A Non-linear Reaction of the Ionosphere and Thermosphere to Solar Cycle EUV Variations

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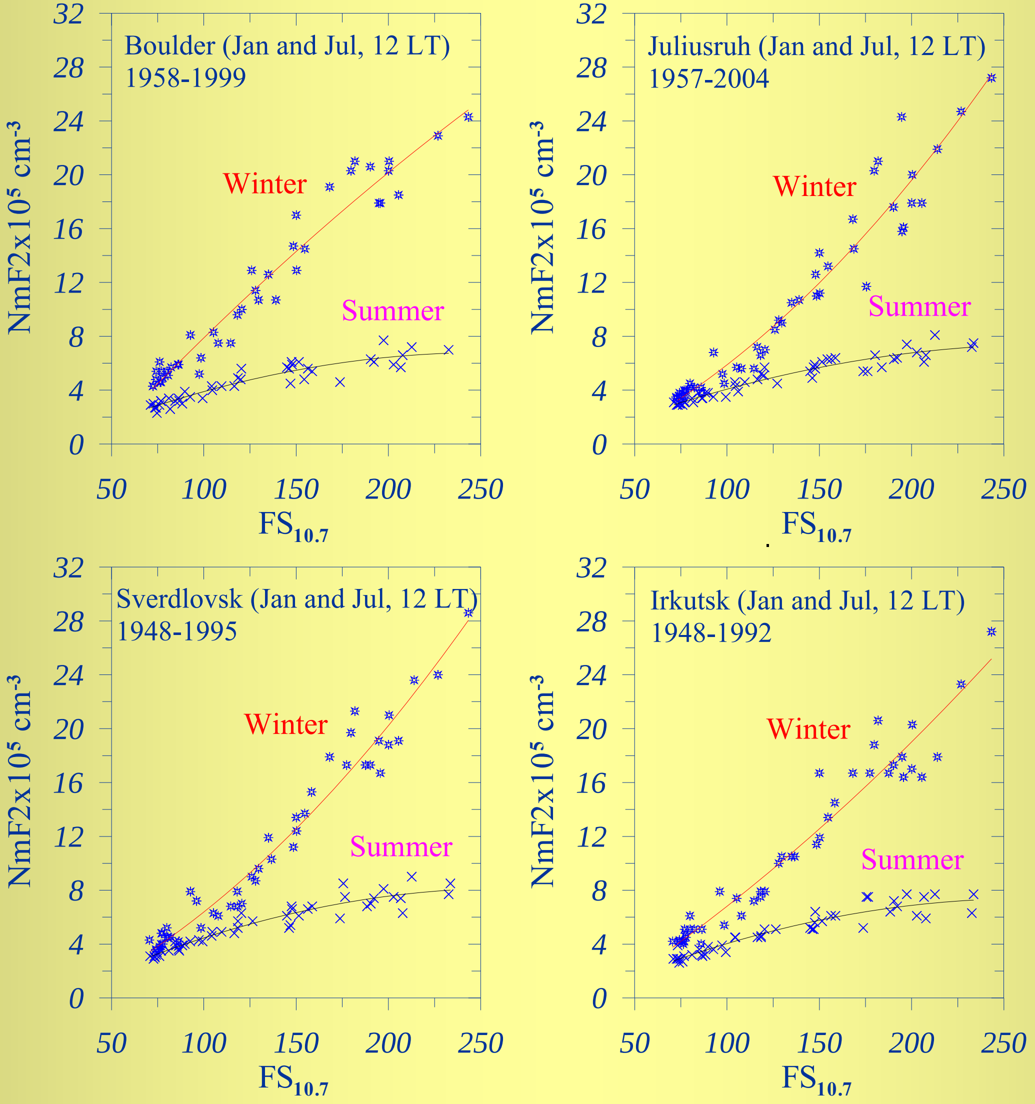
The Problem Formulation

1. Solar EUV flux ionizing F2-region varies by 1.9-2.9 time in solar cycle, while daytime mid-latitude NmF2 varies by 5-6 times in Winter and by 2-2.5 times in Summer.

