

# Guidance for Sea Level in 2100

## Focus on Ice Melt - The Big Unknown

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# Greenland and Antarctic Ice Melt

- Vast ice sheets of Greenland and Antarctica with average thicknesses more than a mile



Greenland



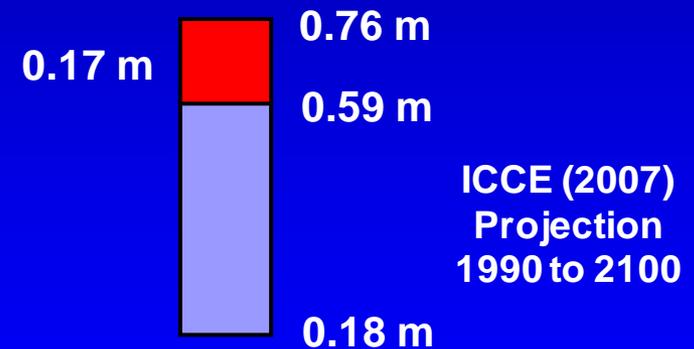
Antarctica

- Their melt contribution to sea level rise in the 20<sup>th</sup> century was small, but they are expected to have a much greater contribution in the 21<sup>st</sup> century

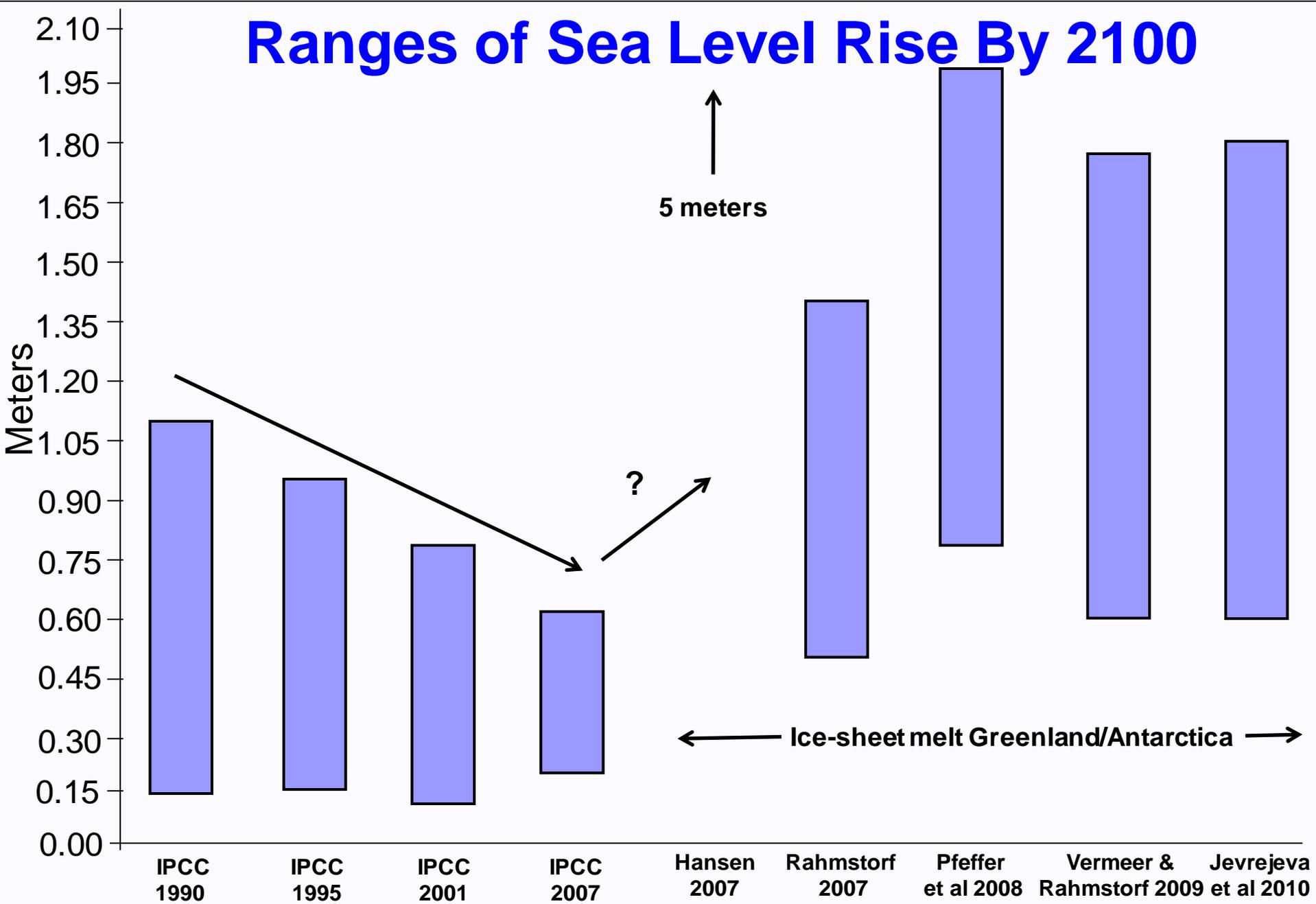
