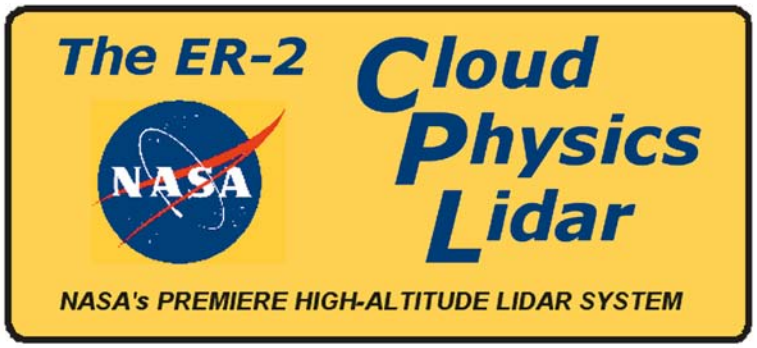
UAV-based lidar sensor for next-generation suborbital platforms

-- and --

Development of a new airborne lidar instrument for aerosol transport studies



Presented by Matthew McGill
with Stan Scott, Shane Wake, Dennis Hlavka, William Hart, and Paul Newman

Presentation overview

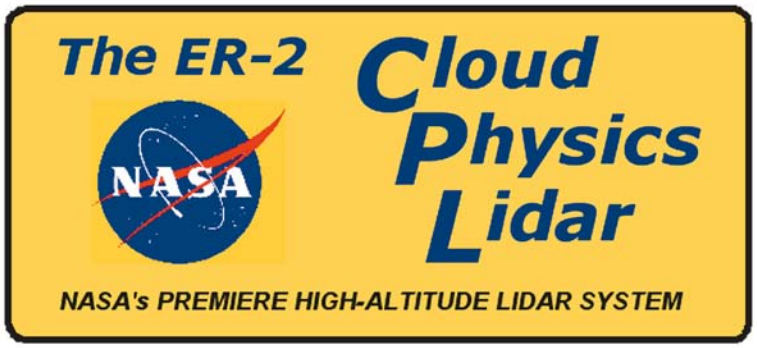
1. CPL: what it is, what it does

1. CPL, CLASIC, and that NASA A-Train

1. UAV-CPL on Global Hawk
   next-generation airborne science

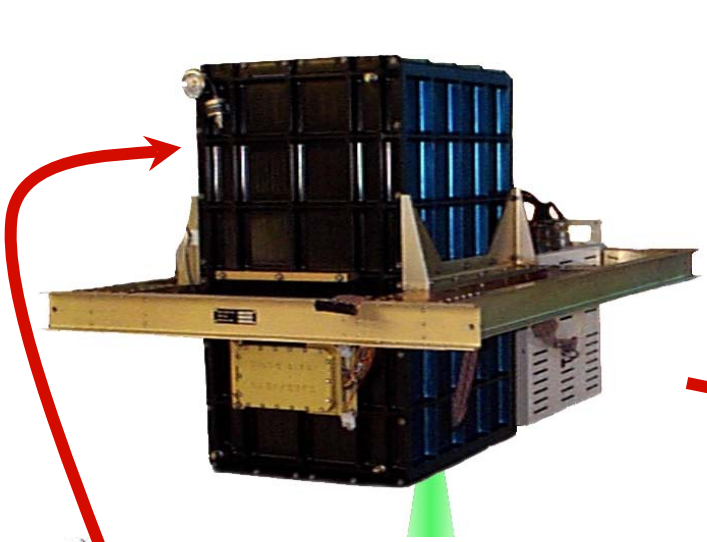
4. Where to next?
   cloud-aerosol transport, a
   new instrument development

The NASA Cloud Physics Lidar: science and satellite validation from high-altitude

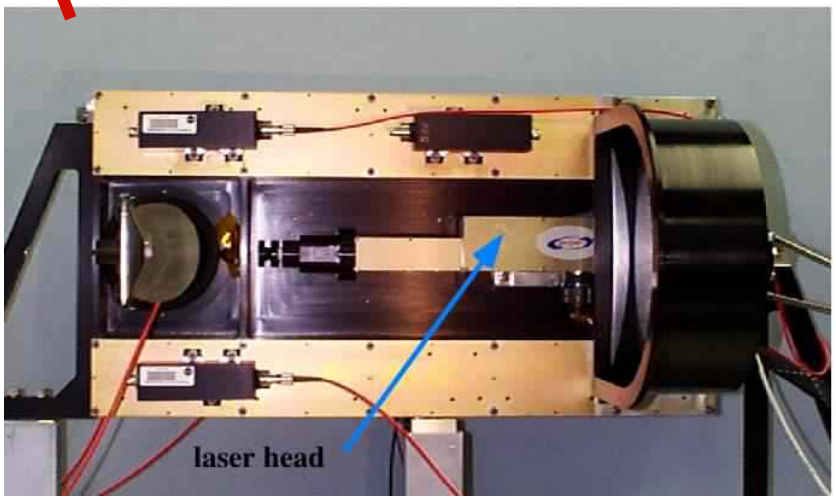


The Cloud Physics Lidar

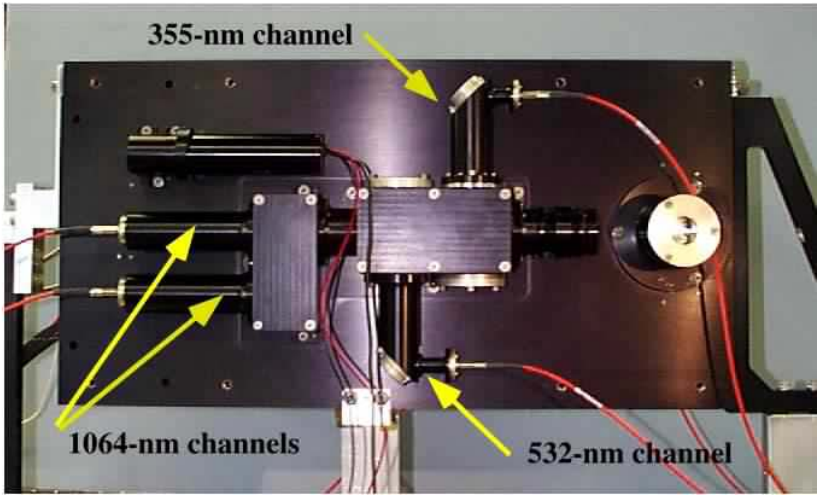
CPL is a self-contained, autonomous backscatter lidar



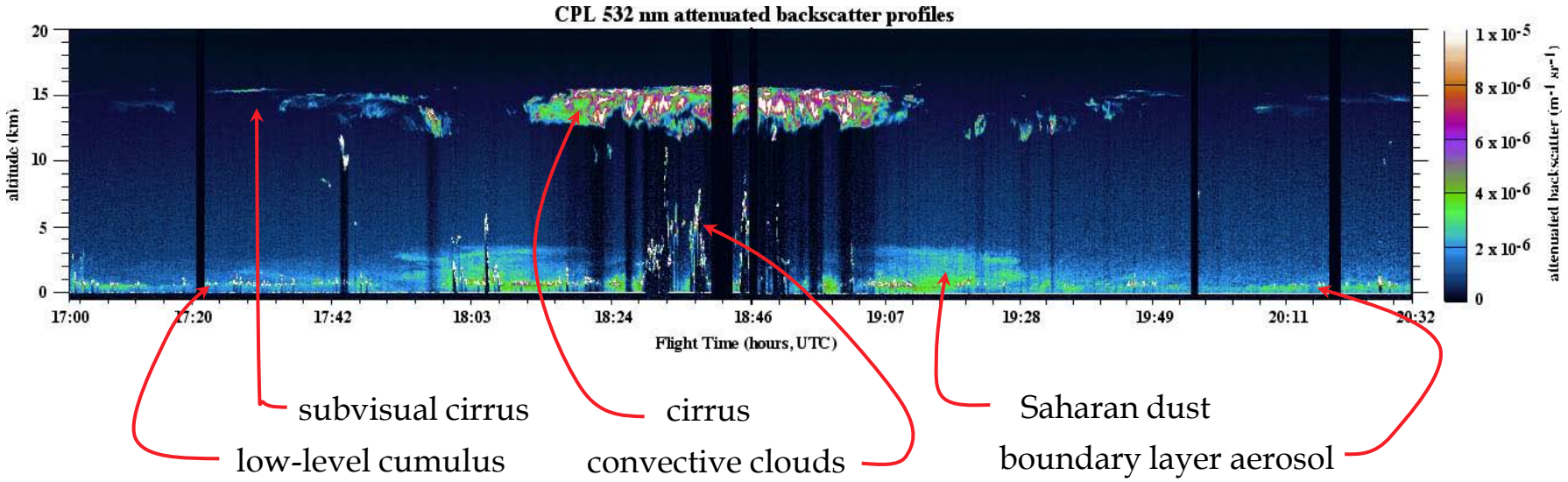
a)



b)



CPL Data Example



Lidar profiling generates a time-height cross-section of the atmosphere, revealing cloud and aerosol structure.

Multiple cloud/layer features can be measured, *up to the limit of signal attenuation* (O.D. 3-4).

From this data we derive layer boundaries, optical depth, extinction, and depolarization.

The CPL web site is: http://cpl.gsfc.nasa.gov

CPL data products

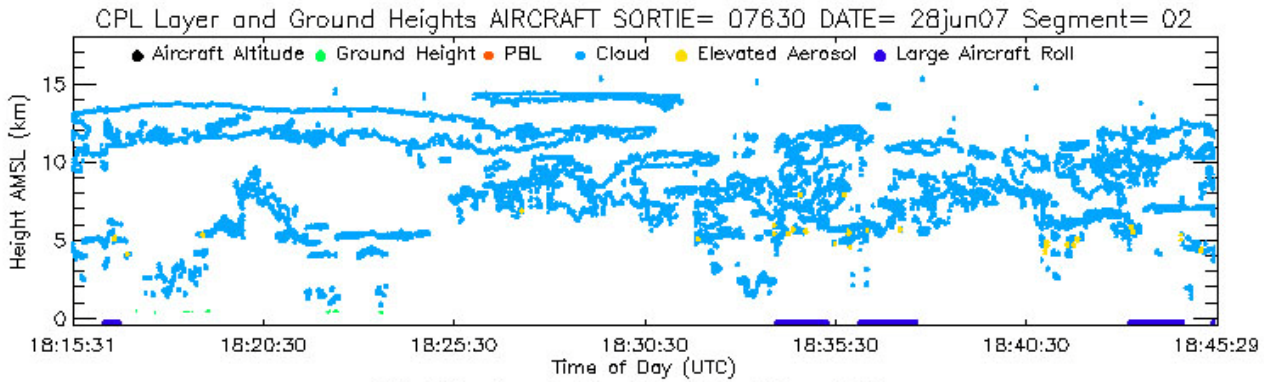
1. Summary images for each flight.
2. Layer boundaries for PBL, elevated aerosol layers, clouds.
3. Optical properties, including
   - layer optical depth (e.g., PBL, cirrus, total)
   - layer extinction-to-backscatter ratio (S) used
   - layer extinction profile
   - layer transmission profile
   - images for extinction and optical depth
   - depolarization ratio (1064 nm only)

All data products are 1 second averages produced from the raw 1/10 second data.

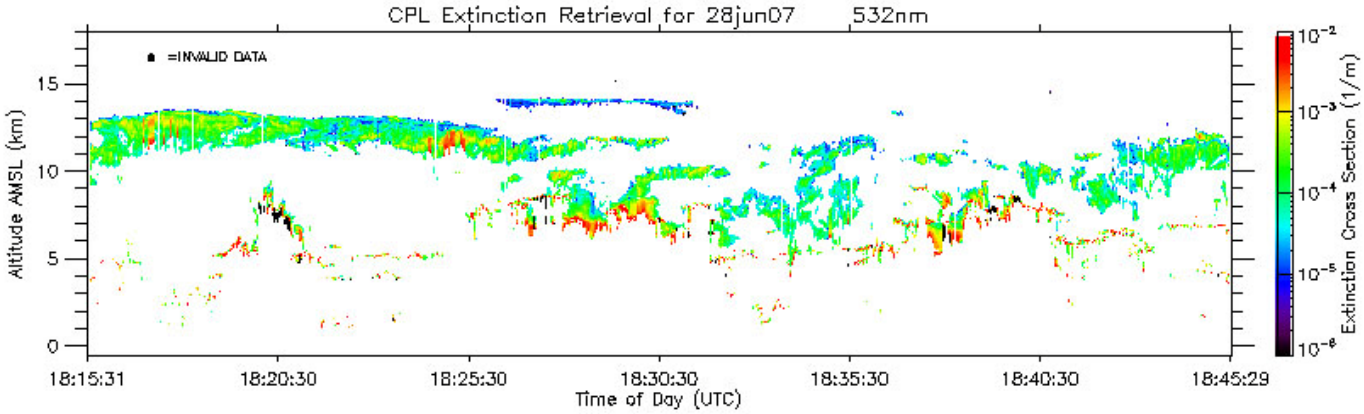
All data products are produced for each wavelength.

