STATEMENT ON SEA LEVEL IN THE COMING CENTURY

Science and Technology Committee
Miami-Dade County Climate Change Task Force.
January 17, 2008

Significant sea level rise is a very real threat to the near future for Miami-Dade County.

BACKGROUND: Over the past 2,500 years south Florida has experienced an average rate of relative sea level rise[1] of about 1.5 inches per century[a]. Over this time our sandy, mangrove and muddy coastlines were mostly stable or expanding seawards. The broad coastal wetlands and historically stable sandy coastlines of south Florida are a product of this prolonged period of very gradual sea level rise.

Since 1932, south Florida has had about a 9 inch relative rise of sea level[b]. This is a rate of one foot per century and is about 8 times the average rate over the past 2,500 years. Much of this accelerated rise is the result of warming (and expansion) of water in the western North Atlantic Ocean in response to global warming[c]. Our coastal and shallow-marine environments are now evolving in response to the stresses of this rising sea level.

EVALUATION: The 2001 report of the United Nations sponsored Intergovernmental Panel on Climate Change (IPCC) projected an additional sea level rise over the coming century of 1-3 feet (median level rise of 2 feet.). The 2007 IPCC report projected a somewhat lower level, but it did not incorporate the significantly accelerated melting being observed in the Greenland Ice Sheet (apparently because the results had not yet been published in peer-reviewed science journals)[d]. As a result, the IPCC report, which should be the guidance for the future, underestimates the amount of sea level rise that is likely to occur in this century[e].

Since 2000, rapid changes have been occurring to the Greenland Ice Sheet - changes that were projected to begin at the end of this century[f]. Over this past decade, there has also been rapid loss of multiyear pack ice in the Arctic Ocean, a phenomenon not projected to occur until 2070. Simply put, climate and glacial scientists now see that models failed to predict the rapidity and quickness with which these critical changes would occur.[g]

Both the Arctic Ocean and Greenland Ice Sheet have important 'positive feedback' effects that are driving these accelerated changes. Positive feedbacks are secondary effects that further reinforce and accelerate the primary changes. For the Greenland Ice Sheet, (a) summer melt water on the lower elevation margins of the ice sheet is forming surface pools on the ice which absorb incoming solar energy, thus accelerating melting; (b) the melted surface water is flushing down to the bottom through fractures and dissolved moulins (vertical holes) in the ice sheet, forming a lubricated layer over the rock which is dramatically accelerating the rate of the ice sheet breakup and movement towards the sea[h]; and (c) as the ice sheet margins melt and move towards the sea, the elevations on the ice sheet are lowering, placing the surface in yet warmer conditions.[i]

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[1] Relative sea level rise for an area is a combination of the change in ocean level and local changes in response to uplift or subsidence of the land. For example, North Carolina has a greater relative sea level rise than south Florida because the land there is subsiding faster.

Melt effects are expanding northwards on both coasts of Greenland. Even the very northern portions of Greenland have seen increased melting over the past decade.[j]

Field observations from this summer in western Greenland have documented amazing acceleration of marginal glaciers. The Illulissat Icefjord, located 150 miles north of the Arctic Circle, is an outlet for about 7% of the Greenland Sheet. This marginal glacier had been receding in response to increased marginal glacier melt. Beginning in 2002, the ice has surged seaward and is presently moving seaward at over 9 miles per year with additional pulses as high as 3.1 miles in 90 minutes! Melt waters seeping down through the ice sheet have created a 1,600 foot thick layer of water on which the interior ice sheet is now floating, fracturing, and surging to the sea. Acceleration of melting of the Greenland ice sheet is the critical factor to the rise of global sea level in the coming century.[k]

The Arctic Ocean has historically been sufficiently blocked with thick floating pack ice that navigation through the 'Northwest Passage' has remained elusive until recently. The pack ice is floating on the water of the Arctic Ocean and its melting would not in itself change sea level (like a melting ice cube in your glass). However, the white pack ice surface reflects nearly all incoming solar energy back into the air and space. Melting of the pack ice leaves areas of open water which absorb nearly 90 percent of the incoming solar energy. This warms the water, which further accelerates the rate of melting in the Arctic summer and reduces cooling in winter. Historically, the pack ice covering much of the Arctic Ocean through the summer was made of large solid masses of ice that were 4-5 years old, thickening each year. In the past decade, the pack ice has become increasingly younger and thinner. Most of the pack ice this summer is only 1-2 years old. It is thin, highly fragmented and contains many open water areas. As of mid September, this year's summer melt has left 30% less pack ice than the previous record low (in 2005).[l] The large open water areas were 9 degrees Fahrenheit warmer than normal. Melting will continue until at least mid September. The pack ice is now so thin and fragmented that it could potentially float out of the Arctic into the Atlantic.

