MARINE FOG

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Definition of fog

Warm fog

- $\text{RH}_w \approx 100\%$ and $\text{Vis} < 1 \text{ km}$

Cold fog

- **Freezing fog**: $T_g \leq 0\degree \text{C}$; $\text{RH}_w \approx 100\%$; $T_a \approx 0\degree \text{C}$ (freezing at surface)
- **Frozen fog**: $-10\degree < T_a \leq 0\degree \text{C}$; $\text{RH}_w \approx 100\%$ (freezing happens in the air)
- **Ice fog**: $T_a < -10\degree \text{C}$; $\text{RH}_i > 100\%$ (Depositional nucleation)
Fog and Precip VIS

\[ \text{Vis} = f(\text{V}_{\text{rh}}, \text{V}_{\text{mix}}, \text{V}_{\text{liquidfog}}, \text{V}_{\text{icefog}}, \text{V}_{\text{drizzle}}, \text{V}_{\text{rain}}, \text{V}_{\text{snow}}, \text{V}_{\text{blows}}) \]
MARINE FOG

Goals

• 1) its formation
• 2) its development and dissipation
• 3) Its impact on environment
• 4) Its prediction and numerical models
• 5) Remote sensing applications
The sea breeze circulation is composed of two opposing flows; one at the surface (called the sea breeze) and one aloft (which is a return flow). These two flows are a result of the difference in air density between the land and sea caused by the sun's heating.

http://www.srh.noaa.gov/jetstream/ocean/seabreezes.htm
OVER NIGHT
As the air warms, its density decreases creating a weak low pressure area called a "thermal low" (1).

Over the adjacent water the cooler, more dense air, being pulled down by gravity, begins to spread inland (2).

This inland push of air from the ocean undercuts the less dense air over land forcing it to rise (3).

A sharp boundary develops due to the large difference between the air temperature over land and over water. This boundary, called a sea breeze front, acts in the same manner as the cold front we typically experience.
ST JOHNS, NL, Cold Fog: (vis <= 1/2SM & temp <= 0°C)
FORMATION

Warm air advection

- Marine fog forms due to large scale warm and moisture air advection from ocean over the colder ocean and land surfaces.
- \( Ta > Ts \)
- \( Ta - Td \sim < 2 \text{C} \)
- Existence of CCN
DEVELOPMENT

• Marine fog intensity (Vis) decreases in early morning because of radiative cooling over land
• Calm air/less turbulence
• Strong advection from warm/moist air regions
• Available CCN (sea salt particles)
DISSIPATION

• 1) Radiative heating

• 2) Wind circulation opposite to conditions occurred during development

• 3) Turbulence/Mixing
3. ITS IMPACT ON ENVIRONMENT

• i. Hydrological cycle
• ii. Plant and vegetation
• iii. Aviation and transportation
• iv. Energy
## i) Hydrological cycle

<table>
<thead>
<tr>
<th></th>
<th>Intensity inches/hour (cm/hour)</th>
<th>Median diameter (millimeters)</th>
<th>Velocity of fall feet/second (meters/second)</th>
<th>Drops per second per square foot (square meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fog</td>
<td>0.005 (0.013)</td>
<td>0.01</td>
<td>0.01 (0.003)</td>
<td>6,264,000 (67,425,000)</td>
</tr>
<tr>
<td>Mist</td>
<td>.002 (.005)</td>
<td>.1</td>
<td>.7 (.21)</td>
<td>2,510 (27,000)</td>
</tr>
<tr>
<td>Drizzle</td>
<td>.01 (.025)</td>
<td>.96</td>
<td>13.5 (4.1)</td>
<td>14(151)</td>
</tr>
<tr>
<td>Light rain</td>
<td>.04 (1.02)</td>
<td>1.24</td>
<td>15.7 (4.8)</td>
<td>26 (280)</td>
</tr>
<tr>
<td>Moderate rain</td>
<td>.15 (.38)</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy rain</td>
<td>.60 (1.52)</td>
<td>2.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excessive rain</td>
<td>1.60 (4.06)</td>
<td>2.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloudburst</td>
<td>4.00 (10.2)</td>
<td>2.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ii) Plant and Vegetation

• Plants need water to survive and some trees need more than others.

• In their growth season, they use their body cells (Leaves) absorbing the water droplets.

• Longer the contact with fog, they can process chemicals found in the fog.

