Overview of ER-2 Payload

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&

Contributions from ER-2 PI Instrument Teams

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SEAC4RS Leadership Meeting

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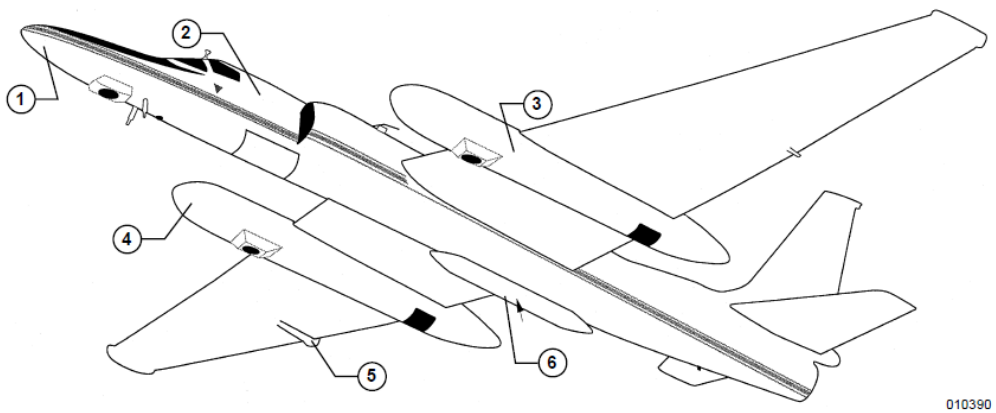
Basic ER-2 Information

Basic ER-2 Information

Crew: 1 pilot
Length: 62 ft., 1 in.
Wingspan: 103 ft., 4 in.
Payload:
Nose (600 lbs.),
Q-bay (750 lbs.),
Wing pods (1360 lbs),
Centerline Pod (350 lbs.)
Cruising Altitude: ~ 70 kft., 20 km
Cruising Speed: ~ 410 knots, 210 m/s, 12.6 km/min, 756 km/hr
Flight Duration: ~6-10 hours
Range: ~ 3000 nm, 5556 km, (8 hours)
Time to Altitude: ~ 30-45 min
Descent Initiated: ~30 min before landing
Required runway winds: < 15 knot crosswind

Area	ft^3	m^3	lb	kg	Electrical Company	
					VAC (3ϕ)	VDC
1. Nose	47.8	1.35	605	294	50A at 115/208	2kW at 28
2. Equipment Bay (Q-Bay)	64.6	1.83	1,300	590	100A at 115/208	4kW at 28
3. Left wing pod	86.0	2.43	650	294	50A at 115/208	2.2kW at 28
4. Right wing pod	86.0	2.43	650	294	50A at 115/208	2.2kW at 28
5. System 20 pod	.74	.02	45	20.4	30A at 115/208	840W at 28
6. Centerline pod	14.0	.40	350	159	30A at 115/208	840W at 28



