The Introduction of a Knowledge-based Approach and Statistical Methods to Make GIS-Compatible Climate Map

Daly, C. et al., 2002; Climate Research, vol. 22, 99-113.

Goshi Fujimoto

at MIG seminar on 16th, May

Objective

- To understand **regional climate changes**, as well as global climate pattern for climate researches.
- To make climate map from sparse observational data set by a knowledge-based approach and statistical analysis
- Regional analysis is needed for the research of climate changes, especially in integrated work for global warming involving multiple elements

Introduction

- Knowledge-based approach
  - Based on topographic analyses
    - The correlation of point climate data and topographic position, slope, exposure, elevation, and wind speed and direction
- Statistical method
  - To weight irregularly spaced point data to estimate a regularly spaced prediction grid
    - Inverse-distance weighting
    - Kriging
    - Splining

PRISM - Parameter-elevation Regressions on Independent Slopes Model

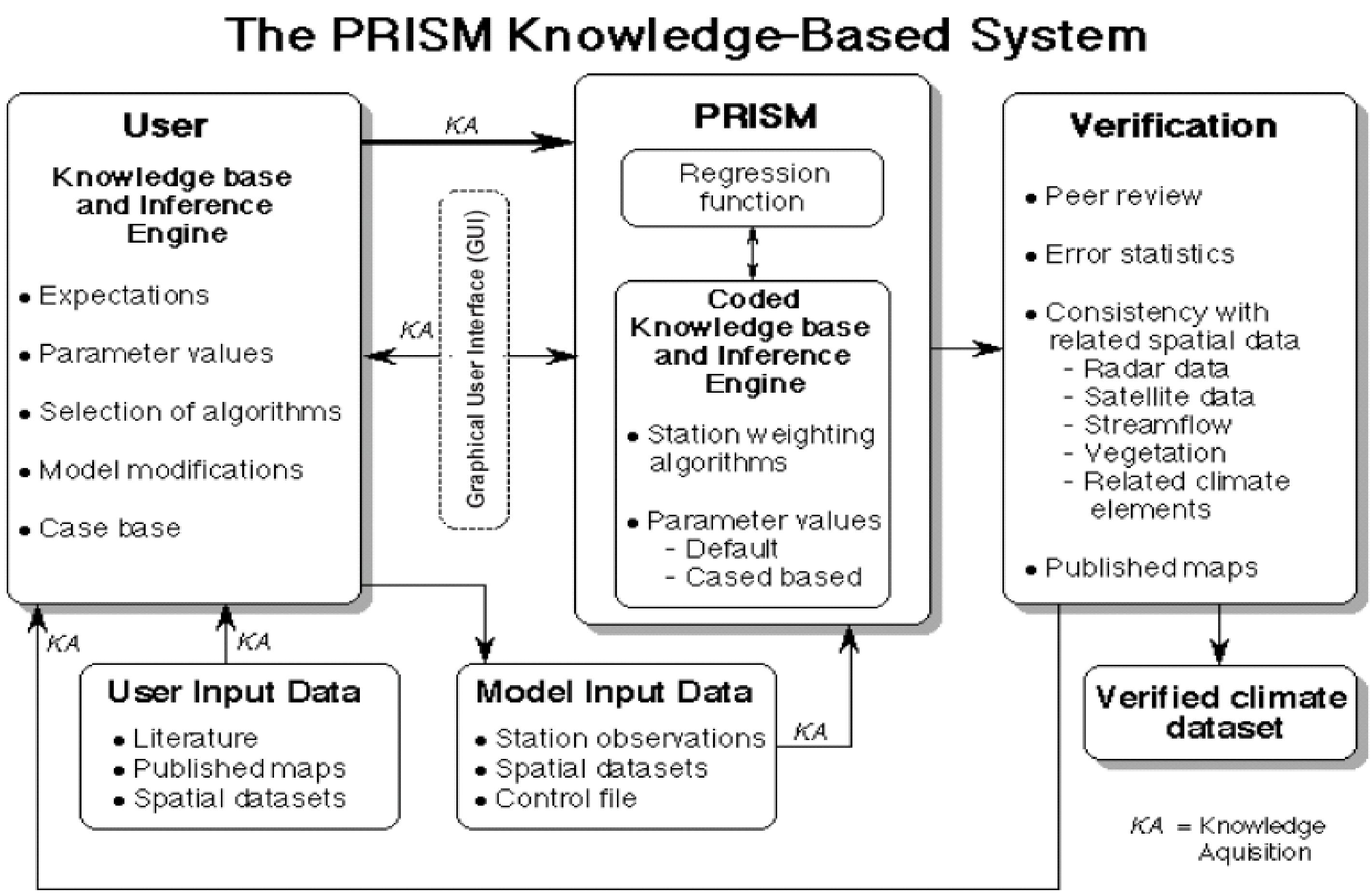


Fig. 1 The conceptual structure of a knowledge-based system for climate.

Regression function

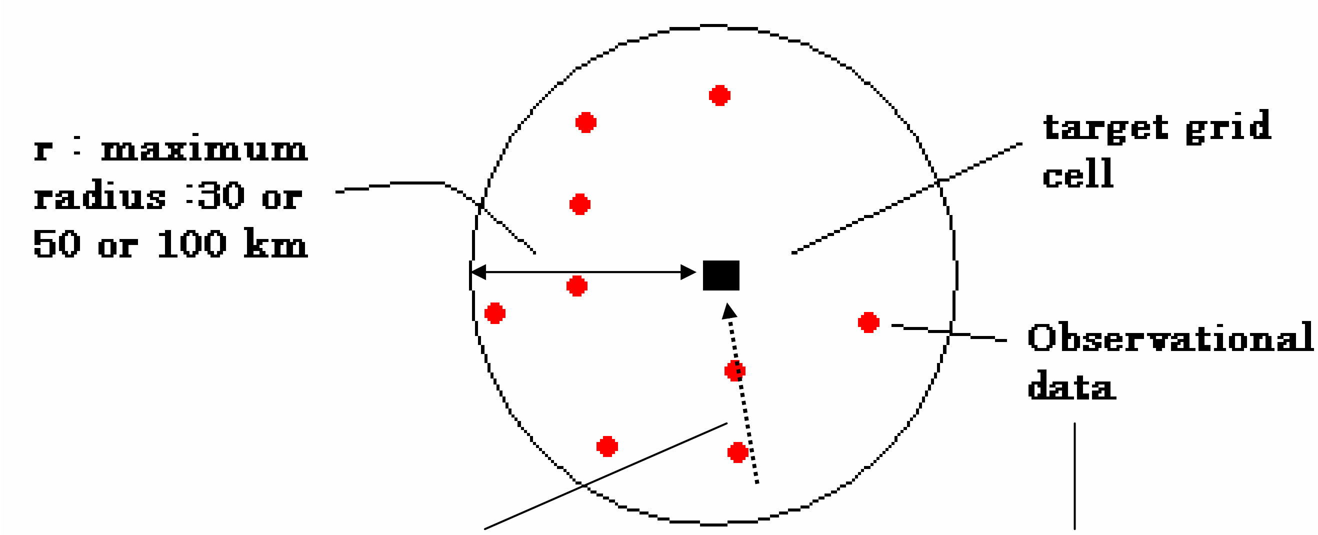
- A regression function between climate and elevation is the main predictive equation.
  - A linear regression is adapted

$$Y = \beta_1 X + \beta_0 \qquad [\beta_{1m} \leq \beta_1 \leq \beta_{1x}]$$

where Y is the predicted climate element, β_1 and β_0 are the regression slope and intercept. X is the elevation at the target grid cell. And β_{1m} and β_{1x} are the minimum and maximum regression slopes (Table 1).

