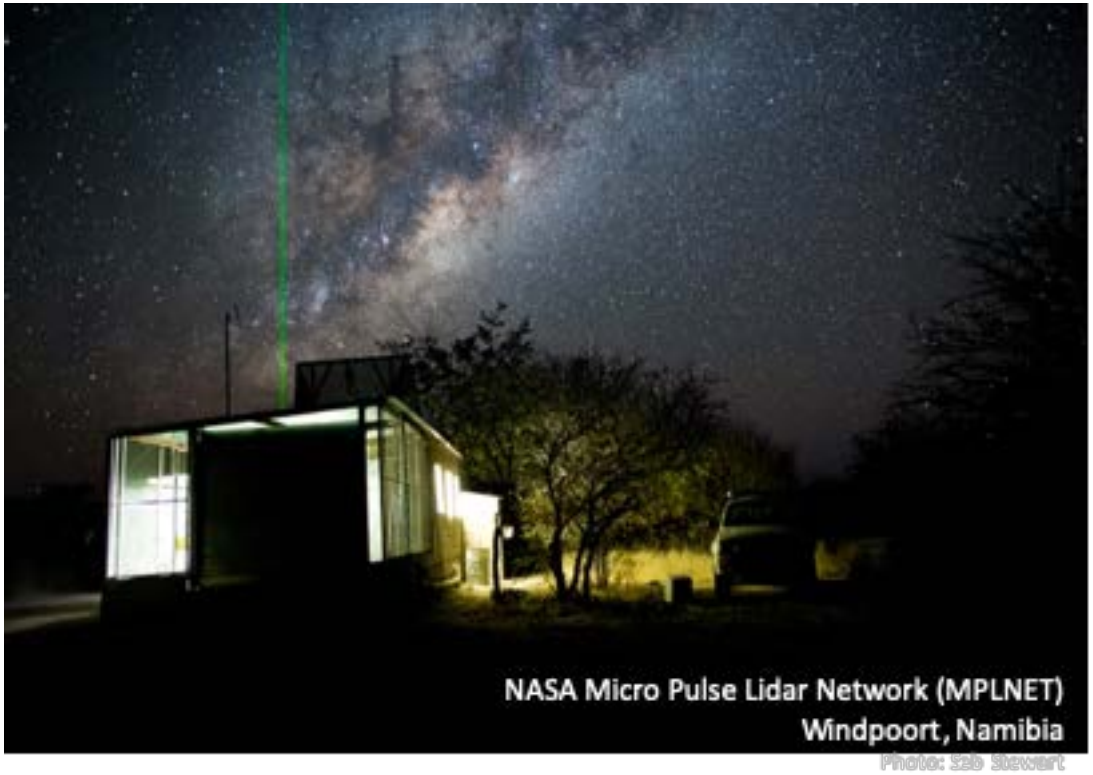
The Evolution of Lidar Networks: a US perspective

Ellsworth J. Welton
NASA Goddard Space Flight Center
PI of the NASA Micro Pulse Lidar Network
Co-Chair of the WMO GAW Aerosol Lidar Observation Network



Introduction: Some Constraints for the Discussion

- Focus on atmospheric lidars providing cloud and aerosol profile data (should have altered title)

- Ceilometers vs Lidar
  - Similar design, here we consider only instruments providing signal profile data
  - Various met agencies have run ceilometer networks for a long time
    - Historically they were limited to providing cloud base height, no signal profiles
  - Newer ceilometers now provide profiling, and are incorporated into networks
    - DWD – Germany, E-PROFILE (EU)

Ground based lidar R&D progressed rapidly from the 1980s to 1990s
- Laser and detector technology led to improvements in data quality and ability to operate for extended periods
- Retrieval techniques matured

Multi-Disciplinary Programs create networks for earth data observations
- DOE Atmospheric Radiation Measurement (ARM) network
- Network for the Detection of Atmospheric Composition Change (NDACC)
- Both networks provide lidar profiling capability, but not dedicated lidar networks

Success of the NASA Aerosol Robotic Network and WMO Global Atmospheric Watch (GAW) in-situ aerosol network proved value of long-term aerosol monitoring
- In 1999-2000 three dedicated aerosol lidar networks were created, independently
  - NASA Micro Pulse Lidar Network (MPLNET)
  - Asian Dust and Aerosol Lidar Observation Network (AD-NET)
  - European Aerosol Research Lidar Network (EARLINET)

The NASA Micro Pulse Lidar Network (MPLNET)

2000 – current

Homogenous instrumentation
- Commercial Micro Pulse Lidar (MPL)
  - elastic backscatter 532 nm, polarized

Network: Over 70 sites, ~20 currently active
- Global distribution
- Objective: provide lidar profiling at NASA AERONET sites
- Co-location & partnership with AERONET
- Sparse regional coverage (esp North America)

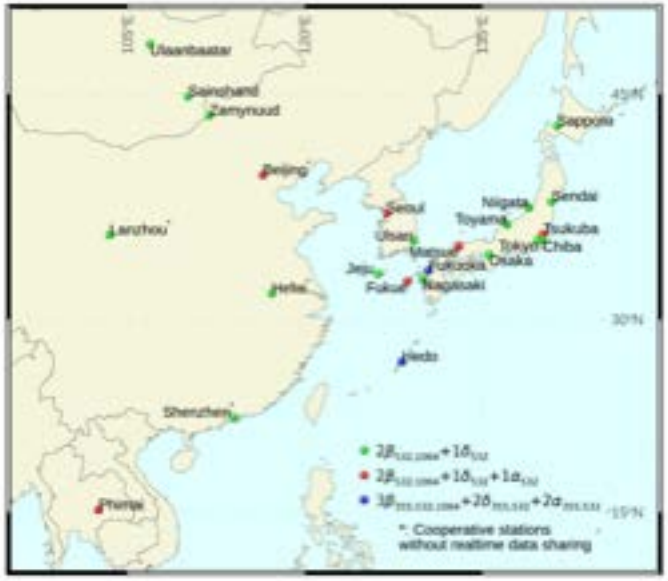
Data Processing:
- MPLNET Calibration Center: GSFC
  - working on calibration device for field sites
- Centralized & Standardized Processing: GSFC
  - NETCDF-4
  - Signal, Cloud, Aerosol, and PBL Products (L1, L1.5, L2)
- Online data browsing (public)
- Online data download (public)
- near real time online delivery (~ 1 hour)

NASA funded, with contributions from international partners

The Asian Dust and Aerosol Lidar Observation Network (AD-Net)

2000 – current

AD-Net



Homogenous instrumentation

- NIES Dual Wavelength Backscatter lidar
  - elastic backscatter 1064 & 532 nm, polarized
- Some now have raman capability

Network: 20 sites

- Dense regional coverage over East Asia

Data Processing:

- Calibration Center: NIES
- Centralized & Standardized Processing: NIES
  - NETCDF
  - Signal, depolarization, extinction, cloud/rain flags
- Online data browsing (public)
- Online data download (public)
- near real time online delivery

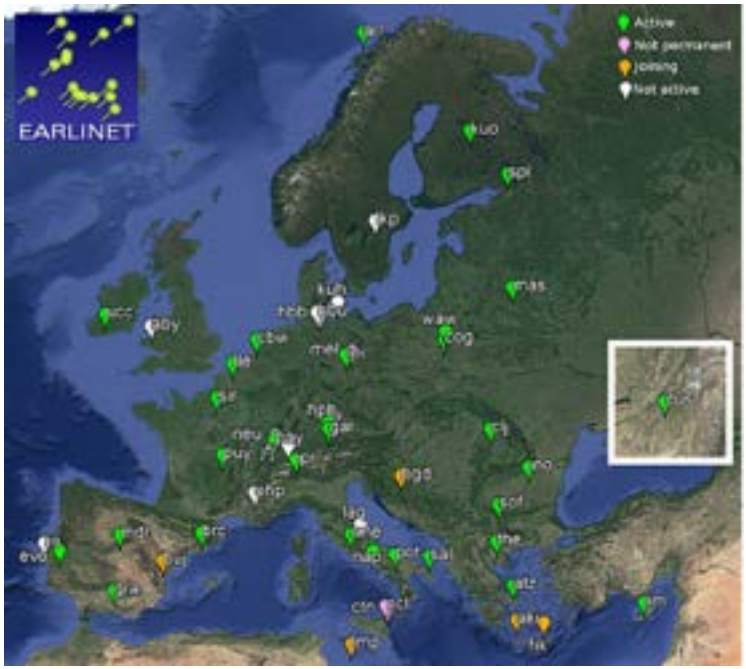
Significant progress with model assimilation of AD-Net Data

