

Impact of the solar rotational cycle on middle atmospheric (stratosphere, mesosphere) ozone

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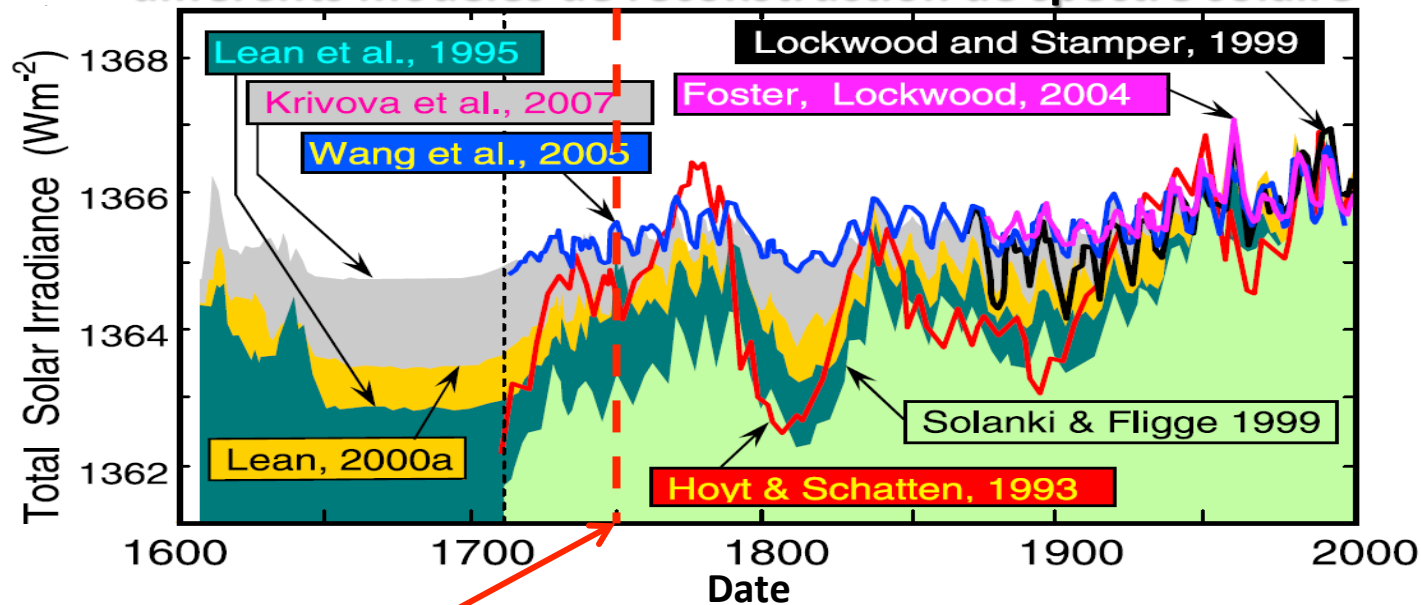


10 March 2015

Uncertainties about the action mechanisms and amplitude of the solar forcing

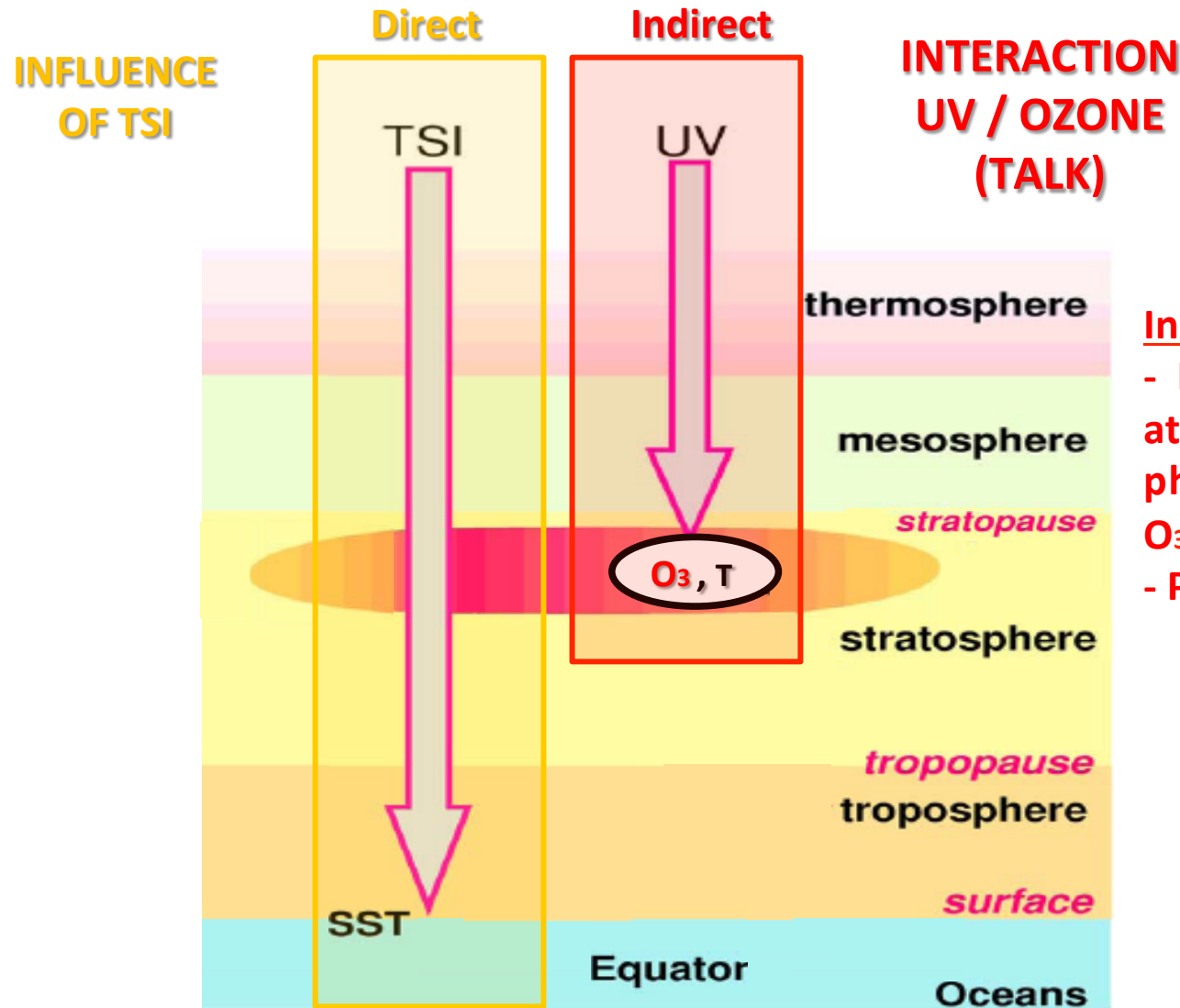
For example : IPCC Solar Radiative forcing (since 1750)= $0.05 (+/-0.05) \text{ W/m}^2$
 Taken from 1 reconstruction (Krivova et al., 2010); « low agreement” and “medium evidence”, this RF value has a low confidence level (IPCC, 2014)

Variations temporelles de l'éclairement solaire total (TSI) tirées de différents modèles de reconstruction de spectre solaire



1750
 (Différences $\approx 2-3 \text{ W/m}^2$)

(Gray et al., Rev. of Geophysics, 2010)

