Mesosphere and Lower Thermosphere wind speed determination using data from the radio forward scatter BRAMS network

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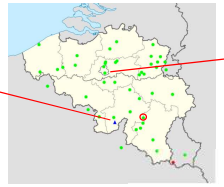
Abstract

BRAMS (Belgian RAdio Meteor Stations) is a network using forward scatter of radio waves on ionized meteor trails to study meteoroids. It is made of a dedicated transmitter and of 44 receiving stations located in or near Belgium. The transmitter emits a circularly polarized CW radio wave with no modulation at a frequency of 49.97 MHz and with a power of ~130 W. Each receiving station uses a 3-element zenith pointing Yagi antenna. The first stations used analog ICOM-R75 receivers and a PC. Since 2018, new improved stations have been installed using digital RSP2 receivers, a GPSDO and a Raspberry Pi, providing better dynamic, sensitivity and stability (1).
Recently, several methods have been developed to reconstruct trajectories from meteor echoes recorded at several BRAMS stations. These methods rely on time delays between meteor echoes, pre-t0 phase measurements, and sometimes information from a radio interferometer, or a combination of all the methods (2). This has opened the possibility to use the BRAMS network to determine the Mesosphere and Lower Thermosphere (MLT) wind speeds using data coming from many meteor echoes.
In this work, we will present the status of the BRAMS network and discuss how BRAMS data can be used to determine MLT wind speeds (3). Using a forward scatter system with a very large number of stations allows to increase the number of detections, to increase the altitudinal coverage, and to relax the homogeneity assumption. We will discuss how this will affect the temporal and spatial resolutions of the MLT wind field measurements. We will finally discuss several upcoming upgrades of the network and their impact on this work (4).

1

The BRAMS network



Stations 1.0

Tx characteristics

- ✓ Crossed dipole + 8m × 8m metallic grid
- ✓ f = 49.97 MHz
- ✓ P ~ 130 W
- ✓ CW with no modulation
- ✓ Circular polarization towards zenith

Stations 2.0

Rx characteristics

- All the receiving stations are using a 3-element Yagi antenna set up vertically and oriented in azimuth towards the transmitter.
- At the time of writing, 13 of the receiving stations are still using analog ICOM-R75 receivers, an external sound card to sample the signal coming from the antenna and are controlled by the freeware program Spectrum Lab running on a PC (Lamy et al., 2015). The other 30 stations use digital SDR-RSP2 receivers controlled by a Linux system running on a Raspberry Pi (Anciaux et al., 2020).
- All stations are equipped with a Garmin GPS that provides timestamps to the BRAMS data and allows a time synchronization between the receiving stations.
- The material is now contained in a single metallic box which is easy to set up (plug and play).
- The Rpi automatically connects to a BRAMS VPN which allows automatic transfer of the data and secure remote connection (ssh).

The interferometer in Humain

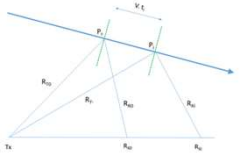
- Red circle on the Belgian map
- Classical 5 antennas Jones configuration

2

Meteoroid trajectory and speed reconstruction using BRAMS data

Specular reflection : $S_i = R_{Ti} + R_{Ri}$ must be minimum for each station i
6 unknowns: 3 coordinates of one specular point P_0 + 3 components of velocity **v**

Set of ≥ 6 non-linear equations which contain the time delays Δt_i between appearances of meteor echoes at station *i* and a reference station



$\Delta t_{i,model}$ Theoretical time delay
$\Delta t_{i,obs}$ Experimental time delay
$\delta\Delta t_{i,obs}$ Experimental uncertainty

Method 1 – Time delays only

Set of n raw signals
↓ *Time delays extraction*

$$J_1 = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\Delta t_{i,model} - \Delta t_{i,obs}}{\delta\Delta t_{i,obs}\cdot\max_i(|\Delta t_{i,obs}|)}\right)^2$$

↓ *Target objective minimization*

$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \\ V_x \\ V_y \\ V_z \end{bmatrix}$ Solution vector

Method 2 – Time delays + interferometer

ε Elevation angle
$\delta\varepsilon$ Elevation uncertainty
θ Azimuth angle
$\delta\theta$ Azimuth uncertainty

