Icefield breezes over Athabasca Glacier, Columbia Icefield.

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CCRN
Changing Cold Regions Network

Motivation: How do mountain glaciers modify the climate they "see"

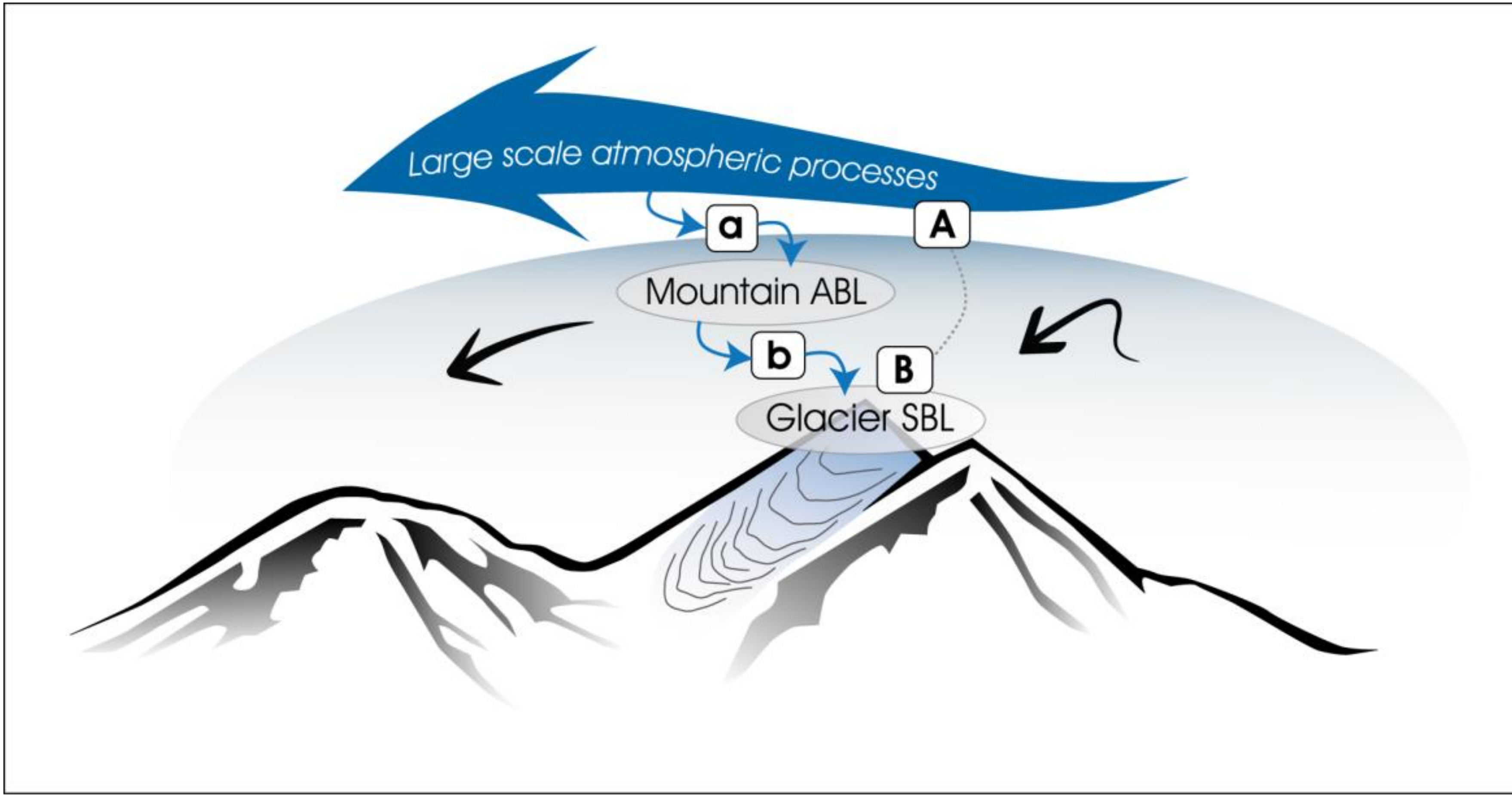
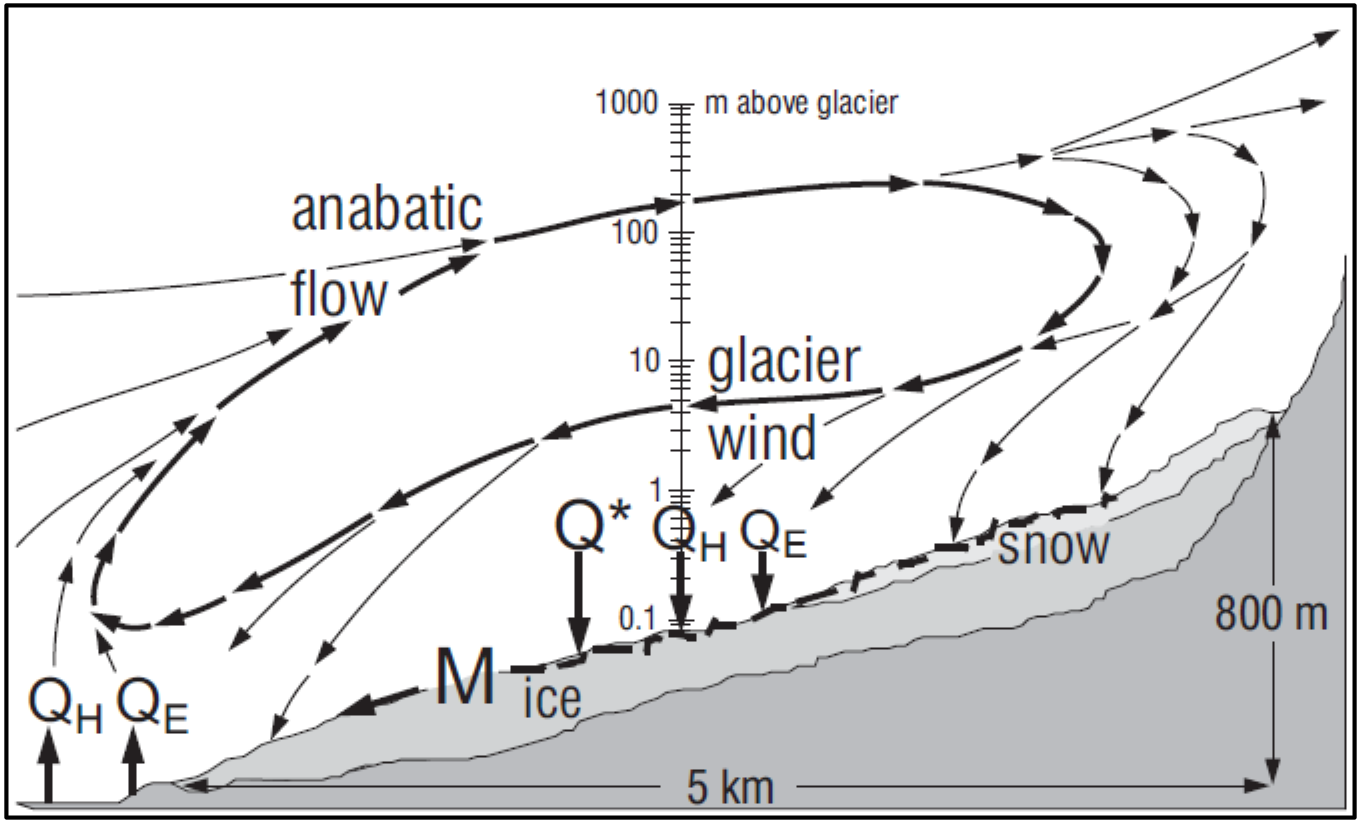


Figure courtesy of Nicolas Cullen

This will have implications for how we model the effect of changing climate on a glacier – both past and future