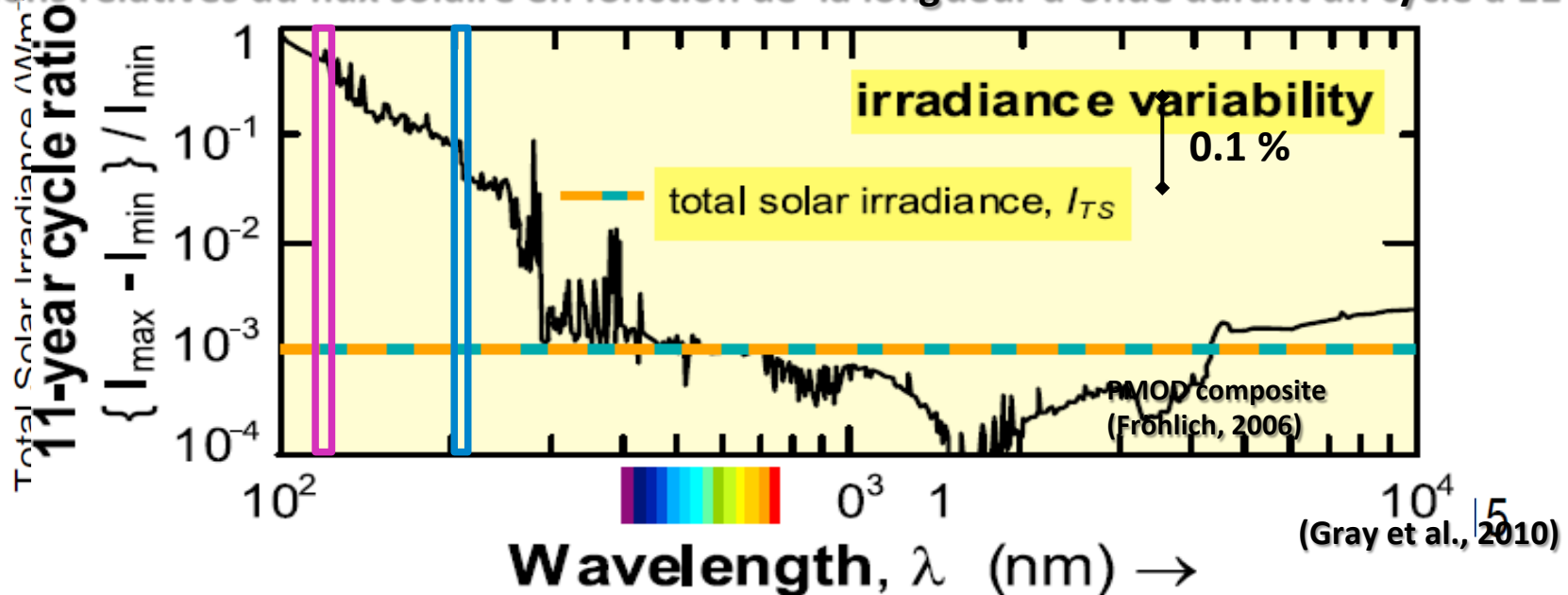


Indirect mechanism:

- Impact of UV on middle atmosphere dominated by photochemistry (notably O₃ chemistry)
- Propagation to surface?

Temporal evolution of total solar irradiance (TSI)

Variations relatives du flux solaire en fonction de la longueur d'onde durant un cycle à 11 ans



Sur le cycle à 11 ans :

$\Delta(\text{Eclairment total ou TSI}) \approx 0.1 \%$

$\Delta(\text{UV, } \lambda=205 \text{ nm}) \approx 5-10\%$

$\Delta(\text{Lyman-}\alpha, \lambda=121.6 \text{ nm}) \approx 50\%$

Variabilité spectrale augmente lorsque la longueur d'onde diminue

Sur le cycle à 27 jours :

Variabilité totale et spectrale comparable à celle du cycle à 11 ans lors des maxima solaires

What is the response of middle atmospheric (stratosphere et mesosphere) ozone to solar variations?

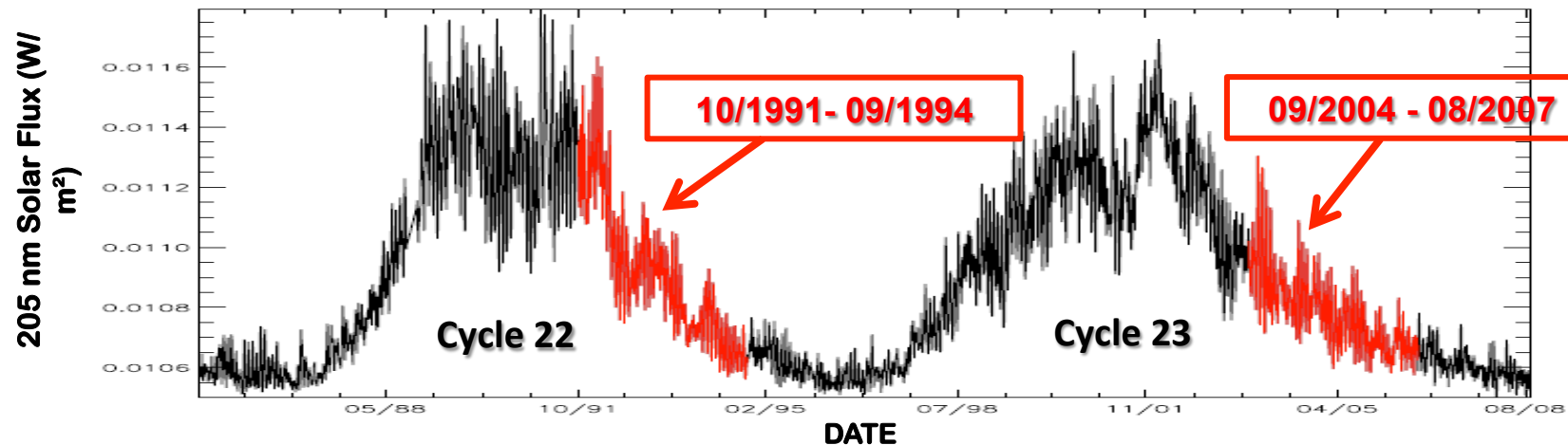
Past studies (observations and models), mostly on 11-yr solar cycles:

- Solar variability impacts middle atmospheric ozone, essentially via UV variability and photochemical processes
- > However , still large differences (observations, models) in ozone response to 11 years solar variability → Origins: at best 3 11-yr solar cycles?

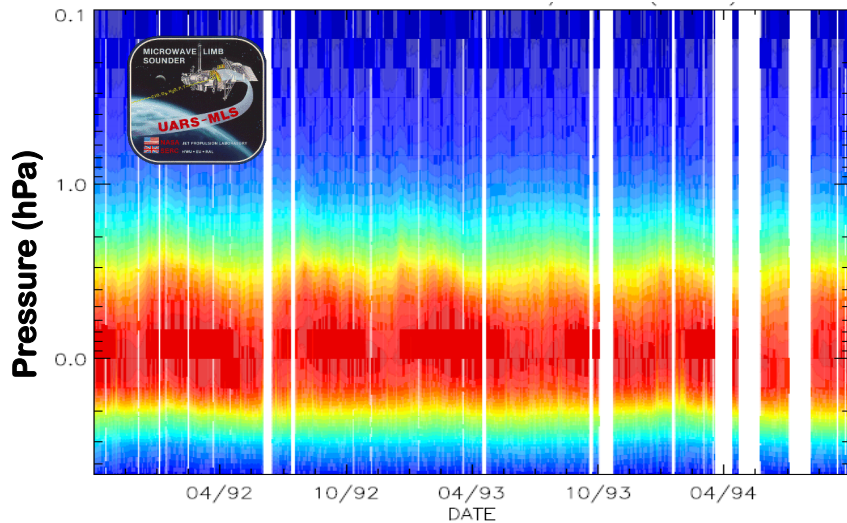
If only interested in estimating the “initial” ozone response, better focus on solar rotational cycle (~27 days):

- same photochemical processes than for 11-yr cycle
- amplitude of spectral variations of the order of the 11-yr cycle
- > Advantage: estimation more robust because observational time series cover about 130 times more rotational cycles than 11-yr cycles
- > Advantage: interpretation easier, is less dynamical feedbacks

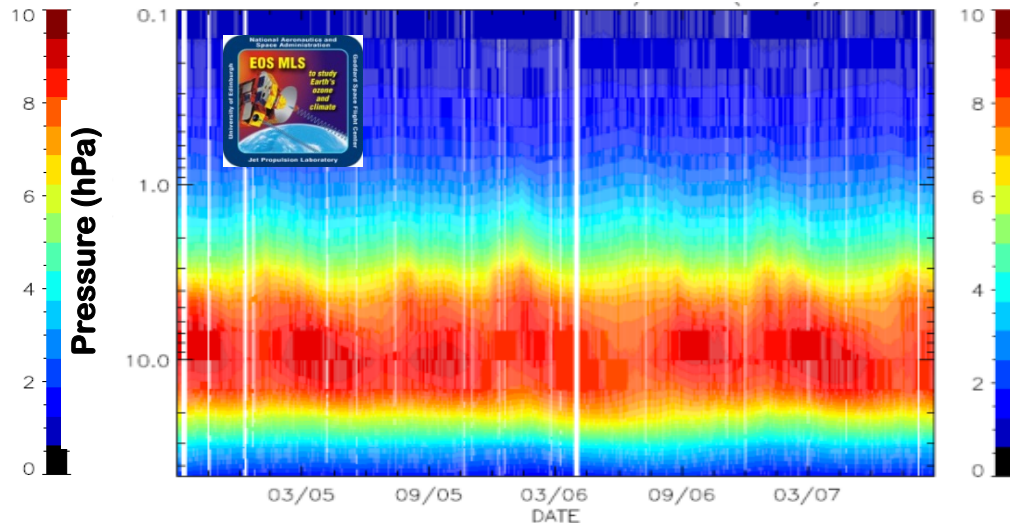
Solar irradiance at 205 nm (W/m²) from NRL-SSI model



Ozone tropical (ppmv)



MLS/UARS (cycle solaire 22)

