Climate Change Impacts and Adaptation Strategies at NASA Ames Research Center: Full Report

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April 2010

Acknowledgments

N. Burroughs would like to thank NASA's Undergraduate Student Research Program for providing funding for this research. She would also like to thank Laura Iraci, Max Loewenstein, and Emma Yates for their assistance during all phases of this research. The authors would also like to give a special thanks to Ann Clarke, Cristina Milesi, Phil Snyder, John West, Kent Stednitz, Don Chuck, and T. Mark Hightower for their contributions to this research.

<u>Cover Images:</u>
Top Left: Flooding pump station during flood of February 1998.
Bottom Right: Flooding of ordnance bunkers during the flood of February 1998.

Source for both images: http://dart2.arc.nasa.gov/Deployments/SF_BayArea_Floods97-98/flds97_98.html.

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Abstract

Climate change poses a great risk to low-lying lands such as NASA Ames Research Center (ARC), which is located at the southern end of the San Francisco Bay estuary. The primary physical factors that are of concern at this facility are sea level rise (SLR) and changes in weather patterns. These changes could result in heavier rainfall events even though there may be a reduction in annual precipitation totals. It is important to realize that even modest SLR in the future will reduce the amount of precipitation needed to cause flooding conditions at NASA ARC, which could meet or exceed the impact of the last major flooding event that occurred at the Center in February 1998. This research examines the climate and sea level changes that have been observed at NASA ARC and compares them with the observed and projected changes in California and globally. An analysis of the weather and sea level conditions immediately before and during the 1998 event and a comparison of these conditions to projected changes will allow adaptation strategy formulation to help prepare NASA ARC for an increased risk of flooding due to climate change. This project is in support of the NASA Climate Change Adaptation Science Team.

I. Introduction

NASA Ames Research Center (ARC), including both the research facilities and the surrounding Moffett Field, like the rest of the world, is feeling the effects of climate change. Located at the southern end of the San Francisco Bay estuary, NASA ARC is at great risk from the effects of sea level rise (SLR) and changes in precipitation patterns, which will put NASA ARC and the San Francisco Bay area at a greater risk of flooding.[1] Examining the conditions seen prior to a previous flood, specifically the one that occurred in February 1998, will help the Center better adapt to and prepare for the increased flooding risk due to climate change.

The historical tidal gauge records show that mean sea level (MSL) in San Francisco Bay has already risen about 20 cm over the previous century.[2] MSL along the California coast is expected to rise 30 to 45 cm, relative to the level in 2000, along by 2050.[3] Cayan, D. et al, in Ref 3, expect that this SLR will increase the number of extreme high sea level events and increase the tendency for these higher sea levels to persist longer. These increases will put NASA ARC at a higher risk for damage resulting from erosion and flooding, especially when combined with the effects of the El Niño Southern Oscillation (ENSO), examined in section II.C.

In addition to examining changes in sea level, the 2009 California Climate Adaptation Strategy,

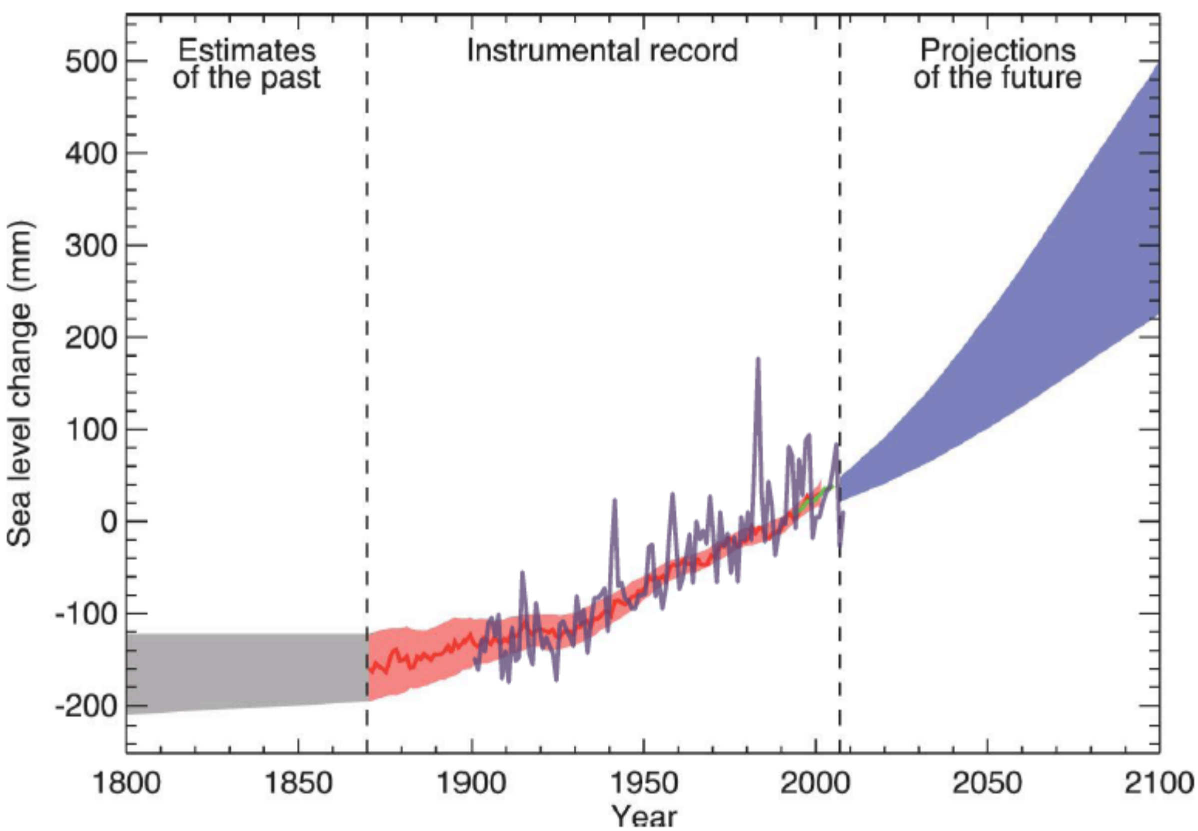

Figure 1. San Francisco Bay, CA local sea level overlaid on IPCC projection of sea level rise. *The light red shaded area is a reconstruction of global mean sea level from tide gauges. The dark purple line is the yearly local mean sea level at San Francisco, CA. The dark blue shaded cone on the right represents the range of model projections for the SRES A1B scenario for the 21st century. Source: NOAA "Verified Monthly Water Levels" Source URL: www.tidesandcurrents.noaa.gov and IPCC.*

Ref. 4, examined possible changes in precipitation patterns in California. This study indicated a 12 to 35 % decrease in the precipitation totals compared to historical annual averages. Despite the projected decreases in total precipitation amounts, there is an overall expectation for an increase in the intensity of rainfall events, thus increasing the likelihood of more frequent and/or extensive flooding.

The goal of this research is to examine the sea level and climate changes observed at NASA ARC and compare them to the analysis of weather conditions surrounding the 1998 flood event, which will also be presented in this report. This comparison will then allow for the suggestion of adaptation strategies and future studies that will help the Center prepare for the increased risk of flooding posed by climate change.

II. Local Climate Change

The Intergovernmental Panel on Climate Change (IPCC) uses global models to estimate the extent to which our planet's climate will change in the future. In order to represent future worlds they have formulated several different emissions scenarios, which are covered in detail in the IPCC *Special Report on Emission Scenarios* (SRES). The SRES scenarios referenced in this paper are SRES A1B, SRES B1 and SRES A2.

SRES A1B scenario is representative of a world where very rapid economic growth occurs, and global population peaks in the mid-century then declines after that with the rapid introduction of more efficient technologies. In this scenario, the technological emphasis is balanced between fossil fuel and non-fossil fuel intensive energy sources. SRES B1 scenario has the same population change as A1B, but there is rapid change in economic structures. The shift is toward a more service and information economy, with an emphasis on global solutions to problems as opposed to local. The SRES A2 scenario represents a very heterogeneous world with the emphasis on self-reliance and preservation of local identities; all economic development is regionally dependent, and new technologies are slow to spread.[5]

A. Sea Level Rise

To evaluate the potential impact that SLR will have on NASA ARC, the local sea level changes of San Francisco Bay were examined. Local sea level is the manifestation of the change in global sea level as observed from a specific point on land, in this case 37°48.4' N by 122° 27.9'W at station number 9414290. Local sea level changes are a result of the combined effects of temperature and salinity changes of the ocean, global MSL increases resulting from ocean mass increase, along with local changes in the elevation of land due to isotonic and tectonic processes.[6] Combined these influences can result in either an apparent increase or decrease in local sea level which may be different from the global MSL change.

Figure 1 shows the adjusted annual mean local sea level of San Francisco, CA, calculated at station 9414290, with the darker purple line. It is overlaid on the reconstructed global MSL (lighter red shaded area) as calculated from tide gauges by the IPCC. The right-most section of the figure shows the range of projected sea level increases under SRES A1B with the dark blue shaded area.

It is clear from this figure that the local sea level in San Francisco Bay generally shows changes

1900-1999	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95%)	Change Per Year	Change Per Decade
MHHW (m)	2.887	0.008	2.873	0.080	0.006	0.363	2.750	3.113	0.016	0.002	0.025
MHW (m)	2.706	0.008	2.688	0.077	0.006	0.350	2.580	2.929	0.015	0.002	0.024
MSL (m)	2.077	0.007	2.064	0.070	0.005	0.352	1.960	2.313	0.014	0.002	0.020
MLW (m)	1.481	0.007	1.472	0.066	0.004	0.391	1.354	1.745	0.013	0.002	0.017
MLLW (m)	1.137	0.007	1.127	0.074	0.005	0.397	0.999	1.396	0.015	0.002	0.017

Table 1. Statistics and trends of sea level parameters for 1900 to 1999 in San Francisco Bay, CA. *The results for Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL), Mean Low Water (MLW) and Mean Lower Low Water (MLLW) are all given in meters. Source: NOAA "Verified Monthly Water Levels" www.tidesandcurrents.noaa.gov* **.**

similar to those seen in the global MSL. Of special note are the large excursions that occur in the local data away from the global mean. These positive extremes, such as the ones that occur in 1983 and 1998, are representative of the local impacts of strong El Niño events.

Overall, San Francisco Bay saw an increase in MSL during the 20th century of 0.204 m per 100 years. During that same time-period: mean higher high water (MHHW) increased 0.249 m per 100 years, mean high water (MHW) increased 0.238 m per 100 years, mean low water (MLW) increased 0.171 m per 100 years, and mean lower low water (MLLW) increased 0.173 m per 100 years. These trends were calculated using the yearly MSL based on 12 monthly mean levels with data collected from NOAA in Ref. 2. The results are within 3 to 7% of the trends calculated by California Coastal Commission's Report.[7] The calculations also show that local MHW levels are rising approximately 20% faster than local MSL over the past century, which agrees with Cayan D., et al. in Ref.8, though the reason for the difference between the rate of increase of MSL and MHW levels are not understood.

In Ref. 7, The California Coastal Commission states that for day-to-day activities, tidal range and the elevation of high and low tide are often more important than MSL. The diurnal tidal range is defined as the difference between MHHW and MLLW. In the San Francisco Bay, this range has increased by 0.061 m per 100 years. The mean tidal range, the difference between MHW and MLW, has increased by 0.056 m per 100 years.

Projected increases in local MSL along the California are expected to increase the number of extreme high sea level events,[2] with a tendency for heightened sea level events to persist for longer periods. The overall projected local SLR is slightly higher than what is expected in the global MSL rise. For San Francisco Bay specifically, if the 100-year trends calculated hold constant, local MSL may increase about 8.1 cm by 2050 and 20 cm by 2100. MHHW could increase about 10 cm by 2050 and 25 cm by 2100, above current levels.

Despite the slight differences between the calculated trends for San Francisco Bay and the state trends presented in Ref. 3, it is clear that the overall increase expected in San Francisco Bay and along the California coast is on the order of tens of centimeters over the next 100 years.

Section A of the Appendix contains full sea level evaluations separated by tidal level over various periods, not addressed in the body of this research. These additional analyses will allow for future comparison and evaluation of changes in SLR trends over time. These comparisons would allow for the determination of which factors have the greatest influence on the sea level of the San Francisco. The Appendix also contains descriptions of the methodology used for the analysis and source data.

Parameters	Mean	Standard Error	Median	Standard Deviation	Peroid Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
Temp (°C)	14.85	0.13	14.88	0.69	0.48	2.22	13.50	15.72	0.26	0.06	0.58
Tmax (°C)	27.23	0.24	27.42	1.32	1.75	5.40	24.23	29.63	0.49	0.11	1.13
Tmin (°C)	6.22	0.14	6.12	0.77	0.60	2.81	4.77	7.58	0.29	0.06	0.55
Dewp (°C)	8.43	0.14	8.60	0.75	0.56	2.95	6.53	9.48	0.28	-0.04	-0.44
SLP (hPa)	1016.95	0.11	1017.16	0.63	0.39	2.47	1015.13	1017.60	0.23	0.00	-0.04
WDSP (m/s)	2.02	0.03	2.00	0.18	0.03	0.72	1.70	2.42	0.07	0.00	-0.02
PRCP (mm)	236.83	42.96	227.46	235.31	55368.65	704.85	0.00	704.85	87.86	14.71	147.13

Table 2. Monthly statistics and trends of weather conditions at Moffett Federal Airfield, CA for period of 1961 to 1990. *Note: Records of Precipitation Totals did not start until January 1, 1973. Units for calculations are degrees Celsius for Temperature (Temp), Maximum Temperature (Tmax), Minimum Temperature (Tmin), and Dew Point (Dewp). Sea Level Pressure (SLP) is given in hPa, Wind Speed (WDSP) is in m/s, and Precipitation (PRCP) is in mm. Source: NCDC "Global Summary of Day" http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

B. Climate Pattern Changes

The World Meteorological Organization (WMO) has defined a climate period to be a 30-year period over which surface weather variables such and temperature, precipitation, and wind are evaluated.* This is done to factor out daily and seasonal fluctuations in weather patterns resulting from temporary and localized events, allowing the overall trend to be observed. The most recent climate period defined by the WMO is 1971 to 2000. Evaluations of the meteorological conditions for NASA ARC (Station Data: Moffett Federal Airfield (KNUQ), COOP# 045747, WBAN# 23244) were completed primarily for the previous climate period, 1961 to 1990. The decision was made to use this period due to several large gaps in the meteorological records for the climate period of 1971 to 2000.

Figure 1. Flooding of the parameter road February 1998. So*urce: http://dart2.arc.nasa.gov/Deployments/SF_BayArea_Floods97-98/flds97_98.html*

Figure 2. Flooding of Moffett Golf Course February 1998. So*urce: http://dart2.arc.nasa.gov/Deployments/SF_BayArea_Floods97-98/flds97_98.html*

Table 2 shows that at NASA ARC, the mean air temperature increased at a rate of 0.06°C per year and 0.58°C per decade from 1961 to 1990. The mean maximum air temperature increased 0.11°C per year and 1.13°C per decade, and the mean minimum air temperature increased 0.06°C per year and 0.55°C per decade.[9]

Based on analysis of the available weather data, the future evaluation of temperature, precipitation, and wind trends appear to provide the best local indicators of climate change. There are several other parameters (listed and evaluated in Section B of the Appendix) that do not currently show a noticable trend and at this time do not appear to be good indicators of climate change at the Center. See Appendix B for methodology and complete trend evaluations for all weather parameters available from the NCDC "Global Summary of Day".

The temperature trends at NASA ARC indicated a faster increase of the daily maximum temperature than minimum or mean temperatures. This does not agree with the observed global trends among coastal regions, where less warming of maximum temperatures is expected due to the impact of less warming of the oceans.[10] The discrepancy at NASA ARC may be a result of the urban-induced climate change or the urban heat island effect,[11] variations in wind patterns, or the elevation/location of the weather station in comparison to the general local topography.[12]

At NASA ARC, precipitation measurements did not begin until 1973, so all precipitation trends were calculated for the 20-year period extending from 1973 to 1992, which corresponds to a positive phase of the Pacific Decadal Oscillation (PDO), which is associated with below average precipitation along the western seaboard of the United States.[13] During this time, there was a decrease in the precipitation totals of -1.35 mm yr^{-1} and -13.48 mm per decade with a mean monthly precipitation of 32.5 ± 2.67 mm.

