PICARD
The Canadian participation

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Outline

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Project: Solar variability and Climate

Objective: investigate the impact of Solar variability on Earth's climate to understand natural variabilities in the climate system.

Funding: CFCAS, FQRNT (proposal submitted), CSA

Motivation

Why we want to get involved?

-The impacts of climate variability and the threat of future changes are issues brought to our attention on an almost daily basis.

-Among the sources of natural variability in the Earth's climate, and maybe one of the most puzzling so far, is the change in the solar energy output.

-One intrinsic difficulty in the evaluation of solar variability forcing in climate models in the present state of our knowledge is that it is based on proxies or empirical models that describe the solar variability only partially.

-Canada is well positioned in both Solar and Climate/atmosphere modeling and measurements to meet the challenge.

-PICARD is a unique mission aimed to measure critical parameters.

Long term goals

- To further develop Canadian climate, atmosphere, and solar models with a focus on investigating the influence of solar variability on Earth's climate,
- To develop interfaces to couple solar activity models based on physical principles with atmospheric and climate models,
- To establish methodologies to integrate models and measurements to improve the understanding of solar effects on climate.

Methodology

1 - We are working with two already existing **climate and atmospheric models**:

- *the Canadian Middle Atmospheric Model (CMAM) in its various versions,*
- *the IGCM-FASTOC Chemistry-Climate Model which is being further developed at McGill University, Quebec*.

2 - We will use an existing **solar model** developed under the leadership of Prof. Paul Charbonneau at Université de Montréal.

3 – We will use ground-based measurements to further analyze inter-relations among different solar activities indexes.

4 – We will develop an interface to integrate solar and climate models.

Canadian Science Team

1) Climate and atmospheric modeling:
   - *Professor Ted Shepherd, University of Toronto;*
   - *Professor Victor Fomichev, York University team;*
   - *Professor John McConnell, York University;*
   - *Professor Michel Bourqui, University McGill*
   - *Dr. Stella M L Melo, CSA (Team leader)*
2) Solar modeling/measurements:
   - *Professor Paul Charbonneau, Université de Montréal;*
   - *Dr. Ken Tapping, National Research Council of Canada;*
   - *Dr. David Boteler, Natural Resources Canada*
   - *Dr. William Liu, CSA;*
   - *Dr. Ashley Crouch, CSA;*
   - *Dr, Mihai Ghizaru, Université de Montreal;*

3) Combining climate/atmospheric and solar models

Climate/atmospheric Models

- *IGCM-FASTOC*
- *CMAM*

A fast climate-chemistry model (IGCM-FASTOC)

<u>Climate-chemistry model:</u>

3 dimensions

Ozone Interactively coupled

Fast

<u>Climate part:</u>

3D General circulation model (GCM)

Dynamics and radiation

<u>Chemical part:</u>

Non-linear stratospheric chemistry (no linearization, tuning, or relaxation towards a climatologic state)

No chlorine or bromine effects

Intermediate GCM developed at the University of Reading

- Spectral dynamical core by Hoskins and Simmons (1975)
- Parameterization schemes of intermediate complexity (convection…)
- Radiation scheme by Morcrette (1991)
- Resolution: T21, 26 vertical levels, 1000 – 0.1 hPa (65km)
- Radiative gases : H_2O, N_2O, CH_4, CO_2, CFC-11, CFC-12, **and O_3**

The stratsopheric chemical model:

FAst STratospheric Ozone Chemistry (FASTOC) Version 1:

