What is the Upper Atmosphere?!

By **Hayanon**
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CAWSES SCOSTEP STEL

Why does the air become thinner at higher altitudes?

As you know the air becomes thinner as you move higher. That is why we find it hard to breathe on a high mountain. For instance, at the summit of Mt. Fuji (3776 m), the air is only two-thirds of that at sea level. Don't you wonder why that is so?

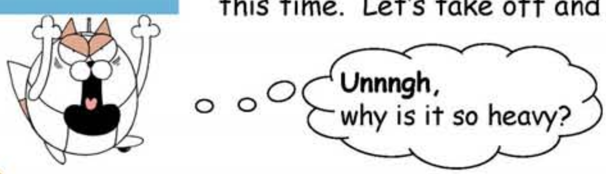
The reason is related to the Earth's gravity. I will explain that now. Air, although light in weight, is pulled down by gravity. Does all the air fall down to the ground then? There is no need to worry. It never happens because air molecules are moving fast in random directions and are colliding with each other. The force exerted by these molecules on a unit area is called air pressure.

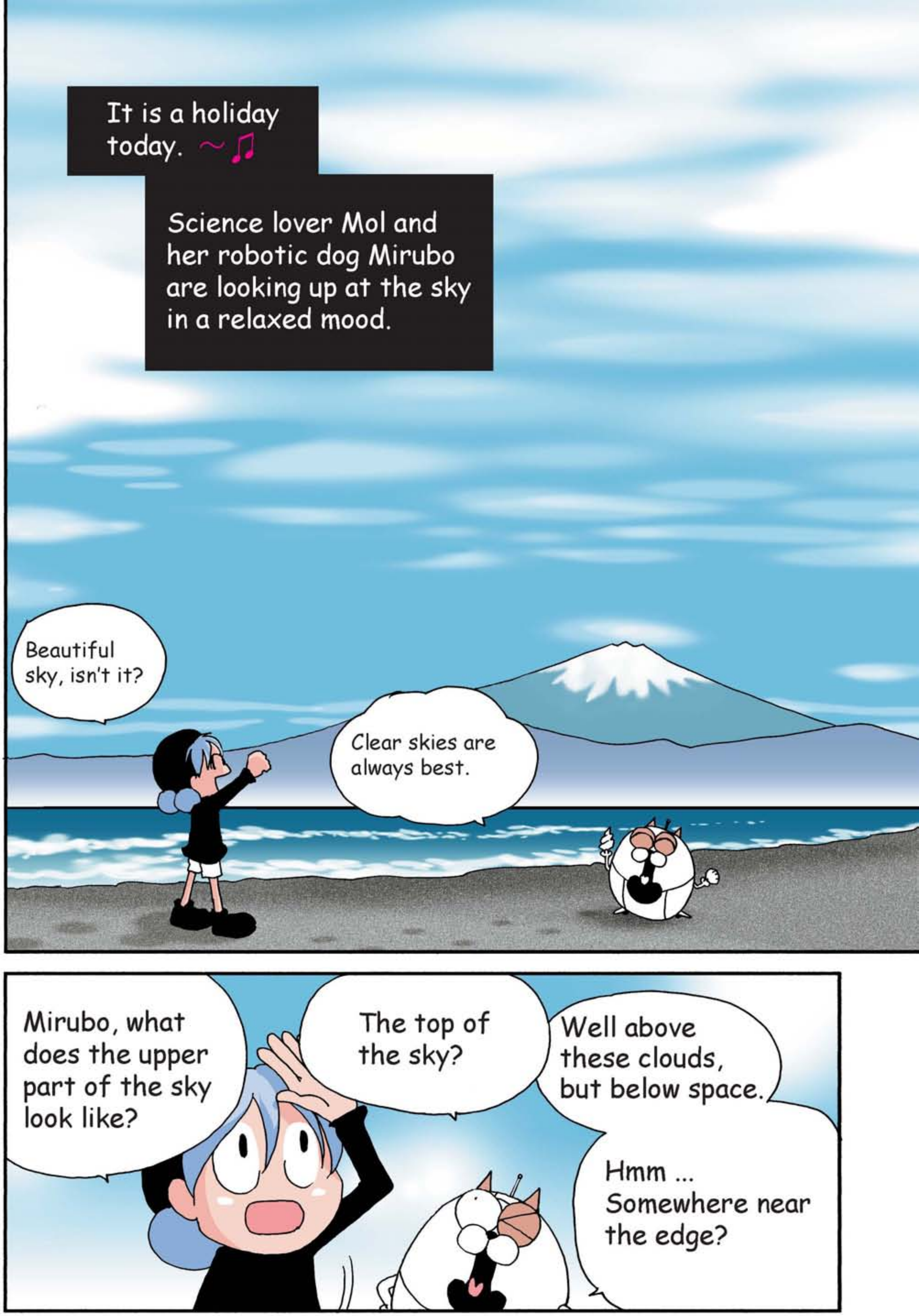
Air pressure is 1 kg/cm^2 at ground level. In other words, accumulated air on your thumb weights about 1 kg. Despite that we are not flattened on to the ground because equal pressure is pushing outward from inside out body.

Our world lies at the bottom of the "heaped" air. The air at the ground is pressed and thick, whereas it is less pressed and lighter at high altitudes. Thus air becomes thinner as we go up higher.

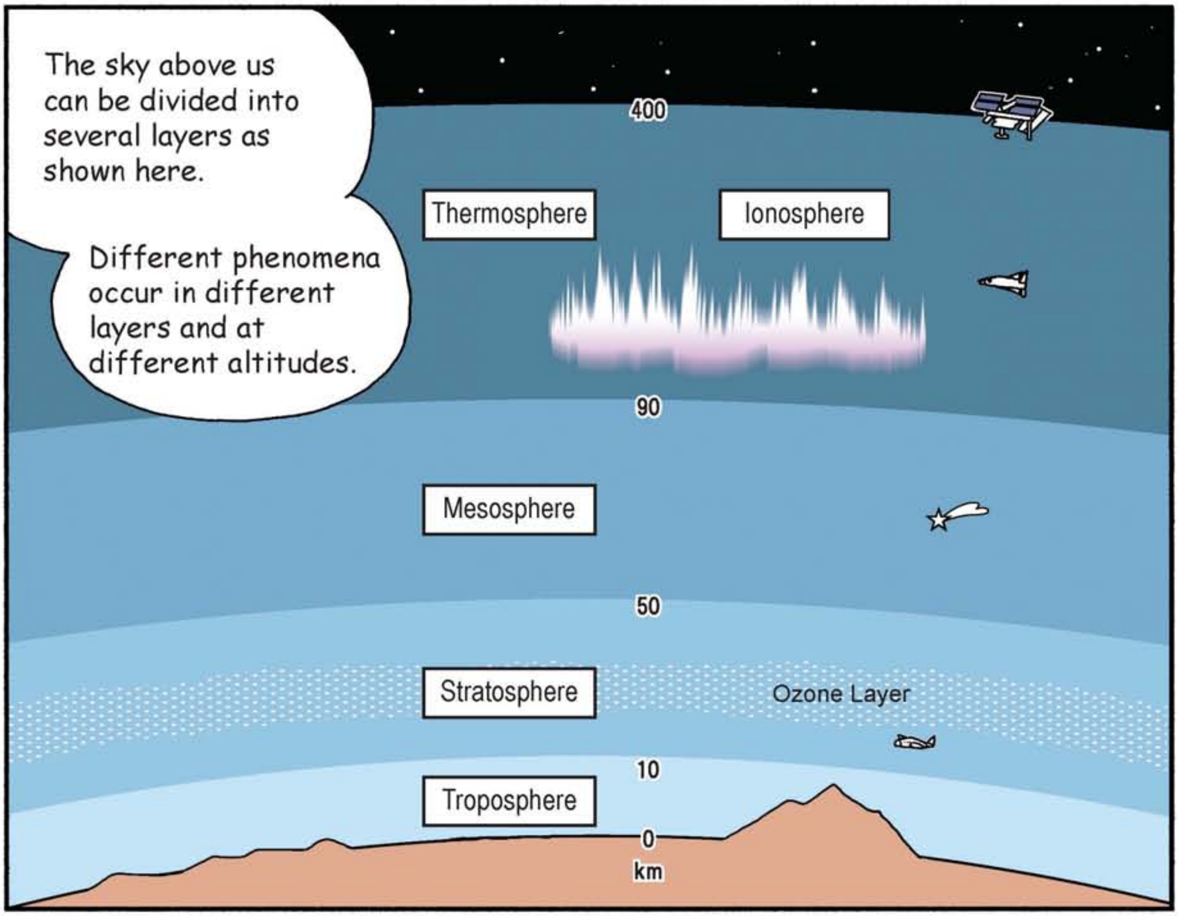
You will find that the thin air at high altitudes has unique characteristics different from those of the air surrounding us on the ground. The air there is electrically charged, experiences changes in its composition, and even emits light! The upper atmosphere is a place filled with those mysteries, and at the same time, it is the boundary between space and the Earth's atmosphere.

