



Understanding Contrails:

A window into conditions in the upper troposphere



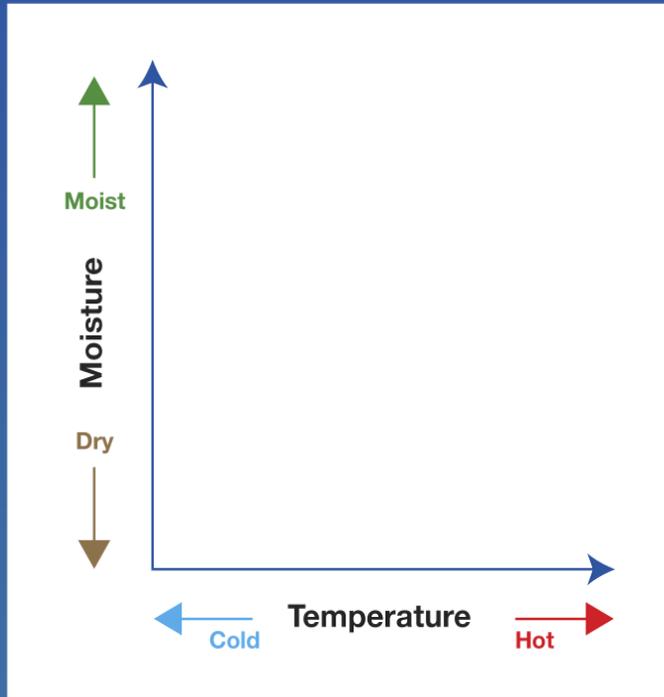
Did you ever wonder about those lines in the sky? Contrails are clouds formed when water vapor condenses and freezes around small particles (aerosols) that exist in aircraft exhaust. These slides explain how and why they occur.

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.

Graphing Conditions



Setting up Contrail Conditions Graph



The X-axis (horizontal axis) represents the temperature and the Y-axis (vertical axis) represents the amount of moisture in the atmosphere.

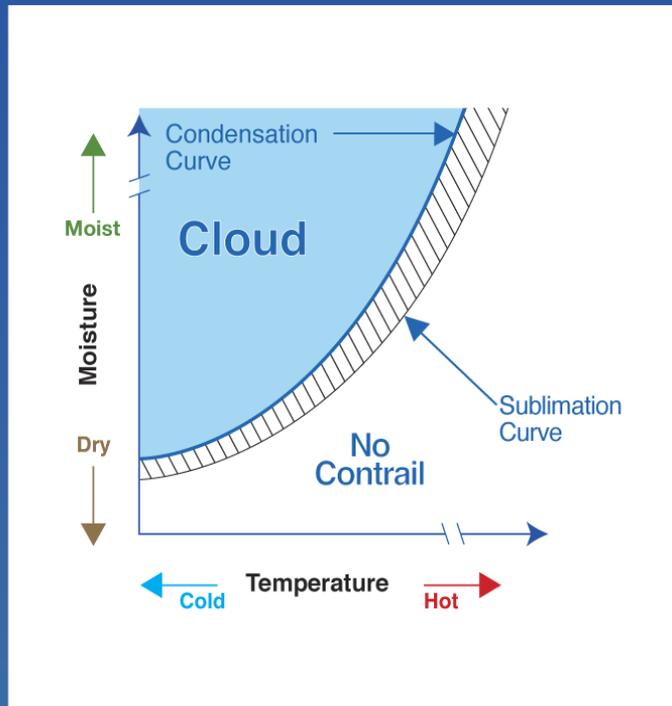
This graph represents possible conditions in the atmosphere for two different variables:

1. Temperature
2. Moisture

The Phases of Water



Where Water Changes State



The blue shaded area (cold and moist) shows the conditions where condensation (gas to liquid) occurs in the atmosphere. Because it is cold where airplanes fly, any water droplets forming in the jet exhaust will freeze into ice (liquid to solid) shortly after they form. The hatched area shows where ice will persist. In the white area, ice will sublime (solid to gas).

