Adaptive Risk Management for Future Climate/Weather Extremes

NIBS Building Innovation 2018

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Acknowledgements

This presentation is based on the white paper “Adapting Infrastructure and Civil Engineering Practice to a Changing Climate” prepared by the Committee on Adaptation to a Changing Climate (CACC) of the American Society of Civil Engineers. It is available for free download at

http://dx.doi.org/10.1061/9780784479193

J.Rolf Olsen, Ph.D., A.M. ASCE, is lead coordinating author

Ted S. Vinson, Ph.D., F.ASCE, is chair of the CACC and identified the applicability of the Observational Method.

Infrastructure

Infrastructure includes:

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

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The Challenge

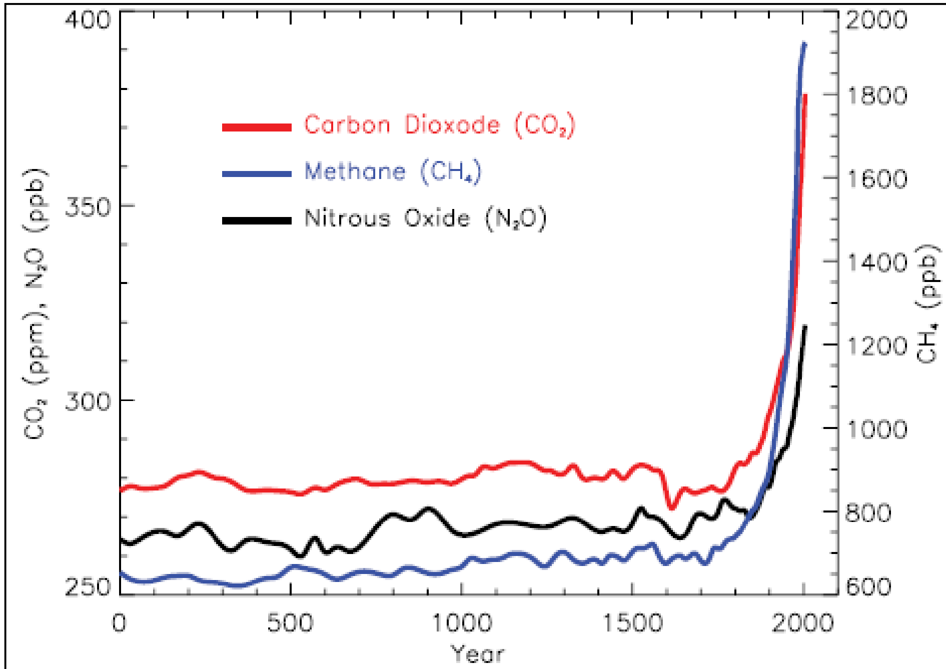
Climate science observations and models strongly indicate that our engineered facilities and systems should adapt to changing climate, weather and extreme events…….but climate science does not yet provide an adequate basis for the needed practices.

Climate, Weather & Extremes

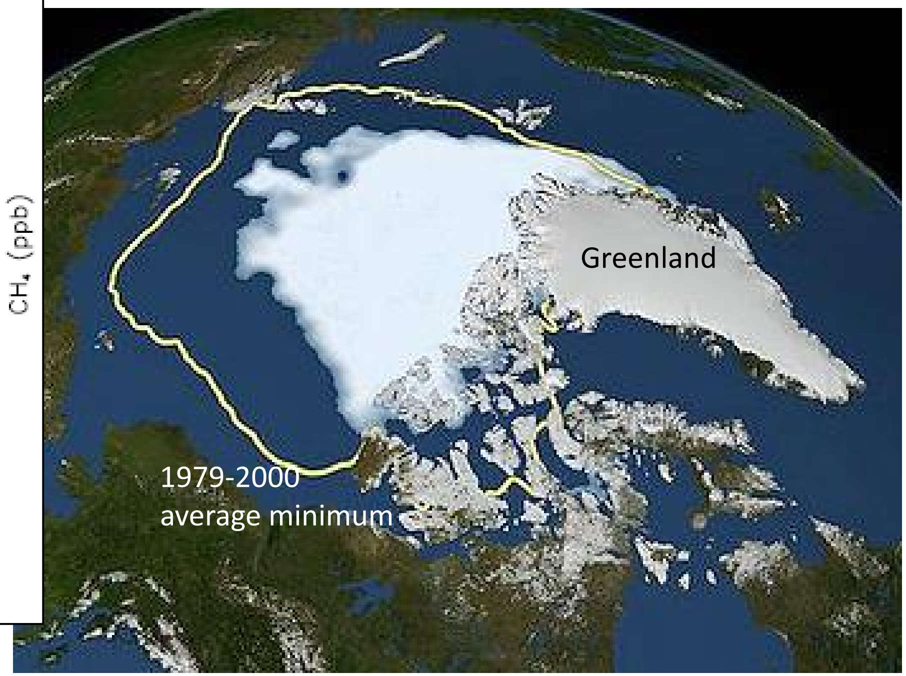
Term	Example
Climate	Average high temperature for date/place
Weather	Today’s high temperature
Extreme	Record high temperature

