The hydrological cycle on a greenhouse Earth—different from today

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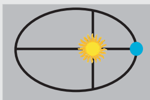
Session: Ocean-Continent-Cryosphere
Interactions: Past and Present
Sub-Theme: Pre-Pleistocene

① Introduction:

Comparison of numeric simulations of the present day "icehouse" and Late Cretaceous "greenhouse" climates suggests not only an enhanced hydrological cycle but a relation between surface and subsurface runoff very different from today.
Surface runoff was less in the Cretaceous, but subsurface and total runoff were much greater. These differences reflect the changes in distribution of land between the northern and southern hemispheres, but more importantly they reflect changes in the way the climate system operated. Snowmelt and intense spring storms are responsible for surface runoff maxima in both the present day and Cretaceous simulations. The Cretaceous simulations show a strong increase of the total volume and fluxes within the hydrological cycle and in subsurface runoff which includes both short term percolation through soils and long term groundwater fluxes.
These changes in the hydrological cycle have significant implications for the geologic record. Chemical weathering is enhanced in greenhouse times while mechanical weathering becomes important in icehouse times.

② Boundary conditions for GCM (GENESIS v.2.0):




Paleogeography - Earliest Turonian (Balukhovsky et al., 2004)

Eccentricity: 0.05
Obliquity: 23.5
Precession: 90

CO_2: 1882 ppm (6 x present value)
Solar constant: 1337.0 W/m^2
Heat transport: 2 x present value
Ocean salinity: -not specified-
Vegetation type: broadleaf trees with groundcover; -savanna-
Soil module: sand: 51%; silt: 29%; clay: 20%
Grid resolution: 2° x 2°

③ Total river runoff, surface - and subsurface runoff:

a

Present day (GENESIS)	Total land area	Northern Hemisph.	Southern Hemisph.	Europe	Asia	Africa	N-America	S-America	Australia
Drainage area (10^6 km^2)	157.98	107.05	50.93	12.04	45.83	33.43	22.70	19.07	8.27
Total runoff [km^3/yr] (=river discharge to the ocean)	34,528	23,947	10,277	2,212	13,109	5,890	5,862	5,953	207
Surface runoff [km^3/yr]	9,654	7,776	472	819	4,804	60	2,782	272	6
Subsurface runoff [km^3/yr]	24,874	16,171	9,805	1,393	8,305	5,830	3,081	5,682	201
Total runoff/Area [10^6 km/yr]	218.56	223.70	201.79	183.72	286.04	176.19	258.24	312.17	25.03
Surface runoff/Area [10^6 km/yr]	61.11	72.64	9.27	68.02	104.82	1.79	122.56	14.26	0.73
Subsurf. runoff/Area [10^6 km/yr]	157.45	151.06	192.52	115.70	181.21	174.39	135.73	297.95	24.30

b

Late Cretaceous (GENESIS)	Total land area	Northern Hemisph.	Southern Hemisph.	Europe	Asia	Africa	N-America	S-America	Australia
Drainage area (10^6 km^2)	128.29	54.56	73.70	5.60	31.40	26.86	13.92	18.80	9.73
Total runoff [km^3/yr] (=river discharge to the ocean)	46,370	19,863	26,507	2,832	9,813	9,801	7,269	4,315	4,929
Surface runoff [km^3/yr]	6,562	2,907	3,655	21	1,661	7	1,142	2	517
Subsurface runoff [km^3/yr]	39,808	16,956	22,852	2,811	7,153	9,794	6,128	4,313	4,412
Total runoff/Area [10^6 km/yr]	361.45	364.06	359.66	505.71	312.52	364.89	522.20	229.52	506.58
Surface runoff/Area [10^6 km/yr]	51.15	53.28	49.59	3.75	52.90	0.26	82.04	0.11	53.13
Subsurf. runoff/Area [10^6 km/yr]	310.30	310.78	310.07	501.96	227.80	364.63	440.23	229.41	453.44

Numerical model simulations of the present day "icehouse" and Cretaceous "greenhouse" climates suggests both an enhanced hydrological cycle during the Cretaceous and very different partitioning between surface and subsurface runoff.

