

A blackbox view of incoherent scatter radar

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2026 IS Radar Summer School



Before we begin..

- ▣ This school and our community uses the abbreviation “ISR” in many places.
- ▣ ISR = “Incoherent Scatter Radar”
- ▣ In the larger radar world, ISR has another meaning.. Do not confuse the two.

ISR (Intelligence, surveillance and reconnaissance) [\[edit \]](#)

ISR is the coordinated and integrated acquisition, processing and provision of timely, accurate, relevant, coherent and assured information and intelligence to support commanders' conduct of activities. Land, sea, air and space platforms have critical ISR roles in supporting operations in general.^{[12][11]} By massing ISR assets, an improved clarity and depth of knowledge can be established.^{[13][14]} ISR encompasses multiple activities related to the planning and operation of systems that collect, process, and disseminate data in support of current and future military operations.^{[15][16][17][18]}

(Wikipedia)

Outline

Blackbox ISR Video 1
(see wiki)

Blackbox ISR Video 2
(see wiki)

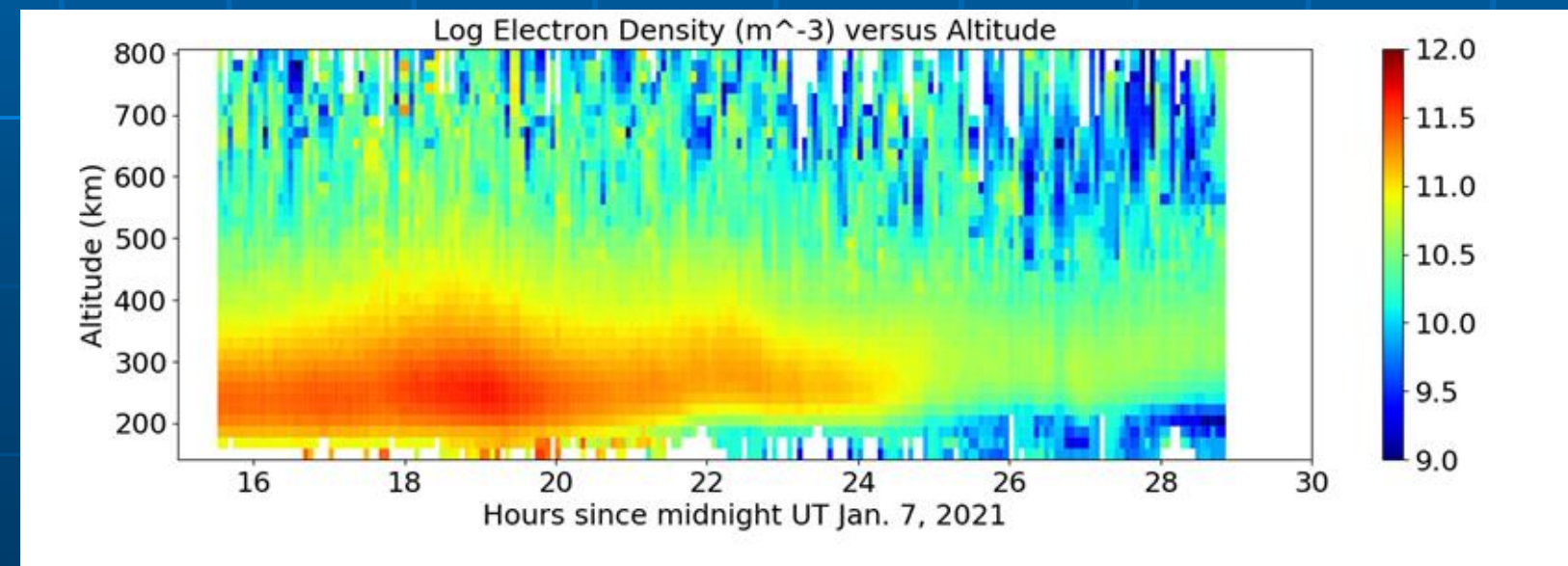
- The nature of ISR measurements
- Brief discussion of ISR blackbox
- Where are there existing ISRs?
- Existing ISRs treated as blackbox
 - Exercise with simulator – control existing ISRs
- New ISRs treated as a black box
 - Exercise with simulator - new ISRs: Simulate creating a new ISR

