Satellite Derived Annual PM2.5 Data Sets in Support of United Nations Sustainable Development Goals

March 15-29, 2017
Pawan Gupta, and Melanie Follette-Cook
Agenda

3 week webinar series

Week 1: ARSET, Remote Sensing and SDGs

Week 2: WHO PM2.5 Data Sets

Week 3: Case Study Analysis
Learning Objectives

• Become familiar with the UN Sustainable Development Goals, as well as the satellite observations of air quality that are used to calculate indicators 3.9.1 and 11.6.2

• Learn about PM2.5 estimates made using satellite, surface, and model data sets

• Understand how to use the 2014 WHO data set and access the indicator data for a city or country
Session 1: Outline

1. Brief Introduction to ARSET Program
2. Introduction to SDGs

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Applied Remote Sensing Training Program (ARSET)
NASA’s Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- Empowering the global community through remote sensing training
- Part of NASA’s Applied Sciences Capacity Building Program
- Goal: increase the use of Earth Science in decision-making through training for:
  - policy makers
  - environmental managers
  - other professionals in the public and private sector
- Trainings offered focusing on applications in:

  Disasters  Ecoforecasting  Health & Air Quality  Water Resources
ARSET Training Levels

**Fundamentals, Level 0**
- Online only
- Assumes no prior knowledge of remote sensing

**Basic Training, Level 1**
- Online and in-person
- Requires level 0 training or equivalent knowledge
- Specific applications

**Advanced Training, Level 2**
- Online and in-person
- Requires level 1 training or equivalent knowledge
- More in-depth or focused topics

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**Fundamentals of Remote Sensing:** Fundamentals of Remote Sensing

**Basic Training:** Introduction to Remote Sensing for Air Quality Applications for the Indian Subcontinent and Surrounding Regions

**Advanced Training:** Advanced Webinar: Satellite Remote Sensing of Particulate Matter Air Quality
ARSET Air Quality Trainings

Remote Sensing

Satellites

Images

Algorithms

Data & Tools

Column to Surface

Dust and Smoke

Transport

Satellite & Model Comparison

Air Quality Trends

Vertical Profiles
ARSET Website

http://arset.gsfc.nasa.gov/
UN Sustainable Development Goals (SDGs)

Transforming Our World: The 2030 Agenda for Sustainable Development

- A plan of action for people, planet and prosperity

- All countries and all stakeholders, acting in collaborative partnership, will implement this plan

- 17 SDGs and 169 targets under this agenda

- Balance the three dimensions of sustainable development:
  
  – economic, social, and environmental

- In this webinar series, our focus will be particle air pollution

Text adapted from “Transforming our world: the 2030 Agenda for Sustainable Development”
Air pollution was responsible for 5.5 million deaths in 2013.
Satellite data can help quantify the impact on human health.
United Nations Sustainable Development Goals

• Goal 11, Target 11.6, Indicator 11.6.2
  – Goal 11:  Make cities and human settlements inclusive, safe, resilient and sustainable
    • Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
      – Indicator 11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)

• Goal 3, Target 3.9, Indicator 3.9.1
  – Goal 3: Ensure healthy lives and promote well-being for all at all ages
    • Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
      – Indicator 3.9.1: Mortality rate attributed to household and ambient air pollution
      – Meta data (http://unstats.un.org/sdgs/metadata/files/Metadata-03-09-01.pdf)
Air Quality Monitoring
Common Terminology

- Aerosols
- Particulate Matter
- Atmospheric Aerosols
- Particles
Motivation: Tiny but Potent
Pollution Sources

Atmospheric aerosols are highly variable in space and time

- Dust
- Soot & Smoke
- Fossil Fuels & Biomass Burning
- Volcanoes

![Diagram of pollution sources](Image)
Traditional Air Quality Monitoring

Images from: http://aqicn.org/products/monitoring-stations/
Air Quality Monitoring and Reporting

Image Credit: AirNow map, USEPA. http://www.airnow.gov
Global Status of PM2.5 Monitoring

Population Density

Ground Sensor Network
Global Status of PM2.5 Monitoring

- Many countries do not have PM2.5 mass measurements
- Spatial distribution of the existing ground network does not support the high population density
- Surface measurements are not cost effective
- How about using remote sensing satellite observations?
Aerosol Optical Thickness (MODIS Aqua)

Several satellites provide state-of-the-art aerosol measurements globally, on a daily basis.
NASA’s Current and Upcoming Missions
Fundamentals of Satellite Remote Sensing
What is remote sensing?

- Collecting information about an object without being in direct physical contact with it
Remote Sensing: Platforms

- The platform depends on the application
- What information do you want?
- How much detail do you need?
- What type of detail?
- How frequently do you need the data?
What Does a Satellite Measure?

Adapted from Peterson (2007) http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm
Measurements to Visual: True Color Images
What can we learn from true color imagery?

MODIS Terra Image, April 19, 2013

- Clouds
- Aerosols Over Land
- Aerosols Over Ocean
- Glint
- Snow
- Aerosols Over Land
- Data Collection Gap
How do we identify aerosols in true color images?