In California, it is projected that there will be a decrease of 12 to 35% in annual precipitation totals, primarily resulting from a slightly higher tendency towards greater winter precipitation totals and

* Defined by the IPCC in Ref. 6, Annex 1.

lower summer precipitation totals.[13] This precipitation pattern continuation is an indication that California will maintain its Mediterranean climate, which consists of cool, wet winters and hot, dry summers. The Committee on Environmental and Natural Resources, in Ref. 10, observed a negative trend in the frequency of precipitation events, though they were unable to determine a clear trend in the intensity of these events compared with current conditions.

Overall, it is projected that there will be a high degree of variability of annual precipitation totals during the 21st century.[3] Models also indicated that droughts are to continue in the western United States. Projections indicate that droughts will be intensified by earlier and possibly reduced spring snowmelt runoff and less water available in the summer.[7]

C. ENSO's Influence

Not all El Niño / Southern Oscillation (ENSO) events are alike, and their impacts vary depending on their strength. But when examining the Southern Oscillation Index (SOI), the likelihood of extreme precipitation and hydrological events can vary ± 30% over neutral years.[14]

Of the past eight Type 1 El Niños, six of them had greater than normal precipitation in San Francisco, and three of these had about 170% of normal rainfall totals. Overall Type 1 El Niño events have averaged 37% more rainfall than the monthly average rainfall totals. To be defined as a Type 1 El Niño, the sea surface temperature anomaly has to be greater than 2.0°C and extend approximately from 160E to 80W.[15]

Due to the close proximity of NASA ARC to San Francisco, it is reasonable to assume that large-scale phenomena will have a similar effect on the precipitation patterns at both locations, though variations in local precipitation totals can be significant. In general El Niño years are associated with wet winters over California, while La Niña years are associated with dry winters.[16] According to Cayan, D. et al. in Ref. 3, this linear correlation between ENSO and precipitation is strongest in Southern California and diminishes northward.

El Niño events that occur during the previous season can also increase the likelihood of extreme warm events occurring during the winter (December, January, February) and spring (March, April, May) at NASA ARC, while the fall (September, October, November) has an increased risk of extreme cold events. La Niña occurrence during a preceding season does not exhibit a change in the likelihood of extreme warm or extreme cold events occurring at NASA ARC. These conclusions were extracted from the national statistical evaluations ENSOs effected on short-term climate extremes, presented by Wolter, K., Dole, R., and Smith, C. in Ref. 17.

However, it is important to remember that flooding is not limited to El Niño years. January and March of 1995[18] and the winter of 1996/97[19], both had unusually high amounts of precipitation that resulted in severe flooding around California.

III. 1998 Flood at NASA ARC

By some measures, the 1997-1998 El Niño was the strongest on record, with its climate impacts felt around the world.[20] That winter was the second warmest and seventh wettest since 1895, and the effects of this El Niño were not limited to the Pacific coast. Across the United States the weather patterns were more severe than normal and were influenced in large part by this El Niño.[21]

During the month of February 1998, NASA ARC was impacted by a series of winter storms, which were in some part affected by this El Niño. These storms caused massive flooding at NASA ARC from February 2nd to February 9th 1998. Figure 2 shows the flooding of the perimeter road of NASA ARC, and Figure 3 is a photograph taken of the flooding at Moffett Golf Course.

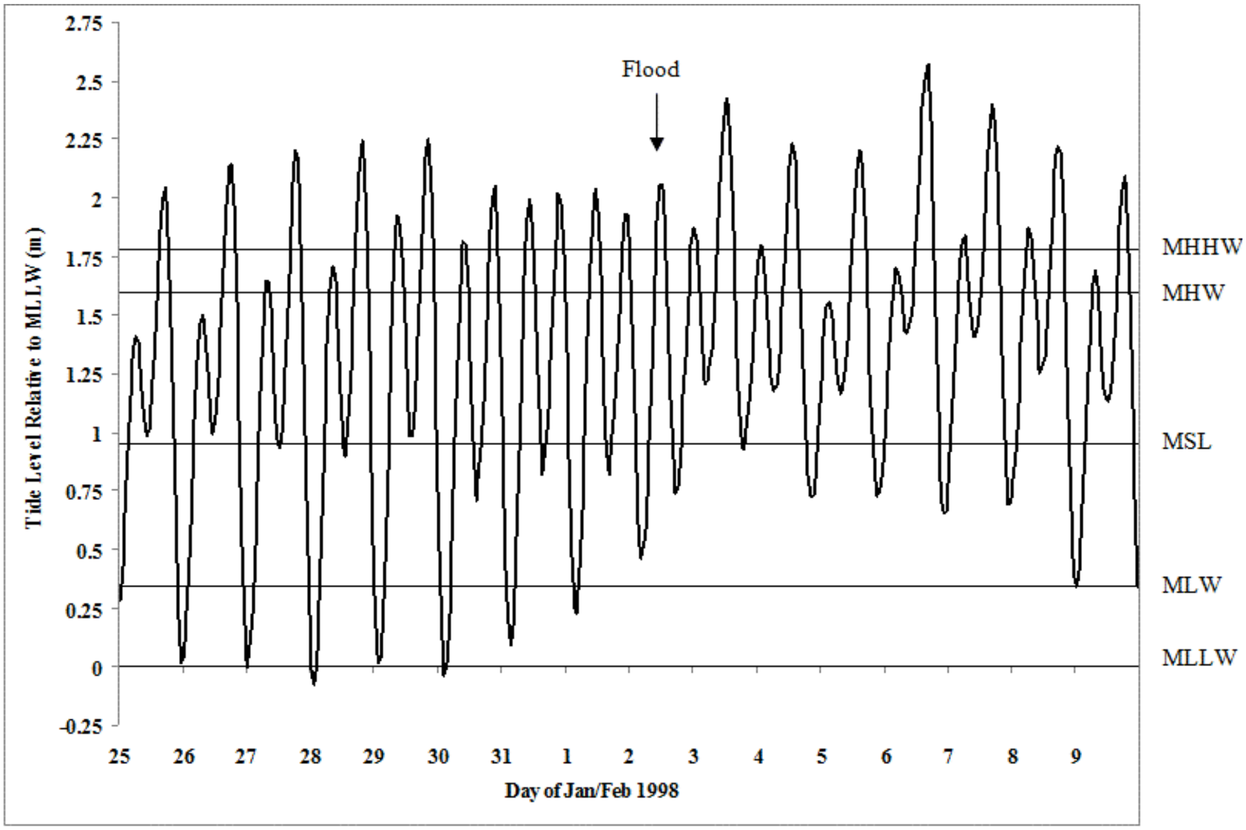

Figure 3. Tide level relative to MLLW datum during February 1998 flood measured at San Francisco, CA. *The curved line is the verified Sea Levels, in meters, at Station 9414290 for the period from Jan 25, 1998 to Feb 9, 199. Day of Jan/Feb is along the x- axis. The horizontal lines represent the average elevation of MHHW, MHW, MSL, MLW, and MLLW, respectively from top to bottom, for the period of 1983 to 2001, with MLLW being equal to zero. Source: NOAA "Verified Water Level": www.tidesandcurrents.noaa.gov*

A. Conditions

1. San Francisco Bay Sea Level

For NOAA Tide Gauge Station 9414290 in San Francisco Bay, CA, the all-time February monthly average MHHW, MHW, MSL, MLW, and MLLW maximum recordings occurred during February 1998, for the period of 1900 to 2009. All measurements are relative to the MLLW datum of 1.822m at this station.

This site experienced a higher high tide (HHT) average depth of 2.21m, over the period of period of January 25, 1998 to February 09, 1998. The HHT maximum depth of 2.55 m occurred on February 06, 1998 at 15:24 GMT, and minimum depth 2.02 m occurring on January 31, 1998 at 21:42 GMT. During the same base period, high tide (HT) averaged a depth of 1.76 m, with a maximum depth of 2.01m occurring on January 31, 1998 at 10:12 GMT and minimum depth of 1.42 m occurring on January 25 at 06:06 GMT. Low tide (LT) averaged a depth of 1.03 m, during the same period, with a maximum depth of 1.42 m occurring on February 06, 1998 at 08:06 GMT and a minimum depth of 0.741m occurring on January 30, 1998 at 14:18 GMT. The lower low tide (LLT) averaged a depth of 0.33 m with a maximum depth of 0.95 occurring on February 3, 1998 at 18:42 GMT and a minimum depth of -0.09 m occurring on January 28, 1998 at 00:48 GMT.

As seen in Figure 4, from January 30 to February 3, 1998, there was a significant reduction in the difference between the HT and HHT of each day. The y-axis of this graph shows the tide level relative to the MLLW level, so that the MLLW level is equal to zero. The horizontal lines represent the average MLW, MSL, MHW, and MHHW levels, respectively from the bottom up. Typically, the HT is 0.5 to 1 m less than the HHT. During this time the HT and HHT were both approximately the same height, about 2.0m above the MLLW Datum Elevation for Station 9414290.

From January 25 to January 30, the LLT was near the station elevation datum for MLLW, which is where it is expected, while the LT was at MSL, nearly 0.5 m above its normal elevation. HT was increasing from slightly below MHW to above MHHW level over this same period and HHT was 0.25m to 0.5m above MHHW.

Table 4. Ranking of winter 1997/98 weather conditions at Moffett Federal Airfield. *Winter (DJF) 1997/98 ranking of average or total values for weather conditions at Moffett Federal Airfield, compared to winter records for the period indicated. The ranking is in descending order, with the highest values for each parameter being ranked the lowest. For the time period 1945 to 1998 there are a total of 53 comparison values for all parameters except precipitation which has 24. For the period of 1945 to 2009 there are 64 total comparison values for all parameters except for precipitation, which has 31. Source: NCDC "Global Summary of Day," http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

Parameter	Jan 1998 Value	1945–1998 Rank	1945– 2009 Rank
Temperature (°C)	11.5	5	5
Sea Level Pressure (hPa)	1017.1	48	54
Mean Wind Speed (m/s)	2.0	18	19
Maximum Sustained Wind (m/s)	9.8	26	29
Mean Maximum Temperature (°C)	15.9	11	13
Mean Minimum Temperature (°C)	7.8	7	7
Total Precipitation (mm)	111.3	5	6

Table 3. Ranking of January 1998 weather conditions at Moffett Federal Airfield. *January 1998 ranking of average or total values for weather conditions at Moffett Federal Airfield, compared to winter records for the period indicated. The ranking is in descending order, with the highest values for each parameter being ranked the lowest. For example the winter of 1998 has the 14th warmest Mean Minimum Temperature for all winters 1945 to 1998. For the time period 1945/49 to 1997/98 there are a total of 53 comparison values for all parameters except precipitation which has 24. For the period of 1945/46 to 2008/09 there are 64 total comparison values for all parameters except for precipitation, which has 31. Source: NCDC "Global Summary of Day," http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

Parameter	Winter 1998 Value	1945–1998 Rank	1945– 2009 Rank
Temperature (°C)	10.9	14	16
Sea Level Pressure (hPa)	1016.9	49	57
Mean Wind Speed (m/s)	2.3	12	13
Maximum Sustained Wind (m/s)	10.3	20	20
Mean Maximum Temperature (°C)	15.3	28	33
Mean Minimum Temperature (°C)	7.3	14	16
Total Precipitation (mm)	412.0	2	2
Average Monthly Precipitation (mm)	137.3	2	2

Starting on January 30, there was a dramatic increase in LLT from the near average level to MSL on February 3. During this same time frame, LT stayed about constant at MSL and then peaked about 0.25m above MSL on February 3. It was not until after February 3, 1998, that LLT started to reduce and not until February 7, 1998 that LT started to recede. HHT peaked over 2.5 m above MHHW on February 6 before it started to return to average.

2. Moffett Federal Airfield Meteorological Conditions

When considering seasonal averages, the winter of 1997/98 (December, January, and February) ranked as the second wettest on record (1945/46 to 2008/09) with a total precipitation amount of 412 mm and a monthly mean of 137 mm. It was only surpassed by the 1977/78 winter, which had a total precipitation amount of 457 mm total and a monthly mean of 152 mm.

Parameter	Feb 1998 Value	1945–1998 Rank	1945– 2009 Rank
Temperature (°C)	11.1	27	31
Sea Level Pressure (hPa)	1013.3	51	58
Mean Wind Speed (m/s)	2.9	4	5
Maximum Sustained Wind (m/s)	11.2	13	13
Mean Maximum Temperature (°C)	15.1	43	48
Mean Minimum Temperature (°C)	7.8	21	23
Total Precipitation (mm)	260.4	1	1

Table 5. Ranking of February 1998 weather conditions at Moffett Federal Airfield. *February 1998 ranking of average or total values for weather conditions at Moffett Federal Airfield, compared to winter records for the period indicated. The ranking is in descending order, with the highest values for each parameter being ranked the lowest. For the time period 1945 to 1998 there are a total of 53 comparison values for all parameters except precipitation which has 24. For the period of 1945 to 2009 there are 64 total comparison values for all parameters except for precipitation which has 31. Source: NCDC "Global Summary of Day," http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

Winter 1997/98 ranked third when examining the total number of days with measureable amounts of rain (48). The precipitation days of January and February accounted for 44 of these days. This season was surpassed by the winters of 1956 and 1969, with counts of 53 and 52 respectively. A full summary of the 1997/98 winter season ranking can be found in Table 3.

January 1998 ranked as the rainiest January on record (1945 to 2009) with a total of 20 days during the month having measureable rainfall. The maximum rainfall occurred on January 19, 1998 with 0.75 in (19.05 mm) of precipitation during a 24-hour period. January 1998 also ranked as the fifth warmest January on record, when examining the mean temperatures, consistent with the expectation during a strong El Niño. See Table 4 for a full summary of January 1998 weather condition rankings.

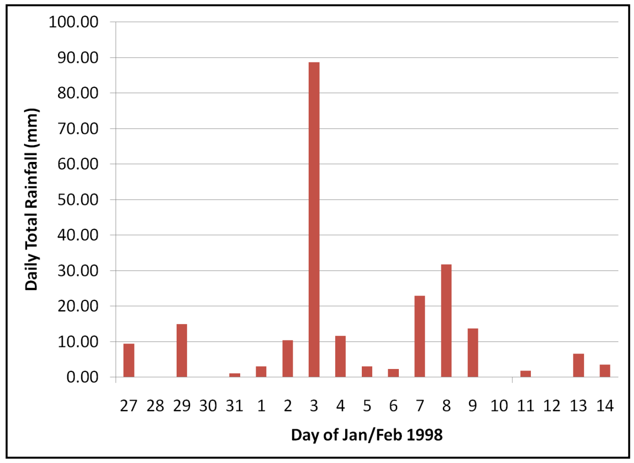

Figure 4. Daily precipitation totals for Moffett Federal Airfield January 25, 1998 to February 9, 1998. *Each bar represents the daily total precipitation at NASA ARC before and during the February 1998 Flood Source: NCDC "Global Summary of Day" http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

February 1998 has the highest number of days with rainfall of all the Februarys on record (1945 to 2009); during that month there were a total of 24 days with measurable rainfall. On February 3, the maximum precipitation rate occurred with 3.49 in (88.64 mm) falling in a 24 hour period. February 1998 also had the highest total precipitation amount on record (1945 to 2009) with the total monthly precipitation reaching 260.35 mm. See Table 5 for a full summary of February 1998 weather condition rankings.

Figure 5 is a graph of the precipitation totals for NASA ARC from January 25, 1998 to February 9, 1998, which shows several spikes in total precipitation. On February 3, 1998, the maximum total precipitation of the event occurred with just over 88.6 mm of rain falling in a 24-hour period. Table 6 displays a detailed summary of daily mean weather conditions for the same period. This shows that on February 3, 1998, the sea level pressure minimum for this event occurred with a pressure of 991.8 hPa.