Searching area from target grid cell

- The climate-elevation regression is developed from pairs of elevation and climate observations.



Make a regression line : the range of β_1, regression slope, must be between β_{1m} and β_{1x}.

is needed number of s_t, minimum number of total stations desired in regression : 10 or 15 or 30 stations

The knowledge base

- The knowledge base is considered for weighting the various of correlations of climate stations and several elements.
  - Elevational influence on climate
  - Terrain-induced climate transitions, ‘facets’
  - Coastal effects
  - Two-layer atmosphere

Station weighting

- Upon entering the regression function, each station is assigned a weight that is based on several factors.
- The combined weight, W, is given as follows:

$$W = [F_d W(d)^2 + F_z W(z)^2]^{1/2} W(c) W(l) W(f) W(p) W(e)$$

where W(d), W(z), W(c), W(l), W(f), W(p), and W(e) are the distance, elevation, cluster, vertical layer, topographic facet, coastal proximity, and effective terrain weights, respectively. F_d and F_z are the distance and elevation weighting importance factors.

The distance weighting

- A station's influence is assumed to decrease as its distance from the target grid cell increases. The distance weight is given as:

$$W(d) = \begin{cases} 1; & d = 0 \\ \dfrac{1}{d^a}; & d > 0 \end{cases}$$

where d is the horizontal distance and a is the distance weighting exponent, is typically set to 2, which is equivalent to an inverse-distance-squared weighting function.

The elevation weighting

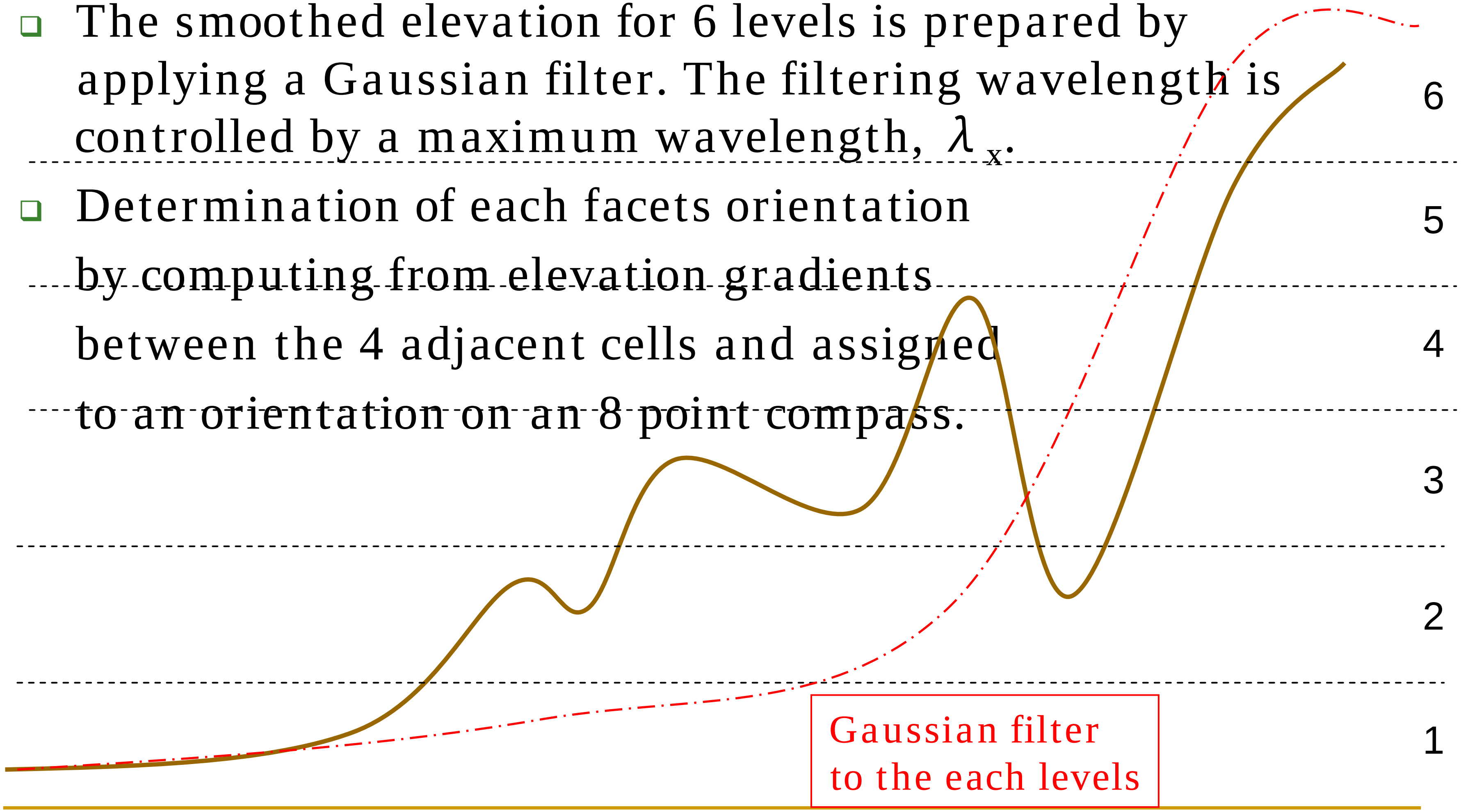
- A station's influence is assumed to decrease as its vertical distance from the target gid cell increases. The elevation weight is given as:

$$W(z) = \begin{cases} \dfrac{1}{\Delta z_{\mathrm{m}}^{b}}; & \Delta z \le \Delta z_{\mathrm{m}} \\ \dfrac{1}{\Delta z^{b}}; & \Delta z_{\mathrm{m}} < \Delta z < \Delta z_{\mathrm{x}} \\ 0; & \Delta z \ge \Delta z_{\mathrm{x}} \end{cases}$$

where Δz is the elevation difference, b is the elevation weighting exponent, is typically set to 1, which is equivalent to a 1-dimensional inverse-distance weighting function. Δz_m is the minimum elevation difference, and Δz_x is the maximum one.

