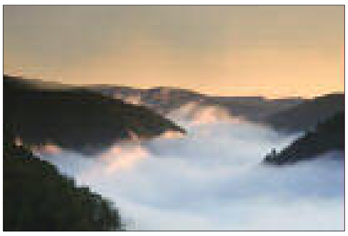
MTO 412E Physics of Cloud and Precipitation

Fundamentals of Fog



Definitions Related to Fog Formation

Atmosphere

- A Mixture of nitrogen, oxygen, trace gasses, and water vapor.
- In this mixture, water vapor is the most variable.
- Water vapor content depends on temperature and pressure.
  - Warmer air can have more water vapor than cooler air.
  - Air with a higher pressure can have more water vapor than air with a lower pressure.

Mixing Ratio

- In air, the ratio of the mass of the water vapor to the mass of the dry air.

Definitions Related to Fog Formation (cont'd)

Saturation

- In air, the maximum amount of water possible under the existent pressure and temperature.

Relative Humidity

- The ratio of the amount of water vapor actually present in the air to the greatest amount possible under the same temperature and pressure.

Condensation

- The conversion of water from the vapor state to the liquid state, usually brought about by a reduction in temperature.

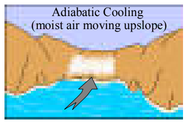
Dew point

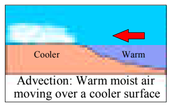
- The temperature at which water vapor begins to condense.

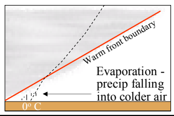
Three Conditions for Fog Formation

Generally, stable conditions, light winds, and a high relative humidity are required.

1. **Cooling processes**
   - Radiational cooling
   - Advection of warm moist air over cooler surface
   - Adiabatic cooling (e.g., upslope motion)
   - Evaporational cooling (precip falling through colder air; frequently occurs at frontal boundaries)







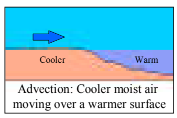
Three Conditions for Fog Formation (cont'd)

2. **Adding moisture**
   - Evaporation (e.g., from a large body of water or a saturated surface)
   - Adding condensation nuclei (high-population areas, etc.)
   - Cold air moving over warm water or a saturated surface

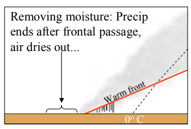
3. **Mixing**
   - This brings more of the moist air in direct contact with the ground.
   - Must be relatively light mixing; too much mixing can entrain nearby dry air and help dissipate fog

Three Conditions for Fog Dissipation

1. **Heating processes**
   - Incoming solar radiation: increases temp/dewpoint spread
   - Advection over a warmer surface
   - Adiabatic warming (e.g., downslope motion)

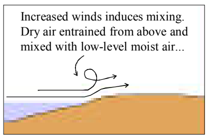


2. **Removing moisture**
   - Condensation and precipitation
   - Frontal passage
   - Dry air entrainment



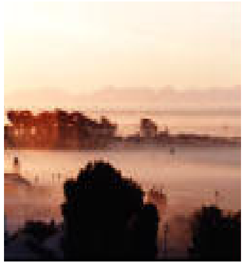
Three Conditions for Fog Dissipation (cont'd)

3. **Mixing** (from surface heating or increased wind speeds)
   - This process involves mixing the lower-level moist air with adjacent drier air, or turbulent transfer of moisture aloft.
   - Either process results in a wider temperature/dewpoint spread.



Fogs

- Fogs are clouds in contact with the ground
- Several types of fogs commonly form
  - Radiation fog
  - Advection fog
  - Upslope fog
  - Evaporation (mixing) fog



Fog

The difference between clouds and fog is that fog forms close to the earth's surface...

Radiation Fog - usually results from the nightly cooling of the earth. The layer of air comes in contact with the earth becomes chilled below its dew point.

