



Learning Earth Science with MIRUBO

Monsoon

By Dr. William K.M. Lau and Hayanon



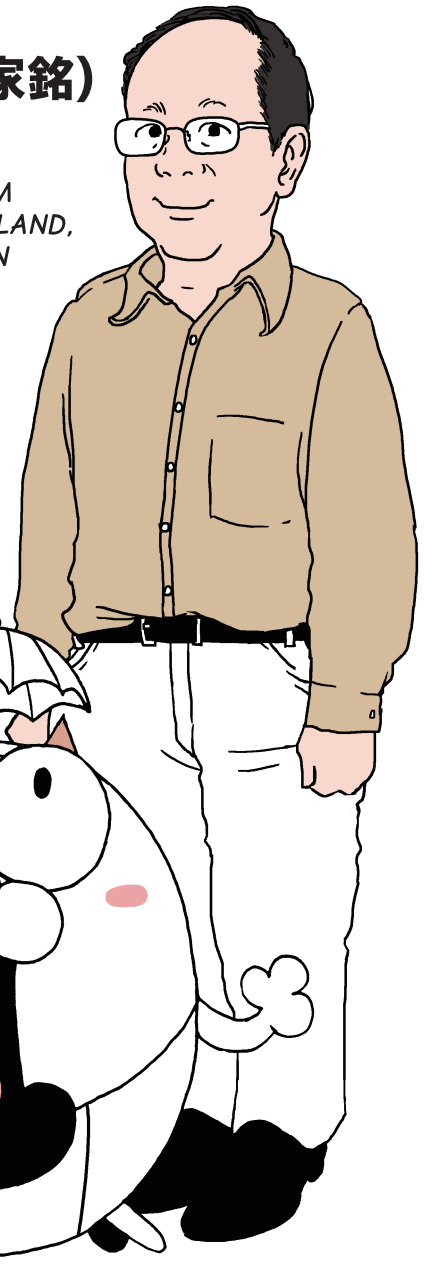
Learning Earth Science with MIRUBO

Monsoon

AN ELEMENTARY SCHOOL GIRL "MOL" AND HER FRIEND "MIRUBO" THE ROBOTIC DOG ARE LEARNING EARTH SCIENCE WITH NASA SCIENTISTS. THEY LEARNED THE FACT THAT "THE EARTH IS WARMING" AND "CLIMATE ON THE EARTH IS CHANGING". ACCORDING TO SCIENTIFIC RESEARCH, SEA-LEVEL RISE FROM ICE MELTING DUE TO CLIMATE CHANGE COULD BE A CAUSE FOR EXTINCTION OF SPECIES. MOL AND MIRUBO ARE AFRAID AND HAVE DECIDED TO FIND OUT MORE ABOUT HOW TO STOP THIS CRISIS. FIRST, THEY NEED TO KNOW WHAT IS HAPPENING TO THE EARTH AS A RESULT OF CLIMATE CHANGE. THEY WILL LEARN ABOUT MONSOONS AND THEIR CONNECTIONS TO THE REST OF THE CLIMATE SYSTEM IN THIS BOOK.

WILLIAM (Dr. William K.M. Lau, 劉家銘)

SENIOR CLIMATE SCIENTIST, FORMER DEPUTY DIRECTOR FOR SCIENCE, EARTH SCIENCES DIVISION, NASA, GODDARD SPACE FLIGHT CENTER (GSFC), CURRENTLY AT EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER, UNIVERSITY OF MARYLAND, IS A LEADING EXPERT ON TROPICAL METEOROLOGY, MONSOON CLIMATE VARIABILITY AND CHANGE.



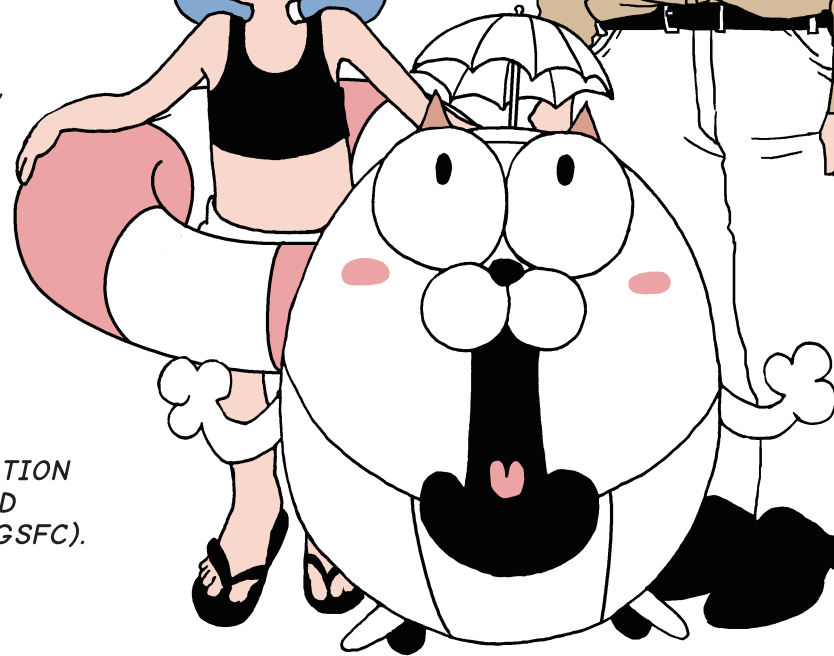
MOL

AN ELEMENTARY SCHOOL GIRL WHO IS ENTHUSIASTIC ABOUT SCIENCE!



MIRUBO

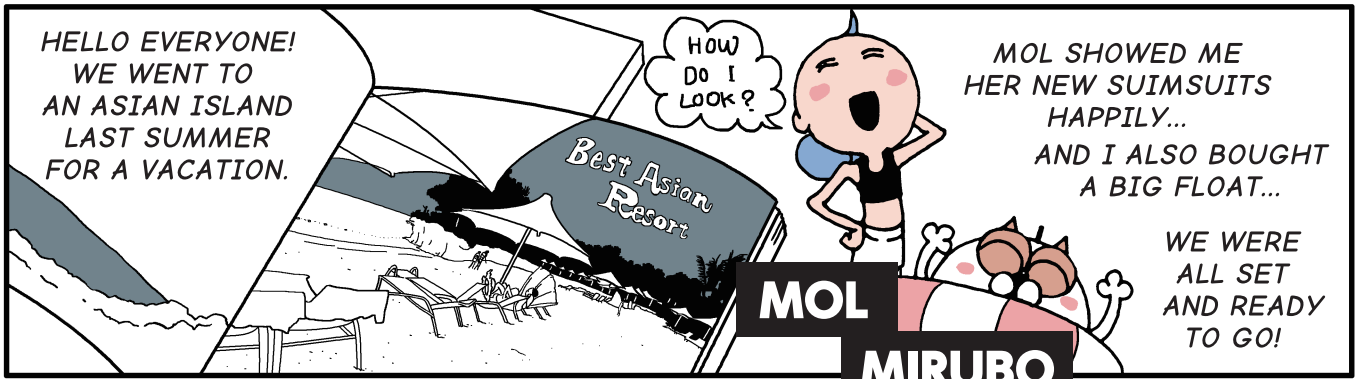
THE ROBOTIC DOG WITH HIGH SPEED CALCULATOR, ROCKET BOOSTERS, AND A STRONG STOMACH!



AND BOB



AN EARTH SCIENTIST, FORMER CHIEF OF THE CLIMATE AND RADIATION LABORATORY AT GODDARD SPACE FLIGHT CENTER (GSFC).



