Accelerated Climate Change and Himalayan Glaciers

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Outline

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Back of the Envelope Physics of the Climate

Evidence of Accelerated Global Warming

Climate Simulation

Why study the Response of the Himalayan Glaciers ?

Physics of glaciers.

Glaciers in the Alakananda Basin

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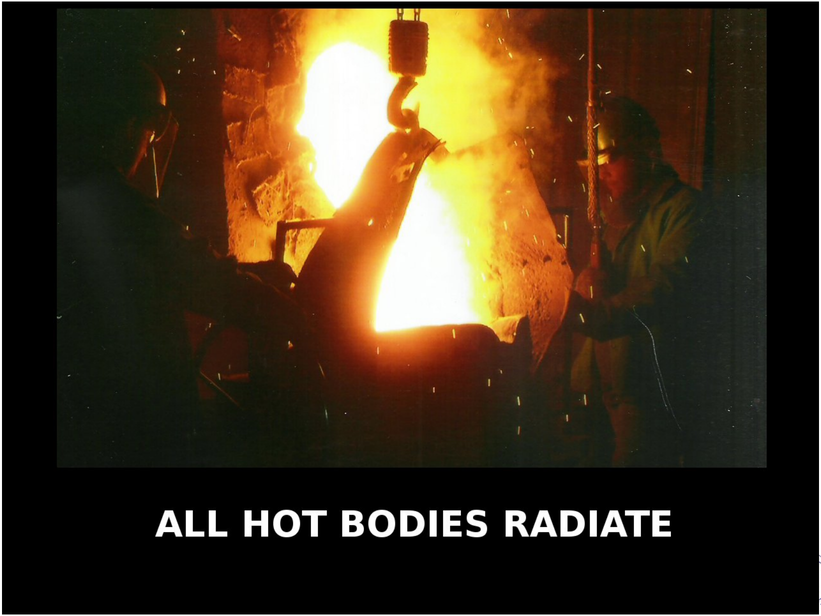
Climate and weather

- Climate is average weather.
- It is described by the mean and variation of TEMPERATURE, PRECIPITATION and WIND averaged over ~ 30*years*
- The climate has always been changing.
  The question is: “How rapidly ?"

Thermodynamics of the Sun and Earth

Black Body Radiation

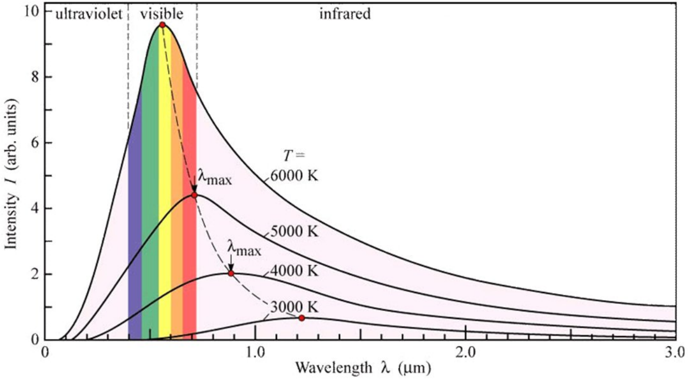
Black Body Radiation



Black Body Radiation

Planck's Law:

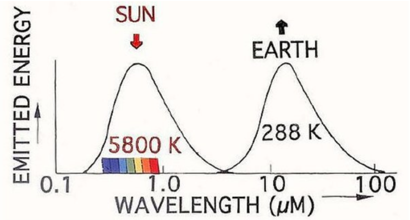
$$I(\nu, T) = \frac{2h}{c^2} \frac{\nu^3}{e^{\frac{h\nu}{kT}} - 1}$$



Black Body Radiation

Wien's Displacement Law:

$$T\lambda_{max} = 2.898 \times 10^6 \; nm \; K$$



Stefan-Boltzman Law:

$$E = \sigma T^4, \qquad \sigma = 5.67 \times 10^{-8} \; W \; m^{-2} \; K^{-4}$$

Hotter the body, the more it radiates.

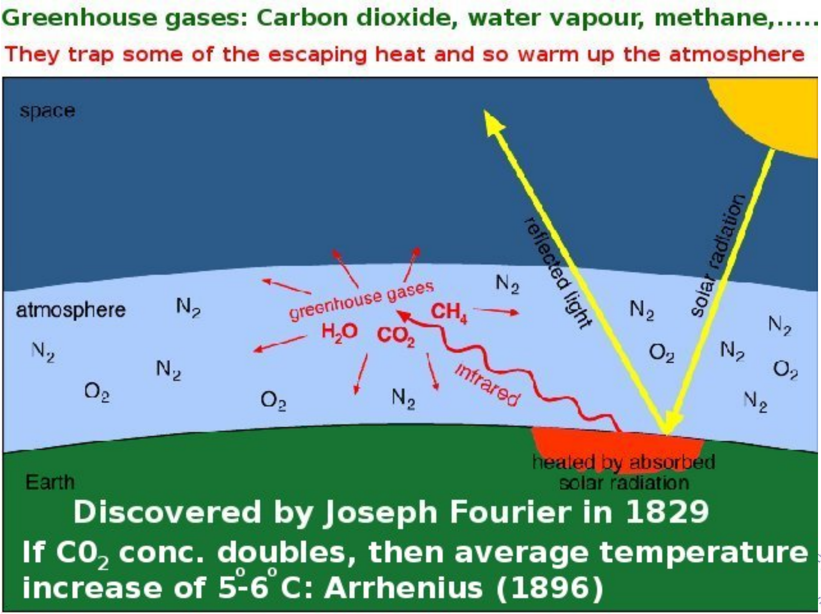
Temperature of the earth

Average temperature of the earth (Ref: Wikipedia, Black body):

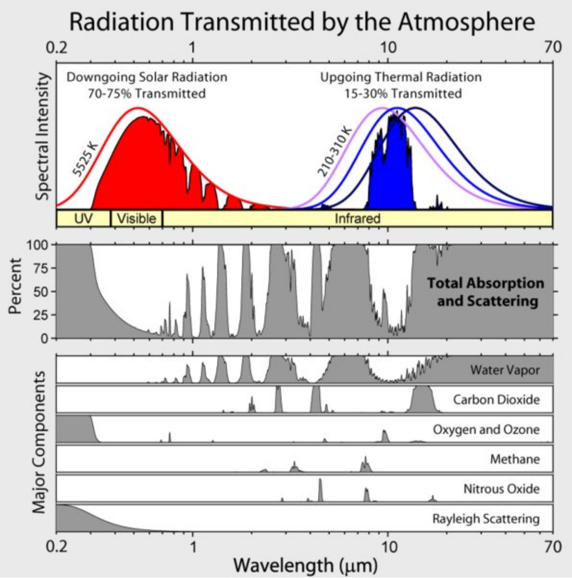
$$\begin{aligned} \text{Energy Flux from Sun} &= \text{Energy Radiated by Earth} \\ 235\ W/m^2 &= \sigma T_E^4 \\ T_E &= 254\ K\ \ (-19^\circ C) \end{aligned}$$

