5-1

ECE 583

Lecture 5
Solar radiometry overview, sensor design, radiometer examples

Applications

•Satellite Solar Occultation Measurement of Gas and Aerosol Concentration

•Airborne Survey Experiments for Aerosol Characteristics and Gas Concentration

•Ground Based Experiments and Global Networks for Aerosol and Cloud Monitoring

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What is solar radiometry?

Viewing the sun directly with a spectroradiometer allows information about the sun and atmosphere to be derived

- Solar radiometry has a long history of use dating to the late 1800s and early 1900s
  - Early efforts more interested in determining solar characteristics
  - Samuel Langley used this approach in an attempt to measure the solar constant
- Improvements in detector technology and spectral selection led to development of systems to derive atmospheric properties
- Solar radiometers are currently used to derive
  - Aerosol amounts
  - Aerosol sizes
  - Water vapor, ozone, and other gaseous absorber amounts
  - Absolute solar output as a function of wavelength

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Why study solar radiometry?

Solar radiometry is an example of a passive remote sensing system that allows a basic understanding of the sensor and applications of remote sensing

- Basic radiometric system
  - Examine the sensor components
  - Sensor design
  - Optimization
- Application requires approaches typical of all remote sensing problems
  - Underdetermined problem requiring assumptions to allow solution
  - Sensor defines outcome
  - Noise
- Results of application can be used to determine changes to the sensor design
  - Diffuse skylight correction
  - Sky radiance measurements

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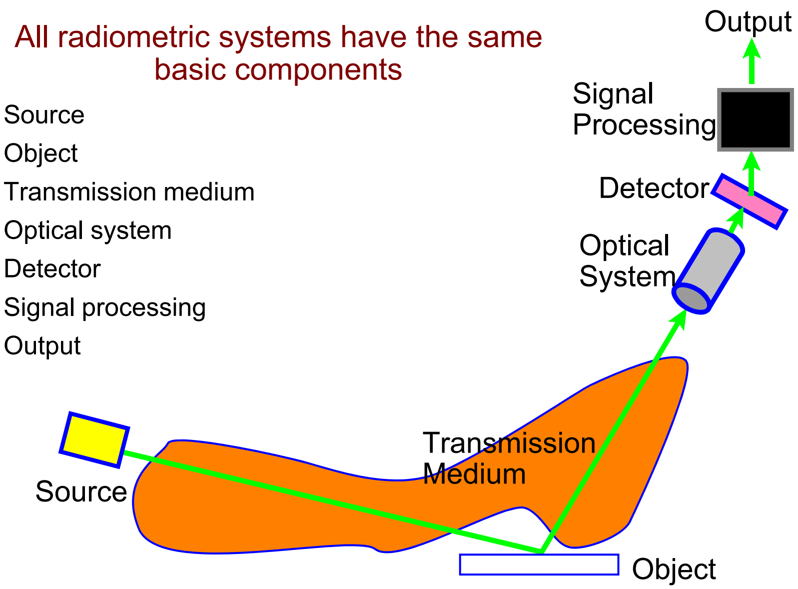
Radiometric system

All radiometric systems have the same basic components

- Source
- Object
- Transmission medium
- Optical system
- Detector
- Signal processing
- Output



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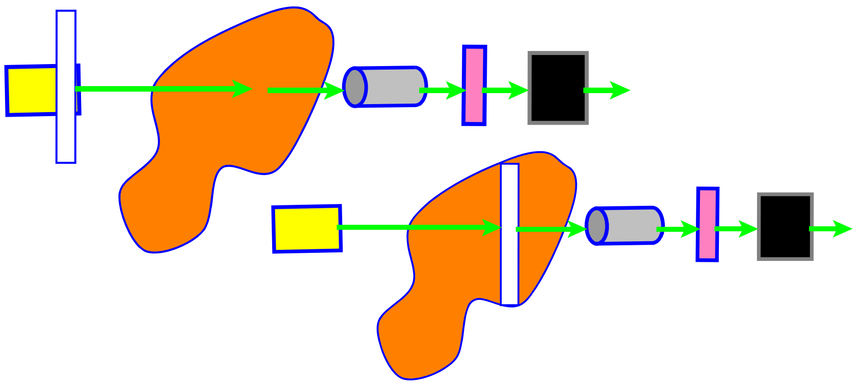
Solar radiometry

In the case of solar radiometry, the source, object, and transmission media become intermingled

- Absolute solar radiometry uses the sun as the source and object
- Atmospheric studies use the sun as the source and the transmission media as the object



Optical Thickness Basics

The optical thickness, τ, of a media is related to the transmission by:

$T = \exp(-\tau)$

Useful approximation for small optical thickness $T = 1 - \tau$

Unlike transmission, optical thickness is proportional to the amount, density times thickness, of the media.

$\tau = 1$ where T = .368 with doubled density or thickness gives $\tau = 2$ where T = .135

The total optical thickness is the sum molecular scattering, gas absorption, aerosol scattering and absorption and cloud scattering losses.