3. Predicted Warning Conditions for Future Floods

To properly evaluate the specific conditions needed to cause flooding conditions at NASA ARC, detailed case studies of multiple rainfall events that both did and did not cause severe flooding need to be compared to the conditions which led to the February 1998 flooding event.

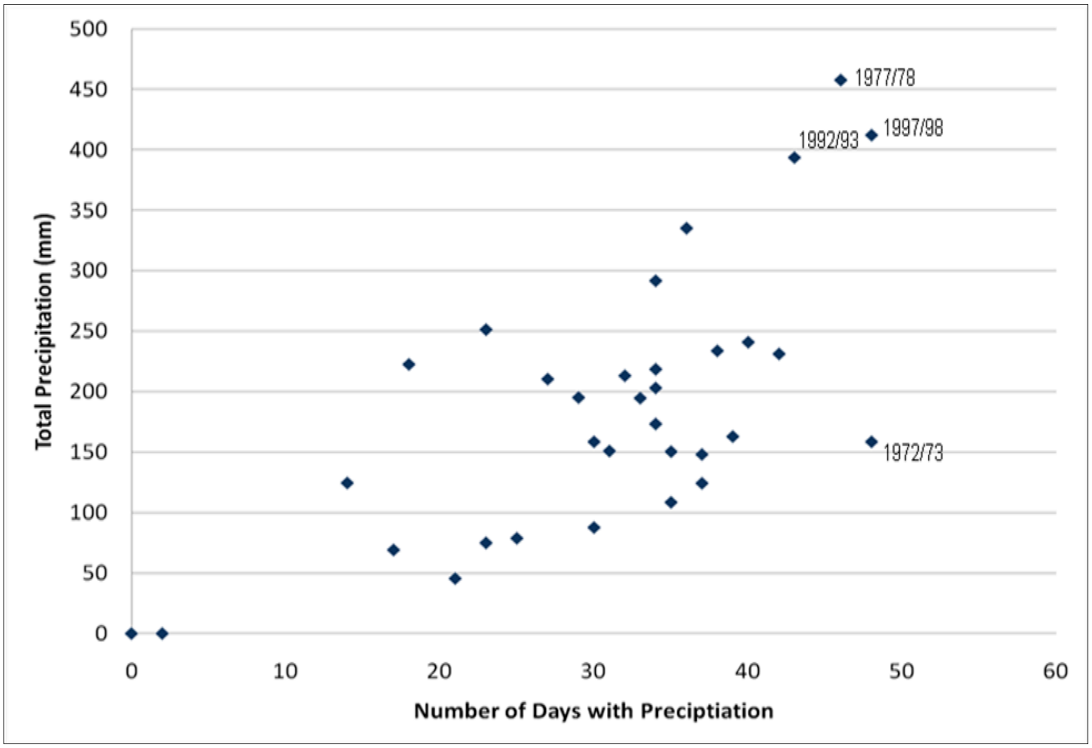

Figure 5. Total Precipitation (mm) for winters (DJF) at NASA ARC plotted against Number of Precipitation Days. *The x coordinate gives the total number of precipitation days during the winter season (Dec., Jan., Feb.) as determined at Moffett Federal Airfield, while the y coordinate provides the total amount of precipitation during the same time frame (1973 -2010). In this format the winter seasons with the highest total precipitation and greatest number of precipitation days are located in the upper right hand portion of the plot. The seasons identified would provide good comparison points for evaluating the impacts of various parameters and thresholds for flooding at NASA ARC. Source: NOAA/ NCDC "Surface, Global Summary of Day" http://www.ncdc.noaa.gov/oa/dataaccesstools.html*

Figure 6 is a scatter plot of the total precipitation that fell during each winter vs. the total number of precipitation days for 1973 – 2010. The 1997/98 winter is located in the upper right hand corner. This indicates that there was both a large number of precipitation days and a high total amount of precipitation. This agrees with the seasonal rankings that were computed earlier in this research (Table 4).

There are two other winter seasons shown in Figure 6 (1977/78 and 1992/93) which had similar precipitation days and total precipitation amounts. These winters would be good choices for further evaluation of both the sea level and meteorological conditions during this period and to determine if flooding did or did not occur at NASA ARC.

Another winter that would be a valuable comparison point is the 1972/73 season, which had the same number of precipitation days at the 1997/98 season, but about half the total precipitation. Thus the effect of the 1972/73 winter on storm water and drainage at ARC will help separate the influence of total precipitation and duration of rainy episodes in years with flooding. Determining the difference in weather system development and progression in 1972/73 will help in better understanding the parameters and indicators for heavy precipitation at NASA ARC.

In addition to these three winters, any other season in which heavy or widespread flooding occurred at NASA ARC should be examined. By conducting these future case studies it will be possible to identify the specific thresholds needed at NASA ARC to result in flooding.

Keeping in mind that more winter seasons need to be examined to fully determine the necessary conditions to result in flooding at NASA ARC, we will examine here the specific conditions surrounding the flood of February 2 - 9, 1998 at the Center. Figure 7 presents the tide level (from San Francisco Bay), temperature, wind speed, precipitation and sea level pressure (from Moffett Field) during January and February 1998. The red box highlighted in Figure 7 indicates the portion of the figure that is expanded in Figure 8. Figure 7 shows clearly the changes in precipitation, sea level pressure and wind speeds immediately prior to and during the 1998 flood event, and each of these parameters is now discussed in turn.

a) San Francisco Tide Levels

Tidal fluctuations are influenced by a combination of astronomical and meteorological conditions. The astronomical tidal cycle which is of most importance when determining flood risk is the spring/neap cycle. During a spring tide, which occurs at both the full and new moon, there is a larger diurnal range (difference between HHT and LLT), which results from the combined gravitational forces of both the sun and the moon. A much smaller diurnal range that averages close to MSL occurs during the neap tide, which occurs at the quarter and three-quarter lunar cycles.

February 3, 1998, was a quarter moon, indicating that according to the astronomical tidal cycle this was a neap tide, which should have resulted in slightly lower tide levels and a moderate diurnal range.

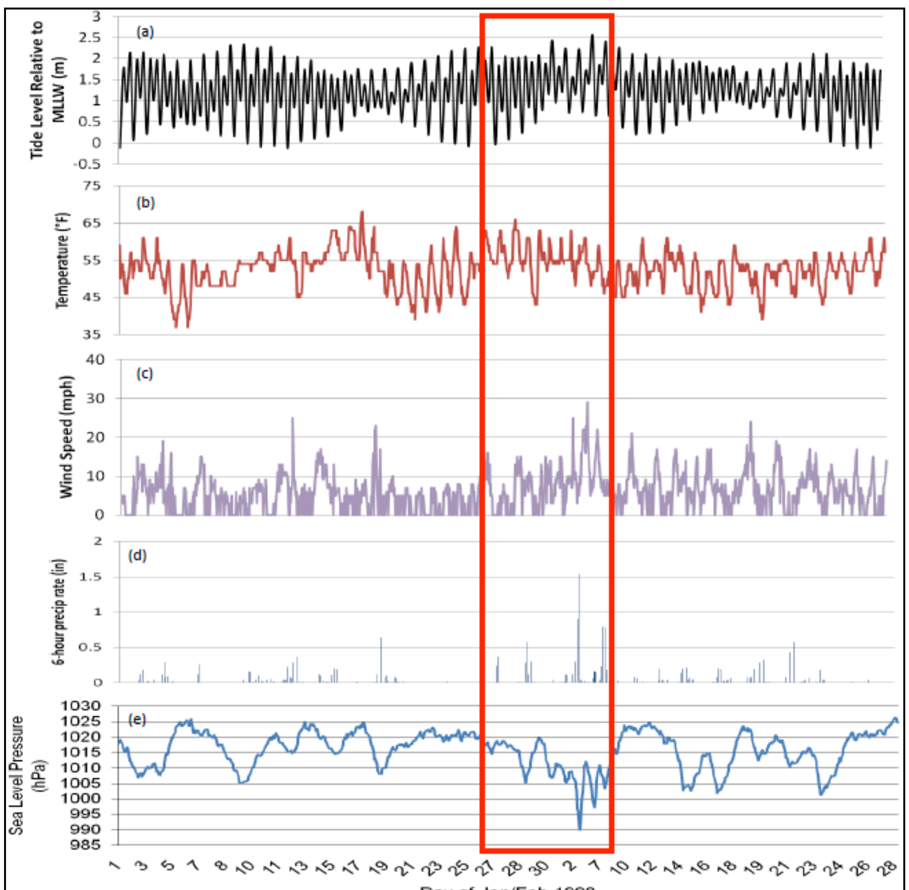

Figure 6. Composite of tide level, hourly temperatures, sustained wind speeds, 6-hour precipitation totals, and sea level pressures during January and February 1998. *Part a is the tide level (m) relative to MLLW datum for San Francisco Bay Station number 9414290. Part b is the temperature measured at Moffett Federal Airfield (°F), part c is the sustained wind speed (mph) at Moffett Federal Airfield, part d is the 6-hr precipitation rates at Moffett Federal Airfield (in), and part e is the sea level pressure at Moffett Federal Airfield (hPa). The red box highlights the period from prior to the flooding event at NASA ARC through its conclusion (January 27, 1998 to February 9, 1998). Source: NOAA Tides and Currents, "Verified Sea Level" http://tidesandcurrents.noaa.gov and NOAA/ NCDC "Hourly Surface Data" http://www.ncdc.noaa.gov/oa/dataaccesstools.html***.**

However, Figure 7a shows that the sea level was approximately 0.5 m higher than the preceding neap tide. This increase in sea level resulted from the additive effect of meteorological tides.

Meteorological tides are influenced by two parameters: atmospheric pressure and winds. Cayan, et al. in Ref 8, stated that 1mb decrease in SLP would cause 1 cm rise in sea level, indicating that intense low-pressure systems, like winter storms, can cause significant increases in local sea level and flooding. When examining Figure 8e, it is possible to see that SLP decreased from 1008 mb on February 2 to 990 mb on February 3. This decrease of 18 mb in SLP should have increased the local sea level by approximately 18 cm, which accounts for 36% of the observed difference from the prior neap tide.

In addition to SLP decreases, sustained winds over a period of several days from the same general direction can result in the stacking-up of water along coastline and other barriers, commonly referred to as storm surge. Figure 8c shows that for the period of February 2 to February 9, 1998, there were consistently sustained winds. The direction of these winds were not examined at this time, but it is likely that storm surge played an important role in the flooding, and accounted for approximately 64% of the 0.5 m increase in neap tide elevation of this event prior to the previous neap tide.

Overall, this indicates that monitoring tide levels and forecasts that include meteorological influences will be vital to properly evaluating the risk a specific storm poses to NASA ARC.

b) Land Surface Temperature

Figure 7b and Figure 8b show the temperature measurements for both January and February 1998 and during the Flood event, respectively. By examining these trends it appears that atmospheric temperatures do not serve as a good indicator of flood conditions occurring at NASA ARC.

c) Wind speeds

As addressed earlier, sustained surface wind speeds have an influence on storm surge.

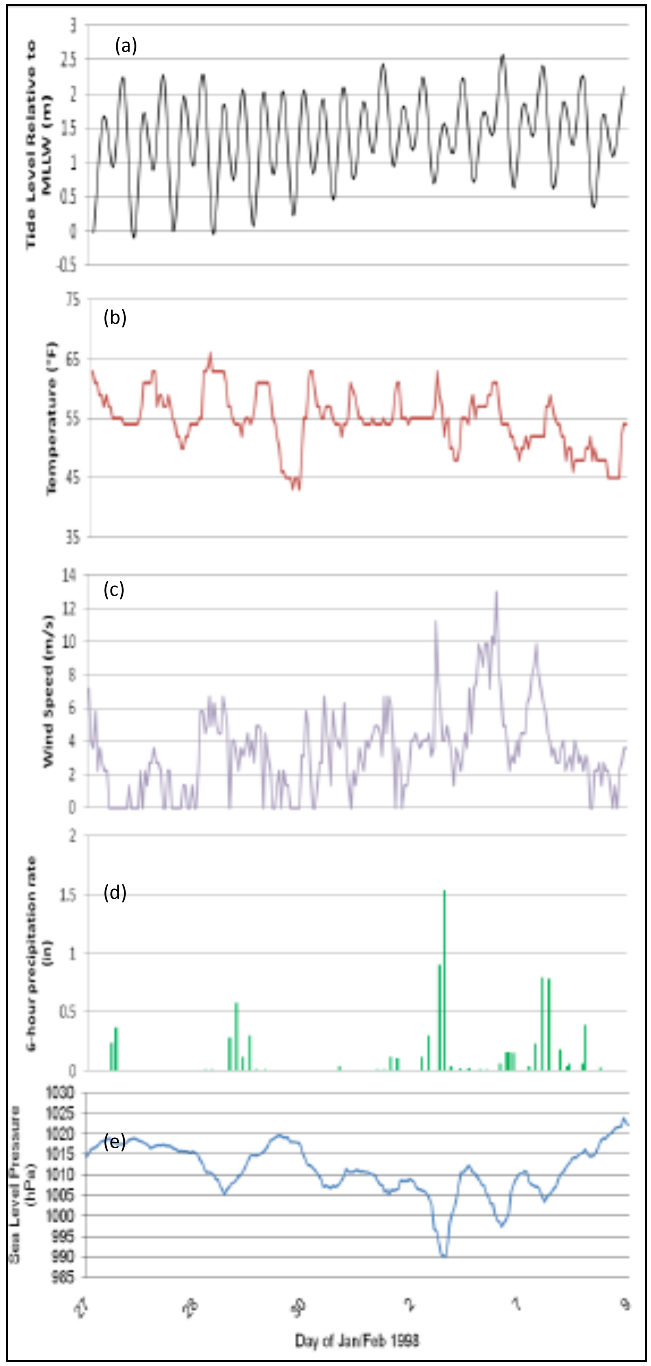

Figure 7. Composite of weather and sea level conditions January 27, 1998 to February 12, 1998. *Data is the same as shown in Figure 7, with the red highlighted region expanded here. Source: NOAA Tides and Currents, "Verified Sea Level" http://tidesandcurrents.noaa.gov and NOAA/ NCDC "Hourly Surface Data" http://www.ncdc.noaa.gov/oa/dataaccesstools.html***.**

This implies that strong winds, possibly from the North, would increase the likelihood that NASA ARC could experience flooding conditions. Figures 7c and 8c show the sustained wind speed during January and February 1998 and during the flood event, respectively.

These measurements show an increase in the sustained wind speeds during this time, and a decrease in the occurrence of no wind conditions, which is consistent with a strong low-pressure system and strong atmospheric pressure gradient in the region. It is important to note that in these figures wind direction cannot taken into account, so at this time it is not possible to directly determine the specific influence that these winds had on the flooding conditions that occurred.

d) Atmospheric Pressure

When examining Figure 7e, which shows the SLP over both January and February 1998, there is a very strong decrease atmospheric pressure when the winter storm passes over NASA ARC. This decrease in pressure coincides with the heaviest precipitation events, increased sustained winds, and strong increases in the tide levels.

Atmospheric pressure, as indicated though other parameters, is a vital indicator of the likelihood of flooding occurring at NASA ARC, due to the interrelation of SLP to other changes in conditions. Thus, monitoring the SLP during severe weather events will provide an indication of the likelihood of flooding at NASA ARC.

e) Precipitation

The 6-hr precipitation rate peaks at the time the event occurred at 1.54 in / 6 hrs. The preceding 6 hr period had a rate of 0.9 in/ 6 hrs. In addition to these high precipitation rates, the data show that there was measureable precipitation on January 27th - 29th, January 31st, and February 1st - 3rd, or 7 of the 8 days preceding the flood. This indicates that both frequent rainfall events, which saturate the ground, and locally heavy precipitation events are contributing factors to flood events at NASA ARC.