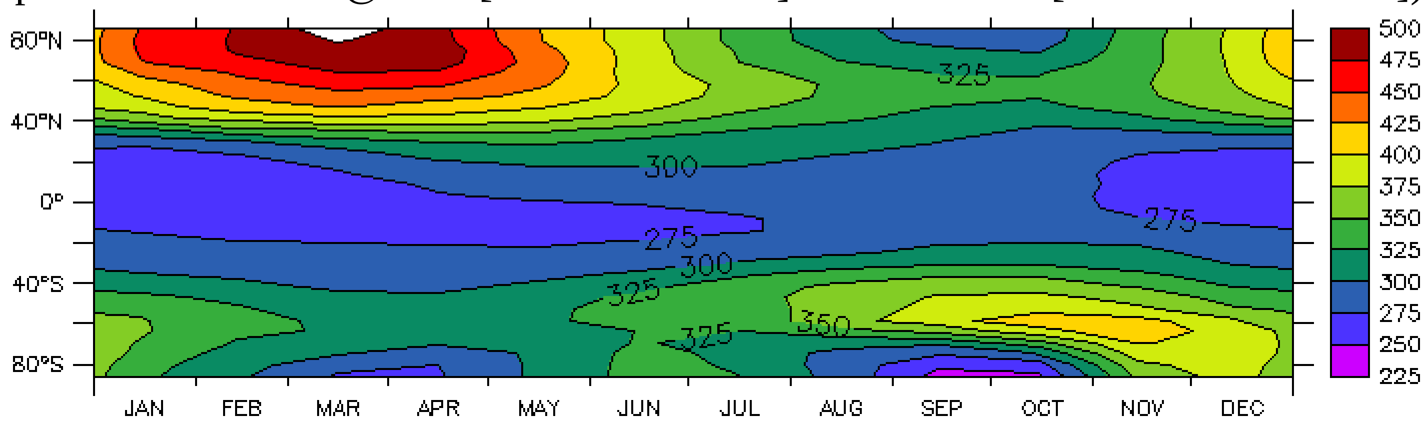
- Input-output model, based on a chemical box model with stratospheric chemistry by Fish et Burton (1997) with knetic energy based on Sander et al. 2002.
- Speed: 10^3 x times fast then the original box model
- NOx et HOx chemistry only (introduction of Clx et Brx in progress)
- Global coverage, 3D, tropopause to 4 hPa (in process of being extended)
- Interactive chemistry: O_3, NOx, N_2O_5, HNO_3
- Non interactive chemistry: H_2O, N_2O, CH_4, CO

Climatology from FASTOC-IGCM:

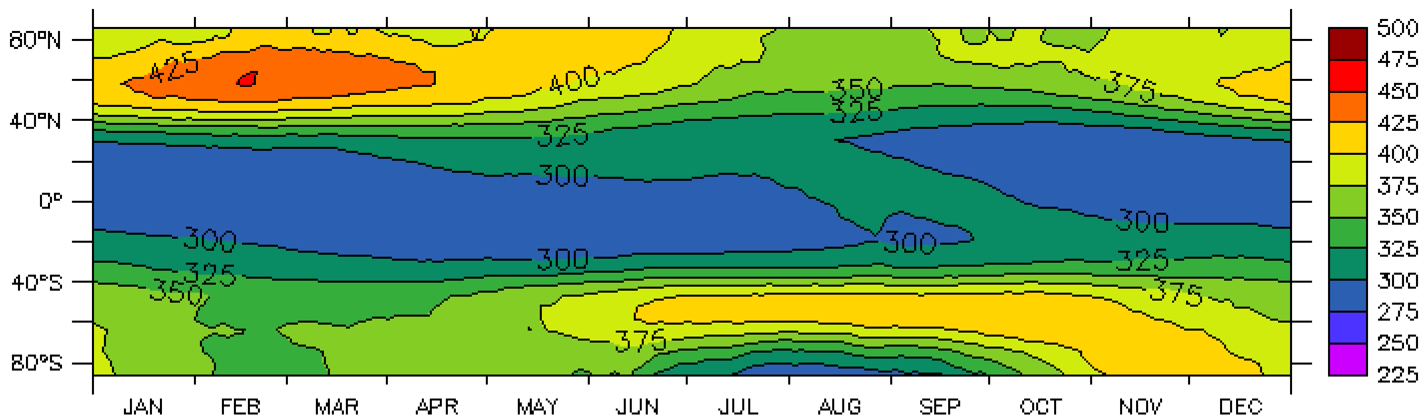
Comparison of control run with observations

« Observations 1979 »:

(Superposition de clim3D@1987 [Li et Shine 1995] + tendance2D [Randel et Wu 1999])



Model 1979:



Courtesy Prof. M Bourqui

IGCM-FASTOC

Summary of recent results: GHG experiment

- **Global effect of the GHG enhancement on stratospheric ozone:**
  - Chemical effect: O_3 decrease by -0.37 DU/decade
  - Radiative effect: O_3 increase by +0.62 DU/decade
  - Somme of effets: O_3 increase by +0.25 DU/decade
  - Effets pris ensemble: O_3 increase by +0.27 DU/decade
- **Global effects of methane on stratospheric ozone (preliminar):**
  - O_3 decreases during polar winters at northern hemisphere when radiative cooling IS considered
  - O_3 increases during polar winters at northern hemisphere when radiative cooling IS NOT considered.

