Resonance fluorescence lidar for study of different species in MLT region

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NSF

Mini lidar Workshop, Cedar 2010

Outline

- Introduction
  - Metals in the MLT (occurrence)
    - How were they discovered (a brief history)
  - Resonance lidar technique
  - Significance of metals
- Distribution and Characteristics
  - Comparison of layers in different metals
  - Topside v/s Main layer
  - Effect of temperature
- Summary

Characteristics of Mesospheric Region

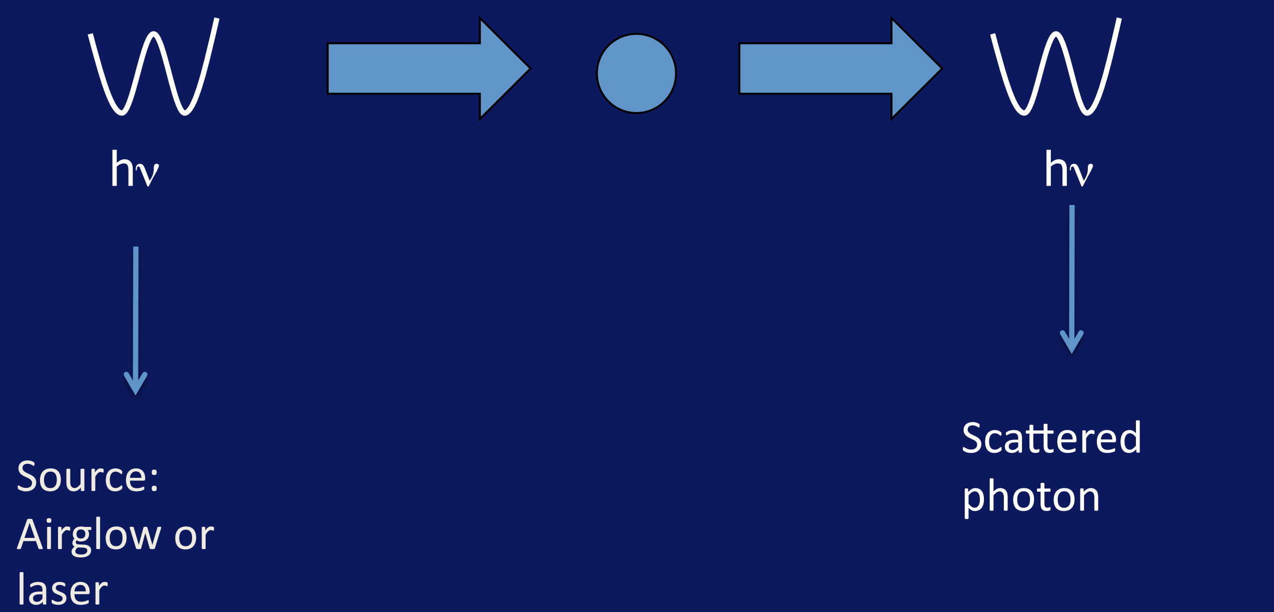
Low temperatures

- Most of EUV removed in thermosphere
- Lack of efficient formation of ozone
- CO_2 contributes directly to the cooling

Occurrence of metallic layers

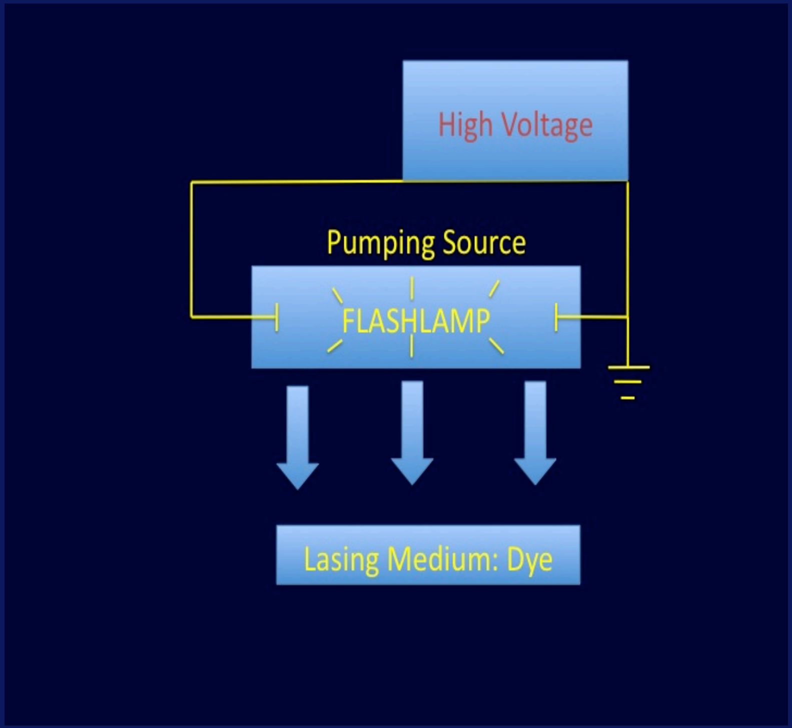
Technique: Resonance Scattering

Resonance : specific atomic transition (source wavelength matched in frequency to the atomic transition frequency.)



A Brief History

- Airglow observations: Existence of Na atoms during twilight (Chamberlain et al., JATP,1958)
- First Lidar observations: Resonance Scattering from atomic Na (Bowman et al., Nature, 1969)
- Long-term Na observations:
  - Clemesha (Southern Hemisphere)
  - C. Y. She (Northern Hemisphere)



A Brief History

- K, Ca, Ca^+ and Fe: Haute Provence, France (44 deg N)
  - Felix et al., 1973 and Megie et al., 1978
  - Observations made one after another
- Na, Fe, Ca^+: Illinois (40 deg N)
  - Gardner et al., (1993)
  - Observed simultaneously
- Ca and Ca^+: (Kulungsborn, Germany)
  - Alpers et al. (1993)

Lidar Equation

$$\left(N(Z)\right) = \left(\eta T_A^2\right) \frac{P_L \tau}{hc/\lambda} \left(\sigma_{eff}\, n(z)\Delta z\right) \frac{A_R}{4\pi z^2} + \left(N_B R\tau\right)$$

- $\left(\eta T_A^2\right)$ → Total Efficiency
- $\frac{P_L \tau}{hc/\lambda}$ → No. of transmitted photons
- $\left(\sigma_{eff}\, n(z)\Delta z\right)$ → Scattering Probability of a photon by an atom
- $\frac{A_R}{4\pi z^2}$ → Probability that a scattered photon will be collected by the telescope
- $\left(N_B R\tau\right)$ → Total Background photons

