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SCIENTIFIC ASSESSMENTS

CONSIDERATION OF THE SECOND ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Addendum

THE SCIENCE OF CLIMATE CHANGE: CONTRIBUTION OF WORKING GROUP I OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Note by the secretariat

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I. INTRODUCTION

1. The Working Group on Scientific Assessment (WG I) of the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and re-established in 1992 to assess available information on the science of climate change, in particular that arising from human activities. The most important aspects were:

(a) Developments in the scientific understanding of past and present climate, of climate variability, of climate predictability and of climate change including feedbacks from climate impacts;

(b) Progress in the modelling and prediction of global and regional change of climate and sealevel change;

(c) Observations of climate, including past climates, and assessment of trends and anomalies;

(d) Gaps and uncertainties in current knowledge.

2. The first IPCC Scientific Assessment completed in 1990 as part of the First Assessment Report (IPCC (1990)) concluded that the increase in atmospheric concentrations of greenhouse gases since pre-industrial times had altered the energy balance of the Earth and that global warming would result.

3. A primary conclusion identified by the 1990 report was the expected continued increase in greenhouse gas concentrations as a result of human activity, leading to significant climate change in the coming century. The projected changes in temperature, precipitation and soil moisture were not uniform over the globe. Anthropogenic aerosols were recognized as a possible source of regional cooling but no quantitative estimates of their effects were available. The 1992 Supplementary Report of Working Group I confirmed, or found no reason to alter, the major conclusions of the 1990 Assessment. It presented a new range of global mean temperature projections based on a new set of IPCC emission scenarios (IS92 a to f) and reported progress in quantifying the effects of anthropogenic aerosols.

4. The 1994 Working Group I report on Radiative Forcing of Climate Change provided a detailed assessment of the global carbon cycle and of aspects of atmospheric chemistry governing the abundance of non-CO_2 greenhouse gases. Some pathways that would stabilize atmospheric greenhouse gas concentrations were examined, and new or revised calculations of the global warming potential for 38 species were presented.

5. The IPCC Second Assessment Report on the Science of Climate Change presents a comprehensive assessment of climate change science as at 1995, including updates of relevant material in all three preceding reports. Key issues examined in the Second Assessment Report concern the relative magnitude of human and natural factors in driving

climate change, including the role of aerosols; the estimation of future climate and sealevel change on both global and continental scales; and whether any human influence on present-day climate can be detected.

6. An important distinction should be noted with respect to the term "climate change". In the Second Assessment Report the term refers to change arising from any source, human or natural. Within the United Nations Framework Convention on Climate Change, this term however, refers exclusively to change brought about by human activities (see annex III to the present note). In many instances the two uses will in effect be the same, and this is particularly true for projections of climate change over the next century.

7. As indicated in document FCCC/SBSTA/1996/7, the contribution of Working Group I will constitute one of the four volumes that make up the IPCC Second Assessment Report. It comprises a Summary for Policymakers and a Technical Summary supported by 11 chapters on relevant scientific issues prepared by teams of scientists with expert knowledge in the respective fields.

8. The purpose of this addendum is to make the material included in the Working Group I contribution more accessible to delegates and to highlight some of the findings. As noted in document FCCC/SBSTA/1996/7, paragraph 19, this is not intended to provide an interpretation of the findings or to serve as replacement for the IPCC text, but as an invitation to consult the Second Assessment Report.

II. MAIN FINDINGS

9. The main findings of the IPCC Working Group I, as adopted by the IPCC at its plenary session in Rome in December 1995, are presented in the Summary for Policymakers of the contribution of Working Group I to the IPCC Second Assessment Report. Copies of the Summary will be available to members of the SBSTA in all official languages of the United Nations.

10. In view of the time constraints, which make it difficult for this Summary to be available in all languages to members of the SBSTA before the start of the session, and in order to avoid excessive duplication, the secretariat has prepared a summary of the main findings of the IPCC, which constitutes annex I to this addendum. In drawing up this summary the secretariat was aware of the difficulties of selecting the findings and presenting them outside the full context of the carefully worded text agreed in the Summary for Policymakers. The presentation in annex I, therefore, is intended primarily to assist delegations that have not received the Summary in their working languages.

III. TECHNICAL SUMMARY AND SUPPORTING CHAPTERS

A. Introduction

11. The Earth absorbs radiation from the Sun, mainly at the surface. The energy is then redistributed by the atmospheric and oceanic circulation and radiated out to space at longer ("terrestrial" or "infrared") wavelengths. On average, for the Earth as a whole, the incoming solar energy is balanced by outgoing terrestrial radiation.

