



# **Inversions du champ magnétique solaire: observations**

*Jean-Marie Malherbe*

**Observatoire de Paris**

**I – L'étoile Soleil**

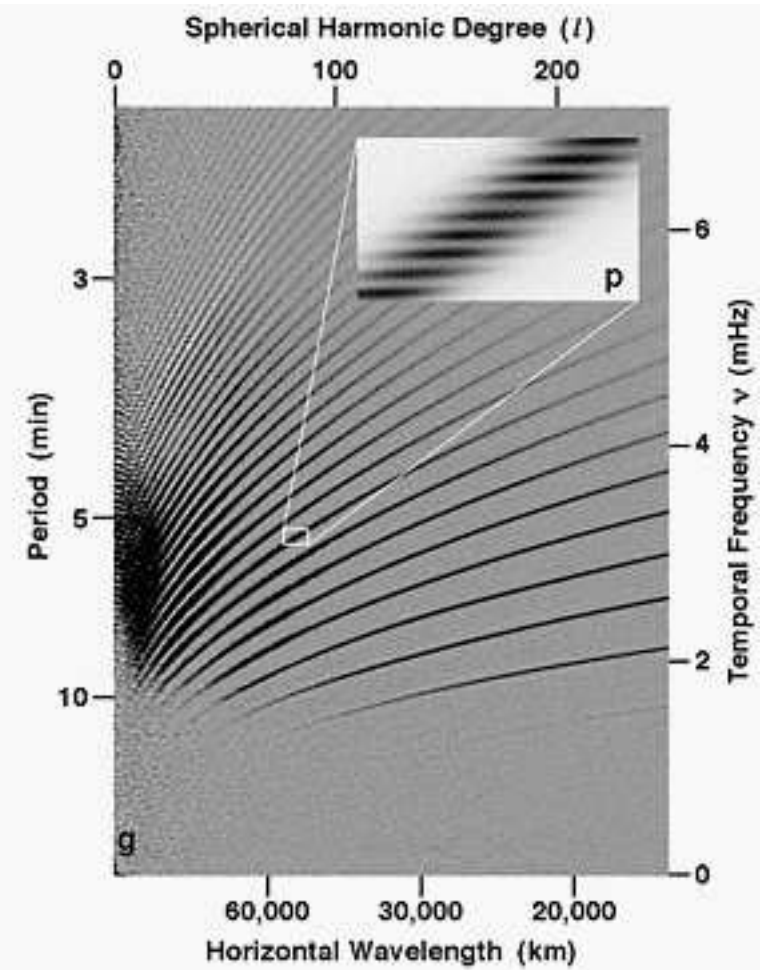
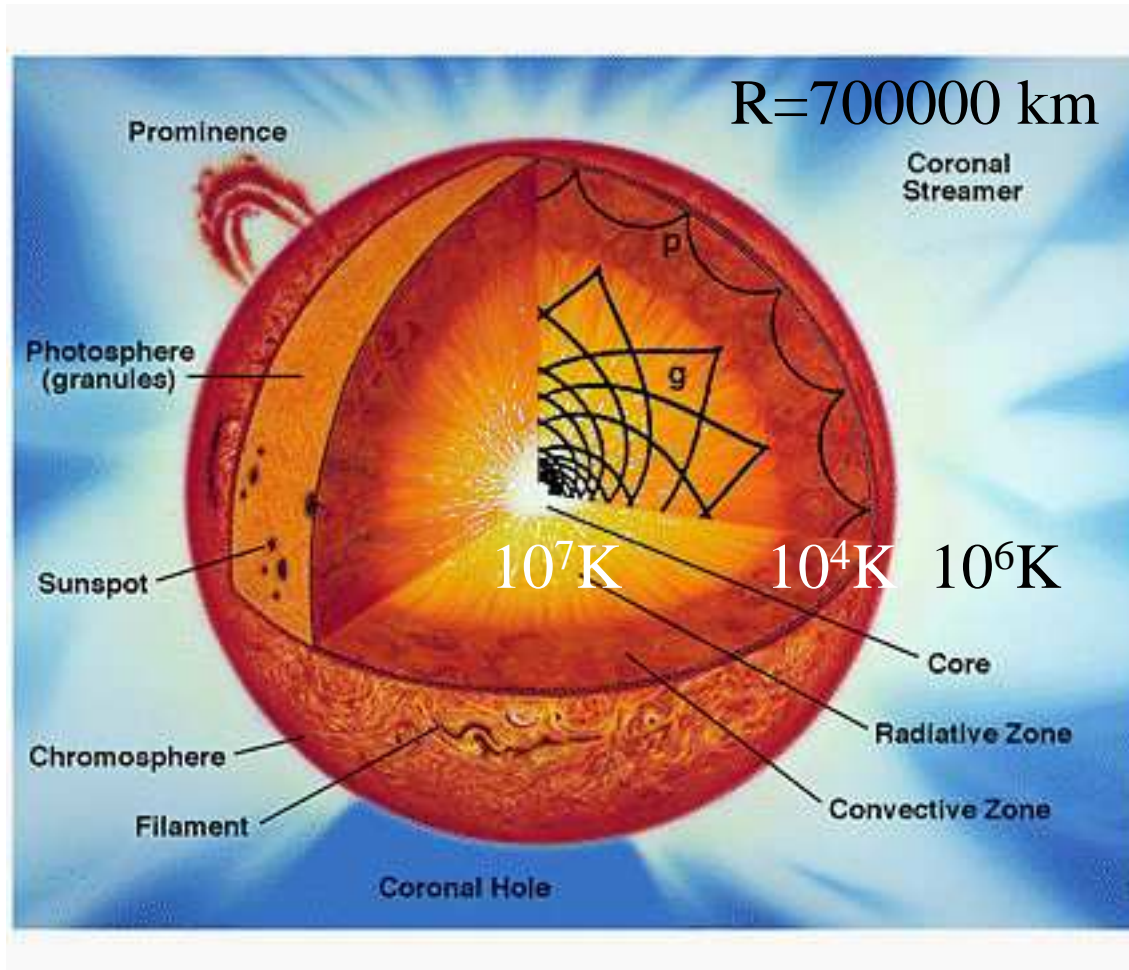
**II – Variabilité/cyclicité multi-longueur d'onde**

**III – Inversions magnétiques**

**IV – Des anomalies dans la cyclicité**



Cœur, zone radiative, zone convective: inaccessibles au télescope  
Photosphère, chromosphère, couronne: observables à distance



Héliosismologie : étude des modes propres de vibration de la surface, permettant un sondage indirect de la structure interne





# **Inversions du champ magnétique solaire:**

## **Observations**

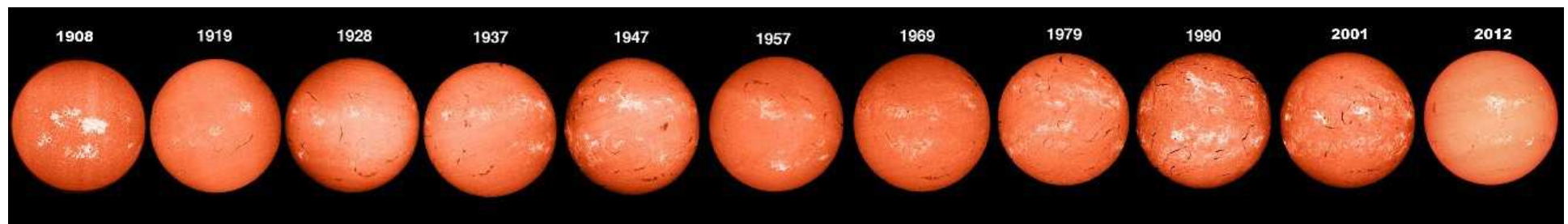
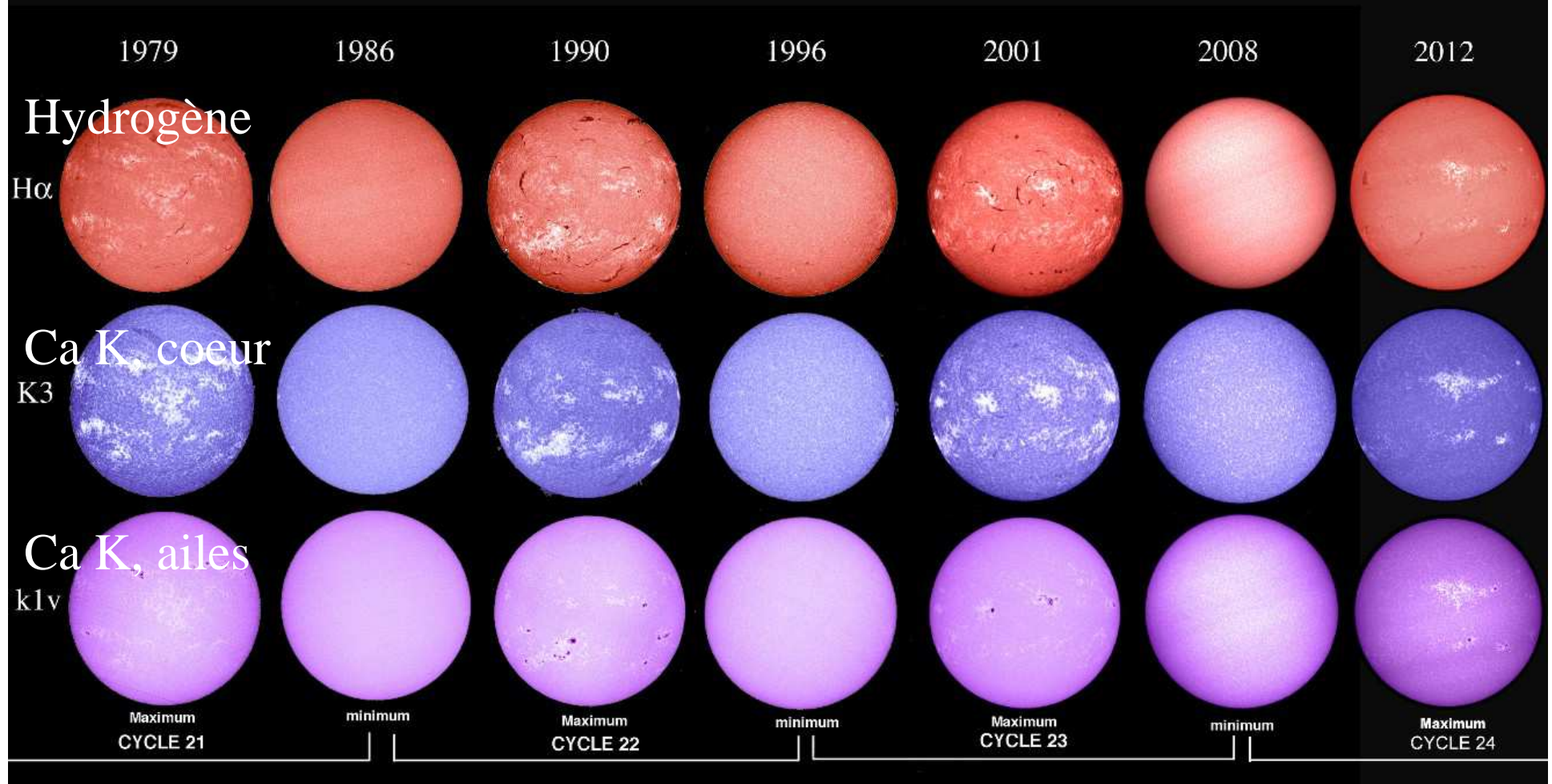
### **II – Variabilité multi-longueur d'onde**

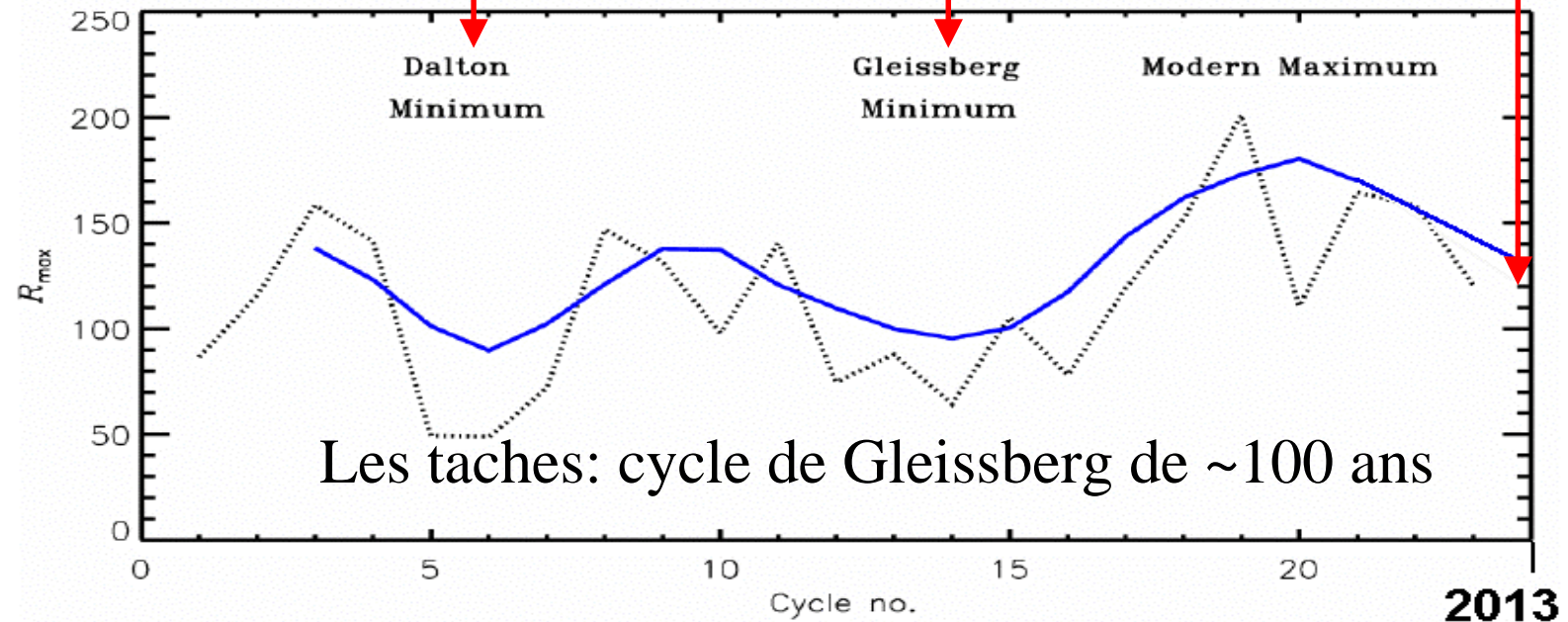
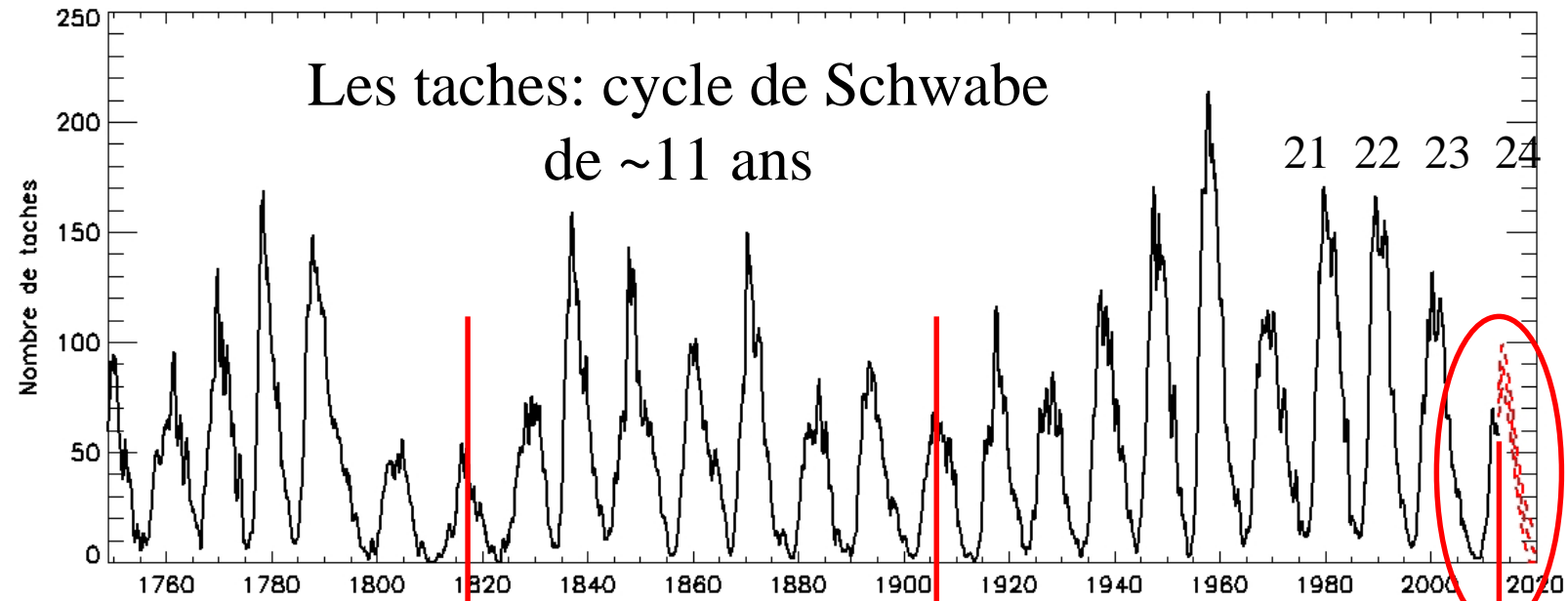
**Optique, rayons cosmiques, irradiance, UV, rayons X**

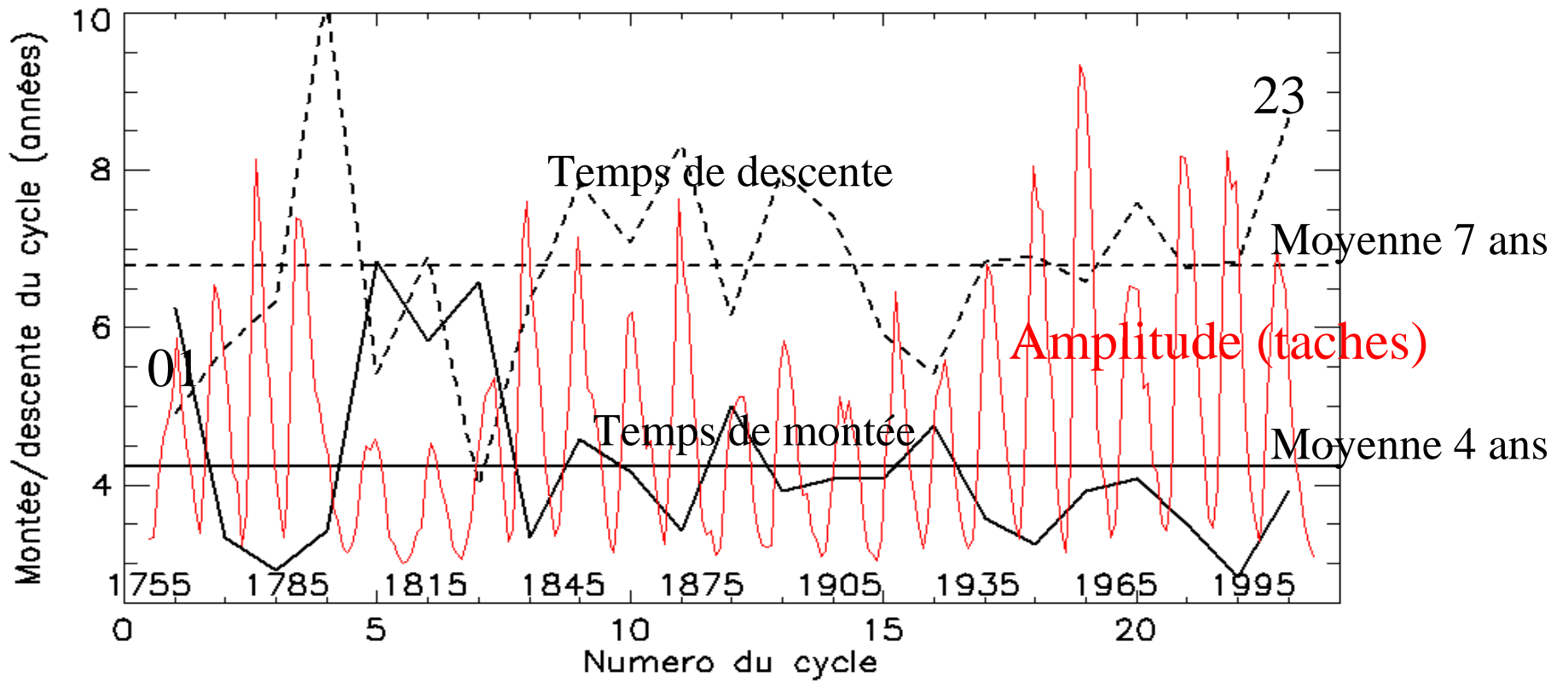
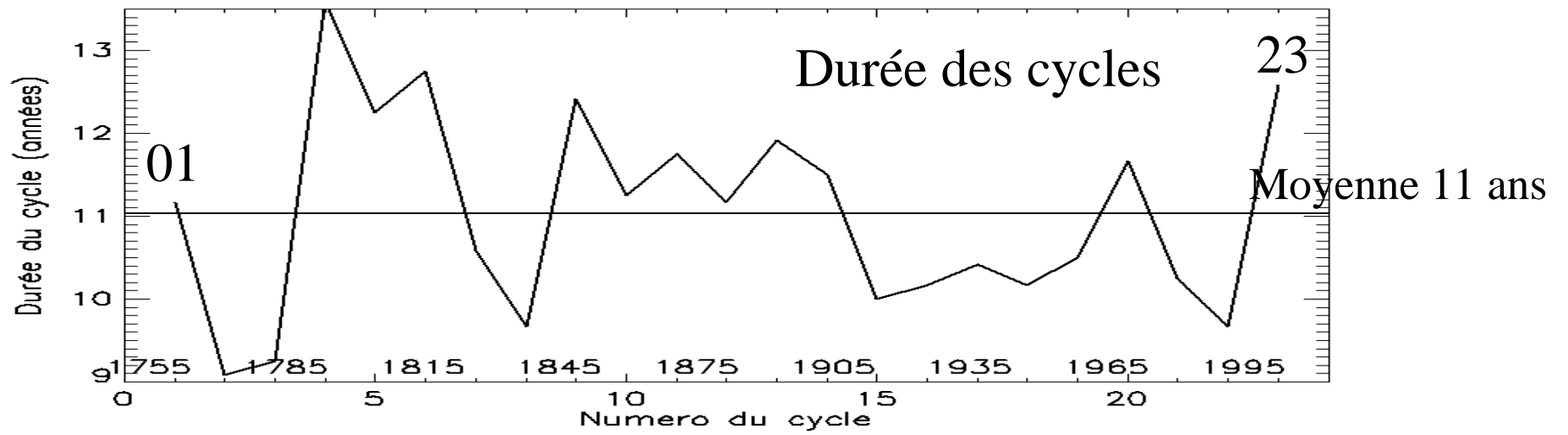