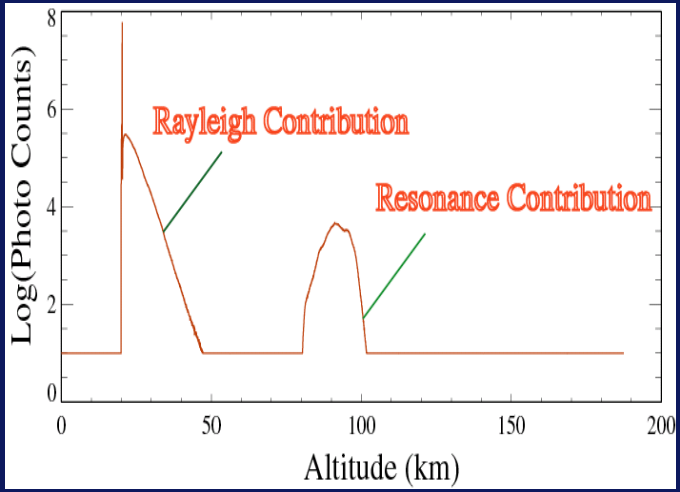
Retrieval of densities: Subtract the measured background counts from the received photon counts

$$n_S(z) = \frac{4\pi z^2 hc/\lambda}{\eta T_A{}^2 P_L A_R \tau \sigma_{eff} \Delta z}\left[N(z) - N_B R\tau\right]$$

Analysis

Absolute Density: Normalize relative to Rayleigh signal from aerosol free region

$$N_R(z) = \left(\eta T_A^{\,2}\right)\left(\frac{P_L\tau}{hc/\lambda}\right)\left(\sigma_R n_A(z)\Delta z\right)\left(\frac{A_R}{4\pi z^2}\right) + N_B R\tau$$



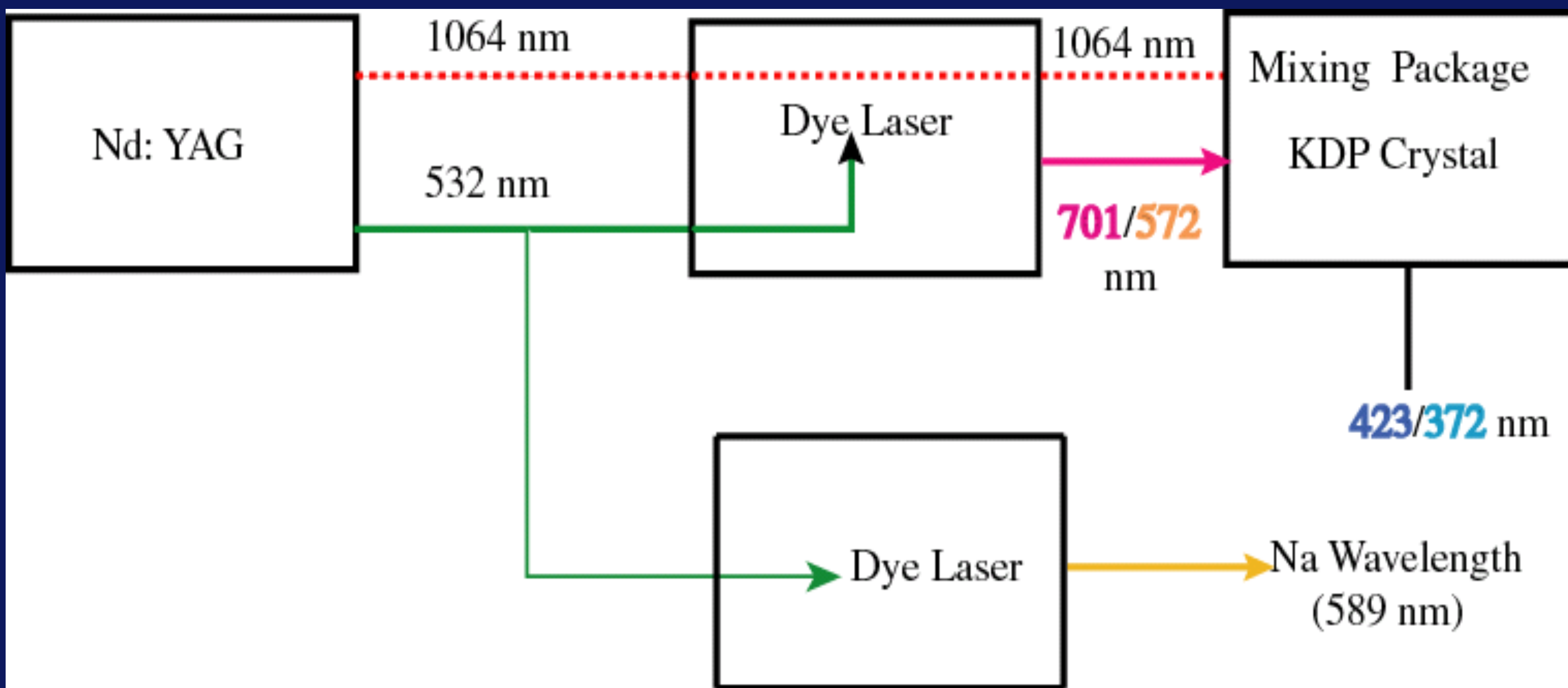
$$n_s(z) = \left(\frac{z^2\sigma_R n_A(z_R)}{z_R^{\,2}\sigma_{eff}}\right)\frac{\left(N(z) - N_B R\tau\right)}{\left(N_R(z_R) - N_B R\tau\right)}$$

Measurement accuracies depend on total photon counts in the profile:

$$N_S = \eta T_A^{\,2}\frac{\left(\sigma_{eff}C_s\right)}{\left(4\pi z^2 hc/\lambda\right)}P_L A_R \tau$$