Mol and Mirubo are going to explore the upper atmosphere this time. Let's take off and join them!

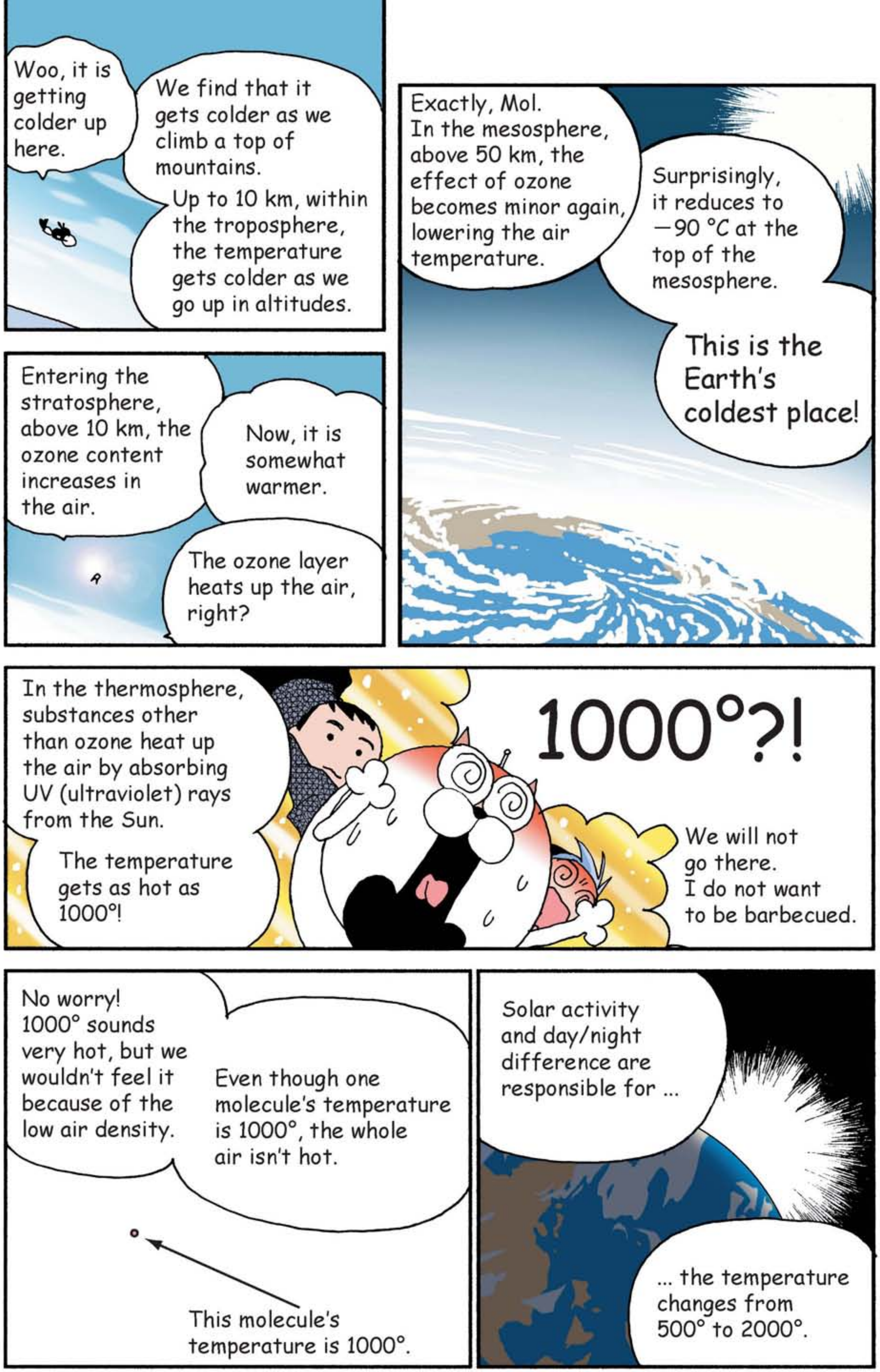


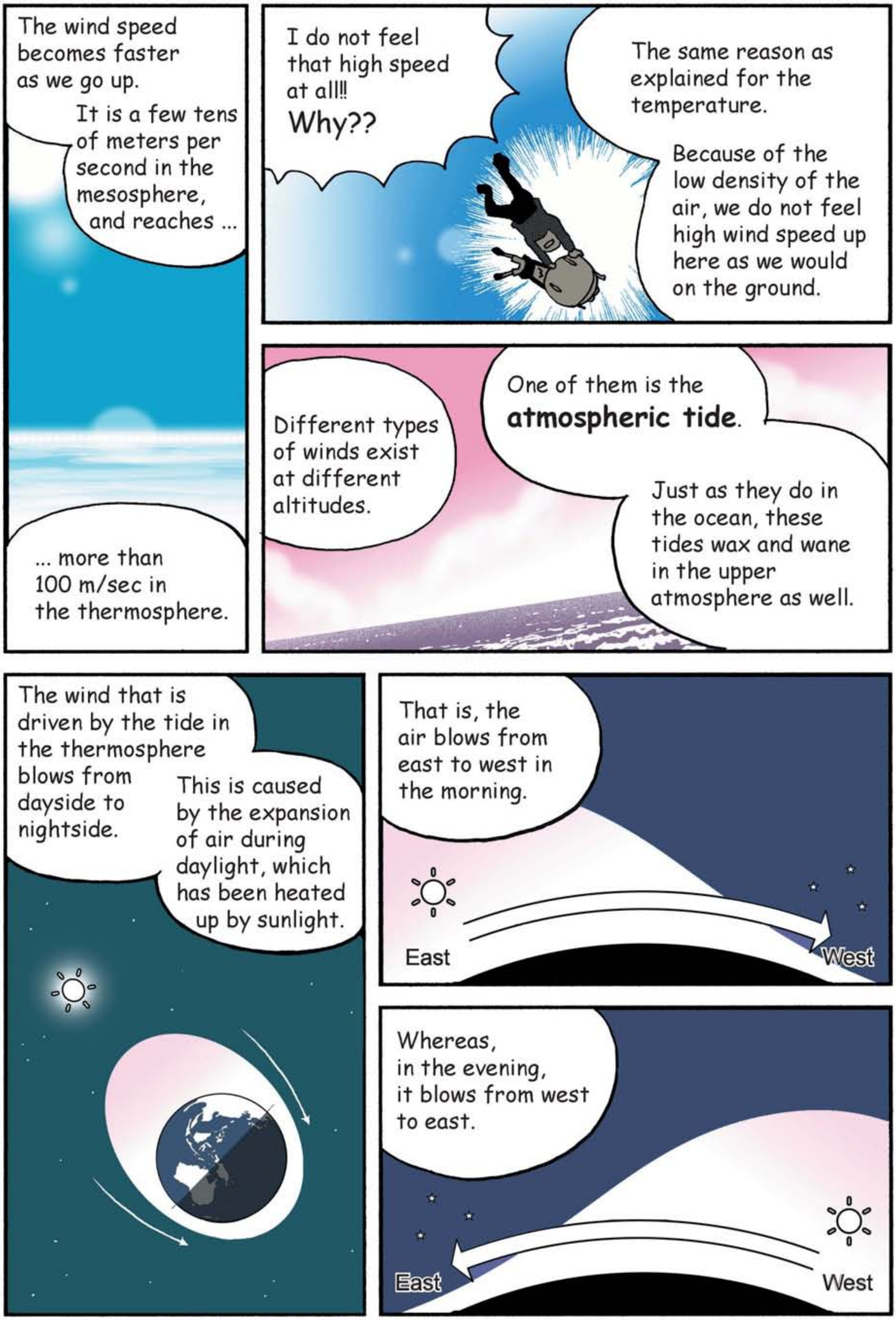

It is a holiday today. ~♫
Science lover Mol and her robotic dog Mirubo are looking up at the sky in a relaxed mood.
Beautiful sky, isn't it?
Clear skies are always best.
Mirubo, what does the upper part of the sky look like?
The top of the sky?
Well above these clouds, but below space.
Hmm ... Somewhere near the edge?


It is impossible to answer this question even with my super computer. Mmm ...