<u>Typical values</u>

Molecular Scattering: .55um – 0.1, 1.06um - .007 (4th power dependence)

Ozone Absorption: .55um – 0.03, .32um - .3

Aerosol Scattering and Absorption: Tucson - .08 SE Asia Cities - .8-2

Cirrus clouds: .001- .5 , All Clouds: To over 1000

Basic Solar Radiometer (Photometer) Principal

$I(\lambda) = I_o(\lambda) \exp[-\tau(\lambda)m]$

Where $I_o(\lambda)$ is the instrument intensity signal outside the atmosphere

And m the relative air mass (to first order - secant of the solar zenith angle)

$\tau(\lambda) = -\log[I(\lambda) / I_o(\lambda)]/m$

Error - $d\tau(\lambda) = d(I(\lambda) / I_o(\lambda))$

for example

A 1% measurement error for τ=.01give a 100% error of the optical thickness

thus

Calibration and Stability are fundamentally important

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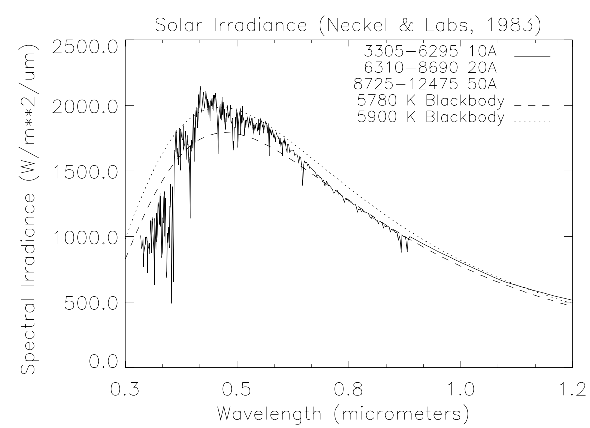
Solar output

Solar irradiance on the earth drives weather and climate

- Solar radiometers have been used to study both the spectral and total irradiance
- Ground-based, balloon-borne, space-borne radiometers
- Accuracy and precision improving but still an issue



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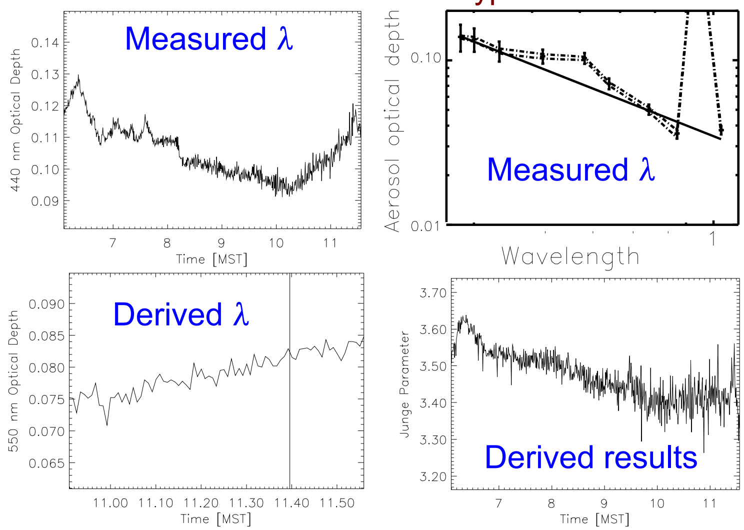
Aerosol parameters

Use measurements as a function of wavelength to infer amount of aerosols and type/size



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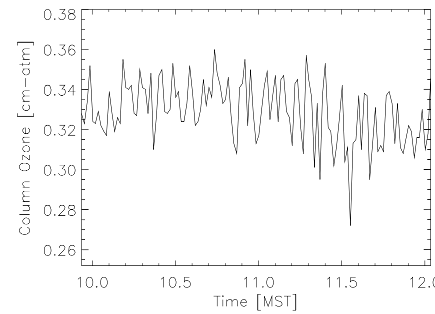
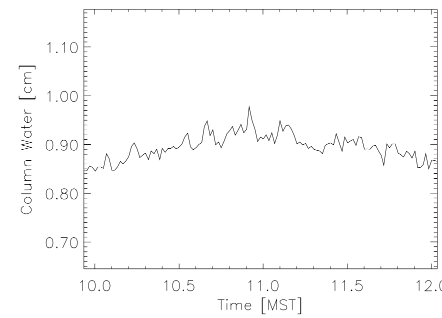
Ozone and water vapor

Once the Junge parameter is known, the total, molecular, and aerosol optical depths can be computed for any wavelength

- Optical depth curves include a measured value (440 nm) and derived value (550 nm)
- Water vapor and ozone amounts are shown for the same period





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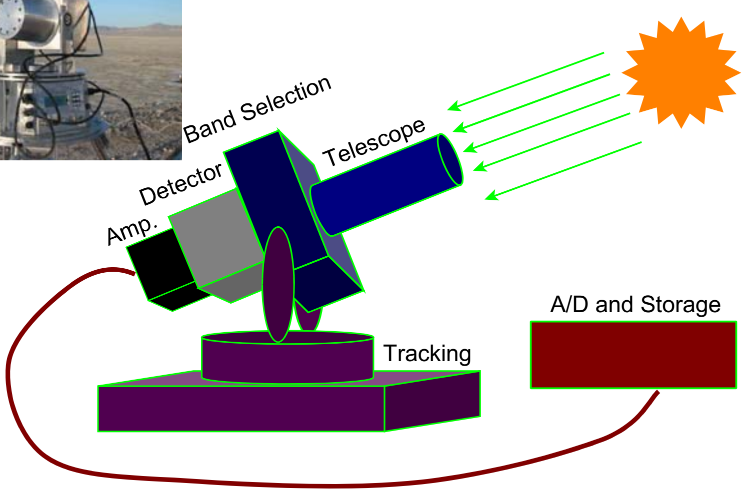
What are solar radiometers

Every solar radiometer has similar components



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Solar radiometer examples

Images below show 10-band solar radiometers constructed at the University of Arizona