Topographic facets

- Delineation of topographic facets
  - The smoothed elevation for 6 levels is prepared by applying a Gaussian filter. The filtering wavelength is controlled by a maximum wavelength, λ_x.
  - Determination of each facets orientation by computing from elevation gradients between the 4 adjacent cells and assigned to an orientation on an 8 point compass.

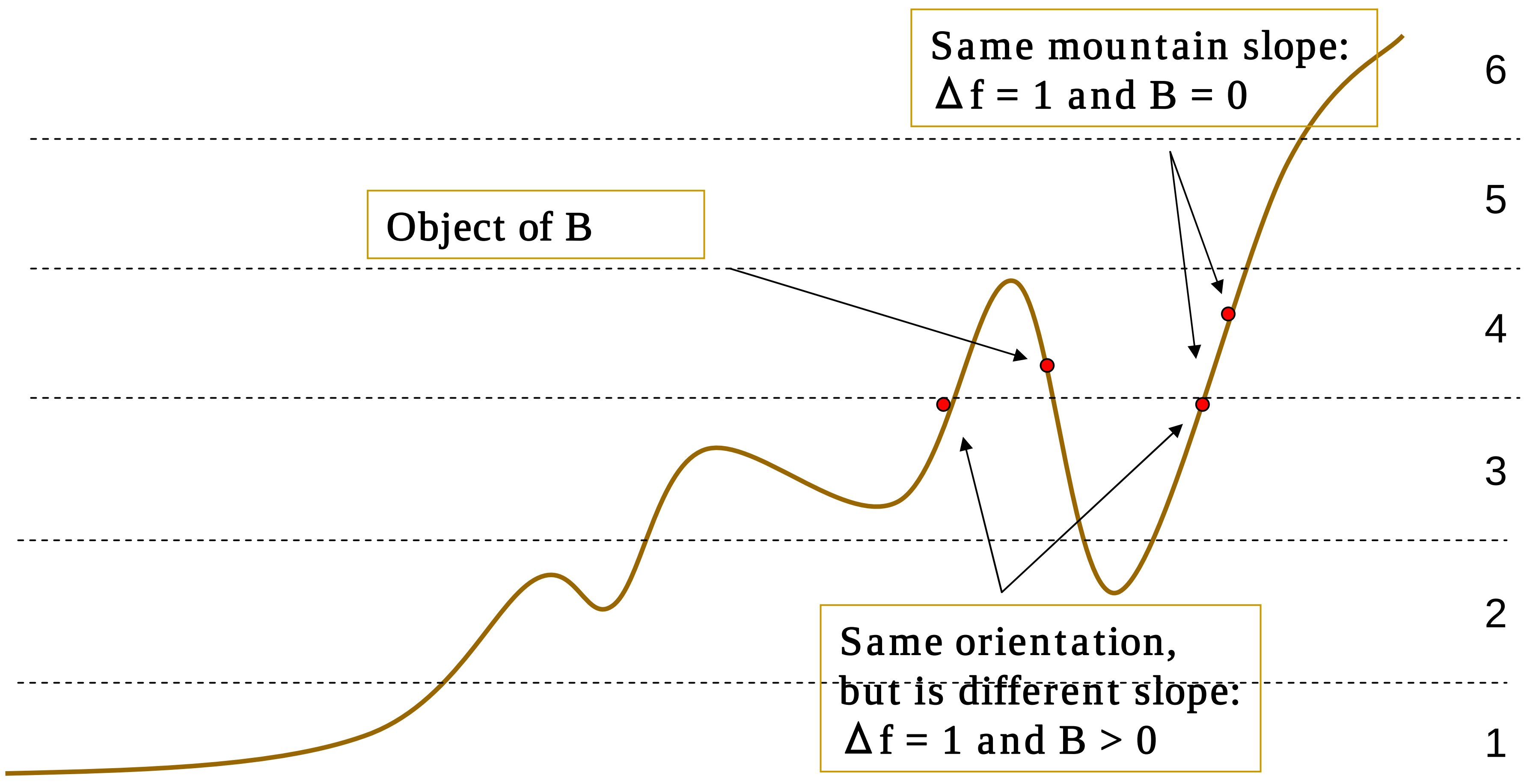


The facet weight

- The facet weight for a station is calculated as:

$$W(f) = \begin{cases} 1; \ \Delta f \le 1 \text{ and } B = 0 \\ \dfrac{1}{(\Delta f + B)^c}; \Delta f > 1 \text{ or } B > 0 \end{cases}$$

where Δf is the orientation difference (maximum possible difference is 4 compass points, or 180°), B is the number of intervening barrier cells with a different orientation with that of the target cell. c is the facet weighting exponent, which is typically set at 1.5 to 2.0, because of the rain shadows that can occur to the leeward of coastal mountains. In inland and flat regions, where rain shadows are less pronounced, a value of 1.5 or less will suffice.


Same mountain slope:
Δf = 1 and B = 0
Object of B
Same orientation,
but is different slope:
Δf = 1 and B > 0
6
5
4
3
2
1

