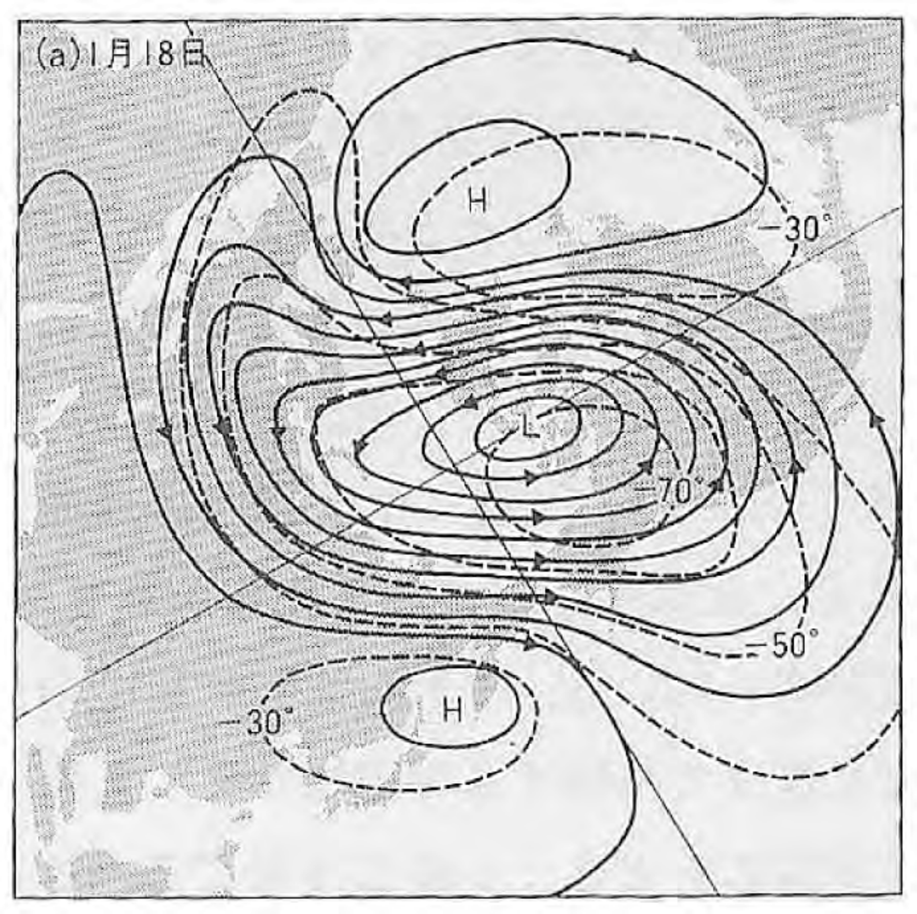
SuperDARN近距離エコーと中性風大気観測網構築 - SuperDARN near range echoes and true meteor wind observing network with SD –

A. S. Yukimatu
ROIS/NIPR, SOKENDAI

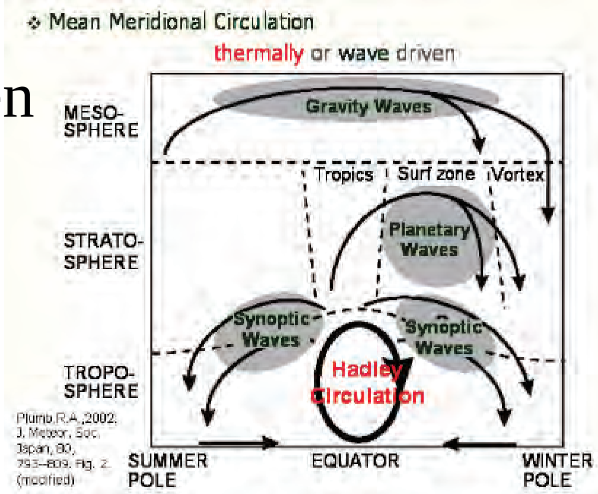
Global Structure of Middle Atmosphere



Stratosphere **Mesosphere**

Background

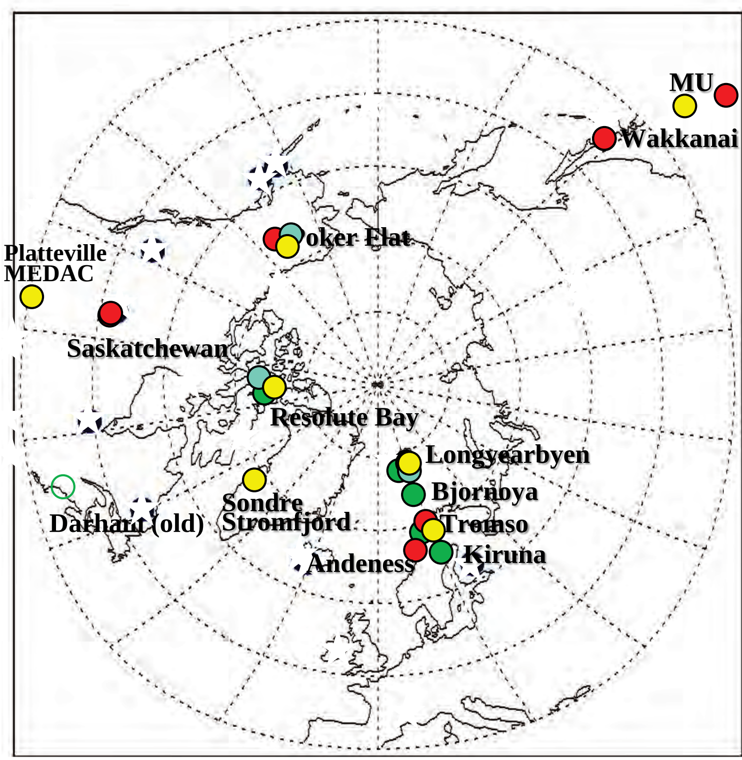
- We still do not know the weather map (neutral wind map) in MLT/mesopause region due to lack of observation especially globally wide longitudinal coverage.
- It is important to know it, e.g., for
  1. understanding **global atmospheric circulation quantitatively**
  2. global distribution and evolution of **non-migrating tide**
  3. background/ambient wind distribution and temporal evolution when TID/PMSE etc happen to know the source region and generation mechanism etc.
     (point mes. cannot distinguish spatial and temporal variation, i.e., advection into and generation at the point)
  4. understanding influences of a variety of geospace phenomena (like geomagnetic storm, high energy particle precipitation, and aurora) onto lower neutral atmosphere (and reverse way as well)
  5. as **very important inputs to MTI region simulation research**.
- So it is important key to understanding MLT region dynamics and vertical coupling between neutral and ionized atmosphere for long term climate change as well as space weather.



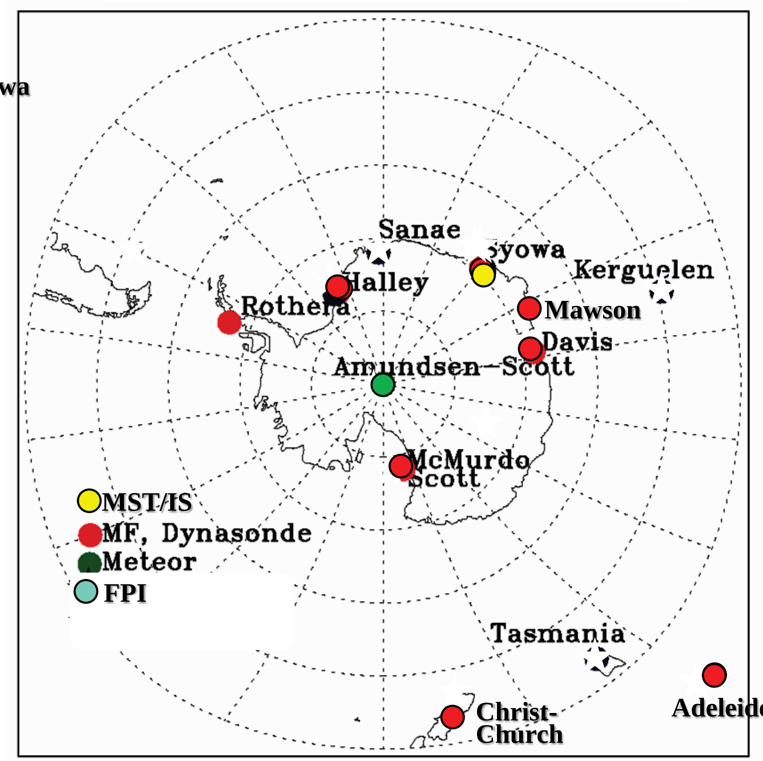
MLT region neutral wind measurement

- # of ground-based neutral wind measurements at MLT region gradually growing - but still limited (globally, especially longitudinal coverage)
- Satellite global observation but poor temporal resolution - difficulty for transient phenomena (also validation issues)

