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Diagnosing Antarctic Fog

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Abstract

Fog affects aviation and other logistical operations in the Antarctic; however, limited studies have been conducted to understand fog behavior in this part of the world. A study has been conducted in the Ross Island region of Antarctica, the location of McMurdo Station and Scott Base – the main stations of the United States and New Zealand Antarctic programs, respectively. Using tools such as multi-channel satellite observations and supported by in situ radiosonde and ground-based automatic weather station observations, combined with back trajectory and mesoscale numerical models, this study discovered that austral summer fog events are advective. The diagnosis finds a primary source region from the southeast over the Ross Ice Shelf (over 72% of the cases studied) while a minority of cases point toward a secondary fog source region to the north along the Scott Coast of the Ross Sea with influences from the East Antarctic Plateau. Part of this examination confirms existing anecdotes from forecasters and weather observers, while refuting others about fog and its behavior in this environment. This effort marks the beginning of our understanding of Antarctic fog behavior.

1. Introduction

Fog is a weather phenomenon found all over the Earth, including the polar regions. A study of Antarctic fog has been conducted over the Ross Island region of Antarctic, where flight operations at Williams Field, Pegasus Field and Ice Runway are impacted by fog occurrences. Observations of fog from satellites, radiosondes, automatic weather stations and other surface observations along with analysis via back trajectory model and mesoscale model are discussed here. The study area (See Figure 1) is a 400 by 600 kilometer area. The time period analyzed covers the austral field seasons 2001 to 2007 during which there were approximately 23 fog event cases.

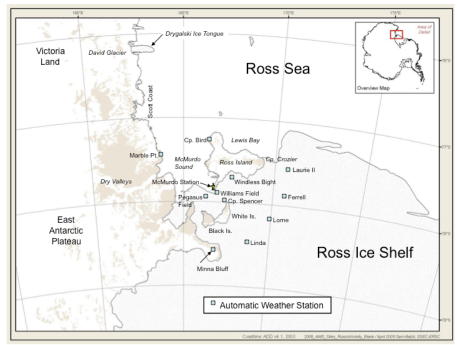

Figure 1: This is the fog study area, located over the Ross Island region of Antarctica.

2. Satellite Analysis

Principal Component (PC) Analysis (PCA) provides a means for depicting features in the satellite imagery (Hillger 1996). This offers one of the first attempts to apply this method for depicting Antarctic fog/low clouds. PCA is often performed on a dataset to reduce the redundancy in it – as is the case with the MODIS multi-spectral observations. It is also used to bring out features in the dataset, which is the objective here.

The Hillger approach (Hillger 1996) takes multiple spectral channels of a sample satellite observation, and determines the principal component "images" (PCI) for a given number of input channels. The first PCI depicts the features from the original observation that explain the most variance of the data and the features that are most common in the input channels. Similarly, the second PCI depicts the features from the observation that explain the second most variance of the data, and typically the differences between the input channels (Hillger 1996). Higher order PCs usually depict noise and other differences between the input channels. In its application here, the PCA provides information on variance spatially and spectrally, and does not offer the additional temporal variance that most Empirical Orthogonal Function (EOF) analyses accomplish.

The PCA is conducted on a selection of MODIS bands - specifically 1, 6, 7, 20, and 31 (See Table 1; Figure 2). This combination of spectral channels offers the best visual depiction of fog in the second PCI. A combination of the first, second, and third PCI through red, green and blue color combinations provides a means of depicting characteristics of more than one PCI. The first PCI contains so much of the infrared window channel signal and some of the low clouds and fog signal, and when combined with the second PCI, which is one of the best depictions of low cloud and fog, provides a display that gives the fog and cloud features an appealing white color while having the ice features, so strongly seen in infrared imagery, blended into the blue or sepia shaded background.

Table 1: These are the MODIS channels utilized in the generation of the RGB PCI imagery.