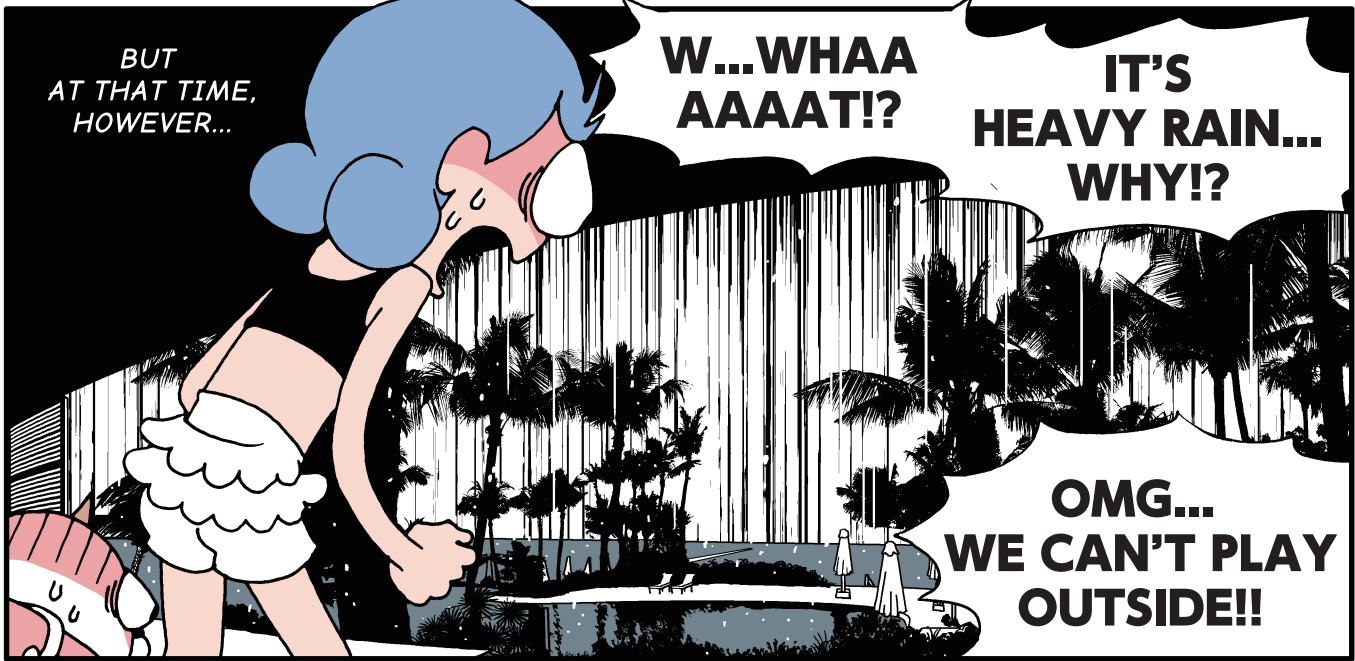
HELLO EVERYONE!
WE WENT TO
AN ASIAN ISLAND
LAST SUMMER
FOR A VACATION.

How
do I
look?

MOL SHOWED ME
HER NEW SUIMSUITS
HAPPILY...
AND I ALSO BOUGHT
A BIG FLOAT...

WE WERE
ALL SET
AND READY
TO GO!

MOL
MIRUBO

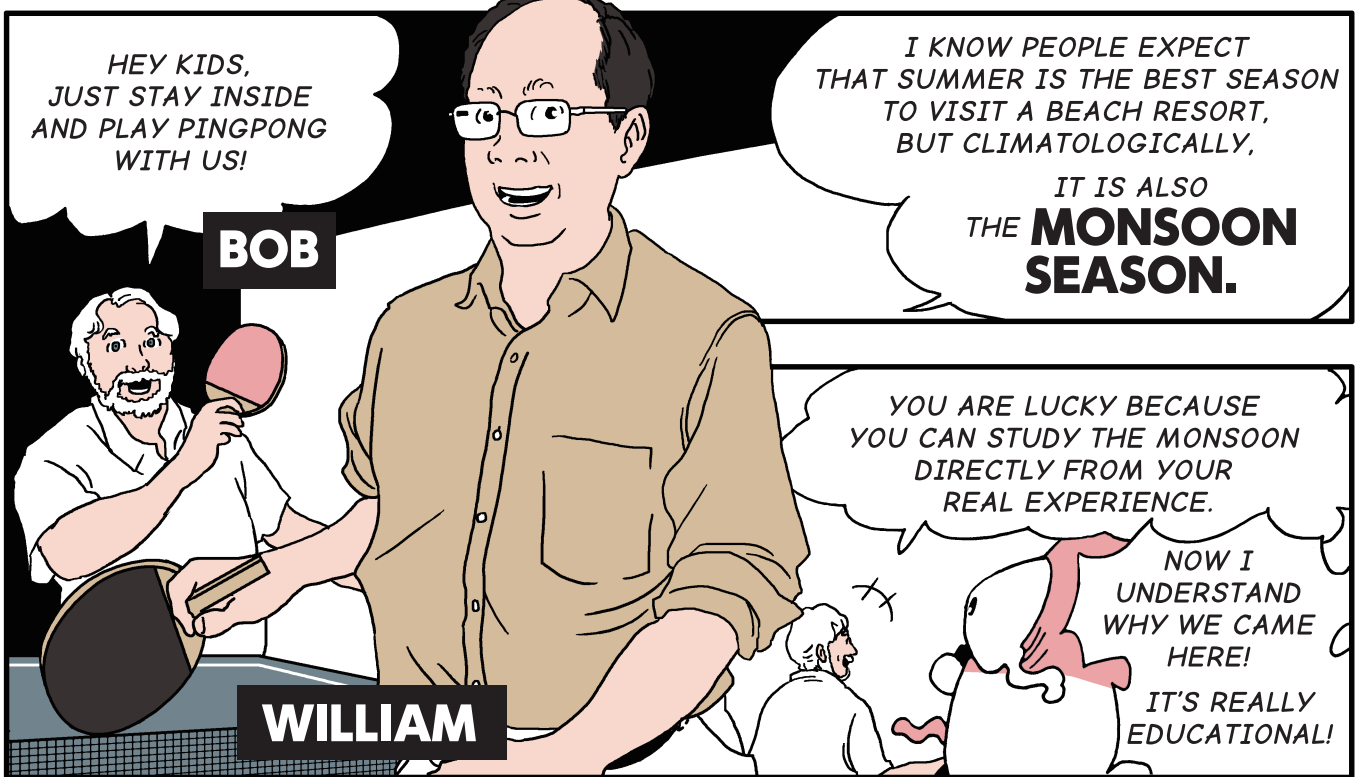


BUT
AT THAT TIME,
HOWEVER...

W...WHAA
AAAAT!?

IT'S
HEAVY RAIN...
WHY!?

OMG...
WE CAN'T PLAY
OUTSIDE!!



HEY KIDS,
JUST STAY INSIDE
AND PLAY PINGPONG
WITH US!

BOB

I KNOW PEOPLE EXPECT
THAT SUMMER IS THE BEST SEASON
TO VISIT A BEACH RESORT,
BUT CLIMATOLOGICALLY,

IT IS ALSO
THE **MONSOON**
SEASON.

YOU ARE LUCKY BECAUSE
YOU CAN STUDY THE MONSOON
DIRECTLY FROM YOUR
REAL EXPERIENCE.

NOW I
UNDERSTAND
WHY WE CAME
HERE!

IT'S REALLY
EDUCATIONAL!

WILLIAM

SO...I DON'T KNOW
WHAT A MONSOON IS.
IS IT JUST RAIN?

THE WORD "MONSOON"
WAS DERIVED FROM THE
ARABIC WORD "MAUSAM"
WHICH MEANS
"SEASON".

A MONSOON CLIMATE HAS
DISTINCT WET AND DRY SEASONS.
A MONSOON ONSET OVER A GIVEN REGION IS
SAID TO OCCUR WHEN THE PREVAILING
WINDS CHANGE DIRECTION
OVER A SHORT TIME PERIOD (SEVERAL DAYS),
BRINGING THE FIRST HEAVY RAINFALL
OF THE RAINY SEASON.