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

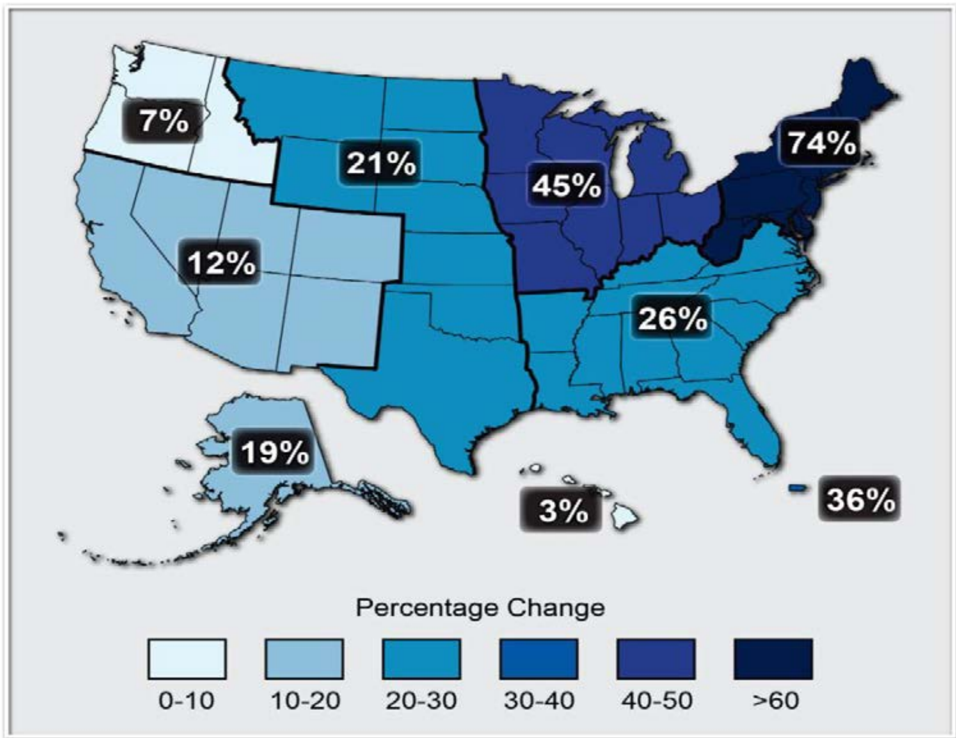
Future CO_2 emissions may increase significantly – even double – by 2100, leading to a likely global average temperature increase between 0.3 to 4.8° C that will translate into sea level rise, storm intensification, sea ice melting, etc.

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

Observed Climate Change Extremes

Percent Change in Very Heavy Precipitation*

(1958 to 2011)