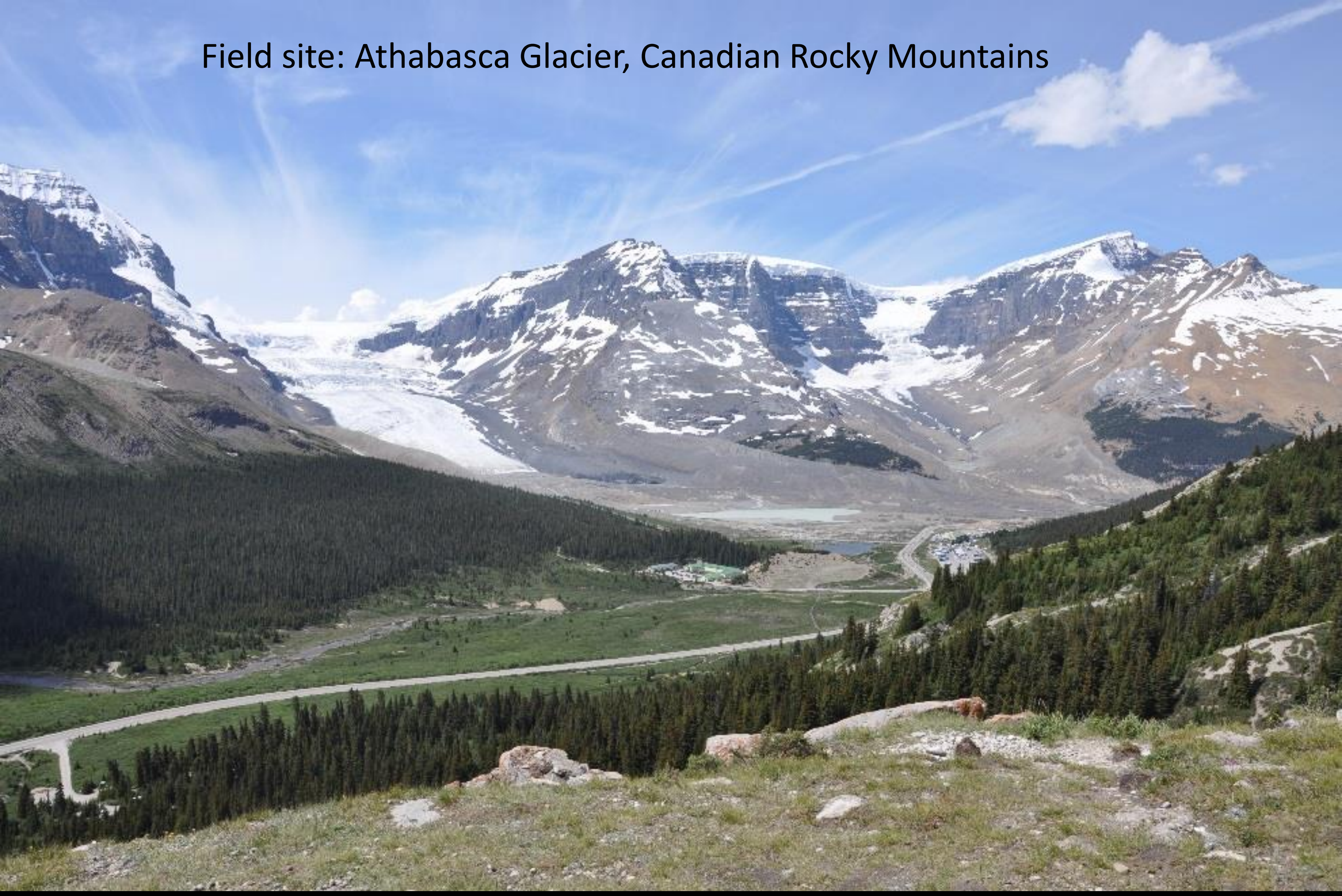
Rationale: what we expect



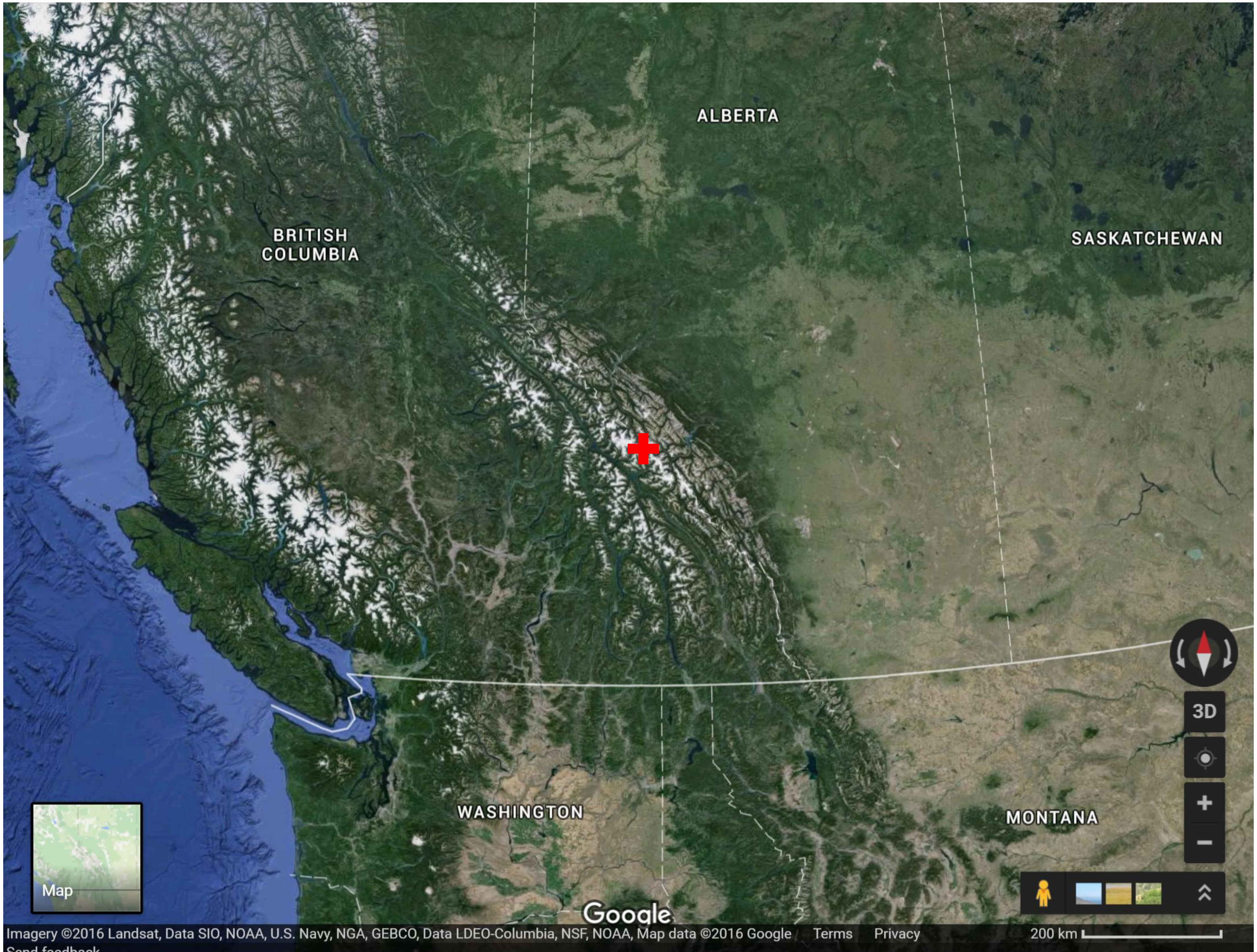
Theoretical daytime circulation above glacier (from Munro, 2006; after van den Broeke, 1997)

>> 'Glacier wind' driven by sensible heat exchange from warm air into glacier surface.
>> Weaker anabatic return flow in valley above.
>> Lapse rate function of cooling from sensible heat and adiabatic warming
>> Limited number of field studies, but basis of empirical lapse rate models.

