DR. SCHUUR: THANK YOU.

I WAS WONDERING HOW MANY PEOPLE IN THIS ROOM MIGHT HAVE DRIVEN AROUND THE ISLAND OF HAWAII, OR MAYBE IF SOME PEOPLE GET A CHANCE TO DO THAT AFTER

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THE CONFERENCE. IF YOU DO THAT AND IF YOU HEAD OUT OF THIS HOTEL TO THE SOUTH AND YOU DRIVE AROUND THE SOUTH SIDE OF MAUNA LOA, AT SOME POINT YOU GET TO A TURN IN THE ROAD, YOU CAN TURN EVEN FURTHER TO THE SOUTH AND DRIVE ONTO THIS PLACE CALLED SOUTH POINT. SOUTH POINT IS REALLY COOL. IT IS A WINDSWEPT POINT. IF YOU DRIVE DOWN TO THE OCEAN, YOU HIT THIS GREEN SAND BEACH THAT'S MADE OF OLIVINE CRYSTALS THAT'S REALLY COOL. AND SOUTH POINT IS THOUGHT TO BE THE PLACE THAT THE POLYNESIANS FIRST ARRIVED INTO THE HAWAIIAN ISLANDS. SO THAT'S REALLY AN INTERESTING FACT.

THE REASON I AM TALKING ABOUT IT IS THAT SOUTH POINT IS ALSO BILLED AS THE SOUTHERNMOST POINT IN THE UNITED STATES, AND I THOUGHT THAT BECAUSE OF THAT, I WAS GOING TO TRY TO MAKE THE CLAIM TODAY AS MAYBE BEING THE SOUTHERNMOST EXPERT ON PERMAFROST CARBON, GIVEN MY AFFILIATION HERE AT THE UNIVERSITY OF FLORIDA.

(LAUGHTER).

THAT IS A COMPLETELY UNVERIFIED CLAIM, BUT I WILL JUST START OFF WITH THAT TODAY.

WE'VE BEEN TALKING ABOUT INCREASED GREENHOUSE GASSES AND IMPACTS ON TERRESTRIAL SYSTEMS, AND I'M GOING TO FOCUS ON A TERRESTRIAL IMPACT THAT

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IS CONSIDERED ONE OF THE MOST LIKELY TO FEED BACK TO INCREASE FUTURE CARBON CONCENTRATIONS IN THE ATMOSPHERE.

THE FEEDBACK CYCLE GOES A LITTLE BIT LIKE THIS: SO THIS HUMAN-INDUCED WARMING THAT WE HAVE BEEN TALKING ABOUT CAUSED BY FOSSIL FUEL EMISSIONS, THAT IS GOING TO CAUSE PERMAFROST TO THAW. ORGANIC CARBON THAT'S STORED IN THESE PERMAFROST SOILS THEN BEGINS TO DECOMPOSE AND IS RESPIRED BY SOIL MICROBES IN THE FORM OF CARBON DIOXIDE IN METHANE. SO THIS CONTRIBUTES TO FUTURE WARMING AND CAUSES THE CYCLE TO CONTINUE.

SO WHAT I WOULD LIKE TO DO TODAY IS GIVE YOU AN OVERVIEW OF WHAT IT IS WE KNOW ABOUT THE PERMAFROST CARBON POOL AND ITS LIKELY IMPACT ON THE GLOBAL CARBON CYCLE IN THE FUTURE.

OKAY, SO PERMAFROST IS DEFINED AS EARTH MATERIALS THAT'S BELOW ZERO DEGREES FOR TWO CONSECUTIVE YEARS, AND THE CURRENT THOUGHT IS THAT IT COVERS 22 PERCENT OF THE EXPOSED LAND IN THE NORTHERN HEMISPHERE. AND THIS MAP SHOWS THE AERIAL EXTENT OF PERMAFROST.