**IN WHAT SEASON
DOES A MONSOON
OCCUR?**

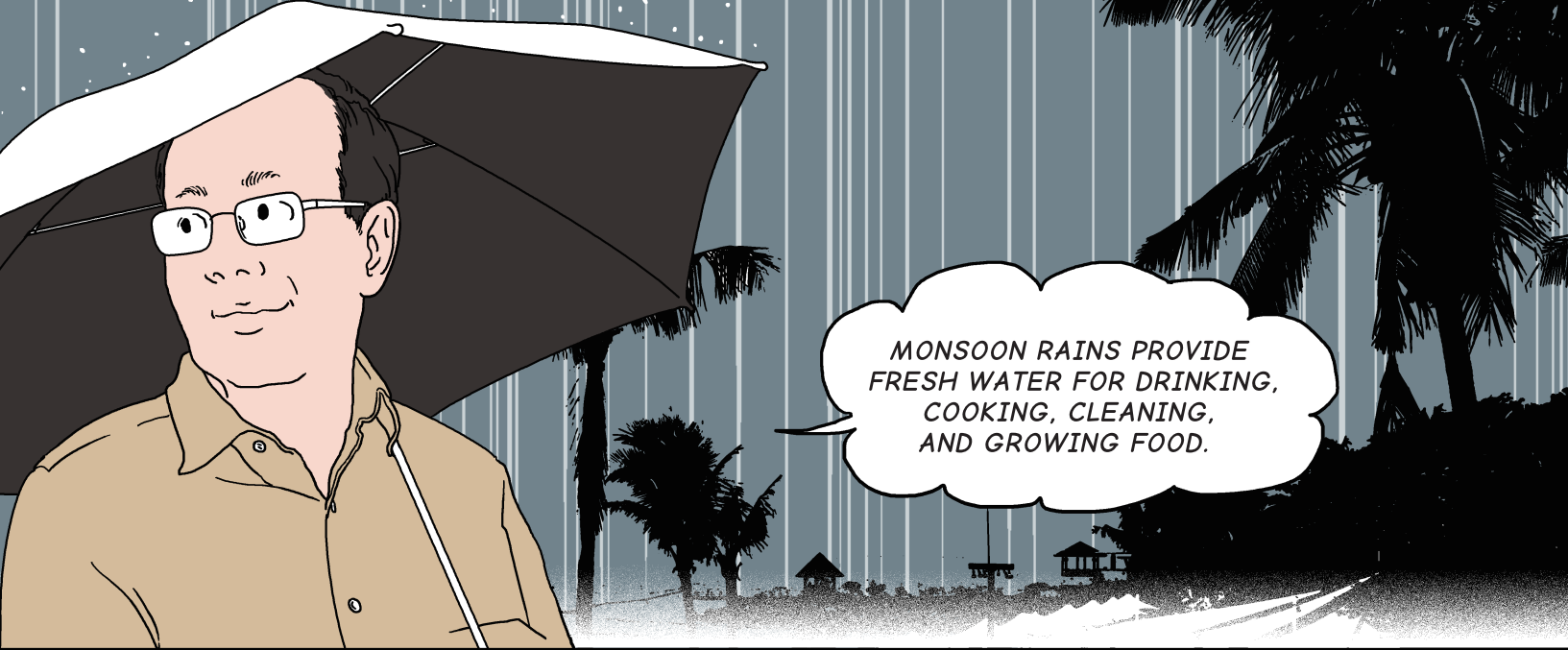
YOU TOLD ME THAT
SUMMER IS THE SEASON
IN WHICH MONSOONS
USUALLY COME,
IS THAT RIGHT?

TO BE MORE PRECISE,
A MONSOON OCCURS IN THE
"WARM AND WET" SEASON.
SO I SAID IT IS MOSTLY
IN SUMMER.

THE MONSOON ARISES
BECAUSE OF THE DIFFERENT WAYS
CONTINENTS AND OCEANS ARE
HEATED BY THE ENERGY
FROM THE SUN.

YOU MEAN,
POWERFUL
SUNLIGHT IS
NEEDED.

EXACTLY!

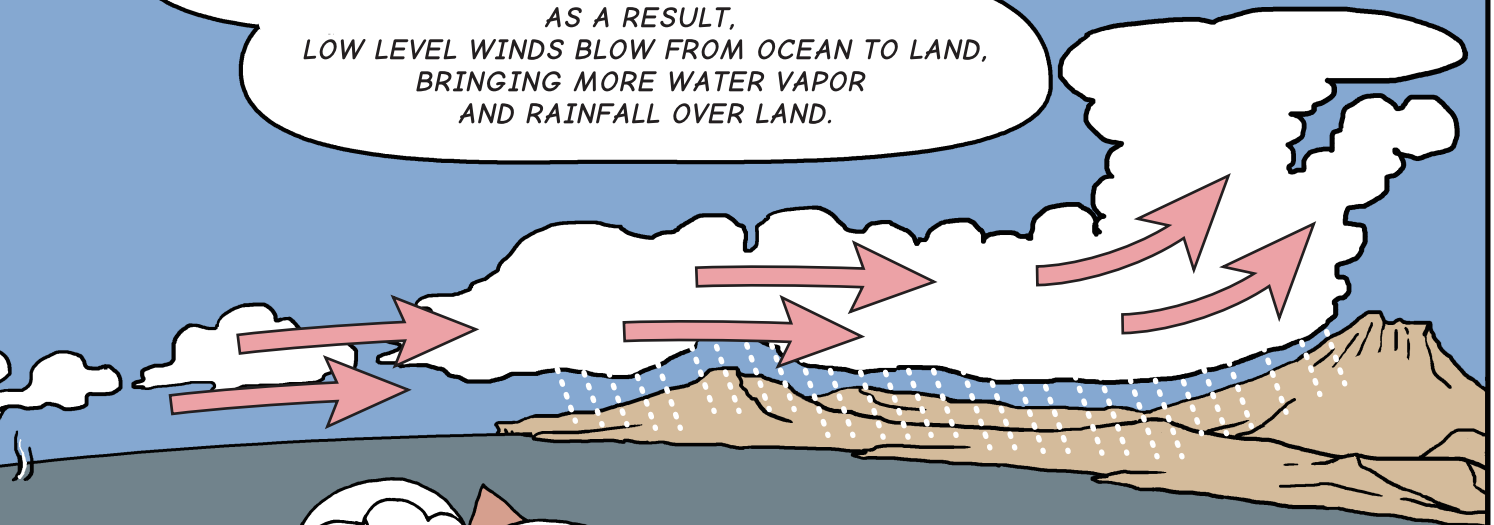


MONSOON RAINS PROVIDE FRESH WATER FOR DRINKING, COOKING, CLEANING, AND GROWING FOOD.

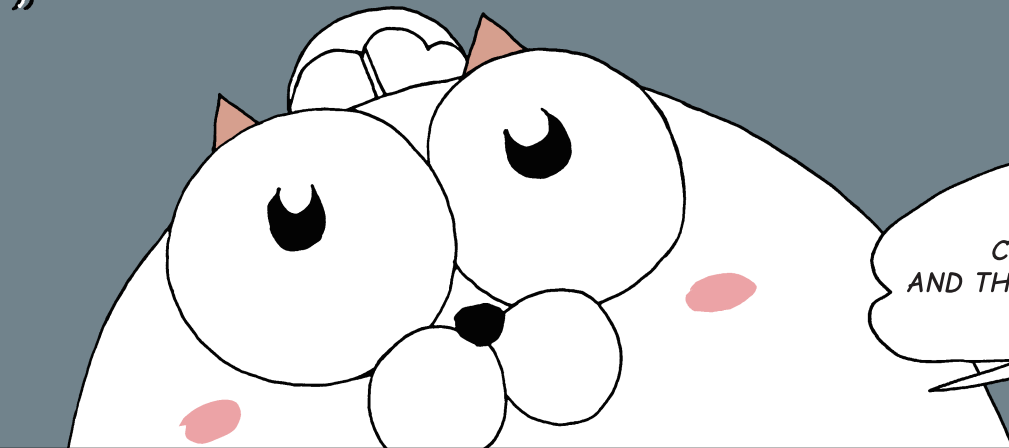
DURING THE MONSOON, SUNLIGHT HEATS UP THE LAND FASTER THAN THE OCEAN.

WARMER AIR OVER LAND IS LIGHTER AND RISES TO FORM CLOUDS. THE RISING AIR DRAWS IN MORE AIR FROM BELOW.

AS A RESULT, LOW LEVEL WINDS BLOW FROM OCEAN TO LAND, BRINGING MORE WATER VAPOR AND RAINFALL OVER LAND.



