平成23年度名古屋大学太陽地球環境研究所研究集会「中緯度短波レーダー研究会」、名古屋大学、愛知、2011.10.24
the 2011 mid-latitude HF radar workshop, Nagoya Univ., Aichi, 2011.10.24

北海道レーダーでの流星風観測

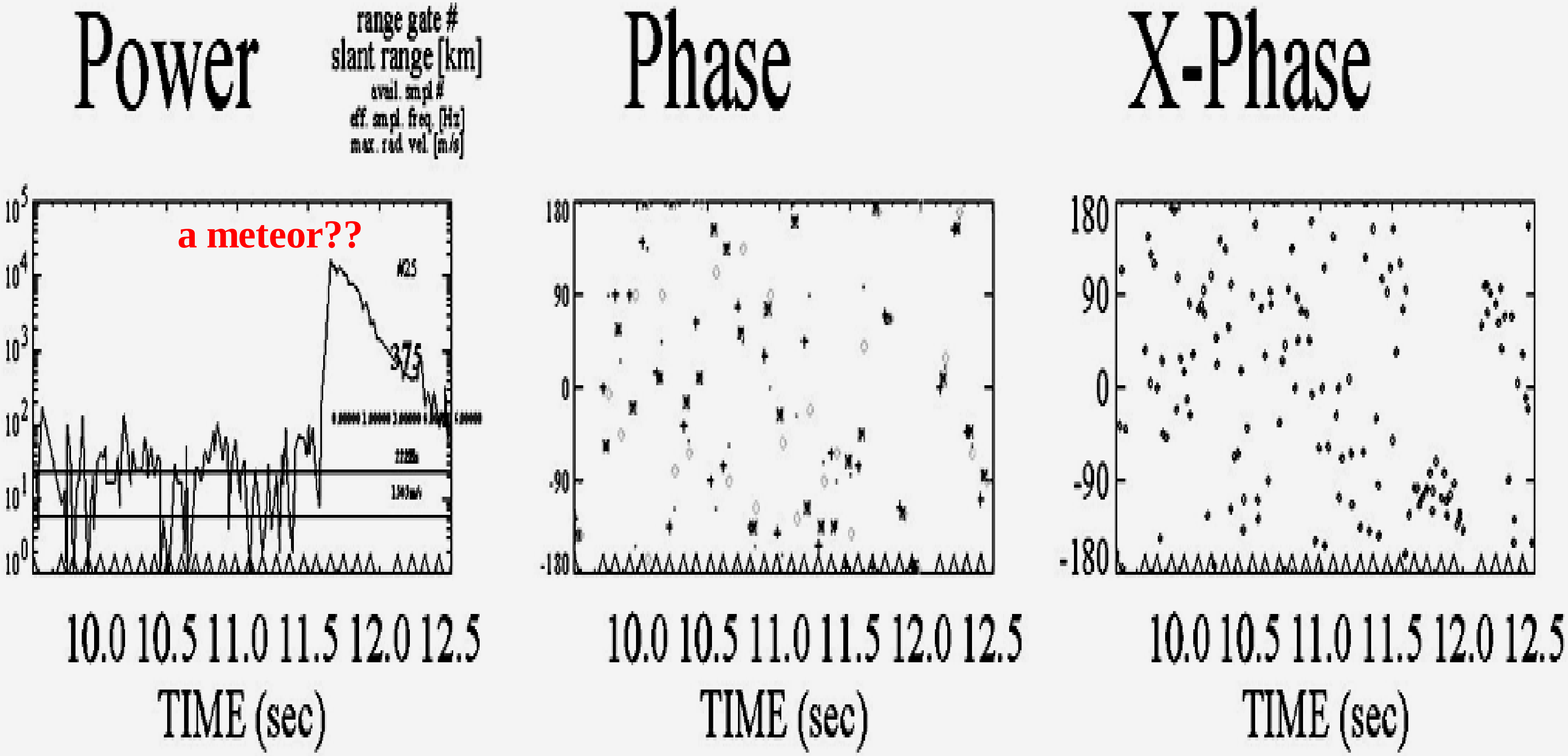
Meteor wind measurement by Hokkaido HF radar

行松彰、堤雅基(極地研)、西谷望(名古屋大)
A. S. Yukimatu, M. Tsutsumi (NIPR),
N. Nishitani (Nagoya Univ.)

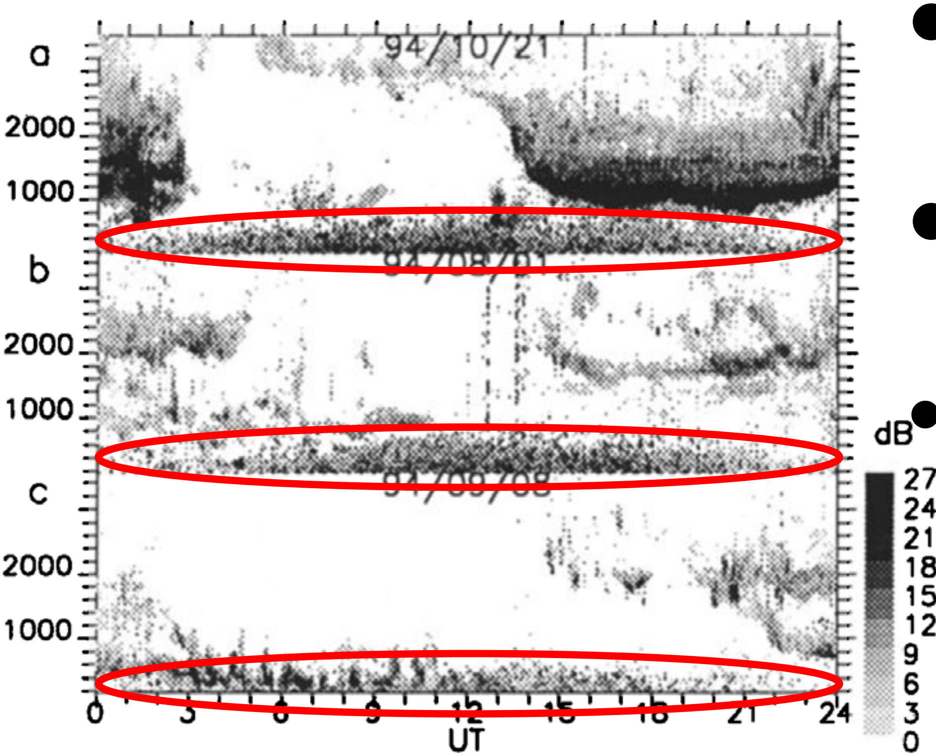
Hokkaido meteor analysis test

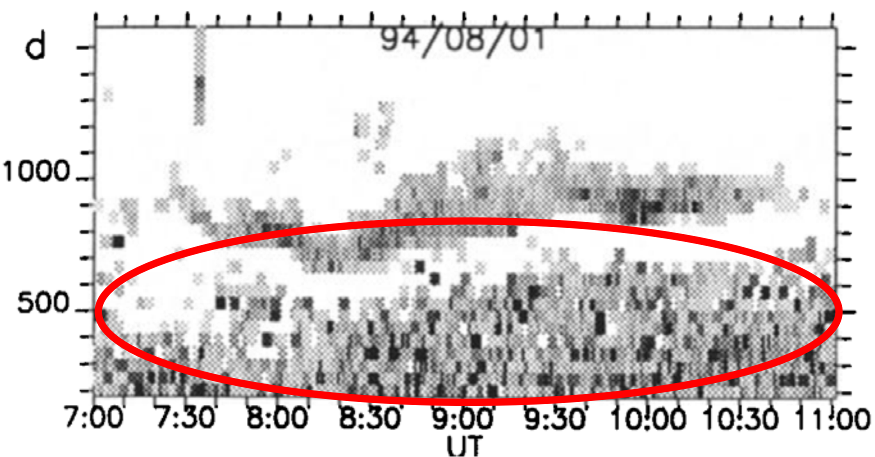
- N. Nishitani has started to obtain IQ samples at Hokkaido radar with new ROS.
- (underdense) meteor echoes should be abled to be extracted to obtain neutral wind velocity and its height profile around mesopause region
- just try to start it.
- There are some issues to be solved to do this...

Hokkaido meteor analysis test – done



SD meteor (neutral) wind obs.





- GNREs(Grainy Near-Range Echoes)
  - r<400km
  - random echo power distrib.
  - both in range, beam, and time
- echoes seen every day
  - independent on geomagnetic activities
  - Dep on UT/Local Time（LT=UT-6h）
  - many echoes in <u>early morning</u> (-> meteors?!)
- Sudden increase of GNRE echoes when Gemini meteor stream happaned on 12/13

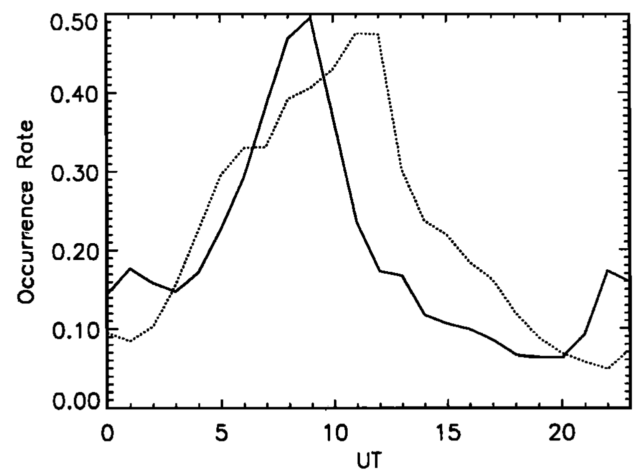


Figure 2. Mean daily occurrence of near-range echoes for May 1994 (solid curve) and October 1994 (dotted curve) for beam 5 of SuperDARN Saskatoon. This graph shows, for each hour, the fraction of integration periods containing echoes at least 10 dB above noise in the five nearest range gates, i.e., ranges between 180 and 405 km.

Hall, G., et al., JGR, 1997

SD meteor (neutral) wind obs.

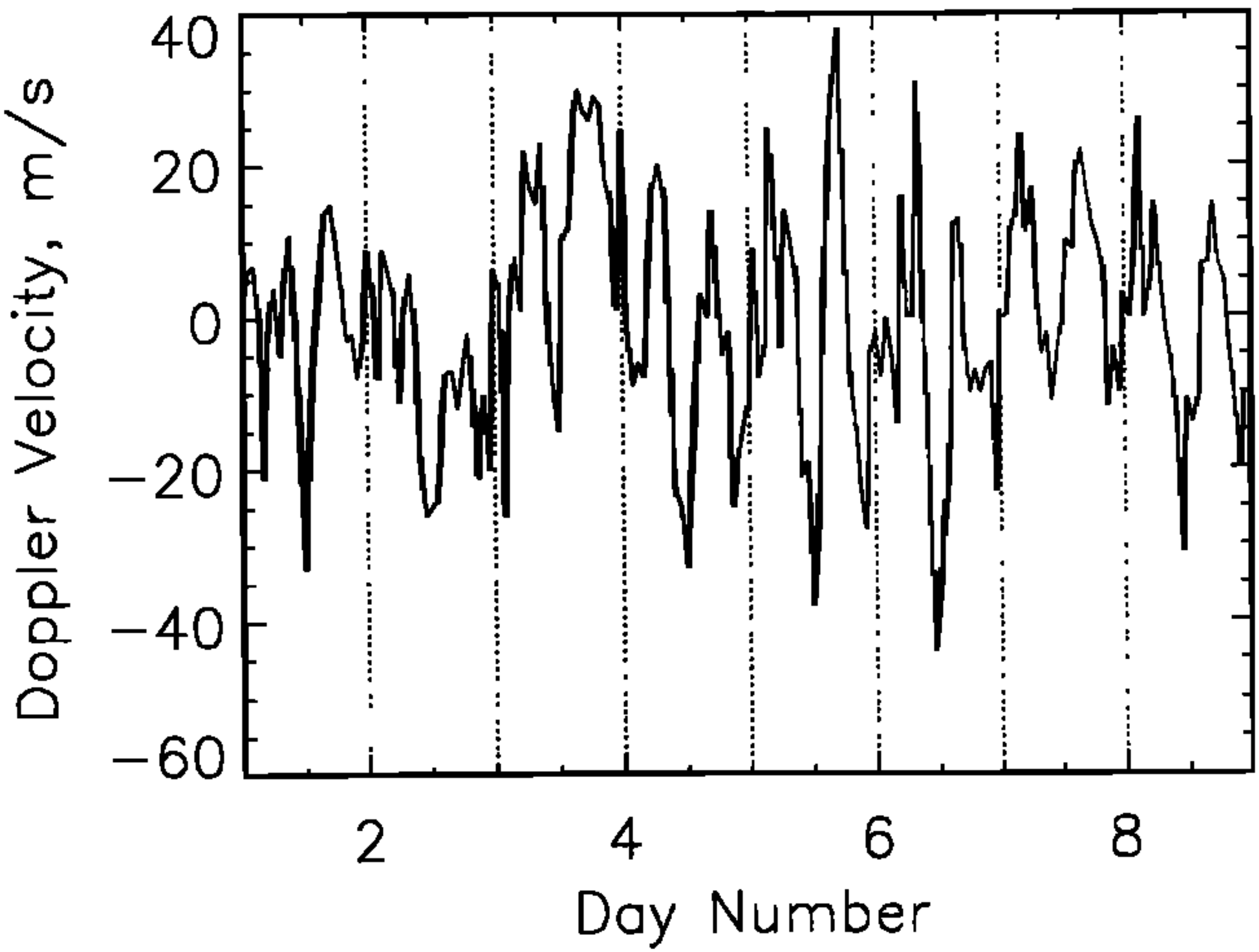


Figure 4. Hourly averaged Doppler velocities for 225 km range, beam 5 SuperDARN Saskatoon during August 1-8, 1994.

- ●variation of hourly avarange of V_{LOS}
- ●|Vlos| much smaller than normal ionospheric ehoces
- ●semi-diurnal component - diminant

- ●similar to variation of semi-diurnal tide of neutral wind

- ●⇒these echoes reflect neutral wind velocities around mesopause region!

Hall, G., et al., JGR, 1997

SD meteor (neutral) wind obs.

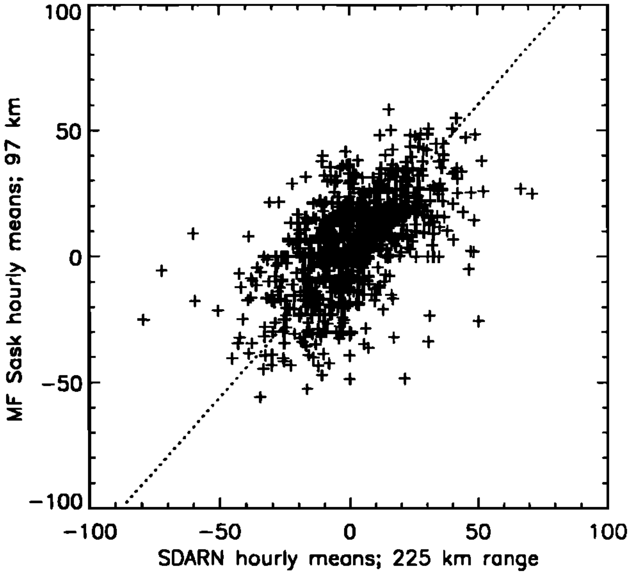


Figure 8. Scatterplot comparison of SuperDARN hourly means (225 km range, beam 5) and the MF velocities at 97 km for August 1994. The dotted line is the least squares fit $V_{MF} = (-2\pm1)+(1.16\pm0.06)\times V_{SDARN}$. The SuperDARN velocities have been rotated into the horizontal plane, and the MF velocities have been rotated into the SuperDARN azimuth direction.

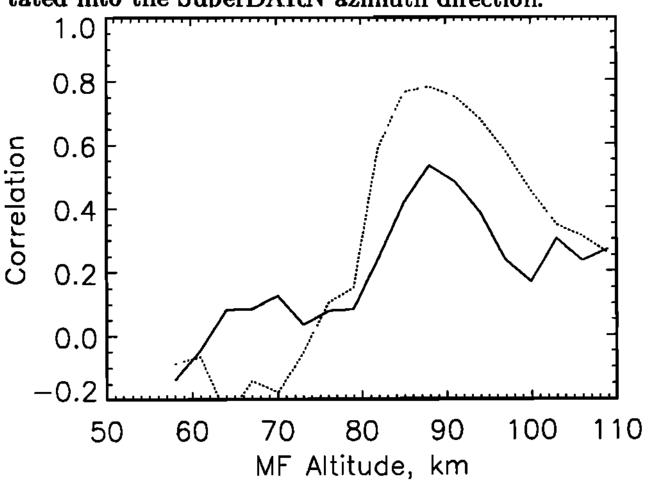


Figure 9. MF-SuperDARN velocity cross-correlation

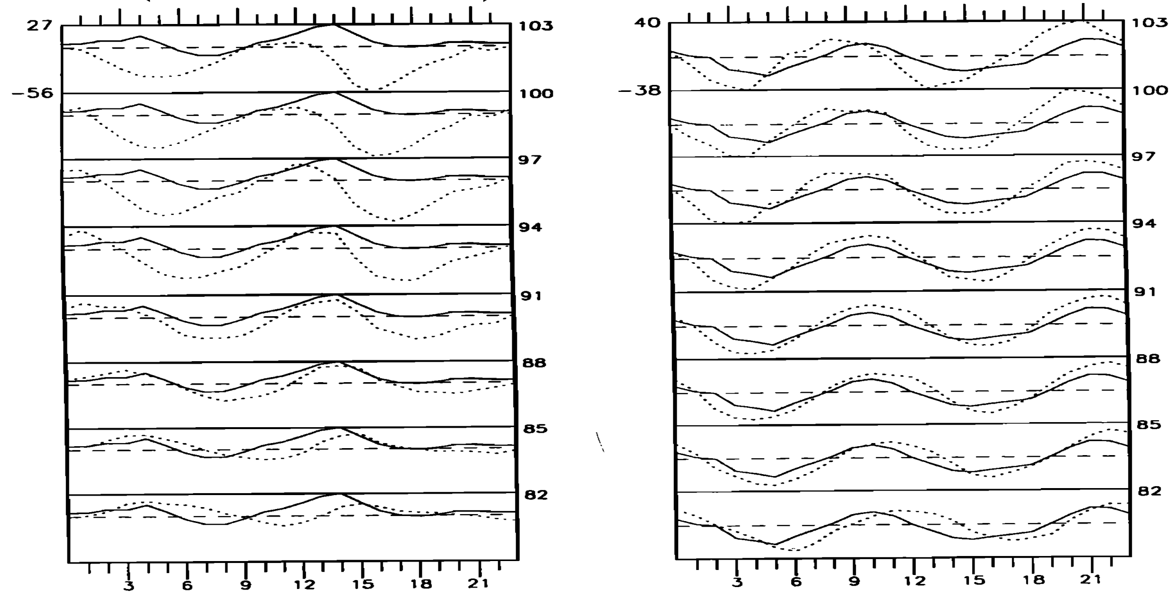


Figure 10. Mean day velocities for SuperDARN for the five nearest ranges, beam 5 (solid curves) and MF Saskatoon for heights from 82-103 km (dotted curves) for (left) August 1994 and (right) September 1994.

Table 2. Summary of SuperDARN Near Range Echo Height Measurements

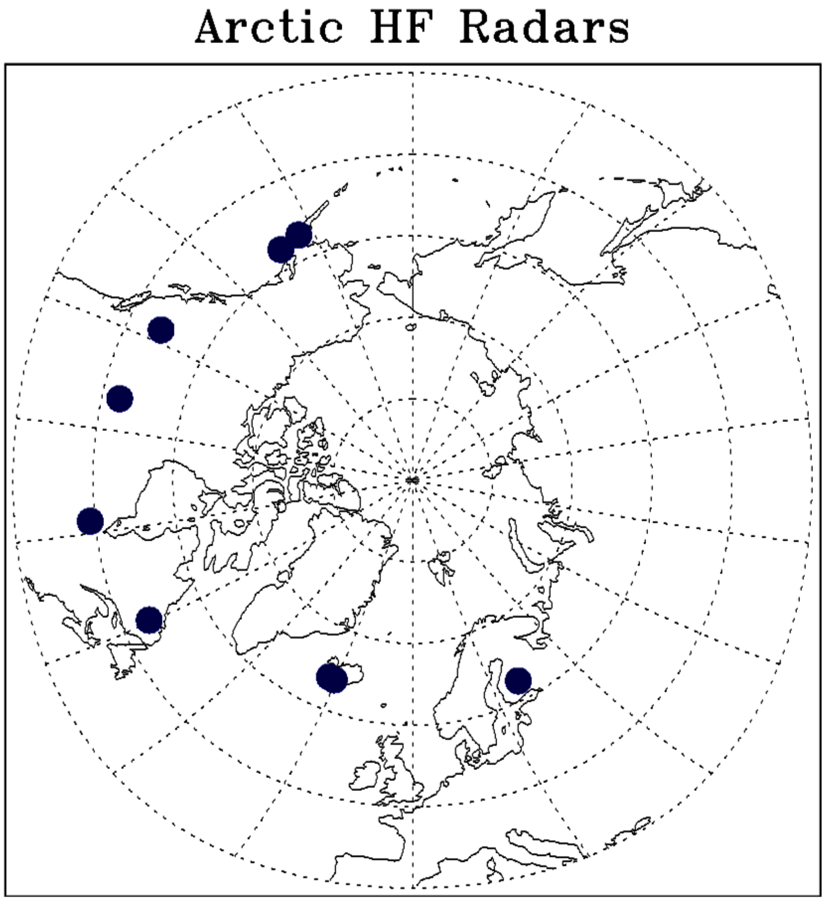
Measurement	Source of Estimate	Height, km
a	cross-correlation with Saskatoon MF	80-100
b	spectral comparison with Sask MF	94-106
c	phase of semi-diurnal tide	94 ± 3
d	vertical angle measurement	80-100
e	spectral width using peak of Fig. 5	91 ± 2
f	spectral width using mean of Fig. 5	97 ± 2

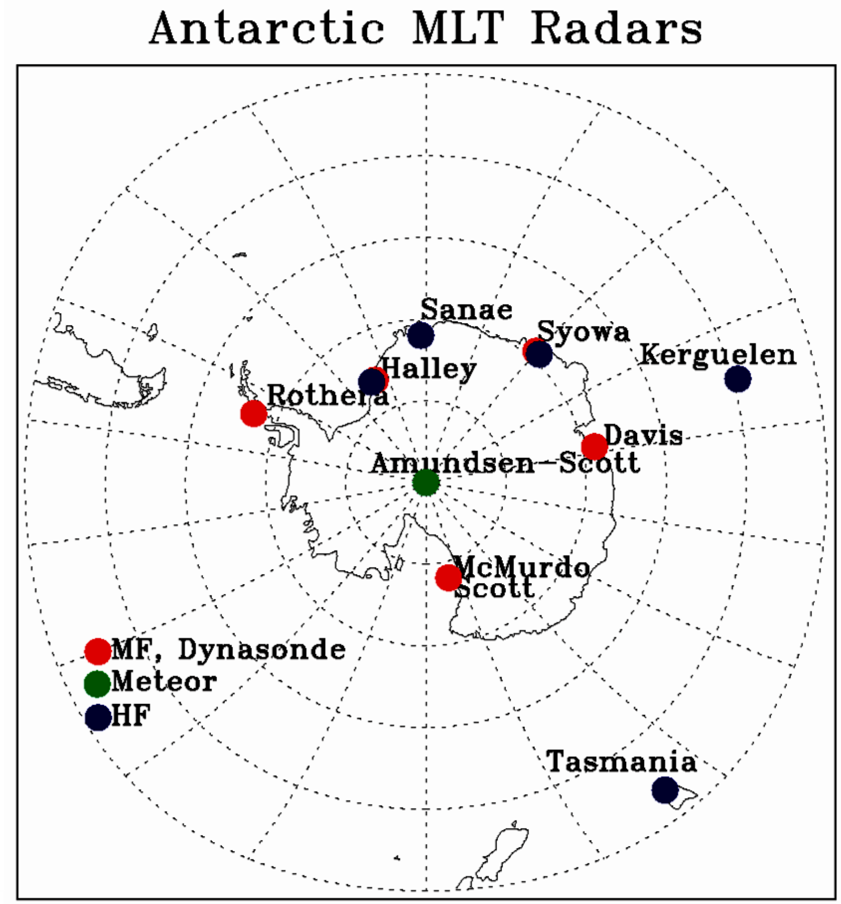
- SD GNREs:meteors @ 94±3km altitude!

