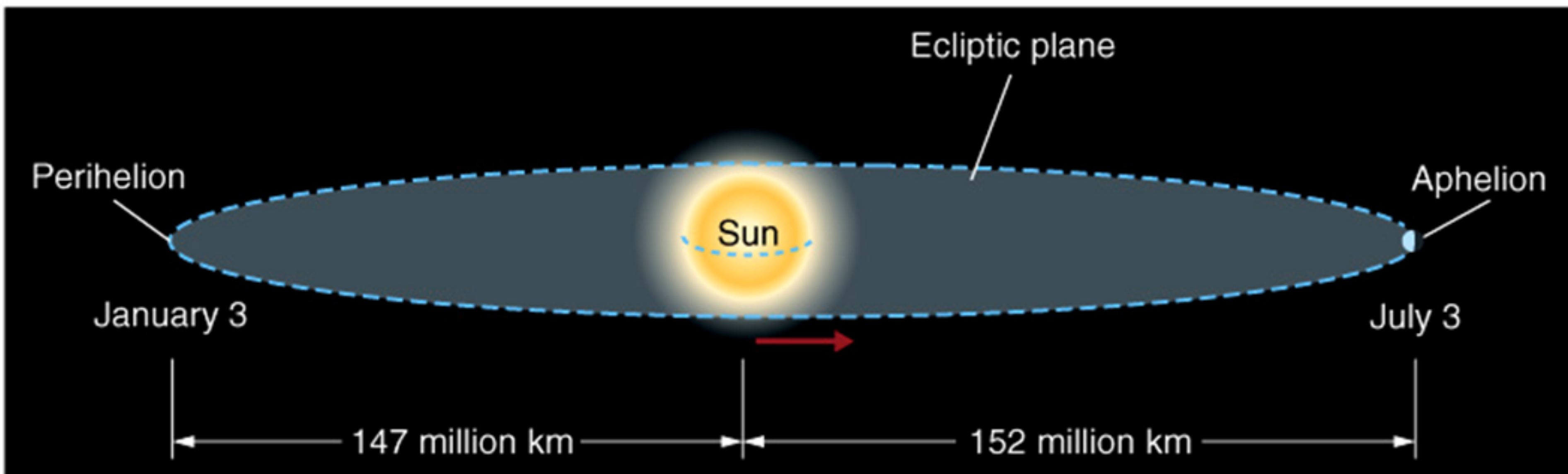
Topic 3

Seasonal and Daily Temperatures

Causes of the Earth's Seasons

- Orbital alignment to the Sun = seasonal variations in solar energy
- Revolution
  - The ecliptic plane
  - Perihelion (Jan 3; 147 mil km)
  - Aphelion (July 3; 152 mil km)
    - Seasonal radiation variation = ~7%



Why the Earth has seasons

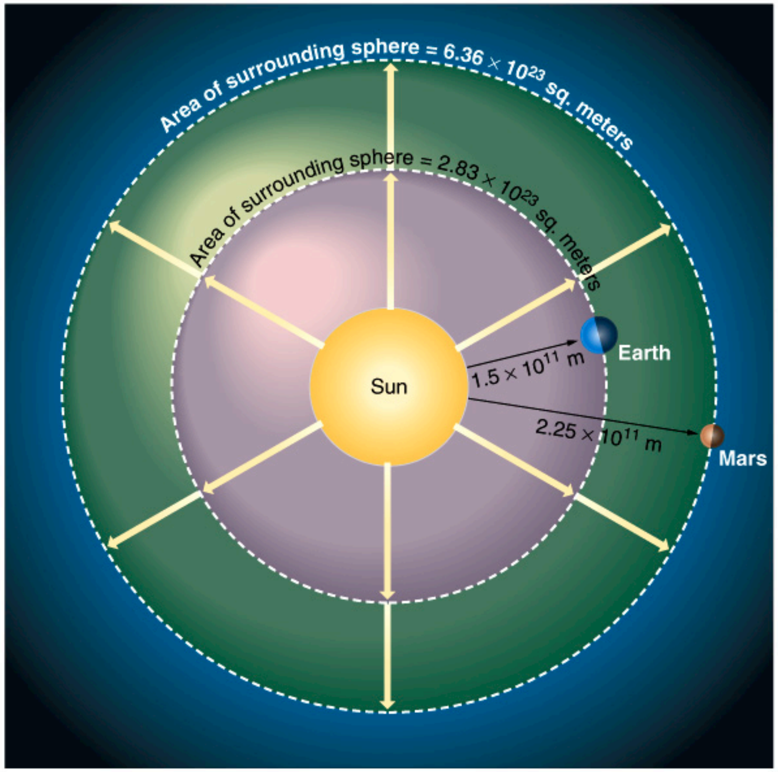
- Distance not the only factor impacting seasons.
- The amount of energy that reaches the Earths surface is influence by the distance from the Sun, the solar angle, and the length of daylight.
- When the Earth tilts toward the sun in summer, higher solar angles and longer days equate to high temperatures.

Solar Constant

- The Solar Constant
  - The amount of incoming solar electromagnetic radiation per unit area, measured on the outer surface of Earth's atmosphere in a plane perpendicular to the rays.

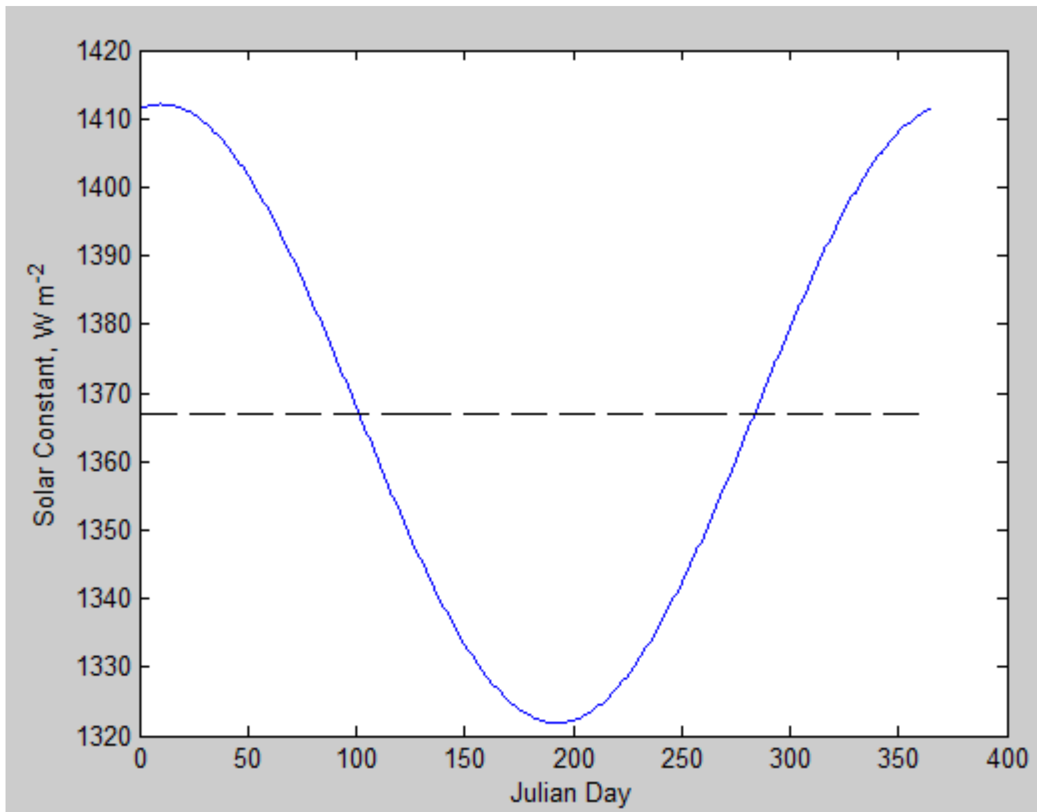
- Inverse square law

$$\frac{3.865 \cdot 10^{26} W}{4 \left(1.5 \cdot 10^{11} m\right)^2} = 1367 \text{ W m}^{-2}$$



Solar constant

$$SC = 1367\ \mathrm{W\ m^{-2}} \quad 1 + 0.033\ \cos\frac{2 \quad (day \quad 10)}{365}$$



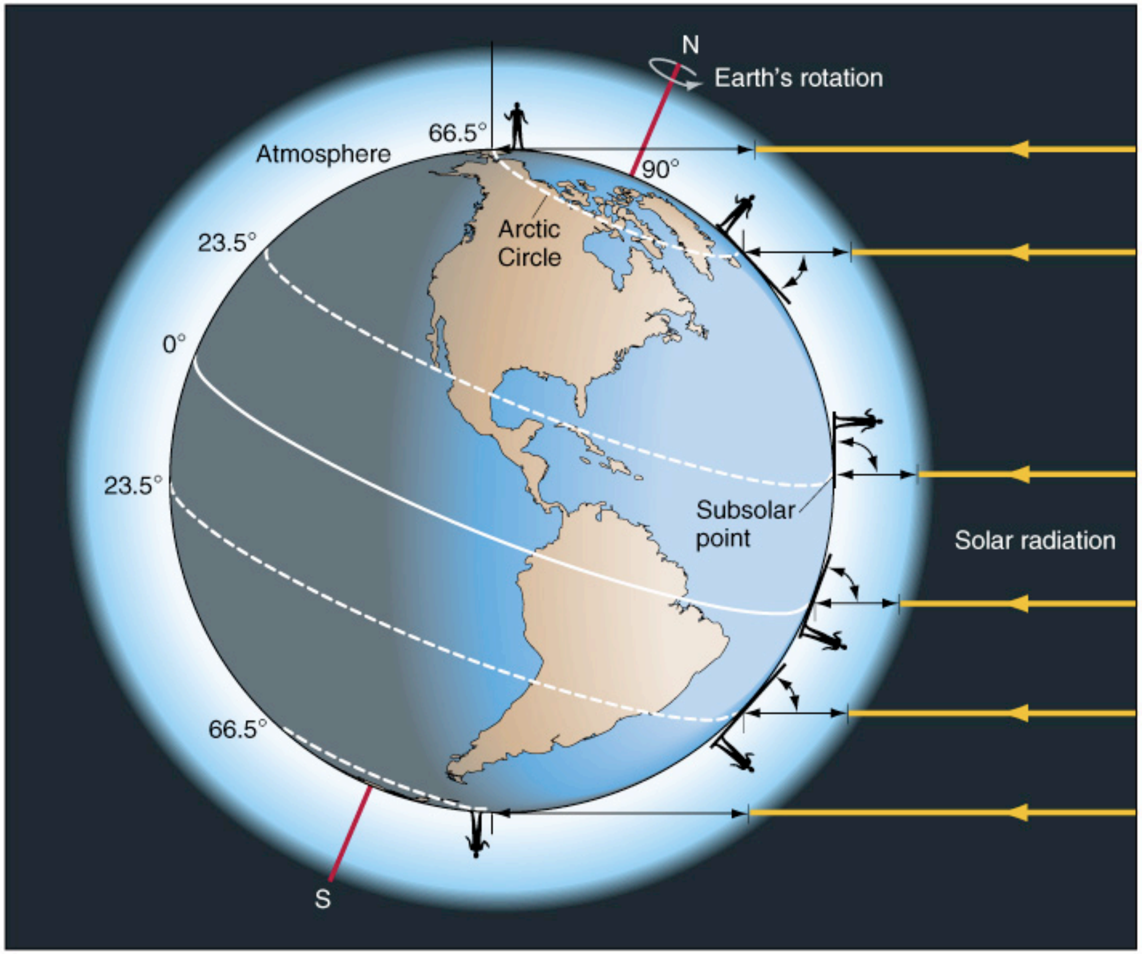
Earth *Rotation*

→Once every 24 hours

Rotational axis offset by 23.5°

→Axis is "fixed"

- Changes hemispheric orientation through orbit
- Causes seasons



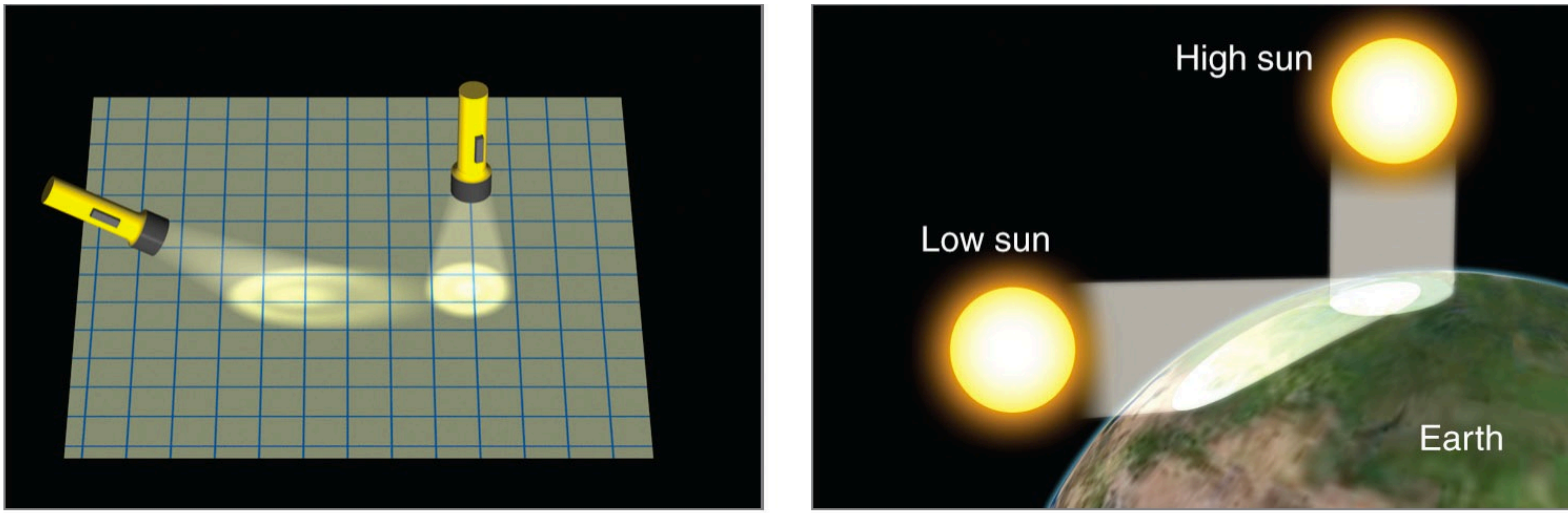
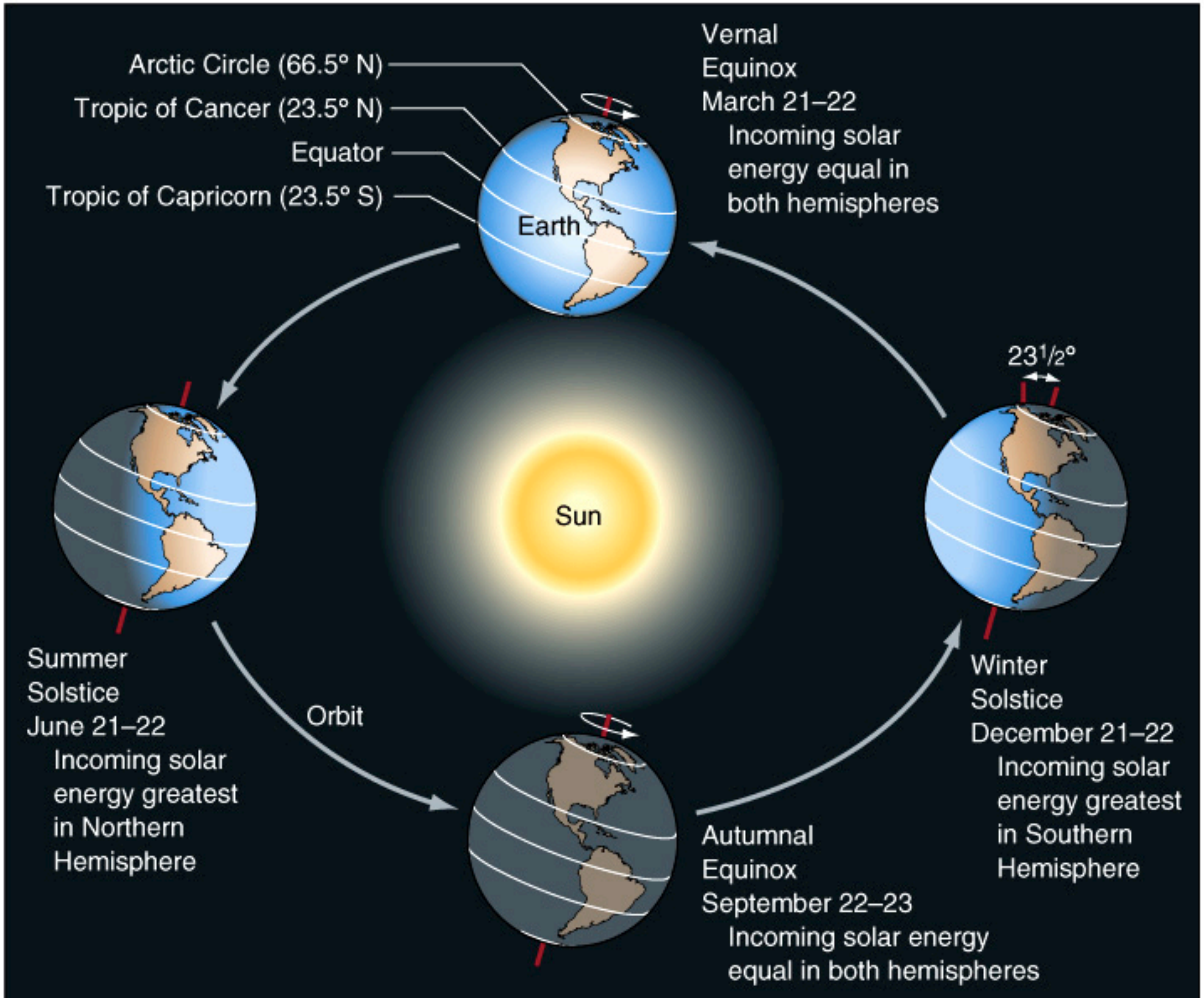


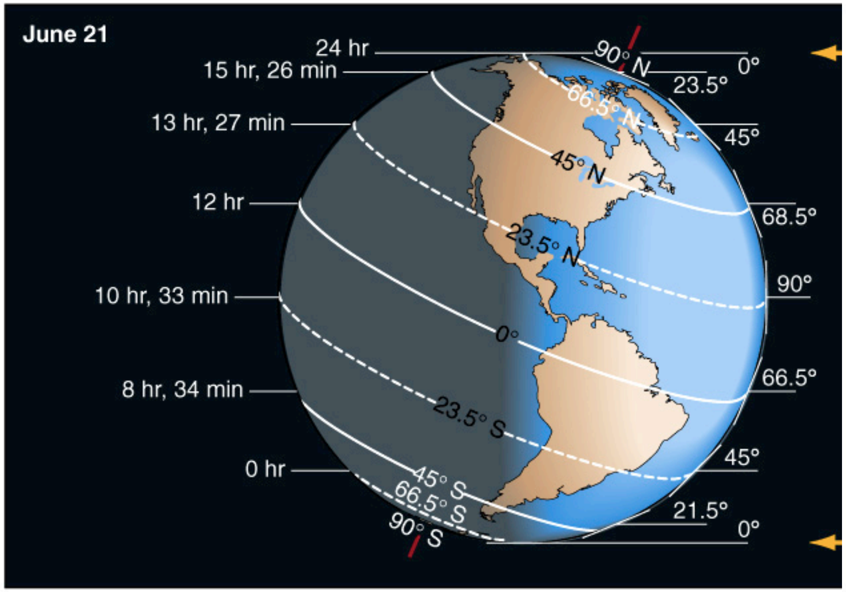
FIGURE 3.2 Sunlight that strikes a surface at an angle is spread over a larger area than sunlight that strikes the surface directly. Oblique sun rays deliver less energy (are less intense) to a surface than direct sun rays.