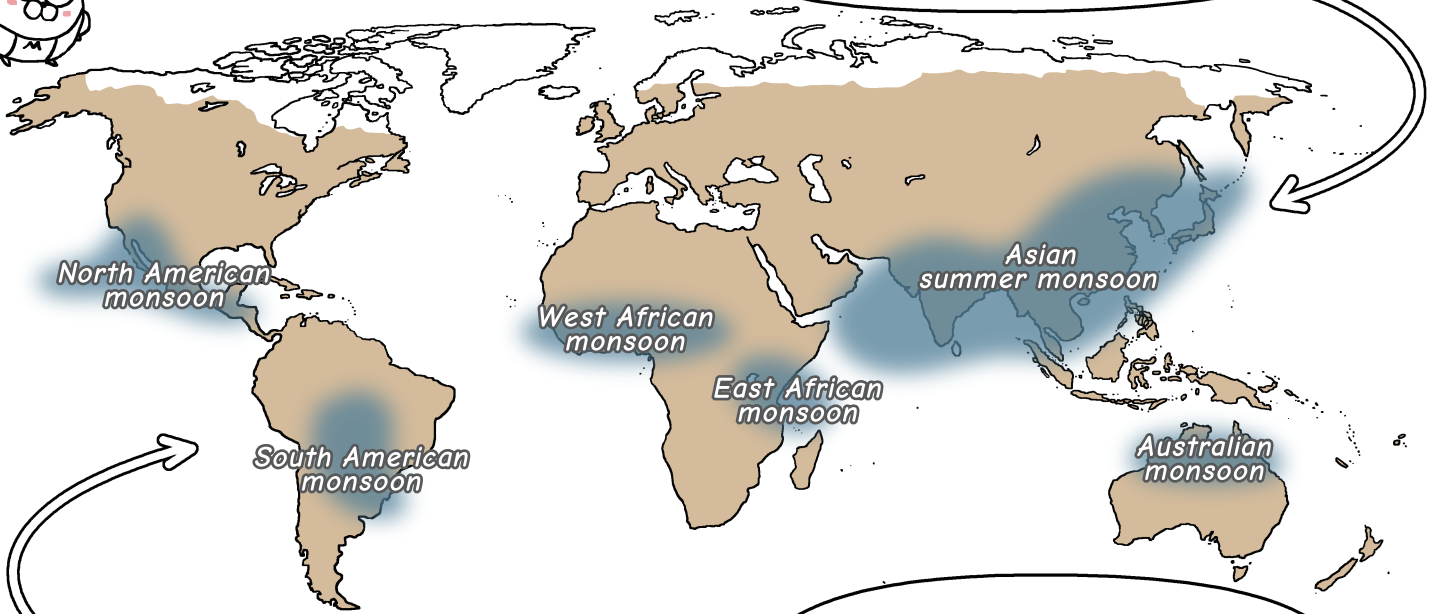
THAT'S WHY CLOUDS ARE CREATED AND THEY COVER THE WHOLE SKY IN SUMMER!



WHERE DO MONSOONS OCCUR?

MOSTLY IN THE TROPICS, IN REGIONS WHERE THERE ARE LARGE LAND MASSES, AND LARGE SPANS OF OCEAN NEAR THE EQUATOR.

BECAUSE OF THE PRESENCE OF THREE MAJOR CONTINENTS IN THE NORTHERN HEMISPHERE, (NORTH AMERICA, ASIA, AND EUROPE/NORTHERN AFRICA)

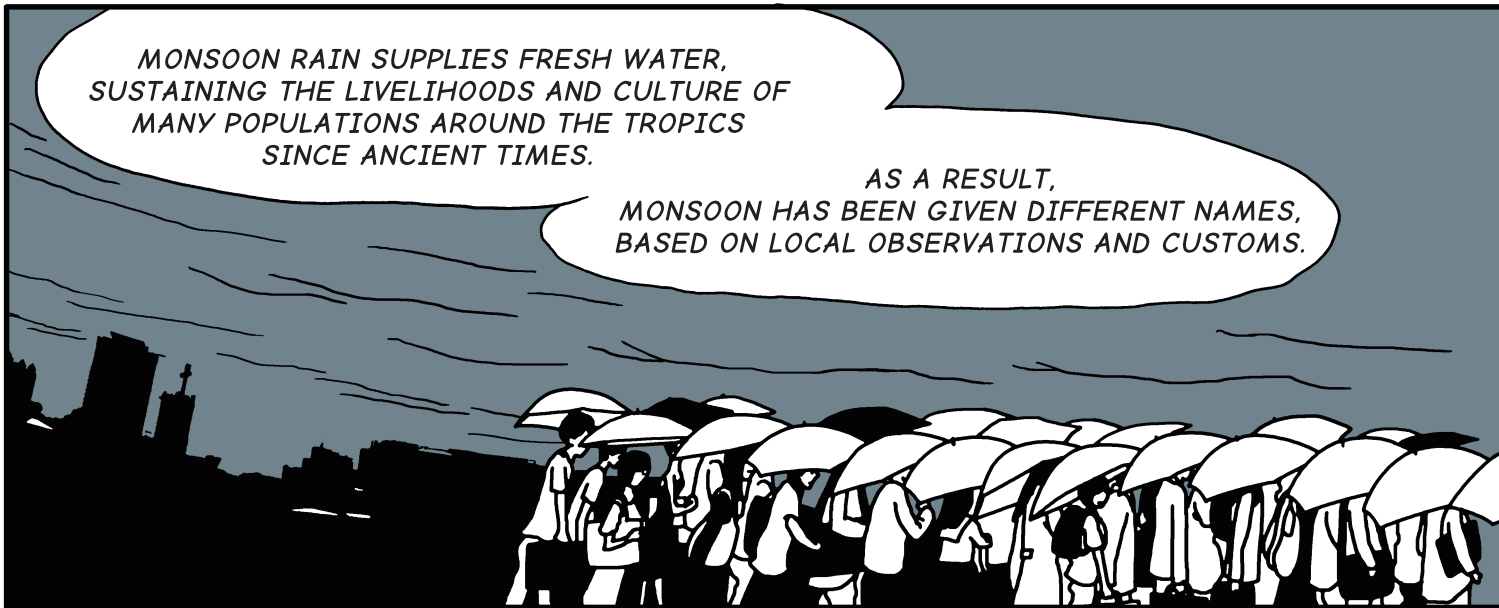


AND THREE IN THE SOUTHERN HEMISPHERE. (SOUTH AMERICA, AUSTRALIA, AND SOUTH AFRICA)

THERE ARE SIX MAJOR MONSOON SYSTEMS IN THE WORLD.

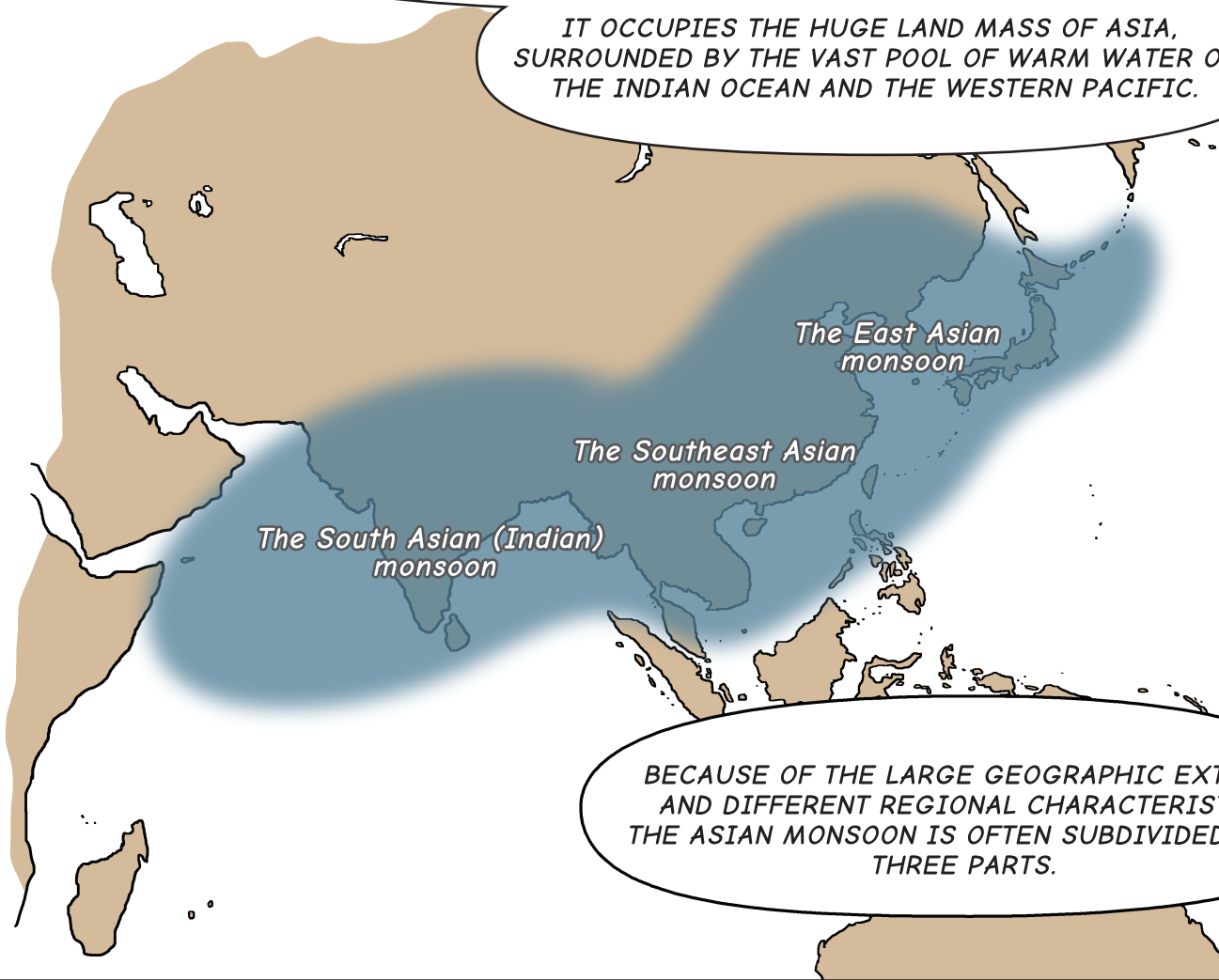
MONSOON RAIN SUPPLIES FRESH WATER, SUSTAINING THE LIVELIHOODS AND CULTURE OF MANY POPULATIONS AROUND THE TROPICS SINCE ANCIENT TIMES.