Measured average temperature of the earth is $287K = 14^\circ C$
The discrepency is mainly due to the Greenhouse Effect

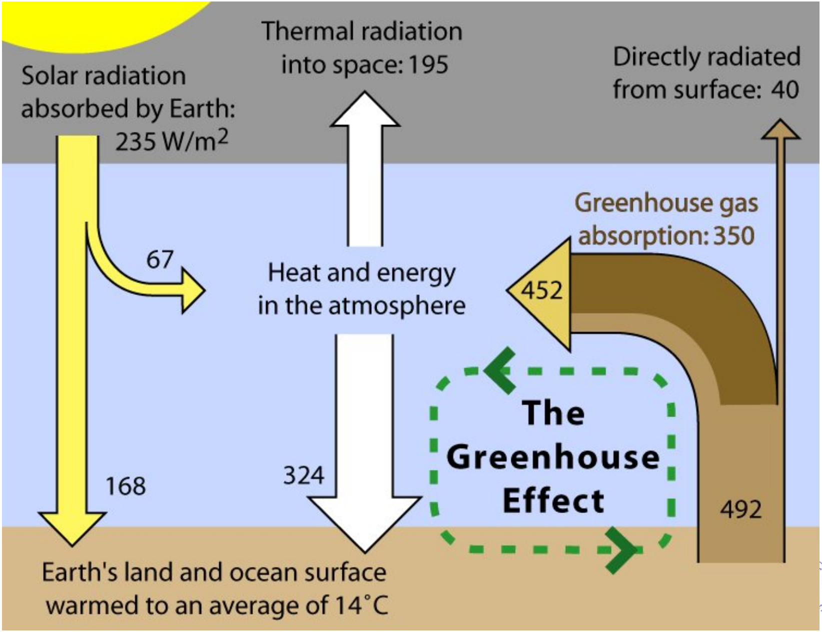
The Greenhouse Effect



The Greenhouse Effect



The Greenhouse Effect



Radiative Forcing

A few percent changes in the outgoing flux will result in measurable changes in temperature.

$$\begin{aligned} \frac{\Delta F_S}{F_S} &= 4\frac{\Delta T_S}{T_S} \\ \Delta T_S &= 0.15\Delta F_S \end{aligned}$$

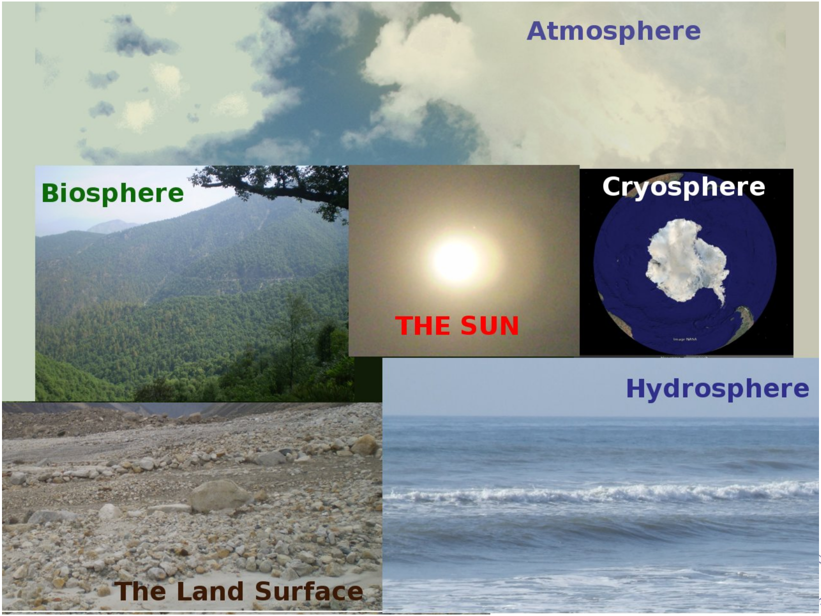
Radiative Forcing of some component (eg CO_2)$\equiv$ The change in energy flux at the top of the atmosphere caused by it.

Response to radiative forcing:

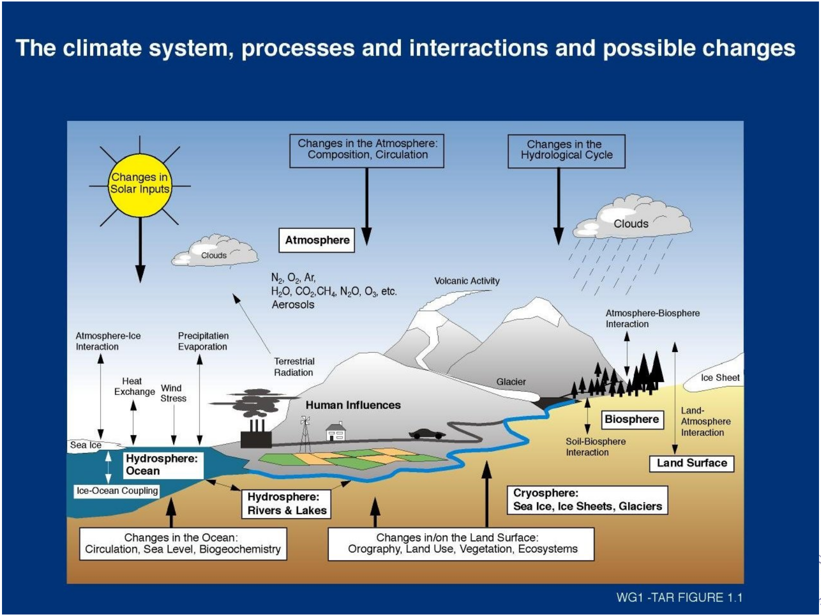
$$\Delta T_S = \lambda \Delta F_T$$

$\lambda = 0.5\ K/(W\ m^{-2})$, is believed to be a robust number.