Arctic neutral wind obs



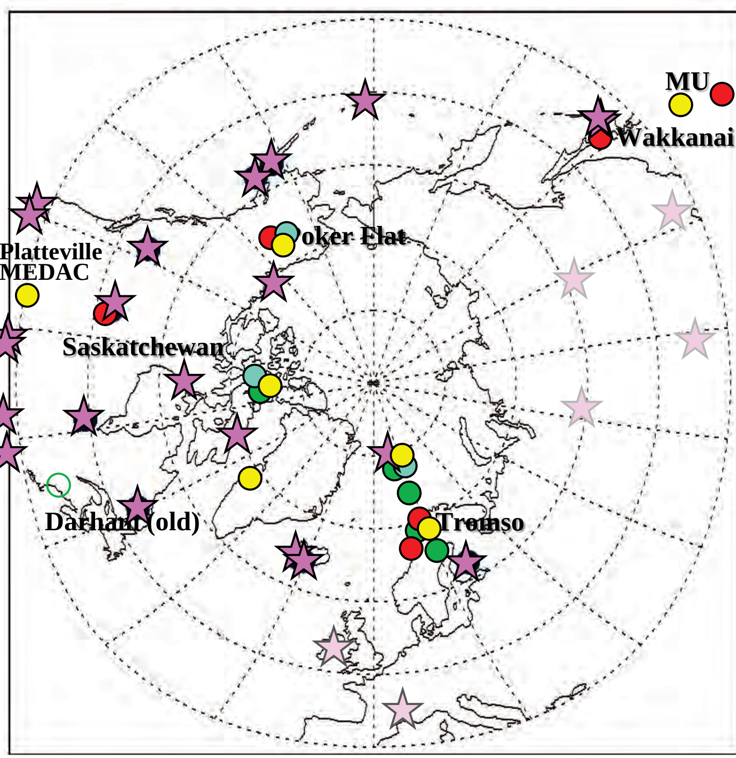
Antarctic neutral wind obs



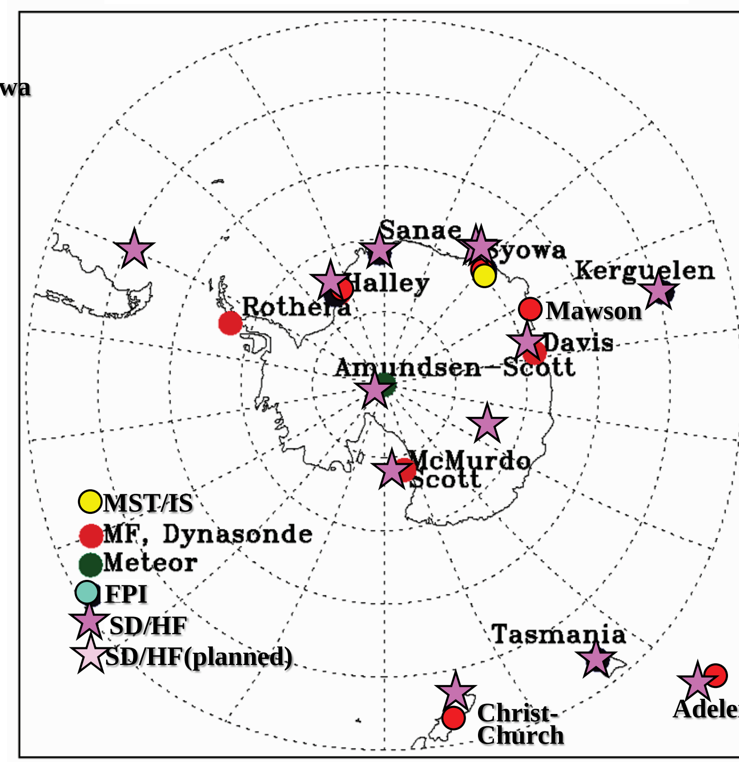
MLT region neutral wind measurement

- # of ground-based neutral wind measurements at MLT region gradually growing - but still limited (globally, especially longitudinal coverage)
- Satellite global observation but poor temporal resolution - difficulty for transient phenomena (also validation issues)
- SuperDARN drastically growing – <u>wide long/lat coverage</u>

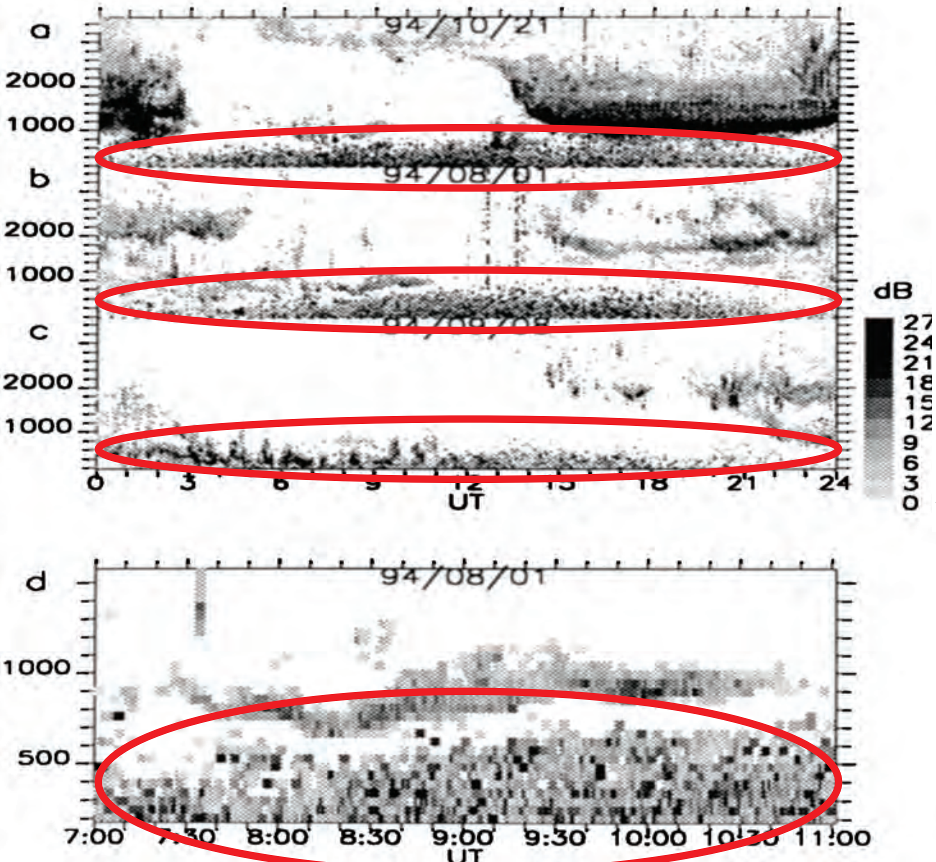
Arctic neutral wind obs

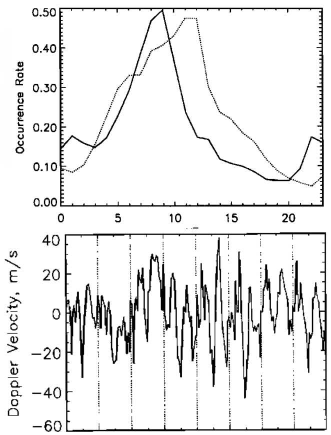


Antarctic neutral wind obs



Early SD meteor (neutral) wind mes.





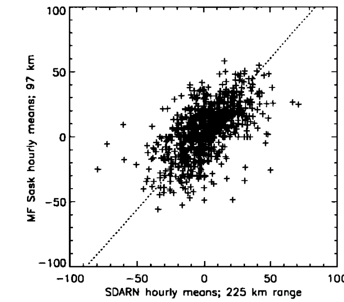


Figure 8. Scatterplot comparison of SuperDARN hourly means (225 km range, beam 5) and the MF velocities at 97 km for August 1994. The dotted line is the least squares fit $V_{MF} = (-2\pm1)+(1.16\pm0.06)\times V_{SDARN}$. The SuperDARN velocities have been rotated into the horizontal plane, and the MF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

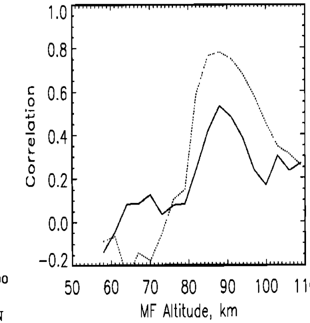


Figure 9. MF-SuperDARN velocity cross-correlation coefficient as a function of MF altitude for the month of January 1994 (solid curve) and August 1994 (dashed curve).

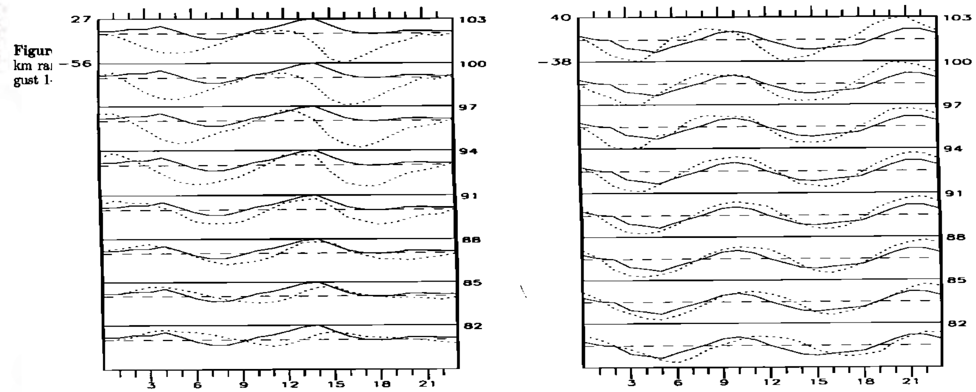


Figure 10. Mean day velocities for SuperDARN for the five nearest ranges, beam 5 (solid curves) and MF Saskatoon for heights from 82-103 km (dotted curves) for (left) August 1994 and (right) September 1994.

- Hall et al. 1997: **<u>GNRE</u>**s are mostly dominated by meteor echoes whose velocity data reflect neutral wind velocity around mesopause region @ ~94±3km – historical 1st big <u>great step for SD. & new capability and new research area</u>.
- Using only fitted parameters: <u>not sure if really underdense meteor echoes</u>?
- Almost <u>no height info</u>：tried to infer height by comparing nearby MF data
  (too coarse even if using well cal'ed interf data)
  <u>impossible to obtain vertical profile</u>

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

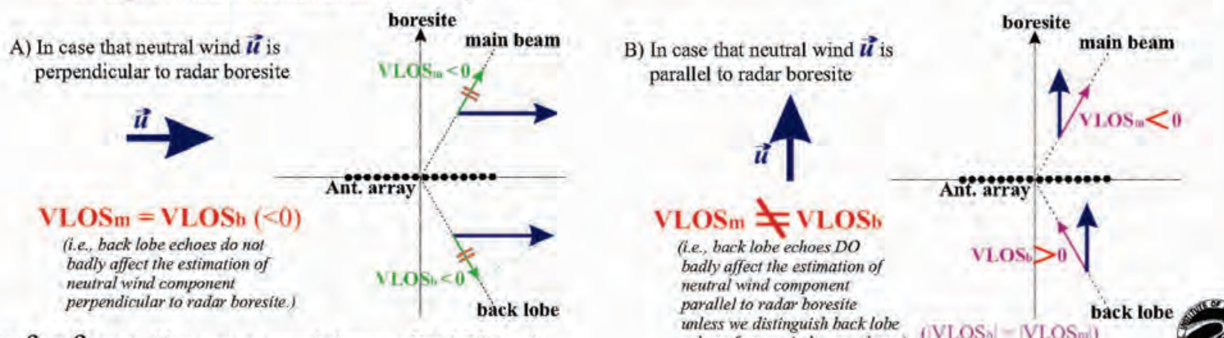
Problems in early SD meteor mes.

