Airborne Observing Systems

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NSF/AGS/LAOF-Supported Aircraft And Airborne Remote Sensing

NSF Deployment Pool Funded Aircraft:
- NSF/NCAR EC-130Q Hercules C130
- NSF/NCAR Gulfstream G-V
- UWYO King Air
- NPS/CIRPAS Twin Otter

Airborne Systems:
- Wyoming Cloud Radar (WCR)
- Wyoming Cloud Lidar (WCL)
- GPS Dropsonde System (AVAPS)
- ELDORA Airborne Doppler Radar (on NRL NP-3D Orion)
NSF C130: Heavy-lift research aircraft

- 10 + Hours Endurance
- Typical payload 15,000 lb
- Range 3100 nmi
- Altitude 26,000 ft

- 40 kVA (400Hz), 28 kVA (60 Hz), 400 A (28 VDC)
- Modified in house (1993-2011)
- 2000 upgrade of engines
- 2010 ~$8 M upgrades of avionics and propellers

Photo courtesy of Tony Clarke, Univ. of Hawaii
Gulfstream V: Global Scale Platform

- Delivered new as major equipment purchase 2000-2004
- Modified as delivered, then by NCAR/EOL
- $14 M ($12.5 M external) of new community instrumentation: now ready to go!

- Fully FAA Certified
- Long-Range (over 6000 n miles--South Pole and back)
- Six under-wing hardpoints
- Up and Down (2) Co-Aligned 20 inch optical viewports
- Ample inlets and fuselage hard points

- High Altitude (up to 51,000 feet)
- 6000+ lb payload
- Up to 12 hours endurance (10 hours typical)
Wyoming King Air: remote sensing, cloud/aerosol, boundary layer

- Ceiling: 26,000 ft
- Wyoming Cloud Radar
- Wyoming Cloud Lidar (up + down)
- Pressurized
- Certified for flights into known icing conditions
- Payload Capacity: 1500 lbs.
- Available Payload Power:
  - 240 Amp of 28 VDC
- 4+ hours endurance, fully loaded
- Purchased new 1977; heavily modified
- Recent avionics and engine upgrades
- Single pilot operation: Scientist in the copilot seat

Photograph courtesy of Sandra D'Aria
NPS/CIRPAS Twin Otter: air-sea interaction, boundary layer, cloud/aerosol studies

- Payload Capacity: 1500 lbs.
- Available Payload Power:
  - 200 Ampere of 28 VDC (5600 Watts)
  - 4000 watts may be inverted to 120V AC at 60 Hz.
- 5 hours endurance, fully loaded.
- Practical Ceiling: 18,000 feet, 12,000 feet without oxygen.
- Non-pressurized
- Not certified for flights into known icing conditions
- NSF/NPS MOU 2010
NRL-P3: ELeictra DOppler RAdar (ELDORA)

- Ceiling: 31,000 ft
- Endurance: 12 hours
- Payload: 4500 lb
- ELDORA developed jointly by NCAR and France’s CRPE

- NSF/NRL MOU (1 year left)
- Service life issue (wings)
- No NSF base funding
Wyoming Cloud Radar: deployable on UWKA and C-130

- 95 GHz (3.16 mm), 0.5° antennas
- First project: 1995
- Base funding 2004
- WCR-2: 2009
  - Higher sensitivity
  - Polarimetry
  - Full Doppler spectrum