* defined as the heaviest 1% of all daily events

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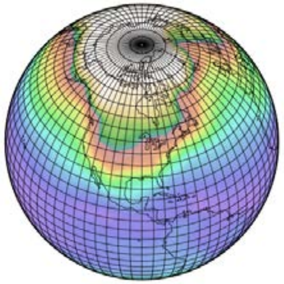
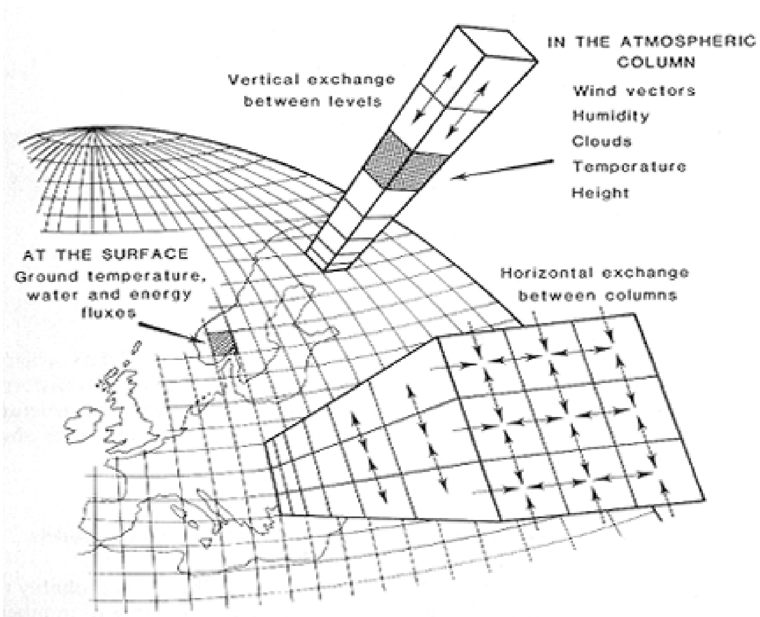
Source National Climate Assessment May 2014, http://nca2014.globalchange.gov

Global Climate Models (GCMs)

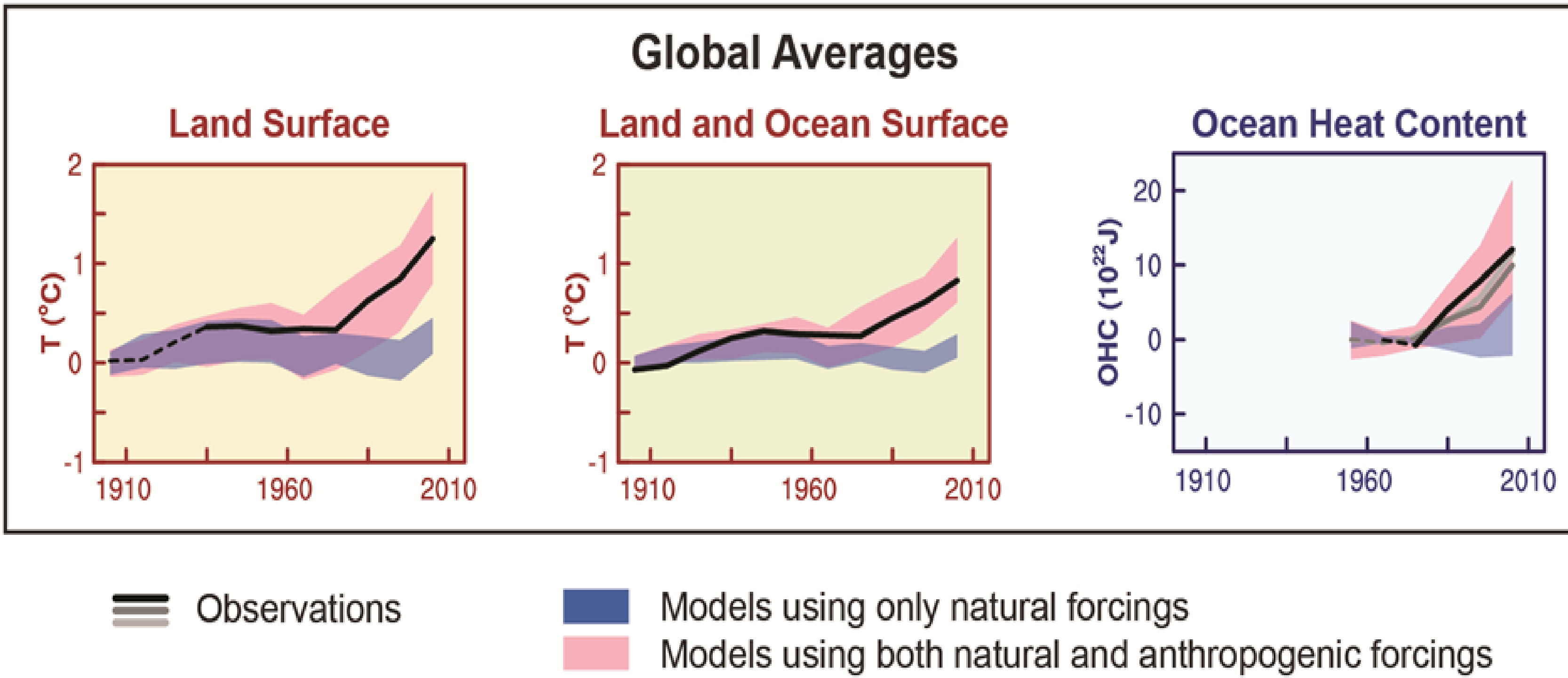
- Model atmosphere, oceans, land surface, sea ice
- Represent the ocean as 0.2° to 2° grid cells
- Represent the atmosphere as 0.5° to 4° grid cells