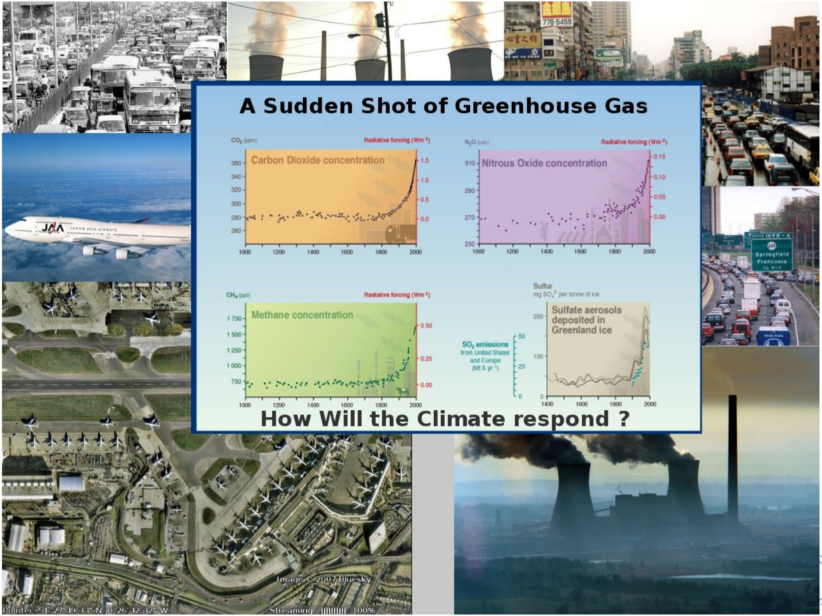
Components of Climate



Climate: A complex system



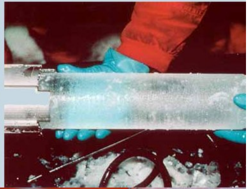
The Question



Outline

The Past Climate: Ice core analysis

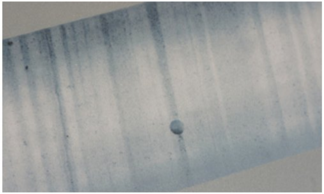
Close up of an ice core

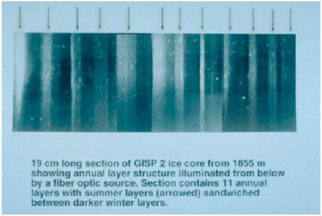


A laboratory in Antartica

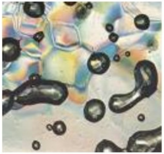
Removing the ice core from the drill

The Past Climate: Ice core analysis





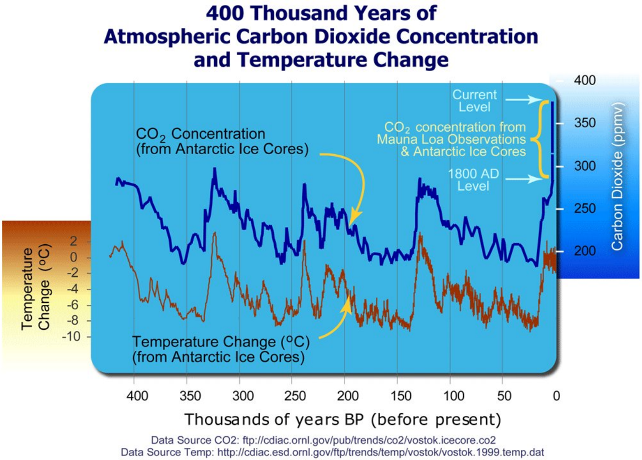
Striations in the ice core. Each layer corresponds to one year of ice.



Cross section of an ice core showing the trapped bubbles of air.

Chemical analysis of the trapped air bubbles gives the composition and the temperature of the atmosphere the time that ice layer was formed.

Past temperatures and CO_2 levels

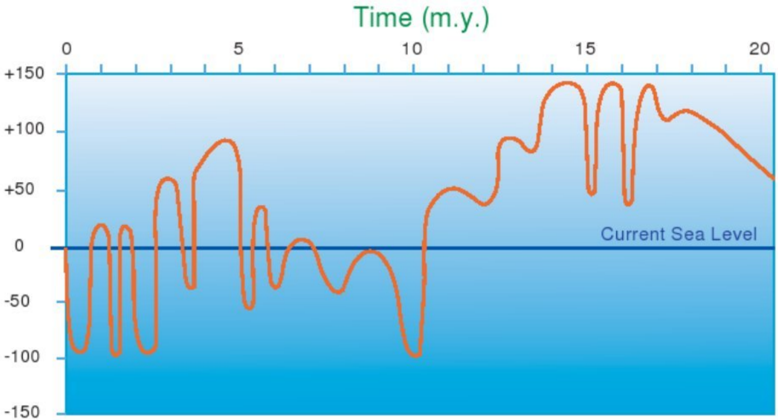


Maximum rate of warming in the past : 0.1 C/century

Maximum rate of CO_2 increase in the past: 10 ppmv/century

Maximum level of CO_2 in the past : < 300 ppmv

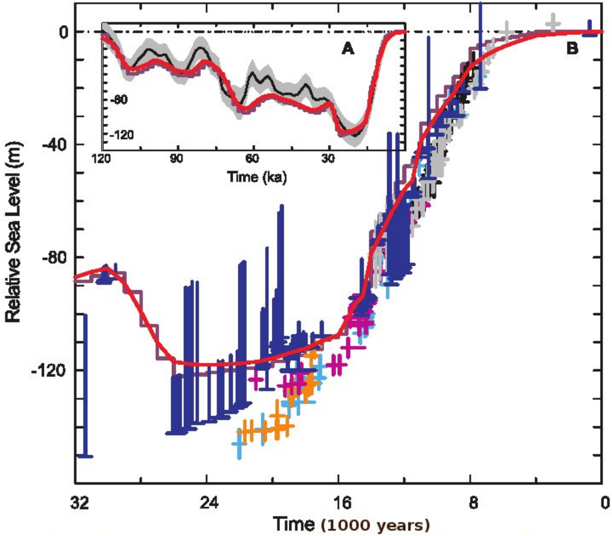
The Past Sea Level



Sea level fluctuations over last 20 million years.

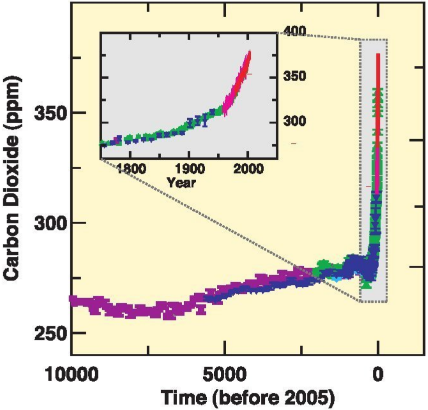
After the last ice age about 18000 years ago, the sea level has risen by 120m. i. e. 66 cm/century on the average.

The Past Sea Level



The rate of rise decreased to almost zero for the past 3000-2000 years till about 150 years ago

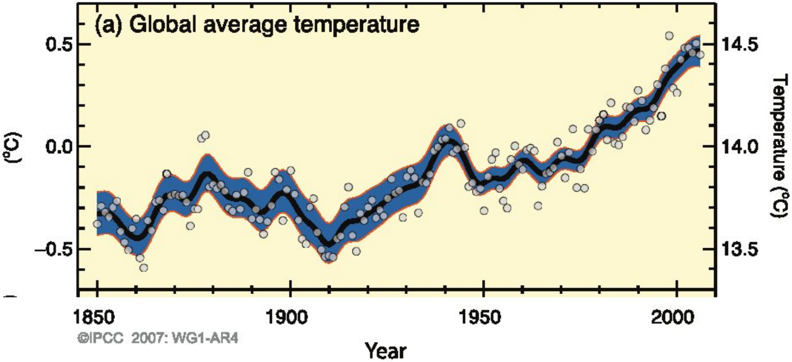
Recent Changes: CO_2 levels



CO_2 concentration today is 380 ppmv. It has never exceeded 300 ppmv in the past 650,000 years.

