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Narrator: GIVEN THE EARTH'S
DISTANCE FROM THE SUN
ITS GLOBAL-AVERAGE
TEMPERATURE SHOULD BE
A CHILLING -18 DEGREES CELSIUS.
FORTUNATELY, GASES IN OUR
ATMOSPHERE
TRAP SOME OF THE SUN'S HEAT
CREATING A HOSPITABLE,
AVERAGE TEMPERATURE
OF 15 DEGREES CELSIUS.
BUT THE BURNING OF FOSSIL
FUELS
IS CHANGING THE COMPOSITION
OF THE ATMOSPHERE
BY INCREASING THE
CONCENTRATIONS OF THESE
HEAT-TRAPPING GASES.
SCIENTIST PIETER TANS AND A
TEAM OF RESEARCHERS
ARE CONTINUOUSLY KEEPING
WATCH ON THIS CHANGE --
ONE THAT COULD ULTIMATELY
ALTER THE ENVIRONMENT
FOR ALL LIVING THINGS.
Dr. Tans: WE USE THE
ATMOSPHERE AS A DIAGNOSTIC
TO MONITOR THAT THE EARTH IS

REALLY DOING
WHAT WE HOPE IT IS DOING.
Narrator: BUT THE ATMOSPHERE
DOES NOT JUST TRAP HEAT
IT MOVES IT AROUND THE WORLD
AND TOGETHER WITH THE
OCEANS SHAPES EARTH'S
CLIMATE
AND WEATHER PATTERNS.
ONE POWERFUL EXAMPLE OF
THIS IS THE TROPICAL CYCLONE
MORE COMMONLY KNOWN IN THE
UNITED STATES
AS THE HURRICANE.
DR. KERRY EMANUEL HAS SPENT
MUCH OF HIS CAREER
TRYING TO UNDERSTAND THESE
LETHAL STORMS
AND THE LARGER ROLE THEY
MIGHT PLAY IN REGULATING
CLIMATE.
THERE'S SOMETHING RATHER
UNEXPECTED
THAT'S TURNED UP FROM
RESEARCH --
THAT HURRICANES MAY HAVE A
PROFOUND EFFECT ON THE
CLIMATE.
Narrator: BOTH OF THESE STUDIES
OFFER US DEEPER INSIGHT
INTO THE COMPLICATED,
EVER-CHANGING, ACTIVE SYSTEM

THAT IS THE OUTERMOST LAYER OF OUR PLANET -- THE ATMOSPHERE.

ALL AROUND THE WORLD, SCIENTISTS FROM
THE NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
COMMONLY KNOWN AS NOAA
ARE MONITORING TRACE GASES IN THE ATMOSPHERE.
ONE OF THEIR FINDINGS IS THAT CARBON DIOXIDE IS INCREASING DUE TO THE BURNING OF FOSSIL FUELS ON EARTH --
AN INCREASE THAT COULD HAVE SIGNIFICANT EFFECTS
ON THE CLIMATE.
FOR LEAD INVESTIGATOR PIETER TANS
THE IDEA THAT OUR BEHAVIOR COULD HAVE ANY INFLUENCE ON THE PLANET
CAME AS A SURPRISE.
Dr. Tans: I RAN INTO A LITTLE BOOK
AND IT WAS CALLED
"INADVERTENT CLIMATE MODIFICATION."
THIS WAS IN 1972.
MY FIRST REACTION WAS, "THAT'S NONSENSE".

"I MEAN, HOW CAN WE HUMANS INFLUENCE THE CLIMATE OF THIS PLANET?
YOU KNOW, WE'RE JUST TOO SMALL FOR THAT."
BUT I STARTED -- I LEAFED THROUGH IT
AND I SAW ABOUT INFRARED ABSORPTION BY CERTAIN GASES
AND I THOUGHT, "OKAY, THERE MAY BE SOMETHING TO THAT."
SO I BOUGHT THE BOOK.
AND I WAS CONVINCED RIGHT THEN
THAT THIS WAS GOING TO BE AN IMPORTANT PROBLEM.
Narrator: THE PROBLEM, HUMAN-INDUCED GLOBAL WARMING
IS CAUSED BY THE HEAT-TRAPPING CHARACTERISTICS
OF CARBON DIOXIDE AND OTHER SO-CALLED GREENHOUSE GASES
--
THE SAME CHARACTERISTICS
THAT MAKE THE EARTH HABITABLE.
Dr. Tans: IT'S CALLED THE GREENHOUSE EFFECT.
YOU CAN LOOK AT IT LIKE A BLANKET.

