# Continuous Modeling of Distributed Snow Accumulation on the Haut Glacier d'Arolla

March 8, 2006

# Outline

# Motivation

1. Detailed understanding of the processes of snow accumulation and ablation on Alpine environments, as well as their climatic sensitivity.
2. Assessing water resources in snow covered and glaciated basins through continuous modelling of distributed mass and energy balance.
3. Improving future investigations concerning the impact on water resources availability due to future climate scenarios.

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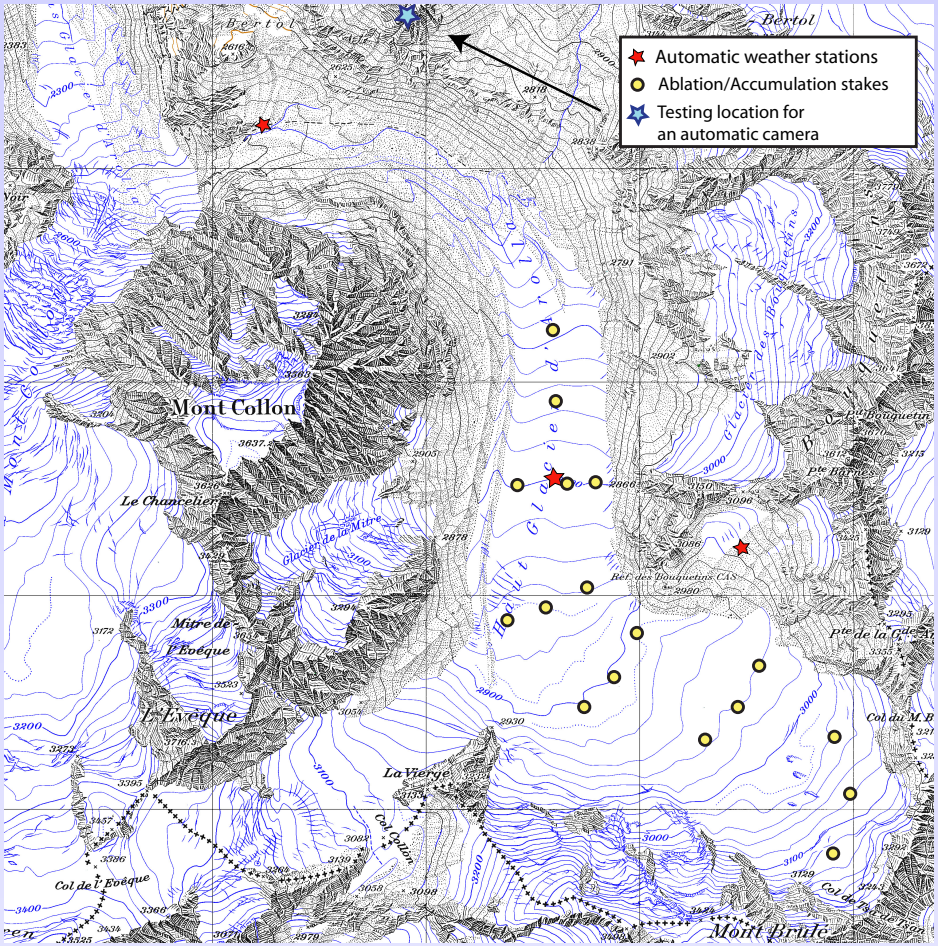
# Arolla


Automatic weather stations
Ablation/Accumulation stakes
Testing location for
an automatic camera
Bertol
Mont Collon
Le Chanrelier
Mitre de
l'Evêque
L'Evêque
La Vierge
Col de l'Evêque
Mont Brulé
Haut Glacier d'Arolla

# Continuous Measurements

- Snow depth and snow density

## Measurements

- 2 AWS outside the glacier (temperature, humidity, SW in/out, LW in/out, wind speed/direction, precipitation)
- 1 AWS on the glacier (air temperature, humidity, snow surface temperature, SW in/out, net radiation, wind speed/direction, snow surface temperature)
- 18 Ablation/accumulation stakes on the glacier
- (Automatic camera overviewing the lower part of the glacier)

