Turbulence and Fog Microphysics from Measurements

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1. As part of the C-FOG team to support the overall C-FOG objectives:
   • **Measurements and sampling setup** that fit within the requirements of the overall C-FOG project design
   • **Analyses in coordination with other C-FOG PIs**

2. Specific interests on:
   • **Fine scale structure across the fog layer top affecting entrainment processes using tethered balloon-based measurements**
   • **Understand the role of surface layer turbulence in fog layer formation and dissipation**
   • **Identify mesoscale model deficiency using detailed observational data**
NPS/MLML Instrument Deployment in Support of C-FOG

1. Ground-based systems
   • Trailer-based NPS Aerosol Sampling Unit (NASU) near surface cloud microphysics, aerosol and radiation measurements
   • Turbulence and mean wind and thermodynamic sampling on tripod mast
   • Tethered balloon system for vertical profiling of turbulence and mean wind and thermodynamics
   • Ceilometer cloud base and aerosol layer measurements
   • Optical turbulence and possibly optical attenuation sampling

2. Ship-based systems
   • Bow mast turbulence
   • ROSR radiometric SST (redundant sensor)
   • Microwave radiometer profiling
Sketch of the vertical profiles in the upper cloud/fog layer showing the sharp gradients at the cloud top (left) and of the physical processes occurring at the cloud-top region (right). The mean liquid water static energy, $h + gz$, and total water content, $q_t$, are approximately constant inside the mixed layer and vary rapidly across the cloud-top region; $-\partial_z R$ and $-\partial_z E$ are the cooling rates due to radiation and evaporation. Dashed lines define control volumes for the integral analyses (figure and caption adapted from Mellado 2017).
Aircraft Observed Cloud Top Undulation

Measurements made by the NCAR Electra during ASTEX on 12 June, 1992 (Flight 5)
Fine Structure at the Cloud Top
Fine Structure at the Cloud Top

RF06 Sounding csleg41 ascent 13-Jun-1992 08:07

[Graphs showing various parameters such as $q_c$, $\theta$, $q_t$, $O_3$, $U$, $V$, $w$, $N_c$, $\theta'$, $q'_t$, $D$, $u'$, $v'$, and $w'$ against height (m) from 780 to 880 meters.]
Fine Structure at the Cloud Top
Limitation of Aircraft ‘Soundings’

1/30 slope (500 ft/min ascent rate, 100 m/s air speed): 20 m vertical ~ 600 m horizontal

✓ Vertical sounding profiles
✓ Good statistics for repeated penetrations

Tethered balloon measurement near the fog layer top is a likely solution
Temporal Variations Seen from Tethered Balloon Soundings

Figure 6. Vertical profiles of the air temperature $T$ (left panel), longitudinal wind velocity $u_p$ (middle panel), and $LWC$ (right panel). The wet-adiabatic lapse rate of $\gamma_s = -0.6 \text{ K (100 m)}^{-1}$ is indicated in the left panel as a straight line. The adiabatic $LWC_{ad}$ is included in the right panel as a straight dashed-dotted line.

(from Siebert et al. 2003)

#3 was made 25 min after #1, #4 was made 5 min after #3
Research Questions

• What is the true vertical variation of temperature, humidity, cloud water, and turbulence at the immediate cloud/fog layer top?
• How different are the fog layer boundaries defined from different variables and what are the physical processes resulting in these differences?
• What are the roles of wind shear at the fog layer top in modifying the entrainment process?
• How does entrainment vary in different development stages of fog?
• What are the major difference in the entrainment into a fog layer vs the stratocumulus cloud layer, and how are these differences related to surface forcing in fog layer?
• What are the implications of the observed small scale structure on entrainment parameterization?
• How one should incorporate the cloud-top small-scale processes in the entrainment parameterization for use in mesoscale models?
Field Campaign Participation

1. Ground-based systems
2. Ship-based systems on R/V Hugh Sharp
NPS Aerosol Sampling Unit (NASU)

• Continuous measurements
• Three-Wavelength Particle Soot Absorption Photometer (PSAP) – aerosol absorption
• TSI Integrating 3563 Nephelometer (NEPH) – aerosol scattering
• Passive Cavity Aerosol Spectrometer Probe (PCASP) – aerosol size distribution
• TSI Integrating 310 Condensate Particle Counter (CPC)
• Weather Sensor Package (T, RH, wind speed)
NASU Modified for C-FOG (1)

1. Trailer-based system

- Self-contained trailer system (office and data collection station)
- Good ventilation to avoid salt and moisture accumulation on sensitive sensors (lesson learned from CASPER-East)
- Shipping container
- Shore power (120V or three phase 240V) or generator power supply

Heavy duty power generator
NASU Modified for C-FOG (2)

2. Addition of Cloud Droplet Spectrum Sampling (under development)

- PVC enclosure
- Fan to draw air through at optimal speed
- Flow meter close to the optical sampling location
- Package to be mounted on top of trailer, turntables based on wind direction

CDP-2 modified with increased flow speed quantified by a flow meter
Tethered Balloon Based Measurements

- 16 m$^3$ or 30 m$^3$ Helikite lifting system with mooring arm and hydraulic winch
- Can park at altitude or make profiling measurements
- Key sensor: Gill 3-D sonic anemometer for turbulence momentum perturbations and virtual temperature perturbations (under development)
- Thermocouple for direct fast temperature perturbation sampling ($C^2_T$)
- Mean Weather Sensor Package (T, RH, wind speed) Measurements between 10 m and 400 m
- Will explore: replacing the 3-D sonic with an Irgason to include water vapor perturbation measurements
*Addition of BLS-900 scintillometer in hope to collect data for another NPS project on laser propagation in foggy conditions*
Bow Mast Data from R/V Sharp

Measurements/Sensors:
- Irgason from Campbell Sci + Rotronics+GPS position and attitude angles
- Measurements were made continuously during the cruise
- Good data sections only when wind came from ~±60° from the centerline of the ship
- Derivable quantities include:
  - mean T, q, P, U, V
  - Momentum, sensible, and latent heat flux over a requested time period
- Measurement altitude: 34 ft above waterline.

Same setup as in CASPER-East
Other Ship-Based Sensors

**ROSR/KT19:**
- High accuracy radiometric calibrated SST from ROSR (3 min interval, may be affected by spray)
- Radiometric skin temperature from KT19 (1 Hz sampling rate, un-calibrated)

(This will be a redundant sensor identical to that to be deployed by Notre Dame)

**Microwave radiometer**
- Continuous profiling of T/RH and cloud water
NPS/MLML Pre-C-FOG Testing

• Field testing and measurements in foggy conditions 9-20 July, 2018 in Watsonville, CA
  - Testing of new NASU in trailer
  - Testing of tethered balloon operation
  - More measurements in foggy conditions
Remaining Issues

• Site conditions (to be determined after site visit)
• Shipping trailer to the island (ferry available?)
• Shipping trailer across country and the paperwork for expensive government equipment going out of country
• Tethered balloon storage on site, helium
• Scintillometer on loan?
• Lodging arrangements