Empirical temperature downscaling:
Improving thermal information detail

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The Problem

High latitude regions are:

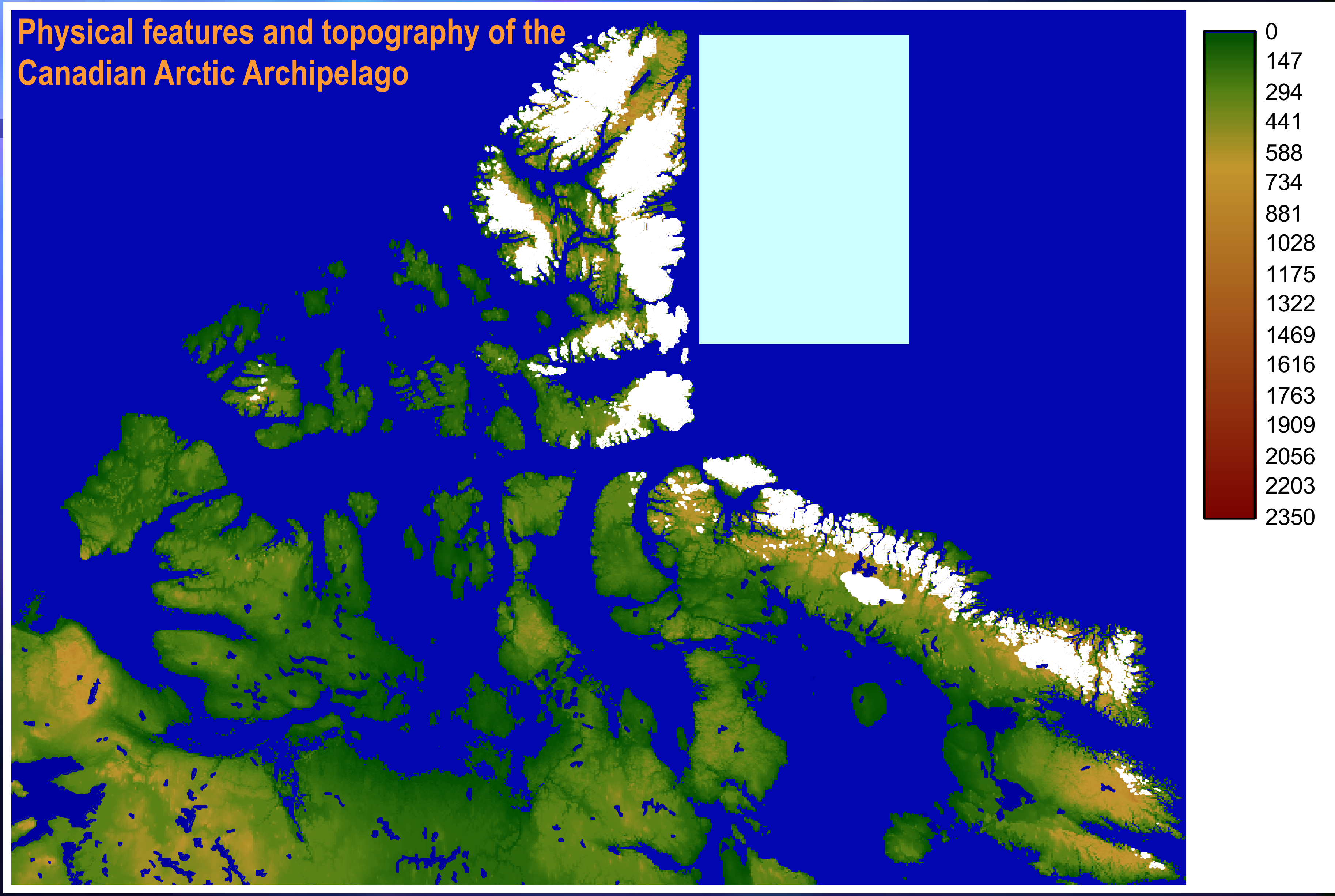
- > large
- > topographically complex and diverse
- > poorly serviced by weather instrumentation

Problematic for users who require spatially detailed temperature

- > biological energetics
  - > plants
  - > hibernation energetics
- > cryological concerns
  - > glacier melt
  - > permafrost modeling
- > hydrology
  - > limnology
- > paleoclimatic work
  - > establish current temperature regime

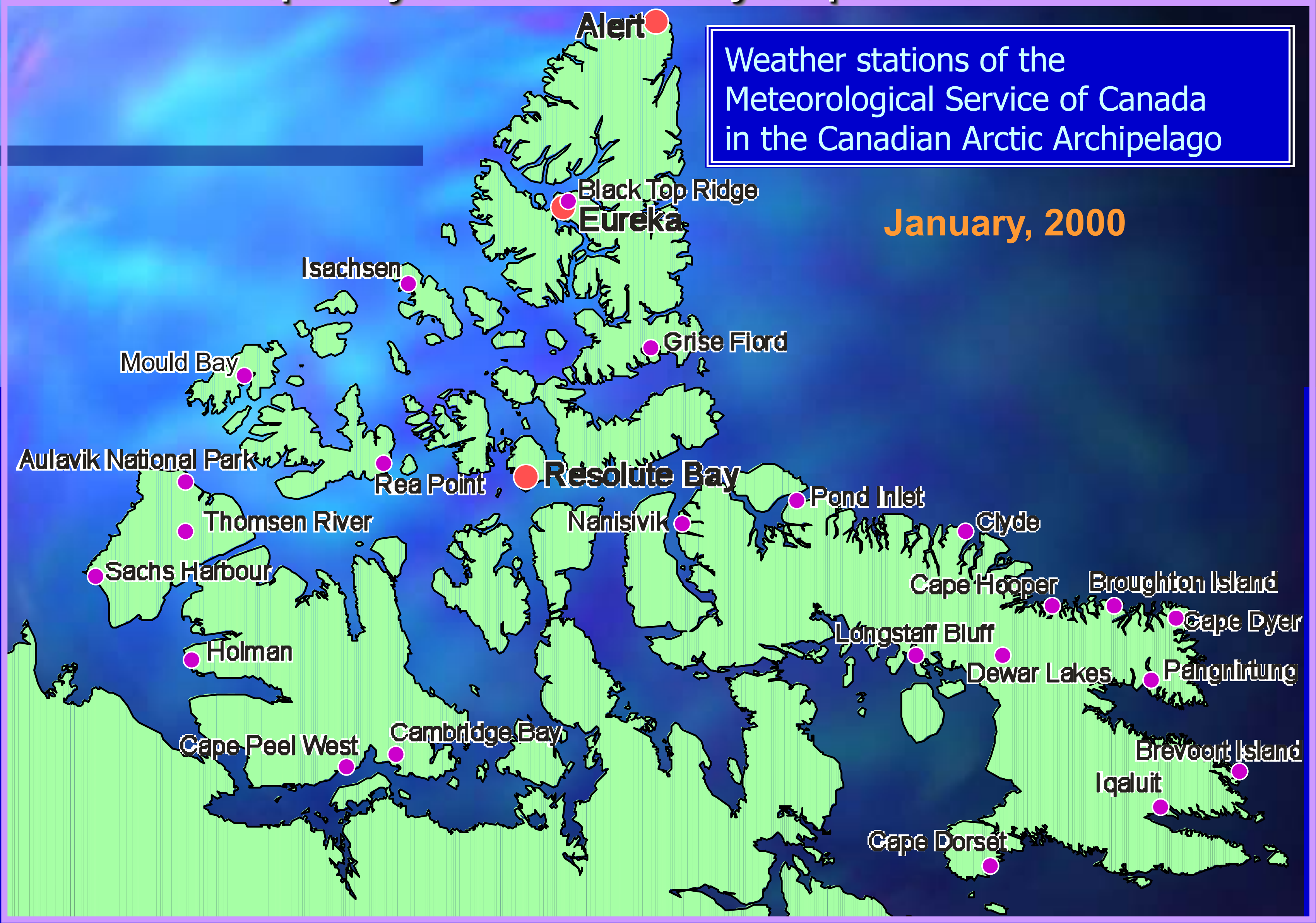
Example: Canadian Arctic Islands

> need: spatially detailed mean July temperatures


Physical features and topography of the Canadian Arctic Archipelago

Example: Canadian Arctic Islands

> need: spatially detailed mean July temperatures



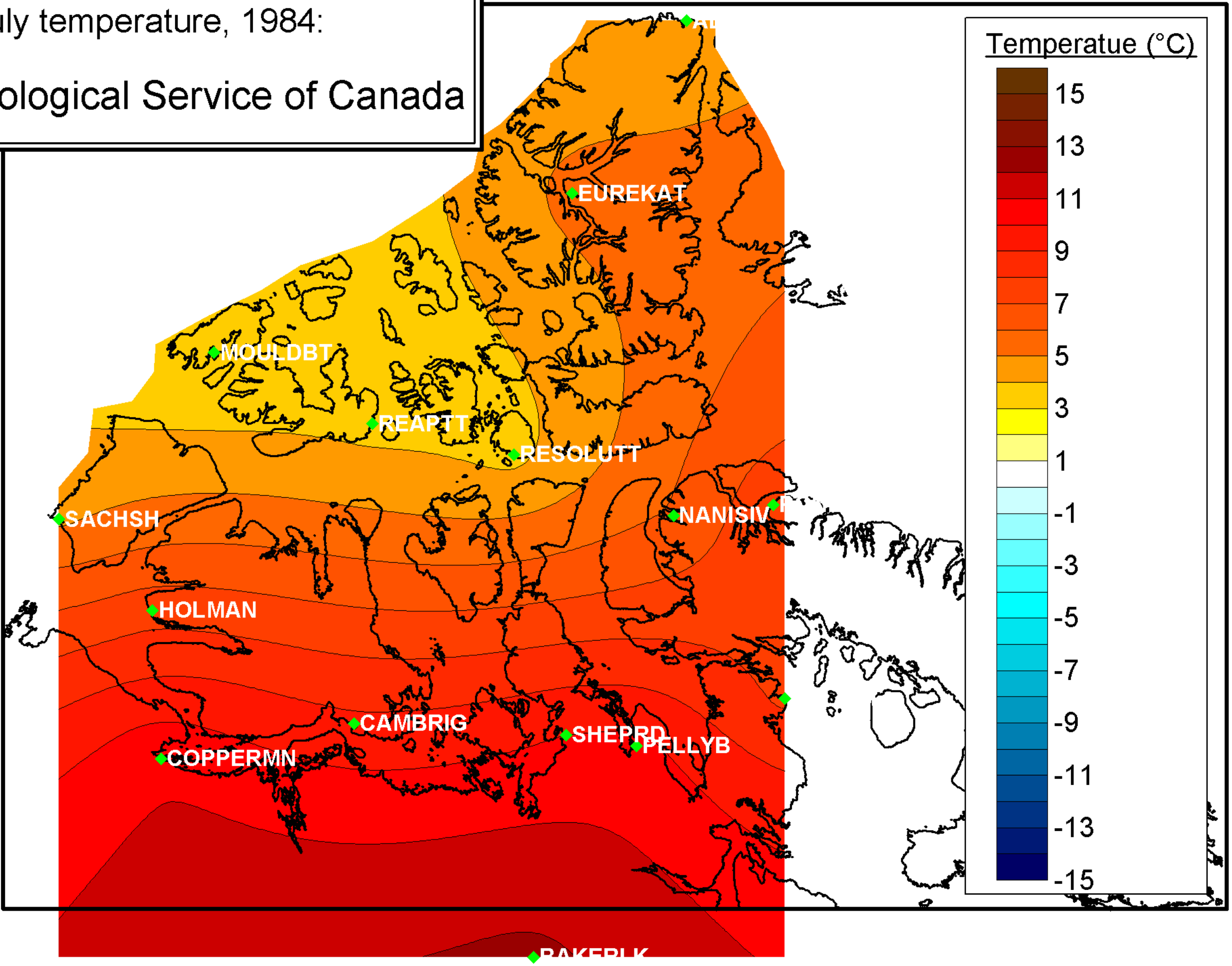
Weather stations of the Meteorological Service of Canada in the Canadian Arctic Archipelago