# Ice Melt

## Contributions from Greenland/Antarctica

- Projections by the Intergovernmental Panel on Climate Change (IPCC, 2007) did not include contributions from Greenland and Antarctica melting because it said projections were highly uncertain and likely not great
- However, it estimated that this melting might add - 0.01 to 0.17 m to the upper range of its forecast



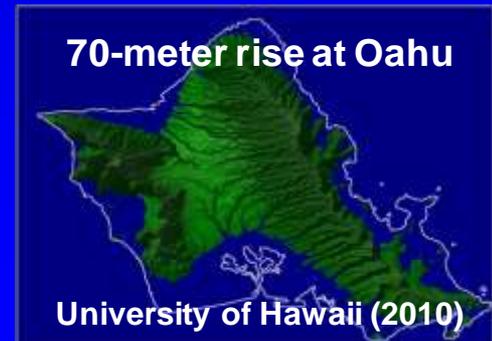
# Ranges of Sea Level Rise By 2100



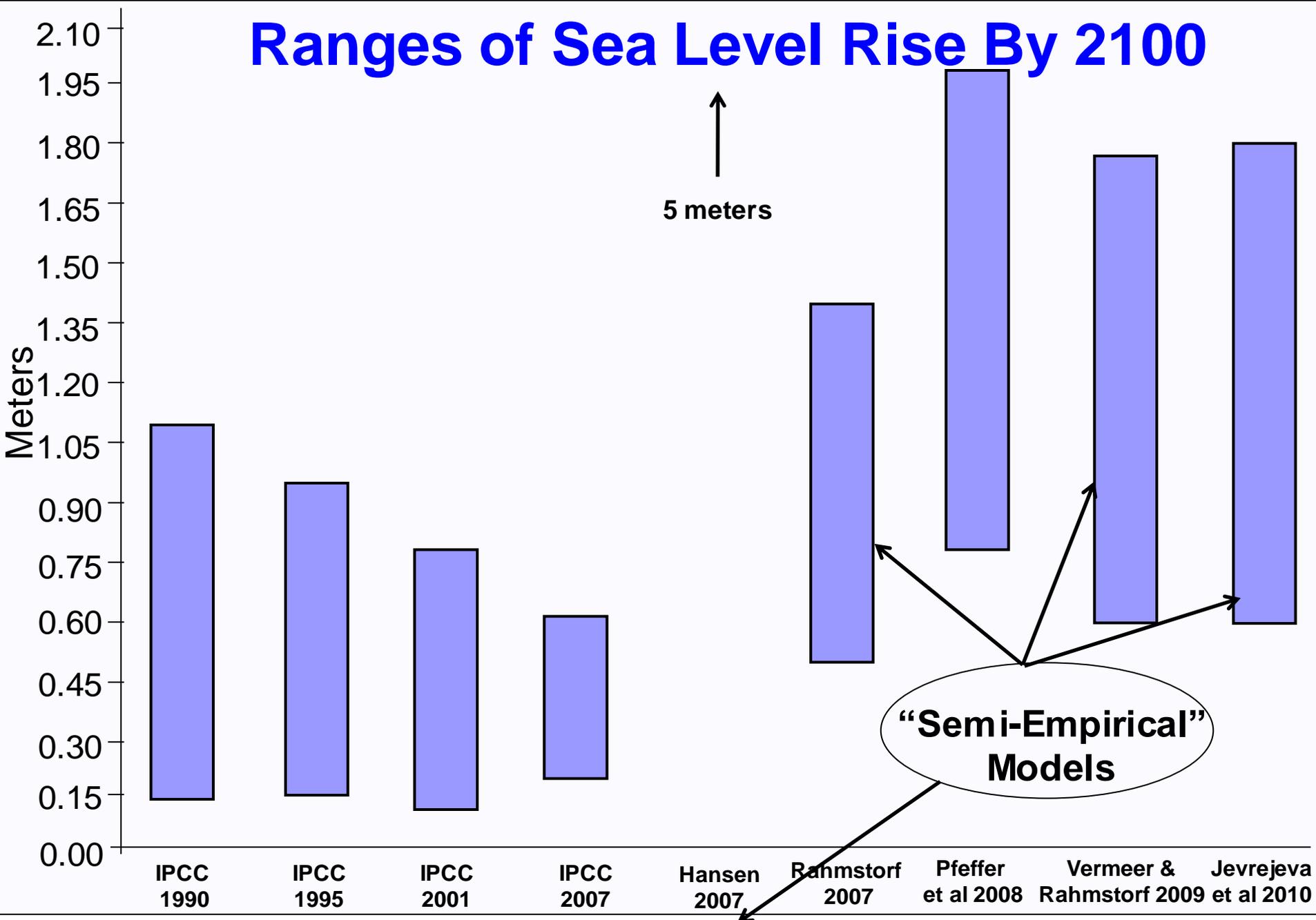
IPCC = Intergovernmental Panel on Climate Change