The Canadian Middle Atmospheric Model

CMAM – Extended version

Development of the extended CMAM for solar variability studies

Activities started on July, 2006

Current version of the extended CMAM

- a GCM extending from the surface to 2×10^{-7} hPa (~210 km).
- includes a comprehensive troposphere (e.g., clouds, convection, hydrologic cycle).
- resolution: T32 (approx 6^o x 6^o); 17 levels below 100 hPa and 53 levels in the MA and thermosphere equally spaced in pressure scale height with a step of 0.4.
- radiation scheme has been updated by inclusion of solar heating in the O_2 SRB and SRC (120-200 nm), and in the EUV region (5-100 nm). NLTE treatment is included.
- prescribed ozone and other radiatively important constituents.
- molecular diffusion & ion drag in thermosphere.
- parameterized gravity wave drag with the inclusion of heating and eddy diffusion generated by gravity waves breaking.

Why the "extended" model?

- Studies with GCMs considerably underestimate 11-year solar signal in the stratosphere (e.g. Labitzke et al. JASTP 2002).

- Variability of the solar irradiance is extremely spectral dependent. In the 11-year solar cycle, the changes are: 0.1% for the TSI; less than 2% at λ > 250 nm; ~8% near 200 nm; 10-30% between 100-200 nm; and can exceed a factor of 2 in the EUV (5-100 nm) region.(e.g. Frohlich&Lean Astron. Astrophys. Rev. 2004; Richards JGR 1994)

- Radiation at λ < 200 nm is mostly absorbed above 100 km and is not considered in MA GCMs → potential problems with reproducing changes below 100 km, e.g. in dynamical fields.

- O_3 varies with solar cycle and the forcings for such variations occur mainly in the upper atmosphere: thermospheric NO production increased by ~30% in response to the EUV increase (Barth JGR 2003); modulations in GCR and SPE occurrence (e.g., Vitt&Jackman JGR 1996)

Requirements for the model:

In order to properly quantify the effects of solar variability on the atmosphere, a model requires 3 ingredients:

- Representation of the thermosphere, where the radiative effects are greatest;
- Radiation code with sufficient spectral resolution to correctly represent the effects of solar variability;
- Fully interactive chemical scheme (both neutral and ion) to simulate variations in radiatively active species (e.g. O_3, O, CO_2) consistently with variations in solar activity.

The extended version of the CMAM (which has been frozen since 2000) is being modified to satisfy these requirements.

