Examination of Three Empirical Atmospheric Models

A Presentation
Given to
The Department of Physics
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In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
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Overview

- Motivation for empirical models
- Models to be discussed
  - IRI
  - MSIS
  - HWM
- Items to consider for each model
  - Model input and output parameters
  - Valid domains within the model
  - Model formulation
  - Examples of model output
Why Create an Analytic Empirical Model?

- Provides a model based on observation
- More useful than data tables
- Theoretical models
  - Initialization (background atmosphere)
  - Verification of results
- Satellites
  - Design
  - Instrument data verification
(National Research Council, 1981)
International Reference Ionosphere 2007 (IRI2007)
IRI Description

- Empirical model
  - ISO/TS 16457 (ISO Standard)
- Input
  - Default: year, time of year, time of day, altitude, location
- Output
  - Electron number density
  - Ion number densities
    - $\text{H}^+$, $\text{He}^+$, $\text{N}^+$, $\text{O}^+$, $\text{NO}^+$, $\text{O}_2^+$
  - Electron, ion, and neutral temperatures
Valid IRI Domains

- Year
  - 1958-Present
- Time of year and time of day: no constraints
- Altitude
  - Electron density: 65-1000 km
  - Ion densities: 100-1000 km
  - Temperatures: 120-3000 km
- Coordinates: global
  - Best at mid-latitudes
IRI Data Sources

- Ground:
  - Ionosonde: $n_e$ altitude profile
  - Incoherent scatter radar: $T_e$, $n_e$, $T_i$, $n_i$, $m_i$, $u_i$
- Satellite:
  - Ionosonde: $n_e$ inverse altitude profile
  - In-situ measurements along satellite trajectory
- Rocket:
  - In-situ measurements along rocket trajectory
- Empirical Models:
  - MSIS-86: $T_n$
  - IGRF: geomagnetic field
Ionosonde Locations

(http://www.ukssdc.ac.uk/wdcc1/ionosondes/world.html)
Incoherent Scatter Radar Locations

(http://www.haystack.mit.edu/atm/mho/iswg/index.html)
IRI Data Fitting

- Altitude profile
  - Epstein transition function
- Day of year
  - Linear interpolation
- Latitude vs. longitude
  - Spherical harmonics
- Time of day
  - Epstein step function
- Magnetic and solar activity
  - Linear interpolation
(Bradley and Dudendy, 1973)
Profile Parameters

- $h_{mF2}$: height of F2 peak
- $f_{oF2}$: plasma frequency at F2 peak
- $N_{mF2}$: plasma density at F2 peak
- $y_{mF2}$: half thickness
Figure 11.24  Calculated electron density contours $(\log_{10} n_e)$ as a function of altitude and dip latitude at 2000 LT for December solstice conditions.\textsuperscript{32}

(Anderson and Roble, 1981)
(Schunk and Nagy, 2000)
Electron Density (cm\(^{-3}\))
Longitude = 270\(^\circ\) E; 12:00 (LT)

December 21; Solar Minimum

June 21; Solar Minimum
Electron Density ($cm^{-3}$)
Longitude = 270° E; 12:00 (LT)

June 21; Solar Minimum

June 21; Solar Maximum
Electron Density (cm$^{-3}$)
Longitude = 270° E; 12:00 (LT)

December 21; Solar Minimum

June 21; Solar Maximum
Electron Density (cm\(^{-3}\))
Longitude = 270° E; 24:00 (LT)

December 21; Solar Minimum

June 21; Solar Maximum
Electron Density (cm⁻³)
Latitude 45° N; 06:00 (UT)

December 21; Solar Minimum

June 21; Solar Maximum
Electron Density (cm$^{-3}$)
Altitude = 300 km; 06:00 (UT)

December 21; Solar Minimum

June 21; Solar Maximum
March 23-1970; 14:22 (LT)  
42.6° N; 288.5° E

(Roble, R. W., 1975)
45° N; 0° E; 12:00 (LT)

21 December; Solar Minimum

21 June; Solar Maximum

[Graphs showing altitude vs. temperature for different components (Electron, Ion, Neutral)]
45° N; 0° E; 12:00 (LT)

21 December; Solar Minimum

21 June; Solar Maximum
Naval Research Laboratory
Mass Spectrometer and
Incoherent Scatter Radar 2000
(NRLMSISE-00)
MSIS Description

