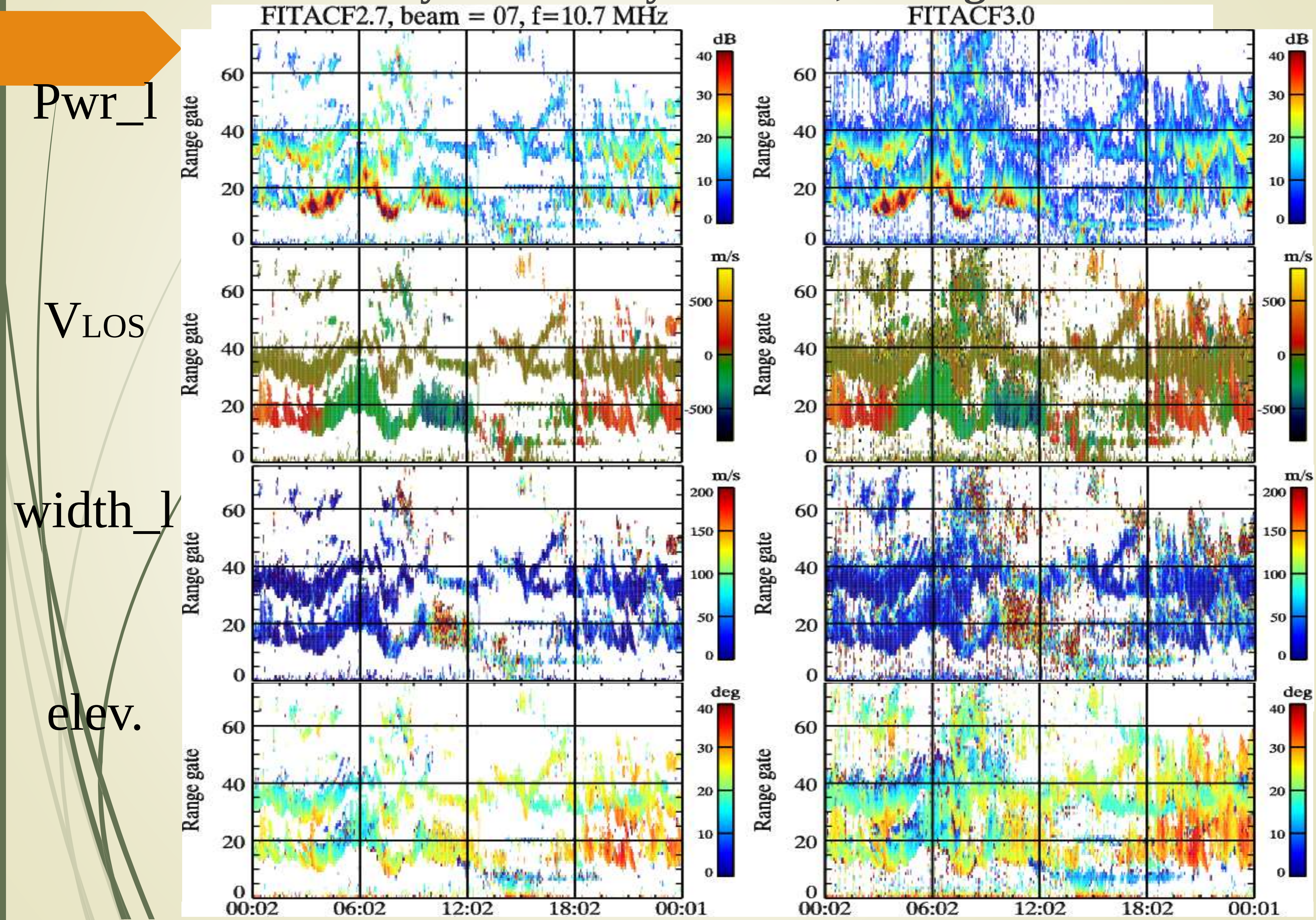
…in near future?…



More radars are planned. Also, Equatorial radar planned (but not clear if joining SD), S. Africa: plan only. Issues on whether Russian and Chinese ML radars can join SD?