MODIS Band	Wavelength	Description
1	0.64 μm	Visible channel
6	1.62μm	Near infrared
7	2.11μm	Near infrared
20	3.78μm	Shortwave infrared
31	11.0μm	Infrared window

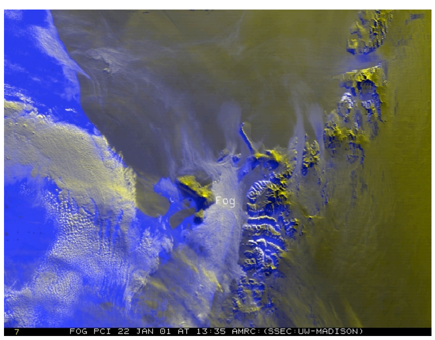

Figure 2:An RGB PCI fog depiction from 22 January 2001 at 13:35 UTC.

3. Boundary Layer Analysis

Moderate to high-resolution radiosonde observations can reveal the structure of the boundary layer. Radiosonde observations launched from McMurdo Station, with data reports every 10 seconds of flight or more recently upgraded to every 3 seconds of flight, are used to illustrate the structure of temperature, moisture and wind in the lowest 1.0 to 1.5 kilometers (km) of the atmosphere. The wind information is analyzed with a 1-2-1 smoothing. Figure 3 is a sample profile launched close to a fog occurrence at McMurdo Station and is an example of the boundary layer structure found in a majority of the fog events analyzed. The typical profiles may reveal a surface or friction layer close to the ground (not in all cases), a fog layer in the core of the boundary layer, an inversion at the top of the fog layer (which also marks the top of the boundary layer), and the lowest portion of the free atmosphere. Fog is difficult to capture via radiosonde observations that are widely spaced every 12 hours (or more in the case of missing observations). This results in radiosonde observations only providing snap shots of fog structure in the vertical during a particular stage of evolution.

The surface or friction layer is often thin in most cases and not well resolved by the radiosonde observations. Additionally, the McMurdo Weather Office practice is to assign the lowest level of the radiosonde report from the surface measurement made at the McMurdo Weather building and not by the radiosonde itself. Since that measurement is not always matched in time and is usually at a slightly different location, in most of the analysis here, this lowest observation level has been often been removed. This example, seen in Figure 3, does not have this removed, hence a surface layer between the lowest two observation points can be envisioned, although for this case, the radiosonde was launched between surface reports of fog and the surface layer may be mixed out given the wind speeds on the order of 10 meters per second (ms^{-1}).

In the example, the fog layer (~100 to 250 meters) is marked with a moist layer of air as compared to air aloft that is drier. This layer is also somewhat cooler than the air aloft. Both dewpoint and temperature have a slight decrease from the bottom to the top of the layer. Winds within this layer, in this sample, reveal an increase of the wind with height through the fog layer to the bottom of the inversion layer, where the wind becomes geostrophic at the level of the free atmosphere (Stull 1988). Wind directions are primarily from the east, which is commonly the case for fog occurrences. In the inversion layer (between ~250 to ~350 meters), temperatures increase from the bottom to the top of the layer, while the layer becomes increasingly drier from the bottom to the top of the layer. This gives the profile a classic "goal post" shape between the temperature and dewpoint (Croft et al. 1997). In this particular example, wind speeds decrease some with increasing height as winds switch toward the southeast. Above the inversion layer is the free atmosphere (above ~350 meters) with different air mass characteristics.

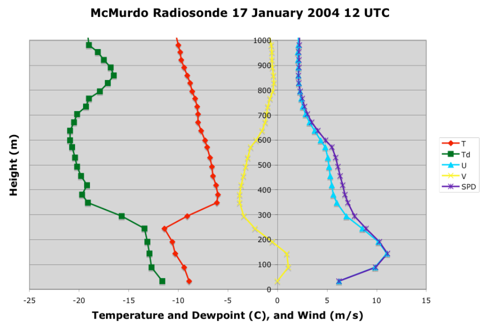

Figure 3: A sample radiosonde from 12 UTC on 17 January 2004 captures the boundary structure temporally close to a fog event at McMurdo Station.

