APPENDIX E

GLACIERS AND POLAR ICE CAPS

GLACIERS

The dictionary defines a glacier as "a large mass of ice and snow that forms in areas where the rate of snowfall constantly exceeds the rate at which the snow melts; it moves slowly outward from the center of accumulation or down a mountain until it melts or breaks away." Over long periods of time, glaciers may stay the same size, decline, or increase in size.

Disappearing Glaciers. People worry about glaciers disappearing and blame global warming, but that is not always the case. The "snows of Kilimanjaro" (glaciers) started disappearing more than a century ago, long before global warming was ever mentioned. Deforestation in the area resulted in decreased snowfall and the glaciers could not sustain the snow volume (Reference 3). Air temperature measurements indicate that air temperatures in the snow area are still well below freezing. The radiant heat from the sun apparently has been causing ***sublimation*** of the snow.

What is sublimation? Sublimation is when a solid goes directly to a gaseous phase without melting. We are familiar with dry ice evaporating and some of us have seen mothballs evaporate or solid iodine disappear. An iodine tincture spilled on a carpet will stain it, but in a few days, the stain will disappear due to sublimation. Ice and snow sublimate, that is, disappear as a gas without melting. That is what happens to frost. If you put a few ice cubes in a freezer for a long period of time, they will disappear. Thus glaciers can disappear over long periods of time even if they are below freezing.

To blame man for the glaciers disappearing on Kilimanjaro is going from the sublime to the ridiculous.

Glaciers can also disappear from melting. Figure 2 shows that the interglacial warming since the last ice age is 5C or 9F. That is equivalent to raising the elevation at which freezing occurs on a mountain by 1670 feet. In other words, the bottom 1670 feet of a glacier will have melted. (Recall that for every 1000 feet of elevation in the troposphere, the temperature drops 5.4F.)

Recent melting of glaciers in Switzerland revealed existing silver mines that were being worked at the start of the "Little Ice Age". These became covered by glaciers. (Workers left their tools neatly placed inside

the mine ready to rework it in the spring when glacier formation stopped their entry.) Greenland, when visited by Eric the Red in 1000AD, had large areas in which they could graze cattle, raise grapes, and farm. Again some of these areas became covered by glaciers during the Little Ice Age. Warming has not returned these areas to the same glacier/snow levels as in the "Medieval Warm Period" (See page 17.)

One tends to think that the colder the weather, the more a glacier grows. This is not necessarily so because the colder the air, the drier it is. To make any intelligent assessment of disappearing glaciers, one must understand changing climate conditions other than global warming.

An ice age lasts about 100,000 years. The first 90,000 years result in the accumulation of snow, sea ice, and glaciers. It only takes about 10,000 years to melt this accumulation. Glaciers have been melting for the last 10,000 +years with only an occasional short mini-ice age (Figure 2) to slow down the melting and/or allowing the glacier to accumulate a little extra ice. Satellites show the world has about 160,000 glaciers and the majority of these are disappearing from the Himalayas, Andes, Alps, Rocky Mountains, Alaska, California, etc.

This is a serious matter for some populations who depend on glaciers for their fresh water supply. If these glaciers melt too fast and disappear, it will be a major hardship. But it is not the end of the world, for water reservoirs can be used. Glaciers have been, and always will be vulnerable to temperature rises. For every one degree Centigrade (1.8F) in temperature rise, it requires a corresponding 25% increase in precipitation to maintain the glacial mass. (Reference: Article published January 22, 2007 by the Associated Press entitled "Climate Experts Predict Most Glaciers Will Vanish from Alps by 2050.") A dry winter followed by a hot summer is bad news for glaciers. The article claims that only those Alpine glaciers above 13,000 feet are expected to survive.

