Advances in Climate Science through the pages of the QJ

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Nils Gustaf Ekholm (QJ 1901)

On the variations of the climate of the geological and historical past and their causes.

"This paper is presented to the Royal Meteorological Society at its Jubilee on April 3, 1900, as a humble expression of homage and gratitude by the author."

Contents.

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction—On the general causes of changes of temperature</td>
<td>2</td>
</tr>
<tr>
<td>2. Geological chronology—The probable duration of life on the earth</td>
<td>7</td>
</tr>
<tr>
<td>3. The radiation of the sun nearly constant during geological ages—The temperature of the earth’s surface explained by the equilibrium between insolation and radiation from the earth into space</td>
<td>14</td>
</tr>
<tr>
<td>4. Variations in the amount of carbonic acid of the atmosphere are the principal causes of the great climatic variations during geological ages</td>
<td>20</td>
</tr>
<tr>
<td>5. The secular cooling of the earth is the principal cause of the variations in the amount of carbonic acid in the atmosphere—Modifying influences</td>
<td>27</td>
</tr>
<tr>
<td>6. Variations of the obliquity of the ecliptic and their influence on climate</td>
<td>36</td>
</tr>
<tr>
<td>7. Climatic variations during historical times, particularly in North-Western Europe</td>
<td>46</td>
</tr>
<tr>
<td>8. Conclusion—Probable variations of the climate in the future</td>
<td>60</td>
</tr>
</tbody>
</table>
Ice Age might possibly occur. But here we find a remarkable circumstance that has hitherto been unexampled in the history of the earth. This is the influence of Man on climate. In fact, we have seen that the present burning of bituminous coal is so great that in one year it灼烧s back to the atmosphere about one-tenth of its present store of carbonic acid. If this continues for some thousand years it will undoubtedly cause a very obvious rise of the mean temperature of the earth. Also Man will no doubt be able to increase the supply of carbonic acid also by digging of deep fountains pumicing out carbonic acid. Further, it might perhaps be possible for Man to diminish the consumption of carbonic acid by protecting the weathering layers of silicates from the influence of the air and by controlling the growth of plants according to his wants and purposes. Thus it seems possible that Man will be able efficiently to regulate the future climate of the earth and consequently prevent the arrival of a new Ice Age. By such means also the deterioration of the climate of the northern and Arctic regions, depending on the decrease of the obliquity of the ecliptic, may be counteracted. It is too early to judge of how far Man might be capable of this regulating of the future climate, but he cannot help thinking that it will afford to Mankind hitherto unforeseen means of evolution.
Guy Stewart Callendar (QJ 1938)
collated $T_s$ measurements

Fig. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930, °C.
Figure 1. Comparison of historical reconstructions of near-global land temperatures using CRUTEM4 (black: Jones et al., 2012) with results of Callendar (1938) (red) and Callendar (1961) (blue), using a reference period of 1880–1935. The CRUTEM4 estimates are for 60°S–60°N (to accord with Callendar’s series), with grey shading representing 95% uncertainty.
**THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE**

TABLE VI.—Increase of mean temperature from the artificial production of carbon dioxide.

Annual excess of CO$_2$ to the air = 4,300 million tons.
P (CO$_2$) is expressed in units of a ten-thousandth of an atmosphere.
$\Delta T$ = increase from mean temperature of 19th century.
Sea water equilibrium time 2,000 years.

<table>
<thead>
<tr>
<th>Period</th>
<th>1910-1930</th>
<th>20th century</th>
<th>21st century</th>
<th>22nd century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean $P$ (CO$_2$)</td>
<td>2.82</td>
<td>2.92</td>
<td>3.30</td>
<td>3.60</td>
</tr>
<tr>
<td>Mean $\Delta T$. $^\circ$C</td>
<td>+0.07°</td>
<td>+0.16°</td>
<td>+0.39°</td>
<td>+0.57°</td>
</tr>
<tr>
<td>Polar displacement of climate zones</td>
<td>15</td>
<td>36</td>
<td>87</td>
<td>127km</td>
</tr>
</tbody>
</table>
Manley (QJ 1974)

Central England temperatures 1659-1973

decadal running averages

Series updated to present: Hadley Centre Central England Temperature (HadCET) dataset longest instrumental record of temperature in the world
Fig. 4.—The approximate distribution of atmospheric absorption for 1 cm. pp. water.
"At the surface of the Earth the average temperature would rise by 3.6°C if the CO₂ concentration were doubled and would fall by 3.8°C if it were halved"
Goody (QJ 1952)

A Statistical Model for Water Vapour Absorption

Assumption that spectral lines distributed randomly

Lorentz lineshape

Line strength distribution

\[ P(k) = \frac{1}{\sigma} \exp \left( -\frac{k}{\sigma} \right) \]

Results in band transmission

\[ \bar{T}(\alpha, m \sigma) = \exp \left[ -\frac{m \sigma \alpha}{\delta \left( \alpha^2 + \frac{m \sigma \alpha}{\pi} \right)^{1/2}} \right] \]

\( m \) absorber amount  \( \alpha \) mean line width  \( \sigma \) mean line strength  \( \delta \) mean line spacing
Rodgers and Walshaw (QJ 1966)
The computation of infra-red cooling rate in planetary atmospheres

Estimates and approximations:

• Height integration using pre-calculated Curtis Matrix.
• Frequency integration using broad band models - using knowledge of spectral line properties and distributions (e.g. Goody random model).
• Path integration using Curtis-Godson approximation.
• Water vapour, ozone and carbon dioxide.
• Assessment of accuracy of cooling-to-space approximation.
Rodgers and Walshaw (QJ 1966)

