

Calculation of Precipitable Water for Stratospheric Observatory for Infrared Astronomy Aircraft (SOFIA)

Airplane in the night sky

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Abstract-

Stratospheric Observatory for Infrared Astronomy, or SOFIA, is the new generation airborne observatory station based at NASA's Dryden Aircraft Operations Facility, Palmdale, CA, to study the universe. Since the observatory detects infrared energy, water vapor is a concern in the atmosphere due to its known capacity to absorb infrared energy emitted by astronomical objects. Although SOFIA is hoping to fly above 99% of water vapor in the atmosphere it is still possible to affect astronomical observation. Water vapor is one of the toughest parameter to measure in the atmosphere, several atmosphere modeling are used to calculate water vapor loading. The water vapor loading, or Precipitable water, is being calculated by Matlab along the planned flight path. Over time, these results will help SOFIA to plan flights to regions of lower water vapor loading and hopefully improve the imagery collection of these astronomical features.

Introduction:

NASA is developing the Stratospheric Observatory for Infrared Astronomy - or SOFIA - as a world-class airborne observatory that will complement the Hubble, Spitzer, Herschel and James Webb space telescopes and major Earth-based telescopes. SOFIA is a joint program by NASA and DLR Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center). Completion of systems installation, integration and flight test operations are being conducted at NASA's Dryden Flight Research Center at Edwards Air Force Base, Calif., from 2007 through 2010. SOFIA's science operations are being planned jointly by the Universities Space Research Association (USRA) and the Deutsches SOFIA Institut (DSI) under leadership of the SOFIA Science project at NASA's Ames Research Center at Moffett Field near San Jose, Calif.

As the world's largest airborne astronomical observatory, SOFIA will provide three times better image quality and vastly increased observational sensitivity than the Kuiper Airborne Observatory. From a base at NASA Dryden, SOFIA mission operations will be conducted over virtually the entire globe. Missions will be flown at altitudes of 39,000 to 45,000 feet, above 99 percent of the water vapor in the lower atmosphere that restrict the capabilities of ground-based observatories over most of the infrared and sub-millimeter spectral range.

Background – Water Vapor and Infrared radiation:

During the transmission of electromagnetic radiation, such as radio waves, microwaves, infrared radiation, visible lights, x-rays, and gamma rays, through a medium containing water molecules (e.g. earth atmosphere), portions of the electromagnetic spectrum are absorbed by water molecules. This water absorption occurs preferentially at certain characteristic wavelengths while the balance of the spectrum is transmitted with minimal effects. Strong absorbance by water vapor occurs at wavelengths around 2900, 1950, and 1450 nanometer (nm), with other absorption all in the infrared spectrum. The effect of water vapor absorption is important consideration in infrared astronomy due to the fact that infrared astronomy is detecting astronomical objects by infrared radiation emission.

Earth's Atmosphere and Geometric Altitude:

Earth's atmosphere reaches over 600 kilometers (372 miles) from the surface of the Earth, and it is distinguished by thermal characteristic, chemical composition, movement, and density, by five different layers, from the highest to the lowest: Exosphere (800mi +), Thermosphere (\approx Mesosphere \sim 400mi), Mesosphere (Stratosphere \sim 50 mi), Stratosphere (Troposphere \sim 31mi), and Troposphere (Sea Level \sim 11mi), which contains 99.13% of water vapor. This is the reason most of the commercial and military aircrafts are flying above this layer; and so is SOFIA.

Tool – weather balloon:

A weather balloon is a type of balloon that will fly to high altitude and carry instruments that can transmit the information of atmospheric pressure, temperature, humidity, and wind speed in different atmospheric layers. In order to obtain wind data, it can be tracked by radar or navigation system, such as satellite based Global Positioning System (GPS).

Method:

Water vapor is one of the toughest parameter to measure in the atmosphere, several atmosphere modeling are used to calculate water vapor loading. The water vapor loading, or Precipitable water, is being calculated by Matlab along the planned flight path. The equation we are writing the program is:

$$\text{Precipitable Water} = \frac{5}{980.616} * \sum_i^{i+1} (W_{i-1} + W_i) * (P_i - P_{i-1})$$

Where 980.616 = acceleration of gravity $\left(\frac{cm}{sec^2}\right)$

W = mixing ratio in grams per kilogram

P = pressure (millibars)

i = index ranging from the surface to the current level

The atmosphere can be divided by 72 vertical layers and “i” is the indication of each layer. “W” (mixing ratio) and “P” (pressure) are the measured data taken at each vertical layer by the weather balloon. Since the mixing ration has to be calculated by the measuring data, it is necessary to derive and combine the equations from humidity, temperatures, and saturation in order to do so. However, the measured data is stored in structure arrays, which is multi-matrices; so having another program to access the data before calculation is mandatory.