Climate projections had talked of the possibility of a summer ice-free Arctic Ocean in 40-80 years. Now it looks like that may happen within a decade if recent trends continue.[m] As the pack ice diminishes over the Arctic Ocean, the adjacent land will warm, vast areas of tundra permafrost will melt releasing potentially catastrophic amounts of methane to the atmosphere[2], and melting of the Greenland Ice Sheet will even further accelerate.

In short, the recent changes occurring in the Arctic and Greenland mean that global warming and sea level rise will happen much more rapidly than had been only recently projected. Even recent model projections of future ice melt for Greenland by 2040 have already happened in 2007.[n]

In the Antarctic, there is no inherent reason why the impacts of warming should follow the pattern of the Arctic Ocean. The Arctic is an ocean surrounded by land, whereas the Antarctic is a continent surrounded by ocean. Nevertheless, there has been a gradual loss

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[2] Methane is another greenhouse gas. One molecule of methane captures 20 times the heat of a molecule of carbon dioxide. In the atmosphere, methane eventually will oxidize to carbon dioxide and water. This takes about 10 years.

of pack ice through the last half of the twentieth century, but a slight expansion in the past decade (as anticipated by climate models); about a 12% increase in the flow rate of 300 glaciers around the margin of Antarctica between 1993 and 2003[o]; and a significant increase in summer snow melt in both marginal and interior areas of the ice sheet since 2005. Antarctica is a critical unknown to future projections; however, it is showing distinctive early signatures of accelerated ice release.[p]

PROJECTION: A further 2-foot sea level rise by the end of the century, as projected in the 2001 IPCC report, would make life in south Florida very difficult for everyone. Spring high tides would be +4.5 to 5 feet above present mean sea level[3 q]; storm surges would be higher; barrier islands, fill islands and low-lying mainland areas would be frequently flooded; salt water intrusion would restrict available freshwater resources; drainage would be more sluggish; Turkey Point would be an offshore island; and so on.

Unfortunately, it looks as though sea level in the coming century will rise significantly more than two feet. With what is happening in the Arctic and Greenland, many respected scientists[4] now see a likely sea level rise of **at least** 1.5 feet in the coming 50 years and a total of **at least** 3-5 feet by the end of the century, possibly significantly more (calculations used are provided at end of statement). Spring high tides would be at +6 to +8 feet[r]. This does not take into account the possibility of a catastrophically rapid melt of land-bound ice from Greenland, and it makes no assumptions about Antarctica.

The projected rises will just be the beginning of further significant releases from Greenland and possibly Antarctica[5]. Hopefully, the IPCC will quickly revisit the question of sea level rise and provide a more valid and meaningful projection; however, to date, that is not planned until about 2012. When they revisit the current estimates, we expect it will be at least in the 3-5 foot range for this century.[s]

Developed Miami-Dade County as we know it will significantly change with a 3-4 foot sea level rise. Spring high tides would be at about + 6 to 7 feet; freshwater resources

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[3] Elevations are relative to a zero, which is 'mean lower low water' (spring low tide) when originally established in the late 1920s. Some topographic maps use MLLW and some correct to mean sea level (MSL) which is about 1.5 feet higher. With the 0.8 foot relative sea level rise since about 1930, today's mean higher high water (MHHW) is +2.3 feet above 1929 MSL (3.8 feet above MLLW), exceptional tides may reach over +3.3 feet (4.8 feet above MLLW), and storm tides and surges are added on to that. For considering future sea level rise, add 2.3 feet to the projected increase for MHHW (average spring high tide). See also endnote 'q'.

