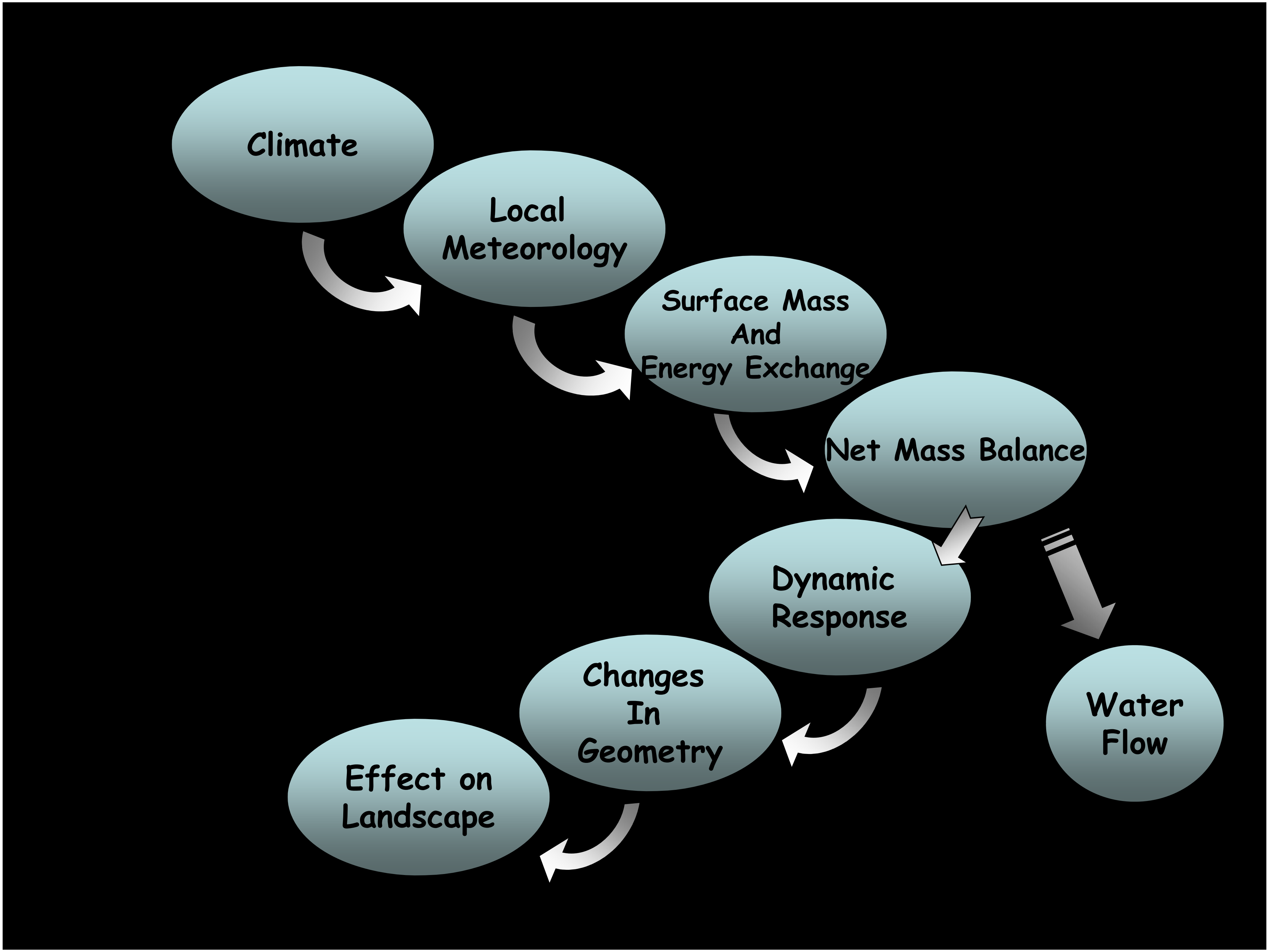
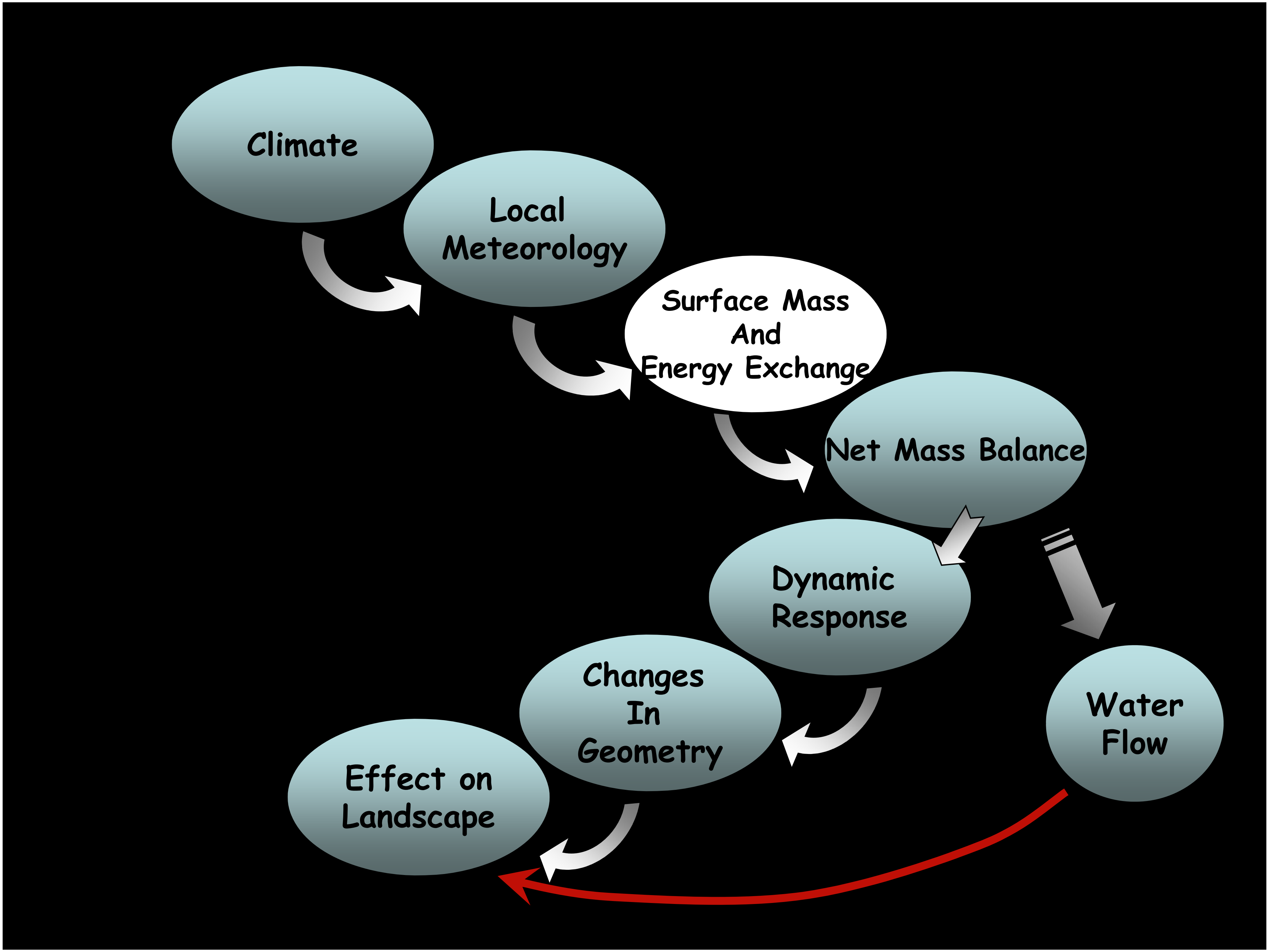
Energy Balance


