Explore.
Discover.
Understand.

Contrail Education

National Aeronautics and Space Administration

Engaging students in authentic science to advance our knowledge of Earth

CLIMATE CHANGE AND THE FUTURE OF AIR TRAVEL

by Natasha Richardson, Engineering and Physical Sciences Research Council

A recent investigation focuses on how aircraft can avoid creating vapor trails, also known as contrails. These spindly threads of condensation may not seem important but some persist for hours and behave in the same way as high altitude cirrus clouds, trapping warmth in the atmosphere and exacerbating global warming .

Air travel is currently growing at between 3 and 5% per year and cargo transportation by air is increasing by 7% per year. Researchers at Imperial College London are combining predictions from climate change models with air traffic simulations to predict contrail formation and identify ways of reducing it.

Contrails behind the engines of a large aircraft.

As the climate changes, so will the general condition of the atmosphere and the new work aims to understand how this will affect contrail formation. They have already found that aircraft could generally minimize contrail formation by flying lower in the atmosphere. Their work suggests that in the summer, when the air is warmer, restricting jets to an altitude of 31,000 feet could be beneficial. In winter, when the air cools, and contrail formation becomes more likely, the ceiling should be no more then 24,000 feet.

(continued on page 6)

Inside this issue:

Climate Change...Air Travel	1
Contrail Science	1
NASA Scientists Use Empty...	2
S'COOL Resources	2
Contrail Science	3
Contrails' Worth of Websites	3
Introducing...SCIENCE Players	4
Contrail Wordsearch	5
Climate Change...Air Travel	6
NASA Scientists Use Empty...	6
NASA STEMS	7
Contrail Prediction Activity	7
Contrail Website Guide	7
GLOBE Contrail ID Chart	8

Contrail Science

by Roberto Sepulveda, SAIC-NASA Langley Research Center

Well, what exactly are CONTRAILS?

A B-52 mothership drops the X-24A experimental plane for a trial flight. Notice the contrails!

The word "contrails" comes from 'condensation trails,' which typically refers to line-shaped clouds produced by jet airplane engine exhaust. This 'condensation' event typically occurs at 8-12 km (about 5-7 miles) above the Earth's surface. Contrails are composed primarily of water in the form of ice. Jet engine exhaust emits water vapor into the surrounding air. The water vapor is a by-product of jet fuel combustion. Tiny particles (aerosols) are also emitted and provide a surface for water droplets to form. Contrails form when the water droplets freeze to form ice particles.

Another factor affecting contrail formation is the humidity (amount of atmospheric moisture) along the airplane's path. If the humidity is low the contrails will evaporate quickly; these are called 'short-lived' contrails. If the humidity is high the contrail will continue to grow; these are called 'persistent spreading' contrails. Persistent contrails can last for hours and can grow considerably in width and height. They often spread due to differences in wind speed along the flight path. You've probably wondered why contrails don't appear daily. We have learned how

(continued on page 3)

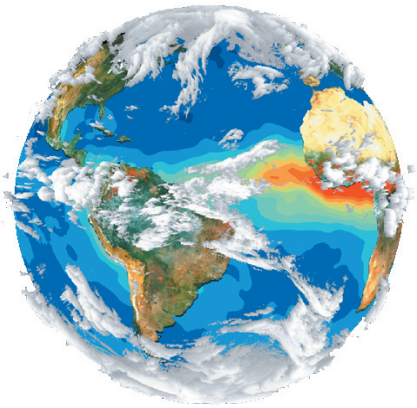
NASA Scientists Use Empty Skies to Study Climate Change

by Julia Cole, SAIC-NASA Langley Research Center

When the tragic events of September 2001 temporarily halted U.S. commercial air traffic, it created an opportunity to study the relationship between aviation and clouds. From satellite observations taken during the air traffic shutdown, NASA scientists gained insight into the atmospheric conditions that govern the formation of contrails -- clouds caused by aircraft emissions.

Jet Contrails: NOAA Image; Flagstaff, AZ

This Earth image is a compilation of data from several different remote sensing satellites.

