



Klimawandel & Meeresspiegelanstieg

aktuelle Szenarien

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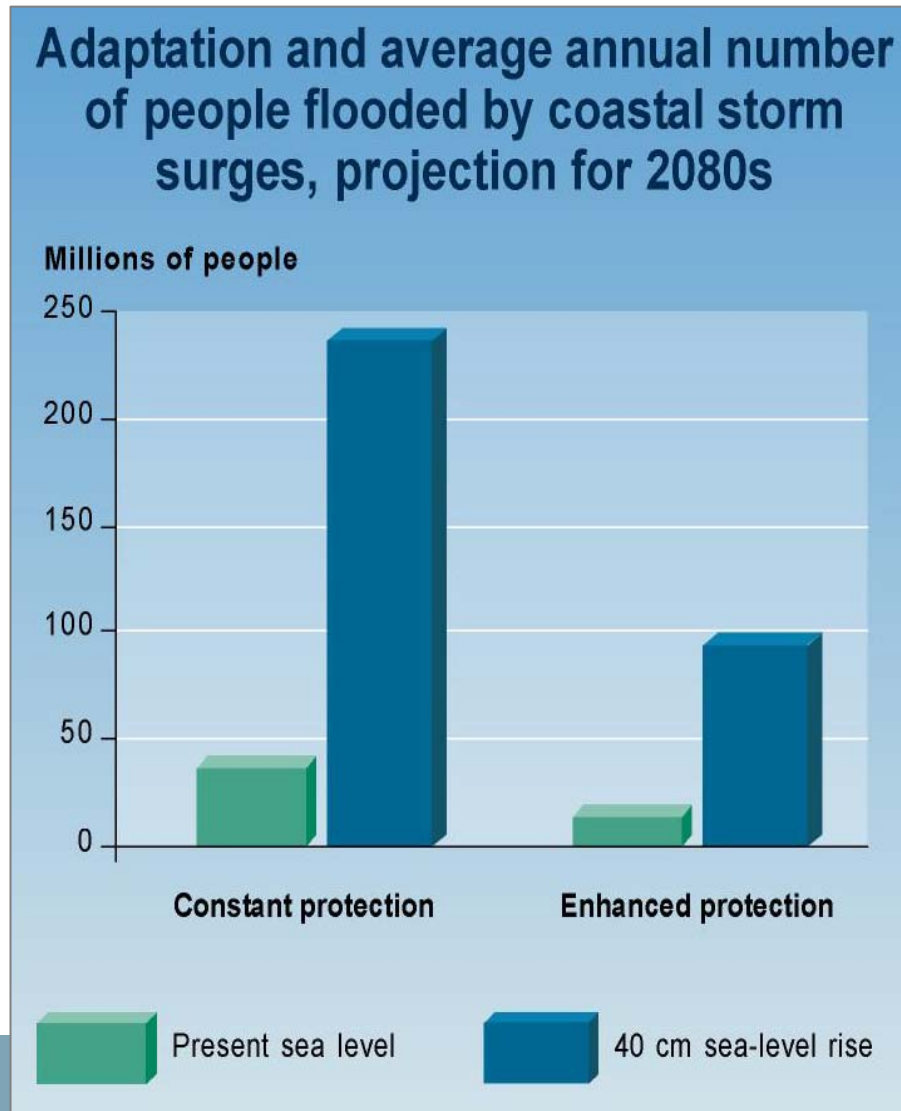
Folgen des Klimawandels für die Küsten?

Meeresspiegelanstieg

Stürme global und regional



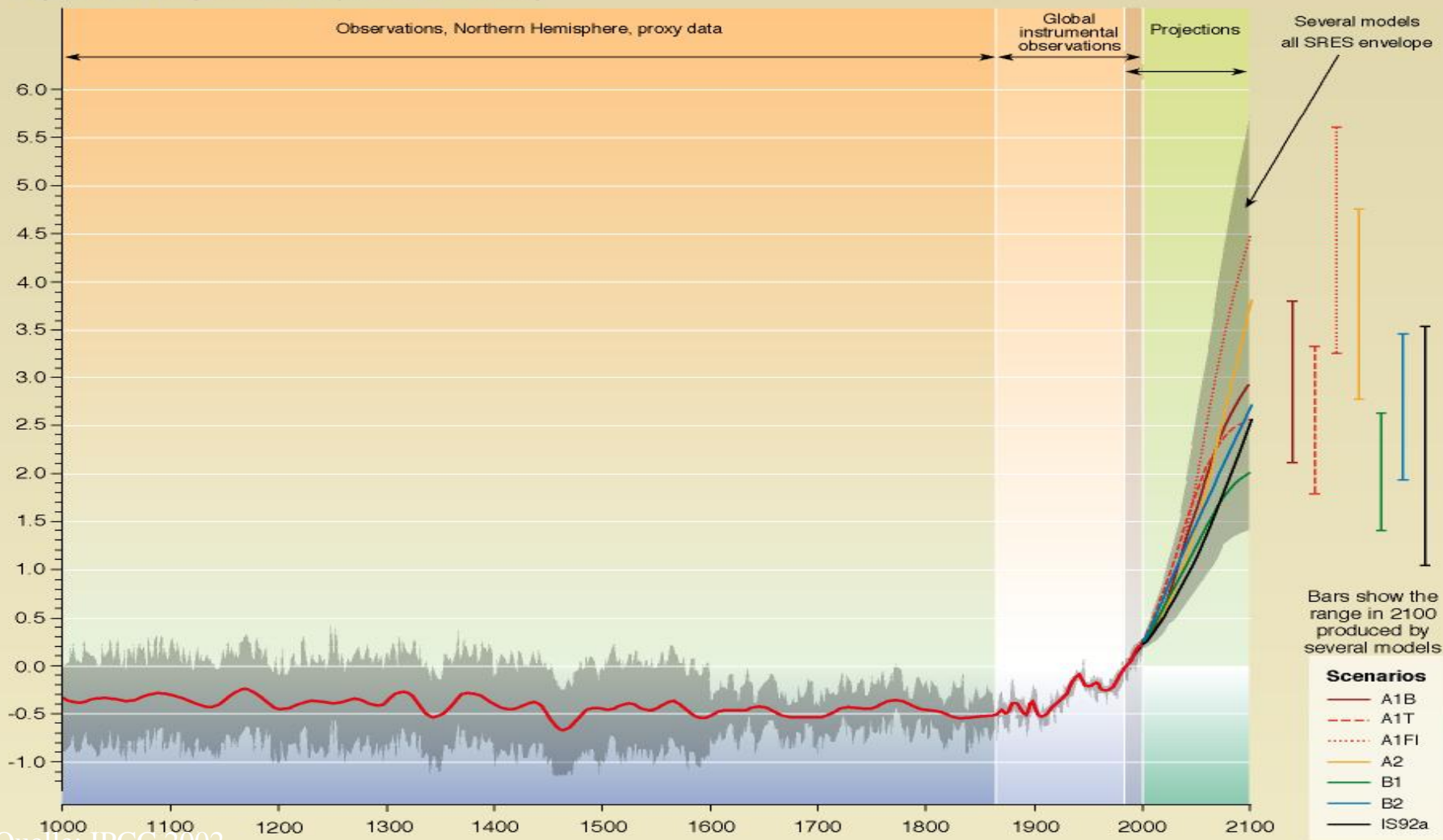
Meeresspiegelanstieg - Effekte





Variations of the Earth's surface temperature: 1000 to 2100

Departures in temperature in °C (from the 1990 value)



Quelle: IPCC 2002



Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise. {6.4, 6.6}

Paläoklimatische Informationen unterstützen die Interpretation, dass die Erwärmung der letzten Hälfte des 20. Jh. ungewöhnlich stark ist, zumindest innerhalb der letzten 1300 Jahre

Als das letzte Mal die polaren Regionen über einen längeren Zeitraum signifikant wärmer waren als heute (vor ca. 125.000 Jahren), führte ein Rückgang des polaren Eisvolumens zu einem Meeresspiegelanstieg zwischen 4 und 6 Metern

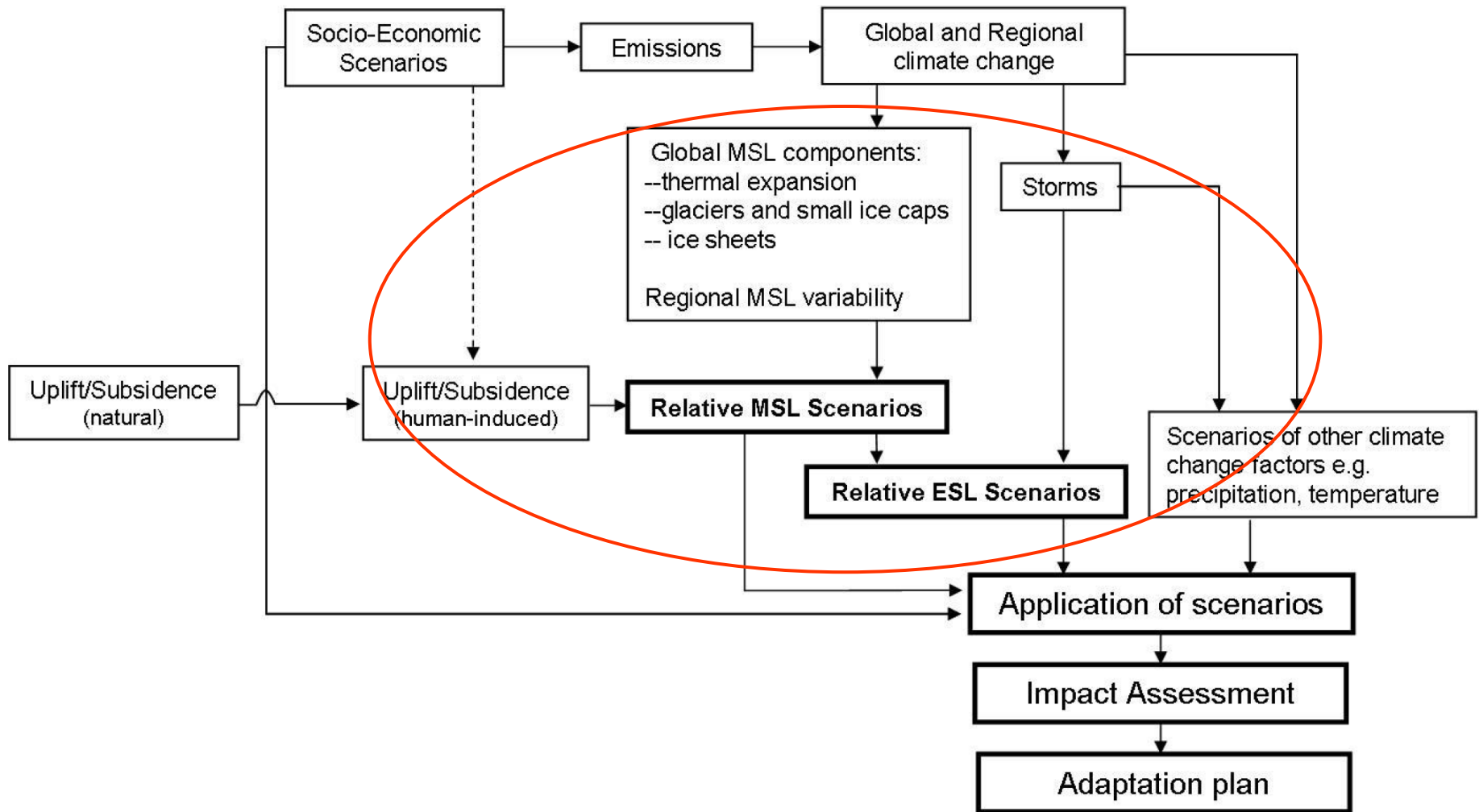
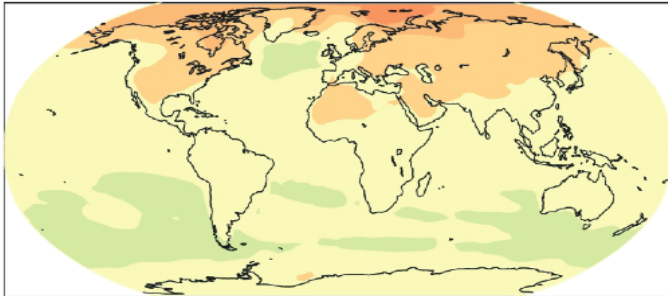


Figure 2: Summary of a methodology commonly applied for developing sea-level scenarios for impact assessment and adaptation planning. MSL – mean sea level; ESL – extreme sea level.