The nature of ISR measurements

Each measurement has a range resolution

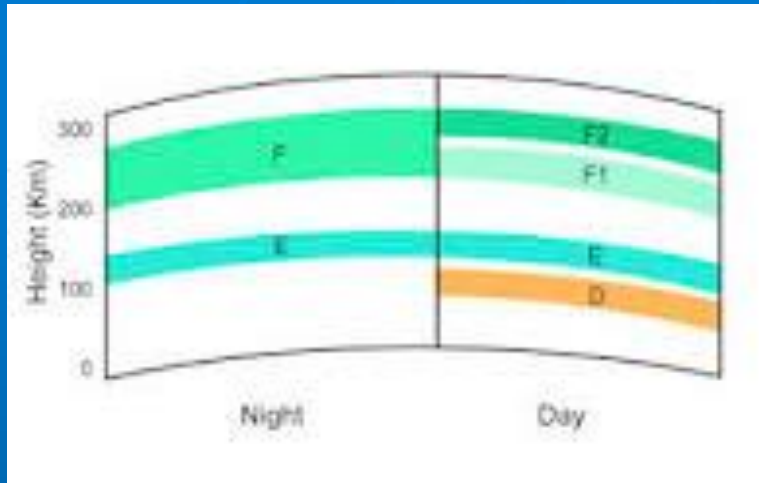
The beam width at a given altitude and the range resolution give the spatial resolution

All ranges are measured at the same time; but multiple pulses need: time resolution



Typical
ISR
plot

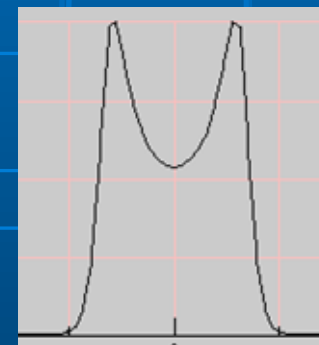
Blackbox ISR Outputs



Ionosphere

Parameters

- Electron density
- Electron temperature
- One (or more) ion temperatures
- One (or more) ion velocities



Directly measured
(spectral
response)

Physics +
instrument
model



Quality of measurement

- Error bar on each parameter
- Spatial resolution
- Time resolution
- Spatial coverage



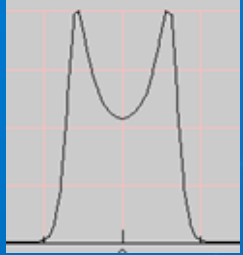
Radar

Treat ISR as a blackbox

- What are the science outputs?
- What knobs can you turn at the input?
 - For an existing ISR
 - If you got to build a new ISR
- Try it yourself with two jupyter notebook tools
 - Existing and new ISR simulators



Error bars 101: The nature of ISR measurements



ISR measurement is a probability distribution, not a deterministic signal...

Imaging trying to determine if a coin is fair in a dark room...



Both the number of tries **and** the chance of mistaking head and tails needs to be taken into account...

Nature of ISR measurements

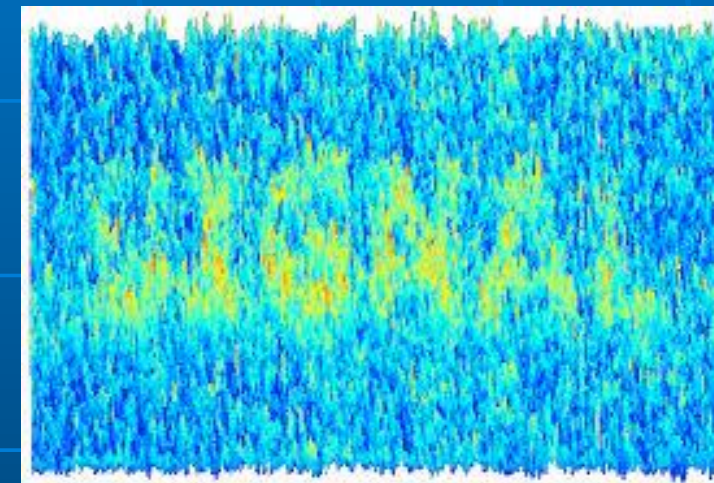
What determines the error bar on a measurement?

