Adapting Infrastructure and Civil Engineering Practice to a Changing Climate

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Acknowledgements

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Infrastructure

Infrastructure includes:

- Buildings of all types
- Communications facilities
- Energy Generation and Distribution
- Industrial facilities
- Transportation of all modes
- Waste Management
- Water Resources

Relevant ASCE Policies

See http://www.asce.org/public_policy_statements/

- PS 360 Impact of Climate Change: ASCE supports government policies that encourage anticipation of and preparation for possible impacts of climate change on the built environment.
- PS 389 Mitigating the Impact of Natural and Man-Made Hazards: ASCE supports sustained efforts to improve professional practices in planning, design, construction, operation, maintenance and reuse/decommissioning that mitigate the effects of natural and man-made hazards.
- PS 488 Greenhouse Gases: ASCE supports the following public and private sector strategies and efforts to achieve significant reductions in greenhouse gas emissions from existing and future infrastructure systems - - -

Relevant ASCE Policies

- PS 418 The Role of the Civil Engineer in Sustainable Development: ASCE defines sustainability as a set of economic, environmental and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural, economic and social resources. The civil engineering profession recognizes the reality of limited natural resources, the desire for sustainable practices (including life-cycle analysis and sustainable design techniques), and the need for social equity in the consumption of resources.

The Challenge

Climate science observations and models strongly indicate that our engineered facilities and systems should adapt to changing climate, weather and extreme events…….but climate science does not yet provide an adequate basis for the needed practices.

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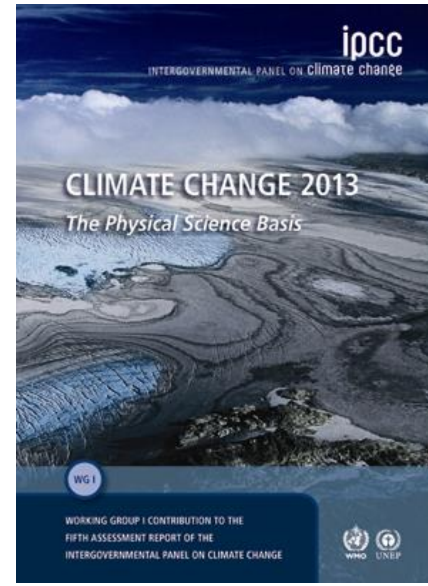
Weather, Climate and Climate Change

- **Weather:** state of the atmosphere with respect to temperature, cloudiness, wind, moisture, pressure, etc.[a]
- **Climate**: average weather over a period of time ranging from months to thousands or millions of years, with 30 years often used as the classical period.[b]

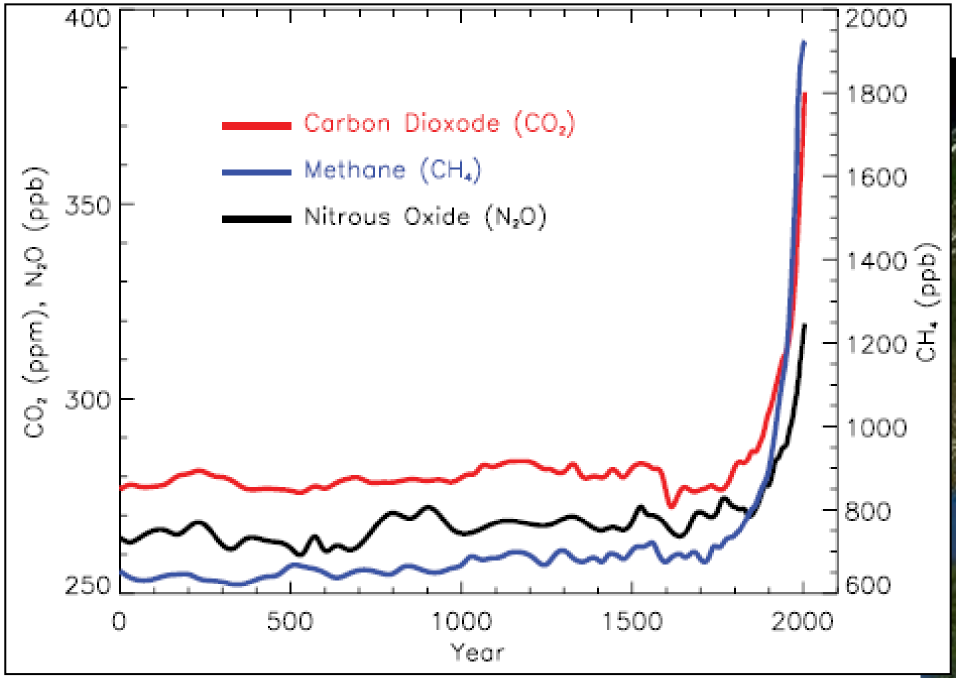


- **Climate change**: change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.[b]

