A detection algorithm for scale analysis of post-sunset low-latitude plasma depletions as observed by the Swarm constellation mission

GFZ Helmholtz Centre Potsdam
www.gfz-potsdam.de

Guram N. Kervalishvili[1,2] (gmk@gfz-potsdam.de), Claudia Stolle[1], and Chao Xiong[1]
[1] GFZ German Research Centre For Geosciences, Potsdam, Germany
[2] M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

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Motivation

ESA's constellation mission Swarm was successfully launched on 22 November 2013. The three satellites achieved their final constellation on 17 April 2014 and since then Swarm-A and Swarm-C orbit the Earth at about 470 km (flying side-by-side) and Swarm-B at about 520 km altitude. The satellites carry instruments to monitor the F-region electron density with a sampling frequency of 2 Hz.

We present an algorithm for detecting the low-latitude post-sunset plasma irregularities (bubbles) using local minima and maxima to detect depletions directly from electron density readings of Swarm. Our analyses were performed in the magnetic latitude (MLat) and local time (MLT) coordinate frame.

We discuss the global distribution of depletion depth and width of plasma irregularities and its seasonal and local time dependence for all three Swarm satellites

Data and Processing

Observations: Apr/2014 – Sep/2015

- **Swarm A, B, and C data**
  https://earth.esa.int/web/guest/swarm/data-access
  - Electron (plasma) density, N_e

Seasonal subdivisions

- **December solstice:** Jan, Feb, Nov, and Dec
- **Combined equinoxes:** Mar, Apr, Sep, and Oct
- **June solstice:** May, Jun, Jul, and Aug

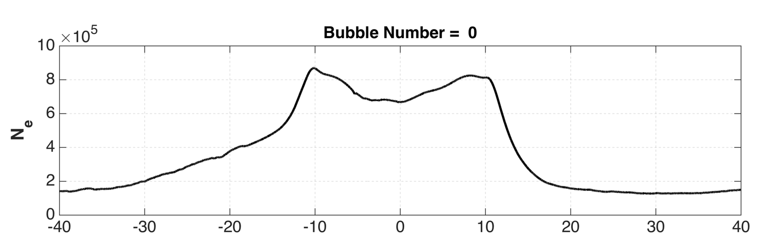
Data binning

- **MLat (Magnetic Latitude), MLT (Magnetic Local Time), and GLon (Geographic Longitude)**
- **Bin size**
  - 5° in MLat and GLon; 1 h in MLT
- **Mean values:** for each bean

Bubble detection algorithm

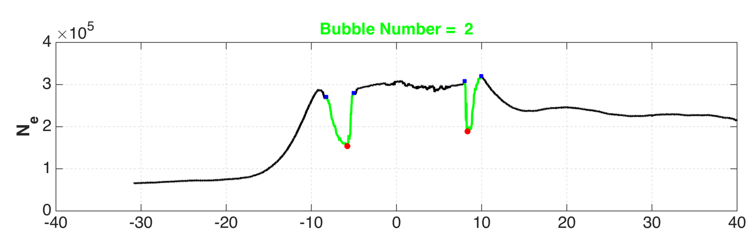
- **Used data:** 18 - 04 MLT and -37.5° - 37.5° MLat
- **Depletion detection:** local minima based
- **Depletion width:** left and right local maxima of local minimum
- **Bubble merging mechanism**
  1. Left and right local maxima are same for two neighbor depletions
  2. And minimum is always smaller than final left and right maxima
- **Depletion depth:** the amplitude of depletion (after merging)
- **Savitzky-Golay filter:** polynomial order 3 and frame sizes 9 (4.5 s) and 201 (100.5 s)
- **Assumption:** minimum depletion depth
  - $4 \cdot 10^4$ cm^{-3} (for Swarm A, B, and C)

Bubble Detection Examples per Orbit (MLat)



No bubbles

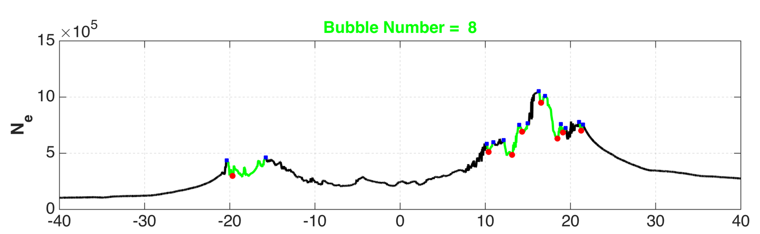
Observation, Swarm A: 02/10/2014 – downleg – orbit 12