- Radiation Fog is also known as ground fog
- Radiation fog is thickest around cities because there are more sources of smoke and dust particles to act as condensation nuclei

http://www.islandnet.com/~see/weather/almanac/arc2002/alm02sep.htm

Advection Fog - forms when warm, moist air moves across a cold surface- warm air cools to its saturation point, forming advection fog

- Advection Fog form along coasts and over the ocean

Upslope Fog - Formed by the lifting and adiabatic cooling of rising air along sloping land. This type of fog is a kind of cloud formation at the ground level. Fog that forms as moist air flows up along an elevated plain, hill or mountain.

Steam Fog - usually forms over inland lakes and rivers

- Steam fog is a shallow layer of fog formed when cool air moves over a warm body of water.
- Fog forming over lakes on autumn mornings, as cold air settles over water still warm from the summer

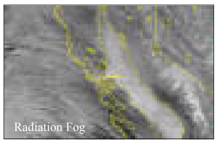
Evaporation (mixing) fog: Fog formed from the mixing of two unsaturated masses of air – e.g., fog produced from our breathing

Ice Fog: Marine air moves over an ice or snow surface, ice crystals form instead of water droplets – produce ice fog

Fog Types - Radiation Fog (“Ground Fog”)

- Caused by radiant cooling of the Earth’s surface.
- Occurs when the air temperature cools to the dew point due to nocturnal cooling.
- Common on clear nights with a shallow layer of moist air near the ground, capped by a drier layer aloft.
- As surface temperatures decrease, a surface inversion occurs; the air within the inversion becomes saturated, forming fog.
- The longer the night, the longer the cooling time and greater the likelihood of fog.
- Common in areas of high pressure; Never forms over water.

Radiation Fog - Formation and Dissipation



- If wind is 0– 2 kts, fog is shallow
- If wind is > 8 kts, no radiation fog is likely.
- Ideal conditions: wind 3 – 7 kts with an inversion present and a constant or increasing dew point through the first 200 – 300 feet.
- Cloudy days (especially low clouds with precipitation) and clear skies at night (or high thin cirrus) allow for maximum radiational cooling provide optimum conditions for this type of fog.
- Dissipates with surface heating or strong mixing.

Radiation Fog

•Surface radiation and conduction of heat away from the overlying air cool air temperatures near the ground
•A layer of air near the ground becomes saturated and fog forms
•Fog deepens as radiative cooling from the fog top continues overnight
•Solar heating warms the ground and causes the fog to “burn off” from the ground up
•What type of meteorological conditions would favor radiation fog?

Radiation fog nestled in a valley

Fog Types - Advection Fog

- Typically produced by transport of warm, moist air over a colder surface.
- Cooling from below builds layer.
- The surface being cooler than the air above causes the transfer of heat from air to surface, which cools the air to its dew point and produces fog.
- Most common along coastal areas, but can be found anywhere warm, moist air is advected (transported) over a colder surface.

Advection Fog - Formation and Dissipation

- Wind less than 3 kts, fog is shallow
- Wind 3– 9 kts, ideal for deep fog
- Wind > 9 kts, too much mixing for fog (more likely stratus formation)
- Dissipates with surface heating, adiabatic warming (downslope motion) or strong winds
- This type of fog usually lifts to stratus before dissipating

Advection Fog Types

Land Advection Fog

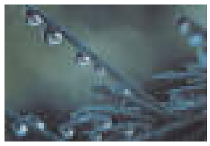
- Found near large bodies of water.
- Cannot exist in high wind speeds
- Forms when on-shore breezes move maritime air over a radiational cooled land surface

Advection Radiation Fog

- Occurs when air that has come inland from the sea during the day undergoes nighttime radiational cooling
- Occurs mainly in late summer/autumn

Advection Fog

- Warm air moves (is *advected*) over cold surface
- Cold surface cools warm air
- If saturation is reached, fog forms
- Common on west coast of U.S.
  - Warm moist air from Pacific is advected over upwelling cold coastal waters
  - As foggy air moves ashore, solar heating warms the ground and overlying surface
    - Fog evaporates near ground
  - Coastal advection fogs are key moisture sources for California Redwoods



Fog: A Cloud on the Ground

This Advectional fog forming in San Francisco is due to Moist Ocean air being moved horizontally over cooler land surfaces

This fog is a common Summer condition Along the California coast As high temperatures Farther inland draw moist ocean Air over coastal areas

Fog by San Francisco Bay

ADVECTION FOG

- CAUSE: Advection of moist air over cool surface
- Need: Movement of relatively warm, moist air over a cool or cold surface. Occurs with moderate or strong winds. Onshore winds for coastal area favor advection fog. Need inversion to be low. Monitor model boundary layer relative humidities.
- Example: Northern flow about the oceanic subtropical high; eastward flow over the cool California current; onshore flow over cold winter land warm flow (warm sector of continental cyclone) over snow cover.

