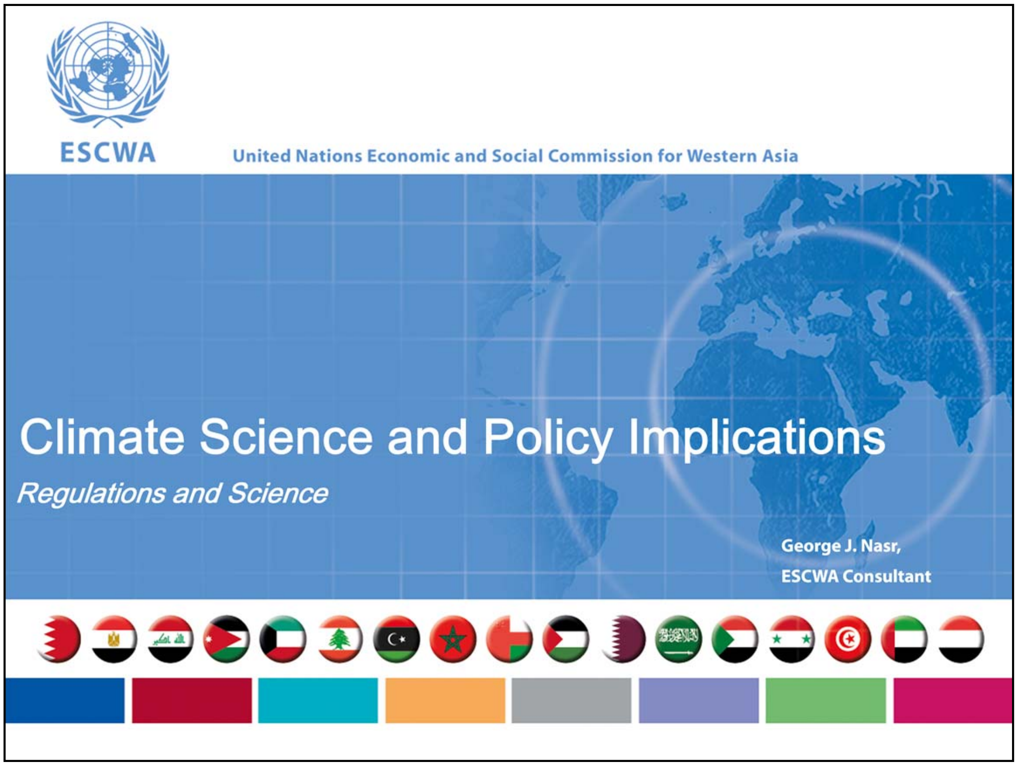


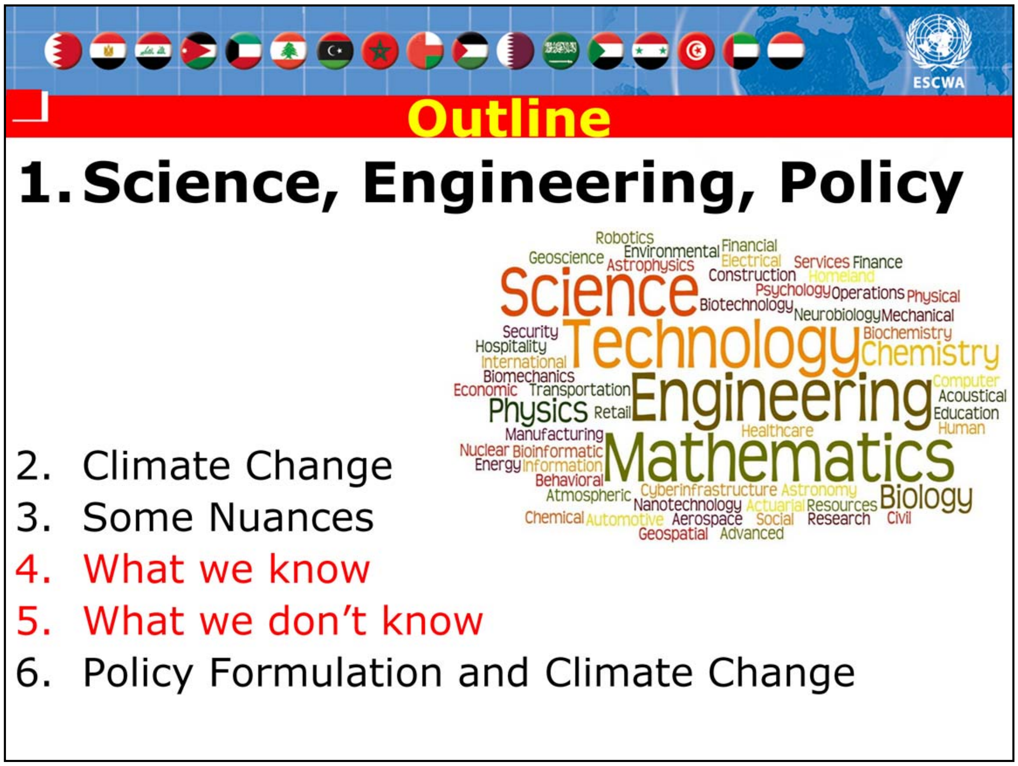
ESCWA

United Nations Economic and Social Commission for Western Asia

Climate Science and Policy Implications

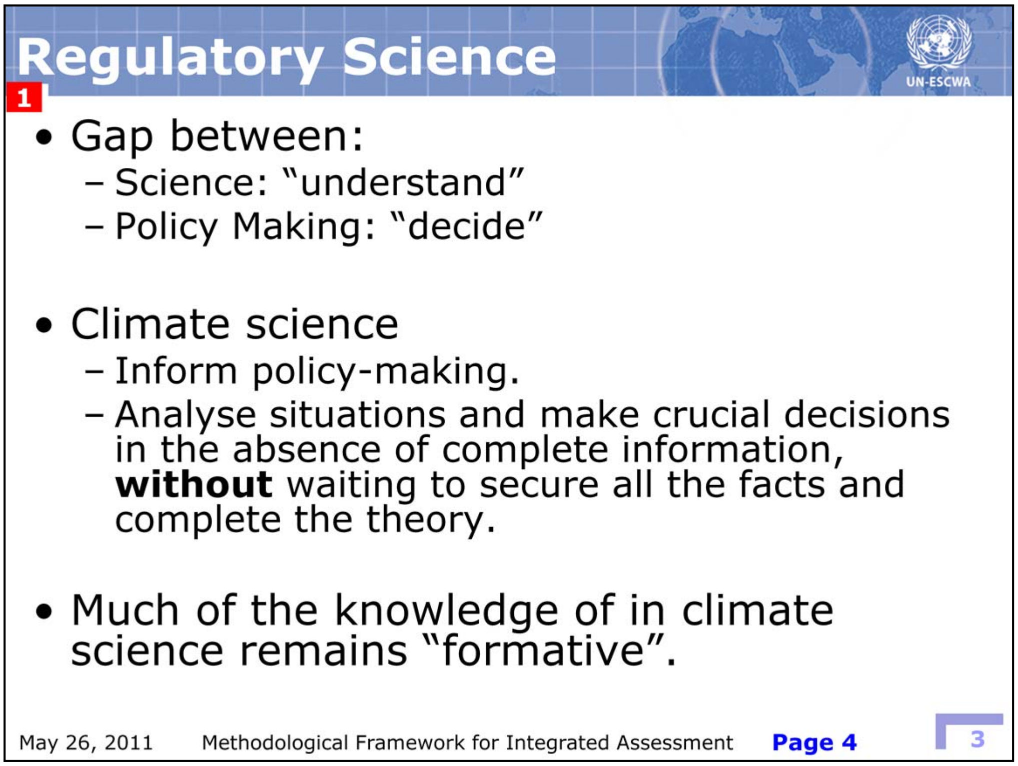
Regulations and Science

George J. Nasr,
ESCWA Consultant



Outline

1. **Science, Engineering, Policy**
2. Climate Change
3. Some Nuances
4. What we know
5. What we don’t know
6. Policy Formulation and Climate Change



Regulatory Science

1

- Gap between:
  - Science: “understand”
  - Policy Making: “decide”
- Climate science
  - Inform policy-making.
  - Analyse situations and make crucial decisions in the absence of complete information, **without** waiting to secure all the facts and complete the theory.
- Much of the knowledge of in climate science remains “formative”.

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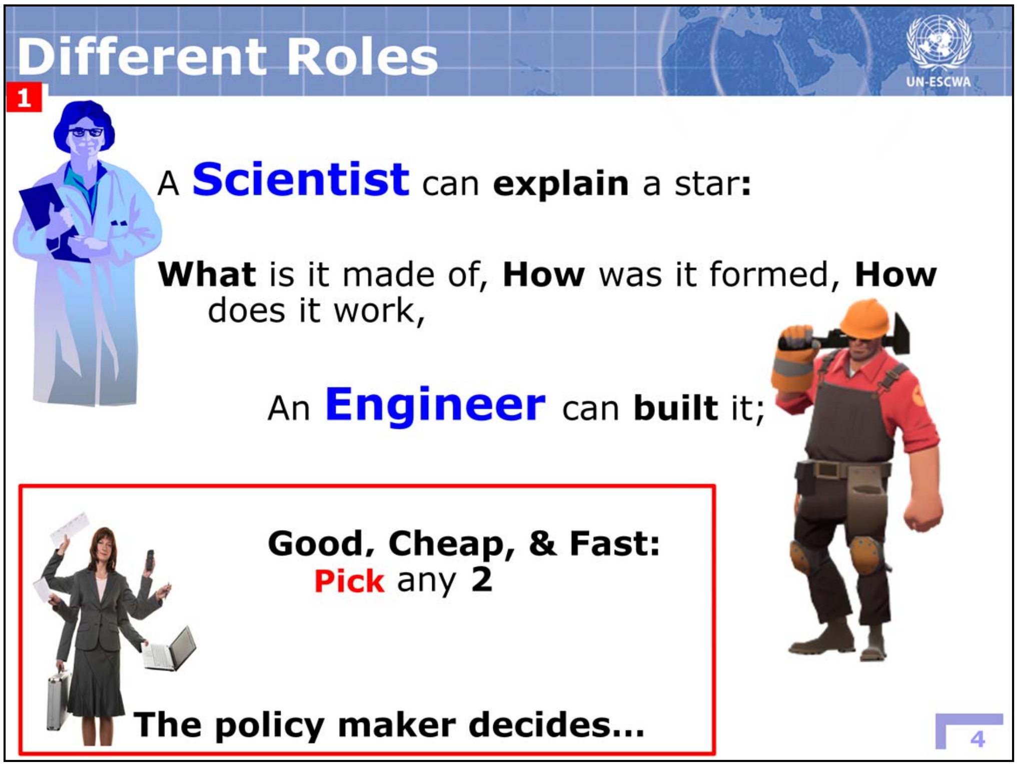
Fundamentally, uncertainty remains because of the knowledge in the climate domain remains still “formative”. Contrary to “normal science”, answers are needed before a complete solution is found for the problem at hand. In this “post-normal science” environment, investigative scientists face a situation similar to that routinely faced by applied scientists such as surgeons or engineers, where decision have to be made without all the facts being made available. In this context, climate scientists have to confront two types of uncertainty.

The first type of uncertainty comes from **climate surprises**, probable events that lay outside the “envelope of possibilities” considered by the climate modellers.

The second type of uncertainty is “**inherent**” to computer modeling. The mathematical or physical models programmed into the computers are idealized representations of the real world. As such, they rely on both mathematical and physical approximations



Different Roles

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1

A **Scientist** can **explain** a star**:**

What is it made of, **How** was it formed, **How** does it work,

An **Engineer** can **built** it;

Good, Cheap, & Fast:
Pick any **2**

The policy maker decides…

4

Scientists focus on addressing the second types of uncertainty, related to the inherent limitation of mathematical and physical approximations in representing the complexity of the real world. This is due to practical limitations in translating well understood equations of energy, momentum, and mass conservation equations into “computable” climate models.

