Questions and Answers on findings from the IPCC Fifth Assessment Report (AR5)

1. How are the future emissions scenarios used in the IPCC Fifth Assessment Report (AR5) different from those in the previous IPCC Fourth Assessment Report (AR4)?

The emissions scenarios used in AR4 were based on alternative socio-economic futures for the world. They incorporated a wide range of different assumptions regarding population, economic growth, technological innovation and attitudes to social and environmental sustainability.

AR5, on the other hand, takes a different approach. It does not start by specifying socio-economic storylines and calculating the associated emissions scenarios. Instead it uses greenhouse gas concentration pathways for the future that are compatible with the range of emissions scenarios available in the current scientific literature. In AR5, mitigation policies were also included. A representative subset of four of these scenarios, known as Representative Concentration Pathways[1] (RCPs), was then used as the "input" to drive climate models.

Emissions scenarios should not be confused with the future *climate scenarios* which arise from the climate model projections. Climate scenarios are the "output" of AR5, and describe plausible trajectories that can be used to investigate the potential consequences of human-induced climate change. With climate scenarios, the goal is not to make pinpoint predictions of the future, but to better understand alternative futures and their uncertainties. This allows policymakers to consider different actions to take under a wide range of possible outcomes.

2. How are the models used in AR5 different to those in AR4?

First, there are a larger number of models used in AR5 than in AR4. Second, models in AR5 generally have a better spatial resolution, which contributes to an improved treatment of the climate processes on a finer scale, enabling an enhanced simulation of regional variations in climate. Third, some models used in AR5 include new interactive 'Earth System' processes, such as the carbon cycle feedback, and are thus able to project future climate more realistically.

Models also need to be evaluated before they are deemed reliable enough for use. There has been a more elaborate evaluation of climate models in AR5, for example the role of cloud processes in climate change.

3. What are the past observed and future projected changes in surface temperature and what is their significance for Singapore?

The global average surface temperature referred to in the IPCC report is the temperature averaged over all the climatic regions of the world, including the tropics where Singapore is situated. The observed and projected global trends are generally relevant to our region although there will be deviations from country to country. There is a strong correlation between the observed global and Singapore's mean surface temperature trends.

[1] The AR5 RCPs are defined by their year 2100 total radiative forcing and range from 2.6 W m^{-2} for RCP2.6 to 8.5 W m^{-2} for RCP8.5.

AR5 analysis of the Past: Averaged across the world, combined land and ocean surface temperature data show an increase of approximately[2] 0.85°C over the period 1880 – 2012. Over this period, almost the entire world has experienced surface warming. Surface temperature trends exhibit substantial variability between decades and longer periods, and this is superimposed on the longer term warming since 1901. The rate of warming over the past 15 years (0.05°C per decade) is smaller than the trend since 1951 (0.12°C per decade). This is due to a global cooling contribution arising from natural variability within the climate system, which can cause shorter-term changes in temperature, and a reduced trend in warming due to increased volcanic activity and cyclical changes in solar activity.

Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased in many places across the world.

The rate of warming over Singapore from[3] 1951−2012 was 0.26°C per decade. This is more than double when compared with the global trend over the same period of 0.12°C per decade. In addition to regional variations in man-made global warming, regional long term natural climate variability and the urbanisation of Singapore may have contributed to the enhanced trend over Singapore. Along with many other regions of the world, since the 1970s Singapore has experienced more frequent warm days and nights.

AR5 projection of the Future: The increase in average surface temperatures across the world from 2081–2100 is projected to likely be in the range[4] 0.3–1.7°C for the lowest greenhouse gas scenario RCP2.6, which assumes the minimum projected change in greenhouse gas concentrations, and in the range 2.6–4.8°C for the highest scenario RCP8.5, which assumes the maximum projected change. The temperature rise for each scenario is given as a range mainly because of the scientific uncertainties in the modelling of the climate system.

Singapore's climatological average daily maximum temperature is 31°C (over 1972–2012) and over the last 40 years we have experienced temperatures above 34°C typically 10% of the time. The highest temperature recorded was 36°C in March 1998. As an illustration, a future rise of 3°C in Singapore's average temperature would mean the daily maximum temperatures that now typically occur 10% of the time (i.e. above 34°C) would become the average daily maximum temperature. Such increases in temperature could be significant because higher temperatures lead to increased heat stress on both humans and natural systems. Higher temperatures also mean more energy use because of the increased need for air conditioning.