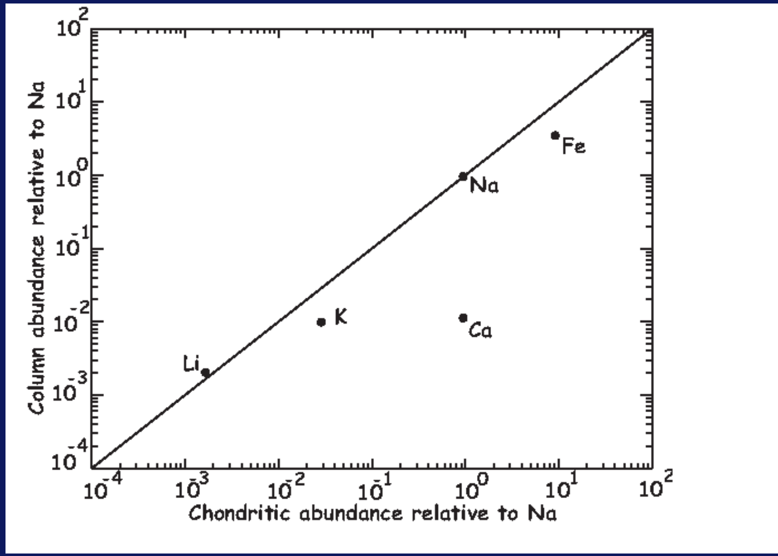
Gardner et al., JGR, 1986

Generation of different wavelengths



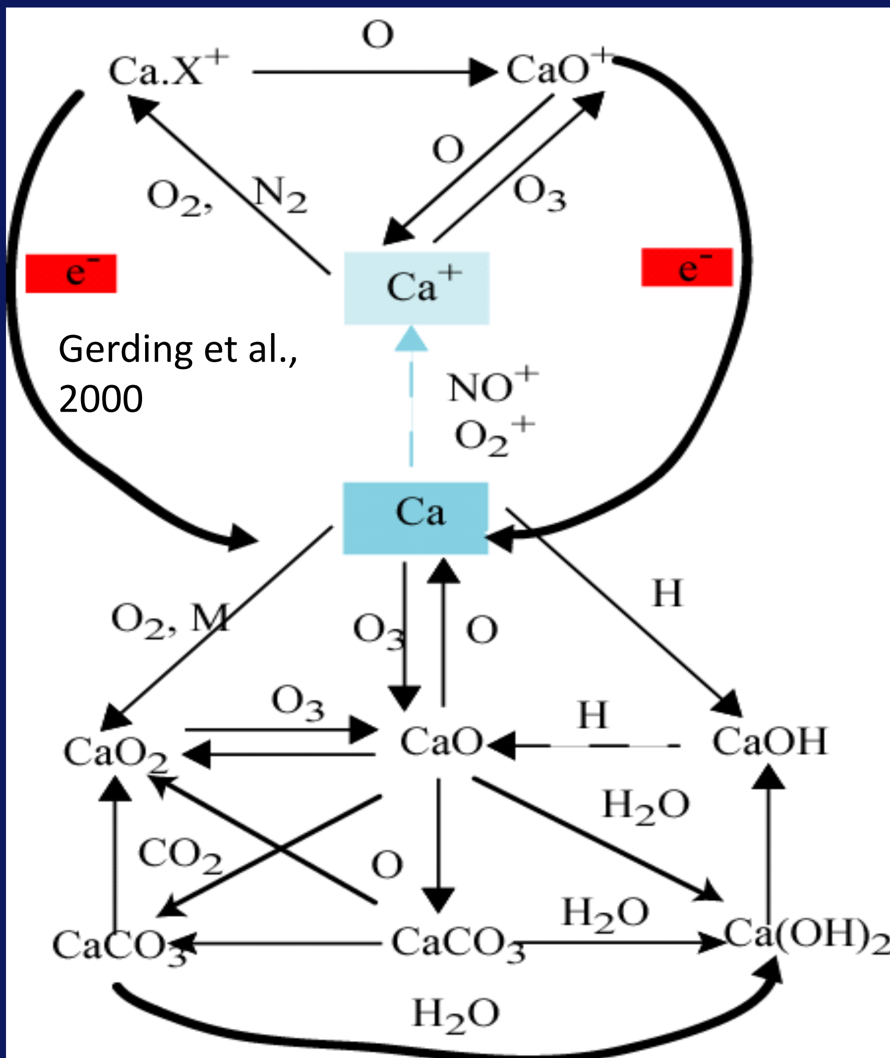
Motivation:

- *Why are some metals more abundant than others?*
  - *Ca and Na: equal abundance in meteoric material but in the mesosphere Na abundance exceeds Ca by a factor of 50 – 100.*
- *Do all the metals behave in similar way?*
- *What factors influence layer structuring?*
- *Is there any difference in the latitudinal distribution of metals?*
- *How are neutrals and ionized species coupled?*

