



AMERICAN METEOROLOGICAL SOCIETY



The AFIT of Today is the Air Force of Tomorrow.

High Performance Computing for 4D Weather Cubes and Real-Time, World-Wide Visualization of Radiative Effects

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The views expressed in this document are those of the author(s) and do not reflect the official policy or position of the United States Air Force, the Department of Defense, or the United States government.

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Overview



The AFIT of Today is the Air Force of Tomorrow.

- Introduction/Goal of Research
- Simulation Tool
- Realistic Atmospheres
 - Numerical Weather Prediction Tools
 - Modeling a Well-Mixed Boundary Layer
- High Performance Computing
- 4D Weather Cubes
- Conclusion/Future Work



Introduction



The AFIT of Today is the Air Force of Tomorrow.

- **Goal:** Immediate, world-wide forecasts of atmospheric effects and radiative transfer to assist with traditional aviation weather services or to manage best employment of emerging national and civil remote sensing capabilities in the form of 4D Weather Cubes, specific to a universal time reference, locations of interest (i.e. geo-referenced light source and remote sensor), and a user-provided output parameter, such as transmission, relative to the ambient atmosphere.
- **Core Analytical / Synoptic Observation Tools:**
 - Laser Environmental Effects Definition and Reference (LEEDR)
 - NOAA's numerical weather prediction tools (i.e. Global Forecast System)
 - Department of Defense HPC network
 - Parallel Computing Toolbox within MATLAB
 - Wrapper Class



Simulation Tool: LEEDR



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- Calculates line-by-line and spectral band radiative transfer solutions by creating correlated, physically realizable vertical profiles of meteorological data and environmental effects (e.g. gaseous and particle extinction, optical turbulence, and cloud free line of sight)
- Accesses terrestrial and marine atmospheric and particulate climatologies
 - Allows graphical access to and export of probabilistic data from the Extreme and Percentile Environmental Reference Tables (ExPERT)

LEEDR
Laser Environmental Effects Definition And Reference

Profile
Inputs
Outputs
Path Radiance
ExPERT Database
ExPERT
Settings
About LEEDR

0%

28-Jan-2014 07:57:07
28-Jan-2014 08:00:05
28-Jan-2014 08:24:13
28-Jan-2014 08:39:30
28-Jan-2014 08:44:05

Location Atmosphere Clouds/Rain Laser/Geometry Ground Level

BERMUDA INTERNATIONAL

Location Type: EXPERT Lat, Lon

Current ExPERT Site: Site Name: ROBINS AFB
Latitude: 32.63
Longitude: -83.6

Favorites: [List]

Sodium Overlay: None
ADDING THIS OVERLAY WILL MAKE THE MAP VERY SLOW TO USE

Create Profile Save Profile Load profile Reference Manual Exit LEEDR

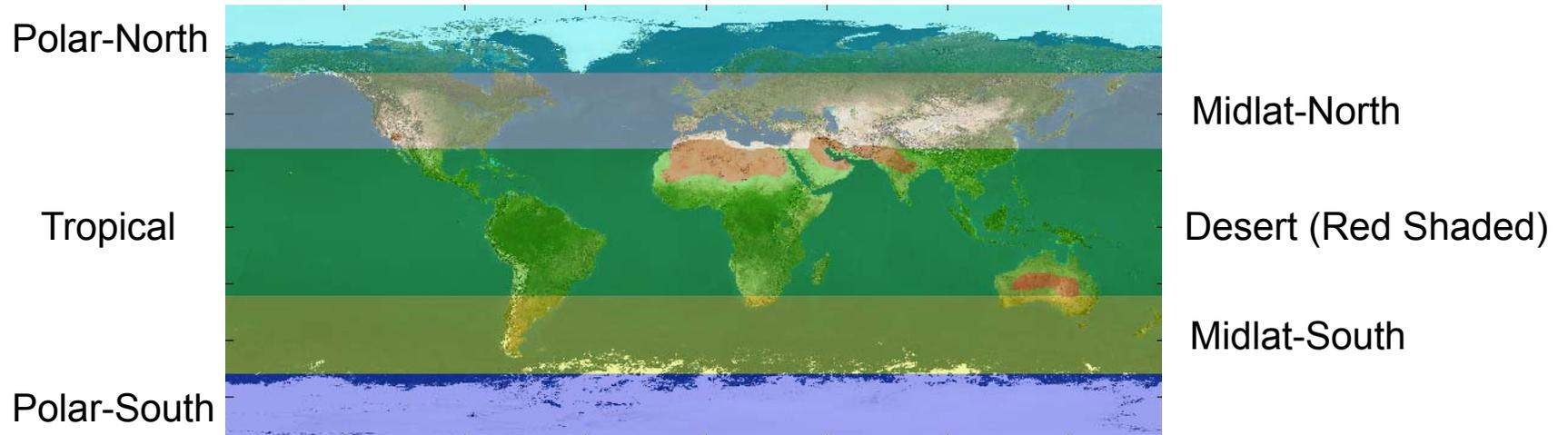


LEEDR

Worldwide Climatology



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LEEDR ocean site selection map and upper air regions



573 ExPERT (land) locations represented in LEEDR

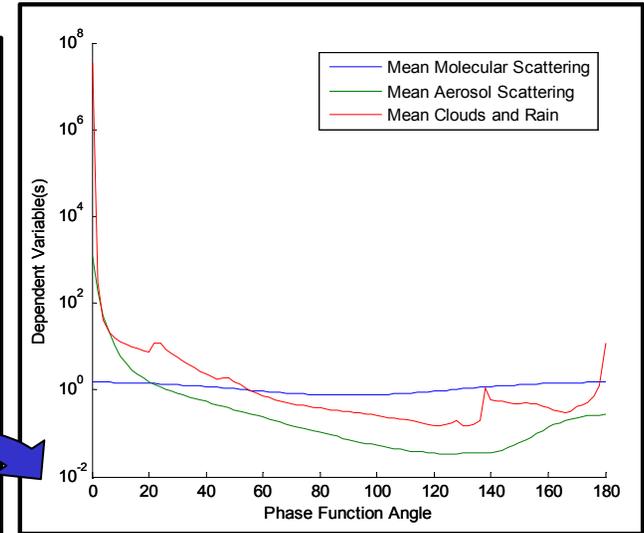
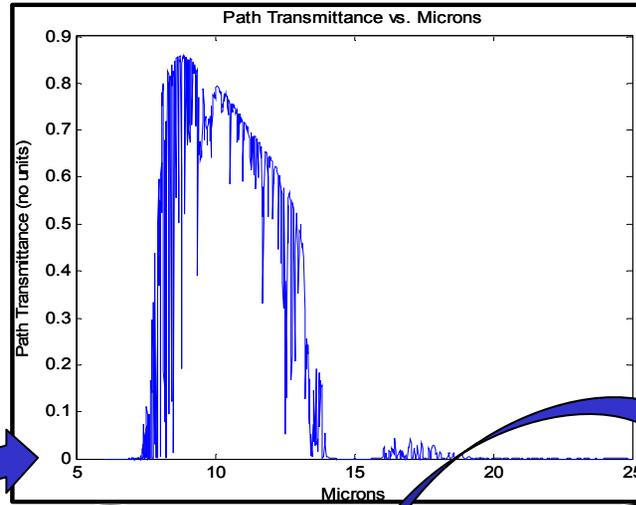
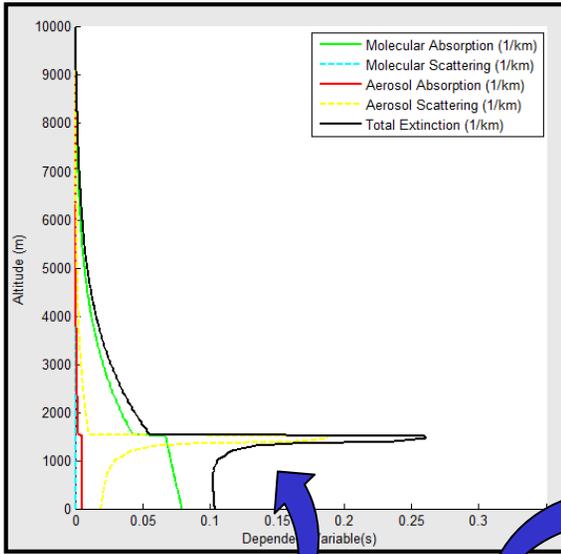


LEEDR

Profiling Atmospheric Effects



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Values	2D Outputs	Comparisons	Backscatter	Phase Functions	Path Bending
Path Results					
Path Transmittance:	0.842301				
Path Extinction (1/km):	0.0171618				
Path Specific Attenuation (dB/km):	0.0745326				
Surface Visibility (km):	21.1957				
Slant Path Visibility (km):	83.4776				
Wavelength (m):	1.31525e-06				

Altitude (m)	Total Backscatter (m ⁻¹ ·1·str ⁻¹)	Aerosol Extinction (1/km)	Aerosol Scattering (1/km)	Aerosol Absorption (1/km)
1	0	7.1847e-07	0.0320	0.0289
2	100	7.2695e-07	0.0323	0.0273
3	200	7.8731e-07	0.0340	0.0269
4	300	7.8994e-07	0.0348	0.0268
5	400	7.8594e-07	0.0340	0.0269
6	500	7.4035e-07	0.0333	0.0262
7	600	7.1821e-07	0.0321	0.0270
8	700	6.8086e-07	0.0309	0.0259
9	800	7.1173e-07	0.0319	0.0260
10	900	7.3698e-07	0.0329	0.0278
11	1000	7.8165e-07	0.0339	0.0268
12	1100	8.1751e-07	0.0362	0.0311
13	1200	8.9642e-07	0.0377	0.0326
14	1300	7.6269e-07	0.0340	0.0269
15	1400	7.2436e-07	0.0325	0.0274
16	1500	6.8699e-07	0.0310	0.0259
17	1600	3.1026e-07	0.0132	0.0110
18	1700	2.8422e-07	0.0121	0.0089
19	1800	2.5311e-07	0.0108	0.0087
20	1900	2.2441e-07	0.0096	0.0076
21	2000	2.0203e-07	0.0086	0.0068
22	2100	1.8471e-07	0.0078	0.0061
23	2200	1.5731e-07	0.0071	0.0054
24	2300	1.5713e-07	0.0068	0.0050
25	2400	1.4022e-07	0.0062	0.0047
26	2500	1.4134e-07	0.0058	0.0044
27	2600	1.3392e-07	0.0055	0.0041
28	2700	1.2693e-07	0.0051	0.0039
29	2800	1.2040e-07	0.0048	0.0036
30	2900	1.1488e-07	0.0046	0.0034
31	3000	1.0910e-07	0.0043	0.0032

Bending Outputs	Value
Miss Distance (m)	10335.1
Horizontal Miss Distance (m)	-10332.8
Vertical Miss Distance (m)	-233.713
Bent Beam Length (m)	29534.6809
Target Distance (m)	10000
Corrected Zenith Angle (deg)	Uncorrected
Original Zenith Angle (deg)	88.66970
Azimuth	0
Target X-Y Coordinates	9997.3 -6.37225e+04

LEEDR provides user multiple interactive views of atmospheric radiative effects



LEEDR Path Bending GUI

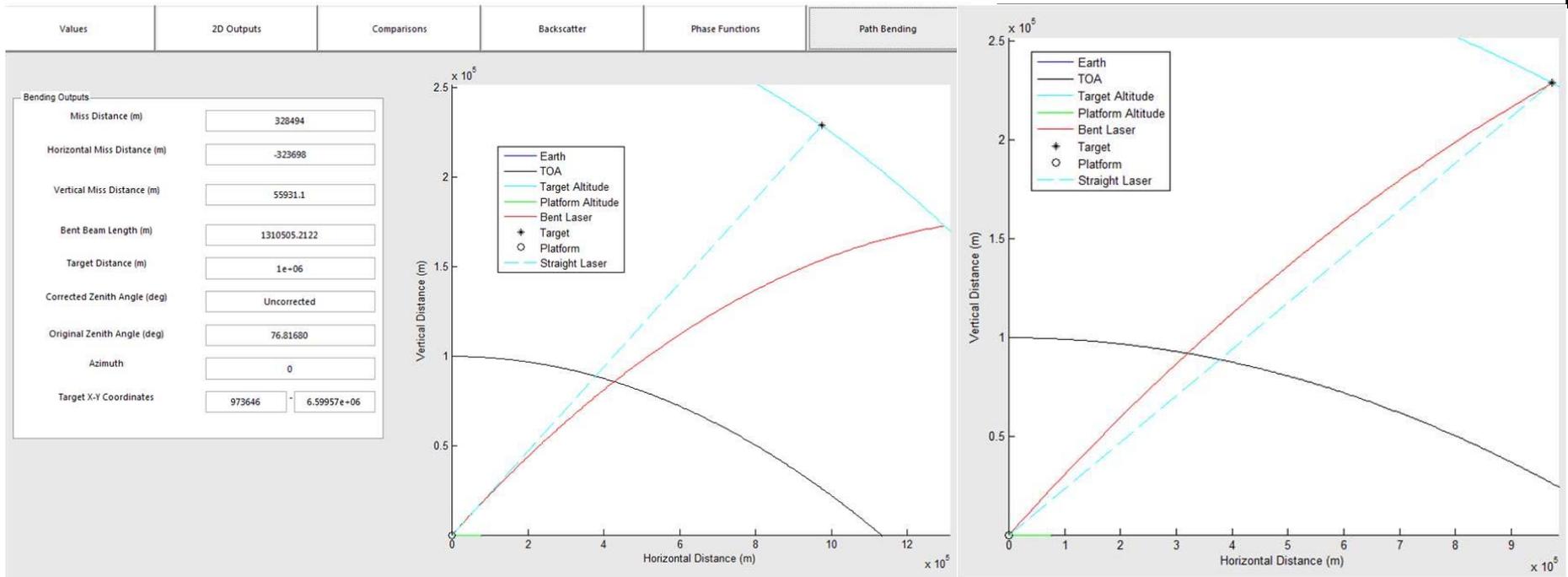
Realistic Atmospheric Refractivity Profiles



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Displaced Path
Calculate actual path of laser when aimed at endpoint

Point to Point
Apply atmospheric compensation correction to improve aim, hit endpoint