PERMAFROST IS DIVIDED INTO FOUR ZONES DEPENDING ON THE DISTRIBUTION OF PERMAFROST. THE CONTINUOUS PERMAFROST ZONE IS FARTHEST TO THE NORTH IN THE DARKEST PURPLE; THEN YOU HAVE THE

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DISCONTINUOUS PERMAFROST ZONE; THE SPORADIC; AND THE ISOLATED. SO THESE ZONES DIFFER IN THEIR EXTENT AND THEIR DISTRIBUTION OF PERMAFROST. IT IS IMPORTANT WHEN YOU THINK ABOUT THIS DISCUSSION ABOUT PERMAFROST CARBON POOL THAT WE'RE ACTUALLY TALKING ABOUT ALL THE LAND AREA IN THESE ZONES, WHETHER OR NOT PERMAFROST IS ACTUALLY PRESENT.

SO THE BEST WAY TO EXPLAIN PERMAFROST TO A BUNCH OF ATMOSPHERIC SCIENTISTS, I THINK, IS TO LOOK AT SOME PICTURES. THIS IS A PICTURE OF A PERMAFROST SOIL FROM SIBERIA, AND THIS PERMAFROST IS THAWING, SO ACTUALLY YOU ARE SEEING THIS THAWED FACE, IT IS ABOUT 10 TO 15 METERS TALL. AND WHAT YOU'RE LOOKING AT IS THESE MASSIVE ICE WEDGES THAT ARE SHOWN IN THESE WHITISH COLORS, AND THOSE ARE SEPARATED BY FROZEN SOIL. NOW, THIS ICE IS CURRENTLY THAWING, BUT IT'S BEEN FROZEN SINCE PLEISTOCENE, AND IT'S AN EXAMPLE OF A PERMAFROST SOIL WITH REALLY HIGH ICE CONTENT. AT THE VERY SURFACE HERE I HAVE OUTLINED WHAT'S CALLED THE ACTIVE LAYER. THAT'S THE SURFACE LAYER THAT NORMALLY THAWS EACH SUMMER AND REFREEZES IN THE WINTER. NOW, THE ACTIVE AREA IS ABOUT 70 CENTIMETERS IN THIS PHOTO, BUT IT RANGES ANYWHERE FROM 30 TO 150 CENTIMETERS DEPENDING ON THE LOCATION.

OKAY. SO IF WE MOVE FROM SIBERIA TO

ANOTHER PLACE, HERE'S A PERMAFROST PEAT SOIL FROM CANADA. NOW, PEAT SOILS ARE DEFINED BY HAVING A LOT OF ORGANIC MATERIAL, OVER 20 PERCENT CARBON. THIS CAN BE A THICK LAYER, ANYWHERE FROM 30 CENTIMETERS TO SEVERAL METERS THICK. THIS PEAT OVERLIES THE PERMAFROST BELOW. NOW, THIS THICK ORGANIC LAYER CAN, ACTUALLY, INSULATE THE PERMAFROST AND KEEP IT COLD. THE REASON WHY I'M SHOWING YOU THE TWO CONTRASTING PICTURES, WHEN WE'RE TALKING ABOUT THE GLOBAL PERMAFROST CARBON POOL, WE'RE ACTUALLY TALKING ABOUT A WIDE RANGE OF SOIL TYPES AND DIFFERENT KINDS OF CARBON THAT ARE OUT THERE.

OKAY. SO LET'S LOOK AT SOME DATA FROM THESE SOILS. WHEN WE THINK ABOUT SOILS GLOBALLY, MOST CARBON THAT'S ENTERING SOILS IS DOING SO VIA PLANT PHOTOSYNTHESIS AND GROWTH SO CARBON IS ENTERING THE SOIL FROM THE SOIL SURFACE. MOST SOIL CARBON INVENTORIES GO DOWN TO ABOUT A METER. NOW, I SHOWED HERE ON THESE THREE PERMAFROST SOILS THERE'S A RED LINE THAT SHOWS THE METER DEPTH IN EACH OF THESE SOILS. YOU CAN SEE THERE'S A Y-AXIS, WHICH IS DEPTH IN THE SOIL PROFILE. IT DIFFERS WIDELY AMONG THESE SOILS. THE MAIN POINT HERE I WANT TO POINT OUT WITH PERMAFROST SOILS IS THAT THERE IS REALLY HIGH CARBON CONCENTRATIONS BELOW A METER. IF WE LOOK AT THIS

