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

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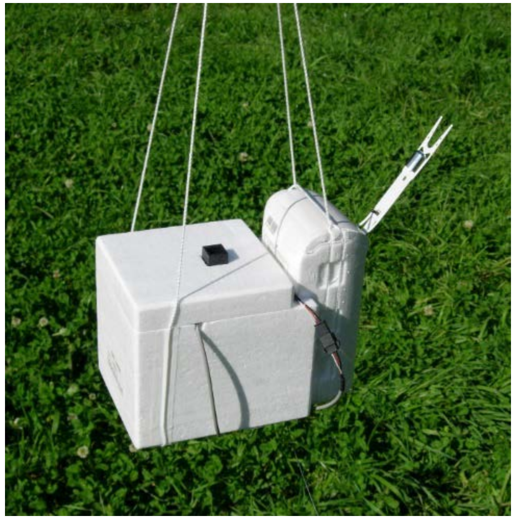
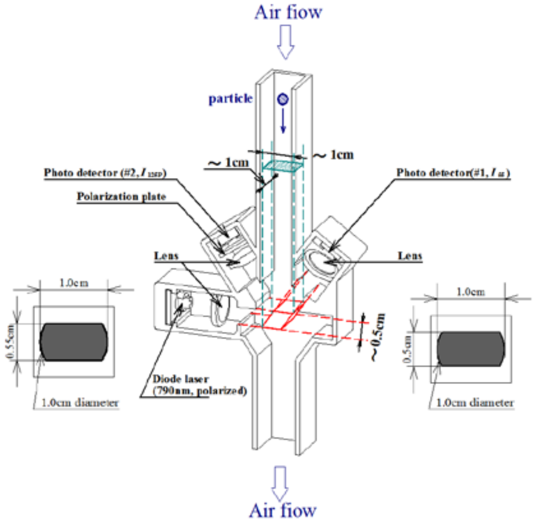
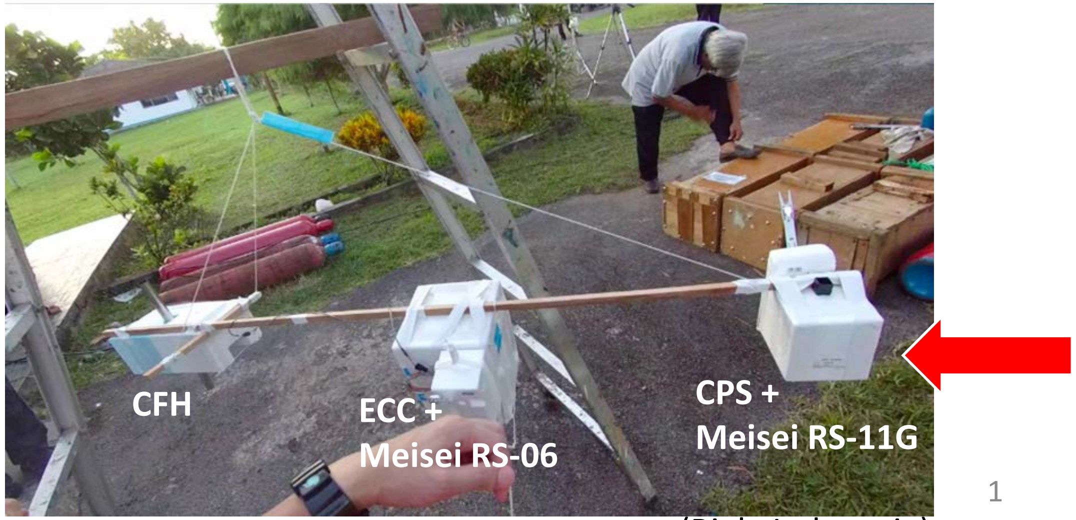






(Biak, Indonesia)

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.

