- above the atmosphere solar "beam" has strength ("energy flux density") ~ 1365 W $m^{-2}$ (solar "constant" $S_0$)

- within the atmosphere, solar photons are subject to *absorption* and *scattering* by gases and particles (including water and ice), while photons neither absorbed nor scattered are "*transmitted*"

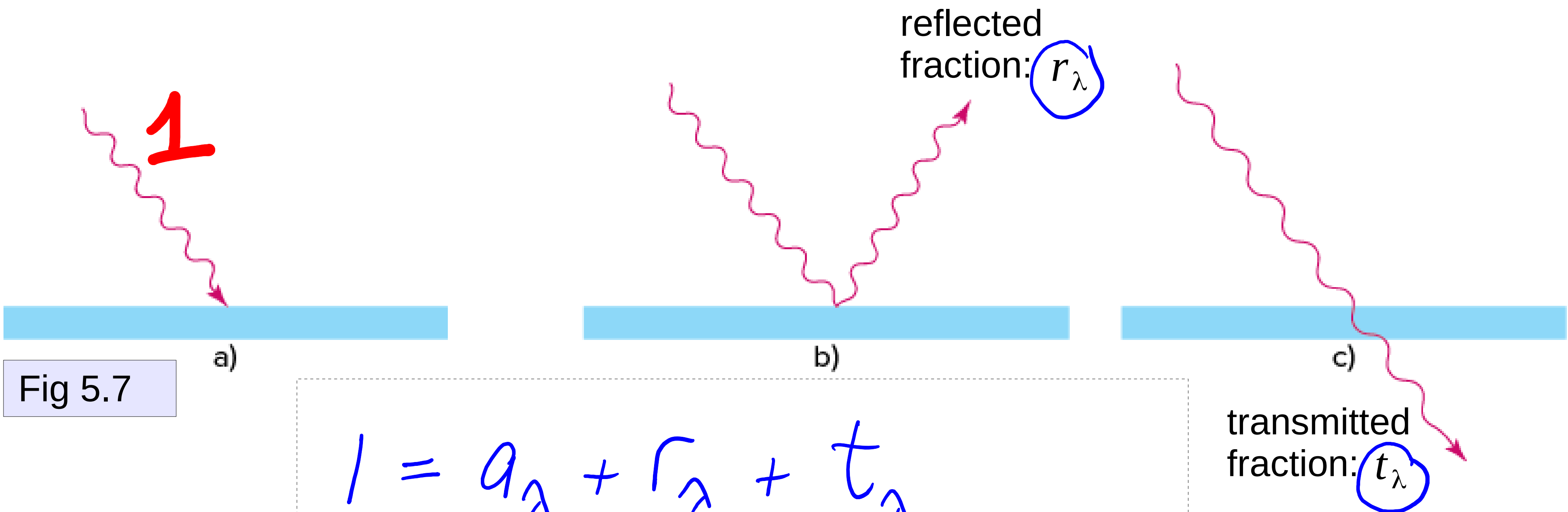


Fig 5.7

$$1 = a_\lambda + r_\lambda + t_\lambda$$

- absorption results in the radiative energy being converted to sensible heat (and possibly a share to latent heat) at the site of absorption

- scattering means photons' direction of motion is changed, producing diffuse solar radiation (what you see when you are not looking directly at the sun)

Why is forest an efficient absorber?

multiple reflections ← high leaf area per unit ground area

Why does water have a low albedo for high sun? has high transmissivity

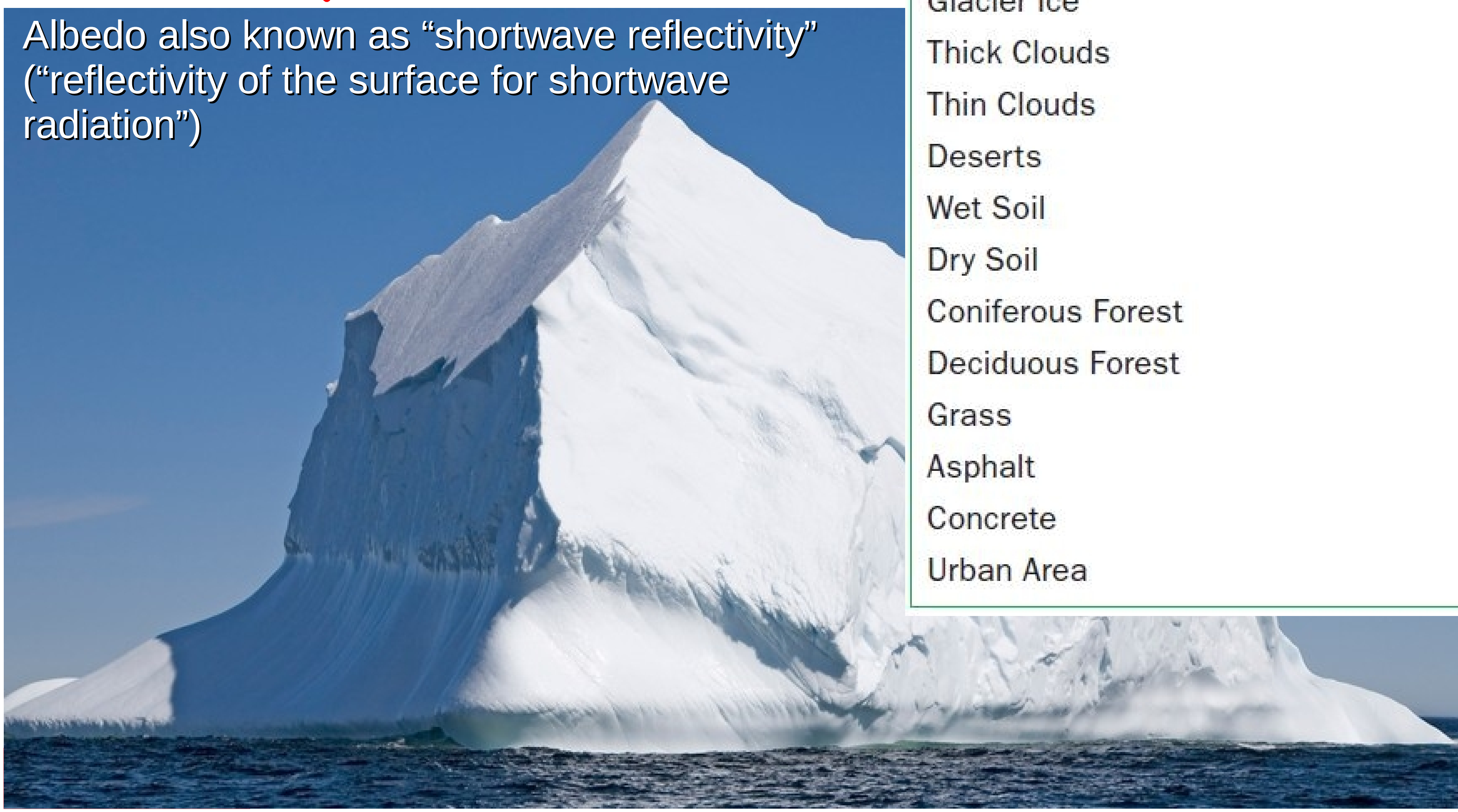


**TABLE 5.2 | Albedos of various surfaces.**

| Surface | Albedo |
|---|---|
| Fresh Snow | 0.75–0.95 |
| Old Snow | 0.40–0.70 |
| Water (Low Sun Angle) → specular reflection | 0.10–1.00 |
| Water (High Sun Angle) | 0.03–0.10 |
| Sea Ice | 0.30–0.45 |
| Glacier Ice | 0.20–0.40 |
| Thick Clouds | 0.70–0.95 |
| Thin Clouds | 0.40–0.60 |
| Deserts | 0.20–0.40 |
| Wet Soil | 0.05–0.15 |
| Dry Soil | 0.25–0.35 |
| Coniferous Forest | 0.05–0.15 |
| Deciduous Forest | 0.15–0.25 |
| Grass | 0.15–0.25 |
| Asphalt | 0.05–0.20 |
| Concrete | 0.10–0.35 |
| Urban Area | 0.15 (average |