Climate
Local Meteorology
Surface Mass And Energy Exchange
Net Mass Balance
Dynamic Response
Water Flow
Changes In Geometry
Effect on Landscape


Climate
Local Meteorology
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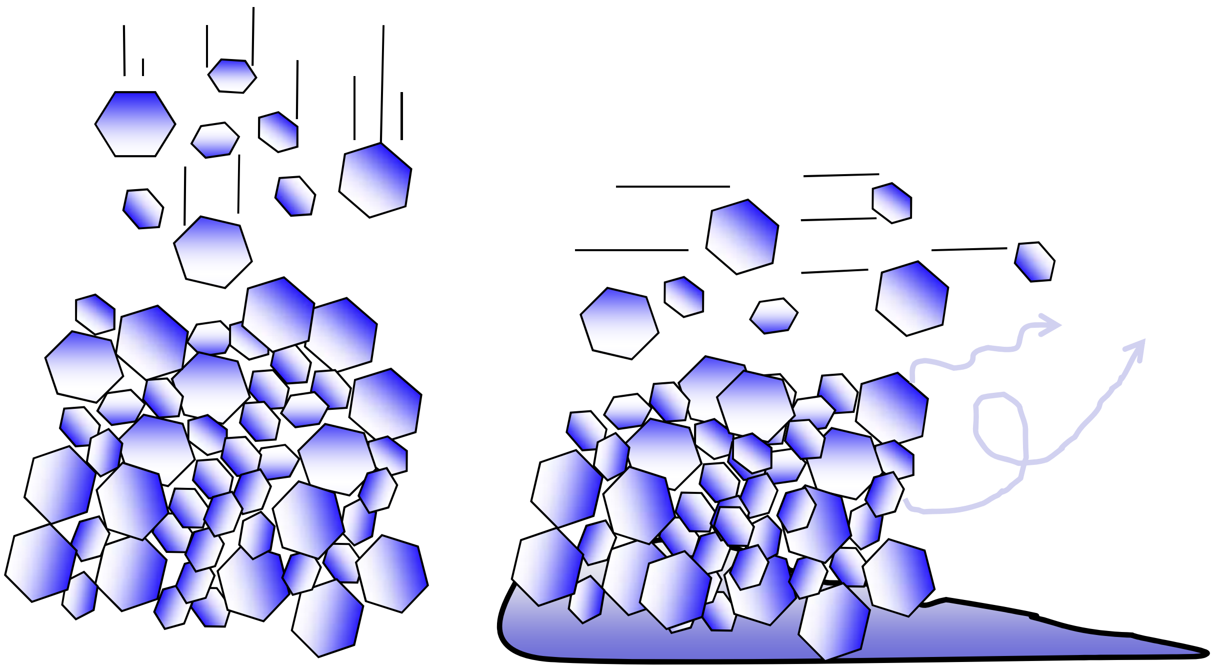
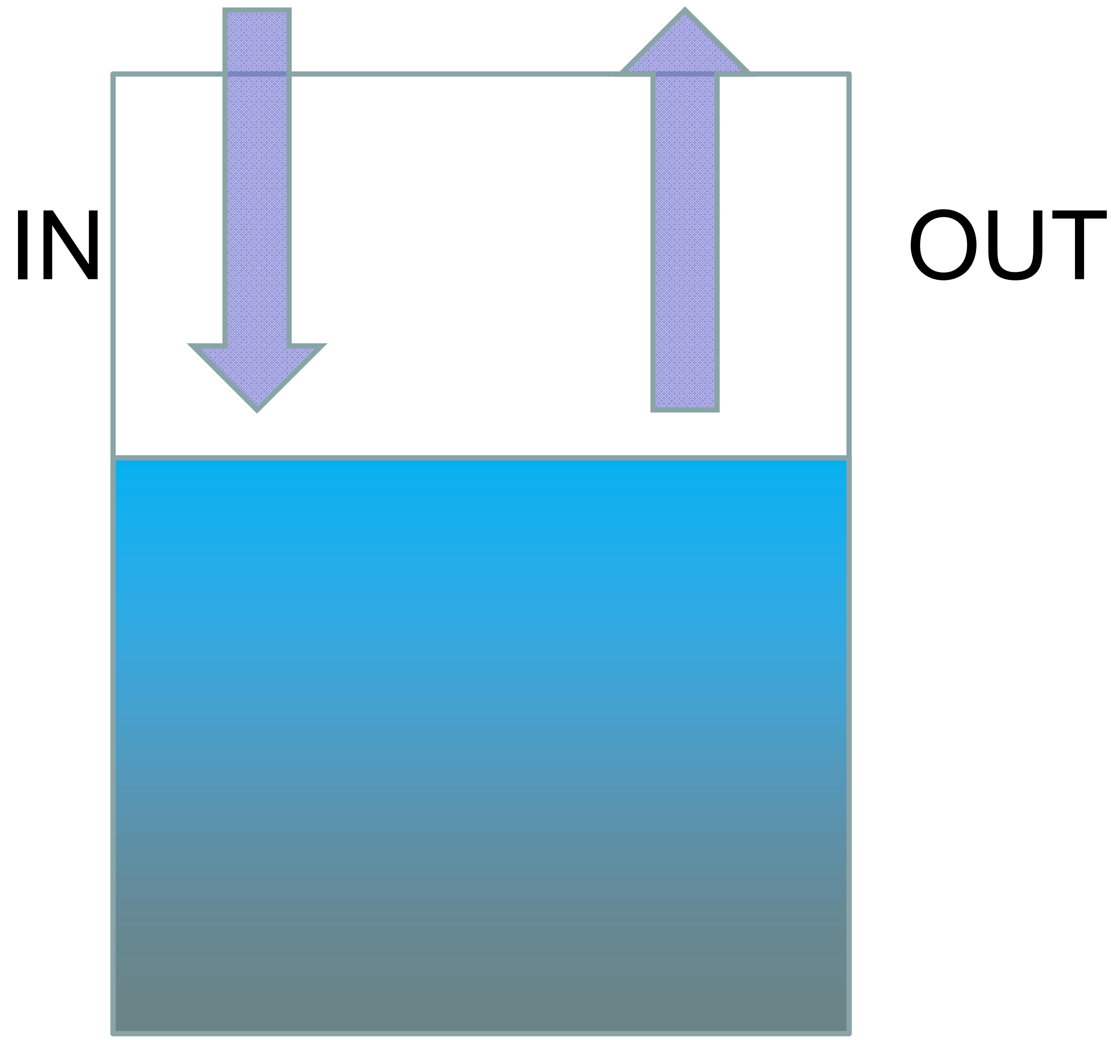
Accumulation - Ablation = Mass Change