In our present day simulations, global mean subsurface runoff (groundwater, ~24,874 km3/yr) is ~75% of total river discharge (~34,528 km3/yr) whereas ~25% of the total river discharge entering the sea today is surface runoff (~9,654 km3/yr) from snow melt and intense rainfall. Here, we present climate model data from a greenhouse analog showing a modified hydrological relationship, with subsurface runoff (~85%) strongly enhanced relative to surface runoff (~15%). In the model, this is due to both reduced snow accumulations and widespread slower rainfall, more evenly distributed throughout the year.

④ Results from GCM experiments:

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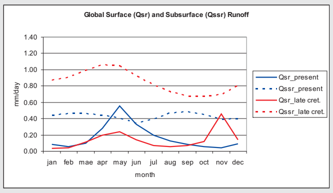

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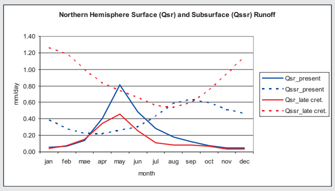

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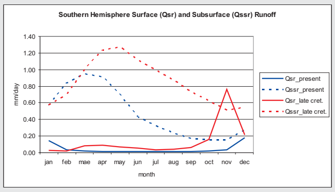
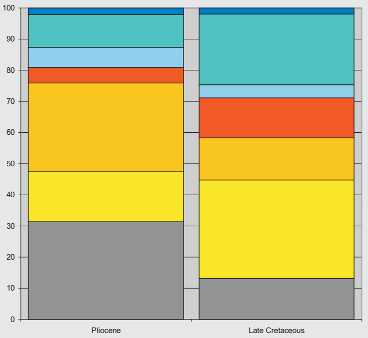


We investigated the sensitivity of the climate and hydrological system using numerical climate modeling. We performed a month-by-month analysis of a suite of sensitivity tests.
The amount and seasonal distribution of surface runoff drive both mechanical erosion and terrigenous biological activity. The amount and distribution of subsurface runoff is of importance for chemical erosion and subsurface dissolution.

During the Late Cretaceous, total river discharge is dominated by water from subsurface runoff importing the chemical characteristics of groundwater. These simulated changes in the hydrological cycle imply fundamental differences in weather during greenhouse versus icehouse climates, with enhanced chemical weathering in the former and increased mechanical weathering in the latter. During the Cretaceous, enhanced chemical weathering would have greatly increased nutrient input into epeiric and shelf seas with important implications for ocean productivity.

⑤ Late Cretaceous vs. Pliocene:



Relative proportions of different sediment types in the Late Cretaceous and Pliocene, based on the data of Ronov[24] (1993).

The Pliocene is the youngest unit for which detailed sediment data are available.

The Late Cretaceous data have been recalculated to take into account the loss of sediment on subducted deep sea floor. Carbonates make up abut 18% of the total Pliocene sediment volume, but are about 27% of the Late Cretaceous sediment volume. Non-marine sediments make up 32% of the Pliocene, but only 14% of the Late Cretaceous sediment, suggesting that accumulation on floodplains was much less. The total amounts of marine terrigenous sediment are similar, and the differences between the amounts shallow marine, hemipelagic and deep sea environments is largely a reflection of the greater sea-level fluctuations during the Pliocene.

⑥ In conclusion:

- Implications of enhanced subsurface runoff:

- **subsurface geological conduits play a critical role in ground water and nutrient supply (changes in ecology) to the margins of continents and islands -- therefore influencing sedimentation.**

- **total river discharge is dominated by water from subsurface runoff, importing the chemical characteristics of groundwater.**
- **enhanced chemical erosion due to a high flow rate which delivers permanently new water.**
- **enhanced chemical processes such as dissolution because they proceed more rapidly under high temperatures (e. g. acidity of rainwater).**

For additional information on model setup and boundary condition see:

Floegel, .S, Hay, W. W., DeConto, R. M., and Balukhovsky, A. (2005): Formation of sedimentary bedding couplets in the Western Interior Seaway of North America - Implications from Climate System Modeling. Palaeo3, 218, 1-2, 125/143.

Hay, W. W., Floegel, S, and Soeding, E. (2005): Is the initiation of glaciation on Antarctica related to a change in the structure of the ocean? Global and Planetary Change, 45, 1-3, 23-33.

Floegel, S. and Wagner, T. (in press): Insolation-control on the Late Cretaceous hydrological cycle and tropical African climate - global climate modeling linked to marine climate records. Palaeo3.