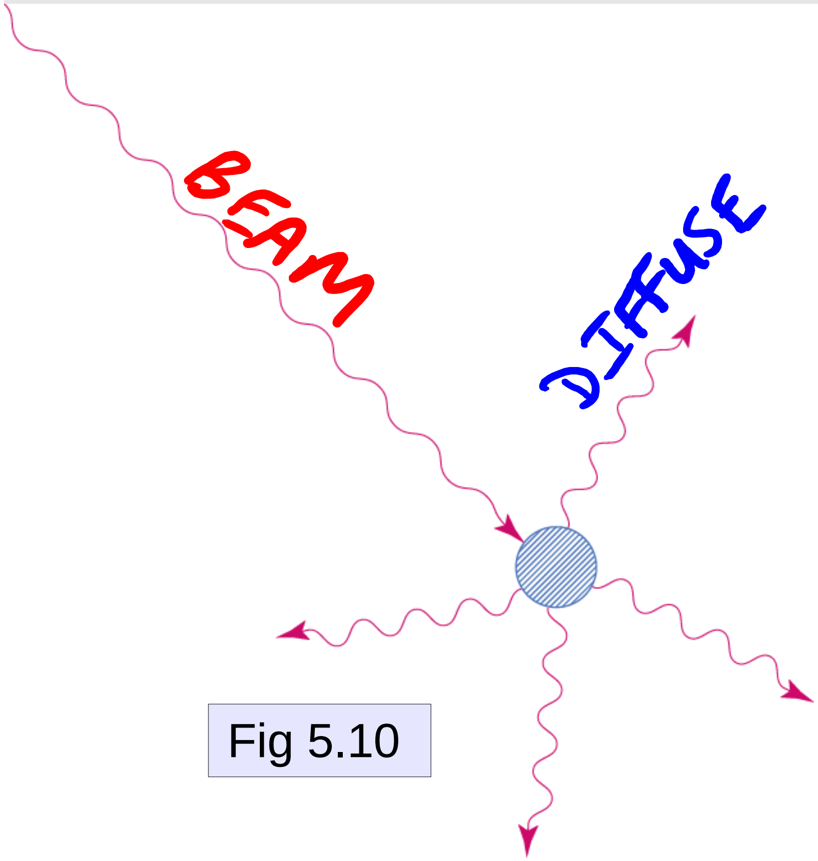


Fig 5.10

Raleigh scattering occurs off particles with radius $r \ll \lambda$

- is wavelength selective
- efficiency $\propto \lambda^{-4}$

"proportional to"

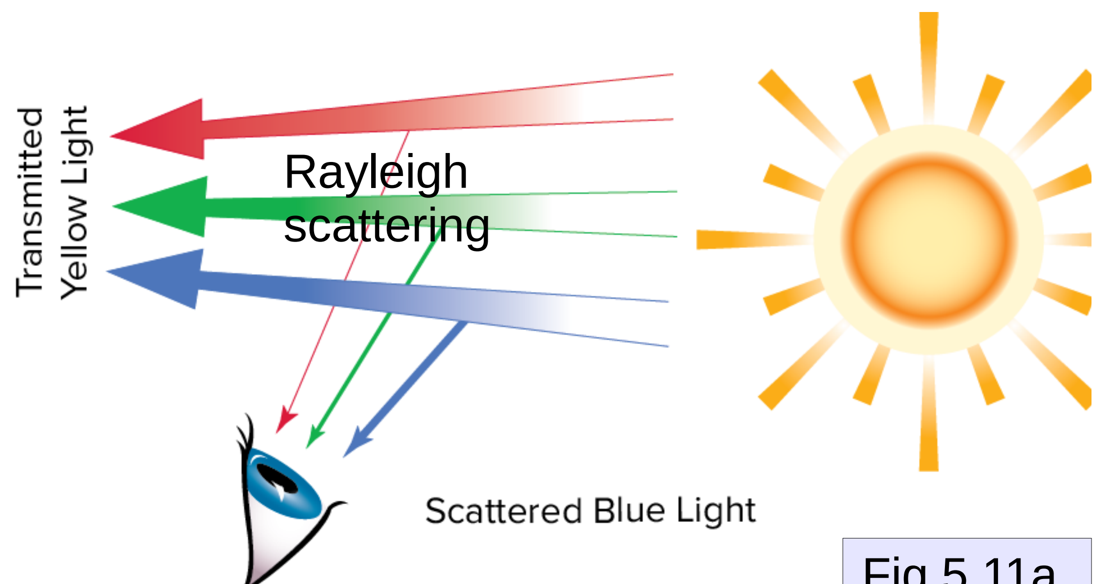


Fig 5.11a

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- aerosols (including cloud droplets) are much larger than the wavelength of solar radiation, and cause *Mie scattering* – which is non-selective with respect to wavelength