SD meteor wind measurements using normal fitacf'ed data

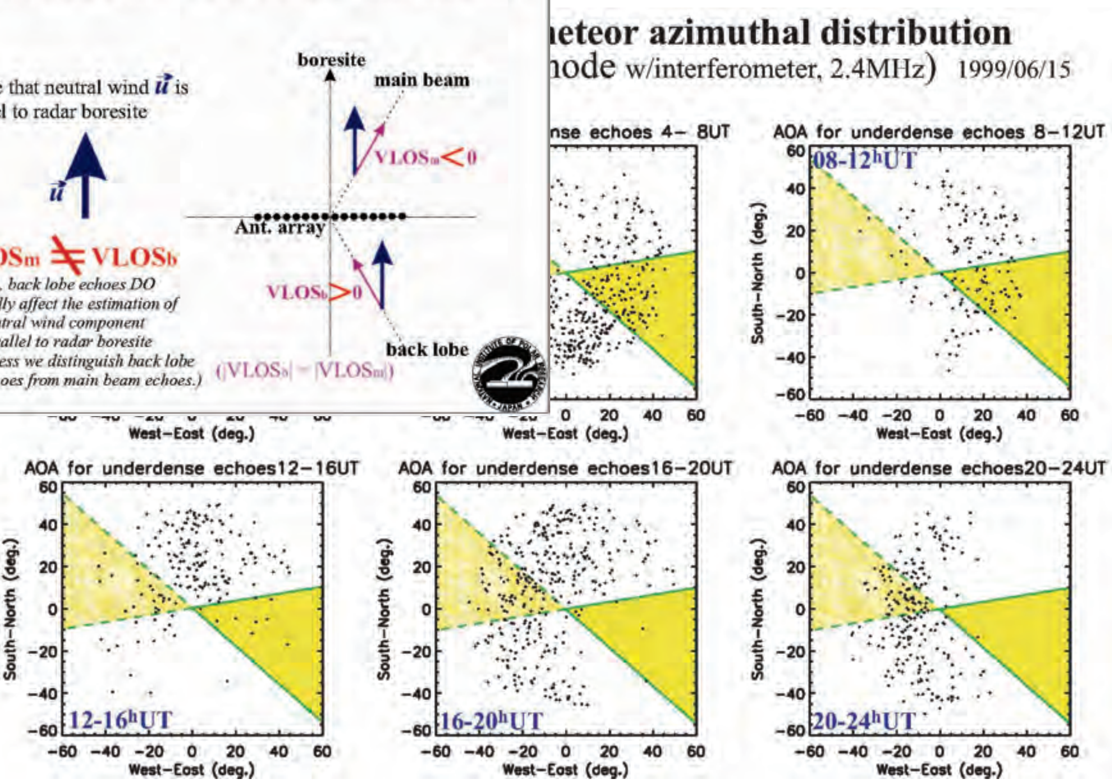
("G_{rainy} N_{ear} R_{ange} E_{choes}") *[e.g., Hall et al., 1997]*

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 → *Altitude structure cannot be resolved*
   for mesopause region dynamics (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)



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

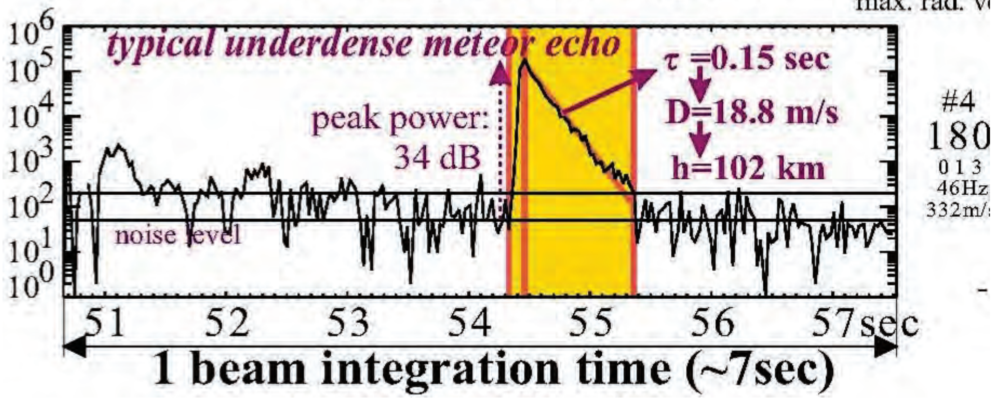


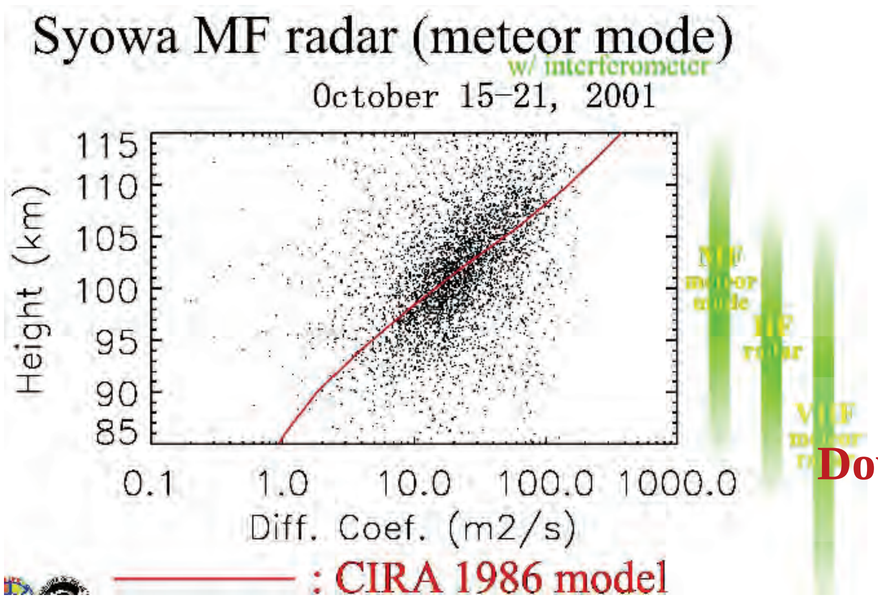
Height: decay height method (w/CIRA model)

(decay time const.→ambipolar diffusion coeff.→model→height)

Yukimatu & Tsutsumi, GRL, 2002

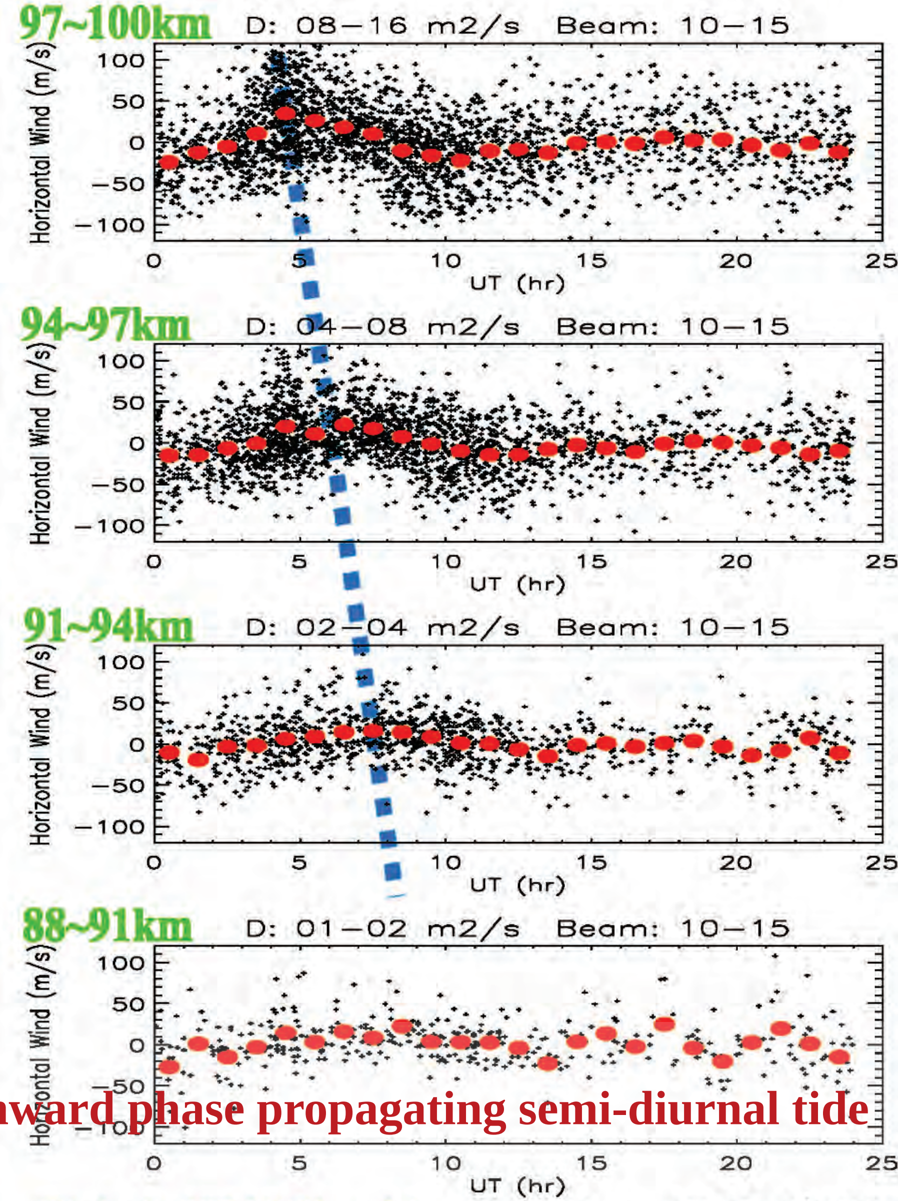
Power for each range gate during 1 beam integ. time





Daily variation of eastward neutral wind at 4 altitudes in the mesopause region

SENSU Syowa East October 15-21, 2001



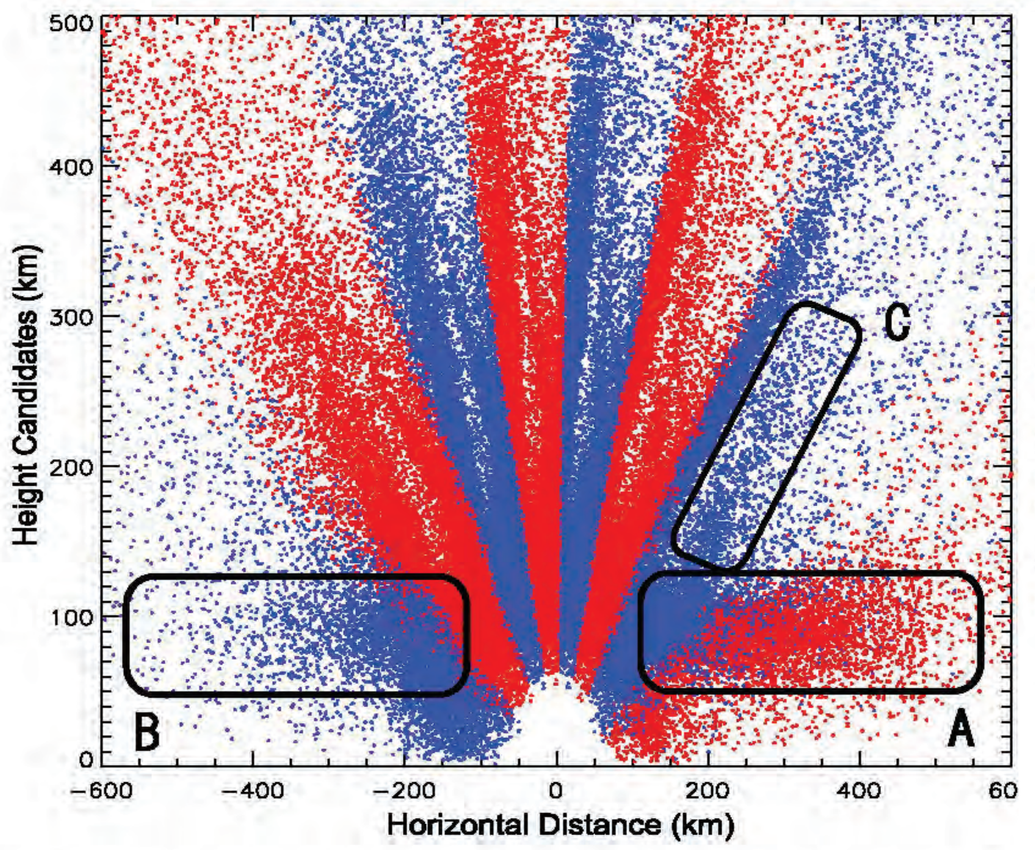
altitudes by CIRA1986 model (Syowa LT=UT+2^h40^m)

SD IQ/TMS meteor (neutral) wind mes.

