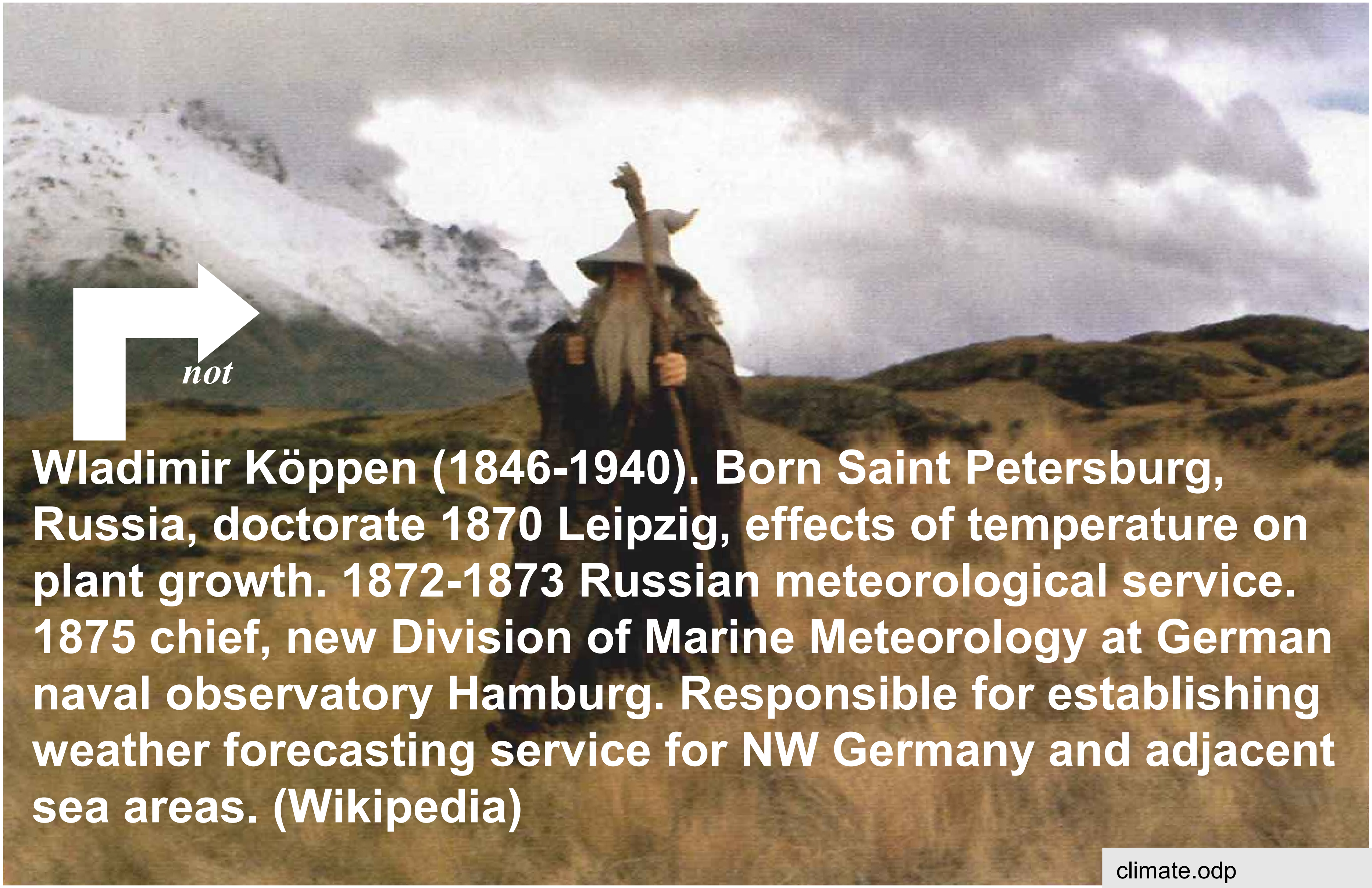
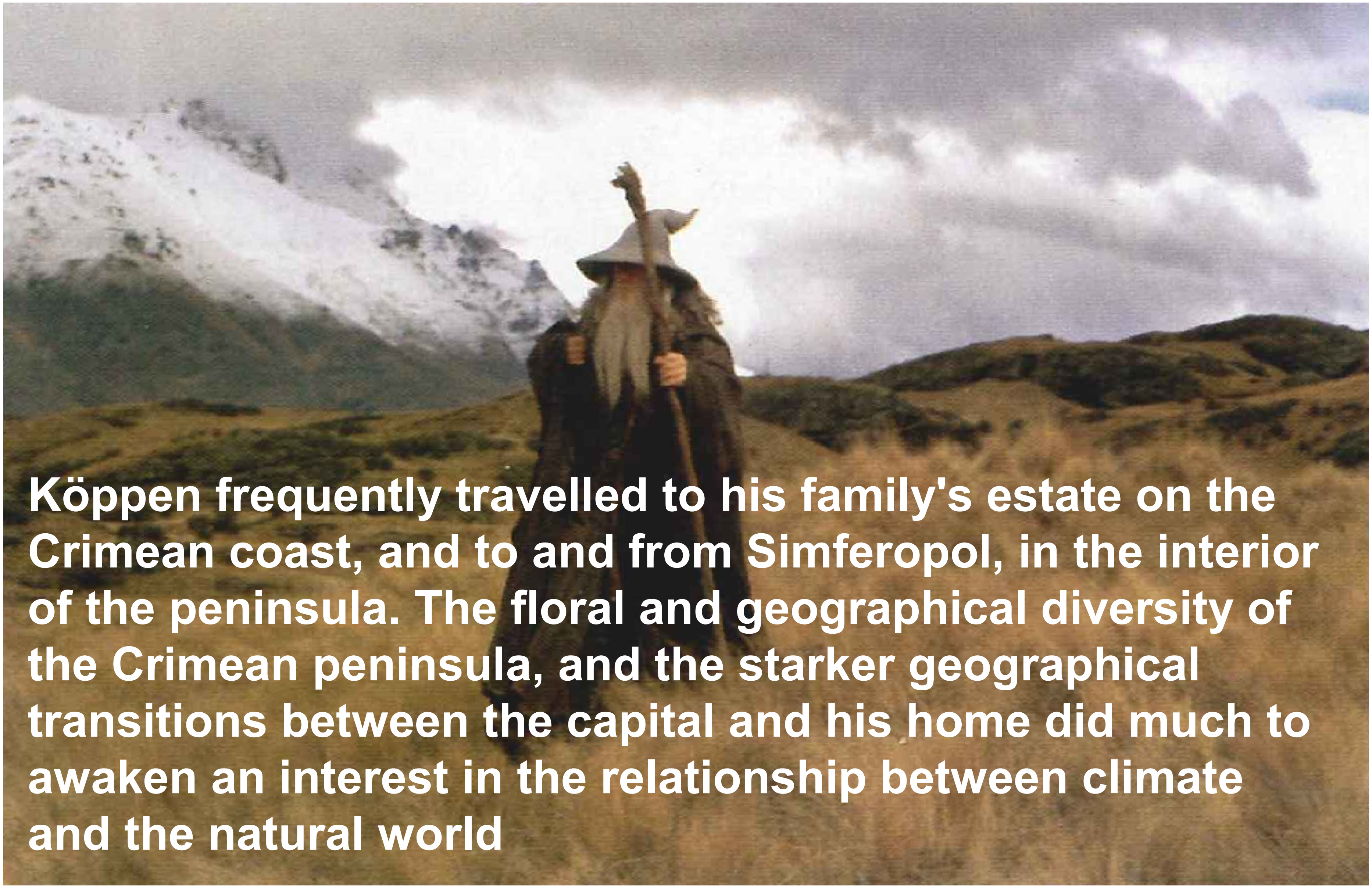
Chapter 15. “Earth’s Climates” 28 Nov 2011