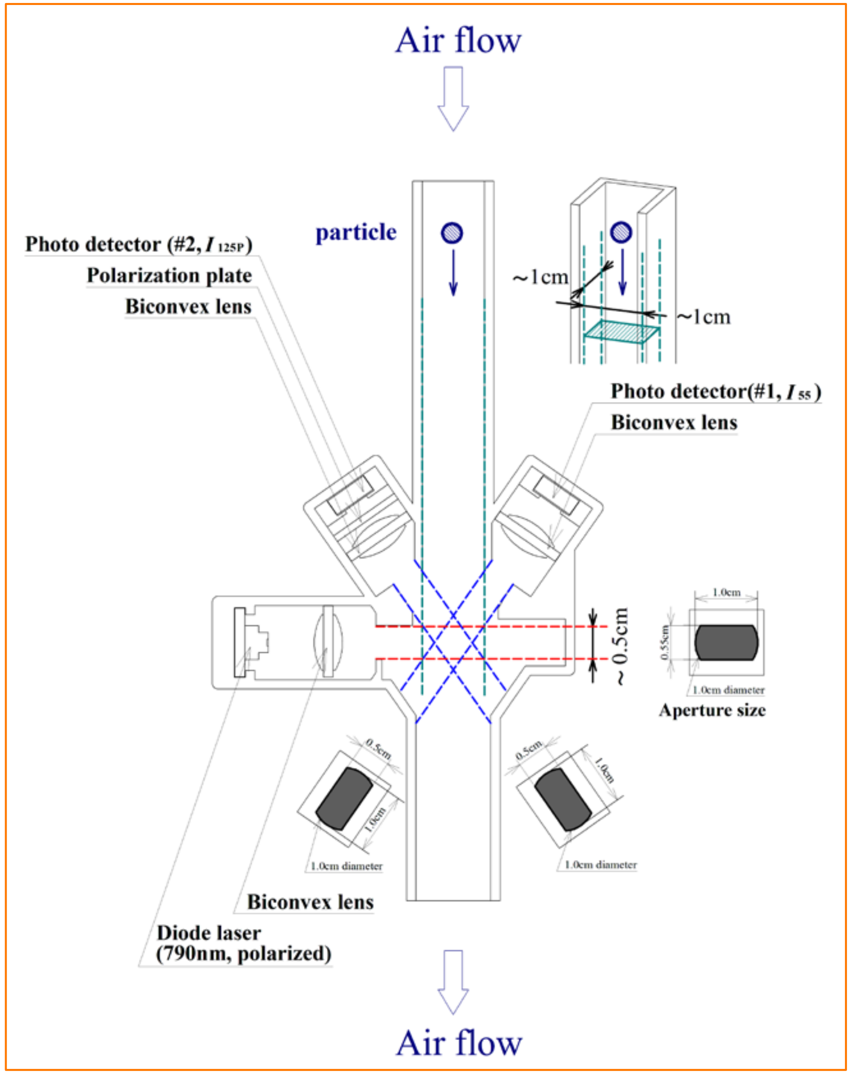
- Shinyei Technology Co. Ltd., Japan, has several particle sensors, including a compact, light, and low-cost optical pollen sensor **PS2**.
- Based on this PS2, with an interface to Meisei RS-06G or RS-11G radiosondes, a balloon-borne small mass (~200 g) cloud sensor called the **Cloud Particle Sensor**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

Two 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 ~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 ~1 cm x 1 cm (horizontally) x ~0.5 cm (vertically). Thus, its volume is ~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**.