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Solar radiometer examples

Images below show a French-built Cimel sun photometer

- Key difference with this instrument is that it is deployed and left behind
- Satellite transmitter allows remote operation
- This system also allows for measurements of sky radiance

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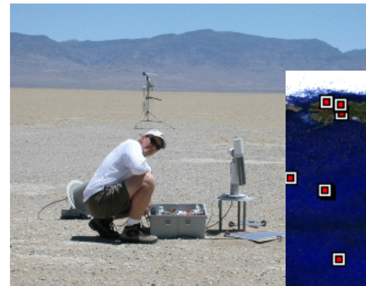
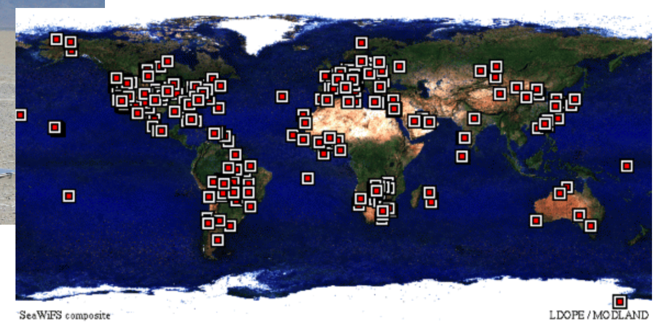
Cimel/Aeronet example

Aeronet is a collection of ground-based radiometers viewing the sun and sky to derive information about dust content

- Goal is to assist in global assessment of dust composition and amount
- Serve as ground truth for satellite-based measurements





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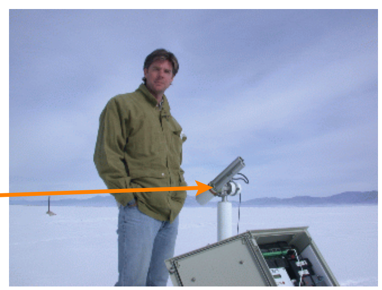
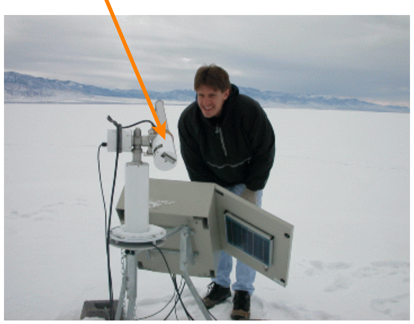
Cimel example

Can see here the components in the following images

- The two telescopes visible give different fields of view
- Band selection and detectors are not obvious but are at the base of the telescope





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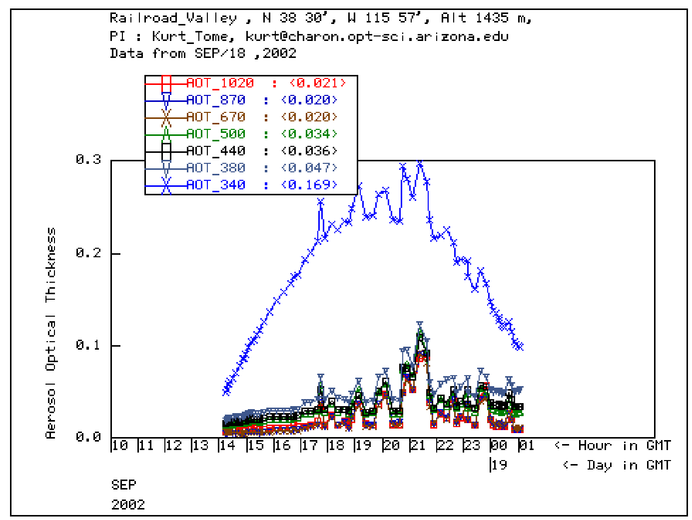
Sky radiance

Sky radiance and optical depth data are used to determine aerosol size distribution



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Sky radiance

The next level of improvement for characterizing the atmosphere is to use sky radiance measurements

- Almucantar scans measure the radiance from the sky at a constant elevation while rotating in azimuth
- Principle plane scans measure the sky radiance at a constant azimuth angle while scanning in elevation through the sun
- Most of the information for retrieving aerosol properties are contained in measurements near the sun
  - Difficult to measure due to MTF and stray light effects
  - Dynamic range is also an issue since the radiance changes rapidly with angle near the sun
- Cimel sun photometers are the most common instrument currently for making these measurements
  - Inversion of the radiance measurements yields aerosol size distribution
  - Advantage to Cimel instruments are that they can be deployed for many months at a time
- Advantage of sky radiance data is that it contains more information regarding the larger aerosol particles

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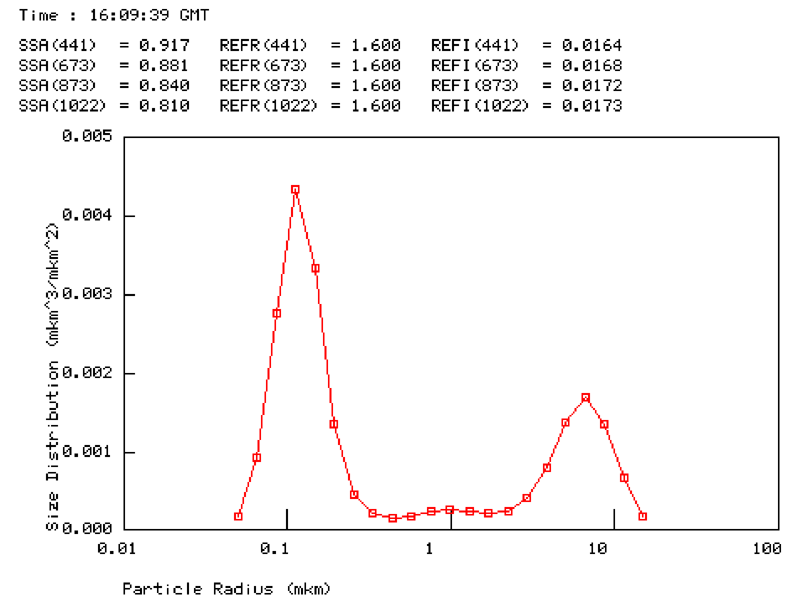
Size distribution retrieval