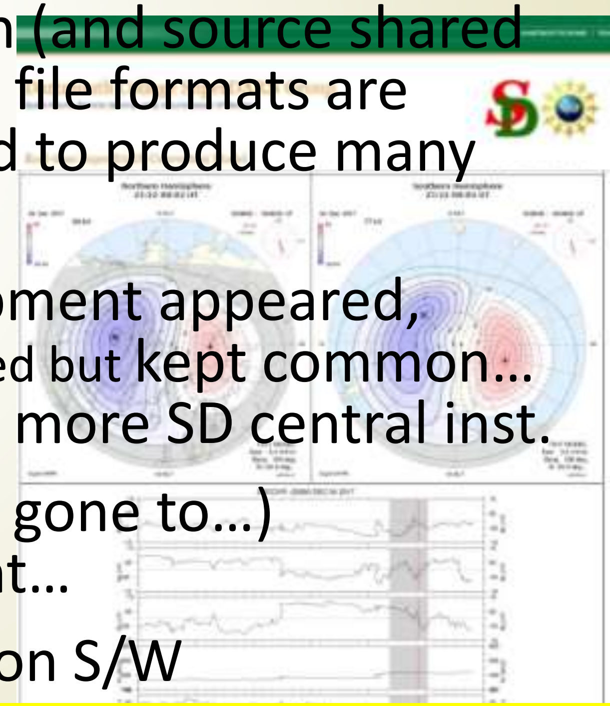
fitacf3 – improved & much more fitted data

- fitacf3 ready & formally released, testing started.



Hardware variability and common software issues

- Originally, SD radars had some hardware variabilities (several institutes/univ. developed since pre-SD era)
- But all the information esp. I/F box between H/W and S/W were well discussed, defined and shared.
- Radar Operating Software (ROS) was common (and source shared with analysis software (RST)) and thus output file formats are common – essential key for SD to glow up and to produce many collaborative scientific results
- These days many individual H/W & S/W development appeared, 2 OSes, many versions of ROS, file formats updated but kept common… causing maintenance issues after JHU/APL no more SD central inst.
- S/W development by younger students (soon gone to…) – WGs activities have become more important…
- Considerable efforts done for improve common S/W
- APL quasi real-time map display gone –



Just revived@ Dartmouth!

Older radar maintenance issues: sometimes fairly serious…

- New radars still increasing and expanding, but more number of older radars maintenance become harder…
- Tx/Rx Refurbishment (Ice W)
- Aged antenna (Iceland E, Syo)
- Radio authority license issue
- Budget
- Man power (inc. initial PIs retirement)
  French J-P. Villain: Ice W
  Australian, S.A.,…

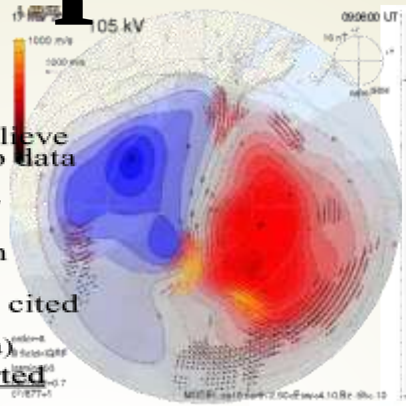
- Halley base (ice-shelf crack-evacuation) issue… (but Folk Island revived…) etc.
- All information tried to be shared, discussed, helped among us.