Growing Glaciers. Glaciers are increasing in size in some areas of the world. These are basically calving glaciers which have a large accumulation area and a small discharge area. For example, consider a long, wide valley filled with a glacier that discharges ice into the sea through a shallow, narrow gorge. Alaska, for example, has ten glaciers that are growing and even California has a few (e.g., 7 on Mt. Shasta, alone). The Hubbard Glacier in Alaska is one of these growing glaciers and is the largest calving glacier in North America. (U. S. Geological Survey Fact Sheet 001-03, January 2003 ---Internet---http://pubs.usgs.gov/fs/fs/-001-03/). ***Global warming has actually accelerated the growth of these glaciers*** because it

brings moist air high enough up on the mountains to offset melting losses. In the Himalayas, satellite images measure that glaciers are thinning by 6-10 meters (19.5-39.5 feet) per year below 4000 meters altitude (~13,000 feet) and are thinning only 2 meters per year above 5000 feet(~16,400 feet).

CONCLUSION: Thank god for glacial melting! My home town in Pennsylvania, like most of North America, Europe, and Western Siberia was covered with glaciers 1.5 to 2 miles thick up to 11,000 years ago. I am happy they melted! Melting of glaciers has continued during this interglacial warming period and, in 50 years, most glaciers will disappear. Some calving glaciers and those above 16,000 feet (depending on the latitude) may remain. One should not get concerned. Man did not cause this. This is the normal ice age cycle that the Earth has undergone several thousand times.

