AOSC400-2015
November 03, Lecture # 17

- Radiation Budget Missions (ERBE; CERES) for Top of the Atmosphere radiation budget-*continued*
- Angular Distribution Models (ADM) Models
- *Suomi National Polar-orbiting Partnership*
- *Joint Polar Satellite System (JPSS*)
- Special Programs to Better Understand Clouds - DOE Atmospheric Radiation Mission (ARM)
- Atmospheric optics
- Chapter 9: Planetary Boundary Layer - Introduction

*Sources of information used for this lecture are listed in updated Syllabus.

Net radiation is defined at top of the atmosphere (TOA) as:

Net (TOA) = Solar_down (TOA) - SW_up (TOA) - LW_up (TOA)

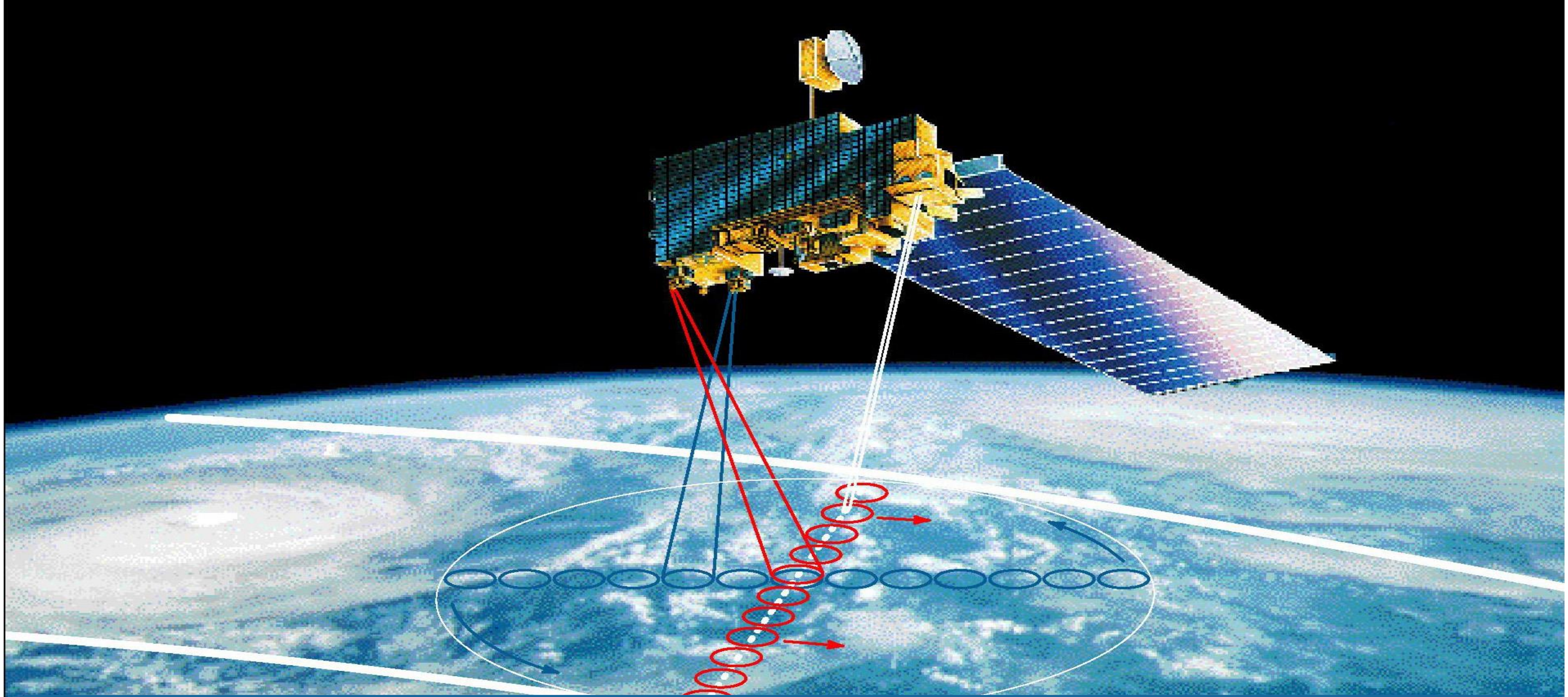
where Solar_down (TOA) is the solar incoming flux at TOA, SW_up (TOA) is the reflected shortwave flux at TOA, and LW_up (TOA) is outgoing longwave flux at TOA.

The sign convention for ERBE net radiation is that positive/negative sign represents a net radiative energy surplus/deficit of the Earth system, respectively.

Cloud Radiative Forcing = Clear-sky Flux - All-sky Flux

http://eosweb.larc.nasa.gov/PRODOCS/erbe/ERBE_FAQ.html#g_1

Clouds and the Earth’s Radiant Energy System

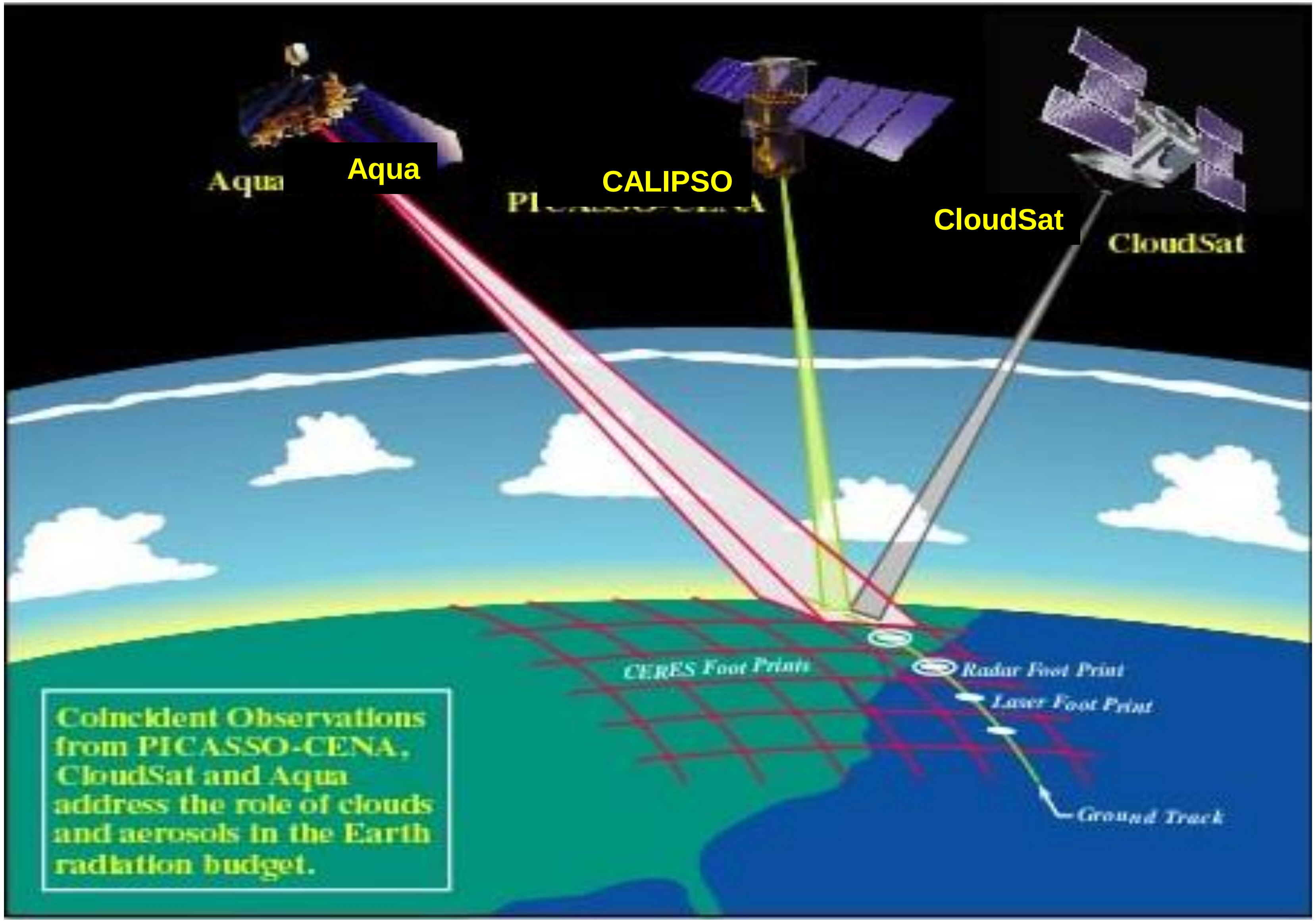


Important issue in climate research:

Is the global energy budget changing?

Effect of clouds on the radiation budget.

A configuration of several satellites with complimentary capabilities is considered as ideal for cloud and radiation research. In particular, the newer systems with active capabilities.



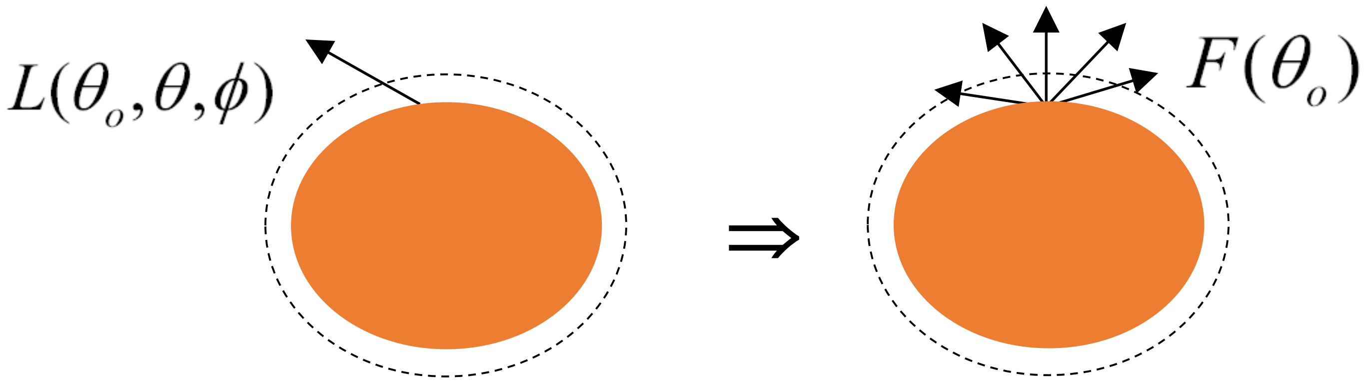
First Earth Radiation Budget Mission was ERBE
Second-CERES
Two types of instruments

1) Scanner - (longwave, shortwave and total energy), all of which scan from one limb of the Earth to the other.

The scanner instrument has a smaller footprint (40 km at nadir) and scanns across the orbit plane to provide maximum spatial coverage. The scanner measures directional radiance, not hemispheric flux. The directional radiance is converted to hemispheric flux using empirical statistical **A**ngular **D**istribution **M**odel (ADM). The scanner is designed for regional to large scale analysis, and due to the smaller footprint, the scanner product is able to separate clear sky data from all-sky data to provide both clear-sky and all-sky estimates.

