NAURU ISLAND CLOUD TRAILS

A STUDY IN ISLAND EFFECTS

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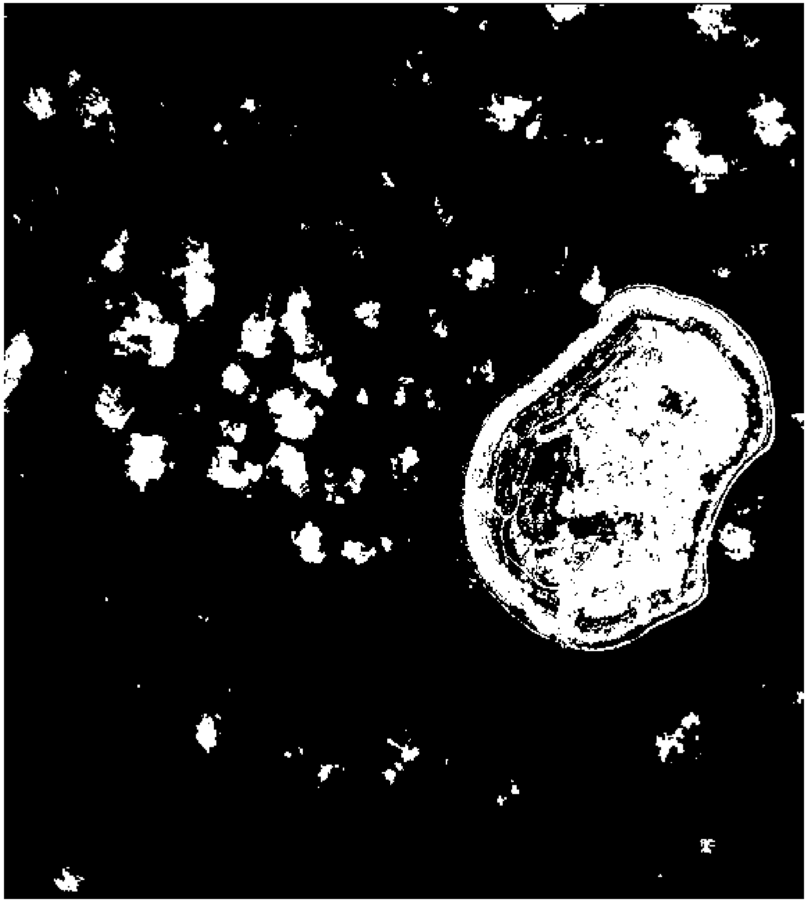
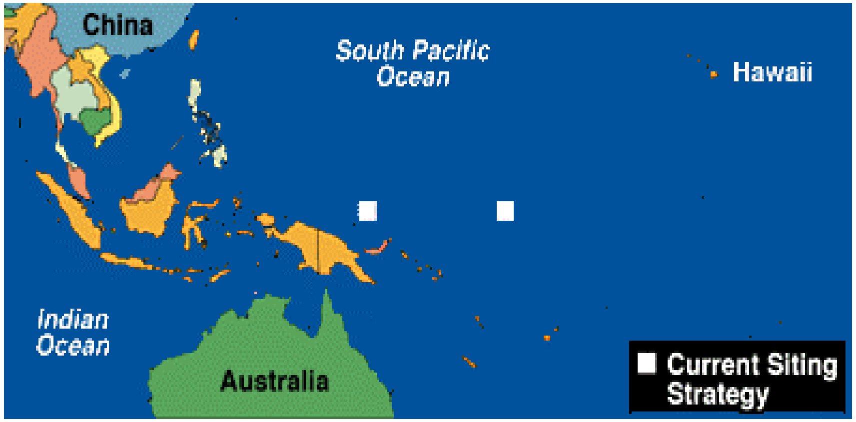
BACKGROUND

THE ISLAND OF NAURU



- Latitude:0.521°S, Longitude: 166.916°E
- The island of Nauru (right), which is the world's smallest republic, is located in the western South Pacific approximately 1,200 miles northwest of Papua, New Guinea.
- More than 10,000 people live on the island, which is 8.2 square miles in size.



NAURU99

Nauru99 was an international research collaboration conducted on and around the island of Nauru in the Tropical Western Pacific during the summer of 1999 from June 16 through July 15, 1999.

The aim of Nauru99 was to improve our understanding of radiant heat transfer and the effects of clouds on ocean weather processes in the tropics through land-, air- and ocean-based measurements.

