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Estimating Future Sea Level Changes, Assessing Coastal Hazards, Avoiding Misguiding Exaggerations, and Recommending Present Coastal Management

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ABSTRACT: Hazard predictions must be anchored in very well established observational facts to be meaningful and trustworthy. We highlight observational facts with respect to sea level changes, and to access a recent, model-based, coastal hazard assessment for the New York City region. We conclude that available facts strongly support a modest rise in sea level during the future centuries, and that the model-based assessment totally fails in predicting future changes in a meaningful and realistic way.
KEYWORDS: Sea level changes; Ice melting; Coastal hazards; Coastal management.

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I. INTRODUCTION

The science of sea level changes is not simple and easy to handle. It calls for a long and deep knowledge in a large spectrum of different scientific sub-disciplines, which means that it must be studied by means of multi-disciplinary methods. Shortcuts are bound to lead to incorrect conclusions and statements, which are misguiding in coastal planning and may hence lead to serious mistakes in economic planning.We will take one example of such misguided exaggeration in future sea level estimates, and follow it up with our views on sound sea level research and glacial melting quantifications.

II. AN UNFORTUNATE CASE OF MISINFORMATION

Garner et al. [1] discussthe rising hazard of storm-surge flooding based on extremely accelerated projections of sea level rise(SLR)by2300. By referring to a zeroin 2010, theysaySLR may reach 0.6 m by 2050, and 2.6 m by 2100,and further postulateSLR may reach 17.5 m by 2300.

The estimate by Garner et al. [1] of theSLR by 2100 is three times larger than the latest IPCC worse case scenario. This prediction requires an acceleration (parabolic fitting) of +0.5556 mm/year^2, which is not recorded by available tide-gauge measurements.

On the contrary, the tide gauge results for rate of rise and acceleration of [2] suggest a likely global "*naïve average*" sea level rise of only 12.2 cm by 2100, a value in good agreement with the estimate of +5 cm ±15 cm in 2100 [3, 4].

There is an obvious need fora clarification of the sea level rise that should be considered for coastal planning.

The rates given in [1] are so high that they violate the physics of glacier melting and our observations of this over time. At the onset of the Holocene, the huge continental ice-sheets of the Last Ice Age melted at a very high rate, but still sea level did not rise more than 10.0 ±1.0 mm/yr or by 1.0 m in a century [5]. Today, under interglacial climatic conditions, sea level can never rise as fast as that, but rather significantly less. This makes the values given in [1] highly questionable.

For the sake of clarification and to avoiderrorsin coastal planning, a group of 11 colleagues wrote a rebuttal for PNAS [6], which was declined for publication.Some of our criticisms follow below.

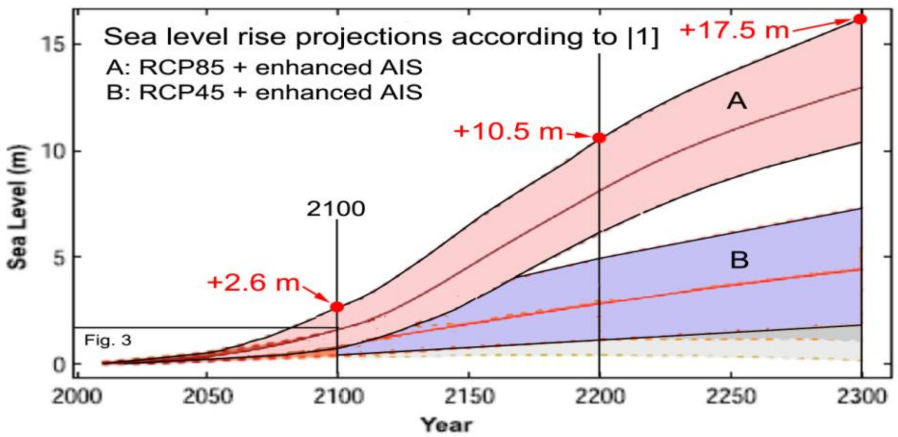

Fig. 1. Hypothetical sea level rise by [1] according to the RCP45 and RCP85 models of the IPCC with a hypothetical Antarctic Ice Sheet (AIS) contribution. The values given by [1] for coastal planning in New York are the maximum values. The values violate physics and geological knowledge, and are of no value; rather they are extremely exaggerated and would lead to false assumptions.

In Fig 1, we reproduce the sea level graph of [1]. It is all based on a hypothetical acceleration in the future. The future rates far exceed anything that is observed, even at the maximum of ice sheet melting at the onset of the Holocene [5]. It must, therefore, be looked upon as pure speculation.