Mathematically, the coupled nonlinear equations that describe the physics of the air, seas, and ice are far too complex to be solved by any known exact technique. Analytic continuous differential equations are therefore replaced with discrete finite difference equations that are solved numerically across “grid cells” and at specific “time steps”. As those numerical solution methods “converge” to the result, some approximations result. For example, when iterations are carried out at different time intervals, they use “time steps” that differ amongst the models, which could create enough difference to cause variability among their outputs.

Physically, approximations are often made as a necessary result of the limitations of our current knowledge. For example, when grid cells are larger than some important small-scale phenomena, scientists rely on a mix of empiricism and fine-resolution to estimate and incorporate their effect. With each new generation of computer models, the extent of this limitation diminishes, but it remains an important feature. This may be of particular concern in the case of localized meteorological phenomena that nonetheless may have larger scale climate effects. For this reason, models adapted fro use in regions such as the Arab world may require significant adjustments.

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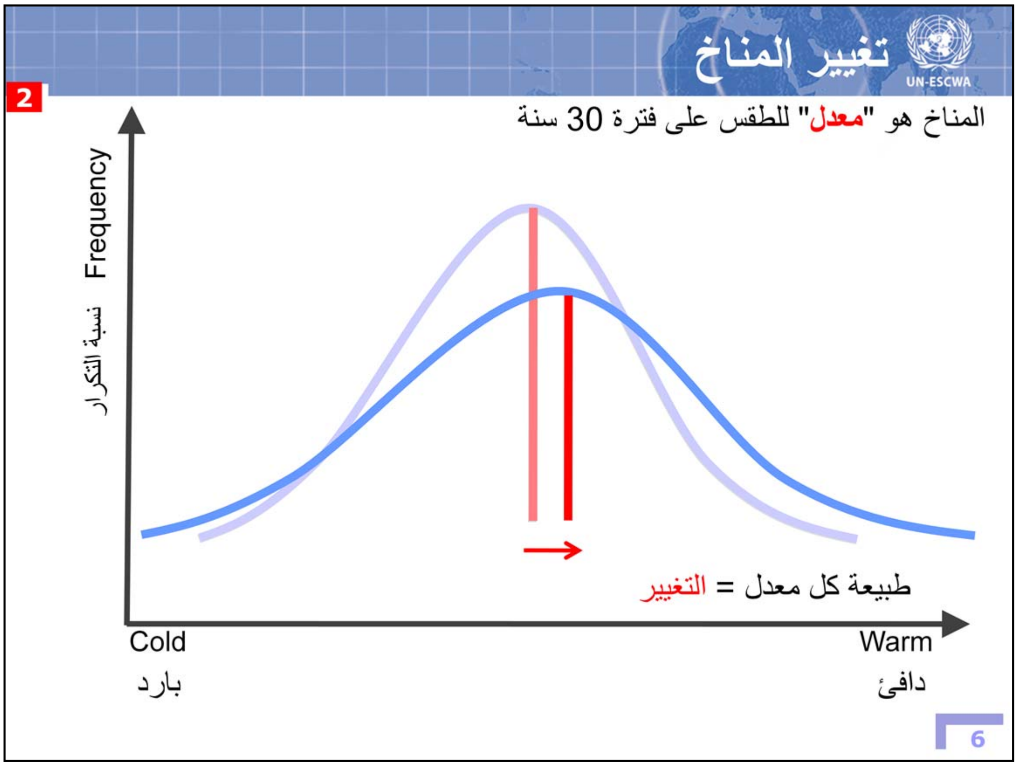


تغيير المناخ

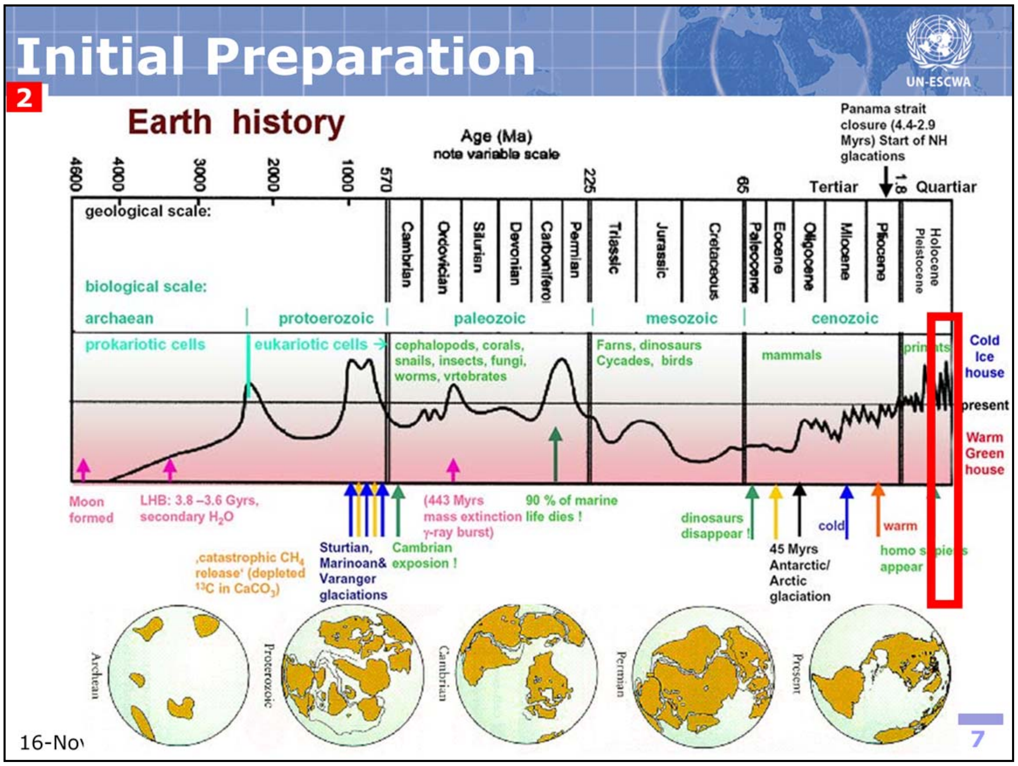
UN-ESCWA

2

المناخ هو "**معدل**" للطقس على فترة 30 سنة

Those oscillations reflect the Earth’s “energy balance” between the incoming solar radiation and earth’s outgoing infrared radiation. Over time, the Earth system maintains a balance between this influx of energy and the outflow, and the atmosphere adjusts dynamically as the system moves towards equilibrium. In a “static” equilibrium, climate variables would be stable, reaching an average value that reflects this “energy balance” between inflows and outflows. However, because the earth is ever evolving, the equilibrium is dynamic; rather than stabilizing, climate variables “oscillate” around the average value that would correspond to a static equilibrium. The “energy budget” changes with the inflows and outflows; when energy inflows outweigh the outflows, the “average” moves up, the slope of the oscillation moves up, and the climate warms. Then, Climatological Standard Normals shift upwards.

The “climate cycle:” reflects the earth’s “energy budget”, a dynamic equilibrium of “energy fluxes” transferred by many mechanisms, one of which being the cycle of water as it goes through evaporation, condensation, and precipitation. As Climactic Standard Normals shift, this “water cycle” also changes, altering rates of evaporation and precipitation, and thus changing the availability of freshwater on the ground surface.



Initial Preparation

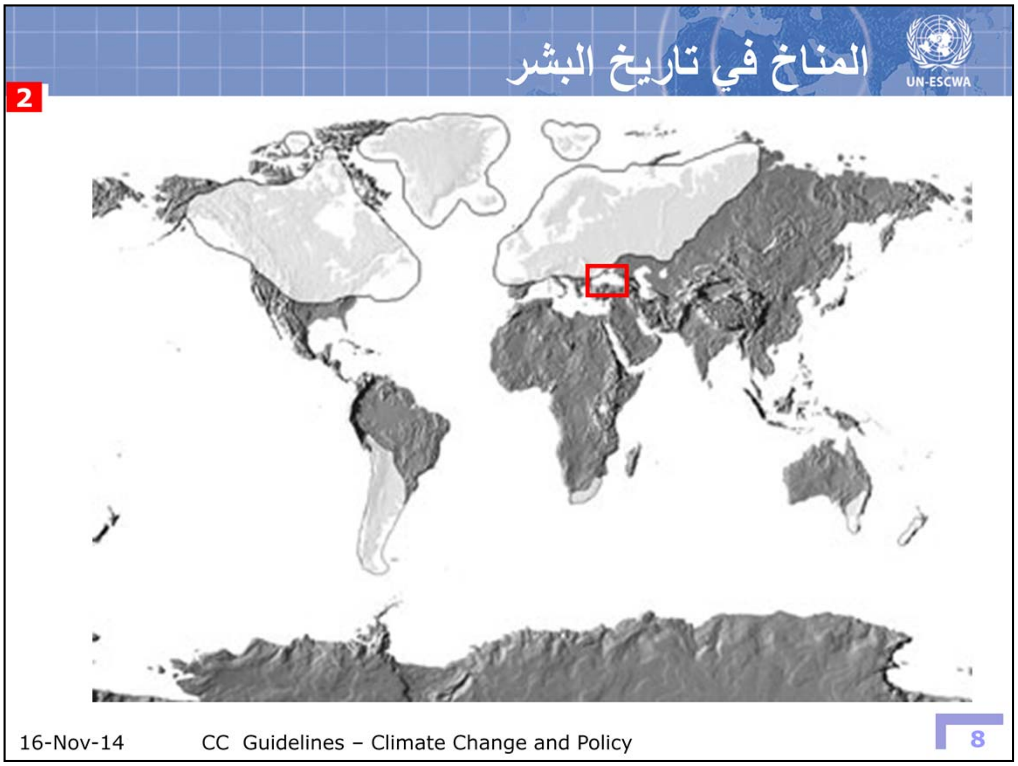
2

Earth history

16-Nov

7

The study of climate change requires the determination of the future state of the climate. This is based on description of the future state of the climate, or “scenarios”. Those scenarios can be either inferred from analogous conditions, or determined based on projections of the main forcing mechanisms. Scenarios that are inferred from similar conditions are either “spatial analogues” or “temporal analogues”.