Calving
Wind Erosion

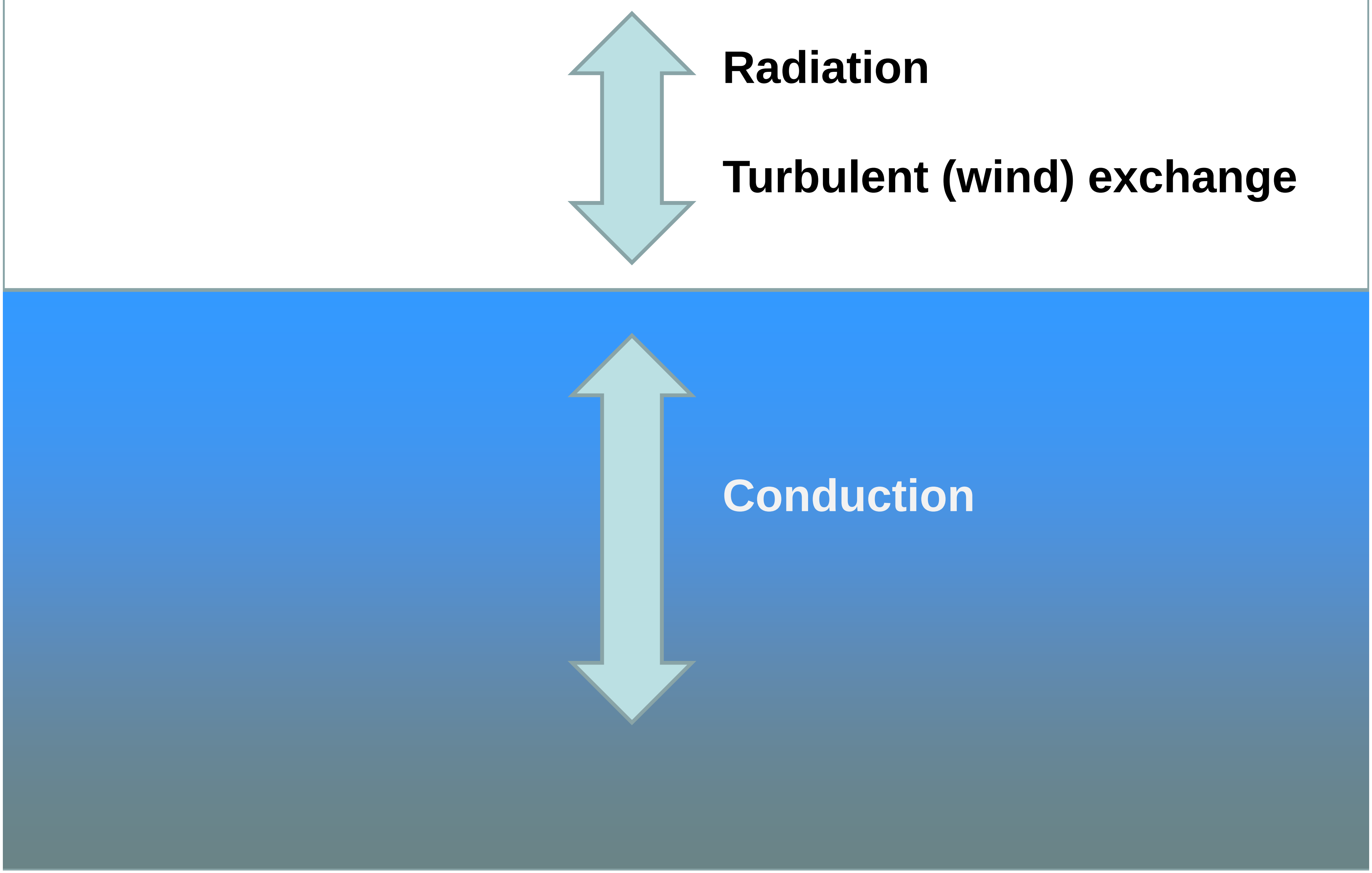
Sublimation
Melt

Mass Balance

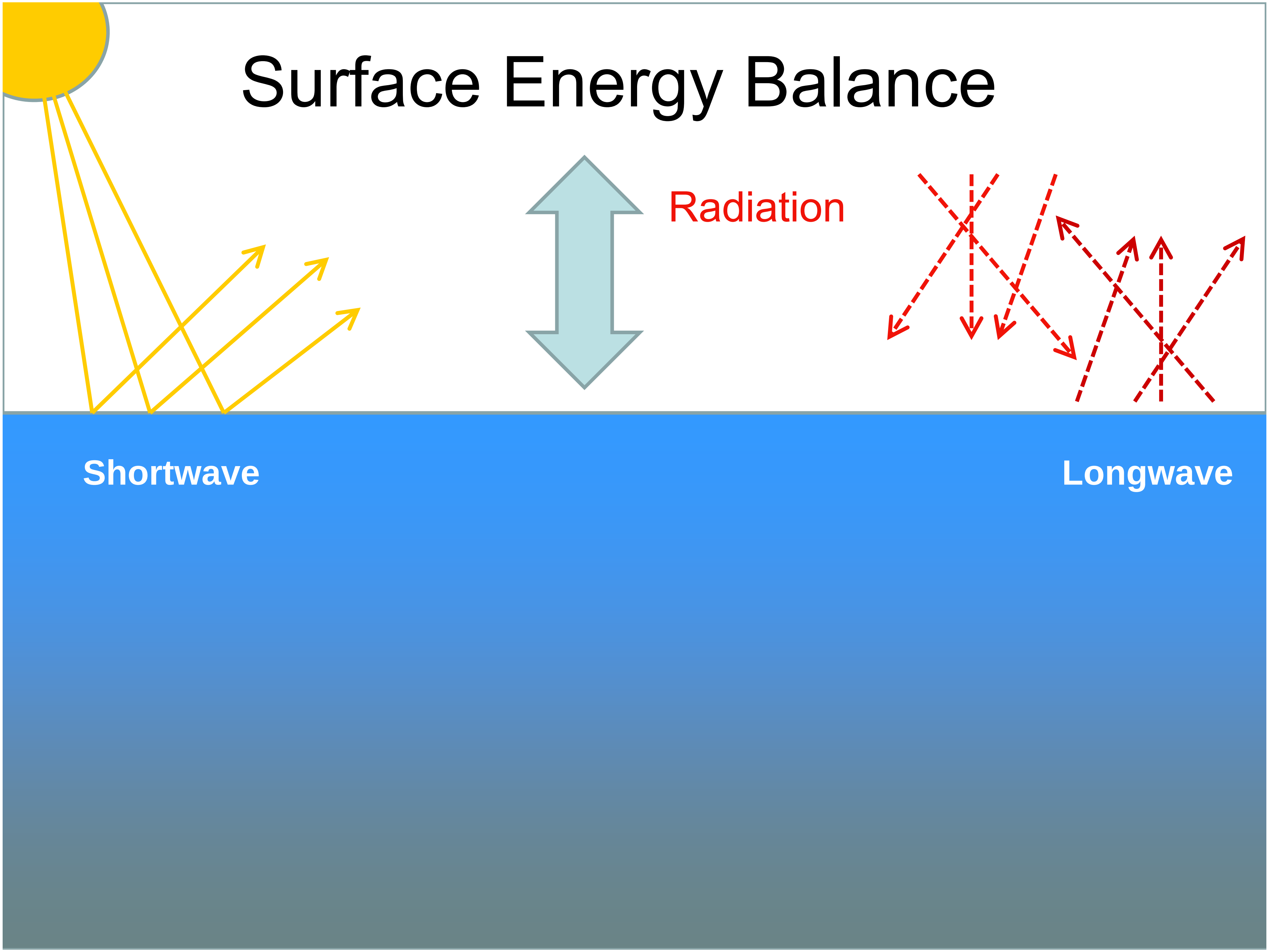


Analogy for heat balance

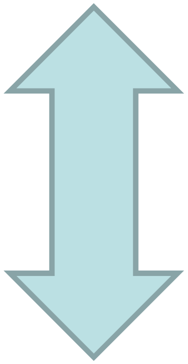
Surface Energy Balance



Surface Energy Balance



Surface Energy Balance



Turbulent (wind) exchange

1. **Sensible Heat**

2. **Latent Heat**

FLUXES: ATMOSPHERE - GLACIER

$$0 = S\downarrow(1-\alpha) + L\downarrow - L\uparrow + Q_H + Q_L + Q_m$$

$S\downarrow$	short-wave incoming radiation flux
a	albedo of the surface
$L\downarrow$	long-wave incoming radiation flux
$L\uparrow$	long-wave outgoing radiation flux
Q_H	sensible heat flux
Q_L	latent heat flux
Q_m	phase change