12. Increases in the concentration of greenhouse gases will reduce the efficiency with which the Earth loses energy to space. More of the outgoing terrestrial radiation from the surface is absorbed by the atmosphere and emitted at higher altitudes and colder temperatures. This results in a positive radiative forcing which will tend to warm the lower atmosphere and surface. This is the enhanced greenhouse effect. The amount of warming depends on the size of the increase in concentration of each greenhouse gas, the radiative properties of the gases involved, and the concentration of other greenhouse gases already present in the atmosphere.

13. Any changes in the radiative balance of the Earth, including those due to an increase in greenhouse gases or in aerosols, will tend to alter atmospheric and oceanic temperatures and the associated circulation and weather patterns. These will be accompanied by changes in the hydrological cycle (for example, altered cloud distributions or changes in rainfall and evaporation regimes).

14. Any human-induced changes in climate will be superimposed on a background of natural climatic variations which occur on a whole range of space- and time-scales. To distinguish anthropogenic climate changes from natural variations, it is necessary to identify the anthropogenic "signal" against the background "noise" of natural climate variability.

15. The IPCC Working Group I has conducted a full assessment of scientific and technical knowledge and understanding of possible climate change due to anthropogenic emissions into the atmosphere. The data for this assessment, which includes conflicting views, have been collated by teams of lead authors, who are eminent in their respective fields and are drawn from developing and developed countries. The data are presented in the 11 chapters supporting the Summary for Policymakers and constituted the basis for the IPCC findings, the more important of which are presented in annex I to this addendum.

B. Observations

16. Annex II provides tables of contents and some observations on the contents of each of the 11 supporting chapters as well as on the preceding Technical Summary. Since the Technical Summary and the 11 supporting chapters will not be available to the SBSTA at its forthcoming session, members of the SBSTA are encouraged to contact their national IPCC focal points for appropriate briefing and advice, as necessary, and to consult the corresponding texts.

Annex I

MAIN FINDINGS OF IPCC WORKING GROUP I

As indicated in the Summary for Policymakers of the contribution of Working Group I to the Second Assessment Report, the main conclusions of the IPCC, in the light of new data and analyses since 1990, are as follows:

(a) Greenhouse gas concentrations have continued to increase

- Since pre-industrial times (around 1750), the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased by 30 per cent, 145 per cent and 15 per cent respectively (1992 values), largely owing to human activities, mostly fossil fuel use, land-use change and agriculture

- The direct radiative forcing* of the long-lived greenhouse gases is due primarily to increases in the concentrations of CO_2, CH_4 and N_2O

- At present, some long-lived greenhouse gases (particularly HFCs (a CFC substitute), PFCs and SF_6) contribute little to radiative forcing but their projected growth could contribute several per cent to radiative forcing during the 21st century

- If carbon dioxide emissions are maintained at near current (1994) levels, they could lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about 500 ppmv (approaching twice the pre-industrial concentration of 280 ppmv) by the end of the 21st century

- A range of carbon cycle models indicates that stabilization of atmospheric CO_2 concentrations at 450, 650 or 1000 ppmv could be achieved only if global anthropogenic CO_2 emissions drop to 1990 levels by, respectively, approximately 40, 110 or 240 years from now, and drop substantially below 1990 levels thereafter

- For a given stabilized concentration value, higher emissions in early decades require lower emissions later on

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* A simple measure of the importance of a potential climate change mechanism. Radiative forcing is the perturbation to the energy balance of the Earth-Atmosphere system (in watts per square metre [Wm^{-2}]).

- Stabilization of CH_4 and N_2O concentrations at today's levels would involve reductions in anthropogenic emissions of 8 per cent and more than 50 per cent respectively

(b) Anthropogenic aerosols tend to produce negative radiative forcings

- Tropospheric aerosols (microscopic airborne particles) resulting from combustion of fossil fuels, biomass burning and other sources have led to a negative direct forcing of about 0.5 Wm^{-2} as a global average, and possibly also to a negative indirect forcing of a similar magnitude

- Locally, the aerosol forcing can be large enough to more than offset the positive forcing due to greenhouse gases

- In contrast to the long-lived greenhouse gases, anthropogenic aerosols are very short-lived in the atmosphere and therefore do not spread far beyond their place of origin

(c) Climate has changed over the past century

- Global mean surface temperature has increased by between about 0.3^o and 0.6^oc since the late 19th century

- Recent years have been among the warmest since 1860, despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption

- Regional changes are evident

- Global sealevel has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature

(d) The balance of evidence suggests a discernable human influence on global climate

- Ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate

(e) Climate is expected to continue to change in the future

- The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased confidence in their use for projection of future climate change