The number of measurements

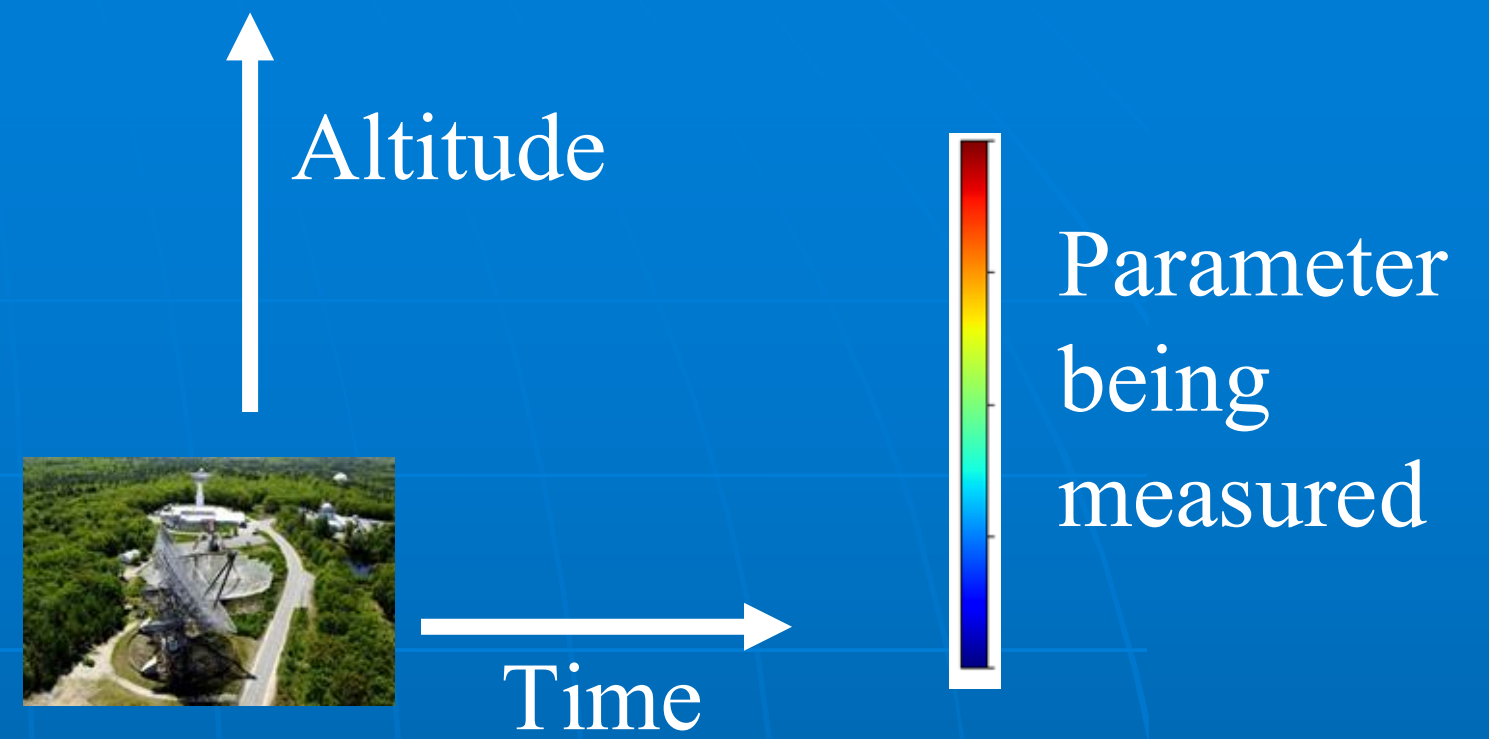
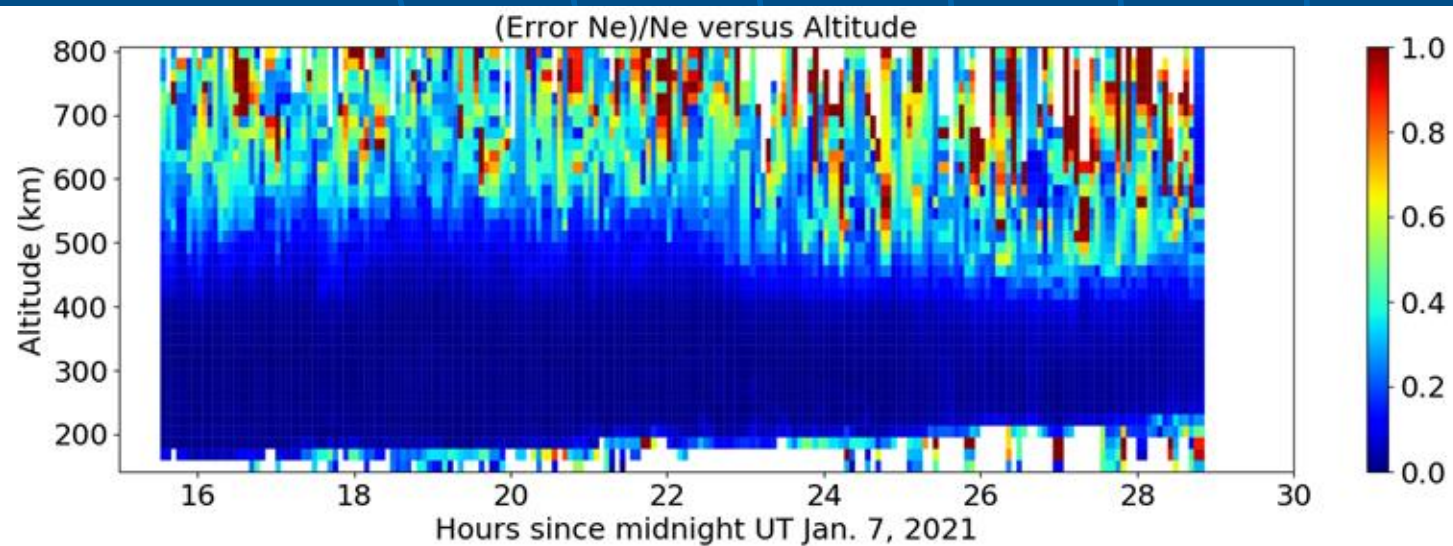