Bubble number: 2

Observation, Swarm B: 18/04/2014 – upleg – orbit 01

- **Two single bubbles**

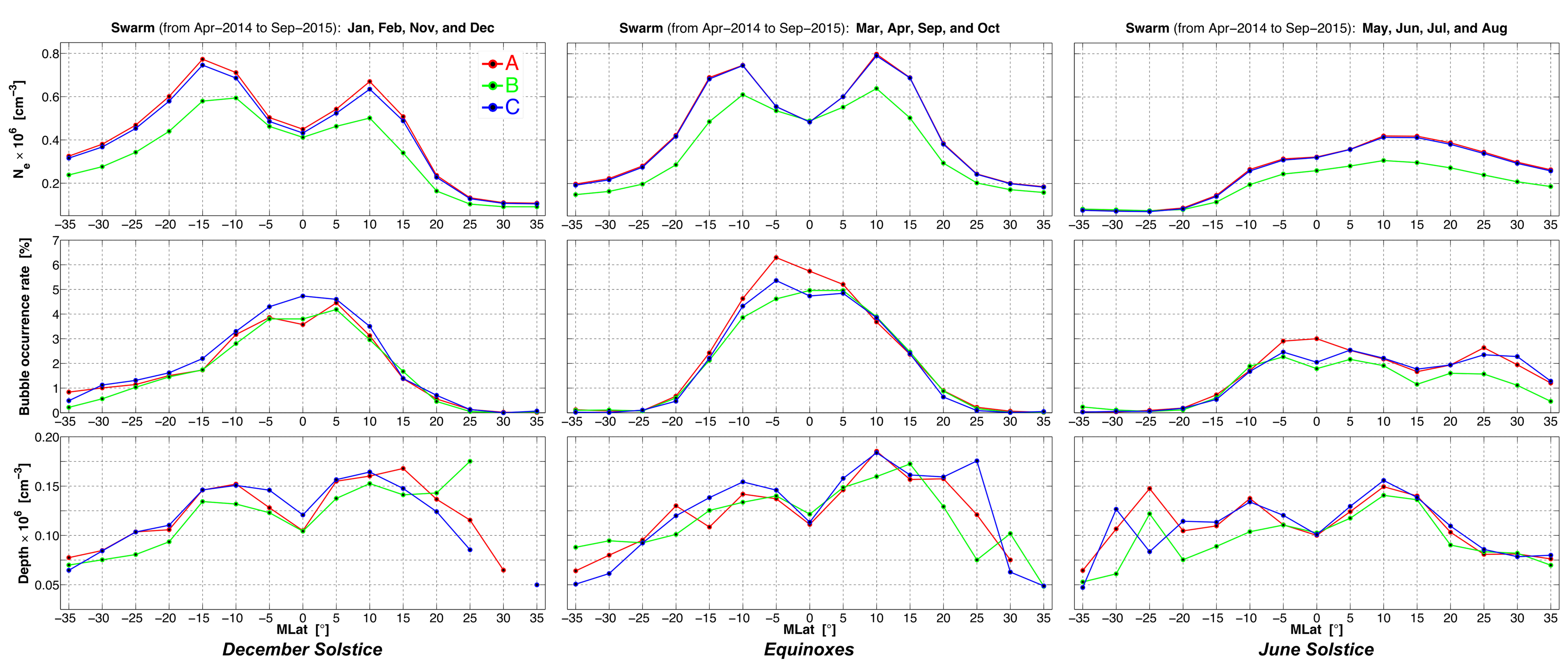


Bubble number: 8

Observation, Swarm A: 17/04/2014 – upleg – orbit 13

- **Around -20 MLat:** bubbles have been merged
- **Around 15 MLat:** bubbles haven't been merged (minimum is larger than neighbor maxima)