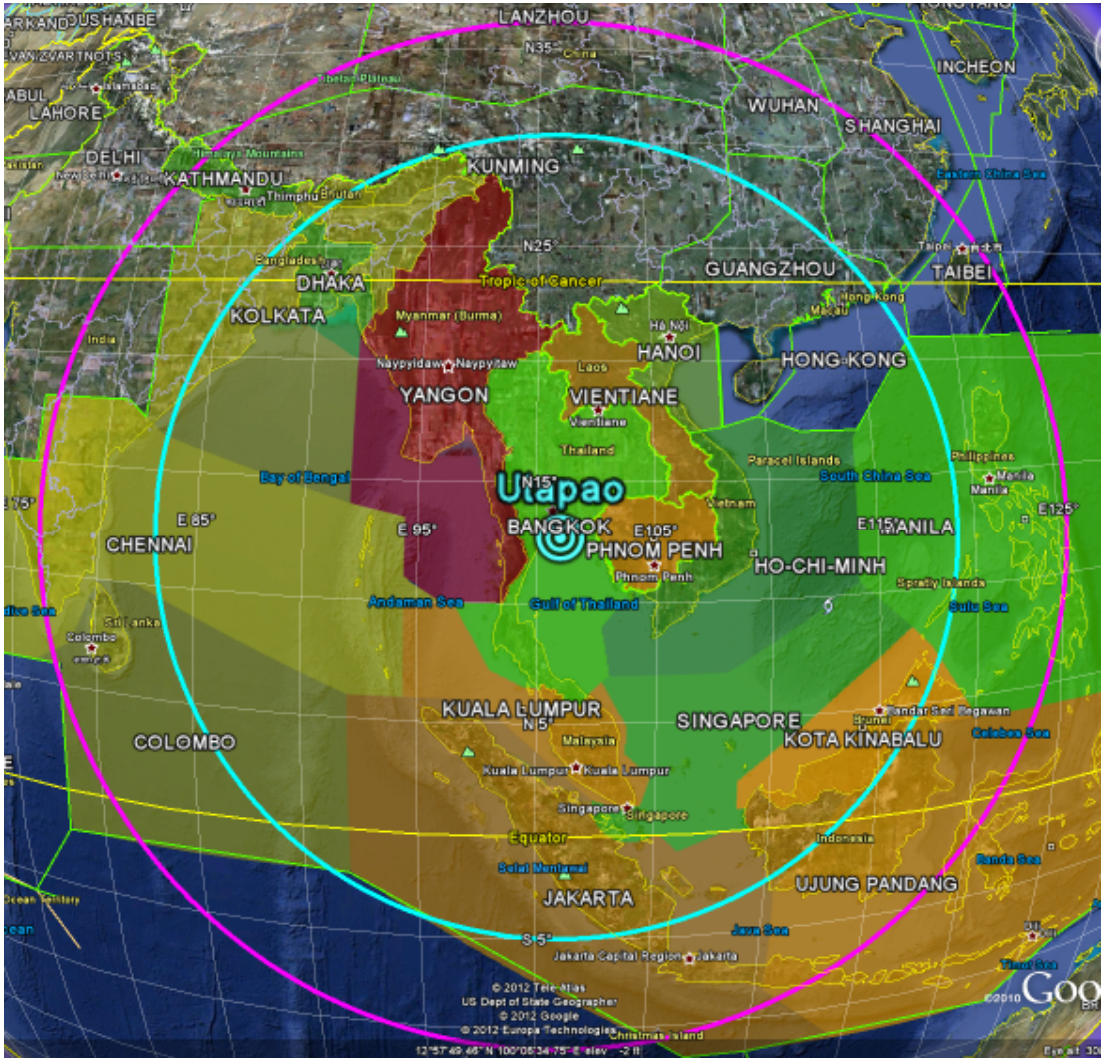
ER-2 Flight Range

Assuming 210 m/s flight speed and

1) 6-hour total transit and 2 hour loiter

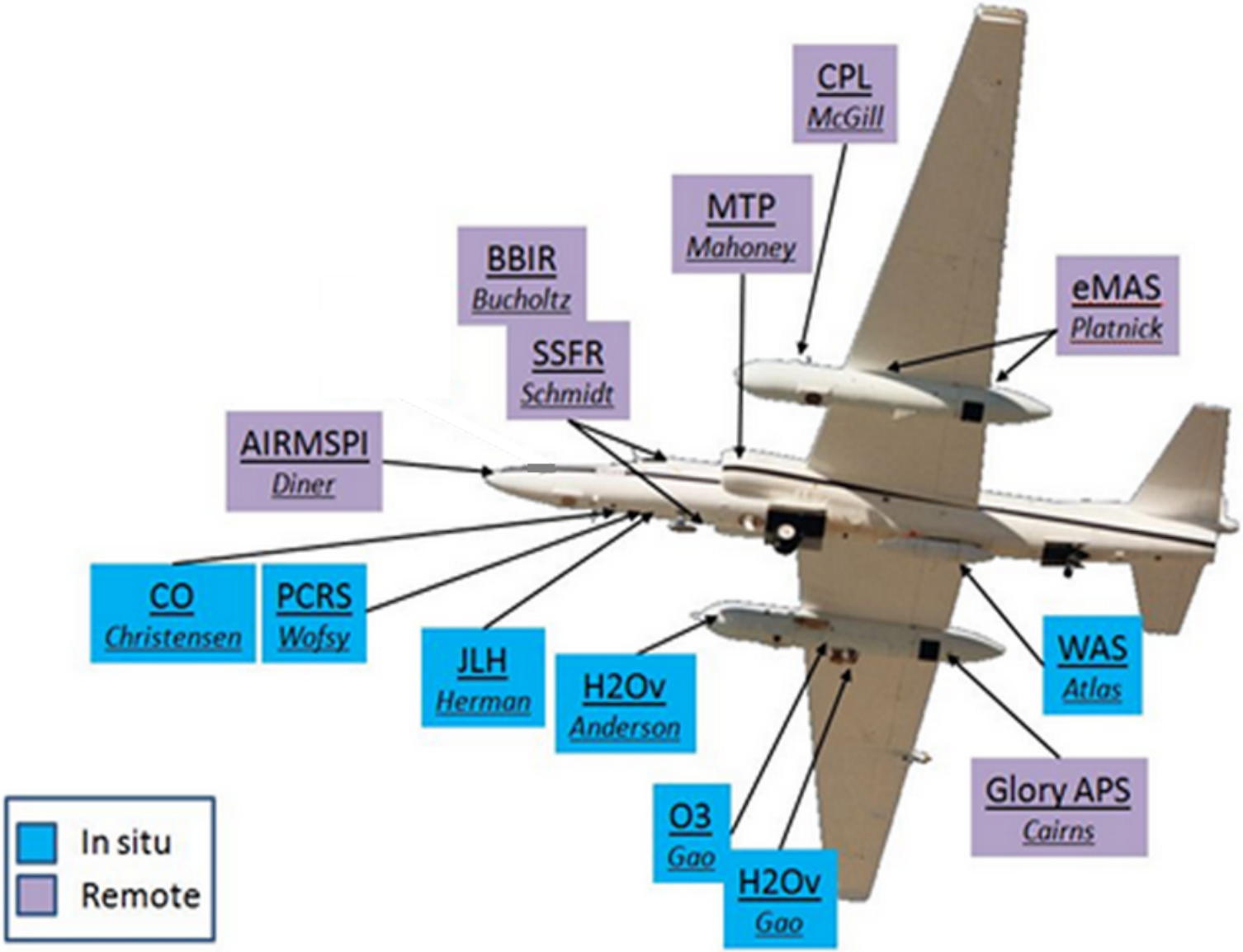
2) 8 hour total transit

ER-2 operating range is similar to that of DC-8



ER-2 Payload

ER-2 Payload for SEAC4RS



ER-2 Payload for SEAC4RS

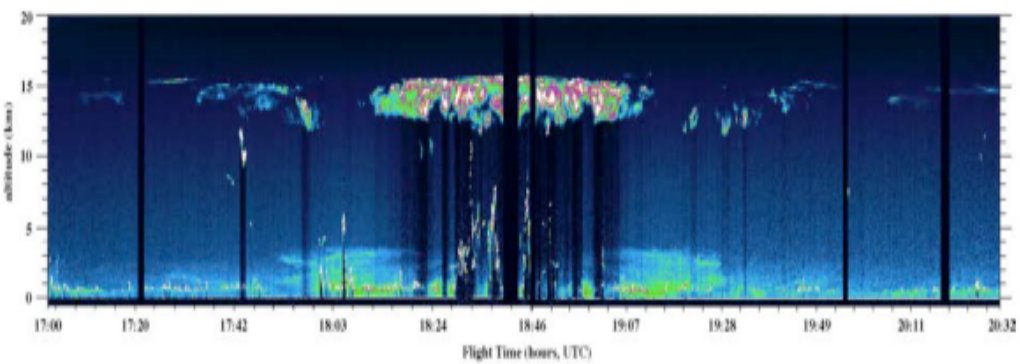
Investigator (Institution)	Acronym	Measurement	Type	Method, sensitivity, resolution
Christensen (JPL)	ALIAS	CO, CH4, N20	In Situ	TDL-spectroscopy, 0.1-0.3 ppb, 1 sec
Wofsy (Harvard)	PCRS	CO2, CH4, CO	In Situ	CRDS, (50, 0.2, 7 ppb), 3 sec
Herman (JPL)	JLH	Water vapor	In Situ	TDL-spectroscopy, <1 ppm, 20 Hz
Anderson (Harvard)	HHH	Water Vapor	In Situ	Fluorescence, TDL-spectroscopy, <1 ppm, 1 sec
Gao (NOAA)	UAS Ozone	Ozone, water vapor	In Situ	Absorption, ~1 ppb, 1 sec
Atlas (Miami)	WAS	Trace gases, VOC, OVOC, CFC, etc.	In Situ	Gas chromatography, few ppt, seconds to minutes
Mahoney (JPL)	MTP	Temperature profile	Remote	Passive Microwave radiometer, <1 K, ~20 sec
Schmidt (Colorado)	SSFR	Spectral Irradiance	Remote	Nadir/Zenith Spectrometers, 350-2150 nm, 1 Hz
Bucholtz (NRL)	BBIR	Solar and IR irradiance	Remote	Nadir/Zenith broad-band radiometers
McGill (GSFC)	CPL	Aerosol/cloud backscatter, depolarization profiles	Remote	Multiwavelength (355, 532, 1064 nm) lidar, 1 sec, 30 m vertical
Platnick (GSFC)	eMAS	Multiwavelength reflectance imagery, cloud retrievals	Remote	Multiwavelength spectrometer
Diner (JPL)	airMSPI	Polarization and radiance imagery	Remote	Multiwavelength, multiangle polarimeter, 10 m resolution, 11 km swath width
Cairns (GISS)	RSP	Multiwavelength polarized radiances, aerosol and cloud properties	Remote	Multiwavelength, multiangle polarimeter

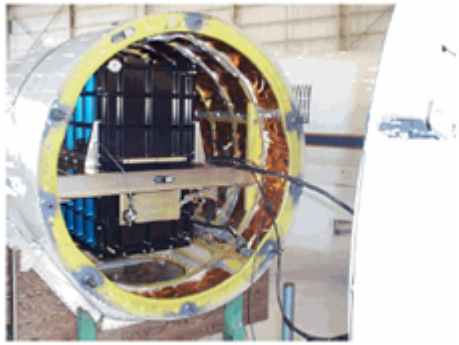
Trace gas, meteorology, irradiance, polarized radiance/reflectance/imagery, lidar backscatter/depolarization

Remote Sensing Instruments

CPL (McGill)

- Cloud Physics Lidar
- Three wavelength (355, 532, 1064 nm) backscatter lidar
- Nadir measurements along track
- Products
  - PBL, aerosol, cloud layer heights
  - Aerosol and cloud layer backscatter, extinction, depolarization profiles
  - Layer optical depth
  - Real-time and quicklook images
- Extensive experience from ER-2





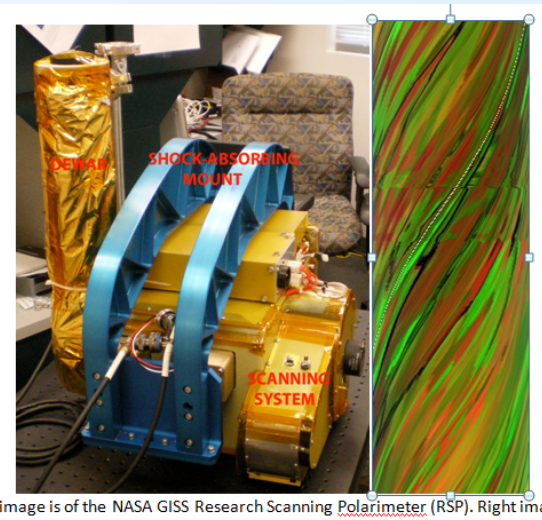
CPL instrument in flight configuration

TABLE 1. CPL INSTRUMENT SPECIFICATIONS

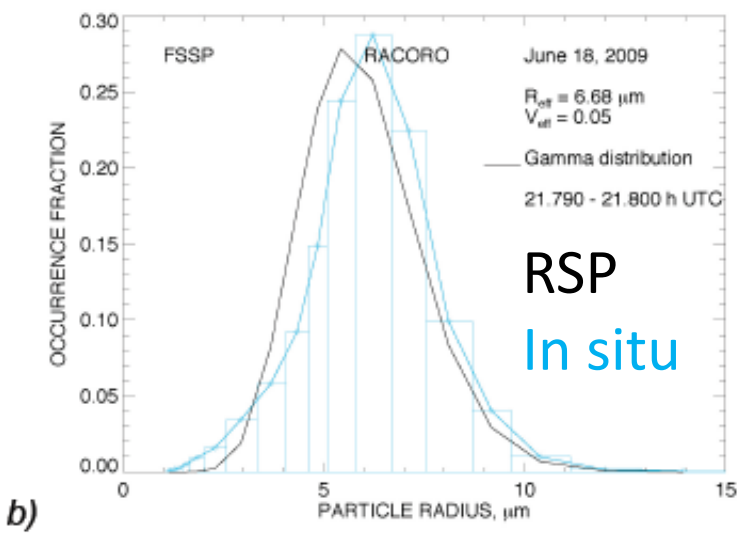
Wavelengths	1064, 532, 355 nm
Laser type	solid state Nd:YVO4
Laser repetition rate	5 kHz
Laser output energy	50 μJ at 1064 nm 25 μJ at 532 nm 50 μJ at 355 nm
Telescope	20 cm diameter, off-axis parabola
Telescope field of view	100 microradians, full angle
Raw data resolution	1/10 second (30 m by 20 m horizontal)
Processed data resolution	1 second (30 m by 200 m horizontal)