LEFT-HAND GRAPH, THIS LOESS SOIL -- AND "LOESS" IS REFERRING TO WIND-BLOWN DUST -- THIS SOIL FROM SIBERIA GOES DOWN ALL THE WAY TO 40 METERS DEEP, AND THERE IS SIGNIFICANT CARBON CONCENTRATIONS AT THAT DEPTH. SO THERE ARE PROCESSES THERE UNIQUE TO THE

PERMAFROST ZONE, LIKE FREEZE-THAW-MIXING, THE DUST DEPOSITIONS THAT PUT A LOT OF SOIL FURTHER DOWN DEEP.

IF WE LOOK AT THE RIGHT-HAND GRAPH, WE'RE LOOKING AT A PEAT SOIL. PEAT SOILS ARE TYPICALLY INVENTORIED BELOW A METER DOWN TO THE BOTTOM OF THE PEAT LAYER. HERE IT IS 4 METERS, BUT OFTEN THE MINERAL CARBON BELOW THAT IS IGNORED. SO IT'S THIS DEEP PERMAFROST CARBON THAT HAS REALLY BEEN POORLY UNDERSTOOD IN THE PAST AND NOW IS ONLY CURRENTLY BEGINNING TO BE RECOGNIZED.

OKAY. SO LET'S TAKE A LOOK AT PERMAFROST CARBON IN THE CONTEXT OF GLOBAL TERRESTRIAL POOLS. IF YOU LOOK AT THESE TOP TWO NUMBERS, THAT'S CARBONS, SO WE'RE TALKING ABOUT UNITS OF CARBONS, NOT CO2, BUT THERE IS ABOUT TWICE AS MUCH CARBON STORED IN THE TOP METER OF SOIL AS COMPARED TO THAT IN VEGETATION GLOBALLY. IF WE LOOK AT THE SOIL IN THE PERMAFROST ZONE, I WILL POINT OUT THE TOTAL HERE, 950 GIGATONS OR PETAGRAMS. SO THAT WE'RE ADDING ANOTHER TWO-THIRDS TO THIS SOIL CARBON ESTIMATE, AND A LOT OF

THAT IS COMING FROM THE DEEP SIBERIAN SOIL THAT IS DOWN MANY METERS IN THE SOIL.

SO IF I COULD TAKE THIS NUMBER AND BORROW A LITTLE BIT FROM THE TALK WE HEARD YESTERDAY, FROM ROB SOCOLOW'S TALK -- AND I'M NOT AN ECONOMIST -- BUT IF WE TAKE THIS THOUSAND GIGATON ESTIMATE AND WE MULTIPLY IT TO GET CO2 UNITS, THAT MAGIC 44/12 UNITS WE GET COME OUT TO 3,700 GIGATONS OF CO2. SO IF WE TAKE THAT ESTIMATE OF 100 GIGATONS OF CO2 COSTING MAYBE $3 TRILLION DOLLARS TO MITIGATE FROM THE ATMOSPHERE, IT COULD BE THAT THIS POOL IS WORTH $111 TRILLION IF WE KEEP IT FROZEN IN THE SOIL. NOW, LIKE I SAID, I'M NOT AN ECONOMIST HERE, BUT CLEARLY IT IS EXPENSIVE IF THIS STUFF ENDS UP IN THE ATMOSPHERE. SO I DON'T KNOW IF WE CAN ANSWER, YOU KNOW, WHETHER THIS IS SAFE OR DANGEROUS WHETHER THIS CARBON IS HERE IF IT GOES INTO THE ATMOSPHERE; BUT CERTAINLY, IT IS GOING TO BE EXPENSIVE IF IT ENDS UP IN THE ATMOSPHERE.