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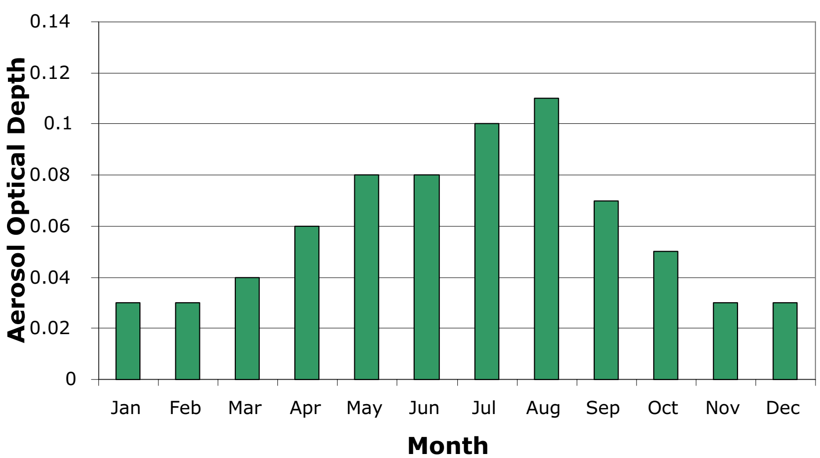
Cimel solar radiometer

Major advantage to Cimel is that it can be used to study the atmosphere at a given site for an extended period

- Results below are from Tucson in 2000



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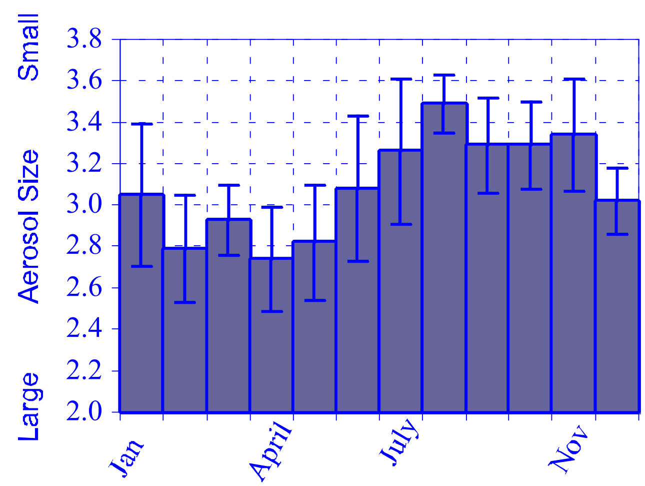
Cimel size distribution

Sky radiance data allows retrieval of size distribution

- The aerosol size has also been evaluated for the year 2000 by month based on the solar transmittance
- Larger particles are seen in spring
- Smaller particles typical in during wet season
- Makes some sense since wind conditions tend to pick up large dust particles



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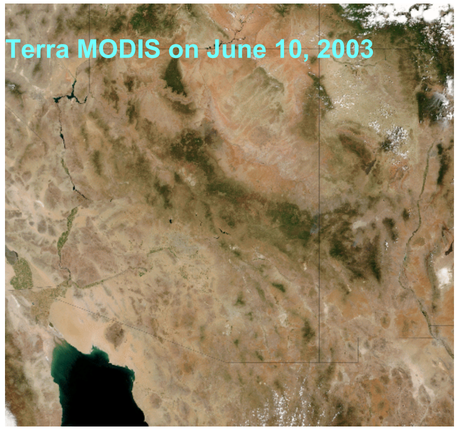
Smoke studies

Ability to study particle concentration and size leads to the conclusion that rare events can be studied

- Requires a combination of routine measurements as well as “fortuitous” winds to bring the smoke to the instrument
  - Cimel radiometer was not in operation in Tucson until July 15, 2003
  - Other RSG radiometers have been operated on a regular basis since February 2003
- Aspen fire started June 10, 2003
  - Prevailing winds kept most of the smoke to the north and east of the Catalinas
  - Could have chased the smoke, but logistics and travel restrictions prevented this
  - Wind shift in late June brought the smoke into the Tucson valley



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Terra and Aqua MODIS June 19

- Clear advantage to having sensors viewing at separate times during the day
- Note the smoke is being driven to the north and east away from the Tucson valley
- Also note the cloud development between the two images