In the last century it increased by about 80 ppmv
Maximum rate of increase in the past: 10ppmv/century

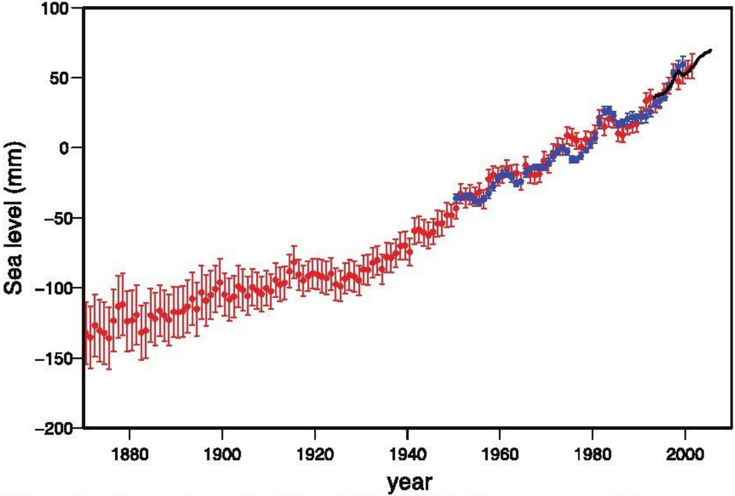
Recent Changes: Temperature



The average temperature rose by about 1 C in the last century.

The maximum rate in the past was about 0.1 C per century

Recent Changes: Mean Sea Level



After being steady for 2000-3000 years, the sea level has risen by about 20 cm in the last 150 years. Today it is rising at about 30 cm/century

Recent Changes: Indian Temperatures and Monsoon

भारत मौसम विज्ञान विभाग, पुणे

India Meteorological Department, Pune

Temperature

Analysis of data for the period 1901-2005 suggests that *annual mean temperature* for the country as a whole has risen to 0.51°C over the period. It may be mentioned that annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across the country, over a larger parts of the data set. However, since 1990, minimum temperature is steadily rising and rate of its rise is slightly more than that of maximum temperature.

Spatial pattern of trends in the mean annual temperature shows significant positive (increasing) trend over most parts of the country except over parts of Rajasthan, Gujarat and Bihar, where significant negative (decreasing) trends were observed.

All India monsoon rainfall

All India summer monsoon season (June to September) rainfall as well the rainfall for all the four monsoon months does not show any significant trend.

Recent Changes: Northern Indian Ocean Sea Level

Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates?

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Abstract

Mean-sea-level data from coastal tide gauges in the north Indian Ocean were used to show that low-frequency variability is consistent among the stations in the basin. Statistically significant trends obtained from records longer than 40 years yielded sea-level-rise estimates between 1.06–1.75 mm yr^{-1}, with a regional average of 1.29 mm yr^{-1}, when corrected for global isostatic adjustment (GIA) using model data. These estimates are consistent with the 1–2 mm yr^{-1} global sea-level-rise estimates reported by the Intergovernmental Panel on Climate Change.

Keywords: regional sea-level rise; mean-sea-level; tide gauge; north Indian Ocean

Recent Changes: Northern Indian Ocean Sea Level

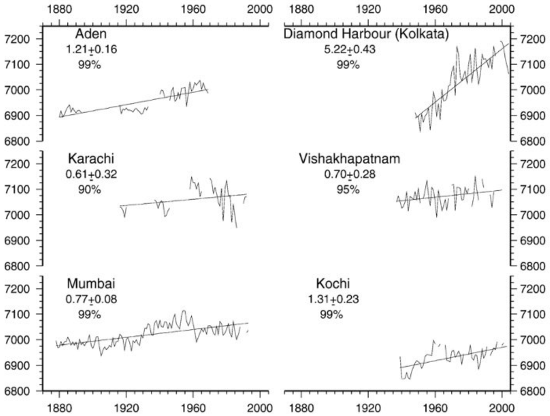

Fig. 3. Annual-mean sea-level and the linear fit for selected tide-gauge stations in the north Indian Ocean. The trends, standard deviation from a linear fit and confidence limit are also shown.

Outline

Climate Models

- 3d models of ocean circulation coupled with atmospheric circulation.
- Basic hydrodynamical equation: Navier-Stokes equations.
- Physics of many other processes input.

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Processes involved in Climate models

7. Physical Climate Processes and Feedbacks

Content

Climate models are complex

- 7.2.4.1 Radiative processes in the troposphere
- 7.2.4.2 Radiative processes in the stratosphere
- 7.2.5 Stratospheric Dynamics
- 7.2.6 Atmospheric Circulation Regimes
- 7.2.7 Processes Involving Orography

7.3 Oceanic Processes and Feedbacks

- 7.3.1 Surface Mixed Layer
- 7.3.2 Convection
- 7.3.3 Interior Ocean Mixing
- 7.3.4 Mesoscale Eddies
- 7.3.5 Flows over Sills and through Straits
- 7.3.6 Horizontal Circulation and Boundary Currents
- 7.3.7 Thermohaline Circulation and Ocean Reorganisations

7.4 Land-Surface Processes and Feedbacks

- 7.4.1 Land-Surface Parametrization (LSP) Development
- 7.4.2 Land-Surface Change
- 7.4.3 Land Hydrology, Runoff and Surface- Atmosphere Exchange

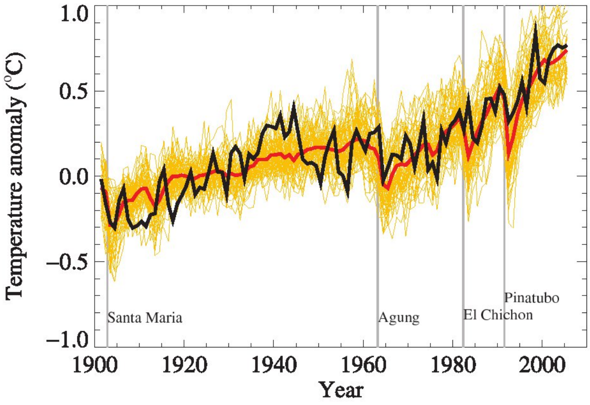
7.5 Cryosphere Processes and Feedbacks

- 7.5.1 Snow Cover and Permafrost
- 7.5.2 Sea Ice

Hierarchy of models

incomplete. Consequently, there is a continuing need to assist in the use and interpretation of complex models through models that are either conceptually simpler, or limited to a number of processes or to a specific region, therefore enabling a deeper understanding of the processes at work or a more relevant comparison with observations. With the development of computer capacities, simpler models have not disappeared; on the contrary, a stronger emphasis has been given to the concept of a 'hierarchy of models' as the only way to provide a linkage between theoretical understanding and the complexity of realistic models (Held, 2005).

How well do they reproduce the past data?

