An 18,000-year multiproxy lacustrine record of climate variability in south-central Chile (40°S): Lago Puyehue, Chilean Lake District

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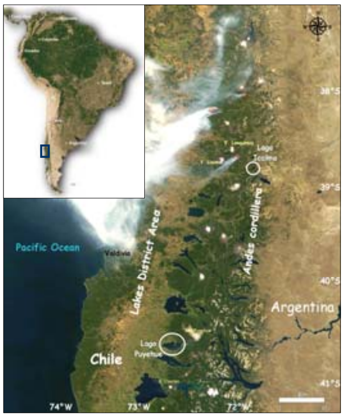
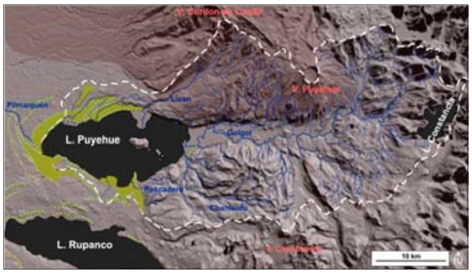
SETTING AND DATA



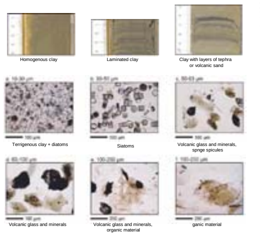
LAKE DISTRICT
South-Central Chile, between 37ºS en 42ºS
17 medium to large lakes
piedmont lakes of glacial origin



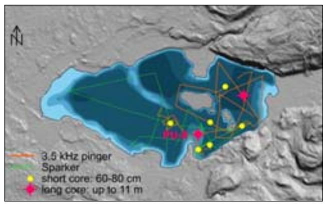
LAGO PUYEHUE: THE WATERSHED
Piedmont of the Cordillera de los Andes; Quaternary volcanics, covered by andosoils
Active volcanoes: Cordon de Caulle – Puyehue – Casablanca
Surface drainage basin: 1267 m2
Inflowing rivers: Golgol, but also Lican, Pescadero;
Outflowing river: Pilmaquen
Frontal moraines: Llanquihue glaciation

LAGO PUYEHUE: THE LAKE
Altitude: 185 m a.s.l.
Surface: 165 km2
Complex morphology with 3 main basins, underwater moraine ridges and islands
maximum depth: 123 m
precipitation: 2000 mm/yr (lake) to 5000 mm/yr (upper part of drainage basin)
oligotrophic, temperate monomictic

PU-II CORE: LITHOLOGY
homogeneous to laminated (varved)
mostly silt-sized sediment
terrigenous particles, diatoms and organic matter
78 tephra layers and weathered pumice layers = markers
instantaneous events (e.g. 1960 seismite)

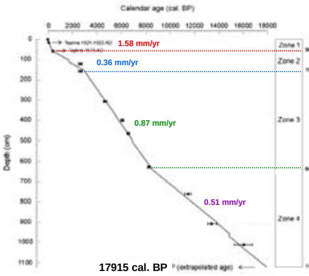


SEISMIC RECONNAISSANCE
135 km seismic profiles
Sparker: general overview of basin structure and stratigraphy
3.5 kHz pinger profiles: detailed analysis of stratigraphy

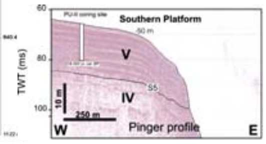


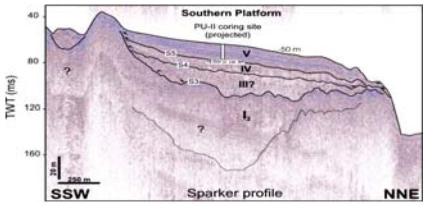
PU-II CORING
6 short cores (< 1 m)
2 long cores (> 11 m): long-record
PU-I = terrigenous input from Golgol
PU-II = background sedimentation
PU-I: poor recovery due to gas
PU-II: 11.22 m