Antennas

- Side or Up (beam 1)
- Side-fore (~35°, beam 3)
- Down (near nadir, beam 2)
- Down-fore (~30°, beam 4)
| **Table 2. WCR specifications.** |
|-------------------------------|-----------------|
| **Transmit frequency | Wavelength** | 94.92 GHz | 3.16 mm |
| **Pulse width | Pulse repetition frequency (PRF)** | 100–500 ns | 1–20 kHz |
| **Antennas** | **Aperture | beamwidth** | 0.305 m | 0.7° |
| • Side or up (beam 1) | | 0.305 m | 0.7° |
| • Side fore (~35°, beam 3) | | 0.457 m | 0.5° |
| • Down (near nadir, beam 2) | | 0.381 m | 0.6° |
| • Down fore (~30°, beam 4) | **2** |
| **Receiver channels** | **Digital (12 bits)** | 65 dB |
| • Outputs | 5 dB |
| • Dynamic range | **Minimum 7.5 m** |
| • Noise figure | **Minimum ~3m** |
| **Sampling rates** | **1st & 2nd moments** |
| • Along beam | 16–512 spectral lines |
| • Along flight | ±15.8 m s⁻¹ at 20 kHz PRF |
| **Doppler radial velocity processor** | **~ 10 km** |
| • Pulse pair | **~ 100 m** |
| • Fast fourier transform (FFT) spectrum |
Wyoming Cloud Lidar: deployable on UWKA and C-130

- 355 nm YAG
- 351 nm pumped diode

Compact polarization lidar (elastic)
- Polarization and Backscatter ratio
- 3.75 m vertical
- 5-2 m horizontal (SNR issue)
- Base funding 2010
## Wyoming Cloud Lidar: Deployable on UWKA and C-130

<table>
<thead>
<tr>
<th>Ultra-pulsed Nd:YAG laser from Big Sky Laser Technique, Inc</th>
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<tr>
<td>Transmit wavelength</td>
</tr>
<tr>
<td>Transmit pulse length</td>
</tr>
<tr>
<td>Range gate resolution</td>
</tr>
<tr>
<td>Pulse Rep. Frequency</td>
</tr>
<tr>
<td>Beam Width</td>
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<tr>
<td>Pulse Averaging (typical)</td>
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<tr>
<td></td>
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<tr>
<td>Detector(s)</td>
</tr>
</tbody>
</table>
NCAR Dropsonde Technology
Complete end to end solution

Atmospheric Profiling
- Research quality sensors
- Fast sample rate - high vertical resolution
  - Pressure
  - Temperature
  - Humidity
  - Winds
- Capability of rapid launch, up to 8 sondes in the air simultaneously.
- Launch Platforms
  - Manned Aircraft Systems
  - Global Hawk UAS
  - Long duration balloons (Driftsonde)

Aircraft Data Systems

Automatic launcher

ASPEN Software
Data Quality and Temp Drop message

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Global Hawk HS3 Dropsonde Mission
North Pacific Cross Sections

Cold tropical tropopause

32 Dropsondes Released every 1° Latitude

Extratropical storm

Dry subtropics

Strong polar jet stream in the upper troposphere at midlatitudes

Slide courtesy Ryan Spackman, NOAA/ESRL
ELDORA
on P3

<table>
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<th>ELDORA Characteristics</th>
<th></th>
</tr>
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<tr>
<td>Number of Radars</td>
<td>2 (fore and aft)</td>
</tr>
<tr>
<td>Wavelength</td>
<td>3.2 cm</td>
</tr>
</tbody>
</table>
Hurricane Rainband and Intensity Change Experiment (RAINEX, 2005)

Blue track: NRL P3
Red/Yellow tracks: NOAA P3

“Eyewall replacement process”: Crucial input to high-resolution numerical models can lead to improvements in forecasting hurricane intensity.

HIAPER Pole-to-Pole (HIPPO) Global scale research: Capturing the carbon cycle in different seasons (Wofsy et al.)

G-V Flight Hours:
- 86 (January 2009)
- 90 (October 2009)
- 85 (March 2010)
- 97 (June 2011)
- 103 (August 2011)

Total Flights: 64
Distance: 171,000 miles
Vertical Profiles: 461
HIPPO sections, January 2009

**CO₂**

**CH₄**

**CO**

**N₂O**

**SF₆**

**O₃**
Universities
Arizona
Arizona State
California Los Angeles
California Irvine
California San Diego
California Santa Cruz
Chile, Chile
Concepción, Chile
Colorado Boulder
Colorado State
Drexel
Hawaii
Iowa
Leeds, UK
Manchester, UK
Miami
N. Andres Bello, Chile
Naval Post. School
North Carolina State
Oregon State
Purdue
Reading, UK
Washington
Wyoming