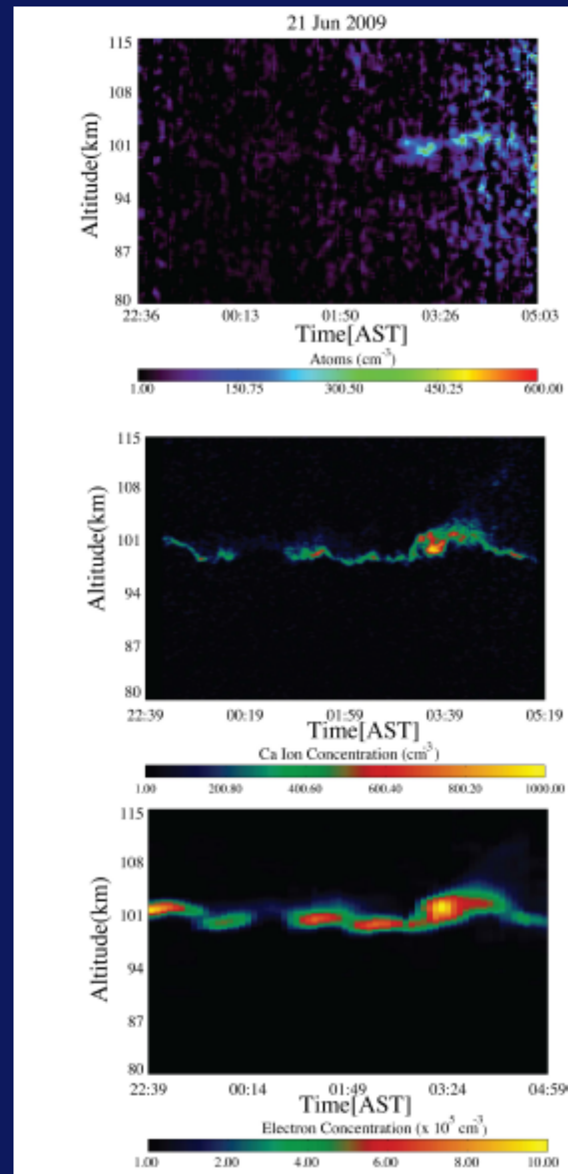


Observations → Development of models

Example of coupling between neutral and ionic species



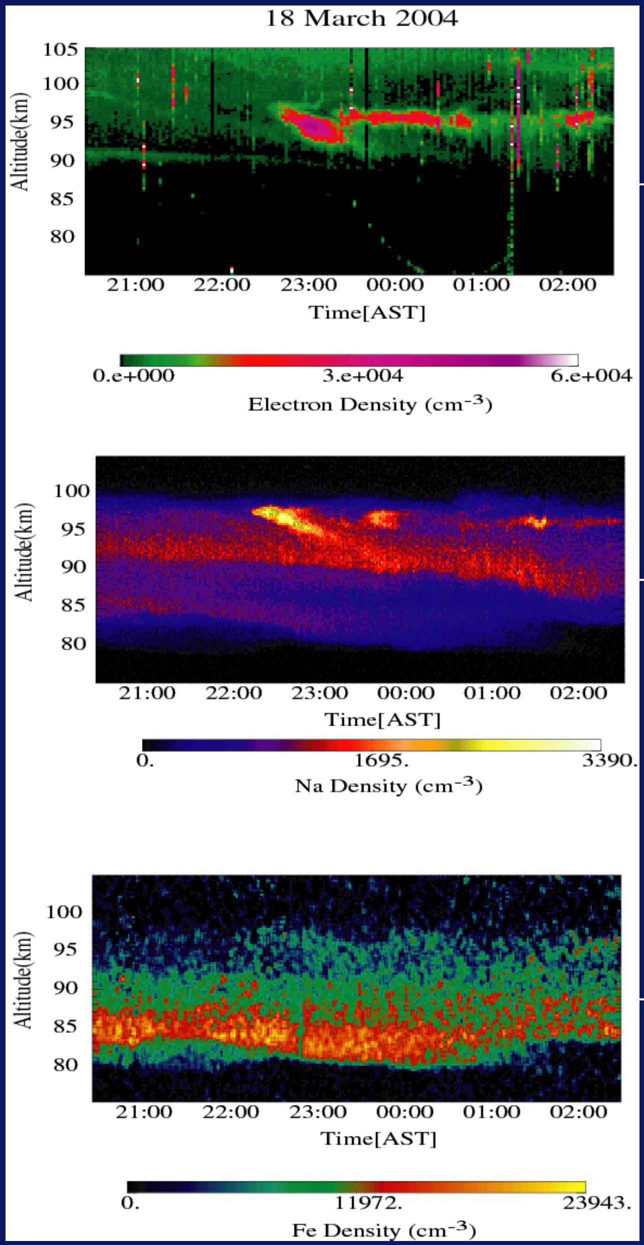
Arecibo Data



Ca neutral from lidar

Ca Ion from lidar

Electron Density from ISR

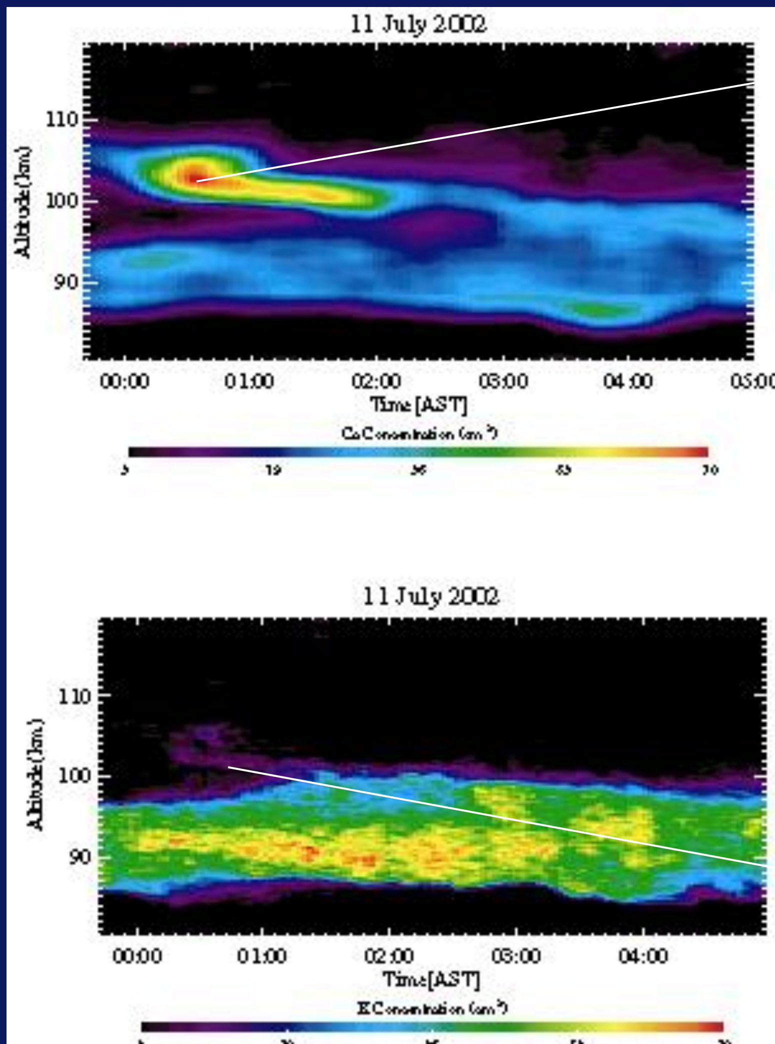


ISR Data: N_e Data

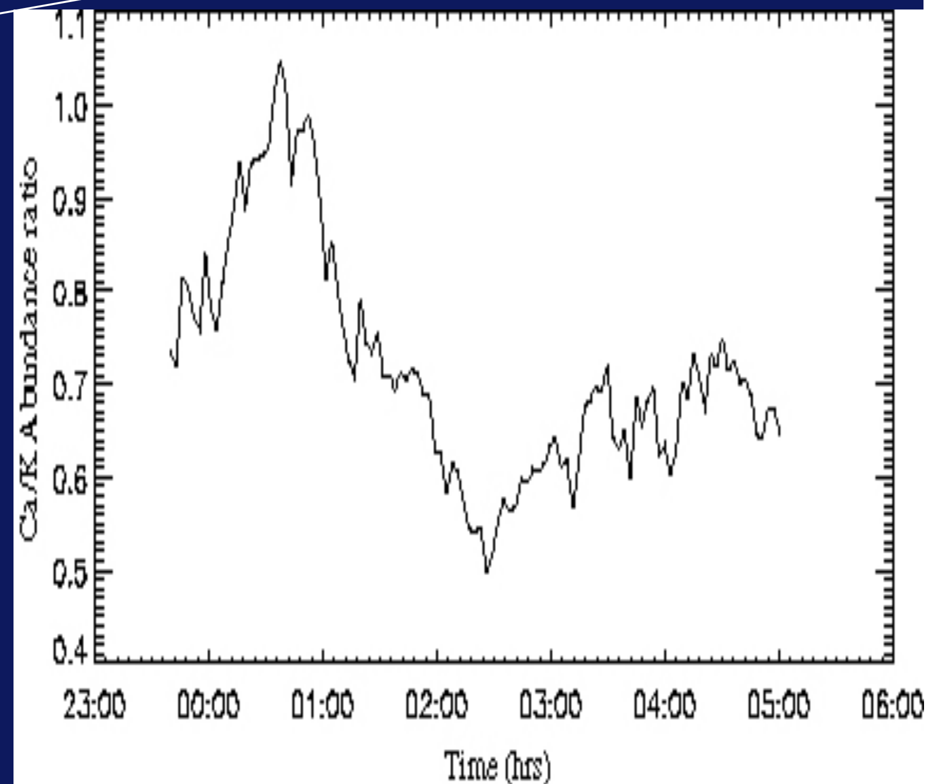
