Monograph:

Biggart, M. and Finney, D. orcid.org/0000-0002-3334-6935 (2025) CLOUDSENSE Collaborative Review of Wikipedia Cloud Physics article. Report. University of Leeds

https://doi.org/10.48785/100/367

Review of Wikipedia *Cloud physics* article [NB: page may have been edited since review]

This review was produced collaboratively by researchers on the UK Natural Environment Research Council programme, CloudSense.

Summary

The current structure and content of the Cloud Physics page is generally logical and easy to follow; however, some issues regarding incorrect definitions of processes (e.g. riming); entirely missing descriptions of key microphysical processes (e.g. primary ice nucleation, growth and secondary ice production); poor sentence structure and repetition of statements; and inconsistent and unhelpful units for cloud droplet and ice crystal sizes need to be addressed. We have provided a detailed breakdown of necessary changes to the current structure, as well as specific edits to existing content, and details of new sections that should be added.

Proposed structure (new sections highlighted in red)

1. **Introduction, covering the following:**
    - Cloud physics definition
    - Cloud composition
    - Role of cloud condensation nuclei and supersaturation
    - Cloud droplet growth and precipitation
    - Ice nucleating particles, primary ice production and growth (1-2 new sentences)
    - Secondary ice production (1-2 new sentences)
    - Bergeron process
2. **Cloud formation**
    - 2.1 Adiabatic cooling (frontal/cyclonic/convective/orographic lifting)
    - 2.2 Non-adiabatic cooling
    - 2.3 Adding moisture to the air
    - 2.4 Supersaturation
    - 2.5 Supercooling
    - 2.6 Collision-coalescence
    - 2.7 Primary ice production (1-2 new paragraphs encompassing the topics below)
        - 2.7.1 Heterogeneous nucleation with INPs
        - 2.7.2 Homogeneous freezing
    - 2.8 Secondary ice production (SIP) (1-2 new paragraphs encompassing the topics below)
        - 2.8.1 SIP definition, introduction to key mechanisms and radiative impacts of ice multiplication
        - 2.8.2 Rime splintering (Hallett-Mossop process)
        - 2.8.3 Frozen droplet fragmentation
        - 2.8.4 Ice-ice collisional breakup
    - 2.9 Bergeron process
3. **Cloud classification**
4. **Determination of properties**
    - a. In-situ aircraft observations (a new paragraph)
    - b. Satellite-retrieved cloud properties
    - c. Surface-based remote sensing (a new paragraph)

5. **Modelling**

Existing content to remove/adapt

- Re-structure the entire ‘Determination of properties’ section, as outlined above, so it comprises separate sub-sections on (a) in-situ aircraft observations, (b) satellite retrievals of cloud properties, and (c) surface-based remote sensing. This will involve folding the current sub-sections: ‘Detection’, ‘Parameters’ and ‘Icing’ into the new, stand-alone satellite retrieval sub-section. And drafting a paragraph for each of the new sections on aircraft and ground measurements.

Targeted changes to current content

- **Introduction - from line 1**, change to: “Cloud physics is the study of the physical processes involved in the formation and growth of particles that make up an atmospheric cloud. The aggregate effect of these particles results in the properties of clouds we commonly observe, including their brightness (i.e. how they reflect or absorb sunlight), or precipitation development. Cloud particles include liquid droplets, raindrops, ice particles made of pristine ice crystals, aggregates, graupel and hail.”

- **Introduction - line 2,** remove: “These aerosols are found in the troposphere, stratosphere, and mesosphere, which collectively make up the greatest part of the homosphere”. Aerosols have not yet been mentioned and the sentence in general isn’t particularly relevant to cloud physics.

- **Introduction - following on from “…aggregates, graupel and hail” above**, add: “Cloud particles first form on a subset of the aerosol population suspended in the atmosphere that can act as (cloud condensation or ice) nuclei, through condensation of water vapour onto them in an environment that is supersaturated with respect to water or ice.” A more concise version of the following could also be added which just states the smallest to largest particle sizes, or the text could be added to the main article text. “Cloud drops are typically the size of a human hair but can grow to a size of about 0.05 mm. Ice particles are of a similar size when newly-formed, but can grow to as large as several mm, particularly when they are aggregated. Graupel particles typically range in size from around 0.3 mm to 5 mm; hail is denser than graupel and can exceed sizes of 5mm.”