As we all know, water can occur in three different forms:

1. Gas (vapor)
2. Liquid (water)
3. Solid (ice)

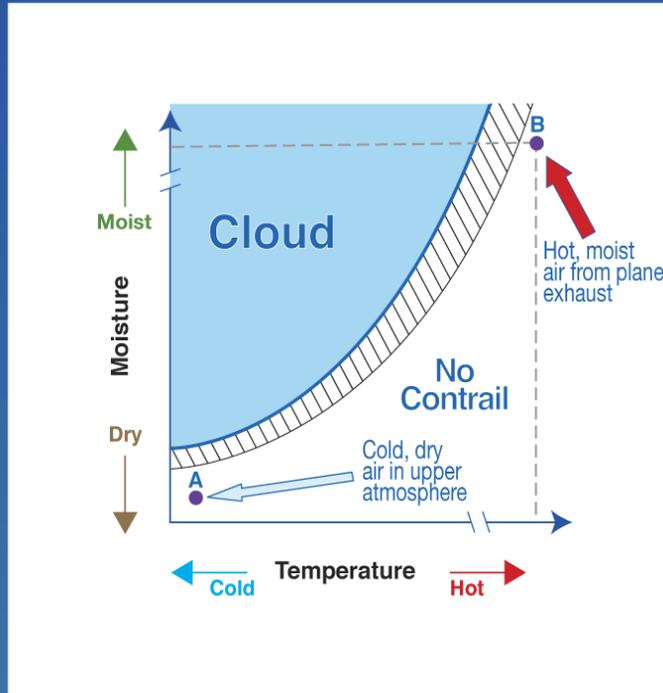
The white (vapor), blue (water), and hatched (ice) areas on this graph show where water takes each form in the atmosphere. Generally, water condenses or freezes when air is cold and moist; it evaporates when air is warm and dry.

Typical Conditions - Atmosphere



Typical Starting Points, A and B

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The cloudless atmosphere at high altitude is generally cold and dry (point A). Aircraft exhaust is hot and moist (point B).

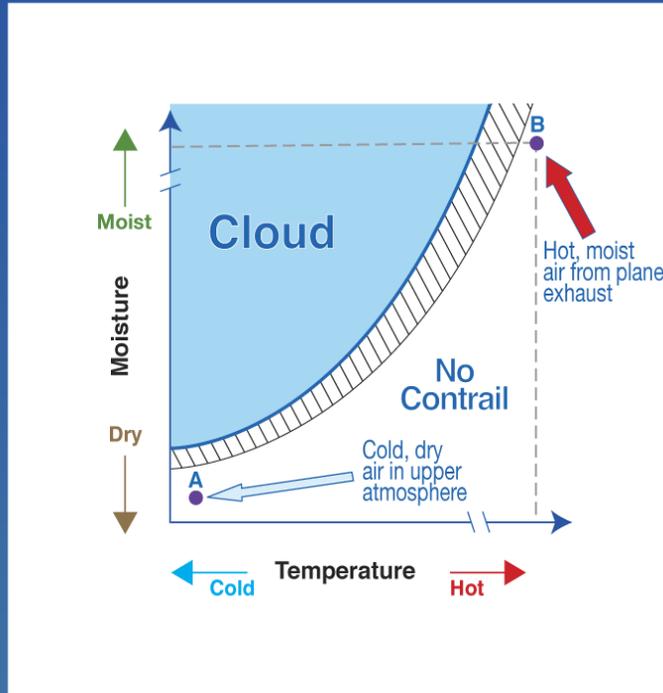
Point A represents typical conditions in the upper troposphere. In this region of the atmosphere where airplanes generally fly the temperature is very low; typically between -35 F and -75 F.

In the absence of clouds, the atmosphere is also relatively dry at flight level.

Typical Conditions - Exhaust



Typical Starting Points, A and B



The cloudless atmosphere at high altitude is generally cold and dry (point A). Aircraft exhaust is hot and moist (point B).

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Point B represents typical conditions of airplane exhaust. As you might imagine, air leaving a jet engine is quite hot. It also contains quite a bit of moisture.

Observation tip:

Watch for water dripping from the tailpipe of cars as you are riding around on the roads. Water (H_2O) is one of the products of combustion – both in car engines and in airplane engines.

A Thought Experiment



Imagine you are sitting in a room, such as a classroom or your living room.

Imagine that you pull one ice cube out of your freezer and set it in a saucer.