Hall, G., et al., JGR, 1997

SD meteor (neutral) wind obs.

- SD GNREs are meteor echoes at 94±3km altitude
- SuperDARN can measure neutral wind
- Neutral wind measurement at mesosphere are very poor.
- SuperDARN can contribute to MLT region research
- many/some studies using neutral wind data derived from ACF triggered

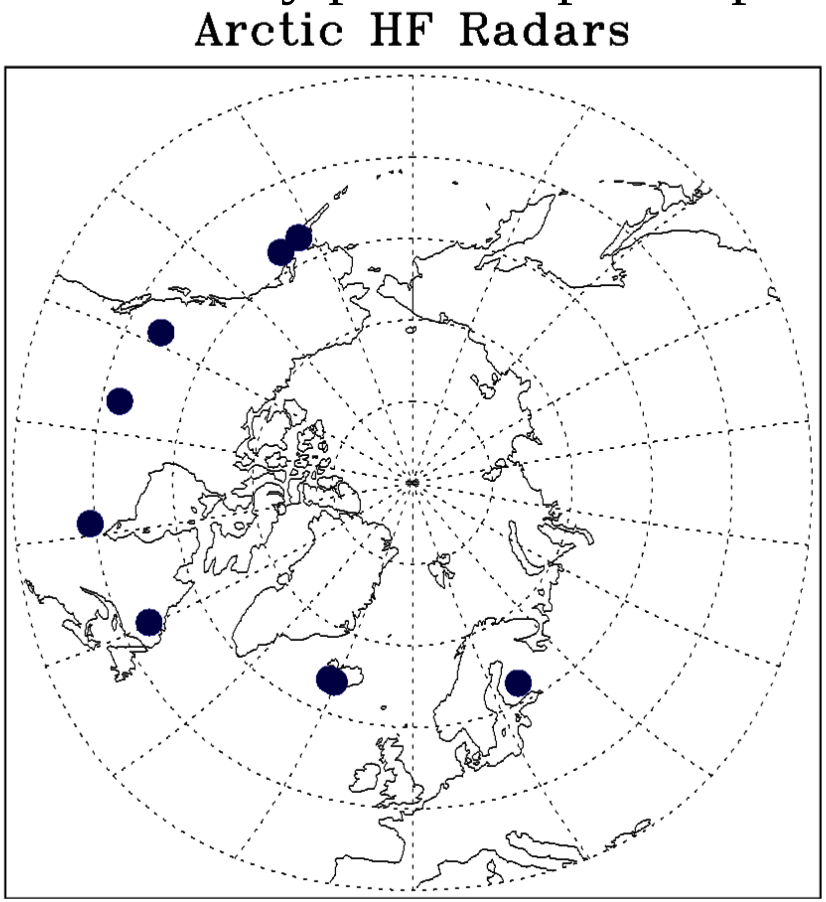


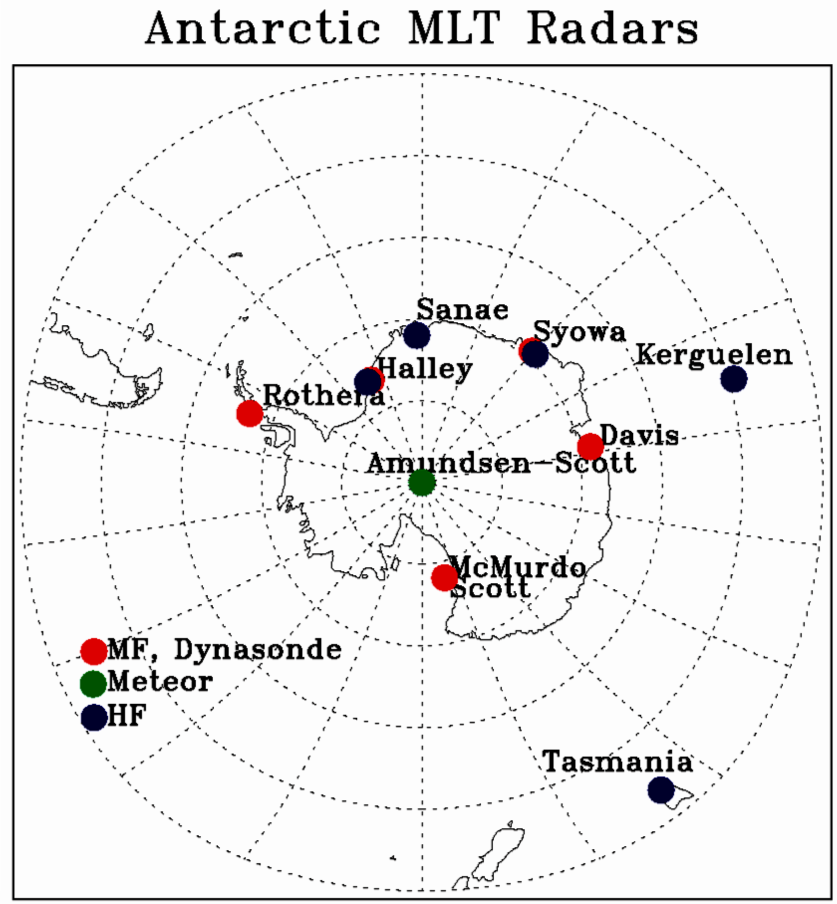


Hall, G., et al., JGR, 1997

SD meteor (neutral) wind obs.

- many/some studies using neutral wind data derived from ACF have been triggered.
- no guarantee whether it is real neutral wind data
- <u>height profile can not be resolved though it is important.</u>
- relatively poor temporal/spatial resolution





Hall, G., et al., JGR, 1997

Problems in early SD meteor obs

SD meteor wind measurements using normal fitacf'ed data

("G_{rainy} N_{ear} R_{ange} E_{choes}") [e.g., Hall et al., 1997]

Shortcomings:

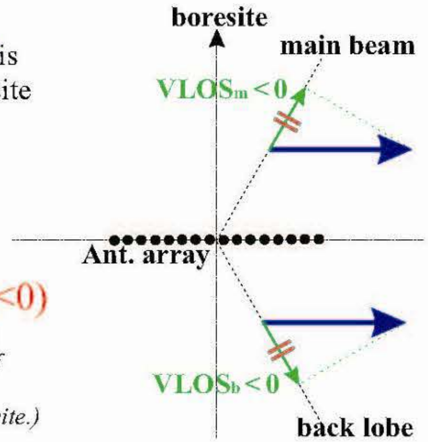
1. Impossible to exclude non-underdense-meteor type echoes thoroughly
(unknown real temporal variation of echoes)
** We cannot know if GNREs are really underdense echoes or not!*

2. Lower SNR (duration of meteor echoes (0.1~1s) << intt (~7s))

3. Too low range (height) resolution for mesopause region dynamics → *Altitude structure cannot be resolved* (even when interferometer technique is applied)

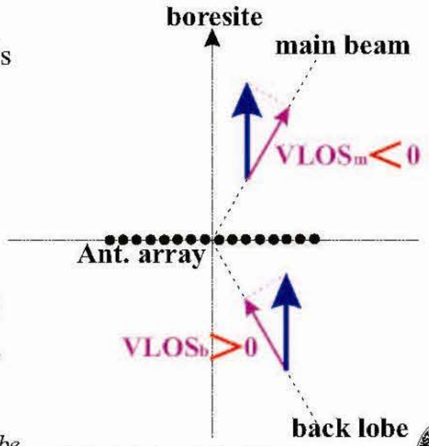
4. Directional ambiguity of echoes *(can be serious!)*
(VLOS component of neutral wind parallel to boresite could be badly affected due to echoes from behind the radar (back lobe)
* near-range meteor echo power - relatively high
* LT dep. of meteor azimuthal distribution)

A) In case that neutral wind $\vec{u}$ is perpendicular to radar boresite



$VLOS_m = VLOS_b$ (<0)
(i.e., back lobe echoes do not badly affect the estimation of neutral wind component perpendicular to radar boresite.)

B) In case that neutral wind $\vec{u}$ is parallel to radar boresite

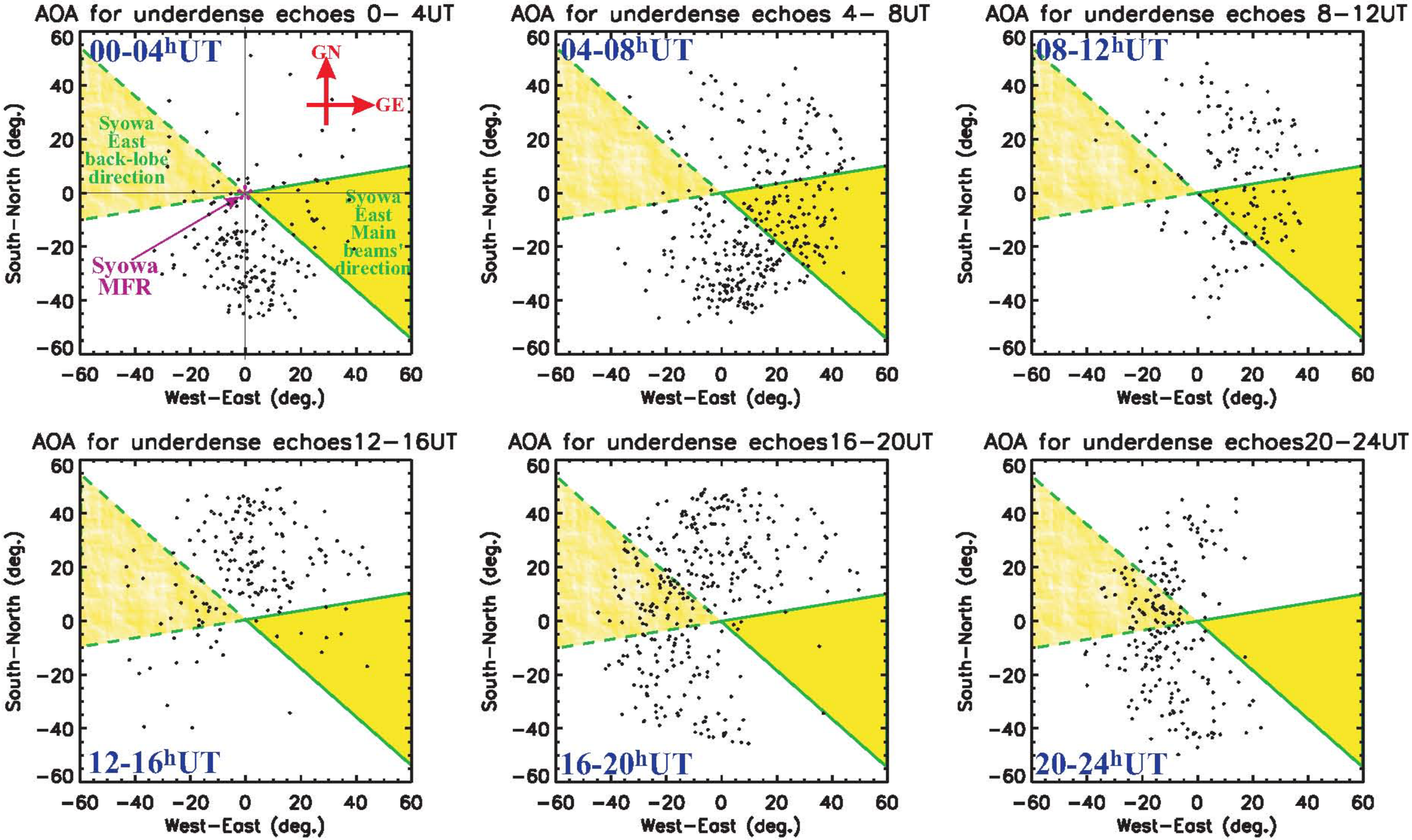


$VLOS_m \neq VLOS_b$
(i.e., back lobe echoes DO badly affect the estimation of neutral wind component parallel to radar boresite unless we distinguish back lobe echoes from main beam echoes.)
($|VLOS_b| = |VLOS_m|$)

5. Too far frang (1st range gate) (normally 180 km)

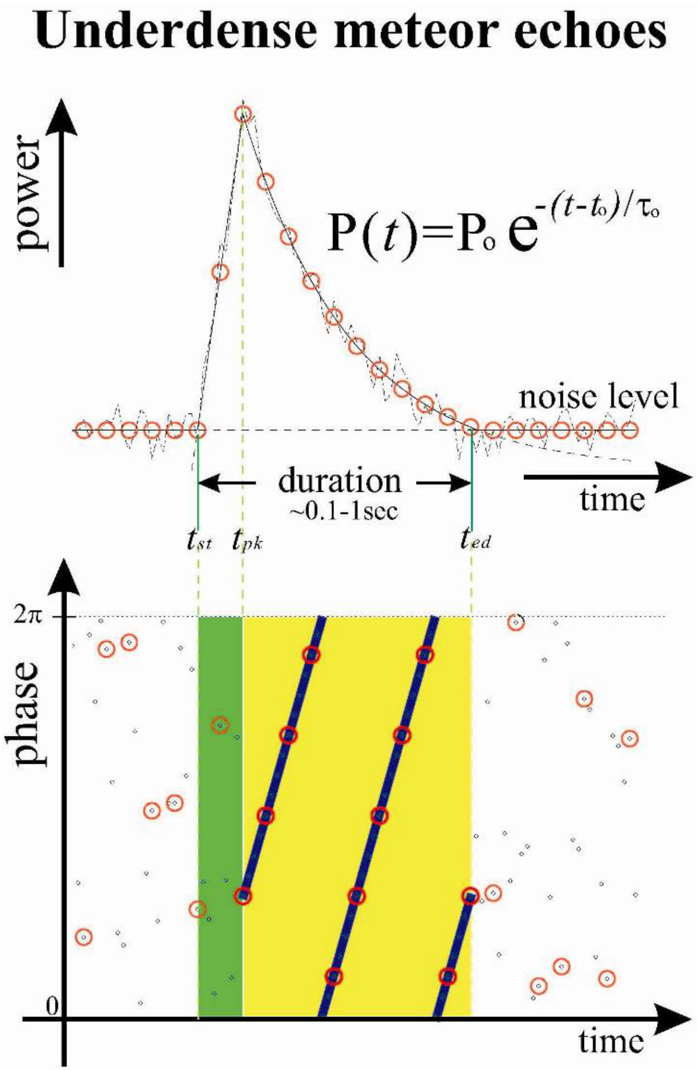
Local time dependency of meteor azimuthal distribution

by Syowa MF (meteor mode w/interferometer, 2.4MHz) 1999/06/15



Syowa LT ~ UT+2^h40^m

IQ raw time series analysis (TMS)



More requirements for raw time series meteor analysis:

1. **Duration of meteor echoes : ~0.1-1s** ⇒ **>= ~20Hz**
2. **| horizontal neutral wind vel. | =<~150m/s** ⇒ **>= ~20Hz (@~10MHz)**

   *(Vd=1/2 * c * Δf / freq)* (~40Hz @~20MHz)

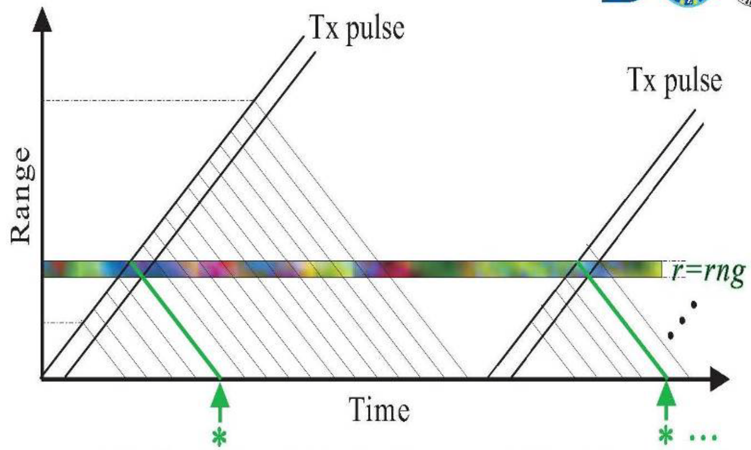
⇒ **Both require at least 20Hz of effective sampling frequency for raw time series analysis.**

⇒ **When current pulse seq. (~100msec) is used, if at least 2 samples per pulse seq. are available for raw time series analysis, it meets the requirements above** *(if freq ~ 10 MHz)*.

like a conventional meteor radar...

IQ raw time series analysis (TMS)

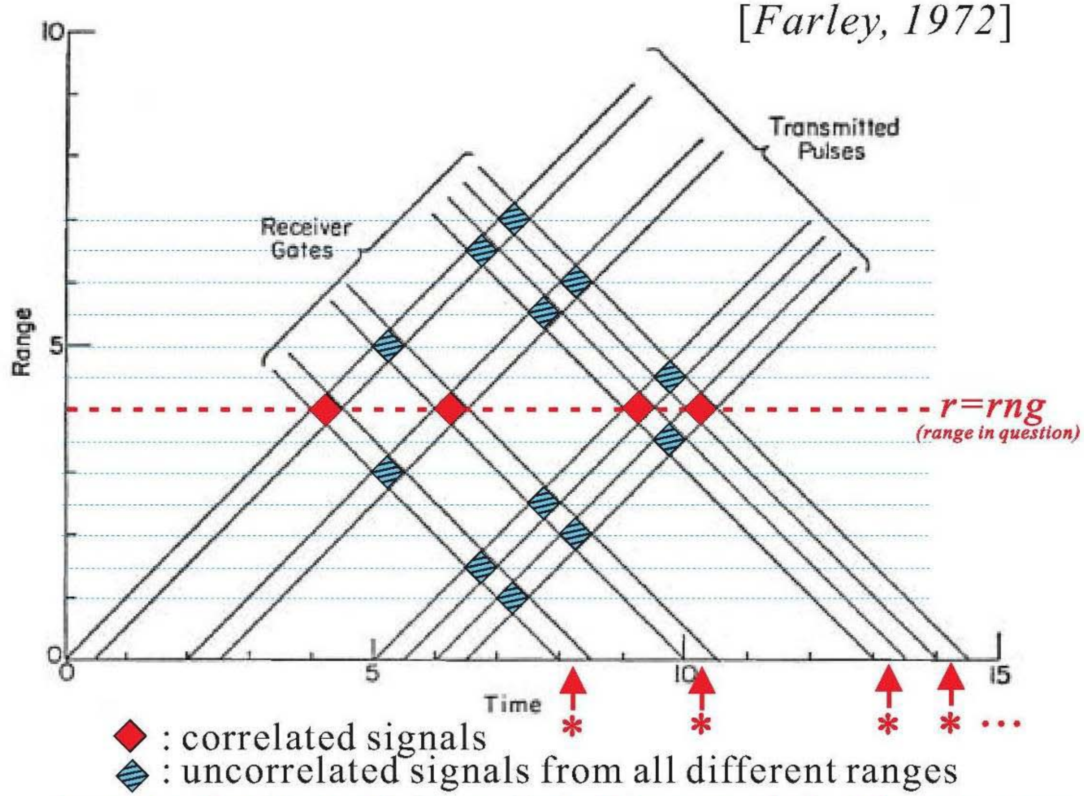
"single-pulse" observation



* : can form (equally spaced) time series for *range=rng* without any range ambiguity

"unequally spaced multi-pulse ACF method"

[*Farley, 1972*]



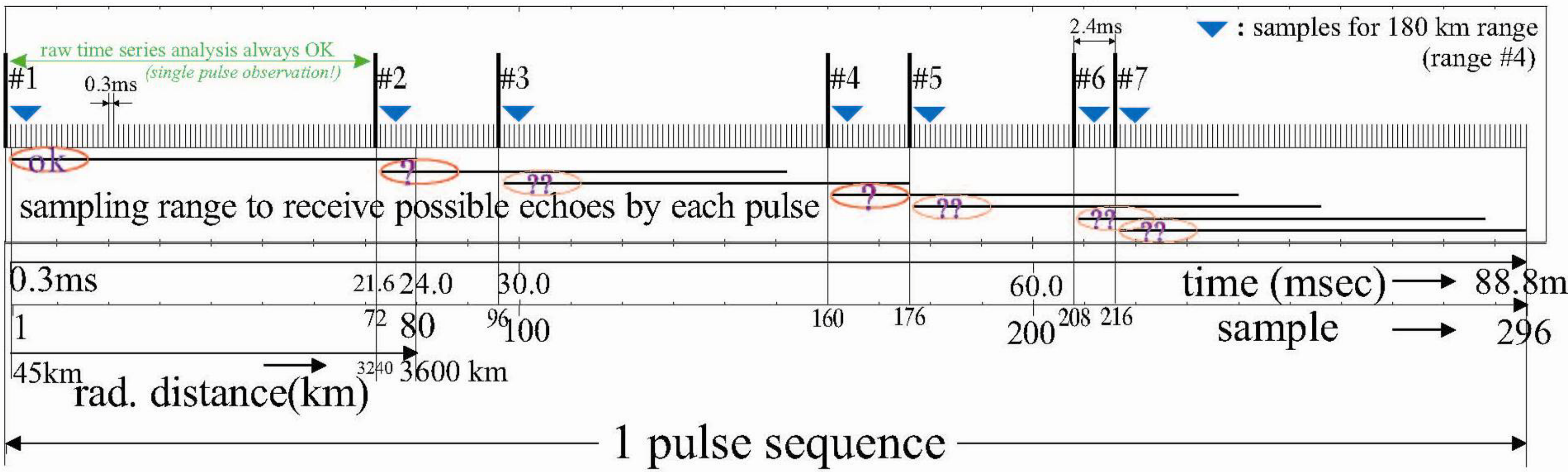
* : can be affected by possible "range-aliasing" ("cross-range" effect) from other ranges

=> Is "raw time series analysis" possible?!?