المناخ في تاريخ البشر

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2

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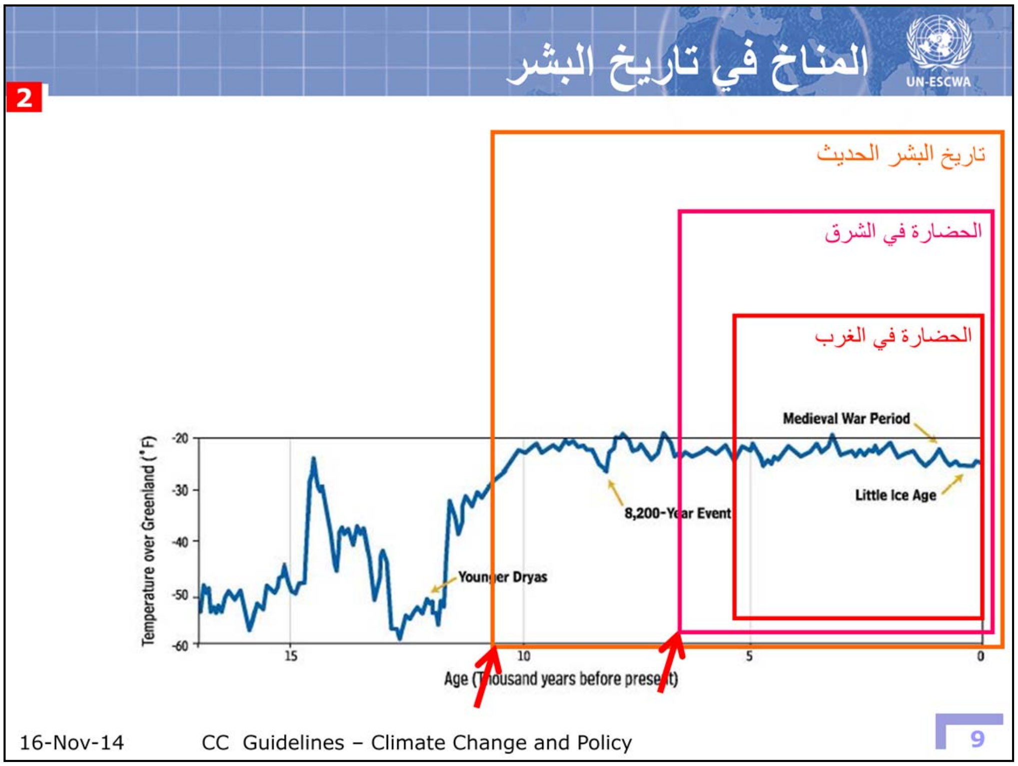
Spatial “Analogues” rely on recorded data over regions that closely resemble the area of interest to the study. However, because few regions completely correspond to one another, this approach is of such limited use that much of the climate change impacts assessment literature had long ago recommended against their use.

Temporal “Analogues” are derived from past climatic records, or reconstructed from fossil evidence or ice cores as a “Paleoclimate”. In general, Historic climate extracted from the “instrumental record”, a record of temperature variations that extends from 1850. It is the use of those temporal analogues that allowed climate scientists to establish that past climatic change was due to human emissions.



2

المناخ في تاريخ البشر

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تاريخ البشر الحديث

الحضارة في الشرق

الحضارة في الغرب

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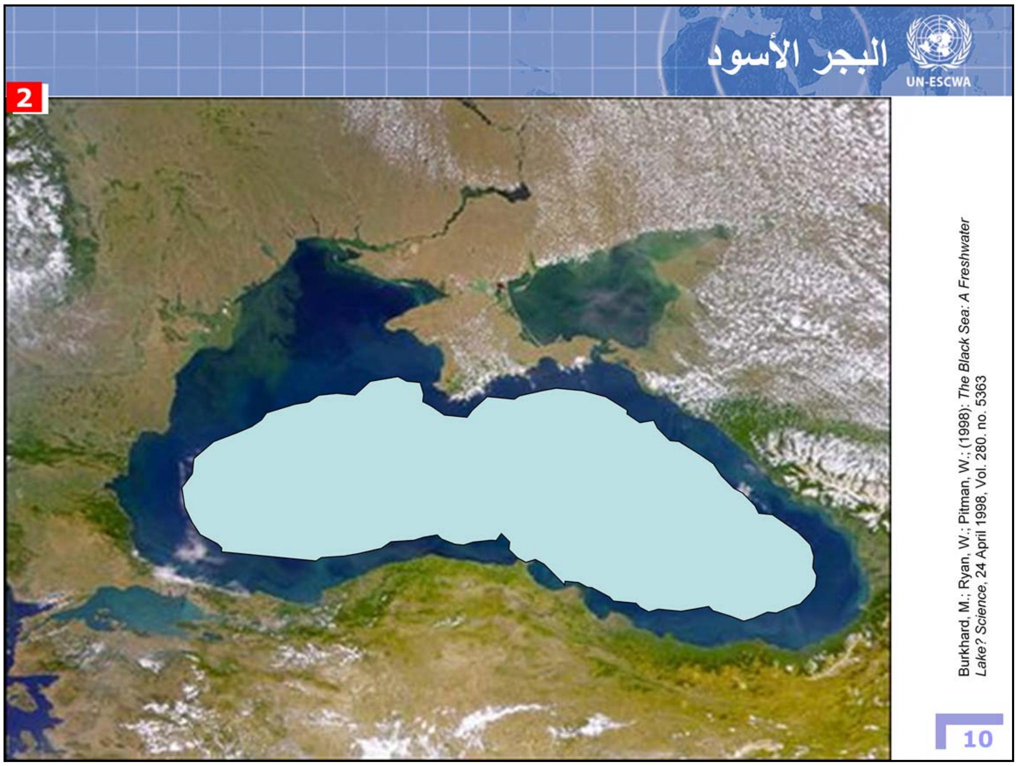

البحر الأسود

Burkhard, M.; Ryan, W.; Pitman, W.; (1998): *The Black Sea: A Freshwater Lake? Science*, 24 April 1998, Vol. 280. no. 5363

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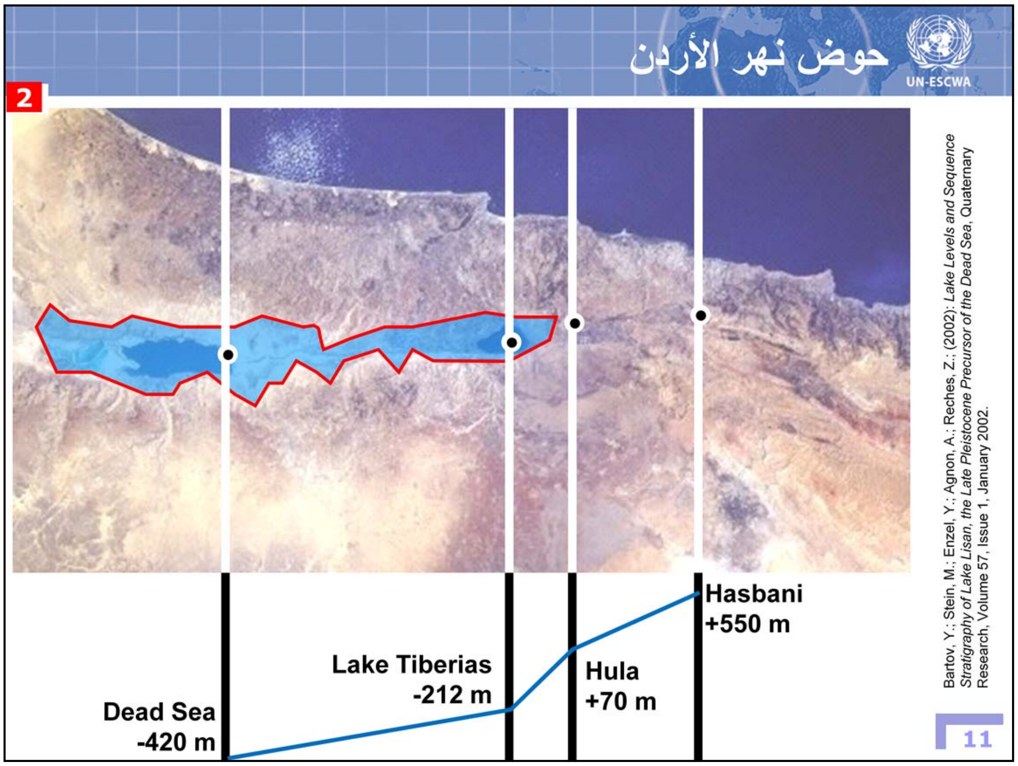
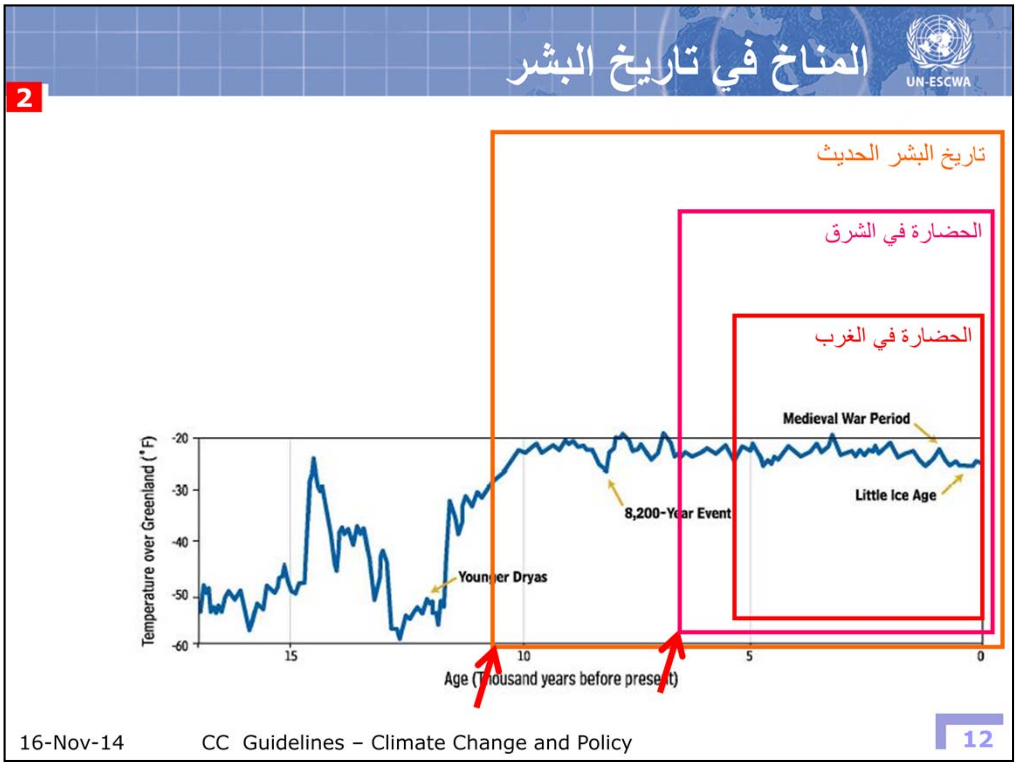


حوض نهر الأردن

Bartov, Y.; Stein, M.; Enzel, Y.; Agnon, A.; Reches, Z.; (2002): *Lake Levels and Sequence Stratigraphy of Lake Lisan, the Late Pleistocene Precursor of the Dead Sea*, Quaternary Research, Volume 57, Issue 1, January 2002.

Spatial “Analogues” rely on recorded data over regions that closely resemble the area of interest to the study. However, because few regions completely correspond to one another, this approach is of such limited use that much of the climate change impacts assessment literature had long ago recommended against their use.