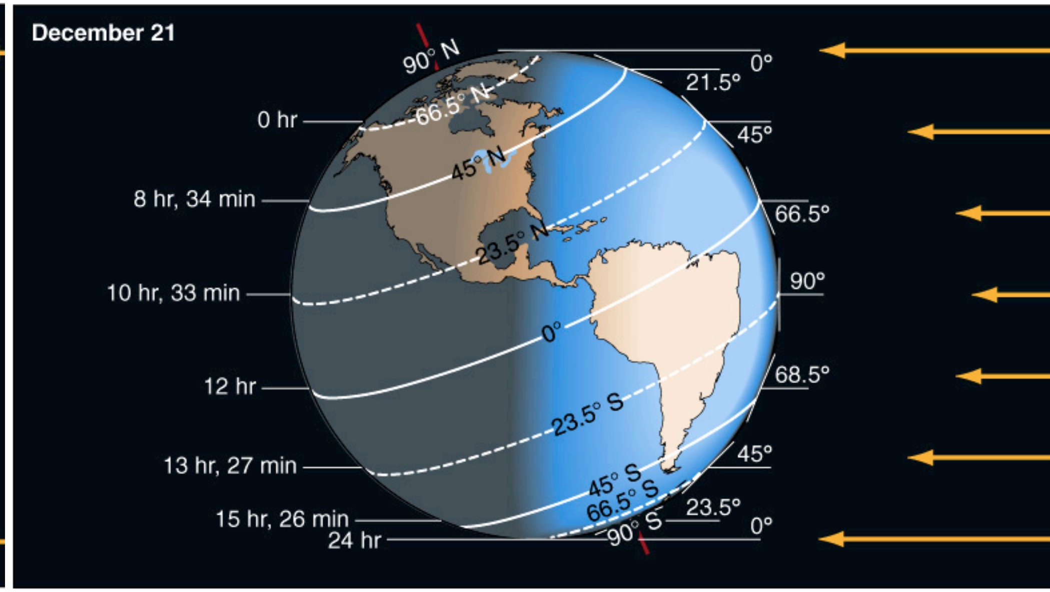
Solstices and Equinoxes

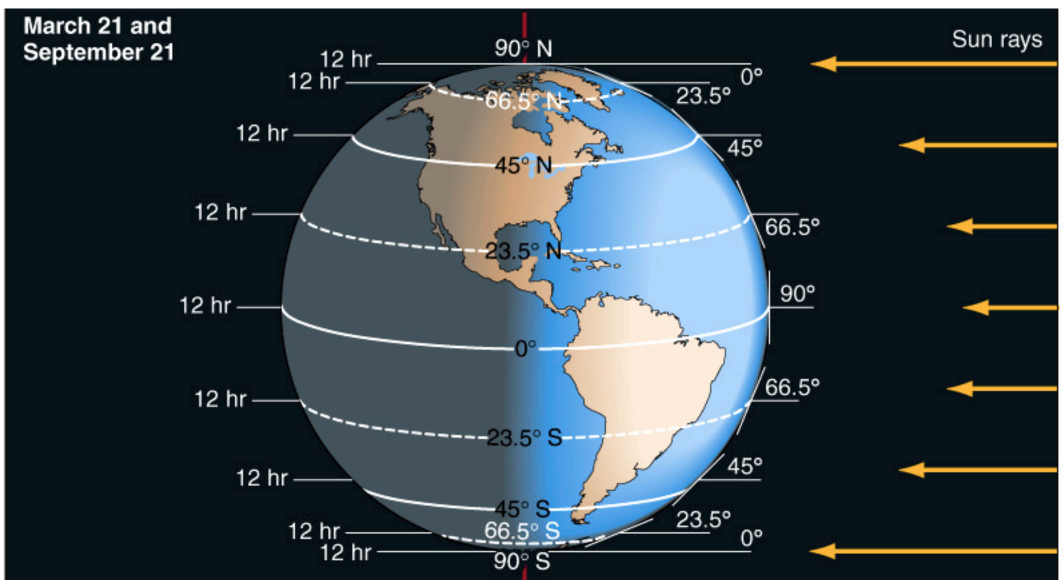
- Solstices 至點
  - Maximum axial tilt in relation to the Sun
    - June and December
  - Hemispheric axes inclined toward or away from Sun
    - Causes maximum or minimum solar radiation receipt
  - June Solstice 夏至(~ June 21)
    - Subsolar point 日下點 = Tropic of Cancer 北迴歸線(23.5^{o}N)
  - December Solstice 冬至(~ Dec. 21)
    - Subsolar point = Tropic of Capricorn 南迴歸線(23.5^{o}S)
  - Subsolar Point Migrates 47^{o}
    - Between the Tropics
- Equinoxes 分點
  - Temporally centered between solstices
  - ~ March 21 春分 and ~ Sept 21 秋分
  - The subsolar point = 0_{o}


Arctic Circle (66.5° N)
Tropic of Cancer (23.5° N)
Equator
Tropic of Capricorn (23.5° S)
Earth
Vernal
Equinox
March 21–22
Incoming solar
energy equal in
both hemispheres
23½°
Sun
Summer
Solstice
June 21–22
Incoming solar
energy greatest
in Northern
Hemisphere
Orbit
Winter
Solstice
December 21–22
Incoming solar
energy greatest
in Southern
Hemisphere
Autumnal
Equinox
September 22–23
Incoming solar energy
equal in both hemispheres

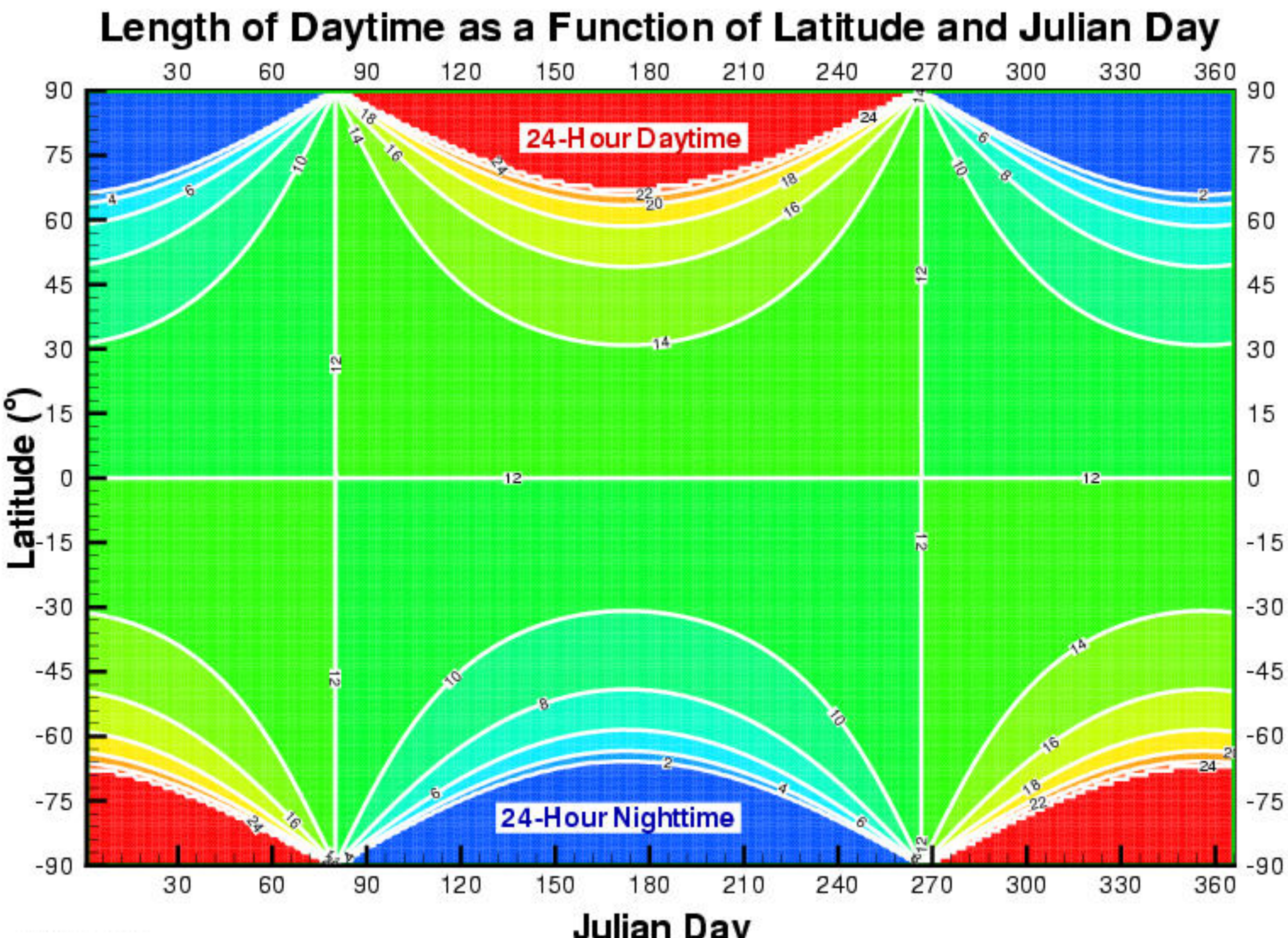
Period of Daylight







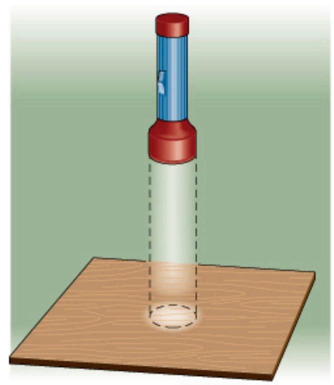
Period of Daylight



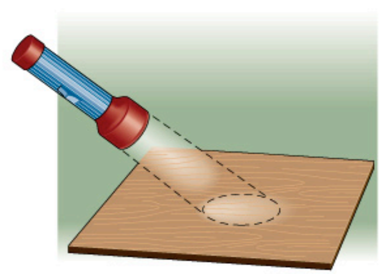
http://en.wikipedia.org/wiki/File:Day_length.jpeg

Solar angle and zenith angle

- Solar Angle (Solar elevation Angle) 太陽角
  - Radiation is proportional to solar angle
  - Higher angles equal reduced beam spreading = greater heating
- Zenith Angle 天頂角



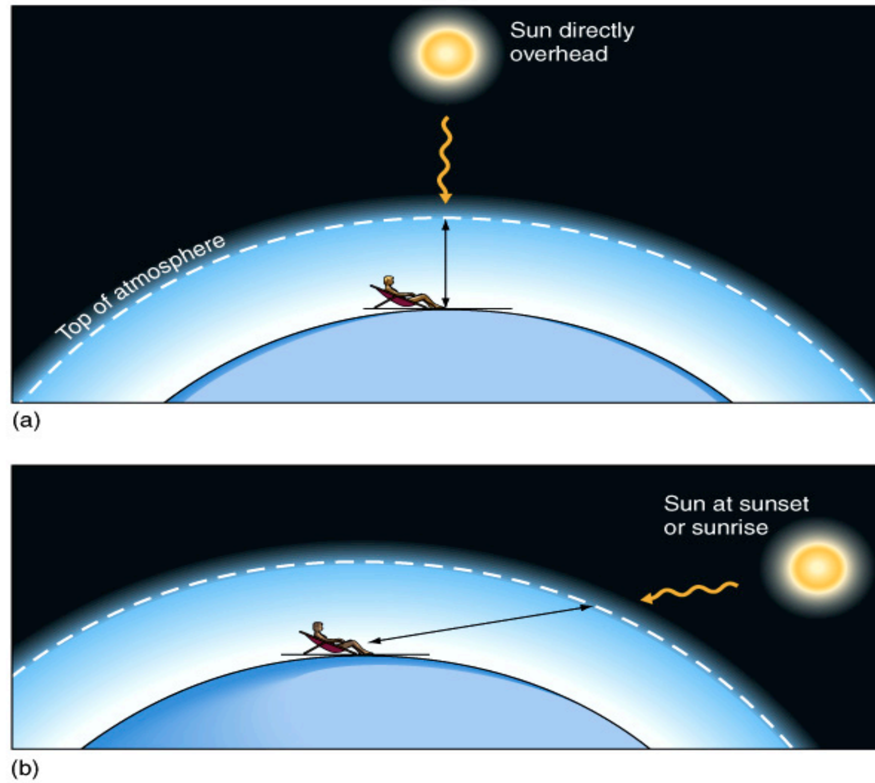
(a)



(b)

Solar angle and zenith angle

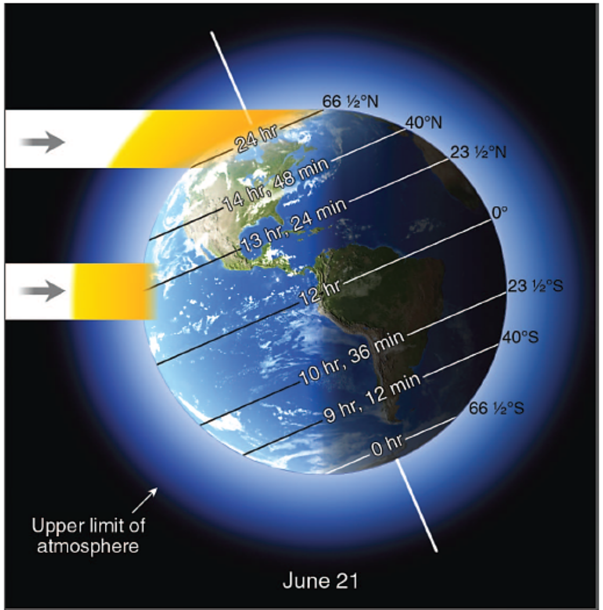
- Beam Depletion
  - Solar radiation diminished relative to path length
    - High solar angles = small energy reductions
- Changes in Energy Receipt with Latitude
  - Solar angle, day length, and beam depletion equal
    - Winter hemisphere = energy deficits
    - Summer hemisphere = energy surpluses



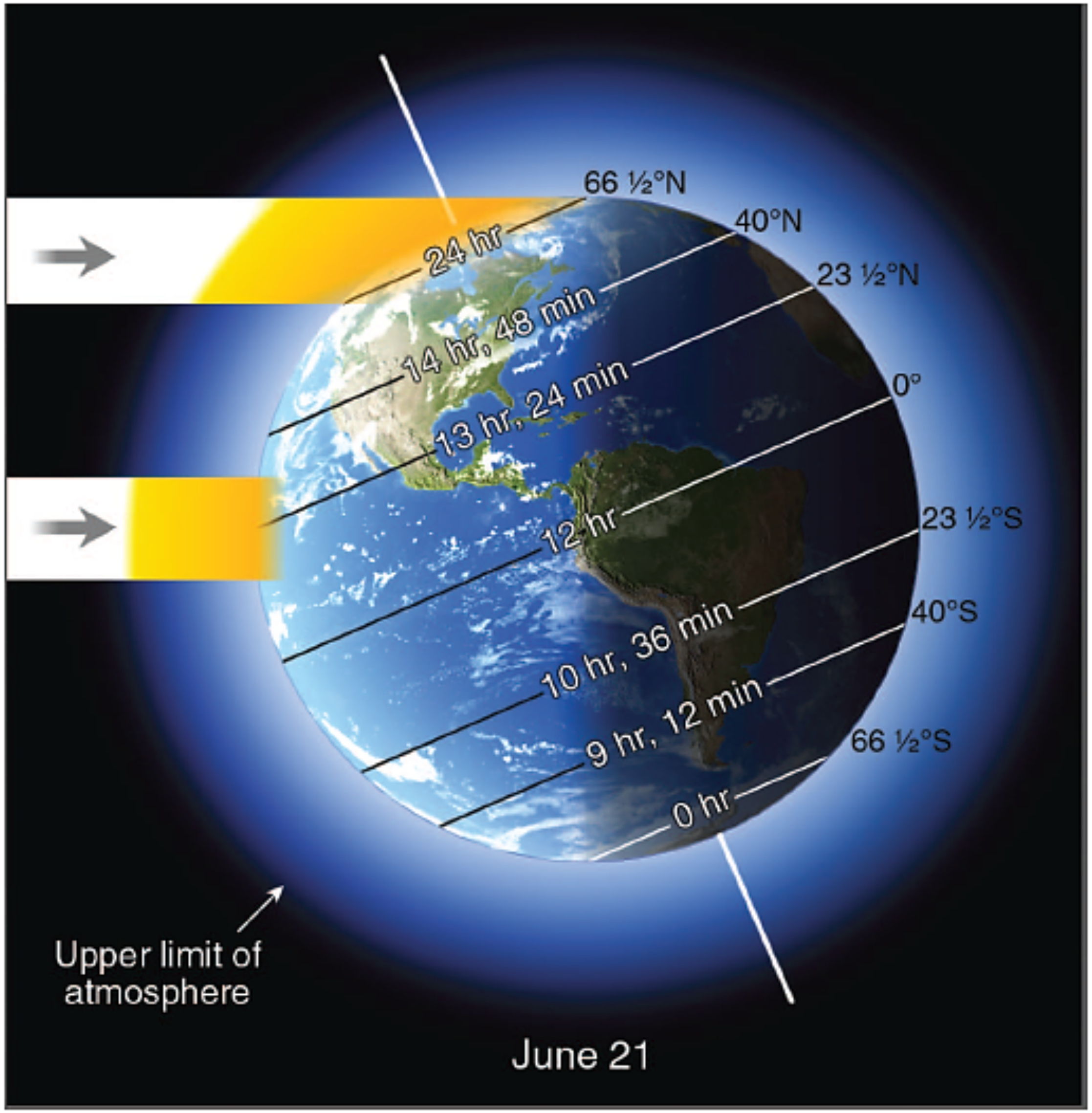
Lower Angles = Increased Path Length

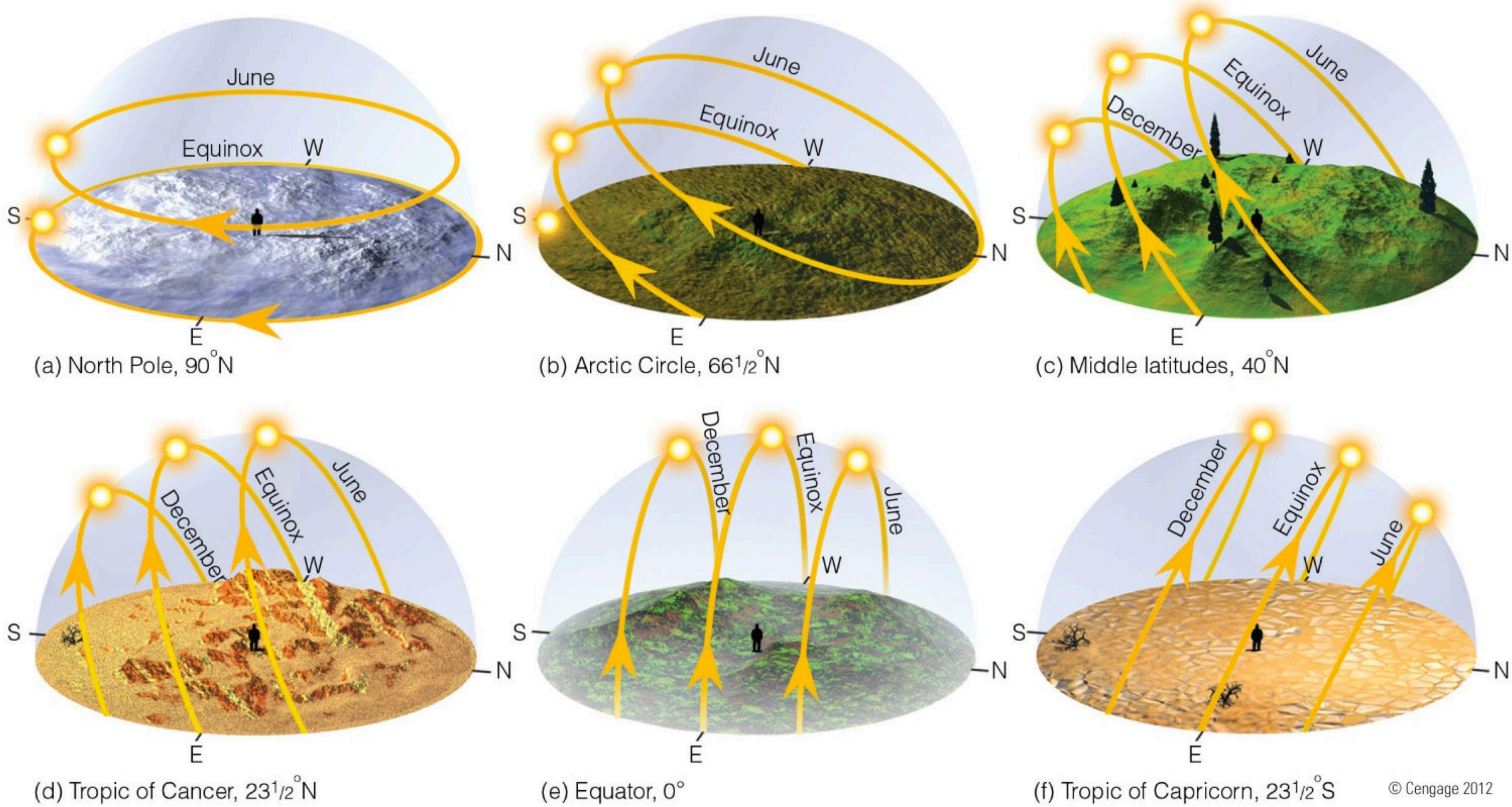
Global Temperature Distributions

- Temperatures decrease with latitude
- Strong thermal contrasts occur in winter
  - Latitudinal temperature gradient is greater in the winter hemisphere
    - Due to the midday solar angle and the length of day
- Isotherms shift seasonally
  - The shift is more obvious over continents
- The gradient is more pronounced in the northern hemisphere



During the Northern Hemisphere summer, sunlight that reaches the earth’s surface in far northern latitudes has passed through a thicker layer of absorbing, scattering, and reflecting atmosphere than sunlight that reaches the earth’s surface farther south. Sunlight is lost through both the thickness of the pure atmosphere and by impurities in the atmosphere. As the sun’s rays become more oblique, these effects become more pronounced.





The apparent path of the sun across the sky as observed at different latitudes on the June solstice (June 21), the December solstice (December 21), and the equinox (March 20 and September 22).