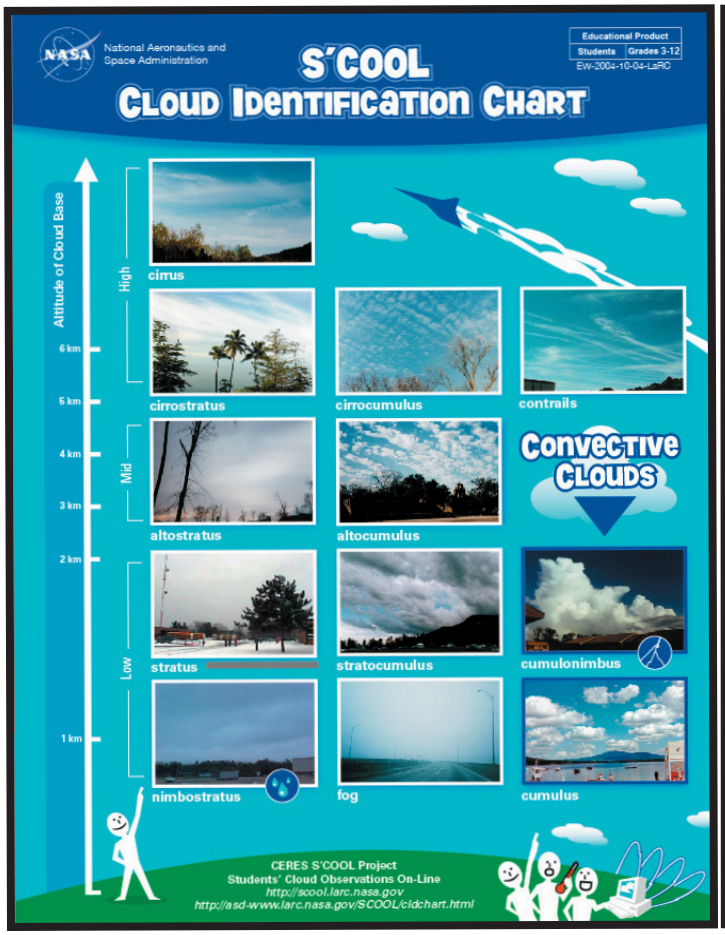


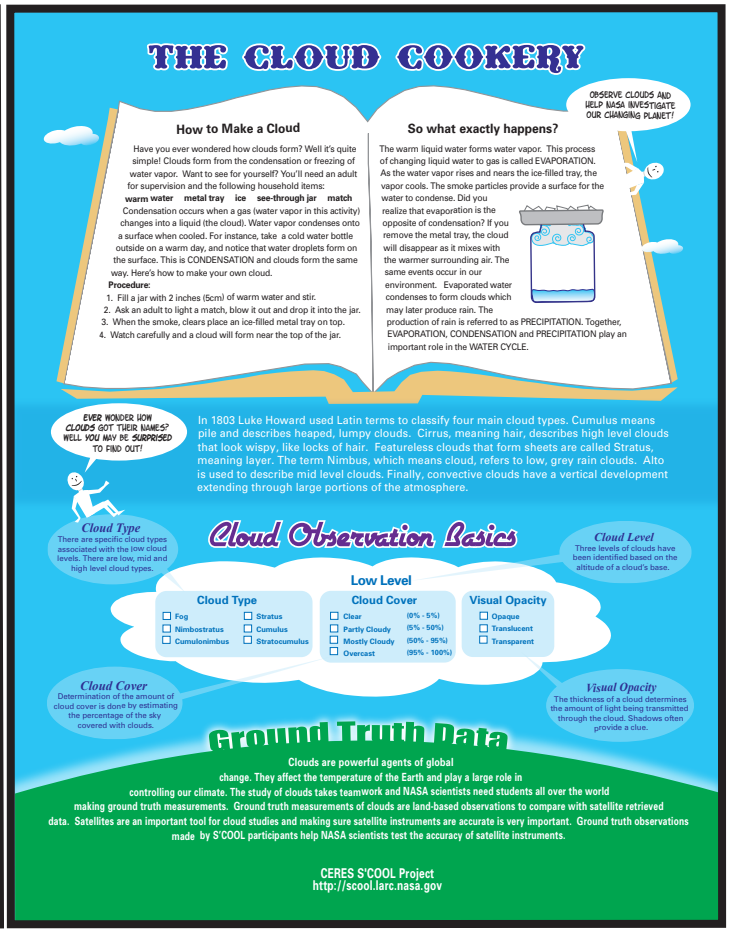
"Because air traffic is expected to grow over the next 50 years, contrail coverage will also increase and may significantly impact the Earth's radiation budget by 2050," said Patrick Minnis, a senior research scientist at NASA's Langley Research Center in Hampton, Va.

