名古屋大・NIPR・NICT共催『極域・中緯度SuperDARN研究集会』於：名古屋大 2015/9/14-15

昭和SENSUイメージングレーダー現況報告
Syowa SENSU imaging radar

A. Sessai Yukimatu
NIPR/SOKENDAI

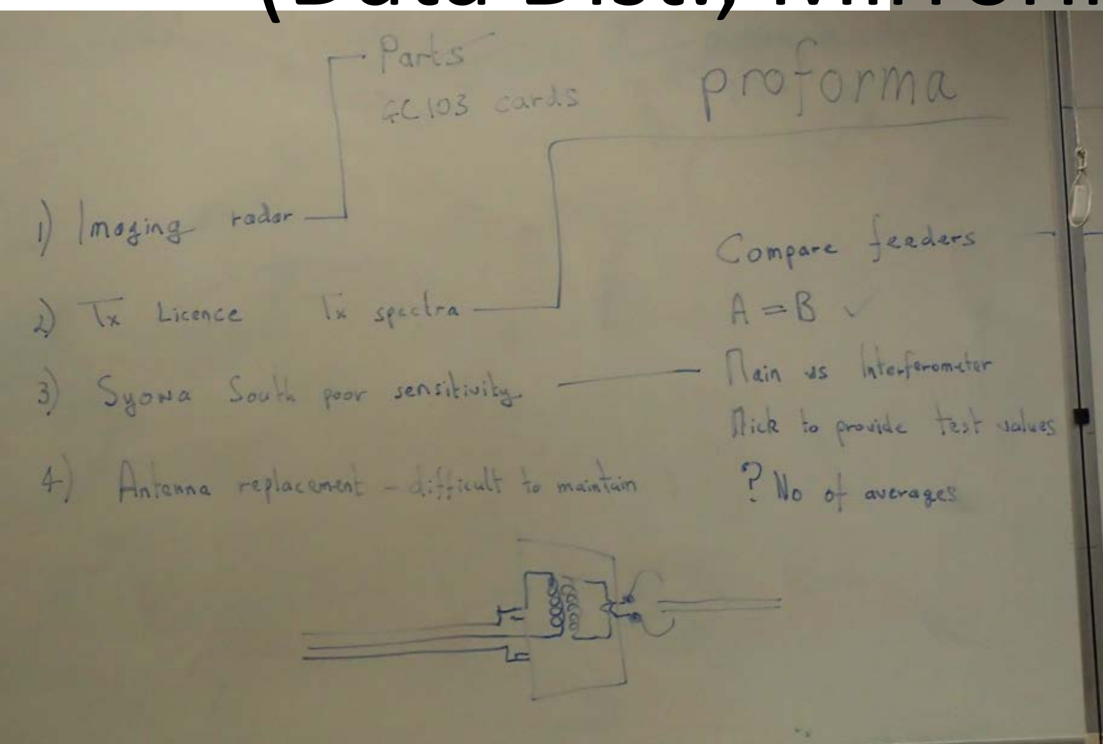
SENSU Syowa South radar taken by Mr. Yasuo Kato, a UAP member of JARE36 in 1995

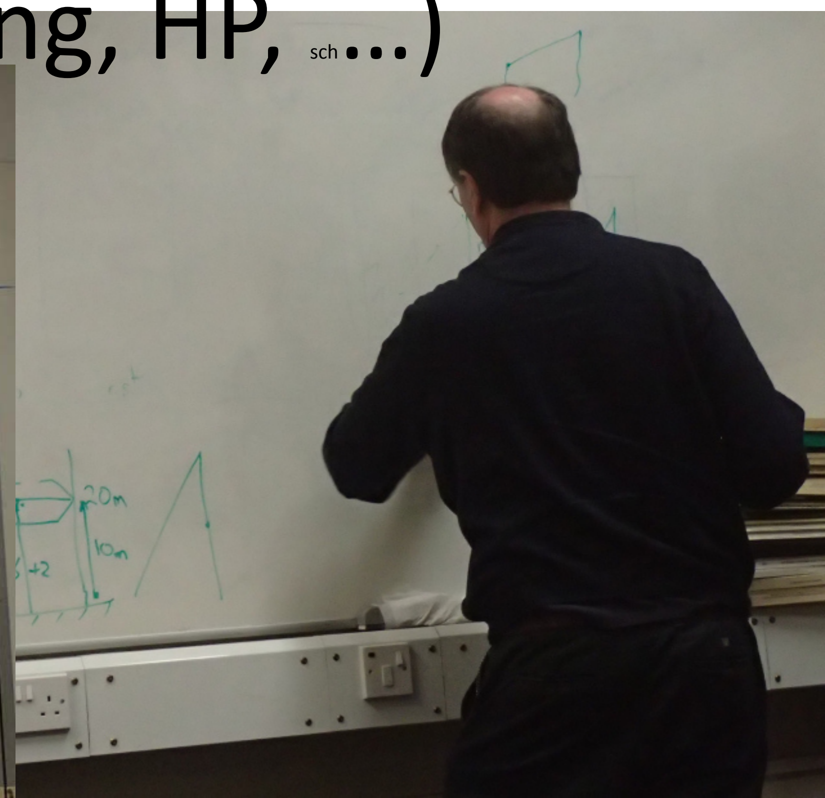
SENSU Syowa brief history

- 1989 Prof. Ogawa proposed to join HFR network
- 1995 SuperDARN started and NIPR joined
  Syowa South installed & started (JARE36)
- 1997 Syowa East installed & started (J37)
- 1999 Syowa South antenna reconstructed (J40)
- 2001- IQ sampling (TMS mode, meteors, OVS, FDI etc.)
- 2005 Syowa South stereo radar (J46)
  Syowa East interferometer added (J46)
- 2008 Syowa South digital Rx (J49)
- 2011-2016: JARE phase XIII (J52-57)
- 2016 Syowa South imaging radar (J57)
- 2017-2022: JARE phase IX (J58-63) project plan…

Syowa current issues

- Imaging radar
- Tx license update (must be solved by 2021)
- S. South sensitivity issue
- Antenna replacement
- ・・・(Data Dist., Mirroring, HP, sch…)





電波法改正対応

・電波法改正対応:

2005(H17).12.1無線設備規則（無線機器スプリアス規格）改正。

2007(H19).11.30以前免許取得の物は、改正後のスプリアス規格で検査を受け免許申請を行っていないor適合しない無線局になる。

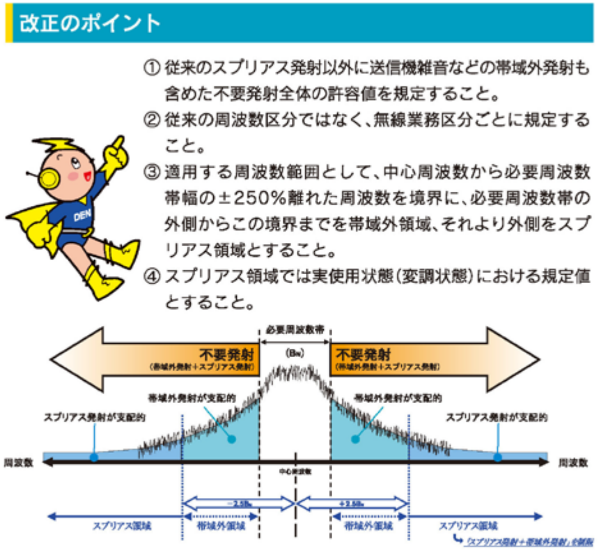
規格不適合局は2017(H29).12.1以降は再免許不可。経過措置期限も最長2022(H34).11.30迄。

SyowaS&Eの次回免許更新は

radar　最初の免許 次回更新　　措置必要期限
旧S(1):1994(H6).8.29
現E(2):1996(H8).
現S(1):2004(H16).

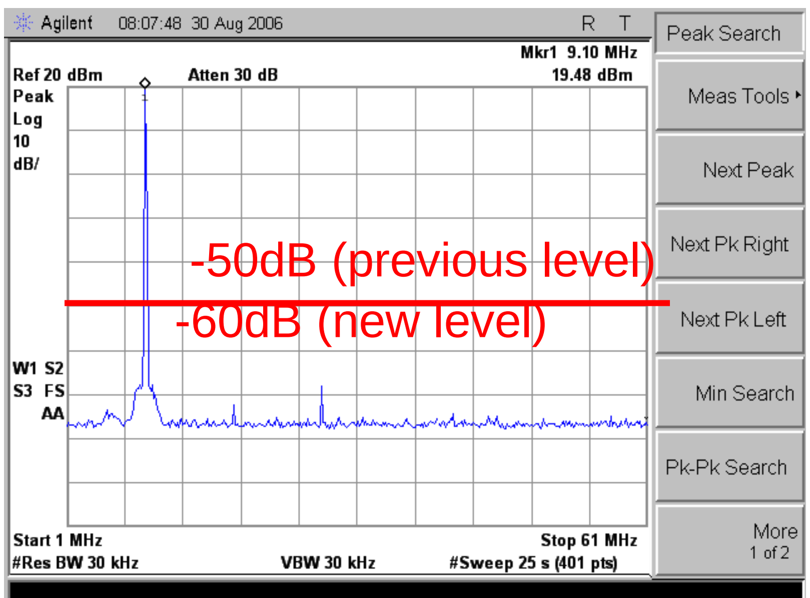
・Hokは2006(H18)か2007(H19)だが
新基準で免許取得でOK!!

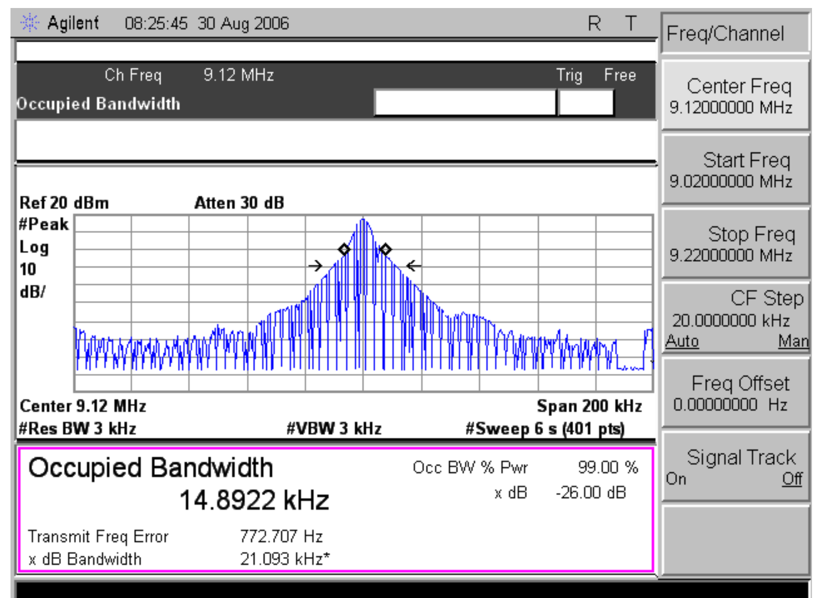
・KSRは米国設置で国内法無関係でOK.



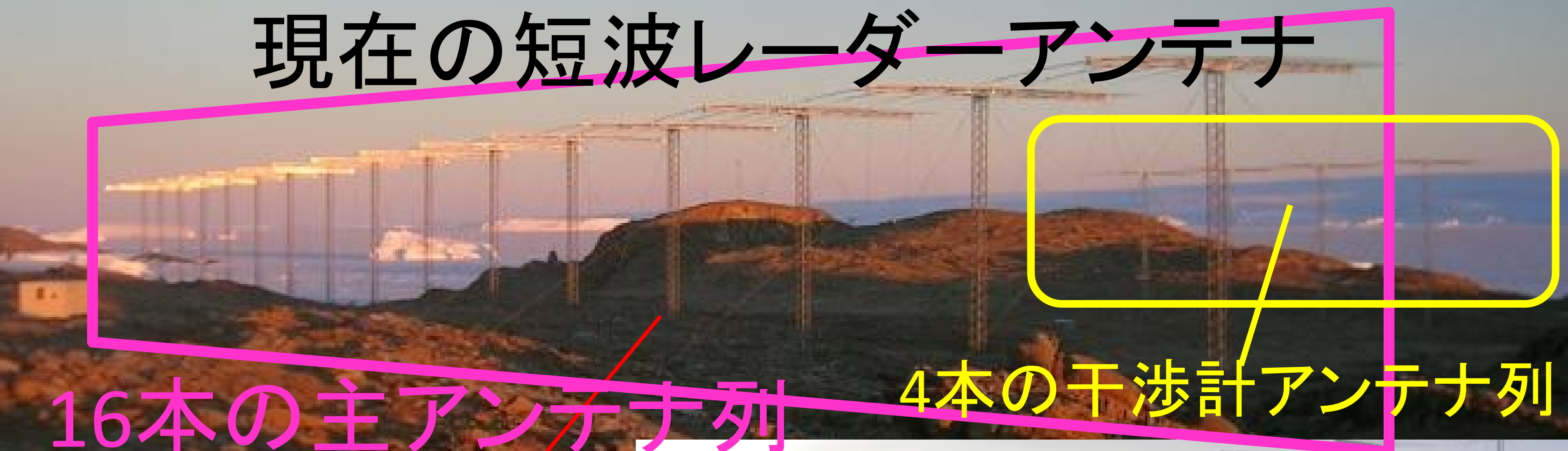
西谷さん2007発表資料より

HokE License test Nov. 2006





現在の短波レーダーアンテナ



※主アンテナ列と干渉計アンテナ列は
平行に約100m離れている。

アンテナ
鉄塔基礎

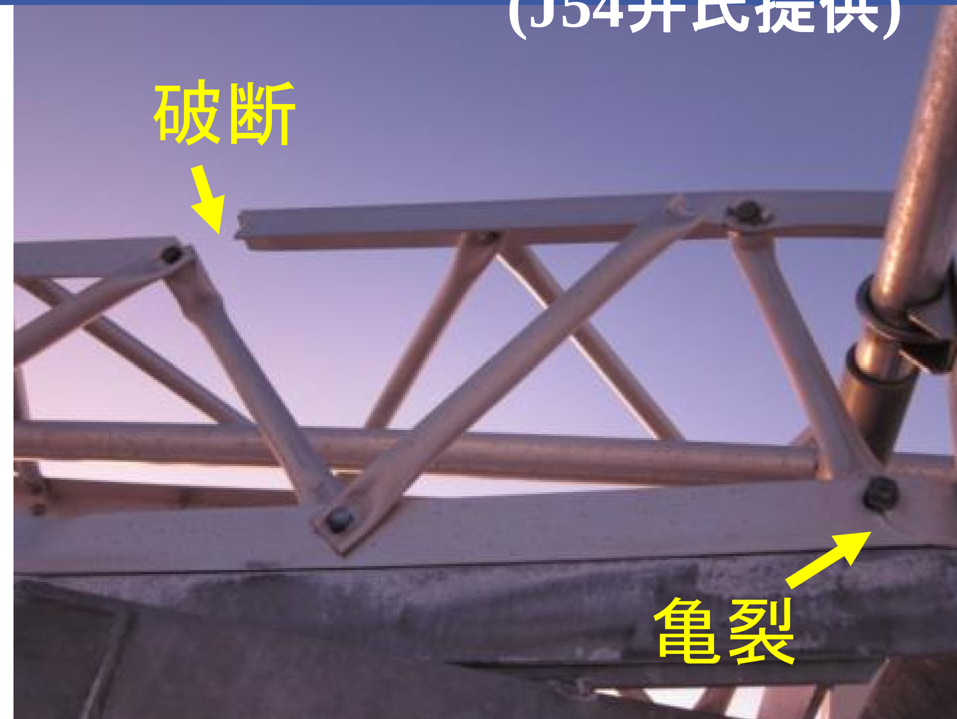
夏期及びブリ後のアンテナ点検と保守作業

SuperDARNレーダー (AP3 HF-J54→AP39-J55)

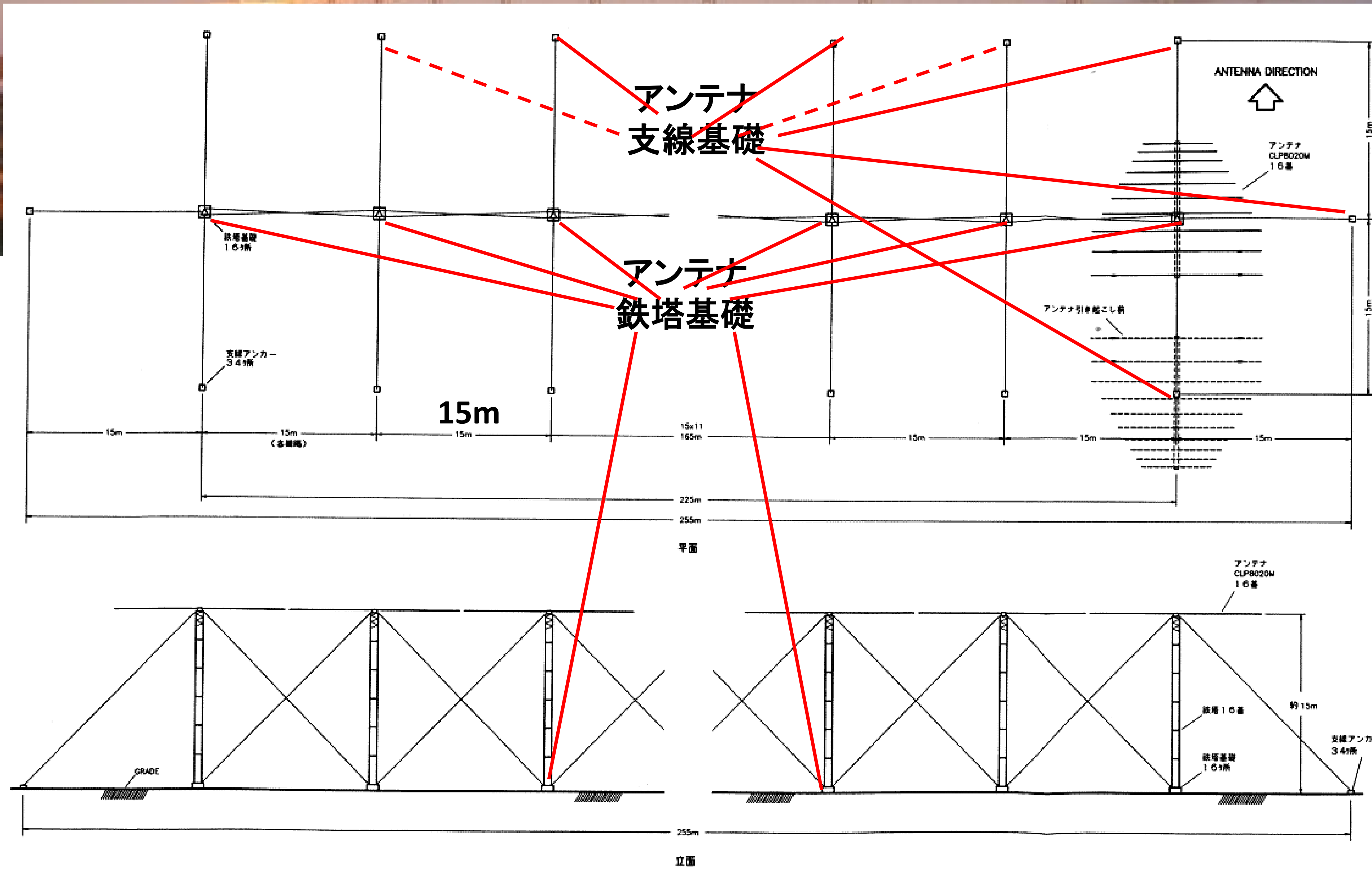
(J54井氏提供)

●アンテナブームトラス折損(J54)

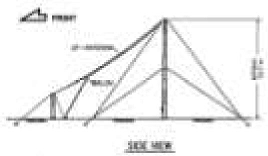
従来のエレメントやサドル、振留線等の破損ではなく、ブームトラスの折損が初めて発生。老朽化か、今後頻発の懸念。将来更新検討。



