Discussion Motivation

- What priorities should be given for instrument development, procurement or testing (wind tunnel or flights) given money is likely to be available for a 1-year period?
- Can we reach consensus on what are most pressing in-situ cloud/aerosol instrument priorities?

How to Summarize Workshop

- Develop recommendations on both short-term & long-term priorities for aircraft instrumentation
  - ARM-centric? Probably should keep our discussions broad due to hope for inter-agency coordination, but focus on applications to human-induced climate change

Recommendations

- Things to consider
  - Calibration facilities, standards or manuals
  - How to reduce & better define error bars
  - Comparison of data processing methods
  - Closure studies, when/where techniques work
  - Merged in-situ/remote sensing techniques (integrated method development)
  - List of parameters that need to be better measured

Workshop Results

- Human-induced climate change
  - What do we need to reduce the error bars
  - Manual (review of calibration facilities & methods)
  - Facility where can be done in consistent manner is needed and needed in short-term
  - Merged approaches (in-situ/remote sensing)
  - Getting away from inlets, explaining what inlets do
  - Closure studies

- Need for uncertainties
- Every technique has gap
- Under what conditions different techniques work
- Integrated method development important and needs to be put on priority list
- Lot of data set, glut of data
- Data processing algorithms & software
  - Lots of differences between algorithms need to be resolved
  - Need for algorithm intercomparison
- Slide of list of parameters that we need to be able to measure
  - Ice nuclei, small crystals and habit, vertical velocities, aerosol absorption, forward-pointing lidar

Lidar Issues

- Near-field lidar measure close to aircraft (aerosols & clouds), temporal/spatial,
  - need ~ O(m) for observations near cloud edges; calibration for near-range is problem if want more than boundaries;
  - how close do we need to get is big question: 3 m or 30 m?
  - Why not just look forward with your lidar, because will get in-situ observations 1 s later (eye safety issue is problematic with FAA if not doing nadir/zenith)
- Remote sensors provide context for in-situ observations
- How important is coincident field of view for different instruments both spatially & temporally
  - How close do they need to be?

Calibration Issues

- Calibration:
  - stray light, radiometric calibration, spectral calibration, cosine response
  - Accuracy depends on the science questions
  - Do standards exist? (in IR can trace back to NIST, radiance use integrating spheres)
  - Cautious & consider uncertainties from errors needs to be emphasized (tools available), need to have checks/comparisons & secondary calibrations during campaigns to compare with laboratory calibrations (enforce these)
  - Absolute calibration needs to be done

Uncertainties & Information Content

- Information content
  - What are we measuring, uncertainty, covariance b/n variables, what info do we actually have due to correlation & assumptions in retrievals
- Closure studies
  - Necessary but not sufficient
  - Constrain above & below layer and make same measurements in-situ (use error propagation techniques here)
- Insist on error bars & propagation of uncertainties
  - What does error bar mean if not measuring quantity correctly?
  - E.g., for hard to quantify error: simulate retrievals under different assumptions of surface albedo can be input to what an error bar is (BRDF especially hard to measure), Bayesian retrievals
  - Think about bias errors and correlated errors really have to think about
- Retrievals vs. in-situ can help tell strength/weakness of each

Where are gaps (remote sensors)?

- Field of view between different sensors
  - Best handle simulation with model fields
- 3-d remote sensed fields
- Measurements of thermodynamics
  - Vertical & horizontal (3-d) profile of T & RH at 100 m resolution
- Two platform at different altitudes can overcome deficiency of different techniques
- Vertical velocities
- Lidar overlap function
- angular fields of radiation
- Horizontal fields/looking remote sensors
- Closure experiments for radiative heating profiles in atmosphere, but has proved difficult experiment (small UAS technology, SSFR for layered heating rate (above/below layer—wide range of aerosol absorption in atmosphere)
- Latent heating profiles in atmosphere (retrieved from space but can't be measured in-situ)