Logistic Support: UCAR JSS
Brookhaven Nat.
COLA
CNRM/GAME France
CNRS/LMD France
IPARPE Peru
Inst. Geofísico del Peru
IPRC
IEBAO
LEGOS
LOCEAN France
NASA/GSFC
NCAR
NCAS, UK
NOAA/ESRL
NOAA/GFDL
NOAA PMEL
NRL
Pacific Northwest
Scripps
Woods Hole

VOCALS Goals
Elimination of CGCM systematic errors in the SEP, and improved model simulations of the coupled system in the region and global impacts of its variability.

Improved understanding and regional/global model representation of aerosol indirect effects over the SEP.

Oper. Centers
EMRC Australia
OPTEC Brazil
ECMWF Intl.
JMA Japan
HerOffice UK
NOAA-US
Climate need: Understand the lifetime and albedo of marine stratus

The C-130 was a key platform for VOCALS due to:

- Long endurance:
  - Needed to capture diurnal variability

- Long range:
  - Needed to capture polluted coastal and clean remote parts of the cloud deck

- Large payload:
  - Turbulent fluxes
  - Trace gases
  - Aerosol particles
  - Cloud and precipitation particles
  - Cloud radar and lidar

- DYCOMS (1985 Electra)
- DYCOMS II (2001)
  - "One last technological development that motivated a new observational attack...was the availability of the NSF/NCAR C130" From Stevens et al. BAMS 2003

- VOCALS (2008)
  - Largest marine stratus study to-date
Multi-sensor retrievals:
Optimally combine

• In situ data: small sample volume, size resolved
• Remote sensing data: integrated properties

Table 3. A list of measurements needed to retrieve ice-, water-, and mixed-phase cloud microphysical properties.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Ice clouds</th>
<th>Water clouds</th>
<th>Mixed-phase clouds</th>
</tr>
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<tr>
<td></td>
<td>IWC and $D_e^*$</td>
<td>LWC, $r_{eff}$, and drizzle property</td>
<td>IWC and $D_e^*$ for ice phase</td>
</tr>
<tr>
<td>WCL</td>
<td>Extinction</td>
<td>Extinction</td>
<td>LWC and $r_{eff}$ for water phase</td>
</tr>
<tr>
<td>WCR</td>
<td>$Z_z$</td>
<td>$Z_z$</td>
<td>Extinction depolarization ratio</td>
</tr>
<tr>
<td>GVR (*)</td>
<td></td>
<td>LWP</td>
<td>$Z_z$ or spectrum</td>
</tr>
</tbody>
</table>

References:
- Donovan and van Lammeren (2001),
- Wang and Sassen (2002),
- Heymsfield et al. (2008),
- Deng et al. (2010)
- Frisch et al. (1995),
- Sassen et al. (1999),
- O’Connor et al. (2005),
- Wang et al. (2004) and Shupe et al. (2008)

(*) G-band (183 GHz) radiometer: 4 channel, PLW and LWP (Pazmany, 2007)
WCR and WCL observations of drizzling stratocumulus clouds during VOCALS:
(a) WCR $Z_e$,
(b) WCL attenuated backscatter power
(c) retrieved visible extinction coefficient
(d) cloud effective radius ($\mu$m) above cloud base,
(e) drizzle effective radius ($\mu$m) below cloud base,
(f) drizzle number concentration below cloud base, and
(g) layer mean cloud droplet number concentration.
In (a) and (b), the solid lines indicate WCL identified cloud base and the dashed lines represent the top of useable WCL data.

Challenges:

• Installation and certification of instrumentation
  • Commonality of instruments among platforms
• Risk Management for unusual research flight operations
  • Volcanic ash
  • High electric fields
  • Lightning (King Air)
  • Dropping sondes
• International Operational challenges (e.g. diplomatic clearances)
• Access to airspace (ATC clearances and related)
Questions?