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Short Wave Radiation

$S\downarrow(1-\alpha)$ ....net shortwave radiation

$S\downarrow$ short-wave incoming radiation flux

α albedo of the surface

Antarctic Snow

$\alpha \sim 0.8$


N5736J
Clean Ice
α ~ 0.5


DIRTY ICE
$\alpha \sim 0.2$
Pasterzeglet

Midtalsbreen 2009

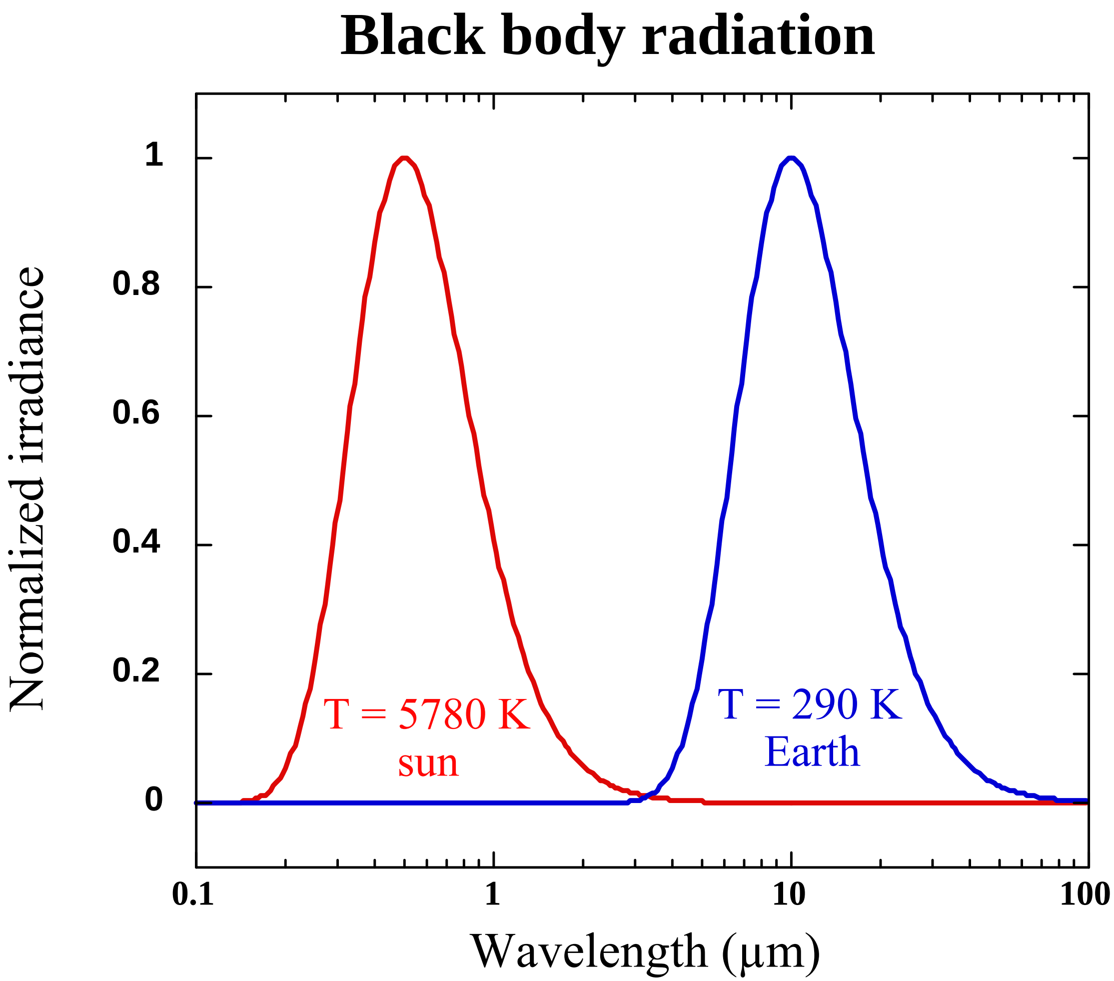
Long Wave Radiation

$$L\downarrow - L\uparrow$$

$L\downarrow$ long-wave incoming radiation flux

$L\uparrow$ long-wave outgoing radiation flux

SHORT- AND LONG-WAVE RADIATION



$$Q = \sigma T^4$$

Q flux (irradiance)

σ Stefan Boltzmann constant ($5.67 \cdot 10^{-8}$ W m^{-2} K^{-4})

T temperature

$$Q = \varepsilon\sigma T^4$$

ε emmisivity

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TURBULENT FLUXES

$Q_H + Q_L$

Vertical transport of properties of the air by eddies

Turbulence is generated by wind shear (du/dz)

Turbulent fluxes increase with wind speed

Heat: sensible heat flux, Q_H

Water vapor: latent heat flux, Q_L

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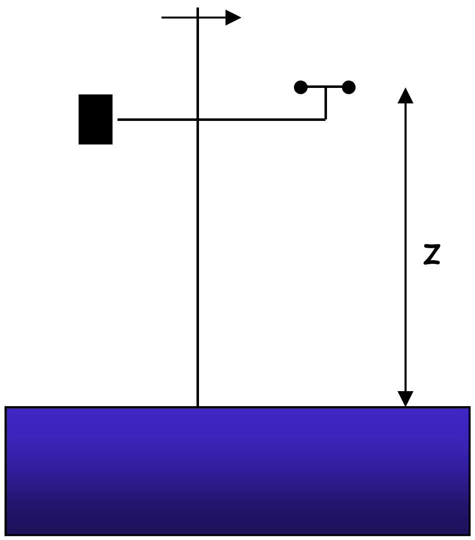
SENSIBLE HEAT FLUX (Q_H)

calculated with the "bulk method"

$$Q_H = \rho_a C_{pa} \frac{\kappa^2 u (T - T_s)}{\left(\ln\frac{z}{z_0} + \frac{\alpha_m z}{L_{ob}}\right)\left(\ln\frac{z}{z_T} + \frac{\alpha_h z}{L_{ob}}\right)}$$



ρ_a	air density
C_{pa}	specific heat capacity of air
k	von Karman constant
u	wind speed
T	air temperature at height z
T_s	surface temperature
z_0	momentum roughness length
z_T	roughness length for temperature
α_m, α_h	constants
L_{ob}	Monin-Obukhov length (depends on u and T-T_s)

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LATENT HEAT FLUX (Q_L)

calculated with the "bulk method"

$$Q_L = \rho_a L_s \frac{\kappa^2 \, u \, (q - q_s)}{\left(\ln \frac{z}{z_0} + \frac{\alpha_m z}{L_{ob}} \right) \left(\ln \frac{z}{z_q} + \frac{\alpha_h z}{L_{ob}} \right)}$$

ρ_a	air density
L_s	latent heat of sublimation
k	von Karman constant
u	wind speed
q	specific humidity at height z
q_s	surface specific humidity
z_0	roughness length for velocity
z_q	roughness length for water vapor
α_m, α_h	constants
L_{ob}	Monin-Obukhov length (depends on u and $T-T_s$)