IQ raw time series analysis (TMS)

SuperDARN pulse sequence and sampling points

mppul=7, mpinc=2400us, ppat[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



Possible Maximum Radial Velocity : $\lambda \cdot f_N/2$ > **150m/s**

(required for neutral wind measurements in mesopause region to study MLT region dynamics)

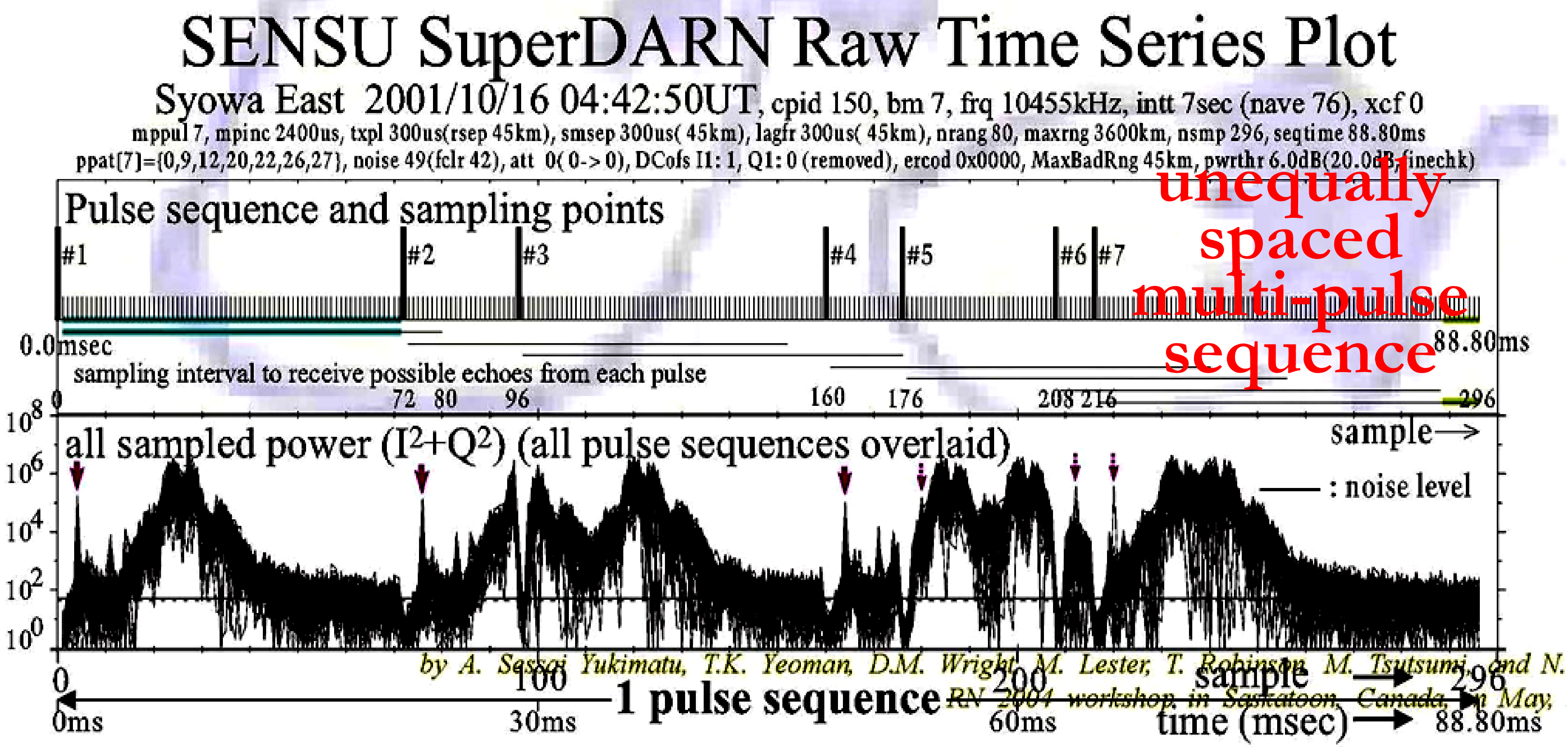
→ Nyquist Frequency(f_N) : > 10Hz *(in case of TxFreq=10 MHz)*

→ Sampling Frequency : > 20Hz

→ # of usable samples required : **>=2** *(per 1 pulse seq (~100 ms))*

IQ raw time series analysis (TMS)

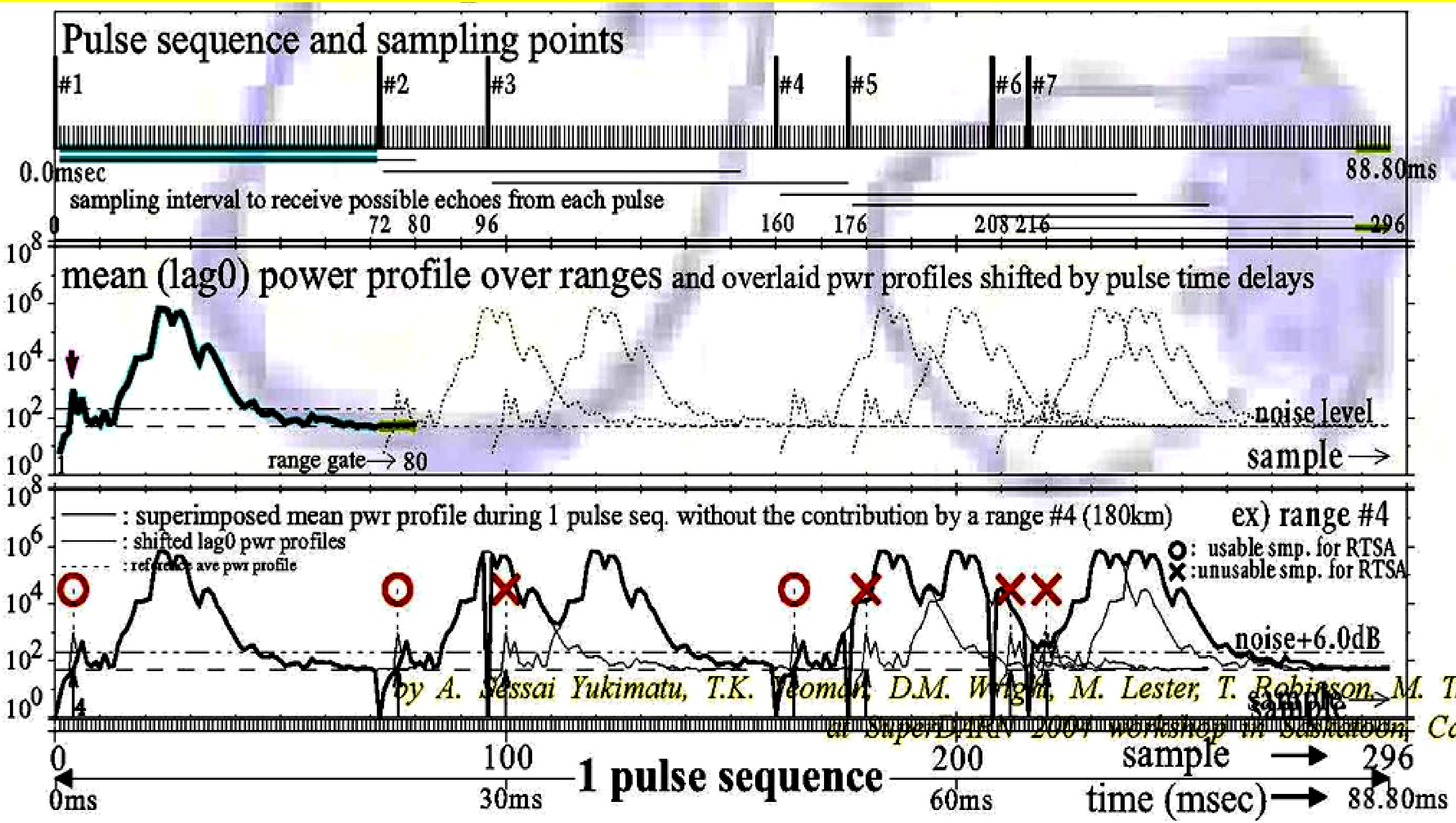
TMS mode does just simply record all the raw IQ samples (with time stamps and all other info)



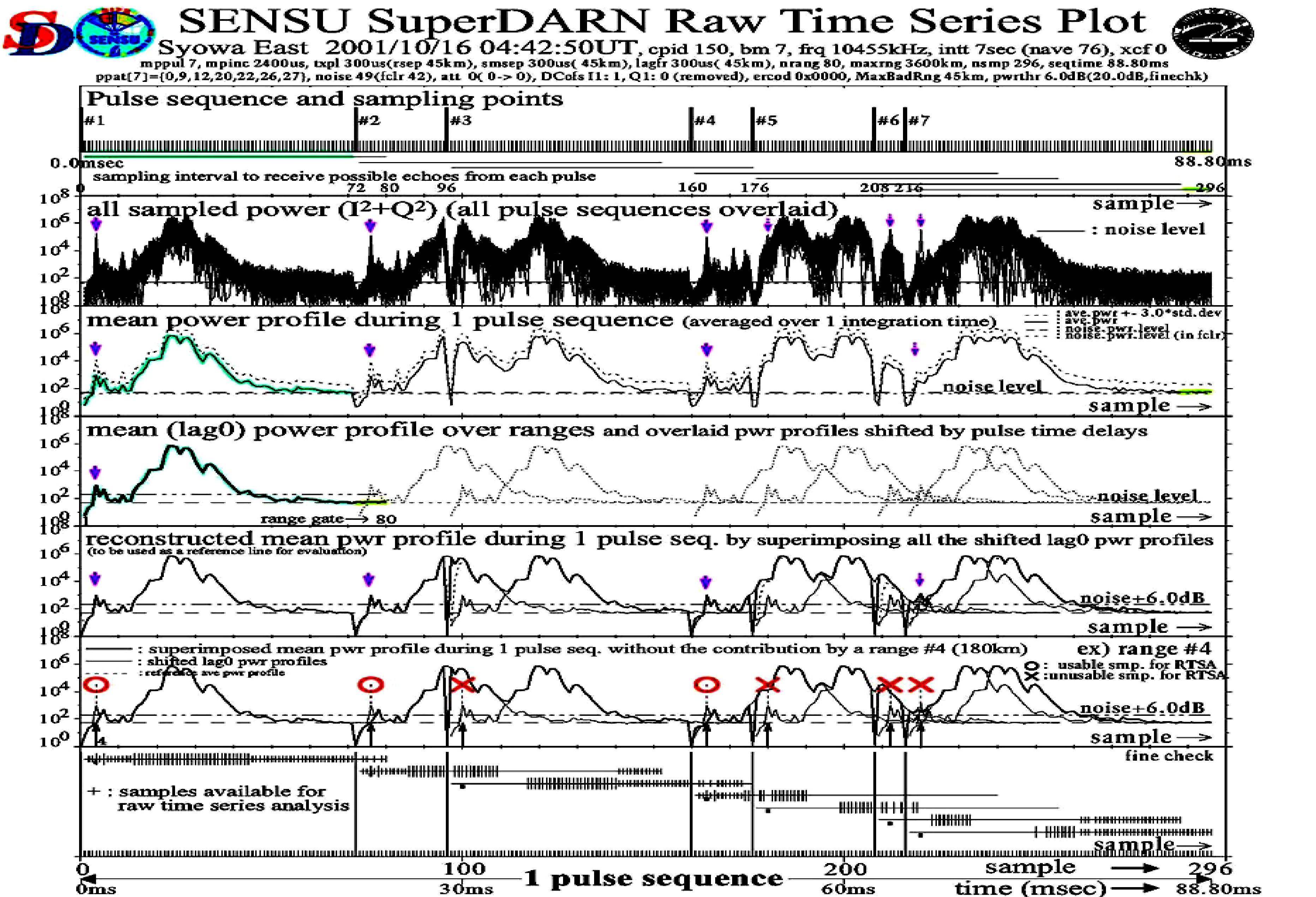
1 pulse sequence ~90msec

IQ raw time series analysis (TMS)

Reconstruct (unequally sampled) raw IQ time series for each range gate, not affected much by cross range noises by checking lag0-pwr range profile.
⇒ Very high time resolution (>10Hz, ~400Hz) time series analysis can be performed.

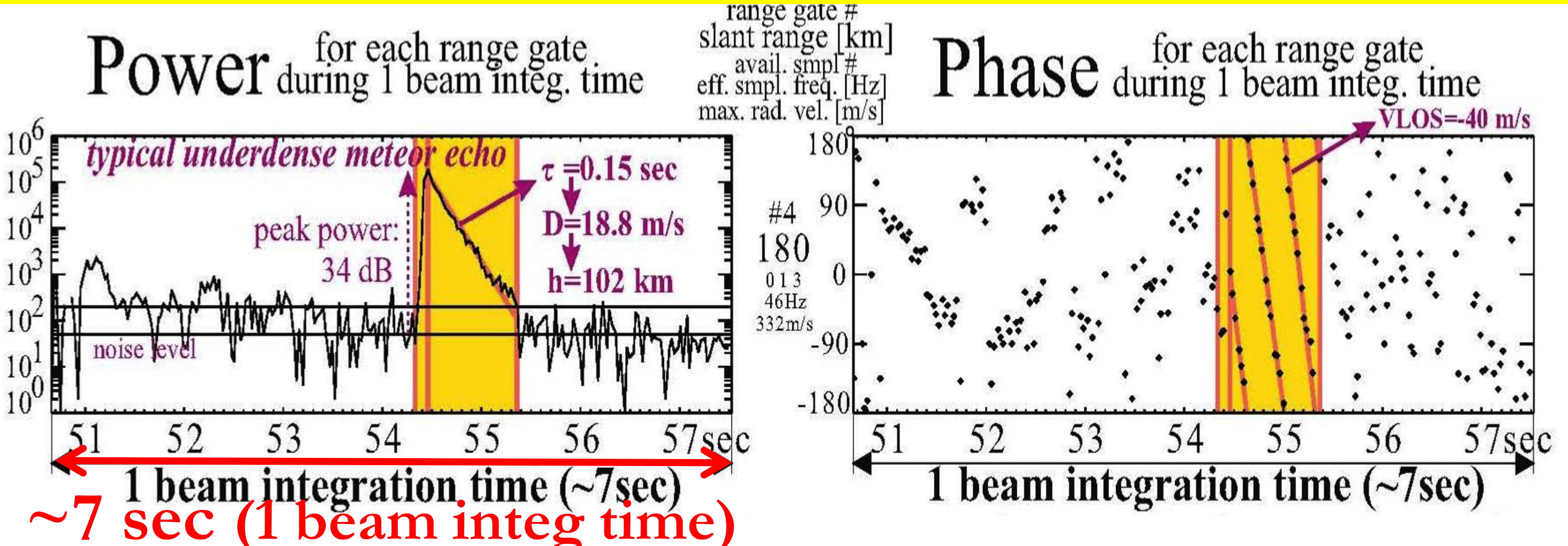


IQ raw time series analysis (TMS)



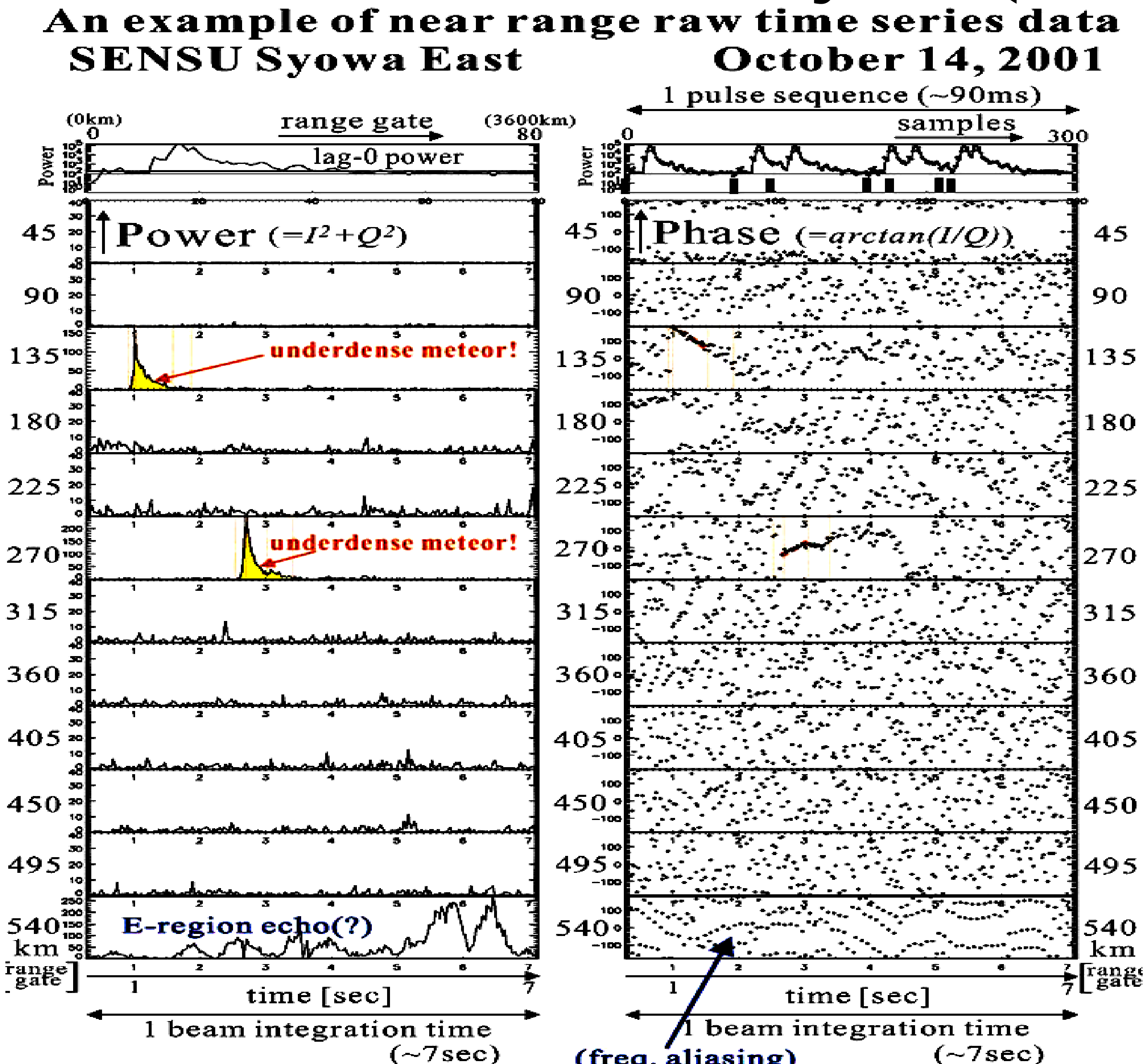
IQ raw time series analysis (TMS)

Reconstructed raw time series for a range gate (Power and Phase) during 1 beam integration time of ~7 sec

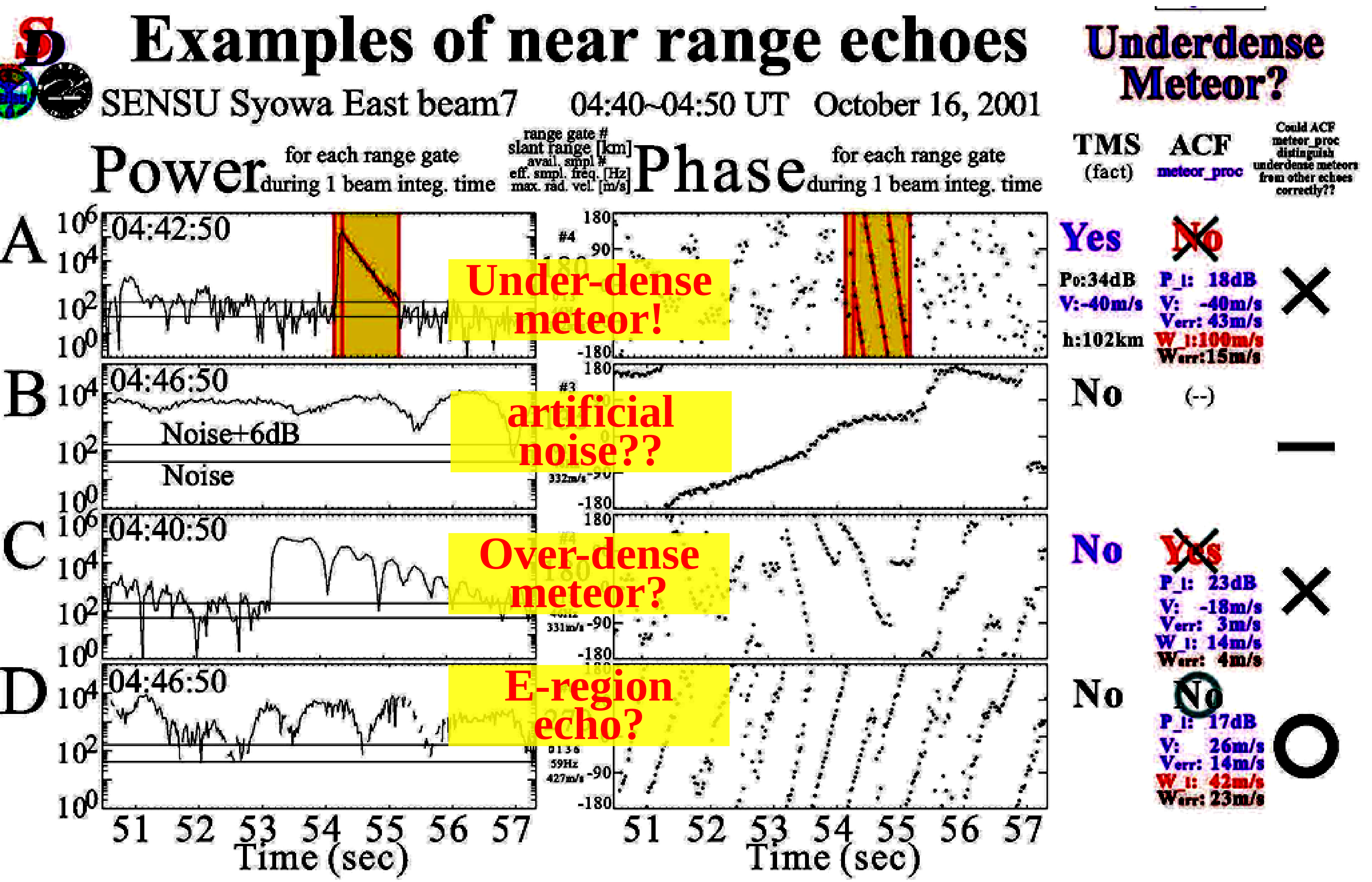


together w/ conducting ACF(frequency domain) obs., record all the IQ samples, extract samples with no cross range effect, which enables time series (time domain) analysis. (TMS mode、Yukimatu & Tsutsumi, GRL, 2002)

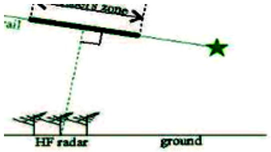
IQ raw time series analysis (TMS)



IQ raw time series analysis (TMS)

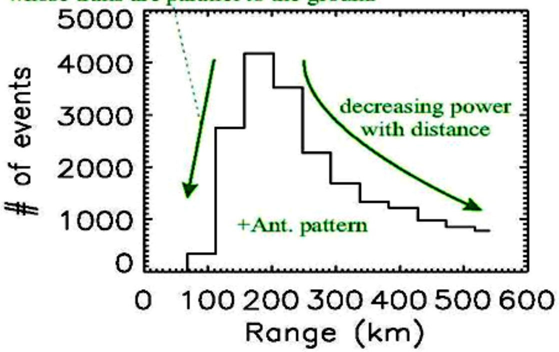


IQ raw time series analysis (TMS)

