Annual Variations of the Upper Atmosphere: IPY Observations

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REU Program 2008
International Polar Year (IPY)

- March, 2007 through March, 2009
- Previous polar years in 1882-83, 1932-33
- Similar efforts: International Geophysical Year (1957-58), International Heliophysical Year (2007-2009)
- Thousands of scientists, over sixty nations, over two-hundred projects
- Focused on Arctic and Antarctic regions
- Research of a physical, biological, and social nature
- Large commitment to atmospheric science: coordinated observations between world’s ten operational incoherent scatter radar (ISR) facilities
Incoherent scatter radars

Millstone Hill ISR, Westford, MA

Poker Flat ISR (PFISR), Fairbanks, Alaska

Sondrestrom ISR
Kangerlussuaq, Greenland

EISCAT Svalbard radar (ESR)
Longyearbyen, Svalbard
Observation Period and Schedule

- Low solar activity, geomagnetically quiet
- EISCAT Svalbard (78.1°N): nearly continuous at low duty cycle
  - Sondrestrom (67.0°N): 8-24 observations/month
  - PFISR (65.1°N): 4-31 observations/month
- Millstone Hill (42.6°N): biweekly 32-hour experiments
Data Processing

- Gridded Madrigal files
  - provide ISR parameters for regular bins of height and UT
- Monthly averages for electron density (Ne), electron temperature (Te), and ion temperature (Ti)
- Monthly averages for the daily F10.7 (solar activity) index and 3-hourly Ap (magnetic activity) indices
- Solar and magnetic effects accounted for in fitting, then effectively set to zero when generating model values
- Filters
  - 9 < Ne < 13
  - 100 < Te, Ti < 4000
  - 50 < F10.7 < 350
  - 0 < Ap3 < 80
Data Fitting

- Multiple linear regression (least-squares fitting)

- Normalized solar activity (F10.7) and magnetic activity (Ap) indices

- Fit for annual and local time variations
  - annual, semiannual components
  - diurnal, semidiurnal, and terdiurnal components

- Cross-terms
  - annual*diurnal, annual*semidiurnal, annual+semiannual
  - semiannual*diurnal, semiannual*semidiurnal

- Fit compared to actual data and median (data-fit) difference computed to evaluate accuracy

\[
\bar{I} = \frac{2 \cdot (I - I_{\text{median}})}{\text{range}(I)}
\]

\[
v_{A,n} = \sin\left(\frac{2\pi n \cdot \text{month}}{12}\right) + \cos\left(\frac{2\pi n \cdot \text{month}}{12}\right)
\]

\[
v_{LT,n} = \sin\left(\frac{2\pi n \cdot \text{LT}}{24}\right) + \cos\left(\frac{2\pi n \cdot \text{LT}}{24}\right)
\]

Model Equation

\[
P = \beta_0 + \beta_1 F10.7 + \beta_2 Ap + \beta_3 v_{A,1} + \beta_4 v_{A,2} + \ldots
\]
Predominant variation is seasonal:
- higher Ne in winter, lower Ne in summer (winter anomaly)
- F2 peak height (hmF2) maximum in late spring
- Neutral composition effects

Bottomside Ne maximum in summer, minimum in winter
- Photochemistry important in this region
- From summer to winter, daily peak shifted from morning to afternoon
• Predominant variation is seasonal: higher Ne in winter, lower Ne in summer (winter anomaly)
• F2 peak height ($h_mF2$) maximum in spring, minimum in summer
• Neutral composition effects

• Topside Ne maximum in late spring/early summer, minimum in winter
• Semiannual component larger above peak height
• From summer to winter, daily peak shifted from evening to afternoon
From winter to summer: solar zenith angle ($\chi$) decreases, EUV photoionization increases and $N_e$ tends to increase
- Solar irradiation effects dominate, neutral composition effects less important
- Peak height decreases from summer to winter

Topside and bottomside behavior closer to that of peak region
- Peak density occurs nearer to summer solstice for bottomside, photochemistry important
- Possibility of an altitude-dependent delay in thermospheric response (causes F2 peak density to be delayed ~1 month)
• From winter to summer: solar zenith angle ($\chi$) decreases, EUV photoionization increases and Ne tends to increase
• Solar irradiation effects dominate, neutral composition effects less important
• Peak height decreases from summer to winter

• Semiannual component larger in topside
• Ne not just determined by solar zenith angle in this region, but perhaps a dynamical process or composition effects as well
Sondrestrom $N_e$

- Maximum $N_m F_2$ in summer when solar zenith angle is small and photoionization is high
- $N_m F_2$ not at summer solstice, but in late summer
- Larger semiannual component above peak height

- Average $F_2$ peak region shows earlier maximum, closer to summer solstice
- Daily $N_m F_2$ close to local noon
- Bottomside (not shown): annual $N_m F_2$ in June, daily $N_m F_2$ in late afternoon
- Topside (not shown): annual $N_m F_2$ in May, daily $N_m F_2$ in late morning
PFISR \( N_e \)

- Clear variation with solar zenith angle
- Maximum \( N_e \) in late summer, minimum in early winter

- Peak region: maximum \( N_e \) at summer solstice, daytime minimum in November
- Bottomside (not shown): minimum in January
- Topside (not shown): daytime minimum in January
Electron Density

Summary:

• Solar zenith angle most important factor for high-latitudes

• Explanation for ‘late’ maxima at high-latitudes needed

• Neutral composition effects most important factor for mid-latitudes

• Altitude dependencies require further investigation

• For given latitude ~65° geodetic, Ne higher in PFISR longitude sector compared to that of Sondrestrom
Electron Temperature

Summary:

• High-latitudes: variation follows that of solar heating, effect of Ne-Te anti-correlation not as important

• Low altitudes: Ne small, Te follows solar heating variation

• Apparent semiannual variations at high altitudes for ESR, SRF - not solar heating effect

• Mid-latitudes: variation with solar heating, with contribution from Ne-Te anti-correlation
Ion Temperature

Summary:

• Semiannual variation with equinoctial asymmetry for ESR, SRF
  • Maximum Ti occurs in spring, secondary maximum in late autumn
  • Minima in summer and winter

• PFISR, MHR: annual variation of solar zenith angle important (low Ti in winter, high in late spring/early summer)

• Semiannual variation stronger at lower altitudes for Millstone Hill (maximum Ti in late spring, minimum in late autumn)
Conclusions

● In general, results are in agreement with theoretical and empirical models of global circulation patterns and photoionization effects in the thermosphere

● IPY achievements:
  – Length of observing campaign is unprecedented for ISRs
  – Most extensive & detailed single ISR data set ever generated - valuable for validating (or modifying) theoretical and global empirical models
  – Possibility of running thorough, long-term ISR campaigns has been demonstrated and may be repeated

● Future work:
  – Integrated electron content (IEC), a good approximation for total electron content (TEC)
  – Neutral temperature, winds, and electric field variations
  – Line-of-sight velocities
Acknowledgments

● My advisors: Shun-Rong Zhang and John M. Holt

● Bill Rideout

● Ching Lue

● The entire Haystack staff and my fellow REU students