The CPL web site is http://cpl.gsfc.nasa.gov

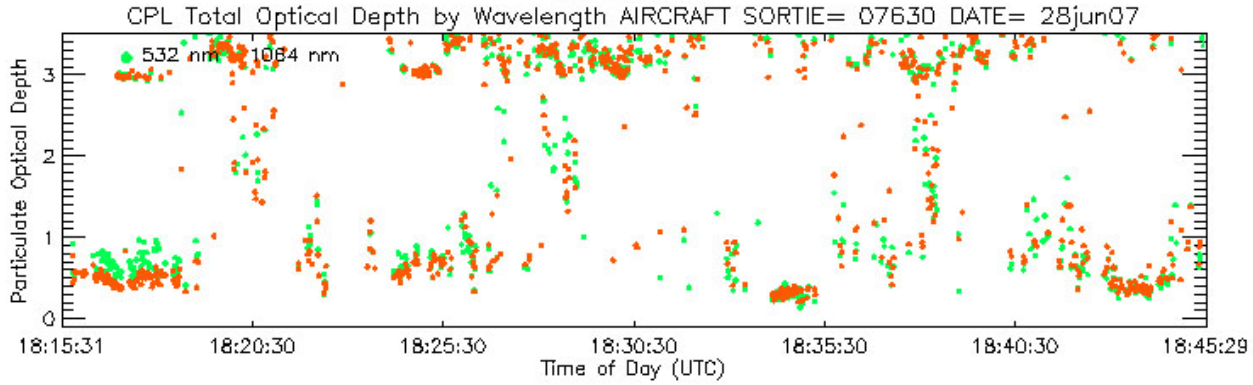
Example of CPL higher level data products



layer finding and typing



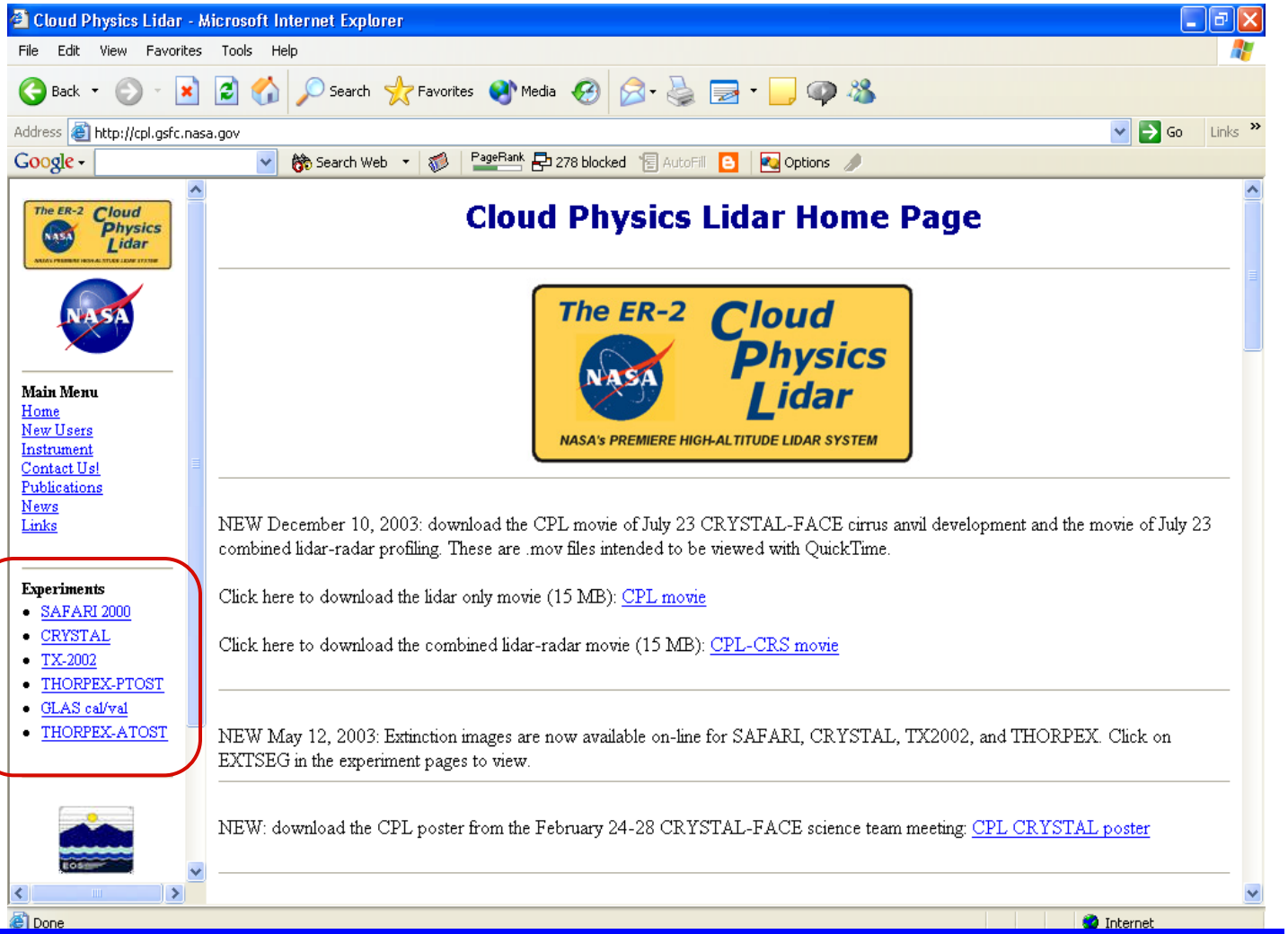
extinction profiles



optical depth (total, cloud only, aerosol only)

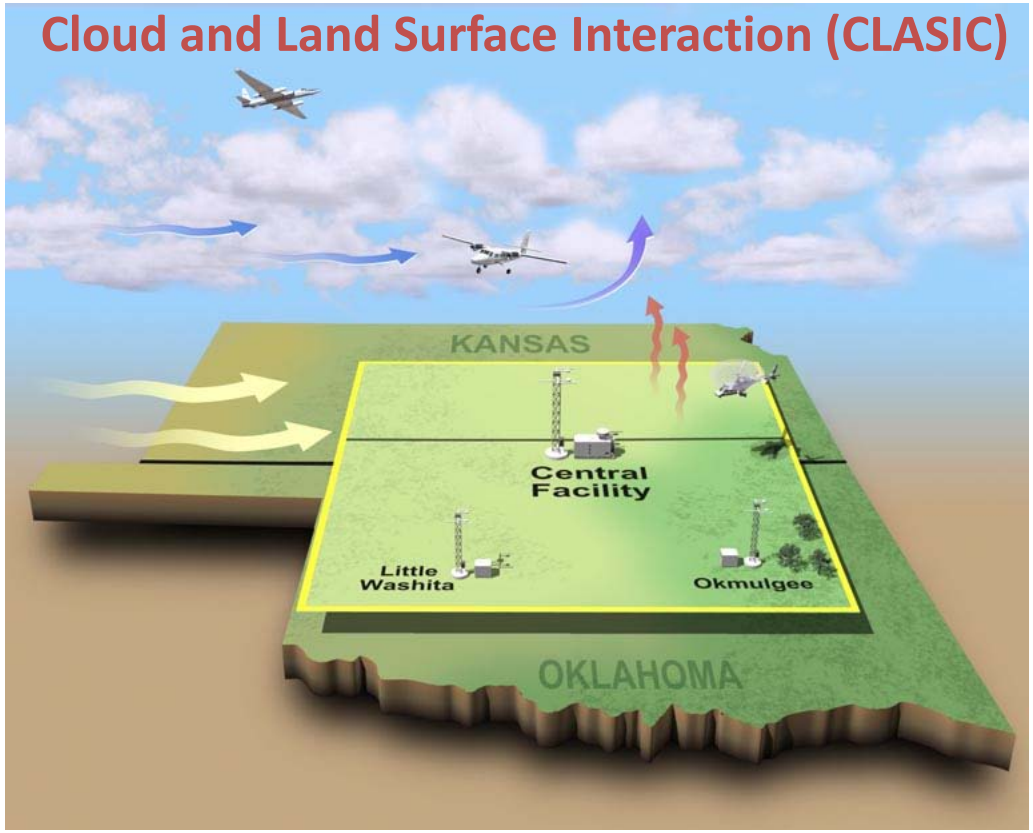
CPL data is archived on the CPL web site

data available
by experiment



http://cpl.gsfc.nasa.gov

The CLASIC campaign



Summary of flights

08 JUNE: transit from Dryden

11 JUNE: survey pattern

12 JUNE: A-Train underflight

21 JUNE: A-Train & survey pattern

22 JUNE: survey pattern

23 JUNE: survey pattern

28 JUNE: A-Train underflight

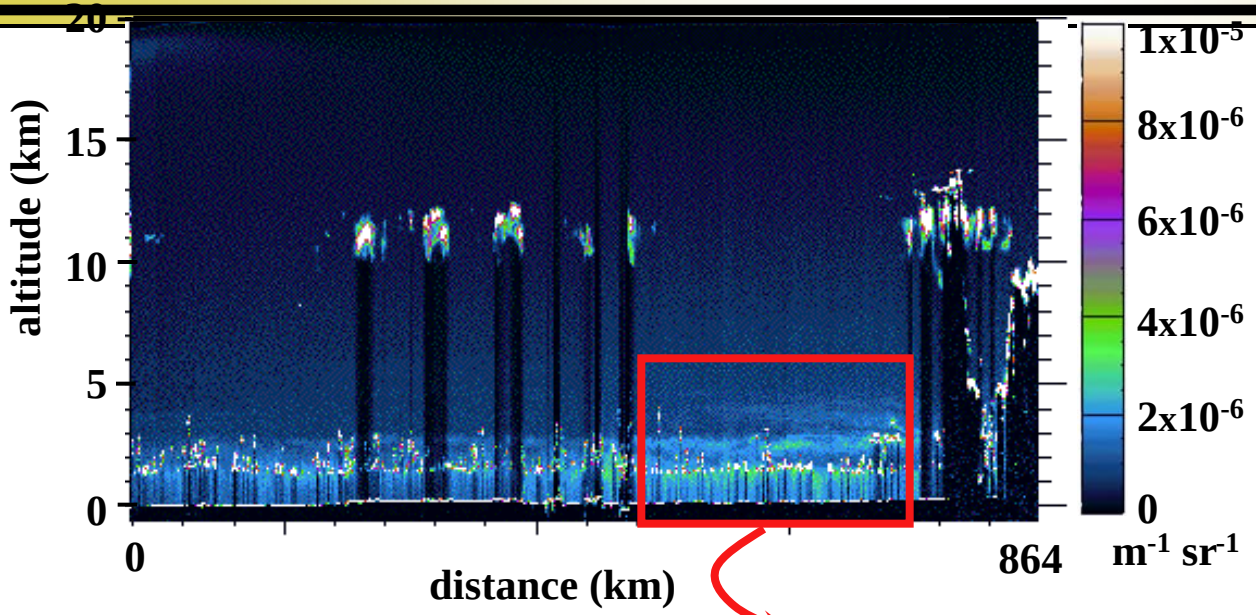
29 JUNE: transit to Dryden

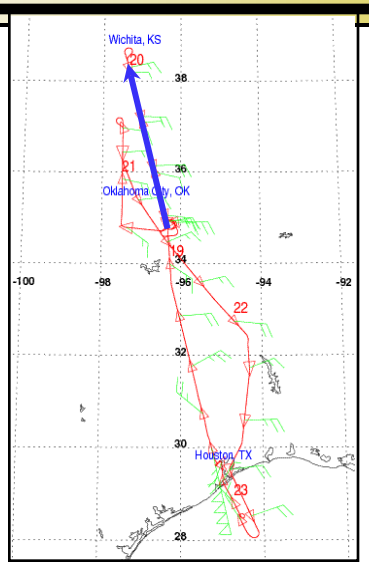
ER-2 carried the NASA "A-Train simulator" payload of CPL, CRS, and MAS.