- Empirical Model
- Input
  - Day of year, time of day, altitude, location, solar activity, magnetic activity
- Output
  - Number densities of neutral species
    - H, He, N, O, N$_2$, O$_2$, Ar
  - Total mass density
  - Temperature of neutral atmosphere
Valid MSIS Domains

• Day of year and time of day: no constraints
• Altitude
  ◦ He, N₂, O₂, and Ar densities: ground to exosphere
  ◦ O, H, and N densities: 72.5 km to exosphere
  ◦ Temperature: ground to exosphere
• Coordinates: global
• Solar and magnetic activity
  ◦ Above 80 km: user input
  ◦ Below 80 km: f₁₀.₇ = 150.0, Ap = 4.0 (recommended)
MSIS Data Sources

- Incoherent scatter radar: neutral temperature, $N_2$ density
- Satellite
  - Mass spectrometer: neutral composition
  - UV absorption: $O_2$ density
  - Accelerometer: total neutral mass density
  - Drag: total neutral mass density
- Rocket
  - Mass spectrometer: neutral composition
  - UV absorption: $O_2$ density
  - Falling sphere: total neutral mass density
  - Grenade: total neutral mass density
  - Pressure gauge: total neutral mass density
- Handbook for MAP (Middle Atmosphere Program)
  - Neutral temperature
  - Total neutral mass density
MSIS Data Fitting

- Altitude profile
  - Bates profile (low altitude)
  - Inverse polynomial (high altitude)
- Latitude vs. longitude
  - Spherical harmonics
- Solar and magnetic activity
  - Polynomials
- Time variations (day of year, time of day)
  - Fourier series
O Density (cm$^{-3}$)
Longitude = 270° E; 12:00 (LT)

December 21; Solar Minimum

June 21; Solar Maximum
O Density (cm$^{-3}$)
Longitude = 270° E; 24:00 (LT)

December 21; Solar Minimum

June 21; Solar Maximum
O Density (cm$^{-3}$)
Latitude = 45° N; 06:00 (UT)

December 21; Solar Minimum

June 21; Solar Maximum
O Density (cm$^{-3}$)
Altitude = 300 km; 06:00 (UT)

December 21; Solar Minimum

June 21; Solar Maximum
Horizontal Wind Model 2007 (HWM07)
HWM Description

- Empirical model
- Input
  - Day of year, time of day, altitude, geographic location, geomagnetic activity
- Output
  - Northern wind speed
  - Eastern wind speed
Valid HWM Domains

- Day of year and time of day: no constraints
- Altitude: 0-500 km
- Coordinates: global
  - Best at low and mid-latitudes
- Low solar activity
HWM Data Sources

- Ground
  - Fabry-Perot interferometer
  - Incoherent scatter radar
  - Medium-frequency radar
  - LIDAR
- Rocket
  - Falling sphere
  - Rocketsonde
  - Trimethyl aluminum release
- Satellite
  - In-situ measurements along satellite trajectory
  - Fabry-Perot interferometer
- Numerical
  - TIME-GCM
  - NOAA GFS Analysis
  - NASA GEOS4 Analysis
HWM Data Fitting

- Altitude profile
  - Cubic spline (low altitude)
  - Bates-Walker function (high altitude)
- Latitude vs. longitude
  - Vector spherical harmonics
- Time variations
  - Fourier series
- Magnetic activity
  - Polynomial
Neutral Wind
Longitude = 270° E; 12:00 (LT)

December 21; Ap Index = 10

Altitude (km)

500
400
300
200
100

-90   -45   0   45   90

Geographic Latitude

286 m/s

June 21; Ap Index = 150

Altitude (km)

500
400
300
200
100

-90   -45   0   45   90

Geographic Latitude

331 m/s
Neutral Wind

Longitude = 270° E; 24:00 (LT)

December 21; Ap Index = 10

Altitude (km)

Geographic Latitude

247 m/s

June 21; Ap Index = 150

Altitude (km)

Geographic Latitude

531 m/s
Neutral Wind
Latitude = 45° N; 06:00 (UT)

December 21; Ap Index = 10

Altitude (km)

104 m/s

June 21; Ap Index = 150

Altitude (km)

304 m/s
Neutral Wind
Altitude = 300 km; 06:00 (UT)

December 21; Ap Index = 10

June 21; Ap Index = 150
45° N; 0° E; 12:00 (LT)

December 21; Ap Index = 10

June 21, Ap Index = 150
45° N; 0° E; 12:00 (LT)

December 21; Ap Index = 10

June 21, Ap Index = 150
References


References (continued)