Velocity/E/Φ_{PC} validation issues

- SuperDARN E fields (in F region) : basically in good agreement with other measurements (Ruohoniemi et al., 1995)
- But they seems underestimated (at least show smaller values than other observational results)
- Very good agreement in case of E fields in artificial FAIs
- Surprisingly Syowa East data seems almost no underestimate statistically in spite of its location at auroral region – still unknown issue.
- Several years ago, it was recognised that it is because V or E calculated from SD assume ionospheric refractive index=1 that causes the issue.
- Several approaches to obtain the refractive index/ true V, E were made, e.g. 1) using AOA data to calc refractive index at backscattered region under some realistic assumption, and 2) using dual frequency operation to obtain refractive indices – both have merits that only SD data is required to solve the issue.
- But in 2), direct measurement using dual freq. obs can never provide the answer due to statistical uncertainty of the obs. and possible echo location difference due to different ray paths and temporal variation (if stereo mode not used) – only statistical treatment can be made using 2).
- In 1), interferometer calibration is essentially important and required.
- Apparently affect map_potential results and Φ_{PC} – still struggled to...

More reliable potential map?

- SuperDARN global high-temporal resolution ionospheric potential map (in quasi real time)
  – early Ray's dream – came true…
  – very much succeeded
- At a first glance at early SD workshop, not small number of participants claimed that they can not believe the results! because there are so wide area where no data are available;-|
- But it became gradually accepted and as number of radars increased, very much widely used for space weather science and making new models etc though underestimated E issues etc were identified
- Used in many scientific (and/or applied) researches cited in many areas / papers, indeed…
  (normally careful use of maps fitted with enough real data)
- <u>Can we really believe the results? Very much distorted and jump one time step to next, etc…?!?</u>



Model Parameter	Description
SML	SuperMAG auroral *AL* index
SMU	SuperMAG auroral *AU* index
SML_s	SML for sunlit locations
SMU_s	SMU for sunlit locations
SML_d	SML for dark locations
SMU_d	SMU for dark locations
SMR00, SMR06, SMR12, and SMR18	SuperMAG partial ring current indices
SYM-H and *SYM-D*	IAGA defined ring current indices
ASYM-H and *ASYM-D*	IAGA asymmetric ring current indices
Solar zenith angle	Solar zenith angle (degrees)
PC	Polar cap magnetic index

Table 1. List of Regression Model Parameters

- Number of problems on current method:
  - Current method need to put model deta in the gaps (no SD data) area to enable us to spherical cap harmonics fitting analysis (SCHFA)
  - Used driver model: classified by IMF magnitude and clock angles – meaning it assumes causality!:
    - IMF variation @ L1 propagate to Earth as a plane wave (w/o structure)
    - Internal magnetospheric processes are excluded (ignored)
    - No delay btw IMF 'cause' & any effects/results on the system
    - States of the system are uniquely characterized by IMF
    - No information included related to history of M-I system (ignored)
    - Time delay/response – unknown, possibly location dependent – ignored…
  - Basic function fit:
    - Coordinate system used is AACGM – non orthogonal partly causing the problem (distortion, etc), too.
    - Boundary conditions are unnecessarily restrictive (H-M boundary)
- There is another way to apply statistical regression methods
- ■<u>Colin Waters, J.W. Gjerlov, M. Dupont and R.J. Barnes Global maps of ground magnetometer data, JGR, 2015.</u>
- For SuperMAG data, multilinear regression (MLR) using least square fit criterion and Bayesian regression methods – coupled with Principal Component Analysis (PCA).
  - <u>PCR (Principal Component Regresion)</u> method.
- Drivers of linear models: avoid difficulties with using SW data chooses from a set of magnetic indices (& solar zenith angle).
  Also try to confine # of indices (basic orthogonal k eigenvectors) to suit statistical confidence level > 99%.
  (Also tried with Vsw, IMF, Pdyn, energy coupling func, etc…
  -> overfitting and unknown time delay -> no success!)
  Important to provide uniform gridded coverage w/o attempting to discern causal relationships.
- PCR process fills in spatial data gaps -> enable SCHA to obtain global maps. -> compared with obs data with very good agreement with errors whose magnitude are comparable to original statistical uncertainty – means successful!!.
- This method can be applied to making new SD map potential! The very smooth and reasonable potential maps and temporal evolution with good agreement with measured data were shown – great result!
- They aims to combine SuperMAG, SuperDARN and AMPERE (>70 Iridium satellite for FAC measurements) to obtain global ionospheric conductance map – key to understand the real MIT coupling.
- SuperDARN potential map will be revised at some point using this new novel way forward…? It will affect many scientific researches and even the data interpretation.