Instantaneous Fluxes at TOA and Angular Distribution Models

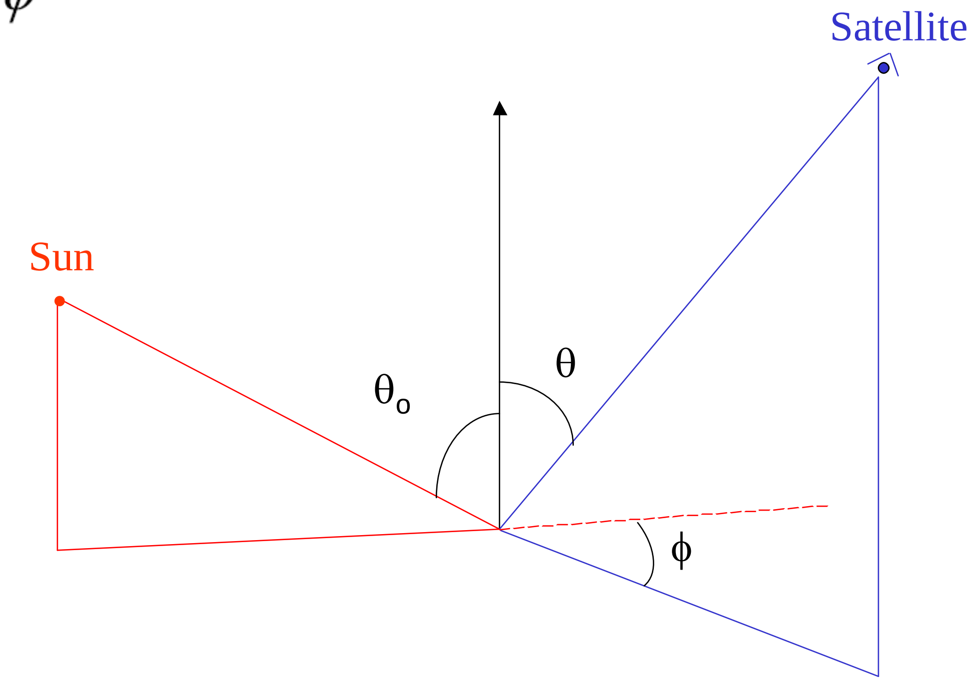
CERES Radiance Measurement | TOA Flux Estimate



SW
LW
WN

$$F(\theta_o) = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} L(\theta_o,\theta,\phi)\cos\theta \,\sin\theta \, d\theta d\phi$$

In order to derive the total radiative flux at the Top of the Atmosphere, one needs to know the angularly dependent properties of the surface, so that proper integrations over all directions can be made.



(after N. Loeb, 2009)

Instantaneous Fluxes at TOA and Angular Distribution Models

TOA flux estimate from CERES radiance:

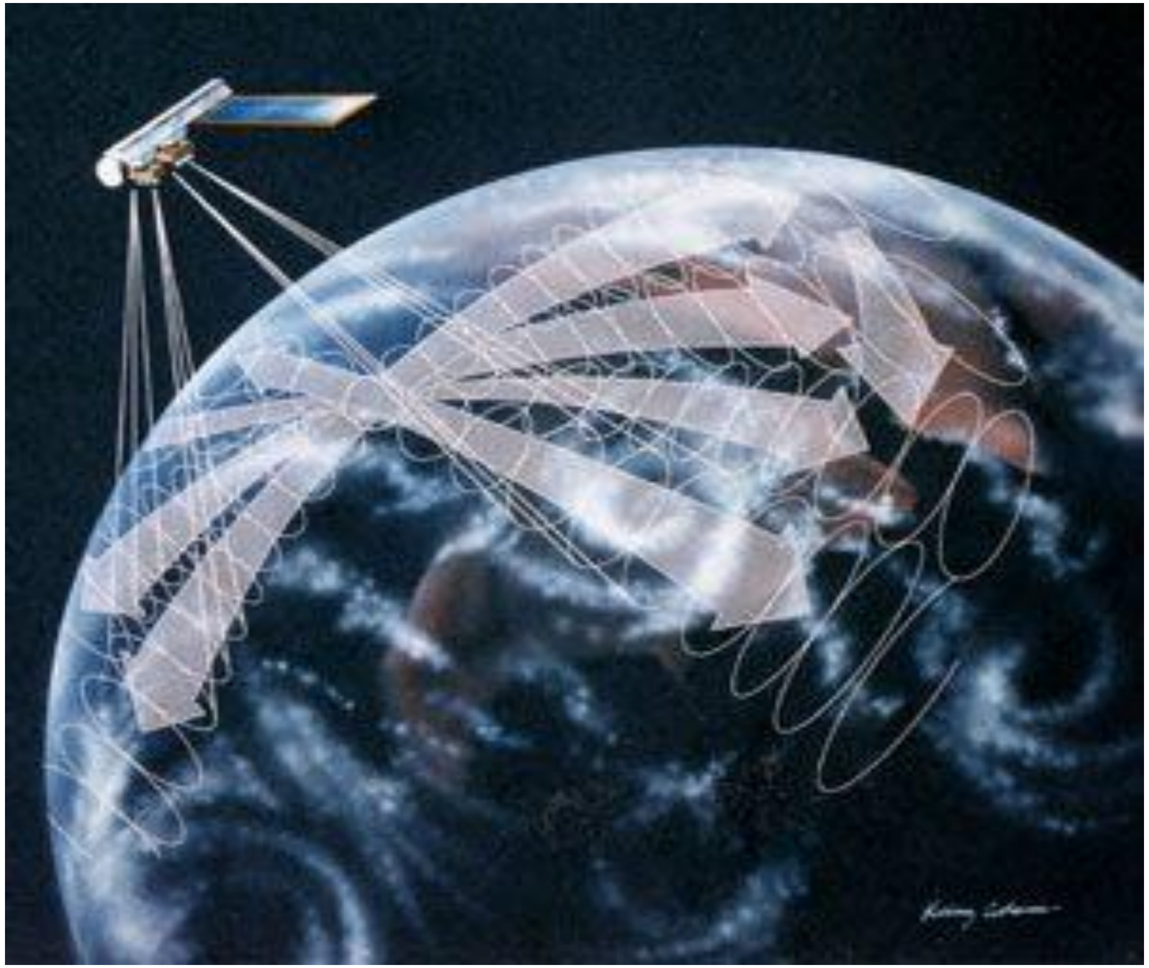
$$\hat{F}(\theta_o,\theta,\phi) = \frac{\pi L(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)}$$

Where:

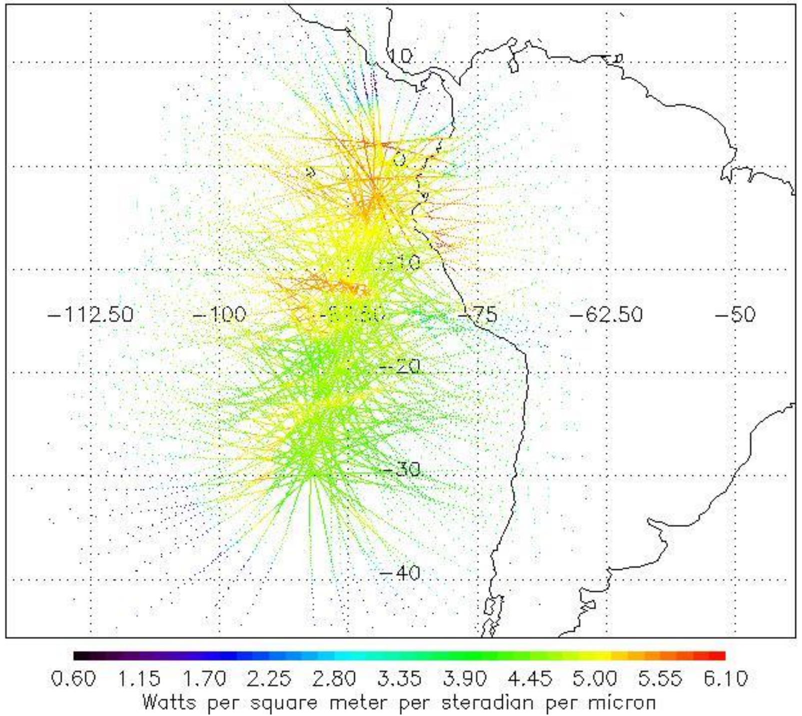
$$R_j(\theta_o,\theta,\phi) = \frac{\pi \overline{L}_j(\theta_o,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \overline{L}_j(\theta_o,\theta,\phi)\cos\theta\,\sin\theta\, d\theta d\phi}$$

$R_j(\theta_o,\theta,\phi)$ is the Angular Distribution Model (ADM) for the "jth" scene type

Angular Distribution Models are built on the basis of special type of observations when the satellite can scan in several direction.



- Multi-angle radiance data are collected using the rotating azimuth plane scanning (RAPS) mode of CERES
- One CERES instrument dedicated to RAPS observations on Terra and Aqua



2) No scanner - A set of five detectors; one which measures the total energy from the Sun, two measure the shortwave and total energy from the entire Earth disk, and two of which measure the shortwave and total energy from a medium resolution area beneath the satellite.

The No scanner large footprint (1000 km) is designed only for large scale analysis, thus products provide only all-sky data. Because the non-scanner had less moving parts, it lasted a lot longer than the scanner instrument.

Clouds and Earth's Radiant Energy System (CERES) **history**

The first CERES instrument was launched in December of 1997 aboard NASA's Tropical Rainfall Measurement Mission (TRMM). CERES instruments are now collecting observations on three separate satellite missions, including the EOS Terra and Aqua observatories and now also on the NPOESS Preparatory Project (NPP) observatory (*see comments on NPOESS in next slide*).

CERES products include both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. Cloud properties are determined using simultaneous measurements by other EOS instruments. Analyses build on previous experience such as the Earth Radiation Budget Experiment (ERBE), leading to a better understanding of the role of clouds and the energy cycle in global climate change.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) was to be the United States' next-generation satellite system that would monitor the Earth's weather, atmosphere, oceans, land, and near-space environment. The estimated launch date for the first NPOESS satellite, "C1" or "Charlie 1" was around 2013. Issues with sensor developments were the primary cited reason for delays and cost-overruns.

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NPOESS was to be a replacement for both the United States Department of Defense's DMSP and the NOAA Polar Operational Environmental Satellites (POES) series. The NPOESS Preparatory Project (NPP) was planned as a pathfinder mission for NPOESS. The project had to go through three Nunn-McCurdy reviews, Congressional hearings that are automatically triggered when a program goes over budget by more than 25%. It was launched five years behind schedule, on October 28, 2011.

How politics enters decision making related to weather issues:

The White House announced on February 1, 2010, that the NPOESS satellite partnership was to be dissolved, and that two separate lines of polar-orbiting satellites to serve military and civilian users would be pursued instead:

- The NOAA/NASA portion is called the Joint Polar Satellite System (JPSS).
- The Defense Department's portion is called DWSS (Defense Weather Satellite System).

Suomi National Polar-orbiting Partnership, formerly known as the NPOESS Preparatory Project (NPP) will serve as a bridge between the EOS satellites and the forthcoming series of *Joint Polar Satellite System (JPSS*) satellites.
Suomi NPP represents a critical first step in building this next-generation satellite system. The JPSS satellites, previously called the National Polar-orbiting Operational Environmental Satellite System (NPOESS), will be developed by NASA for the National Oceanic and Atmospheric Administration (NOAA).

The NPP satellite has 5 instruments on board: *VIIRS, CERES, CrIS, ATMS, and OMPS.* Each one will deliver a specific set of data helping weather prediction and climate studies.