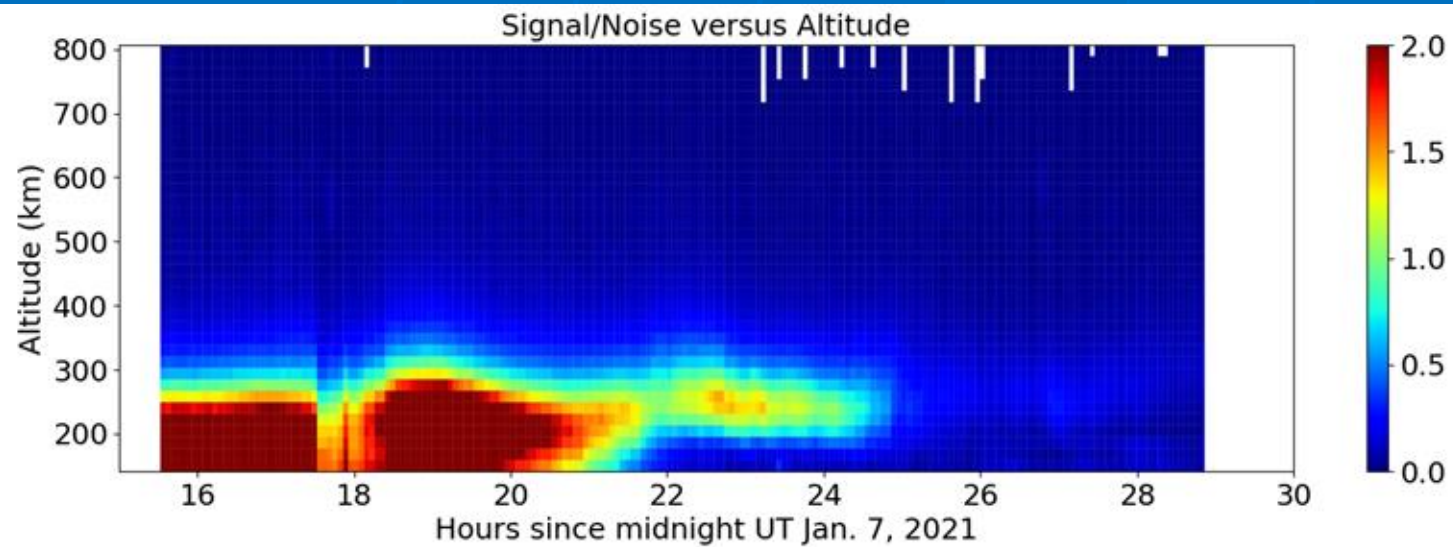
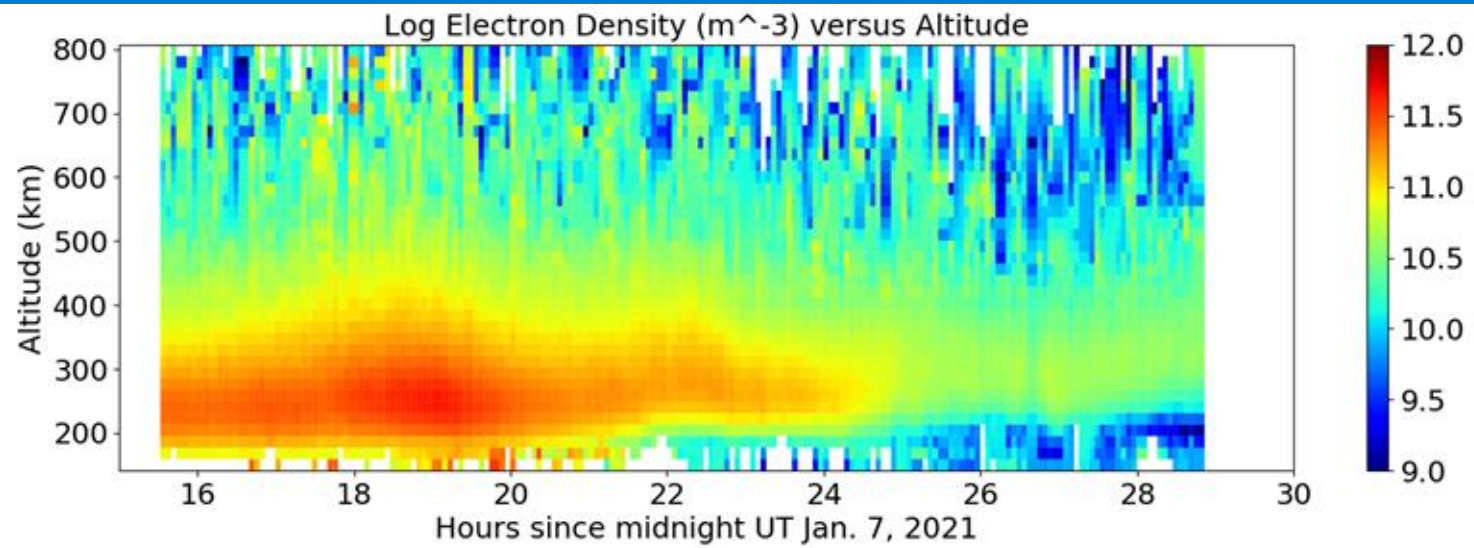