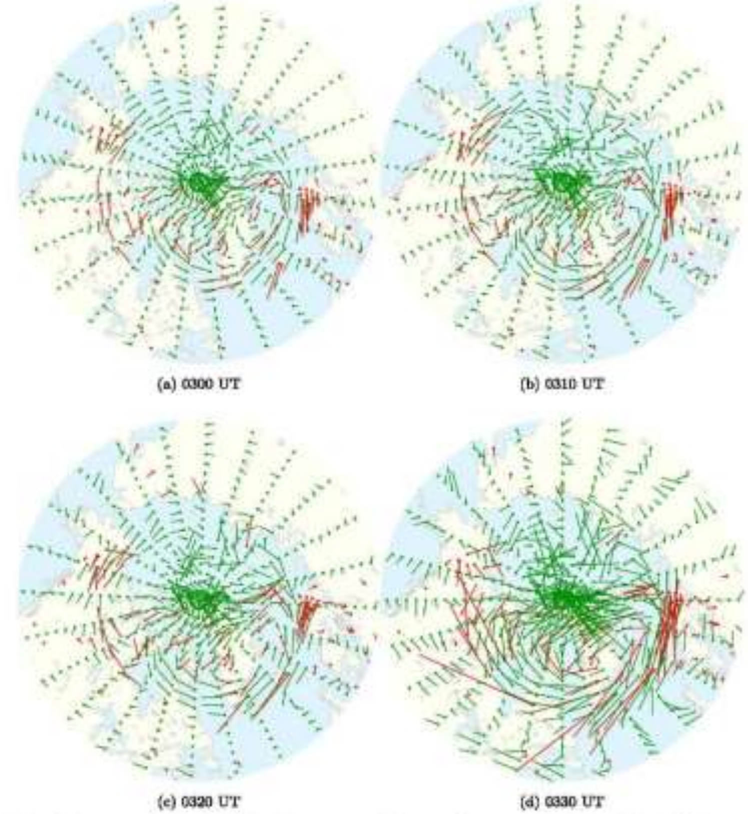
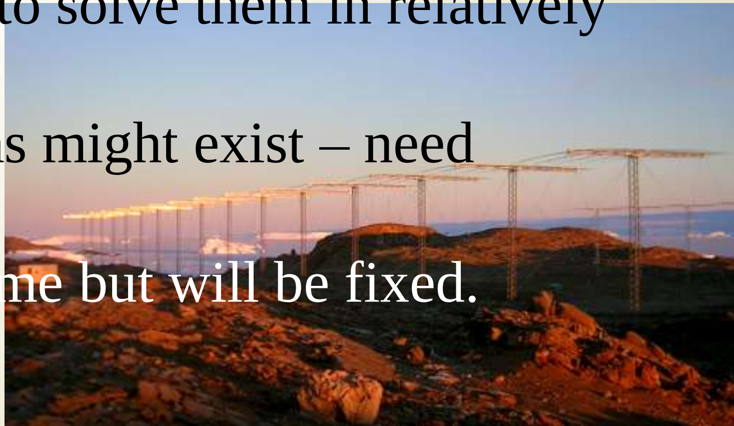


Figure 5. Sequence of maps of the horizontal components of the ground magnetometer data for 0300–0330 UT, 28 October 2001. The red arrows show the input data from SuperMAG, while the green arrows are from the spherical cap basis function fit.

