Chapitre 6 : Océan et climat

- le réchauffement climatique
- le phénomène El Nino et l'oscillation australe
- l'oscillation nord-atlantique (NAO)
- variations de la circulation océanique

climat : ensemble des éléments qui caractérisent l'état moyen de l'atmosphère (typiquement 30 ans)
≠ temps météorologique

http://www.ifremer.fr/lpo/thuck/isen/isen6.pdf ou isen6_2pp.pdf

climat : variations naturelles ou forcées ?

Oscillations naturelles ou forcées ?

- **variations naturelles du climat**

- cycles astronomiques
- activité volcanique
- cycles solaires 11yr, 22yr taches solaires "debat"
- variations propres au système climatique ?

- **variations forcées d'origine humaine**

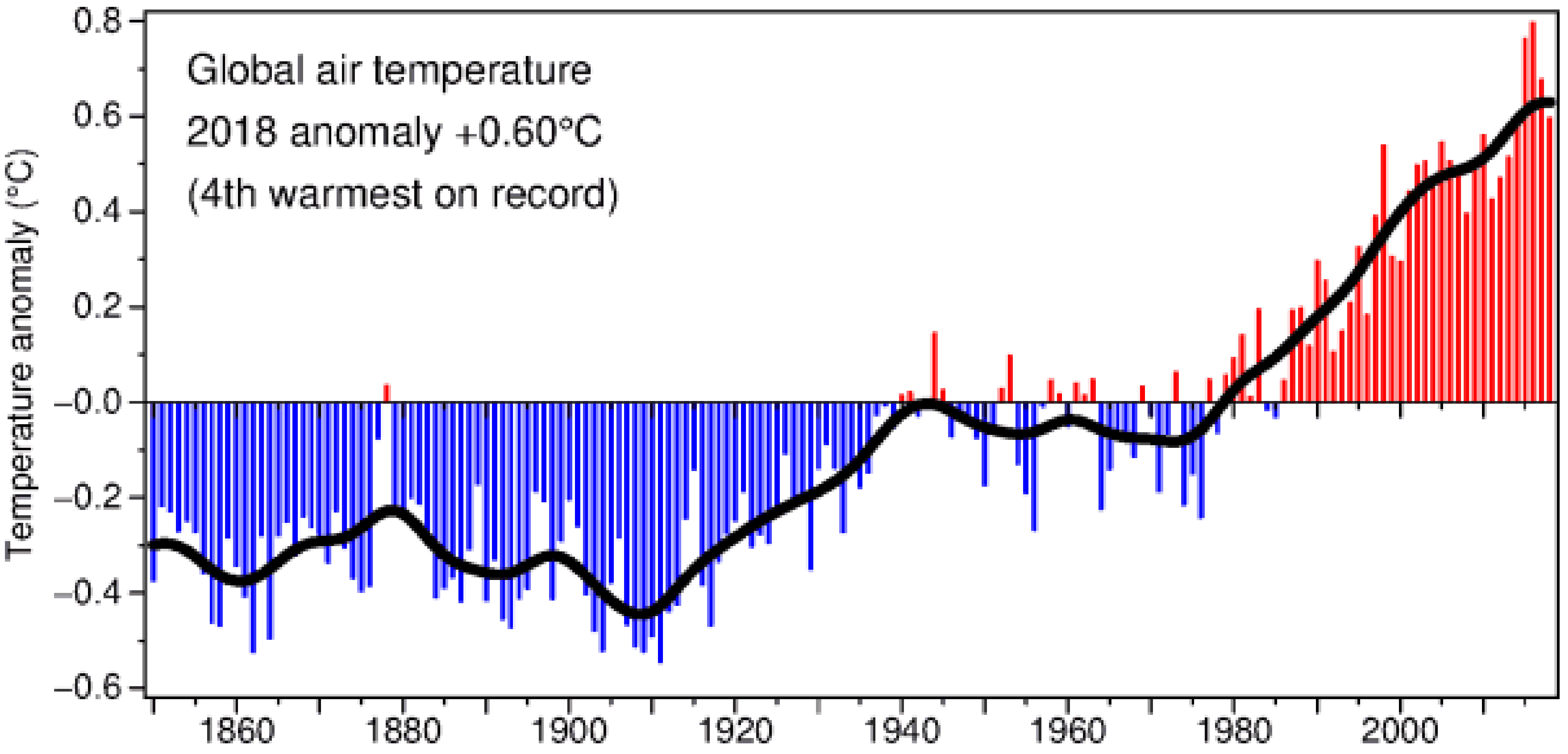
- modification de la composition de l'atmosphère (CO2, CFC, ozone)
- modification de l'albédo terrestre par modifications de la végétation...

- **Attention : rétroactions positives du système**

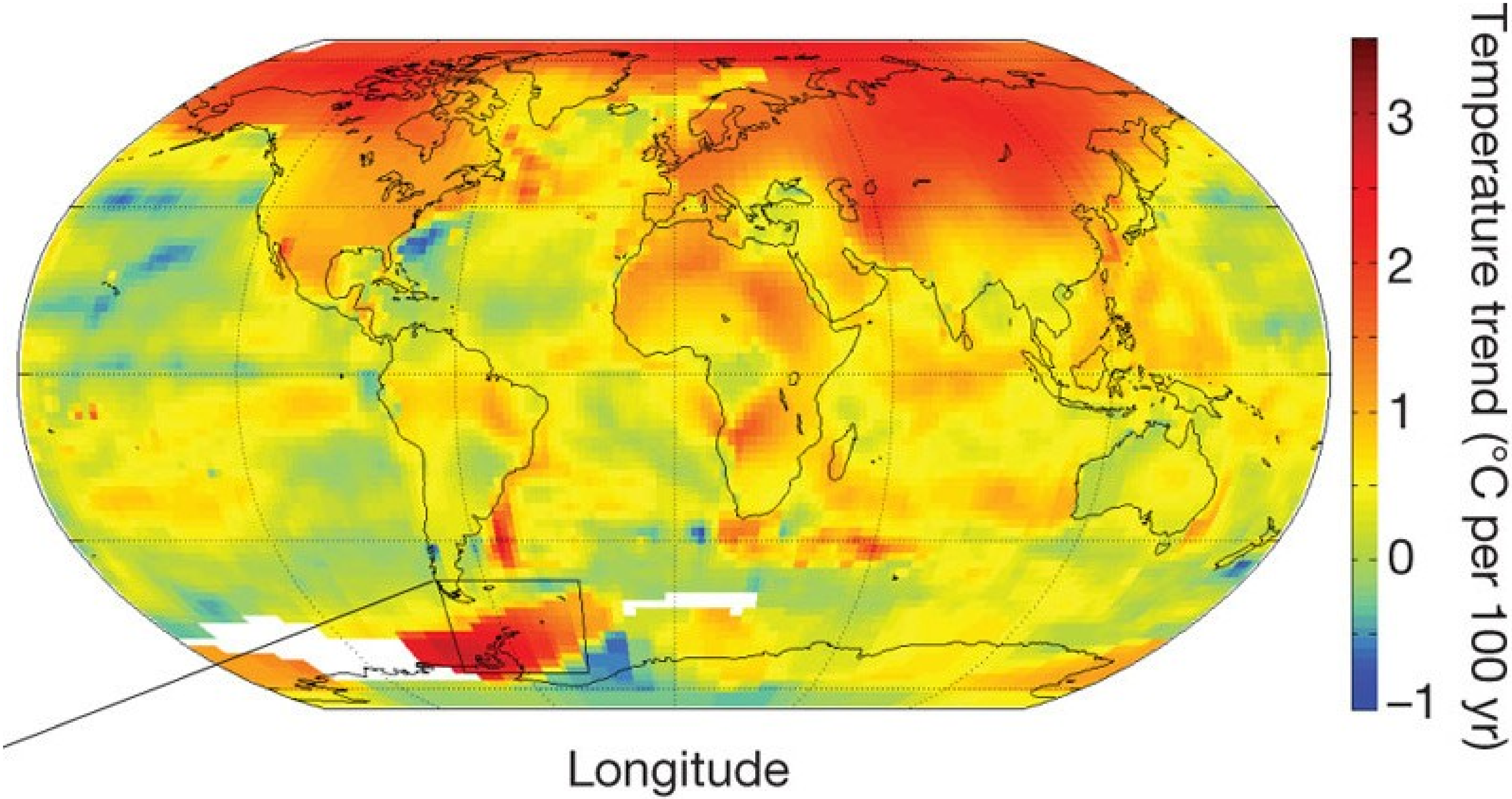
- albédo de la glace (Terre boule de neige)
- réponse linéaire = proportionnelle au forcage

$\neq$ taux CO2 vs temperature (vapeur d'eau dans l'atmosphère $\propto \exp(T)$ - loi de Clausius Clapeyron)

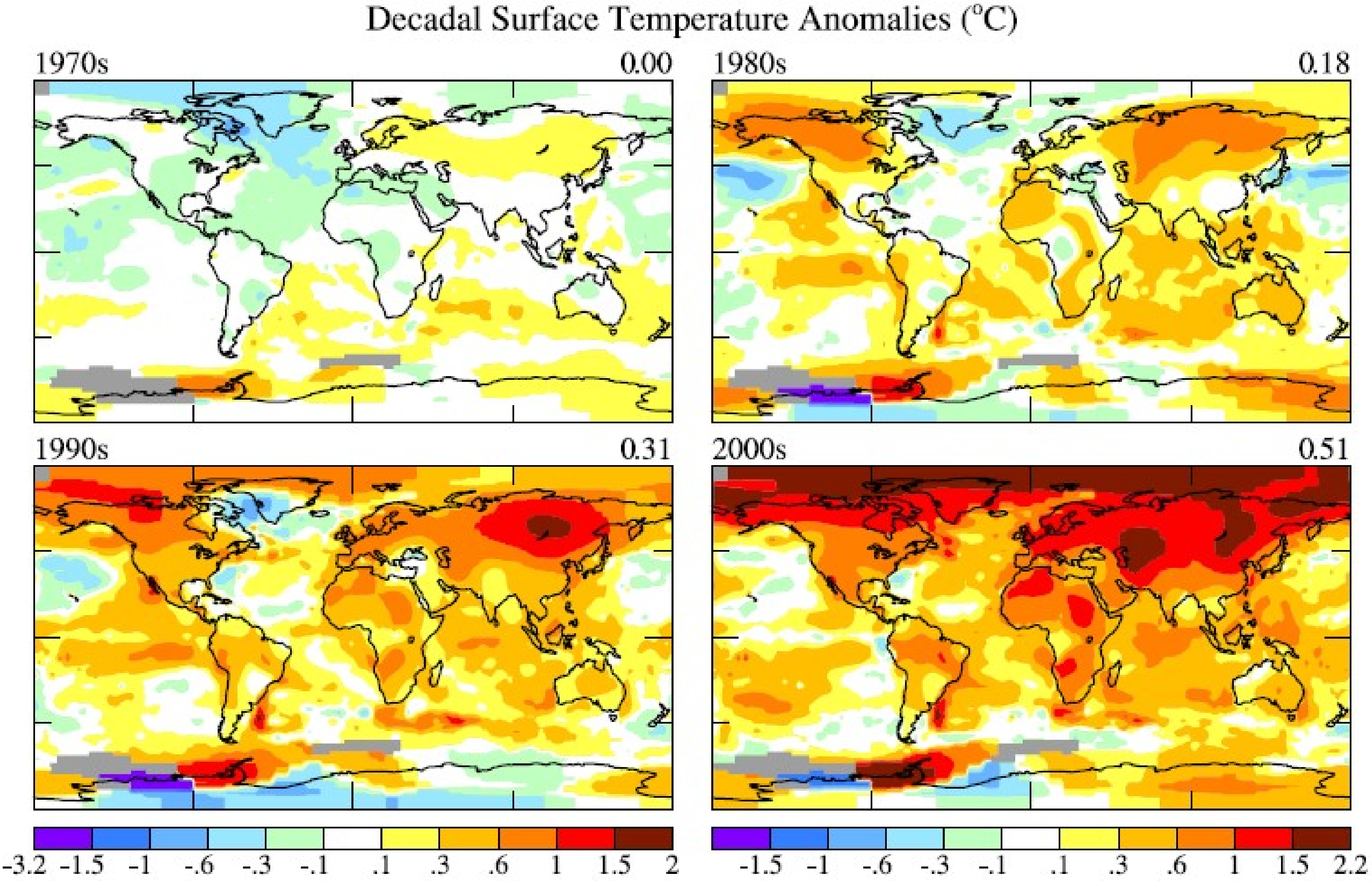
Évolution de la température moyenne de l'air à la surface du globe depuis 1850



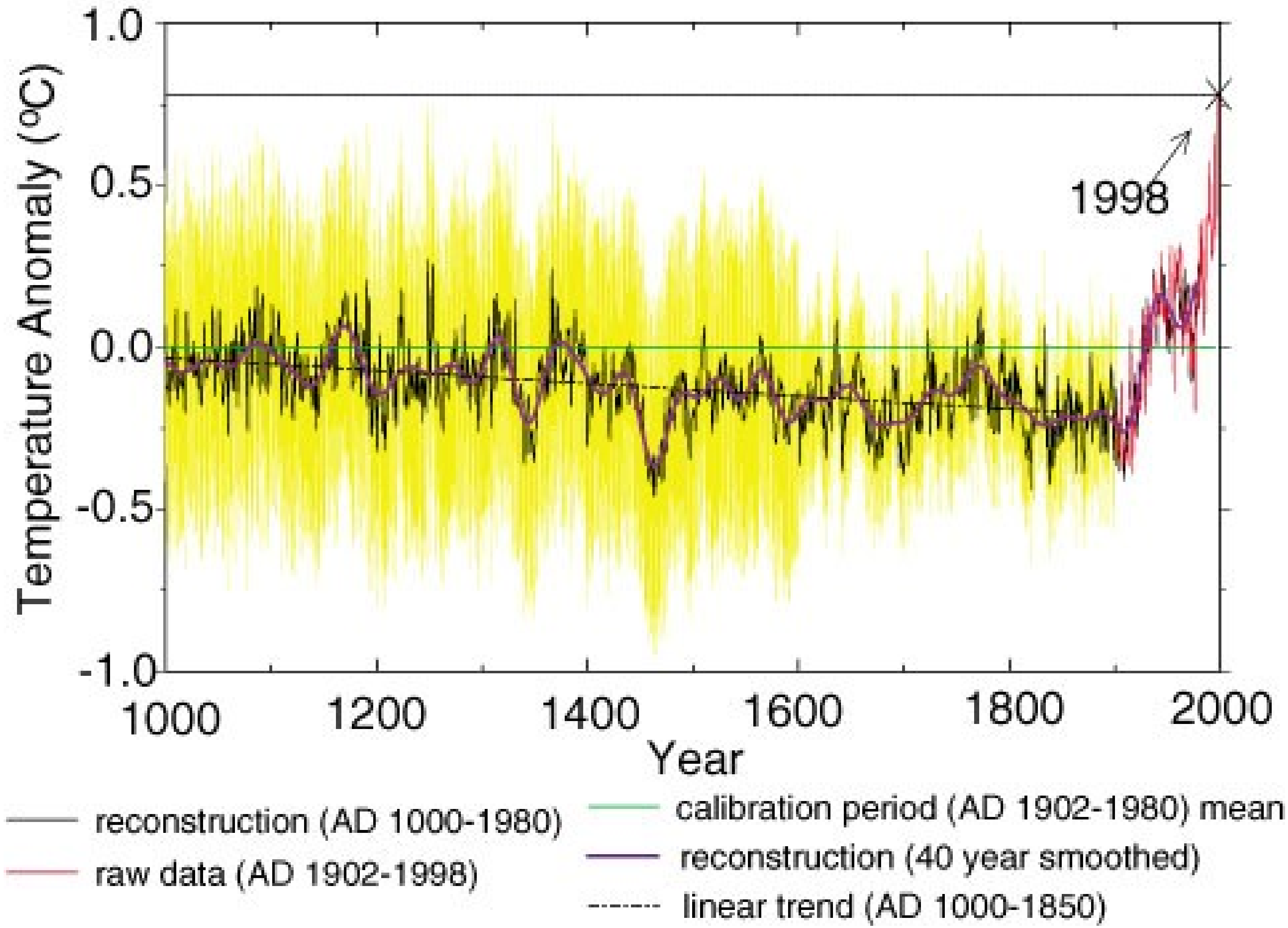
variations géographiques du réchauffement sur le dernier siècle : hémisphère nord vs sud, continents vs océans