- Diffuse light under cloud cover is milky and clouds appear white

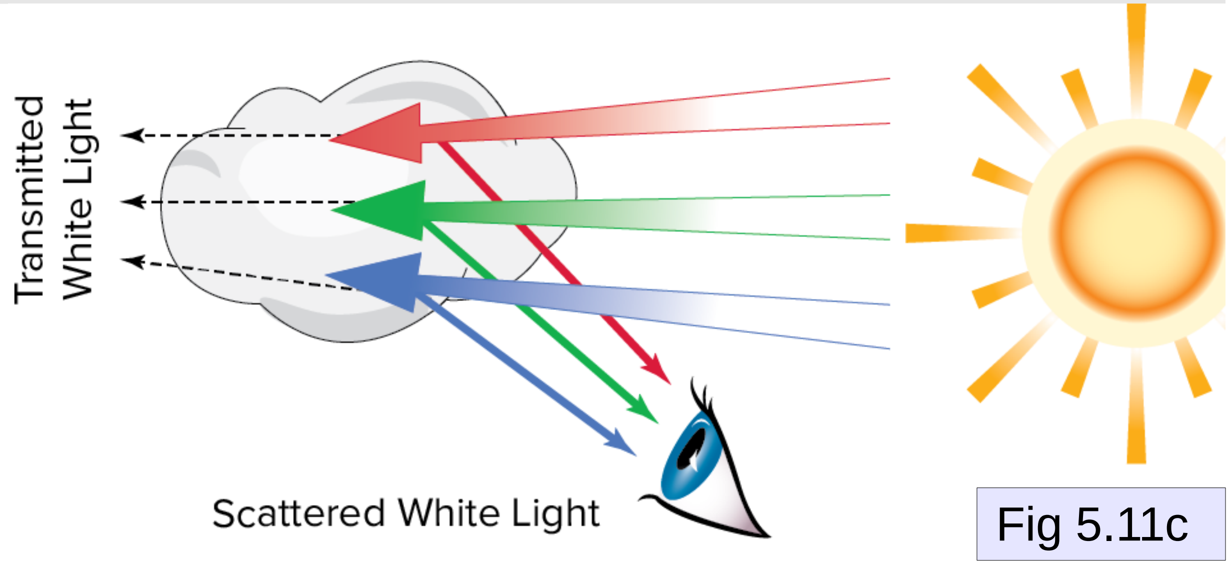



Fig 5.11c

- Under clear skies, apart from some absorption in the uv and nir (respectively 7%, 37% of incident solar energy) a substantial proportion of solar radiation traverses the atmosphere without absorption – though scattering transfers radiation out of the "direct beam" and results in (upward and downward) "diffuse radiation"

- "The atmosphere is more effective at absorbing the longwave radiation from the earth than it is at absorbing the shortwave radiation from the sun"

## NO ATMOSPHERE

- Completely transparent atmosphere (equivalent to no atmosphere)
- steady state energy balance:

$$\pi r_E^2 \underbrace{(1-\alpha)}_{0.7} K\downarrow = 4\pi r_E^2 \, L\uparrow \quad \sigma T^4$$

$\alpha$ = albedo, $r_E$ earth radius

$K\downarrow = S_0$ in this case

- quantitative global energy balance gives a radiative equilib. temp. -18°C

(Very simplistic calculation assumes an isothermal planet)

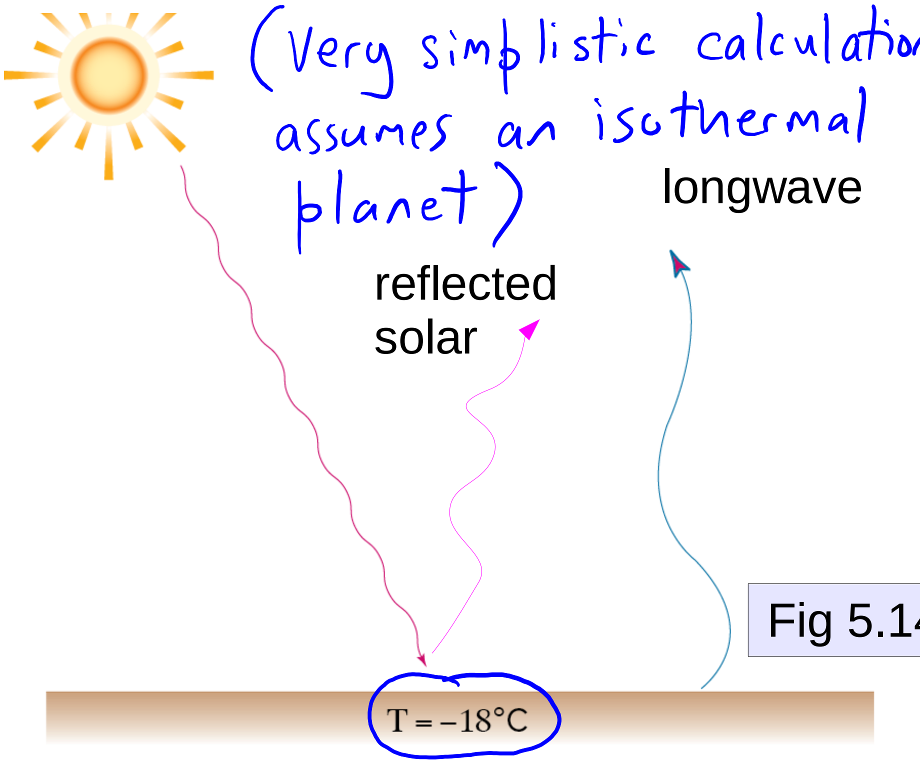
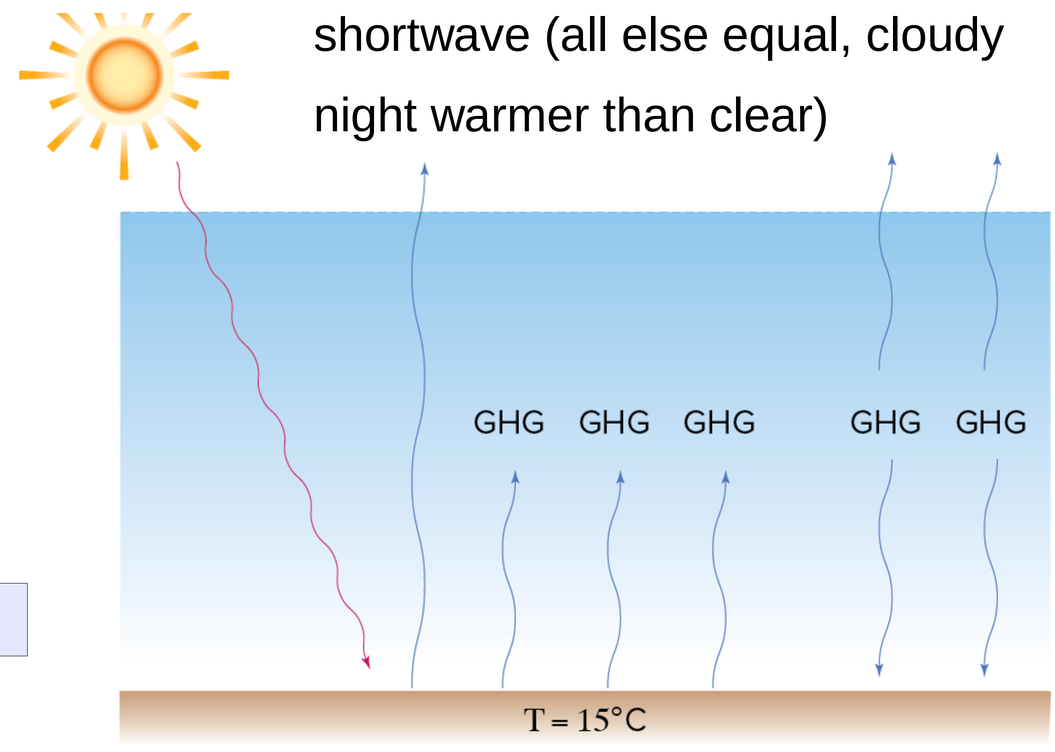



Fig 5.14

## WITH ATMOSPHERE

- GHG absorb and emit longwave radiation
- water vapour is the main GHG
- atmosphere "relatively transparent" to shortwave (exception: water vapour attenuates nir, ozone the uv) but its GHGs strongly interact with longwave
- clouds absorb (and emit) all wavelengths of longwave radiation and reflect/scatter/absorb shortwave (all else equal, cloudy night warmer than clear)



- solar constant ("$S_0$") 1365 W m$^{-2}$ (strength of beam above atmos, when sun-earth distance = avg. value)