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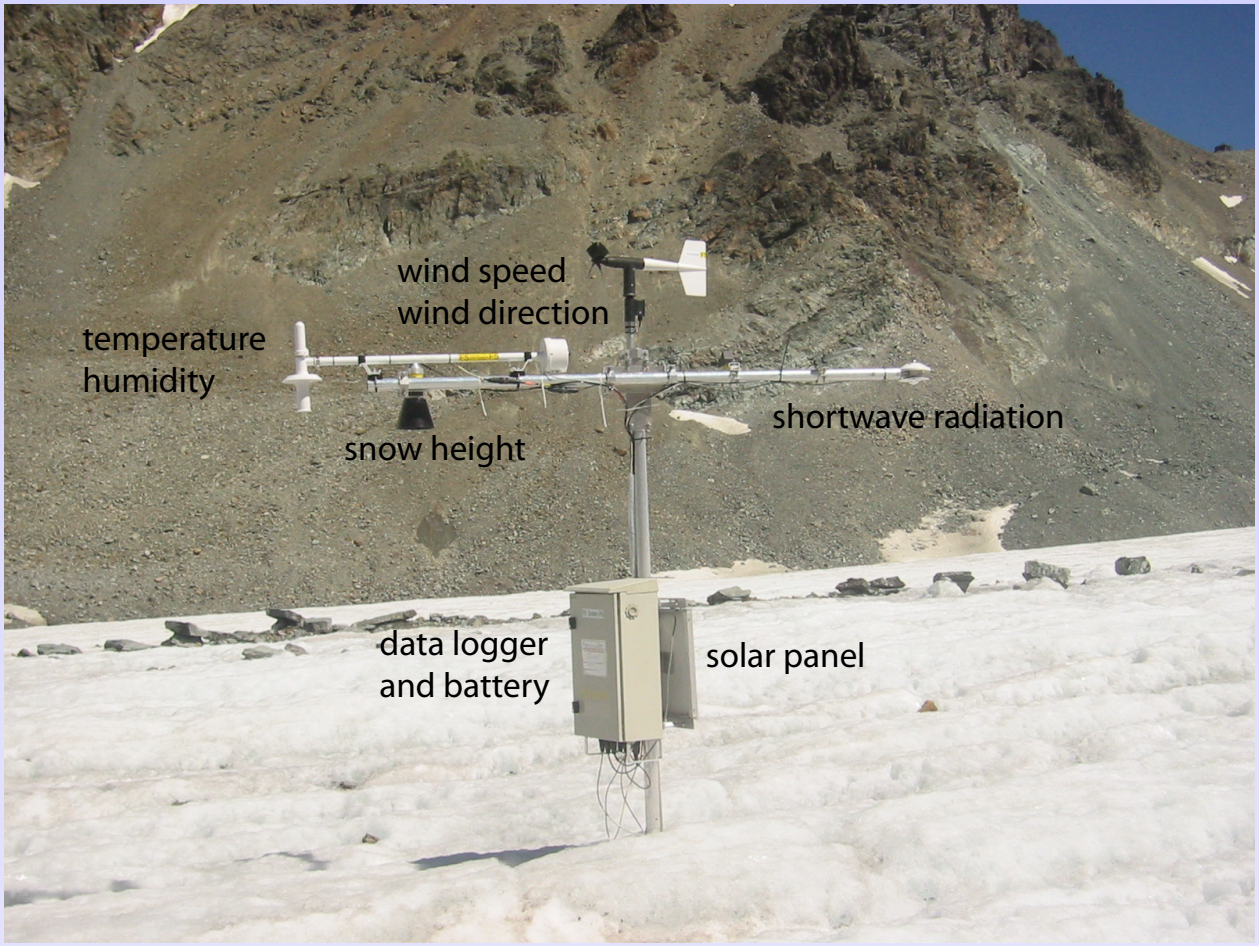
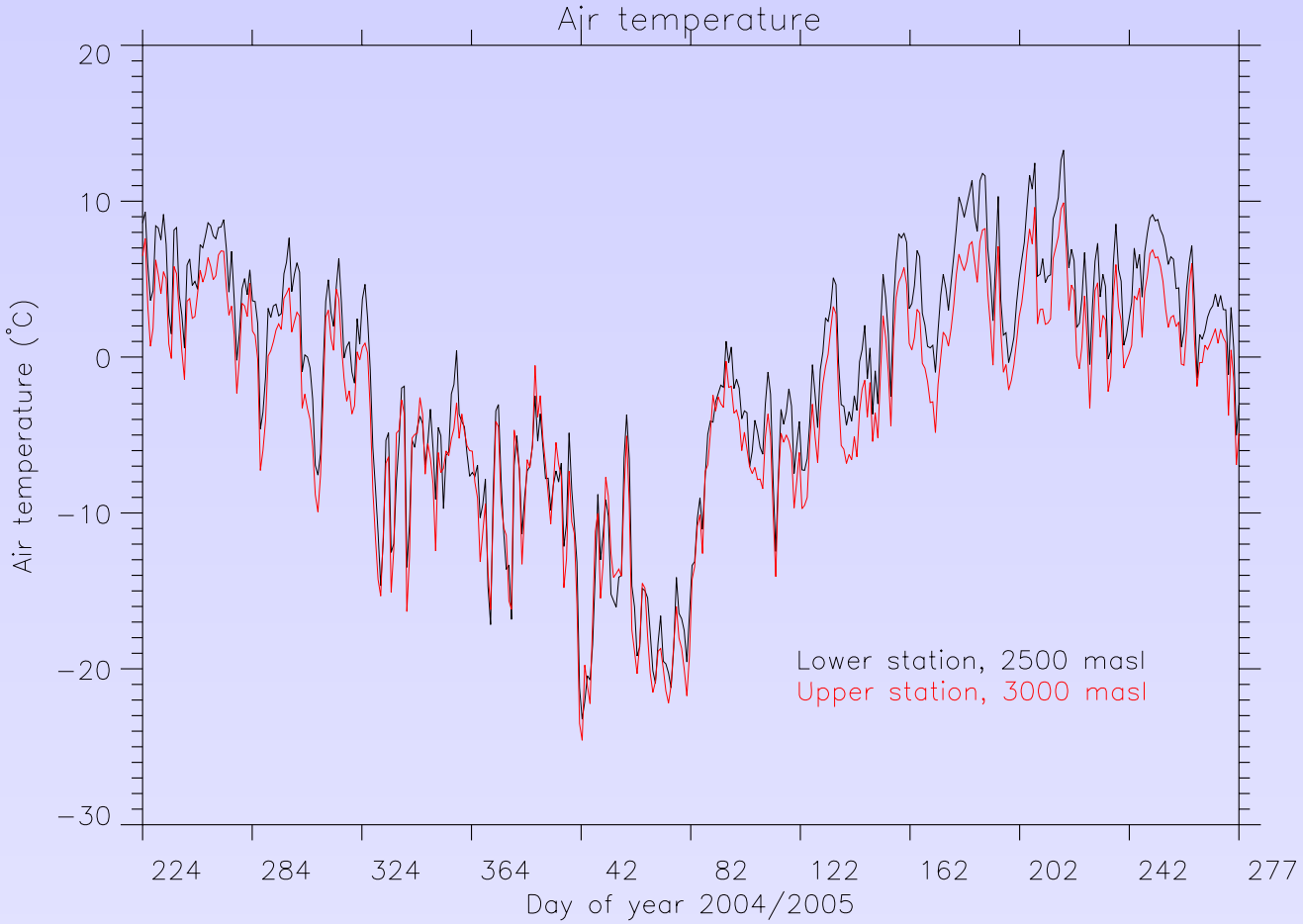
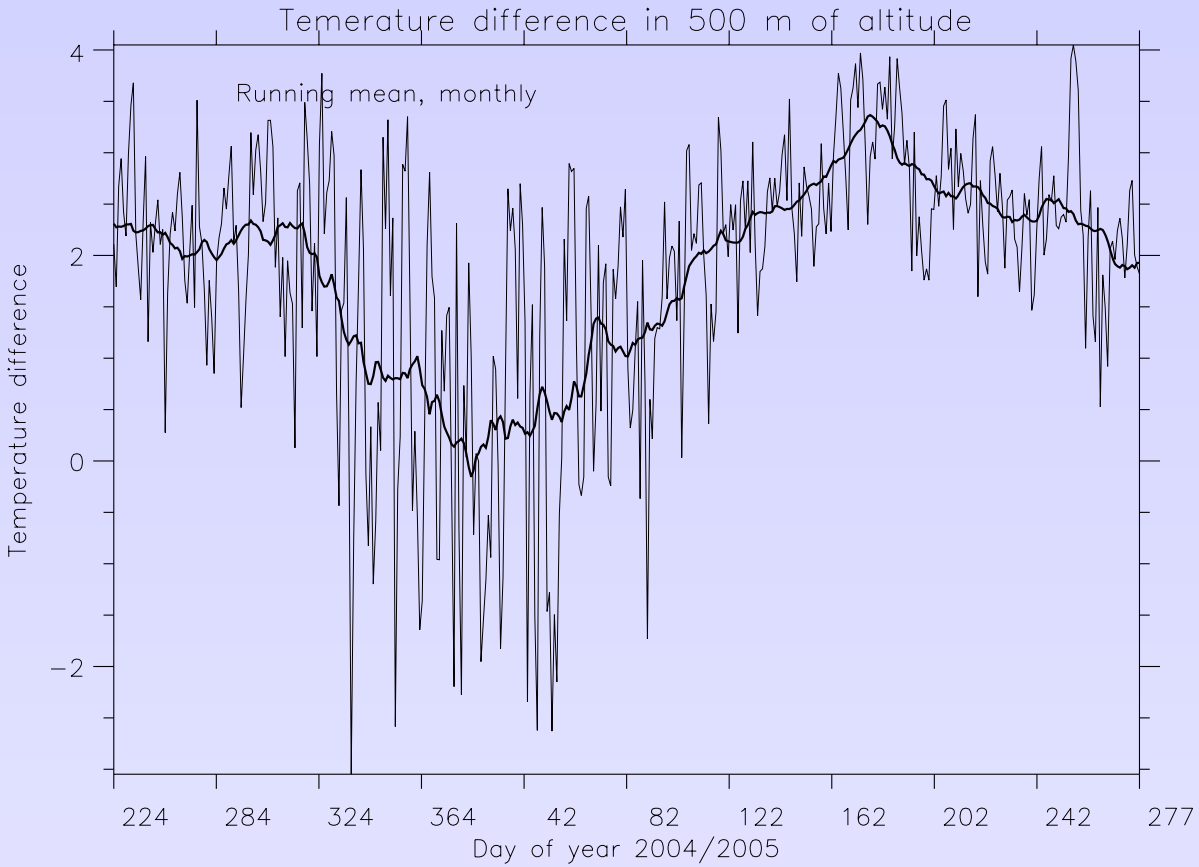
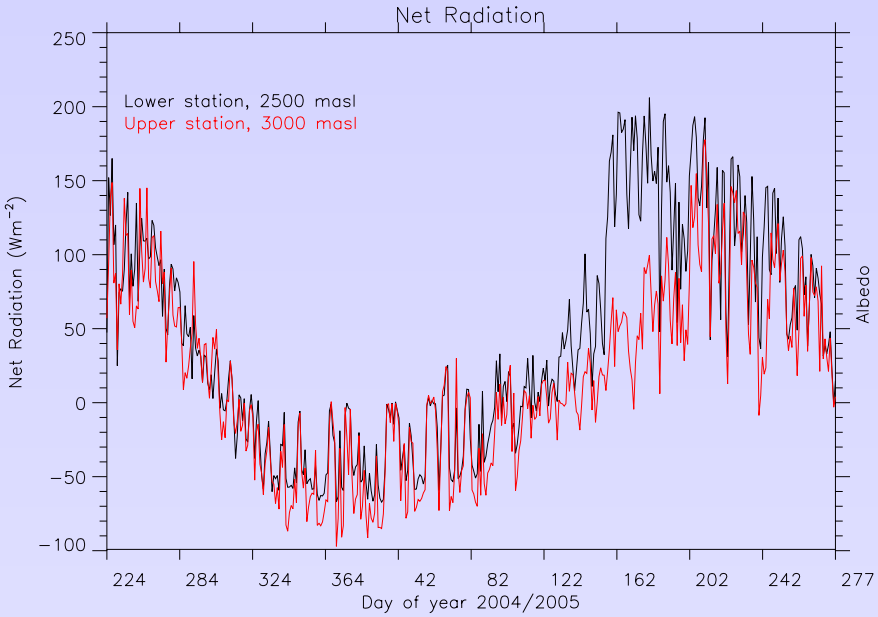
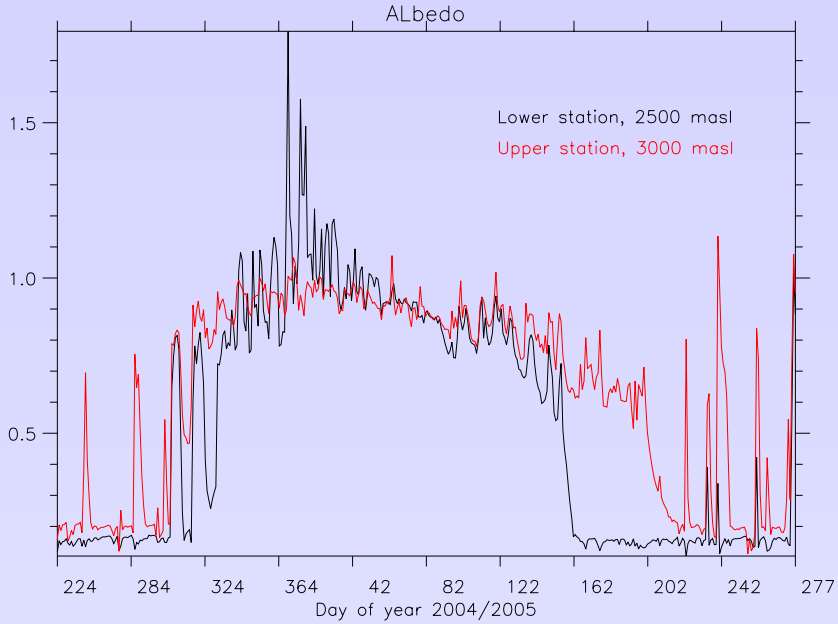

wind speed
wind direction
temperature
humidity
snow height
shortwave radiation
data logger
and battery
solar panel