[4] For example: Dr. Robert Corell, a key contributor to the IPCC and chair of the Arctic Climate Impact Assessment, said this September that there is a consensus that new data collected since the IPCC report (i.e., the last two years) shows a 'massive acceleration' in the loss of ice mass in Greenland, and the consequences are outstripping the capacity of scientific models to predict it. Dr. James Hansen, director of NASA's Goddard Institute for Space Studies, suggests that sea level could rise by one to several meters (1 meter = 3.25 feet) by the end of the century.

[5] Total melting of the Greenland ice sheet would add about 23 feet to global sea level. In Antarctica, the collapse of the West Antarctic Ice Sheet would result in another 20 feet. With the warming we have caused and will cause from greenhouse gas buildup, melting of both of these is a distinct possibility in the future. During the previous interglacial period 130,000 to 120,000 years ago, sea level was about 25 feet higher than present.

Were the ice on Antarctica to totally melt, sea level would rise over 200 feet, but that seems unlikely.

would be gone; the Everglades would be inundated on the west side of Miami-Dade County; the barrier islands would be largely inundated; storm surges would be devastating; landfill sites would be exposed to erosion contaminating marine and coastal environments. Freshwater and coastal mangrove wetlands will not keep up with or offset sea level rises of two feet per century or greater. With a five foot rise (spring tides at nearly +8 feet), Miami-Dade County will be extremely diminished.

REALITY FOR OUR FUTURE: Miami-Dade County, like all other coastal and low-lying counties, is now facing much more challenging decisions than ever imagined. We will work to provide more carefully documented projections, but we hope you see the urgency of reconsidering nearly every aspect of the county's management, zoning, infrastructure, and planning.

One urgent effort is to look at what Miami-Dade County will need to do to remain inhabitable and functional at benchmarks of a further 1, 2, 3, 4 and 5 foot rise in sea level – and at what point portions of the county will need to yield to the rising sea. This will require a detailed documentation of the elevations of infrastructure elements and roadways; susceptibility of coastal, wetland and artificial fill areas to erosion; defining areas of potential pollution and contamination release; determining changing drainage and storm surge risks; assessing structural viability of buildings and levees with changing groundwater levels and saline water intrusion; looking at the future of fresh potable water sources; defining the modifications necessary to maintain connectivity of roadways; and many other aspects.

It should be pointed out that the highly porous limestone and sand substrate of Miami-Dade County (which at present permits excellent drainage) will limit the effectiveness of widespread use of levees and dikes to wall off the encroaching sea.

Respectfully submitted,
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[6] All members of the committee have worked together to develop this statement, and all have signed on.

ASSESSMENT OF MINIMAL SEA LEVEL RISE IN THIS CENTURY

***IPCC 2007 numbers and explanations in italics*; this study's numbers and explanations in regular type.**

Thermal expansion of oceans
IPCC has expansion at over half of their projection for coming century
= 8 inches = 20 cm
But since they assumed a much lower rate of Arctic ice loss and subsequent warming than is happening, this should be at least half again as much
= 30 cm

Non-ice sheet glacial melt
=10-25 cm per century in coming century[t].

Greenland melt
Greenland dramatically increased its melting at the beginning of this century. IPCC comments on this but does not include a significant contribution in coming century.
Presently 150-250 km3 ice per year = a 1 mm thick layer 150,000,000-250,000,000 km2 extent
Area of oceans =~ 361,000,000 km^2. So presently Greenland melt is providing a 0.4-0.7 mm/year contribution to sea level rise (= 4-7 cm / century and is rapidly increasing}.
As present melt is just starting (mostly since 2000) and mostly restricted to the southern portions, one can project that this will increase at least by a factor of 12. This is justified by the rapid warming of the adjacent ocean waters and accelerated melting of Arctic summer pack ice, which will lead to further acceleration of Greenland ice sheet melt.
Minimal contribution this century should be 48-84 cm. There is the possibility that this could approach 200 cm. by the end of the century but probably not more (Pfeffer, 2007[i]).

Antarctica
IPCC 2007 says historical rises were 1961-2003 = 0.14 mm/yr = 1.4 cm/100 yrs
1993-2003 = 0.21 mm/yr = 2.1 cm/century
Current rate has increased to ~5 cm/century.
Antarctica has sort of been ignored even though 300 of the marginal glaciers have increased their forward speed by 12% since 1990, reducing stress on adjacent ice sheets.[o]
In addition, there is elevation reduction of significant areas, and increased upwelling is accelerating melt of the bottom floating ice shelves. [p]
This is a big unknown, but will certainly be at least 15 cm. (three times the current rate). There is the potential to be much, much more.