More reliable when a clear source is in the image

- Australian dust
- Sangeang Api, Indonesia eruption
- Urban: industrial or smoke pollution?
- Indian oil fires
How do we identify aerosols in true color images?

More reliable when a clear source is in the image

- Sahara dust
- Wildfire smoke
- Urban-industrial/smoke pollution?
- Smoke from Alaskan wildfires (2004)
Daily Satellite Coverage

MODIS

VIIRS

MISR
What can we learn from true color imagery?

MODIS Terra Image, April 19, 2013

Clouds

Satellite Observations (Spectral Radiance)

Glint

Physics, a priori information, assumptions, and more

Geophysical Parameters (AOD)

Data Collection Gap

Aerosols Over Land

Aerosols Over Ocean

Snow

Glint
Aerosol Optical Depth (AOD) or Aerosol Optical Thickness (AOT)
Optical Depth

The optical depth expresses the quantity of light removed from a beam by \textit{scattering} or \textit{absorption} during its path through a \textit{medium}

Optical depth $\tau$ as

$$ I = I_0 e^{-m\tau} $$

$$ m = \sec \theta_o $$

$$ \tau = \tau_{Rayl} + \tau_{aer} + \tau_{gas} $$

Optical depth due to aerosols in the atmospheric column is called \textbf{aerosol optical depth}
Inferring AOD and PM2.5 from Visuals

**Pittsburgh**

PM$_{2.5} =$ 45 μgm$^{-3}$

PM$_{2.5} =$ 4 μgm$^{-3}$

*July 2, 2001*  
*July 18, 2001*

Pictures are taken from the same location, at the same time of day, on two different days

AOD = ~0.8  
AOD = ~0.1

Image Credit: Learning with CLEAR: Introduction to Aerosols - What Are Aerosols?  
Inferring AOD and PM2.5 from Visuals

Singapore

High AOD

Low AOD

Image Credit: Roslan Rahman/AFP/Getty Images
Aerosol Optical Depth from Satellites

- Aerosols
- Water vapor + other gases (absorption)
- Rayleigh Scattering
- Ozone
- Column measurement 10km
- Surface
Aerosol Optical Depth from Satellites

AOT(\(\tau\)) = \(\int \beta_{\text{ext}} \, dz\)
- particle size
- composition
- water update
- vertical distribution

There are satellite retrieval issues: inversion (e.g. aerosol model, background)
Aerosol Optical Depth from Satellites

- Seven MODIS bands are utilized to derive aerosol properties
  - 0.47 μm
  - 0.55 μm
  - 0.65 μm
  - 0.86 μm
  - 1.24 μm
  - 1.64 μm
  - 2.13 μm
- 10x10 km² resolution
- 3x3 km² resolution
Satellites Provide Global View of Particles

Aerosol Optical Depth at 550nm
(Mean of 2003 to 2008)

• AOD:
  – column integrated value (top of the atmosphere to surface)
  – optical measurement of aerosol loading
  – Unitless
  – a function of shape, size, type number concentration of aerosols, and wavelength of measurement
AERONET measurements of aerosol optical depth are considered ground truth and are used to validate satellite aerosol retrievals.
AOD to PM2.5
Satellite vs. Ground Observation

AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type and number concentration of aerosols.

Aerosol Optical Depth

PM2.5 mass concentration (µgm⁻³) -- Dry Mass

PM2.5 – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level.
AOD – PM2.5 Relationship

Figure 14. Relationship between 24-hour PM$_{10}$ concentrations and daily averaged AERONET $\tau_a$ measurements from August to October 2000 in northern Italy.

Chu et al., 2003

Wang et al., 2003
Spatial Patterns in AOD–PM2.5 Relationship

Gupta 2008
Satellite Remote Sensing of PM2.5: Summary

- Satellite Observations
  - Statistical Approach
  - Model Scaling
  - Data Assimilation

PM2.5 Mass Concentration (μgm⁻³)
Why Satellites?
Global Status of PM2.5 Monitoring

Population Density

Ground Sensor Network
Global Status of PM2.5 Monitoring: Future View

van Donkelaar et al., 2010
Suggested References


Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land?

**IMPLICATIONS**

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

In 2007, the A&WMA Critical Review by Bachmann discussed the history of the National Ambient Air Quality Standards (NAAQS). The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congress

EPA has taken a satellite observations role for itself in the Exceptional Events Rule. If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is
Homework: Due March 21, 2017

• Available at: [https://goo.gl/forms/z6ORwSeewzsFANPX2](https://goo.gl/forms/z6ORwSeewzsFANPX2)

• All training materials (slides, recordings, and homework assignments) are available at: [http://arset.gsfc.nasa.gov/airquality/webinars/AQ-SDG-17](http://arset.gsfc.nasa.gov/airquality/webinars/AQ-SDG-17)
Next Week

WHO Resources for Global Air Quality Assessment

Week 1: ARSET, Remote Sensing and SDGs

Week 2: WHO PM2.5 Data Sets

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