RSP (Cairns)

- Research Scanning Polarimeter
- Airborne simulator of APS instrument on Glory mission
- Scanning polarimeter measures total and linearly polarized reflectance in nine spectral channels
- ~150 viewing angle samples over +/- 60 deg deg angular range along track
- Resolution ~ 250 m (ground), ~100 m (cirrus anvils)
- Retrievals of column aerosol (optical depth, effective radius, refractive index) and cloud (optical depth, effective radius. LWP, CNC) properties

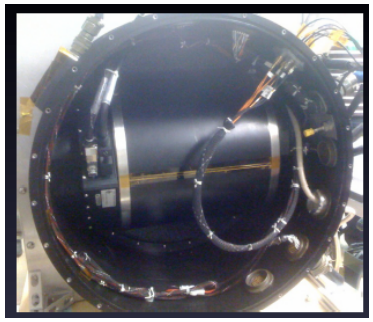


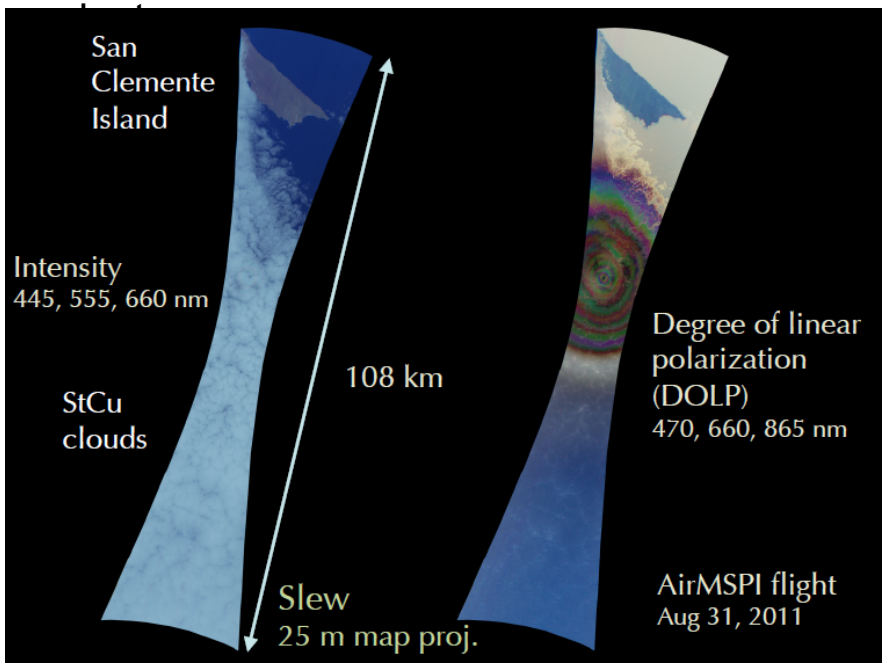
Left image is of the NASA GISS Research Scanning Polarimeter (RSP). Right image is a series of RSP along track scans presented as an image. (see text for description)

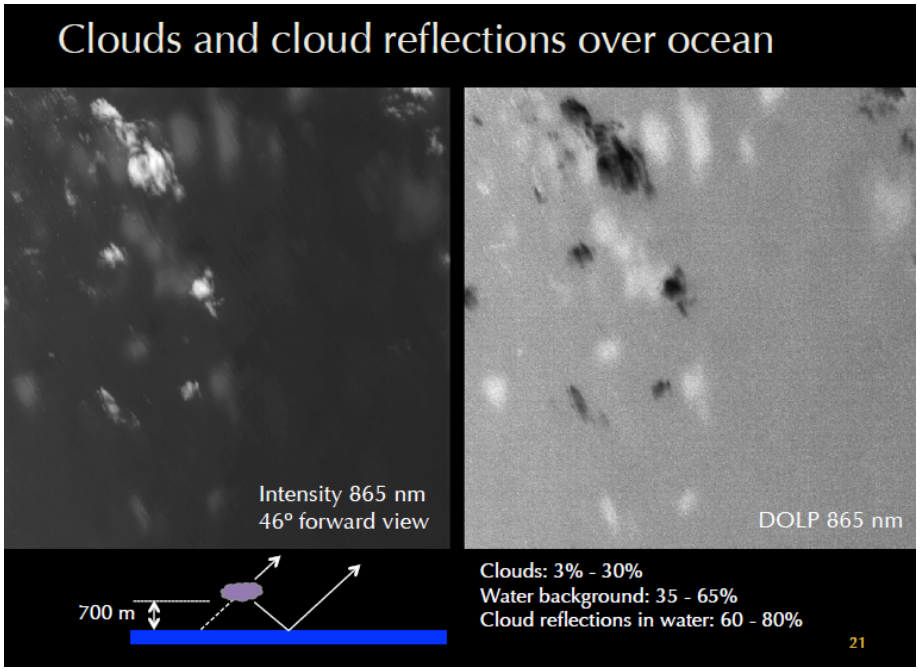


AirMSPI (Diner)

- Airborne Multiangle SpectroPolarimetric Imager
- Eight-band pushbroom camera measuring polarization in three bands
- Multiangular imaging measurements over +/- 67 deg along-track
- Swath width ~ 11 km
- Resolution ~ 10 m (surface)
- Will provide level 1 radiances and degree of linear polarization – not level 2 aerosol/cloud products







eMAS (Platnick)

- Enhanced MODIS airborne simulator
- Narrowband reflected solar and emitted thermal coverage simular to MODIS (vis to IR)
- Spatial resolution ~ 50 m (surface)
- Swath width ~ 37 km
- Separate pushbroom HyperSpectral Imager (HIS) will not be ready
- Cloud property retrievals (phase, optical thickness, effective radius, water path)

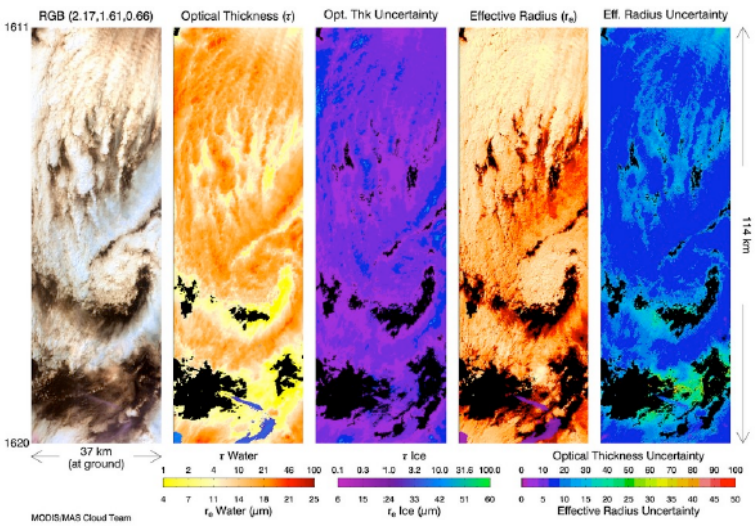


Fig. 3. Example MASTER (MODIS-ASTER simulator) cloud optical retrievals during TC[4] on 6 August 2007. A false color composite of the scene is shown in the left hand panel. Cloud phase is shown via a dual color bar for liquid water (warm colors) and ice retrievals.

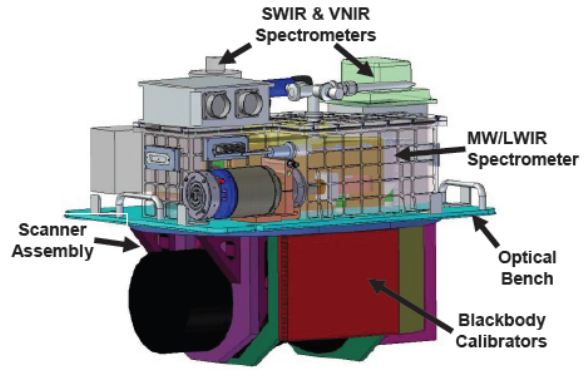
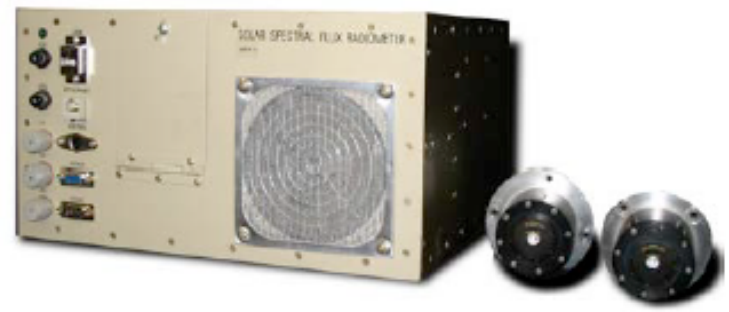