The long-term mean sea level trend in The Battery in New York is +2.84 ±0.09 mm/yr (Fig. 2), with no statistically significant acceleration during the last century.However, about 50% of the rise is caused by crustal subsidence. A continued rise in relative sea level from 2010 to 2100 would, at a straight-line extrapolation, be only 25.7 cm by 2100, which is a very manageable increase in coastal flooding hazard.

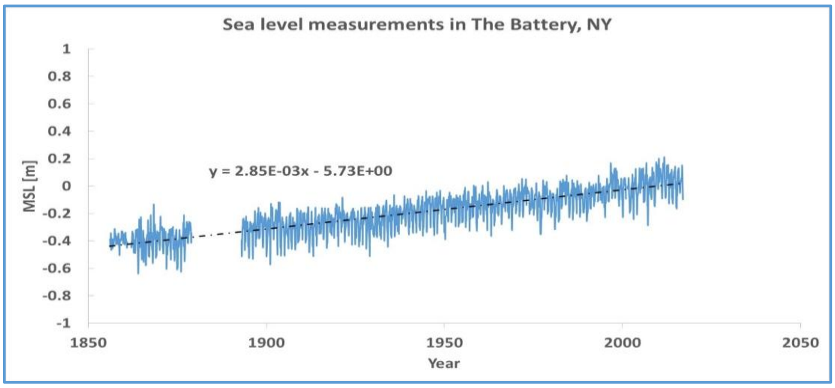

Fig. 2.The tide-gauge record from The Battery in New York City from the PSMSL database. Extrapolated to 2100 gives a rise of 25.7 cm (from the 2010 level), which seems a rise not calling for any urgent actions today.

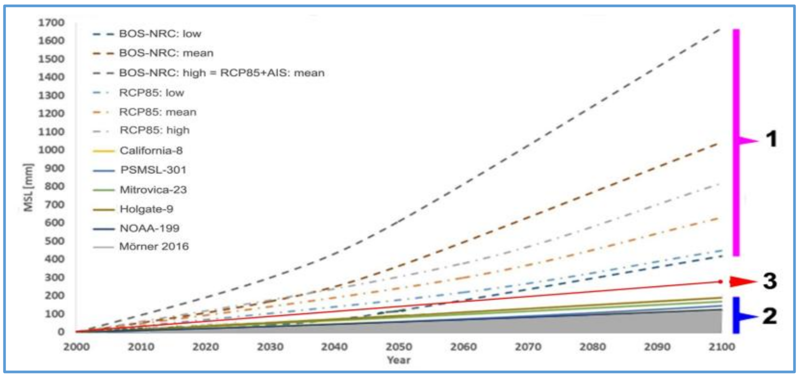

Fig. 3. Comparison between different sets of sea level forecasts: (1) model-based speculations according to [1], (2) observational-based predictions [2, 7-11], and (3) extrapolation of the measured mean long-term trend of +2.85 ±0.09 mm/yr at The Battery.

In Fig. 3, we compare: (1) model-based projections by [1], (2) observational-based predictions from tide gauges of sufficient quality and length [2, 7,8] and coastal high-resolution morphological analyses [9, 10, 11], and (3) the long-term mean sea level trend at The Battery in New York City (PSMSL).

The model-based group-1 graphs [1] exceed, by far, even the extrapolation of The Battery record (3) which is know to include a factor of subsidence of about 50% of the relative sea level record measured. The observational-based group-2 graphs [2, 7-11] give values in 2100 ranging between ±0.0 to 20.0 cm. Obviously, it is within this group we have to search for meaningful values when considering coastal planning.

Owing to the incorporation of tide-gauge data in group-2 (Fig. 3) that include components of subsidence and/or site-specific sediment compaction, the value of the group-2 graphs should be decreased even more, to about ±0.0 to 1.0 mm/yr today and about ±0.0 to 10 cm in 2100 [12].

III. SOME BASIC FACT IN SEA LEVEL RESEARCH

Sea Level Research is a separate, multi-disciplinary, branch of Science calling for wide knowledge in a large area of different scientific fields of study. All ideas and interpretations must be based on solid observational facts and the application of physical laws. The historical evolution of ideas and concepts are important. It is a serious mistake to think that there are shortcuts in the form of time-series statistics and computer modelling.