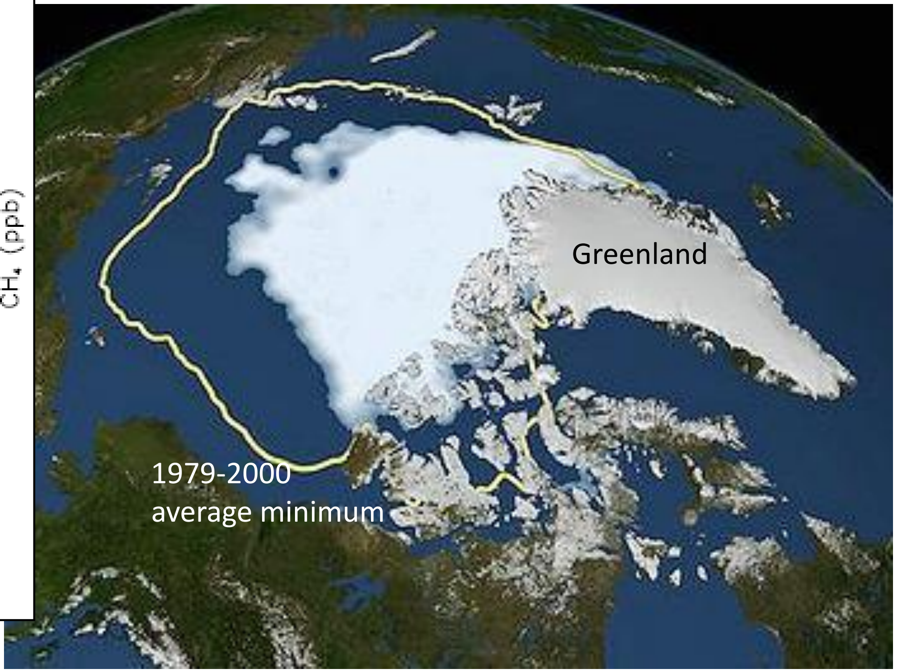
a. NSIDC. (2012). Arctic Climatology and Meteorology Glossary; b. . IPCC, WGI Fifth Assessment Report, Final Draft Underlying Scientific-Technical Assessment, Annex III, Final Draft, 7 June 2013.

Our Changing Climate

Past, Present, Future



a. Greenhouse gas concentrations higher than measured or reconstructed from proxy data in 2000 years



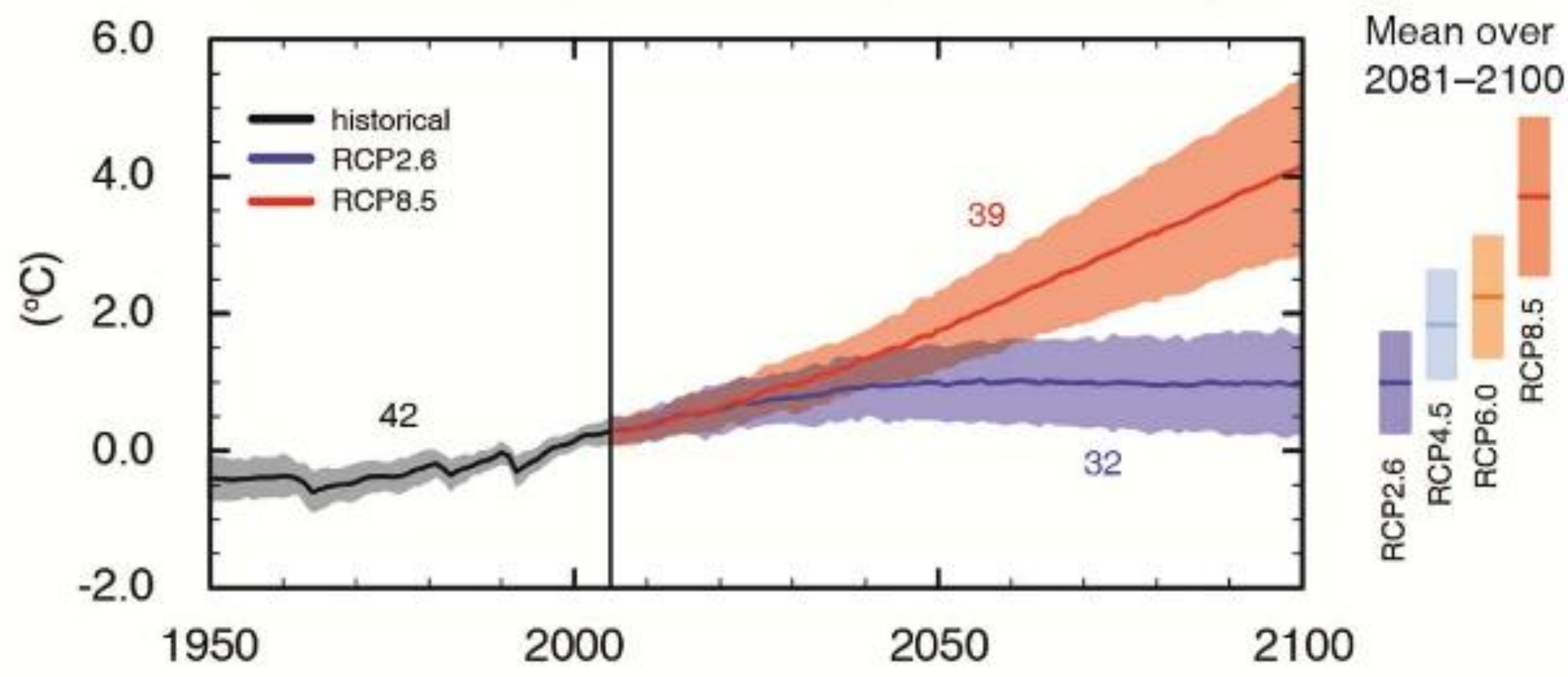
b. Minimum arctic sea ice extent in 2012 compared with the annual minimum averaged over 1979-2000