The increases in precipitation are consistent with the lower atmospheric pressure system and winter storm that were passing over NASA ARC at this time.

B. Impacts[†]

The combination of the unusually high sea level and intense rainfall, a situation that NASA ARC was not completely prepared for, led to severe flooding. At the time, pumping capacity was not sufficient to move the unusually high volume of water from the storm drainage system through the series of channels that shuttle the water to San Francisco Bay. The insufficient pump capacity lead to the eventual flooding and loss of the transformer used to power the pumps, causing the flooding to increase. The top left cover image is a picture showing the flooding of this pump station.

According to the NASA ARC- Disaster Assistance and Rescue Team (DART) website,[‡] because of the high water levels, at least eight of the basements at NASA ARC were significantly flooded, in addition to at least 16 other buildings outside the main research center, but still on Moffett Federal Airfield. There was damage to buildings from roof leaks and flooding of first floors several of buildings. The flooding of buildings resulted in the inability to occupy the buildings at all during the flood. In one case, this resulted in flooding of the building power supply electrical gear which was located in the basement. There were also parts of certain buildings that were unable to be occupied for weeks following the initial event due to mold growth. In addition to flooding, high winds caused damage to many roofs, trees, and buildings around NASA ARC.

[†] Personal Communication with Mr. Phil Snyder, Deputy Chief of Protective Services and Deputy Director of Emergency Services at NASA ARC, on 5 Mar 2010.

[‡] NASA ARC- Disaster Assistance and Rescue Team Website, URL: http://dart2.arc.nasa.gov/ [cited 10 Mar 2010]

There were over 100 underground locations flooded around the facility, including the ordnance bunkers shown in the bottom right cover image. Eventually, power was lost to much of the Moffett Field side of NASA ARC due to water retention in manholes.[§] In addition, there was substantial damage to the levees and storm channels.

Figure 8. Initial sand bagging effort during February 1998 flood. *Source: http://dart2.arc.nasa.gov/Deployments/SF_BayArea_Floods97-98/flds97_98.html.*

C. Response[**]

To attempt to stop the active backflow of water from San Francisco Bay, a large sandbagging effort was implemented. This effort not only included the NASA ARC DART, but also personnel from Plant Engineering, the Moffett Fire Department, the Naval Air Reserve, the California Air National Guard, the Air Force, and NASA ARC volunteers. At the peak, there were over 400 people involved and over 15,000 sandbags used. Figure 8 is a picture of the initial sandbagging operation.

The storm drainage system which was in use during this event remains the same today, with improvements discussed below. Storm water runoff on the west side of the facility utilizes natural drainage areas such as the salt marshes. The Moffett Field area (those parts not included in the NASA Research Center) drains into a holding area that is then pumped over a levee into Moffett Channel. This channel then flows downstream and is pumped into Lockheed Channel. From there the water is pumped into the outer northern channel before flowing to San Francisco Bay. [††]

At the height of the storm, pumps were rented to increase the pumping capacity to nearly 3 million gallons per hour from Moffett Channel to Lockheed channel, as opposed to the normal maximum capacity of 1.2 million gallons per hour. There was an additional 2.75 million gallons per hour of water pumped from Lockheed Channel to the outer levee, which takes water to the San Francisco Bay.

In addition to pumping water off the NASA ARC site, facility personnel worked though the second night in an attempt to plug basement penetrations. There was a round the clock efforts for a week in order to drain the flood waters and return NASA ARC to an operational state.

D. Improvements

Mr. John West, Engineering Technician, stated that following this major weather event, several steps have been taken to prepare for similar events in the future. The pump capacity of the lift station at Moffett Channel was increased, through the addition of permanent and temporary portable pumps, ensuring that NASA ARC will be capable of removing a sufficient volume of water during an event of the same magnitude in the future, without any increase in sea level. The channels protecting NASA ARC were dredged in order to increase their water capacity.

In hope of diverting water away from buildings, there has been a reconfiguration of water retention areas around NASA ARC. This included grading several areas around the facility including some roads, parking lots, and open fields to act as holding and evaporation areas. This was necessary

[§] Personal Communication with Mr. Kent Stednitz, NASA ARC Electrical Engineering Technician (Code JCM), on 22 Mar 2010.

[**] "San Francisco Bay Area Floods Winter '97- '98", NASA ARC- Disaster Assistance and Rescue Team, URL: http://dart2.arc.nasa.gov/Deployments/SF_BayArea_Floods97-98/flds97_98.html, [cited 10 Mar 2010].

[††] Personal Communication with Mr. John West, NASA ARC Engineering Technician (Code JCM), on 10 Mar 2010.

because parts of the facility are located close to or below sea level, preventing a natural downhill flow of storm water away from the facilities.

Currently when storms expected to produce large amounts of precipitation approach the area, all pumps on the base, fixed and moveable, are readied for their potential use. In addition, several pallets of sand bags are filled. During these large storms, the pumps are monitored at least hourly to ensure an adequate amount of water is being removed, and adjustments are made if necessary.

One necessary improvement that was identified following this flood is increasing the height of the cement pad the transformer for the pumps sits on, in order to reduce the likelihood of it flooding in the future. This was not able to be completed at the same time as many of the other levee and channel improvements, due to a lack of funding.

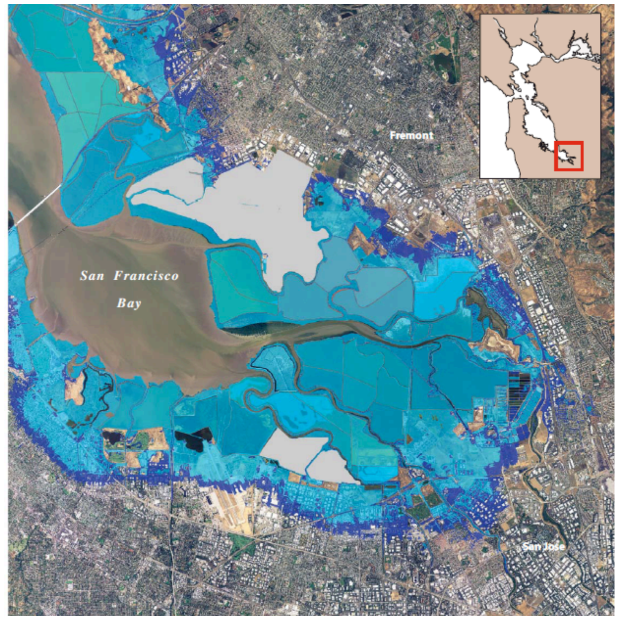

Figure 9. Potential Flooding of Southern San Francisco Bay due to 16 in and 55 in increase in local MSL. *The light blue shading is the area that would be inundated by an increase of 16 in of local MSL, while dark blue shading shows the inundation of a 55 in increase. Source: http://www.bcdc.ca.gov/planning/climate_change/index_map.shtml*

IV. Anticipated Impacts of Climate Change

A. Increased Flooding Risk

1. Sea Level Rise

The location of NASA ARC, with the majority of the active Research Campus located at elevations ranging from below sea level to only about 20 ft above sea level, makes it especially vulnerable to SLR resulting from climate change. Figure 10 shows the projected inundation due to a rise of 16 in (0.4 m) in MSL with light blue shading and 55 in (1.4 m) in dark blue shading. The smaller of the two increases will flood large portions of the airstrips, current drainage areas, and some buildings. The area of inundation expands only slightly when the projections are increased to 55 in (1.4 m), due to the effects of the local topography. However, The San Francisco Bay Conservation and Development Commission (BCDC) projections do not take into account any current or future shoreline protection, such as levees, or wave activity.

Cayan, D, et al., in Ref. 8, indicated that an increase in MSL of 30 cm would shift the frequency of what is now a 100-year storm surge induced flood event to once every 10 years. Figure 11 shows this concept in graphical form. In this figure the y-axis represents the peak high tide elevation relative to MLLW (m), while the x-axis shows the average frequency of occurrence, with a 100-year event (1% chance of occurring each year) on the left and a 1-year event (guaranteed to occur) on the right side of this axis.

The green curve represents the current frequency of the annual high tide peaks, while the red curve shows the projected frequency of occurrence of peaks following an increase in MSL of 30 cm. The star represents the highest-high tide level during the February 1998 flood event.

Following the purple line across, which indicates the same peak sea elevation, it is possible to see that the level of tide elevation during the 1998 flood would shift from nearly a 100-year event, to a 10-year event. This means that by about 2040, NASA ARC should be experiencing sea level events of the same magnitude once every 10 years. In other words, by 2040 NASA ARC will have a 10% chance each year of facing flooding on the same scale as the 1998 event.

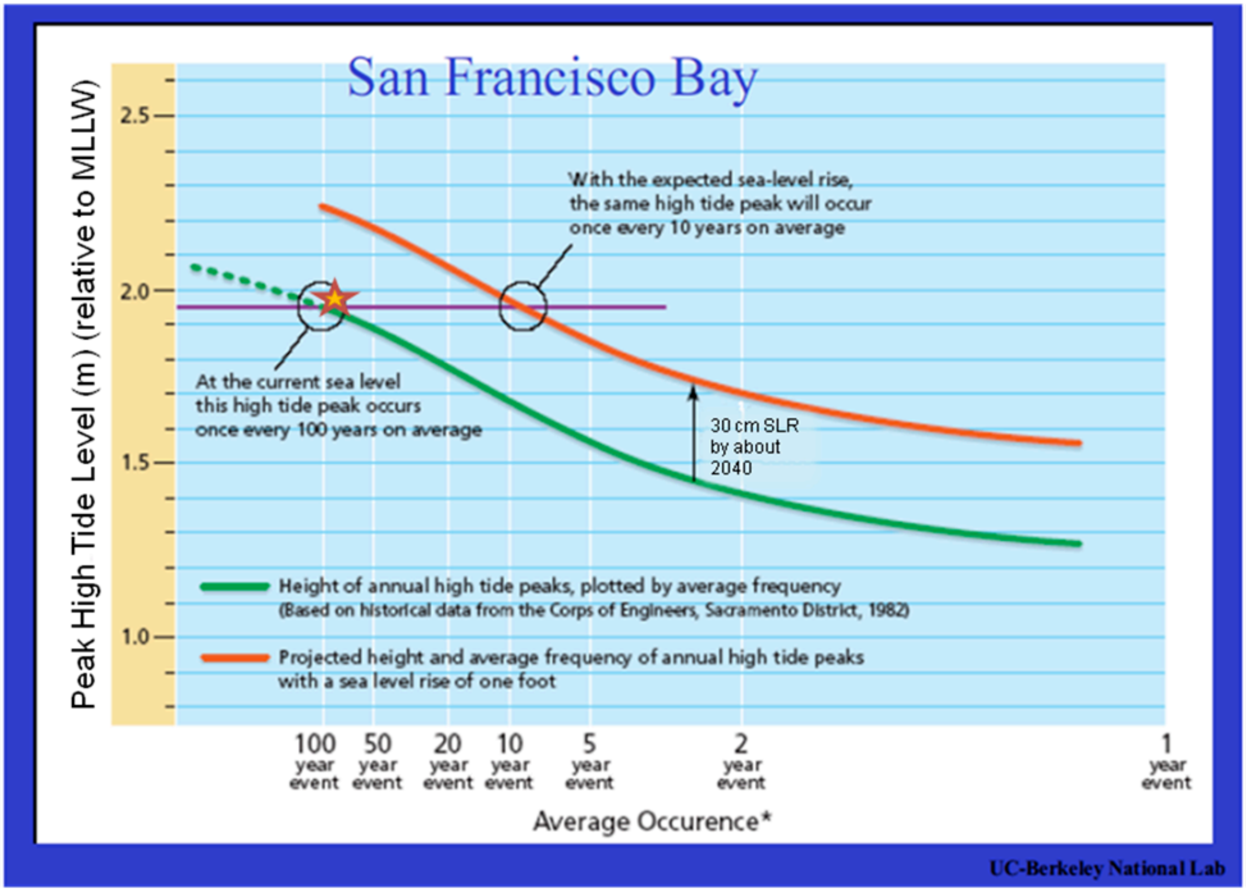

Figure 10. Increasing Frequency of Floods due to Sea Level Rise. *The y-axis represents the peak high tide elevation relative to MLLW (m), while the x-axis shows the average frequency of occurrence with a 100-year event (1% chance of occurring each year) on the left and a 1-year event (guaranteed to occur) on the right side of this axis. The green curve represents the current frequency of the annual high tide peaks, while the red curve shows the projected frequency of occurrence of peaks following an increase in MSL of 30-cm. The star marks the highest-high tide level which occurred during the February 1998 flood event. Source: http://www.water.ca.gov/pubs/climate/progress_on_incorporating_climate_change_into_planning.../progress_on_incorporating_climate_change.pdf*

An increase in MSL also increases the risk to the salt marshes and wetlands that surround NASA ARC. These locations currently serve as natural drainage basins for the Center as well as habitat for endangered species, such as the burrowing owl. The loss of these areas would greatly affect NASA ARCs ability to properly handle storm water runoff.

2. SLR comparison to 500-year flood

Figure 12 shows the 500-year flood plain (solid red line) overlaid on the BCDC sea level rise projections (from Figure 7). Coincidence between the SLR inundation extent and the 500-year flood plain is clearly seen. Due to this agreement it is possible to use information related to both SLR and this potential flood event to gain a practical understanding of the potential impacts from climate change.

The US Army Corps of Engineers is currently conducting a study, in which NASA ARC is a contributing partner[‡‡], into the economic impacts that a 500-year flood will have on the South San Francisco Bay Area. As part of this study, the values of the buildings inside the 500-year flood plain were identified. This list of vulnerable structures provides a fair indication of the structures vulnerable to the effects of a sea level rise of 140cm.

Table 7 shows the current replacement values of the building located in the flood plain, totaling over $384 million. In addition to the replacement cost of the buildings themselves, there is also the value of the equipment located in vulnerable areas of these buildings, which totals about $66 million. These values do not include the clean-up costs associated with such a flood event or the loss to NASA's mission that would occur. One of the key facilities located inside this flood plain is the NASA Advanced Supercomputing Facility, valued at over $32 million (first floor contents and building value). There are also several research and laboratory facilities within this flood plain including Space Projects (N244), Earth and Space Sciences (N245), Fluid Mechanics (N260), and Human Performance (N262).

Figure 11. Comparison of Projected Sea Level Rise and the 500-year flood plain at NASA ARC. *The light blue shaded area shows the projected inundation by 16 in of SLR, the dark blue shaded area shows the inundation by 55 in of SLR, and the red solid line shows the 500-year flood plain as determined by the Army Corps of Engineers. Source: http://www.bcdc.ca.gov/planning/climate_change/index_map.shtml and T. Mark Hightower.*

Increases in sea level will shift the 100- and 500-year flood plains further inland. This would put more facilities at NASA ARC at risk of damage due to flooding. It is clear that the lower of the two SLR estimates, 16 in, encompasses approximately 80% of the five hundred year flood plain. This indicates that in a world with increased sea level, it will take less rainfall to generate the conditions necessary to exceed the current flood protection measures.

3. Impact of SLR and Heavy Rainfall Event Changes on Storm Drainage Needs

The current projections indicate an increase in the frequency of heavy rainfall events, which pose a serious flooding risk. At NASA ARC, an increase in precipitation rates during previous winter storms, compared to the average precipitation rate, has led to flooding in the past, and this is anticipated to be a continued problem in the future.

SLR will reduce the likelihood of the current storm-water drainage system sufficiently handling heavy precipitation events in the future. This would result directly from the inundation of the storm-water-retention ponds and northern channel projected by the BCDC map referenced above.[§§] This may lead to an increase in the frequency and severity of the current drainage problems. This could potentially result in large amounts of unintended and dangerous street flooding. There have been some engineering attempts to increase the size of the storm-drainage system pipes, but this is not always possible due to the configuration of the all-underground utilities.

[‡‡] Personal Communication with Dr. Ann Clarke, Chief NASA ARC Environmental Management Division, 26 Mar 2010.