# Ice Sheet Melt

- Hansen (2007) and Hansen and Soto (2011), providing little evidence, said sea rise might rise 5 m by 2100
- Pfeffer et al (2008) (Journal *Science*) showed that by 2100 ***“... increases in excess of 2 m are physically untenable”***
- ***“... sea level is now projected by most experts to rise by the year 2100 by between 5 ft (1.5 m) and 10 ft (3 m), with the ‘new worst-case scenario’ of a rise of more than 20 feet (6 m)”***
  - Senior Official, NOAA, 2010
- “Most experts” apparently does not include those in the IPCC, Netherlands, UK, Australia, Denmark, etc, since none project a maximum as great as the 1.5 m minimum in the NOAA statement
- US agencies have widely accepted multi-meter rises, e.g., EPA maps of 1.5 to 3.5 m rises
- Rather than research on sea level, US funds flood maps and planning for multi-meter rises



# Ranges of Sea Level Rise By 2100



**Semi-empirical” models starting with Rahmstorf (2007) “implicitly” consider ice melt**

# “Semi-Empirical” Models – Journal Comments

- **“Rahmstorf (2007) presented an approach ... based on a proposed linear relationship ... We find no such linear relationship”**

- Holgate, Jevrejeva, Woodworth (2007)

- **“... this statistical analysis (Rahmstorf, 2007) is based on an application of statistics ... violating basic assumptions of the statistical methods used”**

- Schmith Johansen, Thejll (2007)

- **“... there exist periods in the simulation where the prediction errors are very large ...”**

- Storch et al (2011)

- **“Rahmstorf and Vermeer (2011) have been selective in showing only data that appear to match their modeling and not the data that strongly disagree”**

- Houston and Dean (2011)



Rahmstorf dramatizing sea level rise

# “Semi-Empirical” Models

- *"Rahmstorf is very good at publishing extreme papers ... The problem is that his methods are biased to generate large numbers for sea-level rise which cannot be justified but which attract headlines."*