1D Bubble Climatology: MLat



Bubble Occurrence Rate

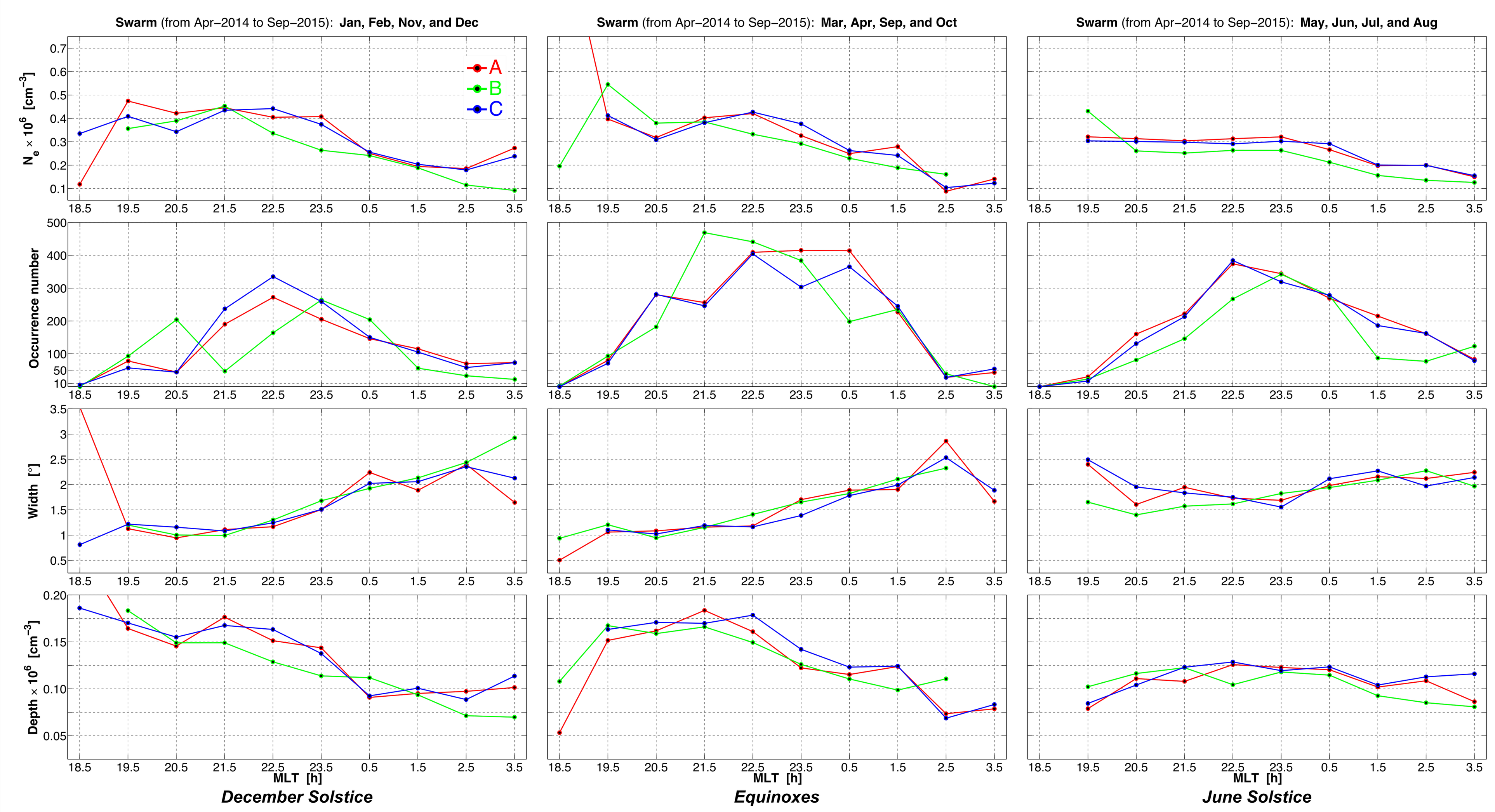
As expected on global average

- **December solstice**
  - Small flat tail in the Southern Hemisphere
  - Peaks between ±5 MLat
- **Combined equinoxes**
  - Highest occurrence rate
  - No flat tails in both hemispheres
  - Peaks between ±5 MLat
- **June solstice**
  - Smallest occurrence rate
  - Pronounced flat tail in the Northern Hemisphere
  - Peaks between ±5 MLat

Depletion Depth

- **December solstice, combined equinoxes, and June solstice**
  - Deepest depletions: *around ±10° MLat*