[§§] Personal Communication with Mr. John West, NASA ARC Engineering Technician, on 10 Mar 2010.

Location	Type	Value of Vulnerable Contents	Current Replacement Value Buildings
ARC	Active	$40,479,673	$203,341,953
ARC	Out Grant	$2,468,057	$19,042,933
ARC	Standby	$4,742,469	$31,210,031
ARC	**Total**	**$47,690,199**	**$253,594,917**
Moffett Field	Active	$50,000	$3,190,139
Moffett Field	Out Grant	$18,225,281	$131,071,077
Moffett Field	**Total**	**$18,275,281**	**$131,071,077**
Property Total		**$65,965,480**	**$384,665,994**

Table 6. Current Building Replacement Value and Value of Vulnerable Contents inside 500-year flood plain. *The data provided is in dollars and is limited to those buildings touching or inside the 500-year flood plain as determined by the US Army Corps of Engineers. NASA ARC has been divided into two parts, the ARC side is strictly the area contained within the current Research Center parameter, where Moffett Field comprises the remaining portion of the site. The values of vulnerable contents is limited to those items contained in the basement (if present) and on the first floor of buildings partially or wholly contained inside the flood plain. The current replacement values of the buildings was determined using a 20- city average. The 500-year flood plain used and along with the values were obtained as part of the Army Corps of Engineers Study, their evaluations of the data was not complete at the time of this report and any changes made on that part would affect the values represented here.*

The anticipated increases in flooding increase the likelihood of the roadways sustaining damage due to standing water. Increases in heavy precipitation events also increase the likelihood of contamination of water supplies by sewage and industrial waste/contaminates.

4. Groundwater Changes

Through the process of salt-water intrusion, increases in sea level could also affect the groundwater level of NASA ARC, which is currently an average of five feet below the surface. This could result more widespread and frequent flooding of basements at NASA ARC, along with increased dewatering costs at excavation and construction sites and reduction in runway capacity.[***]

Salt-water intrusion could also have an effect on the groundwater flow patterns at the NASA ARC site. Changes in groundwater flow are of concern because they could result in the distribution and spreading of the current contamination plumes of trichloroethylene (TCE) and other solvents and fuels. Currently NASA ARC is participating in the cleanup of these toxic plumes, and shifts could necessitate relocating the groundwater cleaning stations or result in the contamination of potential drinking water regulated by the Santa Clara Water District. If contamination of these supplies were to occur, NASA would be charged with cleaning these water supplies.[†††]

Increases in atmospheric and surface temperatures will also put groundwater systems at increased risk of contamination. Dr. Ann Clarke, Chief of the NASA ARC Environmental Management Division, explained that TCE increases in volatility as temperatures increase, and this increased volatility could potentially pose a risk to the heath of individuals in and around NASA ARC, especially if it were to seep into buildings or mix with surface water supplies.

B. Increased Occurrence of Drought

The local climate record, along with state and regional climate projections, shows an overall decline in precipitation totals. The most dramatic decline in precipitation amounts is expected to occur during the summer time, which already receives minimal precipitation due to the Mediterranean climate

[***] Personal Communication in form of presentation copy, "Potential Impacts of a 1-Meter Rise in Mean Sea Level at Ames Research Center" by Don Chuck of NASA ARC Environmental Services Division, original presentation date 29 March 2007.

[†††] Personal Communication with Mr. Don Chuck, NASA ARC Groundwater Restoration Project Manager, on 31 Mar 2010.

of this area of California. Combined with a projected shift in winter precipitation in the Sierra Nevada Mountains from snow to rain, the likelihood of NASA ARC experiencing drought is greatly increased. The greatest risk of drought will occur during the summer, reducing the likelihood of obtaining at affordable rates sufficient cooling water (currently from the potable water supply) for both the Unitary Wind Tunnel and Arc Jet facilities .

Increases in atmospheric temperature would also increase evapotranspiration from land surfaces, plants and bodies of water. This would increase the moisture deficiency at NASA ARC. In turn it would also increase the amount of irrigation that would be needed to maintain the landscaped areas of NASA ARC and Moffett Golf Course.

C. Power Systems and Availability

In general, it is not expected that climate change will have a significant impact on the electrical systems of NASA ARC. All of the underground cabling is submersible, and the distribution switches have been moved above ground to avoid any risk of flooding to them.

SLR may result in increase need in the number of pumping stations with diesel backups in order to handle the increased storm water tidal influences, but the basic electrical system should be able to provide the power needs for NASA ARC. [‡‡‡]

Though increases in atmospheric temperature are expected to result in higher energy demand from cooling, Mr. Steinitz does not expect that increases in temperature should cause much difficulty with the electrical system itself. The increased demand combined with a possible reduction in the thermo cycle relief of cool evenings could shorten the expected lifespan of electrical conveyance systems at NASA ARC, however.

The largest impact on power availability at NASA ARC will likely come from power generation limitations. The majority of the power used by the Center comes from hydroelectric sources located in the Sierra Nevada Mountains. The projected changes in precipitation patterns that include decreased snowfall in the winter, earlier snowpack melt, and warmer and drier summers will likely result in decreased hydropower availability. Coupled with the increased power demands expected with an increase in atmospheric temperature, there is an increased likelihood of increased expense, as well as brown- and black-outs at NASA ARC.

Atmospheric temperature increases may also have an impact on the efficiency of electrical power transmission from the power stations to NASA ARC. This reduction in efficiency would require the generation of increased amounts of electrical power in order to meet the demand. This increase in production and loss in transmission could impact the availability of affordable electrical power.

V. Adaptation Strategies

A. Increased Risk of Flooding

1. Increased shoreline protection

In direct response to sea level rise (SLR), there needs to be a continued effort to increase the height and strength of the levees that protect NASA ARC. Currently the US Army Corp of Engineers is conducting a study into the economic impacts that a 500-year flood would have on the South San Francisco Bay area. According to their website,[§§§] they are identifying and recommending projects that will reduce flood damage and restore ecosystems. Specifically they are considering increasing flood

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[‡‡‡] Personal Communication with Mr. Kent Stednitz, NASA ARC Electrical Engineering Technician (Code JCM), on 22 Mar 2010.

[§§§] South San Francisco Bay Shoreline Study, http://www.southbayshoreline.org/index.html.

capacities of local creeks, increasing man-made shoreline protection measures, and restoring wetlands, which provide natural flood protection.

It is important that during this process that maximum sea level rise scenarios consistent with local observations be taken into consideration, along with examining the extremes that can be seen during severe weather systems.

In addition to modifications to the levee system, other sustainable shoreline protection options should be considered. The BCDC is currently evaluating different methods for shoreline protection throughout the San Francisco Bay area. By working closely with the members of this local governmental organization, NASA ARC can work to maximize protection of the Center while helping guide the evolution of sustainable solutions for dealing with SLR.

Upon finding the right balance of both hard shoreline protection, such as levees, and soft protection such as beach and wetland restoration, NASA ARC should be able to increase the erosion protection and therefore decrease the long term costs associated with shoreline protection.

2. Identification of structures vulnerable to flooding

Steps should be taken to identify buildings around NASA ARC that are vulnerable to damage from flooding due to storms, sea level rise, or a combination of both. The initial step should be compiling a list of all buildings that flooded during February 1998 and the location of the leak points identified. Upon completion of this inventory, steps should be taken to correct leaks and other weaknesses. If such steps are not possible, these locations should be monitored during any severe weather event in which flooding is a possibility.

3. Storm water runoff and drainage studies

A study into the current storm water-runoff patterns needs to be completed and should include modeling of different precipitation events, which will provide an indication of precipitation rates that could pose a risk to NASA ARC.

A study into surface runoff would also prove useful in evaluating the current storm drainage at the Center, providing a basis for possible improvements or changes to the current storm water conveyance systems. In examining the storm-water runoff patterns, parameters that could be evaluated would include variations in precipitation rates, ground water levels, and various SLR scenarios for San Francisco Bay.

4. Groundwater flow studies

A study into the current groundwater flow patterns ought to be completed. This should include modeling of the current groundwater flow and movement of the contamination plume. Currently both NASA ARC and the MEW (Middlefield, Ellis, and Whisman) sites monitor the movement of the contamination plumes using wells. Then semiannually NASA ARC and the MEW sites compile their data to determine the current location of the plume.

Upon completion of a groundwater flow study it will be possible to model the effect that sea level will have on the movement of these plumes. Models based on these studies should be able to show the influence that various SLR scenarios, along with other hydrological changes, will have on groundwater flow. This would allow the Environmental Management group to gain a full understanding of the potential risks that sea level rise will have on the NASA ARC's groundwater supplies and any possible steps that might have to be taken to prevent the contamination from spreading.

5. Studies of San Francisco Bay hydrodynamics

SLR will have an impact on the hydrodynamics of the San Francisco Bay. Evaluating these will allow for a detailed understanding of the erosion processes that the bay is having on NASA ARC. Understanding the hydrodynamics will allow correlations between the tide gauges located around San Francisco Bay and the current conditions at the levees protecting NASA ARC. This type of correlation will allow emergency responders to monitor the current conditions at the levees without physically having to make observations, allowing for better preparation and response during adverse conditions.

There could also be an expansion upon the work currently being performed by the National Atmospheric and Oceanic Administration (NOAA) in the area of tsunami forecasting[22] to allow for predictions of the impact that such waves would have directly at NASA ARC. This is especially important since the airstrip located at NASA ARC is the only one likely to withstand a major earthquake in the San Francisco Bay Area, as it is built on natural land as opposed to fill.[****] Since there is a direct correlation between severe earthquakes and tsunamis, it would be very important to ensure that all steps are taken to prepare for protecting this location.

6. Increased flood management efforts

There should be immediate and long-term efforts to increase the flood management capabilities of NASA ARC. This should include but not be limited to increasing the Center's preparedness and readiness resources, including pumps, sandbags, and training of personnel.

In order to reduce the risk to valuable structures, there should be regular land-use and building-use reevaluations. The main objective of these evaluations should include ensuring that unmovable structures are not put in locations which the scientific climate change assessments have determined to be especially vulnerable to increased risk of flooding. The increased risk of flooding due to SLR and climate change should also be taken into consideration when choosing building sites for all future construction at NASA ARC.

7. Reassess the risk posed by SLR at regular intervals

A plan should be put into place to ensure that the risk posed by SLR and other climate changes will be reevaluated on a regular basis, preferably every five years. These should be scientific climate change assessments which objectively evaluate the current trends of conditions at NASA ARC. By performing these reassessments every five years they will prove a sound basis for facilities and environmental management to base their decisions on the best approaches to proactively safeguard the infrastructure of NASA ARC. This frequency will allow for short term and seasonal fluctuations to be averaged out, while still providing an adequate period for adaptation. In the case of severe or highly noticeable changes in the frequency of climate related problems, it may be necessary to perform these reassessments more frequently or on an as-needed basis.

8. Collection and Archiving of Relevant Data

a) Topographic Data

A topographic study of NASA ARC and the surrounding areas should be completed to determine the specific locations that are most at risk from SLR and climate change. This updated study would allow for comparison to earlier topographic evaluations and allow for a full analysis of surface changes that have already occurred at NASA ARC. In turn there will be a better understanding of the anthropogenic factors that have directly influenced the Center such as groundwater mining which has caused subsidence.

b) Tidal Datum

Tidal datum information should be created and a tidal gauge placed at NASA ARC's end of the bay or on nearby Stevens Creek. The closest tide gauge to NASA ARC is located at Redwood City, CA with a relatively short record. Having that singular point in South San Francisco Bay does not provide a large dataset to analyze when studying the effect that SLR will have on NASA ARC. Having access to local sea level data will allow NASA ARC to better monitor the conditions affecting the Center and thus better prepare for and respond to the changes that are observed.

[****] Personal Communication with Dr. Ann Clarke, Chief NASA ARC Environmental Management Division, 26 Mar 2010.

c) Wetland and Salt Marsh Impact

A detailed study should evaluate the impact that climate change is having on the wetlands that border NASA ARC to the north and the resulting impact on drainage at NASA ARC. The main objective of these assessments should be protecting the sensitive ecosystems and endangered species located in these areas. These assessments would be a continuation of the current efforts already underway by the Environmental Management Division of NASA ARC.

B. Drought

1. Water Conservation and Recycling

To adapt to the potential decreased availability of water during the summer months, continued efforts should be made to increase the amount of reclaimed groundwater is used in various facilities and applications around NASA ARC. Currently reclaimed groundwater is used by the Moffett Golf Course for irrigation, which saves approximately $90,000.00 a year in potable water costs.[23] According to Dr. Clarke there are plans to use reclaimed water for cooling both the Arc Jet and Unitary Wind Tunnel.

In addition, examining the potential of using recycled groundwater in non-potable situations, such as flushing toilets, may lead to additional viable options, assuming all the necessary health and safety requirements are met. It is not feasible to re-plumb the existing buildings at NASA ARC, but as older structures are demolished and replaced, water and energy efficiency should be considered in the replacement buildings.

2. Conversion to Native Plants

NASA ARC has started to replace lawns around the center with native plants. Currently four acres have been completed, in front of the cafeteria and supercomputing buildings. This conversion has led to a saving of as much as 6000 gallons of water per year. Expanding these efforts to include the nearly 1800 acres remaining would reduce the amount of potable water consumed at NASA ARC by nearly 33%. [23]

3. Increase Clean Water Holding Capacity

Increasing the capacity of the Industrial Wastewater Pretreatment Plant at NASA ARC would allow the Center to reclaim more water to be used for cooling the Arc Jet and Unitary Wind Tunnel. Taking this step would reduce NASA ARC's potable water purchase by 20 million gallons per year. Any excess water then could be used for other non-potable applications around the Center.[23]

4. Collection and Archiving of Relevant Data

Collecting and archiving the climate data collected at NASA ARC it will allow for detailed studies into the effects that various climate and atmospheric phenomena have on the center. Also monitoring and archiving water use assessments for individual facilities at NASA ARC will allow for additional measures to be taken to reduce the amount of potable water.

C. Power Systems and Availability

1. Increased Energy Efficiency and Use of Renewable Power Sources

Increasing the energy efficiency of NASA ARC will reduce the annual need for electricity, which is certain to increase in cost as climate change affects the production and transmission of power. By controlling our demand, it conceivable that total electricity costs can be maintained despite likely rate increases. Some steps already underway at NASA ARC to reduce energy consumption include installing prototype LED streetlights around the administrative building. These lights consume 90% less energy than traditional streetlights. Five solar-powered parking lot lights have also been installed.[22]

NASA ARC is in the process of constructing the *Sustainability Base*, a new office building which utilizes the latest green building techniques. In addition to this project there needs to be a continued effort to increase the energy efficiency and reduce consumption within the current facilities. Studies into the power consumption at individual facilities or buildings at NASA ARC will allow determinations to be made about which locations could benefit the most from such energy efficiency improvements.[23]

2. Studies into Influences of Temperature on Power Resources

Studies could be conducted that would look into the effects that temperature increases would have on the transmissions efficiency of electricity to NASA ARC and across the facility. It would also be able to determine the increased stresses that could be faced by the electrical infrastructure. Identification of these stressors and weak points now will allow appropriate actions to be taken to maximize the life span of the systems, reducing urgent and costly replacements.

VI. Conclusions

Climate change is occurring, and its impacts are going to be felt on both local and global scales. NASA ARC can expect to see an increased risk of flooding because of MSL increases and changes in precipitation patterns. These changes can be exacerbated by the presence of El Nino conditions. However, it is important to remember that flooding is not limited to El Nino years.

The increased risk of drought and threats to power availability also need to be addressed in any climate change adaptation studies. This will ensure that NASA ARC is making as little impact on the environment as possible while reducing the amount of resources that are consumed by the facility.

Adaptation is necessary to deal with the changes that are already occurring and will continue to occur even with measures that reduce the human impact on the planet. When implemented, these steps will not only help the center deal with a changing world, but in some cases will help reduce operating costs at NASA ARC.