Let's learn something ...
... about the top of the sky together.
Thank you, Sensei!

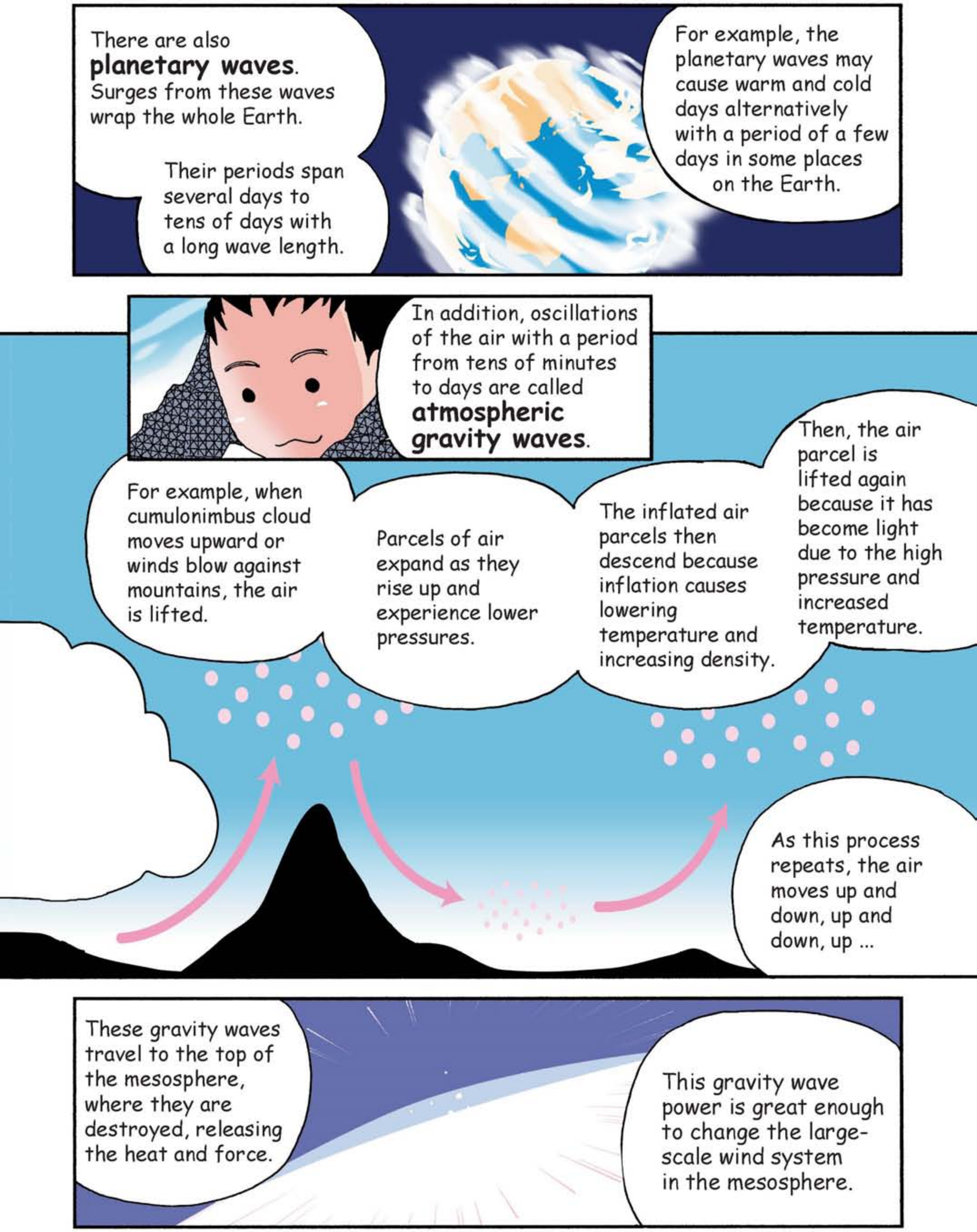

The sky above us can be divided into several layers as shown here.
Different phenomena occur in different layers and at different altitudes.
400
Thermosphere
Ionosphere
90
Mesosphere
50
Stratosphere
Ozone Layer
10
Troposphere
0
km


Today you are going to learn about the **upper atmosphere**. Here we call both the upper mesosphere and the thermosphere/ionosphere as the upper atmosphere.
I don't quite understand...
Then, let's fly all the way to the upper atmosphere.