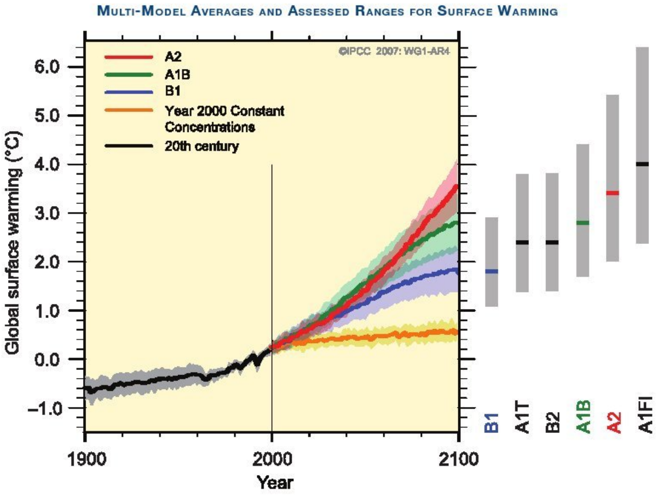


OBSERVATIONS

58 SIMULATIONS FROM 14 MODELS

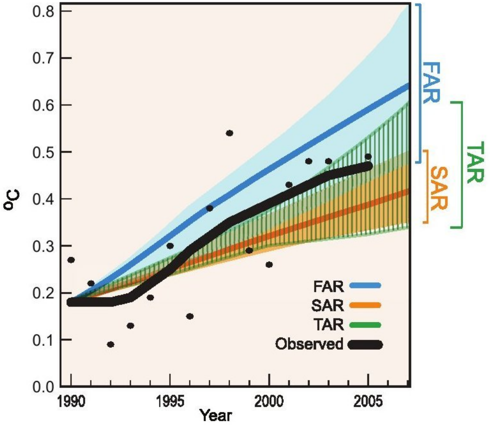
AVERAGE OF ALL THE SIMULATIONS

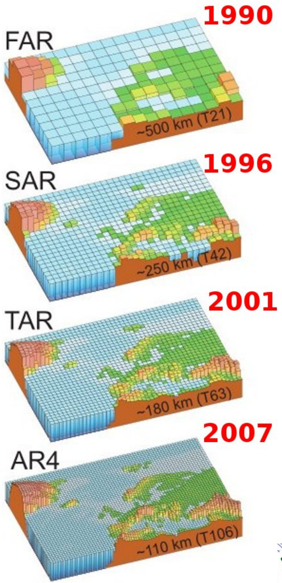
IPCC prediction: Temperature



HOW MUCH WARMING OCCURS IN THIS CENTURY DEPENDS ON HOW MUCH WE REDUCE OUR EMISSIONS

How good are the projections ?



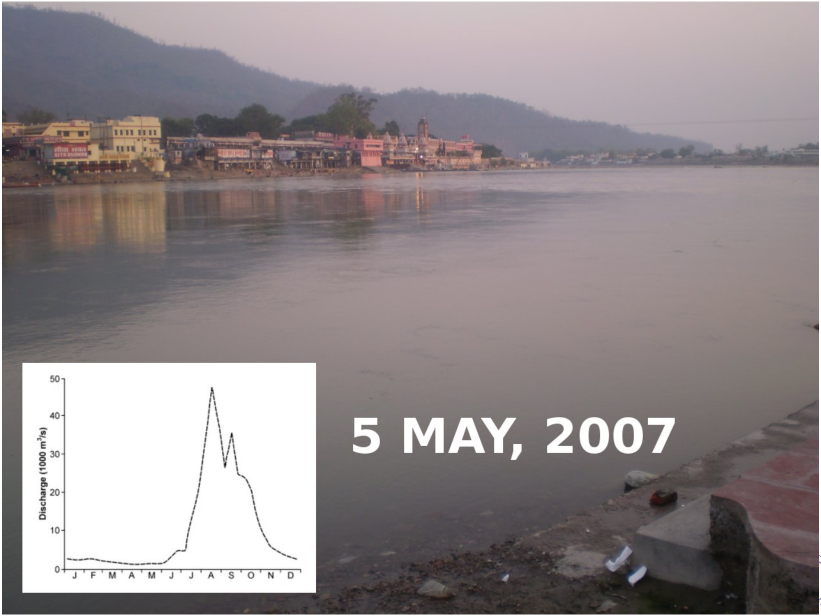


Outline

The Cryosphere

	Vol of ice (km^3)	Sea level rise (m)
Antartica	29528300	73.32
Greenland	2620000	6.55
Rest	180000	0.45

Effect on the Dry Season Runoff ?



Ganga, Aayee Kahan Se ?

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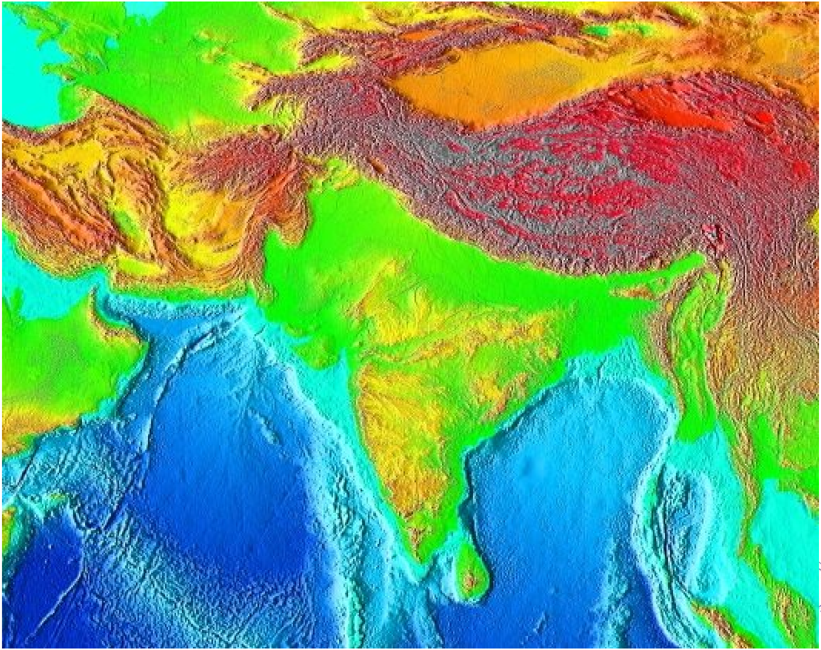
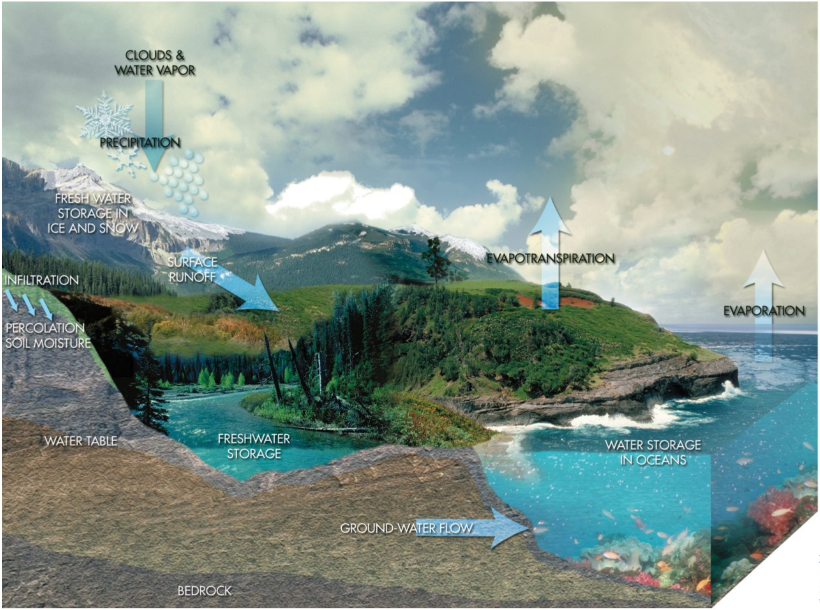


