Possible common program (CP) modes for EISCAT_3D

Yasunobu Ogawa, and EISCAT_3D CP Working Group members

20th EISCAT International symposium

14:00-14:30 CEST, 2022-08-16

Outline

- Background of Common Program (CP) observations and Working Group
- Necessity of considering CP for EISCAT_3D
- Possible CP modes for EISCAT_3D
- Action Items and Schedule

CP working group

Tasks: Prepare a proposal for common program modes for EISCAT_3D radar system. Based on the proposal, discuss and revise it with the user community and EISCAT SWG members, and so on.

Members of the EISCAT_3D Common Program working group:

- Yasunobu Ogawa (NIPR) from SAC
- Andrew Kavanagh (BAS) from SAC
- Ingemar Häggström (EISCAT HQ) as a coordinator of the current EISCAT CP modes
- Johan Kero (IRF) from the viewpoint of meteor observations
- Björn Gustavsson (UiT) from the viewpoint of joint observations with optical instruments
- Dimitry Pokhotelov (DLR)
- Florian Guenzkofer (DLR)
- Devin Huyghebaert (UiT) from the E3D software team

Background of Common Program (CP) observations

From "EISCAT Scientific Programmes and Observing Time Policy" in the EISCAT bluebook (version 2015):

Observing time shall be divided between programmes common to all Associates and Affiliates (Common Programmes), special programmes of Associate and Affiliate scientists (Special Programmes) and peer-reviewed programmes (Open Programmes)*.

Common Programmes are conducted for the benefit of the entire user community and the resulting data products are immediately available to all scientists in the countries or institutions of the EISCAT Associates and Affiliates. Common Programmes are often done simultaneously with other radars around the world. Such operations are scheduled through the URSI Incoherent Scatter World Days working group. Common Programmes also include Unusual Programmes (UP), which are operated ad hoc during special conditions. The EISCAT Common Programmes are negotiated by the users and fixed by EISCAT Council in collaboration with the Science Advisory Committee (SAC).

*Note: Operations of 3000-4000 hours each year are distributed equally between Common Programmes (CP) and Special Programmes (SP).

Background of Common Program (CP) observations

From "EISCAT Scientific Programmes and Observing Time Policy" in the EISCAT bluebook (version 2015):

2. Organization of Common Programmes

1. The Common Programmes (CP) address research topics of interest to the broad EISCAT community and in particular long term routine observations. A regular schedule of well-designed operations shall be adopted.
2. The EISCAT Scientific Advisory Committee (SAC) shall advise the EISCAT Council on the observational procedures for the Common Programmes. To ensure the continuity of the data, substantial changes in the Common Programmes should be avoided except where major changes in EISCAT facilities or scientific objectives make them desirable.
3. Proposals for changes in the Common Programmes shall be submitted to both the Director and the Chair of the SAC. The SAC recommendations shall be submitted to the Council for approval.
4. The choice of observations within the Common Programme, the distribution of time allotted to each, and appropriate scheduling provisions to support important scientific programmes shall be made by the Director on the recommendation of the SAC. The Director may, where appropriate, delegate this task or other tasks related to this policy.

Background of Common Program (CP) observations

In the beginning of EISCAT UHF CP observations early in 1980s.

Williams, P.
The EISCAT common programme at UHF
In Suomalainen Tiedeakatemia The Finn.-Am. Auroral Workshop,
pages 149-153 (SEE N82-24744 15-46)
https://ui.adsabs.harvard.edu/abs/1981stfa.work..149W/abstract

Abstract

The EISCAT UHF system made measurements of incoherent scatter spectra in June 1981. However, the transmitter was unable to operate at the full peak power of 2 MW and neither was it able to use the full range of frequencies. It was decided that initially EISCAT would begin routine operations using a program as simple as possible which could provide useful results with only 500 kW peak power, and with only two frequencies in use. The program, called Common Program Zero (CP 0), is described.

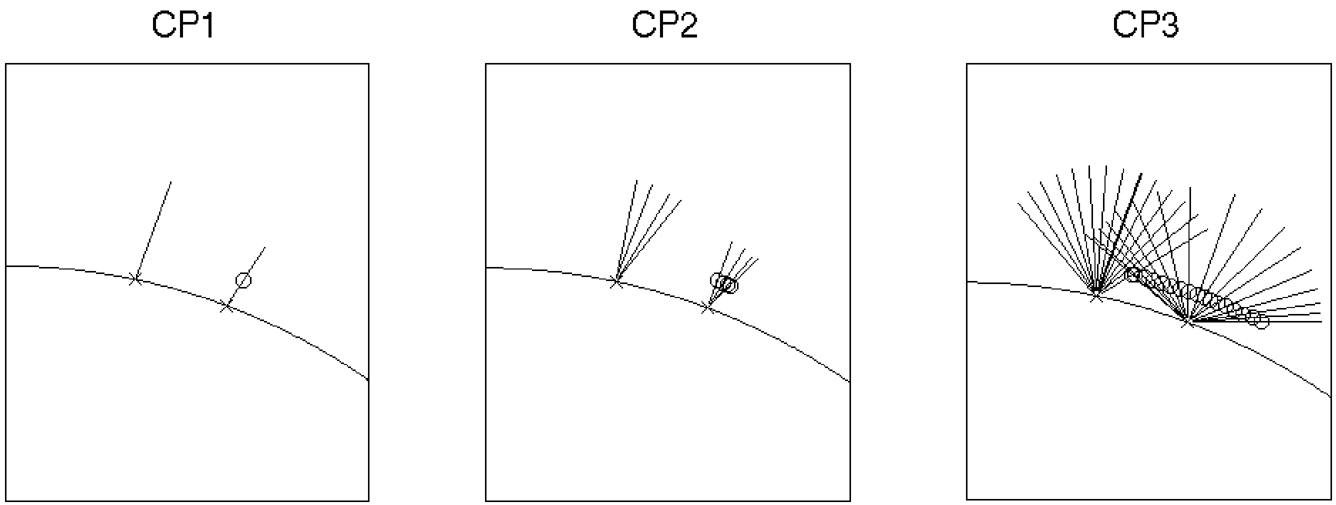
Background of Common Program (CP) observations

Gudmund Wannberg, History of EISCAT – Part 5: Operation and development of the system during the first 2 decades, Hist. Geo Space. Sci., 13, 1–21, 2022. https://doi.org/10.5194/hgss-13-1-2022