and

The measurement S/N



- Flipping a coin in a bright room only one time tells you little (good S/N - small count)
- Flipping a coin a million times in a completely dark room tells you little (poor S/N, large count)



Where would you think good data is using signal/noise?

Where would you think good is using error bars?

Error bars combine S/N with integration time

ISR blackbox inputs

What can an ISR user typically control with an existing ISR?



Pointing direction
pattern



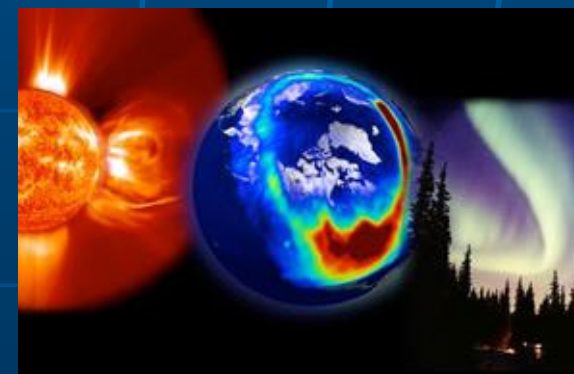
Integration period (sets
count statistics)



Radar mode (pulse length
and coding, interpulse
period)



Time of year and solar
activity during
measurement



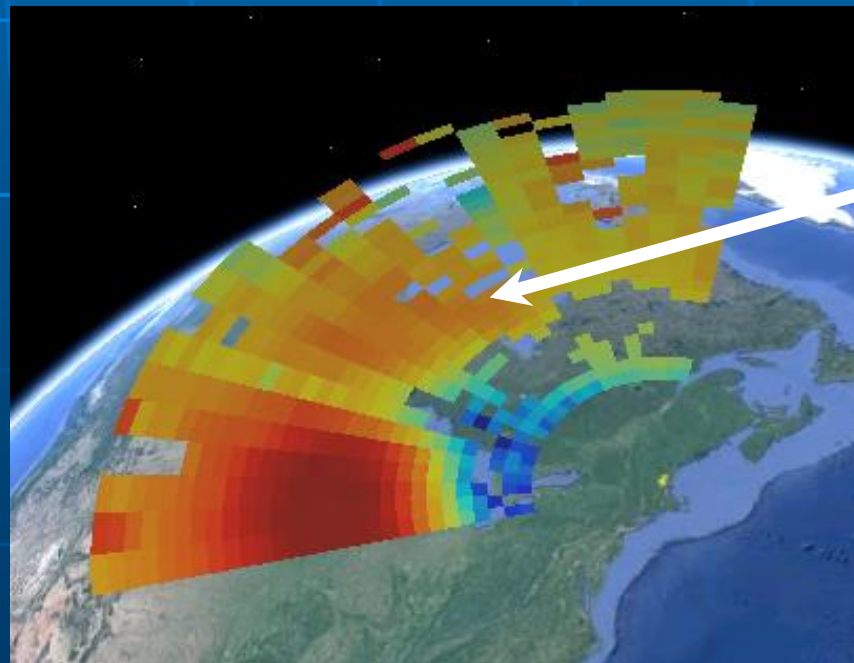
Pointing direction (monostatic*)



