

THE **CARTOON**
INTRODUCTION TO
**CLIMATE
CHANGE**

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THE WORLD'S FIRST AND ONLY **STAND-UP ECONOMIST**

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**PART
ONE**
OBSERVATIONS

CHAPTER 1
INTRODUCTION

**TWO STORIES ARE
GOING TO DOMINATE
THE 21ST CENTURY.**



STORY #1 IS ABOUT **ECONOMIC GROWTH**, ESPECIALLY IN POOR COUNTRIES IN ASIA AND AFRICA.



CAPITALISM AND FREE-MARKET ECONOMICS ARE GOING TO CREATE A LOT OF **NEW WEALTH**...



... AND GIVE MANY MORE PEOPLE THE OPPORTUNITY TO **PURSU**E THEIR DREAMS.



WEALTHIER FAMILIES TEND TO HAVE **FEWER CHILDREN**...



HAVING MORE KIDS IS **NOT** ONE OF MY DREAMS!



... SO THE WORLD POPULATION IS LIKELY TO **PEAK** AT ABOUT **10 BILLION** PEOPLE AND THEN SLOWLY DECLINE.



AS A RESULT, **STORY #1** POINTS IN A DIRECTION THAT'S NOTHING SHORT OF **MIRACULOUS**.

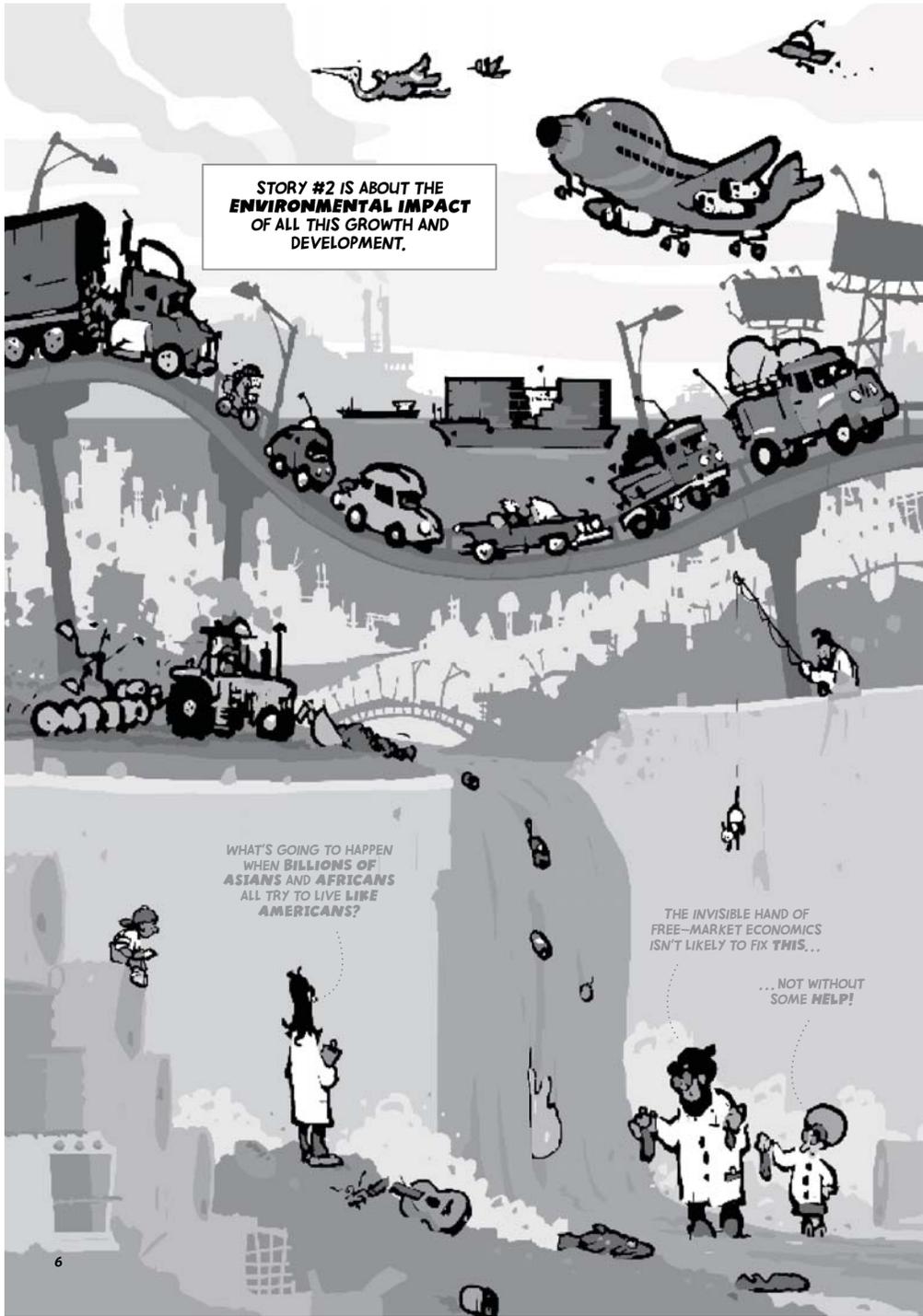


A WORLD OF **2-6 BILLION** WELL-EDUCATED AND THEREFORE **HEALTHY** AND **WEALTHY** PEOPLE!

IT SEEMS **TOO GOOD** TO BE **TRUE!**



BUT WHAT ABOUT **STORY #2**?



STORY #2 IS ABOUT THE ENVIRONMENTAL IMPACT OF ALL THIS GROWTH AND DEVELOPMENT.

WHAT'S GOING TO HAPPEN WHEN BILLIONS OF ASIANS AND AFRICANS ALL TRY TO LIVE LIKE AMERICANS?

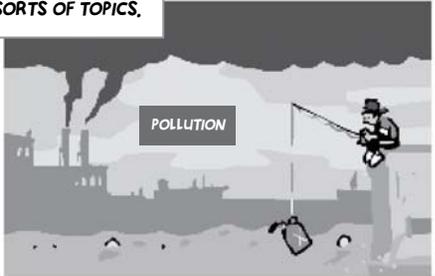
THE INVISIBLE HAND OF FREE-MARKET ECONOMICS ISN'T LIKELY TO FIX THIS...

... NOT WITHOUT SOME HELP!

ENVIRONMENTAL CONCERNS COVER ALL SORTS OF TOPICS.



OVERFISHING



POLLUTION

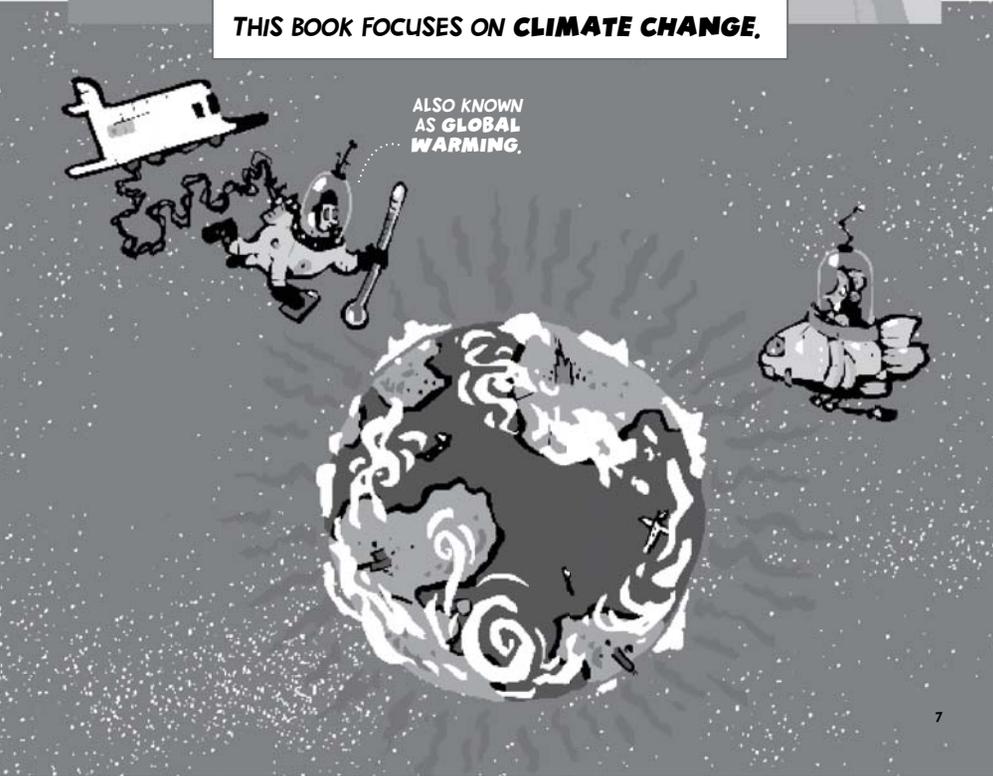


ENDANGERED SPECIES



HABITAT LOSS

THIS BOOK FOCUSES ON **CLIMATE CHANGE**.



ALSO KNOWN AS **GLOBAL WARMING**.

CLIMATE CHANGE IS A **POLITICALLY CHARGED ISSUE.**

YOU'RE A **DENIER!**

YOU'RE AN **ALARMIST!**

BROTHER

SISTER

DAD BETWEEN THEM

BUT IT MIGHT BE POSSIBLE TO FIND SOME **COMMON GROUND...**

THAT COMMON GROUND BETTER BE 6 FEET UNDER BECAUSE **WE'RE ALL GOING TO DIE!**

NONSENSE, **WE'RE ALL GOING TO LIVE!**

... BY THINKING OF CLIMATE CHANGE AS A **THREAT.**

THESE ARE ON THE FRIDGE, LIKE MAGNETIC POETRY, BUT MAGNETIC THREATS.

LIST OF THREATS:

VIOLENT VIDEO GAMES
NATIONAL DEBT
TERRORISM
ASTERIODS

BIRD FLU
STUPIDITY
JUNK FOOD

POLLUTED DRINKING WATER.
BAD SPEELING
POVERTY
SPACE ALIENS
REALITY T.V.

HOW DOES THIS ONE COMPARE?

CLIMATE CHANGE

MAYBE IT'S AN **EXISTENTIAL THREAT...**

... AND MAYBE IT'S ONLY A **MINOR THREAT...**

CLIMATE CHANGE COULD TURN THE EARTH INTO AN **ALIEN PLANET.**

HOW DO YOU KNOW IT WON'T BE AN **AWESOME ALIEN PLANET?**

BROTHER

SISTER

... AND MAYBE IT'LL BE **DECADES** BEFORE WE KNOW FOR SURE.

AND BY THEN IT MIGHT BE **TOO LATE TO DO MORE!**

OR TO DO **LESS!**

NO WONDER CLIMATE CHANGE IS SUCH A **WICKED PROBLEM.**

THIS BOOK WILL HELP YOU **MAKE UP YOUR OWN MIND.**

AND LEARN **WHAT YOU CAN DO ABOUT IT...**

... AND WHAT WE CAN **ALL DO TOGETHER!**

YOU MIGHT FIND IT HARD TO BELIEVE THAT HUMANS CAN INFLUENCE THE ENTIRE PLANET...



... BUT THERE'S LOTS OF SCIENTIFIC EVIDENCE THAT HUMAN ACTIVITY IS CHANGING THE CLIMATE.

MOSTLY AS A RESULT OF BURNING FOSSIL FUELS AND DEFORESTATION.

AND SOMETIMES BOTH AT THE SAME TIME!

1950s

2000s



THIS BOOK IS ABOUT THE SCIENCE OF CLIMATE CHANGE...

ICONS OR SEPARATE SCIENTISTS?

LOOKING IN A MICROSCOPE?

PART ONE:
OBSERVATIONS

[AKA GLOBAL WARMING ("WANTED" POSTER?) OR MAYBE SCIENTISTS SAY "WE SAID THERE'S A LOT OF EVIDENCE, AND HERE IT IS!"]

[AKA GLOBAL WARMING ("WANTED" POSTER?) OR MAYBE SCIENTISTS SAY "WE SAID THERE'S A LOT OF EVIDENCE, AND HERE IT IS!"]

... AND HOW CLIMATE CHANGE MIGHT AFFECT LIFE ON EARTH...

PULLING GOOEY THING FROM A PETRI DISH?

PART TWO:
PREDICTIONS

IMAGES TO COME FROM THOSE CHAPTERS,

... AND WHAT WE CAN DO ABOUT IT.

BICYCLING? OR GENERATING POWER FROM THE GOOEY THING? OR HMMMM,

PART THREE:
ACTIONS

[SO THE THREE PARTS ARE: WHAT'S HAPPENING, HOW BAD WILL IT BE, WHAT CAN WE DO ABOUT IT?]

A GOOD PLACE TO START IS WITH A FEW **DEFINITIONS...**

CLIMATE REFERS TO WHAT THE WEATHER IN A CERTAIN PLACE IS **USUALLY** LIKE.

SEATTLE IN JULY HAS **SUNNY SKIES 90% OF THE TIME.**

AFTERNOON HIGHS ARE USUALLY 21-28C (69-82F)...

... AND IT **ALMOST NEVER RAINS!**

SOUNDS **PERFECT FOR A WEDDING!**

USUALLY DOESN'T MEAN **ALWAYS...**

... SO YOU SHOULD THINK OF CLIMATE AS **AVERAGE WEATHER...**

SORRY! THIS IS VERY **UNUSUAL.**

CLIMATE IS LIKE YOUR **PERSONALITY.**

WEATHER IS LIKE YOUR **MOOD.**

... AND **CLIMATE CHANGE** AS A **CHANGE IN AVERAGE WEATHER.**

ON AVERAGE, THESE FLOWERS NOW BLOOM **ONE WEEK EARLIER** THAN THEY DID 50 YEARS AGO.

... AND WITH AN **OBSERVATION.**

EARTH'S CLIMATE HAS ALWAYS BEEN IN FLUX.

HERE ON PLANET EARTH, CLIMATE CHANGE HAS **ALWAYS BEEN A FACT OF LIFE...**

... AND IT **ALWAYS WILL BE.**

BUT IF THE CLIMATE IS ALWAYS CHANGING THEN WHAT'S DIFFERENT THIS TIME?

WHAT DO PEOPLE HAVE TO DO WITH IT?

GOOD QUESTION!

LET'S START TO ANSWER IT BY TAKING A BRIEF LOOK AT THE HISTORY OF PLANET EARTH.

ONE KID IS DRESSED FOR WARM, THE OTHER DRESSED FOR COLD.



CHAPTER 2

A BRIEF HISTORY OF PLANET EARTH

TELL ME EVERYTHING THAT'S HAPPENED SO FAR.

WELL, FIRST THE EARTH COOLED...

...AND THEN THE DINOSAURS CAME...



THE EARTH FORMED ABOUT
4.6 BILLION YEARS AGO.

Earth 4 bya 3 bya 2 bya 1 bya Grandpa

THAT'S 50 MILLION
TIMES OLDER THAN
GRANDPA.



SCIENTIST OR
DAD TO YOUNG
CHILD, OF AFRICAN
DESCENT

IN THE EARLY DAYS IT WAS A GREAT
MOLTEN BALL OF LIQUID ROCK...

... WHICH BELCHED OUT **HOT GASES** AND **WATER VAPOR**
TO FORM THE EARLY **ATMOSPHERE** AND **OCEANS.**

PRIMITIVE LIFE FORMS APPEARED IN THE OCEANS
SOMETIME WITHIN THE FIRST **BILLION YEARS.**

4.6 bya Now

WHAT DO YOU
CALL A SINGLE-CELLED
ORGANISM **FLOATING IN**
A **PRIMORIDAL SEA?**

BOB.



WHAT DO YOU
CALL A SINGLE-CELLED
ORGANISM **SHAPED**
LIKE A **TUBE?**

ROD.



YOU AND YOUR
JOKES ARE SO
PRIMITIVE!



THEN, AFTER **HUNDREDS OF MILLIONS OF**
YEARS OF EVOLUTION...

4.6 bya Now

WHAT DO YOU
CALL A SINGLE-CELLED
ORGANISM THAT **LIVES IN**
YOUR MAILBOX?

BILL.



WHAT DO YOU
CALL A SINGLE-CELLED
ORGANISM **SMEARED ON**
THE WALL?

ART.



WILL YOU TWO
SHUT UP!

I'M TRYING TO
CONCENTRATE!



... SOME OF THESE ORGANISMS FIGURED OUT
OXYGENIC PHOTOSYNTHESIS...

EUREKA!



EEK! HARRIET, COME
BACK HERE!



... WHICH IS THE **CHEMICAL REACTION** THAT ALLOWS
GREEN THINGS LIKE **PLANTS** AND **ALGAE** TO GROW.

IT TURNS **SUNLIGHT,**
WATER AND **CARBON**
DIOXIDE...

... INTO THINGS LIKE
BROCCOLI AND
BEAN SPROUTS.

GREEN THINGS ARE
THE **BASE OF THE**
FOOD CHAIN.

WITHOUT **THEM**
THERE COULD BE
NO **US.**

OH **GREAT.**



NOWADAYS, GREEN THINGS PLAY A KEY ROLE IN THE CARBON CYCLE...

IN CHAPTER 4 WE'LL SEE THE INFLUENCE OF HUMAN ACTIVITY.

FORAM WILL CHECK THESE NUMBERS!

EVERY YEAR ABOUT 90 BILLION TONS OF CARBON DISSOLVES IN SEAWATER...

... AND ABOUT THAT MUCH RETURNS TO THE ATMOSPHERE THROUGH **OUTGASSING**.

MEANWHILE, ABOUT 120 BILLION TONS GETS SUCKED IN BY **PLANTS** THROUGH **PHOTOSYNTHESIS**...

... AND ABOUT THAT MUCH RETURNS TO THE ATMOSPHERE THROUGH **FIRE, DECOMPOSITION, AND RESPIRATION** BY PLANTS AND ANIMALS.

SEE THE GLOSSARY FOR MORE DETAILS, LIKE **OCEANIC PHOTOSYNTHESIS**.

... WHICH IS CRUCIAL TO ALL LIFE ON EARTH.

YOU ARE WHAT YOU EAT!

MOSTLY WATER AND CARBON,

MOSTLY WATER AND CARBON,

MOSTLY WATER AND CARBON,

BETWEEN ABOUT 2.8 AND 2.0 BILLION YEARS AGO, HOWEVER, GREEN THINGS DID SOMETHING PERHAPS EVEN MORE IMPORTANT.

4.6 bya

Now

THEY PUMPED LOTS AND LOTS OF **OXYGEN** INTO THE ATMOSPHERE.

NO PLANTS IN THIS FRAME, ONLY THE SLIMY STUFF.

99% OF THE OXYGEN IN THE AIR GOT THERE THROUGH **PHOTOSYNTHESIS BY GREEN SLIME.**

GETTING OXYGEN (O₂) INTO THE ATMOSPHERE WAS REALLY IMPORTANT BECAUSE...

DUH! BECAUSE **ANIMALS** NEED OXYGEN TO BREATHE.

WELL, THAT'S TRUE...

... BUT THIS WAS A BILLION YEARS BEFORE **ANIMALS.**

... BECAUSE IT LED TO THE CREATION OF A **LAYER OF OZONE (O₃)** ABOUT 15 MILES ABOVE THE SURFACE OF THE PLANET.

WHAT'S SO IMPORTANT ABOUT **THAT?**

WELL, **DUH.**

TURN THE PAGE TO FIND OUT.

OZONE LAYER

BEFORE THE OZONE LAYER, LIFE HAD TO HIDE FROM THE SUN.

4.6 bya

now

THE SUN GENERATES
VISIBLE LIGHT...

... BUT IT ALSO GENERATES
DEADLY ULTRAVIOLET
RADIATION.

THAT'S WHY WE LIVE
UNDERWATER.

**AFTER THE OZONE LAYER, THE
SUN'S DEADLIEST UV RAYS GOT BLOCKED...**

4.6 bya

now

OZONE IS LIKE
SUNSCREEN
FOR THE ENTIRE
PLANET.