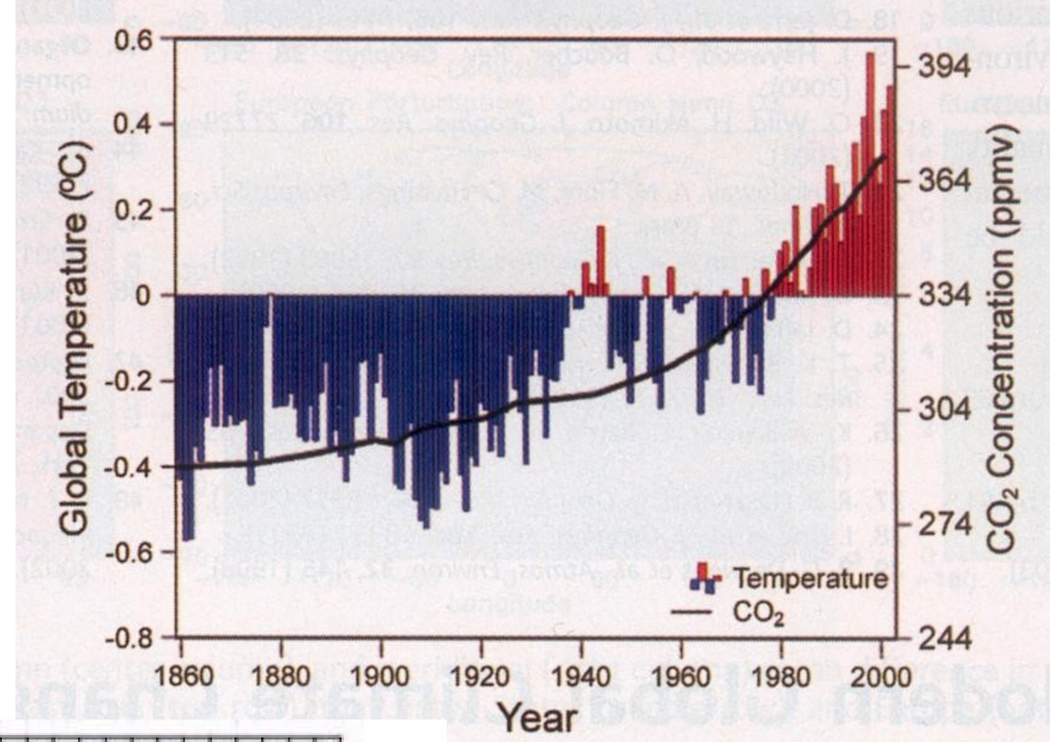
évolution des anomalies de températures moyennes sur 10 ans

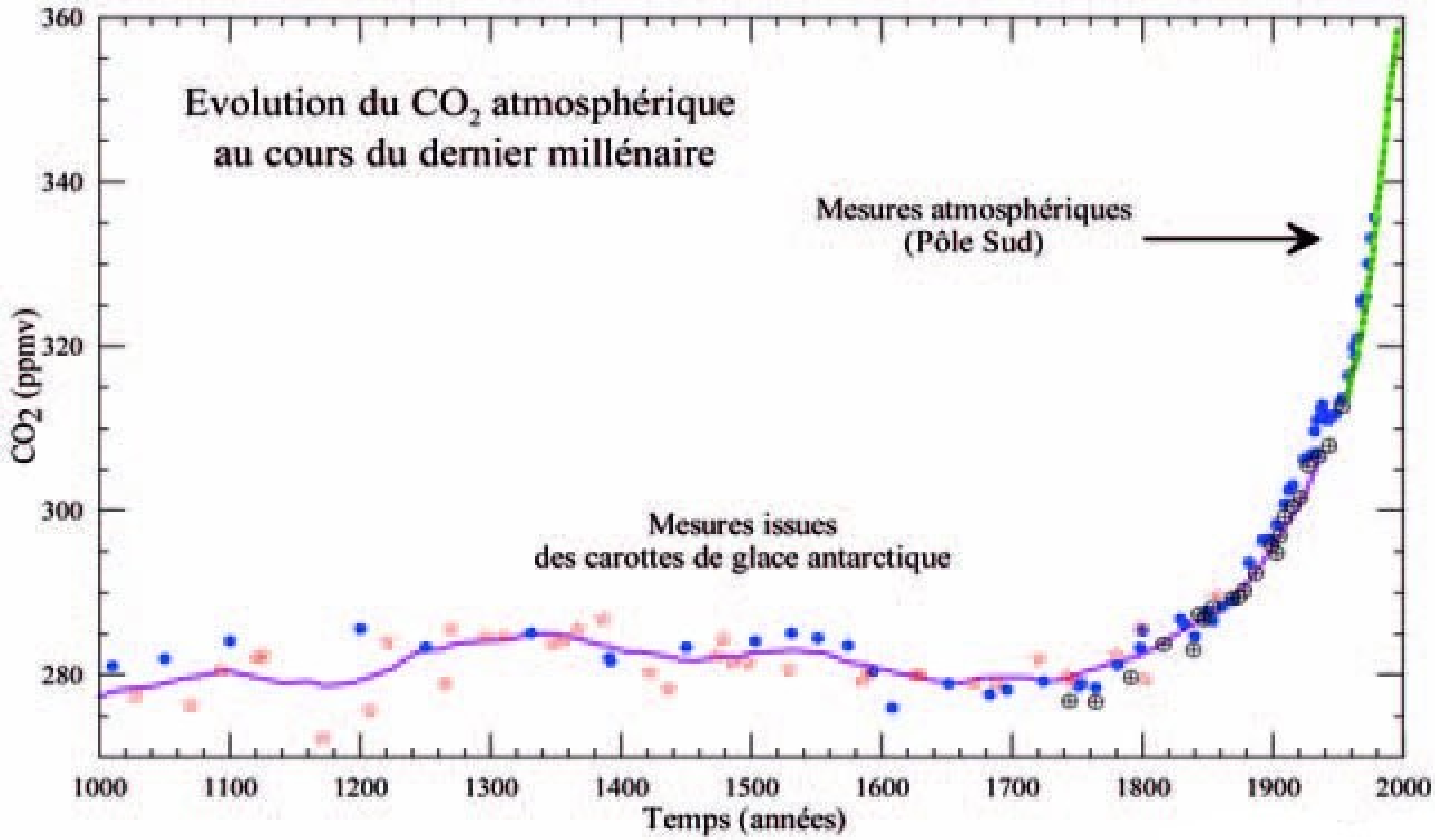


température moyenne dans l'hémisphère nord au cours du dernier millénaire



concentration en CO2 (dioxyde de carbone) dans l'atmosphère (~0.03%)



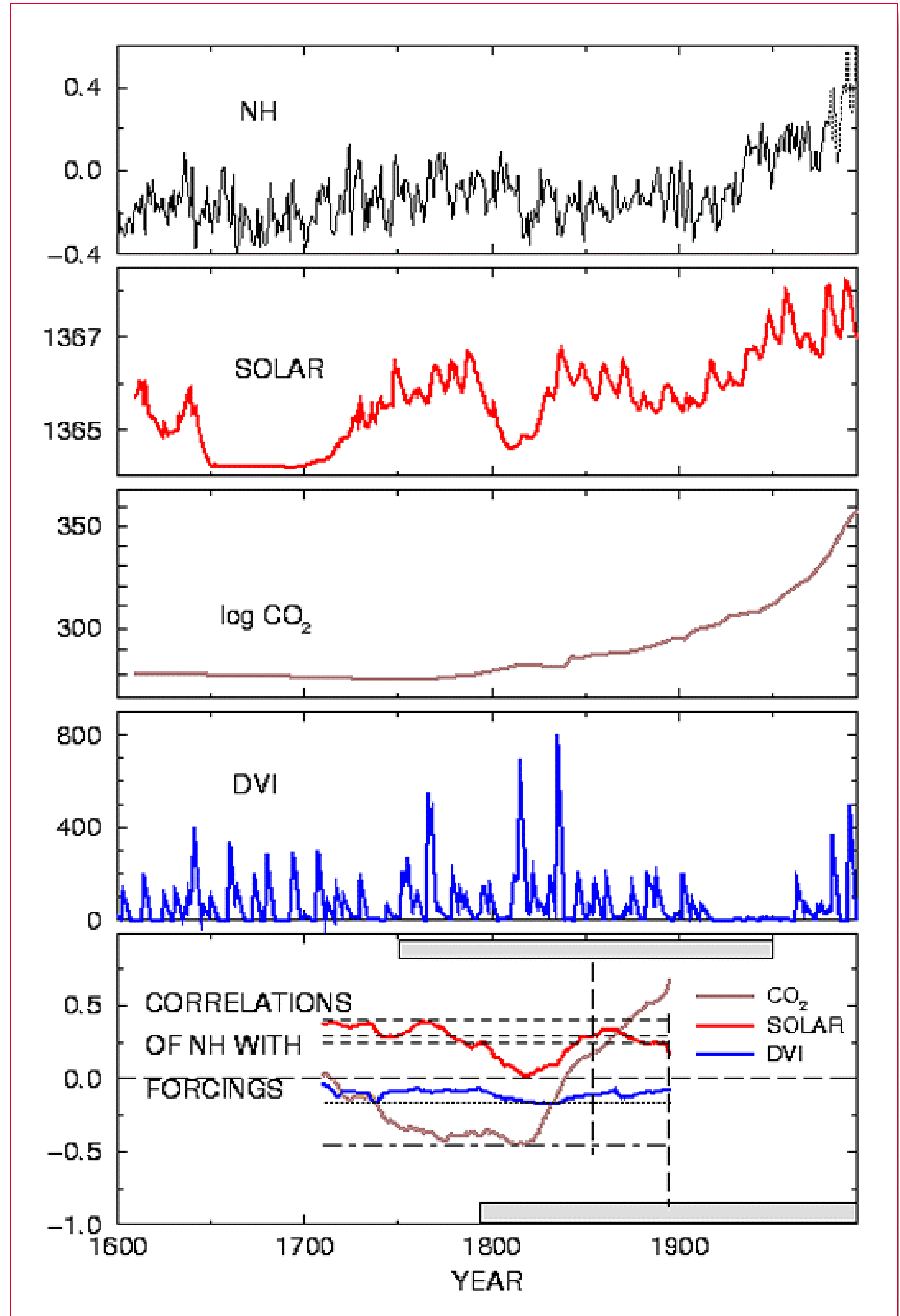


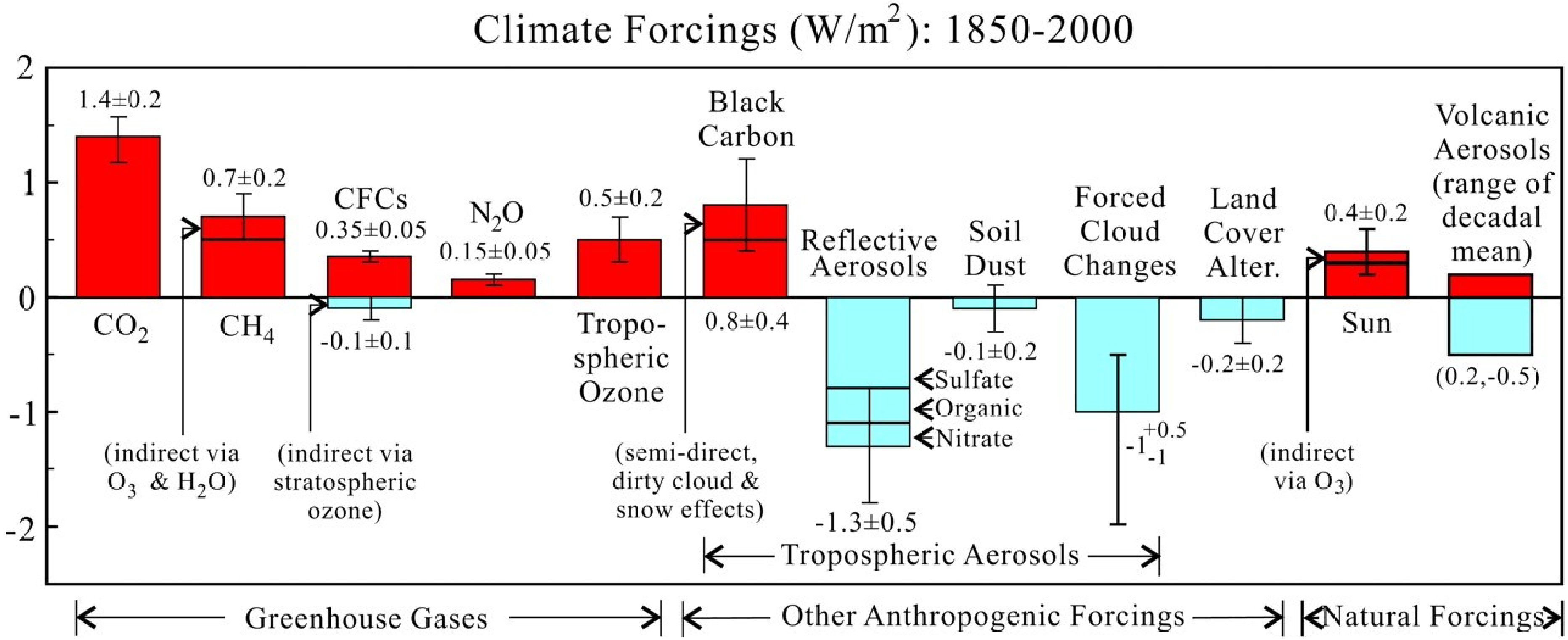
attribution du réchauffement climatique récent dans l'hémisphère nord ?