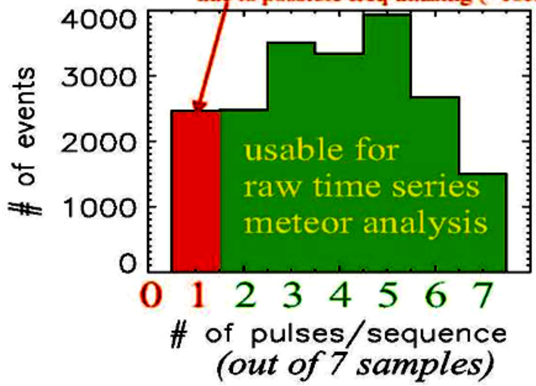


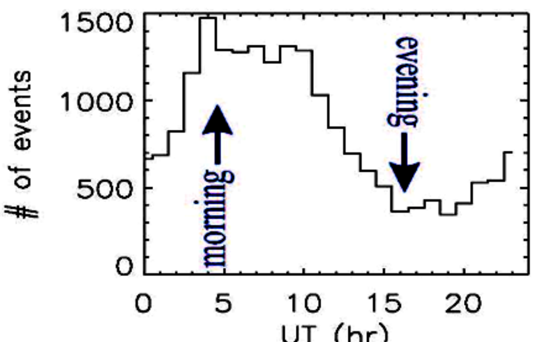
SENSU Syowa East
October 15-21, 2001
(2000~3000 meteors/day)

almost no meteor echoes whose trails are parallel to the ground

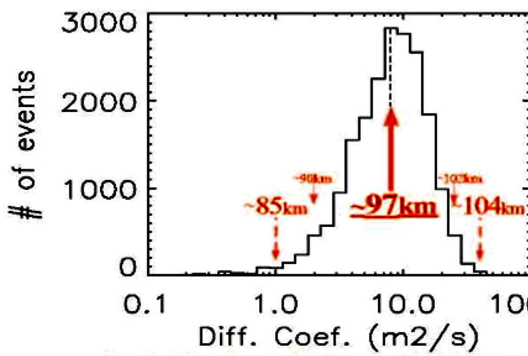


not used for raw time series analysis due to possible freq-aliasing (~10Hz)





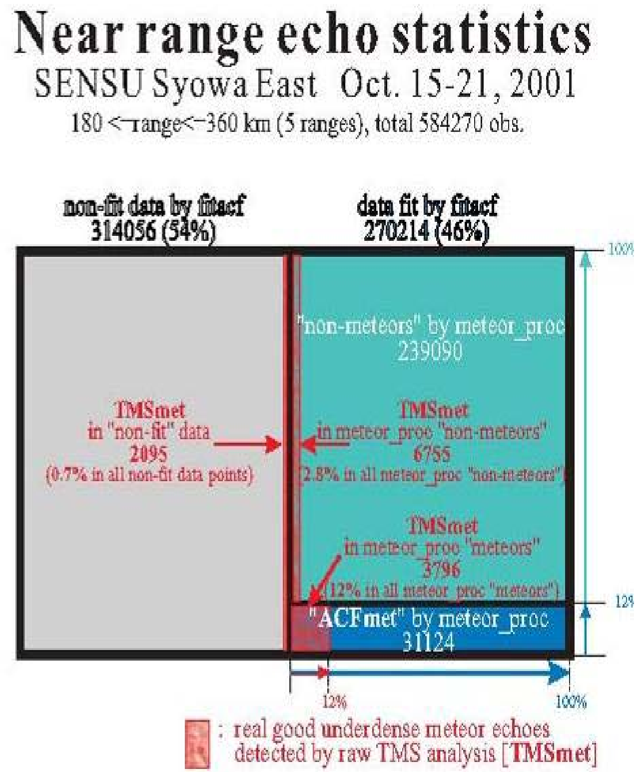
Syowa LT = UT+2^h40^m

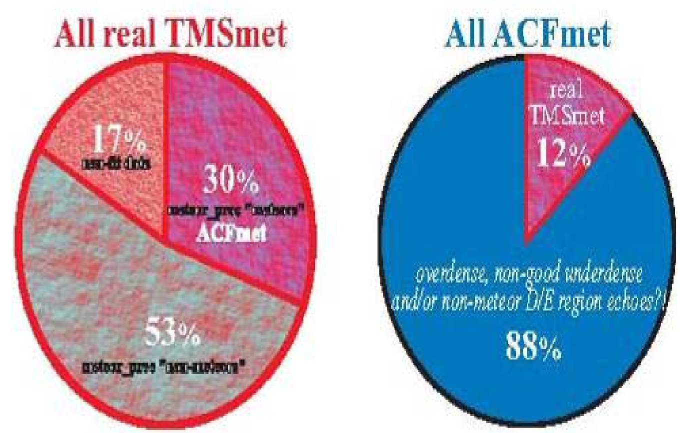


height by CIRA1986 model

All these are expected and reasonable for meteor echoes

~85 - 105 km
peak @ ~97 km
in case of freq~10.4 MHz
(slight TxFreq dependency..)

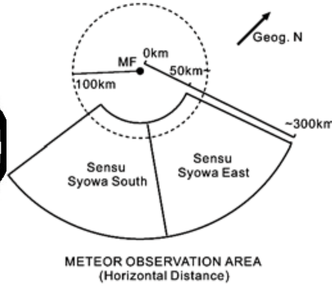


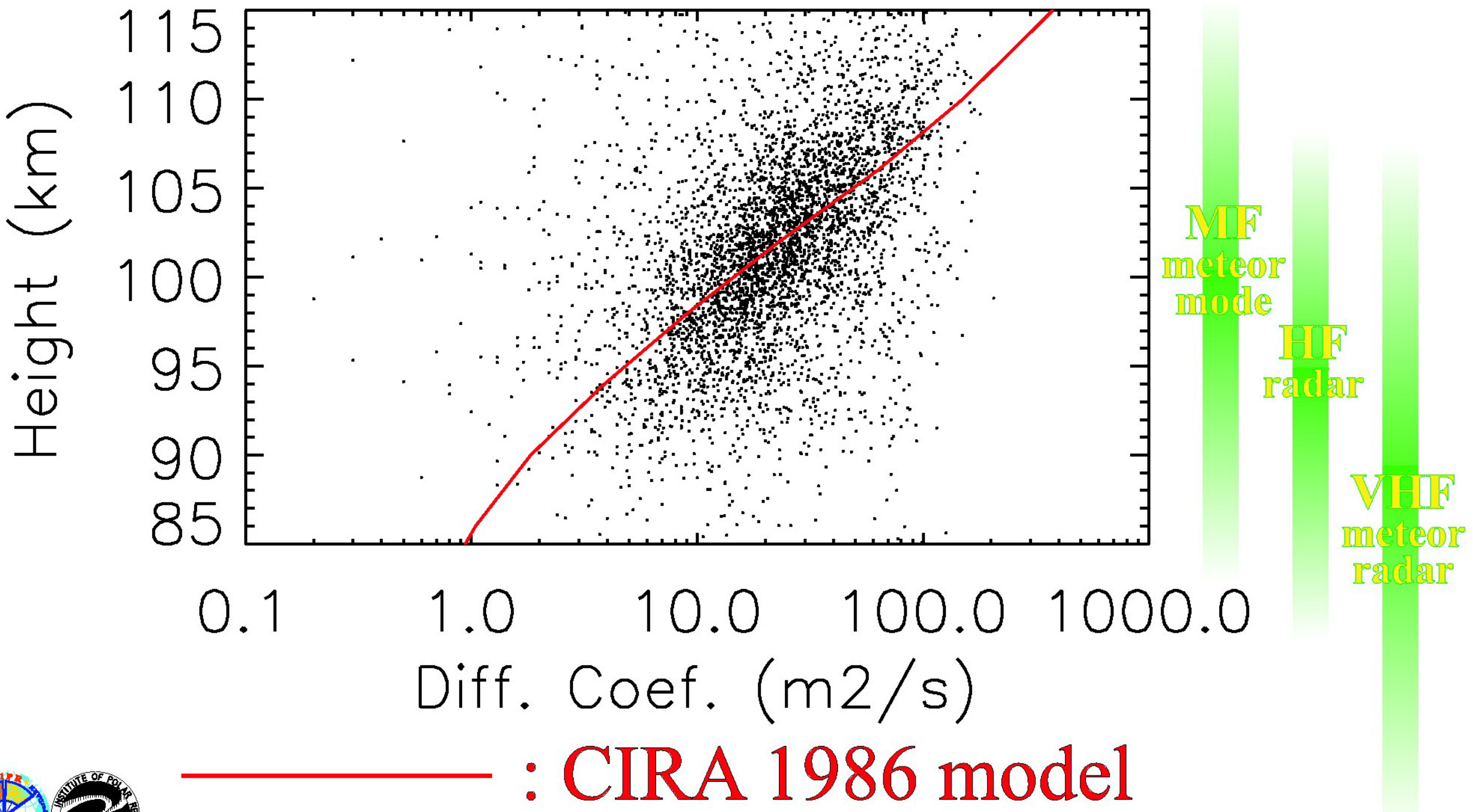


Syowa MF radar (meteor mode)

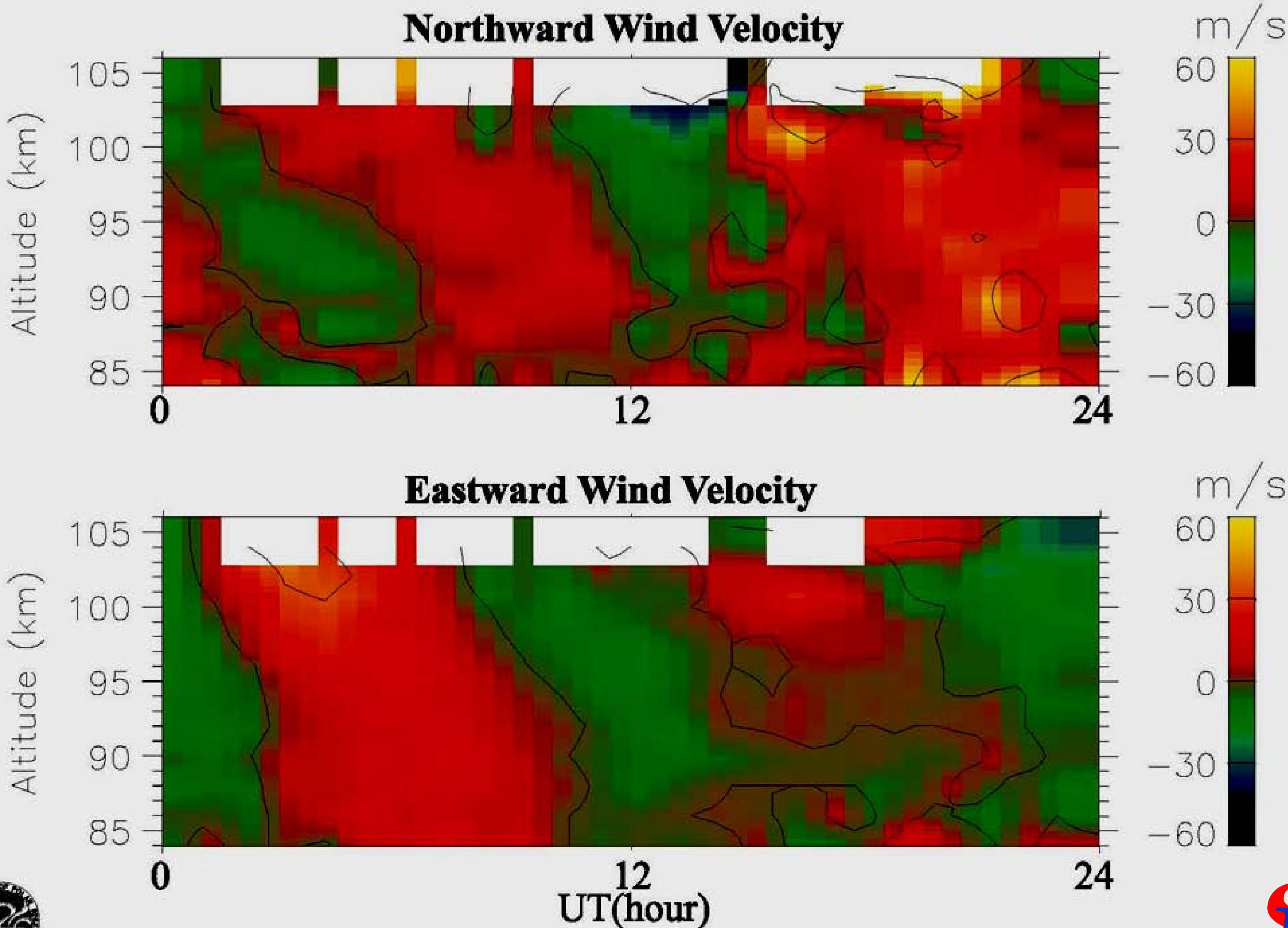
w/ interferometer

October 15-21, 2001

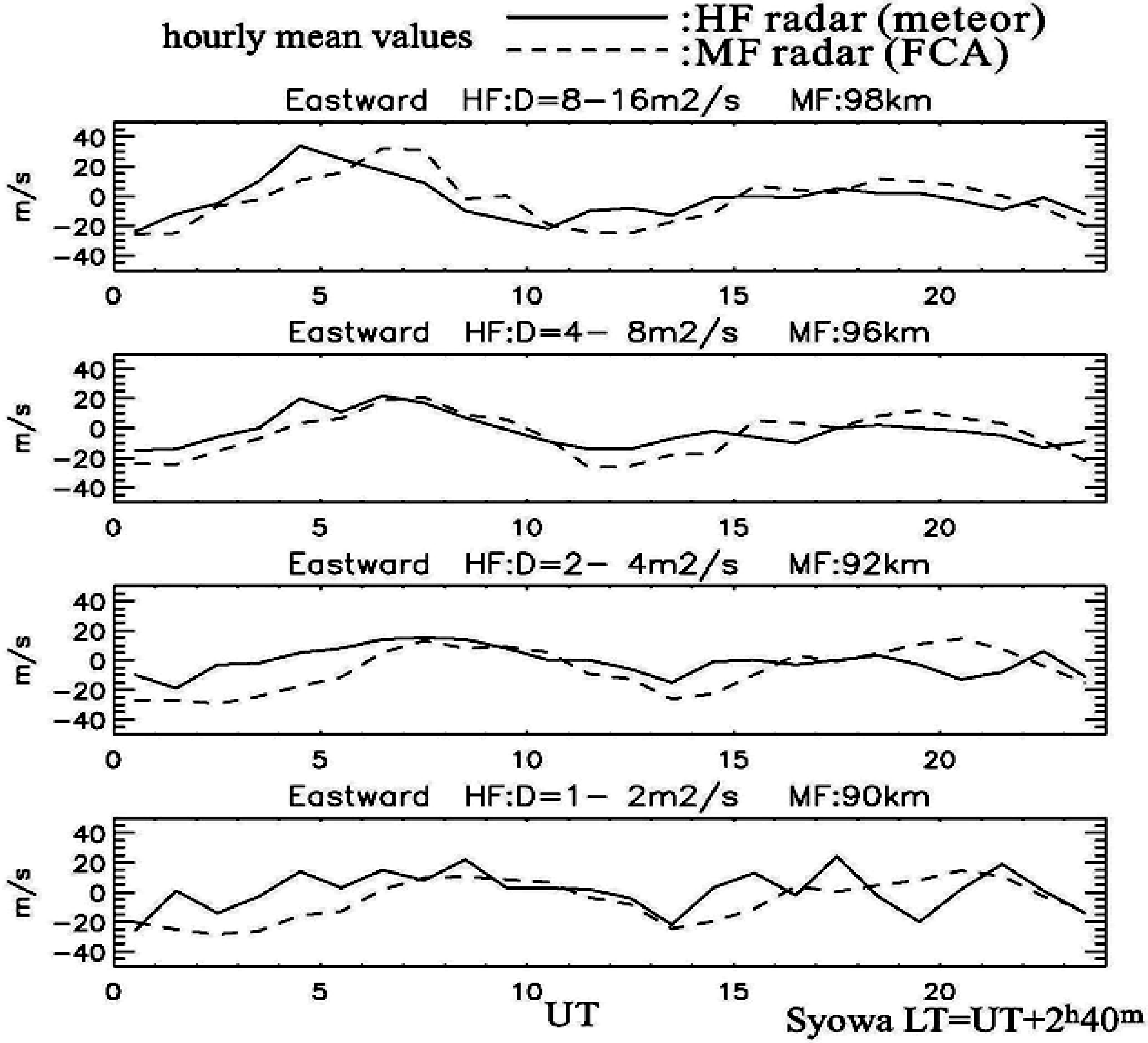




Mean diurnal variation of 2-D neutral wind altitude profile at mesopause region using beam-swing tech. (svdfit) by SENSU Syowa East radar in October, 2001 (monthly mean)

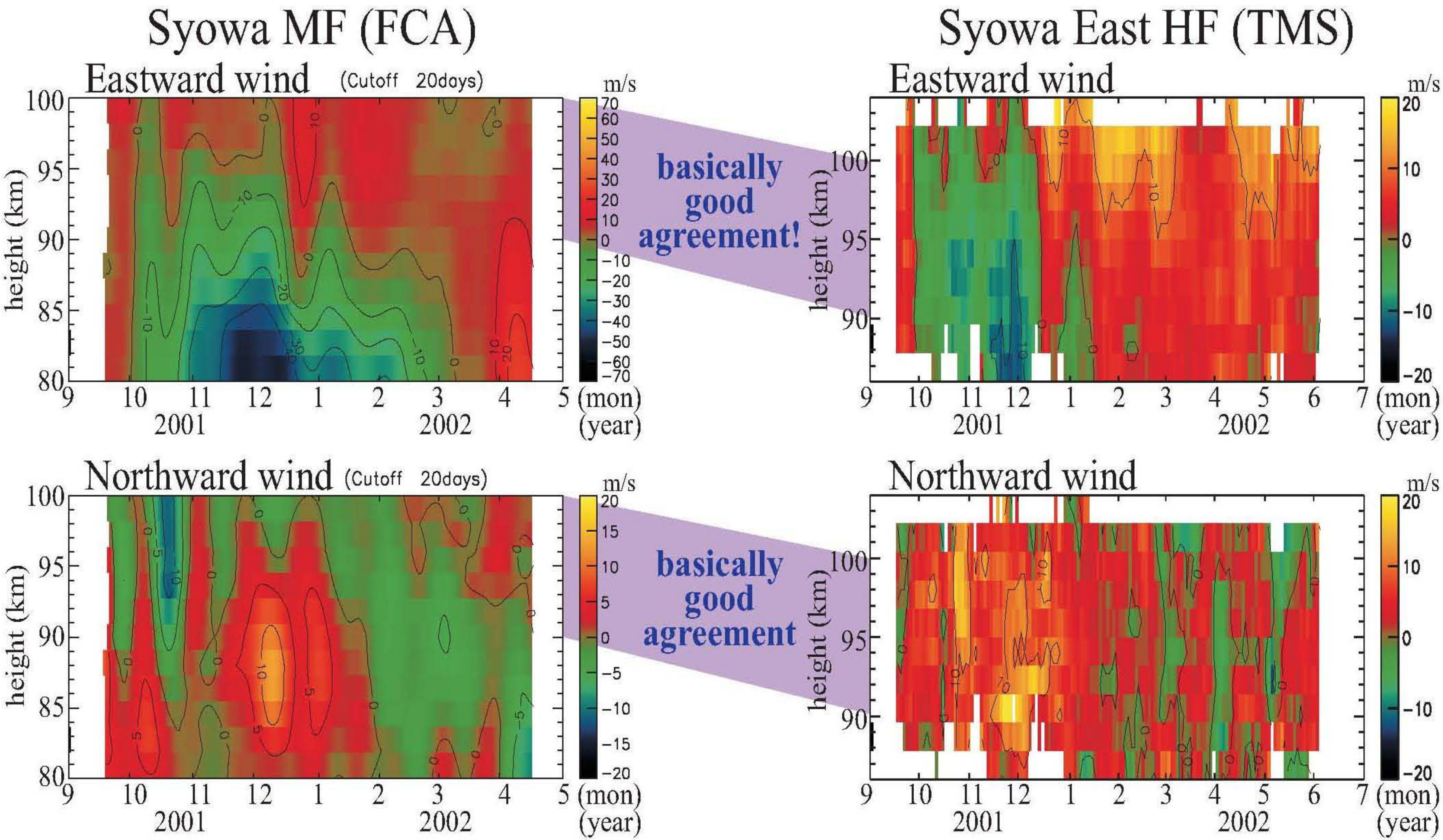


Eastward neutral wind at 4 altitudes at Syowa, Antarctica October 15-21, 2001



*** Basically very good agreement!**

SuperDARN



Syowa MF (FCA)
Syowa East HF (TMS)
Eastward wind
(Cutoff 20days)
Eastward wind
basically good agreement!
Northward wind
(Cutoff 20days)
Northward wind
basically good agreement
height (km)
m/s
(mon)
(year)
2001
2002

