## World Trade Center Hot Spots

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Notes:

- The World Trade Center debris pile fire did not have a significant source of air
- The thermal and hyperspectral images below represent surface temperatures, the "optical depth" is at the most a few millimeters. ACS 919 (ACS919)
- Thermal Data was Used to Direct Firefighting Efforts .
- OSHA safety experts were concerned about the effects of the extreme heat on the crane rigging and the hazards of contact with the hot steel.
- A total of 4 million gallons of water percolated through the debris in the first 10 days and collected at the bottom of the Bathtub. llnl.gov (http://www.llnl.gov/tid/lof/documents/pdf/240430.pdf)
- 2000 gallons of Pyrocool FEF (UV-blocking) foaming agent were sprayed on the "pile" starting 09/28/01. newscientist.com (http://www.newscientist.com/article.ns?id=dn1634)
- Thermal data was acquired until at least 2/12/2002 [[1] (http://www.loc.gov/exhibits/911/911-maps.html) ]

Allows wiki administrators to add free-form widgets to the wiki by editing pages within the Widget namespace. Community-contributed widgets can be found on MediaWikiWidgets.org (http://www.mediawikiwidgets.org/Main\_Page)

2001-11-01 - The LiRo Group - LiRo at GROUND ZERO Work at the World Trade Center Involves the Firm's Top Personnel (link (http://web.archive.org/web/20050520232345/http://www.liro.com/lironews.pdf) )



These sprayers were also used to cool the high temperature debris before it left the site. Several trucks were returned to the site for additional cooling because the law enforcement officers would not let them through the tunnels leaving Manhattan until they stopped steaming.

[2] (http://www.davidmargules.com/images/gallery/08.jpg) [3] (http://web.archive.org/web/20110426061854/http: //www.davidmargules.com/images/gallery/08.jpg) 2002-01-01 - U.S. Army Corps of Engineers - New York City World Trade Center Disaster Deployment (link (http://web.archive.org/web/20020217132034/http://www.spk.usace.army.mil/cespkpao/jan-02/jan02-01.html) )

Leslie Robertson Confirms Molten Metal in WTC Basement: http://www.youtube.com/watch?v=rjmHqES\_lto

## Joe Allbaugh, the Director of FEMA, interviewed by Bryant Gumbel of CBS news on October 10 2001:

GUMBEL: We're seeing a lot of video of smoke pouring up from the debris.

ALLBAUGH: Correct.

GUMBEL: And we're hearing there are places where temperatures are still approaching and sometimes exceeding a thousand degrees.

ALLBAUGH: That's right.

GUMBEL: Why? Why do we have these hot spots? What's going on?

ALLBAUGH: Well, you have normal debris, you know, computers, paper, you have some areas that are hot pockets because of fuel. It's just too hot for rescuers to get into those areas. So we do not know yet what's in those areas, other than very hot,

molten material.

2001-10-04 - FEMA - FEMA Director Allbaugh with Bryant Gumbel, CBS Early Show (link (http://web.archive.org /web/20031211095910/http://www.fema.gov/doc/diz01/gumbel1004.doc) )

WTC Building 6 housed several federal agencies, primarily U.S. Customs (Photo 11). The third floor—now largely inaccessible—contained a firing range. More than 1.2 million rounds of ammunition were stored on this level, as was a vault used to store other explosives and weapons. A seizure vault was also on the third floor; it contained evidence (such as drugs, cash and evidence files) seized during Customs operations. Final status: At great personal risk, Customs officials, the FBI and contractor representatives located and removed the criminal evidence from Building 6 during the fourth week of the effort. The ammunition was finally located on Oct. 24, 2001, melted together into large "bullet balls" that were extremely dangerous to handle and dispose of properly (Photo 12).

Professional Safety 2002-05-01 - The American Society of Safety Engineers - SH&E at Ground Zero Disaster Response (link (http://web.archive.org/web/20030623013242/http://www.asse.org/ps0502vincoli.pdf) )

The debris pile at Ground Zero was always tremendously hot. Thermal measurements taken by helicopter each day showed underground temperatures ranging from 400°F to more than 2,800°F. The surface was so hot that standing too long in one spot softened (and even melted) the soles of our safety shoes.