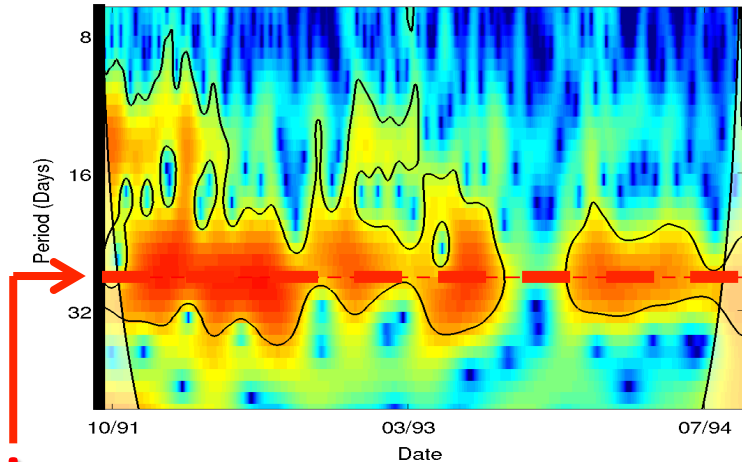
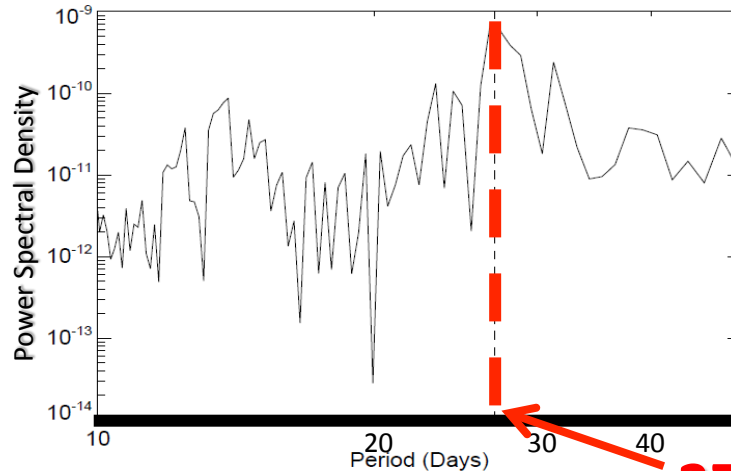


MLS/Aura (cycle solaire 23)

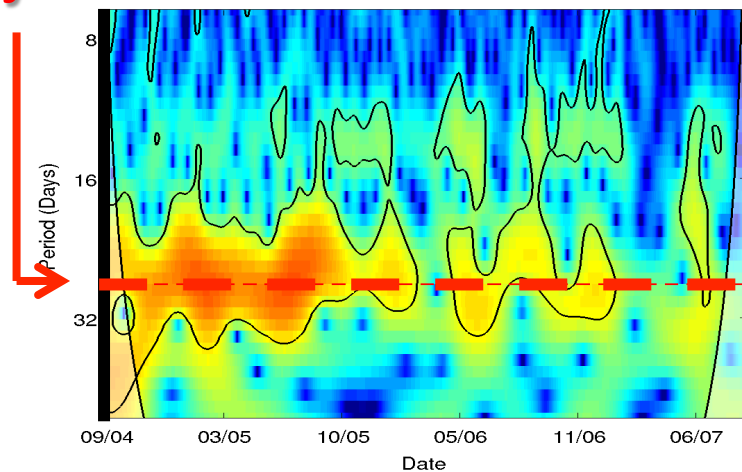
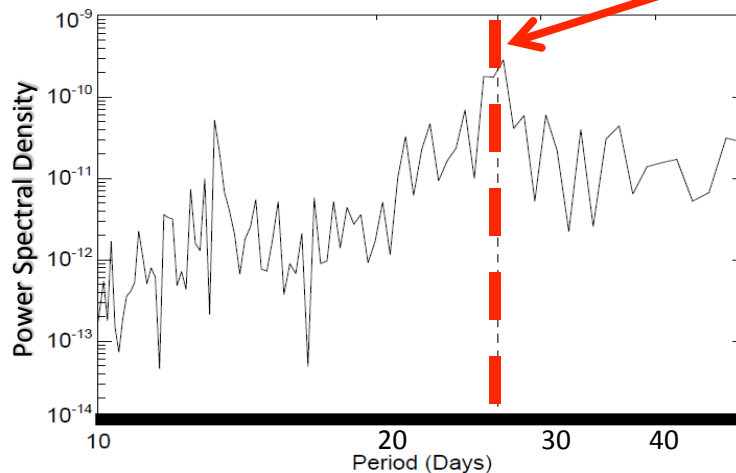
Spectres de puissance

Transformée en ondelettes (CWT)

**Cycle solaire 22
(10/91-09/94)**



**Cycle solaire 23
(09/04-08/07)**



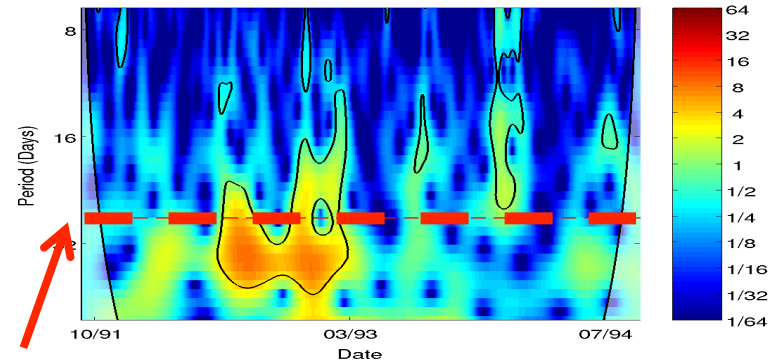
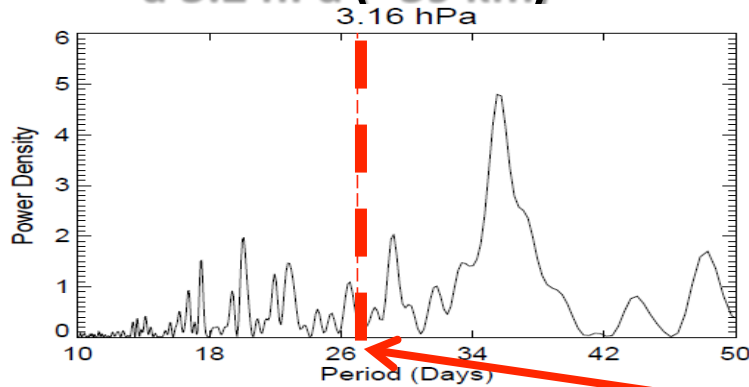
27 jours

- Strong rotational (27 days) component during both periods
- Solar rotational component intermittent

**Périodogramme de Lomb-Scargle
à 3.2 hPa (~39 km)**

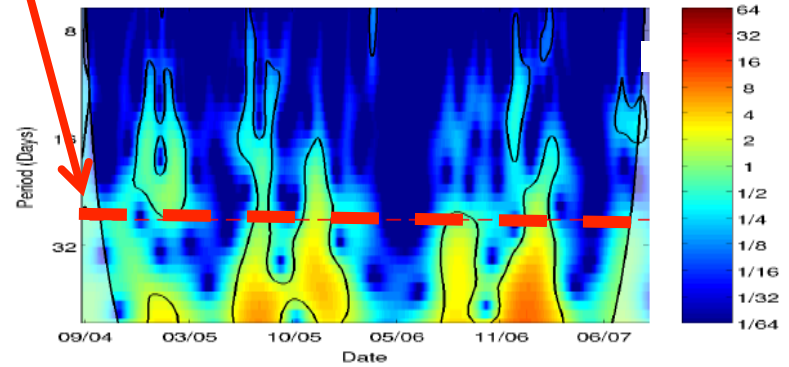
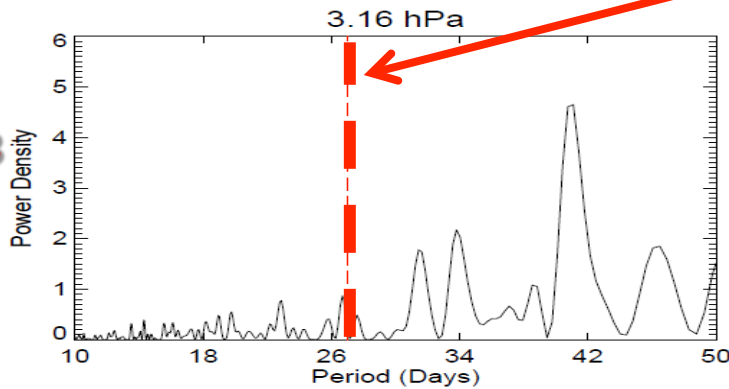
**Transformée en ondelettes (CWT)
à 3.2 hPa (~39 km)**