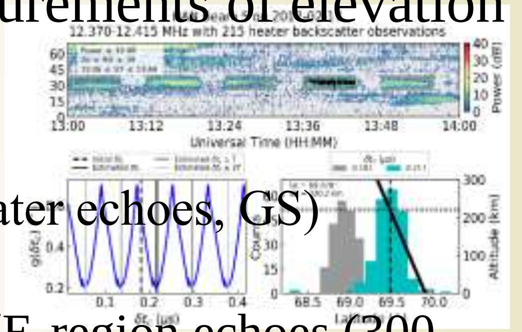
Geolocation, interferometer, range offset issues

- Geolocation (of ionospheric backscatter):
- Interferometer:
  important for esp. near range meteor, D,E-F region studies,
  geo-locations also for choosing only F region for map_pot analysis.
  refractive indices and correct Vlos and E fields measurement
  - only a very limited # of radars are well calibrated
  - Using meteors
  - Using SD elevation angle data themselves to determine "*tdiff*" value
    Using RTI plots to see range gap to determine range offset
  - non-flat ground effect – unknown
  - Tx freq and temperature dep. and long-term variation
  - SD2017 workshop triggered tentative WG to solve them in relatively short time scale – started…
- Range offset issues: several unclear problems might exist – need investigation again.
- Were recognised as very important – need time but will be fixed.
  - also improve neutral wind measurements

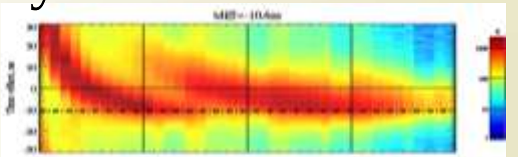


Elevation Angle Task Force – interferometer calibration

- SD workshop 2017 (June, 2017 in Italy): PI agreed to set up a TF.
- to produce a clear proposal for how to calibrate measurements of elevation angles



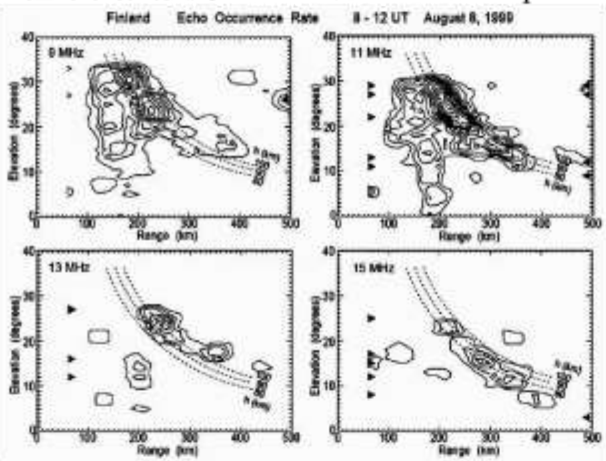
- Methodology
  - #1: Angeline Burrell’s Known Location method (e.g., heater echoes, GS)
  - #2: Gareth Chisham’s Meteor Scatter method
  - #3: Pasha Ponomarenko’s zero elevation scatter method (E-region echoes (300-800km)
  - #4: Simon Shepherd’s ground-sea scatter’s method (GS)
  - #5: Simon’s method based on Chisham Virtual Height (VH) model
- Comparative analysis of calibration (Tdiff) estimates by different methods
  - Reasonably good agreement (but scattered)
  - No significant seasonal variation, …



- Proposal to how to calibrate interferometer will be given hopefully soon
- accuracy, freq. dep., other issue (range offset etc), how often cal should be done, … should also be clearly understood and estimated.