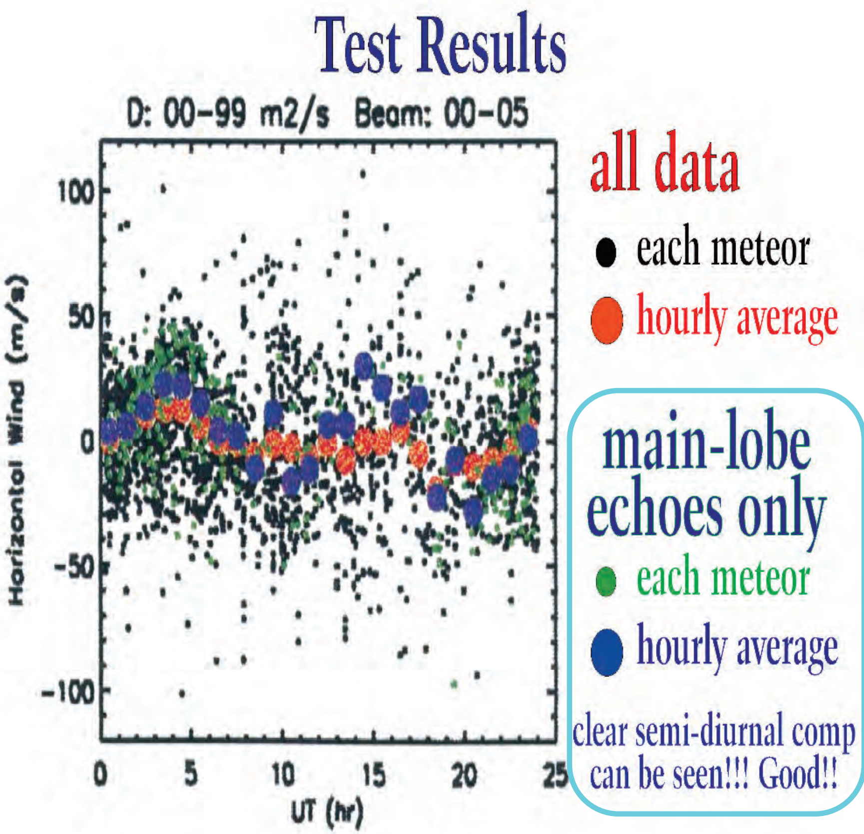
- Yukimatu and Tsutsumi, 2002 successfully done:
  1. record and anlyse raw I/Q samples (TMS method developed)
  2. extract <u>only underdense meteor</u> echoes to derive neutral wind
  3. used <u>decay height method</u> (i.e., obtained ambipolar diffusion coeff. from meteor decay time constant and use CIRA model) to obtain height information
  4. successfully obtained <u>vertical profile of neutral wind</u> and detected downward phase propagating semidiurnal tide.

- Things to be improved:
  1. obtain <u>altitude from interferometer</u> (w/o atm. model)
  2. **<u>Directional ambiguity</u>** still remained:
→distinguish front(main)/back lobe echoes
(difficult if echoes from sidelobes) – use interferometer!
  3. improve <u>height resolution</u> and accuracy

To solve directional ambiguity
distinguish F/B meteors w/interferometer



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

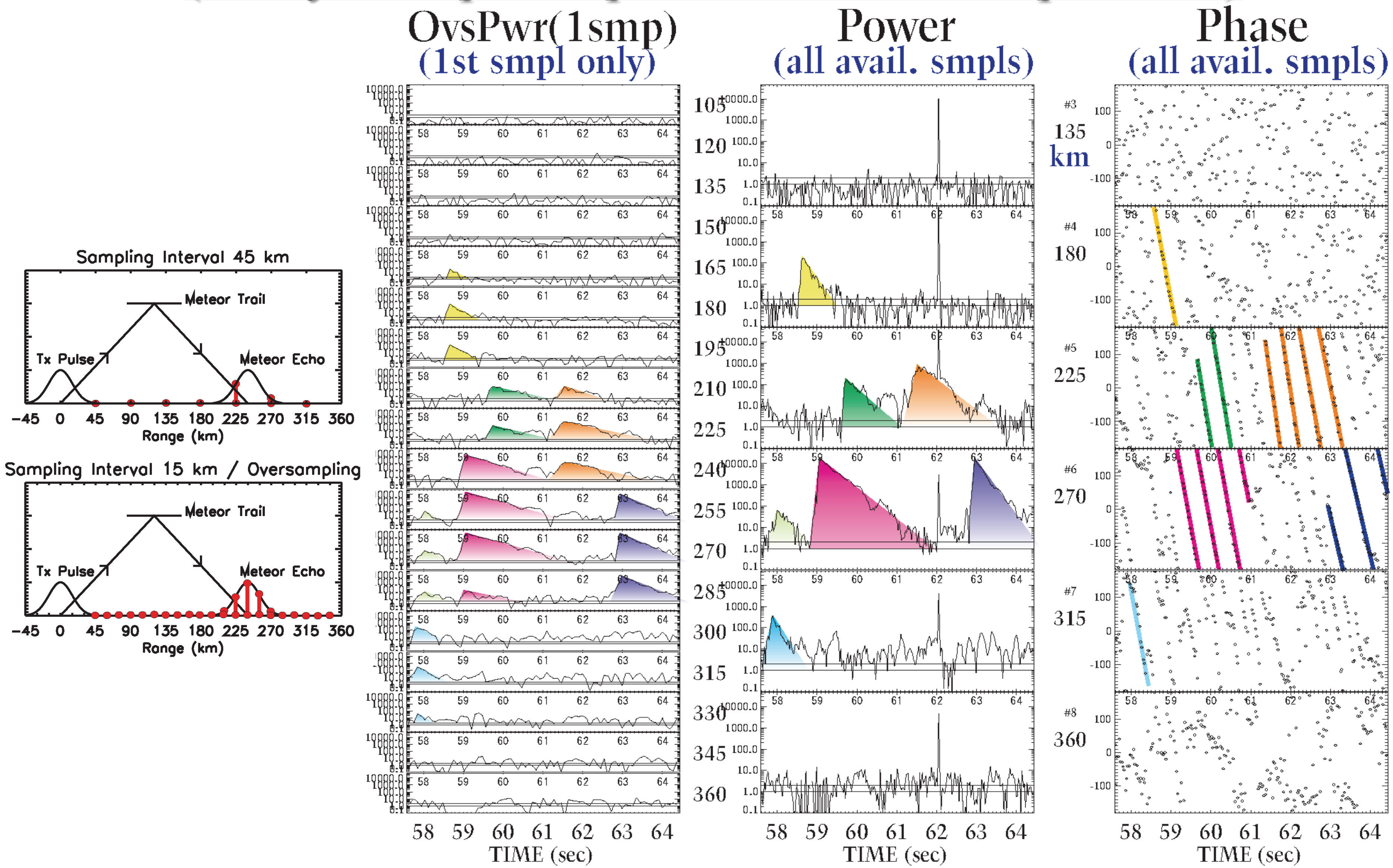


Tsutsumi., et al., Radio Sci., 2009

improvement of spatial resolution

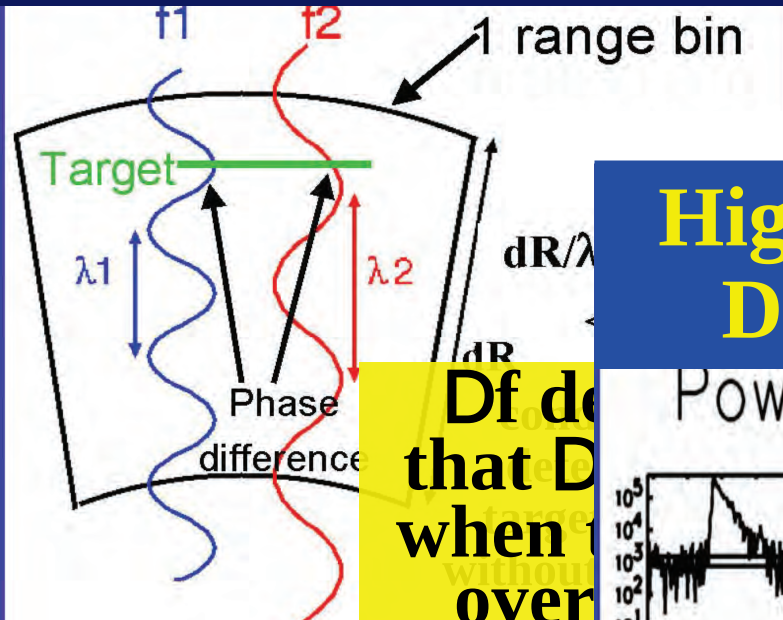
Oversampling

(always sample rsep=15km even if rsep=45km)