SUNSCREEN
Protects against UVA and UVB
for up to 2 HOURS.

OZONE
Protects against DEADLY UVC for
BILLIONS OF YEARS.
Now with CATALYTIC ACTION!

**... AND THAT ALLOWED LIFE TO MOVE ONTO THE LAND
AND INTO THE SUNSHINE.**

OH NO, HARRIET,
NOT AGAIN!

**NO WONDER EVERYBODY GOT WORRIED WHEN SCIENTISTS DISCOVERED
A HOLE IN THE OZONE LAYER IN THE 1980s.**

6

**DESPITE WHAT MANY PEOPLE THINK,
THE OZONE HOLE IS NOT CLOSELY
RELATED TO GLOBAL WARMING...**

ENVIRONMENTAL
PROBLEMS ARE **NOT**
ALL THE SAME...

... AND YOU CAN'T
SOLVE THEM ALL BY
RECYCLING.

... BUT IT IS VALUABLE TO COMPARE AND CONTRAST THE TWO ISSUES...

THE OZONE HOLE IS
RELATED TO HUMAN EMISSIONS OF
OZONE-DESTROYING GASES SUCH
AS **CHLOROFLUOROCARBONS**
(CFCs).

GLOBAL WARMING IS RELATED
TO HUMAN EMISSIONS OF
GREENHOUSE GASES SUCH AS
CARBON DIOXIDE (CO₂).

**... AND WE CAN TAKE HEART FROM THE PROGRESS
WE'VE MADE IN REPAIRING THE OZONE HOLE.**

PRESIDENT REAGAN
HELPED PHASE OUT CFCs
AND THE OZONE LAYER IS
RECOVERING.

IF ONLY GLOBAL
WARMING WERE
SO EASY!

**BUT LET'S GET BACK TO THE
HISTORY OF PLANET EARTH...**

7

THE PAST BILLION YEARS HAVE SEEN WILD CHANGES IN THE CLIMATE.

4.6 bya

THE ONLY THING PERMANENT IS CHANGE.

THERE WERE TIMES WHEN ICE COVERED ALMOST EVERYTHING...

THIS SNOWBALL EARTH IS FREEZING!

GOOD THING THERE WEREN'T ACTUALLY PEOPLE BACK THEN.

THIS IS THE DENIER KID, WHO LIKES SUMMER.

THIS IS THE ALARMIST KID, WHO LIKES WINTER.

...AND TIMES WHEN THE NORTH POLE WAS TROPICAL.

BOY, I COULD REALLY USE SOME ICED TEA!

GOOD THING THERE WEREN'T ACTUALLY PEOPLE BACK THEN.

SORRY, THERE'S NO ICE.

OF CENTRAL IMPORTANCE TO OUR STORY IS THE CARBONIFEROUS PERIOD, SOME 360-300 MILLION YEARS AGO.

4.6 bya

Now

GIANT SCORPIONS!

GIANT COCKROACHES!

GIANT CROCODILES!

SOME OF THE ORGANISMS THAT DIED THEN GOT BURIED...

WHAT DO YOU CALL A SINGLE-CELLED ORGANISM LYING IN A HOLE?

DOUG.

...AND COOKED UNDERGROUND FOR HUNDREDS OF MILLIONS OF YEARS...

KNOCK KNOCK

WHO'S THERE?

OIL.

OIL WHO?

OIL BE BACK.

...AND EVENTUALLY TURNED INTO CARBON-BASED FOSSIL FUELS.

THAT'S WHERE A LOT OF OUR COAL COMES FROM...

...AND PLENTY OF OIL AND NATURAL GAS TOO.

SCORPION LOGO LIKE SINCERE

DURING THE LAST 100 MILLION YEARS...

4.6 bya 4 bya 3 bya 2 bya 1 bya

100 mya 80 mya 60 mya 40 mya 20 mya Now

... THE CONTINENTS SLOWLY DRIFTED INTO THE POSITIONS THEY HAVE TODAY...

CONTINENTS MOVE AT ABOUT THE SPEED THAT YOUR FINGERNAILS GROW...

... ABOUT 100 MILES EVERY MILLION YEARS.

... AND SPECIES EITHER DIED OFF OR SLOWLY EVOLVED INTO THE FORMS THEY HAVE TODAY.

THANKS TO AN ASTEROID 65 MILLION YEARS AGO...

... WE SAID GOODBYE TO THE VELOCIRAPTOR...

... AND HELLO TO THE CHICKEN.

EVEN MORE RECENTLY, THE EARTH'S CLIMATE HAS CALMED DOWN A BIT...

... BUT CALM IS A RELATIVE TERM.

30 MILLION YEARS WITH NO SNOWBALL EARTHS...

... AND NO TROPICAL NORTH POLES!

LOOK, WE'VE CALMED DOWN!

WOW, WHAT WERE YOU LIKE BEFORE?

100 mya

Now

IN PARTICULAR, OVER THE PAST 2.6 MILLION YEARS THE PLANET HAS GONE THROUGH REPEATED CYCLES...

DINOSAURS AND OTHER CREATURES IN THE CAR'S

... OF WARM PERIODS...

... AND COOL PERIODS.

SCIENTISTS CALL THESE COOL PARTS **GLACIAL PERIODS.**

EVERYONE ELSE CALLS THEM **ICE AGES.**

100 mya

Now

FINALLY, ABOUT 200,000 YEARS AGO...

THAT'S ONLY 2,000 TIMES OLDER THAN GRANDPA.

A BLINK OF AN EYE IN TERMS OF THE LIFESPAN OF THE EARTH.

... MODERN HUMAN BEINGS APPEARED IN AFRICA.

TA DA!

DON'T FORGET THIS CHARACTER NEEDS RELATIVELY DARK SKIN.

IT WASN'T LONG BEFORE THEY STARTED ASKING TOUGH QUESTIONS.

I WONDER HOW I CAN AVOID BEING EATEN?

I WONDER WHAT CAUSED THE ICE AGES?

I WONDER WHERE I CAN FIND SOME HOT SAUCE?

SHE'S EATING THE MAMMOTH LEG, IT SHOULD BE CLEAR IN THE DRAWING.

CHAPTER 3 THE ICE AGES

GO BACK 15,000 YEARS AND THIS WAS UNDER A MILE OF ICE!

ALT, SOME WAY TO EXPAND THIS GAG?:
GO BACK 15 MINUTES AND THIS WAS XYZ...
THEN:

GO BACK 15,000 YEARS AND THIS WAS UNDER A MILE OF ICE!

ADD PENGUIN TO PICTURE?

EARLY GEOLOGISTS HYPOTHESIZED THAT THERE **MUST** HAVE BEEN **ICE AGES**.

WHAT COULD HAVE CARRIED THESE **GIANT ROCKS** HERE FROM **THOSE DISTANT MOUNTAINS**?

THERE MUST HAVE BEEN **MASSIVE GLACIERS!**

OR **PREHISTORIC GIANTS!**

20TH CENTURY SCIENTISTS **CONFIRMED THIS** BY STUDYING EARTH'S TWO REMAINING **GIANT ICE SHEETS**.

ONE'S OVER **GREENLAND...**

... THE OTHER'S OVER **ANTARCTICA**

THESE ICE SHEETS WERE BUILT UP OVER **HUNDREDS OF THOUSANDS OF YEARS**.

THINGS SNOW GOT COMPRESSED, TRAPPING ANCIENT AIR IN ANCIENT ICE.

BY **DRILLING DOWN THROUGH THAT ICE...**

I'VE GOT A **6-FOOT COD!**

I'VE GOT A **MILE-LONG ICE CORE!**

... AND **ANALYZING THE VARIOUS LAYERS...**

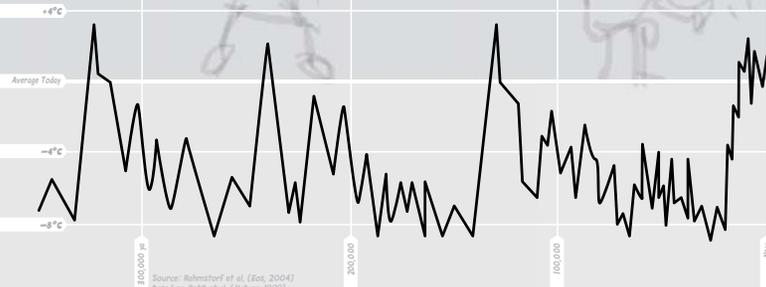
IT'S LIKE **COUNTING TREE RINGS.**

... SCIENTISTS CAN ESTIMATE THE **AVERAGE SURFACE TEMPERATURE** OF PLANET EARTH FAR INTO THE **DISTANT PAST.**

OVER THE PAST 350,000 YEARS THERE HAVE BEEN **WARM PERIODS...**

... INCLUDING THE **PAST 10,000 YEARS.**

BUT THOSE WARM PERIODS HAVE BEEN THE **EXCEPTIONS.**



THESE **ICE CORES** SHOW THAT EARTH HAS USUALLY BEEN ABOUT **6°C (11°F)** **COLDER** THAN IT IS NOW.

THAT TEMPERATURE CHANGE MAY SEEM **SMALL...**

... BUT IT WAS **BIG ENOUGH** FOR GLACIERS TO **BURY CHICAGO.**

THE **MYSTERY** OF THE ICE AGES...

I WONDER WHY THERE AREN'T **GLACIERS** HERE ANYMORE?

AND DON'T SAY **PREHISTORIC GIANTS!**



... WAS MOSTLY SOLVED BY THE SERBIAN MATHEMATICIAN **MILUTIN MILANKOVITCH** DURING THE FIRST WORLD WAR.

COMPARED TO THE **MYSTERY** OF WHY WE'RE FIGHTING THIS **DUMB WAR...**

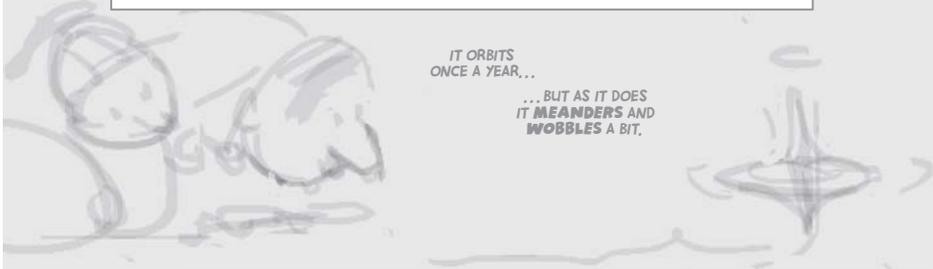
... THIS IS **CHILD'S PLAY.**



HE STUDIED THE **DETAILS** OF THE EARTH'S **ORBIT** AROUND THE **SUN...**

IT ORBITS ONCE A YEAR...

... BUT AS IT DOES IT **MEANDERS** AND **WOBBLES** A BIT.



... INCLUDING THE **TILT** OF THE EARTH, WHICH CAUSES **WINTERS** AND **SUMMERS.**

IN **JULY** THE NORTHERN HEMISPHERE GETS **MORE SUN...**

IN **JANUARY** THE NORTHERN HEMISPHERE IS DARK AND COLD...

... AND THE SOUTHERN HEMISPHERE IS **DARK** AND **COLD.**

... AND THE SOUTHERN HEMISPHERE GETS **MORE SUN.**

APRIL

OCTOBER

NOT TO SCALE.

IT TURNS OUT THAT THE **TILT VARIES** OVER TENS OF THOUSANDS OF YEARS.

AND NOW, IN **ASTRONOMY NEWS,** THE TILT OF THE EARTH IS **23.4 DEGREES** AND SLOWLY GETTING **WEAKER.**

CROLL GIVING TECHNICAL DETAILS.

WE'LL HAVE AN UPDATE IN THE YEAR **11,000.**

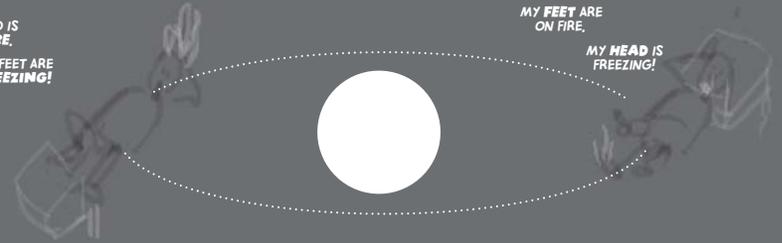
WHEN THE TILT IS STRONGER, **SEASONS ARE STRONGER...**

MY HEAD IS ON FIRE.

MY FEET ARE FREEZING!

MY FEET ARE ON FIRE.

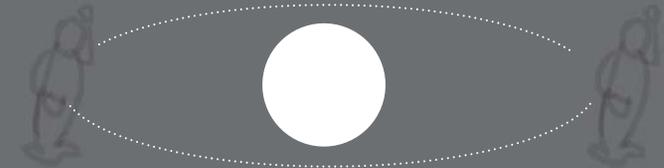
MY HEAD IS FREEZING!



... AND WHEN THE TILT IS WEAKER, **SEASONS ARE WEAKER.**

I'M GETTING COOKED A MORE **EVEN AMOUNT** ALL AROUND...

... NO MATTER WHAT TIME OF YEAR IT IS.



TWO OTHER ORBITAL VARIATIONS ALSO AFFECT THE STRENGTH OF THE SEASONS.

IN ADDITION TO **TILT,** THERE'S **ECCENTRICITY** AND **PRECESSION...**

... BUT YOU CAN THINK OF THEM AS **WIGGLES** AND **JIGGLES.**



THE **MILANKOVITCH CYCLE** THEORY SAYS THAT THESE THREE ORBITAL VARIATIONS...



THEY'RE **WIGGLES**
AND **JIGGLES!**

... SET THE **RHYTHM** FOR THE ICE AGES...



I'M THE
PACEMAKER.

... BY TRIGGERING **POSITIVE FEEDBACK LOOPS.**

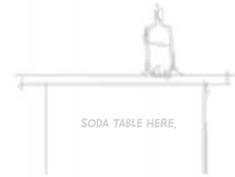


WHEW, I'M
THIRSTY.

MMMMMM,
SODA.

SHAZAM!

SOMETIMES THOSE POSITIVE FEEDBACK LOOPS BRING THE EARTH **OUT OF AN ICE AGE...**

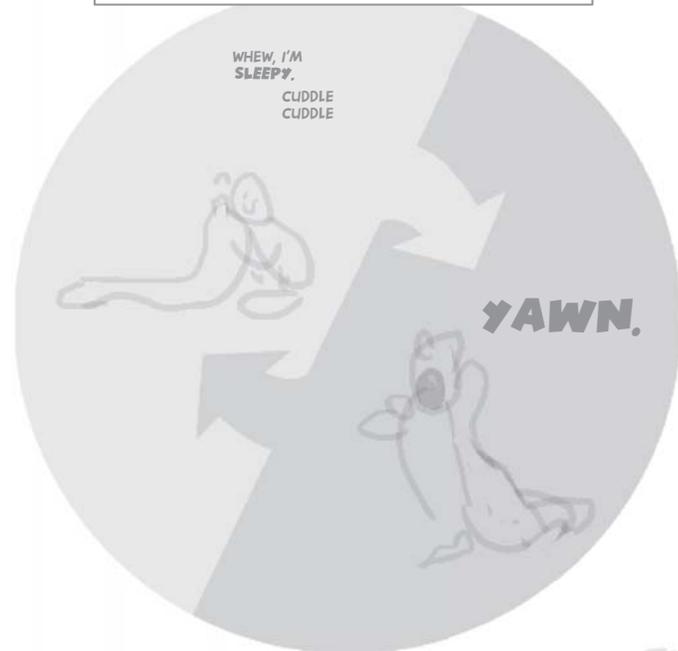


SODA TABLE HERE.

I'M GOING
INTERGLACIAL!



... AND SOMETIMES THEY SEND US **BACK INTO ONE.**



WHEW, I'M
SLEEPY.

CUDDLE
CUDDLE

YAWN.

ZZZZZZZ.

LET'S SEE HOW IT WORKS IN **CLOSER DETAIL.**

FOR A SIMPLIFIED VERSION OF THE MILANKOVITCH STORY...

FOR MORE DETAILS, SEE ICE AGES IN THE GLOSSARY...



MILANKOVITCH:

...OR READ MY 626-PAGE BOOK!

...IMAGINE WE'RE IN CANADA DURING A GLACIAL PERIOD.

LIKE THE ONE THAT PEAKED 20,000 YEARS AGO.



THE MILANKOVITCH CYCLES EVENTUALLY CREATE CONDITIONS WITH STRONG SEASONS.

HOT HOT SUMMERS,

LOTS OF MELTING ICE AND SNOW,



FEET STICKING OUT OF HOLE IN THE ICE.

COLD COLD WINTERS,

BUT THERE ISN'T ENOUGH NEW SNOW TO KEEP UP WITH THE SUMMER MELT,



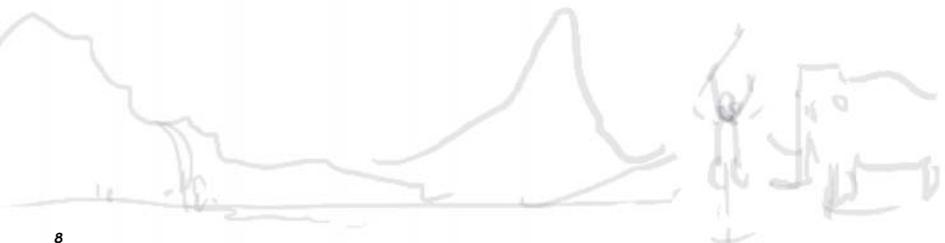
SAME FEET STICK OUT OF THE ICE, BUT NOW THE HOLE IS FROZEN OVER AND THERE'S A BIG ICE CUBE AROUND THE FEET.

THAT CAUSES ICE AND SNOW TO GIVE WAY TO LAND AND WATER.

BACKGROUND HERE IS LAND... IT'S THE SAME BACKGROUND AS THE ABOVE SHOT, BUT MOST OF THE ABOVE IS OBSCURED BY GLACIAL ICE...

IN THIS ONE, THERE'S ONLY ICE UNDERNEATH THEM

NOW WE CAN PLANT MAPLE SYRUP TREES!



AMPLIFYING THE MILANKOVITCH CYCLES ARE THINGS LIKE THE ALBEDO EFFECT...

THIS IS THE BALD BASSIST THEY ARE MEMBERS OF MAM'S BAND!

THIS IS THE LEAD SINGER/GUITARIST WITH ROCK STAR HAIR!!!!

ICE AND SNOW REFLECT LOTS OF SUNLIGHT BACK INTO SPACE,

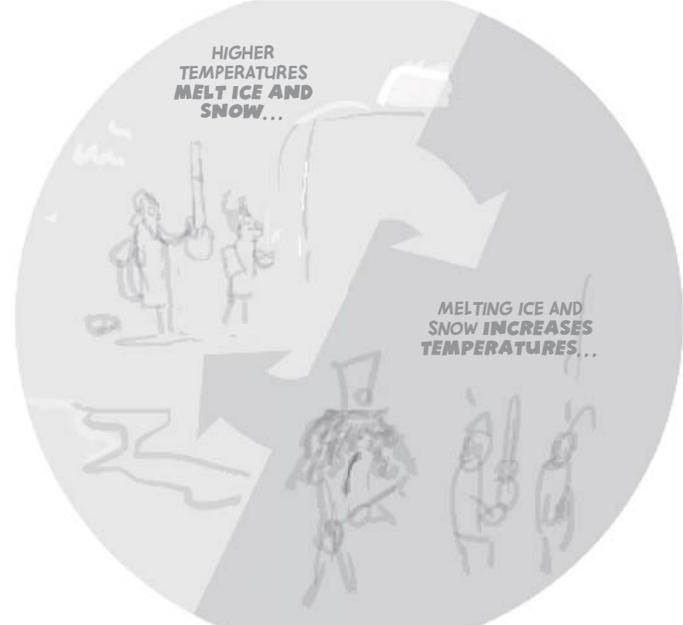
LAND AND WATER ABSORB MORE SUNLIGHT,



... WHICH CREATE POSITIVE FEEDBACK LOOPS...