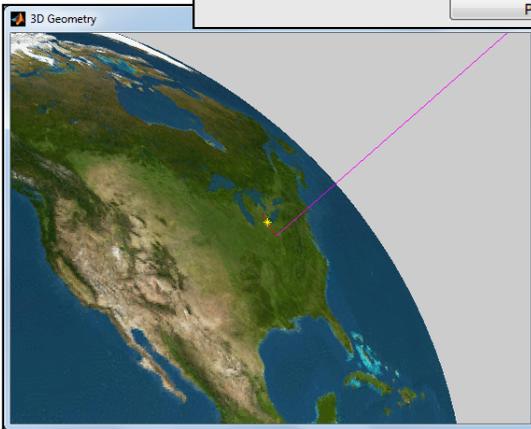
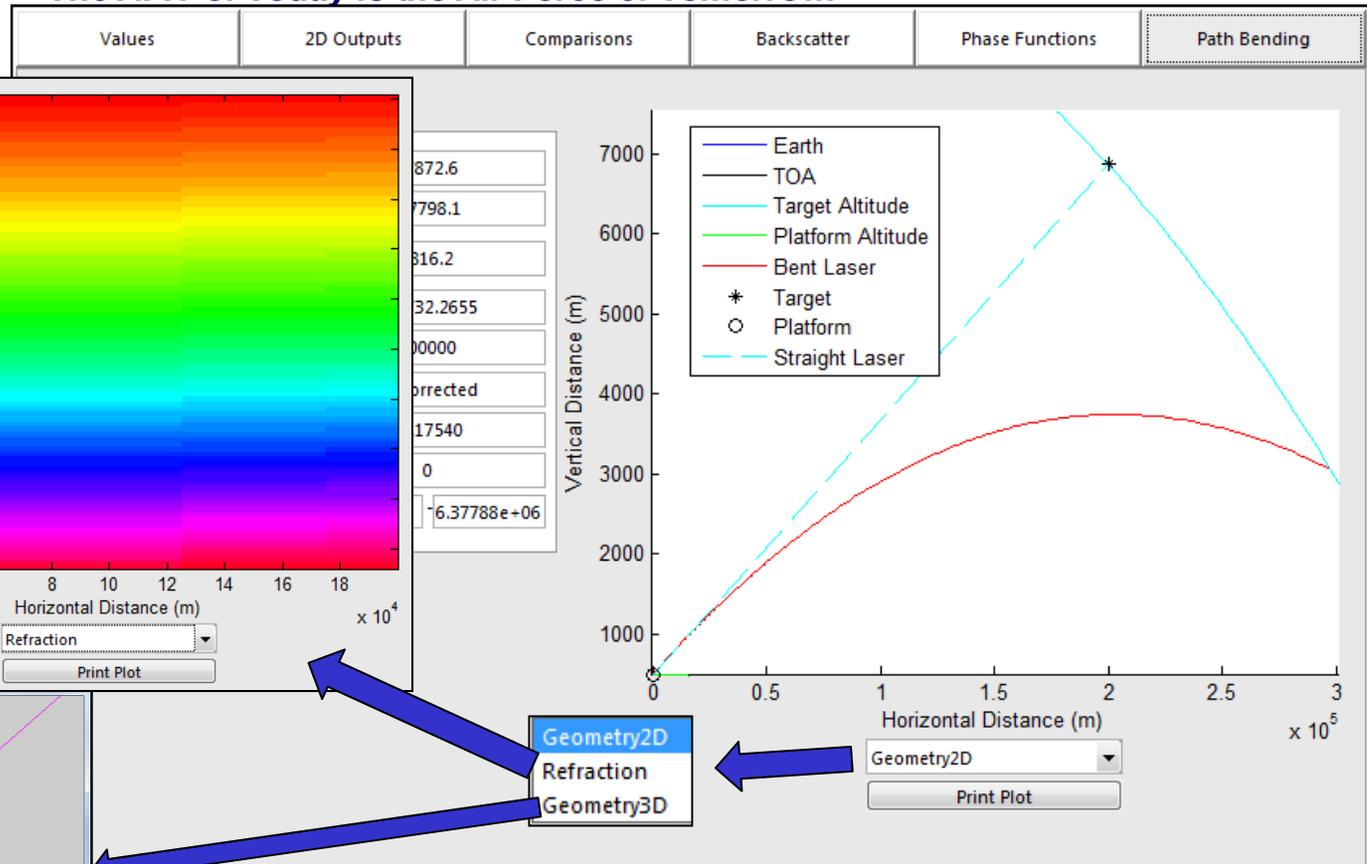




Atmospheric Profile Production Outputs



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- The Refraction plot is helpful to view horizontal atmospheric variations
 - When used in combination with NOMADS, up to 5 nearest neighboring numerical weather grid points may be considered depending on the path geometry



LEEDR Path Radiance GUI



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The screenshot shows the LEEDR Path Radiance GUI with the following sections and values:

- Inputs:**
 - Wavelength: 6e-06 - 2.5e-05
 - Molecular Points: 10
 - Aerosol Points: 10
 - Variation Spacing: 1
 - Use Multi-Scatter:
 - Correlated K:
 - Path: Altitude: 10000, Zenith: 180, Azimuth: 0, Resolution: 50
 - Buttons: Look At Sun, Look At Moon, Calculate
- Surface:**
 - Surface Type: Ocean_Water
 - Albedo Defined From: 2e-07 m to 1.5e-05 m
 - Wavelengths beyond these limits will apply User Emissivity and User Albedo
 - User Emissivity: 1
 - User Albedo: 0.1
 - Temperature: 296
- Date and Time (UTC):**
 - Month: December, Year: 2015
 - Calendar grid showing dates 1-31
 - Hour: 12, Minute: 28, Seconds: 45.999
- Custom Solar Irradiance File:**
 - File name: [Empty]
 - Button: Browse
- Path Type:**
 - Slant Path
- Custom Target Altitude (m):**
 - Value: 100000
 - Button: Reset to Default
- User Sun/Moon Angles:**
 - Enable:
 - Solar Zenith: 0
 - Solar Azimuth: 0

Annotations:

- A blue arrow points from the 'Snow_Cover' dropdown menu (containing options like Forest, Farm, Desert, Ocean, etc.) to the 'Wavelength' input field.
- A blue arrow points from the 'Date and Time (UTC)' calendar to the 'User Sun/Moon Angles' section.
- A text box at the bottom right contains the text: **Important for Solar/Lunar Calculations!**

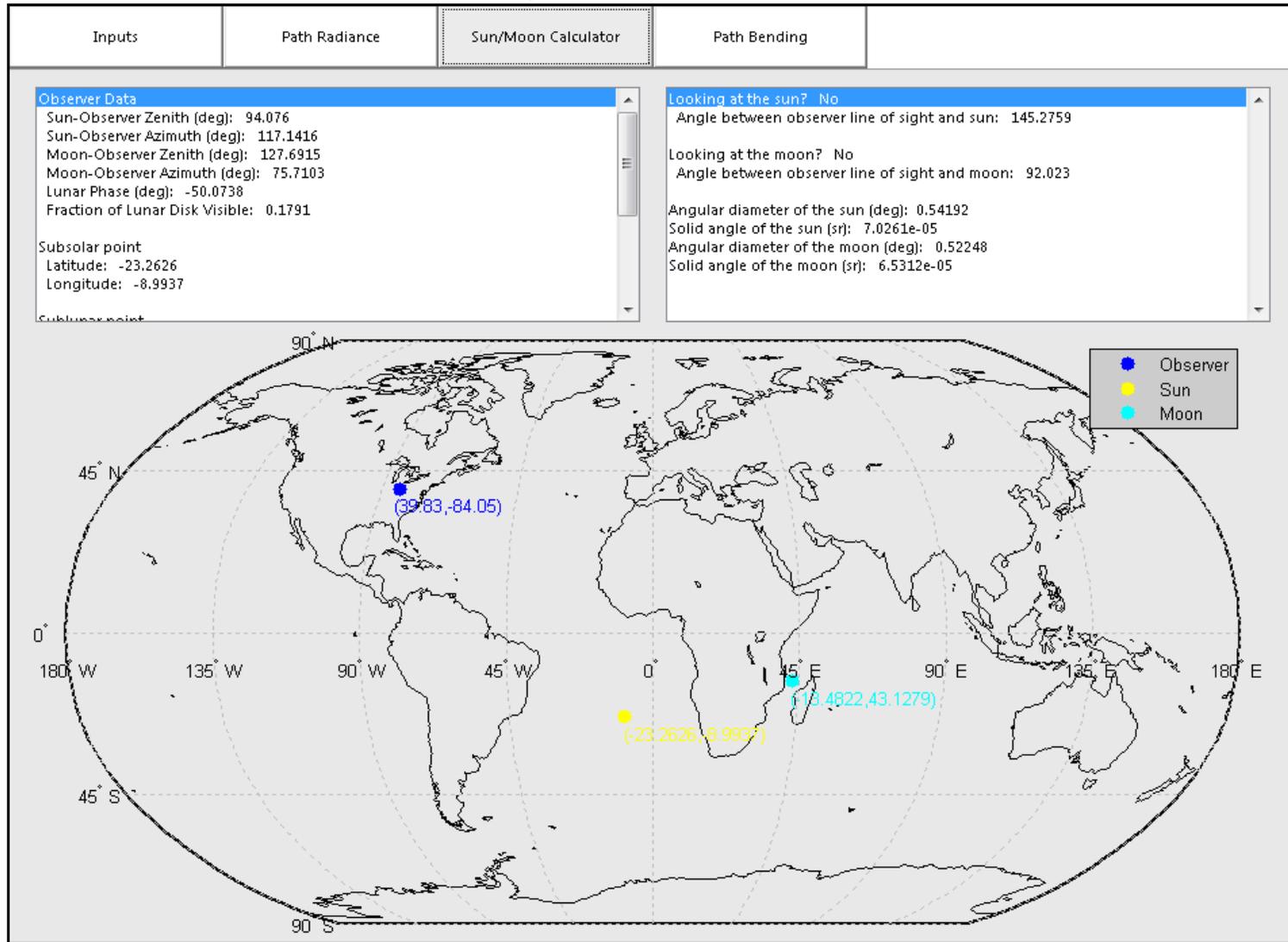


LEEDR Path Radiance GUI

Key Aspect: Earth-Sun-Moon Geometry



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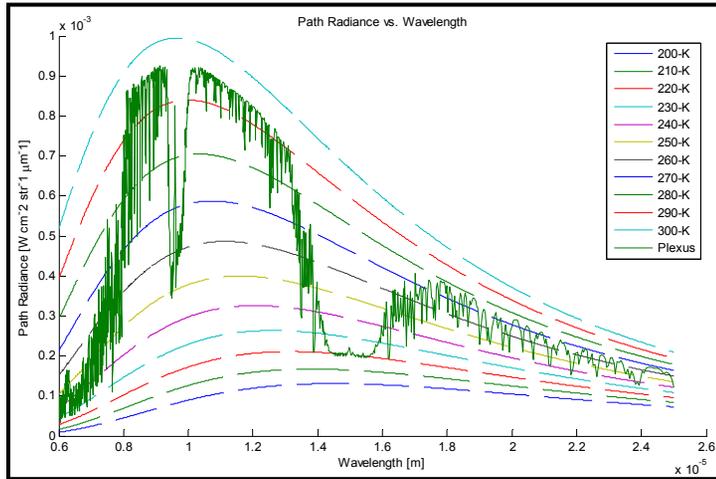


LEEDR Path Radiance

Tailored Derivation / Flexible Solutions

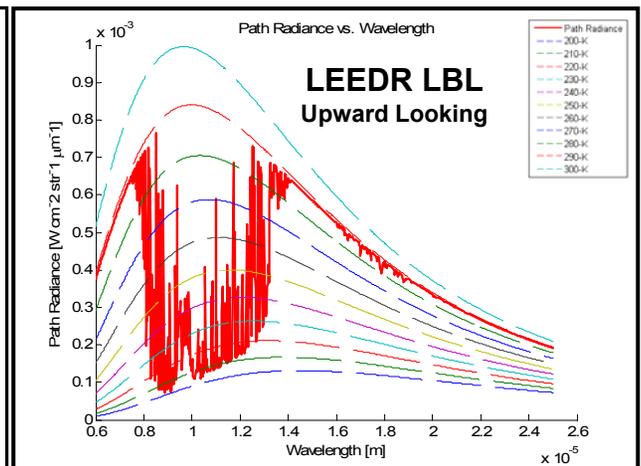
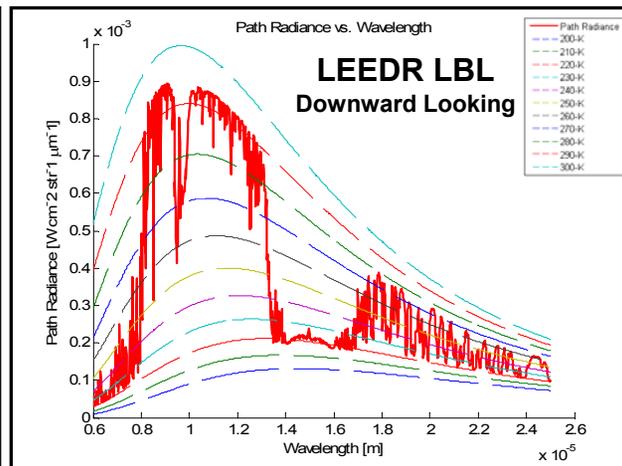
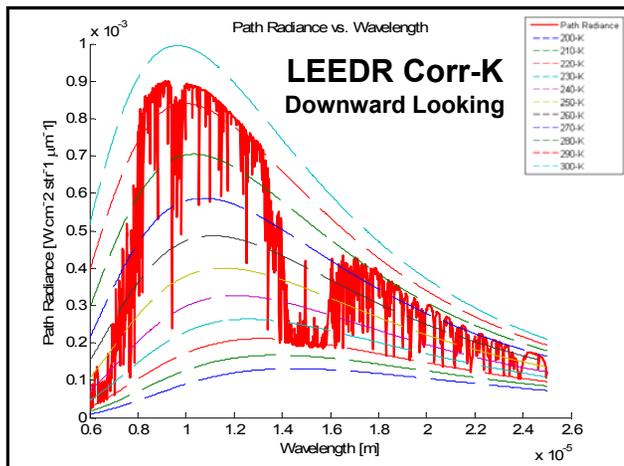
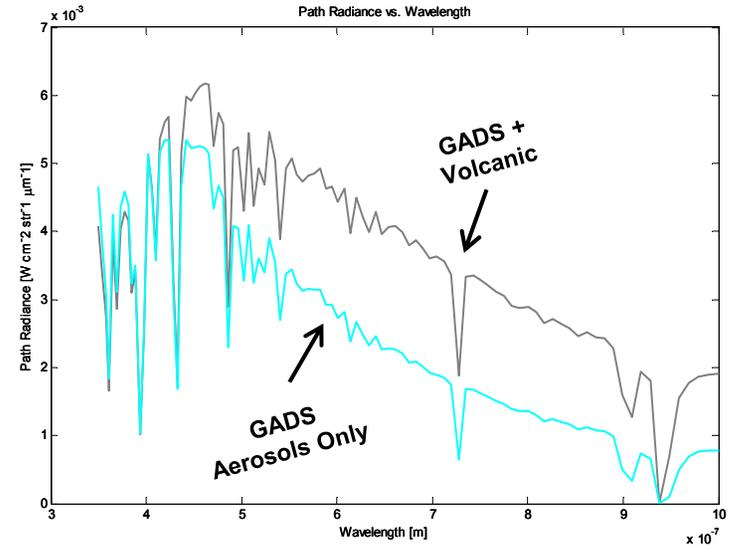


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Upward or downward looking spectral path radiance calculation fully incorporated into LEEDR

- Line-by-line
- Correlated-k
- Multiple scattering
- With / without aerosol effects