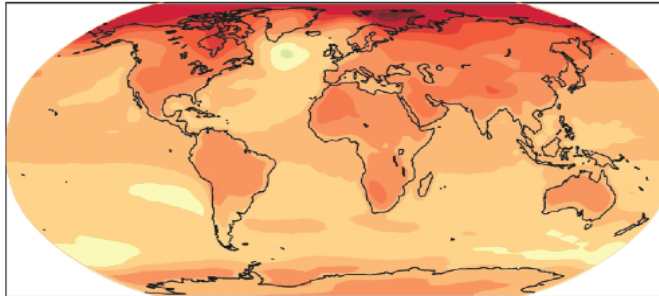


Temperaturänderung in den Szenarien B1, A1B und A2

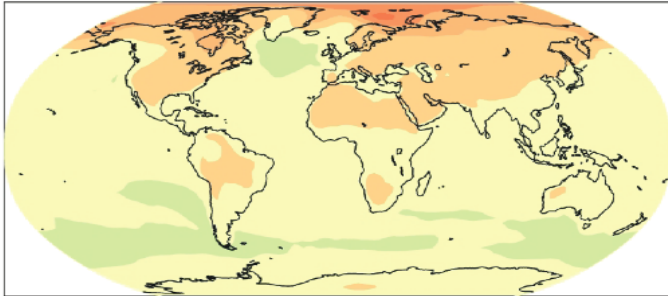
B1: 2020-2029



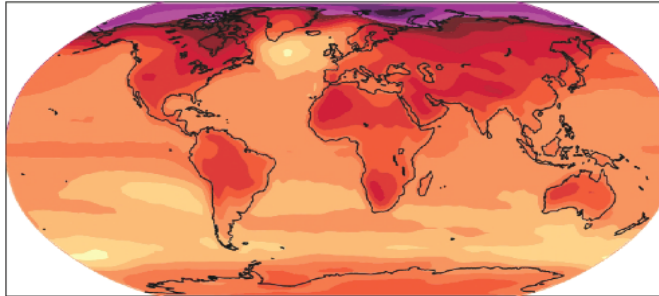
B1: 2090-2099



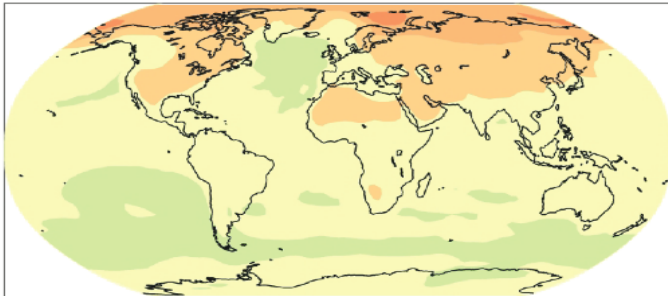
A1B: 2020-2029



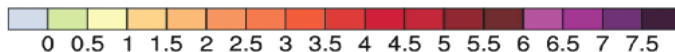
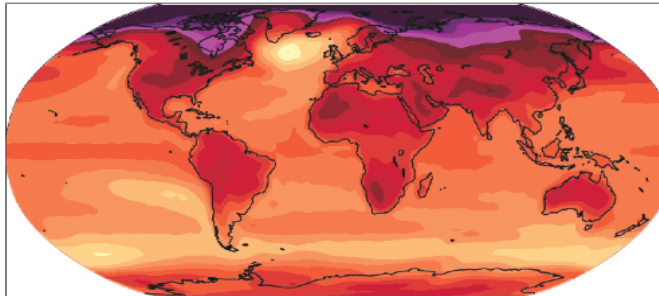
A1B: 2090-2099