Terra MODIS 17:55 UTC

Aqua MODIS 21:05 UTC

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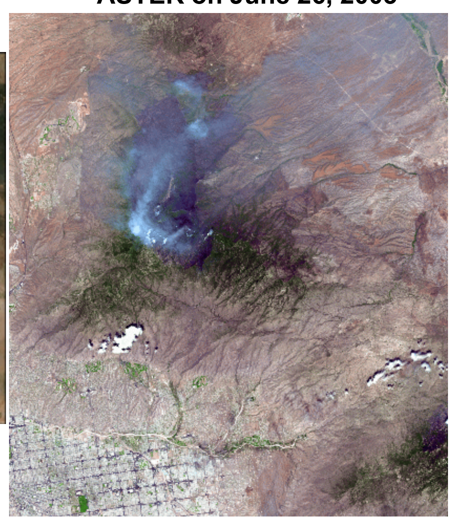
Subsequent dates

June 22, 2003

ASTER on June 26, 2003



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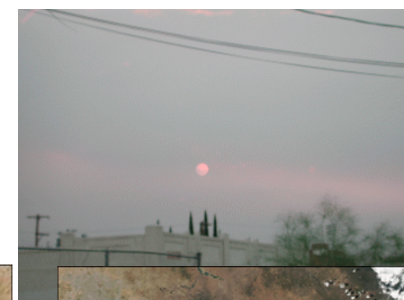
Wind shifted in late June

June 29, 2003

June 30, 2003 in Tucson



July 3, 2003

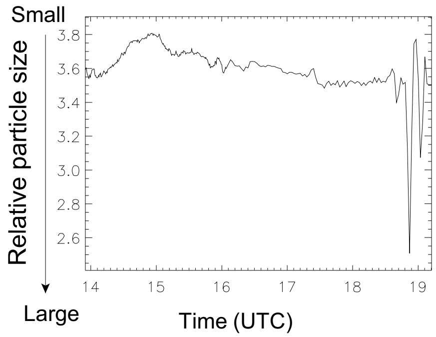
July 7, 2003

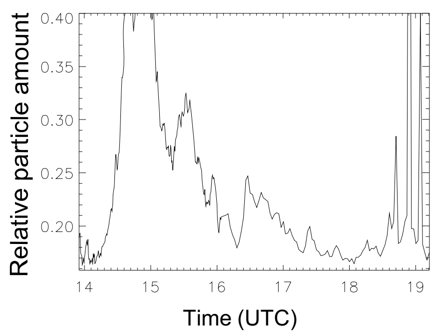
5-23

Smoke data

Results here are from measurements that were made on June 30 near downtown

- Graph on the left shows the relative concentration of particles
- Graph on right is related to particle size
- Historical results from 2000 show that these data are quite different from what is typically expected





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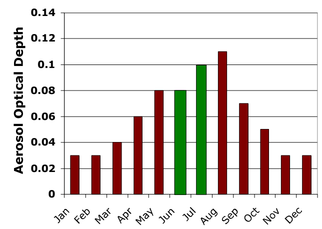
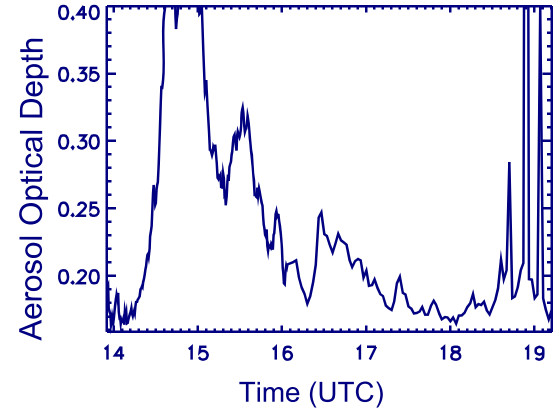
Retrieved AOD

Aerosol optical depth far exceeded typical values for June and July

- Standard deviations of average are 0.05 in optical depth
- Lowest values on June 30 exceed average by 1σ





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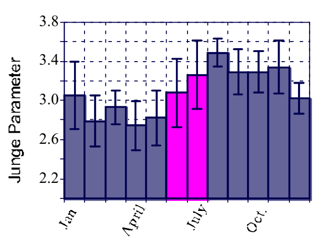
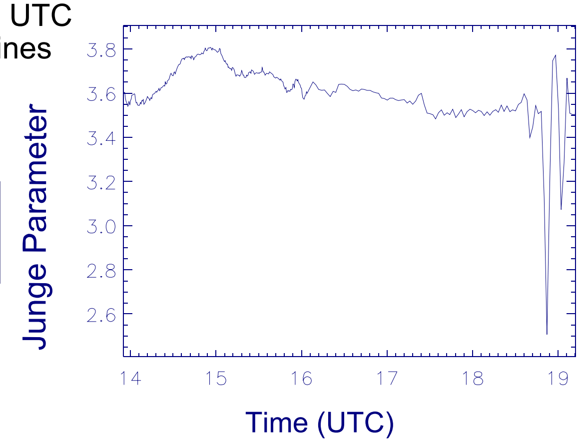
Retrieved Junge Parameter

Junge Parameter values exceed the average from 2000 by 1σ

- Junge parameter is more stable in time than the AOD
- Small values at 19 UTC are due to power lines





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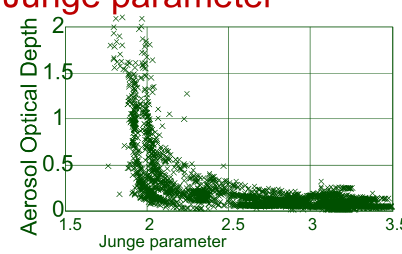
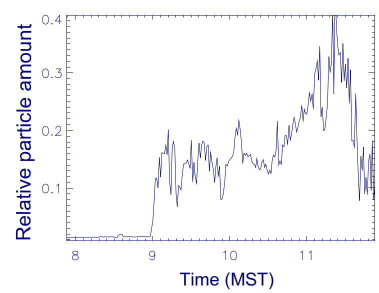
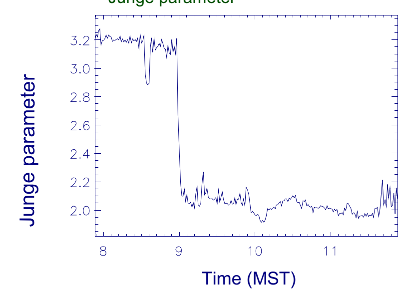
Comparison to cirrus