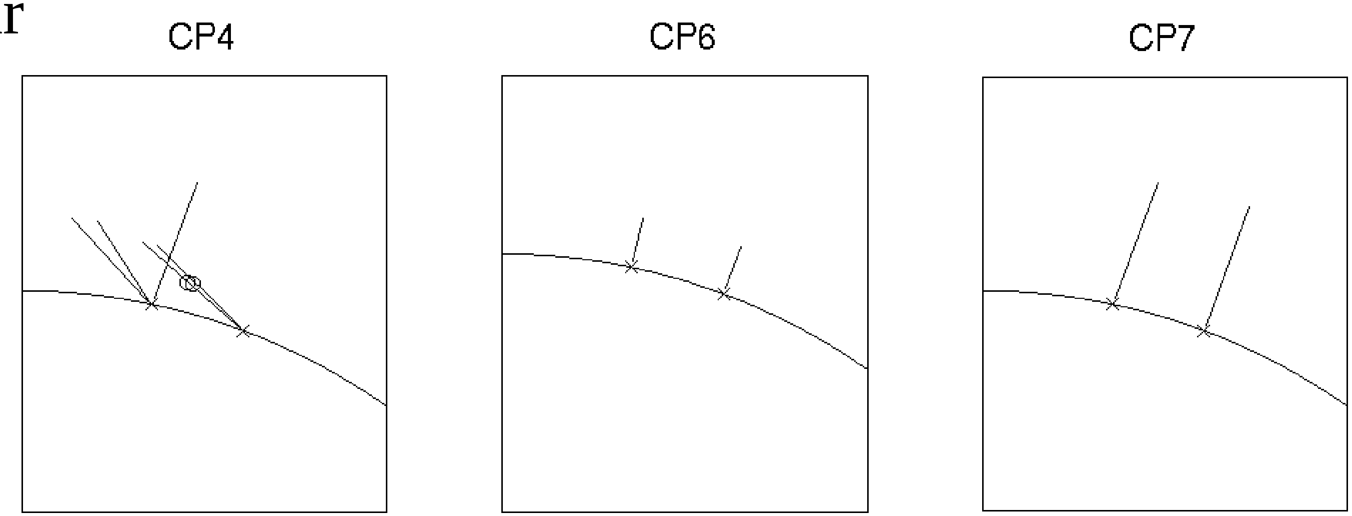
12.5 Common Programmes
Throughout the first 2 decades, the Common Programmes continued to meet the basic concepts drawn up at the outset as far as their areas of coverage were concerned, in agreement with the idea to generate a database covering as long a time span as possible – but their performance increased all the time thanks to the improvements on the signal processing side. CPs 1, 2 and 3 were UHF experiments. CP-1 was a field-aligned experiment with altitude coverage to above 600 km, tristatic velocity measurements in the F region and kilometre-scale altitude resolution in the E region, and CP-2 was essentially the same experiment, but scanning through four closely spaced beam directions enclosing the Tromsø field line. CP-3 implemented an F-region latitude scan covering the entire common field of view of the UHF system. CP-4 was a derivative of the British Polar experiments, using the VHF in dual beam mode to measure the plasma velocity field to the north of Tromsø to Svalbard and beyond. CP-6 was used for high resolution measurements in the E and D regions, and CP-7 was a dedicated high-altitude VHF experiment. The modulations used were essentially variants of Turunen's GEN programmes or (in the case of CP-1 and 2) copies of CP-1-K and remained basically unchanged until the signal processing system was replaced, starting around y2000.

Current Common Program (CP) modes

UHF radar

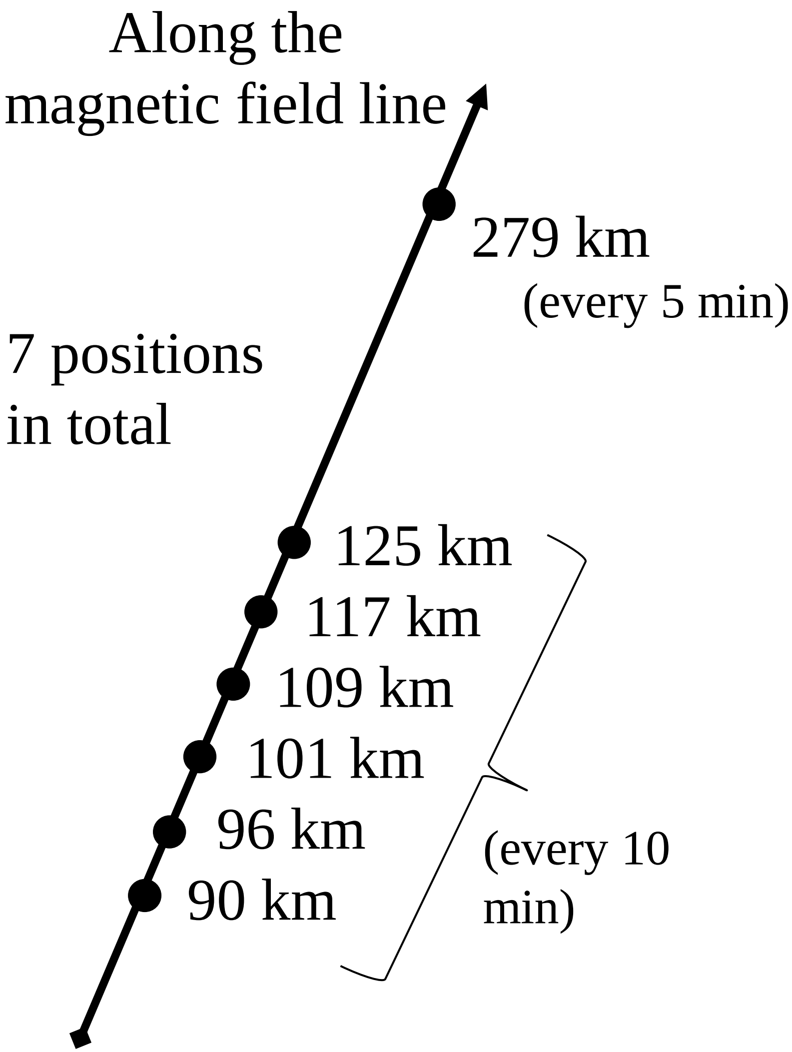


VHF radar



https://eiscat.se/scientist/user-documentation/radar-scan-patterns/

Previous CP-1 (CP-1-i)