AGE MODEL



PU-II CORE: AGE MODEL
9 AMS ^{14}C on bulk sediment
4 zones with uniform sedimentation rates
correction for instantaneous events
Supported by: ^{210}Pb – ^{137}Cs
Supported by varve counting for upper 600 yrs
Extrapolated age of base of core: 17915 cal yr BP





PU-II CORE versus SEISMIC STRATIGRAPHY
core does not reach base of unit V
extrapolated age for base of unit V (same open lacustrine environment): 24750 cal yr BP
base of unit IV (open lacustrine, glacier-fed environment): > 28000 cal yr BP
In conflict with onshore evidence for a deglaciation at 17500 cal yr BP !!

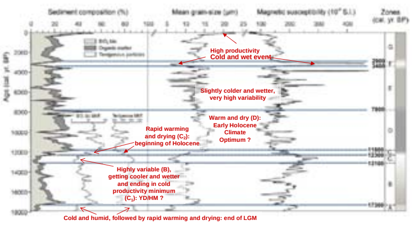
PROXIES

MULTIPROXY ANALYSIS OF CORES
Terrigenous proxies:
- magnetic susceptibility (MS)
- gamma density
- LOI105 (water content), LOI550 (organic matter), LOI950 (inorganic carbonate)
- grain size (laser)
- bulk and clay mineralogy (X-ray diffraction)
- geochemistry: major elements (X-ray fluorescence): SiO_2, TiO2 and Al2O3
- TOC, TON, $\delta^{13}C$ of organic matter

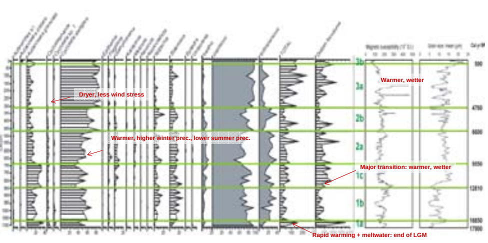
Biological proxies:
- diatoms
- pollen

Validity of proxies tested on short cores (1 cm sampling)
- **MS reflects volcanic material = measure for terrigenous supply**
- **grain size reflects diatoms = measure for diatom productivity**
- **mineralogy: mostly amorphous, cfr. andosoil mineralogy in catchment**
- **$SiO_{2\,bio}$ and OM from in-lake sources = measure for lake productivity**

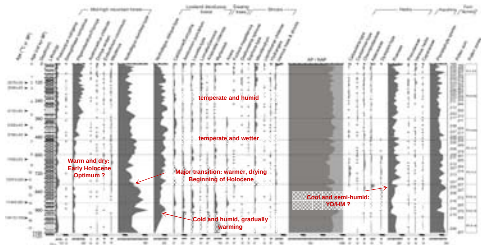
THE LONG-TERM RECORD



MINERALOGICAL/TERRIGENOUS PROXIES
Two rapid warming/drying steps: at 17300 cal yr BP and between 12300 and 11800 cal yr BP
Cold, productivity minimum between 13100 and 12300 cal yr BP: Huelmo-Mascardi Event ?
Warm and dry period between 11800 and ~ 8000 cal yr BP: Early Holocene Optimum
Highly variable period between ~ 8000 and 3400 yr BP



DIATOMS
Base of core (17900 cal yr BP) = open lacustrine environment, i.e. basin is deglaciated
Rapid warming between 17900 and 16850 cal yr BP
No cold reversal
Major transition at 12800 cal yr BP

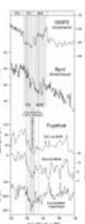


POLLEN
Cold and humid at 17900 cal yr BP, gradually warming until 14000 yr BP
Cooling spell between ~ 13000 and 11600 cal yr BP: Huelmo-Mascardi Event ?
Major warming and drying transition at 11600 cal yr BP
Warm and dry period between 11600 and ~ 8000 cal yr BP: Early Holocene Optimum

