Last Glacial Maximum
CLIMAP Project

• CLImate MApping and Prediction Project
• Interdisciplinary cooperative effort
• reconstruct the surface of the earth during the LGM.
  – Primary focus marine sediments
  – Terrestrial realm
  – Climate modeling
Today: 14.2 million km² (~3% earth surface, 10% of the continents)
LGM: 35 million km² (7% earth surface, 25% of the continents)
Laurentide Ice Sheet

A Ice sheet extent

C Thin ice

Ice elevation (km)
- < 1
- 1 – 2
- 2 – 3
- > 3
Loess and Dust

A Sand dunes active today

B Sand dunes active at glacial maximum
Model Simulations of LGM Climates

A Modern winters

B Glacial winters

- Sea ice
- Ice sheets
- Surface winds
- Jet stream
Climate Changes
Fig. 3. Pollen percentage diagram of selected taxa from Carp Lake Cores 90 and 93. *Pinus* includes Diploxylon-type pollen (black curve) from *P. contorta* and Haploxylon-type pollen (striped curve) from *P. monticola* or *P. albicaulis*. Shaded pattern shows 5× exaggeration.
B  Glacial winters

- Sea ice
- Ice sheets
- Surface winds
- Jet stream
Distribution of spruce pollen

A Modern, observed

B Glacial, observed

C Glacial, simulated

< 1%  1 – 5%  5 – 20%  > 20%
Glacial Tropics?

• Differing observations
  – CLIMAP
    • average 1-2C cooler than today
    • Southern Subtropical Pacific 1C warmer
    • Localized coolings 3C in areas of wind-driven upwelling
  – Other evidence
    • Land temperatures 4-6C cooler than today
Solar radiation changes vs today
(W/m²)

Years ago

CO₂ (ppm)

Ice sheets (% of maximum size)

Winter

Summer

CO₂

Ice
Evidence for Small Tropical Cooling
Evidence for Large Tropical Cooling

Andes today

Last glaciation

Elevation (km)

Grasslands

Forest

Ice

600-1000 meters
Table 1: Pollen from Mera forest bed compared with modern pollen spectra

<table>
<thead>
<tr>
<th></th>
<th>Conru (2,800 m)</th>
<th>Yambo (2,600 m)</th>
<th>Yaguarochocha (2,210 m)</th>
<th>S initiate (3,400 m)</th>
<th>Rum Tum (2,392 m)</th>
<th>Kumpack (700 m)</th>
<th>Añangucocha (230 m)</th>
<th>Puyo Bog (953 m)</th>
<th>Lago Agrio (330 m)</th>
<th>Sta Cecilia (330 m)</th>
<th>Mera (1,100 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Podocarpus</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Plamie</td>
<td>1.4</td>
<td>1.0</td>
<td>0.7</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Cecropia</td>
<td>0.7</td>
<td>2.3</td>
<td>0.4</td>
<td>3.4</td>
<td>4.8</td>
<td>3.4</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Ficus</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Urticaceae-Moraceae</td>
<td>36.8</td>
<td>27.3</td>
<td>14.0</td>
<td>37.7</td>
<td>70.0</td>
<td>13.7</td>
<td>0.9</td>
<td>0.9</td>
<td>2.3</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Compositae</td>
<td>1.7</td>
<td>2.3</td>
<td>2.4</td>
<td>5.7</td>
<td>4.3</td>
<td>1.5</td>
<td>6.3</td>
<td>2.7</td>
<td>0.3</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Planiago</td>
<td>3.8</td>
<td>2.0</td>
<td>1.6</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Rumex</td>
<td>8.3</td>
<td>1.0</td>
<td>1.6</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Chen-Am</td>
<td>1.7</td>
<td>8.7</td>
<td>7.8</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>27.4</td>
<td>5.7</td>
<td>57.8</td>
<td>22.7</td>
<td>1.3</td>
<td>2.7</td>
<td>10.6</td>
<td>2.7</td>
<td>1.7</td>
<td>1.6</td>
<td>13.6</td>
</tr>
<tr>
<td>Monolete</td>
<td>0.7</td>
<td>2.0</td>
<td>0.8</td>
<td>11.3</td>
<td>2.3</td>
<td>2.7</td>
<td>10.6</td>
<td>2.7</td>
<td>1.7</td>
<td>2.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Trilete</td>
<td>0.9</td>
<td>3.0</td>
<td>2.4</td>
<td>5.0</td>
<td>0.3</td>
<td>2.3</td>
<td>5.0</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Others</td>
<td>12.5</td>
<td>31.9</td>
<td>18.7</td>
<td>29.6</td>
<td>11.6</td>
<td>21.0</td>
<td>27.3</td>
<td>19.5</td>
<td>18.9</td>
<td>14.3</td>
<td>53.2</td>
</tr>
</tbody>
</table>

Sites shown on Fig. 1. Añangucocha sample is from surface pinches of moist forest soil; Puyo Bog is surface organic matter of a tropical swamp; Rum Tum is mud from a small pond and Yaguarochocha is from just below the settlement layer of a sediment core to yield pollen from the Interandean Plateau before human disturbance. Remaining samples are from mud-water interfaces of lakes. We distinguish >200 pollen taxa in Amazonian fossil pollen samples, although many of these cannot yet be given taxonomic names. We have included as ‘others’ many identifiable, but infrequent pollen types as well as a considerable number of tricolporate and tricolpate taxa yet to be identified. We have also combined subdivisions of other taxa like Moraceae and Urticaceae.

Andean Pollen

Liu and collinvaux, 1985

Modern upper limit Amazon Rainforest
Reconciliation of Data?

Critics Small Cooling
- Plankton sensitive to cool temperatures
- Food more important limitation
- Pacific Ocean difficult to apply CLIMAP methods to
  - (dissolution of carbonates)

Critics Large Cooling
- Alteration of lapse rate in drier climate
  - 9.8°C/km
- Poor dating of mountain glaciers
  - Could be from older cooler and wetter times
- Veg movement result of lower CO₂