# CYCLES DE 11 ANS

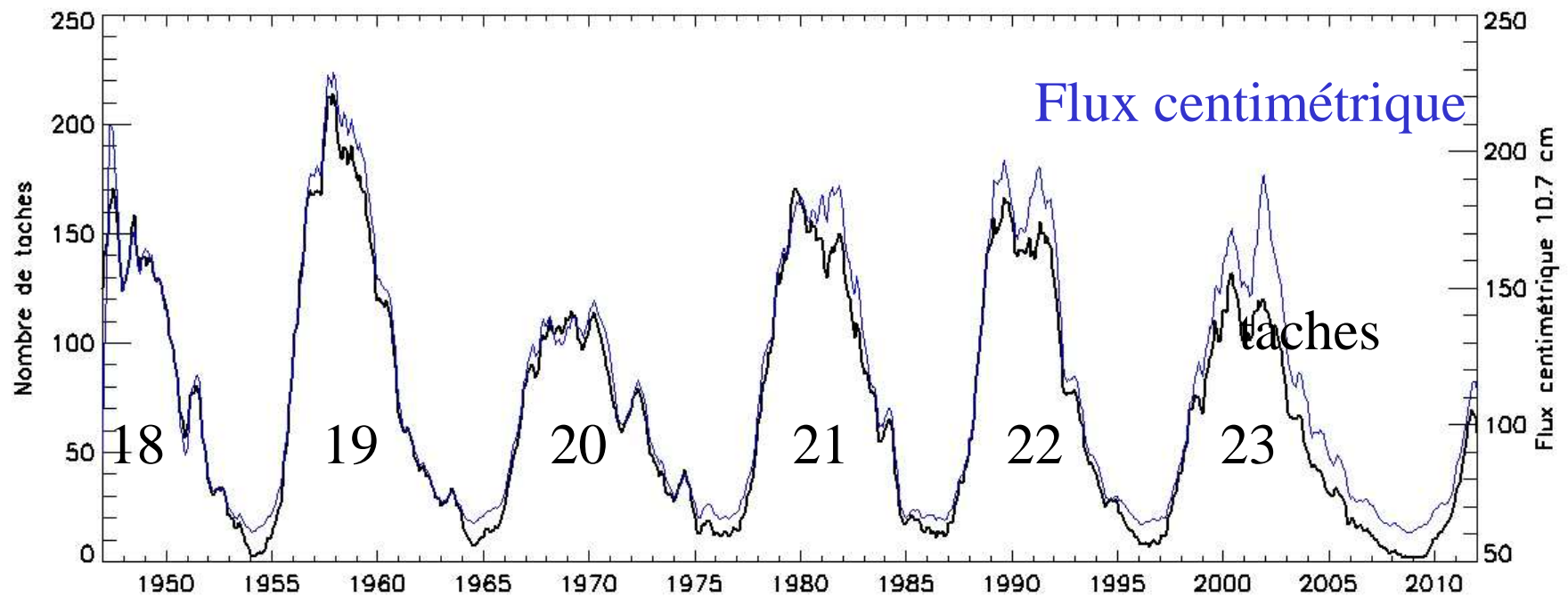
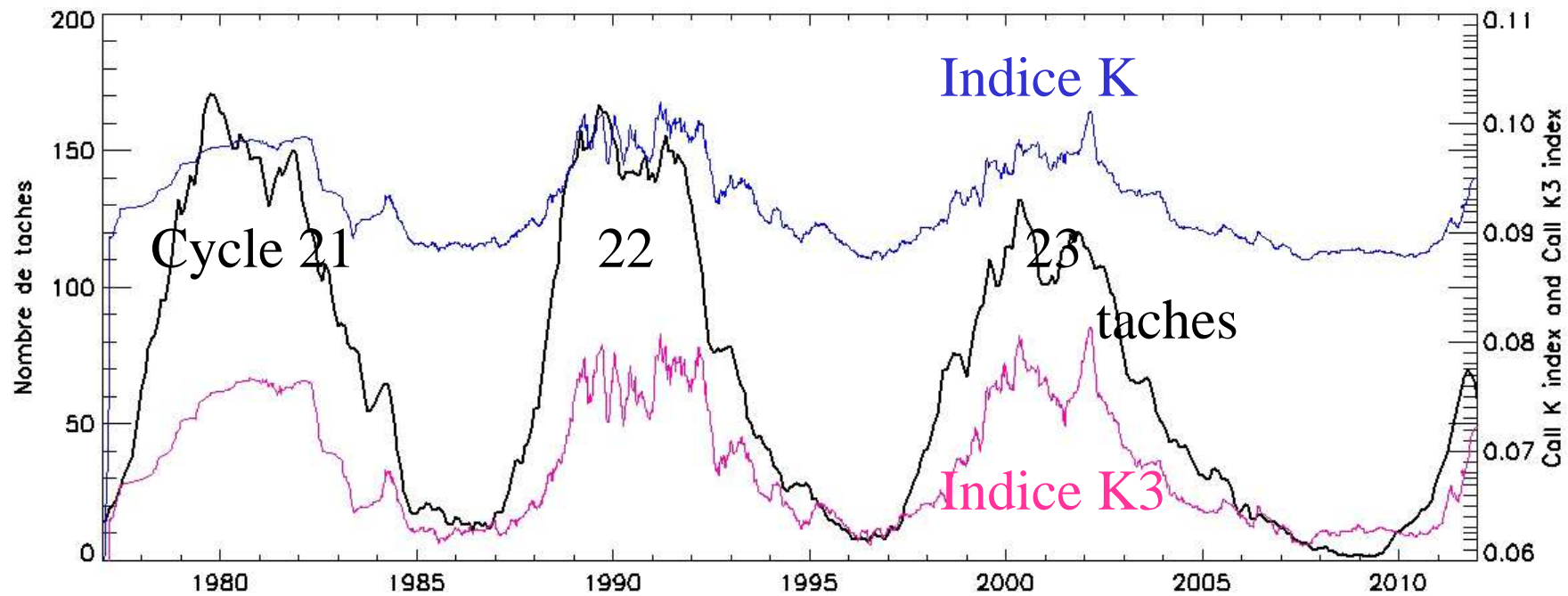
Observatoire de Paris

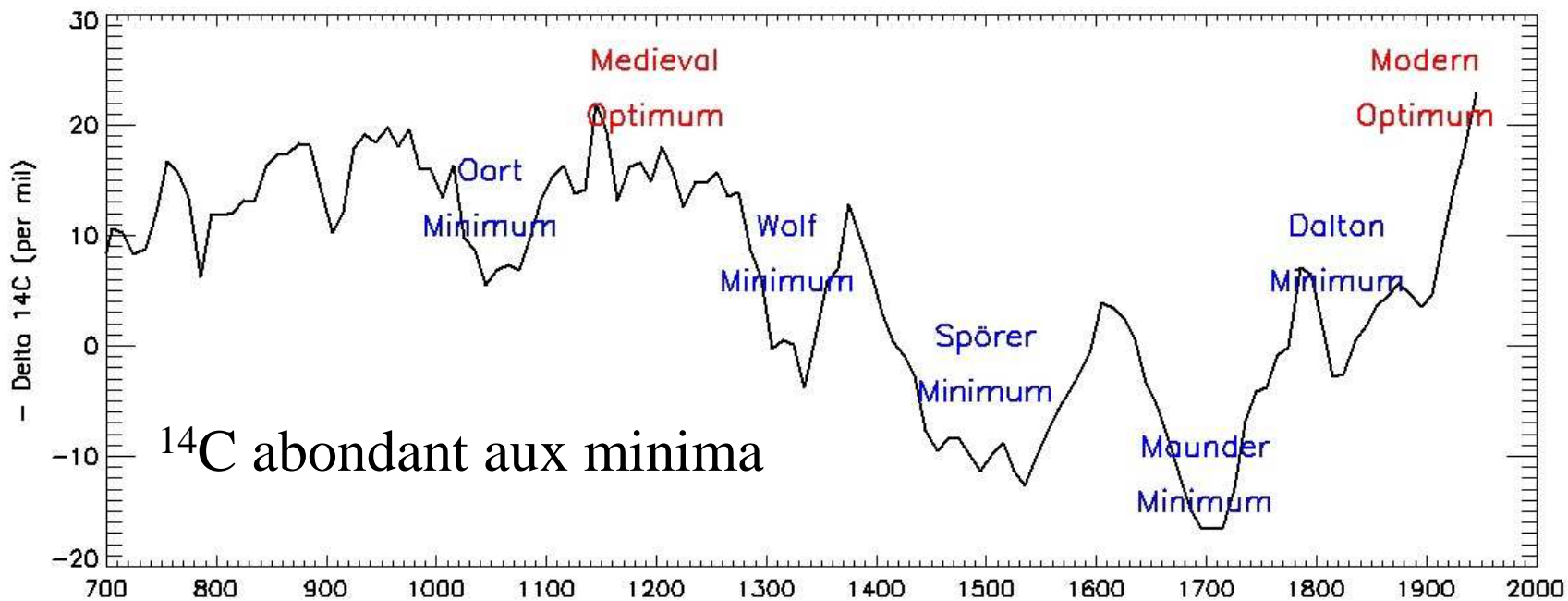
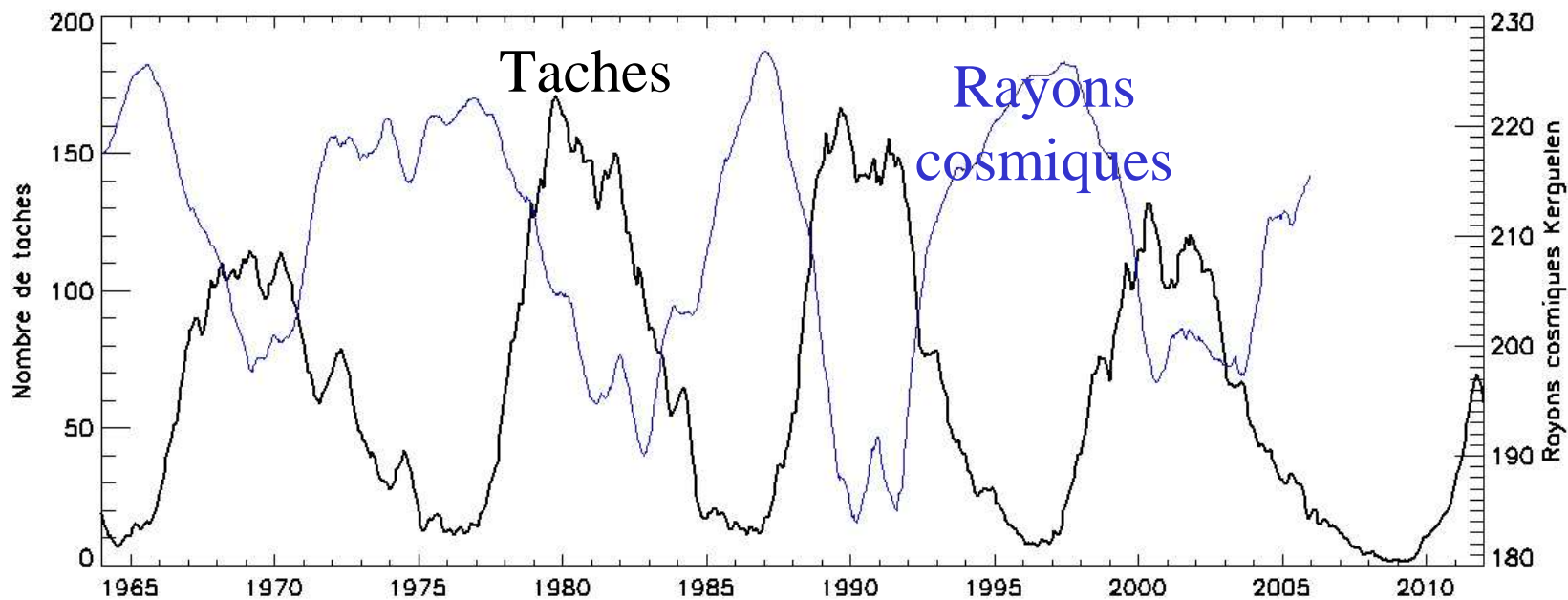




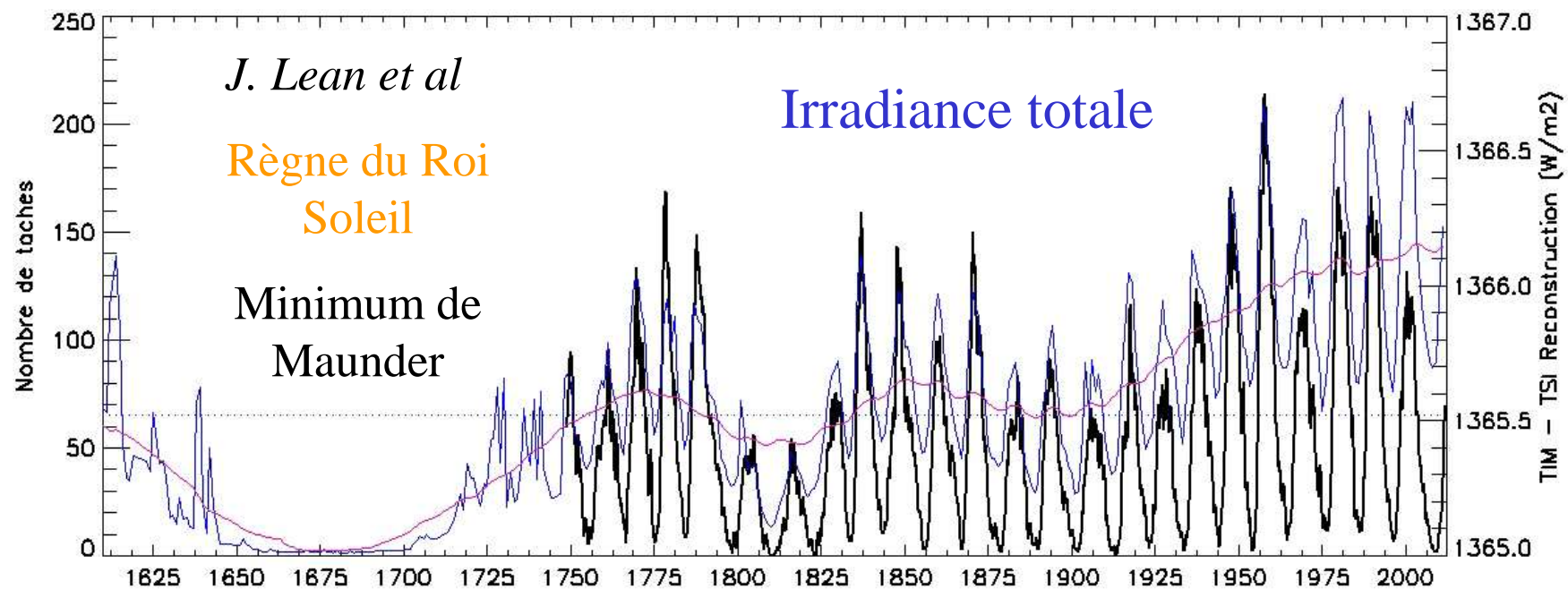
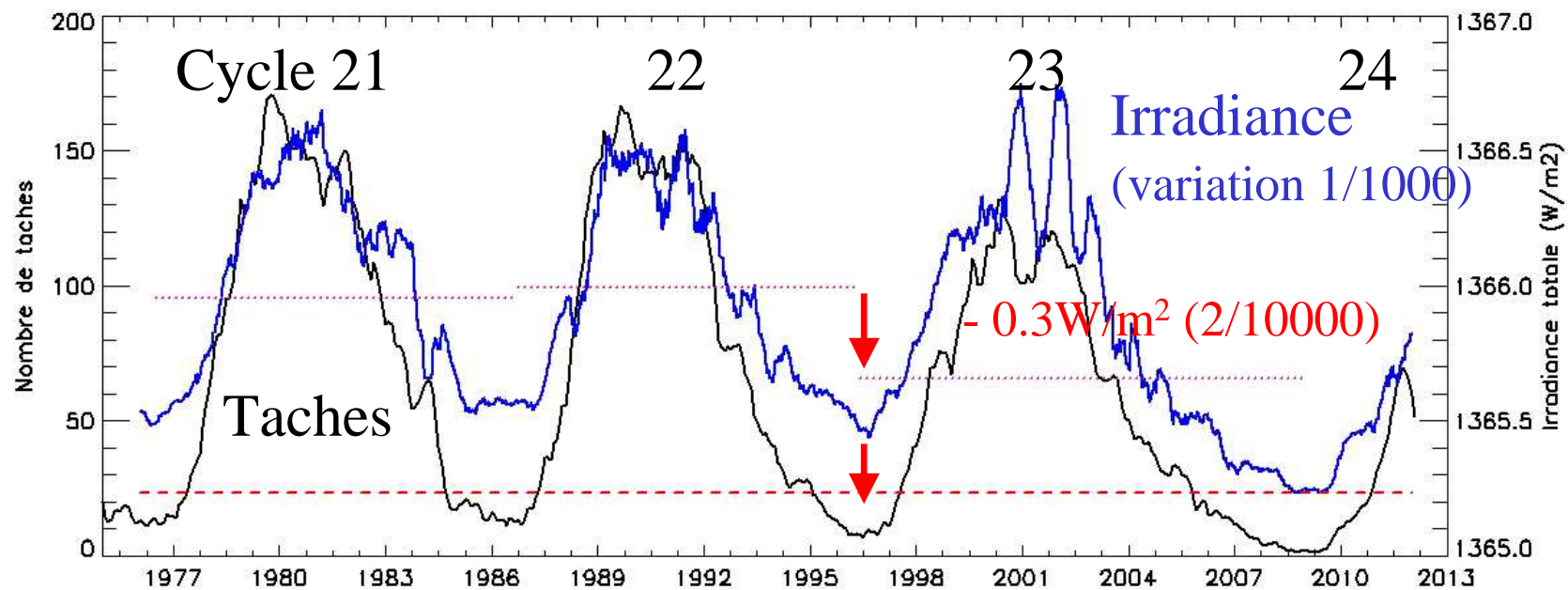