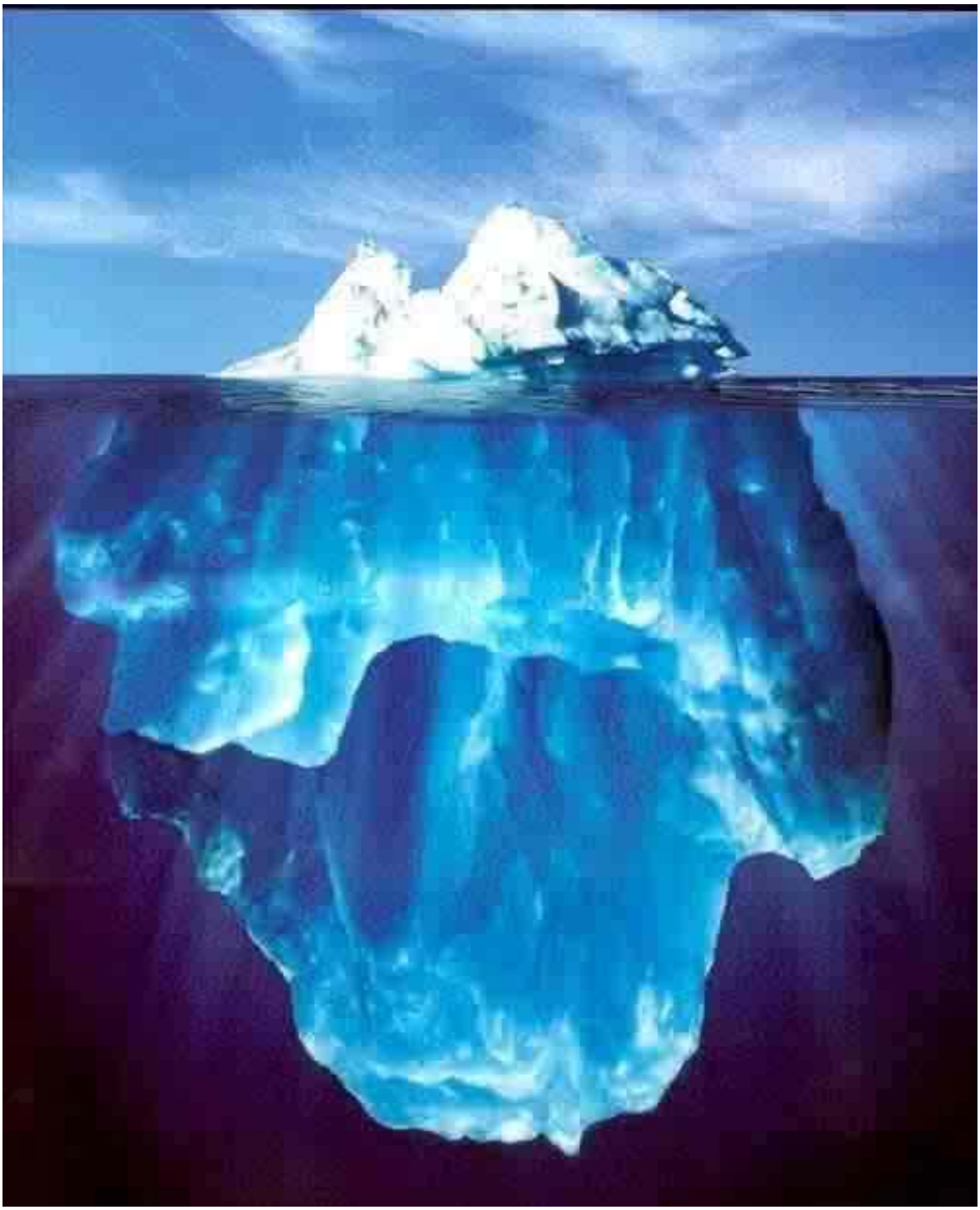

Figure 30. A Typical Iceberg Calved by a Glacier

POLAR ICE CAPS

The Polar Regions are nearly deserts. The water content of the air is easily measured by satellites. Notice the water content near the poles is near zero.