Dye Laser: Na Data

Dye Laser: Fe Data

Characteristics of layers: Examples showing diferences



Ca_S layer



K_S layer

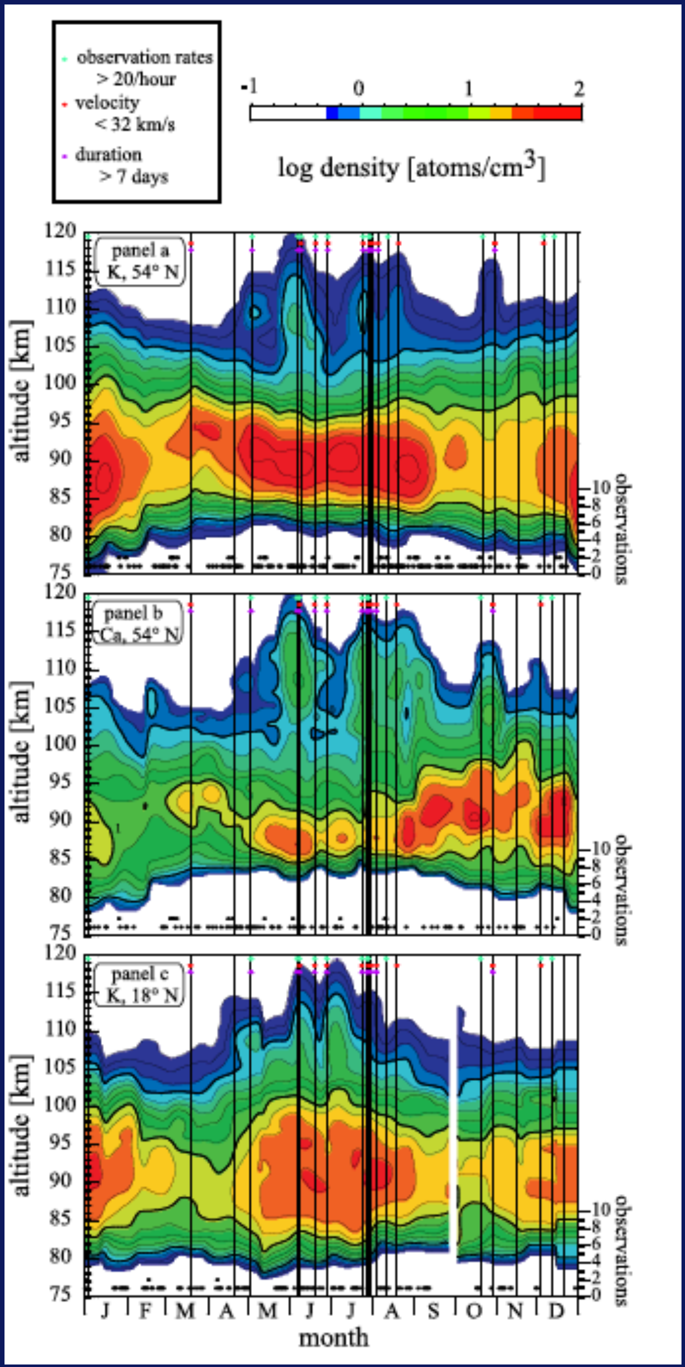
Topside layers

Kühlungsborn (54° N), K data

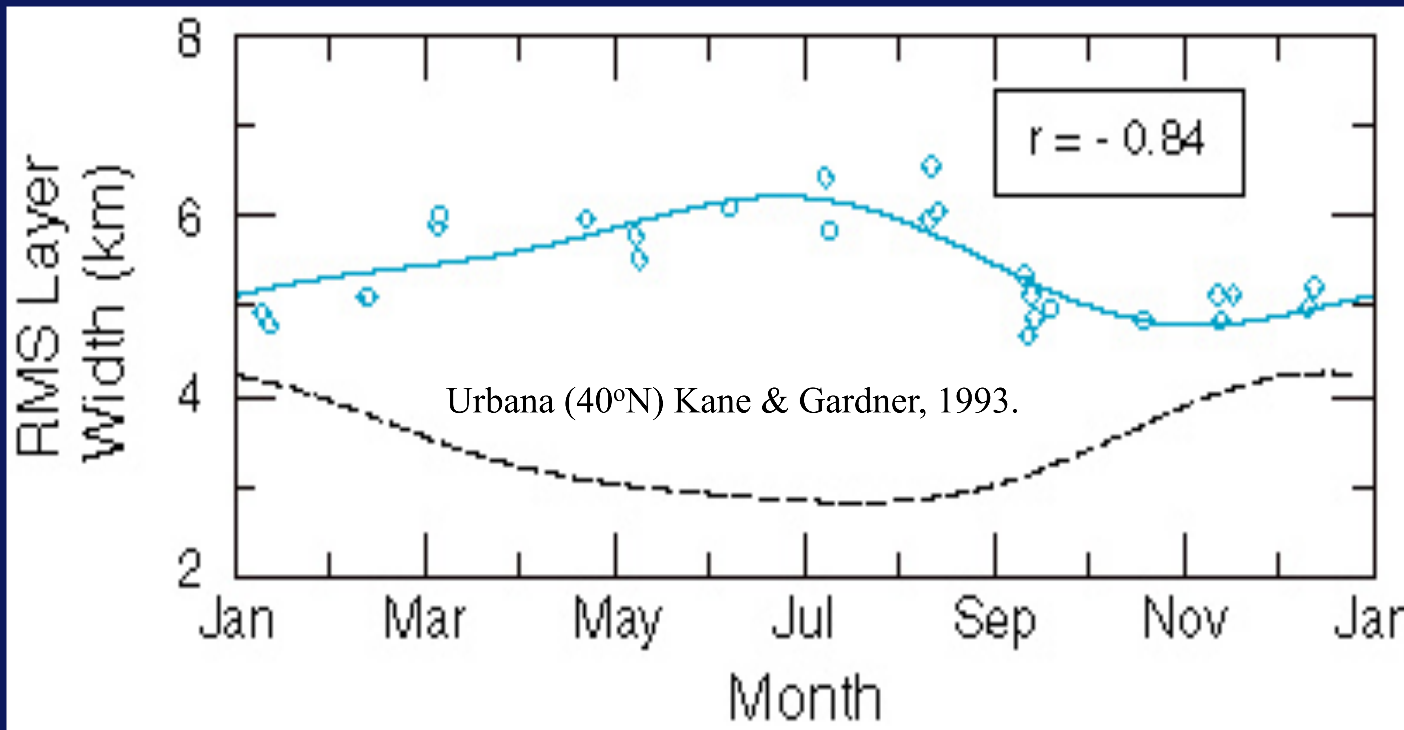
Kühlungsborn (54° N), Ca data

Arecibo (18° N), K data

Höffner and Friedman,
Atmos. Chem. Phys, 2004