**Cycle solaire 22
(MLS/UARS)**



27 jours

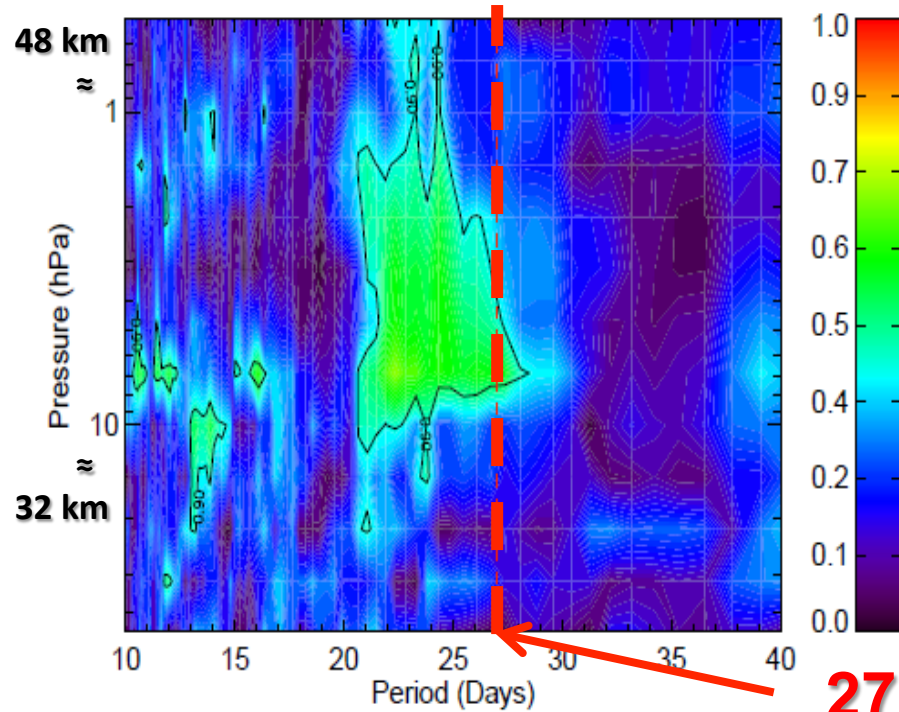
**Cycle solaire 23
(MLS/Aura)**



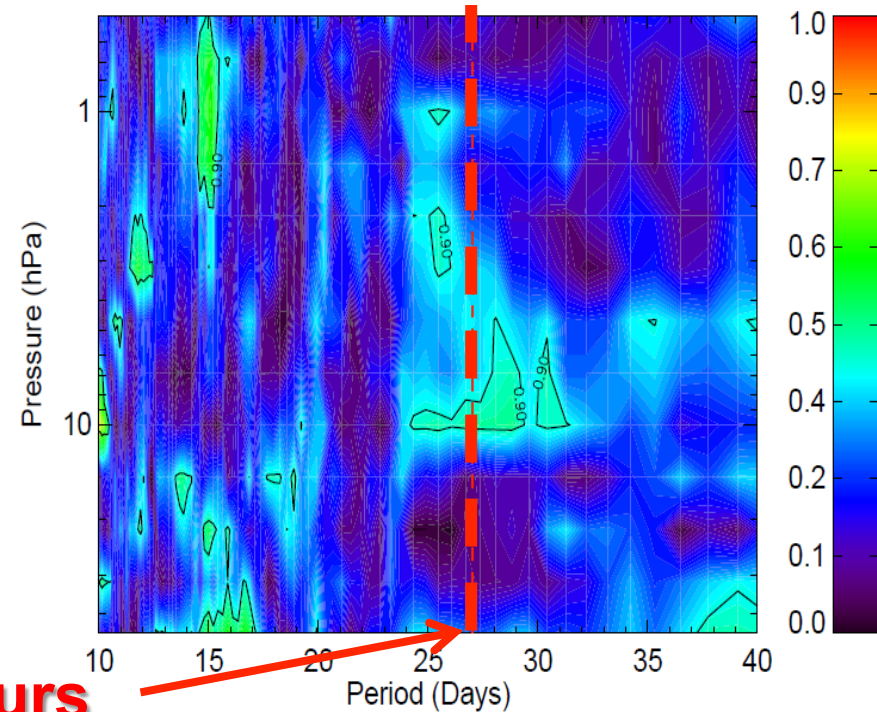
- No significant solar rotational component whatever the period.

Cohérence entre irradiance solaire (F205) et ozone

Cycle solaire 22 (MLS/UARS)



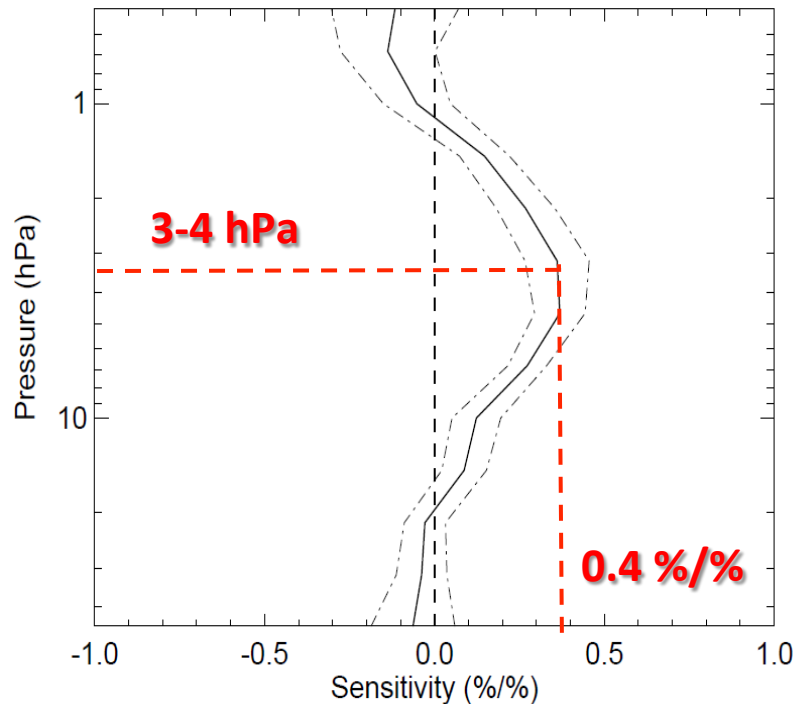
Cycle solaire 23 (MLS/Aura)



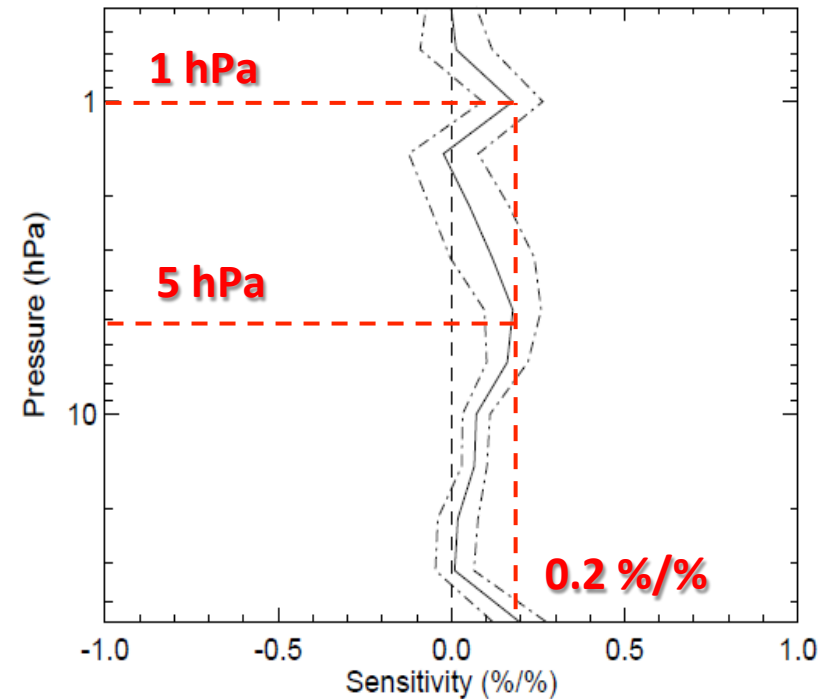
- Cycle 22: Strong coherency between 10 and 1 hPa and between 20 and 28 days
- Cycle 23: Coherency much weaker

Sensibilité ($\% \Delta(O_3) / 1\% \Delta(F205)$) sur 3 ans

Cycle solaire 22 (MLS/UARS)



Cycle solaire 23 (MLS/Aura)