The Earth's radiation budget -- the balance between the planet's incoming sunlight and outgoing heat energy -- drives climate change. Contrails can spread into extensive high, thin cirrus clouds that tend to warm the Earth because they reflect less sunlight back to space than the amount of heat they trap.

Tracking the formation of contrails is key to determining their contribution to cirrus clouds and their effect on the energy balance. But contrails typically form in large numbers from overlapping commercial flights, making it difficult for scientists to follow their development.

(continued on page 6)





As you begin your Cloud Observations be sure to visit the S'COOL website for great downloadable resources on clouds and valuable lesson plans and activities related to weather. S'COOL Resources URL: http://asd-www.larc.nasa.gov/SCOOL/teachers.html

(continued from page 1 - Contrail Science)

temperature and humidity are key factors affecting contrail formation. Since both of these factors undergo daily and seasonal changes, contrails may or may not form over a given location.

Research aircraft captures this picture of contrails forming behind a commercial jet at 35,000 feet.

So why are scientists interested in contrails? Clouds are the largest variable controlling Earth's atmospheric temperature and climate. Any increase in global cloud cover will contribute to long-term changes in Earth's climate. Likewise, any change in Earth's climate may have effects on natural resources. Contrails produce an increase in the Earth's cloudiness. We can now clearly understand that while contrails do not pose a direct threat to humans, the need for contrail research exists to address long-term changes in climate. Scientists are most interested in persistent contrails because they form clouds that would not normally have formed in the atmosphere. Persistent contrails can last for hours and spread, becoming indistinguishable from naturally occurring cirrus clouds. Student observers can collaborate with scientists by observing contrail cover in their area and reporting on the amount and type of contrails present. Persistent contrails are currently estimated to cover about 0.1% of the Earth's surface (note the predominant gray area in figure 1). It is estimated that this will increase considerably over the next four decades (note the increase in dark areas over the US, Europe and Asia – see figure 2). Now that you have a better understanding of contrails, you can appreciate the need for global research on contrails. For more information about this article visit the EPA website at: http://www.epa.gov/otaq/regs/nonroad/aviation/contrails.pdf