3.1. Physical frames

There are physical frames to consider. Ice melting requires time and heating, strictly bounded by physical laws. During the largest climatic jump in the last 20,000 years– viz. at the Pleistocene/Holocene boundary about 11,000 years BP – ice melted under extreme temperature forcing; still, sea level rose only at a rate of about 10 mm/yr [3], or at a mean of 15 ±3 mm/yr for the first 3000 years of the Holocene. Today, under interglacial climatic conditions with all the ice sheets gone, climate forcing can only raise global sea level by a fraction of the 11,000 BP rate, which in comparison with the values of Garner et al. [1] would imply (Figs 1 and 3):

- well below 0.4 m at 2050 instead of +0.6 m,
- well below 0.9 m at 2100 instead of +2.6 m,
- well below 1.9 m at 2200 instead of +10.5 m,
- well below 2.9 m at 2300 instead of +17.5 m.

Consequently, the values given by Garner et al. [1] violate not only physical laws but alsoaccepted scientific knowledge of glaciology. Therefore, their values must not be considered in coastal planning. We also question the reviewing process.

3.2. Estimating future sea levels

There are different ways of estimating future sea level changes, such as tide-gauges, satellite altimetry, and direct coastal studies (i.e. morphology, stratigraphy, biological characteristics).

Tide-gauges offer records of the relative changes in sea level. Out of a total of about 2300 stations (PSMSL), *"a global set of ~300 tide gauges that serves as the backbone of the global in situ sea level network"* in the Global Sea Level Observing System (GLOSS). There is no objective, straightforward solution forestimatinga global mean value. The University of Colorado chose 184 global tide-gauge records. Their rate of distribution has a marked peak in the zone from ±0.0 to +2.0 mm/yr with a mean value at +1.14 mm/yr. Because the majority of stations used include a component of regional subsidence and local sediment compaction, the true mean sea level value should be <+1.14 mm/yr. In a few areas, we have established knowledge about the crustal component and are hence able to test the eustatic component in the tide-gauge record [9, 13]. At Korsör in Denmark, the zero-isobase (or "hinge") of uplift has remained stable for the last 8000 years. The mean sea level rise over the last 125 years is +0.81 ±0.18 mm/yr. At Stockholm in Sweden, the absolute uplift over the last 3000 years is strictly measured at +4.9 mm/yr. The mean tide-gauge change is -3.8 mm/yr, giving a eustatic component of +1.1 mm/yr for the last 150 years. In Amsterdam, the long-term subsidence is known as +0.4 mm/yr. The Amsterdam/Ijmuiden stations record a relative rise of +1.5 mm/yr, which give a eustatic component of +1.1 mm/yr.

Satellite altimetry is a new and important tool, which reconstructs the entire ocean surface changes. But nowhere do the measurements agree with costal observations. Satellite altimetry exceeds tide-gauge records by about 300%. There have even been accusationsofdatamanipulation (14).

Global loading adjustment has been widely used in order to estimate global sea level changes. Obviously, the globe must adjust its rate of rotation and geoid relief in close agreement with the glacial eustatic rise in sea level after the last Ice Age. The possible internal glacial loading adjustment is much more complicated, and one may even say questionable [15].

Direct coastal analysis of morphology, stratigraphy, biological criteria, coastal dynamics, etc usually offer,by far, the best means of recording the on-going sea level variations in a correct and meaningful way. It calls for hard work in the field and a wide knowledge of a number of subjects. We have, very successfully, applied this method in the Maldives, in Bangladesh, in Goa in southern India [10], and now also in the Fiji Islands [11]. In all these sites, direct coastal analyses indicate full eustatic stability over the last 50-70 years, and long-term variations over the last 500 years that are consistent with "rotational eustasy" or "Grand Solar Cycle Oscillations" (GSCO).

IV. SOME BASIC FACTS ON GLACIAL DYNAMICS AND GLACIAL EUSTASY

Garner et al. (2017) propose SLR of up to 2.6 m by 2100, 10.5 m by 2200, and 17.5 m by 2300 (Fig. 1). These SLRs are far greater than those that occurred during catstrophic melting of immense ice sheets at the end of the Pleistocene, so the question arises, where will all the water come from to produce these very large SLRs? Melting of small, temperate, alpine glaciers wouldn't produce anywhere near the SLRs projected by Garner et al. so the only possible sources of water are the Antarctic and Greenland ice sheets.