Professional Safety 2002-05-01 - The American Society of Safety Engineers - SH&E at Ground Zero Disaster Response (link (http://web.archive.org/web/20030623013242/http://www.asse.org/ps0502vincoli.pdf) )

"As of 21 days after the attack, the fires were still burning and molten steel was still running." -Leslie Robertson

SEAU News 2001-10-01 - Structural Engineers Association of Utah - WTC A STRUCTURAL SUCCESS (link (http://web.archive.org/web/20060909104247/http://www.seau.org/SEAUNews-2001-10.pdf) )

"I saw melting of girders in World Trade Center." -Structural Engineer Abolhassan Astaneh

2007-05-10 - PBS Newshour - Collapse of Overpass in California Becomes Lesson in Construction (link (http://www.pbs.org /newshour/bb/science/jan-june07/overpass\_05-10.html) )

"I talked to many contractors and they said they actually saw molten metal trapped, beams had just totally had been melted because of the heat." -Chaplain Herb Trimpe

2002-09-08 - The Times Herald-Record - A Day In September The Chaplain's Tale (link (http://web.archive.org /web/20021006003613/http://www.recordonline.com/adayinseptember/trimpe.htm) )

"You'd get down below and you'd see molten steel -- molten steel! -- running down the channel rails. Like you're in a foundry... like lava... from a volcano." -FDNY Captain Ruvolo

2003-01-01 - Turn Century Pictures - COLLATERAL DAMAGES (link (http://video.google.com /videoplay?docid=-3060923273573302287))

"descended deep below street level to areas where underground fires still burned and steel flowed in molten streams."

2002-08-01 - The Atlantic Monthly Group - 77 NORTH WASHINGTON STREET (link (http://web.archive.org /web/20020806173259/http://www.theatlantic.com/issues/2002/07/77nwash.htm) )

"In some pockets now being uncovered, they are finding molten steel." -Alison Geyh, PhD.

2001-10-01 - Bloomberg School of Public Health - Mobilizing Public Health Danger in the Dust (link (http://www.jhsph.edu /Publications/Special/Welch.htm) )

"Feeling the heat, seeing the molten steel, the layers upon layers of ash, like lava, it reminded me of Mt. St. Helens and the thousands who fled that disaster" -Ron Burger

 $2003-09-01 - National Environmental Health \ Association - Messages \ in the \ Dust \ (link \ (http://www.neha.org /pdf/messages_in_the_dust.pdf) \ )$ 

"They showed us many fascinating slides" ... "ranging from molten metal which was still red hot weeks after the event, to 4-inch thick steel plates sheared and bent in the disaster." -Dr Keith Eaton

The Structural Engineer 2002-09-03 - The Institution of Structural Engineers - President visits ground zero on New York visit New York visit reveals extent of WTC disaster (link (http://web.archive.org/web/20030422113455/http://www.istructe.org.uk /about/files/president/Tour-2002-NewYork.pdf) )

"Smoke constantly poured from the peaks. One fireman told us that there was still molten steel at the heart of the towers' remains. Firemen sprayed water to cool the debris down but the heat remained intense enough at the surface to melt their boots. Massive steel girders were sandwiched in with crushed concrete. Someone told us that they weighed 1,000 pounds a foot. The collapse left them all blackened and twisted. They are among the few recognizable items in the rubble. You find scant evidence of the hundreds of offices that were once part of the twin towers. Most the furniture and equipment was pounded into dust." -Guy Lounsbury of New York Air National Guard's 109th Air Wing

National Guard 2001-12-01 - The National Guard Association of the United States - Serving on 'sacred ground' Guardsman Sees Humanity's Best and Worst during Two Weeks at 'Ground Zero' (link (http://911research.wtc7.net/cache/wtc/evidence /ai\_n9015802.html))

"the ominous groaning of weakened structures overhead, or, in the early days, the streams of molten metal that leaked from the hot cores and flowed down broken walls inside the foundation hole." -William Langewiesche

 $2002-10-24 - North Point Press - American Ground: Unbuilding the World Trade Center (link (http://s3.amazonaws.com /nasathermalimages/public/images/BOOK_American_Ground_p32.png) )$ 

He remembers seeing in the darkness a distant, pinkish glow-molten metal dripping from a beam-but found no signs of life. -Lee Turner of The Boone County Firefighters

2002-09-12 - U.S. News & World Report - They came to help at Ground Zero. What they experienced they can't forget Memories (link (http://www.usnews.com/usnews/9\_11/articles/911memories.htm) )

"In the first few weeks, sometimes when a worker would pull a steel beam from the wreckage, the end of the beam would be dripping molten steel" -Greg Fuchek

2002-09-09 - 1105 Government Information Group - Handheld app eased recovery tasks (link (http://gcn.com/Articles /2002/09/09/Handheld-app-eased-recovery-tasks.aspx?p=1) )

O'Toole remembers in February seeing a crane lift a steel beam vertically from deep within the catacombs of Ground Zero. "It was dripping from the molten steel," -Joe O'Toole FDNY

2002-05-29 - Knight Ridder Newspapers - Recovery worker reflects on months spent at Ground Zero (link (http://911research.wtc7.net/cache/wtc/evidence/messengerinquirer\_recoveryworker.html) )

