TP-80-23
5 September 1980

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Point Mugu, California 93042

DISCRIMINANT ANALYSIS OF DIURNAL OSCILLATION OF STRATUS OVER SOUTHERN CALIFORNIA (AIRTASK A370-370G/076B/OF59-551-792 (NEPRF))

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SUMMARY

Previously established diurnal properties of marine stratus observed from geostationary satellite imagery were examined in an attempt to statistically relate satellite-observed features to ground-truth meteorological parameters. Using 7-day-a-week upper air observations from Los Angeles near the center of the Southern California Bight, attempts were made to perform correlation, regression, and discriminant analyses between marine stratus margins and sounding-derived parameters. In general, it was found that satellite features could be related to ground-truth parameters from a single station with difficulty. Morning sounding parameters failed to provide a satisfactory degree of accuracy for determining stratus locations unless the stratus is divided into inland and offshore categories. A moderate degree of accuracy was observed in discriminating those days with diurnal stratus dissipation from those days with no diurnal burnoff of low clouds.

Publication UNCLASSIFIED.

INTRODUCTION

The widespread occurrence of stratus over the eastern Pacific Ocean and along the California coast is most pronounced during the warm months, May through September. The landward edge of this stratus is subject to diurnal formation and dissipation with inland advances at night and in the early morning, and seaward retreats in the afternoon. This phenomenon can be detected and is especially amenable to study using GOES daytime imagery produced at 30-minute intervals.

Many efforts have been made to investigate the causes of this diurnal oscillation in stratus. Neiburger, et al, (1945) attributed the daytime dissipation of the low clouds to subsidence associated with divergence in the sea breeze circulation. Simon (1977) noted that daytime insolation promotes stratus burnoff while radiational cooling from cloud tops favors stratus formation at night. It was also observed that the seaward extent of the diurnal burn-off is greater over the Southern California Bight than over adjacent ocean and coastal areas further north and south. In addition to the previously described factors, this latitudinal dependence may also be attributable in part to the warm waters within the southern California area and to the warm return flow aloft associated with land-heated sea breezes moving inland (Rosenthal and Posson, 1977). Lee (1979) quantitatively determined the bounds of stratus margins along the California coast and found that inland penetration in morning is limited by the 600-meter contour. Because low ceilings and visibilities are significant limiting factors in the conduct of southern California coastal Navy operations, it is useful to determine whether some of the features in stratus patterns can be predicted from a knowledge of conventional synoptic parameters. This study attempts to relate the dirunal oscillation of stratus to selected weather variables observed at a nearby coastal station. Since 7-day-a-week upper air observations were desired for this study, Los Angeles International Airport, near the center of the Southern California Bight, was selected as the coastal station. Using data from this station, an attempt was made to perform the following:

1. Correlation analysis of the dirunal range of stratus and weather variables.

2. Regression analysis of the location of stratus using parameters from the morning sounding as independent variables.

3. Discriminant analysis of the diurnal range of stratus using parameters from the morning sounding as discriminating variables.

4. Study of the relationship between oxidant concentrations and the diurnal extent of stratus over southern California because aerosols and pollutants are important factors in the performance of Navy electro-optical systems.

APPROACH

In order to simplify the selection of stratus margin parameters on which to perform statistical analysis, the stratus boundaries at 1515Z and 2315Z were determined by Lee's method, but only for latitude 34°N (near Los Angeles International Airport). The regression and discriminant analyses were then carried out using the computer program library (Nie, 1975) available at California State University, Northridge. The study period selected extends from 1 June to 10 September 1977. Independent variables used for this study include:

1. TSFC: Ground surface temperature (°C).

2. T950MB: 950-mb temperature (°C).

3. T850MB: 850-mb temperature (°C).

4. TINVB: Inversion base temperature (°C).

5. HTINVB: Height of the inversion base (feet).

6. HTINVTO: Height of the inversion top (feet).

7. INVMAG: Inversion magnitude (defined as the temperature difference between the inversion top and base, ^{o}C).

8. TINBRK: Inversion breaking temperature (^{o}F) (that surface temperature required for adequate mixing to destroy the inversion structure).

9. DP: Dewpoint temperature (^{o}C).

10. PG: Pressue difference (mb) between Los Angeles International Airport and Lancaster (a station well inland from the coast).