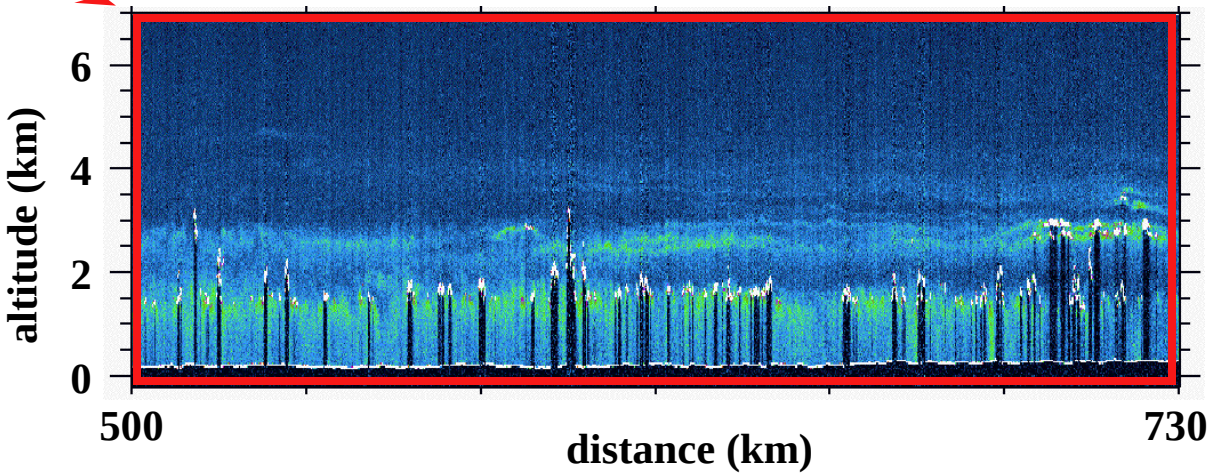
Three A-Train underpasses provided unique validation opportunity.

NASA thanks DoE for the A-Train validation opportunity.

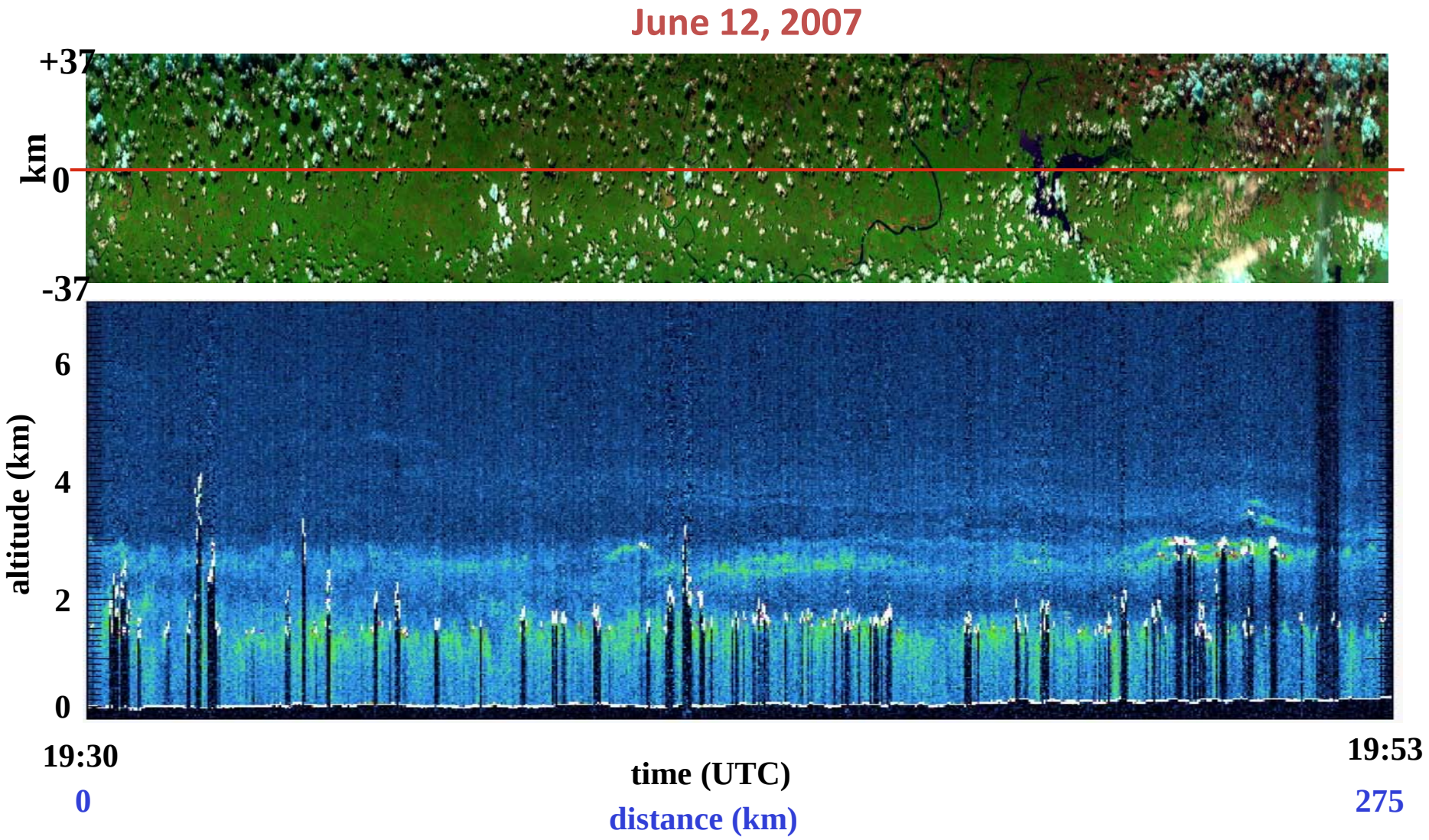
Example of CPL data from June 12, 2007



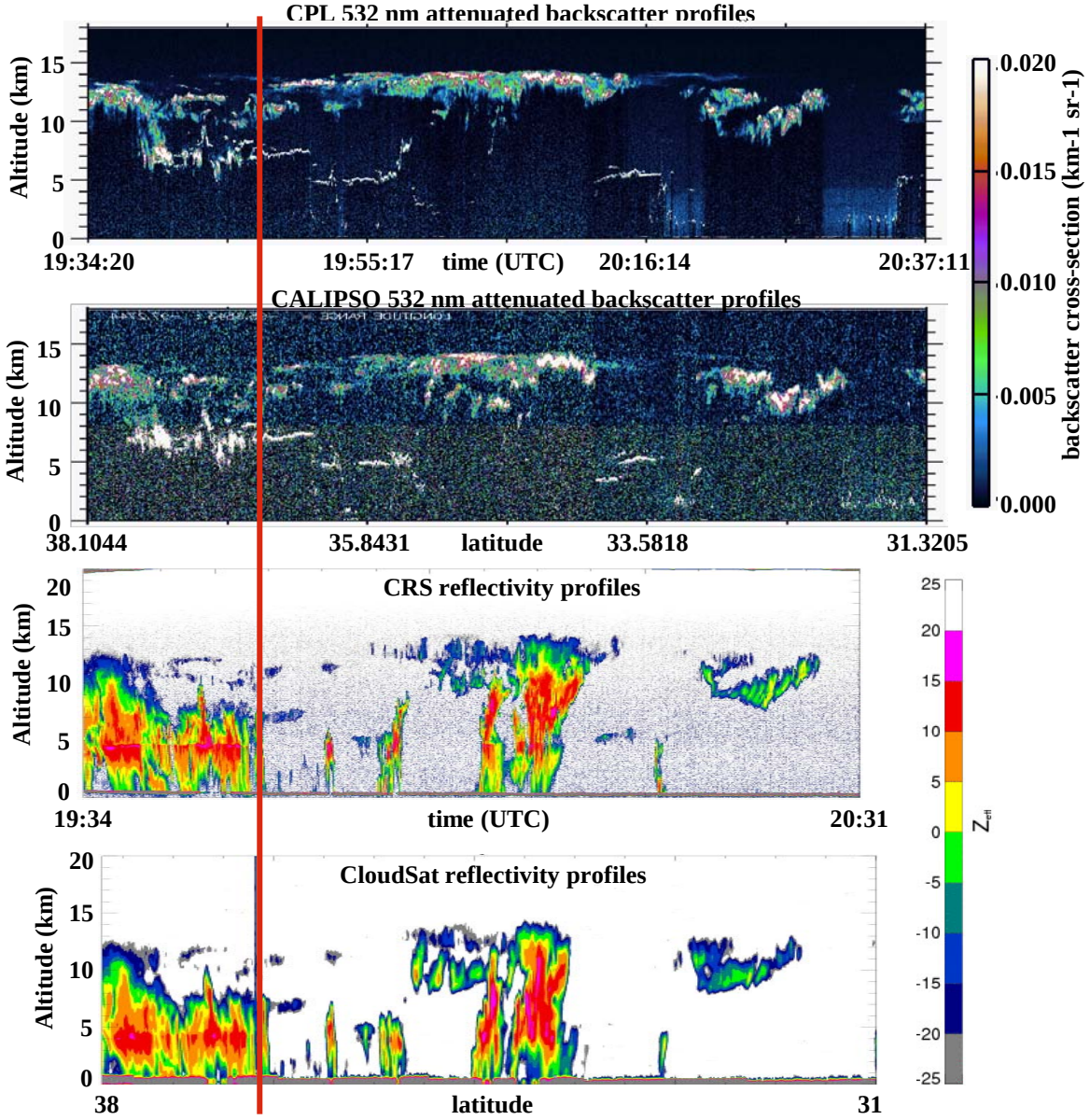


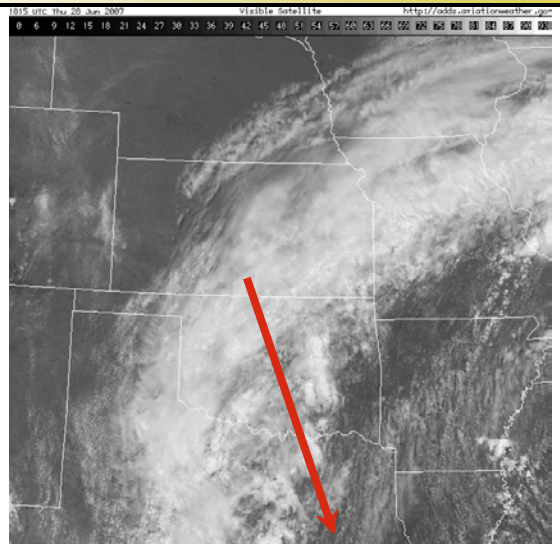


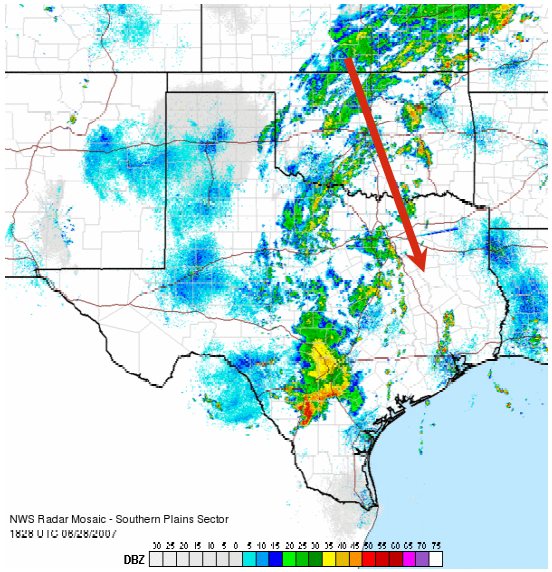
CPL backscatter profiles and MAS comparison