- **Introduction - from line 4**, change to: “Clouds can consist solely of liquid droplets (often called “warm” clouds) or ice crystals (cold clouds), or a combination of both (mixed-phase clouds), along with microscopic particles of dust, smoke, or other matter, which can continue act as condensation nuclei. [1]”

- **Introduction - from line 9**, change to: “Cloud condensation nuclei (CCN) are necessary for cloud droplet formation at supersaturation values observed, allowing droplets to form as a result of the combined effects of the Kelvin effect and Raoult’s law. The Kelvin effect describes the change in saturation vapour pressure due to a curved surface. Raoult's law…" And add a quality secondary reference that introduces kohler, raoults and kelvin effect.

- **Introduction - line 13**, change to: "At concentrations typical of CCN, when the cloud droplets are small, the supersaturation required for condensation to occur is smaller than without the presence of a soluble (or partially soluble) nucleus."

- **Introduction - from line 16**, change to: "The warm-rain process involves the collision and coalescence of cloud drops of different sizes. Collisions can take place as a result of either different drop fall speeds or in-cloud turbulence. When the drops become large enough (greater than around 0.1 mm), they can fall as precipitation." [citation needed, preferably secondary or an open-access review]

- **Introduction - from line 21**, change: "The collision and coalescence is not as important in mixed-phase clouds…." to: "Cloud drops can freeze to become ice crystals at temperatures as high as -5 ºC if suitable ice nucleating particles (INP link to INP page) are present. More ice particles are formed at lower temperatures…"

  Continue with: "In mixed-phase clouds, if relatively strong updrafts are present (cumulus type clouds), there will likely be many more cloud droplets than ice particles until the temperature where homogeneous freezing occurs (-37 ºC); the droplets are supercooled. Collision and coalescence can still occur in this region because of the high concentrations of remaining liquid droplets. The ice particles grow initially by diffusion, but once they reach sizes of about 0.3 mm, they will grow following collisions with supercooled liquid drops. These drops freeze on impact with ice particles, a process called riming. Continuation of this process generates graupel particles."

- **Introduction - following on from above with brief introduction to secondary ice production,** add: "In-situ airborne measurements have shown that ice particle concentrations can be many orders of magnitude greater than the observed number of ice nuclei active at the associated cloud top temperature; this discrepancy can often be accounted for by ice multiplication, or secondary ice production (SIP), mechanisms."

- **Introduction - remove sentence on line 25**, starting: "The precise mechanics of how a cloud forms and grows is not completely understood…" as cloud formation is covered in detail in the next section and the microphysics of individual droplets is not necessarily related to the formation and growth of a cloud as such.

- Add links between "clouds", "cloud feedback" and "cloud physics" pages

<u>New content to be added</u>

- Following proposed new structure of page outlined above, add new section **2.7 Primary ice production** after existing section **2.6 Collision-coalescence.**

- New paragraph potentially including the following:

  - **2.7.1 Heterogeneous nucleation with INPs** Description of key nucleation modes (e.g. immersion mode freezing), INP sources (e.g. mineral dust, sea spray, biogenic etc) (Hoose and Möhler, 2012), INP measurement techniques (e.g. droplet-on-filter) (Sanchez-Marroquin et al. 2019) and temperature dependence. *A link to ice nucleus article should be added.*
  - **2.7.2 Homogeneous freezing** Brief description, i.e. “process by which supercooled liquid drops freeze in the absence of an ice nuclei at temperatures colder than about -37 °C”.

- Following newly added section 2.7, we recommend adding a complete section on **SIP processes** (currently not mentioned anywhere on the Cloud Physics page).

- New paragraph potentially including the following:
  - **2.8.1 Introduction to SIP** SIP definition, most studied mechanisms, impacts on cloud radiative effects
  - **2.8.2 Rime splintering (H-M process)** Experimental and in-situ observational evidence, favourable environmental conditions etc (Hallett and Mossop, 1974; Choularton et al. 1980; Mossop, 1985)
  - **2.8.3 Freezing droplet fragmentation** (Korolev and Leisner, 2020).
  - **2.8.4 Ice-ice collisional break-up** Limited existing knowledge of the mechanism is derived from early laboratory experimental work conducted by Vardiman (1978) and Takahashi et al. (1995).

General comments

- The existing short paragraph in the ‘Models’ section exclusively discusses the representation of cloud hydrometeor particle size distributions in models. The section could be expanded to discuss: Different types of models and their treatment of clouds, parameterisations of cloud physical processes, treatment of aerosol-cloud interactions in models. Example material:
  - Different types of models (e.g. GCM, LAM, large-eddy, RCM etc.) and both their treatment of clouds on the macro- and microscale.
  - Parameterisations of cloud physical processes, with useful textbook references (e.g. Khain and Pinksy, Physical Processes in Clouds and Cloud Modelling, 2018).
  - Treatment of aerosol-cloud interactions in models, with focus on CCNs and INPs.