January, 2000

Typical result when data are contoured:
> significant spatial detail not present

Mean July temperature, 1984:

Meteorological Service of Canada



Need

Improve spatial detail for surface air temperature

Options include:

- **> targeted monitoring networks**
- **> dynamical weather models**
- **> empirical models**

Focus here on an <u>empirical</u> modeling solution to calculate surface air temperature at high spatial resolution

Definition

An "Empirical" or distributed model:

> ***uses information about location to improve interpolation***

Does not "generate" original data - works with existing estimates

> weather stations or model input

Topoclimate Model v2.0 (2007)

Atkinson and Francois Gourand
(MA student, MeteoFrance)

Input data sources

- Digital Elevation Model - GTOPO30
- NOAA National Weather Service GFS0.5 model inputs:
  - @ Surface
    - SLP
    - Lup, Kup, Kdn
  - @ Standard reporting levels
    - T, u, v, cloud water
  - Total cloudiness
- Surface weather observations
  - (for correction of final estimate - sfc obs are not used to develop the temperature estimate)

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USGS GTOPO30 DEM ~1km resolution

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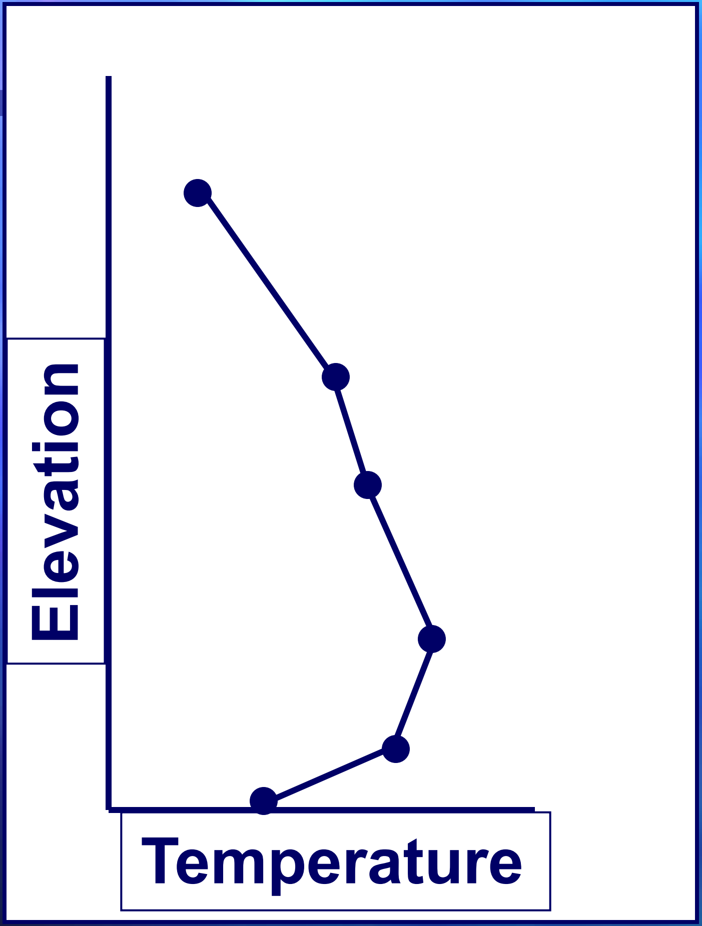
Model processes

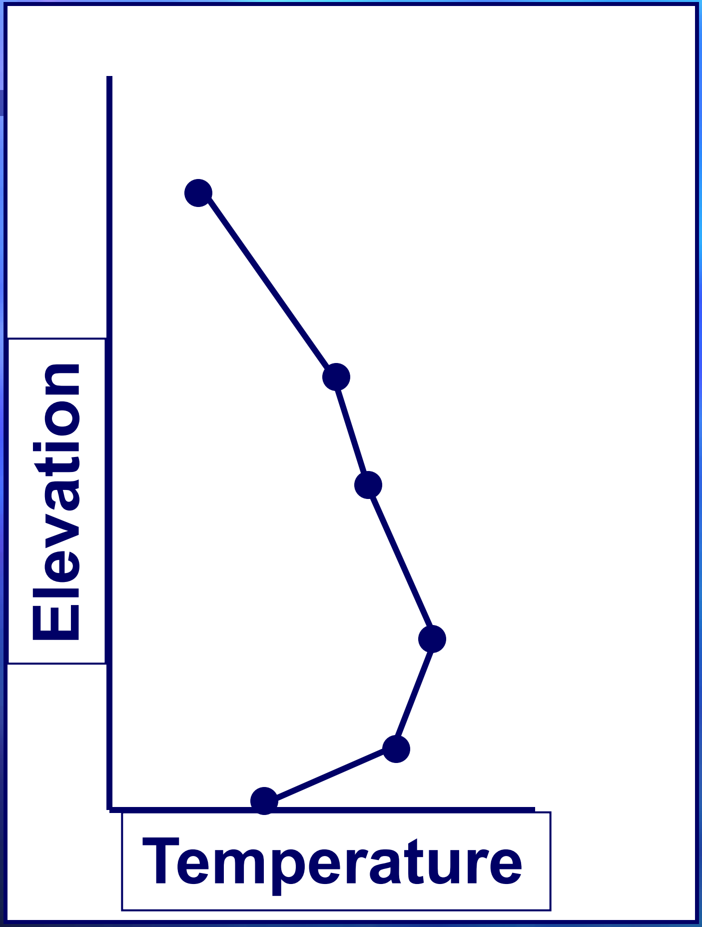
- Elevation effects
- Drainage flow
- Adiabatic compression/Foehn effect
- Surface radiation effects
- Coastal modification

Coarse temperature profile from \Weather Service model



Elevation values from DEM

> Need temperature estimates
For all possible elevation values

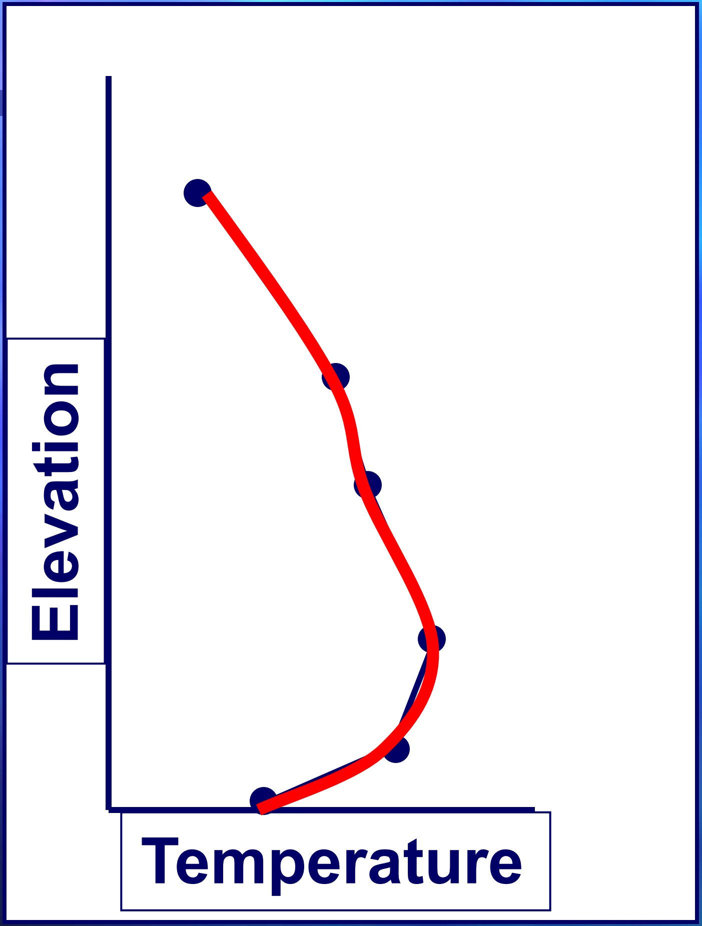


Elevation cross section

Represent using a function

> solve for T at all possible values of elevation

> one T estimate for every pixel on the DEM



$$T = B_0 + B_1{*}E + B_2{*}E^2 \dots \text{etc}$$

Elevation effects

> Polynomial fit to vertical profile

> Upper and lower range - “split” profile - to handle strong low-level inversions