Field site: Athabasca Glacier, Canadian Rocky Mountains



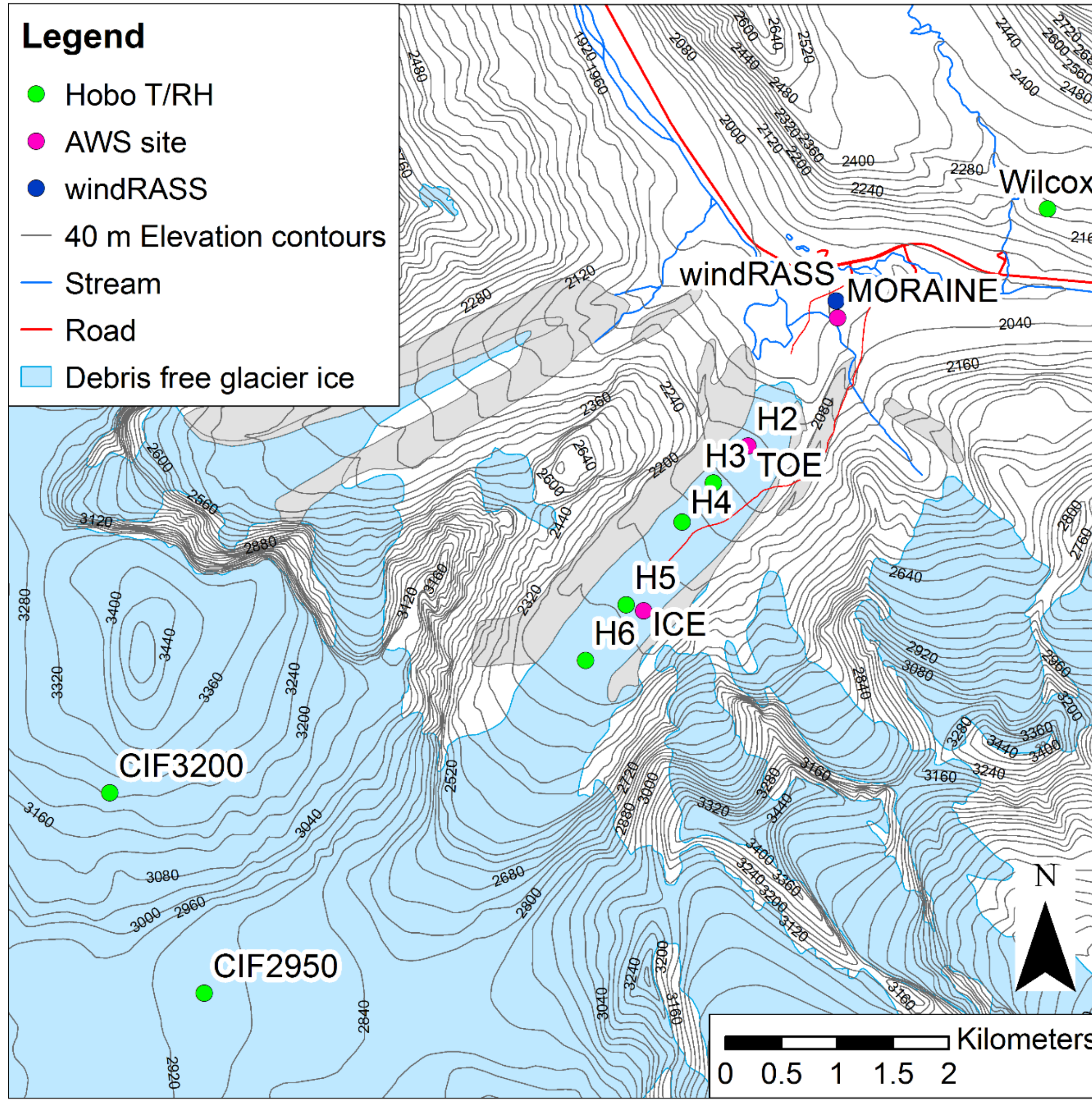
Columbia Icefield – hydrological apex of North America



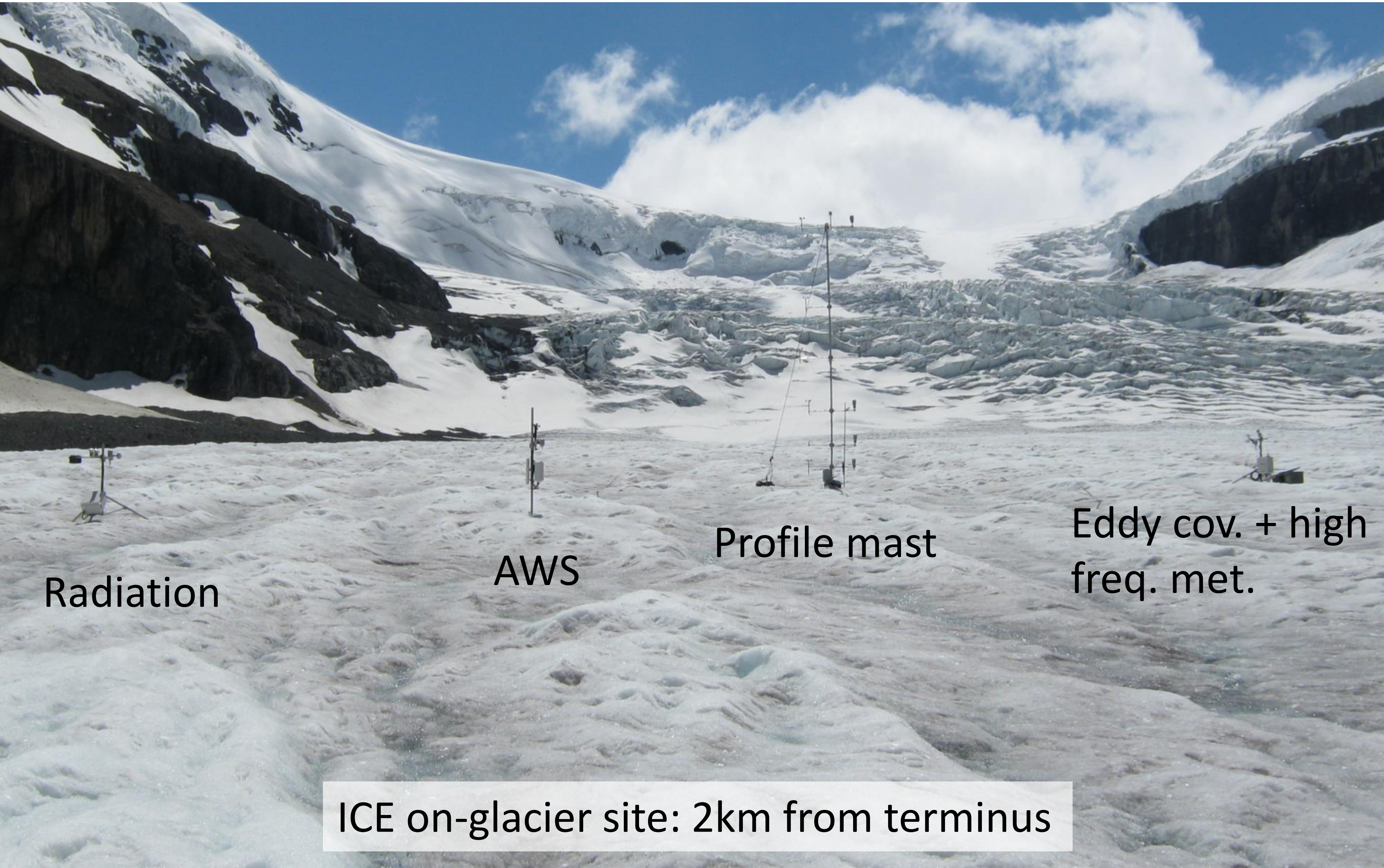
Field campaign: Athabasca Glacier

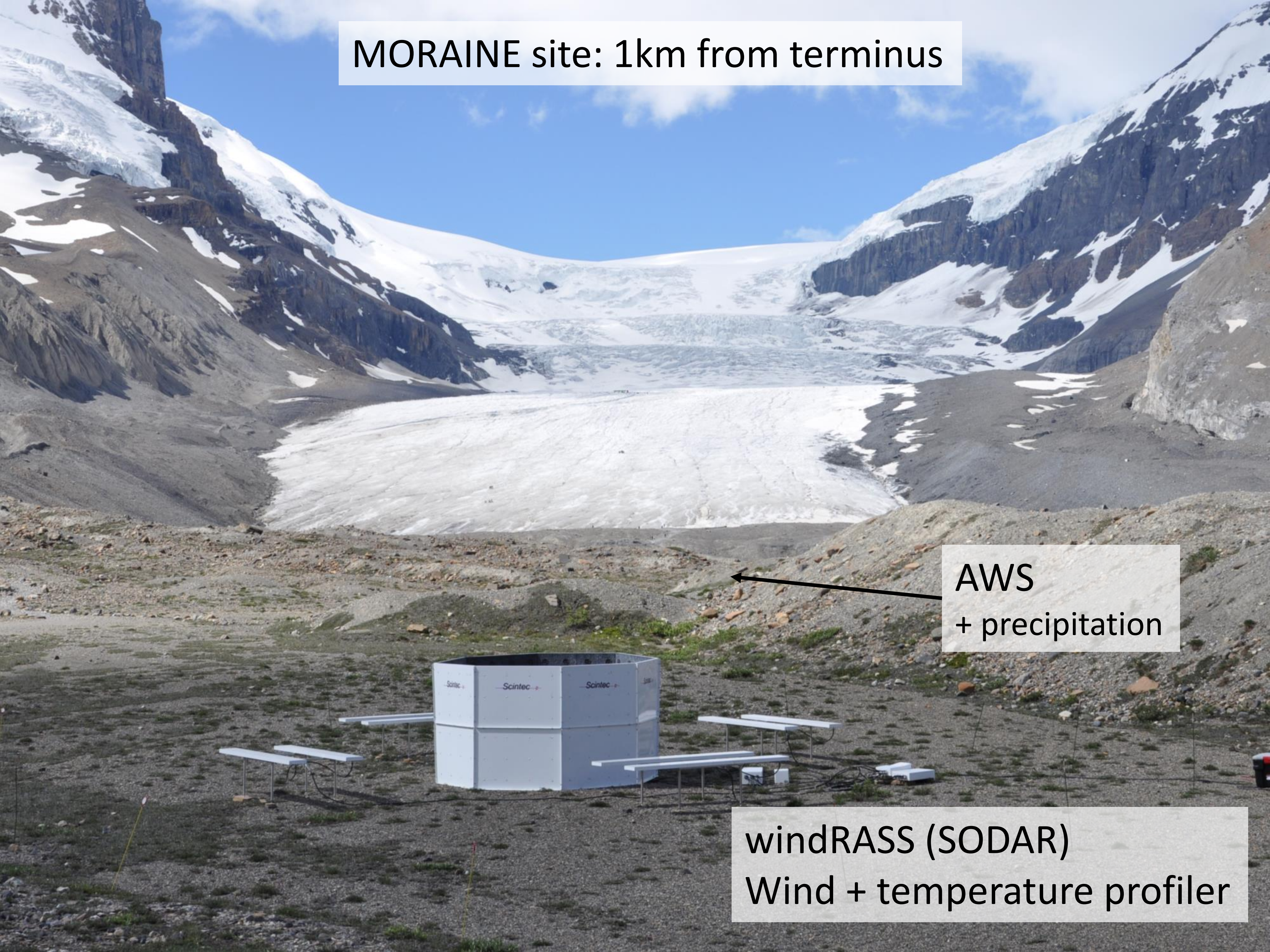
Intensive surface observations and ground based remote sensing June 17-30, 2015