SO THE EARTH RECEIVES ENERGY FROM THE SUN
AND, IN FACT, WHEN WE SIT IN THE SUN
WE FEEL THAT WE'RE BEING HEATED.
BUT IT'S NOT VISIBLE TO THE NAKED EYE.
IT'S INFRARED RADIATION.
BUT THE EARTH ALSO EMITS THAT ENERGY BACK INTO SPACE.
AND WHEN WE PUT MORE OF THESE ABSORBING GREENHOUSE GASES
INTO THE ATMOSPHERE
THE INFRARED RADIATION WILL BE PROHIBITED FROM REACHING SPACE.
IT WILL BE TRAPPED IN THE ATMOSPHERE
AND EMITTED BACK TO THE SURFACE.
Narrator: GREENHOUSE GASES IN THE ATMOSPHERE
CONTROL THE EARTH'S TEMPERATURE.
THE GREATER THE AMOUNT OF GREENHOUSE GASES
THE HIGHER THE TEMPERATURE.
LESS GREENHOUSE GAS MEANS A LOWER TEMPERATURE.
CARBON DIOXIDE IS CYCLED

THROUGH THE ATMOSPHERE
THROUGH MANY NATURAL
PROCESSES SUCH AS
PHOTOSYNTHESIS
RESPIRATION AND DECAY OF
VEGETATION
AND SEA SURFACE GAS
EXCHANGE.
THIS NATURAL TRANSFER, KNOWN
AS THE CARBON CYCLE
IS IN NEAR BALANCE.
THE AMOUNT BEING EMITTED TO
THE ATMOSPHERE
IS CLOSE TO THE AMOUNT BEING
ABSORBED.
BUT THE BURNING OF FOSSIL
FUELS IS ADDING CO2
FASTER THAN NATURAL SYSTEMS
CAN RESPOND.
PIETER TANS IS TAKING CAREFUL
MEASUREMENTS
OF THE ATMOSPHERIC
CONCENTRATION OF CARBON
DIOXIDE
TO BETTER UNDERSTAND THE
CARBON CYCLE.
Dr. Tans: WHEN YOU STUDY THE
CARBON CYCLE
WHAT MATTERS IS WHAT
HAPPENS TO CO2 EXCHANGE
BETWEEN THE ATMOSPHERE AND
THE OCEANS.

WHAT ARE TERRESTRIAL ECOSYSTEMS DOING?
ARE THEY LOSING CARBON? GAINING CARBON? WHY?
SO WE USE THE ATMOSPHERE AS A DIAGNOSTIC
TO GET A HANDLE ON THESE PROCESSES
TO QUANTIFY WHERE THESE PROCESSES TAKE PLACE
AND HOW LARGE THEY ARE.
WE WANT TO DIAGNOSE HOW THE CARBON CYCLE IS DEVELOPING
AND WE WANT TO UNDERSTAND WHY.
NOW, THE FIRST ACCURATE MEASUREMENTS OF CARBON DIOXIDE
IN THE ATMOSPHERE WERE DONE IN 1956 BY DAVID KEELING.
HE WAS ALSO THE FIRST TO START CONTINUOUS MONITORING OF CARBON DIOXIDE FROM A MOUNTAINTOP IN HAWAII.
THE MAUNA LOA VOLCANO.
Narrator: NOAA's GLOBAL MONITORING DIVISION
HAS CONTINUED TAKING MEASUREMENTS AT MAUNA LOA FOR THE PAST 30 YEARS.
BUT TO ENHANCE THE ACCURACY OF THESE MEASUREMENTS

THEY HAVE EXPANDED THEIR
DATA COLLECTION EFFORT
TO MANY OTHER REMOTE
LOCATIONS ACROSS THE GLOBE.

Dr. Tans: FOR MANY DECADES
WE'VE HAD A
GLOBAL-FLASK-SAMPLING
NETWORK
WHERE BY PEOPLE SEND US AIR
FROM SPECIFIC LOCATIONS
THAT ARE DOWNWIND FROM A
LARGE STRETCH OF OCEAN
WATER.
OR WE GET THESE SAMPLES
FROM DESERTS OR
MOUNTAINTOPS.
TYPICALLY AWAY FROM
TERRESTRIAL VEGETATION.
SO WE GET AIR THAT IS VERY
CLEAN AND WELL MIXED
SO THAT THE WEEKLY SAMPLE
ACTUALLY MEANS SOMETHING.
IT REALLY INDICATES THIS IS A
CONCENTRATION
OVER A VERY LARGE AREA.
Narrator: THESE SAMPLES ARE
SHIPPED TO NOAA's LAB
IN BOULDER, COLORADO, WHERE
THEY ARE ANALYZED.
IN EACH SAMPLE, WE MEASURE
CARBON DIOXIDE, METHANE

CARBON MONOXIDE, HYDROGEN
NITROUS OXIDE, AND SULFUR
HEXAFLUORIDE.
WE'LL TAKE AIR FROM THE
BOTTLE
AND SEND IT TO THREE
DIFFERENT INSTRUMENTS.
THIS IS THE ONE USED TO
MEASURE CARBON DIOXIDE.
IT'S INTERESTING -- THE WAY WE
MEASURE CARBON DIOXIDE
IS BY ABSORPTION OF INFRARED
ENERGY
WHICH IS THE SAME PRINCIPLE AS
THE GREENHOUSE EFFECT.
SO WE'RE USING THE SAME
PROPERTY OF THE GAS --
HOW IT AFFECTS CLIMATE -- TO
ACTUALLY MEASURE IT.
THEN AT NIGHT, WE CONNECT
THESE SUITCASES
THAT CONTAIN FLASK SAMPLES
COLLECTED BY AIRCRAFT.
COME BACK IN THE MORNING AND
THEY'RE ALL MEASURED.
COMBINED, GROUND SAMPLES
AND AIRCRAFT -- UP TO 100 A DAY.
Narrator: FROM THESE HUNDREDS
OF THOUSANDS OF AIR SAMPLES
NOAA HAS COMPILED A
COMPREHENSIVE DATABASE
OF CLIMATE-CHANGING GAS