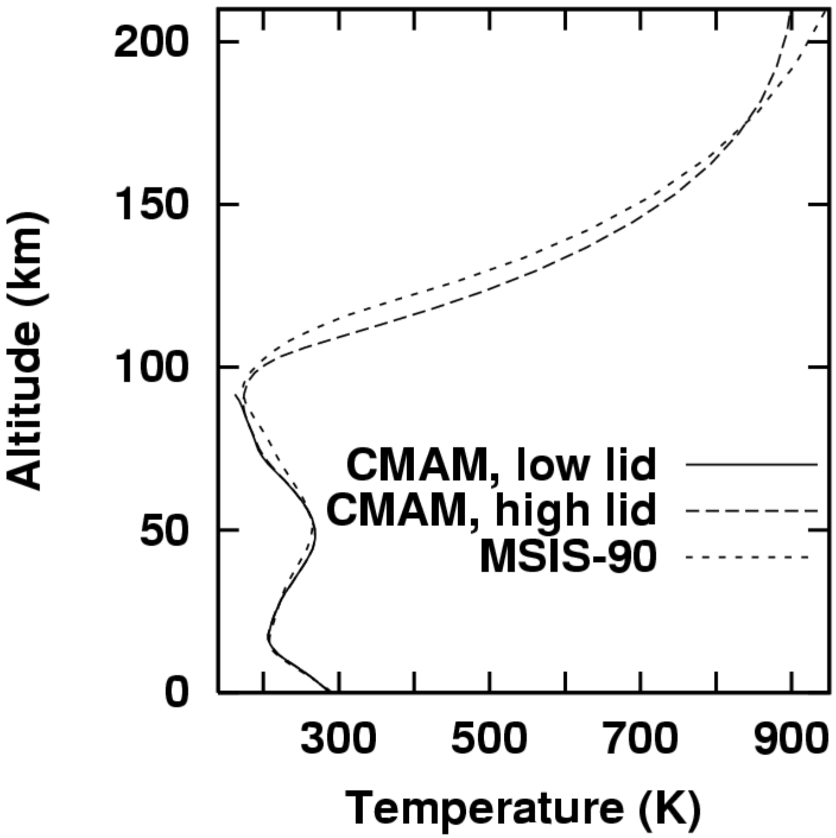
Results from the extended CMAM

Publications:

- Beagley et al. GRL 2000: *first publication showing the general performance of the model*;
- Fomichev et al. JGR 2002: *model description, zonal mean climatology and energy budget*;
- McLandress JAS 2002: *migrating diurnal tide*;
- Ward et al. GRL 2005: *non-migrating tides*;
- McLandress et al. JGR 2006: *large scale dynamics of the mesosphere and lower thermosphere*.

Results from the extended CMAM:

Globally averaged temperature profiles



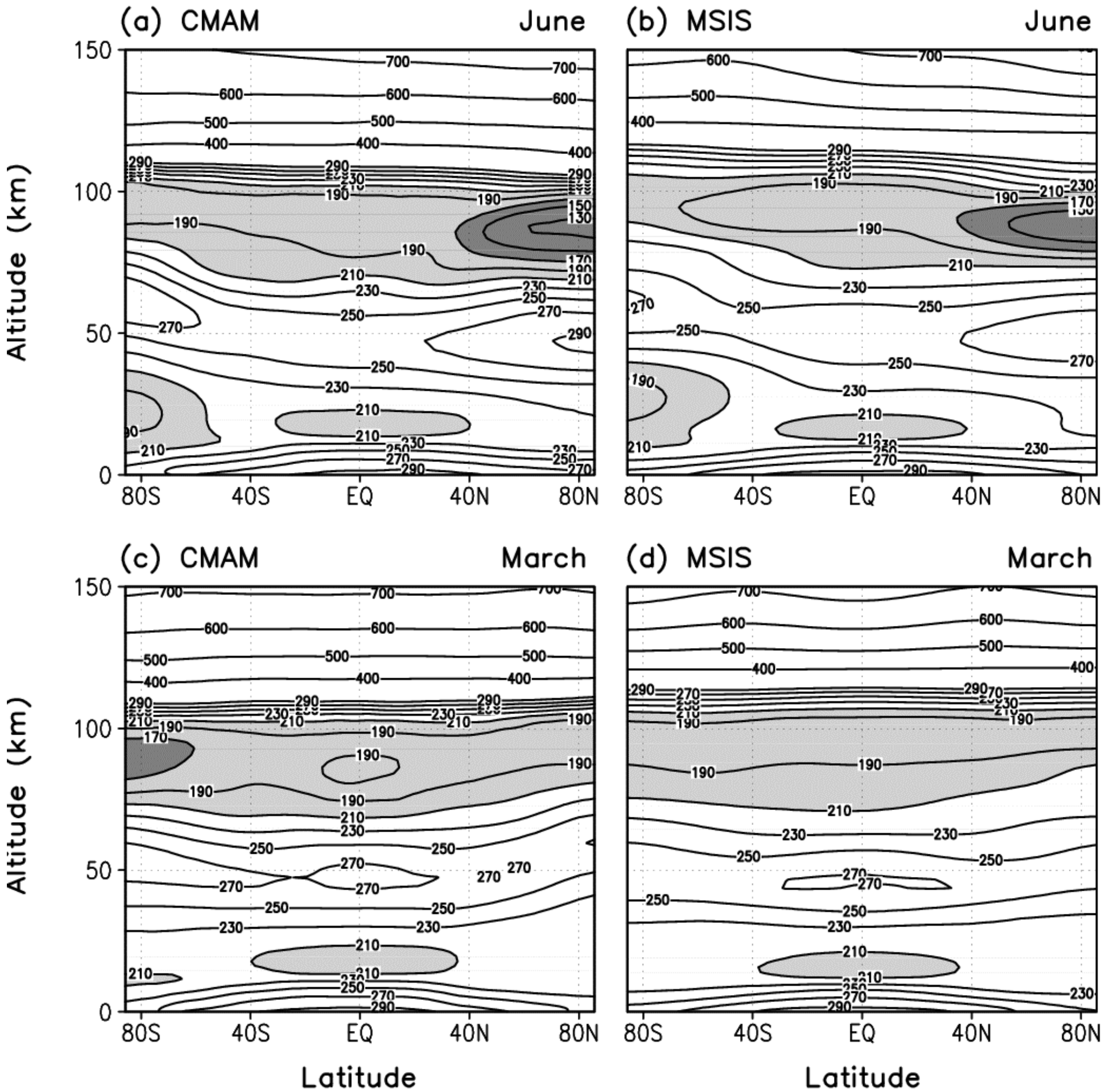
The T profile produced by the extended model is similar to that of the standard version up to ~90 km.