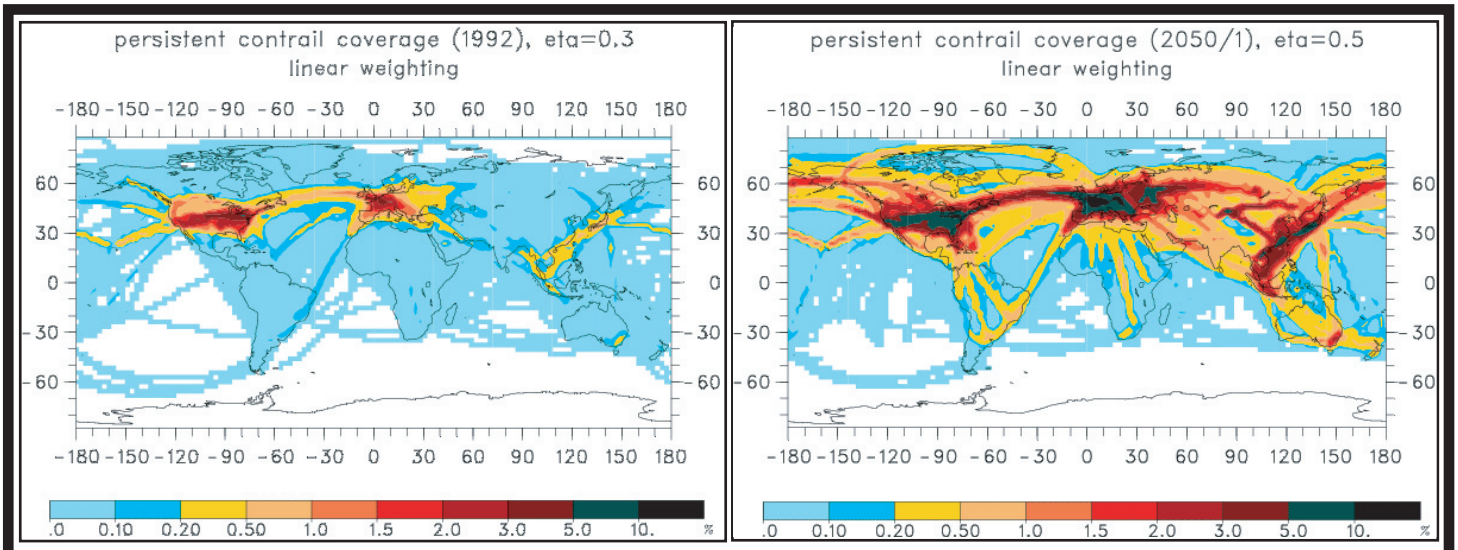


Fig. 1 & 2. Comparison of estimated global contrail coverage between 1992 and 2050. Air traffic and persistent contrail coverage are predicted to continue to increase. By 2050, the warming due to contrails may be 2.5 to 25 percent of the current greenhouse gas warming.

Contrails' Worth of Websites

Contrail Education: http://asd-www.larc.nasa.gov/GLOBE/
Find answers to many of your contrail questions at the most complete contrail website supported by NASA researchers. This website is loaded with information about contrail research and resources. For a more complete description of this website, check out page 7 of this newsletter.

S'COOL Project: Students' Cloud Observations On-Line: http://scool.larc.nasa.gov
S'COOL is a unique hands-on project that involves students in collaborative research with NASA scientists on Earth's climate. Science, math and geography are used as students observe, compute and locate vital information through groud truth observations for the CERES instrument on board several NASA satellites.

GLOBE Program: http://www.globe.gov
GLOBE is a worldwide hands-on, primary and secondary school-based education and science program. For students, GLOBE provides the opportunity to learn by taking scientifically valid measurements, reporting data and collaborating with scientists. For teachers, GLOBE provides training workshops, teacher's guides, videos and other materials.

Earth Observatory: http://earthobservatory.nasa.gov/
The purpose of NASA's Earth Observatory is to provide a freely-accessible publication on the Internet where the public can obtain new satellite imagery and scientific information about our home planet. The focus is on Earth's climate and environmental change. Many of the materials published on the Earth Observatory are freely available for re-publication.

Introducing the SCIENCE PLAYERS!

by Roberto Sepulveda, SAIC - NASA Langley Research Center

Teamwork! "The cooperative effort by the members of a group to achieve a common goal." How does that sound for a dictionary definition of teamwork? Well, we here at NASA believe that the word **teamwork** symbolizes so much more.

Throughout the course of time great individuals have commented about their ideas on teamwork. Take for instance this anonymous statement, "Teamwork: simply stated, it is less me and more we." This statement goes right along with the fact that "there is no **I** in TEAMWORK." Other great clichés which describe teamwork include: a successful team beats with one heart, the fuel that allows common people to attain uncommon results, the ability to work toward a common vision, and people working together effectively and efficiently.

Thomas Edison, when asked why he had a team of twenty-one assistants stated, "If I could solve all the problems myself, I would." Simply stated, working together works! The great NBA coach, Phil Jackson, once stated, "The strength of the team is each individual member…the strength of each member is the team." It is amazing how much can be accomplished when it doesn't matter who gets the credit.

The NASA Langley's Science Directorate Team is proud to exemplify these team concepts as they strive together to understand the complexity of Earth's climate and how to use this knowledge to benefit mankind worldwide. It is our hope that students will gain a true appreciation for the value teamwork plays in the world around them.