- Asian Dust forecasting

Supported by Japanese Ministries of Environment and Education

The European Aerosol Research Lidar Network (EARLINET)

2000 – current



Heterogenous instrumentation
- From basic elastic backscatter to
  - multi-wavelength & polarized raman lidars

Network: over 30 sites
- Dense regional coverage in Europe
- Some sites globally

Data Processing:
- Decentralized at first
- Have since solved issues running heterogenous network
- Lidar Calibration Center Established
  - Instrument training, standards, & calibration
- Centralized & Standardized Processing & Products
  - Single Calculus Chain (SCC)
  - NETCDF-4
- Online data browsing (public)
- Online data download (login required)
- A few sites have NRT capability
  - many still only have a few obs per week
- Advanced aerosol retrievals (have set standards)

Currently supported under ACTRIS program

Introduction: cont..

These three networks + ARM & NDACC have common traits for success:

- Strong emphasis on calibration and quality control processes
- Centralized processing for standardization, traceability, and QA
- Core funding
- Multi-disciplinary science focus, integration with research community
    - Leads to strong publication history and data usage

EARLINET and AD-Net are regional networks with strong core funding

- these projects coalesced ground lidar activities in their regions
- end result is a mature, dense lidar network for these areas

MPLNET, ARM, and NDACC have a global focus

- No mandate to coalesce ground lidar work, nor provide dense network for USA/NA
- Ex: MPLNET was created to provide profiling at key AERONET sites worldwide
- Despite US funding of these efforts:
    - sparse coverage in North America
    - disparate ground lidar activities and fractured network projects in development
    - Very little or no interaction

Until 2008, these issues extrapolate globally.
No one network provides dense global coverage.

WMO Global Atmospheric Watch (GAW) Aerosol Lidar Observation Network (GALION)

WMO GAW Aerosol Lidar Observation Network (GALION):
A lidar network of networks organized through the WMO Global Atmospheric Watch (GAW) program, and is composed primarily of the world's leading lidar networks. Each is an official contributing network to GAW (or soon will be).
See GAW Report 178 (2008)

GALION Networks:
EARLINET
AD-NET
CIS-LINET
LALINET
~~CORALNET~~
CREST
MPLNET (global)
NDACC (global)

GALION Co-Chairs:
Gelsomina Pappalardo (CNR IMAA)
Ellsworth J. Welton (NASA)

Steering Committee:
Network Heads, GAW Leadership

Work Groups:
Calibration, QA/QC, processing/products, applications, data center

Not complete site listing
From WMO GAWSIS Database

Successes:
More frequent interaction between the networks
Some joint planning
Development of standards for lidar types/models: calibration, processing, products
Subsequent creation of newer networks (e.g. LALINET)
Integration with related WMO & GAW projects:
- SDS-WAS: Sand and Dust Storm Warning and Advisory System
- World Data Centers: current plan is to build GALION data center for lidar networks

Lidar Network Developments After the Creation of GALION:

Regional networks within Europe after Eyjafjallajökull Eruption in 2010:

- Led to significant enhancement of EARLINET and funding stability
- Several met services upgrade ceilometer networks or create lidar networks
  - DWD, KNMI, UK, France, Spain, etc
- EUMETNET creates E-PROFILE
  - Includes Europe-wide ceilometer and lidar sites
  - Address use of commercial ceilometers to provide lidar-like data

North America:

- TOLNET (Ozone lidar network, connection to NDACC)
- Univ of Wisconsin HSRL network (global)
- NYS Mesonet (some sites have lidar)
- EPA PAMS (E-PAMS) (some sites have ceilometers)
- New Canadian lidar network

I may be missing some, new efforts keep growing ….

North American Ceilometer & Lidar Networks Situation:

First, we must recognize the successes of older and newer lidar networks….. **BUT**

MPLNET:	mature lidar network but sparse coverage
NWS:	ceilometers, no signal profiles (as of now)
E-PAMS:	new, some ceilometers (mix)
NYS Meso:	some lidars, NY only
UW HSLR:	advanced lidar, sparse regional coverage
TOLNET:	ozone and aerosol data, sparse coverage
CREST:	education focus, sparse coverage
CORALNET:	dismantled several years ago
New CA Net:	new, currently sparse coverage

Common Theme:
Sparse coverage individually, but if combined provide dense network
Networks may benefit from experience of long running GALION networks and E-PROFILE

Suggestion: we meet to develop a framework to work together

Following slides demonstrate aspects of a mature lidar network
Using MPLNET as example

MPLNET: new Version 3 processing system (result of 20 years of network experience learned the hard way)

Easy, public online data browsing and data download
With data center interoperability (links to other data centers)

Data product descriptions, file formats, variable and flag documentation (peer-review papers & online ATBD)

Processing & Calibration Traceability
Publication lists with citations for each topic area

Management:

- Secure data communications
- Well maintained, detailed metadata database
    - instrument tracking
    - calibration histories
    - site information
    - data availability
- Real time instrument health & data quality tracking & alerts
- Multi-threaded processing system with logging and control app
    - Web based ideal

Overview of MPLNET: Version 3 Product Suite

Detailed information on V3 Products: mplnet.gsfc.nasa.gov/product-info/

QA Screening: Confidence Levels

V3 Product	
NRB	
CLD	
AER	
PBL	
Product F	
Formats	

QA Confidence Level	Value	Descriptions
n/a	0	Only set if variable has no QA inspection applied.
High	1	Long history with variable and QA procedures results in high confidence
Moderate	2	Lower confidence in an ancillary data input results in lower overall QA confidence
Low	4	Reserved for variables that are new and require more study to elevate confidence
Fail	8	Data fail QA screen, variable data replaced with NaN