Single direction
gives best time
resolution



Multiple directions in local area gives
vector velocities



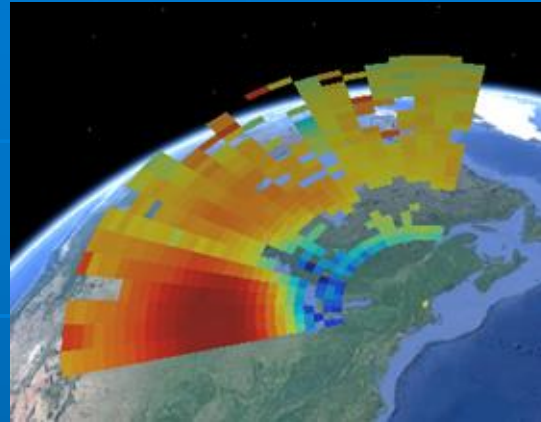
Measurements can be combined
into scans

Tradeoff: number of pointing directions
versus time resolution

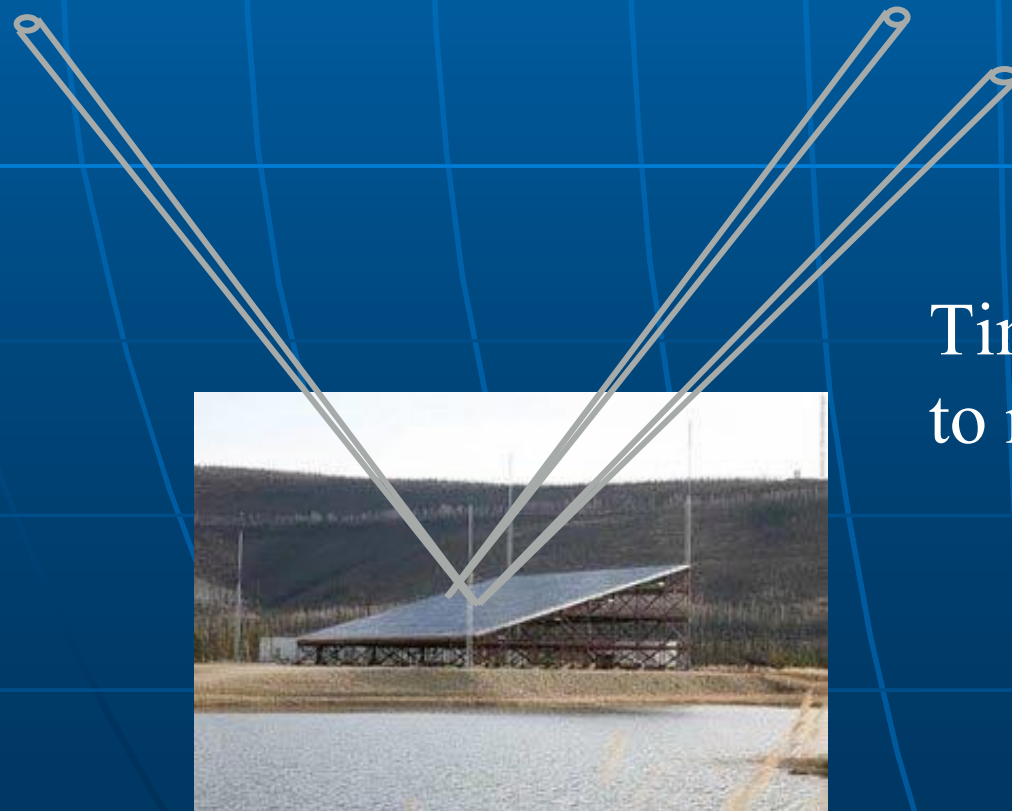
* Monostatic = same antenna for both transmit and receive; looks in one direction per radar pulse

Integration period

For dish antenna with multiple positions, integration periods must be selected beforehand.



For phased array antenna or single position dish antenna, can be chosen after the experiment is run.