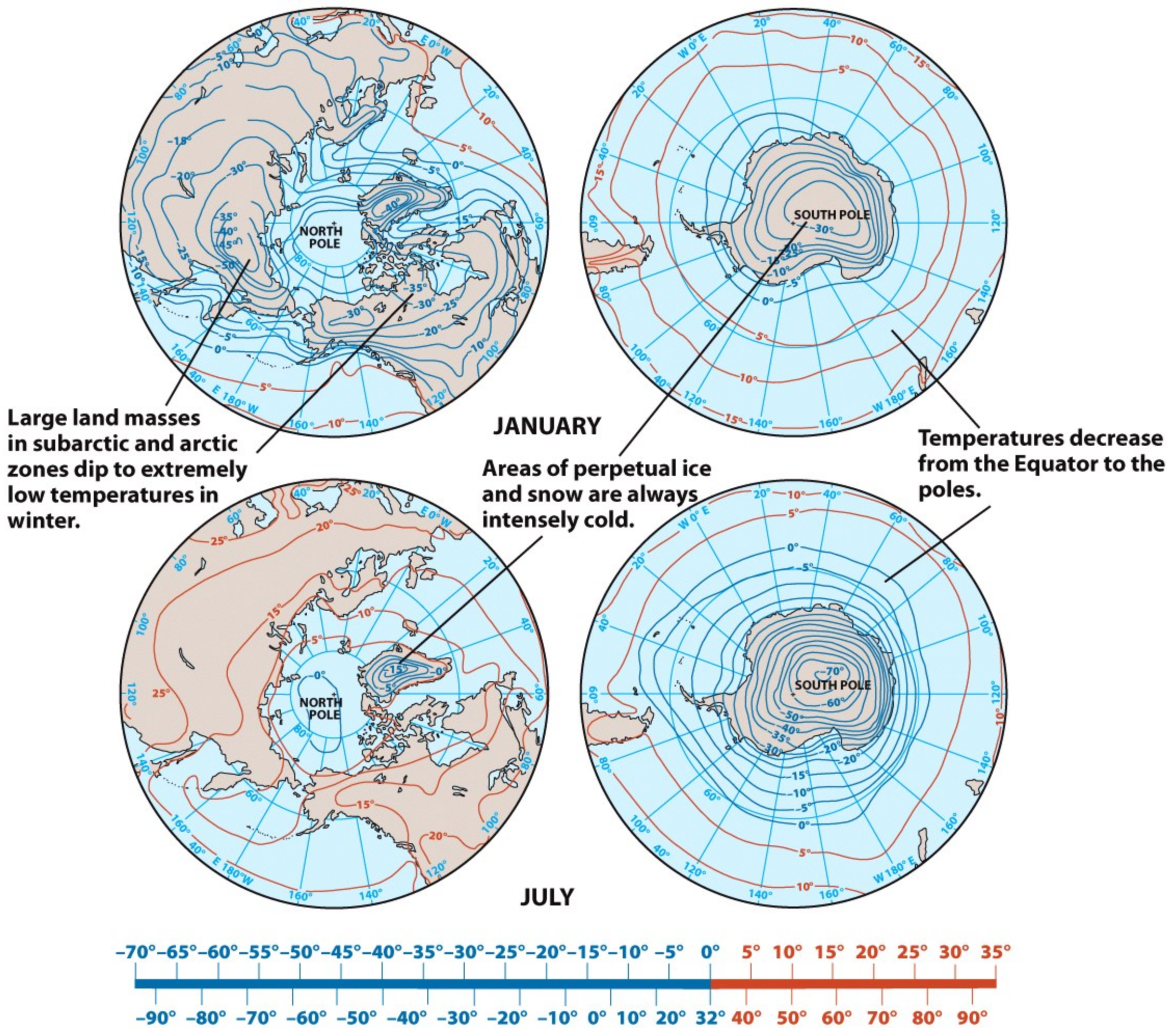
World air temperatures patterns

Large land masses located in the subarctic and arctic zones dip to extremely low temperatures in winter.

Temperatures **decrease** from the Equator to the poles.

Areas of **perpetual ice** and snow are always intensely cold.

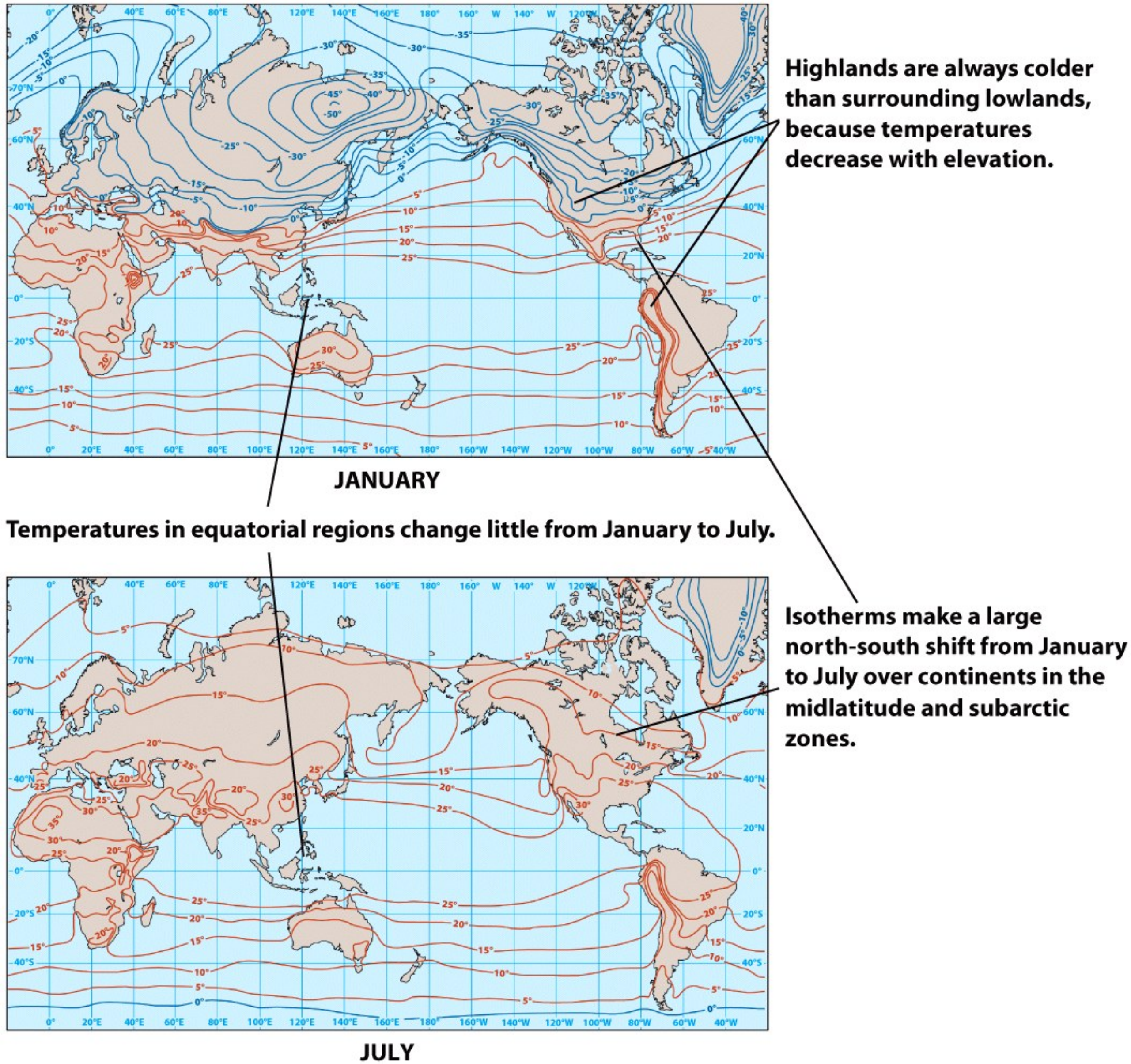
Highlands always colder than surrounding lowlands



World air temperatures patterns

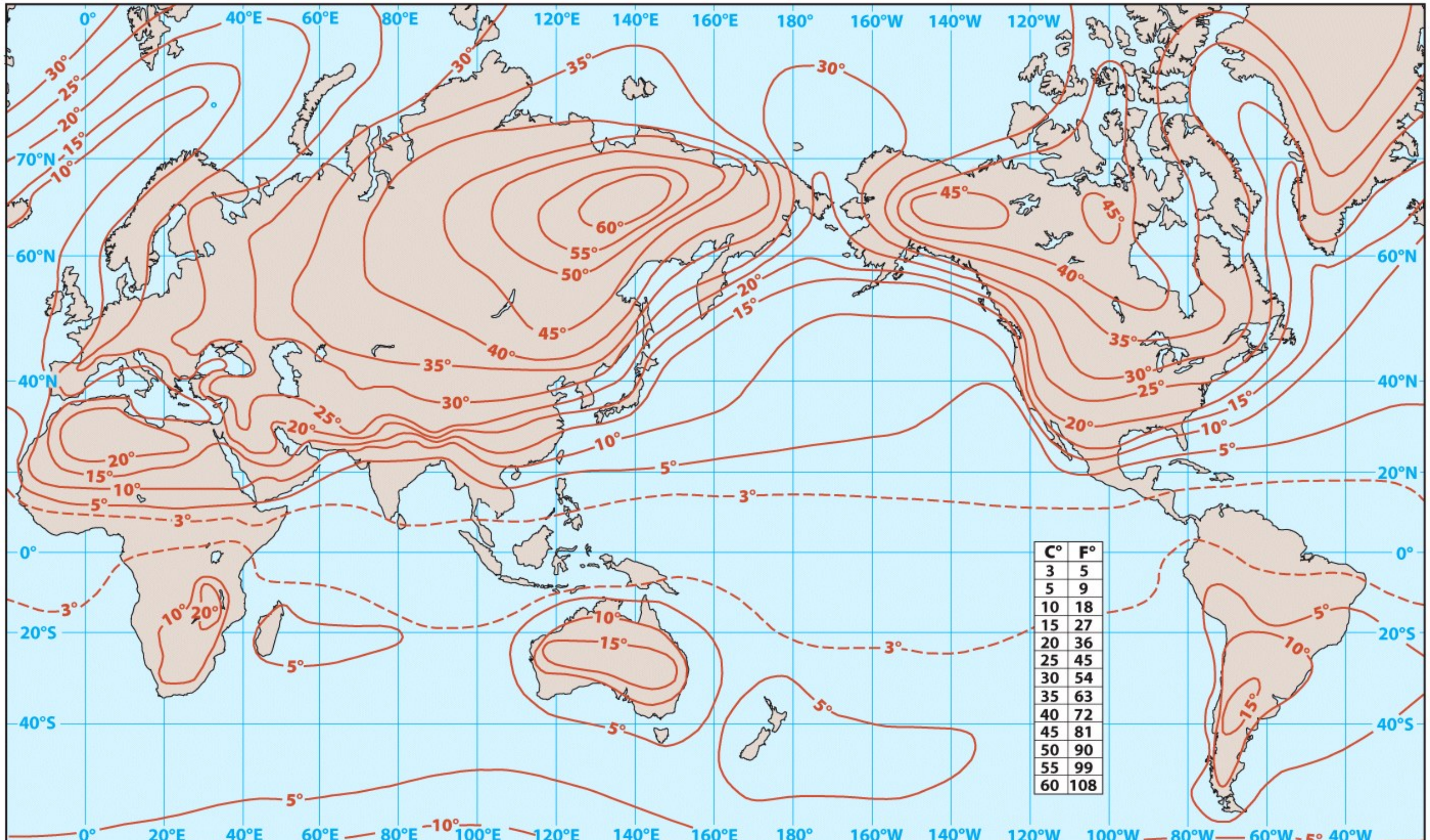
Temperatures in **equatorial** regions change little from January to July

Isotherms make a large north-south shift from January to July over continents in the midlatitude and subarctic zones



The annual range of air temperatures

Annual range of air temperature - **difference between January and July means**
Equator - small range
Continental interiors- range larger (60°C (108°F) in Siberia.



補充資料：State of the Climate Global Analysis

- https://www.ncdc.noaa.gov/sotc/

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
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February US Release: Wed, 7 Mar 2018, 11:00 AM EST

State of the Climate

- Climate Monitoring
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- Societal Impacts
- Snow and Ice
- Teleconnections
- GHCN Monthly
- Monitoring References

State of the Climate Reports | Summary Information | Monthly Climate Briefings | RSS Feed XML

The State of the Climate is a collection of monthly summaries recapping climate-related occurrences on both a global and national scale.

Report: Global Climate Report Year: 2018 Month: January Submit

National

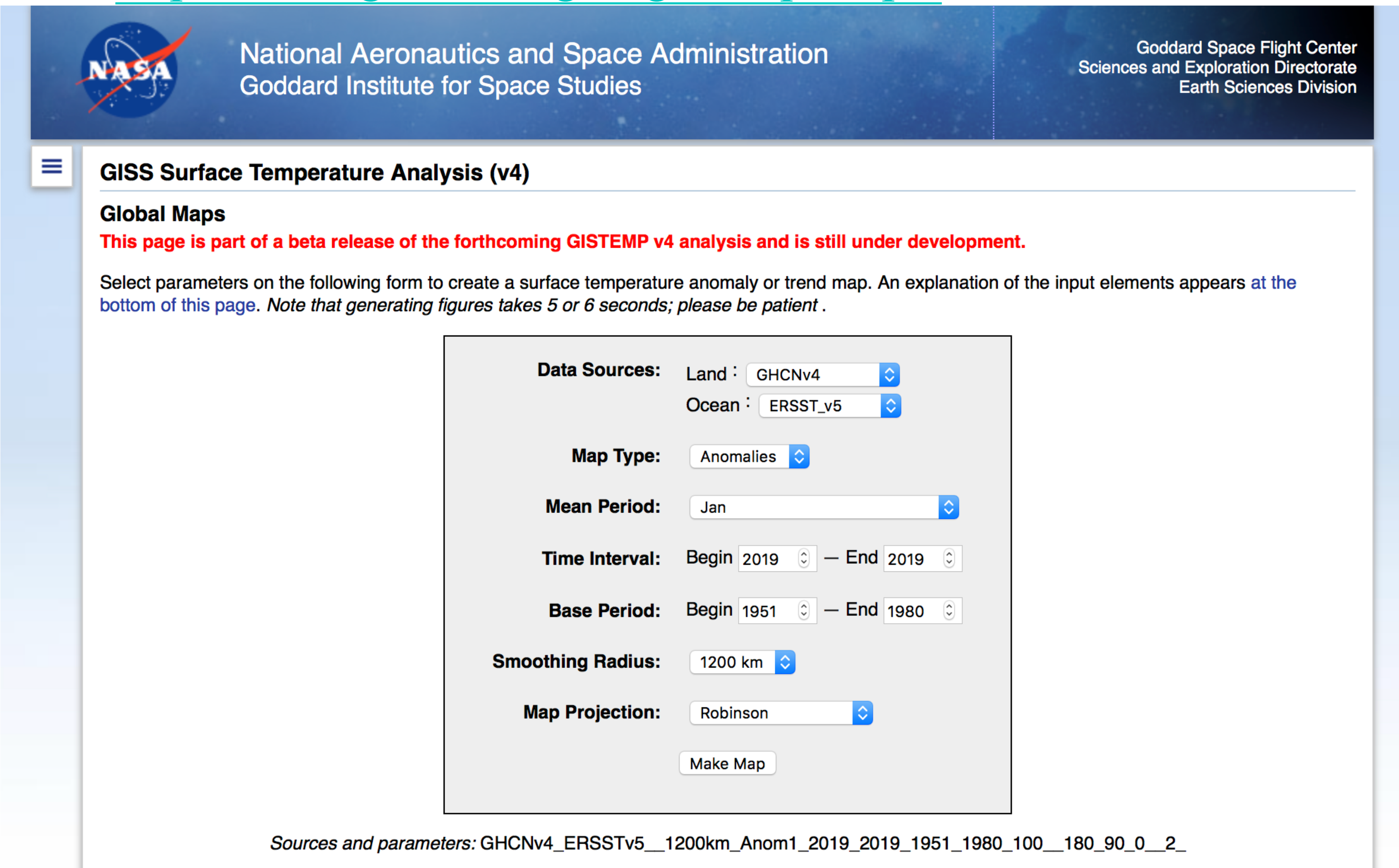
- National Summary Information — a synopsis of the collection of national summaries released each month
- National Climate Report — an analysis of national temperatures and precipitation, placing the data into a historical perspective

Global

- Global Summary Information — a synopsis of the collection of global summaries released each month
- Global Climate Report — an analysis of global temperatures and precipitation, placing the data into a historical perspective

補充資料：GISS Dataset

- https://data.giss.nasa.gov/gistemp/maps/



National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

GISS Surface Temperature Analysis (v4)

Global Maps

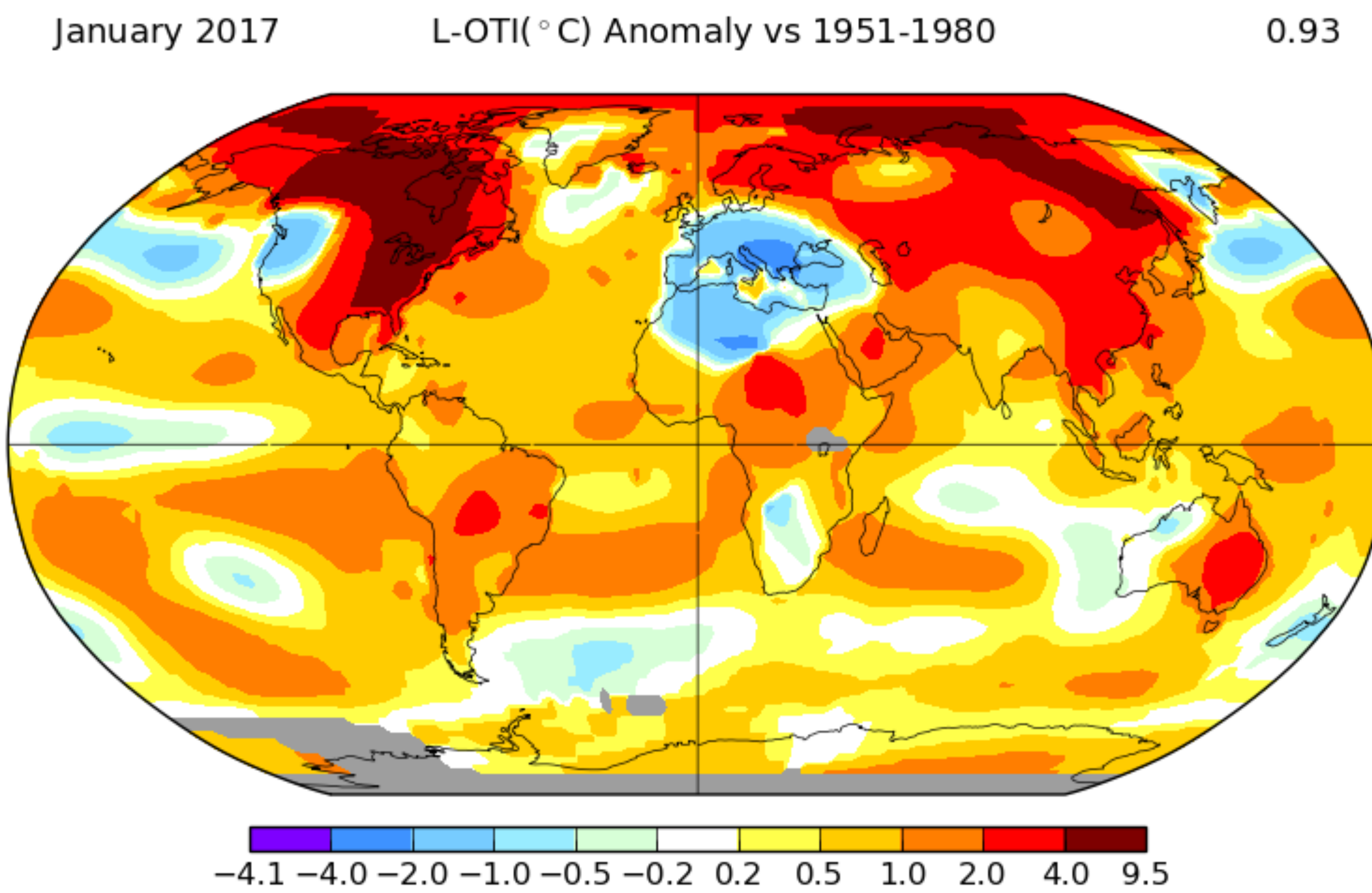
This page is part of a beta release of the forthcoming GISTEMP v4 analysis and is still under development.

Select parameters on the following form to create a surface temperature anomaly or trend map. An explanation of the input elements appears at the bottom of this page. *Note that generating figures takes 5 or 6 seconds; please be patient* .