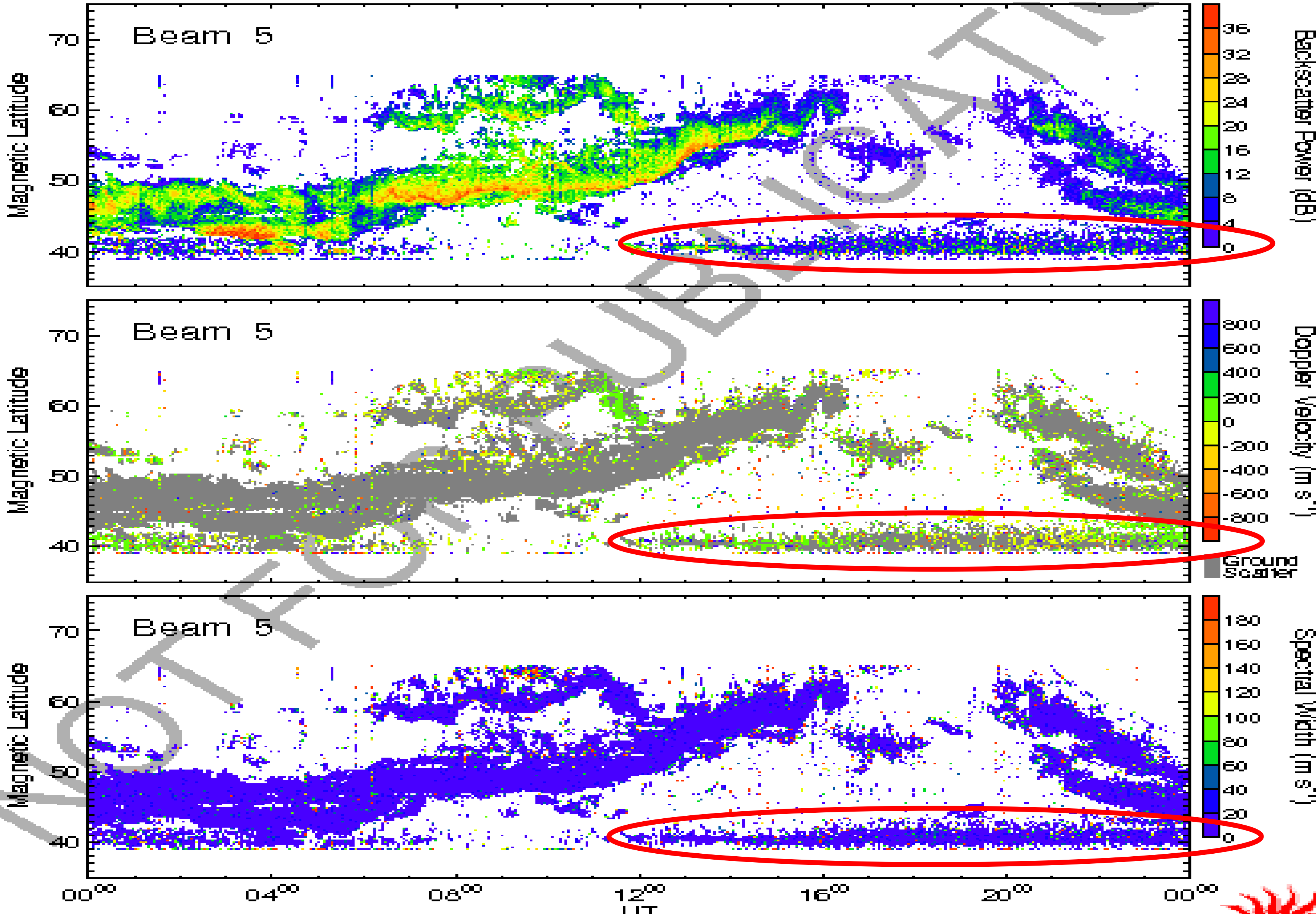
Syowa so far

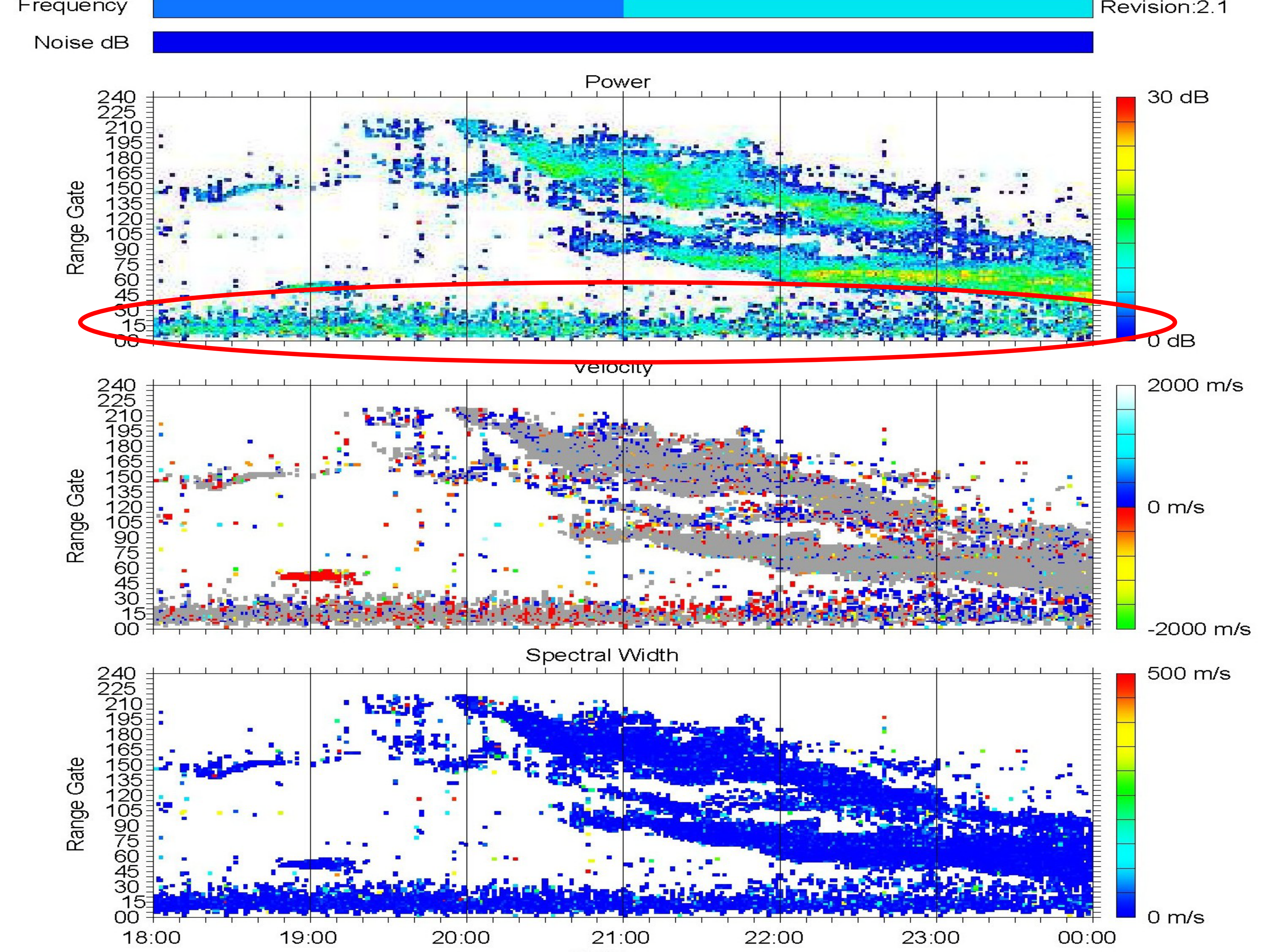
- older Radops with TMS mode
  ⇒should be upgraded to newer ROS
  with iqwrite
- tms/nre -> tms_read/tms_plot.pro (idl)
  ⇒iqdat format (dmap)
- extract meteors (idl)
- fitting vectors (svdfit on idl)

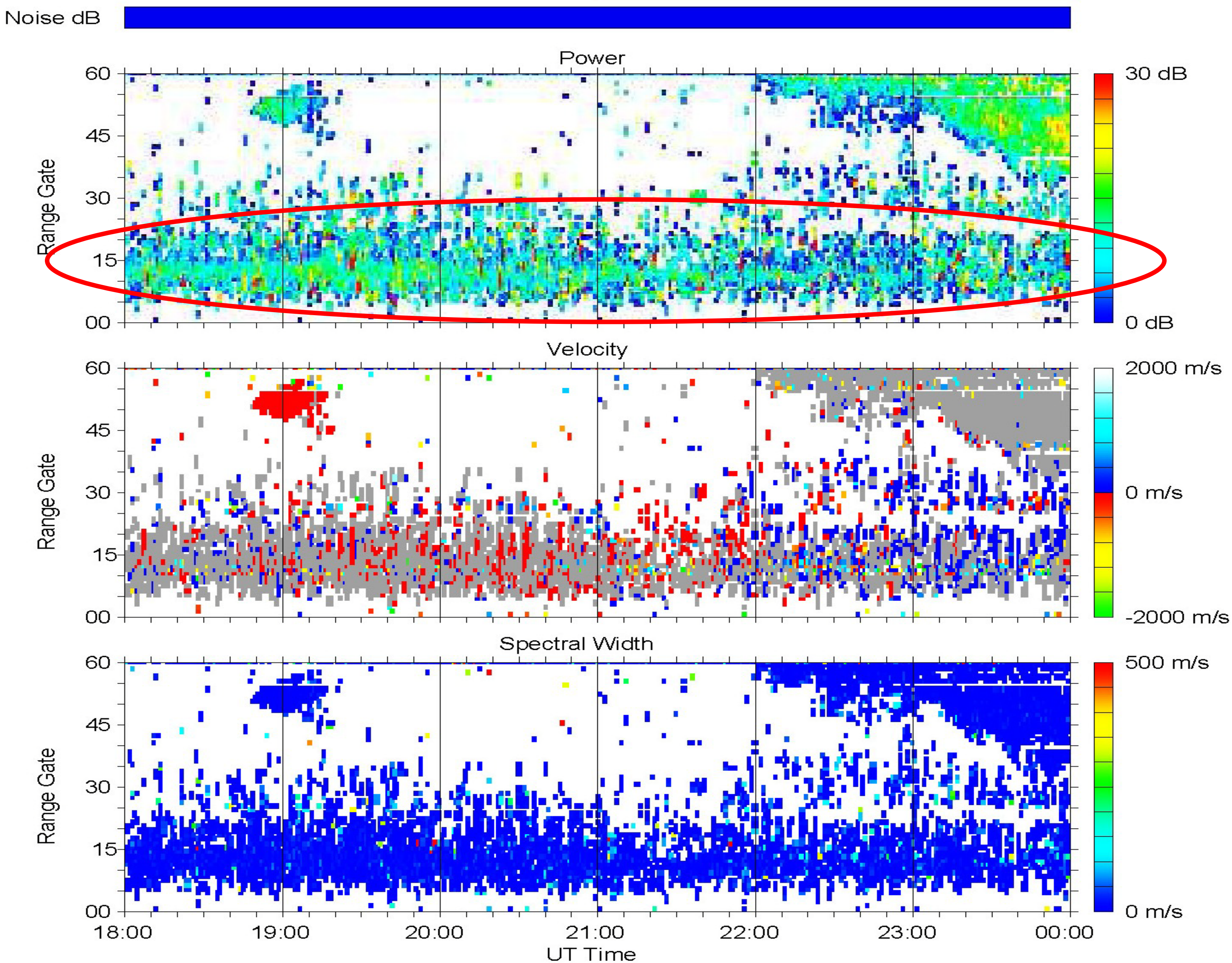
Hokkaido test

- Newer ROS to make iqdat with iqwrite
- convert iqdat to tms -> tms_read/tms_plot.pro
  - ⇒ tms_read.pro should directly read iqdat
- extract meteors (idl)
  - ⇒ should migrated to C
- fitting vectors (svdfit on idl)
  - ⇒ should migrated to C

Hokkaido test 2011/Sep/04




Frequency
Revision:2.1
Noise dB
Power
Range Gate
30 dB
0 dB
Velocity
2000 m/s
0 m/s
-2000 m/s
Spectral Width
500 m/s
0 m/s
240
225
210
195
180
165
150
135
120
105
90
75
60
45
30
15
00
18:00
19:00
20:00
21:00
22:00
23:00
00:00



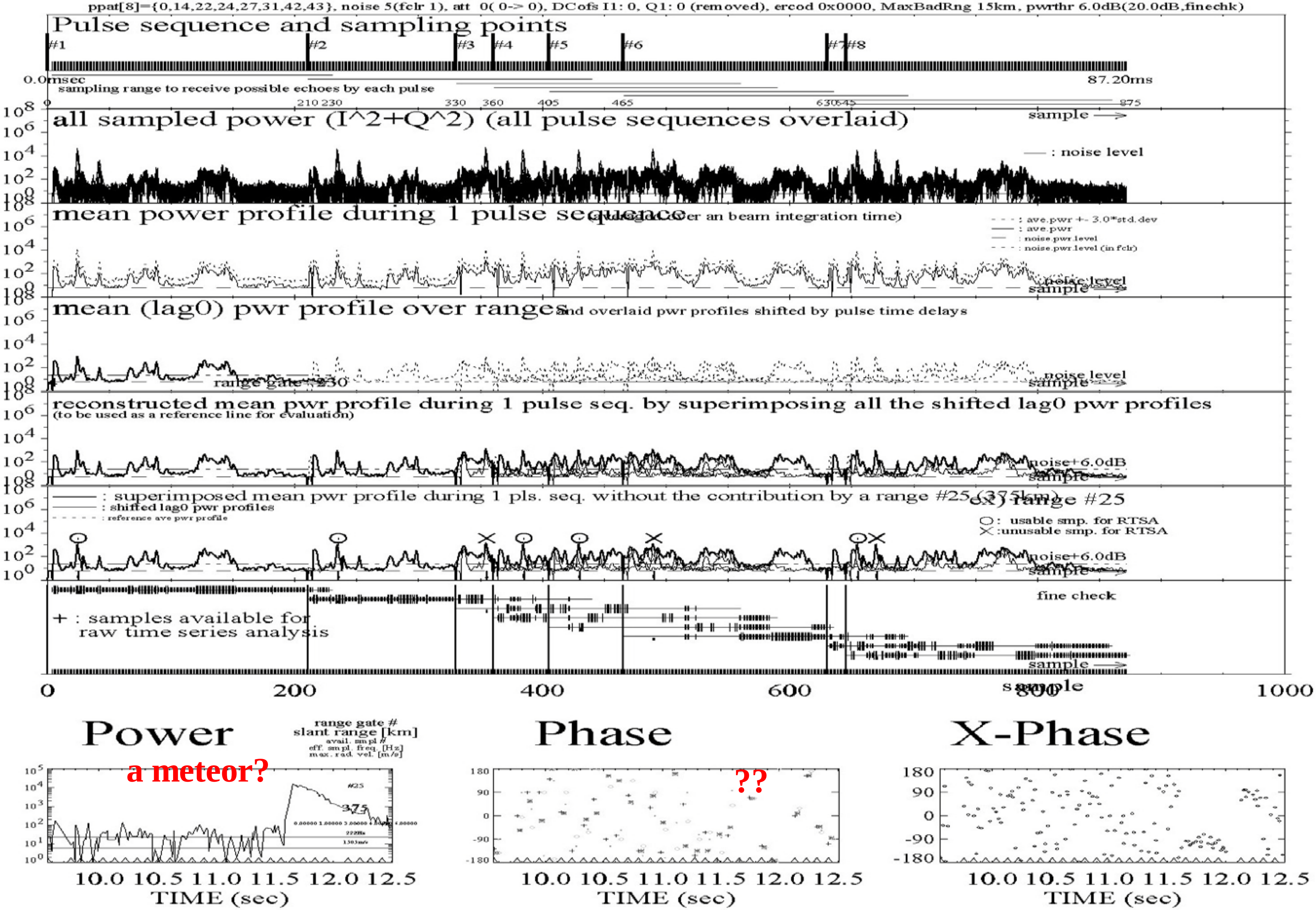
Noise dB
Power
30 dB
0 dB
Velocity
2000 m/s
0 m/s
-2000 m/s
Spectral Width
500 m/s
0 m/s
Range Gate
60
45
30
15
00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
UT Time

SENSU SuperDARN Raw Time Series Plot

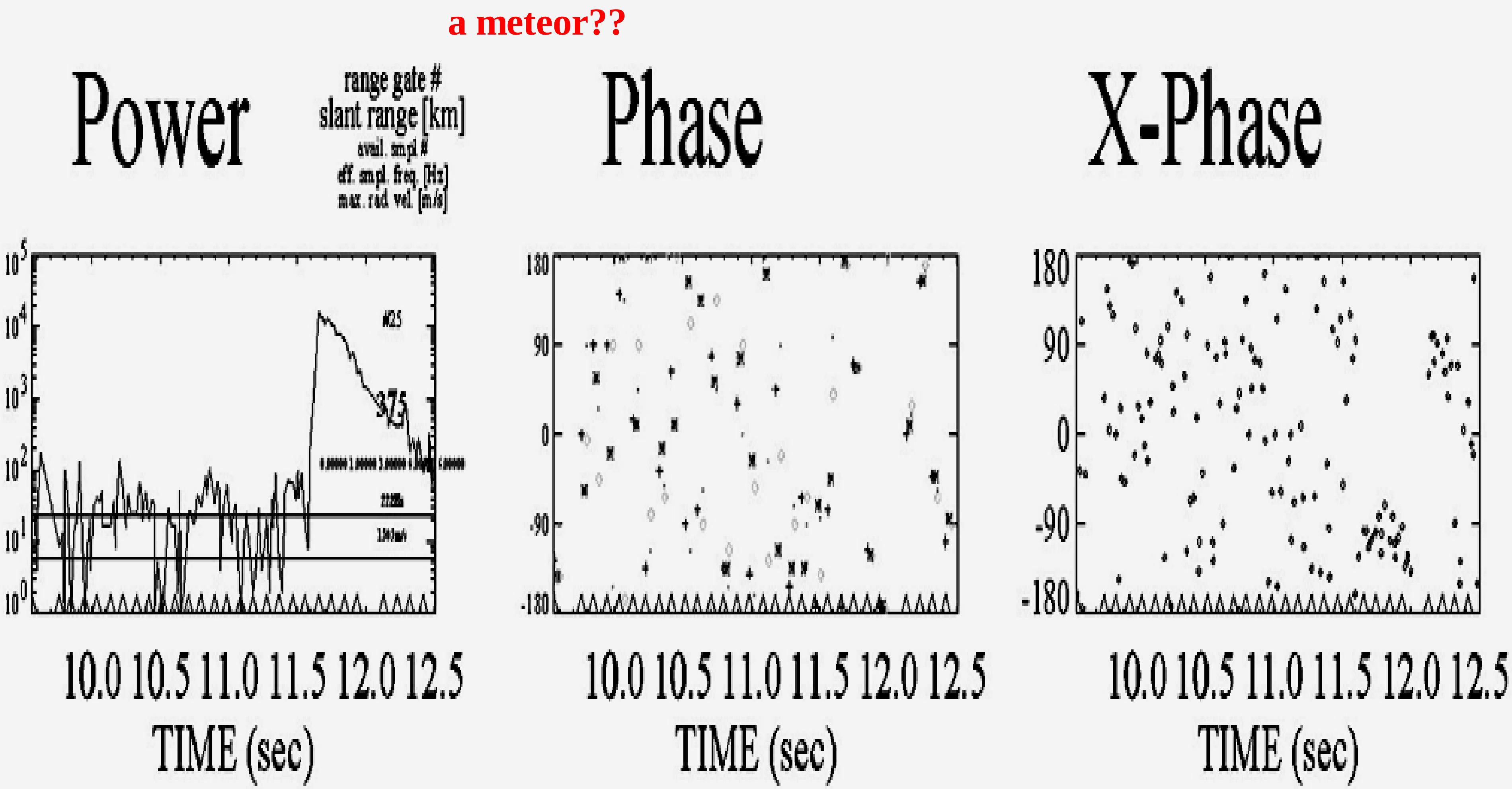
Hokkaido 2011/09/04 22:02:09UT, Mono cpid -151, bm12, frq 11074kHz, intt3sec (nave29), xcf 1

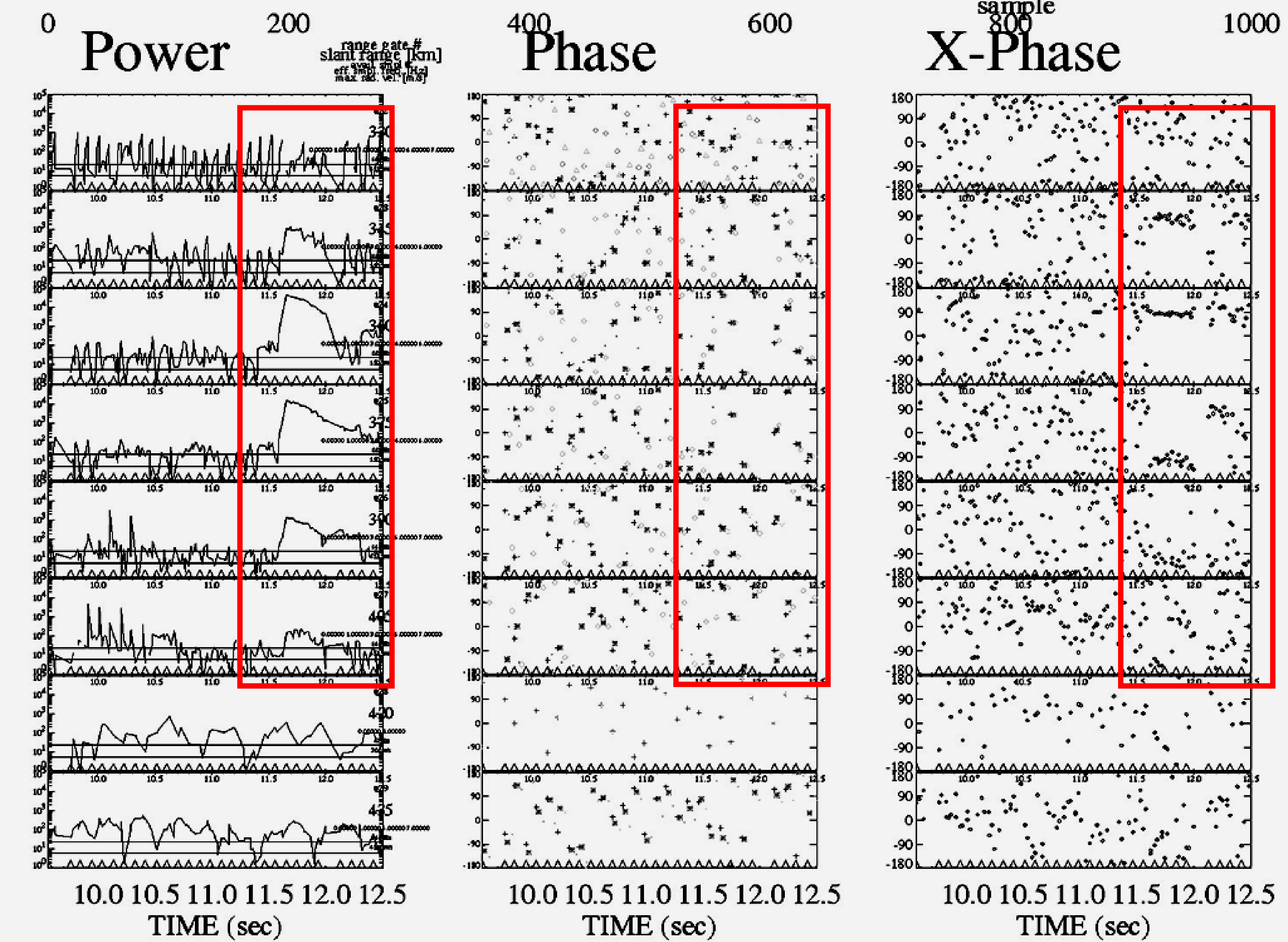
mppul 8, mpinc 1500us, txpl 100us(rsep 15km), smsep 100us(15km), lagfr 400us(60km), nrang227, maxrng 3600km, nsmp 869, seqtime 87.20ms

ppat[8]={0,14,22,24,27,31,42,43}, noise 5(fclr 1), att 0(0-> 0), DCofs I1: 0, Q1: 0 (removed), ercod 0x0000, MaxBadRng 15km, pwrthr 6.0dB(20.0dB,finechk)

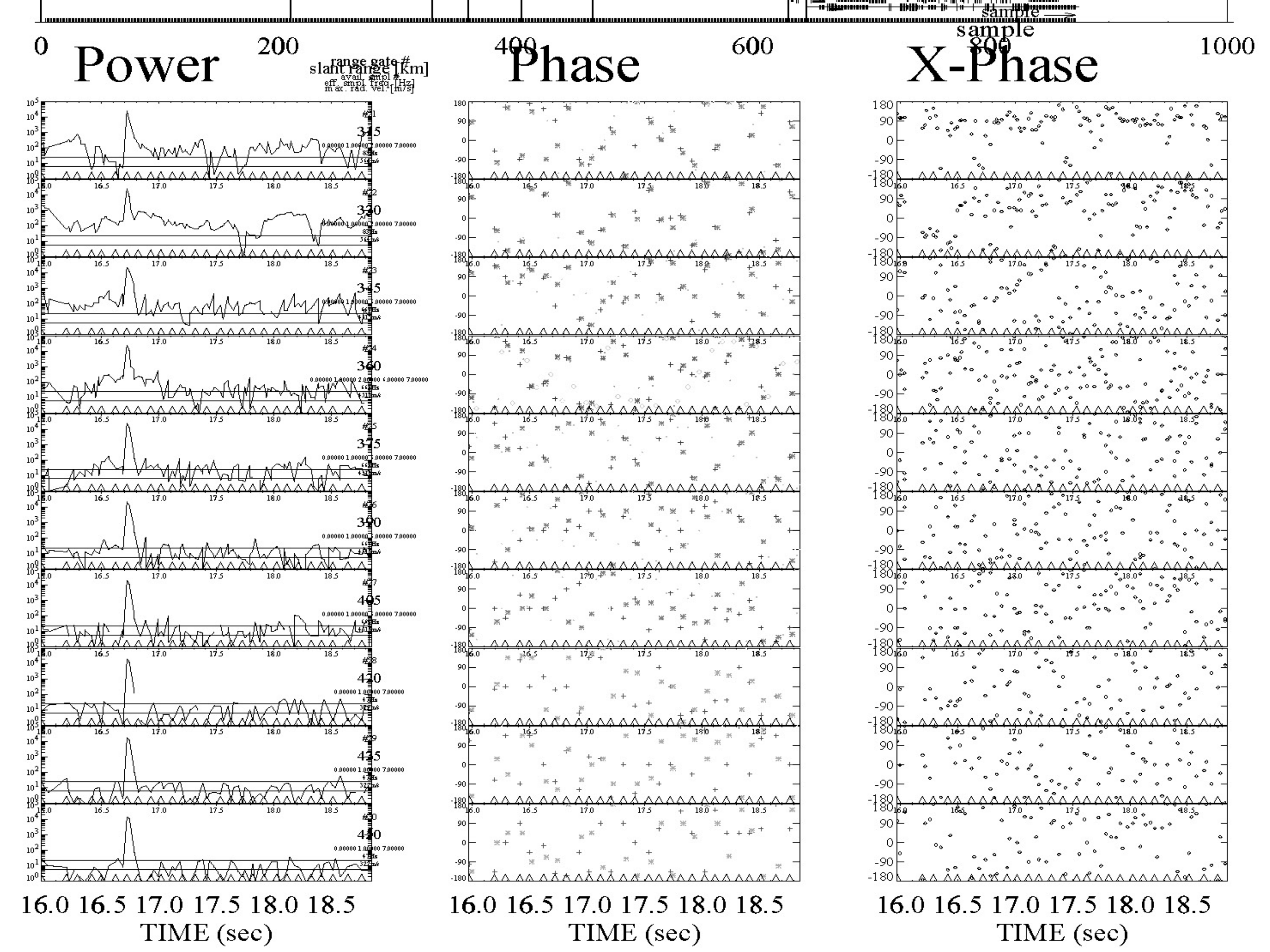


Hokkaido test





0
200
400
600
sample
800
1000
Power
Phase
X-Phase
range gate #
slant range [km]
10.0 10.5 11.0 11.5 12.0 12.5
TIME (sec)
10.0 10.5 11.0 11.5 12.0 12.5
TIME (sec)
10.0 10.5 11.0 11.5 12.0 12.5
TIME (sec)