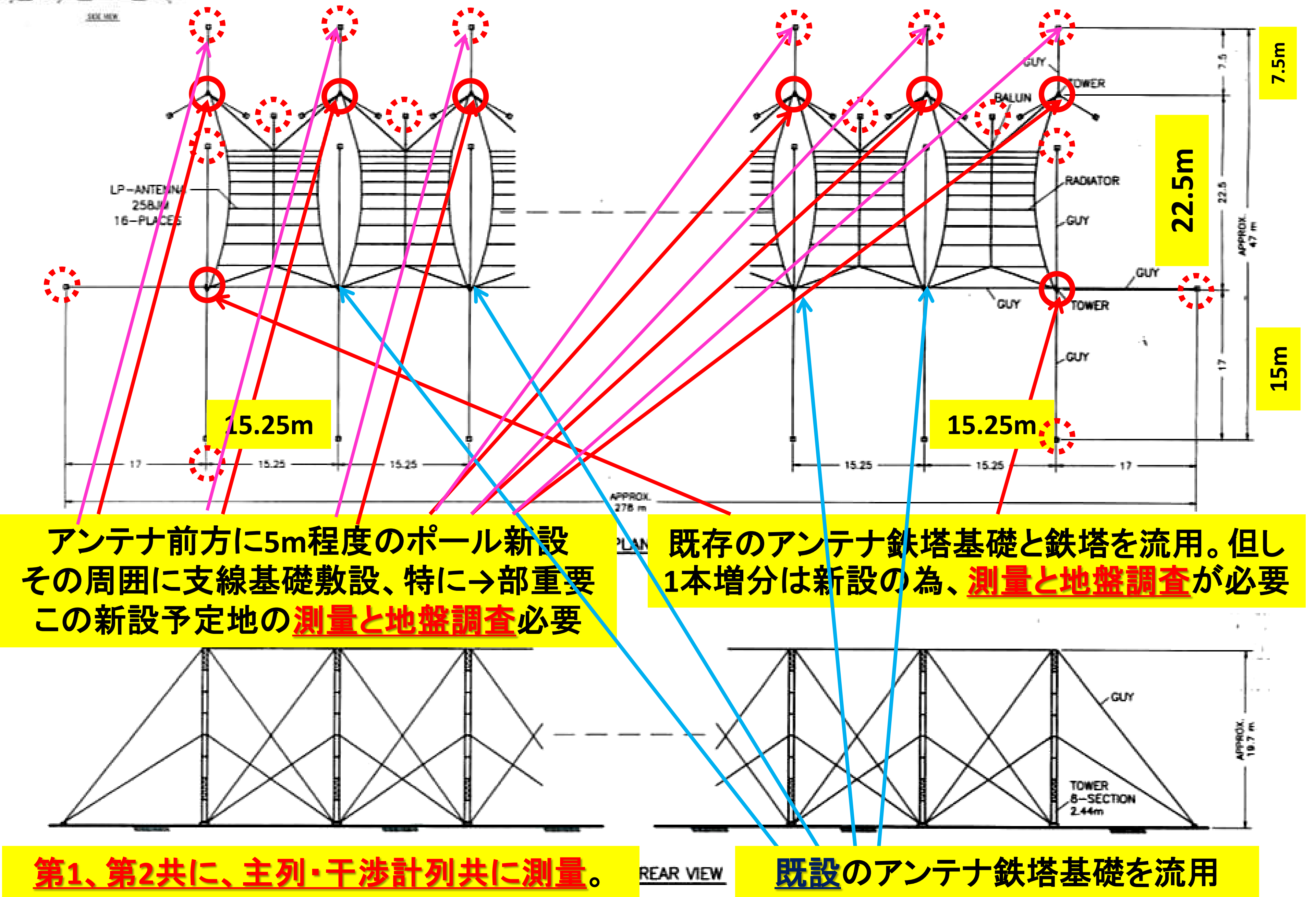
現在の短波レーダーアンテナ



更新アンテナ概略図

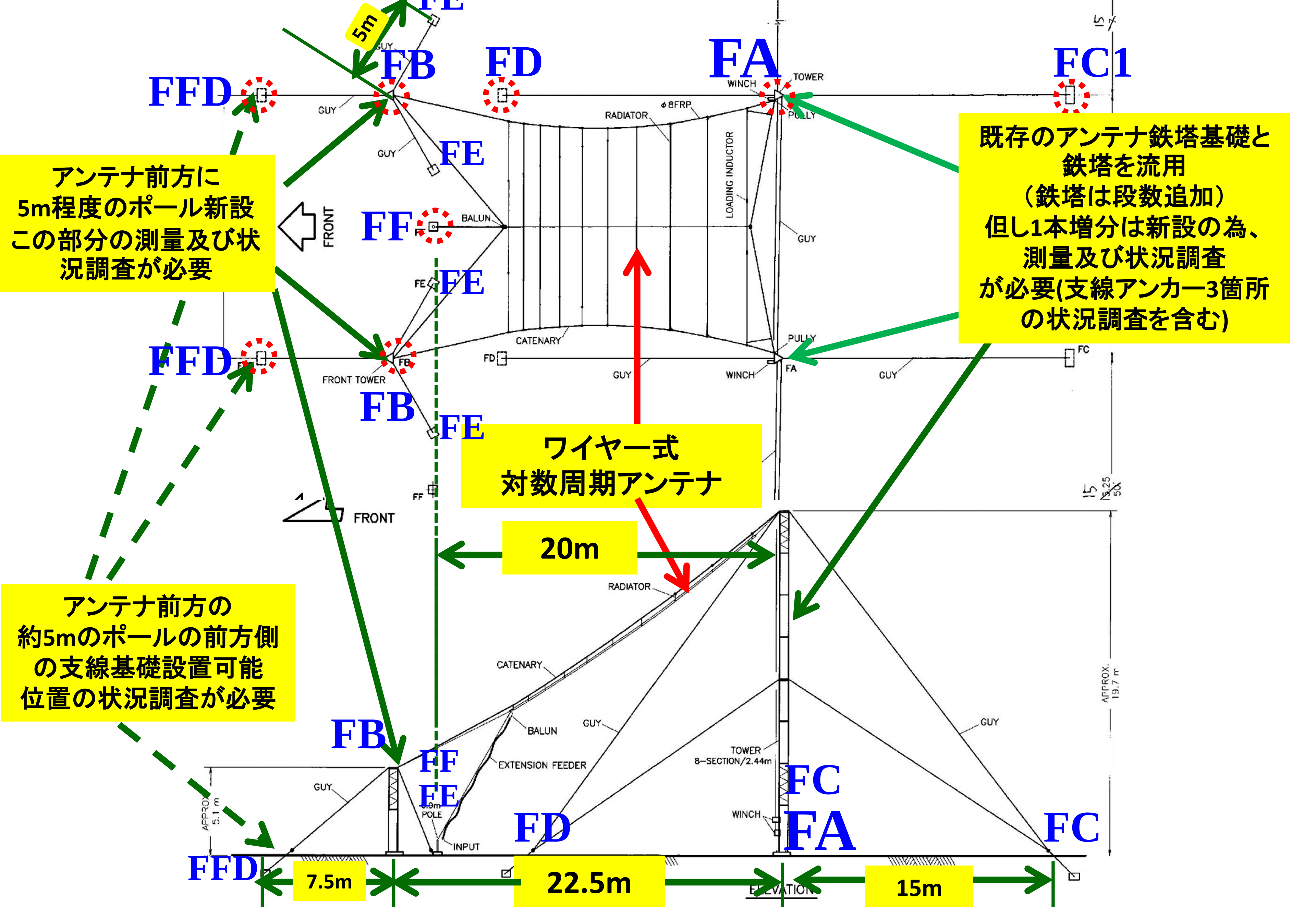


SIDE VIEW



7.5m
22.5m
15m
15.25m
15.25m
GUY
TOWER
BALUN
RADIATOR
LP-ANTENNA
258JJM
16-PLACES
7.5
22.5
17
APPROX. 47 m
15.25
APPROX. 278 m
アンテナ前方に5m程度のポール新設
その周囲に支線基礎敷設、特に→部重要
この新設予定地の測量と地盤調査必要
既存のアンテナ鉄塔基礎と鉄塔を流用。但し
1本増分は新設の為、測量と地盤調査が必要
APPROX. 19.7 m
TOWER
8-SECTION
2.44m
REAR VIEW
第1、第2共に、主列・干渉計列共に測量。
既設のアンテナ鉄塔基礎を流用

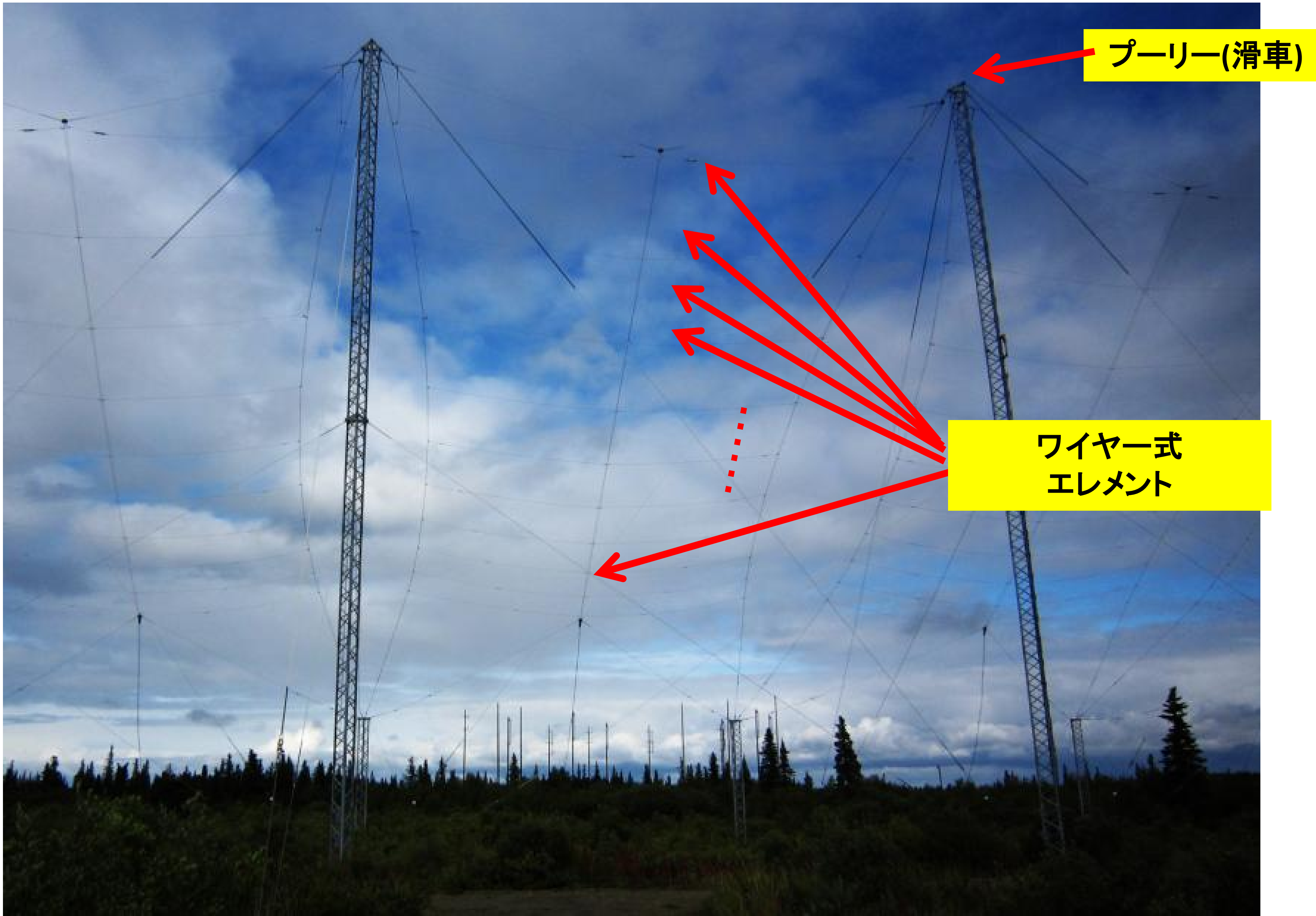
更新アンテナ案概略図



FC2
FC
5m
FE
GUY
FB
FD
FA
FC1
FFD
WINCH
TOWER
φ8FRP
RADIATOR
PULLY
LOADING INDUCTOR
GUY
FRONT
FF
BALUN
CATENARY
FRONT TOWER
FD
FA
FC
既存のアンテナ鉄塔基礎と
鉄塔を流用
（鉄塔は段数追加）
但し1本増分は新設の為、
測量及び状況調査
が必要(支線アンカー3箇所
の状況調査を含む)
アンテナ前方に
5m程度のポール新設
この部分の測量及び状
況調査が必要
ワイヤー式
対数周期アンテナ
20m
RADIATOR
CATENARY
BALUN
EXTENSION FEEDER
TOWER
8-SECTION/2.44m
WINCH
INPUT
POLE
APPROX. 5.1 m
APPROX. 19.7 m
アンテナ前方の
約5mのポールの前方側
の支線基礎設置可能
位置の状況調査が必要
7.5m
22.5m
15m
ELEVATION

更新案と同型のNICT Wireアンテナ@Alaska

NICTのAlaska King Salmon SuperDARN radarのwire antenna (NICT長妻氏提供)



更新案と同型のNICT Wireアンテナ@Alaska

NICTのAlaska King Salmon SuperDARN radarのwire antenna (NICT長妻氏提供)

更新案と同(類似)型の中山 Wireアンテナ@中山

PRICのZhongshan SuperDARN radarのwire antenna (PIのHu氏提供)

by Radio Propagation Institute of China

Fig. 2−2 Sketch map of the antenna

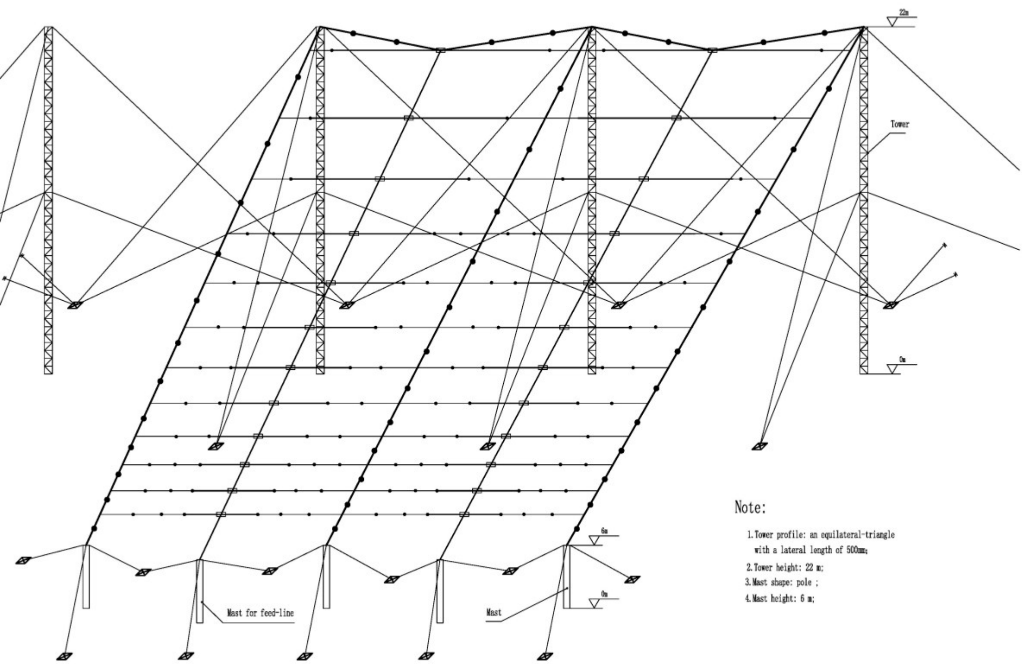
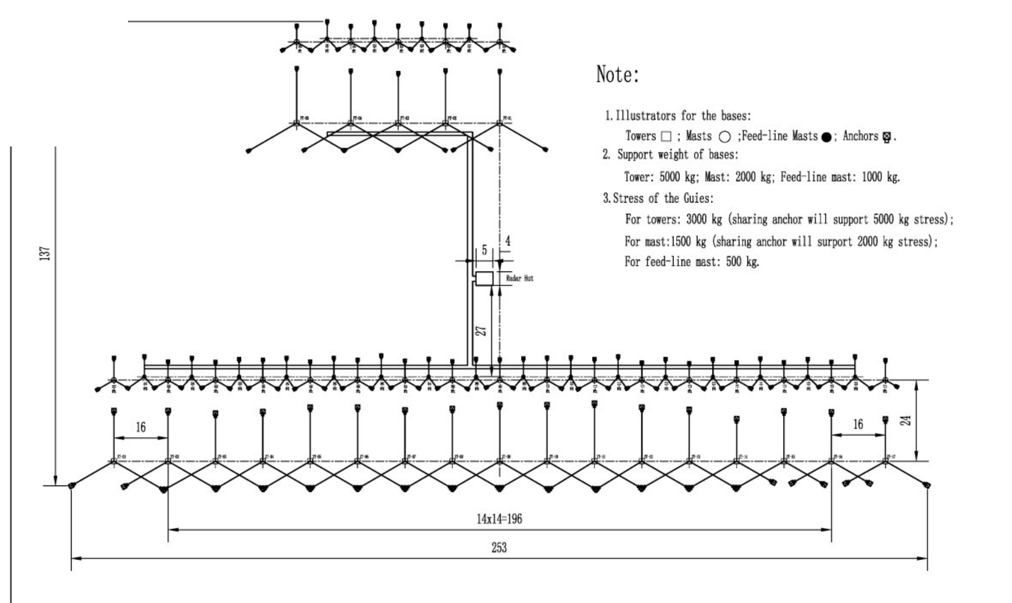
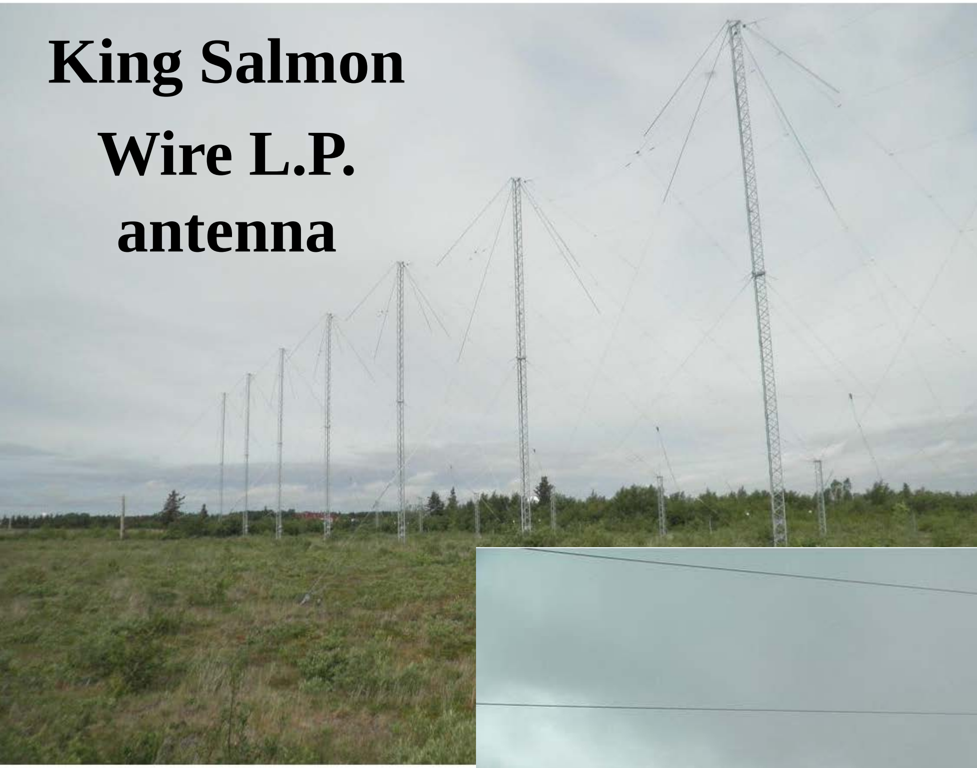


Fig. 2−1 Distribution of the bases and anchors for the whole array



Typical 3 types of SD antenna



King Salmon

Wire L.P. antenna

ing Salmon Array

Convensional Sabre type Antenna

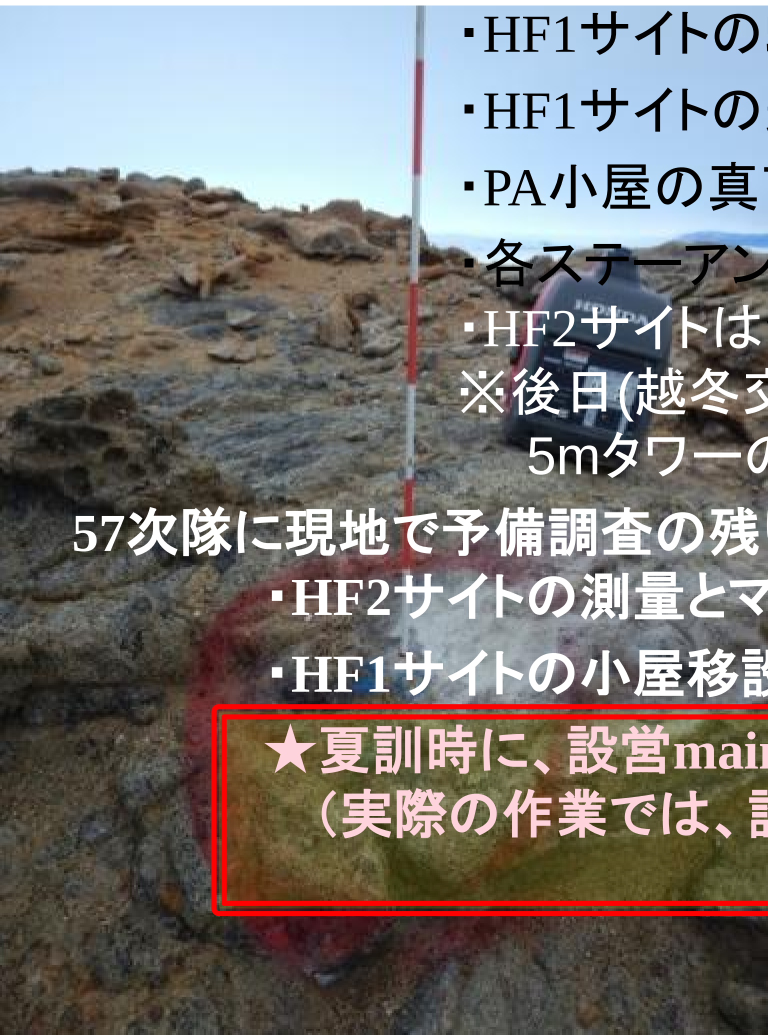
Rankin Intel TTFD (Twin Terminated Folded Dipole) antenna

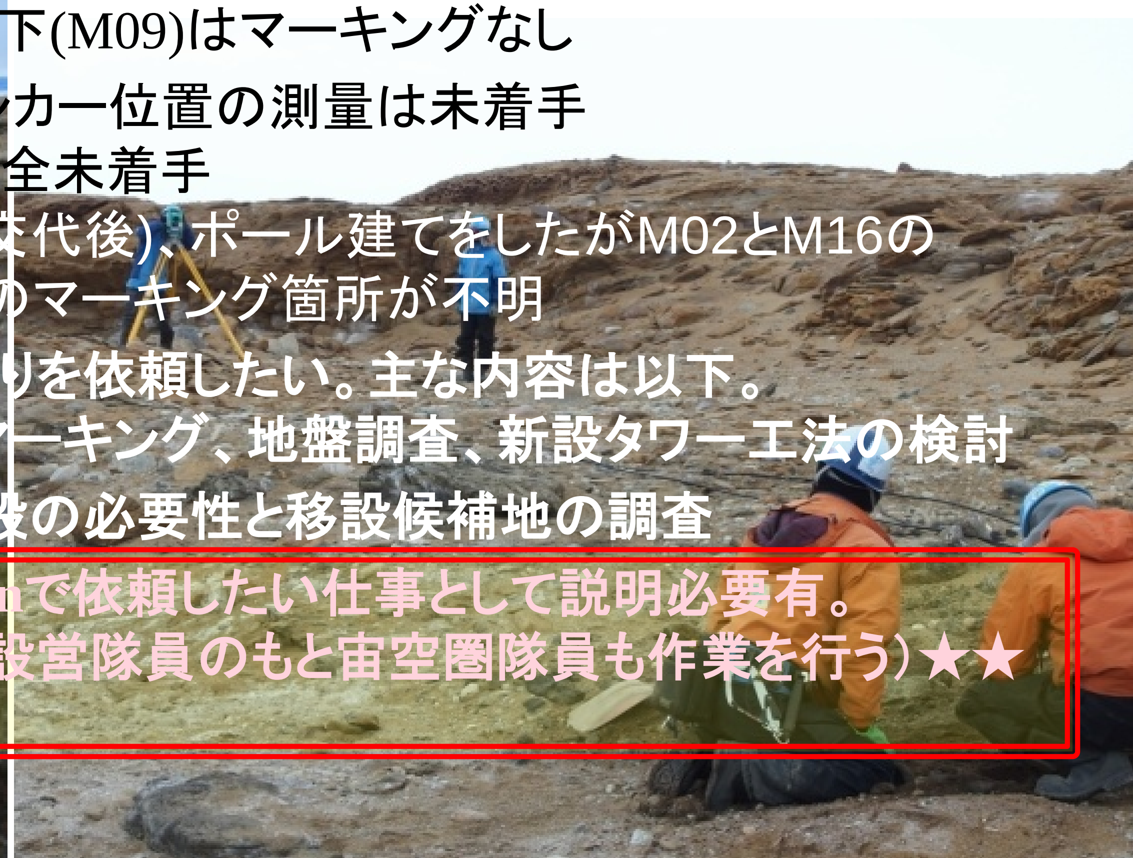
Good F.B. ratio

Maintenance not bad?

