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Measuring XCO2 with the Airborne Demonstrator for the NASA Decadal Survey “ASCENDS” Mission

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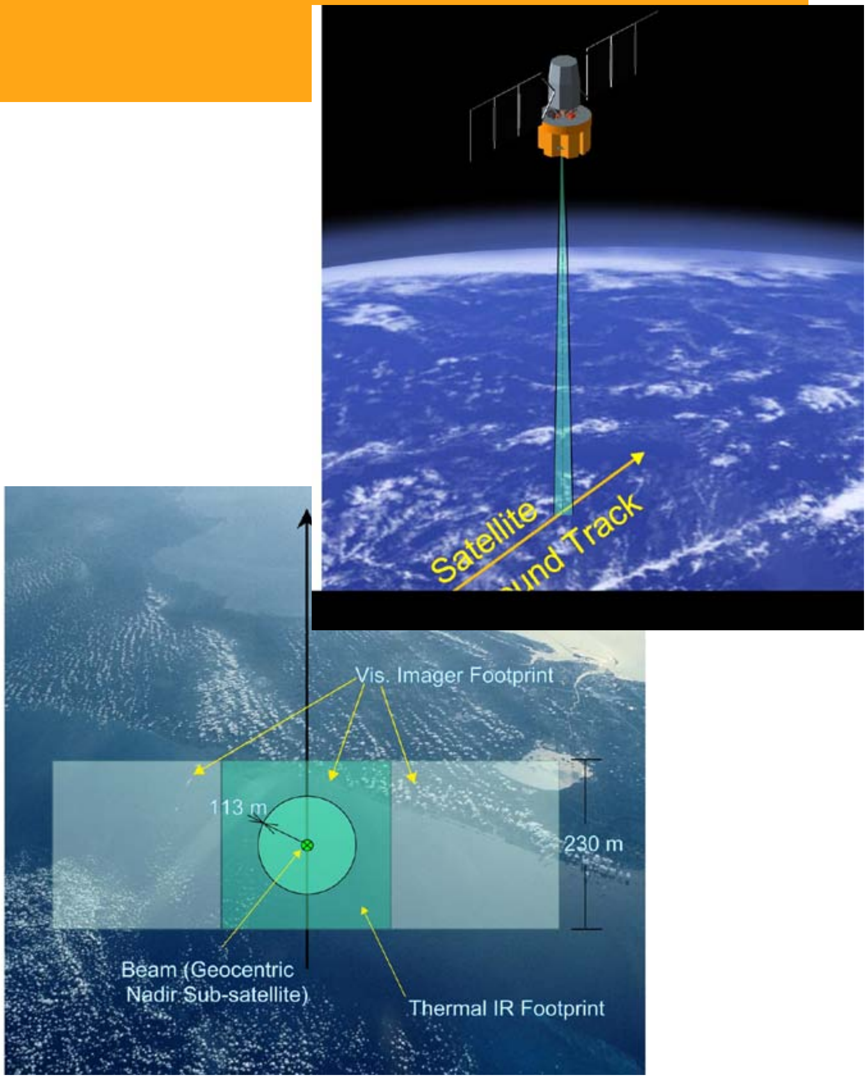
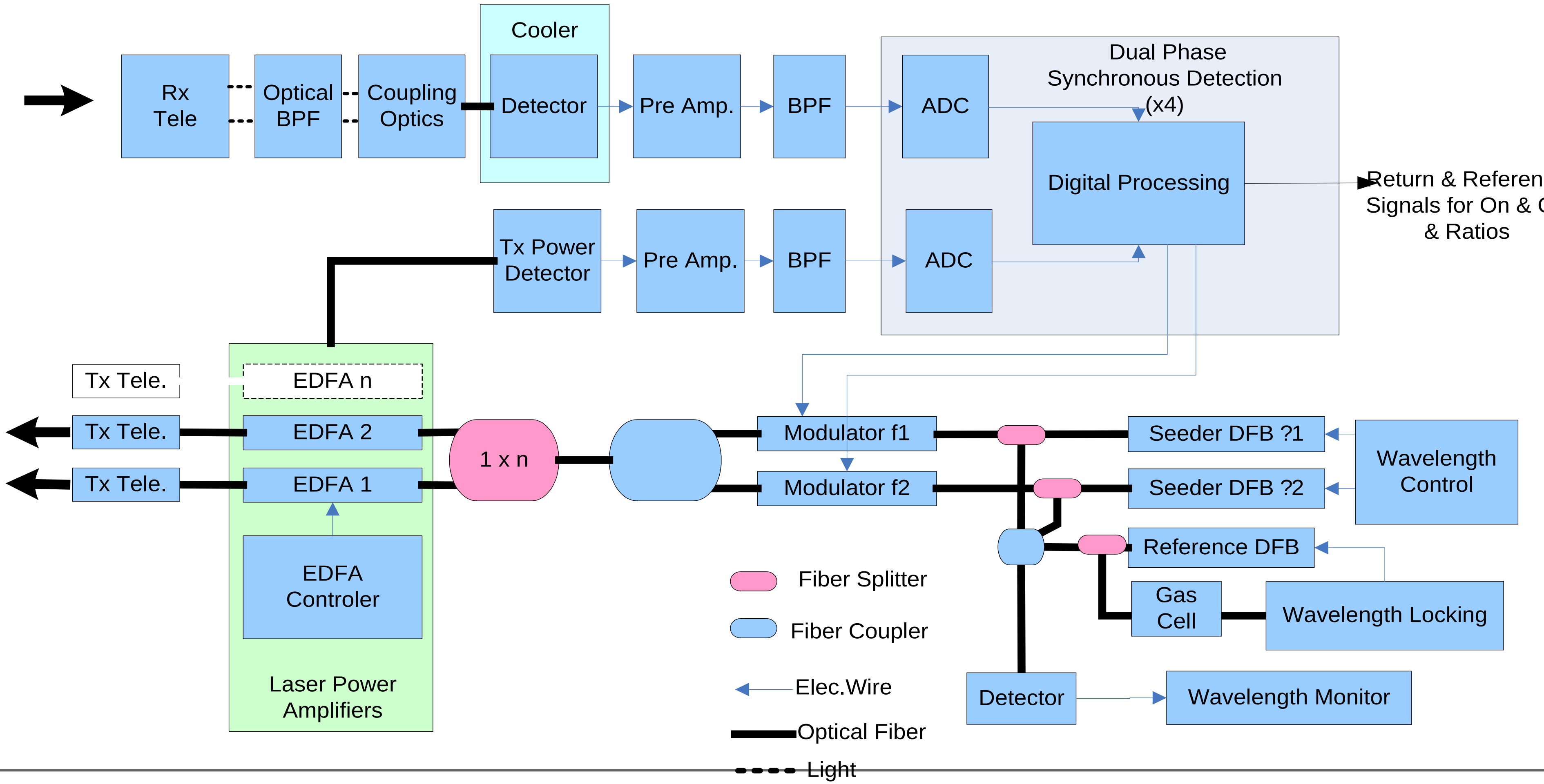
Engineered for life