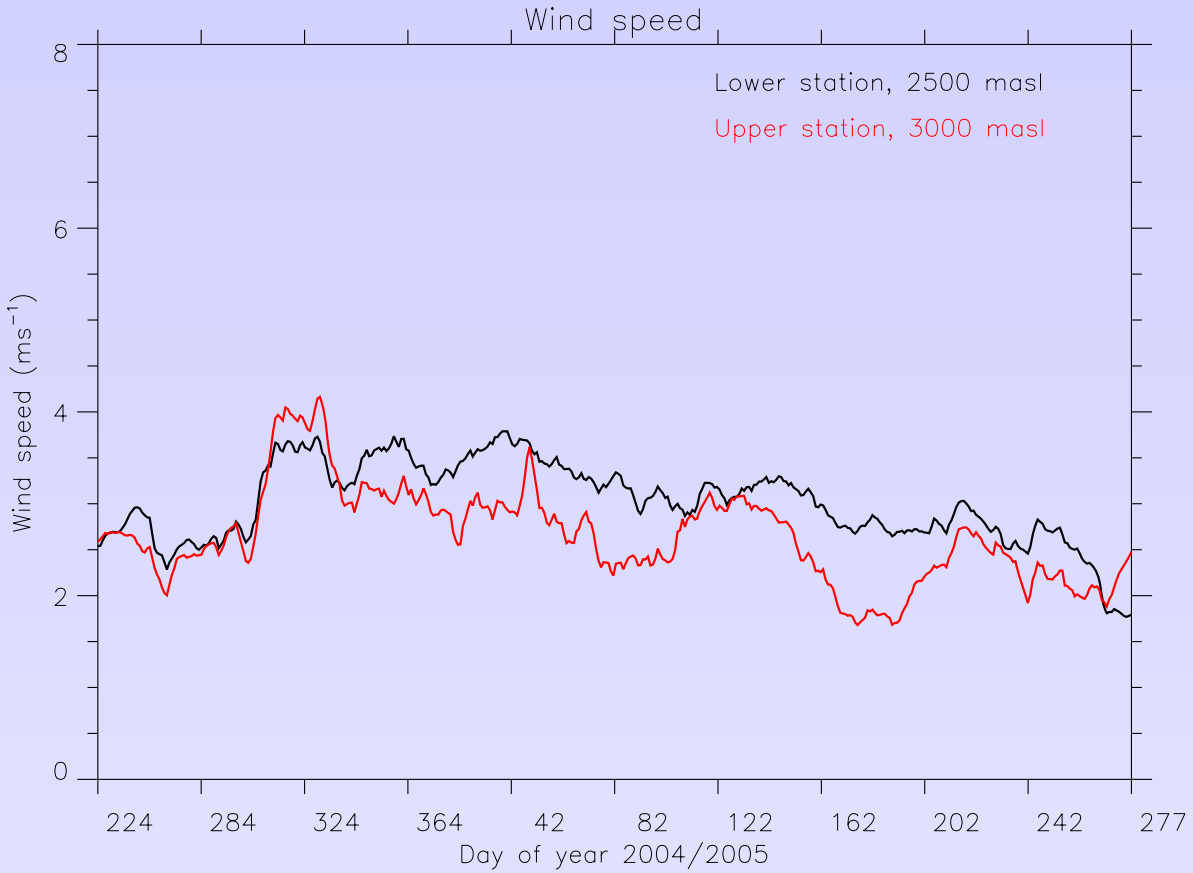
# Arolla

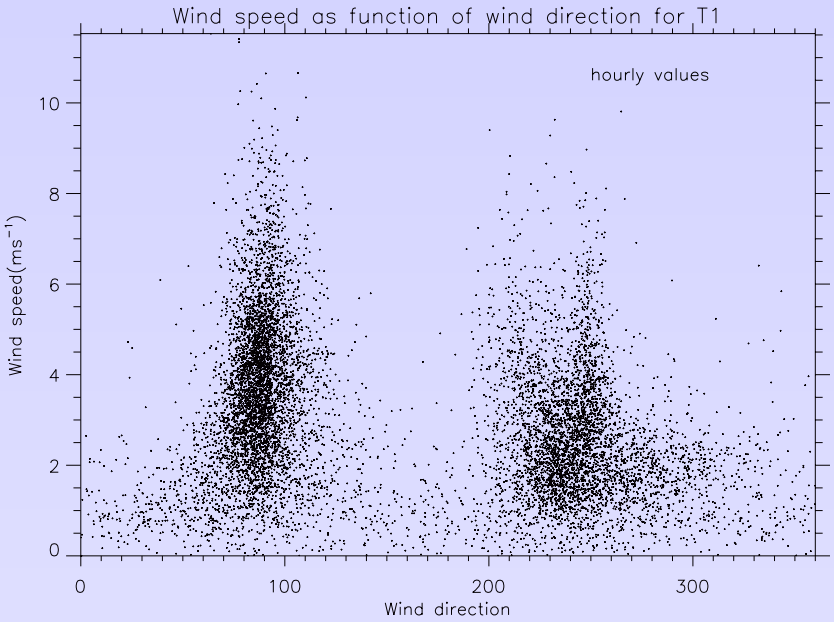

Air temperature
Air temperature (°C)
20
10
0
−10
−20
−30
224
284
324
364
42
82
122
162
202
242
277
Day of year 2004/2005
Lower station, 2500 masl
Upper station, 3000 masl

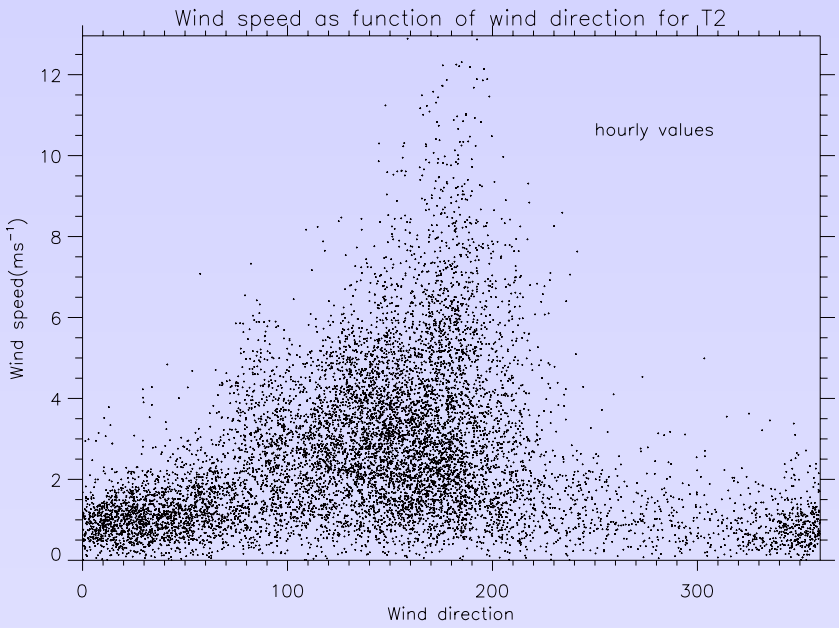

Temerature difference in 500 m of altitude
Running mean, monthly
Temperature difference
4
2
0
−2
224
284
324
364
42
82
122
162
202
242
277
Day of year 2004/2005

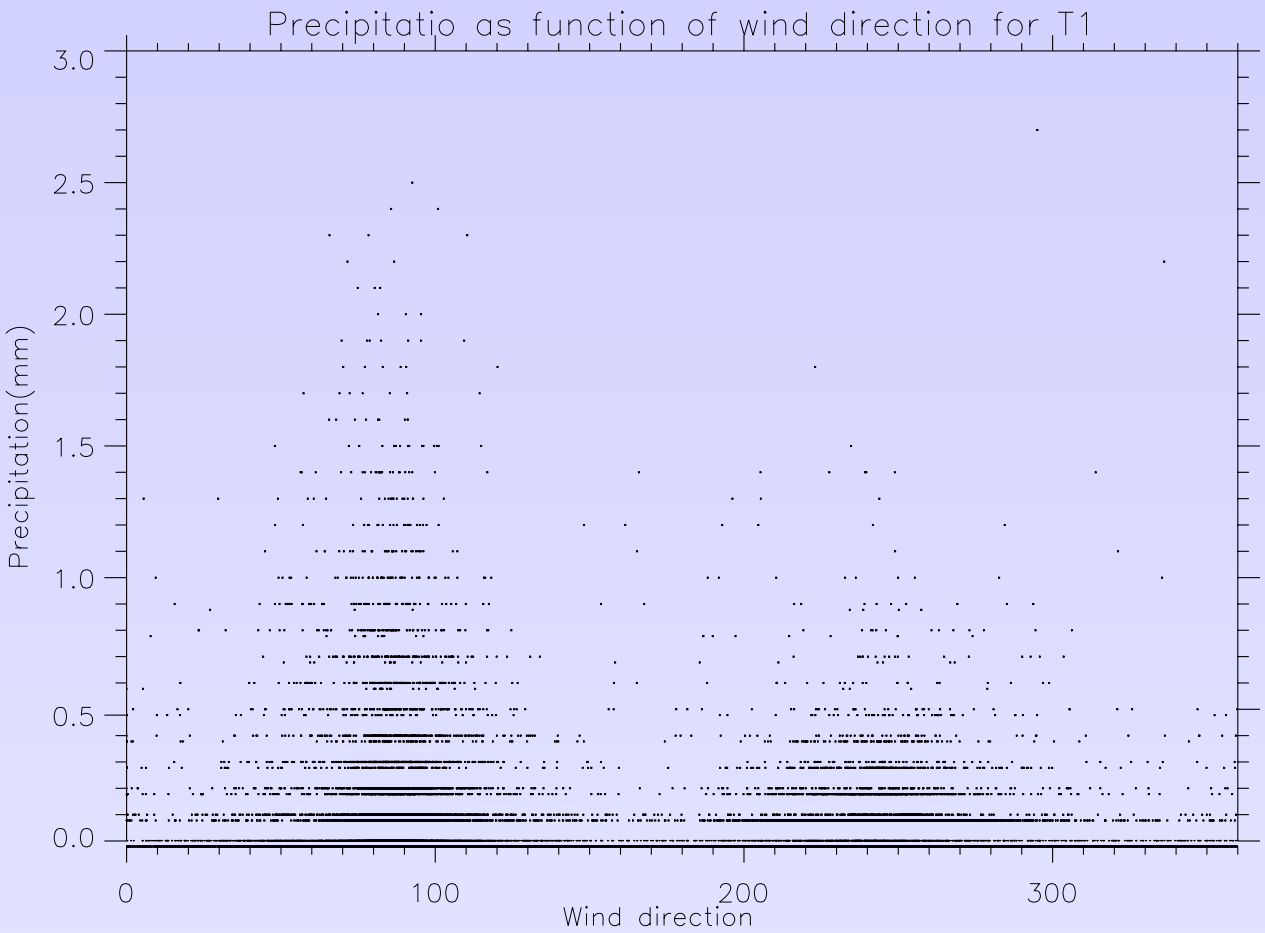

Net Radiation
Lower station, 2500 masl
Upper station, 3000 masl
Net Radiation (Wm$^{-2}$)
250
200
150
100
50
0
−50
−100
224
284
324
364
42
82
122
162
202
242
277
Day of year 2004/2005