"Underground, it was still so hot that molten metal dripped down the sides of the wall from Building 6." -Kenneth Holden, Commissioner of the New York City Department of Design and Construction

2003-04-01 - National Commission On Terrorist Attacks Upon The United States - Public Hearing (link (http://www.9-11commission.gov/archive/hearing1/9-11Commission\_Hearing\_2003-04-01.htm) )

"Going below, it was smoky and really hot... The debris past the columns was red-hot, molten, running." -Richard Garlock, structural engineer for LERA

2002-09-10 - Public Broadcasting Systems - America Rebuilds A year at Ground Zero (link (http://www.pbs.org /americarebuilds/engineering/engineering\_debris\_06.html) )

"a fire truck 10 feet below the ground that was still burning two weeks after the towers collapsed, its metal so hot it looked like a vat of molten steel." -Jim McKay, Post-Gazette Staff Writer interviewing Vance Deisingnore, OSHA Officer at WTC

2002-09-11 - Pittsburgh Post-Gazette - Vance Delsignore: OSHA officer at WTC (link (http://old.post-gazette.com/nation /20020911designore0911p9.asp) )

"The average temperature beneath the rubble is said to be 1500 F. so that when steel is brought up it is molten and takes two or three days to cool down." -Father Edward A. Malloy

2001-10-24 - - Reflections in the Wake of September 11: Visit to Ground Zero, New York City (link (http://web.archive.org /web/20020225010154/http://www.nd.edu/~ndmag/reflect/malloydiary.html) )

"I spent several hours tonight, walking "the pile" and attempting to soak it all in for the last time and find a bit of closure...deep below ground a portion of the pile was still on fire and boiled with molten material. Sometimes, open flame would erupt as a crane pulled debris out and air rushed in. Fire hoses constantly poured streams of water causing huge billowing steam clouds to rise up over the site into the huge lights above." -Ed Pfister, Disaster Medical Assistance Team

2001-10-30 - National Institutes of Health - At Ground Zero NIH'ers Respond to Tragedy in NYC (link (http://web.archive.org/web/20020203074606/http://www.nih.gov/news/NIH-Record/10\_30\_2001/story01.htm) )

The four men sat on a sunny sidewalk in Greenwich Village on a recent workday and ate their lunch staring at the steel skeleton of a building going up on West Third Street. One of them commented on how much easier it was to eat a sandwich in front of steel that was strong and straight and new, not molten and mangled and laden with debris. The men -- Larry Keating, Danny Doyle, Mike Emerson and Bobby Graves -- are veteran ironworkers in Local 40.

2002-11-11 - The New York Times - Ironworkers' Job of Clearing Ground Zero Is Over, but the Trauma Lingers (link (http://www.nytimes.com/2002/11/11/nyregion/ironworkers-job-of-clearing-ground-zero-is-over-but-the-trauma-lingers.html?pagewanted=print&src=pm) )

But the two towers — they were 110-story buildings. And there was nothing that you could put your hands on that resembled anything that would tell you this once was two 110-story office buildings. What you had were large columns of steel that were just stuck into massive amounts of molten steel and other metals, that had just fused together from the heat and bonded together from the strength of the collapse. We dug and we dug and we dug, and we cut and we cut, and we did not see anything that resembled any type of furniture, any type of personal belongings. We found some pieces of things like a telephone, things like that. I think we found credit cards a few times, and we found a couple of stuffed animals. But you would expect to see, like, a bunch of desks, a bunch of chairs. The only way I can explain it is, if you take a car and put it in one of those machines where they crush it and make it look like a cube, and you can't recognize what it is, that's what the whole area looked like. It looked like a massive, molten mess that had been fused together, like a car that had been cubed and crushed. With all that heavy, heavy stuff, there were wires, rebar, concrete. Most of it was just steel. A lot of what we were walking on was just molten steel. -Fire Department Chief Mike Donoho of Texas Task Force 1 Urban Search and Rescue

2002-09-11 - The Eagle - Reluctant hero narrates horror of N.Y. mission (link (http://archive.theeagle.com/septanniv /091102firefighter.htm) )

"The workers go through three pairs of rubber boots a day because they melt in the three-week-old fire of molten metal and jet fuel. The health hazards are everywhere: the fire, molten metal, the lack of breathable air and 3000+ decomposing bodies." -Ben Robinson

2001-10-17 - MAGIC@GROUND ZERO (link (https://web.archive.org/web/20100225015212/http://www.illusiongenius.com/articles/11-01.html) )

"In mid-October, in the evening," said Thomas A. Cahill, a retired professor of physics and atmospheric science at the University of California, Davis, "when they would pull out a steel beam, the lower part would be glowing dull red, which indicates a temperature on the order of 500 to 600 °C. And we know that people were turning over pieces of concrete in December that would flash into fire - which requires about 300 °C. So the surface of the pile cooled rather rapidly, but the bulk of the pile stayed hot all the way to December."