CONCENTRATIONS
OVER A LONG PERIOD OF TIME.
THEIR FINDINGS ARE CONSISTENT
WITH THOSE FIRST DISCOVERED
BY DAVID KEELING.
IN THE 1950s
KEELING'S FIRST MEASUREMENTS
SHOWED CO2 AT THE LEVEL
OF 315 PARTS PER MILLION.
IN 2005
NOAA's MEASUREMENTS PEGGED
CO2 AT 380 PARTS PER MILLION.
BEYOND THE STEADY RISE
IN AVERAGE CO2
CONCENTRATIONS EVERY YEAR
NOAA's DATA ALSO SHOWED THAT
THESE LEVELS FLUCTUATE
MAINLY DUE TO THE CAPTURE OF
CARBON DIOXIDE
THROUGH PHOTOSYNTHESIS.
FOR EXAMPLE
DURING THE NORTHERN
HEMISPHERE WINTER
CARBON DIOXIDE LEVELS PEAK
BECAUSE SO MUCH VEGETATION
IS DORMANT AT THAT TIME.
ON THE OTHER HAND
DURING THE NORTHERN
HEMISPHERE'S SUMMER
GROWING SEASON
CO2 LEVELS ARE AT THEIR
LOWEST.

THIS FLUCTUATION CAN EVEN BE SEEN IN A 24-HOUR PERIOD REFLECTING THE DAYTIME UPTAKE OF CARBON DIOXIDE BY PLANTS
WHEN THEY ARE PHOTOSYNTHESIZING
AND THEIR RELEASE OF CARBON DIOXIDE AT NIGHT
THROUGH RESPIRATION.
THE NEXT STEP IN NOAA's DIAGNOSIS OF THE ATMOSPHERE IS TO TAKE MEASUREMENTS CLOSE TO WHERE GREENHOUSE GASES
ARE EMITTED OR ABSORBED.
CARBON DIOXIDE IS EMITTED BY NATURAL PROCESSES
SUCH AS PLANT RESPIRATION AND DECAY
AS WELL AS MAN-MADE PROCESSES
SUCH AS THE BURNING OF FOSSIL FUELS.
THESE GAS EMITTERS ARE KNOWN AS SOURCES.
CARBON DIOXIDE IS ABSORBED BY TERRESTRIAL AND OCEANIC PLANTS
THROUGH PHOTOSYNTHESIS
AND ALSO THROUGH SEA SURFACE GAS EXCHANGE.

THESE GAS ABSORBERS ARE KNOWN AS SINKS.

IF YOU TALK ABOUT THE BUDGET OF THE GREENHOUSE GASES -- THAT IS, TO THE ATMOSPHERE. THAT IS THE SUM OF THE SOURCES AND THE SINKS.
SO IF THERE'S MORE SOURCES THAN SINKS
THE CONCENTRATION WILL GO UP.
NOW, ESPECIALLY FOR NORTH AMERICA
WE DO THINK THAT THERE'S A SIGNIFICANT SINK -- SIGNIFICANT ABSORPTION OF CARBON DIOXIDE
ON THIS CONTINENT.
RIGHT NOW WE REALLY CAN'T TELL WHERE OR WHY.
SO WE NEED TO DO MORE SPECIFIC MEASUREMENTS CLOSER TO WHERE THESE SOURCES AND SINKS ARE
TO TRY TO UNTANGLE THAT.

Narrator: IN NORTH AMERICA THESE MEASUREMENTS ARE BEING TAKEN
BY NOAA's TALL-TOWER PROGRAM

LED BY NOAA SCIENTIST ARLYN ANDREWS.
ANDREWS IS ATTEMPTING TO TEASE OUT NORTH AMERICA'S SPECIFIC CONTRIBUTIONS TO THE GLOBAL CARBON CYCLE.
WE'RE TRYING TO GET MEASUREMENTS THAT ARE AS CLOSE AS POSSIBLE
TO WHERE ALL THE ACTION HAPPENS.
SO WE WANT TO BE VERY CLOSE TO THE FORESTS
CLOSE TO THE CITIES SO THAT WE CAN SEE THE BIGGEST SIGNALS.
SO WHAT WE DO IS WE USE A SYSTEM LIKE THIS
WHICH MEASURES CARBON DIOXIDE
AND CARBON MONOXIDE CONTINUOUSLY.
SO 24 HOURS A DAY, WE GET A MEASUREMENT EVERY 5 MINUTES.
Narrator: JOHN LEE OF THE UNIVERSITY OF MAINE MONITORS ONE OF THE TALL-TOWER SITES.
Dr. Lee: ALL WE DO IS BASICALLY SUCK AIR ALL THE WAY DOWN THE TOWER