- Use fundamental physical equations:
  - Conservation of momentum
    $\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \cdot \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d$
  - Conservation of energy
    $\rho c_{\vec{v}} \frac{\partial T}{\partial t} = -\rho c_{\vec{v}} (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S$
  - Conservation of mass
    $\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla)\rho - \rho(\nabla \cdot \vec{V})$
  - Conservation of H_2O (vapor, liquid, solid)
    $\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E$
  - Equation of state
    $p = \rho R_d T$
- Solve: temperature, pressure, humid-ity, winds, cloud condensate, etc.

GCM Validation:
Role of Anthropogenic Inputs



Source: IPCC 2013 WG1 SPM Fig. 6

Future Emissions Scenarios

- Anthropogenic forcings: future concentrations of green-house gases (GHGs), aerosols, other pollutants, land use
- Intergovernmental Panel on Climate Change (IPCC) presents a wide range of these factors based on future demographic, technology and policy scenarios
- See the IPCC 5th Assessment Report at www.ipcc.ch

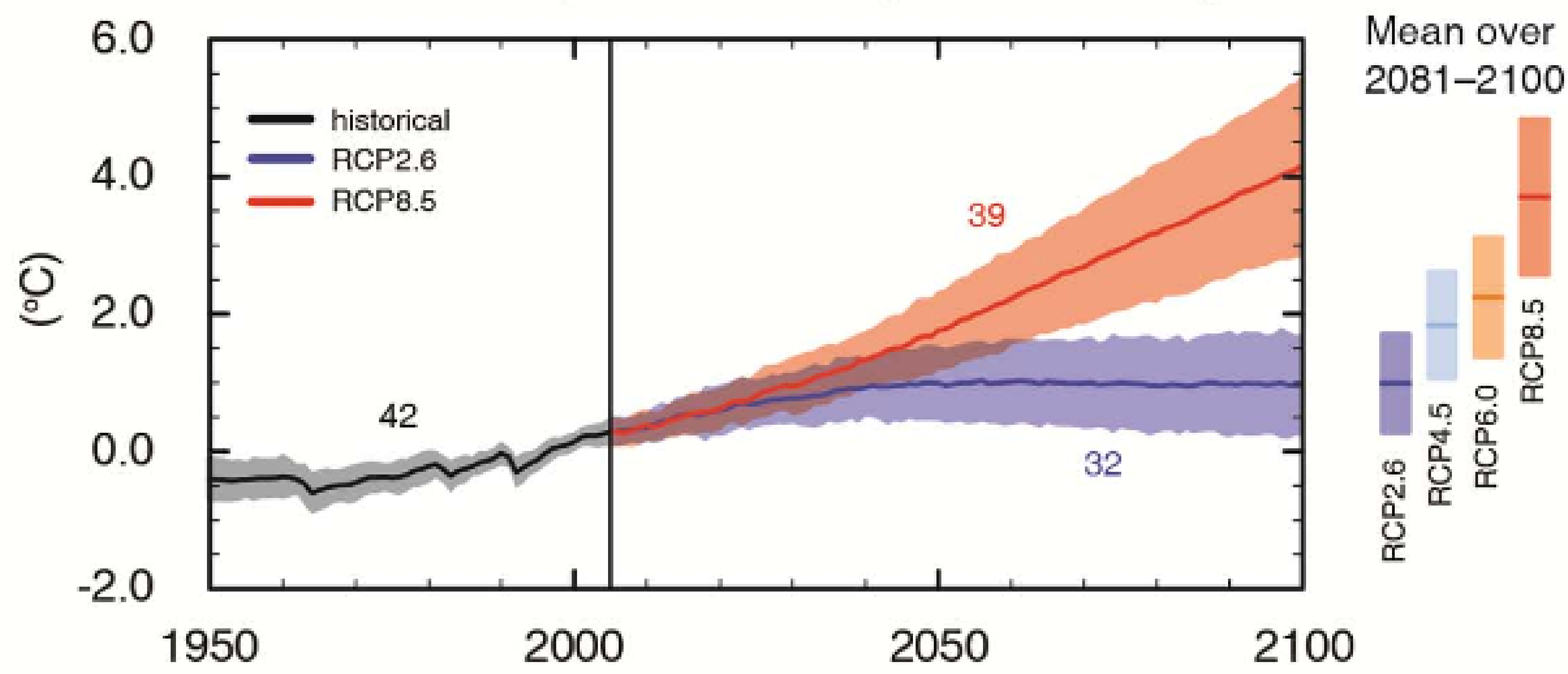
Representative Concentration Pathways

Scenario Name	Radiative Forcing	CO_{2e} (ppm)	Mean Temp Anomaly (°C)	Pathway	SRES Temp Anomaly Equiv
RCP8.5	8.5 W/m^2 in 2100	1370	4.9	Rising	SRES A1F1
RCP6.0	6.0 W/m^2 post 2100	850	3.0	Stabilization without overshoot	SRES B2
RCP4.5	4.5 W/m^2 post 2100	650	2.4	Stabilization without overshoot	SRES B1
RCP2.6	3 W/m^2 before 2100, declin-ing to 2.6 W/m^2 by 2100	490	1.5	Peak and decline	None

Source: from Moss et.al. 2010. Median temperature anomaly over pre-industrial levels and SRES comparisons based on nearest temperature anomaly, from Rogelj et.al. 2012.

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)

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Status of Climate Science *A National Strategy for Advancing Climate Modeling,* NRC 2012

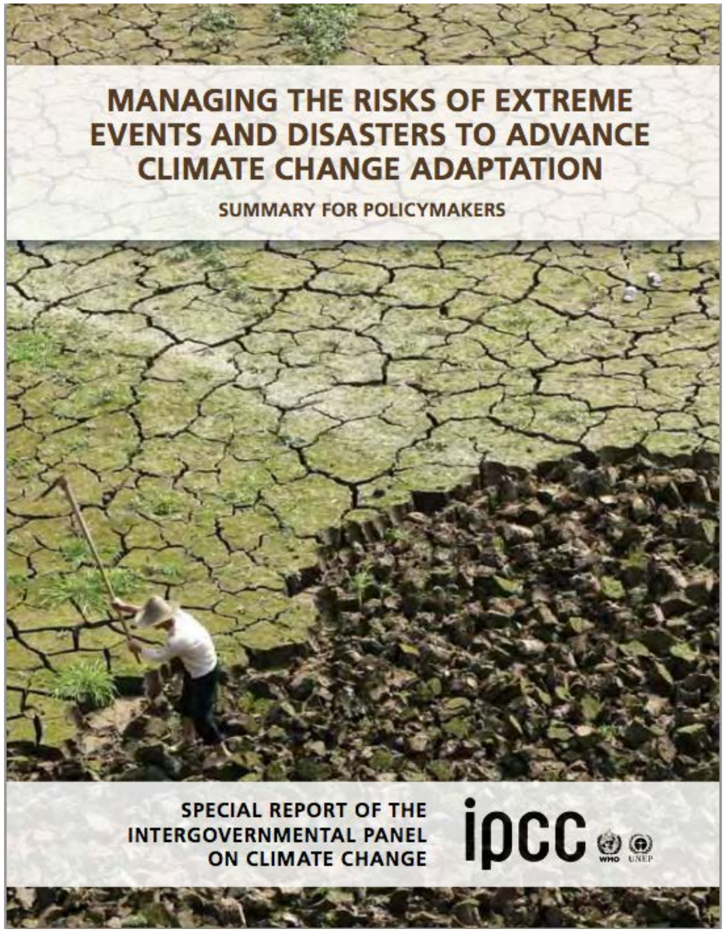
The Nation should:

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 extremes, which to date generally have not been modeled or measured directly.)