2. Practically linear NmF2 increase in Winter, but a saturation effect in Summer

This is a well-known feature of the F2-layer Solar Cycle variations

Winter and Summer median NmF2 Solar Cycle Variations

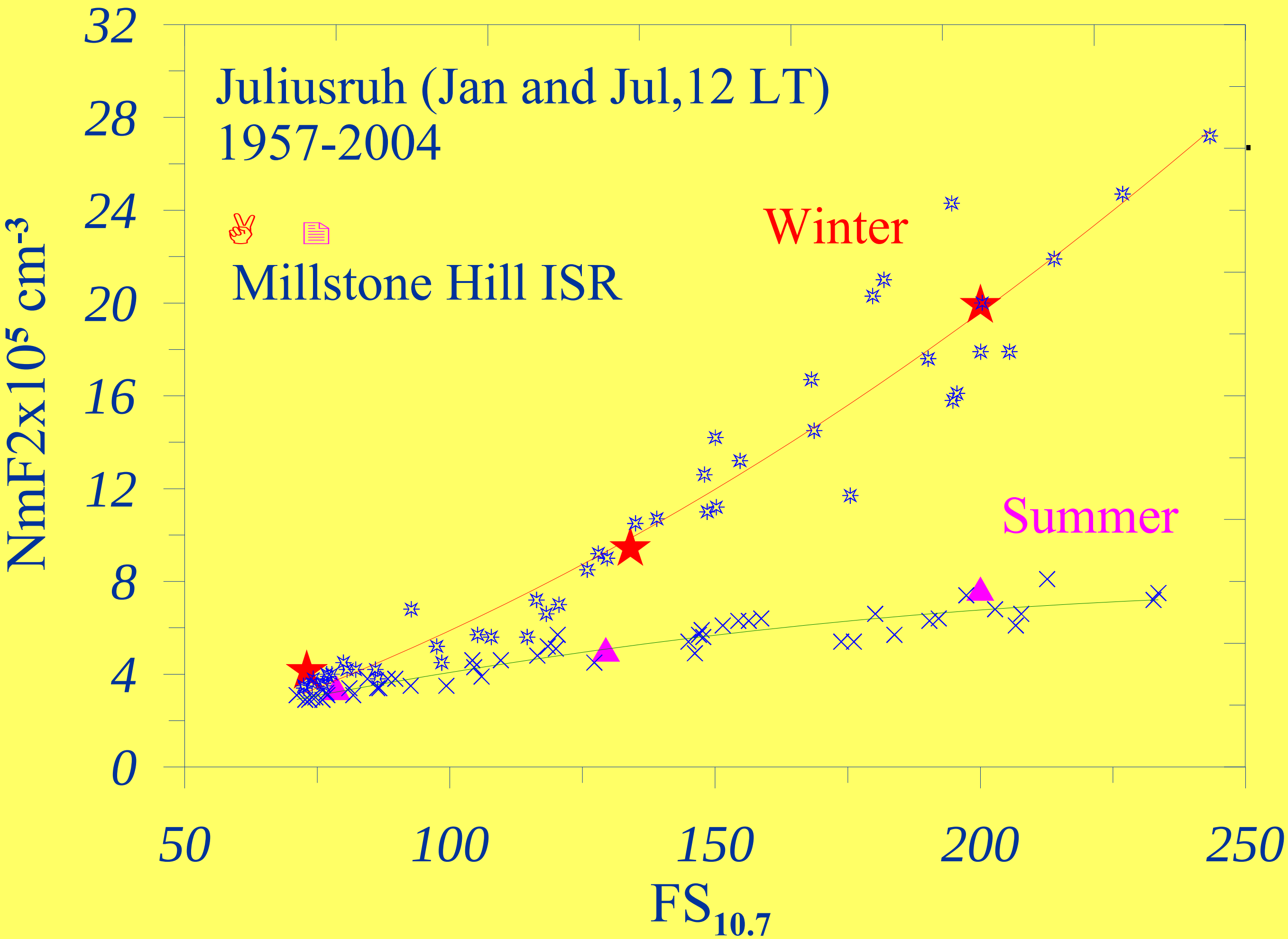


To understand the reason of these variations accurate ionospheric observations should be used and main Aeronomic Parameters:

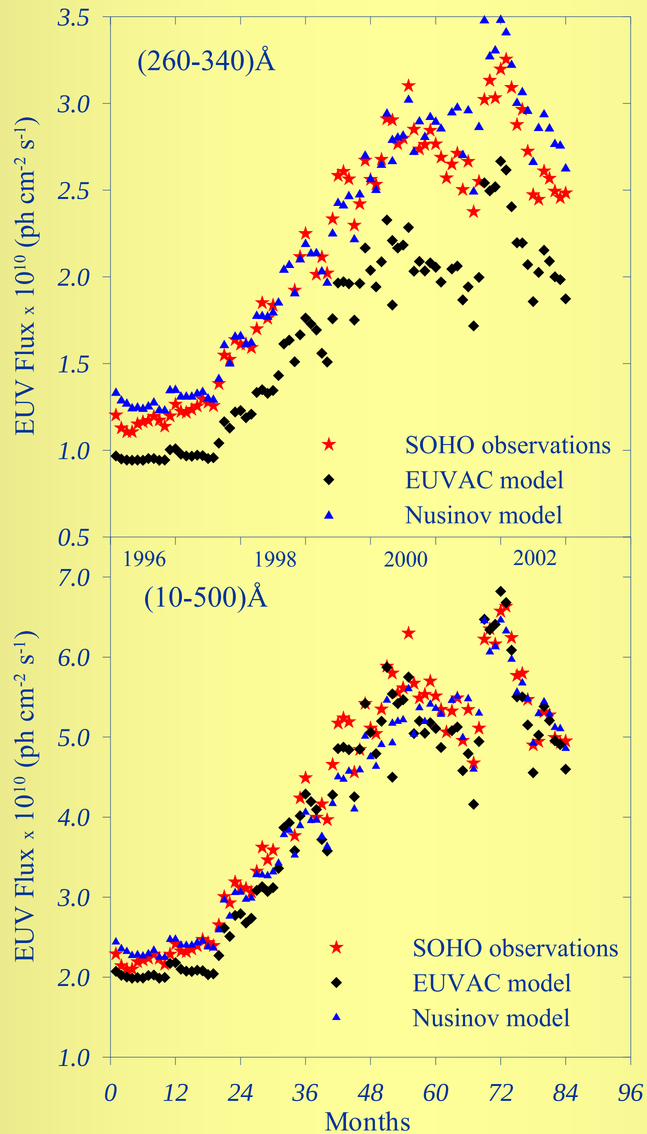
1. Ionizing Solar EUV radiation
2. Neutral composition ([O],[O_2],[N_2]) and temperature T(h)
3. Vertical plasma drift

should be specified for the conditions in question

Only Incoherent Scatter Observations can be used for such analysis



A comparison of EUV models with SOHO observations



EUV Model by
A. Nusinov (1984)
can be used for our
aeronomic calculations

A Self-Consistent Method for Modeling Ne(h) in the F2-region Using ISR Observations