AND SEND IT TO AN ANALYZER
THAT'S DOWN BELOW.
YOU WANT TO BE IN THE
ATMOSPHERE
OTHERWISE YOU'D HAVE TOO
MUCH OF THE SURFACE
INFLUENCE
AFFECTING YOUR
MEASUREMENTS.
IF WE WERE RIGHT NEXT TO THE
SURFACE
WE'D ONLY BE MEASURING
WHAT'S IMMEDIATELY BELOW US
AND UPWIND OF US.
BY GOING UP HIGHER
WE GET ALL THIS WELL-MIXED AIR
FROM A MUCH LARGER AREA.

THIS IS A PRETTY GOOD EXAMPLE
OF NORTHERN FORESTS
THAT HAPPEN SOME WHERE
AROUND THIS LATITUDE
ALL AROUND THE GLOBE.
THERE'S KIND OF THIS GREEN
RING AROUND THE EARTH
COMPRISED OF THESE NORTHERN
FORESTS.
WITHOUT FORESTS LIKE THESE
THE LEVELS OF CARBON DIOXIDE
WOULD LIKELY BE HIGHER
INCREASING THE EFFECT OF
GLOBAL WARMING

BECAUSE CARBON DIOXIDE IS
OUR MAJOR GREENHOUSE GAS.
Dr. Andrews: NORTH AMERICA
DOES TAKE UP A LOT OF CO2.
ONE REASON THAT WE'VE TAKEN
UP A LOT OF CO2, HISTORICALLY
IS THAT WHEN THE EASTERN
PART OF NORTH AMERICA WAS
SETTLED
A LOT OF FORESTS WERE
CLEARED FOR AGRICULTURE.
AND THOSE HAVE BEEN
REGROWING
OVER THE PAST 100, 150, OR 200
YEARS.
AND SO THOSE FORESTS HAVE
TAKEN A LOT OF CARBON DIOXIDE
OUT OF THE ATMOSPHERE, BUT
THEY'RE NEARING MATURITY
AND SO THEY PROBABLY WON'T
BE SUCH A STRONG NET SINK
FOR ATMOSPHERIC CARBON
DIOXIDE IN THE FUTURE.

Narrator: BY INCREASING THE
NUMBER OF TALL TOWERS
NOAA SCIENTISTS WILL ENHANCE
THEIR ABILITY
TO UNDERSTAND THE RATE THAT
NATURAL ECOSYSTEMS
ARE ABSORBING OR RELEASING
CARBON DIOXIDE.

Dr. Andrews: WE'RE REALLY
TRYING TO DEVELOP A SAMPLING
NETWORK
THAT WILL ALLOW US TO KIND OF
KEEP OUR FINGER ON THE PULSE
OF THE BIOSPHERE
CONTINUOUSLY.
SO SOMETHING THAT'S
SUSTAINABLE
AND THAT WE CAN USE TO
MONITOR NET CARBON DIOXIDE
EMISSIONS
FOR MANY YEARS.

Narrator: TAKEN TOGETHER
THE PROGRAMS AT NOAA's
GLOBAL MONITORING DIVISION
HAVE REVEALED NOT ONLY HOW
QUICKLY
GREENHOUSE GASES ARE RISING
IN THE ATMOSPHERE
BUT ARE ALSO PROVIDING A
BETTER UNDERSTANDING
OF SINKS AND SOURCES IN THE
CARBON CYCLE.
THIS INFORMATION, IN TURN, WILL
ALLOW US
TO MORE ACCURATELY PREDICT
EARTH'S FUTURE CLIMATE.

Dr. Tans: WHEN YOU'RE TALKING
ABOUT

INCREASING GREENHOUSE GASES, YOU'RE TALKING CLIMATE CHANGE.
SEE, THERE'S ONE THING THAT IS PRETTY CERTAIN.
THE BIGGEST CONTRIBUTOR TO THE RISE IN CARBON DIOXIDE
IS THE EMISSIONS CAUSED BY BURNING COAL AND GAS AND OIL.
THAT'S THE BIGGEST FACTOR.
IT'S BIGGER THAN NATURAL PROCESSES
THAT COUNTERACT THESE EMISSIONS A LITTLE BIT.
SO IF YOU CAN GET AN UNDERSTANDING
OF WHAT THE NATURAL SYSTEM -- WHAT THE EARTH ITSELF IS DOING
WITH THIS EXCESS OF GASES THAT WE'VE CAUSED
WE CAN ACTUALLY MAKE BETTER PROGNOSES
OF WHAT FUTURE CLIMATE CHANGE MIGHT BE LIKE.