- For the mid-range IPCC emission scenario, IS92a, assuming the "best estimate" value of climate sensitivity* and including the effects of future increases in aerosols, models project an increase in global mean surface temperature relative to 1990 of about 2^{o}C by 2100. This estimate is approximately one third lower than the "best estimate" in 1990. This is due primarily to lower emission scenarios (particularly for CO_2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario (IS92c) with a "low" value of climate sensitivity, and including the effects of future changes in aerosol concentrations, leads to a projected increase of about 1^{o}C by 2100. The corresponding projection for the highest IPCC scenario (IS92e), combined with a "high" value of climate sensitivity, gives a warming of about 3.5^{o}C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Because of the thermal inertia of the oceans, only 50-90 per cent of the eventual equilibrium temperature change would have been realized by 2100, and temperature would continue to increase beyond 2100

- Average sealevel is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice sheets. Models project an increase in sealevel of about 50 cm from the present to 2100. This estimate is approximately 25 per cent lower than the "best estimate" in 1990 owing to the lower temperature projection, but also reflecting improvements in the climate and ice melt models. Regional sealevel changes may differ from the global mean value owing to land movement and ocean current change

- A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days

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* In IPCC reports, climate sensitivity usually refers to the long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent $C0_2$ concentration. More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing ($^{0}C/Wm^{-2}$).

- Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Knowledge is currently insufficient to predict whether there will be any changes in the occurrence or geographical distribution of severe storms, for example, tropical cyclones

- Sustained rapid climate change could shift the competitive balance among species and even lead to forest dieback, altering the terrestrial uptake and release of carbon

(f) <u>There are still many uncertainties</u>

Many factors currently limit ability to project and detect future climate change. In particular, to reduce uncertainties, further work is needed on the following priority topics:

- Estimation of future emissions and biogeochemical cycling (including sources and sinks) of greenhouse gases, aerosols and aerosol precursors, and projections of future concentrations and radiative properties

- Representation of climate processes in models, especially feedbacks associated with clouds, oceans, sea ice and vegetation, in order to improve projections of rates and regional patterns of climate change

- Systematic collection of long-term instrumental and proxy observation of climate system variables (for example, solar output, atmospheric energy balance components, hydrological cycles, ocean characteristics and ecosystem changes) for the purposes of models testing, assessment of temporal and regional variability and detection and attribution studies.

Annex II

IPCC WORKING GROUP I - TABLES OF CONTENTS OF THE TECHNICAL SUMMARY AND SUPPORTING CHAPTERS

Technical Summary

1. Introduction
2. Greenhouse gases, aerosols and their radiative forcing
3. Observed trends and patterns in climate and sealevel
4. Modelling climate and climate change
5. Detection of climate change and attribution of causes
6. The prospects for future climate change
7. Advancing our understanding

This provides an extended but concise Technical Summary of the detailed information provided in the supporting chapters. A useful attachment to this Summary is a glossary of terms used in the Working Group I contribution to the Second Assessment Report. This glossary is contained in annex III.

Chapter 1 - The Climate System: An Overview

1.1. Climate and climate system
1.2. The driving forces of climate
1.3. Anthropogenic climate change
1.4. Climate response
1.5. Observed climate change
1.6. Prediction and modelling of climate change

This chapter provides a general overview of the climate change problem from interference with the global energy balance through an enhanced greenhouse effect due to anthropogenic causes, climate response and the effects of the land and oceans, climate predictability and climate projection. The text includes five figures and four references.

Chapter 2 - Radiative Forcing of Climate Change

2.1. CO_2 and the carbon cycle
2.2. Other trace gases and atmospheric chemistry
2.3. Aerosols
2.4. Radiative forcing
2.5. Trace gas radiative forcing indices

This chapter represents an update of the IPCC Working Group I report on Radiative Forcing of Climate Change published in 1994. Most of the main findings are already reflected in annex I above. The text includes 16 figures and some 240 references.

Chapter 3 - Observed Climate Variability and Change

3.1. Introduction
3.2. Has the climate warmed?
3.3. Has the climate become wetter?
3.4. Has the atmospheric/oceanic circulation changed?
3.5. Has the climate become more variable or extreme?
3.6. Is the 20th century warming unusual?
3.7. Are the observed trends internally consistent?

The findings of this chapter, which poses questions concerning changes in temperature, rainfall and atmospheric circulation are reflected in annex I above. The text includes 23 figures and some 380 references.