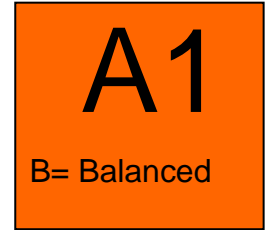
A2: 2020-2029



A2: 2090-2099



B1



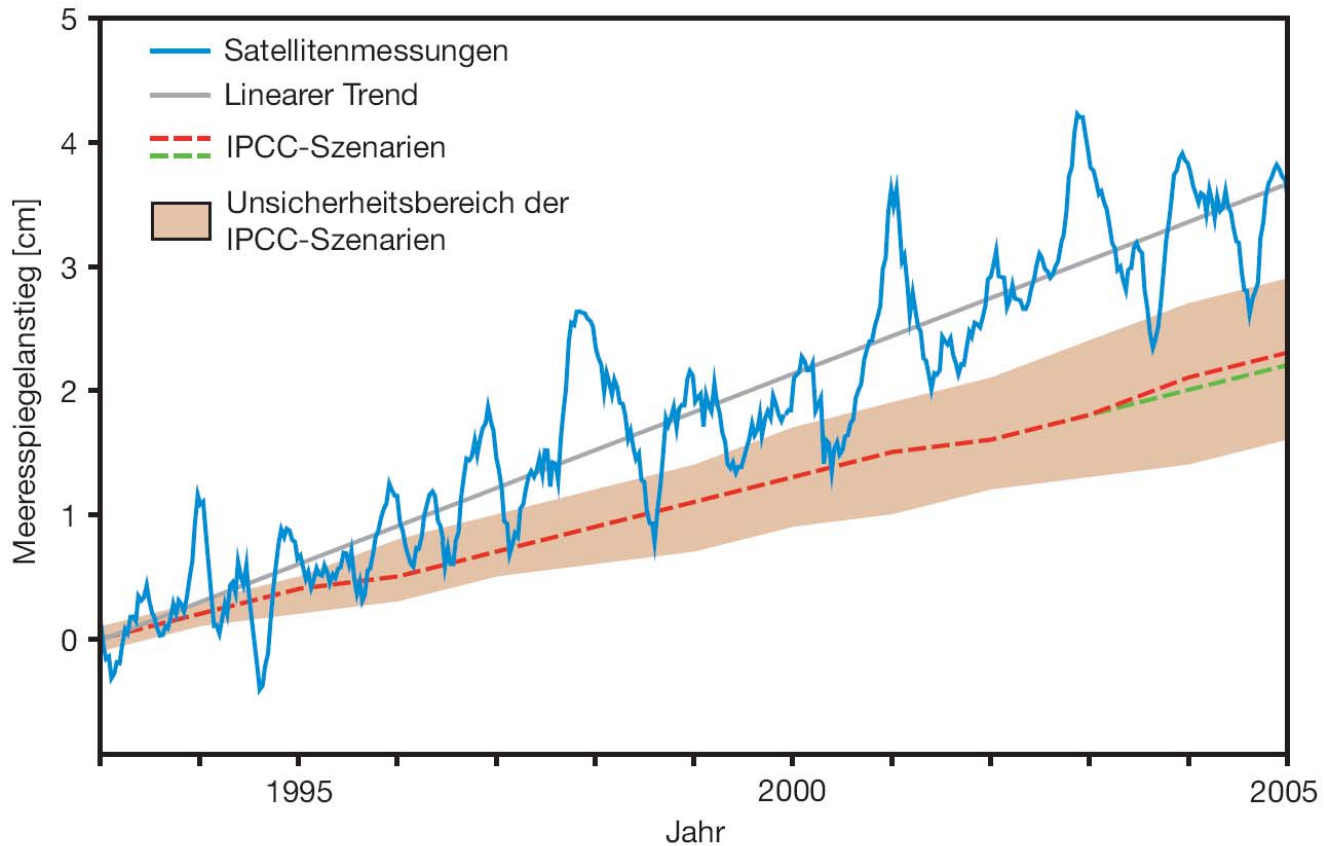
A1

B= Balanced



A2

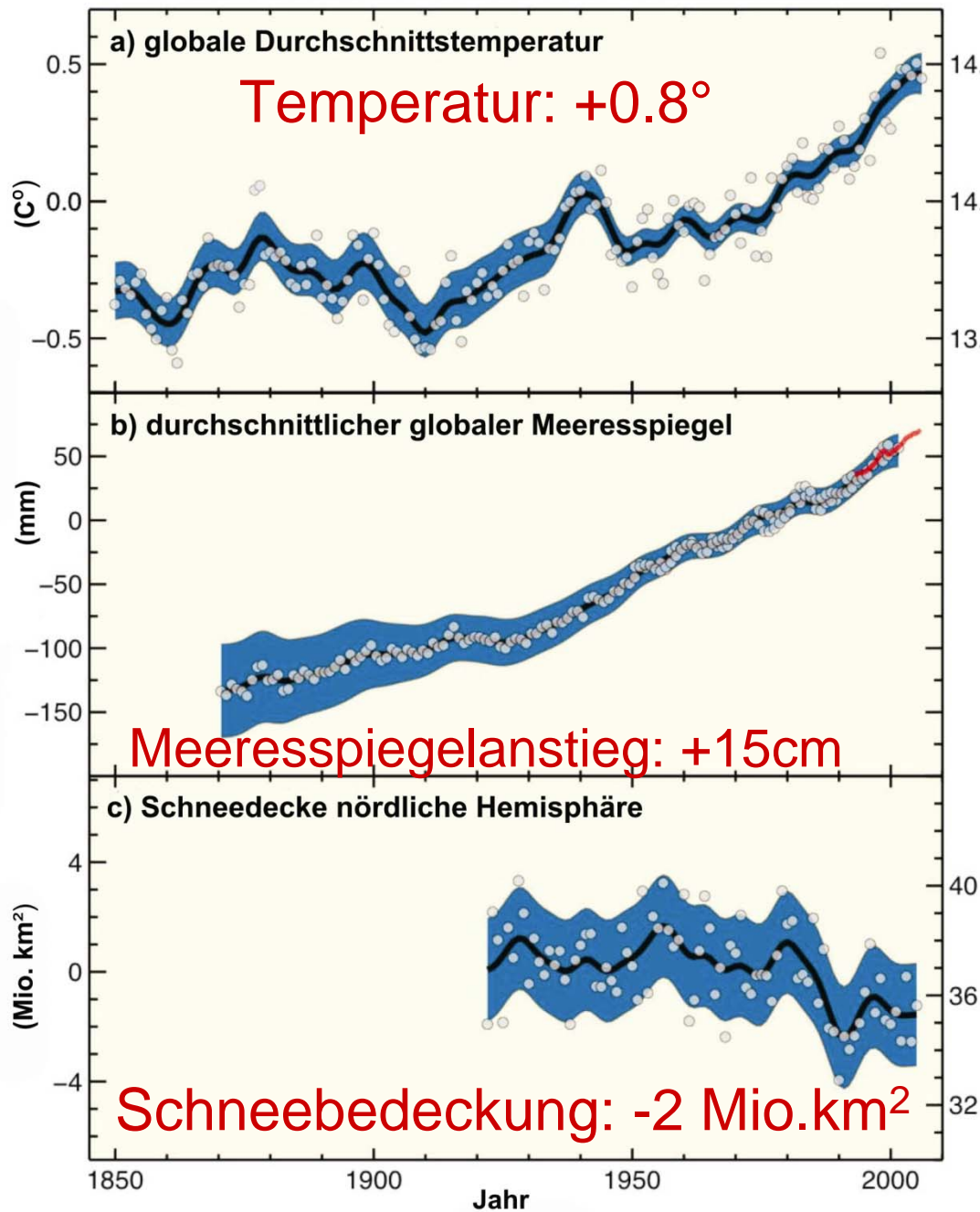
©IPCC 2007: WG1-AR4



Der Anstieg des globalen Meeresspiegels aus Satellitenmessungen (obere Linie, mit ihrem linearem Trend) sowie die Projektionen des IPCC (2001a) mit ihrem Unsicherheitsbereich. Quelle: WBGU 2006



Differenz von 1961-1990



Beobachtete Veränderungen

- a) der globalen Durchschnittstemperatur*
- b) des durchschnittlichen globalen Meeresspiegelanstieg (Pegeldaten = blau; Satellitendaten = rot)*
- c) der Schneedecke der nördlichen Hemisphäre (März – April)*

Alle Veränderungen sind relativ zu den Durchschnittswerten der Jahre 1961-1990. Geglättete Kurven wurden aus dekadischen Durchschnittswerten gebildet, Kreis stellen jährliche Werte dar, schattierte Bereiche stellen geschätzte Unsicherheitsintervalle dar (aus umfassenden Analysen bekannter Unsicherheiten (a,b) sowie aus Zeitreihenanalysen (c))

Quelle: WBGU 2006



Contributions to sea level rise

For 1961-2003: 1.6 mm/yr:

(Source: Domingues et al., Nature 2008)

- ▲ Thermal expansion (ca. 40 %)
- ▲ Glaciers and ice caps (ca. 35 %)
- ▲ Continental ice sheets (ca. 25 %)

For 2003-2008: 2.5 mm/yr:

(Source: Cazenave et al., GPC 2008)

- ▲ Thermal expansion (ca. 20%)
- ▲ Glaciers and ice caps (ca. 40 %)
- ▲ Continental ice sheets (ca. 40 %)

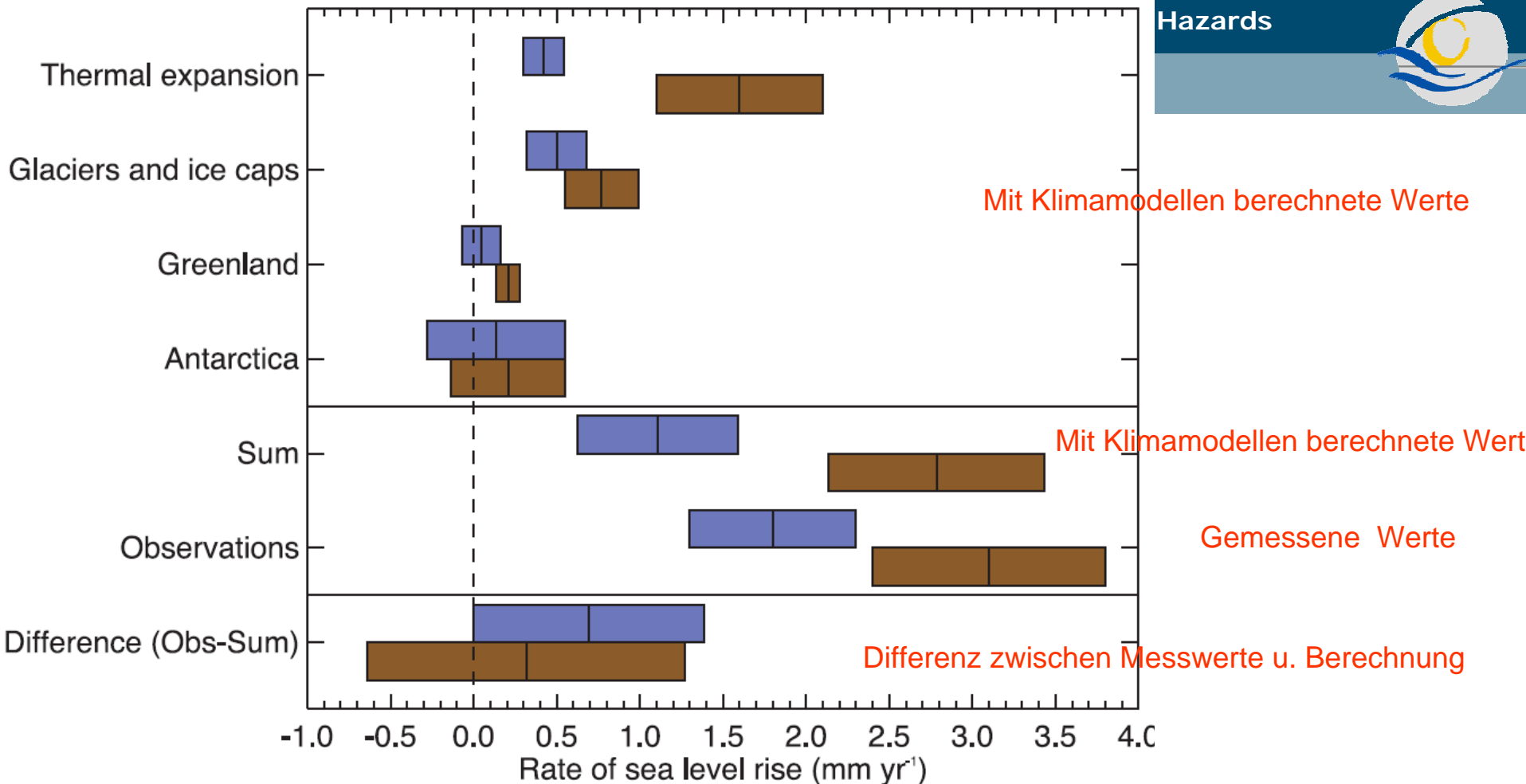


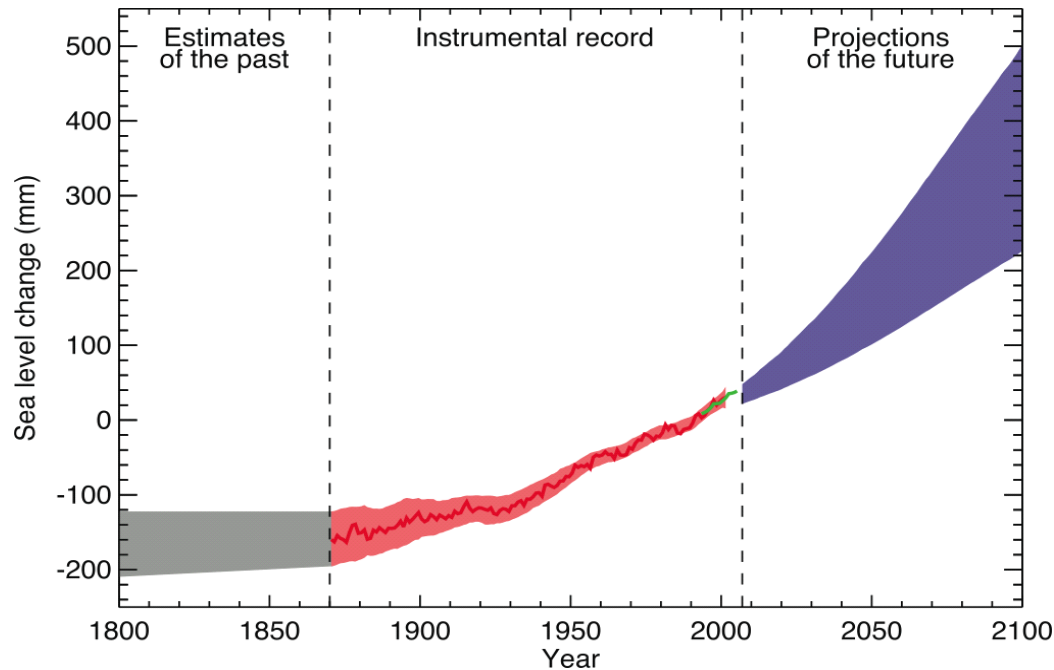
Figure 5.21. Estimates of the various contributions to the budget of the global mean sea level change (upper four entries), the sum of these contributions and the observed rate of rise (middle two), and the observed rate minus the sum of contributions (lower), all for 1961 to 2003 (blue) and 1993 to 2003 (brown). The bars represent the 90% error range. For the sum, the error has been calculated as the square root of the sum of squared errors of the contributions. Likewise the errors of the sum and the observed rate have been combined to obtain the error for the difference.