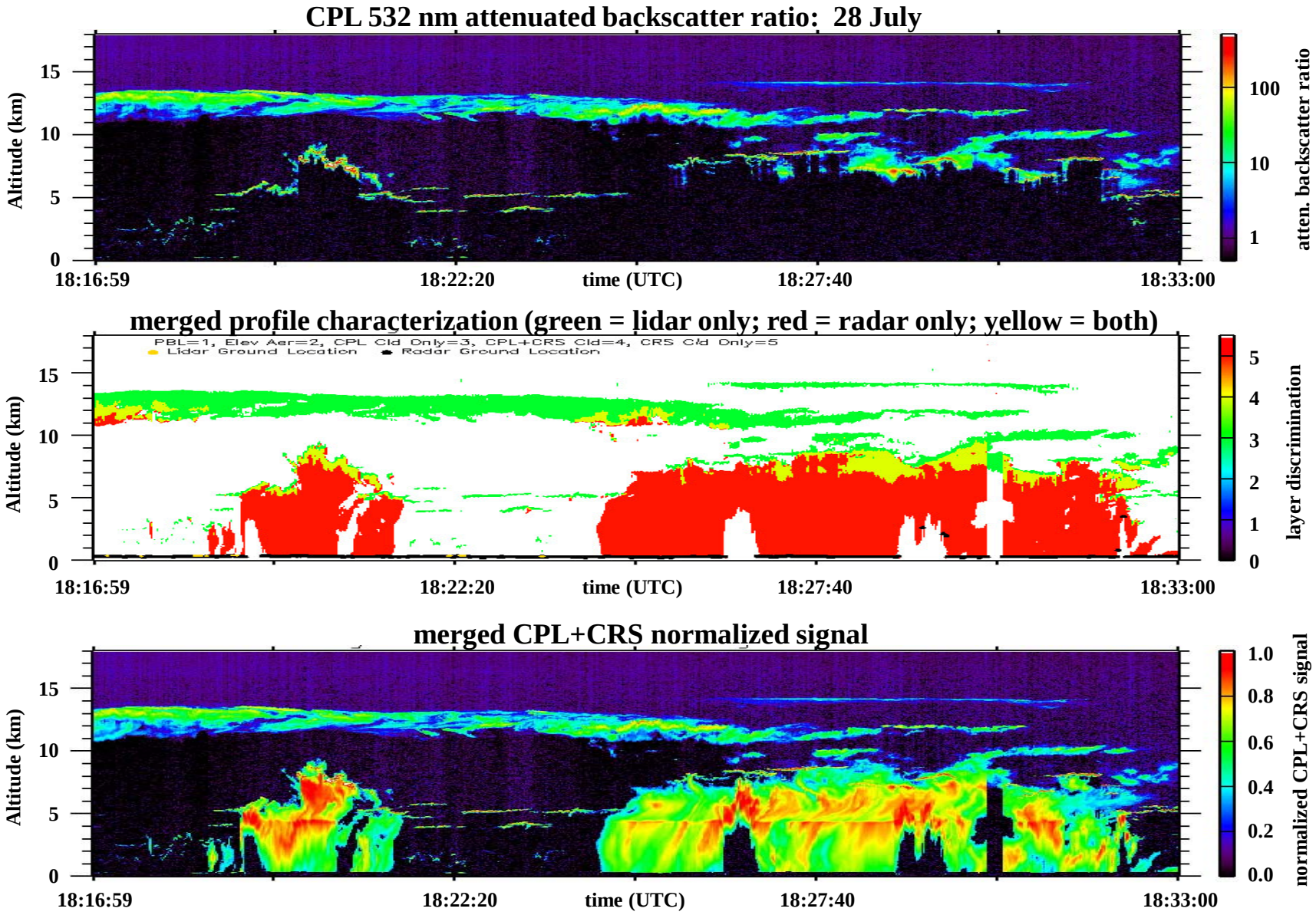
CPL-CALIPSO comparison: June 28, 2007







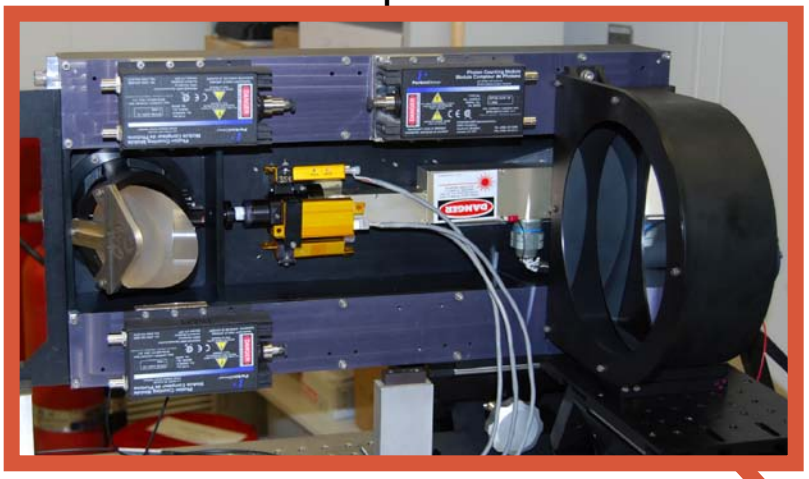
Combining lidar and radar reveals the whole profile



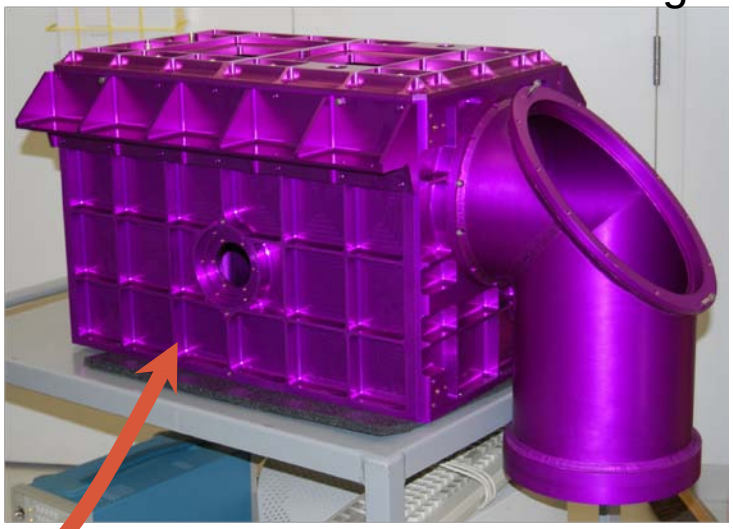
The new UAV-version of CPL: first to be integrated to NASA's Global Hawk

CPL on Global Hawk

UAV-CPL optical bench



UAV-CPL instrument housing

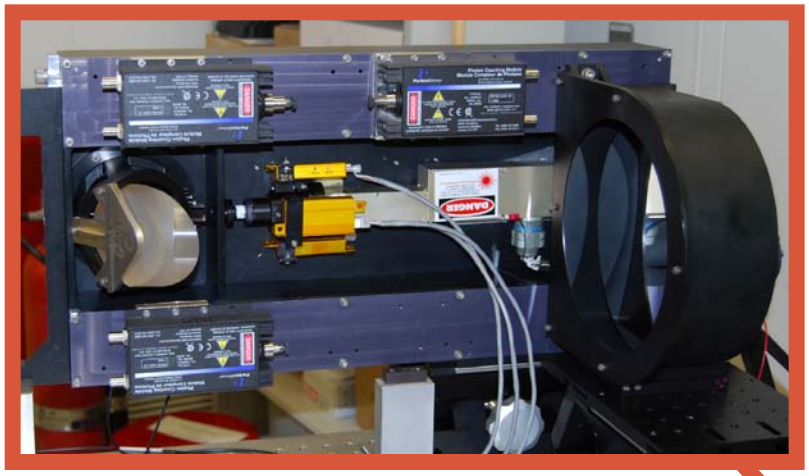


UAV-CPL mounting assembly

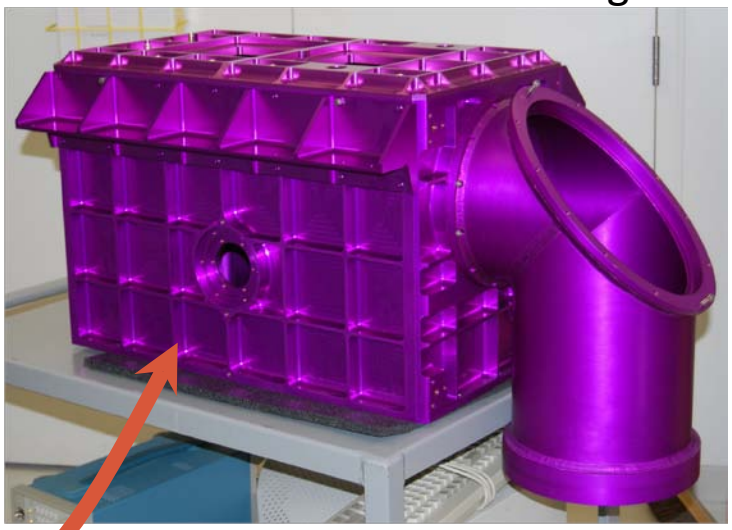
UAV-CPL handling cart and carrier assembly
("carrier assembly" is N-G's term for the frame and outer skin assembly)