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INSTRUMENTS

measure short-wave radiation with a pyranometer (glass dome)

measure long-wave radiation with a pyrgeometer (silicon dome)

measure sensible heat flux with a sonic anemometer

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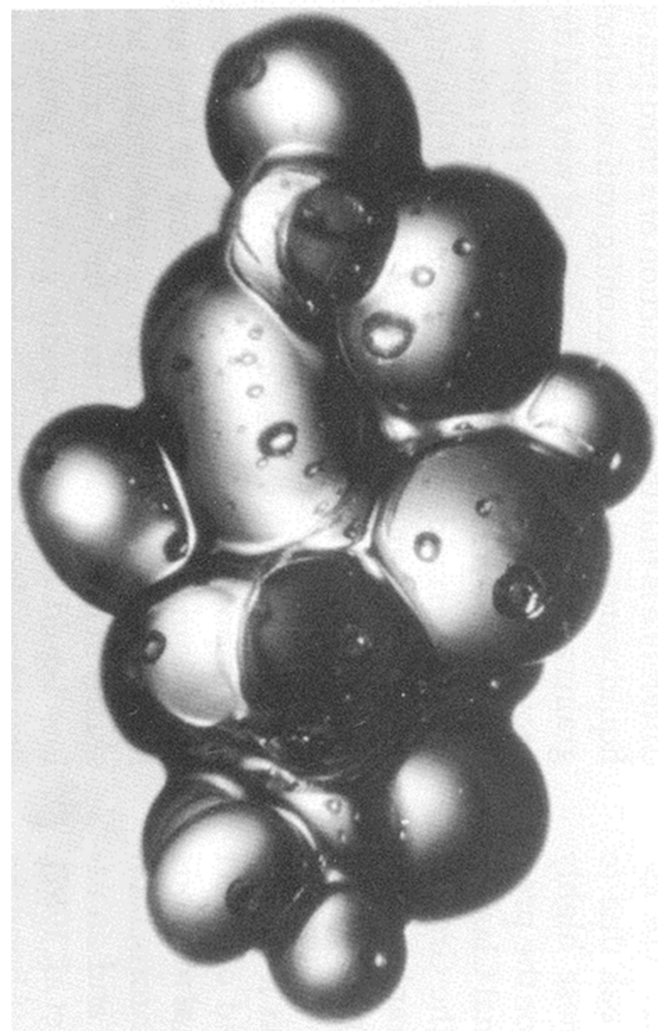
ZERO-DEGREE ASSUMPTION

Assumption: surface temperature = 0°C



Leads to:

$Q_0 > 0$: Q_0 is consumed in melting

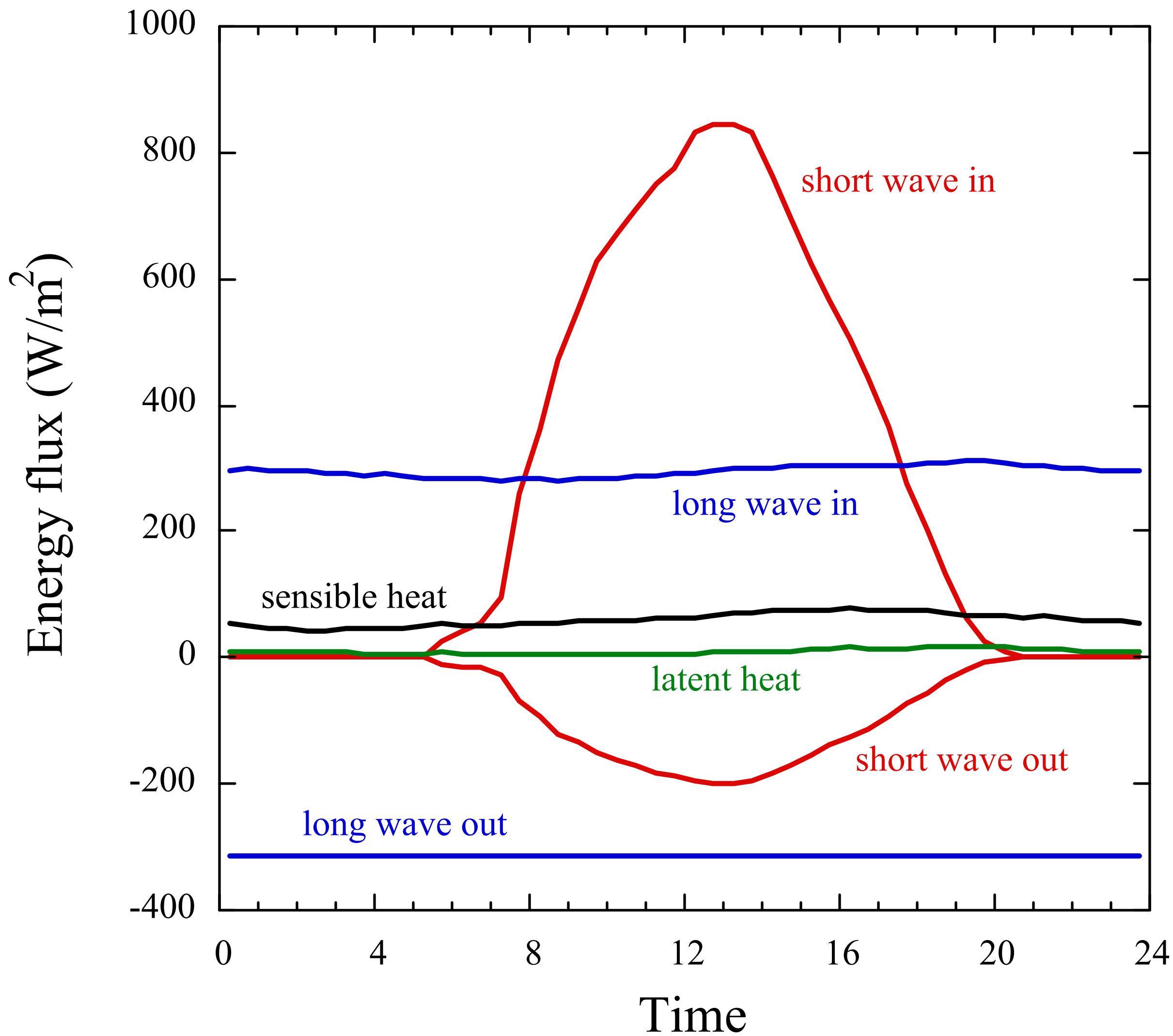
$Q_0 \leq 0$: nothing occurs

Assumption okay when melting conditions are frequent

Not okay when positive Q_0 causes heating of the snow (spring, early morning, higher elevation)