Table 1. Overview of **eMAS-Scanner**, consisting of a new Infrared module (eMAS-IR) plus the two legacy VNIR/SWIR spectrometers

Altitude on ER-2	20 km (nominal)
Ground speed	206 ms^{-1} (nominal)
Total FOV	85.92°
Swath width	37.25 km (at 20 km altitude)
Instantaneous FOV	2.5 mrad
Pixel spatial resolution	50 m at nadir (20 km altitude)
Pixels per scan line	716 (roll corrected)
Scan rate	6.25 scan lines per second
Spectral range	0.47–13.94 μm
Spectral channels	38
Output channels	38 at 16 bits
Data rate	1.31 GB hr^{-1}
Instrument mass	96 kg
VNIR/SWIR calibration	Integrating sphere (ground)
IR calibration	Two temperature controlled onboard blackbodies

SSFR (Schmidt)

- Solar Spectral Flux Radiometer
- Measures upwelling and downwelling spectral irradiance from 350-2150 nm in zenith and nadir directions simultaneously
- Hemispheric FOV
- Spectral resolution ~ 8-12 nm
- Will attempt to use stabilizing platform
- Derive spectral albedo, net flux, flux divergence
- Retrievals of cloud/aerosol radiative forcing and absorption, heating rates, cloud optical thickness and effective radius, water path, aerosol SSA and asymmetry parameter



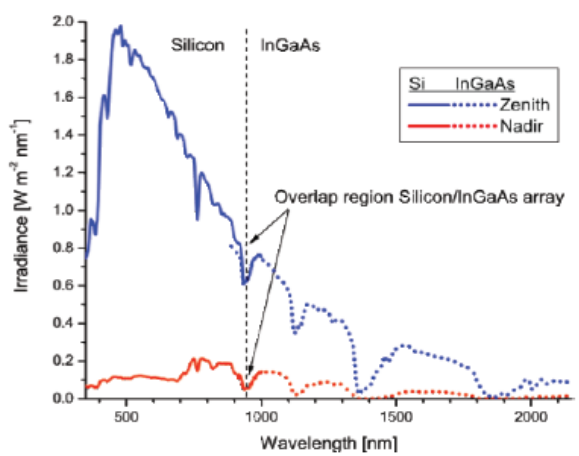


Figure 7: Typical downward (blue) and upward (red) spectra from a recent field experiment (CalNex, 2010).

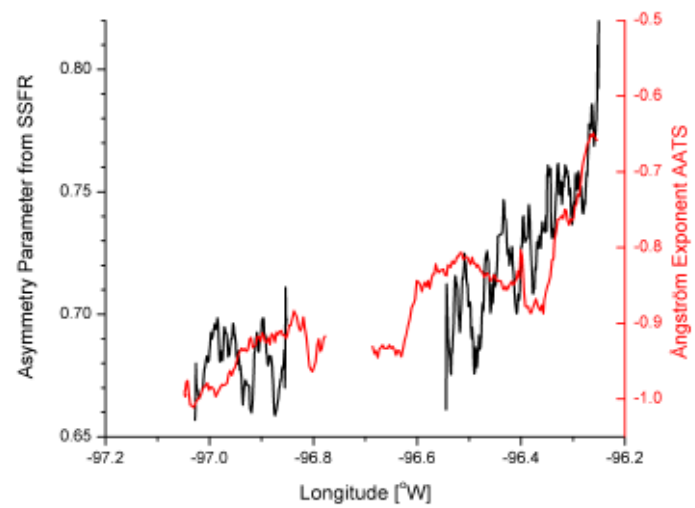
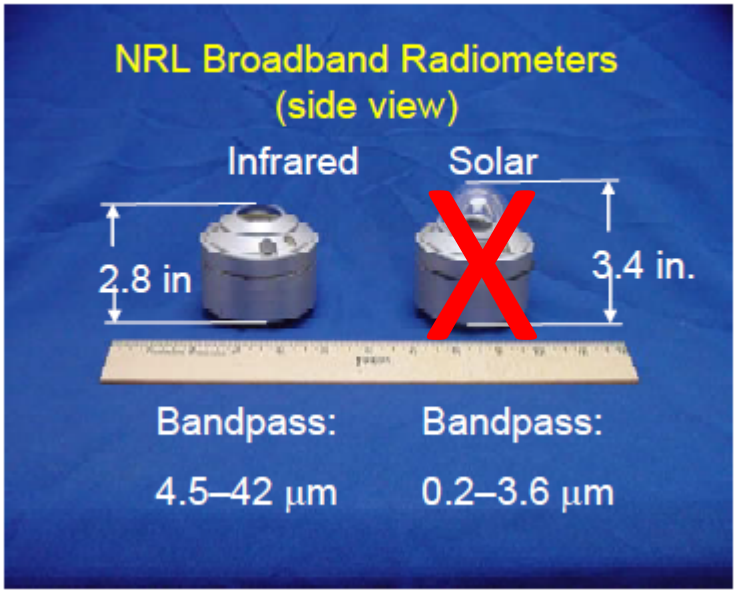


Figure 4 - From Schmidt et al. (2010b): Asymmetry parameter and Ångström exponent, derived from a flux divergence leg.

BBIR (Bucholtz)

- Broadband Radiometers
- Kipp&Zonen CG-4 pygeometers (IR irradiance) (nadir and zenith)
- ~~K&Z CM-22 pyranometers (solar irradiance) nadir and zenith~~ (Anthony says no room on aircraft)
- Measure up and downwelling ~~solar~~ and IR irradiance
- Derive net ~~solar~~ and IR irradiance, solar and IR heating rates, Albedo

Broadband Radiometers (BBR)



MTP (Mahoney)

- Microwave Temperature Profiler
- Profiles of temperature below ER-2
- Provides heights of tropopause, cold point
- Coarse vertical resolution (150 m at flight level degrades to a few kilometers)
- 1-3 km horizontal resolution

MTP located on the ER-2's right engine cheek (HDPE window just visible)

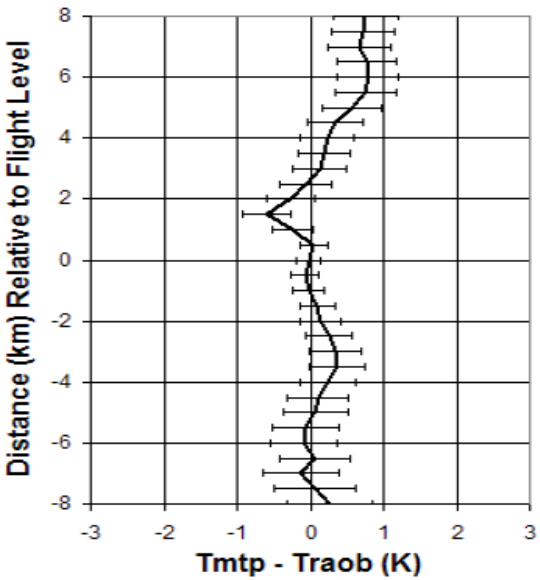
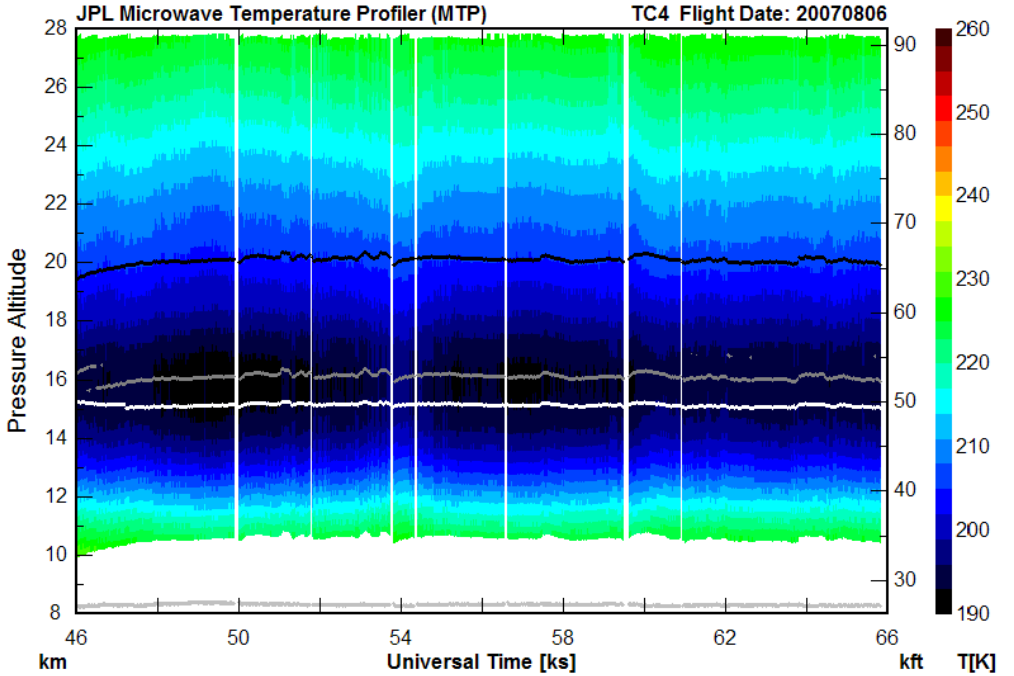


Figure 1-4. DC-8 MTP performance compared to radiosondes during the PAVE campaign in January 2005. The accuracy is <1 K within 8 km of flight level.