The Water Cycle



The Reservoir of Ice

The Reservoir of Lakes

The Reservoir of Ground Water

The Reservoir of Ground Water

Ice contribution: $\sim$ 25% ??

Response of Glaciers Worldwide

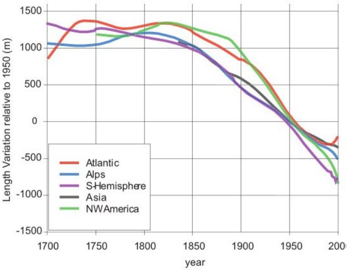


Figure 4.13. *Large-scale regional mean length variations of glacier tongues (Oerlemans, 2005). The raw data are all constrained to pass through zero in 1950. The curves shown are smoothed with the Stineman (1980) method and approximate this. Glaciers are grouped into the following regional classes: SH (tropics, New Zealand, Patagonia), northwest North America (mainly Canadian Rockies), Atlantic (South Greenland, Iceland, Jan Mayen, Svalbard, Scandinavia), European Alps and Asia (Caucasus and central Asia).*

August 13, 1941, by William O. Field	Muir Glacier	August 31, 2004, by Bruce F. Molnia

July of 1958 taken by Austin S. Post	McCall Glacier	August 13, 2003 by Matt Nolan.

Response of Glaciers Worldwide

Extracting a Climate Signal from 169 Glacier Records

J. Oerlemans

www.sciencemag.org SCIENCE VOL 308 29 APRIL 2005

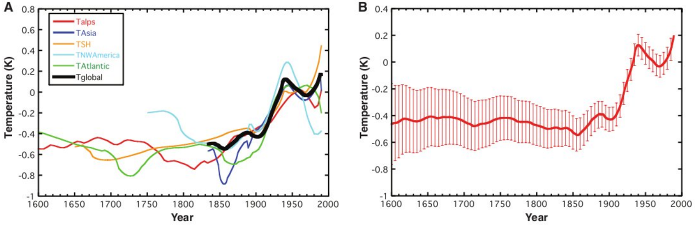
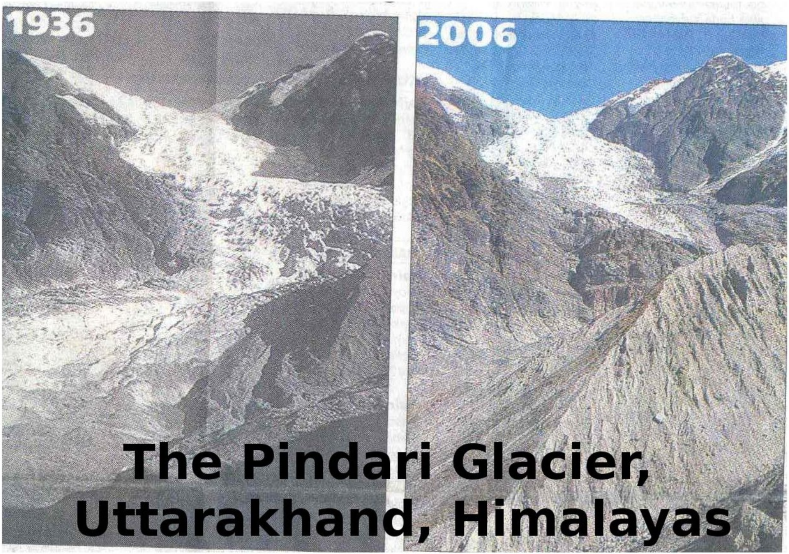


Fig. 3. (A) Temperature reconstruction for various regions. The black curve shows an estimated global mean value, obtained by giving weights of 0.5 to the Southern Hemisphere (SH), 0.1 to Northwest America, 0.15 to the Atlantic sector, 0.1 to the Alps, and 0.15 to Asia. (B) Best estimate of the global mean temperature obtained by combining the weighted global mean temperature from 1834 with the stacked temperature record before 1834. The band indicates the estimated standard deviation.

Response of Himalayan Glaciers



Response of Himalayan Glaciers

Glacial retreat in Himalaya using Indian Remote Sensing satellite data

Anil V. Kulkarni[1], I. M. Bahuguna[1], B. P. Rathore[1], S. K. Singh[1], S. S. Randhawa[2], R. K. Sood[2] and Sunil Dhar[3]

[1]Marine and Water Resources Group, Space Applications Centre, Indian Space Research Organization, Ahmedabad 380 015, India
[2]Himachal Pradesh Remote Sensing Cell, Shimla 171 009, India
[3]Department of Geology, Government College, Dharamsala 176 215, India

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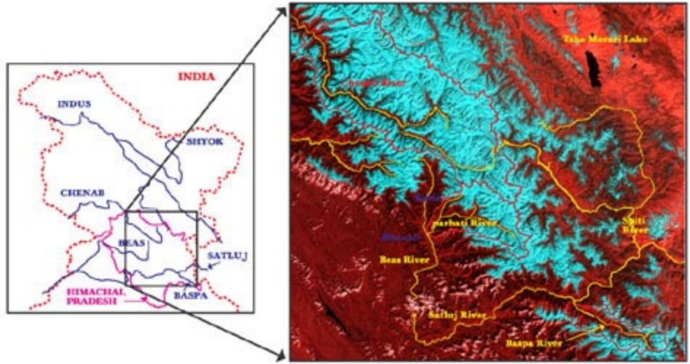


Response of Himalayan Glaciers

Response of Himalayan Glaciers

Table 3. Basin-wise loss in glacier area in Chenab, Parbati and Baspa basins

		Glacier area (sq. km)			Volume (cubic km)		
Basin	Glacier number	1962	2001–04	Loss (%)	1962	2001–04	Loss (%)
Chenab	359	1414	1110	21	157.6	105.03	33.3
Parbati	88	488	379	22	58.5	43.0	26.5
Baspa	19	173	140	19	19.1	14.7	23.0
Total	466	2077	1628	21	235.2	162.73	30.8