AS A RESULT, MONSOON HAS BEEN GIVEN DIFFERENT NAMES, BASED ON LOCAL OBSERVATIONS AND CUSTOMS.



HOME TO MORE THAN 60% OF THE WORLD POPULATION,
**THE ASIAN MONSOON IS
THE LARGEST AND THE STRONGEST.**

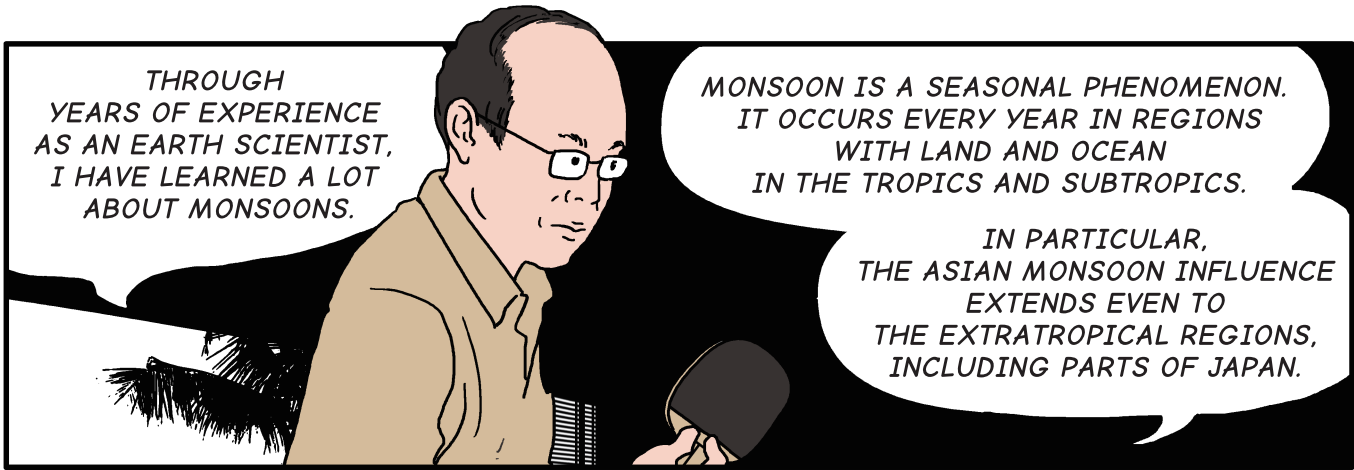
IT OCCUPIES THE HUGE LAND MASS OF ASIA,
SURROUNDED BY THE VAST POOL OF WARM WATER OF
THE INDIAN OCEAN AND THE WESTERN PACIFIC.



BECAUSE OF THE LARGE GEOGRAPHIC EXTENT,
AND DIFFERENT REGIONAL CHARACTERISTIC,
THE ASIAN MONSOON IS OFTEN SUBDIVIDED INTO
THREE PARTS.

THE MONSOON RAIN IS KNOWN AS
"MEI-YU" IN CHINA,
"BAI-U" IN JAPAN, AND
"CHANGMAI" IN KOREA.
THE SOUTHWEST MONSOON WINDS
IN INDIA ARE CALLED
"NAIRUTYA MAARUT".

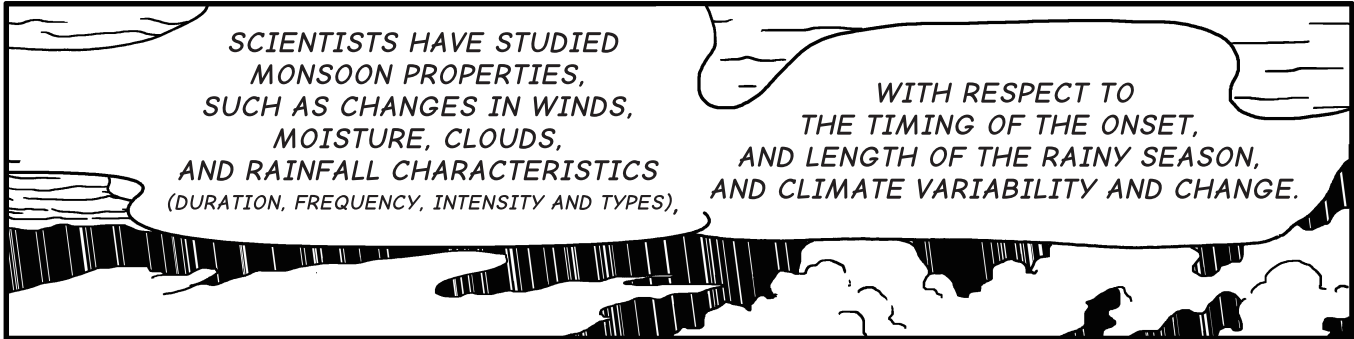
I CAN IMAGINE THAT
ASIAN PEOPLE KNOW
THE MONSOON WELL BECAUSE
THEY HAVE LIVED WITH
THE MONSOON FOR SO LONG!



THROUGH YEARS OF EXPERIENCE AS AN EARTH SCIENTIST, I HAVE LEARNED A LOT ABOUT MONSOONS.

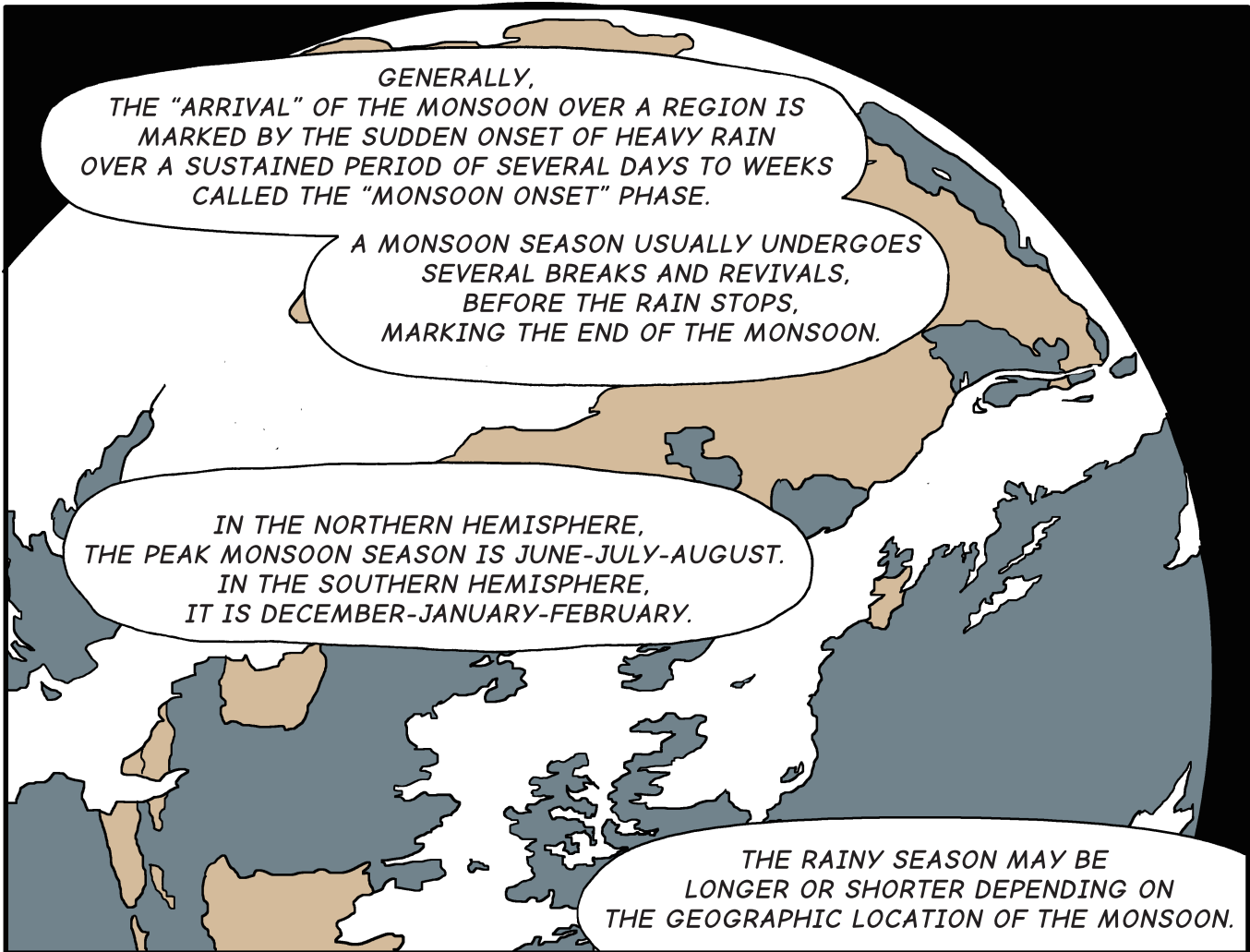
MONSOON IS A SEASONAL PHENOMENON. IT OCCURS EVERY YEAR IN REGIONS WITH LAND AND OCEAN IN THE TROPICS AND SUBTROPICS.