A. Suggested Data Sets to Collect and Archive in the future

1. Updated topographic mapping of NASA ARC
2. Monitoring of sea levels directly at the site
3. Direct satellites measurements of the sea level to in San Francisco Bay, assuming the resolution is high enough, at various locations
4. Improvement in the consistent hourly monitoring and archiving of weather data at NASA ARC. Temperature, precipitation, fog occurance, and wind speed and direction appear to be the best correlated with climate change at NASA ARC, and should be a top priority for measurement. Sea level pressure should be monitored due to the influence that it plays in local sea level and as a possible indicator for flooding. The other parameters listed in Appendix B do not appear to have a strong of local correlation with climate change and do not appear to be vital to determining the impacts that NASA ARC will see in the future.
5. Records of the stream flow for Stevens Creek and the other waterways that flow through/near NASA ARC
6. Water use of individual facilities
7. Power consumption rates of individual facilities

B. Suggested Future Research

1. Shoreline protection feasibility and alternatives studies
2. Identification and assessment of vulnerable structures
3. Modeling of local precipitation patterns and storm water runoff and drainage
4. Modeling of ground water flow patterns and the possible changes caused by SLR and salt water intrusion
5. Detailed studies into bay hydrodynamics and tsunami and other wave risk assessment
6. Water use assessment and conservation studies

7. In-depth comparative study of weather data for Moffett Federal Airfield and surrounding locations to gain an understanding of the differences observed at NASA ARC and possible influencing factors
8. Perform a detailed analysis of possible influences on local temperature anomalies. Possible parameters to examine include land/sea breezes, topographic influences, and urbanization.
9. Potential impact analysis of changes in the drainage holding ponds and salt water marshes
10. Additional research into the impacts that climate change will have on wildlife habitat at NASA ARC
11. Evaluation of the impacts that climate change will have on human capital at NASA ARC

Appendix

A. Full Analysis of Sea Level Data in San Francisco Bay

Station Information:

Name	San Francisco, CA
Latitude	37° 48.4' N
Longitude	122° 27.9' W
Established	Jun 30, 1854
Present Installation	Sep 1, 1988
NOAA Chart #	18649
Station ID	9414290
Time Meridian	120 W

Description:

The following parameters are evaluated: Mean Higher High Water, Mean High Water, Mean Sea Level, Mean Low Water, and Mean Lower Low Water

For each parameter the average and standard deviation for the following seven periods were calculated: 1900- 1999 (20th century), 1900- 2009 (past 110 years), 1946 – 2009 (full weather record match (63 years)), 1951- 1980 (30-year climatology period), 1961 – 1990 (30-year climatology period), 1971- 2000 (30-year climatology period), 2005 – 2009 (most recent five years). These include the values for each of the 12 calendar months and an annual value. Values are shown in the following tables.

A second set of annual parameters has also been calculated for each of these five periods. They include: Mean, Standard Error, Median, Standard Deviation, Period Variance, Range, Minimum, Maximum, Confidence Level (95.0%), Change Per Year, and Change Per Decade. Values are shown in the following tables.

Calculation Procedure:

The average of each monthly period was calculated from the "Verified Monthly WL" retrieved from NOAA's Tides and Currents page, for Station 9414290. The data was retrieved relative to MSL and then was adjusted to a true depth using the MSL Datum (2.792 m) for this location.

The yearly value was calculated by averaging the monthly results for all parameters. The normal values are calculated by adding the yearly values for the appropriate month and then diving by the number of years in that period.

The additional annual parameters were calculated from the yearly values of each parameter using Microsoft Office 2007 Excel's "Descriptive Statistics Function".

Abbreviations:

Avg = Mean of parameter for all months (or annual values) for the period.
Std Dev = Standard Deviation for all months (or annual values) for the period.
00-99 = 1900 though 1999 Previous Full Century
00-09 = 1900 though 2009 Full Tide Gauge Record
46-09 = 1946 through 2009 Full Period of Available Weather Record
51-80 = 1951 through 1980 Climate Period
61-90 = 1961 through 1990 Climate Period
71-00 = 1971 though 2000 Climate Period
05-09 = 2005 though 2009 Most Recent Five Year

Mean Higher High Water (m):

MHHW		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00-99	**Avg**	2.959	2.908	2.810	2.762	2.830	2.907	2.953	2.930	2.887	2.844	2.894	2.956	2.887
	Std Dev	0.102	0.110	0.101	0.083	0.083	0.079	0.075	0.078	0.085	0.084	0.098	0.099	0.080
00-09	**Avg**	2.966	2.917	2.817	2.771	2.840	2.917	2.965	2.941	2.898	2.855	2.902	2.966	2.896
	Std Dev	0.102	0.110	0.101	0.087	0.086	0.083	0.080	0.083	0.088	0.088	0.098	0.102	0.083
46-09	**Avg**	3.025	2.974	2.870	2.822	2.894	2.974	3.018	2.996	2.955	2.910	2.963	3.025	2.952
	Std Dev	0.083	0.096	0.089	0.067	0.061	0.052	0.056	0.059	0.063	0.066	0.072	0.079	0.056
51-80	**Avg**	3.008	2.945	2.833	2.799	2.861	2.946	2.984	2.969	2.924	2.882	2.944	3.004	2.925
	Std Dev	0.057	0.082	0.069	0.051	0.049	0.034	0.033	0.035	0.044	0.053	0.058	0.059	0.034
61-90	**Avg**	3.032	2.974	2.872	2.822	2.883	2.967	3.010	2.997	2.960	2.913	2.978	3.034	2.953
	Std Dev	0.069	0.084	0.084	0.063	0.051	0.044	0.048	0.048	0.061	0.050	0.065	0.062	0.044
71-00	**Avg**	3.058	3.011	2.912	2.843	2.914	2.990	3.034	3.015	2.978	2.937	2.986	3.044	2.977
	Std Dev	0.084	0.094	0.086	0.057	0.051	0.049	0.048	0.050	0.059	0.053	0.076	0.078	0.046
05-09	**Avg**	3.050	3.008	2.894	2.879	2.965	3.034	3.098	3.081	3.017	2.974	2.992	3.062	3.004
	Std Dev	0.064	0.057	0.095	0.107	0.051	0.040	0.032	0.033	0.024	0.041	0.024	0.076	0.038

MHHW	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
00-99	2.887	0.008	2.873	0.080	0.006	0.363	2.750	3.113	0.016	0.002	0.025
00-09	2.896	0.008	2.885	0.083	0.007	0.363	2.750	3.113	0.016	0.002	0.024
46-09	2.952	0.007	2.949	0.056	0.003	0.274	2.839	3.113	0.014	0.002	0.023
51-80	2.925	0.006	2.932	0.034	0.001	0.127	2.867	2.994	0.013	0.002	0.018
61-90	2.953	0.008	2.947	0.046	0.002	0.238	2.875	3.113	0.017	0.003	0.030
71-00	2.977	0.009	2.969	0.048	0.002	0.208	2.905	3.113	0.018	0.002	0.023
05-09	3.004	0.017	3.014	0.038	0.001	0.093	2.952	3.045	0.047	-0.010	-0.097

Mean High Water (m):

MHW		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00-99	**Avg**	2.733	2.717	2.673	2.633	2.647	2.681	2.721	2.731	2.748	2.730	2.723	2.736	2.706
	Std Dev	0.100	0.107	0.099	0.080	0.078	0.077	0.076	0.079	0.081	0.079	0.092	0.093	0.077
00-09	**Avg**	2.740	2.725	2.680	2.641	2.656	2.691	2.731	2.742	2.758	2.739	2.731	2.744	2.715
	Std Dev	0.099	0.107	0.098	0.083	0.082	0.080	0.080	0.083	0.084	0.081	0.091	0.095	0.079
46-09	**Avg**	2.793	2.777	2.728	2.689	2.708	2.745	2.783	2.796	2.811	2.789	2.785	2.796	2.767
	Std Dev	0.084	0.096	0.089	0.066	0.059	0.052	0.057	0.060	0.061	0.063	0.071	0.075	0.056
51-80	**Avg**	2.780	2.751	2.694	2.666	2.676	2.718	2.752	2.770	2.784	2.766	2.767	2.779	2.742
	Std Dev	0.057	0.082	0.067	0.054	0.040	0.033	0.039	0.037	0.041	0.052	0.054	0.057	0.035
61-90	**Avg**	2.798	2.775	2.730	2.692	2.701	2.740	2.778	2.798	2.816	2.793	2.799	2.803	2.768
	Std Dev	0.072	0.083	0.081	0.063	0.046	0.042	0.048	0.043	0.055	0.047	0.065	0.058	0.043
71-00	**Avg**	2.825	2.813	2.772	2.711	2.730	2.765	2.806	2.822	2.837	2.818	2.808	2.813	2.793
	Std Dev	0.090	0.096	0.084	0.056	0.052	0.048	0.046	0.046	0.054	0.050	0.076	0.074	0.046
05-09	**Avg**	2.809	2.799	2.737	2.723	2.770	2.792	2.850	2.868	2.859	2.828	2.795	2.816	2.804
	Std Dev	0.066	0.057	0.093	0.101	0.060	0.042	0.028	0.028	0.027	0.048	0.021	0.068	0.037

MHW	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
00-99	2.706	0.008	2.688	0.077	0.006	0.350	2.580	2.929	0.015	0.002	0.024
00-09	2.715	0.008	2.706	0.079	0.006	0.350	2.580	2.929	0.015	0.002	0.022
46-09	2.767	0.007	2.765	0.056	0.003	0.267	2.662	2.929	0.014	0.002	0.022
51-80	2.742	0.006	2.749	0.035	0.001	0.122	2.674	2.796	0.013	0.002	0.021
61-90	2.768	0.008	2.762	0.044	0.002	0.228	2.701	2.929	0.016	0.002	0.025
71-00	2.793	0.009	2.786	0.050	0.002	0.228	2.701	2.929	0.019	0.003	0.027
05-09	2.804	0.017	2.810	0.037	0.001	0.093	2.752	2.844	0.046	-0.010	-0.104

Mean Sea Level (m):

MSL		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00-99	**Avg**	2.103	2.102	2.061	2.013	2.020	2.050	2.086	2.100	2.119	2.095	2.080	2.092	2.077
	Std Dev	0.099	0.110	0.098	0.074	0.069	0.066	0.064	0.069	0.073	0.072	0.087	0.088	0.070
00-09	**Avg**	2.109	2.109	2.066	2.020	2.028	2.058	2.095	2.110	2.128	2.104	2.087	2.100	2.084
	Std Dev	0.097	0.108	0.096	0.078	0.072	0.069	0.069	0.073	0.076	0.075	0.086	0.090	0.071
46-09	**Avg**	2.157	2.154	2.105	2.058	2.070	2.101	2.137	2.157	2.175	2.148	2.136	2.147	2.129
	Std Dev	0.086	0.102	0.092	0.070	0.058	0.051	0.053	0.056	0.058	0.060	0.069	0.072	0.054
51-80	**Avg**	2.148	2.132	2.071	2.036	2.040	2.076	2.106	2.131	2.146	2.124	2.119	2.132	2.105
	Std Dev	0.064	0.089	0.069	0.058	0.038	0.030	0.032	0.031	0.036	0.049	0.056	0.059	0.033
61-90	**Avg**	2.161	2.151	2.104	2.059	2.059	2.093	2.129	2.157	2.177	2.150	2.149	2.154	2.129
	Std Dev	0.077	0.097	0.092	0.071	0.049	0.045	0.049	0.044	0.056	0.047	0.067	0.061	0.047
71-00	**Avg**	2.182	2.187	2.145	2.075	2.085	2.114	2.154	2.177	2.196	2.171	2.152	2.158	2.150
	Std Dev	0.096	0.111	0.096	0.065	0.057	0.053	0.049	0.047	0.057	0.050	0.077	0.073	0.052
05-09	**Avg**	2.175	2.168	2.111	2.099	2.132	2.153	2.207	2.231	2.227	2.190	2.147	2.164	2.167
	Std Dev	0.078	0.052	0.091	0.125	0.067	0.041	0.030	0.029	0.029	0.050	0.021	0.066	0.043

MSL	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
00-99	**2.077**	0.007	2.064	0.070	0.005	0.352	1.960	2.313	0.014	0.002	0.020
00-09	**2.084**	0.007	2.070	0.071	0.005	0.352	1.960	2.313	0.013	0.002	0.019
46-09	**2.129**	0.007	2.122	0.054	0.003	0.272	2.040	2.313	0.014	0.002	0.019
51-80	**2.105**	0.006	2.113	0.033	0.001	0.125	2.040	2.165	0.012	0.001	0.013
61-90	**2.129**	0.009	2.121	0.048	0.002	0.244	2.069	2.313	0.018	0.002	0.021
71-00	**2.150**	0.010	2.139	0.054	0.003	0.244	2.069	2.313	0.020	0.003	0.026
05-09	**2.167**	0.019	2.168	0.043	0.002	0.111	2.108	2.219	0.053	-0.012	-0.125

Mean Low Water (m):

MLW		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00-99	**Avg**	1.508	1.515	1.474	1.428	1.433	1.462	1.485	1.494	1.515	1.490	1.475	1.489	1.481
	Std Dev	0.106	0.121	0.106	0.079	0.068	0.062	0.059	0.061	0.068	0.067	0.082	0.089	0.066
00-09	**Avg**	1.515	1.520	1.479	1.434	1.441	1.470	1.495	1.504	1.524	1.500	1.483	1.498	1.489
	Std Dev	0.106	0.118	0.105	0.084	0.073	0.066	0.065	0.068	0.072	0.072	0.083	0.091	0.069
46-09	**Avg**	1.561	1.560	1.512	1.465	1.473	1.505	1.529	1.545	1.565	1.539	1.528	1.542	1.527
	Std Dev	0.098	0.117	0.107	0.085	0.070	0.059	0.059	0.058	0.060	0.061	0.070	0.078	0.059
51-80	**Avg**	1.550	1.534	1.472	1.441	1.439	1.476	1.492	1.515	1.532	1.507	1.504	1.520	1.498
	Std Dev	0.085	0.106	0.084	0.071	0.051	0.042	0.035	0.030	0.036	0.050	0.059	0.067	0.040
61-90	**Avg**	1.561	1.554	1.508	1.463	1.456	1.491	1.518	1.540	1.564	1.537	1.536	1.549	1.523
	Std Dev	0.093	0.119	0.115	0.086	0.066	0.059	0.060	0.052	0.064	0.054	0.073	0.073	0.059
71-00	**Avg**	1.576	1.590	1.550	1.476	1.480	1.507	1.539	1.555	1.579	1.554	1.535	1.544	1.540
	Std Dev	0.112	0.134	0.119	0.082	0.072	0.065	0.060	0.055	0.064	0.054	0.080	0.080	0.062
05-09	**Avg**	1.596	1.579	1.528	1.527	1.555	1.575	1.618	1.636	1.631	1.597	1.557	1.570	1.581
	Std Dev	0.095	0.052	0.089	0.156	0.089	0.043	0.034	0.034	0.032	0.049	0.021	0.063	0.051

MLW	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
00-99	1.481	0.007	1.472	0.066	0.004	0.391	1.354	1.745	0.013	0.002	0.017
00-09	1.489	0.007	1.478	0.069	0.005	0.391	1.354	1.745	0.013	0.002	0.017
46-09	1.527	0.007	1.520	0.059	0.003	0.319	1.427	1.745	0.015	0.002	0.018
51-80	1.498	0.007	1.504	0.040	0.002	0.163	1.427	1.589	0.015	0.000	0.003
61-90	1.523	0.011	1.516	0.060	0.004	0.319	1.427	1.745	0.023	0.002	0.024
71-00	1.540	0.012	1.526	0.063	0.004	0.319	1.427	1.745	0.024	0.003	0.028
05-09	1.581	0.023	1.570	0.051	0.003	0.133	1.518	1.651	0.063	-0.017	-0.171

Mean Lower Low Water (m):