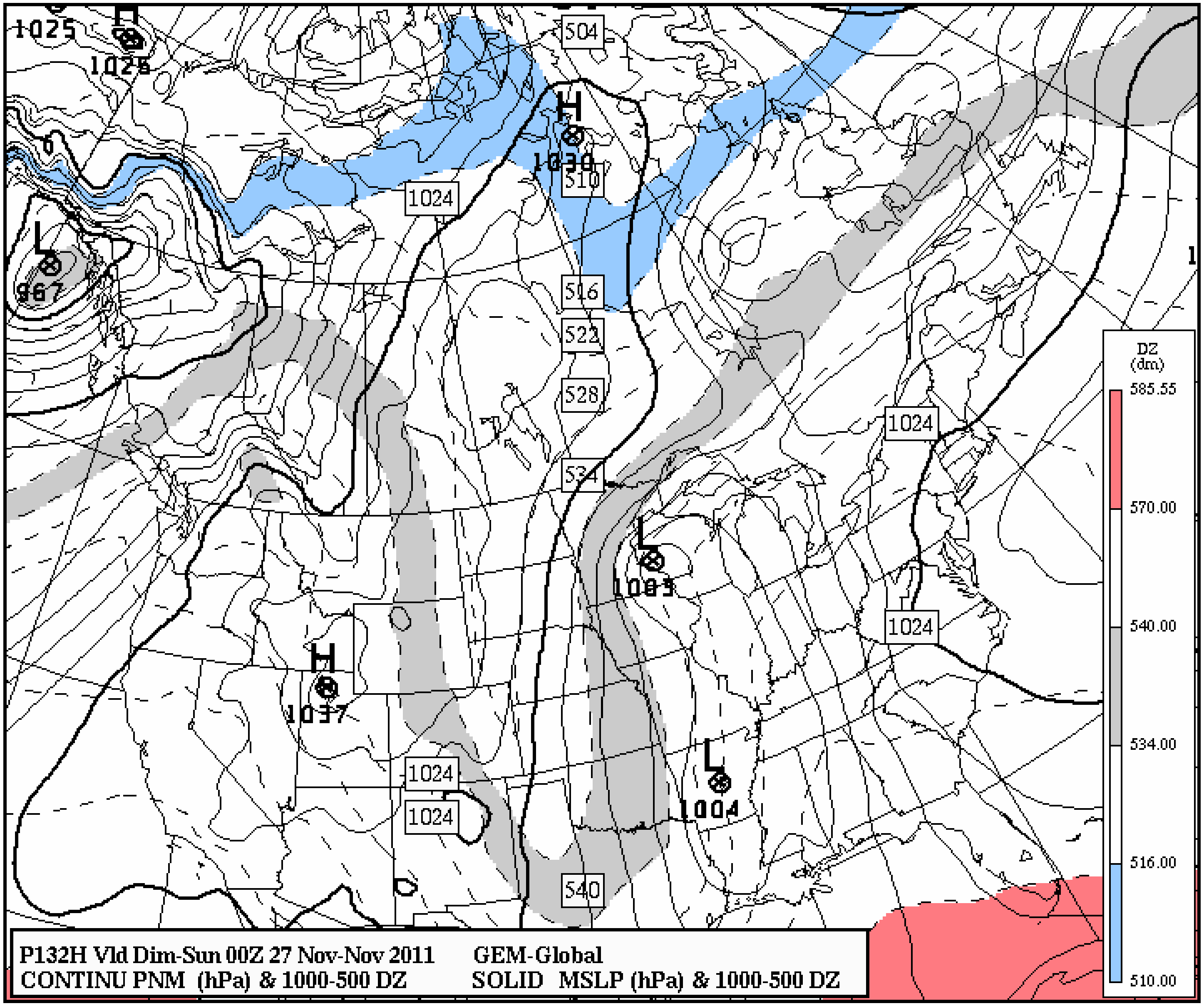
• We’ll cover the Koeppen classification (introduced in 1900; updated by various scientists including Geiger, Trewartha, others)



• and we'll briefly look at other plant/vegetation related approaches to climate classification