> Provides initial T estimate

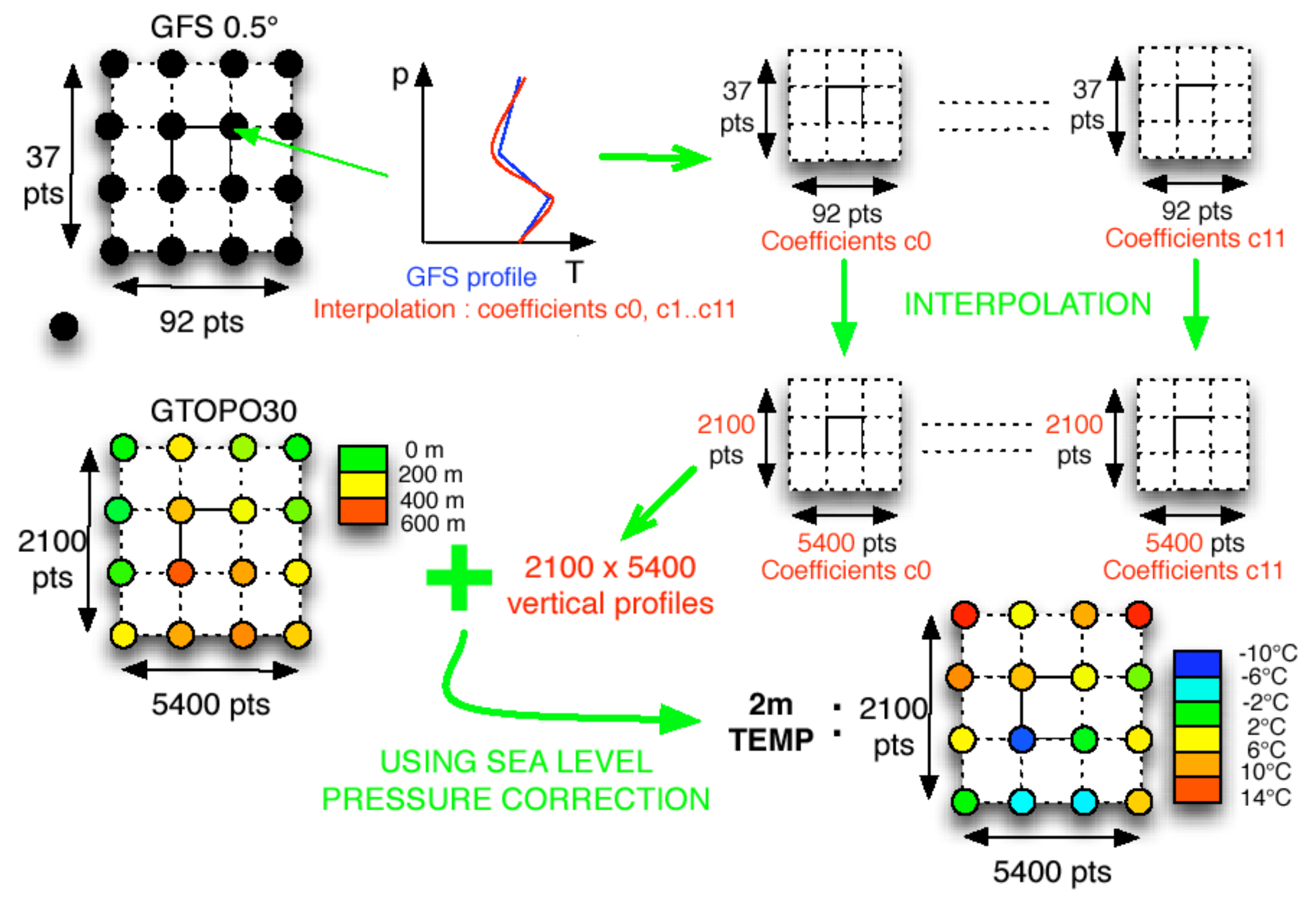


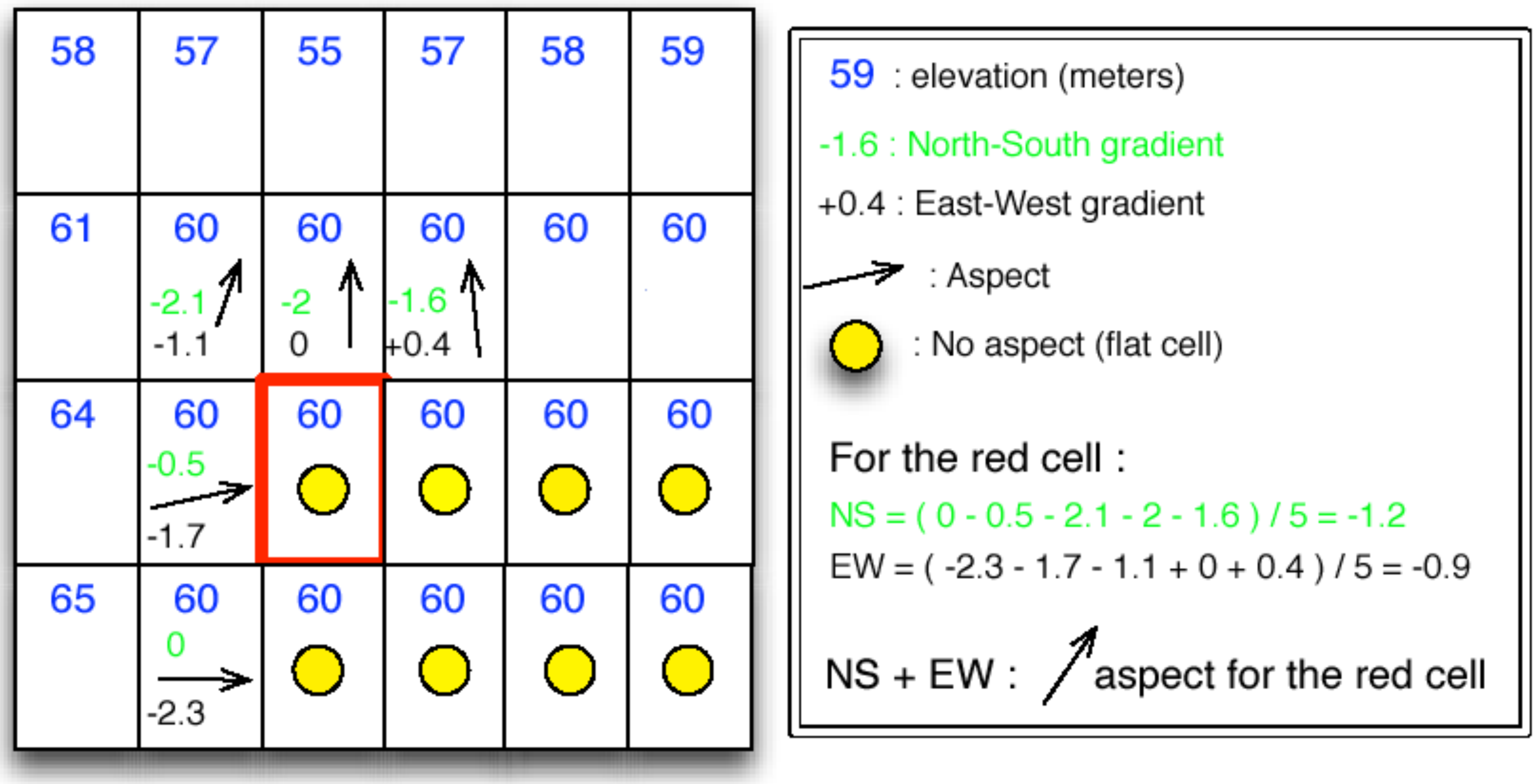
FIG. 2.7 – Method to get a first guess of 2 m temperature, using the DEM and GFS vertical profiles

Flow accumulation

> aspect/gradient driven

> Handles density drainage

1. Establish the flow pattern



59 : elevation (meters)

-1.6 : North-South gradient

+0.4 : East-West gradient

→ : Aspect

● : No aspect (flat cell)

For the red cell :

NS = (0 - 0.5 - 2.1 - 2 - 1.6) / 5 = -1.2

EW = (-2.3 - 1.7 - 1.1 + 0 + 0.4) / 5 = -0.9

NS + EW : ↗ aspect for the red cell

FIG. 2.5 – Method to compute a flow direction in flat areas

2. Perform accumulation

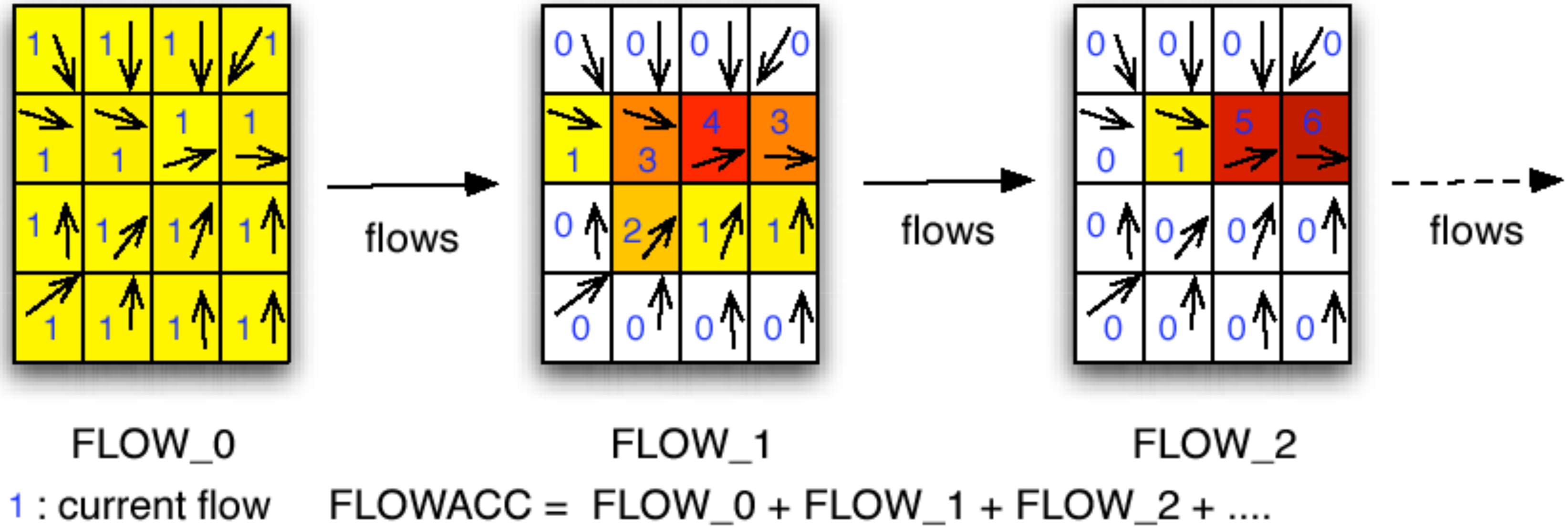


FIG. 2.6 – Method to compute the flow accumulation, step by step.

Drainage flow

> Critical for properly representing sfc. radiation cooling

> Define a scaling using Lup (left plot) (i.e. drainage potential increases as $1/T^2$)

- form of scaling curve response to insufficient cooling at lowest T, excessive at higher T

> Cold air generation

- function of slope, shelter, cloudiness

$$dr = (coef * coldgen * sh + fl) * cld$$

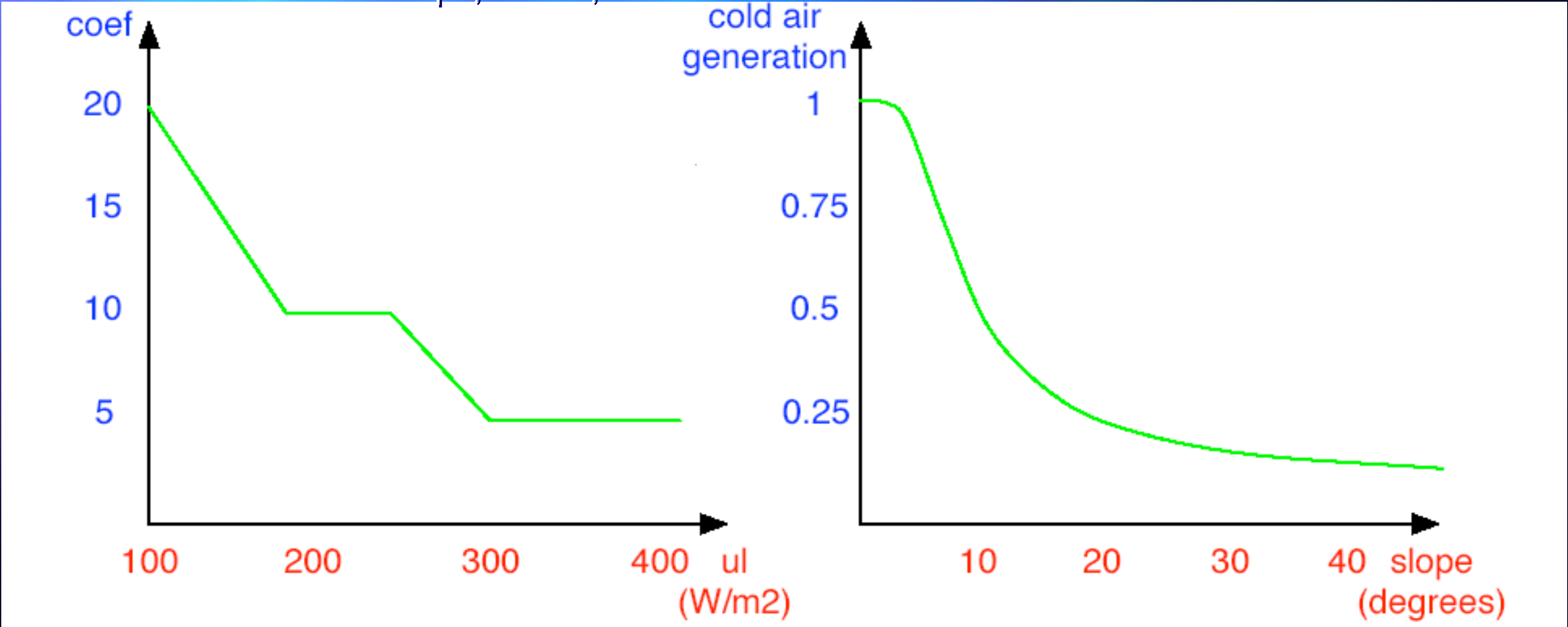


FIG. 2.8 – On the left : empirical function used to scale drainage effect. On the right : cold air generation function.