HIGHER TEMPERATURES MELT ICE AND SNOW...

MELTING ICE AND SNOW INCREASES TEMPERATURES...



... THAT BRING ABOUT A GLOBAL INTERGLACIAL PERIOD.

IT SURE IS HOT AND LOUD IN HERE,

WHAT??



TO SEE HOW IT WORKS IN THE OTHER DIRECTION,
IMAGINE WE'RE IN THE MIDDLE OF AN **INTERGLACIAL PERIOD**.

LIKE THE ONE
WE'RE IN **NOW**.



THE MILANKOVITCH CYCLES EVENTUALLY CREATE CONDITIONS WITH **MILD SEASONS**.

MILD SUMMERS,

DRIP OF
WATER,

NOT MUCH
MELTING ICE
AND SNOW.



MILD WINTERS,

TURNS
INTO AN
ICYCLE,

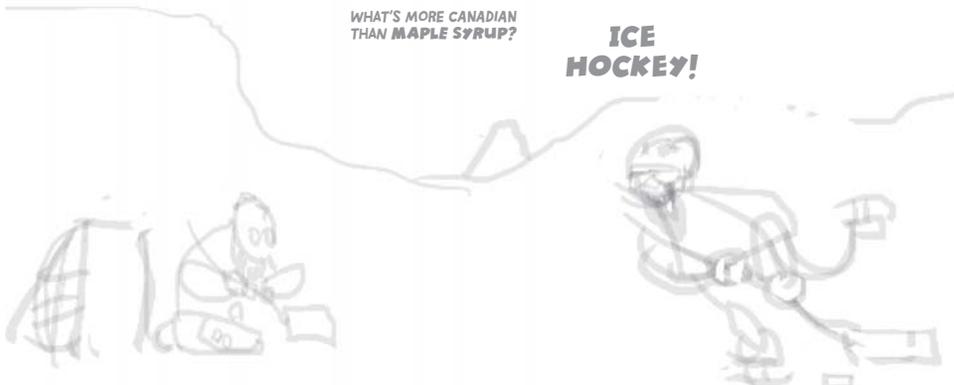
BUT STILL COLD
ENOUGH FOR SNOW
IN PLACES LIKE
CANADA.



THAT CAUSES **ICE AND SNOW** TO SLOWLY REPLACE **LAND AND WATER**.

WHAT'S MORE CANADIAN
THAN **MAPLE SYRUP?**

**ICE
HOCKEY!**



HOCKEY... THEY WEAR SOME KIND OF SKINS AND THE GOAL IS MADE OF SOME
MEGAFALUNA RIBCAGE AND THE GOALIE HAS A SKULL OVER HIS FACE AS A FACEMASK...

BALD GUY AGAIN,

NOW THINGS LIKE THE **ALBEDO EFFECT** WORK IN THE **OTHER DIRECTION...**

LAND AND WATER THAT
USED TO **ABSORB** LOTS
OF SUNLIGHT...

... GET COVERED WITH
ICE AND SNOW THAT
REFLECT SUNLIGHT,
COOLING THE PLANET.



... CREATING **POSITIVE FEEDBACK LOOPS** THAT COOL THE PLANET.

LOWER
TEMPERATURES
**INCREASE ICE
AND SNOW...**

**MORE ICE AND
SNOW LOWERS
TEMPERATURES...**

SEE THE
GLOSSARY FOR
DETAILS.



ALL THIS BRINGS UP A **PRETTY OBVIOUS QUESTION**.

GIVEN THAT WE'RE
CURRENTLY IN AN
**INTERGLACIAL
PERIOD...**

... SHOULD WE
WORRY ABOUT THE
NEXT ICE AGE?



THE **ANSWER** IS THAT MOTHER NATURE IS
GEARING UP FOR **ANOTHER ICE AGE...**

OH NO, WE BETTER
STOCK UP ON
HEATING OIL!

... BUT NOT FOR AT LEAST **30,000 YEARS.**

AH, **NEVER
MIND!**

AND LONG BEFORE THAT HAPPENS WE'RE GOING TO HAVE TO COME
TO TERMS WITH WHAT **WE'RE** DOING TO THE CLIMATE.

UM, ABOUT THAT
HEATING OIL...

CHAPTER 4

CARBON DIOXIDE

EMPTY YOUR
MIND ...

... AND FOCUS ON
SOMETHING **ODORLESS,**
COLORLESS, AND
INVISIBLE.

WHAT WE CALL **AIR** IS ACTUALLY A MIXTURE THAT'S ABOUT **21% OXYGEN...**

... AND ABOUT **78% NITROGEN.**

CREATED OVER THE EONS BY ALL THAT PHOTOSYNTHESIZING GREEN STUFF.

7th Annual Nitrogen Day

N₂ DEEP

I'm into N₂

N₂ the Nrh Power

N₂ the Dragon

THE **REMAINING 1%** INCLUDES **WATER VAPOR...**

... AND RELATIVELY **TINY AMOUNTS** OF OTHER GASES...

... INCLUDING **CO₂ (CARBON DIOXIDE)**

AIR IS ONLY ABOUT **0.04% CO₂...**

... BUT THAT EQUALS ABOUT **4,000,000,000,000,000,000,000** MOLECULES OF **CO₂** IN EVERY BREATH YOU TAKE.

STANDING WITH UMBRELLA, OBSCURED BY FOG.

IN THE EARLY 1950s A CHEMIST NAMED **CHARLES DAVID KEELING...**

CALL ME **DAVE.**

... FIGURED OUT A WAY TO ACCURATELY MEASURE **THE CONCENTRATION OF CARBON DIOXIDE IN AIR.**

WHAT'S THE CO₂ DIFFERENCE BETWEEN THESE TWO SAMPLES?

ONE IN A MILLION!



STARTING IN 1958, KEELING AND HIS COLLEAGUES MADE **DAILY MEASUREMENTS** OF CO₂ AT THE **MAUNA LOA OBSERVATORY** IN HAWAII...

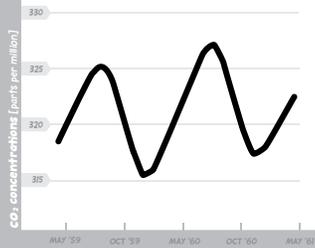
C'MON DAD, LET'S GO TO THE **BEACH!**

SORRY, KID, NOT NOW.



... AND THE RESULTS MADE HIM **FAMOUS.**

KEELING MADE **TWO BIG DISCOVERIES**. FIRST, HE DISCOVERED AN **ANNUAL CYCLE** IN CO₂ CONCENTRATIONS.



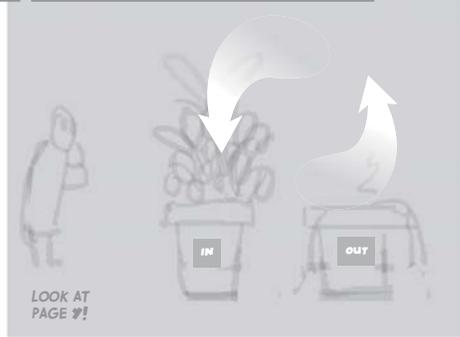
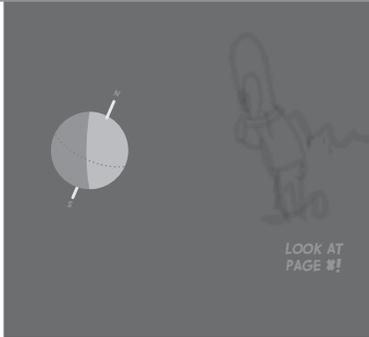
DUDE, IT'S LIKE THE PLANET IS **BREATHING!**

OKAY, HIPPIE, TAKE IT EASY.



THIS CYCLE IS RELATED TO THE **SEASONS**...

... AND TO THE **CARBON CYCLE**...



... AND TO THE FACT THAT **MOST OF THE LAND ON EARTH IS IN THE NORTHERN HEMISPHERE**.

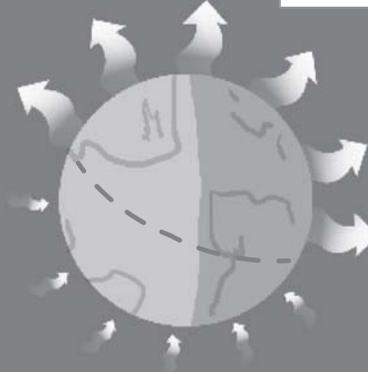
LOOK AT A **MAP!**

MORE LAND MEANS MORE GREEN STUFF.



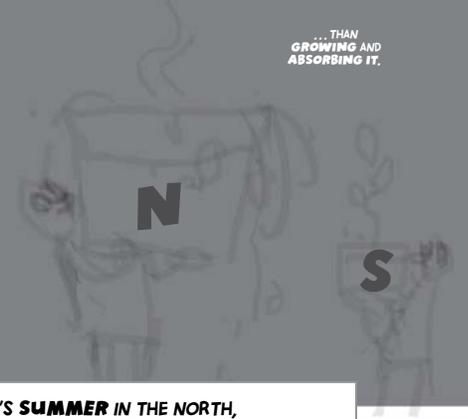
WHEN IT'S **WINTER** IN THE NORTH, EXTRA CO₂ GETS "EXHALED" INTO THE ATMOSPHERE.

... THANKS TO PROCESSES LIKE THE **DECOMPOSITION OF FALLING LEAVES**.



PLANET-WIDE, LOTS MORE GREEN STUFF IS **DECAYING** AND **RELEASING CO₂**...

... THAN **GROWING** AND **ABSORBING** IT.



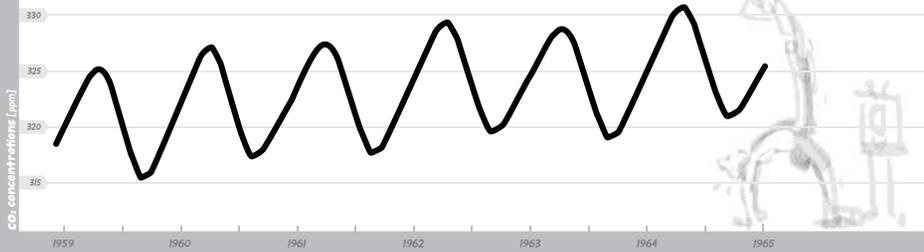
CONVERSELY, WHEN IT'S **SUMMER** IN THE NORTH, THAT EXTRA CO₂ GETS "INHALED" BY **INCREASED PHOTOSYNTHESIS**.

PLANET-WIDE, LOTS MORE GREEN STUFF IS **GROWING** AND **ABSORBING CO₂**...

... THAN **DECAYING** AND **RELEASING** IT.



KEELING'S **SECOND BIG DISCOVERY** WAS THAT CO₂ CONCENTRATIONS IN THE ATMOSPHERE WERE **INCREASING OVER TIME**.



WHEN KEELING STARTED IN 1958, THE INCREASE WAS ABOUT **1 PART PER MILLION (ppm) PER YEAR**.

AN INCREASE OF **1ppm**...

... MEANS ABOUT **8 BILLION EXTRA TONS** OF CO₂ IN THE ATMOSPHERE.



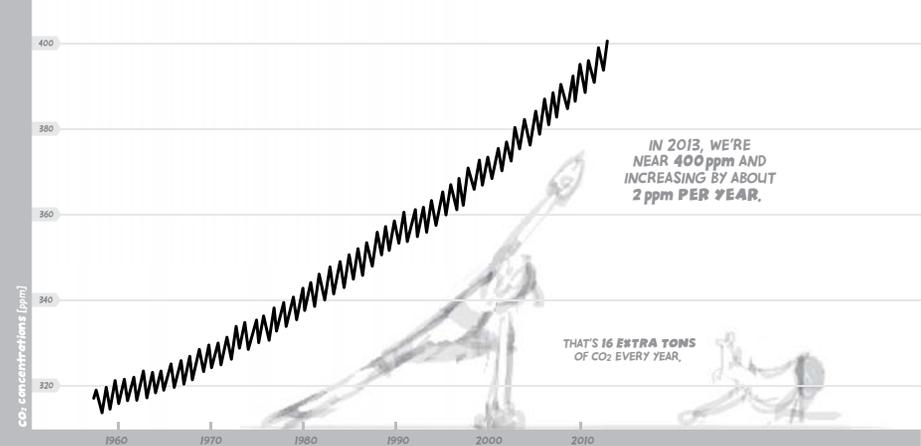
KEELING'S MEASUREMENTS CONTINUED FOR **YEARS**, AND THEN **DECADES**, AND AFTER HIS RETIREMENT HIS SON STEPPED INTO HIS SHOES.

C'MON SON, LET'S GO TO THE BEACH!

SORRY, DAD, NOT NOW.



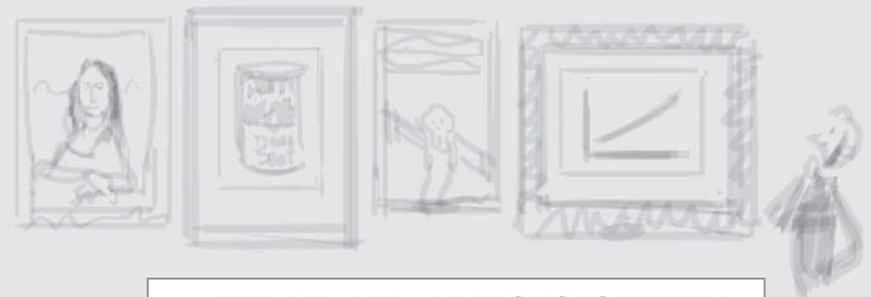
THE GRAPH OF THE DAILY MEASUREMENTS THAT THEY AND THEIR COLLEAGUES HAVE MADE SINCE 1958 IS CALLED THE **KEELING CURVE**.



IN 2013, WE'RE NEAR **400 ppm** AND INCREASING BY ABOUT **2 ppm PER YEAR**.

THAT'S **16 EXTRA TONS** OF CO₂ EVERY YEAR.

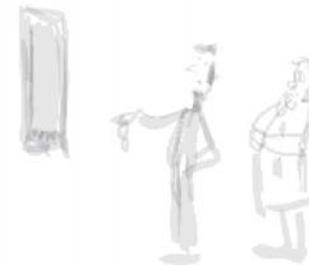
IT IS NOW ONE OF THE **MOST FAMOUS IMAGES** IN THE WORLD...



... AND ONE OF THE CENTRAL PIECES OF **EVIDENCE** IN THIS BOOK.

WHAT DOES IT MEAN?

IT MEANS THAT **HUMAN ACTIVITY** IS **CHANGING THE PLANET**.



YOUR MIND NEEDS TO COMPARE WITH IEA/IEO NUMBERS.

IN THE 19TH CENTURY THE MAJOR SOURCE OF HUMAN CO₂ EMISSIONS WAS **DEFORESTATION...**

CLEARING TREES TO MAKE ROOM FOR FARMS AND CITIES...

... RELEASES THE **CARBON** THAT WAS **STORED IN THOSE TREES** INTO THE ATMOSPHERE.

... BUT NOW IT'S THE **FOSSIL FUELS** THAT PROVIDE MOST OF OUR **ELECTRICITY** AND POWER OUR **FACTORIES** AND **CARS**.

COAL-BURNING POWER PLANTS ARE THE #1 SOURCE OF CO₂.

BY 2010 WE WERE BURNING THROUGH 44,000 GALLONS OF PETROLEUM EVERY SECOND.

NATURAL GAS PRODUCTION IS GROWING THANKS TO **FRACKING**.



ABOUT **HALF** OF THAT EXTRA CO₂ GETS ABSORBED BY **PLANTS...**

... AND BY OTHER **CARBON SINKS** SUCH AS THE **OCEANS...**

FORESTS STILL COVER ABOUT 1/3 OF THE EARTH'S LAND.

WE'LL COME BACK TO THIS IN CH 15.

WE'LL COME BACK TO THIS IN CHAPTER 8, ON **OCEAN ACIDIFICATION**.

... BUT THE REST **STAYS IN THE ATMOSPHERE**, PUSHING UP THE **KEELING** CURVE.

HERE'S HOW THE **CARBON CYCLE** IS AFFECTED BY THE **10 BILLION TONS** OF CARBON WE **EMIT EACH YEAR**:

EACH 3.5 TONS OF CO₂ CONTAINS ABOUT 1 TON OF CARBON.

SEE THE GLOSSARY TO LEARN HOW TO COMPARE CARBON AND CO₂.

ABOUT 3 BILLION TONS ARE ADDED TO THE **OCEANS...**

... ABOUT 4 BILLION TONS REMAIN IN THE **ATMOSPHERE...**

... AND ABOUT 3 BILLION TONS ARE ABSORBED BY **PLANTS AND SOILS**.

HUMAN EMISSIONS ARE A **SMALL FRACTION** OF THE NATURAL CYCLE...

10 TONS IS SMALL COMPARED TO THE 200 TONS THAT CIRCULATE NATURALLY.

SEE PAGE X FOR A REMINDER.

... BUT OVER TIME IT **ADDS UP**.

INHALE MORE THAN YOU **EXHALE...**

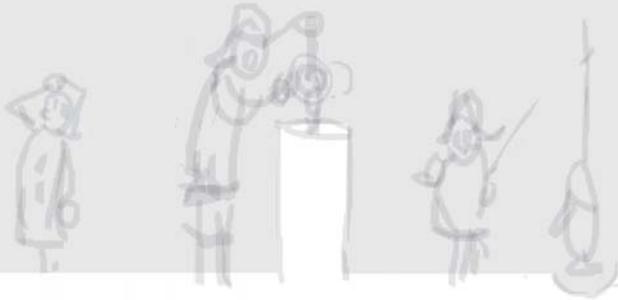
... AND PRETTY SOON YOUR LUNGS WILL **EXPLODE**.

SCIENTISTS HAVE ALSO PUT THE KEELING CURVE IN **HISTORICAL CONTEXT...**

... BY STUDYING THE AMOUNT OF CO₂ TRAPPED IN **ICE CORES.**

WHAT DID CO₂ CONCENTRATIONS LOOK LIKE **BEFORE 1958?**

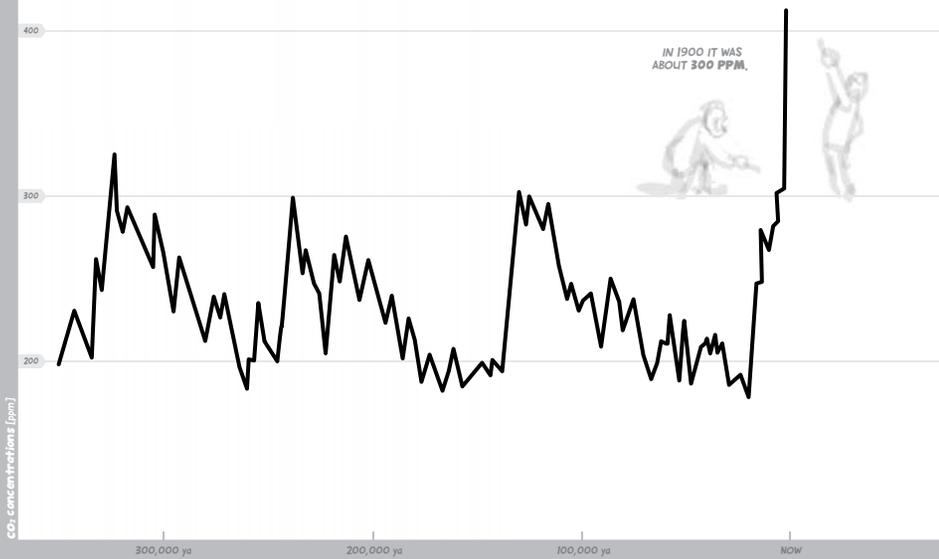
DRILL BABY, DRILL.