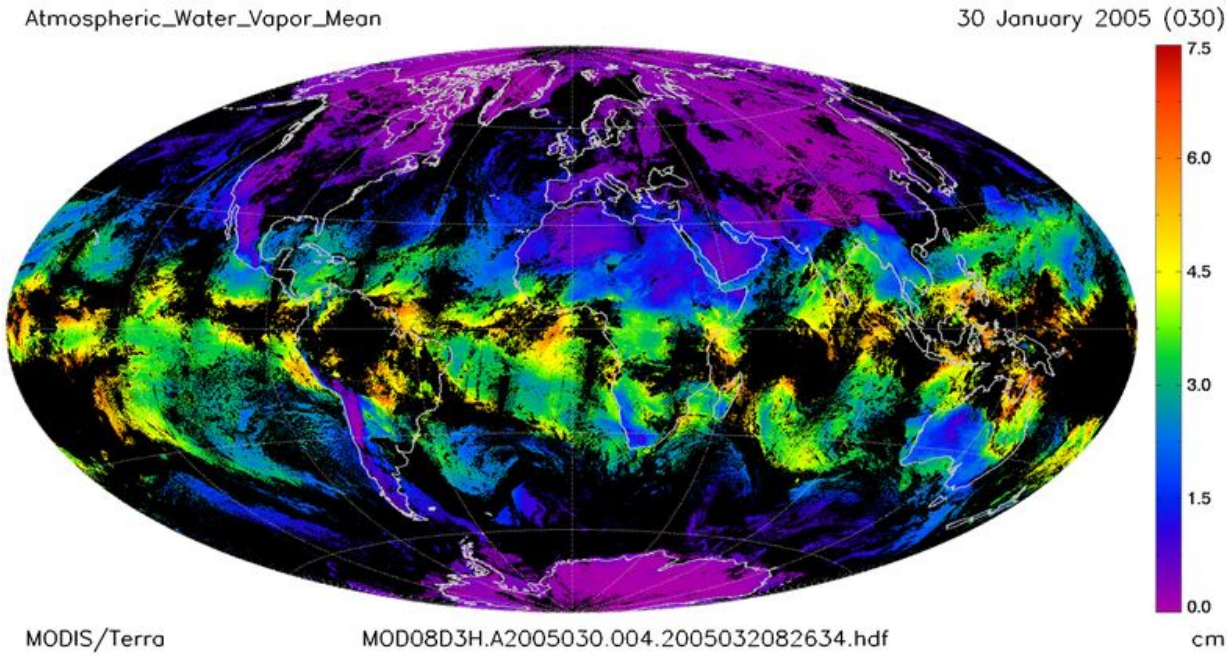

Figure 31. Mean Atmospheric Water Vapor

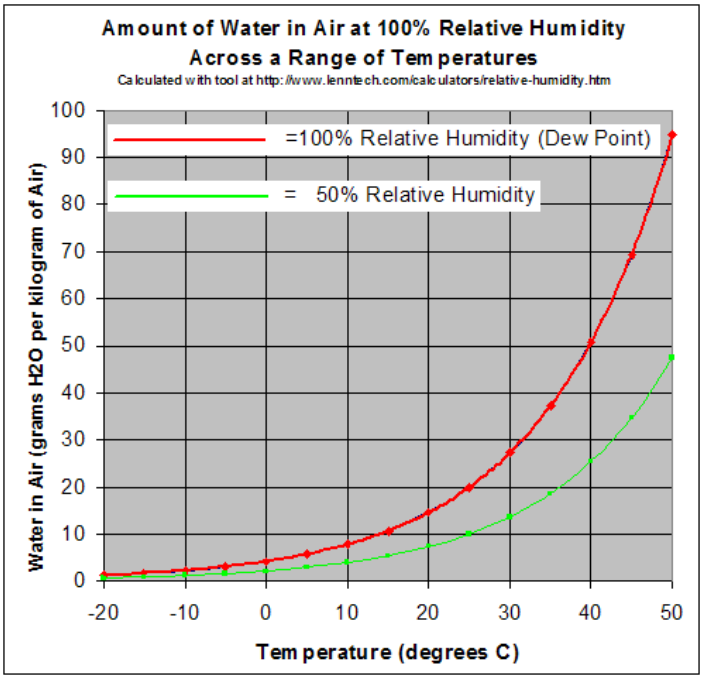

Figure 32. Cold Air Has Very Little Moisture, Slowing Ice Cap Build-Up

Arctic Sea Ice

On the next page are satellite pictures of the Arctic Ice Caps taken 24 years apart. It is obvious that melting of the ice cap is taking place due to warmer temperatures over northern Siberia and Alaska (See Figure 7, page 23). The ice loss occurring is actually sea ice, probably accelerated by warmer waters. Melting of sea ice does not raise the ocean sea level.

No satellite pictures are available for 2008. The National Oceanic and Atmospheric Administration (NOAA) reports that, based on the severe 2007-2008 winter, almost all of the "lost ice" has come back. Ice levels, which had shrunk from 5 million square miles in January 2007 to just 1.5 million square miles in October, are almost back to their original coverage levels (Newsmax.com 2/24/2008).

Polar Glaciers

There are three major glaciers in the Polar Regions: the Greenland Ice Sheet, the West Antarctic Ice Sheet and the East Antarctic Ice Sheet. In the last 24 years, the ice sheet on Greenland has shown little change (Figures 33 and 34). Major concerns would arise if massive melting of any of these ice sheets occurred.

Although it takes 2400 cubic miles of melted ice to raise the ocean level by one inch, these land-based ice sheets hold enough ice to increase the sea level by 213 feet (West Antarctica---19 feet, Greenland--- 24 feet, East Antarctica---170 feet.)

The years 2007-2009 have been designated as the Fourth International Polar Year. ***More than 50,000 scientists from 60 countries are participating in research concerning the history, stability, melting, and movement of these three ice sheets.*** A study in the April 2007 issue of *Environment and Urbanization* stated that 634,000,000 people live in coastal areas within 30 feet of sea level. (Wikipedia: *Sea level rise*). One third of the world's population lives within 300 feet of sea level (Scientific American, February 2008, ***The Unquiet Ice*** by Robin E. Bell). I would highly recommend the last two sources for an interested student!

Greenland. The entire island of Greenland was covered with conifers as recently as 400,000 years ago and current ice core samples reveal beetles and butterflies were common. I cannot find out on the Internet whether Greenland's glaciers, during the Medieval Warm Period, were significantly smaller than they are today, but, as previously stated, it was known that the Vikings did extensive farming in coastal areas, including planting vineyards, grazing cattle, and raising crops. (Viking records stop about 1409AD).

It is claimed that the melting of Greenland's glaciers would cause a 24-foot rise in sea levels and flood London, yet London was not flooded during the Medieval Warming period. Reports also indicate that Greenland's glaciers ***are melting twice as fast as expected***, losing 100 billion tons of ice per year. This adds 22 cubic miles of water to the oceans and will raise the oceans by $1/110^{th}$ inch in a year. There is also satellite evidence that the interior of Greenland's glaciers have increased 2 inches in the last 11 years, due to snowfall. Presumably this is because the Gulf Stream brings warm moist air toward Greenland.