An example for facet weighting process

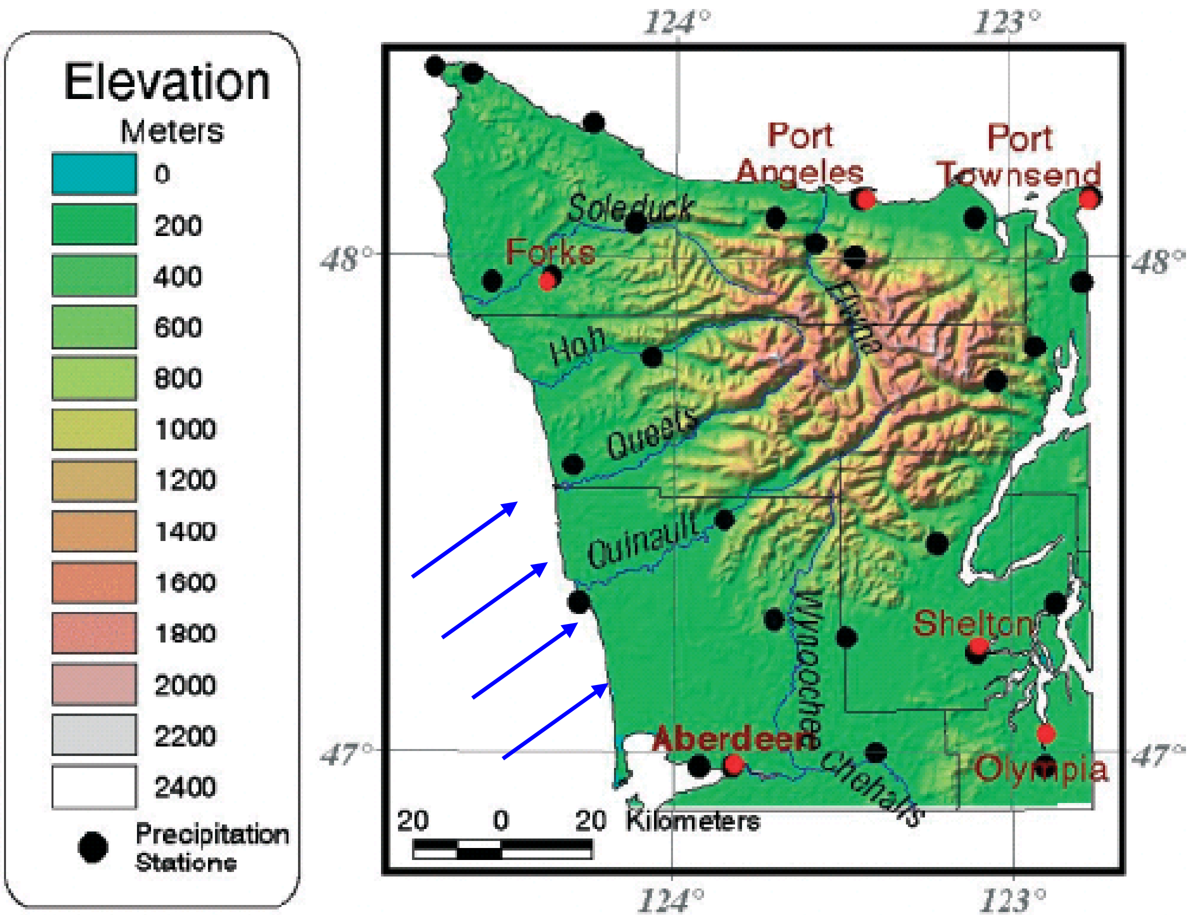


Fig. 2 Terrain map of the Olympic Peninsula, in the northwest corner of Washington State, USA. Terrain resolution is 500 m. Location of precipitation stations used in mapping are shown as black dots.

Estimation of facet direction

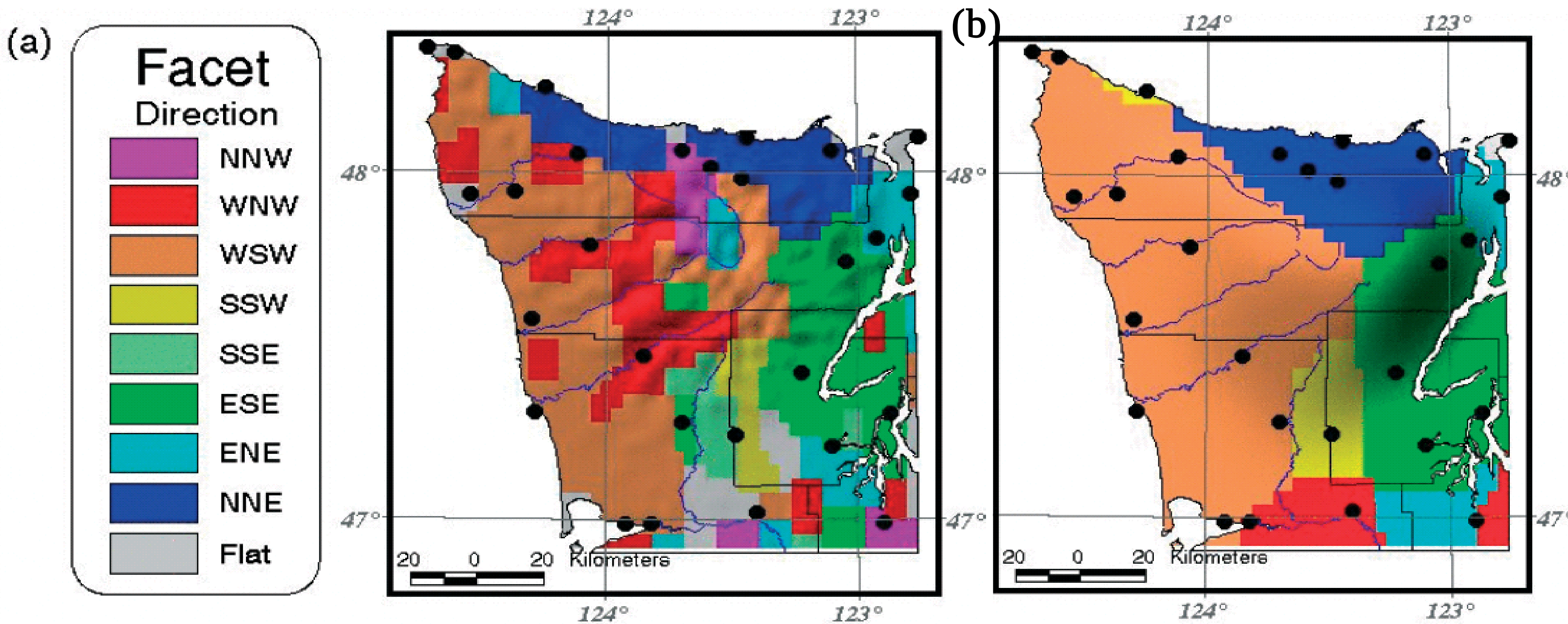
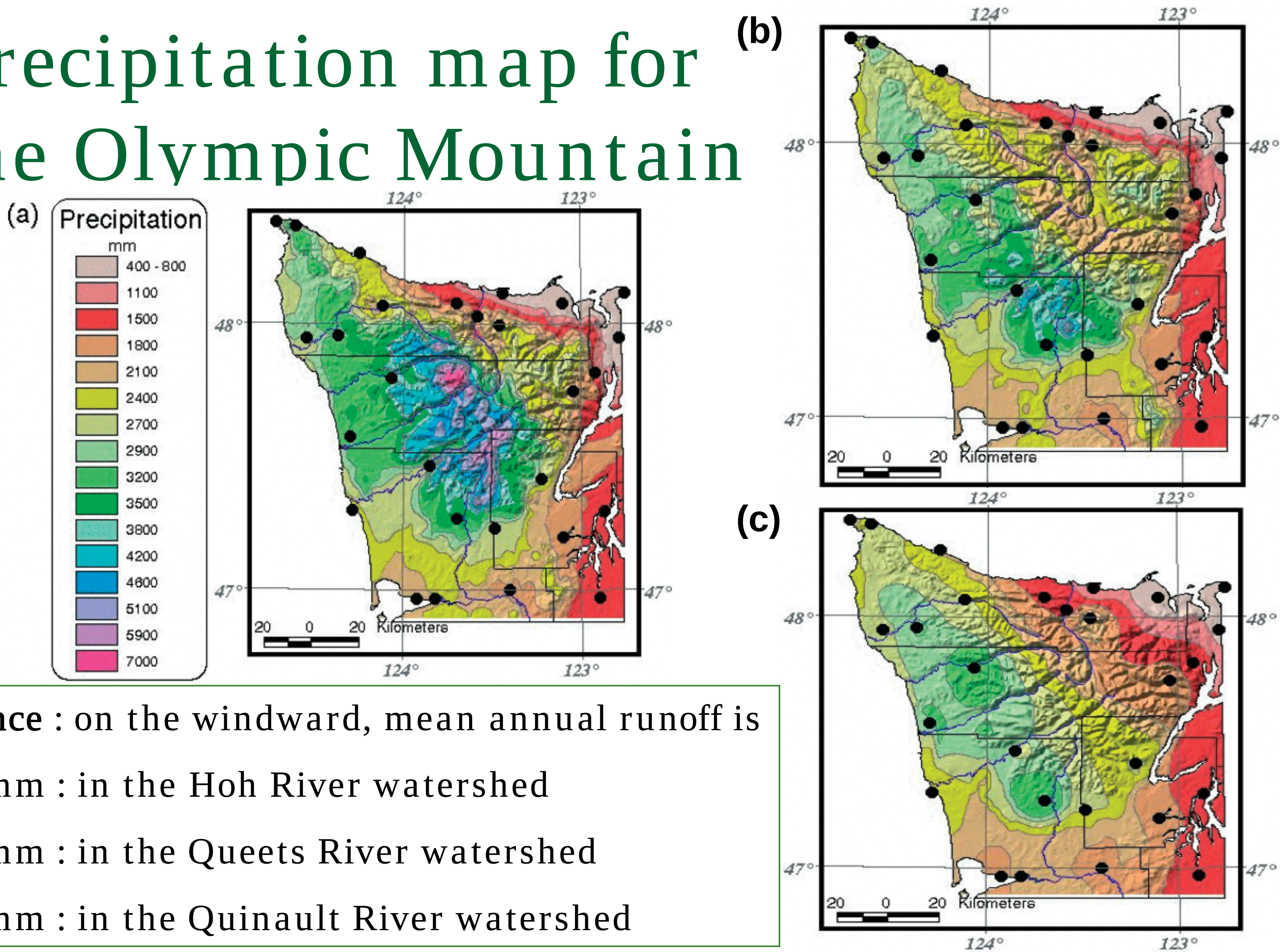