OKAY, SO THE REASON THAT PERMAFROST CARBON IS RECEIVING A LOT OF ATTENTION IS PARTLY DUE TO THIS LARGE SIZE THAT I'M TALKING ABOUT, BUT THERE IS ALSO THESE THRESHOLD DYNAMICS I WANT TO POINT OUT. SO THE TOP GRAPH SHOWS YOU THE ECOSYSTEM RESPIRATION, SO THIS IS THE RETURN OF CARBON FROM TERRESTRIAL TUNDRA

TO THE ATMOSPHERE. IT'S SHOWN HERE AS A FUNCTION OF TEMPERATURE, WITH ZERO IN THE MIDDLE. WHAT I WANT YOU TO FOCUS ON IS THESE RED LINES SHOWING YOU THE TEMPERATURE SENSITIVITY OF THIS. AND THERE IS NO SINGLE RED LINE THAT DESCRIBES THE TEMPERATURE SENSITIVITY BOTH ABOVE AND BELOW ZERO. THERE IS A THRESHOLD HERE IN THE MIDDLE, RIGHT AT THE FREEZING POINT. THERE IS AN ABRUPT CHANGE WHERE THE RED LINE HERE THAT'S RETURNED AFTER THE ATMOSPHERE CHANGES BY ABOUT AN ORDER OF MAGNITUDE. SO THERE IS A

BIOLOGICAL THRESHOLD HERE RIGHT AT THE FREEZING POINT.

NOW, WITH PERMAFROST, THERE IS ALSO PHYSICAL THRESHOLDS. THIS IS THE PICTURE AGAIN OF PERMAFROST THAWING IN SIBERIA. NOW, HERE IS AN AREA -- IT IS A LITTLE HARD TO MAKE OUT -- BUT THE LARGE MASS OF ICE WEDGES THAT ARE SHOWING HERE ARE NOW THAWED, AND THEY HAVE MELTED AND GONE, AND WHAT YOU ARE LEFT WITH ARE THESE CONES OF UNFROZEN SOIL, SO THAT'S WHAT THESE LITTLE PYRAMIDS ARE. THIS PERMAFROST CARBON IS NOW DECOMPOSING. AND YOU CAN IMAGINE THERE IS HUGE CHANGES TO THE TERRESTRIAL ECOSYSTEM CARBON CYCLE AS A RESULT OF THIS THAW. SO MY MAIN POINT HERE IS THERE ARE THESE NONLINEAR BIOLOGICAL AND PHYSICAL THRESHOLDS THAT MEANS ONCE

PERMAFROST CARBON STARTS TO BE EMITTED TO THE ATMOSPHERE, IT'S GOING TO BE A PROCESS THAT IS VERY DIFFICULT TO REVERSE.

OKAY. SO IF WE THINK ABOUT PERMAFROST THAW, HOW AND WHERE IS THIS GOING TO HAPPEN? THE SIMPLEST WAY TO THINK ABOUT PERMAFROST THAW IS TO THINK ABOUT THE ACTIVE LAYER, AND IT IS GETTING THICKER. SO HERE IS THE ACTIVE LAYER AT THE SURFACE THAT THAWS EACH SUMMER. WELL, IF IT GETS THICKER, IT'S THAWING INTO THE TRANSIENT LAYER AND DOWN INTO THE PERMAFROST SOIL BELOW. THAT'S A VERY EASY WAY TO THINK ABOUT THE SURFACE THAWING OF PERMAFROST.

NOW, THERE'S A GOOD NETWORK OF BORE HOLES THAT ARE DISTRIBUTED AROUND THE CIRCUMPOLAR NORTH, THESE RED DOTS HERE BOTH IN NORTH AMERICA AND ASIA, WHERE PEOPLE ARE MONITORING PERMAFROST IN ACTIVE-LAYER THICKNESS. NOW, PERMAFROST HAS BEEN OBSERVED TO BE WARMING OVER THE PAST SEVERAL DECADES, CONCURRENT WITH INCREASED AIR TEMPERATURES; AND IF YOU TAKE THIS RECENT WARMING FROM THE PAST COUPLE DECADES AND YOU PROJECT IT OUT TO THE FUTURE, YOU CAN MAKE SOME PROJECTIONS ON WHEN PERMAFROST IS GOING TO HIT ZERO DEGREES CELSIUS, THE FREEZING POINT. AND YOU GET A RANGE, DEPENDING ON WHERE YOU'RE AT, BETWEEN 60 AND 150 YEARS.