Sun earth distance varies by about 5 parts in 150 (~3%)

Beam intensity varies by 6% $E \propto 1/D^2$

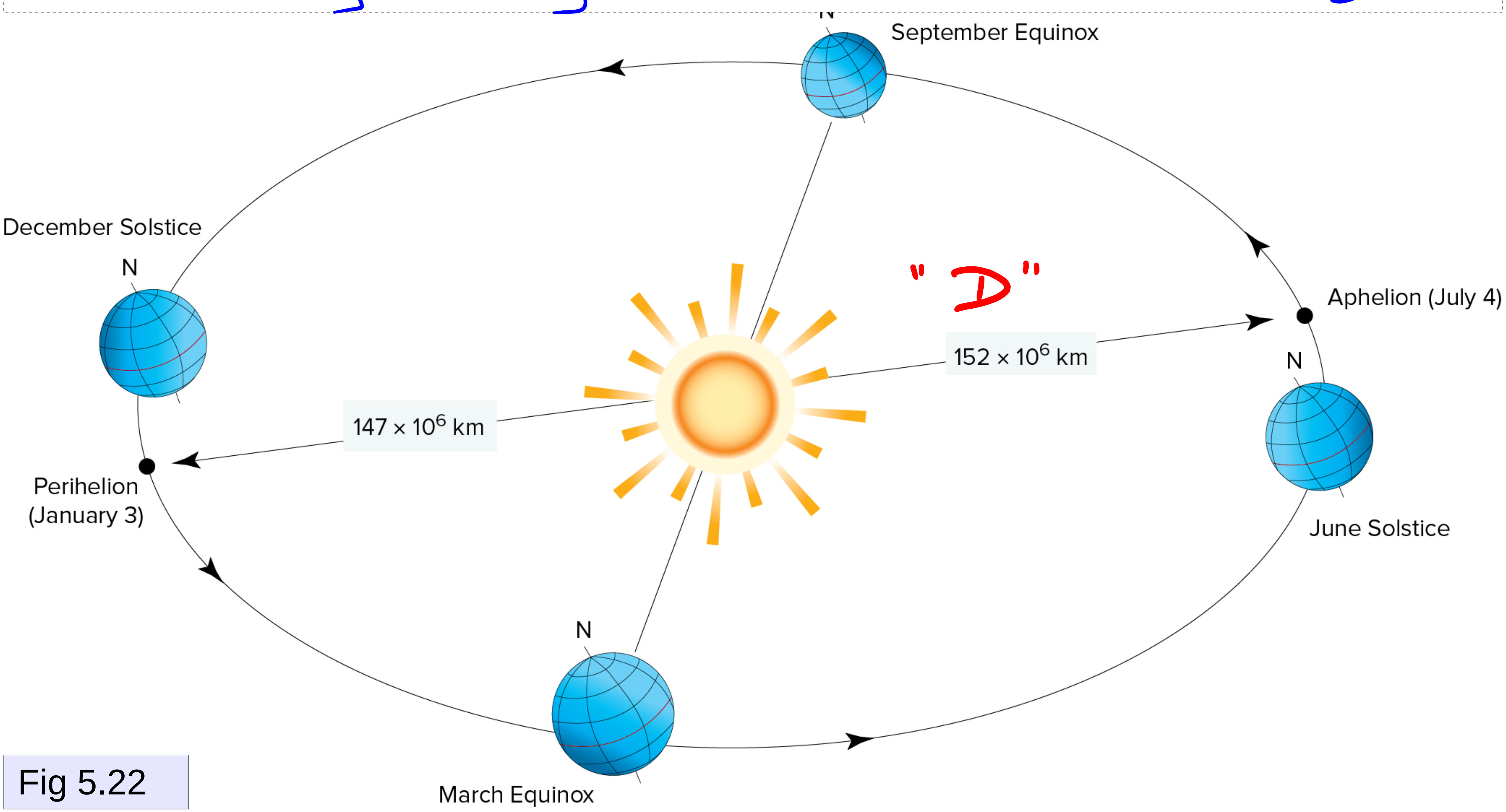



Fig 5.22

Let $K\downarrow$ = solar radiant energy flux density at base of atmos. measured on horiz. surface

= beam component + $D\downarrow$ diffuse part

In a clear atmosphere $K\downarrow$ is controlled by Solar elevation, due to influences of:

① beam depletion

② beam spreading

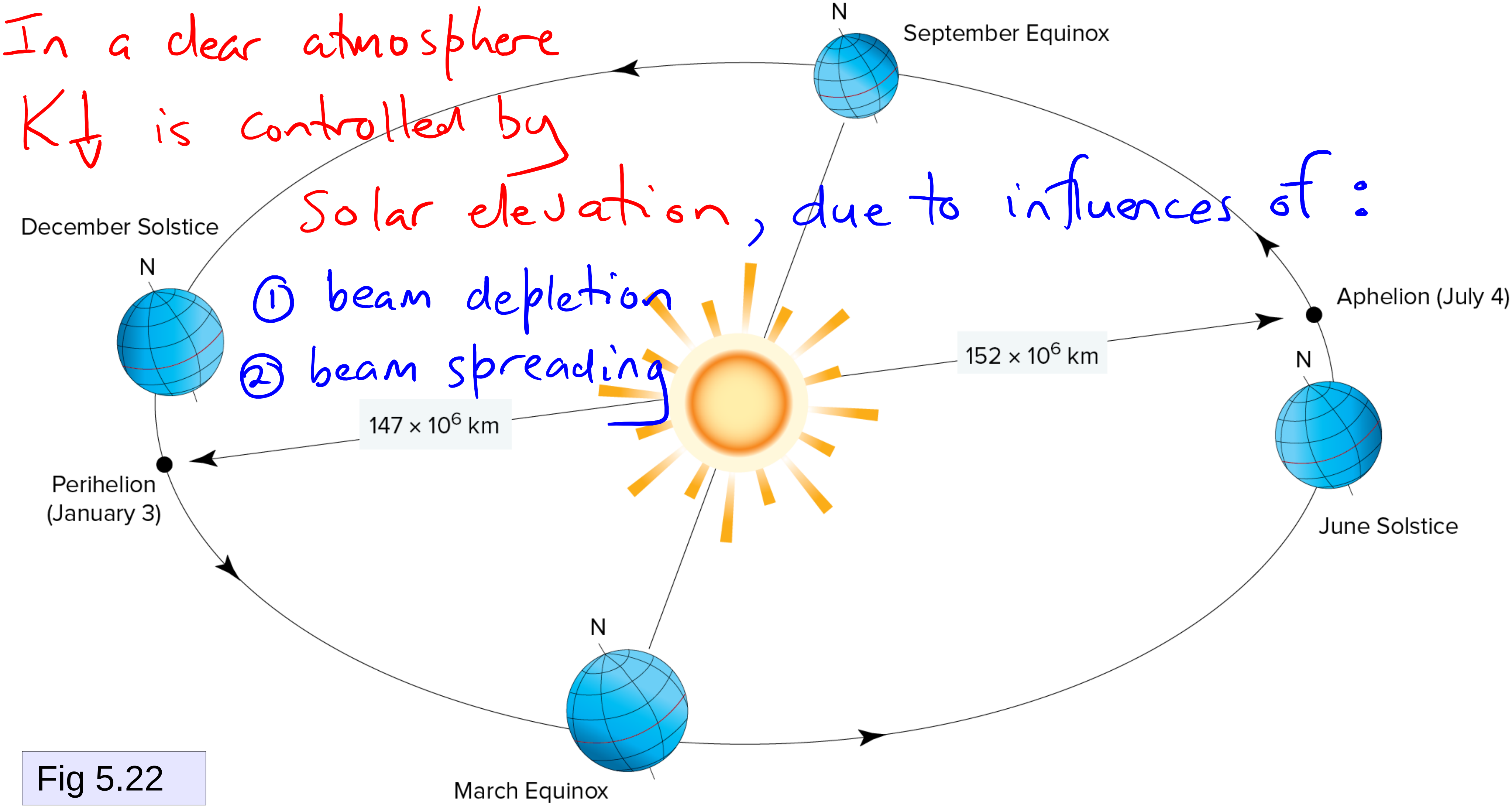



Fig 5.22

Beam depletion: longer path increases $S_i$, the strength of the beam at base of atmos.

Beam spreading:

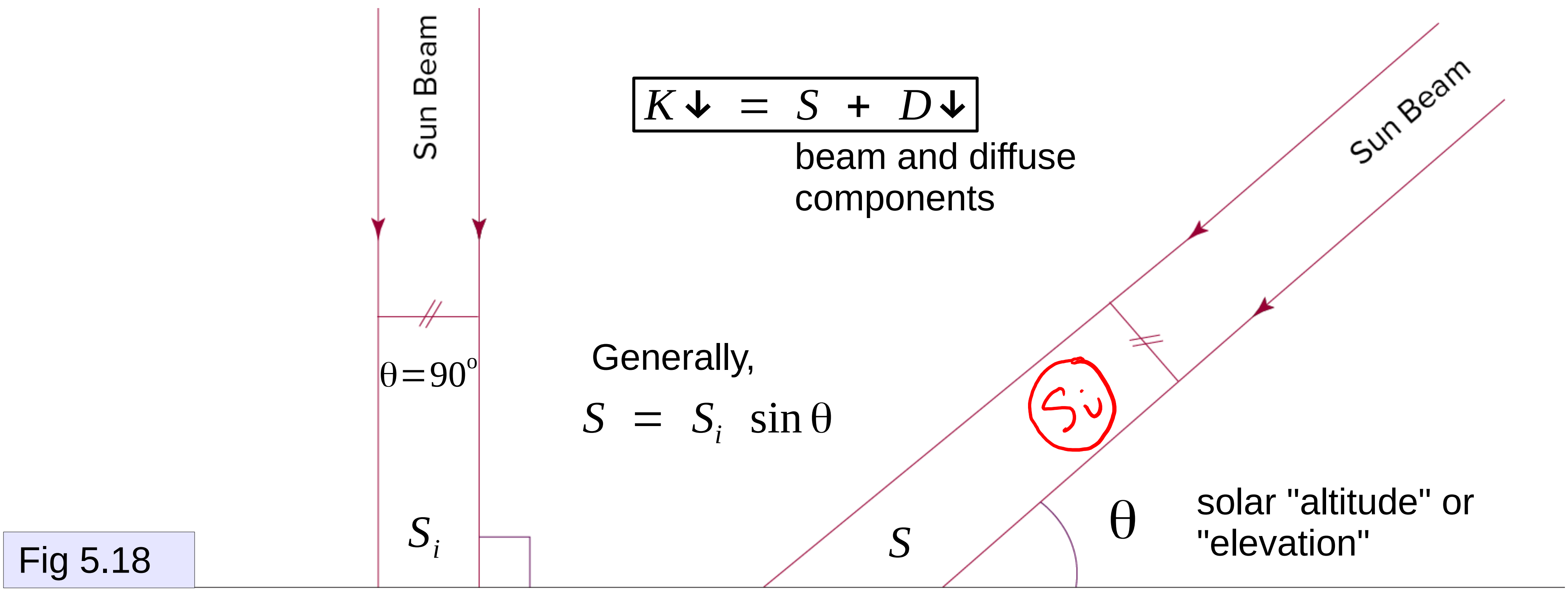



Fig 5.18

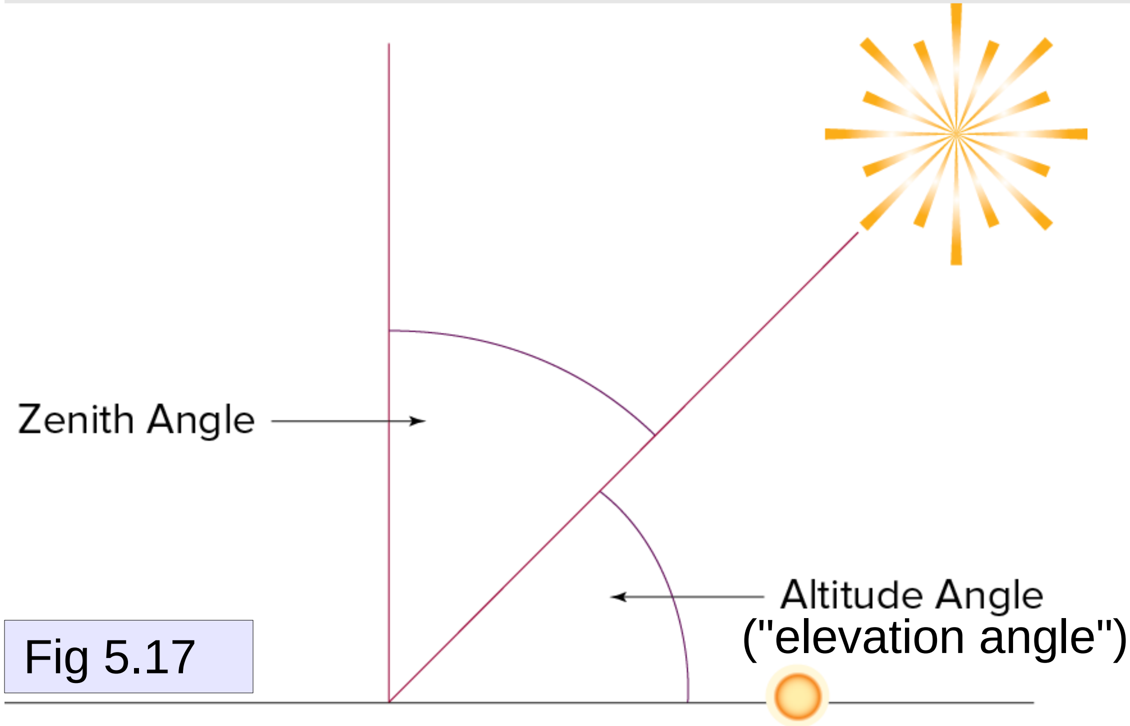



Fig 5.17

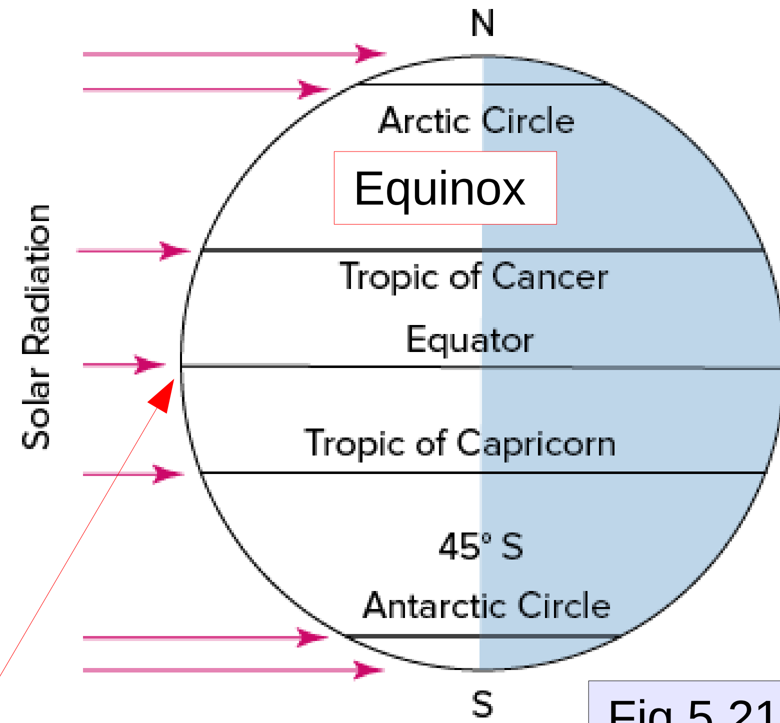



Fig 5.21

Subsolar point revolves around which latitude line?

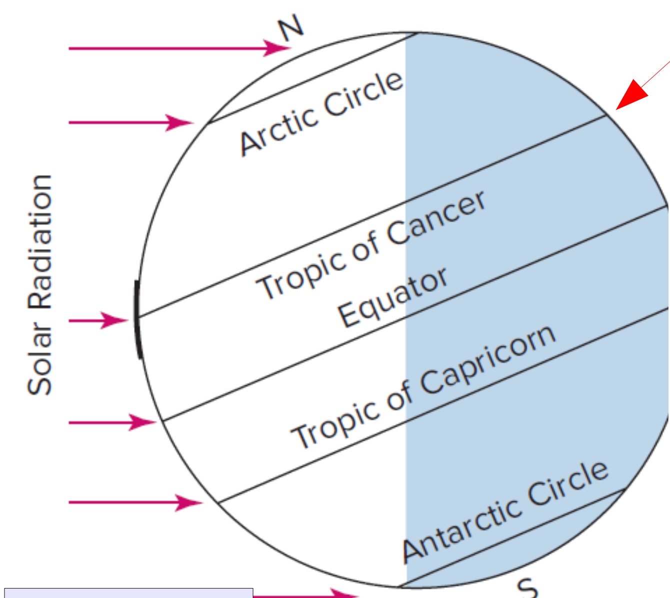


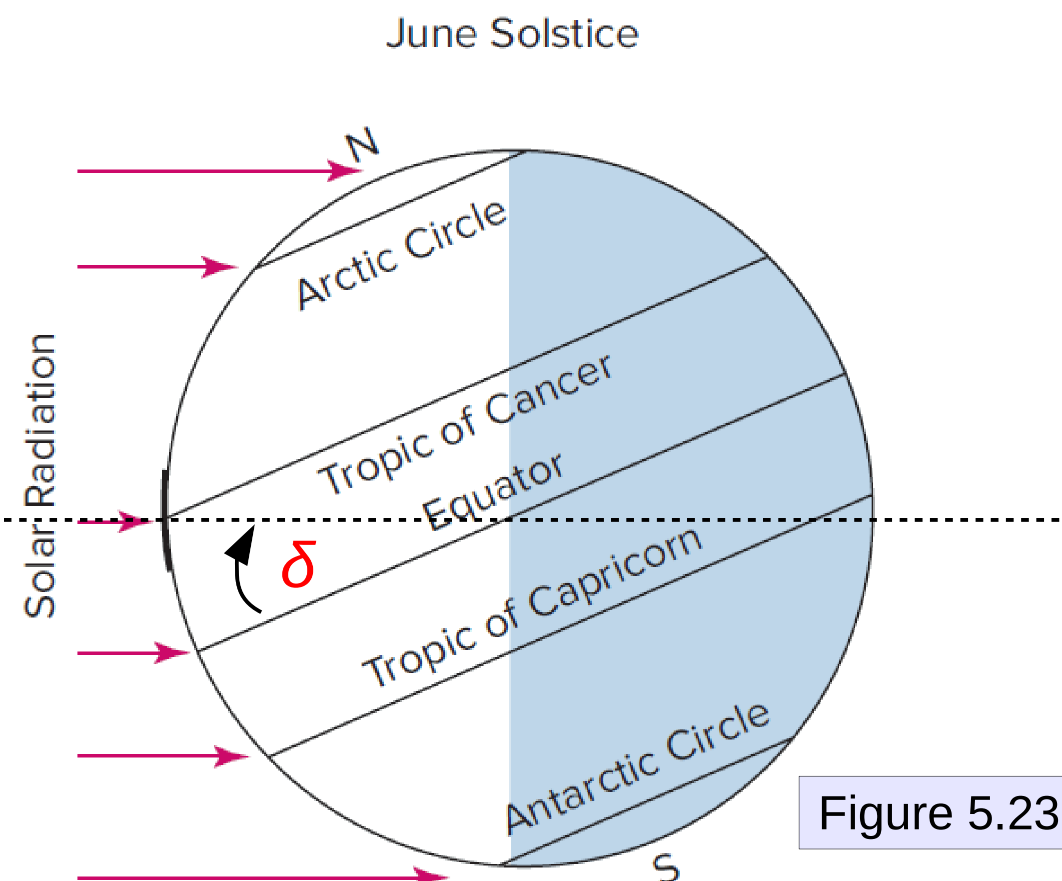

Fig 5.23a

- subsolar point: (single) point on earth at which solar zenith angle is $0^o$
- subsolar point circles along a latitude line
- circle of illumination cuts "circles of latitude" & daylength is 24 hr x % illuminated

Subsolar point revolves around?