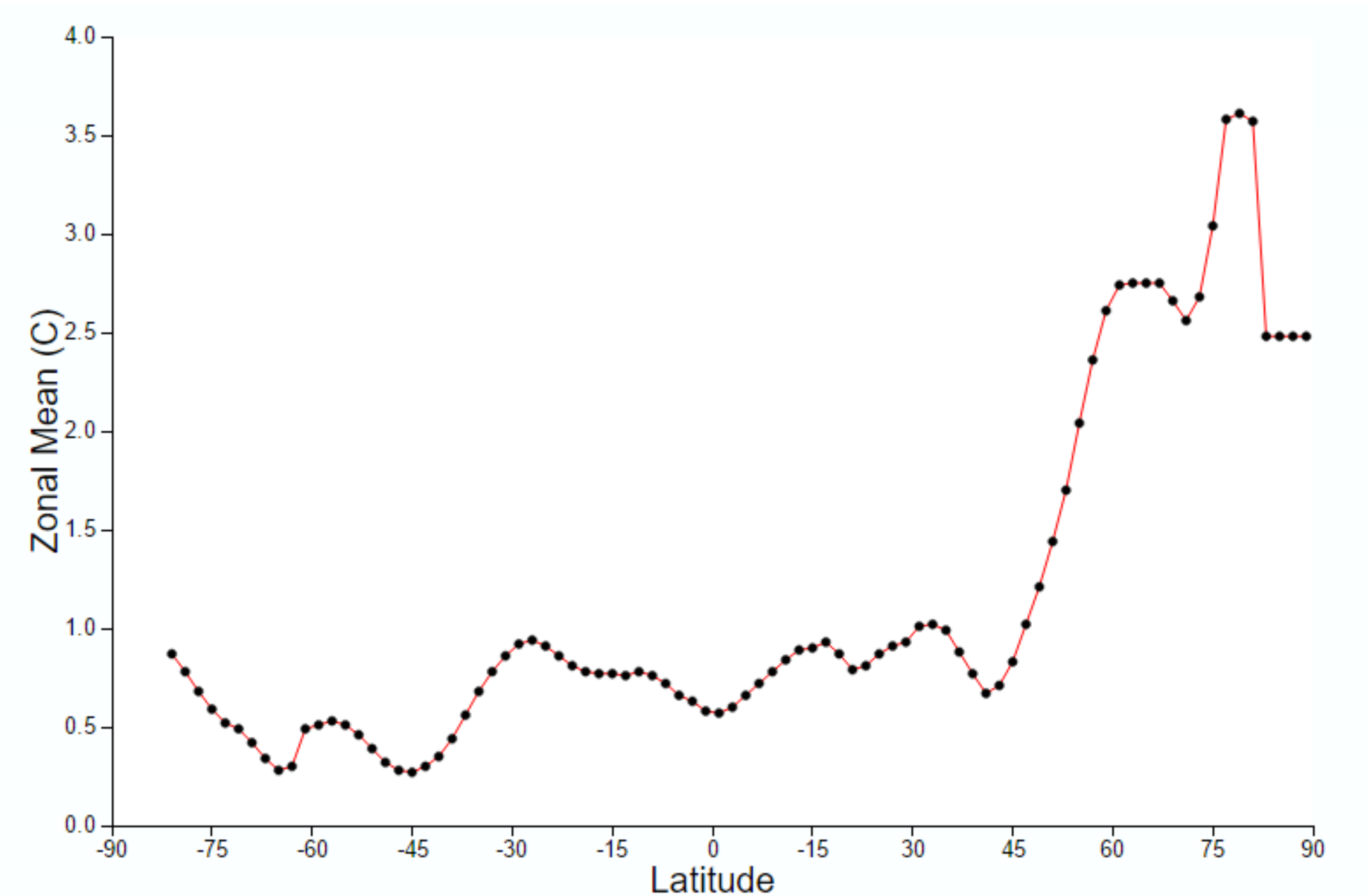
Data Sources:	Land : GHCNv4 Ocean : ERSST_v5
Map Type:	Anomalies
Mean Period:	Jan
Time Interval:	Begin 2019 — End 2019
Base Period:	Begin 1951 — End 1980
Smoothing Radius:	1200 km
Map Projection:	Robinson
	Make Map

Sources and parameters: GHCNv4_ERSSTv5__1200km_Anom1_2019_2019_1951_1980_100__180_90_0__2_

Mean Surface Temperature Anomaly



http://data.giss.nasa.gov/gistemp/maps/



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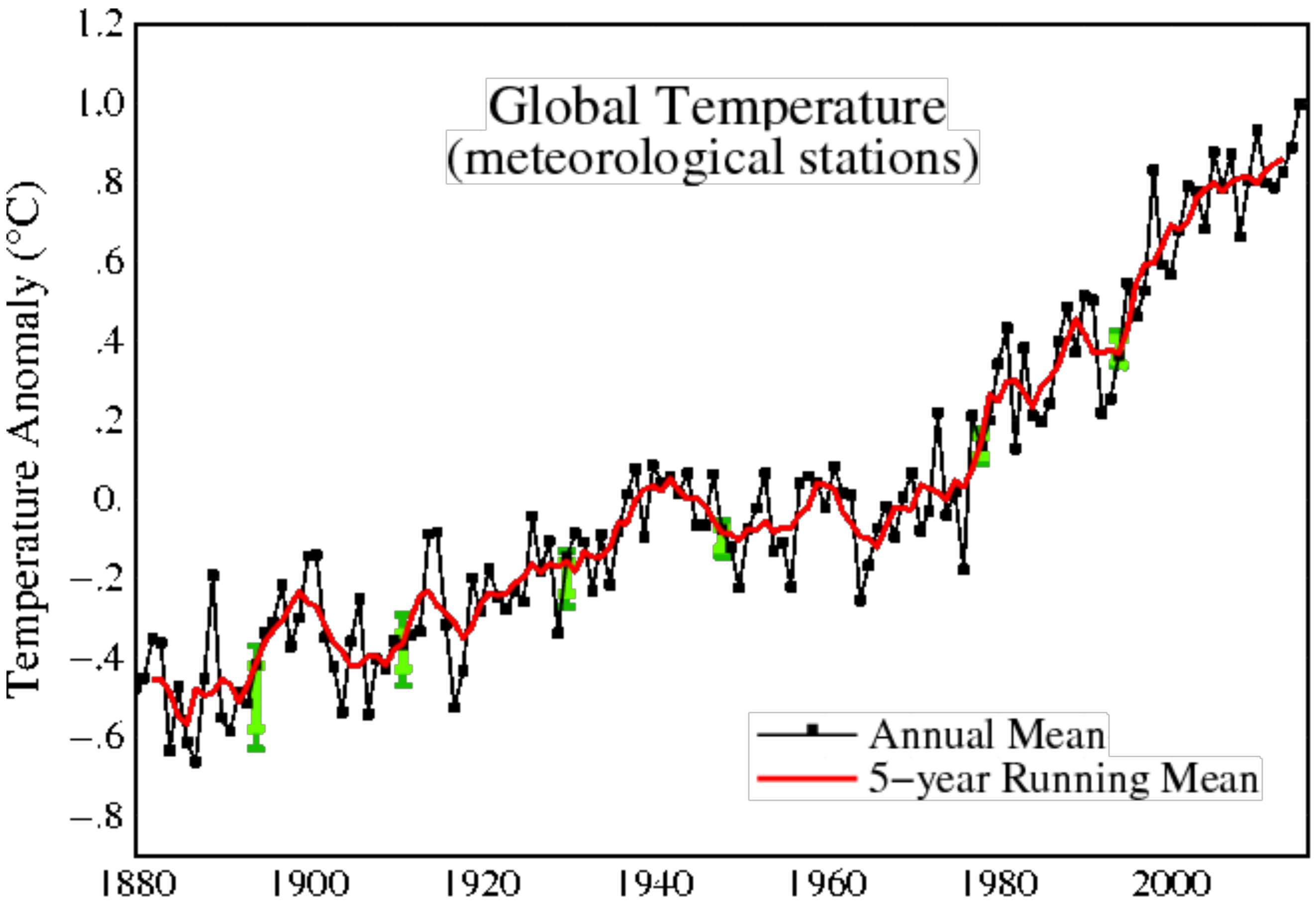
http://data.giss.nasa.gov/gistemp/graphs_v3/



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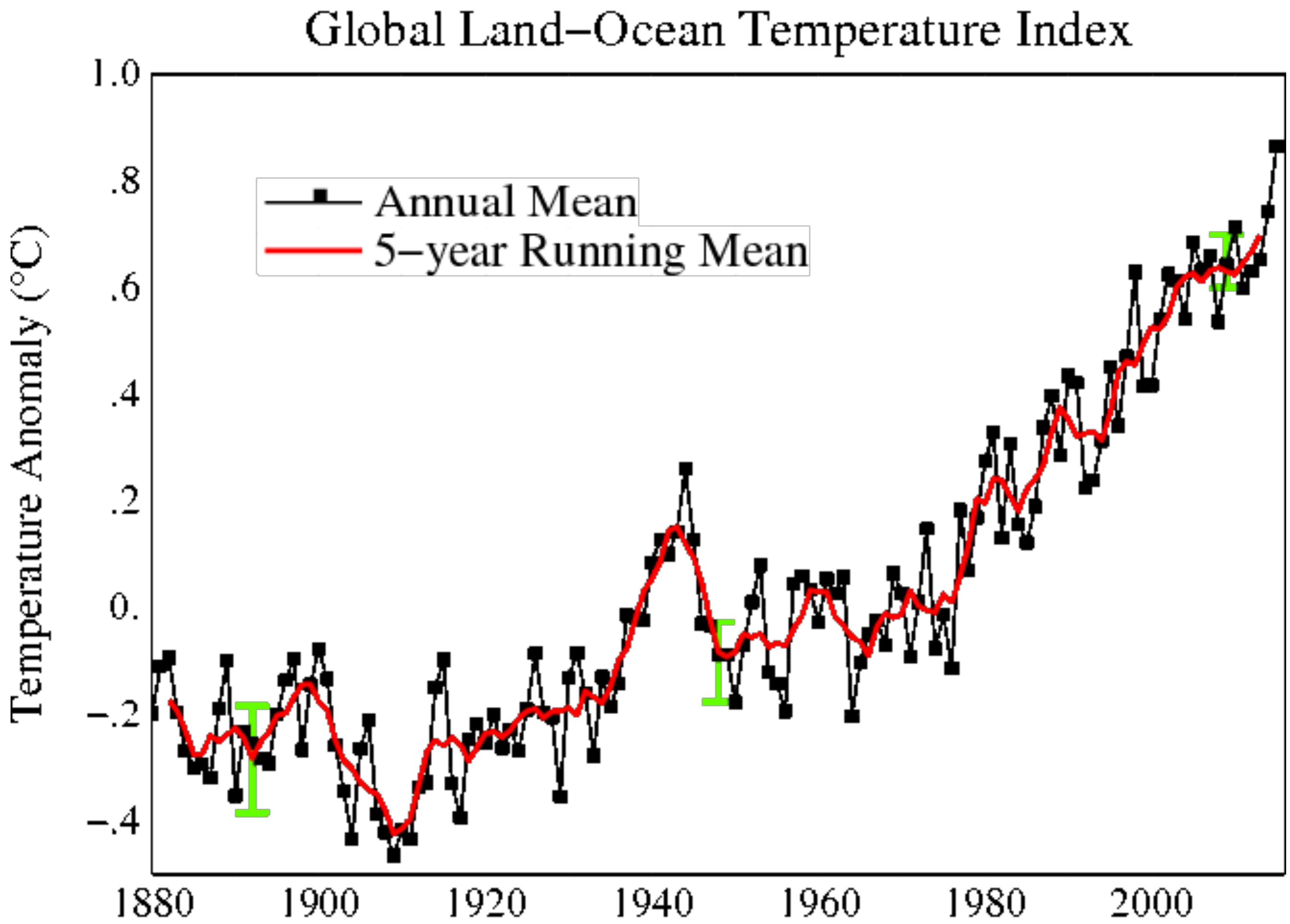

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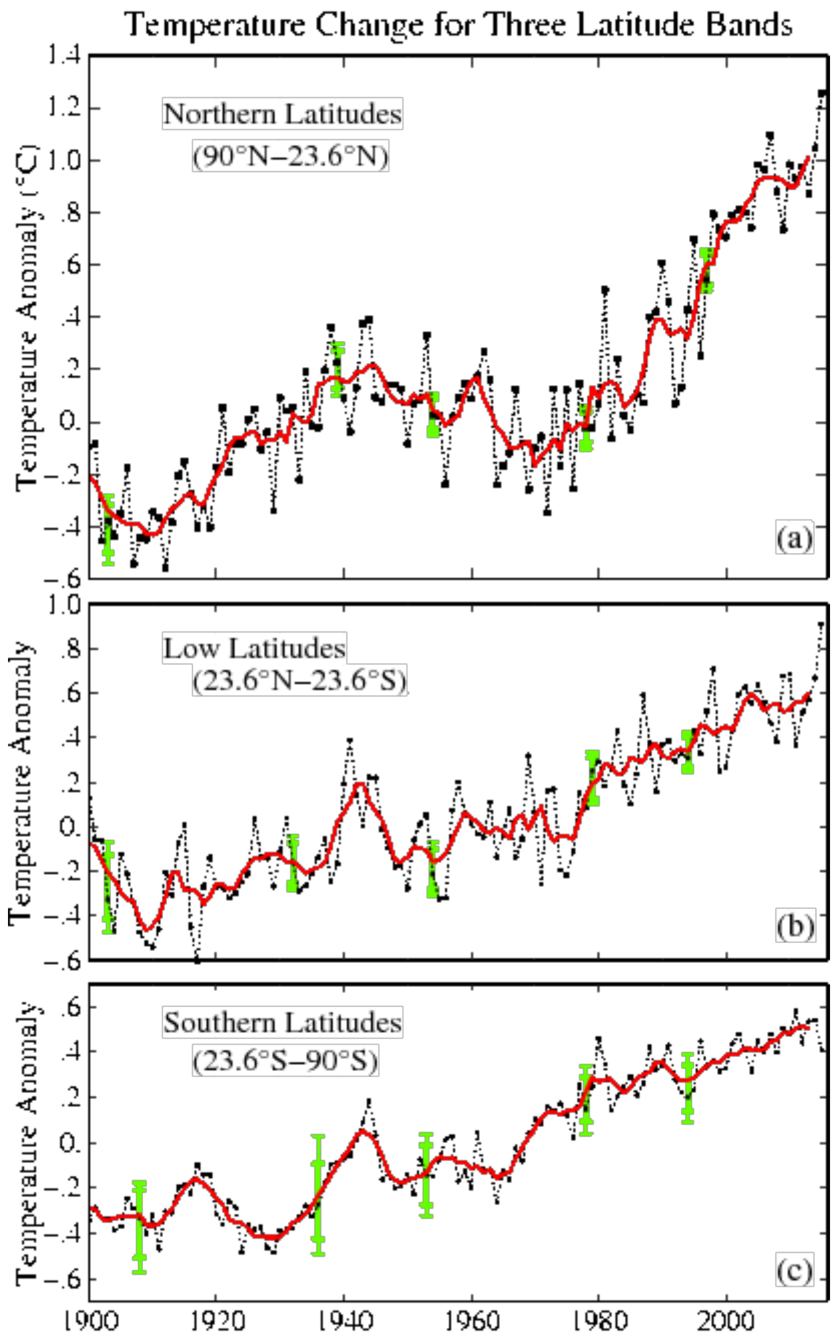

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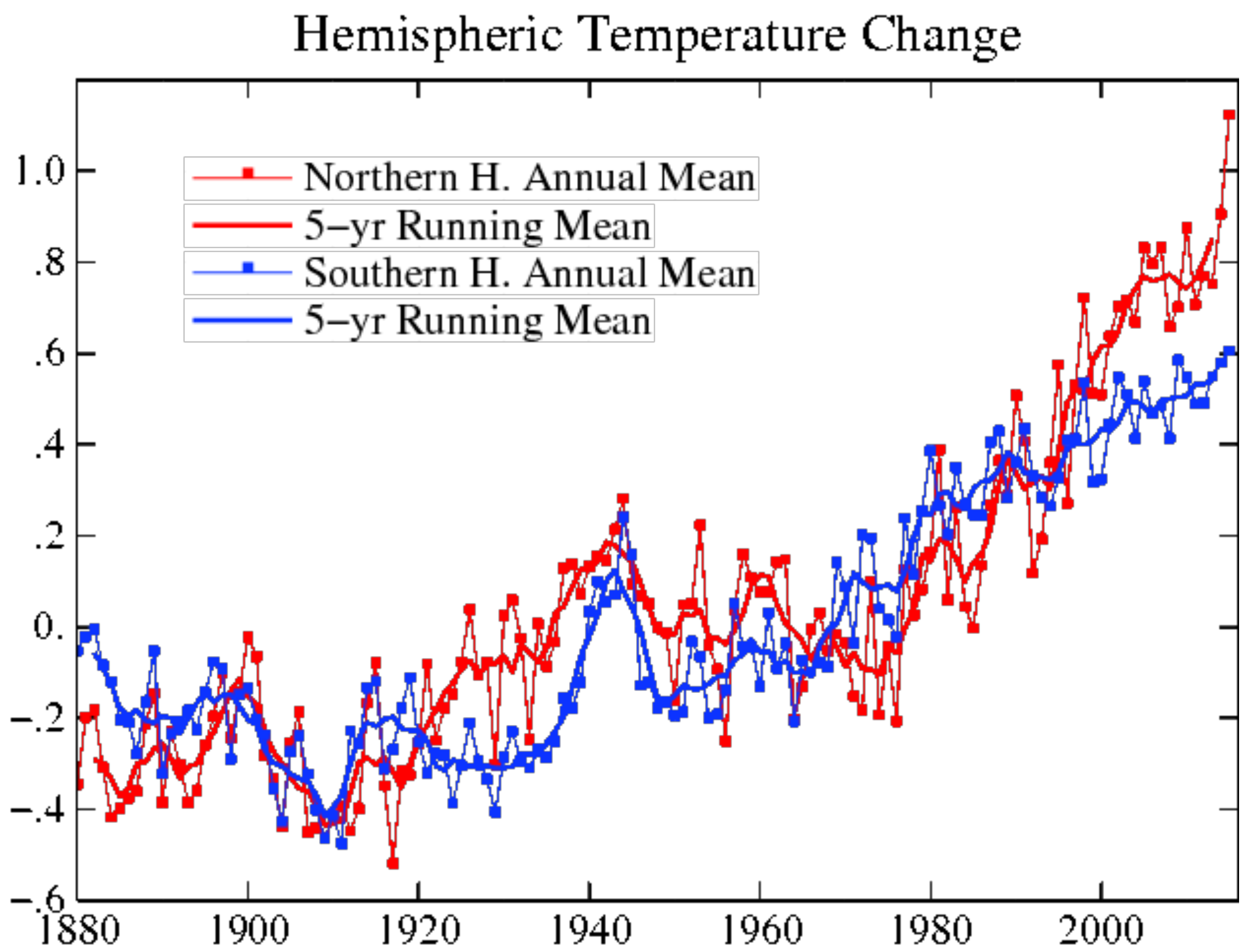

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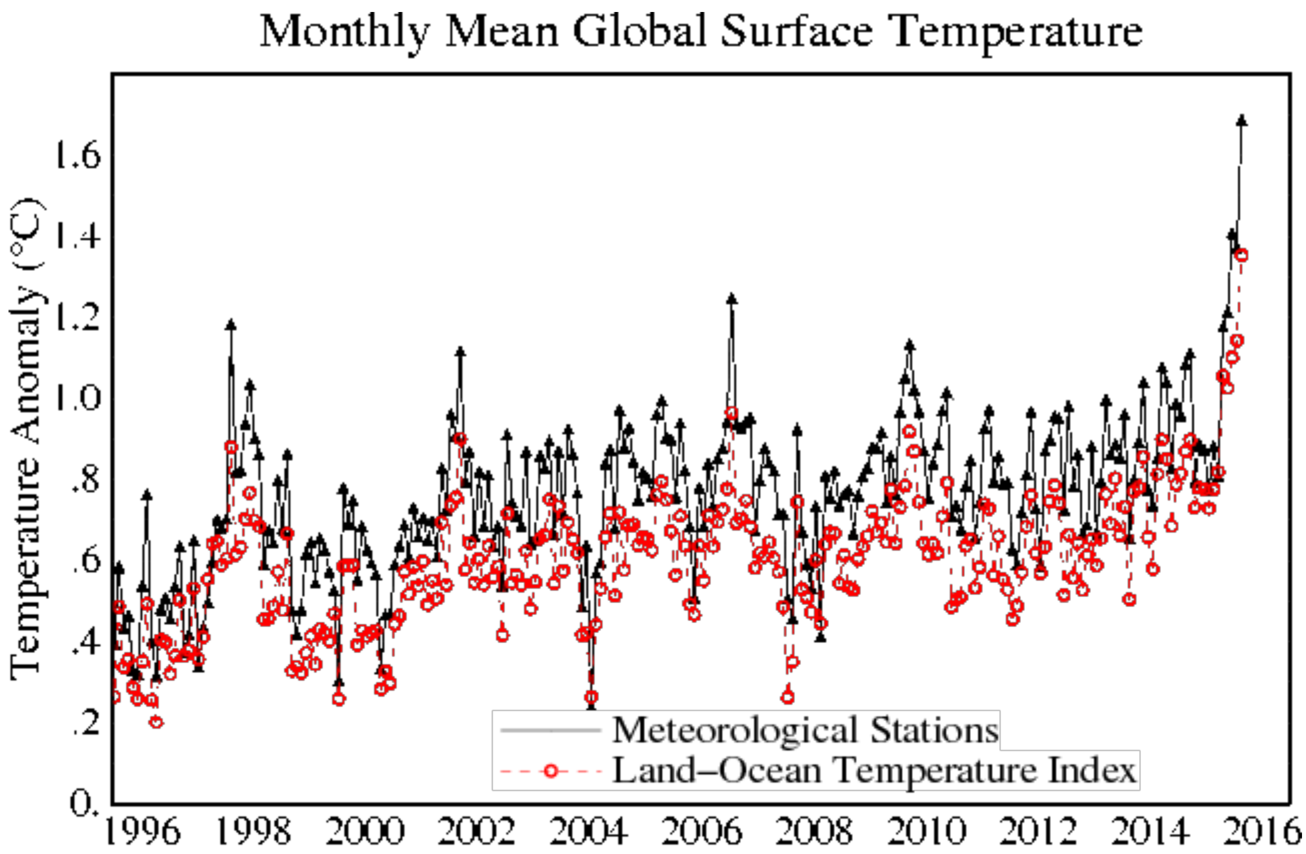