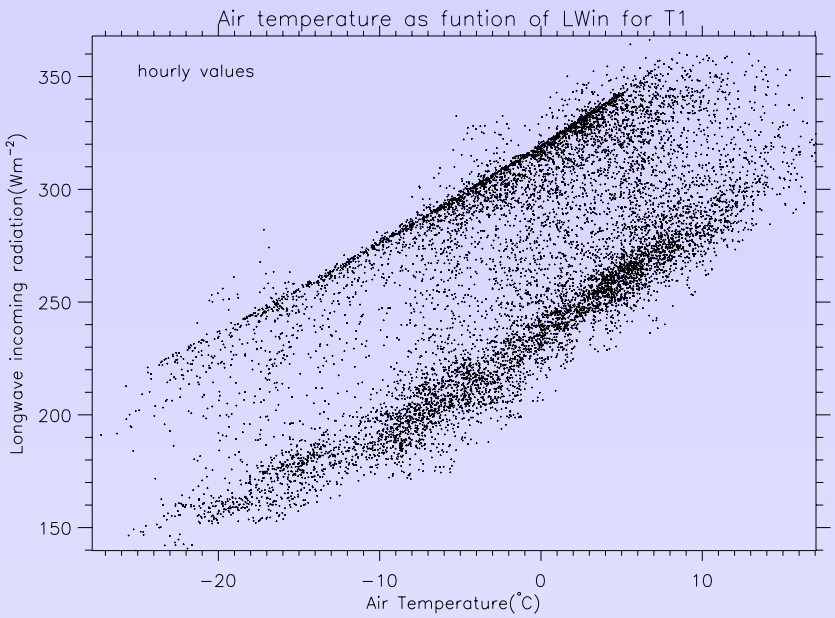

ALbedo
Lower station, 2500 masl
Upper station, 3000 masl
Albedo
1.5
1.0
0.5
224
284
324
364
42
82
122
162
202
242
277
Day of year 2004/2005

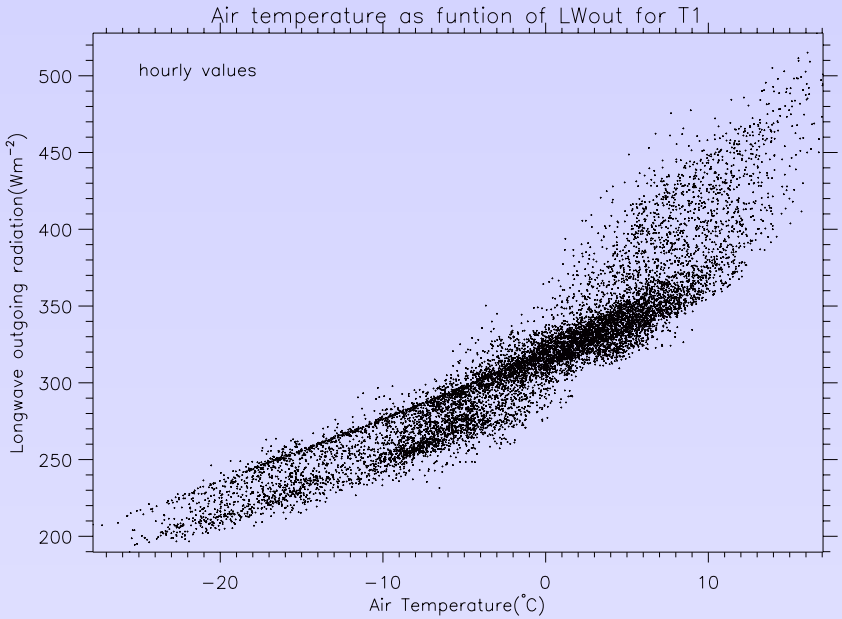

Wind speed
Lower station, 2500 masl
Upper station, 3000 masl
Wind speed (ms$^{-1}$)
0
2
4
6
8
224
284
324
364
42
82
122
162
202
242
277
Day of year 2004/2005


Wind speed as function of wind direction for T1
hourly values
Wind speed(ms$^{-1}$)
Wind direction
0
2
4
6
8
10
0
100
200
300

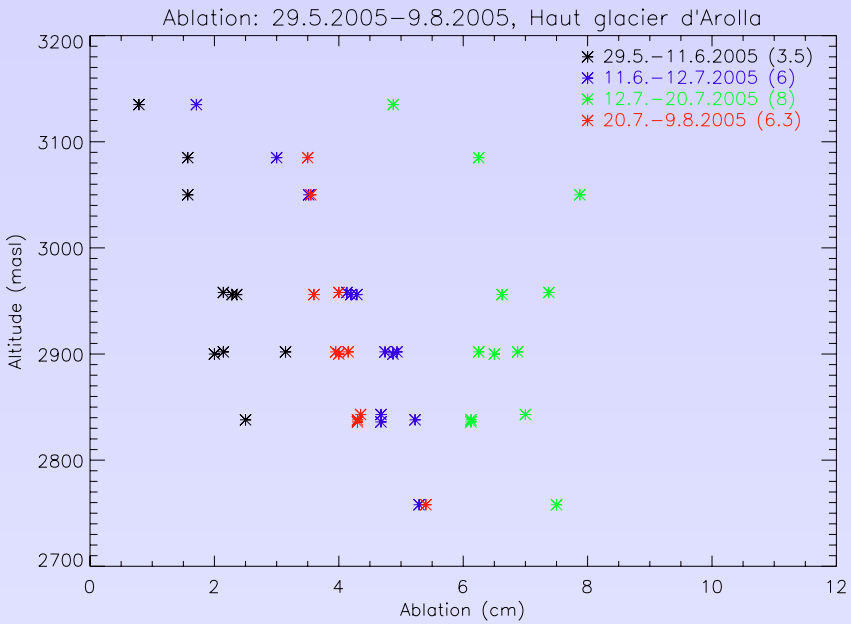

Wind speed as function of wind direction for T2
hourly values
Wind speed(ms$^{-1}$)
Wind direction
0
2
4
6
8
10
12
0
100
200
300

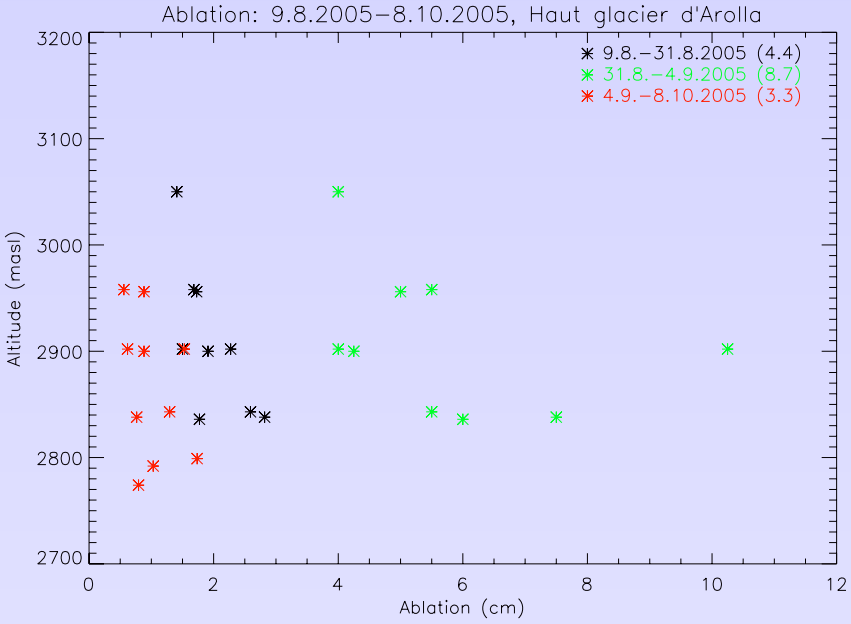

Precipitatio as function of wind direction for T1
Precipitation(mm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
Wind direction