Chemican and Engineering News 2003-10-20 - CENEAR 81 42 pp. 26-30 Volume 81, Number 42 - CHEMICAL ANALYSIS OF A DISASTER Scientists struggle to understand the complex mixture of aerosols released during and after the destruction of the World Trade Center (link (http://pubs.acs.org/cen/NCW/8142aerosols.html) )

"Ferer was one of several people in a visiting United Services Organization (USO)-Tribeca group who had lost family members. As they visited troops, they carried Port Authority pins, baseball caps, and a piece of molten steel from the WTC."

The Journal of American Culture 2005-02-09 - - Rituals of Mourning and National Innocence (link (http://onlinelibrary.wiley.com/doi/10.1111/j.1542-734X.2005.00152.x/abstract) )

"Even as the steel cooled, there was concern that the girders had become so hot that they could crumble when lifted by overhead cranes. As a result, additional safeguards were put in place to limit the dangers associated with lifting the damaged steel and to protect the workers in the vicinity. Another danger involved the high temperature of twisted steel pulled from the rubble. Underground fires burned at temperatures up to 2,000 degrees. As the huge cranes pulled steel beams from the pile, safety experts worried about the effects of the extreme heat on the crane rigging and the hazards of contact with the hot steel. And they were concerned that applying water to cool the steel could cause a steam explosion"

2003-11-01 - Occupational Safety & Health Administration - A Dangerous Worksite The World Trade Center (link (http://www.osha.gov/Publications/dangerous\_worksite.pdf) )

The "hot spots", where intensely burning debris generated temperatures in excess of 1300 degrees Fahrenheit, posed a significant danger to relief workers. NASA had an instrument that could provide information that would be useful to emergency responders. NASA's Airborne Visible infrared Imaging Spectrometer (AVIRIS) science instrument was capable of providing data that could be used to filter smoke and locate extreme hot spots.

2002-02-13 - NASA SE-2002-02-00007-SSC - NASA Involvement in National Priority Support for Disasters (link (https://ssctdpub.ssc.nasa.gov/servlet/sm.web.Fetch/SE-2002-02-00007-SSC-M.pdf?rhid=1000&did=22698&type=released) )

The temperature at the core of "the pile," is near 2000 degrees Fahrenheit, according to fire officials

2001-09-18 - ABC News - Search Continues (link (http://web.archive.org/web/20010918182531/http://abcnews.go.com /sections/us/DailyNews/WTC\_recovery010918.html) )

The US&R Teams were provided access to thermal imagery and began superimposing thermal data on collapse maps in October. This thermal imagery was collected on the same over flights of the WTC as the airborne LIDAR data that was being used to map the surface elevations each day. The National Information and Mapping Agency (NIMA), located at Pier 90 produced these maps. Firefighters and other responders contended with intense heat associated with the super-heated steel for weeks; some were coming back from shifts with the bottoms of their boots melted.

2002-06-01 - George Washington University - Assessment of Geospatial Technology Applications by the U.S. Army Corps of Engineers during World Trade Center Operations (link (http://www.gwu.edu/%7Eicdrm/publications/usace911/index.html) )

"Two weeks after the attack, the rubble, the Pile, is still 7 stories tall. Below, in the Pit it burns like the gates of hell. It is 1200 degrees, so hot that the steel work lifted by the grapplers comes out soft. I've never seen anything like this" -Capt. Susanne Caviness conversation with FDNY Firefighter

2001-09-30 - U.S. Public Health Service - WTC Ground Zero : Images from Firefighters and Steel Workers (link (http://web.archive.org/web/20030113000841/http://www.ukfssart.org.uk/wtc%20ground%20zero.htm) )

"The fires are so hot in pockets on the Pile that some of the firefighters change boots 3-4 times a day. Smoke and flame come up from the Pit deep within the Pile when a piece of heavy equipment with a huge grappler pulls out a mass that allows a swish of oxygen inside". -Capt. Susanne Caviness conversation with FDNY Firefighter

2001-09-30 - U.S. Public Health Service - WTC Ground Zero : Images from Firefighters and Steel Workers (link (http://web.archive.org/web/20030113000841/http://www.ukfssart.org.uk/wtc%20ground%20zero.htm) )

"Some of the structural steel sections being removed were still red-hot." -James DeStefano P.E.