- constante solaire < 1800

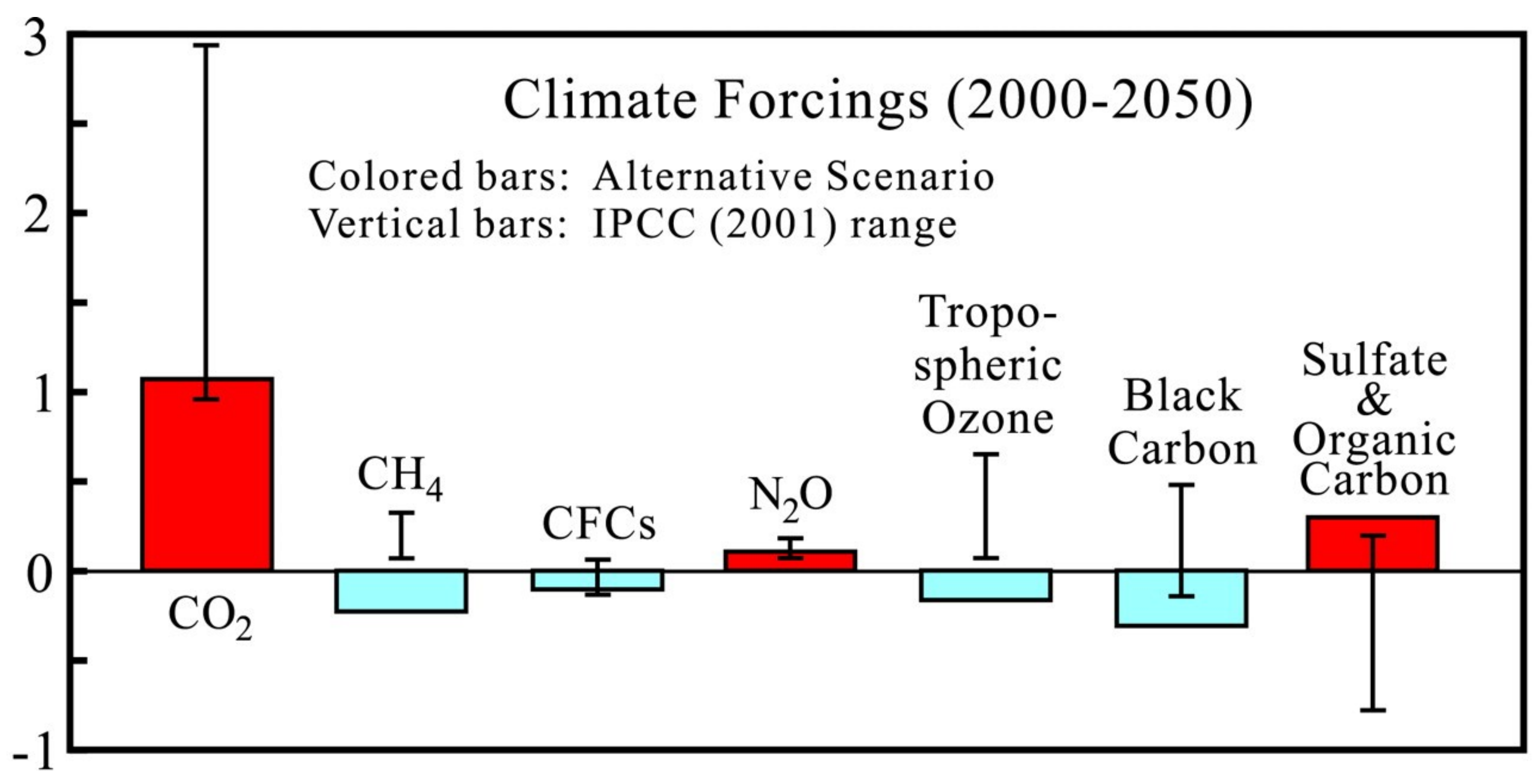
- CO_2 atmosphérique depuis 1850

- poussières volcaniques



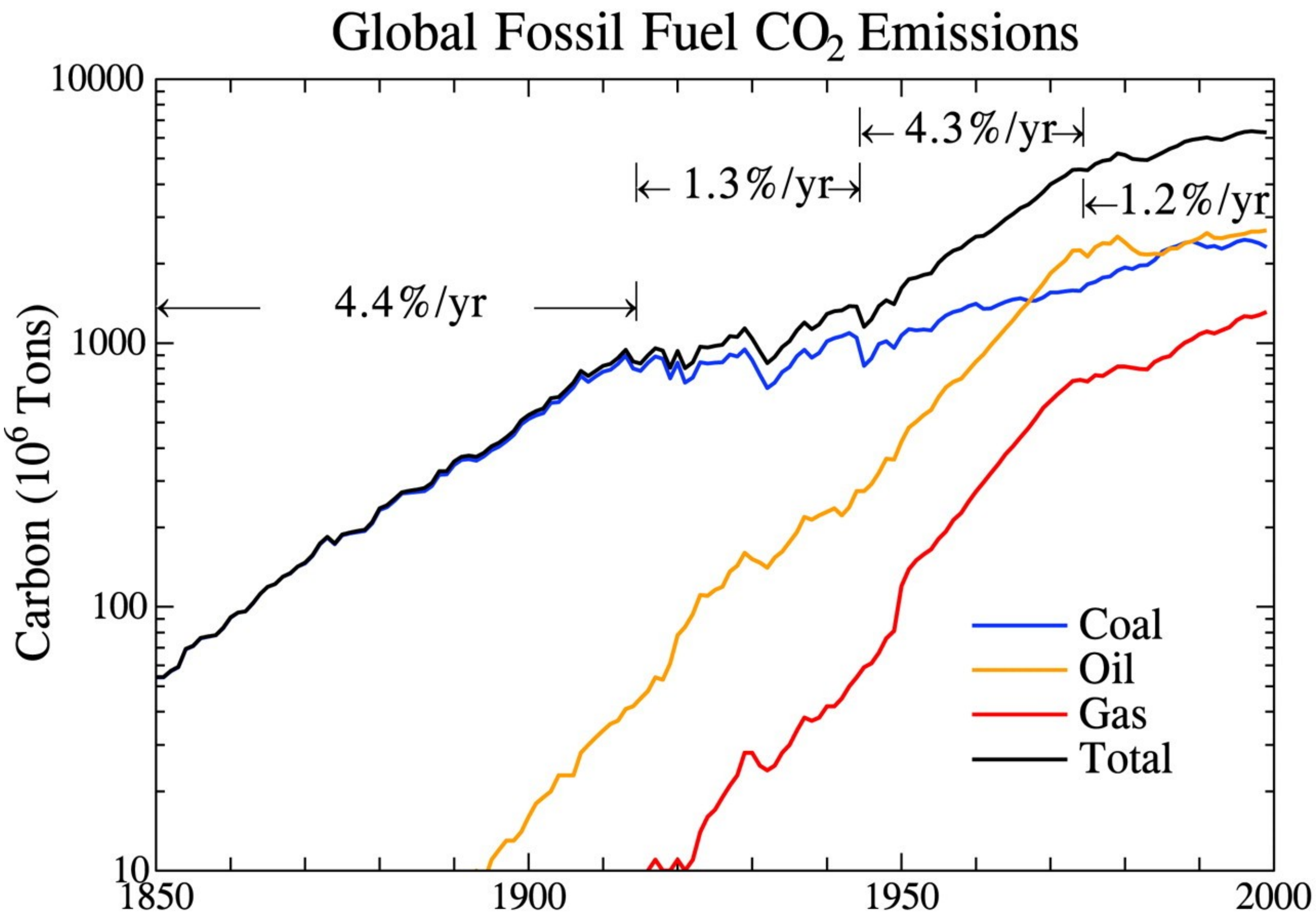


Climate Forcings (W/m^2): 1850-2000
2
1
0
-1
-2
1.4±0.2
0.7±0.2
CFCs
0.35±0.05
N_2O
0.15±0.05
0.5±0.2
Black Carbon
Reflective Aerosols
Soil Dust
Forced Cloud Changes
Land Cover Alter.
0.4±0.2
Volcanic Aerosols (range of decadal mean)
CO_2
CH_4
-0.1±0.1
Tropo-spheric Ozone
0.8±0.4
Sun
-0.1±0.2
-0.2±0.2
(0.2,-0.5)
Sulfate
Organic
Nitrate
$-1^{+0.5}_{-1}$
(indirect via O_3 & H_2O)
(indirect via stratospheric ozone)
(semi-direct, dirty cloud & snow effects)
-1.3±0.5
(indirect via O_3)
Tropospheric Aerosols
Greenhouse Gases
Other Anthropogenic Forcings
Natural Forcings



Climate Forcings (2000-2050)
Colored bars: Alternative Scenario
Vertical bars: IPCC (2001) range
3
2
1
0
-1
CO_2
CH_4
CFCs
N_2O
Tropo-spheric Ozone
Black Carbon
Sulfate & Organic Carbon

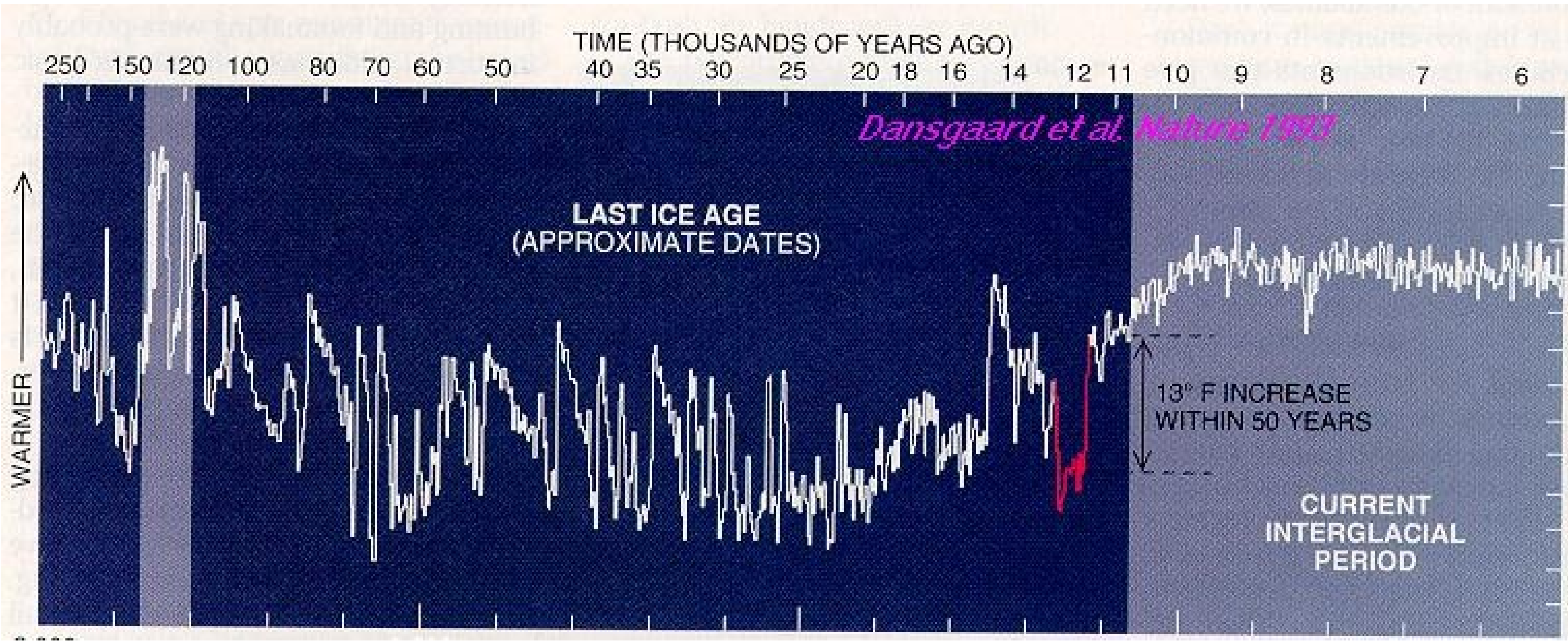
principale source de CO_2 atmosphérique : combustion des énergies fossiles (chauffage, transport, électricité...)



Conséquences du réchauffement climatique

- réchauffement des océans
- fonte des glaces continentales, retrait des glaciers
- élévation du niveau de la mer 3mm/an
- augmentation du CO_2 océanique et du Ph : acidification des océans (coquilles calcaires)
- fonte des glaces arctiques (50% ?)
- stabilité de la circulation océanique actuelle
- cyclones, évènements atmosphériques extrêmes

Estimation des températures à la surface du globe depuis 250.000 ans

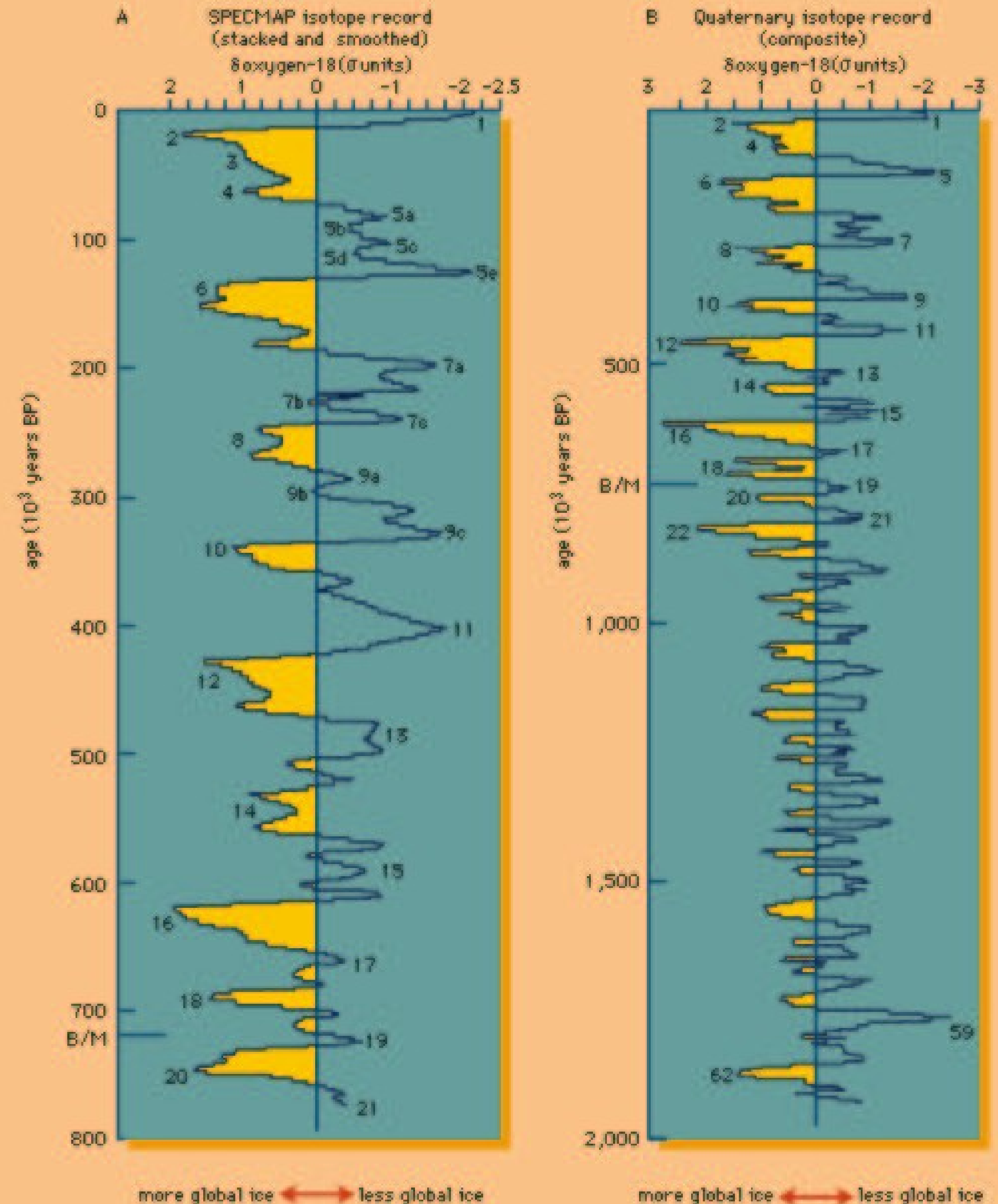


L'analyse de carottes glaciaires, comme ici au centre du Groenland, permet de reconstituer une estimation de la température à la surface du globe (on parle de "proxy") depuis plus de 250.000 ans. L'échelle verticale représente une température, plus chaude vers le haut, variant peut-être de plusieurs degrés des périodes glaciaires à la période actuelle. Depuis 10.000 ans, fin du dernier âge glaciaire, les variations de température sont relativement faibles comparées aux 250.000 ans précédents. Il semblerait donc que **le climat de la Terre n'ait jamais été aussi stable que depuis le dernier maximum glaciaire** !