	Start Time		End Time	
Year	Date	UT	Date	UT
1989	Jan. 10	0900	Jan.11	2255
1989	Feb. 7	0905	Feb. 8	0930
1989	March 28	0810	March 29	2145
1989	May 2	0800	May 3	0755
1989	Aug. 1	1300	Aug. 3	1550
1989	Sept. 5	1000	Sept. 6	1250
1989	Nov. 14	1000	Nov. 16	1600
1990	April 9	1020	April 10	1555
1990	June 5	1000	June 6	1555
1990	June 12	0800	June 13	1335
1990	July 2	1030	July 3	1550
1990	July 30	1940	Aug. 1	0355
1990	Sept. 25	1000	Sept. 27	2150
1990	Nov. 27	1000	Nov. 28	1550
1991	Feb. 20	1000	Feb. 21	1135
1991	May 2	1010	May 3	1345
1991	July 10	1430	July 11	1550
1991	Sept. 10	0900	Sept. 11	1555
1991	Dec. 8	1055	Dec. 10	1555

From Fujii et al., *JGR*, 1998

Scan patterns of CP-2 and ip-2

Scan	Date from	Azimuth Elevation [degrees]				Dwell time [s]	Scan time [s]	Max. Distance [km]
(a)	(b)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
cp2	20/01/1987	Vertical	166.5° 63.5°	133.3° 60.5°	183° 77.4°*	40-80 (M=60)	360	139
ip2	12/12/2007	Vertical	185° 77.4°*	Vertical	114.3° 75.4°	25-65 (M=55)	240	64

Table. Scan patterns (a) used in the monostatic measurements. Dates from which they appear in the data are shown (b) are listed. The locations of the dwell points are provided in (e-h) as azimuth and elevation from the radar site. * indicates the field aligned position. The integration time for each dwell is listed (i) including the median value (M) since not all dwells are for the same time. (j) gives the total scan time (including transition time between dwell positions), (k) gives the maximum distance from vertical in the horizontal plane for each scan.

Courtesy of Dr. Kavanagh

Since one scan of CP2 takes six minutes, it takes into account the effect of the movement of the observation area due to the Earth's rotation when determining the beam positions.

Common Program (CP) observations

Important points for EISCAT_3D CP:

- Continuation from current EISCAT CP observations

For examples, statistical analysis including long-term data analysis since 1981, and comparison study with past events.

- Joint observations with other ISR radars (URSI Incoherent Scatter World Days)

To provide data that can be used by researchers all over the world for various research purposes.

Individual unique experiments will be conducted in Special Programs (SP) and Peer-reviewed programs (PP), and so on.

Common Program (CP) modes of AMISR

AMISR has 3 primary CP modes (IPY, World Day, and Themis mode). The temporal resolution for the AMISR data is decided post production but it is generally provided at 1 minute, 3 minute and 5 minute resolution.

Inputs from Dr. Roger Varney at the 80th SAC meeting

IPY mode of PFISR

J.J. Sojka, M.J. Nicolls, C.J. Heinselman, J.D. Kelly,
The PFISR IPY observations of ionospheric climate and weather, Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 771–785.

… The normal IPY mode is a single-look direction (up the local magnetic field line: azimuth 154.31, elevation 77.51), low duty cycle mode (1%) that is designed for background characterization of the Poker Flat ionosphere. Augmented IPY modes include an additional two beams designed for characterization of the background electric field (e.g., Heinselman and Nicolls, 2008) and a full duty cycle mode operated for 24 h approximately every 2 weeks…

Necessity of considering CP for EISCAT_3D

Technical and Scientific points of view

Necessity of considering CP for EISCAT_3D

- EISCAT_3D will be used for various innovative observation studies. → How much of them can be incorporated into CP observations?
- As with the current EISCAT, we anticipate the future development of EISCAT_3D CP observations.
- In the beginning, we would like to solidify a robust and simple CP observation mode(s).
- Comparison of EISCAT_3D observational results with current EISCAT UHF/VHF observations for validation would be another important factor in the early phase.

Technical point of view

Limitation at the reduced 1st stage

- Maximum Tx power: ~3.4 MW
- High power 'scanning' experiments should follow interlaced rulers
- Max 10 directions would be possible to interlace.
- More directions have to be done at separate 'dumps'.

(Inputs from Dr. Häggström (E3D_CP WG member))

Low power CP mode(s) for EISCAT_3D

- Full power on transmitters, with large IPPs.
- The IPPs should be non-regular and follow a good ruler.
- There are several different rulers with different properties so one need to investigate this.

(Inputs from Dr. Häggström (E3D_CP WG member))

Scheduling of the EISCAT_3D operation becomes more important because multiple experiments can be conducted simultaneously.

Scientific point of view

The key point is how many subjects of the EISCAT_3D science case can be covered.

Various research targets:

- Large-scale / Meso-scale / Small-scale phenomena
- Low-altitude / High-altitude phenomena
- Short-lived (transient) / long-lived phenomena
- Moving / stable phenomena
- ...

Science possible at each stage

	Stage 1	Stage 2	Stage 3	Stage 4
1. Atmospheric physics and global change				
a. Vertical coupling between the atmospheric layers				
i. Troposphere	X	X	X	X
ii. Stratosphere	P	X	X	X
iii. Mesosphere	P	P	X	X
b. Turbulence and waves in the mesosphere and lower thermosphere				
i. Polar mesospheric summer echo (PMSE) interferometry	P	X	X	X
ii. MAARSY collaborations (Andøya, Norway)	P	P	X	X
iii. Polar mesospheric winter echo (PMWE) interferometry	P	X	X	X
2. Space and plasma physics				
a. Multiple scale interactions in ionosphere-magnetosphere plasmas				
i. Aurora (tens of meters, fractions of a second) density and velocity	P	X	X	X
ii. Magnetospheric-driven convection (localized & transient)		P	X	X
iii. Substorm processes over a large spatial region		P	P	X
b. Plasma turbulence and active experiments				
i. Naturally enhanced ion acoustic lines (NEIALs)	P	X	X	X
ii. Heating experiments (volumetric imaging of entire pump beam)	P	P	X	X
iii. Self heating in the EISCAT_3D beam		X	X	X
3. Inflow and outflow of matter in the Earth's atmosphere				
i. Meteoroid-atmosphere interactions	P	X	X	X
ii. Meteoric smoke particles (dusty plasmas)	P	X	X	X
iii. Ion upflow	P	X	X	X
4. Space debris, near-earth objects and space weather				
i. Space debris and meteoroid orbital parameters with wide coverage	P	P	X	X
ii. Near-earth objects (NEOs)	P	X	X	X
iii. Continuous measurements for space weather monitoring	P	P	P	X
5. Radio astronomy				
i. Epoch of reionization (EoR)	(P)	(P)	P	X
ii. Exoplanet detection via auroral kilometric radiation (AKR)-like emissions	(P)	(P)	P	X
iii. Trans-ionospheric imaging support	P	X	X	X