• Keep the soil moisture in the certain level.
iii) Aviation and Transportation

- Visibility affects aviation and transportation
- Approximately 30-40% of aviation accidents related to weather conditions
- ~60 people dies in Canada because of fog related accidents per year
- This number increases up 600-1000 people per year in US (assuming same rate)
- 30 Million dollars per day costs to the aviation industry if a large airport stops the commercial flights.
PART 91 NTSB WEATHER RELATED ACCIDENTS BY WEATHER CONDITION 1994-2003

17,129 PART 91 ACCIDENTS

WEATHER RELATED 79%
NON-WEATHER RELATED 21%

51.0% WIND
19.8% VISIBILITY/CEILING
7.5% TURBULENCE
7.1% ICING
4.2% DENSITY ALTITUDE
1.9% THUNDERSTORM
1.2% WINDSHEAR
0.1% OTHER

PART 91 WEATHER OCCURRENCES BY CONDITION

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIND</td>
<td>2514</td>
</tr>
<tr>
<td>VISIBILITY/CEILING</td>
<td>977</td>
</tr>
<tr>
<td>TURBULENCE</td>
<td>371</td>
</tr>
<tr>
<td>ICING</td>
<td>350</td>
</tr>
<tr>
<td>DENSITY ALTITUDE</td>
<td>347</td>
</tr>
<tr>
<td>PRECIPITATION</td>
<td>208</td>
</tr>
<tr>
<td>WINDSHEAR</td>
<td>94</td>
</tr>
<tr>
<td>THUNDERSTORM</td>
<td>59</td>
</tr>
<tr>
<td>OTHER</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4927</td>
</tr>
</tbody>
</table>

Between 1994 and 2003, there were 19,562† aircraft accidents, involving 19,823 aircraft, of which 17,129 were correlation, of which 3,617 of the Part 91 accidents. This chart identifies the breakout of Part 91 weather-related accidents according to
† Accidents include final reports only where causal factors were identified.
§ A single accident may involve multiple weather conditions.
**iv) Energy**

- Fog affects surface air temperature (also heat) significantly.
- This effect can be about 100 W m\(^{-2}\) depending on fog microphysics and optical thickness.
- It also affects power lines because of freezing fog conditions.
- Its effect on climate change assessment is very limited/even unknown.
FOG PREDICTION

• FRAM Projects have been done over various regions of the world.
• Observations for some cases were collected nearby the ocean
• Microphysical observations were done using FMD (DMT fog device)
• All weather sensors were used for Vis meas.
• Remote sensing platforms were utilized
FMD (fog measuring device)

FOG + DRIZZLE DROPLET SPECTRA AT 10 AM LST.
The graph illustrates the relationship between temperature [°C] and RHw [%] with the equation:

\[ y = 0.0458x^2 + 3.2338x + 117.35 \]

and an R² value of 0.7857.
Visibility vs. LWC ($\Delta t = 1$ sec), 27-Jun-2006

![Graph showing the relationship between visibility and liquid water content with a linear fit equation and error metrics.]

Equation: $y = 0.026236 x^{-0.96496}$
RMSE = 0.14042
Corr Coeff = -0.6276
Visibility-Nd (Δt= 1 s), 27-Jun-2006

Equation: \( y = 291.6482 \times 1.2345 \)
RMSE = 0.12623
Corr Coeff = -0.4214
Visibility vs. $1/(\text{LWC} \times \text{Nd})$ ($\Delta t = 1\text{sec}$), 27-Jun-2006

Equation: $y = 0.87706 x^{0.49034}$
RMSE = 1.0713
Corr Coeff = 0.9673
FOG FORECASTING

Issues

• Microphysical algorithms
• Boundary layer characteristics
• Horizontal and vertical time/space resolutions
• 2D versus 3D models
• Validation of numerical forecast model simulations
INTEGRATED VISIBILITY

$$\beta_{ext} = \sum Q_{ext}n(r)\pi r^2 dr$$

$$\beta_{int} = \beta_{RHw} + \beta_{LWC;IWC} + \beta_{R;S}$$

$$Vis = -\ln(0.02) / \beta_{ext}$$

$$V_n = 1.8507V_d^{0.814}$$

Daytime Vis versus nighttime Vis
Vis = f(XWC); neglected $N_d$

**TABLE 1. Relationships between the mass concentration ($C$, g m$^{-3}$) and the extinction coefficient ($\beta$, km$^{-1}$).**

<table>
<thead>
<tr>
<th>Hydrometeor</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud liquid water, fog</td>
<td>$\beta = 144.7 \ C^{0.88}$</td>
</tr>
<tr>
<td>Rain</td>
<td>$\beta = 1.1 \ C^{0.75}$</td>
</tr>
<tr>
<td>Cloud ice</td>
<td>$\beta = 163.9 \ C^{1.00}$</td>
</tr>
<tr>
<td>Snow</td>
<td>$\beta = 10.4 \ C^{0.78}$</td>
</tr>
</tbody>
</table>
FOG Vis parameterization

\[ \text{Vis} = f(LWC, N_d) \]

\[ \text{vis} = 1.02 (LWC \times N_d)^{-0.52} \]
LWC, Nd, VIS
VIS VERSUS TIME RND station