UAV-CPL components

UAV-CPL optical bench



UAV-CPL instrument housing

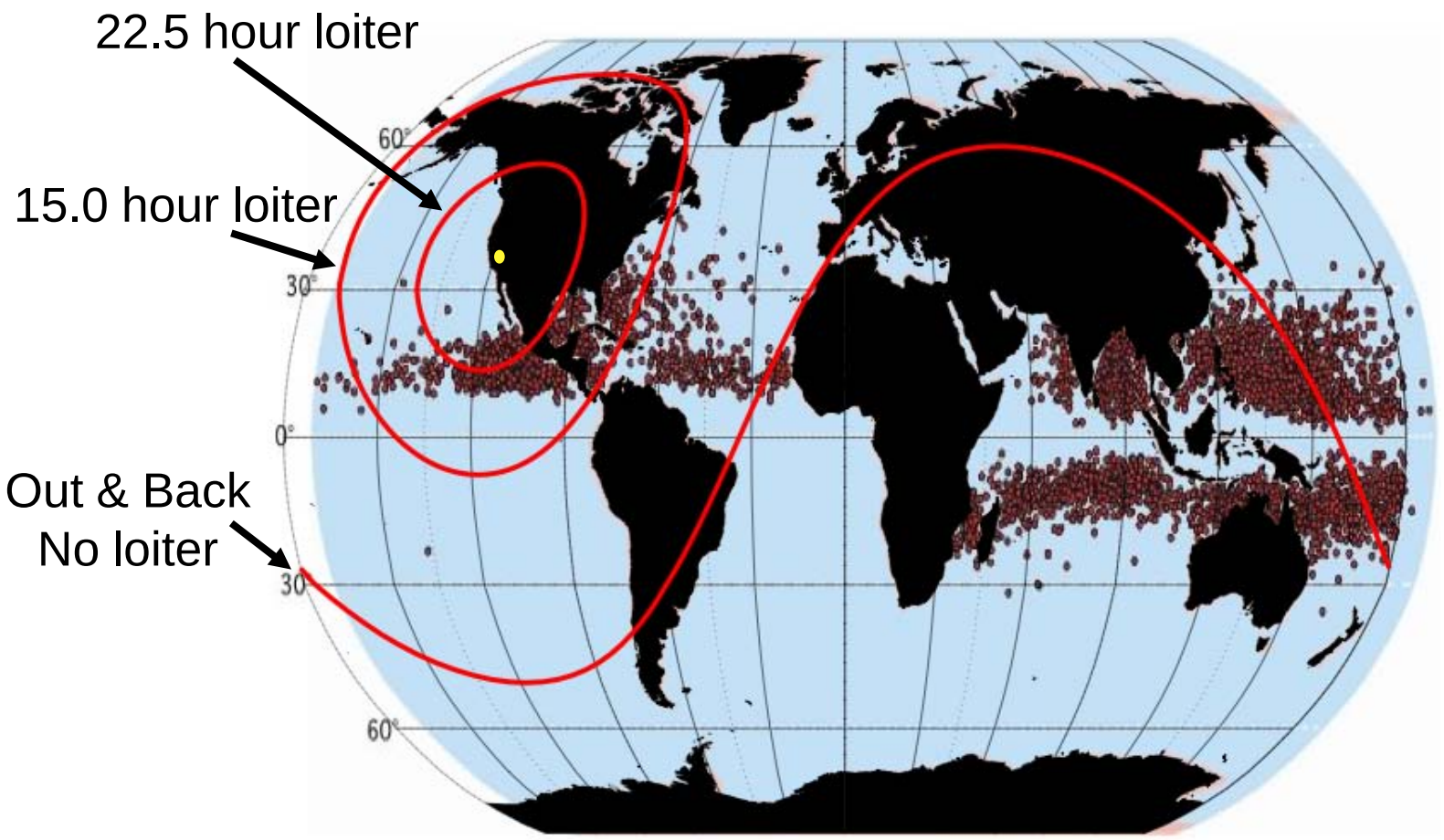


data system box

laser power supply box

Global Hawk Capability

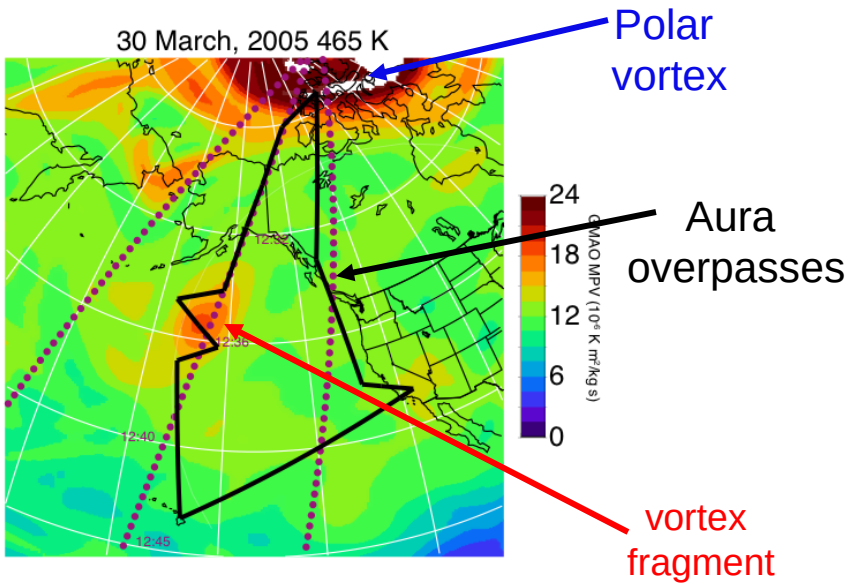
30 hour Global Hawk flights from Dryden



Nearly all Atlantic, East Pacific, and Central Pacific hurricanes are within range

graphic stolen from Paul Newman, who stole it from someone else

Intended UAS-AVE Flights

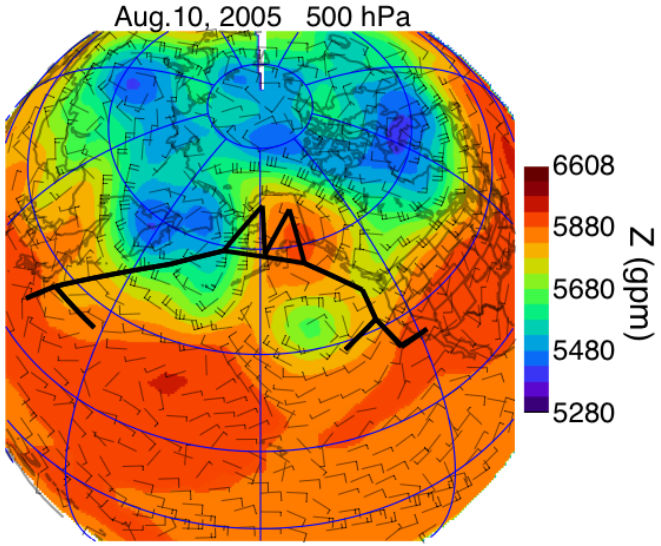


#1. vortex fragment flight

Flight objectives:
- sample polar vortex for ozone depleted air
- sample polar fragment over Pacific
- coordination with Aura satellite overpass
- Pole-to-tropics sampling of air masses
- overflight of Mauna Loa lidar

#2. aerosol & pollution flight

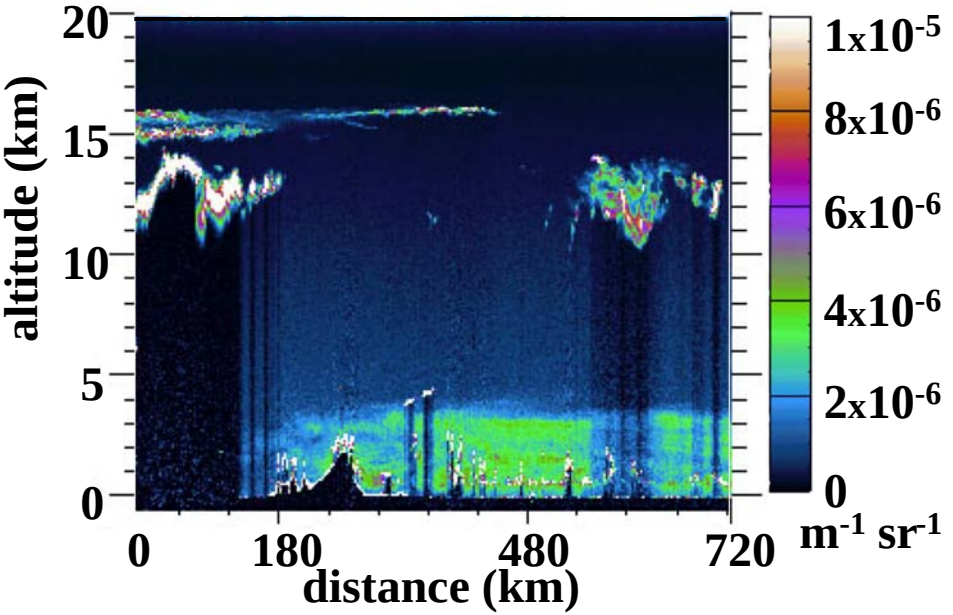
Flight objectives:
- after takeoff, fly over plume near cyclone
- fly NW to Alaska, zig-zag across fire plumes
- fly SW to just east of Japan and examine aerosol and pollution outflow from Asia
- return along same path

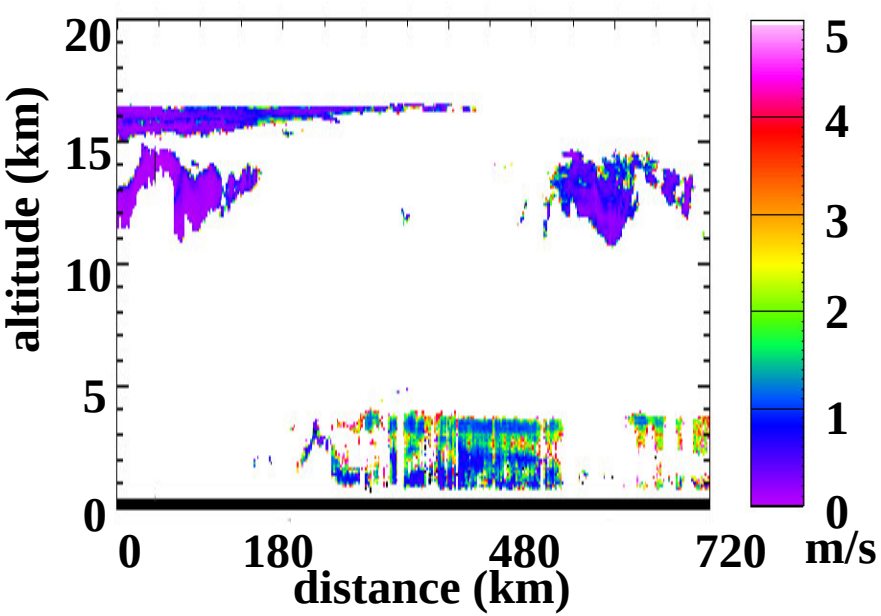


CATS*:
a new instrument for cloud-aerosol transport

*Suggestions for better acronym gladly accepted

Intended CATS data products

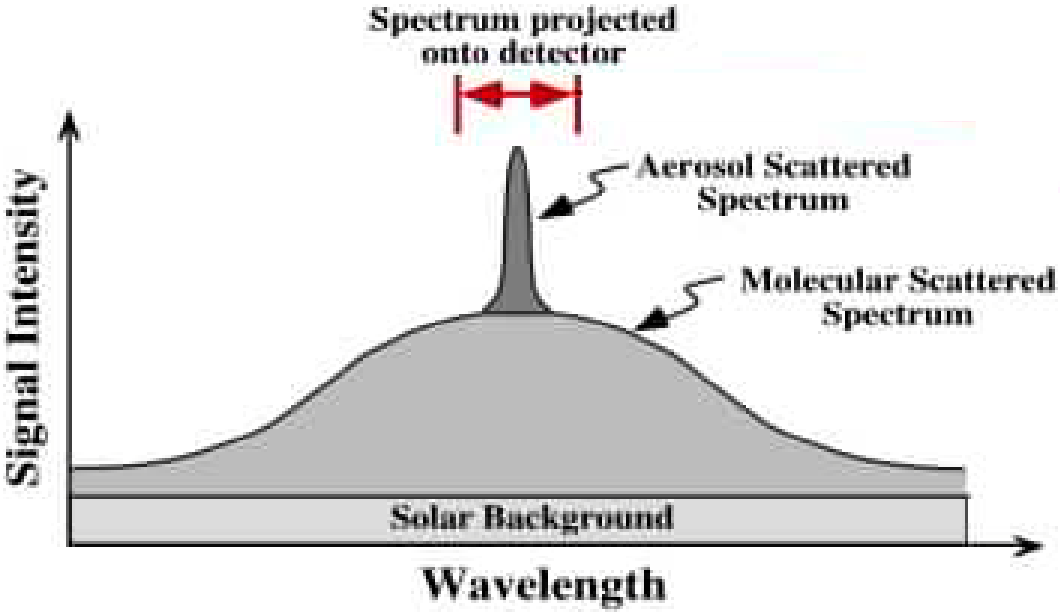




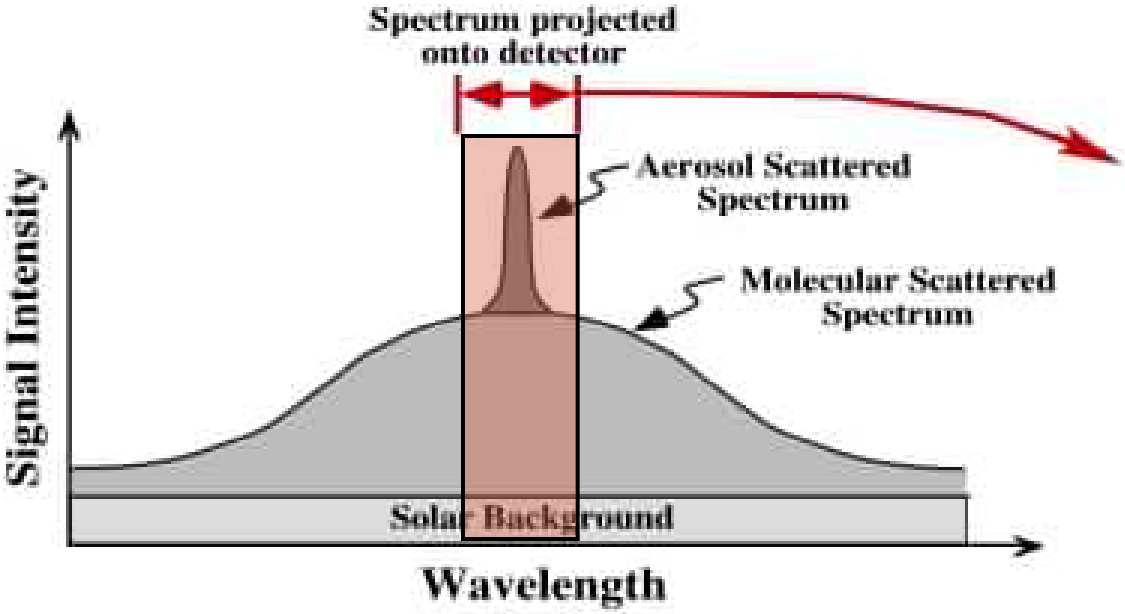
Simultaneous measurement of aerosol and wind, inherently provides off-nadir data.