(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**



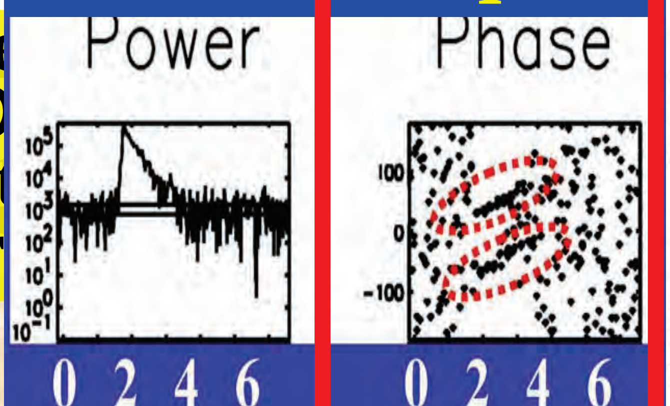
freq difference

|Δf | < dR/c

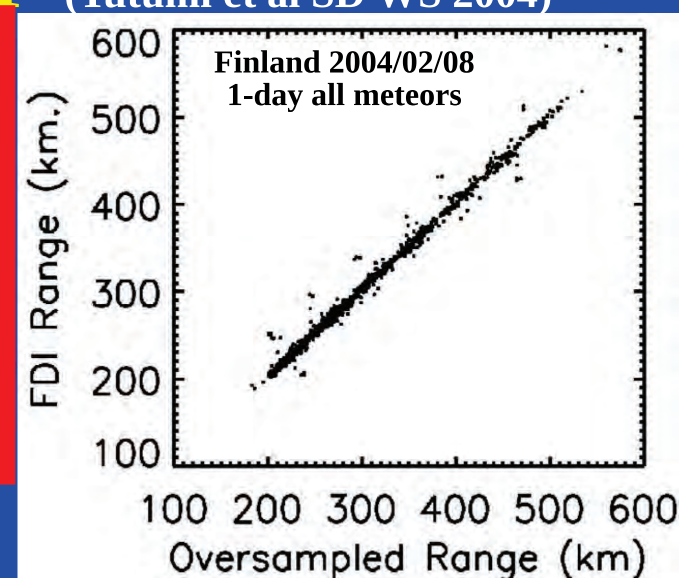
Df de
that D
when t
over

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!

Improved SD IQ/TMS method

- Tsutsumi, et al., 2009 successfully done:
  1. Use interferometer to derive meteor height
  2. Successfully calibrate SD interferometer using meteor echoes so that meteors distribute at the same height region.
  3. Successfully improved height resolution by oversampling method and FDI (frequency domain interferometry) method. (both results are in very good agreement)
  4. Successfully distinguished echoes from front/main lobes and those from backlobe (the same method as Steve's paper)

- Things to be considered:
  1. Height resolution and accuracy/reliability enough??
  2. It was difficult to calibrate interferometer using meteor echoes at some radars possibly due to non-flat ground plane?
     →How to calibrate interferometers at all the SD radars??
     →SD "Elevation Angle Task Force"!
  3. Calculation of IQ/TMS meteor detection and win derivation done in separate computer off-line – need to store large IQ files.
     → all the process is better to be done in real-time on Radops.
     → many radars now using different flavor of Radops…

SD tms/met accuracy of met height

Improvement of SuperDARN meteor wind measurements with raw time series analysis method.

Limitation of meteor height estimation
--- Causes of errors in height estimation ---

1. **First Fresnel Zone length**

   * **Each meteor** data is *already* **integrated** (averaged) **over a certain height** corresponding to **this length**:

   $\Delta h_F = \mathrm{sqrt}(2 \cdot \lambda \cdot \mathrm{range}) \cdot \cos(\mathrm{elev})$ $\quad (\sigma_F = \Delta h_F/2)$

2. **sampling (range) resolution**

   $\Delta h_S = \Delta r * \sin(\mathrm{elev})$

   stddev: $\sigma_S = \mathrm{sqrt}(<\Delta h_S^2>) = \Delta h_S/2 / \mathrm{sqrt}(3)$

3. **interferometer errors** (ambiguity of phase difference between 2 Rx's)

   $\Delta h_I = r * (\sin(\mathrm{elev}+\Delta \mathrm{elev})-\sin(\mathrm{elev}))$

   $L(\cos(\mathrm{elev})-\cos(\mathrm{elev}+\Delta \mathrm{elev})) = \lambda \cdot \Delta\varphi/2\pi$

   stddev: $\sigma_I = \mathrm{sqrt}(<\Delta h_I^2>) = \Delta h_I/2 / \mathrm{sqrt}(3)$

4. **receiver rise time ~=100usec** *(corresponding to Rx integration time???)*

   This only affects delay time or also affect range ambiguity???

   This value can never be decreased using current receiver bandwidth, in principle.

   ⇒ *Too much over sampling data might not be independent of close samples???*

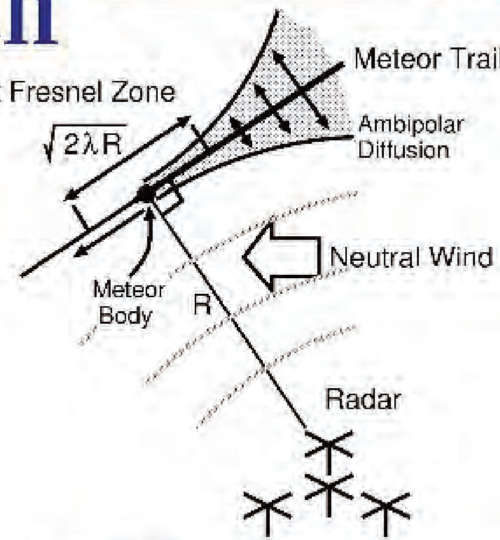
$$\Rightarrow \sigma_{total}^2 = \sigma_F^2 + \sigma_S^2 + \sigma_I^2$$ *(error propagation)*

by A. Sessai Yukimatu, M. Tsutsumi, M. Lester, S.E. Milan and N. Sato at SuperDARN workshop in Finland, in May, 2003.

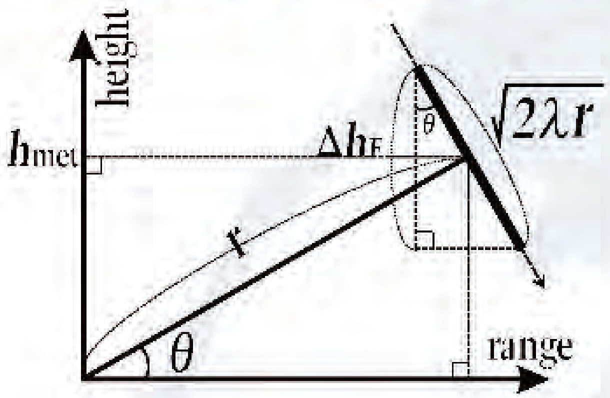
SD tms/met accuracy of met height

Improvement of SuperDARN meteor wind measurements with raw time series analysis method

First Fresnel Zone length



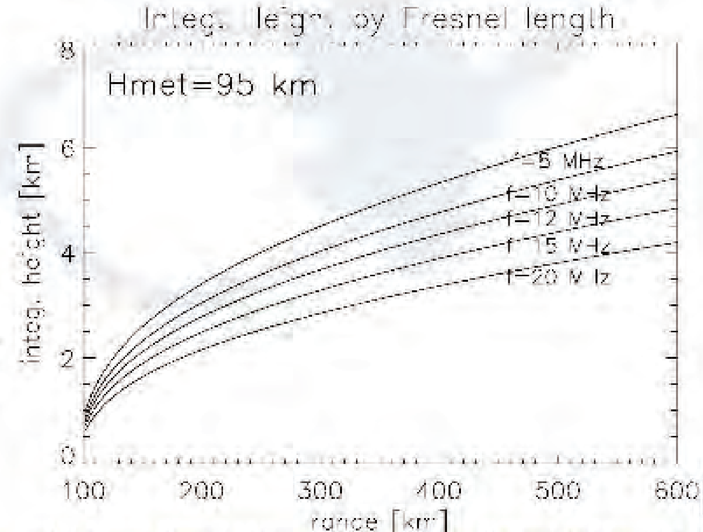
Each meteor echo data contains the effect of neutral wind integrated over a certain height range ($h_{met} \pm \Delta h_F/2$) corresponding to this length



$$\Delta h_F = \sqrt{2\lambda r} \cdot \cos\theta$$

$$= \sqrt{2\lambda\left(r - \frac{h_{met}^2}{r}\right)} \quad (r \geq h_{met})$$

λ : Tx wave length

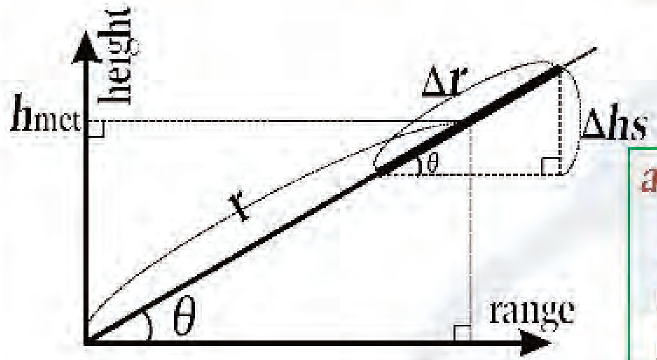


by A. Sessai Yukimatu, M. Tsutsumi, M. Lester, S. E. Milan, and N. Sato at SuperDARN workshop in Kiljava, Finland, in May 2003.

SD tms/met accuracy of met height

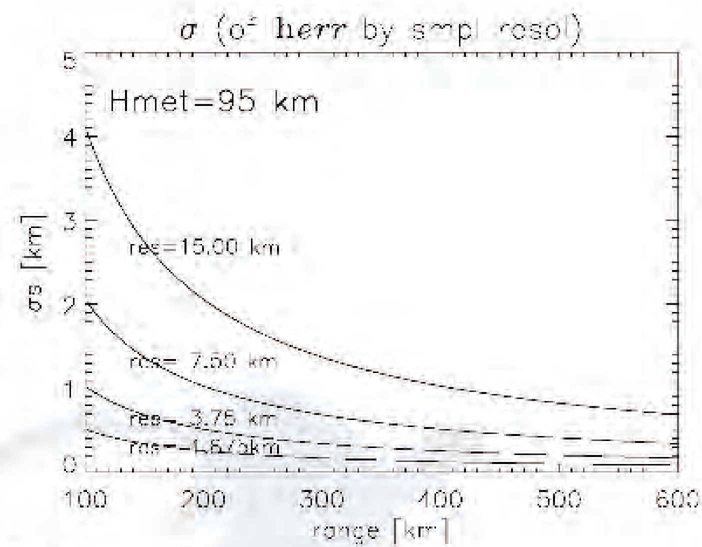
Improvement of SuperDARN meteor wind measurements with raw time series analysis method

Height ambiguity by discrete sampling



assuming...