RND: 2010-03-08 14:00 UTC

Visibility (m)

FD12P  Parsivel  LAM1k  LAM2.5k  Reg-BI
Sentry  LAM1k-BI
LWC comparisons at various forecast hours (NCEP-NAM)
# GOES-R ABI Bands

<table>
<thead>
<tr>
<th>Future GOES Imager (ABI) Band</th>
<th>Wavelength Range (μm)</th>
<th>Central Wavelength (μm)</th>
<th>Sample Objective(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45-0.49</td>
<td>0.47</td>
<td>Daytime aerosol-over-land, Color imagery</td>
</tr>
<tr>
<td>2</td>
<td>0.59-0.69</td>
<td>0.64</td>
<td>Daytime clouds fog, insolation, winds</td>
</tr>
<tr>
<td>3</td>
<td>0.846-0.885</td>
<td>0.865</td>
<td>Daytime vegetation &amp; aerosol-over-water, winds</td>
</tr>
<tr>
<td>4</td>
<td>1.371-1.386</td>
<td>1.378</td>
<td>Daytime cirrus cloud</td>
</tr>
<tr>
<td>5</td>
<td>1.58-1.64</td>
<td>1.61</td>
<td>Daytime cloud water, snow</td>
</tr>
<tr>
<td>6</td>
<td>2.225 - 2.275</td>
<td>2.25</td>
<td>Day land/cloud properties, particle size, vegetation</td>
</tr>
<tr>
<td>7</td>
<td>3.80-4.00</td>
<td>3.90</td>
<td>Sfc. &amp; cloud/fog at night, fire</td>
</tr>
<tr>
<td>8</td>
<td>5.77-6.6</td>
<td>6.19</td>
<td>High-level atmospheric water vapor, winds, rainfall</td>
</tr>
<tr>
<td>9</td>
<td>6.75-7.15</td>
<td>6.95</td>
<td>Mid-level atmospheric water vapor, winds, rainfall</td>
</tr>
<tr>
<td>10</td>
<td>7.24-7.44</td>
<td>7.34</td>
<td>Lower-level water vapor, winds &amp; SO(_2)</td>
</tr>
<tr>
<td>11</td>
<td>8.3-8.7</td>
<td>8.5</td>
<td>Total water for stability, cloud phase, dust, SO(_2)</td>
</tr>
<tr>
<td>12</td>
<td>9.42-9.8</td>
<td>9.61</td>
<td>Total ozone, turbulence, winds</td>
</tr>
<tr>
<td>13</td>
<td>10.1-10.6</td>
<td>10.35</td>
<td>Surface properties, low-level moisture &amp; cloud</td>
</tr>
<tr>
<td>14</td>
<td>10.8-11.6</td>
<td>11.2</td>
<td>Total water for SST, clouds, rainfall</td>
</tr>
<tr>
<td>15</td>
<td>11.8-12.8</td>
<td>12.3</td>
<td>Total water &amp; ash, SST</td>
</tr>
<tr>
<td>16</td>
<td>13.0-13.6</td>
<td>13.3</td>
<td>Air temp &amp; cloud heights and amounts</td>
</tr>
</tbody>
</table>

Based on experience from:

Current GOES Imagers
SSA versus Reff at 3.9 micron for liquid and ice particles
CLOUD TOP TEMPERATURE AND HEIGHT
The MRR particle fall velocities \([ \text{m s}^{-1} ]\) versus height from 1000 UTC to 2000 UTC, 26 March 2009. The red color represents fall velocities greater than 7 m s\(^{-1}\).
AEROSOLS/ACTIVATED AEROSOLS (CCN)

CAP (Climatronics Aerosol Profiler) sensor
(7 channels between >0.3 ....... 7 micron)

HEAVY FOG\(\text{Nd}=\sim 200 \text{ cm}^3\)

BACKGROUND AEROSOLS
\(\text{Na} \leq 5 \text{ cm}^3\)
CONCLUSIONS

• Rule Based Marine fog predictions need measurements of T, Td, Ts, wind speed and direction, and LWC.

• 3D numerical forecasting needs better prediction of LWC, Nd, RHw, and PR to simulate Vis

• Remote sensing platforms e.g. mm radar, ceilometer, and satellites should be used for fog related parameters when surface observations do not exist
REFERENCES


Technical Reports