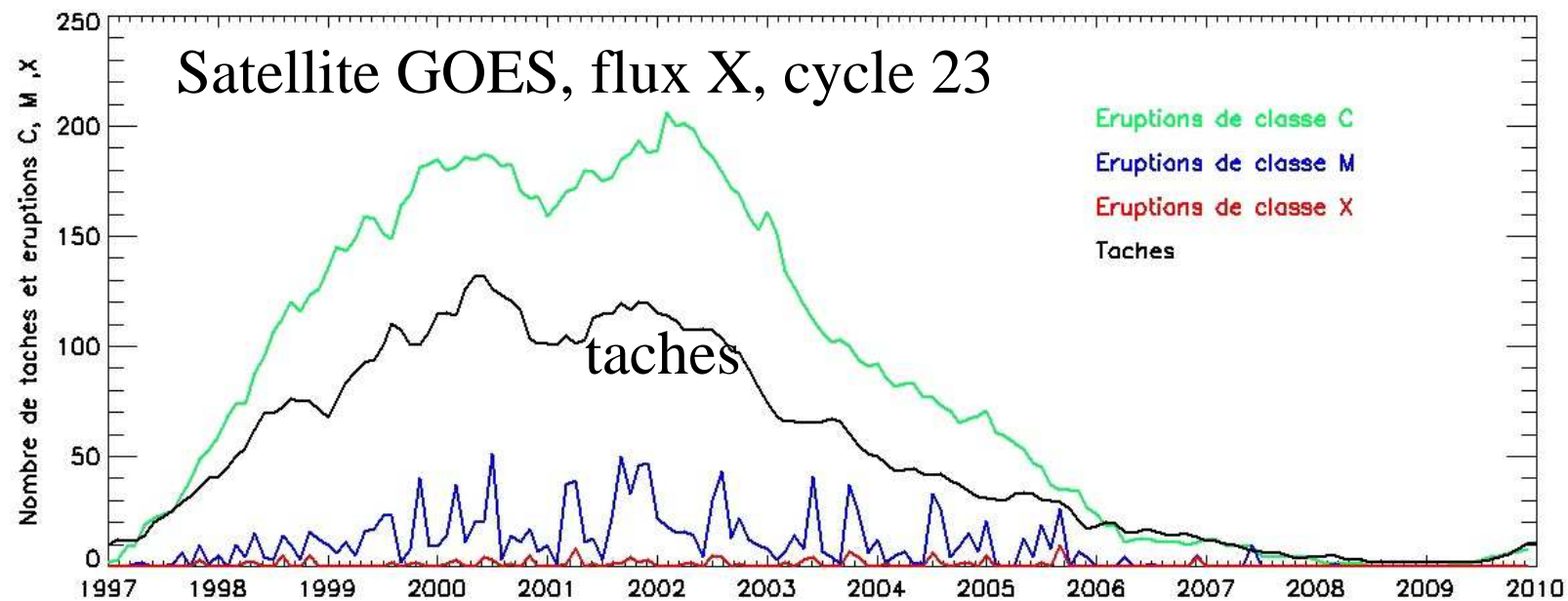
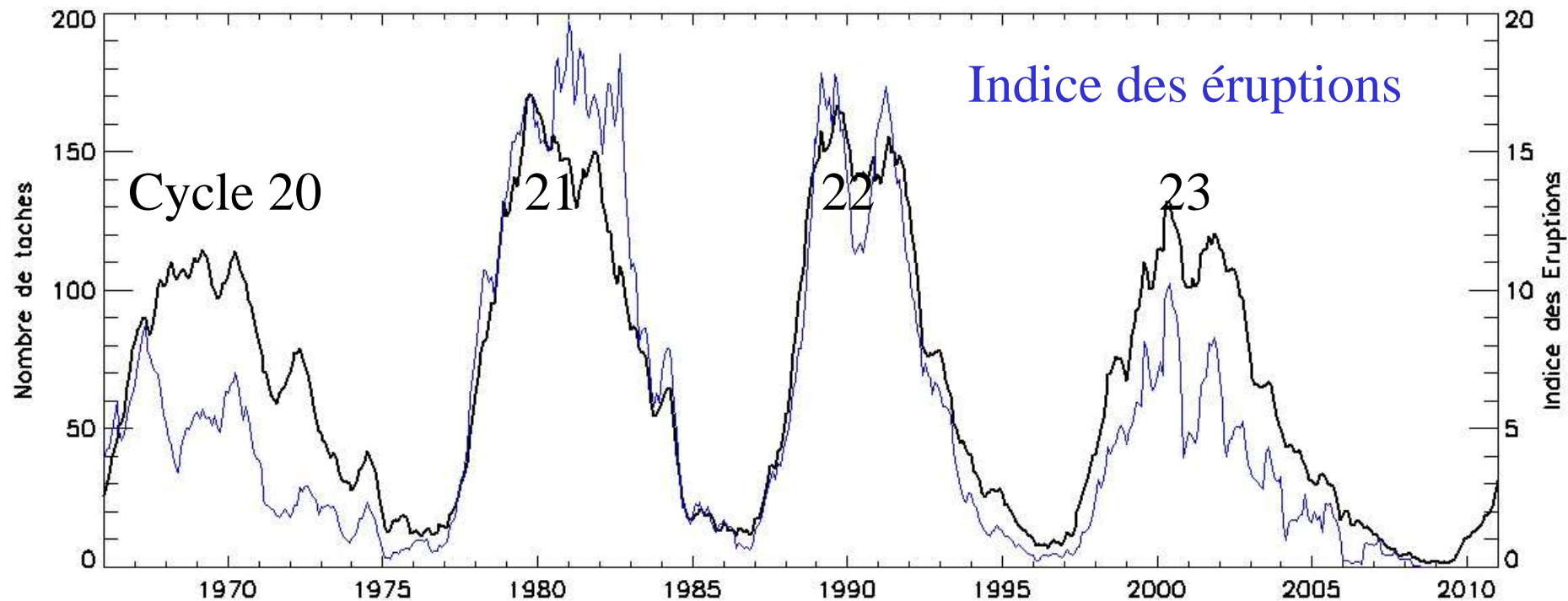




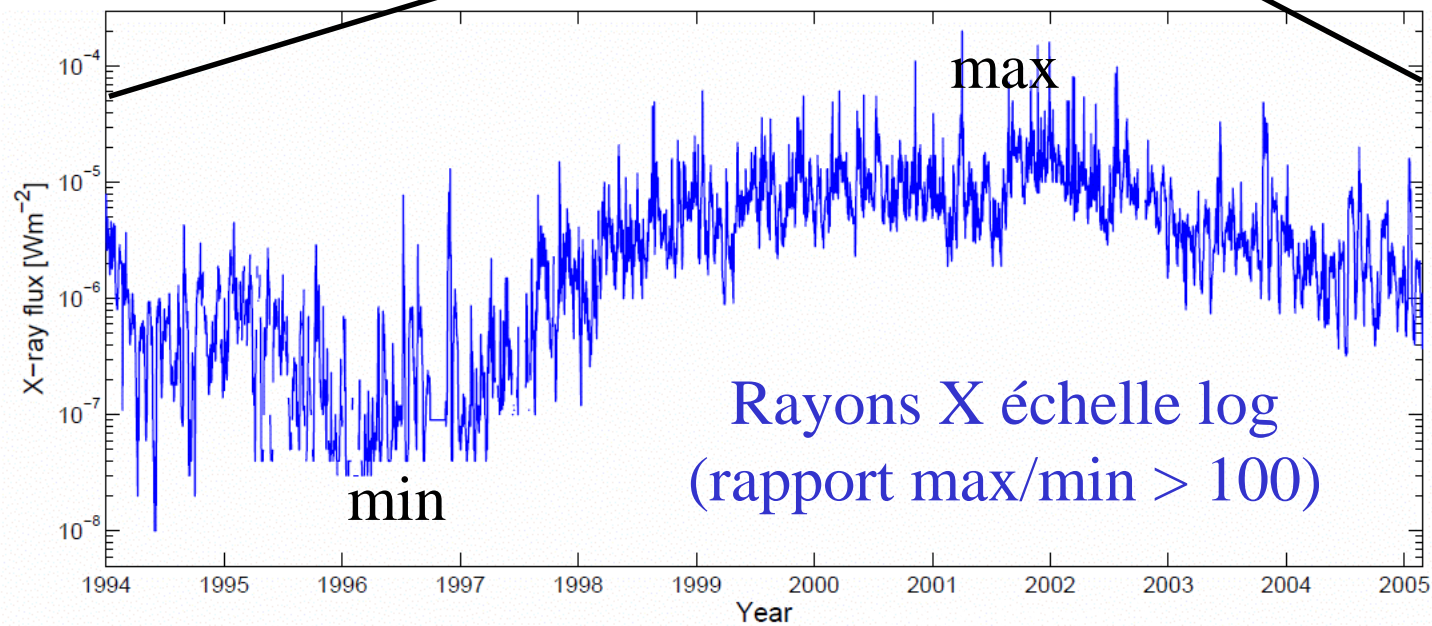
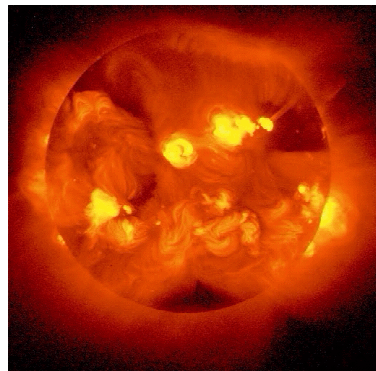
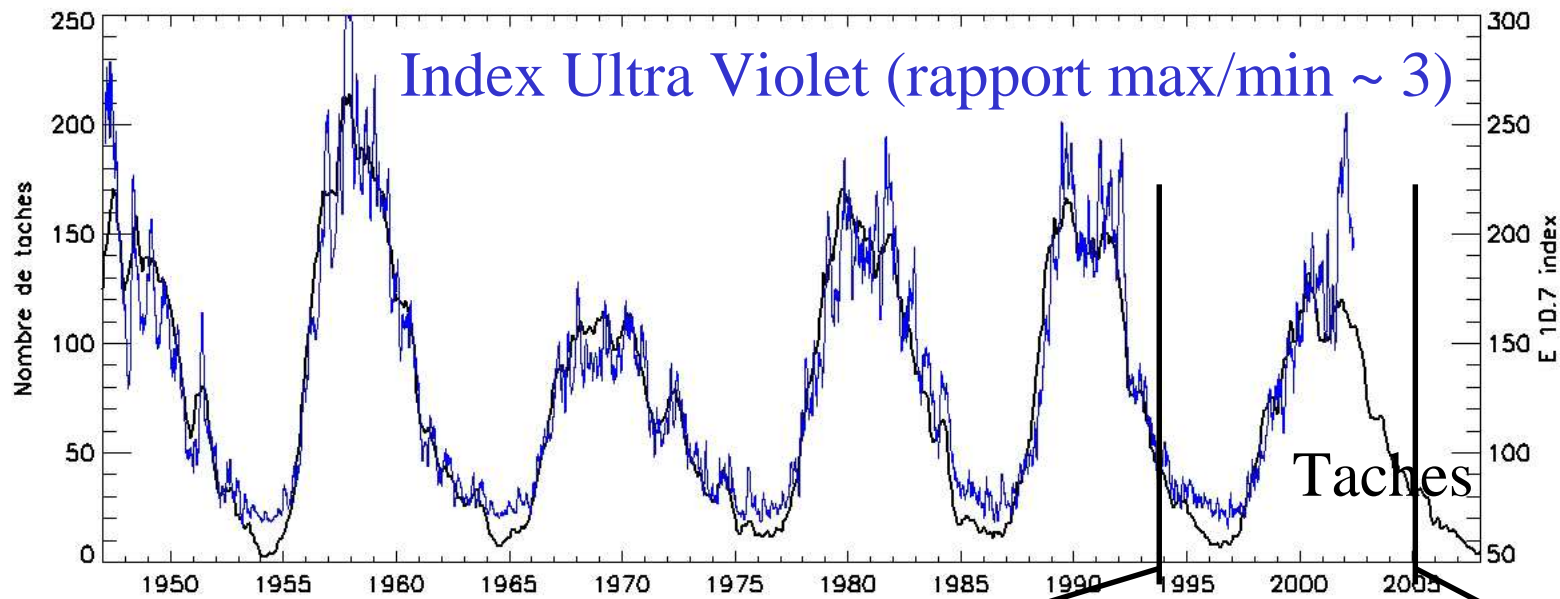














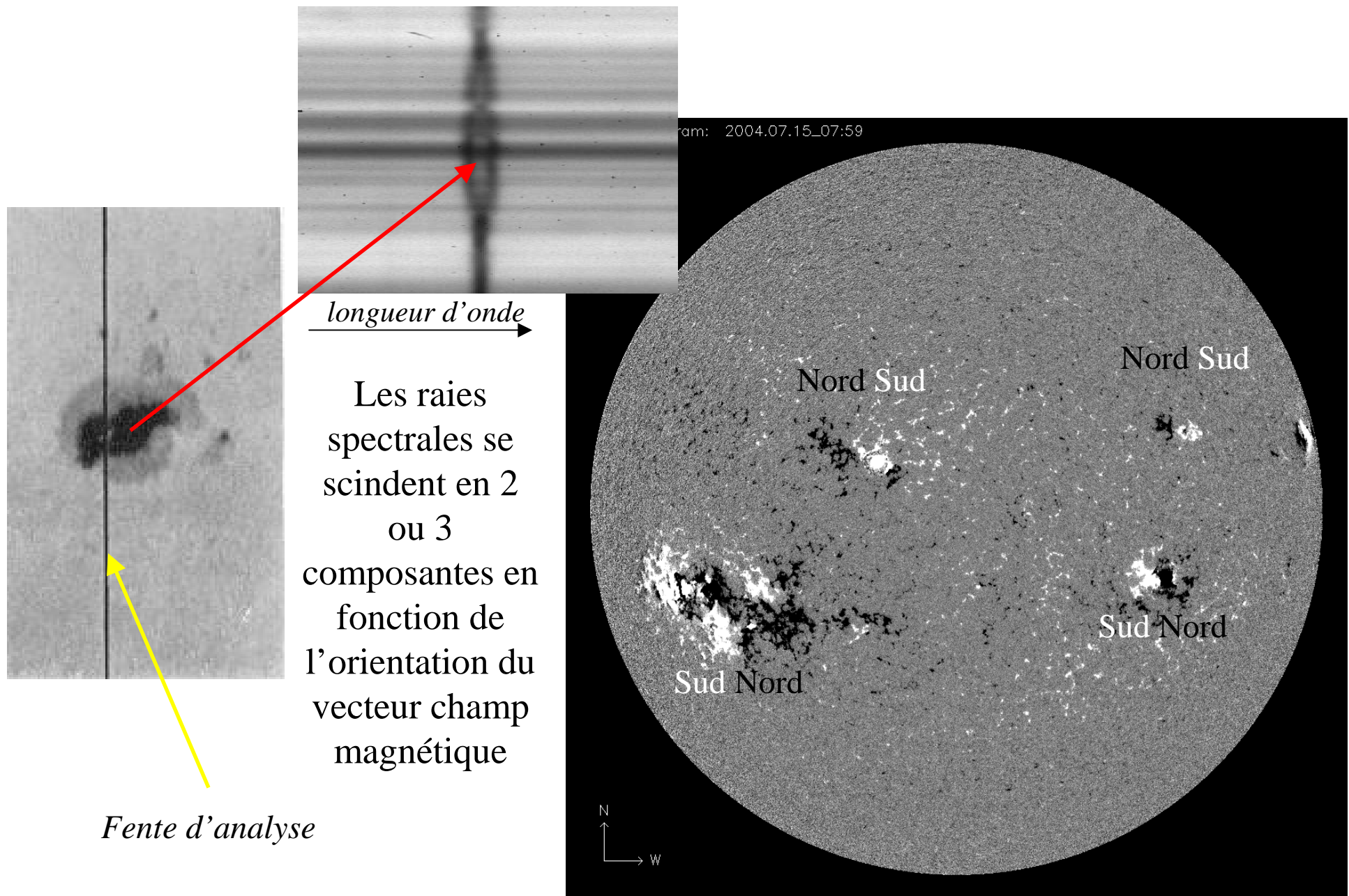


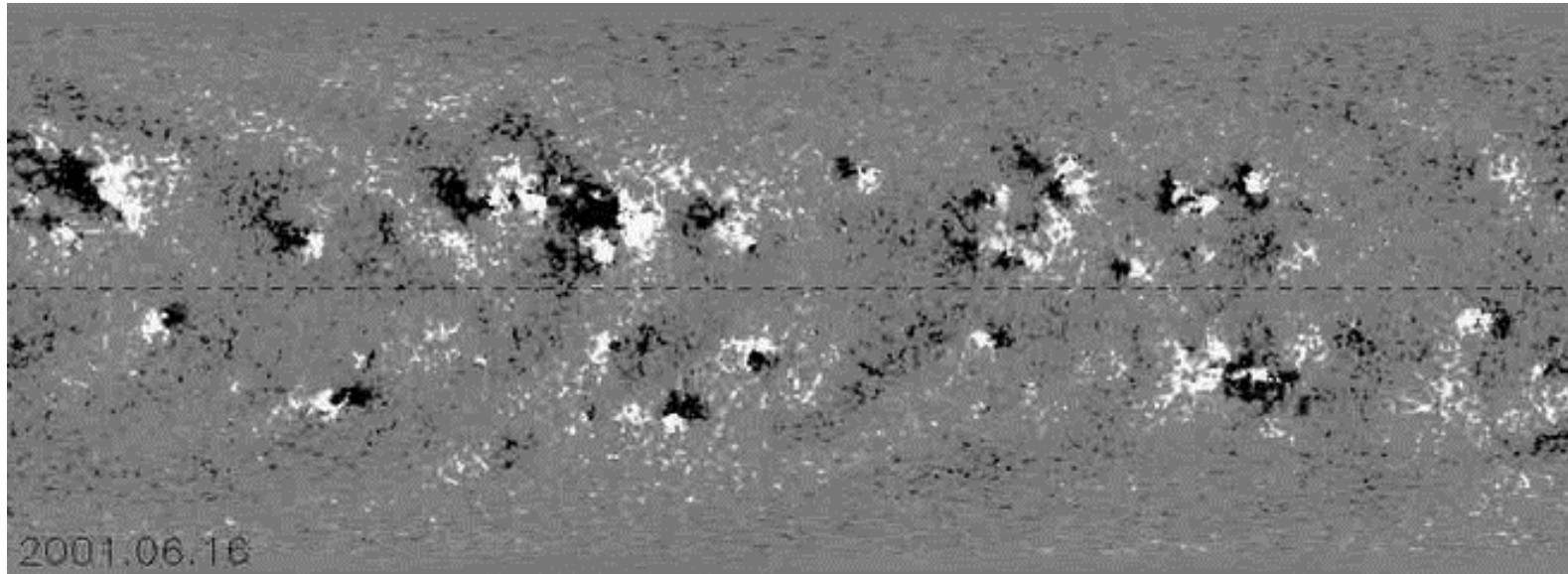
# **Inversions du champ magnétique solaire: observations**