Last Monday's class (21 Nov.) included this 5½ day prog. for 5 pm MST Saturday

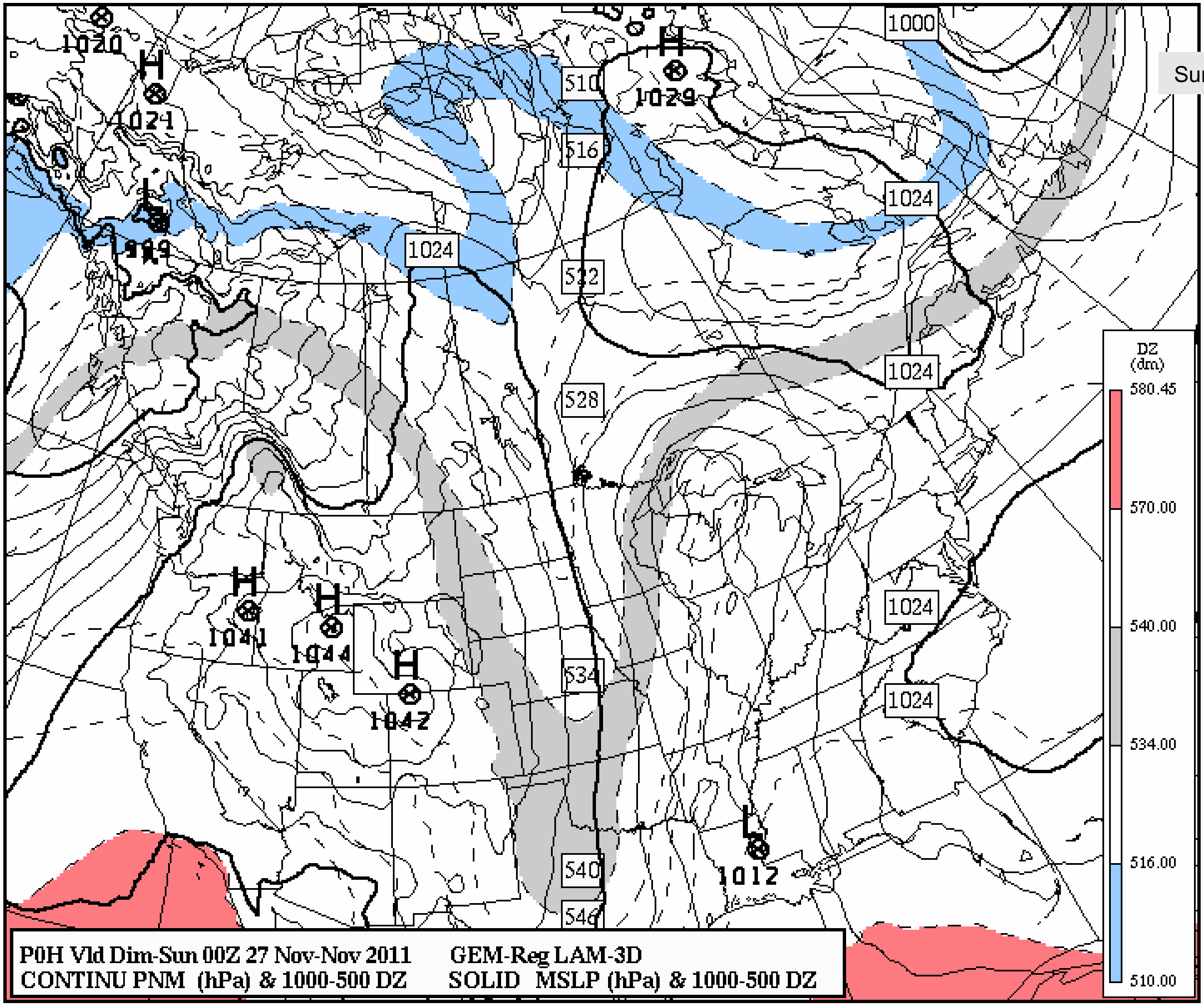


Here's the analysis for 5 pm MST Saturday

Environment Canada Environnement Canada

Home > Current Conditions and Forecasts > Alberta > Provincial Summary >

Pincher Creek
Past 24 Hour Conditions



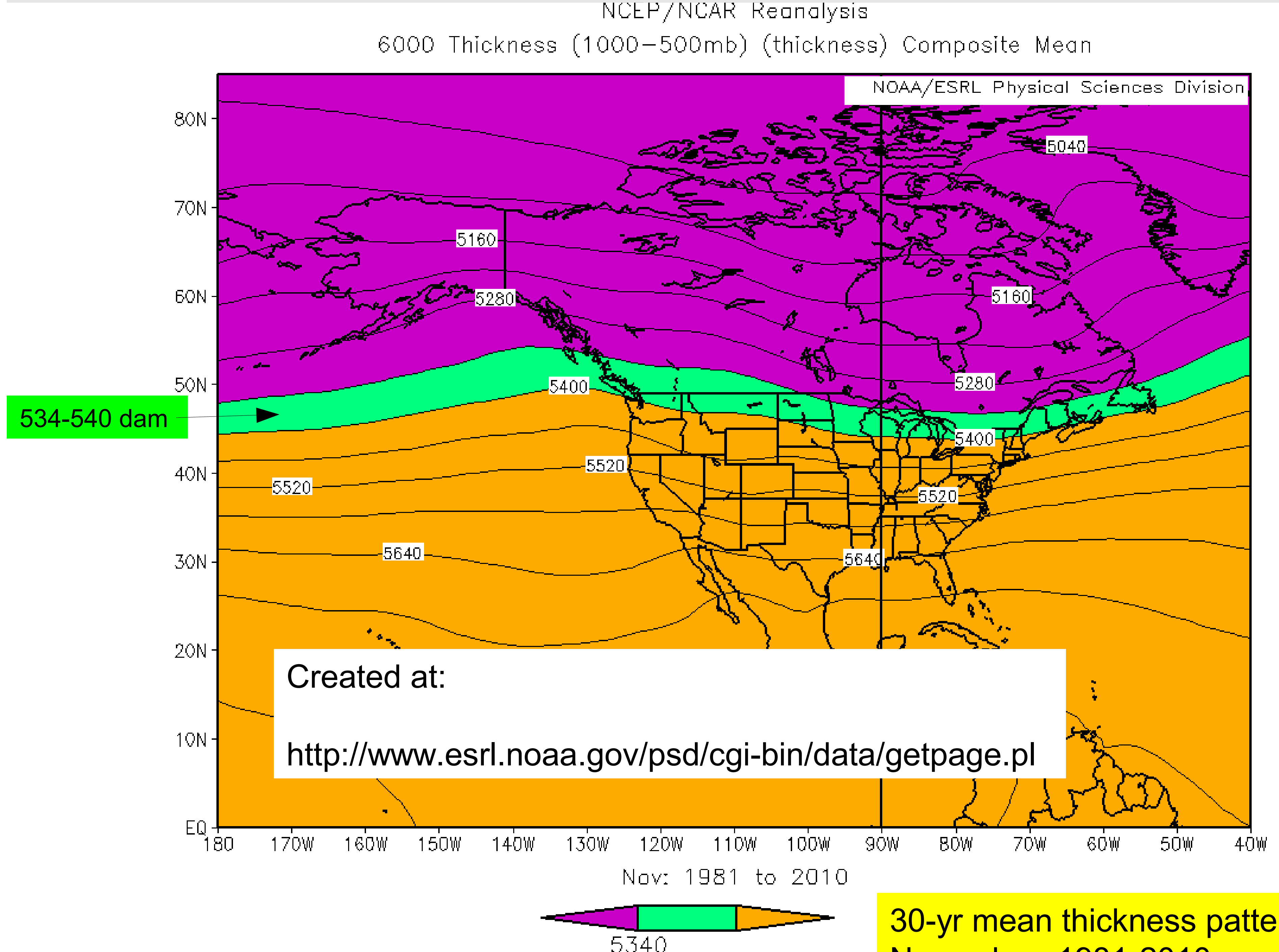
Sun 14MST

Wind (km/h)
WSW 55 gust 87
WSW 67 gust 89
WSW 72 gust 104
WSW 72 gust 98
W 68 gust 87
W 63 gust 80
W 52 gust 87
W 46 gust 72
WSW 52 gust 80
WSW 41 gust 70
WSW 55 gust 76
WSW 46 gust 70
WSW 57 gust 76
WSW 68 gust 87
WSW 52 gust 72
WSW 59 gust 78
WSW 50 gust 78
WSW 33 gust 57