INPUT

Routine ISR Observations

$N_e(h)$

$T_e(h)$

$T_i(h)$

$V_i(h)$

→

F2-layer Theoretical Model

→

OUTPUT

A Self-Consistent Set of Thermosphere Parameters

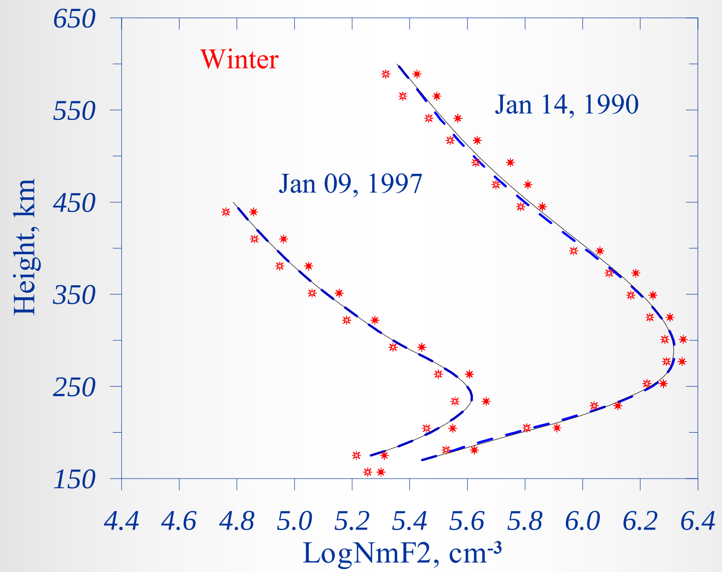
$T_n = f(T_{ex}, T_{120}, S)$

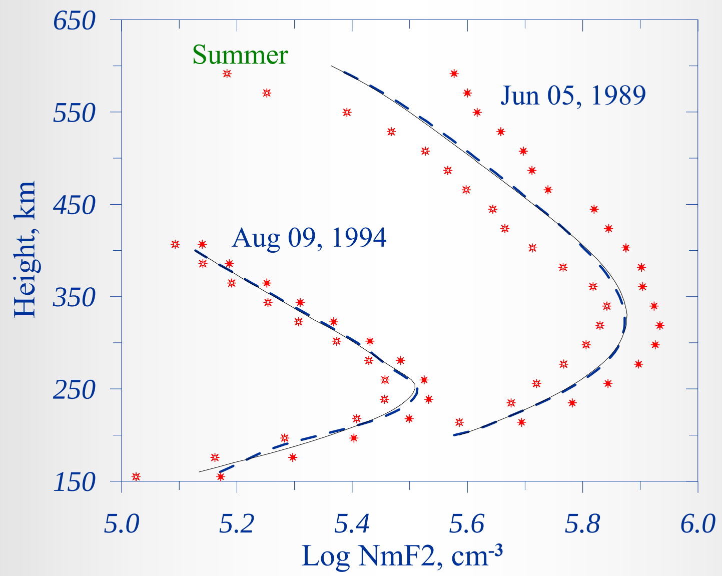
$[O], [O_2], [N_2]$

$W(h) \rightarrow V_{nx}$

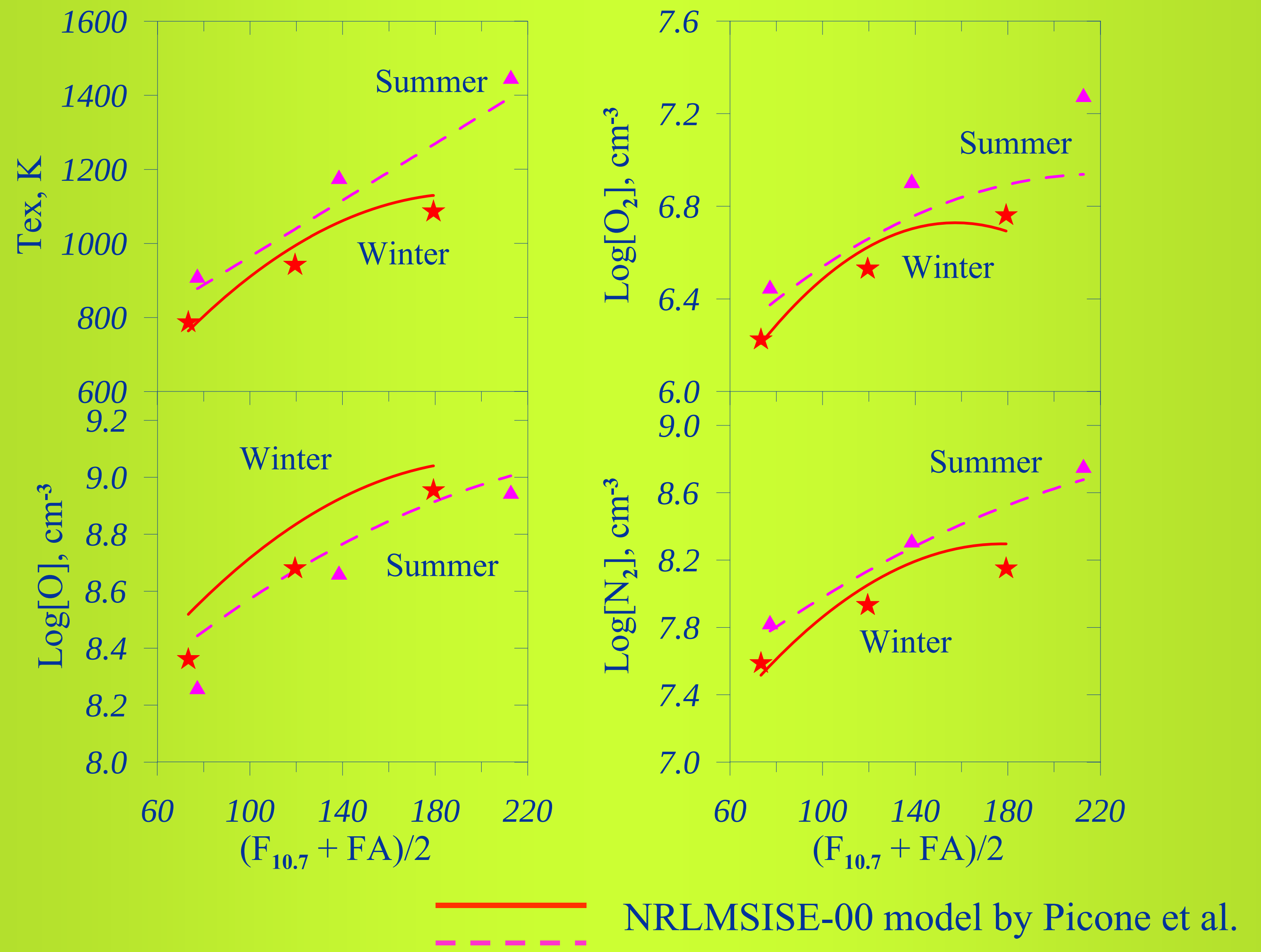
Ion Composition

Observed (ISR) and Calculated Ne(h) Profiles for Winter and Summer under Solar Maximum and Minimum





Calculated and Model Thermospheric Parameters at 300 km



The retrieved aeronomic parameters controlling the Ne(h) distribution do not bear the shortcomings of thermosphere empirical models.

They constitute a consistent set of basic parameters which can be used for quantitative estimates.

This is the basic difference from other similar approaches

For mid-latitude daytime F2-layer the well-known expressions by Rishbeth and Barron (1960) can be used.

$$NmF2 = 0.75 q_m / \beta_m \qquad \beta_m = 0.6 D_m \sin^2 I / H^2$$

where all parameters are given at the hmF2 height

q_m – O^+ ion production rate

D_m – ambipolar diffusion coefficient