短波レーダー新たなアンテナ損傷と更新予備調査

54次隊でのアンテナブームトラス折損を受け、より保守性に優れたワイヤー式対数周期アンテナへの近い将来の更新の可能性を考慮し、実現可能性確認の為、55次隊に現地で予備調査（測量等）を開始。J55夏実施内容は、以下の通り。





- HF1サイトの5mタワー基礎中心マーキング完了(17ヶ所)
- HF1サイトの追加タワー1本(M01側)基礎中心マーキング完了
- PA小屋の真下(M09)はマーキングなし
- 各ステーアンカー位置の測量は未着手
- HF2サイトは全未着手

※後日(越冬交代後)、ポール建てをしたがM02とM16の5mタワーのマーキング箇所が不明

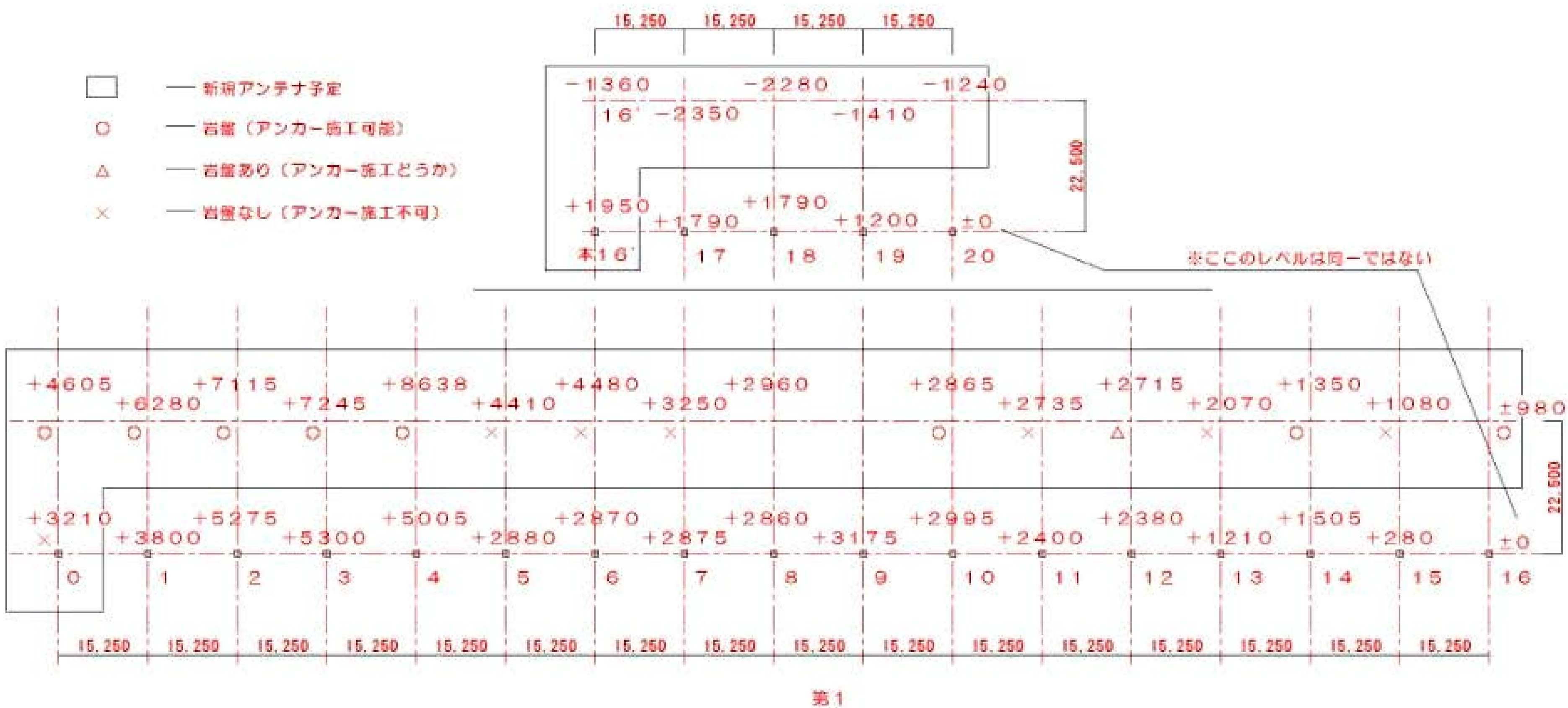
57次隊に現地で予備調査の残りを依頼したい。主な内容は以下。

- **HF2サイトの測量とマーキング、地盤調査、新設タワー工法の検討**
- **HF1サイトの小屋移設の必要性と移設候補地の調査**

★夏訓時に、設営mainで依頼したい仕事として説明必要有。
（実際の作業では、設営隊員のもと宙空圏隊員も作業を行う）★★

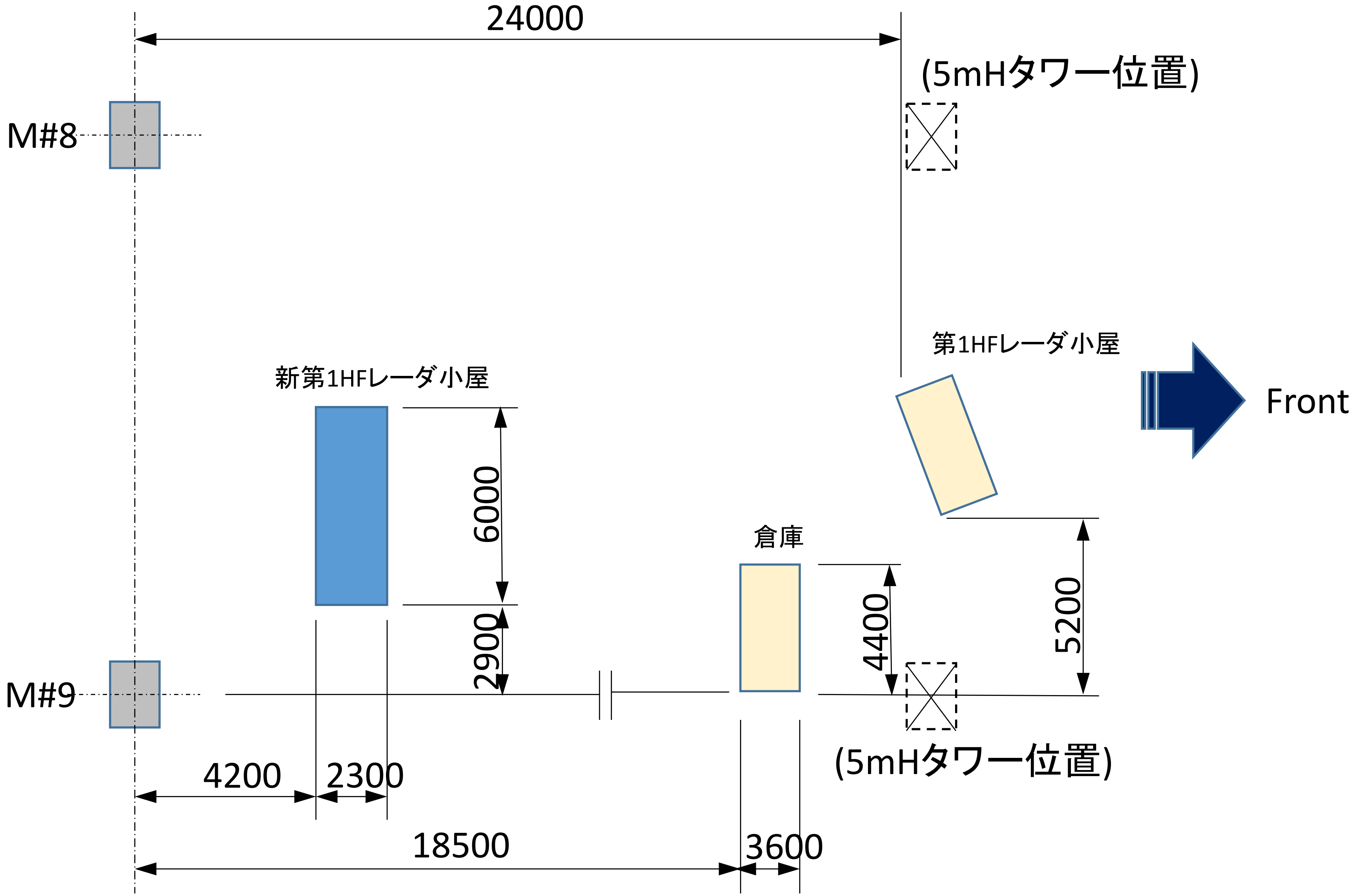
HF1測量結果

- HF1サイトの5mタワー基礎中心マーキング完了(17ヶ所)
- HF1サイトの追加タワー1本(M01側)基礎中心マーキング完了
  （#16側は雪深く、設置困難。#1は傾斜地有だがbetterと判断）
- PA小屋の真下(M09)はマーキングなし
- 各ステーアンカー位置の測量は未着手
- HF2サイトは全未着手



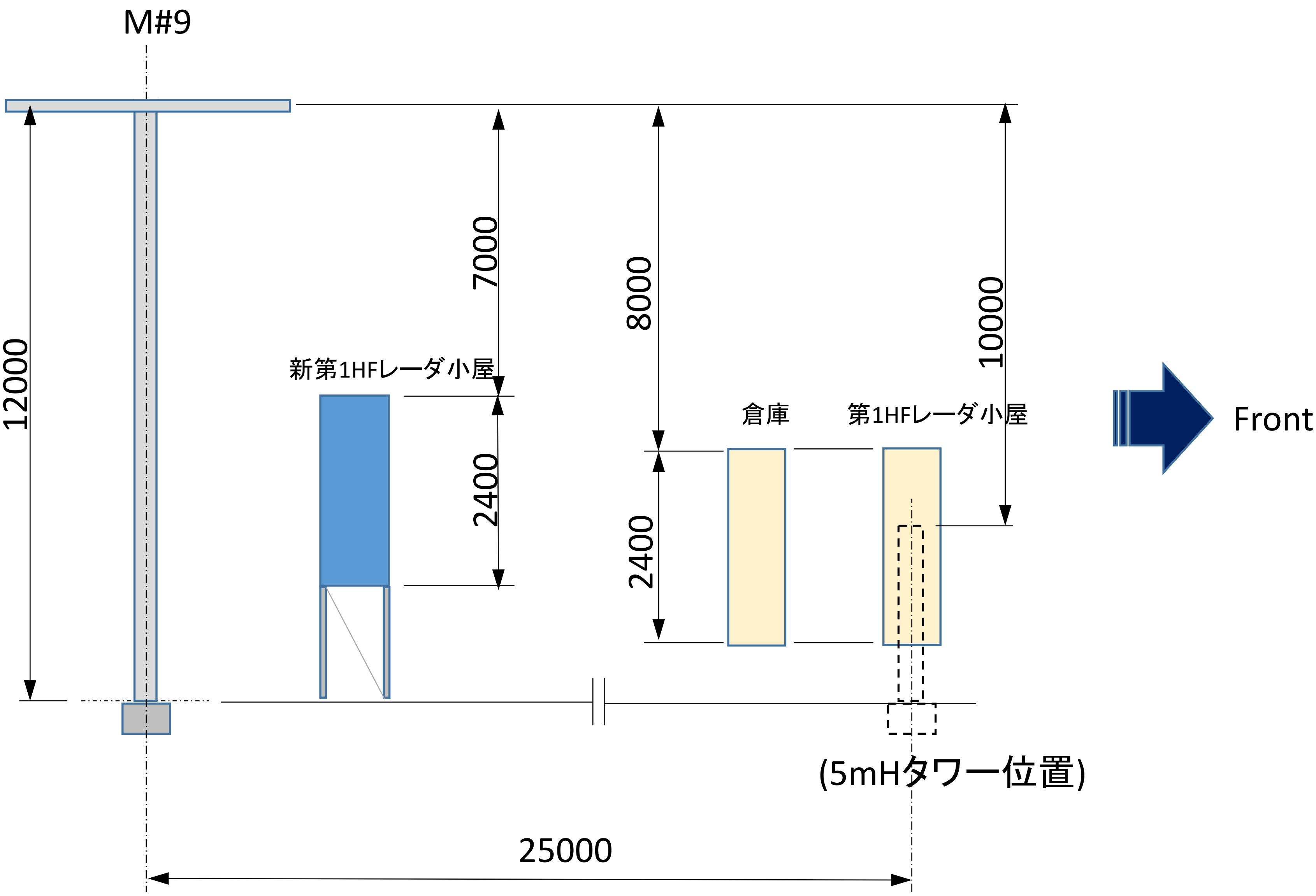
第1HFレーダサイト　小屋周り配置図(平面)

2013.12.29 JARE55吉川康文

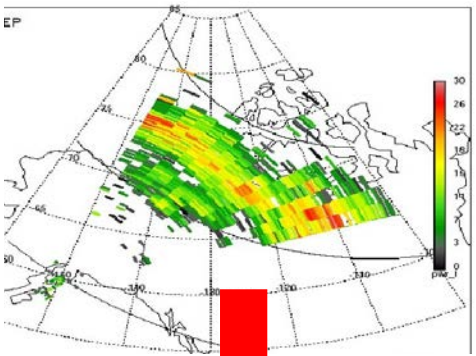


第1HFレーダサイト　小屋周り配置図(立面)

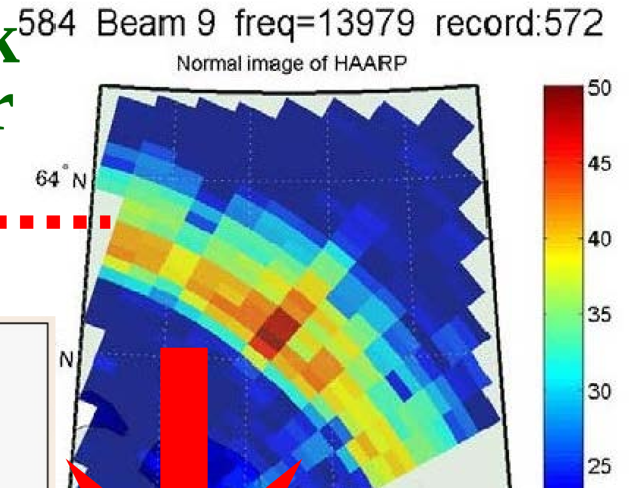
2013.12.29 JARE55吉川康文

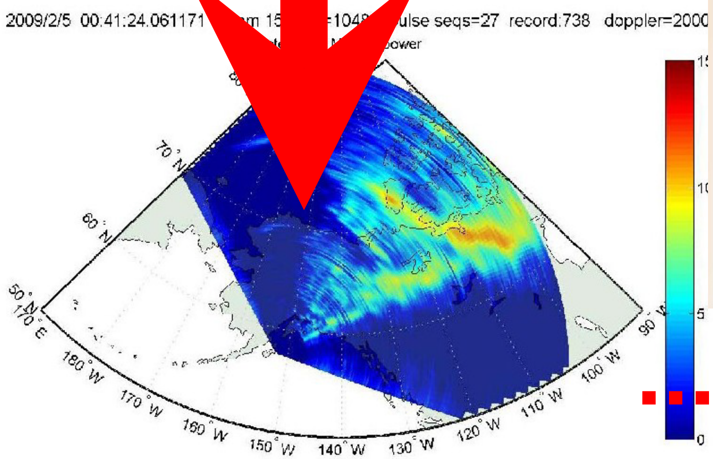


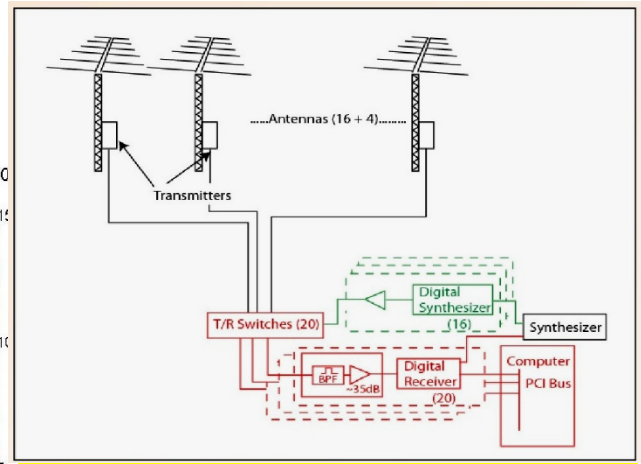
Todd's Kodiak imaging radar



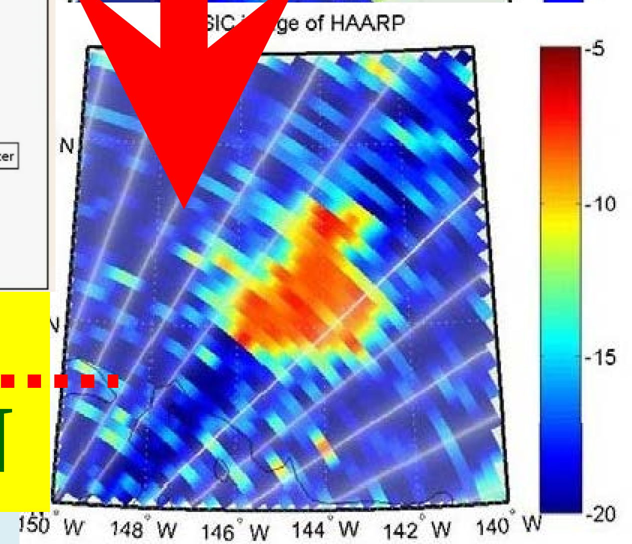
Conventional SD





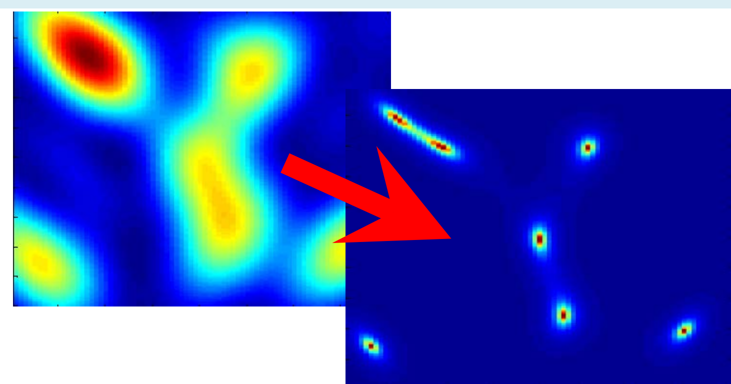


Imaging SuperDARN



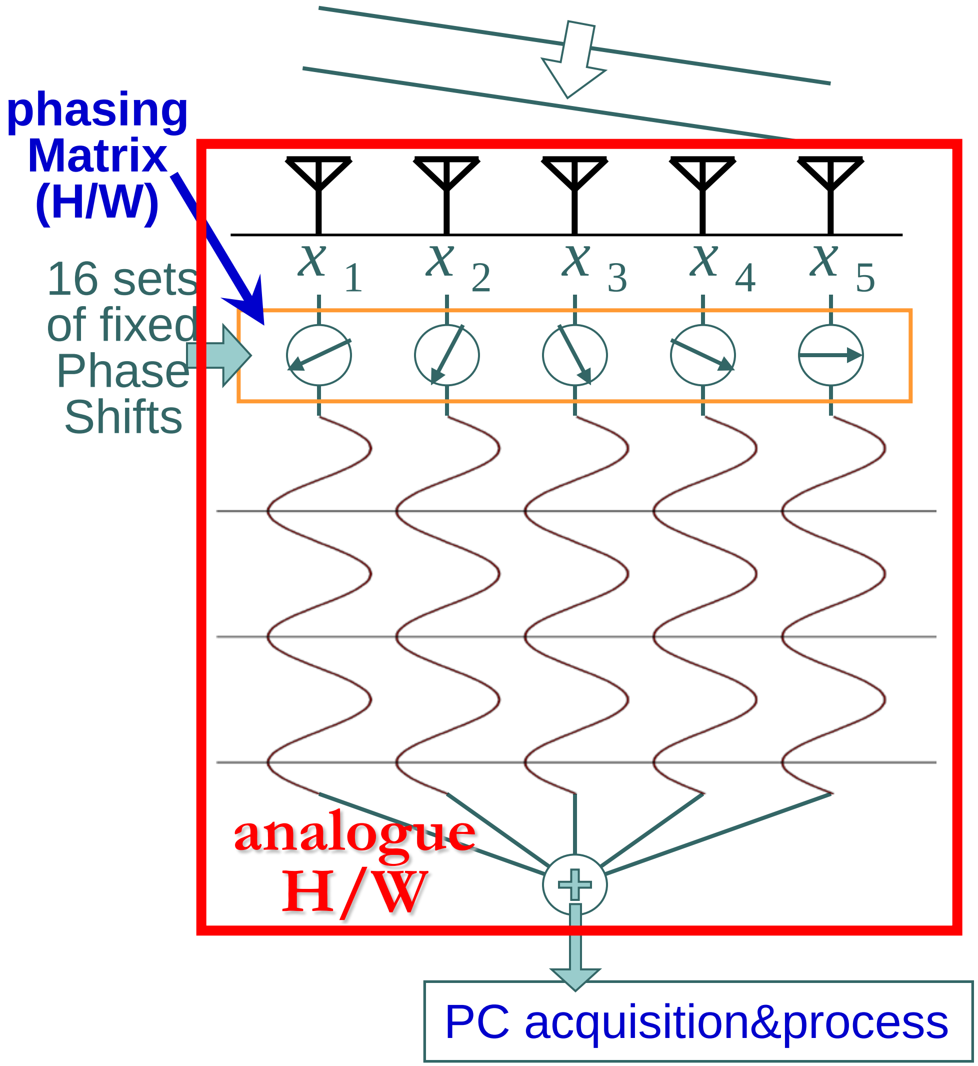
SuperDARN Imaging radar:

- **~1 order higher spatial resolution（15km⇒~a few km if conditions meet）** enable us to perform next generation observation. Simultaneous global and small-middle scale observation to understand M-I dynamics
- Together with **Stereo capability** & **raw IQ time series analysis method**, detailed electric field temporal & spatial evolutions around auroras and its dynamics, FAI generation/decay physical processes by comparing with simultaneous gound-based optical or other radar measurements etc. collaboration with **PANSY**…
- Put range imaging using FDI or pulse-code technique, 3-D imaging might be possible.



principle of imaging radars

Fourier method to form beams using conventional phasing matrix

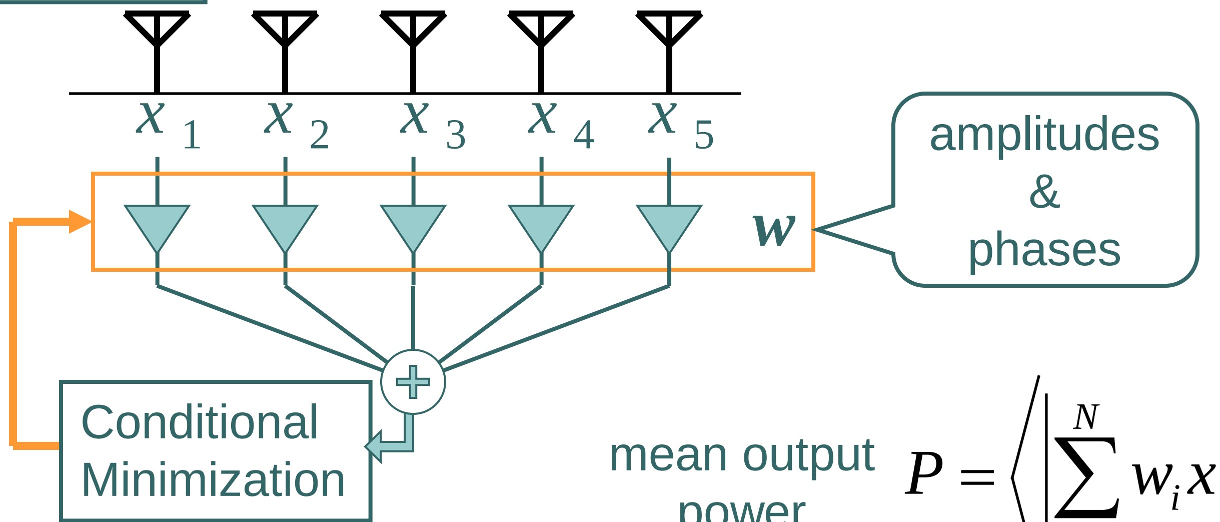


- Using phasing matrix with 16 sets of fixed length phase delays,
  forming beams in 16 fixed directions,
  data combined in analogue H/W circuit are recorded (both Rx&Tx)
- beam width: fixed
- unwanted interferences due to side-lobes – difficult to distinguish

Spatial Domain Interferometer(beam forming)

Capon Method (Adaptive beam forming)

System Model



mean output power
$$P = \left\langle \left| \sum_i^N w_i x(t) \right|^2 \right\rangle$$

Capon's Algorithm

Statement

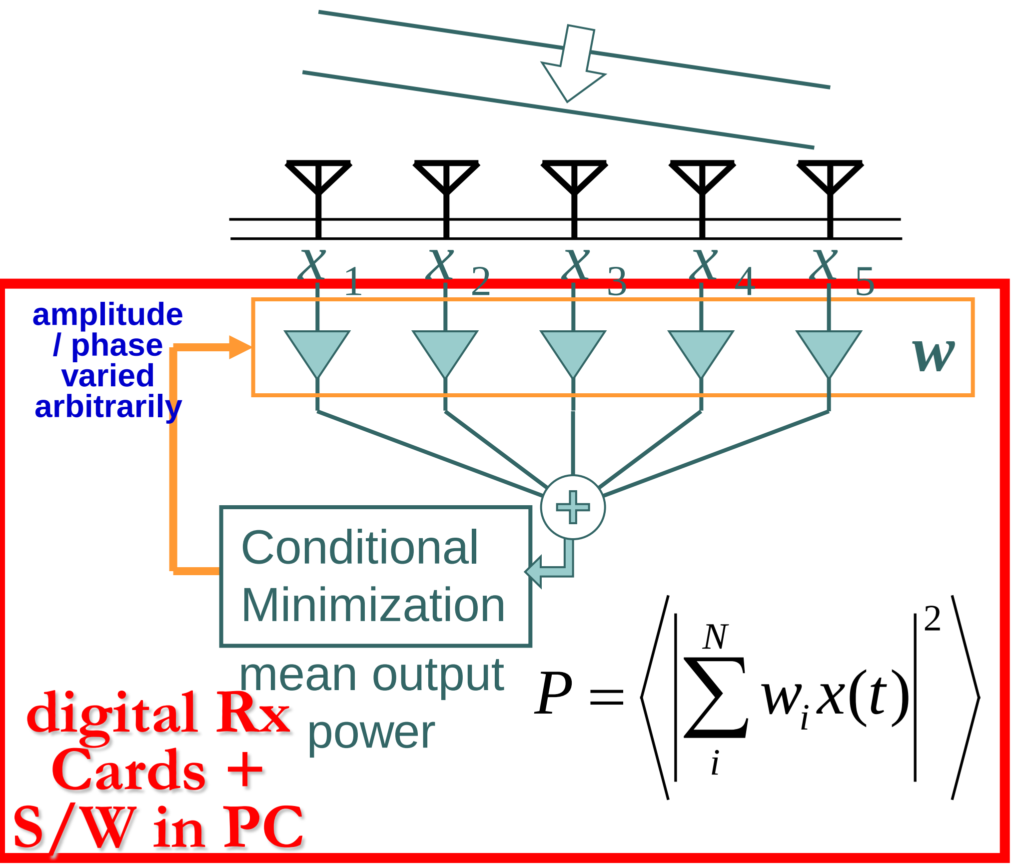
$$\underset{\mathbf{w}}{\text{minimize}} \left\{ P = \mathbf{w}^{\mathrm{H}} R_{xx} \mathbf{w} \right\}$$

$$\text{subject to } \mathbf{w}^{\mathrm{H}} \mathbf{c} = 1$$

Solution

$$P(\theta) = \frac{1}{\mathbf{c}^{\mathrm{H}} R_{xx}^{-1} \mathbf{c}}$$

Adaptive beam forming (Capon method)



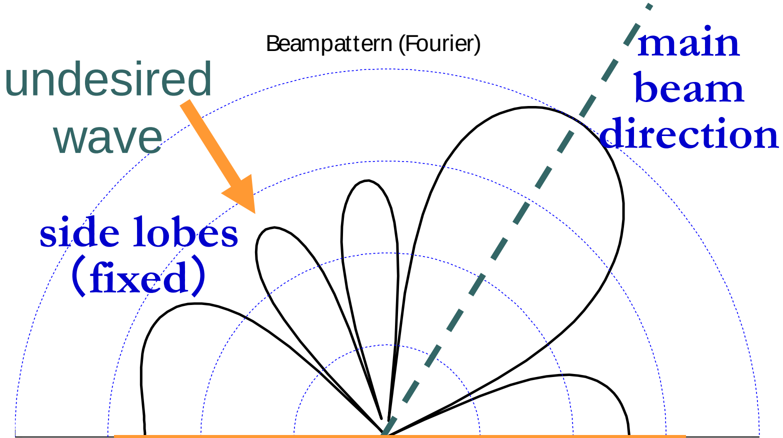
$$P = \left\langle \left| \sum_{i}^{N} w_i x(t) \right|^2 \right\rangle$$

Each antenna output separately record through digital Rx, any Rx beam-forming in SW in PC

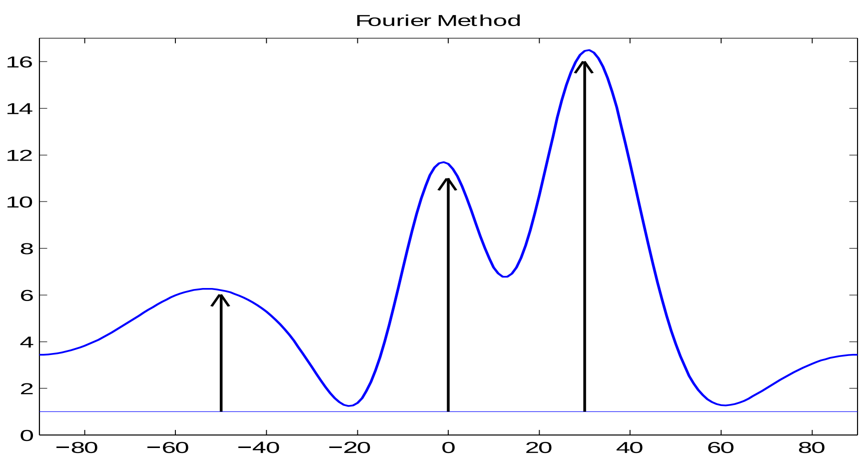
- In Rx, each antenna output independently recorded through digital Rx boards without combining in phasing matrix, then perform adaptive beam-forming in S/W (Tx – conventional way)
- Unwanted interference removed adaptively, higher resolution in azimuthal direcion possible
- imaging in a conventional single beam enabled (resolution depends on S/N ratio of received signals – 10 times higher if possible)

Fourier vs. Capon

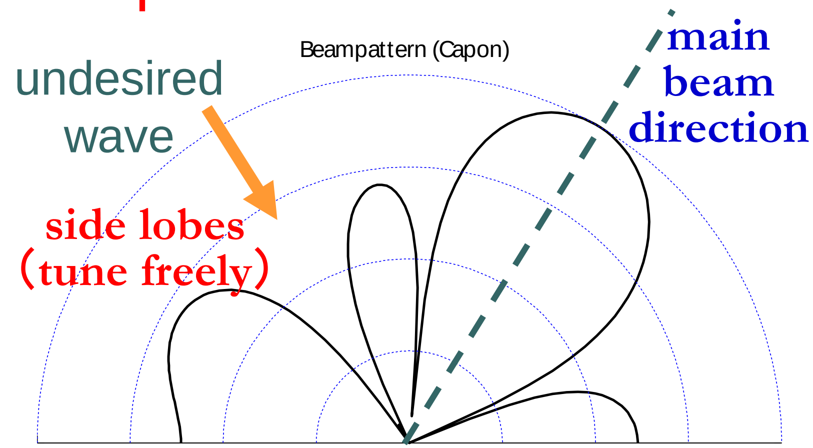
Fourier Method



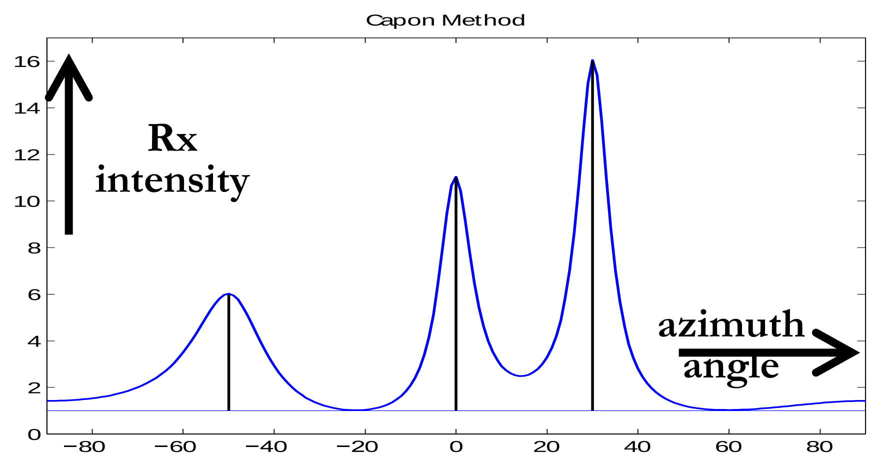
impossible to remove unwanted interference



Capon Method



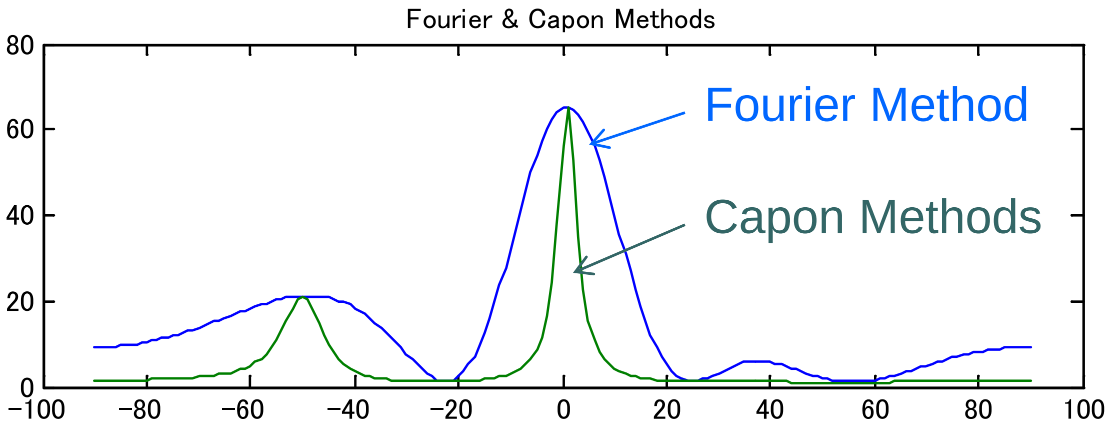
remove unwanted waves (except main beam)
enable higher resolution in beam



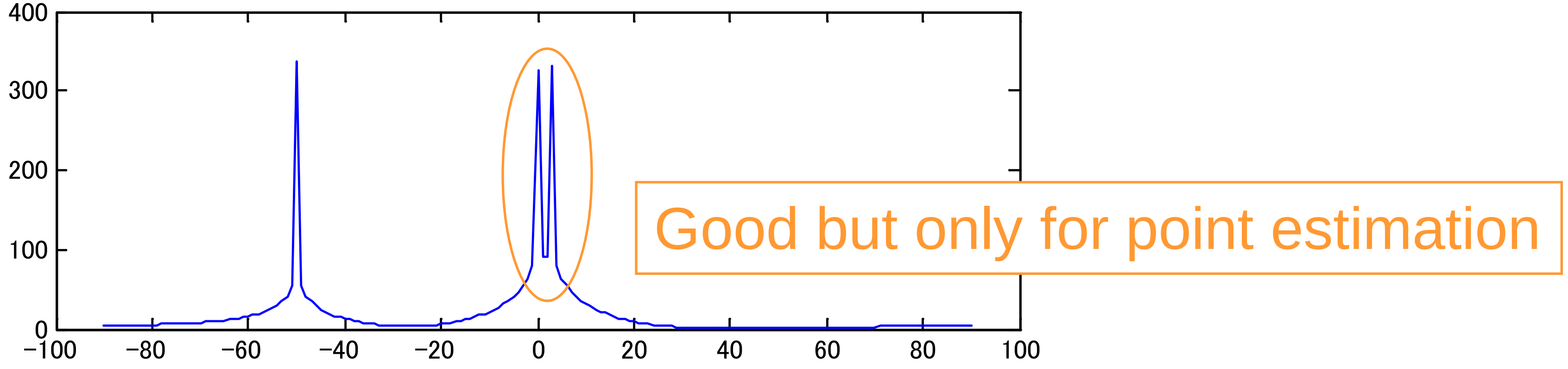
Resolution depends on S/N

Examples of Estimation Schemes

- Capon and MUSIC Methods



MUSIC (=Multiple Signal Classification) Method



The concept of radar imaging (by Todd. P.)

- What?
  - Radar imaging in the process of determining a brightness distribution (backscatter power vs. azimuth) of the radar taget.
  - Taking a ‘snap-shot’ of the field of view of the radar
- How?
  - Observe echoes from multiple spatially separated antennas, then use the phase information from each antenna to get an estimate of the spatial (azimuthal) target distribution.
  - Extracting azimuthal information ($d\phi/dx$) from spatially sampled signals is analogous to extracting spectral information ($d\phi/dt$) from temporally sampled data.
  - Many different brightness distribution estimators (spectral estimators are available, and each has it’s benefits.
    - FFT
    - Yule-Walker
    - MUSIC
    - Maximum Entropy
    - Etc.

Imaging

(by Todd. P.)