* Each data variable in all products has a corresponding QA confidence variable

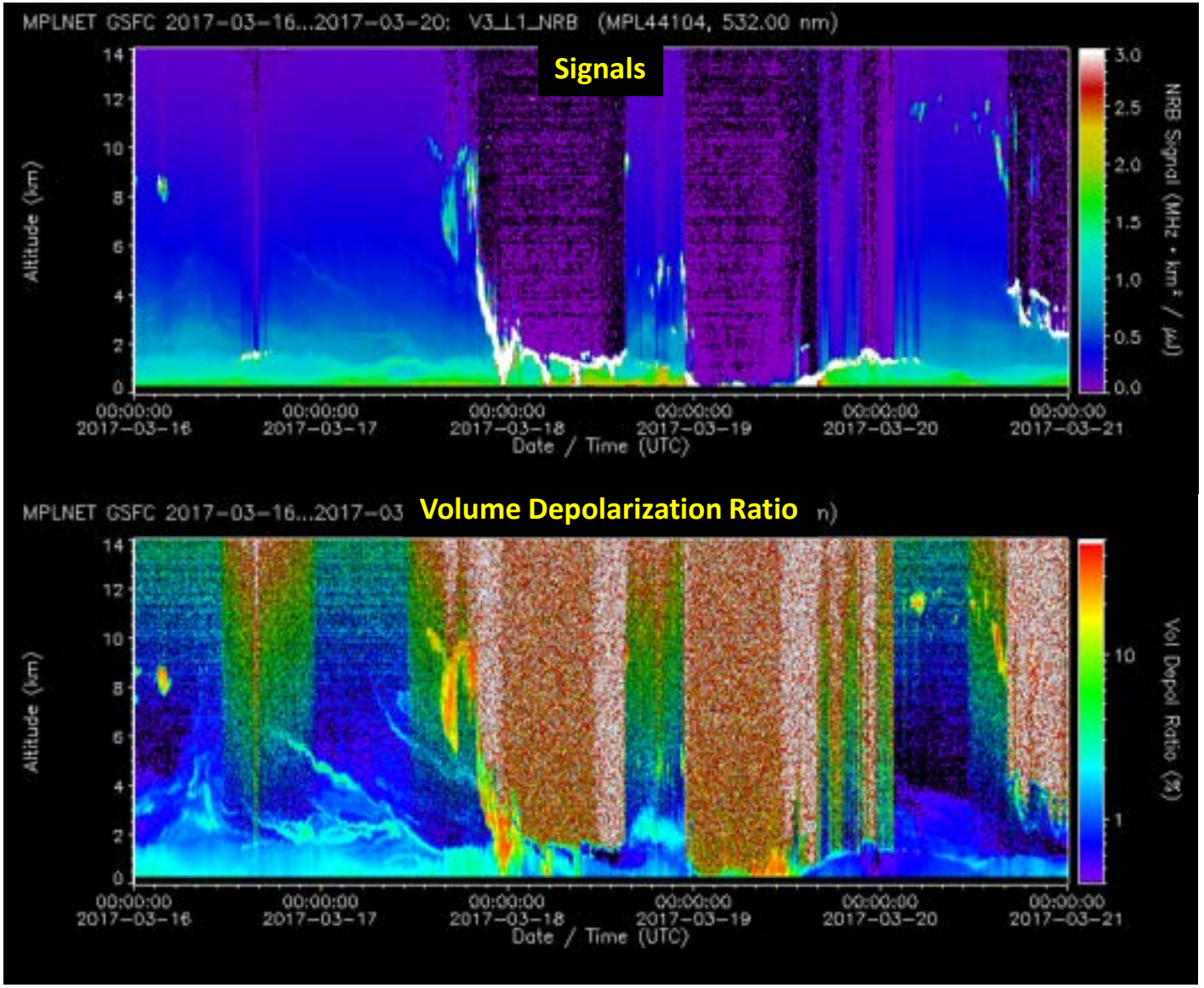
Product Levels	Availability	Calibration	QA Screen	Ancillary Input
L1_NRB L1_CLD L1_PBL L1_AER	Automated Browse: Near Real Time Download: Next Day *	intial, ongoing field calibrations	none	GEOS5 Forecast NRT, reprocessed next day with GEOS5 Assimilated, AERONET L15 AOD
L15_NRB L15_CLD L15_PBL L15_AER	Automated Browse: Near Real Time Download: Next Day *	intial, ongoing field calibrations	L15	GEOS5 Forecast NRT, reprocessed next day with GEOS5 Assimilated, AERONET L15 AOD
L2_NRB L2_CLD L2_PBL L2_AER	upon request †	intial, ongoing field calibrations, post calibration, additional‡	L2	GEOS5 Assimilated, AERONET L2 AOD

* Near real time data can be provided to site partners and forecasting/modeling centers

† L2_AER products subject to availability of L2 AERONET data

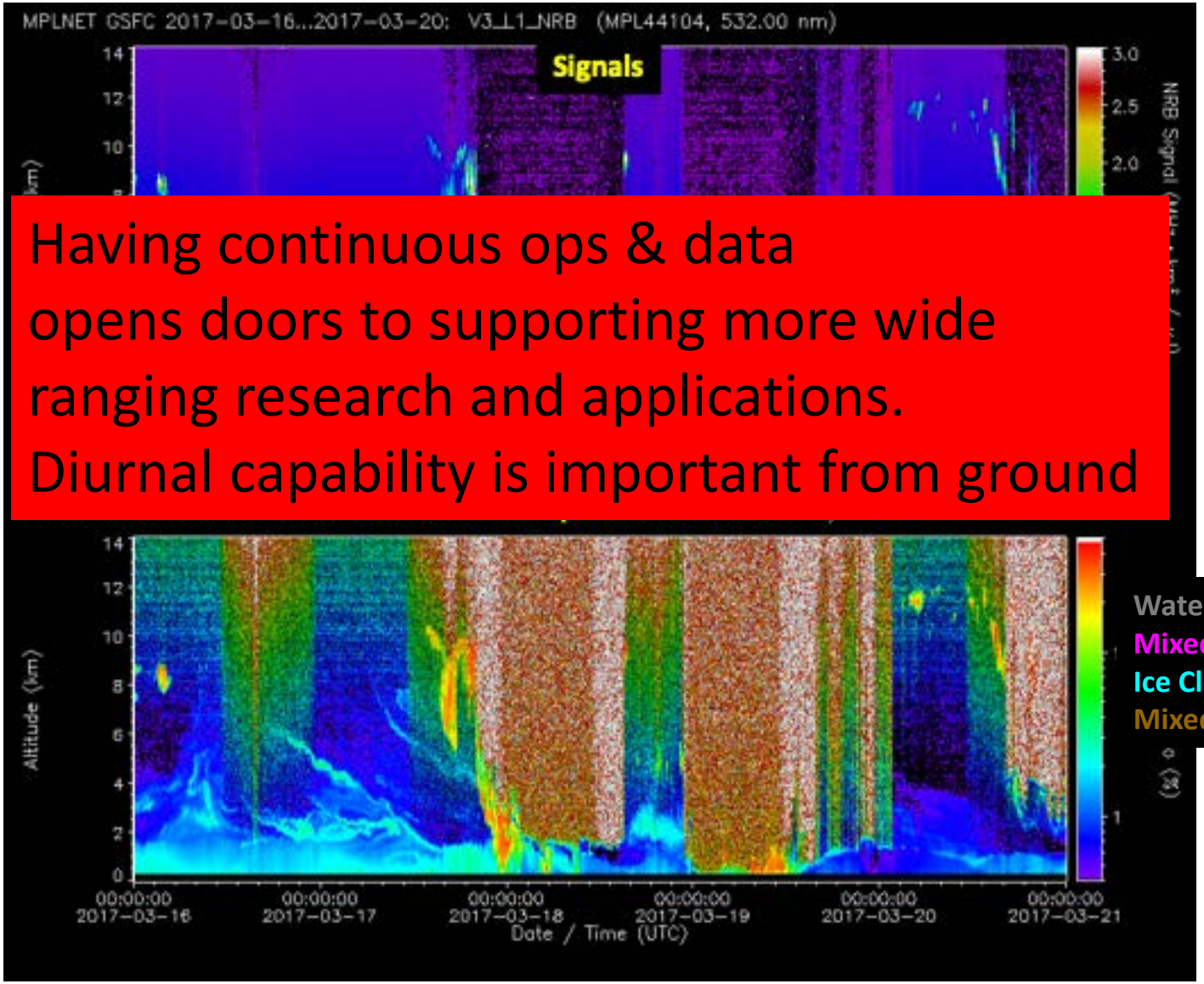
‡ Additional L2 calibrations may include corrections for instrument temperature and manual inspection of data

Overview of MPLNET: Level 1 (and L1.5) NRB Product. (Signals and Diagnostics)