## **III – Inversions magnétiques**

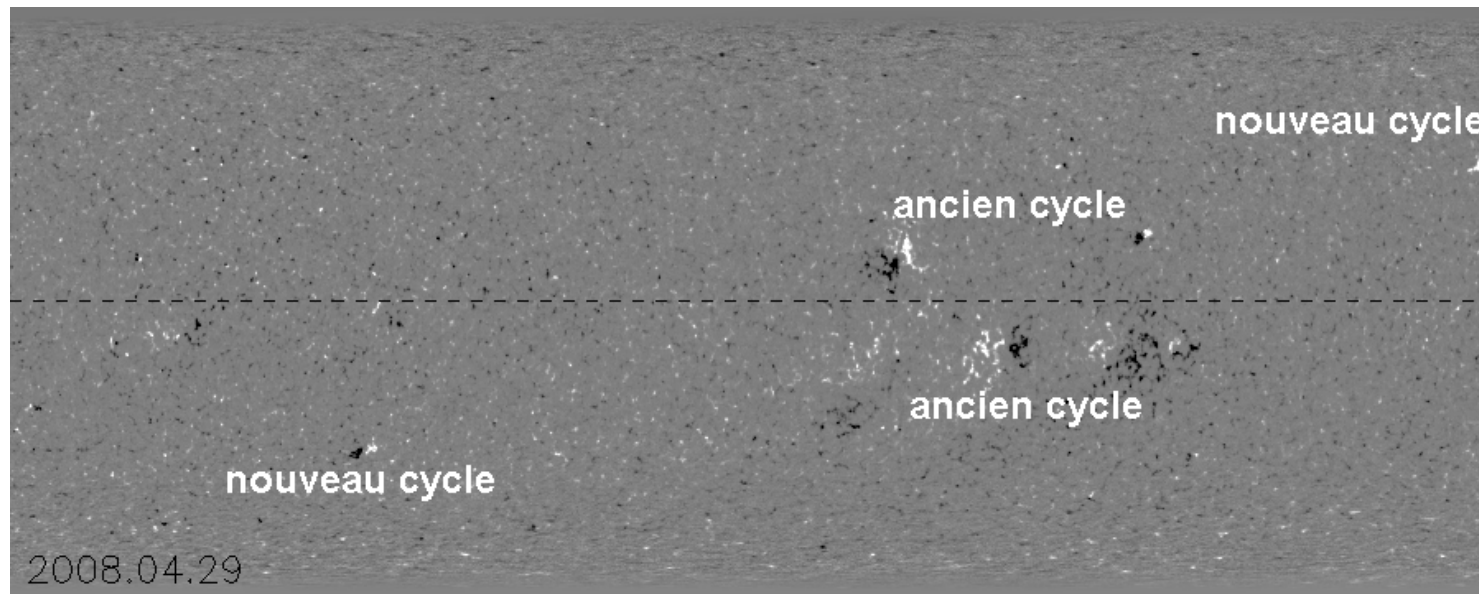


# La nature magnétique des taches (1908) et le cycle de 22 ans (1919)

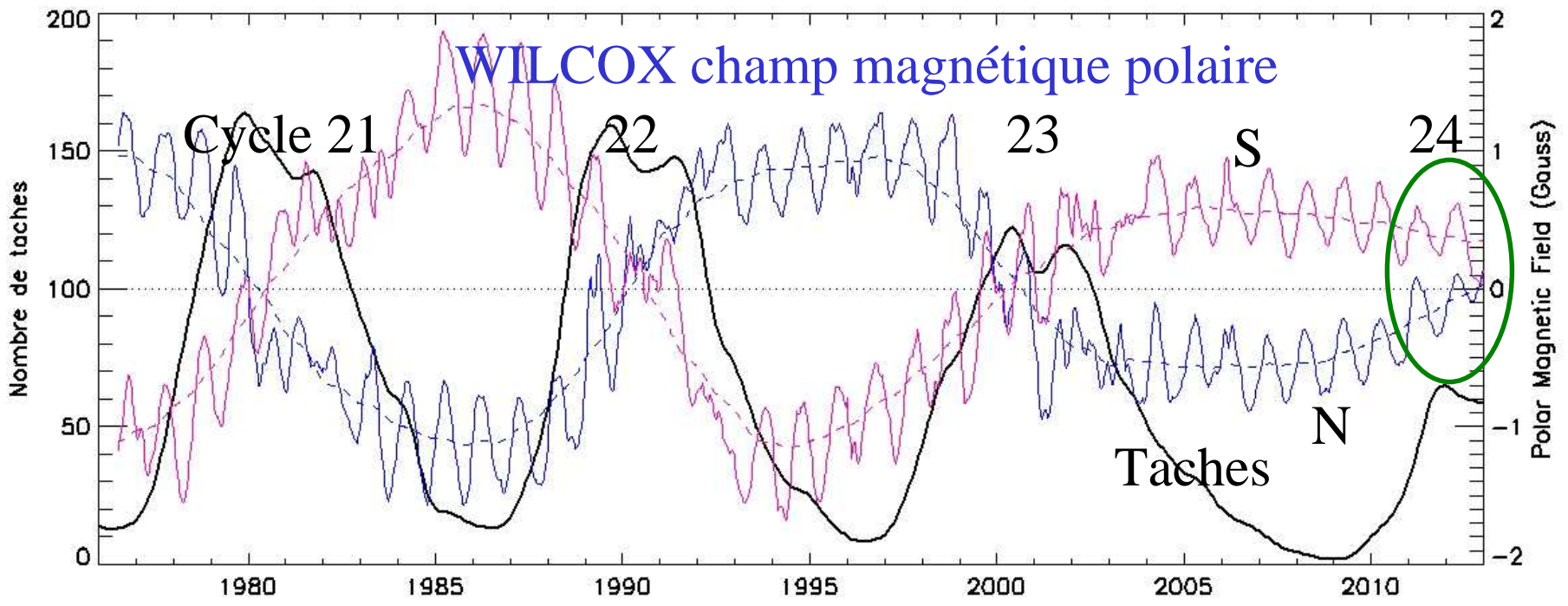
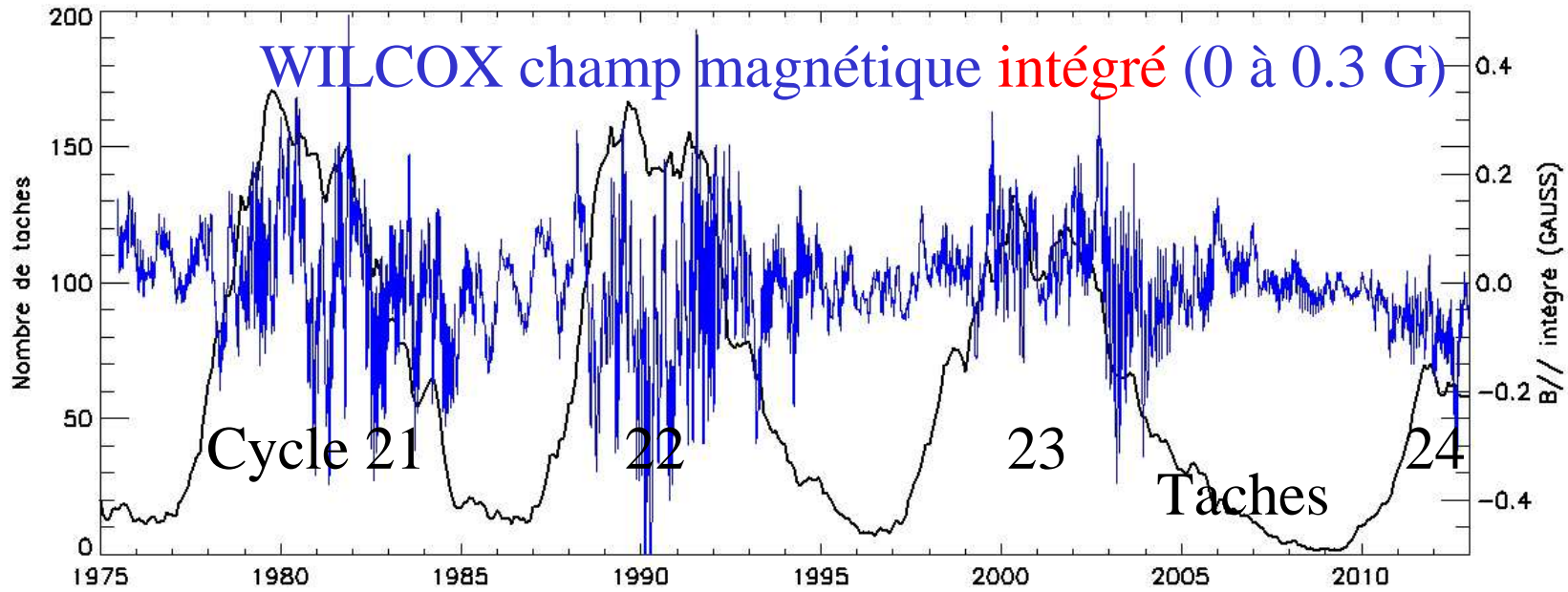


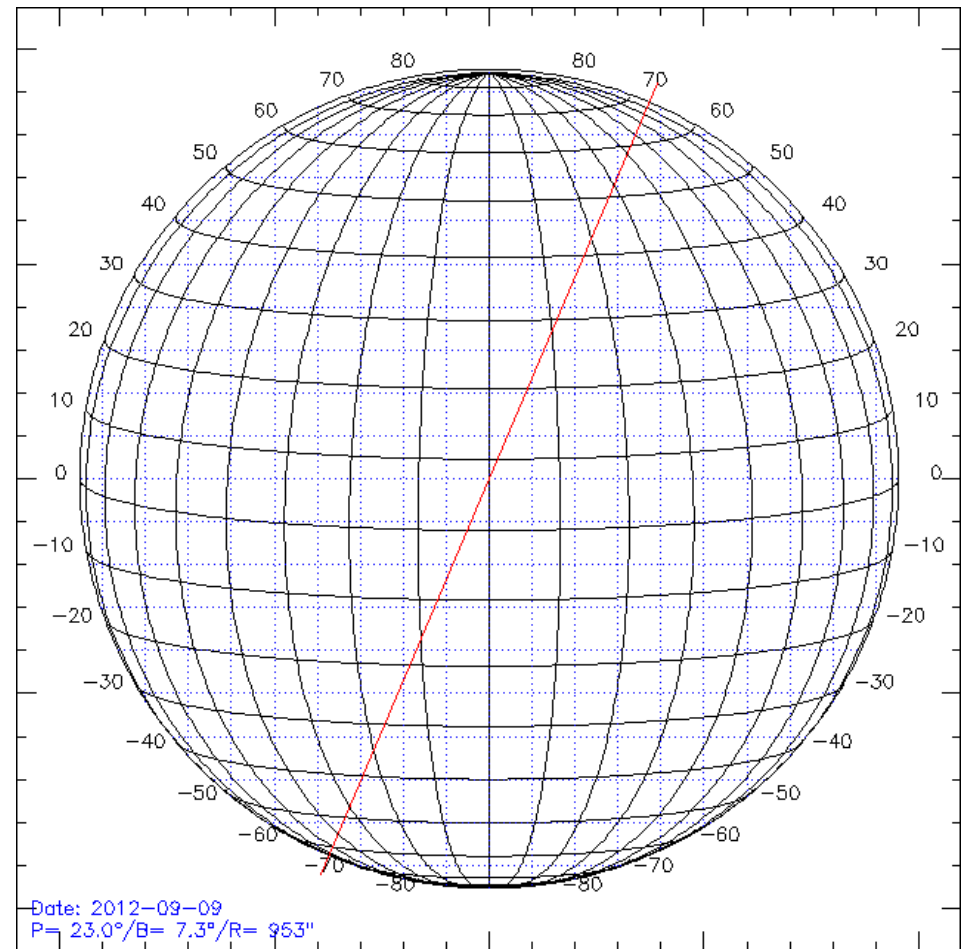
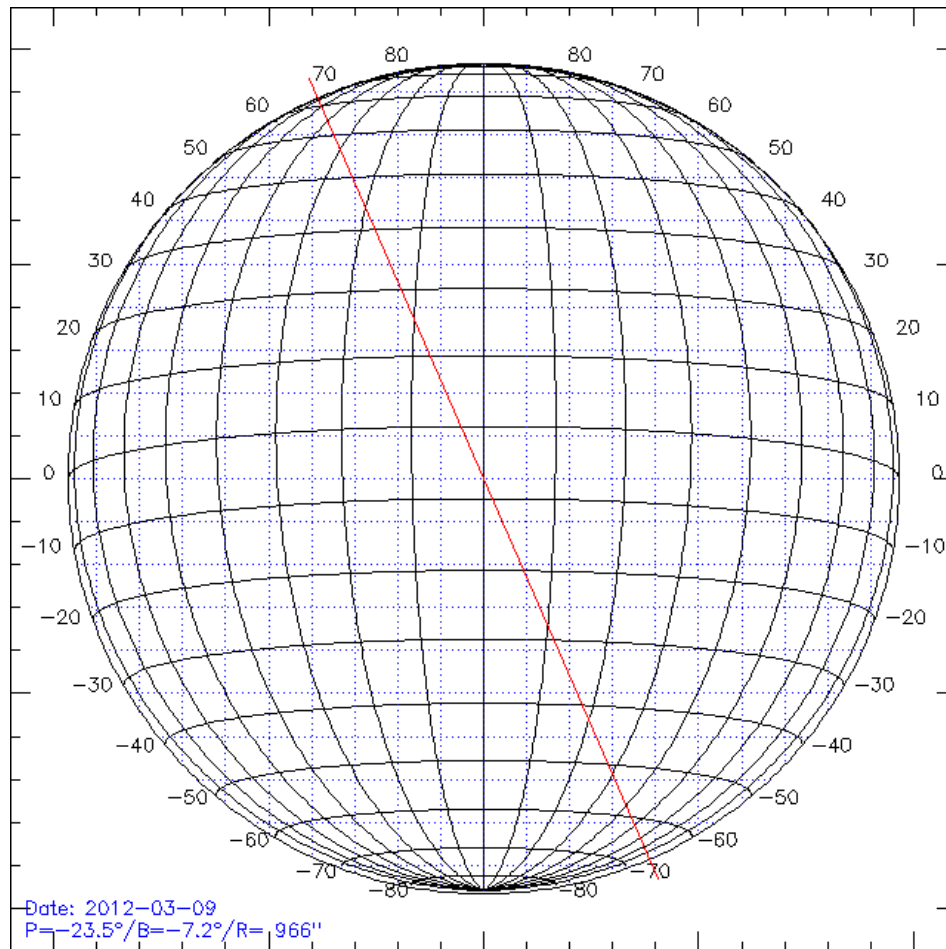


Cartes synoptiques SOHO/MDI au maximum (2001) et au minimum solaire (2008)



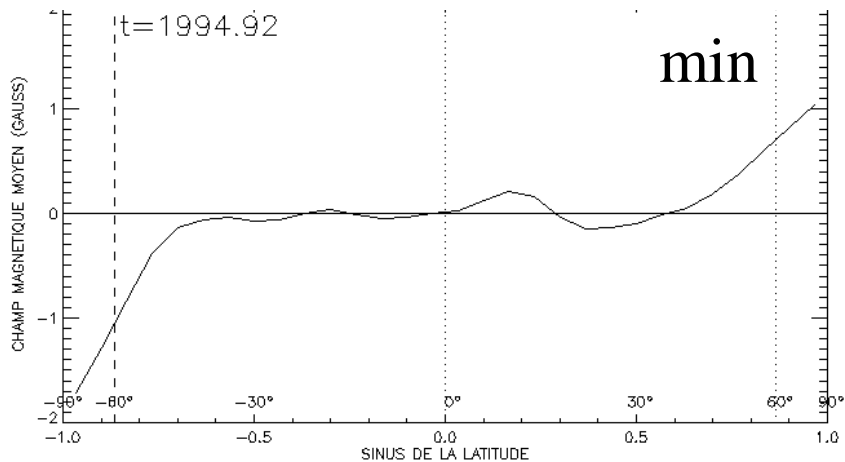
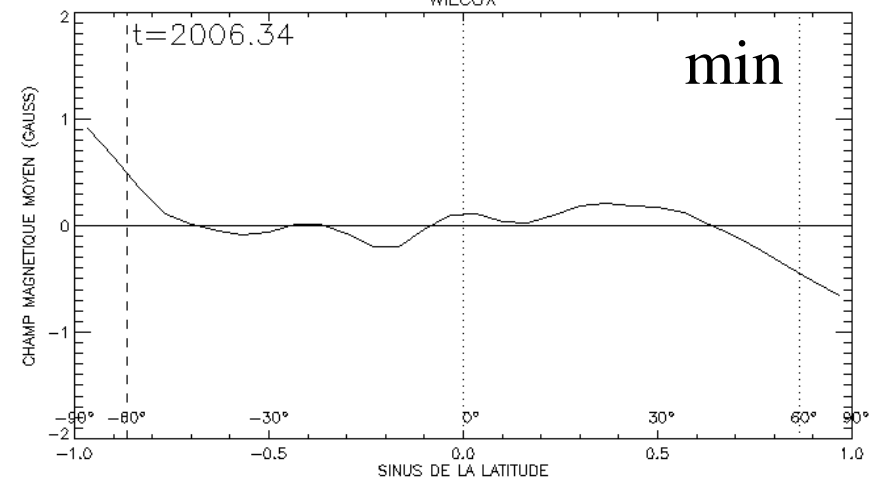
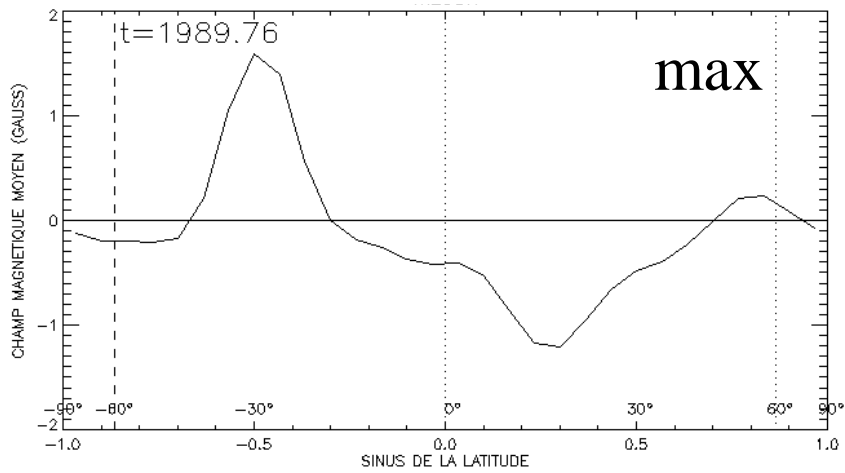
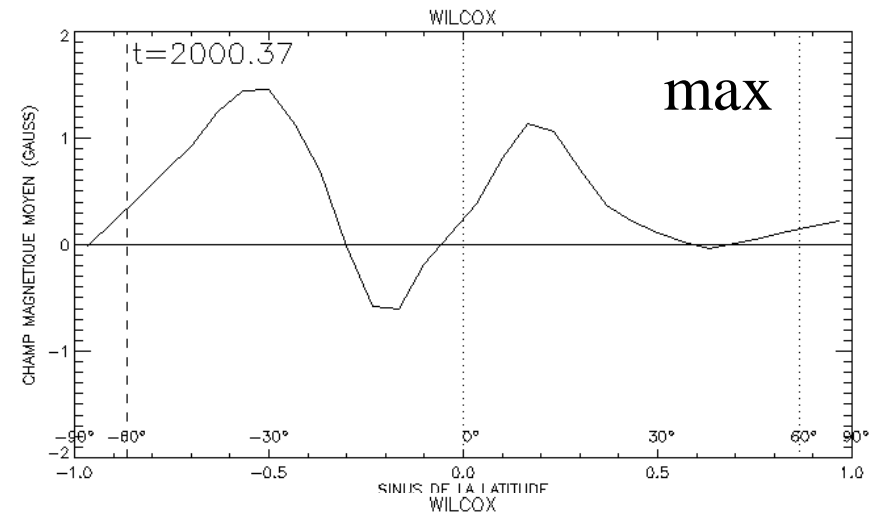
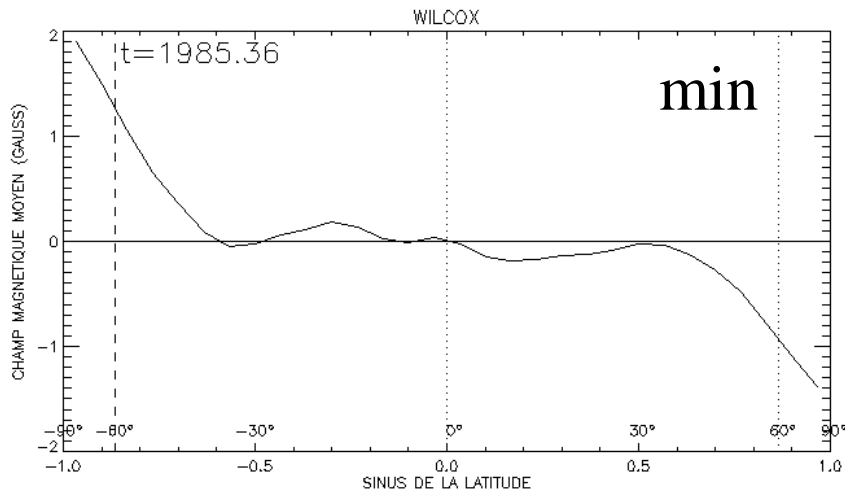