Foehn effect

Scale for obstacle height - greater height = greater potential effect

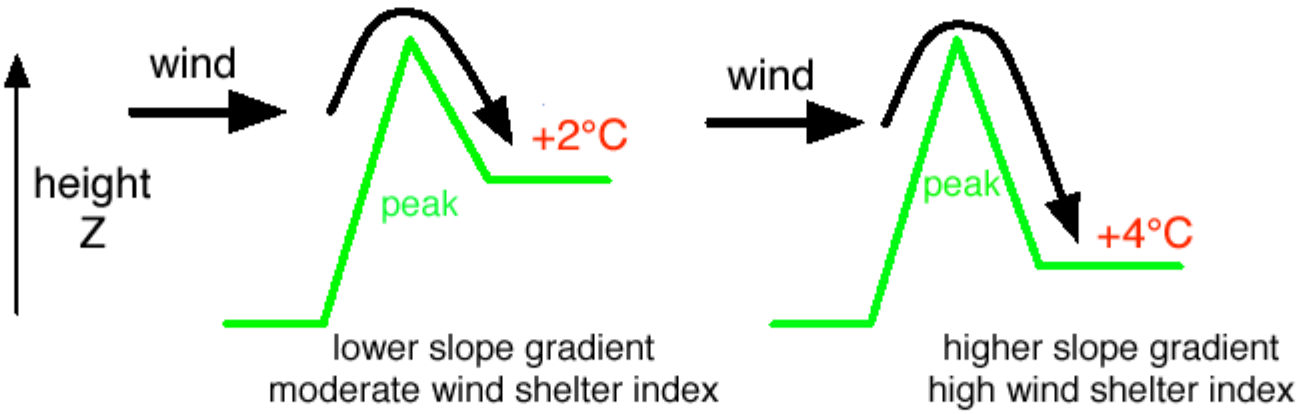
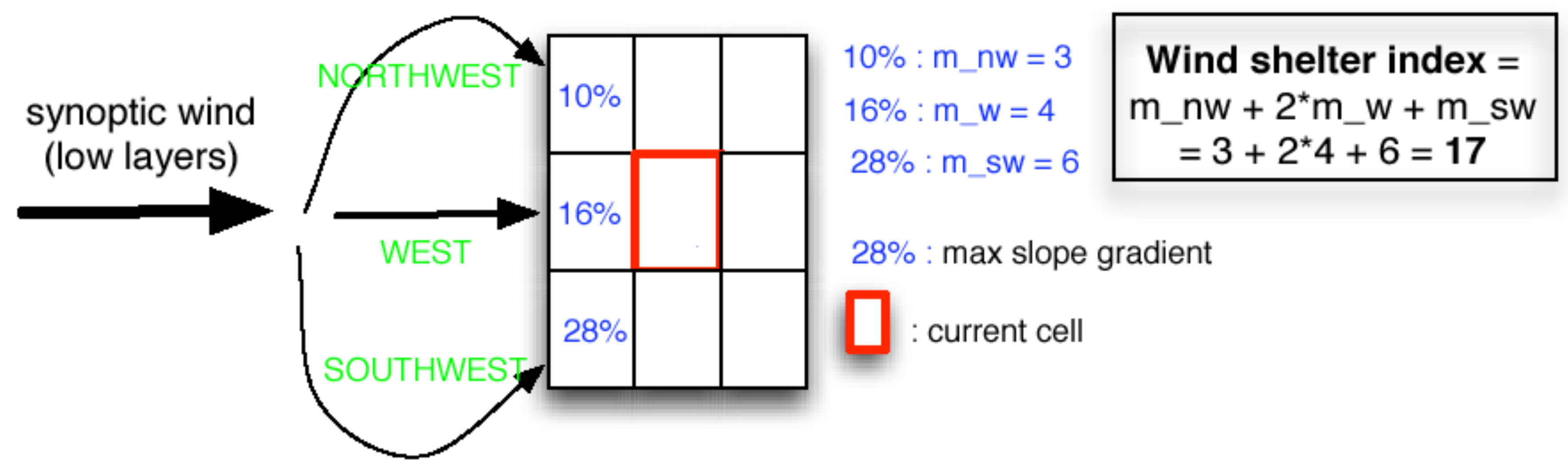


FIG. 2.10 – Magnitude of the wind shelter index, potential for Foehn effect

Grad (%)	0	]0,3]	]3,7]	]7,12]	]12,18]	]18,25]	]25,35]	]35,50]	]50,65]	> 65
$m_{direction}$	0	1	2	3	4	5	6	7	8	9

TAB. 2.1 – Magnitude m of the wind shelter index, function of the maximum slope gradient

Scale for deflection considerations



10% : m_nw = 3
16% : m_w = 4
28% : m_sw = 6

Wind shelter index =
m_nw + 2*m_w + m_sw
= 3 + 2*4 + 6 = **17**

28% : max slope gradient

: current cell

FIG. 2.11 – Build of the wind shelter index, including wind potential deviation

Local surface radiation considerations

> Two parameters derived:

$$\textbf{net radiation} \quad nr = dl + ds - ul - us$$

$$\textbf{energy balance} \; c_G \frac{\partial T_G}{\partial t} = nr - sh - lh + gf$$

> But results were not consistent

> Simpler parameter adopted using only Kdn to drive daytime sfc heating

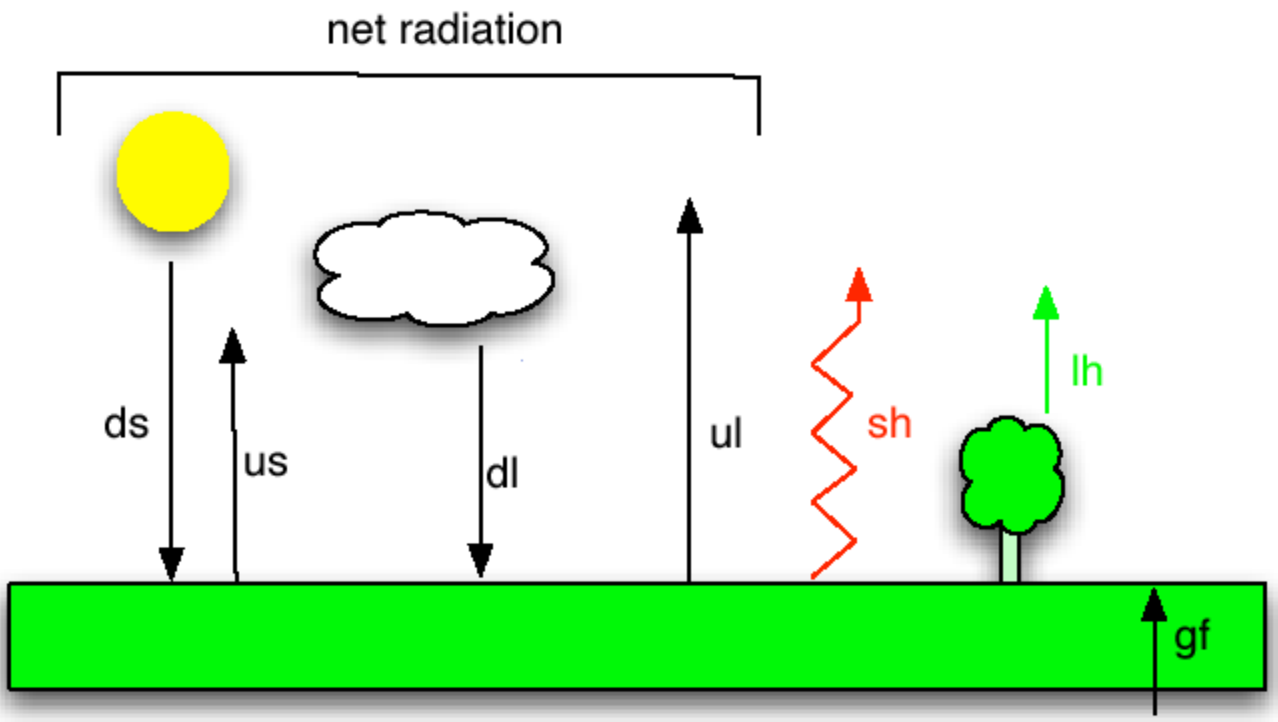
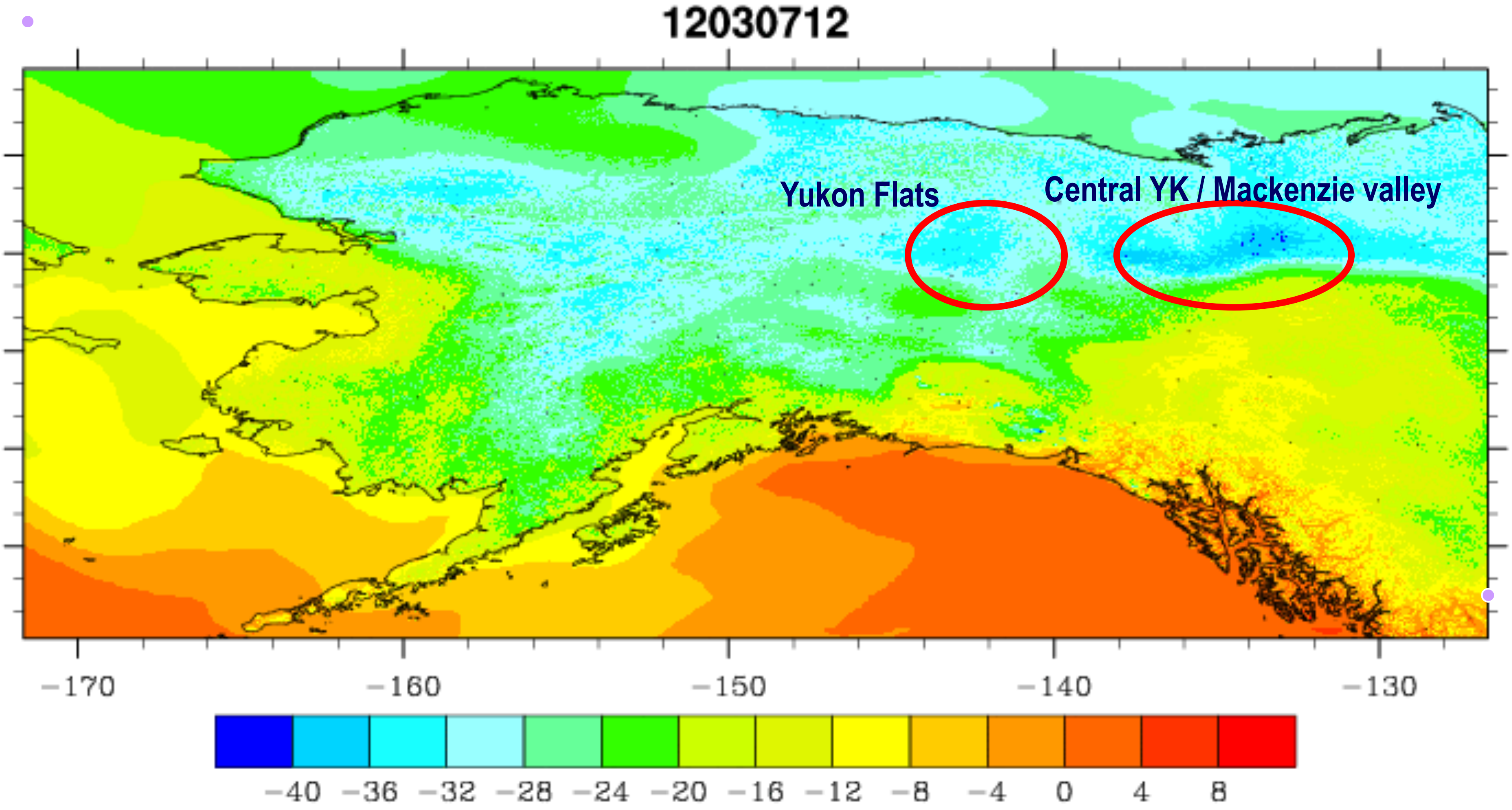