Future CO_2 emissions may increase significantly – even double – by 2100, leading to a likely global average temperature increase between 0.3 to 4.8^{o} C that will translate into sea level rise, storm intensification, sea ice melting, etc.

Source: a. IPCC (2007), Chapter 2, Figure FAQ 2.1 Figure 1. b. Image courtesy NASA/Goddard Scientific Visualization Studio.

Global Average Temperature Change:

Historical and Projected



Source: Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis Summary for Policymakers, http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf accessed 11/10/13.

Uncertainties in GCM Projections

- Sources
  - Natural variability of climate
  - Uncertainties in model parameters, structure, feedback
  - Uncertain future emissions
- Downscaling
  - Engineers' interests are at local and regional scales, much smaller than GCM grid cells
  - Statistical downscaling applies historical proportioning
  - Dynamical downscaling can include topographic, land use and vegetation features with Regional Climate Models (RCM)

Status of Climate Science

A National Strategy for Advancing Climate Modeling, NRC 2012

The Nation should:

- Nurture a unified weather-climate modeling effort that better exploits the synergies between weather forecasting, data assimilation, and climate modeling
- Continue to contribute to a strong international climate observing system capable of comprehensively characterizing long-term climate trends and climate variability

  (Note that both the modeling and observations would be extended to extreme events, which to date generally have not been modeled or measured directly.)

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Extreme Weather and Climate Events:
Definitions

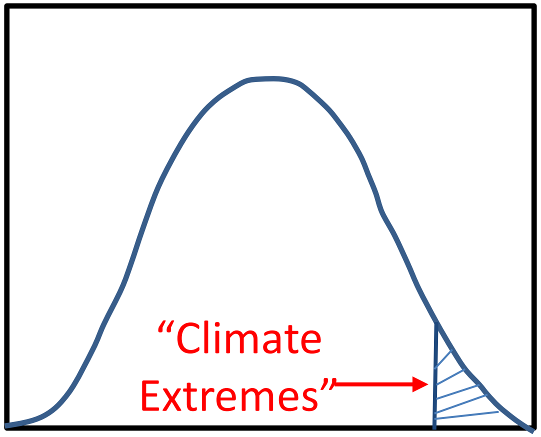
- An **Extreme Weather Event** "is an event that is rare at a particular place and time of year… *as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations*. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense.
- When a pattern of extreme weather persists for some time, such as a season, it may be classed as an **extreme climate event**, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)."