h_{met} ~95 km
no Fresnel zone
no Interf. error



$$\Delta h_s = \Delta r \cdot \sin\theta = \frac{\Delta r \cdot h_{met}}{r}$$

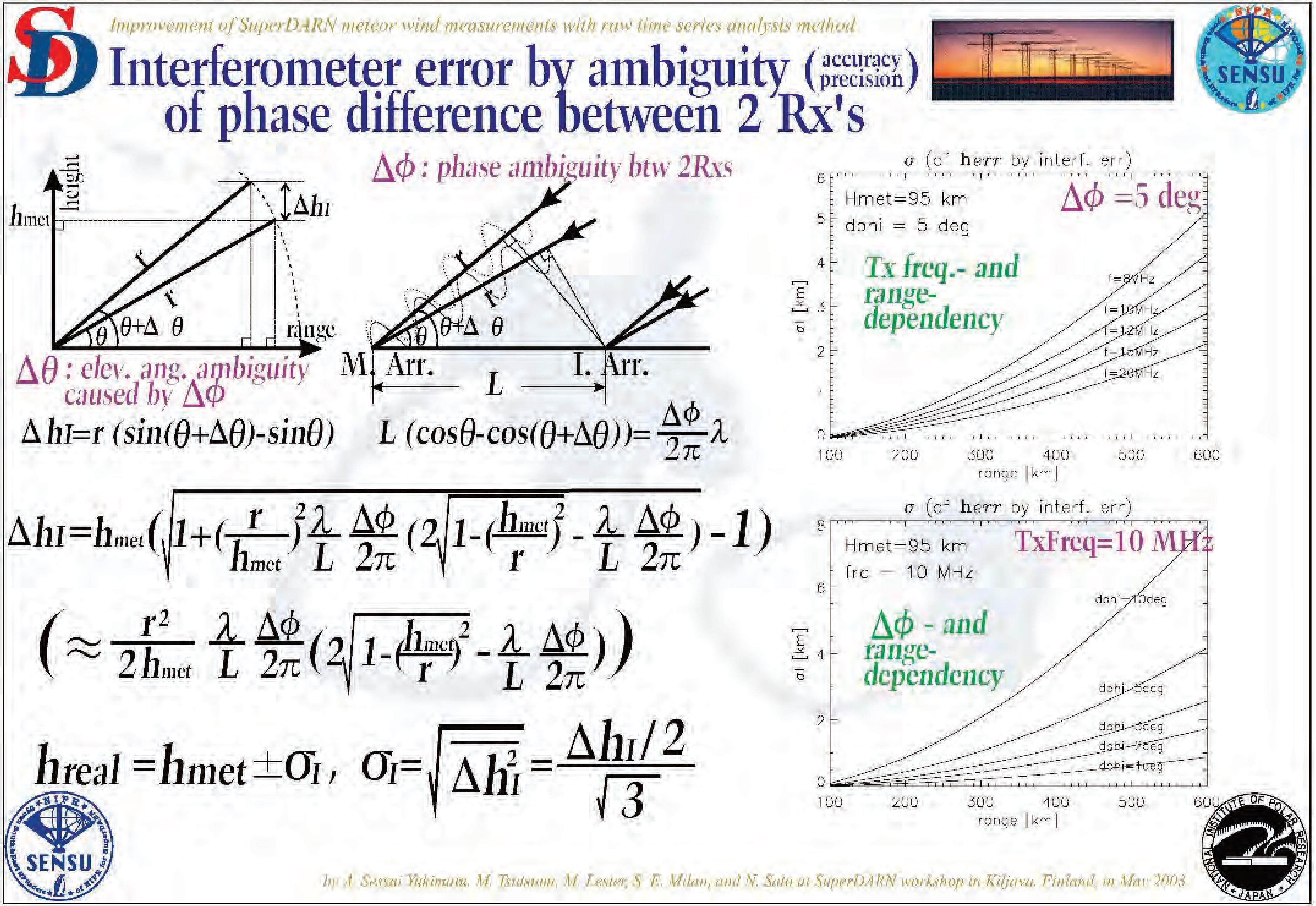
$$h_{real} = h_{met} \pm \sigma_s, \quad \sigma_s = \sqrt{\overline{\Delta h_s^2}} = \frac{\Delta h_s / 2}{\sqrt{3}}$$

(if no range fitting is made!)

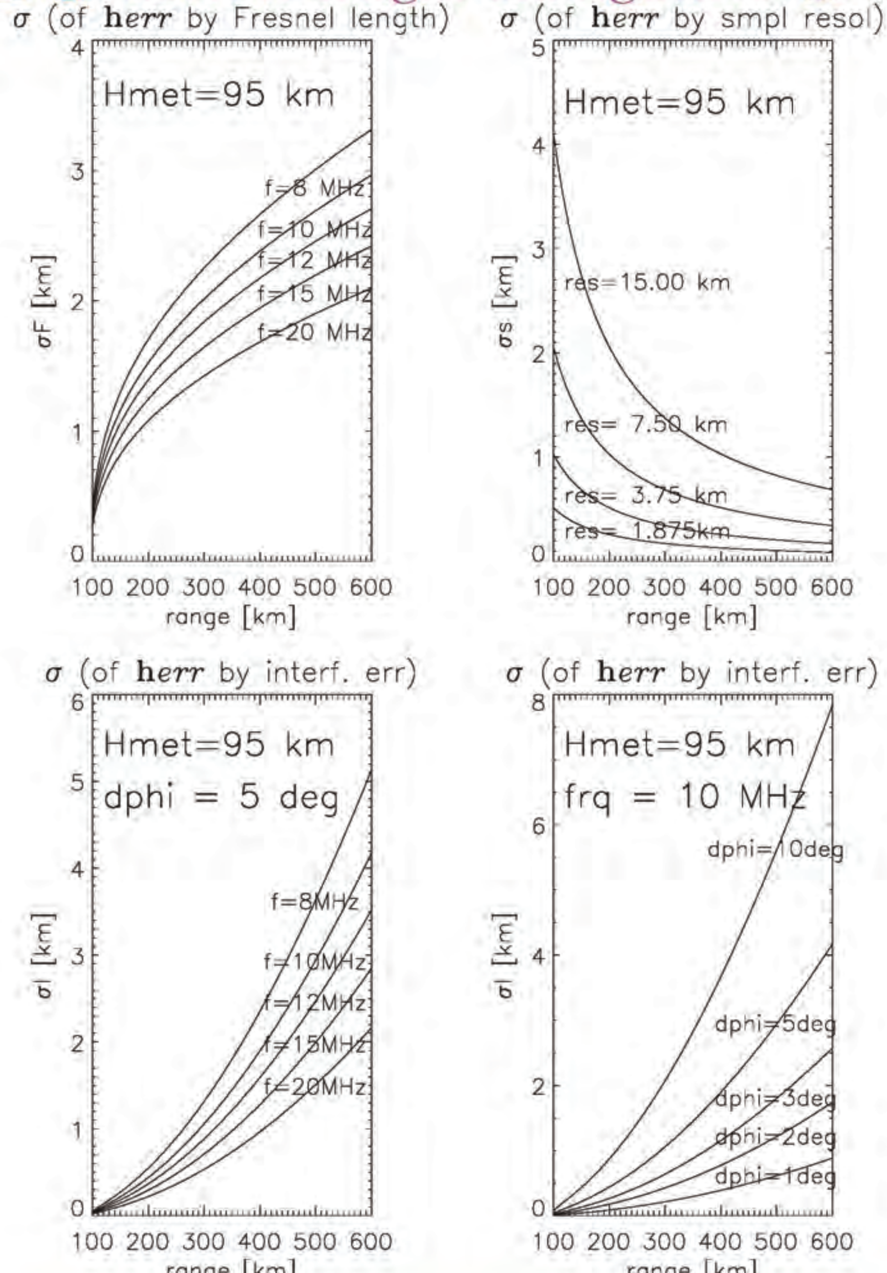
If range fitting is made, height (range) resolution will be even better

by A. Sessai Yukimatu, M. Tsutsumi, M. Lester, S. E. Milan, and N. Sato at SuperDARN workshop in Kiljava, Finland, in May 2003.

SD tms/met accuracy of met height

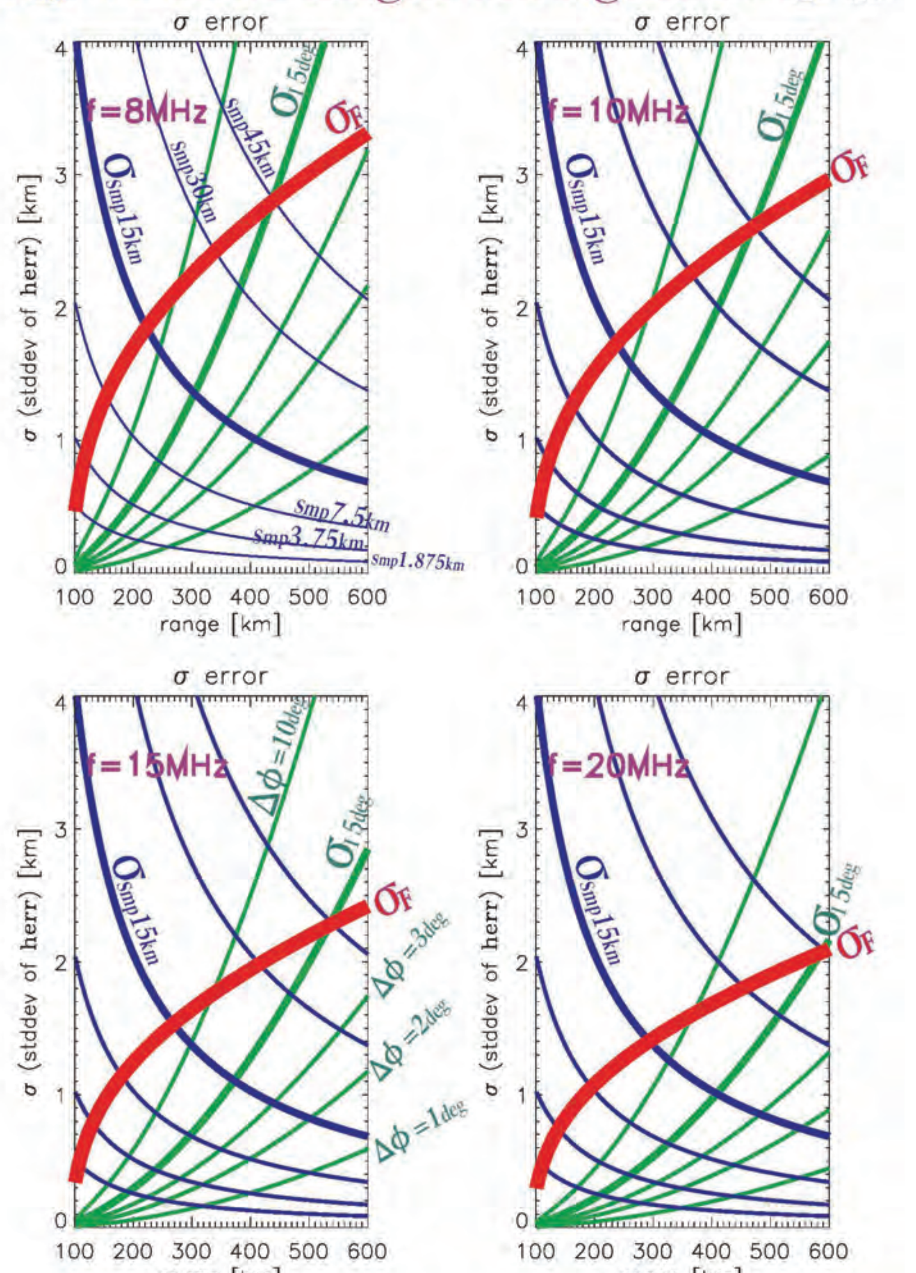


Meteor height ambiguities



Improvement of SuperDARN meteor wind measurements with raw time series analysis method