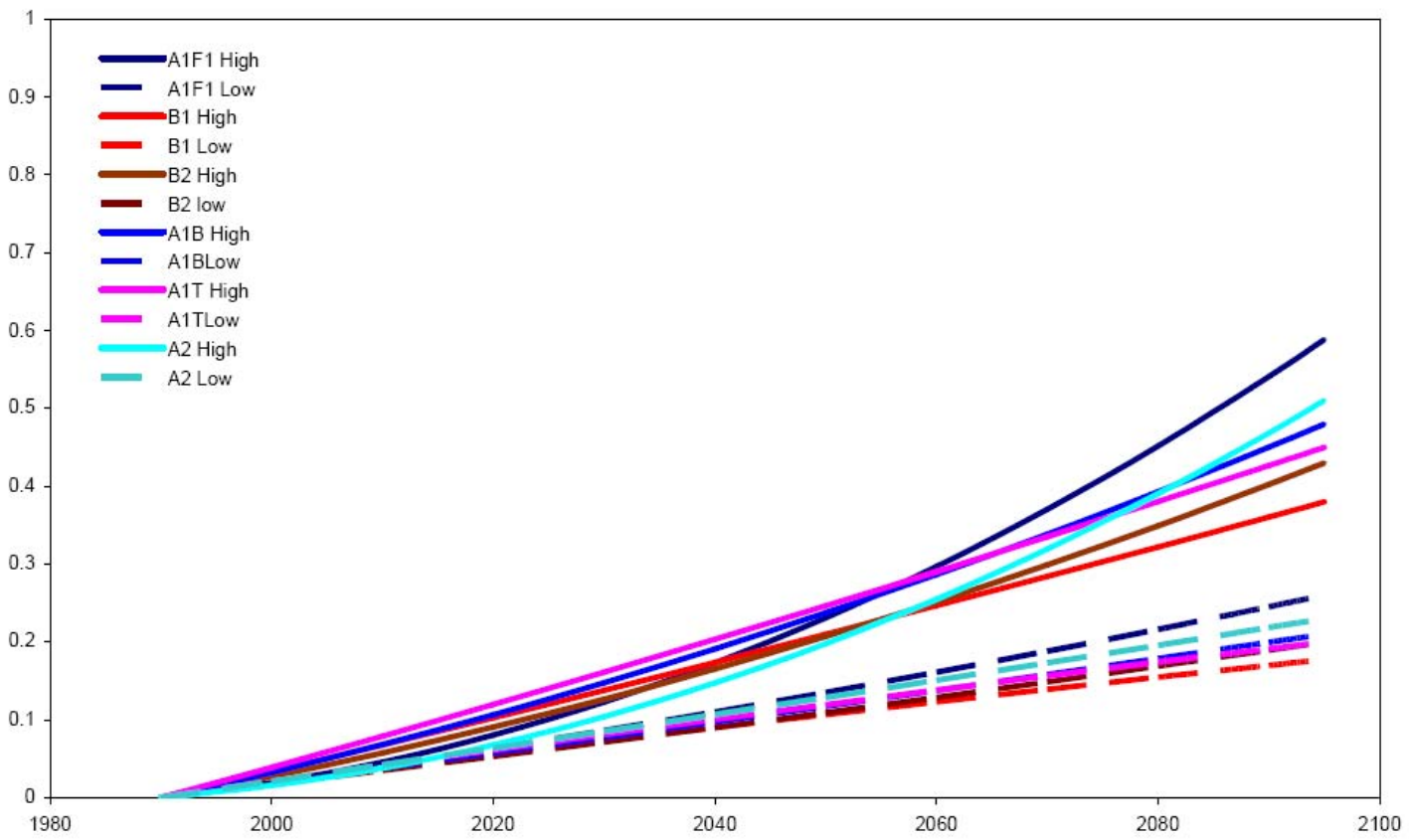
Table 5.3. Estimates of the various contributions to the budget of global mean sea level change for 1961 to 2003 and 1993 to 2003 compared with the observed rate of rise. Ice sheet mass loss of 100 Gt yr⁻¹ is equivalent to 0.28 mm yr⁻¹ of sea level rise. A GIA correction has been applied to observations from tide gauges and altimetry. For the sum, the error has been calculated as the square root of the sum of squared errors of the contributions. The thermosteric sea level changes are for the 0 to 3,000 m layer of the ocean.

| Source | Sea Level Rise (mm yr ⁻¹) | | Reference |
|-----------------------------|---------------------------------------|-------------|-----------------|
| | 1961–2003 | 1993–2003 | |
| Thermal Expansion | 0.42 ± 0.12 | 1.6 ± 0.5 | Section 5.5.3 |
| Glaciers and Ice Caps | 0.50 ± 0.18 | 0.77 ± 0.22 | Section 4.5 |
| Greenland Ice Sheet | 0.05 ± 0.12 | 0.21 ± 0.07 | Section 4.6.2 |
| Antarctic Ice Sheet | 0.14 ± 0.41 | 0.21 ± 0.35 | Section 4.6.2 |
| Sum | 1.1 ± 0.5 | 2.8 ± 0.7 | |
| Observed | 1.8 ± 0.5 | 3.1 ± 0.7 | Section 5.5.2.1 |
| | | | Section 5.5.2.2 |
| Difference (Observed – Sum) | 0.7 ± 0.7 | 0.3 ± 1.0 | |

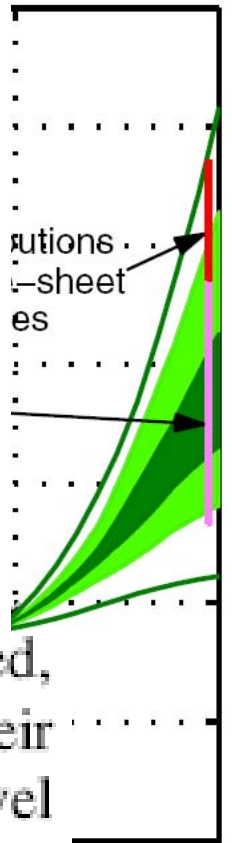
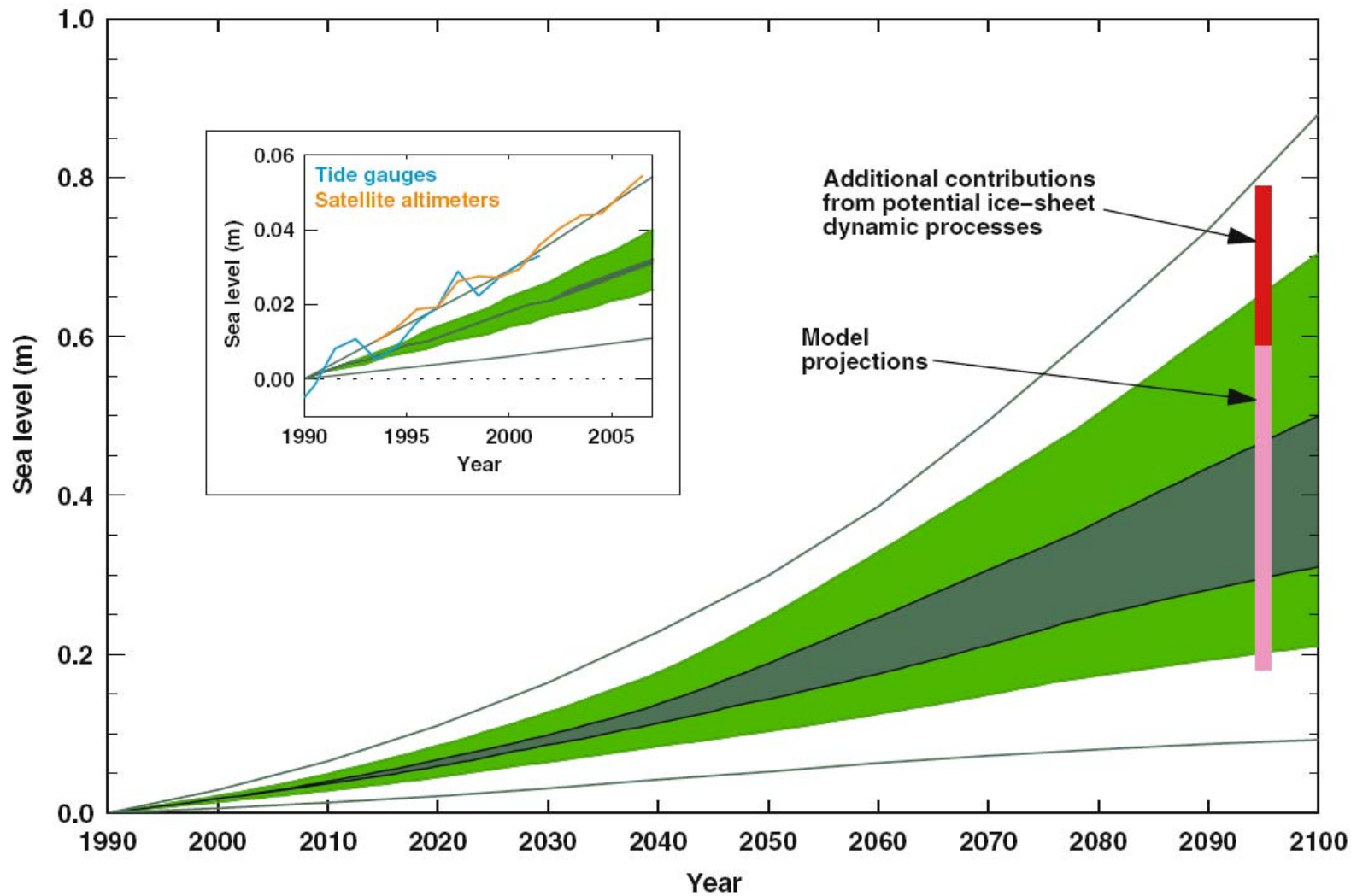
SLR Berechnungen vs. Messungen



Modellsimulationen mit Klima- und Eismodellen können diese Effekte berechnen, allerdings noch nicht mit befriedigender Genauigkeit. Für 1961-2003 ergeben die IPCC-Modelle im Mittel eine Anstiegsrate um 1,2 mm/Jahr, gemessen wurden aber 1,8 mm/Jahr. Die Modelle unterschätzen also den tatsächlichen Meeresspiegelanstieg. Ähnliches galt übrigens bereits für die Modelle im letzten IPCC-Bericht: im Zeitraum 1990-2006 stieg der Meeresspiegel etwa 50% rascher als in den damals publizierten mittleren Szenarien (Rahmstorf et al. 2007).



Die oben genannte Spanne von 18-59 cm enthält kaum einen Beitrag der Kontinentaleismassen, da der IPCC-Bericht davon ausgeht, dass ein Eiszuwachs in der Antarktis den Eisverlust in Grönland weitgehend ausgleichen wird. Tatsächlich deuten aber Messungen mit dem GRACE-Satelliten darauf hin, dass auch die Antarktis insgesamt in den letzten Jahren an Eis verloren hat – dies sind aber noch vorläufige Daten, da dieser Satellit erst seit wenigen Jahren im Einsatz ist.