The projections of Garner et al. of SLR of 7–8 m per century would require about seven times the end of the Pleistocene SLR when immense ice sheets were collapsing under warming of up to 20 °F in less than a century. To get these huge SLRs would require melting of an immense amount of ice from the Antarctic ice sheet. The average winter temperature in Antarctica is about –55 °F and temperatures have reached as low as 135 °F, so any significant melting of the Antarctic ice sheet would require 55° + 32° = 87 °F of warming just to get to the freezing point plus another 10 degrees or so to melt much ice. So Antarctica would have to warm up by 90–100 °F to melt enough ice to substantially raise sea level.

We can also ask the question, is Antarctica warming and is the Antarctic ice sheet presently melting? Measured satellite and surface temperatures confirm the lack of warming over most of Antarctica [16]. The UAH and RSS satellite records (Fig. 4) are the most comprehensive because of their extensive coverage of Antarctica. Surface temperatures at the south pole show no warming since 1957 (Fig. 5). They show the same lack of warming as the surface temperature records. The main conclusion to be drawn from these data is that glacial ice in Antarctica is increasing, not melting [16].

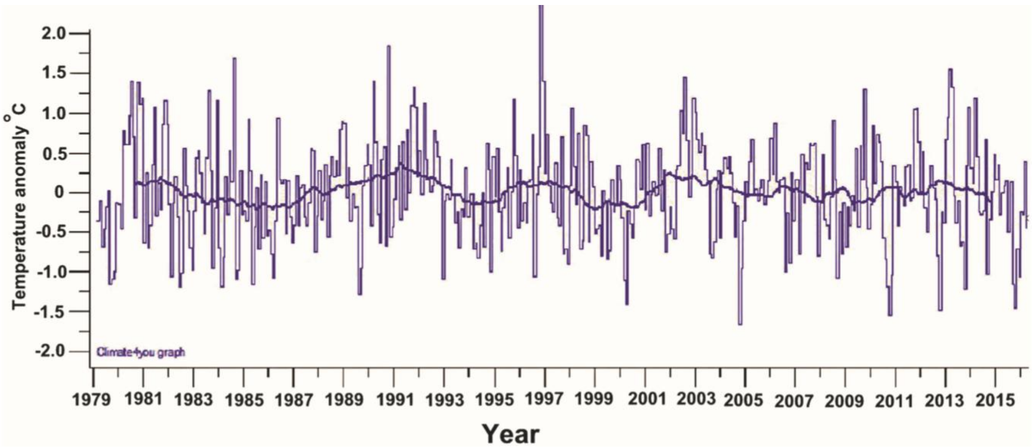

Fig. 4. UAH Antarctic satellite temperatures show no warming for 37 years.

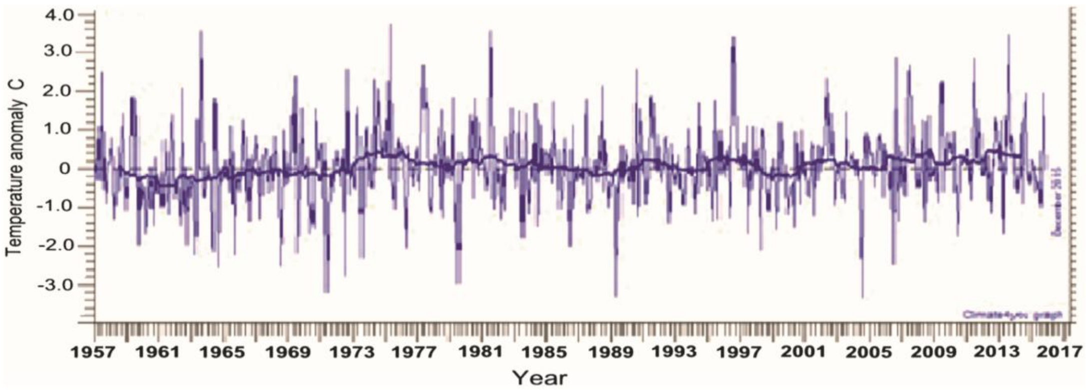

Fig. 5. Surface temperatures aat the south pole show no warming since 1957. (HADCRUT.)

The Antarctic Peninsula has been cooling sharply since 2006. Ocean temperatures have been plummeting since about 2007, sea ice has reached all-time highs, and surface temperatures at 13 stations on or near the Antarctic Peninsula have been cooling since 2000 [16]. Fig. 6 is a plot of temperature anomalies at 13 Antarctic stations on or near the Antarctic Peninsula. These data show that the Antarctic Peninsula was warming up until 2000 but has been cooling dramatically since then. The Larsen Ice Shelf Station has been cooling at an astonishing rate of 1.8 °C per decade (18 °C per century) since 1995. Nearby Butler Island records even faster, cooling at 1.9 °C/decade. Sea ice around Antarctica is increasing because ocean temperature from the surface to 100 m dropped below the freezing point in 2008 and has stayed there since.

