Drought Management Using Cloud Seeding

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Abstract

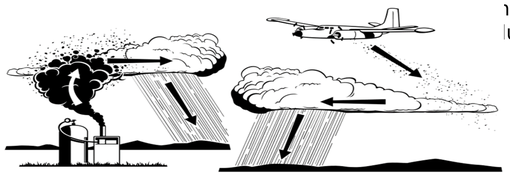
Cloud seeding is the method by which dry ice or silver iodide aerosols are distributed into clouds to form precipitation. The goal of this project is to lessen the impact of drought in California by examining and analyzing cloud data to predict when and where cloud seeding will be most effective. Cloud data from January and July 2009 was used to analyze cloud properties including cloud fraction, optical thickness, cloud effective radius, cloud top pressure, and cloud top temperature. This data was retrieved from the Terra and Aqua satellites. Both of these satellites have an instrument called MODIS that measures cloud properties. Using the satellite data, the software ENVI was then used to georeference the data. After georeferencing the data, a set of parameters were used to find the best areas for cloud seeding. Then, using precipitation data collected by weather stations, the possible precipitation increase and the effectiveness of cloud seeding was calculated. To determine if cloud seeding is a feasible form of weather modification is needed. Cloud seeding is a method that changes the amount of precipitation that falls from the clouds. By dispersing chemicals into clouds, it enhances the cloud's ability to produce precipitation. Cloud seeding began in the late 1940s when it was discovered that dry ice could be used to transform supercooled water droplets to ice crystals.

Cloud seeding can be conducted by means of aircrafts or ground based generators. Aircrafts disperse cloud seeding agents at the base or at the top of the cloud. Seeding from the ground is especially useful for treating low-level clouds over complex terrain.

This method requires chemical materials to disperse into the cloud for processing cloud condensation process. These materials include silver iodine, potassium iodine, dry ice (solid carbon dioxide) and liquid propane.

Droughts have posed serious problems around the whole world. With difficulties with lack of water resources, droughts have brought about damages to agriculture and economy in many countries. Recently, many media outlets have reported on the California Drought. California is a state located on the west coast of the United States and has been the most populous state with 38 millions residents. However, this third largest state by area in the United States has been in an environmental crisis. The state of California is currently in its fourth year of one the most severe droughts ever recorded. This high impact drought has brought about water shortages and caused humongous damages to agriculture and the economy. As a result, California is now in a state of emergency. Therefore, California is a prime candidate for cloud seeding and the focus of this study.

Our goal is to increase the amount of precipitation through cloud seeding in order to prevent those problems from droughts. **Our** [illegible] at are fitting for cloud [illegible] ume and effectiveness



Tools for cloud seeding
Left: ground generator
Right: air craft

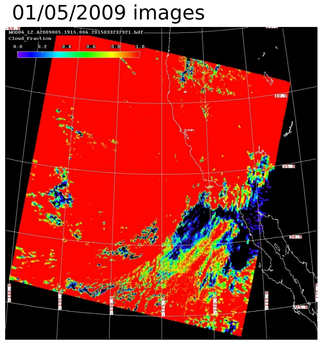
Material and Methods

The source of the data used in this study was the NASA LAADS database. The data was obtained by ordering it through the site. By using this database, parameters such as the longitude and latitude of the desired area, satellite and instrument, the group and products of the instruments, the range for the data and time, and collection were used. The coordinates for California used in this project were 42 North, 32 South, -126 West and -114 East. The satellites and instruments used were Terra MODIS and Aqua MODIS. The groups used were Terra Atmosphere Level 2 Products and Aqua Atmosphere Level 2 Products. For both of these satellites, only the cloud products were used. The ranges for the date and time were 01/01/2009 00:00:00 to 01/31/2009 23:59:59 and 07/01/2009 00:00:00 to 07/31/2009 23:59:59. In this study only the cloud data from the daytime hours retrieved from the satellites were used since cloud seeding can be very difficult when performed at night time. These satellites record data for each day during the daytime at 2 to 4 different times. With all of these parameters in place, the data could then be downloaded from the database in HDF format.

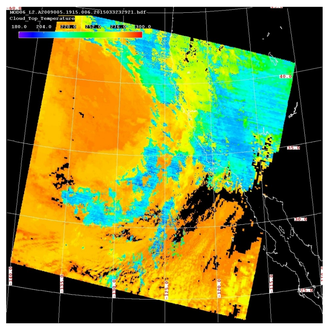
With such large amounts of data obtained from satellites, the data was filtered by examining the cloud cover of California as a whole. The data was narrowed down to the January 5th, 6th and 22nd, and July 11th, 19th, 27th and 29th.