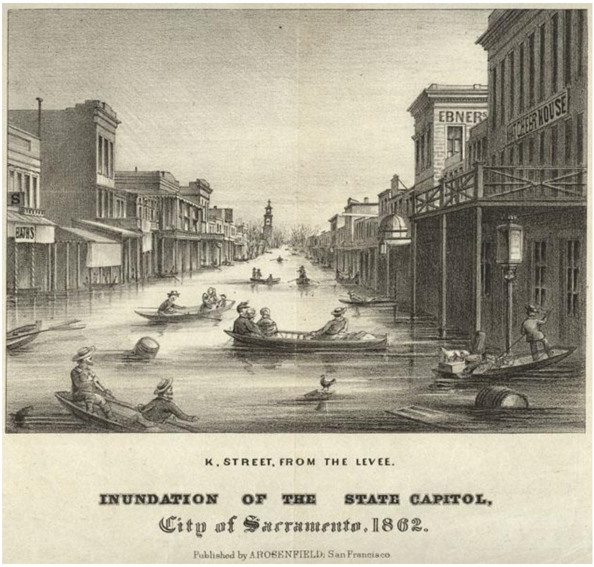
a. IPCC, WGI Fifth Assessment Report, Final Draft Underlying Scientific-Technical Assessment, Annex III, Final Draft, 7 June 2013,

Engineering Design & Extreme Events

- Engineering Design for Extremes
  - Usually concerned with more extreme "extremes"
  - Generate new distributions based on the "tail" of the observed distribution ~ extrapolations made beyond observed data (dotted line)
- Commonalities:
  - Typically probability and/or threshold based
  - Most commonly described by "return period"