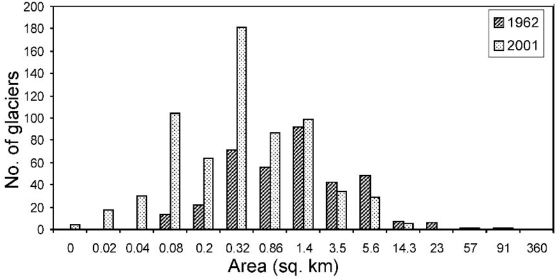
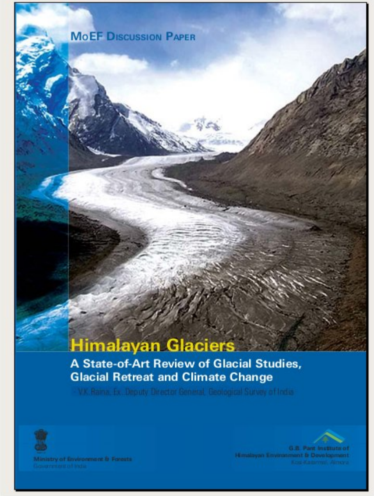


Figure 9. Number of glaciers as a function of area for Chenab basin. Areal extent in bin is increasing by a power of 2.

Response of Himalayan Glaciers

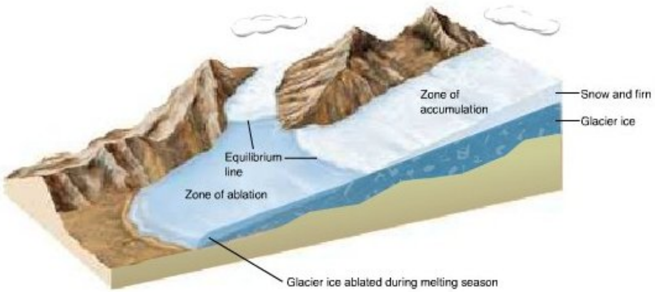


1. Glaciers in the Himalayas (India) have been exhibiting a continuous secular retreat since the earliest recording began around the middle of the nineteenth century. Kumdan glaciers, of the Upper Shyok valley, have been the only exception for their periodic fluctuations.

Average annual retreat of the glaciers, under observation, which generally was around 5m till up to late 50s of the 20th century, increased many folds in some glaciers in the Central and the Eastern Himalayas during the decade of mid seventies to late eighties, touching a value of as high 25m-30m as in the case of the Gangotri glacier. The retreat, with the advent of the decade of the nineties, began to slow down and in some cases like the Siachen glacier, Machoi glacier, Darung Drung glacier, Gangotri glacier, Satopanth-Bhagirath Kharak glaciers and the Zemu glacier, it has practically come down to stand still during the period 2007-09. It may be noted here

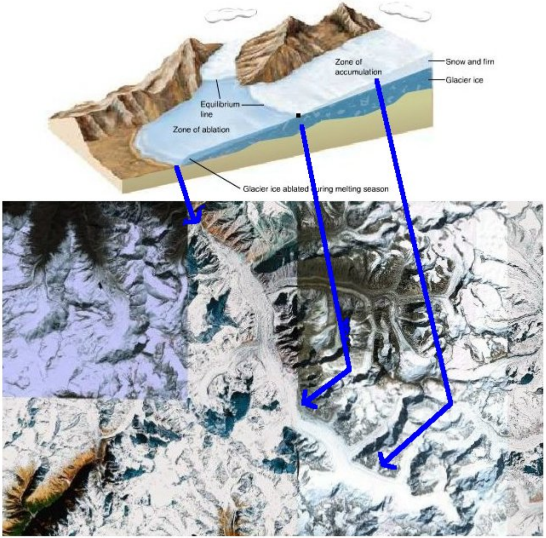
Outline

A generic Glacier

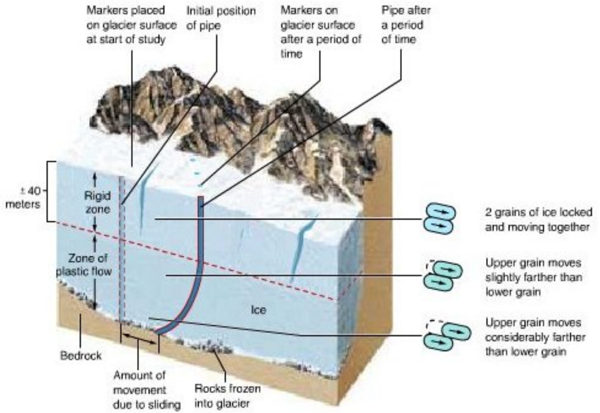


Lengths	5-50 km
Widths	≈ 500 m
Slopes	$\approx 2^\circ - 5^\circ$

Gangotri Bamak



Glacial Flow



Typical surface speeds: 10-80 meters/year (2.5-20 cm/day)

Continuum Mechanics of Glaciers

Newtons Law:

$$\rho \frac{d^2 u_i}{dt^2} = -\partial_j \sigma_{ij} - \rho g_i$$

LHS is negligible for glacial flow

Continuity equation:

$$\rho \partial_i v_i = b$$

b incorporates accumulation and ablation

Constitutive relation:

$$\begin{aligned}
\dot{\epsilon}_{ij} &= A\tau^{n-1} s_{ij}, \qquad n \approx 3 \\
s_{ij} &= \sigma_{ij} - \frac{1}{3}\delta_{ij}\sigma_{kk}, \quad \tau \equiv \left(\frac{1}{2} s_{ij} s_{ji}\right)^{\frac{1}{2}} \\
A &= A_0 e^{-Q/kT}, \qquad Q \approx 0.62\ eV
\end{aligned}$$

Continuum Mechanics of Glaciers

Newtons Law:

$$\partial_j \sigma_{ij} + \rho g_i = 0$$

Continuity equation:

$$\rho \partial_i v_i = b$$

b incorporates accumulation and ablation

Constitutive relation:

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\dot{\epsilon}_{ij} &= A\tau^{n-1} s_{ij}, \qquad n \approx 3 \\
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A &= A_0 e^{-Q/kT}, \qquad Q \approx 0.62\ eV
\end{aligned}$$

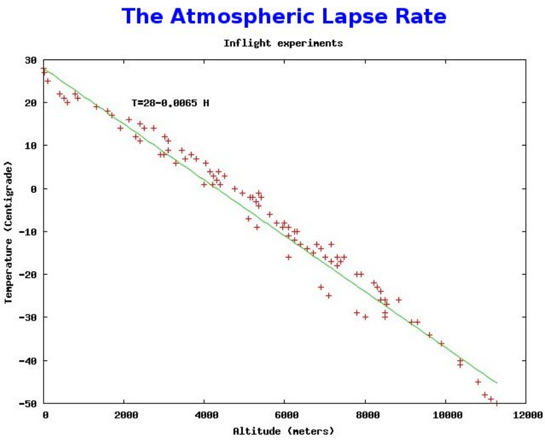
Oerleman's Model for recession

$$\frac{dL'}{dt} = \frac{1}{\tau}\left(c\Delta T - L'\right)$$

τ: Response time,
c: Climate sensitivity.