THEY DISCOVERED THAT **TODAY'S LEVELS ARE OFF THE CHARTS** COMPARED TO THE LAST 350,000 YEARS.

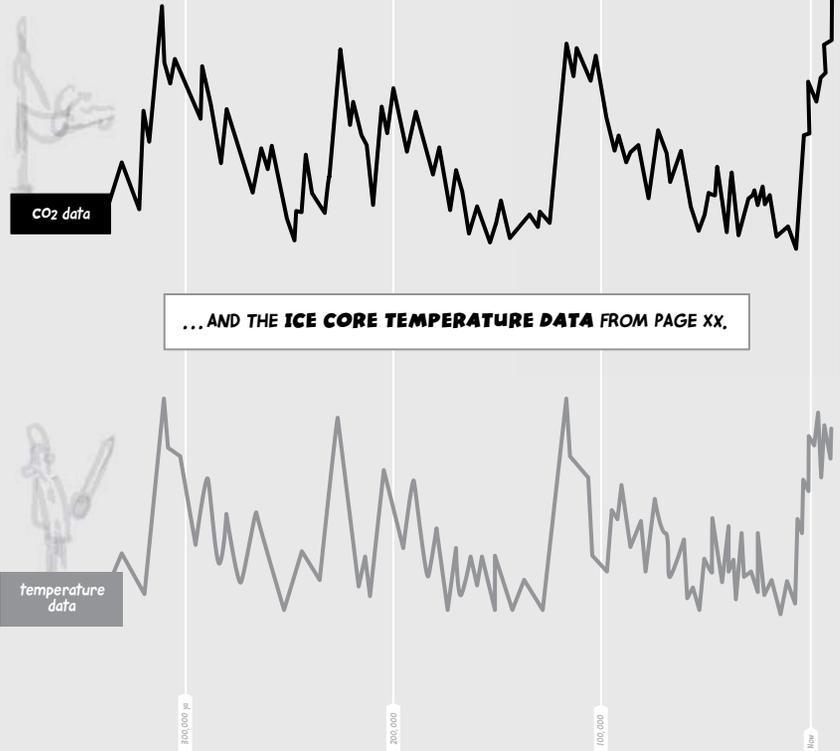
BY 2013 IT WAS UP TO 400 PPM.

IN 1900 IT WAS ABOUT 300 PPM.



EVEN **MORE AMAZING** IS THE RELATIONSHIP BETWEEN THIS **HISTORIC CO₂ DATA...**

... AND THE **ICE CORE TEMPERATURE DATA** FROM PAGE XX.



IT'S **OBVIOUS** THAT CO₂ AND TEMPERATURE HAVE BEEN **CLOSELY RELATED** FOR THE PAST 350,000 YEARS.

WHAT ARE THE ODDS OF THAT HAPPENING **BY CHANCE?**

LESS THAN **ONE IN A MILLION!**



THE **CONNECTION** BETWEEN CO₂ AND TEMPERATURE IS SO STRONG THAT IT'S **EASY TO GET CARRIED AWAY**.

CO₂ MUST BE THE **DRIVING FORCE** BEHIND THE ICE AGES!

BE CAREFUL, THAT'S **NOT TRUE!**

CORRELATION IS NOT CAUSATION.



SO KEEP IN MIND WHAT WE **LEARNED IN THE LAST CHAPTER...**

THE **MILANKOVITCH CYCLES** SET THE TEMPO FOR THE ICE AGES.



... AS WE MOVE ON TO LEARN ABOUT HOW CO₂ **INFLUENCES THE PLANET'S TEMPERATURE.**

CO₂ **AMPLIFIES THE MESSAGE!**



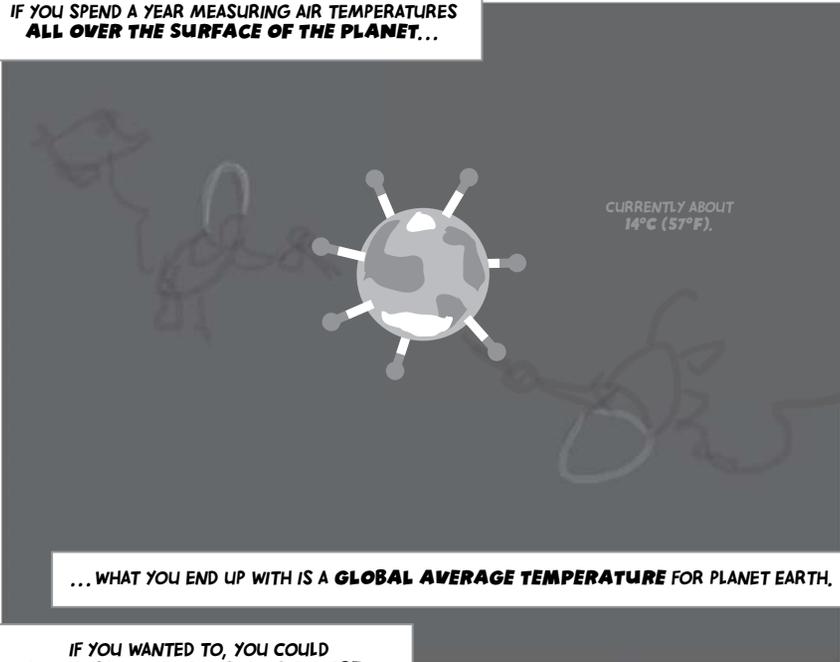
CHAPTER 5 ENERGY

YOUR **BANK ACCOUNT** DEPENDS ON **MONEY IN** AND **MONEY OUT...**

... AND THE **EARTH'S TEMPERATURE** DEPENDS ON **ENERGY IN** AND **ENERGY OUT.**



IF YOU SPEND A YEAR MEASURING AIR TEMPERATURES
ALL OVER THE SURFACE OF THE PLANET...

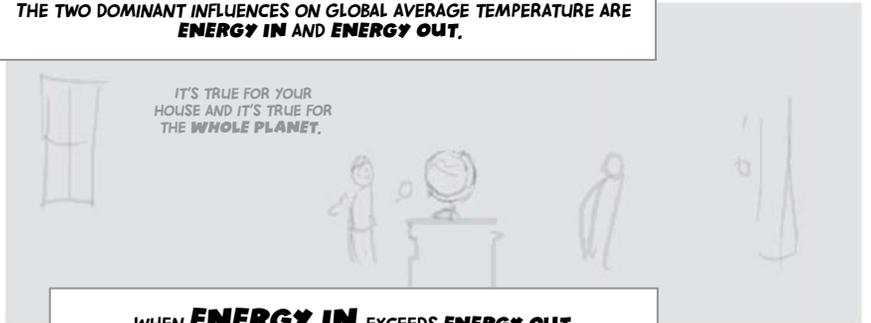


... WHAT YOU END UP WITH IS A **GLOBAL AVERAGE TEMPERATURE** FOR PLANET EARTH.

IF YOU WANTED TO, YOU COULD
DO THE SAME THING FOR YOUR **HOUSE**.



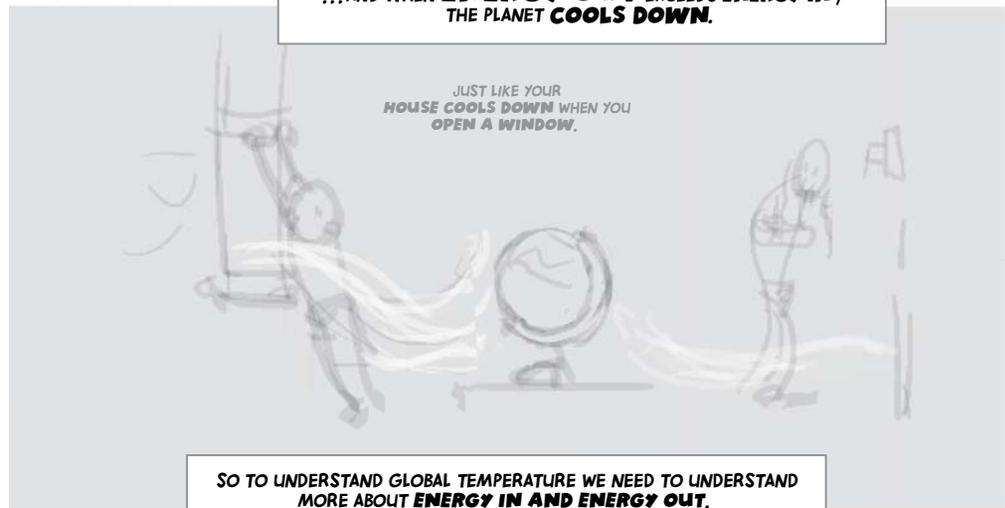
THE TWO DOMINANT INFLUENCES ON GLOBAL AVERAGE TEMPERATURE ARE
ENERGY IN AND **ENERGY OUT**.



WHEN **ENERGY IN** EXCEEDS **ENERGY OUT**,
THE PLANET **WARMs UP...**



...AND WHEN **ENERGY OUT** EXCEEDS **ENERGY IN**,
THE PLANET **COOLs DOWN**.



SO TO UNDERSTAND GLOBAL TEMPERATURE WE NEED TO UNDERSTAND
MORE ABOUT **ENERGY IN** AND **ENERGY OUT**.

ENERGY IN IS SIMPLE,

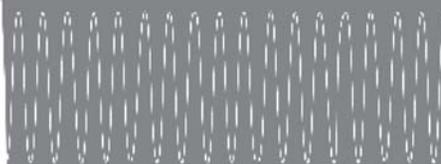


IF YOU PICTURE THE SUN AS A BASKETBALL ON ONE END OF A FULL-SIZED COURT...

... THEN THE EARTH WOULD BE A LARGE GRAIN OF SAND UNDER THE OTHER BASKET.

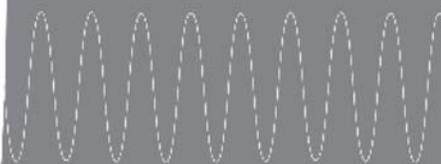
ENERGY FROM THE SUN COMES IN THE FORM OF ELECTROMAGNETIC RADIATION, WHICH INCLUDES...

... ULTRAVIOLET (uv) RADIATION, WITH VERY SHORT, HIGH-ENERGY WAVELENGTHS...



UV IS PARTIALLY BLOCKED BY THE OZONE LAYER. (SEE PAGE XXX.)

... VISIBLE LIGHT, WHICH COVERS THE WHOLE RAINBOW (LITERALLY!)...



VISIBLE LIGHT IS THE ONLY KIND OF ELECTROMAGNETIC RADIATION PEOPLE CAN SEE.

... AND INFRARED (IR) RADIATION, WITH VERY LONG, LOW-ENERGY WAVELENGTHS.



WE'LL COME BACK TO THIS IN A MOMENT.

ENERGY OUT IS MORE COMPLICATED.

FOR EXAMPLE, IT INCLUDES SOLAR ENERGY THAT IS REFLECTED BACK INTO SPACE...

... BY CLOUDS AND BY THE EARTH'S SURFACE.

CHECK OUT THE GLOSSARY FOR MORE.

IT'S THE ALBEDO EFFECT!

ABOUT 30% OF ALL INCOMING ENERGY IS REFLECTED BY CLOUDS, ICE, SNOW, SAND, ETC.

GLOSSARY ENTRY WILL INCLUDE THIS TECHNICAL NOTE: IF YOU STUDY MORE CLIMATE SCIENCE, YOU'LL LEARN THAT REFLECTED SOLAR ENERGY IS USUALLY SUBTRACTED FROM ENERGY IN RATHER THAN BEING ADDED TO ENERGY OUT. WE'RE FOLLOWING A MORE INTUITIVE APPROACH, BUT OF COURSE BOTH WAYS ARE CORRECT

CRUCIALLY, ENERGY OUT ALSO INCLUDES RADIATION GIVEN OFF BY THE EARTH ITSELF.

THE EARTH DOESN'T EMIT AS MUCH ENERGY AS THE SUN...

... BUT IT DOES EMIT ENERGY.

WIMPY EARTH SUPERHERO

THIS OUTGOING ENERGY IS IN THE INFRARED PART OF THE ELECTROMAGNETIC SPECTRUM...

THE EARTH'S INFRARED WAVELENGTHS ARE EVEN LONGER AND LOWER ENERGY...

... THAN INFRARED FROM THE SUN.

... AND IS FAMILIAR TO ANYBODY WHO HAS USED **THERMAL IMAGING EQUIPMENT...**

THERE'S A **LEAKY PIPE** INSIDE THIS WALL...

... AND A **MAN HIDING** IN THAT CLOSET.

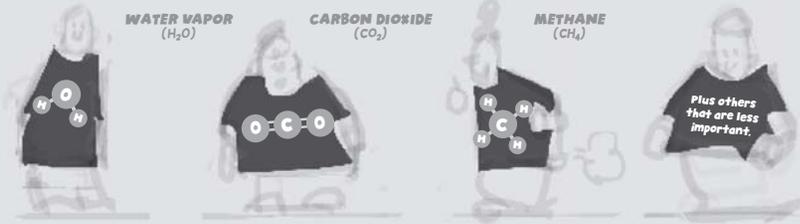
... OR **HUDDLED NEAR A HOT FIRE,**

YOU CAN'T SEE INFRARED LIGHT, BUT YOU CAN FEEL IT.

IN THE MORNING IT WON'T BE **RED HOT** ANYMORE...

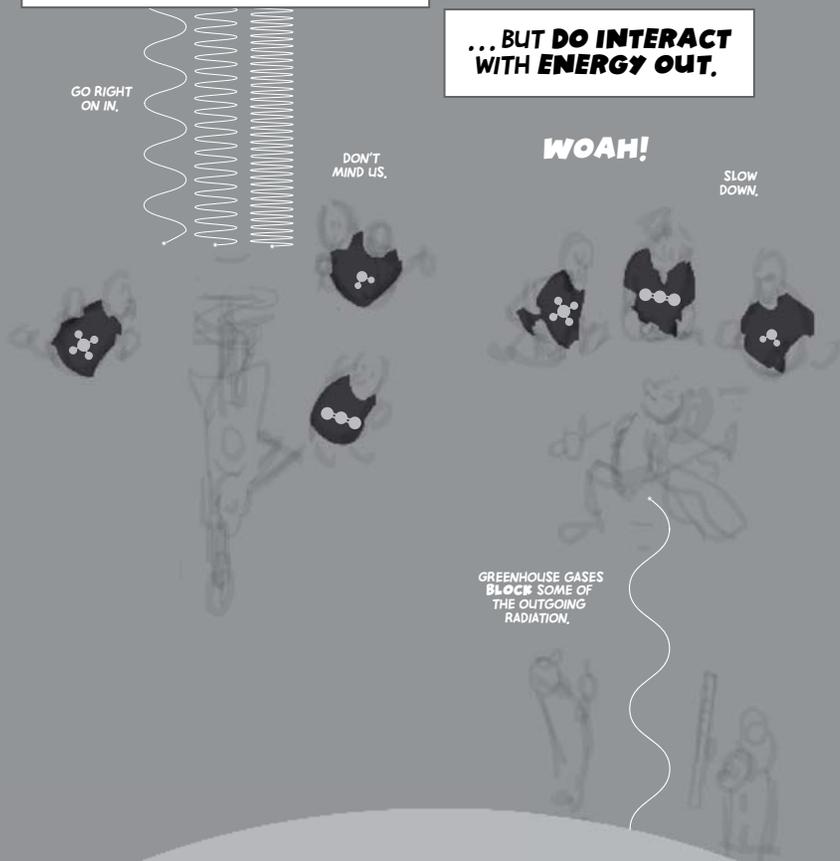
... BUT IT WILL STILL BE **INFRARED HOT.**

AND THAT BRINGS US TO **GREENHOUSE GASES**.



WHAT MAKES THEM **GREENHOUSE GASES** IS THAT THEY **DON'T INTERACT** MUCH WITH **ENERGY IN...**

... BUT **DO INTERACT** WITH **ENERGY OUT.**



BY REDUCING ENERGY OUT, GREENHOUSE GASES **WARM THE PLANET.**

REDUCING ENERGY OUT IS ALSO HOW **INSULATION** WARMS UP YOUR **HOUSE...**

... OR A **BLANKET** WARMS UP YOUR **BODY...**

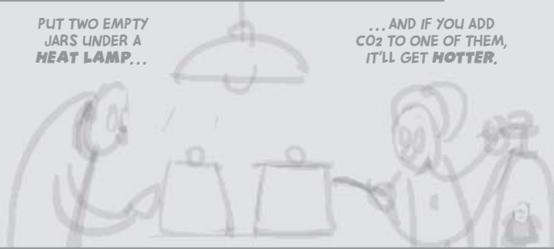
... OR A **GREENHOUSE** WARMS UP YOUR **TOMATOES.**



THE **GREENHOUSE EFFECT** CAN BE EASILY REPLICATED IN A LAB...

PUT TWO EMPTY
JARS UNDER A
HEAT LAMP...

... AND IF YOU ADD
CO₂ TO ONE OF THEM,
IT'LL GET **HOTTER**.



... AND BY THE **1800s** SCIENTISTS HAD FIGURED OUT THAT IT HAS A **MAJOR IMPACT**
ON THE EARTH'S TEMPERATURE.

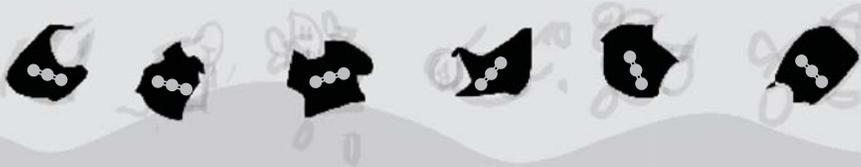


THE **ACTUAL** SURFACE
TEMPERATURE IS ABOUT
14°C (57°F)...

... BUT **WITHOUT**
GREENHOUSE GASES IT
WOULD BE **-18°C** (0°F).



TODAY, SCIENTISTS KNOW THAT SIMILAR GREENHOUSE EFFECTS EXIST
ON **OTHER PLANETS** LIKE **VENUS**.



VENUS HAS **70 TIMES**
MORE ATMOSPHERIC
CO₂ THAN EARTH.

THAT'S A BIG REASON
THE SURFACE TEMPERATURE
IS **462°C** (863°F).

**HOTTER THAN A
PIZZA OVEN!**



THE GREENHOUSE EFFECT ON **VENUS** IS OF COURSE
NOT CAUSED BY HUMANS...

OR BY
MARTIANS!

OR BY
**PREHISTORIC
GIANTS!**



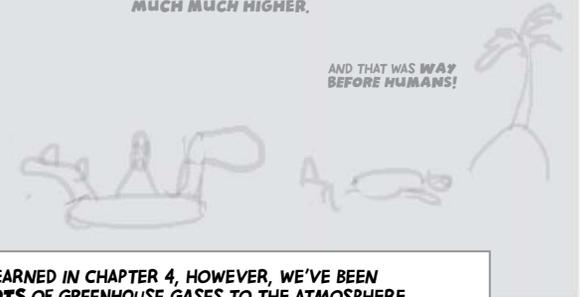
... AND WE DIDN'T CREATE THE **NATURAL GREENHOUSE EFFECT** ON EARTH EITHER.

DURING THE PAST 2 MILLION YEARS
CO₂ LEVELS VARIED BETWEEN
180PPM AND **280PPM**...

... AND DURING **HOTHOUSE
EARTH PERIODS**, THEY WERE
MUCH MUCH HIGHER.



AND THAT WAS **WAY**
BEFORE HUMANS!



AS WE LEARNED IN CHAPTER 4, HOWEVER, WE'VE BEEN
ADDING LOTS OF GREENHOUSE GASES TO THE ATMOSPHERE.

SINCE THE START OF THE
INDUSTRIAL REVOLUTION IN
THE LATE 1700s...

... WE'VE INCREASED
CO₂ LEVELS FROM **280PPM**...