Fig. 3 Topographic facet grids overlain on shaded terrain grids for the Olympic Peninsula delineated at 2 wavelengths; (a) 4 km and (b) 60 km

Precipitation map for the Olympic Mountain



Evidence : on the windward, mean annual runoff is

3452 mm : in the Hoh River watershed

3442 mm : in the Queets River watershed

4042 mm : in the Quinault River watershed

Fig. 4. Mean annual (1961–1990) precipitation with: (a) elevation regression functions and topographic weighting at each grid cell; (b) same as (a) except without topographic facet weighting; and (c) same as (b) except without terrain (all elevations set to zero). Mapping grid resolution is 4 km.

Coastal proximity weight

- Coastal proximity grids have been developed that estimate the proximity of each grid cell to major water bodies. Its weight for a station is calculated as:

$$W(p) = \begin{cases} 1; & \Delta p = 0 \\ 0; & \Delta p > p_x \\ \dfrac{1}{\Delta p^{v}}; & 0 < \Delta p \le p_x \end{cases}$$

where Δ p is the absolute difference between the station and target cell, y is the coastal proximity weighting exponent, is typically set at 1.0, and p_x is the maximum proximity difference.

An example for coastal proximity

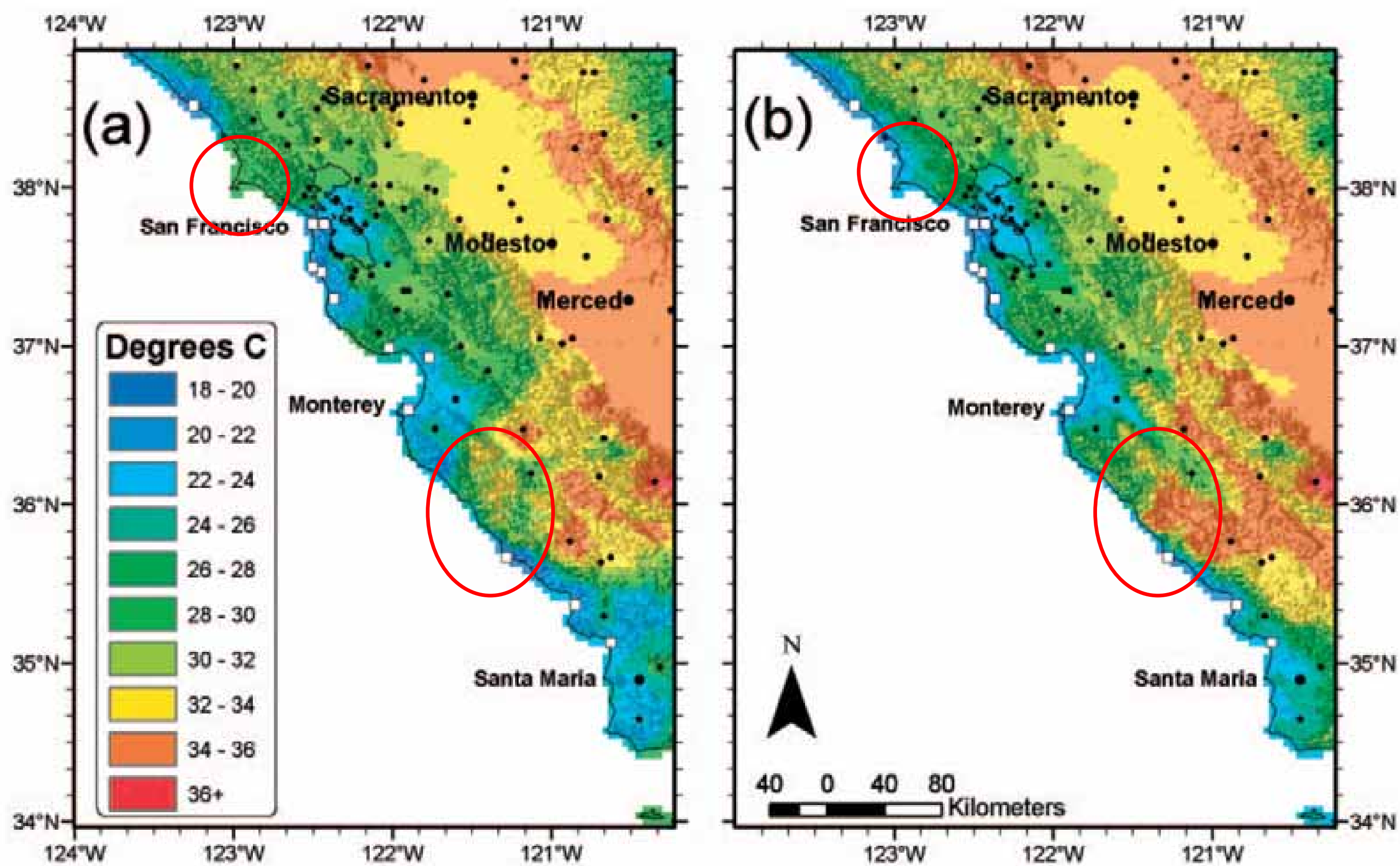


Fig. 5 Map of 1961–1990 mean August maximum temperature for the coast of central California (a) without and (b) with coastal proximity weighting. Open squares denote locations of coastal stations. Solid dots denote inland stations. Modeling grid resolution is 4 km.