THE ROLE OF CLOUDS & HOW THEY AFFECT THE ENERGY BUDGET

The role of clouds and water vapor in climate change is not well understood; yet water vapor is the largest greenhouse gas and directly affects cloud cover and the propagation of radiant energy.

Water vapor is not the only form of water in the atmosphere. Water vapor is present as a solid and liquid in clouds, and the effects of clouds are major factors in determining the potential for global climate change.

Modeling the impact of clouds is difficult because of their complex and differing effects of weather and climate. Clouds can reflect incoming sunlight and, therefore, contribute to cooling. But they also absorb infrared radiation leaving the earth and contribute to warming. High cirrus clouds, for example, may have the impact of warming the atmosphere. Low-lying stratus clouds, which are frequently found over oceans can contribute to cooling. In order to successfully model and predict climate we must be able to both describe the effect of clouds in the current climate and predict the complex chain of events that might modify the distribution and properties of clouds in an altered climate.

All classes of boundary layer clouds shade the surface. Over a land surface this results in a negative feedback because less solar heating of the ground will trigger fewer or weaker thermals and will cause the mixed layer to grow more slowly, resulting in fewer new cumulus clouds being triggered. Thus on days over land where solar heating is the primary driving force for free convection (rather than cold air convection, ground thermal inertia, or forced mechanical convection), fair-weather cumulus clouds will tend to reach an equilibrium cloud cover that is scattered or broken but not overcast.

PAST ISLAND CLOUD TRAILS RESEARCH

- Cloud formation studies in the past have emphasized aerosol effects, while cloud dynamic aspects have been largely ignored. This is due to the subtle boundary layer cloud perturbations that may trigger clouds and the difficulty in measuring these perturbations. Innis et al. (1998, manuscript submitted to *J. Atmos. Sci.*) calculate that temperature differences as small as 0.1°C can increase cloud-level aerosol concentrations by over a factor of two in decoupled boundary layer conditions.
- In their study of ship-tracks observed during the Monterey Area Ship Tracks (MAST) experiment, Porch et al. (1998, *J. Applied Meteorology*) concluded that cloud dynamics may often be an important component of ship-track features.
- Like ships, islands also influence the dynamics of the clouds above.
- In his study of cloud trails over Guadalupe island, Dorman (1994, *Monthly Weather Review*) observed that during times of a high inversion, 575 meters above the top of Guadalupe, the cloud trails appeared. Later, when the inversion was brought down below the peak height of the island, the trails disappeared. Dorman concluded two concepts important to island trails: ‘the cloud trail must have occurred near the inversion base as there is too much turbulent mixing below and too little moisture above,’ and that ‘simple advection does not explain the development of the cloud trail downwind of Guadalupe Island.’

DATA & MEASUREMENTS

• Balloon-Borne Sounding System

- The BBSS provides in situ measurements, vertical profiles, up to approximately 30km. This instrument measures and calculates pressure temperature, relative humidity, wind speed and direction, altitude, dew point temperature, ascent rate, latitude, longitude and the u,v-components of wind velocity
- From this data I have calculated the following to attempt to distinguish a difference in boundary layer structures on days with and without cloud trails.

1. θ - Potential Temperature
2. LCL - Lifting Condensation Level
3. *e* - Vapor Pressure
4. *es* - Vapor Pressure
5. *r* - Mixing Ratio
6. *rs* - Saturation Mixing Ratio
7. θe - Equivalent Potential Temperature

$$\theta(\ C) = T * \left(\frac{P_{SURF}}{P}\right)^{\frac{2}{7}}$$

$$T_{LCL}(\ C) = T_d * (0.001296 * T_d + 0.1963) * (T - T_d)$$

$$P_{LCL}(mb) = P_{SURF} * \left(\frac{T_{LCL} + 273.15}{\theta}\right)^{\frac{2}{7}}$$