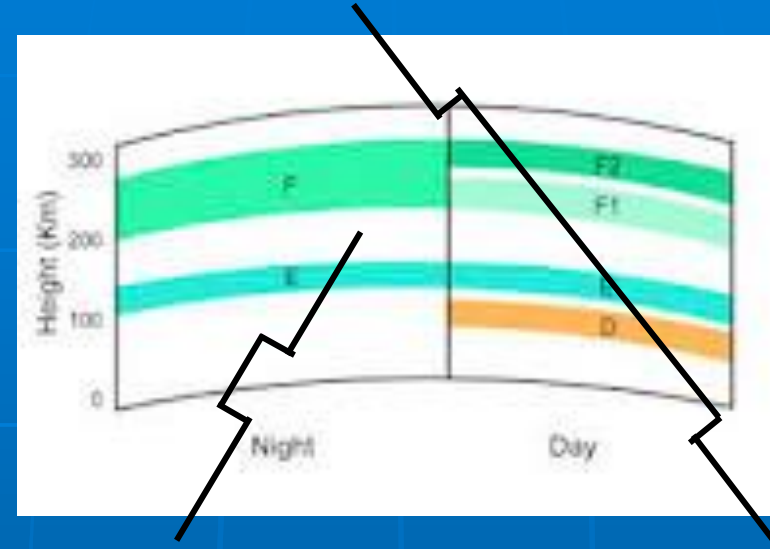
Time resolution is inversely related to number of beams.

ISR modes - single pulse

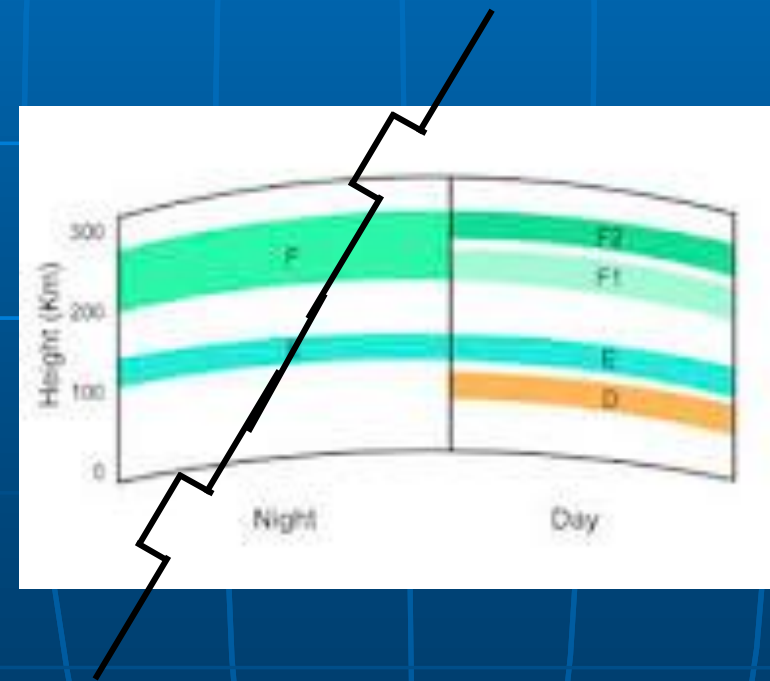
Parameters to set:

Pulse length

Shorter uncoded pulses:
Better spatial resolution,
worse S/N



Longer uncoded pulses:
Worse spatial resolution,
better S/N



Interpulse period

Shorter time increases counts/sec, limited by duty cycle of transmitter
and need to not mix up return from previous pulse with the current one

Where in the world are/were/will there be ISRs?

Resolute
N+S



Sondrestrom



Poker Flat



Svalbard
(EISCAT)



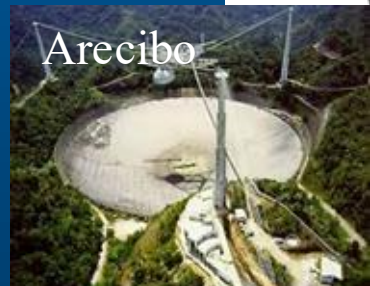
Millstone Hill



Tromsø
(EISCAT)