... TO **400** PPM.



THE SWEDISH CHEMIST **ARRHENIUS** WAS ONE OF THE FIRST PEOPLE TO SPECULATE ABOUT THE CONSEQUENCES OF AN **ENHANCED GREENHOUSE EFFECT**.

THIS IS GOING TO BE GREAT FOR **FARMERS IN SWEDEN!**

IN 1896 HE STUDIED WHAT WOULD HAPPEN IF WE **DOUBLED** CO₂ CONCENTRATIONS...

WHAT IF WE WENT FROM 280 ppm...
... TO **560 ppm?**

... AND MADE A ROUGH CALCULATION OF THE **EVENTUAL INCREASE IN GLOBAL AVERAGE TEMPERATURE**.

ABOUT 5°C (9°F).

INCREDIBLY, HE CAME **VERY CLOSE** TO THE RANGE THAT CLIMATE SCIENTISTS CALCULATE TODAY.

ABOUT 2–4.5°C (3.6–8.1°F).

CHAPTER 6 SCIENCE

WHY SHOULD I TRUST YOU?

DON'T TRUST **US**.

TRUST THE **SCIENTIFIC METHOD**.



THE **SCIENTIFIC METHOD** INVOLVES **DEVELOPING HYPOTHESES...**

THE **FORCE OF GRAVITY** LOOKS LIKE THIS!



... **TESTING THEM AGAINST THE REAL WORLD...**

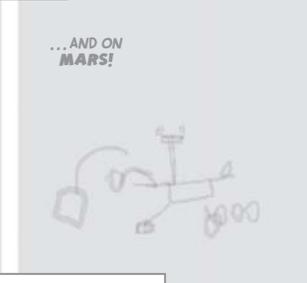
YUP, IT WORKS ON THE **EARTH...**



... AND ON THE **MOON!**

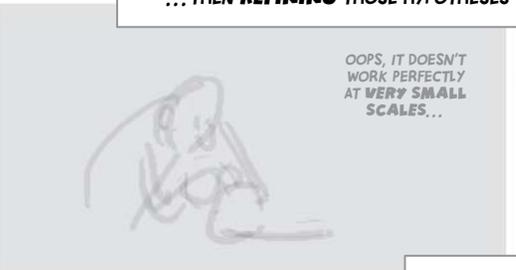


... AND ON **MARS!**

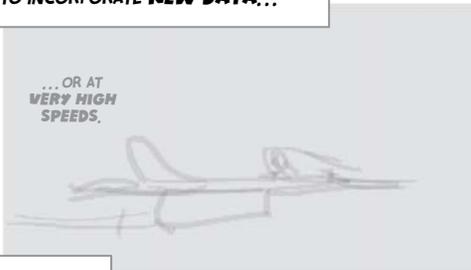


... THEN **REFINING** THOSE HYPOTHESES TO INCORPORATE **NEW DATA...**

OOPS, IT DOESN'T WORK PERFECTLY AT **VERY SMALL SCALES...**

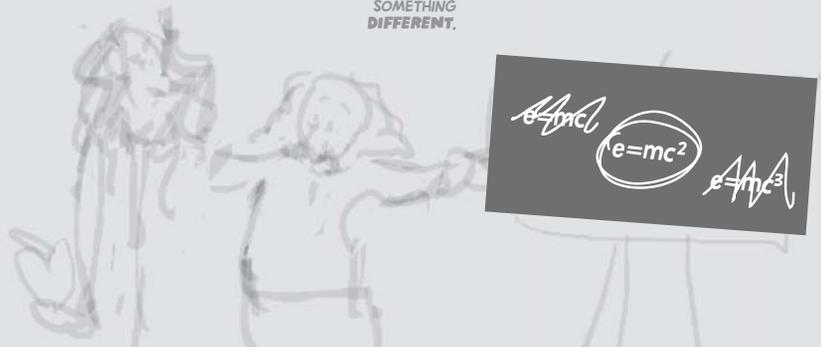


... OR AT **VERY HIGH SPEEDS.**



... AND **NEW IDEAS.**

LET'S TRY SOMETHING **DIFFERENT.**



BECAUSE THIS PROCESS INVOLVES AN **ENDLESS SUPPLY OF NEW QUESTIONS...**

MOMMY, WHERE DO **ATOMS** COME FROM?

MOMMY, HOW OLD IS THE **UNIVERSE?**

MOMMY, WHY DO **PRAYING MANTISES** EAT THEIR HUSBANDS?



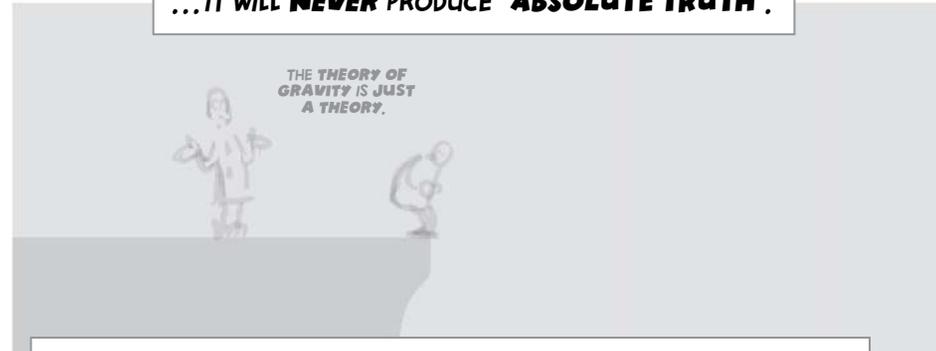
... AND **NEW EXPERIMENTS...**

LET'S TRY MIXING **THESE THINGS** TOGETHER.



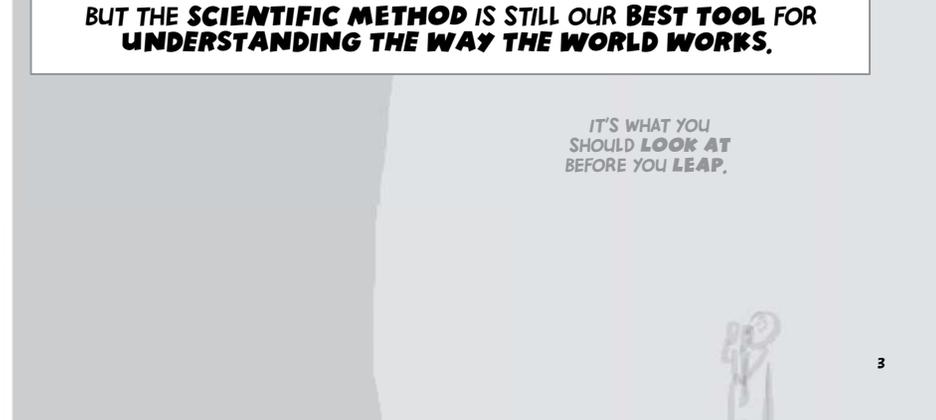
... IT WILL **NEVER** PRODUCE "**ABSOLUTE TRUTH**".

THE **THEORY OF GRAVITY** IS JUST A **THEORY.**



BUT THE **SCIENTIFIC METHOD** IS STILL OUR **BEST TOOL** FOR **UNDERSTANDING THE WAY THE WORLD WORKS.**

IT'S WHAT YOU SHOULD **LOOK AT** BEFORE YOU **LEAP.**



THE IDEAL WAY TO TEST A **HYPOTHESIS** IS WITH A **CONTROLLED EXPERIMENT...**

WE GAVE **LOTS OF WATER** TO THESE PLANTS...

...AND **NO WATER** TO THESE ONES,

LET'S SEE **WHICH ONES SURVIVE.**



WE GAVE **CHILLANTROL** TO THESE **HYPERACTIVE** KIDS...

...AND **NOT** TO THESE ONES,

LET'S SEE WHICH ONES CAN **CONCENTRATE** BETTER.



... BUT THAT'S **NOT ALWAYS POSSIBLE.**

FOR EXAMPLE, YOU CAN'T DO **CONTROLLED EXPERIMENTS** ABOUT **SMOKING...**

WE GAVE **ADDICTIVE NICTONE STICKS** TO THESE KIDS...

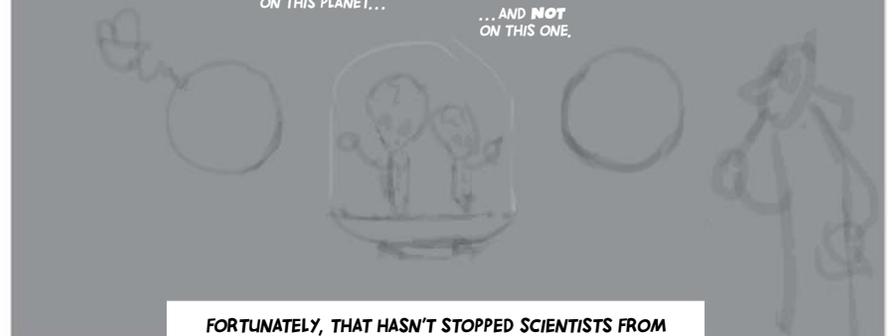
...AND **NOT** TO THESE ONES,



... OR ABOUT **CLIMATE CHANGE.**

WE **DOUBLED THE CO₂** ON THIS PLANET...

...AND **NOT** ON THIS ONE,



FORTUNATELY, THAT HASN'T STOPPED SCIENTISTS FROM **MAKING PROGRESS** ON BOTH THESE ISSUES.

WHEN YOU CAN'T WORK IN THE LAB...

... YOU HAVE TO GO OUTSIDE AND **SEARCH FOR CLUES.**



IN FACT, THE SCIENTIFIC HISTORIES OF SMOKING AND CLIMATE CHANGE ARE SIMILAR.

WHAT SIMILARITIES COULD THERE POSSIBLY BE?



COUGH
COUGH

OVER TIME, THE LINK BETWEEN SMOKING AND CANCER HAS GROWN CLEARER...

...AND CLEARER...

...AND CLEARER.

"THE WEIGHT OF THE EVIDENCE SUGGESTS THAT EXCESSIVE SMOKING IS ONE OF THE CAUSATIVE FACTORS IN LUNG CANCER."



Surgeon General
1957

"CIGARETTE SMOKING IS CAUSALLY RELATED TO LUNG CANCER IN MEN."



Surgeon General
1964

"CERVICAL CANCER, KIDNEY CANCER, PANCREATIC CANCER..."



Surgeon General
2004

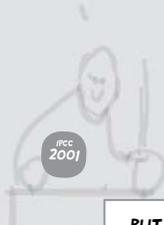
AND SO HAS THE LINK BETWEEN GREENHOUSE GAS EMISSIONS AND GLOBAL WARMING.

"THE EVIDENCE SUGGESTS A DISCERNABLE HUMAN INFLUENCE ON GLOBAL CLIMATE."



IPCC
1995

"THERE IS NEW AND STRONGER EVIDENCE."



IPCC
2001

"IT IS EXTREMELY LIKELY THAT HUMAN ACTIVITIES HAVE CAUSED MORE THAN HALF OF THE OBSERVED INCREASE IN GLOBAL AVERAGE SURFACE TEMPERATURE SINCE THE 1950S."



IPCC
2013

BUT THAT'S NOT THE ONLY SIMILARITY.

JUST AS SCIENTISTS HAVE LEARNED TO MAKE ACCURATE PREDICTIONS ABOUT SMOKING...

SMOKING WILL CAUSE OVER 400,000 DEATHS THIS YEAR IN THE UNITED STATES.



... SOME OF THE BEST EVIDENCE FOR CLIMATE CHANGE COMES FROM SUCCESSFUL PREDICTIONS FROM DECADES PAST.

WE PREDICT THAT RISING TEMPERATURES WILL BECOME OBVIOUS BY THE TURN OF THE 21st CENTURY.



1975

SINCE THE 1970s TEMPERATURES HAVE INCREASED ABOUT 0.15°C (0.3°F) PER DECADE.

WE PREDICTED 0.2°C (0.4°F).

NOT BAD!



OUR FASHION SENSE WAS TERRIBLE...

... BUT OUR PREDICTIONS WERE GREAT.

AND CLIMATE SCIENTISTS HAVEN'T JUST BEEN RIGHT ABOUT THE BIG PICTURE...



THE FACT IS, CLIMATE SCIENCE IS LIKE DETECTIVE WORK.



... THEY'VE ALSO BEEN RIGHT ABOUT LOTS OF THE DETAILS.

MORE WARMING AT NIGHT THAN DURING THE DAY?

YUP.



MORE WARMING NEAR THE POLES THAN NEAR THE EQUATOR?

YUP.



LESS ENERGY ESCAPING INTO THE STRATOSPHERE AND INTO SPACE?

YUP.



THOSE DETAILS ARE LIKE FINGERPRINTS AT A CRIME SCENE.



100 YEARS OF SCIENTIFIC DETECTIVE WORK...



... HAS CONVINCED THE VAST MAJORITY OF SCIENTISTS, THAT HUMAN ACTIVITY IS WARMING THE PLANET.



IPCC = INTERGOVERNMENT PANEL ON CLIMATE CHANGE; AAAS = AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE; AMS = AMERICAN METEOROLOGICAL SOCIETY; ACS = AMERICAN CHEMICAL SOCIETY; ASA = AMERICAN STATISTICAL ASSOCIATION; WIPCC = NONGOVERNMENTAL INTERNATIONAL PANEL ON CLIMATE CHANGE; INCLUDES THE NATIONAL ACADEMIES OF THE U.S., BRAZIL, CANADA, CHINA, FRANCE, GERMANY, INDIA, ITALY, JAPAN, RUSSIA, THE U.K., AUSTRALIA, BELGIUM, THE CARIBBEAN, INDONESIA, IRELAND, MALAYSIA, NEW ZEALAND, SWEDEN.

OF COURSE, IT'S ALWAYS POSSIBLE THAT ALL THOSE SCIENTISTS ARE **WRONG**.



WHOOOPS, GLOBAL WARMING IS ACTUALLY CAUSED BY BROCCOLI...

... AND SO IS LUNG CANCER.

AND THE KILLER REALLY WAS QUEEN VICTORIA!

BUT SO FAR **NOBODY** HAS BEEN ABLE TO IDENTIFY A **GOOD COMPETING THEORY** FOR GLOBAL WARMING...



IS IT SUNSPOTS?

NOPE.

EL NINO?

NOPE.

MILANKOVITCH CYCLES?

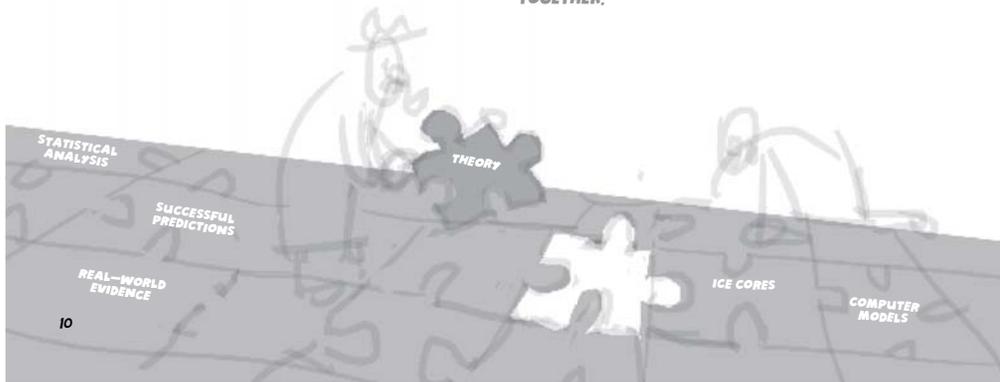
NOPE.

BROCCOLI?

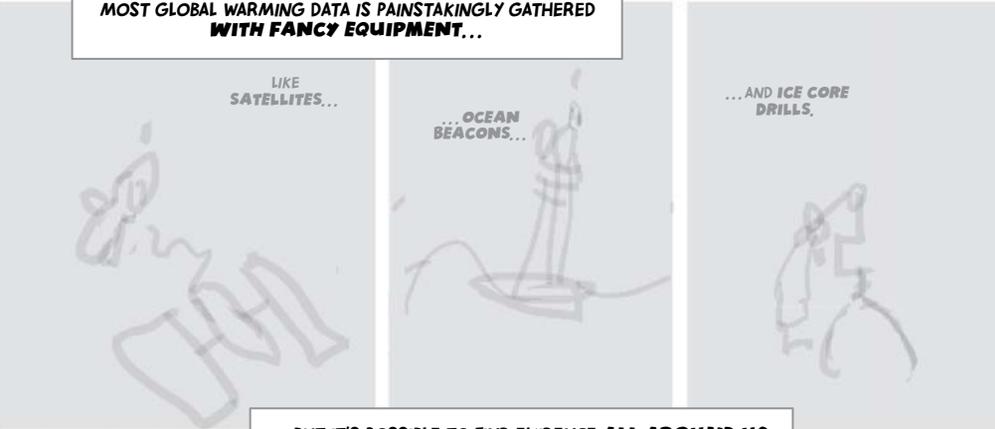
WHA?

... AND THE CASE FOR **ANTHROPOGENIC CLIMATE CHANGE** HAS GOTTEN **STRONGER AND STRONGER**.

IT'S ALL COMING TOGETHER.



MOST GLOBAL WARMING DATA IS PAINSTAKINGLY GATHERED **WITH FANCY EQUIPMENT**...



LIKE SATELLITES...

... OCEAN BEACONS...

... AND ICE CORE DRILLS.

... BUT IT'S POSSIBLE TO FIND EVIDENCE **ALL AROUND US**.



FLOWERS ARE BLOOMING EARLIER.

BIRDS ARE MIGRATING EARLIER.

ALLERGY SEASON IS STARTING EARLIER.

DRAWING NOTE: THIS IS A GREAT PLACE FOR 3 CAMEOS

YOU MIGHT EVEN FIND THIS SORT OF **PHENOLOGICAL EVIDENCE** IN **YOUR OWN BACKYARD**.



A PIED FLYCATCHER, AND IT'S ONLY APRIL 10!

SOME BIRDS HAVE A NATURAL INSTINCT TO MIGRATE...

... AND SOME HUMANS HAVE A NATURAL INSTINCT TO KEEP RECORDS.

THESE DAYS, EVERYTHING WE KNOW ABOUT CLIMATE CHANGE IS INCORPORATED INTO **CLIMATE MODELS RUN BY SUPER COMPUTERS.**

THESE MODELS DO A PRETTY GOOD JOB OF SIMULATING EVERYTHING FROM THE **ICE AGES...**

... TO **VOLCANIC ERUPTIONS...**

CHECK OUT
CHAPTER 3.

SHORT-TERM
COOLING FOR A
FEW YEARS, BUT
NO LONG-TERM
IMPACT.