Meteor height ambiguities



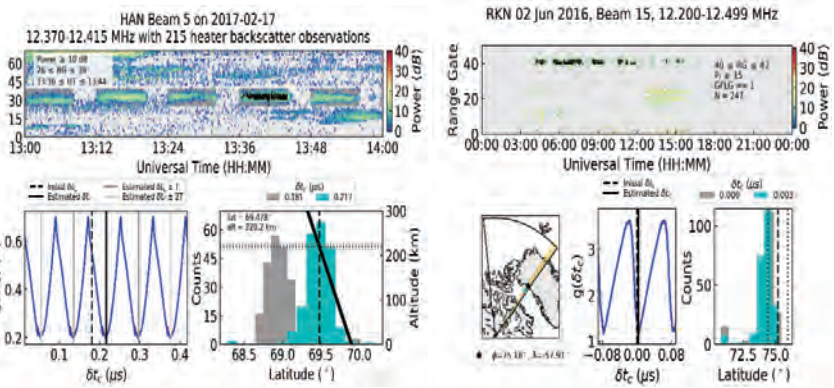
Accuracy of meteor height

- To obtain reliable data which can contribute to MLT region research:
  1. Interferometer phase accuracy: <5 deg is preferable
  2. Range resolution is very poor if rsep>15km
     →**<u>Should use OVS at least to keep a certain height accuracy</u>** for any SD schedule/operational mode
     →recommend to use oversampling(OVS) and/or FDI method.
     →for OVS, it is relatively easy (just modify Radops a bit and no influence for other process)
     →For FDI, we need 2 frequencies very closely (<10kHz) separated each other and change TxFreq every pulse sequence
     →It is likely that it will NOT affect the normal ACF observation might need to be checked if it is really no problem.

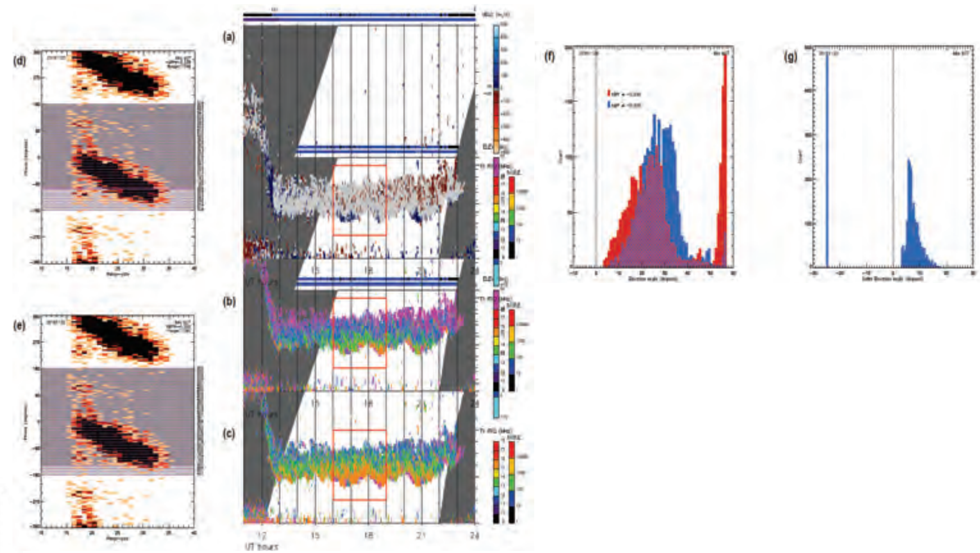
- Things to be considered:
  1. Calibrate interferometer reliably with 5 degree phase difference →tdiff (<u>elevation angle) TF</u>!
  2. <u>Demonstrate the OVS/FDI results and its effect and whether it will never affect normal ACF observation.</u>

SD “tdiff(elevation Angle)” Task Force

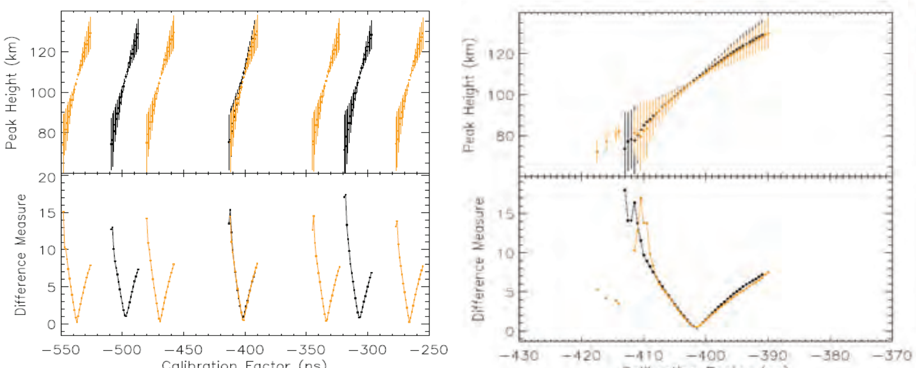
- Angeline’s Known Location method (heater,GS,…)



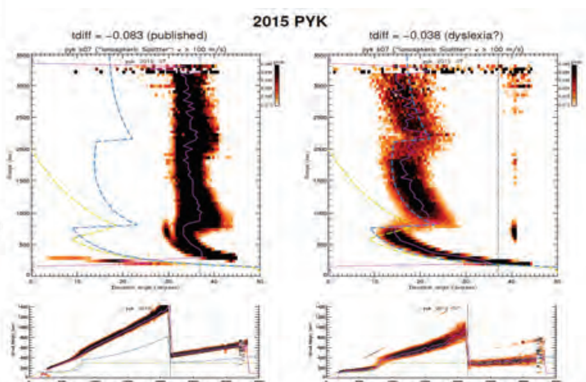
- Simon’s GS scatter’s method

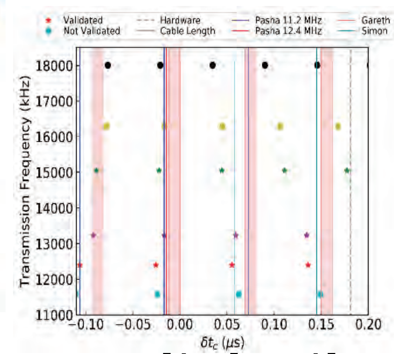


- Gareth’s Meteor Scatter method

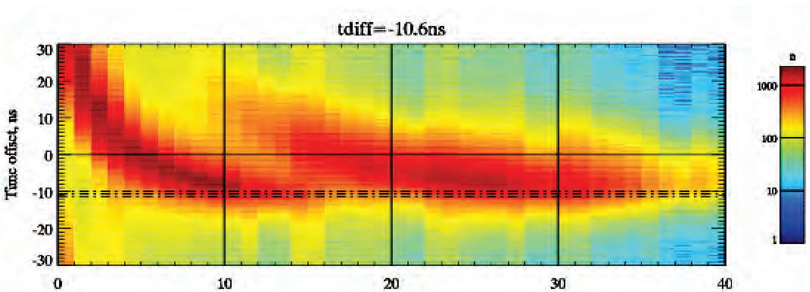


- Simon’s based on Chisham Virtual Height (VH) model





- Pasha’s zero elevation scatter method



The independent calibration results for the same data set provided mostly a good agreement – great jobs and many thanks!!

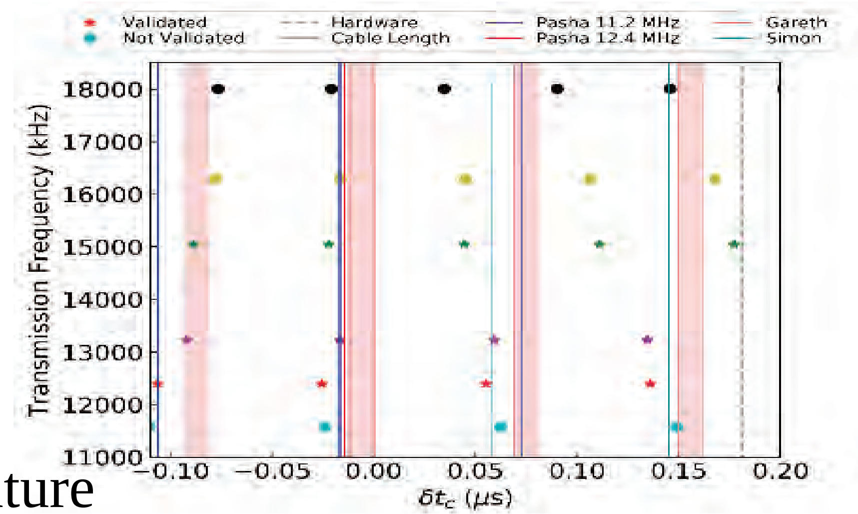
SD “tdiff(elevation Angle)” Task Force

・Angeline’s Known Location method (heater,GS,…)：
Targetないと困難でイマイチ。
・Gareth’s Meteor Scatter method：うけは良い。
・Simon’s GS scatter’s method
・Simon’s based on Chisham Virtual Height (VH) model
・Pasha’s zero elevation scatter method: E region echoes – 2-3 ns uncertainty

The independent calibration results for the same data set provided mostly a good agreement – great jobs and many thanks!!

Not much seasonal variation.
Freq/Temp dependency?
Why some radars show beam dep?

Meteor method: range offset?
Backlobe echoes? – should be distinguish



Regular calibration will be made in near future
much more reliable data expected. – early warning of HW issues as well
- Some radars have no interf arrays… recommended to implement!