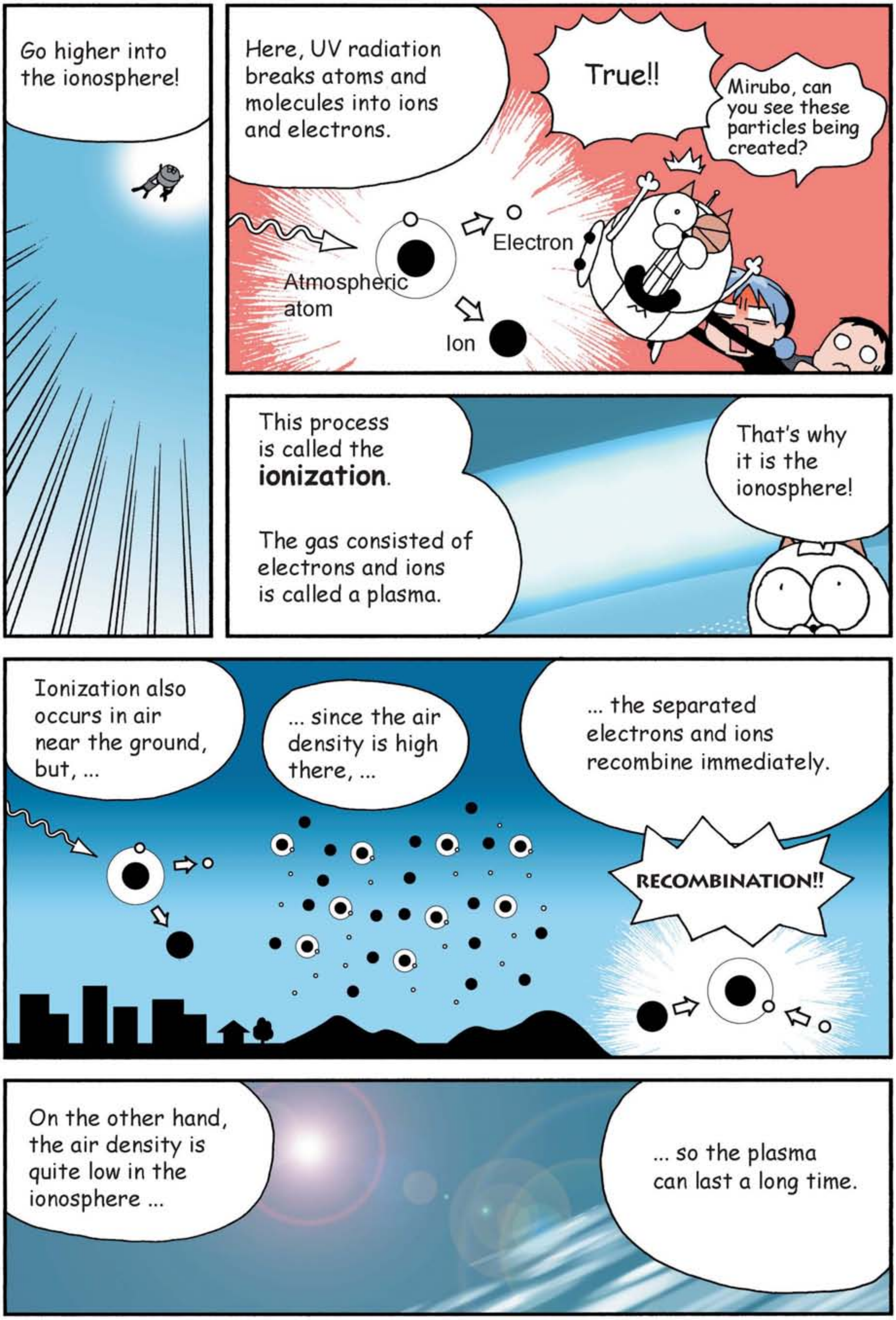

Woo, it is getting colder up here.
We find that it gets colder as we climb a top of mountains.
Up to 10 km, within the troposphere, the temperature gets colder as we go up in altitudes.
Exactly, Mol. In the mesosphere, above 50 km, the effect of ozone becomes minor again, lowering the air temperature.
Surprisingly, it reduces to −90 °C at the top of the mesosphere.
This is the Earth's coldest place!
Entering the stratosphere, above 10 km, the ozone content increases in the air.
Now, it is somewhat warmer.
The ozone layer heats up the air, right?
In the thermosphere, substances other than ozone heat up the air by absorbing UV (ultraviolet) rays from the Sun.
The temperature gets as hot as 1000°!
1000°?!
We will not go there. I do not want to be barbecued.
No worry! 1000° sounds very hot, but we wouldn't feel it because of the low air density.
Even though one molecule's temperature is 1000°, the whole air isn't hot.
This molecule's temperature is 1000°.
Solar activity and day/night difference are responsible for ...
... the temperature changes from 500° to 2000°.

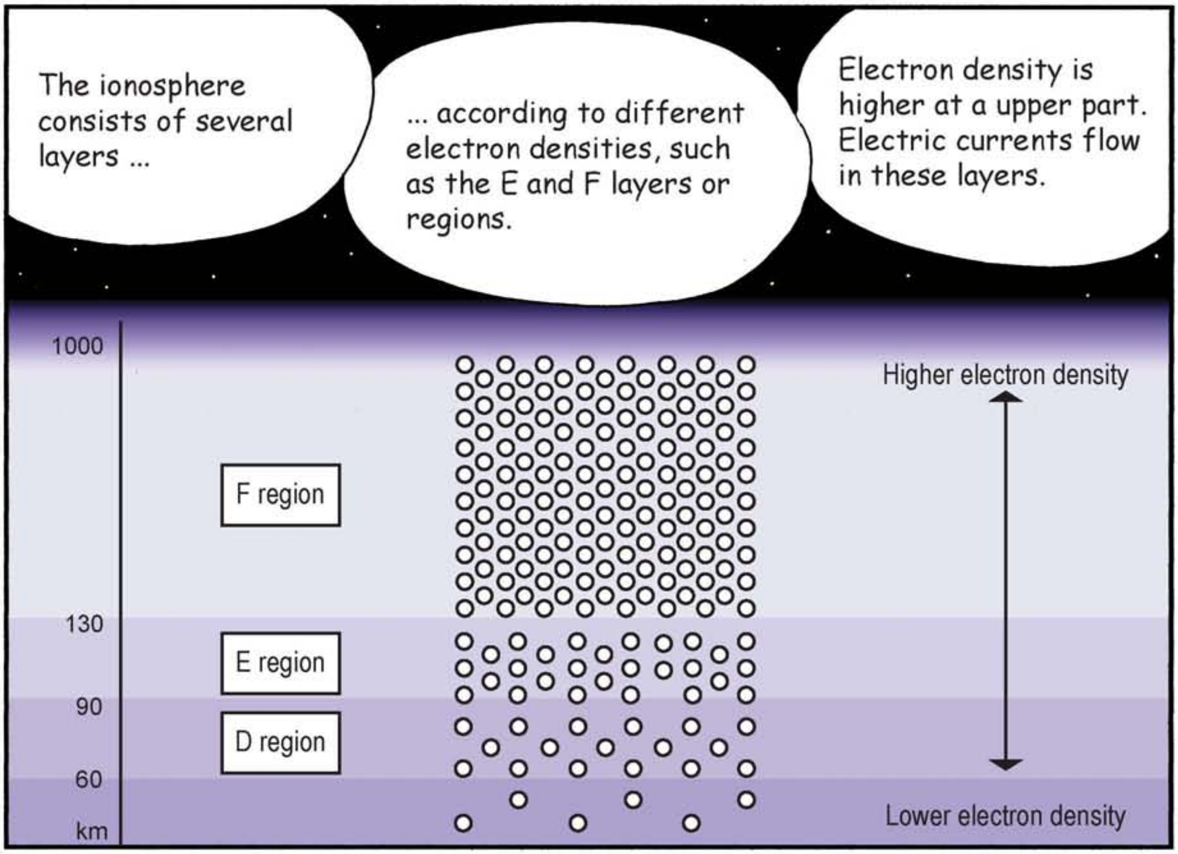


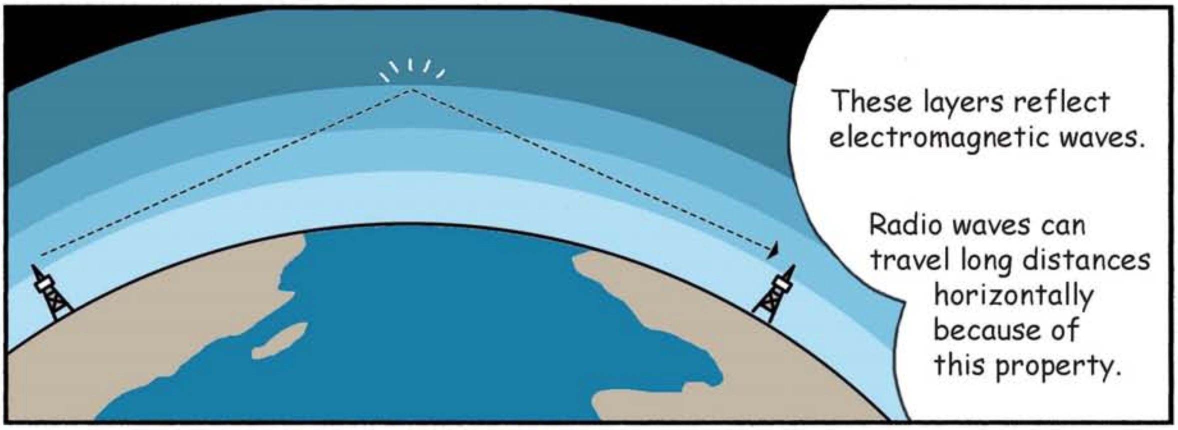
The wind speed becomes faster as we go up.
It is a few tens of meters per second in the mesosphere, and reaches ...
I do not feel that high speed at all!! Why??
The same reason as explained for the temperature.
Because of the low density of the air, we do not feel high wind speed up here as we would on the ground.
... more than 100 m/sec in the thermosphere.
Different types of winds exist at different altitudes.
One of them is the **atmospheric tide**.
Just as they do in the ocean, these tides wax and wane in the upper atmosphere as well.
The wind that is driven by the tide in the thermosphere blows from dayside to nightside.
This is caused by the expansion of air during daylight, which has been heated up by sunlight.
That is, the air blows from east to west in the morning.
East
West
Whereas, in the evening, it blows from west to east.
East
West