Can also get high optical depths from cirrus as well but this gives small Junge parameter

- Fresh smoke can also give large optical depth and small Junge parameter
- True of fresh smoke







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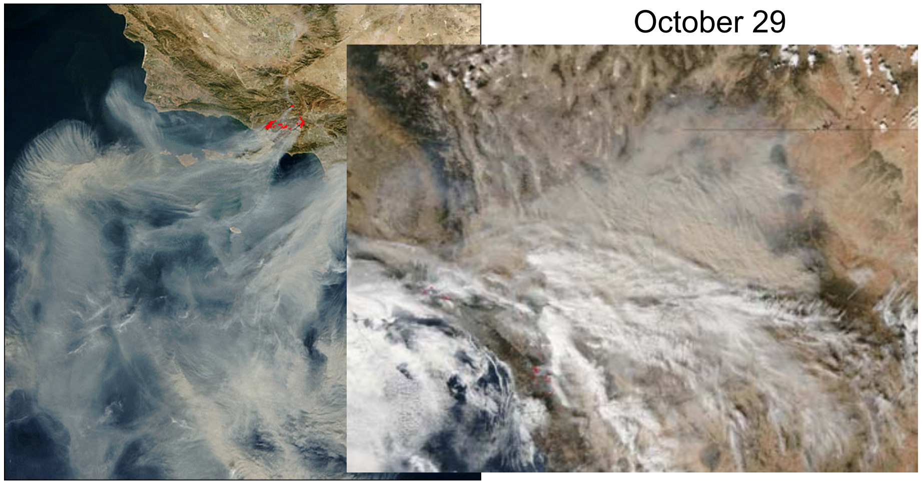
October 2003 case study

Fires in Southern California in October 2003 provided another opportunity to study smoke



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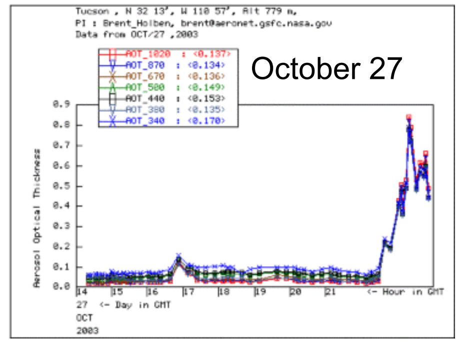
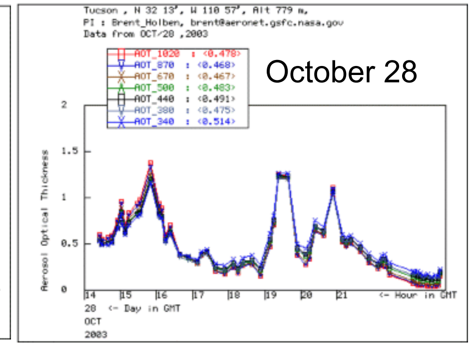
Optical depth results

Optical depths increased dramatically due to a frontal system moved in with strong winds and clouds

- Aerosol amount increased due to blowing dust and clouds
- What about smoke?





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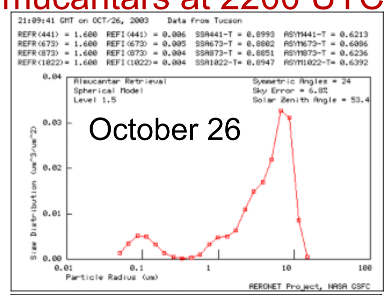
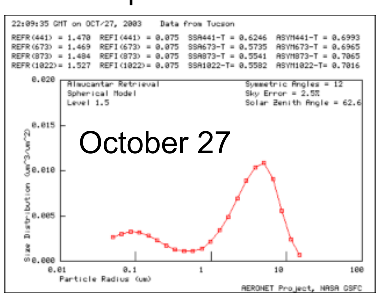
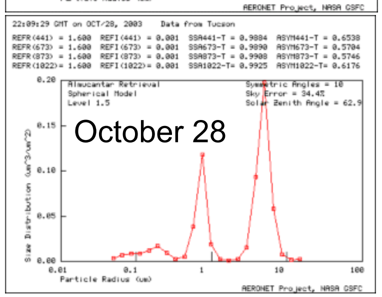
Size distributions

Size distributions from almucantars at 2200 UTC

- Plots are number densities for given particle sizes
- Upper right is Oct. 26 and shows a dominance of large particles as does Oct. 27 below
- Note 2nd peak on Oct. 28