$\delta = +23.5^\circ$

$\delta = -23.5^\circ$



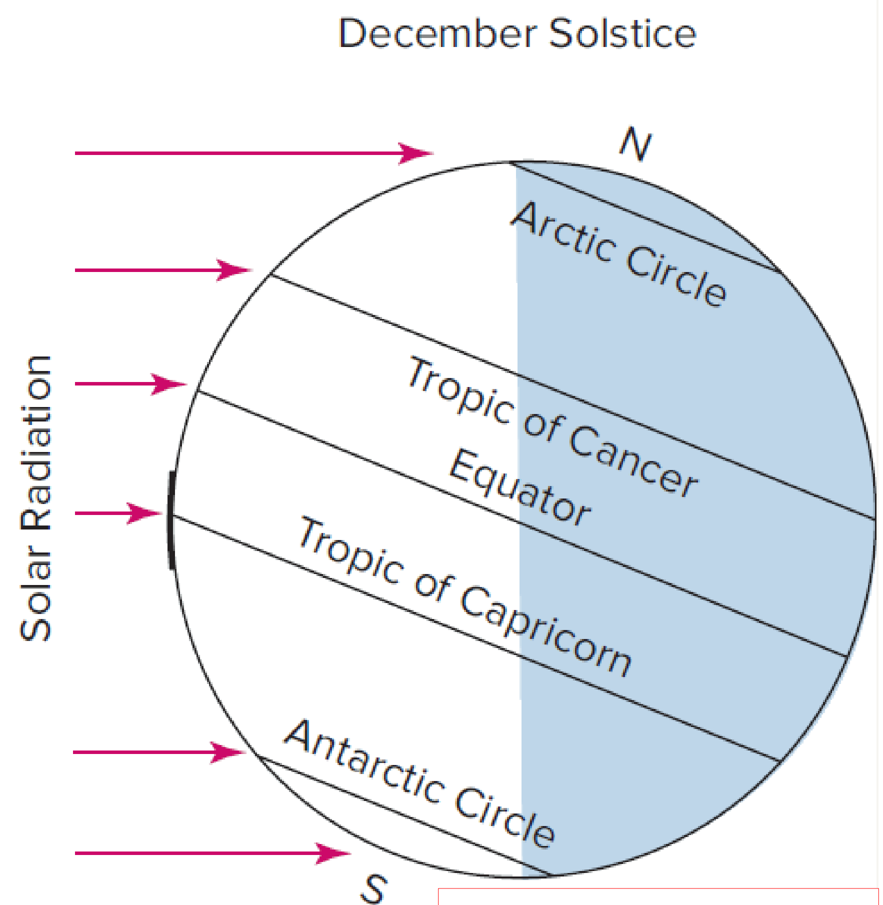
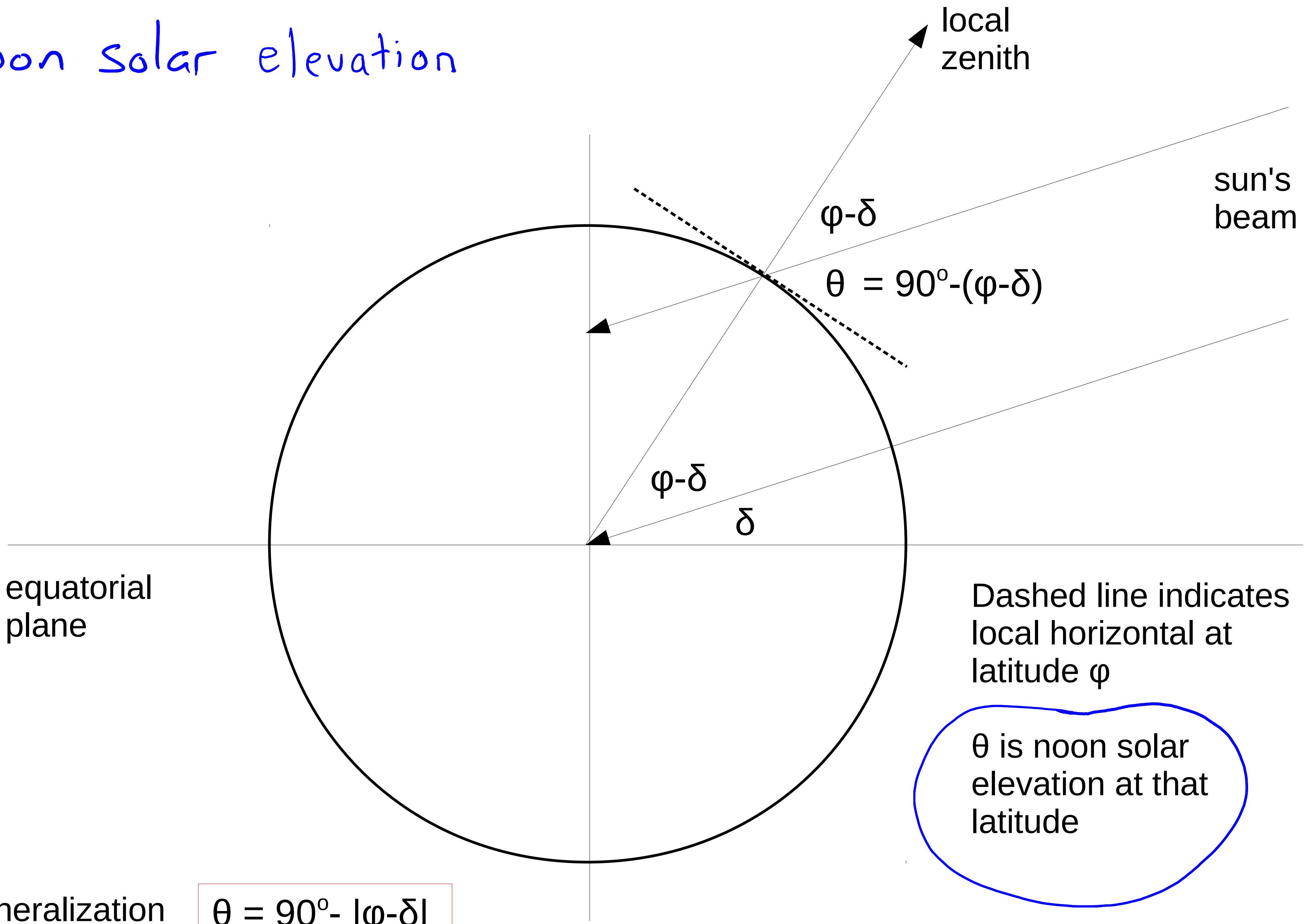




Figure 5.23

June solstice

December solstice

# Noon solar elevation




Dashed line indicates local horizontal at latitude φ

θ is noon solar elevation at that latitude

Generalization $\theta = 90^{o} - |\varphi - \delta|$

allows for negative (southern) latitude and solar declination

Let $\varphi$ be latitude, and recall $\delta$ is the solar declination angle ($\varphi < 0$ in S. hemisphere, and $\delta < 0$ in S. hemisphere summer). Then

$$\theta_{noon} = 90 - |\phi - \delta|$$

Edmonton (lat 53.5°) 2 January?

$$\theta_{noon} = 90 - |53.5 - (-22)| = 13.5^{\circ}$$

Edmonton, 2 June?

Auckland (lat - 36.8°), 10 May?