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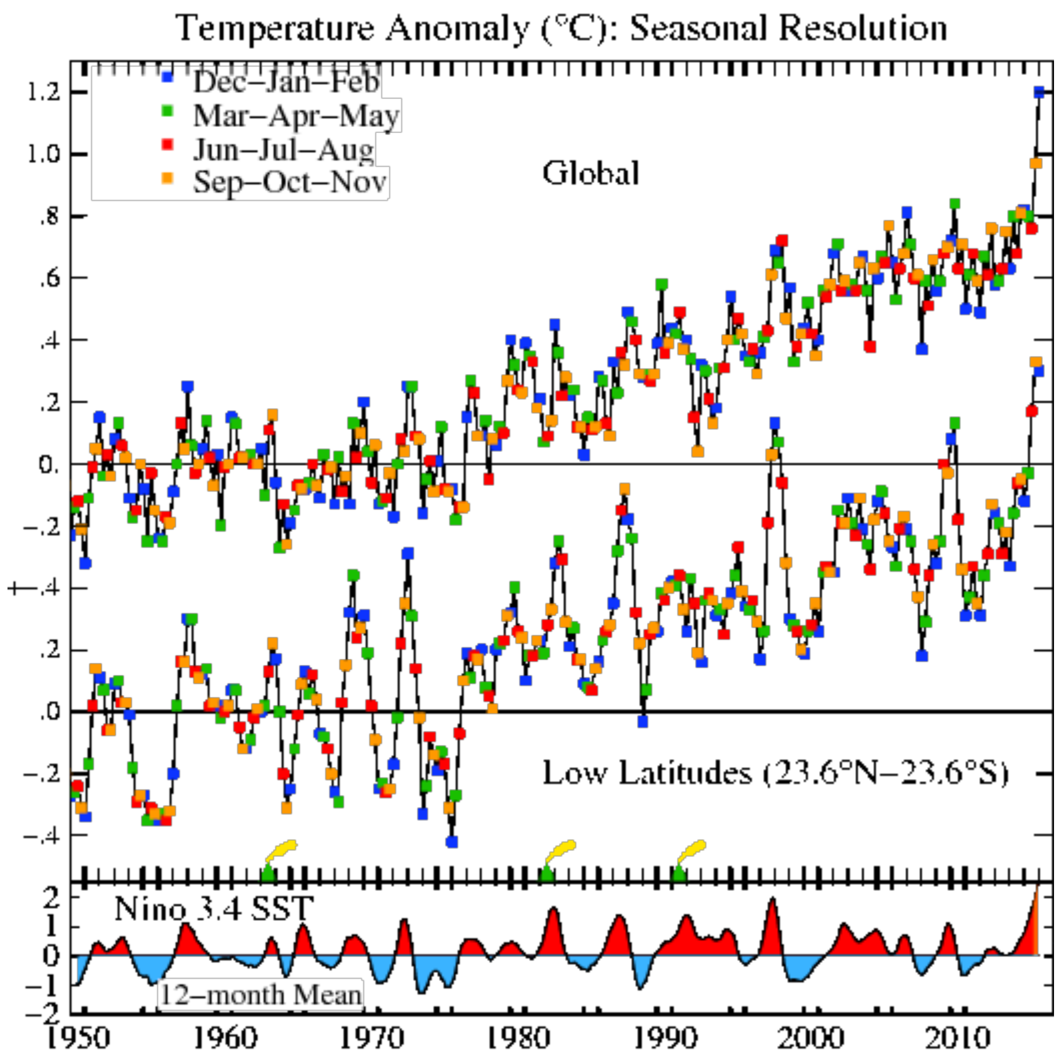
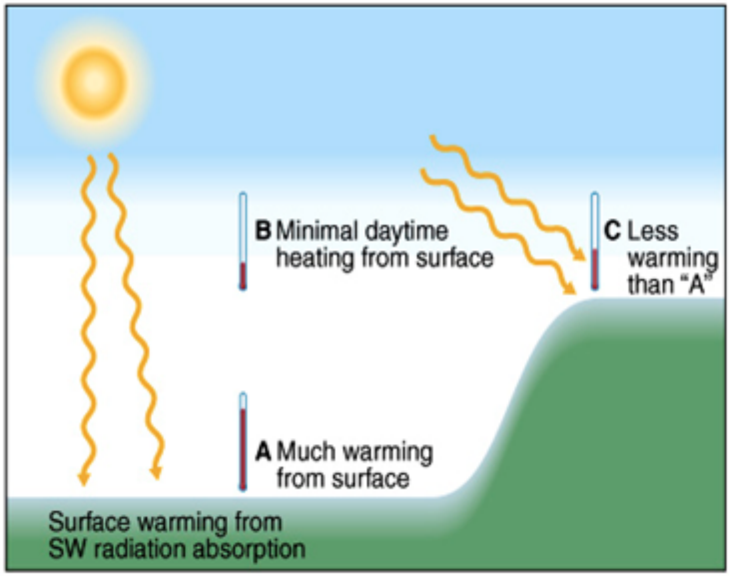


http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.E.gif

Influences on Temperature

- Latitude
  - Due to axial tilt
    - Solar angles, day-lengths, beam depletion, beam spreading
- Altitude
  - Temperatures decline with altitude
  - High altitudes have fairly constant temperatures
    - More rapid diurnal fluxes
- Atmospheric Circulation
  - Latitudinal temperature and pressure differences cause large-scale advection
- Contrasts between Land and Water
  - Continentality versus maritime effects
  - Different values of specific heat



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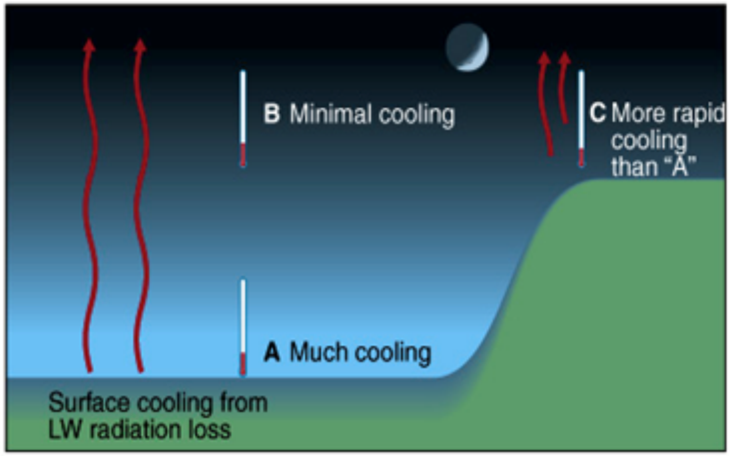
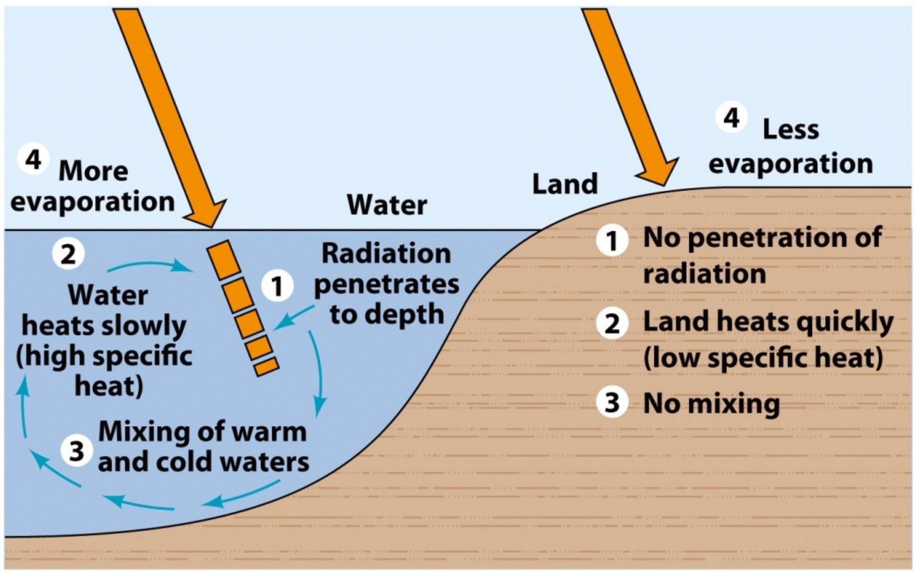


(b)

Influences on Temperature

Land and water contrasts



Incoming solar radiation

Rays strike land and water equally.

Land - radiation cannot penetrate soil or rock,
so heating is concentrated just at the surface

Water - radiation penetrates below the surface, distributing heat at depth.

Heat capacities

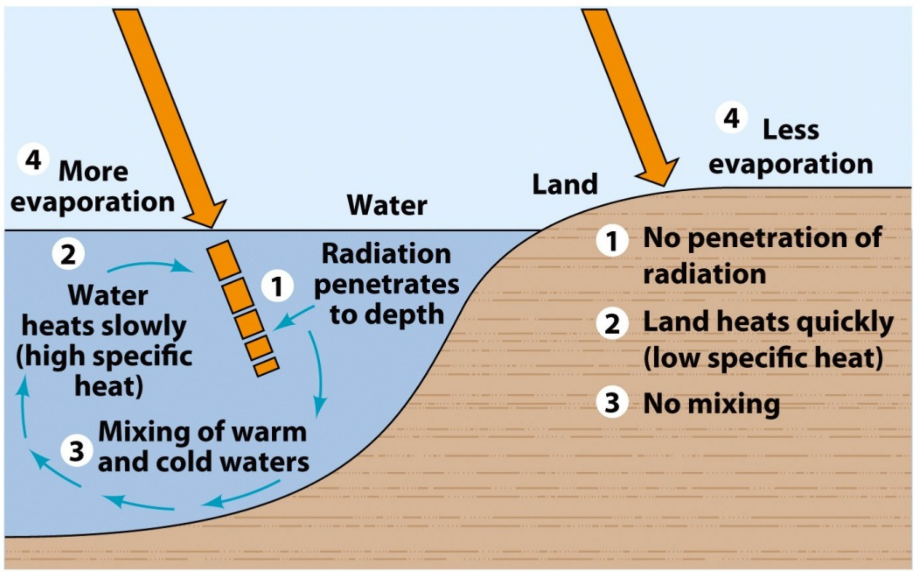
Rock (and dry soil) - **low specific heat capacity**, temperature increases easily as heat energy is applied.

Water - **high specific heat capacity**, requires five times more energy to raise temperature

Water temperature remains more uniform than land temperature.

Influences on Temperature

Land and water contrasts



Mixing

Water - fluid, allows mixing. Warming surface water mixes with cooler water at depth to produce uniform temperature. Mixing driven by wind-generated waves.

Rock - immobile, preventing mixing.

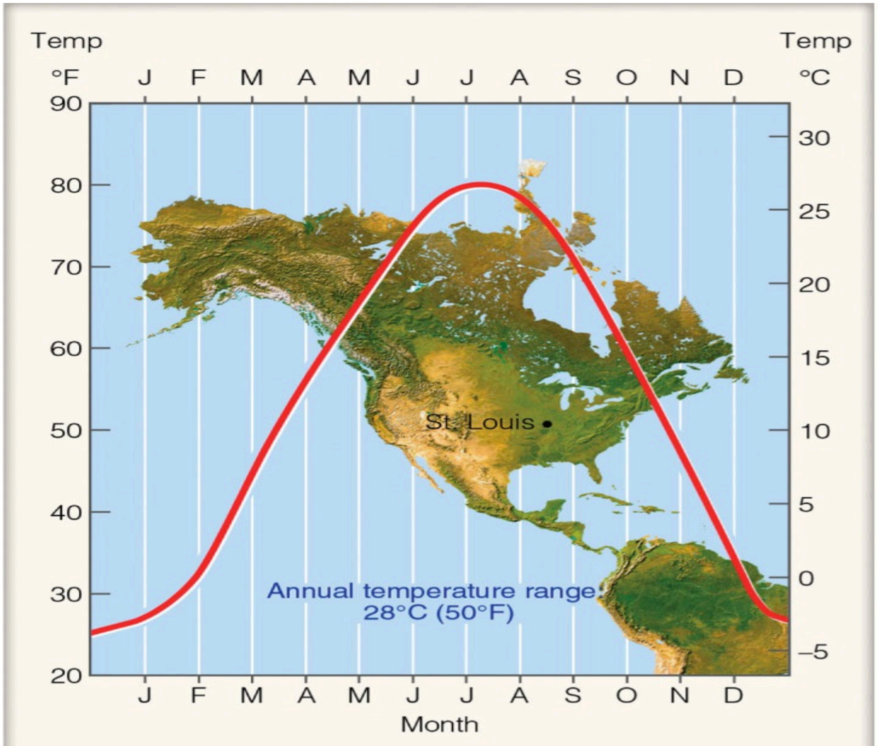
Evaporation

Water surfaces cool as water molecules evaporate, absorbing heat from their surroundings. Water surface will always evaporate.

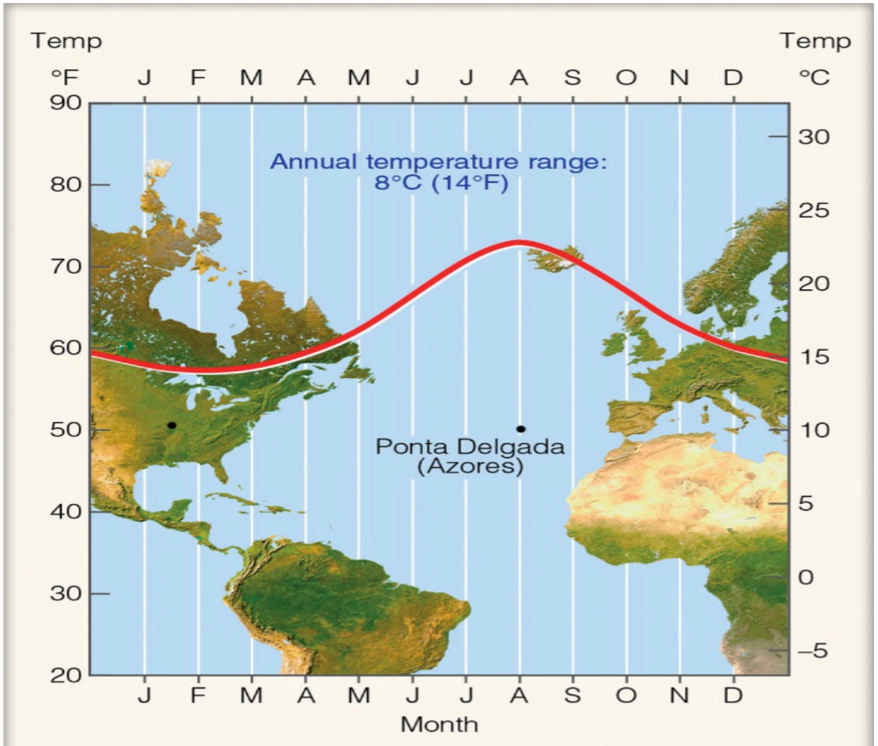
Land surfaces can be cooled by evaporation if water exists near the soil surface. If dry, no evaporation, no cooling.

Influences on Temperature

- Contrasts between Land and Water
  - Continentality versus maritime effects
  - Different values of specific heat



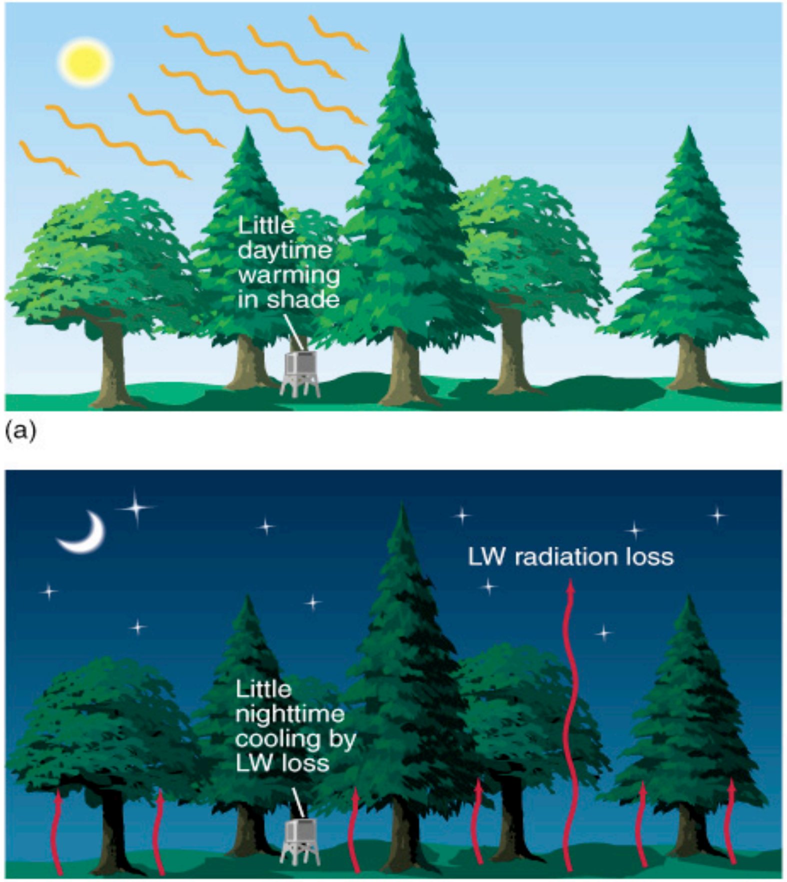
(a) St. Louis, Missouri, 39°N



(b) Ponta Delgada, Azores 38°N

Influences on Temperature

- Local Conditions
  - Small spatial scale features impact temperatures
  - Slope
  - Land use

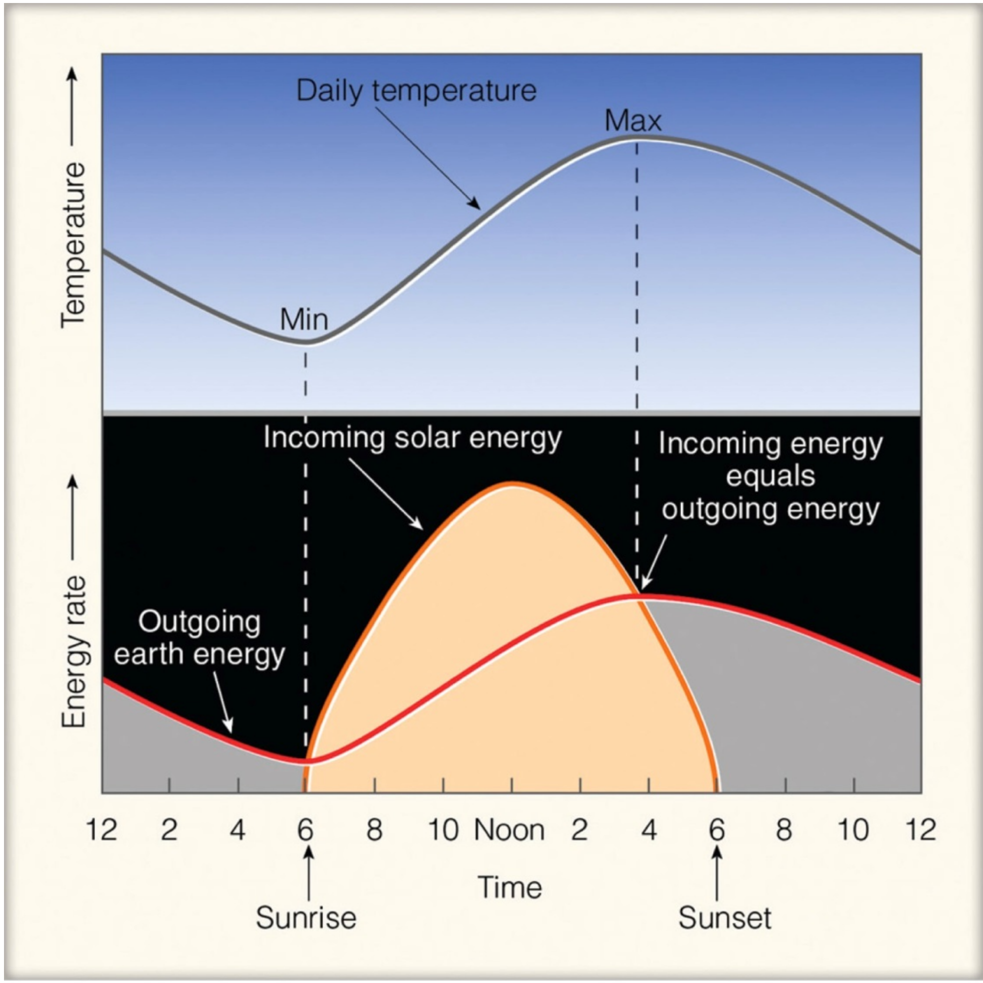


(a)