MINIMAL TOTALS

Glaciers	10 to 25 cm
Greenland	48 to 84 cm
Antarctica	10 to15 cm
Total	98 to 151 cm or 3.3 to 5.0 feet

So we project that we will have at least an additional 3-5 feet of global sea level rise over the coming century. This is a reasonable conservative assessment of what is likely to happen in the coming century. We are constantly seeing positive feedbacks that accelerate initially small forcings and changes. Scientists do not see Arctic warming or Greenland melting as reversible over the coming century.

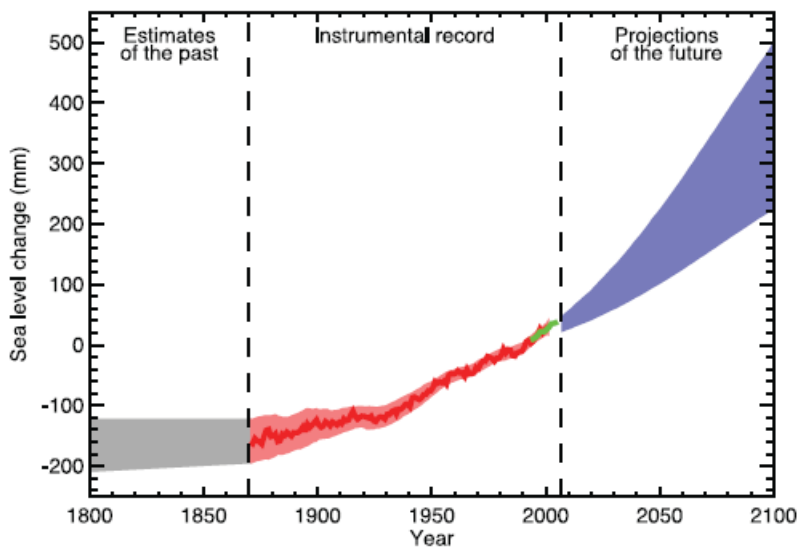
ENDNOTES and REFERENCES

[a] Wanless, H.R., Parkinson, R., and Tedesco, L.P. Sea level control on stability of Everglades wetlands, *in Proceedings of Everglades Modeling Symposium*. St. Lucie Press, FL, p. 199-223.

[b] Ibid. Data on historical sea level is archival tidal gauge data from Miami Harbor Entrance, Key West and Naples, collected and provided online by the National Oceanic and Atmospheric Administration, National Oceans Services (NOAA/NOS). With the advent of satellite altimetry, a global record of ocean level is now available over the past decade. Over that period, global sea level has risen 3 cm – a rate of 30 cm (one foot) per century (see Bindoff, N.L., et al., 2007 IPCC, Working Group 1: *The Physical Science Basis of Climate Change, Fourth Assessment Report 2007*, Chapter 5, report Chapter 5, Observation: Oceanic Climate Changes and Sea Level, page 411 and Figure 5.13.).

[c] Bindoff, N.L., et al., 2007 IPCC, Working Group 1: The Physical Science Basis of Climate Change, Fourth Assessment Report 2007, Chapter 5, report Chapter 5, Observation: Oceanic Climate Changes and Sea Level, page 391, Figure 5.2. Also, Levitus, S., J.I. Antonov, and T.P. Boyer, 2005a: Warming of the World Ocean, 1955-2003. *Geophys. Res. Lett.*, **32**, L02604, doi:10.1029/2004 GL021592).

[d] Bindoff, N.L., et al., 2007 IPCC, Working Group 1: *The Physical Science Basis of Climate Change, Fourth Assessment Report 2007*, Chapter 5, report Chapter 5, Observation: Oceanic Climate Changes and Sea Level, page 409, Figure 5.2., and Figure FAQ 5.1-1 (shown below with caption).