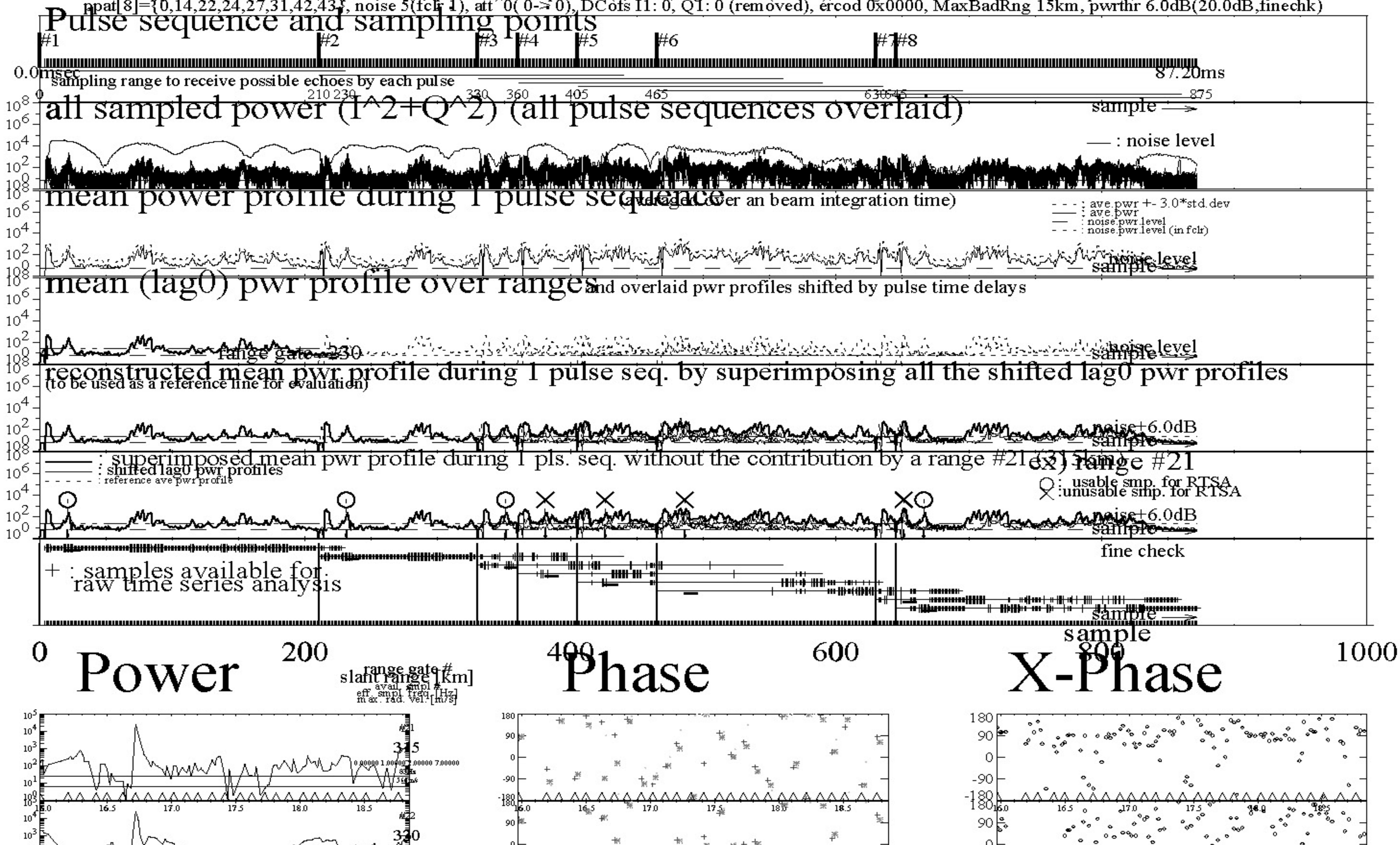
0
200
400
600
800
1000
sample
Power
Phase
X-Phase
range gate #
slant range [km]
avail. smpl #
eff. smpl. freq. [Hz]
max. rad. vel. [m/s]
16.0 16.5 17.0 17.5 18.0 18.5
TIME (sec)
16.0 16.5 17.0 17.5 18.0 18.5
TIME (sec)
16.0 16.5 17.0 17.5 18.0 18.5
TIME (sec)

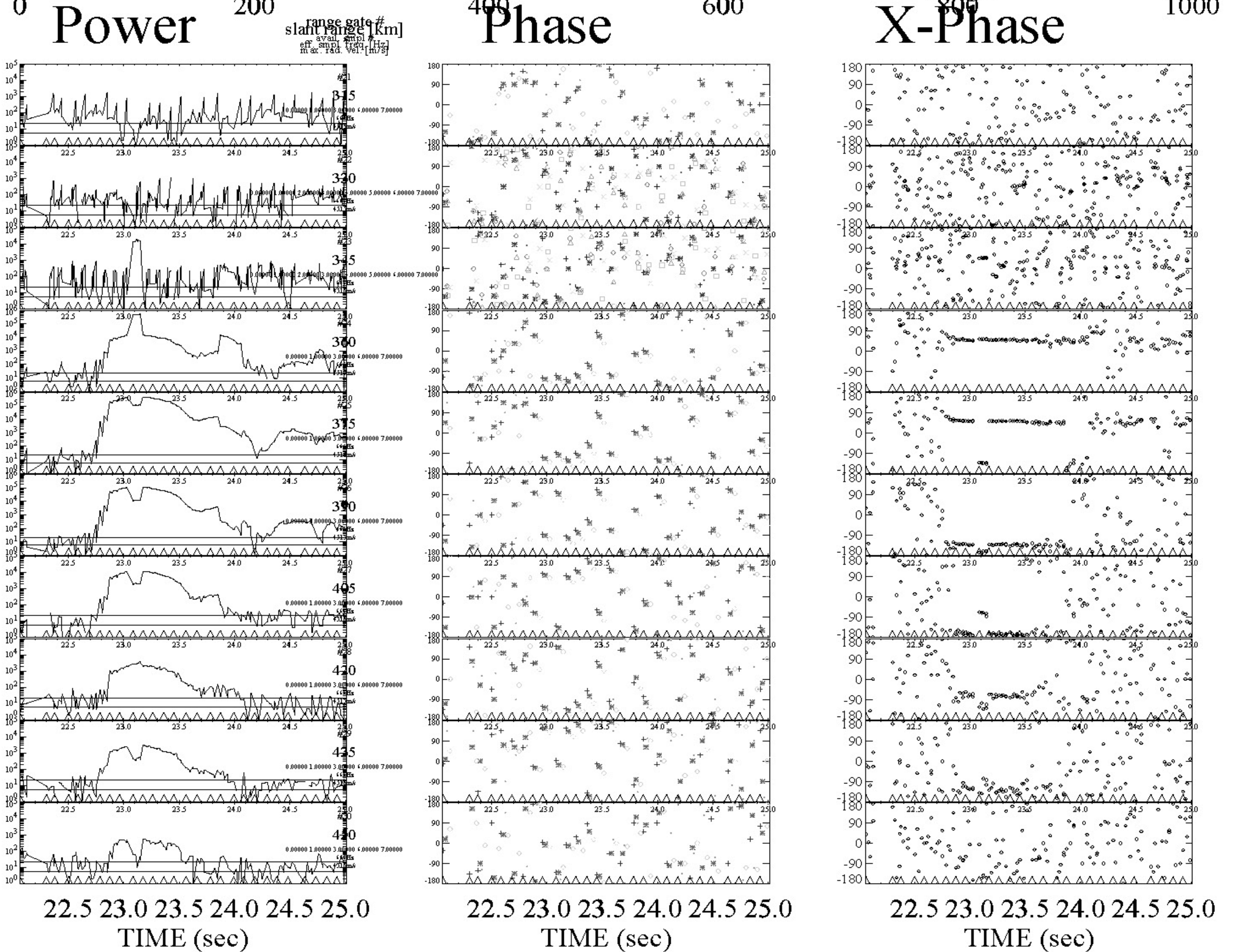
SENSU SuperDARN Raw Time Series Plot

Hokkaido 2011/09/04 22:04:15UT, Mono cpid -151, bm10, frq 11074kHz, intt3sec (nave27), xcf 1

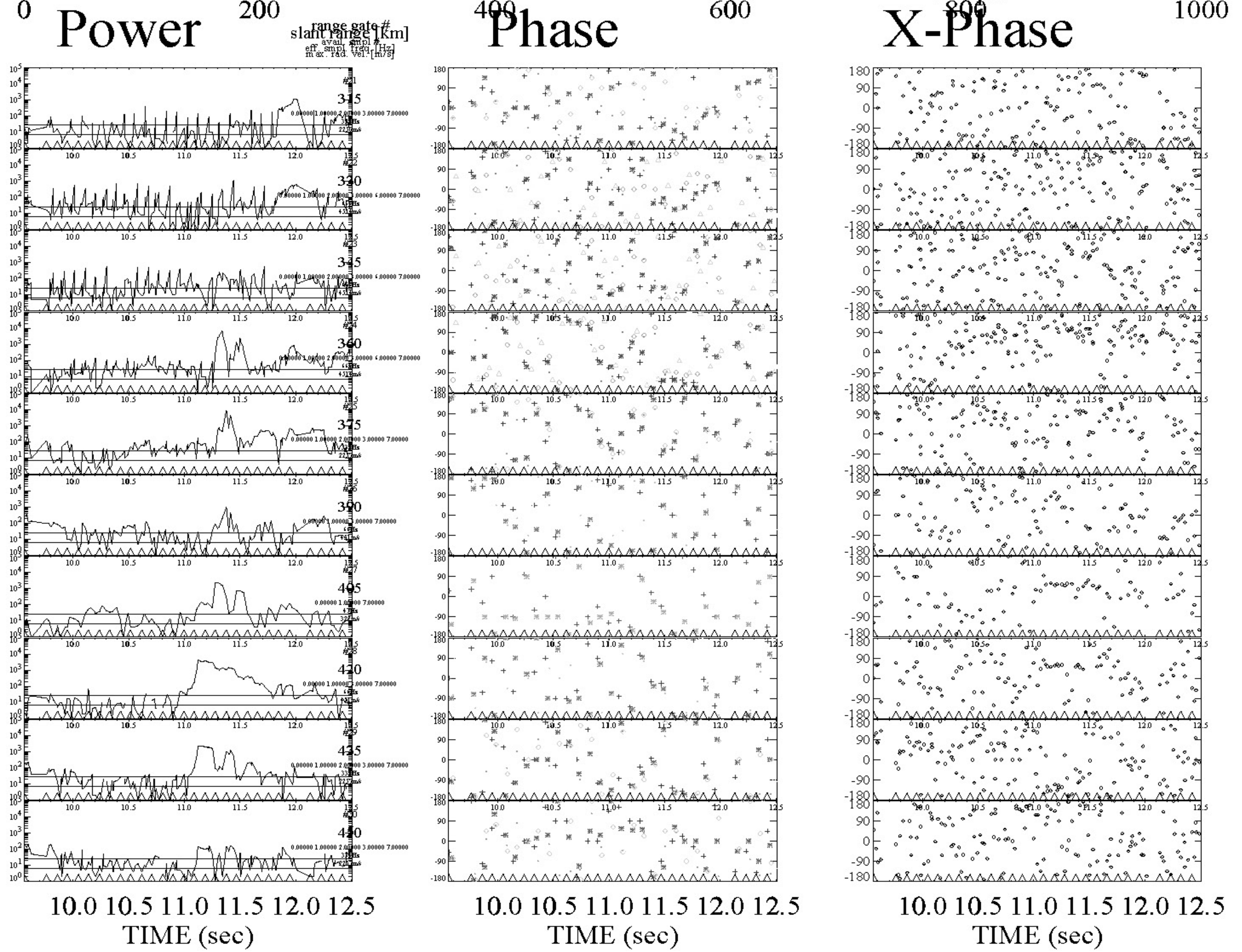
mppul 8, mpinc 1500us, txpl 100us(rsep 15km), smsep 100us(15km), lagfr 400us(60km), nrang227, maxrng 3600km, nsmp 869, seqtime 87.20ms

ppat[8]={0,14,22,24,27,31,42,43}, noise 5(fclr 1), att 0(0-> 0), DCofs I1: 0, Q1: 0 (removed), ercod 0x0000, MaxBadRng 15km, pwrthr 6.0dB(20.0dB,finechk)





Power
Phase
X-Phase
range gate #
slant range [km]
avail. smpl #
eff. smpl freq. [Hz]
max. rad. vel. [m/s]
22.5 23.0 23.5 24.0 24.5 25.0
TIME (sec)
22.5 23.0 23.5 24.0 24.5 25.0
TIME (sec)
22.5 23.0 23.5 24.0 24.5 25.0
TIME (sec)



Power
Phase
X-Phase
range gate #
slant range [km]
avail. smpl #
eff. smpl. freq. [Hz]
max. rad. vel. [m/s]
TIME (sec)
TIME (sec)
TIME (sec)

Hokkaido test

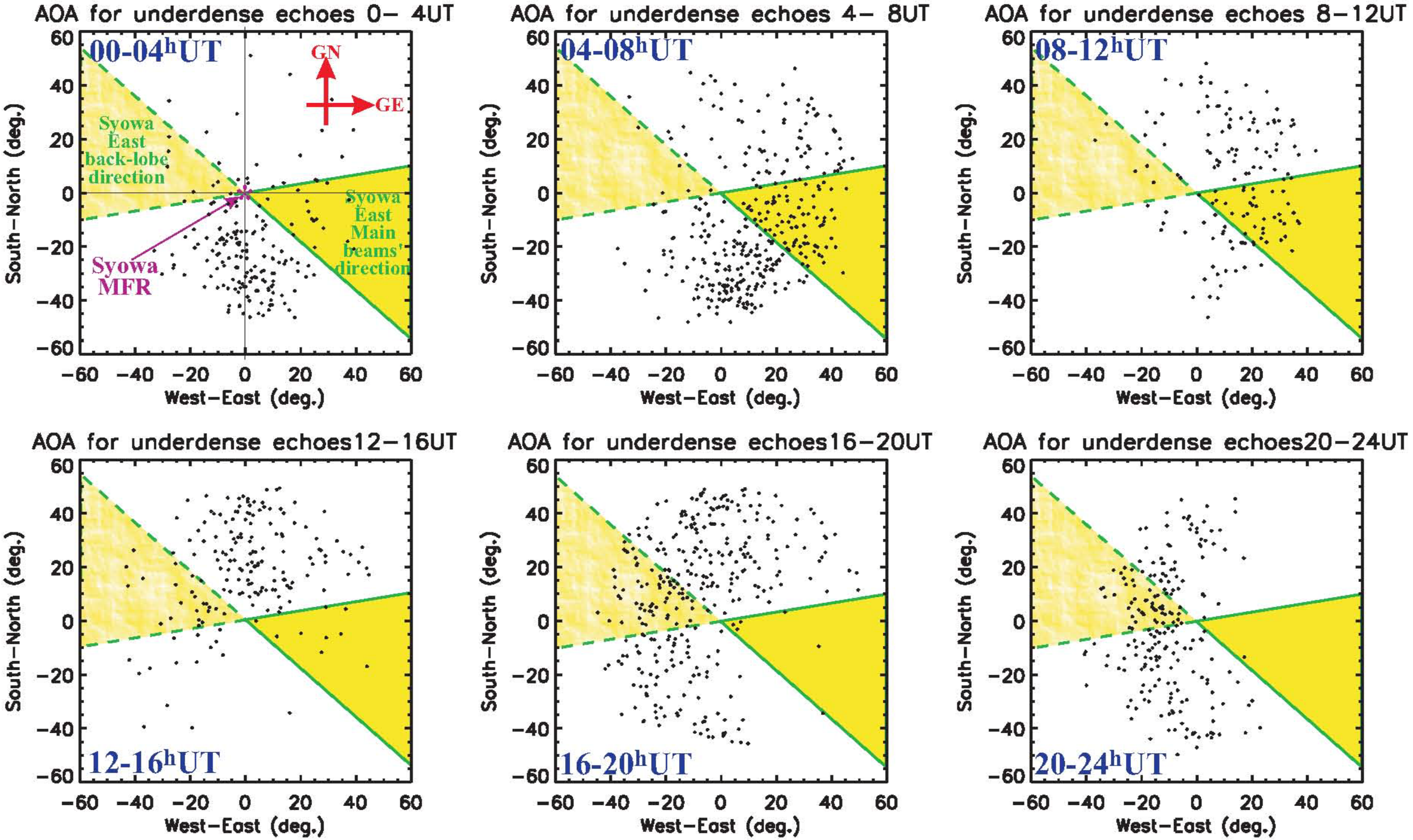
- frang=120km, lagfr=400μsec?! (should be 800??)
- should be "frang = rsep (lagfr=smsep)" to properly estimate cross-range effects.
- smpnum value (869): strange (exp: 872)
  nsmp=mpinc/smsep x pat(mppul-1) + nrang – lagfr/smsep
  (something is wrong??)
- difficult to find clear underdense meteors yet...
  (something wrong??)
- some spiky noises??
- interferometer, oversampling, FDI?

Hokkaido : near future

- frang/lagfr, smpnum inconsistency ⇒ should be resolved
- frang/lagfr should be changed to minimum
- confirm if meteors properly sit there
- move from "iq2tms" to directly analyse iqdat
- determine meteor height with interferometer data and try to calibrate interferometer (elev. angl.) data as well as to confirm if range offset is adequate
- oversampling/FDI etc to always get higher spatial resolution even during CT mode
- automatic meteor extractions and move to routine work
- apply IQ analysis to other researches, e.g. other MLT/MI studies, sea scatters, etc.

Local time dependency of meteor azimuthal distribution

by Syowa MF (meteor mode w/interferometer, 2.4MHz) 1999/06/15



Syowa LT ~ UT+2^h40^m

improvement of spatial resolution

distinguish F/B meteors w/interferometer

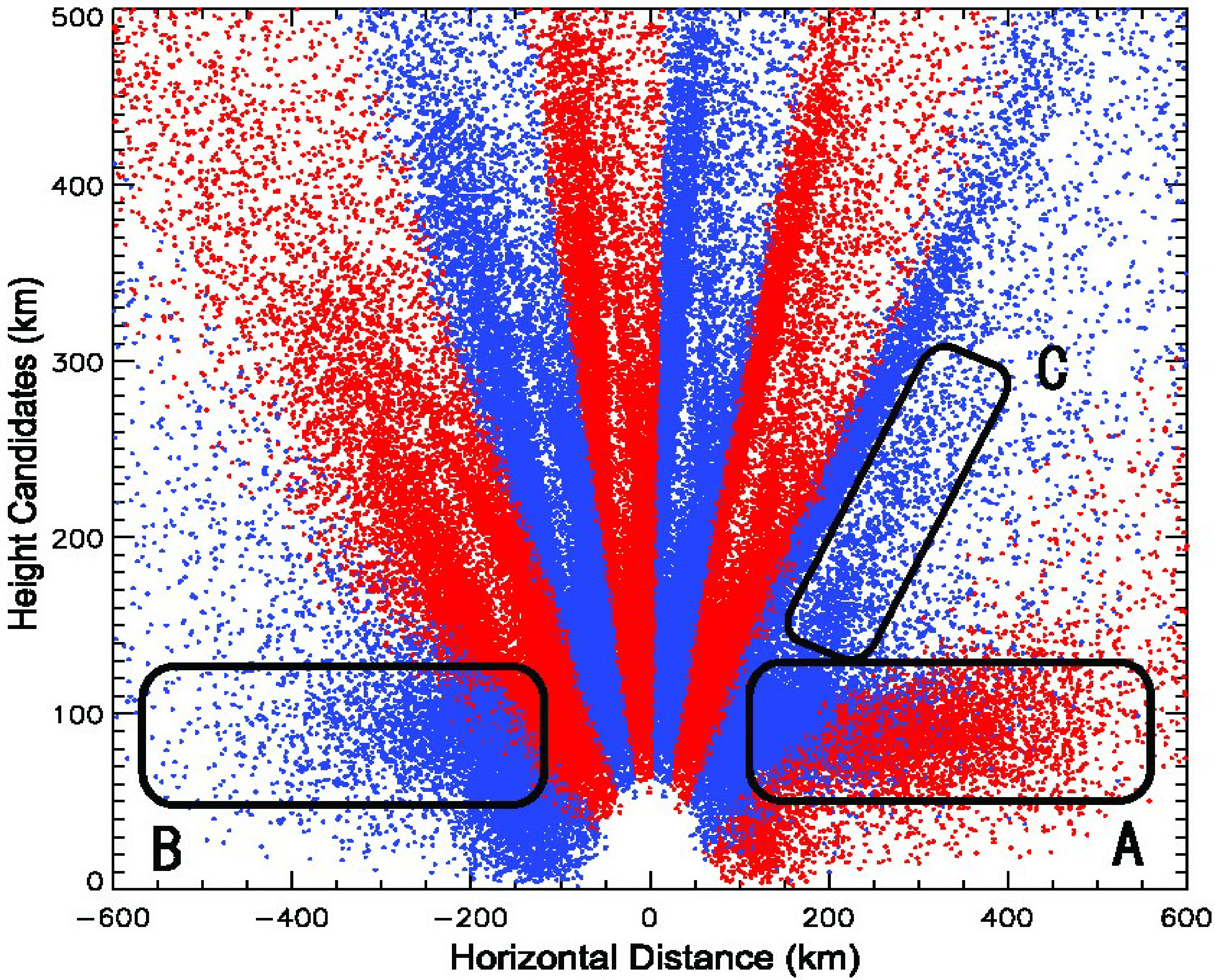


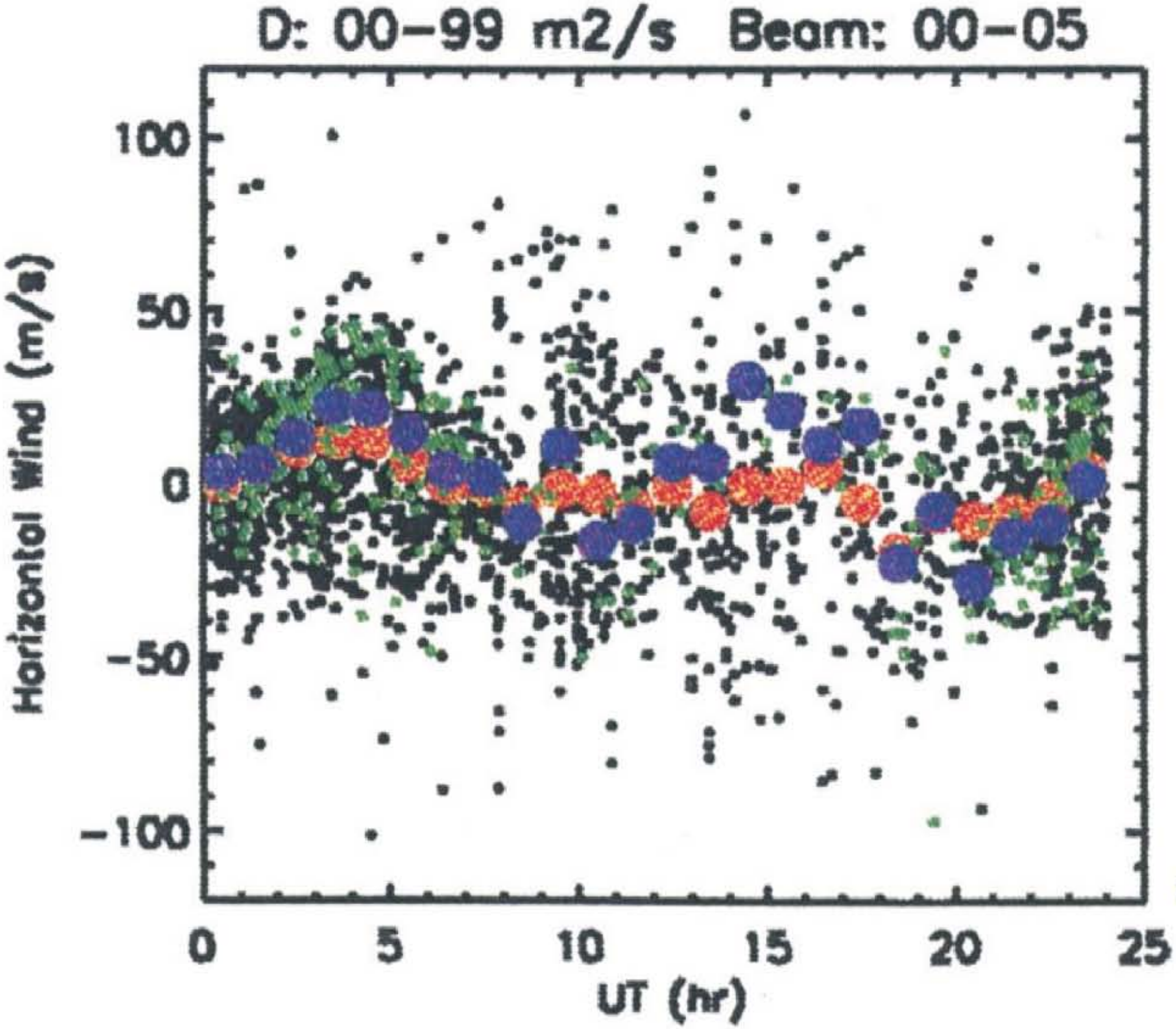
Figure 6. Same as Figure 5 except for the Iceland radar observations. See text for the explanation of areas A, B, and C.