THIS ACTIVE LAYER THICKENING IS GREAT FOR CONCEPTUALIZING AND GOOD FOR MODELING, BUT THE PROBLEM WITH PERMAFROST THAW, IT ALSO CAN HAPPEN OTHER WAYS. AND THIS IS CALLED THERMOKARST, WHAT YOU'RE LOOKING AT HERE. SO THERMOKARST IS GROUND SURFACE SUBSIDENCE. WHEN THIS GROUND ICE MELTS AND DRAINS AWAY, THE WHOLE GROUND WILL COLLAPSE. SO THIS FEATURE HERE IS ABOUT HALF THE SIZE OF A FOOTBALL FIELD. THIS APPEARED IN THE TIME SPAN OF ABOUT ONE TO TWO YEARS. SO IT IS A CATASTROPHIC COLLAPSE THAT CAN OCCUR QUITE RAPIDLY. AND THE THING WITH THERMOKARST IS THERE IS NO MONITORING NETWORK. SO WE DON'T KNOW ABOUT THIS PROCESS. WE KNOW MUCH LESS THAN THIS SURFACE THAWING FROM ACTIVE LAYER THICKNESS. NOW, THERE HAVE BEEN EFFORTS TO MAP THIS,

AND PEOPLE HAVE LOOKED AT AREAS LIKE ALASKA. AND IF YOU LOOK AT THE CONTINUOUS PERMAFROST ZONE, THERE IS ABOUT 54 PERCENT OF THE LANDSCAPE HAS THESE THERMOKARST FEATURES ON IT. IN THE DISCONTINUOUS ZONE, IT'S ABOUT 5 PERCENT. SO A LOT OF THE LANDSCAPE HAVE THESE THAWED FEATURES. WE DON'T, AGAIN, KNOW MUCH ABOUT HOW FAST IT IS GOING TO CHANGE, BUT THERE HAVE BEEN SOME VERY LOCALIZED STUDIES ABOUT THERMOKARST CHANGE; AND OVER THE PAST 50 YEARS, WE HAVE SEEN INCREASES IN BOTH THE

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CONTINUOUS AND THE DISCONTINUOUS ZONE IN THE DISTRIBUTION OF THESE THERMOKARST FEATURES. SO ON A VERY SMALL SCALE, IT APPEARS THAT THE AMOUNT OF THIS PERMAFROST THAW MECHANISM IS INCREASING. SO PERMAFROST SEEMS TO BE THAWING. IT'S GOING TO HAPPEN IN THIS NONLINEAR WAY THAT'S VERY HARD TO MODEL.

OKAY. TO FURTHER COMPLEXIFY THE PICTURE, YOU HAVE THERMOKARST THAT'S OCCURRING IN LOWLANDS. SO WHEN DRAINAGE IS REALLY POOR, YOU GET THERMOKARST LAKES. SO THE GROUND SUBSIDES, AND IT FILLS UP WITH WATER. SO THEN YOU HAVE THERMAFROST CARBON THAT'S FALLING INTO THE BOTTOM OF THE LAKE IN AN ANAEROBIC SITUATION. SO THERE'S BEEN STUDIES IN SIBERIA OVER THE PAST SEVERAL DECADES THAT HAVE SHOWN THAT THERE IS AN INCREASE IN THE NUMBER AND AREA OF LAKES IN THE CONTINUOUS ZONE. SO IT IS INTERPRETED AS THAWED PERMAFROST HAS CREATED MORE LAKES. HOWEVER, THEY HAVE ALSO FOUND THAT THERE IS A DECREASE IN LAKE AREA AND LAKES IN THE DISCONTINUOUS ZONE.

