Airborne Instruments for Measuring Concentrations and Size Distributions of Hydrometeors

Airborne Instrumentation Talk #2

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1. Uses and General Nature of Hydrometeor Measurements
   - Some Measurements Needed for Studies of Clouds
   - Examples of Measured Hydrometeor Size Distributions

2. Survey of Instruments
   - Cloud Droplets
   - Hydrometeor Spectrometers
   - Imaging Probes For Hydrometeors
   - Other Measurements (e.g., LWC/IWC)

3. Conclusion
   - Unmet Needs and Summary
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COMMON MEASUREMENTS OF INTEREST
Measurements Often Used In Research

- Determine concentrations of:
  - Cloud droplets
  - Rain and drizzle drops
  - Ice crystals

- Determine size distributions \([n(d)]\)

- Determine ice concentrations, ice \(n(d)\), habits

- Determine moments of \(n(d)\): LWC, \(r_e\), \(Z\), etc..
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Types of Instruments

- Instruments that measure moments of the size distribution (LWC, effective radius)
- Instruments that measure portions of the size distribution
- Instruments that record images of the hydrometeors
- Instruments that distinguish water from ice
- “Special”: e.g., holographic imaging, multiple-view imaging, instruments to measure the distance between particles, impactors, ...
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Sources of Information on Instruments for Airborne Research
Web Sites With More Information

- **Facilities Assessment Database:**
  - http://www.eol.ucar.edu/fai/
  - NSF Facilities Assessment Final Report.pdf

- **EUFAR Database:**
  - http://www.eufar.net – see “instruments”
Challenges
Why These Measurements Are Difficult

Hydrometeors of Interest:
- Sizes range from 1-10000 µm
- Concentrations of $10^{-6}$ to $10^3$ cm$^{-3}$
- Complex range of ice shapes

Measurements from research aircraft must be made at speeds of 100–200 m/s
- High data rates: up to 100,000 hydrometeors/s
- Short times for detection: 10 µm at 200 m/s => 50 ns response for imaging probes
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EXAMPLE CLOUD DROPLET SIZE DISTRIBUTION

FSSP Measurements

RICO, Flight #rf01
12/07/2004, 18:45:09 - 18:45:10, 1 second average

William A Cooper
Hydrometeor Measurements from Aircraft
EXAMPLE DRIZZLE DROPLET SIZE DISTRIBUTION

260X+FSSP Measurements

RICO, Flight #rf02
12/08/2004, 14:40:00 - 14:45:00, 300 second average

William A Cooper

Hydrometeor Measurements from Aircraft
EXAMPLE RAIN SIZE DISTRIBUTION
2DC+2DP

RICO, Flight #rf04
12/10/2004, 17:35:00 - 17:40:00, 300 second average
EXAMPLE ICE IMAGES
2DC
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Really Old Techniques

- Impactors [Formvar, soot-coated slides]
  - issues: collection efficiency, need for short exposure, crater-to-size conversion
  - analysis laborious!

- Hot-wire sensors [“Johnson-Williams”] for LWC

- Icing detectors [Rosemount Icing Probe] for supercooled liquid water content
The Forward Scattering Spectrometer Probe (FSSP)

- Entered use about 1976
- Detects light scattered from a laser beam as a droplet passes through
- Counts and sizes individual droplets, 15 channels, 2-47 µm
- The standard/conventional measurement for about 3 decades
The FSSP-100
DEFINITION OF THE SAMPLE VOLUME

FSSP Sample Volume

- The laser is focused to the center of the sampling aperture.
- The focal plane is focused again on a detector where the beam is split.
- One sensor is masked so that, in the focal plane, the scattered light is focused on the mask.
- Pulses are rejected if the light sensed by the masked detector exceeds a fixed fraction of that sensed by the unmasked detector.
ADVANTAGES OF THE FSSP

- Provides automated measurement of the droplet size distribution (15 channels)
- A routine and standard measurement that rapidly became the world-wide standard
- Contributed to many scientific studies
Some Problems with the FSSP

- Uneven laser illumination causes variations in measured sizes and degrades size resolution.
- Coincidence effects on the measurements were serious at modest concentrations (700 cm\(^{-3}\)).
- Slow electronics in older versions.
  - Pulses were undersized even at 125 m/s
  - Elongated pulses increased coincidence effects
- Particle shattering causes false counts
- False counts also obtained from ice particles
SOME MODIFICATIONS