FAQ 5.1, Figure 1. *Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change (Section 6.4.3). The red line is a reconstruction of global mean sea level from tide gauges (Section 5.5.2.1), and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario (see Chapter 10 for a discussion of sea level rise projections for other scenarios considered in this report). Over many centuries or millennia, sea level could rise by several metres (Section 10.7.4).*

[e] The above published IPCC 2007 diagram does not give a valid indication of sea level for the coming century of because (a) the median and lower projections begin at a lower level and lower slope (rate of rise) than is presently occurring (the green line is the global rate of sea level rise over the past decade); (b) the median rise for the end of the century is basically only a continuation of the current rate of se level rise, (c) is does not include the rapidly accelerated melting that is and will continue to occur in Greenland and

possibly in the Antarctic; (d) it ignores the fact that sea level rise has been rising at the upper limit of IPCC projections since they first were made; and (e) it does not include the various effects of the rapidly warming Arctic and Arctic Ocean. The climate scientists web site realclimate.org has a good discussion of this (http://www.realclimate.org/index.php/archives/2007/03/the-ipcc-sea-level-numbers/).

[f] The IPCC 2007 report comments that this is occurring but does not incorporate this acceleration into future projections.

[g] These are oral statements made by Dr. Robert Corell, Chair Arctic Climate Impact Assessment, and by Dr. Veli Albert Kallio, Finnish polar/ice scientist, at a meeting in Greenland on September 8, 2007)

[h] Zwally, H.J., Abdalati, W., Herring, T., Larson, K., Saba, J., and Steffen, K., 2007. Surface Melt–Induced Acceleration of Greenland Ice-Sheet Flow, *Science,* vol. 297, p. 218-222.

[i] These feedbacks are now a focus of study in order to better understand exactly to what extent they will drive accelerated melting. Results are emerging for specific aspects at presentations at scientific meetings and in rapid turnaround journals, but it will be some time until an improved understanding of these positive feedbacks become integrated into a coherent global picture. At the recent American Geophysical Union Meeting, there were several sessions on recent research on polar research and ice sheet dynamics. Pfeffer, for example focused on the subglacial rock topography and concluded that ice melt from Greenland could not cause more than about a 2 meter (7 foot) rise in sea level in the coming century (Pfeffer, W.T., 2007. *Kinematic constraints on Greenland Contribution to sea level rise in the next century*, American Geophysical Union, annual Meeting , abstract C53A-02, session on Glacier and Ice Sheet Hydrology).

[j] Ibid.

[k] Ibid.

[l] Widely publicized news with data being provided by NOAA, the National Snow and Ice Data Center and numerous foreign sources. See for example the NSIDC web site: http://nsidc.org/news/press/2007_seaiceminimum/20071001_pressrelease.html.

[m] The climate scientists web site www.realclimate.org has a prolonged discussion of this concern (http://www.realclimate.org/index.php/archives/2007/08/arctic-sea-ice-watch/) and the NSIDC site has maps and discussion of the progressive year to year thinning and loss of area of summer pack ice.

[n] Statement was made by Dr. Veli Albert Kallio, Finnish polar/ice scientist, at a meeting in Greenland on September 8, 2007. In Hansen (2007), cited below, leading climatologist James Hansen evaluates the inadequacy of glacial melt models, the IPCC 2007 sea level projection , the non-linearity of climate and glacial response, and the importance of short and long-term positive feedbacks that will dramatically affect global warming and sea level rise rates, but are not included in IPCC models.

Hansen, J.E., 2007. Scientific reticence and Sea Level Rise. Environmental Research Letters, Vol. 2, 024002. doi:10.1088/1748-9326/2/2/024002. Access at: http://www.iop.org/EJ/article/1748-9326/2/2/024002/erl7_2_024002.html#erl246875s4.

[o] From press release by British Antarctic Survey on June 5, 2007. Access at: http://www.antarctica.ac.uk/press/press_releases/press_release.php?id=91.

[p] Numerous journal articles and current research findings are finding that the Antarctic is responding to global warming because of slight atmospheric warming and the warming or water s reaching up under the floating ice shelves. Representative citation is: David G. Vaughan, D.G., Holt, J.W., and Blankenship, D.D., 2007. West Antarctic Links to Sea Level Estimation, *EOS, Transactions, American Geophysical Union,* Vol. 88, No. 446, p. 485-487.

Recent findings by NASA have documented widespread melting in west Antarctica in 2005 "up to 900 kilometers (560 miles) inland from the open ocean, farther than 85 degrees south (about 500 kilometers, or 310 miles, from the South Pole) and higher than 2,000 meters (6,600 feet) above sea level." (http://www.jpl.nasa.gov/news/news.cfm?release=2007-058; and http://winds.jpl.nasa.gov/publications/shelf_melting.cfm).