Structure 2001-10-01 - STRUCTURAL ENGINEERS ASSIST IN THE AFTERMATH (link (http://www.engr.psu.edu /ae/WTC/STRUCTURE/jim\_destefano.pdf) )

"The rubble pile was so hot in places that it melted the soles of work boots. Companies donated supplies of work shoes, and construction workers laboring on the hotter parts of the rubble pile reportedly went through a pair a day. A boot wash was established where workers could cool their feet."

 $2006-01-01 - RAND - Protecting Emergency Responders Lessons learned from Terrorist Attacks (link (http://www.rand.org /pubs/conf_proceedings/2006/CF176.pdf) )$ 

"Boots (especially rubber boots) were not fitted properly and melted in the high-heat environment."

 $2006-01-01 - RAND - Protecting Emergency Responders Lessons learned from Terrorist Attacks (link (http://www.rand.org /pubs/conf_proceedings/2006/CF176.pdf) )$ 

"At the World Trade Center, the rubble pile was so hot in places that it melted the soles of boots (a problem noted by members of the trades, lawenforcement, and firefighter panels). Work shoes with steel reinforcements in the soles and toes protected feet against punctures by sharp objects but often could not be worn because they conducted and retained the heat, causing blistered or scorched feet."

 $2006-01-01 - RAND - Protecting Emergency Responders Lessons learned from Terrorist Attacks (link (http://www.rand.org /pubs/conf_proceedings/2006/CF176.pdf) )$ 

"The dogs were trained to sniff out bodies. They weren't trained to recognize heat. So when they hopped on a smoldering I-beam [some of which were hot enough to melt the firefighters' rubber-soled boots] they'd get hurt. Some of them even ignited," -Mike Bellone FDNY

2002-09-11 - Massachusetts Institute of Technology - N.Y. firefighters describe sorrow, exhaustion at Ground Zero cleanup (link (http://web.mit.edu/newsoffice/2002/911-sunday-0911.html) )

"There are pieces of steel being pulled out that are still cherry red" -Don Carson, National Operating Engineers Union

2001-11-01 - NY Daily News - Fire May Smolder For Months (link (http://articles.nydailynews.com/2001-11-01 /news/18367479\_1\_smolder-state-fire-marshals-national-interagency-fire-center) )

"Ground Zero at the World Trade Center was a search site like few others after a major disaster event. Multiple sources of hazards were everywhere. There were shards of steel piled on steel, a two-million-ton pile of debris, red hot steel beams still being pulled from the earth"

2002-10-01 - - Ground zero (link (http://michigan.gov/documents/CIS\_WSH\_minwsw02\_28059\_7.pdf) )

"The first indication of "Ground Zero" is the smoke. It's still smoking. Many of the beams are still red hot as they are uncovered, and start new fires as the oxygen reaches them." -Congressman Pete Hoekstra

2001-09-19 - - New York: A City With an Attitude... and a Heart (link (http://web.archive.org/web/20041225022353/http:

//hoekstra.house.gov/UploadedFiles/newyork.pdf) )

"I went outside and saw a large hole in the left-hand tower, approximately 80 stories up. There was smoke coming out but not a lot of fire. I could also see streams of molten metal coming from undamaged areas of the building, in three different places. The streams looked like the sparks from a welders torch, orange in colour and about the length of one floor. These streams were very odd in that they were coming from undamaged parts of the building. I watched from Vesey for about 10 minutes." -David Long

2011-09-09 - ABC News - 'Real fear': Your September 11 stories (link (http://www.abc.net.au/news/2011-09-09/eyewitness-accounts-of-september-11/2866958) )

"Temperatures in the pile were over 1,200 °F. Every time an area was opened, fire started in any buried combustible debris. Water trucks and fire engines were used continually. The high temperature debris and water created steam."

2002-01-01 - U.S. Army Corps of Engineers - New York City World Trade Center Disaster Deployment (link (http://web.archive.org/web/20020217132034/http://www.spk.usace.army.mil/cespk-pao/jan-02/jan02-01.html) )

"When I am not moving, I notice that the soles of my boots are melting from the heat inside the pile of debris."

2002-02-01 - A call to rescue: Sappers assist at the World Trade Center (link (http://www.highbeam.com /doc/1P3-113195661.html) )

With no special protective gear, he worked within a few feet of still burning fires, "like a volcano," hot enough that molten steel could be seen dripping down. "My boots melted every night," he recalled. "You just didn't stand in one place too long." -Tom Hickey

2005-09-09 - The River Reporter - WTC injuries hobble local man (link (http://www.riverreporter.com/issues/02-09-05 /wtc.htm) )