(choose your favorite technique)

Fourier Example

- Discrete Fourier Transform

$$S_{RX}\left(\bar{k},t\right)=\sum_{n=0}^{N-1}s_n(t)e^{i\bar{k}\cdot\bar{d}_n}$$

For all desired α (within limits of sampling theorem)

  - Can now take FT at each azimuth to get Doppler spectrum
  - Same as phasing matrix, but looking at all directions simultaneously

Choose your favorite spectral (hyperspectral) estimator

- Fourier
- CLEAN (algorithmic)
- Capon (adaptive beam-forming)

$$B(\bar{k},f)=\frac{1}{w(\bar{k})^H V(f)^{-1} w(\bar{k})}$$

where $V(f)$ is the cross-spectral matrix,

$$V(f)=\begin{bmatrix} X_{11}(f) & X_{12}(f) & \dots & X_{1n}(f) \\ X_{21}(f) & X_{22}(f) & \dots & X_{2n}(f) \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1}(f) & X_{n2}(f) & \dots & X_{nn}(f) \end{bmatrix}$$

and w is the weight vector,

$$w(\bar{k})=\left[e^{j\bar{k}\cdot\bar{d}_1} \quad e^{j\bar{k}\cdot\bar{d}_2} \quad \dots \quad e^{j\bar{k}\cdot\bar{d}_n}\right]^T$$

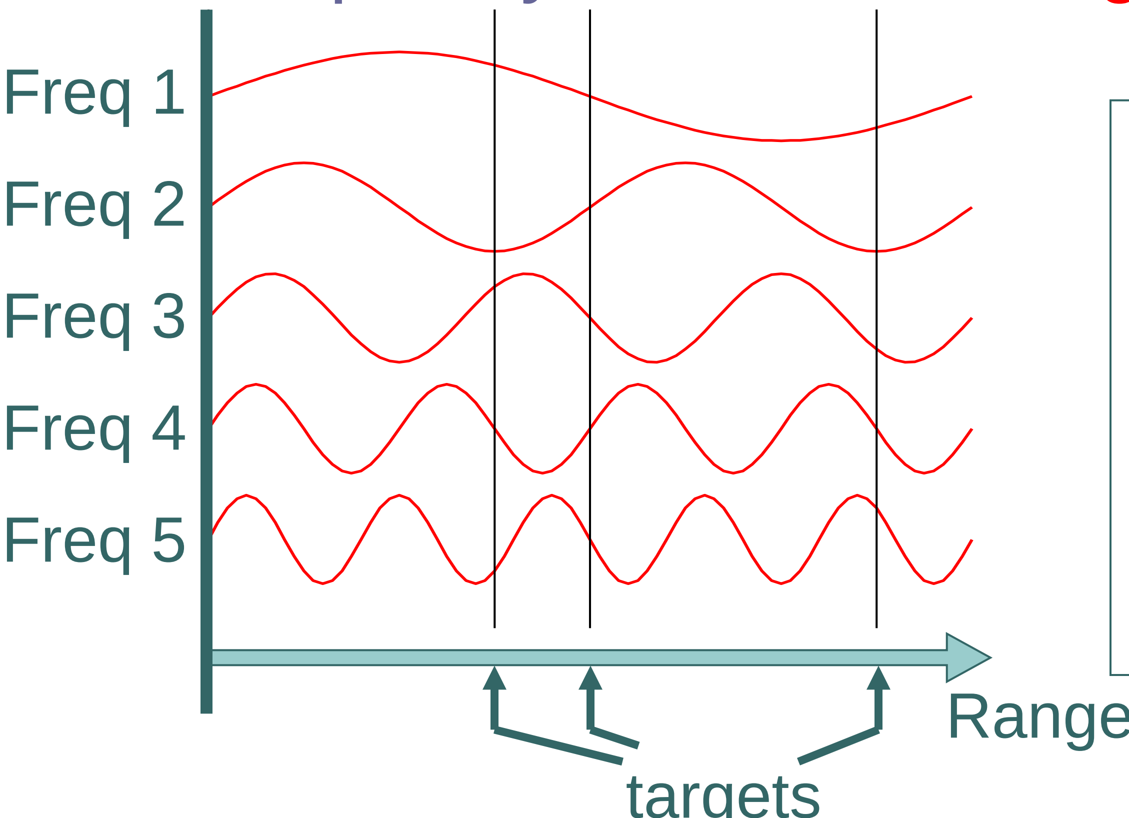
- Yule-Walker (autoregressive)
- Maximum entropy (Bayesian)
- MUSIC (Eigen vector)
  - Calculate Eigen vectors of $V(f)$, choose noise vectors, $v_n(f)$, and signal vectors, $v_s(f)$, then brightness is given by,

$$B(\bar{k},f)=\frac{1}{w(\bar{k})^H\left(\sum_{noise}v_n(f)v_n^H(f)\right)w(\bar{k})}$$

- Etc…

System in Frequency Domain: FDI

- Same principle can be applied to frequency domain for range imaging



Similarity

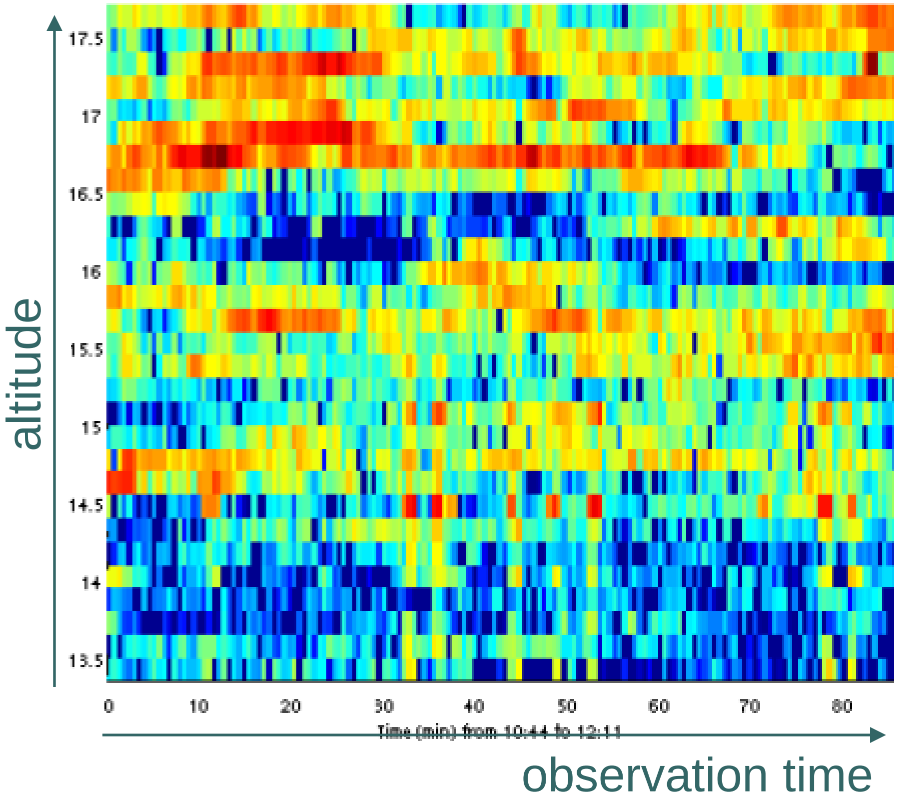
Range Space		Angular Space
Range	⇔	Angle
Multiple Freqs	⇔	Multiple Antenna
Frequency	⇔	Antenna Position
FDI range imaging		**SDI** angular imaging

FDI & SDI are mathematically equivalent!

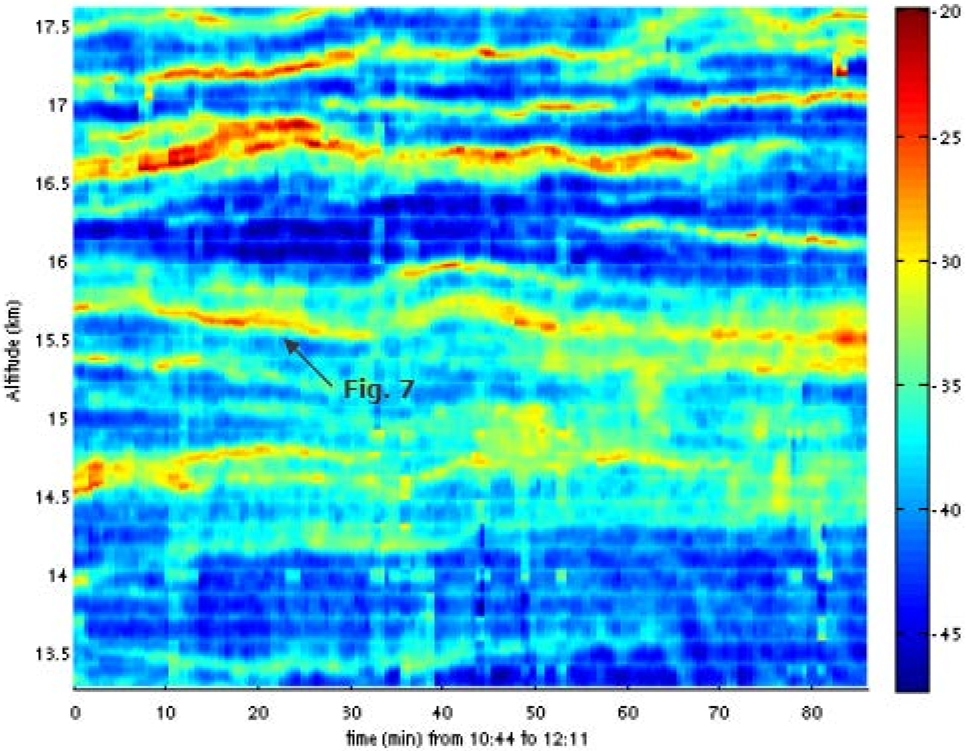
FDI in atmospheric radar

- 5 frequency observation with the MU Radar

Conventional



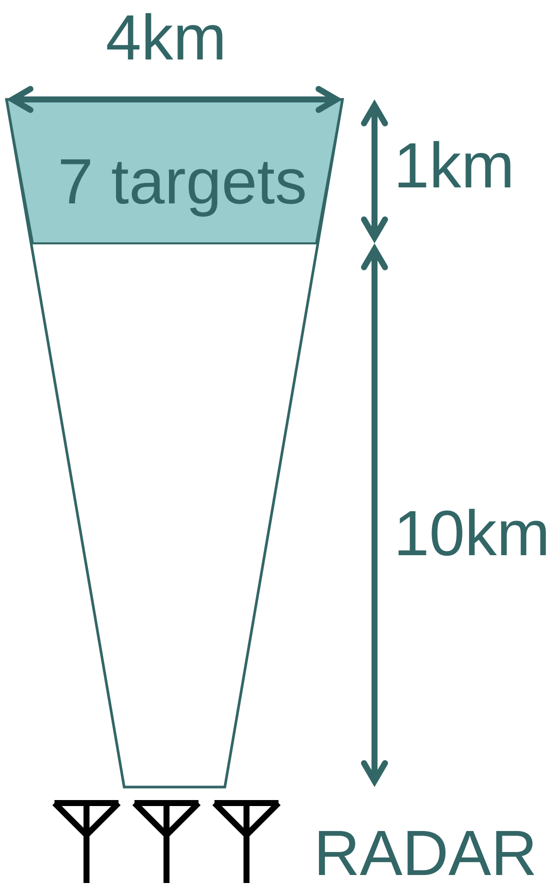
FDI



Luce, *Ann. Geophys.* 24, p.791, 2006.

Angular + Range High-Resolution

- 2D imaging simulation



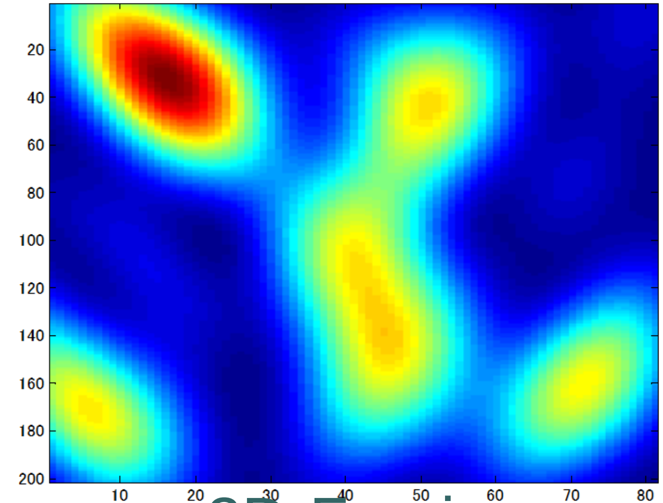
Radar

5 Antennas
Δx=3m (1λ)

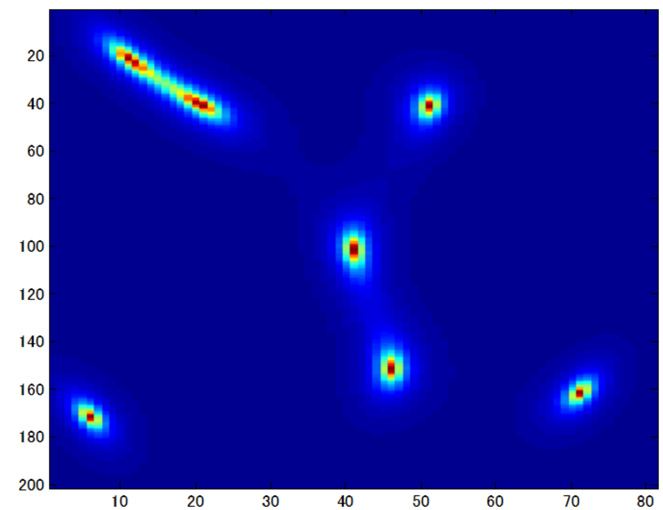
5 Frequencies
F_0=100MHz
ΔF=100kHz

Targets

7 targets
S/N=7dB each
infinite time observation



2D-Fourier



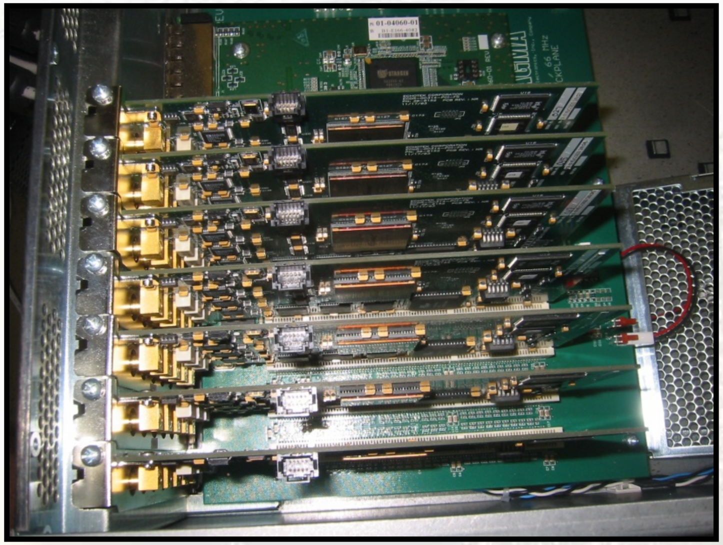
2D-Capon

Syowa imaging radars

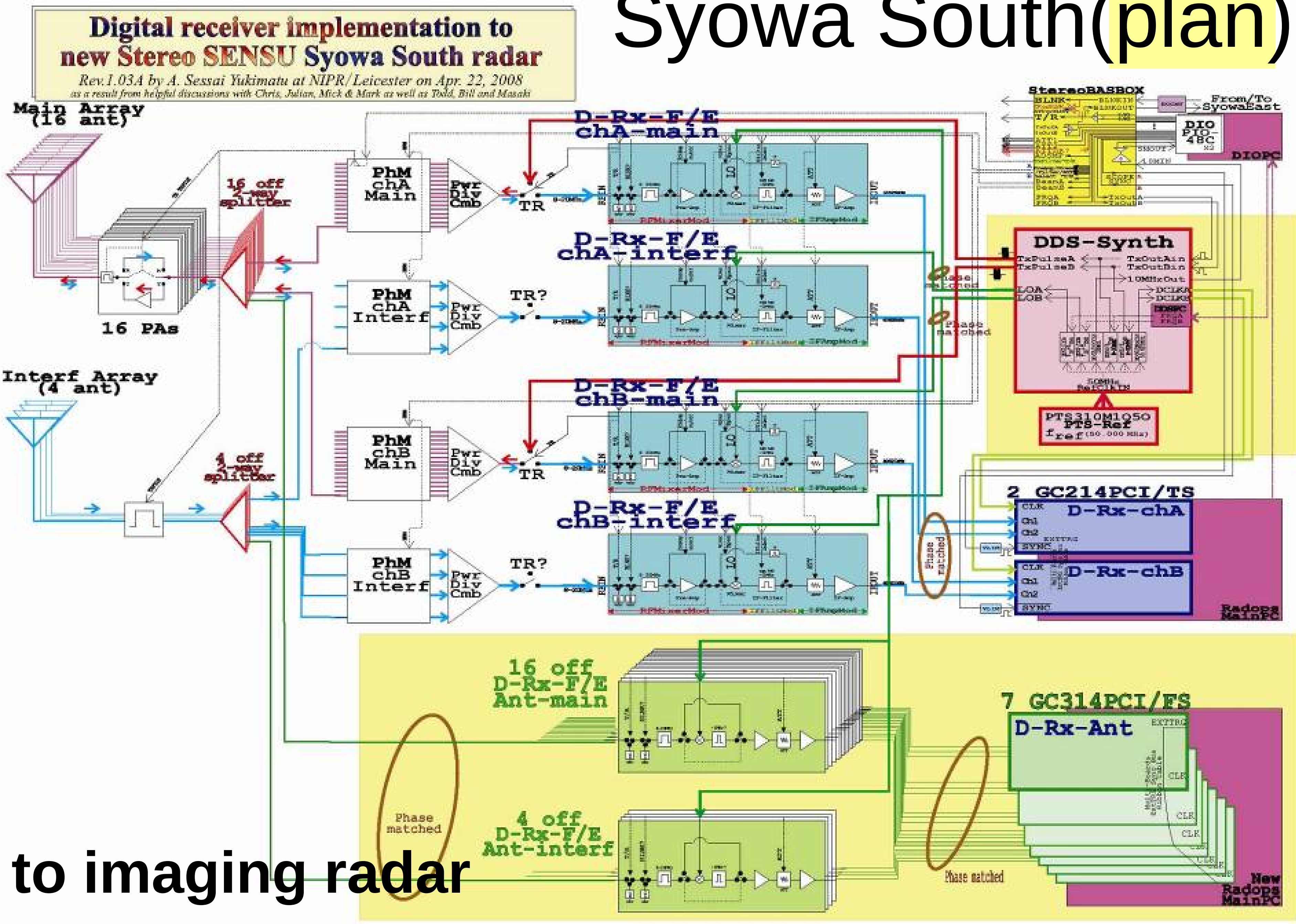
- IQ sampling (TMS), meteor, oversampling, FDI
- SYS: migration to digital Rx – done in 2008
- RF/IF sampling comparison in 2009
- imaging radar development(SDI) for SYS
  - recording antenna output directly without passing through Phasing Matrix & enabling adaptive beam-forming in PC.
  - Stereo imaging is easy if RF sampling works – confirm at prototype test at CUTLASS Finland site before bringing down to Syowa
- digital Tx for pulse-phase coding (sub-pulses)
- synchronizing Syowa SENSU twin radars
  - Tx simultaneously to minimize contamination
- plan to upgrade SYE to an imaging radar (future)

Digital Receiver and Imaging (by Todd P.)

- Imaging requires receivers on each antenna
- For our implementation, we have chosen the Echotek GC314-PCI/FS
  - 3 analog inputs and A/Ds
  - 100 MHz sampling
  - 4 receiver channels per antenna
  - Up to 2 MHz BW per channel
  - 7 GC314s total
- Clocked with same 10/100 MHz reference as all other radar components
- Sample all antennas simultaneously, and process the samples across the array into an image



Syowa South(plan)