- Dr Simon Holgate, Proudman Oceanographic Laboratory, 2010

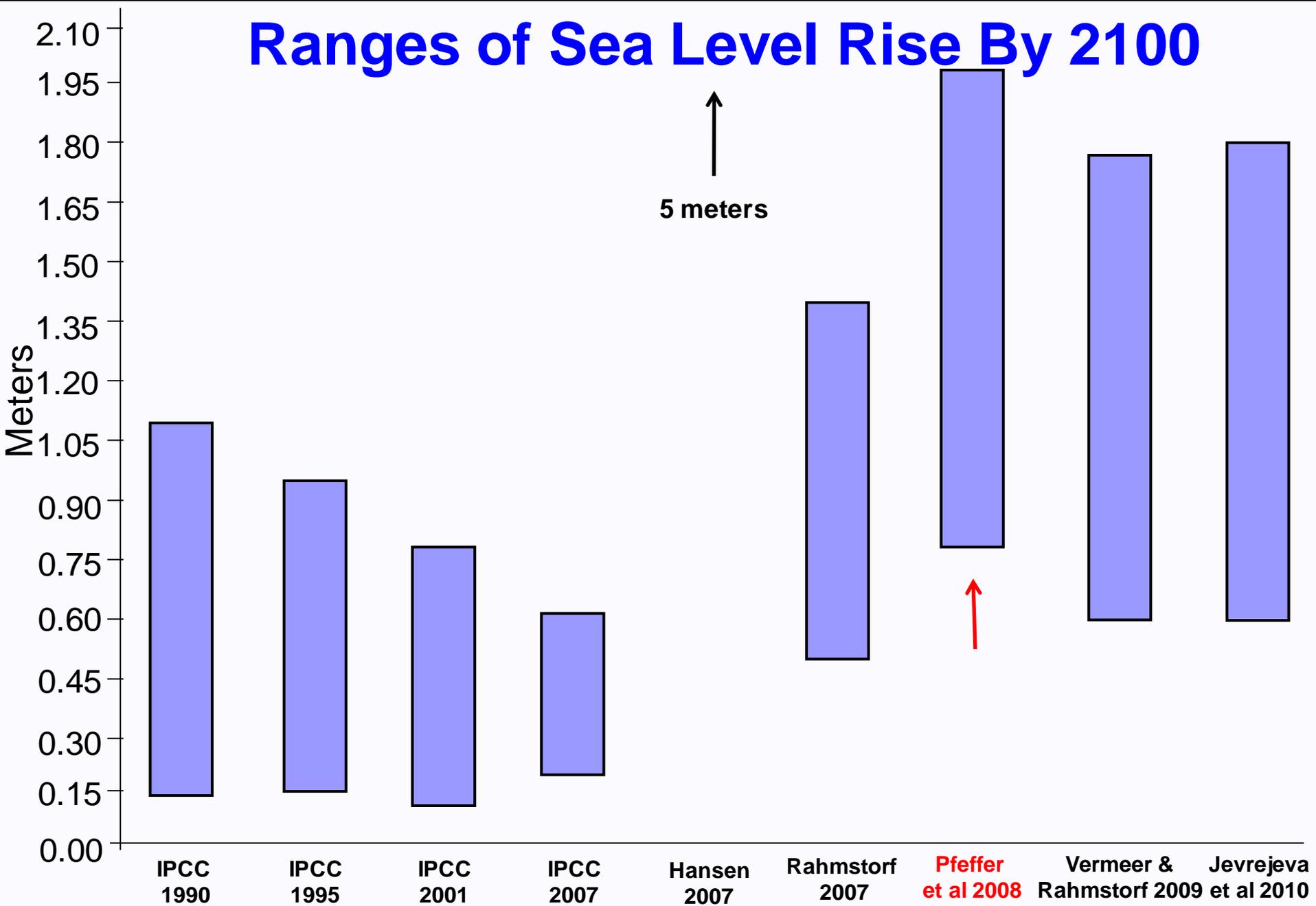


- *"No physically-based information is contained in such models ..."* and *"The physical basis for the large estimates from these semi-empirical models is therefore currently lacking"*

- Intergovernmental Panel on Climate Change (IPCC) Sea Level Rise & Ice Sheet Instabilities (2010) - over 100 experts

- Despite these criticisms, in 2011 the FEMA selected the 0.75 - 1.90 m predictions of Vermeer and Rahmstorf (2009) for the National Flood Insurance Program, which will drive insurance rates, building codes, and development

# Ranges of Sea Level Rise By 2100

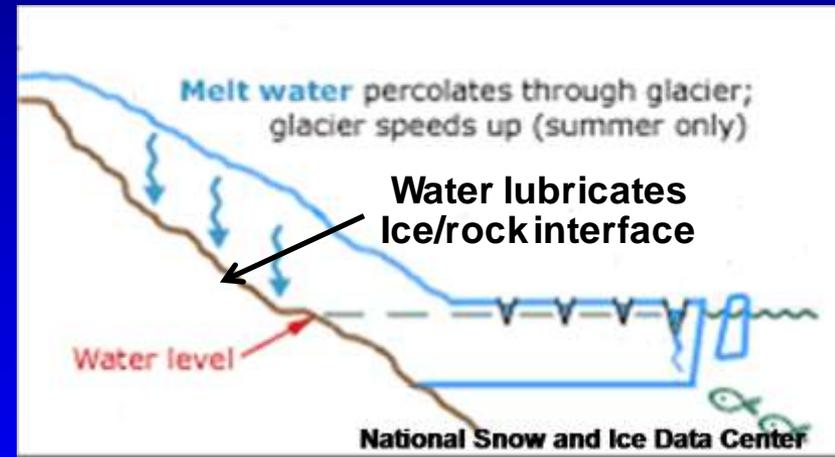


# Glacier Discharge Into the Ocean is Key

- Pfeffer et al (2008) conclude glacier discharge into the ocean is the key to possible large sea level rise – e.g., surface-ice melt would contribute only about 4% to a rise of 2 m