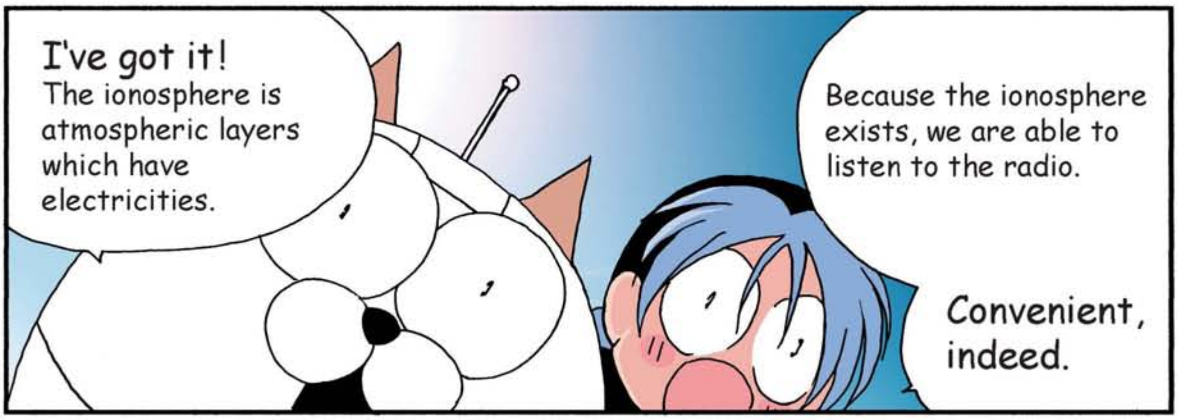


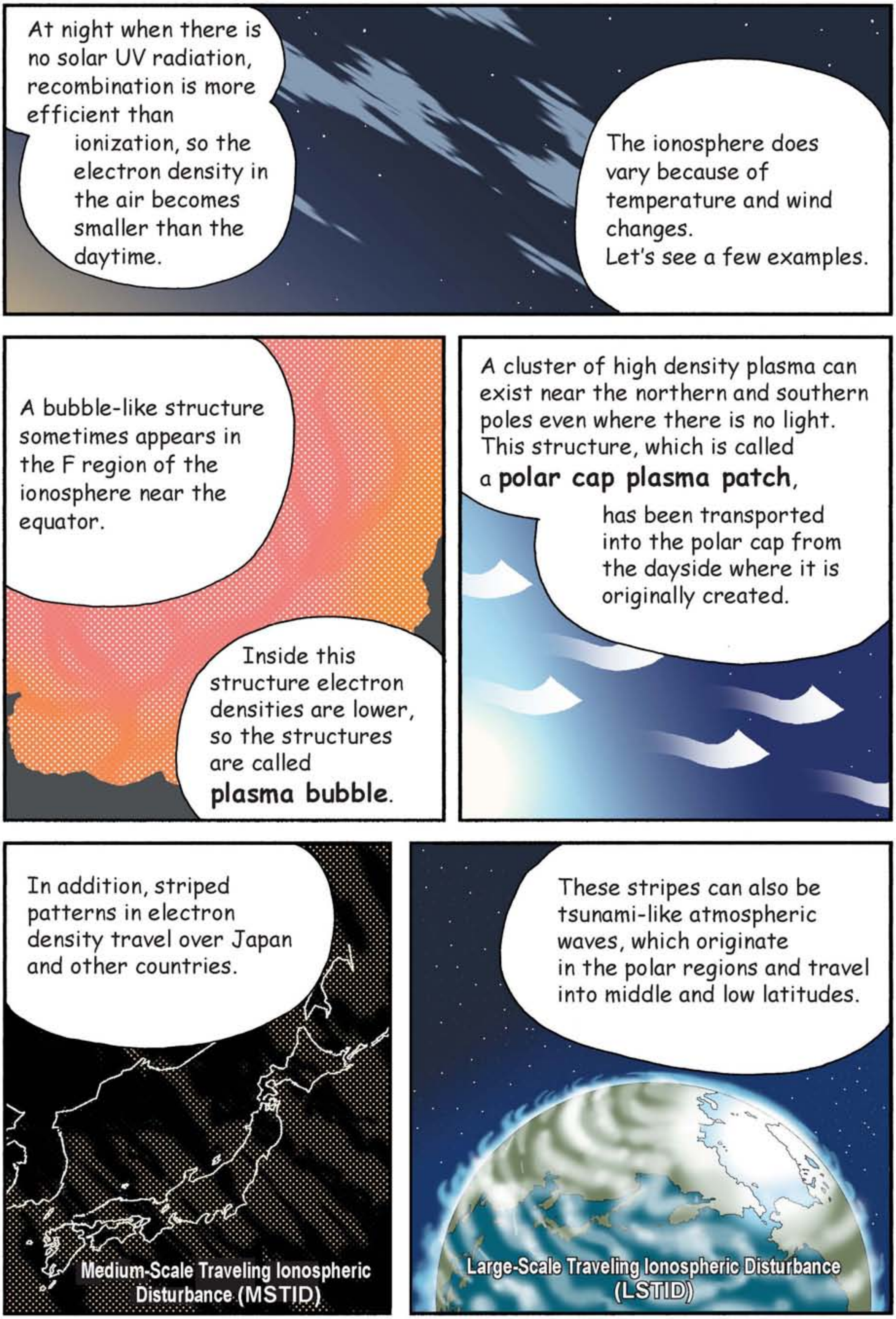
There are also **planetary waves**. Surges from these waves wrap the whole Earth.
Their periods span several days to tens of days with a long wave length.
For example, the planetary waves may cause warm and cold days alternatively with a period of a few days in some places on the Earth.
In addition, oscillations of the air with a period from tens of minutes to days are called **atmospheric gravity waves**.
For example, when cumulonimbus cloud moves upward or winds blow against mountains, the air is lifted.
Parcels of air expand as they rise up and experience lower pressures.
The inflated air parcels then descend because inflation causes lowering temperature and increasing density.
Then, the air parcel is lifted again because it has become light due to the high pressure and increased temperature.
As this process repeats, the air moves up and down, up and down, up ...
These gravity waves travel to the top of the mesosphere, where they are destroyed, releasing the heat and force.
This gravity wave power is great enough to change the large-scale wind system in the mesosphere.