Blank – insufficient capabilities X – full capabilities P – partial capabilities (P) – partial capabilitie

Courtesy of Swedish E3D community members, 2017

From the EISCAT_3D Science Case

Table 1 EISCAT_3D resolution and range extent requirements for the different science topics. A phased array system with fast pointing, multiple beams and calibrated signal is assumed

Science topic	Parameter for which resolution is given	Temporal resolution (s)	Horizontal resolution (km)	Vertical resolution (km)	Height range (km)
Mesoscale electrodynamics and flows (including BBFs)	N_e, T_e, T_i, V_i	10	20 in the F region	2	85–400
Small-scale (auroral) dynamics	N_e	1	(1) 10~20 beams?	0.5	70–500
	T_e, T_i, V_i	– "–	– "–	– "–	85–400
Fine-scale auroral structures	N_e, T_e, T_i	0.1	0.1	0.2	70–200
	V_i	0.1	0.1	5	120–400
Ion outflow (natural and heater-induced)	N_e, T_e, T_i, V_i, ion comp.	10	(10) 1 beam	20	200–1500
NEIALs (aperture synthesis imaging)	Raw data	0.03	0.05 at 300 km	1	100–1500
Ionospheric irregularities	N_e, T_e, T_i, V_i	1	(1) 1 beam	1	90–800
Topside composition (O^+, He^+, H^+)	mi (and N_e, T_e, T_i, V_i)	10	N/A	N/A	300–1500
Transition region composition (NO^+/O_2^+ vs. O^+)	mi (and N_e, T_e, T_i, V_i)	10	N/A	10 km	100–300
High-energy particle events (SEPs, etc.)	N_e	1	(10) 1 beam	1	50–400
	T_e, T_i, V_i	– "–	– "–	– "–	100–400

Partially achieved with E3D CP data at the reduced 1st stage (Tx ~ 3.4 MW)

From the EISCAT_3D Science Case (I. McCrea, A. Aikio, et al., *PEPS*, 2015)

From the EISCAT_3D Science Case *(continued)*

Table 1 EISCAT_3D resolution and range extent requirements for the different science topics. A phased array system with fast pointing, multiple beams and calibrated signal is assumed

Science topic	Parameter for which resolution is given	Temporal resolution (s)	Horizontal resolution (km)	Vertical resolution (km)	Height range (km)
Atmosphere-ionosphere coupling (AGW, winds)	N_e, T_e, T_i, V_i, V_n	<1 min	(1) 10~30 beams?	0.1 or better	As low as possible—120 km
Mesosphere-stratosphere-troposphere (MST) small-scale dynamics	Vector neutral wind, N_e	<1 min	1	0.1 or better	As low as possible—110 km
D region phenomena	N_e, T_e (=T_i) V_i (=V_n)	(1)	(1) 1 beams	0.3	70–90
PMSE, PMWE	Raw data, Doppler velocity, spectral width	<1 min	1	0.1 or better	55–95
Meteoroids and their effects on the background (Es, PMSE etc.), high-power mode	Raw data, polarisation matrix, and N_e, T_e, T_i, V_i	1 ms	(0.01)	0.01	(30) 70–200 (1000)
Planets and asteroids	Raw data, power, polarisation matrix	10-MHz sampling		15 m	
Interplanetary scintillation	Raw data	0.01	N/A	N/A	N/A
Heating experiments	N_e, T_e, T_i, V_i	1	1	1	100–2000
Heating experiments, aperture synthesis imaging	Spectra (raw data)	IPP (~2 ms)	0.01–0.05	0.1	100–300
Space debris monitoring and satellite tracking	Raw data, power, Doppler velocity	10-MHz sampling		15 m	
Meteoroid monitoring (piggyback and low-power mode)	Raw data, polarisation matrix, and N_e, T_e, T_i, V_i	IPP ~100 ms for low-power mode	(0.01)	Down to 10 m	(30) 70–200 (1000)

Partially achieved with E3D CP data at the reduced 1st stage (Tx ~ 3.4 MW)

From the EISCAT_3D Science Case (I. McCrea, A. Aikio, et al., *PEPS*, 2015)

Possible CP modes for EISCAT_3D (under discussion)

One-beam *FA* observation with multi-static measurements

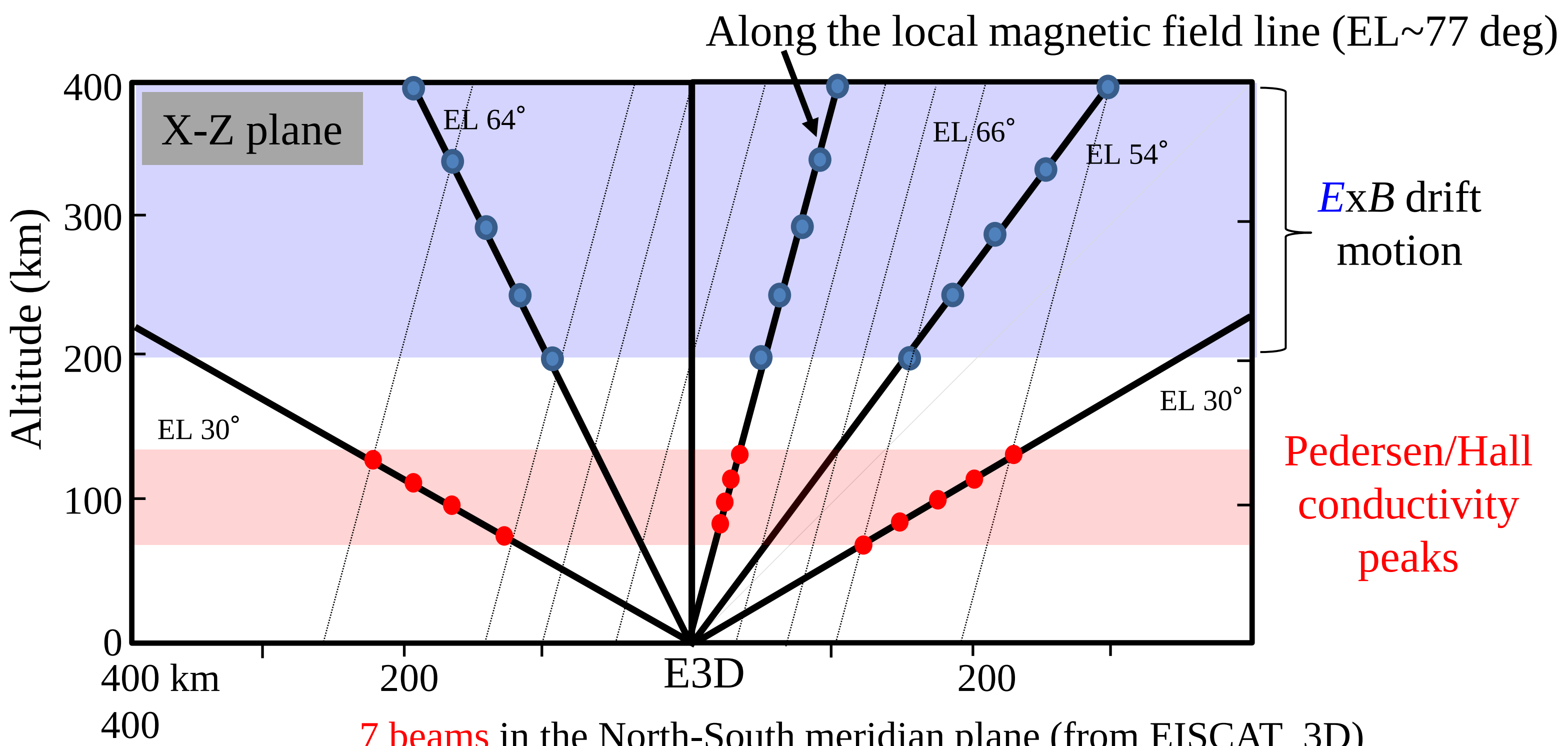
- Point along the local magnetic field line at Skibotn.
- Use Alternating Codes (ACs) similar to those used in current EISCAT UHF/VHF radars
(AC is the most robust code, so that is the obvious one to start with. (Inputs from Dr. Häggström))