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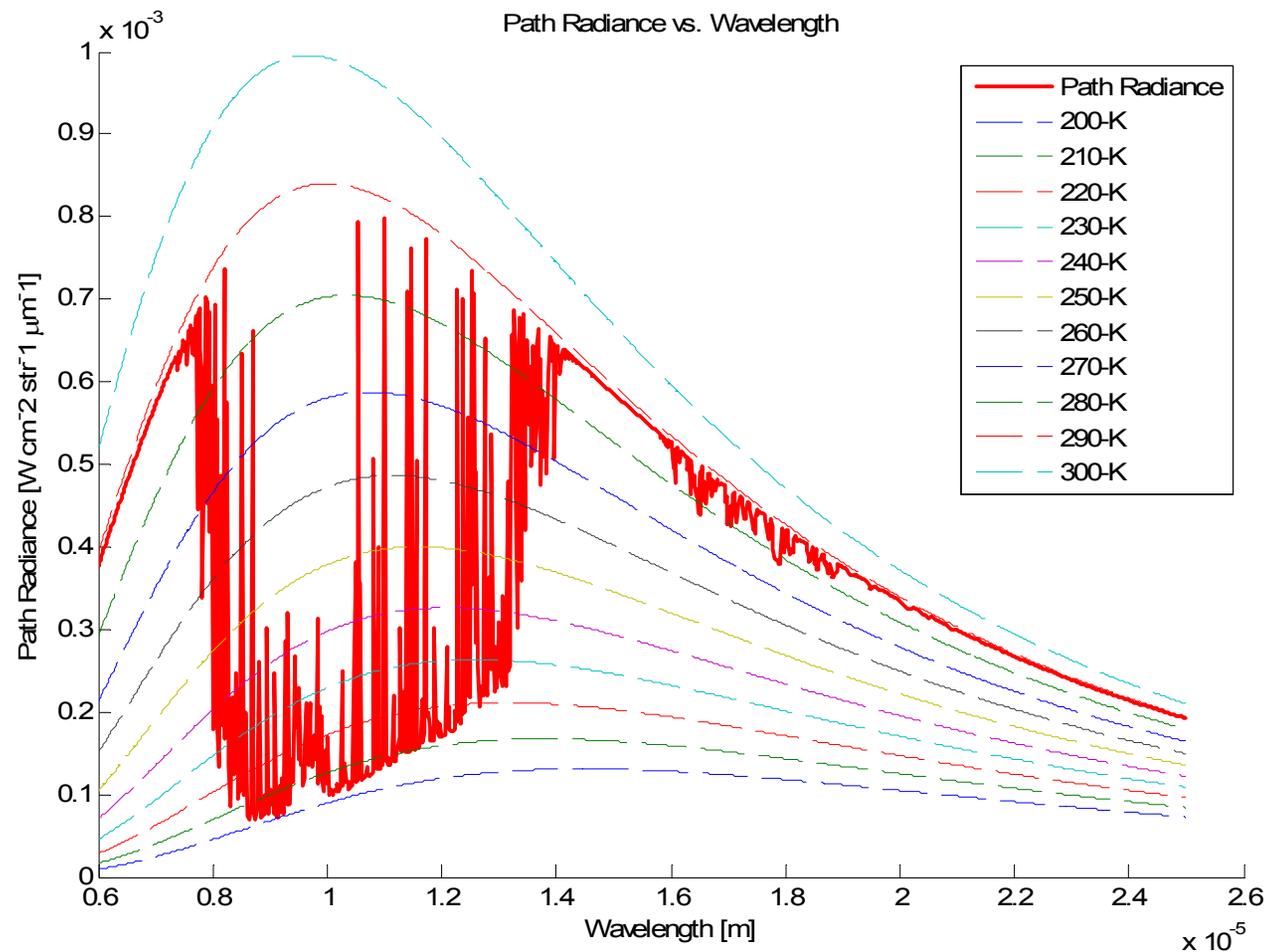
Path Radiance Tab



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➤ Printable Plot
• 1000
molecular
points, 10
aerosol points

➤ Uplooking
radiance from
sky versus
wavelength





LEEDR

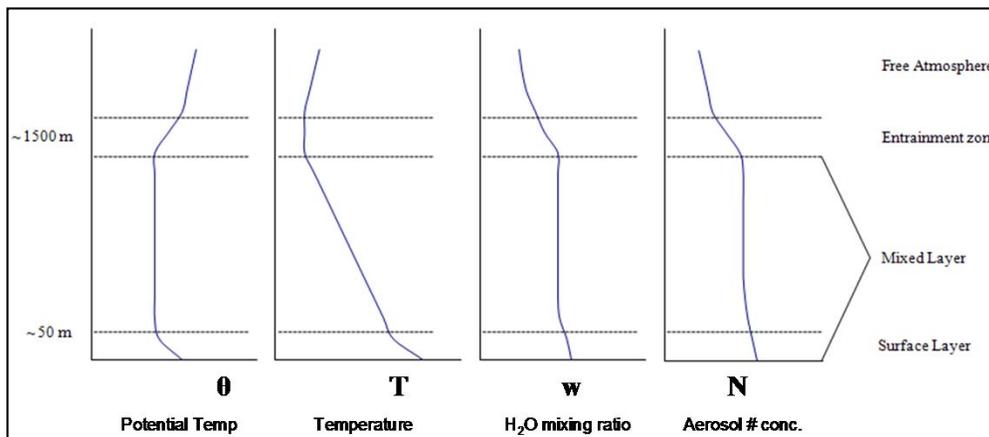


Atmospheric Boundary Layer (BL): Realistic Lapse Rate

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- Description
 - Well mixed layer up to 1.5-2.0 km thick
 - Capped by temperature inversion
- Effects
 - Trap pollutants & aerosols
 - Location of wind shear
 - Atmospheric turbulence (surface layer)
 - Increasing RH & extinction with height



$$\left(\frac{dT}{dz}\right)_{dry} = -\frac{g}{c_p} = -9.8K \cdot km^{-1}$$

Dry adiabatic temperature lapse rate

$$\left(\frac{dT_d}{dz}\right) = -\frac{g}{\epsilon_l v} \frac{T_d^2}{T} \approx -1.8K \cdot km^{-1}$$

Lapse rate of dewpoint temperature

$$\left(\frac{dT}{dz}\right)_{moist} = -\frac{g}{c_p} \frac{1 + l_v w_s / RT}{1 + l_v^2 w_s / c_p R_v T^2}$$

Moist (saturated) lapse rate

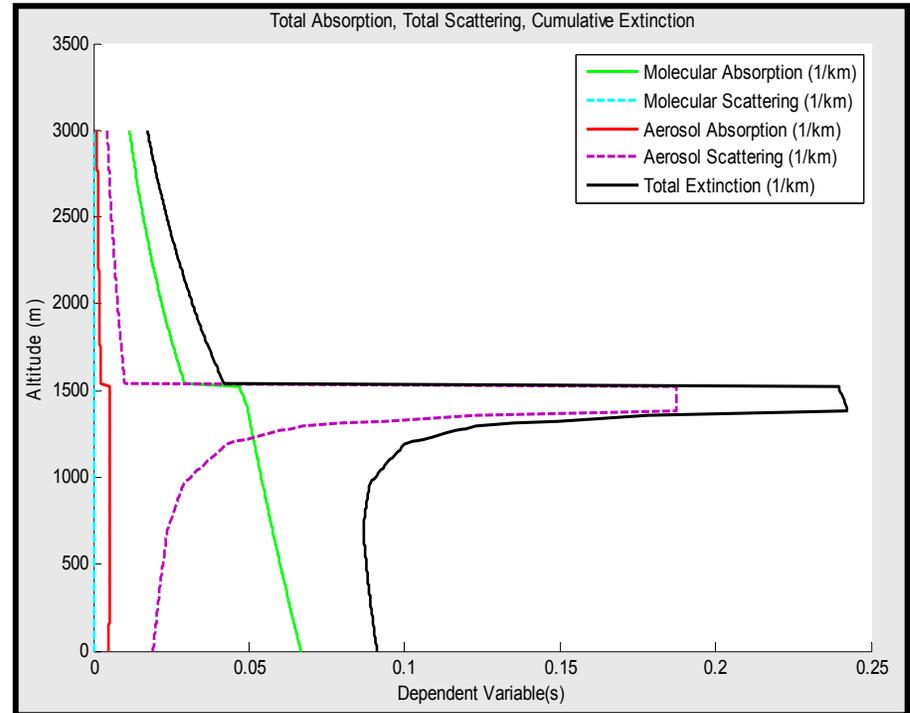
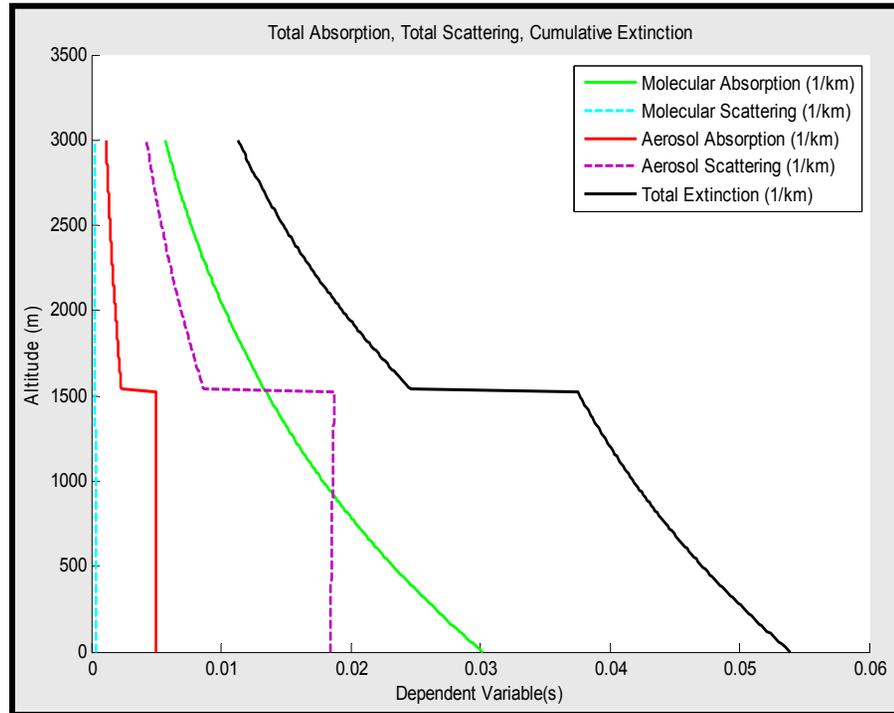


LEEDR

Standard vs Realistic Extinction Profiles



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Left panel: Absorption and scattering effects on 1.31525 μm radiation over a 6000 m slant path from 3000 m altitude to the surface in a US Standard Atmosphere where the boundary layer is only defined with a constant aerosol concentration through the lowest 1524 m. Right Panel: Same slant range geometry as the left panel, but for a Wright-Patterson AFB summer atmosphere at 1500-1800 local time where the boundary layer is defined by constant aerosol concentrations.



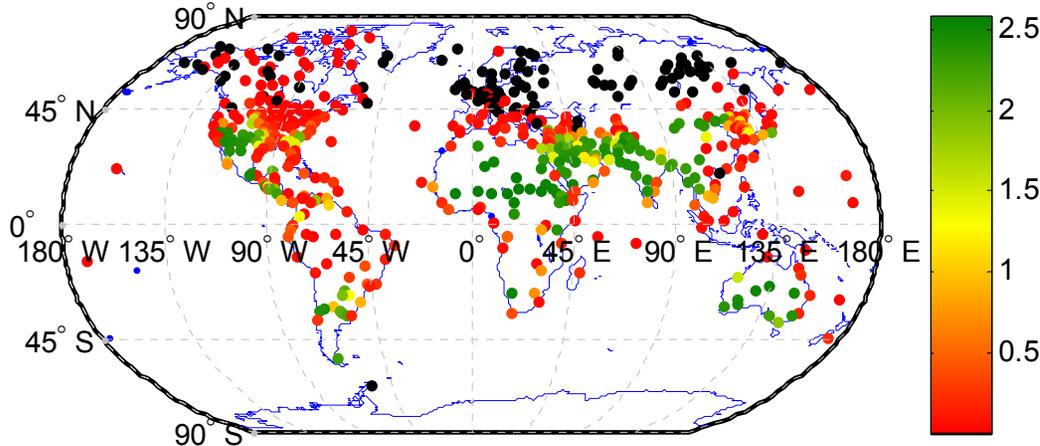
LEEDR Realistic Atmospheres

The Impact of Elevated Aerosol Extinction

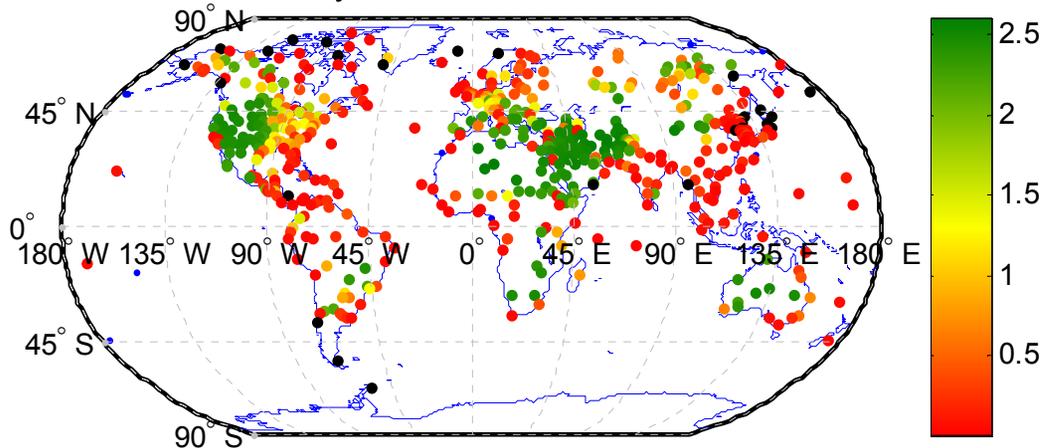


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Irradiance Ratio: January, 20-1500m Altitudes, 5km Slant Path



Irradiance Ratio: July, 20-1500m Altitudes, 5km Slant Path



- Ratios of HEL irradiance; realistic aerosol environment over standard environment
 - Std: US Std Atm with 23km Modtran Rural aerosols
- Realistic conditions at land sites are in general worse than standard in terms of DE propagation

Fiorino, Shirey, Via, Grahn, and Krizo, 2012 'Potential Impacts of Elevated Aerosol Layers on High Energy Laser Aerial Defense Engagements'. Proc. of SPIE Vol. 8380 83800T



LEEDR Realistic Atmospheres

Atmospheric Profile Inputs

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Location Atmosphere Clouds/Rain Laser/Geometry Ground Level

CHRISTCHURCH

Location Type: EXPERT Lat/Lon

Current EXPERT Site: COTONOU

Site Name: COTONOU

Latitude: 6.35

Longitude: 2.38

Sodium Overlay: Turn off Alpha Back None

ADD THIS OVERLAY TO THE MAP VERY SLOWLY

Location Atmosphere Clouds/Rain Laser/Geometry Ground Level

Atmosphere: Nomads

Date Selector: [Date]

Cycle: 0 Time: 0

May 2015						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Aerosols: GADS

Volcanic: None Summer Moderate Summer High Summer Extreme Winter Moderate Winter High Winter Extreme

Settings: Use Correlated-K? (km) Surface Visibility: [] (m) Boundary Layer: 500 1000 Layers

Wind: Climatological

Turbulence: HV 5/7 Multiplier: 1

Molecular: Use Excel Please Select a File Browse

LEEDR can create a realistic atmospheric profile and put it into an Excel file for use in other programs (i.e. HELEEOS, MODTRAN, HELCoMES, other M&S codes)



LEEDR Realistic Atmospheres

Numerical Weather Forecast Input



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- Use NOMADS to obtain GFS numerical weather data in combination with Climo aerosols and turbulence to mirror a more Real-Time, realistic atmosphere.
 - NOMADS = NOAA National Operational Model Archive & Distribution System
 - <http://nomads.ncdc.noaa.gov/>
 - GFS = Global Forecast System

Real Time Weather!