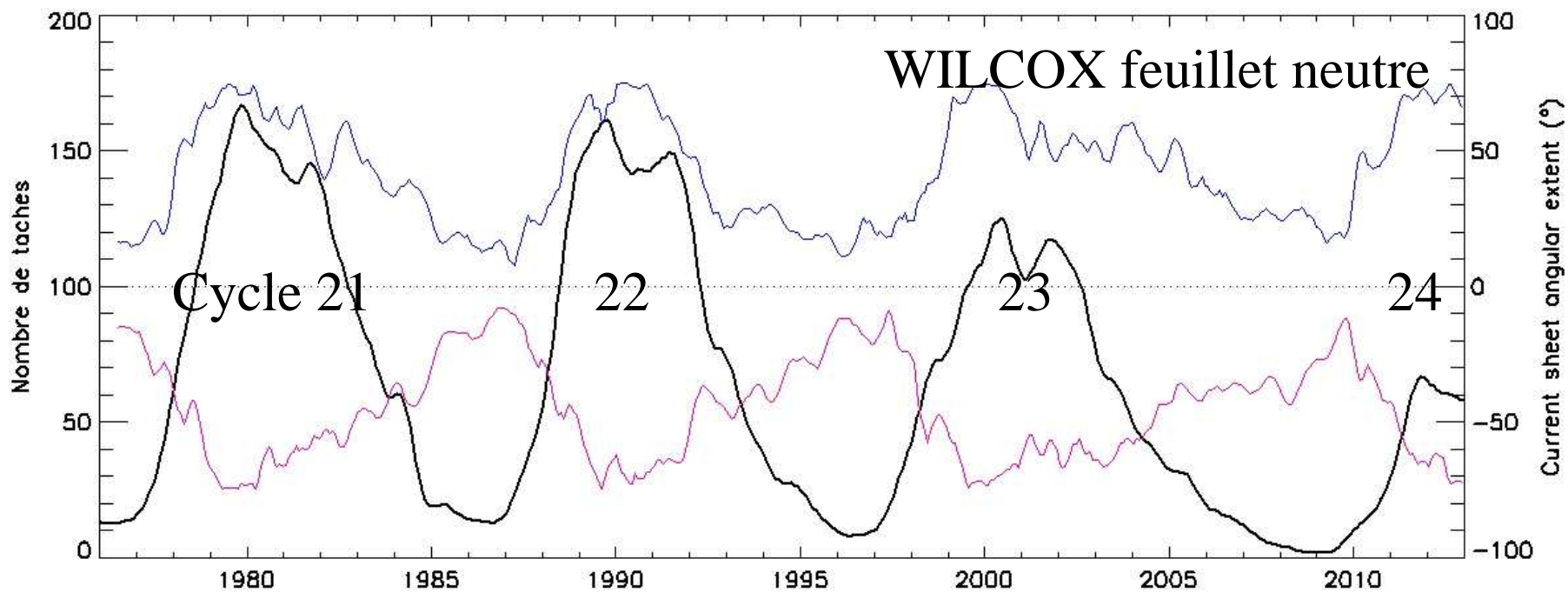
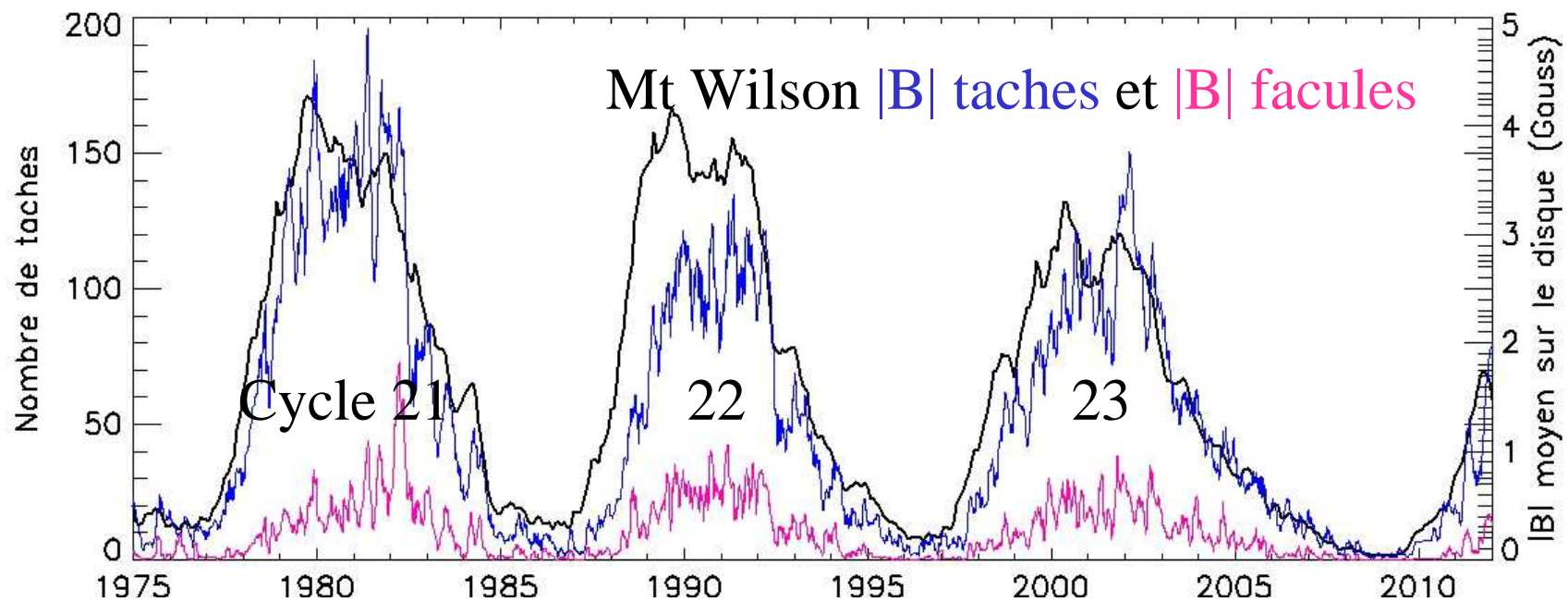


Variation annuelle de visibilité des pôles à l'origine de la modulation annuelle des mesures des champs magnétiques polaires radiaux

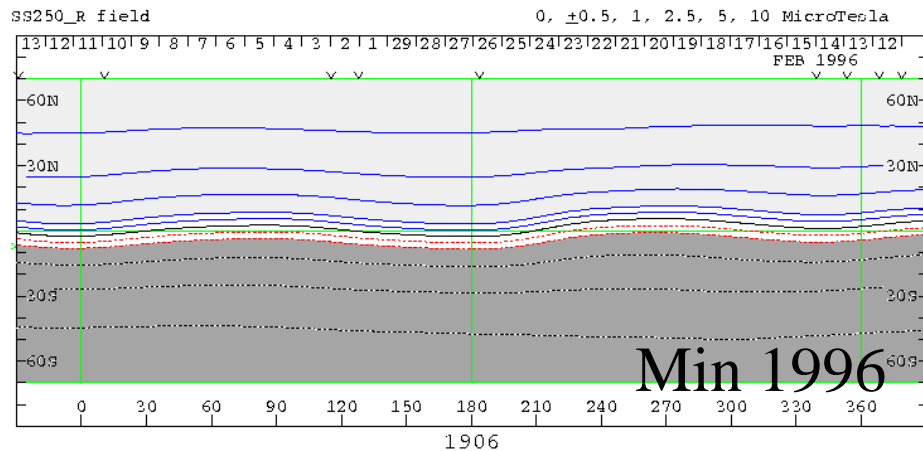
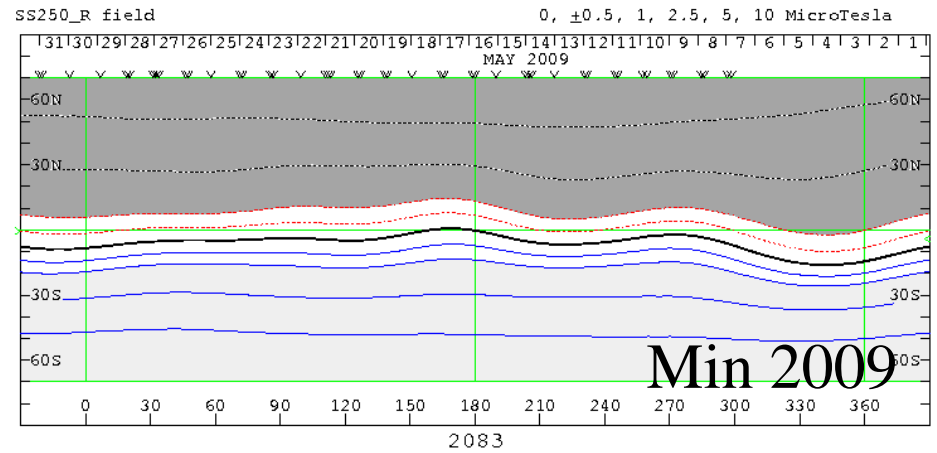
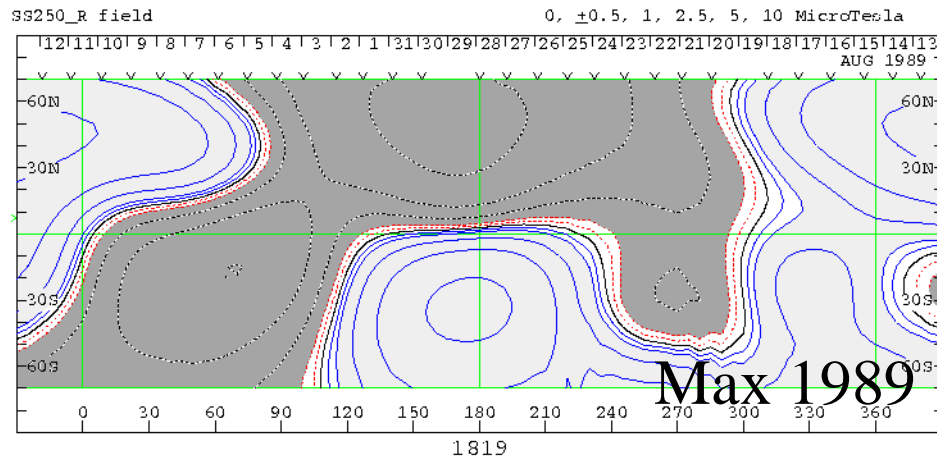
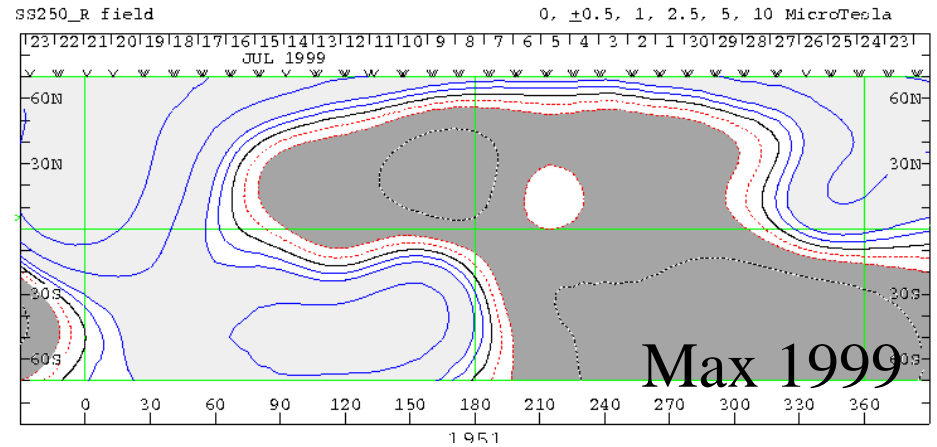
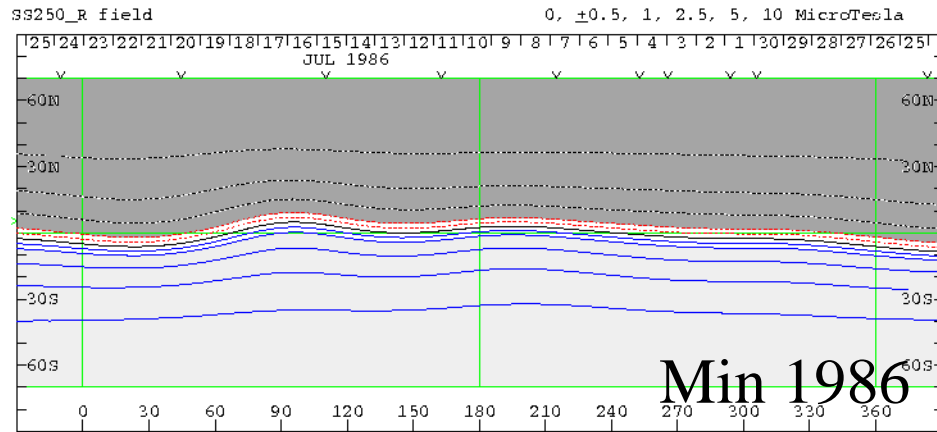




WILCOX (USA), champ magnétique moyen en fonction de la latitude de 1985 à 2006

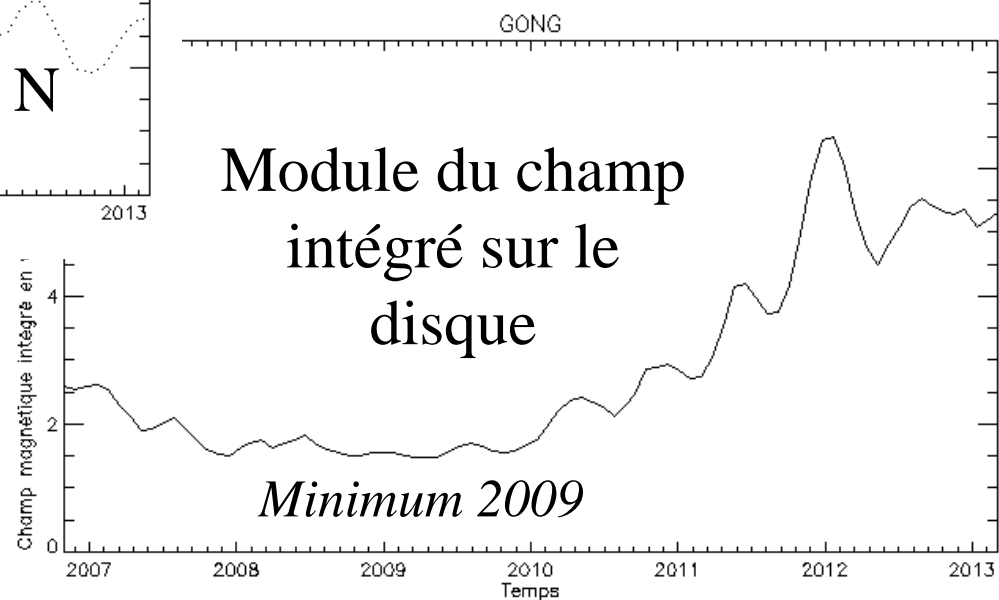
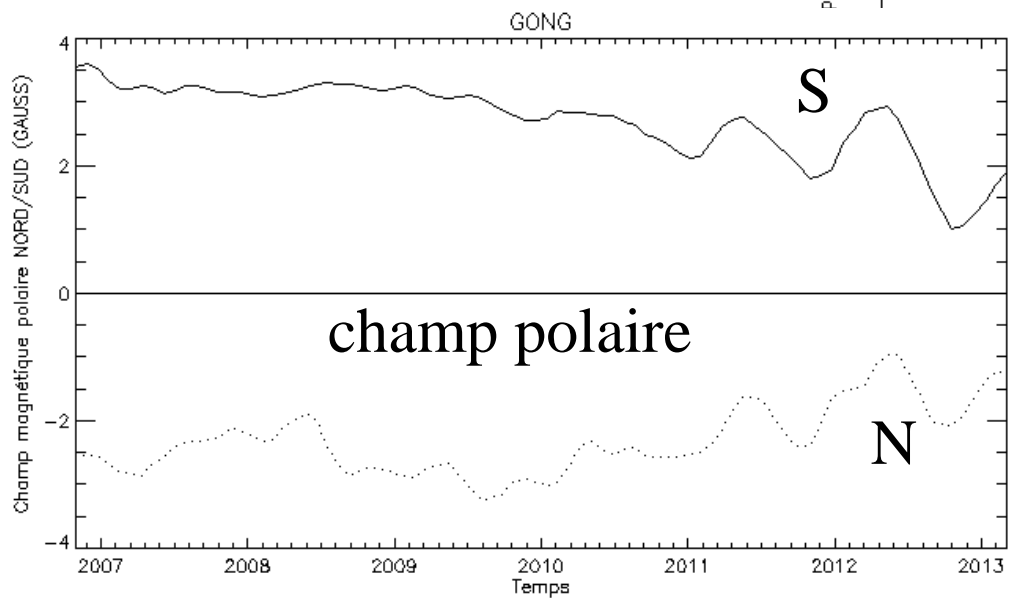
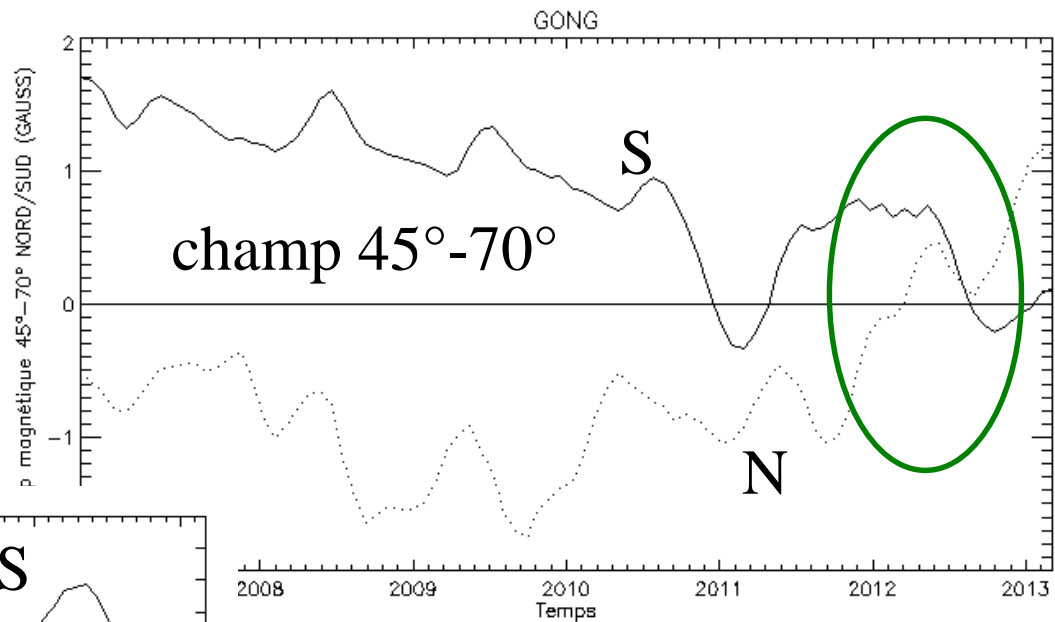






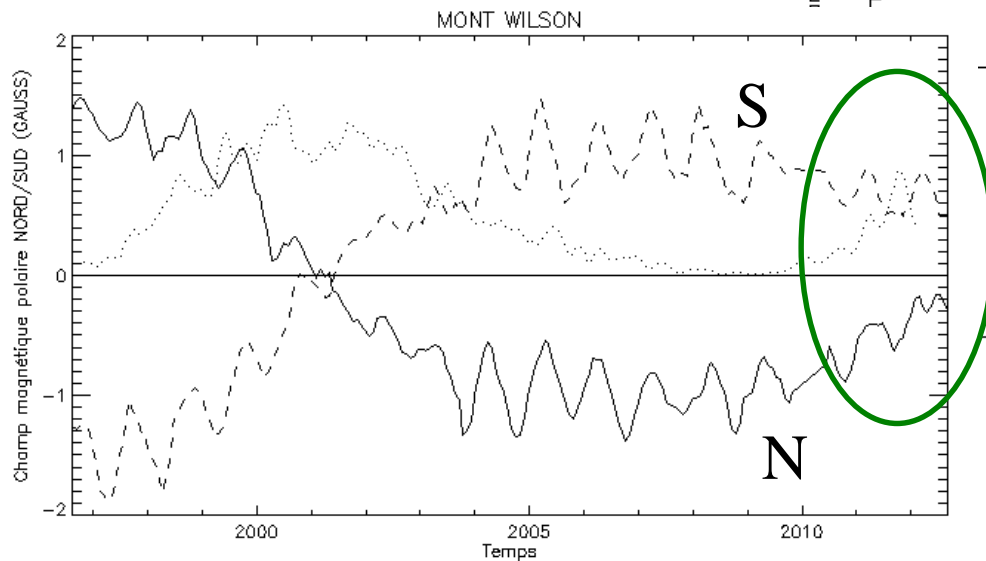
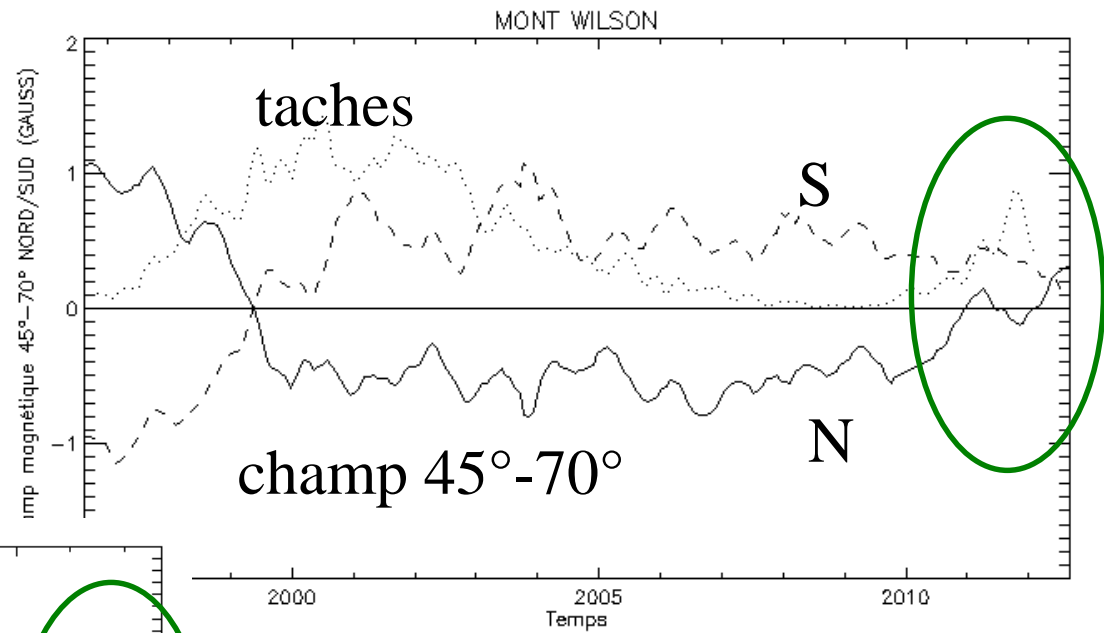
Champ radial à 2.5 rayons solaires, entre  $-70^\circ$  et  $+70^\circ$  de latitude (pôles exclus), WILCOX (USA)