Upslope Fog

- As moist air flows up an elevated plain, hill, or mountain, upslope fog forms due to gradual orographic lift, which cools the air temperature to the dewpoint temperature.

Upslope Fog

- Fog formation is caused by adiabatic cooling of rising air.
- May occur in relatively high wind speeds; however, winds greater than 12 kts will usually produce stratus.
- Dissipates with a change in air mass, a change in wind direction (downslope vs. upslope), or surface heating.

UPSLOPE FOG

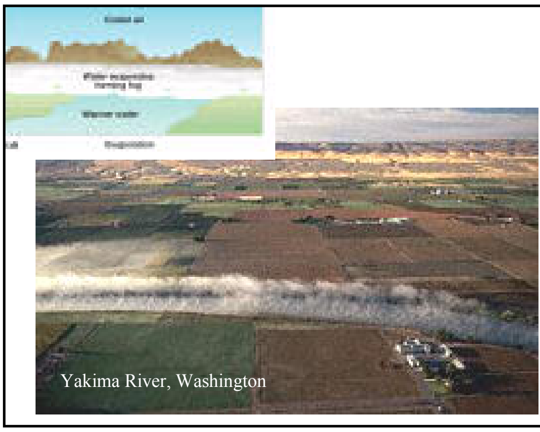
- CAUSE: Cooling of air due to orographic ascent
- Need: Near saturated air forced to rise over a mountain barrier
- Common with frontal passages over high terrain

Sea Fog

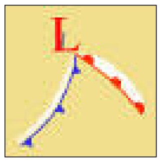
- This is a type of advection fog that forms when warm moist air moves over colder water
- Occurs when sea air is cooled over a cold ocean current
- A greater temperature yields a deeper, denser fog
- This fog may lift to stratus as it moves on shore
- Can exist with stronger winds
- Dissipates by air mass modification, or if transported over warm land

Steam Fog ("Arctic Sea Smoke")

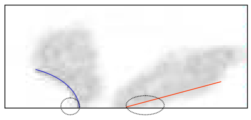
- This is a type of advection fog caused by cold air moving over warmer water
- Occurs when cold air moves over warm water
- Forms on clear nights inland over lakes and rivers
- Caused by rapid evaporation of moisture into relatively cold air. Usually 2 - 3 ft thick
- Most common in mid-latitudes in fall or early winter, over lakes and rivers
- Dissipates as air heats, with a change in air mass, or a change in wind direction



Frontal Fog

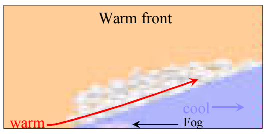


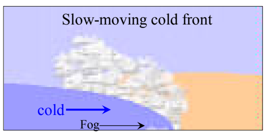
- Can form in advance of a warm front or behind a warm front if the warm air dew point is higher than the cold air temperature.)
- Can form behind a slow moving cold front when the air becomes saturated
- Forms in the shallow layer of cold air just ahead of an approaching warm front or behind a cold front



Frontal Fog

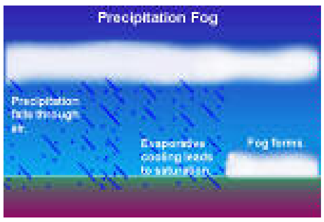
- Warm fronts: fog is more widespread than with cold fronts; caused by warm rain falling into colder air
- Cold fronts:
  - Fog occurs with both active (slow moving) and inactive (fast moving) cold fronts
  - Usually found up to 150 - 200 miles behind the surface front due to the saturated surface
  - Fog formation ceases with passage of the 850 mb frontal trough





PRECIPITATION OR FRONTAL FOG

- CAUSE: Cooling of near saturated boundary layer. Fog is common in major rain events and near frontal zones.
- New satellite tools for fog analysis: Use of differences between 3.7 micron and 11.5 micron channels can reveal fog areas at night.