11. HTMAX: Maximum mixing height (in hundreds of feet).

These variables were selected from the Los Angeles International Airport morning sounding at 0600 PST with the exception of PG, which is an index of the strength of the onshore gradient flow. In addition, HTMAX was calculated, based on the surface temperature observed at the Los Angeles Civic Center, approximately 15 miles inland from the coast.

It should be pointed out that selection of inversion-related parameters involved subjective interpretation, thus, the basis for identifying the inversion may not always have been identical. For instance, in the event that isothermal conditions on the airport soundings existed adjacent to the bottom or top of the inversion layer, the inversion base was usually defined by South Coast Air Quality Management District (SCAQMD) analysts as the lowest height of the coldest temperature, and the inversion top was defined as the highest height of the warmest temperature.

In general, SCAQMD analysts compiled data for the lowest inversion layer when more than one was present on the same sounding. However, for those intermittent, surface-based inversions which formed beneath a major time-persistent inversion layer, subjective interpretation and careful analysis usually selected the major feature of continuity as the lowest inversion. Deviations from such practices may have introduced some errors or uncertainty to the results.

DISCUSSION

Table 1 presents correlation coefficients between weather variables and stratus margin locations for both morning (NAM) and afternoon (NPM). It appears that temperature at the inverison base and top, and at the 950-mb level, have a moderate correlation (0.4 to 0.5) with the morning location of the stratus edge. However, correlation coefficients between afternoon location of the stratus edge and the morning sounding parameters are very low. Regression analysis indicates that about 36 percent of the variation in the morning location and 32 percent of the variation in the afternoon location of stratus margins can be accounted for by the sounding-derived weather variables.

Discriminant analysis was employed to separate those days with stratus penetrating inland from those days where the stratus edge remained along the coast or offshore. This analysis was performed for both morning and afternoon stratus conditions. During the study period, a total of 47 days were found with stratus penetrating inland, and 55 days were found without inland penetration in the morning. On the average, those occurrences of morning stratus penetration past the coastline were found to be accompanied by relatively cool air, as evidenced by lower temperatures at 950 mb, 850 mb, and at the inversion base (table 2). The maximum mixing height and the height of the inversion base and top are higher in the morning when stratus extends across the coastline than when the stratus margin remains at sea or is absent. Inland stratus penetration is also associated with a stronger onshore flow, as reflected by the larger mean value of PG. Standardized discriminant function coefficients indicate that the inversion breaking temperature and 850-mb temperature are the two most significant variables in separating days with

Table 1. Correlation Coefficients Between LAX Morning Sounding Parameters and Stratus Margins in Morning (NAM) and Afternoon (NPM); and Summary of Regression Analysis With NAM and NPM as Dependent Variables

CORRELATION COEFFICIENTS

A value of 99.000 is printed if a coefficient cannot be computed.

	TSFC	T950MB	T850MB	TINVB	HTINVB	HTINVTO	INVMAG	TINBRK	DP	PG	HTMAX	NAM
TSFC	1.00000	0.35659	0.36710	0.53267	-0.14305	-0.23320	-0.06356	0.24439	0.78358	-0.41992	-0.19746	0.17356
T950MB	0.35659	1.00000	0.62818	0.75449	-0.74568	-0.58727	0.26947	0.31896	0.59200	-0.70331	-0.73135	0.43945
T850MB	0.36710	0.62818	1.00000	0.67499	-0.60081	-0.25145	0.62061	0.78063	0.56256	-0.47894	-0.74490	0.25222
TINVB	0.53267	0.75449	0.67499	1.00000	-0.83454	-0.55778	0.01660	0.35795	0.76513	-0.60765	-0.64069	0.51495
HTINVB	-0.14305	-0.74568	-0.60081	-0.83454	1.00000	0.63456	-0.17608	-0.25771	-0.45019	0.52383	0.69758	-0.49218
HTINVTO	-0.23320	-0.58727	-0.25145	-0.55778	0.63456	1.00000	-0.12100	0.28383	-0.41563	0.51397	0.51950	-0.32718
INVMAG	-0.06356	0.26947	0.62061	0.01660	-0.17608	-0.12100	1.00000	0.54903	0.05673	-0.26081	-0.51284	-0.09712
TINBRK	0.24439	0.31896	0.78063	0.35795	-0.25771	0.28383	0.54903	1.00000	0.37066	-0.21359	-0.41388	0.01807
OP	0.78358	0.59200	0.56256	0.76513	-0.45019	-0.41563	0.05673	0.37066	1.00000	-0.60536	-0.47591	0.27198
PG	-0.41992	-0.70331	-0.47894	-0.60765	0.52383	0.51397	-0.26081	-0.21359	-0.60536	1.00000	0.58298	-0.24672
HTMAX	-0.19746	-0.73135	-0.74490	-0.64069	0.69758	0.51950	-0.51284	-0.41388	-0.47591	0.58298	1.00000	-0.29558
NAM	0.17356	0.43945	0.25222	0.51495	-0.49218	-0.32718	-0.09712	0.01807	0.27198	-0.24672	-0.29558	1.00000
NPM	0.08120	0.09564	-0.14392	-0.03098	-0.10754	-0.09961	-0.09339	-0.20977	-0.10629	-0.02336	0.02762	0.23681