Dr. Bruce A. Wielicki

Principal Investigator

Responsible for leading the science efforts for the CERES project.

Born 1952 in Milwaukee, Wisconsin, USA

Spotlight on Atmospheric Careers

Education:
B.S. Applied Math and Engineering Physics at University of Wisconsin - Madison
PhD Physical Oceanography at Scripps Institute of Oceanography

Favorite School subject(s):
I liked Science and Creative Writing

Favorite Hobbies:
Reading, Golf, Radio Control Airplanes and Woodworking

What made you enter your profession?
Putting clouds into a toy climate model and watching it run off to an ice covered Earth.

What do you like most about your job?
Working on something important to society, something unknown and working with a great team of researchers. Every day is different!

What advice do you have for someone interested in an Atmospheric Science Career?
Get a solid background in applied math, engineering and basic physics at the undergrad level. Choose a grad school excellent for both teaching and research then get training in Earth science particulars.

Dr. Lin Hartung Chambers

Physical Scientist

Responsible for leading education and outreach efforts for CERES and doing analysis of data products.

Born 1963 in Madison, Wisconsin, USA

Spotlight on Atmospheric Careers

Education:
B.S. & M.E. Aeronautical Engineering at Rensselaer Polytechnic Institute
PhD Aerospace Engineering at North Carolina State

Favorite School subject(s):
I liked most subjects and in particular finding the connections between them.

Favorite Hobbies:
Knitting, Volleyball and reading

What made you enter your profession?
As a child I spent a lot of time on airplanes. Dad was a physicist and private pilot.

What do you like most about your job?
Having the chance to share knowledge and ideas with educators.

What advice do you have for someone interested in an Atmospheric Science Career?
It's a very broad and inter-connected field, so learn as much as you can and find the part that most interests you.

Dr. Patrick Minnis

Senior Research Scientist

Lead on a research team responsible for converting MODIS images into cloud properties

Born 1950 in Shawnee, Oklahoma, USA

Spotlight on Atmospheric Careers

Education:
B.S. Engineering, Vanderbilt University
M.S. Atmospheric Science, Colorado State University
PhD Meteorology, University of Utah

Favorite School subject(s):
Science

Favorite Hobbies:
Swimming, reading and landscaping.

What made you enter your profession?
As I grew up I became an avid sky watcher, with a special interest in clouds. During April 1974, an enormous tornado crossed my path on the highway and I narrowly missed being one of its victims. From that point I was convinced weather was my calling.

What do you like most about your job?
I like solving problems and interpreting satellite data.

What advice do you have for someone interested in an Atmospheric Science Career?
Don't be afraid of mathematics and science. And very importantly, learn how to write well.

Carrie S. Phelps

Software Application Engineer

Science data support and Web development for NASA outreach projects.

Born 1972 in Martin, Tennessee, USA

Spotlight on Atmospheric Careers

Education:
B.S. Meteorology, Penn State University
M.S. Meteorology, University of Maryland

Favorite School subject(s):
I liked math and chemistry the best.

Favorite Hobbies:
Tennis, shopping and travel!

What made you enter your profession?
I was glued to the Weather Channel when it debuted. Initially, I sought training to become a broadcast meteorologist.

What do you like most about your job?
I enjoy being able to help people understand earth science.

What advice do you have for someone interested in an Atmospheric Science Career?
Choose a reputable university with a strong program in your field. Find a good mentor early in your profession to help with career choices.

NASA encourages all students to explore the many fascinating subjects available in Earth Science. Spark your students by challenging them to explore a career in Earth Science that will help them make a difference!

For more career information, visit the following web sites.