- overall thermal (thickness) pattern well predicted
- centre of coastal low a bit off, but pressure pattern good overall

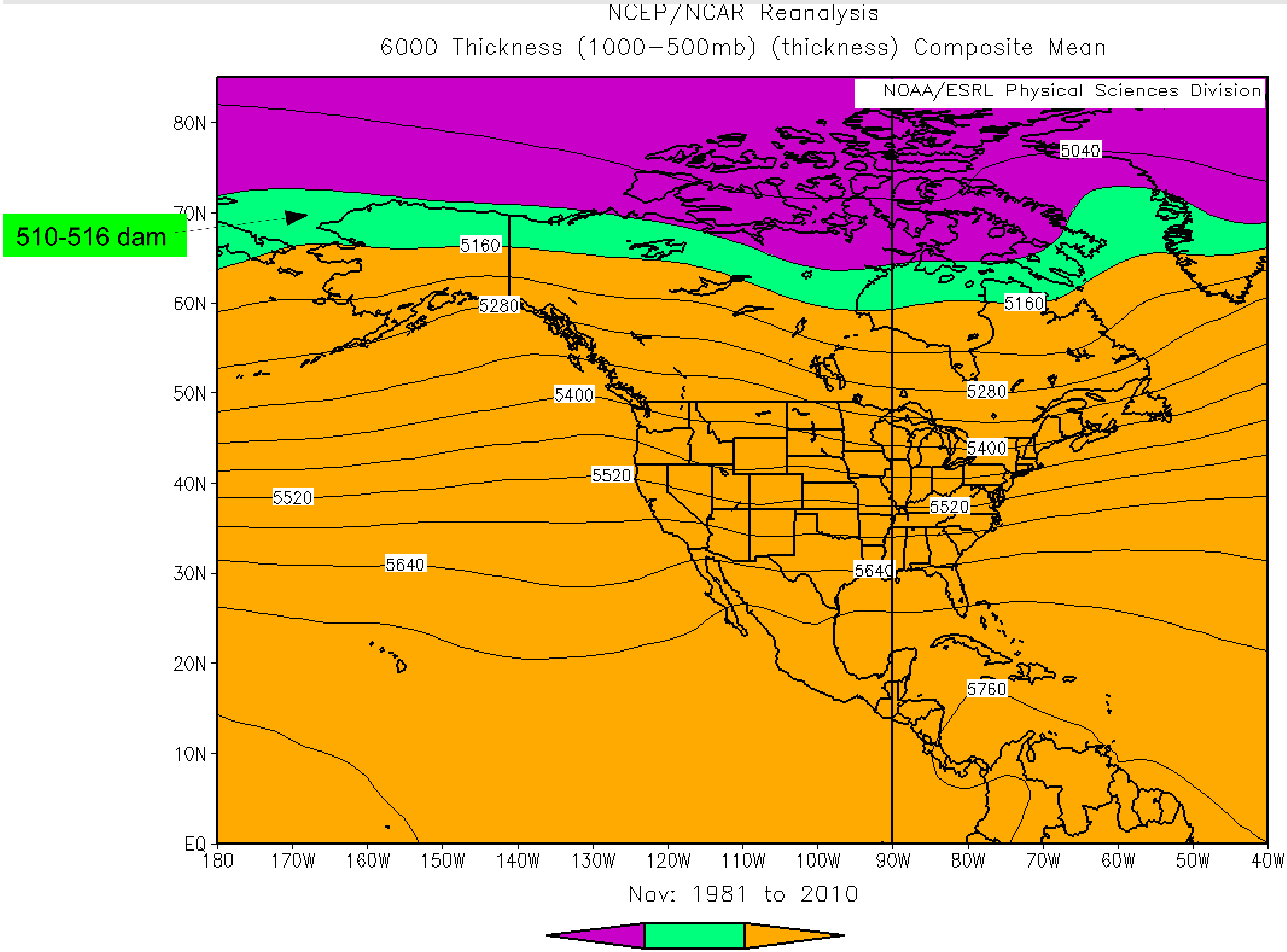
- huge Δp across Rockies
- lee trough

But is GEM merely forecasting a climatologically normal November state? – no!



30-yr mean thickness pattern for November, 1981-2010

But is GEM merely forecasting a climatologically normal November state? – no!



Then is GEM merely “remembering” its initial state? To *some* extent, yes – as it should (persistence)

Definition of “climate”

• “climate consists of all statistical properties” of the atmosphere (p426)

• logically, we must include ocean too – for climate is linked to ocean state – and to the cryosphere – and to a layer of land substrate

• the longer the averaging period on which we define climate statistics the broader the range of participating processes and the deeper the reaches of ocean/ice/earth interior whose heat storage is pertinent

• criteria by which distinct climates are delineated “requires considerable subjectivity”

• more an exercise in Geography than atmospheric science

Köppen’s criteria for climate classification

• based on temperature and precipitation

• Koeppen considered “what combinations of monthly mean temperature ($\overline{T}_{mm}$) and precipitation ($\overline{P}_{mm}$) were associated with” boundaries separating “natural vegetation types”

• categories “tend to arrange themselves… in response to: latitude, degree of continentality, location relative to topography, elevation

Natural vegetation types in Alberta? – *boreal forest* (mostly coniferous); *parkland* (transitional area between the prairie grasslands and the coniferous regions; rich soil, isolated stands of trees, esp. aspen); *prairie*

Köppen's climate classification

Recognizes five major climate types based on the annual and monthly averages of temperature and precipitation. Each type is designated by a capital letter.

