The impact of orbital forcing on the Arctic climate during the Last Interglacial simulated by the IPSL-CM6A-LR model

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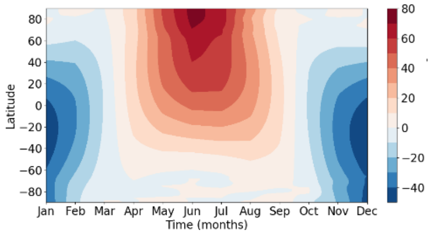
What is the Last Interglacial (129,000-116,000 BP)?

- **Different orbital configuration** causing **strong insolation anomalies** in the high latitudes of the Northern Hemisphere;
- **GHG concentrations similar** than those of the pre-insdustrial;
- **Higer annual surface temperature** than today[1] :
  - Global air temperature : + 0.8 ± 0.3ºC
  - Central Greenland air temperature : + 4-11ºC
- **Higher global sea level** than today[2] : + 6-9 m



LIG-PI anomaly of solar radiation at the top of the atmosphere ($W.m^{-2}$) through latitudes and months.

How do these solar radiation anomalies impact the Arctic surface conditions ?

Methodology

To answer this question, we compute the **Arctic heat budget** for summer (JJA), spring (MAM), autumn (SON) and winter (DJF)

Tools – Numerical simulations with IPSL-CM6A-LR model

- Two simulations following the **PMIP4/CMIP6** protocol[3] :
  - a pre-industrial one (PI);
  - a snapshot at 127 ka (LIG).
- Correction of the LIG outputs thanks to the PaleoCalAdjust algorithm[4].

Method – Heat budget decomposition[5]

- **Surface heat flux** (F_{SFC}) as the sum of radiative fluxes and turbulent fluxes.
- **Ocean heat storage** (OHS) as the time derivative of the ocean heat content.
- **Northward atmosphere/ocean heat transport** (AHT/OHT) as the residual of :
  - F_{SFC} and the top-of-the-atmosphere (SW and LW);
  - F_{SFC} and OHS for the ocean[6].
- **Sea ice-ocean heat flux** (F_{OCE}) as the time derivative of the sea ice thickness times the sea ice energy of melting[7].

All results are averaged **between 60°N and 90°N.**

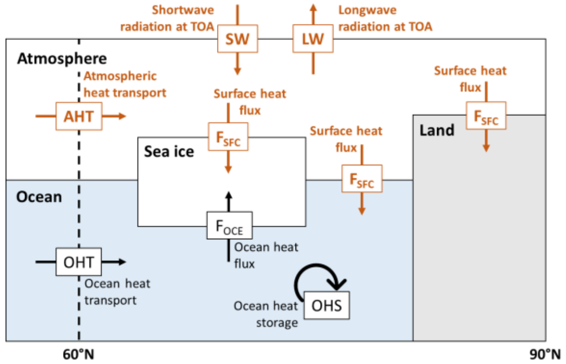
Results

ATMOSPHERE

Table 1 : LIG-PI SAT anomalies (°C)

JJA	SON	DJF	MAM	Annual
+ 3.1	+ 4.2	- 0.1	- 0.1	**+ 1.8**

- Increase of the annual mean surface air temperature;
- **Significant warming in JJA (mainly over land) and SON (mainly over ocean)**;
- In JJA, solar radiation anomalies are positive. The atmosphere receives **more energy** and warms up;
- In SON, solar radiation anomalies are negative. The atmosphere receives less energy. It is compensated by higher **AHT** and higher **upward longwave radiation and turbulent fluxes over ocean**.



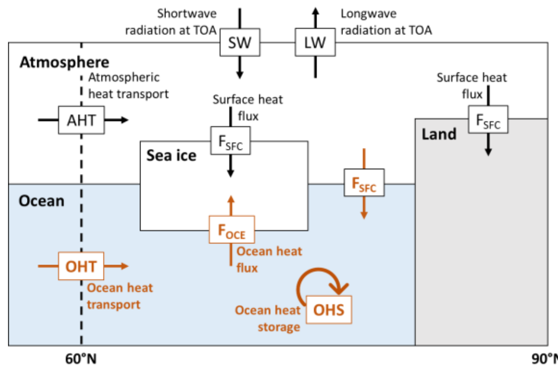
Processes involved in the atmosphere heat budget computation (in orange).