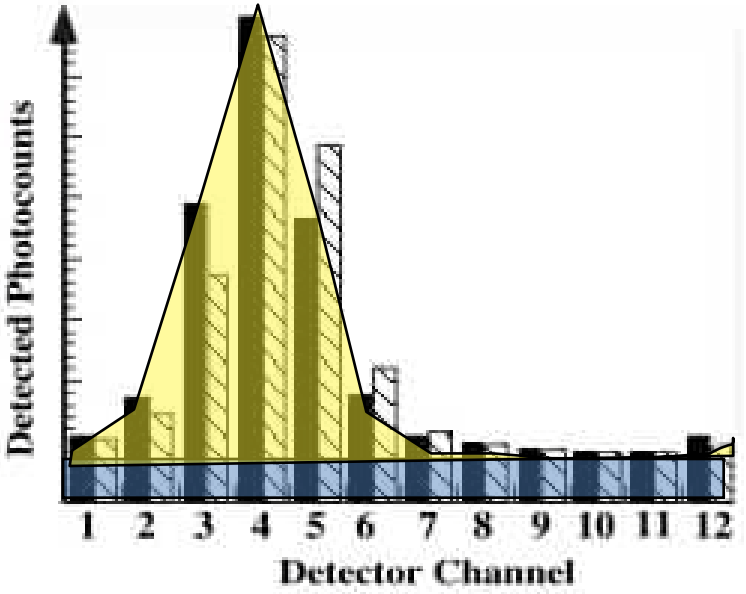
Primary objective is to enable transport studies,
Secondary objective is cloud-aerosol interaction.

Measurement concept

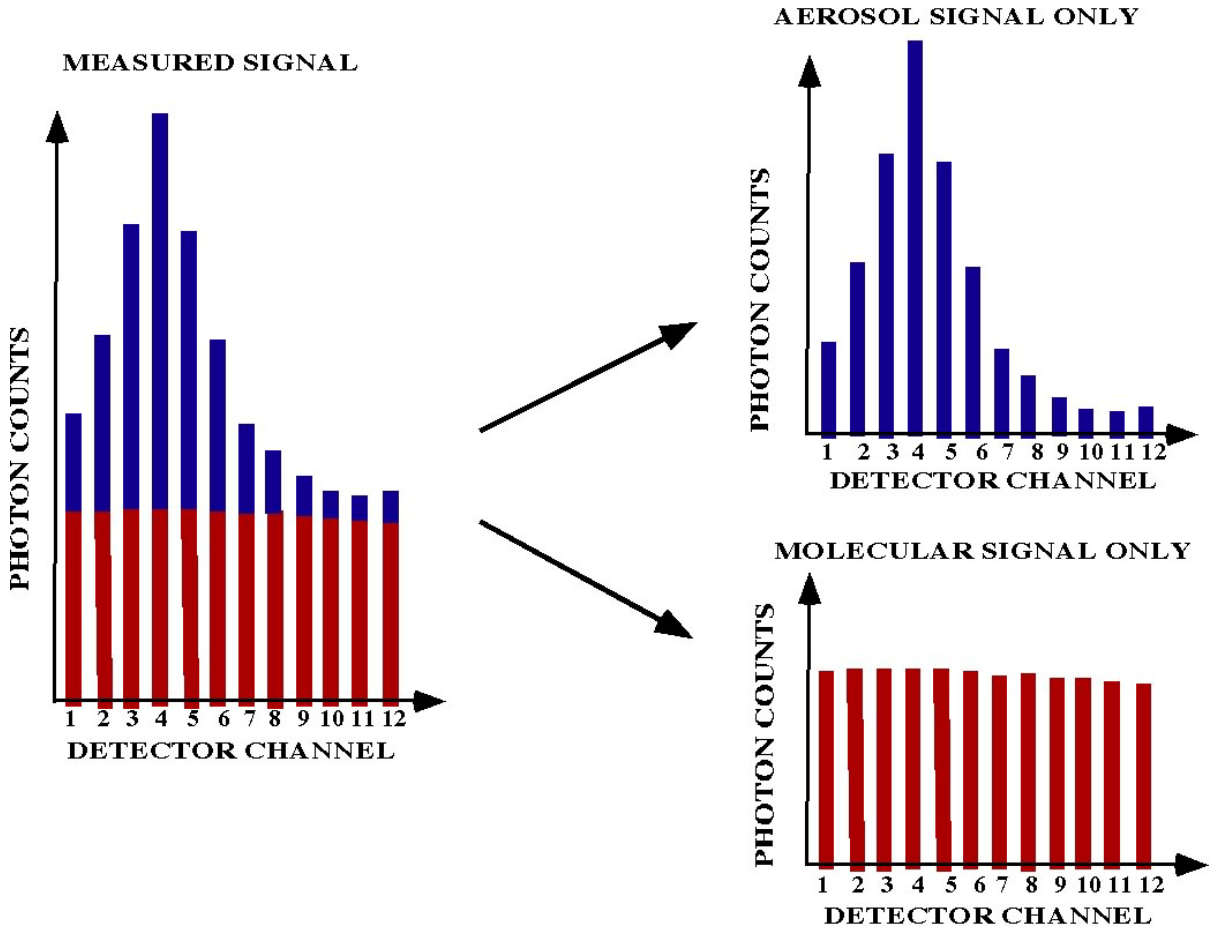


Measurement concept



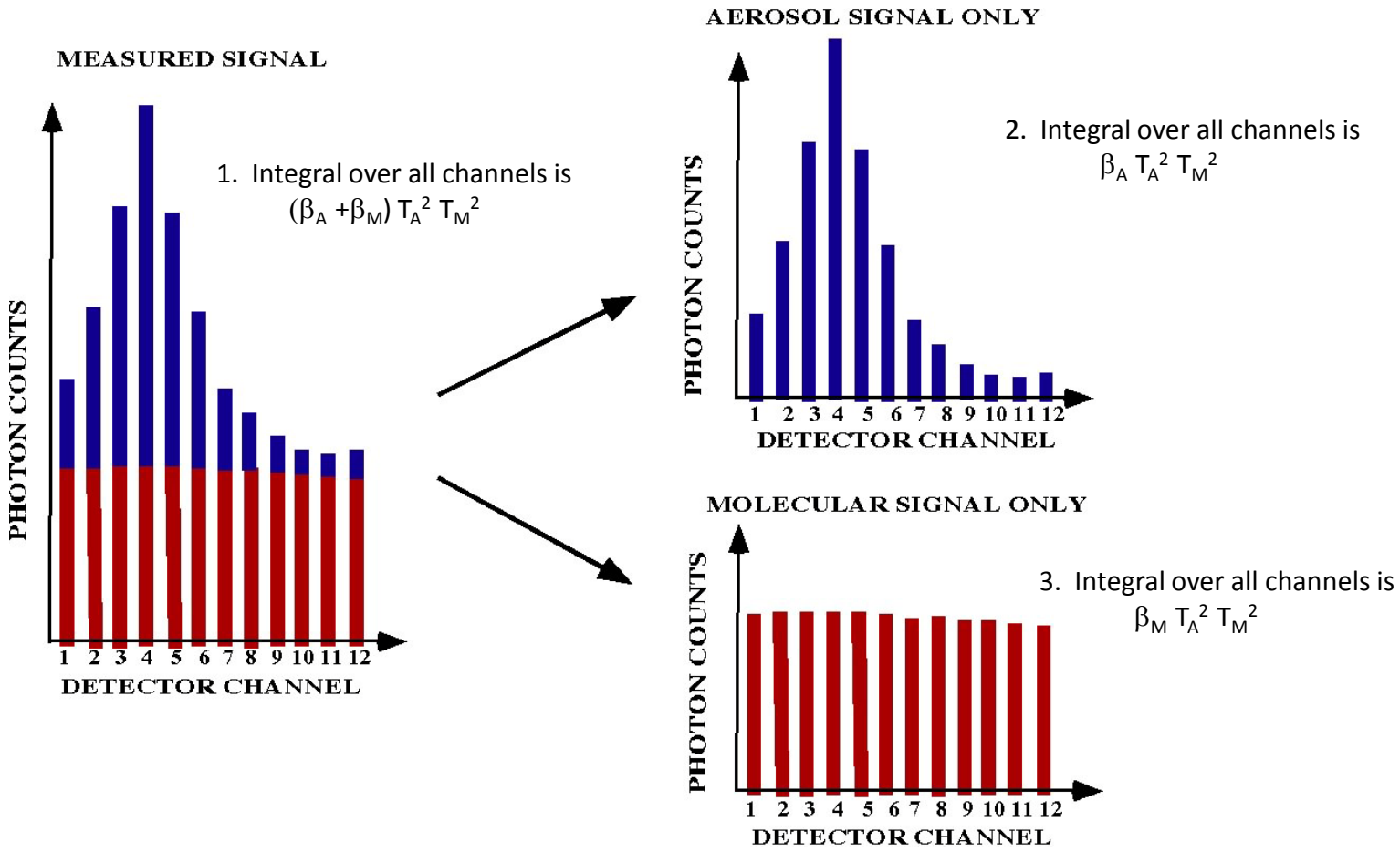


Key: we can separate the components



Use of a Fabry-Perot interferometer results in different system response for the aerosol and molecular components of the total signal. In fact, the molecular return is imaged as a nearly flat spectrum that is easily subtracted from the total signal.