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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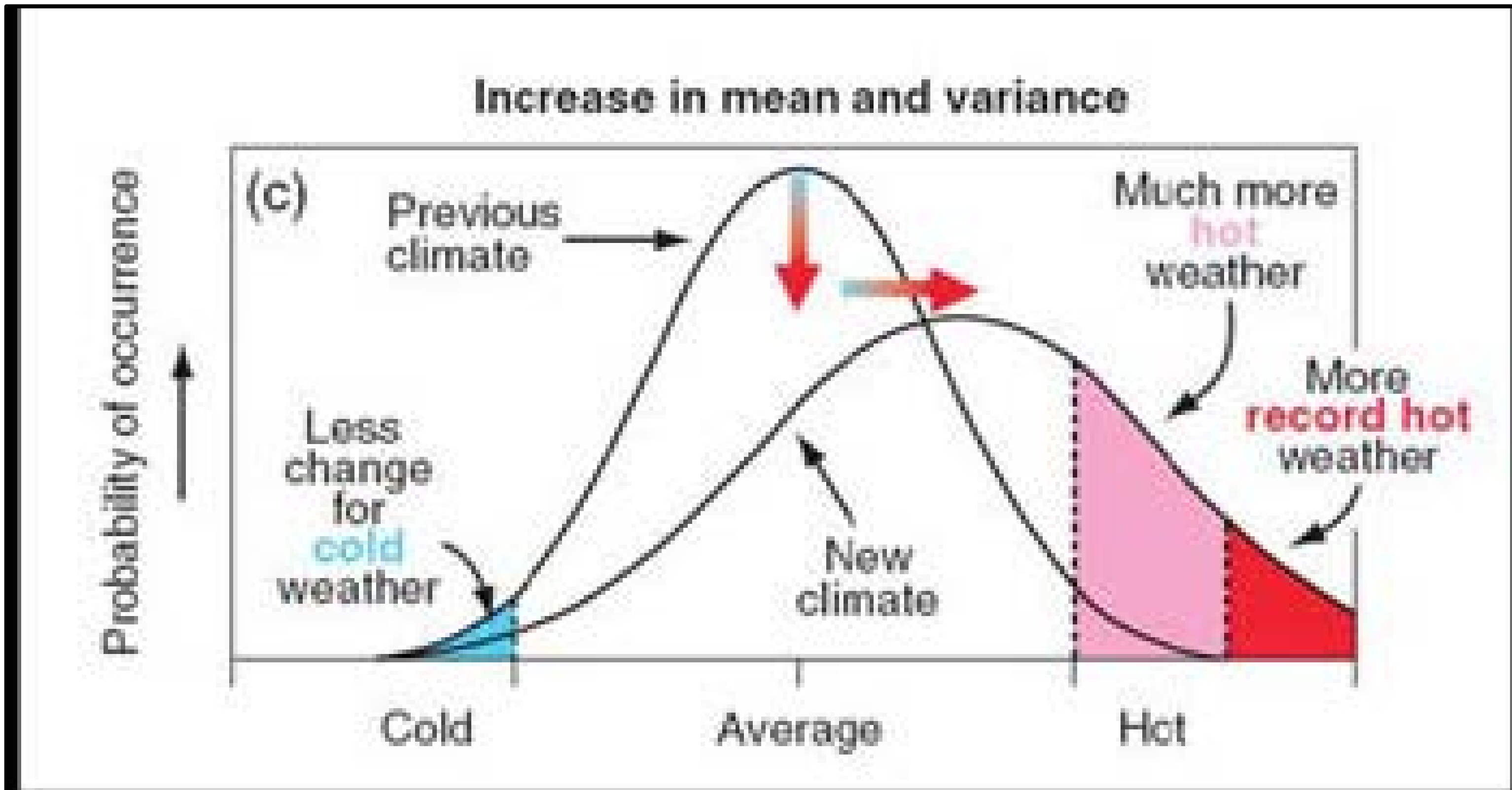
Climate Change and the Likelihood of Extreme Events



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.

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.

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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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Projected Temperature Extremes

Through the 21st Century

Virtually certain global

- increase in frequency and magnitude of unusually warm days and nights and
- decrease in frequency and magnitude of unusually cold days and nights.

Projected Wind Extremes

Through the 21st Century

- *Low confidence* in projections of extreme winds (with the exception of wind extremes associated with tropical cyclones).

Cyclones (Wind and Precipitation)

- *Likely* decrease or no change in frequency of tropical cyclones.
- *Likely* increase in mean maximum wind speed, but possibly not in all basins.
- *Likely* increase in heavy rainfall associated with tropical cyclones.
- Likely impacts on extra-tropical cyclone activity but low confidence in detailed regional projections due to only partial representation of relevant processes in current models.
- Medium confidence in a reduction in the numbers of mid-latitude storms.