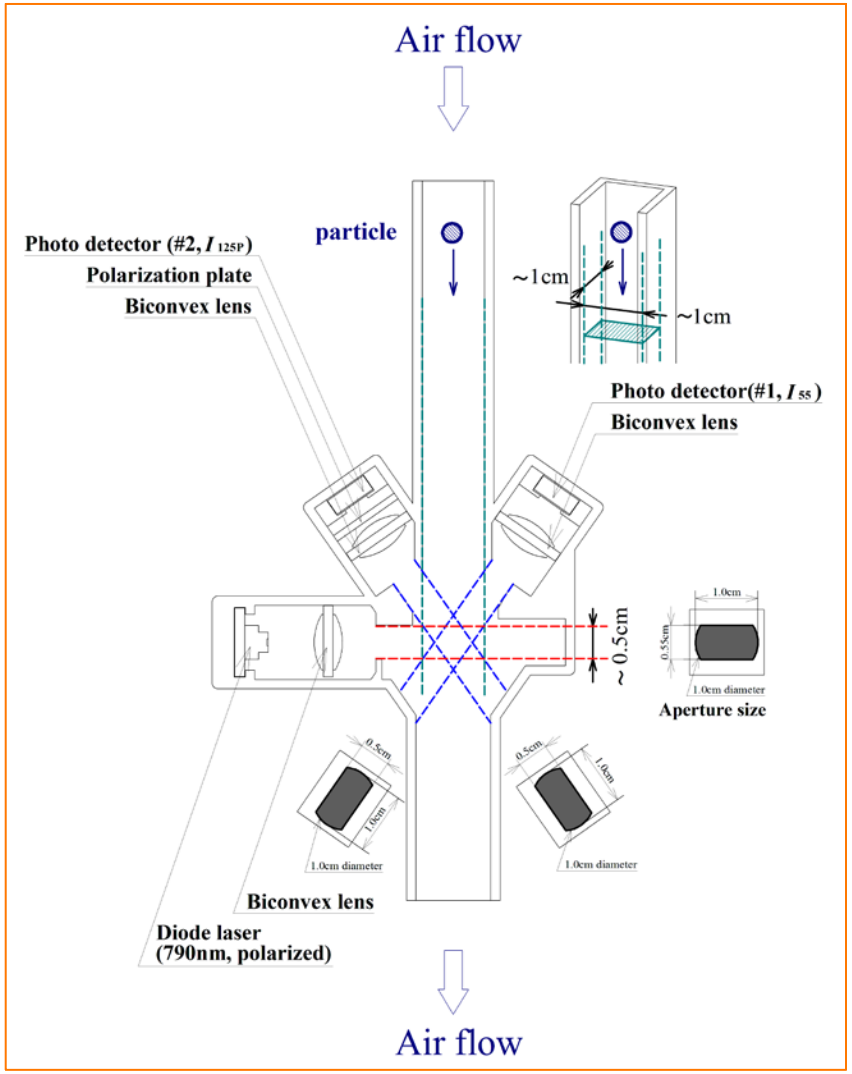
Instrumentation (2)

- The degree of polarization (**<u>DOP</u>**) is defined, to characterize the phase of the cloud particle, as:

  $DOP = (I_{55} - I_{125p}) / (I_{55} + I_{125p})$
- DOP should be close to unity for spherical (i.e. liquid) particles (as I_{125p} = ~0), while DOP would take various values between –1 and +1 for non-spherical ice crystals.

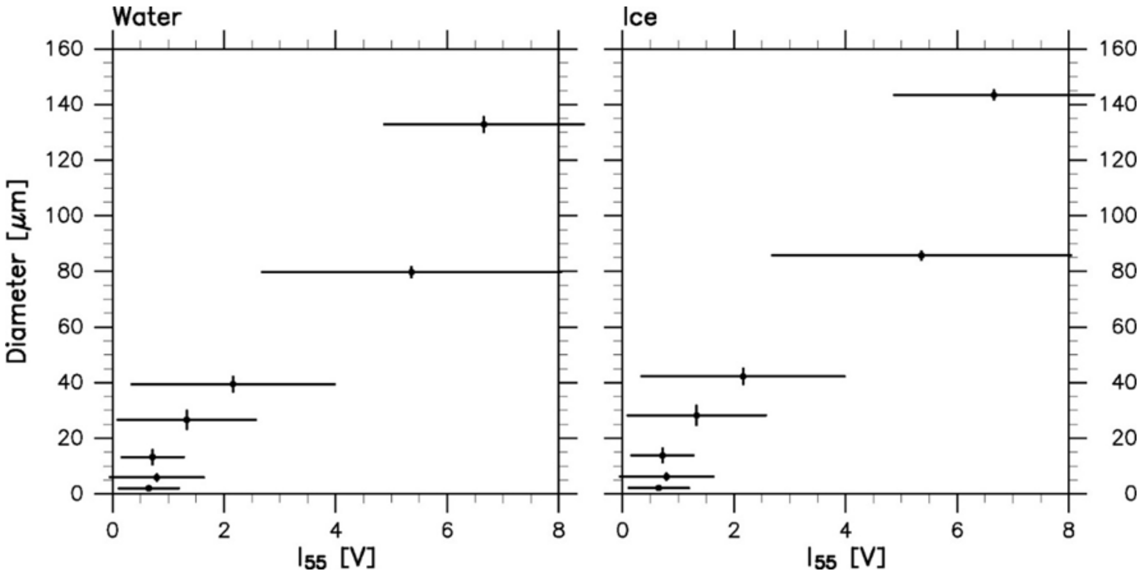
- The original measurement is **<u>number of particles counted per second</u>**. It can be converted to **<u>number concentration</u>** if the flow speed in the detection area is known/inferred.