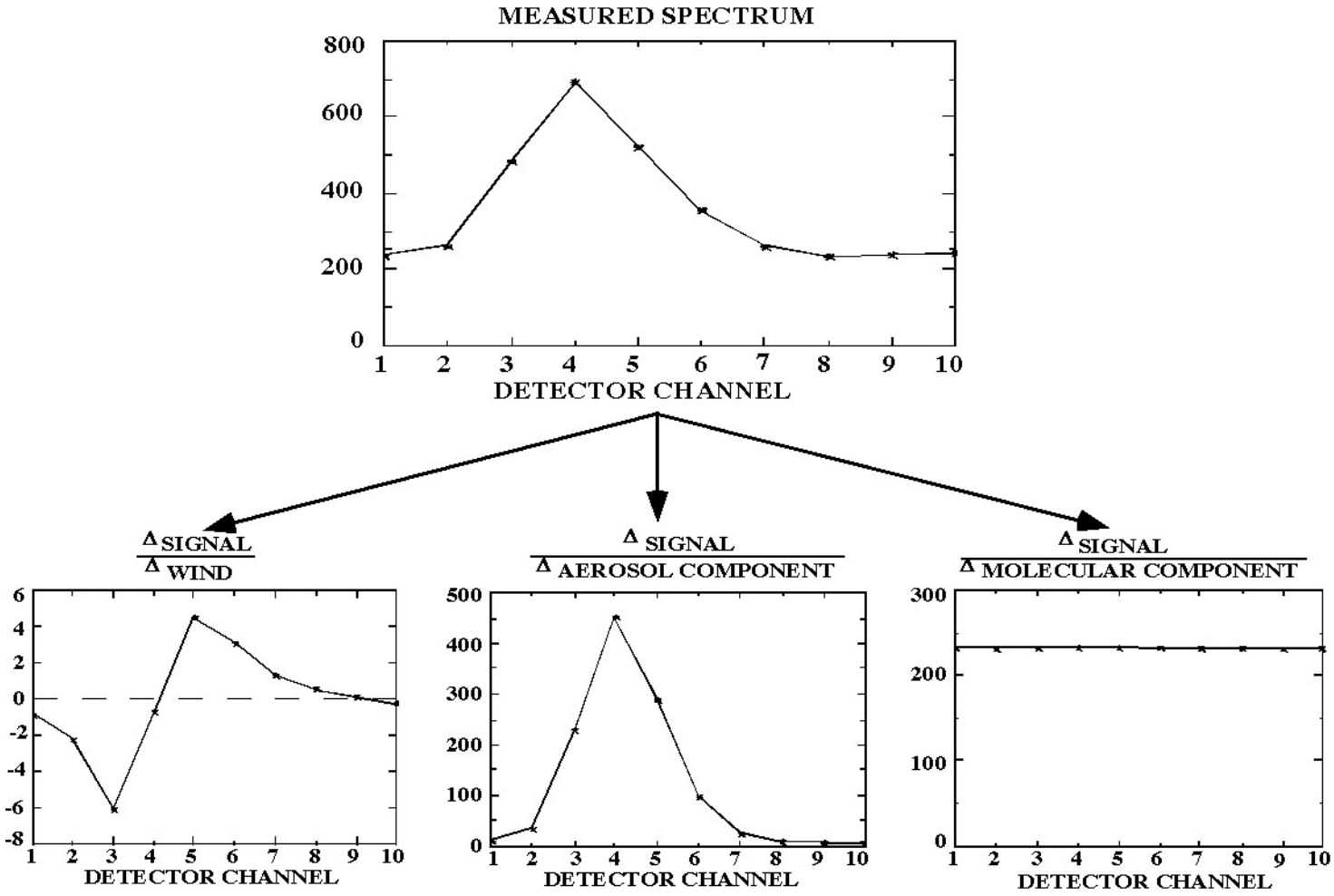
Key: we can separate the components



4. We also inherently have the aerosol-molecular ratio, (A + M)/M.

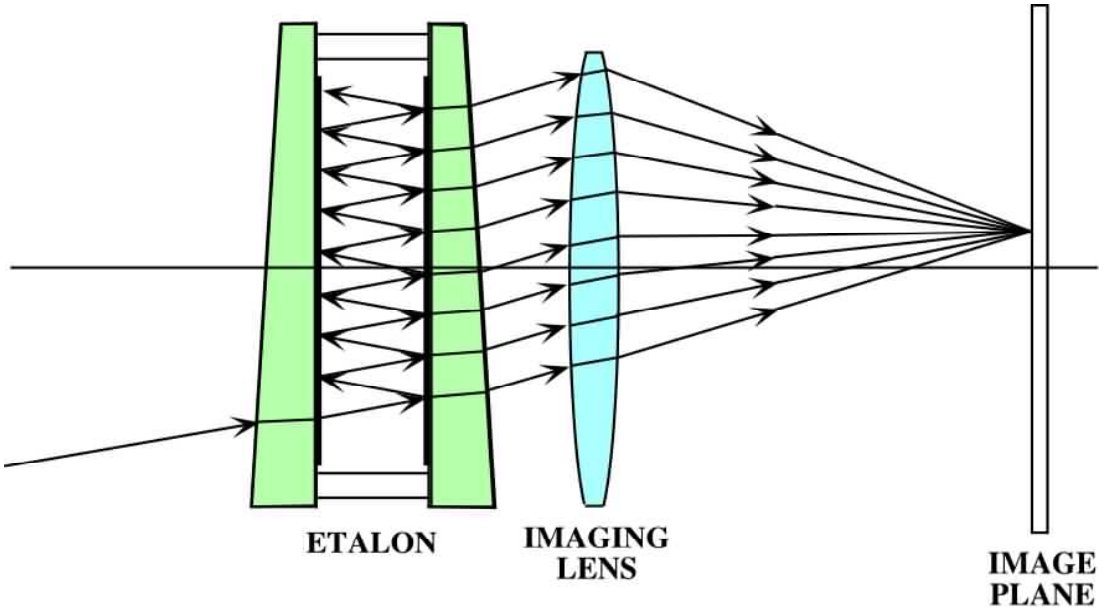
5. We can use rawinsonde or climatology to get molecular profile, $\beta_M T_M^2$

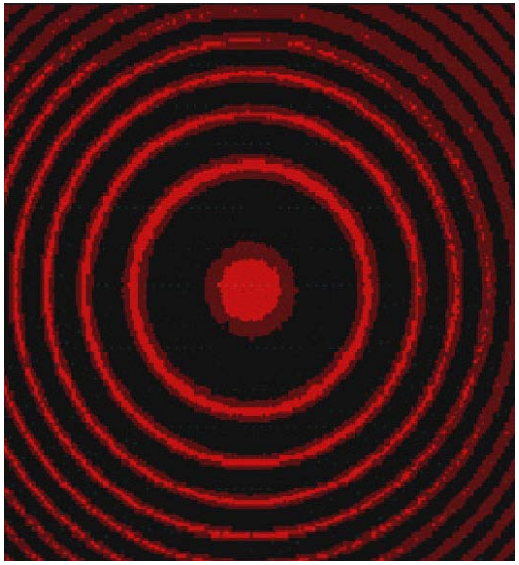
Inversion process



3 unique and uncorrelated pieces of information. Use of a multi-element detector results in an over-determined set of equations. The three components can be separated using a non-linear least-squares fitting method that uniquely extracts the components of the total signal.

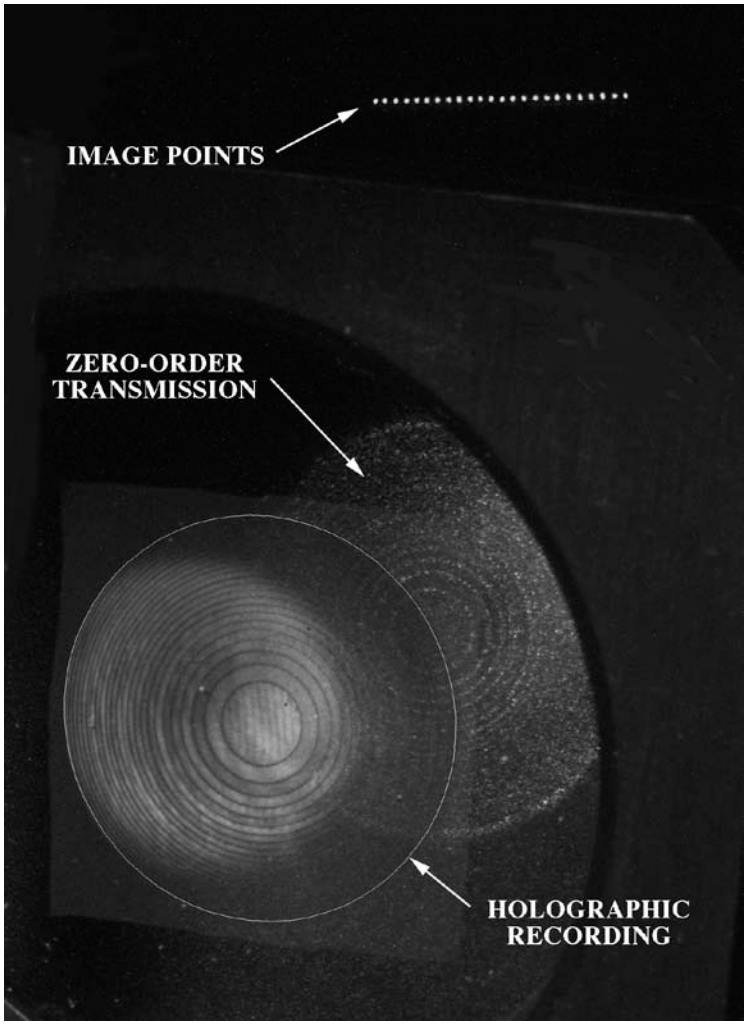
How does the concept work?



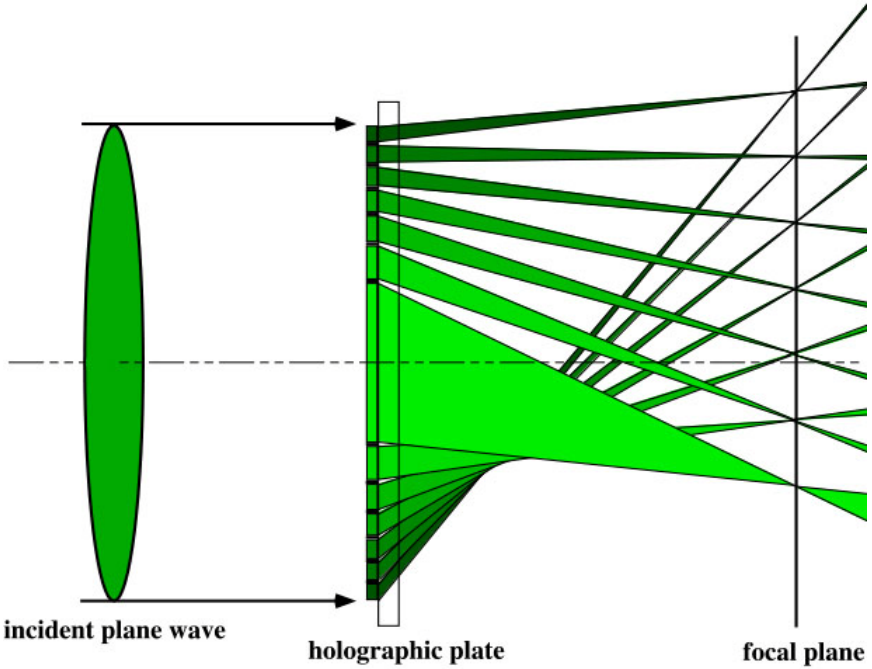


A Fabry-Perot interferometer is used to resolve the spectral signature.
Wavelength is a function of radius in the image plane.
The challenge is to efficiently measure the annular image.

Holographic circle-to-point converter

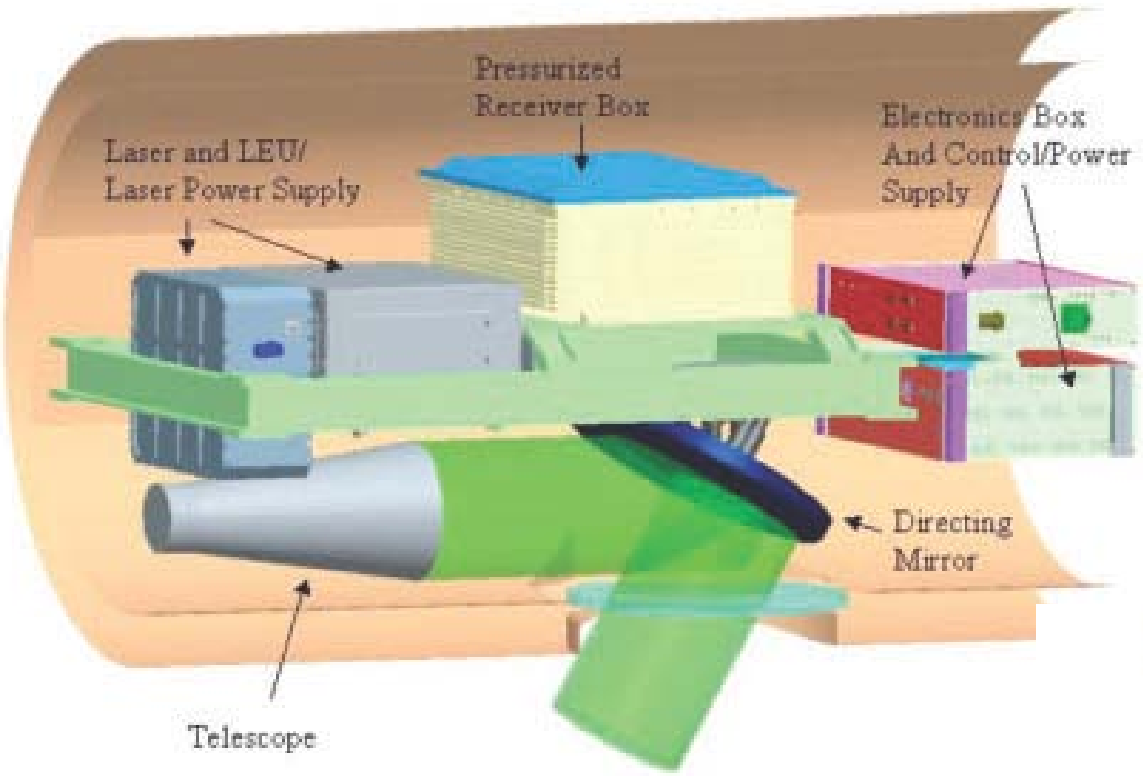


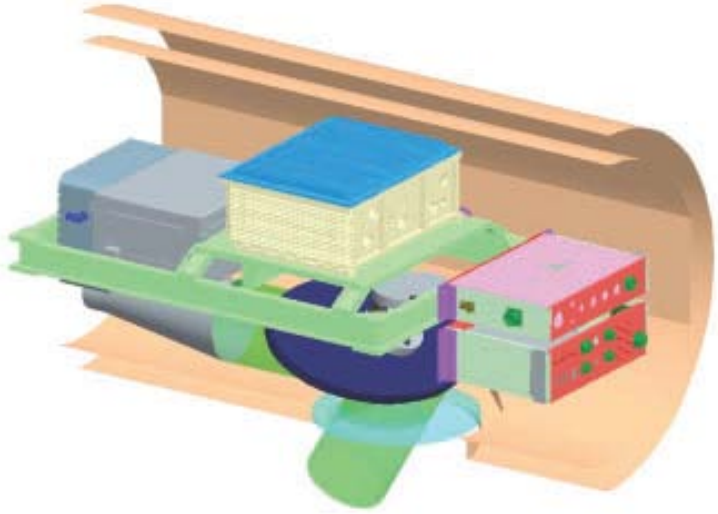
U.S. Patent #631908



Our solution: use a custom holographic optical element with a linear array detector to measure the fringe pattern.

