Overview of the Millstone Hill Incoherent Scatter Radar for Madrigal users

The Millstone Hill incoherent scatter radar is located in Westford, MA, USA. The latitude is 42.61° and the longitude is 288.51°. The invariant latitude is approximately 53°. There are two incoherent scatter radar antennas used at Millstone Hill, a 67 meter zenith antenna and a 46 meter fully steerable antenna (MISA).

Figure 1: The 67 meter zenith antenna and the 46 meter steerable antenna. The steerable antenna is often referred to as the MISA antenna.

The Millstone Hill ISR is located on the top of a hill, so it is able to measure down to four degrees of elevation in many directions. See Figure 2 for an exact map of where the MISA can point.

Most Millstone Hill ISR experiments use both antennas, although typically just one is being used at any given time. For this reason, there are actually three different instrument codes (kinst, as this code is called in Madrigal):

30: The combination of both the Zenith and MISA antennas
31: The MISA (steerable) antenna
32: The Zenith antenna

Every experiment in Madrigal has an instrument code/kinst, and for all Millstone experiments after 1978 the experiment instrument code is 30. However, Madrigal also assigns an instrument code/kinst to every record in a Madrigal file. This instrument code does not have to be the same one as for the experiment. Indeed, at Millstone Hill the instrument code at the record level is usually 31 (MISA) or 32 (Zenith). So if you want to know which antenna any particular piece of data come from, you have two choices:

1. Look at the instrument code/kinst for that record.
2. Use a Madrigal file that contains only Zenith or MISA records.

The different files that contain Millstone Hill ISR data will be described later. Of course, if you find a record with an elevation less than 87 degrees elevation, it must have come from the MISA antenna (but the inverse is not true – both antennas can point straight up.)

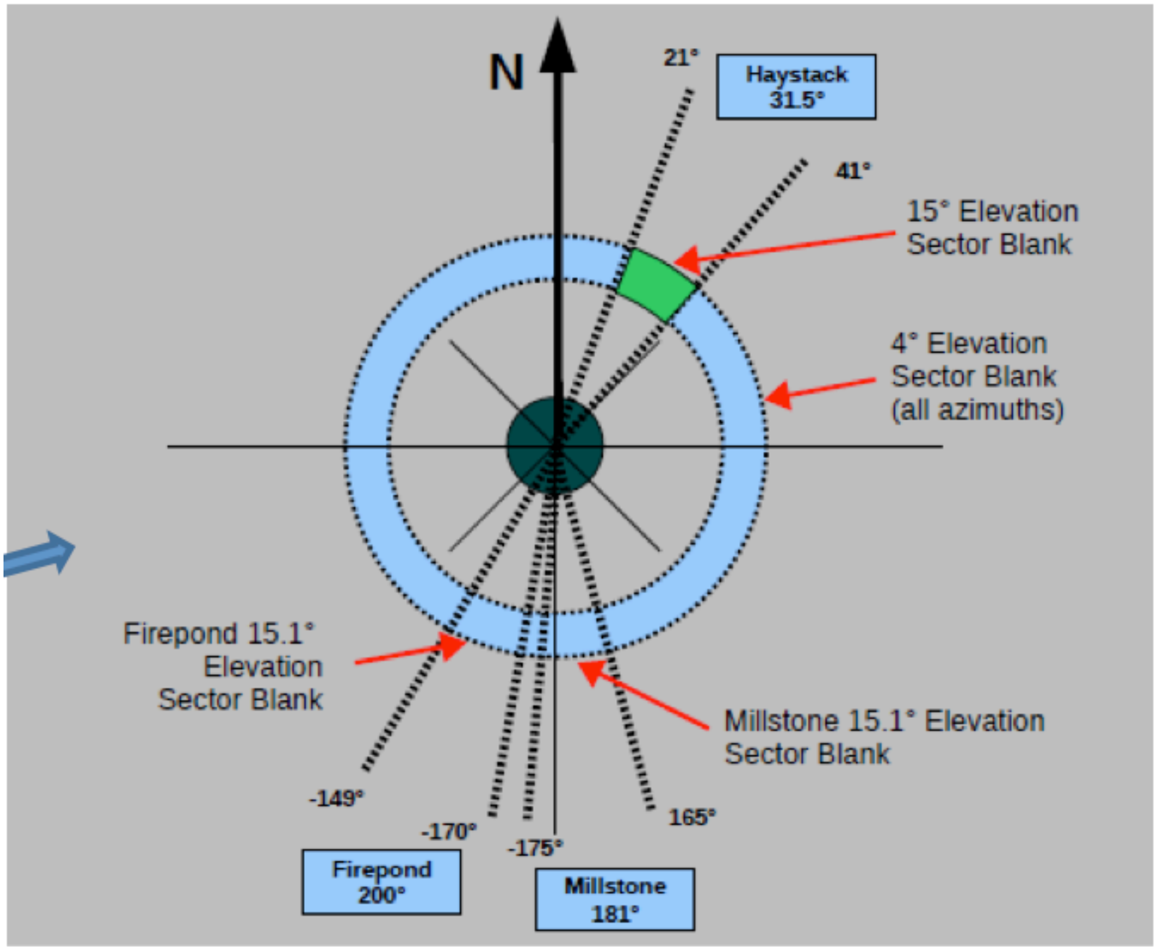

Figure 2: An azimuth map of the lower elevation limit of the MISA antenna.