(b)

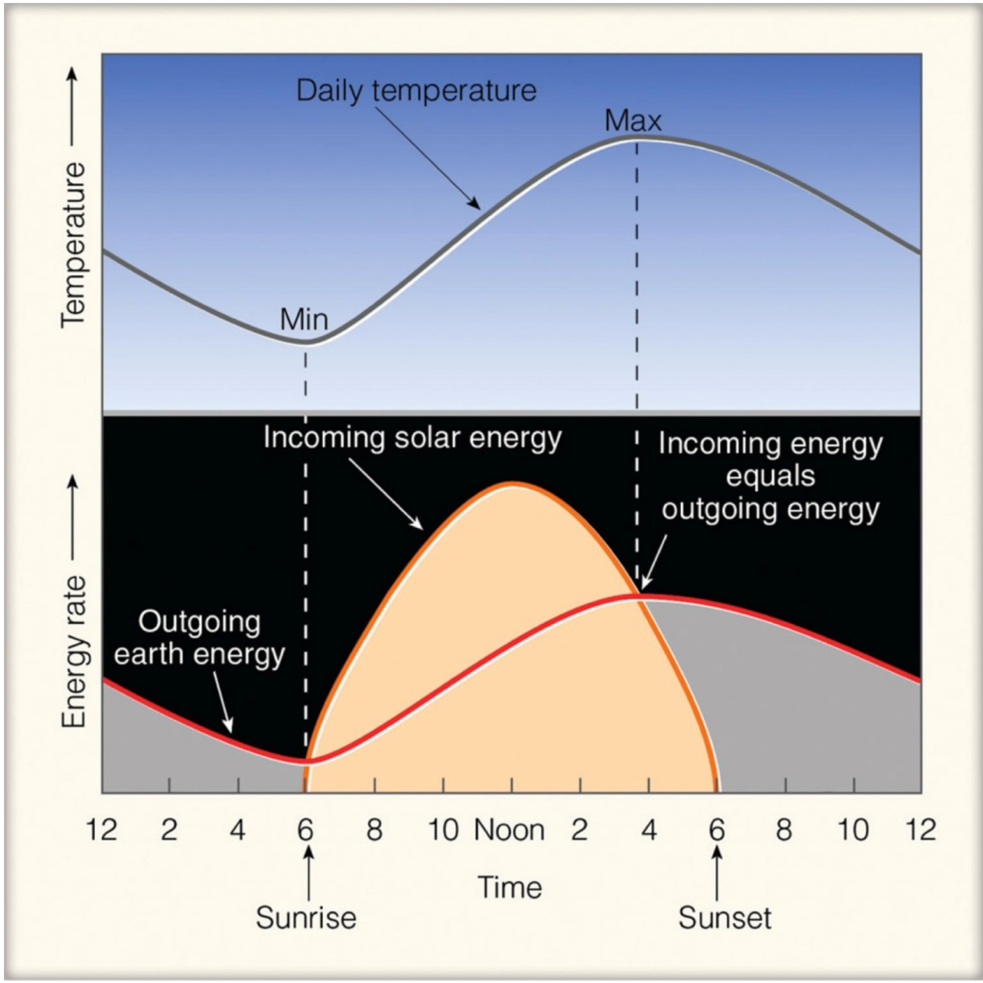
Daily temperature variations

- Each day like a tiny season with a cycle of heating and cooling
- Daytime heating
  - Air poor conductor so initial heating only effects air next to ground
  - As energy builds convection begins and heats higher portions of the atmosphere
  - After atmosphere heats from convection high temperature 3-5PM; lag in temperature

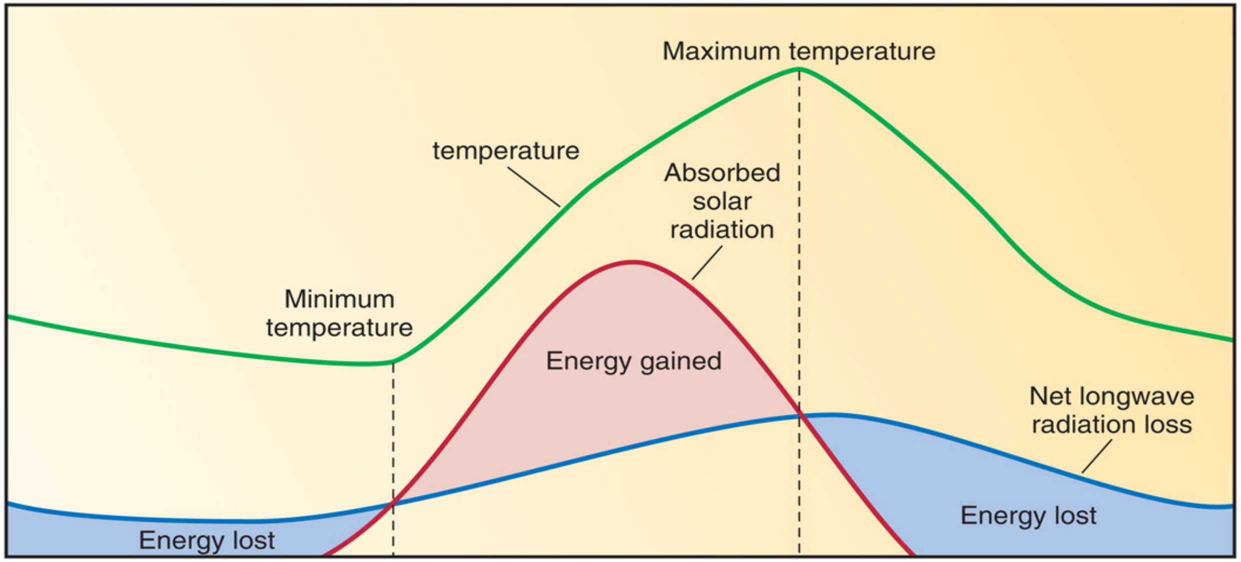


Daily temperature variations

- Nighttime cooling
  - As sun lowers, the lower solar angle causes insolation to be spread across a larger area
  - Radiational cooling as infrared energy is emitted by the Earth's surface
  - Radiation inversion: air near ground much cooler than air above
  - Thermal belt



Daily temperature variations

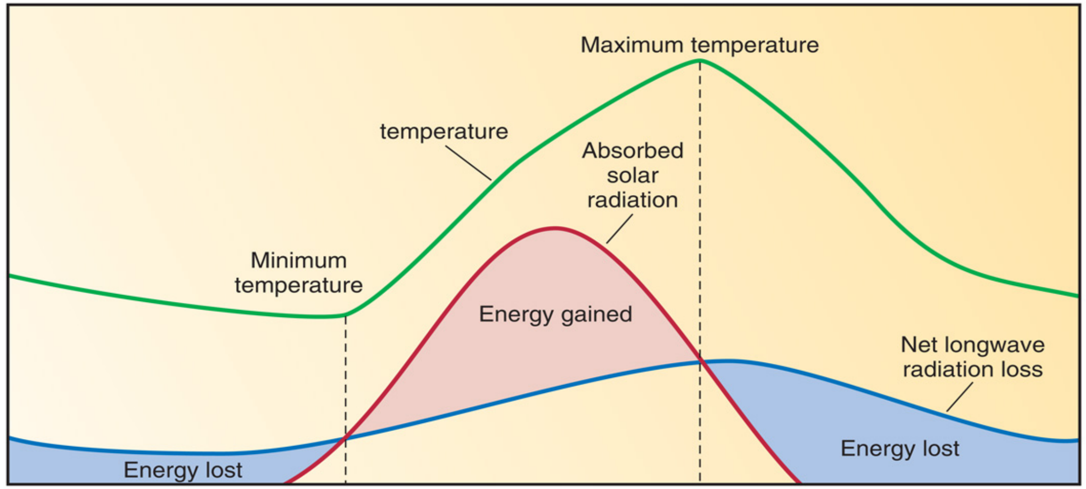


Air Temperature

- Minimum daily temperature occurs about a *half hour after sunrise*. (Net radiation negative during the night, heat flowed from ground, and cooled the surface air layer)
- Net radiation becomes positive, the surface warms and transfers heat to the air above.
- Air temperature rises sharply in the morning hours and continues to rise long after the noon peak of net radiation.

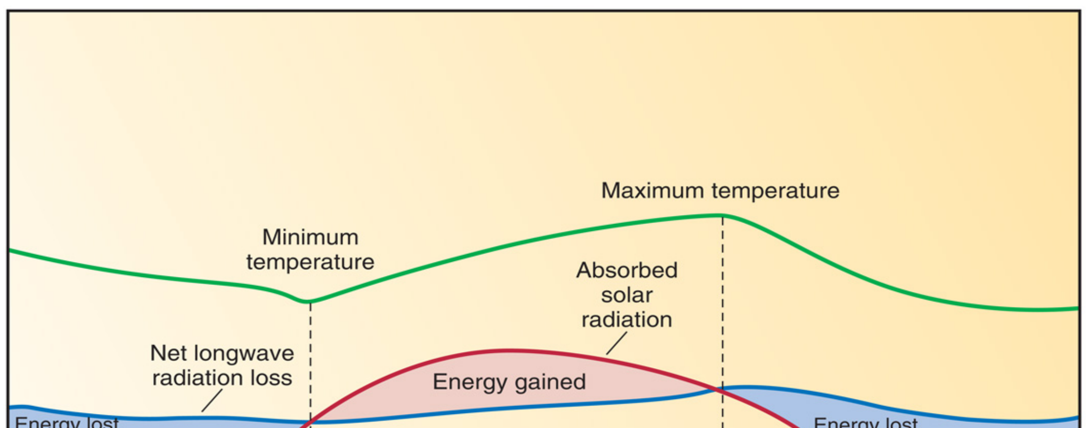
Daily temperature variations

- Clear Sky



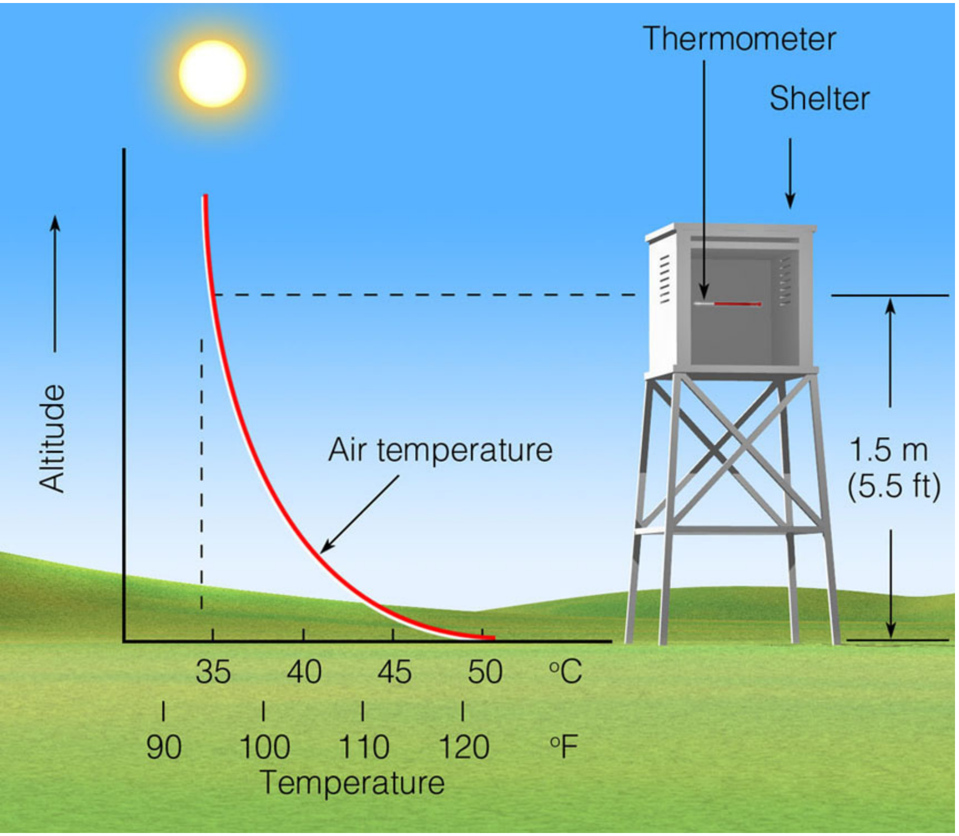
(a)

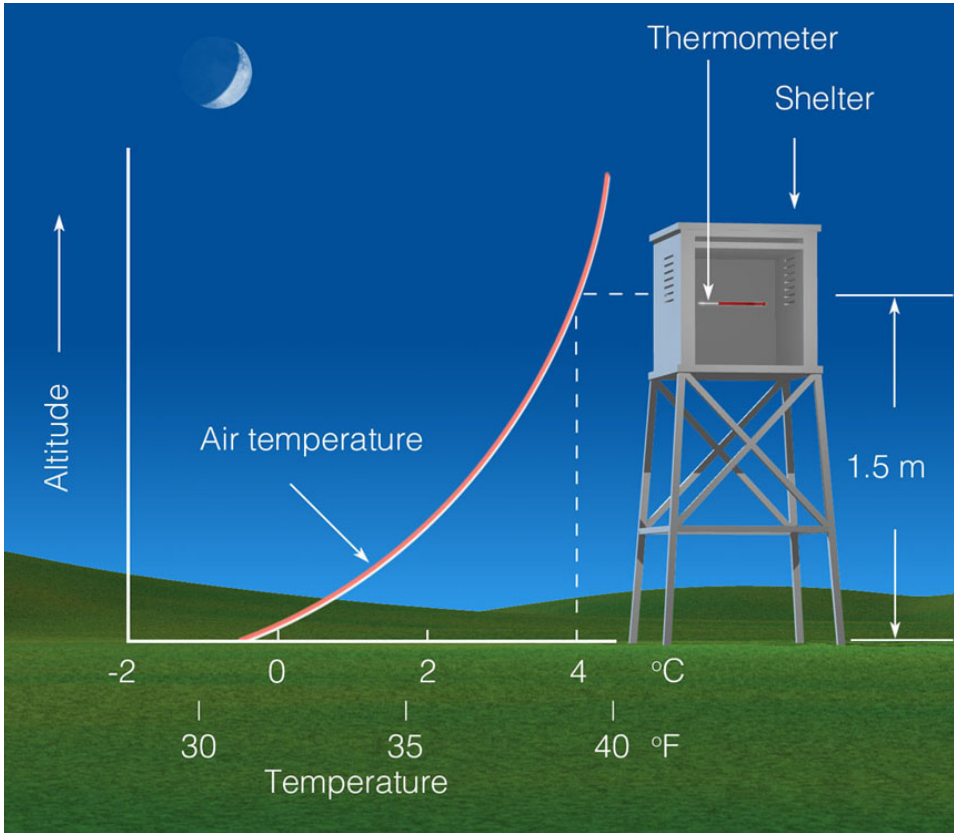
- Overcast



(b)

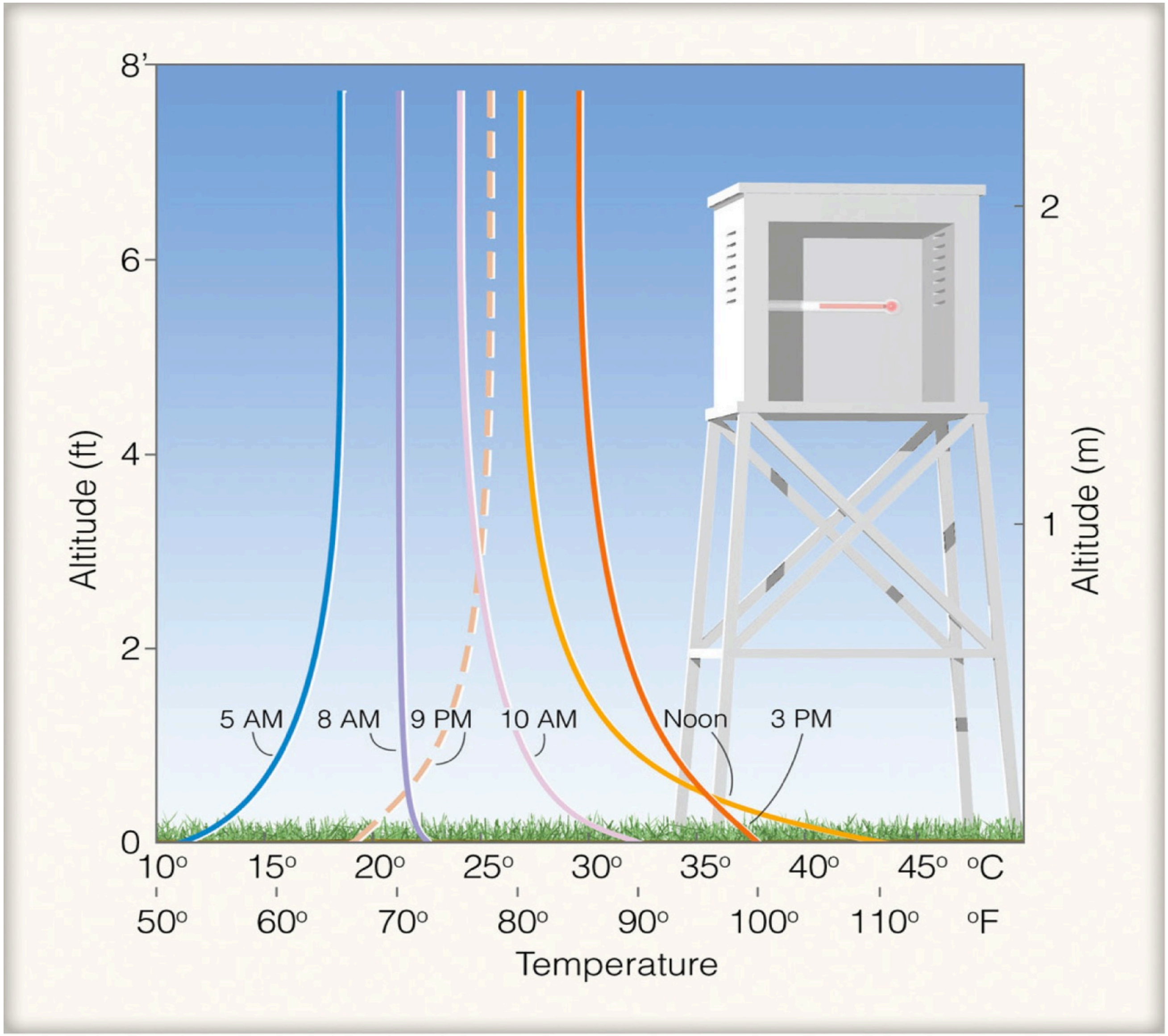
Daily temperature variations





a radiation temperature inversion

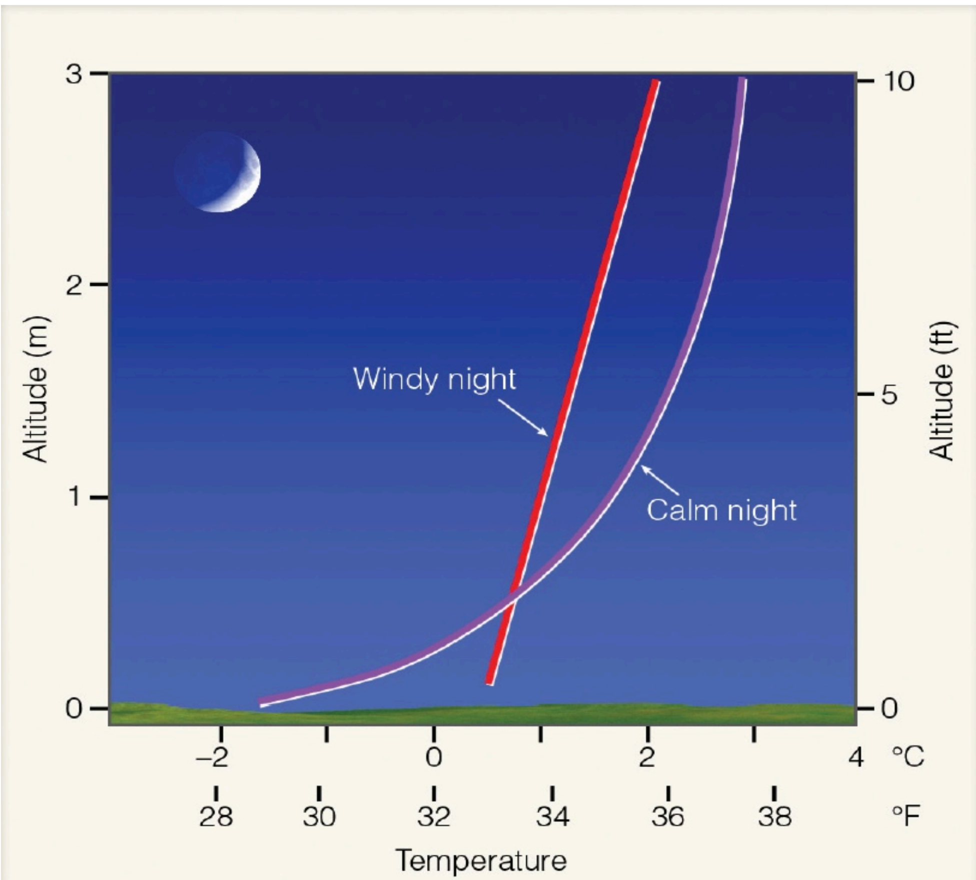
Daily temperature variations



The temperature curves represent the variations in average air temperature above a grassy surface for a mid-latitude city during the summer under clear, calm conditions.