Priorities

- Gain confidence in specific measurements needed for science questions in upcoming field campaigns
  - POTENTIAL METHOD: Need for calibration standard/facility/ laboratory/methods for concentration of & size/shape characterization of aerosols, liquid and ice (specific test flight opportunities)
    - partnerships could be beneficial (NIST facility, action item for Rick Petty, talk with Mike Kurylo)
    - Platforms for testing without certification
- Need for funding for innovative concepts at universities/government labs (not just companies)

Instrument Uncertainty

- Main source of uncertainty is volume sampled (transverse/longitude)
  – More effort in development of multi-particle instruments for sampling in transverse direction with well-defined sample volume (e.g., HOLODEC, PVM), fills gap b/n remote sensing & in-situ

Questions

- Small Ice Crystals
- Splashing on inlets & representative sampling
- Large aerosols/sea salt measurements
- What do we need to measure for indirect effect?
  - Clouds & how they are distributed is biggest science priority
    - Large-scale impacts thru micro-scale
    - Airborne may tell you about interaction b/n aerosols, clouds, radiation & dynamics
    - Consistent set up of integrated suite instruments on aircraft (dynamics/fluxes/radiation/aerosols)
    - Interaction b/n global satellite observations & local aircaft observations
- How long do we need to wait to reduce error bars in measurements if we spend $10^6 year on instruments
  - ICCAGRA ISPRS-WGI

Measurement Priorities

- Updraft velocity
- Integrated measurements of LWP
- Lidar working close to airplane in tandem with in-situ observations
- Location of aerosol/cloud instruments on airplane (e.g., inlets too close to fuselage, what instruments need to be close together when looking at fine-scale structure)
- Portable containers that can be exchanged between aircraft

Where are gaps?

- Wind measurements: because mesoscale wind fields important for validating models & getting dynamics right
  - Remote sensing solutions (do they have needed accuracy/precision)? Doppler lidar promising for winds (u and v); stereo-cameras; feature tracking from H20v images; Doppler radar
- Phase function (for aerosols & clouds)
  - Which parts (moments/integrals)
  - Asymmetry parameter for aerosols/clouds useful substitute if talking about flux transmission, but other aspects need complete P(theta)
  - Circles of aircraft over homogeneous surface (visible spectrometer); aeronet gets phase function for aerosols; 4-STAR is airborne aeronet; in-situ polarnephelometer, CAR (need remote sensing & in-situ to determine consistency)
- Aerosol absorption (over wider range of λ, across solar spectra and in UV and in IR and in ambient conditions to be useful, dependence on RH)
  - Remote tecnhiques using solar energy give wide range of lamda and ambient conditions
  - Heating rate solutions listed below
  - Multiple UAVs with SSFR & direct beam transmission or remote sensing measurements solve
  - Multi-wavelength HSRL for retrievals to get heating rates in atmosphere
  - Flux measuring radiometers on balloons to get heating rates?
  - Tethered balloons look really promising; tow platforms
  - SYNERGY between remote sensing & in-situ
- Aerosol properties near cloud edges (finer spatial resolution measurements needed in ambient conditions)
  - Airborne sun photometry look at λ dependence of aerosol optical depth; lidar; how do you define cloud edges
- Better measurements of ice nuclei
- Finer spatial resolution observations
- Span the range of length scales in clouds
- Extinction/ice water content in mixed-phase clouds
- Small ice crystals
- Spectrally resolved radiation distribution inside clouds
- 3-d spatial distribution of clouds
  - Airborne imagery

UAS Discussion

- Difference between UAS & UAV
- Difficulties:
  - Standardized control system for UAS difficult because of proprietary issues, need standard methodology for FAA to reference for risk mitigation & air worthiness (FAA also needs database)
  - Inability to generate power on-board (need to return or ditch by time when battery runs out)
  - Aircraft meant to be reused rather than just a few uses (cf. military)
  - Pilots, model planes
  - Stepwise progression, prove can fly without incident (e.g., using airspace over Oliktok Point)
  - Exciting new technology for the future (will take off as efforts continue once reasonable regulations for flying)