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Droughts

- *Medium confidence* in projected increase in duration and intensity of droughts in some regions of the world, including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa.
- Overall *low confidence* elsewhere because of insufficient agreement of projections.

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Wildfires

Drought, coupled with extreme heat and low humidity, can increase the risk of wildfire.

FEMA

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Floods

- *Low confidence* in global projections of changes in flood magnitude and frequency because of insufficient evidence.
- *Medium confidence* (based on physical reasoning) that projected increases in heavy precipitation would contribute to rain-generated local flooding in some catchments or regions.
- *Very likely* earlier spring peak flows in snowmelt- and glacier-fed rivers.

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Coastal Impacts

- *Very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels.
- *High confidence* that locations currently experiencing coastal erosion and inundation will continue to do so due to increasing sea level, in the absence of changes in other contributing factors.

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Cold Regions

- *High confidence* that changes in heat waves, glacial retreat, and/or permafrost degradation will affect (cold regions and) high mountain phenomena such as slope instabilities, mass movements, and glacial lake outburst floods.

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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, "<u>learn-as-you-go</u>" process to enable previously defined changes to be made during and after construction
- Based on <u>new knowledge</u> derived during/after construction

Karl Terzaghi

Ralph Peck

Source: Creative Commons

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

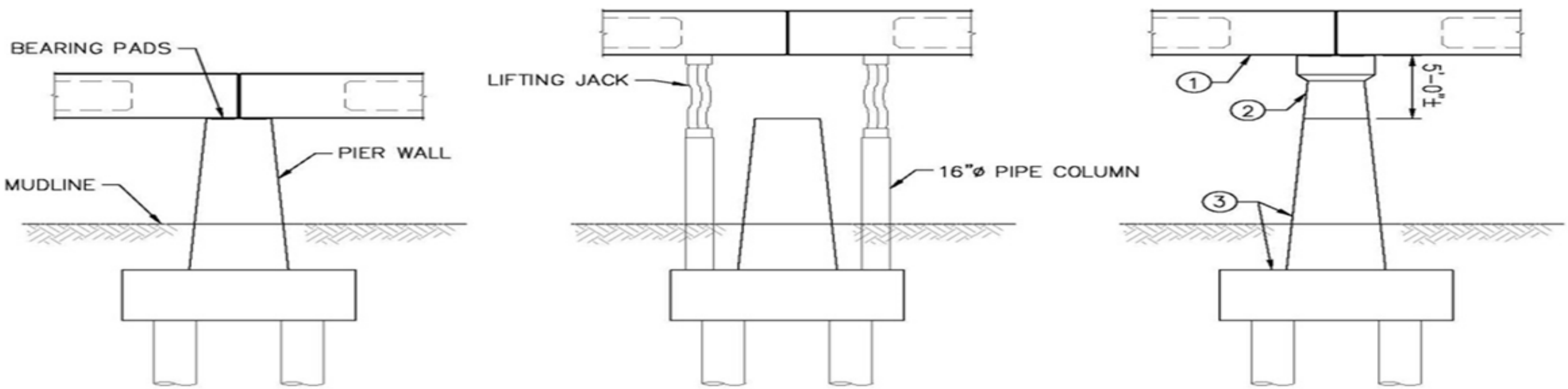
- Develop a monitoring plan to detect changes in environmental conditions and system performance
- Establish an action plan for putting in place system alterations
  - Set decision points for implementing system alterations
- Monitor environmental conditions and system performance
- Implement action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

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

Proposed ASCE Manual of Practice

The ASCE Committee on Adaptation to a Changing Climate is developing an ASCE manual of practice "Climate Resilient Infrastructure: Manual of Practice on Adaptive Design and Risk Management. It will guide standards committees in incorporating adaptive risk management in their standards and guide practicing engineers in using adaptive risk management prior to the updating of standards

Needed from Climate/Weather Science

- Authoritative forecasts of the design basis (most likely) climate/weather extremes 20, 50 and 100 years in the future for Mean Recurrence Intervals of 10 to 1000+ years (annual probabilities of being exceeded of 0.1 to 0.001).
- Authoritative forecasts of the maximum credible (worst case) climate/weather extremes 20, 50 and 100 years in the future for Mean Recurrence Intervals of 10 to 1000+ years (annual probabilities of being exceeded of 0.1 to 0.001)
- This information will allow ready adaptation of existing standards and regulations because the load and resistance factors that have been developed to provide the intended reliability will remain valid.

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