Atmosphere

Nomads

Date Selector

Output Excel File

Cycle: 0

Time: 0

<		January					2016		>	
S	M	T	W	T	F	S				
					1	2				
3	4	5	6	7	8	9				
10	11	12	13	14	15	16				
17	18	19	20	21	22	23				
24	25	26	27	28	29	30				
31										





Methodology



Ingest Numerical Wx Prediction and Remote Sensor Data

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Upgrade radiative transfer code tools
(e.g. Path Bending, Path Radiance)

- Initial state: climo-based effects

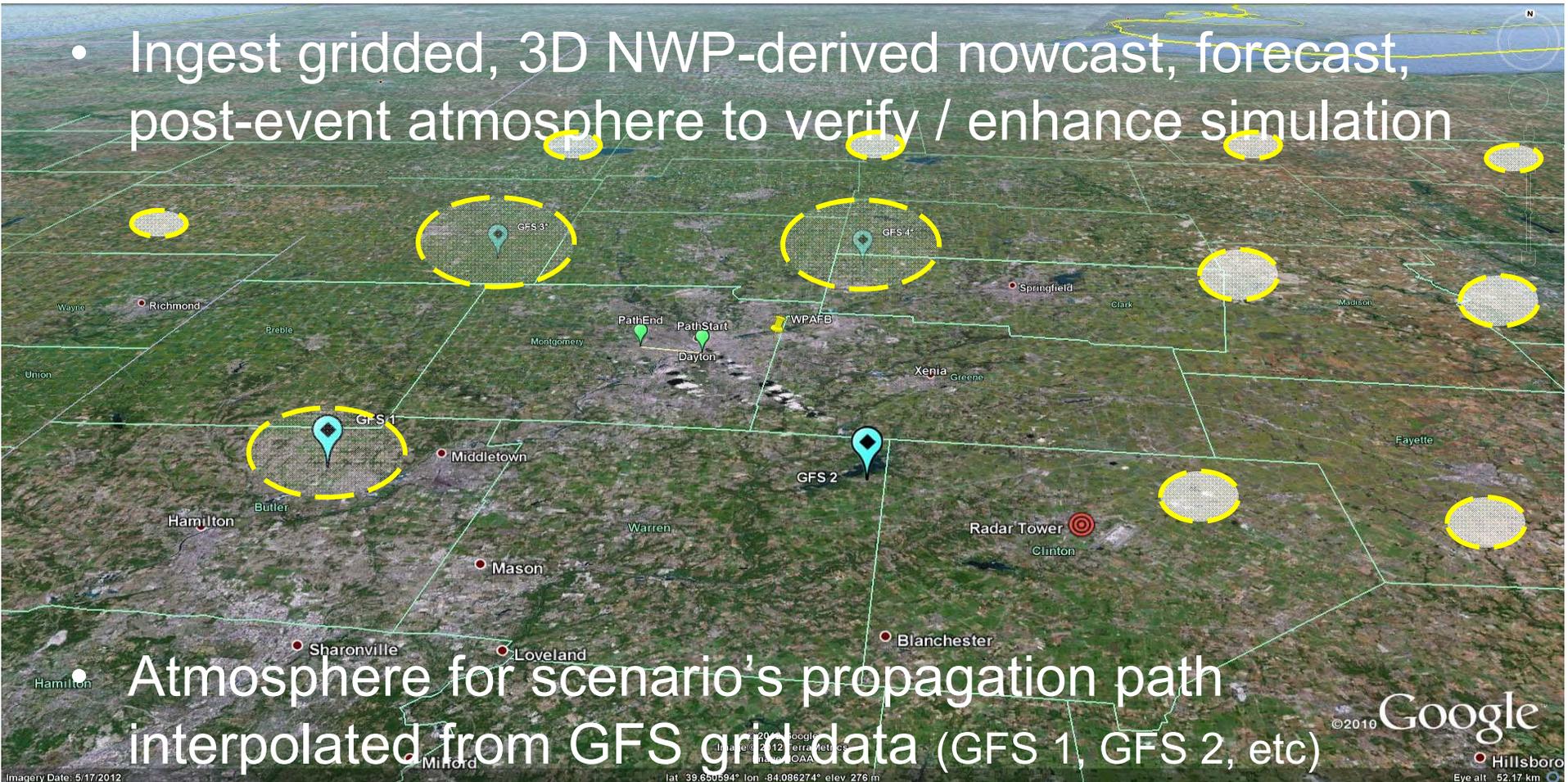
Integrate gridded numerical **Wx** forecast data and remote sensor profiles

Evaluate / compare atmospheric characterization methods

Optimize Path Bending / Radiance code

Evaluate impact : Remote sensing and Directed Energy Propagation Applications

- Ingest gridded, 3D NWP-derived nowcast, forecast, post-event atmosphere to verify / enhance simulation



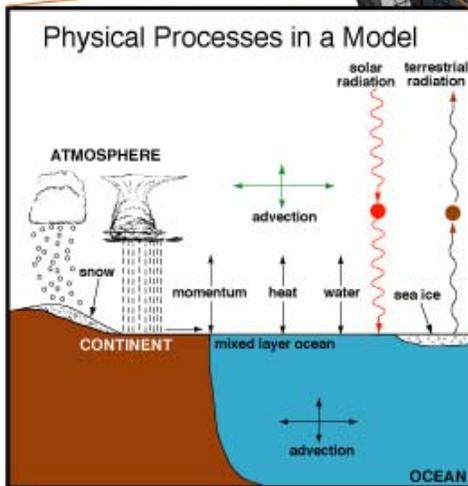
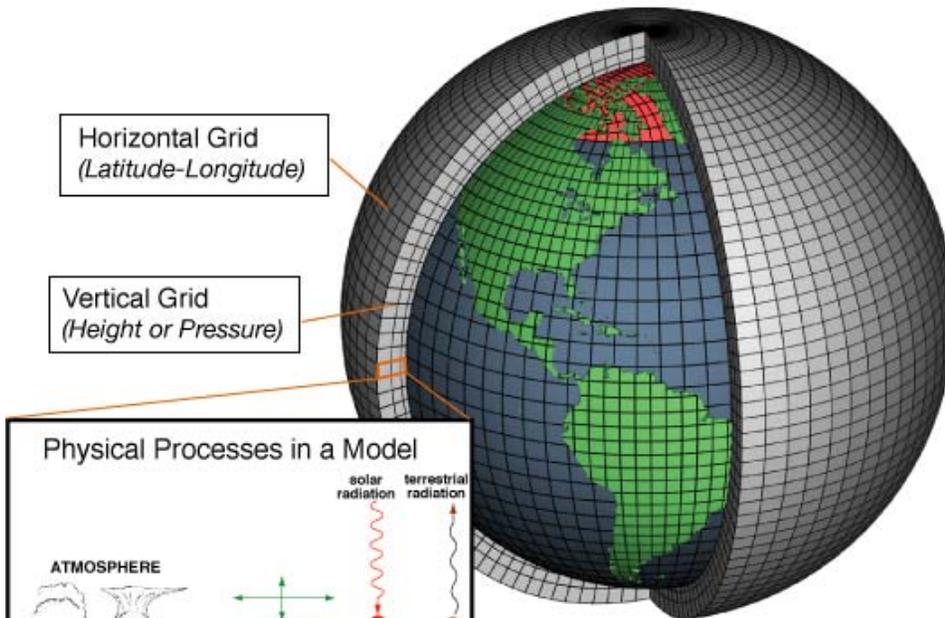


Numerical Weather Prediction (NWP) Models for Gap Filling

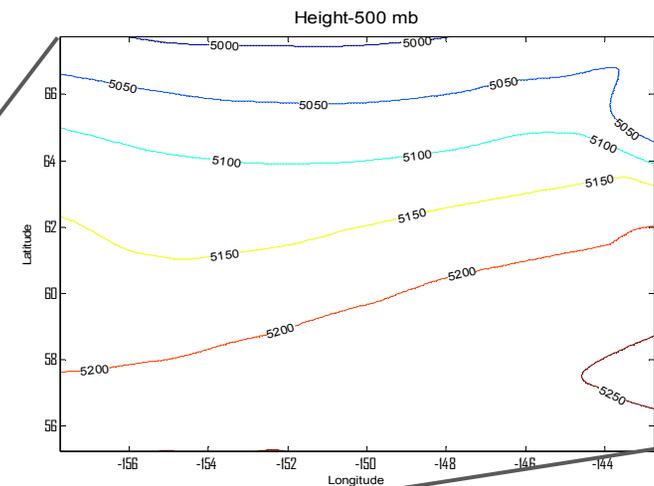
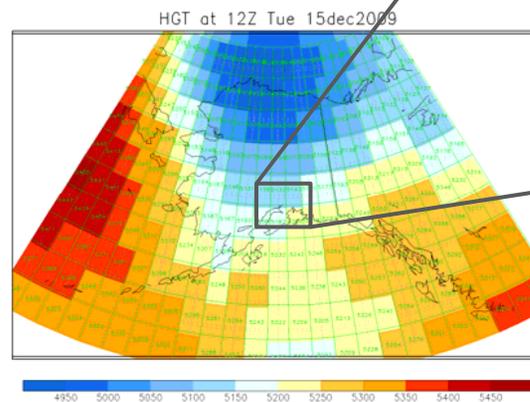


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- Global Forecast System (GFS)
- Global 3-D gridded GFS data available with 0.5 deg horizontal resolution, and 3-hour time increments



NOAA Website [Online]
http://celebrating200years.noaa.gov/breakthroughs/climate_model/

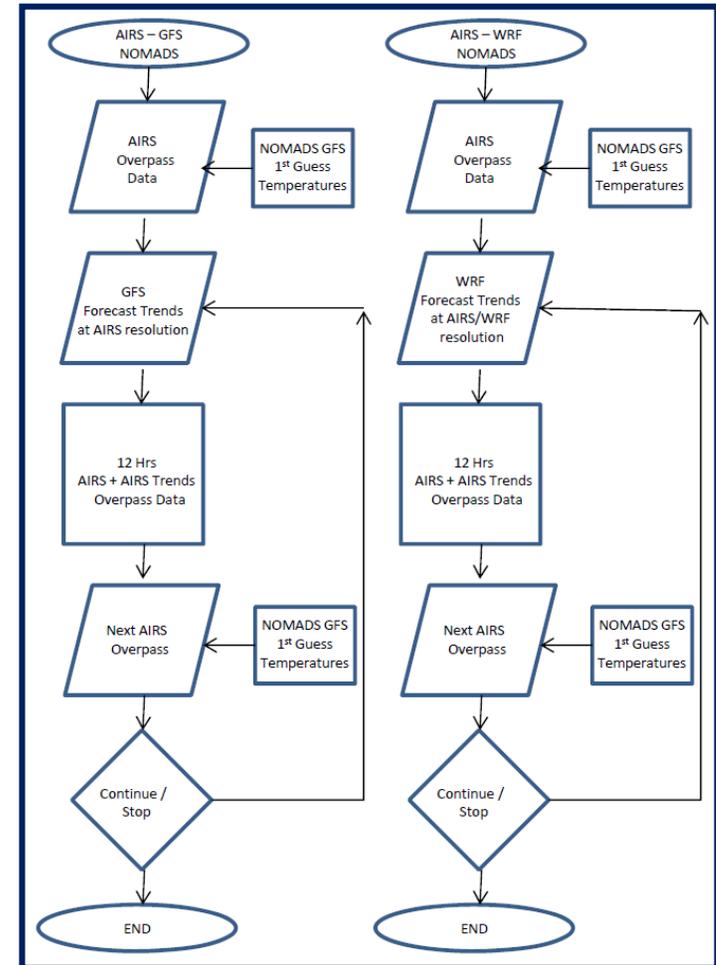
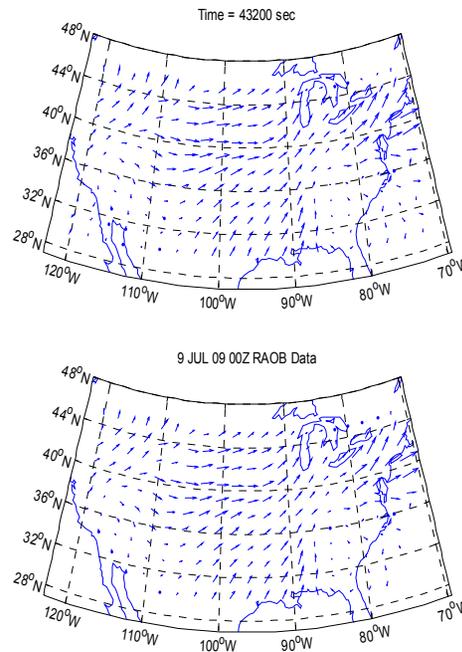
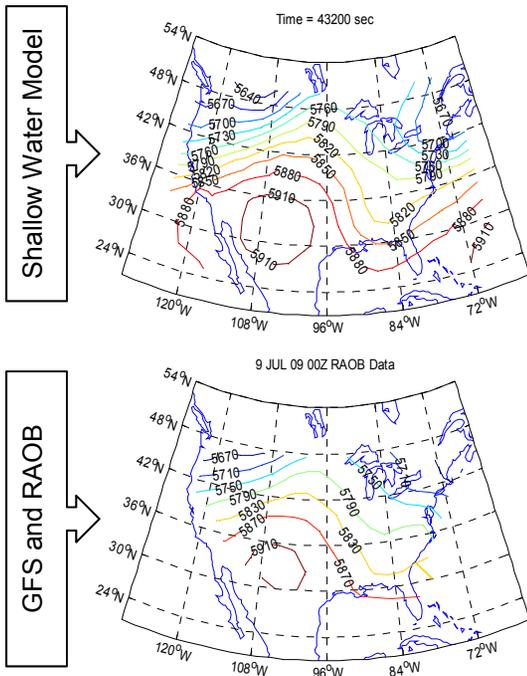


Gap Filling with NWP

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- Simple weather model initialized with gridded GFS data and rawinsonde observations
- Model runs at 1-min time-step for next 12 hours