ASCENDS – an Integrated Suite of Lidars, Passive Sounders and Imagery



- **CO2 Column Measurement**
  - **CO2 Laser Absorption Spectrometer to resolve (or weight) the CO2 altitude distribution, particularly across the mid to lower troposphere.**
  - **1.6 μm LAS only baseline or integrated 1.6 μm + 2.0 μm LAS option.**
- **Surface Pressure Measurement**
  - **O2 Laser Absorption Spectrometer to convert CO2 number density to mixing ratio XCO2.**
- **Surface/cloud top altimeter**
  - **Laser altimeter to measure column length; surface, clouds.**
- **Temperature Sounder**
  - **Six channel passive radiometer to provide temperature corrections.**
- **CO Sensor**
  - **Gas Filter Correlation Radiometers (at 2.3 & 4.6 μm) to separate biogenetic fluxes from biomass burning and fossil fuel combustion.**
- **Imager**
  - **Context**

ITT's Laser Absorption Spectrometer is Robust, Compact, & Affordable because we use telecom lasers. Modular, wavelengths can be added/removed. 100% fiber Tx & Rx optical paths simplifies installation on Aircraft, Helicopters, UAS, pods, spacecraft.



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ITT's mature Laser Absorption Spectrometer has several 'field proven' advantages.

- Simultaneous transmission of all 'probe' wavelengths. Precludes artifacts from temporal/spatial displacement of wavelengths.
- Common Tx and Rx optical and signal paths converts most noise sources - atmospheric and instrument – to common-mode noise which is largely attenuated.
- Common Rx path for all wavelengths eliminates artifacts, bias and drift due to different paths and the opportunity for them to change with time.
- Common Tx path eliminates artifacts and opportunity for them to change with time.
- "No risky scaling" of subsystems required for transition to space. Just add more fiber amplifiers. 5 watts fits in 8x10x1 inch and operates at 20% to 10% wall plug efficiency.
- No water cooling required.
- Good range of wavelengths – science gets to chose versus being stuck with 1um stock answer.

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The suite was successfully migrated to the NASA UC-12 aircraft for our 7th Flight Campaign this Sept '08

- CO_2 Laser Absorption Spectroscopy @ 1.57um
- Laser Altimeter – range to surface & clouds @ 1um; changing to 1.6 um
- O_2 Laser Absorption Spectroscopy @ 1.27um; in process
- In-Situ Sensor Suite – NIST traceable CO_2, Temperature, Pressure, Relative Humidity, INS/GPS
- Real-Time Display of OD, Signal Strength, Diagnostics, Housekeeping.
- Ready for Op's or UAS – Automated via LabView. Suite requires limited operator interaction. Remote operator over network is standard with LabView.

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Prior to the UC12 the suite has flown for 4 Years on a Lear 25C operated for 7 years at ITT test site.

- More than 30 flight sorties completed since 2004.
- The Laser Transmitter has been in operation since 2001.
- Key components are identical for space, air and ground.
  - **DFB (seed laser)**
  - **Fiber Amplifier**
  - **APD Detector**
- All validation conducted at space-based received power levels. No ‘scaling’ risk.
- Electronics implemented with COTS strictly for cost savings. All electronics have Flight equivalents

Flight Tracks designed to validate performance over multiple surface types Grassland, Forest, Lake, Bay, Ocean

- All surface types provided excellent signal strength; with the exception of small inland lakes which are highly specular.
- Signal strength from Bay and Ocean is strong even in light winds.
- 10 second SNR >>500 at the same power levels as would be received from space-based mission simulated by NASA LaRC