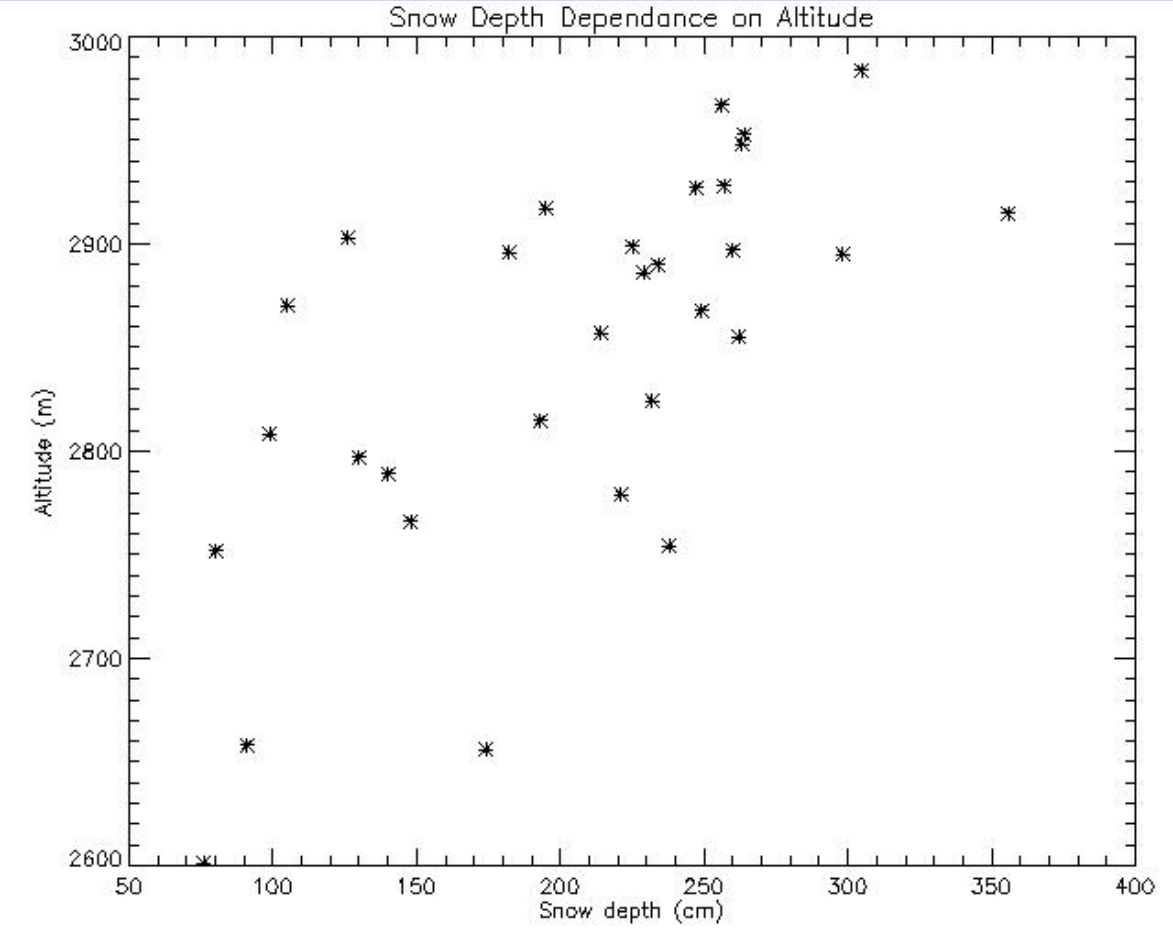

Air temperature as funtion of LWin for T1
hourly values
Longwave incoming radiation(Wm$^{-2}$)
350
300
250
200
150
−20
−10
0
10
Air Temperature(˚C)


Air temperature as funtion of LWout for T1
hourly values
Longwave outgoing radiation(Wm$^{-2}$)
500
450
400
350
300
250
200
−20
−10
0
10
Air Temperature(˚C)

# Daily Ablation




Snow Depth Dependance on Altitude
Altitude (m)
3000
2900
2800
2700
2600
50
100
150
200
250
300
350
400
Snow depth (cm)

# Sub-models

Spatially-distributed snow-evolution modeling system

- Preprocessing of AWS-data: filling in of missing data, and checking the files for realistic values
- MicroMet: distribution of meteorological variables
- EnBal: surface energy exchange
- SnowPack: snow depth and water equivalent evolution
- SnowTran-3D: snow redistribution by wind

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## Simulated Processes

- Snow accumulation
- Blowing snow redistribution and sublimation
- forest-canopy interception, unloading and sublimation
- Snow-density evolution
- Snowpack melt

## Scale

- Spatial scale: 5m to global
- Temporal scale: 10 minutes to seasonal

# Required Model Inputs

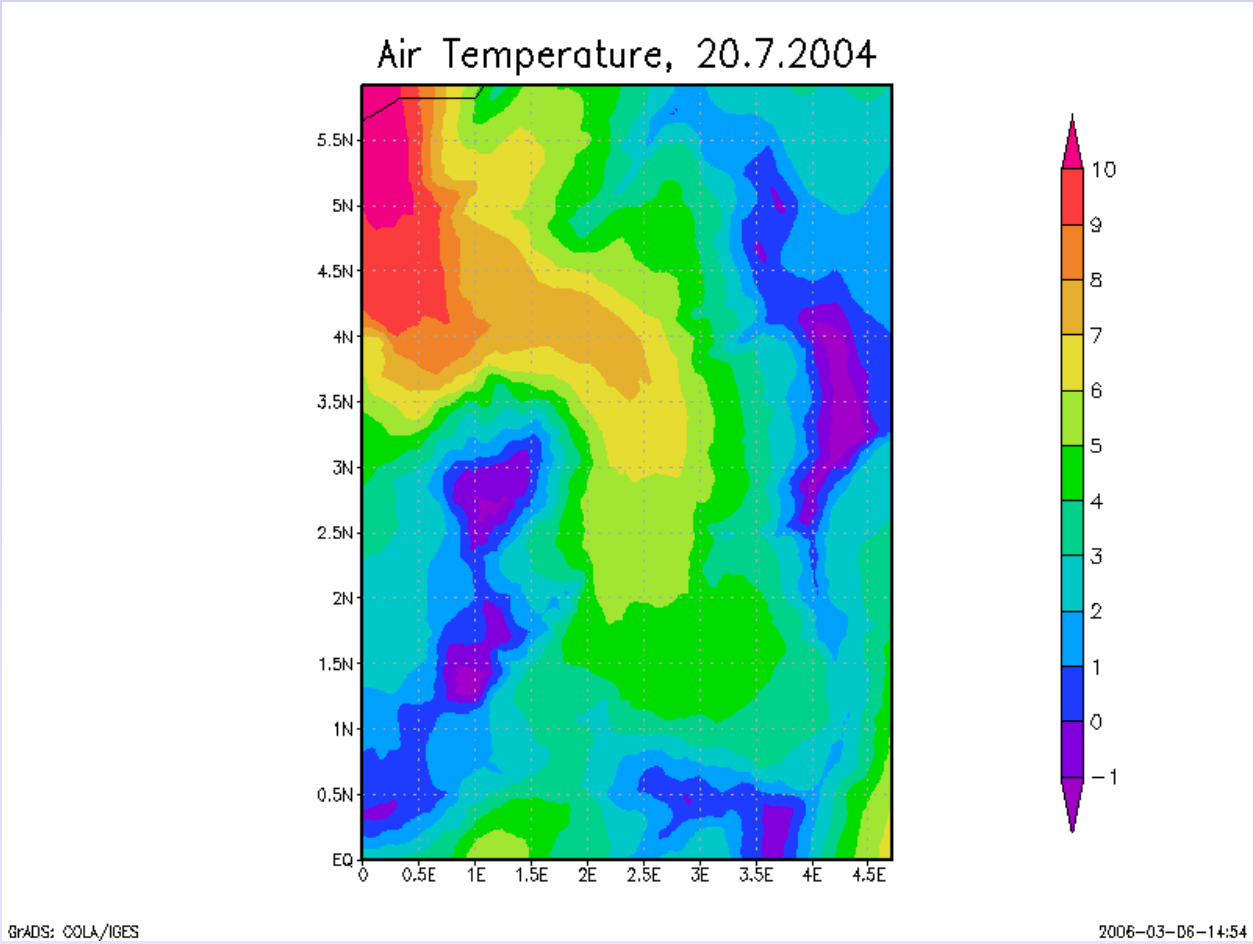
- DEM
- Vegetation type mask
- Precipitation
- Wind speed and wind direction
- Air temperature
- Relative humidity

# Micromet: Distributed Variables

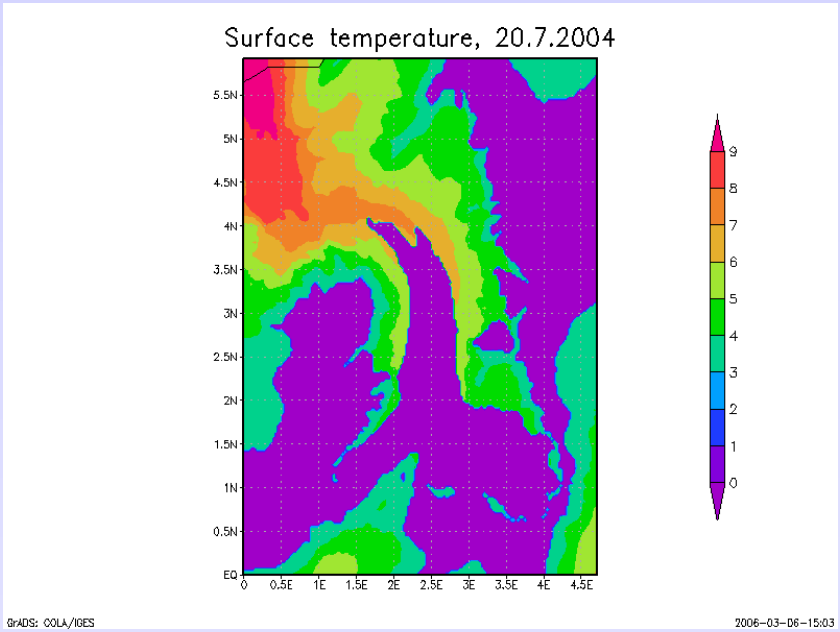
- !tair: with monthly defined lapse rates
- rh: monthly defined lapse rates depending on tair and elevation
- !ws and wd: topographically driven wind model (slope, azimuth and curvature)
- !swin: DEM(sloping terrain), cloud cover (derived from tair and rh)
- lwin: cloud cover, tair
- surface pressure: time independent atmospheric pressure distribution
- !precipitation: elevation, monthly defined lapse rates