IN PARTICULAR, THE ASIAN MONSOON INFLUENCE EXTENDS EVEN TO THE EXTRATROPICAL REGIONS, INCLUDING PARTS OF JAPAN.



SCIENTISTS HAVE STUDIED MONSOON PROPERTIES, SUCH AS CHANGES IN WINDS, MOISTURE, CLOUDS, AND RAINFALL CHARACTERISTICS (DURATION, FREQUENCY, INTENSITY AND TYPES),

WITH RESPECT TO THE TIMING OF THE ONSET, AND LENGTH OF THE RAINY SEASON, AND CLIMATE VARIABILITY AND CHANGE.



GENERALLY, THE "ARRIVAL" OF THE MONSOON OVER A REGION IS MARKED BY THE SUDDEN ONSET OF HEAVY RAIN OVER A SUSTAINED PERIOD OF SEVERAL DAYS TO WEEKS CALLED THE "MONSOON ONSET" PHASE.

A MONSOON SEASON USUALLY UNDERGOES SEVERAL BREAKS AND REVIVALS, BEFORE THE RAIN STOPS, MARKING THE END OF THE MONSOON.

IN THE NORTHERN HEMISPHERE, THE PEAK MONSOON SEASON IS JUNE-JULY-AUGUST. IN THE SOUTHERN HEMISPHERE, IT IS DECEMBER-JANUARY-FEBRUARY.

THE RAINY SEASON MAY BE LONGER OR SHORTER DEPENDING ON THE GEOGRAPHIC LOCATION OF THE MONSOON.

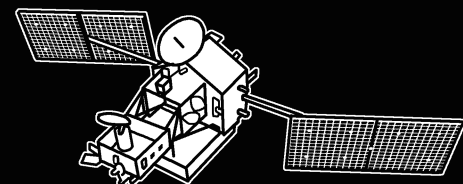
HOW DO SCIENTISTS GET DATA?

IN ANCIENT TIMES, PEOPLE KNEW THE MONSOON WAS COMING BY SEEING AND FEELING CHANGES IN TEMPERATURE, WINDS, HUMIDITY, CLOUDS AND RAINFALL.

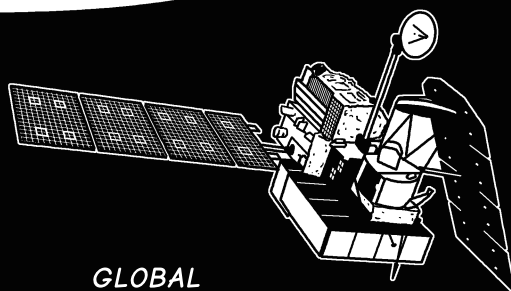
NOWADAYS, ALL THESE QUANTITIES ARE MEASURED BY STANDARDIZED INSTRUMENTS ON THE GROUND,

AND ATTACHED PAYLOADS ON BALLOONS (CALLED RADIOSONDE), AIRCRAFT, AS WELL AS DETECTORS ONBOARD SATELLITES THAT CAN SEE THE EARTH FROM SPACE, AS THEY CIRCLE AROUND IT.

SATELLITE OBSERVATIONS ARE BECOMING MORE AND MORE IMPORTANT FOR MONITORING GLOBAL WEATHER AND CLIMATE, ESPECIALLY RAINFALL.



TROPICAL RAINFALL MEASURING MISSION (TRMM)



GLOBAL PRECIPITATION MISSION (GPM)

...AND THERE ARE ALSO OTHER SATELLITES

SINCE 1989, THERE HAVE BEEN TWO MAJOR JOINT US-JAPAN SATELLITE MISSIONS CALLED THE TROPICAL RAINFALL MEASURING MISSION (TRMM), FOLLOWED BY THE GLOBAL PRECIPITATION MISSION (GPM) TO MEASURE RAINFALL FROM SPACE.

BECAUSE RAINFALL IS ESSENTIAL TO MAINTAIN LIFE ON EARTH, IT IS BY FAR THE MOST IMPORTANT ELEMENT OF NOT ONLY THE MONSOON, BUT ALSO THE ENTIRE EARTH.

Satellites in this part are illustrated based on official images provided by NASA

WHILE MONSOON RAINFALL SUSTAINS LIFE, IT CAN ALSO AFFECT THE ENVIRONMENT AND SOCIETY IN A BAD WAY.

TOO MUCH MONSOON RAINFALL CAN CAUSE FLOODING. TOO LITTLE MONSOON RAINFALL CAN LEAD TO DROUGHT.

MONSOON FLOODS CAN CAUSE LANDSLIDES, DESTRUCTION OF PROPERTY, AND LOSS OF LIFE.

DROUGHTS CAN CAUSE EXCESSIVELY HOT WEATHER, CROP FAILURE, WILDFIRES, AND MAJOR HEALTH HAZARDS TO HUMANS AND ANIMALS.

HMM.. I DON'T LIKE EITHER!

KNOWING WHEN MONSOON RAIN WILL COME, AND HOW HEAVY THE RAIN WILL BE, WHEN A DROUGHT WILL OCCUR, AND HOW LONG IT WILL LAST, WILL ALLOW FARMERS, RANCHERS, DISASTER PREVENTION ORGANIZATIONS, AND GOVERNMENTS TO TAKE PREVENTATIVE ACTIONS BEFORE FLOODS AND DROUGHTS OCCUR, AND HELPS TO EASE THE BAD EFFECTS OF MONSOON.

HENCE,
PREDICTING MONSOON RAINFALL IS VERY IMPORTANT.

SCIENTISTS ARE WORKING HARD TO IMPROVE THE SKILLS OF MONSOON RAINFALL PREDICTIONS.

MONSOONS ARE DEFINITELY AFFECTED BY **CLIMATE CHANGE.**

OH... MOL AND I ARE LEARNING ABOUT THAT!

WE NOW KNOW THAT THERE ARE TWO MAIN MAN-MADE FACTORS, WHICH ARE GREENHOUSE GASES AND AIR POLLUTION AEROSOLS, THAT CAN STRONGLY AFFECT THE MONSOON.

AIR POLLUTION AEROSOLS

THE FACTORS COULD CHANGE THE LAND-SEA THERMAL CONTRASTS, DISTRIBUTIONS OF WIND, MOISTURE, CLOUDS AND RAINFALL IN MONSOON REGIONS.

GREENHOUSE GASES

OTHER FACTORS SUCH AS LAND USE AND CHANGE, RELATED TO URBAN DEVELOPMENT, IRRIGATION, DEFORESTATION AND MINING, CAN ALSO AFFECT THE MONSOON.

ADDITIONALLY, LONG-TERM CHANGES IN SEA SURFACE TEMPERATURE AND WINDS IN OTHER PARTS OF THE WORLD CAN ALSO AFFECT MONSOON CLIMATE CHANGE.