... AND THEY GIVE US THE BEST INDICATION OF WHAT TO EXPECT **IN THE DECADES AHEAD.**

PART TWO PREDICTIONS

CHAPTER 7

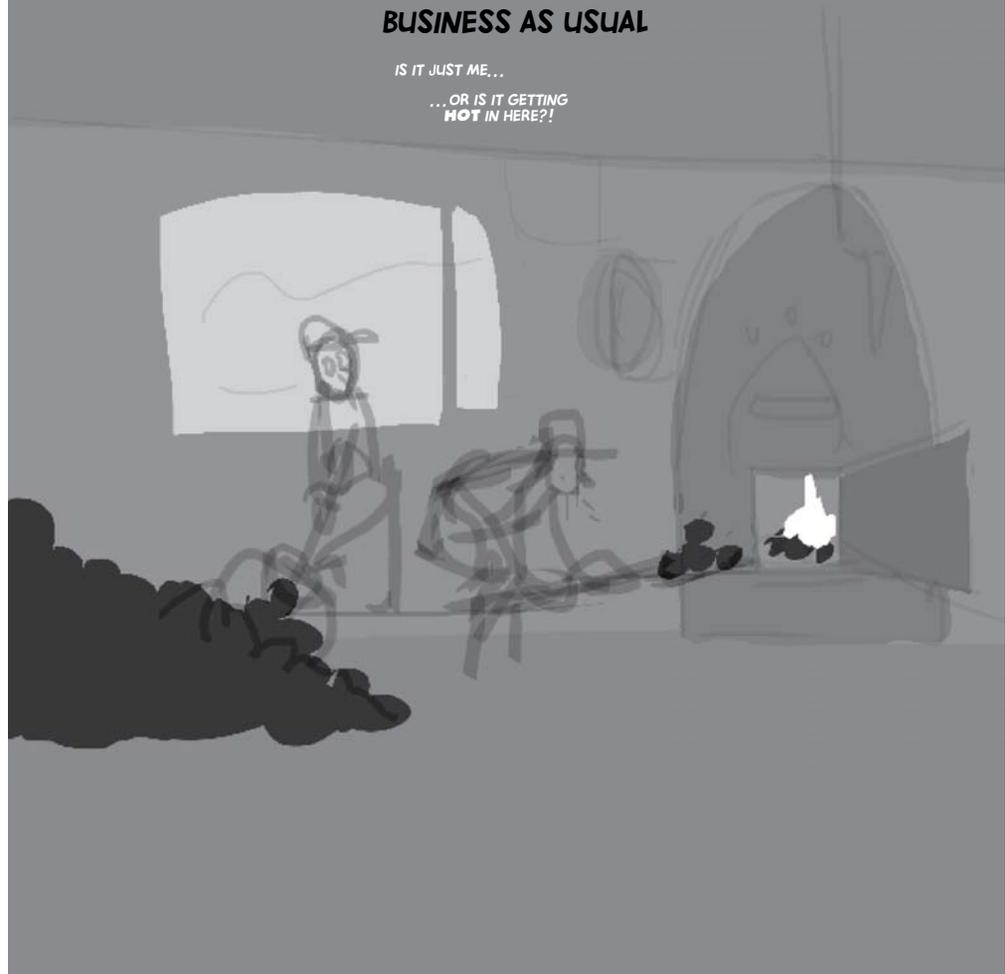
GLOBAL WARMING

OR:

BUSINESS AS USUAL

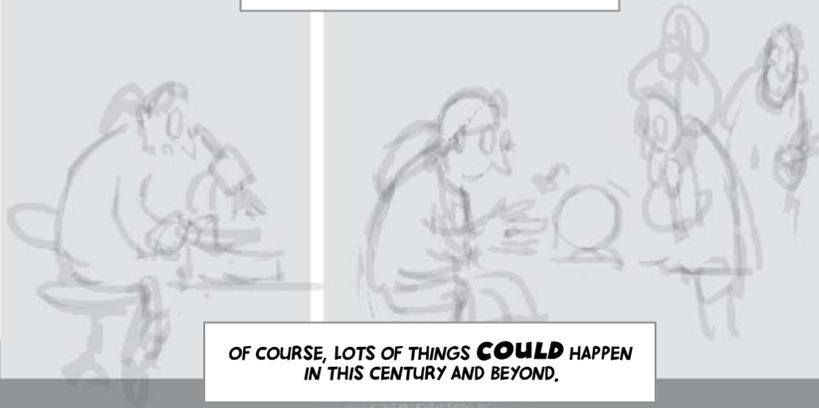
IS IT JUST ME...

...OR IS IT GETTING
HOT IN HERE?!



NOW THAT WE'VE COVERED THE
BASIC SCIENCE OF CLIMATE CHANGE...

... LET'S TAKE A LOOK AT
WHAT MIGHT HAPPEN.



OF COURSE, LOTS OF THINGS **COULD** HAPPEN
IN THIS CENTURY AND BEYOND.

WE COULD
DEVELOP **COLD
FUSION...**

... OR **FLYING
WINDMILLS...**

... OR **CARBON-EATING
TREES...**

... OR **PERPETUAL
MOTION MACHINES!**

ACTUALLY, THAT ONE
COULDN'T HAPPEN;
IT'S IMPOSSIBLE.

ONE **VERY UNLIKELY** POSSIBILITY IS THAT
HUMAN CARBON EMISSIONS WILL STOP **COLD TURKEY.**

THAT'S IT,
**PARTY'S
OVER.**

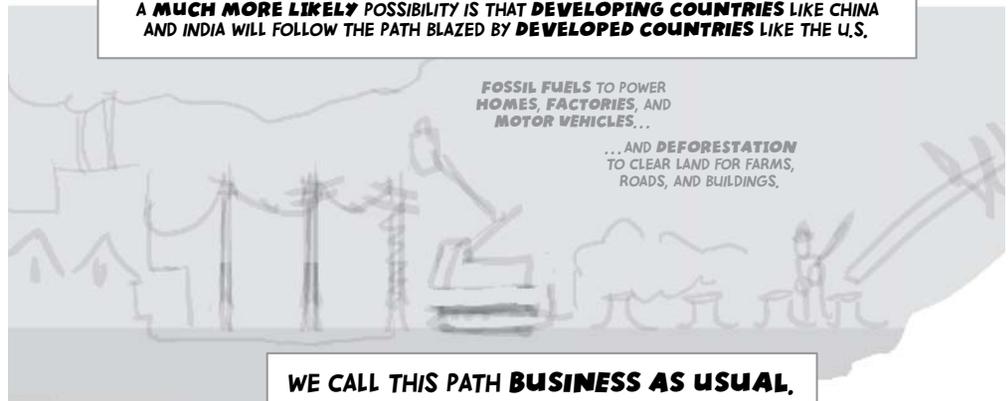
SHUT EVERYTHING
DOWN **RIGHT NOW.**



A **MUCH MORE LIKELY** POSSIBILITY IS THAT **DEVELOPING COUNTRIES** LIKE CHINA
AND INDIA WILL FOLLOW THE PATH BLAZED BY **DEVELOPED COUNTRIES** LIKE THE U.S.

FOSSIL FUELS TO POWER
**HOMES, FACTORIES, AND
MOTOR VEHICLES...**

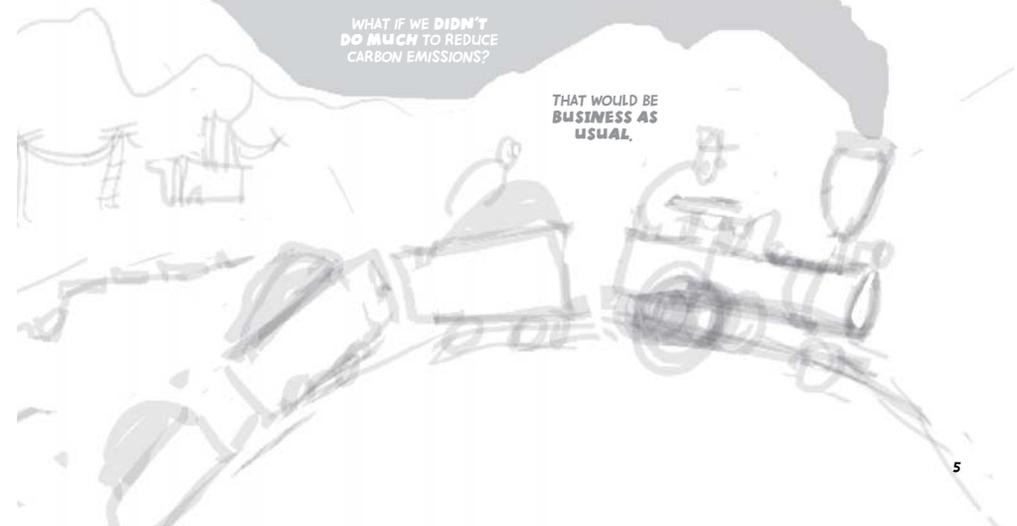
... AND **DEFORESTATION**
TO CLEAR LAND FOR FARMS,
ROADS, AND BUILDINGS.



WE CALL THIS PATH BUSINESS AS USUAL.

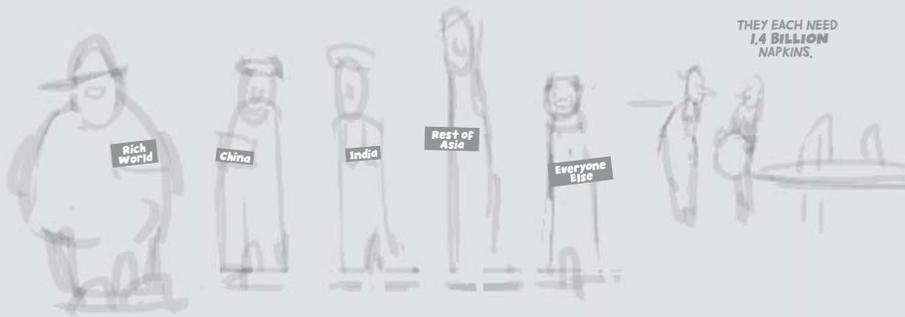
WHAT IF WE **DIDN'T
DO MUCH** TO REDUCE
CARBON EMISSIONS?

THAT WOULD BE
**BUSINESS AS
USUAL.**



THE KEY FACT ABOUT **BUSINESS AS USUAL** IS THAT IT WOULD MAKE CO₂ EMISSIONS **EXPLODE.**

TO SEE WHY, NOTE THAT WE CAN NEATLY DIVIDE THE WORLD'S ENTIRE POPULATION INTO **5 CHINA-SIZED CHUNKS.**



THE RICH WORLD MAKES UP **JUST ONE** OF THOSE FIVE CHINAS...

... BUT AT THE START OF THE 21ST CENTURY IT WAS RESPONSIBLE FOR ABOUT **HALF** OF THE WORLD'S FOSSIL FUEL CONSUMPTION.

ONE CAKE FOR YOU.

YOU ALL CAN SHARE THE SECOND CAKE.



UNDER **BUSINESS AS USUAL...**

THANKS TO RAPID ECONOMIC GROWTH...

... WE CAN NOW AFFORD **MORE CAKE!**



... THE OTHER FOUR CHINAS COULD **CATCH UP** BY 2100.

THAT'S **THREE** MORE CAKES.

PLUS, POPULATION GROWTH COULD **ADD ANOTHER 2 CHINAS** TO THE PLANET.



MEANING THAT OVER THE COURSE OF THE CENTURY WE'D **INCREASE OUR FOSSIL FUEL CONSUMPTION BY 250%.**

THAT'S LIKE GOING FROM 2 CAKES...

... TO 7.



SURE ENOUGH,
UNDER BUSINESS AS USUAL,
EMISSIONS COULD RISE 250%
DURING THE NEXT CENTURY...

Year	CO ₂ Emissions (Gt)	Carbon (Gt)
1900	0.5	1.5
1950	1.5	4.5
2000	23	68
2050	58	174
2100	125	375

... PUSHING ATMOSPHERIC CO₂
CONCENTRATIONS UP NEAR 1000 PPM.

CO₂ CONCENTRATIONS
HAVEN'T BEEN THAT
HIGH FOR **MILLIONS**
OF YEARS.

CO₂ concentrations (ppm)

300,000 ya

200,000 ya

100,000 ya

NOW

8

AS A RESULT, THE **GLOBAL
TEMPERATURE CHANGE**
BETWEEN 2000 AND 2100...

... IF WE DON'T DO MUCH
TO REDUCE EMISSIONS...

... WILL LIKELY BE ABOUT **4°C (7°F)**.

THAT ESTIMATE COULD
BE A BIT **HIGH**...

MAYBE IT'LL BE
ONLY 3°C.

... OR TOO **LOW**...

MAYBE AS MUCH
AS 6° OR 7°C.

WE'LL COME BACK TO
UNCERTAINTY IN
CHAPTER II.

MEH.

... BUT IT MAKES A GOOD **STARTING POINT**
FOR UNDERSTANDING THE CHANGES THAT ARE COMING.

IT'S JUST
A NUMBER...

... WHAT EXACTLY
DOES IT **MEAN**?

9

FOR SOME PEOPLE, A GLOBAL INCREASE OF 4°C SOUNDS LIKE **NO BIG DEAL...**

I'LL JUST **PAY A BIT MORE** FOR AIR CONDITIONING IN THE SUMMER...

... AND A **BIT LESS** FOR HEATING IN THE WINTER.

WHY ALL THE **FUSS?**



... WHILE TO OTHERS IT SOUNDS LIKE **A BIG BIG DEAL.**

IN MOST PLACES ON EARTH, THE **AVERAGE SUMMER** IN 2100...

... WILL BE **HOTTER THAN THE HOTTEST SUMMER OF THE 20TH CENTURY!**



BUT NEITHER OF THESE IS THE **BEST WAY TO THINK ABOUT IT.**

LET'S PUT THOSE NUMBERS IN **PERSPECTIVE.**



THE **BEST WAY TO THINK ABOUT 4°C** IS LIKE **THE TITLE OF A HUGE BOOK.**



NEVER **JUDGE A BOOK BY ITS COVER.**

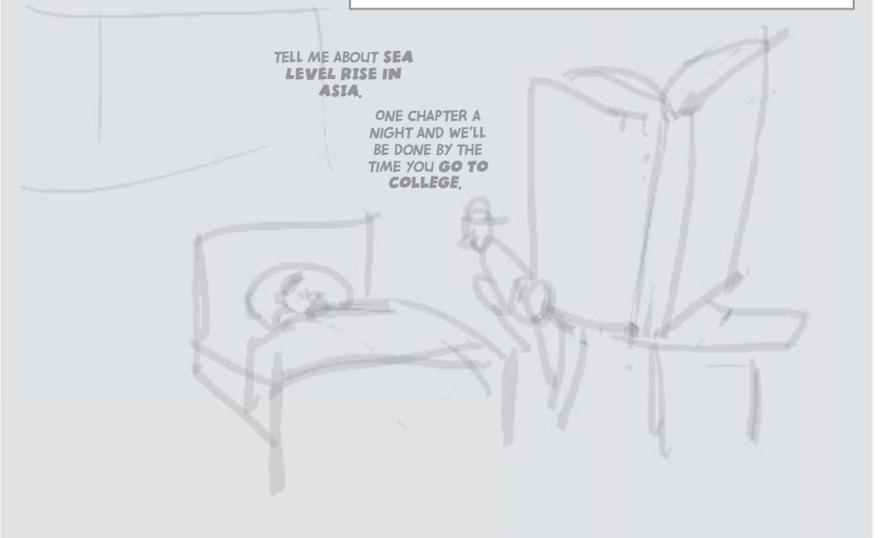


INSIDE THE BOOK ARE DESCRIPTIONS OF **LOTS OF DIFFERENT CHANGES...**

... IN **LOTS OF DIFFERENT PLACES.**

TELL ME ABOUT **SEA LEVEL RISE IN ASIA.**

ONE CHAPTER A NIGHT AND WE'LL BE DONE BY THE TIME YOU **GO TO COLLEGE.**



FOR EXAMPLE, A GLOBAL INCREASE OF **4°C (7°F)** WOULD LIKELY WARM **OCEANS BY ONLY 3°C (5°F)**...

... **LAND AREAS BY MORE, AROUND 5°C (9°F)**...



OUCH OUCH OUCH OUCH.

... AND THE **ARCTIC BY A WHOPPING 8°C (15°F)**.

LESS ICE MEANS MORE ABSORPTION OF SOLAR ENERGY,

IT'S THE **ALBEDO EFFECT!**

AND THAT'S JUST THE **TIP OF THE ICEBERG.**

Welcome to the

ARCTIC CIRCLE



Titanic 2.0

"Well, there **used to be icebergs** here."

THE FACT IS, A GLOBAL INCREASE OF **4°C (7°F)** WOULD **TRANSFORM THE ENTIRE WORLD...**

Salaam From the **FERTILE FARMLAND** of

BANGLADESH

"Well, there **used to be farmland** here."

SMOKEY THE BEAR KNOWS...



... YOU GET MORE **FOREST FIRES** WHEN IT'S **HOT AND DRY.**

The **World's Deserts** NOW EVEN **BIGGER & DRIER!**



Swim the **Great Barrier Reef**

HURRY, Offer **ENDS SOON!**

Auf Wiedersehen **FROSTBITE**



Hallo **HEATSTROKE**



WHEN IT COMES TO **LATITUDE:**

50 IS THE NEW 40

Monsoons just got...

Monsoonier



SIBERIA

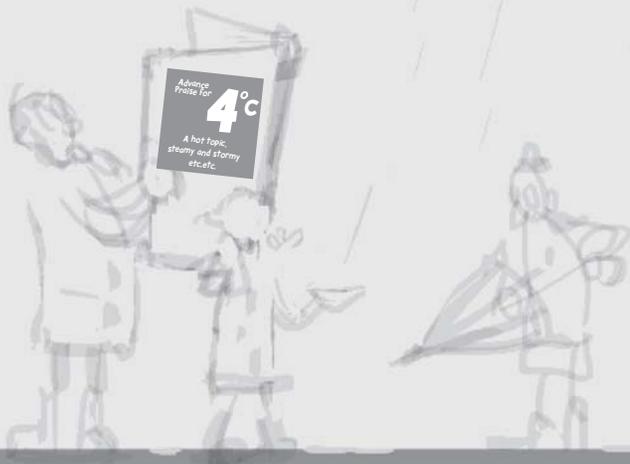
THE NEW **AGRICULTURAL HEARTLAND.**



... BECAUSE WHEN THE CLIMATE CHANGES, **EVERYTHING CHANGES.**

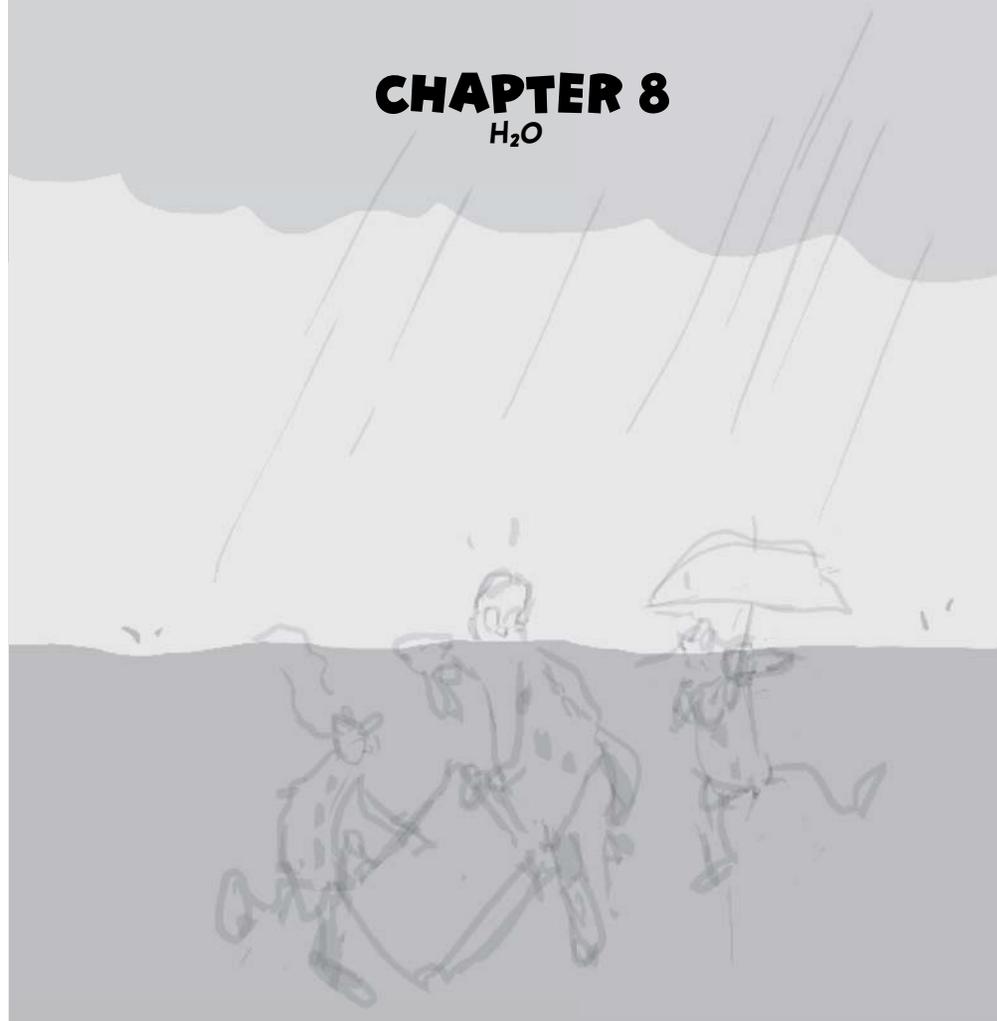
WE'RE GOING TO SPEND THE NEXT TWO CHAPTERS
LEARNING ABOUT SOME OF THESE CHANGES IN **GREATER DETAIL**.