In the past century, Greenland's contribution to the global sea level rise is only 0.1 mm per year or 0.4 inch per century. Note in Figure 7, some areas of Greenland are actually colder than they were 30 years ago. Because Greenland's ice sheet is so high in latitude and has an elevated summit (3200 feet), it will not get above freezing. Melting of Greenland's glaciers is occurring at the margins, while the interior is building up. Melting of Greenland's ice sheet would take several millennia. However, ice streams between the mountains are accelerating the flow toward the sea, particularly in the south, lubricated by sub-glacial water. Half of the ice goes to sea as icebergs and half as melt water. Under a worst possible scenario of accelerated ice stream flow, Greenland's ice sheet will last at least 1500 years. The IPCC, in their third assessment report (TAR) predicted that Greenland's glaciers will contribute between -0.8 and +3.6 inch to the sea level from 1990 to 2100 (IS92a & SRES predictions). This is quite a range of uncertainty!

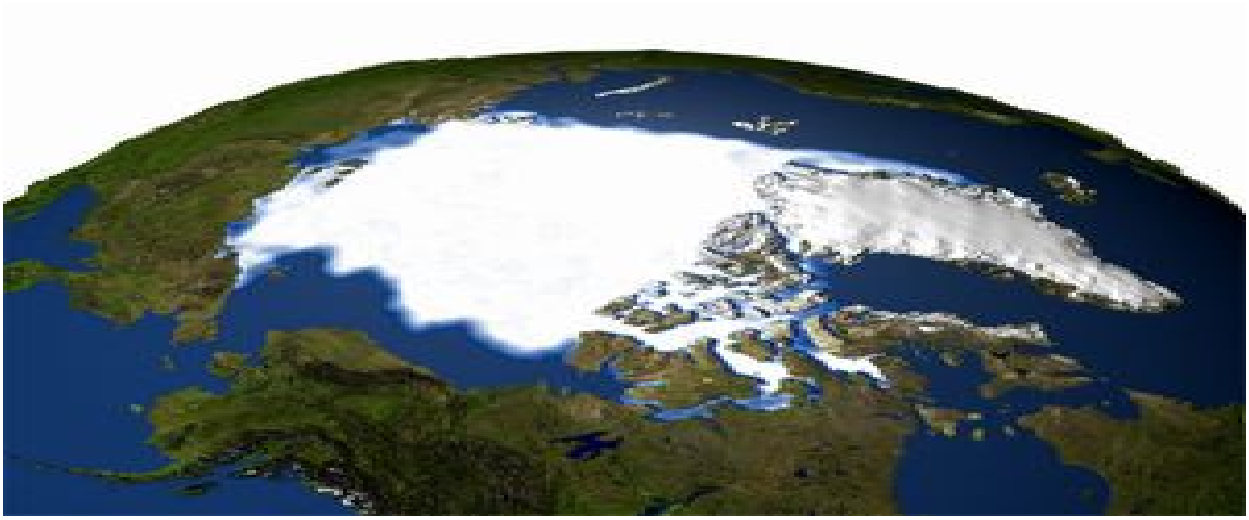

Figure 33. Arctic Ice Cap--February 1979

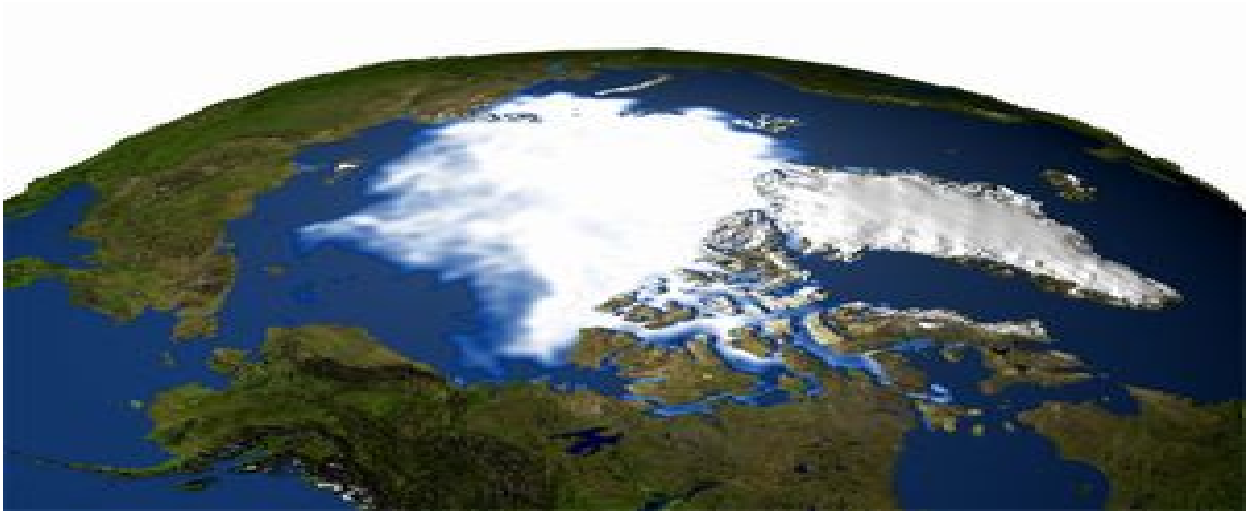

Figure 34. Arctic Ice Cap—February 2003

West Antarctic Ice Sheet

There is less warming in the Southern Hemisphere than the Northern Hemisphere. In fact, over the past 30 years, the average temperature is essentially constant. (See Figure 4 on page 20). Note, except for 1998-1999, various years show high peaks of +0.4C and low readings of -0.4C from the average temperature. Why is the Southern Hemisphere not heating up as much as the Northern Hemisphere? Don't both hemispheres have the same atmospheric CO_2 levels? (The answer is yes!) Again this shows that CO_2 is ***not*** the temperature driver.

In the 1970's, satellites had developed ice-penetrating radar. Scientists learned that sub-glacial lakes and rivers flowed beneath ice sheets. An extremely complex system of lakes, rivers and melt waters lie under the Antarctic Ice Sheets, lubricating their flow toward the sea. The Larson B ice shelf, a very thick shelf of floating frozen ice, collapsed in 2002. There were warning signs based on melt waters on the surface of the shelf forming small blue lakes. As the water moved subsurface, cracks began to form. Warmer water could also have caused thinning of this ice