Tsutsumi., et al., Radio Sci., 2009

improvement of spatial resolution

distinguish F/B meteors w/interferometer

Test Results



all data

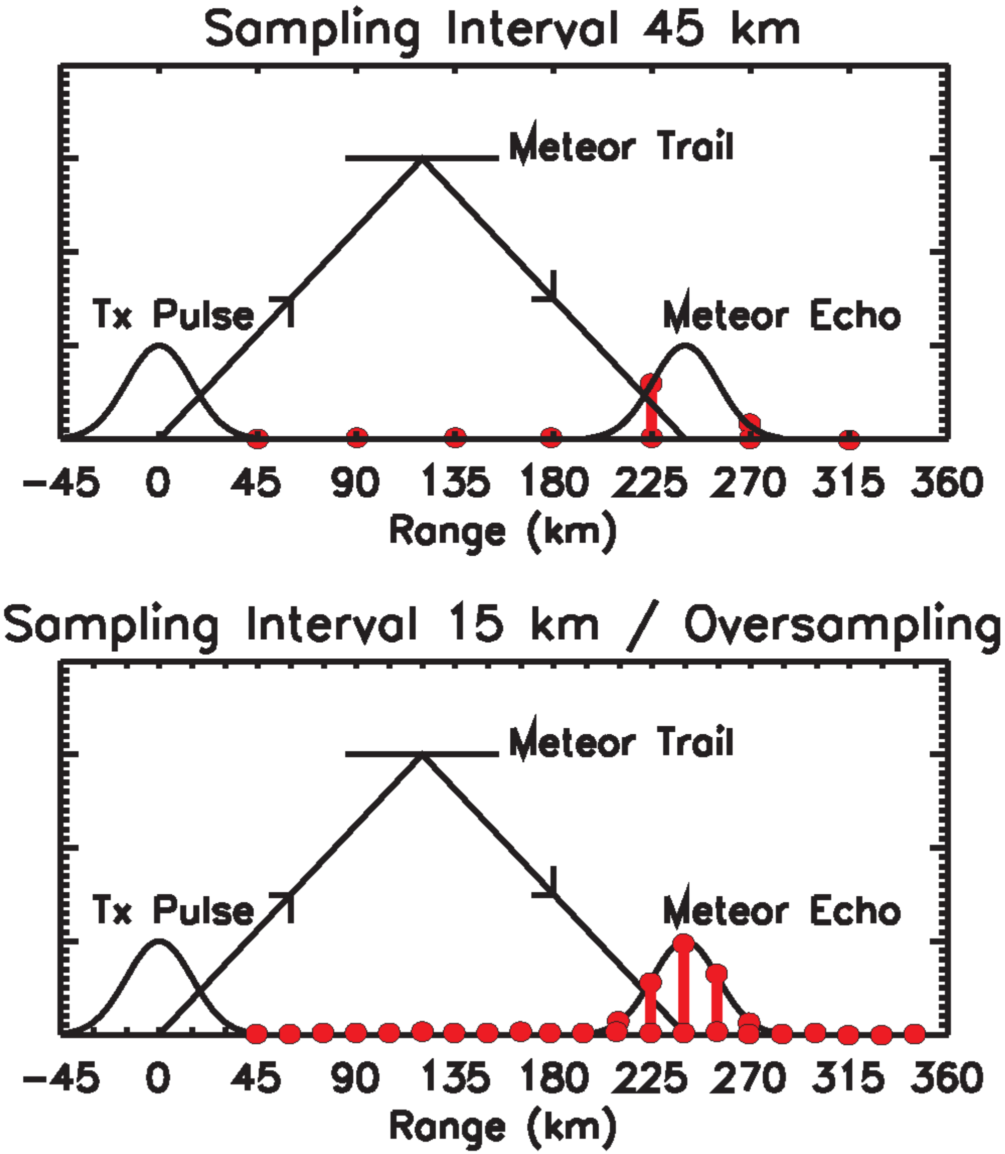
- each meteor
- hourly average

main-lobe echoes only

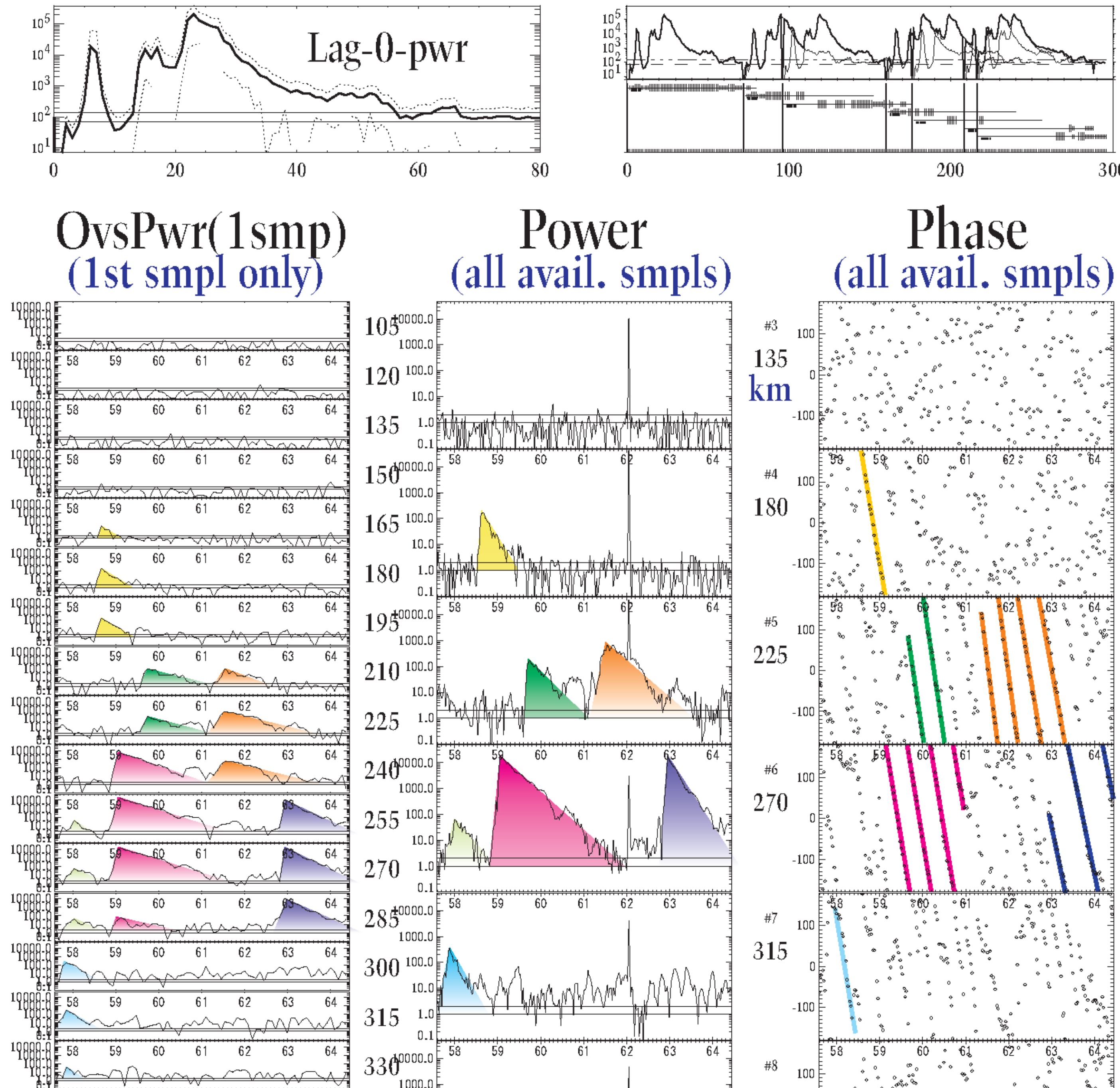
- each meteor
- hourly average

clear semi-diurnal comp can be seen!!! Good!!

improvement of spatial resolution
oversampling

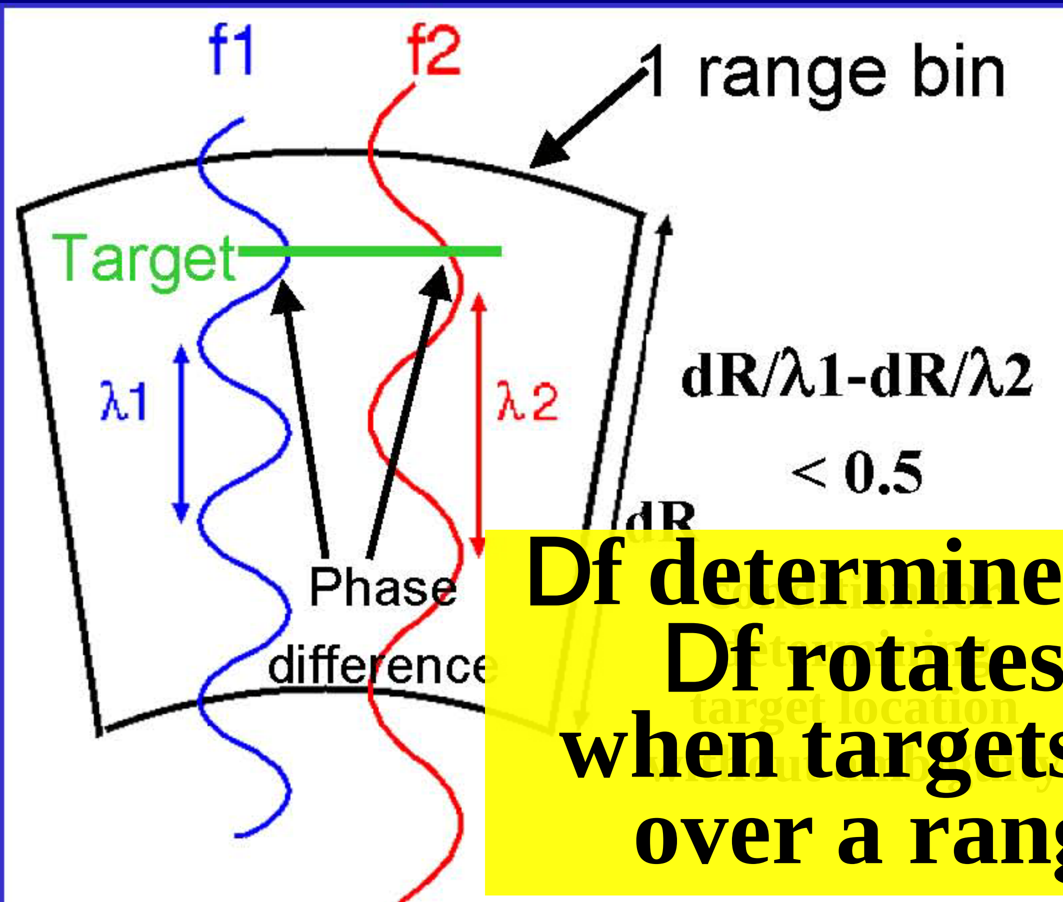


mppul 7, mpinc 2400us, txpl 300us(rsep 45km), smsep 300us(45km), lagfr 300us(45km), lag0nrang 80, nrnrang 12(1-> 12), nsmp 296, seqtime 88.80ms
ppat[7]={0,9,12,20,22,26,27}, noise 71, att 0(0-> 0), DCofs:(removed), ercod 0x0000, MaxBadRng 45km, pwrthr 3.0dB(20.0dB,finechk), OVS:1/1/100us



(Dual freq) FDI
(Frequency Domain Interferometer)

Use **2 closely adjacent freqs** **(Δf~kHz)**
Infer **fine range location within a range cell**
using **phase differences** by **dual freq observation**



freq difference

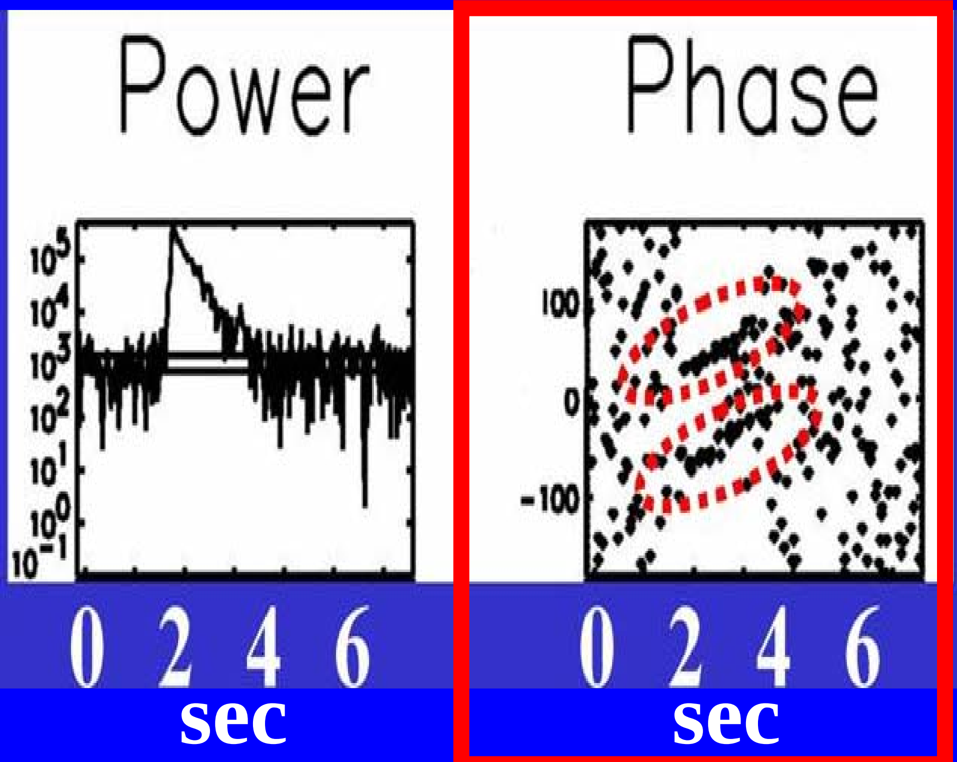
$|\Delta f| < dR/c$

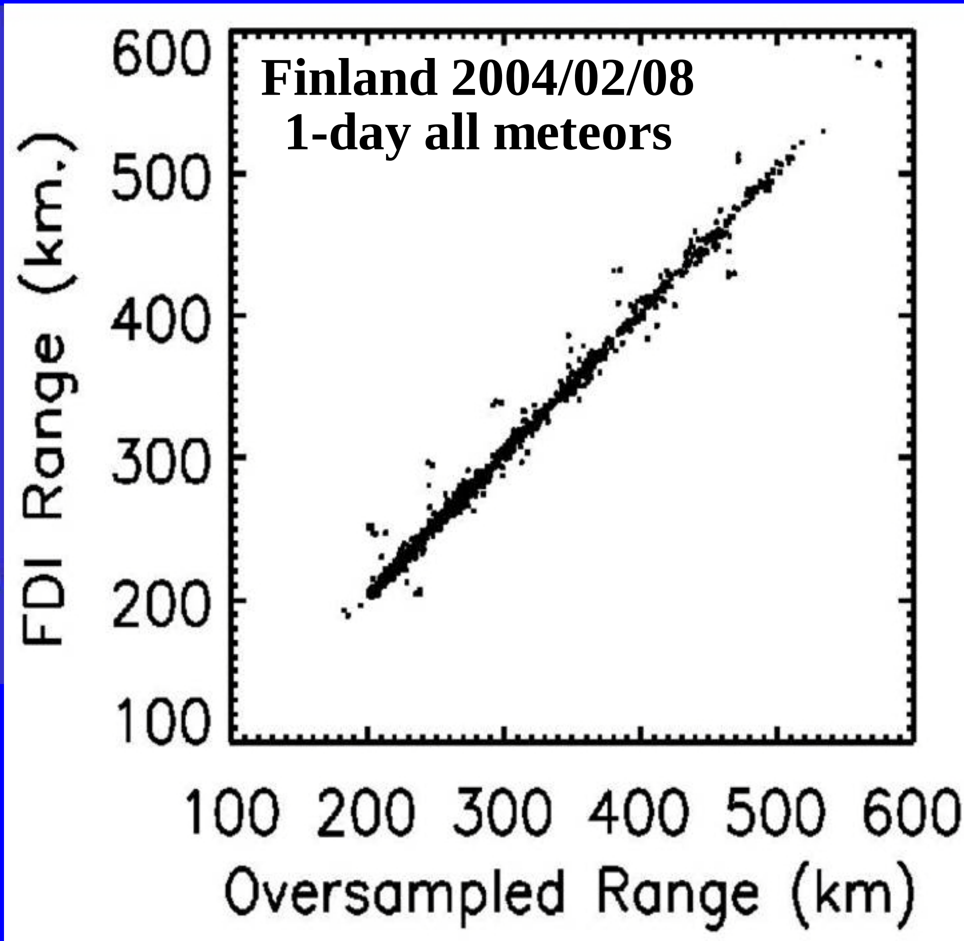
$|\Delta f| < 3.33$ kHz (rsep 45km)
$|\Delta f| < 5.0$ kHz (rsep 30km)
$|\Delta f| < 10$ kHz (rsep 15km)

N frequencies may resolve up to (N-1) targets

Df determined so that Df rotates < 2p when targets moved over a range cell

High Range Res. Meteor Obs. by Dual Freq FDI (Tutumi et al SD WS 2004)

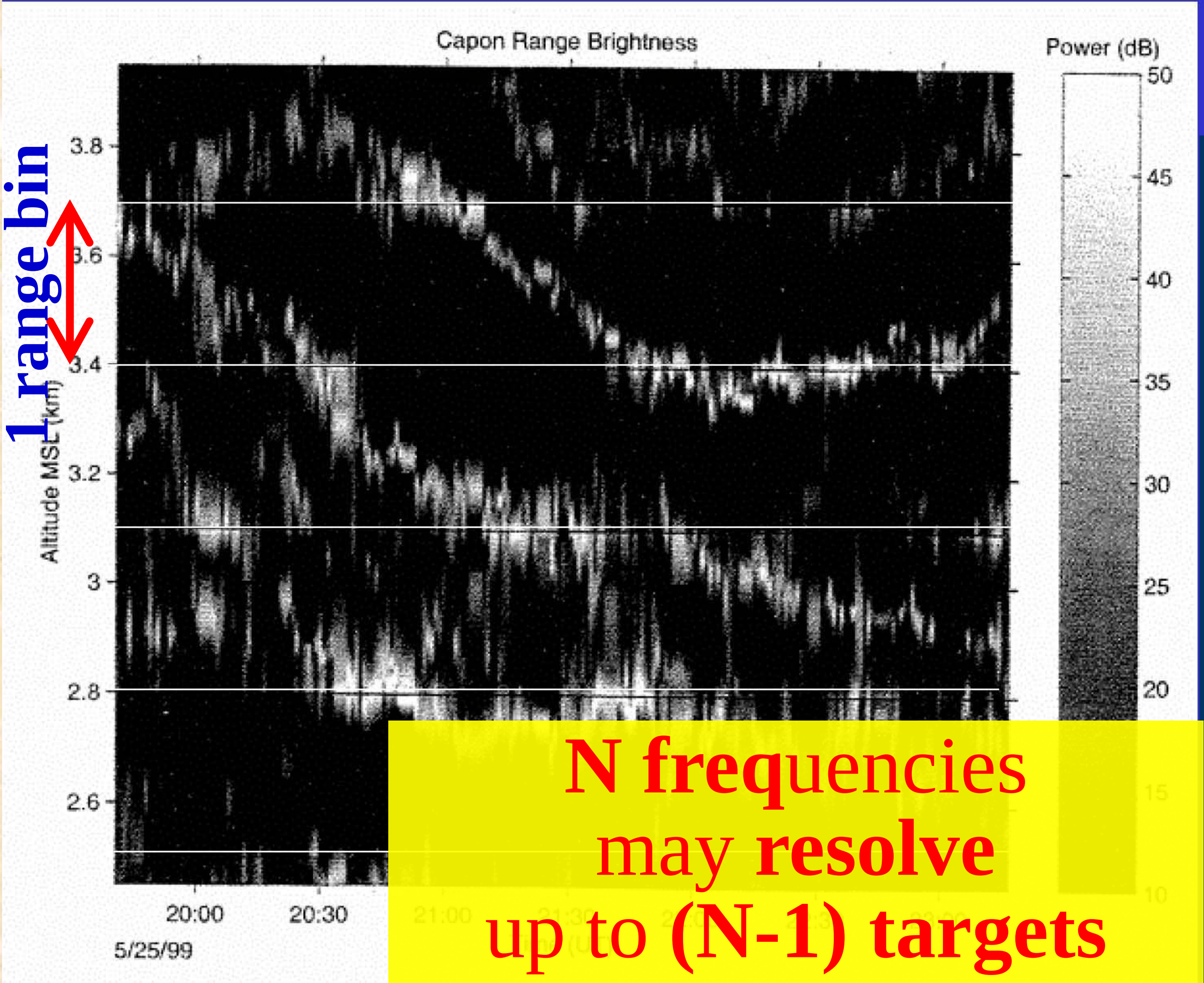




Change TxFreq every pulse sequence (i.e., Tilt TxFreq), 2 phase groups seen

FDI vs Over-Sampling Nice Agreement!