As part of Singapore's Second National Climate Change Study, carried out by the Centre for Climate Research Singapore in collaboration with the UK Met Office, projected temperature ranges for Southeast Asia and Singapore will be studied in detail.

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[2] The IPCC report provides error bars on this type of estimate. For example for the global warming figure it is 0.85 [0.65 to 1.06] °C.

[3] To enable comparison with the IPCC figures, these values are based on linear fitted trends over the time periods indicated.

[4] For all scenarios: 0.3 to 1.7°C (RCP2.6), 1.1 to 2.6°C (RCP4.5), 1.4 to 3.1°C (RCP6.0), 2.6 to 4.8°C (RCP8.5). All are relative to 1986 – 2005.

4. What are the past observed and future projected changes in rainfall and what is their significance for Singapore?

Predicting rainfall in the tropics is a major challenge and is currently an active area of research in the scientific community. As such, care must be taken in interpreting how large scale changes in rainfall (as described in the AR5 WGI SPM) translate into the consequences for Singapore at country/city-scale.

> AR5 analysis of the Past: In assessing changes in precipitation (which includes rain, hail and snow) averaged across the world, it has remained difficult to discern significant long term world-wide trends due to insufficient geographical data coverage. Across the world there are likely more land regions where the number of heavy precipitation events has increased than where it has decreased.

Generally, in Singapore we have observed upward trends in the frequency and intensity of short duration heavy rainfall over the past few decades. Over this period, the number of days each year with heavy rainfall of more than 70 mm in an hour increased from 5 in 1980 to 10 in 2012. The annual maximum rainfall intensity in an hour also increased from 80 mm in 1980 to 107 mm in 2012. There was no significant trend observed for prolonged dry spells over this period. However it is not scientifically possible, using current models, to attribute these observed rainfall changes in Singapore to global warming, natural variability or other effects (e.g. urbanisation).

> AR5 projection of the Future: There are substantial geographical variations in the confidence ascribed to the future projected rainfall. In our region, there is considerable uncertainty in the projection of average rainfall. Some models project future increases in average rainfall, whilst others project decreases. In a warmer world however, extreme precipitation events over wet tropical regions will very likely become more intense and more frequent.

Despite the uncertainty in future average rainfall in our region, we should expect more intense and more frequent extreme rainfall events. This is significant because increases in both average and extreme rainfall will have an impact in Singapore. Changes in average rainfall could put pressure upon water resources. Increased frequency or intensity of extreme rainfall can lead to more frequent or severe flash flooding, putting pressure on drainage systems.

Quantitative estimates of future local rainfall changes, that are consistent with the AR5 results, will be derived as part of Singapore's Second National Climate Change Study.

5. What are the past observed and future projected changes in sea level rise and what are their significance for Singapore?

Care must be taken in interpreting how global projections of sea level rise translate to local projections specific to Singapore. This is because oceanographic regional variations and local land movements have a significant effect and must also be taken into account.

> AR5 analysis of the Past: Based on historical data, the rate of global mean sea level rise has accelerated during the last two centuries. It is very likely that the mean rate of global averaged sea level rise was 1.7[2] mm yr^{-1} for 1901−2010 (i.e. a total rise over this period of 0.19 m) and 3.2[2] mm yr^{-1} for 1993−2010.

Recent studies indicate that annual measured sea levels in Singapore Strait rose at the rate 1.2–1.7 mm yr^{-1} for 1975 – 2009[5]. These values of measured sea level rise are broadly consistent with the global average estimates. It is noteworthy, however, that sea levels appeared to rise more gradually than the global average over 1901 – 2010, and more rapidly than the global average over 1993 – 2010.