Principal Investigator: MJ Mahoney (Michael.J.Mahoney@jpl.nasa.gov)
Flight: 2007 08 06 00:00:00 Retrieved: 2007 08 06 20:18:19 Editted: 2007 08 06 20:27:56 Plotted: 2007 08 06

In Situ Instruments

WAS (Atlas)

- Whole Air Sampler
- Collects air samples (≤ 32 samples/flight) for measuring concentrations of trace gases
- Temporal resolution of seconds to minutes
- Sampling to focus on areas expected to have large gradients and during profiles
- Sampled returned to lab for analysis (gas chromatography)
- Measurements used to trace air mass ago, origin, and history

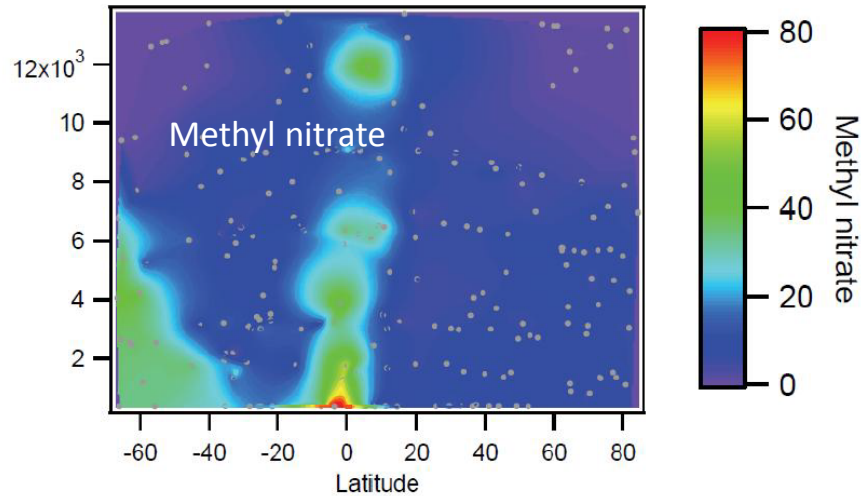


Figure 5. Vertical cross-section of methyl nitrate measured during the HIPPO-3 mission (Spring, 2010) in the central Pacific. Grey dots indicate the location of whole air samples.

Figure 1. Picture of ER-2 aircraft noting location of the Whole Air Sampler (WAS) in the belly pod of the aircraft. ***Inset:*** Canisters used in the WAS being prepared for flight. Actual configuration in the pod is 2 canisters wide.

JLH (Herman)

- JPL Laser Hygrometer
- Singel channel, open path, tunable laser diode spectroscopy (1.37 μm band)
- 1 Hz data rate
- Harmonic (fast, precise) and direct detection (accurate) spectroscopy
- Requires accurate static P, T measurements
- Detection range 1 to 500 ppmv
- Precision 1% or 0.05 ppmv
- Real-time data possible

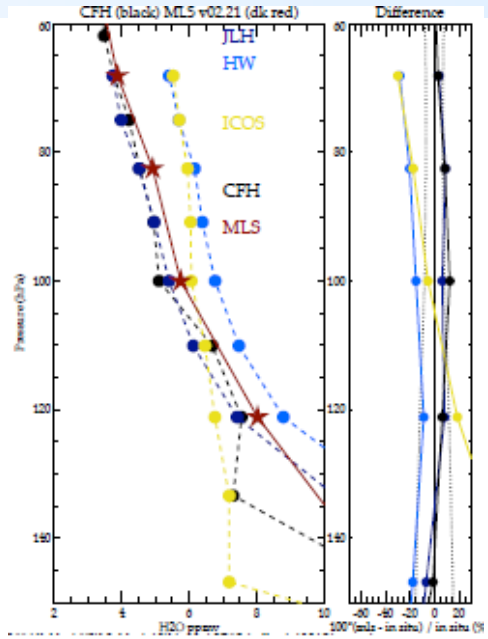
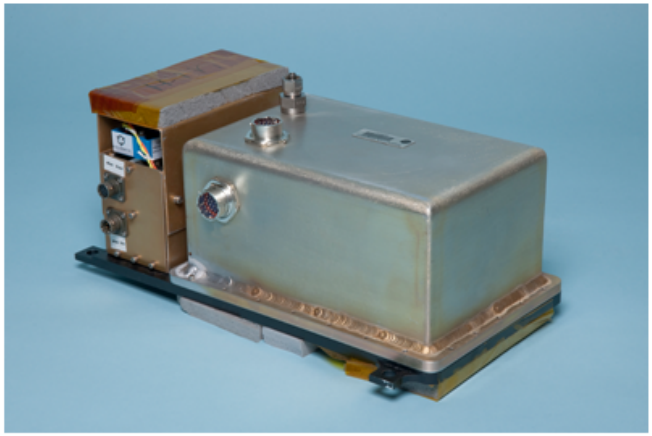
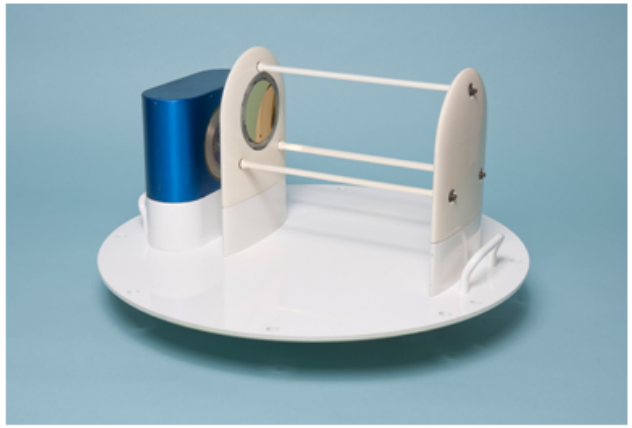


Figure 1-3. Comparison of JLH (dark blue), Harvard Water (light blue), Harvard ICOS (yellow), CFH (black), and Aura MLS (red) from the WB-57 flight on 3 August 2007 during TC4-Costa Rica, courtesy of W. Read. The right hand panel shows the differences with respect to MLS. JLH agrees with MLS to better than 15% at all altitudes.

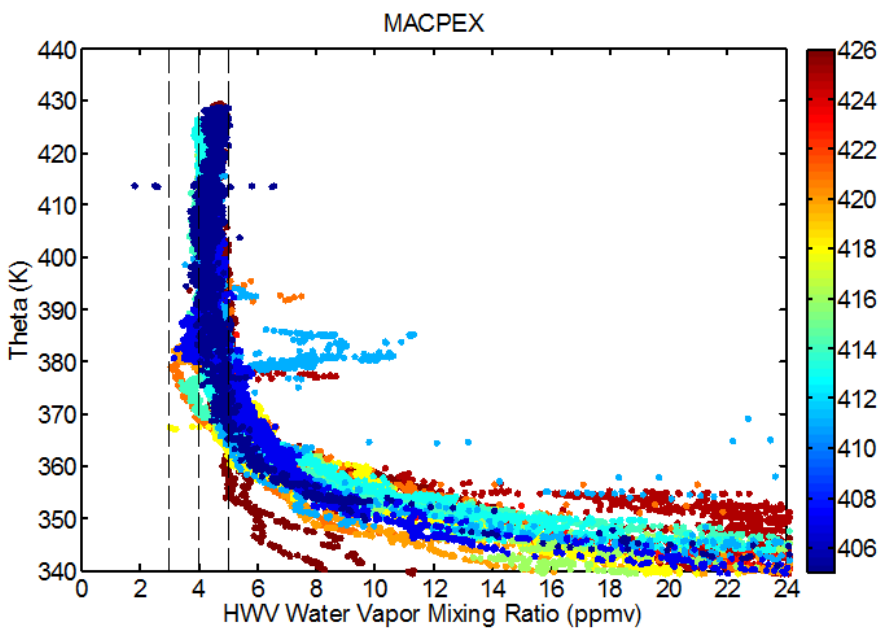




HU/Water vapor (Anderson)