SO HOW IS THIS RECONCILED? WELL, IT TURNS OUT THAT IN THE DISCONTINUOUS ZONE THE PERMAFROST ACTUALLY IS TRAPPING WATER AND CREATING LAKES. SO WHEN THAT PERMAFROST THAWS, IT THAWS DOWN AND EXPOSES THESE GRAVEL LAYERS BELOW, AND THE LAKE CAN DRAIN AWAY. SO YOU HAVE BOTH INCREASING LAKE AREA AND

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DECREASING LAKE AREA; AND IN THIS PARTICULAR, THE NET EFFECT WAS A DECREASE BECAUSE THERE'S GREATER AREA IN THE DISCONTINUOUS ZONE. SO IT'S A COMPLICATED PICTURE.

OKAY. SO ONCE YOU HAVE THAWED THIS PERMAFROST, WHAT HAPPENS TO THE CARBON THAT'S IN IT? WELL, THIS ORGANIC CARBON THAT'S THE REMAINDERS OF THE PLANTS AND ANIMALS FROM TIMES PAST, THIS WILL BE DECOMPOSED BY SOIL MICROBES, AND THERE ARE THREE MAIN DECOMPOSITION PRODUCTS: CARBON DIOXIDE, METHANE, AND DISSOLVED ORGANIC CARBON, DOC. NOW, THE CO2, OF COURSE, IS THE BIG ONE, SO MOST OF THE EMISSIONS, IT HAS 100 TO 1,000 TIMES THE EMISSION RATE OF METHANE. SO MOST OF THE CARBON THAT'S COMING OUT IS COMING OUT IN THE FORM OF CO2. NOW, UP HERE IN THESE THERMOKARST LAKES, IN A SITUATION WHERE OXYGEN IS LIMITED, YOU'LL ALSO GET THE PRODUCTION OF METHANE ALONG WITH CO2. AND OF COURSE, WE KNOW THAT METHANE HAS A MUCH HIGHER GREENHOUSE WARMING POTENTIAL. THIS IS FROM THE LATEST IPCC, 2007 ON A 100-YEAR TIME SCALE.

NOW, DISSOLVED ORGANIC CARBON IS IMPORTANT BECAUSE IT'S AN EXPORT OF CARBON FROM THE TERRESTRIAL TO AN AQUATIC ECOSYSTEM, ALTHOUGH IT'S STILL NOT IN THE ATMOSPHERE. HERE, IN THE AQUATIC ECOSYSTEM, IT CAN ENTER THE FOOD CHAIN AND BE MINERALIZED TO CO2, AS

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WELL.

OKAY. I WILL SHOW YOU THE RESULTS OF AN EXPERIMENT FROM TAKING SOME PERMAFROST CARBON AND LETTING IT THAW IN THE LABORATORY AND MEASURING THE RELEASE RATE AS SOIL MICROBES BREAK DOWN THAT ORGANIC CARBON. AND IF YOU LOOK AT THIS LEFT-HAND-SIDE GRAPH, THE RESPIRATION RATE, THAT'S THE AMOUNT OF CARBON THAT'S RELEASED AS A FUNCTION OF CARBON IN THE PERMAFROST SOILS. SO NOT SURPRISINGLY, THE MORE CARBON THAT'S IN THE PERMAFROST, THE FASTER IT COMES OUT.

WHAT I DO WANT TO POINT OUT IS THAT THIS PERMAFROST CARBON IS VERY LABILE. IT IS DECOMPOSED QUITE RAPIDLY. IF WE COMPARE THAT TO A SURFACE SOIL, THE RED POINT, YOU SEE THE PERMAFROST CARBON IS AT OR ABOVE THE LEVELS OF RESPIRATION FROM THESE NORMAL SURFACE SOILS. IF YOU TAKE A LOOK AT THE GRAPH ON THE RIGHT-HAND SIDE HERE, IT'S SHOWING THE SAME CARBON DIOXIDE THAT IS BEING RELEASED BY THESE SOIL MICROBES, BUT NOW I'VE PLOTTED THE ISOTOPE CONTENT. IN PARTICULAR, I WANT TO HIGHLIGHT THE CARBON-14 CONTENT OF THE CO2 THAT'S BEING RELEASED BY DECOMPOSITION. IF YOU LOOK AT THE SCALE ON THE RIGHT-HAND SIDE, IT IS PLOTTED IN RADIOCARBON YEARS. AND THE CO2 THAT'S RELEASED FROM DECOMPOSING