shelf. When the shelf collapsed, it was realized that it was like a plug which kept ice streams from the West Antarctica Ice Sheet from flowing into the ocean. Once the plug was broken, accelerated flow of these streams occurred. Up to that time, computer models of sea rise had ignored the possible acceleration of ice streams by sub-glacial waters. The Larsen B ice shelf, a floating mass of ice bigger than Rhode Island, broke into many pieces, some the size of Manhattan. As a result, the West Antarctic Ice sheet is losing mass at a faster rate.

In the region along the margin of the ice streams in West Antarctica, the margins collapsed about 30 feet in 24 months. This brought to the attention of glaciologists that lakes existed under the ice sheet. When an ice stream, which usually travels about 10 feet per year, hits a lake, it may accelerate to 65 to 100 feet per year. The Recovery Ice Stream in West Antarctica is over 500 miles long and up to 60 miles wide and acts as a conveyor belt bringing ice to the sea, helped by 4 sub-glacial lakes. This ice stream is 3500 to 6500 feet thick.

Ice core data, from the West Antarctic Ice Sheet indicates that the ice sheet did not exist 400.000 years ago, based on open-water life forms found in the cores.

What causes the sub-glacial water and lakes? In the case of the West Antarctic Ice Sheet, it is the friction occurring on the bottom of the flowing ice that melts it.

East Antarctic Ice Sheet

This is by far the largest glacier. It rests upon a complex system of sub-glacial lakes----perhaps 160 or so. These lakes hold 30% of the volume of all surface lakes in the world. These lakes occasionally belch, drain, and flow to downstream lakes. The largest lake is the Vostok Lake, directly under the Russian Vostok station. It is the size of Lake Ontario. The East Antarctic Ice Sheet has been stable for 30,000,000 years and has probably survived over 800 ice-age cycles. It is still stable today and it is growing on the interior and melting on the margins. The East Antarctic Ice Sheet, separated from the West Antarctic Ice Sheet by the Transantarctic Mountains, is up to 2 miles thick. It is so thick that it is nearly a perfect insulator. Heat coming from the Earth, itself, is trapped under the ice sheet and thought to be the principal cause of melting, resulting in the sub-glacial streams and lakes.