A - Tropical – high temperatures year round and large amount of year round rain $\overline{T}_{mm} > 18^{o}\mathrm{C}$, all months

B - Dry – little rain and a huge daily temperature range. "Potential evaporation" exceeds precip. Two subgroups are used with the B climates:

S - semiarid or steppe
W - arid or desert

C - Mild midlatitude. These climates have warm, dry summers and cool, wet winters $-3 \leqslant \left(\overline{T}_{mm}\right)^{min} \leqslant 18^{o}\mathrm{C}$ (i.e. coldest month of year has mean monthly temperature in this range)

Köppen's climate classification

D - Severe midlatitude – interior regions of large land masses.
Total precipitation not very high, seasonal temperatures vary widely

$$\left(\overline{T}_{\mathrm{mm}}\right)^{\mathrm{min}} \leq -3^{\mathrm{o}}\mathrm{C}, \text{some snow}$$

Winters have at least occasional snow cover, coldest month has mean temperature below -3^{o}C, summers typically mild

E - Cold Climates. Permanent ice and tundra always present.
Only about four months of the year have above freezing temperatures

$$\overline{T}_{\mathrm{mm}} < 10^{\mathrm{o}}\mathrm{C}\ , \text{ all months}$$

Köppen's climate classification

Further subgroups are designated by a second, lower case letter which distinguish specific seasonal characteristics of temperature and precipitation.

f - Moist with adequate* precipitation in all months and no dry season. This letter usually accompanies the A, C, D climates

*precip exceeds potential evapotranspiration?

m - Rainforest climate in spite of short, dry season in monsoon type cycle. This letter only applies to A climates.

s - There is a dry season in the summer of the respective hemisphere (high-sun season).

w - There is a dry season in the winter of the respective hemisphere (low-sun season).

Köppen's climate classification

To refine the classification a third letter was added to the code.

a - Hot summers where the warmest month is over 22°C. Qualifies C and D climates. (Strip of north-central and northeast US)

b - Warm summer with the warmest month having mean temperature below 22°C. Qualifies C and D climates.

c - Cool, short summers with less than four months having monthly mean temperature exceeding 10°C in the C and D climates

d - Very cold winters, coldest month below -38°C (D climates only)

h - Dry-hot with a mean annual temperature over 18°C (B only)

k - Dry-cold with a mean annual temperature under 18°C (B only)

Table 15-1

TYPE	SUBTYPE	LETTER CODE	CHARACTERISTICS
A—Tropical	Tropical wet	Af	No dry season
$\overline{T}_{mm} > 18^{o}C$, all months	Tropical monsoonal	Am	Short dry season
	Tropical wet and dry	Aw	Winter dry season
B—Dry	Subtropical desert	BWh	Low-latitude dry
$\overline{P}_{mm} < \text{Pot'l Evap'n}$	Subtropical steppe	BSh	Low-latitude semi-dry
	Midlatitude desert	BWk	Midlatitude dry
	Midlatitude steppe	BSk	Midlatitude semi-dry
C—Mild	Mediterranean	Csa	Dry, hot summer
	Midlatitude	Csb	Dry, warm summer
$-3 \leqslant \left(\overline{T}_{mm}\right)^{min} \leqslant 18^{o}C$	Humid subtropical	Cfa	Hot summer, no dry season
		Cwa	Hot summer, brief winter dry season
	Marine west coast	Cfb	Mild throughout year, no dry season, warm summer
		Cfc	Mild throughout year, no dry season, cool summer
D—Severe Midlatitude	Humid continental	Dfa	Severe winter, no dry season, hot summer
$\left(\overline{T}_{mm}\right)^{min} \leqslant -3^{o}C$, some snow		Dfb	Severe winter, no dry season, warm summer [Edmonton]
		Dwa	Severe winter, winter dry season, hot summer
		Dwb	Severe winter, winter dry season, warm summer
	Subarctic	Dfc	Severe winter, no dry season, cool summer
		Dfd	Extremely severe winter, no dry season, cool summer
		Dwc	Severe winter, winter dry season, cool summer
		Dwd	Extremely severe winter, winter dry season, cool summ
E—Polar	Tundra	ET	No true summer
$\overline{T}_{mm} < 10^{o}C$ all months	Polar ice cap	EF	Perennial ice
H—Highland	Highland	H	Highland