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PERMAFROST RANGES ANYWHERE FROM BETWEEN TWENTY AND TWENTY-FOUR THOUSAND YEARS OLD. SO THE TAKE-HOME MESSAGE OF THIS GRAPH IS THAT IF YOU THOUGHT THIS PERMAFROST CARBON -- NOT ONLY DOES IT DECOMPOSE RAPIDLY, BUT YOU TAKE CARBON THAT'S BEEN ISOLATED FROM THE ATMOSPHERE FOR THOUSANDS OF YEARS AND YOU INJECT IT BACK INTO THE ATMOSPHERE.

OKAY. SO LET'S LOOK AT A GRAB BASKET OF EMISSION ESTIMATES, AND I'VE DIVIDED THIS INTO TOTAL EMISSIONS, METHANE, AND DISSOLVED ORGANIC CARBON. THERE'S SOME CAVEATS HERE. I SHOWED YOU THE MANY ESTIMATES. FIRST OF ALL, SOME OF THESE ESTIMATES ARE FOR REGIONS, SOME ARE FOR CIRCUMPOLAR, SO THEY'RE NOT ALL THE SAME THING. BUT IF YOU LOOK AT EMISSIONS, WE SEE 1 TO SEVERAL PETAGRAMS PER YEAR PROJECTED OVER THE NEXT 100 YEARS. SOME OF THESE ESTIMATES COME FROM SIMPLE EMISSION ESTIMATES; SOME COME FROM MORE COMPLEX ECOSYSTEM MODELS. I WANT TO HIGHLIGHT THAT ECOSYSTEM MODELS THAT MAKE PROJECTIONS OF PERMAFROST (A) DO NOT INCLUDE THERMOKARST, THEY'RE ONLY LOOKING AT ACTIVE LAYERS; AND THEY (B) DO NOT INCLUDE THIS DEEP CARBON THAT I HAVE BEEN TALKING ABOUT. SO THESE ARE LIKELY UNDER-ESTIMATES.

METHANE IS THOUGHT TO MAYBE INCREASE OR DOUBLE OVER THE NEXT 100 YEARS. AND DISSOLVED

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ORGANIC CARBON IS A LITTLE BIT MORE COMPLICATED. THERE'S BEEN SOME PROJECTIONS OF INCREASING DOC EXPORTS FROM PLACES LIKE SIBERIA, BUT IT HAS BEEN NOTED IN THE YUKON BASIN IN ALASKA THAT DISSOLVED CARBON HAS ACTUALLY DECREASED IN EXPORT OVER THE LAST 20 YEARS. IN ANY CASE, NO MATTER WHAT HAPPENS TO THE DOC EXPORT, IN THE ARCTIC OCEAN, IT HAS A VERY SHORT HALF-LIFE, IT IS ONLY THERE ON THE AVERAGE OF SEVEN YEARS BEFORE IT IS DECOMPOSED AND IT ENTERS THE ATMOSPHERE THERE.

OKAY. SO UP TILL NOW I HAVE BEEN GIVING YOU SORT OF A GRIM PICTURE OF THESE EMISSION ESTIMATES, INCREASED TEMPERATURE, DECOMPOSITION, THIS POSITIVE FEEDBACK CYCLE. BUT WHEN WE THINK ABOUT TERRESTRIAL ECOSYSTEMS IN THE NORTH, IT'S IMPORTANT TO THINK THAT THERE ARE OTHER THINGS HAPPENING TO THESE SYSTEMS AND THERE'S OTHER OFFSETS THAT COULD OCCUR; AND IN PARTICULAR, WE CAN THINK ABOUT CHANGES THAT OCCUR TO PLANTS OR WHAT I HAVE HERE IS PRODUCTION, BECAUSE PLANTS TAKE CARBON DIOXIDE OUT AND CAN OFFSET SOME OF THESE CO_2 RELEASES. SO PLANT PHOTOSYNTHESIS AND GROWTH IS AFFECTED DIRECTLY BY INCREASES IN TEMPERATURE BUT ALSO INDIRECTLY BY INCREASES IN NUTRIENT AVAILABILITY AS A RESULT OF PERMAFROST THAW. SO BOTH OF THESE CAN STIMULATE

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PLANT GROWTH AND ACTUALLY TAKE MORE CARBON DIOXIDE OUT OF THE ATMOSPHERE.