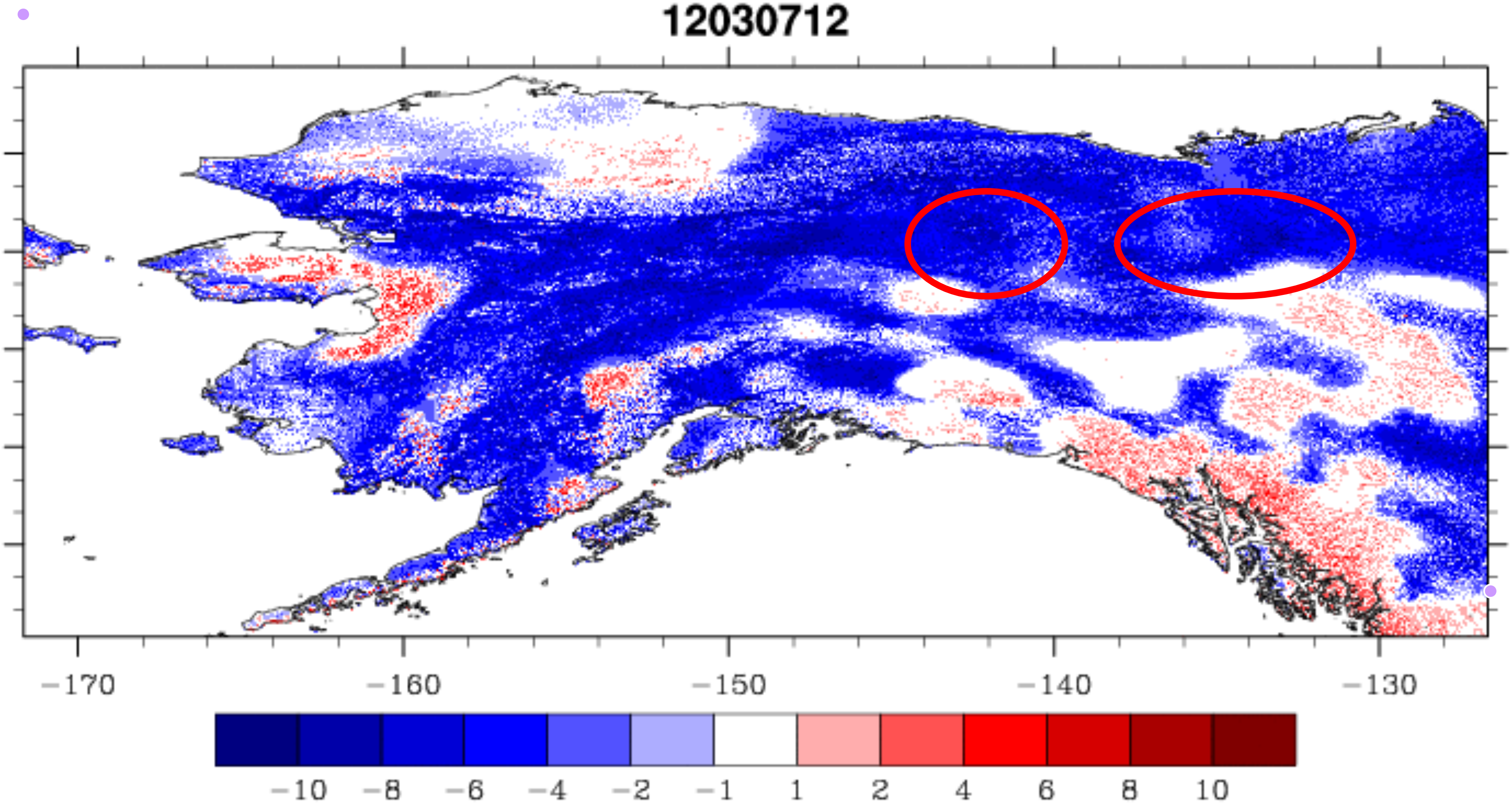
FIG. 2.12 – Radiatives flux at ground level

Cold interior lowlands - drainage effect - captured



Impact of adding drainage, winds, adiabatic compression

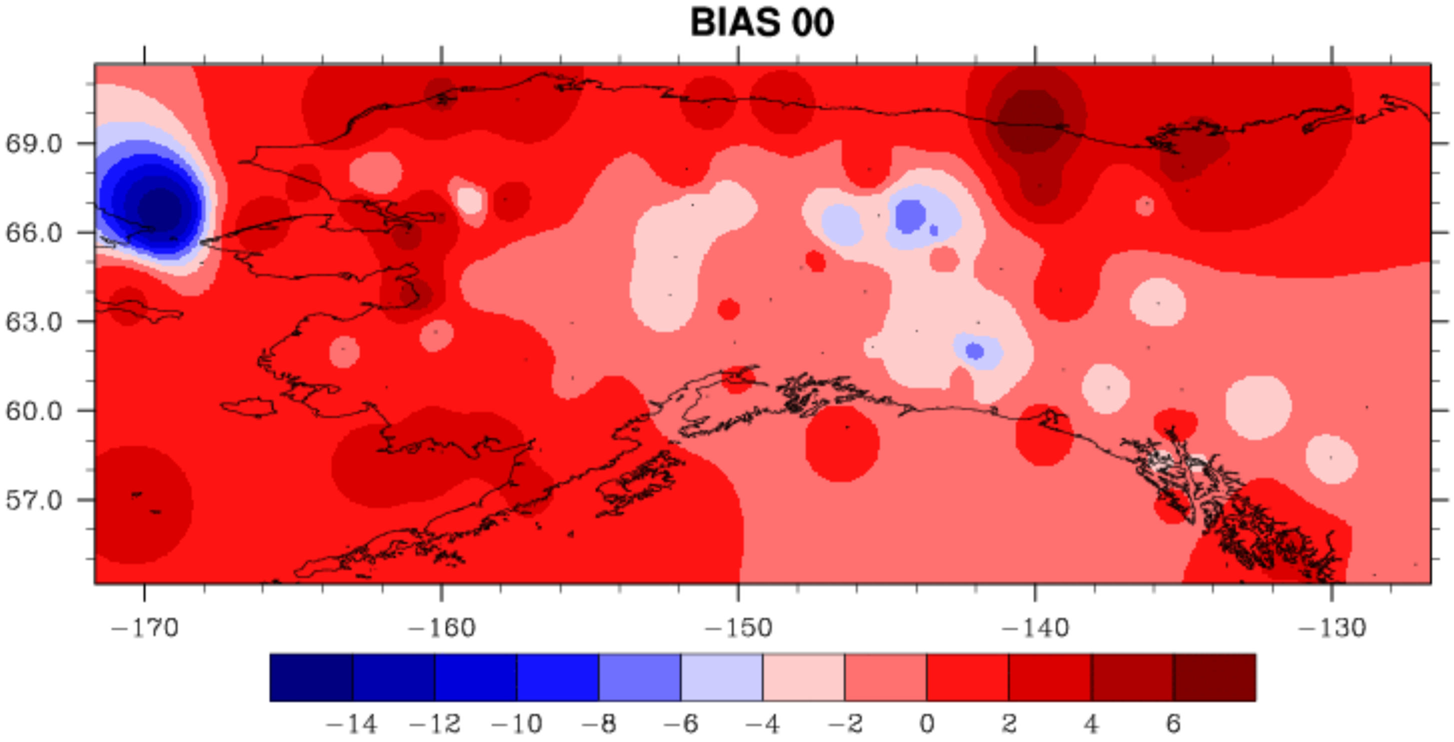
> 10 deg C diff in many areas



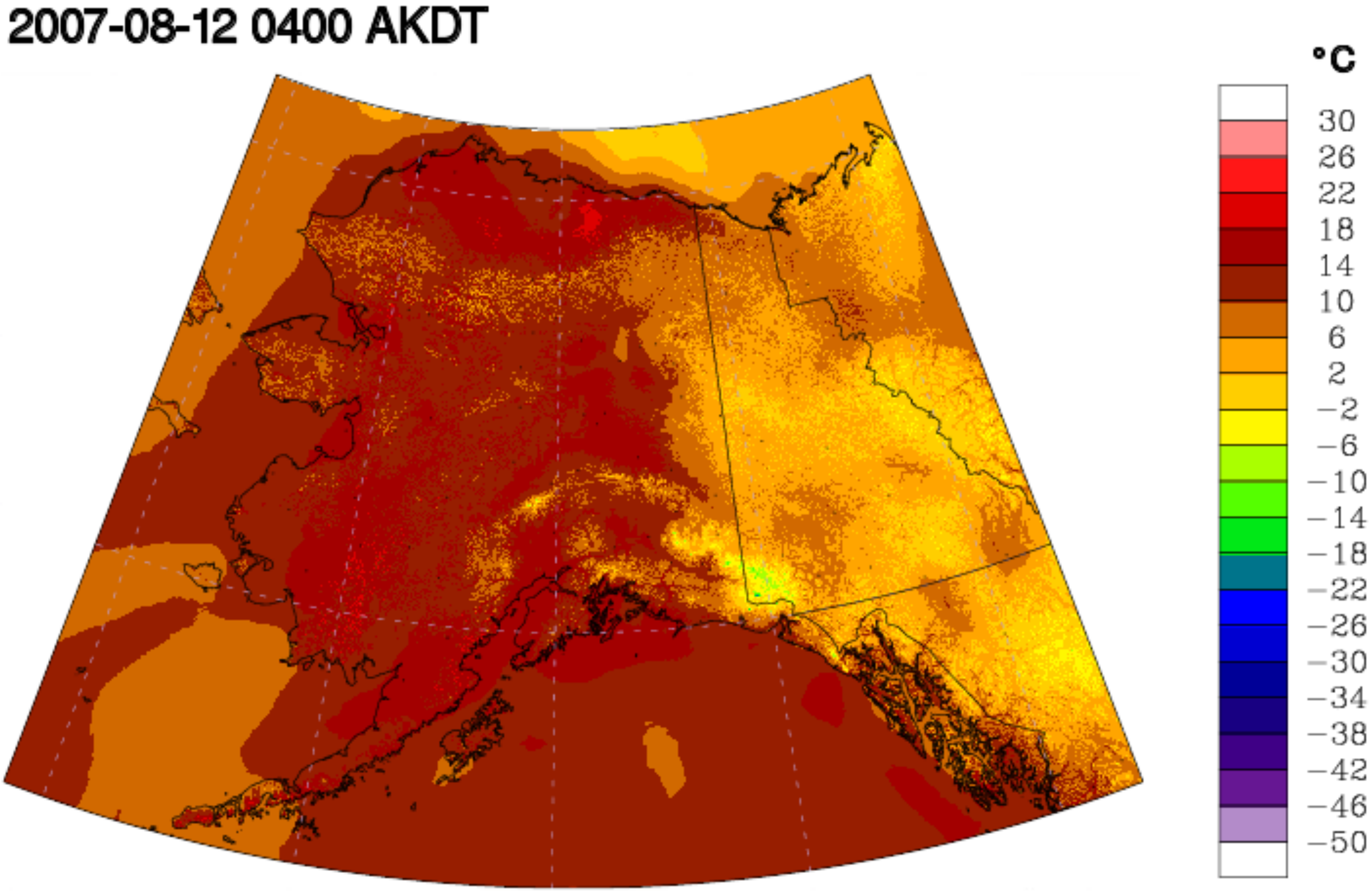
Diagnostics

> spatial plot of bias

> these form the basis for the nudging of the final results



Real-time delivery to web



Areas of improvement

> Grid cells assumed square; really are not

> Cloud levels (high, medium, low)

> Dig into questions of GFS low level wind behavior and relationship to topography

> Vertically interpolate winds to improve their deployment within the model

> Continue working on using radiation budgets rather than individual components

> Expand to run with other models for input

- opens up futurecast/hindcast climatologies

> Tighter control of weather stations used for verification

- improve nudging interpolation (more PRISM based rather than a IDW contour)

> Introduce soil/land properties - vegetation (e.g. affects drainage?)