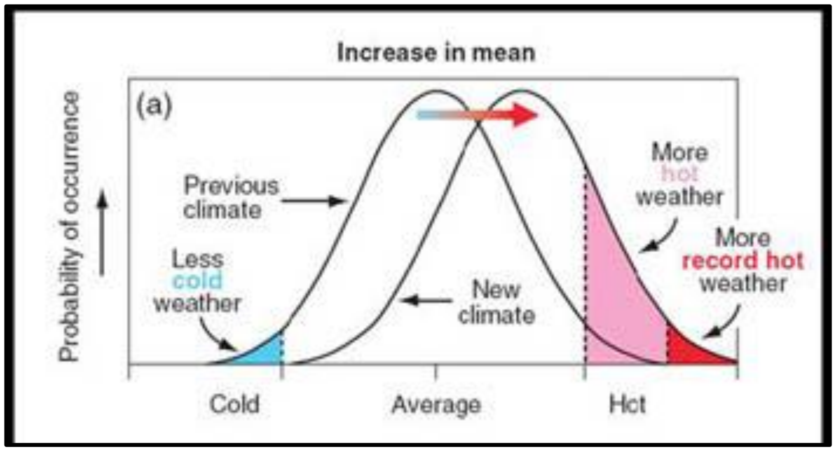
Observed Probability Distribution

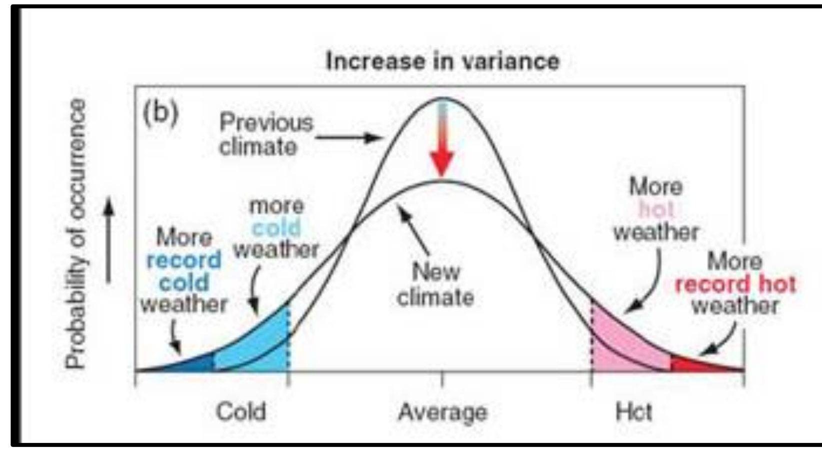


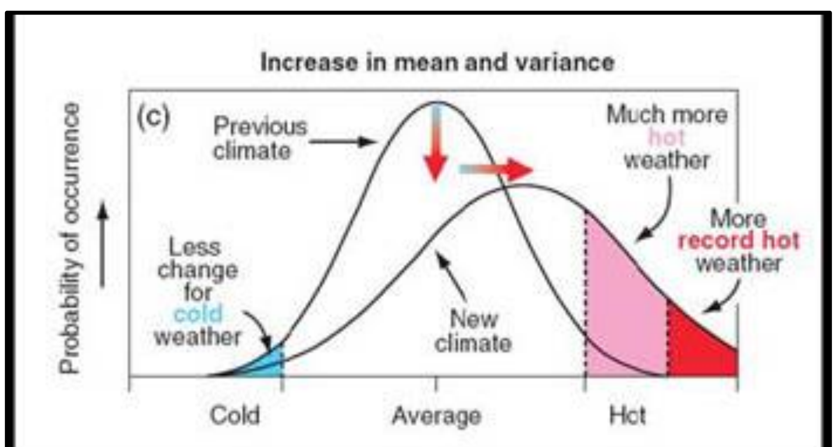


USGS

Climate Change and the Likelihood of Extreme Events

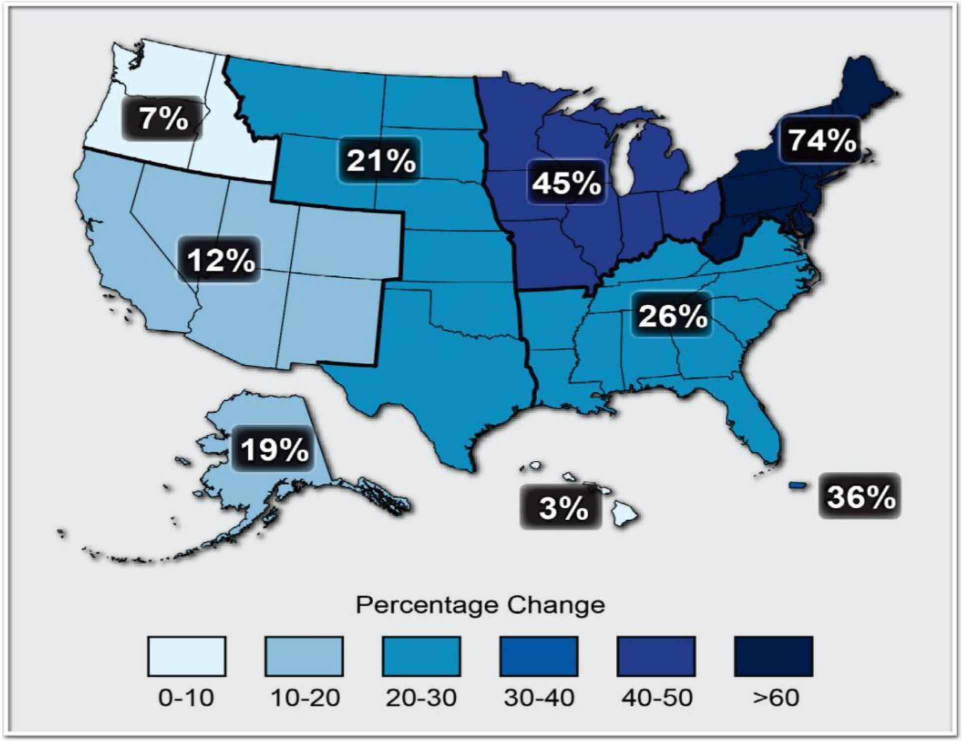






Observed Climate Change Extremes

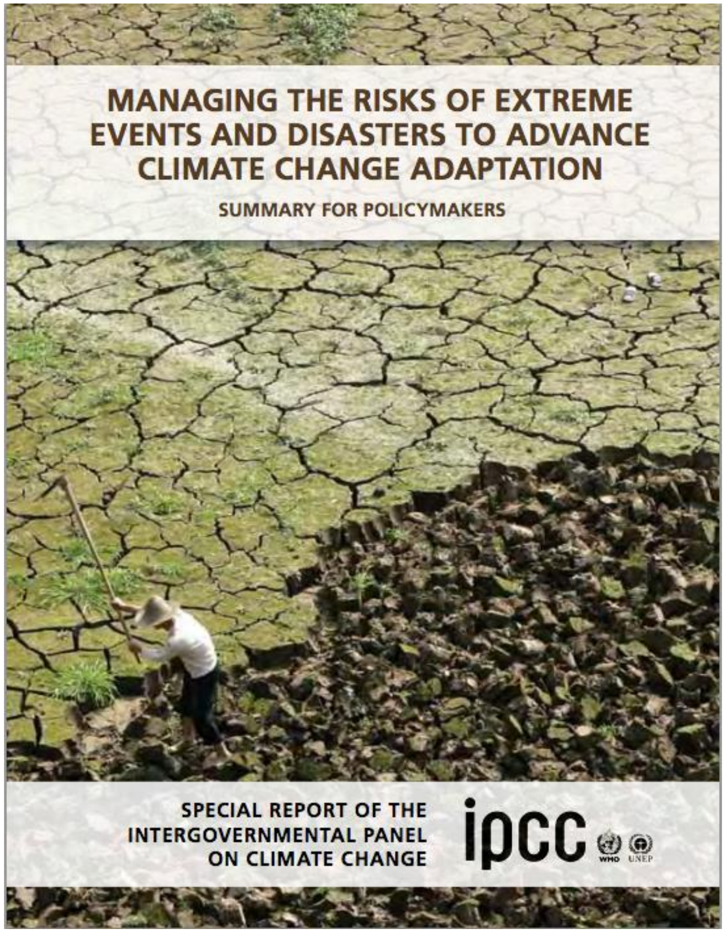
Percent Change in Very Heavy Precipitation*
(1958 to 2011)



