Physics Research and Technology

Clouds

Classification, Microbiology and Environmental Effects

Marta Thelin
Julienne Maheux
Editors

Novinka

PHYSICS RESEARCH AND TECHNOLOGY

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PREFACE

The authors of this book present current research in the study of the classification, microbiology and environmental effects of clouds. Topics discussed include cloud microorganisms and their potential implication in atmospheric chemistry; cloud classification by water vapor and cloud budgets; radial systems of dark globules in our galaxy; studies on clouds and spherial harmonis decomposition; and heteronuclear diatomics in diffuse and translucent clouds.

Chapter 1 - Clouds can be considered as very complex reactors where multiphase chemistry takes place. Understanding these processes is crucial since they impact cloud formation and precipitation and thus the climate. Up to very recently only abiotic processes leading to the transformation of organic matter in clouds were studied by atmospheric scientists, they involved radical chemistry and particularly photochemistry. New actors have been now highlighted with the discovery of metabolically active microorganisms in cloud water. A new scientific question has been raised: are microorganisms able to biotransform organic compounds thanks to their metabolism? Are these biological processes competitive compared to abiotic processes? The aim of this chapter is to give updated information related to this emerging topic.

The first part of this chapter introduces the cloud system, where a complex multiphase chemistry takes place leading to the transformation of chemical species in the gas, solid and aqueous phases. In this frame, during the cloud lifetime, cloud chemistry can lead to the formation of new low volatile compounds that will modify the physical and chemical properties of aerosols after cloud evaporation and can also contribute to the formation of secondary aerosols.

The second part describes the cloud microbial population. About 10^5 bacteria and 10^3 fungi are present per mL of cloud water. The biodiversity is dominated by *Sphingomonas*, *Pseudomonas*, *Dioszegia*, *Udeniomyces* and *Cryptococcus* genera and shows similarities with the one found in dry atmosphere and precipitation. As a large fraction of the microbial cells is metabolically active, microorganisms could transform chemical species in atmospheric waters.

The last part of this chapter focuses on the implication of microbial activity in cloud chemistry. Most of the studies concern the biodegradation pathways of mono- and dicarboxylic acids, methanol and formaldehyde. The quantitative comparison of microbial activity *vs* radical chemistry suggests that microorganisms could be active both during the day and during the night to biodegrade organic compounds in cloud water, while their activity will be only dominant at night in the case of methanol and formaldehyde. Moreover, very recent investigations are related to the biosynthesis of various compounds such as biosurfactants, and exopolymeric substances (EPSs) that could consequently modify the physico-chemical properties of aerosols.

Although the results reported in the literature up to now are consistent with a potential contribution of microorganisms to atmospheric chemistry, some more work is needed to fully demonstrate and accurately quantify this contribution; new routes could be explored (macromolecules synthesis, oxidative stress metabolism).

Chapter 2 – Numerical modeling provides information about water vapor and cloud microphysical processes. Thus, precipitating and non-precipitating clouds can be partitioned based on water vapor and cloud budgets. These separation schemes are applied to the grid-scale simulation data from a two-dimensional cloud-resolving model experiment forced by large-scale vertical velocity, zonal wind, horizontal advection, and sea surface temperature observed and derived from TOGA COARE. The analysis is conducted over two distinct periods of strong-forcing (SF) and weak-forcing (WF). The rainfall from precipitating cloud type associated with local atmospheric drying, water vapor divergence, and hydrometeor loss/convergence have the largest contributions (30%) to total rainfall among eight rainfall types. The rainfall contribution of this precipitating cloud type to total rainfall is larger in the WF phase than in the SF phase. About 27% of total rainfall results from hydrometeor convergence and additional 17-20% of total rainfall is associated with hydrometeor convergence and the net condensation. The rainfall associated with water vapor convergence and hydrometeor divergence contributes much less to total rainfall than convective rainfall does. The non-precipitating cloud types associated with hydrometeor loss/convergence and with hydrometeor gain/divergence cover about 65% and 35% of non-precipitating stratiform cloud areas in the two phases, respectively.

Chapter 3 – Dark molecular clouds often contain star-formation regions of massive stars. In these regions bright massive stars are originated. After their origin these stars ionize and evaporate molecular gas in their vicinity. Molecular clouds contain dense cores. When ionization front reaches these cores, they are evaporated if are situated close to the bright stars and are streamlined by ionizing gas if the cores are situated farther from the stars. The gas gives to these cores the form of globules of radial systems: the globules have such orientation, that their axis of symmetry have direction towards the central bright stars. There are two types of radial systems.