> Study need for inclusion of explicit coastal effect handler

- introduce sea breeze module

> Drainage issues and low level jets - LLJ can form just above strong thermal gradients and can break them up

> Glacier cooling/katabatic effects

> Slope heating differential effects

Uncertainty issues

For downscaling work,

> Finer-scale measurements and representation have greater uncertainty

> Error bars can be difficult to assign *a priori* - for many models multiple runs are conducted - ensembles - that provide feeling for ranges

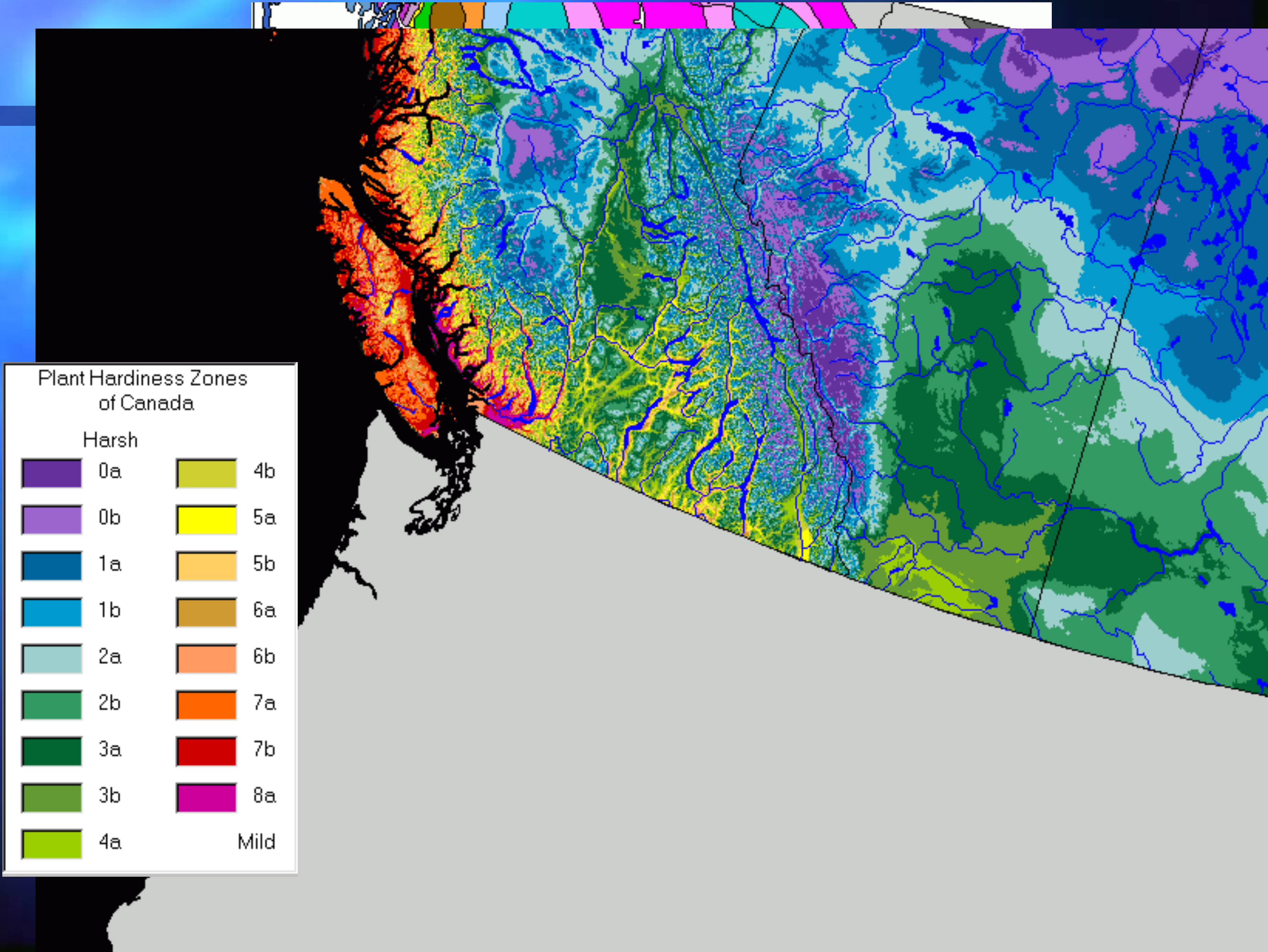
> Also comparisons where ever possible with observed data are conducted

> For projection downscaling work, key lies in selecting most appropriate large-scale simulations

> Eg Pete Larsen - a lot of effort went into identifying the five GCMs that seemed to work the best for AK

Agriculture Canada Plant Hardiness Zones

- Parameters include:
  - Canadian plant survival data
  - minimum winter temperatures
  - length of the frost-free period
  - summer rainfall
  - maximum temperature
  - snow cover
  - January rainfall
  - maximum wind speed


Plant Hardiness Zones of Canada
Harsh
0a
0b
1a
1b
2a
2b
3a
3b
4a
4b
5a
5b
6a
6b
7a
7b
8a
Mild

Topoclimate Model v2.0 (2007)

Derived parameters (static)

- Slope gradient and aspect (8 directions)
- Shelter/Exposure rating
  - A location behind a mountain range, for example, will be less exposed to cold air advection than a location on a plain
- Flow accumulation
  - Classic hydrology parameter but applies when density flows are a factor

Coastal effect

> Built but not implemented

> Coastal results worked fairly well without intervention

Shelter/Exposure determination

> Determines extent to which cell affected by large-scale flow

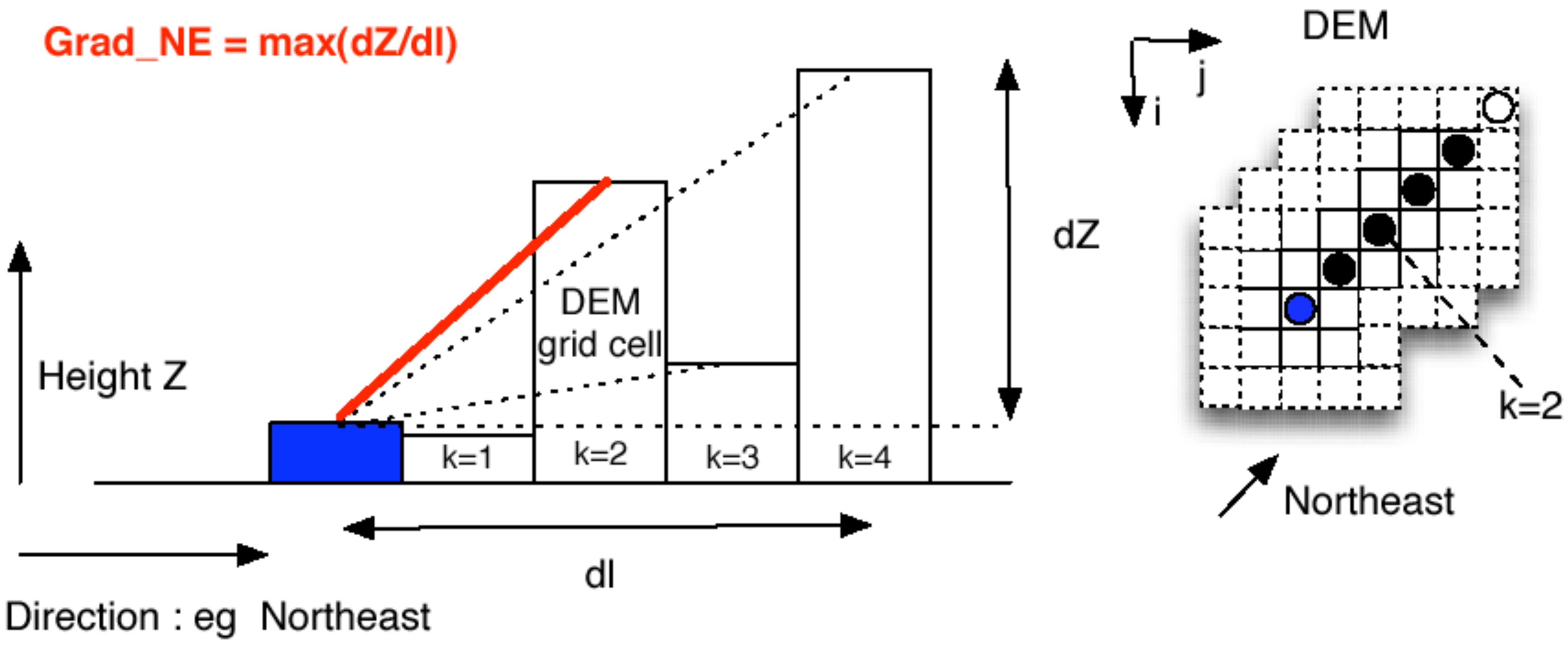


FIG. 2.4 – Maximum slope gradient in a given direction (Northeast on the figure)

Adiabatic compression/Foehn effect

> Build mean wind vector over lowest layers (atm stability factored in w. Froude #)

> Determine nature of exposure (shelter, obstacle wrt wind dir)