PMSE obs w/ SD

極中間圏夏季エコー（**P**olar **M**esospheric **S**ummer **E**choes）



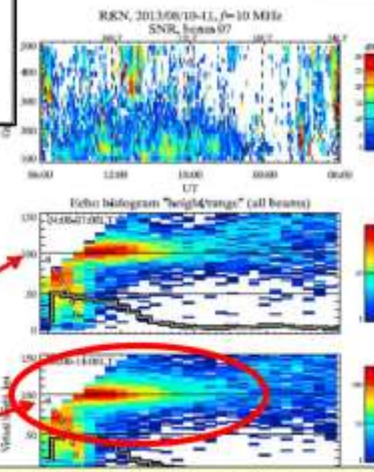
Contour maps of the echo occurrence rate of near-range echoes, for four SuperDARN operation frequencies (9, 11, 13, and 15 MHz), as a function of range and elevation angle, indicating the altitude of PMSEs. The contour lines have intervals of 0.5 for 9 MHz and 0.25 for other frequencies. The relationship between range and elevation angle for three constant altitudes (h = 80, 90, and 100 km) is represented by the dashed curves. This figure is reproduced from Ogawa et al. (2005), copyright by the European Geophysical Union

Ogawa, et al., Ann. Geophys., 2003

- 極域の夏に、中間圏界面高度(D層高度、地球上で最も低温の領域)に出現。
- 約90kmの高度に出現する、19世紀末に初めて見つかった夜光雲との関連指摘
- 地球温暖化（上層では寒冷化）や気候変動と関連していると想像されており、注目を集めている。
- SDでも季節変化、原因、温暖化との関連等の研究…

Reassessment of SD Near range echoes

- Near Range Echoes (NREs): r<500 km. Ponomarenko et al [2016]
  - Statistics/morphology for range gate 1 for 5 radars world wide
  - Unexpected occurrence peak at early pm, particular in summer
- Three populations found during the single 15-km pulses day.
  - Morning ($h_v \approx$100 km)
    - Meteor trails
  - Midday summer ($h_v \approx$100 km)



- **1 population of near range echoes seen around summer noon (not meteors): has average height >~100km (results from interferometer calibration).**
- **Ogawa et al 2002 reported Syowa and other radars detected PMSE in the same condition meaning height ~<90km.**
- **Reassesment of SD/SENSU near range echoes is important & required!**
  - **・Interferometer calibration (to be established in SD community very soon)**
  - **・Comparison with PMSE with VHF radar at Syowa, NH SD NREs…**

JGR Space Physics

RESEARCH ARTICLE

10.1029/2019JA027473

On the Origin of Far-Aspect Angle Irregularity Regions Seen by HF Radars at 100-km Altitude

FAIR

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J.P. St-Maurice and Nishitani, JGR, 2020

Key Points:
- A Gradient Drift instability at the bottomside of the ionosphere triggers decameter structures at 100 km in the afternoon sector
- The instability evolves decaying far-aspect angles because the frequency is a (weak) function of altitude, much like "HAIR" echoes higher up
- The instability mechanism favors a summer afternoon occurrence at higher latitudes, but its effect should be visible at times at lower latitudes

Supporting Information:
- Supporting Information S1

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Citation:
St.-Maurice, J.-P., & Nishitani, N. (2020). On the origin of far-aspect angle irregularity regions seen by HF radars at 100-km altitude. *Journal of*

Abstract A special summer midday population of echoes has been reported by high-frequency (HF) radars at ranges less than 300 km. These echoes come from a narrow altitude region near 100 km. Their spectral width indicates that they decay at a rate controlled by ambipolar diffusion. We label the echo regions as "far-aspect angle irregularity regions" by contrast with "high-aspect angle irregularity regions" (HAIR) documented in the past. Both types are from structures that decay after an initial growth phase. We show that each type decays at a rate controlled by the altitude where it is produced. The large aspect angles and decaying process come from a monotonic aspect angle increase due to a weak altitude dependence of the "eigenfrequency." HAIR echoes are produced by the decay of otherwise standard E-region irregularities. However, HAIR echoes are usually not far-aspect angle irregularity regions because the latter are the result of a Gradient Drift Instability in the bottomside of the E-region where the vertical density gradients can sometimes be so strong that a less than 10 mV/m northward electric field is able to destabilize 10-m structures in the afternoon sector. Owing to smaller dip angles, the Gradient Drift Instability requirement is smaller at midlatitudes although it still needs a combined electron drift and eastward neutral wind contribution of the order of 100 m/s. With northward electric fields of 2 to 3 mV/m, the minimum midlatitude eastward wind requirement is of the order of 50 m/s.