The vertical layer weight

- To simulate situations where non-monotonic relationships between climate and elevation are possible, climate stations are divided into 2 vertical layers.
- The vertical layer weight is given as follows:

$$W(l) = \begin{cases} 1; & \Delta l = 0 \text{ or } \Delta z \le \Delta z_m \\ \dfrac{1}{(\Delta z - \Delta z_m)^y}; & \Delta l = 1 \text{ and } \Delta z > \Delta z_m \end{cases}$$

where Δl is the layer difference (1 for adjacent layer, 0 for same layer), Δz is the elevation difference, and y is the vertical layer weighting exponent. Δz_m is the minimum elevation difference. A value of y is 0.5 to 1.0.

Estimation of potential wintertime inversion height

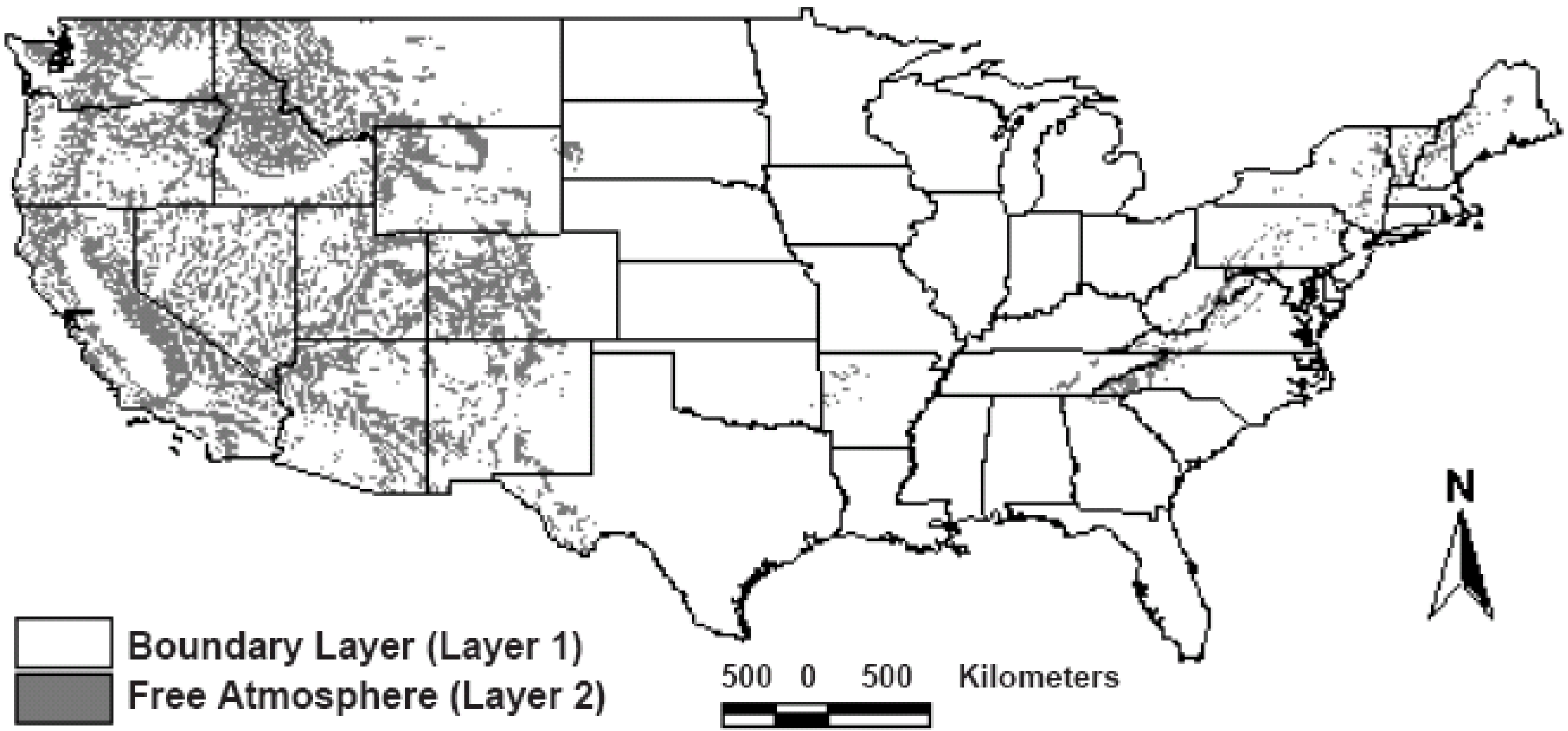
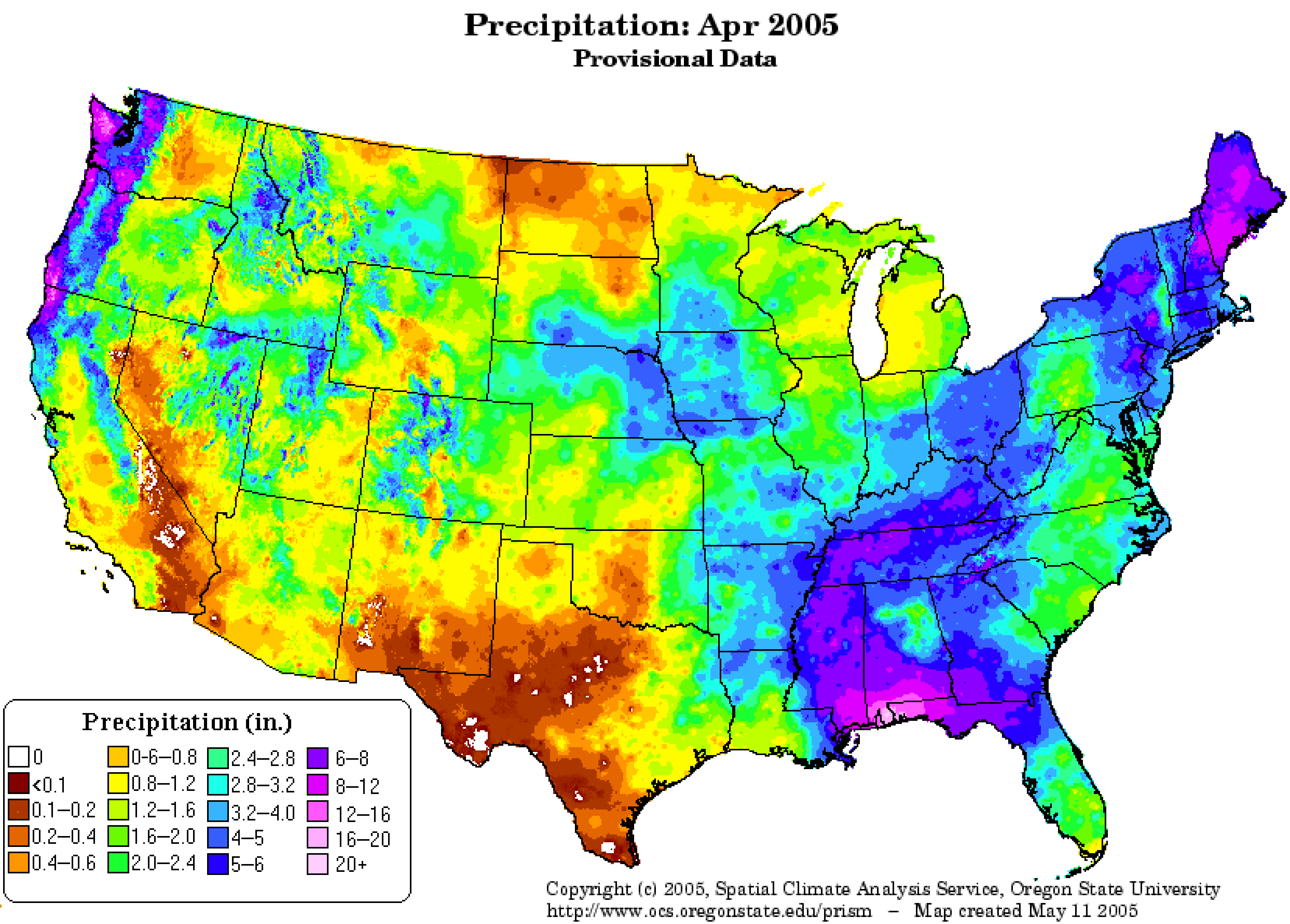