* defined as the heaviest 1% of all daily events

Source National Climate Assessment May 2014, http://nca2014.globalchange.gov

IPCC Projections of Extreme Events



Special Report on Managing the **R**isks of **Ex**treme Events and Disasters to Advance Climate Change Adaptation (SREX), IPCC, 2012.

Download from http://ipcc-wg2.gov/SREX/at www.ipcc.ch

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Impacts on Buildings and Other Structures

Climate Change Effects	Impacts on Function	Impacts on Integrity
Increased temperatures and more severe heat waves	**Lower heating and greater cooling requirements.** **Health, safety and productivity of occupants.**	**Sizing of HVAC systems. Durability of building materials.**
Increases of heavy precipitation and flooding	Interruptions due to flooding of sites, basements and lower stories.	Failures from excessive water, ice and snow loads on roofs and other exposed structures. Erosion and scouring of foundations. Water and mold damage to flooded equipment and materials

FEMA

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Impacts on Buildings and Other Structures

Climate Change Effects	Impacts on Function	Impacts on Integrity
Sea Level Rise, Hurricanes and Storm Surge	Permanent flooding of low-lying areas. Losses in property values. Evacuations for storms.	Damages from high winds, forces of moving water and wind. Equipment, contents and materials damages from water and mold.
Droughts and Wildfires	Water use limitations. Losses of agriculture and landscaping. Evacuations of fire-threatened areas.	Foundation instabilities from desiccation. Fire damages to buildings, contents and sites.

NWS

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Engineering Practice

- Involves the **whole life cycle** of the product or system: planning, design, construction or manufacture, operation, maintenance, and renovation or removal
- Seeks to provide a high probability of safe and sustainable performance
- Requires accounting for climate/weather/extreme events over the whole service life

Sustainable denotes economically, environmentally and socially desirable long-term performance.

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Stationarity

- Most of our engineering standards and regulations for extreme events use "stationarity" as their basis for risk assessment
- Stationarity implies that the statistics for past occurances define the statistics for the future
- Climate change means that history is an unreliable measure of future risk. **"Stationarity is dead"**

Remember that mean recurrence interval is the inverse of the annual probability of exceedance. Design for a 100 year flood does not mean you are safe for 100 years. It means that you have a 1% chance every year of one or more **greater** floods.

Note:
$P(T>100)=0.368$

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So What If Stationarity is Dead?

While it is important to learn from the past, such as learning from failures, the environment for engineered products and systems never has been stationary:

- Societal demands and expectations change
- Conditions of service change – including climate, weather and extreme events

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Dilemma for Engineering Planning and Design

- Planning and design of new infrastructure should account for the climate of the future
- Designs and plans as well as institutions, regulations, and standards will need to be updated and made adaptable to accommodate a range of future climate conditions
- There is great uncertainty about potential future climate/weather/extremes

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Low Regret, Adaptive Strategies

- Explore performance of alternative solutions in various scenarios
- Use a "low regret" alternative (or alternatives) that performs well (satisfactorily) across the scenarios
- The white paper ASCE (2015) includes a case study using the low regret strategy for Lake Superior Water Level Regulation

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Observational Method: Applications in Sustainable/Resilient Engineering

- A geotechnical engineering technique developed by Karl Terzaghi and Ralph Peck
- Integrated, "learn-as-you-go" process to enable previously defined changes to be made during and after construction
- Based on new knowledge derived during/after construction

Karl Terzaghi

Ralph Peck

Source: Creative Commons

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Imagery supplied by Clipart.com

Eurocode EC7 (EN1997-2004)

Geotechnical design - Part 1: General rules

2.7 Observational method

(1) When prediction of geotechnical behaviour is difficult, it can be appropriate to apply the approach known as "the observational method", in which the design is reviewed during construction.