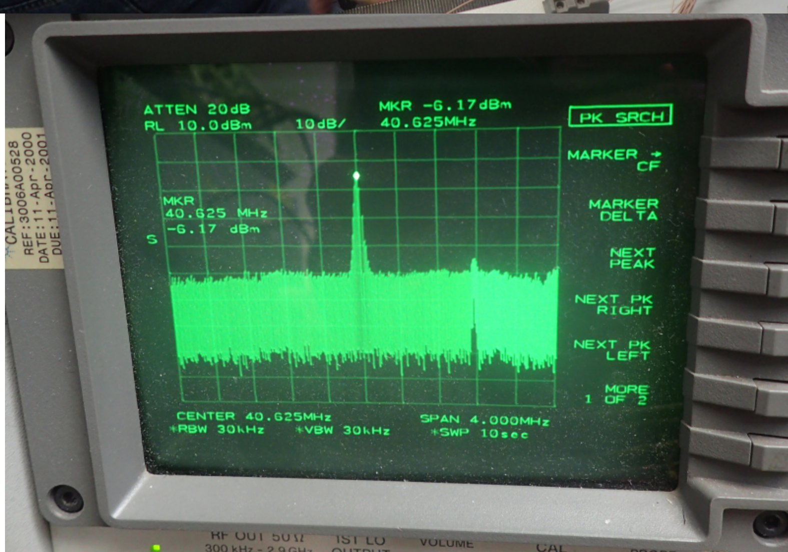
to imaging radar

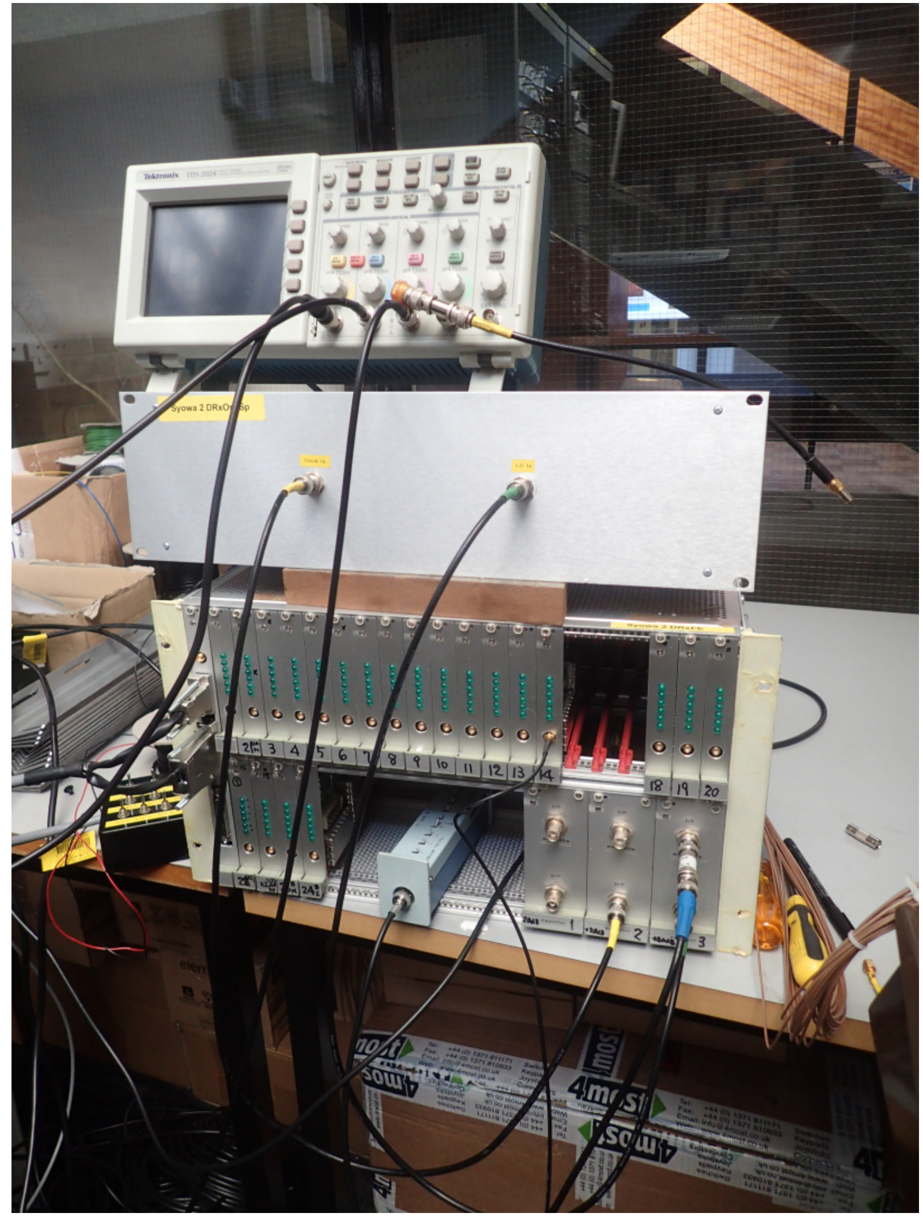
Syowa imaging preparation

Lisa's toy – Svalbard radar @Leicester, 2015

Syowa imaging preparation

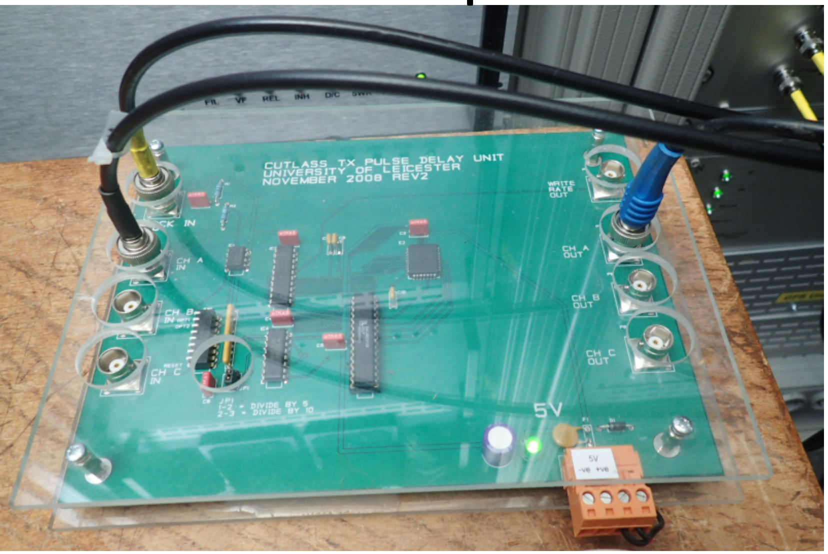
Syowa imaging preparation

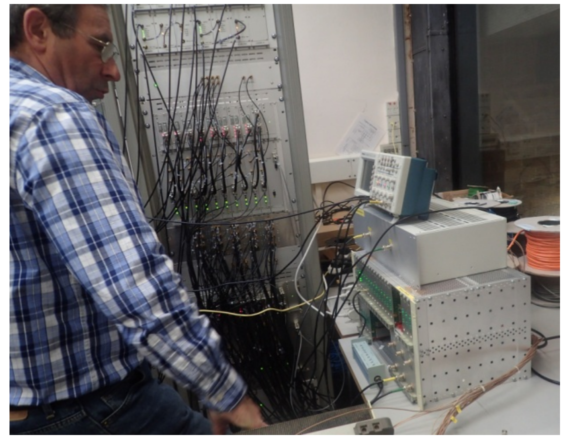


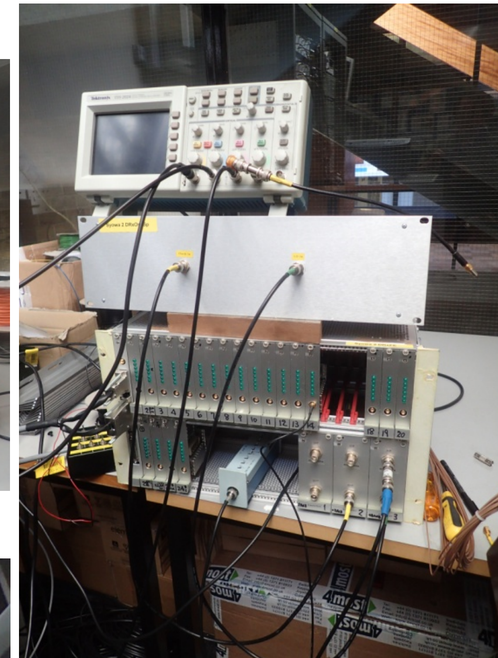


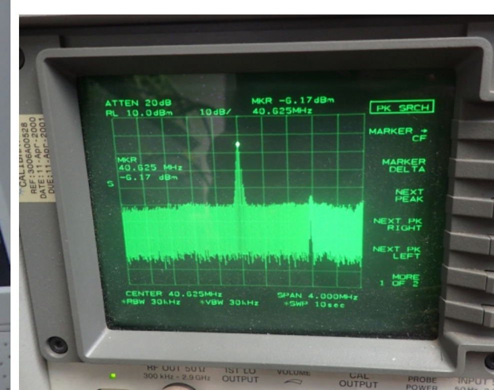
Syowa imaging preparation

Artificial Ionosphere



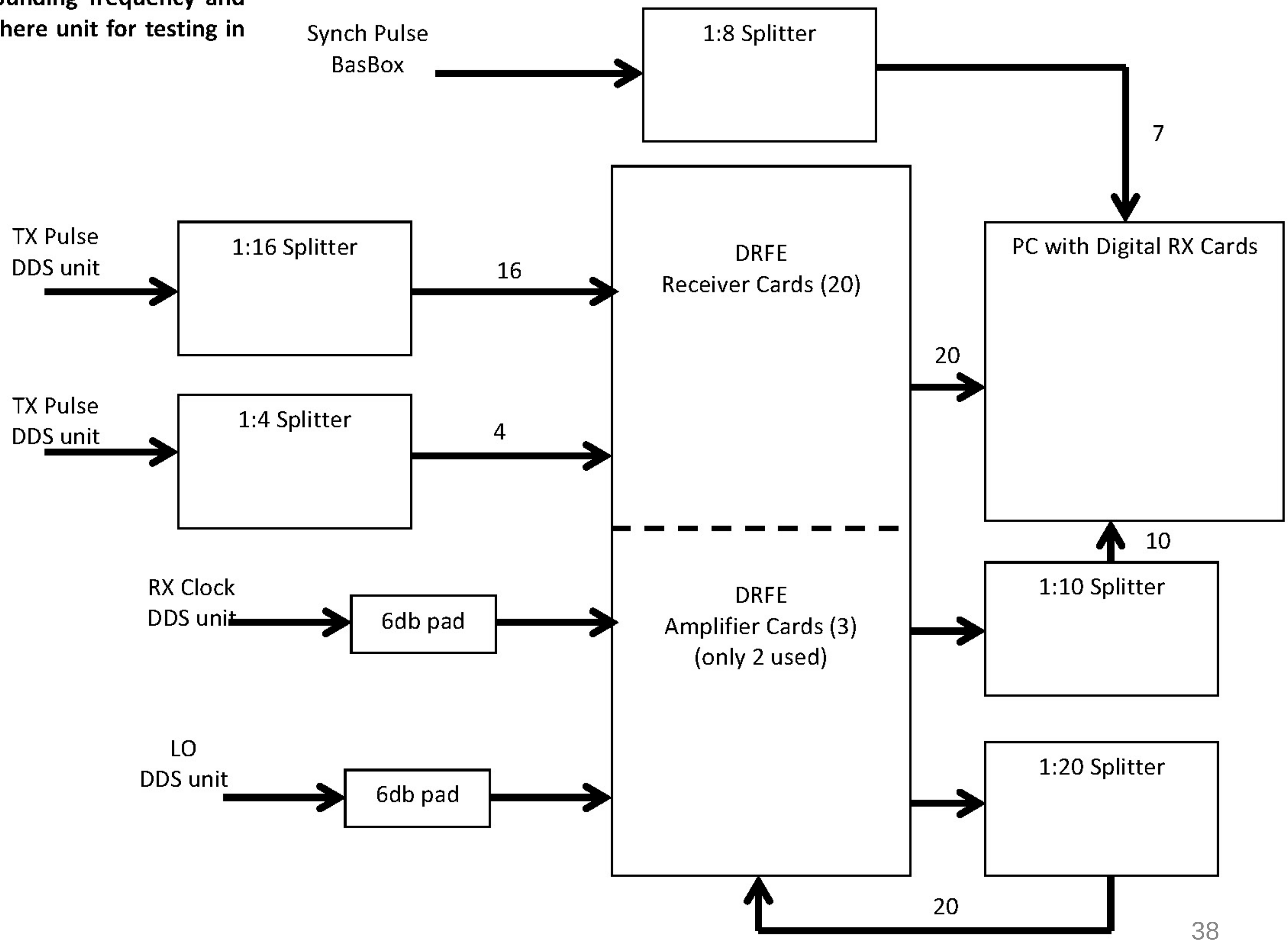






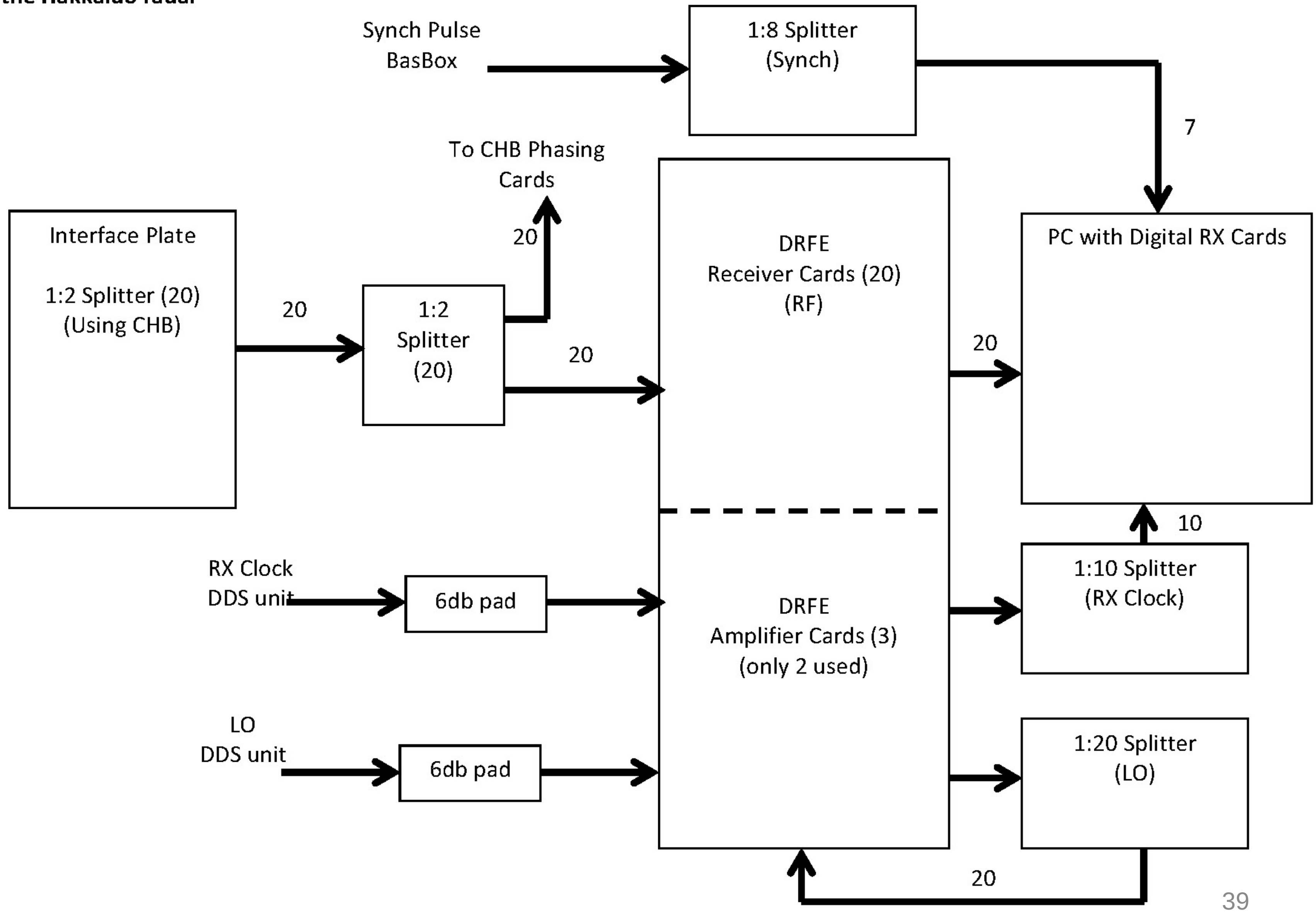
Syowa imaging test setup @ NIPR

Set up using sounding frequency and artificial Ionosphere unit for testing in Tokyo



Syowa imaging test setup @ HokW

Set using the Hakkaido radar

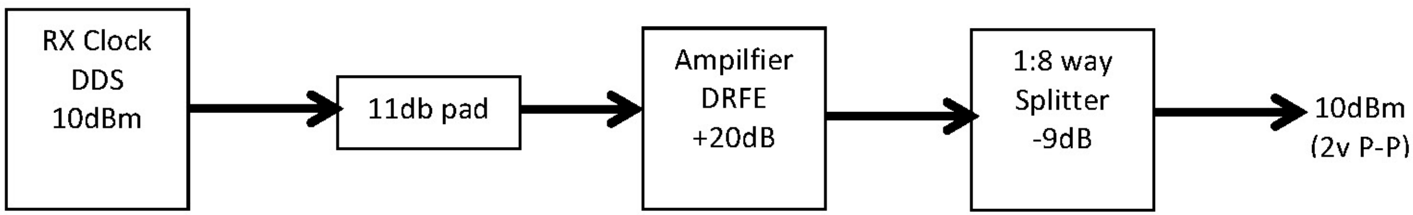


Syowa imaging test setup

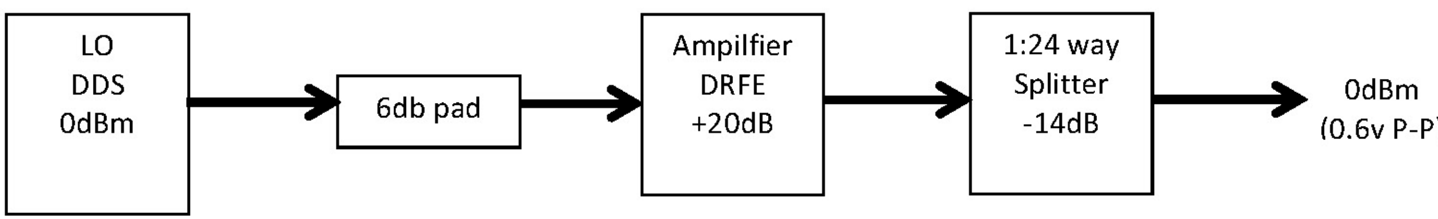
*The set up in Syowa will be the same as Hakkaido with the omission of the splitter between the interface plate and the phasing matrix. The Syowa radar has 4-way splitters on its interface plate so the DRFE can be connected directly.

*Note the value of the attenuators should be set before connecting to the receivers and digital receiver cards. All levels measured should be terminated into 50 ohms with any unconnected ports terminated. **The pad size below is just a guide.**

RX Clock

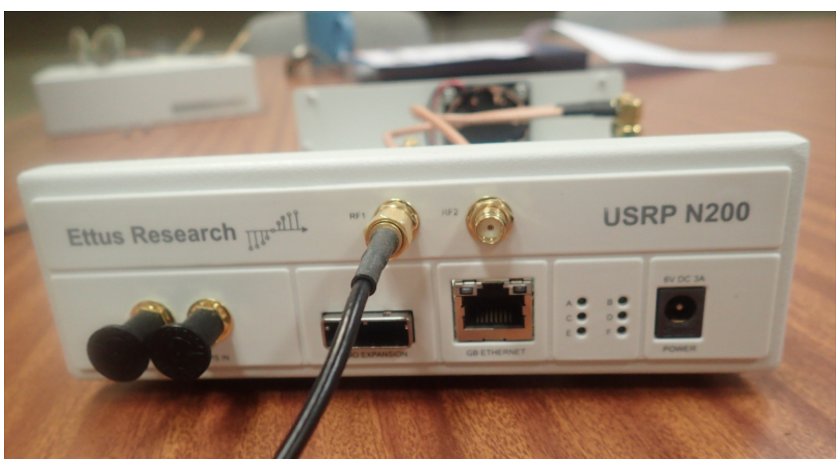


*LO



Radar H/W future - USRP

- Current Echotech boards : discontinued.
- USRP (Universal Software Radio Peripheral)
  (or SDR (User's software defined radio))
- Alaska group has started to develop implementing USRP to SD radar hardware – will run soon...
- Software development already almost done.
- SD will possibly move to the direction at some point.



Science Future directions with new SuperDARN capabilities

- comparison with mid- & small scale auroral structure – M-I (Magnetosphere – Ionosphere) coupling physics
- FAI physics – fine structure of FAIs – solitons?? – creating & decaying processes? differences between natural and artificial induced FAIs?
- detailed Doppler spectral analysis – to reveal instabilities creating FAIs, roles of various MHD waves to determine spectral width, multiple peaks of Doppler spectra, etc
- to classify echo regions by Doppler spectral characteristics for M-I mapping – dream!!!!
- to improve meteor wind observations especially to improve height resolution to contribute to MLT (mesosphere – lower thermosphere) dynamics
- PMSE studies
- unique collaboration with satellites, PANSY and other ground-based instruments including special optical obs. setup at Syowa.

Studies On Polar Upper Atmosphere in Possible Grand Minimum Period and Inner Magnesosphere Dynamics with SuperDARN Towards Phase IX JARE Research Program 2016-22

SuperDARNレーダーを中心としたグランドミニマム期における極域超高層大気と内部磁気圏のダイナミクスの研究 ～南極観測第IX期研究観測計画にむけて～

A. S. Yukimatu and NIPR SPUAS group
NIPR/SOKENDAI, Tokyo
行松 彰(極地研/総研大)、極地研宙空圏研究グループ

SENSU Syowa South radar taken by Mr. Yasuo Kato, a UAP member of JARE36 in 1995

8th JARE planning - AP39 (2014-16)

SuperDARNとオーロラ多点観測から探る磁気圏･電離圏結合過程

Study on magnetosphere-ionosphere coupling processes with SuperDARN radars and ground-based optical observations

JARE55-57(2014-2016)

A. Sessai Yukimatu, H. Miyaoka, N. Sato, H. Yamagishi,
A. Kadokura, Y. Ogawa, Y. Tanaka (NIPR),
K. Hosokawa (UEC), Y. Ebihara (Kyoto U.), T. Motoba (JHU/APL)

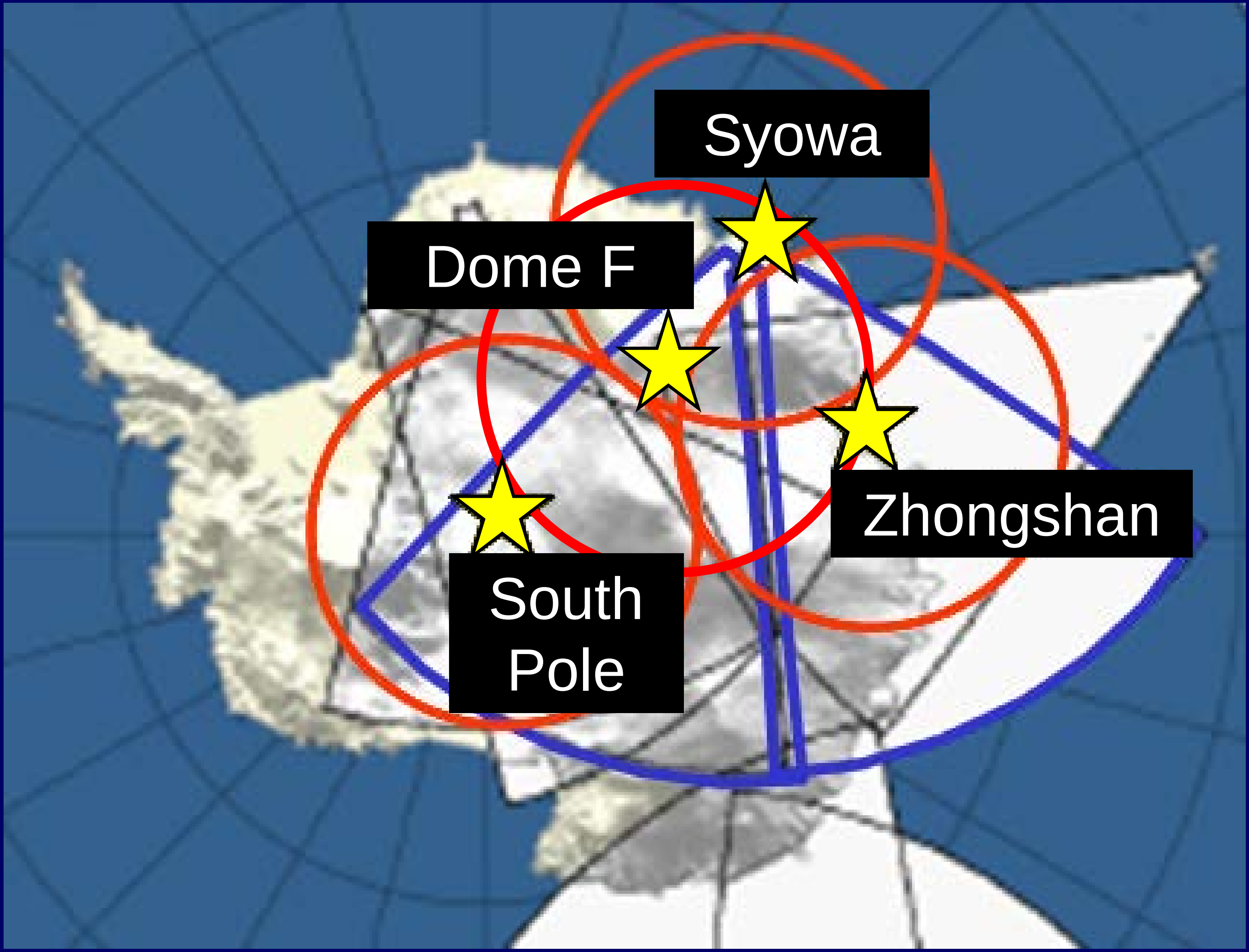
■ Objectives

■ **<u>SENSU Syowa SuperDARN imaging radars</u>** and all sky camera network at Dome-F, Zhongshan, & South Pole st. whose FOVs are all under SENSU FOVs conduct simultaneous obs. This will reveal…