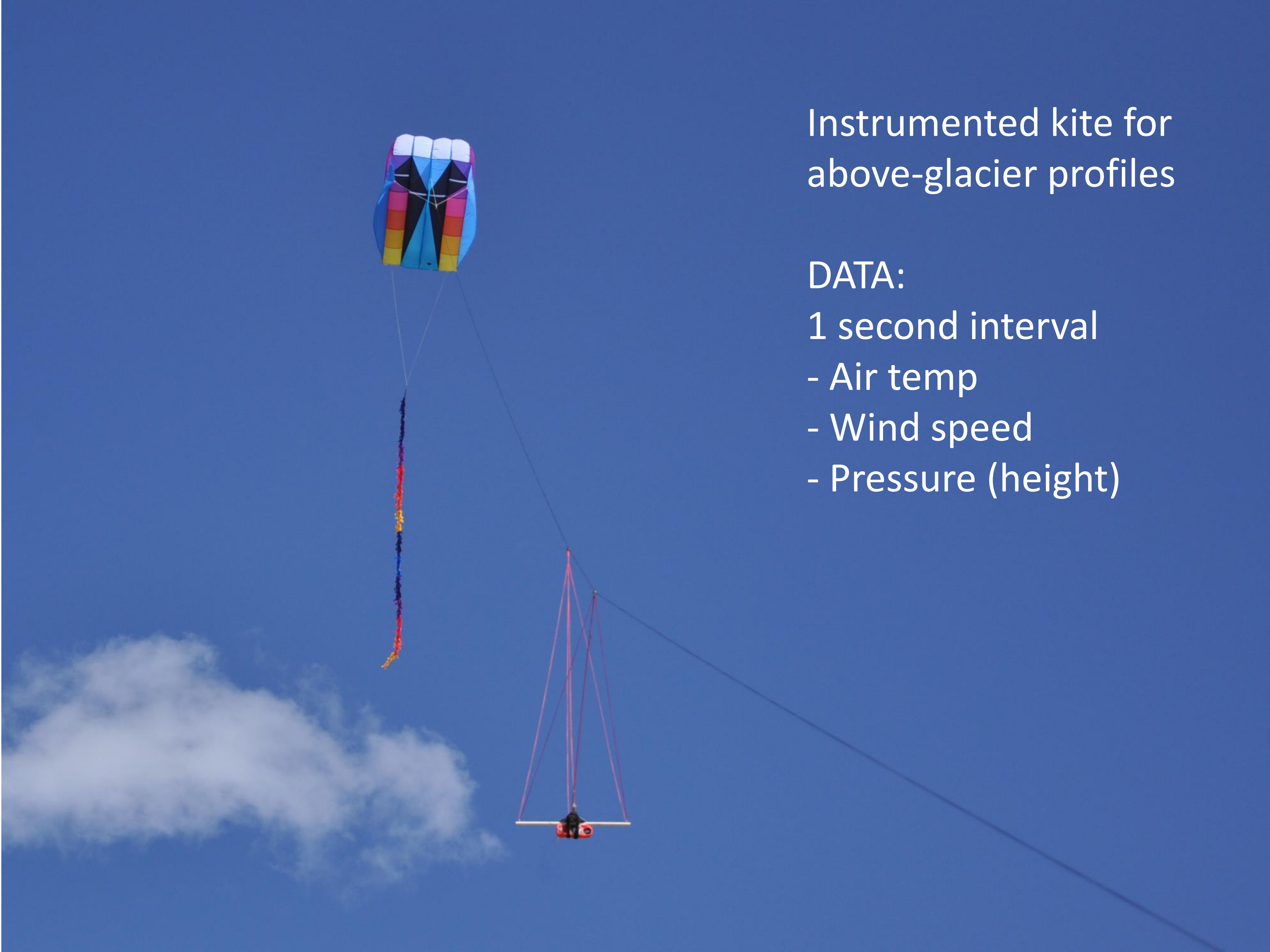
AIM: characterize the atmospheric circulation in the glacier-valley system and how it influences spatiotemporal variations in surface meteorological



Instrumentation: Observing the glacier atmospheric surface boundary layer




MORAINE site: 1km from terminus
AWS
+ precipitation
Scintec
windRASS (SODAR)
Wind + temperature profiler



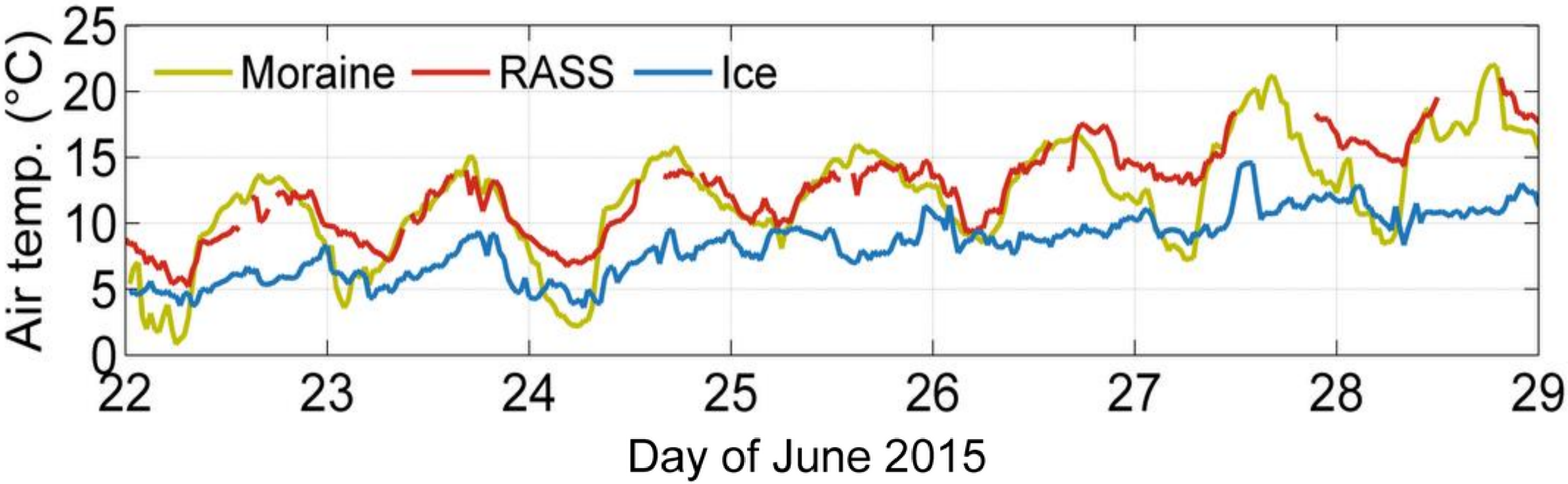
Instrumented kite for above-glacier profiles

DATA:

1 second interval

- Air temp
- Wind speed
- Pressure (height)