Note that the IPCC AR4 states that “larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea-level rise.” The *inset* shows the 2001 projection compared with the



Flächen des Grönlandeises (orange), die einen Massenverlust aufweisen



Observed Sea Level Rise

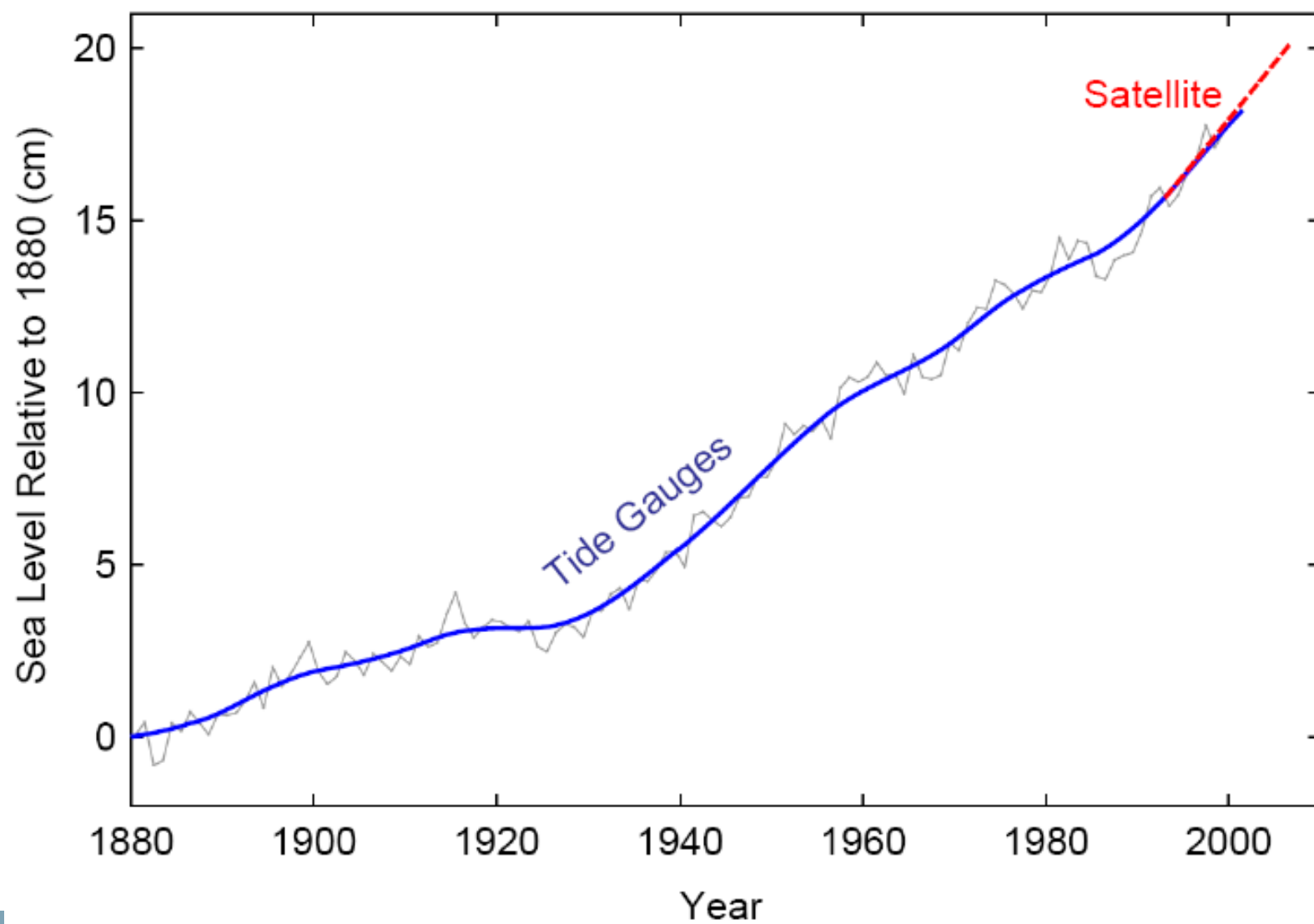
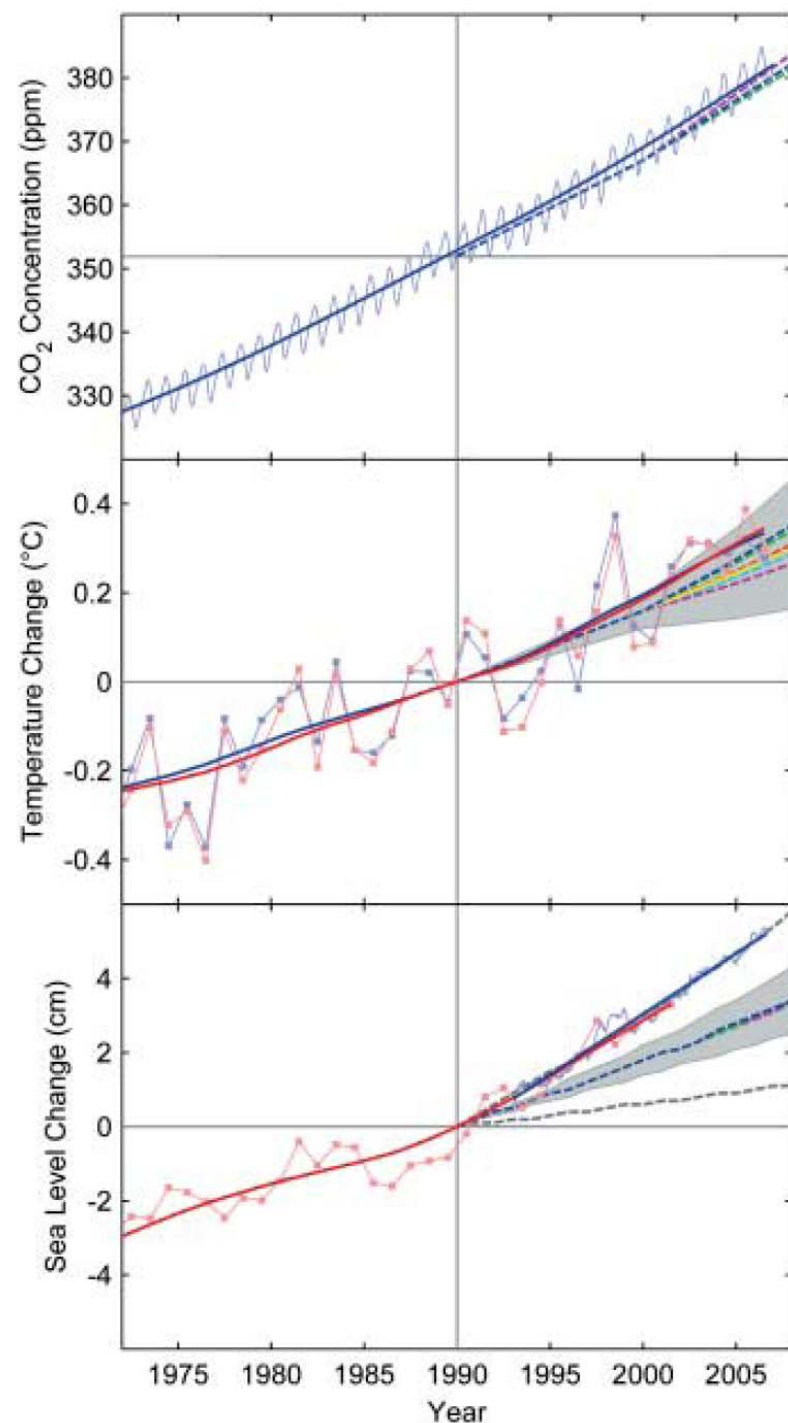


Fig. 1. Changes in key global climate parameters since 1973, compared with the scenarios of the IPCC (shown as dashed lines and gray ranges). **(Top)** Monthly carbon dioxide concentration and its trend line at Mauna Loa, Hawaii (blue), up to January 2007, from Scripps in collaboration with NOAA. ppm, parts per million. **(Middle)** Annual global-mean land and ocean combined surface temperature from GISS (red) and the Hadley Centre/ Climatic Research Unit (blue) up to 2006, with their trends. **(Bottom)** Sea-level data based primarily on tide gauges (annual, red) and from satellite altimeter (3-month data spacing, blue, up to mid-2006) and their trends. All trends are nonlinear trend lines and are computed with an embedding period of 11 years and a minimum roughness criterion at the end (6), except for the satellite altimeter where a linear trend was used because of the shortness of the series. For temperature and sea level, data are shown as deviations from the trend line value in 1990, the base year of the IPCC scenarios.



Sea Level Response to Temperature

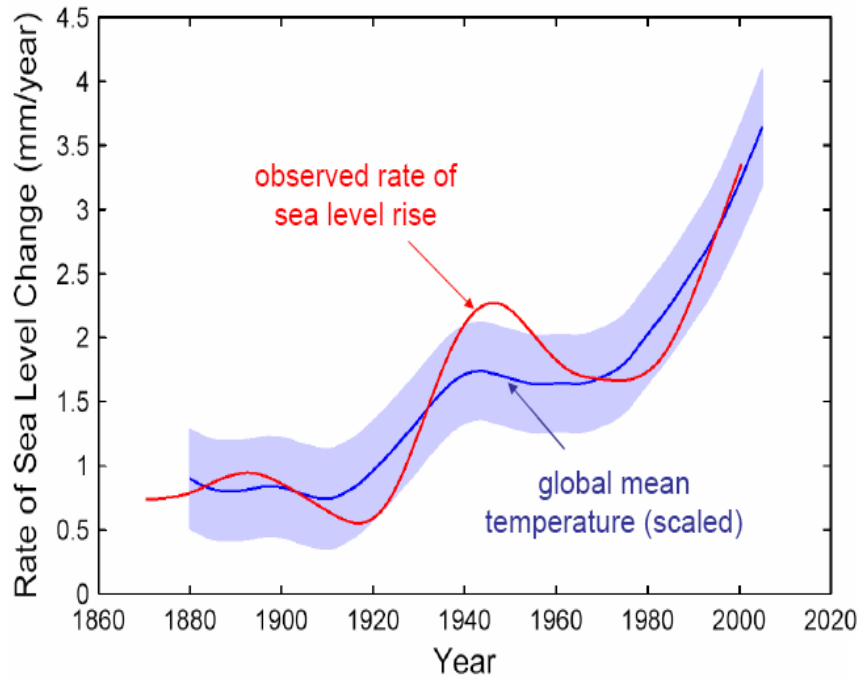


Fig. 3. (Top) Rate of sea-level rise obtained from tide gauge observations (red line, smoothed as described in the Fig. 2 legend) and computed from global mean temperature from Eq. 1 (dark blue line). The light blue band indicates the statistical error (one SD) of the simple linear prediction (15). **(Bottom)** Sea level relative to 1990 obtained from observations (red line, smoothed as described in the Fig. 2 legend) and computed from global mean temperature from Eq. 2 (blue line). The red squares mark the unsmoothed, annual sea-level data.