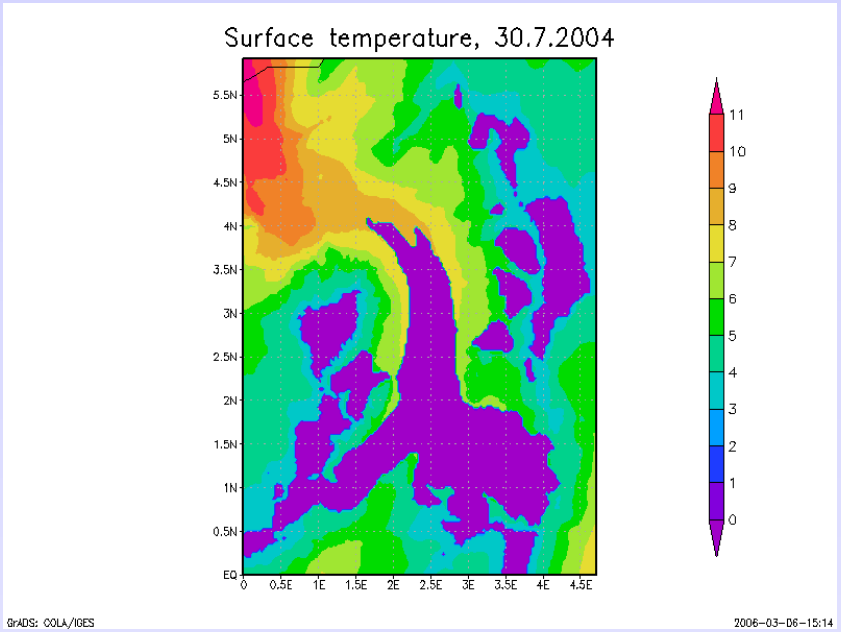
- SnowModel has been applied in Alaska, Norway, Greenland, Antarctica, and mountains of the western United States, but it has never been applied to topographic distributions as steep and complex as the Swiss Alps
- Does not represent wind field realistically
- Does not have a process to get the snow down from the steep slopes
- Precipitation in complex terrain is not represented correctly
- Air temperature in summer over glacier is wrong