> Scale for obstacle height - greater height = greater potential effect

> Scale for deflection considerations

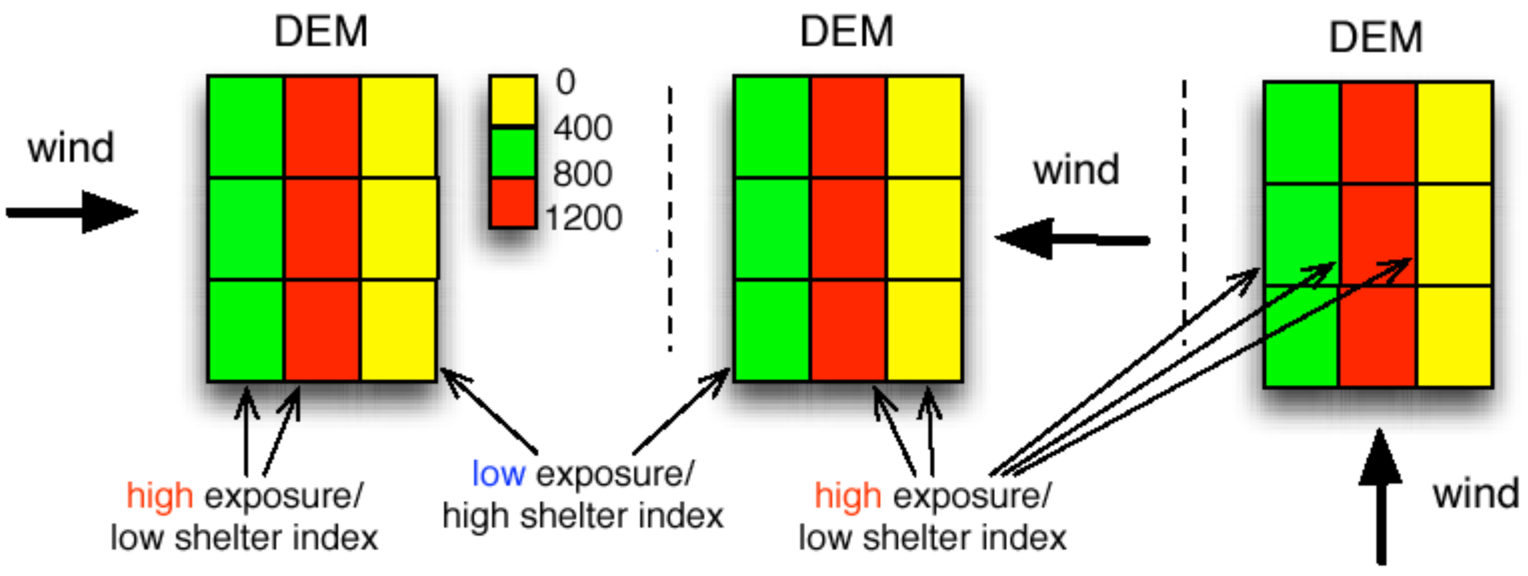
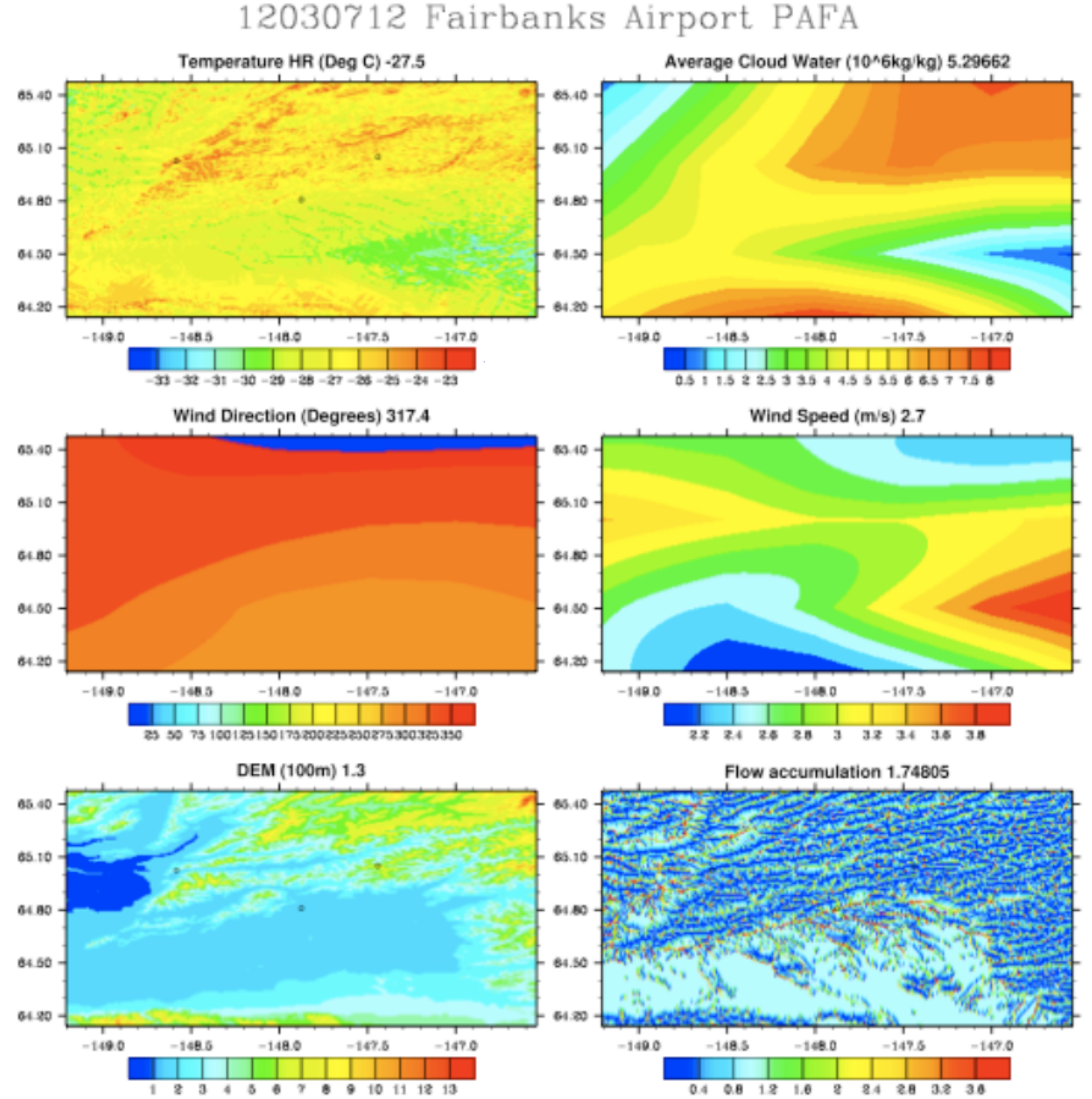


FIG. 2.9 – Exposure to wind/shelter index mechanism

Results

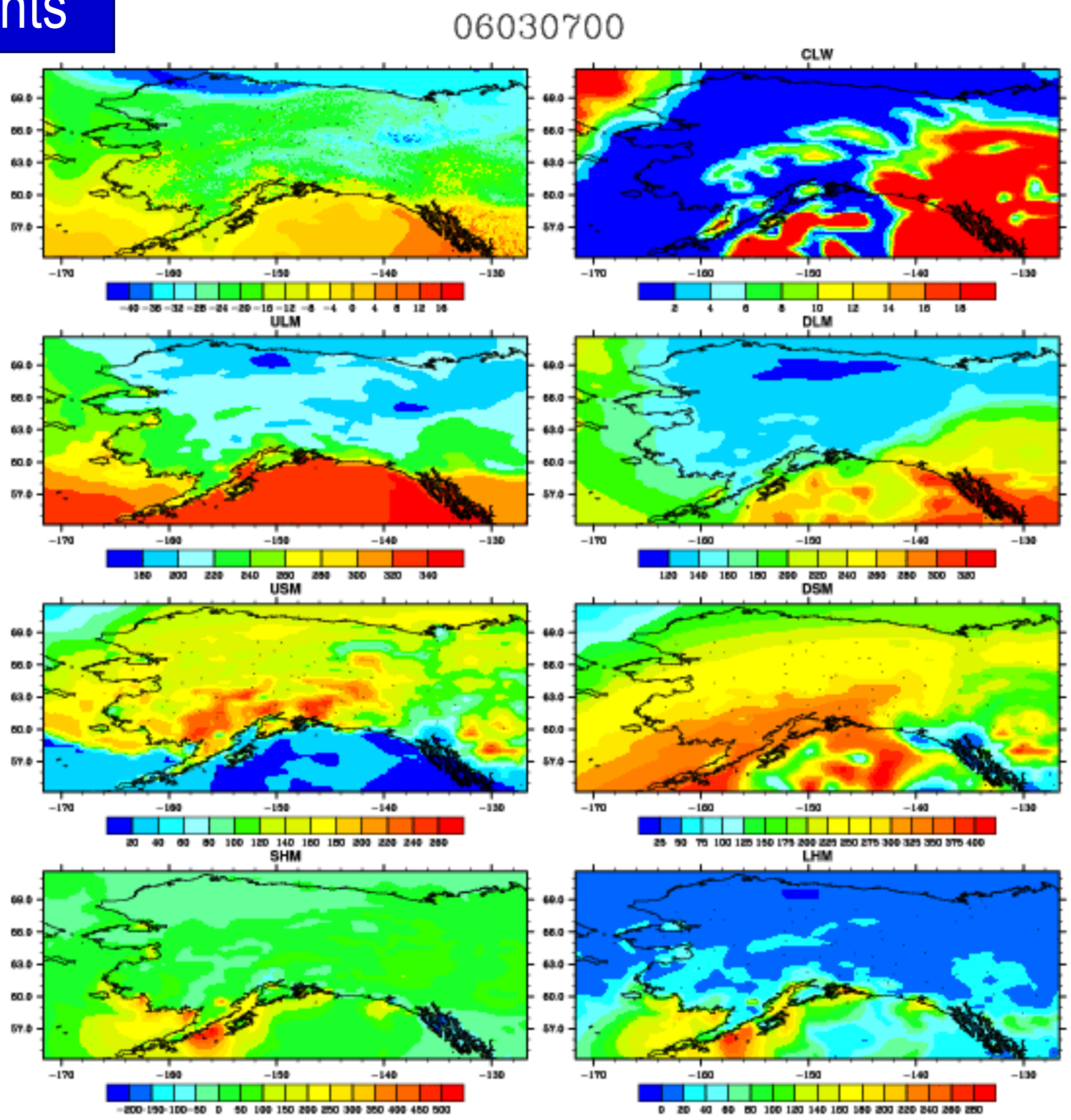
Diagnostics panels output

> various static and run-time parameters



Diagnostics panels output

> radiation components

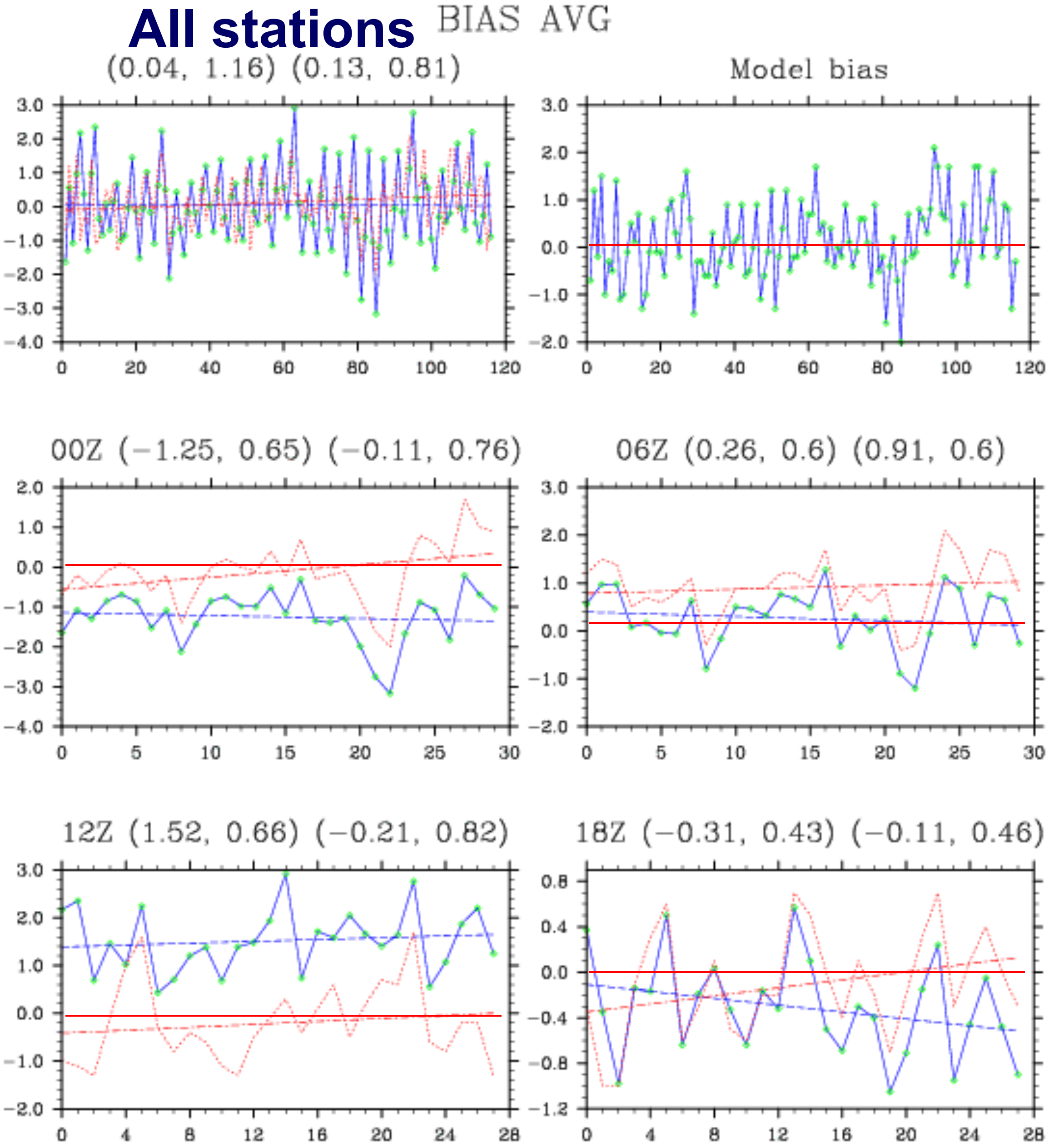


Diagnostics - biases

> comparisons w. stations

> 115 stns available

Average, April 2007: All stations



Blue line= base est.