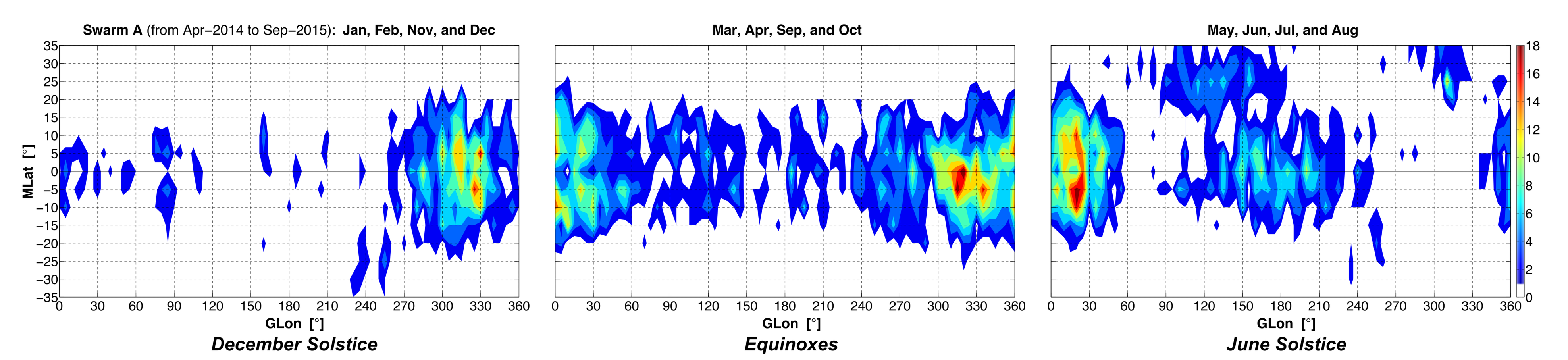
1D Bubble Climatology: MLT



Swarm A, B, and C

- **MLT distribution of the electron density**
  - **December solstice and equinoxes:** decreases from post-sunset to post-midnight
  - **June solstice:** about constant from post sunset to midnight and decreases from midnight to post-midnight
- **MLT distribution of the bubble occurrence number:** sharp increase at about 19 MLT and decreases towards post-midnight hours
- **Inverse relation between:** depth and width of bubbles as function of MLT for all seasons
- **Bubble depth:** decreases from post-sunset to post-midnight for December solstice and equinoxes with about the same amplitude values
- **Bubble width:** increases from post-sunset to post-midnight for December solstice and combined equinoxes with about the same amplitude values
- **Bubble depth and width for June solstice:** less deep and do not change significantly throughout the evening

2D Bubble Climatology (Swarm A): MLat & GLon



Swarm A

- **Seasonal variations:** strongest in combined equinoxes
- **December solstice:** flat tail distribution part comes from 210° - 270° GLon
- **June solstice:** flat tail distribution part comes from 60° - 180° and 270° - 330° GLon
- **Equinox:** symmetry about the magnetic equator

Swarm B and C: similar to Swarm A

Conclusions and Summary

MLT distribution shows an inverse relation between the depletion depth and width of bubbles. This is true for all seasons and for all Swarm satellites. The bubble depth (width) is decreasing (increasing) from post-sunset to post-midnight for December solstice (Jan, Feb, Nov, and Dec) and combined equinoxes with about the same amplitude values for bubbles depth (width).

We suggest that at post-midnight when the depletions are less steep the structures of the depletions is broader than earlier after sunset. However for June solstice the depletions are less deep and the bubble depth and width do not change significantly throughout the evening. Deepest depletions occur at around ±10° magnetic latitude that is at the inner edge of the ionization anomaly with density maxima at around 10° - 15° MLat.

The bubble occurrence maximum is around the equator between ±5° MLat, but the deepest depletions occur at about ±10° MLat. This is true for all seasons and satellites. The latitude of the deepest depletions correspond to the latitude of maximum occurrence of magnetic signatures.

Flat tail in 1D MLat irregularity occurrence rate for June solstice in the Northern Hemisphere occurs due to bubble detection at about 25° - 30° MLat and 60° - 180° GLon which is clear visible from the 2D bubble climatology figure. While bubbles are not expected above 20° MLat, this requires additional investigations and analysis (future plans).