A closer look at near-range echoes

W. Merett, P. Ponomarenko, St.-Maurice at SD 2018 Workshop

This work represents continuation of the previous research on the morphology and possible sources of the near-range (> 400 km) SuperDARN returns by Ponomarenko et al [2016], who described three distinct echo populations: (i) dawn echoes attributed to backscatter from the meteor trails, (ii) pre-midnight returns ascribed to the auroral E-region and (iii) midday mid-summer population whose origin is still unclear. While the early work was based on the "normal" 45-km resolution data starting at 180 km from the radar, this study is focused on 15-km resolution data with initial range of 90 km obtained during discretionary time (2-3 days/month from December 2016 until July 2017 at all Canadian radars). In combination with accurate interferometry calibration, this allowed for more precise estimates of the scatter altitude and range. On the other hand, the limited data availability enforced event study approach. The observations show that both the dawn (meteor trail) and the midday echo populations are generally centred near the 100-km altitude. However, in contrast to "grainy" appearance of the meteor trail echoes in the range-time domain, the daytime population occurs in continuous patches ("blobs") which last for one to two hours and span several range gates. Furthermore, the altitude extent of the morning echoes is noticeably wider than that observed for their daytime counterparts, _˜20-30 km vs _˜10 km, respectively. In comparison with the other two populations, the evening E-region echoes are centred near the _˜120 km altitude, are observed further away from the radar and show larger values of velocity and spectral width. In addition to the "normal" E region echoes covering 20-30 km in altitude, we also observed a distinct sub-population with a very narrow vertical extent of _˜10 km, which could be related to the sporadic E layer. The obtained information will be discussed in terms of clarifying possible origins of the near-range echo populations.

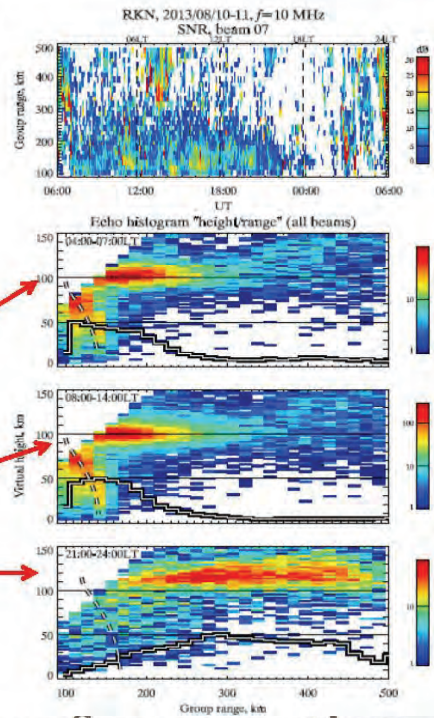
Reference

Ponomarenko, P. V., B. Iserhienrhien,and J.-P. St.-Maurice (2016), Morphology and possible origins of near-range oblique HF backscatter at high and midlatitudes, Radio Sci., 51, 718–730, doi:10.1002/2016RS006088.

Merett, Ponomarenko, St.-Maurice at SD 2018 Workshop

Initial results from our earlier study

- 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)
    - Unknown origin
  - Evening ($h_v \approx 120$ km)
    - E Region irregularities



Merett, Ponomarenko, St.-Maurice at SD 2018 Workshop

Preliminary survey of properties

- LOWER CONTIGUOUS
  - Peak at 100 +- 2 km
  - Echo region 10-15 km thick
  - Range = 90 to 220 km
  - Most probable SNR: 5dB
  - Most likely Doppler width is 5 m/s and independent of altitude
  - Spread in Doppler width: 20 m/s
  - Occur preferably in summer in late am/early pm in 1-2 hour bunches
- GRAINY
  - Peak near 105 km
  - Echo region 30 km thick
  - Range = 150 to 350 km
  - Most probable SNR: 2dB
  - Most likely Doppler width is 5 m/s and independent of altitude
  - Spread in Doppler width: 50 m/s
  - Occur preferably in the morning hours, all year long

Tentative Explanations

- "Grainy" population: meteor trails still looking good
- 120 km Contiguous
  - Narrow height width: regular E region irregularities??
  - Wider height width: regular E region irregularities
  - *Further studies based on Doppler shift should help sorting it out/confirming the assumption*
- 100 km Contiguous
  - Should not be meteors: not "Grainy", more powerful, different morphology, lower altitude on average, less altitude spread, smaller altitude spread, closer range
  - Doppler width comparable to that of meteors, though it does not get as wide as some of the grainy echoes.
  - *Possible maybe:* neutral turbulence inducing ion structures that decay through ambipolar diffusion, just like meteors do.
    - Large shears often observed near 100 km, and Raleigh-Taylor is expected.

Radio Science

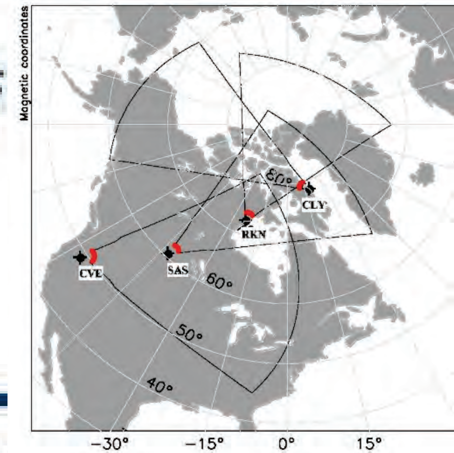
RESEARCH ARTICLE

10.1002/2016RS006088

Morphology and possible origins of near-range oblique HF backscatter at high and midlatitudes

Pavlo, V. Ponomarenko[1], Blessing Iserhienrhien[1], and Jean-Pierre St.-Maurice[1]

[1] Institute of Space and Atmospheric Studies, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

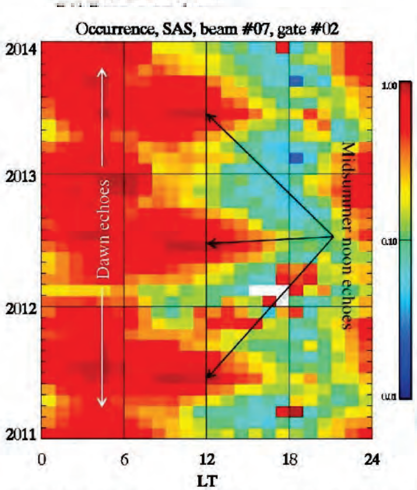


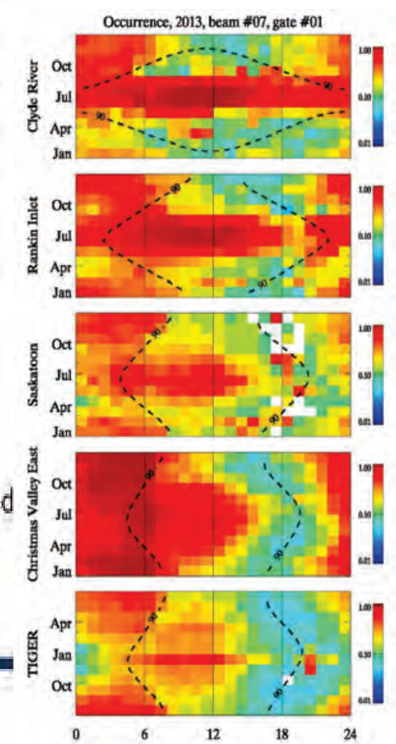
Key Points:

- Morphology of near-range HF backscatter was established across a wide range of latitudes with three major populations being identified
- Midday-midsummer echoes show characteristics incompatible with Polar Mesospheric Summer Echoes invoked previously for interpretation
- Based on the obtained information, these echoes are tentatively attributed to neutral turbulence effects at altitudes near 100 km

Correspondence to:

Abstract High-frequency radars (HF, ~10–20 MHz) forming the Super Dual Auroral Radar Network (SuperDARN) regularly observe returns from very close ranges of ≲300–400 km (near-range echoes, NREs). These echoes are conventionally attributed to backscatter from meteor trails, but other sources of NRE have been invoked, including polar mesospheric summer echoes (PMSE), and non-field-aligned *E* region irregularities leading to high-aspect ionospheric returns. In order to relate NRE to a particular mechanism, it is essential to establish beforehand their spatiotemporal trends with respect to season, local time, and latitude. Systematic information of this kind is generally lacking from the literature, so we attempt to fill the gap by performing a statistical analysis of such echoes observed by five radars covering midlatitudes to polar latitudes over all seasons and local times. We detected two major echo populations which were observed at each radar site: (i) a nightside-early morning returns representing the well-known meteor backscatter and (ii) a midsummer population centered near the local noon. At high latitudes the summer daytime echoes are usually interpreted as PMSE, but the observed population extends to much lower latitudes and is centered well above the conventional PMSE height range. We hypothesize that this population could be related to neutral turbulence in the lower *E* region. In addition, there was a pronounced evening population restricted to the auroral region which we provisionally attribute to irregularities generated by the precipitating energetic particles and strong electric fields.





BOTTOM LINE

Merett, Ponomarenko, St.-Maurice at SD 2018 Workshop

- At 100 km, the generating mechanism should not matter:
  - the ions are strongly coupled with the neutrals and
  - they should follow the neutrals unless there is a very strong electric field.

Near range echoes should remain a tool of choice for mesosphere wind studies, but short pulses need to be used (as discussed by Sessai earlier in the week).

PMSEではない筈！高度高過ぎる(Interf Calibのお蔭)（別paperで広い緯度で出現も）
何等かのNeutral turbulence によると考えるのが自然だろう。
いずれにしても、強い電場や降込、磁気嵐等でなければ、中性風が観測できている筈との主張。-JPから大分個人的に議論を求められた。

これまでPMSEと言っていたSDエコーの再検討必要。
Syowa Interferometer Calibration、高いrange/height分解能観測と校正の実施。
SENSU SDレーダーと大型大気レーダーのPMSE観測の同時性、相互関係の検証重要。

Summary: SD meteor network & Near range echoes studies – future direction

- As SuperDARN radars are distributed in mid to high latitude in a wide longitudinal (also latitudinal) range globally, it could contribute much to understand mesosphere-lower-thermosphere (MLT) region dynamics and vertical coupling between ionosphere and neutral upper atmosphere (MTI vertical coupling).
- Basic algorithm to obtain neutral wind around mesopause region using SuperDARN meteor echoes are basically established.
  → Real-time processing should be made available→We'll try soon.
- Thanks to great effort by SD "Elevation Angle" TF, the interferometer will hopefully be calibrated reliably. If it is realised….,
- It is now perfect timing to realise make SD network to become a true reliable neutral wind measurement network (around mesopause region) (purely as a by-product of normal ionospheric meas.) by combining the online meteor detection routine and adequate interferometer calibration routine scheme.
- Also better/important to improve the range resolution for better research contribution. Oversampling and FDI should be considered. To keep a certain accuracy, we need always 15km oversampling.
- Near range echoes are important to be investigated.
  Esp. "PMSE/PMWE"-like echoes etc must be reassessment by interferometer calibration and simultaneous other radar observations.