Diurnal Variation

site on glacier ice in summer



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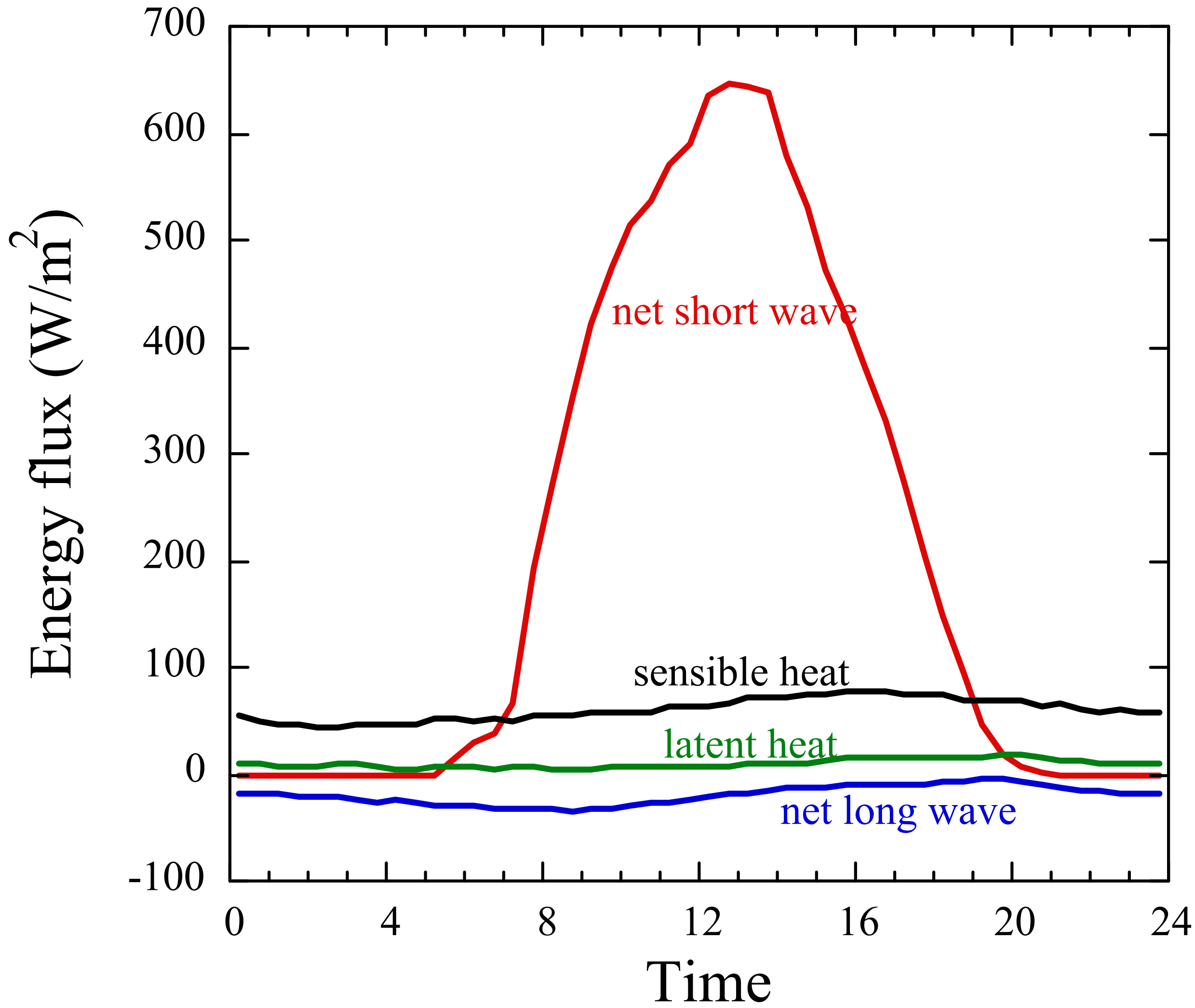
NET FLUXES



Energy flux (W/m^2)
700
600
500
400
300
200
100
0
-100
0
4
8
12
16
20
24
Time
net short wave
sensible heat
latent heat
net long wave