Observations: Diurnal cycle of air temperature



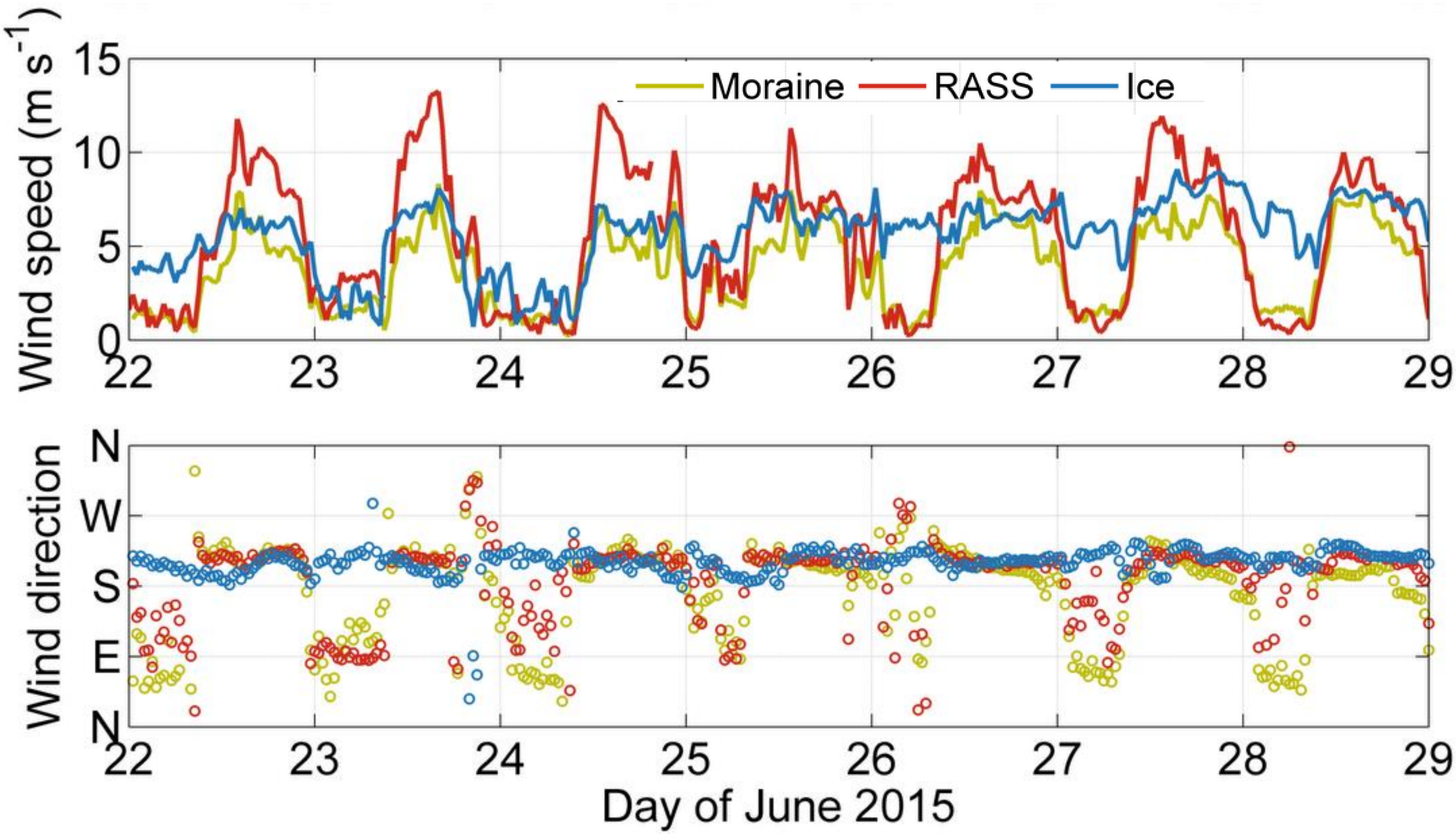
Air temperature (°C) at selected sites over the 7 day period in June

>> Period with little synoptic pressure gradients and no precipitation chosen. General warming trend over 7 days.

>> Strong diurnal cycle off-glacier seen at both 2 m and 50 m.