	NPM
TSFC	0.08120
T950MB	0.09564
T850MB	-0.14392
TINVB	-0.03098
HTINVB	-0.10754
HTINVTO	-0.09961
INVMAG	-0.09339
TINBRK	-0.20977
DP	-0.10629
PG	-0.02336
HTMAX	0.02762
NAM	0.23681
NPM	1.00000

Dependent Variable NAM

Variable	Multiple R	R Square	RSQ Change	Simple R
TINVB	0.51495	0.26518	0.26518	0.51495
DP	0.54872	0.30110	0.03592	0.27198
TINBRK	0.56873	0.32345	0.02235	0.01807
T950MB	0.57673	0.33262	0.00917	0.43945
HTINVTO	0.58931	0.34729	0.01467	-0.32718
PG	0.59533	0.35442	0.00713	-0.24672
INVMAG	0.60039	0.36047	0.00605	-0.09712
HTMAX	0.60142	0.36170	0.00123	-0.29558
HTINVB	0.60229	0.36275	0.00105	-0.49218
T850MB	0.60305	0.36367	0.00092	0.25222
TSFC	0.60325	0.36391	0.00024	0.17356
(CONSTANT)				

Dependent Variable NPM

Summary Table

Variable	Multiple R	R Square	RSQ Change
TINBRK	0.20977	0.04400	0.04400
T950MB	0.27095	0.07341	0.02941
DP	0.30777	0.09473	0.02131
TSFC	0.43219	0.18679	0.09206
HTINVB	0.46460	0.21585	0.02906
TINVB	0.52750	0.27825	0.06240
HTINVTO	0.56107	0.31480	0.03655
T850MB	0.56175	0.31556	0.00076
INVMAG	0.56239	0.31628	0.00072
PG	0.56260	0.31652	0.00024
(CONSTANT)			

Table 2. Summary of Discriminant Analysis of Inland Stratus Penetration (Group 1) Against Offshore (or Along Coast) Stratus (Group 0) in Morning

Means

	Group 0	Group 1	Total
TSFC	17.6327	17.7511	17.6873
T950MB	19.6364	16.0851	18.0000
T850MB	21.6109	20.2000	20.9608
TINVB	15.5655	13.3426	14.5412
HTINVB	1139.5273	1940.7447	1508.7157
HTINVTO	3215.9455	3908.2553	3534.9510
INVMAG	8.4236	8.4319	8.4275
TINBRK	91.0545	91.7447	91.3725
DP	61.8545	60.3617	60.7353
PG	1.0964	1.8574	1.4471
HTMAX	24.9091	28.0638	26.3627

Classification Function Coefficients

	Group 0	Group 1
TSFC	2.73666	2.98438
T950MB	0.49658	0.29126
T850MB	-7.61428	-8.12817
HTINVB	0.01045	0.01153
HTINVTO	-0.02062	-0.02130
TINBRK	6.37350	6.67049
HTMAX	1.56466	1.46101
CONSTANT	-229.17685	-242.78638
CANONICAL CORRELATION	0.555	
WILKS' LAMBDA	0.6921	