R = net radiation

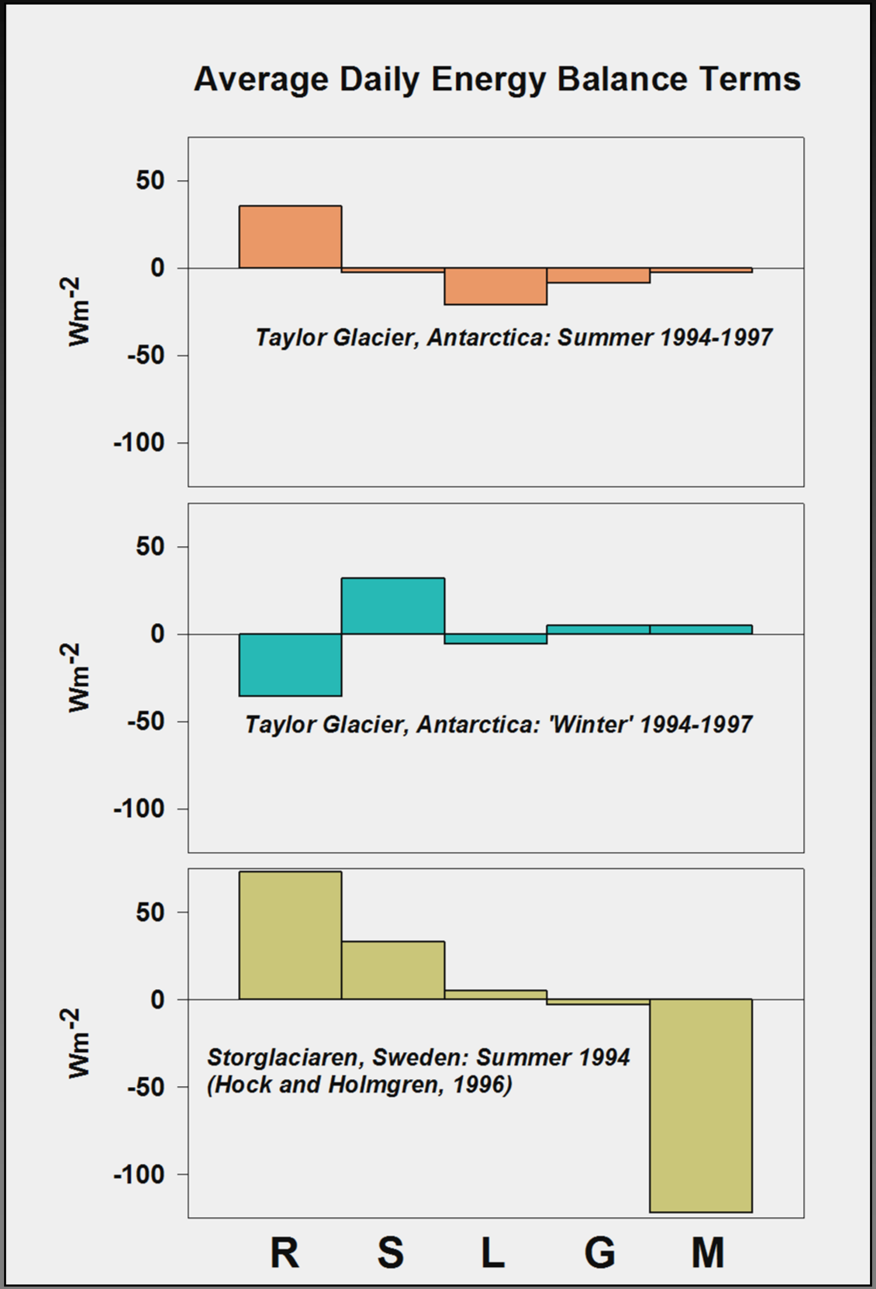
S = sensible heat

L = latent heat

G = ground heat flux

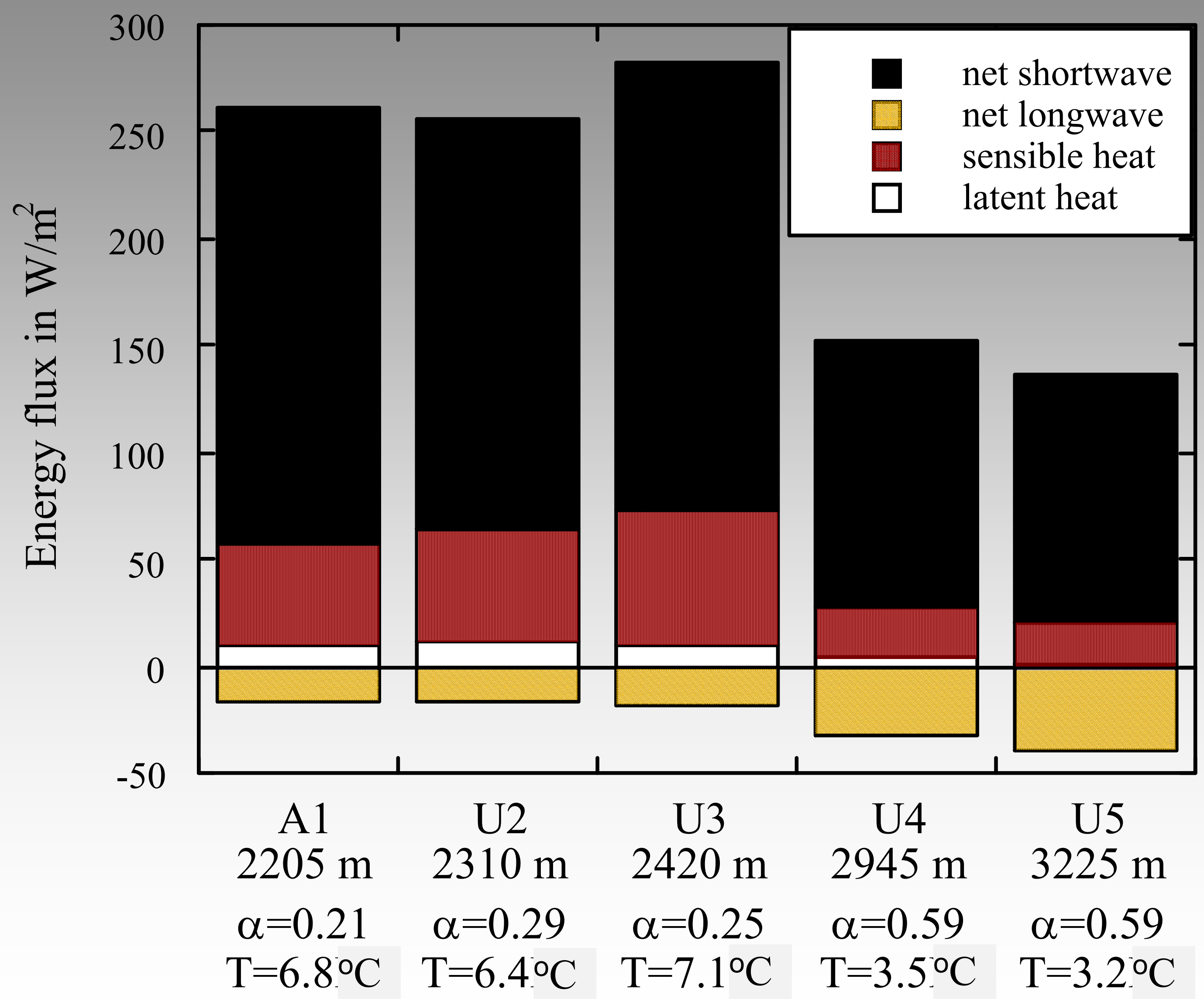
M = melt

POSTIVE FLUX IS TOWARDS
THE SURFACE



ENERGY BALANCE AT 5 ELEVATIONS

Pasterzegletscher



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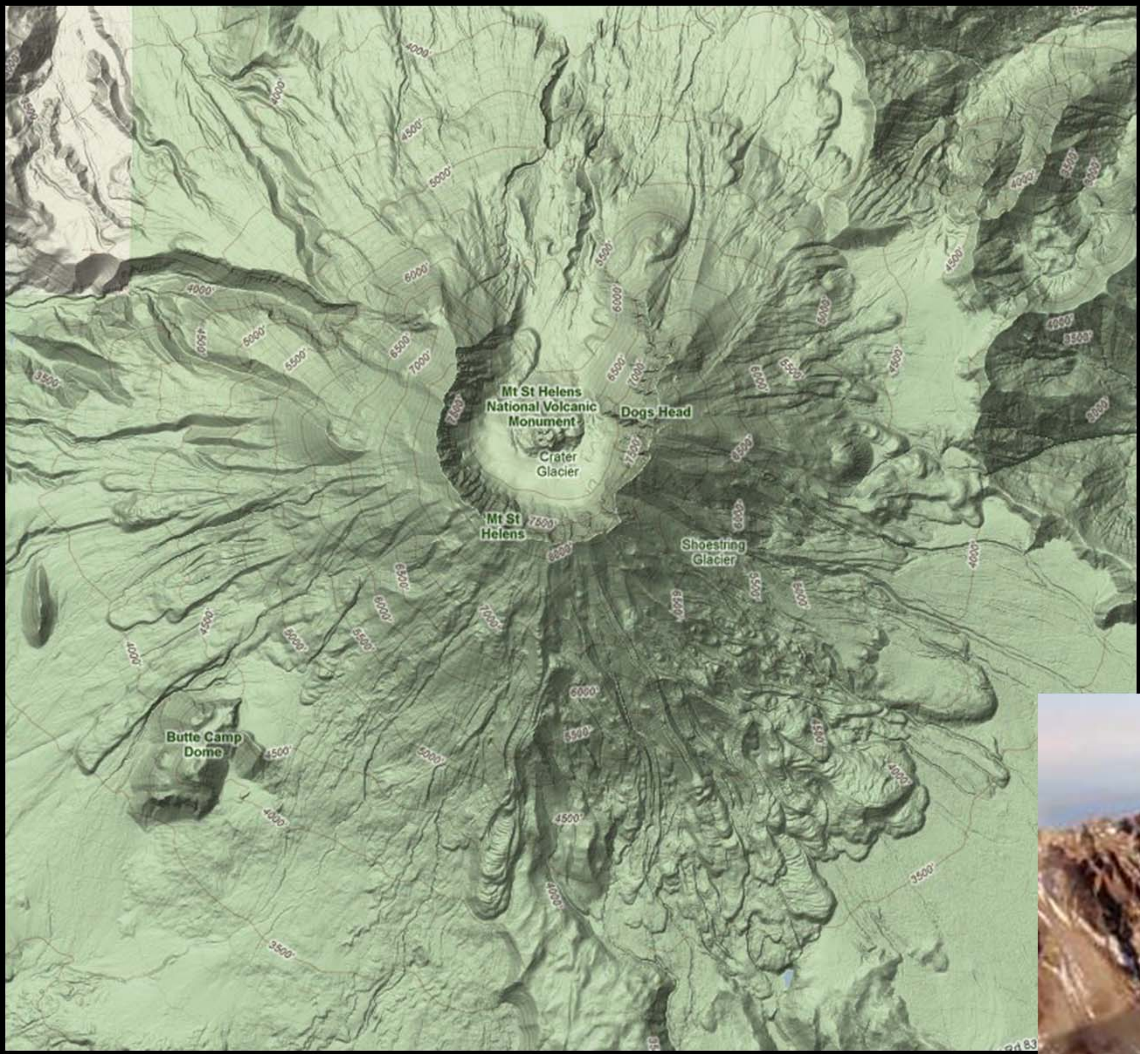
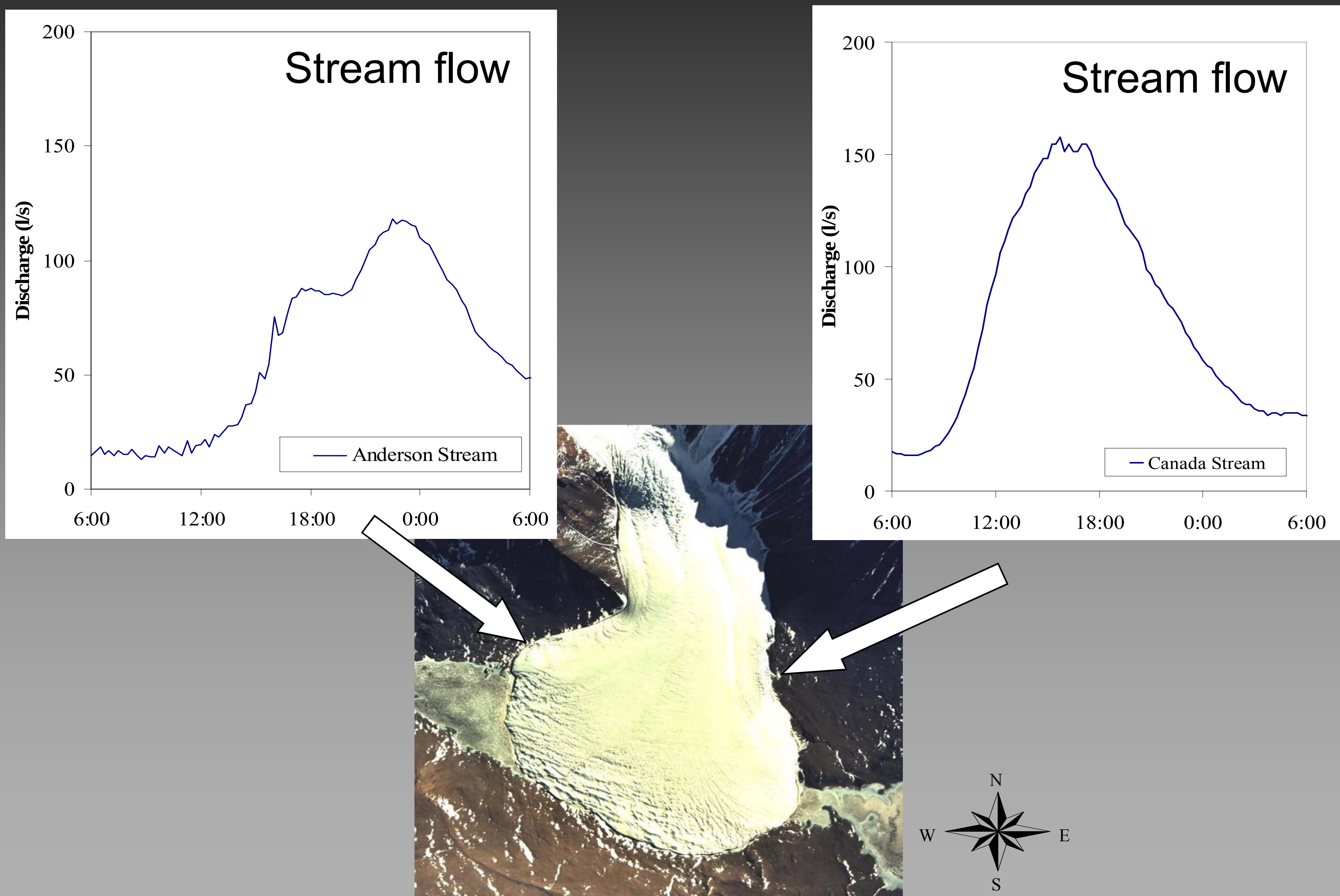
Effect of Solar Radiation