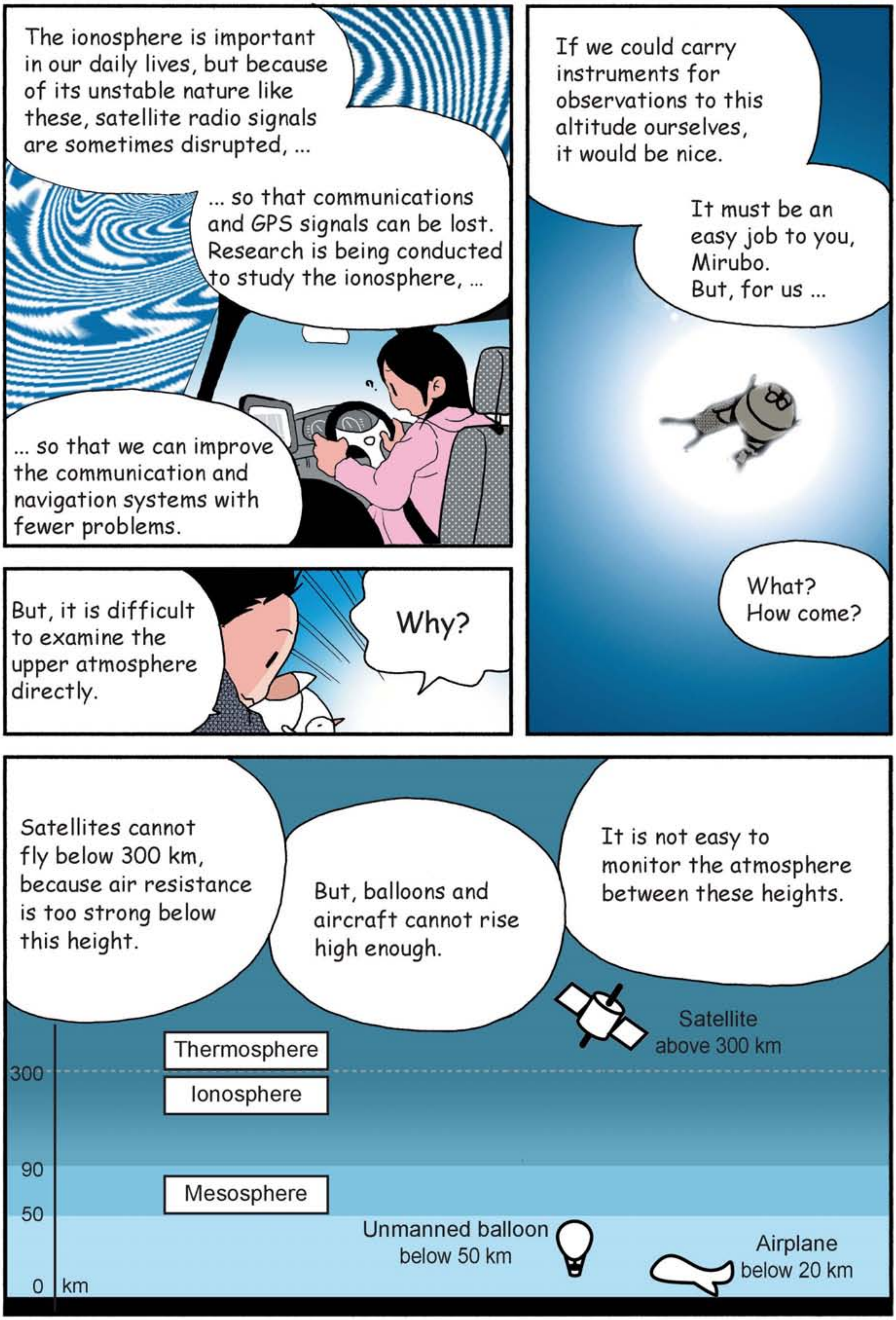

Go higher into the ionosphere!
Here, UV radiation breaks atoms and molecules into ions and electrons.
True!!
Mirubo, can you see these particles being created?
Electron
Atmospheric atom
Ion
This process is called the **ionization**.
The gas consisted of electrons and ions is called a plasma.
That's why it is the ionosphere!
Ionization also occurs in air near the ground, but, ...
... since the air density is high there, ...
... the separated electrons and ions recombine immediately.
RECOMBINATION!!
On the other hand, the air density is quite low in the ionosphere ...
... so the plasma can last a long time.

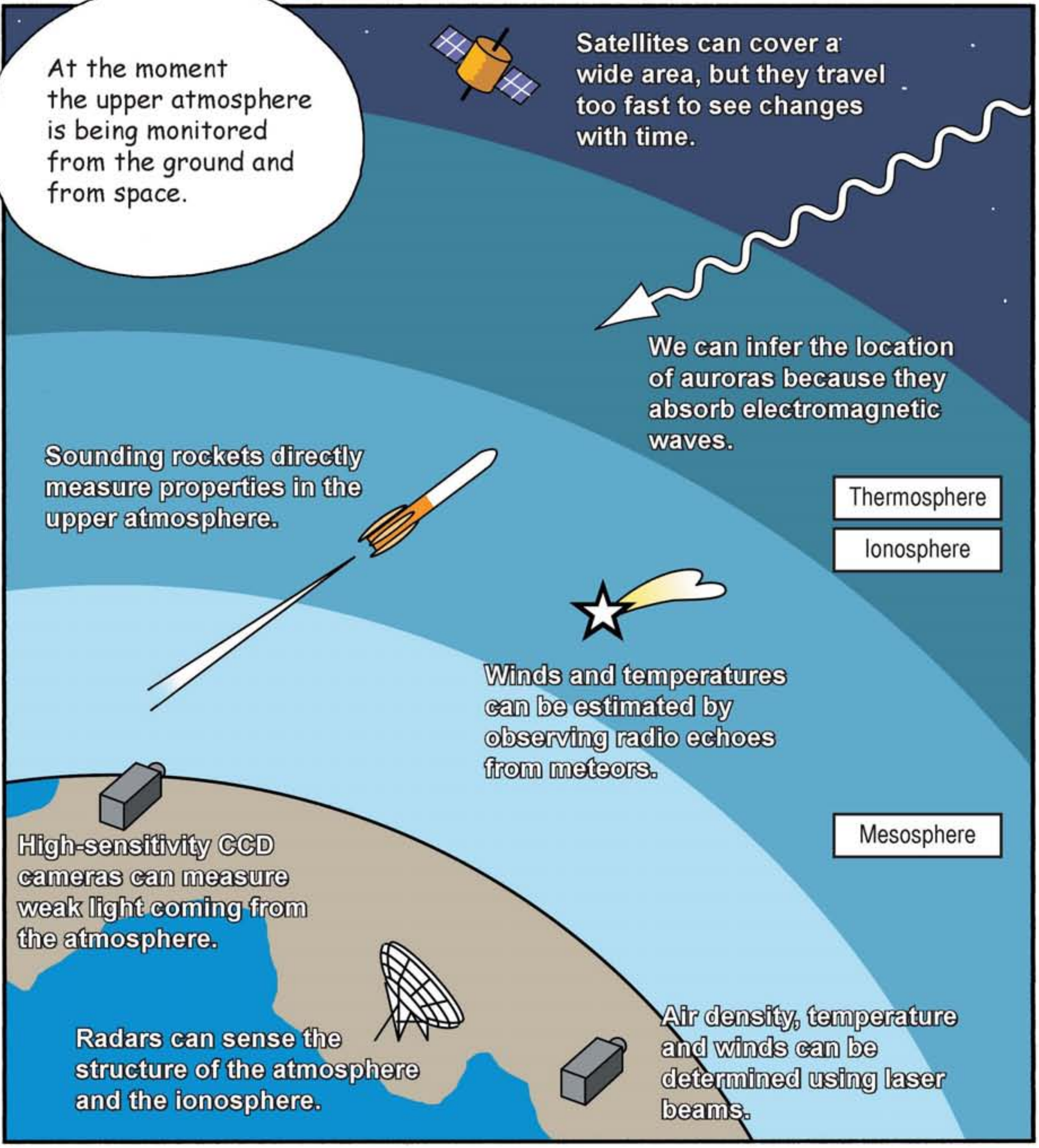

The ionosphere consists of several layers ...
... according to different electron densities, such as the E and F layers or regions.
Electron density is higher at a upper part. Electric currents flow in these layers.
1000
130
90
60
km
F region
E region
D region
Higher electron density
Lower electron density


These layers reflect electromagnetic waves.
Radio waves can travel long distances horizontally because of this property.