β_m – linear loss coefficient for O^+ ions

H – atomic oxygen scale height

I – magnetic inclination

In fact the above expression for NmF2 and hmF2 reflect the idea of isobaric F2-layer by Rishbeth and Edwards (1989) – the F2-layer follows the level of P=const in its variations

Calculated aeronomic parameters at the hmF2 height for Winter and Summer days under Solar Minimum and Solar Maximum

Date	lgNmF2 hmF2, km	T_{ex} K	$lg[O]_m$ cm^{-3}	$lg[O_2]_m$ cm^{-3}	$lg[N_2]_m$ cm^{-3}	γ_1 $x10^{-13}$ $cm^3\ s^{-1}$	γ_2 $x10^{-12}$ $cm^3\ s^{-1}$	q_m $x10^2$ $cm^{-3}\ s^{-1}$	β_m $x10^{-4}$ s^{-1}	q_m/β_m $x10^6$ cm^{-3}	W $m\ s^{-1}$
09.01.97	5.616 238	787	9.001	7.490	8.695	5.411	9.528	3.358	5.625	0.597	-6.7
14.01.90	6.315 289	1086	9.063	6.975	8.338	6.699	7.627	7.688	2.178	3.530	-8.2
09.08.94	5.509 252	907	8.694	7.300	8.570	5.851	8.708	1.882	3.911	0.481	+7.1
05.06.89	5.876 328	1444	8.803	7.003	8.511	10.09	6.222	4.954	3.895	1.272	-9.2

This set of aeronomic parameters enables us to make all quantitative estimates

Seasonal/Solar Cycle Variations of q_m/β_m ~NmF2

The q_m/β_m variations are: 5.91 time for Winter

and 2.64 times for Summer.