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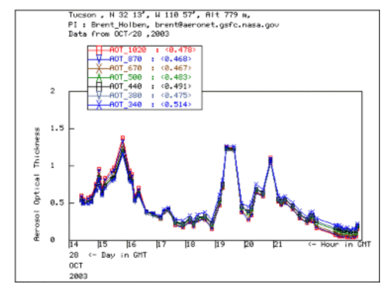
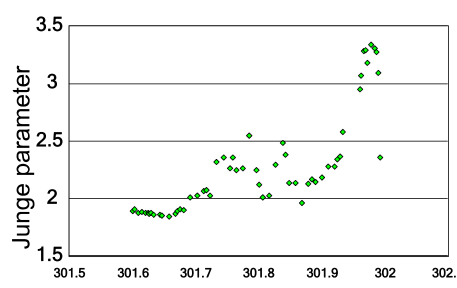
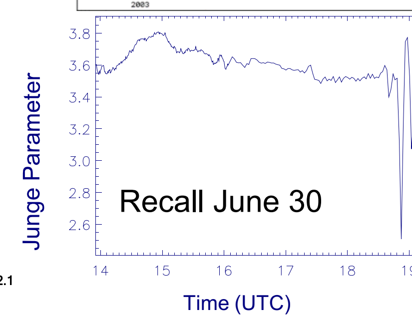
Smoke presence?

Numerous reports of citizens smelling smoke on Oct. 28

- Trajectory analysis by NOAA indicated the smoke traveled further north by >200 km
- Passive radiometer data shows primarily dust and clouds







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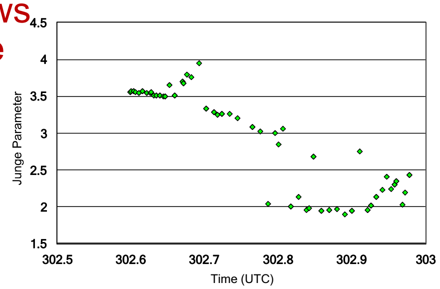
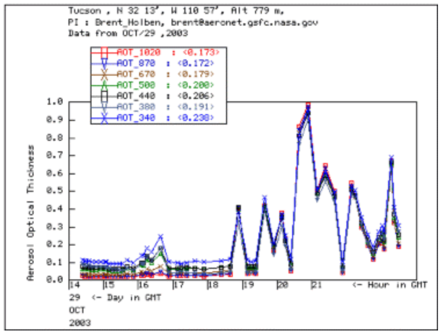
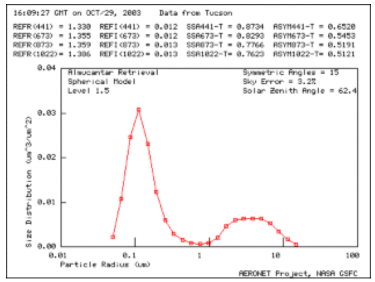
October 29

Data from October 29 shows possible smoke signature

- No reports of smoke on this date
- Sizes are more indicative of smoke







El Chichon Solar Photometer Experiment on NASA CV990 Airborne Laboratory – 1982/1983

(Spinhirne and King, JGR 1985)

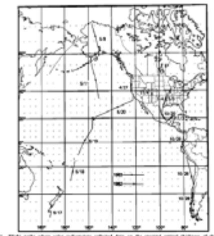


Fig. 1. Flight paths where solar radiometers collected data on the spectral optical thickness of the El Chichon stratospheric aerosol layer. Data were obtained from the NASA Electra aircraft from October 20 to November 4, 1982, and from the NASA Convair 990 aircraft from April 27 to May 28, 1983.

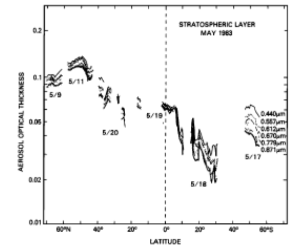


Fig. 3. Stratospheric aerosol optical thickness as a function of latitude for May 1983 and for all wavelengths in the range 0.440 μm ≤ λ ≤ 0.871 μm. Only results for flights through the central Pacific are shown.

El Chichon Solar Photometer Experiment on NASA CV990 Airborne Laboratory – 1982/1983

Aerosol Size Distribution Inversion

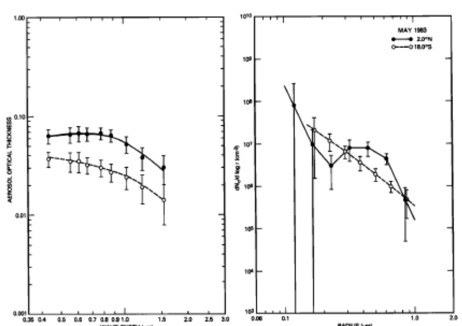


Fig. 7. As in Figure 5 except for data collected at 2°N and 18°S.

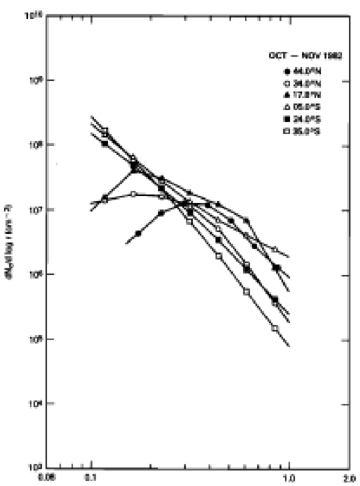


Fig. 11. Inverted size distributions for October and November 1982 for latitudes from 44°N to 35°S, where optical thickness data were only available from the visible solar radiometer (0.440 μm ≤ λ ≤ 0.871 μm).