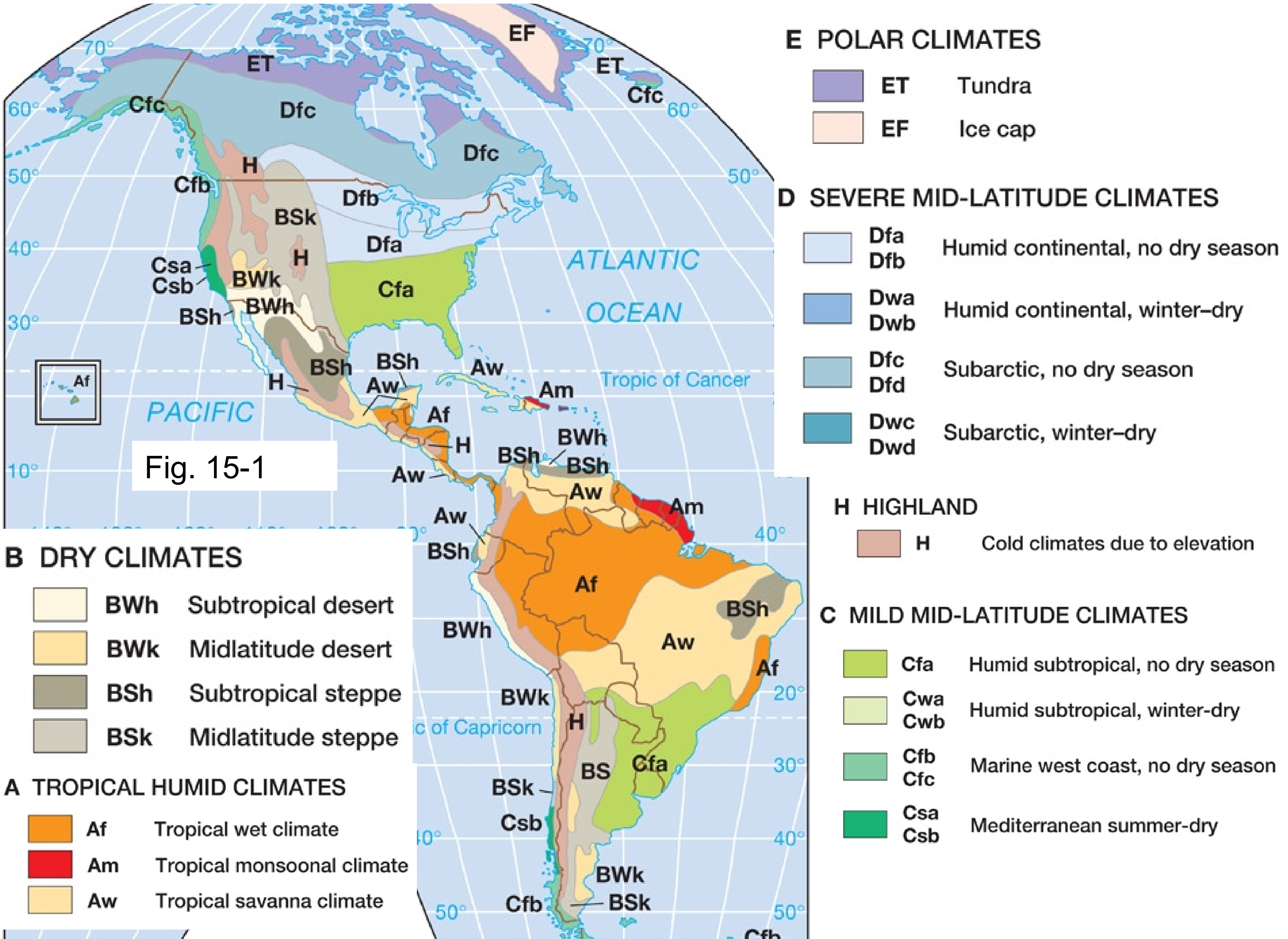
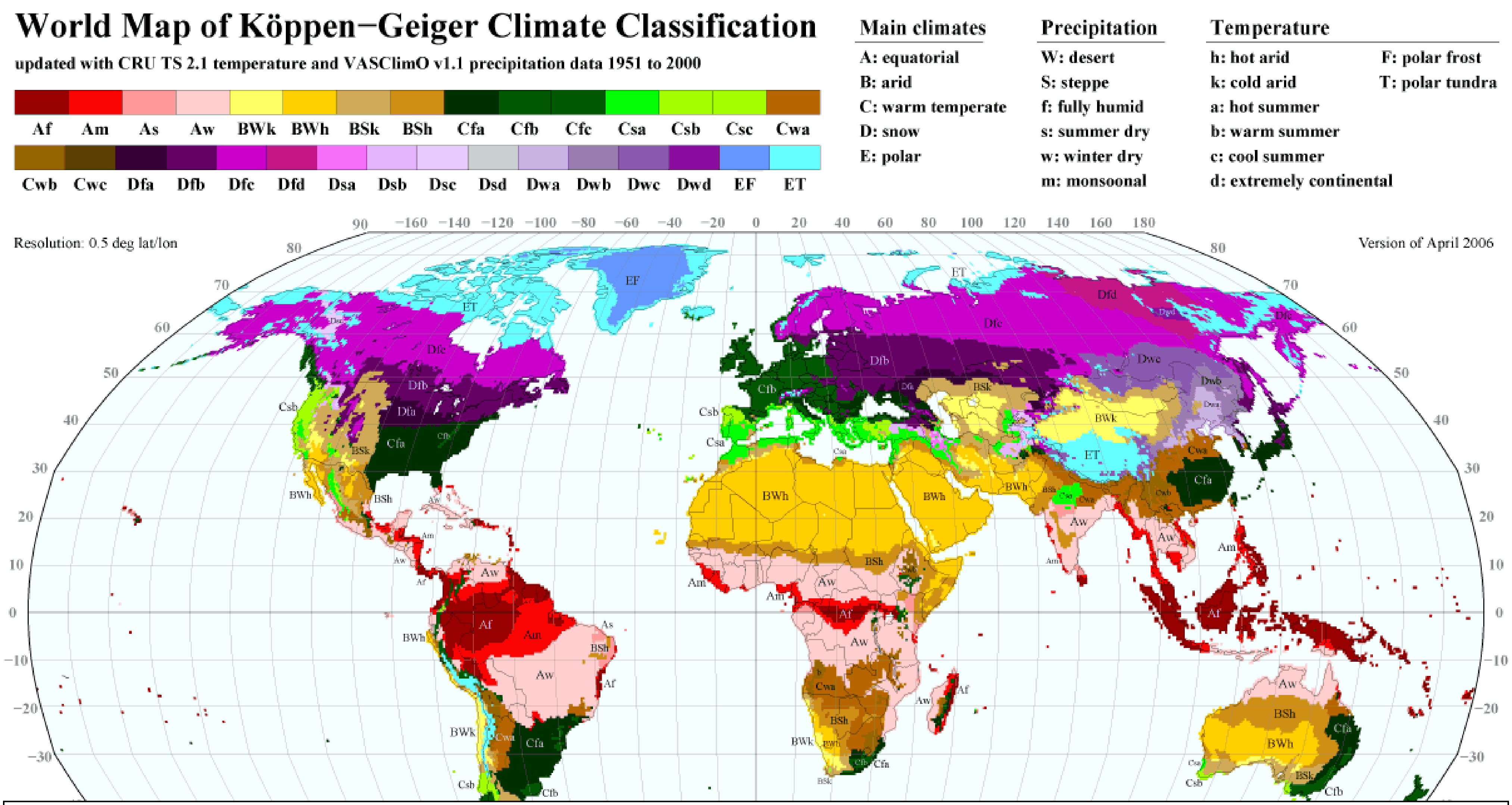

E POLAR CLIMATES
ET Tundra
EF Ice cap
D SEVERE MID-LATITUDE CLIMATES
Dfa Dfb Humid continental, no dry season
Dwa Dwb Humid continental, winter–dry
Dfc Dfd Subarctic, no dry season
Dwc Dwd Subarctic, winter–dry
H HIGHLAND
H Cold climates due to elevation
C MILD MID-LATITUDE CLIMATES
Cfa Humid subtropical, no dry season
Cwa Cwb Humid subtropical, winter-dry
Cfb Cfc Marine west coast, no dry season
Csa Csb Mediterranean summer-dry
B DRY CLIMATES
BWh Subtropical desert
BWk Midlatitude desert
BSh Subtropical steppe
BSk Midlatitude steppe
A TROPICAL HUMID CLIMATES
Af Tropical wet climate
Am Tropical monsoonal climate
Aw Tropical savanna climate
ATLANTIC
OCEAN
PACIFIC
Tropic of Cancer
Tropic of Capricorn
EF
ET
Cfc
Dfc
Dfb
Dfa
Cfa
Cfb
H
BSk
BWk
BWh
BSh
Csa
Csb
Aw
Am
Af
BS
70°
60°
50°
40°
30°
20°
10°