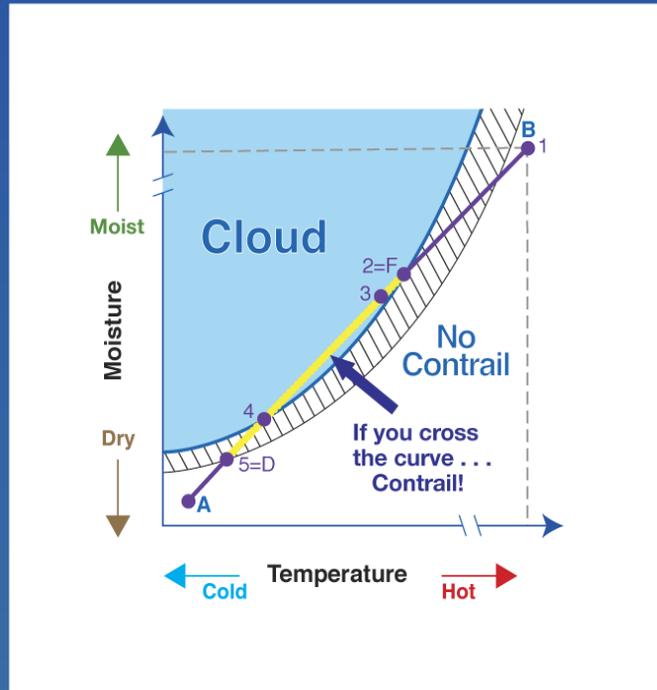
If you let that ice cube sit until it melts, will it have any impact on the temperature or humidity of the air in the room?

Contrails are Mixing Clouds



The air in the exhaust of a plane is similar in its impact on the atmosphere to the impact of the single ice cube on a room. It will equilibrate to the ambient conditions. This happens through a mixing process along the straight line from **point B** to **point A**.

Because the mixing line is straight while the condensation line is curved (exponential), it is possible for the mixture to cross into the condensation area even if both **points A** and **B** are in the white (vapor) portion of the graph.

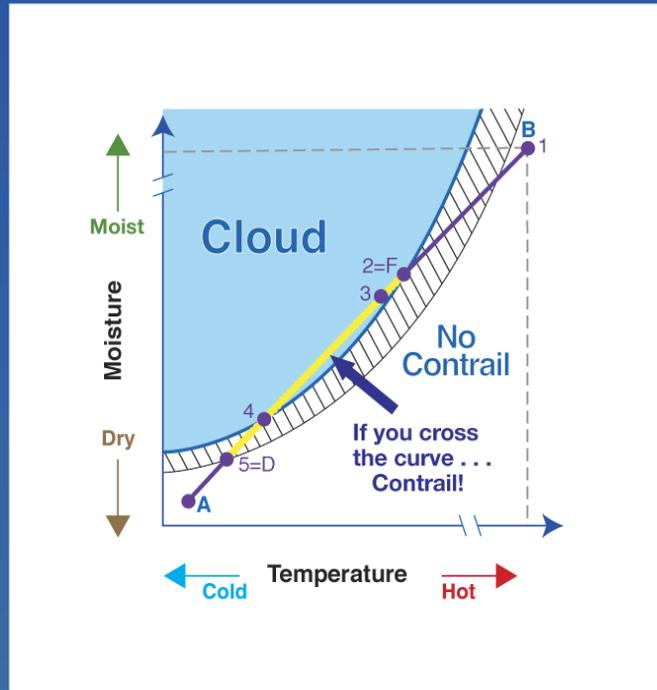


1. Hot, moist exhaust from jet airplanes cools as it mixes with the air until it reaches saturation at the condensation curve
2. (=F Formation of contrail)
3. Water drops freeze to ice crystals
4. Water drops would evaporate, but the ice crystals persist
5. (=D Dissipation of contrail) Ice crystals sublimate, and the contrail dissipates

Contrails are Mixing Clouds



The Mixing Process Starts at B and Moves Toward A



If the mixing line crosses the condensation line, a contrail will begin to form at point F.

The location of point A determines what type of contrail will result.

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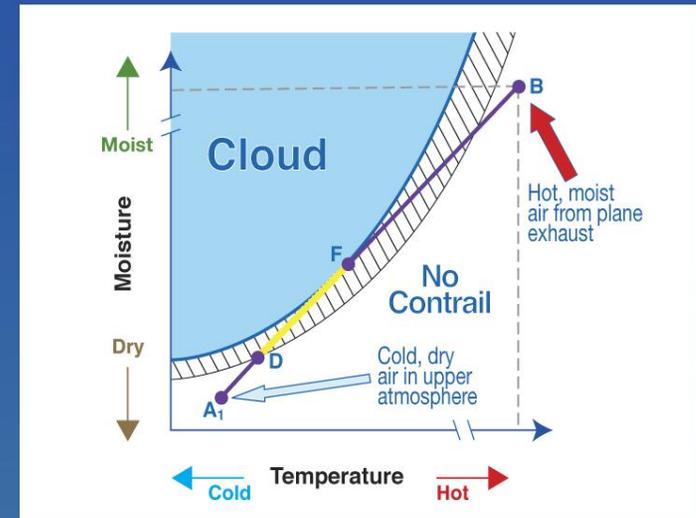
Short-Lived

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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.