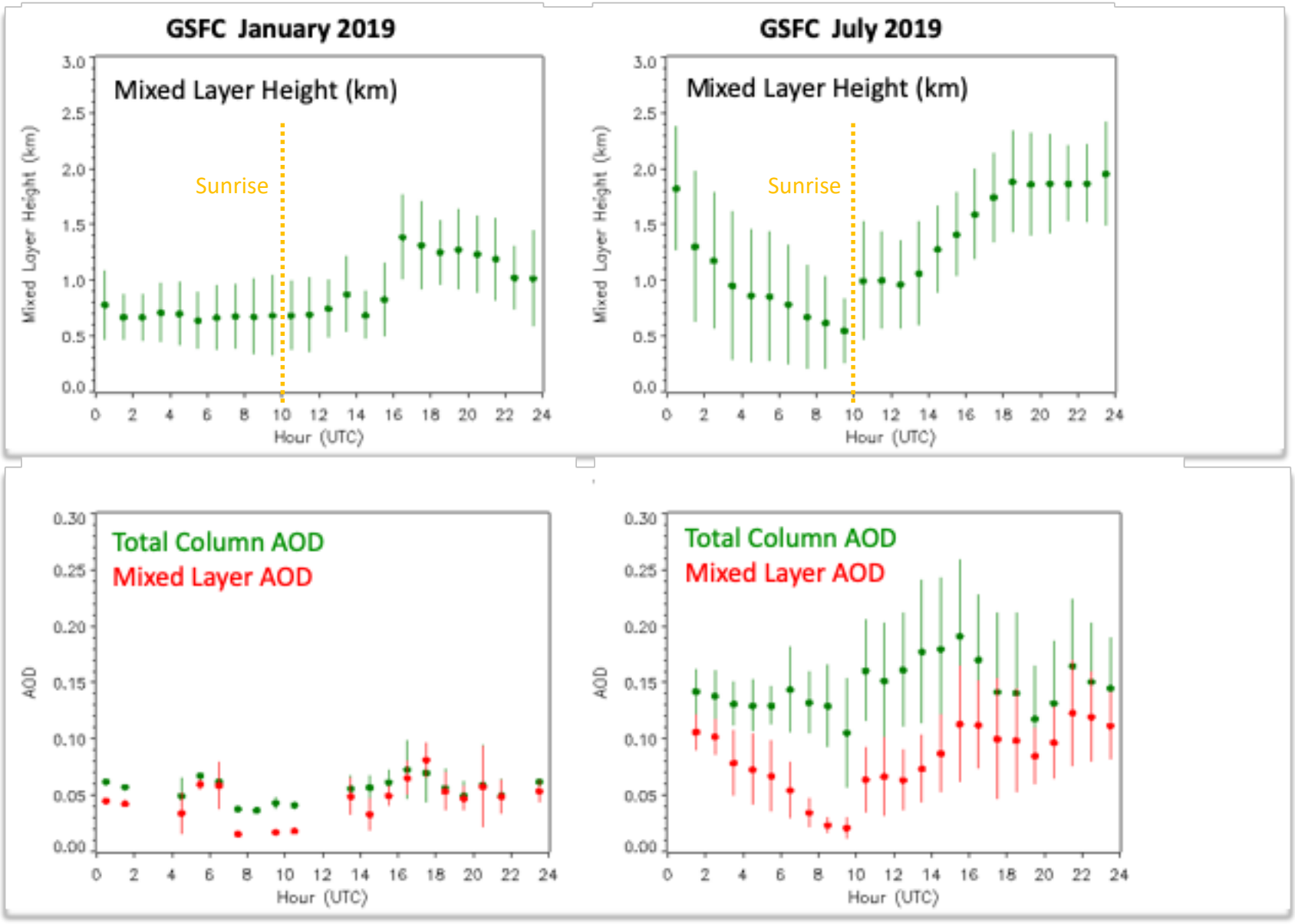
Overview of MPLNET: Level 1 (and L1.5) CLD, AER, PBL Products