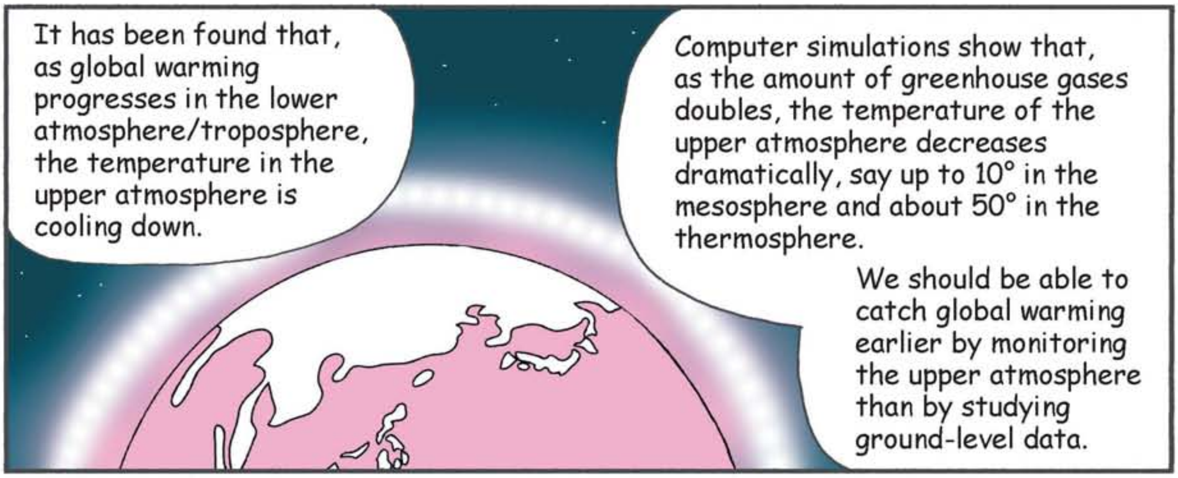

I've got it! The ionosphere is atmospheric layers which have electricities.
Because the ionosphere exists, we are able to listen to the radio.
Convenient, indeed.

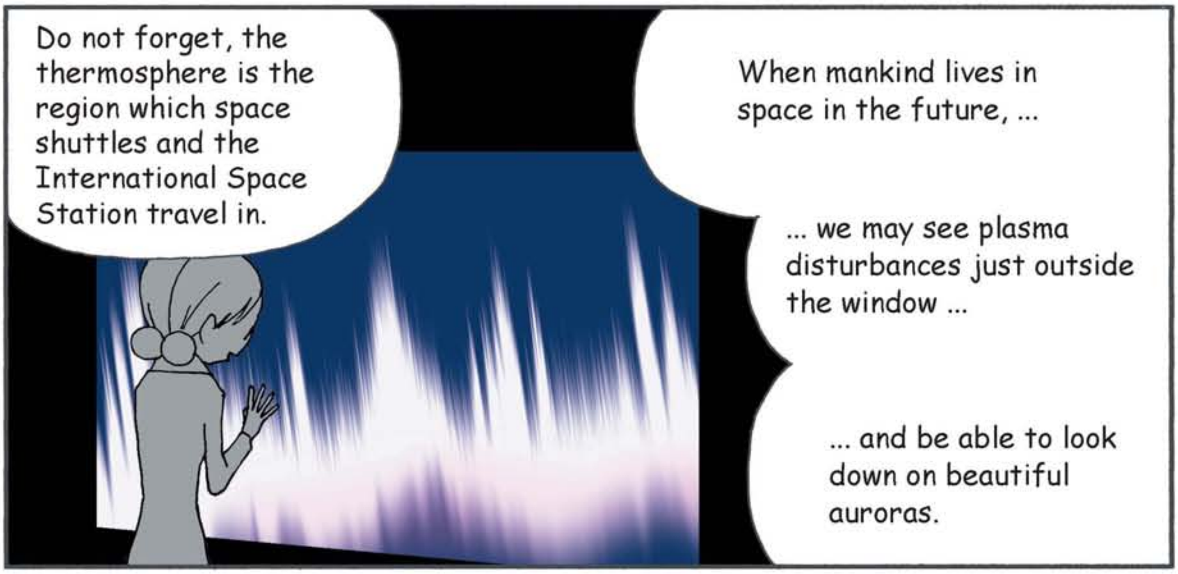

At night when there is no solar UV radiation, recombination is more efficient than ionization, so the electron density in the air becomes smaller than the daytime.
The ionosphere does vary because of temperature and wind changes.
Let's see a few examples.
A bubble-like structure sometimes appears in the F region of the ionosphere near the equator.
Inside this structure electron densities are lower, so the structures are called **plasma bubble**.
A cluster of high density plasma can exist near the northern and southern poles even where there is no light. This structure, which is called a **polar cap plasma patch**,
has been transported into the polar cap from the dayside where it is originally created.
In addition, striped patterns in electron density travel over Japan and other countries.
Medium-Scale Traveling Ionospheric Disturbance (MSTID)
These stripes can also be tsunami-like atmospheric waves, which originate in the polar regions and travel into middle and low latitudes.
Large-Scale Traveling Ionospheric Disturbance (LSTID)


The ionosphere is important in our daily lives, but because of its unstable nature like these, satellite radio signals are sometimes disrupted, ...
... so that communications and GPS signals can be lost. Research is being conducted to study the ionosphere, ...
... so that we can improve the communication and navigation systems with fewer problems.
If we could carry instruments for observations to this altitude ourselves, it would be nice.
It must be an easy job to you, Mirubo. But, for us ...
But, it is difficult to examine the upper atmosphere directly.
Why?
What? How come?
Satellites cannot fly below 300 km, because air resistance is too strong below this height.
But, balloons and aircraft cannot rise high enough.
It is not easy to monitor the atmosphere between these heights.
Thermosphere
Ionosphere
Mesosphere
Satellite
above 300 km
300
90
50
0
km
Unmanned balloon
below 50 km
Airplane
below 20 km


At the moment the upper atmosphere is being monitored from the ground and from space.
Satellites can cover a wide area, but they travel too fast to see changes with time.
We can infer the location of auroras because they absorb electromagnetic waves.
Sounding rockets directly measure properties in the upper atmosphere.
Thermosphere
Ionosphere
Winds and temperatures can be estimated by observing radio echoes from meteors.
Mesosphere
High-sensitivity CCD cameras can measure weak light coming from the atmosphere.
Radars can sense the structure of the atmosphere and the ionosphere.
Air density, temperature and winds can be determined using laser beams.


Why do investigators persist in investigating ...
... that part of the atmosphere, even though direct measurements of the upper atmosphere are difficult?
Remember what I told you about the ionosphere?
Again, the upper atmosphere is indispensable in our life.


It has been found that, as global warming progresses in the lower atmosphere/troposphere, the temperature in the upper atmosphere is cooling down.
Computer simulations show that, as the amount of greenhouse gases doubles, the temperature of the upper atmosphere decreases dramatically, say up to 10° in the mesosphere and about 50° in the thermosphere.
We should be able to catch global warming earlier by monitoring the upper atmosphere than by studying ground-level data.


Do not forget, the thermosphere is the region which space shuttles and the International Space Station travel in.
When mankind lives in space in the future, ...
... we may see plasma disturbances just outside the window ...
... and be able to look down on beautiful auroras.


That sounds amazing! The upper atmosphere will become more and more familiar to us.
I cannot wait to see the progress of this research!

What is the Upper Atmosphere?!

Hi, Sensei. I would like to know what it looks like at the top of the Earth's atmosphere.

So would I. Do you see a clear ceiling on the atmosphere?

Of course not. It is a vast region beyond the upper atmosphere. Because there is no air in space, the upper atmosphere is called the border between the Earth and space, or the top of the atmosphere.

How can you divide the atmosphere into different layers as you do when you say the "upper" atmosphere?

Good question, Mol. The thickness of the Earth's atmosphere is only a few hundred kilometers, and it is very thin when compared with the Earth's radius. It is just like a membrane surrounding our planet. Although it is very thin, different characteristics are found at different altitudes when you look closely.

I get it now. Then what characteristics does the upper atmosphere have?

Above all, the upper atmosphere includes the layer called the ionosphere where the air is partially charged. The ionosphere reflects an electromagnetic wave sent from the ground. We make use of this behavior to observe the upper atmosphere using radar echoes.

Why does electricity exist in the atmosphere?