Coastal Fog

Fog: a cloud that "touches" the surface of the earth.

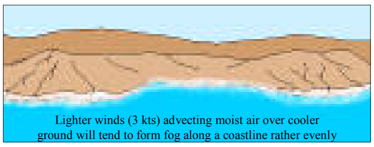
- Causes of clouds/fog
  - Clouds are formed by the cooling of saturated air by the ocean or land surface beneath.
- Prediction of fog
  - If the difference between air temperature and dew point is less than 2°F, fog may result.

Marine Fog

Fog Formation - Onshore Winds

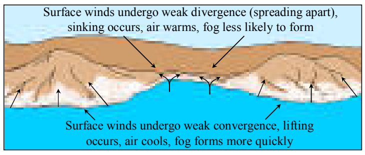
Headlands vs beaches: fog formation with onshore winds

- Knowledge of local climatology and terrain effects aids in understanding fog formation in these regions.
- With onshore flow, fog formation factors are the wind speed, ground temperature, and near-coastal topography.
- Lighter winds (around 3 kts) advecting moist air over cooler ground will tend to form fog along a coastline rather evenly.



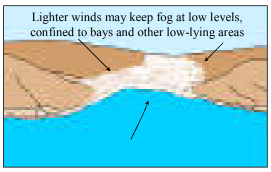
Fog Formation - Onshore Winds (cont'd)

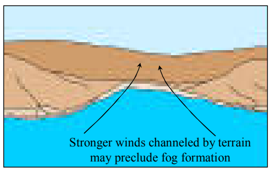
- "Stronger winds" (approaching about 10 kts) advecting moist air onshore over cooler ground will tend to form more unevenly distributed fog areas along the coastline
- Fog tends to form more along along the headlands (more "convex" areas) and less along bays or beaches (more "concave" areas)



Fog Formation - Onshore Winds (cont'd)

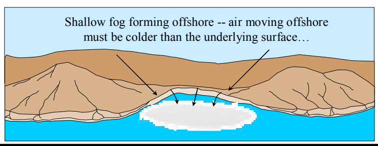
- Depending on the surrounding topography, winds at the bay/beach areas may also be faster than at the headland areas because of channeling, precluding fog formation in this area.
- If the wind speed is too great, no fog will form due to mixing.
- Lighter winds advecting moist air over onshore over cooler ground may keep the fog from forming along the headlands and instead move it into bays or other low-lying areas along the coast





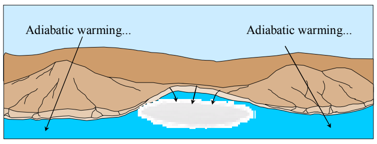
Fog Formation - Offshore Winds

- Shallow fog can occur with offshore flow when cold air moves over warm water. The fog usually forms a short distance offshore because the evaporation process needs time to take place. This type of fog will usually not form if the winds are too strong (mixing with drier air above occurs).
- Offshore fog formation can also occur with warm moist air moving over cooler water (e.g., southerly flow preceding a warm front). This fog can occur with stronger winds (and is usually deeper in extent) because there is a more steady source of moisture available.



Fog Formation - Offshore Winds (cont'd)

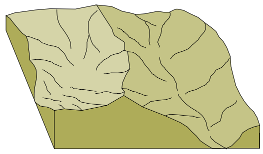
- When this type of fog occurs in a region of variable topography, it is more common offshore from the lower-lying areas of the coast.
- Any adiabatic warming from the air descending from higher regions on the shoreline may offset the temperature difference between the cooler air and warmer water.



Fog and Terrain

Why does fog occur in some valleys, but not in others (even the "next valley over")?