Type 1. In the center of the system are bright O-B2 type stars, the system is embedded in HII region, the globules have such orientation, that their axis of symmetry are directed towards the central stars. Type 2. In the center of system already exist stars later than O-B2, there is no HII region, but an HI cloud can be present, the orientation of globules still persists.

Chapter 4 – A cloud is a visible mass of condensed droplets or frozen crystals floating in the atmosphere above the surface of the Earth or another planetary body. Cloud albedo is a measure of the reflectivity of a cloud. High values mean that the cloud can reflect more solar radiation. Studies show that Cloud albedo varies from less than 10% to more than 90% and depends on drop sizes, liquid water or ice content, thickness of the cloud, and the sun's zenith angle. Several analysis show that clouds, however, remain one of the largest uncertainties in future projections of climate change by global climate models, owing to the physical complexity of cloud processes and the small scale of individual clouds relative to the size of the model computational grid. The cloud forming processes take place on fractions of a millimetre, while global climate models typically operate with a grid size of 50-100 km. In their work the authors have used monthly data series of low cloud amounts (LCA) describing the repartition and evolution of these cloud amounts in space and time. Thus the authors have decomposed values of low cloud amounts into spherical harmonics. For each month the authors have decomposed in spherical harmonics the values of LCA varying in space. Limiting their development to the fourth spherical wave we have obtained 35 components for each month covering the period 01/1990-12/1992. Each correspondent spherical component describing monthly variations of LCA is then submitted to Morlet wavelet analysis. Generally the authors can notice that the most LCA are obtained for winter and spring. Indeed Sun angle, solar intensity and clouds are important controls of the weather. At the equinox the Sun passes directly overhead at solar noon at the equator. Although the noon solar Sun angle on the equinox is greater than that on the first day of winter, the first remains low inducing also high amounts of clouds.

Chapter 5 - Diffuse and translucent molecular clouds are very special environments in the Interstellar Medium (ISM). Recent advances in observational techniques of modern optical and ultraviolet spectroscopy led to detection of many features of atomic and molecular origin in spectra of such clouds. Molecular spectra of heteronuclear diatomic molecules, ie. OH, CH CH+, CN, NH, CO play important role in understanding chemistry and physical conditions in environments where they exist. Review of astronomical observations of molecules together with history is reported. Recent results concerning visual and ultraviolet observations; appearance of molecular features in spectra of early type OB-stars are presented and discussed.

Appearance of vibrational-rotationl spectra with observed correct transitions based on high-quality spectra, oscillator strengths and column densities are also presented. Relations between fundamental column densities of heteronuclear diatomics (based on recommended oscillator strengths) and relations with interstellar extinction and intensities of diffuse interstellar bands (DIBs) are also presented and discussed.

CONTENTS

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Chapter 1

CLOUD MICROORGANISMS AND THEIR POTENTIAL IMPLICATION IN ATMOSPHERIC CHEMISTRY

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ABSTRACT

Clouds can be considered as very complex reactors where multiphase chemistry takes place. Understanding these processes is crucial since they impact cloud formation and precipitation and thus the climate. Up to very recently only abiotic processes leading to the transformation of organic matter in clouds were studied by atmospheric scientists, they involved radical chemistry and particularly photochemistry. New actors have been now highlighted with the discovery of metabolically active microorganisms in cloud water. A new scientific question has been raised: are microorganisms able to biotransform organic compounds thanks to their metabolism? Are these biological processes competitive compared to abiotic processes? The aim of this chapter is to give updated information related to this emerging topic.

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Although the results reported in the literature up to now are consistent with a potential contribution of microorganisms to atmospheric chemistry, some more work is needed to fully demonstrate and accurately quantify this contribution; new routes could be explored (macromolecules synthesis, oxidative stress metabolism).

INTRODUCTION

Clouds are a very special medium of the atmosphere since they present substantial amounts of condensed-phase water (liquid or solid) that can dissolve gases, and permit reactions to occur that would not occur in the gas phase or would be much slower. In this frame, clouds can be considered to serve as "catalysts" of atmospheric reactions. Understanding these processes is of interest as they impact cloud formation and precipitation and thereby the climate.