> AR5 projections of the Future: Global mean sea level rise for 2081−2100 will likely be in the ranges[6] of 0.26–0.55 m for RCP2.6 and 0.45–0.82 m for RCP8.5. For RCP8.5, the projected range in year 2100 is 0.52–0.98 m. In some coastal locations, past and current glacier and ice sheet mass loss, tectonic processes, coastal processes, and local human activities are also important contributors to changes in sea level relative to the land. Larger sea level rise could result from sustained loss of ice sheets. In particular, a near-complete loss of the Greenland Ice Sheet over a millennium or longer, would cause a global mean sea level rise of up to 7 m compared to present day. Further research is required to increase the confidence in these very long term projections.

Quantitative projections of sea level rise based on the latest AR5 findings and local information on land movement will be derived for Singapore as part of the Second National Climate Change Study.

6. How important are vertical land movements around Singapore in estimating future sea level rise? *Contribution from the Earth Observatory of Singapore (Asst. Prof. Emma Hill).*

AR5 provides projections of global sea level rise and does not comment on very specific locations. At the local level, however, vertical land movements also affect the relative sea level.

One scenario that is significant for Singapore is the possibility of downward motion of the land during the years and decades following a major earthquake in the region. There is a good example of this process already taking place: following the 2004 Aceh-Andaman earthquake, parts of Thailand have been moving downward by as much as 1 cm per year due to the longer-term effects of that earthquake.

Research by the Earth Observatory Singapore (EOS) shows that a large earthquake is likely to take place sometime in the coming decades in West Sumatra province, though it cannot be predicted exactly when this may happen. Singapore could experience downward land movement in the years to decades following this earthquake, similar to the situation in Thailand post-2004. EOS is conducting further research to estimate the amount and rate of downward motion of the land around Singapore that may result from this scenario earthquake in West Sumatra. Any such downward motion of the land would increase the rate of sea level rise.

7. How do the AR5 sea level rise (SLR) estimates differ from those in AR4?

Overall, in AR5 the projected ranges of global sea level are higher than in AR4. It is worth noting, however, that because greenhouse gas emission scenarios and reference time periods in AR4 and AR5 were approached differently, a direct comparison of estimates is not possible.

- In AR4 for the A1FI scenario (maximum projected change in emissions), the projected SLR was in the range 0.26–0.59 m for the time period 2090–2099 relative to 1980–1999.

[5] The range in values comes from the spread of measurements at different locations in the Singapore Strait.

[6] For all scenarios: 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5. All values are relative to the time period 1986-2005.

- In AR5 for the RCP8.5 scenario, the projected range is 0.45–0.82 m for the time period 2081–2100 relative to 1986–2005.

As in AR4, thermal expansion (where water increases in volume due to higher temperatures) is still cited in AR5 as the largest contributor to SLR. The second largest contribution comes from melting glaciers.

Models used in AR4 did not include the full effects of changes in ice sheet flow (the slow movement of ice sheets towards the ocean). Scientific understanding at the time was not sufficient to allow an assessment of the possibility of future rapid changes in ice sheet dynamics. The projections in AR5 include rapid changes in outflow from both the Antarctic and Greenland ice sheets, and this will likely make a contribution to global sea level in the range of 0.03 to 0.20 m by 2081 – 2100.

8. What changes in specific regional climate phenomenon may impact Singapore?

In its natural state, the Earth exhibits variability that can take place at a range of time scales and spatial scales. The El Niño-Southern Oscillation (ENSO), for example, is a phenomenon that involves fluctuating ocean temperatures in the equatorial Pacific, with a cycle of 2 – 7 years. The AR5 reports that ENSO will very likely remain a dominant source of variability in the tropical Pacific, with global influences in the 21st century. With climate change, AR5 also suggests that the variability of rainfall related to ENSO will likely intensify. This intensification may impact Singapore particularly in the Southwest monsoon season.

AR5 also includes an analysis of global monsoon systems and provides indication as to how these systems may change in the future. The implications of these changes for the dominant Northeast monsoon system in our region are not clear and more focused regional studies are required before detailed conclusions can be drawn.

9. What is said about the future likelihood of heavy rainfall and flooding in Singapore?

In a warmer world, extreme rainfall events over wet tropical regions will very likely be more intense and more frequent by the end of this century. In our region we should therefore expect more intense and more frequent extreme rainfall events, and quantitative estimates of these changes will be derived as part of Singapore's Second National Climate Change Study.