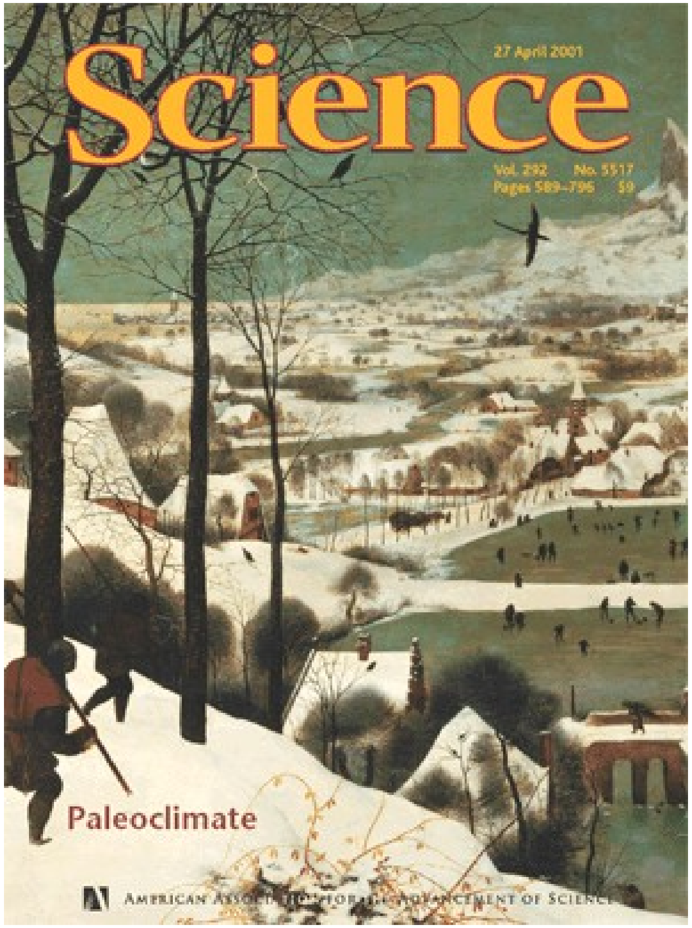
Dans une perspective encore plus longue, une estimation du volume de glace à partir de l'analyse isotopique de carottes de sédiments marins montre très clairement des cycles d'environ 100.000 ans au cours du dernier million d'années. On trouve ainsi certaines fréquences particulières de variations climatiques liées aux variations astronomiques des paramètres orbitaux de la Terre (cycles de Milankovitch) :

- 100.000 ans et 430.000 ans pour l'excentricité (la forme allongée ou arrondie de l'ellipse de l'orbite de la Terre autour du soleil, varie entre 0.001 et 0.054, actuellement 0.017),
- 41.000 ans pour l'obliquité de l'ecliptique (l'angle entre l'axe de rotation de la Terre et la normale au plan de son orbite autour du soleil, qui varie entre 22° et 24°5 - 23°4 actuellement - et détermine les variations saisonnières, importantes surtout aux hautes latitudes),
- 19.000 et 23.000 ans pour la précession des équinoxes (angle entre la périhélie, point le plus proche du soleil, et l'équinoxe vernal).

En fait, la théorie n'est pas vraiment capable de tout expliquer, comme la simultanéité des variations climatiques dans les 2 hémisphères, peut-etre due aux gaz à effets de serre, et l'amplitude des variations climatiques comparé aux faibles changements d'insolation : le système étant fortement non-linéaire, il est probable que le forcage astronomique détermine les les période d'oscillations par un phénomène de vérrouillage de phases (phase locking).



(A) The SPECMAP (Spectral Mapping Project) record based on five low- and middle-latitude deep-sea cores and (B) a composite record of four cores from the equatorial Pacific, the Caribbean, and the North Atlantic. Isotopic stages and substages are indicated; B/M shows the level of Brunhes/Matuyama reversal.



Pieter Bruegel 1565

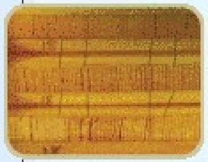
1595

The frozen Thames 1677

Myriad Ways to Reconstruct Past Climate

How fast can climate change? How drastic are the swings? What parts of the world will be hit with typhoons or drought? To answer questions like these, climate scientists look at records of past climate. Direct measurements, such as thermometer records, extend back about 2 centuries. Humans have also noted aspects of climate change for about 1000 years in historical records of cherry blossoms in Japan and grape harvests in Europe, and Egyptian hieroglyphs tell of 4000-year-old droughts. For older evidence of past climate—such as the so-called last Glacial Maximum depicted on this map, roughly 20,000 years ago—a wide variety of records span different times and areas. This illustration presents a sample of them and their uses. Further information can be found at www.ngdc.noaa.gov/paleo and gcmd.gsfc.nasa.gov

—Erik Stokstad



Tree rings

Information: Temperature and rainfall—even seasonal changes—from ring width and density; records contain patterns of cycles such as El Niño and the Pacific decadal oscillation; ring scars can be used to reconstruct frequency and area of wildfires.

Resolution: Annual.

Dating: Counting of rings; radiometric carbon; correlation between trees, as shown in 700-year-old Douglas firs (*left*) from El Malpais National Monument in New Mexico.

Comments: Only terrestrial record with widespread and continuous annual resolution. Limited use in tropical and subtropical regions, where trees don't form well-defined rings. Interpretation complicated because tree growth is influenced by many local factors.

Time range: Typically 500 to 700 years ago to present. In a few cases, 11,000 years ago to present. One 1200-year record extends back to 50,000 years ago.

Areas studied:

Pollen

Information: Shifts in vegetation patterns can reveal temperature and moisture.

Resolution: Typically 50 years, depending on deposition rate, down to subannual in some places.

Dating: Radiocarbon in lake sediment or wetlands; volcanic ash layers or oxygen isotope correlation in marine sediments.

Comments: Pollen grains such as this *Tilia* (*left*) are very good for revealing temperature. Useful only as far back as analogies to modern vegetation hold. Can work on a variety of scales from microclimate of a small lake to average conditions over an entire continent.

Time range: Present to several million years ago.

Areas studied:

Geomorphology

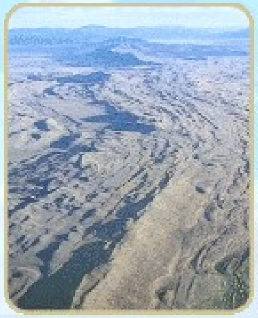
Information: Many aspects of past climates can be traced in the shape of the landscape. The extent of glaciers and ice sheets, for example, is revealed by erratic boulders, rounded valleys, or long piles of gravel and rocks, called moraines, like these (*right*) from the Last Glacial Maximum of New Zealand. Sea level can be reconstructed from ancient wave-cut terraces on coastal hillsides and from the shape of sea bottom.

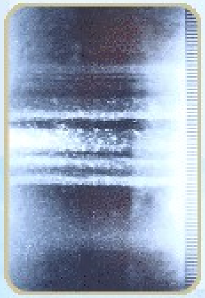
Resolution: Varies.

Dating: All sorts, including radiocarbon dating of wood in moraines or coral stranded on hillsides after sea level dropped.

Time range: From glaciation 2.9 billion years ago to the little Ice Age of the 19th century.

Areas studied: Worldwide.





Ice cores

Information: Volume of continental ice from oxygen isotopic composition of the oceans; levels of CO_2 and methane in the atmosphere from trapped gas bubbles; wind strength and source from dust, sea salt, pollen; surface temperature from isotopic ratios in ice, borehole temperatures, gas fractionation, melt layers; snow accumulation rates from thickness of annual layers; sunspot cycles from isotopes formed by solar cosmic rays.

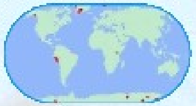
Resolution: Subseasonal to decadal; highly accurate to 40,000 years.

Dating: Counting of annual layers, such as these (*left*) from Greenland; correlation to other cores; ice-flow models.

Comments: These cores provide a direct sample of the atmosphere. Cores also contain information about places ranging from the local environment to distant deserts, which helps scientists figure out which aspects of climate change at the same time.

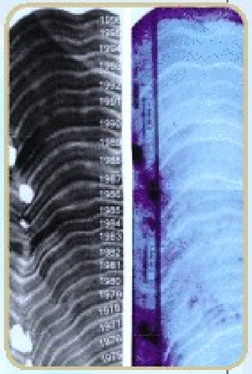
Time range: 440,000 years ago to present.

Areas studied:



Corals

Information: Sea surface temperature from oxygen isotopes and elemental ratios, also salinity. River discharge and precipitation cycles on land from isotopes. Records reveal El Niño frequency, impacts, and relation to background climate; sea level from dating of coral. Oxygen isotopes in coral from Kenya (*right*) show a connection to El Niño in the Pacific.



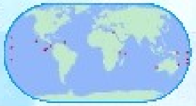
Resolution: Typically months; weekly in exceptional cases.

Dating: Annual banding from coral density, stable-isotope ratios, or elemental ratios.

Comments: One of the few tropical records that show seasonal changes in ocean systems. Accurate multivariate data sets. Disadvantage: hard to find records that are 400 or more years long.

Time range: Continuous records to about 400 years. Large fossil corals give short time intervals about 130,000 years ago.

Areas studied:



Marine sediments

Information: Isotopes in microfossils reveal temperature, salinity, ice volume, atmospheric CO_2, and ocean circulation. Sands can reveal ocean currents, dust storms, and iceberg calving.

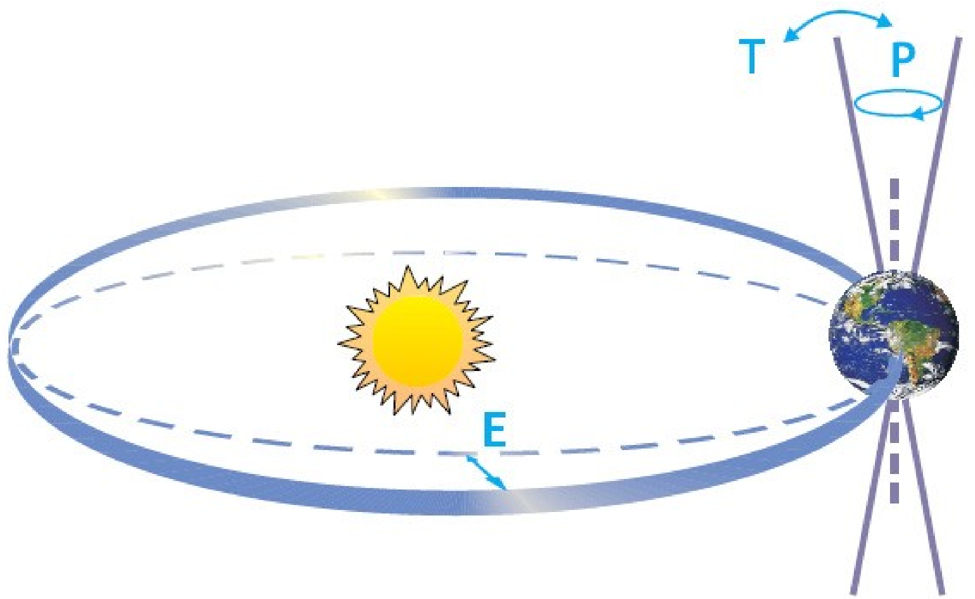
Resolution: Typically thousands of years to centuries; in rare settings, seasonal.

Dating: Radiometric for fossils as old as about 40,000 years. Correlated by stable isotopes to regular changes in Earth's orbit going back millions of years.

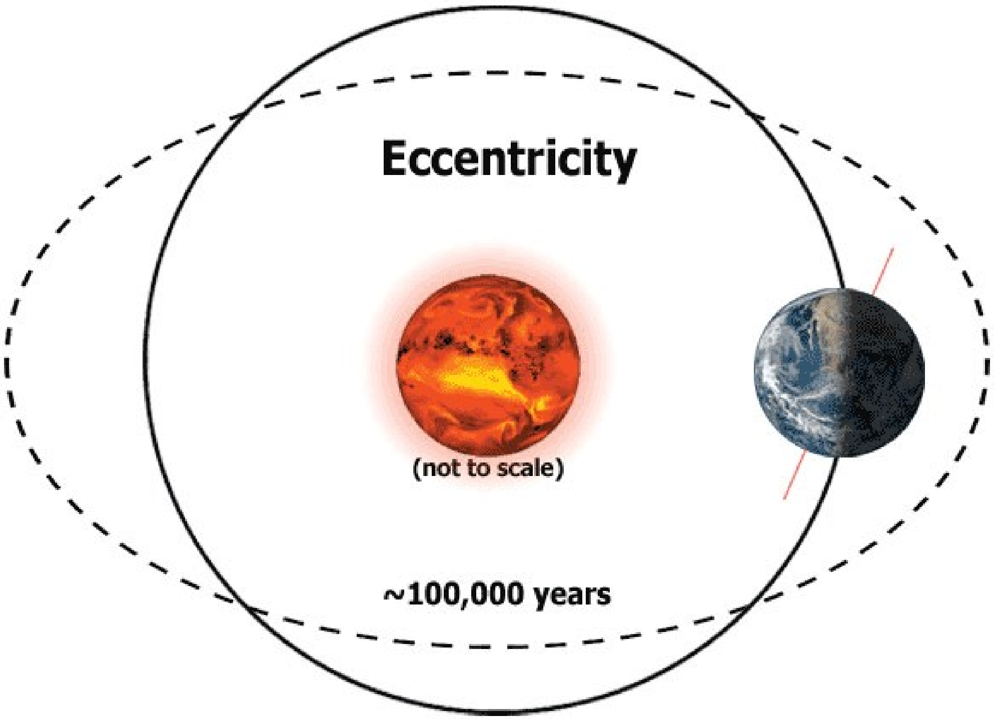
Comments: Marine sediments cover much of Earth and provide continuous records that are often protected from erosion, although some layers have been mixed by burrowing animals or are subject to dissolution or diagenesis. Cores of sediment contain proxies for both local and global changes, synchronizing different events.

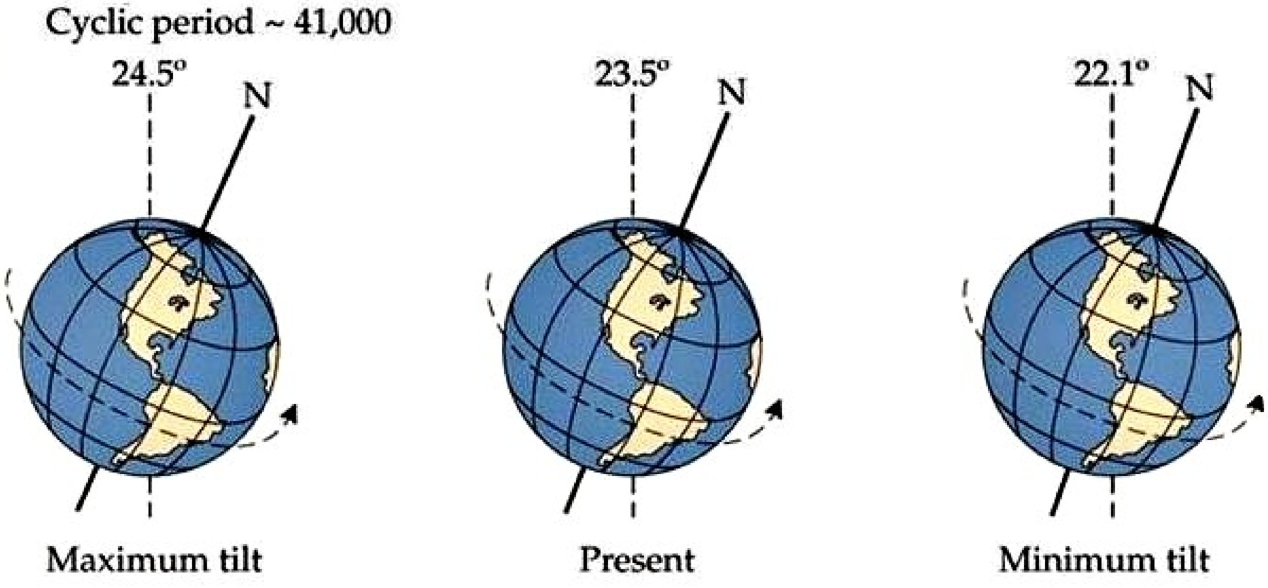
Time range: As far back as 180 million years in some places. Higher resolution records are increasingly available from shorter, more recent intervals, such as the last 20,000 years.