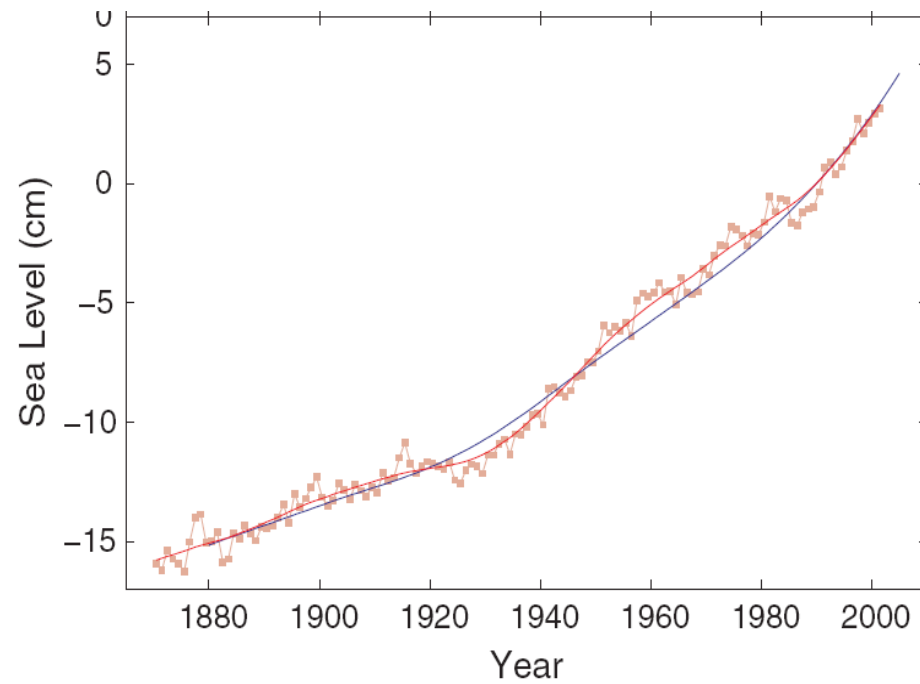
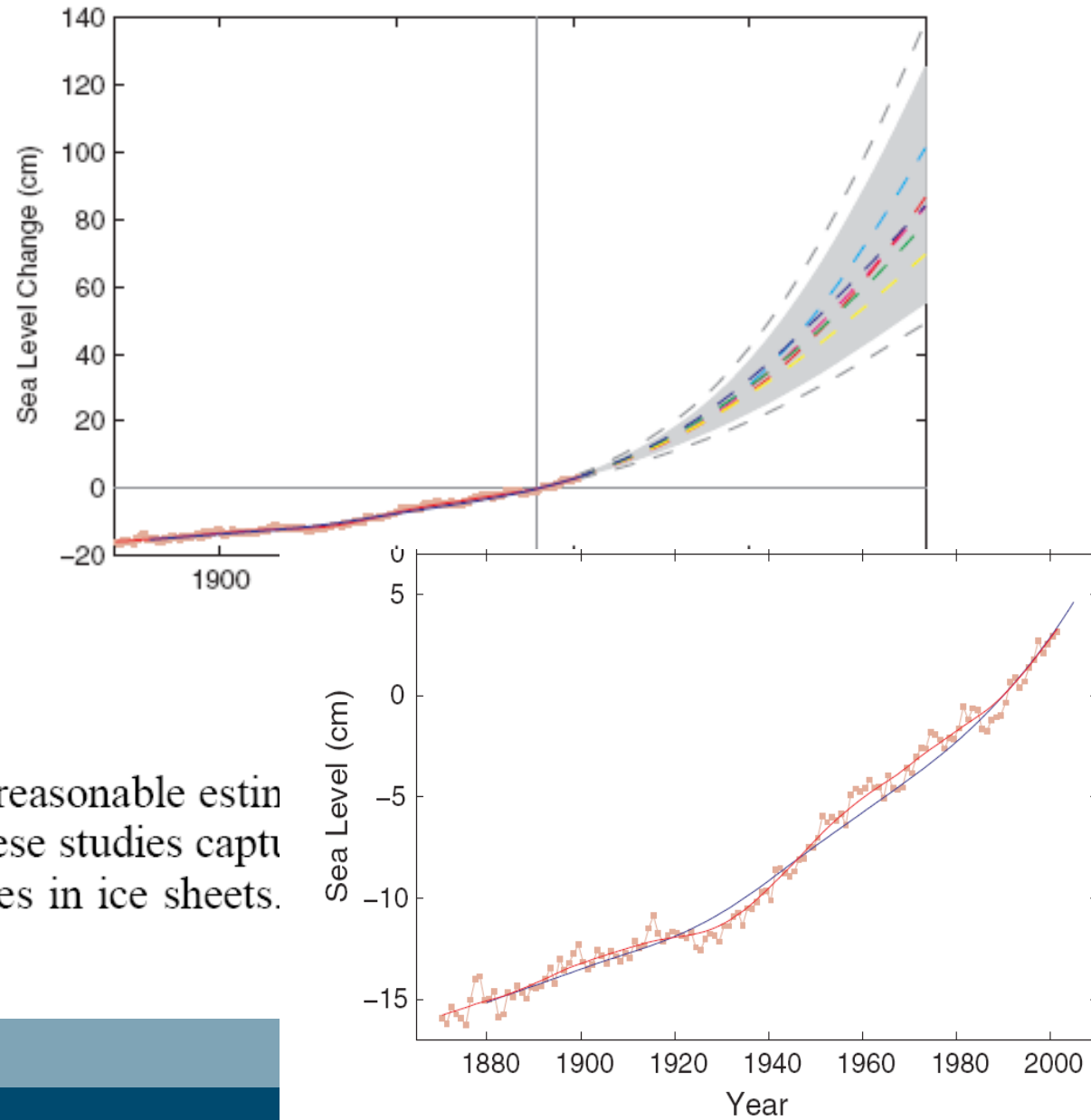




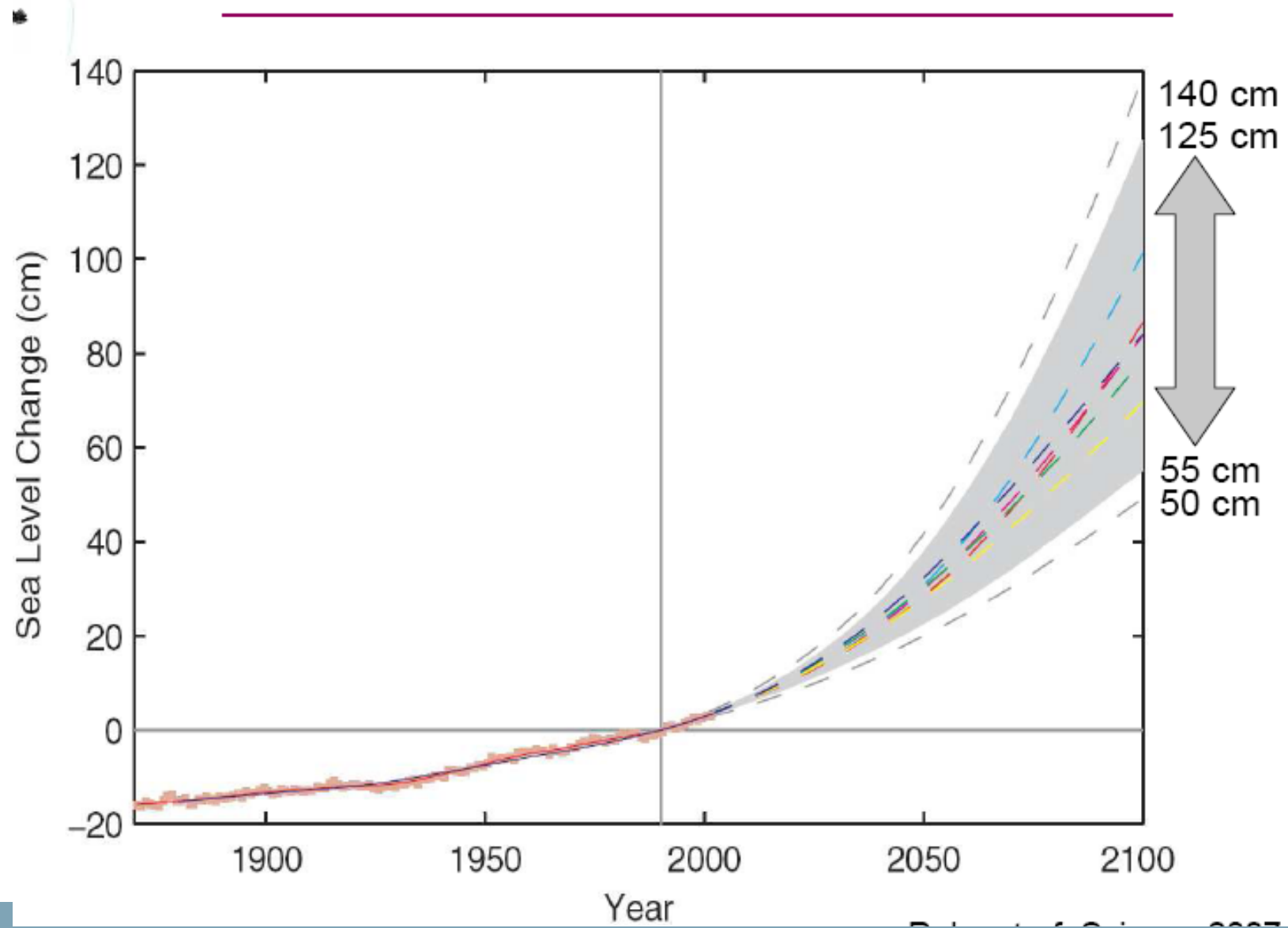
Fig. 4. Past sea level and sea-level projections from 1990 to 2100 based on global mean temperature projections of the IPCC TAR. The gray uncertainty range spans the range of temperature rise of 1.4° to 5.8° C, having been combined with the best statistical fit shown in Fig. 2. The dashed gray lines show the added uncertainty due to the statistical error of the fit of Fig. 2. Colored dashed lines are the individual scenarios as shown in (1); the light blue line is the A1FI scenario, and the yellow line is the B1 scenario.



Both the TAR and AR4 provide reasonable estimates of sea level. However, neither of these studies captures due to large and/or abrupt changes in ice sheets.



Sea Level Projections





Both the TAR and AR4 provide reasonable estimates of the central tendency for global-mean sea level. However, neither of these studies capture the physically plausible high-end changes due to large and/or abrupt changes in ice sheets.

Further concern about rapid changes is also found in the analogue of the last interglacial (about 110,000 to 127,000 years ago) when sea level, climate and ice masses were similar to today. Sea levels are estimated to have risen at around 2m/century with contributions coming from both the Greenland and Antarctic ice sheets (ROHLING *et al.*, 2008). However, this