(2) The following requirements shall be met before construction is started:

- acceptable limits of behaviour shall be established;
- the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
- a plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;
- the response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;
- a plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.

(3) During construction, the monitoring shall be carried out as planned.

(4) The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put into operation if the limits of behaviour are exceeded.

(5) Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity.

Observational Method Applied to Sustainable/Resilient Infrastructure Projects

Steps

- Design to the most probable environmental conditions
  - Incorporate considerations of robustness, adaptability, resiliency and redundancy
- Identify worst-case changes in environmental conditions
  - Identify effects on the system
  - Identify system alterations needed to cope with changes

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Observational Method Applied to Sustainable/Resilient Infrastructure Projects

Steps

- Develop a monitoring plan to detect changes in environmental conditions and system performance
- Establish an action plan for putting in place system alterations
  - Set decision points for implementing system alterations
- Monitor environmental conditions and system performance
- Implement action plan as necessary

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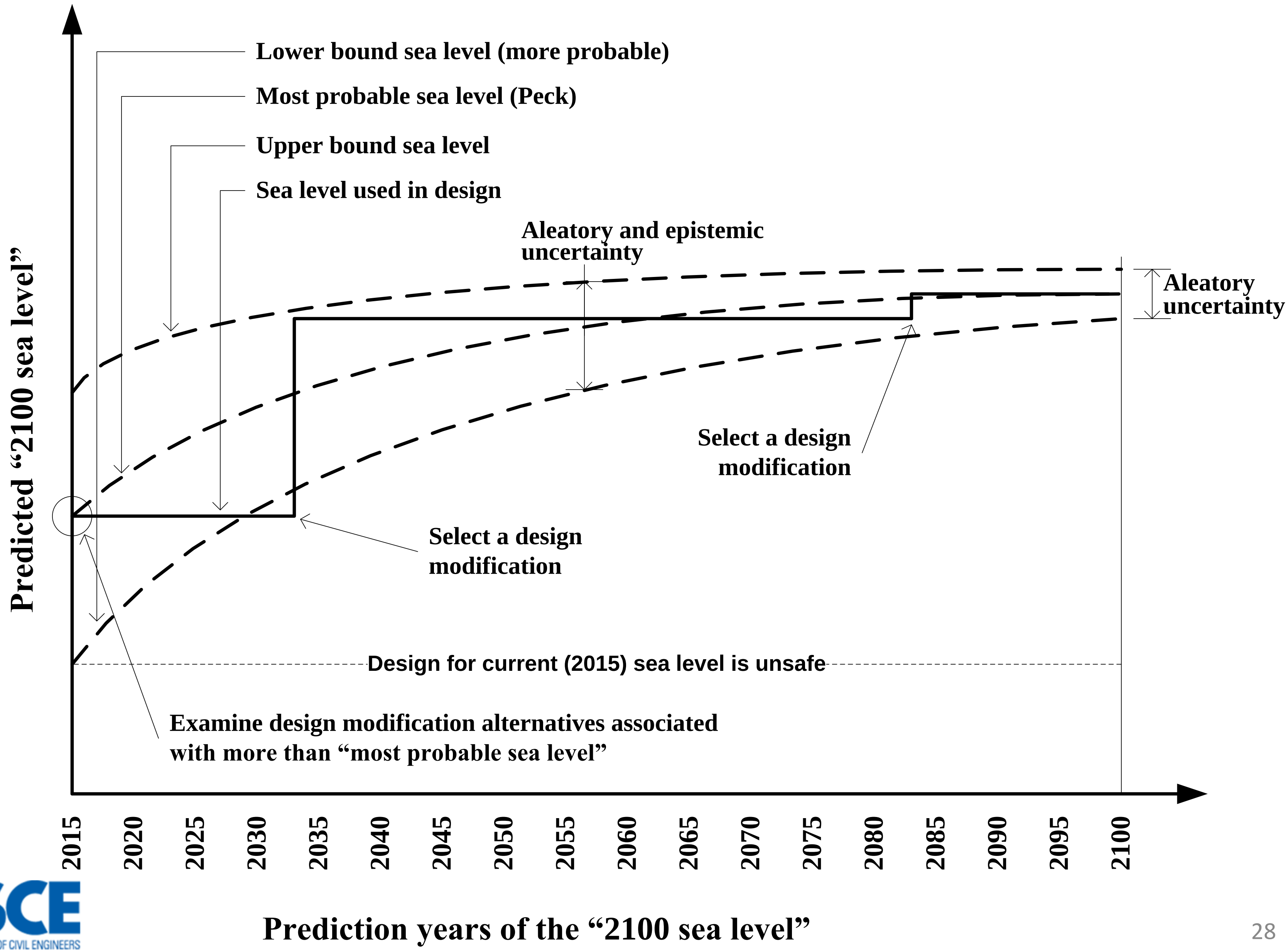
Case A. Adaptation in 2015 with increasing sea level and decreasing uncertainty