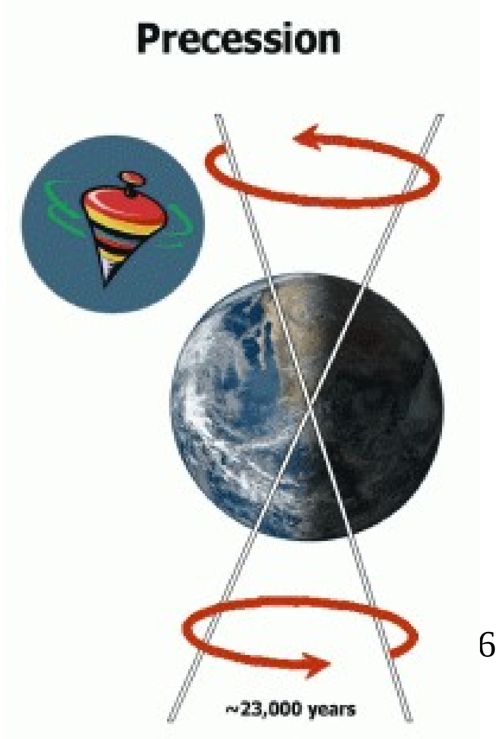
Areas studied:



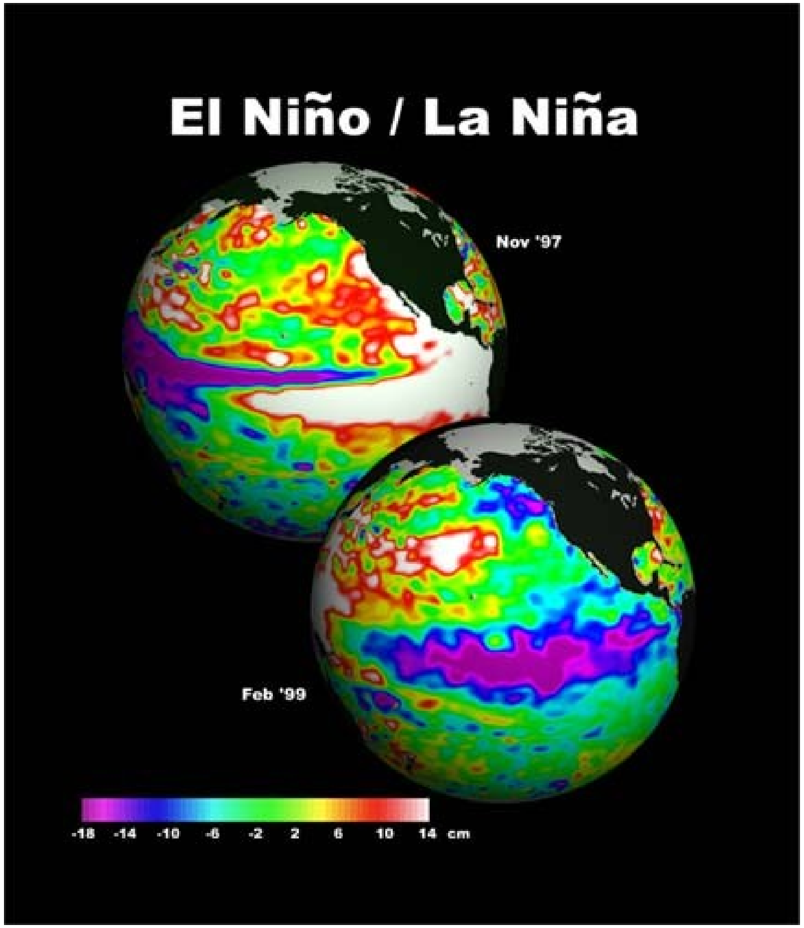
Milankovitch Cycles. *Schematic of the Earth's orbital changes (Milankovitch cycles) that drive the ice age cycles. 'T' denotes changes in the tilt (or obliquity) of the Earth's axis, 'E' denotes changes in the eccentricity of the orbit (due to variations in the minor axis of the ellipse), and 'P' denotes precession, that is, changes in the direction of the axis tilt at a given point of the orbit. Source: Rahmstorf and Schellnhuber (2006).*