# Air Temperature

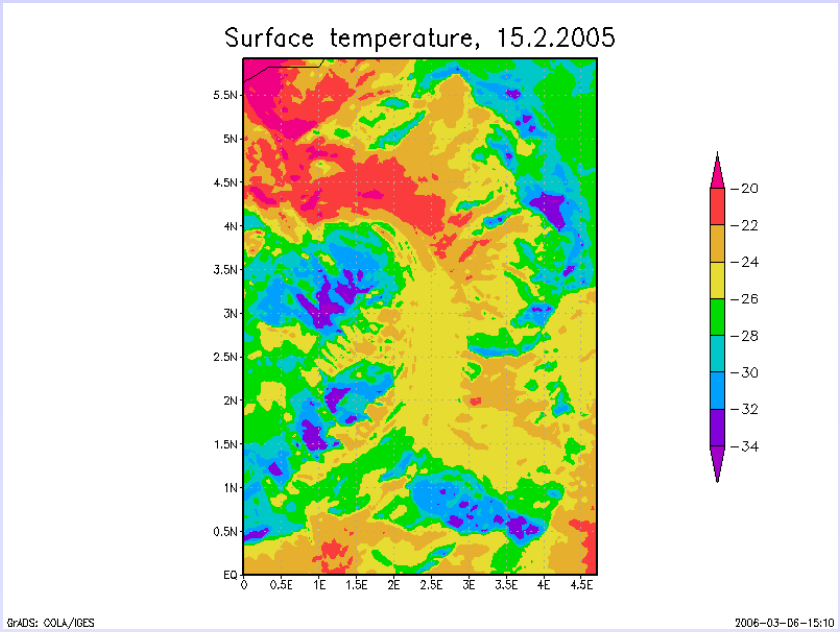


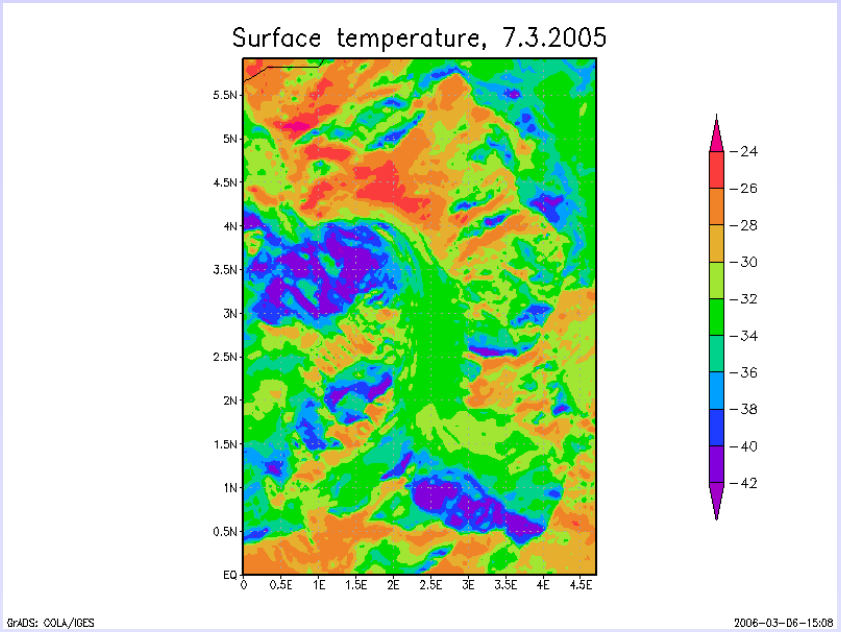
# Surface (skin) temperature 2004



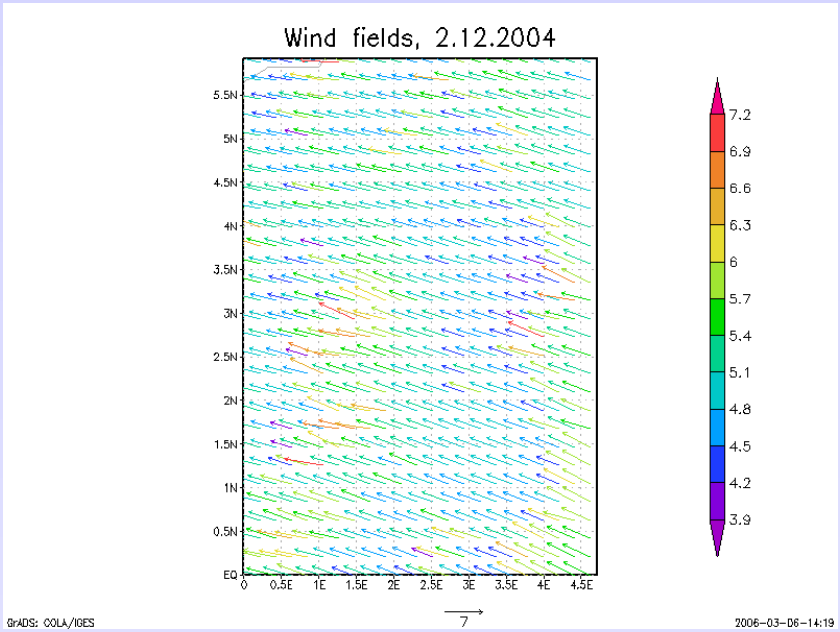



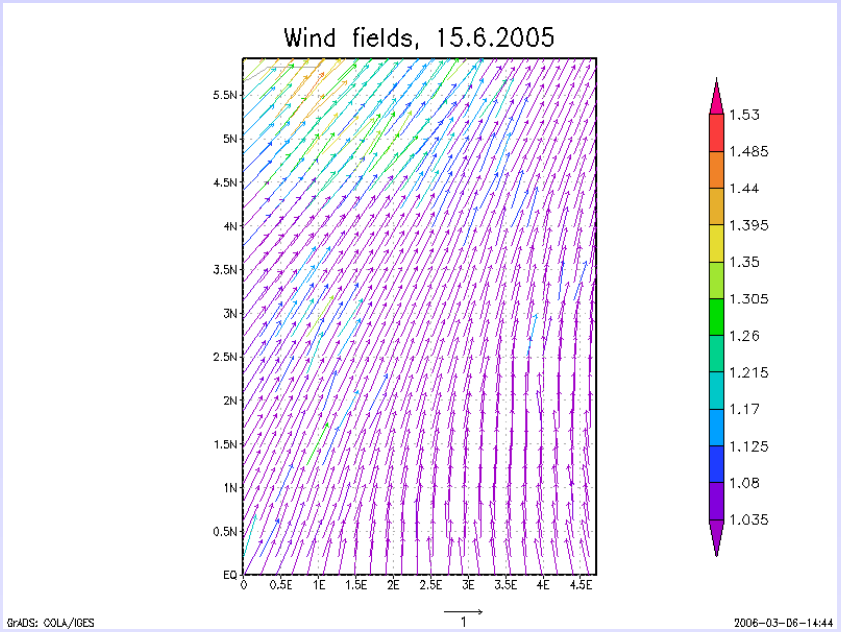
# Surface (skin) Temperature 2005



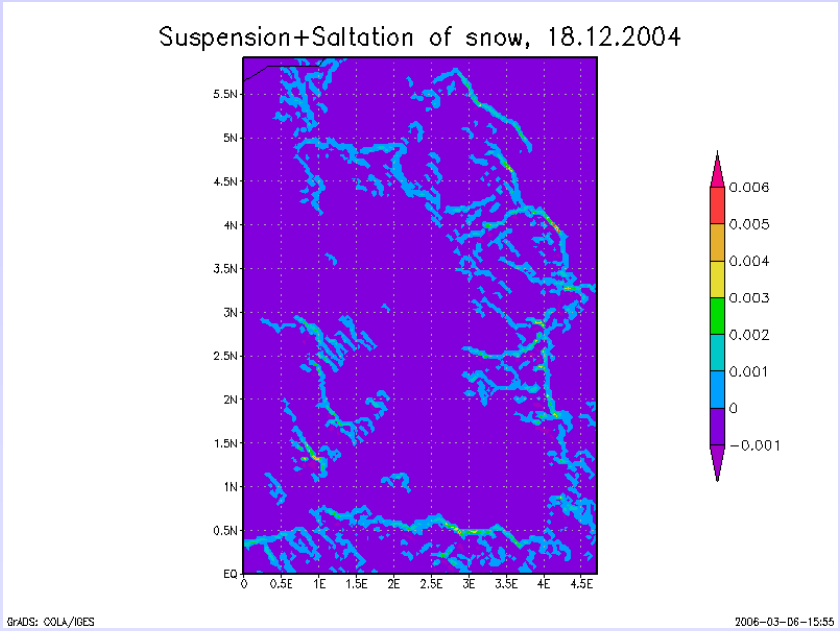



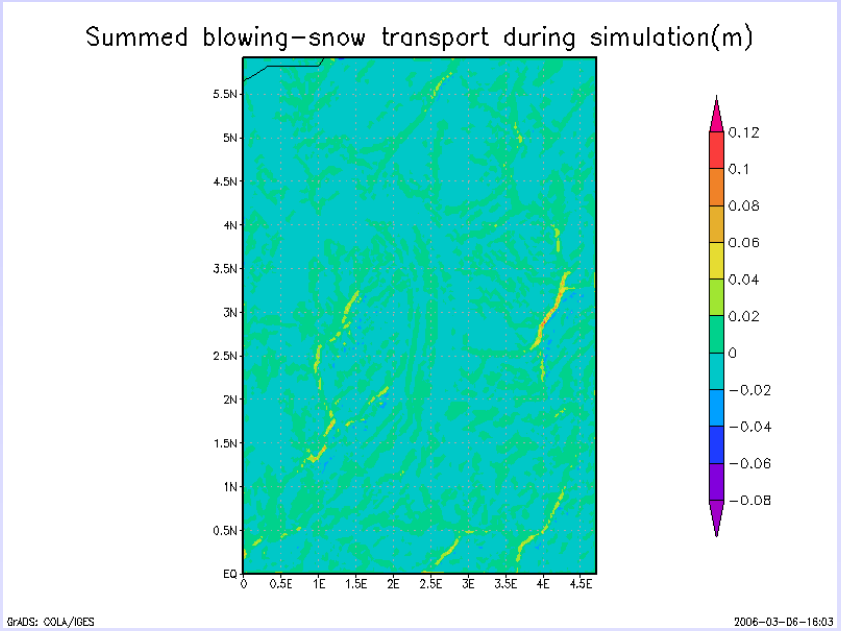
# Wind Field


Wind fields, 2.12.2004
5.5N
5N
4.5N
4N
3.5N
3N
2.5N
2N
1.5N
1N
0.5N
EQ
0
0.5E
1E
1.5E
2E
2.5E
3E
3.5E
4E
4.5E
7.2
6.9
6.6
6.3
6
5.7
5.4
5.1
4.8
4.5
4.2
3.9
7
GrADS: COLA/IGES
2006-03-06-14:19


Wind fields, 15.6.2005
5.5N
5N
4.5N
4N
3.5N
3N
2.5N
2N
1.5N
1N
0.5N
EQ
0
0.5E
1E
1.5E
2E
2.5E
3E
3.5E
4E
4.5E
1.53
1.485
1.44
1.395
1.35
1.305
1.26
1.215
1.17
1.125
1.08
1.035
1
GrADS: COLA/IGES
2006-03-06-14:44

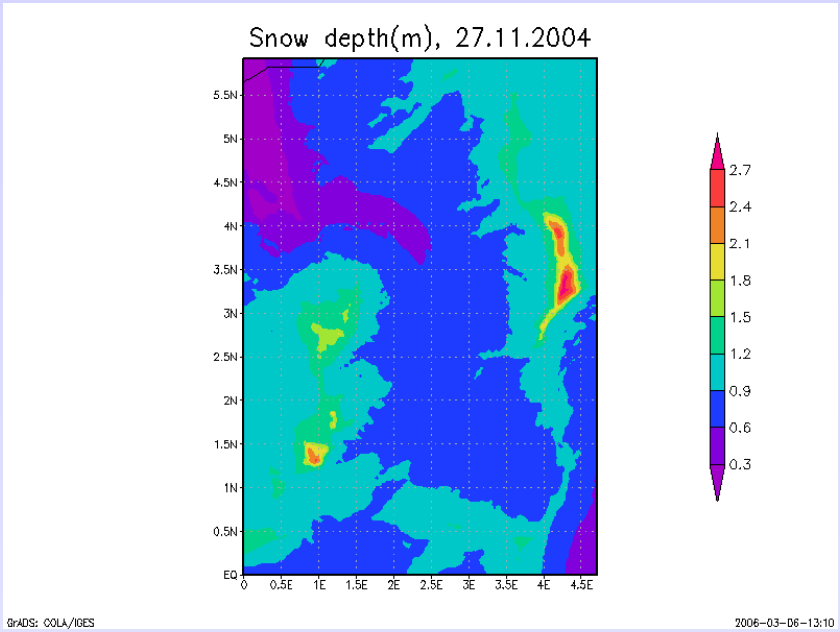
# Snow Transport

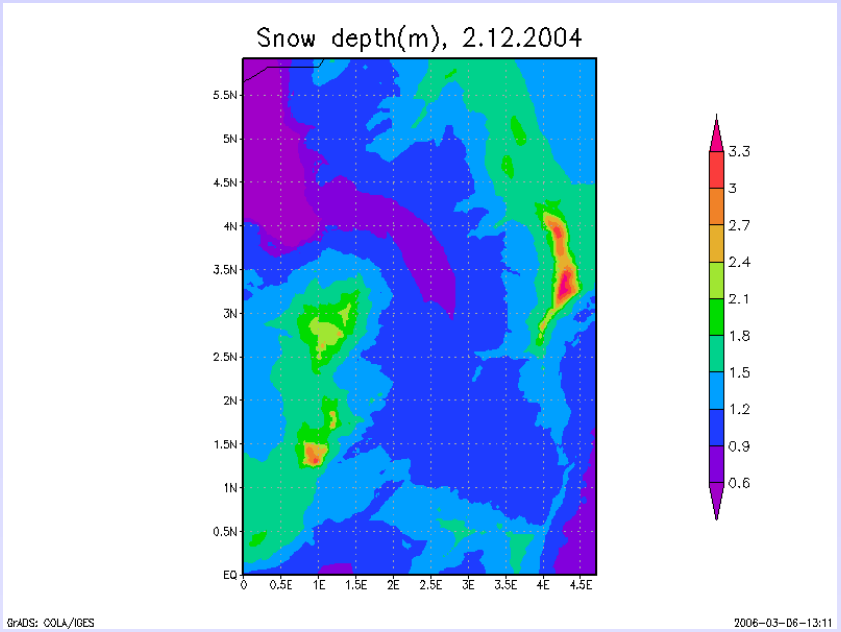


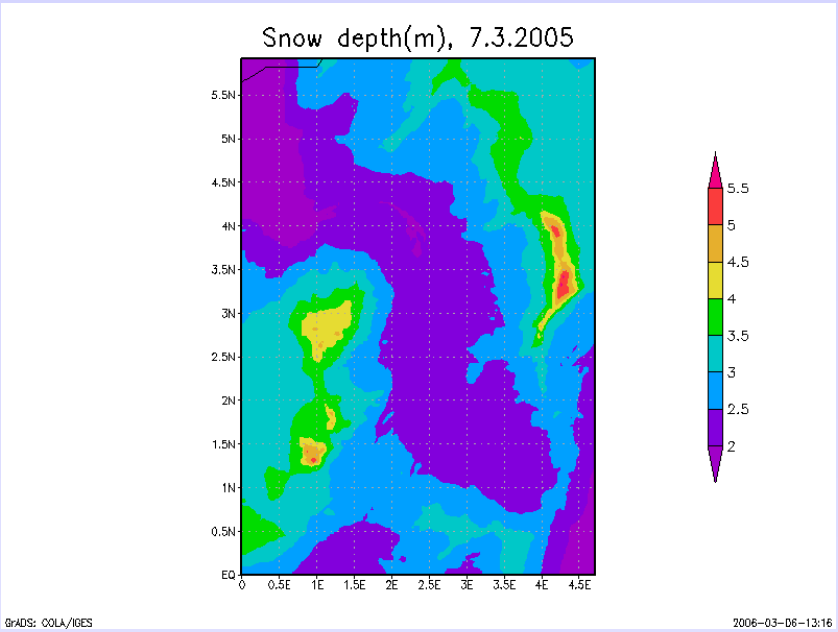

Very low rates of snow transported by wind $\Rightarrow$ The model uses the same threshold friction velocity for all sorts of snow. This needs to be changed for different snow densities.