- Use a wide altitude range mode (similar to CP-1), and a low altitude equivalent mode (similar to CP-6)

- Multipurpose modulations using Aperiodic Transmitter Coding (ATC) [Virtanen et al., Ann. Geophys, 2009] will be followed by ACs, for example.

Multi-beam observations with EISCAT_3D

(Case1) An example of multi-beam and multi-static observations



7 beams in the North-South meridian plane (from EISCAT_3D)

Electric field data & Pedersen/Hall conductivity data → Ionospheric current data

$$\mathbf{J} = \underline{\sigma_P}\,(\underline{\mathbf{E}} + \mathbf{u}_n \times \mathbf{B}) - \underline{\sigma_H}\left[(\underline{\mathbf{E}} + \mathbf{u}_n \times \mathbf{B}) \times \frac{\mathbf{B}}{B}\right]$$

Multi-beam observations with EISCAT_3D

(Case1) An example of multi-beam and multi-static observations

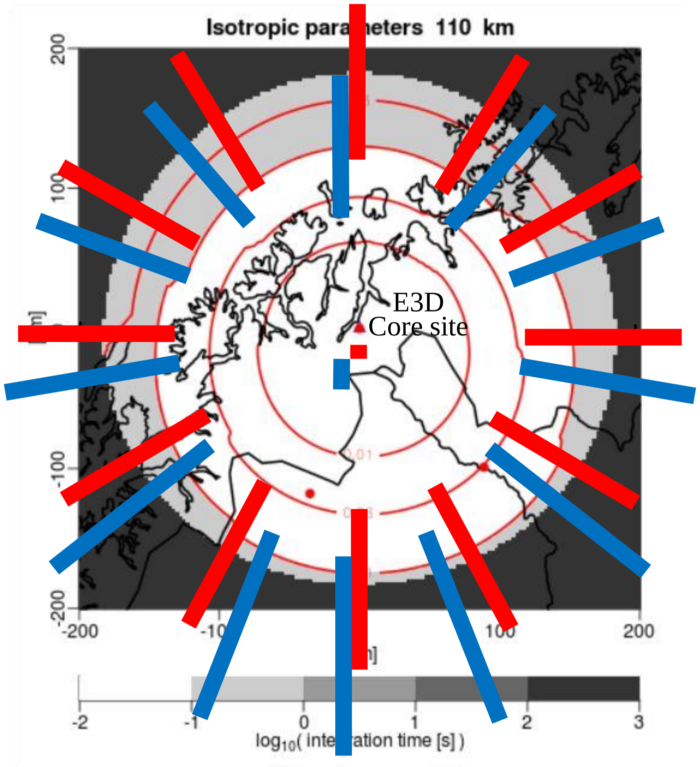
(Continued from the previous page)

3 + 12 x 2 = 27 beams in total

Minimum time resolution required: ~34-sec
(= ~0.3-s *12 beams for E-region
+ ~2-s *15 beams for F-region.
TX will be divided between the beams on pulse-to-pulse basis, so that the final time-resolution can be selected afterwards.)

200-400 km alt.	(Beam with 55~63 deg EL)
80-130 km alt.	(Beam with 30 deg EL)