Red line= all effects

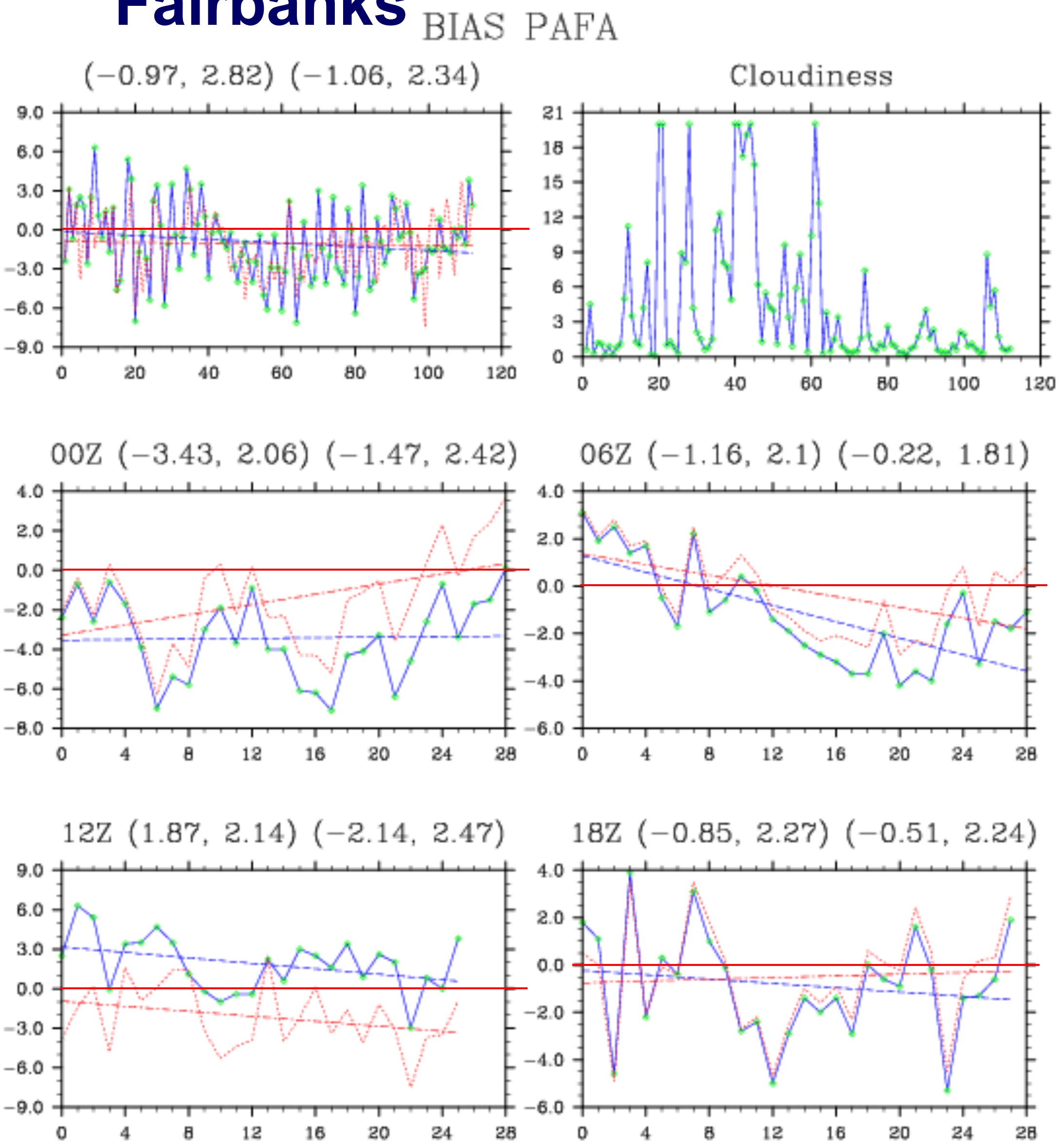
Diagnostics - biases

- > comparisons w. stations
- > 115 stns available

Blue line= base est.

Red line= all effects

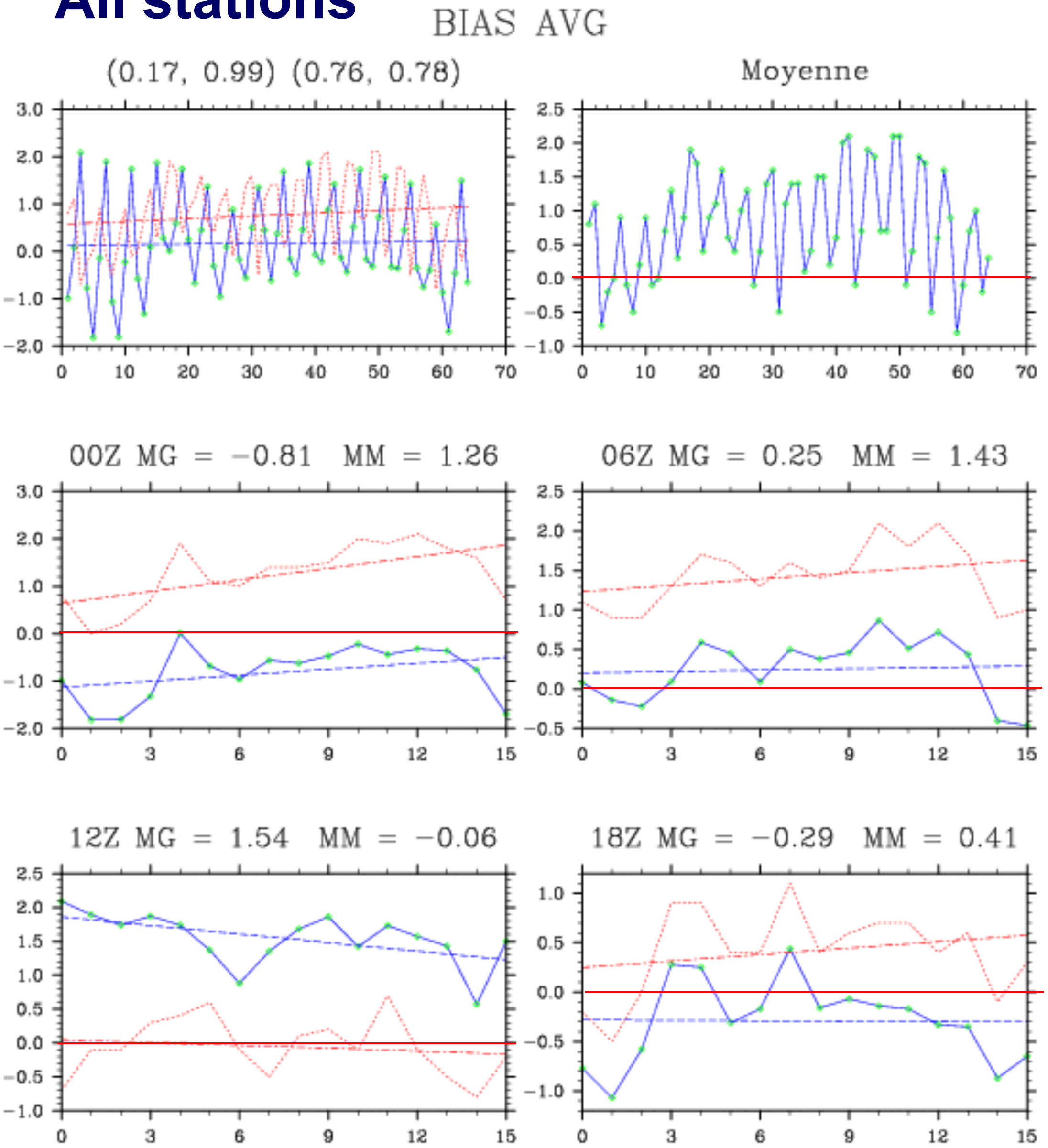
Average, April 2007: Fairbanks



Diagnostics

- > comparisons w. stations
- > 115 stns available

Average, May 2007: All stations



Blue line= base est.

Red line= all effects

Diagnostics

- > visual inspection for problems
- > GFS bug revealed - persistent snow patches

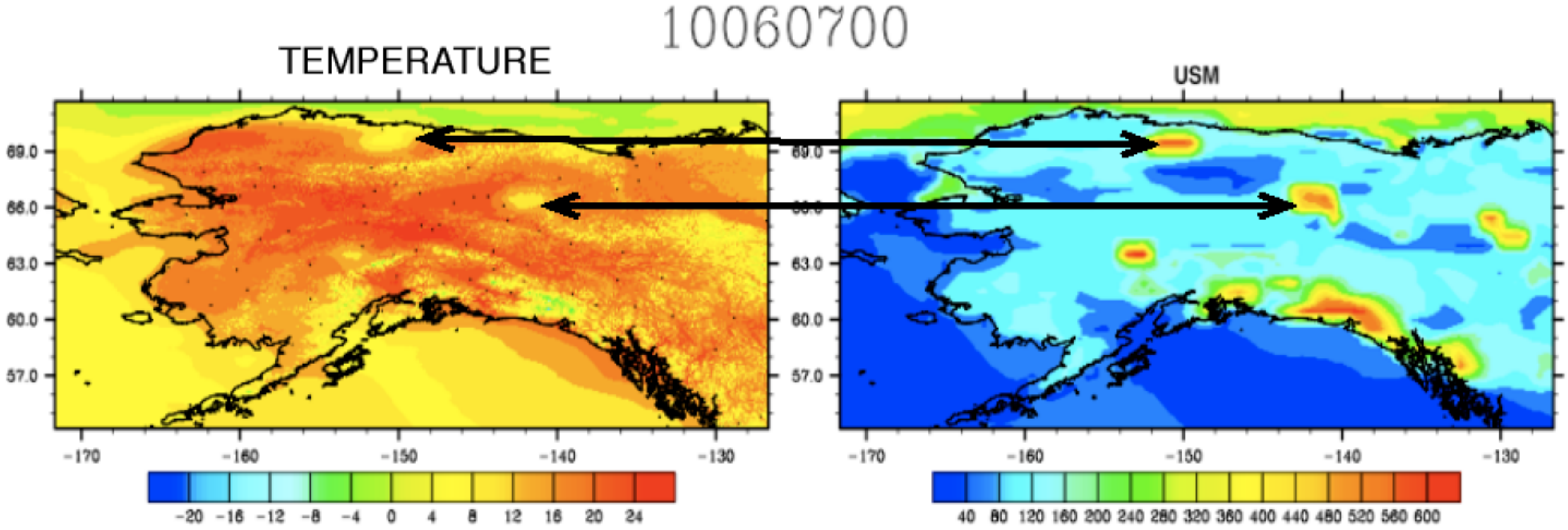


FIG. 3.10 – Albedo bias in GFS and its consequence on temperature