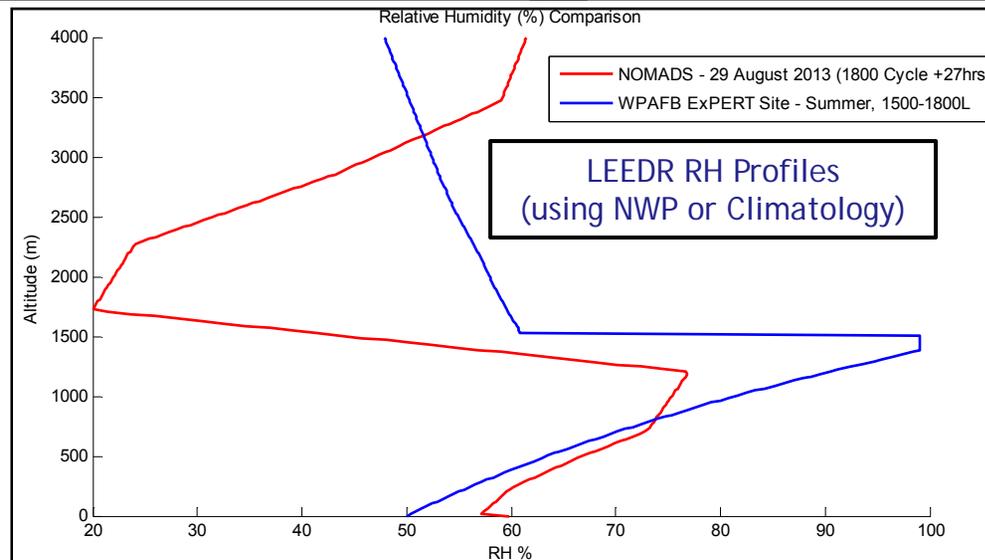
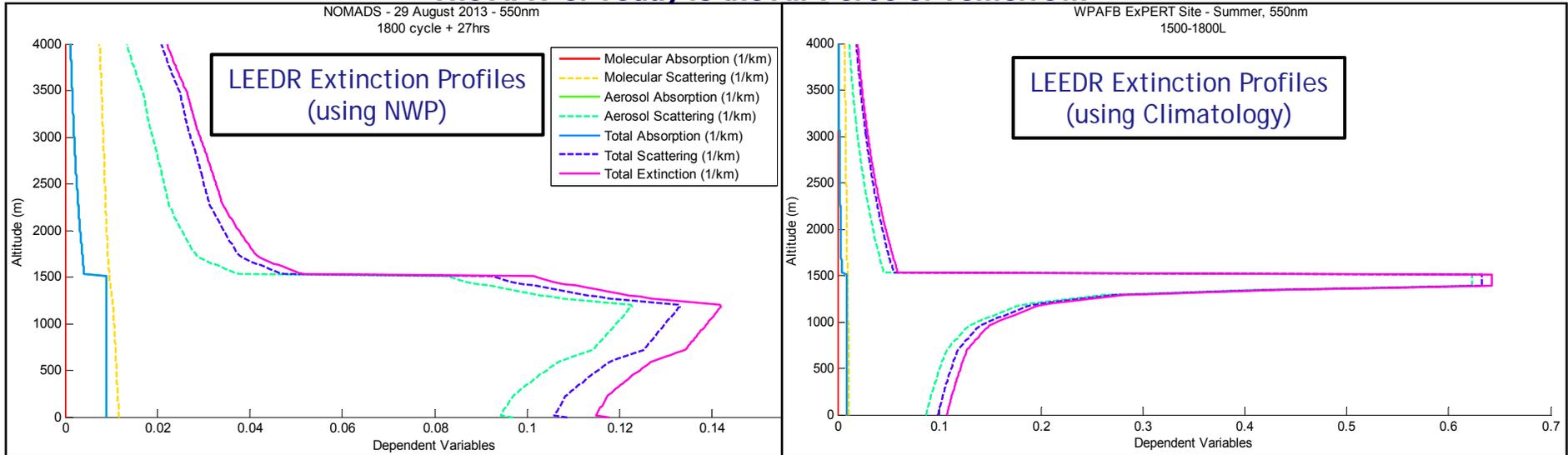


NWP Impact

Extinction / RH Comparisons



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Ground-Based LIDAR

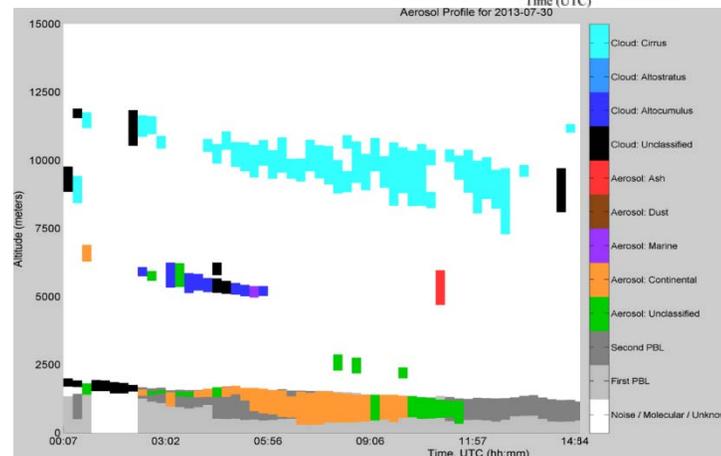
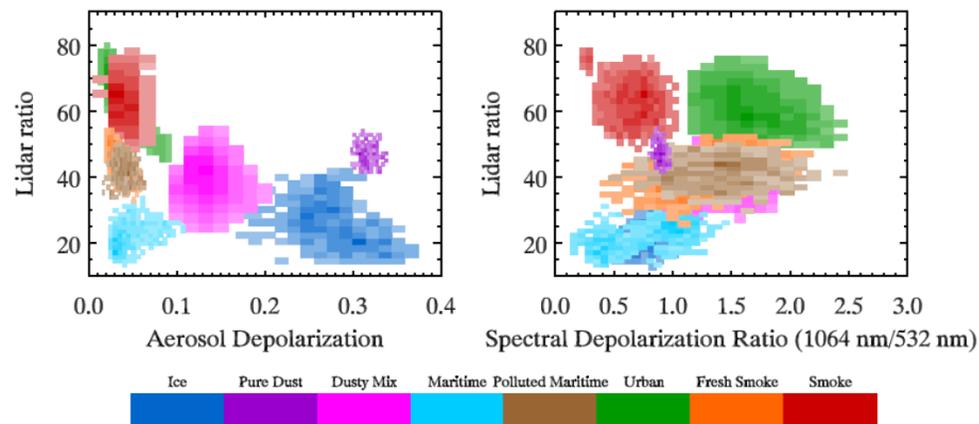
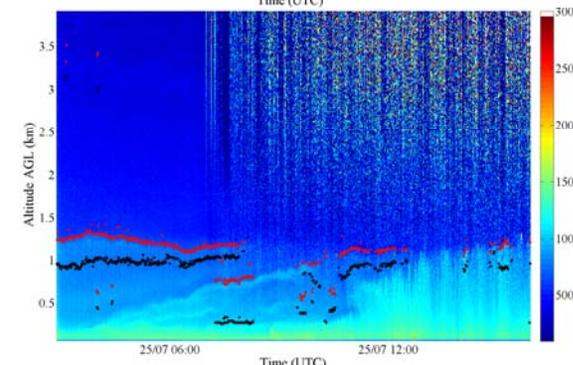
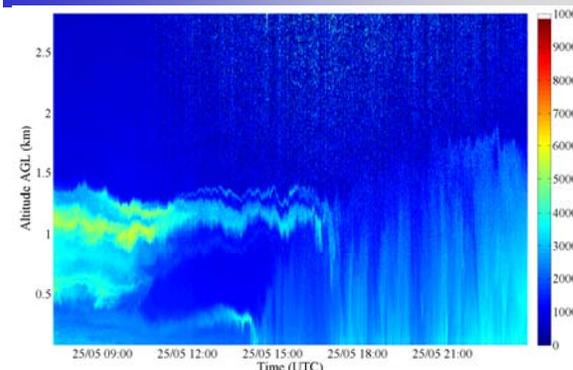
AFIT's R-MAN 510



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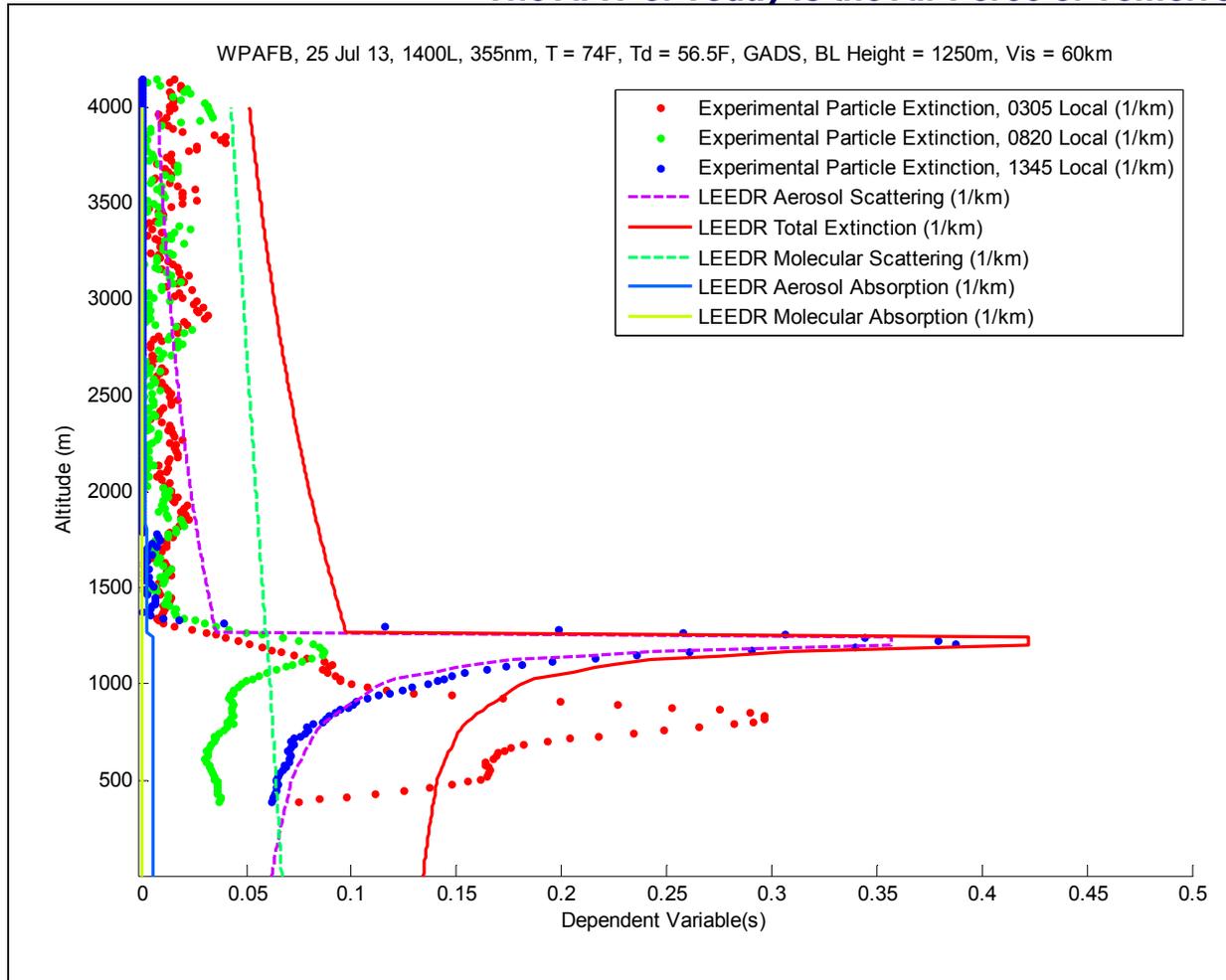
- Diode Pumped Tripled Nd:YAG
- Parallel / Cross channels (355 nm)
- Nitrogen Raman Channel (387 nm)
 - 355 nm light backscatters at 387 nm, to find total extinction
 - Record LIDAR ratio for aerosol classification
- ~21 km cloud ceiling
 - ~2 km aerosol ceiling during day
 - ~12 km aerosol ceiling during night



S. T. Fiorino, C. Rice, K. Keefer and M. Via, "LIDAR Validation Experiments of LEEDR Aerosol Boundary Layer Characterizations," in *Directed Energy Professional Society - Annual Directed Energy Symposium*, Huntsville, AL, 2014.

Example Extinction Plot – WPAFB Validation

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➤ Example LEEDR plot using a BL height of 1250 m at WPAFB ExPERT site, GADS summer aerosols, visibility of 60 km, and surface conditions for WPAFB for 25 Jul 13 at 1400L (T = 23°C, T_d = 13 °C) vs. measurements from the roof of Bldg 640 conducted with a lidar operating at 355 nm



The Importance of a Well-Mixed BL

Measured vs LEEDR-Modeled Path Radiance



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The October 2015 edition of the *Bulletin of the American Meteorological Society* contains an article on a Multi-Institutional, Student-Led, Lower Atmospheric Boundary Layer Experiment (LABEL) conducted at the Southern Great Plains site in Oklahoma. The AERI-measured downwelling infrared radiance data [See Figure SB1 below] is used to compare LEEDR results using Global Forecast System (GFS) data with a well-mixed Boundary Layer (BL). LEEDR provides users the capability to input surface observations to accurately characterize the BL.

LABLE: A Multi-Institutional, Student-Led, Atmospheric Boundary Layer Experiment

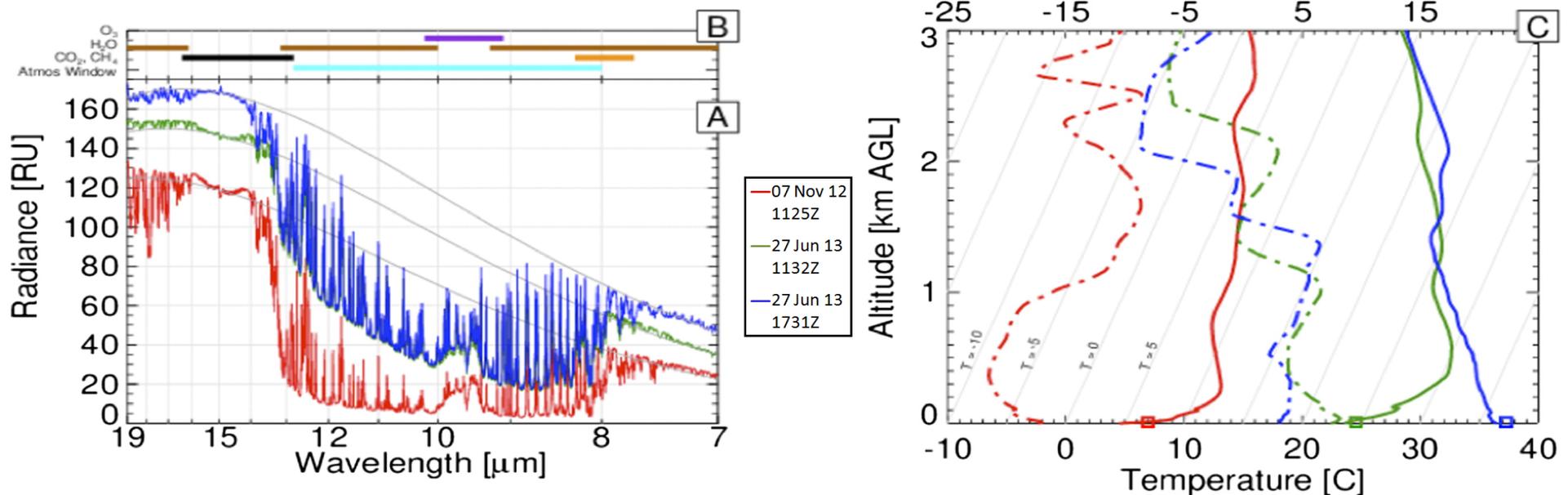


Figure SB1.