# RESEAU GONG

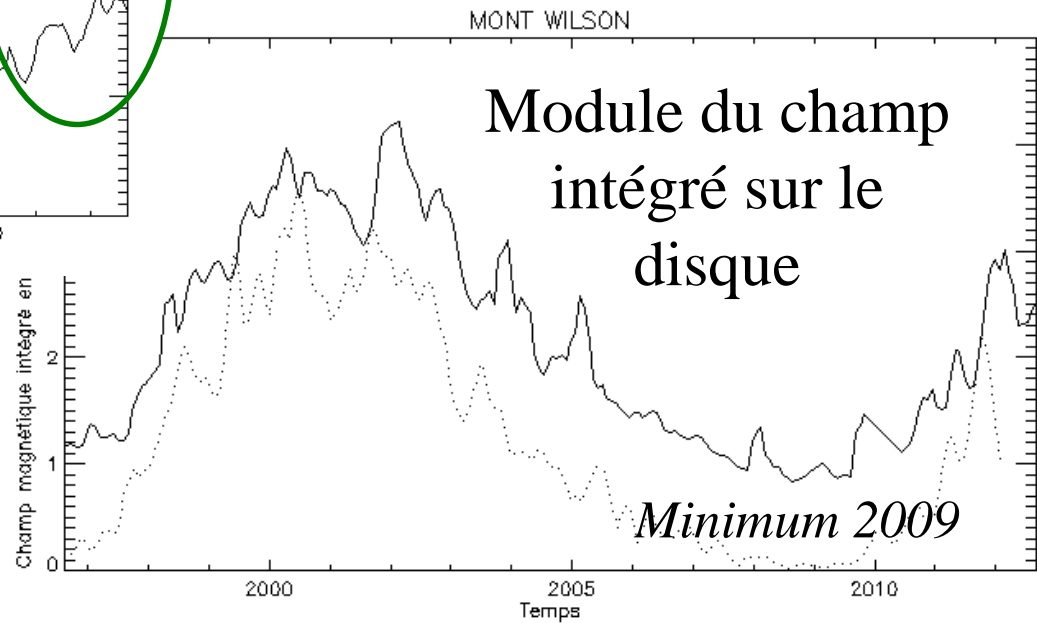




# MONT WILSON



champ polaire

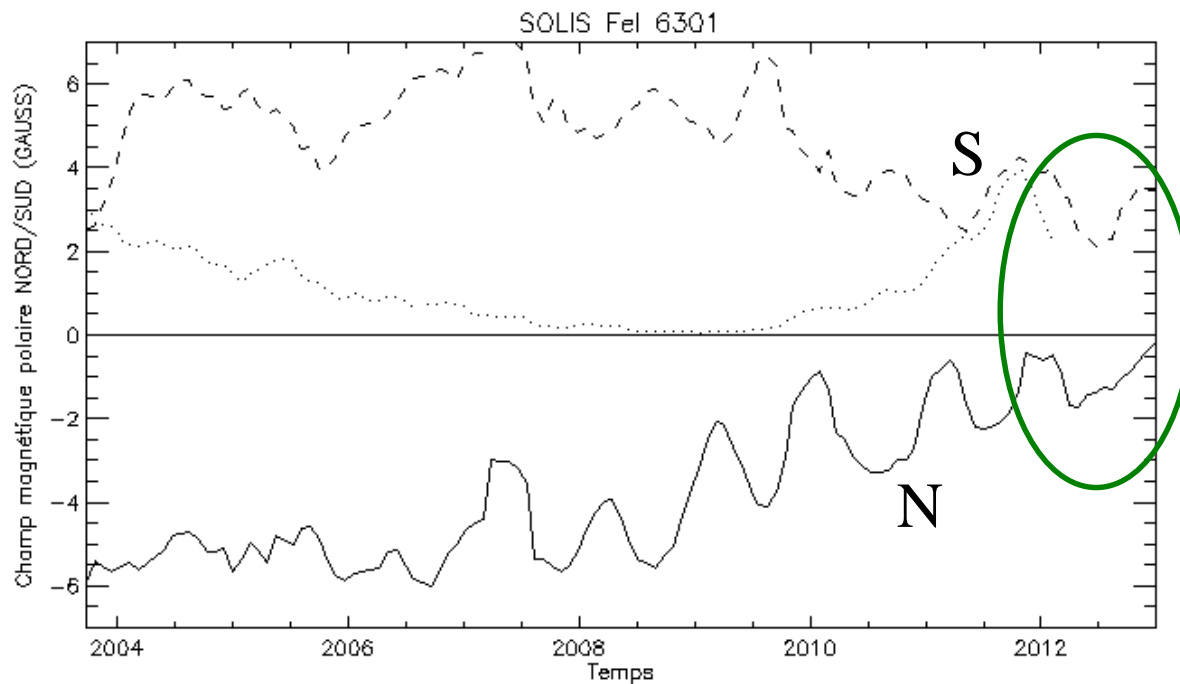
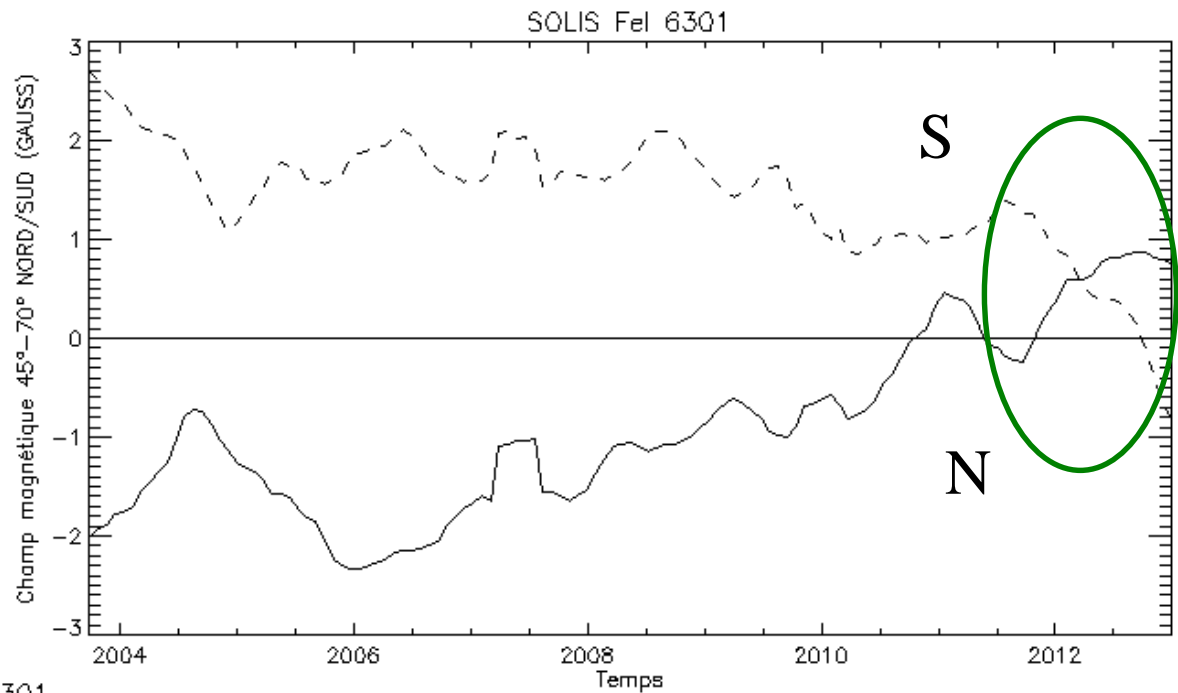


# SOLIS KITT PEAK

Inversion ceinture  
45°-70°

Nord mi 2011

Sud mi 2012



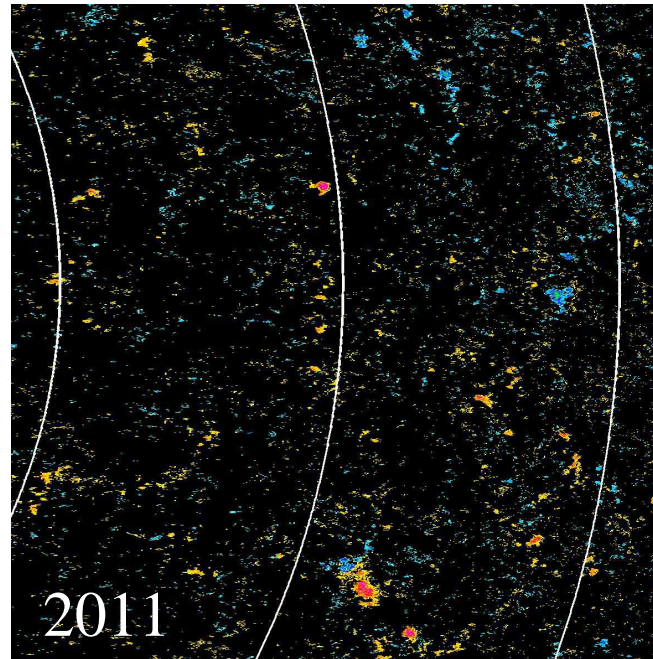
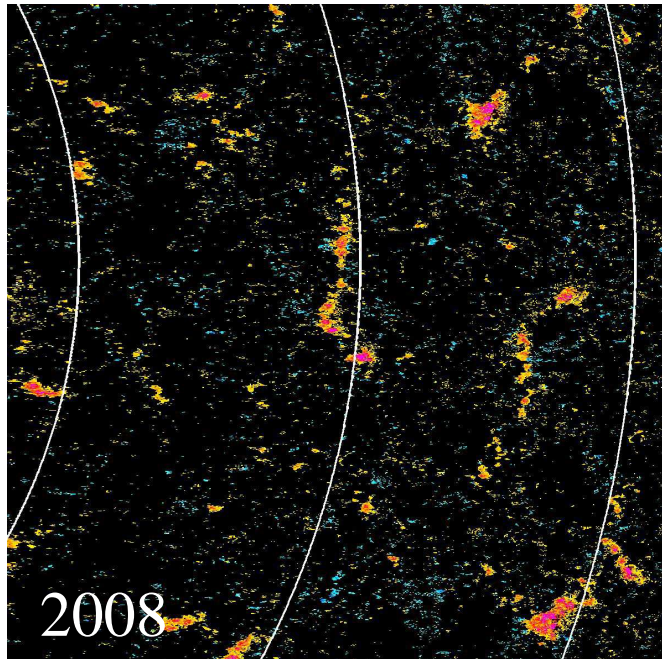
# SOLIS KITT PEAK

Inversion polaire

Nord fin 2012

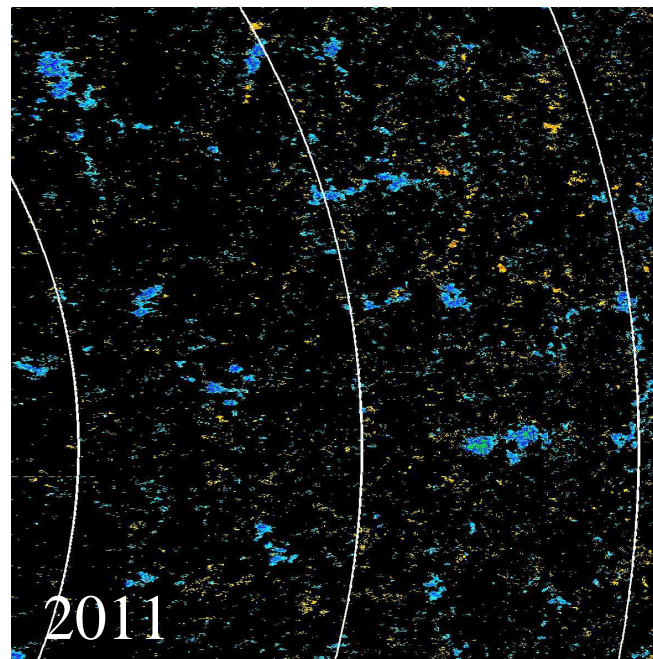
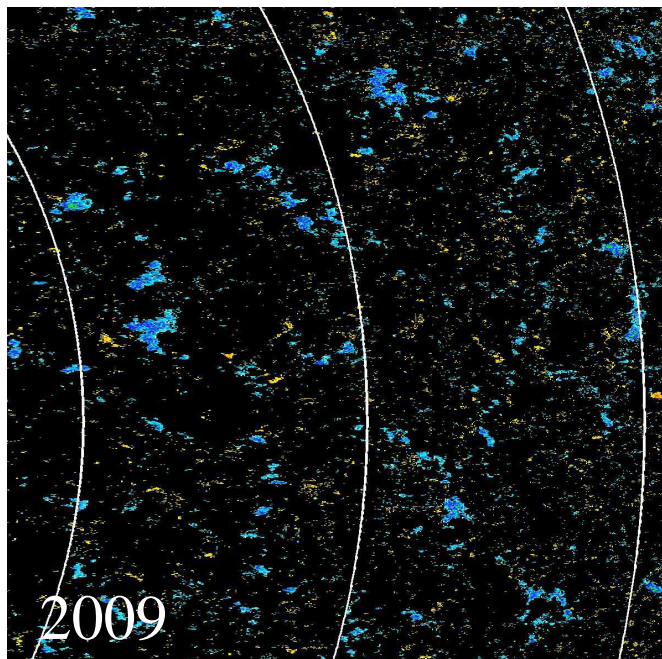
Sud fin 2013 ?





Satellite  
Hinode, pôle  
NORD 70°-85°

Inversion  
N/S en  
avance d'un  
an sur  
l'inversion  
S/N

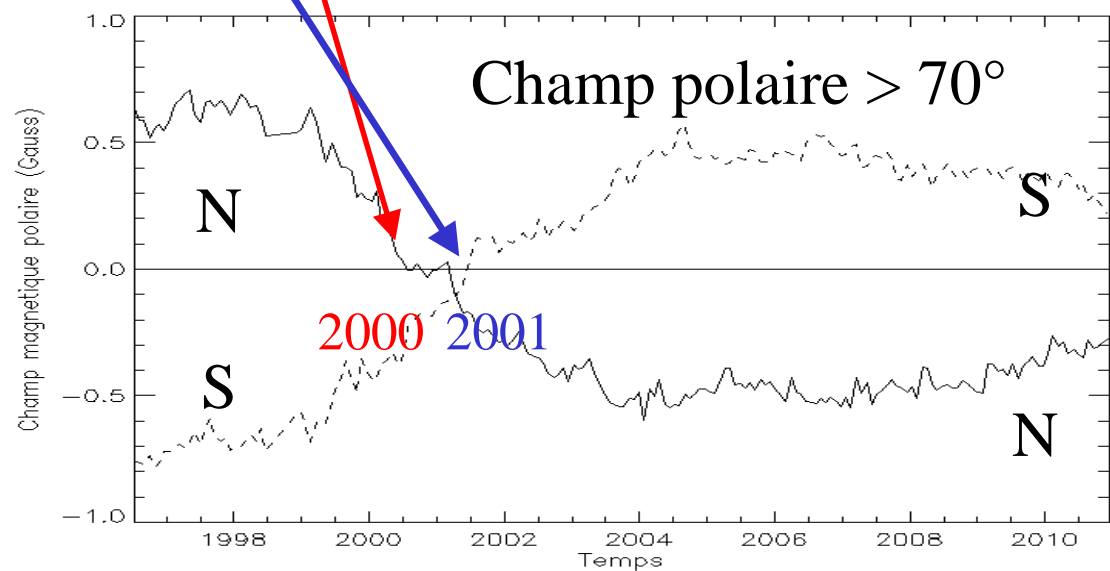
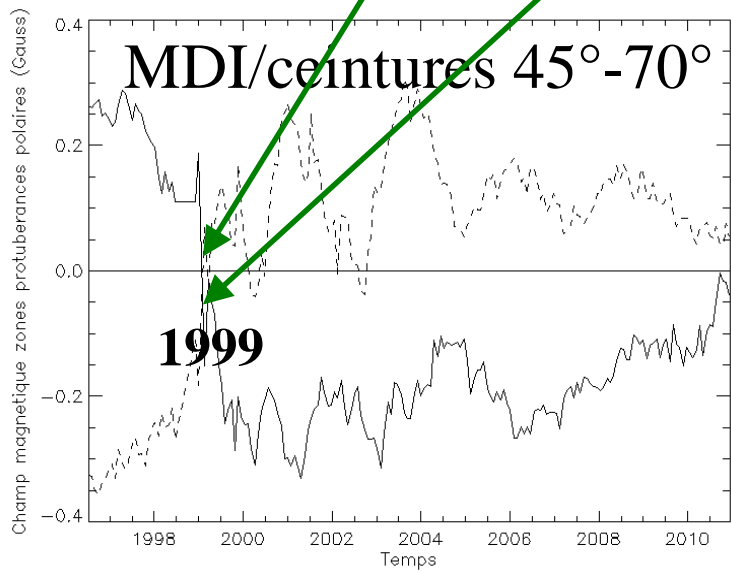
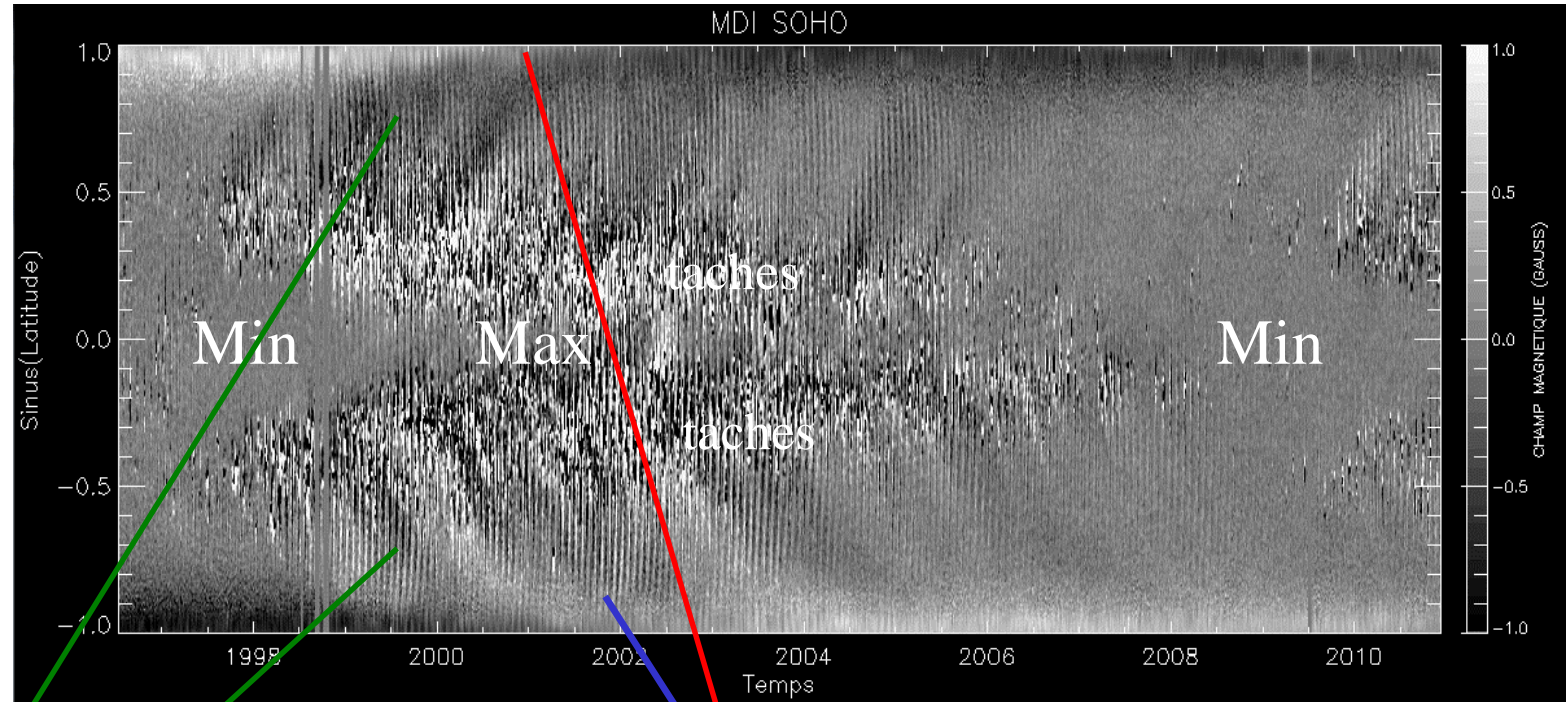