Data

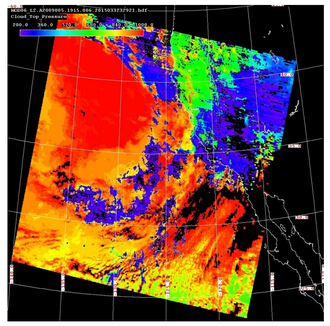
01/05/2009 images



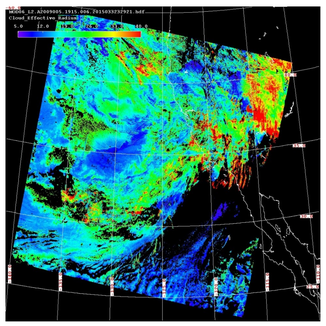
Cloud Fraction



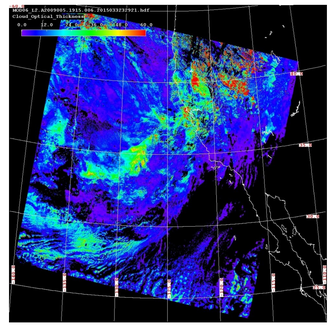
Cloud Top Temperature



Cloud Top Pressure



Cloud Effective Radius

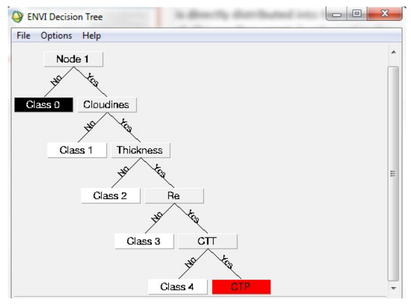


Cloud Optical Thickness

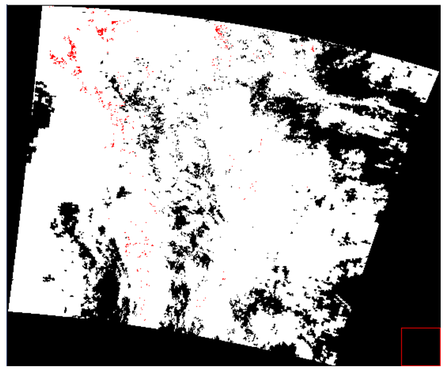
In this study only the cloud data from the daytime hours retrieved from the satellites were used since cloud seeding can be very difficult when performed at night time. These satellites record data for each day during the daytime at 2 to 4 different times. With all of these parameters in place, the data could then be downloaded from the database in HDF format.

In order to find the best areas for cloud seeding, a decision tree was used. The following criterion were set for each of the cloud properties: Cloud fraction must be greater than 0.7. The optical thickness should be greater than 40. The cloud effective radius must be greater than 12 microns. Cloud top temperature must be less than 263 Kelvin. Cloud top pressure must be greater than 500 hPa. After implementing the decision tree, the areas that met the criteria were calculated in pixels. Since MODIS has a resolution of 1 km, the area in kilometers was calculated.

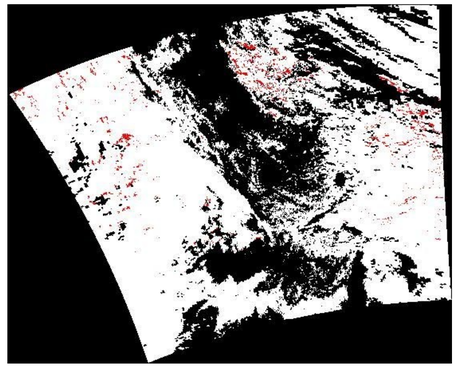
There are in total of 235 stations in California that collect precipitation data.



Decision Tree
Cloudiness: Cloud Fraction Re: Cloud Effective Radius
Thickness: Cloud optical thickness CTT: Cloud top temperature CTP: Cloud top pressure



Terra (01/22/2009 10:20AM)
The blue areas are the fitted area for doing cloud seeding



Aqua (01/05/2009 12:55 PM)
Blue areas represent best areas for cloud seeding

Results and Conclusion

Effectiveness of Cloud Seeding

Satellite	*Date*	*Time*	*Area(km²)*	*Precipitation before Cloud Seeding(mm)*	*Precipitation After Cloud Seeding(mm)*	*Volume before (m³)*	*Volume after (m³)*	*Difference in Volume (m³)*	*Difference in Volume (m³)*
Terra	*01/05/2009*	*11:15 AM*	*10640*	*1*	*1.13*	*10640000*	*12023000*	*1383000*	*1383000*
Aqua	*01/05/2009*	*12:55 PM*	*21862*	*0.5*	*0.565*	*10931000*	*12352000*	*1421000*	*1421000*
Terra	*01/06/2009*	*10:20 AM*	*4498*	*3.6*	*4.068*	*16193000*	*18297900*	*2105000*	*2105000*
Aqua	*01/06/2009*	*12:00 PM*	*1692*	*2.4*	*2.712*	*4068000*	*4588700*	*521000*	*521000*
Terra	*01/22/2009*	*10:20 AM*	*17973*	*18.2*	*20.566*	*327109000*	*379633000*	*173972000*	*52524000*
Aqua	*01/22/2009*	*13:40 PM*	*30761*	*16.275*	*18.3907*	*50063500*	*56571700*	*65082000*	*65082000*

Date	*Area(km²)*	*Rain before Cloud Seeding(mm)*	*Rain After Cloud Seeding(mm)*	*Volume before (m³)*	*Volume after (m³)*	*Difference in Volume (m³)*	*Difference in Volume (m³)*
01/05/2009	*32502*	*1.5*	*1.695*	*21571000*	*24375000*	*2804000*	*2804000*
01/06/2009	*6190*	*6*	*6.78*	*20261000*	*22886600*	*2626000*	*2626000*
01/22/2009	*48734*	*34.475*	*38.9567*	*827740000*	*945350000*	*117610000*	*117606000*

Conclusion:

Cloud seeding can significantly increase the amount of precipitation in an area. In the month of January, three days were good for cloud seeding. For all of the days the total increase in the volume of precipitation was greater than 2,000,000 m^3 . This shows that cloud seeding can be effective in January. However, this was not the case for the month of July. Although there were sufficient areas for cloud seeding, the weather stations recorded no precipitation for the selected days. Therefore, measuring the effectiveness of the cloud seeding could not be done on those days.

For further research, different methods can be developed in order to perform cloud seeding on clouds that do not produce any precipitation. In the July data, they reveal that California does not have precipitation and there are less areas that are able to process cloud seeding during the summer time. Moreover, other months can be examined to see if there are clouds that are fit for cloud seeding. By examining the clouds during different volumes, the quality of clouds during different seasons can also be assessed. This will then aid in managing and lessening the impacts of drought.

Acknowledgements
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