P. Klein, T. A. Bonin, J. F. Newman, D. D. Turner, P. B. Chilson, C. E. Wainwright, W. G. Blumberg, S. Mishra, M. Carney, E. P. Jacobsen, S. Wharton, and R. K. Newsom, 2015: LABEL: A Multi-Institutional, Student-Led, Atmospheric Boundary Layer Experiment. *Bull. Amer. Meteor. Soc.*, **96**, 1743–1764. doi: <http://dx.doi.org/10.1175/BAMS-D-13-00267.1>



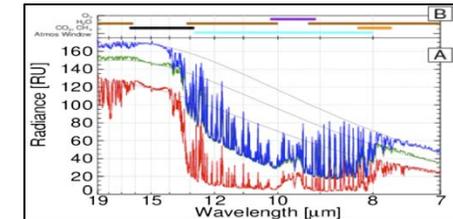
The Importance of a Well-Mixed BL

Measured vs LEEDR-Modeled Path Radiance



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In general, LEEDR defines the well-mixed atmospheric boundary layer (BL) with a worldwide, probabilistic surface climatology that is based on season and time of day and, then computes the radiative transfer and propagation effects from the vertical profile of meteorological variables. The LEEDR user can also directly input surface observations or use numerical weather prediction (NWP) data to create a near real-time atmospheric profile.” (JAMC, 2014).

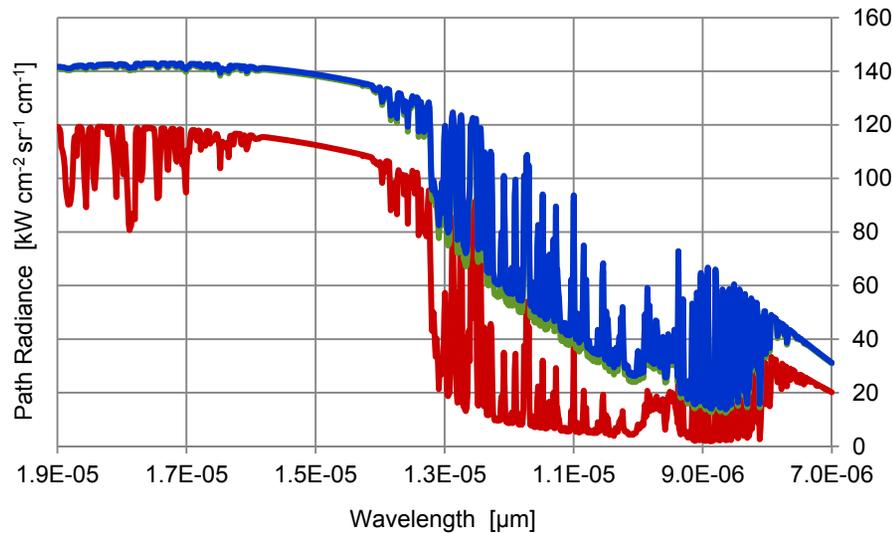


AERI Measured Downwelling Infrared Radiance

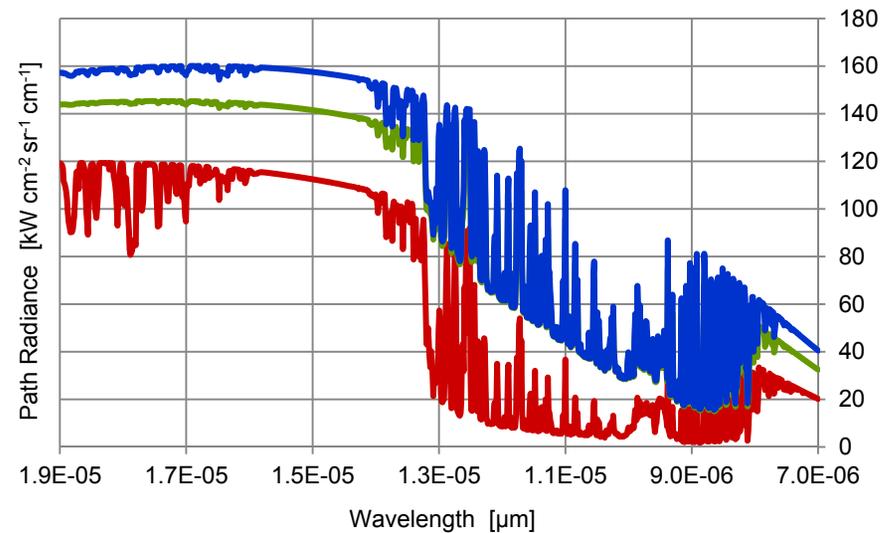
- 07 Nov 12 1125Z
- 27 Jun 13 1132Z
- 27 Jun 13 1731Z

The plots shown below display the significance of using surface observation inputs during LABEL in conjunction with Global Forecasting System (GFS) data, validating LEEDR’s ability to model atmospheric effects and radiative transfer processes.

LEEDR using GFS – Without a Well-Mixed BL Sfc Conditions Not Included



LEEDR using GFS – With a Well-Mixed BL Sfc Conditions Included



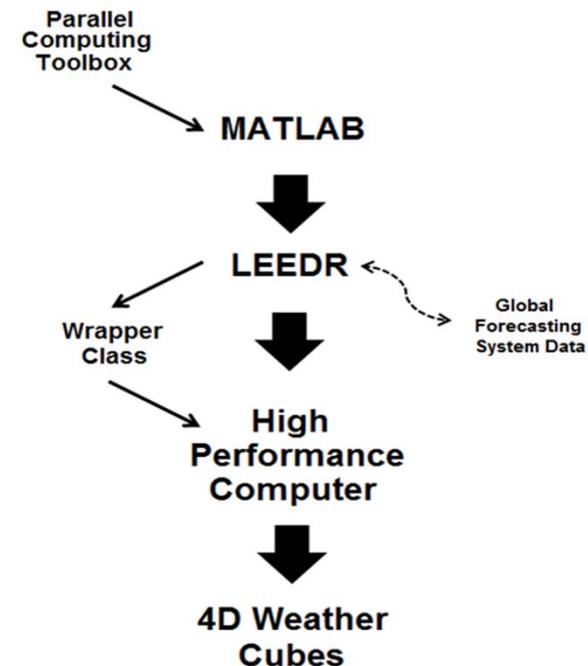


Parallel Computing & Wrapper Class



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- The **Parallel Computing Toolbox** within MATLAB allows for multiple calculations to take place simultaneously, greatly reducing run time. This, paired with a high performance computer, allows computational intensive problems to be split into manageable sections for each processor. The limiting factor to the number of calculations executed in parallel becomes the number of processors available.
- Based on user-defined outputs, a decision is made within the wrapper class as to which calculations are necessary and proceeds to parallelize their execution. General capabilities of the **wrapper class** include setting any LEEDR specific option for various locations and allowing the user to visualize some of LEEDR's most popular outputs such as total extinction or optical turbulence, C_n^2 .





Parallel Computing & Wrapper Class



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- MATLAB: parallel computing toolbox (threading)
- LEEDR wrapper class
- Cluster vs. Spirit, Excalibur, or Copper
 - Cluster runtime: 20 sec. - 2 min. for 25 locations ($\frac{1}{2}$ deg. grid)
 - World extrapolation: ~8hrs – 2 days
 - Spirit and/or Excalibur run time:
 - World extrapolation: **seconds**
 - Copper runtime:
 - World extrapolation: 1 – 5 min.

	Cores	Time
Cluster	7	approx. 8hrs - 2 days
Supercomputer ¹	36720	seconds

¹Air Force Research Lab Spirit Supercomputer
 Runtime Comparison for 260,281 Calculations

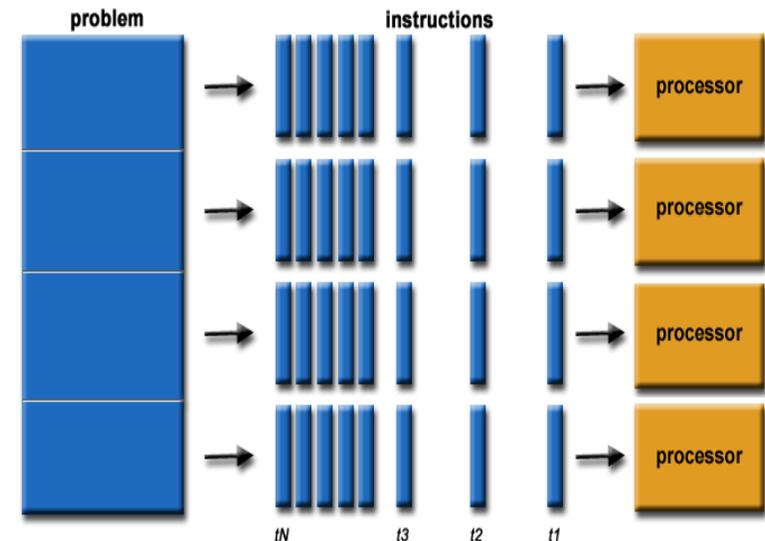


Image courtesy of Blaise Barney
 Lawrence Livermore National Laboratory



4D Weather Cubes



The AFIT of Today is the Air Force of Tomorrow.

The 4D Weather Cube simulations allow for visually stunning and realistic-looking visible-spectrum images to accurately translate to propagation and atmospheric effects outside of the visible spectrum via Air Force Institute of Technology (AFIT)/Center for Directed Energy's LEEDR physically-based atmospheric characterization model output.

- Created the thermodynamic conditions specified in each scenario by applying **numerical weather prediction model data** (Global Forecast System) **with microphysical & optical properties characterizations** for the clouds, rain, and aerosols from LEEDR.

Clouds, precipitation, and aerosol haze effects are shown as people see them will be captured at wavelengths for any electro-optical infrared sensor or microwave/radio frequency tracking/illumination system.



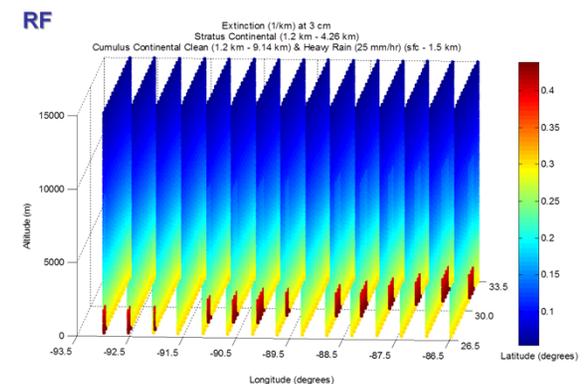
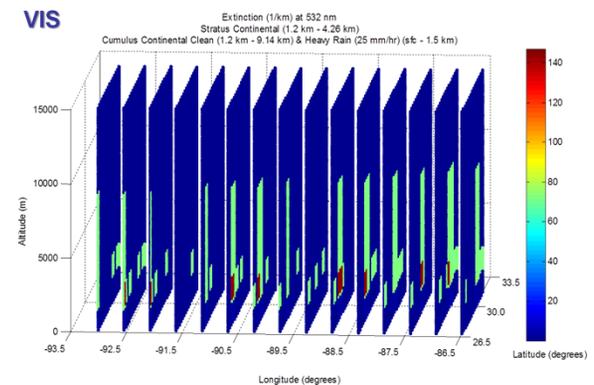
4D Weather Cubes



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The following slides depict the variability of total extinction, the reduction in the intensity of energy due to absorption and scattering as it passes through a given medium, for specific wavelengths ranging from the visible to the radio frequency spectrums for the parameters listed below:

- Location: Volume centered on New Orleans, LA
- Date: August 5, 2015
- Time: 1500 local time
- Weather: A line of thunderstorms present.