- Harvard Univ./Lyman-α hygrometer + HHH TDL
- Measurements of H_2O vapor
- Accuracy: ±7.5%
- Precision: ±0.1 ppmv (1 – 10 ppmv) ±1% (10 – 100 ppmv)
- Artifacts/offsets: <+0.3 ppmv

	1 - 10 ppmv	10 - 100 ppmv	100 - 1000 ppmv
Sampling Period	1 second	1 second	1 second
Pressure Range	<500 hPa	<500 hPa	<500 hPa
Precision (typical)	<±0.1 ppmv	±1%	±1%
Accuracy	±5%	±5%	±5%
Artifacts/Offset	<+0.2 ppmv	<+0.2 ppmv	<+0.2 ppmv



UAS Ozone, Water Vapor (Gao)

- Ozone via UV absorption at 254 nm
- Accuracy ~ 5%
- Precision ~ 1.4 ppb at 10 km
- 1 Hz data
- Flown on WB-57, Global Hawk
- **Will also provide water vapor via calibrated TDL**

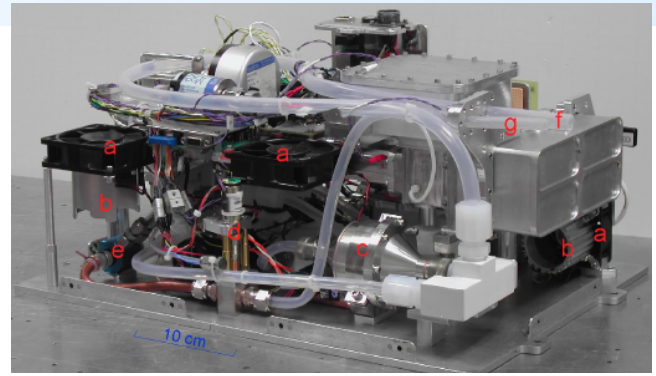


Table 1. Specifications of the NOAA-2 O_3 instrument

Data rate	2 Hz
Accuracy	3%
Precision with sample flow	1.1 x 10^{10} O_3 molecules cm^{-3}
Size	48 cm x 34 cm x 22 cm
Weight	18 kg
Power (28 VDC)	~200 W (peak) [a]; ~50 W (normal)

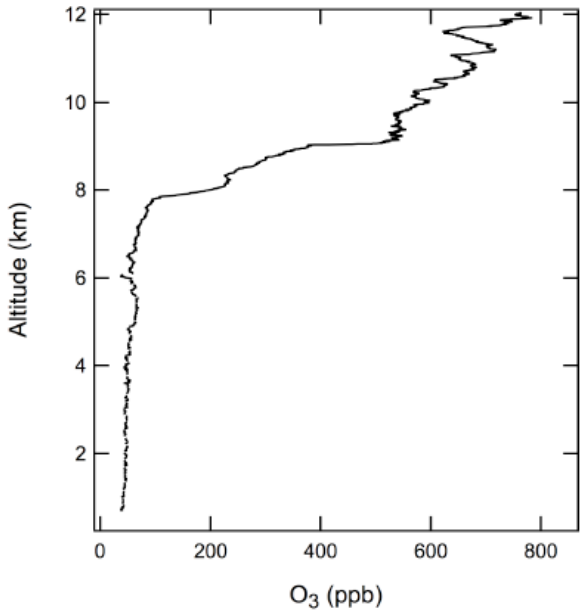
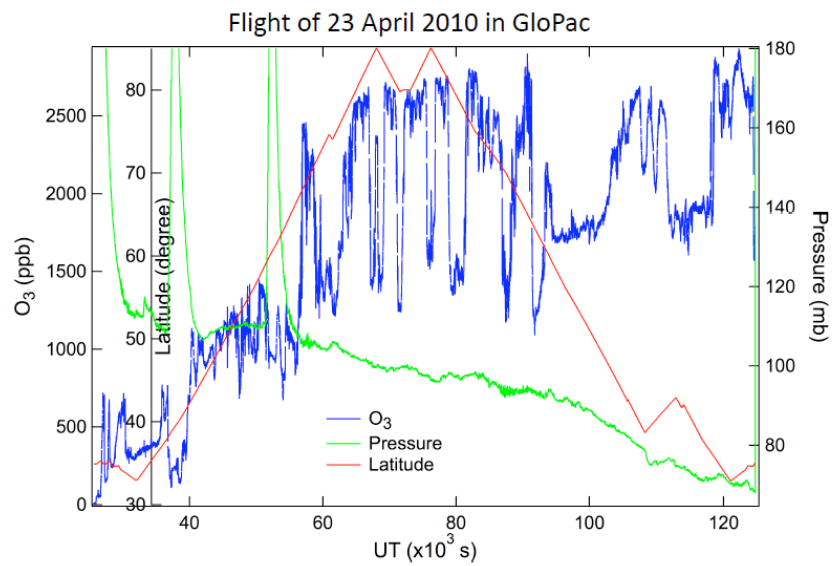


Figure 2: A vertical profile of O_3 mixing ratio measured by the NOAA UAS O_3 instrument on board the NASA Global Hawk during the GloPac mission in 2010.



ALIAS (Christensen)

- Aircraft Laser Infrared Absorption Spectrometer
- CO, CH4, N2O
- Tunable diode laser absorption
- CRAVE (2006), MACPEX (2011)

Table 1. ALIAS measurements

Measurement	Sensitivity (1 s)	Accuracy	ER-2 priority
CO	300 ppt, 1 Hz	3%	required
Total water	10 ppb, 1 Hz	3%	required
CH_4	100 ppt, 1 Hz	1%	desired
N_2O	100 ppt, 1 Hz	1%	useful

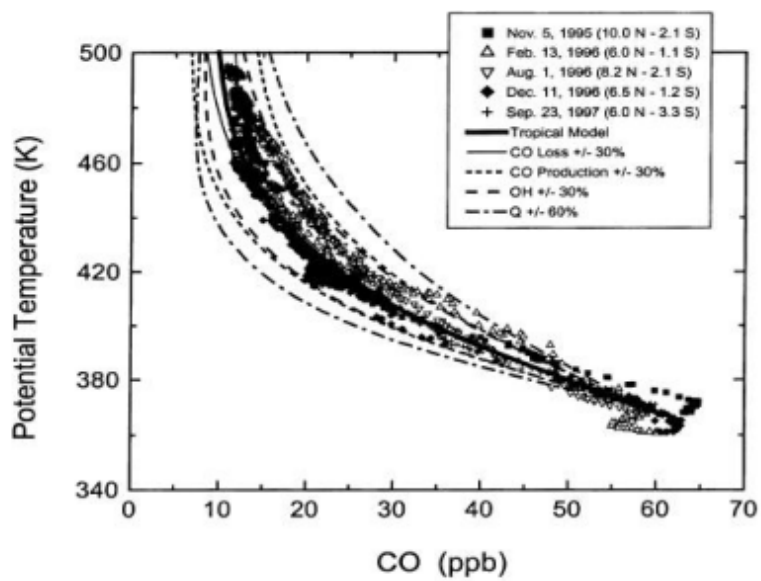


Figure 4. ALIAS measurements of CO from the ER-2 during 1995 STRAT and 1997 South-survey portion of POLARIS. These measurements agree with TTL transport and photochemistry in the absence of the Asian monsoon perturbance. From [9].

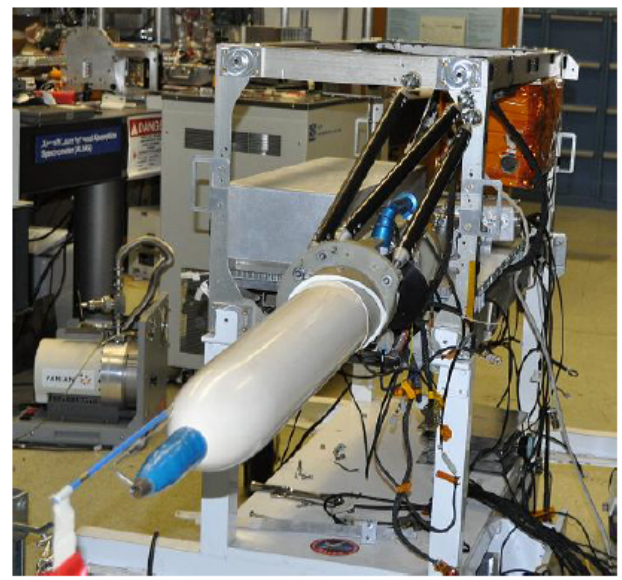
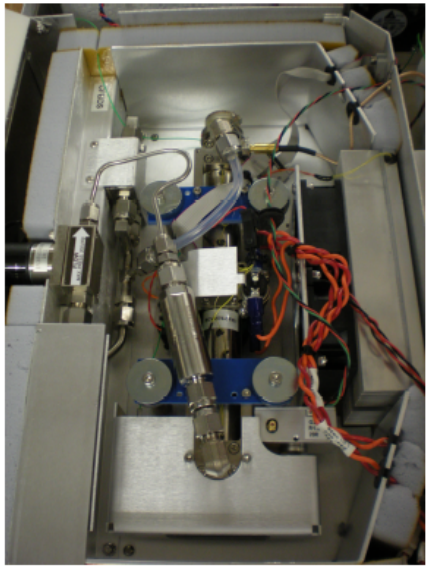
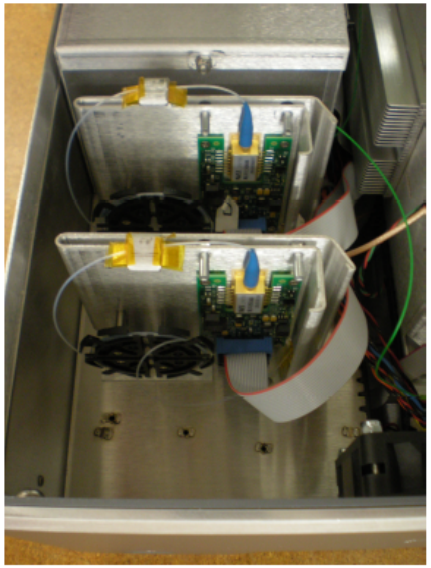