10. What about the future likelihood of droughts?

In many mid-latitude and subtropical regions, mean precipitation (rainfall, snow etc) will likely decrease by the end of this century. Phenomena such as the ENSO in the tropical Pacific and the Indian Ocean Dipole (IOD)[7] may be influenced by global-scale changes in the atmosphere and this may lead to an increased incidence or severity of dry conditions in the region around Singapore. Further work is required to better quantify these effects.

[7] The Indian Ocean Dipole (IOD) is a coupled ocean and atmosphere phenomenon in the equatorial Indian Ocean. It can lead to fluctuations in sea surface temperature that then influence rainfall in remote regions.

11. The AR5 report has a lower bound on equilibrium climate sensitivity than that given in AR4. Does this mean that climate change may be a less serious issue than previously thought?

Equilibrium Climate Sensitivity (ECS) is defined as the change in global average surface temperature at equilibrium (i.e. after sufficient time has passed for the climate system to fully adjust) that is caused by a doubling of the atmospheric CO_2 concentration. AR5 suggests that ECS is likely to range between 1.5–4.5°C, compared to the previously reported 2.0–4.5°C in AR4. It is also assessed in AR5 to be extremely unlikely for the ECS to be under 1.0°C and very unlikely to exceed 6.0°C. The reduction in the lower bound on ECS from 2°C to 1.5°C does not suggest that climate change is a less serious issue. Consideration needs to be given to the full range (1.5–4.5°C) rather than only the lower bound.

12. What part does the urbanisation of Singapore play in our locally observed climate changes?

As urban areas develop, changes occur in the landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry; this development leads to the formation of an Urban Heat Island (UHI) – the phenomenon whereby urban regions experience warmer temperatures than their rural surroundings.

In terms of their localised effects, there are similarities in the impacts from UHI and global climate change. For example, UHI and global climate change can both increase energy demand in Singapore, particularly air conditioning demand and associated greenhouse gas emissions. In the First National Climate Change Study, the Urban Redevelopment Authority (URA) worked together with the Housing Development Board (HDB), Jurong Town Corporation (JTC), Building and Construction Authority (BCA) and NEA to better understand the impact of urban morphology and climate change on the urban temperature profile and energy consumption (UTPEC). (Findings are in Question 14.)

13. Given the progress at international negotiations, which AR5 climate scenario is most likely to manifest?

Annual average levels of CO_2 in the atmosphere are now above 394 ppm (parts per million by volume), the average for 2012 measured from the National Oceanic and Atmospheric Administration's Mauna Loa Observatory. There is, however, an annual variation in the atmospheric CO_2 concentration and the peak earlier this year hit 400 ppm. Both the 2012 concentration and the concentration trend since 2000 are within the range of the four scenarios used in AR5. It is also worth noting that up to about 2025, there is very little difference in the projections for all four scenarios.

Looking ahead, the trajectory will be highly dependent on energy and climate policies, particularly those of major economies.

14. How is Singapore taking into account the latest AR5 projections?

In light of the long term nature of climate change, Singapore is not sitting back but is taking a proactive approach. Our plans will be continuously reviewed and adjusted as new knowledge and information on the effects of climate change become available. Through the First National Climate

Change Study, which made use of IPCC AR4 Greenhouse Gas Emission Scenarios to project the effects[8] and look at the impacts of global climate change on Singapore up to the year 2100, we have gained a preliminary understanding of how climate change could affect Singapore. Phase 2 of the study concluded this year (2013), and particularly looked into the impacts of climate change effects on public health, the urban temperature profile and energy consumption of buildings, and tropical biodiversity.

Through the study, climate change was found to have some impact on respiratory disease, although not the main factor. Transboundary haze is one possible factor that could lead to respiratory disease. Together with the Ministry of Health (MOH), NEA coordinates measures for haze-related illness through the National Haze Task Force. (Elaborated further in Question 15.)

With regard to urban temperature profile and energy consumption, urban morphology was found to strongly influence temperature at both the macro and micro scale levels. Of the morphology factors, greenery had the highest impact, followed by building height and building density. Reduction of heat gain through the use of appropriate materials, paints and glazing was found to be effective. It was also determined that an expected increase in indoor air temperature from climate change could adversely affect thermal comfort. The Urban Redevelopment Authority (URA) is working together with the Housing Development Board (HDB), Jurong Town Corporation (JTC), the Building Control Authority (BCA), National Parks Board (NParks) and NEA to better understand the effects of urbanisation together with climate change, and will work towards identifying possible measures to ameliorate the effects.