Google Maps

Rueters

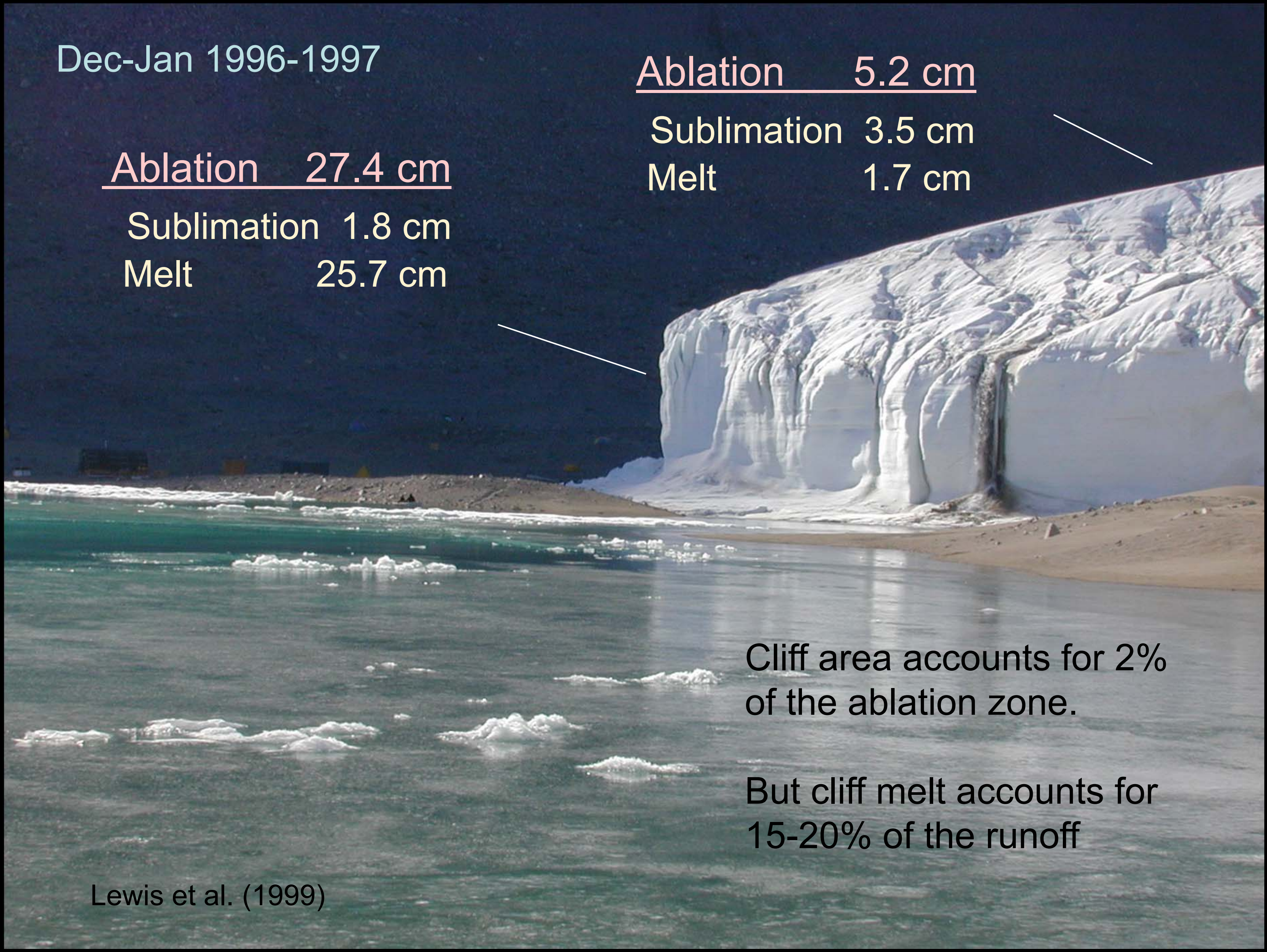
Effect of Solar Radiation



Bomblies (2000)

Jan 2, 1994

Effect of Solar Radiation, Turbulent Exchange



Effect of Solar Radiation, Turbulent Exchange

Penitentes are the name of the caps of the nazarenos; literally those doing penance for their sins. *Photo: Sanbec Wikipedia*

Neve Penitentes Upper Rio Blanco, Argentina *Photo: Arvaki Wikipedia*

Mount Rainier
0.5 m tall.

Photo: Mark Sanderson Wikipedia

Notice the tilt angle

person

DEGREE-DAY METHOD

$\mathbf{M = \beta\, T_{pdd}}$

M: melt
β: degree-day factor [mm day^{-1} K^{-1}]
T_{pdd}: sum of positive daily mean temperatures

Why does it work:
- net long-wave radiative flux, and sensible and latent heat flux ~ proportional to T
- feedback between mass balance and albedo

Advantages:
- computationally cheap
- input: only temperature needed

Disadvantages:
- more tuning to local conditions needed: e.g. b depends on mean solar zenith angle
- only sensitivity to temperature can be calculated

REGRESSION MODELS

$$M_n = c_0 + c_1 T_s + c_2 P_w$$

M_n: mean specific mass balance

c_i: coefficients determined by regression analysis

T_s: Annual mean summer temperature

P_w: Winter Precipitation


End