In the thermosphere, there is reasonable agreement with the MSIS model (Hedin JGR 1991).

(Fomichev et al. JGR 2002)

Results from the extended CMAM:

Altitude-latitude temperature distribution (Fomichev et al. JGR 2002):



Reasonable agreement with the MSIS model *(Hedin JGR 1991).*

The model reproduces the latitudinal T gradients quite well: *cold tropical tropopause, cold winter lower stratosphere, elevated winter stratopause, warm summer stratopause, cold summer mesopause).*

T increases rapidly in the thermosphere reaching ~700 K near 150 km).

Modifications: extended CMAM

- The model transported from NEC to a new parallel IBM computer. --- Done ---
- Some modifications to dynamics (e.g. allow molecular diffusion to act on parameterized GWs). --- Done ---
- Neutral chemistry from the regular CMAM should be implemented and modified (varying O_2 and CO_2, transport by molecular diffusion, interactive CO_2 and O in the LW NLTE scheme, etc) --- In progress ---
- Implement ion chemistry (primary goal: NO_x production)
  - box model exists: 6 neutrals (O_2, N_2, O, NO, $N(^4S)$, $N(^2D)$),
  - 7 ions (O_2^+, N_2^+, NO^+, $O^+(^4S)$, $O^+(^2D)$, $O^+(^2P)$, N^+), and electrons.
  - 60 photochemical reactions.
- Implement effects of SPEs, GCR, Aurora --- Not started ---

Modifications: extended CMAM

- O_3 heating in the current CMAM is treated in one wide spectral interval (0.25 - 0.69 µm). The new version of the extended CMAM will be based on a new CCCma GCM which uses a correlated-k distribution (CKD) scheme *(Li & Barker JAS 2005)* and has a much better spectral resolution. Moving to a new GCM will be done in 2 steps:
  (1) regular CMAM - In progress (collaboration with CCCma)

  (2) extended CMAM --- Will start upon completion of step 1
- The original CKD scheme should be modified to be applicable in the MA --- Off-line code exists ---

CKD scheme for solar heating:

No.	Spectral Interval (µm)	Absorbers	Modifications done for the MA
1.	0.20 – 0.24	O_3, O_2	Non-unit heating efficiency for the O_3
2.	0.24 – 0.267	O_3	Harley band at z > 50 km (int. 1 to 5)
3.	0.267 – 0.28	O_3	(Mlynczak & Solomon JGR 1993)
4.	0.28 – 0.294	O_3	NLTE for O_2 at z > 40 km in int. 9, 10
5.	0.294 – 0.311	O_3	(Mlynczak & Marshall GRL 1996)
6.	0.311 – 0.33	O_3	H_2O heating reduced to 0 above 15, 20,
7.	0.33 -- 0.40	O_3	and 85 km for int. 10, 11, and 12
8.	0.40 – 0.50	O_3	due to NLTE effects
9.	0.50 – 0.69	O_3, O_2	(Lopez-Puertas & Taylor 2001)
10.	0.69 – 1.19	O_3, O_2, H_2O	NLTE for the CO_2 NIR bands
11.	1.19 – 2.38	H_2O, CO_2	at z > 60 km (int. 11 and 12)
12.	2.38 – 4.00	H_2O CO_2	(Ogibalov & Fomichev, ASR 2003)

- J-values and heating rates will be calculated on-line using the same scheme

- LW scheme has 9 spectral intervals and treats 6 species (H_2O, CO_2, O_3, CH_4, N_2O, CFCs) and should also be modified for NLTE --- off-line code exists ---

Planned experiments and timelines

- Model development is planned to be completed by July 2007.
- 2007-2008: Timeslice simulations at solar max and solar min. Both versions (regular and extended) of the CMAM to be used → **effect of the high lids**.
- 2008-2009: Transient (1950-2100) simulations with solar variability (include QBO, changes in CO_2, chlorine loading, SST and, likely, volcanic activity --- scenarios to be determined).