Up to very recently, only abiotic processes leading to the transformation of organic matter in clouds were studied by atmospheric scientists. These processes involve radical chemistry leading to oxidation processes. New actors have been now highlighted with the discovery of metabolically active microorganisms in cloud waters. A new scientific question has arisen: are microorganisms able to biotransform organic compounds thanks to their metabolism? Are these biological processes competitive with abiotic processes?

The aim of this chapter is to give updated information related to this emerging topic. The first part of this chapter will introduce the cloud system, including its composition and its reactivity. The second part will detail quantitatively and qualitatively the cloud microbial population. The last part of this chapter will focus on the implication of microbial activity in cloud chemistry. More precisely the metabolic pathways and the comparison of microbial activity *vs* radical chemistry will be described.

THE CLOUD SYSTEM: CHEMICAL COMPOSITION AND REACTIVITY

1. Tropospheric Aerosol Processing

The troposphere is a complex multiphase and multi-component environment that consists of gases and dispersed solid and aqueous particles including hydrometeors such as fog drops, cloud droplets and ice crystals. The gaseous molecules and the dispersed inside particles refers to the term of "tropospheric aerosol" [1]. Primary aerosol particles are emitted to the troposphere by anthropogenic activities (as for example fuel combustion) and natural processes (such as dust, sea spray and biogenic activity).

A considerable amount of aerosol particles results from anthropogenic activities and significantly contributes to air pollution especially in urban areas. Secondary particles are also formed by gas-to-particle conversion (see Raes *et al.* [2] and Hallquist *et al.* [3] for an overview). The physical and chemical properties of the aerosol particles strongly depend on both their origin and the transformations they undergo throughout their atmospheric transport. During their residence time in the atmosphere, they are modified in size and composition through for example the condensation of less volatile gaseous compounds or by coagulation with other particles, by evaporation and by chemical reactions inside and at the surface of the particles.

These aerosol particles directly interact with incoming solar radiation by scattering and light absorption but they also have an indirect effect on the earth's radiative budget [4] (Figure 1). This effect is linked to the ability of aerosol particles to act as cloud condensation nuclei (CCN) when they are activated into cloud droplets.

The physico-chemical properties of the CCN will control the properties of the formed clouds such as their reflectivity (optical properties) [5] and their lifetime (precipitation capability) [6]. Consequently, aerosol particles and clouds play a crucial role in the troposphere due to their influence on the earth radiative budget but this negative climate forcing is still subject to strong uncertainties [7] (Figure 1).

When aerosol particles are activated and form cloud droplets, their physico-chemical properties are strongly modified [8]. Chemical aqueous phase interactions contribute to the aerosol cycling as well as the microphysical processes that are able to modify the size distribution and the chemical composition of aerosol particles. Particles that have been processed in clouds generally contain a larger soluble fraction after evaporation and they consequently become activated into cloud droplets at lower supersaturation. This leads to the formation of clouds that are optically brighter and that are composed by smaller droplets increasing the cloud/particle lifetime and reducing their precipitation potential. This effect has been highlighted through the formation of atmospheric sulfate by in-cloud chemistry [9].

While many works have been carried on the in-cloud chemistry of inorganic species such as sulfur [10], the aqueous phase chemistry of organic aqueous phase compounds and their effects have been studied to a much smaller extent. The troposphere contains numerous VOCs from secondary formation by reactivity and many of them are water soluble, *i.e.* associated with high Henry's law constants [11–13]. Additionally, organic compounds represent a significant mass fraction of the tropospheric aerosol particles and can undergo aqueous phase oxidation reactions. Thus, the dissolved organic matter is directly or indirectly linked to the aqueous chemistry of radicals, radical anions, non-radical oxidants and transitional metal ions (TMIs). Organic oxidation inside clouds can also be a potential source of SOAs (Secondary Organic Aerosols) in the atmosphere after the evaporation of cloud droplets [14–17].