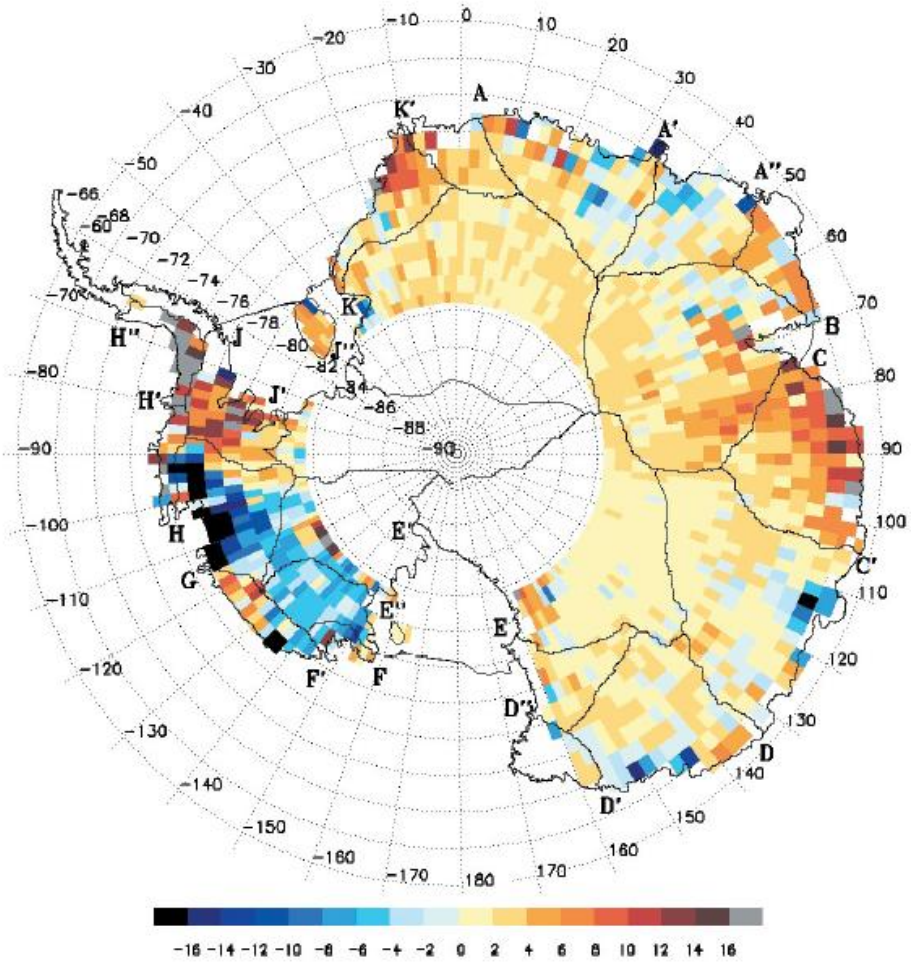

Figure 35. Satellite Measurement of Antarctic Cap Build-up

The East Antarctic Ice Sheet has actually been growing at the rate of 5±1 mm per year (Internet article from ***CO_2 Science*** by D. J. Wigham, et al.), based on an analysis of 120 million remote sensing altimeter echoes. Between 1992 and 2003, the East Antarctic Ice Sheet has added 50 billion tons of ice (45 billion metric tonnes). The IPCC sea level change estimate for the years 1990-2100 due to the Antarctic Ice Sheet build-up/melting is in the range of -6.8 inches to +0.8 inch.

CONCLUSION: The buildup or melting of the three major polar ice caps will affect the sea level by -7.6 inch to +4.4 inches by the year 2100. This is far from the rhetoric of Al Gore and environmentalists, and is actually based upon IPCC studies. World-wide, some 50,000 scientists are now involved in studying the polar ice caps.