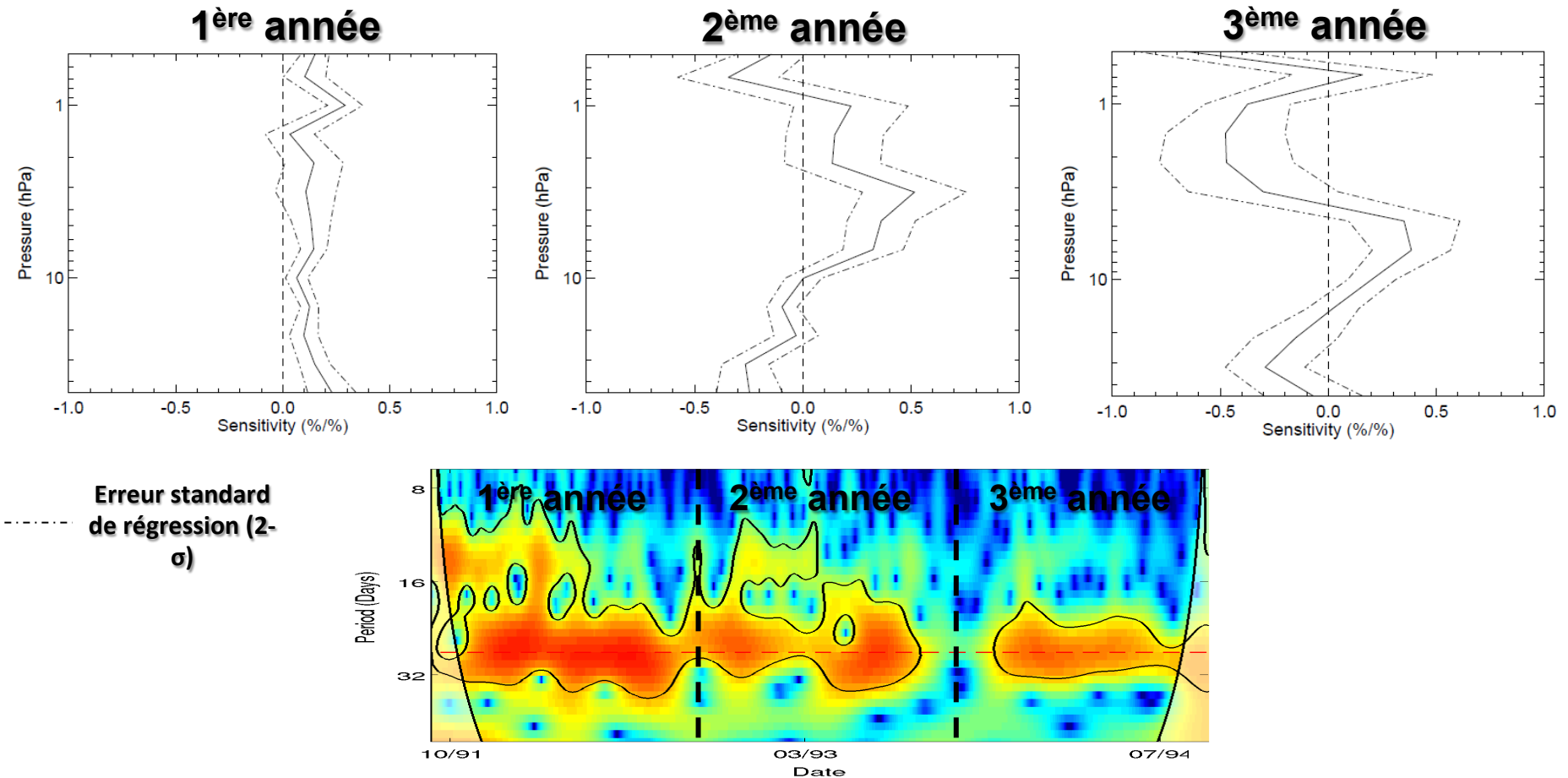


— Profil de régression

- - - Erreur standard de régression (2- σ)

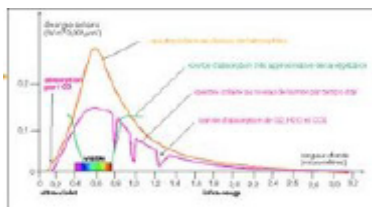
- Cycle 22: Sensibility maximum of 0.4%/ at 3-4 hPa
- Cycle 23: Sensibility maximum de 0.2%/ at 5 hPa et 1 hPa

Cycle solaire 22 (MLS/UARS) – 3 intervalles d'1 an

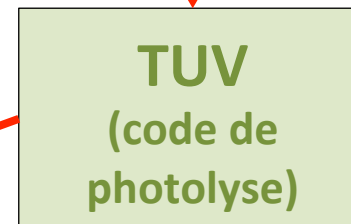
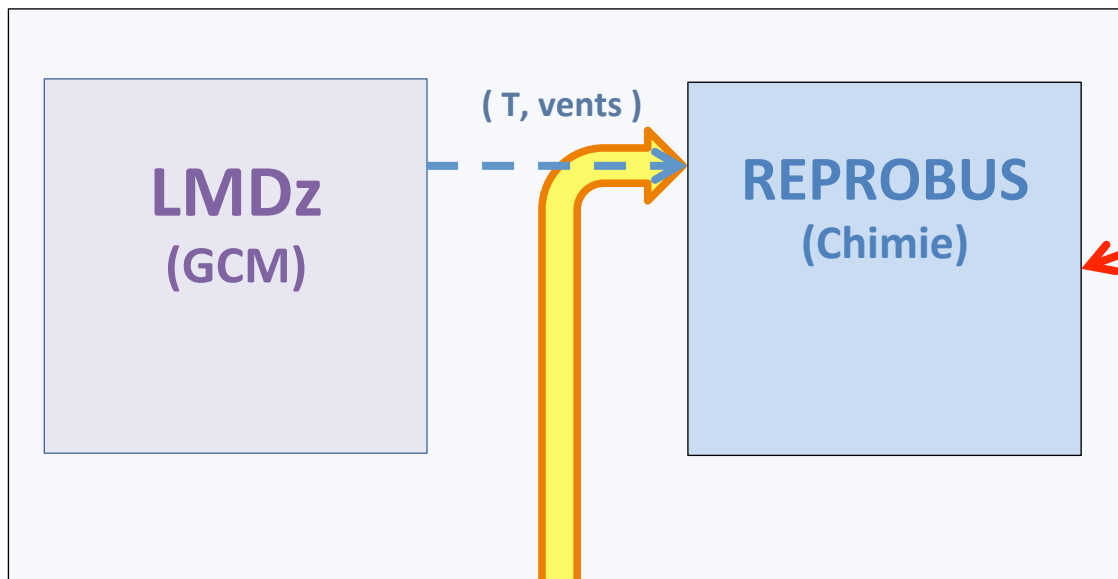


- Very large year-to-year variability for both periods.
- Ozone response and intensity of solar rotational forcing: No positive correlation on annual averages for 3-year periods ... (!)

Version Chimie-Transport (CTM) ou modèle guidé



Variabilité solaire:
Spectres solaires journaliers (NRL-SSI)

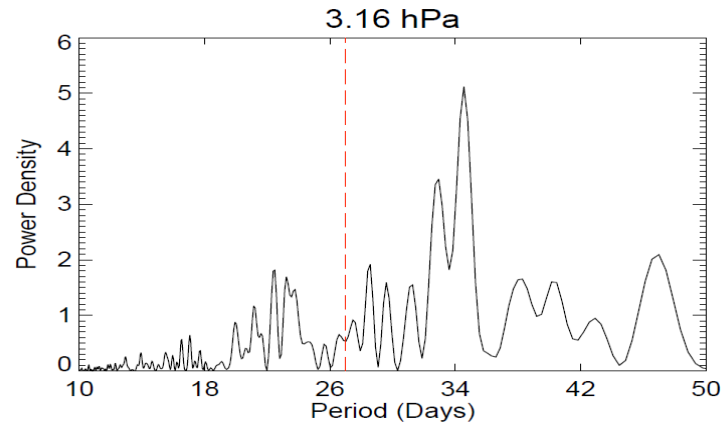


Taux de photolyse (journaliers)
(Madronich et Flocke, 1999)

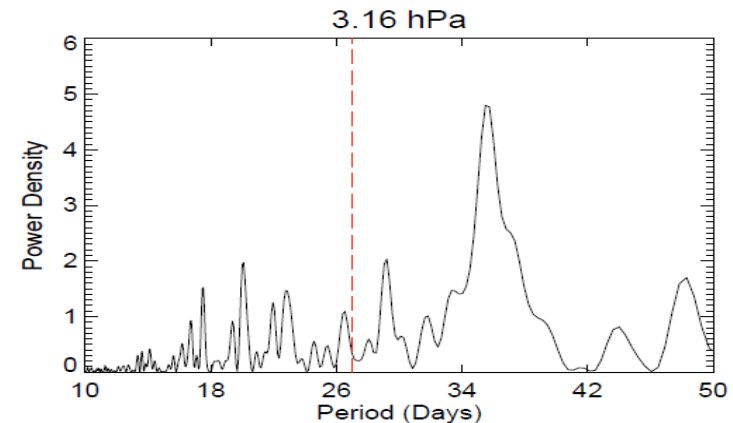
Analyses météorologiques (T, vents) du centre européen, T et vents « proches de la réalité »

CTM

Cycle 22 (10/1991-09/1994)