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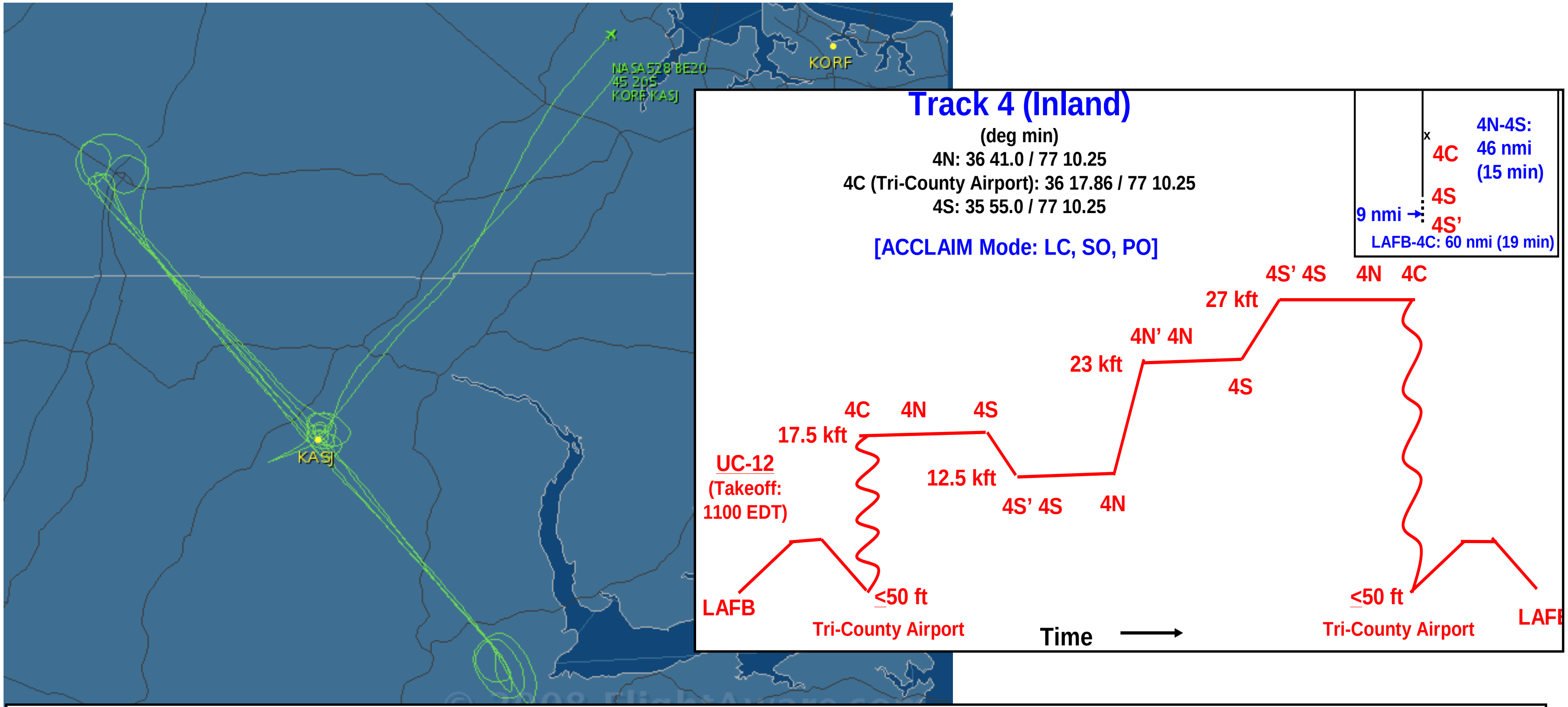
The total column OD measured by the LAS is compared to the OD modeled from layer-by-layer CO2, Temp, Pressure, RH measured by the In-Situ suite & Sondes.



Spirals were flown down to 50ft to maximize information on PBL.
Each spiral was supported by co-located radiosonde launch.

Preliminary results show typical agreement of ±1%.

This is within the error budget build-up from uncertainties in spectroscopy (under study), variation in CO2 observed from beginning to ending, residual uncertainty in wavelengths (resolved), and calibration of sonde and in-situ sensors.

IDENT	FLIGHT	FILE	Start Hour	End Hour	Delta Time, sec	CH2, CH3, CH4	ALT	CL/SO OD			
								MEASURED * (M)	MODEL-1 (A)	DIFF (M-A)	(DIFF/A)* 100
100408_flight5		**4-O**	12.195	12.218	82.8	CL, SO, PO	**4493**	**0.479100**	0.482825	-0.003725	**-0.77**
100408_flight5		**5-O**	12.23	12.31	288.0	CL, SO, PO	**4508**	**0.480128**	0.484525	-0.004397	**-0.91**
100408_flight5		**5-L**	12.335	12.365	108	CL, SO, PO	**4510**	**0.487917**	0.483680	0.004237	**0.88**
100408_flight5		**5-B**	12.405	12.505	360	CL, SO, PO	**4519**	**0.481935**	0.485682	-0.003748	**-0.77**