Standard Deviations

	Group 0	Group 1	Total
TSFC	1.7756	2.1369	1.9414
T950MB	4.4453	4.4877	4.7856
T850MB	2.9760	3.9177	3.4964
TINVB	2.3526	3.7014	3.2309
HTINVB	694.0451	1006.6796	938.1745
HTINVTO	1044.4839	1079.6575	1111.0529
INVMAG	3.0677	2.6206	2.8564
TINBRK	7.2070	7.2336	7.1917
DP	2.5416	3.1857	2.8630
PG	1.4775	1.4841	1.5217
HTMAX	5.4849	7.4932	6.6449

Standardized Discriminant Function Coefficients

	Function 1
TSFC	-0.30351
T950MB	0.62007
T850MB	1.13370
HTINVB	-0.63998
HTINVTO	0.47820
TINBRK	-1.34792
HTMAX	0.43466

Prediction Results

Actual Group	No. of Cases	Predicted Group Membership Group 0	Group 1
Group 0	55	40 72.7%	15 27.3%
Group 1	47	12 25.5%	35 74.5%

Percent of 'Grouped' Cases Correctly Classified 73.53%

inland penetration of stratus from those mornings when the coast remains free of stratus. The classification function can be written as:

$$CO = -229.177 + 2.737\ (TSFC) + 0.497\ (T950MB) - 7.614\ (T850MB) + 0.010\ (HTINVB)$$

$$-0.021\ (HTINVTO) + 6.374\ (TINBRK) + 1.565\ (HTMAX)$$

for the absence of inland stratus penetration, and:

$$C1 = -242.786 + 2.984\ (TSFC) + 0.291\ (T950MB) - 8.128\ (T850MB) + 0.012\ (HTINVB)$$

$$-0.021\ (HTINVTO) + 6.670\ (TINBRK) + 1.461\ (HTMAX)$$

for the occurrence of stratus penetration past the coastline.

If the calculated C0 is greater than C1, no penetration of stratus past the coast is expected, and vice versa. The canonical correlation, Wilks' lambda, and accuracy of classification are 0.555, 0.692, and 73.53 percent, respectively, illustrating that the morning sounding could be useful for determining the occurrence of inland stratus penetration in the morning.

Table 3 shows the result of discriminant analysis for the occurrence of inland stratus margins vs. those cases when inland stratus penetration does not occur for the afternoon hours. Inland stratus penetration tends to occur when the morning sounding indicates higher inversion bases and higher ground surface temperature. Height and temperature of the inversion base are the two most important variables for determining the occurrence of inland stratus penetration during the afternoon. The canonical correlation, Wilks' lambda, and accuracy of classification are 0.304, 0.908, and 68.63 percent, respectively, indicating that the morning sounding is less useful for determining stratus margins that cross the coastline in the afternoon than they are in the morning.

Another trial was made to relate weather variables to those days with pronounced diurnal burnoff of stratus. Diurnal stratus dissipation is typically observable on satellite imagery as a clear strip or hole off the Southern California Bight, extending approximately from Point Conception to San Diego during the afternoon. It was found that days with marked diurnal burnoff are characterized by lower temperatures from the surface to the 850-mb level, with higher inversion bases and tops than days without notable diurnal burnoff. In addition, stronger onshore flow occurs on days with prominent diurnal burnoff, as reflected by greater PG values (table 4). Heights of the inversion base and top, and temperature at the inversion base, are the three most important variables for discriminating those days with strong diurnal burnoff of stratus from those days without diurnal burnoff. The canonical correlation, Wilks' lambda, and accuracy of classification are 0.516, 0.733 and 74.51 percent, respectively, indicating that the morning sounding provides a reasonable degree of accuracy for forecasting the diurnal burnoff of stratus.

Stratus over the southern California area is sometimes superimposed by cellular cumulus. An attempt was also made to study the correlation of morning sounding parameters with the presence of cumulus. It appears that temperatures from the surface to the 850-mb level are lower and the inversion base and top are higher on days when cumulus is present than on days without cumulus. The canonical correlation, Wilks' lambda, and accuracy of classification are 0.455, 0.793, and 77.45 percent, respectively, indicating that the morning sounding could be used to predict the presence of cumulus with a moderate degree of accuracy (table 5).