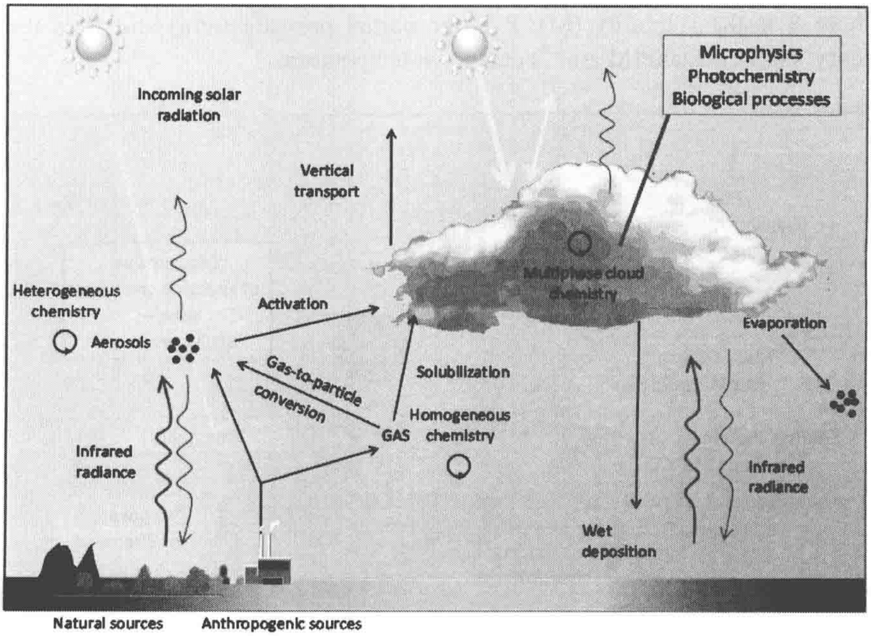

Figure 1. Cloud/aerosol/chemistry interactions. Red arrows correspond to infrared radiation emitted by the ground and yellow arrows represent the solar radiation.

2. Aqueous Particle and Cloud Processing

a. Sources of Chemical Compounds

Chemical compounds are found in deliquescent particles and cloud droplets and they originate from various sources: from the soluble fraction of the aerosol particles which can also act as cloud condensation nuclei (CCN), from the dissolution of soluble trace gases as well as from scavenging processes. Cloud reactivity will also lead to the formation of new chemical compounds (Figure 2).

The partitioning of chemical compounds between the gas and the aqueous atmospheric phases is usually described on the basis of Henry's law [18–23] which expresses the relationship between the solubility of a gas in a liquid and its partial pressure above the liquid:

$$S = H \times P$$

where S is the solubility (M), P is the partial pressure (atm) and H is the Henry's law constant (M atm^{-1}) at a given temperature.

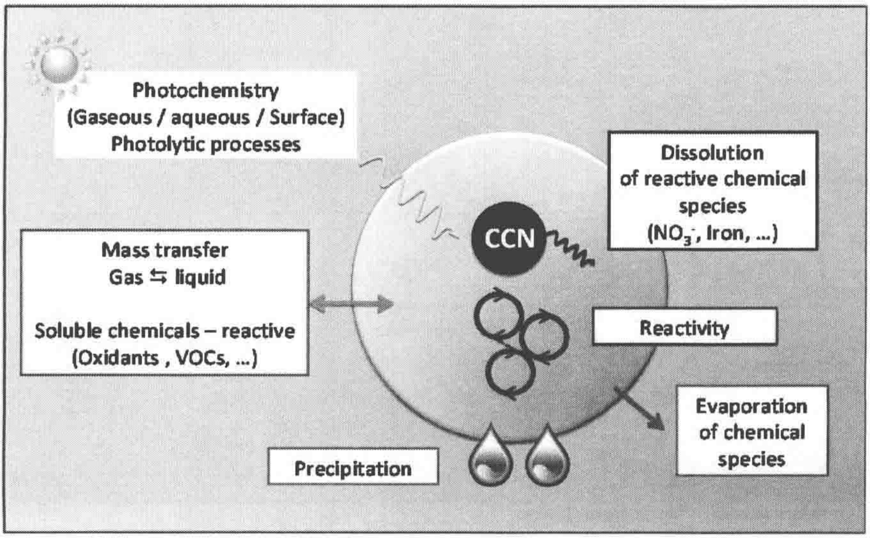

Figure 2. Multiphase cloud processes. Black and green boxes correspond to the sources of chemical compounds in droplets. Red and yellow boxes represent the homogeneous chemical pathways. Blue boxes correspond to the microphysical processes that redistribute chemical compounds among the different phases.

However, Henry's law provides a limiting rate that strictly applies to ideally dilute solutions [24]. The mass transfer between gas and liquid phases should be dynamically described and strongly depends on the drop surface and its properties linked to the size of hydrometeors [25-27].

b. Chemical Composition of Clouds

The aqueous phase of clouds is a very complex mixture of inorganic and organic chemical compounds. The major inorganic ions commonly found in cloud water are the sulfate (SO_4^{2-}), chloride (Cl^-) and nitrate (NO_3^-) anions and