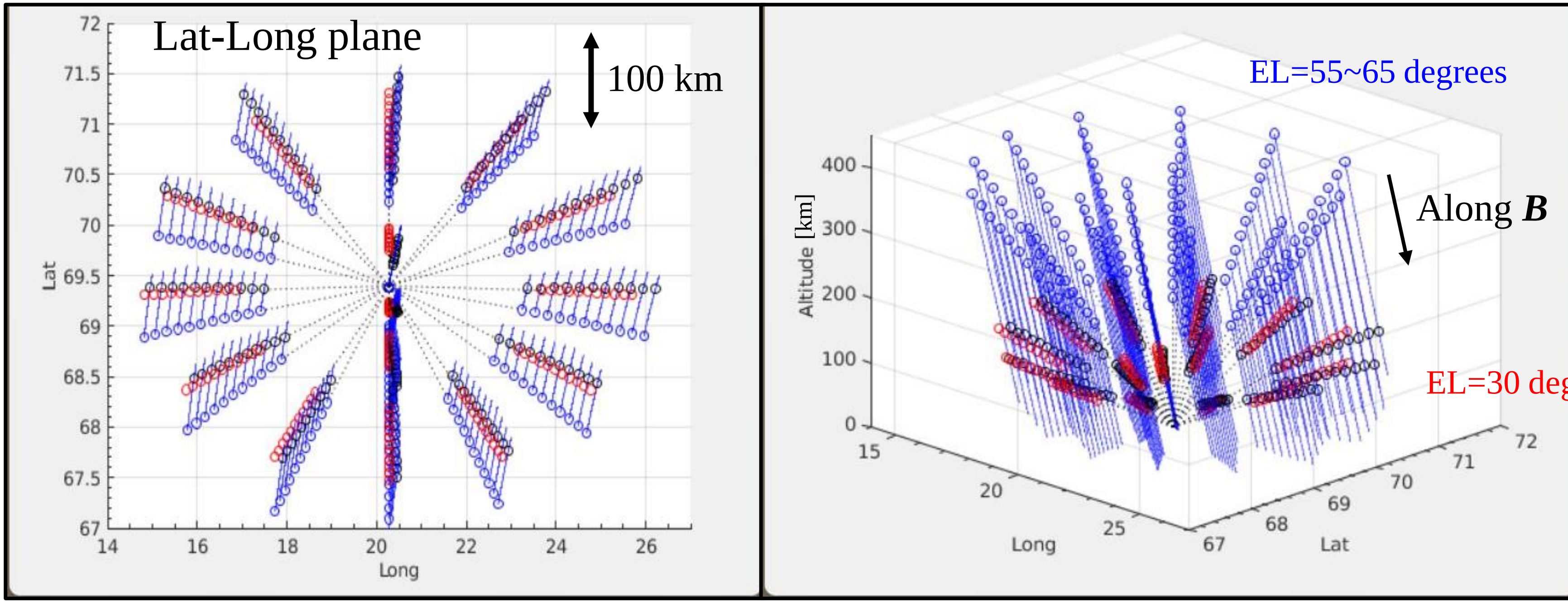
X-Y plane



Parameters changed from [Virtanen, 2011]

110 km altitude, 3 sites, 3.5MW Tx power,
5% Noise level, 2 km range resolution,
Background Ne = 2×10^{11}[m^{-3}].

Scalar parameters in the E-region, and Vector parameters in the F-region



Horizontal separation of the radar beams in the *E*- and *F*-regions: **70~100 km**

In terms of deriving a velocity from multiple beams with monostatic methods, it is a trade-off between good angular separation and the spatial separation. The current CP-2 mode probably does that balance as best it can. Keeping the beam separation more towards 50 rather than 100km would be better for a standard EISCAT_3D mode.

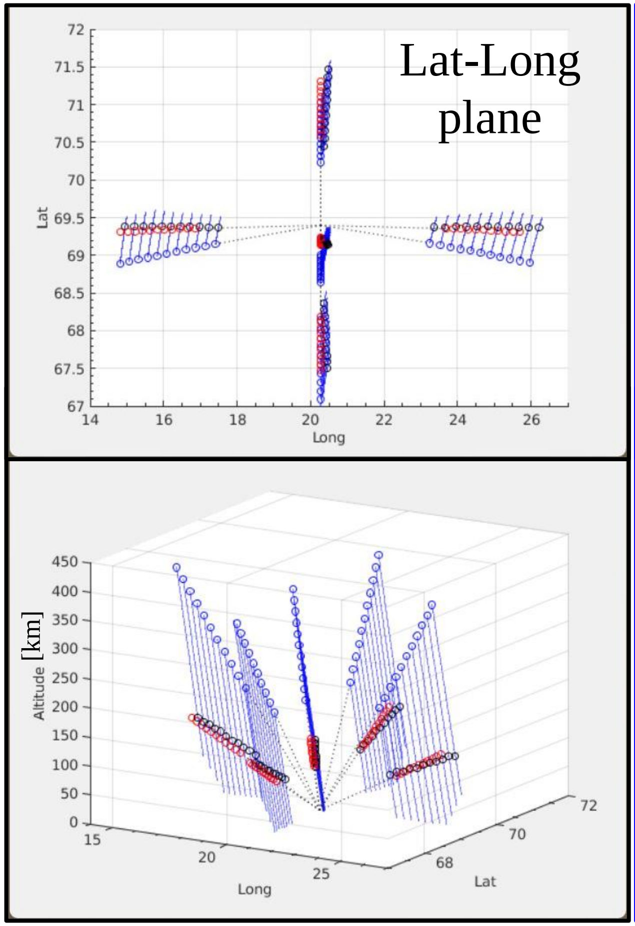
(Inputs from Dr. Kavanagh (E3D_CP WG member))

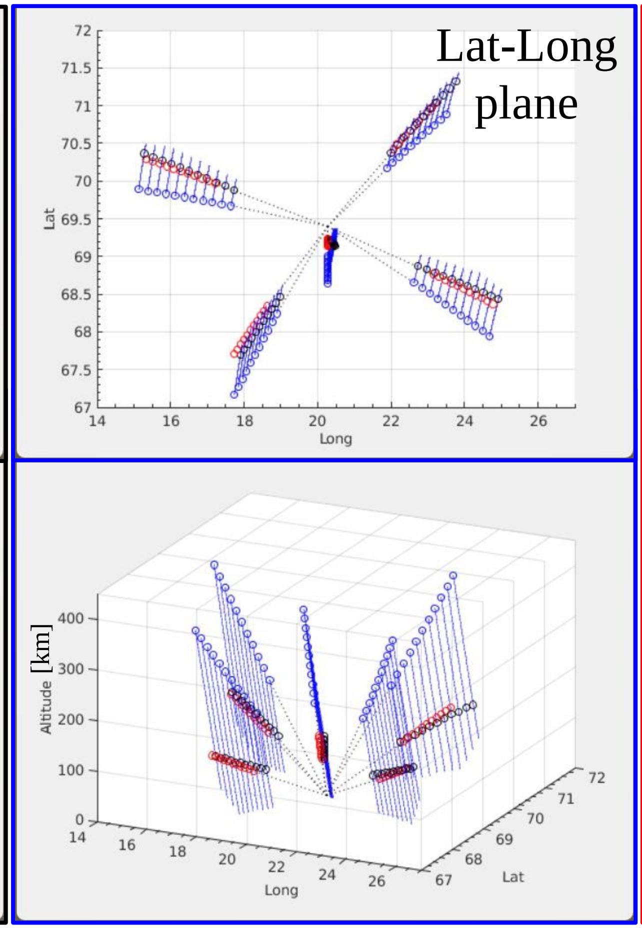
→ This case1 uses elevation angles of 30 degrees and 55~65 degrees to cover a wide field of view, but we consider using higher elevation angles (e.g., **40 degrees and 65~75 degrees**).