ALL THESE FACTORS CAN INTERACT IN **COMPLEX WAYS** TO CAUSE CLIMATE CHANGE IN THE ASIAN MONSOON THAT WE DON'T QUITE UNDERSTAND.

MANY SCIENTISTS AROUND THE WORLD ARE STUDYING THE MONSOON TO FIND OUT HOW IT HAS BEEN, AND WILL BE, AFFECTED BY CLIMATE CHANGE.

I GOT IT!

NOW WE KNOW WHAT SCIENTISTS DO, AND IS THERE ANYTHING WE CAN DO?

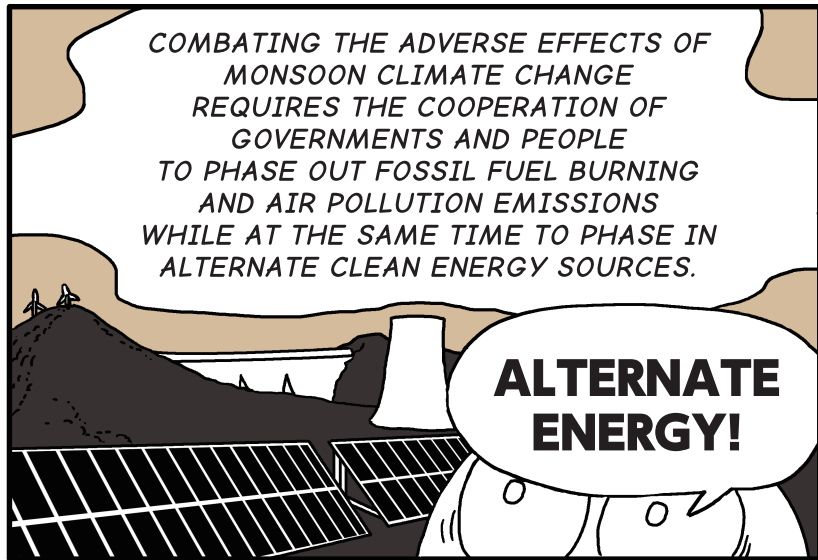


WE NEED TO REDUCE EMISSIONS OF **GREENHOUSE GASES** FROM FOSSIL FUEL BURNING, AS WELL AS **AEROSOLS** FROM INDUSTRIAL AND URBAN AIR POLLUTION.

HOWEVER, SIMPLY CUTTING BACK ON FOSSIL FUEL BURNING AND INDUSTRIAL POLLUTION MAY CAUSE MAJOR DISRUPTION AND SETBACKS TO OUR ECONOMY.



HMM... INDEED. WHAT SHOULD WE DO?



COMBATING THE ADVERSE EFFECTS OF MONSOON CLIMATE CHANGE REQUIRES THE COOPERATION OF GOVERNMENTS AND PEOPLE TO PHASE OUT FOSSIL FUEL BURNING AND AIR POLLUTION EMISSIONS WHILE AT THE SAME TIME TO PHASE IN ALTERNATE CLEAN ENERGY SOURCES.

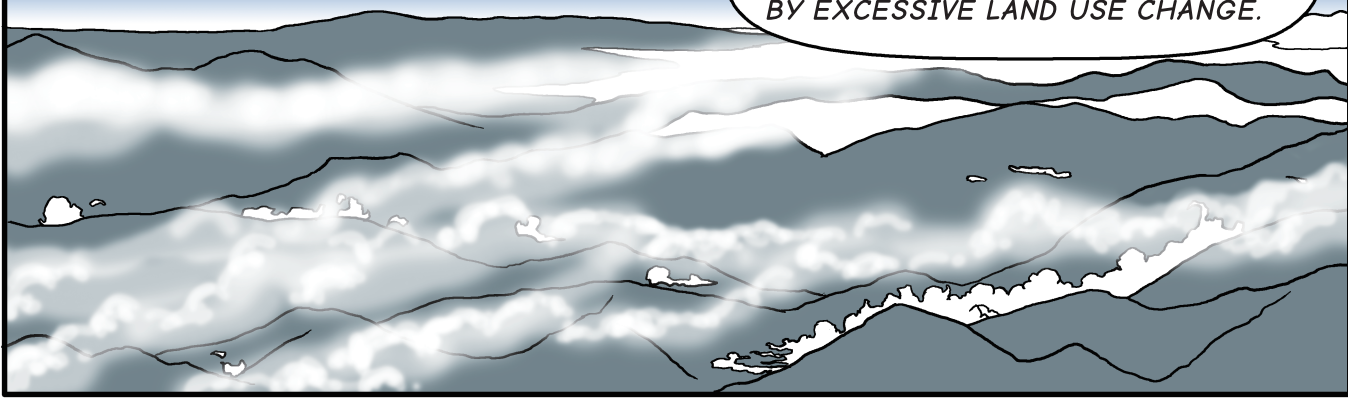
ALTERNATE ENERGY!

TREES AND VEGETATION CAN ABSORB CARBON DIOXIDE (A MAJOR GREENHOUSE GAS) IN THE ATMOSPHERE.

THUS PLANTING MORE TREES AND VEGETATION CAN REDUCE THE GREENHOUSE WARMING EFFECT.

REDUCING POLLUTION AEROSOLS WILL IMPROVE AIR QUALITY AND HUMAN HEALTH.

WE SHOULD ALSO CONSERVE THE NATURAL ENVIRONMENT, AND PREVENT OVERDEVELOPMENT BY EXCESSIVE LAND USE CHANGE.



CAN YOU REMEMBER?
TODAY WE LEARNED...

1. THE WORD **“MONSOON”** WAS DERIVED FROM THE WORD **“SEASON”**.
A MONSOON ONSET OVER A REGION IS SAID TO OCCUR WHEN A SUDDEN CHANGE IN WIND DIRECTION BRINGS ON THE FIRST HEAVY RAINFALL OF THE RAINY SEASON.

2. THERE ARE SIX MAJOR MONSOON SYSTEMS IN THE WORLD.

THE ASIAN MONSOON IS THE LARGEST AND STRONGEST.

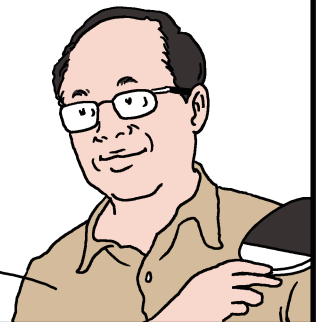
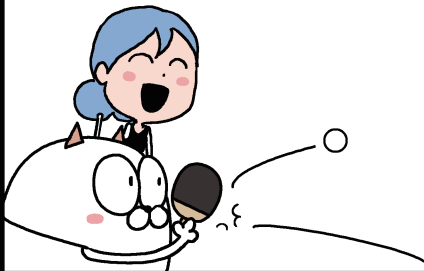
3. NOWADAYS, **SATELLITE OBSERVATIONS** ARE VERY IMPORTANT IN THE STUDY OF CLIMATE CHANGE, BECAUSE THEY CAN OBSERVE CHANGES IN RAINFALL, WEATHER AND CLIMATE GLOBALLY, ESPECIALLY IN DENSELY POPULATED MONSOON REGIONS.

4. SCIENTISTS HAVE FOUND THAT MONSOON SYSTEMS ARE BEING **CHANGED BY MAN-MADE GREENHOUSE GAS WARMING AND AIR POLLUTION**, CAUSING MORE FLOODS AND DROUGHTS, WITH DISASTROUS EFFECTS ON SOCIETY AND THE ENVIRONMENT.

5. MONSOONS ARE AFFECTED BY CLIMATE CHANGE IN VERY COMPLEX WAYS. WE NEED FURTHER STUDIES TO BETTER UNDERSTAND AND **PREDICT THE MONSOON**, IN A CHANGING CLIMATE.