Figure 11. The ALIAS instrument, 2011.

HU/PCRS (Wofsy)

- Harvard Univ./Picarro Cavity Ringdown Spectrometer
- Measurements of CO_2, CH_4, CO
- Picarro gas analyzer with separate calibration system
- Wavelength-scanned Cavity Ringdown Spectroscopy
- Sensitivities: 50, 0.2, and 7 ppb, respectively @3 sec resolution



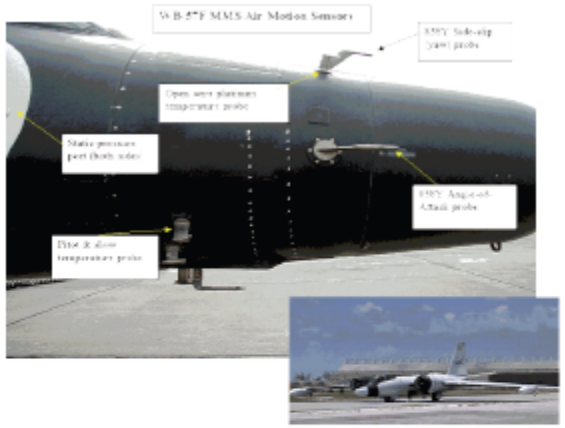


Specifications:

Precision:	$CO_2 \pm 0.04$ ppm; $CH_4 \pm 0.25$ ppb; CO $\pm$ 7.25 ppb	
Weight:	170 lbs.	
Power:	115VAC / 400Hz, single phase:	500W max., 200W typical
	28VDC:	340W max., 100W typical
Response Time:	approx. 2.5 seconds	

MMS (Bui) ?

- Meteorological Measurement Systems
- State Parameters (P, T, turbulence, winds)
- Several ER-2 PIs have expressed concern/desire for MMS measurements of P,T
  - Accurate P,T required for evaluating and using in situ water vapor
  - MTP requires accurate P,T
- MMS has flown extensively before, and PIs expect these or similar measurements
- If not MMS, what is alternative?



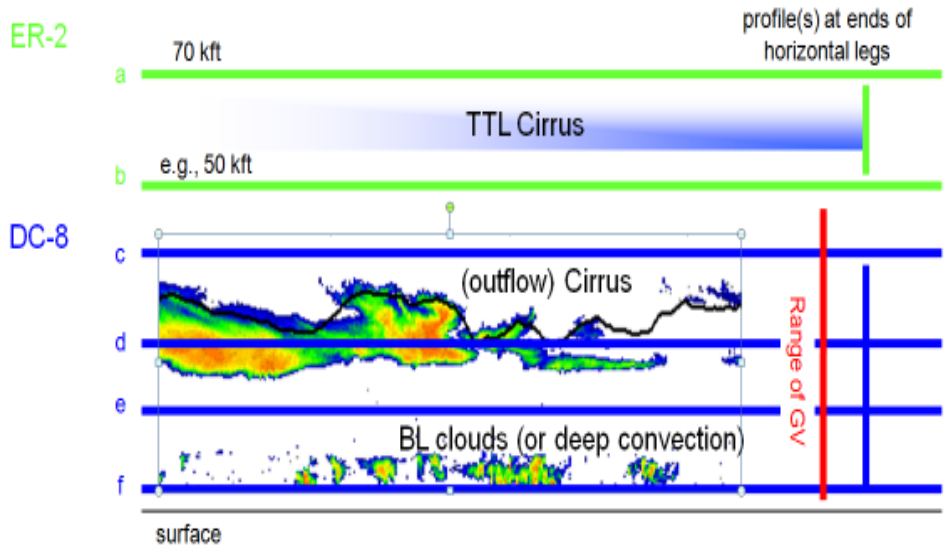
Primary Products @ 20 Hz

	Typical value	Precision	Accuracy
Pressure	~ 60 mb	0.1 mb	± 0.3 mb ~ 0.5%
Temperature	~180 K	0.1 K	± 0.3 k ~ 0.2%
Horizontal Wind	~ 30 ms^{-1}	0.1 ms^{-1}	±1 ms^{-1} ~3.3%
Vertical Wind	< 1 ms^{-1}	0.1 ms^{-1}	time averaged ~ 0.0 ms^{-1}

Example Measurement Scenarios

Cloud-aerosol remote sensing and radiative effects (Schmidt, Bucholtz et al.)

- **Objectives:**
  - **Examine shortware albedo, absorption and spectral irradiance in presence of clouds, and examine why these are different from model values**
  - **Computing heating rates**
  - **Test remote sensing retrievals**
- **Remote Sensing Synergy**
  - **ER-2 (SSFR, BBIR, CPL, air MSPI, RSP)**
    - **Spectral and broadband radiance**
    - **Polarization**
    - **Aerosol/cloud profiles**
    - **Cloud retrievals**
    - **ER-2 legs straight and level above and below TTL cirrus**
  - **DC-8 (SSFR, AATS, HSRL, BBR, CAFS, in situ aerosols and cloud)**
    - **DC8 legs above and below outflow cirrus and BL clouds**
  - **GV (SSFR)**



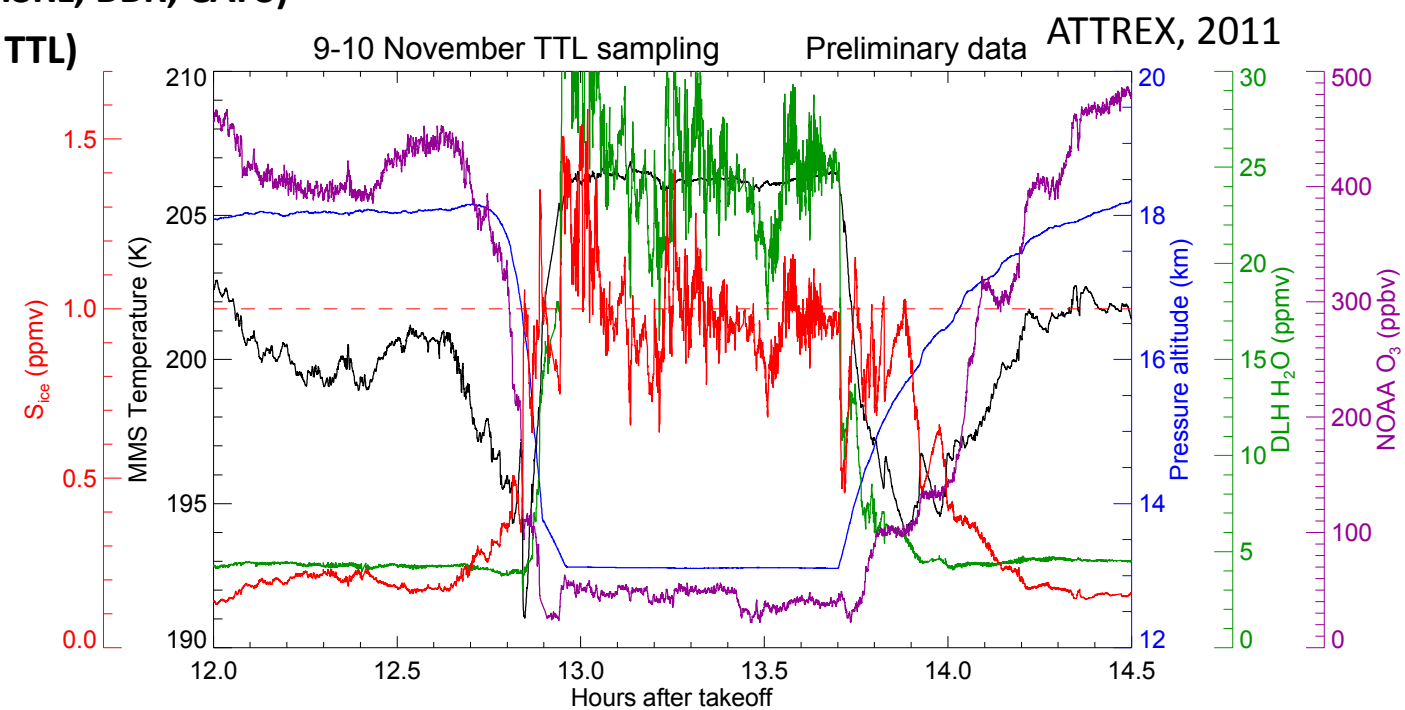
Notes:

a = ER-2 leg @ 70 kft (nominal altitude)
b = ER-2 leg below TTL Ci
c = DC-8 leg below TTL Ci and above UT Cirrus
d = DC-8 in-situ legs (**at various altitudes**)
e = **one DC-8 leg below UT Cirrus** and above BL clouds (if there is a gap)
f = DC-8 leg between BL clouds and surface

DC-8 legs may all be complemented by GV legs which carries radiometers very much alike SSFR

Tropical Tropopause Layer (TTL) profiling

- **Objectives:**
  - **Measure tracers and water vapor water vapor through the depth of the TTL (~14 – 19 km)**
  - **Profiling both inside and outside the anticyclone and downstream of deep convection**
- **In Situ/Remote Sensing Synergy**
  - **ER-2 (HU/PCRS, HU/Ly-α, O_3, JLH, AWAS, ALIAS, MMS, SSFR, CPL)**
    - **H_2O and relative humidity, tracers with a range of lifetimes, CO_2 clock**
    - **ER-2 legs straight and level above and descent and ascent through upper TTL**
  - **DC-8 (SSFR, AATS, HSRL, BBR, CAFS)**
  - **GV (profiling lower TTL)**



Aerosol-Clouds-Ecosystems (ACE) Retrieval Studies

- Some objectives:
  - Evaluate measurement needs and retrieval capabilities for associated with aerosol/cloud retrievals for NASA ACE mission
  - Examine how aerosol properties (size, complex refractive index) (e.g. biomass burning smoke) vary with age and transport
  - Investigate retrievals of aerosol properties above clouds
- Remote Sensing Synergy
  - ER-2 (RSP, airMSPI, CPL, eMAS)
    - Multiangle, polarized radiance meaurements from RSP and airMSPI to be used for aerosol and cloud retrievals
    - Obtain measurements to evaluate the number of angles, information content in various wavelengths, etc. used for polarimetric aerosol retrievals
    - Examine combined active (lidar)+passive (polarimeter) retrieval algorithms of aerosol properties – how do products and uncertainties vary with different combinations of channels
    - Start simple – cloudfree skies, over thick aerosol (smoke), then aerosols above clouds
  - DC-8 measurements of aerosol and cloud parameters coincident with ER-2 measurements to provide correlative data
  - Measurements over ground sites (AERONET/MPL) to provide correlative data
  - Measurements coincident with MODIS and/or MISR and/or PARASOL overpasses

Cloud Retrievals (Platnick)

- Objectives
  - Evaluate remote sensing retrievals of cloud properties and the use of these retrievals for assessing aerosol impacts of clouds
  - Satellite calibrations/characterizations and assessments of algorithm assumptions
  - Evaluation of active vs. passive retrievals of cirrus cloud properties
- Remote Sensing Synergy
  - ER-2 (eMAS, CPL, SSFR, RSP, airMSPI), DC8 (radar), GV (in situ cloud probes)
    - Avoid multilayer scenes and severely heterogeneous scenes
    - Ice clouds - relatively homogeneous scenes with range of optical depths
    - Water clouds – Overcast PBL clouds with no cirrus
  - Radiometric calibrations require flight segments along satellite ground tracks (MODIS, VIIRS, AIRS, IASI)

Real-time Data Download

Real-time Data Download

Instrument	Data type	Data downlink before?	Why needed?	Does Pi plan to downlink?
CPL	Lidar, clouds and aerosols	Yes, TC4	To detect clouds	Yes
MTP	Temperature profile	Yes, ATTREX	To locate tropopause	Yes (if 9600 baud RS232 Nav data available)
Ozone	Ozone, water vapor	Yes, ATTREX	Locate gradients	Yes
JLH	Water vapor	Yes, ATTREX	Locate gradients	Yes

Higher priority & Positive responses

Instrument	Data type	Data downlink before?	Why needed?	Does PI plan to downlink?
HHH	Water vapor	No	gradients	No – provide quicklook data and archive within 24 hours
WAS	WAS	No		No---samples must be analyzed in lab
Bucholtz	IR irradiances	No	Clear vs. cloud	No – post-flight data and quickooks
Cairns	Aerosol/cloud optical depth and size	No	Aerosol/cloud amounts and types	No
Diner	Multispectral polarized radiances	No	Aerosol/cloud/ surface interpretation	No – postflight quicklook images
Platnick	Multiwavelength imagery	No	Cloud/surface	No – post-flight browse images
Schmidt	Spectral radiance	No	Cloud scenes	No – could provide near-real time cloud optical thickness and effective radius
Wofsy	Trace gases	No	Gradients	Could provide real-time data, will provide quicklook data after flight

Other responses

<u>Data transmission will be limited by Iridium downlink</u>

PI Requirements and Desires

(see ER-2 spreadsheet for more details)

Flight Parameters and Patterns (remote sensors)

- Need daylight
- Generally desire straight and level with pitch, roll within 5 deg
- airMSPI, RSP (strongly) prefer orientation along principal plane
- airMSPI desires minimal pitch variations, ground speed ~ 207 m/s
- airMSPI requires acquisition of discernible land targets for each flight (Utapao airfield would be fine)
- airMSPI wants to avoid complex topography, desires Case 1 waters
- airMSPI wants nose heat
- eMAS – for cloud retrievals avoid sun glint, desire water and dark vegetation
- On ground RSP needs connection to dry N2
- Close RSP door in clouds
- Avoid precipitation during ascent/descent
- So far, all instruments can handle flights up to 8 hours

Flight Parameters and Patterns (in situ sensors)

- In situ sensors, and to a lesser degree (BBIR) would like some dips to sample gradients and/or clouds – ascent/descent rates < 2000 ft/min (HU/PCRS)
- Harvard water vapor wants:
  - Multiple vertical samples at different locations
  - Level legs through tropopause, lowest water vapor, lowest temperature
- Harvard water vapor has interest in night flight
- HU/PCRS desires both north-south and east-west transects of TTL
- NOAA ozone, water vapor desires latitudinal transects (especially to far north)
- So far, all instruments can handle flights up to 8 hours
- HU/PCRS wants Q-bay temp < 35 deg C
- Avoid precipitation during ascent/descent

General Cloud and Aerosol Conditions Desired

- WAS, NOAA Ozone, water vapor desire some in-cloud sampling
- eMAS
  - clear sky, ocean (warm) and anvil (cold) scenes (for IR calibration)
  - avoid multilayer and severely heterogeneous clouds (for cloud retrievals)
  - Moderately thick (for microphysical retrievals)
  - Relatively homogeneous cirrus without low clouds (ice cloud retrieval)
  - Relatively overcast PBL (for water cloud retrievals)
- SSFR
  - Sandwich cloud run with multiple aircraft and/or ER-2 above/below TTL cirrus
- (airMSPI, RSP, SSFR, eMAS) – for aerosol retrieval testing, desire cloud-free skies
- Thin cirrus of interest for many sensors
- Wide variety of aerosol loading conditions and types desired
- NOAA ozone wants to avoid very high aerosol to prevent contamination of instrument

Coincident Data Desired

- DC-8
  - Trace gas, water vapor measurements
  - Radiometers, AATS14, DIAL/HSRL for characterizing radiation, irradiance, surface reflectance, aerosol/cloud amounts
  - In situ aerosol/cloud measurements to provide correlative data for aerosol/cloud retrievals
- GV
  - TOGA, trace gas, water vapor
  - Solar and IR radiometers
  - Aerosol/cloud in situ measurements for correlative data
- Satellites
  - MODIS, MISR, CALIPSO, PARASOL, VIIRS, AURA, AIRS, CrIS, IASI, CLOUDSAT, MLS, MTSAT-2
- Surface
  - AERONET, MPL
  - Ozonesondes, frostpoint sondes for intercomparisons
  - Surface radiation (Singapore, Vietnam)
  - Yokelson mobile FTIR for fire conditions