Careers in Earth Science: http://kids.earth.nasa.gov/archive/career/
American Geophysical Union: http://www.earthinspace.org/careers/index.html

Contrail Education Wordsearch

P	T	P	S	A	I	R	C	R	A	F	T	E	X	H	A	U	S	T
E	N	Z	U	W	A	T	E	R	V	A	P	O	R	U	Z	L	L	M
P	E	R	S	I	S	T	E	N	T	S	P	R	E	A	D	I	N	G
I	T	W	H	N	A	S	K	D	U	C	D	E	F	P	E	C	E	T
R	S	C	O	D	P	A	W	U	S	C	T	L	K	J	F	E	D	E
C	I	I	R	S	S	M	I	O	P	O	T	A	K	C	C	P	U	M
T	S	I	T	P	C	T	A	L	L	N	C	T	M	B	A	A	T	P
M	R	O	L	E	V	Z	E	C	I	T	H	I	G	H	K	R	I	E
L	E	R	I	E	S	Q	X	O	N	R	K	V	A	I	J	T	T	R
E	P	O	V	D	Z	P	P	I	E	A	G	E	F	D	S	I	L	A
S	B	X	E	A	A	W	U	I	A	I	L	H	X	B	R	C	A	T
O	A	F	D	E	E	P	O	E	R	L	M	U	V	C	L	L	X	U
C	L	O	U	D	S	R	T	U	E	S	S	M	C	F	D	E	A	R
C	I	U	T	Y	D	A	O	B	A	S	X	I	E	Z	P	S	R	E
K	J	R	M	F	M	A	O	S	R	A	D	D	F	R	C	L	P	S
Z	Y	C	R	I	T	W	O	I	O	U	V	I	W	A	A	J	U	V
C	E	O	L	U	R	A	B	I	N	L	A	T	E	R	V	T	E	O
P	S	C	A	V	S	O	I	B	C	L	S	Y	R	S	T	C	U	T

Find the following words hidden in this wordsearch. Read across, up, down and diagonally.

AEROSOLS
AIRCRAFT EXHAUST
ALTITUDE
CIRRUS
CLIMATE
CLOUD
CLOUDS
CONTRAILS
DEW POINT
HIGH
ICE PARTICLES
JET
LINEAR
PERSISTENT
PERSISTENT SPREADING
RELATIVE HUMIDITY
SHORTLIVED
TEMPERATURE
WATER VAPOR
WIND SPEED

Visit the Contrail Education Activity website for a copy of the Contrail Education Crossword Puzzle at: http://asd-www.larc.nasa.gov/GLOBE/resources/activities/

(continued from page 1 - Climate Change and the Future of Air Travel)

Day to day variability in atmospheric conditions was also found to have a substantial effect on the ability of simple altitude restrictions to be an effective policy. Current work is aiming to examine more complex aircraft routing strategies aimed at avoiding air masses that lead to persistent contrail formation.

At present the production of contrails and their effect on the environment is not taken into account in government assessments of the environmental impact of air travel. Team leader, Dr. Robert Noland, thinks it should be. He says, "We'd like this research to inform government policies, not just in the UK but throughout the rest of the world so that decision makers can take all the environmental issues into account and do the right thing."

Dr. Noland also believes that the work has direct relevance to aircraft manufacturers. He says, "There is little more that aircraft designers can do to increase engine fuel efficiency at high altitude, but designing new aircraft that can be as fuel efficient flying at 20,000 feet, as today's aircraft are at 35,000 feet, would help eliminate contrails."

This photo shows the extensive build-up of persistent contrails resulting from its location along the East Coast flyway. Some of these contrails are showing signs of spreading, but the spreading is not particularly pronounced. There are also some natural cirrus clouds visible in the mix.