Daily temperature variations

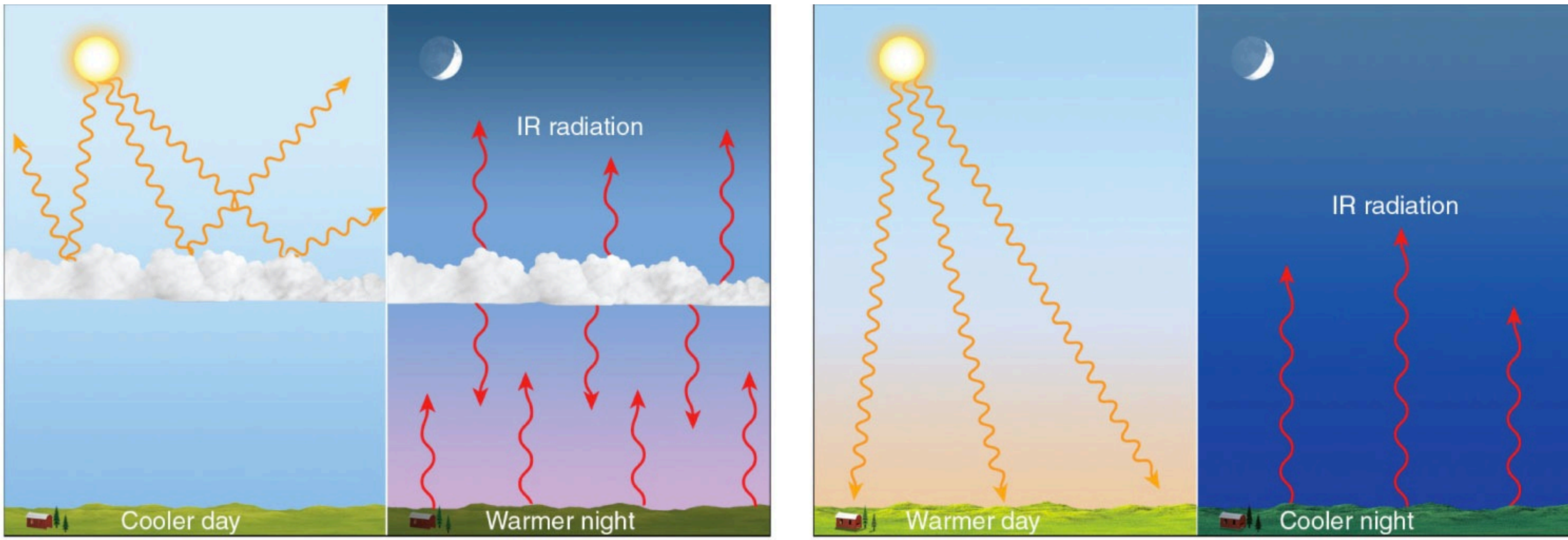
- Properties of soil affect the rate of conduction from Earth to atmosphere
- Wind mixes energy into air column and can force convection.



Vertical temperature profiles just above the ground on a windy night and on a calm night. Notice that the radiation inversion develops better on the calm night.

Daily temperature variations

- Cloud effect



(a) Small daily temperature range

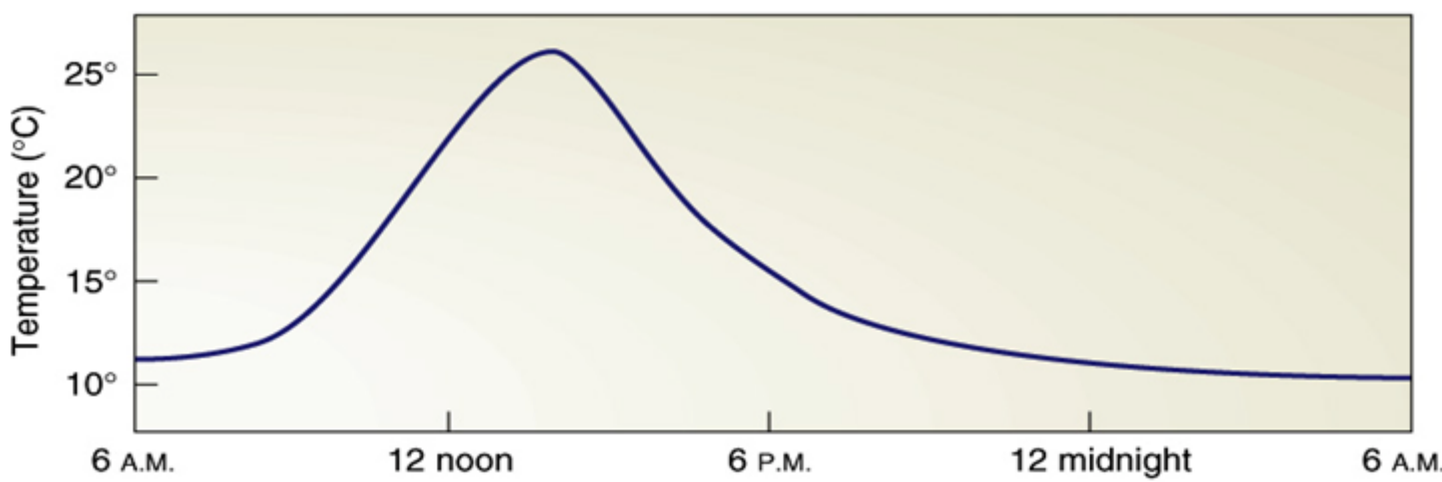
(b) Large daily temperature range

Clouds tend to keep daytime temperatures lower and nighttime temperatures higher, producing a small daily range in temperature.

In the absence of clouds, days tend to be warmer and nights cooler, producing a larger daily range in temperature.

Temperature Means and Ranges

- Daily, monthly, yearly temperature
  - Range: maximum minus minimum
  - Mean: average of temperature observations
  - Maximum: highest temperature of time period
  - Minimum: lowest temperature of time period
- Daily Mean=(Maximum + Minimum)/2
  - Standard averaging procedures used to obtain daily means
  - Observation biases may occur



Temperature Means and Ranges

- Monthly mean
- Annual mean
- Annual range=(highest monthly mean - lowest monthly mean)

Temperature and Human Comfort

- Human discomfort due to temperature compounded by other weather factors
- Wind Chill Temperature Index 風寒溫度指數
  - Effect of wind speed
- Heat Index 熱指數
  - Effect of humidity

Apparent temperature (AT) as a Wind Chill - after Steadman 1994

Temperature (°C)

Wind Speed (km/h)	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	17	19	20	21
2	-9	-8	-6	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	18	20	21
4	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	15	17	18	19	21
6	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	18	19	20
8	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19	20
10	-10	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	16	17	18	20
12	-11	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	16	18	19
14	-11	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19
16	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	14	16	17	18
18	-12	-11	-10	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	17	18
20	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16	18
22	-13	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	15	16	17
24	-13	-12	-11	-10	-9	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	12	13	14	15	17
26	-13	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16
28	-14	-13	-12	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	8	9	11	12	13	15	16
30	-14	-13	-12	-11	-10	-9	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	7	8	9	10	12	13	14	16
32	-14	-13	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	3	4	5	6	7	9	10	11	13	14	15
34	-15	-14	-13	-12	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	8	10	11	12	13	15
36	-15	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	-1	1	2	3	4	5	7	8	9	10	12	13	14
38	-16	-15	-13	-12	-11	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	1	3	4	5	6	8	9	10	11	13	14
40	-16	-15	-14	-13	-12	-11	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	8	10	11	12	14
42	-16	-15	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	-1	1	2	3	4	5	7	8	9	11	12	13
44	-17	-16	-15	-14	-12	-11	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	1	3	4	5	6	8	9	10	12	13
46	-17	-16	-15	-14	-13	-12	-11	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	9	10	11	13
48	-18	-16	-15	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	-1	1	2	3	4	6	7	8	9	11	12
50	-18	-17	-16	-15	-14	-12	-11	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	1	3	4	5	6	8	9	10	12
52	-18	-17	-16	-15	-14	-13	-12	-11	-10	-8	-7	-6	-5	-4	-3	-1	0	1	2	4	5	6	7	9	10	11
54	-19	-18	-17	-15	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	-1	1	2	3	4	6	7	8	10	11
56	-19	-18	-17	-16	-15	-14	-13	-11	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	2	3	4	5	7	8	9	11
58	-20	-18	-17	-16	-15	-14	-13	-12	-11	-10	-8	-7	-6	-5	-4	-3	-1	0	1	2	4	5	6	8	9	10
60	-20	-19	-18	-17	-16	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	-1	1	2	3	5	6	7	8	10
62	-20	-19	-18	-17	-16	-15	-14	-13	-11	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	2	3	4	5	7	8	9
64	-21	-20	-19	-17	-16	-15	-14	-13	-12	-11	-10	-8	-7	-6	-5	-4	-2	-1	0	1	2	4	5	6	8	9
66	-21	-20	-19	-18	-17	-16	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	0	1	2	3	5	6	7	9
68	-21	-20	-19	-18	-17	-16	-15	-14	-13	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	2	3	4	6	7	8
70	-22	-21	-20	-19	-17	-16	-15	-14	-13	-12	-11	-10	-8	-7	-6	-5	-4	-2	-1	0	1	3	4	5	6	8
72	-22	-21	-20	-19	-18	-17	-16	-15	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	0	1	2	3	5	6	7
74	-23	-22	-20	-19	-18	-17	-16	-15	-14	-13	-12	-10	-9	-8	-7	-6	-4	-3	-2	-1	1	2	3	4	6	7
76	-23	-22	-21	-20	-19	-18	-16	-15	-14	-13	-12	-11	-10	-8	-7	-6	-5	-4	-2	-1	0	1	3	4	5	7
78	-23	-22	-21	-20	-19	-18	-17	-16	-15	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	0	1	2	4	5	6
80	-24	-23	-22	-21	-19	-18	-17	-16	-15	-14	-13	-12	-10	-9	-8	-7	-6	-4	-3	-2	-1	1	2	3	5	6

Apparent temperature with no radiational heating and relative humidity fixed at 70%

Formula from *Norms of apparent temperature in Australia* , **Aust. Met. Mag**, Vol 43, 1994, 1-16.

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution   Extreme Caution   Danger   Extreme Danger

補充教材: Vertical Variation in Air Temperature

$$T(z) = T_0 - \frac{H}{0.4\hat{\rho}c_p u^*} \ln \frac{z-d}{z_H} \tag{2.1}$$

where $T(z)$ is the mean air temperature at height z, T_0 is the apparent aerodynamic surface temperature, z_H is a roughness parameter for heat transfer, H is the sensible heat flux from the surface to the air, $\hat{\rho}c_p$ is the volumetric specific heat of air (1200 J m^{-3} C^{-1} at 20° C and sea level), 0.4 is von Karman's constant, and u* is the friction velocity (related to the friction or drag of the stationary surface on the moving air). The reference level from which z is measured is always somewhat arbitrary, and the correction factor d, called the zero-plane displacement, is used to adjust for this. For a flat, smooth surface, d $=$ 0. For a uniformly vegetated surface, $z_H \simeq 0.02h$, and $d \simeq 0.6h$, where h is canopy height.

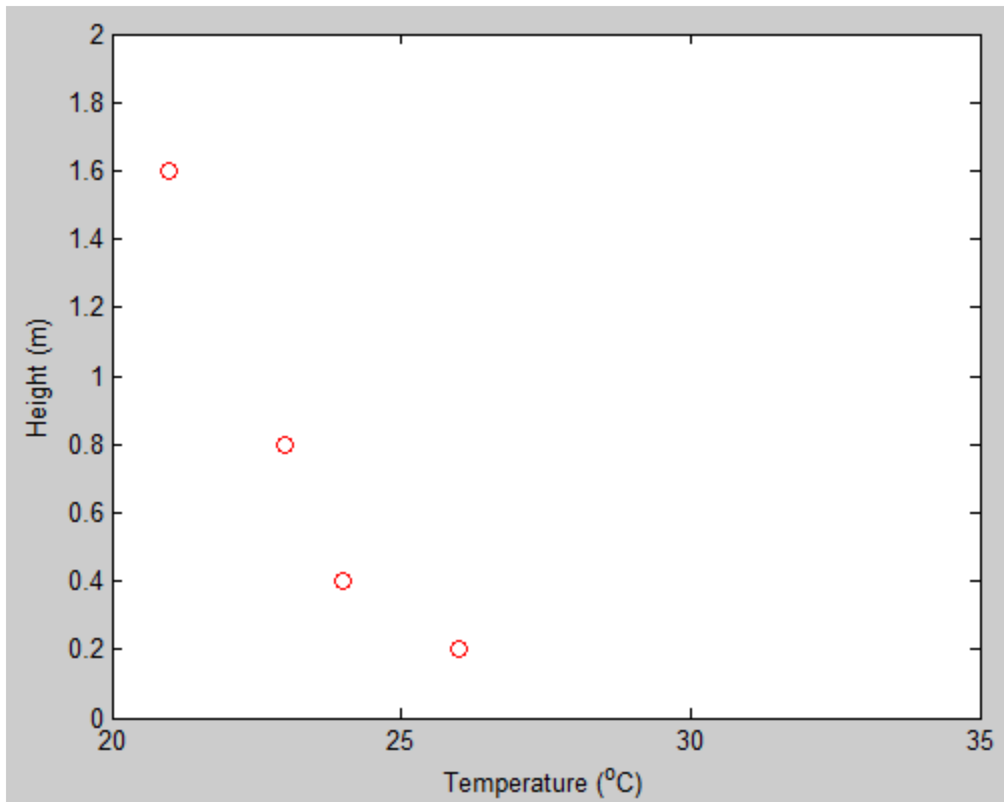
Vertical temperature profile

- Interpret the shape of the temperature profile
  - The temperature profile is logarithmic
    → a plot of $ln\,(z-d)/z$ v.s. $T(z)$ is a straight line
  - Temperature increases with height when H is negative (heat flux toward the surface) and decreases with height when ***H*** is positive. During the day, sensible heat flux is generally away from the surface so T decreases with height.
  - The temperature gradient at a particular height increases in magnitude as the magnitude of H increases, and decreases as wind or turbulence increases.

$$T(z) = T_0 - \frac{H}{0.4\hat{\rho}c_p u^*} \ln \frac{z-d}{z_H}$$

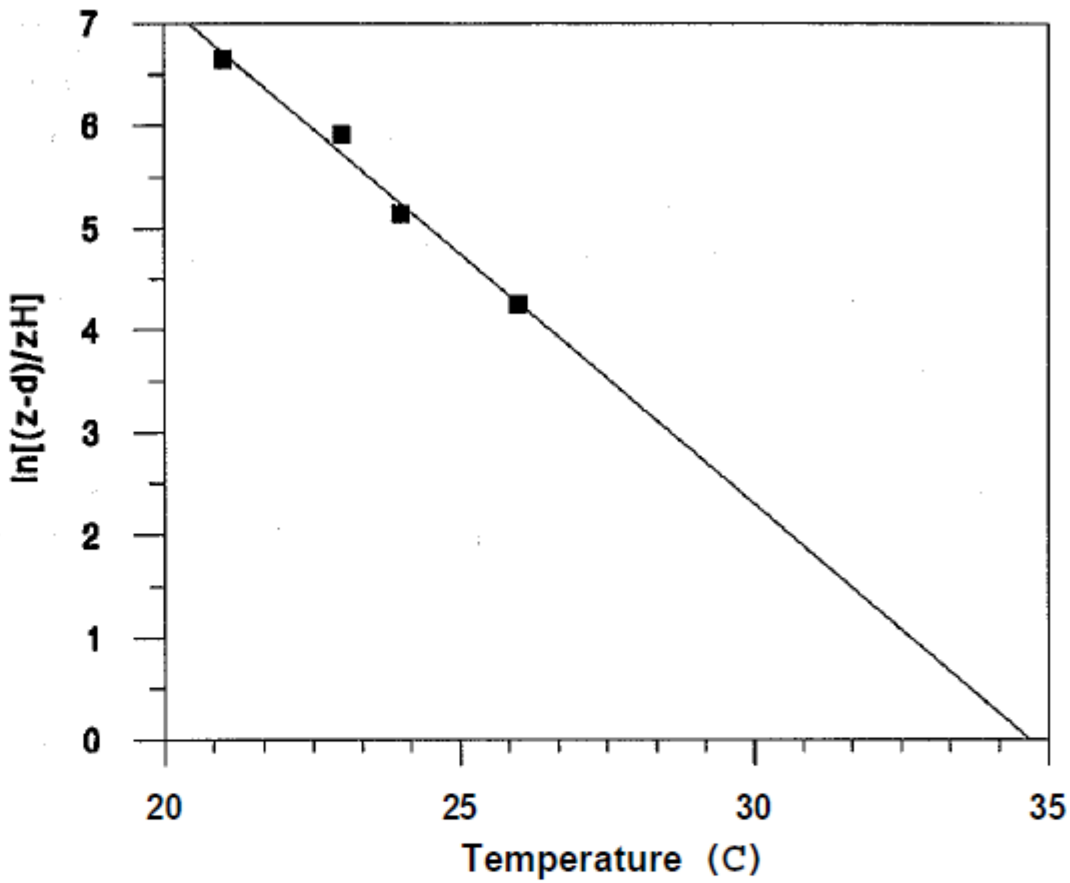
Example 2.1. The following temperatures were measured above a 10 cm high alfalfa crop on a clear day. Find the aerodynamic surface temperature, T_0.

Height (m)	0.2	0.4	0.8	1.6
Temperature (C)	26	24	23	21



$$T(z) = T_0 - \frac{H}{0.4\hat{\rho}c_p u^*} \ln \frac{z-d}{z_H}$$

Height (m)	0.2	0.4	0.8	1.6
Temp. (C)	26	24	23	21
$(z-d)/z_H$	70	170	370	770
$\ln[(z-d)/z_H]$	4.25	5.14	5.91	6.65.