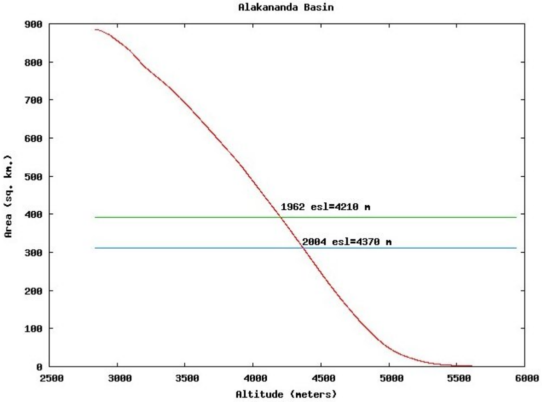
$$\begin{aligned}\tau &= 2.3p^{0.6}s^{-1}\\ c &= \frac{13.6}{0.006s\sqrt{p(1+20s)L}}\end{aligned}$$

Back of the Envelope



$$\frac{dT}{dh} = 0.65^\circ C/100m, \qquad \frac{dh}{dT} = 154m/^\circ C$$

Back of the Envelope



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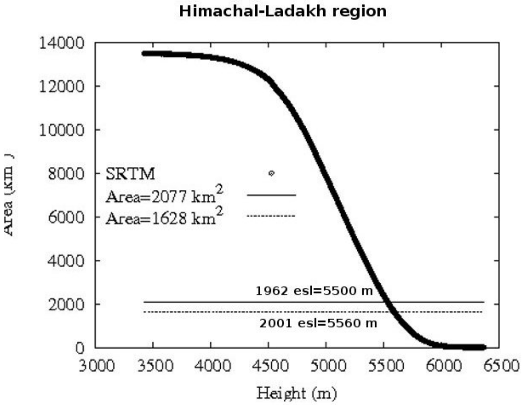
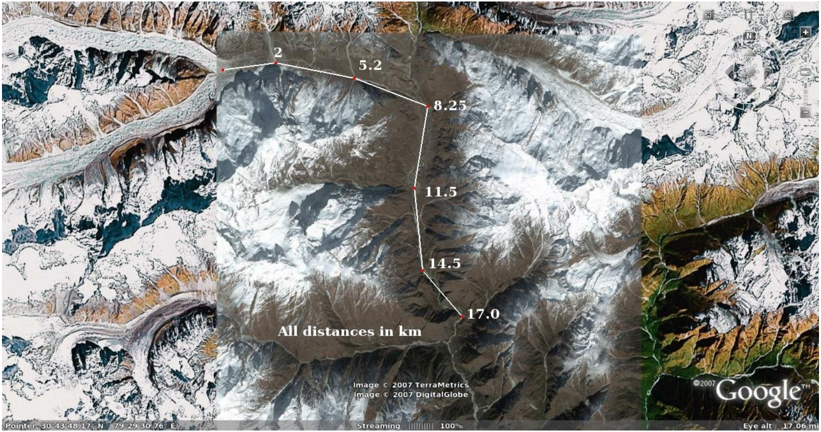


Himalayan ice cap may reduce by $\sim$ 50% but likely to survive the 21st Century

Outline

The Study Area

The Study Area

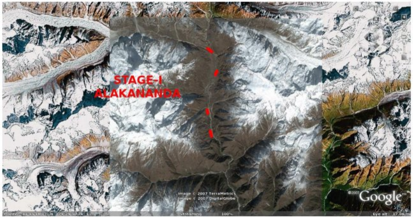


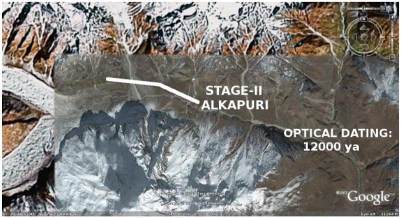
History of Glaciation

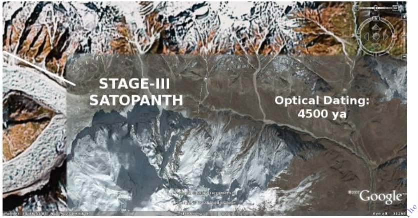
Chronology of the Late Quaternary glaciation around Badrinath (Upper Alaknanda Basin): Preliminary observations

H. C. Nainwal[1,*], M. Chaudhary[1], N. Rana[1], B. D. S. Negi[1], R. S. Negi[1], N. Juyal[2] and A. K. Singhvi[2]

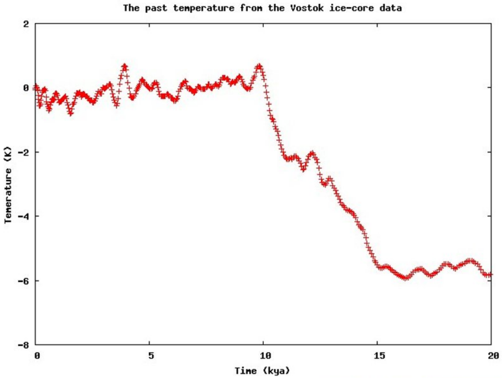
[1]Department of Geology, HNB Garhwal University, Srinagar (Garhwal) 246 174, India
[2]Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India



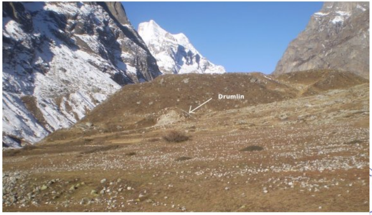




Temperature from Ice Cores



Luminescence age of 12 ka is obtained on the recessional moraine (Stage-II) located at around 3600 m asl and is separated from the terminus of Stage-II by a prominent depression. This would imply that during the recessional phase, there was a temporary hiatus which is also indicated by the presence of drumlins above the dated horizon (Figures 4 *b* and 6)[24]. It is suggested that due to



Sathopanth

Sathopanth Front

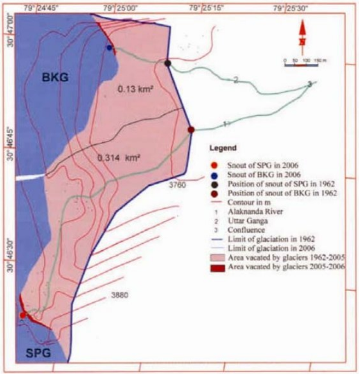
Surveying

Recent Recession

Temporal changes in rate of recession: Evidences from Satopanth and Bhagirath Kharak glaciers, Uttarakhand, using Total Station Survey

H. C. Nainwal*, B. D. S. Negi, M. Chaudhary, K. S. Sajwan and Amit Gaurav

Department of Geology, HNB Garhwal University, Srinagar (Garhwal) 246 174, India



	62-05	05-06	06-07	07-08
Satopanth (m/y)	22.9	6.5	5.5	4.5
Baghirath Kharak (m/y)	7.4	1.5	1.0	1.0

Flow Measurement

THANK YOU !