>> Dampened diurnal cycle on-glacier, especially later in period

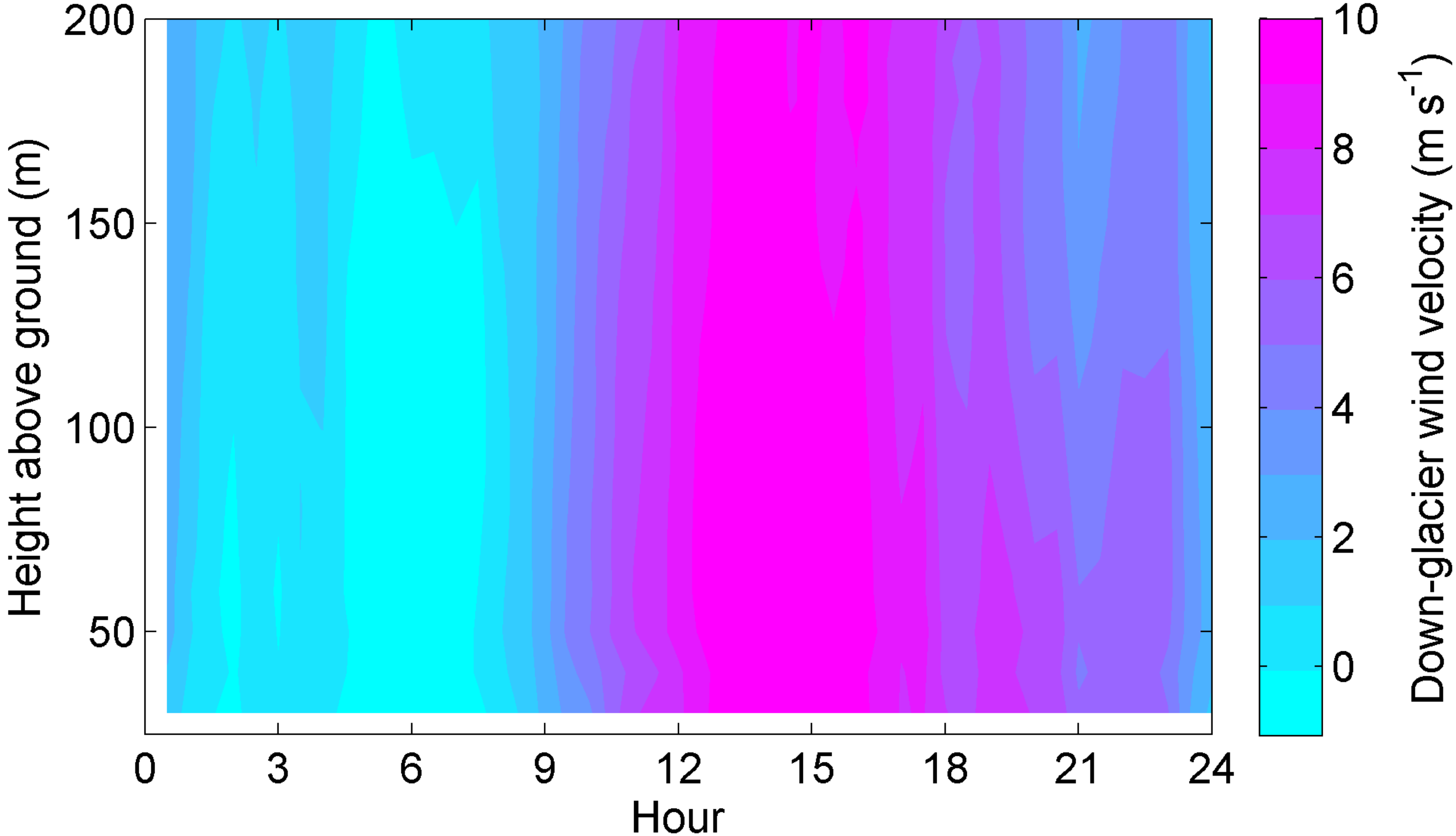
Observations: Wind speed and direction



Wind speed (top) and direction (bottom) at selected sites over 7 day period

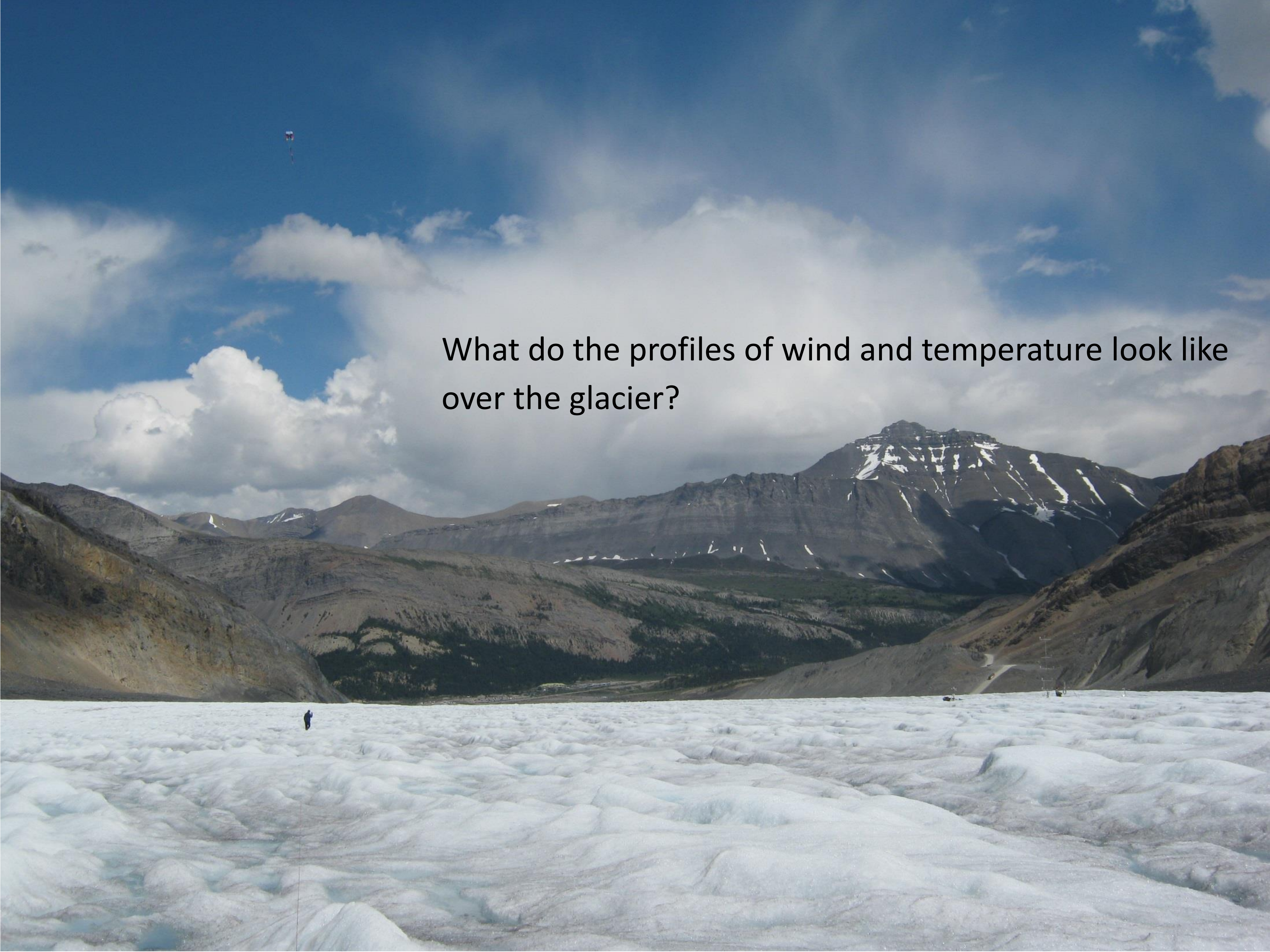
>> On-glacier – "katabatic" dominant. Shows threshold with air temperature.
>> Off-glacier – strong winds come from glacier, mid-morning till midnight

Observations: Vertical structure of winds in ice free valley



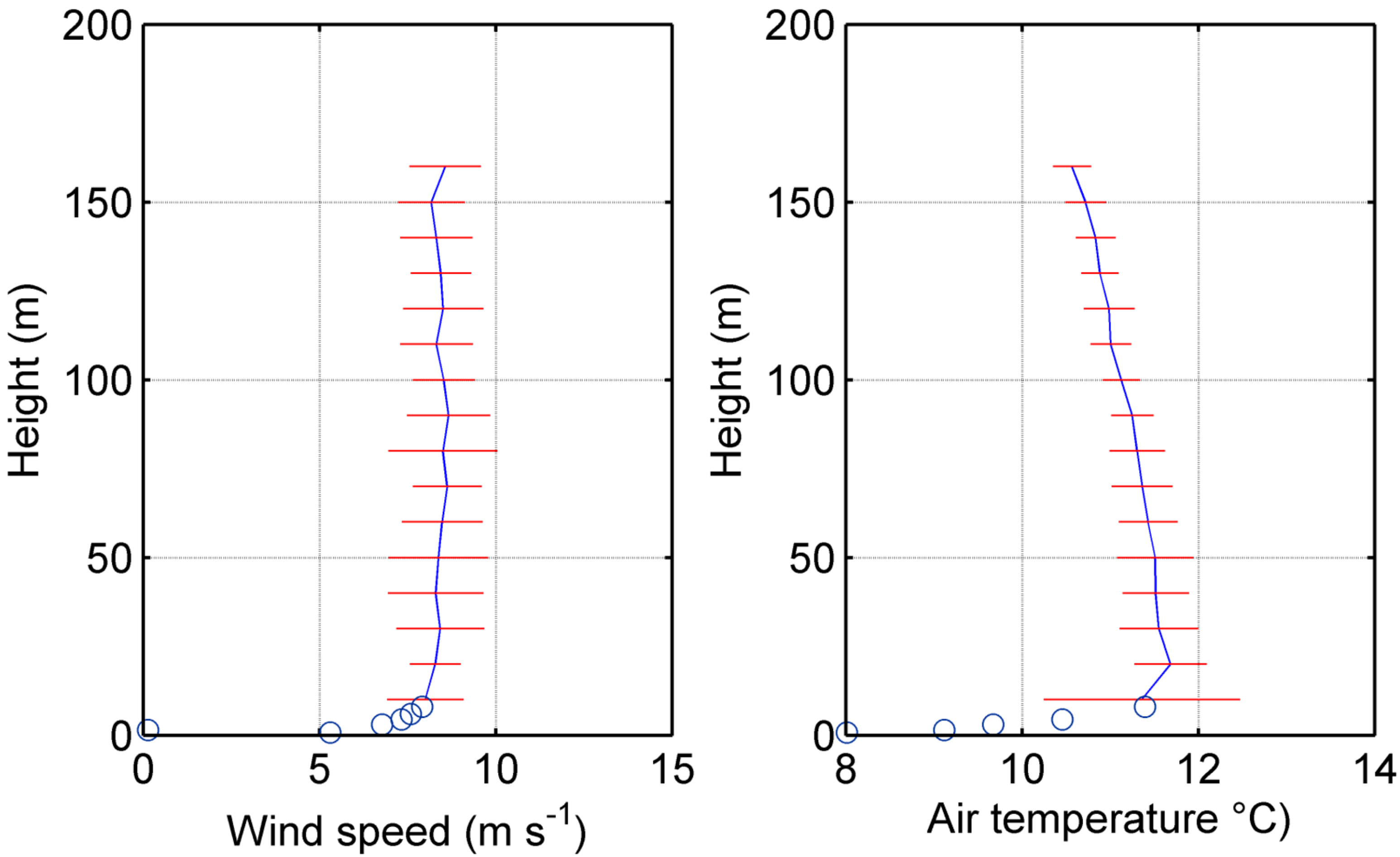
Mean diurnal cycle of down-glacier wind velocity 22 - 28 June above MORAINE site

>> Onset of off-glacier winds is fairly rapid through lowest 200m


What do the profiles of wind and temperature look like
over the glacier?