Arecibo



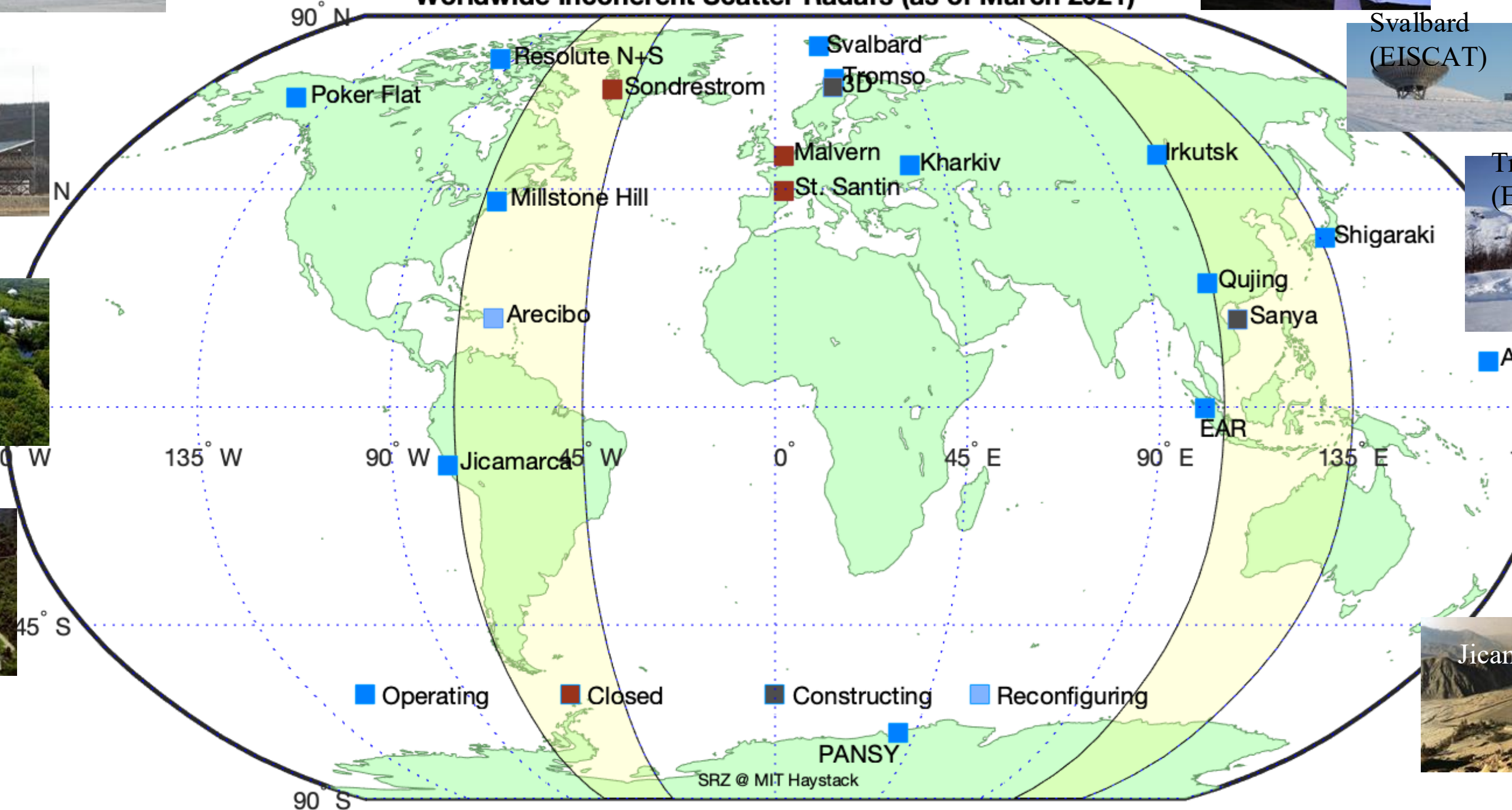
Kharkov



Jicamarca



Worldwide Incoherent Scatter Radars (as of March 2021)



Where to get ISR data

- Active ISRs fully in Madrigal
 - Poker Flat (Alaska), RISR North and RISR South (northern Canada)
 - Millstone Hill (Massachusetts), Jicamarca (Peru)
 - Eiscat (Svalbard, mainland ISRs)
- Active ISRs partially or not in Madrigal
 - Kharkov (Ukraine), Irkutsk (Siberia)
 - Sanya (China), Qujing (China)
- Historical ISRs in Madrigal
 - Arecibo (Puerto Rico), Sondrestrom (Greenland), Malvern (UK), St. Santin (France)
- Radars that run occasionally in ISR mode
 - Altair (Kwajalein), Shigaraki MU (Japan) - some in Madrigal
 - EAR (Indonesia), PANSY (Antarctica)
- ISR Radars under construction
 - Eiscat 3D (Scandinavia)

Existing ISR simulator exercise

User chooses inputs: get outputs

<https://tinyurl.com/2026-ISR>

Blackbox ISR exercises (see wiki)

ISR blackbox inputs for a new radar

What design decisions affect a new monostatic ISR?

- Radar frequency
- Aperture (m^2)
- Peak power
- Location
- Steering method and range

New ISR simulator exercise

Ionosphere generated by
IRI model (quiet day)

Full code available
(~650 lines of python)

All equations to be covered in
rest of this course

<https://tinyurl.com/2026-ISR>

Blackbox ISR exercises (see wiki)