$$H_{LCL}(km) = \frac{T_{SURF} - T_{LCL}}{9.71(\ C/km)}$$

$$e_s = 6.1078 * e^{\frac{17.2694*T}{T+273.15-35.86}}$$

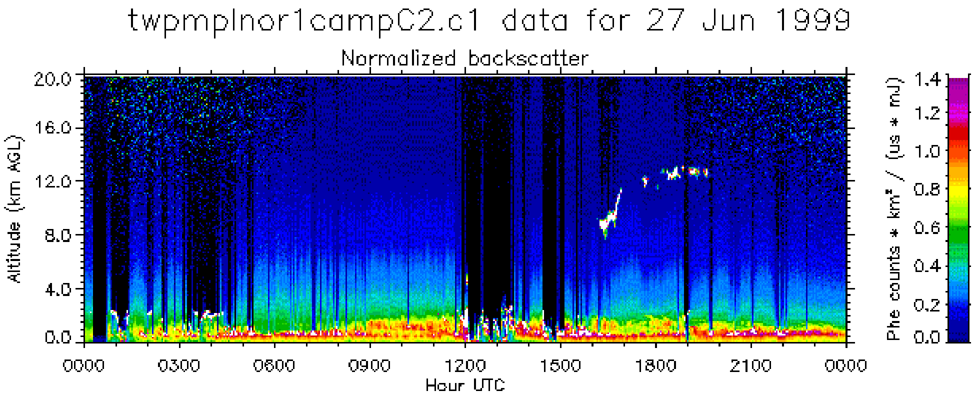
$$e = \frac{rh * e_s}{100}$$

$$r_s(g/kg) = 622 * \left(\frac{e_s}{P - e_s}\right)$$

$$r(g/kg) = \frac{rh * r_s}{100}$$

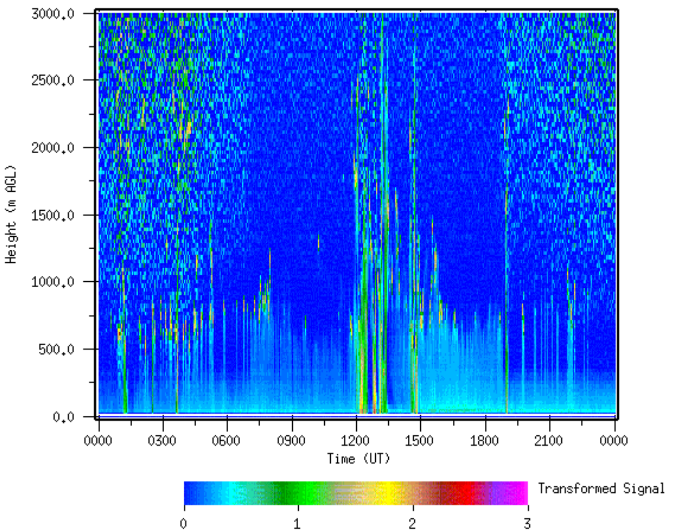
$$\theta_e(K) = T_K * \left(\frac{P_{SURF}}{P}\right)^{0.2854(1-0.28*10^{-3} r)} * e^{\left(\frac{3.376}{T_{LCL}} - 0.00254\right) * r(1+0.81*10^{-3} r)}$$

- # Micropulse Lidar
  - The MPL is a ground-based optical remote sensing system designed primarily to determine the altitude of clouds overhead. Besides real-time detection of clouds, post-processing can also characterize the extent of the tropospheric mixing layer, or other particle-laden regions.



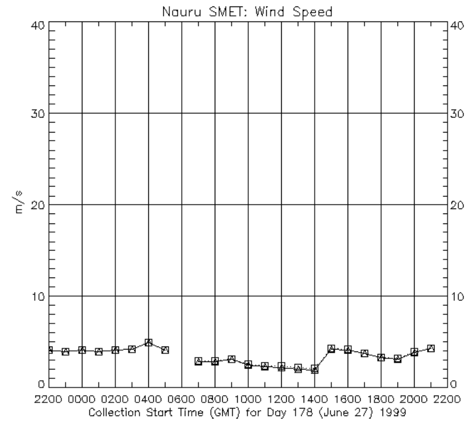
MPL data showing the backscatter for June 27,1999

- # Vaisala Ceilometer
  - The VCEIL is a ground based, remote sensing device to measure cloud base height at up to three levels and potentially backscatter signals by aerosols. It transmits near-infrared pulses of light and the receiver telescope detects the light scattered back by clouds and precipitation.



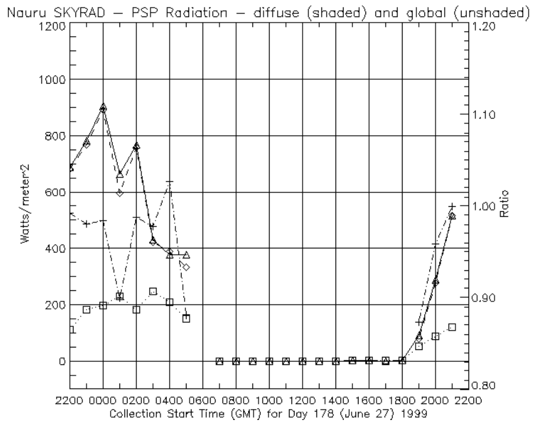
VCEIL data showing clouds and precipitation on June 27, 1999

- Surface Meteorology Station
  - The SMET uses mainly conventional in situ sensors to obtain 1-minute statistics of surface wind speed, wind direction, air temperature, barometric pressure, and rain-rate.