IDENT	FLIGHT	FILE	Start Hour	End Hour	Delta Time, sec	CH2, CH3, CH4	ALT	CH3/CH4 OD			
								MEASURED (M)	MODEL-1 (A)	DIFF (M-A)	(DIFF/A)* 100
100808_flight7		**7***	13.216	13.294	280.4	CL, SL, PO	**3906**	**0.279730**	0.279843	-0.000113	**-0.04**
100808_flight7		**8***	13.367	13.525	568.4	CL, SL, PO	**3903**	**0.276990**	0.279437	-0.002447	**-0.88**
100808_flight7		**9***	13.648	13.664	57.6	CL, SL, PO	**3905**	**0.278852**	0.279500	-0.000648	**-0.23**
100808_flight7		**9***	13.687	13.707	72.0	CL, SL, PO	**3905**	**0.278759**	0.279457	-0.000698	**-0.25**

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Next Steps

- Integrate 1.27um O2 pressure channel for full XCO2 capability.
- Integrate 1.6um altimeter developed by ITT with funding from NASA Instrument Incubator Program. (Replaces 1um altimeter)
- Develop partnerships with DOE, NOAA, NSF
  - See next slide for notional regional scale study of CO2 Transport …
  - Develop "data sheets" for XCO2, Methane @ 1.6um, Near-Field up-looking lidar (per D Murphy, Session 2)
    - Early work indicated that the CH4 version almost fit the Aerosonde.
- Implement upgraded and more compact version of the instrument suite which would support climate - carbon community science, and support the ASCENDS mission risk-reduction efforts.

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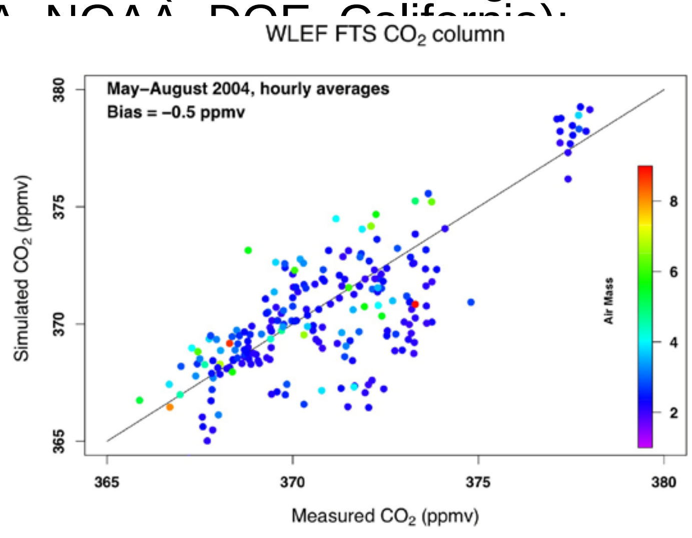
Notional Airborne Campaign in support of Regional CO_2 and Greenhouse Gas Modeling [chart supplied by Januz at AER Inc.]

- Science Questions: Flux/Transport Model Validation, Regional Flux Estimates, Source Attribution, Future Projections. Possible Regulatory Role (Compliance with Emission Controls).
- Requires: Model-Data Fusion Framework Integrating Measurements from a Variety of Platforms, a Regional Transport Model (WRF-STILT), High-Resolution *A Priori* Flux Models, and Optimization Procedures. Rigorous Error Characterization a Central Focus.
- Utilize: Coordinated towers, aircraft (in-situ/remote sensors), upward-looking FTS, satellite (e.g. GOSAT)
- Framework Exists: Developed and Actively Used by an International Consortium Including Private Industry (AER), Academia (Harvard, Michigan, …), and Federal/State Governments (NSF, NAS
Aircraft Column CO_2 Sensor (ITT-NASA LaRC); I
Network.

Example of Successful Simulation: Comparison of Measurement with Model



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Acknowledgements

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Colleagues

- Berrien Moore III, Climate Central, U New Hampshire
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Questions