Results & Discussion:

Before calculating the data from multi-matrices, running sample data from weather stations and calculating water vapor at each geometric altitude seems to be a good start. Most of the data from

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weather station in the United States are taken by the weather balloon. After calculating water vapor loading in the atmosphere from weather station, It is good to compare the results with published results to verify the code.

Resources:

http://www.nasa.gov/mission_pages/SOFIA/page2new_rd.html

http://en.wikipedia.org/wiki/Water_vapor#Water_vapor_in_Earth.27s_atmosphere

http://en.wikipedia.org/wiki/Atmosphere_of_Earth

http://en.wikipedia.org/wiki/Electromagnetic_absorption_by_water

Photos: (In the order from left to right and then top to bottom)



327573main_ED09-0089-88c_946-710

Several NASA science aircraft, including (from bottom) the SOFIA observatory, the DC-8 airborne laboratory and an ER-2 high-altitude aircraft, along with one of NASA's modified 747 Shuttle Carrier Aircraft, occupied the Dryden Aircraft Operations Facility during dedication ceremonies and an open house for employees and their families on April 9, 2009.

http://www.nasa.gov/mission_pages/SOFIA/multimedia/imagegallery/index.html



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The high-tech German-built infrared telescope and its associated lower flexible telescope cavity door are rotated upward to their maximum 58-degree vertical position in this photo taken during the last flight in the SOFIA observatory's flight envelope-expansion test series. The pilot in a NASA F/A-18 keeps a close watch on the airborne observatory while flying in close formation during the tests. August 4, 2010 (NASA photo / Carla Thomas)

http://www.nasa.gov/mission_pages/SOFIA/multimedia/imagegallery/index.html



254362main_ED08-0067-19c_946-710

NASA's SOFIA flying observatory was captured in striking relief during nighttime telescope characterization tests in Palmdale, Calif., in March 2008.



292292main_ED08-0296-11c_946-710

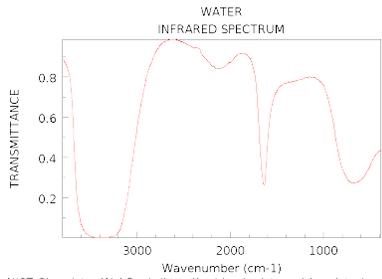
**The 2.5-meter infrared telescope peers out from its cavity in the SOFIA airborne observatory during nighttime line operations testing at Palmdale, Calif. November 12, 2008
NASA Photo / Tom Tschida**

http://www.nasa.gov/mission_pages/SOFIA/multimedia/imagegallery/index.html

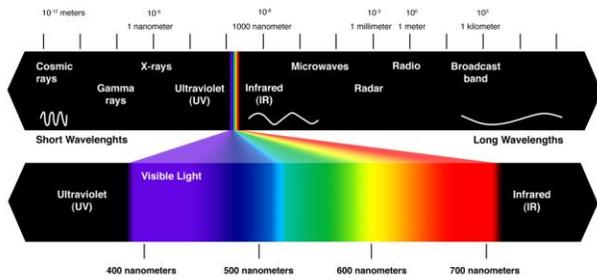


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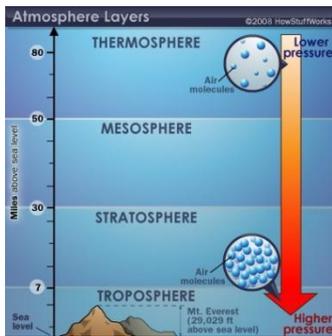
Author's illustration of how water vapor loading can possibly affect the data for SOFIA



NIST Chemistry WebBook (<http://webbook.nist.gov/chemistry>)

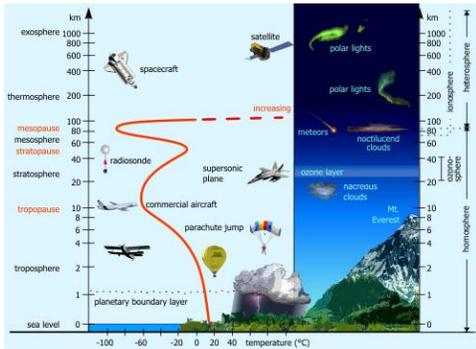


<http://local.content.compendiumblog.com/uploads/user/2af9dc1d-8541-42e4-a91f-6aaf97caf33a/4844a17e-a4fb-4018-9d3a-31dc846044ee/Visible%20spectrum.jpg>



weather-atmosphere-layers

<http://mail.colonial.net/~hkaiter/AaimagesNEW/weather-atmosphere-layers.jpg>



atmosphere_02

http://www.theozonehole.com/images/atmosphere_02.jpg



View from 4500 feet above the surface of the Earth

http://farm4.static.flickr.com/3086/3119009289_4d8fc0bc78.jpg



Filling up the weather balloon in Mojave desert in **NASA Spaceward Bound 2010**, Zzyzx rd, CA

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The author works with Mat Lab @ NASA Dryden Flight Center in Edwards AFB



Weather Balloon flying, Zzyzx, CA 2010