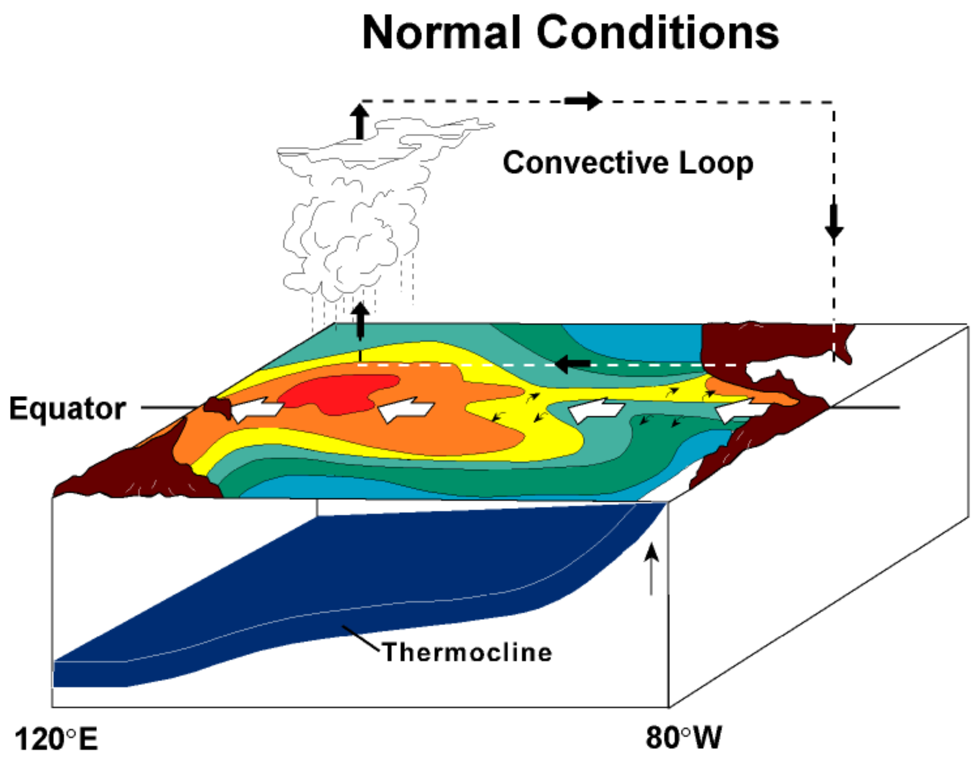


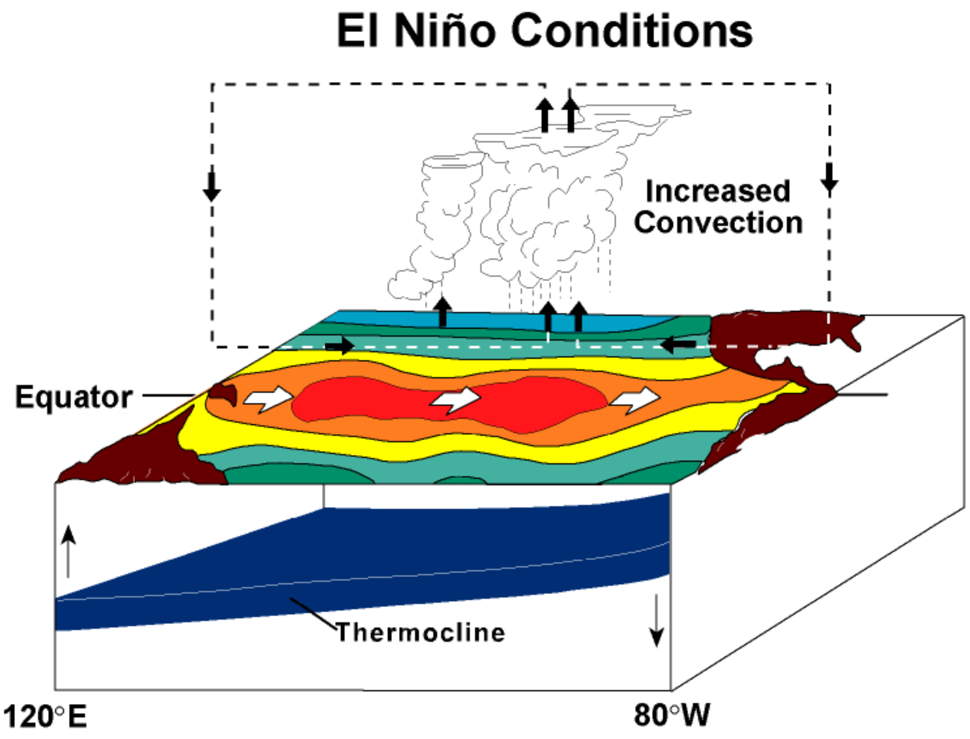




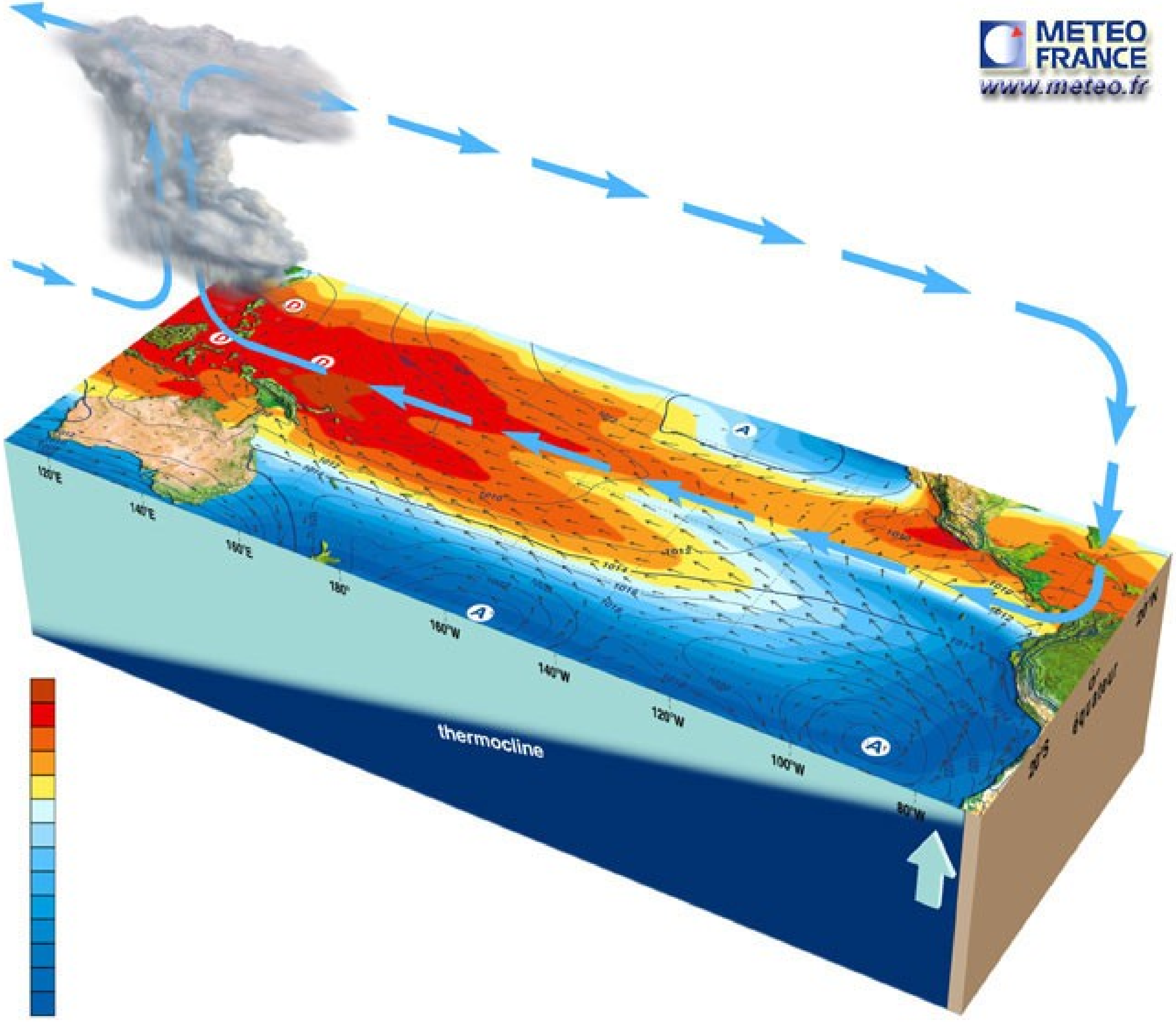
El Niño et l'oscillation australe ENSO



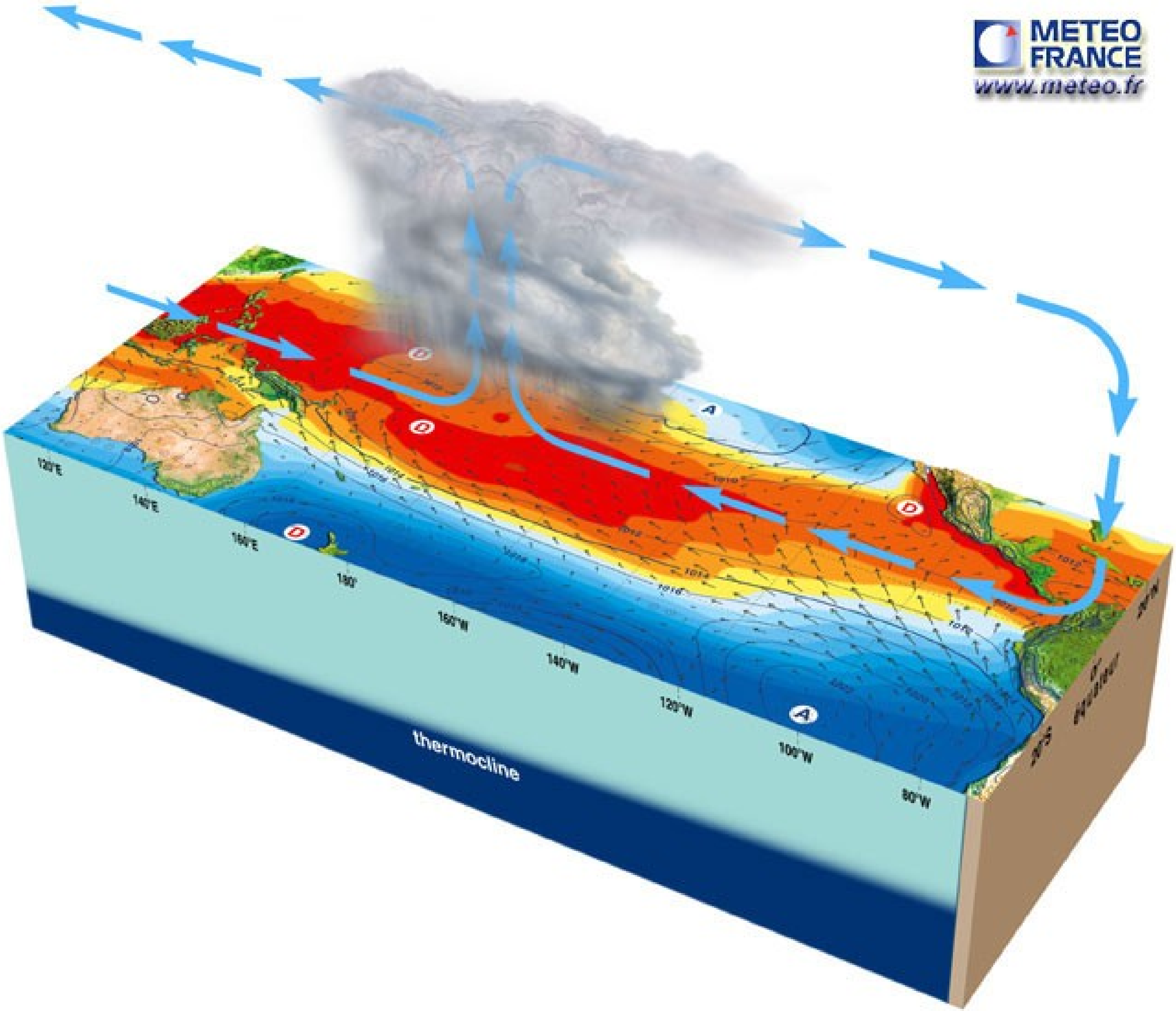




conditions normales - septembre 1996



El Niño - 1997



EL NIÑO IMPACTS

June-September 1997

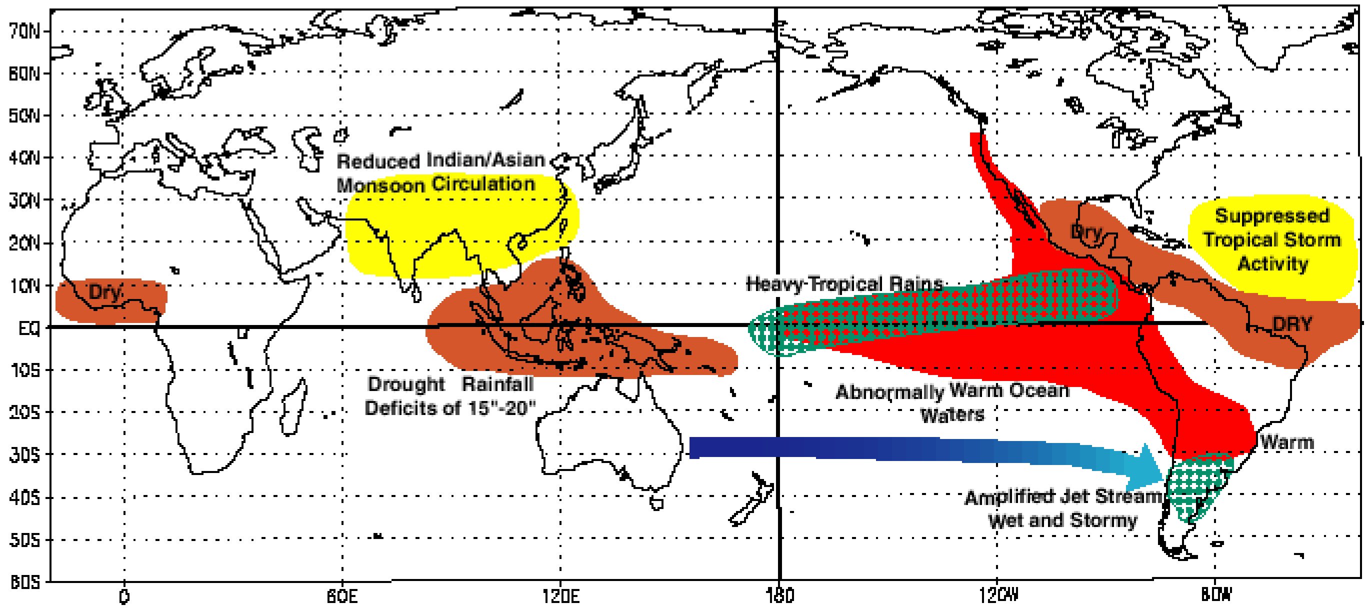
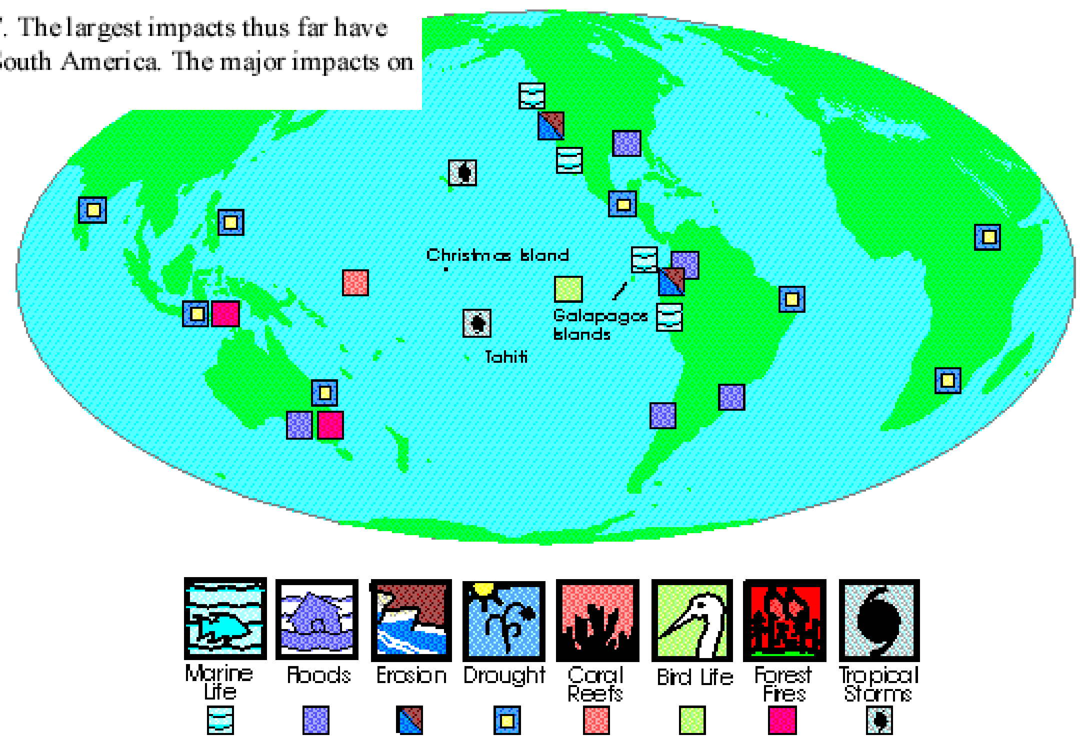
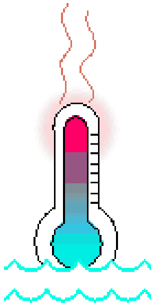


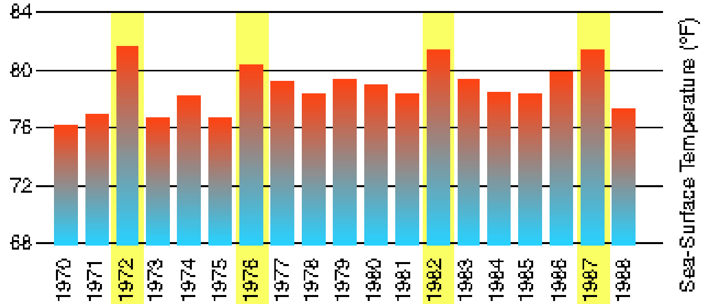
Figure 1. Schematic representation of major El Niño impacts during June-September 1997. The largest impacts thus far have been in the tropics and subtropics, and over the middle latitudes of the South Pacific and South America. The major impacts on the United States are not expected until the winter season.



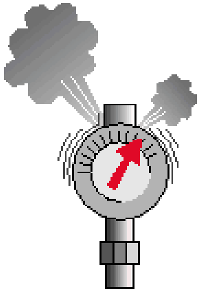
El Niño : un phénomène couplé océan atmosphère

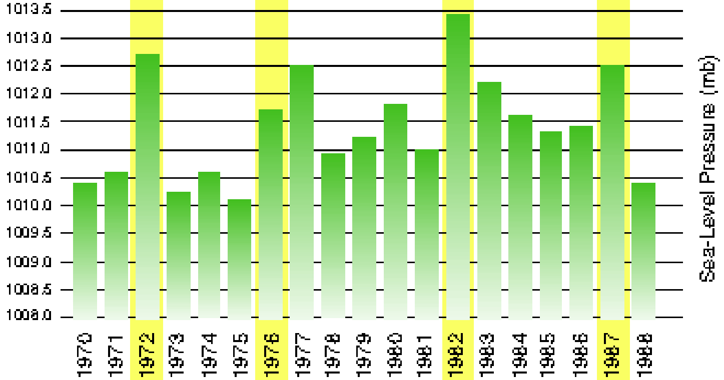
- Température le long de l'équateur dans le Pacifique est