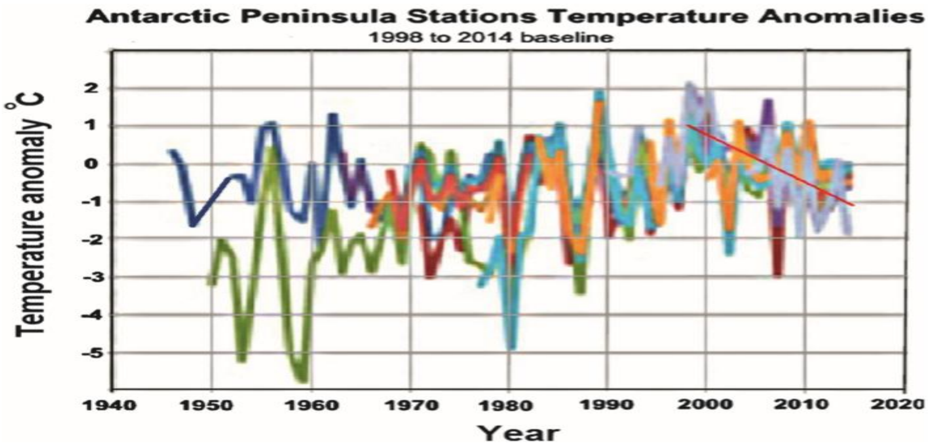

Fig. 6. Temperature anomalies at 13 Antarctic stations on or near the Antarctic Peninsula, showing that the Antarctic Peninsula was warming up until 2000 but has been cooling dramatically since then. (From GISTemp)

These satellite and surface temperature records show that both the East Antarctic Ice Sheet and the West Antarctic Ice Sheet are cooling, not warming. Satellite and surface temperature measurements of the southern polar area show no warming over the past 37 years. Satellite Antarctic temperature records show cooling since 1979. The Southern Ocean around Antarctica has been getting sharply colder since 2006. Antarctic sea ice is increasing, reaching all-time highs. Surface temperatures at 13 stations show the Antarctic Peninsula has been sharply cooling since 2000.

Greenland has much less ice than Antarctica, but if it melted could it provide enough meltwater to raise sea level significantly? Is Greenland warming and the ice sheet melting away? Chylek et al. [17] analyzed temperature histories of coastal stations in southern and central Greenland having almost uninterrupted temperature records between 1950 and 2000 and found that coastal Greenland's peak temperatures occurred between 1930 and 1940, after which subsequent decrease in temperature was so substantial and sustained that current coastal temperatures "are about 1°C below their 1940 values." At the summit of the Greenland Ice Sheet, the summer average temperature has decreased at the rate of 2.2 °C per decade since the beginning of measurements in 1987.

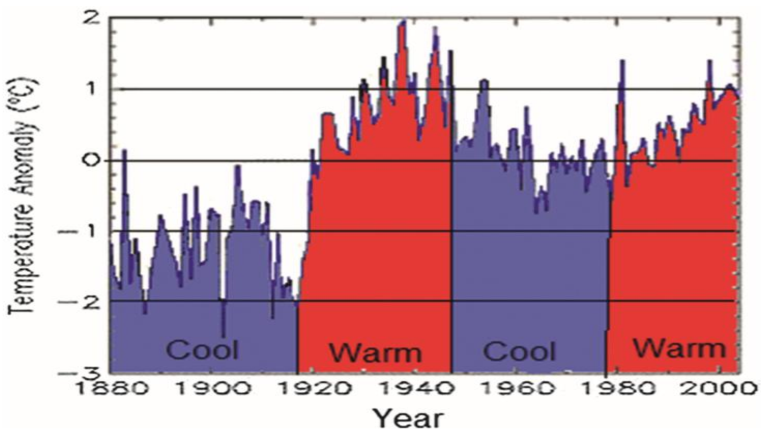

Fig. 7. Temperature fluctuations in Greenland from 1880 to 2004 showing that temperatures from 1920 to the late 1940s were warmer than present.

Two weather stations, Godthab Nuu and Angmagssalik, on opposite coasts of Greenland, have the longest records, dating back more than a century. Both show similar annual temperature patterns–strong warming in the 1920 and 1930s followed by cooling from 1950 to 1980 and warming from 1980 to 2005. The significance of these recent temperature records is that they show that temperatures in the past several decades have not exceeded those of the 1930s and Greenland temperatures have fluctuated normally in step with global temperatures changes [18].