Annual variation of RMS width of Fe layer at Arecibo



- RMS widths Summer to winter ratios:

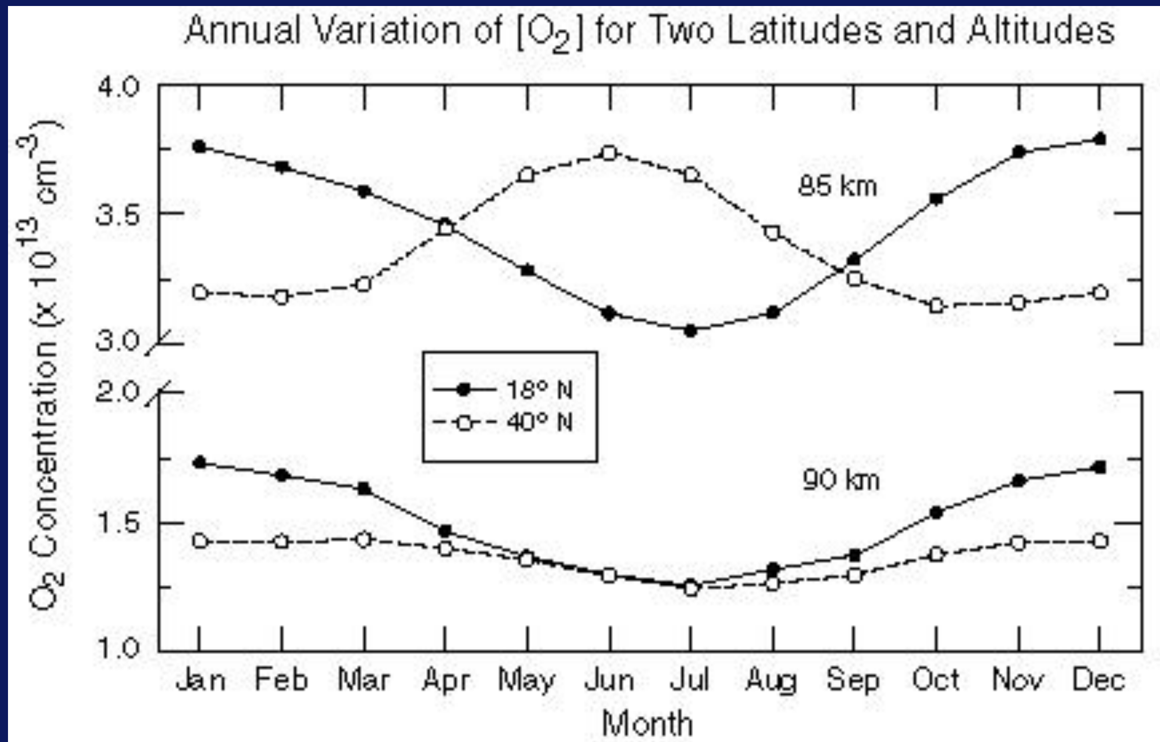
  At Arecibo ≈ 1.30

  At Urbana ≈ 0.66

- Widths mainly governed by the reaction

  $Fe + O_2 + M \rightarrow FeO_2 + M$ (Inverse Temp. Dependence)

Raizada and Tepley, 2003



$Fe + O_2 + M \rightarrow FeO_2 + M$ (Inverse Temp. Dependence)