المناخ في تاريخ البشر

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2

تاريخ البشر الحديث

الحضارة في الشرق

الحضارة في الغرب

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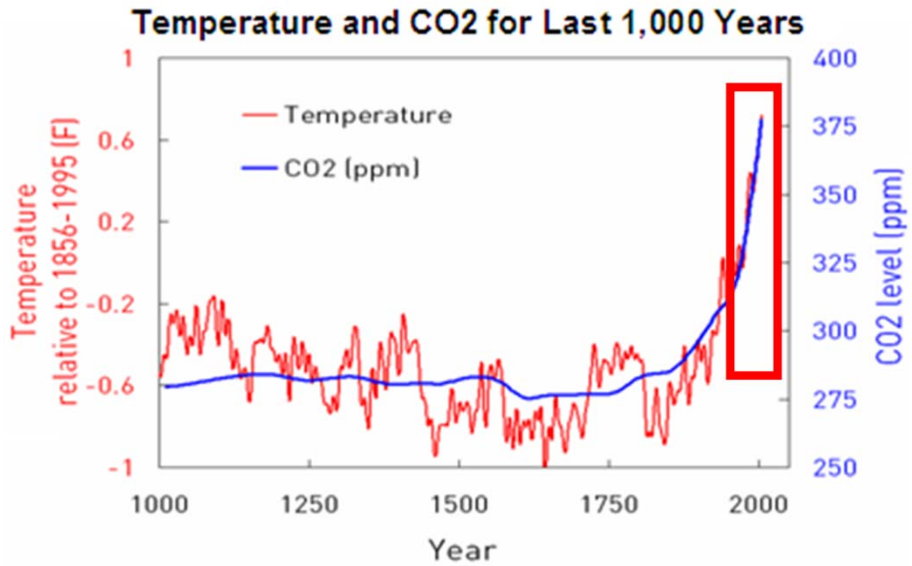
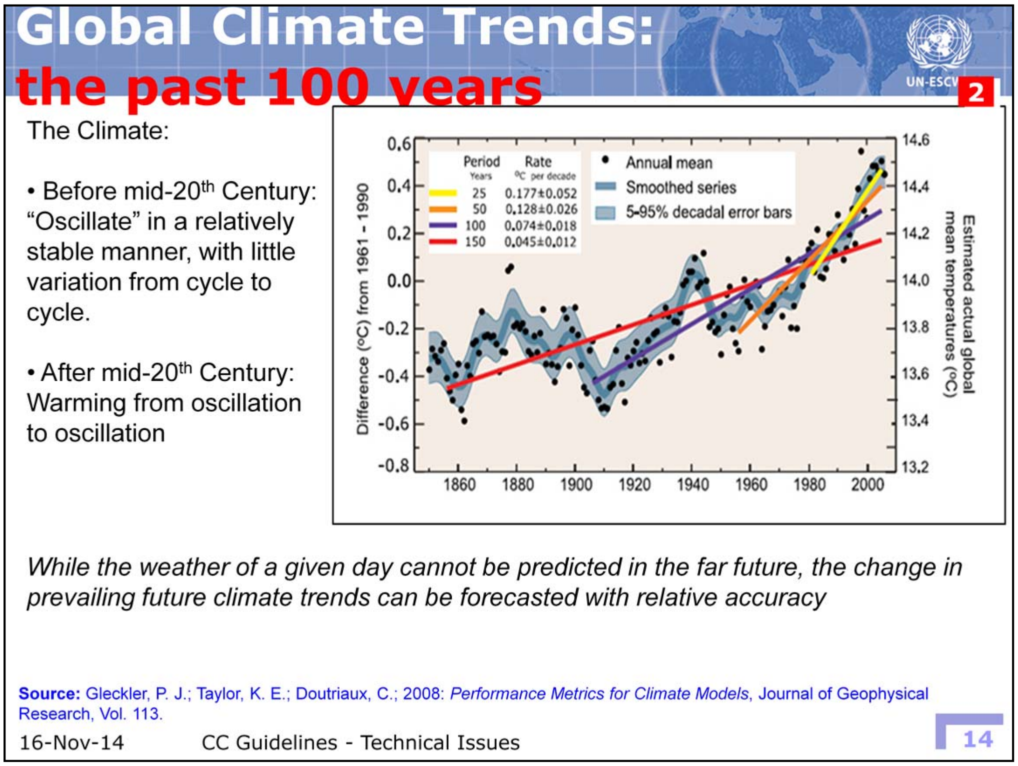
Temporal "Analogues" are derived from past climatic records, or reconstructed from fossil evidence or ice cores as a "Paleoclimate". In general, Historic climate extracted from the "instrumental record", a record of temperature variations that extends from 1850. It is the use of those temporal analogues that allowed climate scientists to establish that past climatic change was due to human emissions.

Climate Change Today

2





Global Climate Trends: the past 100 years

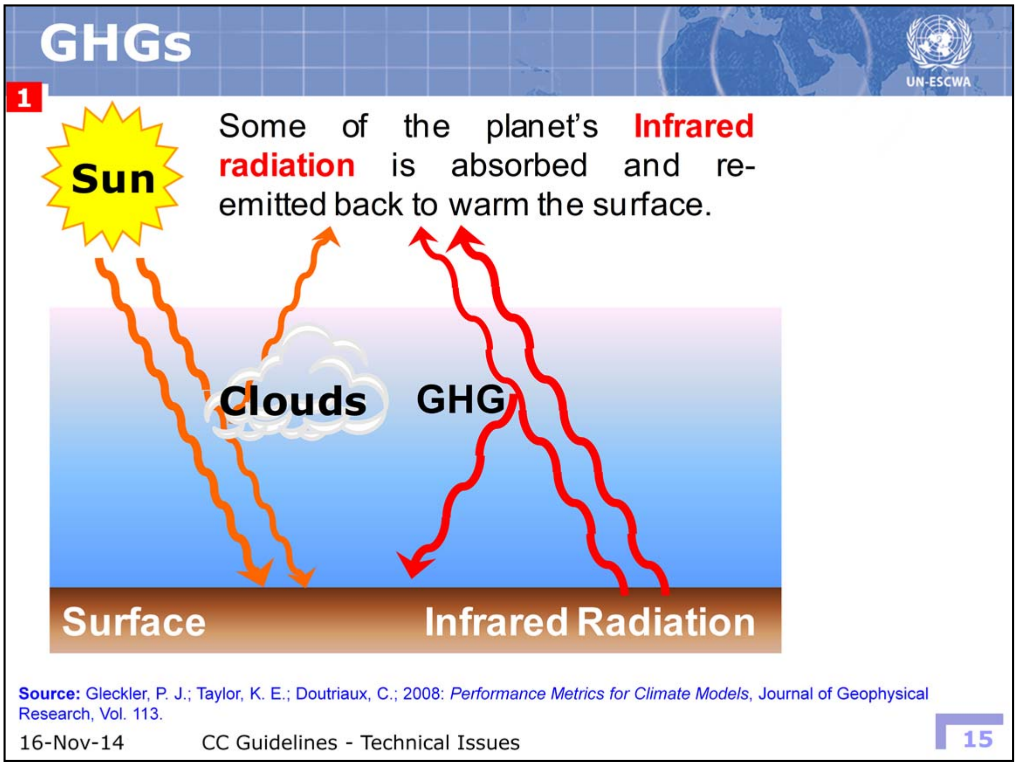
The Climate:

- Before mid-20th Century: “Oscillate” in a relatively stable manner, with little variation from cycle to cycle.
- After mid-20th Century: Warming from oscillation to oscillation

While the weather of a given day cannot be predicted in the far future, the change in prevailing future climate trends can be forecasted with relative accuracy

Source: Gleckler, P. J.; Taylor, K. E.; Doutriaux, C.; 2008: *Performance Metrics for Climate Models*, Journal of Geophysical Research, Vol. 113.

Research to date has established the fact that “most of the current change in Climatological Standard Normals is due to past increases in GHGs”. For all practical purposes, in the short term, regardless of mitigation actions, the ongoing climate change is set to continue. Even if mitigation actions led to levels of atmospheric GHGs that we back to their 19th Century level, the current climate change would continue for at least part the 21st Century. In addition, because the Arab Region’s negligible past emissions, any regional climatic change will likely be the direct consequence of global changes. However, the Arab region is likely to be deeply affected by climate change, because its prevailing aridity makes it vulnerable to any significant changes to the water cycle.



GHGs

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1

Some of the planet's **Infrared radiation** is absorbed and re-emitted back to warm the surface.

Source: Gleckler, P. J.; Taylor, K. E.; Doutriaux, C.; 2008: *Performance Metrics for Climate Models*, Journal of Geophysical Research, Vol. 113.

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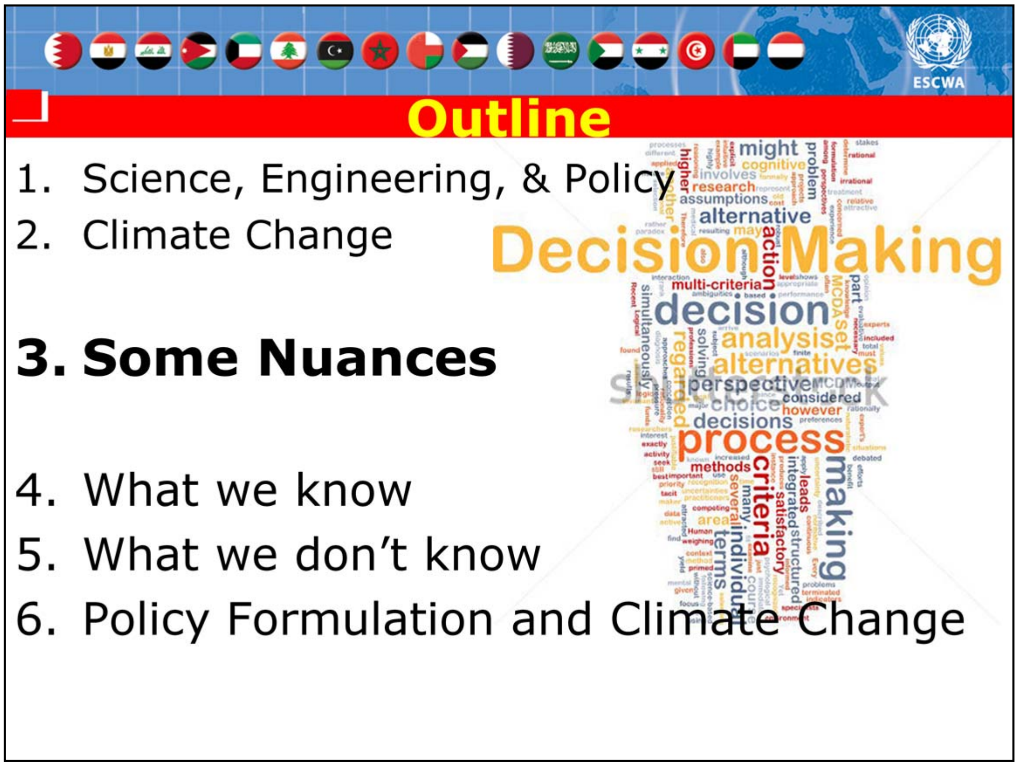
Gases in the atmosphere tend to be transparent to shorter wavelengths of visible light, but they tend to absorb the longer wavelengths of infrared radiations, most of which is emitted by the earth's surface. The most "opaque" of those are the "Greenhouse Gases" (GHG); water vapour, Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and Fluorinated Gases such as Hydrofluorocarbons (HFC), perfluorocarbons (PFC), and Sulfur Hexafluoride (SF_6).



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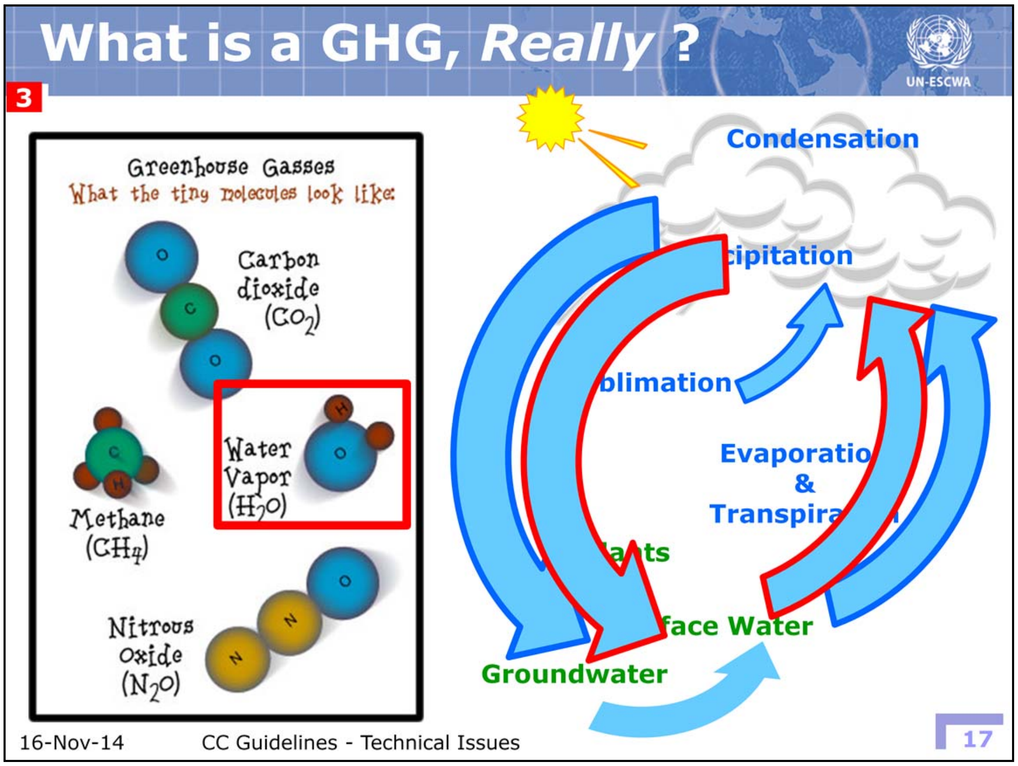

What is a GHG, *Really* ?