Example 2.2. The mean temperature at 5:00 hrs, 2 m above the soil surface is 3" C. At a height of 1 m, the temperature is 1° C. If the crop below the point where these temperatures are measured is 50 cm tall, will the crop experience a temperature below freezing?

$$T(z) = T_0 - \frac{H}{0.4\hat{\rho}c_p u^*} \ln \frac{z-d}{z_H}$$

$$3 = T_0 - A \ln \frac{2 - 0.6 \times 0.5}{0.02 \times 0.5} = T_0 - 5.14A$$

$$1 = T_0 - A \ln \frac{1 - 0.6 \times 0.5}{0.02 \times 0.5} = T_0 - 4.25A.$$

Subtracting the second equation from the first, and solving for A gives A = −2.25" C. Substituting this back into either equation gives T_0 = −8.6" C. Knowing these, now solve for $T(h)$ where h = 0.5 m:

$$T(h) = -8.6 + 2.25 \ln \frac{0.5 - 0.6 \times 0.5}{0.5 \times 0.02} = -1.9\,\mathrm{C}.$$

補充教材: Temporal variation in air temperature

- Assumption:
  - Min. temperatures normally occur just before sunrise and max. temperatures normally occur about two hours after solar noon.
  - The dimensionless diurnal temperature function (experimental equation):

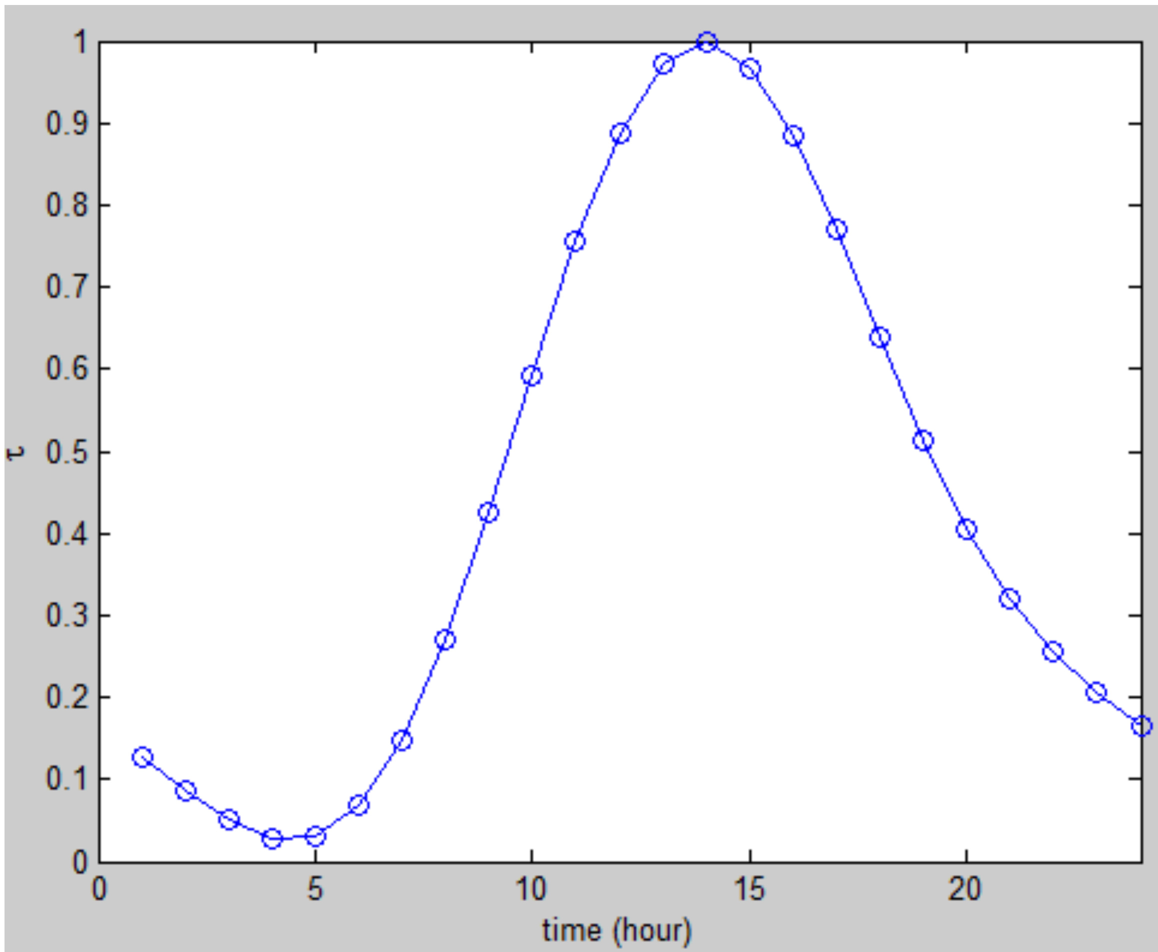
$$\Gamma(t) = 0.44 - 0.46\sin(\omega t + 0.9) + 0.11\sin(2\omega t + 0.9) \qquad (2.2)$$

where $\omega = \pi/12$, and t is the time of day in hours (t = 12 at solar noon). Using this function, the temperature for any time of the day is given by

$$\begin{aligned}
T(t) &= T_{x,i-1}\Gamma(t) + T_{n,i}[1-\Gamma(t)] && 0 < t \le 5 \\
T(t) &= T_{x,i}\Gamma(t) + T_{n,i}[1-\Gamma(t)] && 5 < t \le 14 \qquad (2.3) \\
T(t) &= T_{x,i}\Gamma(t) + T_{n,i+1}[1-\Gamma(t)] && 14 < t < 24.
\end{aligned}$$

Here, T_x is the daily maximum temperature and T_n is the minimum temperature. The subscript i represents the present day; i − 1 is the previous day, and i + 1 is the next day.

$$\Gamma(t) = 0.44 - 0.46\sin(\omega t + 0.9) + 0.11\sin(2\omega t + 0.9)$$



Example 2.3. Estimate the temperature at 10 AM on a day when the minimum was 5" C and the **maximum** was 23" C.

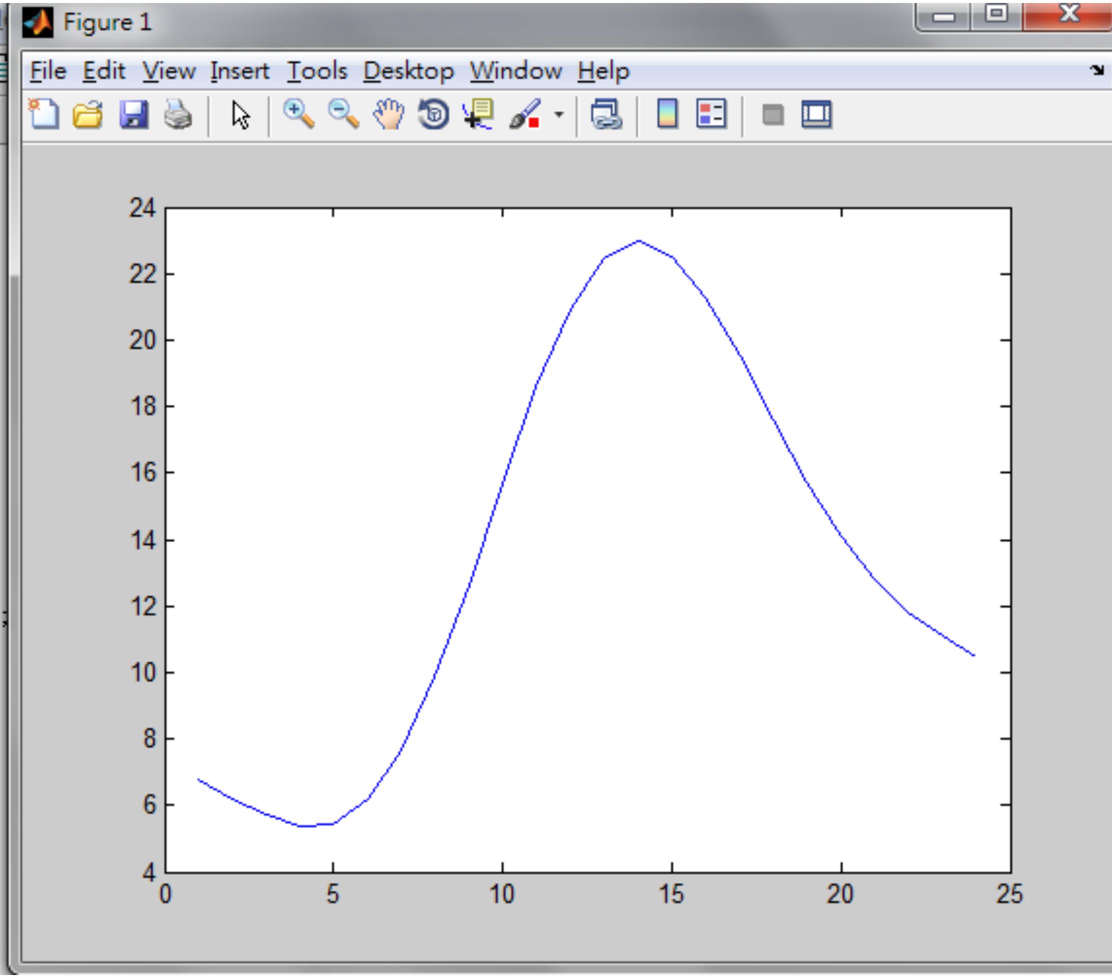
Solution. At t = 10 hrs, (note that angles are in radians)

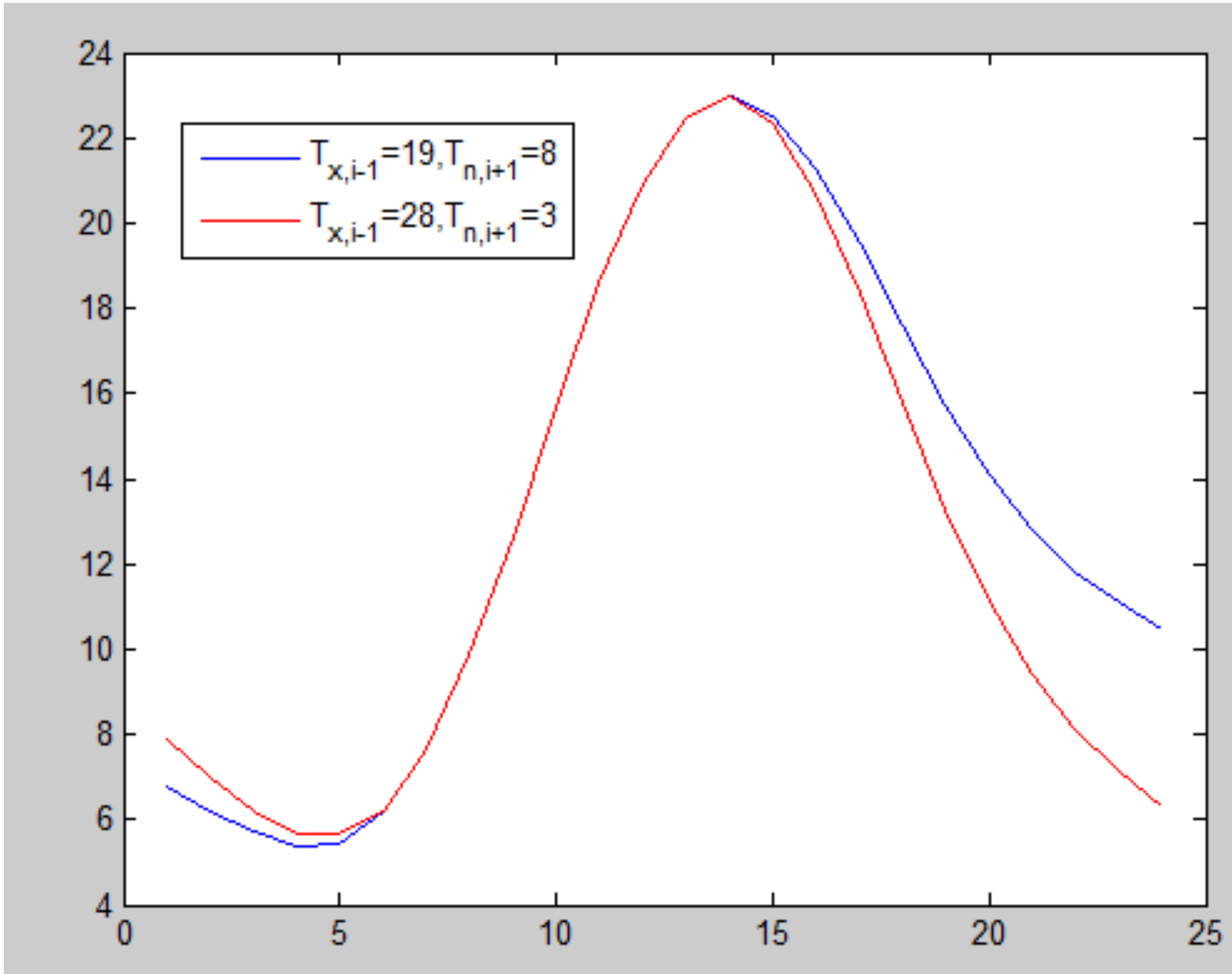
$$\Gamma = 0.44 - 0.46 \sin\left(\frac{3.14 \times 10}{12} + 0.9\right)$$
$$+ 0.11 \sin\left(\frac{2 \times 3.14 \times 10}{12} + 0.9\right) = 0.593.$$

Since 10 is between 5 and 14, the middle form of Eq. (2.3) is used, so

$$T(10) = 23 \times 0.593 + 5 \times (1 - 0.593) = 15.7.$$

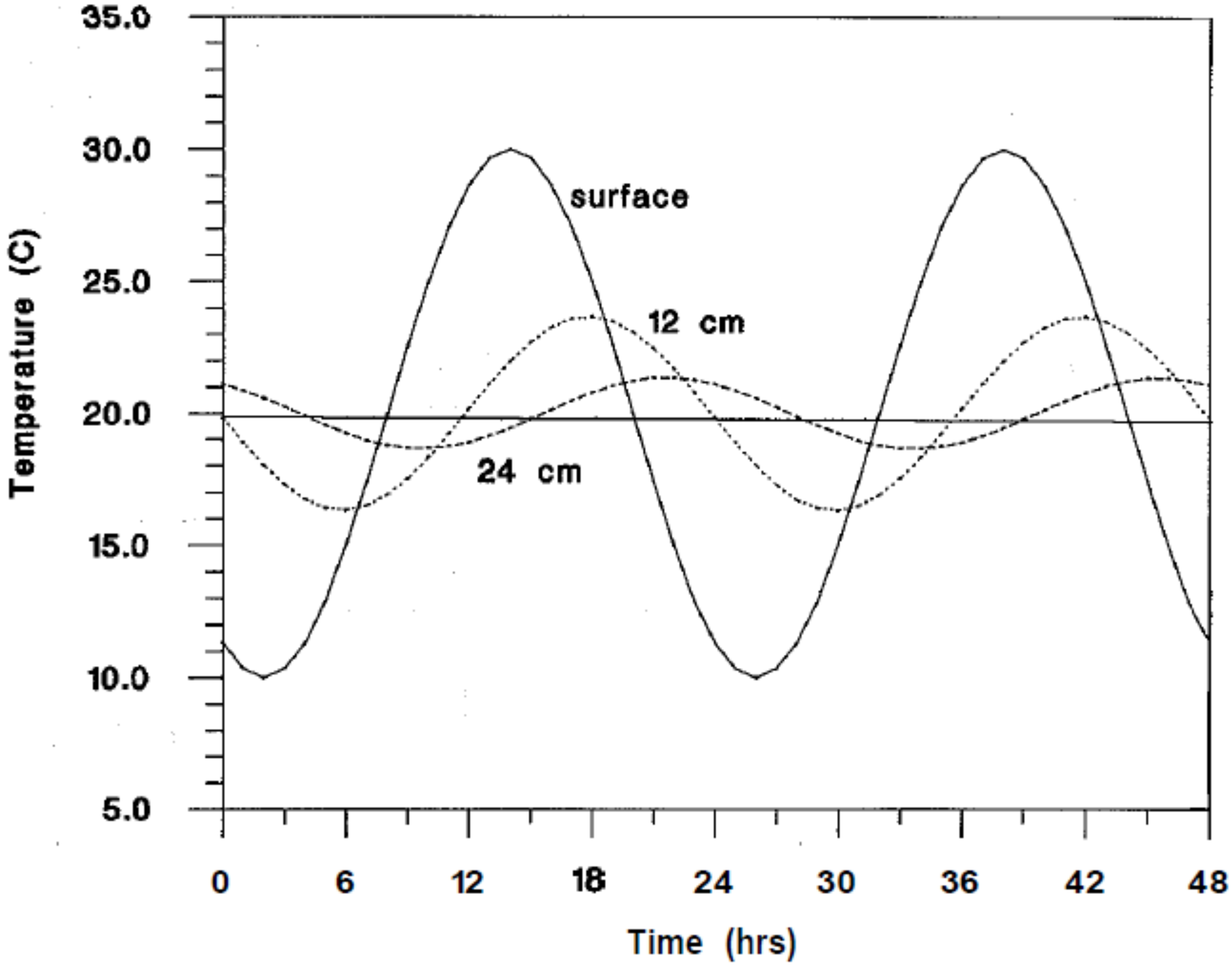
```
hr=1:1:24
tau=0.44-0.46.*sin(pi./12*(hr)+0.9)...
    +0.11.*sin(2*pi./12*(hr)+0.9);

Txi0=19
Tni1=5;
Txi1=23;
Tni2=8;

T(1:1:5)=Txi0.*tau(1:1:5)+Tni1.*(1-tau(1:1:5));
T(6:1:14)=Txi1.*tau(6:1:14)+Tni1.*(1-tau(6:1:14));
T(15:1:24)=Txi1.*tau(15:1:24)+Tni2.*(1-tau(15:1:24));

plot(hr,T)
```



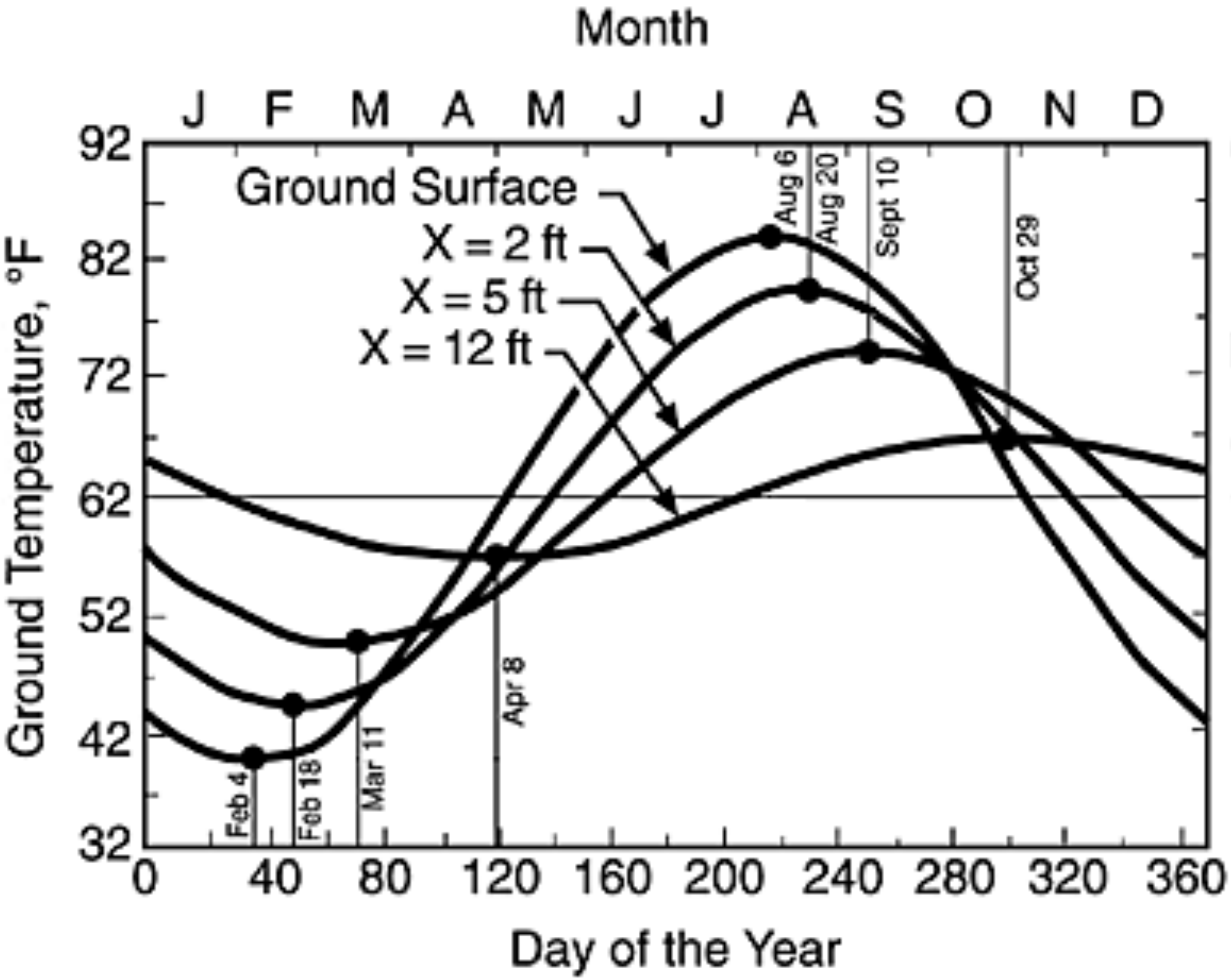


$T_{x,i-1}$=19,$T_{n,i+1}$=8
$T_{x,i-1}$=28,$T_{n,i+1}$=3
24
22
20
18
16
14
12
10
8
6
4
0
5
10
15
20
25

Soil temperature changes with depth/time



Soil temperature changes with depth/time



Soil temperature changes with depth/time

- Modeling the soil temperature changes with depth and time
  - This model assumes uniform soil properties throughout the soil profile and a sinusoidally varying surface temperature.

$$T(z, t) = T_{\text{ave}} + A(0) \exp(-z/D) \sin[\omega(t - 8) - z/D] \qquad (2.4)$$

where T_{ave} is the mean daily soil surface temperature, ω is $\pi/12$, as in Eq. (2.2), $A(0)$ is the amplitude of the temperature fluctuations at the surface (half of the peak-to-peak variation) and D is called the damping depth. The "–8" in the sine function is a phase adjustment to the time variable so that when time $t = 8$, the sine of the quantity in brackets is zero at the surface ($z = 0$). We discuss computation of diurnal damping depth in Ch. 8. It has a value around 0.1 m for moist, mineral soils, and 0.03 to 0.06 m for dry mineral soils and organic soils.

Soil temperature changes with depth/time

$$T(z,t) = T_{ave} + A(0)\exp(-z/D)\sin[\omega(t-8) - z/D] \qquad (2.4)$$

- In many cases we are not interested in the time dependence of the soil temperature, but would just like to know the range of temperatures at a particular depth. It is known that the range of the sine function is - 1 to 1 so Eq. (2.4) gives the range of soil temperature variation as

$$T(z) = T_{ave} \pm A(0)\exp(-z/D) \qquad (2.5)$$

Example 2.4. At what depth is the soil temperature within ±**0.5°** C of the mean daily surface temperature if the temperature variation at the surface (amplitude) is ±15° C?

Solution. The amplitude of the desired temperature variation is 0.5" C. Rearranging Eq. (2.5) and taking the logarithm of both sides gives

$$\frac{z}{D} = -\ln \frac{T(z) - T_{\text{ave}}}{A(0)} = -\ln \frac{0.5}{15} = 3.4.$$

If D = **12 cm,** then the depth for diurnal variations less than **±0.5° C** would be 3.4 x 12 cm = 41 cm. Therefore a depth of at least 40 cm needs to be dug to obtain a soil temperature measurement that is not influenced by the time of day the temperature is measured.