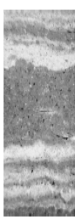
LONG-TERM RECORD: SUMMARY

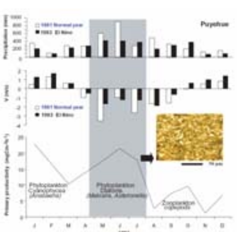
Multiproxy analysis of 11.22 m long core from Lago Puyehue shows:

- Sedimentary record is (much) older than previously believed
- Rapid warming at 17300 cal yr BP: end of LGM, but the lake was already deglaciated well before that time
- Some indications for a Late-Glacial cold reversal at 13100-12300 cal yr BP: in timing in between northern-hemisphere Younger Dryas and Antarctic Cold Reversal, but more or less coeval with Huelmo-Mascardi event from Chile and Argentina
- Rapid warming at 12300-11800 cal yr BP
- Early Holocene Climate Optimum
- Strong climate variability in middle Holocene



THE LAST 600 YEARS



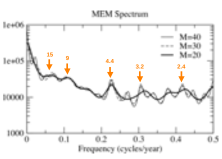


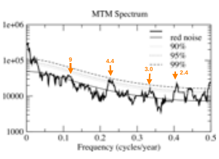
PU-II: VARVES
Upper 592 years are laminated: couplets of light layer (diatoms) and dark layers (terrigenous/organic material)

Laminations are annual = supported by ^{210}Pb and ^{137}Cs and event deposits (e.g. 1960 seismite): varves

Total varve thickness is related to (austral) winter precipitation: normal winter years are characterized by high precipitation and thick varves

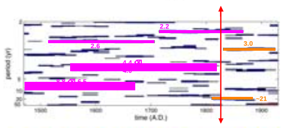
Several varve thickness intervals: significantly dryer period at 1408-1510 AD (Medieval Warm Period?), and significantly wetter periods at 1630-1730 AD and 1920-1950 AD (confirmed by instrumental records). From around 1820-1840 AD onwards, the varve thickness indicates stronger inter-annual variability in precipitation.



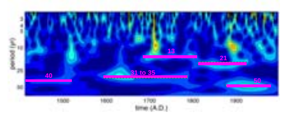


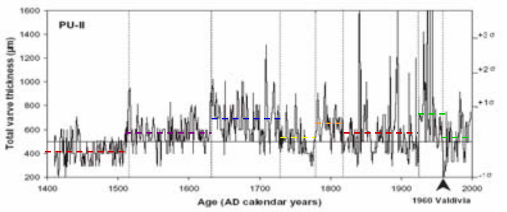
SPECTRAL ANALYSIS
- Spectral estimate of the varve thickness series by the maximum entropy method (MEM). Most robust peaks are at 15, 9, 4.4, 3.2 and 2.4 years.
- Multi-taper method (MTM) spectrum of the varve thickness series. Most significant periods are 2.4, 3.0 and 4.4 years, which are typical QBO (Quasi-Biennial Oscillation) and ENSO periodicities.

SPECTRAL ANALYSIS
Evolutive MTM spectrum of the varve thickness series. Only the period at 90 % significance level or higher are displayed. Dark lines indicate the time interval (X-axis) over which a periodicity (Y-axis) is identified. A distinct change in periodicity occurs at 1820 AD.



Wavelet analysis of the varve thickness series. Periodicities of 13, 21, 35 and 50 years could point to a link with PDO (Pacific Decadal Oscillation).





SHORT-TERM RECORD: SUMMARY

Varve analysis from top 592 yr of annually laminated sediments shows:
- Periods with either reduced (MWP?), enhanced or highly variable winter precipitation.
- Decadal PDO-periodicities and typical QBO and ENSO periodicities

*The ENSO-CHILE project (EV/02/10A) is supported by the Belgian **SSTC** (Federal Office for Scientific, Technical and Cultural Affairs).*