3

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While water vapour is chiefly part of the hydrologic cycle, the other GHG’s are mostly emitted by human activity. Those GHG’s have **two noteworthy effects**:

The **Greenhouse Effect**, caused when GHG’s absorb infrared radiation from Earth's surface and re-emit it back down. This “reflection” then warms the surface by retaining any heat that would otherwise escape to space.

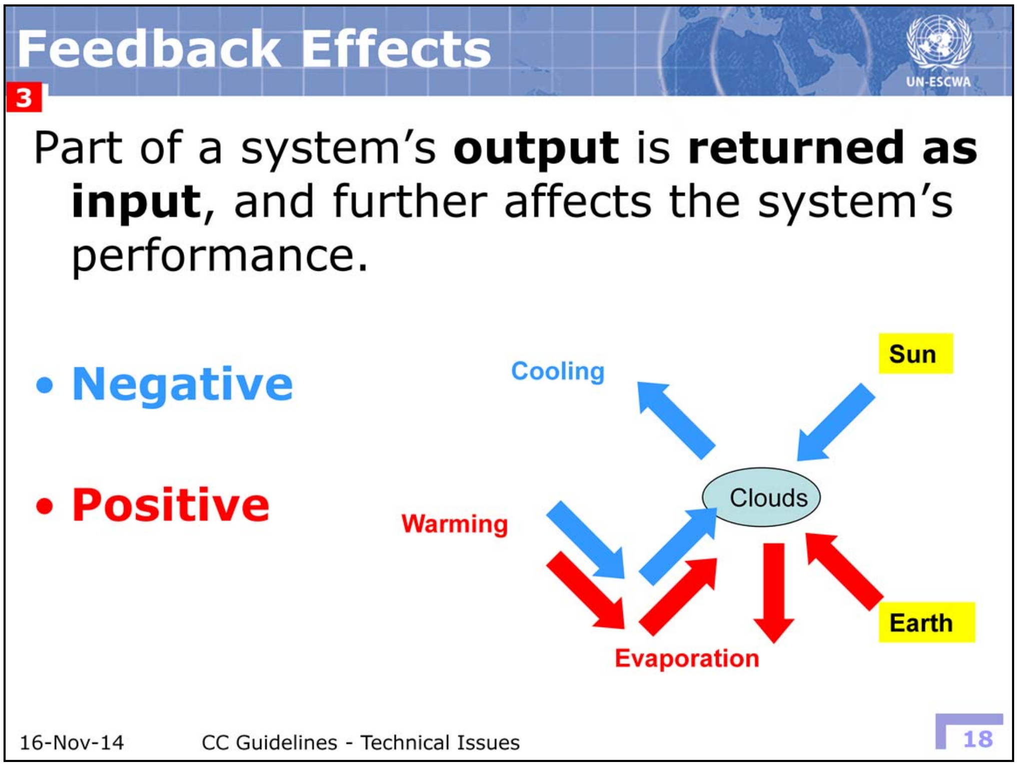
Global warming, a rise in temperatures caused by an increase in the levels of human emissions of GHG’s. It is “too much of a good thing” as it exacerbates this effect and accelerates the water cycle, and the energy from this “reflected” infrared radiation remains much higher than any energy from solar radiation that clouds reflect back into space.

The importance and the complex role of the Greenhouse Effect can best be illustrated by comparing the earth and its two planetary neighbours, Mars and Venus, which illustrate two other extremes:

On **Earth**, average surface temperatures would be an average of at least 15°C colder without the Greenhouse effect. Temperature variations are much less pronounced.

The planet **Mars** is about half the size of earth, and can only retain a thin atmosphere retains so little heat that average surface temperature is as low as -63 °C, and varies widely from -140 °C to 20 °C.

Venus is about the same size of Earth, with a thick atmosphere that experienced a “runaway greenhouse effect” raised the planet’s average surface temperature so high that water evaporated and was lost to space, and GHG’s such as CO2 were “baked out” of the rocks, further reinforcing the planetary warming. The planet’s temperature is now 477 °C, hot enough to melt lead, and twice as hot as it would be if Venus did not have an atmosphere



Feedback Effects

3

Part of a system's **output** is **returned as input**, and further affects the system's performance.

- **Negative**
- **Positive**

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There are two types of climate feedback effects; positive, and negative.

In **Positive feedback**, disturbances are amplified by the system's reaction to them, as it acts to increase the magnitude of the initial perturbation.

In **Negative feedback**, disturbances are attenuated by the system's reaction to them, as it acts to dampen the magnitude of the initial perturbation.

Clouds are an example of both feedbacks; as surface temperatures increase, so do evaporation rates, which increases atmospheric water vapour, which then grows larger clouds. The clouds then have both a negative and a positive feedback on planetary warming:

By shielding the ground from the warming effect of the sun, clouds have a **negative feedback** effect on the planetary warming. They decrease surface temperatures and thus dampen the initial warming.

However, larger clouds increased atmospheric moisture can also have a **positive feedback** effect, as they can absorb and reemit more of Earth's outgoing thermal radiation. As this downward thermal radiation increases surface temperatures, it leads to more evaporation and an increased moisture content in the upper atmosphere, which can thus amplifies the initial warming.

The positive feedback predominates under the present climate change, in large part due to increased levels of human-emitted GHG’s.

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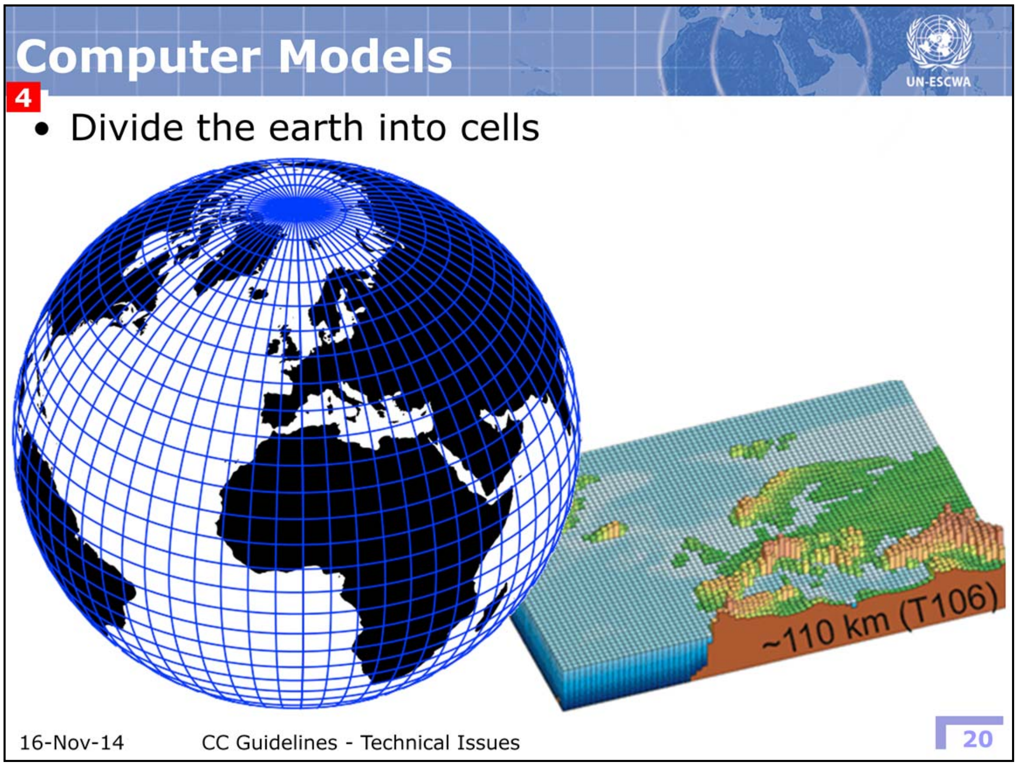

Computer Models

4

- Divide the earth into cells

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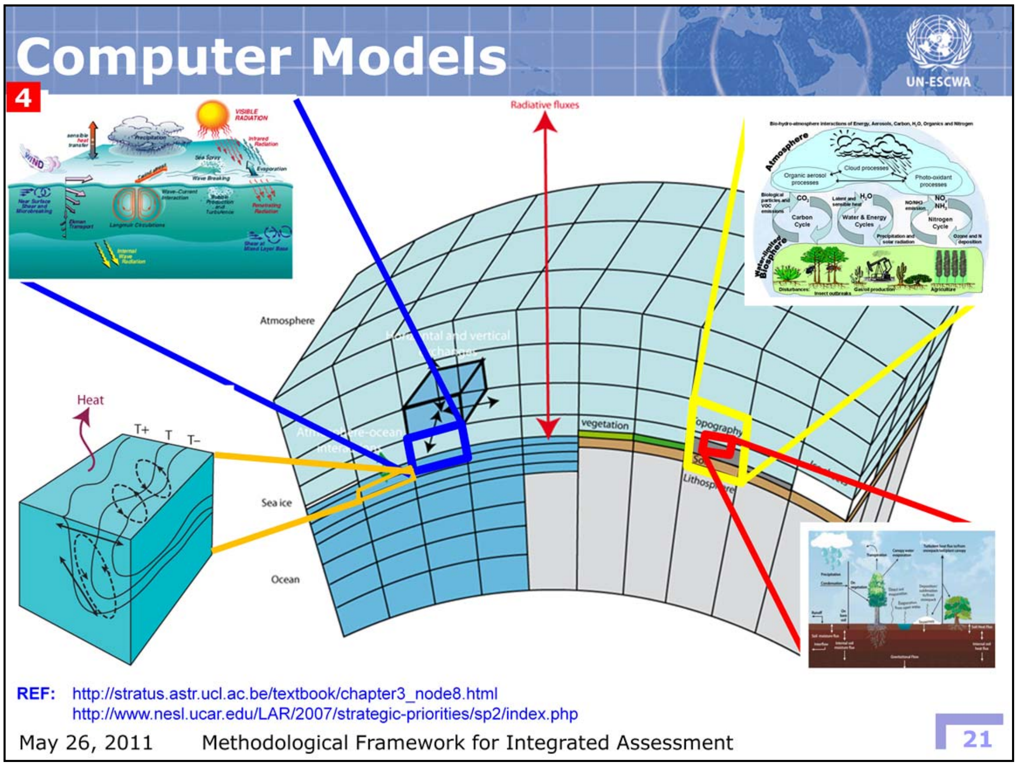
Mathematical equations describing the Earth’s various subsystems are known as “Energy-Balance Models” (EBM). Those equations rely on physical laws and incorporate relevant chemical process and biologic processes to test hypotheses on the workings of the planet. They “abstract” the climate system in three basic classes of Bio-Physical processes;

1- Radiative processes transmit heat or electromagnetic radiation through the climate system by emission, absorption or reflection.