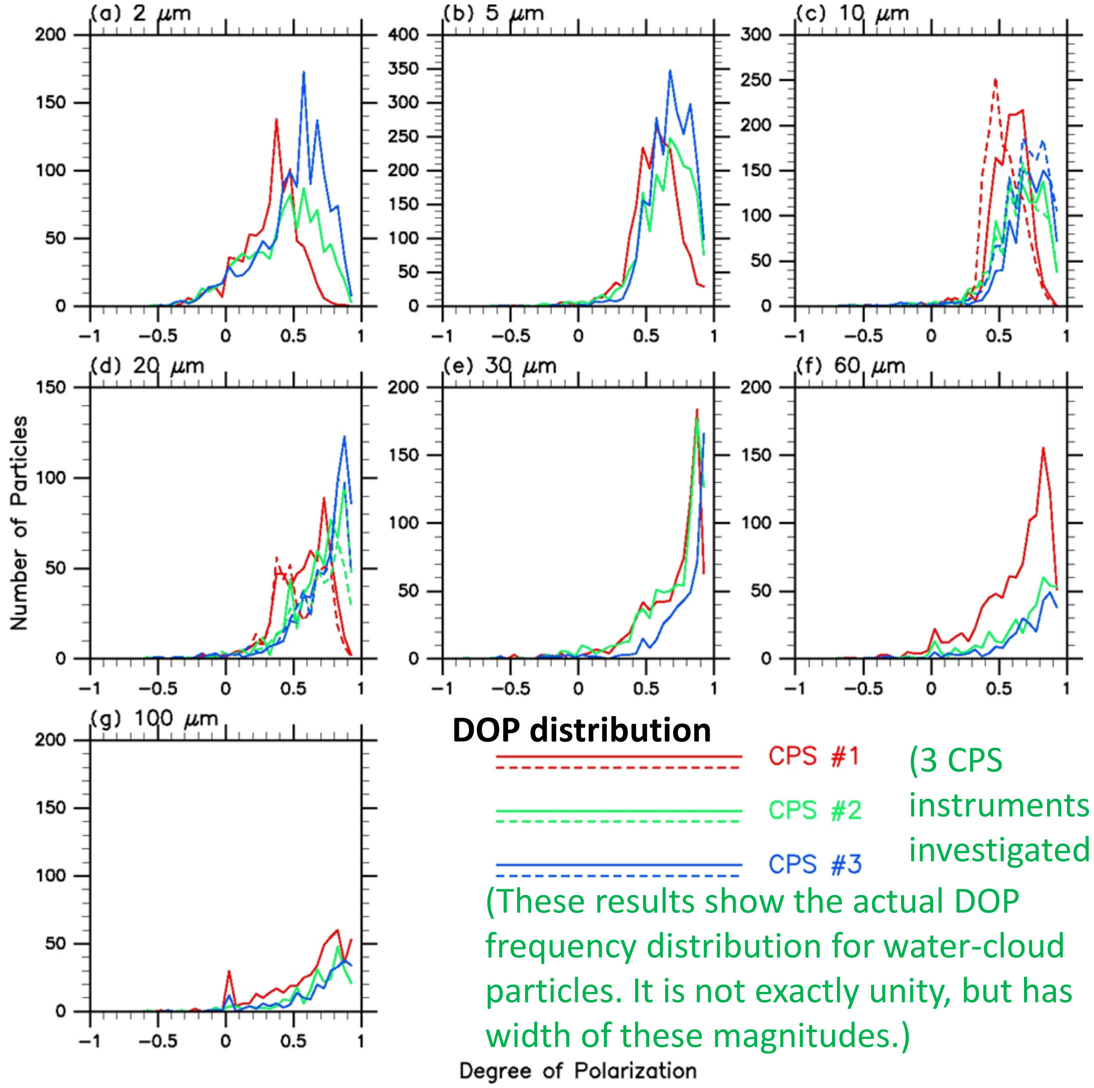
- Upper limit for the number concentration & a proposed partial correction of the number of particles:
  - The volume of the detection area is non-zero and estimated as ~0.5 cm^3.
  - If there are 2 particles or more, CPS cannot count particles correctly – thus, the upper limit would be ~2 cm^{-3}.
  - **<u>Particle signal width</u>** (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 µm diameter polystyrene particles but could **detect 2 µm diameter** borosilicate glass particles.