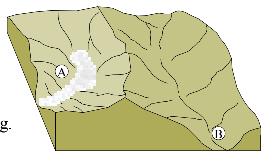
- Access to a good terrain map will answer the question; the physical aspects of the valley are the key.
- These aspects include:
  - Valley location and orientation (e.g., N – S, E – W)
  - Access to a source of moist air, either from a maritime air mass, saturated ground, nearby (relatively) large body of water, or precipitation



Fog and Terrain (cont'd)

Valley "A" has ready access to a maritime air mass; valley "B" does not.

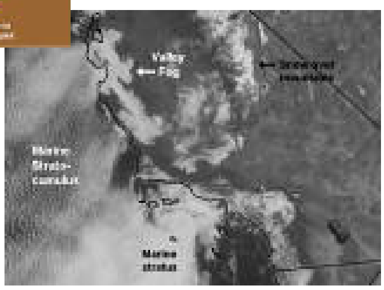
- It also takes the proper amount of heating and cooling. How much a valley area heats or cools is driven by its surface albedo, orientation to the sun, and slope of the valley walls (e.g., steeper slopes may have less heating time than shallow slopes).
- Bottom line: access to no moisture means no fog.
- In valleys or basins with access to moist air, with proper heating and cooling conditions (and the right season), fog can form at night, lift to stratus (higher elevations: still fog) during the day because of heating, and become fog at night due to cooling.



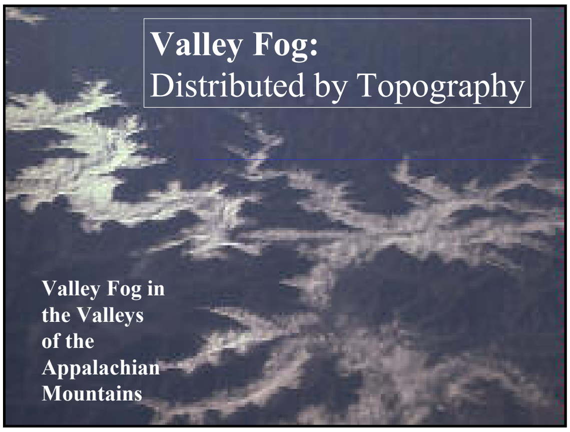
More on Valleys and Fog

- If the valley area has a tendency towards mountain/valley breezes:
  - Fog will not form at night (mountain breeze) because of adiabatic warming.
  - Fog will only form during the day if the winds are not too strong and there is a source of moisture.
- If the valley area has a tendency towards land/sea breezes because of its proximity to a coastline or large body of water:
  - If the air is cool enough, fog can form offshore as cooler air leaving the valley passes over warmer water. This fog is usually relatively shallow.
  - If the ground is cool enough, fog can form in the valley as warm, moist air moving in from the water area passes over the cooler surface.

Valley Fog



Valley Fog: Distributed by Topography



Visible images give meteorologists extra information that may not appear on Infrared temperature images. For example, fog appears in Visible images, but may not in Infrared images when the fog and the land are at the same temperature.

The visible satellite image shows a classic dendritic pattern created by early morning fog in the valleys of New York and Pennsylvania. Fogs such as this develop during nights favorable for radiational cooling - conditions of clear skies and light winds.

www.erh.noaa.gov/er/ bgm/wia/wiafog.html

Where is the fog?

Visible image

Infrared image

September 5, 1999 13:45 UTC

South of the North Sea. On the visible image, a clouds strip (1) appears along England. The sky is clear elsewhere over the sea, except a small crescent of clouds (2). On the infra-red image, the clouds strip (3) along England is only slightly clearer than the sea. The temperature of the top of these clouds is not much colder than the temperature of the sea. That means that they are low clouds, probably stratus or fog. On the other hand, the small crescent of clouds (4) appears definitely whiter than the sea, they are thus higher clouds.

http://www.allmetsat.com/en/exemple3.html

Importance of FOG FORECASTING

1. Fog is a major source of flight delays and cancellations. Fog will reduce ceiling and visibility to below airport minimum permitted values or will stop dual runway operations at major airports.
2. Maritime fog is extremely dangerous at sea. Major ship accidents have occurred with fog conditions. The sinking of the ANDREA DORIA after it collided with the cargo ship STOCKHOLM occurred in an intense fog event.