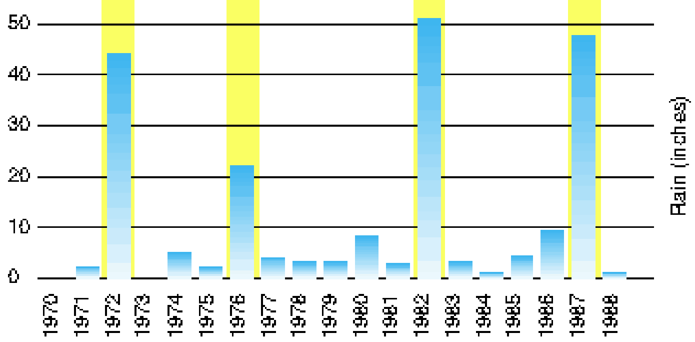


- Pression atmosphérique à Darwin, Australie

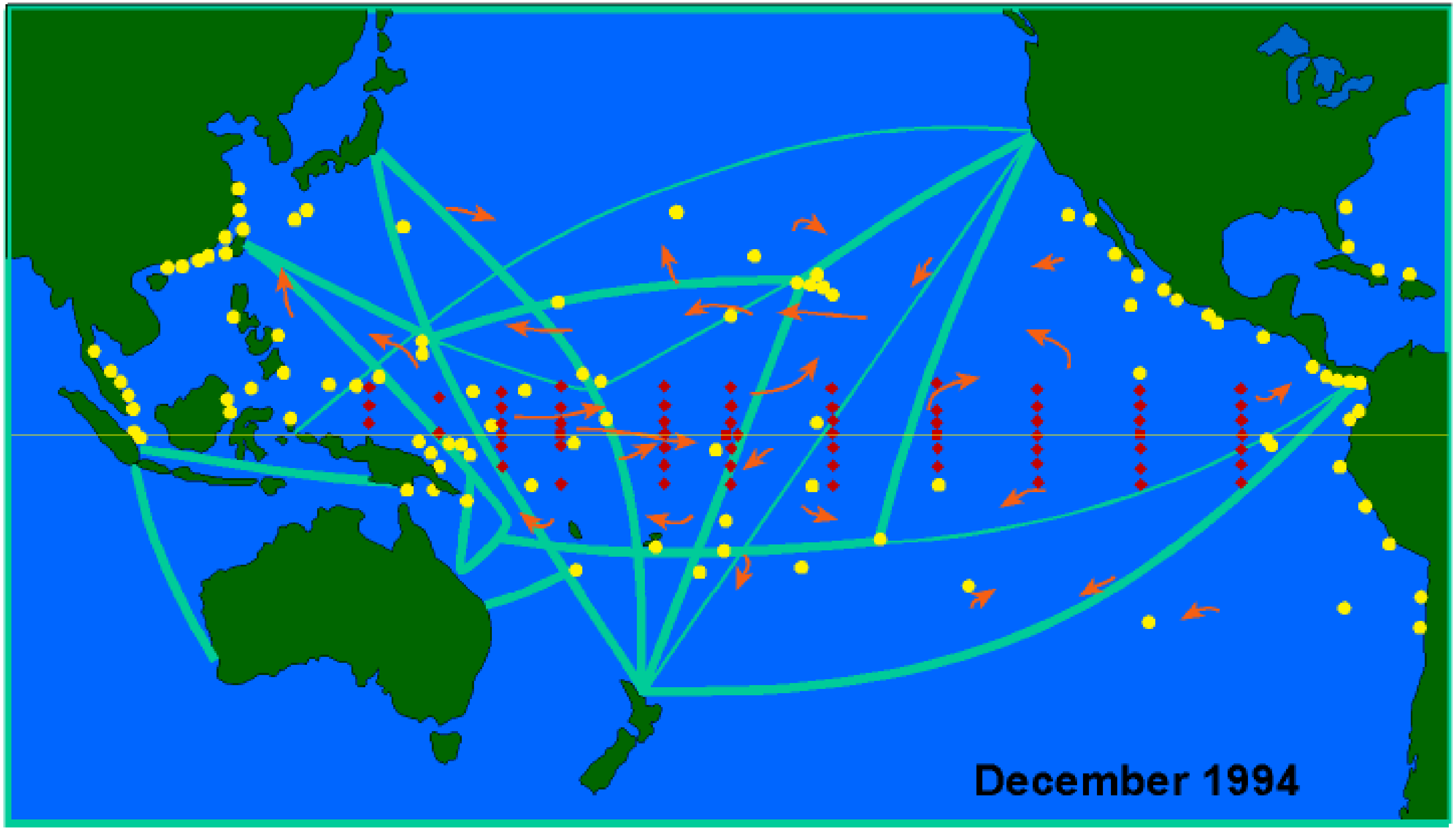


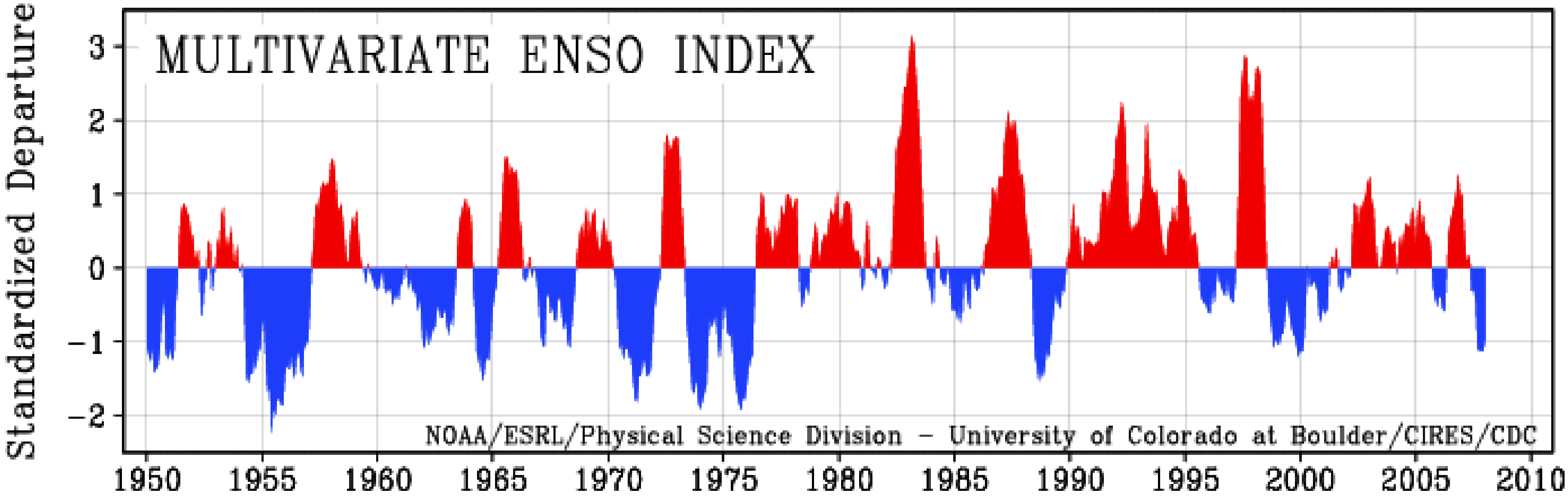


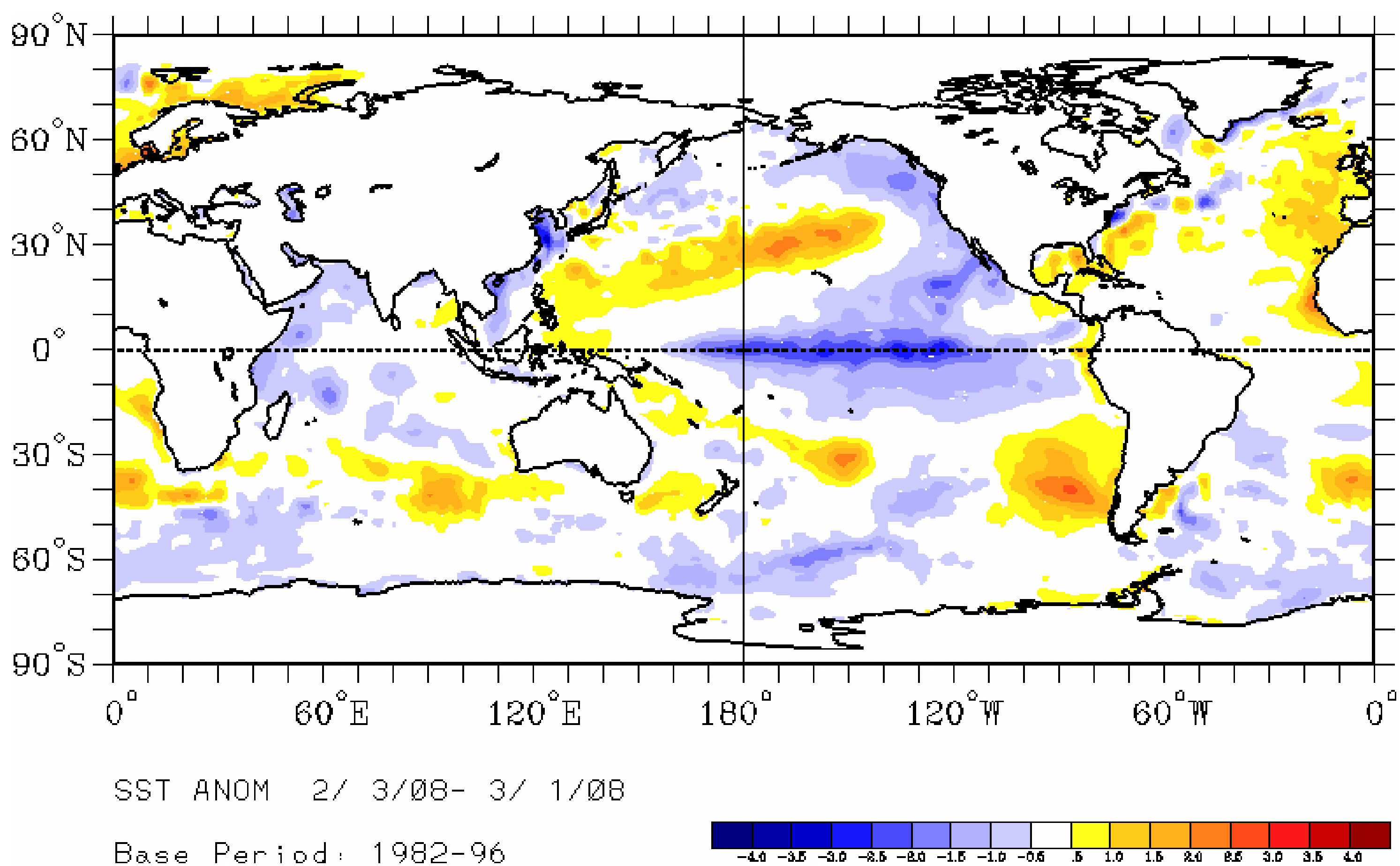
- Précipitations aux îles Christmas, Pacifique central



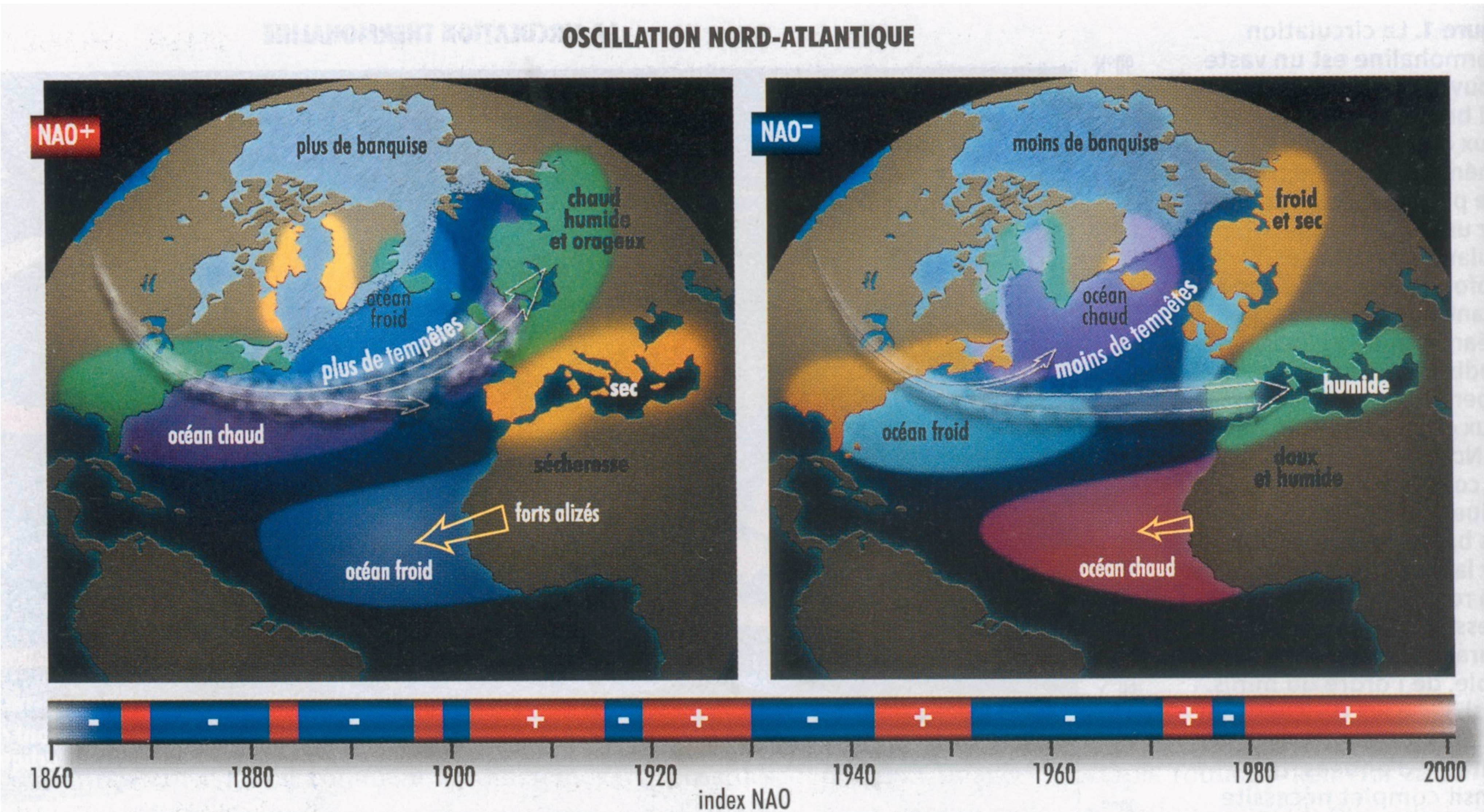
Le réseau d'observation de l'océan Pacifique tropical TOGA



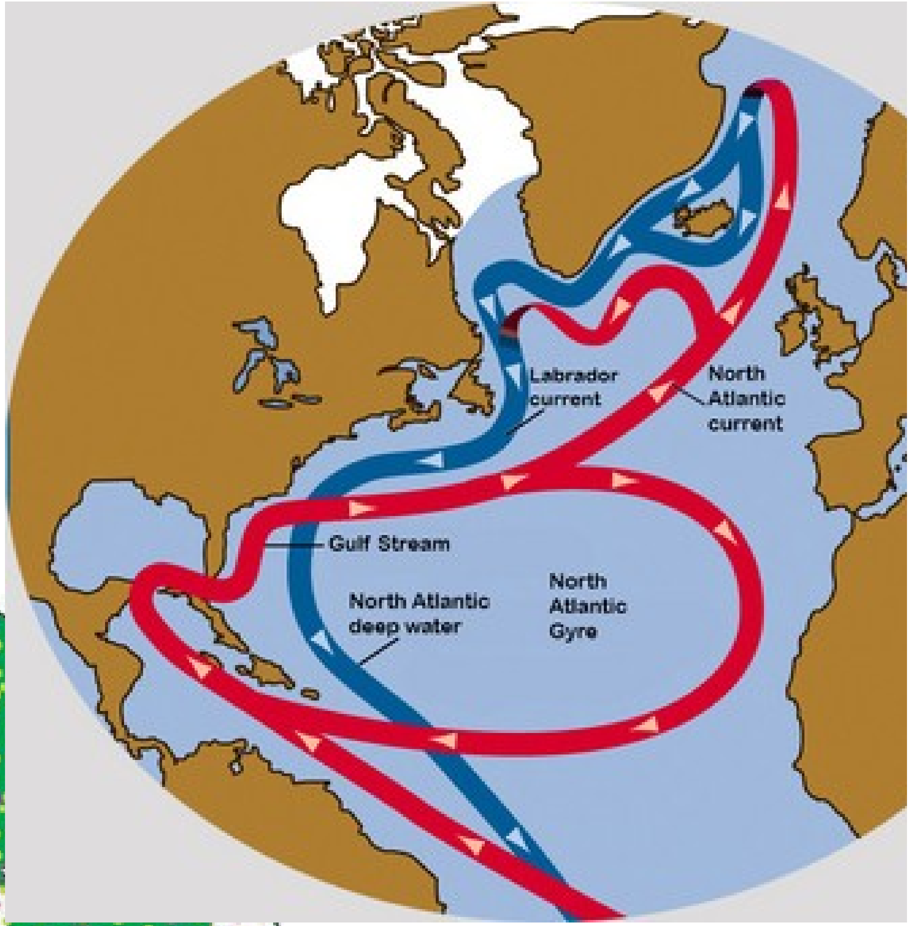

MULTIVARIATE ENSO INDEX
Standardized Departure
3
2
1
0
−1
−2
NOAA/ESRL/Physical Science Division – University of Colorado at Boulder/CIRES/CDC
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

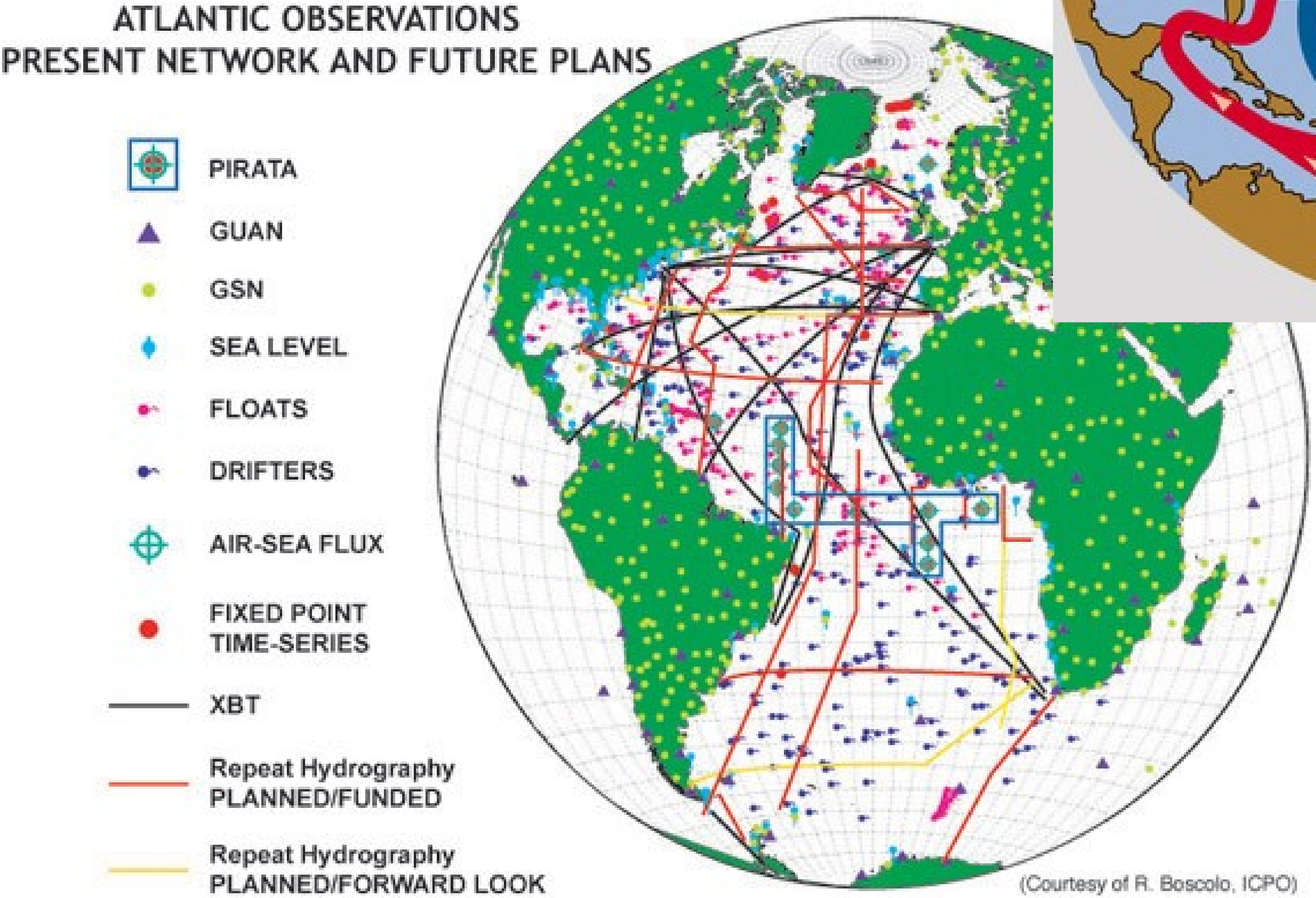

90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W
0°
SST ANOM 2/ 3/08- 3/ 1/08
Base Period: 1982-96
-4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 .5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