Instrumented kite for above-glacier profiles
- No permits needed
- $1000 for full system
- One person operation
- Deploys in minutes
DATA:
1 second interval
- Air temp
- Wind speed
- Pressure (height)

Observations: Vertical structure of ABL on-glacier from kite profiling

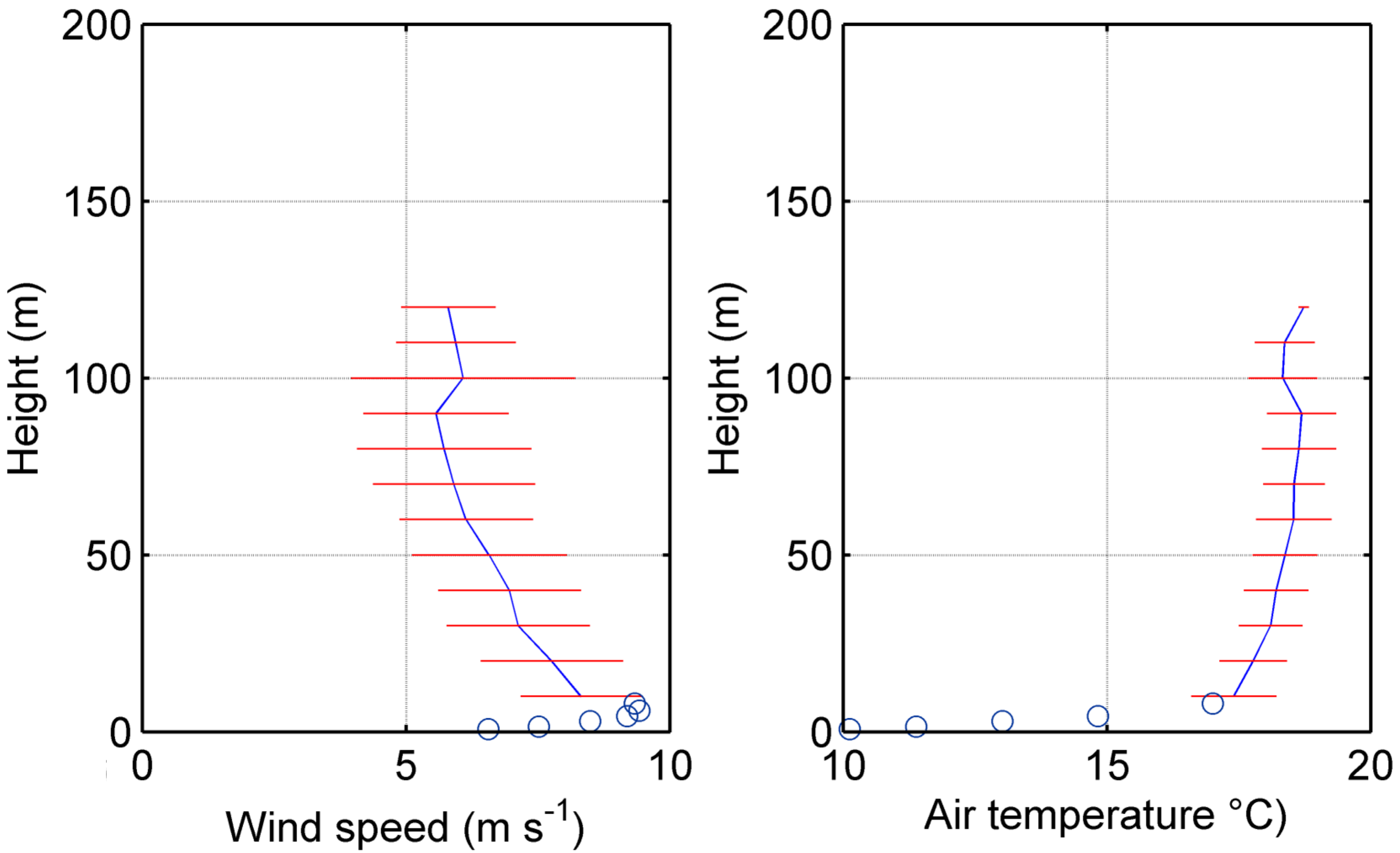


Characteristic profile of wind speed and air temperature above ICE (1600 h on 24th June)

>> Even wind gradient with no return flow in lowest 200 m

>> Shallow surface boundary layer (~20 metres) – decoupled?

Observations: Vertical structure of ABL on-glacier from kite profiling

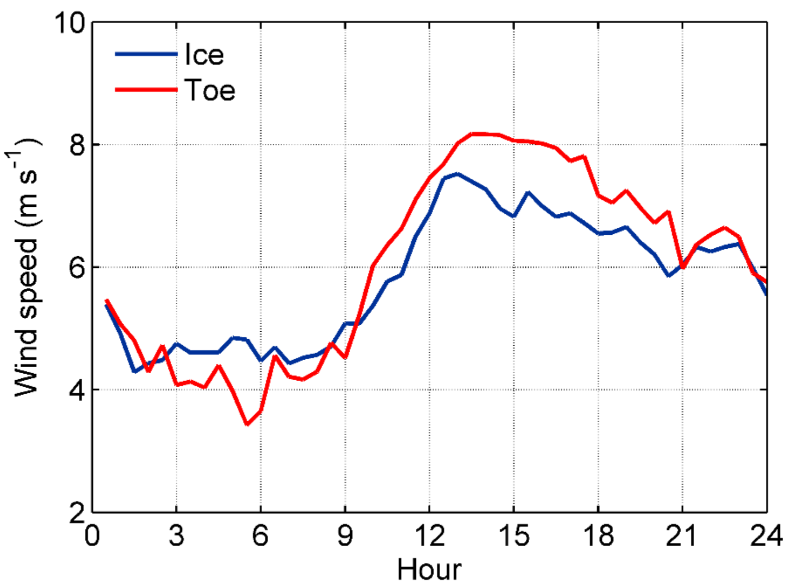


Profile of wind speed and air temperature ICE at 1500 h on 28th June

>> Shallow wind speed max at 6 m and extensive cooling typical of 'glacier wind' observed on one day only.

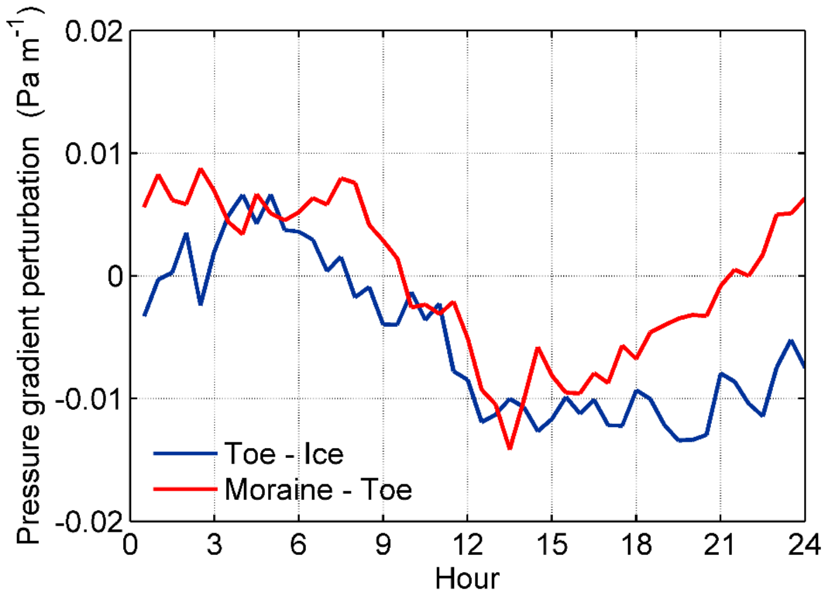
Drivers: mechanism for down-glacier winds

Wind speed



Mean diurnal cycle of wind speed at ICE and TOE sites 22 - 28 June.

Horizontal pressure gradient

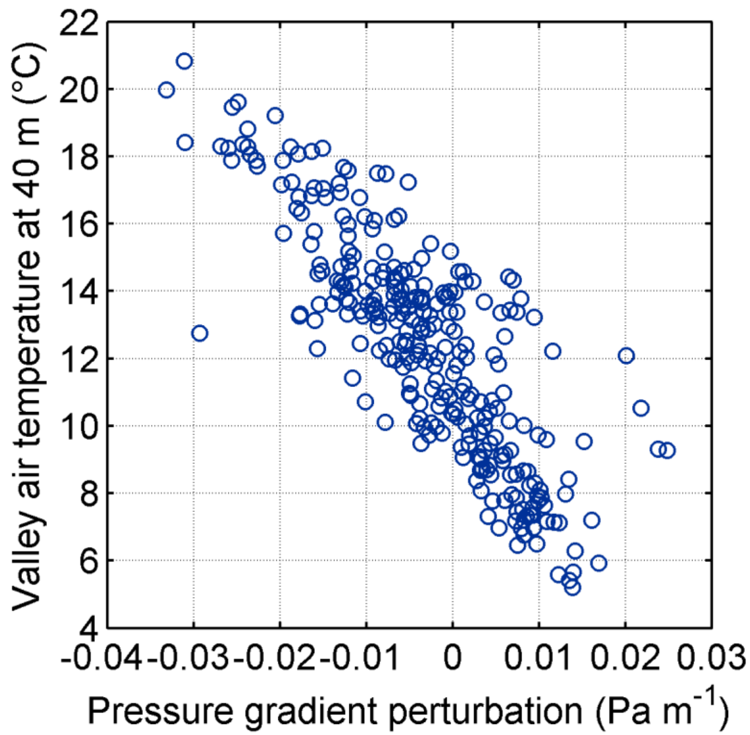


Mean diurnal pressure gradient perturbation (dP/dx) between AWS sites, 22 - 28 June.