From the standpoint of aerosol and pollutant accumulation within the marine layer, it has been found that the oxidant concentration in the South Coast Air Basin inland from the southern California area is highly correlated with temperatures at the 950-mb and 850-mb levels. As discussed previously, temperatures at these levels are higher when there is an absence of inland stratus than when morning inland penetration of stratus occurs. Thus, aerosol loading and continental contamination may be expected to increase on days with no inland penetration of morning stratus.

Table 3. Summary of Discriminant Analysis of Inland Stratus Penetration (Group 1) Against Offshore (or Along Coast) Stratus (Group 0) in Afternoon

Means

	Group 0	Group 1	Total
TSFC	17.5820	18.4077	17.6873
T950MB	18.0315	17.7846	18.0000
T850MB	20.9640	20.9385	20.9608
TINVB	14.5270	14.6385	14.5412
HTINVB	1459.5506	1845.3077	1508.7157
HTINVTO	3526.2809	3594.3077	3534.9510
INVMAG	8.4124	8.5308	8.4275
TINBRK	91.1573	92.8462	91.3725
DP	60.6404	61.3846	60.7353
PG	1.4584	1.3692	1.4471
HTMAX	26.3933	26.1538	26.3627

Classification Function Coefficients

	Group 0	Group 1
TINVB	6.58085	6.99666
HTINVB	0.01611	0.01826
HTMAX	0.98347	0.89020
CONSTANT	-72.53503	-79.69637

CANONICAL CORRELATION 0.304

WILKS' LAMBDA 0.9077

Standard Deviations

	Group 0	Group 1	Total
TSFC	1.8789	2.2780	1.9414
T950MB	4.7741	5.0553	4.7856
T850MB	3.4357	4.0412	3.4964
TINVB	3.0716	4.3198	3.2309
HTINVB	879.0815	1265.0542	938.1745
HTINVTO	1076.1190	1375.9532	1111.0529
INVMAG	2.8807	2.7936	2.8564
TINBRK	6.9624	8.7830	7.1917
DP	2.7890	3.3798	2.8630
PG	1.4605	1.9593	1.5217
HTMAX	6.2407	9.2722	6.6449

Standardized Discriminant Function Coefficients

	Function 1
TINVB	-1.35820
HTINVB	-2.03644
HTMAX	0.62651

Prediction Results

Actual Group	No. of Cases	Predicted Group Membership Group 0	Group 1
Group 0	89	60 67.4%	29 32.6%
Group 1	13	3 23.1%	10 76.9%

Percent of 'Grouped' Cases Correctly Classified 68.63%

Table 4. Summary of Discriminant Analysis of Stratus Exhibiting Strong Diurnal Burnoff (Group 1) Against Stratus Showing No Diurnal Burnoff (Group 0)

Means

	Group 0	Group 1	Total
TSFC	18.3351	17.3185	17.6873
T950MB	19.6189	17.0785	18.0000
T850MB	21.1784	20.8369	20.9608
TINVB	15.5919	13.9431	14.5412
HTINVB	1412.5135	1563.4769	1508.7157
HTINVTO	3057.5405	3806.7077	3534.9510
INVMAG	8.2432	8.5323	8.4275
TINBRK	90.9459	91.6154	91.3725
DP	61.8919	60.0769	60.7353
PG	0.7622	1.8369	1.4471

Classification Function Coefficients

	Group 0	Group 1
TSFC	-0.30094	0.03750
T850MB	-9.38116	-9.10490
TINVB	7.29720	6.75454
HTINVB	0.02825	0.02578
HTINVTO	-0.02558	-0.02400
TINBRK	6.92142	6.73068
PG	6.21401	6.58780
CONSTANT	-252.73415	-241.39292

CANONICAL CORRELATION 0.516

WILKS' LAMBDA 0.7333

Standard Deviations

	Group 0	Group 1	Total
TSFC	1.8204	1.9243	1.9414
T950MB	5.4561	4.1255	4.7856
T850MB	3.8278	3.3178	3.4964
TINVB	3.3671	3.0157	3.2309
HTINVB	1101.2581	835.7282	938.1745
HTINVTO	1290.3051	897.1214	1111.0529
INVMAG	3.3640	2.5456	2.8564
TINBRK	8.8347	6.1280	7.1917
DP	2.7160	2.7517	2.8630
PG	1.7852	1.1984	1.5217