Key science objectives and capabilities of Suomi NPP:

Climate change -- contribute to long-term records of global environmental data critical for understanding climate change

Health of the ozone layer -- daily measurements of the atmospheric ozone layer that will determine whether the ozone layer is recovering as expected

Natural disasters -- monitor wildfires, volcanic eruptions, snowstorms, droughts, floods, hurricanes and dust plumes

Weather predictions -- a sounding instrument will collect information about cloud cover, atmospheric temperatures, humidity and other variables critical to accurate weather prediction

Vegetation -- map global land vegetation and quantify changes in plant productivity to understand the global carbon cycle and monitor agricultural processes to predict and respond to food shortages and famines

Global ice cover -- monitor changes to Earth’s sea ice, land ice and glaciers to track the pace of climate change

Air pollution -- monitor the spread of health-sapping pollutants such as soot, particulate matter, nitrogen dioxide and sulfur dioxide

Temperatures -- maintain a global record of atmospheric, land surface and sea surface temperatures critical to understanding the long-term dynamics of climate change

Earth’s energy budget -- make measurements to determine how much energy is entering and exiting Earth's atmosphere

The five instruments on the NPP satellite are:

Advanced Technology Microwave Sounder (ATMS)

22-channel passive microwave radiometer, to create global models of temperature and moisture profiles that meteorologists will enter into weather forecasting models.

Cross-track Infrared Sounder (CrIS)

Michelson interferometer, will monitor characteristics of the atmosphere, such as moisture and pressure that will be used to produce improvements in both short-and-long term weather forecasting.

Ozone Mapping and Profiler Suite (OMPS)

OMPS, built by Ball Aerospace, incorporates an advanced nadir-viewing sensor and a highly innovative limb-viewing sensor. OMPS instrument continues Ball's history of building ozone-measuring instruments and will continue the long-term continuous data record of ozone measurements from space.

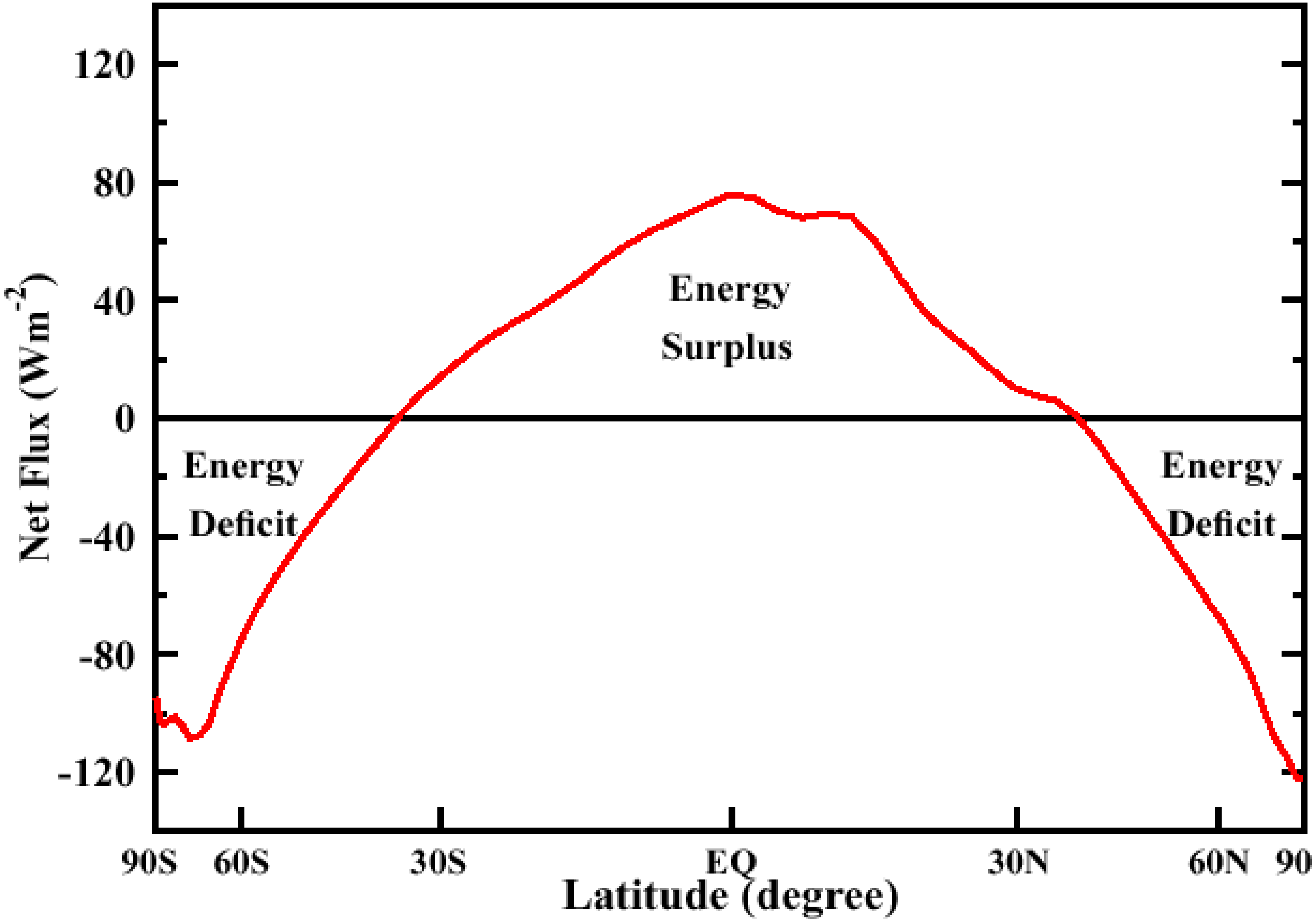
Visible Infrared Imaging Radiometer Suite (VIIRS)

VIIRS, developed by Raytheon Space and Airborne Systems, has a 22-band radiometer similar to the MODIS instrument. It will collect visible and infrared views of Earth's dynamic surface processes, such as wildfires, land changes, and ice movement. VIIRS will also measure atmospheric and oceanic properties, including clouds and sea surface temperature.

Clouds and the Earth's Radiant Energy System (CERES)

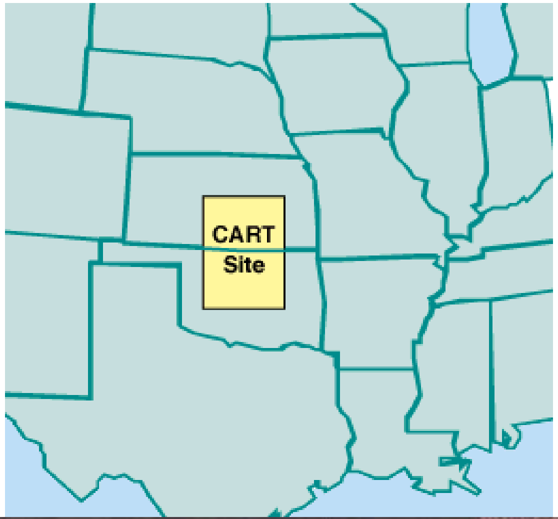
3-channel radiometer measuring reflected solar radiation, emitted terrestrial radiation, and total radiation, will monitor the natural and anthropogenic effects on the Earth's total thermal radiation budget.

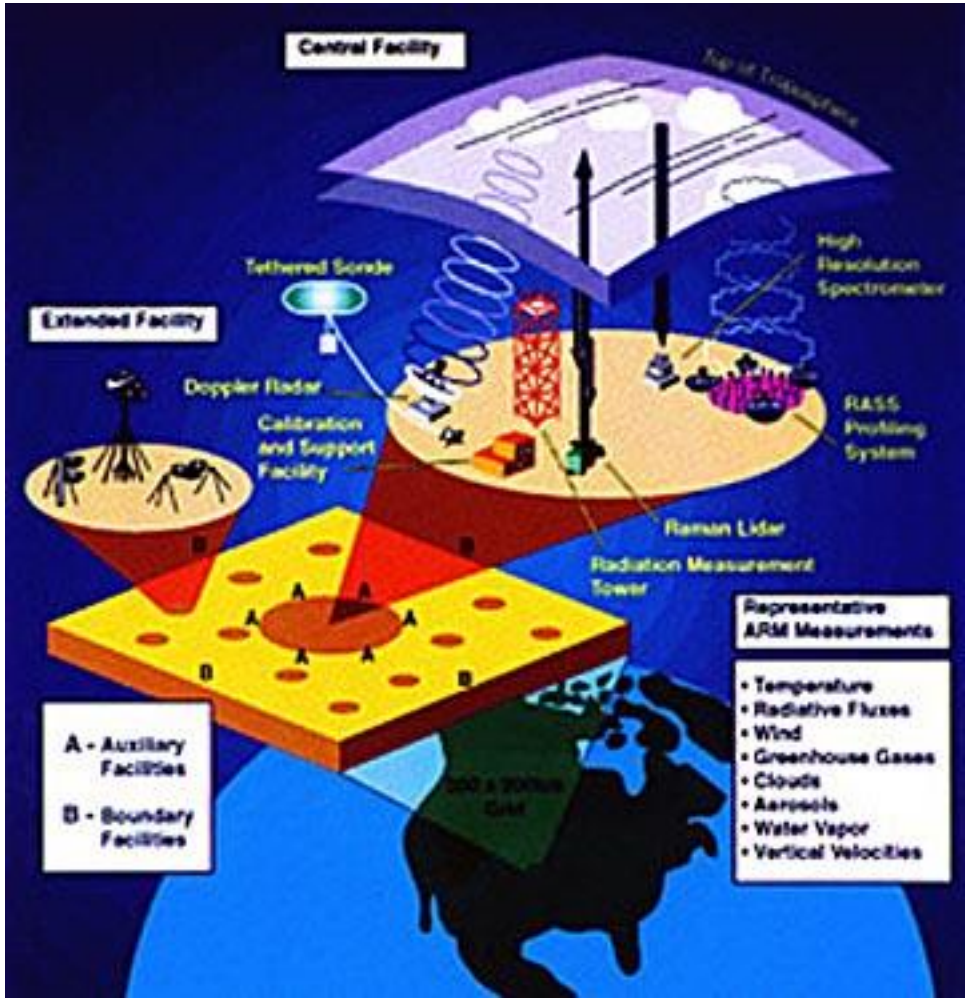
Annual Average Zonal Mean Net Flux from CERES/TERRA, 3/2000 to 2/2001



This figure shows an excess of radiant energy at the surface at low latitude and deficit at high latitude. Atmospheric and oceanic motions have to distribute this energy around.

Special efforts to obtain ground truth on many atmospheric and surface parameters for model evaluation. Shown is the DOE Atmospheric Radiation Mission (ARM) focused on Oklahoma.