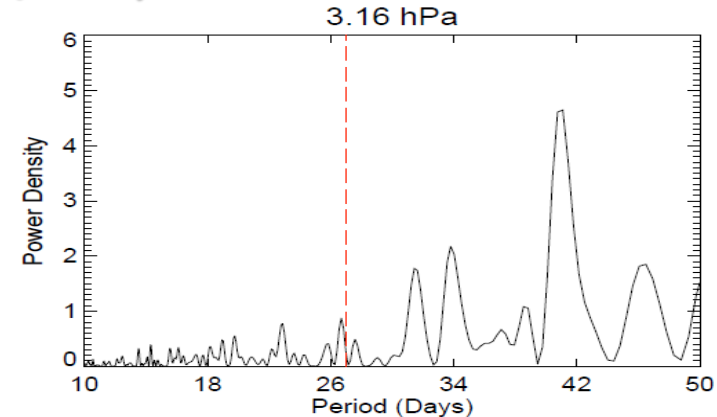
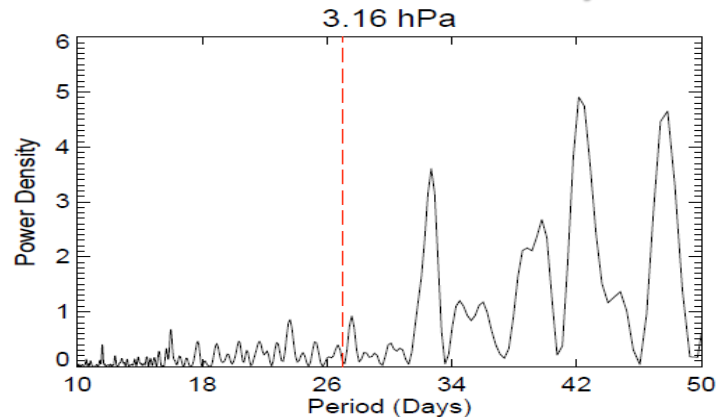


Observations



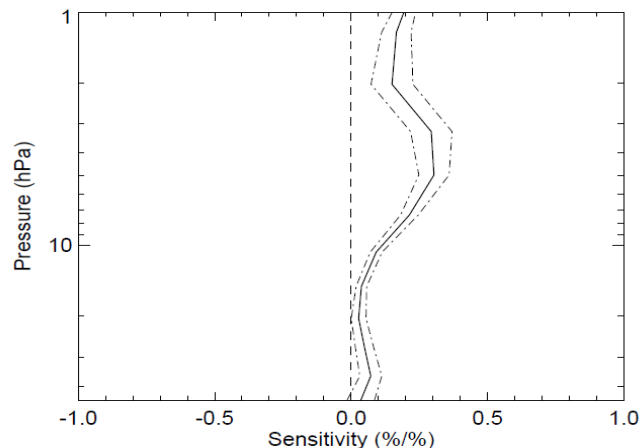
-- 27 jours

Cycle 23 (09/2004-08/2007)



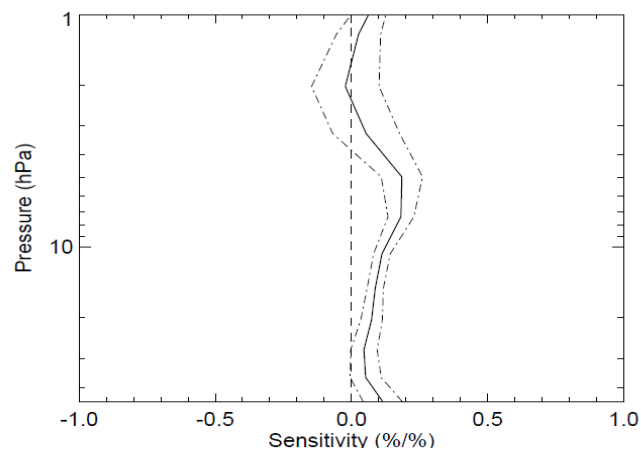
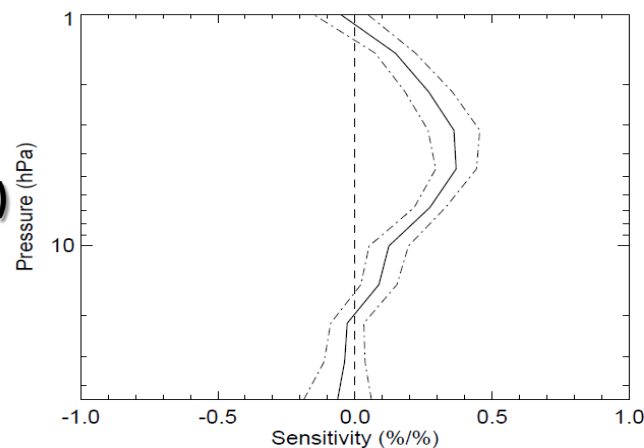
- No significant peak at 27 days in the CTM ozone series (as in obs .)

CTM

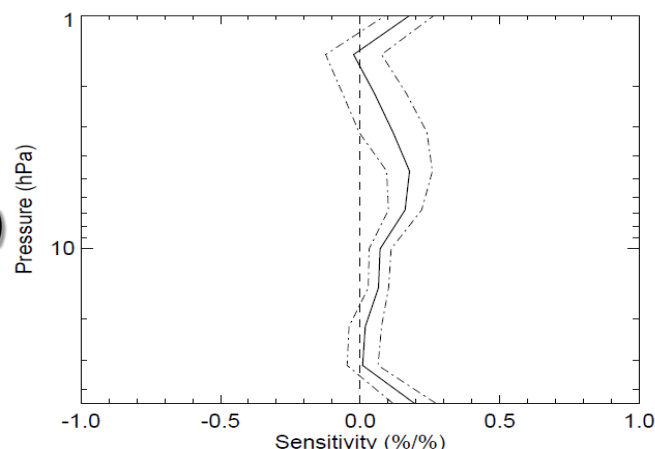


Cycle 22
(10/1991-09/1994)

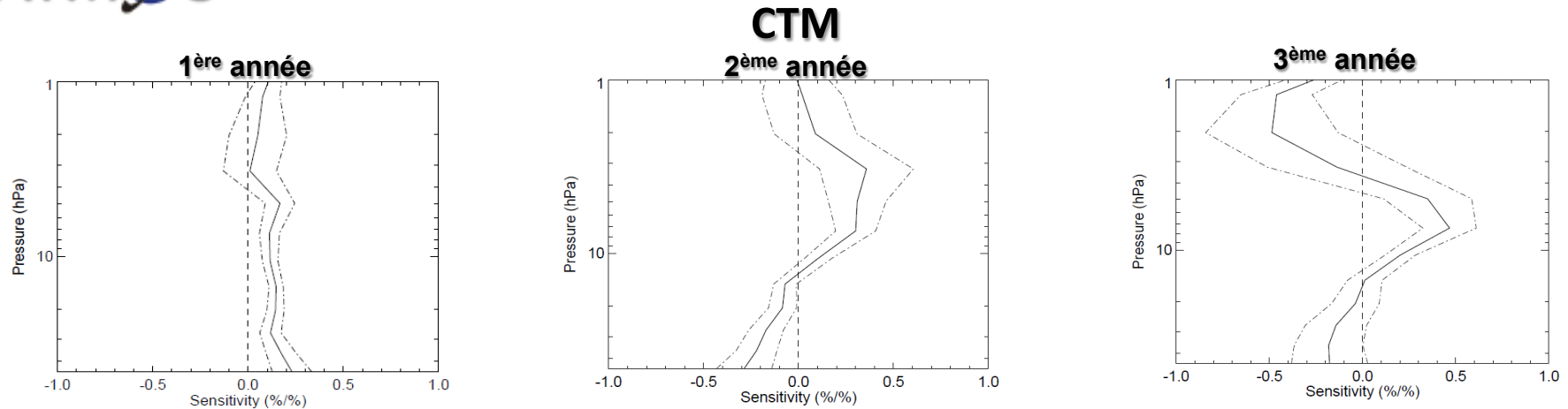
Observations



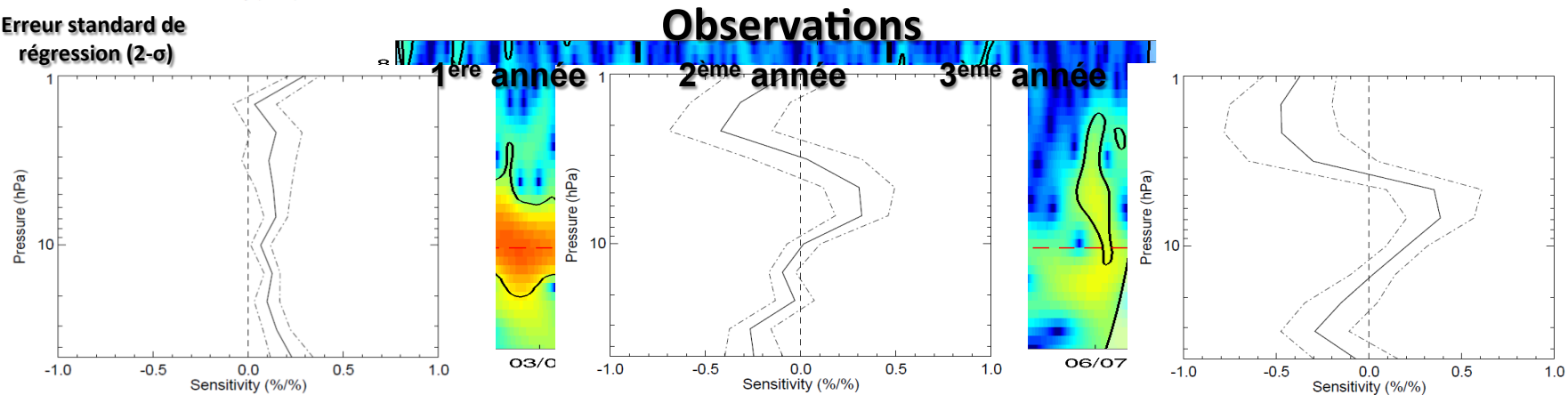
Cycle 23
(09/2004-08/2007)