Ion production rate q_m increases:

by 2.29 times in Winter

and by 2.63 times in Summer

Loss coefficient β_m decreases:

by 2.58 times in Winter

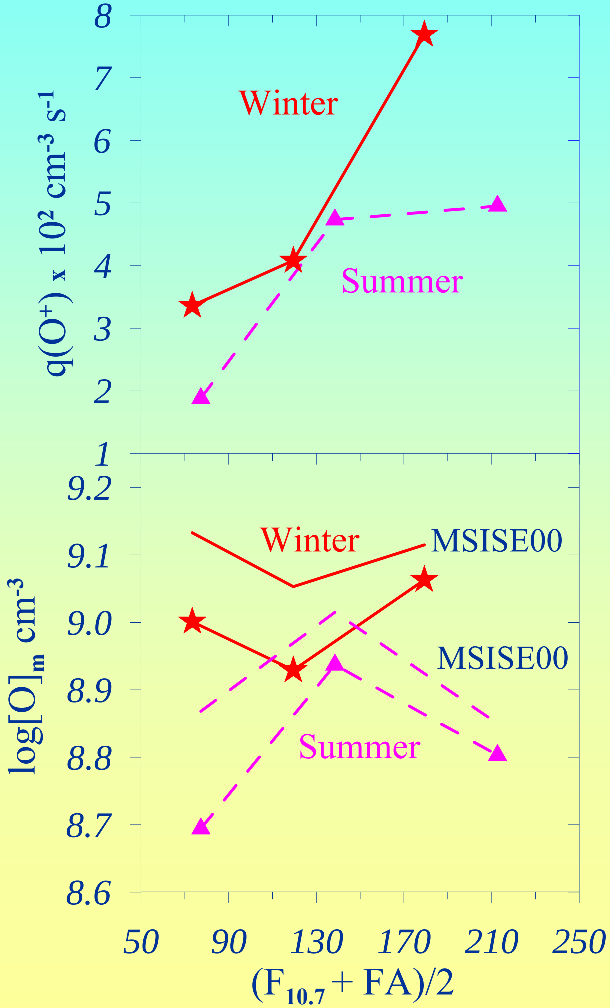
and by ≈1.0 times in Summer !

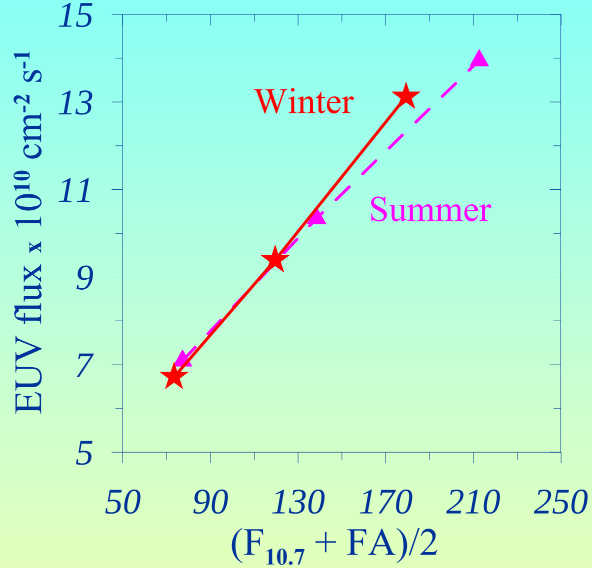
when we pass from Solar Minimum to Solar Maximum

That is loss coefficient β does not practically change at the hmF2 height in Summer and the NmF2 increase is totally due to q_m increase.

In Winter the contributions of q_m and β_m to the NmF2 increase are comparable.

Under Δβm ≈ 1 the leading role in forming the Summer Saturation Effect belongs to $[O]_m$ variations as $NmF2 \sim q_m/\beta_m$ and $q_m \sim I_{EUV}[O]_m$





A two-component model by Nusinov

Notice - there is no saturation effect in EUV variations with solar activity as it is widely accepted to think.