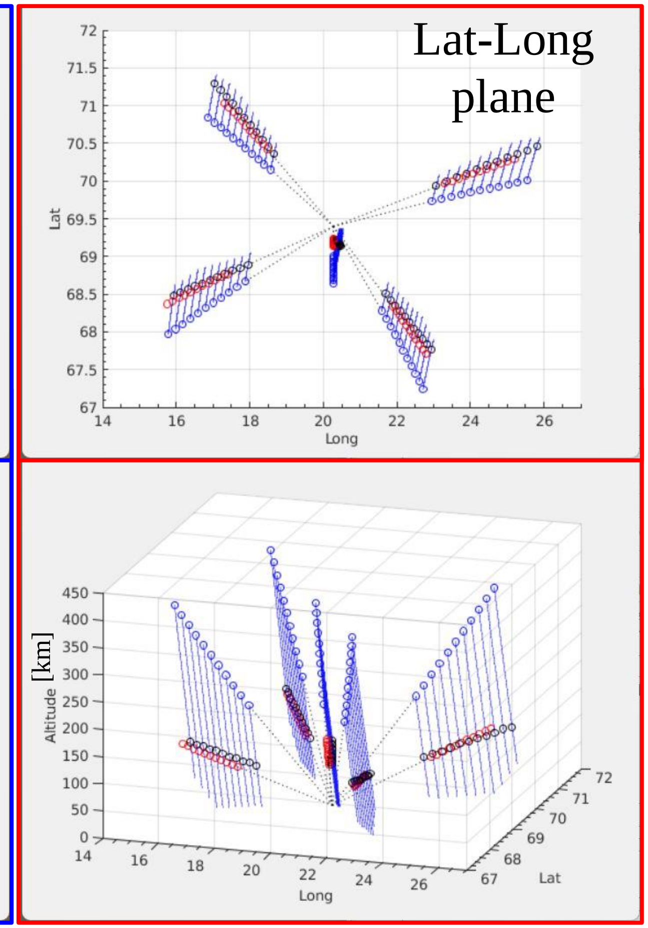
The number of possible interlaces (up to ~10 directions)

1st dump (a few sec) → 2nd dump → 3rd dump

1st dump (a few sec)	2nd dump	3rd dump
9 beams	9 beams	9 beams








```
Az = [ 0 90 180 270   0 101 180 258  180];
El = [30 30  30  30 64  58  54  59 77.5];
```

FA

```
Az = [30 120 210 300 35 130 204 288  180];
El = [30 30   30  30 61  57  54  61 77.5];
```

FA

```
Az = [60 150 240 330 69 156 231 323  180];
El = [30 30   30  30 60  55  57  61 77.5];
```

FA

Random sampling for Multi-beam observations with EISCAT_3D (suggestions from Prof. Mervyn Freeman)

Advantage:

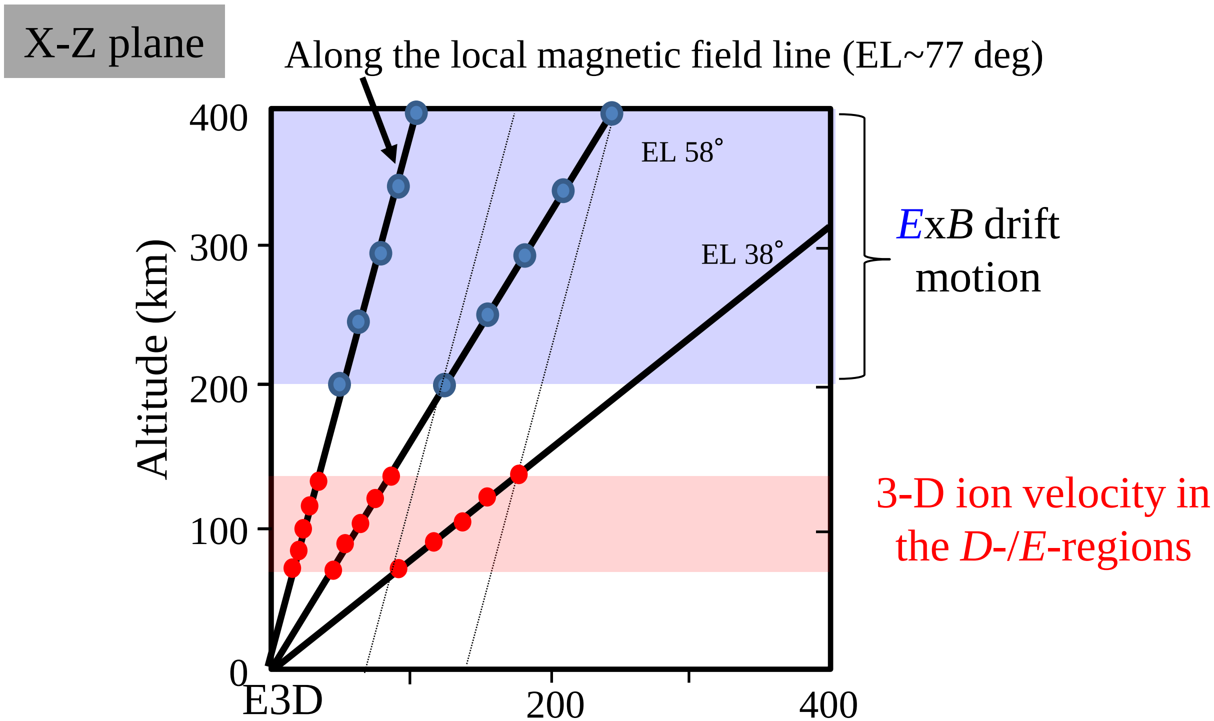
- Useful for many beam observations such as 8x8 grids, because it minimize spatial scale bias.
- Less influence of beam direction on ionospheric/atmospheric moving structures

Disadvantage at the earlier phase of E3D:

- *Does it complicate data analysis?*

Multi-beam observations with EISCAT_3D

(Case 2) An example of multi-beam and multi-static observations



3 beams in the North-South meridian plane (from EISCAT_3D)

Electric field data & *D*-/*E*-region 3-D ion velocity data → Neutral wind data

$$\boldsymbol{u}_n = \boldsymbol{V}_i - \frac{\Omega_i}{|\mathbf{B}|\nu_{in}}(\boldsymbol{E} + \boldsymbol{V}_i \times \mathbf{B})$$

$$\boldsymbol{j} = n_e \mathrm{e}(\boldsymbol{V_i} - \boldsymbol{V_e})$$

Multi-beam observations with EISCAT_3D

(Case2) An example of multi-beam and multi-static observations

(Continued from the previous page)