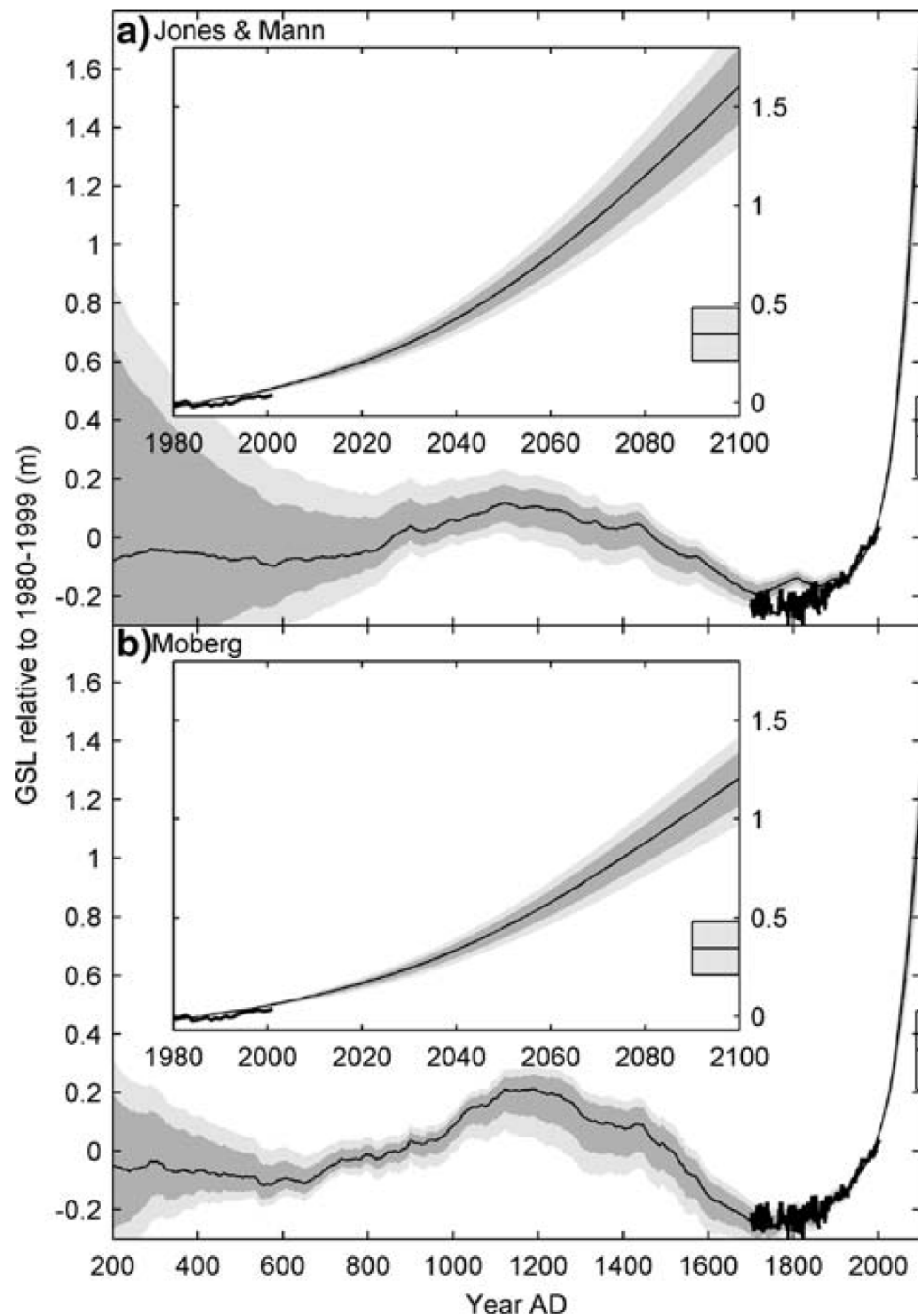
Table 2 Projected sea level rise 2090–2099

| | A1B | A1 |
|------------------------|-----------|-----|
| Moberg | 0.91–1.32 | 1.1 |
| Jones and Mann | 1.21–1.79 | 1.4 |
| Historical only | 0.32–1.34 | 0.3 |
| Imm./Inf. ^b | 0.8/0.8 | 1.2 |
| IPCC | 0.21–0.48 | 0.2 |

Range is 5–95 percentiles

Quelle: Grinstead, A. et al. (2008)

Reconstructing sea level from paleo and projected temperatures 200 - 2100

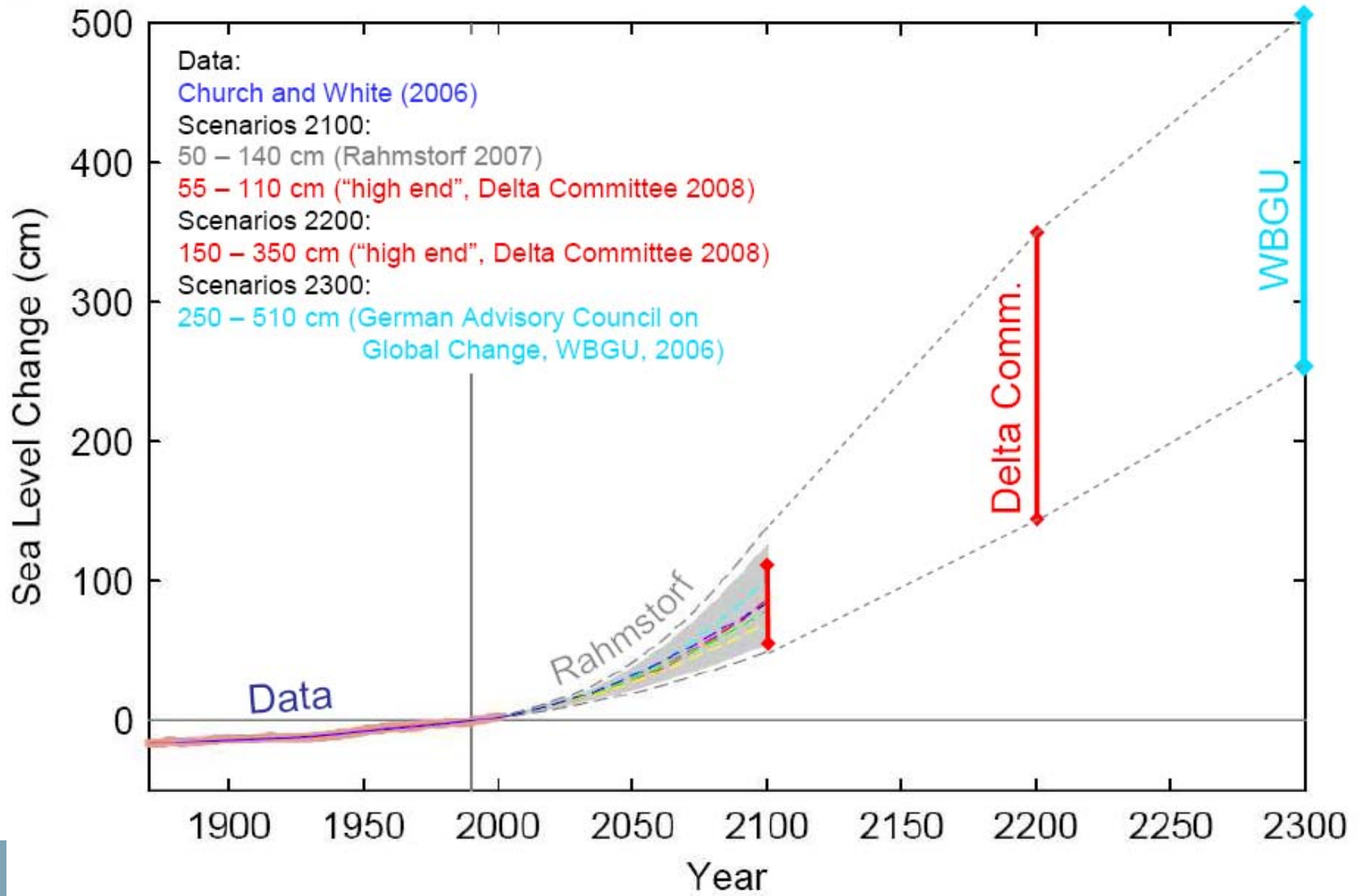




| Mechanismus | Anstieg in m |
|-----------------------|----------------|
| Thermische Ausdehnung | 0,4–0,9 |
| Gebirgsgletscher | 0,2–0,4 |
| Grönland | 0,9–1,8 |
| Westantarktis | 1–2 |
| <i>Summe</i> | <i>2,5–5,1</i> |

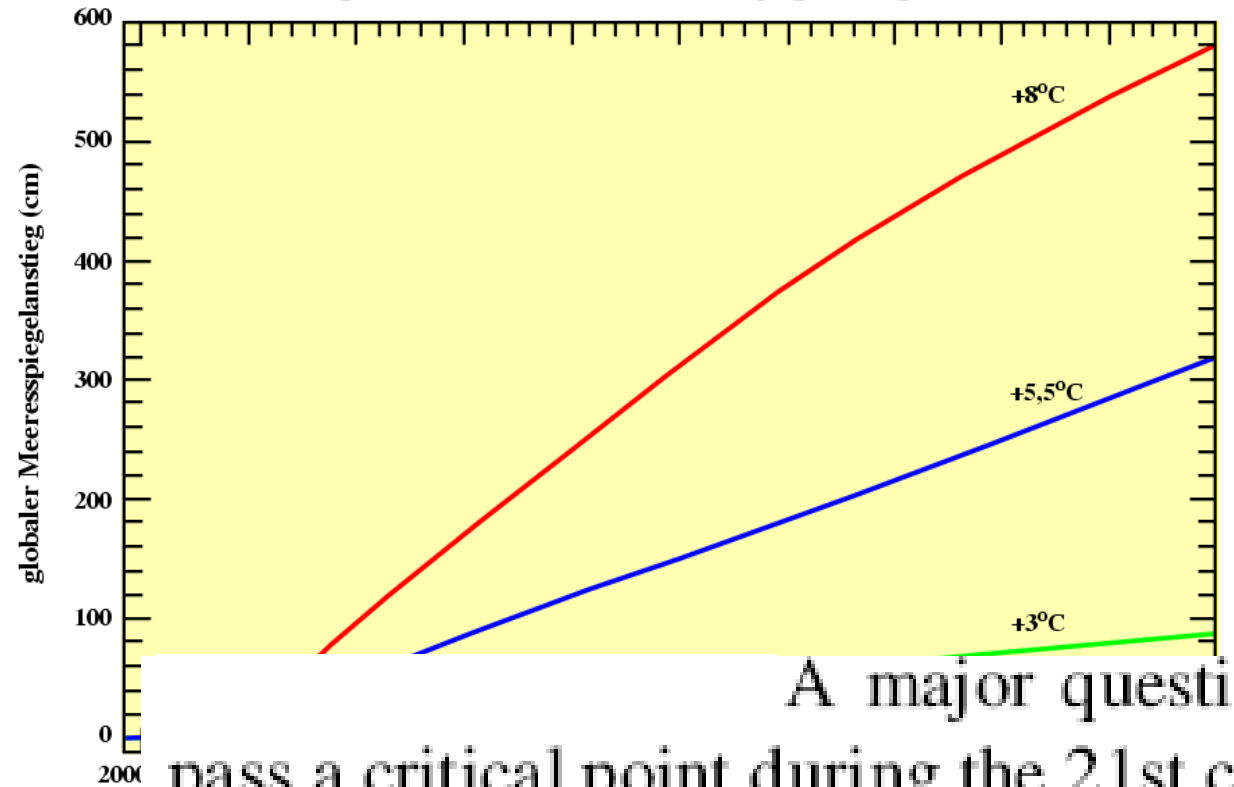
Tab. 3 Geschätzter globaler Meeresspiegelanstieg bis zum Jahr 2300 bei einer auf 3°C begrenzten globalen Erwärmung (Quelle: WBGU 2006)