An **Example of Multi-freq FDI obs.** in case of **ST radar stratosphere obs**



Palmer et al., Radio Sci, 2001.

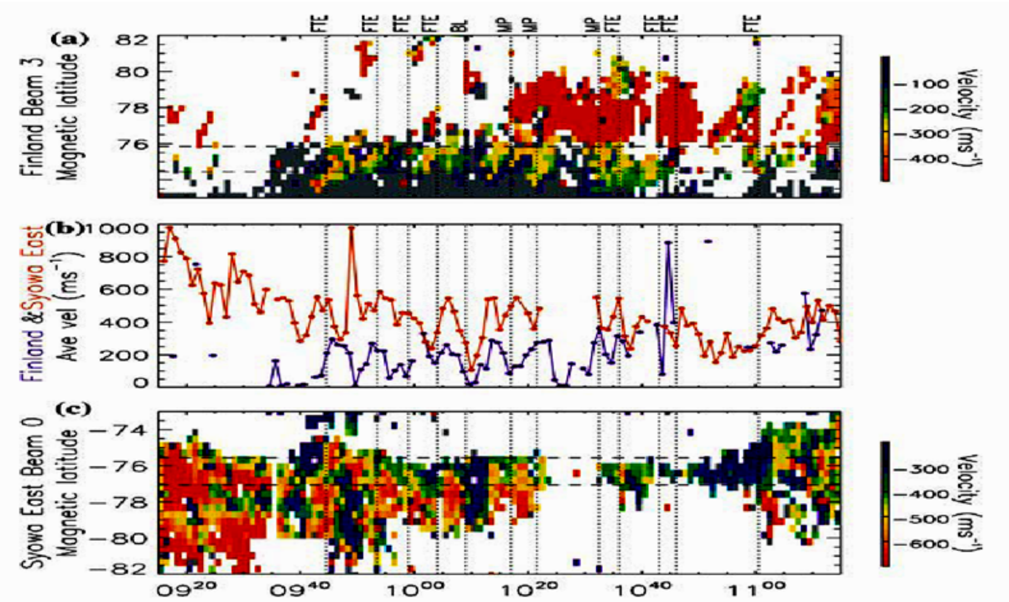
4-freq FDI echo Power by ST radar.

original rsep=300m

FDI resolved much thinner turbalence layer structures within range cells

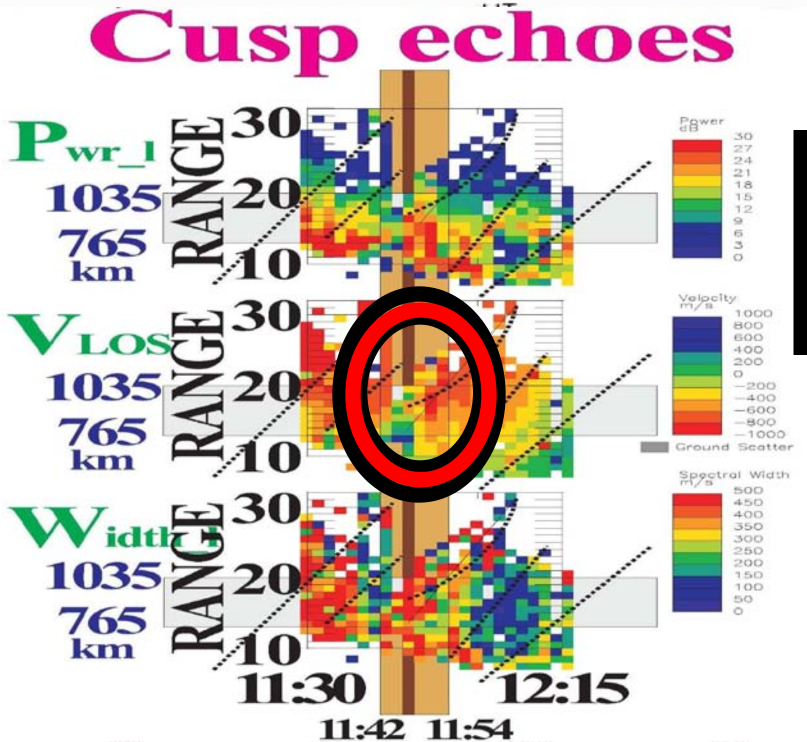
N frequencies may **resolve** up to **(N-1) targets**

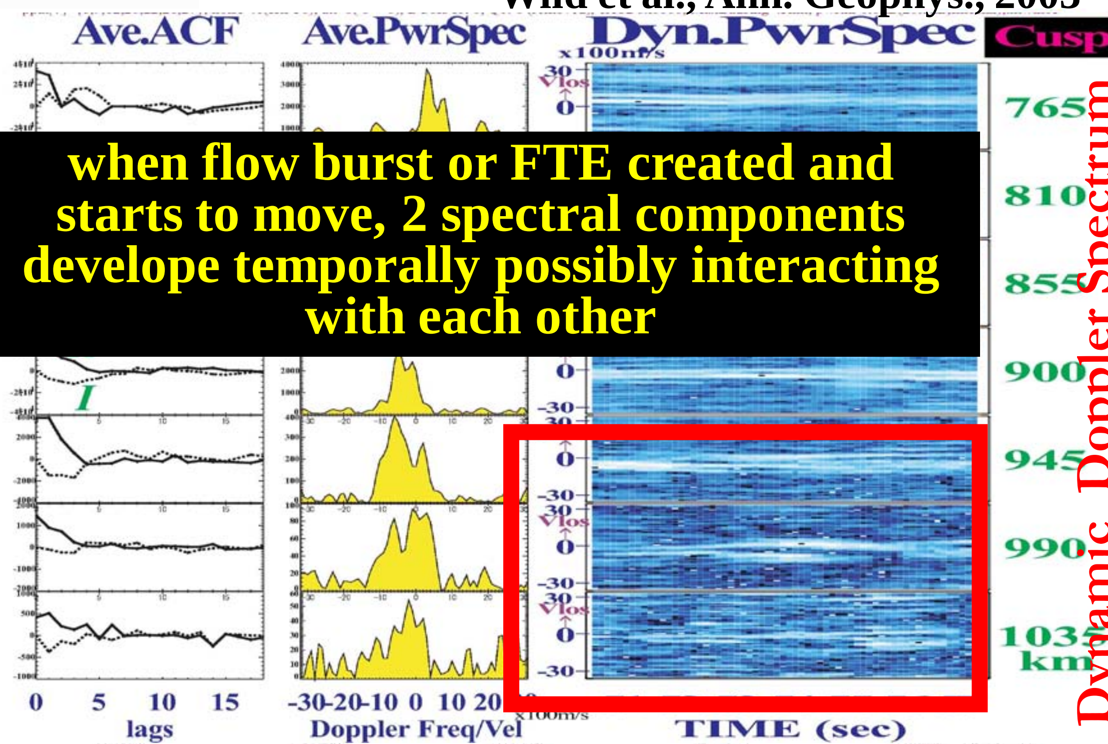
PIFs & FTEs



- Pulsed Ionospheric Flows (PIFs) seen at conjugate Finland & Syowa East pair every several minutes intermittently
- PIFs & those Vlos variation: one-to-one correspondence between the conjugate pair
- FTEs observed by conjugate Cluster : one-to-one correspondence with ground-based SD PIFs
- PIFs is ionospheric signature of FTEs [Wild et al., 2003]
- similar results also with Equator-S & with Geotail

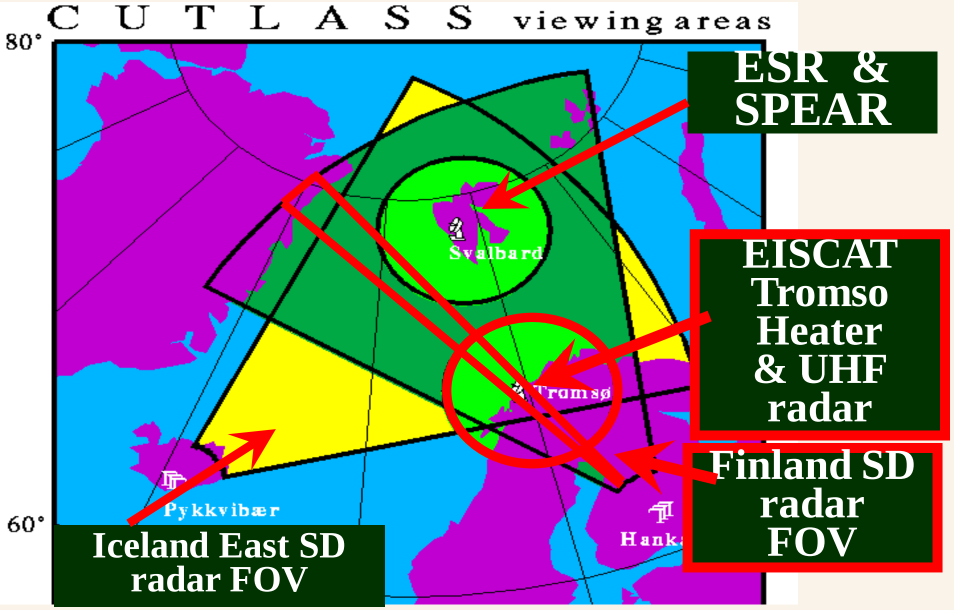
Wild et al., Ann. Geophys., 2003

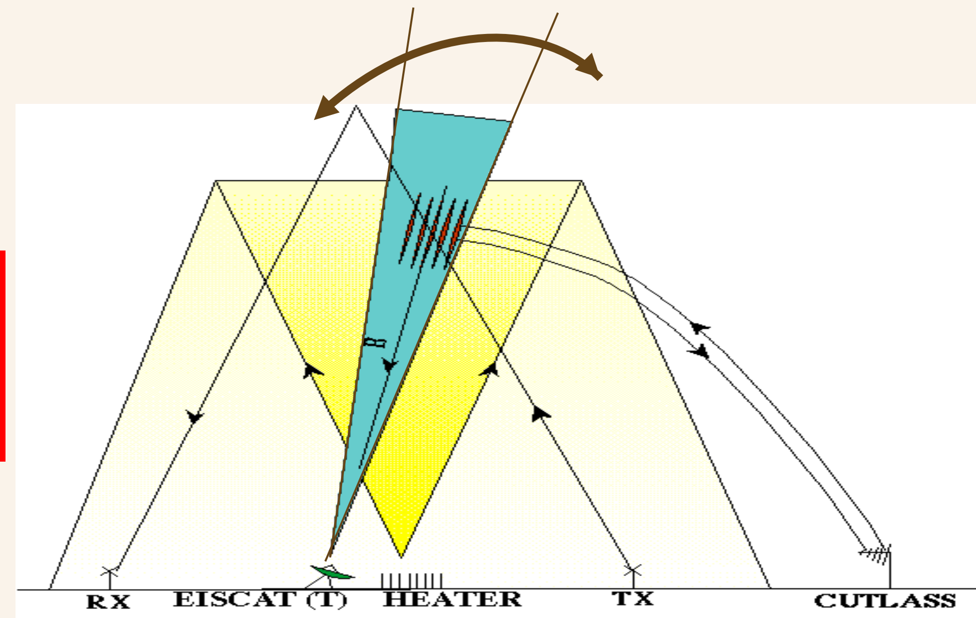


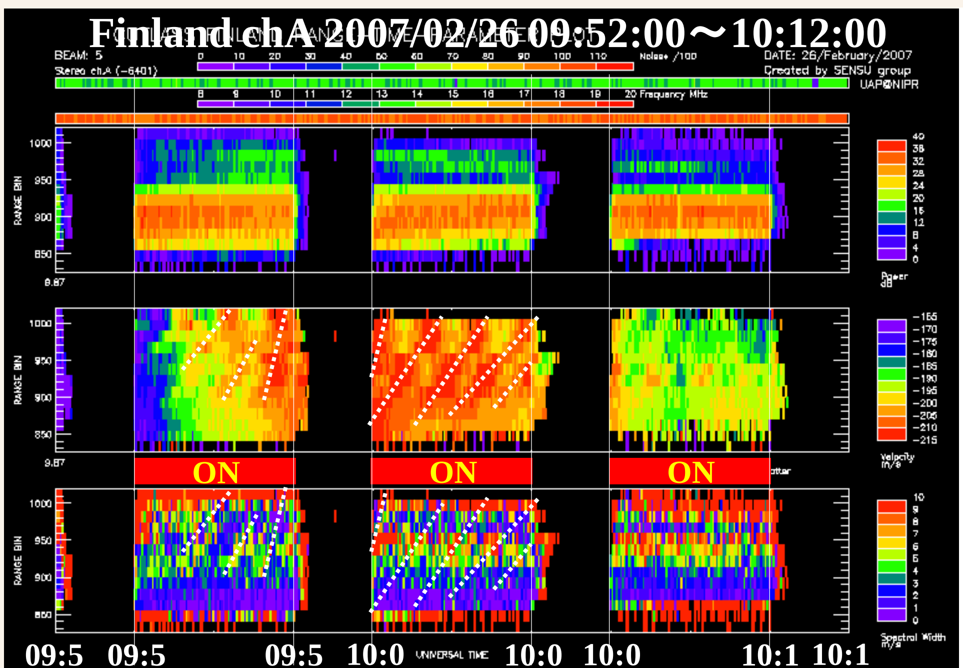


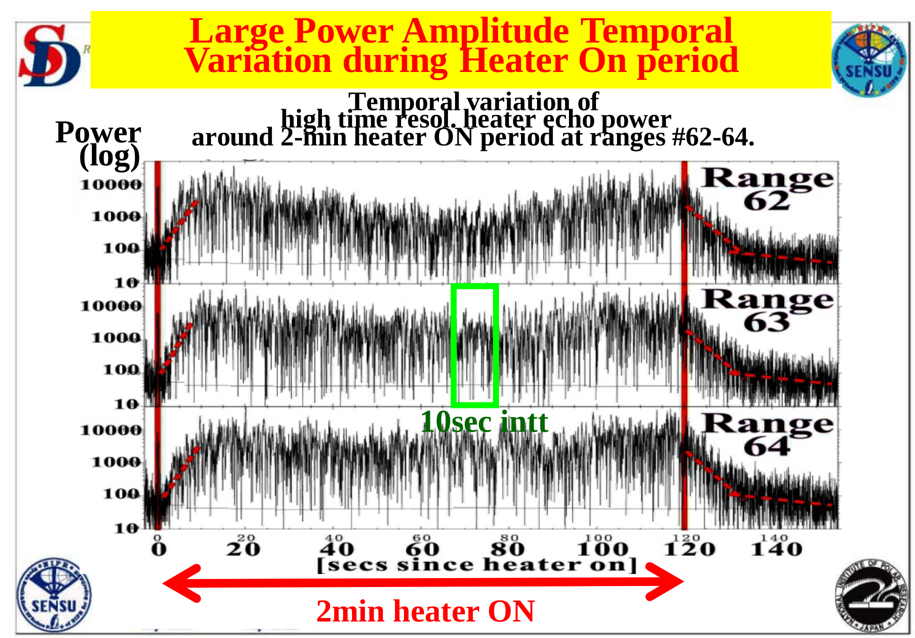
when flow burst or FTE created and starts to move, 2 spectral components develope temporally possibly interacting with each other

F-region FAIs with heater & SD

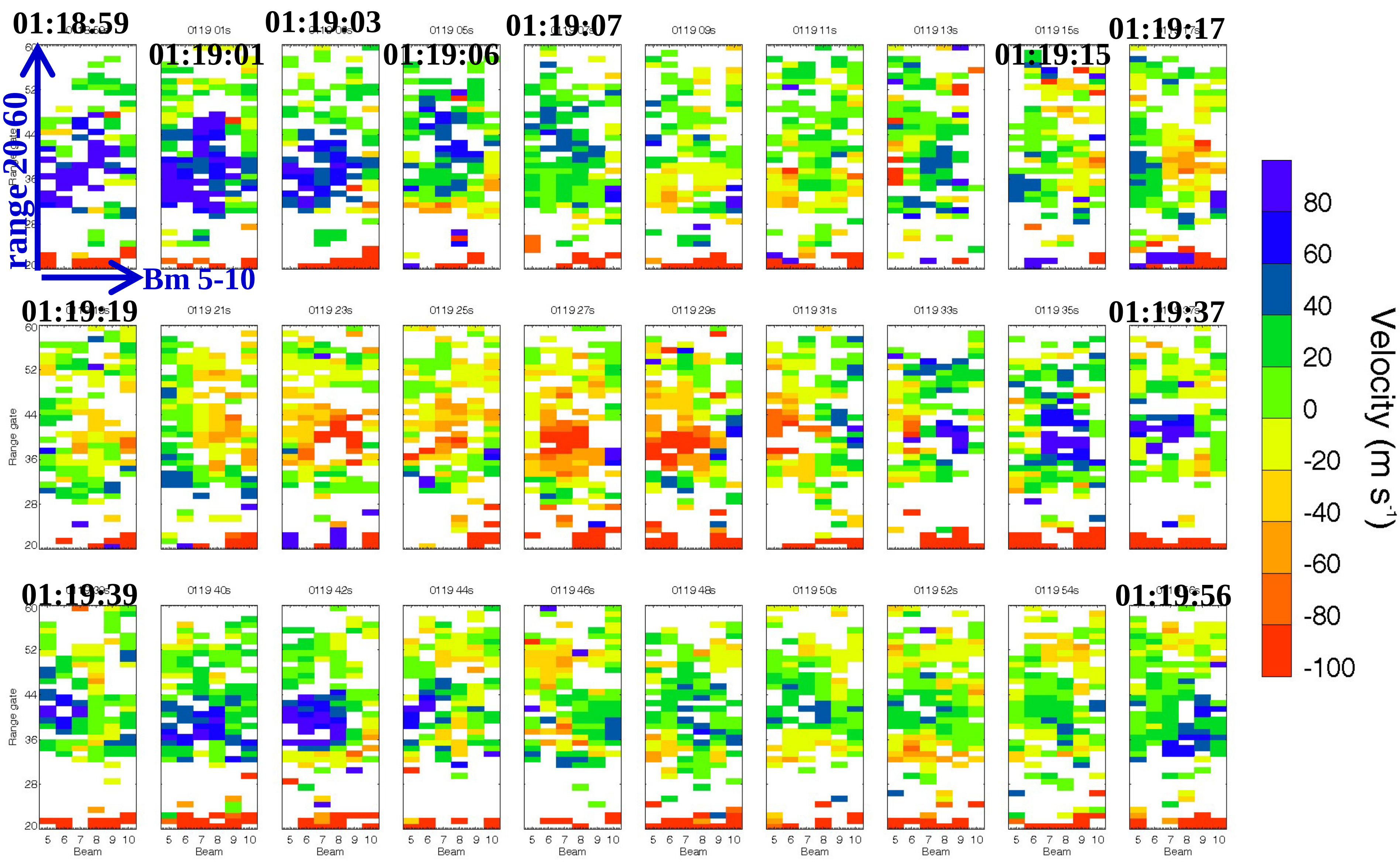




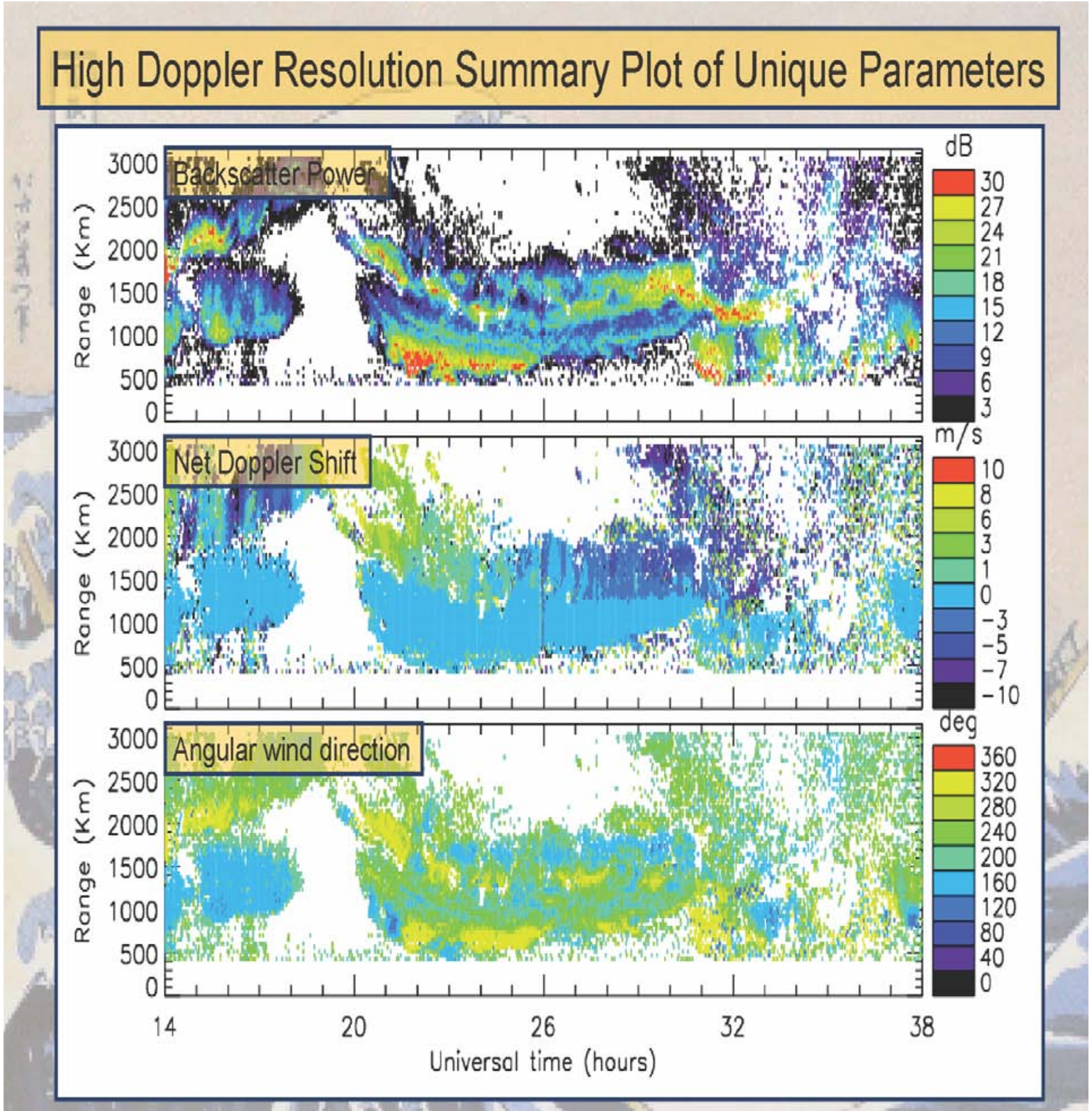




2-D Vel field evolution assoc. with pulsating aurora during 1-min interval with ~2 sec temp. resolution



Sea scatter (sea surface wave) (TMS application)



thank you