MLLW		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00-99	**Avg**	1.135	1.209	1.202	1.118	1.061	1.058	1.103	1.170	1.240	1.183	1.093	1.074	1.137
	Std Dev	0.113	0.134	0.122	0.088	0.075	0.068	0.070	0.077	0.076	0.076	0.092	0.096	0.074
00-09	**Avg**	1.137	1.211	1.204	1.121	1.067	1.063	1.108	1.178	1.248	1.190	1.099	1.080	1.142
	Std Dev	0.110	0.129	0.119	0.091	0.075	0.068	0.070	0.079	0.077	0.077	0.091	0.096	0.073
46-09	**Avg**	1.177	1.246	1.231	1.143	1.093	1.091	1.140	1.221	1.286	1.227	1.145	1.119	1.177
	Std Dev	0.108	0.131	0.122	0.093	0.073	0.064	0.064	0.066	0.064	0.069	0.076	0.083	0.065
51-80	**Avg**	1.179	1.235	1.200	1.129	1.069	1.074	1.116	1.200	1.260	1.204	1.128	1.106	1.158
	Std Dev	0.083	0.113	0.090	0.080	0.057	0.045	0.046	0.043	0.046	0.059	0.057	0.070	0.042
61-90	**Avg**	1.172	1.236	1.225	1.139	1.073	1.072	1.126	1.216	1.279	1.224	1.156	1.121	1.170
	Std Dev	0.097	0.127	0.124	0.092	0.071	0.060	0.062	0.052	0.059	0.053	0.073	0.077	0.059
71-00	**Avg**	1.201	1.287	1.283	1.162	1.106	1.101	1.161	1.251	1.312	1.254	1.168	1.136	1.202
	Std Dev	0.130	0.149	0.132	0.091	0.083	0.072	0.068	0.059	0.061	0.059	0.083	0.083	0.070
05-09	**Avg**	1.174	1.226	1.209	1.160	1.133	1.125	1.188	1.281	1.325	1.252	1.139	1.115	1.194
	Std Dev	0.097	0.059	0.105	0.168	0.078	0.058	0.046	0.037	0.045	0.070	0.030	0.053	0.053

MLLW	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
00-99	1.137	0.007	1.127	0.074	0.005	0.397	0.999	1.396	0.015	0.002	0.017
00-09	1.142	0.007	1.131	0.073	0.005	0.397	0.999	1.396	0.014	0.002	0.015
46-09	1.177	0.008	1.169	0.065	0.004	0.323	1.073	1.396	0.016	0.002	0.018
51-80	1.158	0.008	1.155	0.042	0.002	0.182	1.089	1.271	0.016	0.001	0.011
61-90	1.170	0.011	1.160	0.059	0.004	0.305	1.091	1.396	0.022	0.002	0.016
71-00	1.202	0.013	1.185	0.073	0.005	0.305	1.091	1.396	0.027	0.003	0.034
05-09	1.194	0.024	1.196	0.053	0.003	0.143	1.123	1.265	0.066	-0.014	-0.135

Mean Temperature (°C):

T_{mean}		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	9.6	11.3	12.3	13.9	15.8	17.8	18.7	18.8	18.6	16.5	12.9	9.9	14.7
	Std Dev	1.5	1.5	1.4	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.1	1.4	1.2
51-80	Avg	9.6	11.1	11.9	13.4	15.4	17.3	18.1	18.3	18.3	16.3	12.6	9.8	14.3
	Std Dev	1.3	1.4	1.2	1.4	1.2	1.4	0.9	1.0	1.1	1.1	1.0	1.4	0.7
61-90	Avg	9.9	11.6	12.5	14.1	15.9	17.9	18.7	19.0	18.8	16.8	13.1	10.0	14.8
	Std Dev	1.2	1.3	1.2	1.6	1.3	1.4	1.1	0.9	1.3	1.0	0.9	1.4	0.7
71-00	Avg	10.2	11.8	13.0	14.6	16.4	18.4	19.3	19.5	19.1	17.2	13.2	10.1	15.1
	Std Dev	1.1	1.2	1.3	1.4	1.3	1.3	1.0	1.0	1.4	1.0	1.1	1.4	1.2
05-09	Avg	9.7	11.4	12.5	13.7	16.4	18.2	19.5	19.3	18.6	16.3	13.5	10.0	14.9
	Std Dev	1.0	0.6	1.3	0.3	0.4	0.6	0.9	0.4	1.0	0.6	0.7	1.2	0.2

T_{mean}	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	14.67	0.15	14.72	1.17	1.36	8.57	9.79	18.36	0.29	0.03	0.27
51-80	14.35	0.13	14.27	0.69	0.48	2.61	13.03	15.64	0.26	0.05	0.55
61-90	14.85	0.13	14.88	0.69	0.48	2.22	13.50	15.72	0.26	0.06	0.58
71-00	15.08	0.22	15.35	1.21	1.47	6.94	9.79	16.73	0.45	0.00	0.00
05-09	14.92	0.08	14.87	0.19	0.04	0.49	14.72	15.21	0.23	-0.04	-0.37

Mean Daily Maximum Temperature (°C):

T_{max}		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	14.7	16.3	17.8	20.1	21.9	23.8	24.5	24.6	25.1	23.0	18.7	14.9	20.4
	Std Dev	1.5	1.5	1.7	2.0	2.0	1.9	1.7	1.5	1.9	1.4	1.6	1.5	1.5
51-80	Avg	14.5	16.1	17.3	19.3	21.4	23.1	23.6	23.8	24.4	22.6	18.4	14.8	19.9
	Std Dev	1.4	1.4	1.4	2.0	2.0	2.1	1.5	1.3	1.7	1.5	1.3	1.7	1.0
61-90	Avg	15.0	16.8	18.0	20.4	22.1	24.0	24.5	24.7	25.2	23.2	18.8	15.0	20.6
	Std Dev	1.3	1.5	1.6	2.3	2.1	2.2	1.8	1.3	2.1	1.5	1.4	1.6	1.1
71-00	Avg	15.4	16.9	18.4	20.9	22.8	24.6	25.3	25.5	25.6	23.6	19.0	15.4	20.9
	Std Dev	1.1	1.3	1.6	1.7	1.8	2.0	1.4	1.1	2.1	1.3	1.8	1.2	1.5
05-09	Avg	15.1	16.8	18.6	20.3	22.9	24.8	25.9	25.9	25.9	23.4	19.8	15.2	21.2
	Std Dev	1.4	0.6	2.1	1.2	0.4	0.7	1.3	0.7	1.5	1.0	0.7	1.2	0.2

T_{max}	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	26.98	0.29	26.94	2.32	5.39	18.22	15.06	33.28	0.58	0.02	0.18
51-80	26.58	0.20	26.52	1.08	1.17	4.92	24.23	29.15	0.40	0.06	0.57
61-90	27.23	0.24	27.42	1.32	1.75	5.40	24.23	29.63	0.49	0.11	1.13
71-00	27.38	0.48	27.85	2.65	7.05	16.65	15.06	31.70	0.99	-0.04	-0.38
05-09	28.23	0.43	27.92	0.96	0.92	1.96	27.29	29.25	1.19	0.52	5.23

Mean Daily Minimum Temperature (°C):

T_{min}		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	5.8	7.4	8.1	9.2	11.3	13.2	14.5	14.7	14.1	11.9	8.8	6.2	10.4
	Std Dev	1.7	1.9	1.5	1.4	1.3	1.2	1.1	1.2	1.3	1.4	1.5	2.0	1.0
51-80	Avg	6.0	7.3	7.7	8.7	10.8	12.8	14.0	14.3	13.8	11.6	8.5	6.2	10.1
	Std Dev	1.6	1.8	1.3	1.1	1.0	1.2	0.9	1.1	1.2	1.2	1.3	1.6	0.7
61-90	Avg	6.2	7.7	8.4	9.3	11.3	13.4	14.5	15.0	14.3	12.3	9.1	6.4	10.7
	Std Dev	1.4	1.5	1.2	1.4	1.1	1.1	1.0	0.9	1.1	1.1	1.0	1.8	0.6
71-00	Avg	6.5	7.8	8.9	9.8	11.8	13.7	15.1	15.4	14.7	12.6	9.3	6.6	11.0
	Std Dev	1.4	1.5	1.5	1.4	1.3	1.0	1.0	0.9	1.0	1.2	1.4	2.2	0.8
05-09	Avg	5.4	7.3	8.0	9.1	11.9	13.4	15.4	15.1	14.0	11.6	8.8	6.1	10.5
	Std Dev	0.9	0.7	0.8	0.6	0.4	0.7	0.6	0.4	1.0	0.6	1.1	1.1	0.1

T_{min}	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	6.07	0.16	6.06	1.25	1.55	6.63	3.37	10.00	0.31	0.05	0.46
51-80	5.57	0.15	5.60	0.81	0.66	3.84	3.37	7.21	0.30	0.05	0.54
61-90	6.22	0.14	6.12	0.77	0.60	2.81	4.77	7.58	0.29	0.06	0.55
71-00	6.61	0.16	6.88	0.90	0.81	3.48	4.77	8.25	0.34	0.05	0.47
05-09	6.27	0.20	6.24	0.45	0.20	1.19	5.69	6.88	0.56	-0.14	-1.41

Mean Daily Dew Point Temperature (°C):

DewPt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	4.8	6.0	6.2	7.0	8.9	10.8	12.7	13.0	12.1	9.8	7.2	5.0	8.6
	Std Dev	2.0	2.0	1.4	1.4	1.2	1.2	1.0	1.1	1.1	1.3	1.7	2.2	0.9
51-80	Avg	5.2	6.2	6.0	7.0	8.9	11.1	12.8	13.0	12.2	10.0	7.4	5.3	8.8
	Std Dev	1.7	2.1	1.3	1.5	1.1	1.3	0.7	1.0	1.2	1.4	1.4	2.0	0.6
61-90	Avg	4.6	5.9	6.1	6.6	8.5	10.9	12.4	12.7	11.8	9.8	7.2	4.7	8.4
	Std Dev	1.7	2.2	1.4	1.3	1.1	1.3	1.1	1.0	1.2	1.3	1.5	2.4	0.8
71-00	Avg	4.8	5.9	6.3	6.5	8.6	10.5	12.4	12.8	12.1	9.8	6.9	4.5	8.4
	Std Dev	1.9	2.0	1.6	1.2	1.3	1.2	1.3	1.3	1.2	1.2	1.7	2.6	1.0
05-09	Avg	4.4	6.0	6.2	6.3	9.2	10.7	13.3	12.9	11.5	8.7	7.4	4.8	8.5
	Std Dev	2.1	1.2	1.5	1.3	1.3	1.1	0.6	0.4	0.8	0.6	1.5	1.7	0.6

DewPt	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	8.58	0.12	8.71	0.92	0.84	4.51	6.35	10.86	0.23	-0.01	-0.10
51-80	8.75	0.11	8.87	0.63	0.40	2.62	7.68	10.30	0.23	-0.02	-0.18
61-90	8.43	0.14	8.60	0.75	0.56	2.95	6.53	9.48	0.28	-0.04	-0.44
71-00	8.36	0.19	8.33	1.02	1.03	4.41	6.45	10.86	0.38	0.01	0.08
05-09	8.46	0.29	8.47	0.64	0.41	1.64	7.78	9.43	0.80	-0.26	-2.57

Mean Daily Sea Level Pressure (hPa):

SLP		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	1019.9	1018.6	1017.5	1016.9	1015.2	1014.1	1014.1	1014.0	1013.4	1015.9	1018.6	1019.9	1016.5
	Std Dev	3.1	3.9	3.6	3.1	2.8	2.1	1.9	2.0	1.8	2.2	2.7	3.0	2.3
51-80	Avg	1020.0	1019.4	1018.2	1017.3	1015.9	1014.5	1014.4	1014.2	1013.7	1016.4	1019.0	1020.4	1016.9
	Std Dev	1.9	2.5	1.8	1.1	1.3	1.3	0.9	1.2	0.9	1.0	1.5	1.8	0.7
61-90	Avg	1020.3	1019.4	1018.0	1017.4	1015.9	1014.5	1014.4	1014.2	1013.8	1016.5	1018.7	1020.2	1017.0
	Std Dev	1.9	2.5	1.8	1.2	1.1	1.2	0.8	1.1	1.0	0.9	1.6	1.6	0.6
71-00	Avg	1019.4	1017.8	1016.6	1016.4	1014.6	1014.0	1014.0	1013.9	1013.3	1015.8	1018.4	1019.8	1016.2
	Std Dev	4.0	5.2	4.5	4.2	3.8	2.8	2.6	2.7	2.6	3.0	3.6	3.9	3.2
05-09	Avg	1021.4	1019.0	1019.4	1018.1	1015.8	1014.4	1014.1	1013.7	1014.3	1016.7	1019.9	1021.0	1017.3
	Std Dev	2.4	1.7	2.3	1.5	0.4	1.0	0.6	0.9	0.7	1.1	0.7	2.0	0.5

SLP	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	1016.52	0.29	1016.85	2.26	5.12	18.56	1001.70	1020.26	0.57	-0.01	-0.11
51-80	1016.94	0.12	1017.03	0.66	0.43	2.73	1015.37	1018.10	0.25	0.01	0.12
61-90	1016.95	0.11	1017.16	0.63	0.39	2.47	1015.13	1017.60	0.23	0.00	-0.04
71-00	1016.24	0.58	1016.91	3.17	10.05	18.56	1001.70	1020.26	1.18	-0.08	-0.84
05-09	1017.32	0.21	1017.25	0.47	0.22	1.25	1016.76	1018.01	0.58	0.09	0.94

Mean Daily Wind Speed (m/s):

$WdSpd_{mean}$		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	1.8	2.0	2.3	2.5	2.7	2.8	2.7	2.5	2.1	1.8	1.6	1.7	2.2
	Std Dev	0.5	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.4	0.4	0.6	0.4
51-80	Avg	2.0	2.1	2.4	2.6	2.7	2.8	2.6	2.4	2.1	1.8	1.7	1.8	2.2
	Std Dev	0.5	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.6	0.4
61-90	Avg	1.6	1.7	2.1	2.3	2.4	2.6	2.5	2.3	1.9	1.6	1.5	1.5	2.0
	Std Dev	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.5	0.2
71-00	Avg	1.5	1.7	2.1	2.3	2.5	2.6	2.6	2.4	2.0	1.7	1.5	1.5	2.0
	Std Dev	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.5	0.4
05-09	Avg	1.6	1.9	2.2	2.3	2.7	2.9	2.8	2.6	2.1	1.8	1.4	1.7	2.2
	Std Dev	0.3	0.1	0.4	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.1

$WdSpd_{mean}$	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	2.21	0.05	2.13	0.43	0.18	2.69	0.71	3.40	0.11	-0.01	-0.08
51-80	2.24	0.06	2.13	0.35	0.13	1.06	1.80	2.86	0.13	-0.03	-0.30
61-90	2.02	0.03	2.00	0.18	0.03	0.72	1.70	2.42	0.07	0.00	-0.02
71-00	2.00	0.07	2.00	0.38	0.15	1.92	0.71	2.63	0.14	0.00	-0.02
05-09	2.17	0.04	2.13	0.08	0.01	0.18	2.08	2.26	0.10	-0.05	-0.47

Maximum Daily Wind Speed (m/s):

$WdSpd_{max}$		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	10.0	9.4	8.7	8.8	8.9	9.0	8.5	8.4	8.0	8.6	9.1	9.9	8.8
	Std Dev	2.3	2.9	2.1	1.6	1.3	1.5	1.1	1.8	1.0	2.1	2.0	2.3	1.3
51-80	Avg	10.9	10.3	9.3	9.0	8.8	8.9	8.6	8.1	7.9	8.7	9.5	10.0	9.2
	Std Dev	2.4	3.5	1.8	1.7	1.6	1.2	1.0	2.3	1.2	2.1	1.8	1.7	1.1
61-90	Avg	9.8	8.7	8.5	8.2	8.6	8.5	8.2	8.3	7.6	8.1	8.8	9.6	8.6
	Std Dev	2.0	1.7	1.0	1.0	1.5	1.2	0.8	2.3	0.8	1.4	1.5	1.4	0.5
71-00	Avg	9.1	8.3	8.0	8.4	8.6	8.4	8.2	8.4	7.6	7.6	8.4	9.3	8.2
	Std Dev	2.1	2.0	1.2	1.3	1.5	1.4	1.1	2.4	0.9	1.2	1.7	2.0	1.2
05-09	Avg	9.8	8.3	8.1	8.4	8.7	8.9	8.9	9.0	8.0	7.9	8.3	8.4	8.6
	Std Dev	1.9	0.8	0.8	0.4	0.5	0.4	0.9	0.8	0.4	1.2	1.5	1.4	0.2