6. THERE ARE THINGS WE CAN DO TO **LESSEN THE BAD IMPACTS** OF MONSOON CLIMATE CHANGE.

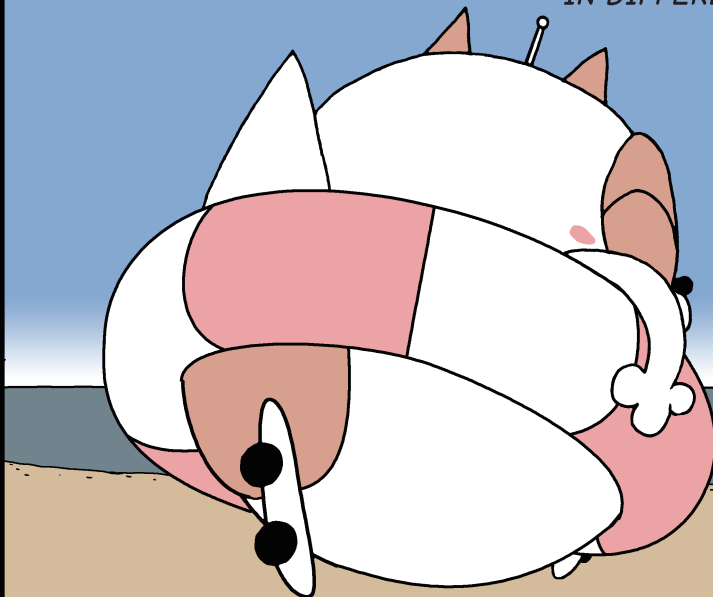
SCIENTISTS STUDY
THE MONSOON
TO UNDERSTAND
THE CLIMATE SYSTEM.



ENVIRONMENT AND CLIMATE ARE CLOSELY CONNECTED.
SOMETHING THAT HAPPENS HERE CAN AFFECT SOMETHING ELSE
IN DIFFERENT PLACES AT DIFFERENT TIMES.

SO WE NEED TO KNOW MORE ABOUT
EARTH SCIENCE,
AND KEEP GOOD HABITS TO MAKE
OUR ENVIRONMENT BETTER!

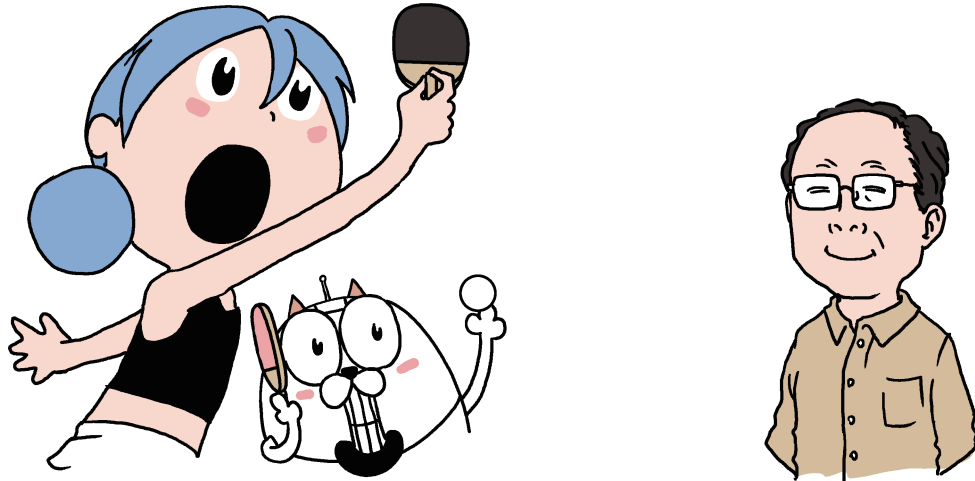
LET'S DO IT
TOGETHER!





Learning Earth Science with MIRUBO


Monsoon


Talking with a Climate Scientist




 **MOL:** *Dr. Lau, thank you for telling us about monsoon and climate change. You said monsoon is driven by land-sea temperature differences. Monsoon land has high mountains? Can mountains affect the monsoons?*


 **Dr. LAU:** *Mol, this is a very good question. During late spring to early summer, high mountains heat up faster than lower land because it is closer to the sun. Furthermore, mountains can deflect wind flow, alter moisture transport and change locations where monsoon rains fall.*


 **MOL:** *This is interesting. Can you give me an example?*

 **Dr. LAU:** *For the Asian monsoon, the Tibetan Plateau, known as the rooftop of the world, acts as an “elevated” heat source. During May to early June, before the onset of the monsoon, as the seasonal low-level southwesterly winds blow over the Indian subcontinent, it hits the southward facing slope of the Tibetan Plateau, and is forced to rise. The forced rising motion draws in more low-level moisture from the Arabian Sea and the Indian Ocean to form clouds and heavy rain to initiate the onset of the Indian monsoon.*


 **MOL:** *High mountains have snowcover. Can snowcover change the monsoon?*

 **Dr. LAU:** *Yes, indeed. Because snow is white, it can reflect more sunlight, and reduce the amount of solar energy reaching the land surface. Less sunlight reaching the surface will lead to less heating, and reduced land-sea thermal contrast.*


 **MOL:** *Reduced land-sea thermal contrast? Hmmmm, Does that mean a weaker monsoon?*


 **Dr. LAU:** *Yes, you are so smart. Scientists have found that following a cold winter, with heavy snow cover over the Tibetan Plateau, the India monsoon tends to be weaker. On the other hand, a mild winter with less snow cover over the Tibetan Plateau is likely to be followed by a stronger Indian monsoon.*


 **MOL:** *What other factors can affect the monsoon?*


 **Dr. LAU:** *Besides land-sea contrast within the monsoon region, there are other factors outside the monsoon region that can affect the monsoon. These are known as “remote forcings”. Remote forcings of the monsoon include snow cover over Eurasia, and sea surface temperature changes due to El Nino.*

 **MIRUBO:** *El Nino? What is that?*

 **Dr. LAU:** *El Nino is a natural cycle of warming and cooling of sea surface temperature over the equatorial central and eastern Pacific, every 3-5 years. The warming phase is the El Nino. The cooling phase is the La Nina. Scientists have found that during El Nino, the Indian monsoon is generally weaker, and stronger during La Nina. Additionally, surface temperature in the Indian Ocean, the North Pacific, and the northern Atlantic Ocean, sea and land ice extent in polar regions are all remote forcings of the monsoon. In this way, the monsoon is connected to all the rest of the earth.*

 **MOL:** *You mentioned greenhouse gases and aerosol can cause monsoon climate change? How so? Which is more important?*

 **Dr. LAU:** *Both are important. Globally, greenhouse gases cause warming by trapping heat, and aerosols cause cooling by blocking off sunlight reaching the surface. Over monsoon regions, the situations are more complicated. Depending on their optical properties, aerosols can absorb sunlight and heat the atmosphere, or scatter sunlight and cool the atmosphere. Aerosols can also change the ways clouds and rainfall are formed. Thus aerosols may actually “amplify” or alternatively “mask” greenhouse warming. Furthermore, naturally occurring aerosols such as desert dust, and wildfires may also affect the monsoon.*

 **MOL:** *WOW! There is so much to be learned about monsoon climate change. We should all be doing our part to deepen and spread our understanding of the monsoon, so that we can come up with the right policy and tools to deal with the threats of monsoon climate change to society.*

Monsoon

Science Educational Content
Dr. William K.M. Lau
Character Designs, Artwork, and Story
Hayanon

About this project

This is the third of several manga books about climate change in which NASA scientists discuss aspects of the climate system with two manga style characters, Mirubo the robotic dog, and Mol, an elementary school girl who is enthusiastic about science. These are intended to excite the curiosity of children and their families and friends about changes in Earth's climate, and to encourage them to get involved in their community's action efforts.

About GSFC

Goddard Space Flight Center is a major NASA center located in Greenbelt, Maryland, and is the largest combined organization of scientists and engineers in the United States dedicated to increasing knowledge of the Earth, the Solar System, and the Universe via observations from space.

About authors

Hayanon has more than 15 years' experience in educational publishing in Japan as a science manga artist. She holds a Bachelor's degree in physics and a Master's degree in education. The characters Mirubo and Mol, created by Hayanon also appear in several books distributed by Nagoya University. (See references below.)

Dr. Lau, former Deputy Director of Science, Earth Sciences Division, NASA/GSFC, currently senior climate scientist at the Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, has been involved for 40 years in research in tropical meteorology, monsoon dynamics, aerosols, climate variability and changes. He is a Fellow of the American Geophysical Union, and of the American Meteorological Society. He is a former President of the Atmospheric Science Division of the American Geophysical Union.

Thanks to

William and Hayanon would like to thank Marion August and Cathy Newman of SSAI for their tireless administrative support for this work, and Bob Cahalan for his continuing encouragement and enthusiasm for the climate-change manga series.

References

This booklet may be downloaded as a PDF file at: <https://science.gsfc.nasa.gov/610/manga.html>

Mol and Mirubo also appear in science manga books at: <http://www.stelab.nagoya-u.ac.jp/ste-www1/doce/outreach.html>



Produced by NASA's Goddard Space Flight Center, Greenbelt, Maryland, February 2017.