No physical connection with PMSEs at all? How can yearly variation be explained? Solar variation? (not H/W issue?)

FAIR NOT by meteors, E echoes, PMSEs and atmospheric turbalance!

FAIR created by **GDI at the bottom side of ionosphere**
GDI triggered in summer noon to afternoon sector by combination of
1. steep vertical density gradients (due to sunlit condition),
2. Northward E >~10mV/m, and 3. Eastward neutral winds.

Reassesment of SD near range echoes

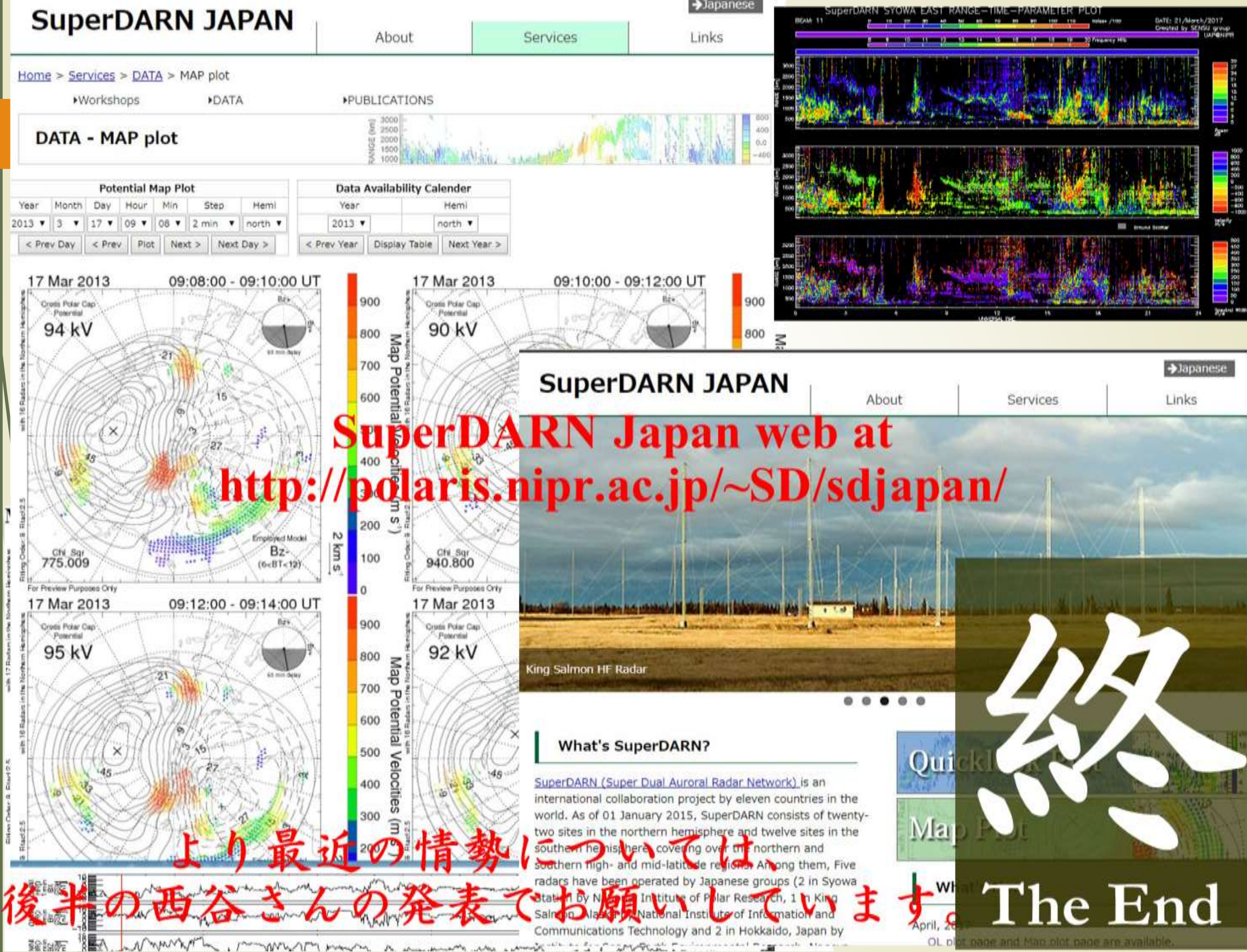
Recent SD related issues

- More data! (data coverage): more radars&FOVs, mid&polarDARN, Siberian, Chinese, & equatorial radars to SD? Radars looking over Syowa and Iceland?!
- Older radar maintenance issues: refurbishment, license, budget, man power, Halley issue!
- Hardware variability and common software issues:
- RST 4.x released, Algorithm to fit ACFs: fitacf3
- Geolocation, Interferometer, range offset issues: NR meteor, D,E-F region
- E field, Velocity validation (Why artificial FAIs & sye no underestimate?)
- More reliable space weather potential maps (& real time product issues)
- Satellite collaboration and scheduling issues: VAP/ERG/THEMIS/e-POP/SWARM/…
- Higher temporal / spatial resolution? (imaging radar etc.)
- Plasma instabilities, FAIs, heating..., global and meso-scale comparison or meso-scale in global context Conjugacy Long-term changes...
- Other physical parameters – I-M mapping @ ionosphere
- SD Japan activities, SD WG activities
- More papers: citation >1000/year!
- Individual radar issues… SENSU:aged Tx & antenna w/ non-flat ground plane and sensitivity, imaging, interference, radio authority license issue, etc…