Fig. 6 Estimated wintertime inversion layer grid for the conterminous US. Shaded areas denote terrain estimated to be in the free atmosphere (layer 2) under winter inversion conditions, should they develop. Unshaded areas are expected to be within the boundary layer (layer 1). Grid resolution is 4 km.

Apply to my future work

- Adaptation to the case in Japan (Hokkaido?) this algorithm
  - Japan has much observation points than United States of America in this case.
- Application to global warming conditions (by several global warming scenarios) based on the case in Japan above
- Adding to various of elements, correlations of climate and the vegetation, the population, and the economy, in this algorithm for integrated research for global warming.


Precipitation: Apr 2005
Provisional Data
Precipitation (in.)
0
<0.1
0.1–0.2
0.2–0.4
0.4–0.6
0-6–0.8
0.8–1.2
1.2–1.6
1.6–2.0
2.0–2.4
2.4–2.8
2.8–3.2
3.2–4.0
4–5
5–6
6–8
8–12
12–16
16–20
20+
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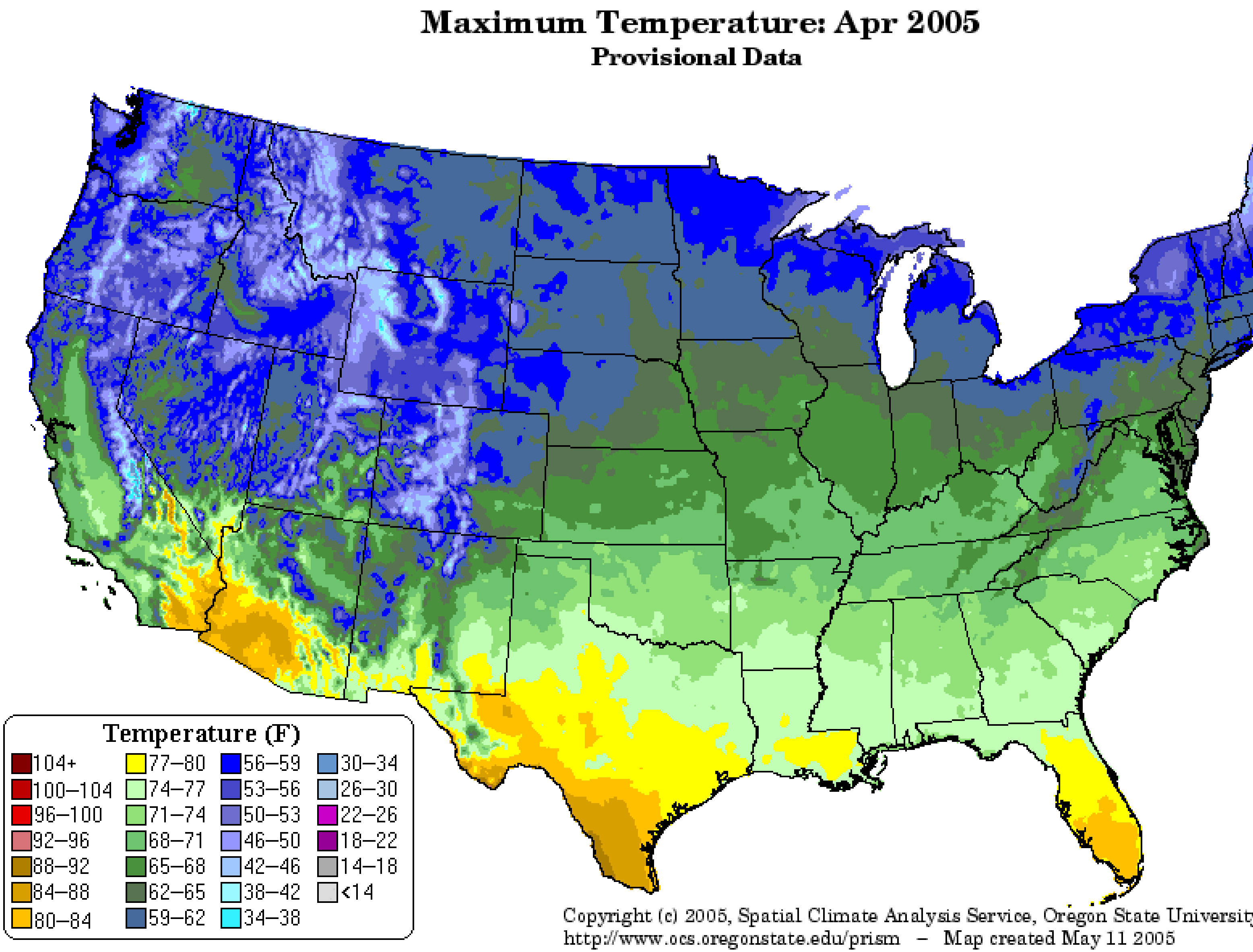
http://www.ocs.oregonstate.edu/prism – Map created May 11 2005