Recent Sea Level Projections



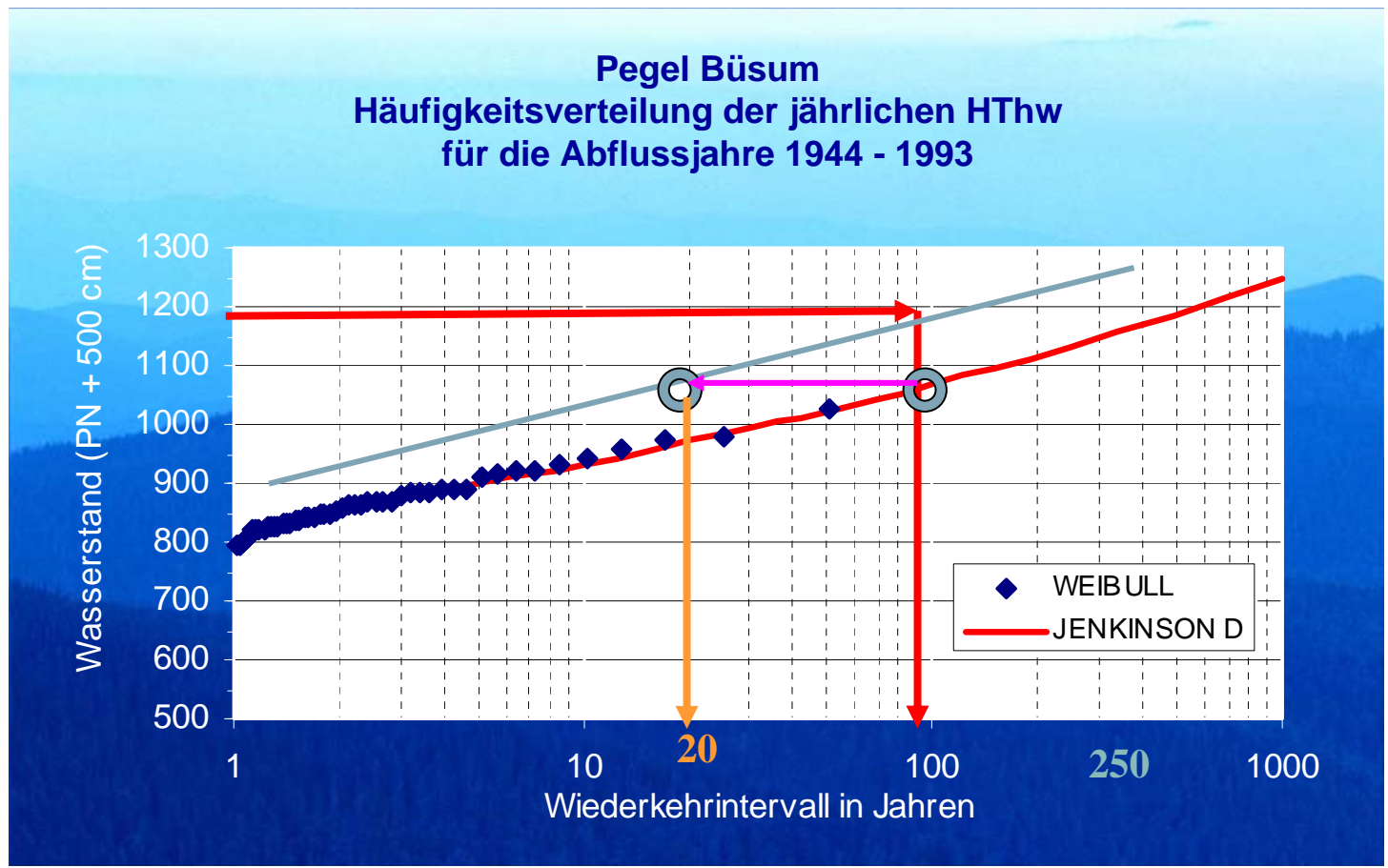


Beitrag des Grönland-Eises zum Meeresspiegelanstieg 1990 bis 3000



A major question is whether we will pass a critical point during the 21st century that will lead to an ongoing and, possibly irretrievable, melting of the Greenland or west Antarctic ice sheets and a sea-level rise of several metres. Our current understanding of ice-sheet dynamics is insufficient to predict whether any such large rise would occur in a few centuries or over many centuries to millennia.

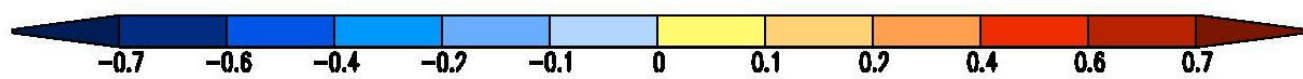
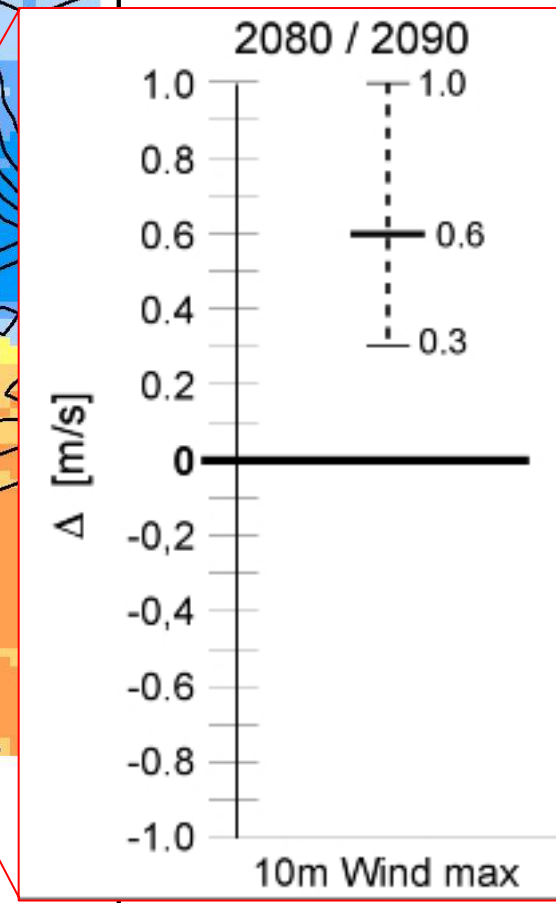
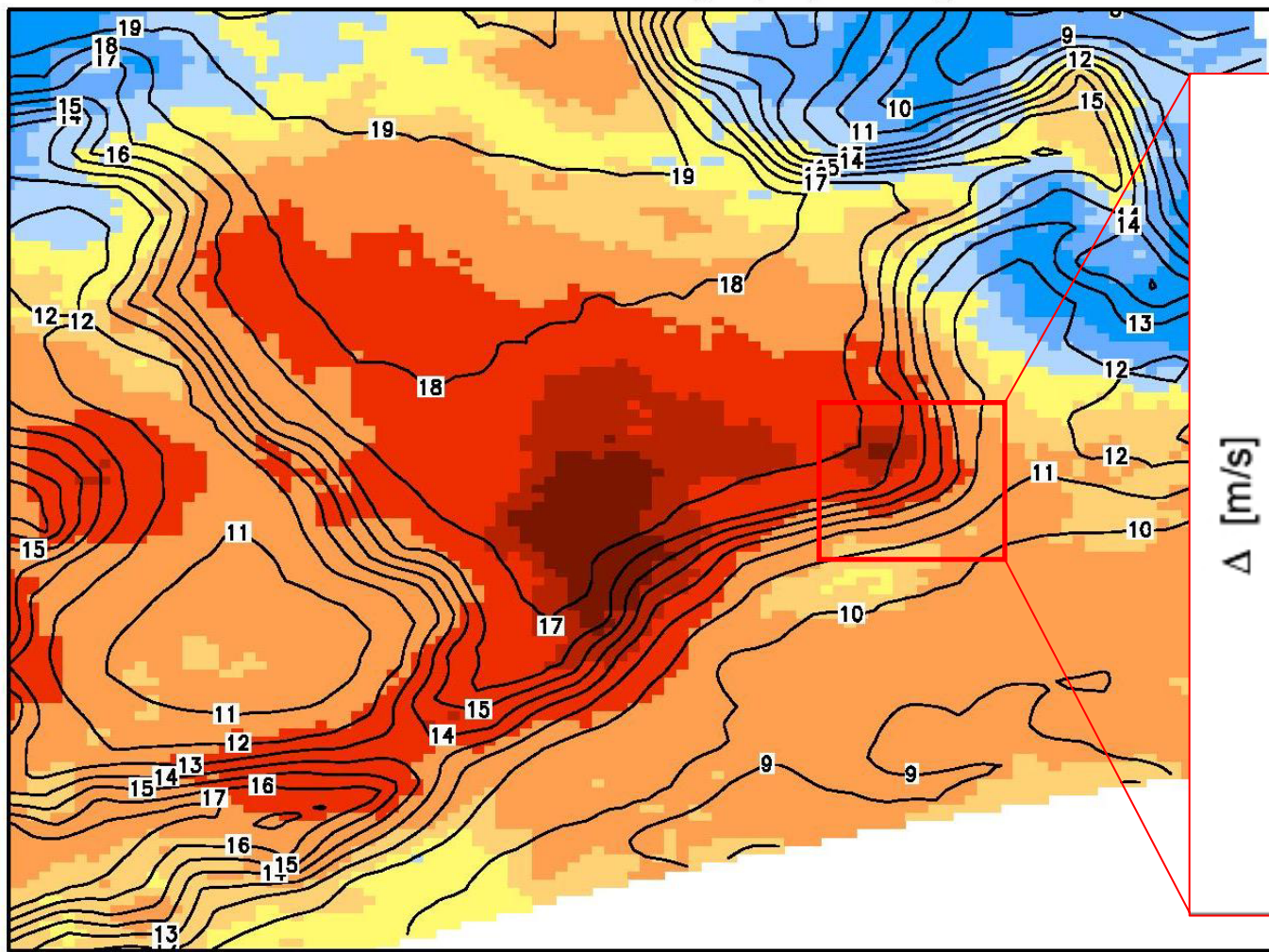
Einfluss des Meeresspiegelanstiegs auf die Häufigkeit von Sturmflutwasserständen: bei einer Anhebung des Pegelniveaus um 80 cm wird aus einer Jahrhundertflut eine „Zwanzigjahres-Flut“



Quelle: MLR, 2000



Mean 99.5%tile [m/s/Year]



Abnahme

Zunahme

Woth, 2005









Table 5. Range of global-mean sea-level rise scenarios only and global-mean sea-level rise plus maximum regional meteo-oceanographic effects, based on the $\pm 50\%$ method using the global TAR scenarios (CHURCH *et al.*, 2001).

| SRES Scenario | Range of global-mean sea-level rise only (cm) | | | Range also including maximum regional meteo-oceanographic effects (cm) | | |
|---------------|---|---------|----------|--|---------|----------|
| | 2020s | 2050s | 2080s | 2020s | 2050s | 2080s |
| B1 | 4 to 14 | 7 to 30 | 9 to 48 | 2 to 21 | 4 to 45 | 5 to 72 |
| B2 | 4 to 14 | 7 to 32 | 11 to 54 | 2 to 21 | 4 to 48 | 6 to 81 |
| A2 | 4 to 14 | 8 to 32 | 13 to 59 | 2 to 21 | 4 to 48 | 7 to 89 |
| A1FI | 4 to 14 | 9 to 36 | 16 to 69 | 2 to 21 | 5 to 54 | 8 to 104 |

Die oben genannte Spanne von 18-59 cm enthält kaum einen Beitrag der Kontinentaleismassen, da der IPCC-Bericht davon ausgeht, dass ein Eiszuwachs in der Antarktis den Eisverlust in Grönland weitgehend ausgleichen wird. Tatsächlich deuten aber Messungen mit dem GRACE-Satelliten darauf hin, dass auch die Antarktis insgesamt in den letzten Jahren an Eis verloren hat – dies sind aber noch vorläufige Daten, da dieser Satellit erst seit wenigen Jahren im Einsatz ist.