- Overall, good agreement between ozone sensitivity profiles from the guided model (CTM) and those of observations for both periods
- Sensitivity (CTM) during the downward phase of the cycle 22 is stronger than that of cycle 23 (as in observations)

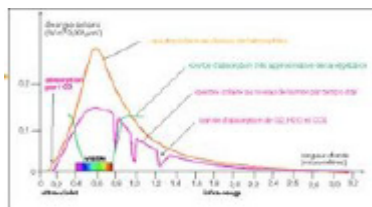


----- Erreur standard de régression (2- σ)

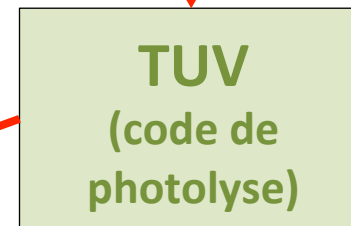
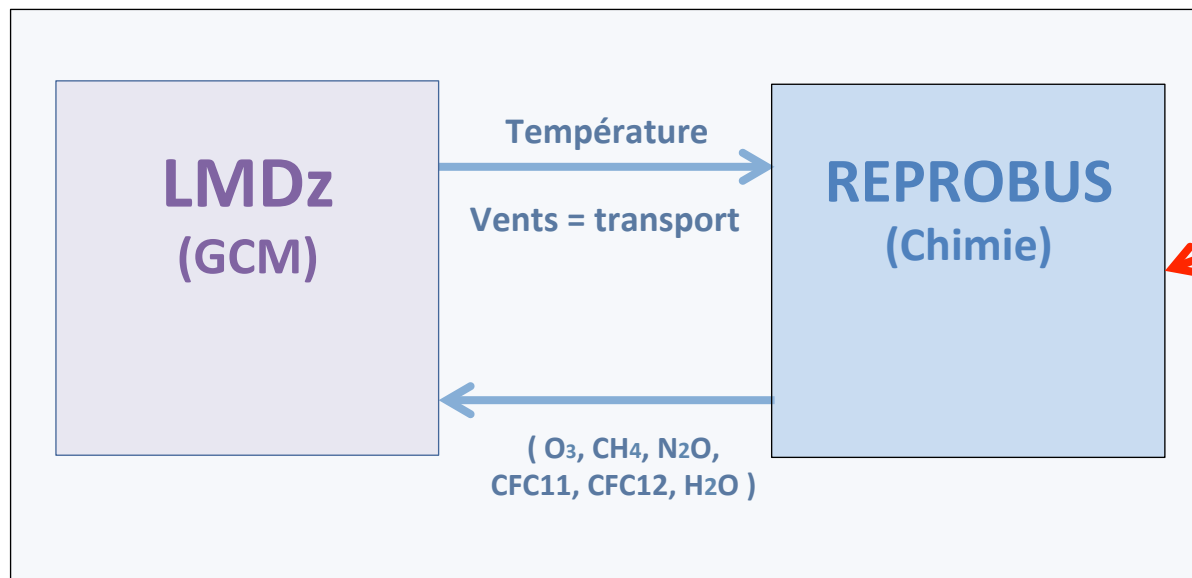


- Guided Model (CTM) is able to reproduce the interannual variability (from obs .)
- No correlation between ozone response and intensity of solar rotational forcing in CTM (As in obs.) for 3-year periods → interannual variability in sensitivity is not of solar origin for these specific periods.
- As the only other source of ozone variability in the model (CTM) is dynamics (T, winds), this variability can mask the solar variability of solar over 1 year.

Version Chimie-Climat (CCM)

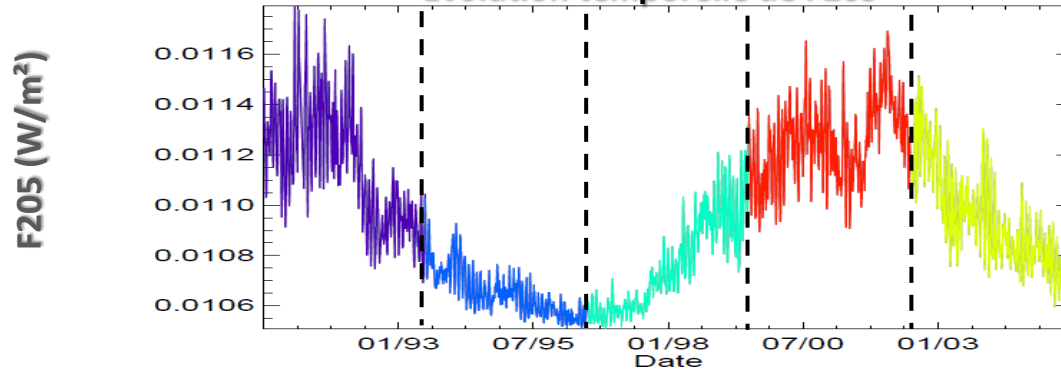


Variabilité solaire:
Spectres solaires journaliers (NRL-SSI)



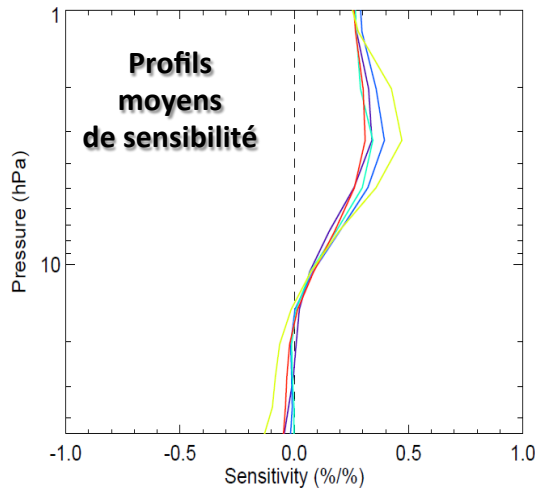
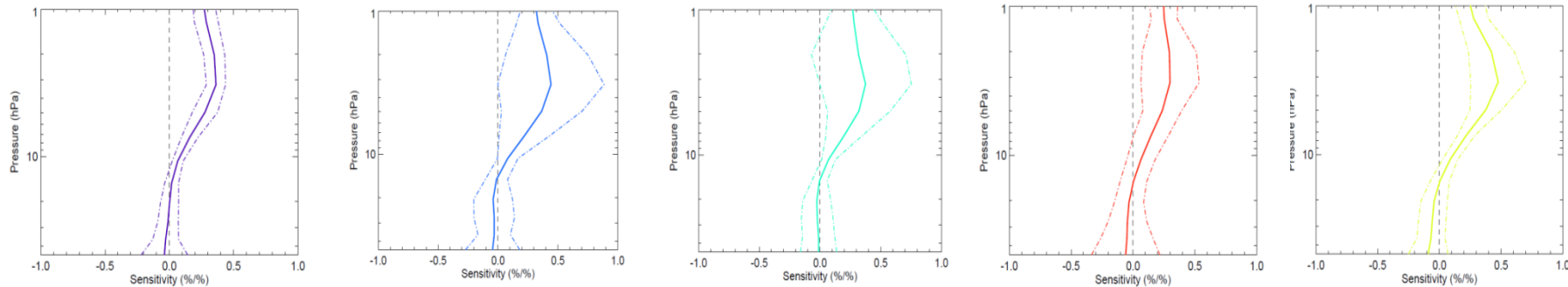
Taux de photolyse (journaliers)
(Madronich et Flocke, 1999)

Evolution temporelle de F205



Simulations d'ensemble de 15 ans (CCM) : 5 intervalles d'analyse de 3 ans

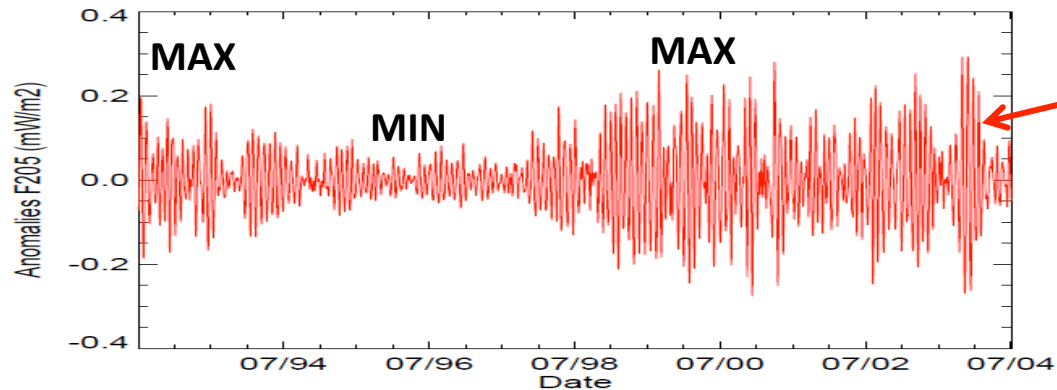
----- dispersion (2- σ) calculée à partir des simulations d'ensemble