Radar coding at Millstone Hill

There are many different types of coding used in incoherent scatter radar, but the two must common codes used up until now at Millstone Hill are single-pulse and alternating code.

Single-pulse codes are transmitted pulses sent out without modulation. Their range resolution is limited to the pulse length, but their signal-to-noise is increased by longer pulse length. A typical single-pulse length used at Millstone Hill is 480 microseconds, which gives a range resolution of around 70 km. Longer pulse lengths are often used for low elevations of for topside measurements, with corresponding larger range resolutions.

Alternating code pulses are series of phase-modulated pulses that can be combined to yield better range resolution. A typical alternating code used at Millstone Hill has a 480 microsecond overall pulse length, with a 30 microsecond baud length. In the E-region, this yields a range resolution of around 4.5 km. At higher ranges, the noise performance of the alternating code can be worse than that of single pulse codes with the same pulse length.

In order to tell whether an individual measurement is single-pulse or alternating code, you again have two choices:

1. Look at the ***mdtyp*** parameter. It will be 97 ('a') for alternating code, and 115 ('s') for single-pulse.
2. Use a Madrigal file that contains only single-pulse or alternating code records

Range resolution at Millstone Hill

The range resolution of any ISR measurement at Millstone Hill will be given by either the ***MRESL*** or ***RESL*** parameter. Many users mistakenly assume the range resolution is given by the spacing of the range data – that is, if the ranges measured are 120km, 130km, 140km, etc, then the range resolution is 10 km. This is usually **not correct**. Use the ***MRESL*** or ***RESL*** parameter instead.

Summary of kinds of Millstone Hill ISR data files

Description	Kindat code
Zenith single-pulse basic parameters	3420
Zenith alternating-code basic parameters	3425
MISA (steerable) single-pulse basic parameters	3430
MISA (steerable) alternating-code basic parameters	3435
Combined basic parameters file - all antennas and modes	3000-3410
Gridded basic and derived parameters	13300
Derived F region vector ion velocities	13305

Gridded data files at Millstone Hill

In addition to out standard line-of-sight data with the standard ISR parameters (electron density, ion temperature, electron temperature, and line-of-sight ion velocity), Millstone Hill also offers a higher level data product called a gridded or regularized file. This gridded product offers a uniform data product – the time spacing is always 15 minutes, the direction is always vertical, and the range spacing is always the same.

The intended user of this data product is modelers. Modelers often find is easier to fit regular data than typical ISR data with varying pointing directions and modes.

The gridded datasets should be used with a certain amount of care. The spline fits smooth the data, which reduces statistical errors but can also hide real variations in the data. Also note that while random errors in the data are reduced they are not entirely eliminated. However unlike in the basic derived parameter data nearby gridded data points are correlated. As a result any statistical errors show up as smooth wiggles in the data and care should be taken not to assign undo significance to these.

These gridded data files have a Madrigal kind of data code (kindat) of 13300, so you can use either eliminate these files or select only these files using Madrigal scripts that filter files using the kindat code.

Derived F region vector ion velocities

Certain Millstone Hill ISR experiments can derive F region vector ion velocities. These are typically experiments with three or more local pointing directions. A local pointing direction is typically one with an elevation greater than 30 degrees. The idea is to combine line-of-sight ion velocities from the basic ISR measurements that are far enough apart to separate out the different directions without violating the assumption of uniformity.

To derive F region vector ion velocities, basic ISR measurements are combined. We use a spline fit with a 15 minute cadence to produce these files.

These derived F region vector ion velocity data files have a Madrigal kind of data code (kindat) of 13305, so you can use either eliminate these files or select only these files using Madrigal scripts that filter files using the kindat code.

Experiments that do not allow the derivation of F region vector ion velocities will simply not have this file type/kindat.

Standard Millstone Hill fitting using INSCAL

INSCAL analyzes incoherent scatter autocorrelation functions (ACFs) to determine ionospheric plasma parameters.