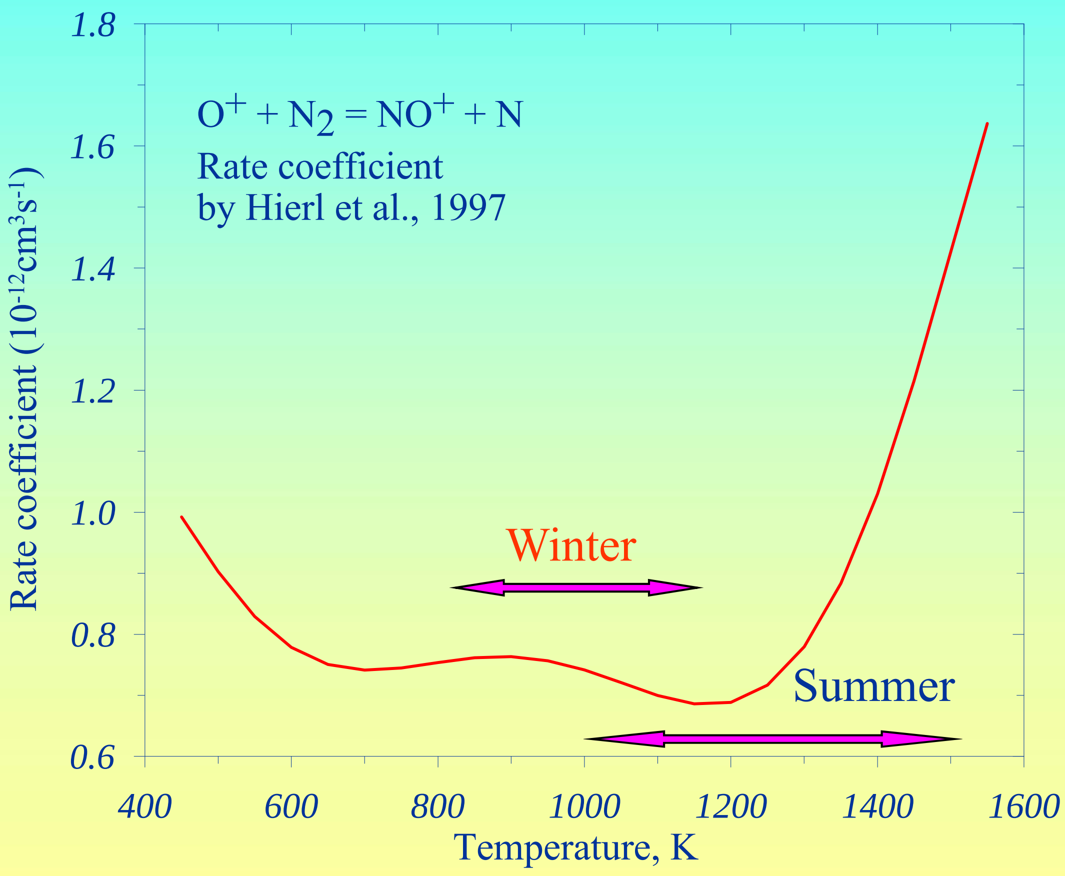
Why Δβm is small in Summer ?

Winter	Summer
$[N_2]$ decrease at hmF2 height by	
2.27 times	1.15 times
$\gamma\ (O^+ + N_2)$ increase at hmF2 height by	
1.08 times	1.72 times

That is in summer the $\gamma\ (O^+ + N_2)$ increase overcompensates the $[N_2]$ decrease