2- Dynamic processes transfer energy across the atmosphere in the horizontal and vertical transfer of energy by advection, convection, diffusion…

3- The interaction of land, ocean, and sea ice defines Surface processes (Albedo, emissivity, and surface-atmosphere energy exchanges).

This **future climate** is obtained by “backcasting” from projections based on ongoing trends. The earth chaotic system is therefore simulated through advanced computer programs that run repeated iterations describing two types of systems;



Computer Models

4

REF: http://stratus.astr.ucl.ac.be/textbook/chapter3_node8.html
http://www.nesl.ucar.edu/LAR/2007/strategic-priorities/sp2/index.php

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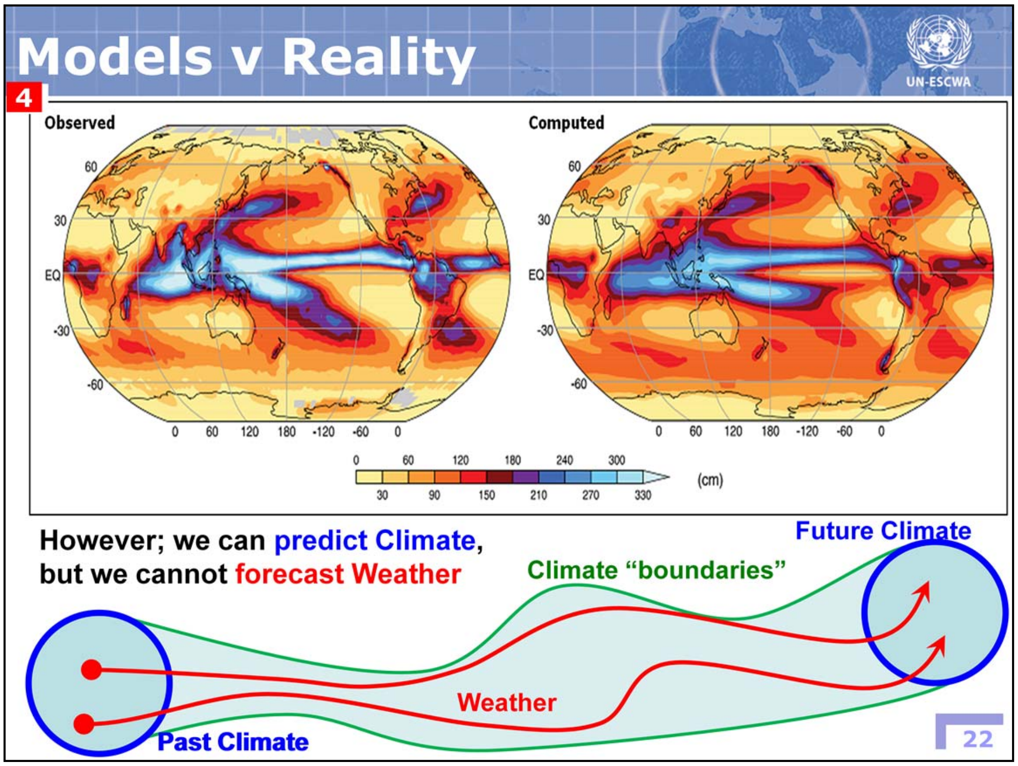
Bio-Physical systems, created by the interaction between “Physical” systems such as the atmosphere, oceans, and the surface, with “Biological” systems such as trees or plankton. Those systems are modeled by computer programs to an increasing extent.

Socio-Economic systems, created by essentially unpredictable human actions and their economic interaction. They are best investigated through scientifically defined “Scenarios” that “bound” their possible evolution patterns.



Models v Reality

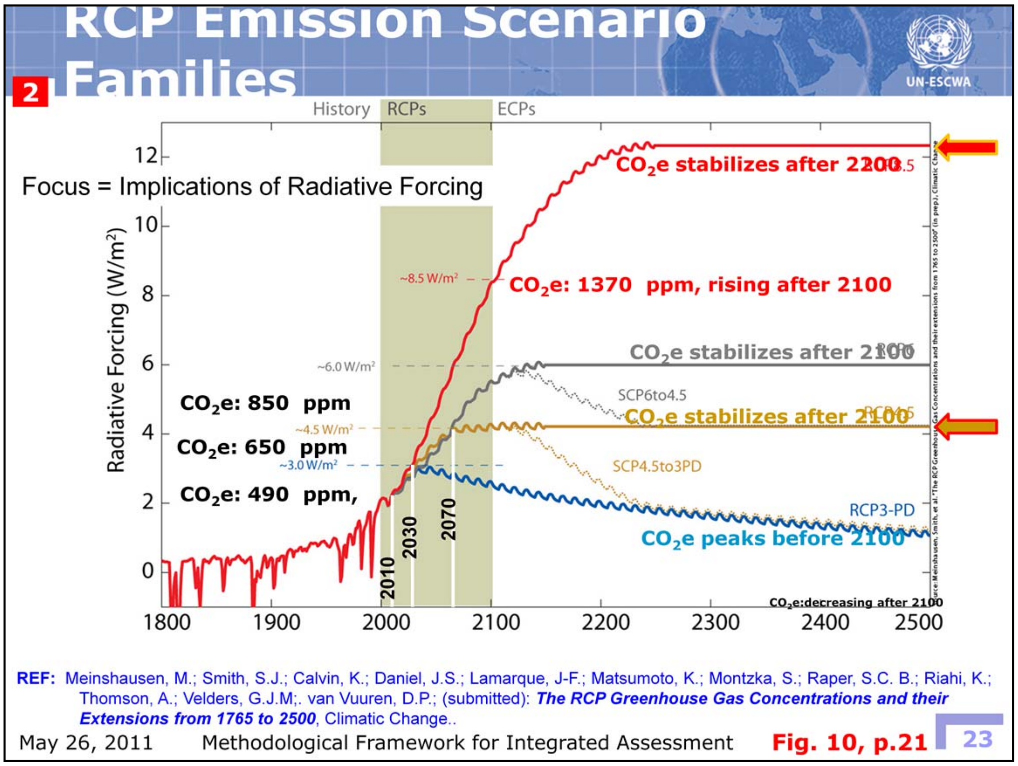
4

Observed

Computed

However; we can predict Climate, but we cannot forecast Weather

Thanks to the “deterministic” interaction amongst those parameters, computer could be programmed to simulate the climate. Those simulations showed that the roots of this global “climate change” are chiefly due to the increase in Greenhouse Gas (GHG) emissions due to the acceleration of Western industrialization after the 19th Century. In the Earth's atmosphere, the primary GHG’s that reflect the earth’s thermal energy back to the ground surface are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.



RCP Emission Scenario Families

2

UN-ESCWA

Focus = Implications of Radiative Forcing

REF: Meinshausen, M.; Smith, S.J.; Calvin, K.; Daniel, J.S.; Lamarque, J-F.; Matsumoto, K.; Montzka, S.; Raper, S.C. B.; Riahi, K.; Thomson, A.; Velders, G.J.M;. van Vuuren, D.P.; (submitted): ***The RCP Greenhouse Gas Concentrations and their Extensions from 1765 to 2500***, Climatic Change..

May 26, 2011 Methodological Framework for Integrated Assessment **Fig. 10, p.21** 23

The current scenarios rely on redesigned radiative forcing trajectories, and identifies four “radiative forcings” that correspond to the different peak levels of atmospheric CO2 and to “storylines” associated with possible mitigation policies. Those new “benchmark scenarios” are currently known as “Representative Concentration Pathways” (RCP). The new scenario process will develop global scenarios for two time periods; a “near-term” that covers the period from _ to about 2035; and a “long-term” that covers the period from _ to 2100 and, “in a more stylized way, the period to 2300”. This led to four RCP’s; RCP8.5, RCP6, RCP4.5, and RCP3-PD. The Changes in Radiative forcing would be equivalent to increases in GHG’s which varied from about 455 ppm of **CO_2-Equivalent** in 2005, to between 490 ppm and 1370 ppm in 2100. The difference amongst those scenarios is whether they consider cases of constant emissions, constant forcing, or adapted emissions:

Scenarios versions that consider “Constant Emissions” are developed to take into account the “do nothing” case, when GHG emissions continue to increase until 2100.

> RCP8.5 allows climate Models to consider this extreme case. In RCP8.5, Radiative forcing reaches >8.5 W/m^2 by 2100 and continues

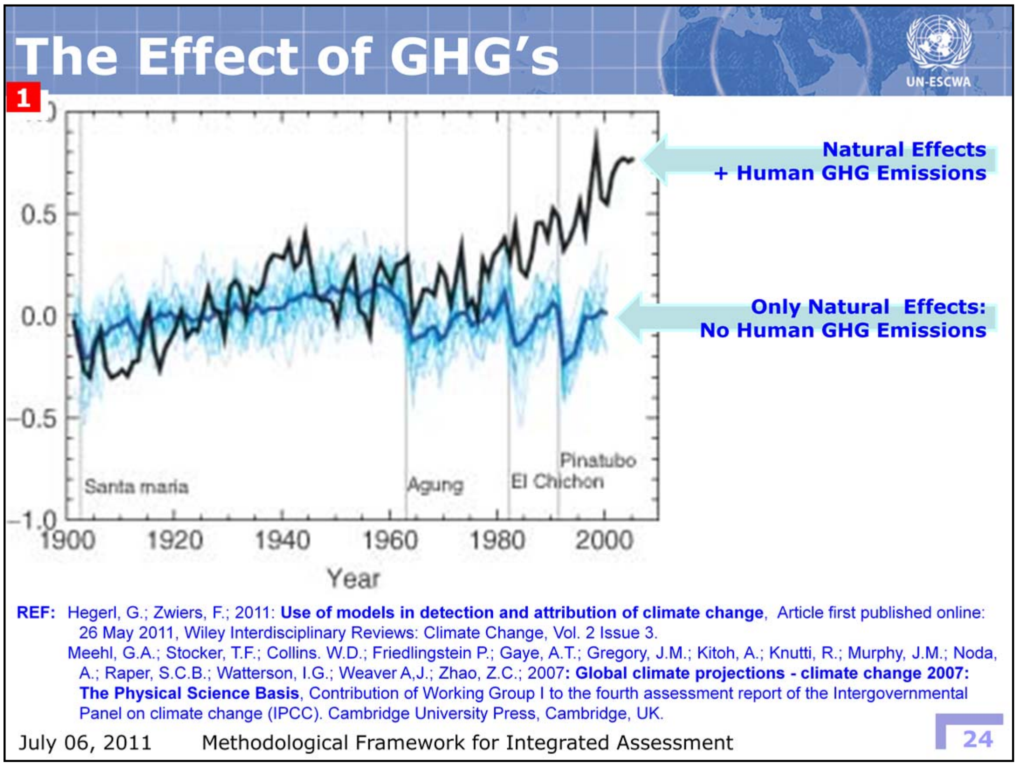
> to rise for some amount of time.

The option of “Constant Forcing” allows for two scenarios to account for a range of behaviours that assume intermediate “stabilization pathways”, RCP6 and RCP4.5:

> RCP4.5 allows climate Models to consider a slow decline in radiative forcing after a peak of 4.5 W/m^2 in 2100.
>
> With 6 W/m^2, RCP6 exhibits a larger radiative forcing than RCP4.5, and allows the study of “the irreversibility of climate change and its impacts, a topic relevant to research and policy making”.
>
> An alternative pathway for RCP6 is one that peaks at 6 W/m^2 in 2100 and declines thereafter, stabilizing at 4.5 W/m^2, which allows climate Models to evaluate the impact of “overshoot” scenario that later stabilizes, thereby reflecting the effect of delayed policy action and climate inertia.