Solar models and measurements

Solar Model - need

- Numerous reconstructions of the solar irradiance on century timescales can be found in the literature.

- The vast majority of these reconstructions are based on semi-empirical or statistical relationships established using twentieth century solar observations.

- Generally speaking, great caution must be exerted in extrapolating statistical models outside of the range in which they are calibrated.

- One way out of this difficulty is to establish a physical, rather than statistical, relationship between irradiance excess contributors such as the network and faculae, and observables such as sunspots for which a relatively homogeneous time series exists all the way back to the mid-seventeenth century.

Solar Model - UdeM

- At UdeM we developed a **model for the decay of sunspots** based on a **fragmentation process** that produces the magnetic elements that comprise network and faculae.

- The model has **several adjustable parameters**. Currently, we are using a genetic algorithm to adjust these parameters in order to optimize the agreement between our model and the observations.

Solar Model - UdeM

-The goal is to investigate via modeling activities the contributions from each of the proposed variability mechanisms. Such an understanding is vital to developing models that can accurately reconstruct total solar irradiance for the past several hundred years (including periods of very low activity such as the Maunder Minimum, 1645-1715) and, thus, **be used as input to long-term climate models.**

- In addition a to the fragmentation-based model of irradiance variations, the team is also developing a fully 3-D magnetohydrodynamics simulation for the whole solar convective envelope, including in particular magnetic fields in a self-consistent manner. This would be useful to investigate **magnetically-mediated changes in the overall convection patterns**, and thus **deep modulation of the solar irradiance on decadal timescales and up.**

Solar Model at UdeM

Model of the solar cycle (sunspot number) reproduce reasonably well the amplitudes including intermittency

See: http://www.astro.umontreal.ca/~paulchar/grps/grps.html

Solar Model - Measurements

Empirical model

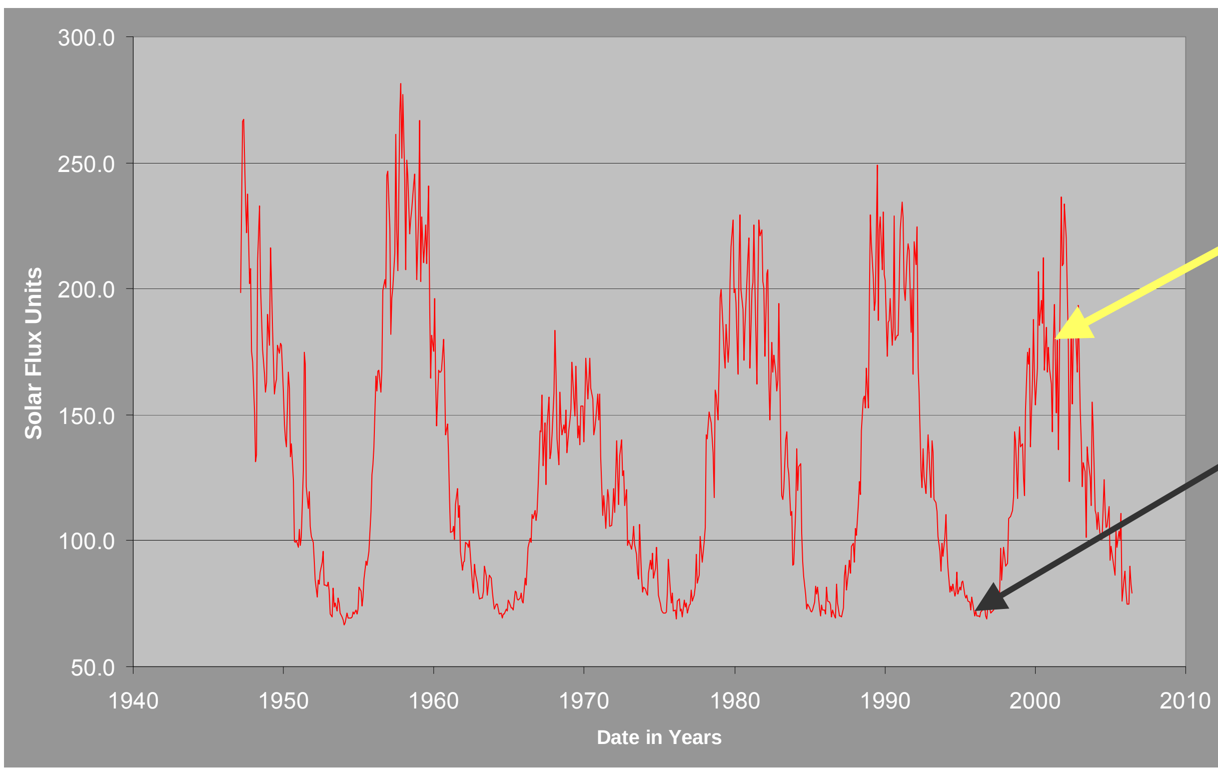
Long term F10.7 measurements: a joint programme between the National Research Council and the Canadian Space Agency