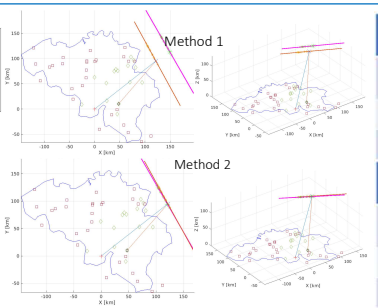
$$J_2 = J_1 + \left(\frac{\varepsilon - \operatorname{atan}\left(\frac{z_H - z_R}{\sqrt{(x_H - x_R)^2 + (y_H - y_R)^2}}\right)}{\delta\varepsilon}\right)^2 + \left(\frac{\theta - \operatorname{atan}\left(\frac{y_H - y_R}{x_H - x_R}\right)}{\delta\theta}\right)^2$$

Humain specular point position $\begin{bmatrix} x_H \\ y_H \\ z_H \end{bmatrix}$

↓ *Target objective minimization*

$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \\ V_x \\ V_y \\ V_z \end{bmatrix}$ Solution vector

Comparison with optical observations from the CAMS BeNeLux network



Theoretical solution
X_0 = 121.59 km
Y_0 = 95.16 km
Z_0 = 99.39 km
V_x = -18.88 km/s
V_y = 34.43 km/s
V_z = -12.87 km/s

Method 1 reconstruction error
Reference specular point: 33.12 km
Velocity norm: 0.85 km/s
Inclination: 1.21°
Method 2 reconstruction error
Reference specular point: 1.34 km
Velocity norm: 0.08 km/s
Inclination: 1.12°

3

Conclusions and perspectives on trajectory reconstructions and MLT wind speed measurements

- **Conclusions** : method 1 recovers the inclination of the trajectory and the speed quite well but fails to reconstruct the exact position of the trail. The problem is ill-posed (strong sensitivity to error measurements). The problem is particularly striking for high-speed meteors and/or high-inclination trajectories. In both cases, measurements errors impact more the reconstruction since time delays between meteor echoes are smaller. Method 2 highly improves the precision on the position of the trail (Balis et al., 2023).

- **Perspectives and improvements**:
  - ✓ Including a deceleration model (either linear or exponential)
  - ✓ Use of pre-t0 phase technique (Mazur et al. 2020) adapted to forward scatter case. This provides an additional constraint on the magnitude of the speed at the reference station (for which the position of the specular reflection point is retrieved)
  - ✓ Use of pre-t0 phase technique for all meteor echoes with a good S/N → this would provide constraints on the speed at different altitudes and could therefore be used in combination with the deceleration model.

- **Advantages and disadvantages for MLT wind speed measurements**:
  - ✓ Method 1 : many trajectories available but poor accuracy on exact position of the trail, in particular in altitude.
  - ✓ Method 2 : much better accuracy on the vertical position of the specular reflection points but much less trajectories available and we cover a lower portion of the sky

- **Advantages and disadvantages of BRAMS for MLT wind speed measurements**:
  - ✓ Larger number of detected meteors (see e.g., Stober and Chau, 2015). This might decrease the temporal resolution of the wind speed measurements.
  - ✓ With soon ~ 50 Rx stations, this will allow to relax the assumption on the spatial homogeneity of the wind speed in the scanned volume.
  - ✓ BRAMS is a forward scatter system and so less sensitive to the ceiling echo effect, so can provide a better altitudinal coverage
  - ✓ Current limitations : transmitted power of only 130 W, no information on range (CW with no modulation), limited accuracy on altitude of the reflection points using method 1.

4

SORBET : Services and OpeRability of the BRAMS nETwork

- SORBET is a project which has recently been accepted for funding for 3 years
- One of the two main goals is to determine MLT wind speeds using BRAMS data
- We also plan improvements to the BRAMS network :
  - ✓ Increase power of the current Tx to ~ 400-450 W (~ 5-6 dB increase)
  - ✓ Add a second interferometer in Limburg (North-East of Belgium)
  - ✓ Add a second Tx in North of Belgium

We are looking for a postdoc position for 2 years, starting near end of 2023.

If you are interested, please contact me at **herve.lamy@aeronomie.be**

References:
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