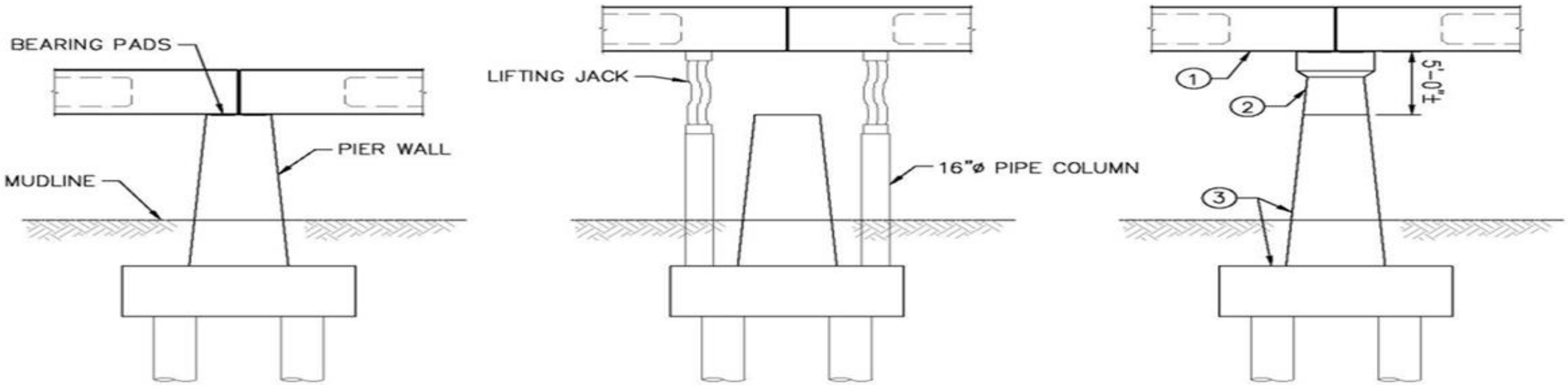


LOSSAN Example of the Observational Method

LOSSAN (Los Angeles to San Diego) Rail Corridor follows the sea coast and crosses low-lying areas on trestles.

LOSSAN Example of Observational Method

Used Moffat and Nichol concept of precast piers and caps to allow insertion of additional pier segments if needed to adapt to flooding hazard.



Richard Dial, Bruce Smith and Gheorghe Rosca, Jr., "Evaluating Sustainability and Resilience in Infrastructure: Envision™, SANDAG and the LOSSAN Rail Corridor"
Proceedings of the 2014 International Conference on Sustainable Infrastructure, American Society of Civil Engineers, pp 164-174.
ISBN 978-0-7844-4

ENVISION

Sustainability Rating System for Infrastructure Projects

- Institute for Sustainable Infrastructure – joint venture of ACEC, APWA and ASCE: www.sustainableinfrastructure.org
- Rates Sustainability in 5 Categories
  - Quality of Life
  - Leadership
  - Resource Allocation
  - Natural World
  - Climate and Risk
- Accredits Engineers in Use of Envision

Summary

Climate is changing but there is significant uncertainty regarding the magnitude of the change over the design life of the systems and elements of our built environment. It will be difficult to reliably estimate the change that will occur over several decades, long after the infrastructure is built and the financing and governance have been established.

Engineering designs, plans, and institutions and regulations will need to be adaptable for a range of future conditions (conditions of climate, weather and extreme events, as well as changing demands for infrastructure).

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Recommendations for Engineering Research and Practice

1. Engineers should engage in cooperative research, involving climate, weather, life and social scientists, to gain an adequate, probabilistic understanding of the magnitudes and consequences of future extremes.
2. Practicing engineers, project stakeholders, policy makers and decision makers should be informed about the uncertainties in projecting future climate/weather/extremes.
3. Engineers should use low-regret, adaptive strategies, such as the Observational Method to make projects resilient to future climate and weather extremes.
4. Critical infrastructure that is most threatened by changing climate should be identified and decision makers and the public be informed of these assessments.

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