ARM: Major Cloud Characterization Instruments

Whole Sky Imager (DoD)

Microwave radiometer (for liquid water path)

Chase the Rainbow

Matt Evans, 8, runs through the fountain at Georgetown Waterfront Park. Friday was humid with a high close to 90 degrees. It will be similar on Saturday until a *cold front brings the possibility of severe storms* in the late afternoon and evening. 09/08/2012 *(Washington Post)*

Atmospheric optics

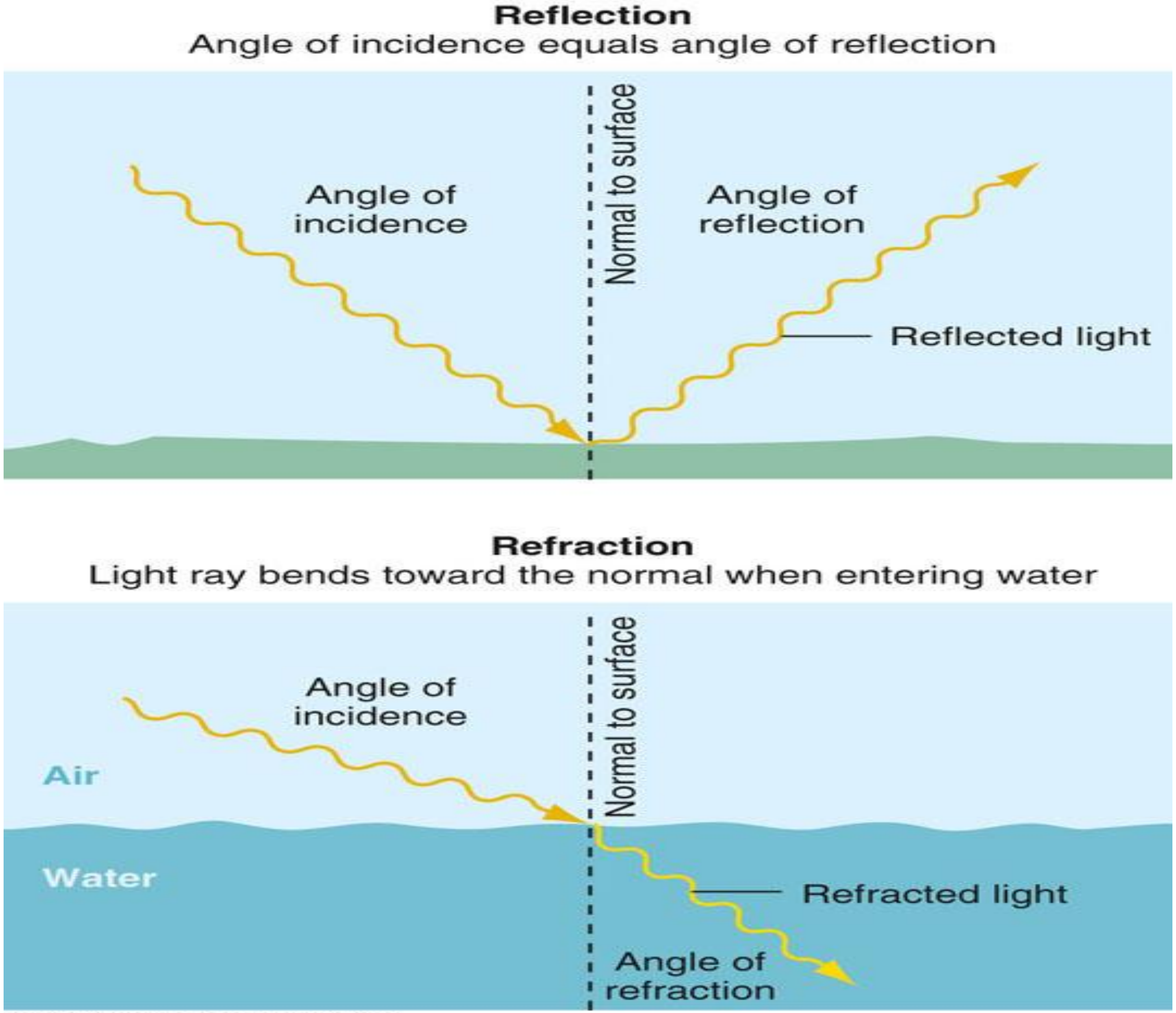
Light falling on water drops, dust or ice crystals in the atmosphere produces a host of visual spectacles - rainbows, halos, glories, coronas and many more.

Some can be seen almost every day, some, only once in a lifetime.

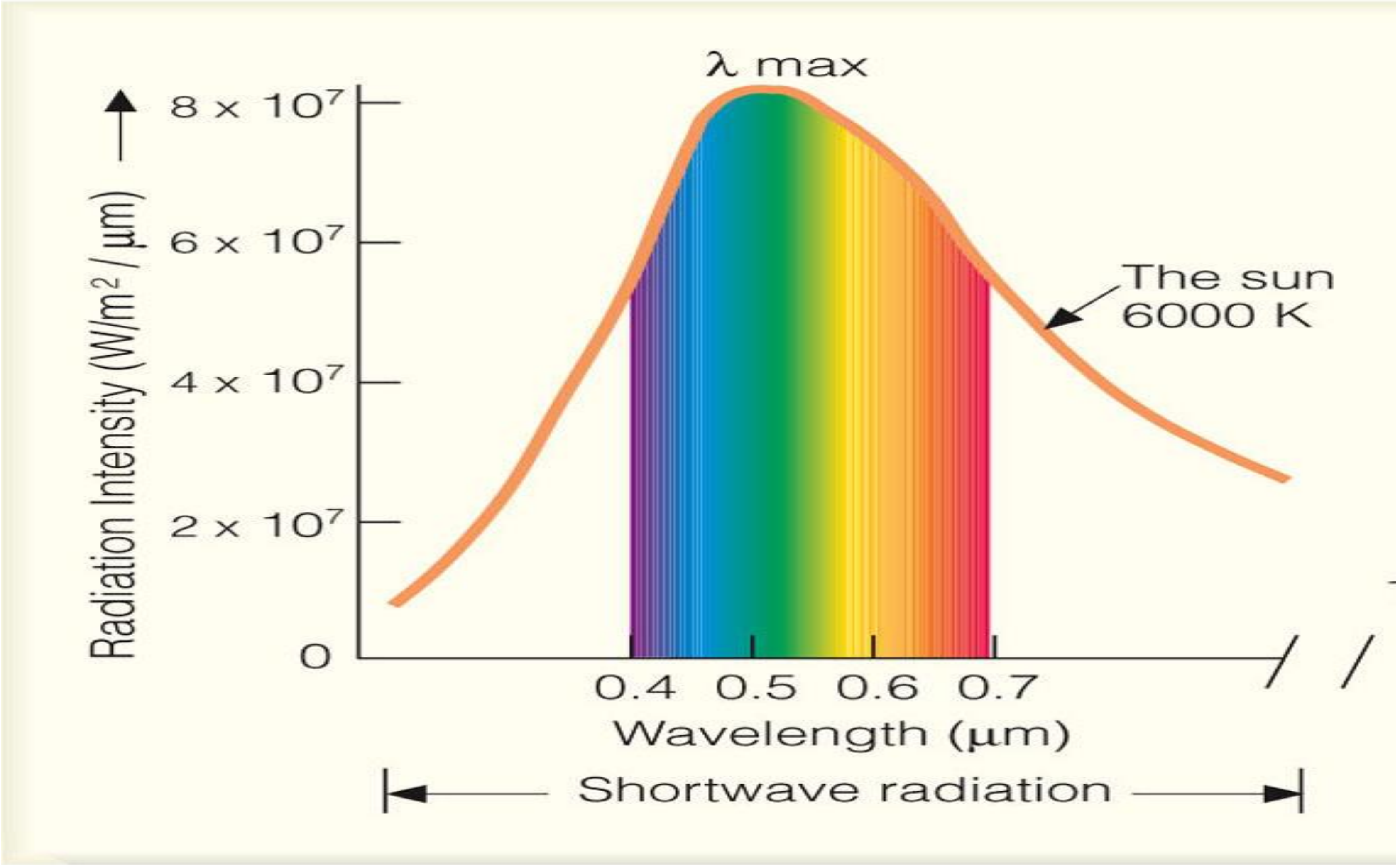
First, refresh the concept of refraction that plays an important role in creating such phenomena.

Chase the Rainbow

Matt Evans, 8, runs through the fountain at Georgetown Waterfront Park. Friday was humid with a high close to 90 degrees. It will be similar on Saturday until a *cold front brings the possibility of severe storms* in the late afternoon and evening. 09/08/2012 *(Washington Post)*

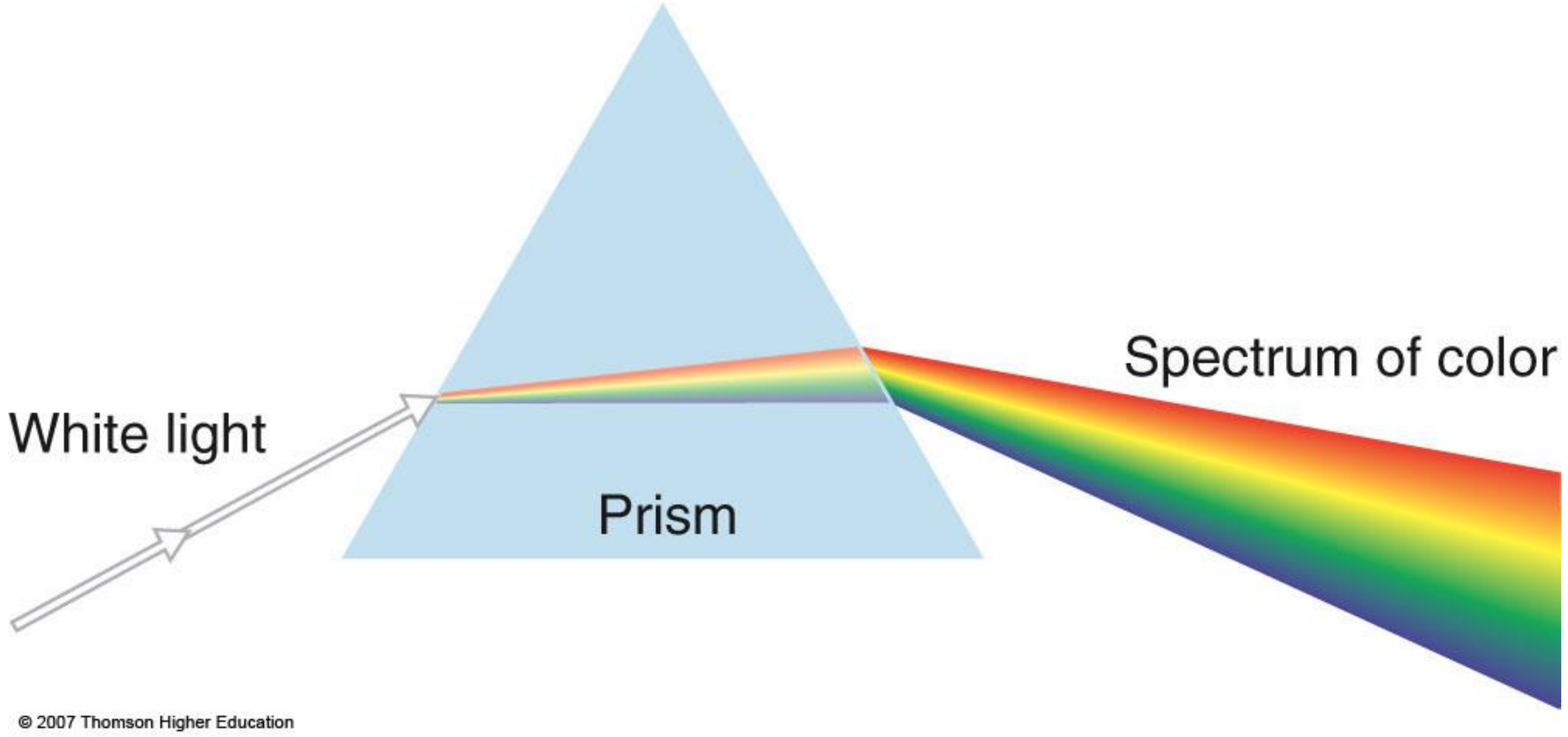

Reflection
Angle of incidence equals angle of reflection
Angle of incidence
Normal to surface
Angle of reflection
Reflected light
Refraction
Light ray bends toward the normal when entering water
Angle of incidence
Normal to surface
Air
Water
Refracted light
Angle of refraction

The visible spectrum



Sir Isaac Newton used a prism to split sunlight into its fundamental colors of the rainbow.