Chapter 4 - Climate Process

4.1. Introduction to climate processes
4.2. Atmospheric processes
4.3. Oceanic processes
4.4. Land surface processes

This chapter assesses the processes in the climate system that are believed to be the major contributors to the uncertainties in current projections of greenhouse warming. Many of these processes involve the coupling of the atmosphere, ocean and land through the hydrological cycle. Continued progress in climate modelling will depend on the development of comprehensive data sets and their application to improving important parametrizations. The text contains 9 figures and some 200 references.

Chapter 5 - Climate Models - Evaluation

5.1. What is model evaluation and why is it important?
5.2. How well do coupled models reproduce current climate?
5.3. How well do the component atmosphere, land surface, ocean and sea-ice models perform?
5.4. How well do models perform under other conditions?
5.5. How well do we understand model sensitivity?
5.6. How can our confidence in models be increased?

This chapter considers and evaluates the models currently in use to simulate and predict the climate system. It reviews performance under different conditions and considers how confidence in models can be increased. The text contains 34 figures and some 260 references.

Chapter 6 - Climate Models - Projection of Future Climate

6.1. Introduction
6.2. Mean changes in climate simulated by three-dimensional climate models
6.3. Global mean temperature change for the IPCC (1992) emission scenarios
6.4. Simulated changes of variability induced by increased greenhouse gas concentration
6.5. Changes in extreme events
6.6. Simulation of regional climate change
6.7. Reducing uncertainties, future model capabilities and improved climate change estimates

This chapter focuses on the estimation of the effects on future climate of changes in atmospheric composition due to human activities. An important development since the IPCC First Assessment Report (1990) is the improved quantification of some radiative effects of aerosols, and climate projections presented include, in addition to the effects of increasing greenhouse gas concentrations, some potential effects of anthropogenic aerosols. The text includes 38 figures and some 260 references.

Chapter 7 - Changes in Sealevel

7.1. Introduction
7.2. How has sealevel changed over the last 100 years?
7.3. Factors contributing to sealevel change
7.4. Can sealevel change during the last 100 years be explained?
7.5. How might sealevel change in the future?
7.6. Spatial and temporal variability
7.7. Major uncertainties and how to reduce them

This chapter assesses the current state of knowledge regarding climate and sealevel change, with special emphasis on scientific developments since the 1990 IPCC Report. The main focus is on changes that occur on the time-scale of a century. Evidence of sealevel changes during the last 100 years are identified and examined for factors that could be responsible for such changes. Possible changes in sealevel which could occur in the next 100 years as a result of global warming are then considered. The text contains 15 figures and some 250 references.

Chapter 8 - Detection of Climate Change and Attribution of Causes

8.1. Introduction
8.2. Uncertainties in model projections of anthropogenic emissions
8.3. Uncertainties in estimating natural variability
8.4. Evaluation of recent studies to detect and attribute climate change
8.5. Qualitative consistency between model predictions and observations
8.6. When will an anthropogenic effect on climate be identified?

This chapter considers progress in attempts, since the 1990 IPCC Report, to identify an anthropogenic effect on climate. The first area of significant advance is that model experiments are now starting to incorporate the possible climatic effects of human-induced changes in sulphate aerosols and stratospheric ozone. The inclusion of these factors has modified in important ways the picture of how climate might respond to human influences. Thus, the potential climate change "signal" due to human activities is better defined, although important signal uncertainties still remain. The text contains 12 figures and some 130 references.

Chapter 9 - Terrestrial Ecosystems : Biotic Feedbacks to Climate

9.1. Introduction
9.2. Land-atmosphere CO_2 exchange and the global carbon balance : the present
9.3. Possible effects of climate change and atmospheric carbon dioxide increases on ecosystem structure
9.4. Effects of climate change and carbon dioxide increases on regional and global carbon storage : transient and equilibrium analyses
9.5. Methane : effects of climate change and increase in atmospheric CO_2 on methane flux and carbon balance in wetlands
9.6. Nitrous oxide
9.7. Global-scale biogeophysical feedbacks: changes in ecosystem structure and function affect climate

This chapter considers the closely coupled effects of terrestrial ecosystems. Changes in climate and the CO_2 concentration in the atmosphere cause changes in the structure and function of terrestrial ecosystems. In turn, changes in the structure and function of terrestrial ecosystems influence the climatic system through biogeochemical processes that involve the land-atmosphere exchanges of radiatively-active gases such as CO_2, CH_4 and N_2O, and changes in biogeophysical processes that involve water and energy exchanges. The combined consequence of these effects and feedbacks are taken into account in evaluating the future state of the atmosphere or of terrestrial ecosystems. The text contains 7 figures and some 300 references.