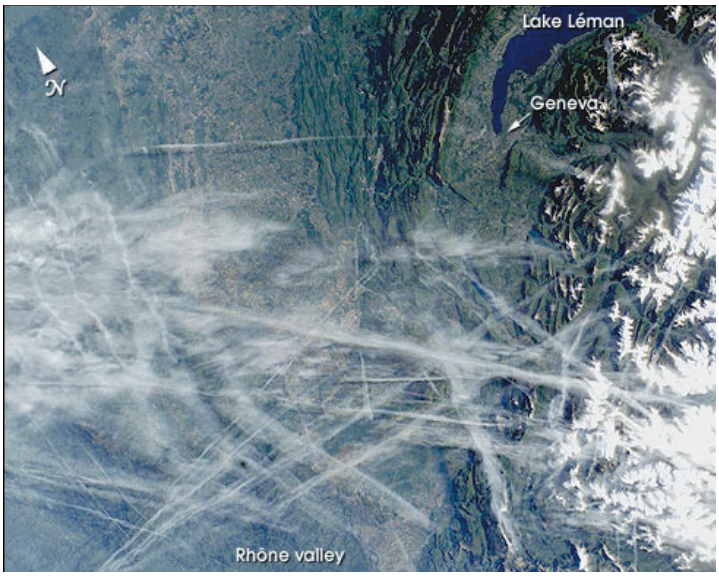
A key consideration in this study is the proliferation of short-haul flights. These are currently thought to be more environmentally disruptive than long-haul flights because of the high quantity of fuel needed for take-off and landing. In a short haul, this is not balanced by a long, fuel-efficient cruise. However, contrail effects are not taken into account in current assessments of air travel. The team is investigating whether the picture would change if they were. The reason is that short-haul flights seldom reach the altitude where contrails form and this might make them overall more environmentally friendly than high-flying long-haul flights.

As well as the seasonal variation in atmospheric conditions, which the team estimated would require a general ceiling on flight altitudes (summer: 31,000 feet, winter: 24,000 feet), they also found significant day to day variations, so any contrail reduction strategy would work better if it were reactive on a daily basis. They also found days when the atmospheric conditions made it almost impossible to avoid contrail formation.

Aircraft already measure the exterior air conditions, so a simple piece of software, programmed with the details of the jet exhaust temperature and humidity could immediately alert a pilot to when his aircraft is creating a contrail. Although lower flying aircraft expend more fuel to push themselves through the thicker atmosphere, the team found this less damaging than the radiative forcing effect of the contrails. Lower altitude flying does, however, slightly increase travel time.

Radiative forcing is any change in the balance between radiation coming into the atmosphere and radiation going out. Positive radiative forcing tends to warm the surface of the Earth, and negative radiative forcing tends to cool it. This effort is being led by Dr. Robert Noland in Civil & Environmental Engineering. Dr Ralf Toumi in the Physics Dept is the co-investigator and Dr. Victoria Williams in Civil & Environmental Engineering is an EPSRC-funded Research Fellow.

The Engineering and Physical Sciences Research Council (EPSRC) is funding the work, which is a joint effort between the Department of Civil & Environmental Engineering and the Department of Physics at Imperial College London.
For more information visit EPSRC at: http://www.epsrc.ac.uk/



Digital photograph taken through the windows of the International Space Station shows contrails over Eastern France.

(continued from page 2 - NASA Scientists Use Empty Skies...)

The air traffic shutdown gave Minnis and his team the chance to track individual, persistent contrails from military aircraft on September 12.

"Six aircraft were responsible for the formation of cirrus clouds that covered more than 20,000 square kilometers within an area between Virginia and central Pennsylvania," said Minnis. "During normal days, the area is crossed by thousands of jetliners that could each produce contrails similar to those from the military jets."

The results of the study provide the basis for improved prediction of persistent contrails and their effects on climate.

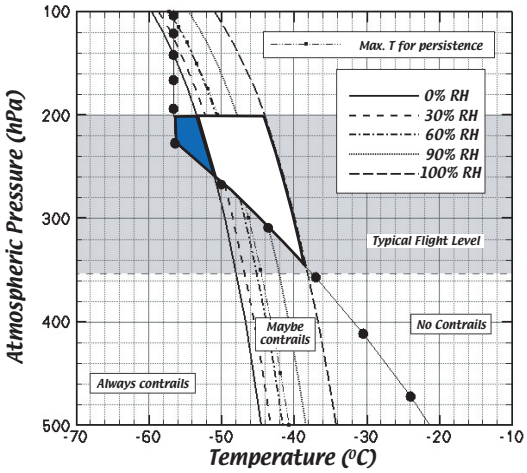
"If scientists determine that contrails are negatively impacting climate change, we could minimize their formation by predicting where they will occur and then suggesting alternate flight altitudes accordingly, when feasible," said Minnis. David Duda, of Minnis' team, has used improved estimates of relative humidity (the amount of water vapor in the atmosphere) from Minnis' study to enhance computer simulations of contrails and their predictability.