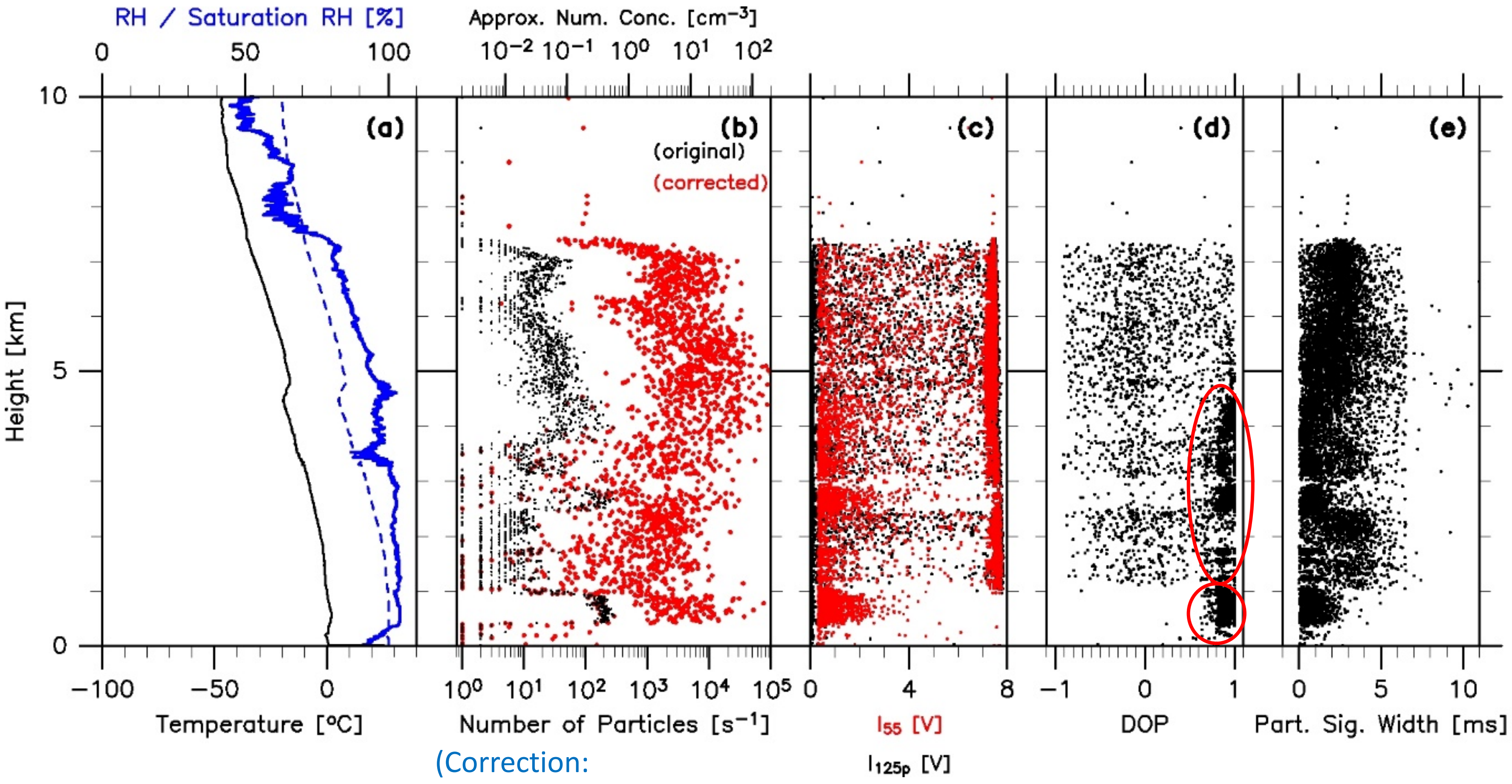


(3 CPS instruments were investigated.)

(These results show the actual DOP frequency distribution for water-cloud particles. It is not exactly unity, but has width of these magnitudes.)

- Standard spherical particles are: polystyrene (1 µm), borosilicate glass (2, 5, 10, and 20 µm), and soda lime glass (30, 60, and 100 µm).
- ~1000 to ~8000 particles were used for each type.