★MI coupling processes associated with meso-scale (~10~100km) cusp and polar cap aurora

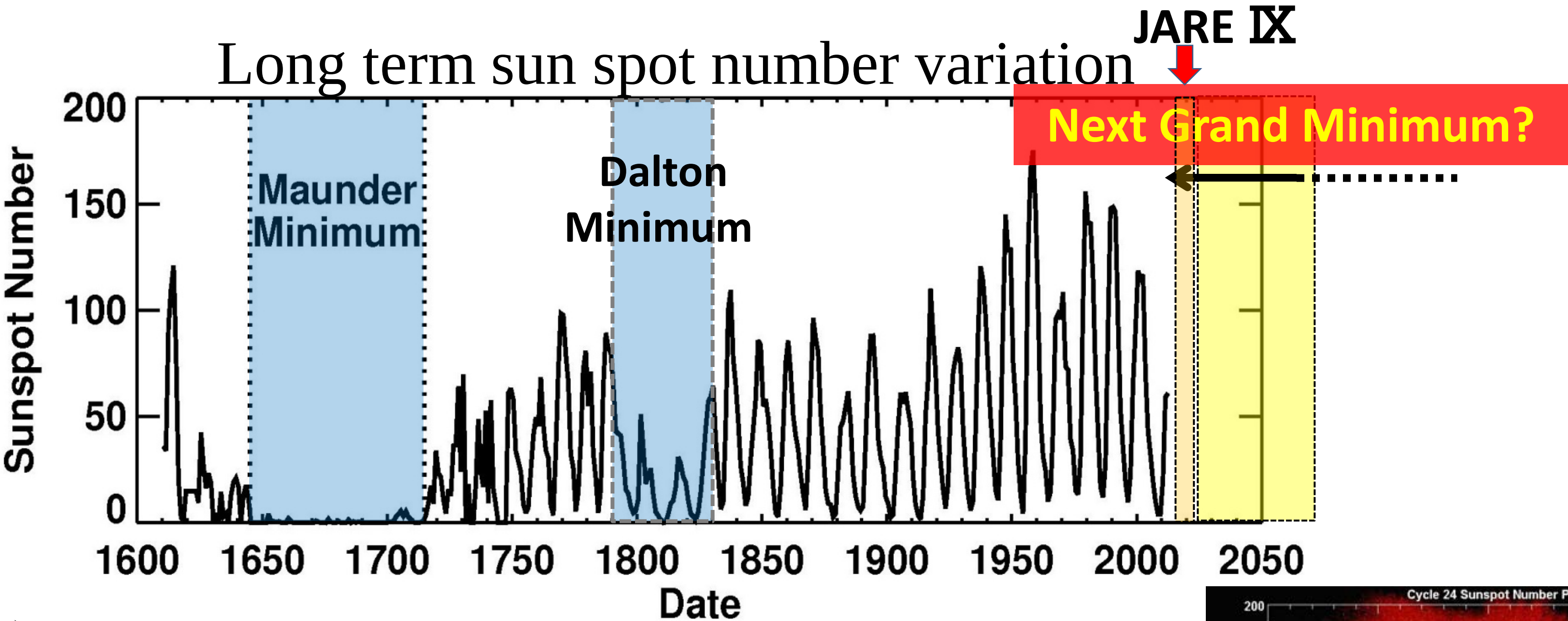
★cross-scale coupling shown in aurora and ionospheric disturbances

FOVs of all sky camera network under SENSU FOVs

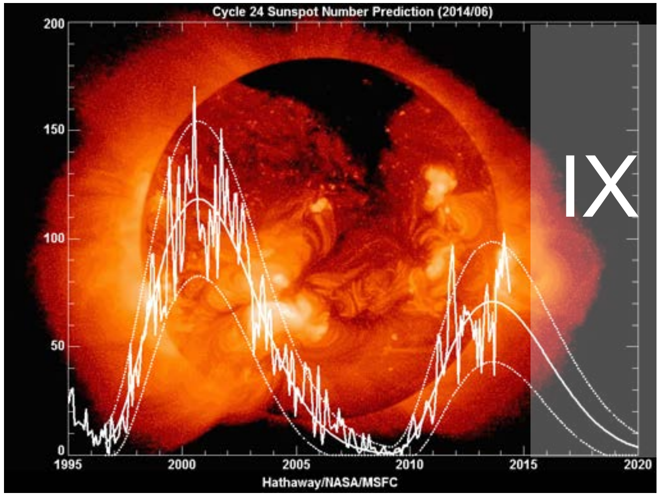


JARE IX 6-year project period (FY2016-2021)

- Enter into solar minimum period (during normal 11-year cycle)
- Historical lowest solar activity since IGY expected



- GM influence on global climate env. change : unknown incl. relation. w/global warming – quantitative evaluation is necessary.
- Polar upper atm. – most sensitive to external env. change including of solar activity, solar wind



JARE: Japanese Antarctic Research Expedition

from Kadokura et al., NIPR Antarctic Observation Symposium 2014

Submitted project plan for JARE IX 3(+3)-year project period

“Study on polar upper atmosphere in possible grand minimum period and inner magnetosphere dynamics with SuperDARN”

by Yukimatu, Miyaoka, et al.

To investigate and understand quantitatively:

● G.M. influences on polar upper atm. & geospace env.

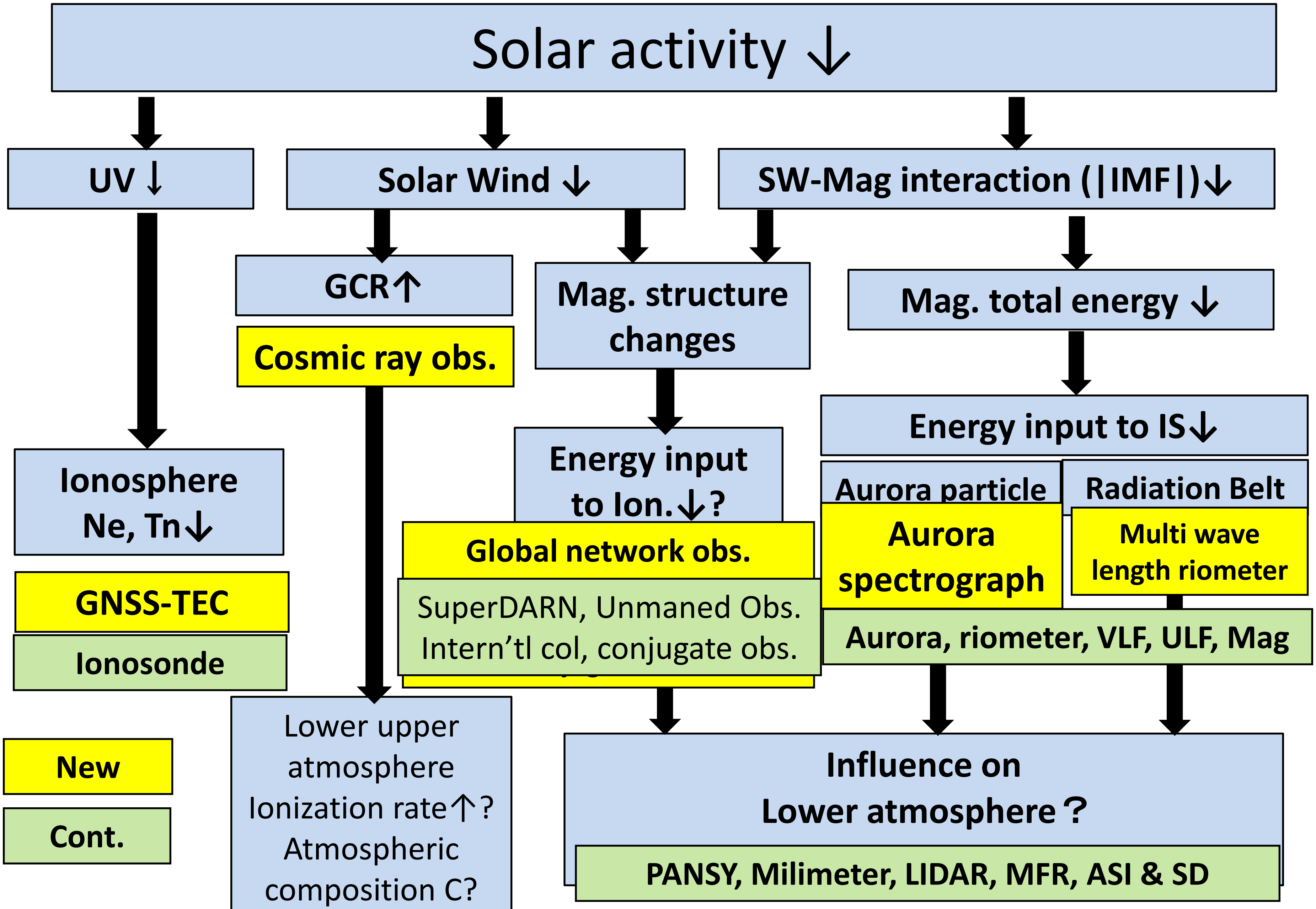
- geospace env. changes: (global SD+opt. network)
  - SW energy input and distribution of high energy particles
- its impact on polar upper atmospheric env.:
  - storms/substorms, cusp/polar cap, auroral oval, ion. convection, other unexpected upper/lower atmospheric and climate changes?

● Inner magnetosphere dynamics (with ERG/VAP)

- contribute to understanding particle acceleration & storms

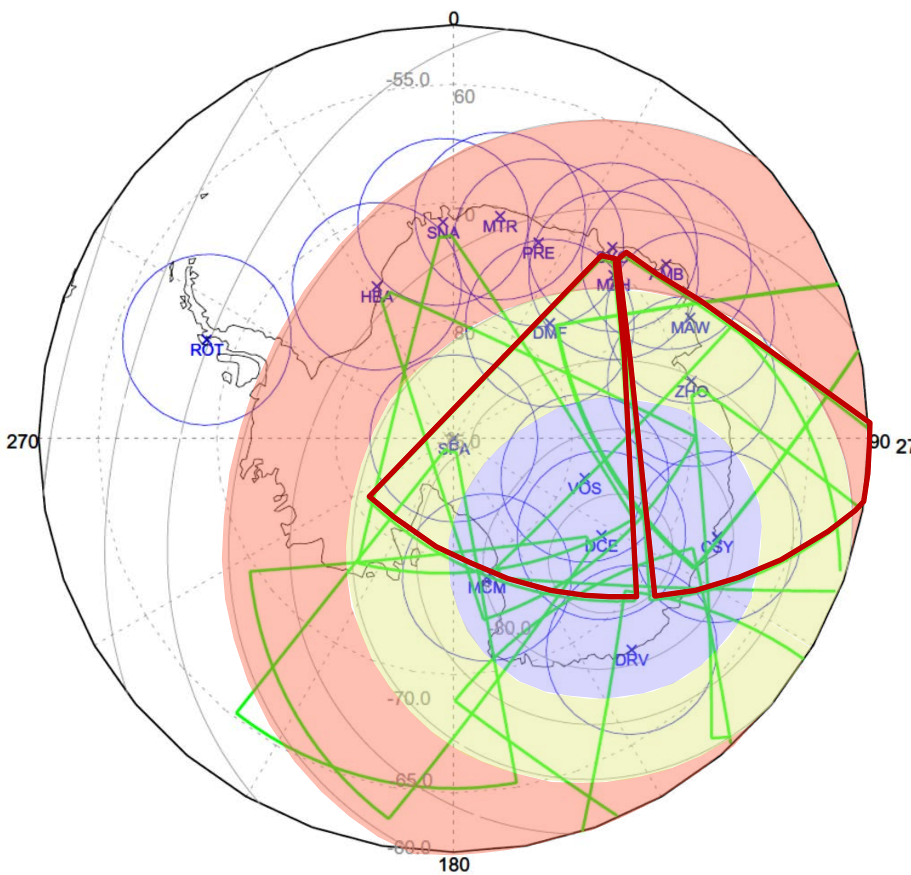
■ Closely related to SCOSTEP VarSITI program ■

ISEST/MinMax24, SPeCIMEN & ROSMIC

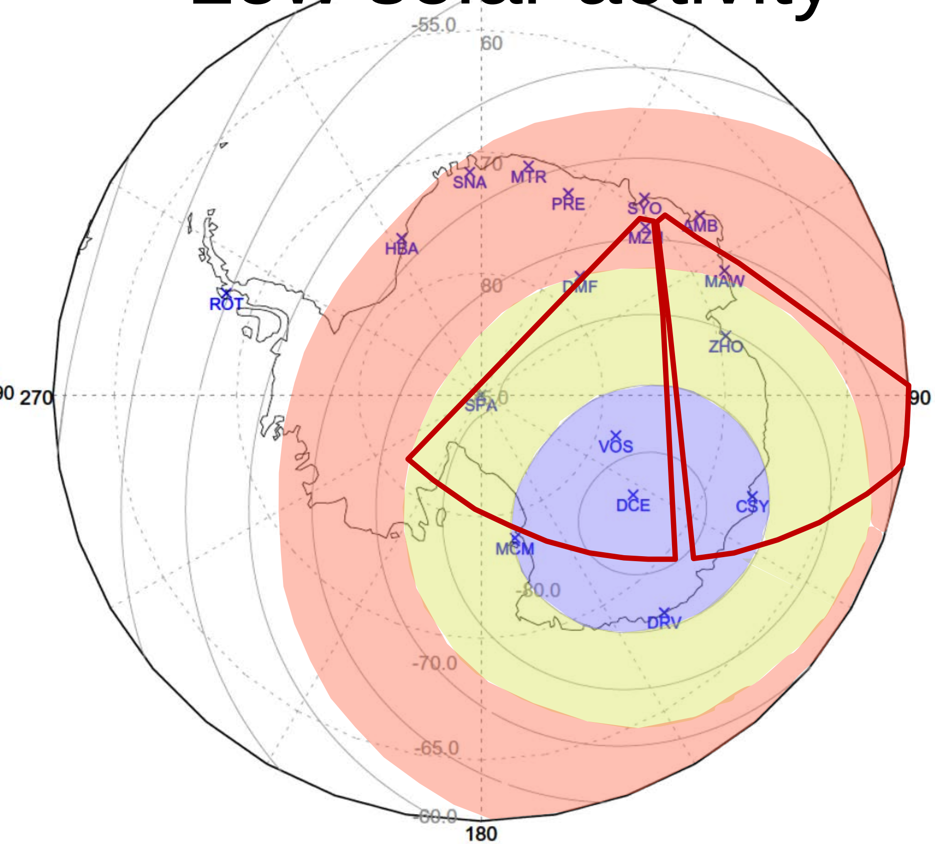


from Kadokura et al., NIPR Antarctic Observation Symposium 2014

SuperDARN & global G.B. obs. Networks & JARE Ⅸ future expansion plan



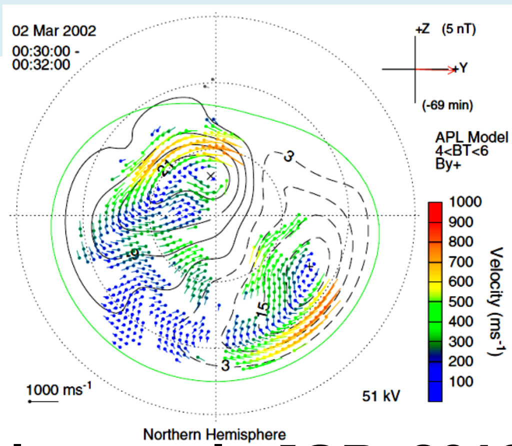
Low solar activity



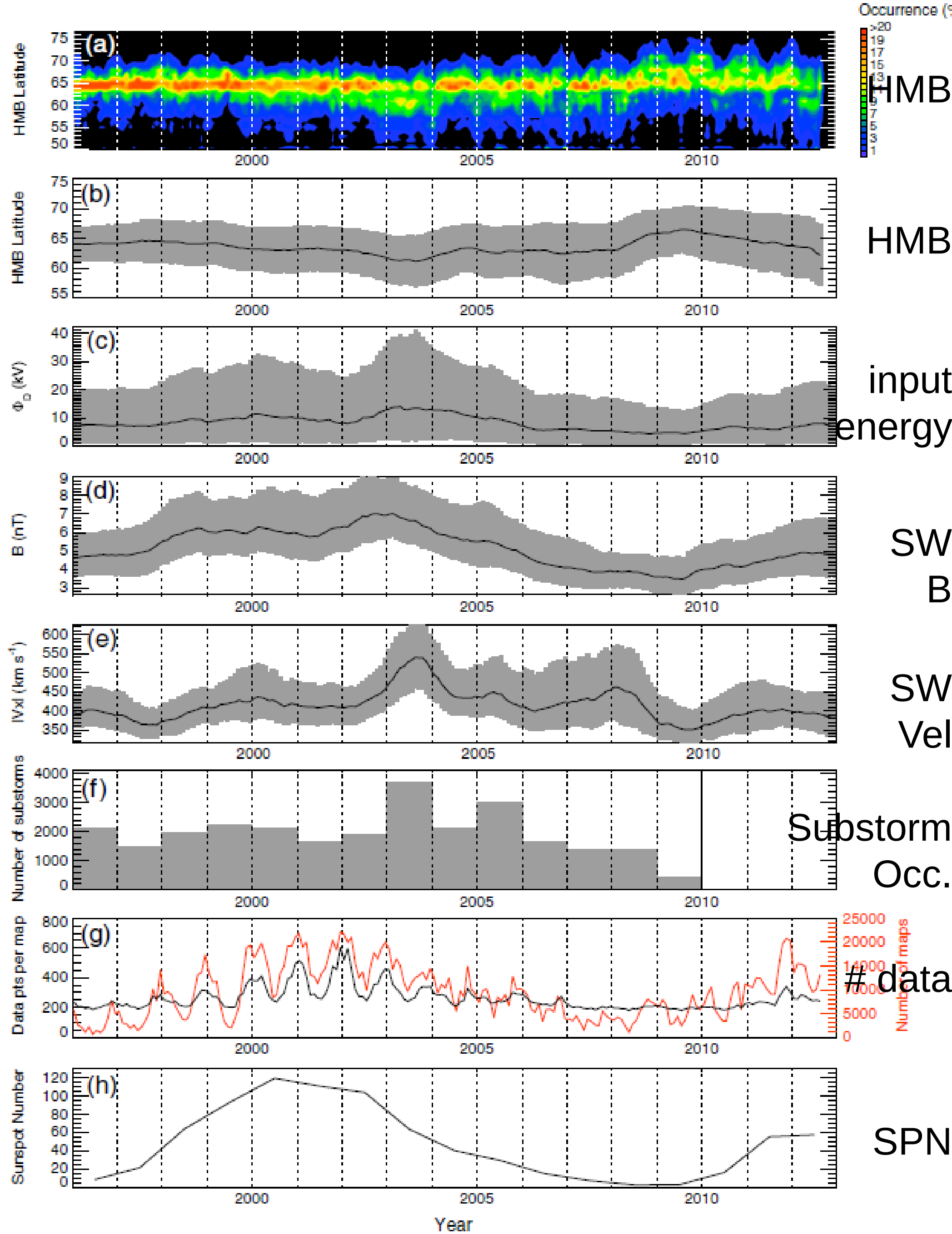
Polar Cap Tail Lobe	Cusp, LLBL, HLBL, PSBL	Auroral zone Plasma sheet	Plasmasphere Radiation belt

from Kadokura et al., NIPR Antarctic Observation Symposium 2014

HMB long term statistical variation obs. by SD → cusp latitude?



Imber, et al., JGR, 2013

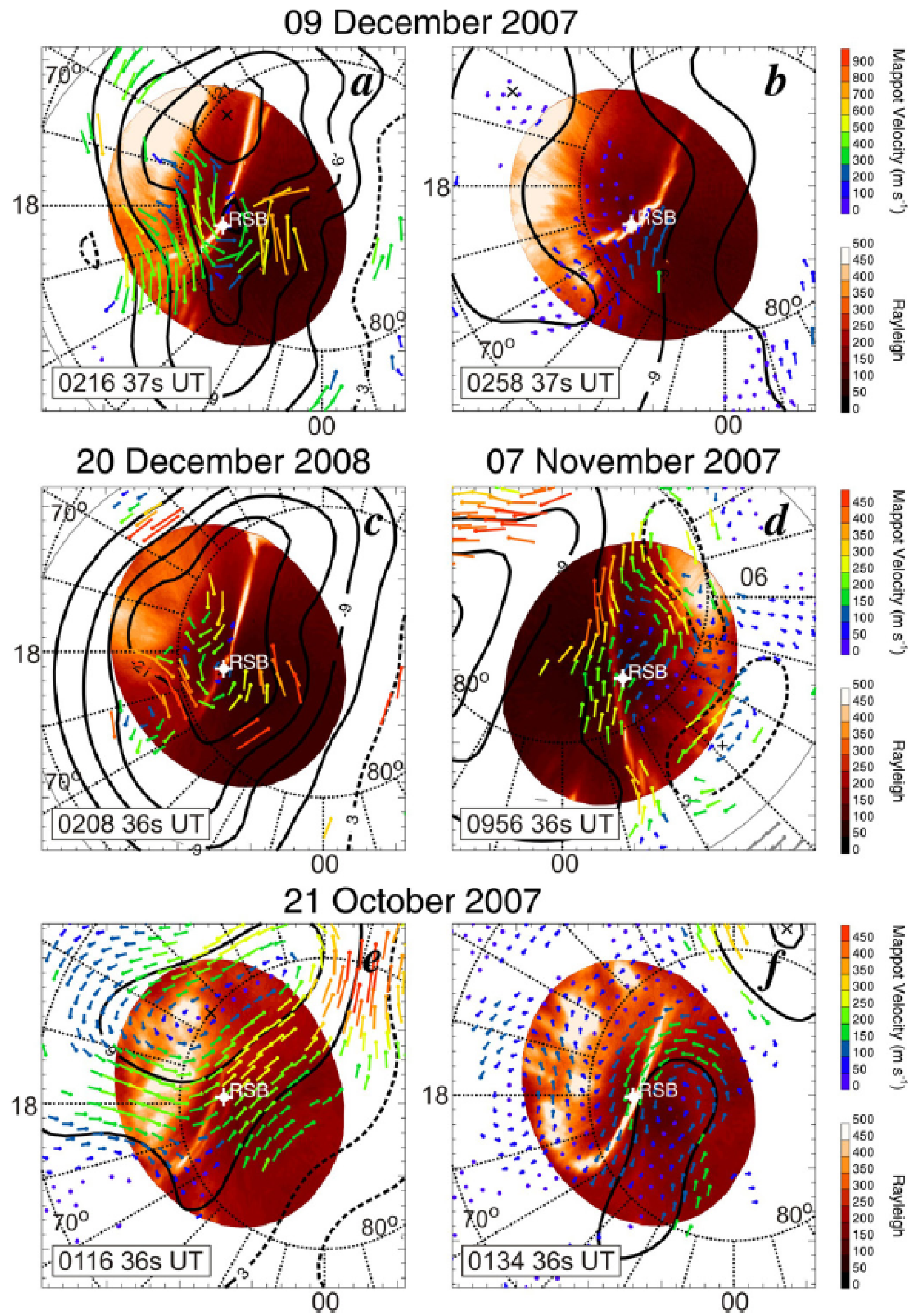


Small IMF |B| causes less active convection or not?
- Iwaki et al.