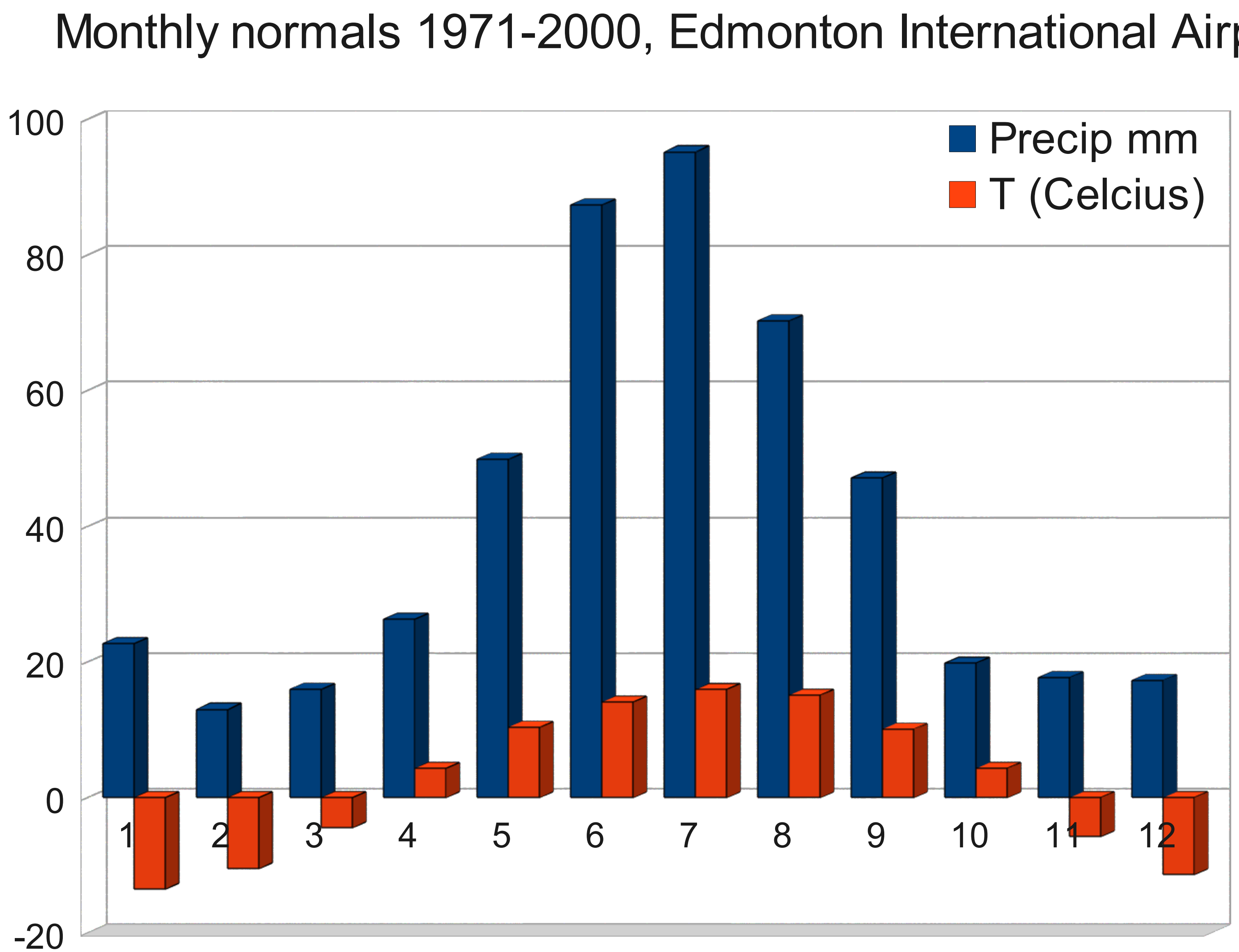
Fig. 15-1



Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel, 2006: World Map of the Köppen-Geiger climate classification updated. Meteorol. Z., 15, 259-263. DOI: 10.1127/0941-2948/2006/0130.

Central Alberta has a dry continental climate, with most places falling under the humid continental classification (Köppen climate classification Dfb), though some areas in the southeast of this region, close to the border with Saskatchewan ... are semi-arid (Köppen Bsk)... [Wikipedia]

Dfb Severe midlatitude (D) – Humid continental (f) – warm summer (b)



Mean annual temperature at Edmonton Int'l Airport from 1971-2000 normals: +2.4°C (City Centre +3.9°C)

Corresponding 1961-1990 normals were 2.1°C and 3.6°C

Highland climates – mountain or plateau areas

Tussock tops, Rock & Pillar range, South Island, New Zealand

… plans for about 150 wind generators (controversial)

Now I've been around some stations way out back upon the hills,
Round about the roarin' rivers, round about the ripplin' rills,
By the mountain creeks that murmur where the matagauri grows,
An' the rustlin' yaller tussock points the way the bleak wind blows;

From "Another Station Ballad" by Hamilton Thompson

Other bases for climate classification

- the Koeppen system appeals to "natural vegetation types," but temperature and precipitation alone "do not directly determine the geographic limits of natural vegetation" (p480)

- the "water balance" is crucial for vegetation type

$$P = E + R + \Delta S$$

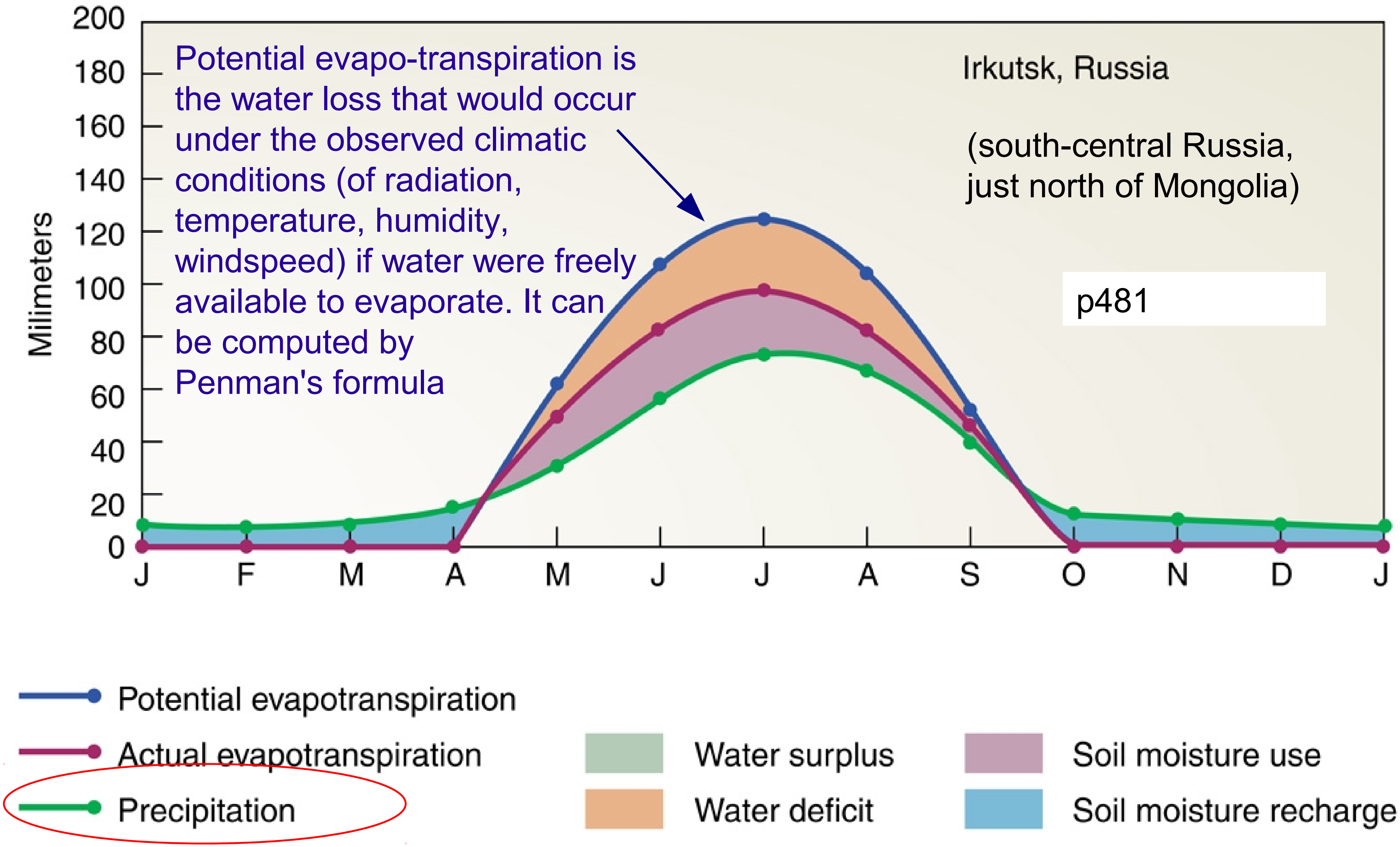
- over the budget interval (duration T_{avg}), precipitation *P* must balance