Cloud, Aerosol, & PBL Product Overview

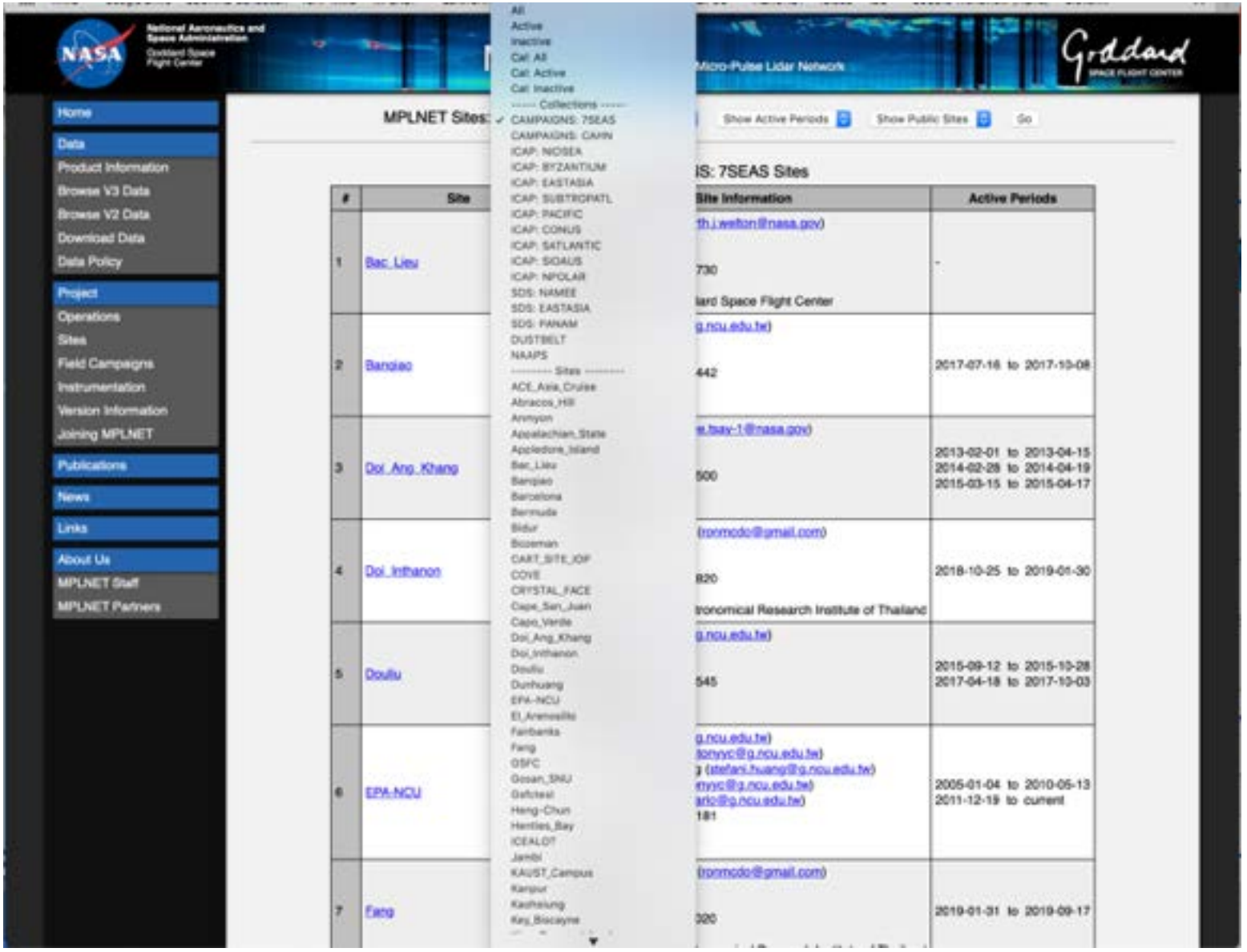


Overview of MPLNET: Long term, continuous sites lead to Diurnal Climatologies

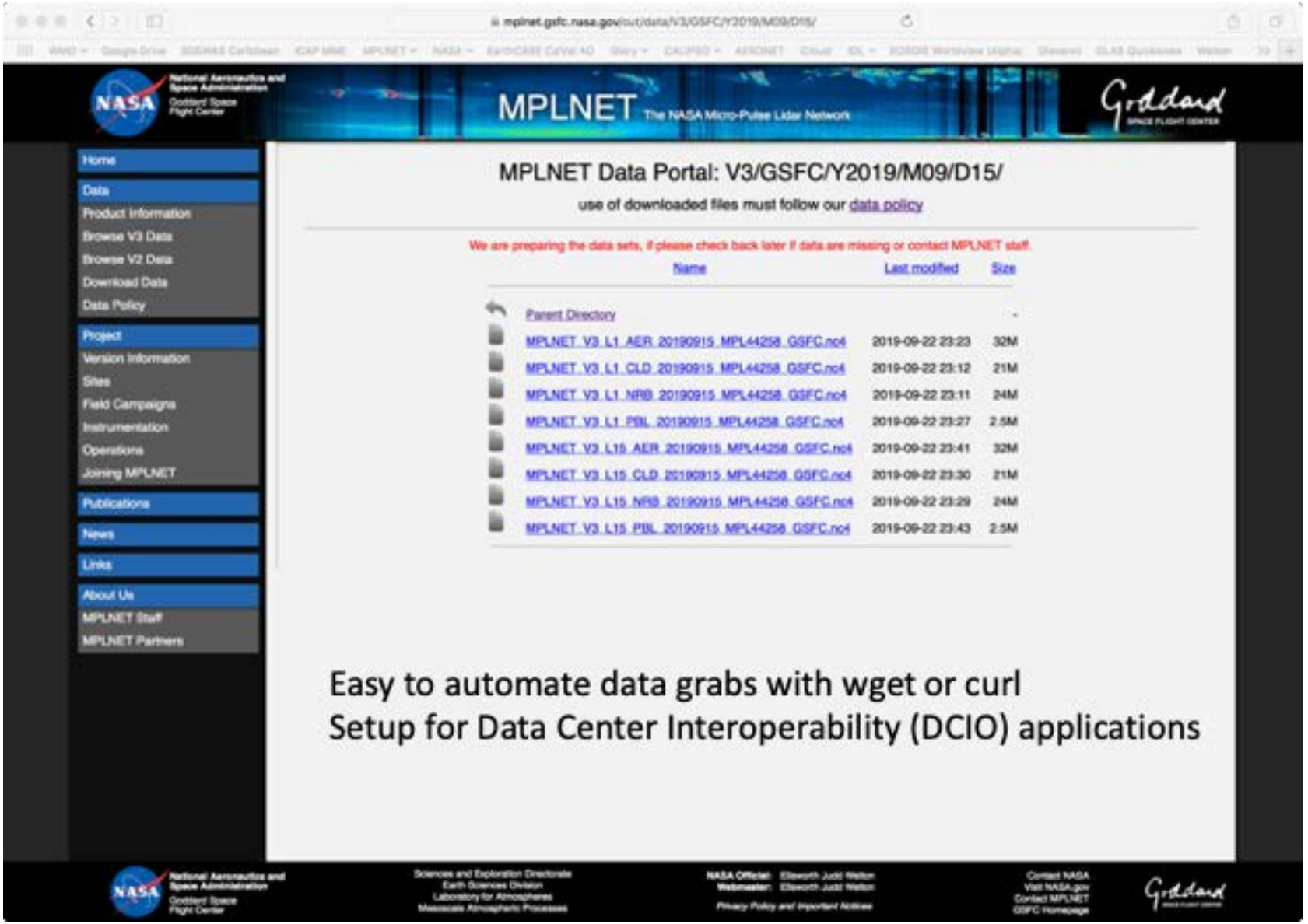
Ground data play a key role as most satellite obs do not provide diurnal information. None do with profiling.



New MPLNET Site Page: Site contacts & metadata



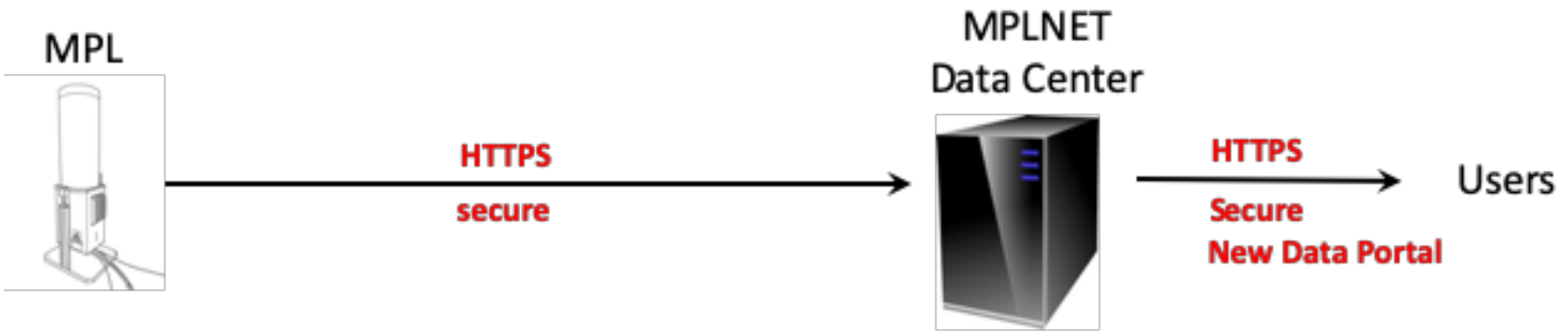
Overview of MPLNET: New Online Data Portal