While in Winter the situation is quite different

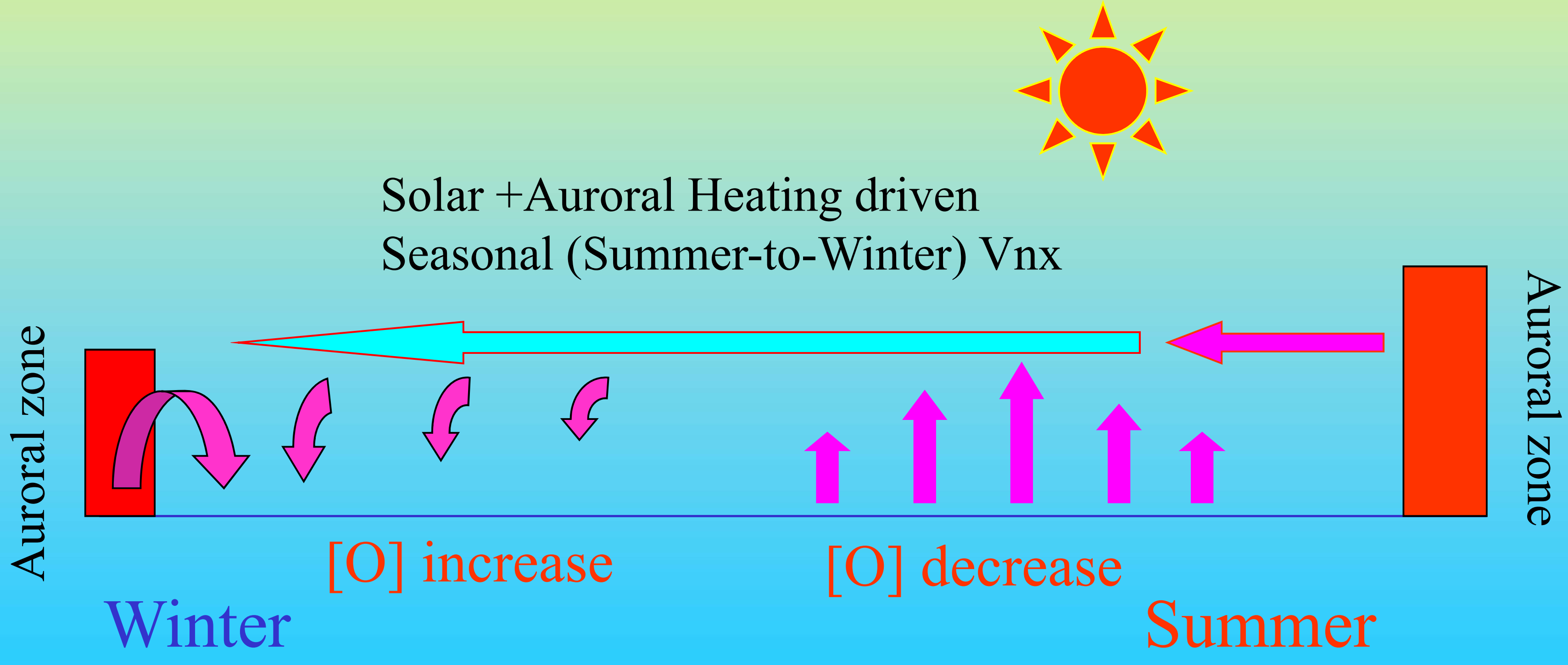
The main difference between Summer and Winter is in Temperature variation range when we pass from Solar Minimum to Solar Maximum



Seasonal Thermosphere Circulation

Leading to the [O]/[N_2] Summer Decrease

This is the first step in the chain of processes leading to the Summer NmF2 saturation effect



The Chain of Processes Leading to the Summer Saturation Effect

O/N_2 summer decrease due to Tn increase, upwelling with summer-to-winter hemisphere transfer

↓

NmF2 decrease as NmF2 ~ q_m/β_m

↓

Te increase due to a decrease of electrons cooling ⇨ Tn increase

↓

Tv increase

↓

γ ($O^+ + N_2$) increase

↓

β increase

↓

NmF2 decrease as NmF2 ~ q_m/β_m

But this an avalanche type process stops in some steps at Te ≈ 2600K in the F2-layer under solar maximum due to:
Confined solar EUV energy;
Confined plasmaspheric energy reservoir;
Cooling effect of winter hemisphere;
Thermal conductivity
Cooling in collisions with ions and neutrals

Summer/Winter difference in NmF2 variations is mainly due to different temperatures

and a corresponding decrease in thermospheric species

([O], $[N_2]$, $[O_2]$) at the hmF2 height

($P = nkT \approx$ constant)

The leading role belongs to Temperature.

Conclusions

1. The observed NmF2 increase in Solar cycle is due to two reasons: one is EUV increase by a factor of 2, the other reason is due to [O] and β variations at the hmF2 height.

2. The difference between Winter and Summer in the course of Solar cycle is in temperature: T< 1200 K in Winter and T >1200 K in Summer. This results in different $\gamma_1(O^+ + N_2)$ and larger hmF2 in Summer.

Conclusions

3. Summer decrease in [O] and small variation in $\beta = \gamma_1[N_2]+\gamma_2[O_2]$ at hmF2 under high solar activity results in the <u>saturation effect in NmF2 under solar maximum.</u>

4. The Summer saturation effect in NmF2 results from a long chain of non-linear processes:

 → O/N_2 ↓ → NmF2 ↓ → Te ↑ → (Tn, Tv) ↑ → γ_1 ↑ → β ↑ → NmF2 ↓ → O/N_2 ↓ due to upwelling and so on.