SuperDARN & Polar cap aurora simultaneous study

↓

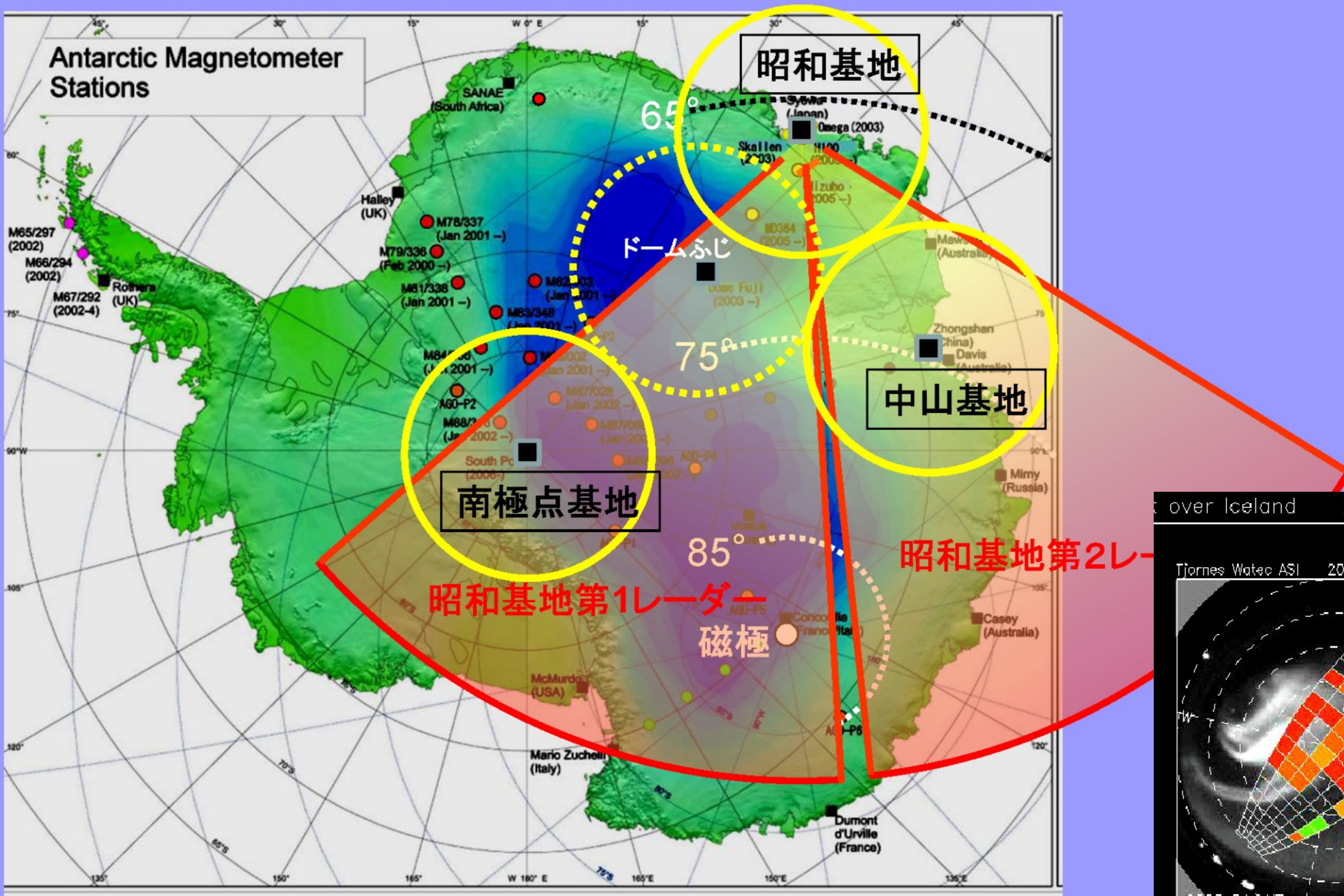
Imaging radar will enable more detailed studies

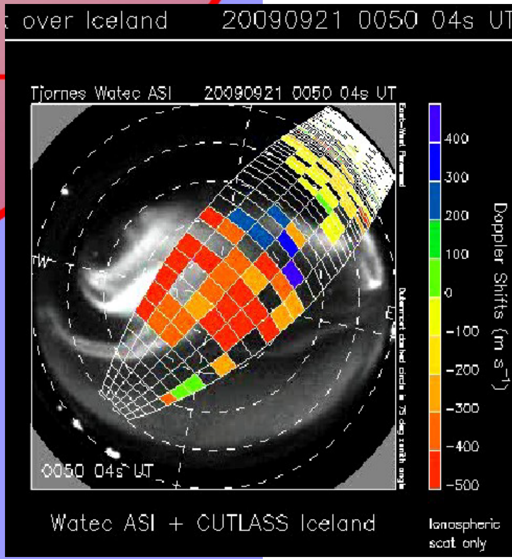


Koustov, et al. (Ann. Geophys., 2012)

FOVs of all sky camera network under SENSU FOVs & 2-D high temp. resol. Aurora SD/Opt. observation

昭和SuperDARNレーダーと光学観測の観測領域





Strategy

■ Studies on **influences of Possible Grand minimum (less active solar activities in a longer term) on Coupling processes of Solar Wind, M-I coupling, storms/substorm activities, neutral-ionized atmos. coupling (cross-region couplings) and interaction btw high and mid lat. ionosphere**

- **Less storms? Also less substorms activities??**
- Less auroral activities? smaller auroral oval? less bright?
- Shrunk polar cap? – higher latitude for OCFLB? – how about cusp lat.??

  SD, optical auroral measurement network
- how subauroral region phenomena will change and how it will influence on high and mid latitude ionosphere and interaction inbtw?
- Radiation belt at higher latitude? Ring current & plasmapause?
- Less sources of high energy particles due to less active acceleration mechanisms?
- Or **increasing GCR** causes higher population and more active energetic particles?

  Ne increase at lower upper atmos.? How about altitude of ionosphere?

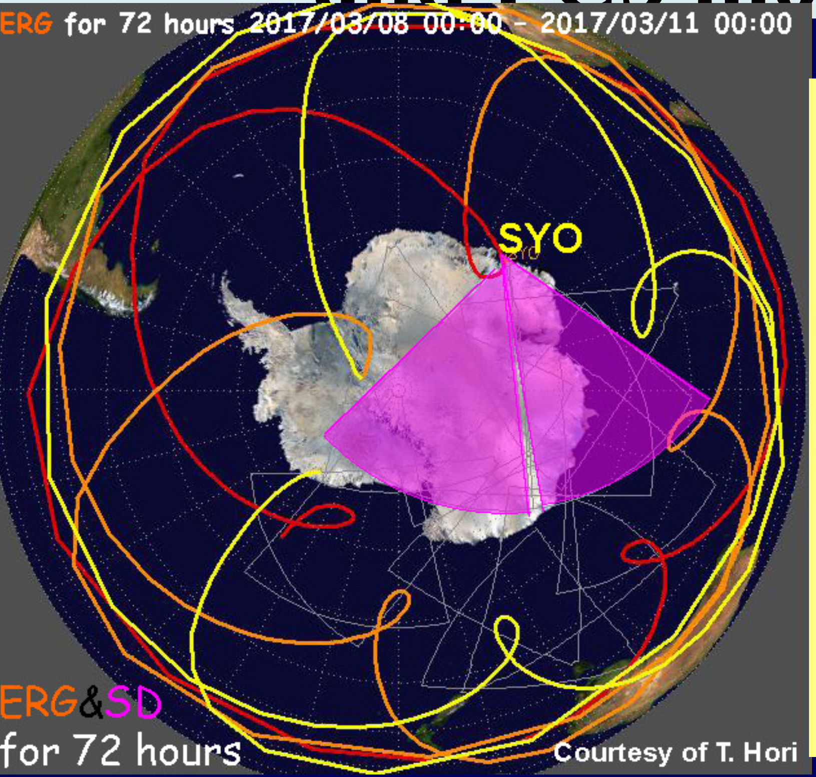
  -VAP, ERG, SD, … all closely related to…

  - **SCOSTEP/VarSITI/ISEST/MinMax24 and SPeCIMEN**
- How less active ionospheric phenomena could cause lower atmosphere climate?

  SD and PANSY with optical inst. over and around Syowa

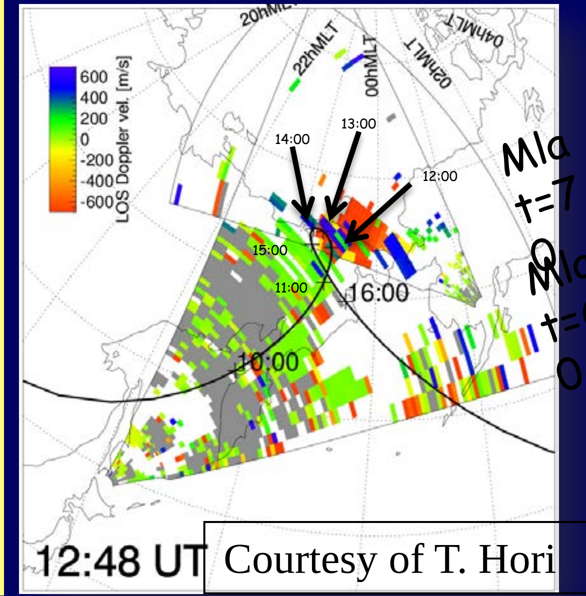
  -**SCOSTEP/VarSITI/ROSMIC**

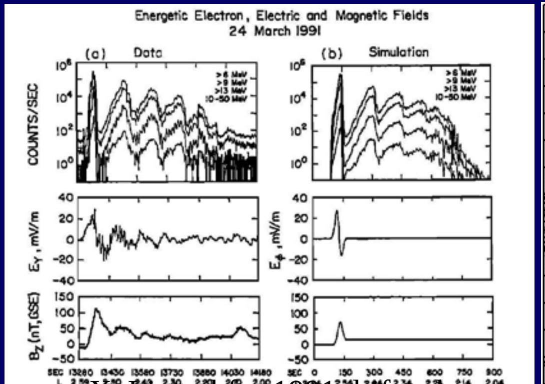
ERG & VAP footprints under SD FOVs and PC5 monitoring, SC events



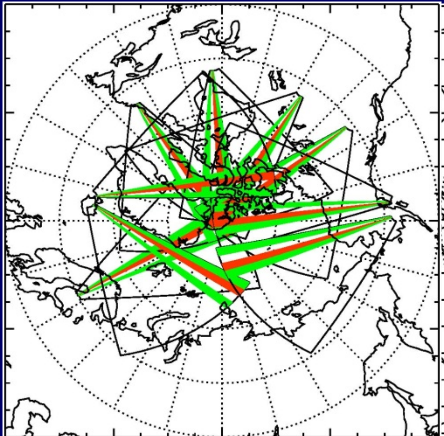
SD-ERG collaboration

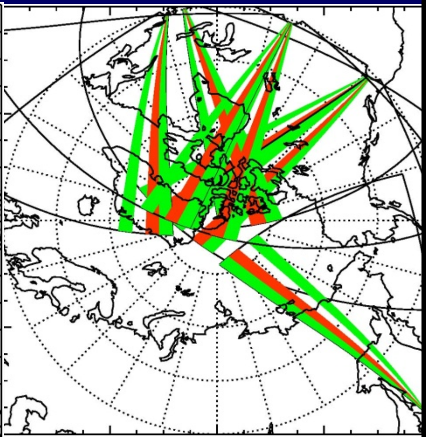
Global E & Pc5 monitoring – particle accelaration mechanisms
Special mode for conjugate obs.
Global E at SCs …

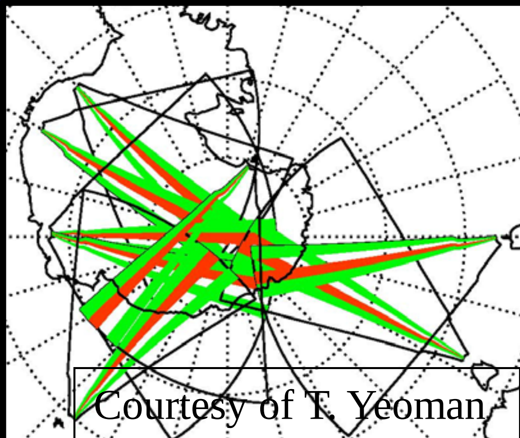




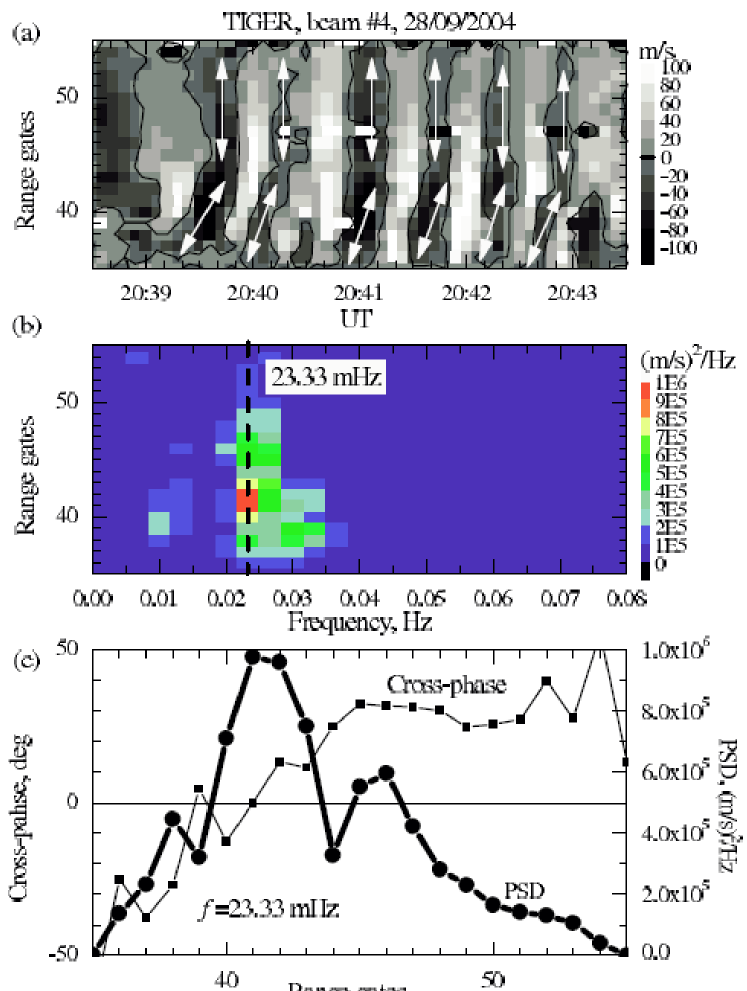
X. Li et al for 1991 drift echo events triggered by an large SC





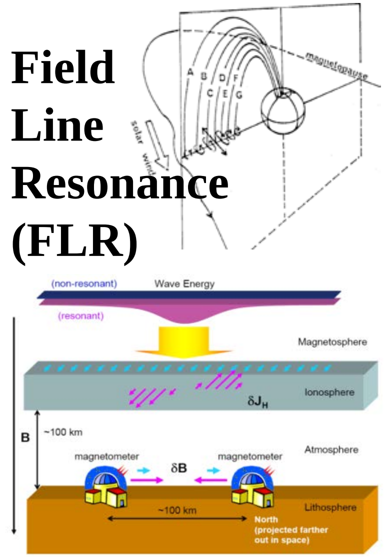


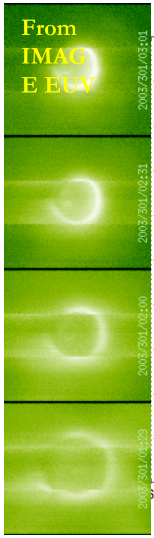
SD P.P. Detection by monitoring Pc5 FLR (collaborative work w/Kawano@Kyushu)



Ponomarenko 2005

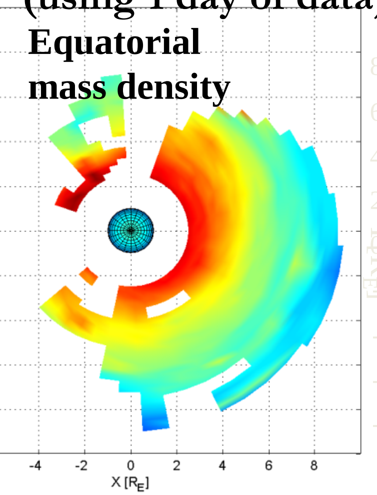
Field Line Resonance (FLR)



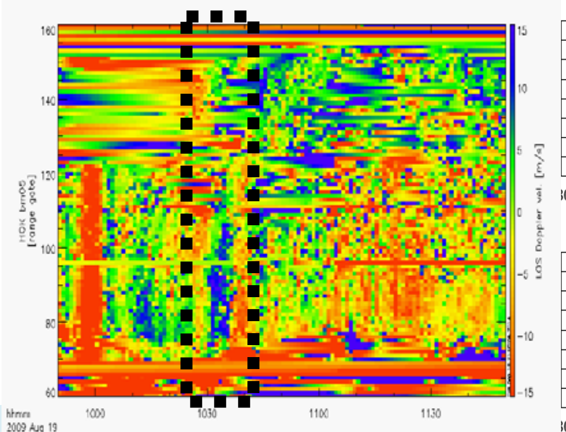


From ground FLR (using 1 day of data)

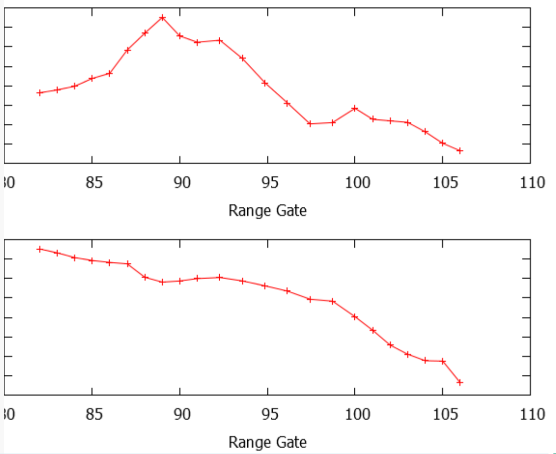
Equatorial mass density



October 28, 2003



Kawano 2015 (submitted)



SD EMIC detection w/special obs mode? – col. w/T. Hori

Summary and Future (1) Next JARE 6-year project phase IX

- Wider global coverage by SD FOVs will provide more accurate global potential maps and other physical parameters for SW-M-I-C studies.
- Esp. deep contributions to IM physics w/ VAP/ERG and G-B. obs. network and theoretical works. Also try to enable I-M mapping with SD.
- Higher spatial and temporal resolution capability will enable us to study smaller scale E field structure and related transient phenomena like substorms, aurora, patches, FAIs etc by collaborating with satellites, rockets and other g.b. radars and optical inst. network to understand MIC.
- Make SD be higher resolution global meteor radar network to contribute to MTI region dynamics and cross-region coupling studies in collaboration with other MLT related instruments.
- To achieve most or all above, close collaboration with other observational techniques and theoretical works are essentially important. Collaboration with EISCAT-3D and PANSY radars etc are particularly of great importance for comprehensive cross region coupling studies.
- Collaborative research proposals are always welcome.

Summary and Future (2) Importance on Grand Minimum studies

- Current unusual low solar activity suggests possible entrance into next historical Grand minimum. It is important to investigate and understand quantitatively its long term impacts on polar upper atmospheric environment and moreover global atmosphere or climate changes. It is just time for comprehensive researches, which also fits one of the main themes of SCOSTEP/VarSITI program.
- Changes of possible solar wind (and cosmic ray) energy inputs, influences on magnetospheric structure, e.g., cusp, polar cap, auroral oval, ionospheric convection, precipitating particles and distribution of high and low energy particles including radiation belts and those influences especially on polar upper atmosphere should be carefully investigated. E.g. Statistical study on relationship between solar activity/SW prms and SD covection/cusp lat. has been started.
- Recent still growing SuperDARN network with wider FOV coverage in both hemispheres as well as higher spatial and temporal resolutions, also with capability of neutral wind detection, in conjunction with satellites and other ground based observation network has great advantage for the studies on SW-M-I-UA-LA cross region coupling.