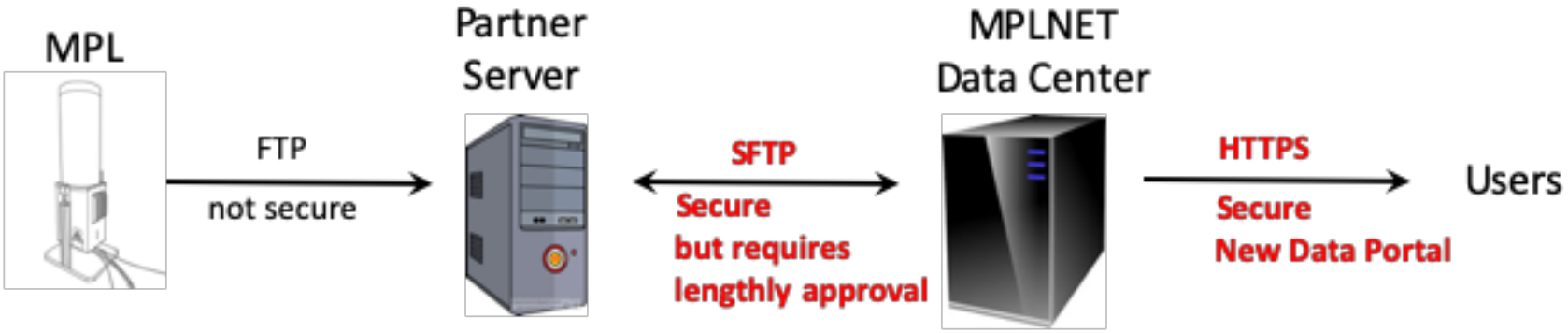


MPLNET: Data Communications

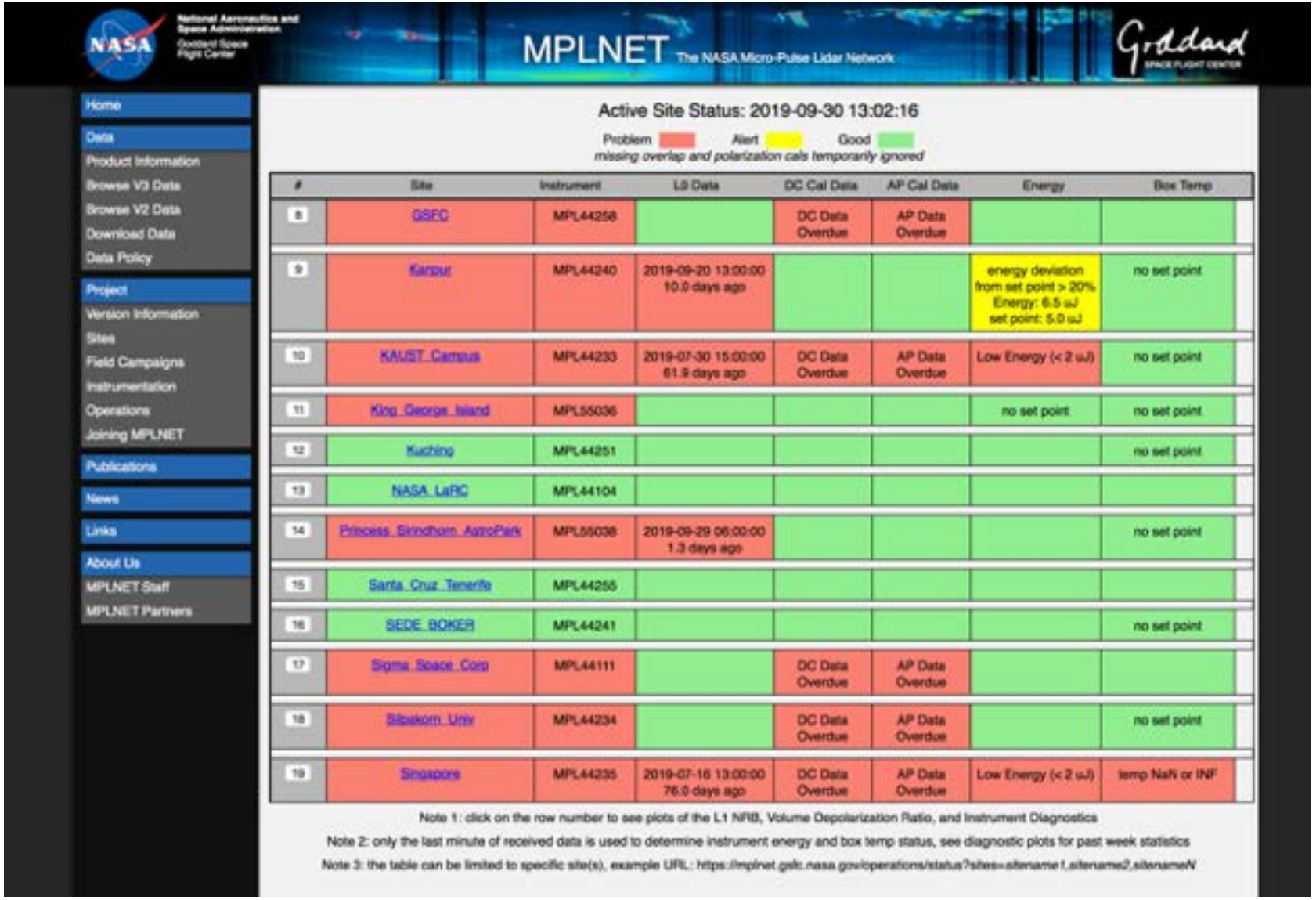
Automated Push scripts on instruments

Automated Processing Hourly





MPLNET Network Management: Site Status & Automated Alert System



National Aeronautics and Space Administration
Goddard Space Flight Center

MPLNET The NASA Micro-Pulse Lidar Network

Goddard Space Flight Center

Home
Data
Product Information
Browse V3 Data
Browse V2 Data
Download Data
Data Policy
Project
Version Information
Sites
Field Campaigns
Instrumentation
Operations
Joining MPLNET
Publications
News
Links
About Us
MPLNET Staff
MPLNET Partners

Active Site Status: 2019-09-30 13:02:16

Problem Alert Good

missing overlap and polarization cals temporarily ignored

#	Site	Instrument	L0 Data	DC Cal Data	AP Cal Data	Energy	Box Temp
8	GSFC	MPL44258		DC Data Overdue	AP Data Overdue		
9	Kanpur	MPL44240	2019-09-20 13:00:00 10.0 days ago			energy deviation from set point > 20% Energy: 6.5 uJ set point: 5.0 uJ	no set point
10	KAUST Campus	MPL44233	2019-07-30 15:00:00 61.9 days ago	DC Data Overdue	AP Data Overdue	Low Energy (< 2 uJ)	no set point
11	King George Island	MPL55036				no set point	no set point
12	Kuching	MPL44251					no set point
13	NASA LaRC	MPL44104					
14	Princess Sirindhorn AstroPark	MPL55038	2019-09-29 06:00:00 1.3 days ago				no set point
15	Santa Cruz Tenerife	MPL44255					
16	SEDE BOKER	MPL44241					no set point
17	Sigma Space Corp	MPL44111		DC Data Overdue	AP Data Overdue		
18	Silpakorn Univ	MPL44234		DC Data Overdue	AP Data Overdue		no set point
19	Singapore	MPL44235	2019-07-16 13:00:00 76.0 days ago	DC Data Overdue	AP Data Overdue	Low Energy (< 2 uJ)	temp NaN or INF

Note 1: click on the row number to see plots of the L1 NRB, Volume Depolarization Ratio, and Instrument Diagnostics

Note 2: only the last minute of received data is used to determine instrument energy and box temp status, see diagnostic plots for past week statistics

Note 3: the table can be limited to specific site(s), example URL: https://mplnet.gsfc.nasa.gov/operations/status?sites=sitename1,sitename2,sitenameN

MPLNET Network Management: Processing Monitor

MPLNET Processing Monitor:

Log: mpl_auto_3 **Auto Date:** 2019-09-30 **Auto Hour:** Current View Log View active processes Go to MPLNET Operations Page

mpl_auto_1	mpl_auto_2	mpl_auto_3	mpl_auto_4	mpl_auto_5	mpl_auto_6	mpl_auto_7	mpl_auto_8	mpl_auto_9
10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour	10 mins after hour
Process Time: 00:36:27	Process Time: 00:19:50	Process Time: 00:34:27	Process Time: 00:02:48	Process Time: 00:01:45	Process Time: 00:03:24	Process Time: 00:32:37	Process Time: 00:51:04	Process Time: 00:03:58
Appalachian_State Barcelona Bidur	Cape_San_Juan El_Arenosillo EPA-NCU	Fairbanks GSFC KAUST_Campus	Kanpur King_George_Island Kuching	MPL44244-NCU MPL44250-NCU MPL44250-WFR0708-NCU	MPL44254-WFR0704-UMBC MPL44255-WFR0705-TEN MPL44258-WFR0706-LAB	NASA_LaRC Princess_Sirindhorn_AstroPark SEDE_BOKER	Santa_Cruz_Tenerife Sigma_Space_Corp Silpakorn_Univ	Singapore Songkhla_Regional_Observatory South_Pole UMBC Xitun

Saved V3_staff download file: MPLNET_V3_L1_CLD_20190927_MPL44258_GSFC.nc4
Saved V3_partners download file: MPLNET_V3_L1_CLD_20190927_MPL44258_GSFC.nc4
% Time elapsed: 52.171768 seconds.
Processing L1_CLD for GSFC on 2019-09-28.
Saved archive file: MPLNET_V3_L1_CLD_20190928_MPL44258_GSFC.nc4
/MPLNET/download/V3/GSFC/
/MPLNET/download/V3_staff/GSFC/
/MPLNET/download/V3_partners/GSFC/
/MPLNET/download/nrt/GSFC/
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download/nrt/GSFC': No such file or directory
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download/nrt': No such file or directory
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download': No such file or directory
Saved V3 download file: MPLNET_V3_L1_CLD_20190928_MPL44258_GSFC.nc4
Saved V3_staff download file: MPLNET_V3_L1_CLD_20190928_MPL44258_GSFC.nc4
Saved V3_partners download file: MPLNET_V3_L1_CLD_20190928_MPL44258_GSFC.nc4
Saved NRT download file: MPLNET_V3_L1_CLD_20190928_MPL44258_GSFC.nc4
% Time elapsed: 40.333944 seconds.
Processing L1_CLD for GSFC on 2019-09-29.
Saved archive file: MPLNET_V3_L1_CLD_20190929_MPL44258_GSFC.nc4
/MPLNET/download/V3/GSFC/
/MPLNET/download/V3_staff/GSFC/
/MPLNET/download/V3_partners/GSFC/
/MPLNET/download/nrt/GSFC/
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download/nrt/GSFC': No such file or directory
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download/nrt': No such file or directory
rmdir: failed to remove '/MPLNET/download/nrt/GSFC//download': No such file or directory
Saved V3 download file: MPLNET_V3_L1_CLD_20190929_MPL44258_GSFC.nc4
Saved V3_staff download file: MPLNET_V3_L1_CLD_20190929_MPL44258_GSFC.nc4
Saved V3_partners download file: MPLNET_V3_L1_CLD_20190929_MPL44258_GSFC.nc4
Saved NRT download file: MPLNET_V3_L1_CLD_20190929_MPL44258_GSFC.nc4
% Time elapsed: 44.623764 seconds.
Processing L1_CLD for GSFC on 2019-09-30.