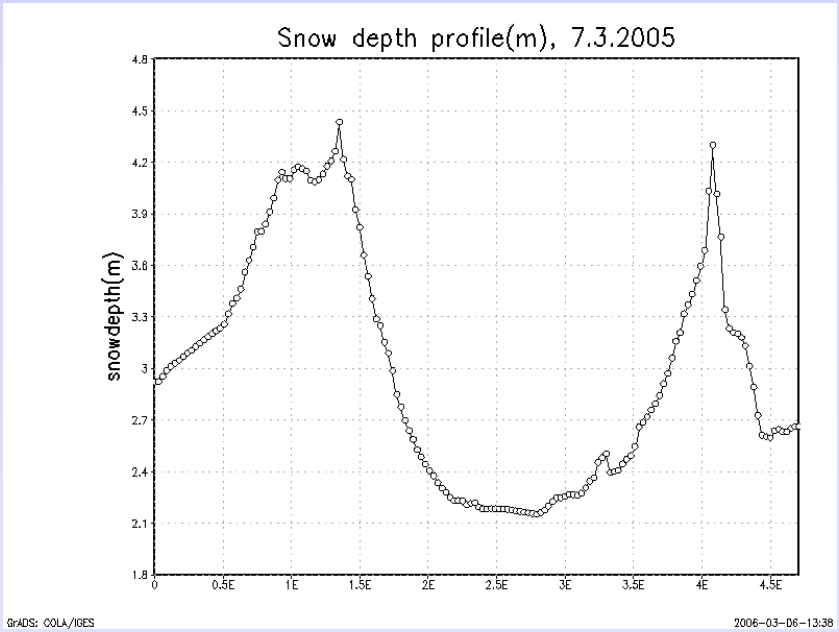
# Snow Depth, Dec / Jan 2004



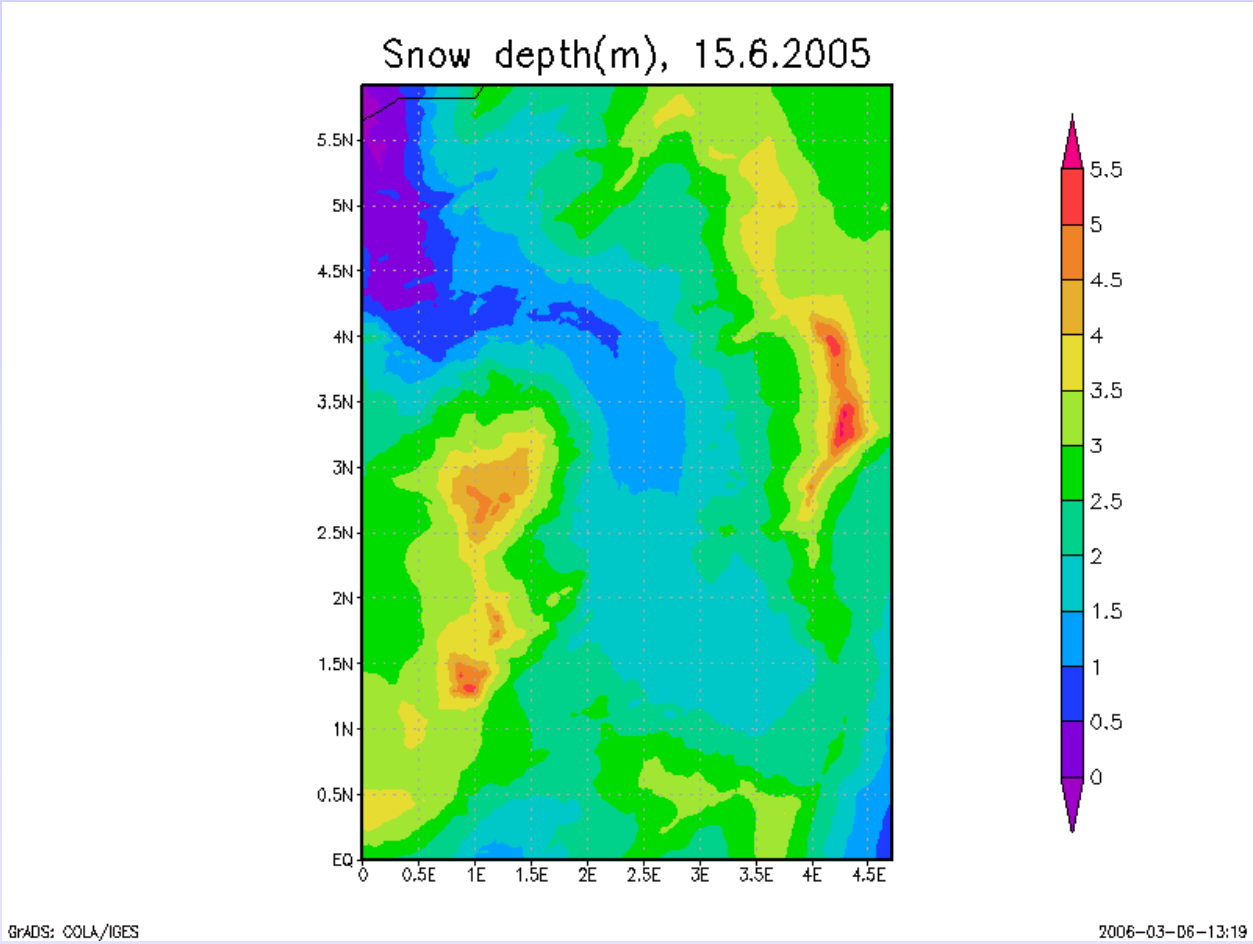



# Snow Depth, Feb / Mar 2005

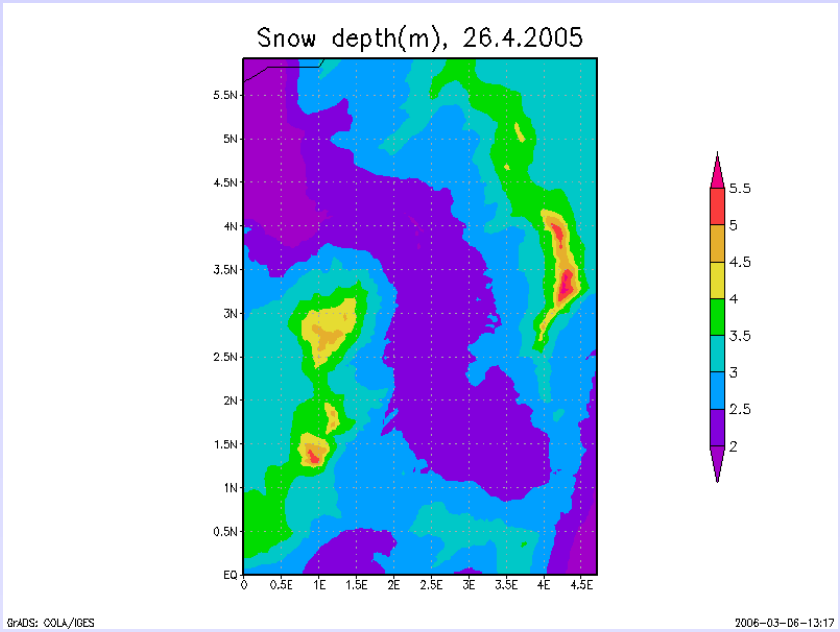


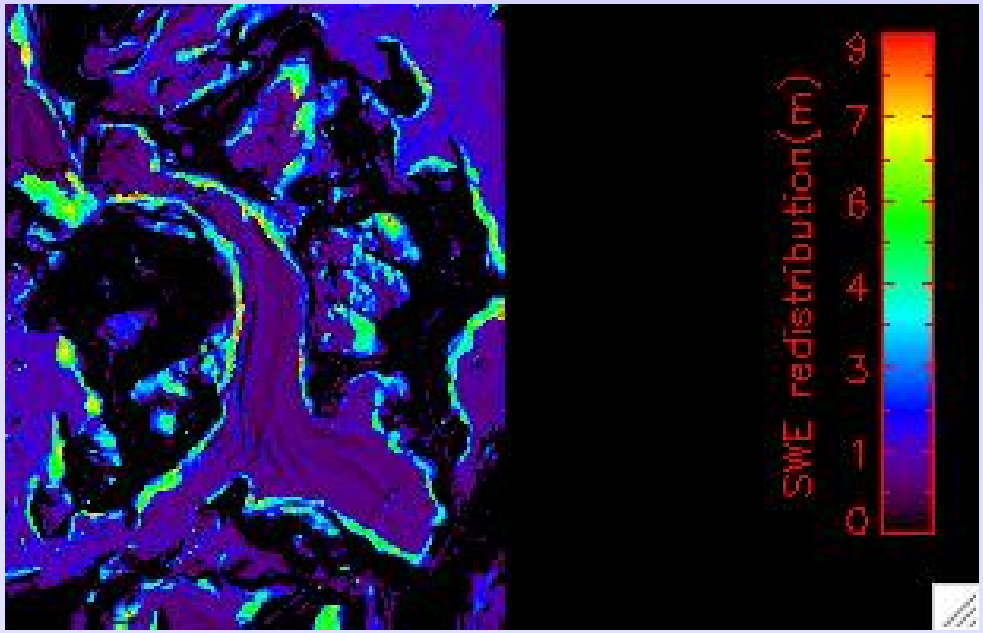



# Snow Depth, June 2005



# Snow depth, including avalanches: 16.4.2005



## Meteorological Variables

- Energy balance for glaciers $\Rightarrow$ Javier's model
- Wind field

## Accumulation Processes

- Precipitation distribution
- Snow Transport
- Avalanching $\Rightarrow$ S.Gruber