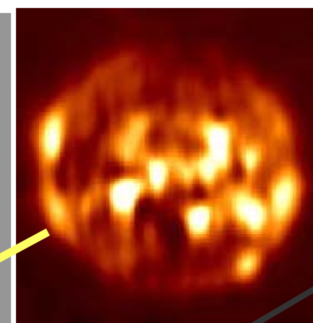
Dominion Radio Astrophysical Observatory, near Penticton, British Columbia, Canada

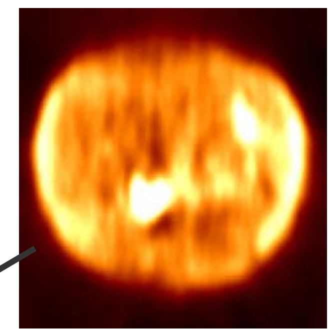
Solar Radio Monitoring Programme

Objective, consistent and absolutely calibrated measurements of solar magnetic activity over almost **60 years**.

The 10.7 cm Solar Radio Flux (F10.7) values are used as a stand-alone index of solar magnetic activity, and also as a proxy for a number of other solar parameters.







Solar radio images recorded using the synthesis radio telescope at the Dominion Radio Astrophysical Observatory

Relevance to the PICARD Mission

- PICARD will cover a small time interval compared with the duration over which we have to model and estimate solar variability. Extending outside the limited set of quality data requires the use of ground-based proxies.
- $F_{10.7}$ is probably the best ground-based indicator of solar activity we have, going back to 1946. Used as measured, it is an excellent proxy for total irradiance and some irradiance components. We have models for estimating $F_{10.7}$ from sunspot number, which takes the record back to at least 1700.
- **We have developed irradiance models based upon $F_{10.7}$ that can be related to existing irradiance data.** Being able to relate those models to PICARD data will simplify them significantly, and should facilitate more effective modelling of irradiance components in various wavelength bands.
- The long-term commitment Canada has to ground-based solar monitoring may brings an important complement to the main thrust of the PICARD mission.

Next Generation Flux Monitor

- The 10.7 cm Solar Radio Flux contains two major thermal emission mechanisms: thermal bremsstrahlung (free-free) emission from the active region and thermal gyroresonance over sunspots. On occasion there can be non-thermal emission contributions.
- Use of the radio data as proxies for different irradiance components requires the emission contributions from bremsstrahlung and gyroresonance to be separated. This can only be done from simultaneous, consistently calibrated measurements over a range of wavelengths (possibly 10 channels, sampling the spectrum from 2cm to 30 cm wavelength).
- Construction of such an instrument is possible using currently off-the-shelf components. Operation would be more automatic than is the case with the current flux monitors.
- Three such instruments, located at DRAO (primary location) and two or more other locations around the world, appropriately distributed in longitude, would give 24-hour coverage.

Summary

- A Canadian team was formed to investigate the impact of Solar variability on Earth's climate: our goal is to understand natural variabilities in the climate system.

- We have a strong interest in the PICARD mission since it is a mission uniquely designed to addressing both solar and climate physics with the objective of unravel the links between the two.

Thanks!