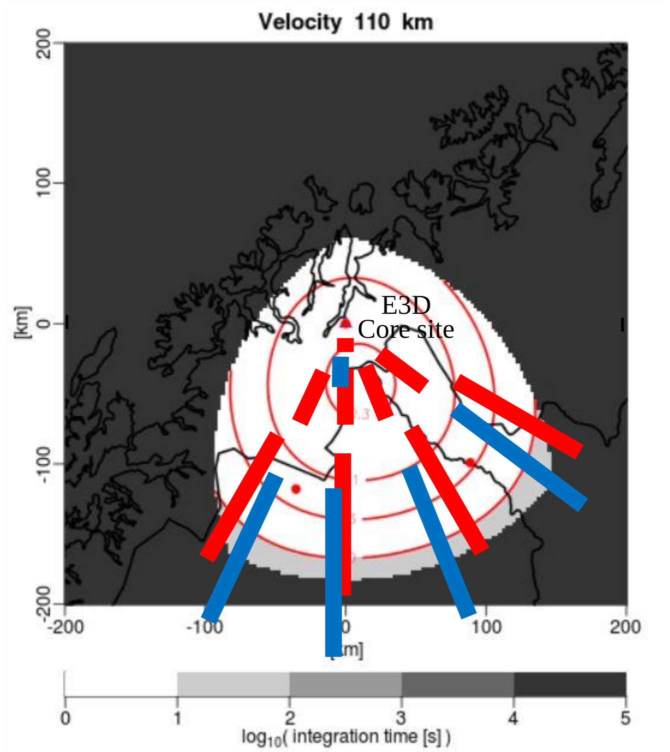
1 + 4 x 2 = 9 beams in total

Minimum time resolution required: ~23-sec
(= ~3-s *5 beams for E-region
+ ~2-s *4 beams for F-region.)

(blue line)	200-400 km alt.	(Beam with 58~60 deg EL)
(red line)	80-130 km alt.	(Beam with 38 deg EL and 58~60 deg EL)

It is also possible to derive Joule heating rate ($\boldsymbol{J} \cdot \boldsymbol{E'}$) at 9 regions. (Note: $\boldsymbol{E'} = \boldsymbol{E} + \boldsymbol{u}_n \times \boldsymbol{B}$)

X-Y plane

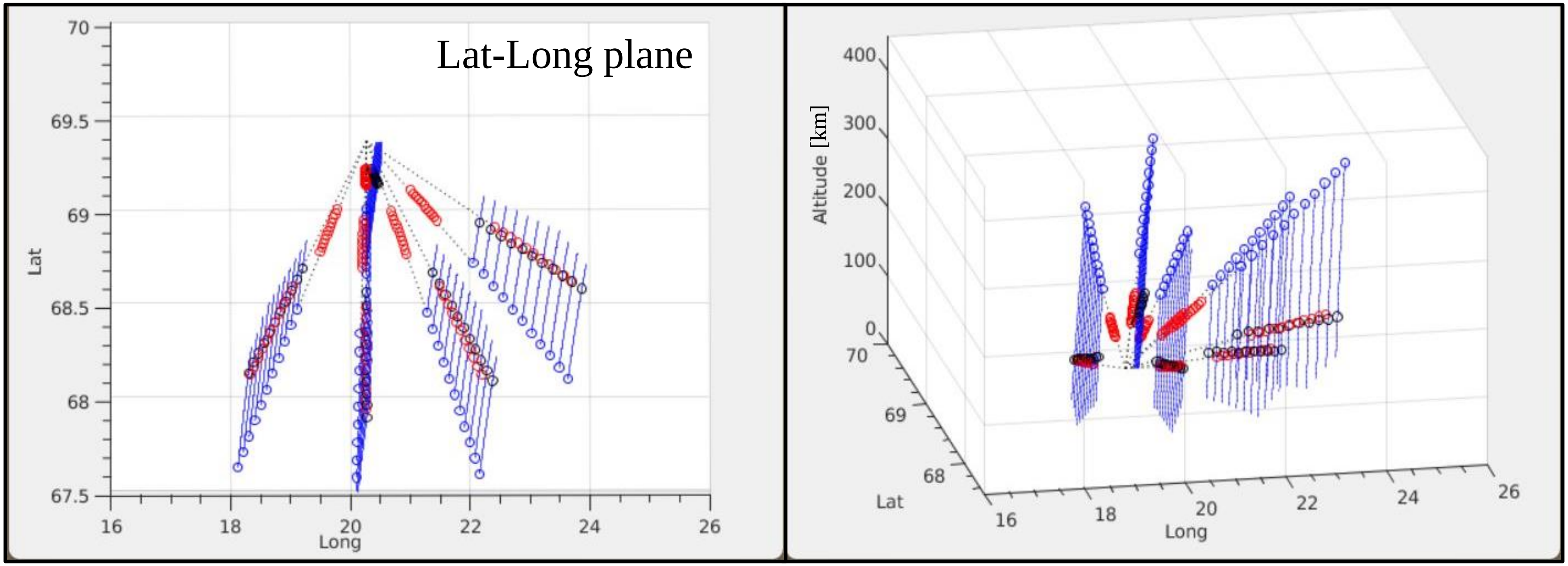


Parameters changed from [Virtanen, 2011]

110 km altitude, 3 sites, 3.5MW Tx power,
5% Noise level, 2 km range resolution,
Background Ne = 2x10^{11}[m^{-3}].

Multi-beam observations with EISCAT_3D

Vector parameters in the E-region and F-region



EL=[38 38 38 38 62 60 59 60 77.5];
AZ=[120 150 180 210 135 158 182 205 180];

FA

Meteoroid monitoring

- The current manda pulse code experiment works perfectly fine for both meteors and D/E region studies.
- For EISCAT_3D it would be preferrable to use a high-power CP program with aperiodic IPP (similar to what Dr. Ilkka Virtanen has developed, tested and published in 2009 - multi-purpose experiments) and that we find a CP mode that covers a wide range of altitude to always enable a variety of purposes, at least to some extent.
- Meteor monitoring can be performed to some extent from any general mode as long as echoes are received from ~70-200 km altitude.
- Any setting of IPP and beam width will be interesting to begin with and that we will find out what is the preferrable after some time of observations.

(Inputs from Dr. Johan Kero (E3D_CP WG member))

Action Items and Schedule (plan)

- Various reviews and discussions during this symposium in August
- CP WG meeting in early September (online)
- Deployment of the first draft of E3D CP proposal at the end of September (on slack)
- Continuous discussion and modification with the user community and SW WG members till early November.
- Fix the draft manuscript in November/December.