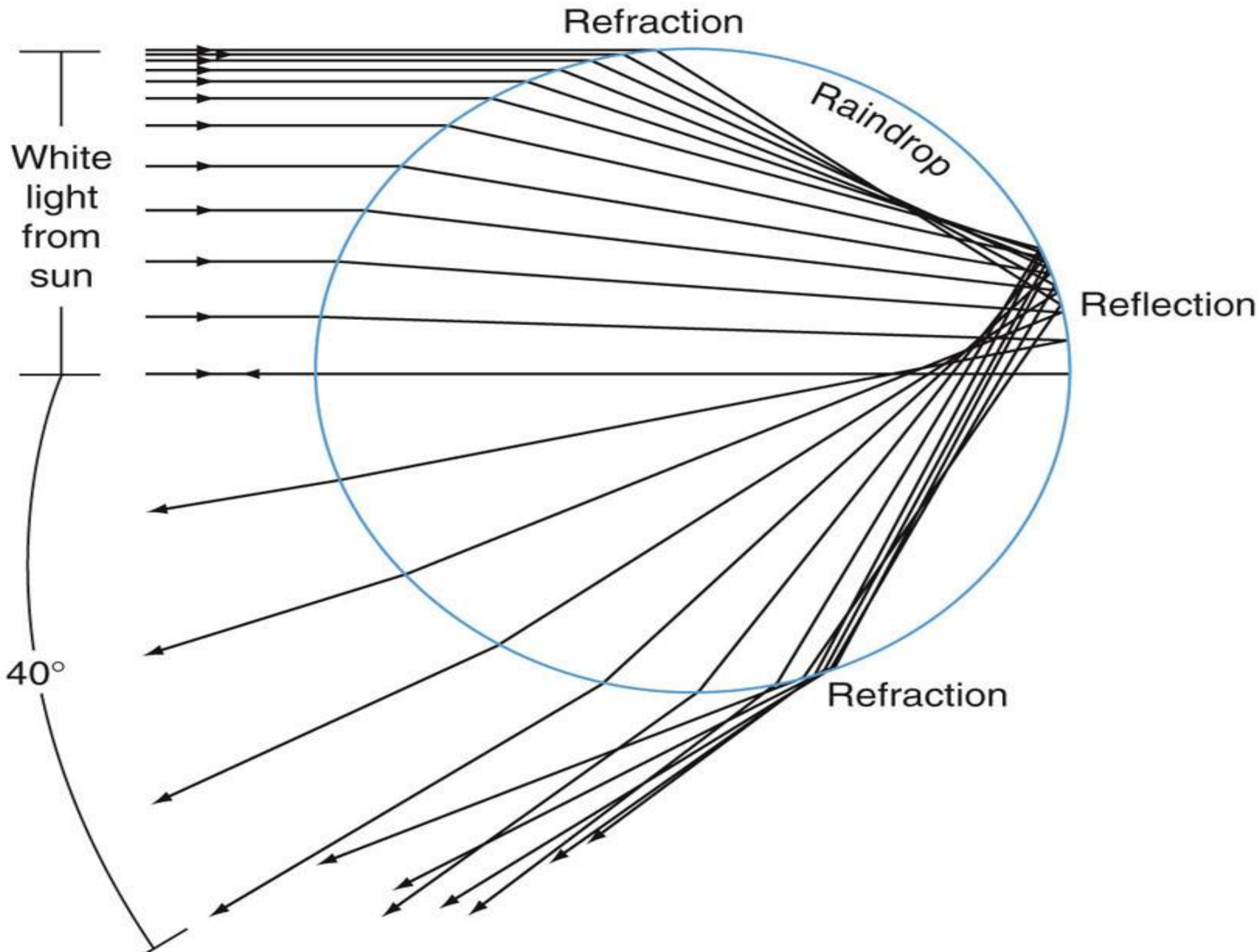
Each wavelength is refracted differently

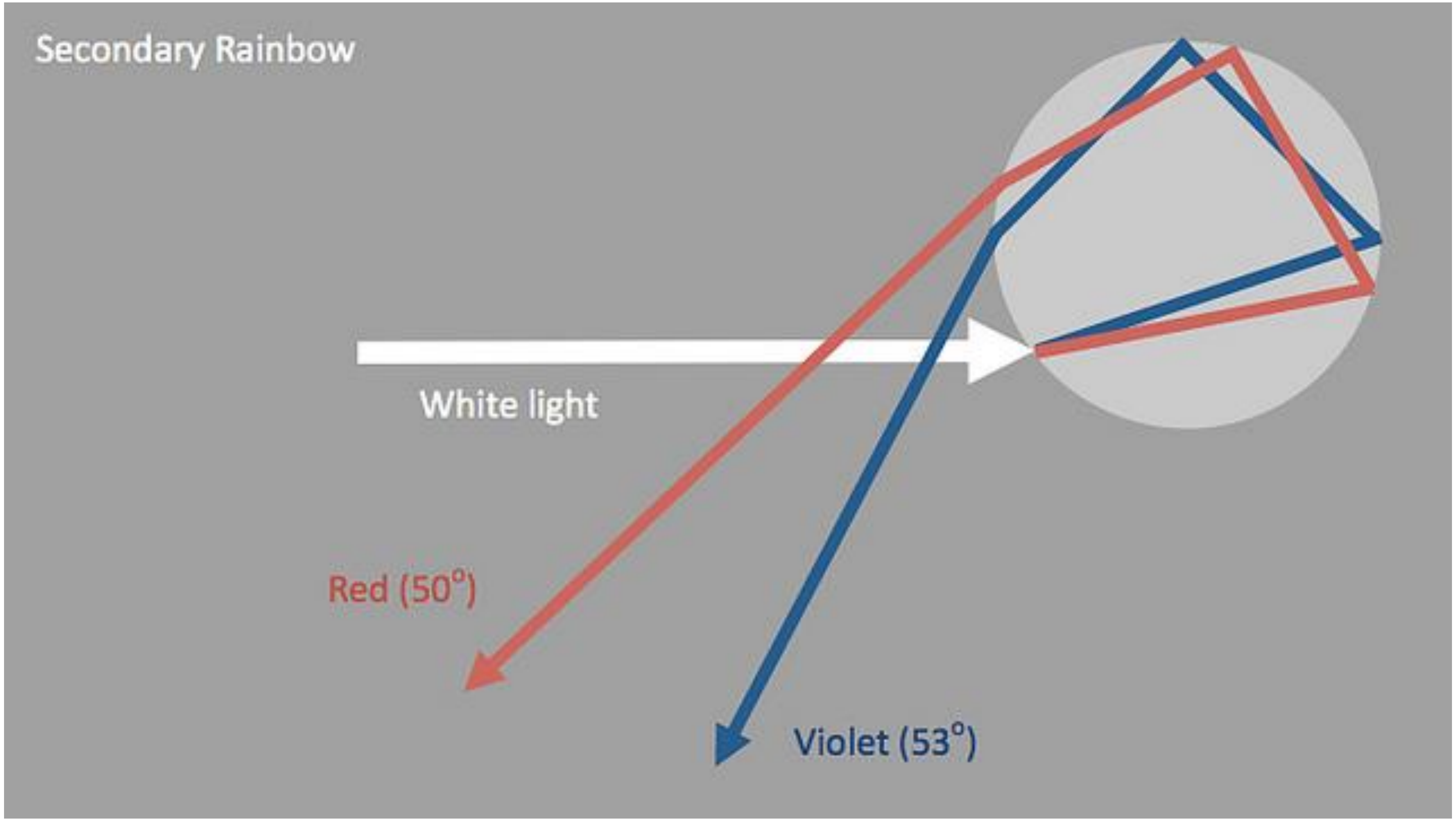


Example of the concepts of refraction and reflection:
The Rainbow

Rainbows result from *refraction* of sunlight in falling water droplets plus reflection of the light from the back of the droplet.

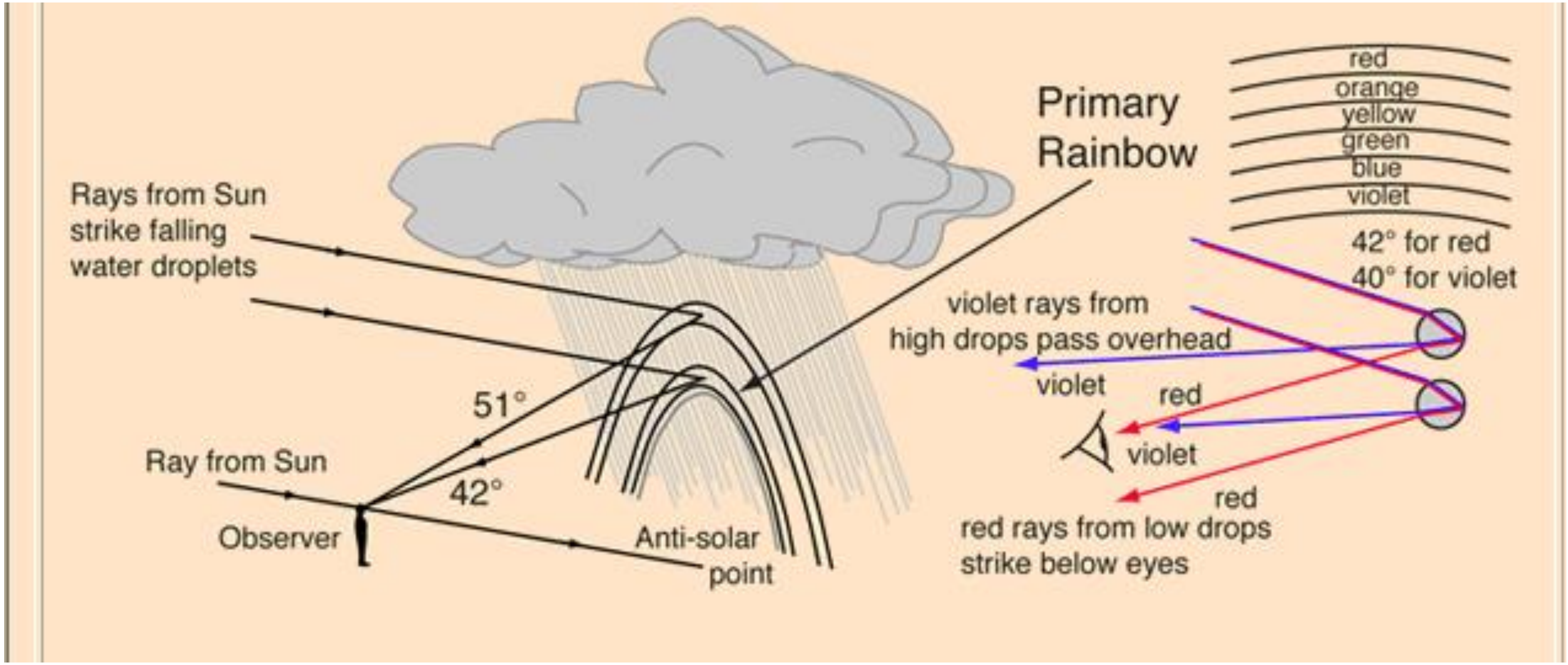
Principle of rainbow formation: *series of refractions and reflections.*





Light can be reflected more than once inside a raindrop. Rays escaping after <u>two reflections</u> make a **secondary bow**

More details on rainbow formation:



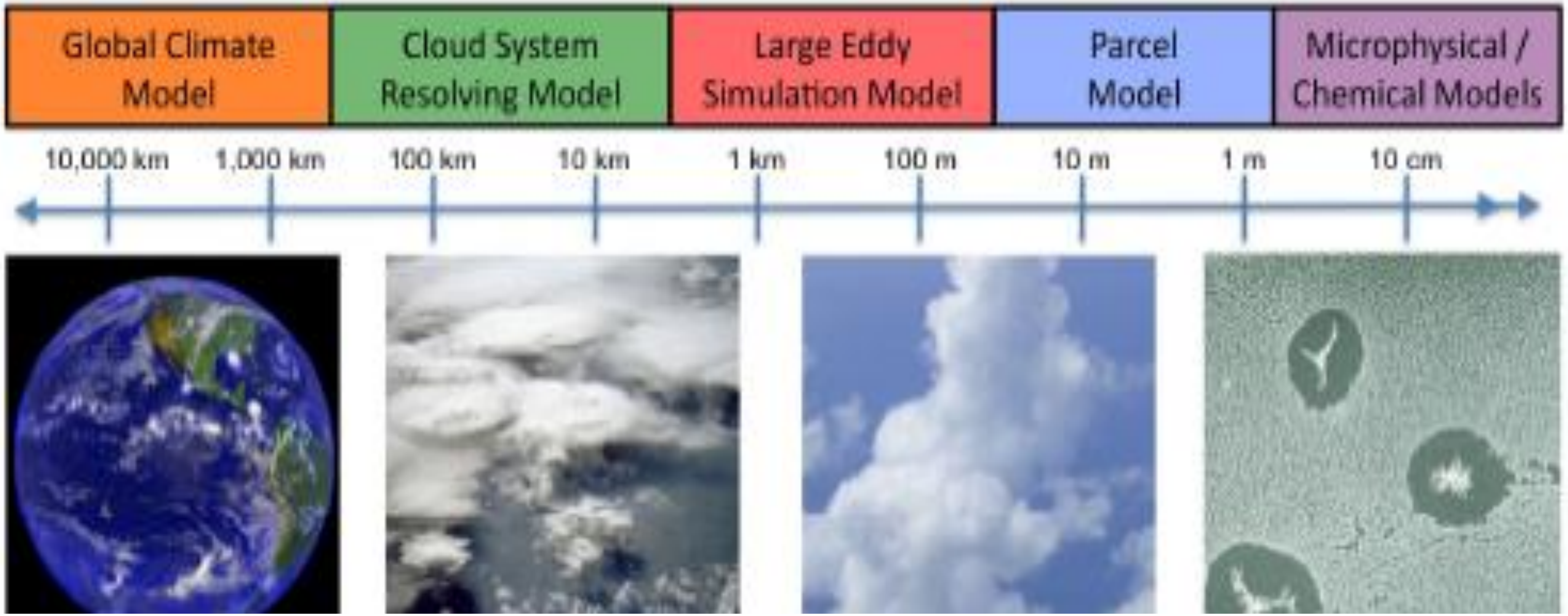
The primary rainbow forms between about 40° and 42° from the anti-solar point. The light path involves refraction and a single reflection inside the water droplet. If the drops are large, 1 millimeter or more in diameter, red, green, and violet are bright but there is little blue.

Rainbows are not seen in midday since the whole 42° circle is below the horizon at most latitudes. So rainbows tend to be seen most in the later afternoon when a thundershower has passed and the sun from the west is illuminating the receding edge of an eastwardly moving raincloud. It is possible to see the entire circle of the rainbow from an airplane since there can be falling droplets both above and below you.

Additional optical phenomena in the atmosphere

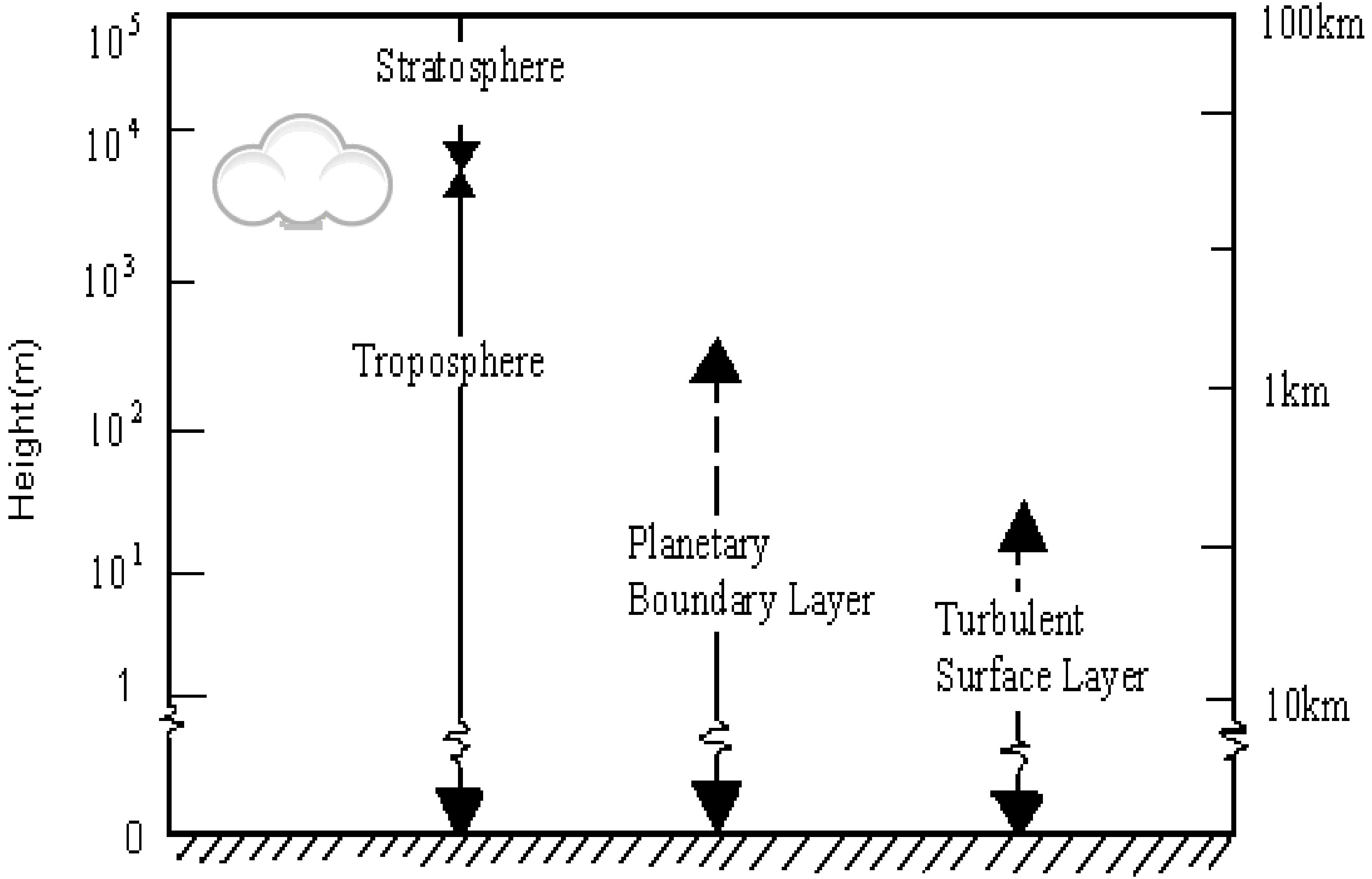
Chapter 9

Planetary Boundary Layer



Various scales of phenomena represented in climate models that are used in climate research (from Kruger).

Where is Planetary Boundary Layer? (PBL)



Components of the Surface Energy Budget (SEB):

One Component of SEB: Surface Radiation Budget *(Review)*

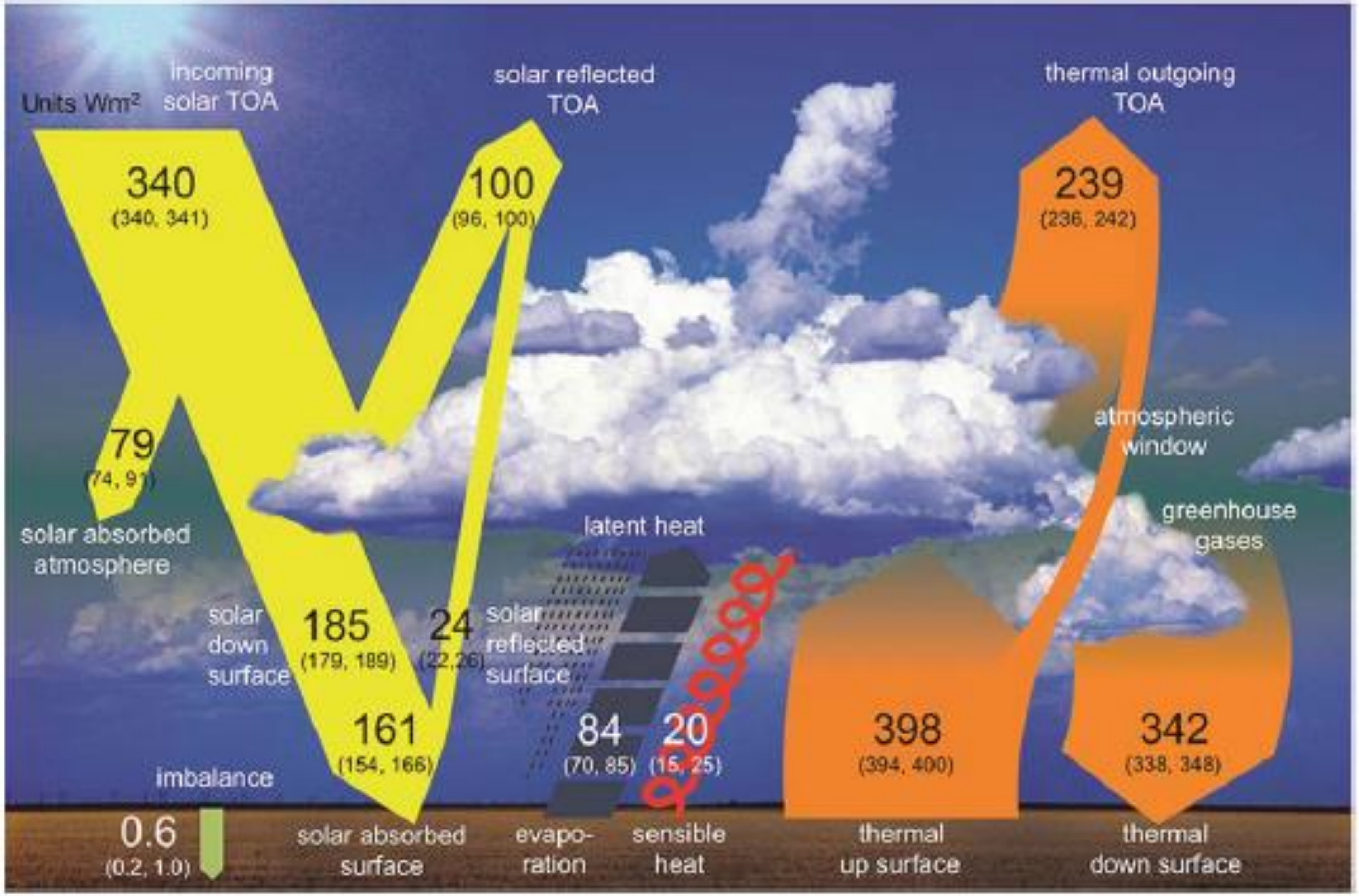
Other components:

Surface Turbulent Fluxes of heat and moisture

Heat into ground

So far, in the following slide we have discussed only the radiative fluxes. We will continue to discuss the additional terms, namely sensible and latent heat.