  - evapotranspiration *E*

  - runoff *R*

  - change in landscape water storage ΔS

Other bases for climate classification



Penman's "combination equation" for "potential evapotranspiration" (also known as "atmospheric demand")

Derived by combining

- "Ohm's Law model" for transport, viz. heat flux driven by T_s-T_a, vapour flux by e_s-e_a

$$Q_H \propto \frac{T_s - T_a}{r_a} \quad , \quad Q_E \propto \frac{e_s - e_a}{r_a}$$

- conservation of energy

$$Q_H + Q_E = Q^* - Q_G$$

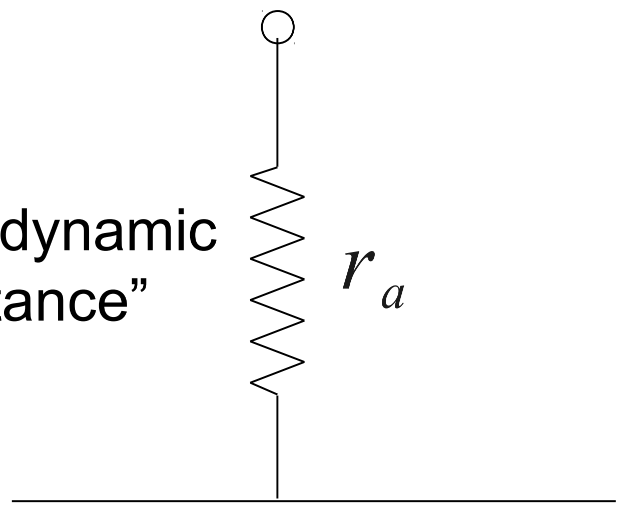
Small for daily budget

Transfer resistance depends (inversely) on wind speed, i.e. decreases with increasing wind speed:

$$r_a \propto \frac{1}{\sqrt{U}}$$

Net radiation Q^*, air temp T_a and vapour pressure e_a

"aerodynamic resistance"



r_a

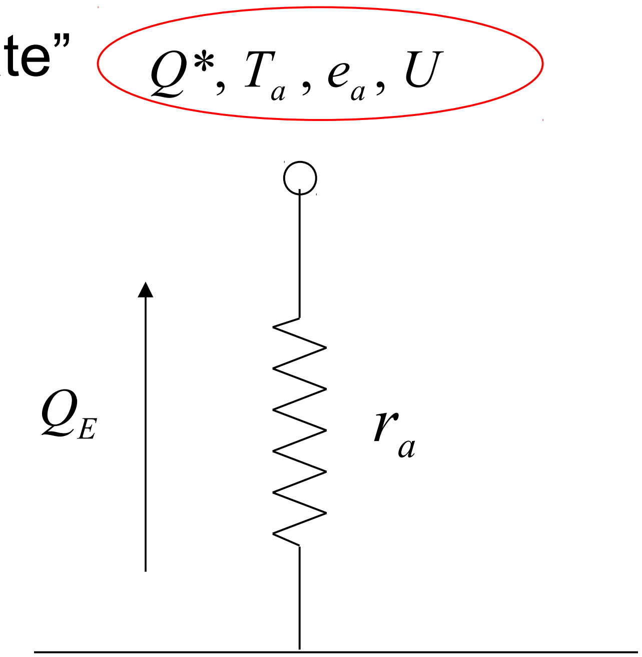
freely-evaporating surface with temperature T_s and vapour pressure $e_s(T_s)$

Penman's "combination equation" for "potential evapotranspiration" (also known as "atmospheric demand")

Penman's formula gives the evaporation that ***would*** result from the "imposed" regime (climate) of Q^*, T_a, e_a, U ***if*** water were freely available at the surface

"imposed climate"

responding evaporation



• potential evapotranspiration depends mainly on three factors: the net radiative energy supply, vapour pressure deficit (vpd), & wind

net radiative energy supply

vapour pressure deficit (vpd)

$$Q_E \approx \frac{s}{s+\gamma} Q^* + \frac{\rho\, c_p \left[e_s(T_a) - e_a \right] / r_a}{s+\gamma}$$

• can be used to compute pot'l evap'n for hourly or daily intervals

(c_p, s, γ known "constants")

s ≈ 150 Pa/°C, slope of sat'n vapour pressure curve; γ ≈ 66 Pa/°C, psychrometric constant; c_p ≈ 1000

Other bases for climate classification…
eg. growing degree days (GDD)

e.g. suppose "base temperature" 5°C. Then a day with mean temp 25°C contributes:
GDD= 1 * (25 - 5) = 20 GDD

GDD classifies only the growing season; does so quantitatively, for a specific purpose:

A given crop/variety requires a certain number of degree days to mature

- *Brassica napus* canola ≈ spring wheat ≈ 1040 GDD
- *Brassica rapa* canola ≈ barley ≈ 850 GDD

Growing degree days do not limit canola production in northern areas as much as might be expected since long daylight hours partially compensate for lower temperatures