The acfs are formed from the measured lag-products using a trapezoidal summation rule. A multidimensional non-linear least squares fit to each acf is then performed to compute estimates of the plasma parameters. Parameter error bars are computed by assuming that chi square is 1.0. Analysis parameters for this experiment are summarized below. More details, including the actual INSCAL input parameters, output listing and error messages are available from http://www.haystack.mit.edu.

1. The search parameters for 90-130 [km] were:

Ion Temperature, ACF Normalization Factor, Collision Frequency and Ion Drift Velocity

Assumed or model parameters for 90-130 [km]:

Temperature Ratio = 1.0

Density (Before temperature correction) =
    Calfac(i) * [S/N](i) * Systmp * Range(i)**2 / Xmtr_power
where Calfac = radar calibration factor
    S/N = signal to noise ratio
    Systmp = system temperature (K)
    Range = range (km)
    Xmtr_power = transmitter peak power (MW)
    i = range index

n(H+)/Ne = 0.0

n(mass 31)/Ne: if Altitude < 120 km then = 1.0
        else = 1. - 2./(1. + SQRT(1.+8.*EXP(ZZ2)))
 where:
  ZZ2 = MIN(-(Altitude-180.)/H, 50.)
  H = 10. - 6.*EXP(ZZ1)
  ZZ1 = MIN(-(Altitude-120.)/40., 50.)

The measurements were not sensitive to the H+ Drift velocity

2. The search parameters for 130-400 [km] were:

Ion Temperature, ACF Normalization Factor, Temperature Ratio,
and Ion Drift Velocity

Assumed or model parameters for 130-400 [km]:

Collision Frequency = 0.0

Density (Before temperature correction) =
  Calfac(i) * [S/N](i) * Systmp * Range(i)**2 / Xmtr_power
where Calfac = radar calibration factor
  S/N = signal to noise ratio
  Systmp = system temperature (K)
  Range = range (km)
  Xmtr_power = transmitter peak power (MW)
  i = range index

n(H+)/Ne = 0.0
n(mass 31)/Ne: if Altitude < 120 km then = 1.0
    else = 1. - 2./(1. + SQRT(1.+8.*EXP(ZZ2)))
where:
  ZZ2 = MIN(-(Altitude-180.)/H, 50.)
  H = 10. - 6.*EXP(ZZ1)
  ZZ1 = MIN(-(Altitude-120.)/40., 50.)

The measurements were not sensitive to the H+ Drift velocity

The search parameters for 400-1200 [km] were:

Ion Temperature, Temperature Ratio, n(H+)/Ne, ACF Normalization Factor, and Ion Drift Velocity

Assumed or model parameters 400-1200 [km]:

Collision Frequency = 0.0

Density (Before temperature correction) =
  Calfac(i) * [S/N](i) * Systmp * Range(i)**2 / Xmtr_power
where Calfac = radar calibration factor
  S/N = signal to noise ratio
  Systmp = system temperature (K)
  Range = range (km)
  Xmtr_power = transmitter peak power (MW)
  i = range index

n(mass 31)/Ne = 1. - 2./(1. + SQRT(1.+8.*EXP(ZZ2)))

where:
ZZ2 = MIN(-(Altitude-180.)/H, 50.)
H = 10. - 6.*EXP(ZZ1)
ZZ1 = MIN(-(Altitude-120.)/40., 50.)

The measurements were not sensitive to the H+ Drift velocity

Chirp Correction:

A chirp correction has been applied to the line of sight velocities to compensate for a frequency offset produced in the UHF transmitter. This is computed from the measured transmitter ACF. Typical values of the chirp correction range from 10-30 m/s.

Density Calibration:

Millstone Hill Incoherent Scatter electron densities from the main ion-acoustic mode ("ion line"; produces ion and electron basic and derived parameters) are calculated by inserting into the radar equation a calibration factor relating radar signal temperature to electron density. This process requires a reference electron density, measured at the F2 peak. Prior to January 2016, this F2 peak reference density was provided by NmF2 measurements from the on-site digisonde operated by University of Massachusetts at Lowell (station code MHJ45). Since January 2016, F2 peak reference densities have been provided by the radar itself using daytime measurements of the weaker Langmuir resonance ("plasma line"), which produces an absolutely calibrated density using fundamental physical constants. The radar calibration constant for ion line derived electron density is calculated and maintained in a stable fashion by ongoing direct comparison of the relevant F2 peak reference density with high elevation angle radar signal temperature measurements at the F2 peak.

Robust Integration:

Incoherent scatter data are often contaminated by radio frequency interference and satellites passing through the beam. Most of this contamination has been removed by a robust processing technique. Estimated lag-products for each integration period are computed by taking the median of a series of short sub-integrations. In practice, most interference occurs in bursts shorter than the integration period and as a result the median technique is very effective.