>> Surface (horizontal) pressure gradient occurs along with diurnal cycle of wind speed.

>> Order of magnitude larger than synoptic pressure gradient

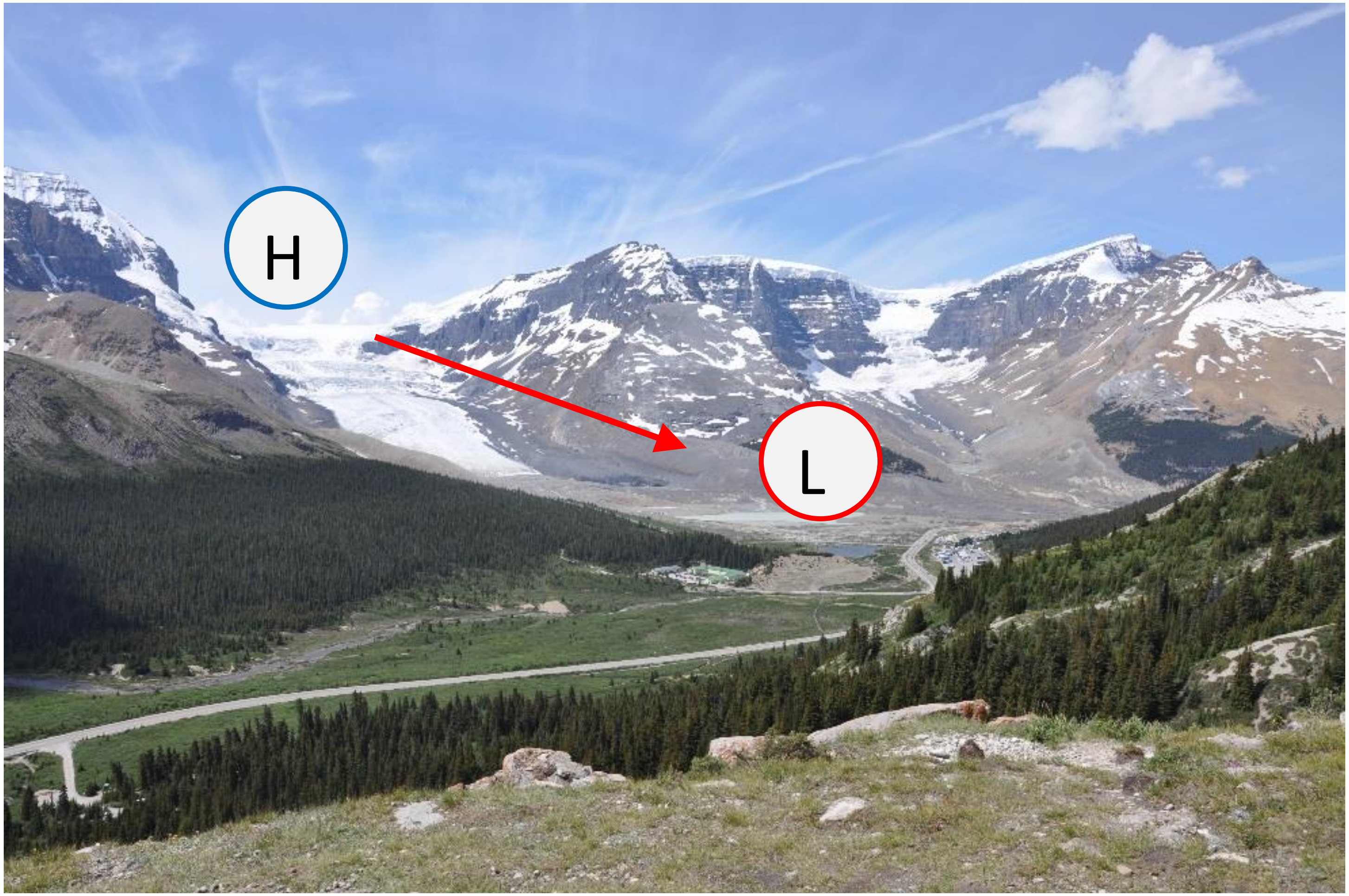
Drivers: mechanism for down-glacier winds



Scatter of dP/dx (TOE-ICE) and air temperature at 40 m above MORAINE, 18-29th June.

>> As air temperature in valley increases, pressure gradient between icefield and valley develops, which in turn sucks air down into valley.

Drivers: Thermal contrast appears to drive strong down-glacier wind

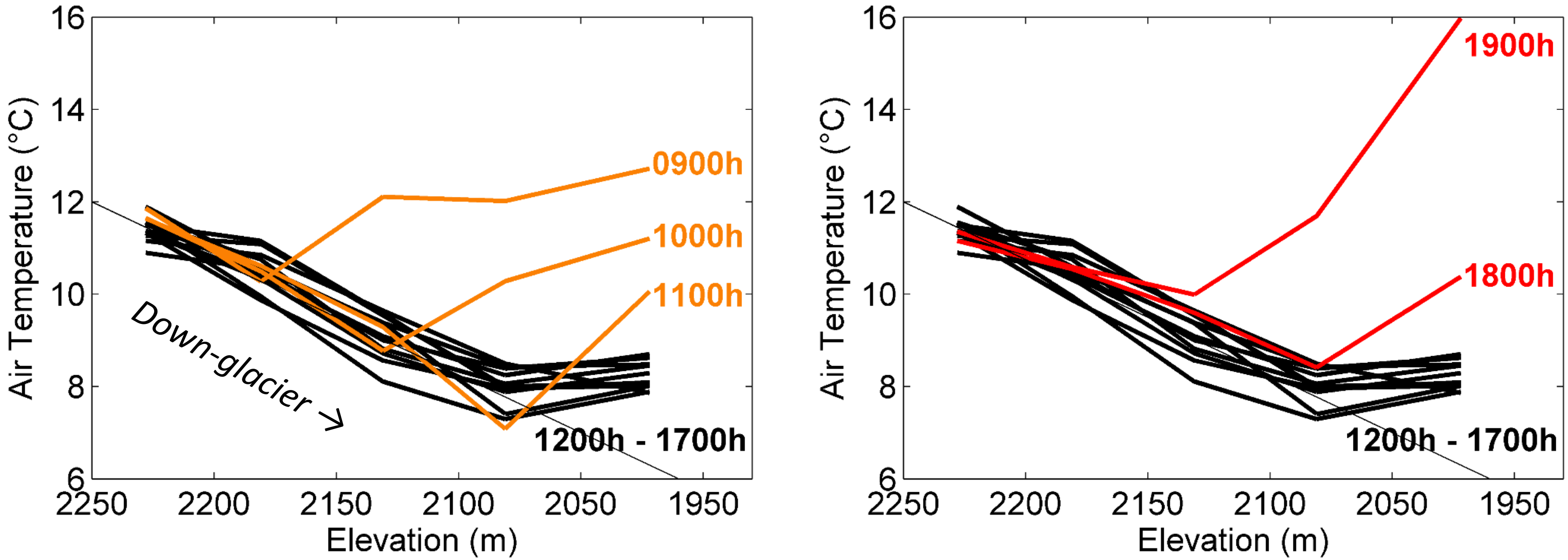


Results suggest down-glacier winds are result of thermal contrast between icefield and surrounding ice-free terrain (meso-scale circulation over order few km), rather than glacier wind being driven by sensible heat exchange at glacier surface.

So we see a well developed circulation in the valley – glacier system that extends beyond glacier surface.

But what is the effect on the lapse rates of air temperature that, in turn, control the distribution of melt?

Observations: Evolution of air temperature along glacier flowline



Air temperature vs elevation (reversed) on lower glacier from icefall to terminus 28th June.

>> Down-glacier cooling sets up during morning – decoupling and intense sensible heat exchange reverses environmental LR.
>> Consistent warming at site closest to glacier toe.
>> Late in day glacier surface layer is disrupted, air temperature increases 8 K.

Conclusions and looking ahead

- Classic on-glacier meteorology during fair weather – strong down glacier winds and minimal temperature range.
- Well developed diurnal valley circulation appears to be driven by thermal contrast between valley and icefield.
- Glacier surface largely decoupled from air above, leading to reversal of free-air lapse rate
- Disruption of surface layer causes large temporal variability in lapse rates
- Challenges ahead – incorporating into glacier modelling – determining geographic distribution and persistence.