Contrails in Dry Air →
Short-Lived Contrails



The exhaust from the airplane mixes with the air from the atmosphere along the straight line between points B and A₁. A contrail forms at point F and persists to point D. When the straight line between points A₁ and B barely crosses into the condensation curve, a short-lived contrail is formed.

Short-lived contrail(s) => Dry upper atmosphere

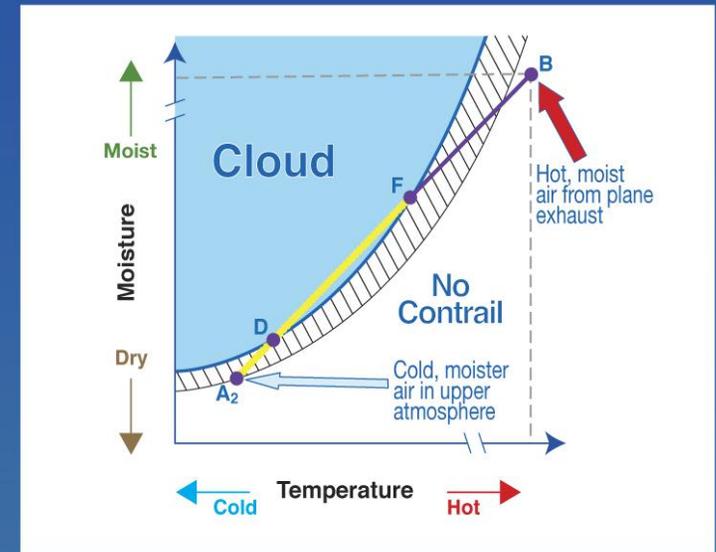
Persistent



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.

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Contrails in Colder Air → Persistent Contrails



When point A_2 is such that the straight line between points B and A_2 crosses further into the condensation area, and A_2 is closer to the sublimation curve, a longer lasting, or persistent, contrail forms between points F and D.

Persistent contrail(s) => Moister upper atmosphere

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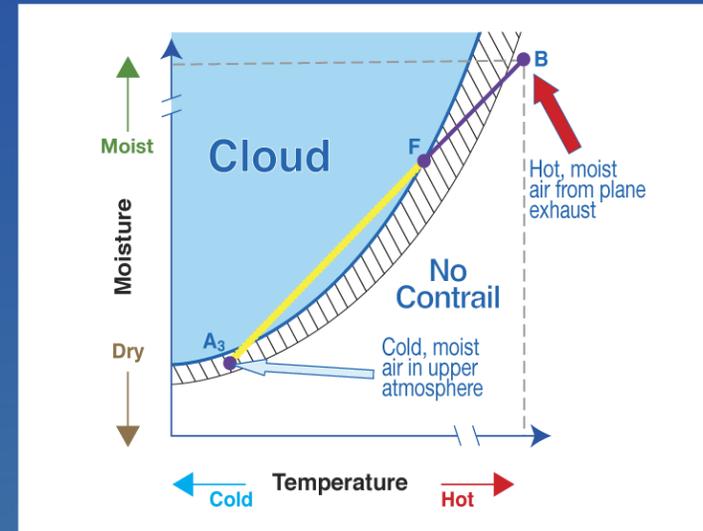
Persistent Spreading

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

Contrails in Moister Air → Persistent Spreading Contrails



When point A_3 is in the hatched area (moister air), the addition of warm, moist airplane exhaust leads to a persistent, possibly spreading, contrail since the ice particles created at point F will not sublimate at point A_3 .

Persistent spreading contrail(s) => Moist upper atmosphere

Follow Up Activity



- Over the next few weeks, keep an eye on the sky and take pictures when clouds aren't in the way.
- Once you have a collection of 6 or more photos, classify them according to what they indicate about the atmosphere at flight level:

Very dry (no contrail)

Dry (short-lived contrail)

Moist (persistent contrail)

Very moist (persistent spreading contrail)