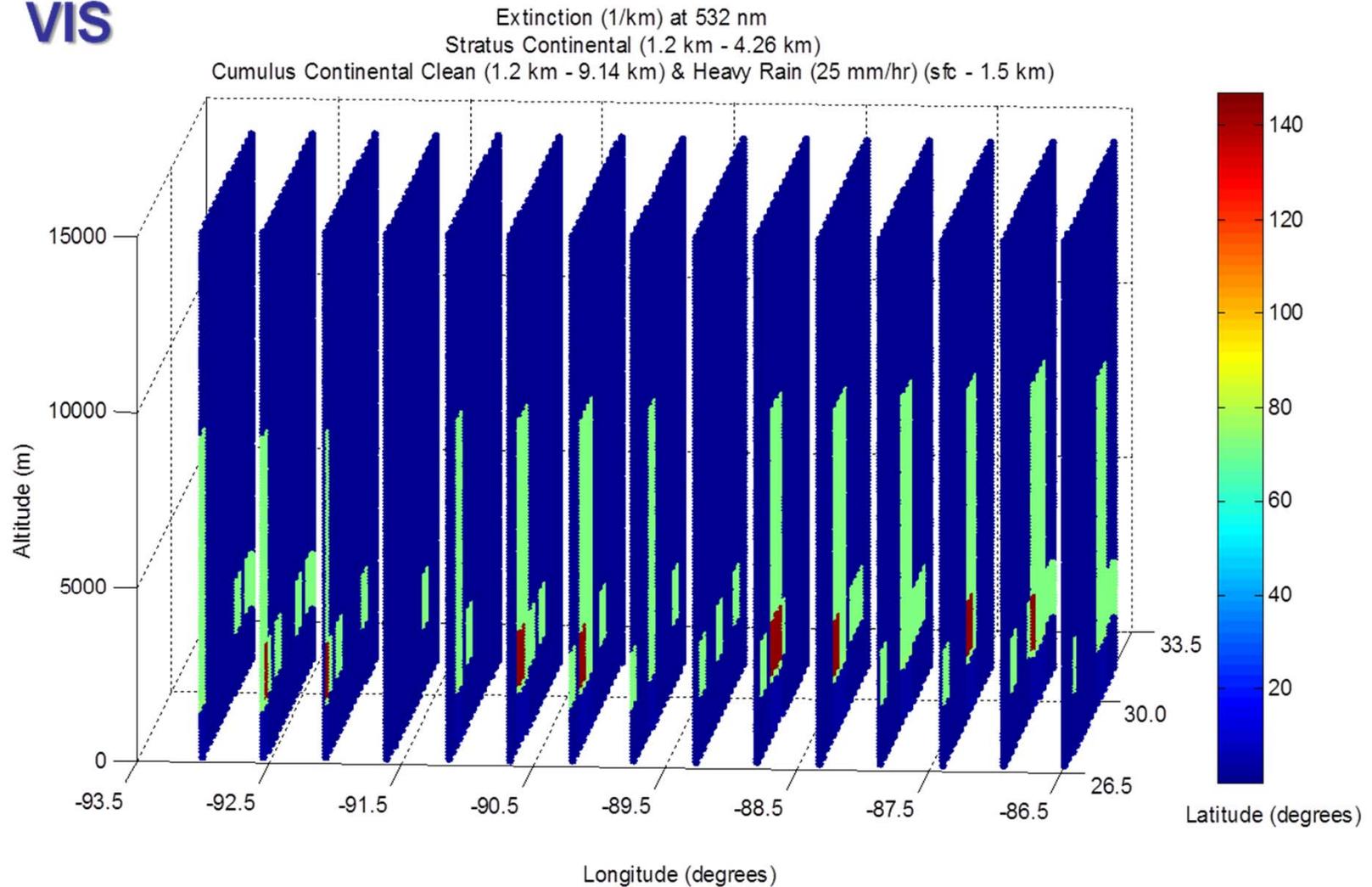
4D Weather Cubes

Extinction at 532 nm



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VIS





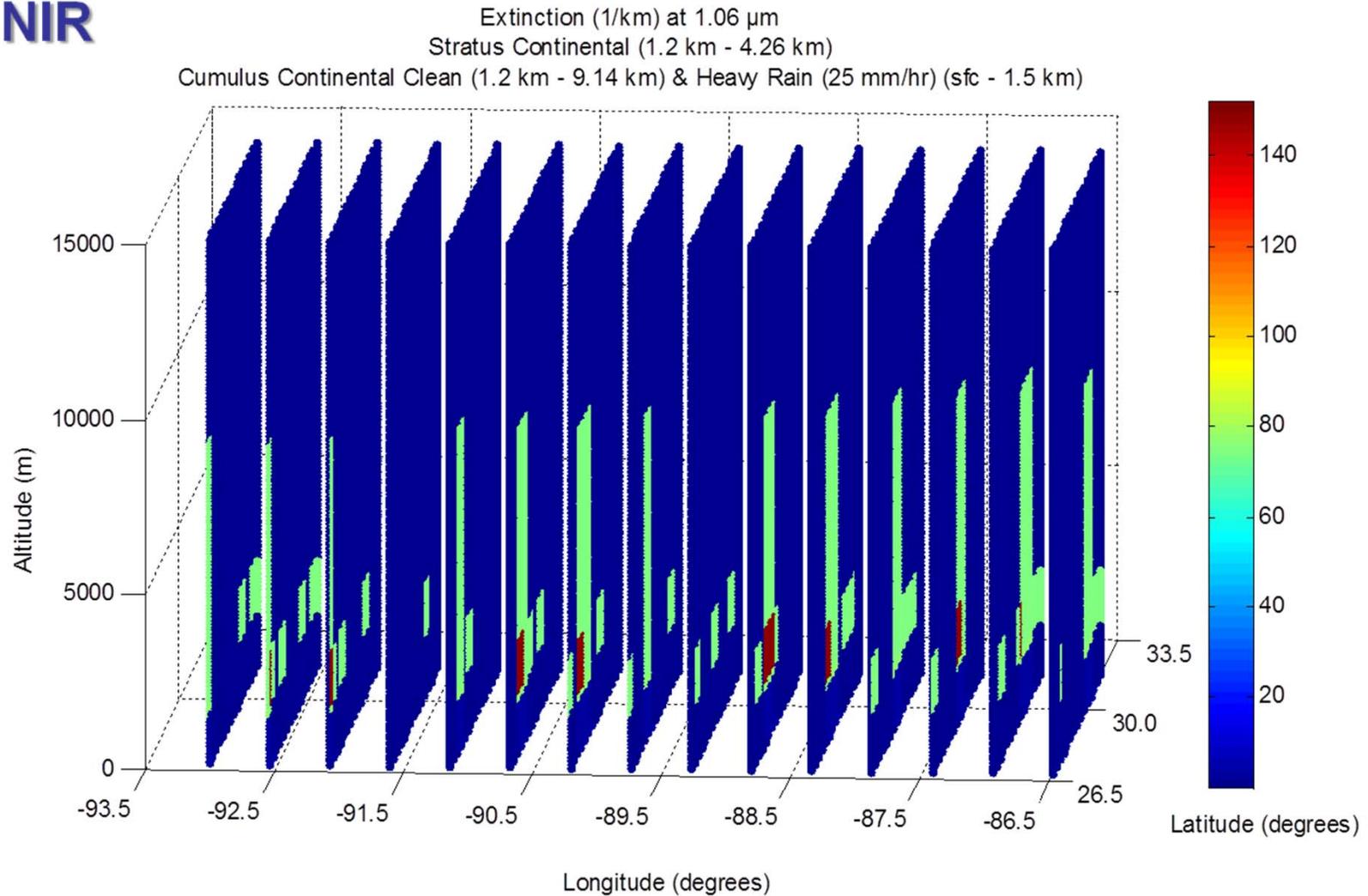
4D Weather Cubes

Extinction at 1.06 μm

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NIR





4D Weather Cubes

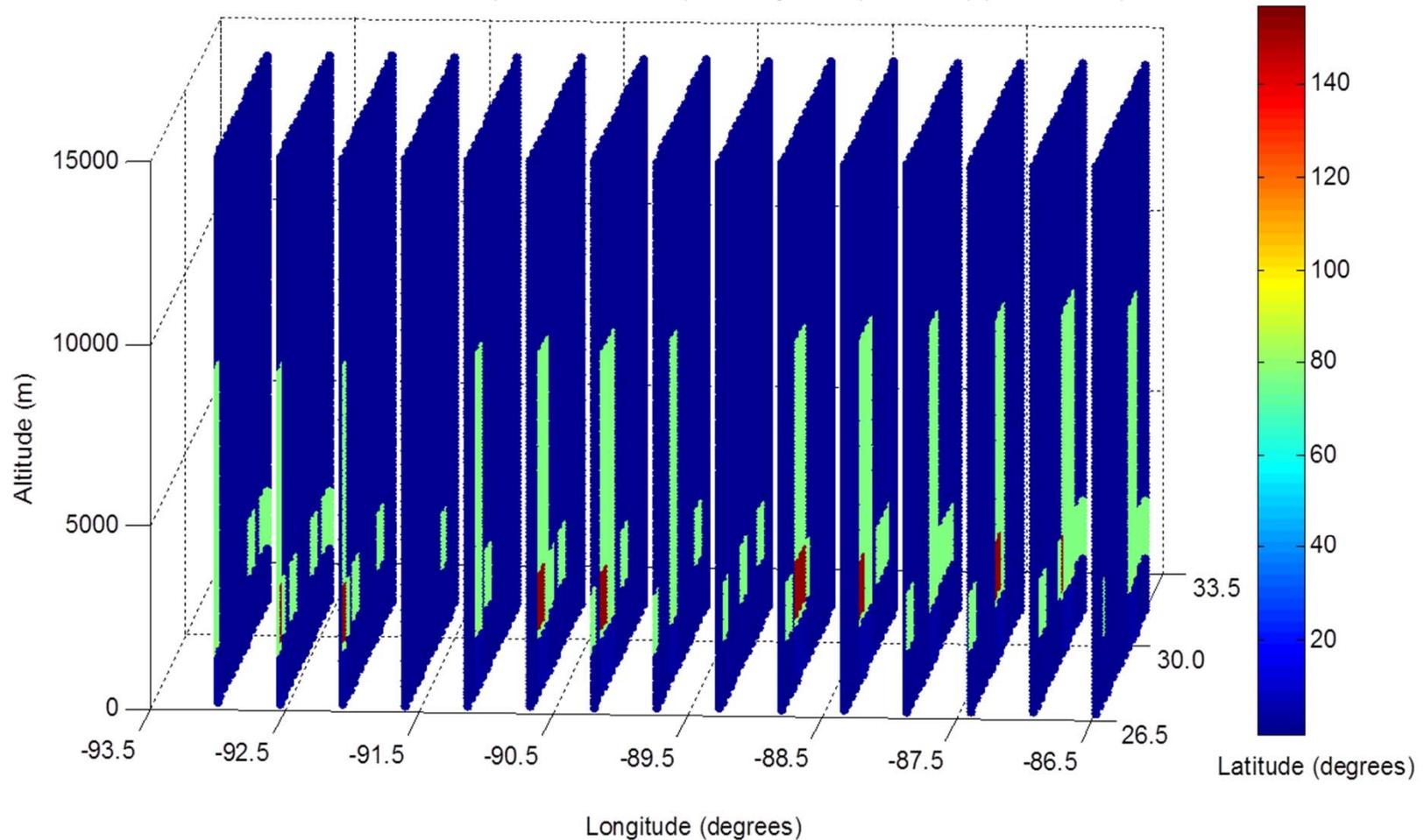
Extinction at 1.6 μm

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SWIR

Extinction (1/km) at 1.6 μm
Stratus Continental (1.2 km - 4.26 km)
Cumulus Continental Clean (1.2 km - 9.14 km) & Heavy Rain (25 mm/hr) (sfc - 1.5 km)