CATS instrument concept drawing

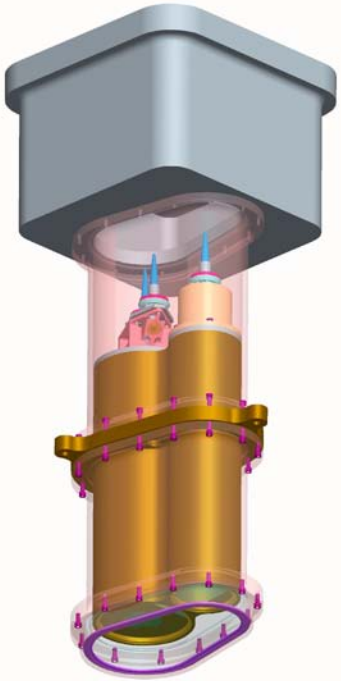


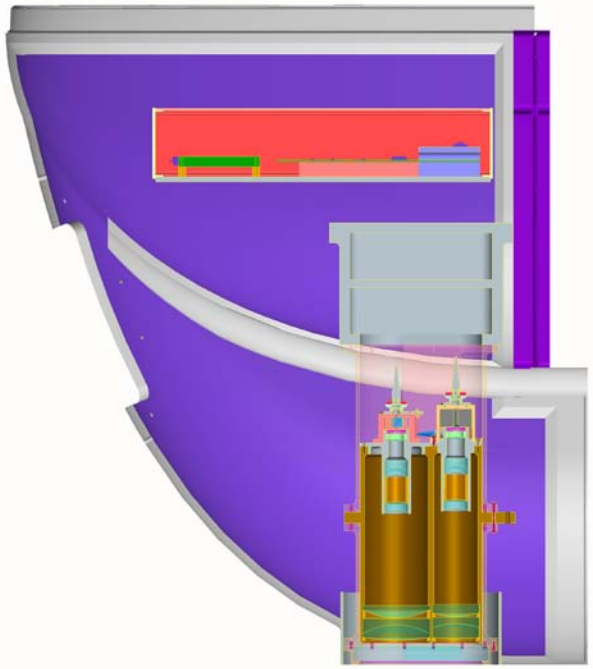


designed for ER-2 superpod,
also adaptable to Global Hawk

Nadir-pointing mini-lidar system

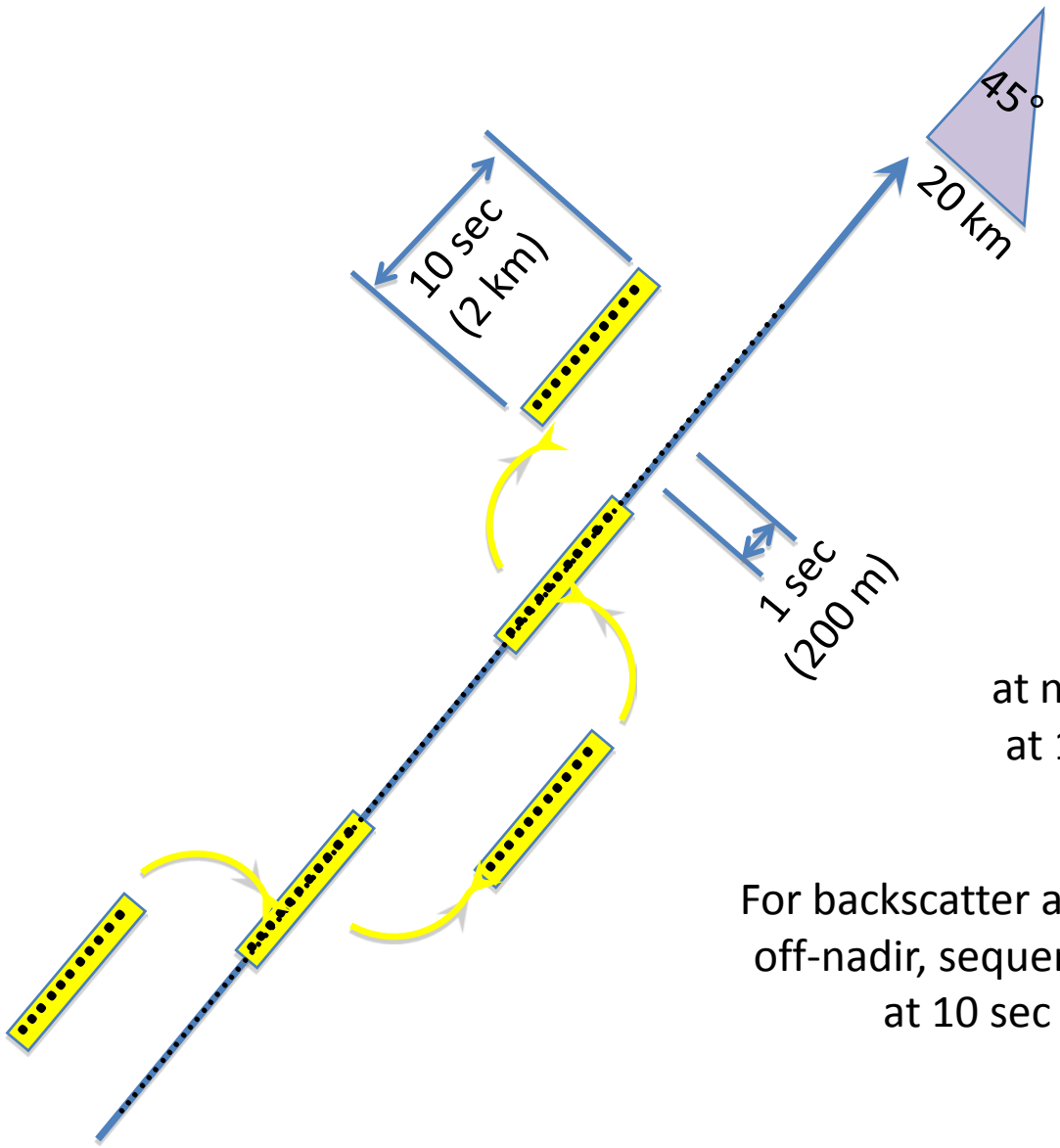
2-wavelength (532, 1064 nm), with depolarization at both wavelengths.
High rep-rate, photon-counting detection, like CPL, but using a fiber laser.





Originally conceived as a “mini-CPL” for Ikhana or Global Hawk.
It is funded, it is real…but now we want to combine it with the CATS instrument to provide continuous nadir profiling.

Measurement geometry



For wind, aerosol products:
at nadir, continuous measurements
at 1 sec (200 m) x 30 m resolution

For backscatter aerosol, depolarization products:
off-nadir, sequential orthogonal measurements
at 10 sec (2 km) x 60 m resolution

System parameters

CATS system parameters

laser type	Nd:YAG, seeded
operating wavelength	532 nm
laser repetition rate	200 Hz
laser output energy	≤10 mJ/pulse
laser beam divergence	100 microradians, full angle
telescope diameter	6 inches
viewing angle	45 degrees
telescope field of view	200 microradians, full angle
bandpass filter	150 pm FWHH
etalon spacing	10 cm
etalon reflectivity	85%
orders imaged	1.2
detector channels	16
dynamic range	400 m/s
vertical resolution (wind)	100 m
vertical resolution (aerosol)	30 m
platform speed	~200 m/s
horizontal resolution (wind)	10 seconds (~2 km)
horizontal resolution (aerosol)	1 second (~200 m)
platform altitude	~20 km (65,000 ft)

development timeline

Project initiated	Aug 2008
Scanning telescope complete	July 2009
Receiver subsystem complete	Dec 2009
Nadir channel complete	Jan 2010
Initial test flight	Oct 2010

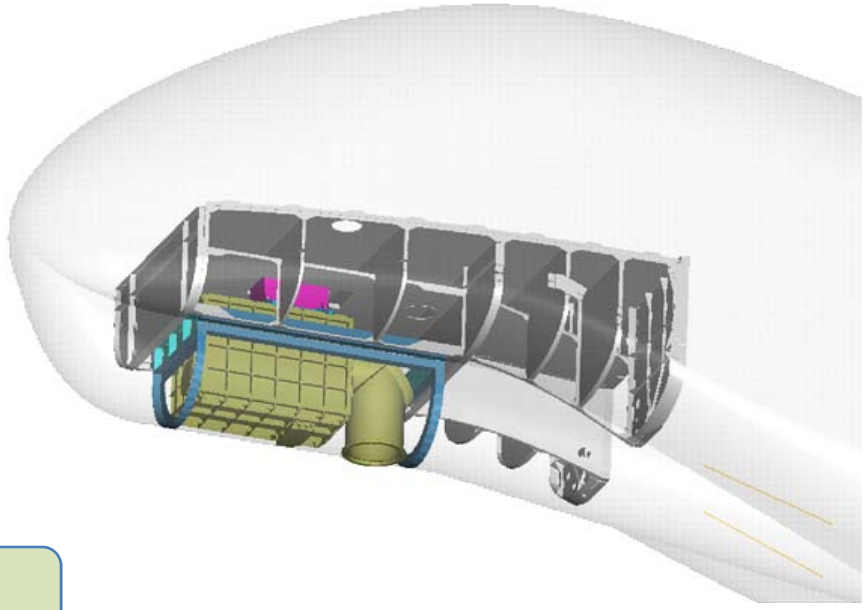
Summary/conclusion

We have existing capability, as demonstrated by CLASIC ER-2 flights, that DoE-ARM can utilize for science. NASA is generally happy to partner in exchange for satellite validation opportunities.

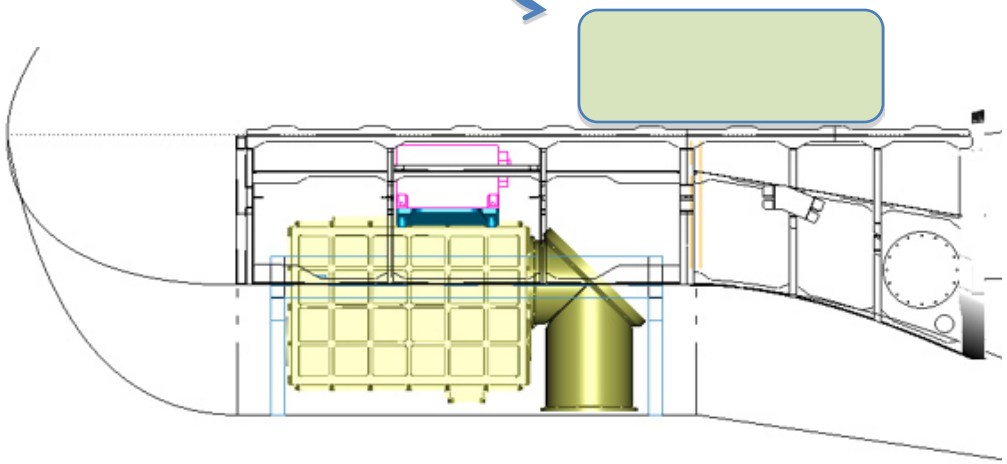
We will soon have Global Hawk capabilities that DoE-ARM can utilize for science.

With my group's reputation for building quality, cost-effective instruments, we are embarking on development a new cloud-aerosol transport lidar. Targeted for completion in the 2010-2011 timeframe, this new instrument should be of interest to DoE-ARM.

UAV-CPL Global Hawk mounting



power supply, data box go up here



UAV-CPL instrument specifications

Instrument specifications:

Mechanical and Electrical

Size: instrument: 40”H x 16”W x 18”D
power supply: 18”H x 19”W x 8”D
data system: 17”H x 19”W x 6”D

Weight: instrument, 182 lbs (carrier assembly ~45 lbs);
power supply, 67 lbs;
data system, 18 lbs. Total: 312 lbs (est.)

Power: laser ~10 Amps 28VDC;
heaters ~35 Amps 28VDC;
data system ~2 Amps 110 VAC 400 Hz.

View ports/windows: 9” dia. nadir-viewing port (window supplied as part of instrument)

Instrument Requirements:

Control and Communication

 # Control Switches: 2 (master power, laser enable)

Communication Bandwidth: as much as possible, but we can sub-sample the CPL data as was done during TC4

Nav / Time inputs: yes (similar to ER-2 nav data, presumably)

Programmatics:

Cloud/aerosol profiling
Prototype has been flying on ER-2 since 2000
Designed to mount in Bay 3
Pathfinder for interfaces, cost estimating, operations
First instrument for integration on GH