Global mean energy budget under present day climate conditions (from IPCC 2013)



Radiation Balance at the Earth Surface

The net flux of radiation at the earth's surface results from a balance between the solar and terrestrial

radiation fluxes:

$$F^{sfc}{}_{rad} = F_{SW} + F_{LW}$$

The short-wave and long-wave radiation balance can be expressed:

$$F_{SW} = F_{SW}\downarrow - F_{SW}\uparrow \quad F_{LW} = F_{LW}\downarrow - F_{LW}\uparrow$$

The net radiation balance being:

$$F^{sfc}{}_{rad} = F_{SW}\downarrow - F_{SW}\uparrow + F_{LW}\downarrow - F_{LW}\uparrow$$

- The incident solar radiation $F_{SW}\downarrow$ is the sum of the direct and diffuse solar radiation. It has a pronounced diurnal and seasonal variation, and is also strongly affected by clouds. The outgoing short-wave solar radiation is the part reflected by the surface $F_{SW}\uparrow = A_{sfc} F_{SW}\downarrow$, where A_{sfc} is the surface albedo so that the net short-wave radiation is:

$$F_{SW} = (1 - A_{sfc})\, F_{SW}\downarrow$$

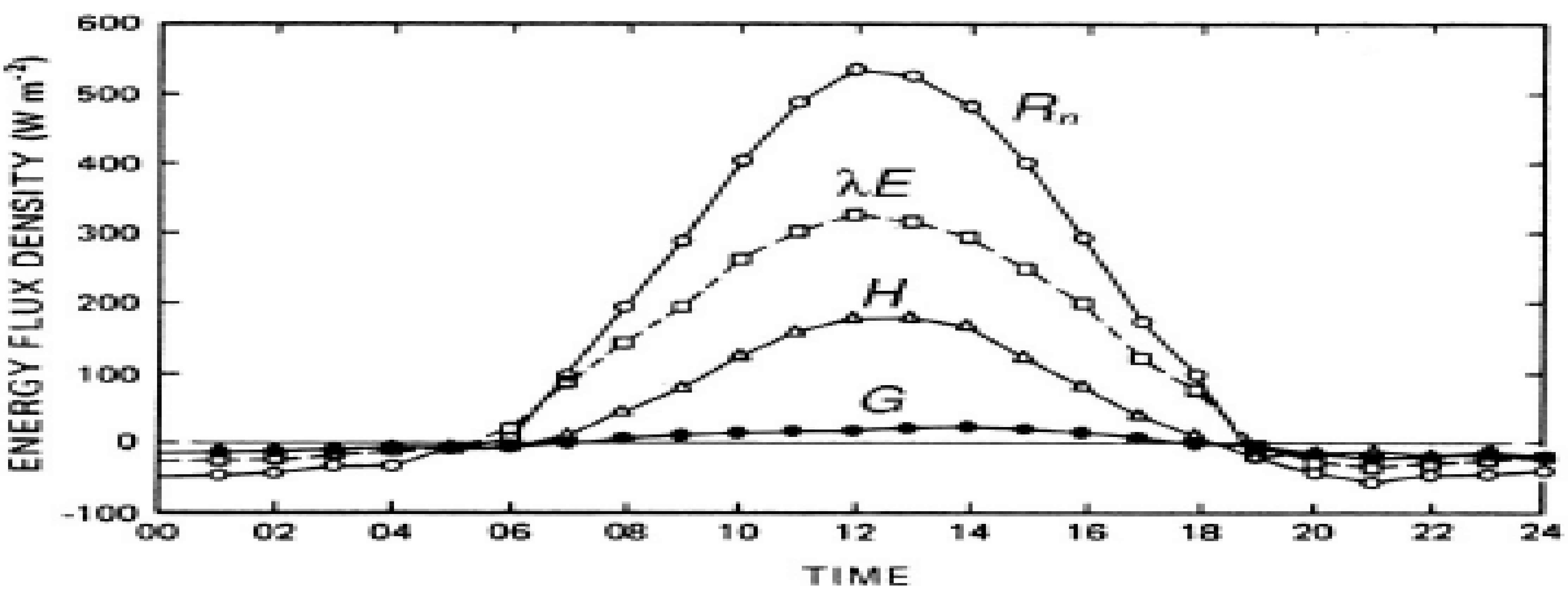
- The outgoing long-wave radiation $F_{LW}\uparrow$ is given by the Stefan-Boltzmann law, assuming a given emissivity ϵ for the earth's surface.
- The net radiation flux at the surface is then given by :

$$F^{sfc}{}_{rad} = F_{SW}\downarrow\,(1 - A_{sfc}) - \sigma \epsilon T^4{}_{sfc} + F_{LW}\downarrow$$

Energy Balance at the Earth Surface

The main part of the energy absorbed at the surface is used to evaporate water, another part is lost to the atmosphere as sensible heat, and a smaller part is lost to the underlying layers or used to melt snow and ice. Thus, there are essentially four types of energy fluxes at the earth's surface. They are the net radiation flux F_{rad}, the (direct) sensible heat flux $F_{SH}\uparrow$, the (indirect) latent heat flux $F_{LH}\uparrow$, and the heat flux into the subsurface layers $F_G\downarrow$. Under steady conditions the balance equation for the energy is given by

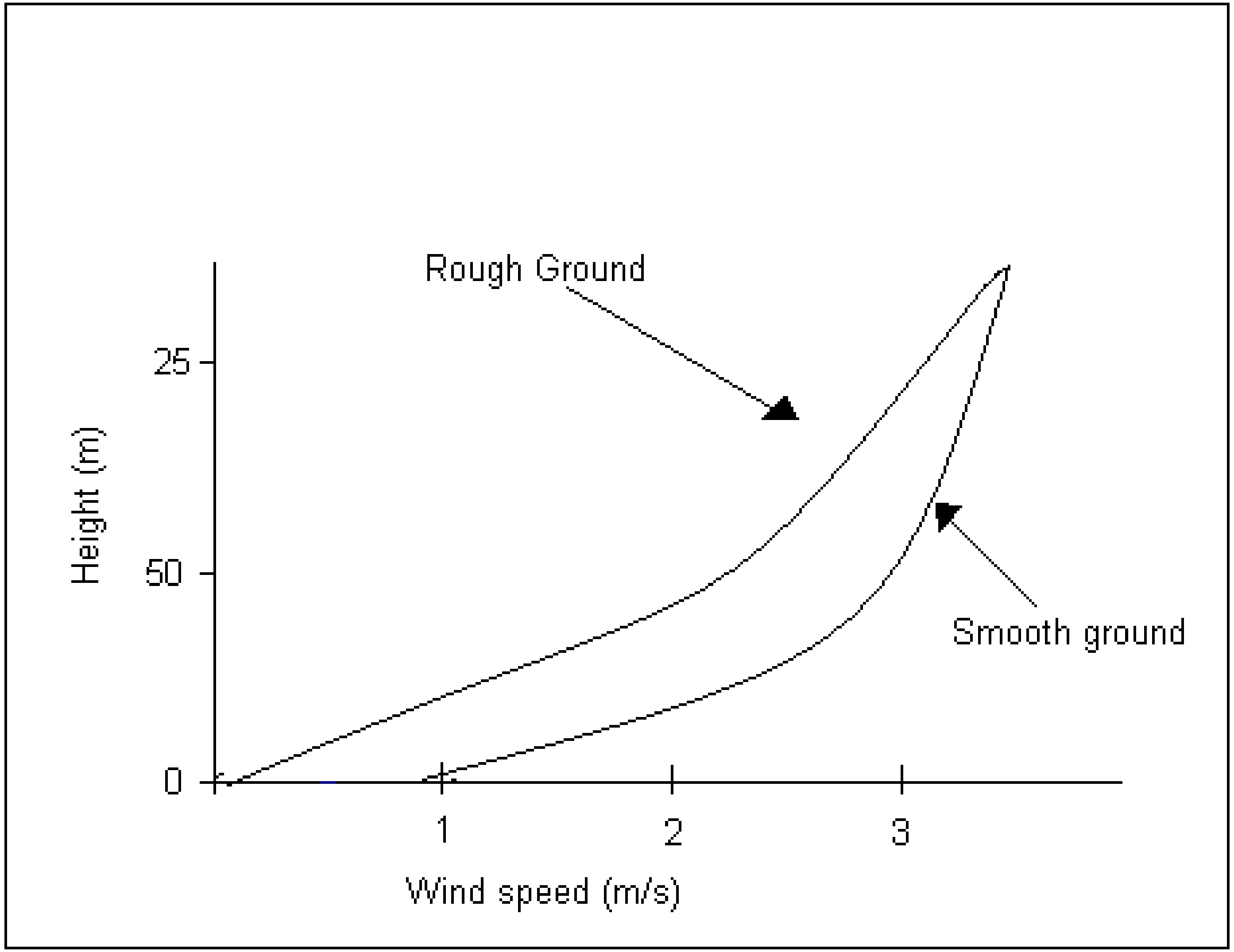
$$F^{sfc}_{rad} - F_{SH}\uparrow - F_{LH}\uparrow - F_G\downarrow - F_M = 0$$



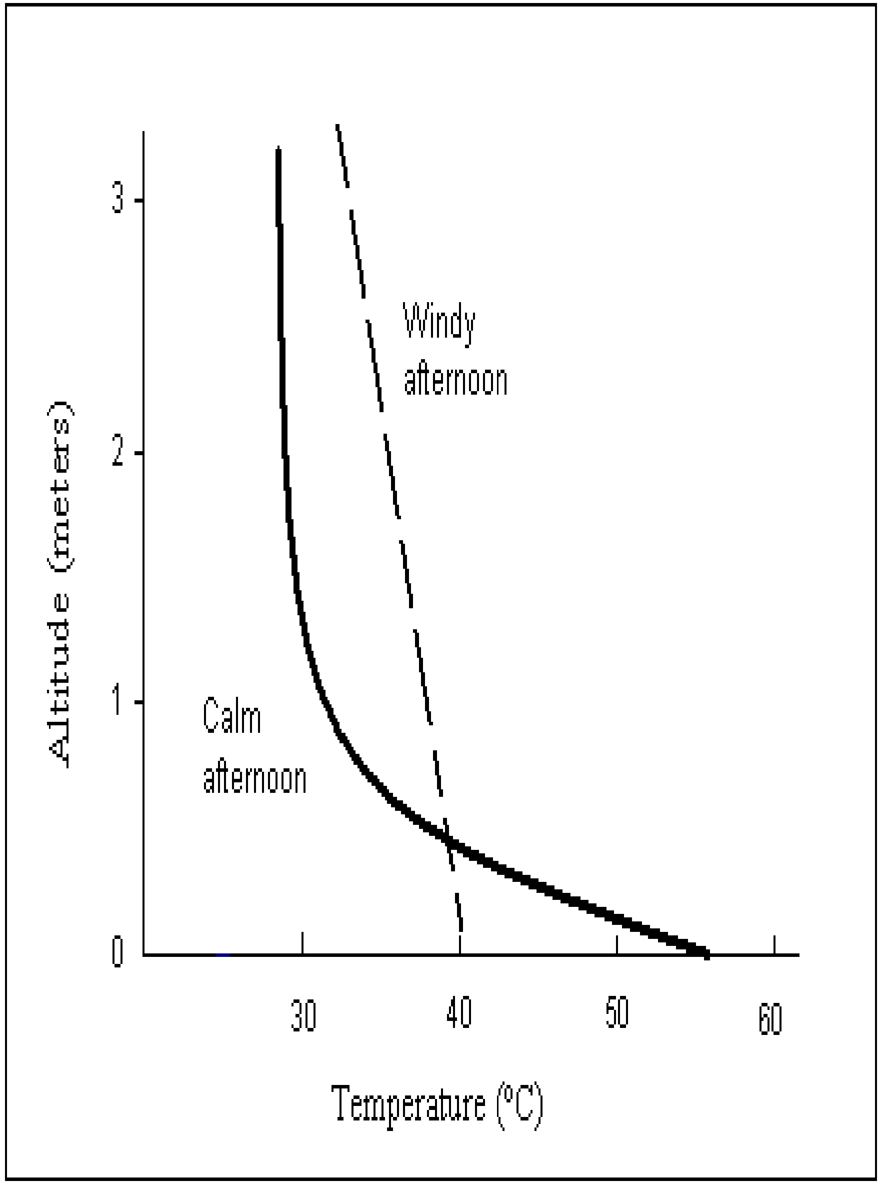
Diurnal variation of the components of the surface energy budget in cloudless conditions at a rural mid-latitude site.