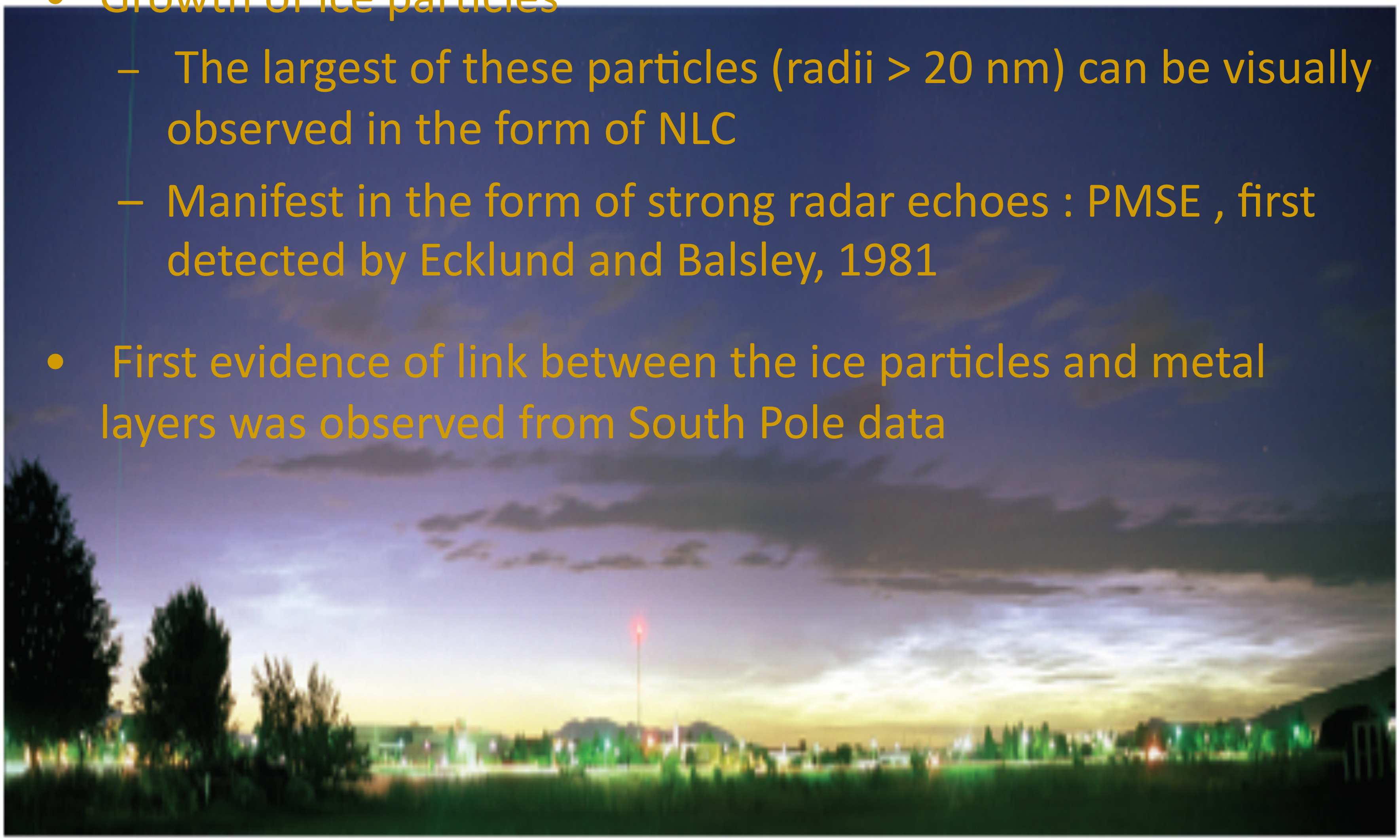
- Smaller widths during summer at mid-latitudes: (a) Cold mesopause temperatures and (b) increase in $[O_2]$

- Warmer temperatures along with less $[O_2]$ at low latitudes slows the removal of Fe during summer time causing broader widths.

Other consequences of low temperatures :

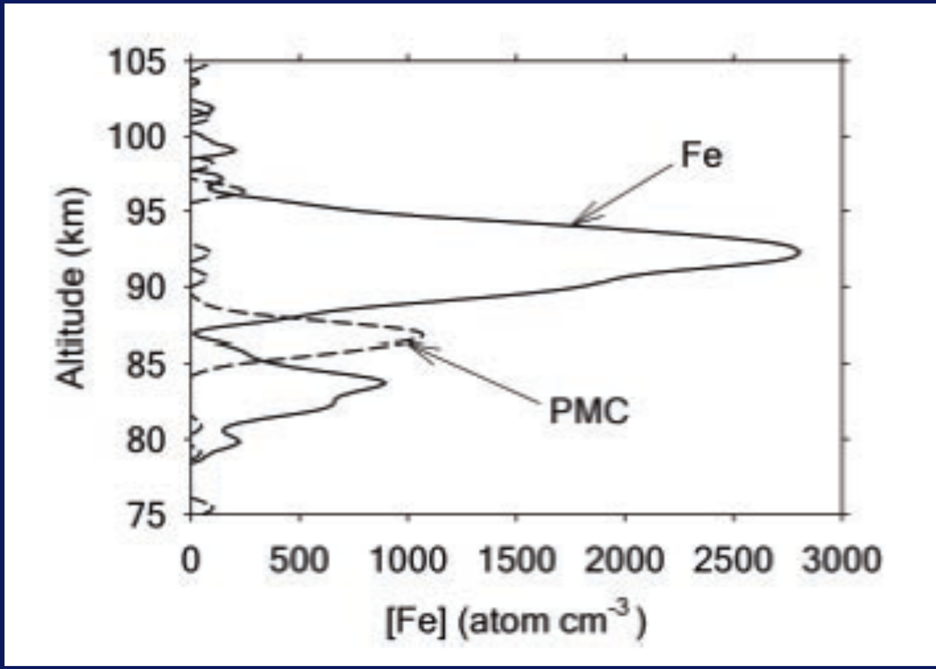
- Growth of ice particles
  - The largest of these particles (radii > 20 nm) can be visually observed in the form of NLC
  - Manifest in the form of strong radar echoes : PMSE , first detected by Ecklund and Balsley, 1981

- First evidence of link between the ice particles and metal layers was observed from South Pole data