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Solar radiometer examples

MFRSR - Multifilter rotating shadowband radiometer

- The MFRSR does not strictly fit our notion of the solar radiometer
- However, the analog of all parts are still present in this example
- A critical difference from the others is that the receiver is permanently mounted in a horizontal position

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MFRSR

Multi-filter, rotating, shadowband radiometer is a commercial system used to measure downwelling irradiance

- Both total (solar and skylight) and diffuse (block the solar disk)
- Can derive the solar component by differencing the total (also referred to as the global) irradiance and the diffuse
- The diffuse gives information regarding clouds and aerosol absorption
- MFRSR can also be deployed for extended periods
  - Will suffer some degradation of the collector
  - However, most often the ratio of diffuse to global is used to assess the aerosol absorption and this is not as sensitive to changes in collector
  - BRDF tends to remain constant with time, thus Langely method can be used to assess any degradation

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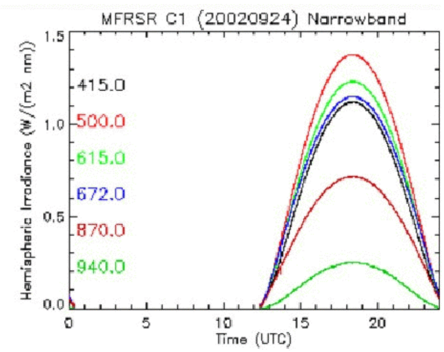
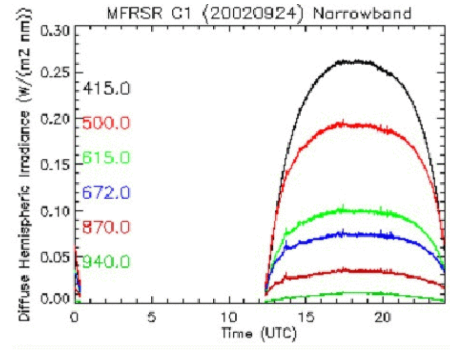
Measured downwelling irradiance

Current shadowband designs allow for direct and diffuse measurements in a spectral sense

- Graph on the left is the global or total irradiance and the graph on the right is the diffuse component only
- Note that the diffuse measurement at 415 nm is the largest
- The global irradiance at 500 nm is the largest





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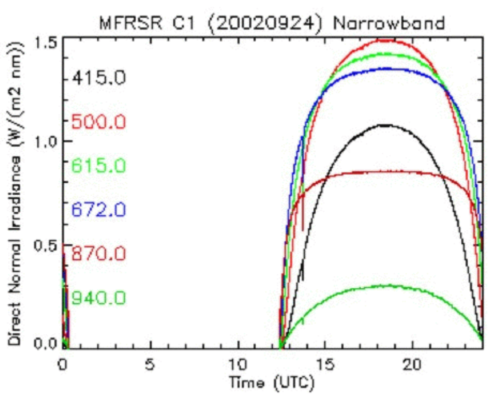
Measured downwelling irradiance

Because the angular response of the sensors is reasonably well known, the cosine incident effect of the direct irradiance can be corrected

- Graph to the right is the global irradiance corrected so as to simulate an instrument always pointing directly at the sun
- Note how the lines cross early and late in the day
- Also note that the 870-nm band has the flattest curve



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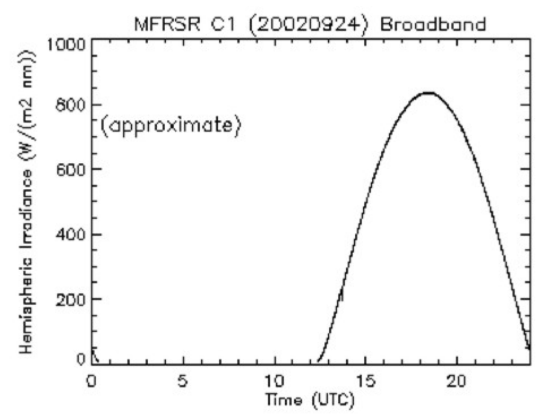
Measured downwelling irradiance

Most climate and meteorological models are interested in total downwelling irradiance (over all wavelengths)

- Spectral values can be “integrated” to give a total downwelling value
- Makes assumptions regarding the spectral shape of the downwelling irradiance
- The data on this page and previous page were obtained from the Department of Energy’s ARM (Atmospheric Radiation Measurement) program



http://education.arm.gov/nsdl/Visualization/nsa_quicklook_interface.shtml

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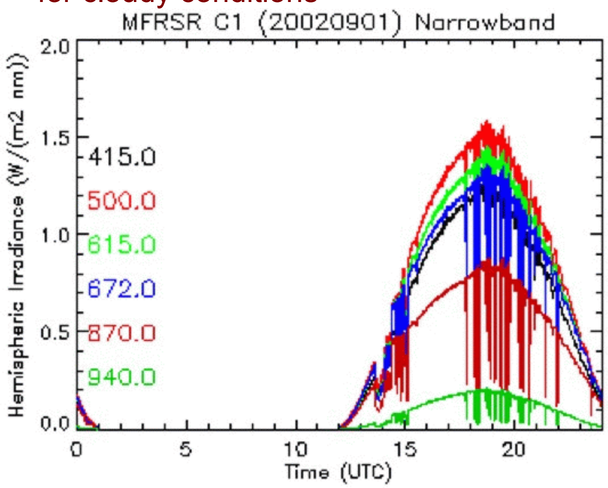
Measured downwelling irradiance - cloudy

Previous graphs were for clear skies while the figures below is for cloudy conditions

- Clouds are most noticeable in the global when the sun is obscured
- Clouds will still be apparent in the diffuse even if the sun is never covered



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Diffuse irradiance in cloudy skies

Diffuse irradiance in cloudy skies can increase dramatically in the presence of clouds