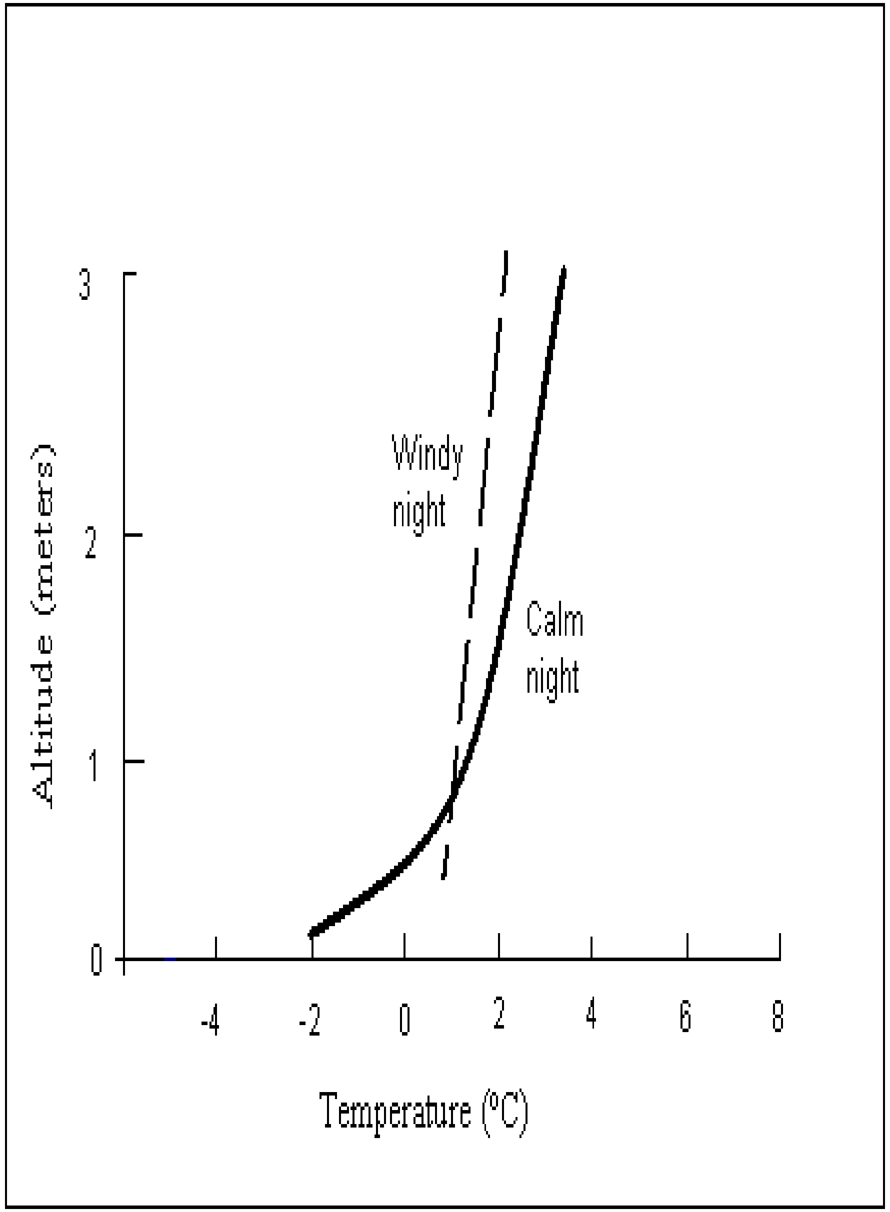
These surface fluxes are associated with land processes and depend on:

- vertical stability; roughness
- surface temperature
- subsurface heat conduction
- vegetation
- surface hydrological balance
- potential evapotranspiration
- radiative flux



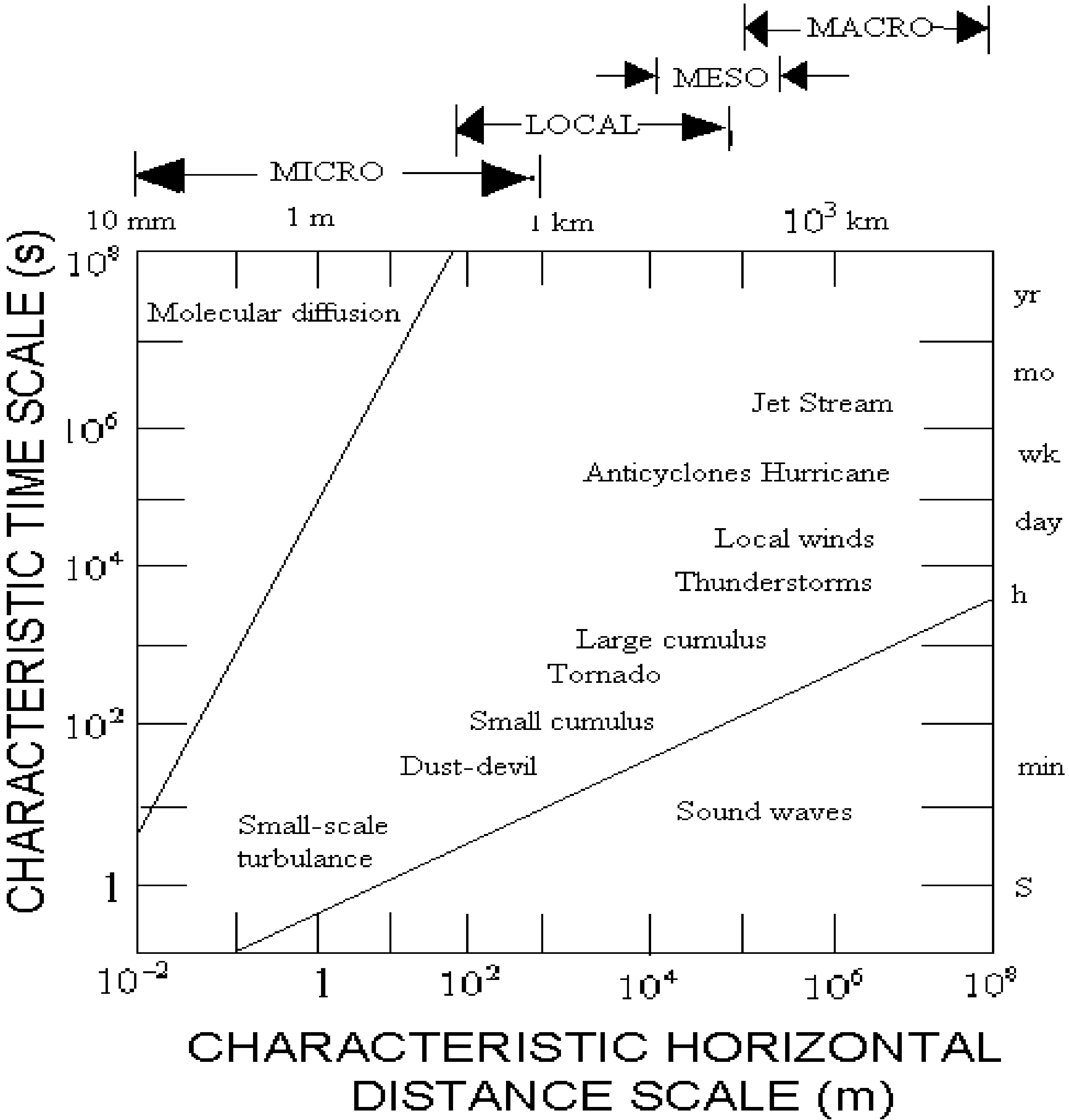
Example of the effect of surface roughness on wind structure.

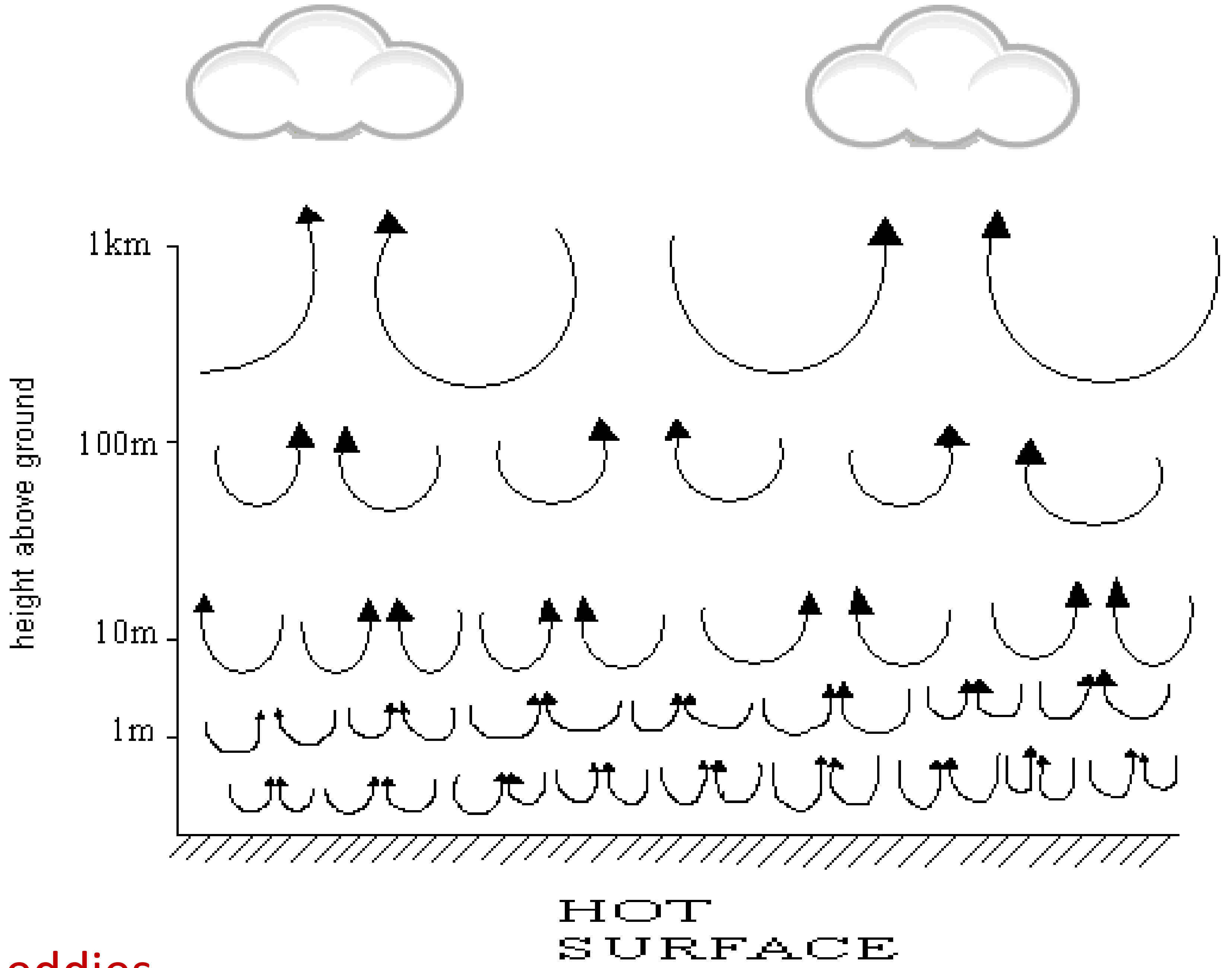




Example of the effect of wind on vertical temperature profile.

The location of small scale turbulence in the atmospheric scheme of motions.





Turbulent eddies.