SMET Wind Speed data for June 27, 1999

- Pyranometer
  - The Precision Spectral Pyranometer, PSP, measures broadband solar irradiance, direct, global and diffuse, on a planar surface.



Global PSP (+) data for June 27, 1999

RESULTS

WIND SPEED

Dorman concluded that advection by wind could not account for the cloud trails downwind of Guadalupe Island on those days of his study

There is no correlation between the presence of island cloud trails and surface wind speed.

- Wind speed comparisons of SMET data taken at the surface (10 m) suggest otherwise. Of the 11 cases where no cloud trails were formed, there were 8 days where recorded surface wind speeds were 3 m/s or slower. Thus, there is likely a correlation between wind speed and cloud trail formation.

HIGH CLOUDS

Comparing MPL data for days when there are and are not cloud trails, there was a significant presence of high clouds on day where no cloud trails were detected by satellite.

When high clouds are present - not allowing the surface to warm, cloud trails will not form.

- On 9 of the 11 “no cloud trail” days, high clouds were present.
- On the other hand, on 13 of the 30 “cloud trail” days, high clouds were also present.
- Thus, it is better to say that when cloud trails are not present it is *most likely* due to the appearance of high clouds.

PSP

It is insufficient to claim that high clouds prevent the formation of cloud trails since on 13 of the 30 “cloud trail” days, high clouds are present. One possible reason cloud trails form during days when high clouds are present may be because the surface warms enough by diffuse and reflected sunlight to produce thermal convection. The PSP global measurement is a useful tool for this comparison.

A warming of the earth’s surface, via other means than by direct sunlight, will produce significant thermals and thus cause the formation of a cloud trail.

- It is a necessary but not sufficient condition to conclude that cloud trails form only when mean PSP is greater than 500 W/m^2
- There is no trend in mean PSP, alone, that impedes cloud trail formation.

BOUNDARY LAYER DEPTH

In their study of ship tracks off the California Coast, Porch et al. concluded that ship tracks seem to occur only within a relatively narrow range of boundary layer depths (about 0-600 m).

A conflicting conclusion was determined by Dorman. He described Guadalupe Island Cloud Trails forming when the inversion base was lifted high above the island, cloud trails disappeared when the inversion dropped below the peak height of the island.

Island induced cloud trails will form only when there is a shallow boundary layer depth, 600 meters or less.

- There is no trend associated with boundary layer depth and the formation of island cloud trails.

CONCLUSION

- High wind speeds coupled with high PSP measurements will most likely produce a cloud trail.
- The plot of mean PSP vs. Wind Speed also indicates that low wind speeds and low PSP are two conditions that most likely impede the formation of a cloud trail.
- Since the presence of cloud trails indicates a relationship to the warming and cooling of the surface, an anomaly in the structure of the boundary layer on “no cloud trail” days should b observed.

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QUESTIONS TO CONSIDER/FUTURE WORK

- Although in this project I am only considering dynamic aspects of cloud formation, their formation may also be influenced by aerosol effects. Therefore, a question to consider. Would a desert island without human life, industry or vegetation produce the same island trail phenomena?

- Consider water vapor structure in the atmosphere, keeping in mind that the atmosphere mixes vertically. Since water vapor is the element that allows clouds to form, if there is little or no water vapor at the top of the cloud environment, all air that will potentially be mixed in will be dry air thus preventing cloud formation. Therefore, a question to consider. Is there a noticeable difference in water vapor content above the mixed layer between days when there are and are not cloud trails?

- During Nauru99, in addition to island based measurement, there were also measurements taken from buoys and two ships, the Japanese Ship Mirai and the NOAA Ship Ron Brown, forming a triangular pattern. Sea Surface Temperatures (SSTs) were recorded. Is there an anomaly is SSTs that could help to explain cloud trail formation?

ISLAND INDUCED CLOUD TRAIL OBSERVED ON THE LEE SIDE OF THE ISLAND DURING NAURU99

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