The IPCC also allowed for an “Adapted Emissions” scenario to take into account the positive effect of emissions reduction. Under this RCP3-PD scenario, Radiative forcing would still peak at approximately 3 W/m^2 before 2100 because of climate inertia, but it would decline thereafter. This scenario allows the investigations of the “reversibility” of climate change and impacts.

The additional RCP3-PD was “proposed to reflect the possibility of limits on negative emissions”. However, in areas whose emissions remain negligible compared to the rest of the world, the effect of any actions to limit emissions is likely to be negligible. Furthermore, the inertia of the climate is such that any decreases to anthropogenic forcings are unlikely to bring benefits in the short to medium term. For this reason, the RCP3-PD may have limited use in the regions most vulnerable to the effects of climate change.



The Effect of GHG's

Natural Effects
+ Human GHG Emissions

Only Natural Effects:
No Human GHG Emissions

REF: Hegerl, G.; Zwiers, F.; 2011: **Use of models in detection and attribution of climate change**, Article first published online: 26 May 2011, Wiley Interdisciplinary Reviews: Climate Change, Vol. 2 Issue 3.
Meehl, G.A.; Stocker, T.F.; Collins. W.D.; Friedlingstein P.; Gaye, A.T.; Gregory, J.M.; Kitoh, A.; Knutti, R.; Murphy, J.M.; Noda, A.; Raper, S.C.B.; Watterson, I.G.; Weaver A,J.; Zhao, Z.C.; 2007**: Global climate projections - climate change 2007: The Physical Science Basis**, Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on climate change (IPCC). Cambridge University Press, Cambridge, UK.

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Before any “forecasting” is carried out, the validity of GCM’s is verified by making sure they can “backcast” and replicate the past behaviour of Earth. This “backcasting” is done by running simulations against existing records of the past climate, using past emission data.

This is what established the role of human emissions in the current climatic change. Temperature records of the past 150 years could only be replicated when the increased atmospheric concentrations of GHG’s were taken into account. Because most of those GHG’s are result from industrial emissions, it is now well established the ongoing climate change is “largely the result of human activities” which have “very likely caused most of the observed global warming over the last 50 years” regardless of the influence of all other factors.

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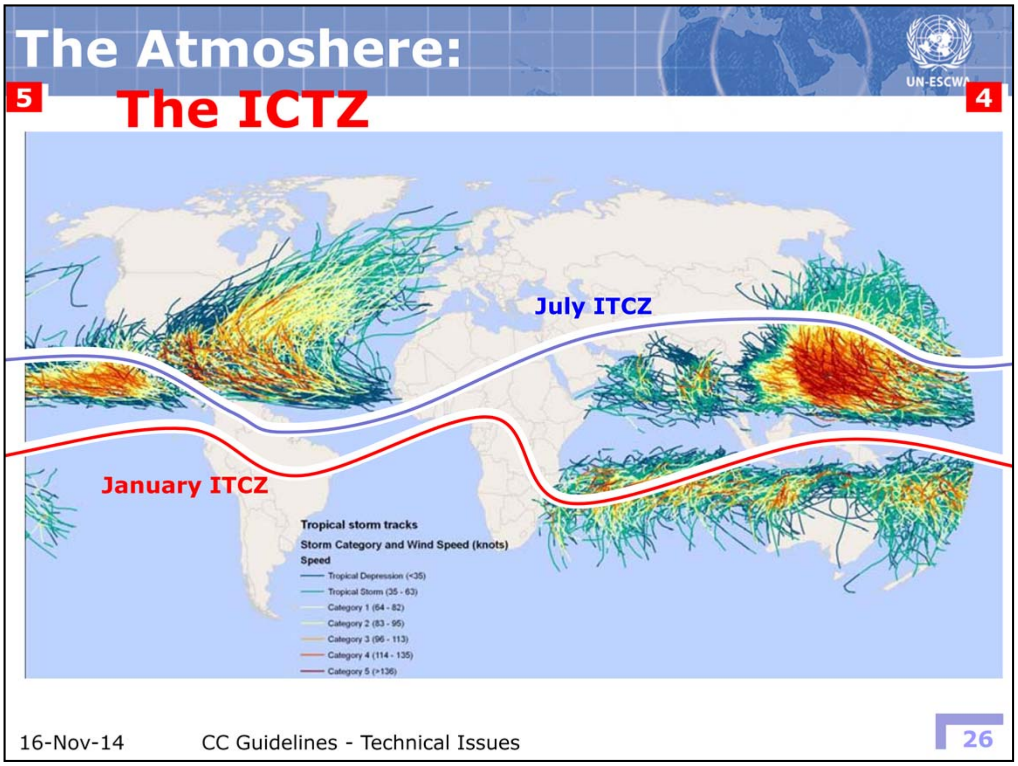

The Atmoshere:

5

The ICTZ

4

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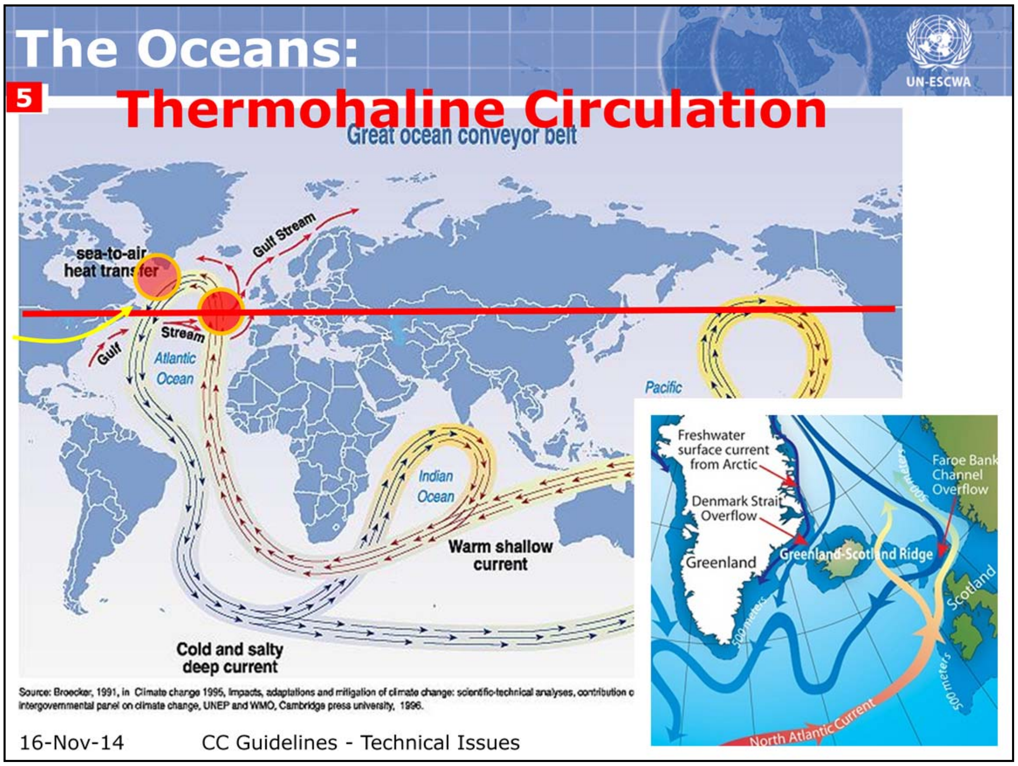
At the regional level, this may prove to be the most critical source of uncertainty, as it may be related to the fact that GCM's still struggle to properly simulate variations in some key climatic events such as "El Niño-Southern Oscillation" (ENSO) and the "Inter-Tropical Convergence Zone" (ITCZ). While the effects of those large scale climatic oscillations tends to be more pronounced at the regional level, their regional impacts remain hard to simulate, particularly in varied topographies where extreme climatic events may differ from one basin to another.

The Arab Region is affected by weather patterns that develop well outside its boundaries, such as changes in either the "El Niño-Southern Oscillation" (ENSO) and the "Inter-Tropical Convergence Zone" (ITCZ). In spite of "overall improvement in the AOGCM simulation of the spatial pattern and frequency of" the crucial ENSO episodes in the Pacific Ocean and its interaction with the ITCZ remains poorly understood



The Oceans:

5 **Thermohaline Circulation**

Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution c intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

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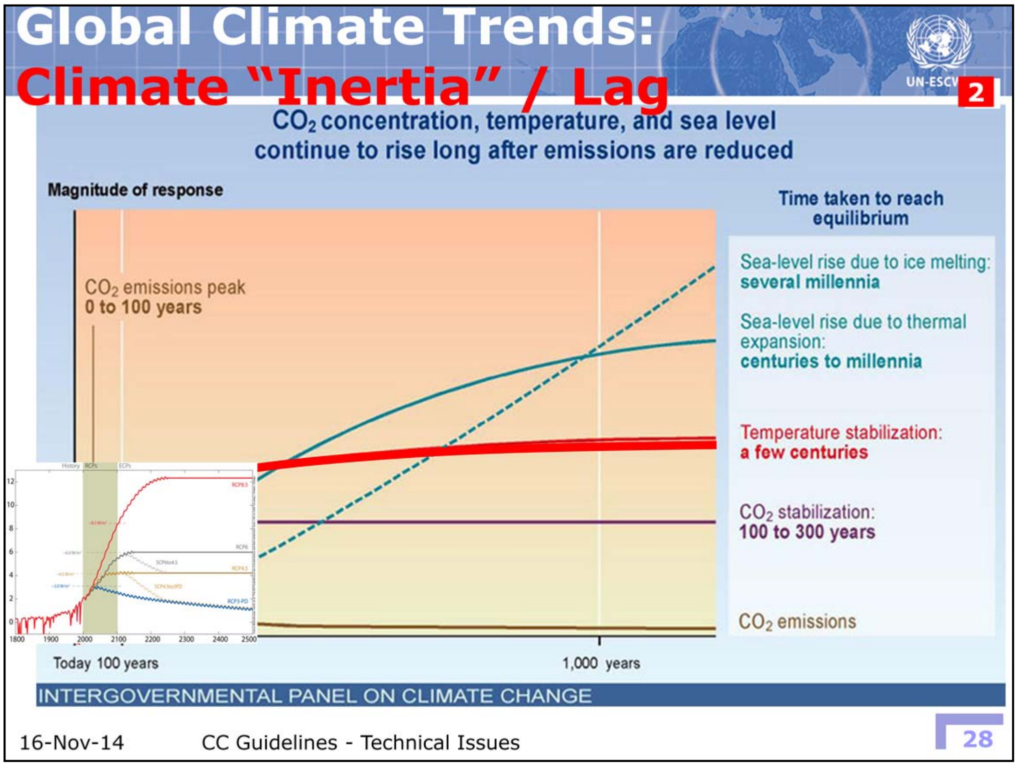
At the present rate of emissions, GHG’s tend to accumulate in the atmosphere much faster than they are removed by other natural processes. This could cause **irreversible effects**, because the climatic history of earth suggests that, on the very long run, climate change may not be smooth.

When the climate is stable, it tends to oscillate around an equilibrium point. Under current conditions of continuously rising GHG levels, this equilibrium point appears to be shifting towards higher average temperatures. As GHG’s accumulate, a “**critical threshold**” could be reached where climate could abruptly shift to another equilibrium point. However, this “tipping point” and the new equilibriums are “notoriously hard to predict” by other than empirical evidence



Global Climate Trends:

Climate "Inertia" / Lag

CO₂ concentration, temperature, and sea level continue to rise long after emissions are reduced

Time taken to reach equilibrium

Sea-level rise due to ice melting: **several millennia**

Sea-level rise due to thermal expansion: **centuries to millennia**

Temperature stabilization: **a few centuries**

CO₂ stabilization: **100 to 300 years**

CO₂ emissions

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Over time, changes in climate acquire a momentum of their own.