WE'LL START WITH THE
CHANGES THAT HAVE
TO DO WITH **WATER**.



CHAPTER 8

H₂O



WATER COVERS **MOST** OF THE EARTH'S SURFACE...

...AND THE **WATER CYCLE**...

WATER CONTINUOUSLY **EVAPORATES** INTO THE ATMOSPHERE...

... WHERE IT LINGERS AS CLOUDS AND WATER VAPOR BEFORE **PRECIPITATING** AS RAIN AND SNOW.

SOME WATER ACCUMULATES ON LAND AS **SNOW AND ICE** AND IN FRESHWATER **LAKES AND RIVERS**...

... AND SOME SEEPS **UNDERGROUND**...

... BUT **MOST** RETURNS TO THE OCEANS.

97% OF THE EARTH'S WATER IS STORED IN THE OCEANS.

DRAWING NOTE, BUT THESE ARROWS IN PHOTOSHOP THROUGHOUT.

... IS AS CRUCIAL TO **LIFE ON EARTH** AS THE CARBON CYCLE.

YOU ARE WHAT YOU DRINK!

MOSTLY WATER AND CARBON.

MOSTLY WATER AND CARBON.

MOSTLY WATER AND CARBON.

WATER AND CLIMATE ARE ALSO CLOSELY RELATED...

HUMID AIR AND OCEAN CURRENTS MOVE HEAT FROM THE EQUATOR TOWARD THE POLES.

LIKE A **COOLING AND HEATING** SYSTEM!

... SO IT'S NOT SURPRISING THAT MANY OF THE **MOST IMPORTANT IMPACTS OF CLIMATE CHANGE**...

LIKE **SEA LEVEL RISE**...

... **FLOODS AND DROUGHTS**...

... AND **OCEAN ACIDIFICATION**.

... ARE THOSE RELATED TO **THE THREE FORMS OF WATER**.

LIQUID



WATER

SOLID



ICE AND SNOW

GAS



WATER VAPOR



WE BEGIN WITH THE **OCEANS**, WHICH—LIKE THE REST OF THE PLANET—ARE **WARMING UP**.

MOST OF THE EXTRA ENERGY TRAPPED BY GREENHOUSE GASES **ENDS UP IN THE OCEANS**.

AS WATER HEATS UP, IT **EXPANDS...**

JUST LIKE **MERCURY** IN A **THERMOMETER...**

...OR **HOT AIR** IN A **BALLOON**.

...AND THE RESULT IS **RIISING SEA LEVELS**.

THERMAL EXPANSION ACCOUNTED FOR ABOUT **HALF** OF THE SEA LEVEL RISE WE SAW DURING THE 20TH CENTURY.

THE OTHER **HALF** WAS FROM **MELTING GLACIERS AND ICE SHEETS**.

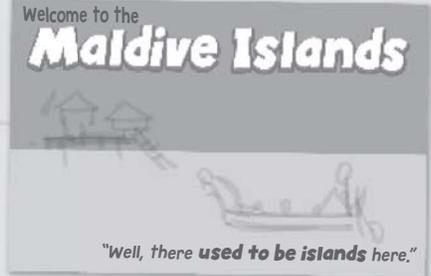
SEA LEVEL RISE IS LIKELY TO **ACCELERATE** IN THE YEARS AHEAD, **POSING RISKS TO AGRICULTURE...**

INSTEAD OF WORRYING ABOUT **WEEDS...**

...I'M WORRIED ABOUT **SEAWEEDS**.

... TO **LOW-LYING CITIES...**

...AND EVEN TO **ENTIRE COUNTRIES**.



ALL TOLD, **BUSINESS AS USUAL** WILL LIKELY LEAD TO ABOUT **2 FEET OF SEA LEVEL RISE THIS CENTURY**.

BUT IT COULD BE **TWO OR THREE TIMES** AS MUCH...

... DEPENDING ON WHAT HAPPENS TO **ICE AND SNOW**.



THE ICE SHEETS OF GREENLAND AND ANTARCTICA ARE CRUCIAL TO SEA LEVEL RISE,

IF THEY MELT SLOWLY, SEA LEVEL RISE WILL BE ABOUT 2 FEET.

IF THEY MELT QUICKLY, IT COULD BE AS MUCH AS 6 FEET.

IN CONTRAST, MELTING ICE IN THE ARCTIC DOES NOT RAISE SEA LEVELS BECAUSE IT'S FLOATING...

WHEN FLOATING ICE MELTS...

...THE WATER LEVEL DOESN'T CHANGE.

YOU CAN WATCH IT HAPPEN IN YOUR DRINK.

... BUT IT DOES MEAN BIG CHANGES IN THE ARCTIC ENVIRONMENT.

Welcome Back to the

ARCTIC CIRCLE

"An emerging Epicenter of Industry and Trade..."

...akin to the MEDITERRANEAN SEA."

GLOBAL WARMING ALSO MEANS A SHIFT FROM SNOW TO RAIN...

THESE WINTER OLYMPICS SURE ARE WEIRD!

MAYBE WE SHOULD TRY WATER SKIING INSTEAD.

... AND FASTER MELTING OF THE SNOW THAT DOES FALL,

OF COURSE, SNOW ISN'T JUST FOR SKIING...

IT'S ALSO A NATURAL RESERVOIR THAT STORES WATER FROM THE WINTER...

... AND RELEASES IT IN THE SPRING AND SUMMER.

... SO LACK OF SNOW COULD MEAN BIG TROUBLE FOR FARMERS, CONSUMERS AND INDUSTRY.

ESPECIALLY WHEN COMBINED WITH CHANGES IN RAINFALL...

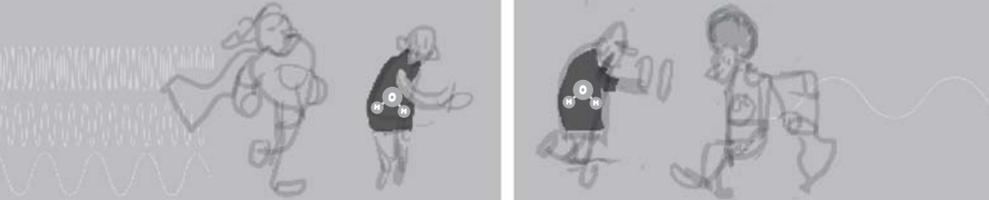
... WHICH IS OUR NEXT TOPIC.



WE LEARNED IN CHAPTER 5 THAT WATER VAPOR IN THE ATMOSPHERE WORKS AS A **GREENHOUSE GAS** TO **WARM THE PLANET**.

ENERGY IN?
GO RIGHT AHEAD.

ENERGY OUT?
YOU SHALL NOT PASS!



BUT IT TURNS OUT THAT AS THE PLANET WARMS, THE ATMOSPHERE HOLDS MORE WATER VAPOR.

THE **CLAUSIUS-CLAPEYRON** RELATIONSHIP...

... SHOWS HOW 1°C MEANS 7% MORE WATER VAPOR.

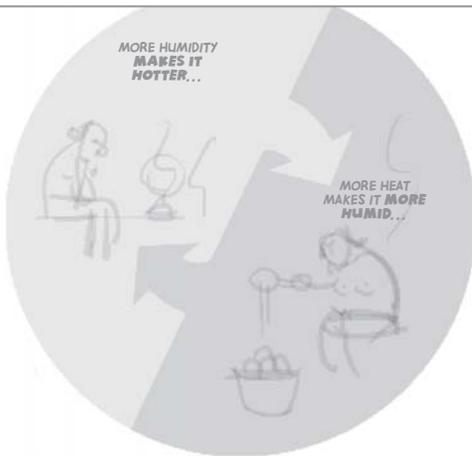
HEAT AND HUMIDITY GO HAND IN HAND.



AND THAT CREATES YET ANOTHER POSITIVE FEEDBACK LOOP.

MORE HUMIDITY MAKES IT HOTTER...

MORE HEAT MAKES IT MORE HUMID...



GLOBAL WARMING ALSO MEANS BIG CHANGES IN PRECIPITATION.

MORE DROUGHTS?
YUP.

AND MORE FLOODS?!

YUP.

AS THE PLANET WARMS, THERE WILL BE MORE EVAPORATION FROM THE SURFACE...

... WHICH MEANS DRY PLACES WILL GET DRIER.

I'M SWEATY.

I'M THIRSTY.



BUT THE EXTRA MOISTURE IN THE ATMOSPHERE ALSO CAUSES MORE INTENSE RAINSTORMS...

... SO WET PLACES WILL GET WETTER.

THE WATER CYCLE IS GOING CRAZY!



CALLBACK!
LIQUID WATER

FINALLY, WE RETURN TO THE OCEANS.

THEY'RE NOT JUST WARMING UP AND EXPANDING...

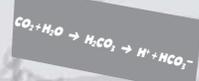
... THEY'RE ALSO GETTING MORE ACIDIC.



OCEAN ACIDIFICATION HAPPENS WHEN CO₂ FROM THE ATMOSPHERE DISSOLVES IN OCEAN WATER...

RECALL FROM CHAPTER 4 THAT OVER 25% OF OUR CO₂ EMISSIONS END UP DOWN THERE.

RECALL THIS FROM CHEMISTRY CLASS!



SHOW OFF!



... INCREASING THE CONCENTRATION OF HYDROGEN IONS IN THE WATER.

MORE HYDROGEN IONS...
... MEANS MORE ACIDIC.



Bleach
PH 12.2



Sea Water
PH 8.1



Coca Cola
PH 2.5

INCREASED ACIDITY ERODES CORAL REEFS...

EXTRA HYDROGEN IONS BREAK DOWN THE REEF FASTER THAN THE CORAL CAN BUILD IT UP.



... AND DISSOLVES THE SHELLS OF CRUSTACEANS...

YUCK,

... AND MOLLUSKS...

DOUBLE YUCK,



... AND TINY SEA CREATURES.

LIKE PTEROPODS...



... COCCOLITHOPHORES...



... AND FORAMINIFERA.



EVEN THOUGH YOU'VE
PROBABLY NEVER
HEARD OF THEM...

CACALITHOFARTS!
FORBADIFADALIDA!

PHPHPTHHTHTHBBBB!



... THOSE TINY SEA CREATURES FORM THE **BASE OF THE MARINE FOOD CHAIN.**

AS A RESULT, OCEAN
ACIDIFICATION THREATENS
JUST ABOUT **EVERYTHING**
IN THE SEA...

... AND **EVERYONE** CONNECTED TO IT.

UH-OH

IT'S NO WONDER **OCEAN ACIDIFICATION**
IS SOMETIMES CALLED GLOBAL WARMING'S **EVIL TWIN.**

LET'S PUT COCA-COLA IN THE
BUCKET AND **WATCH THE**
SHELLFISH DISSOLVE.

WE'RE **DOUBLE**
TROUBLE!



CHAPTER 9

LIFE ON EARTH



WHEN CIRCUMSTANCES CHANGE,
LIVING THINGS **ADAPT...**

SORRY, NO
SEAL MEAT
TODAY.

IN THAT CASE,
GIVE ME 50
POUNDS OF THE
SNOW GOOSE.

...AND SPECIES **EVOLVE...**

GO BACK 100,000
GENERATIONS AND YOUR
ANCESTORS JUST WERE REGULAR
OLD **BROWN BEARS.**

...AND IF THEY DON'T SUCCEED **IT'S CURTAINS.**

WHAT USE ARE BIG WEBBED FEET
AND TRANSPARENT FUR IF
THERE'S **NO MORE ICE?**

THAT'S WHY YOU
NEED TO **GO TO
SCHOOL AND PAY
ATTENTION!**

MANY OF THE **CHANGING
CIRCUMSTANCES** IN THE WORLD
TODAY ARE **CAUSED BY HUMANS...**

BOY IS THAT AN
UNDERSTATEMENT!

.... AND CLIMATE CHANGE IS GOING
TO ADD AN **EXTRA CHALLENGE.**

HABITAT
LOSS

INVASIVE
SPECIES

POLLUTION

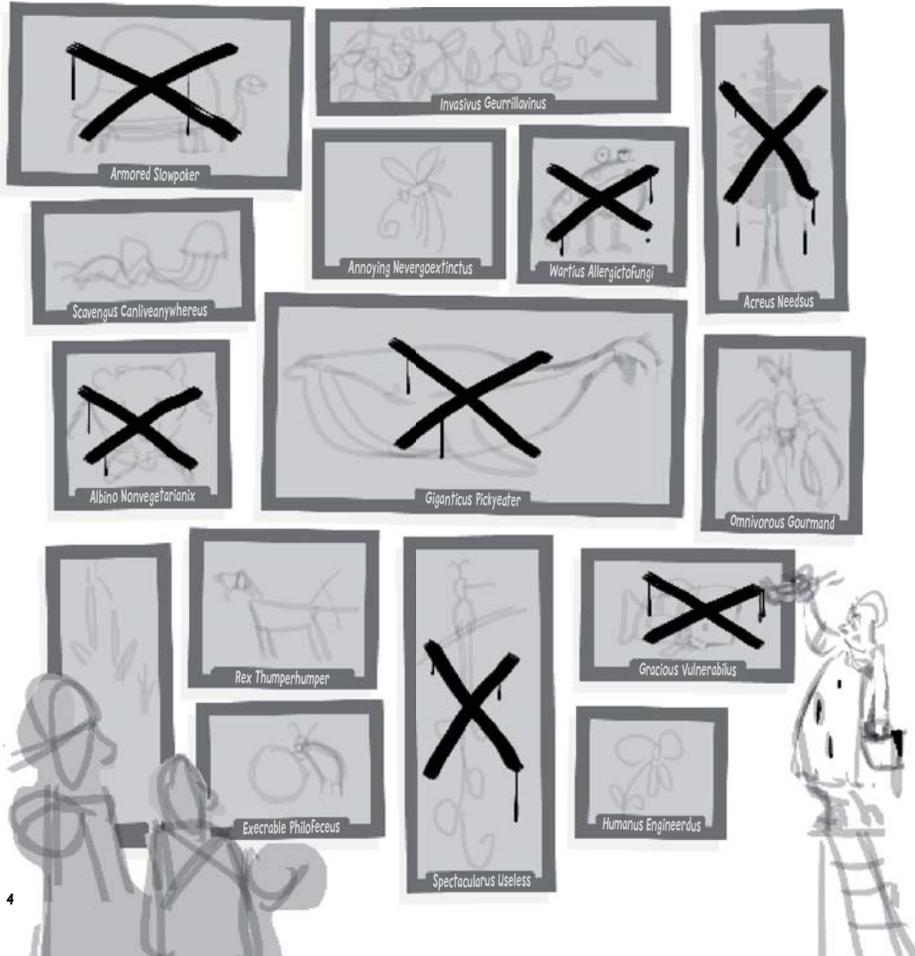
POPULATION
INCREASE

OVERHARVESTING

CLIMATE CHANGE IS LIKELY TO BE A BIG PROBLEM FOR SPECIES THAT **EVOLVE SLOWLY**...

WE TAKE **EVERYTHING SLOWLY**.

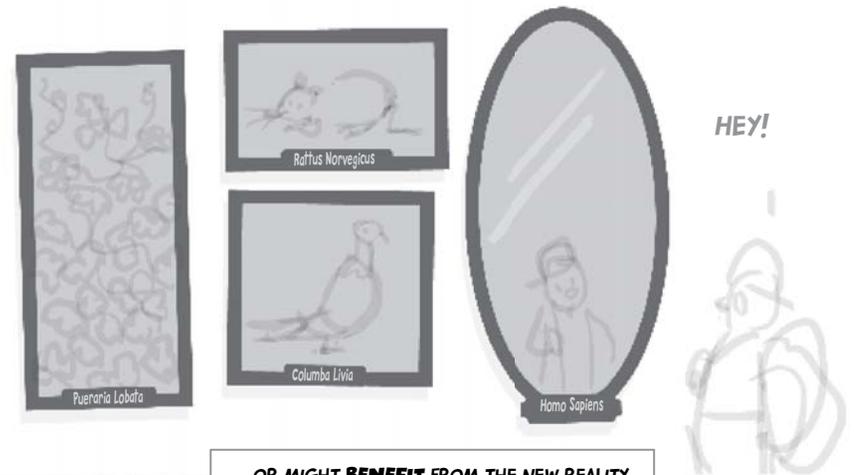
... AND SCIENTISTS ESTIMATE THAT **40-70%** OF ALL THE SPECIES ON EARTH MAY GO **EXTINCT** OVER THE NEXT 100 YEARS.



A CHANGING WORLD MAY BE LESS OF A PROBLEM FOR SPECIES THAT **EVOLVE QUICKLY**...

WE BREED LIKE **RABBITS!**

... OR CAN **ADAPT QUICKLY**...



... OR MIGHT **BENEFIT** FROM THE NEW REALITY.

CERTAIN PLANTS DO **BETTER** WITH MORE CO₂...

... AS LONG AS IT DOESN'T GET **TOO HOT**.

AS FOR HOW CLIMATE CHANGE WILL AFFECT **HUMANS...**

HALL OF MAN
AND WOMAN!

FINALLY,
SOMETHING
I CAN CARE
ABOUT.

C'MON DAD, LET'S
GO BACK TO THE
ANIMALS!

... IT'S A BIT **HARD TO SAY**
BECAUSE WE'RE SO GOOD AT
ADAPTING.

WHAT IF **OCEAN
ACIDIFICATION** DESTROYS
MARINE ECOSYSTEMS?

WE'LL JUST EAT
FARMED FISH!

BUT WHAT WOULD
YOU **FEED** THE
FARMED FISH?

CORN!

BUT HOW ARE YOU
GOING TO **GROW**
ALL THAT **CORN?**

**GENETIC
MODIFICATION!**

BUT THEN THE FISH WILL
TASTE LESS LIKE FISH AND
MORE LIKE **CORN.**

MY TASTE
BUDS WILL
ADAPT.

OF COURSE **ADAPTATION**
WON'T NECESSARILY BE
EASY.