- Conventional wisdom is that global warming increases melt water that then percolates through glaciers, lubricating the ice/rock interface and thus increasing the velocity of glacier sliding into the ocean



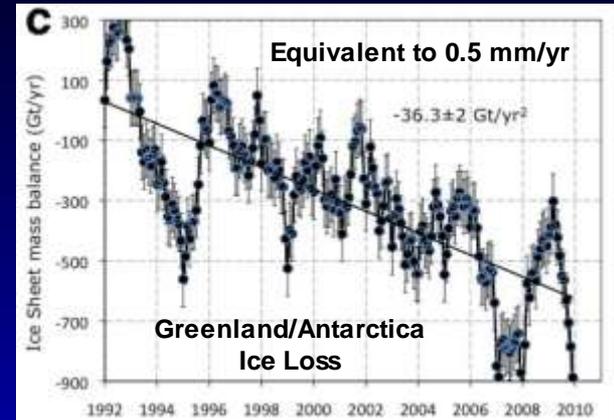
- Pfeffer et al said a 2.0 m rise could occur by 2100 only if velocities of ice-sheet discharge increased immediately by a multiple of 70 – much faster than ever observed

# Studies Up End Conventional Wisdom

- Greenland measurements by Sundal et al (2011) show glaciers slide more slowly during warmer summers than cooler summers
- During warmer summers, the melt runs off with less flowing to and lubricating the ice/rock interface, thereby slowing ice-sheet movement
- Bingham et al (2003) and Truffer et al (2005) measured the same decreased velocities of Arctic and Alaskan glaciers during years of high melt
- Van de Wal et al (2008) measured decreased velocity of a Greenland ice-sheet as temperatures warmed over past 17 years
- IPCC (2010) noted glaciers in southeast Greenland have been slowing during warming



# Ice Melt Contribution



- Wu et al (2010) determined the present ice loss of Greenland + Antarctica would raise sea level only 1.9 inches by 2100 – so present rise not a big problem
- However, Rignot et al (2011) show the ice loss is accelerating
- IPCC (2007) notes the acceleration may be a fluctuation similar to that from 1920-1960. However, for the worse case we assume it is permanent
- We determined from Wu and Rignot that the current trend plus acceleration could raise sea level 0.47 m from 1990 to 2100
- 0.47 m = 0.28 m from Greenland + 0.19 m from Antarctica. Conservative

<b>Greenland</b>	<b>0.28 m</b>	Our projection
	<b>0.10 – 0.19 m</b>	Projection by 200 of world's expert glaciologists (2011 Arctic Monitoring & Assessment Program)

<b>Antarctica</b>	<b>0.19 m</b>	Our projection
	<b>0.07 – 0.15 m</b>	Projection by Katsman et al (2011)

# Projecting World-Wide Rise by 2100

- Adding the ice melt of 0.47 m to the worse-case scenario of IPCC (2007) for thermal expansion, etc, of 0.59 m, yields