Satellite  
Hinode, pôle  
SUD 70°-85°

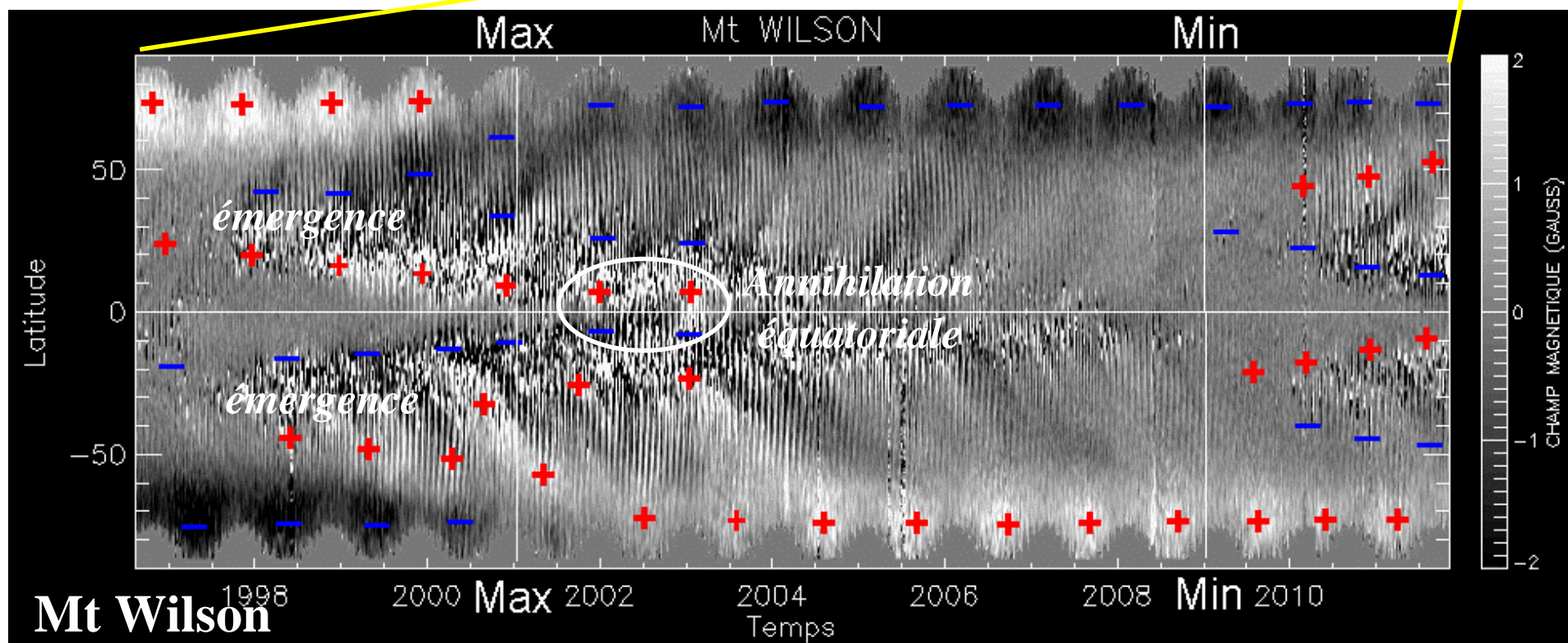
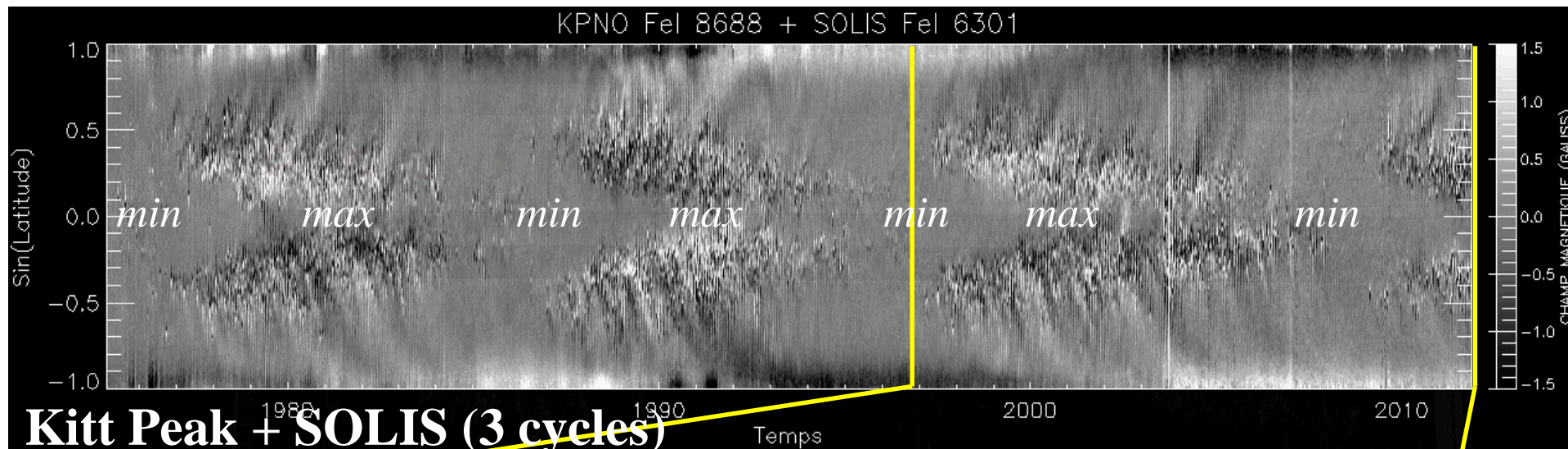
Satellite  
SOHO/MDI

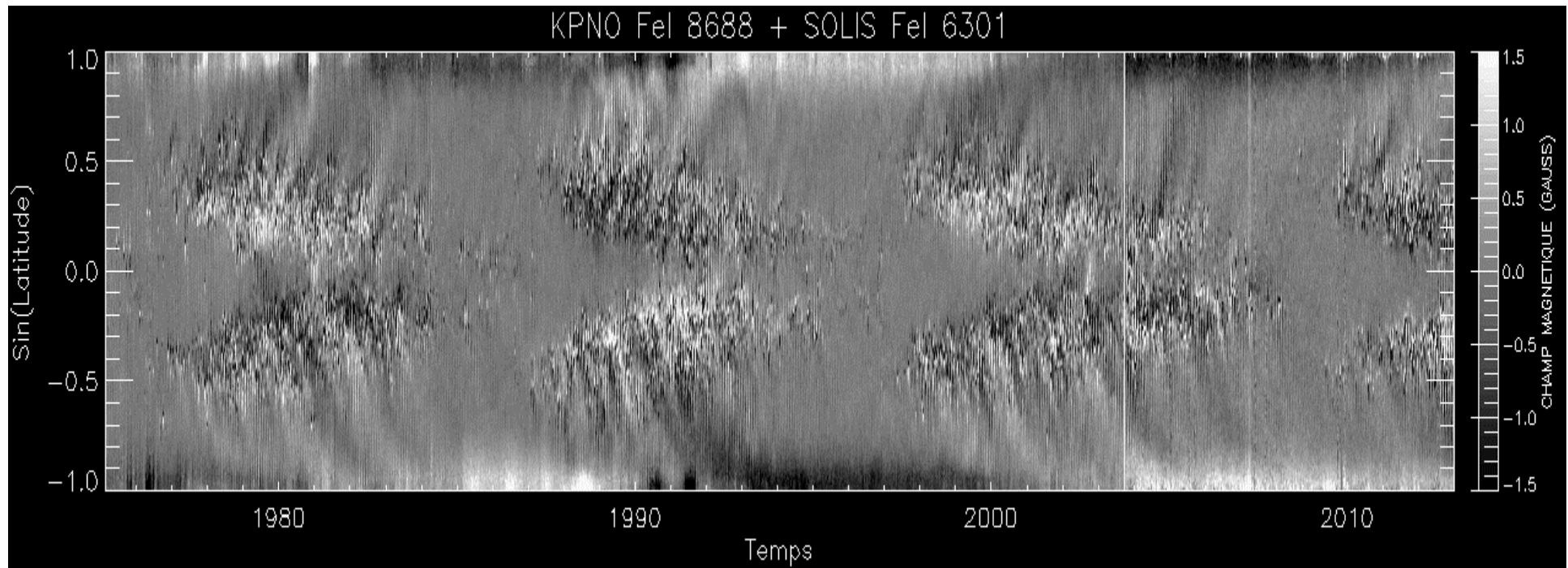
Champs  
magnétiques

1996 à 2011  
(temps,  
latitude)

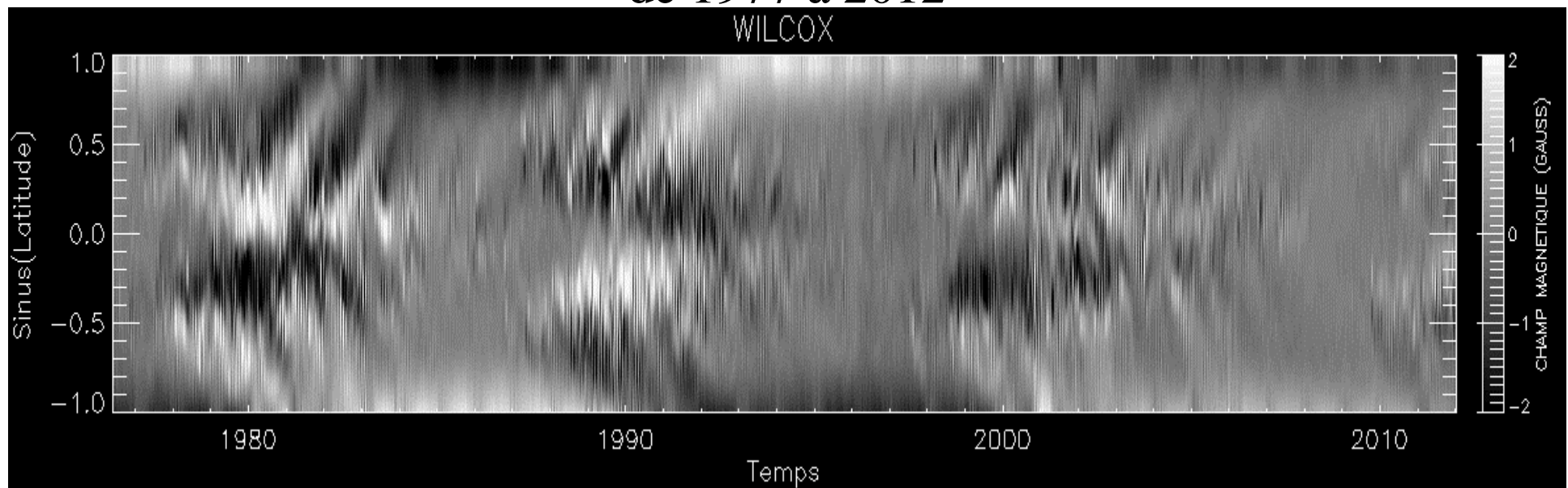


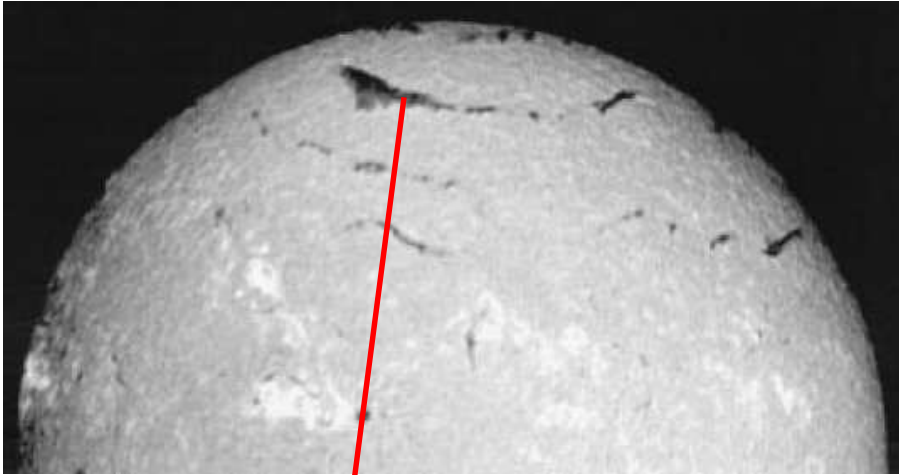




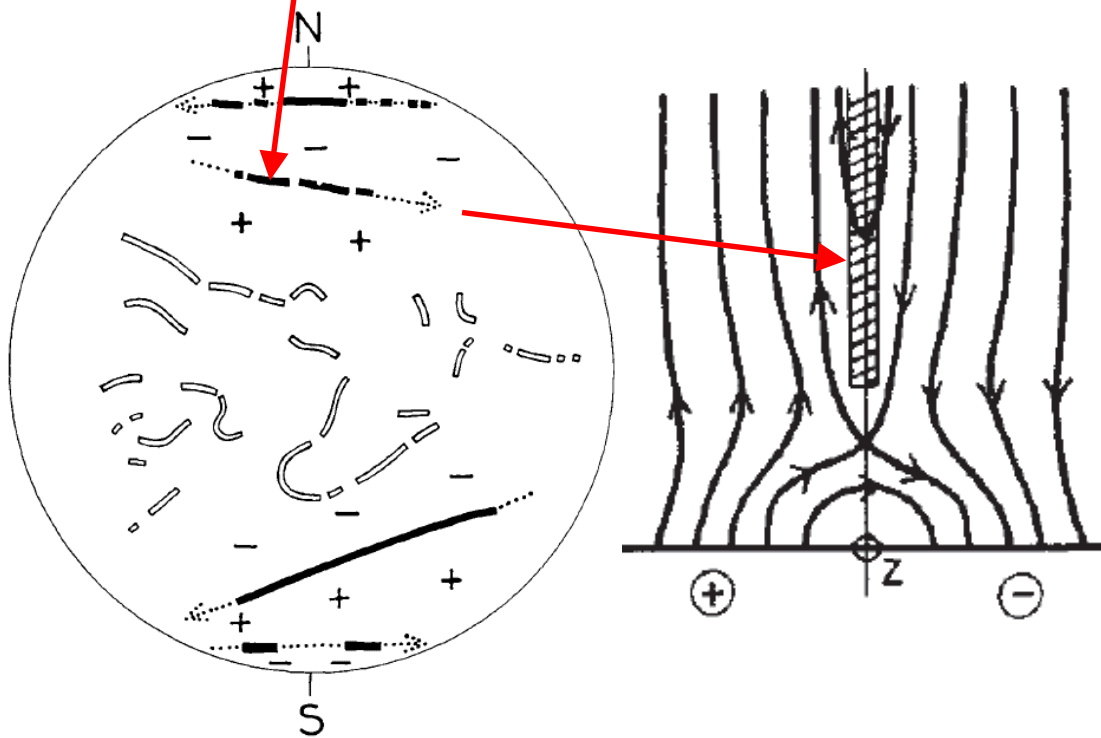


WILCOX et KPNO (USA), champ magnétique en fonction de la latitude de 1977 à 2012



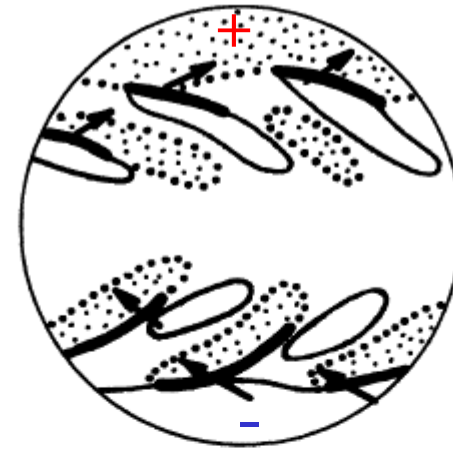


Inversions du champ magnétique axial  
des protubérances des ceintures polaires



filaments des ceintures polaires

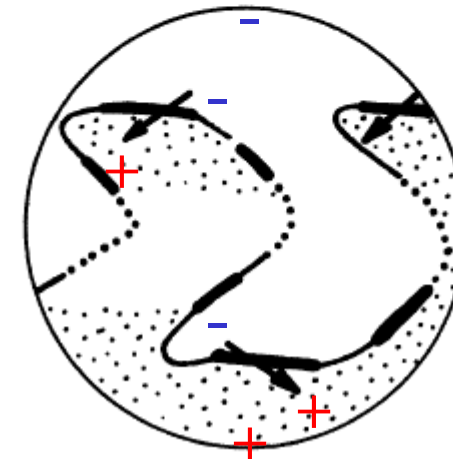
(a)



Minimun cycles 19/20

filaments des ceintures polaires

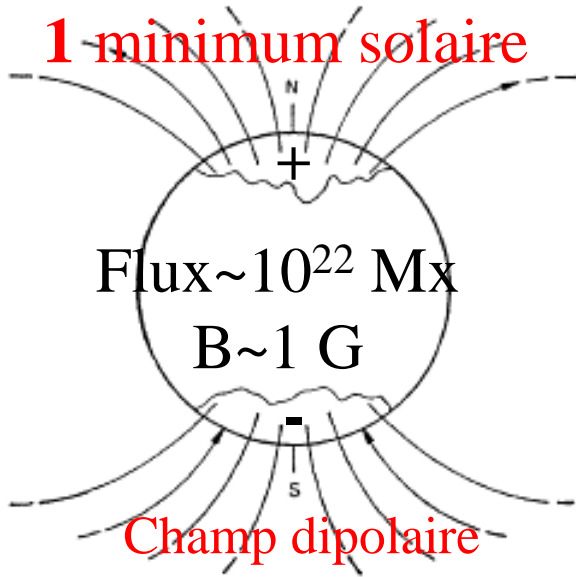
(b)



Minimun cycles 20/21



**1 minimum solaire**

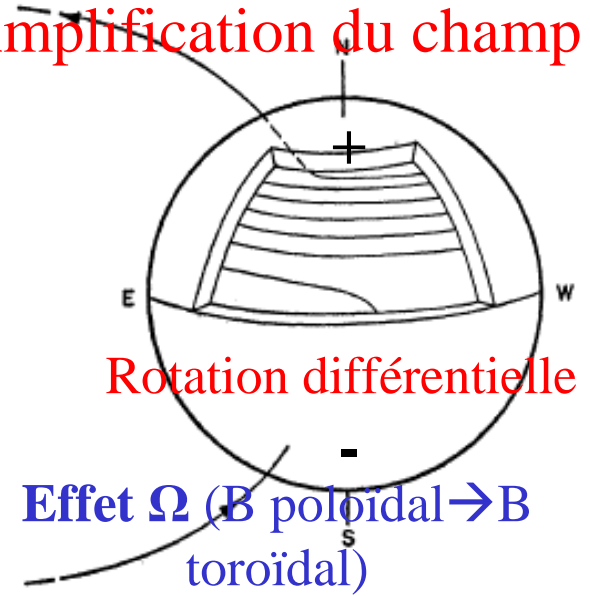


**Modèle dynamo de Babcock Leighton**

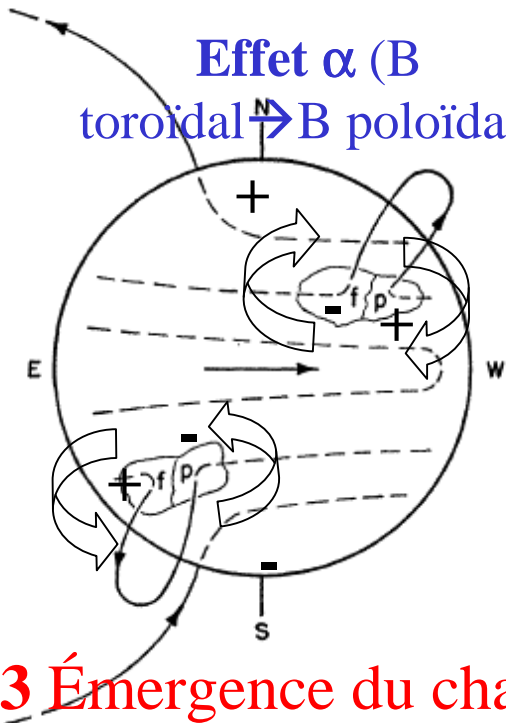
Au maximum

Flux  $\sim 10^{25}$  Mx  
 B  $\sim 1000$  G

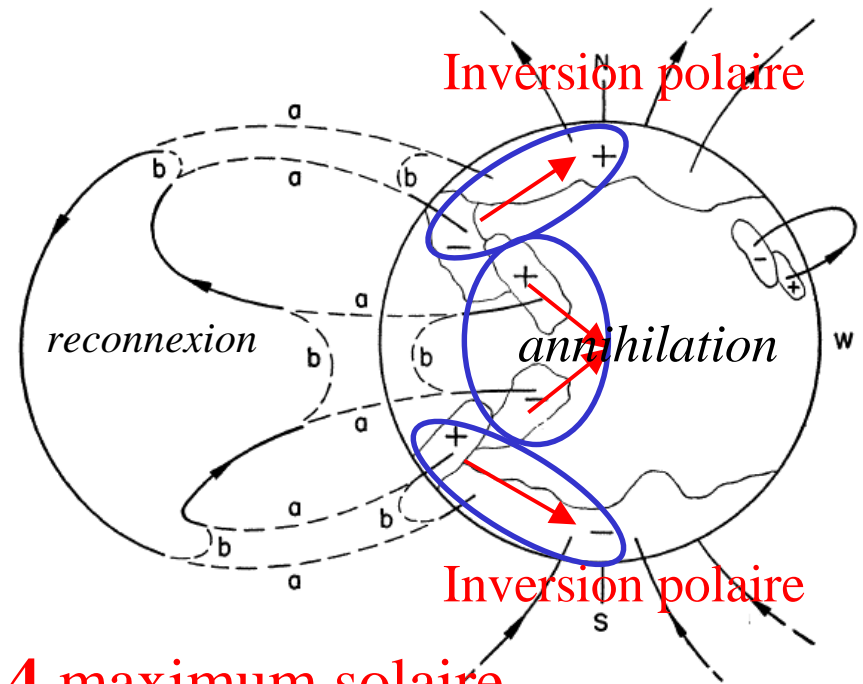
**2 Amplification du champ**



Effet  $\alpha$  (B toroidal  $\rightarrow$  B poloidal)