$WdSpd_{max}$	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	8.82	0.17	8.70	1.34	1.80	8.65	3.13	11.78	0.34	-0.05	-0.46
51-80	9.17	0.20	8.79	1.08	1.17	4.01	7.76	11.78	0.40	-0.08	-0.84
61-90	8.58	0.11	8.57	0.58	0.34	2.31	7.60	9.90	0.22	0.00	0.01
71-00	8.19	0.22	8.41	1.21	1.47	6.65	3.13	9.78	0.45	-0.05	-0.53
05-09	8.56	0.08	8.59	0.19	0.04	0.51	8.27	8.78	0.23	0.03	0.32

Mean Monthly Total Precipitation (mm):

$Prcp_{ttl}$		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	34.3	36.1	29.3	15.3	7.9	4.6	1.9	5.6	3.7	10.3	17.8	29.8	185.4
	Std Dev	48.2	54.8	40.4	31.3	18.5	17.1	6.5	25.9	8.5	16.6	29.4	42.3	216.2
51-80	Avg	18.3	17.6	16.6	12.1	5.4	7.2	3.4	10.4	2.6	4.5	6.5	18.3	123.1
	Std Dev	41.1	35.6	29.7	36.7	15.6	23.8	8.9	35.9	7.3	15.4	16.7	46.1	222.1
61-90	Avg	36.5	34.7	37.7	20.8	8.2	7.6	3.6	10.5	6.3	11.8	23.4	35.7	236.8
	Std Dev	44.5	46.5	43.8	39.6	16.7	23.7	8.8	35.8	11.0	17.1	33.5	49.3	231.2
71-00	Avg	58.9	63.1	51.9	27.0	14.8	9.6	3.7	11.7	7.3	15.8	33.8	51.3	331.0
	Std Dev	50.6	63.3	39.9	40.1	24.2	24.7	9.1	37.6	11.4	16.2	35.8	47.3	199.2
05-09	Avg	67.7	67.0	50.5	27.2	7.5	1.4	0.3	0.5	2.7	24.4	18.6	51.5	319.2
	Std Dev	51.2	35.9	52.3	27.5	14.6	2.1	0.7	0.6	3.6	29.4	11.9	28.9	75.6

$Prcp_{ttl}$	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	185.36	27.24	111.51	216.25	46762.25	704.85	0.00	704.85	54.46	5.80	57.98
51-80	123.06	40.05	0.00	219.39	48132.01	704.85	0.00	704.85	81.92	17.43	174.26
61-90	236.83	42.96	227.46	235.31	55368.65	704.85	0.00	704.85	87.86	14.71	147.13
71-00	330.96	37.52	328.55	205.52	42238.00	704.85	0.00	704.85	76.74	-5.05	-50.47
05-09	319.18	33.79	340.87	75.57	5710.20	182.12	198.37	380.49	93.83	-16.05	-160.53

***Precipitation amount measurements did not start at Moffett Field Until 1/1/1973.**

Monthly Number Fog Days:

Fog		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	11.6	7.7	4.1	3.0	2.4	1.9	4.7	5.5	5.9	7.3	9.1	11.6	70.6
	Std Dev	5.9	5.6	3.6	3.3	2.6	2.8	5.3	6.1	4.7	5.8	5.8	7.1	45.0
51-80	Avg	12.8	9.4	4.7	3.7	2.9	2.4	6.2	7.4	7.3	9.2	11.2	14.2	91.5
	Std Dev	3.9	5.2	2.7	3.5	3.0	3.1	5.5	7.0	4.2	5.6	4.5	5.0	28.9
61-90	Avg	14.0	9.2	5.5	3.0	2.5	2.5	4.9	5.5	6.9	8.5	11.0	14.9	88.4
	Std Dev	4.9	5.1	3.6	2.5	2.2	3.5	4.7	4.7	4.4	3.8	4.6	5.9	27.2
71-00	Avg	12.5	7.8	5.2	2.6	2.4	2.5	4.2	4.5	5.8	7.1	8.5	11.7	70.6
	Std Dev	6.1	5.5	4.0	2.6	2.2	3.6	4.9	4.7	5.1	5.0	5.9	7.5	45.2
05-09	Avg	2.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.8	1.8	7.6
	Std Dev	1.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.6	1.3	3.9

Fog	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	70.59	5.67	76.00	45.04	2028.47	164.00	0.00	164.00	11.34	-1.45	-14.50
51-80	91.47	5.28	87.00	28.94	837.36	108.00	48.00	156.00	10.81	-1.85	-18.46
61-90	88.40	4.84	83.00	26.49	701.70	116.00	48.00	164.00	9.89	1.57	15.69
71-00	70.57	8.12	74.50	44.50	1980.19	163.00	1.00	164.00	16.62	-3.12	-31.23
05-09	7.60	1.75	7.00	3.91	15.30	10.00	4.00	14.00	4.86	1.00	10.00

Monthly Number Rain Days:

Rain		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	10.9	10.5	10.7	6.8	4.3	1.6	0.7	1.0	2.0	4.6	8.4	10.2	67.5
	Std Dev	4.4	5.3	5.3	4.8	3.4	1.4	0.9	1.4	1.9	3.0	4.6	5.3	24.5
51-80	Avg	11.4	11.1	10.3	7.3	4.2	1.5	0.8	1.1	2.1	4.8	8.7	10.9	74.2
	Std Dev	4.1	4.7	4.1	4.9	3.4	1.5	0.9	1.6	1.9	3.3	4.6	5.4	10.0
61-90	Avg	10.5	10.3	11.4	7.5	3.9	1.5	0.9	1.2	2.6	4.9	9.9	11.5	76.1
	Std Dev	3.8	4.7	4.8	4.9	3.1	1.3	0.9	1.6	2.3	2.9	4.9	5.3	11.4
71-00	Avg	10.3	9.9	10.9	6.8	4.0	1.4	0.7	1.0	2.3	4.3	8.6	9.5	66.1
	Std Dev	4.6	5.5	5.9	4.0	3.9	1.3	1.0	1.5	2.1	3.1	5.2	5.5	27.5
05-09	Avg	12.0	12.6	10.2	8.0	4.2	1.6	0.2	0.4	0.8	3.8	6.6	11.6	72.0
	Std Dev	4.2	3.6	5.8	5.3	2.7	1.5	0.4	0.5	0.8	2.4	3.1	1.5	11.4

Rain	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	67.51	3.09	72.00	24.53	601.77	119.00	0.00	119.00	6.18	-0.49	-4.86
51-80	74.23	1.73	73.50	9.45	89.29	46.00	49.00	95.00	3.53	-0.24	-2.43
61-90	76.13	2.02	73.50	11.05	122.19	65.00	54.00	119.00	4.13	0.15	1.49
71-00	66.13	4.93	70.00	27.02	730.26	119.00	0.00	119.00	10.09	-1.32	-13.24
05-09	72.00	5.09	71.00	11.38	129.50	28.00	60.00	88.00	14.13	-4.20	-42.00

Monthly Number Snow Days:

Snow		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	Std Dev	0.4	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
51-80	Avg	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	Std Dev	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
61-90	Avg	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	Std Dev	0.5	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
71-00	Avg	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	Std Dev	0.3	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
05-09	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Snow	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	0.16	0.06	0.00	0.48	0.23	2.00	0.00	2.00	0.12	0.00	-0.02
51-80	0.23	0.10	0.00	0.57	0.32	2.00	0.00	2.00	0.21	0.00	0.00
61-90	0.27	0.12	0.00	0.64	0.41	2.00	0.00	2.00	0.24	0.00	0.00
71-00	0.20	0.10	0.00	0.55	0.30	2.00	0.00	2.00	0.21	-0.01	-0.15
05-09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Number Hail Days:

Hail		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	0.1	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	Std Dev	0.2	0.3	0.5	0.3	0.2	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.6
51-80	Avg	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	Std Dev	0.0	0.0	0.5	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7
61-90	Avg	0.0	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	Std Dev	0.2	0.4	0.6	0.4	0.3	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.7
71-00	Avg	0.1	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
	Std Dev	0.3	0.4	0.6	0.4	0.3	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.7
05-09	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Hail	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	0.46	0.08	0.00	0.64	0.41	2.00	0.00	2.00	0.16	0.00	-0.01
51-80	0.47	0.12	0.00	0.68	0.46	2.00	0.00	2.00	0.25	0.02	0.17
61-90	0.63	0.13	0.50	0.72	0.52	2.00	0.00	2.00	0.27	0.02	0.21
71-00	0.67	0.13	1.00	0.71	0.51	2.00	0.00	2.00	0.27	-0.02	-0.15
05-09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Number Thunder Days:

Thunder		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	0.3	0.4	0.4	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.2	2.7
	Std Dev	0.6	0.8	0.9	0.8	0.5	0.3	0.4	0.4	0.5	0.7	0.7	0.4	2.7
51-80	Avg	0.4	0.4	0.2	0.3	0.3	0.1	0.2	0.2	0.1	0.3	0.3	0.3	3.0
	Std Dev	0.8	0.8	0.6	1.0	0.6	0.3	0.5	0.4	0.3	0.9	0.8	0.5	2.6
61-90	Avg	0.5	0.5	0.5	0.4	0.2	0.1	0.2	0.3	0.2	0.5	0.4	0.2	4.1
	Std Dev	0.7	0.9	1.1	1.0	0.5	0.3	0.5	0.5	0.6	0.9	0.9	0.4	2.8
71-00	Avg	0.5	0.6	0.7	0.2	0.1	0.2	0.2	0.3	0.3	0.5	0.3	0.1	3.6
	Std Dev	0.7	0.8	1.2	0.8	0.5	0.4	0.4	0.5	0.6	0.9	0.7	0.4	2.9
05-09	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Thunder	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	2.65	0.34	2.00	2.68	7.20	11.00	0.00	11.00	0.68	-0.02	-0.15
51-80	3.03	0.48	3.00	2.65	7.00	8.00	0.00	8.00	0.99	0.15	1.51
61-90	4.07	0.51	3.50	2.79	7.79	11.00	0.00	11.00	1.04	0.10	0.97
71-00	3.63	0.52	3.50	2.85	8.10	11.00	0.00	11.00	1.06	-0.15	-1.52
05-09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Monthly Number Tornado Days:

Tornado		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
46-09	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
51-80	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
61-90	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71-00	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
05-09	Avg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Tornado	Mean	Standard Error	Median	Standard Deviation	Period Variance	Range	Minimum	Maximum	Confidence Level (95.0%)	Change Per Year	Change Per Decade
46-09	0.02	0.02	0.00	0.13	0.02	1.00	0.00	1.00	0.03	0.00	-0.01
51-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71-00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

B. Analysis of Weather and Climate Data at NASA Ames Research Center

Station Information:

Name	Moffett Federal Airfield
Country	United States
State	California
County	Santa Clara
Latitude	37.40583 (37°24'20.988" N)
Longitude	-122.04806 (122°02'53.016" W)
Elevation	11.9 meters (39 feet) above sea level
Type of Station	Land Surface ASOS ASOS-NWS
In Service	October 09, 1933 to Present
Climate Division	04- Central Coast Drainage
COOP Number	045747
FAA Location Identifier	NUQ
ICAO ID	KNUQ
NCDC Station ID Number	20002413
WBAN Number	23244
WMO Number	74509

Description:

The following parameters are evaluated: Mean Temperature, Maximum Temperature, Minimum Temperature, Dew Point Temperature, Sea Level Pressure, Wind Speed, Maximum Wind Speed, Precipitation Total, Fog Days, Rain Days, Snow Days, Hail Days, Thunder Days, and Tornado Days.

For each parameter the average and standard deviation for the following five periods were calculated: 1946 – 2009 (full record (63 years)), 1951- 1980 (30-year climatology period), 1961 – 1990 (30-year climatology period), 1971- 2000 (30-year climatology period), 2005 – 2009 (most recent five years). These include the values for each of the 12 calendar months and an annual value. Values are shown in the following tables.

A second set of annual parameters has also been calculated for each of these five periods. They include: Mean, Standard Error, Median, Standard Deviation, Period Variance, Range, Minimum, Maximum, Confidence Level (95.0%), Change Per Year, and Change Per Decade. Values are shown in the following tables.

Calculation Procedure:

The average of each monthly period was calculated from the "Global Summary of Day" retrieved from NOAA's NCDC page, for Moffett Federal Airfield.

For each month:

- Average for Mean Temperature, Maximum Temperature, Minimum Temperature, Dew Point Temperature, Sea Level Pressure, Wind Speed, and Maximum Wind Speed.
- Sum for Precipitation Total.
- Count of occurrence for Fog Days, Rain Days, Snow Days, Hail Days, Thunder Days, and Tornado Days.

The yearly value was calculated by averaging the monthly results for all parameters except for precipitation total, fog days, rain days, snow days, hail days, thunder days and tornado days. For these parameters, the sum was taken of the monthly values.

The normal values are calculated by adding the yearly values for the appropriate month and then diving by the number of years in that period.

The additional annual parameters were calculated from the yearly values of each parameter using Microsoft Office 2007 Excel's "Descriptive Statistics Function".

The entire data record was used for the calculations and there were no adjustments made to the temperature data to account for urban heat island effect.

Abbreviations:

Avg = Mean of parameter for all months (or annual values) for the period.
Std Dev = Standard Deviation for all months (or annual values) for the period.
46-09 = 1946 through 2009 Full Period of Available Record
51-80 = 1951 through 1980 Climate Period
61-90 = 1961 through 1990 Climate Period
71-00 = 1971 though 2000 Climate Period
05-09 = 2005 though 2009 Most Recent Five Year

Gaps in record and description:

Period	Description
Oct 1933 to Feb 1945	No Digital Record Available
Mar 1945	Incomplete Digital Daily Record for Month
Oct 1958	Incomplete Digital Daily Record for Month
Jul 1994	Incomplete Digital Daily Record for Month
Aug 1994 to Jan 1995	No Digital Record Available
Feb 1995 to May 1995	Incomplete Digital Daily Record for Month
Aug 1995 to Oct 1995	Incomplete Digital Daily Record for Month
Dec 1995 to May 1996	Incomplete Digital Daily Record for Month
Jun 1996	No Digital Record Available
Sep 1999 to Oct 1999	Incomplete Digital Daily Record for Month
Nov 1999 to Oct 2000	No Digital Record Available
Nov 2000 to Dec 200	Incomplete Digital Daily Record for Month
Jan 2001 to May 2002	No Digital Record Available
Jun 2002	Incomplete Digital Daily Record for Month
Jul 2002 to Feb 2003	No Digital Record Available
Mar 2003	Incomplete Digital Daily Record for Month
Apr 2003 to May 2003	No Digital Record Available
Jun 2003	Incomplete Digital Daily Record for Month
Jul 2003 to Nov 2003	No Digital Record Available
Dec 2003	Incomplete Digital Daily Record for Month
Jan 2004	No Digital Record Available
Feb 2004	Incomplete Digital Daily Record for Month
Mar 2004	No Digital Record Available
Apr 2004	Incomplete Digital Daily Record for Month
May 2004 to Jul 2004	No Digital Record Available
Aug 2004	Incomplete Digital Daily Record for Month
Aug 2005	Incomplete Digital Daily Record for Month
Aug 2006	Incomplete Digital Daily Record for Month
Feb 2008	Incomplete Digital Daily Record for Month
Aug 2008	Incomplete Digital Daily Record for Month