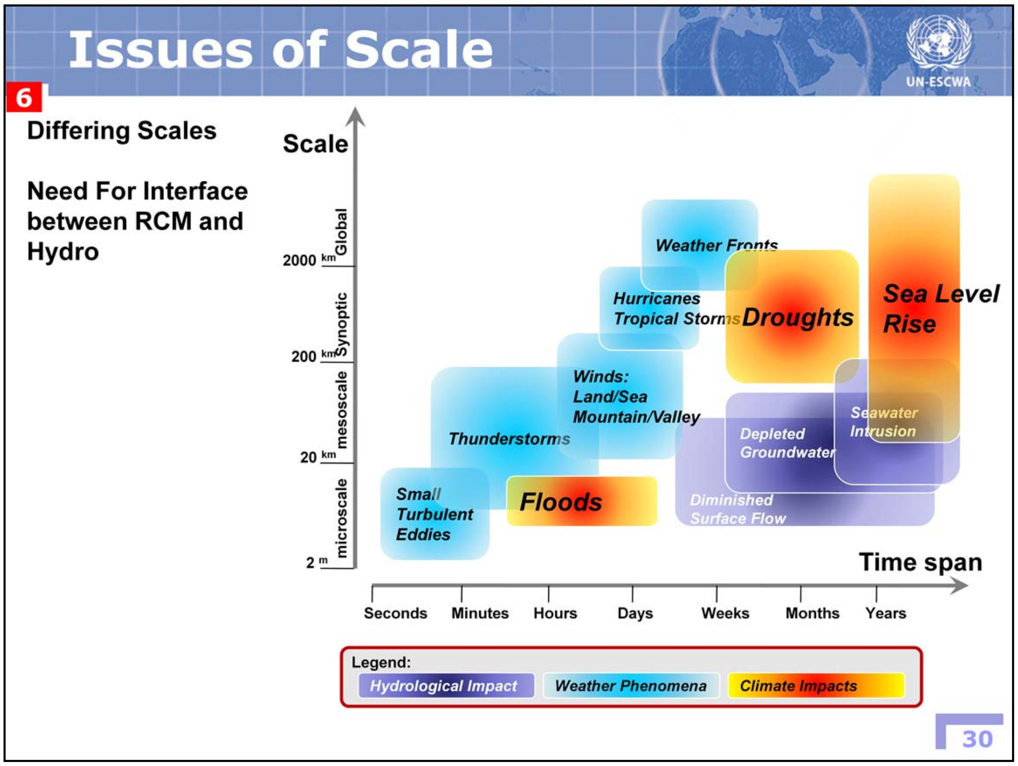
This is mostly because of water's "thermal inertia", which means that the oceans tend to store and release excess energy slowly. On earth, because the oceans cover more than 70% of the surface, the planet warmed much slower than it would have under the current enhanced Greenhouse effect.

The current climate change is therefore a delayed reaction to past emissions of GHG's. As a result, future changes will depend largely on today's mitigation efforts aimed at decreasing atmospheric GHG concentrations. Furthermore, because of the ocean's thermal inertia, the climate is likely to "adjust" slowly to any mitigation efforts; even if GHG emissions were reduced and the amount of CO2 equivalent peaked within the next 100 years, climate change will continue on its acquired momentum. Surface air temperature are likely to continue rising for a century, before stabilizing. The ocean's thermal inertia is such that their thermal expansion will continue, and ice-cap melting will not stop right away. Both factors will continue to contribute to the rise in sea levels

Outline

1. Science, Engineering, Policy
2. Climate Change
3. Some Nuances
4. What we know
5. What we don't know

6. Policy Formulation & Climate Change



Issues of Scale

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6

Differing Scales

Need For Interface between RCM and Hydro

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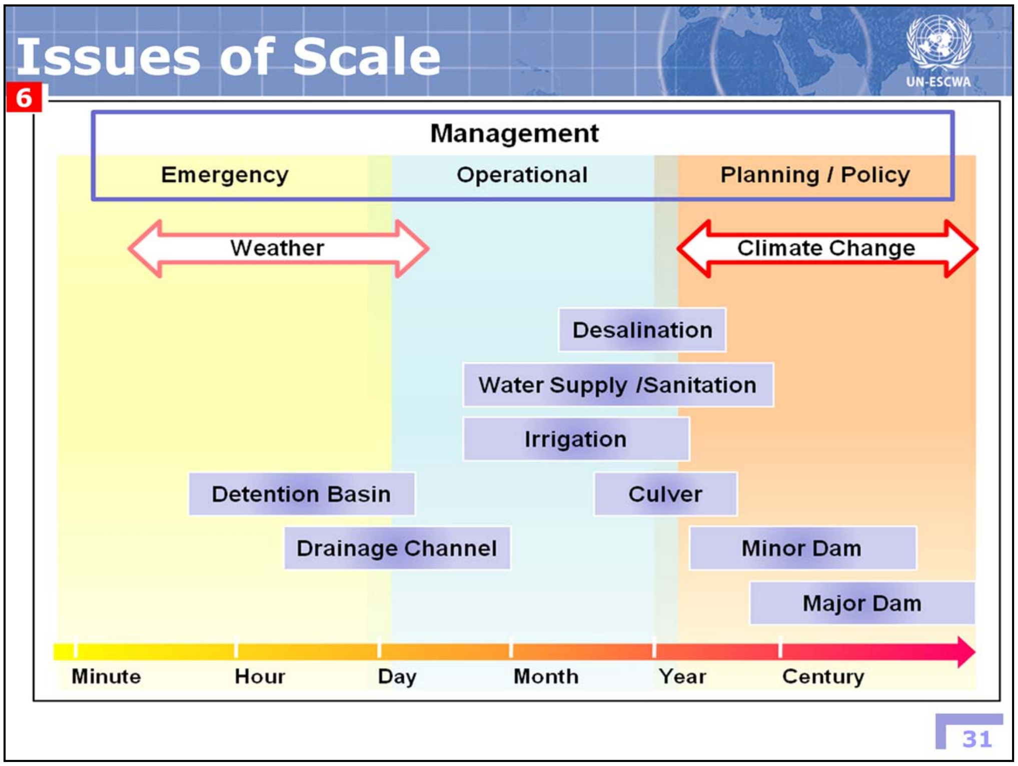
Climate models cannot be linked directly to hydrological models. Any “straight” linking of climate models and hydrological models would yield poor results, since the outputs of GCM’s and RCM’s preclude “their direct use for hydrological impact studies”.

This is because the main challenge in linking RCM’s to hydro-M’s is the issue of scale; while the water cycle is essentially the climate cycle, the scales of the simulated phenomena are different.

Climate models were designed with coarse grids to evaluate large scale events, and even when scaled down to RCM. Any lateral transfer of water between grid cells that is implemented deal with large volumes over large distances, and RCM’s grid remain far too large for the resolutions required by Hydro-M’s.

In turn, by Hydro-M’s were initially designed to manage hydrological basins, and were operated for time intervals that are far below those of climate models. Fowler et al., 2007, p.1557.



Issues of Scale

6

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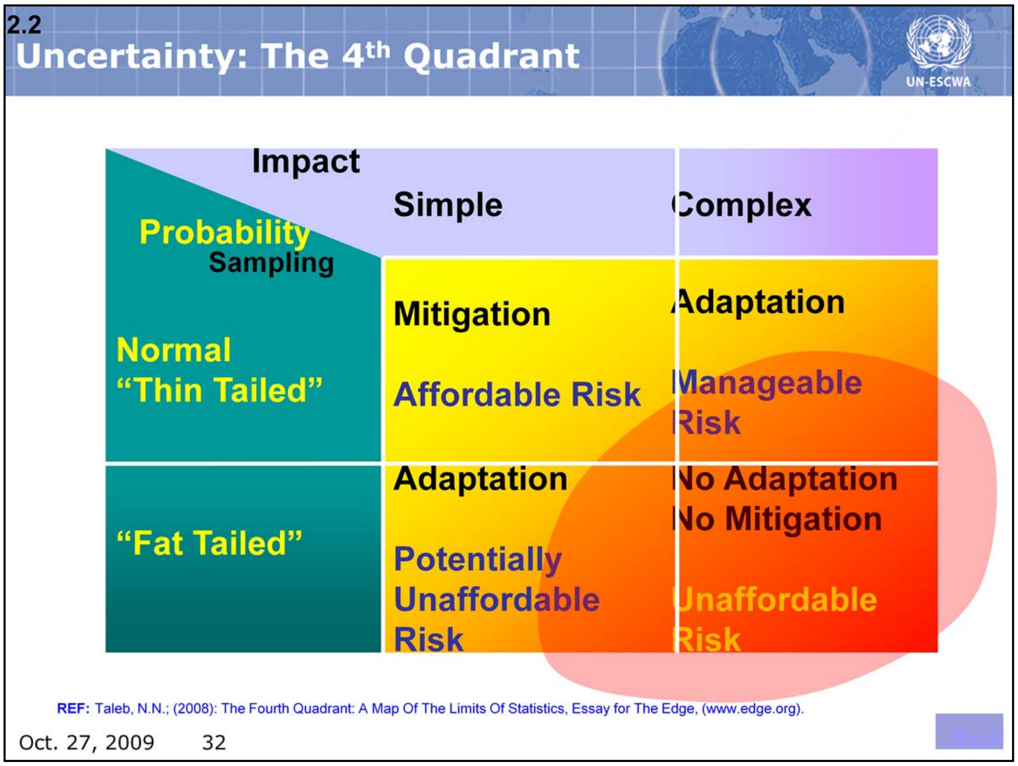
To scientists, the main challenge is related to their unprecedented level of complexity. This complexity is related to the “multi-level” nature of environmental challenges, where causes, consequences, and responses span multiple levels, from the local to the global. in addressing those challenges, scientists approach them by striving to integrate the current state of knowledge across various disciplines in a context of uncertainty.

Policy makers also face a challenge in implementing a “radical shift” in the relationship between knowledge and action, away from “centralized, top-down assessment efforts”. At some levels, policy makers can still respond within shorter time-frames; those are the domains of “emergency” and “operational” management. However, issues involving planning and policy are now in the domain of climate change, and require approaches that extend across multiple disciplines, levels and scales Cash and Clark, 2001, p.10.



2.2

Uncertainty: The 4th Quadrant

Impact Probability Sampling	Simple	Complex
Normal “Thin Tailed”	Mitigation Affordable Risk	Adaptation Manageable Risk
“Fat Tailed”	Adaptation Potentially Unaffordable Risk	No Adaptation No Mitigation Unaffordable Risk

REF: Taleb, N.N.; (2008): The Fourth Quadrant: A Map Of The Limits Of Statistics, Essay for The Edge, (www.edge.org).

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In many ways, uncertainty lies at the heart of science. This challenge is confronted differently in either mathematics and the physical sciences In Mathematics, clear cut algorithms are used to prove the falsehood of a theorem. In the physical sciences, theories are based on hypotheses which are tested by “falsification”, as a single result can falsify them. In confronting uncertainty, scientists follow either of two approaches;

Bound the Uncertainty. This is done in normal scientific study, when scientists isolate the studied system or its components. They then proceed to identify and investigate any “unknowns” and resolving them one by one.

Manage Uncertainty. Rather than attempting to “break up” the system in its core components, scientists focus is on creating models, or “representations of reality”. They use those models to investigate its a system’s response to various disturbances under various scenarios.

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Thank You

1. Science, Engineering, Policy
2. Climate Change
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