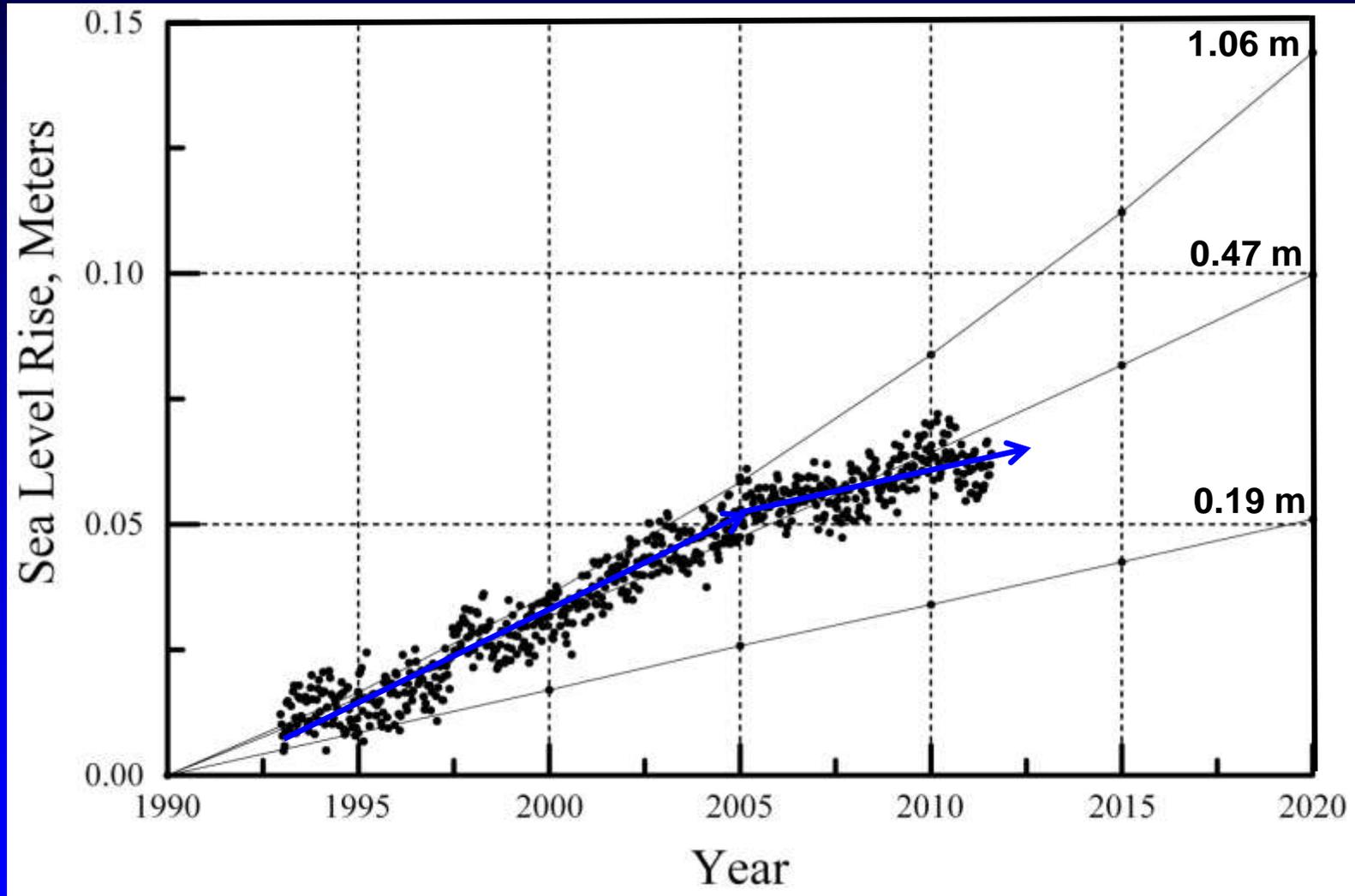
$$0.47 \text{ m} + 0.59 \text{ m} = 1.06 \text{ m from 1990 to 2100}$$

- Upper limit of 1.06 m from 1990 to 2100 is similar to other projections determined using different approaches
- The Netherlands (2008) projects an upper limit of 1.1 m by 2100 and Australia (2011) an upper limit of 1.0 m
- Lower limit of 0.19 m – assumes 20<sup>th</sup> century rate of sea level rise continues to 2100
- Most probable value of 0.47 m – adds mid-point of IPCC (2007) to mid-point IPCC assumed for ice-melt contribution of Greenland & Antarctica