Chapter 10 - Marine Biotic Responses and Feedbacks to Climate Change

10.1. Introduction
10.2. Ocean processes - biogeochemical responses
10.3. Feedbacks : Influence of marine biota on climate change
10.4. The state of biogeochemical ocean modelling

This chapter considers the responses of marine biogeochemical processes to and influence on climate. Atmospheric CO_2 is the most important greenhouse gas increasing rapidly due to human activities. The oceans contain about 40,000 GtC in dissolved particulate, and living forms. By contrast, land biota, soils and detritus total about 2,200 GtC. It is imperative therefore to understand the contribution of biogeochemical processes in maintaining the steady state functioning of the ocean carbon cycle. The chapter contains 7 figures and some 200 references.

Chapter 11 - Advancing our Understanding

11.1. Introduction
11.2. Framework for analysis
11.3. Anthropogenic emissions
11.4. Atmospheric concentrations
11.5. Radiative forcing
11.6. Response of the climate system
11.7. Natural climate variations and detection and attribution of climate change
11.8. Impacts of climate change
11.9. Cross-cutting issues
11.10. International programmes
11.11. Research priorities

This chapter looks at future activities required to advance understanding of climate change. The findings are reflected in annex I.

Annex III

IPCC WORKING GROUP I - GLOSSARY OF TERMS

Term	**Definition**
Aerosols	Airborne particles. The term has also come to be associated, erroneously, with the propellant used in "aerosol sprays".
Climate change (FCCC usage)	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods.
Climate change (IPCC usage)	Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction between its components, or because of changes in external forcing either for natural reasons or because of human activities. It is generally not possible to make attribution clearly between these causes. Projections of future climate change reported by IPCC generally consider the influence on climate or anthropogenic increases in greenhouse gases and other human-related factors.
Climate sensitivity	In IPCC reports, climate sensitivity usually refers to the long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric CO_2 concentration. More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing ($^{\circ}C/Wm^{-2}$).
Diurnal temperature range	The difference between maximum and minimum temperatures over a period of 24 hours.
Equilibrium climate experiment	An experiment where a step change is applied to the forcing of a climate model and the model is then allowed to reach a new equilibrium. Such experiments provide information on the difference between the initial and final states of the model, but not on the time-dependent response.

Equivalent CO_2	The concentration of CO_2 that would cause the same amount of radiative forcing as the given mixture of CO_2 and other greenhouse gases.
Evapotranspiration	The combined process of evaporation from the Earth's surface and transpiration from vegetation.
Greenhouse gas	A gas that absorbs radiation at specific wavelengths within the spectrum of radiation (infrared radiation) emitted by the Earth's surface and by clouds. The gas in turn emits infrared radiation from a level where the temperature is colder than the surface. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planetary surface. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.
Ice-cap	A dome-shaped glacier usually covering a highland near a water divide.
Ice sheet	A glacier more than 50,000 km^2 in area forming a continuous cover over a land surface or resting on a continental shelf.
Radiative forcing	A simple measure of the importance of a potential climate change mechanism. Radiative forcing is the perturbation to the energy balance of the earth-atmosphere system (in Wm^{-2}) following, for example, a change in the concentrations of carbon dioxide or a change in the output of the sun; the climate system responds to the radiative forcing so as to re-establish the energy balance. A positive radiative forcing tends to warm the surface and a negative radiative forcing tends to cool the surface. The radiative forcing is normally quoted as a global and annual mean value. A more precise definition of radiative forcing, as used in IPCC reports, is the perturbation of the energy balance of the surface-troposphere system, after allowing for the stratosphere to re-adjust to a state of global-mean radiative equilibrium (see chapter 4 of the 1994 IPCC Report). Sometimes called "climate forcing".

Spatial scales	continental	10-100 million square kilometres (km^2)
	regional	100,000 - 10 million km^2
	local	less than 100,000 km^2

Soil moisture — Water stored in or at the continental surface and available for evaporation. In the First Assessment Report of 1990 a single store (or "bucket") was commonly used in climate models. Today's models, which incorporate canopy and soil processes, view soil moisture as the amount held in excess of plant 'wilting point'.

Stratosphere — The highly stratified and stable region of the atmosphere above the troposphere extending from about 10 km to about 50 km.

Thermohaline circulation — Large-scale density-driven circulation in the oceans, driven by changes in temperature and salinity.

Transient climate experiment — An experiment in which the time-dependent response of a climate model is analysed in response to a time-varying change of forcing.

Troposphere — The lowest part of the atmosphere from the surface of the Earth to about 10 km is the altitude in mid-latitudes (ranging from 9 km in high latitudes to 16 km in the tropics on average) where clouds and "weather" phenomena occur. The troposphere is defined as the region where temperature generally decreases with height.

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