Analemma graph asymmetric as earth's orbit not circular

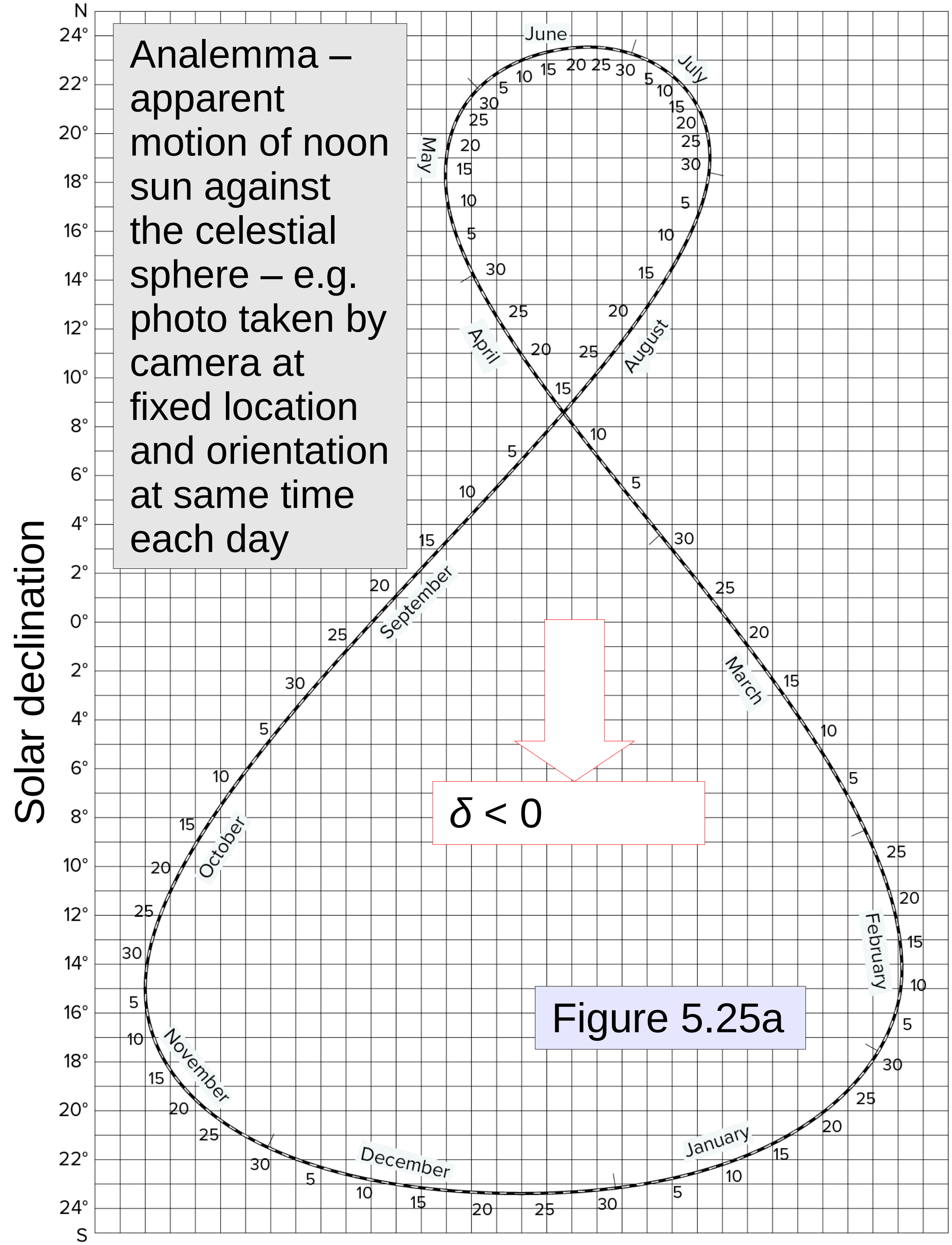


Figure 5.25a

Edmonton's latitude 53.5°N

Greater beam intensity on an inclined surface

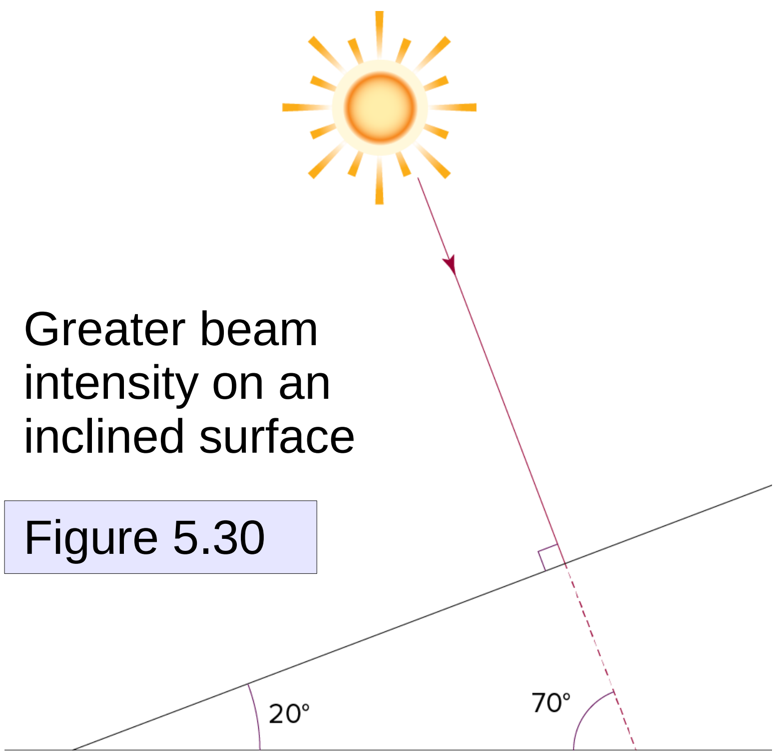



Figure 5.30

**TABLE 5.3 | Day lengths by latitude and date.**

| Latitude | December Solstice | Equinoxes | June Solstice |
|---|---|---|---|
| 90° N | 0 hr 0 min | 24 hr on horizon | 24 hr 0 min |
| 80° N | 0 hr 0 min | 12 hr 0 min | 24 hr 0 min |
| 70° N | 0 hr 0 min | 12 hr 0 min | 24 hr 0 min |
| 60° N | 5 hr 33 min | 12 hr 0 min | 18 hr 27 min |
| 50° N | 7 hr 42 min | 12 hr 0 min | 16 hr 18 min |
| 40° N | 9 hr 8 min | 12 hr 0 min | 14 hr 52 min |
| 30° N | 10 hr 4 min | 12 hr 0 min | 13 hr 56 min |
| 20° N | 10 hr 48 min | 12 hr 0 min | 13 hr 12 min |
| 10° N | 11 hr 25 min | 12 hr 0 min | 12 hr 38 min |
| 0° | 12 hr 0 min | 12 hr 0 min | 12 hr 0 min |
| 10° S | 12 hr 38 min | 12 hr 0 min | 11 hr 25 min |
| 20° S | 13 hr 12 min | 12 hr 0 min | 10 hr 48 min |
| 30° S | 13 hr 56 min | 12 hr 0 min | 10 hr 4 min |
| 40° S | 14 hr 52 min | 12 hr 0 min | 9 hr 8 min |
| 50° S | 16 hr 18 min | 12 hr 0 min | 7 hr 42 min |
| 60° S | 18 hr 27 min | 12 hr 0 min | 5 hr 33 min |
| 70° S | 24 hr 0 min | 12 hr 0 min | 0 hr 0 min |
| 80° S | 24 hr 0 min | 12 hr 0 min | 0 hr 0 min |
| 90° S | 24 hr 0 min | 24 hr on horizon | 0 hr 0 min |

## Topics/concepts covered

- Rayleigh (selective) scattering, and sky colour
- Mie scattering & cloud colour/ milky skies
- qualitative view of the impact of greenhouse gases as func. of wavelength
- sine law of illumination
- sun-earth geometry in relation to the seasons
- annual cycle in the solar declination and noon solar elevation