SO THE QUESTION BECOMES, OF THIS RED ARROW AND THIS GREEN ARROW, DO WE HAVE PERMAFROST WINNING THE BATTLE; OR DO WE HAVE THIS GREENING OF THE ARCTIC POSSIBLY OFFSETTING SOME OF THESE EMISSIONS?

WE CAN START TO LOOK AT THIS QUESTION A LITTLE BIT BY CONSIDERING STEADY STATE POOLS OF CARBON. SO WHAT I'M SHOWING YOU HERE IS THE CARBON CONTAINED IN THE VEGETATION OF DIFFERENT VEGETATION TYPES OF HIGH-LATITUDE ECOSYSTEMS. SO IF YOU START OUT WITH THE TUNDRA, YOU HAVE ABOUT A LITTLE LESS THAN HALF A KILOGRAM OF CARBON PER METER SQUARED. AND ONE OF THE PATTERNS THAT HAS OCCURRED IN THE NORTH, AS THINGS HAVE GOTTEN WARMER, TUNDRA HAS MORE SHRUBS IN IT. SO SHRUB TUNDRA HAS ABOUT TWICE AS MUCH CARBON, ABOUT .8 KILOGRAMS. AND IF YOU EVENTUALLY GROW A BOREAL FOREST WHERE WE USED TO HAVE TUNDRA, YOU GET UP TO AN AVERAGE OF ABOUT 4 AND A HALF KILOGRAMS, SO YOU'VE GAINED ABOUT 4 KILOGRAMS OF CARBON PER METER SQUARED.

AND WHAT HAPPENS TO THE SOIL BELOW THAT? OKAY, ON THE LEFT-HAND SIDE HERE, I HAVE A PERMAFROST SOIL, AND I'M SHOWING YOU THAT THE CARBON DENSITY IN THE TOP 3 METERS DIVIDED BY LAYERS HERE, AND ON THE

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RIGHT-HAND SIDE, WE HAVE A BOREAL FOREST THAT IS A NONPERMAFROST SOIL. AND JUST LOOKING AT THESE DIFFERENCES, YOU CAN SEE THAT IF YOU GO FROM PERMAFROST TO NONPERMAFROST, YOU LOSE A LOT OF

CARBON. SUMMED UP, ACTUALLY, YOU LOSE ABOUT 120 KILOGRAMS OF CARBON PER METER SQUARED FROM THE SOIL. SO YOU GAIN 4 KILOGRAMS ABOVE; YOU LOSE 120 BELOW. SO IF WE THINK ABOUT THAT FEEDBACK CYCLE, WE HAVE THESE EMISSIONS FROM PERMAFROST. YES, WE MIGHT HAVE THIS FEEDBACK FROM INCREASED PLANT GROWTH, BUT IT IS GOING TO BE MUCH, MUCH SMALLER THAN THE RED ARROW.

OKAY, LET ME JUST TRY TO SUMMARIZE THIS. WHAT I HAVE BEEN SHOWING YOU IS THAT PERMAFROST CARBON POOLS ARE LARGE. THEY'RE QUITE SENSITIVE TO CHANGES IN TEMPERATURE, AND RAPID DESTABILIZATION OF THESE POOLS ON A DECADAL TIME SCALE IS POSSIBLE GIVEN THESE THRESHOLD DYNAMICS THAT I HAVE TALKED ABOUT. SO IF WE KIND OF MAKE A ROUGH ESTIMATE OF FUTURE ANNUAL CONTRIBUTION TO THE ATMOSPHERE, IT COULD BE SIMILAR IN SIZE TO THAT COMING FROM LAND USE CHANGE, BUT IT IS CURRENTLY VERY POORLY CONSTRAINED.

THANK YOU VERY MUCH.