Narrator: SCIENTISTS ARE PONDERING
IF FUTURE CLIMATE CHANGE WILL AFFECT HURRICANE ACTIVITY ON EARTH.
SOME SAY HURRICANE KATRINA

WHICH IN 2005 DEVASTATED THE GULF COAST
OF THE UNITED STATES, IS EVIDENCE THAT IT ALREADY HAS.

DR. KERRY EMANUEL
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAS BEEN STUDYING HURRICANES FOR OVER 20 YEARS.
Dr. Emanuel: I MEAN, THERE WAS NOTHING METEOROLOGICALLY VERY EXCITING OR INTERESTING ABOUT KATRINA.
WHAT WAS UNUSUAL ABOUT IT IS IT HIT A VERY VULNERABLE PLACE.
BUT PEOPLE HAVE WORRIED FOR SOME YEARS
ABOUT WHETHER CLIMATE CHANGE AFFECTS HURRICANE ACTIVITY.
YOU KNOW, EVERYTHING FROM "WELL, WERE THERE MORE OR FEWER HURRICANES
DURING THE LAST ICE AGE? "FOR EXAMPLE.
"WILL THERE BE MORE OR FEWER HURRICANES
IF WE HAVE GLOBAL WARMING?" THERE'S A LOT OF ARGUMENT

ABOUT HOW THIS WORKS.
Narrator: WHILE THIS ARGUMENT CONTINUES TODAY
HISTORIC RECORDS DO POINT TO A RELATIONSHIP
BETWEEN THE RECENT WARMING OF THE OCEANS
AND THE INTENSITY OF TROPICAL CYCLONES.

THIS GRAPH SHOWS A PRONOUNCED UPWARD TREND
IN THE TOTAL ENERGY
GENERATED BY HURRICANES
OVER THE PAST 50 YEARS.
THIS TREND IS WELL CORRELATED WITH THE UPWARD TREND
IN AVERAGE TROPICAL SEA SURFACE TEMPERATURES.

BUT THERE IS ANOTHER QUESTION ABOUT THE RELATIONSHIP
BETWEEN HURRICANES AND THE CLIMATE
THAT HAS RECEIVED MUCH LESS ATTENTION.
COULD HURRICANES SERVE A VITAL ROLE
IN MODERATING EARTH'S CLIMATE?

Dr. Emanuel: VERY FEW PEOPLE HAVE ASKED THE QUESTION "DO HURRICANES PLAY SOME CENTRAL ROLE IN THE CLIMATE?" WE TEND TO THINK OF THEM AS FREAK STORMS
THAT DON'T REALLY AFFECT THE CLIMATE IN AN IMPORTANT WAY.

BUT THERE'S SOMETHING RATHER UNEXPECTED
THAT'S TURNED UP FROM RESEARCH --
THAT HURRICANES MAY HAVE A PROFOUND EFFECT ON THE CLIMATE.
Narrator: FOR EMANUEL, IT'S QUESTIONS LIKE THESE
THAT PIQUED AN INTEREST IN HURRICANES EARLY IN HIS CAREER.
Dr. Emanuel: OFTEN YOU THINK YOU UNDERSTAND SOMETHING AND IT'S NOT UNTIL YOU HAVE TO TEACH IT
THAT YOU UNDERSTAND THAT YOU DON'T UNDERSTAND IT.
AND THIS HAPPENED TO ME IN THE CASE OF HURRICANES.
I WAS ASKED TO TEACH A COURSE IN TROPICAL METEOROLOGY.

I THOUGHT I UNDERSTOOD HOW HURRICANES WORKED.
I KNEW WHAT THE CONVENTIONAL EXPLANATION WAS.
SO I STARTED TO TEACH IT
AND I HAD ONE OF THOSE HORRIBLE EXPERIENCES
WHERE YOU START TALKING ABOUT SOMETHING
AND YOU REALIZE IT DOESN'T REALLY MAKE ANY SENSE.
AND THAT LEADS YOU DOWN A PATH
OF TRYING TO UNDERSTAND WHAT DOES MAKE SENSE.
AND THAT'S WHAT WE CALL RESEARCH.
Narrator: ONE OF THE MOST IMPORTANT TOOLS EMANUEL USES
IN HIS WORK IS COMPUTER MODELING.
Dr. Emanuel: MOST PEOPLE BELIEVE THAT MODELS ARE USED PRINCIPALLY
TO MAKE FORECASTS, AND OF COURSE THEY ARE.
BUT A LOT OF MODELING IS DONE NOT FOR THE PURPOSE
OF FORECASTING A PARTICULAR PHENOMENON
BUT FOR UNDERSTANDING IT.