THIS IS A THREAT
TO MY **QUALITY
OF LIFE!**

THIS IS A THREAT TO
MY **ACTUAL LIFE.**

BUT IT WILL DEFINITELY BE **EASIER FOR THE WEALTHY...**

Homo Sapiens Opulentus

... THAN **FOR THE POOR.**

Homo Sapiens Penuriosus

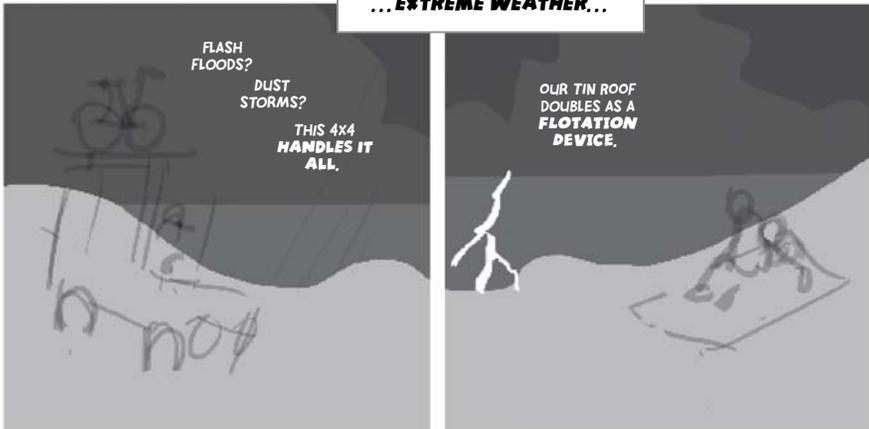
YOU CAN SEE THE **GAP BETWEEN RICH AND POOR** WHEN YOU LOOK AT **SEA LEVEL RISE...**



... **HEAT WAVES...**



... **EXTREME WEATHER...**



... **HIGHER FOOD PRICES...**



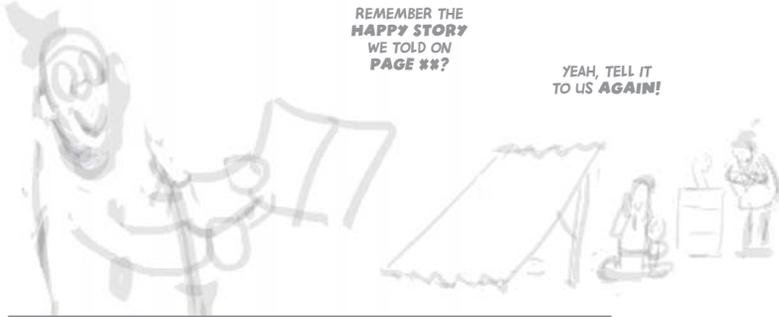
... **AND DISEASE OUTBREAKS.**



AND THE IMPACT ON THE POOR IS ESPECIALLY UNFAIR SINCE THEY **HAVEN'T CONTRIBUTED MUCH TO THE PROBLEM.**



FORTUNATELY, **ECONOMIC GROWTH** WILL LIKELY MEAN **MORE RICH PEOPLE AND FEWER POOR PEOPLE** IN THE DECADES AHEAD.



REMEMBER THE **HAPPY STORY** WE TOLD ON **PAGE ##?**

YEAH, TELL IT TO US **AGAIN!**

BUT EVEN THOSE WHO **BENEFIT** WILL FACE **BIG CHALLENGES...**



I MISS ALL THAT **BIODIVERSITY.**

I MISS **BEACHES.**

WHADDYA MEAN I CAN'T EAT **MONET?**

...AND THERE'S A CHANCE THAT EVEN THE RICH WILL BE **OVERWHELMED.**

ESPECIALLY TOWARDS THE **END OF THE CENTURY.**



CHAPTER 10 BEYOND 2100

THE WORLD WILL CONTINUE **BEYOND 2100**, YOU KNOW.

AT LEAST WE **HOPE SO!**



SO FAR WE'VE FOCUSSED ON THE IMPACTS OF CLIMATE CHANGE **IN THIS CENTURY.**

I DON'T LIKE THIS BOOK!



IN OTHER WORDS, WE'VE FOCUSSED ON HOW CLIMATE CHANGE WILL AFFECT **US...**

... AND OUR **CHILDREN AND GRANDCHILDREN.**



BUT NOW WE'RE GOING TO LOOK AT WHAT MIGHT HAPPEN IN THE EXTRA LONG TERM.

LIKE TO **OUR** GREAT GREAT GREAT GREAT GRANDCHILDREN,



UNFORTUNATELY, EVEN IF WE WENT **COLD TURKEY** AND STOPPED EMITTING GREENHOUSE GASES **TODAY...**

STOP!
PARTY'S OVER.



... HUMAN-INDUCED CLIMATE CHANGE WOULD **CONTINUE BEYOND 2100.**

I SAID "**STOP,**" BY ZORG!



IN FACT, TEMPERATURES AND SEA LEVELS WOULD CONTINUE TO RISE FOR HUNDREDS OF YEARS.

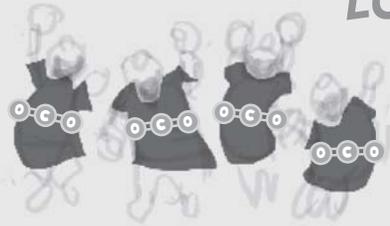
THEY'D JUST RISE **MORE SLOWLY** THAN IF WE KEEP POLLUTING.

BUT **WHY?**



ONE REASON CLIMATE IMPACTS **GO ON AND ON** IS THAT CO₂ IS A **LONG-LIVED GAS**.

LONG LIVE CO₂!



WELL THAT'S NOT REALLY WHAT WE MEANT.



ABOUT **HALF** OF THE CO₂ WE'RE EMITTING NOW WILL **STILL BE WARMING THE PLANET IN 100 YEARS...**



NYAA NYAA!

MOST OF THE REST WILL HAVE **DISSOLVED IN THE OCEANS...**

... MAKING THEM **MORE ACIDIC.**



... AND ABOUT **HALF OF THAT AMOUNT** WILL STILL BE AT IT IN **A THOUSAND YEARS.**



AS FAR AS HUMANS ARE CONCERNED, THAT'S PRETTY MUCH **FOREVER.**

LIKE **TATTOOS...**

... OR **NUCLEAR WASTE.**



ANOTHER REASON IS THAT **THE EARTH'S CLIMATE SYSTEM IS SLUGGISH.**



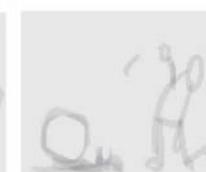
THIS MEANS THAT THE PLANET DOESN'T RESPOND **INSTANTANEOUSLY** TO CHANGES IN ENERGY BALANCE.



INSTEAD IT RESPONDS **GRADUALLY...**



... WHICH IN THIS CASE CAN MEAN **HUNDREDS** IF NOT **THOUSANDS OF YEARS.**



ONE ESPECIALLY **SLUGGISH** PART OF THE EARTH'S CLIMATE SYSTEM IS **SEA LEVEL RISE.**

OK CLASS, TODAY WE'RE GOING TO WATCH ICE MELT.

ZZZZZZ

WE SAW IN CHAPTER 8 THAT SEAS ARE LIKELY TO RISE ABOUT **2 FEET BY 2100.**

BUT THERE'S A GOOD CHANCE SEAS WILL CONTINUE TO RISE FOR **SEVERAL CENTURIES BEYOND THAT...**

LOW TIDE IN 2200...

... MIGHT BE **HIGHER** THAN HIGH TIDE IN 2100.

... BECAUSE ONCE **GLACIERS START TO MELT,** IT'S HARD TO TELL WHEN THEY'LL **STOP.**

IF ALL OF **GREENLAND** EVENTUALLY MELTS, THE SEAS WILL RISE BY ABOUT **20 FEET.**

GOODBYE **NEW ORLEANS.**

IF THE **WEST ANTARCTIC ICE SHEET** MELTS, THEY'D RISE **ANOTHER 20 FEET.**

GOODBYE **FLORIDA.**

IF **ALL OF ANTARCTICA** MELTS, THEY'D RISE **ANOTHER 200 FEET.**

GOODBYE **NEW YORK CITY.**

BUT REMEMBER, MELTING MILE-THICK ICE SHEETS WOULD TAKE **MANY HUNDREDS OF YEARS...**

... AND **WHO KNOWS** WHAT THE WORLD WILL LOOK LIKE IN **HUNDREDS OF YEARS?**

THE WORLD POPULATION COULD BE **2 BILLION...**

... OR **36 BILLION.**

WE COULD DISCOVER **TECHNOLOGICAL MIRACLES...**

... OR RETURN TO THE **STONE AGE.**

WE COULD HAVE **UNDERWATER CITIES...**

... OR WIND UP **SWIMMING WITH THE FISHES.**

TO SEE HOW HARD IT IS TO LOOK **BEYOND 2100**, IMAGINE SOMEONE IN **1900...**

HOWDY, **STRANGER!**

... TRYING TO ANTICIPATE **TODAY'S WORLD.**

ANTIBIOTICS?
COMPUTERS?

SATELLITE-GUIDED
TRACTORS?

WHAT KIND OF
NONSENSE ARE
YOU TALKING?

INDEED, WHEN THE SWEDISH CHEMIST **ARRHENIUS** FIRST STUDIED CLIMATE CHANGE **100 YEARS AGO...**

... HE THOUGHT THE RESULTS WOULD BE **GOOD.**

THE **INCREASING PERCENTAGE** OF **CARBONIC ACID [CO₂]** IN THE ATMOSPHERE...

... WILL BRING FORTH MUCH MORE **ABUNDANT CROPS** THAN AT PRESENT.

OF COURSE, HE LIVED IN **SWEDEN.**

BRRRR,

WHICH JUST SHOWS HOW **TOUGH** IT IS TO **MAKE PREDICTIONS...**

... ESPECIALLY ABOUT THE **FUTURE.**

IN 100 YEARS WE'LL ALL BE **BETTER OFF** BECAUSE OF **ECONOMIC GROWTH...**

... UNLESS WE'RE **WORSE OFF** BECAUSE OF **ENVIRONMENTAL DEGRADATION.**

IN SUM, ALTHOUGH THE **GENERAL TRAJECTORY** FOR THE EARTH'S CLIMATE IS PRETTY CLEAR...



I'M JUST GETTING STARTED.

... THE **LONG TIME SPAN** ASSOCIATED WITH GLOBAL WARMING...

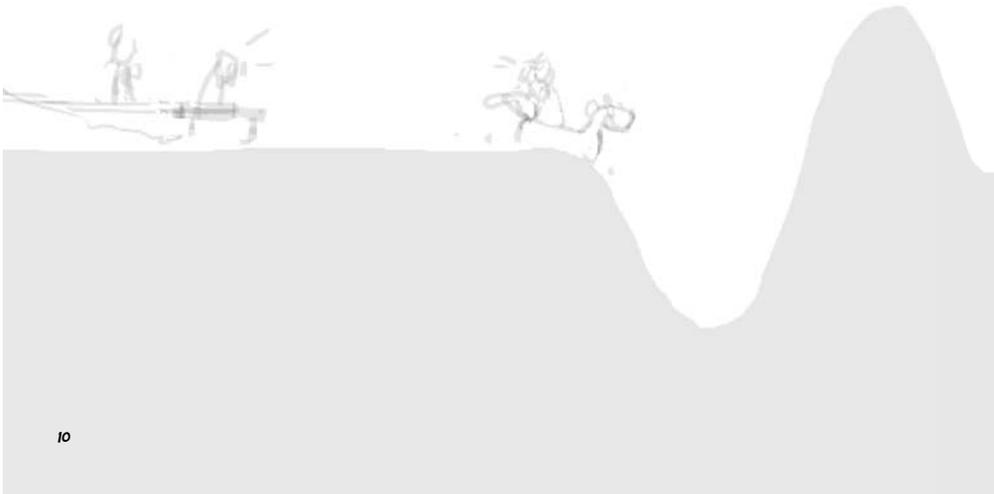
THE CHOICES **YOU MAKE** WILL HAVE CONSEQUENCES FOR YOUR **GREAT GREAT GREAT GRANDCHILDREN.**



... IS ONE OF THE **TWO MAJOR ISSUES** THAT ADD **UNCERTAINTY** TO THE PROBLEM OF CLIMATE CHANGE.

WHAT'S THE **OTHER MAJOR ISSUE?**

UNCERTAINTY.



CHAPTER 11 UNCERTAINTY

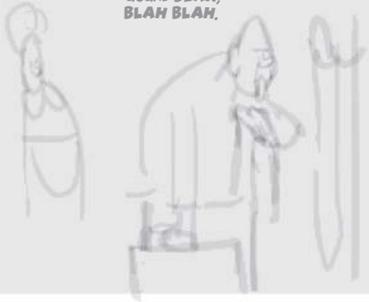
WELL, IF YOU WANT TO BE **CERTAIN...**

... WE'LL JUST HAVE TO **WAIT AND SEE.**



IN THIS CHAPTER WE'RE GOING TO TAKE A BREAK FROM **LIKELY OUTCOMES**...

TODAY WAS THE USUAL **BLAH, BLAH, BLAH**.



... AND THINK FOR A BIT ABOUT **UNLIKELY OUTCOMES**.

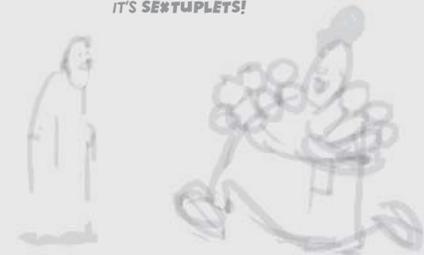
THE **CEO GOT FIRED** AND **BURNED DOWN THE BUILDING!**



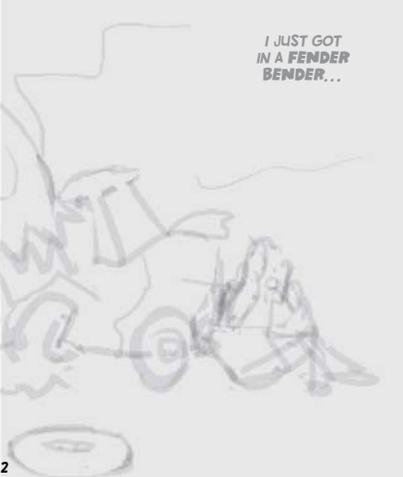
CONGRATULATIONS, IT'S A **GIRL!**



CONGRATULATIONS, IT'S **SEXTUPLETS!**



I JUST GOT IN A **FENDER BENDER...**



... WITH AN **ALIEN SPACECRAFT.**



WHEN IT COMES TO CLIMATE, **UNLIKELY OUTCOMES** ARE, WELL, **UNLIKELY**.

COULD ALL OF ANTARCTICA MELT?

THAT WOULD BE **EXTREMELY UNLIKELY**.



BUT NO MATTER HOW YOU **MEASURE THE ODDS...**

... **UNLIKELY DOESN'T MEAN IMPOSSIBLE**.

THESE ODDS ARE **1 IN 3**.

THESE ODDS ARE **1 IN 10**.

THESE ODDS ARE **1 IN 100**.

THESE ODDS ARE **1 IN 100,000,000,000**.

DUDE, I **WON THE LOTTERY!**

UNLIKELY

VERY UNLIKELY

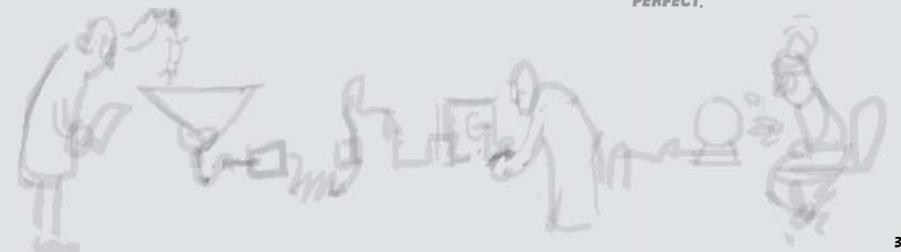
EXTREMELY UNLIKELY

EXTRA SUPER DUPER UNLIKELY



WE CAN SEE THIS BY LOOKING AT **PAST PREDICTIONS** MADE BY CLIMATE SCIENTISTS.

HEY, NOBODY'S **PERFECT**.



WHILE MANY SCIENTIFIC PREDICTIONS ABOUT CLIMATE CHANGE HAVE **HIT THE TARGET...**

WE THOUGHT TEMPERATURES WOULD RISE THIS MUCH...

... AND THEY DID.

WE THOUGHT SEAS WOULD RISE THIS MUCH...

... AND THEY DID.

... OTHERS HAVE **MISSED...**

... BOTH FOR **BETTER...**

WE THOUGHT METHANE WOULD RISE THIS MUCH...

... BUT IT ROSE LESS.

... AND FOR **WORSE,**

WE THOUGHT ARCTIC GLACIERS WOULD MELT THIS MUCH...

... BUT NOT THIS FAST.

IN OTHER WORDS, SOME SCENARIOS SCIENTISTS THOUGHT WERE **UNLIKELY...**

... **ACTUALLY** CAME TO PASS.

XYZ IS **VERY UNLIKELY.**

NEWS FLASH:
XYZ JUST HAPPENED!

MADDENING THOUGH IT IS, THIS SORT OF **UNCERTAINTY** IS UNAVOIDABLE.

ARRRRGH!

TOUGH LUCK.

AND THAT LEAVES US WITH
A **CONUNDRUM**.

ARRRRGH!

IF REALITY TURNS OUT TO BE **BETTER**
THAN WE'D THOUGHT...

CARBON EMISSIONS
HAVE **LEVELED**
OUT...

... THE CLIMATE HAS
STABILIZED.

WHEW, WE
DODGED A BULLET
BACK THERE.

1°C

... THEN BUSINESS AS USUAL MIGHT
NOT BE SO BAD.

THANKS TO RAPID
ECONOMIC GROWTH,
WE ALL GET **MORE**
CAKE...

... **AND** THERE'S NOT TOO
MUCH EXTRA SUFFERING FROM
CLIMATE CHANGE.

BUT IF REALITY TURNS OUT TO BE **WORSE**
THAN WE'D THOUGHT...

CARBON EMISSIONS
KEEP INCREASING...

... THE GULF
STREAM HAS
STOPPED...

... THE SAHARA
IS **MOLTEN...**

... THE OCEANS
ARE LIKE **LEMON**
JUICE.

6°C

... THEN BUSINESS
AS USUAL COULD BE
CATASTROPHIC.

WE THOUGHT
WE'D ALL GET
MORE CAKE...

... BUT ALL
THE CROPS ARE
ROTTEN...

... AND THE ONLY
OTHER THING TO
EAT IS **SAND.**

ALL THIS TALK ABOUT
POTENTIAL CALAMITIES...

... SHOULD MAKE YOU THINK
ABOUT **INSURANCE**.

FOR \$5⁹⁹
I'LL TELL YOUR
FORTUNE...

... BUT FOR AN EXTRA
\$99⁹⁹ I'LL THROW IN
CATASTROPHIC
COVERAGE.

FOR EXAMPLE, WHILE IT'S
UNLIKELY THAT YOU'LL GET
INTO A **HORRIFIC ACCIDENT...**

ESPECIALLY WITH
AN **ALIEN**.

... OR BECOME **DEATHLY ILL...**

TRIAGE!

IT'S ANOTHER CASE OF
STOCHASTIC ANXIETY
DISORDER.

... IT'S A GOOD IDEA TO **BUY INSURANCE**, JUST IN CASE.

INSURANCE GIVES
YOU A WAY TO **PAY**
SOMETHING NOW...

... TO EASE POTENTIAL
PROBLEMS **IN THE**
FUTURE.

SIMILARLY, ALTHOUGH IT'S **UNLIKELY** THAT
CLIMATE IMPACTS WILL BE **CATASTROPHIC...**

THE WHOLE PLANET
COULD BECOME LIKE
VENUS!

... WE SHOULD **BUY INSURANCE**, JUST IN CASE.

I LIKE **SCIENCE**
FICTION.

BUT WE DON'T WANT
OUR **KIDS** TO **LIVE**
THROUGH IT.

WHICH BEGS A **QUESTION:**

YOU CAN **BUY**
INSURANCE FOR
ALL KINDS OF
THINGS...

I'VE GOT
LIFE
INSURANCE.

PET
INSURANCE.

DEATH
INSURANCE.

EVEN **ALIEN**
ABDUCTION
INSURANCE.

FLOOD
INSURANCE.

... BUT HOW DO YOU **BUY INSURANCE** FOR THE **WHOLE PLANET?**

AS IT TURNS OUT,
OUR **BEST INSURANCE POLICY...**

... IS TO **REDUCE EMISSIONS** OF CO₂
AND OTHER GREENHOUSE GASES.

THE MORE WE
REDUCE **NOW...**

... THE LESS LIKELY
WE'LL **MEET**
CATASTROPHE.



AND WE'LL LEARN MORE ABOUT THAT IN THE **NEXT PART OF THIS BOOK.**

DON'T WORRY...

... WE CAN ALL STILL
HAVE CAKE!