"this is a picture of Tower #1 ..2 months later, molten steel" -Franck Sillechia [4] (http://www.wtcgodshouse.com/images /steel.jpg) [5] (http://web.archive.org/web/20021211182244/http://www.wtcgodshouse.com/photos.html) [6] (http://web.archive.org/web/20030810005741im\_/http://www.wtcgodshouse.com/photogal/tsteel.jpg) [7] (http://web.archive.org/web/20030810005741/http://www.wtcgodshouse.com/photogal/tsteel.jpg) [7]



Red hot metal. -Franck Sillechia [8] (http://img412.imageshack.us/img412/9740/911wtcmoltenmetalla0.jpg)

http://video.google.com/videoplay?docid=-7180303712325092501

John Gross of NIST giving a lecture at the University of Texas



SPOT satellite image of Manhattan, using the HRVIR (High Resolution Visible Infra Red instrument) on SPOT 4, acquired on September 11 at 11:55 AM EST, 3 hours after two planes crashed into the World Trade Center. The colors result from the use of infrared bands to identify the actual fire hot spots (see red spots near the base of the smoke plume). The SPOT satellites orbit at an altitude of 822 km." (c) CNES/SPOT Image 2001

Zoomed Out Image: [9] (http://www.directionsmag.com/gisresponse/images/maps/nyc/15\_NYC-091101.jpg)

Resolution: 20 meters; Acquisition time: 09/11/01 11:55 AM EDT; Orbital altitude: 822 km

Band combination: Not specified, but presumed to be:

R 0.79 - 0.89um

G 0.61 - 0.68um

B 0.50 - 0.59um

ncsu.edu (http://www.ceo.ncsu.edu/attack/index.html)

As part of the World Trade Center disaster response, the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) was flown over the site on the 16th and 18th of September 2001. AVIRIS measures the solar reflected spectrum from 370 to

2500-nm at 10-nm sampling. For this flight the data were acquired at 1.5-m spatial sampling with image coverage of the entire disaster site. AVIRIS measurements are spectrally, radiometrically, spatially calibrated in the laboratory and validated in flight. Rapid examination of the World Trade Center AVIRIS data in the 2300 nm spectral region showed numerous high radiance targets indicative of burning fires. A new spectroscopic algorithm was implemented to simultaneously solve for the temperature and fractional area of the fires. This algorithm uses the Planck function in conjunction with the full spectral shape measured by AVIRIS to determine the temperature and fractional area of the fire. This spectral algorithm overcomes the ambiguity between temperature and area that exists in single-spectral-band temperature estimation methods. With these AVIRIS data set and new algorithm, 8 hot spot zones were identified in the September 16th data with temperatures ranging from 700K to 1019K and fractional areas from 1.1 to 18%. Analysis of the data set acquired on September 18th showed 7 of the hot spot zones still present with temperatures ranging from 471K to 952K and fractional areas from 0.5 to 36%. These imaging spectrometer derived physical parameters of fire temperature and fractional-area were found useful to the personnel making decisions on the ground. The complete set measurements, analyses, and results of this effort are reported in this paper. cosis.net (http://www.cosis.net/abstracts/COSPAR02/00015/COSPAR02-A-00015.pdf)



AVIRIS 2300-nm wavelength image of the World Trade Center disaster site acquired on the 16th of Septernasa.gov (ftp://popo.jpl.nasa.gov/pub/docs/workshops/02\_docs/2002\_Green\_wtc\_web.pdf)

Additional World Trade Center Disaster Site thermal images from 09/16/01



VRML visualization of Ground Zero from several perspectives, with orthophotography and thermal data draped over a LIE Datasets were acquired by EarthData on September 17th. http://gis2.esri.com/library/userconf/proc03/p0136.pdf esri.com

(additional thermal image from 09/17/01) (http://www.newyork.earthdata.com/images/thermal\_sept172001\_800.gif)



AVIRIS false color images showing the core affected area around the World Trade Center extending from 5 to 12 days after the collapse... The image on the 18th is dark because of clouds which blocked sunlight but not light emitted by the fires.

http://speclab.cr.usgs.gov/wtc/

Image from 09-16-01 (http://pubs.usgs.gov/of/2001/ofr-01-0405/wtc-r09.091601.usgs-thermal.jpg) usgs.gov (http://pubs.usgs.gov/of/2001/ofr-01-0405/ofr-01-0405.html)

Image from 09-18-01 (http://speclab.cr.usgs.gov/wtc/clark-wtc-chapter/figure1.jpg) usgs.gov (http://speclab.cr.usgs.gov/wtc/)

Image from 09-23-01 (http://s3.amazonaws.com/nasathermalimages/public/images/wtc-r14.092301.usgs-thermal.jpg) usgs.gov (http://pubs.usgs.gov/of/2001/ofr-01-0405/ofr-01-0405.html)