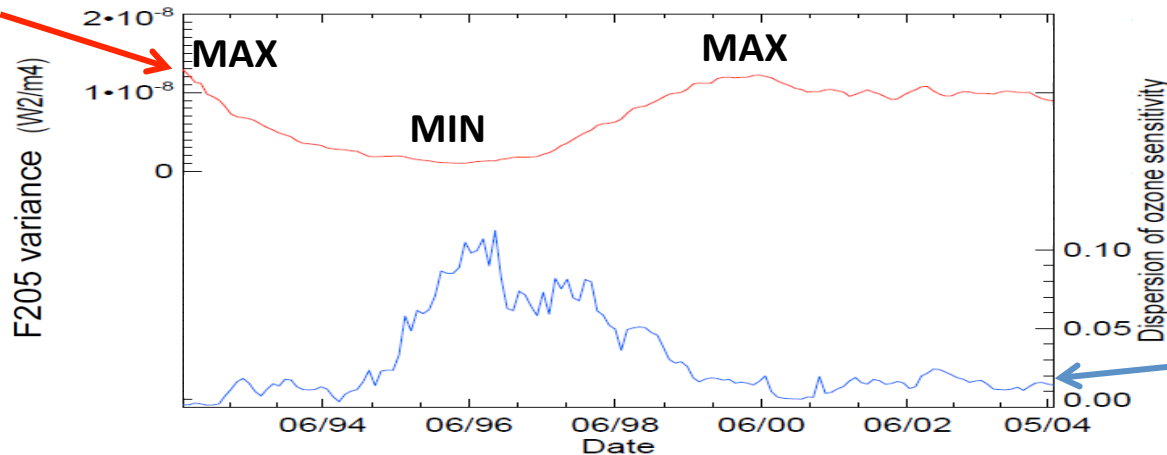
- Average profile of ensemble simulations varies little from a 3-year period (5 simulations x3yr=15 year) to another, insensitive to the phase of the 11-year solar cycle.
- Model dispersion very sensitive to the phase of the 11-year solar cycle.

Relationship between solar activity (phase to 11 year cycle) and dispersion of ozone sensitivity (3 hPa) calculated from a sliding window of 3 years instead of arbitrary 3-year intervals

Evolution temporelle des anomalies de F205 (indicateur de l'activité solaire)



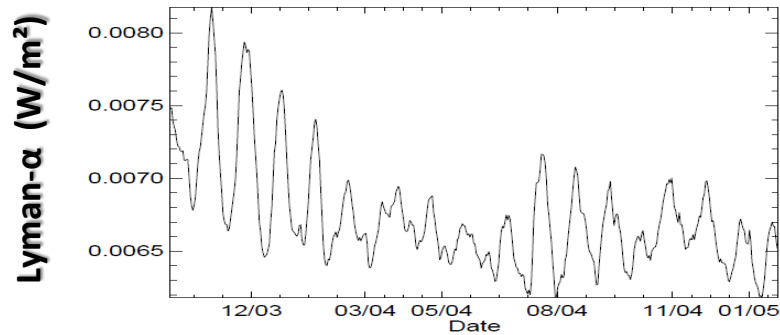
Variance (F205)



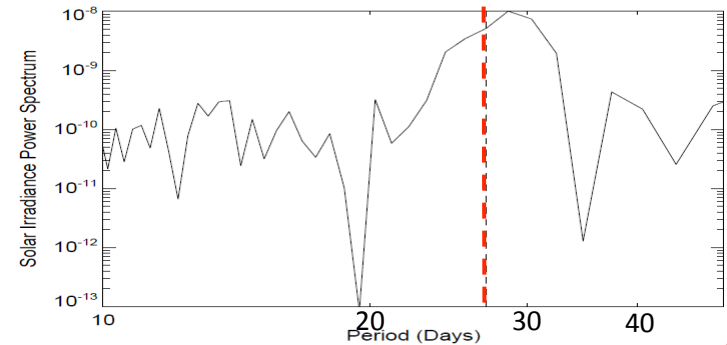
Model dispersion in O₃ sensibilité

- Clear anti correlation between solar activity level (phase) and dispersion in ozone sensitivity estimates (CCM model).

Série temporelle de la raie Lyman- α (NRL-SSI)

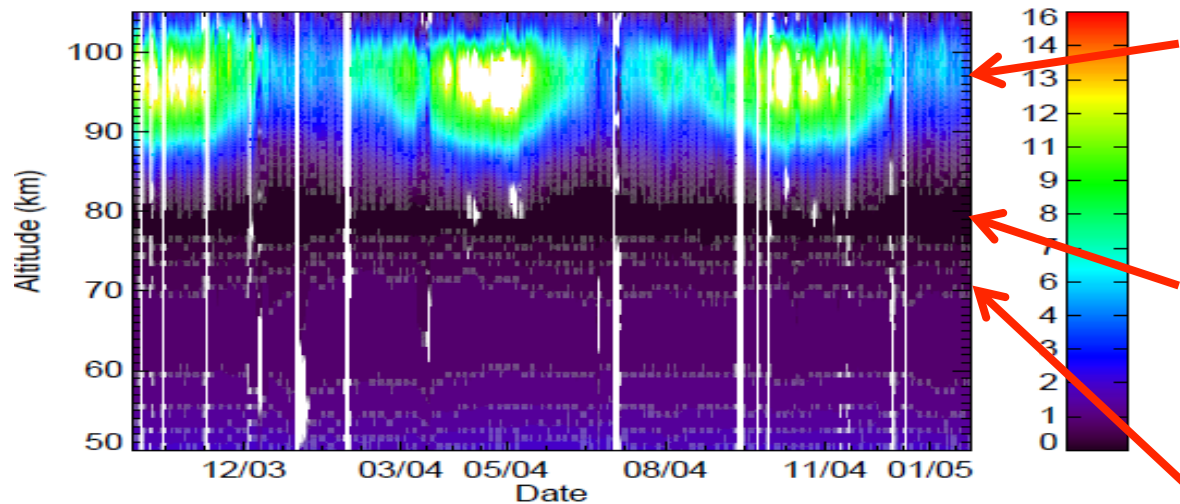


Spectre de puissance raie Lyman- α

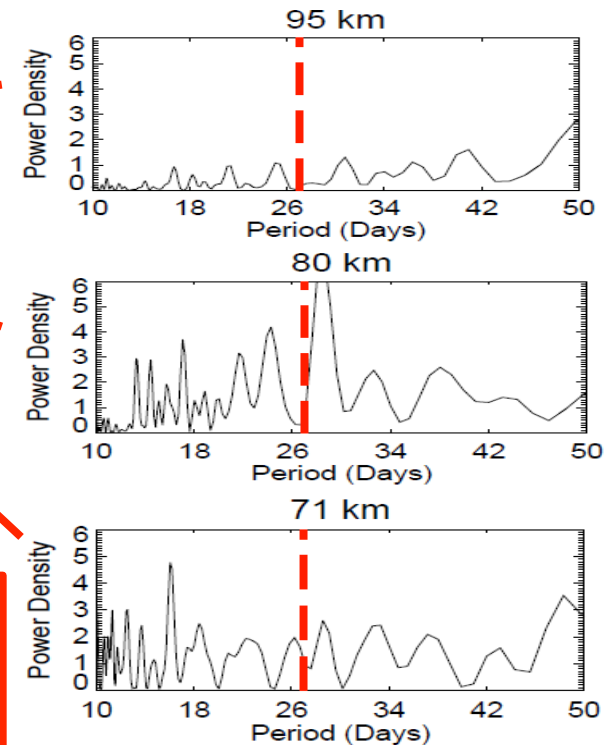


--- 27 jours

Ozone tropical (ppmv) mesuré par GOMOS (nuit)



Périodogrammes



- Pic à 27 jours dans séries Lyman- α
 - Pic à 27 jours au minimum d'ozone GOMOS (80 km)

Ozone stratosphérique

- Ozone response to solar rotational variations: stronger during the descending phase of cycle 22 (max = 0.4%/%) than cycle 23 (max = 0.2%/%).
- Very large year-to-year variability in ozone response (linked to dynamical variability)
- For acceptable errors in estimation of ozone sensitivity:
 - long period of analysis → more than 10 years
 - short period of analysis → solar maximum

CMIP6: SolarMIP simulations

- « **Solar only** »: Historical solar-only transient simulation using settings from Nucleus but fixed GHG & ODS (1850 level)
- « **Future solar min** »: Future simulation using solar forcing running into a new Dalton/Maunder Minimum type
- « **NRL Sens.** »: sensitivity experiment using a different spectral solar irradiance (NRLSSI) forcing than the Nucleus simulation