FSSP

“Fast FSSP” – Brenguier et al., France
- Measures times between droplet arrival
- Modified optics to improve definition of the sample volume

Particle Spacing Monitor
- RAF instrument to measure the interarrival times
THE DMT CLOUD DROPLET PROBE

Droplet Measurement Technologies CDP

Similar to FSSP but with:

- fast electronics (200 m/s)
- more channels (20-40)
- Laser diode instead of He-Ne
- Positive optical mask
- No dead-time losses

Sample rate (25 cm³/s at 100 m/s)
Phase Doppler Interferometer

A fundamentally different way of measuring droplet size:
- PDI measures droplet size by reference to the wavelength of the light.
- Not subject to intensity fluctuations; high stability.
- Schematic from Chuang et al., 2006: AST, 42, 685-703.
PDI Sizing by Phase Shift

- Droplets pass through interference fringes
- Small droplets scatter light over a larger cone, so detectors see a small phase difference (top)
- Large droplets scatter light in a narrower beam, so detectors see a larger phase difference (bottom)
- Phase shift and the fringe pattern spacing $\Rightarrow$ size and velocity.

Also from Chuang et al. (2008):
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SIZE DISTRIBUTIONS FOR LARGER HYDROMETEORS

drizzle, ice graupel, rain
OPTICAL CONFIGURATION

OAPs

- Focussed Laser
- Sampling Area
- Flight Direction
- Viewing Volume
- Sampled Volume
VARIETIES OF OAPs

- 200X (20 μm resolution)
- 200Y (300 μm resolution)
- 260X (10 or 12.5 μm resolution)
- DMT CIP=Cloud Imaging Probe (25 μm resolution) and PIP=Precip. Imaging Probe (100 μm resolution) – also 2D probes
- SPEC “HVPS” (200 μm resolution)
WEAKNESSES OF OAP SPECTROMETERS

- Depth-of-field uncertainty:
  - At small size, DOF is < aperture
  - Away from the focal plane, diffraction distorts size, requiring correction to the measured size

- In common with almost all hydrometeor probes, shattering can contaminate the measurements

- Sample volumes are sometimes too small for statistically reliable measurement

- Some (probably small) errors may arise from coincidence of particles in the sample volume
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2D OPTICAL ARRAY PROBES

- Optically similar to 1D OAPs
- record images of particles:
  - record the status of the diode array at high frequency
  - as the hydrometeor shadow passes over it, the images is recorded
  - typically 25 $\mu$m or 200 $\mu$m resolution
  - new versions now available with higher resolution
- Weaknesses similar to 1-D OAPs
- Image information can help identify spurious images (e.g., “streaking” or fragments from shattering)
- Sophisticated processing algorithms are possible (circle fits to rain images, pattern recognition for crystal habits, etc.)
From SPEC:
CPI Measurements
Small Ice Detector (SID)
University of Hertfordshire

- Uses multiple detectors to detect light scattered in various directions
- Discriminates ice from water on the basis of non-uniformity in the scattering pattern
- Counts and sizes small ice (few µm)
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Liquid Water Content
LWC/IWC

- **Heated elements:**
  - **King LWC**: constant-temperature element heated to evaporate water
  - Other collectors attempt to collect ice and measure ice water content

- **Counterflow virtual impactor and other evaporators:**
  - collect the cloud water (in the CVI, by virtual impaction),
  - evaporate the water
  - measure the LWC from the resulting water vapor density.

- **Gerber PVM:**
  - uses scattering from an ensemble of droplets at specific angles chosen to respond to the 3rd moment of the size distribution
  - can also measure the 2nd moment (effective radius)
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Weaknesses in Capabilities

- Need standardized calibration facilities and procedures!
- Inadequate size resolution for cloud droplets (but promising new approach in the PDI).
- Uncertainties in sample volume for many instruments.
- Inadequate sample volume for some hydrometeor sizes (esp. rain)
- Uncertain detection of small ice crystals and drizzle (e.g., 50-100 \( \mu m \)) with adequate sample rates.
- Uncertainties in how airflow affects the measurements.
- Contamination of measurements by shattering.
Conclusion

- An impressive array of automated airborne hydrometeor sensors is now available.
- There has been significant recent progress toward addressing key uncertainties.
- Further progress will probably require in-depth study of the nature of the instruments and the measurements, esp. regarding sample volumes, calibration, and data interpretation.