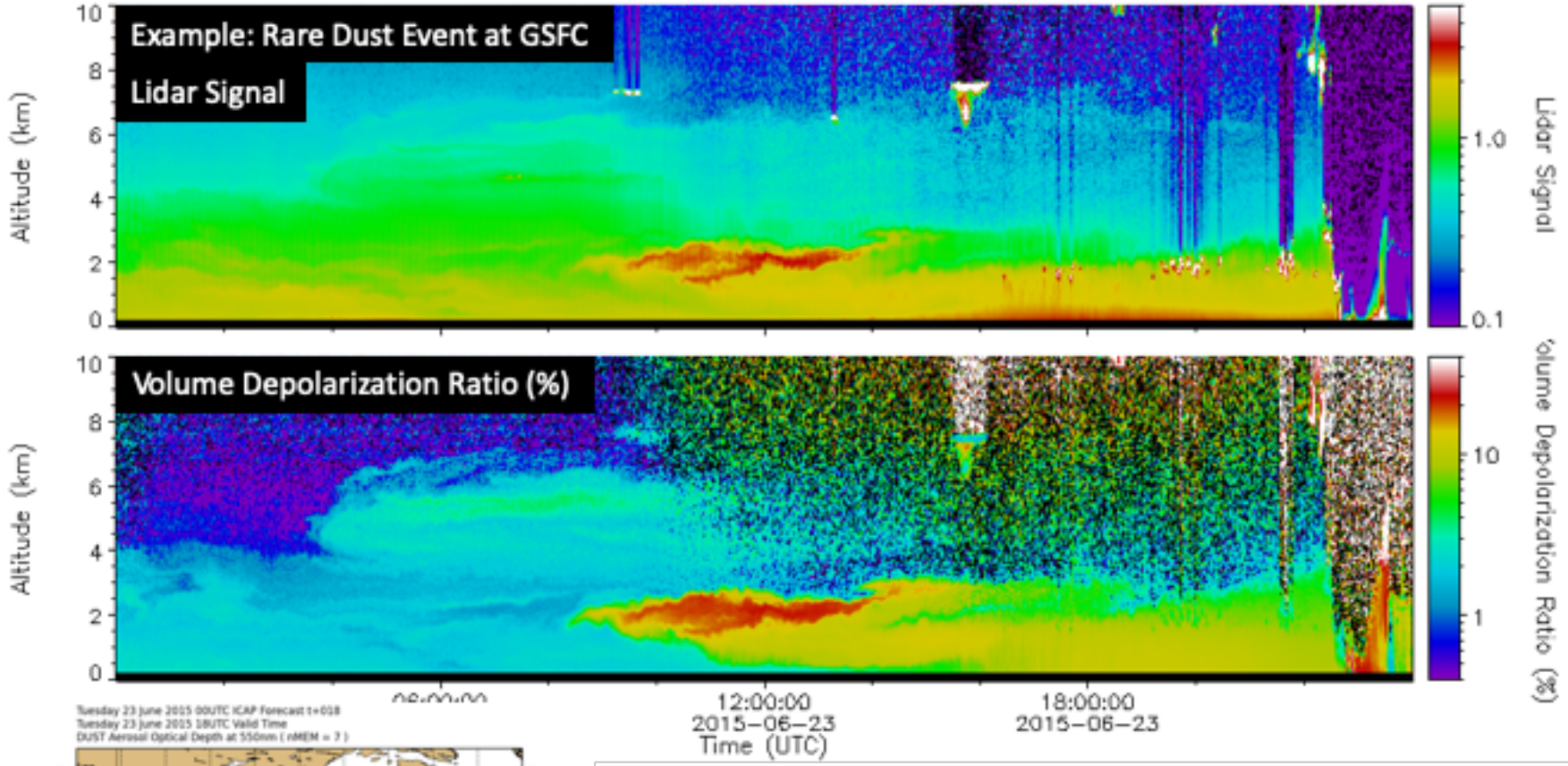
Fact of life for long running projects:
when a new Version is released its already out of date

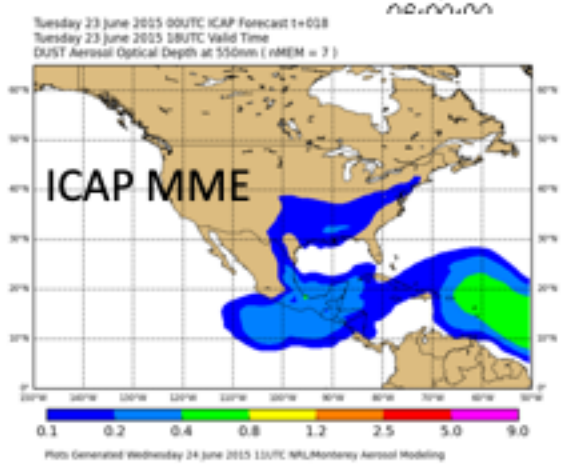
MPLNET is developing new V4 products, testing in V3

- Precipitation Product (see Lolli et al later this session)
- A NRT attenuated backscatter product
    - New aerosol & cloud detection algorithms
- Dust Alert System

Balancing R&D enhancements and network operations has been challenging with fixed budgets