4. Back Trajectories and Mesoscale Model Streamlines

The HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model, available from the NOAA Air Resources Laboratory (ARL) offers a means of generating back trajectories. HYSPLIT is designed for air pollution and dispersion applications. Used in its basic form, it offers single particle forward or backward trajectories treated, in essence, as a parcel of air (Rolph 2003, Draxler and Rolph 2003). HYSPLIT version 4.8 used in back trajectory computations was initialized with conditions from the Global Data Assimilation System (GDAS) one-degree by one-degree resolution data. In only a couple of cases where input data was not available from the GDAS, 2.5 by 2.5 degree resolution NCEP/National Center for Atmospheric Research (NCAR) reanalysis data was used as an alternate initialization. All back trajectories were computed to end at the Williams Field AWS location (77.866° South, 166.983° East). Families of back trajectories are computed with final altitudes of 50, 100, 250, 500 and 1500 meters above ground level. A 48-hour back trajectory family set included six back trajectories - one inserted every 2 hours prior to the final end time. In all cases, the model's vertical velocity was used. The ending back trajectory date and time was selected from 20 fog cases, to match the occurrence of the fog. With fog often reported over several hours, the lowest visibility (or densest) portion of the fog, as reported from surface observations at McMurdo Station, was used as the final time of the back trajectory.

The results of the back trajectories are summarized in Table 2. The largest source region for air is from the Southern Ross Ice Shelf, with approximately half of the events having this characteristic (Figure 4). For 23 percent of the events, air originating purely from the East Antarctic Plateau may often come through the dry valleys over McMurdo Sound (not shown). Air from both the East Antarctic Plateau and the Ross Ice Shelf were found as well as a mix of the two source regions is seen in these cases. Finally, there is a unique case of air that originally was from the south of McMurdo Sound on the Ross Ice Shelf, but then circled over the Sound (not shown). Overall, if the two Ross Ice Shelf source are a combined, 72% of the air that leads to fog comes from the south and east of Ross Island.

Table 2: The source regions of fog as revealed with the HYSPLIT model back trajectories.

Source region	Occurrence (%)
Southern Ross Ice Shelf/Southern Ross Ice Shelf & East Antarctic Plateau mix	72%
East Antarctic Plateau	23%
South with circling over McMurdo Sound	5%

A combination of the satellite (especially reviewing time sequences), back trajectories, and Antarctic Mesoscale Prediction System (AMPS) model (Powers et al. 2003) streamlines agree that the fog impacting the region is "advective" in nature – forming over the Ross Ice Shelf and moving into the area (See Figure 5).

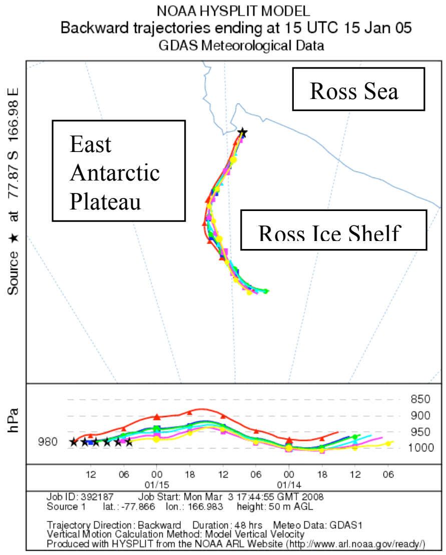

Figure 4: Back trajectory analysis ending at 20 UTC 24 January 2007 exemplifies how a majority of air originates from the south of the Ross Island region.

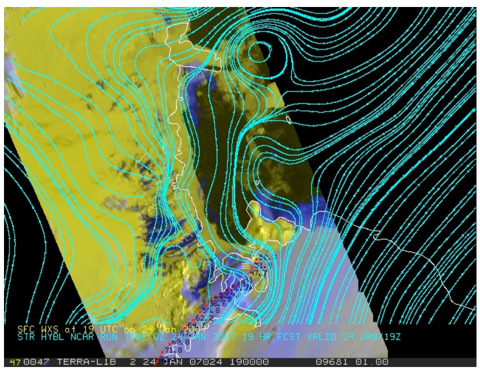

Figure 5: RGB PCI fog satellite imagery with AMPS streamlines at the second sigma layer above the surface and HYSPLIT back trajectory valid at 19 UTC 24 January 2007.

5. Summary and Conclusions

The examination of fog occurrence in the Ross Island region of the Antarctic has found most austral summer fog events to be "advective." Satellite observations along with corroborating model and back trajectory analyses reveal austral summer fog events often form outside the current Mac Weather AWS fog network. The analysis identifies two key source areas. The primary region is from the south and east of Ross Island over the Ross Ice Shelf. A secondary region, of very few events not shown here, is from the north and east along the northern Scott Coast of McMurdo Sound.

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