UV radiation from the Sun and plasma from space kick out electrons that are encircling atmospheric atoms and molecules, making the air electrically charged. Because the air density is quite low in the ionosphere, it takes time for free electrons to recombine, which means that the air retains its electricity longer.

Eh, Sensei, can that electricity be used for an electric BBQ grill?

If you collected all the electricity in the Earth's upper atmosphere, you could continue grilling meat far longer than you could possibly want.

Why do you study the ionosphere? Does it have any impact on us?

The variability in the ionosphere could cause disruptions of the satellite communications and GPS navigation, and TV/radio broadcast. To utilize the ionosphere more efficiently, we need to understand it better.

Oh, you should worry, Mirubo. You have no sense of direction and can do nothing without GPS.

Far from it! In fact, my high precision computer is very delicate, but sometimes becomes too delicate for the direction.

Now kids, the upper atmosphere, like the ozone layer, absorbs harmful UV radiation from the Sun. You should also know that auroras occur at the height of the upper atmosphere.

Auroras can be seen only in polar regions, right?

Basically, yes. When a geomagnetic storm happens, the auroras can occur at lower latitudes, too.

Is there a chance that I can see aurora in Japan?

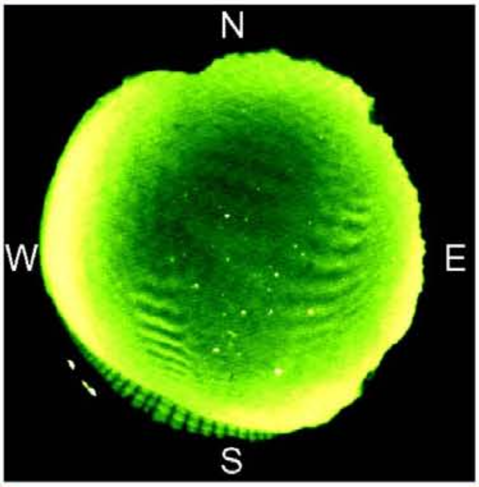
Auroras have been observed with high sensitive instruments more than 20 times in Japan in the past 10 years. Though, the aurora was bright enough to be visible a few of these times.

I definitely want to see it in Japan, and will keep watch until I can. You can't join me Mol, you have to keep your bedtime.

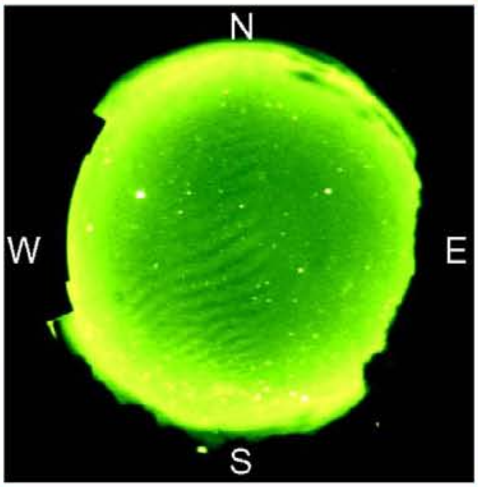
That's not fair!!

Stripe Patterns in the Upper Atmosphere

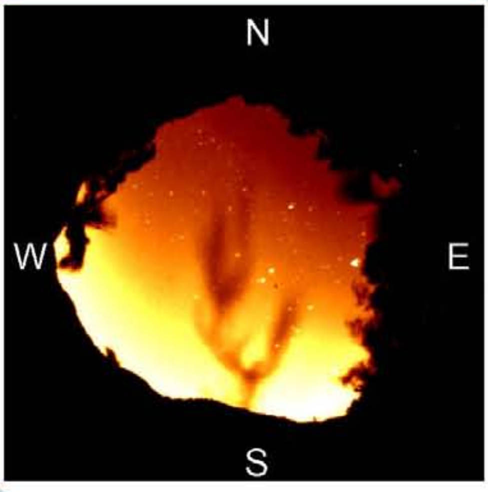
The upper atmosphere emits very weak, barely visible light called the airglow. Two-dimensional images of this low-intensity light can be obtained by using high-sensitivity, cooled CCD cameras. It has recently become possible, through this means, to record various patterns resulting from gravity waves and plasma bubbles in the upper atmosphere. The progress in this area of science is faster than ever.



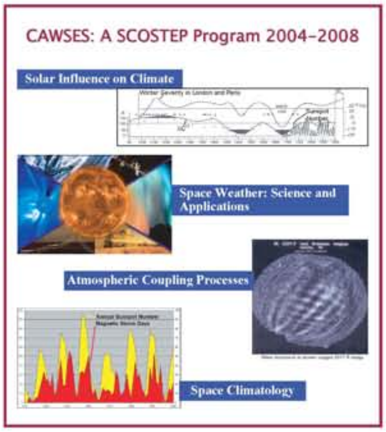
Example of striations of 20 - 30 km wave-length scale, showing the existence of gravity waves in the upper atmosphere. This 557.7 nm (green) all-sky image was obtained at the MU Observatory of Kyoto University in Shigaraki, Japan with 105 sec exposure time, resulting from oxygen atoms at 90 - 100 km altitude, i.e., upper mesosphere.



Example of striations of 20 - 30 km wave-length scale, showing the existence of gravity waves in the upper atmosphere. This 557.7 nm (green) all-sky image was obtained at Kototabang of Sumatra Island in Indonesia with 105 sec exposure time, resulting from oxygen atoms at 90 - 100 km altitude, i.e., upper mesosphere.



Example of plasma bubbles (like wings of a tree) in the upper atmosphere. This 630.0 nm (red) all-sky image was obtained at the Sata Station of the Solar-Terrestrial Environment Laboratory in Kagoshima, Japan with 165 sec exposure time, resulting from oxygen atoms at 200 - 300 km altitude, i.e., ionosphere.



Climate and Weather of the Sun-Earth System (CAWSES)

CAWSES is an international program sponsored by SCOSTEP (Scientific Committee on Solar-Terrestrial Physics) and has been established with the aim of significantly enhancing our understanding of the space environment and its impacts on life and society. The main functions of CAWSES are to help coordinate international activities in observations, modeling and theory crucial to achieving this understanding, to involve scientists in both developed and developing countries, and to provide educational opportunities for students at all levels. The CAWSES office is located at Boston University, Boston, MA, USA. The four science Themes of CAWSES are shown in the figure.

http://www.bu.edu/cawses/
http://www.scostep.ucar.edu/

Solar-Terrestrial Environment Laboratory (STEL), Nagoya University

STEL is operated under an inter-university cooperative system in Japan. Its purpose is to promote "research on the structure and dynamics of the solar-terrestrial system," in collaboration with a number of universities and institutions both in Japan and abroad. The Laboratory consists of four research Divisions: Atmospheric Environment, Ionospheric and Magnetospheric Environment, Heliospheric Environment, and Integrated Studies. The Geospace Research Center is also affiliated to the Laboratory to coordinate and promote joint research projects. At its seven Observatories/Stations, ground-based observations of various physical and chemical entities are conducted nationwide.

http://www.stelab.nagoya-u.ac.jp/

はやのん Hayanon

Graduated from the Department of Physics of Ryukyu University, Hayanon, a writer and cartoonist, has contributed a number of serials in popular magazines on the basis of her strong background in science and computer games. Her consistent writing style, expressing a love for science, is well accepted.

http://www.hayanon.jp/

子供の科学 Kodomo no Kagaku (Science for Kids)

Kodomo no Kagaku, published by the Seibundo Shinkosha Publishing Co., Ltd. is a monthly magazine for juniors. Since the inaugural issue in 1924, the magazine has continuously promoted science education by providing various facets of science, from scientific phenomena in everyday life to cutting edge research topics.

http://www.seibundo.net/

"What is the Upper Atmosphere?!" is published with cooperation of "Kodomo no Kagaku." Mol, Mirubo, and Sensei thank Alan Burns for his help in preparing the English version of our story.

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