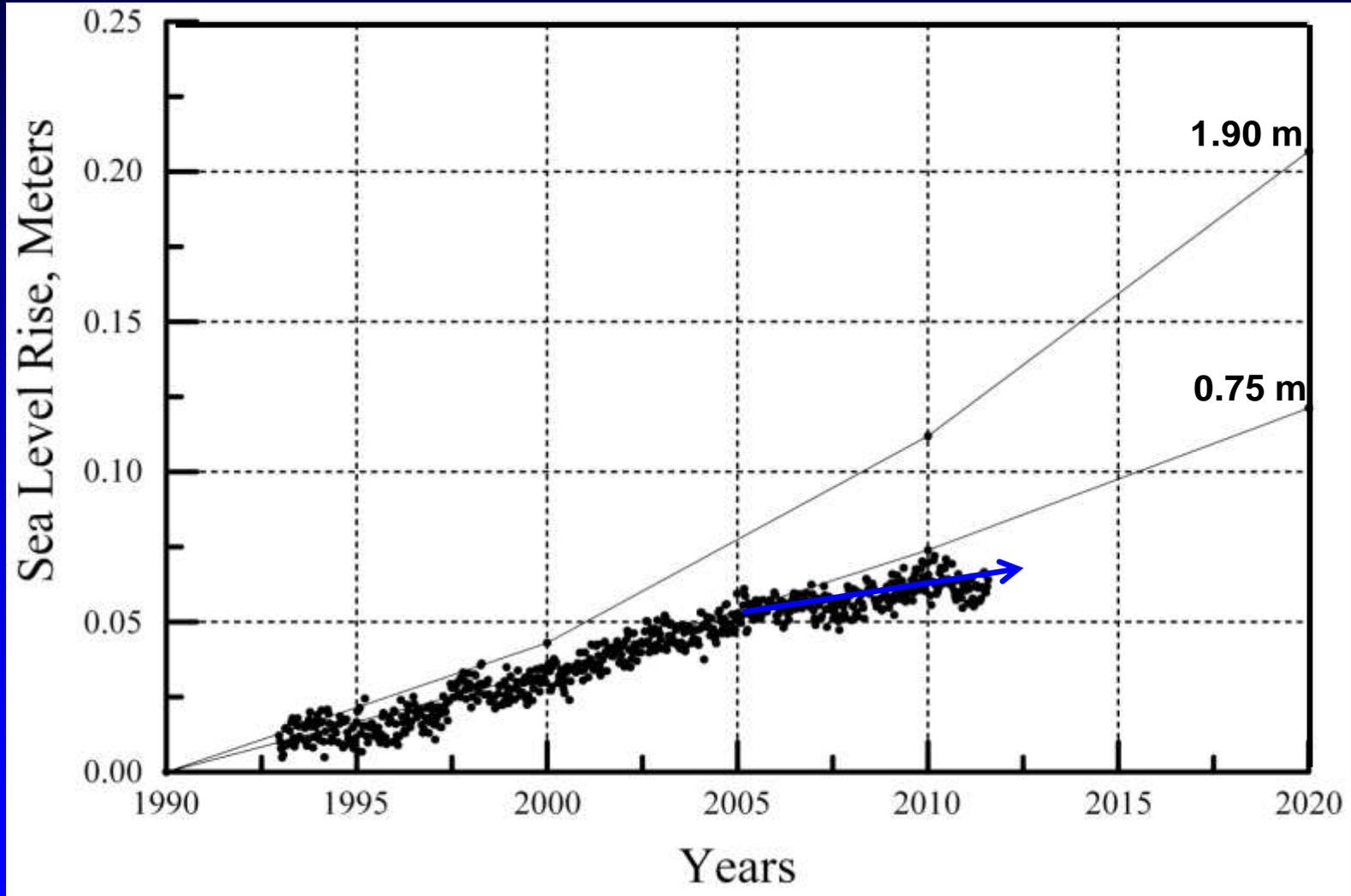
## 2010 to 2100 Projection (in meters)

	1990 - 2100	1990 - 2010	2010 - 2100
Maximum	1.06	0.06	1.00
Most likely	0.47	0.06	0.41
Minimum	0.19	0.06	0.13

# Our Projections Versus Satellite Altimeter Measurements



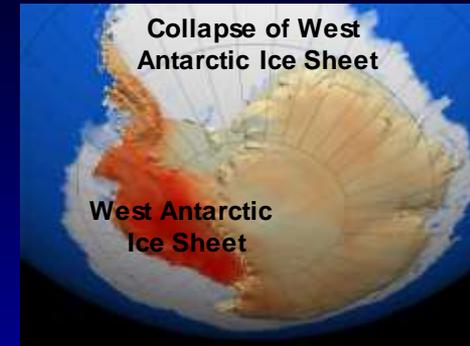
# FIA Projections Versus Satellite Altimeter Measurements



# What About Possible Catastrophes?

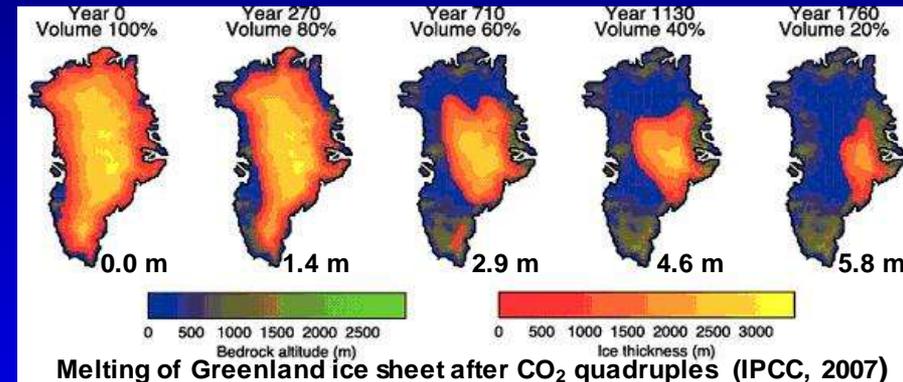
## Antarctica

- Odds of collapse of West Antarctic ice sheet by 2100 estimated as 1:50 to 1:2500
- Bamber et al (2009) show a total collapse would raise sea level 3.26 m, but over 500 - 1735 years