Solid line: LW radiative heating rate
Dashed line: Cooling-to-space approximation

CO₂

O₃

H₂O (trop)

Cooling rate (°C/day)

ρ (mb)

1

10

100

1000
Edwards and Slingo (QJ 1996)
A flexible new radiation code

**TABLE 2. The band structure, the gases included, and the number of ESFT terms for versions C and D (see text) of the 9-band long-wave spectrum (after Woodward et al., personal communication)**

<table>
<thead>
<tr>
<th>Band</th>
<th>Wave numbers (cm(^{-1}))</th>
<th>(\text{H}<em>2\text{O}</em>{(l+f)})</th>
<th>(\text{H}<em>2\text{O}</em>{(s)})</th>
<th>(\text{CO}_2)</th>
<th>(\text{O}_3)</th>
<th>(\text{CH}_4)</th>
<th>(\text{N}_2\text{O})</th>
<th>CFC11</th>
<th>CFC12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0–400</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>400–550</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>550–800</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>800–880</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>880–990</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>990–1120</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1120–1200</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1200–1500</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1500–3000</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Two-stream approach for LW & SW.
- ESFT frequency integration - resolution flexible.
- Various applications, multiple gases.
- SW scattering by cloud.

The subscript \((l+f)\) refers to lines plus the foreign-broadened continuum, while the subscript \((s)\) refers to the self-broadened continuum.
Phillips (QJ 1956)

The general circulation of the atmosphere: a numerical experiment

- Two-level quasi-geostrophic model
- Single hemisphere
- Friction, radiative heating, vertical stability specified

“One of the main purposes of this numerical experiment was the investigation of the energetics of the atmosphere”

“furnishing valuable experience in the numerical problems to be encountered in making long-range predictions”
Phillips (QJ 1956)

Figure 11. Variation with latitude (j) and time of the mean meridional velocity, $V_m$, in the upper half of the atmosphere. Units are cm sec$^{-1}$.

Figure 14. Variation of $\bar{u}$, at 1,000 mb with latitude (j) and time. Units are m sec$^{-1}$.

zonal wind at surface

meridional wind in upper level

Evolution over first 30 days
Equations derived for all these terms. Evaluated during integration.

Figure 3. Energy flow diagram. The flow of energy is in the direction of the arrow if the associated transformation \( \{ \cdot \} \) is positive. The numerical computations give positive values for all the transformations except \( \{ \bar{P} \cdot \bar{K} \} \).
Radiative heating rate $H$ determined from measurements of the mean non-adiabatic processes in the atmosphere

One conclusion:

the latitude of maximum $\frac{\partial T}{\partial y}$ in the atmosphere may be determined to some extent dynamically, and not merely by the latitudinal gradient in radiation
\[ \frac{dT}{dC} = \left( \frac{dT}{dF_N} \right) \left( \frac{dF_N}{dC} \right) \]

\[ = \left( \frac{\partial T}{\partial F_N} \right) \left( \frac{\partial F_N}{\partial C} \right) \left\{ 1 - \left( \frac{\partial T}{\partial F_N} \right) \sum_{i=1}^{n} \left( \frac{\partial F_N}{\partial u_i} \right) \left( \frac{du_i}{dT} \right) \right\}^{-1} \]

\( T \) surface temperature  
\( F_N \) downward flux TOA  
\( C \) CO\(_2\) concentration  
\( u_i \) climate parameter

see also Ray Bates (QJ 2007) on definition of climate feedback
Garth Paltridge - climate feedbacks

cloud feedback (QJ 1980) u_i:
1D RT model liquid water path
cylindrical level cirrus cloud amount
3 cloud levels low cloud amount
R&W LW scheme total cloud amount

Conclusion: cloud reduces sensitivity of climate to increased CO$_2$

rainfall-albedo feedback (QJ 1991) via change in land surf vegn
dT for double CO$_2$:
4.16 K w/o this fbk
4.58-6.38 K inc this fbk
<table>
<thead>
<tr>
<th>Mechanism</th>
<th>$f_i$</th>
<th>$dT(K)$ (from Eq. (3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Water vapour amount</td>
<td>0.445</td>
<td></td>
</tr>
<tr>
<td>Water vapour distribution</td>
<td>0.216</td>
<td></td>
</tr>
<tr>
<td>Lapse rate</td>
<td>-0.264</td>
<td></td>
</tr>
<tr>
<td>Surface albedo (sea-ice)</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>Cloud height</td>
<td>0.123</td>
<td></td>
</tr>
<tr>
<td>Cloud cover</td>
<td>0.101</td>
<td></td>
</tr>
<tr>
<td>Total $f$ of GISS model</td>
<td>0.712</td>
<td>4.16</td>
</tr>
<tr>
<td>Rainfall–albedo ($f_n$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Case A)</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>(Case B)</td>
<td>0.026</td>
<td></td>
</tr>
<tr>
<td>Total $f$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Case A)</td>
<td>0.812</td>
<td>6.38</td>
</tr>
<tr>
<td>(Case B)</td>
<td>0.738</td>
<td>4.58</td>
</tr>
</tbody>
</table>
Previdi et al (QJ 2013)

Review Article: Climate sensitivity in the Anthropocene

[Diagram showing climate sensitivity with axes for $2\times CO_2$ sensitivity (°C) and time to reach equilibrium (years).]
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