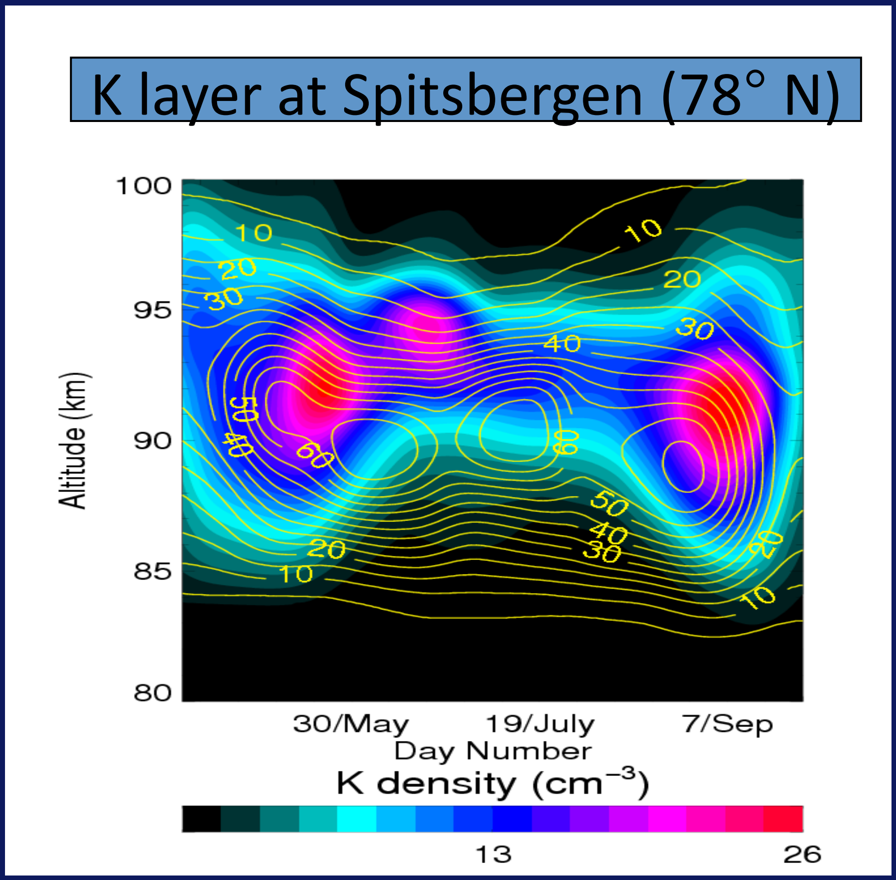


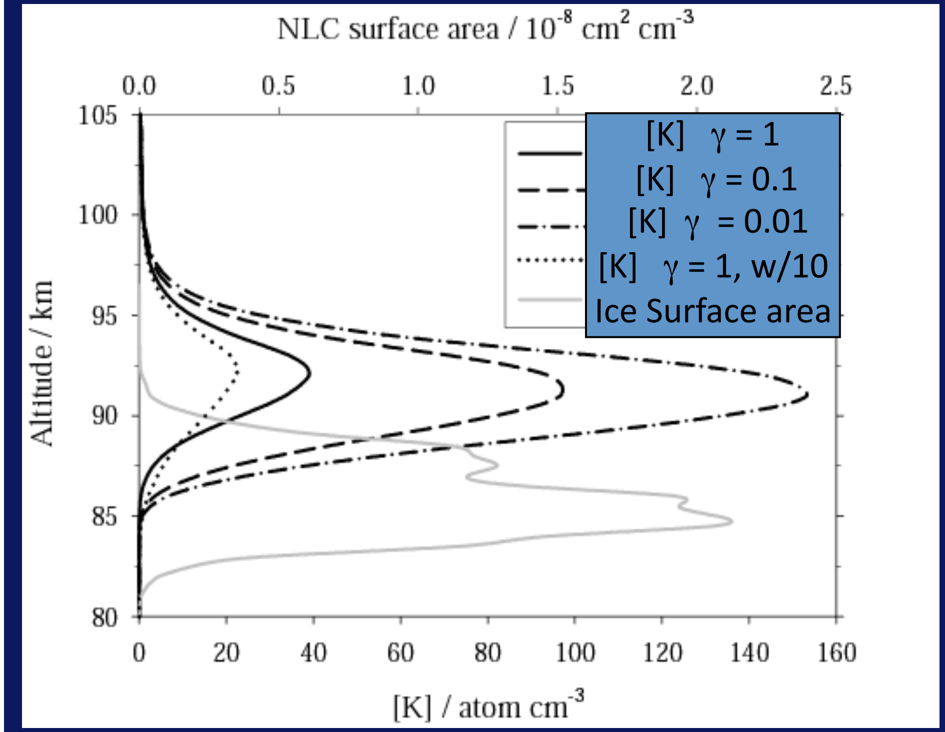
Wickwar V. B., M. J. Taylor, & J. P. Herron, JGR, 2002

The coldest part of the mesosphere occurs during summertime at high latitudes.



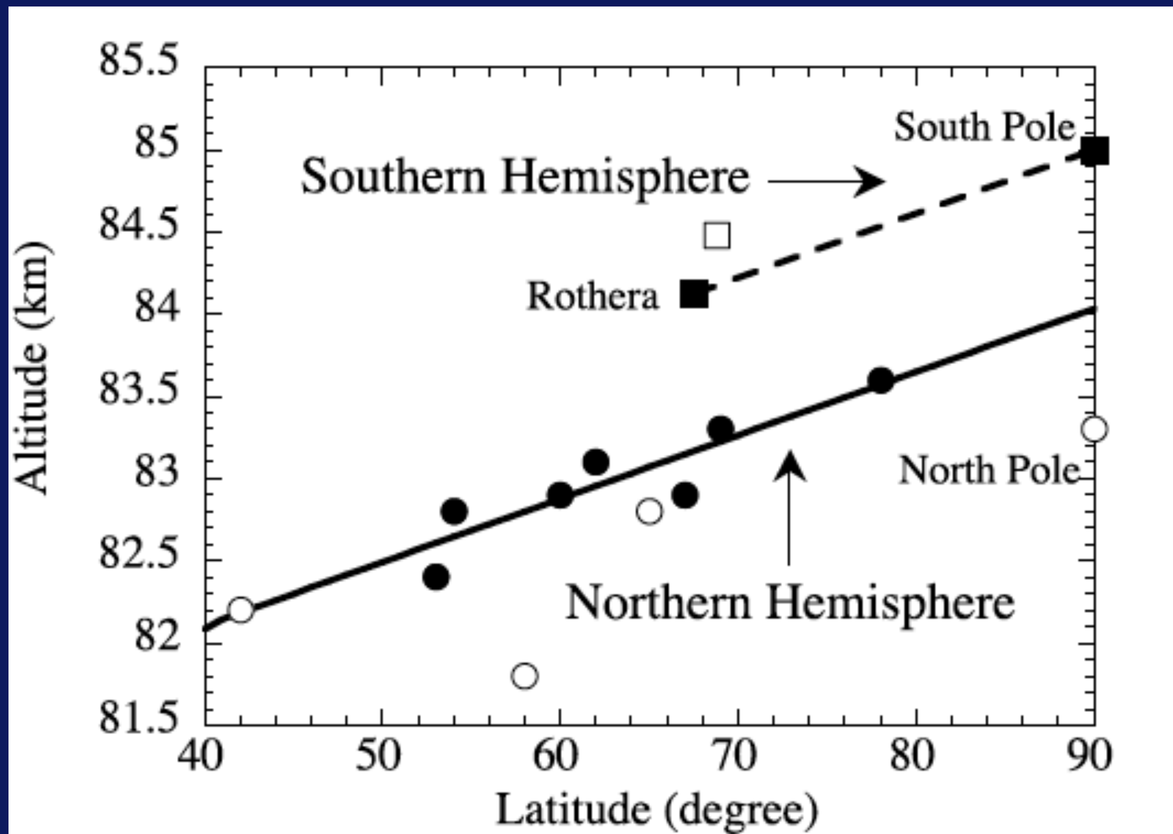
Plane et al., Science, 2004





(Raizada et al., JGR, 2008)

Hemispheric differences in PMC altitudes



Modeling work: differences in solar flux and mean flow driven by GWs can contribute to this variation in PMC altitudes.

(Chu et al., JGR, 2006)

Summary

- Different metal layers often display layering structures that are not correlated
- Main layers show seasonal distribution that varies from one metal to other, along with strong latitudinal variation
- Topside layers, even though weak, show same seasonal variation for different metals and a weak latitudinal variation.
- At high latitudes, PMC cause removal of metals.