## Greenland

- Worst-case IPCC scenario: CO<sub>2</sub> quadruples in 225 yrs and after another 200 yrs (425 yrs total) the Greenland melt raises sea level 1 m



## Incredibly Unlikely + Impossible

- In the next 10 minutes both the West Antarctic ice sheet collapses and CO<sub>2</sub> quadruples (rather than waiting 225 years)

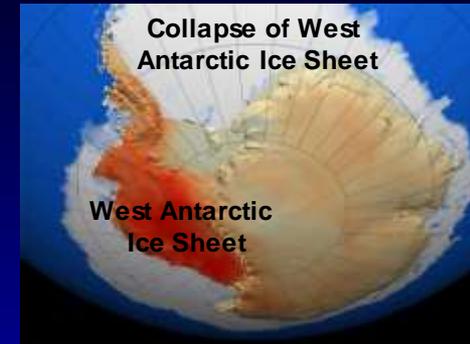
## Rise by 2100 Based on Maximum Values from Bamber and IPCC

West Antarctic Ice Sheet Collapse	~ 0.57 m	Total ~ 1.56 m
Greenland Melt from Quadrupling of CO <sub>2</sub>	~ 0.46 m	
Maximum from IPCC	~ 0.53 m	

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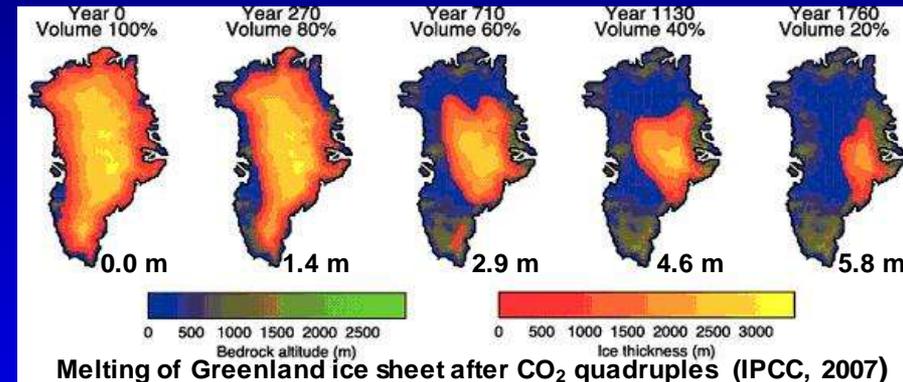
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*“... sea level is now projected by most experts to rise by the year 2100 by between 5 ft (1.5 m) and 10 ft (3 m), with the ‘new worst-case scenario’ of a rise of more than 20 feet (6 m)”*

Total ~ 1.56 m

– Senior Official, NOAA, 2010

# Intergovernmental Panel on Climate Change (2013)

- IPCC has telegraphed its projections for 1990 to 2100
- Its interim meeting in 2010, “Sea Level Rise and Ice Sheet Instabilities,” rejected semi-empirical modeling
- Studies to determine the contribution of Greenland and Antarctica to sea level were funded in support of IPCC
- Katsman et al (2011) determined Antarctica contribution of 0.07- 0.15 m and Graversen et al (2010) a Greenland contribution of 0.0 - 0.17 m
- Adding maximums of 0.59 (IPCC, 2007) + 0.15 (Katsman et al, 2011) + 0.17 m (Graversen, 2010) = 0.92 m
- Adding mid-points of IPCC, Katsman, Graversen = 0.55 m
- IPCC (2013) most probable level  $\approx$  0.55 m and maximum  $\approx$  0.9 m
- Similar to our most probable for 1990 to 2100 of 0.47 m and less than our maximum of 1.06 m

# Conclusions

- US agencies accept predictions by Rahmstorf et al that are heavily criticized in the peer-reviewed literature and ignore studies by world experts with high credibility (IPCC, Netherlands, Australia, etc)
- Agencies in Europe, Australia, etc, make reasonable projections, the public accepts, concrete steps taken. US agencies exaggerate, the public is skeptical, no actions are taken
- Exaggerated predictions cause the public to lose confidence in the science of climate change, leading to inaction in preparing for rises which will occur
- The most probable rise from 2010 - 2100 is about 0.4 m (1.3 ft) with a worst case rise  $< 1$  m. The most probable rise will cause problems that need to be addressed



# Thank You!