Narrator: USING MODELS
EMANUEL CAN RUN SIMULATED HURRICANES
HUNDREDS OF TIMES A DAY
AND COMPARE THE RESULTS
WITH DATA TAKEN FROM REAL HURRICANES.
WHEN DIFFERENCES ARE SEEN
BETWEEN THE SIMULATED HURRICANES
AND THE REAL ONES
HE CAN PINPOINT THE CAUSE OF THOSE DIFFERENCES IN THE MODELS
AND ACHIEVE NOT ONLY BETTER UNDERSTANDING
OF REAL HURRICANES
BUT ALSO CREATE MORE ACCURATE MODELS
FOR FUTURE RESEARCH AND FORECASTS.
RECENTLY, ONE OF THOSE DIFFERENCES AROSE
WHICH MAY SHOW HURRICANES SERVING A FUNCTION
NEVER BEFORE CONSIDERED.
IN ORDER FOR A TROPICAL CYCLONE
TO REACH THE GREATEST INTENSITY --
CATEGORY FIVE, LIKE KATRINA DID IN 2005 --

IT MUST HAVE AN UNUSUALLY ABUNDANT SUPPLY
OF ITS RAW FUEL -- WARM SEAWATER.
BUT NOT ALL REAL HURRICANES REACH THIS MAXIMUM INTENSITY.
IN FACT, THEY RARELY DO.
Dr. Emanuel: IT'S A SPEED LIMIT.
NO STORM EVER EXCEEDS THIS LIMIT
AND A VERY SMALL PERCENTAGE OF THEM
ACTUALLY COME RIGHT UP TO THE LIMIT.
MOST OF THEM FALL FAR SHORT.
NOW, THE COMPUTER MODELS BEHAVED IN SOME WAYS VERY DIFFERENTLY
FROM REAL HURRICANES
IN THAT THEY ALWAYS SPUN UP TO THEIR SPEED LIMIT.
Narrator: ESSENTIAL TO ANSWERING WHY THE HURRICANES IN THE MODELS WERE BEHAVING DIFFERENTLY FROM REAL HURRICANES
IS AN UNDERSTANDING OF HOW REAL HURRICANES WORK.
Dr. Emanuel: IF YOU LOOK AT A PHOTOGRAPH
OF A HURRICANE FROM SPACE, WHAT YOU SEE, OF COURSE

IS THIS BEAUTIFUL, WHITE SPIRAL MASS OF CLOUDS.
IT'S A LITTLE BIT HARD TO TELL BUT THOSE CLOUDS EXTEND FROM VERY CLOSE TO THE OCEAN SURFACE
UP ABOUT 10 MILES HIGH.
AND THE OCEAN SURFACE IS AT A PRETTY HIGH TEMPERATURE -- 25 TO 30 DEGREES CENTIGRADE.
BUT THE TOPS OF THE CLOUDS IN A HURRICANE
REPRESENT THE TEMPERATURE THAT YOU FIND
IN THE UPPER PART OF THE ATMOSPHERE.
IT'S VERY, VERY COLD.
IT'S AROUND -80 DEGREES CENTIGRADE.
SO THE HURRICANE'S OPERATING ACROSS A RATHER SPECTACULAR TEMPERATURE GRADIENT.
Narrator: THIS TEMPERATURE GRADIENT
IS JUST ONE OF THE MANY REASONS
THAT HURRICANES GROW INTO SUCH POWERFUL STORMS.
THE WARM OCEAN WATER EVAPORATES INTO THE COOL AIR ABOVE IT
TAKING HEAT ENERGY OUT OF

THE OCEAN
AND STORING IT IN THE FORM OF WATER VAPOR.
WHEN THAT WATER CONDENSES INTO CLOUDS
THIS ENERGY IS TRANSFERRED TO THE AIR
WARMING IT AND INCREASING WIND SPEEDS EVEN FURTHER.
Dr. Emanuel: ONCE THIS PROCESS GETS UNDER WAY
THE FEEDBACK THAT ALLOWS THE HURRICANE TO GROW
IS ONE BETWEEN WIND AND EVAPORATION.
THE STRONGER THE HURRICANE WINDS, THE MORE EVAPORATION.
THE MORE EVAPORATION, THE MORE HEAT GOES INTO THE HURRICANE.
THE MORE HEAT GOES INTO THE HURRICANE
THE STRONGER IT GETS.
AND THAT WOULD JUST GO ON FOREVER
BUT THERE'S ONE OTHER THING THAT'S STOPPING IT FROM DOING THAT -- IT'S FRICTION.
Narrator: FRICTION IS CAUSED BY THE SAME THING
THAT'S AIDING EVAPORATION -- SEA SPRAY.

Dr. Emanuel: SEA SPRAY IS FUNDAMENTAL TO A HURRICANE. WHEN A SPRAY DROPLET GOES UP AND PARTIALLY EVAPORATES IT TURNS OUT THAT PROCESS TRANSFERS AN ENORMOUS AMOUNT
OF HEAT TO THE AIR.
AND SO SEA SPRAY IS A VERY EFFICIENT
HEAT-TRANSFER MECHANISM.
NOW, THOSE SPRAY DROPS ARE ALSO SLOWING THE ATMOSPHERE DOWN.
THEY'RE EXERTING A DRAGON THE WINDS.
THE PHYSICS OF THAT IS VERY COMPLICATED.
VERY COMPLICATED. AND WE DON'T UNDERSTAND IT.
AND WE'RE TRYING TO UNDERSTAND THOSE PHYSICS.
WE'RE TRYING TO CAREFULLY MEASURE THE FRICTION
AND THE HEAT TRANSFER OF THE SPRAY.
SO WE FLEW AIRPLANES INTO HURRICANES OVER THE ATLANTIC TO MAKE MEASUREMENTS TO HELP US UNDERSTAND
HOW SEA SPRAY AFFECTS THIS HEAT-TRANSFER