The [aerosol] plume detected by IKONOS on September 16 was much less intense and much darker than the plume of September 12, and the lofting is not as evident. All of these were consistent with the improved conditions on the collapse pile observed during rescue operations. informaworld.com (http://www.informaworld.com/smpp/section?content=a714044206& fulltext=713240928)

Hotspot					09/16/01				09/18/01				09/23/01			
Spectrum	Latitude	Longitude	MA [m^2]	°K	°C	°F	A [m^2]	°K	°C	°F	A [m^2]	°K	°C	°F	A [m^2]	
A	40°42'47.18"	74°00'41.43"	430	1003	730	1346	0.60	1003	730	1346	1.80	<453	<180	<356	-	
В	40°42'47.14"	74°00'43.53"	120	833	560	1040	0.08	903	630	1166	2.40	<453	<180	<356	-	
C	40°42'42.89"	74°00'48.88"	130	903	630	1166	0.80	603	330	626	0.60	<423	<150	<302	-	
D	40°42'41.99"	74°00'46.94"	180	793	520	968	0.80	703	430	806	1.00	<453	<180	<356	-	
E	40°42'40.58"	74°00'50.15"	130	713	440	824	0.40	<423	<150	<302	-	<423	<150	<302	-	
F	40°42'38.74"	74°00'46.70"	930	703	430	806	0.40	803	530	986	1.30	<403	<130	<266	-	
G	40°42'39.94"	74°00'45.37"	740	1023	750	1382	0.04	803	530	986	1.40	603	330	626	1.30	
Н	40°42'38.60"	74°00'43.51"	80	823	550	1022	0.08	<443	<170	<338	-	<443	<170	<338	-	
Ι	40°42'46.94"	74°00'42.75"	230	903	630	1166	0.08	603	330	626	0.70	603	330	626	1.00	
J	40°42'37.68"	74°00'44.91"	20	513	240	464	4.00	903	630	1166	1.10	<453	<180	<356	-	

[calibrated reflectance data Calibrated reflectance] temperature measurements. Positions are estimated to be  $\pm 6m$  (18ft). T is temperature as the highest recorded in a 4m<sup>2</sup> pixel covering part of the pixel. MA is the total size of the area >130°C (266°F, 403°K) in m<sup>2</sup>. A is the area in m<sup>2</sup> of the listed temperature. Temperatures listed as "<" are upper limits and represent no detection. Hot spot J grew to 60m<sup>2</sup> on September 18. [ACS 919 (source ACS 919 p71)]

AVIRIS images obtained from an airplane flying over the WTC complex were processed to indicate thermal hot spots, shown as bright red, orange, and yellow spots on the images to the left. The dark areas are shadows of buildings and other structures. The numbers show the original locations of Towers 1 and 2 in the WTC complex. The September 16, 2001 image (left) reveals a number of thermal hot spots in the region where the WTC buildings collapsed. Analysis of these data indicated temperatures greater than 800°F (orange pixels), with some areas reaching over 1300°F (yellow pixels). These results were released to emergency response agencies on September 18, 2001. By September 23 (right), most of these hot spots that were initially detected by AVIRIS had been eliminated or reduced in intensity. usgs.gov (http://pubs.usgs.gov/fs/fs-0050-02 /fs-050-02\_508.pdf)

calibrated radiance calibrated radiance temperature measurements

 $AVIRIS \ is also used \ to \ estimate \ the \ temperature \ of \ volcanic \ vents \ (http://s3.amazonaws.com/nasathermalimages/public /images/2001Green_lava_web.pdf) \ .$ 



earthdata.com (http://www.newyork.earthdata.com/thermal.html)



09/25/01 earthdata.com (http://www.newyork.earthdata.com/thermal.html)



Thermal image of Ground Zero acquired by EarthData on October 7th using a Raytheon airborne sensor. The data are overlaid on an orthophotograph obtained on October 8th. Variations in temperature are evident across the site. However, these values were acquired (and are therefore displayed) using an 8-bit radiometric scale, rather than an absolute calibration such as degrees Fahrenheit. (source) (http://s3.amazonaws.com/nasathermalimages/public/images/wtc\_eev.pdf)

Sensor: Raytheon Nightsight (http://www.raytheon.com/newsroom/photogal/nightsight200\_l.htm)

EarthData Thermal Images



Thermal data acquired by EarthData over the World Trade Center site on October 18, 2001, overlaid on digital orthophotography collected on October 7, 2001 with a Kodak Megaplus 16.8i camera. (source) (http://s3.amazonaws.com /nasathermalimages/public/images/JOE002120.pdf)

Sensor: FLIR ThermaCAM PM 695, a radiometric thermal camera developed by FLIR Systems of North Billerica, Massachusetts (source p4) (http://s3.amazonaws.com/nasathermalimages/public/images/JOE002120.pdf)