Findings also showed that past fragmentation of Singapore's forest makes them vulnerable to future long-term changes such as increased likelihood or duration of drought, and higher average temperatures. Wetlands may be at risk to water quality changes related to warming and changes in precipitation which may "drown" or "dry" the wetlands. To help our biodiversity withstand the potential impacts of climate change, NParks plans to work with other agencies and the community to safeguard existing species, connect fragmented patches, and enhance the resilience of ecosystems. This includes measures to restore forest and mangrove areas, diversify plant species and intensify planting, increase connectivity between green areas, and minimise number of fallen trees through intensified inspections and pruning. Monitoring will be necessary to assess the effectiveness of measures taken, so as to refine and improve them in the long term.

As updated information becomes available, we will take these into account to guide our adaptation planning with a stronger scientific basis. Following AR5, Singapore's Second National Climate Change Study (carried out by the Centre for Climate Research Singapore in collaboration with the UK Met Office), will provide localised updated projections of temperature, rain, wind and sea level changes. It will be completed by end of 2014 and will be useful to various government agencies in updating the findings on the impacts of climate change from the first study.

[8] The study indicated that by 2100, average temperatures could increase by 2.7 to 4.2 degrees, while average sea levels could increase by 0.24 to 0.65m, not inclusive of ice-sheet melt. The IPCC projections from AR4 did not include uncertainties due to possible increased future ice flows in Greenland and West Antarctica. Estimates at the time of AR4 put this additional rise in the region of 0.2m.

15. Do these new findings imply anything for future risks of smoke haze and dengue events?

Haze

In Southeast Asia, forest and peat land fires are commonly caused by the use of slash-and-burn methods to clear land for agriculture. If this does not change, human activity will still be a root cause of major haze events. However, the severity of smoke haze events could be affected by climate change in two main ways.

Firstly, rising temperatures and reduced rainfall would make it conducive for fires to start and to spread. For example, from 1997–1998, a prolonged drought caused by the El Niño-Southern Oscillation (ENSO) led to widespread fires in large areas of peatlands in Sumatra and Kalimantan. Secondly, wind patterns could change over Southeast Asia and further work beyond that in AR5 is required to assess these effects. Smoke haze from land and forest fires in neighbouring countries is carried to Singapore by the prevailing wind. Should there be a shift in the existing wind patterns (eg more frequent southwesterly or westerly low level winds), the risk of transboundary smoke haze affecting Singapore could increase accordingly.

Singapore views the transboundary haze issue very seriously. Transboundary haze creates health and social problems for all in the region, and has adverse impacts on the economy, tourism and the transportation/aviation industry. Together with the Ministry of Health (MOH), NEA coordinates measures for haze-related illness through the National Haze Task Force.

Dengue and vector-borne diseases

Dengue and various other vector-borne diseases are ‘endemic’ to Singapore and the region, meaning that there is a sufficiently large susceptible group that keeps the disease process active. A large part of disease risk also arises from the spread of the vector – in the case of dengue, mosquitoes. Human actions are important in reducing the spread of the vector. However, although not the main factor, the occurrence of vector-borne diseases could be affected by climate change. Historically, more dengue cases are observed during the warmer periods of the year.

To minimise dengue incidence through suppressing the mosquito vector population, NEA has put in place a nation-wide integrated programme, which entails mosquito, virus and human surveillance as well as public education and participation, law enforcement and research. NEA is also collaborating with the Ministry of Health to study the relationship between climatic factors – such as temperature, humidity and rainfall – and public health risks such as dengue fever, and heat disorders and respiratory diseases. The study will also look into forecasting the risk of disease transmission under different scenarios. NEA’s Environmental Health Institute (EHI), a World Health Organisation Collaborating Centre for the Reference and Research of Arbovirus and their Associated Vectors, will leverage its research capability in vector-borne diseases to support efforts to strengthen Singapore’s public health resilience to climate change.