AND MOMENTUM-TRANSFER PROCESS.
AND WHEN WE START TO BETTER UNDERSTAND THIS PROCESS
WE CAN, WITH ANY LUCK
MAKE BETTER FORECASTS OF HOW HURRICANES WILL EVOLVE.
Narrator: BUT OVERFLIGHTS ARE LIMITED
IN THE DATA THEY CAN PROVIDE
SO EMANUEL ALSO STUDIES HURRICANE MACHINES
TO GET A CLOSEUP VIEW OF WHAT MAY BE HAPPENING
WHEN THE ATMOSPHERE AND THE OCEAN INTERACT.
Dr. Emanuel: SO WE HAVE BUILT A LABORATORY APPARATUS
IN WHICH WE CAN SIMULATE THESE VERY FANTASTIC CONDITIONS --
VERY HIGH WIND SPEEDS, AIR BLOWING ACROSS WATER
THE AIR IS FILLED WITH SPRAY.
WHEN THE WINDS START TO BLOW
MORE THAN ABOUT 80 OR 90 MILES PER HOUR
SO MUCH SPRAY IS LOFTED INTO THE AIR
THAT EVENTUALLY IT BECOMES HARD TO EVEN TALK ABOUT THE

SURFACE
OF THE OCEAN.
AND I'M NOT SPEAKING
METAPHORICALLY.
YOU JUST GO FROM WATER,
WHICH IS FILLED WITH BUBBLES
TO AIR, WHICH IS FILLED WITH
SPRAY GRADUALLY.
AND THERE'S NO LONGER
ANYTHING
YOU CAN CALL THE SURFACE OF
THE OCEAN.
SO IT BECOMES A REAL, REAL
CHAOS IN THE CORE OF A
HURRICANE.
Narrator: THE INTERFACE
BETWEEN OCEAN AND
ATMOSPHERE
IS A VITAL CLUE TO WHY ALL OF
THE SIMULATED HURRICANES
IN EMANUEL'S MODELS WERE
REACHING MAXIMUM INTENSITY
COMPARED TO REAL
HURRICANES, WHICH RARELY DO.
IT ALSO MAY SHOW HURRICANES
PLAYING A SIGNIFICANT ROLE
IN CONTROLLING THE CLIMATE.
Dr. Emanuel: IN THE IDEALIZED
MODELS
WE HOLD THE OCEAN
TEMPERATURE FIXED.
WE DON'T LET IT CHANGE. IT'S

JUST WHATEVER IT IS.
BUT A REAL HURRICANE
PROFOUNDLY CHANGES THE
TEMPERATURE
OF THE SEAWATER.
NOT BECAUSE IT'S TAKING HEAT
OUT OF THE OCEAN --
IT IS DOING THAT, AND THAT DOES
COOL THE WATER
BUT IT'S MAYBE A TENTH OF A
DEGREE OR SO.
IT'S NOT REALLY NOTICEABLE
BECAUSE IT'S SUCH A HUGE HEAT
RESERVOIR.
WHAT THE REAL HURRICANES DO
IS THEY CHURN UP THE OCEAN.
YOU DON'T HAVE TO GO VERY FAR
DOWN IN THE TROPICAL OCEAN
BEFORE YOU FIND VERY COLD
WATER.
IT'S ONLY HOT RIGHT WITHIN THE
FIRST 100 FEET OR SO
OF THE SURFACE.
THE HURRICANES COME ALONG
AND THEY MIX THIS COLD WATER
UP TO THE SURFACE.
AND YOU CAN LOOK AT A
SATELLITE PICTURE
TO SEE THESE REALLY COLD
WAKES
THAT ARE LEFT BEHIND BY
HURRICANES.

AND SO THE HURRICANE IS
COOLING OFF THE OCEAN
TEMPERATURE.
Narrator: THIS OCEAN COOLING
OFFERS SOME EXPLANATION
AS TO WHY REAL HURRICANES DO
NOT ALWAYS GROW
TO THEIR MAXIMUM POTENTIAL
INTENSITY.
WHEN THIS EFFECT IS
INCORPORATED INTO THE
COMPUTER MODELS
THE SIMULATED HURRICANES ACT
MUCH MORE LIKE REAL STORMS.
THIS FINDING IMPLIES THAT A
HURRICANE'S RELATIONSHIP
WITH THE ATMOSPHERE AND THE
OCEAN
MAY BE MUCH MORE DYNAMIC
THAN PREVIOUSLY THOUGHT
LEADING TO FURTHER
IMPLICATIONS
FOR HOW THE ATMOSPHERE AND
THE OCEANS
MODERATE EARTH'S CLIMATE.
Dr. Emanuel: THE REASON THAT
THE CLIMATE
ISN'T MORE EXTREME THAN IT IS
IS BECAUSE BOTH THE
ATMOSPHERE AND THE OCEAN
TAKE HEAT FROM THE TROPICS
AND BODILY MOVE IT TO THE