Inversion polaire



**3 Émergence du champ**

**4 maximum solaire**

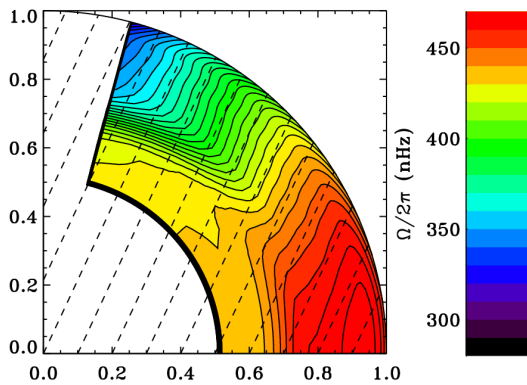
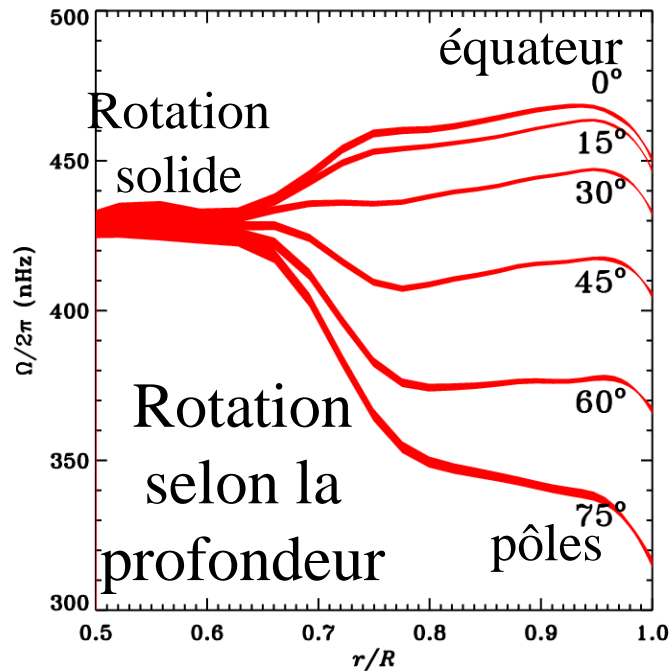


# **Inversions du champ magnétique solaire: observations**

**IV – Des anomalies dans la cyclicité  
Cycle 23 et Grand Minimum de Maunder**



# Rotation différentielle



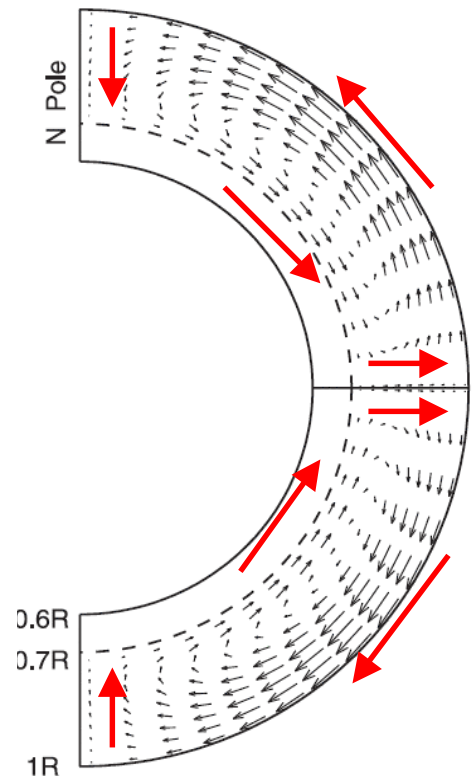
# Circulation méridienne

(dépend de la latitude,  
de la profondeur et du  
temps)

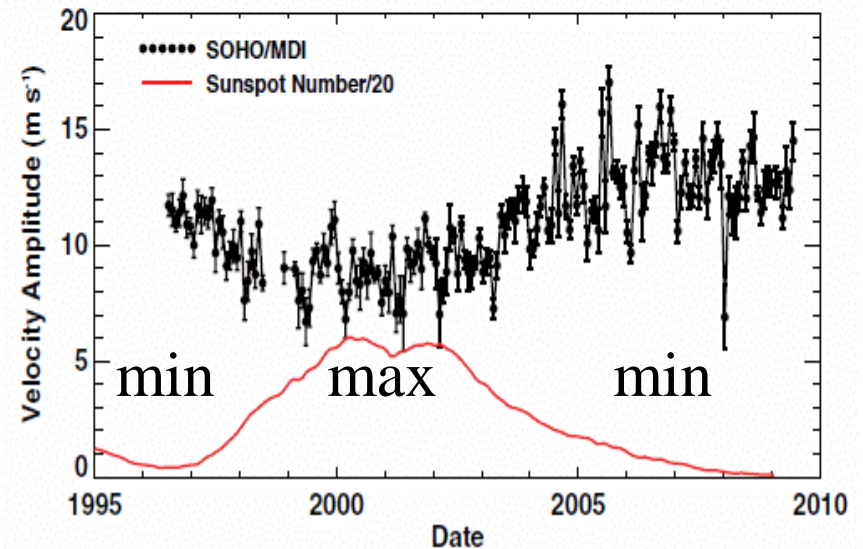
$$v \sim 10 \text{ m/s}$$

→ Durée du cycle

$$T \sim \pi R/v \sim 10 \text{ ans}$$

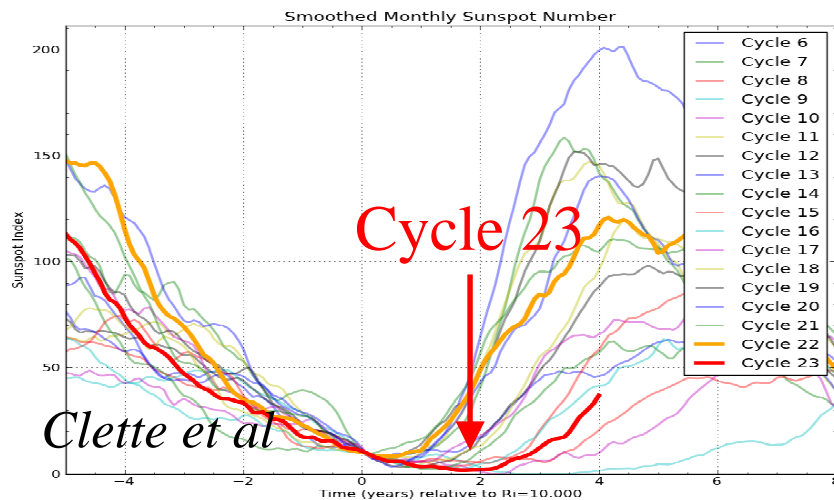


# Résultats SOHO/MDI

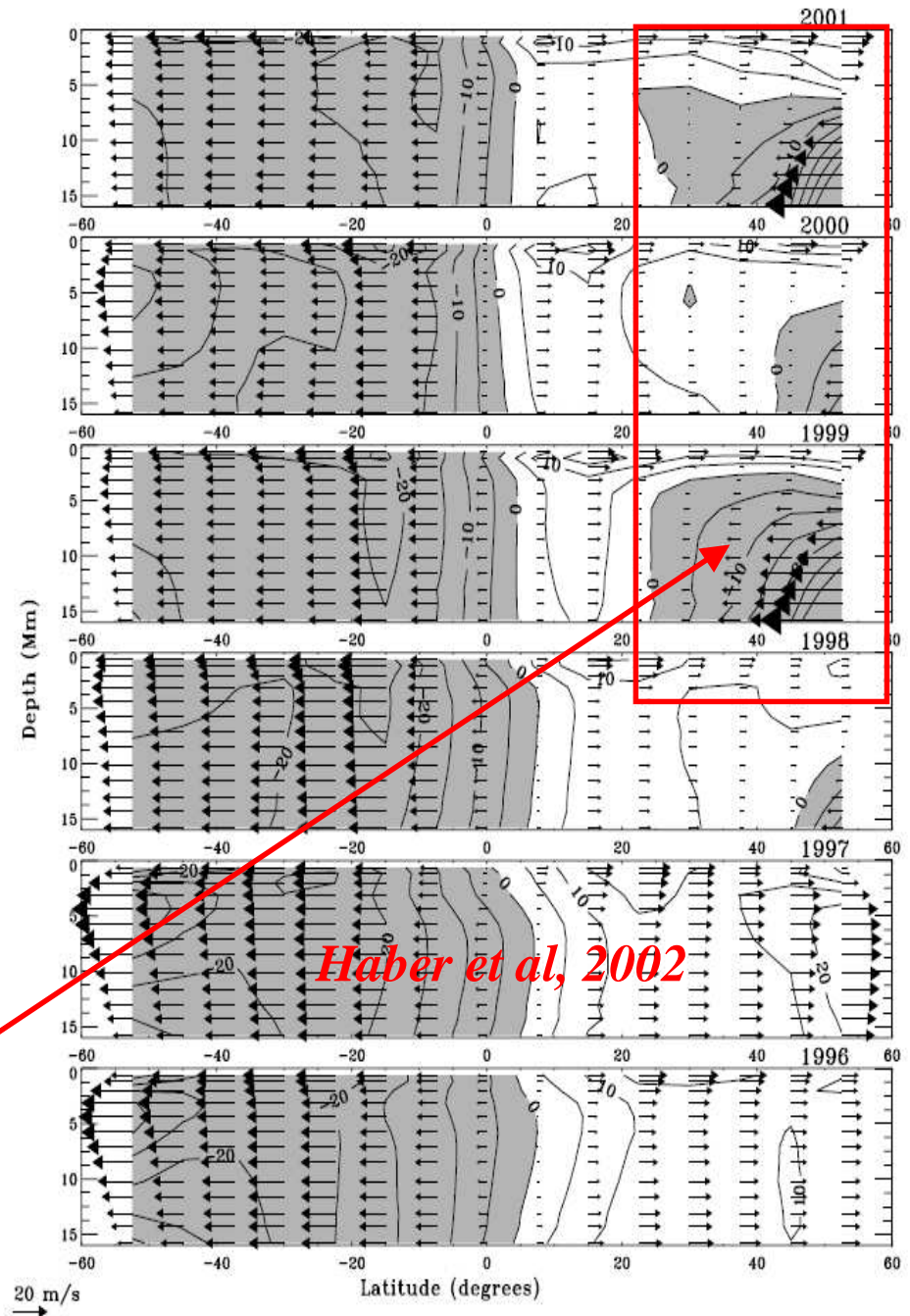


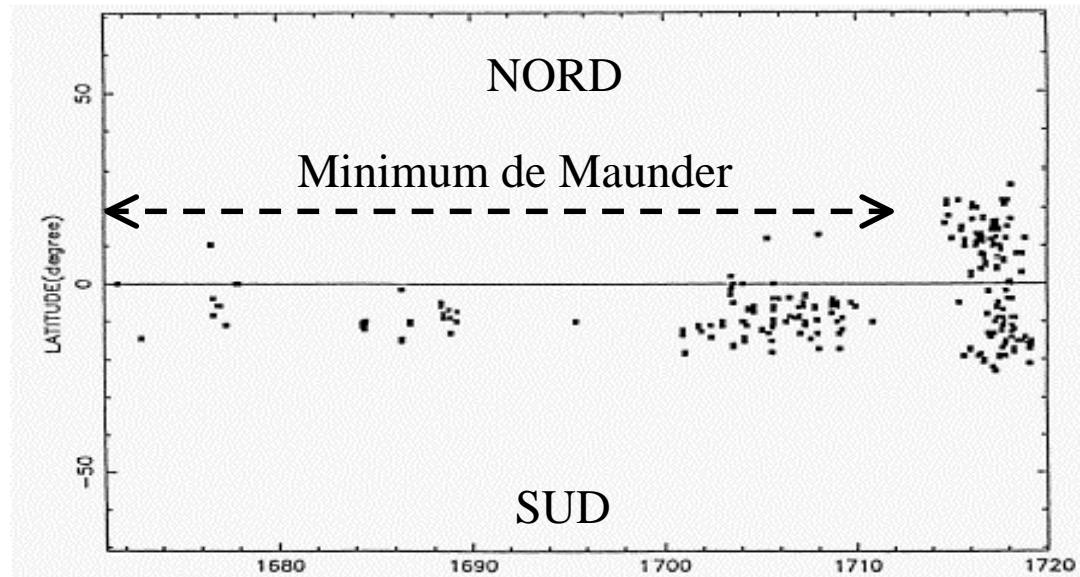


Cycle 23: long (12.7 ans),  
 minimum prolongé, champ  
 magnétique polaire faible,  
 nombre de jours sans taches le  
 plus petit depuis 100 ans



cellule profonde au Nord avant  
 le maximum du cycle 23  
 (résultat SOHO/MDI)

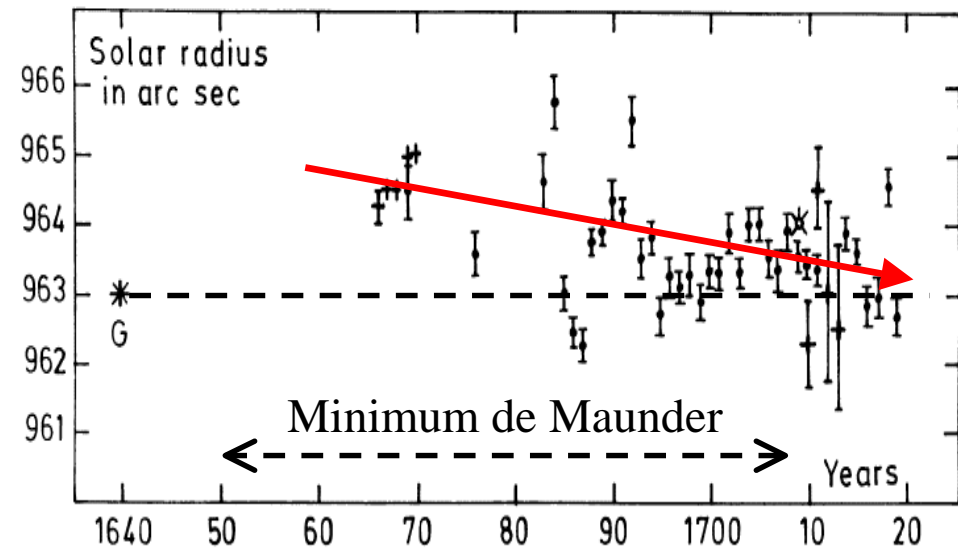
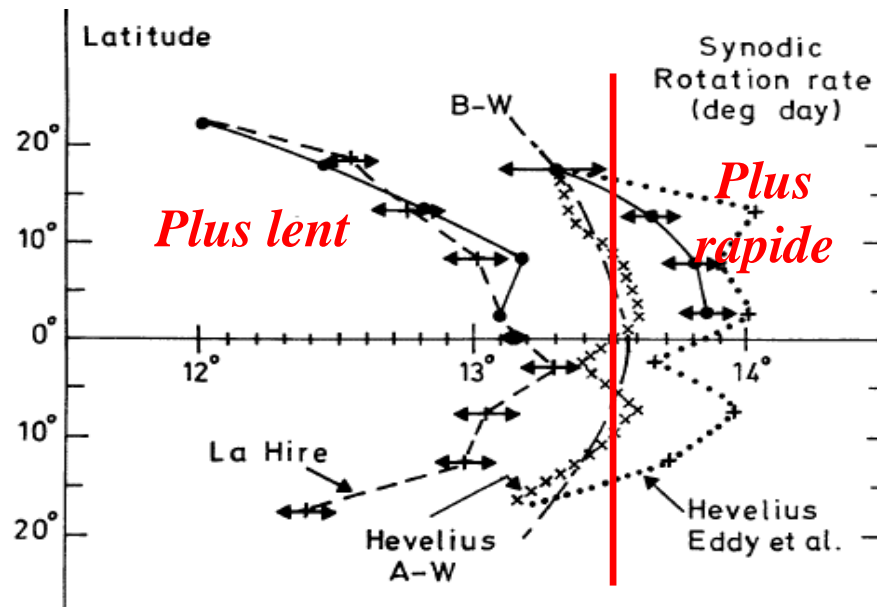




Minimum de Maunder  
1645-1705

Asymétrie marquée  
Nord Sud des taches ?  
Rotation plus rapide ?  
Soleil plus gros ?

*Minimum de Maunder, à l'époque du « Roi Soleil »*



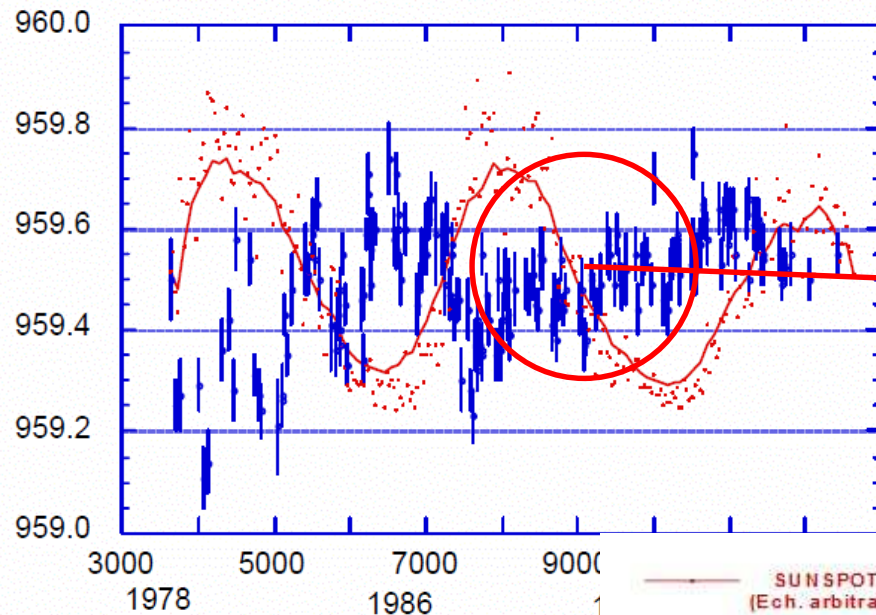


## DEMI-DIAMETRE A CALERN

- RAYON (Groupes de 40 mesures au zénith)

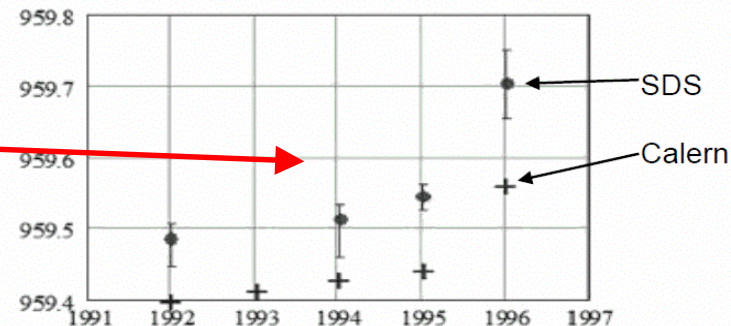
(1978 - 2002)

SUNSPOT NUMBERS  
(Echelle arbitraire)



## VARIATION DU DIAMETRE SOLAIRE OBSERVEE A PARTIR DE MESURES EN BALLON

Sofia et al. (1994) ont construit l'instrument Solar Disk Sextant (SDS) comportant une référence angulaire. Quatre vols sous ballons stratosphériques ont été effectués.



Une augmentation de 0.2'' a été mesurée tandis que l'activité solaire diminuait (Egidi et al., 2006).

L'activité solaire décroît depuis 3 cycles.

Le rayon solaire semble augmenter de 0.2'' (CALERN); effet solaire ? rôle de l'atmosphère ?

SUNSPOT  
(Ech. arbitraire)

ASTROLABE SOLAIRE 1978-2006  
Mesures Visuelles  
Observateur: F. LACLARE  
(Groupes de 40 Mesures au zénith)

