Development of a Cloud Particle Sensor (CPS) for radiosonde sounding

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Introduction

- Clouds play various roles in the weather and climate . . . through latent heat transport, precipitation and the hydrological cycle, and shortwave and longwave radiative processes.
- There are several in situ cloud microphysical sensors for aircraft and weather balloon platforms.

- Balloon sensors include: **NCAR Formvar replicator**, **HYVIS** (Hydrometer Video-Sonde, JMA-MRI/Meisei), **Videosonde** (Kyushu Univ./Yamaguchi Univ., Japan), **Backscattersonde**, **COBALD** (Compact Optical Back-scatter Aerosol Detector, ETH), etc.

- The masses of these balloon-borne particle instruments range from 1 to 6 kg, except for COBALD whose mass is **500 g**.
- A cloud particle instrument of similar mass (and cost) to radiosondes would be useful for e.g., cloud sciences, radiosonde RH sensor validation, etc.

- Shinyei Technology Co. Ltd., Japan, has several particle sensors, including a compact, light, and low-cost optical pollen sensor **PS2**.
- Based on this PS2, with an interface to Meisei RS-06G or RS-11G radiosondes, a balloon-borne small mass (~200 g) cloud sensor called the **Cloud Particle Sensor (CPS)** has been developed.

[Image of PS2 instruments in an instrument shelter.](http://www.shinyei.co.jp/stc/eng/)
Instrumentation (1)

- Particles are introduced into the detection area in CPS using balloon ascent/descent motion:
  - A diode laser: Source of linearly polarized light at \( \sim 790 \) nm.
  - Two photo detectors: Silicon photo diodes, placed at angles of 55 deg. (detector #1) and 125 deg. (detector #2) with respect to the source-light direction. A polarization plate is placed in front of detector #2.
  - Detection area: Roughly \( \sim 1 \) cm x 1 cm (horizontally) x \( \sim 0.5 \) cm (vertically). Thus, its volume is \( \sim 0.5 \) cm\(^3\).

- A particle that passes through the detection area scatters the laser light, and the two detectors receive the **scattered light signal** and thus count that particle.
Instrumentation (2)

- The degree of polarization (DOP) is defined, to characterize the phase of the cloud particle, as:
  \[ \text{DOP} = \frac{I_{55} - I_{125p}}{I_{55} + I_{125p}} \]
- DOP should be close to unity for spherical (i.e. liquid) particles (as \( I_{125p} \approx 0 \)), while DOP would take various values between –1 and +1 for non-spherical ice crystals.
- The original measurement is **number of particles counted per second**. It can be converted to **number concentration** if the flow speed in the detection area is known/inferred.
- Upper limit for the number concentration & a proposed partial correction of the number of particles:
  - The volume of the detection area is non-zero and estimated as \( \sim 0.5 \text{ cm}^3 \).
  - If there are 2 particles or more, CPS cannot count particles correctly – thus, the upper limit would be \( \sim 2 \text{ cm}^{-3} \).
  - **Particle signal width** (in milli-second) is also monitored, which can be used to infer the degree of particle overlapping.
Laboratory experiments

- Various types of **standard spherical particles** were used
  - (1) to determine the lower detection limit and the relationship between the $I_{55}$ value and the water/ice diameter,
  - (2) to investigate the DOP distributions for spherical (thus water) particles
- (Mie scattering theory was used to convert the diameters of the standard spherical particles to those of spherical water droplets and those of hypothetical spherical ice particles.)
- The CPS was unable to detect 1 $\mu$m diameter polystyrene particles but could detect 2 $\mu$m diameter borosilicate glass particles.

- Standard spherical particles are: polystyrene (1 $\mu$m), borosilicate glass (2, 5, 10, and 20 $\mu$m), and soda lime glass (30, 60, and 100 $\mu$m).
- ~1000 to ~8000 particles were used for each type.
Flight results (1/2) Mid-latitude site
Moriya, Japan, 17:30 LT, 21 January 2015

(d) DOP:
This suggests that the clouds at 1–4.5 km were in **mixed phase** where water and ice clouds co-existed.

**Correction:**
If Part. Sig. Width is $>1$ ms, particles are overlapped.
Two cirrus layers in the upper troposphere

Water clouds in the planetary boundary layer

(RH from CFH is also shown (in red).)
Summary and future plans

• CPS is a small-mass (~200 g) optical particle counter for radiosounding (currently with Meisei radiosondes).

• Lower limit of the particle size is ~2 μm; capable of ice/liquid water distinction; upper limit of number concentration is ~2 cm⁻³, with a proposed correction algorithm.

• (Because of the near-IR light measurements, day-time soundings need some special considerations.)

• Possible scientific applications include:
  • cirrus cloud processes in the upper troposphere
  • radiosonde RH sensor validation e.g., during radiosonde intercomparison campaigns
  • applications for dropsonde systems, long-duration balloon systems, etc.

• Intercomparisons with other, well-characterized cloud particle instruments are necessary for the uncertainty quantification for (corrected) number concentration measurements.

  [http://doi.org/10.5194/amt-9-5911-2016]
  • Four flight results (including the two cases in previous slides) are shown and discussed in detail in this paper!

• During 2016-2018, several flights have been made in Japan (with HYVIS), India (including BATAL project), and Tarawa (Kiribati; SOWER).

• Currently, Version 2/3 of the CPS is being developed, aiming at the use in dropsonde systems.