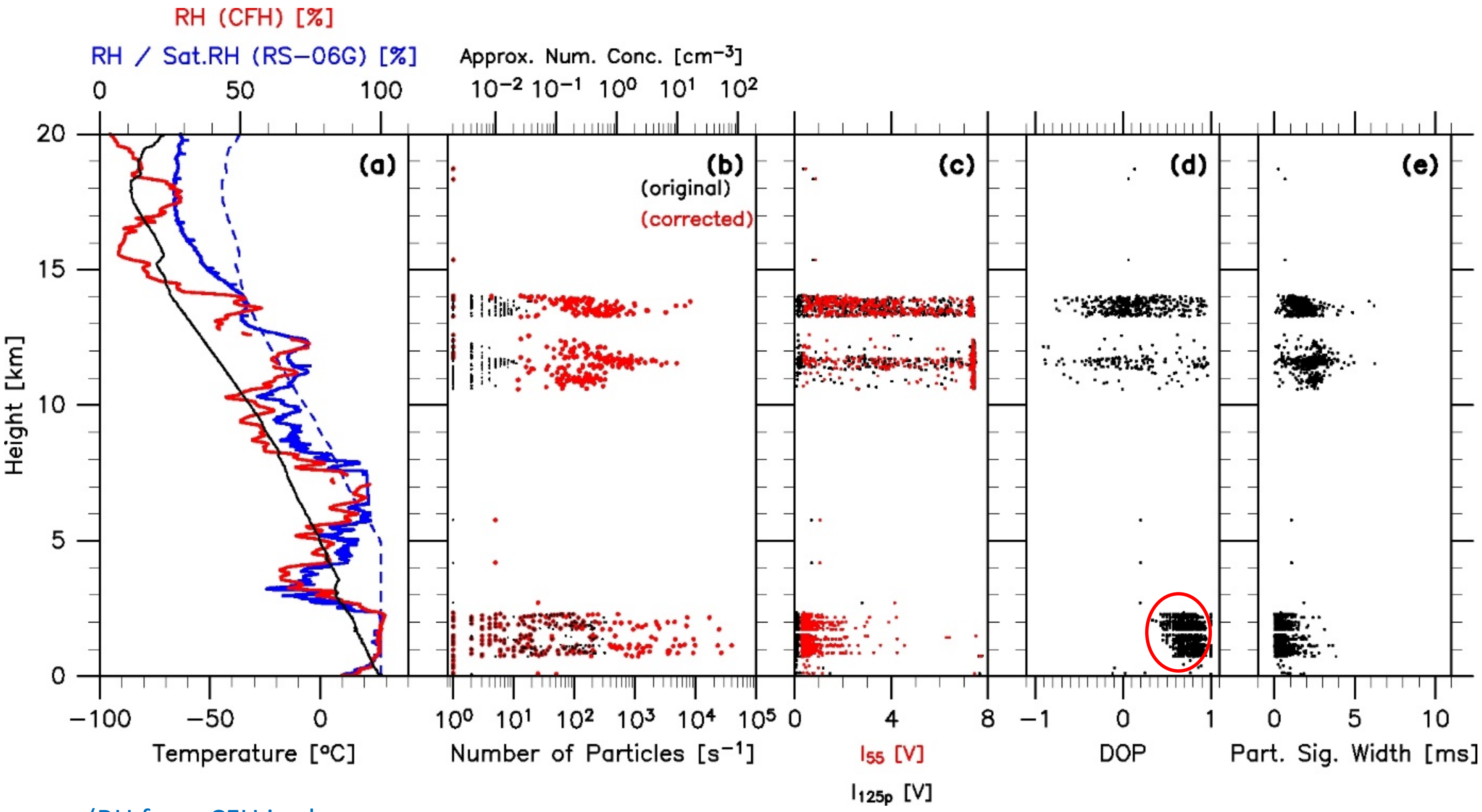
Flight results (1/2) Mid-latitude site Moriya, Japan, 17:30 LT, 21 January 2015



(Correction:
If Part. Sig. Width is >1 ms, particles are overlapped.)

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

Flight Results (2/2) Tropical site
Biak Indonesia, 18:00 LT, 27 February 2015



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.

- Reference: Fujiwara, M., Sugidachi, T., Arai, T., Shimizu, K., Hayashi, M., Noma, Y., Kawagita, H., Sagara, K., Nakagawa, T., Okumura, S., Inai, Y., Shibata, T., Iwasaki, S., and Shimizu, A.: Development of a cloud particle sensor for radiosonde sounding, ***Atmos. Meas. Tech., 9***, 5911-5931, doi: 10.5194/amt-9-5911-2016, 2016. [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.