NASA STEMS

NASA Science Trivia to Excite & Motivate Students

By now it's not a mystery that scientists are studying contrails. But did you know that contrails were first noticed during high-altitude flights in the 1920's? However, interest in contrails really blossomed during WWII when bombers could be sighted from miles away. In fact, numerous WWII veteran accounts tell of problems to aviation due to massive contrail formations. Planes could not find their targets, and sometimes collided with each other. The picture to the left depicts one of the oldest contrail photos. It was taken during dogfights over London's St. Paul's Cathedral during the Battle of Britain in 1919.

Contrail Prediction Activity: The Appleman Chart



■ Definitely contrails ☐ Maybe contrails

In 1953, a scientist named H. Appleman published a chart that can be used to determine when a jet airplane would or would not produce a contrail. Appleman showed that when the air outside of the airplane is cold enough and moist enough, the mixture of the jet exhaust and the air would form a cloud.

http://asd-www.larc.nasa.gov/GLOBE/resources/activities/

Importance | Science | History of Contrails | Satellite Imagery | Reporting Instructions

Resources | Contrail Gallery | FAQ | Team Page | Glossary

Visit the most complete contrail website supported by NASA's leading atmospheric scientists. Find answers to many questions currently being investigated.

Importance: Contrails, especially persistent contrails, represent a human-caused increase in the Earth's cloudiness, and are likely to be affecting climate and ultimately our natural resources.

Science: What are contrails? Are there different types of contrails? How are contrails different from other clouds? Can contrails move, or do they stay in the location where they were formed?

HIstory: When were the earliest contrails observed? When did scientists learn how contrails formed?

Satellite Imagery: Can contrails be seen from space? How do scientists use satellite imagery to study contrails? View some satellite images of contrails.

Resources: Lesson plans, Quick Ideas, Activities, Presentations, Websites and Contrail ID Chart.

Contrail Gallery: View a collection of contrail photographs with explanations.

FAQ: Find out what questions folks from around the world are asking and what the scientists are replying.

Glossary: A great source for terminology related to the study of atmospheric sciences.

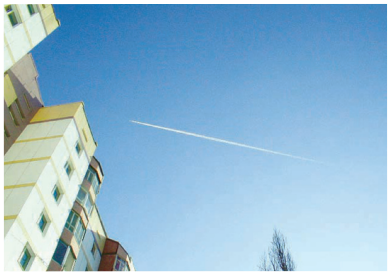
National Aeronautics and
Space Administration
www.nasa.gov
Explore.Discover.Understand.

CONTRAIL ID CHART

http://asd-www.larc.nasa.gov/GLOBE/

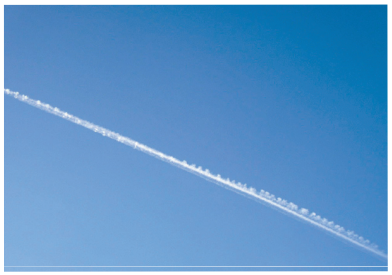
Short-lived

A contrail that forms and disappears as the plane moves along. Although its length remains about constant it may be very short, or it may span a large fraction of the sky. Generally it is very thin.



Persistent

A thin contrail that remains in the sky after the plane has disappeared. These contrails are not much wider than the short-lived contrails and are thinner than 1 finger held at arm's length.



Persistent Spreading

A thick contrail that remains in the sky after the plane has disappeared. They are wider than 1 finger held at arm's length. These contrails can grow to resemble natural cirrus clouds.

Contrails are clouds formed when water vapor condenses and freezes around small particles (aerosols) that exist in aircraft exhaust. Some of that water vapor comes from the air around the plane; and, some is added by the exhaust of the aircraft. Clouds are the largest variable controlling Earth's atmospheric temperature and climate. Any change in global cloud cover may contribute to long-term changes in Earth's climate. Contrails, especially persistent contrails, represent a human-caused increase in the Earth's cloudiness, and are likely to be affecting climate and ultimately our natural resources. Scientists today are trying to learn more about the longevity of persistent contrails and how much they may affect the climate in the future.

This material is based upon work supported in part by the National Science Foundations.