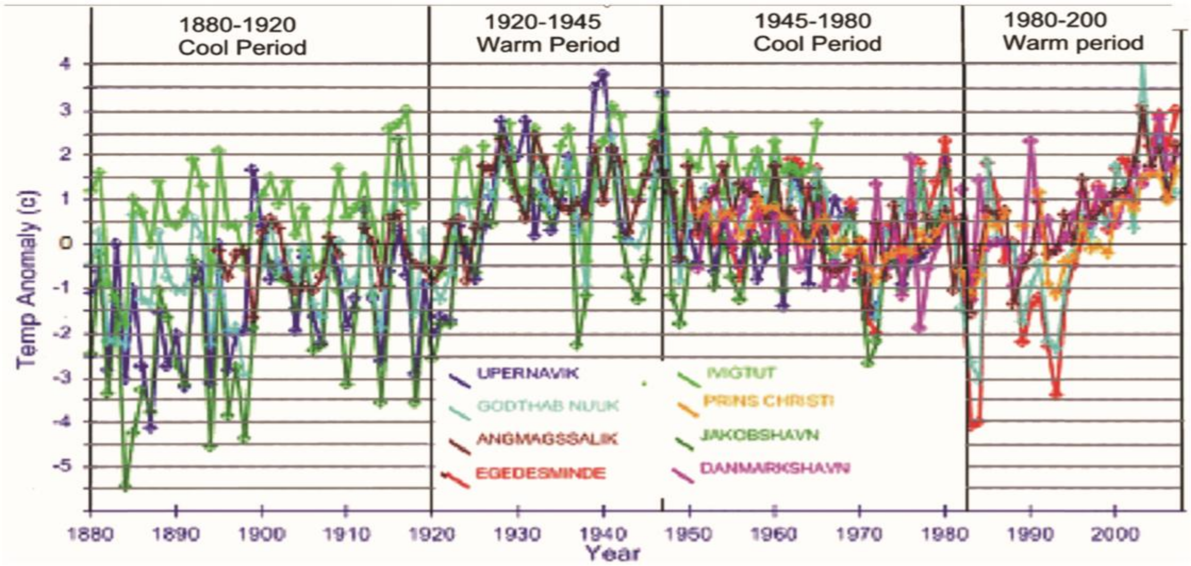

Fig. 8. Temperatures since 1880 at eight Greenland stations. Temperatures were cool from 1880 to about 1920, and then warmed from 1920 to about 1945. Temperatures were cooler from ~1945 to ~1980, and then warmed again from 1980 to 2004 to levels close to, but not exceeding, temperatures in the 1930s. (Modified from Jones et al. data set).

These data show that there is no unusual warming in Greenland and the Arctic and that temperatures in the 1930s were slightly warmer than they are now. Thus, Greenland cannot be considered a source of possible meltwater that would significantly raise sea level.

V. CONCLUSIONS

Hazard prediction is important, but the essence of science is the testing of predictions by comparison with observational facts. Without that validation, predictions are really just idle speculations. The future sea level values given by Garner et al. [1] are deeply flawed and therefore misleading for coastal planning. They must be rejected as nonsense.

Sea level research has its own well established means of recording past and present sea level changes and from those data to estimate likely sea level changes in the future. There are also physical frames to consider, some of which are absolute and must not be violated.

Satellite and surface temperature records and sea surface temperatures show that both the East Antarctic Ice Sheet and the West Antarctic Ice Sheet are cooling, not warming,

- Satellite and surface temperature measurements show that the East Antarctic Ice Sheet is cooling, not warming, and glacial ice is increasing, not melting.
- Satellite and surface temperature measurements of the southern polar area show no warming over the past 37 years.
- Growth of the Antarctic ice sheets means sea level rise is not being caused by melting of polar ice and, in fact, is slightly lowering the rate of rise.
- Satellite Antarctic temperature records show 0.02 °C/decade cooling since 1979.
- The Southern Ocean around Antarctica has been getting sharply colder since 2006.
- Antarctic sea ice is increasing, reaching all-time highs.
- Surface temperatures at 13 stations show the Antarctic Peninsula has been sharply cooling since 2000.

This indicates that the hypothetical "enhanced Antarctic Ice Sheet contribution" of Garner et al. [1] is a serious mistake (Fig. 1) not anchored in facts.

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