Maximum Temperature: Apr 2005
Provisional Data
Temperature (F)
104+
100–104
96–100
92–96
88–92
84–88
80–84
77–80
74–77
71–74
68–71
65–68
62–65
59–62
56–59
53–56
50–53
46–50
42–46
38–42
34–38
30–34
26–30
22–26
18–22
14–18
<14
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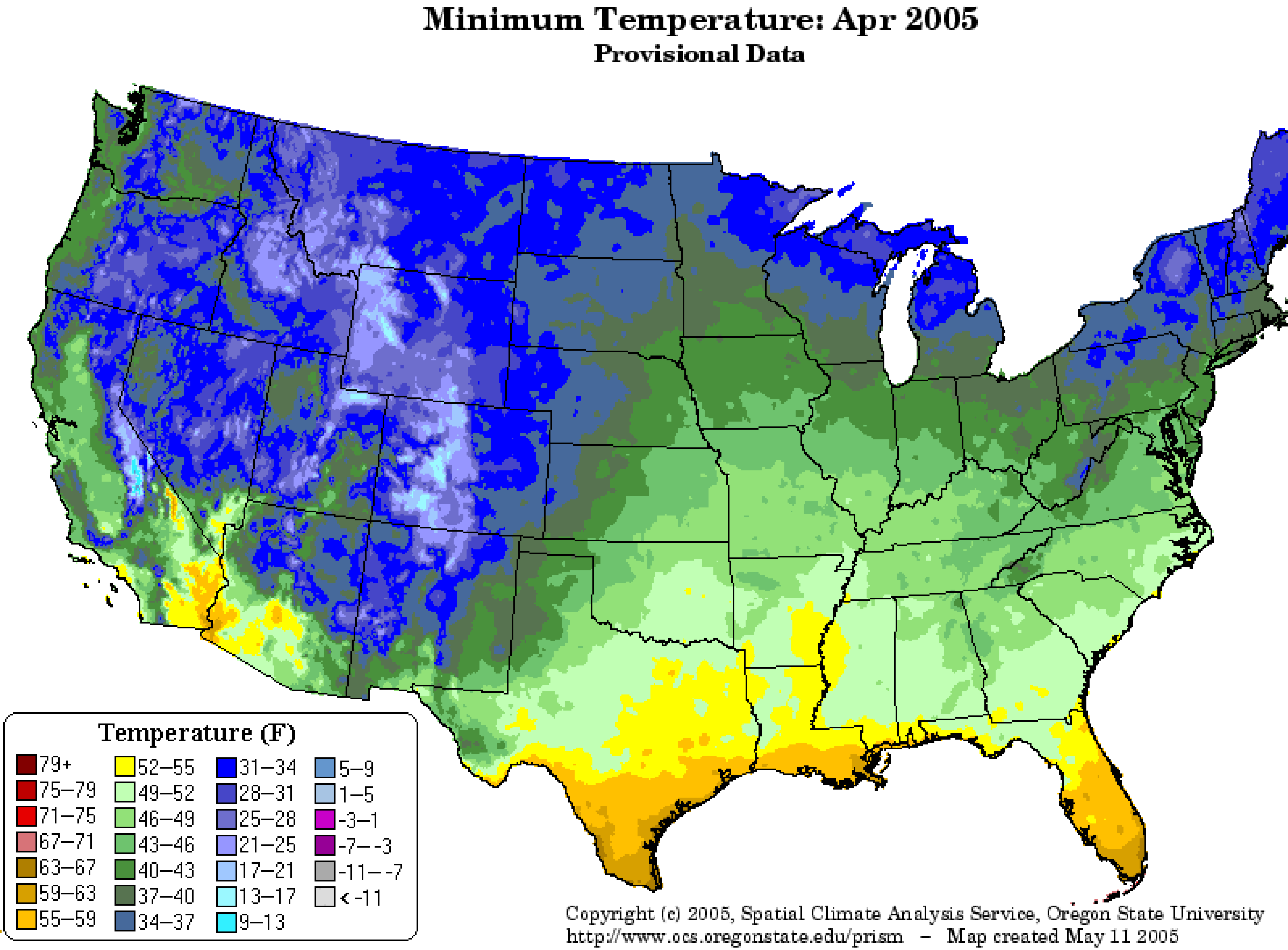
Minimum Temperature: Apr 2005
Provisional Data
Temperature (F)
79+
75–79
71–75
67–71
63–67
59–63
55–59
52–55
49–52
46–49
43–46
40–43
37–40
34–37
31–34
28–31
25–28
21–25
17–21
13–17
9–13
5–9
1–5
-3–1
-7–-3
-11–-7
<-11
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http://www.ocs.oregonstate.edu/prism – Map created May 11 2005

Table 1. Descriptions and typical ranges and default values of relevant PRISM parameters for regional-scale climatological modeling. In an application, the model operator may: (1) use the default values; (2) adjust the parameters based on expert judgement; or in some cases, (3) allow the model to estimate the values (see parameters annotated with [a] or [c]). Parameters showing only 1 (default) value are those that are infrequently varied from application to application

Name	Description		Typical min.default/max. values	
Regression function				
r	Radius of influence		30/50/100 km[a]	
s_f	Minimum number of on-facet stations desired in regression		3/5/8 stations[a]	
s_t	Minimum number of total stations desired in regression		10/15/30 stations[a]	
			Precipitation (km^{-1})[b]	**Temperature** (°C km^{-1})
β_{1m}	Minimum valid regression slope	Layer 1	0.0	–10
		Layer 2	–0.5	–10
β_{1x}	Maximum valid regression slope	Layer 1	3.0	0/10/20
		Layer 2	0.0	0
β_{1d}	Default valid regression slope	Layer 1	0.8	–6
		Layer 2	–0.2	–6
Distance weighting				
a	Distance weighting exponent		2.0	
F_d	Importance factor for distance weighting		0.8	
Elevation weighting				
b	Elevation weighting exponent		1.0	
F_z	Importance factor for elevation weighting		0.2	
Δz_m	Minimum station-grid cell elevation difference below which elevation weighting is maximum		100/200/300 m	
Δz_x	Maximum station-grid cell elevation difference above which elevation weight is zero		500/1500/2500 m	
Facet weighting				
c	Facet weighting exponent		0.0/1.5/2.0	
g_m	Minimum inter-cell elevation gradient, below which a cell is flat		1 m/cell[c]	
λ_x	Maximum DEM filtering wavelength for topographic facet determination		60/80/100 km	
Coastal proximity weighting				
p_x	Maximum coastal proximity difference, above which proximity weight is zero		Varies with application	
v	Coastal proximity weighting exponent		0.0/1.0/1.0	
Vertical layer weighting				
y	Vertical layer weighting exponent		0.0/1.0/1.0[c]	

[a]Can be optimized automatically with cross-validation statistics
[b]Precipitation-elevation slopes are normalized by the mean precipitation in the regression function, e.g. (100 mm km^{-1} slope)/(1000 mm mean precipitation) = 0.1 km^{-1} normalized slope
[c]Can be varied dynamically by the model