Standard Discriminant Function Coefficients

	Function 1
TSFC	0.45530
T850MB	0.66933
TINVB	-1.21493
HTINVB	-1.60001
HTINVTO	1.21637
TINBRK	-0.95052
PG	0.39415

Prediction Results

Actual Group	No. of Cases	Predicted Group Membership Group 0	Group 1
Group 0	37	26 70.3%	11 29.7%
Group 1	65	15 23.1%	50 76.9%

Percent of 'Grouped' Cases Correctly Classified 74.51%

Table 5. Summary of Discriminant Analysis of Stratus Accompanied by Cumulus (Group 1) Against Stratus Without the Presence of Cumulus (Group 0)

Means

	Group 0	Group 1	Total
TSFC	17.7690	17.2133	17.6873
T950MB	18.1678	17.0267	18.0000
T850MB	21.3092	18.9400	20.9608
TINVB	14.7908	13.0933	14.5412
HTINVB	1440.7126	1903.1333	1508.7157
HTINVTO	3444.1264	4061.7333	3534.9510
INVMAG	8.5379	7.7867	8.4275
TINBRK	91.5287	90.4667	91.3725
DP	61.0345	59.0000	60.7353
PG	1.4046	1.6933	1.4471
HTMAX	25.9195	28.9333	26.3627

Classification Function Coefficients

	Group 0	Group 1
TSFC	-14.21415	-13.77262
T950MB	0.42014	0.62394
T850MB	-3.19723	-4.02900
TINBRK	2.65122	2.91941
DP	18.59896	18.07312
HTMAX	3.27817	3.19874
CONSTANT	-574.87037	-560.10748

CANONICAL CORRELATION 0.455

WILKS' LAMBDA 0.7932

Standard Deviations

	Group 0	Group 1	Total
TSFC	1.8415	2.4649	1.9414
T950MB	4.6230	5.7223	4.7856
T850MB	3.0015	5.2652	3.4964
TINVB	2.5929	5.6015	3.2309
HTINVB	828.0817	1393.5987	938.1745
HTINVTO	998.8053	1558.4673	1111.0529
INVMAG	2.8329	3.0083	2.8564
TINBRK	6.8723	9.0543	7.1917
DP	2.5990	3.7225	2.8630
PG	1.4633	1.8641	1.5217
HTMAX	5.6594	10.6534	6.6449

Standardized Discriminant Function Coefficients

	Function 1
TSFC	0.53737
T950MB	0.61144
T850MB	-1.82319
TINBRK	1.20915
DP	-0.94378
HTMAX	-0.33088

Prediction Results

Actual Group	No. of Cases	Predicted Group Membership Group 0	Group 1
Group 0	87	70 80.5%	17 19.5%
Group 1	15	6 40.0%	9 60.0%

Percent of 'Grouped' Cases Correctly Classified 77.45%

CONCLUSIONS

Cloud features observed on GOES satellite imagery may be related to various ground-truth parameters derived from rawinsonde data with difficulty. Some of this lack of a clear relationship may be attributed to possible inconsistencies in the manner in which inversion parameters are derived for cases of multiple inversions. It was found that morning soundings at Los Angeles International Airport correlated moderately well with the morning extent of marine stratus but correlated poorly with the afternoon extent of stratus. The regression analysis indicates that the morning sounding fails to provide a satisfactory degree of accuracy for determining the location of stratus, either for morning or for afternoon. However, if the location of stratus is grouped into two categories, inland and offshore (including along the coast), the morning sounding provides a reasonable degree of accuracy (75 percent) for separating the two groups. It also provides a moderate degree of accuracy in discriminating those days with diurnal burnoff from those days with no diurnal burnoff of stratus, and in discriminating days with cumulus from days without cumulus.

The penetration of stratus inland in the morning tends to correlate with reduced pollution concentrations inland from the southern California area, thus providing a possible supplemental criterion for forecasting continental aerosol loading.

In addition to possible ambiguities in selection of significant inversions, one reason for the unimpressive correlations between the Los Angeles sounding parameters and the satellite-observed cloud coverage is the inherent difficulty in relating a space- and time-varying condition over a wide area to a single point measurement. Because of the large number of influences on cloud coverage over the eastern Pacific, it is believed that a statistical study employing space-averaged ground-truth parameters will show higher correlations with satellite-derived cloud pattern data. Such studies are currently underway at PACMISTESTCEN.

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