POLES.
SO WE HAVE WARM AIR FLOWING
FROM THE TROPICS
TOWARD THE POLES.
AND WE HAVE COLD AIR FLOWING
FROM THE POLES
TO THE TROPICS.
THE OCEAN DOES THE SAME KIND
OF THING.
WE HAVE WARM GULF STREAM
WATERS FLOWING POLEWARD.
AND UNDERNEATH THEM
WE HAVE VERY COLD WATER
MOVING SOUTHWARDS.
AND IF YOU CHANGE THOSE
TRANSPORTS SOMEHOW
YOU'VE CHANGED THE CLIMATE.
Narrator: EMANUEL'S RESEARCH IS
SHOWING THAT HURRICANES
HELP THE OCEANS TO PLAY THIS
HEAT-TRANSPORTING ROLE.
Dr. Emanuel: IT WAS ACTUALLY
PROVED ABOUT 100 YEARS AGO
THAT THE ONLY WAY YOU COULD
MAKE THE OCEAN
TRANSPORT A LOT OF HEAT FROM
THE TROPICS TO THE POLES
IS IF YOU COULD TURBULENTLY
MIX HOT WATER IN THE TROPICS
DOWN INTO THE DEEP TROPICAL
OCEAN.
THAT'S WHAT YOU NEED TO DO.

AND OCEANOGRAPHERS ARGUED FOR YEARS
ABOUT WHAT'S DOING THIS MIXING.
WE'VE DONE SOME CALCULATIONS
THAT SUGGEST THAT GLOBAL TROPICAL CYCLONE ACTIVITY --
"TROPICAL CYCLONE" IS A GENERIC NAME FOR A HURRICANE --
IS WHAT'S DOING THIS MIXING.
Narrator: PUTTING THIS THEORY TO THE TEST
EMANUEL HAS BUILT HURRICANE MODELS
WHERE THE HURRICANES CONTROL THE HEAT FLUX IN THE OCEANS.
THESE MODELS MAY PROVIDE AN EXPLANATION
FOR THE CLIMATE ON EARTH 50 MILLION YEARS AGO --
THE TIME KNOWN AS THE EOCENE HEAT WAVE
WHEN THE TEMPERATURES IN THE TROPICS
WERE ABOUT THE SAME AS THEY ARE TODAY
BUT THE POLES WERE MUCH WARMER.
THIS IS WHEN THERE WERE

CROCODILES
WANDERING AROUND
GREENLAND
AND ALLIGATORS IN LONDON AND
PLACES LIKE THAT.
AND THIS IS A GREAT MYSTERY.
BUT WE THINK IT WAS A VERY
STORMY CLIMATE
AND THERE WERE A LOTOF
HURRICANES
AND THAT THIS WAS DRIVING
A FANTASTIC POLEWARD HEAT
FLUX IN THE OCEAN
WHICH WAS RESPONSIBLE
BOTH FOR KEEPING THE TROPICS
RELATIVELY COOL
AND FOR KEEPING THE HIGH
LATITUDES WARM.
Narrator: THE IDEA THAT
HURRICANES ARE IN SOME WAY
DRIVING THE EARTH'S CLIMATE
COMPLICATES OUR
UNDERSTANDING OF HOW THE
CLIMATE SYSTEM WORKS
PRESENTING NEW CHALLENGES
AS WE TRY TO PREDICT FUTURE
CLIMATE AND HURRICANE
ACTIVITY.
Dr. Emanuel: NOW, IF THIS IS TRUE
IT MEANS THAT WE HAVE TO
COMPLETELY RETHINK
OUR UNDERSTANDING OF HOW

THE CLIMATE WORKS IN GENERAL.
BECAUSE IN THE BIG, HUGE
COMPUTER MODELS
THAT ARE USED TO SIMULATE
CLIMATE
THIS MIXING IS JUST SPECIFIED.
IT'S CONSTANT.
IT DOESN'T CHANGE WITH TIME
OR CLIMATE.
IT'S SPECIFIED OUT OF
IGNORANCE. WE DON'T KNOW
WHAT ELSE TO DO.
IF IT'S HURRICANES THAT ARE
DRIVING THIS MIXING
WE HAVE A DIFFERENT PROBLEM
ALL TOGETHER.
WE HAVE A DIFFERENT SYSTEM
DYNAMIC
BECAUSE THE HURRICANES
THEMSELVES ARE FUNCTIONS
OF THE CLIMATE.

SO THIS IS A NEW BRANCH OF
RESEARCH
THAT NOW TIES HURRICANES
INTO THE WHOLE CLIMATE
SYSTEM
IN A WAY THAT MIGHT PROVE TO
BE VERY INTERESTING.

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