OCEAN

Table 2 : LIG-PI SST anomalies (°C)

JJA	SON	DJF	MAM	Annual
+ 1,4	+ 1,4	- 0,1	- 0,1	**+ 0,7**

- Weaker increase of the annual mean surface sea temperature;
- **Significant warming in JJA and SON**;
- In JJA, **air-sea heat exchanges** intensify by 42% and contributes to warm the Arctic ocean. **OHS** increases too;
- SON warming is a **reminiscence** of what happens in JJA. **Subsurface heat accumulated during summer** is released, which leads to an increase of SSTs.



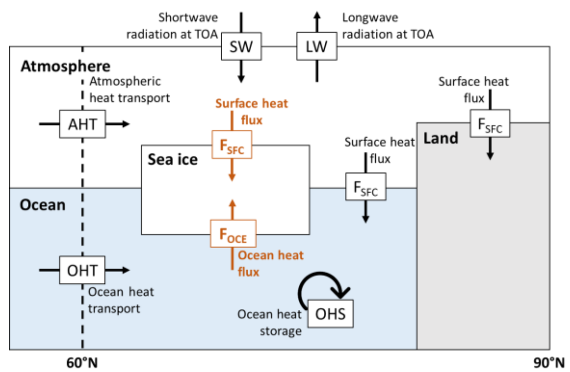
Processes involved in the ocean heat budget computation (in orange).

SEA ICE

Table 3 : LIG-PI sea ice area anomalies (10^6 km^2)

JJA	SON	DJF	MAM	Annual
- 1,9	- 3,5	- 0,5	- 0,3	**- 1,6**

- **The largest loss happens in SON**.
- The decrease of sea ice cover plays a **key role** : it intensifies air-sea heat fluxes, warming the surface of the ocean in JJA and the surface of the atmosphere in SON;
- **Ocean has a greater impact** on sea ice cover than atmosphere : F_{OCE} is more than twice F_{SFC} during JJA and SON.



Processes involved in the sea ice heat budget computation (in orange).

Take-home message : Ocean seems to play a significant role in warming during the Last Interglacial due to its ability to store heat and its major contribution to sea ice melt.

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Annex – Heat flux values

	Heat flux (W.m-2)	JJA	SON	DJF	MAM
Atmosphere	SW	235.8	44.1	8.7	125.7
	LW	230.6	200.0	175.8	197.4
	F_{SFC}(total)	53.0	-34.9	-46.4	≈ 0.0
	AHT	47.8	121.0	120.7	71.7
Ocean	F_{SFC}(ocean)	41.1	-24.8	-27.2	4.9
	OHT	20.7	-0.8	-15.0	1.3
	OHS	61.8	-25.6	-42.2	6.2
Sea ice	F_{SFC}(sea ice)	11.9	-10.1	-19.2	-4.9
	F_{OCE}	25.4	13.8	-25.0	-17.6

Table 1 : PI heat fluxes for each component of the Arctic climate system : atmosphere, ocean and sea ice. Heat fluxes are in $W.m^{-2}$.

	Heat flux (W.m-2)	JJA	SON	DJF	MAM
Atmosphere	SW	43.7	1.1	-1.2	11.3
	LW	10.9	5.1	-1.0	-0.3
	F_{SFC}(total)	20.8	-0.6	-5.7	2.2
	AHT	-12.1	3.4	-5.5	-9.4
Ocean	F_{SFC}(ocean)	17.2	-5.5	-9.3	1,1
	OHT	7.0	0.4	1.6	0.7
	OHS	24.1	-5.0	-7.7	1.9
Sea ice	F_{SFC}(sea ice)	3.6	4.9	3.6	1.0
	F_{OCE}	10.6	11.5	-6.8	-5.1

Table 2 : LIG-PI heat fluxes anomalies for each component of the Arctic climate system : atmosphere, ocean and sea ice. Heat fluxes are in $W.m^{-2}$. Positive anomalies are represented in red, negative anomalies in blue.

References

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