L'oscillation nord atlantique : NAO

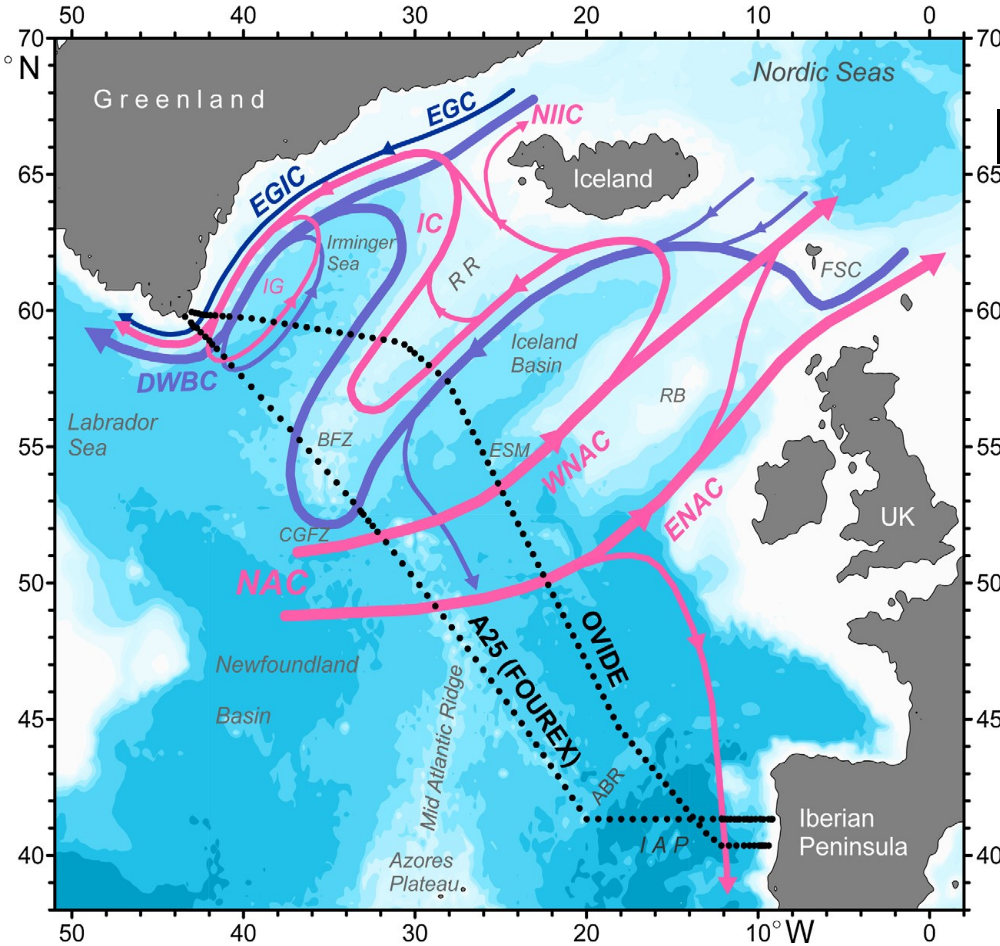


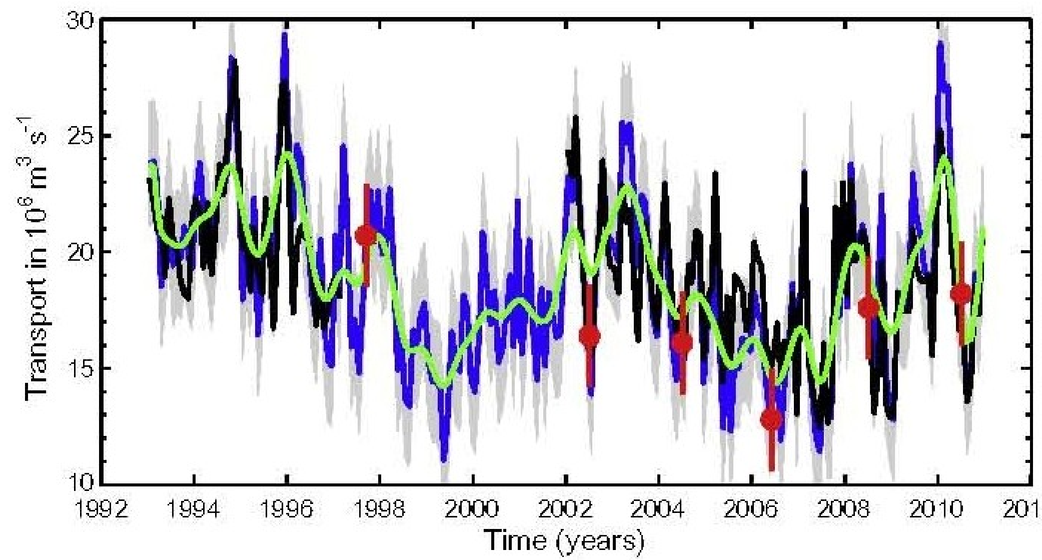
La circulation générale dans l'Atlantique Nord : Gulf Stream et cellule méridienne de retournement



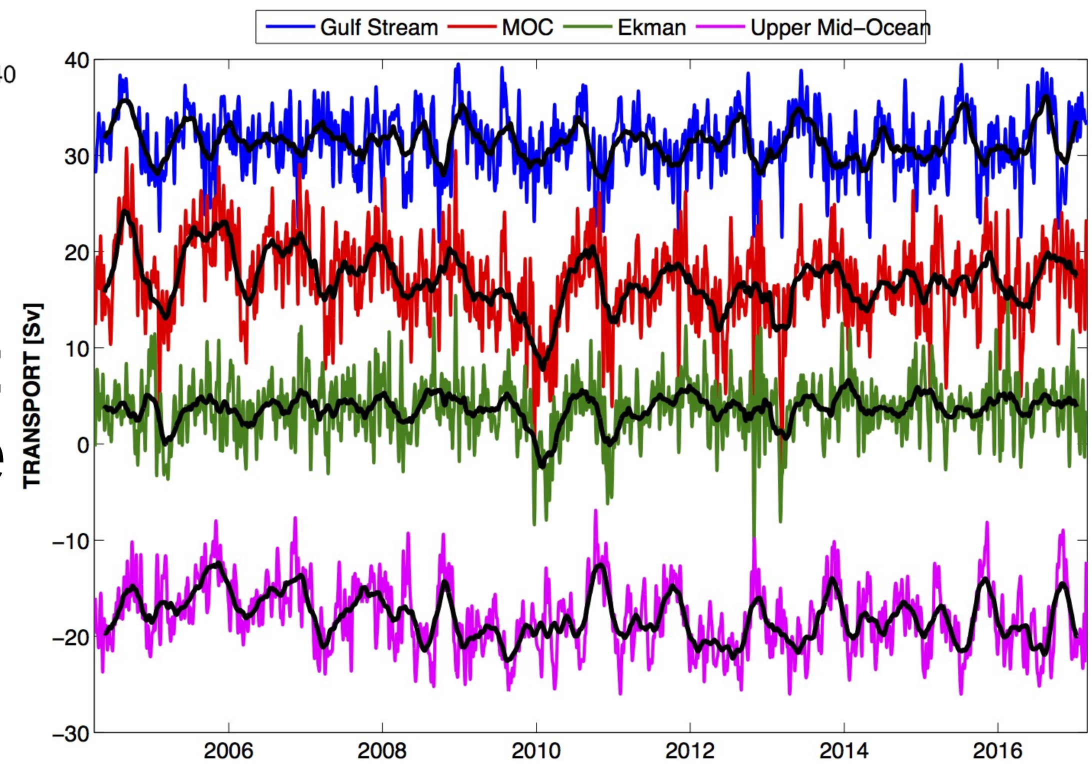


Section OVIDE Groenland-Portugal + altimétrie satellitaire



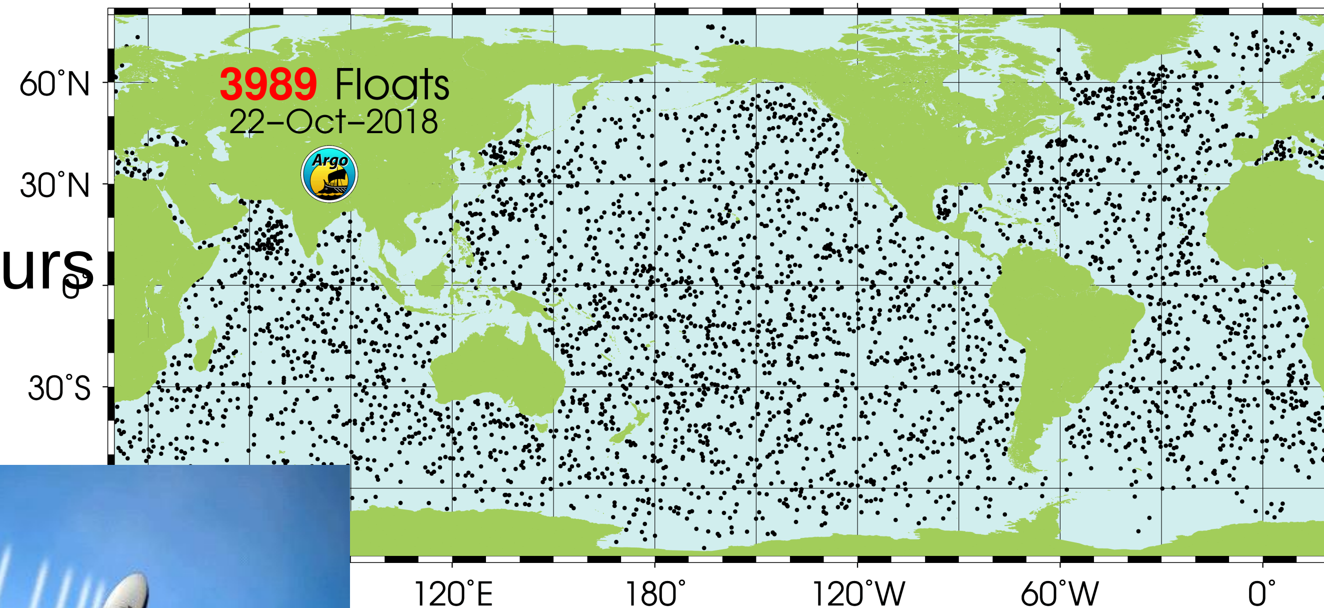


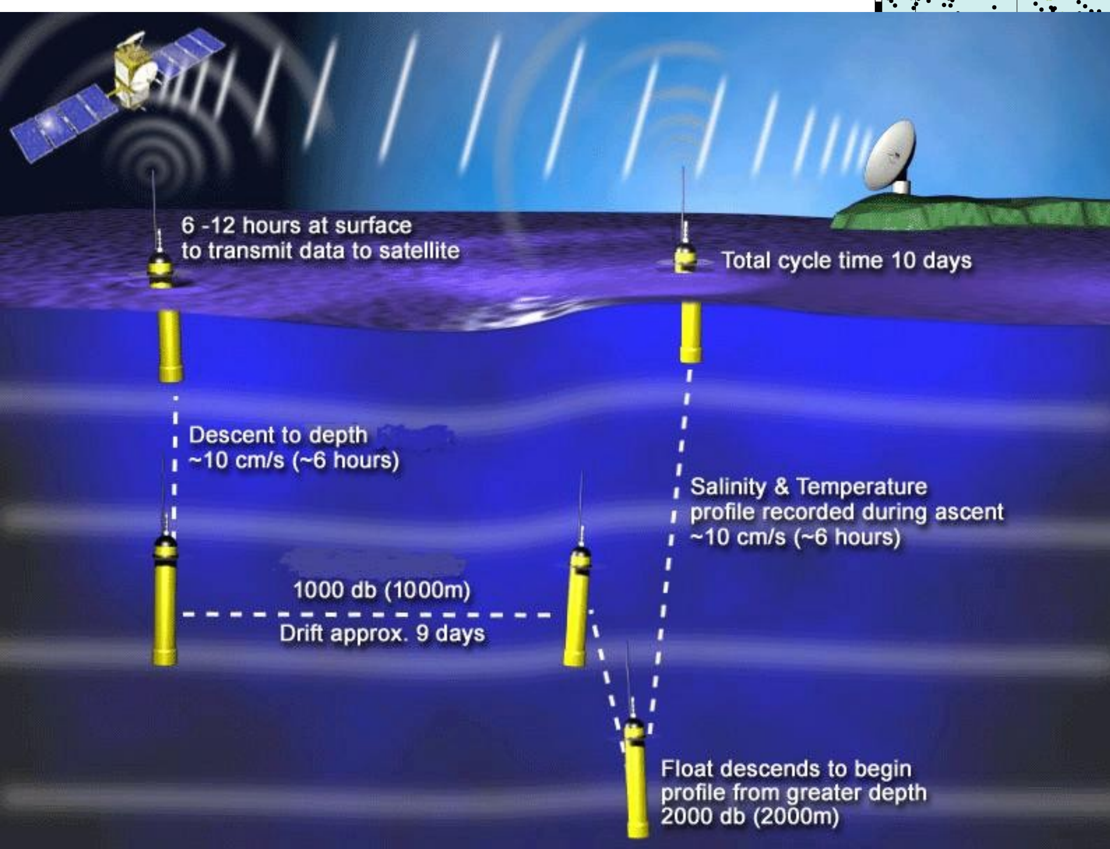
RAPID à 26°N depuis 2004 : encore difficile d'extraire une tendance !

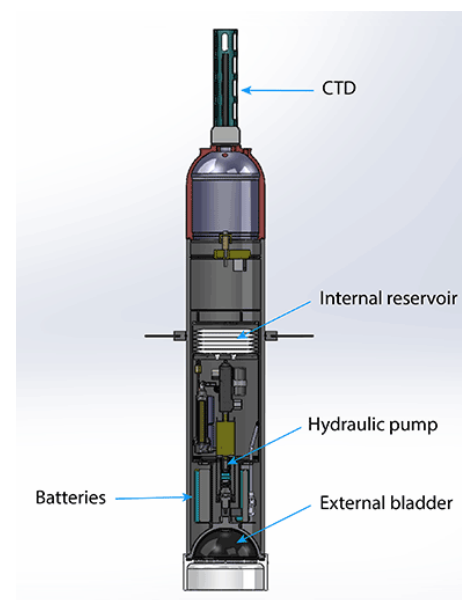


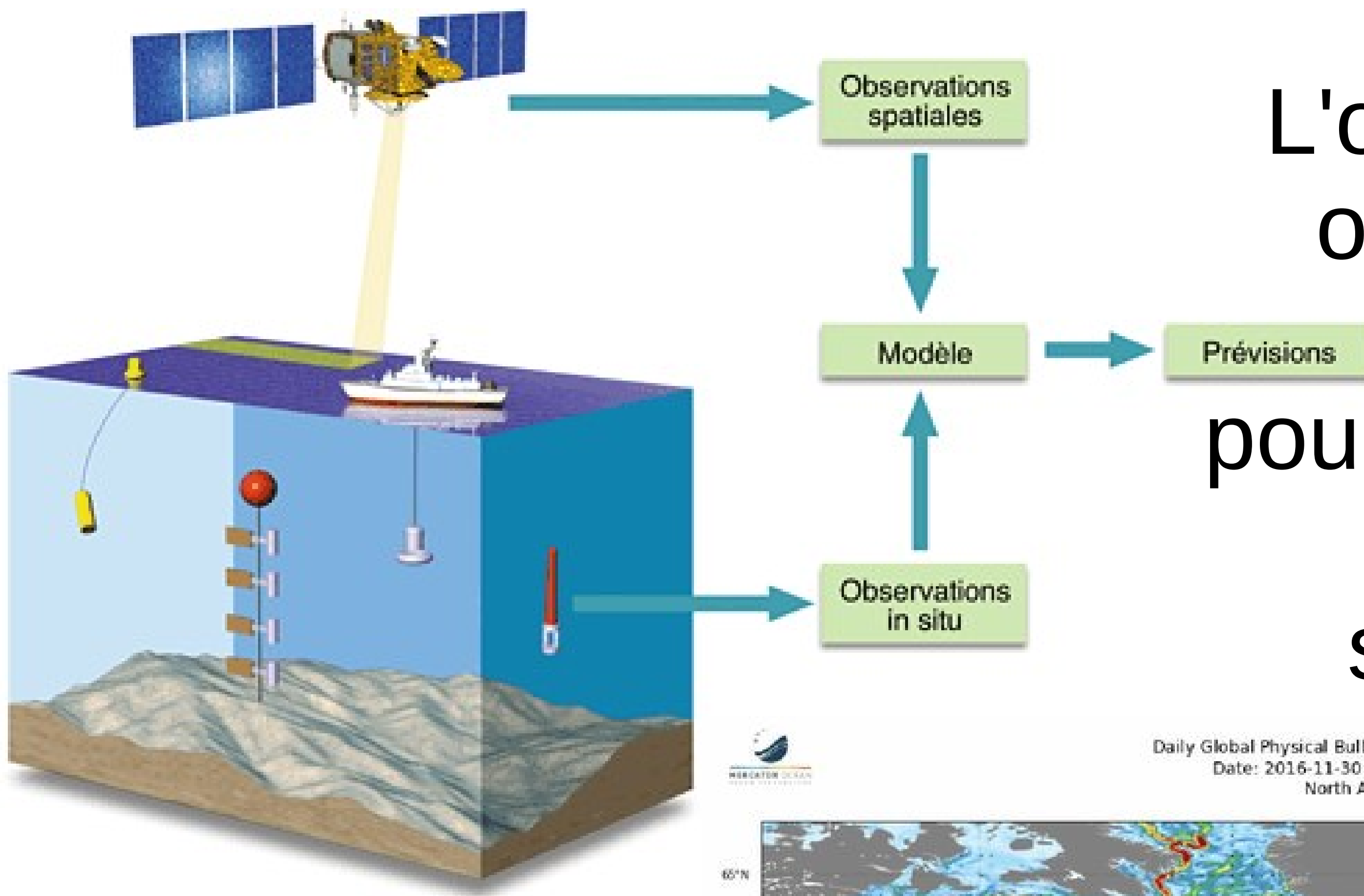
The Global Ocean Observing System, pour une surveillance de l'océan mondial : niveau de la mer, SST, SSS, contenu thermique,...

4000 flotteurs profileurs
Argo : T,S 0-2000m/10jours









L'océanographie opérationnelle : pour des prévisions climatiques saisonnières