Sensor: FLIR ThermaCAM SC2000 (gwu.edu p19) (http://www.gwu.edu/spi/RS-TransREP-wcover.pdf)



WTC – Thermal Imagery, October 18, 2001. New York State, Office for Technology (c2001) and EarthData International. loc.gov (http://www.loc.gov/exhibits/911/911-maps.html)

## Absolute Temperature (<sup>o</sup>F)



Change in Temperature (<sup>o</sup>F)

The sequence of temperature readings on the top row of were acquired by EarthData between 18th-22nd October, using the FLIR thermal imagining device. They are overlaid here with the aerial orthophotography from October 7th. Notably, the thermal data are calibrated to record temperature in degrees Fahrenheit, thereby addressing the limitations of relative magnitudes acquired using the Raytheon sensor. The red areas correspond with temperatures exceeding 125F and the yellow class equates with temperatures from 75F to 125F. Values < 75oF are omitted.

Sensor: FLIR ThermaCAM SC2000 (esri.com) (http://gis2.esri.com/library/userconf/proc03/p0136.pdf)

An overlay of the above image from 09-18-01 with the [

corresponding AVIRIS image from 09-18-01] is available in gimp(xcf) (http://www.gimp.org/) format here: http://s3.amazonaws.com/nasathermalimages/public/images/09-18-01\_FLIR\_overlay\_with-09-18-01\_AVIRIS\_and\_visible\_background\_from\_10-07-01.xcf





WTC – Thermal Imagery, February 12, 2002. New York State, Office for Technology (c2001) and EarthData International. loc.gov (http://www.loc.gov/exhibits/911/911-maps.html)

htp:///www.loc.gov/exhibits/911/images/



Thermal Imagery of the progression of molten steel hotspots from September 18 to September 25. Notice how the heat becomes concentrated towards the center from the fringe areas. The threshold between color ranges was 1/2 of the energy, so that in a range of 0-255, everything above 127.5 was kept (0-127.5) and everything below was ignored. -Maddalena Romano cuny.edu (http://www.geo.hunter.cuny.edu/geonews/october2001.pdf) Document.htm (source2) (http://www.geography.hunter.cuny.edu/carsi/INDEX/CURRENTAFFAIRS/ARTICLES/CUNYMatters/Untitled)

September 16-Thermal imagery measures the progression of underground heat on about a weekly basis. These images are

produced in 8-bit grayscale, with brightness levels of 0-255, 0 being the hottest and expressed as pure white. This is known as emissive data, or heat being given off from the structure from underlying hot debris or molten steel. Smoldering is yet undetectable, because potential fires appear cold until they are exposed to air. The first thermal images produced began on September 16, and are repeated on two day intervals. I would like to thank Jeff Bliss for the wonderful information and imagery he provided for this story, and acknowledge the 16-20 hours days CARSI Lab director Dr. Sean Ahearn has been putting in at the OEM. I would also like to credit Jeff Bliss, Constandinos Theophilides, and Bob Sklar for their tireless analysis. For a more in-depth look on CARSI, see the upcoming January special issue. cuny.edu (http://www.geo.hunter.cuny.edu/geonews/october2001.pdf)

The gravitational potential energy of the collapse was capable of raising the entire mass of debris only a few degrees K. The largest energy sources available are the combustible materials present in the buildings and furnishings and a significant body of fuel, [Additional WTC7 Diesel Information especially under WTC #7], in the form of diesel fuel for emergency electrical generators and large quantities of oil in various forms in the Consolidated Edison substation, also under WTC #7. Very high temperatures occurred in the burning floors of the buildings prior to collapse and during the first few days of active surface fires, as shown by the melting of metals. Later, infrared surveys showed surface temperatures in the collapse pile were as high as 30 K above ambient in October, and much higher subsurface temperatures were inferred from the lower portions of removed steel beams glowing red. The subsurface of the collapse piles remained hot for months despite use of massive amounts of water to cool them, with the last spontaneous surface fire occurring in mid-December. informaworld.com (http://www.informaworld.com/smpp/section?content=a714044206&fulltext=713240928)

Journal Of 9/11 Studies: Extremely High Temperatures During The World Trade Center Destruction (http://journalof911studies.com/articles/WTCHighTemp.pdf)

Melting Steel With Gravitational Potential Energy: The Mechanical Equivalent Of Heat (http://journalof911studies.com /volume/200704/ProfMorroneOnMeltingWTCsteel.pdf)

http://www.nytimes.com/2001/11/15/nyregion/a-nation-challenged-the-site-below-rubble-a-tour-of-a-still-burning-hell.html

## Additional WTC Hot Spot Information

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