Most recently, Ringolt et al (2008) have reported dramatic increases in melting in the past decade primarily as a result of increased winds increasing ocean upwelling and circulation of warmer waters under the ice shelves. "In West Antarctica, widespread losses along the Bellingshausen and Amundsen seas increased the ice sheet loss by 59% in 10 years to reach 132±60 Gt yr^{-1} in 2006. In the Peninsula, losses increased by 140% to reach 60±46 Gt yr^{-1} in 2006." Reference: Eric Rignot, E., Bamber, J.L., van den Broeke, M.R., Davis, C., Yonghong Li, Y., van de Berg, W.J., and van Meijgaard, E., 2008. Recent Antarctic ice mass loss from radar interferometry and regional climate modeling. *Nature Geoscience,* doi:10.1038/ngeo102 (http://www.nature.com/ngeo/journal/vaop/ncurrent/abs/ngeo102.html**).**

[q] Committee co-chair Dr. Stephen Leatherman and member Peter Harlem provided a more detailed statement on sea level elevations as follows: For the International Hurricanes Research Center (IHRC) based LIDAR used locally (see reference below), its sea level is at datum NAVD88 which is the new standard and is corrected for problems with sea level in Florida and elsewhere which did not fit the old datum properly. NAVD88 is a fix for NGVD29 which was based on using a benchmark at Galveston, Texas as MLW (the old term for Mean Low Water). Generally, elevations here are actually lower than the old 29 standard found on most USGS maps and the difference can be close to a foot lower. The difference varies from location to location so you just cannot take a fudge factor and subtract it from the old maps to get the correct elevation.

For a description of datum used in the IHRC LIDAR data set see the descriptive document IHRC (2004), page 15. The elevations in IHRC LIDAR data are referenced to NAVD88. NAVD88 is a datum referenced to the terrestrial geoid and not directly translatable to general sea level. A general description of the difference between NAVD88 datum and the NGVD1929 datum is at: http://www.ngs.noaa.gov/PUBS_LIB/NAVD88/navd88report.htm.

National Hurricane Research Center, 2004. *Windstorm Simulation and Modeling Project: Airborne LIDAR DATA and Digital Elevation Models in Miami-Dade, Florida*. Final Report to the Miami-Dade County Enterprise Technology Services Department, 26p. Available online at: (http://www.ihrc.fiu.edu/lcr/data/data.htm) and the metadata of the online LIDAR data distribution site (http://gis.ihrc.fiu.edu/website/ihrclidar/metadata/miami_dade/metadata.htm).

[r] The Science and Technology Committee was provided with a 'Climate Change Community Tool Box' by the South Florida regional Planning Council. We have looked at the maps to determine what they used to define elevations. Their +5 foot sea level rise map corresponds closely with the +5 foot contour on the topographic maps in which base level (zero elevation) is mean sea level relative to the datum of 1929 (NGVD 1929). In other words, it appears that their map for +5 foot sea level rise represents conditions at mean sea level prior to the approximately 0.8 feet of sea level rise since the 1929 datum was established. Mean higher high water (MHHW) today is about +2.5 feet above 1929 mean sea level, and with a two-foot rise in sea level would be about +4.5 feet. The +5 foot maps used by the SFRPC appear to reflect MHHW level only for about a sea level rise of about 2.5 feet.

This points out a general concern over mapping future projected sea levels. The maps should convey a number and level that is meaningful to the public and decision makers. Mean higher high water (MHHW) is a level that is reached on the average of twice a month. Some spring tides exceed this level by as much as a foot, but MHHW provides a level that is more meaningful than MSL when considering drainage, flooding, habitation, and wetlands.

[s] Since issuing this statement in September, 2007, several scientists of the IPCC have given very positive reviews of this statement (and none have criticized it). In addition, review articles in *Science* and elsewhere have made estimates similar to those in this statement. See also endnote 'n'.

Kerr, R.A., 2007. Pushing the scary side of global warming. *Science,* v. 316, p. 1412-1414.

[t] Meier, M.F., et al., 2007. Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century**,** *Science,* vol. 317, p. 1064-1066; DOI: 10.1126/science.1143906