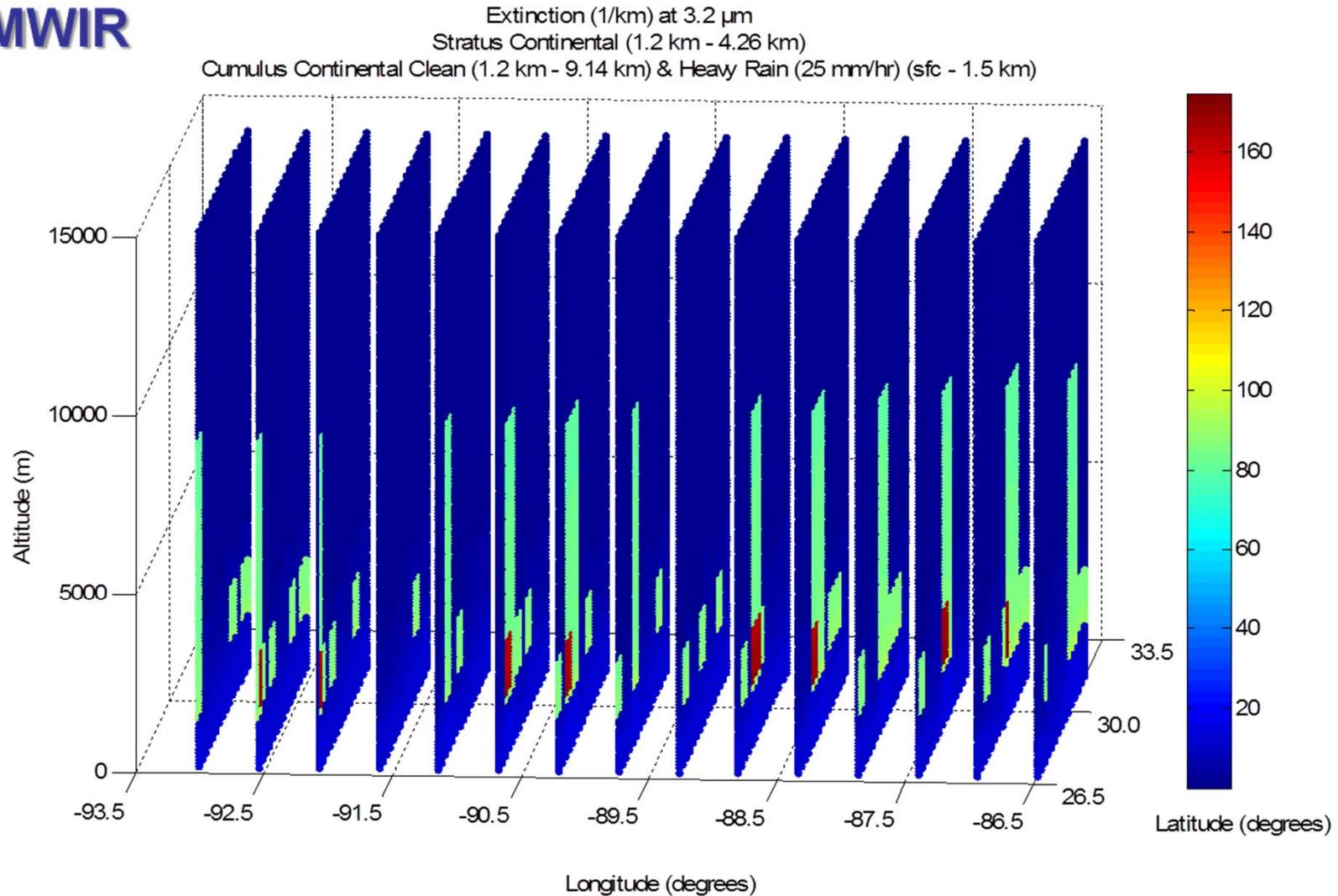
4D Weather Cubes

Extinction at 3.2 μm

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MWIR





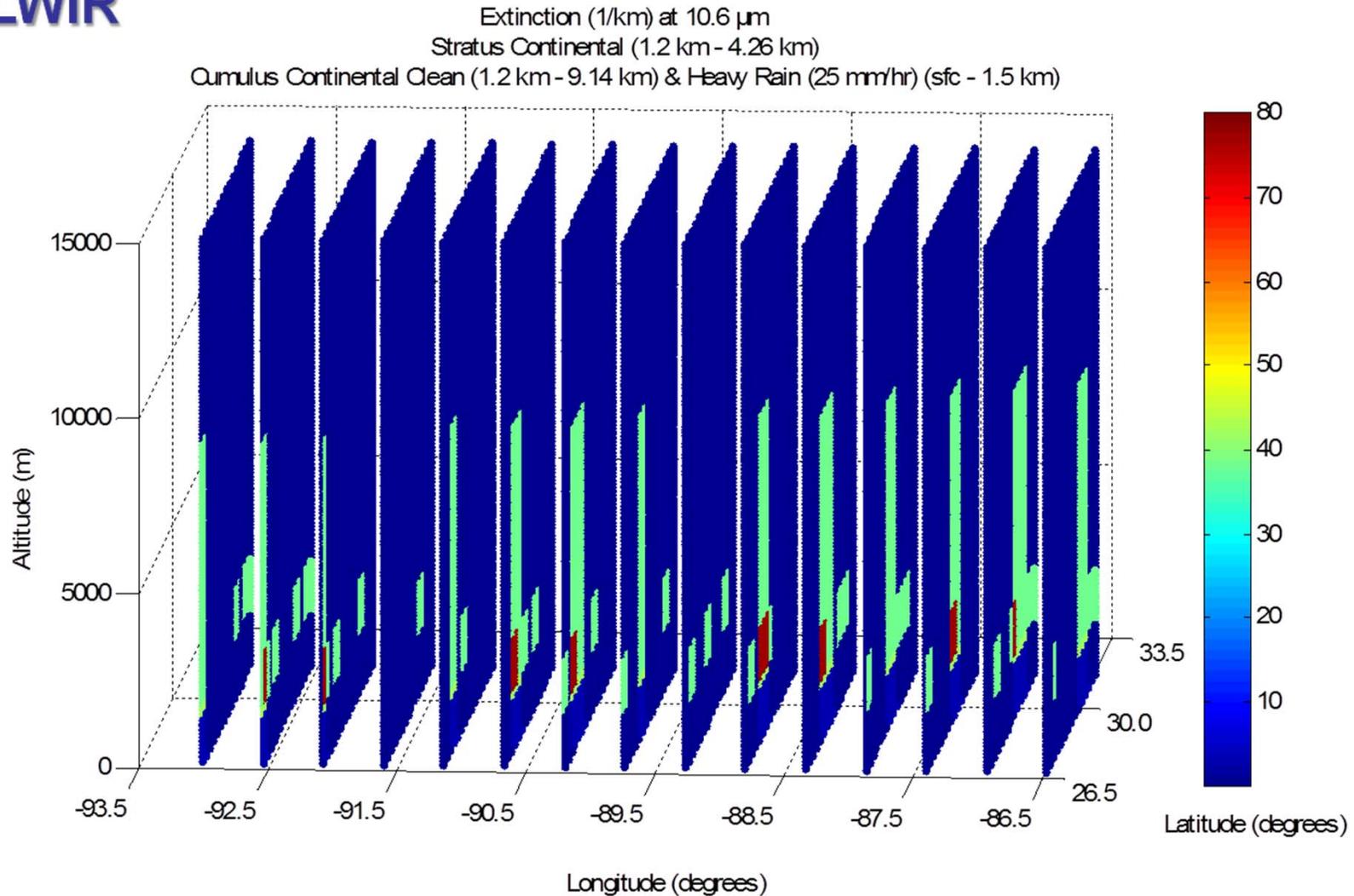
4D Weather Cubes

Extinction at 10.6 μm

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LWIR





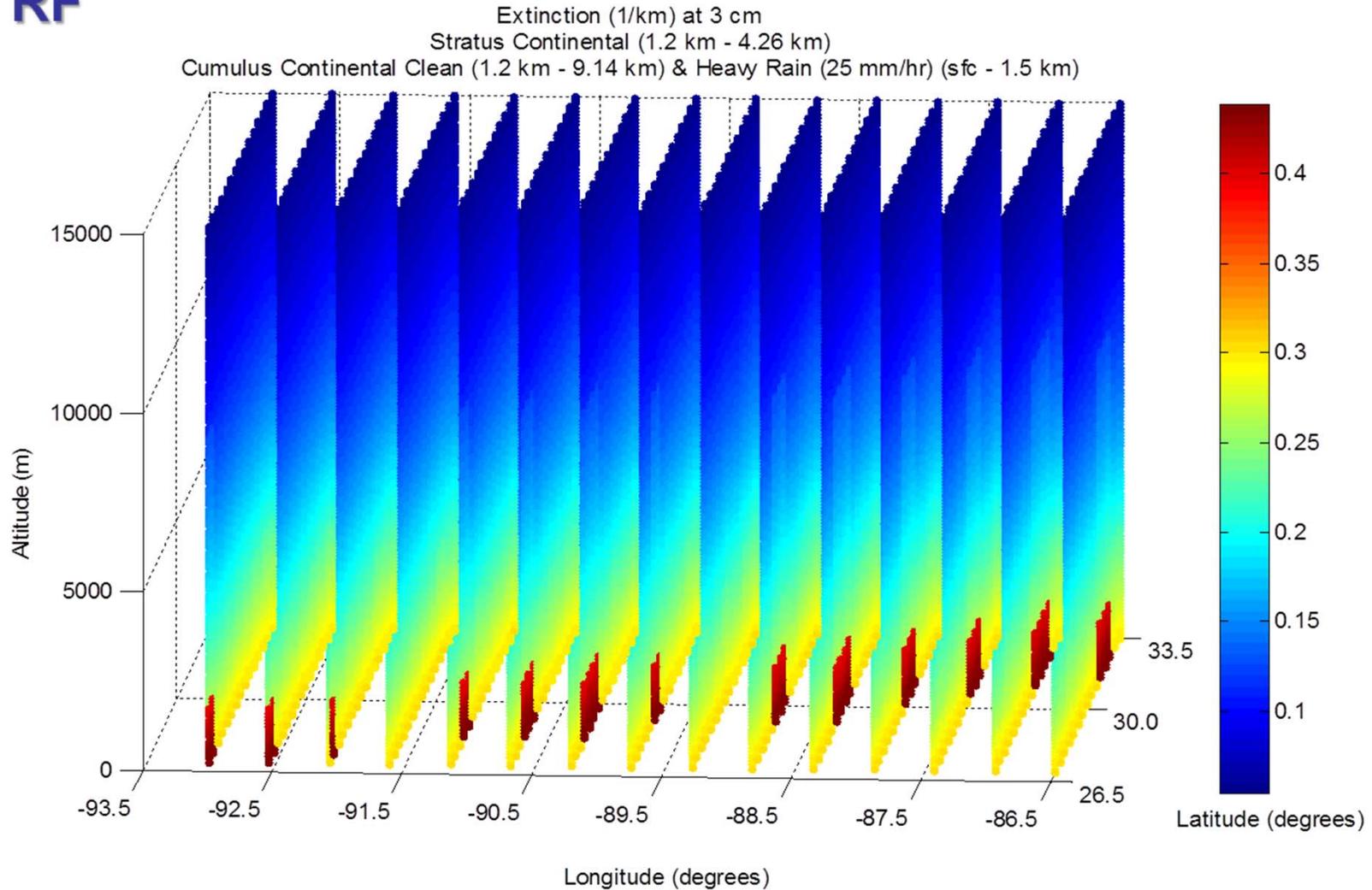
4D Weather Cubes

Extinction at 3 cm

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RF





Conclusions



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- The parallel computer toolbox within MATLAB in conjunction with a wrapper class and HPCs drastically reduce run-time, making computationally intensive problems now a viable solution.
- The 4D weather cubes provide the user with ready access to radiative and other atmospheric effect parameters, as well as for realistic-looking images accurately translating to propagation and atmospheric effects outside of the visible.
- Real-time battlespace surveillance is now a possibility with HPC computing power.



Future Work



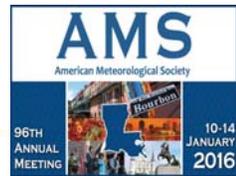
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- Model Verification and Validation (V&V)
 - Next intended use to be validated: Remote sensing
 - Results accuracy: Compare with field test campaigns
- Expand NWP data integration to higher resolution weather models (WRF, AFWA models, and Fleet Numerical models)
 - Utilize this improved resolution gridded data in DE propagation models (e.g. AFIT's High Energy Laser End to End Operational Simulation and Tactical Decision Aid)
- Incorporate higher resolution aerosol model data (CALIPSO, NAAPS)
- Validate multiple-scattering algorithm in DE propagation models at shorter wavelengths



AMERICAN METEOROLOGICAL SOCIETY

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Air Force Institute of Technology
Center for Directed Energy
Wright-Patterson AFB, Ohio



High Performance Computing for 4D Weather Cubes and Real-Time, World-Wide Visualization of Radiative Effects

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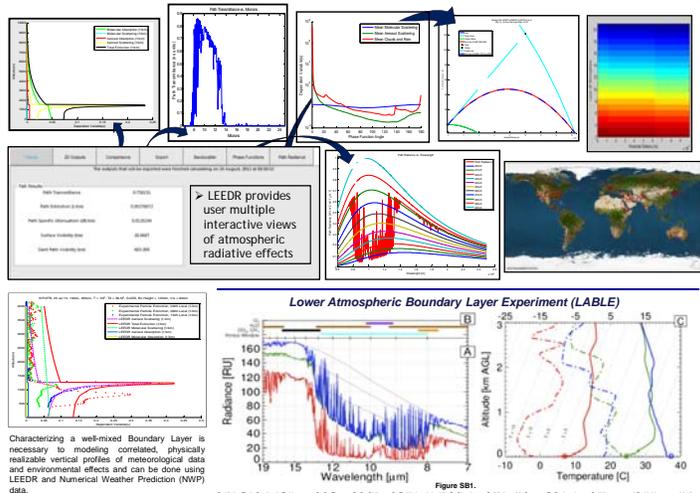
The requirement of high performance computers is inherent in the overarching goal of immediate, world-wide forecasts of atmospheric effects and radiative transfer whether to assist with traditional aviation weather services or to manage best employment of emerging national and civil remote sensing capabilities. The Laser Environmental Effects Definition and Reference (LEEDR) is a verified and validated atmospheric propagation and radiative transfer code which creates physically realizable vertical and horizontal profiles of meteorological data and environmental effects using climatological and Global Forecast System numerical weather data. Using these inputs, the code proceeds to produce nowcast and forecast, as well as post-event, atmospheric radiative effects including particle-induced extinction, turbulence profiles, and path refraction (light bending). By itself, LEEDR and its graphical user interface (GUI) has the capability to provide a "2D" picture of localized atmospheric radiative properties and processes. In an effort to migrate to a world-wide 4D visualization capability, LEEDR was optimized and parallelized for migration onto the Department of Defense HPC network. Wrapper classes and the Parallel Computing Toolbox within MATLAB (LEEDR's source code language) aided in the optimization of LEEDR. The wrapper classes were written as a means to circumvent LEEDR's GUI and easily execute batch runs for efficient, speedy parametric analyses. With the use of these classes, computationally intensive analyses supporting anywhere, anytime atmospheric effects visualization are able to be demonstrated. The results of the analyses are displayed in the form of a 4D weather cube specific to a universal time reference, locations of interest (i.e. geo-referenced light source and remote sensor), and a user-provided output parameter such as transmission. Each weather cube depicts the variability of output parameter with respect to the source-endpoint geo-referenced location and, most importantly, relative to the ambient atmosphere.

Simulation Tool:



LEEDR radiative transfer code augmented by:

- Probabilistic Extreme and Percentile Environmental Reference Tables (ExPERT) data for 573 land sites; Surface Marine Gridded Climatology
- 4D real-time and/or archived NWP now-cast / forecast and weather satellite data



Characterizing a well-mixed Boundary Layer is necessary to modeling correlated, physically realizable vertical profiles of meteorological data and environmental effects and can be done using LEEDR and Numerical Weather Prediction (NWP) data.

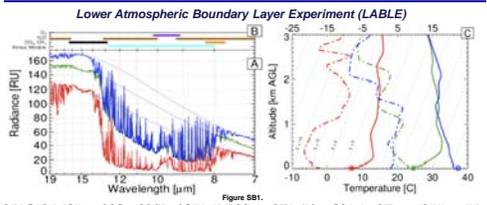
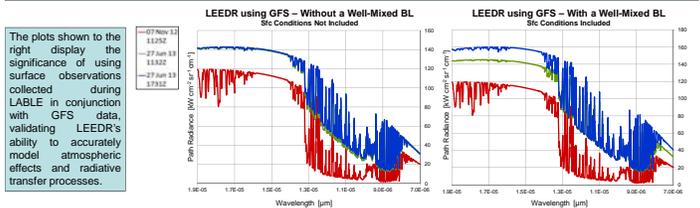
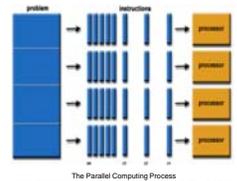


Figure SB1. P. Klein, T. A. Rosen, J. F. Neuman, D. D. Turner, P. S. Chubb, C. E. Wainwright, W. G. Boring, S. Mohr, M. Conroy, E. P. Jacobson, S. Whorton, and R. Newkum, 2015. LABEL: A Multi-Institutional, Student-Led, Atmospheric Boundary Layer Experiment. Bull. Amer. Meteor. Soc., 96, 1743-1764. doi:10.1175/BAMS-12-00067.1

The October 2015 edition of the *Bulletin of the American Meteorological Society* contains an article on a Multi-Institutional, Student-Led, Lower Atmospheric Boundary Layer Experiment (LABEL) conducted at the Southern Great Plains site in Oklahoma. The AERI-observed downwelling radiance data (See Figure SB1 above) is used to compare LEEDR results using Global Forecast System (GFS) data with a well-mixed Boundary Layer (BL). LEEDR provides users the capability to input surface observations to accurately characterize the BL.



The parallel computing toolbox within MATLAB allows for multiple calculations to take place simultaneously, greatly reducing run time. This, paired with a high performance computer, allows computationally intensive problems to be split into manageable sections for each processor. The limiting factor to the number of calculations executed in parallel becomes the number of processors available.



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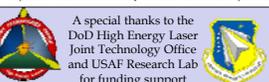
Comparison

Powerful computers that have the capability to provide near instantaneous runtimes open the door for real-time battlespace surveillance.

Computer	Cores	Time
Cluster	1	Approx. 10-12 days
Supercomputer	26720	seconds

Importance

Compared to a single vertical profile, 4D weather cubes provide the user with a sense of how meteorological data and environmental effects change with location and time. That is, rather than assuming a profile holds for a nearby location and subsequent time, a user is able to account for climatic variability.



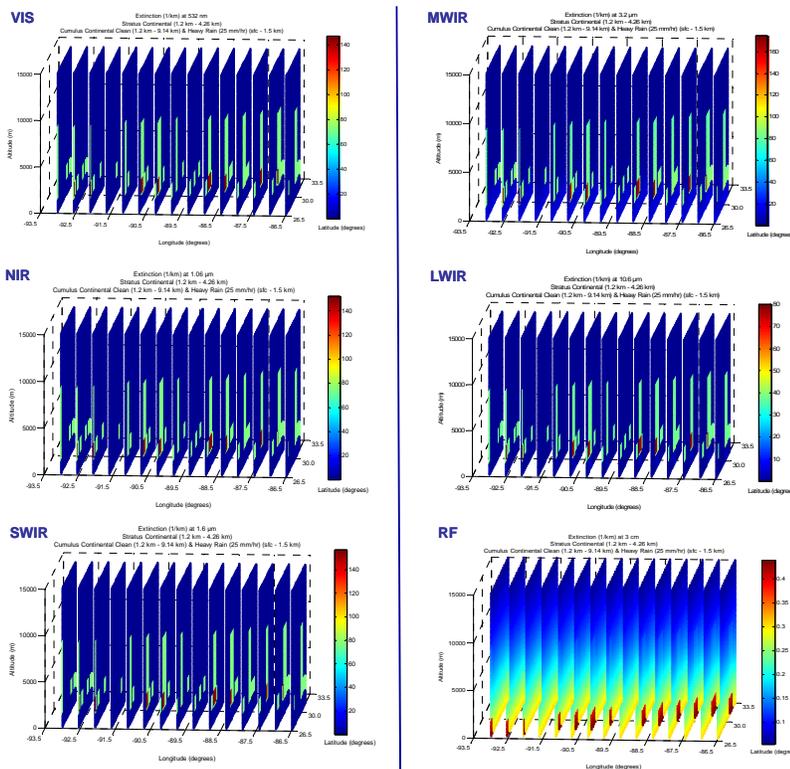
¹Air Force Institute of Technology
²Southwestern Ohio Council for Higher Education
³Oak Ridge Institute for Science and Education
⁴Applied Research Solutions, Inc.

The views expressed in this document are those of the author(s) and do not reflect the official policy or position of the United States Air Force, the Department of Defense, or the United States Government.

Results:

The 4D Weather Cube simulations allow for visually stunning and realistic-looking visible-spectrum images to accurately translate to propagation and atmospheric effects outside of the visible spectrum via AFIT/CDE's LEEDR physically-based atmospheric characterization model output.

Clouds, precipitation, and aerosol haze effects are shown as people see them will be captured at wavelengths for any electro-optical infrared sensor or microwave/radio frequency tracking/illumination system.



The figures above depict the variability of total extinction, the reduction in the intensity of energy due to absorption and scattering as it passes through a given medium, for specific wavelengths ranging from the visible to the radio frequency spectrums within a volume centered on New Orleans, Louisiana, on August 5, 2015, at 1500 local time with a line of thunderstorms present.

Conclusions:

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