Importance of FOG FORECASTING

3. Fog also causes car accidents on major highways due to cars traveling too fast for the visibility in the fog.
4. Fog is a key element of the ceiling and visibility forecast

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TYPES OF FOG- Named for the processes which produce the fog.

1. *Radiation Fog* -- due to nocturnal cooling
2. *Advection Fog* -- due advection of warm, moist air over cooler surface.
3. *Upslope Fog* -- cooling due to orographic lifting
4. *Precipitation or Frontal fog* -- saturation of boundary layer due to precipitation
5. *Advective/Radiation Fog* -- radiation cooling of advected air from a moist source

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Average annual # of days with heavy fogs in USA

FORECASTING FOG

- Need to form a cloud on the surface. HOW? Cool the surface to the saturation point. Moisten the surface to saturation.
- RADIATION FOG
  - CAUSE: Nocturnal cooling of relatively moist air
  - Need: Clear night -- Max cooling
  - Calm or weak winds -- No mixing of the air concentrates the cooling at surface
  - Moderate surface dew point -- Will the cooling drop the min to and below the dew point? Compare your or MOS minimum temperature forecast with dew point
  - Examples: Winter, valley locations
  - Winter coastal locations
  - Thule fog of the California central valley

Steps in cloud/fog formation

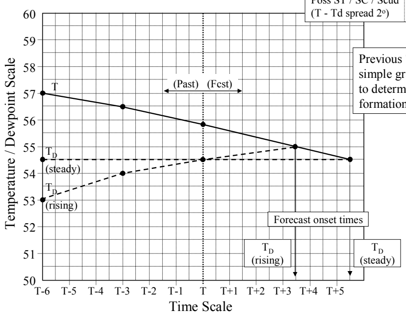
- Air parcel cools causing RH to increase
  - Radiative cooling at surface
  - Expansion in rising parcel
- CCN (tenths of µm) take up water vapor as RH increases
  - Depends on particle size and composition
- IF RH exceeds critical value, drops are *activated* and grow readily into cloud drops (10's of µm)

Forecasting Fog - One Method

After other factors are considered, the forecast comes down to determining the temp / dewpoint spread. One method is provided here.

Example: T = 55.7°, T-3 = 56.5°, T-6 = 57.0°	T_d (rising): T_d = 54.5°, T_d-3= 54.0°, T_d-6= 53.0°	T_d (steady): T_d = 54.5°, T_d-3 = 54.5°, T_d-6 = 54.5°
Fog Onset:	T + 3:30	T + 5:30
Poss ST / SC / Scud (T - Td spread 2°)	T - 1:35	T - 3:00

Previous T / Td are plotted on a simple graph, then forecast past T+0 to determine possibility of fog formation...



Other Fog Types

- Evaporation (mixing) fog
  - Mixing of warm, moist air with colder air produces saturated air parcel
  - Examples
    - Exhale on a cold day
    - Evaporation of water from relatively warm, wet surface and mixing with colder air above.
    - (Smokestack plume, contrails)
- Upslope fog
  - Moist air flows up along sloped plain, hill or mountain
  - Expansion of rising air causes cooling and RH increases

Fogs and visibility

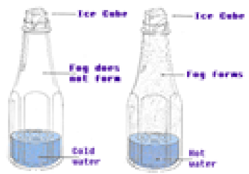
- Light scattering by fog drops (geometric scatterers) degrades visibility, leading to
  - Traffic fatalities
  - Airport accidents and closures
- Remedies
  - Fog monitoring and warning (optical sensors)
  - Fog dispersal (expensive and of limited utility)

Fog
Mission Impact

- Severely reduced visibility and ceilings
  - Halts all air operations
  - Can reduce and/or inhibit ground operations
- Speciatl hazard during night SAR ops
  - Beware small temp/dew point spread
  - Decreasing temperature dew point spreads

Fog

Homework: Do it yourselves!



starryskies.com/try_this/ fog.html

Homework: Learn it yourselves!

http://meted.ucar.edu/mesoprim/mpradfog/index.htm