国内SD core研究機関による共同研究契約とSD Japan Web

- SuperDARNは、国際協力と競争のバランスの上に発展。SD宇宙天気図やSD内での日本の活動は国際的に広く認知。引用論文数は年間1000件を越えるに至っている。
- SD日本teamのproductivityを上げる為、共同研究や情報共有等協力体制を強化する為に、国内3PIを含む主要core 5研究機関で共同研究契約締結(2016/10)。
- Core研究機関の協力を得てNIPRでSD Japan Webを立上げ、定期的会合を行い、全SD dataのdatabase、QLやPotential map図の提供を行い、共同研究の推進に貢献。特に、あらせproject(ERG-SC)やIUGONETと密に連携。

SD Japan @ http://polaris.nipr.ac.jp/~SD/sdjapan/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Data Availability Calender
17 Mar 2013 09:08:00 - 09:10:00 UT
17 Mar 2013 09:10:00 - 09:12:00 UT
17 Mar 2013 09:12:00 - 09:14:00 UT
Map Potential Velocities (m s⁻¹)
SuperDARN SYOWA EAST RANGE-TIME-PARAMETER PLOT
SuperDARN Japan web at
http://polaris.nipr.ac.jp/~SD/sdjapan/
より最近の情勢については、
後半の西谷さんの発表でお願いしています。
SuperDARN JAPAN
Japanese
About
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King Salmon HF Radar
What's SuperDARN?
SuperDARN (Super Dual Auroral Radar Network) is an international collaboration project by eleven countries in the world. As of 01 January 2015, SuperDARN consists of twenty-two sites in the northern hemisphere and twelve sites in the southern hemisphere, covering over the northern and southern high- and mid-latitude regions. Among them, Five radars have been operated by Japanese groups (2 in Syowa Station by National Institute of Polar Research, 1 in King Salmon, Alaska by National Institute of Information and Communications Technology and 2 in Hokkaido, Japan by
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The End