MPLNET Support for operational aerosol forecasting: dust detection





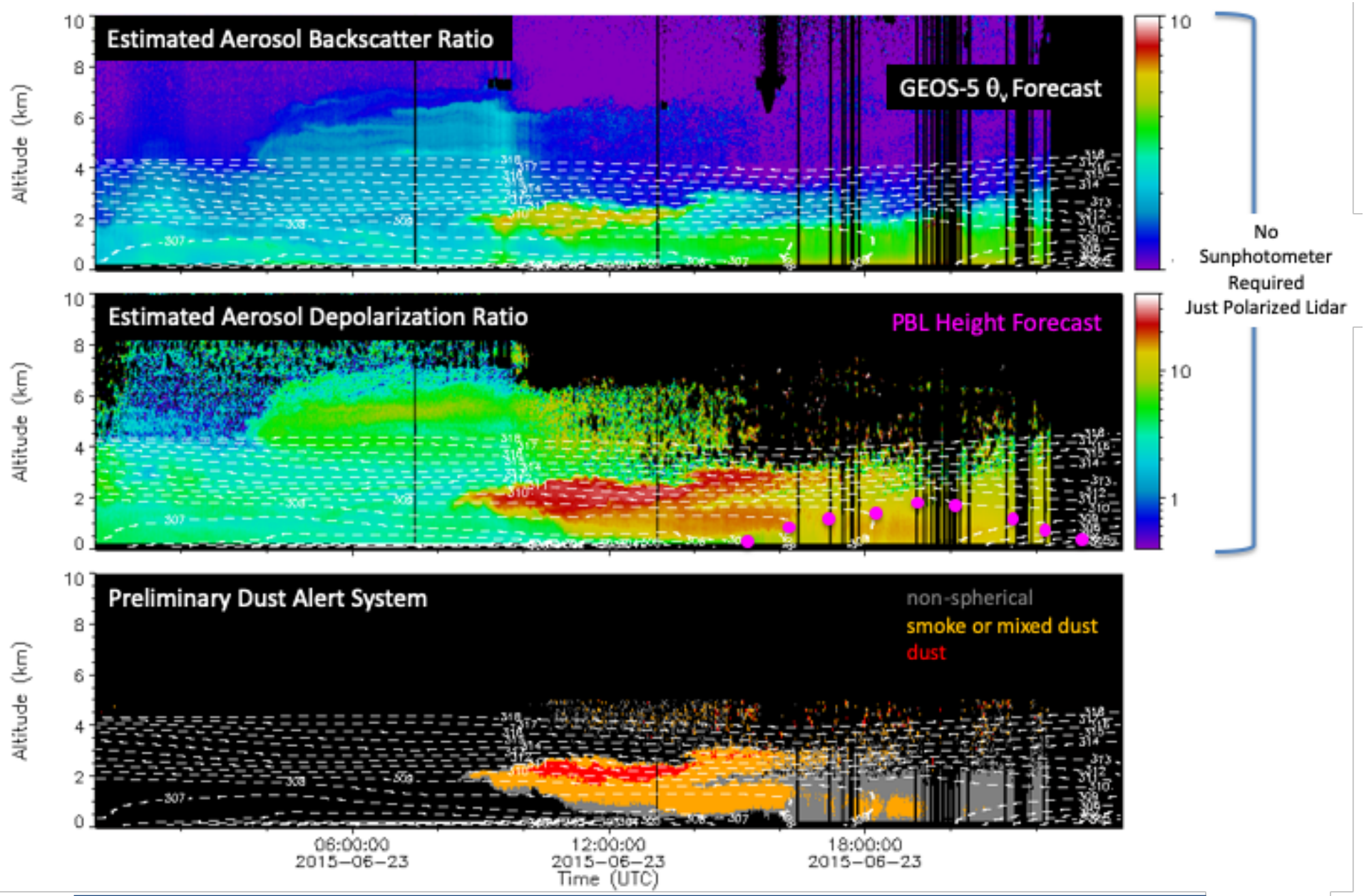
International Cooperative for Aerosol Prediction (ICAP)

- Members from operational forecast centers worldwide & data providers
- Developed Research Multi-model Ensemble (MME) forecasting speciated AOD

Dust detection, alert system

- Local air quality assessment
- Aerosol forecasting (ICAP members)
  - Includes WMO Sand & Dust Storm Warning & Advisory System (SDS-WAS)
  - Model verification (NRT and historical)
  - Eventual assimilation
- Research support (catalog dust occurrences)

MPLNET Support for operational aerosol forecasting: dust detection



Conclusion

GALION networks and related ceilometer and lidar networks have grown drastically this century

- Global coverage has increased correspondingly, more data available

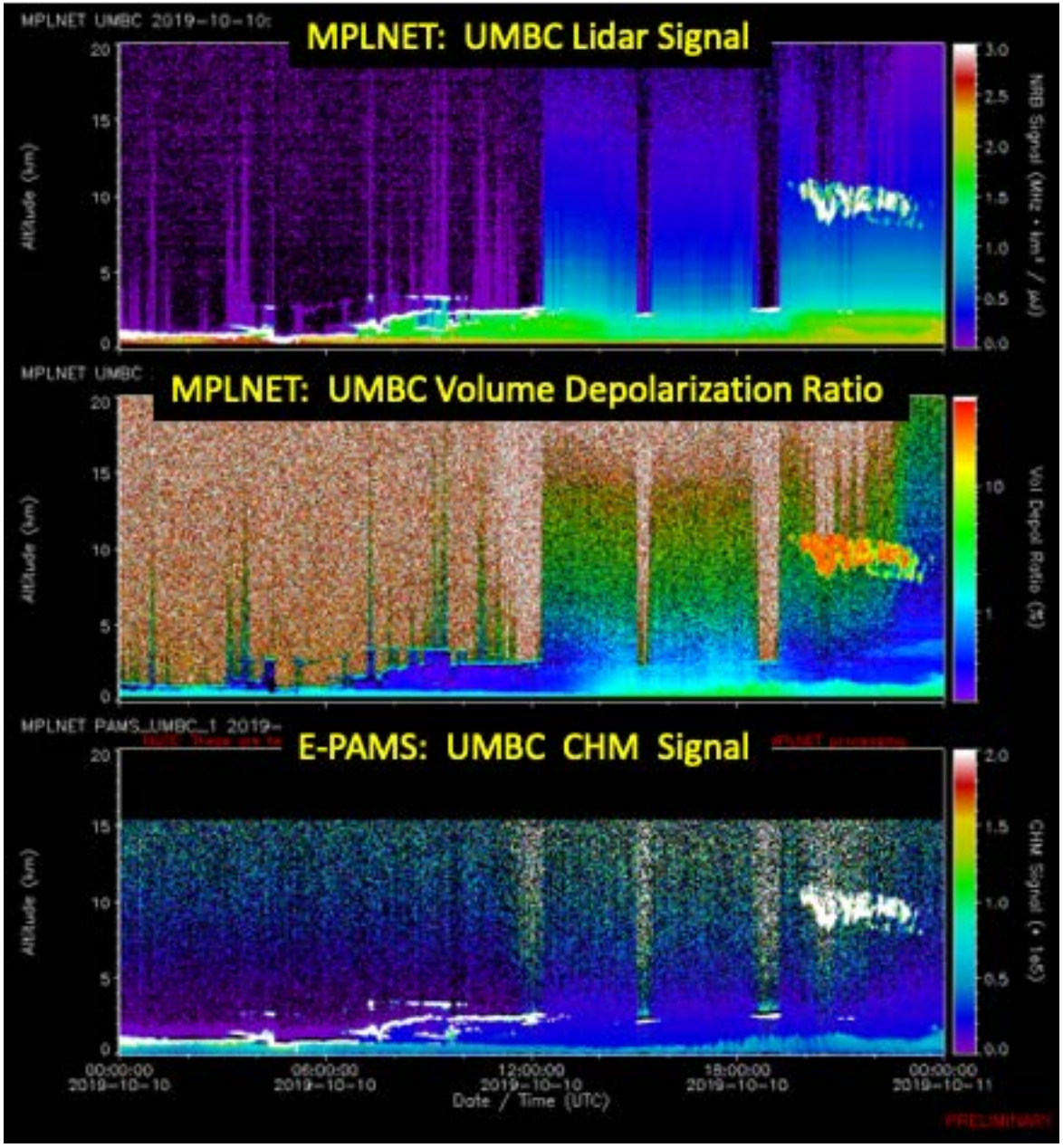
However, ground lidar data is now dispersed over many different data centers

- also, products, file formats, NRT capability, etc all vary
- more complicated process for users to discover & access all this new data

GALION Goal: create a world data center for lidar network data

- Distributed approach utilizing existing network level data centers
  - Provide common metadata archive for search & discovery
  - eventually common data products & file download
- MPLNET is planning to build a US GALION data center node
  - can support lidars outside MPLNET

MPLNET & UMBC: E-PAMS Collaboration



Conclusion

GALION networks and related ceilometer and lidar networks have grown drastically this century

- Global coverage has increased correspondingly, more data available

However, ground lidar data is now dispersed over many different data centers

- also, products, file formats, NRT capability, etc all vary
- more complicated process for users to discover & access all this new data

GALION Goal: create a world data center for lidar network data

- Distributed approach utilizing existing network level data centers
  - Provide common metadata archive for search & discovery
  - eventually common data products & file download
- MPLNET is planning to build a US GALION data center node
  - can support lidars outside MPLNET

NA Contribution to GALION could grow with addition of new networks

- I propose creation of a NA lidar network working group
  - Gather information on each network
  - develop plans to fill coverage gaps
  - teams for processing/calibration standards
  - Consider a common, distributed data center ala GALION
  - Provide career pathways for students