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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
U. S. Weather Bureau

Southern Region Technical Memorandum No. 21, Aug. 1966

A REVIEW OF THE METHODS DEVELOPED FOR FORECASTING STRATUS IN SOUTH CENTRAL TEXAS

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A REVIEW OF THE METHODS DEVELOPED FOR FORECASTING STRATUS IN SOUTH CENTRAL TEXAS

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(Presented at First Forecasters' Conference, Southern Region Headquarters, Fort Worth, Texas, April 27-29, 1966)

1. INTRODUCTION

A stranger coming to South Central Texas is impressed with the little puffs of clouds which appear quite frequently during the late evening and then gradually thicken into a solid layer as the night progresses.

A native of this region has been so conditioned to the presence of these clouds that he scarcely notices them other than to appreciate the shade they offer well into the morning.

A meteorologist observing the regularity with which these clouds form, in regards to both time and space, feels that here at last is something that he can get his teeth into, forecast wise. He is apt to recallLord Kelvin's quotation:

> "When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager, unsatisfactory kind".

The meteorologist says to himself, at last I have found something to forecast that should enable me to start on the road of changing weather forecasting from an art into a science. Let us look into the forecasting of stratus clouds in South Central Texas, and see if this has come about.

2. LOCATION AND TOPOGRAPHY

South Central Texas is a sloping coastal plain about 150 miles wide, bounded on the South by Brownsville, and on the North by Waco. From the Gulf of Mexico, the land rises slowly to an elevation of 500-800 feet in the San Antonio area, and then rises abruptly to 2,000 - 2,400 feet along the Balcones Escarpment, which is located about 15 miles Northwest of San Antonio.

A good portion of the year, the weather over South Central Texas is influenced by its proximity to the Gulf of Mexico. So much so is this the case that by common usage the night time stratus clouds which form in air that has had a trajectory over the Gulf of Mexico are called "Gulf Stratus".

In order to gain a better understanding of the formation of these stratus clouds, it might be well to look at some of the characteristics of the air mass in which they form.

3. AIR MASS CHARACTERISTICS

From Figure 1, we see that the dominant circulation feature over the Gulf of Mexico is the Bermuda high pressure system. This high pressure system is centered at 35 degrees North latitude (43), in the summer time, and causes South to Southeasterly winds at 6 to 8 knots over the Gulf. The air temperature over the Gulf of Mexico at this time of the year averages 85 degrees, and the water temperature averages 84 degrees. The relative humidity is 88 percent (36). Computations show that there is a dew point gradient directed upward from the sea at 84 degrees, to the air at 81 degrees.

Looking at figure 2, we find that by winter time the Bermuda high pressure system has shrunk in size and moved southward to 30 degrees North latitude. It now causes Northeast to East to Southeast winds of 10 to 12 knots over the Gulf of Mexico. The air temperature averages 60-70 degrees and the water temperature averages 65-75 degrees. The relative humidity is 83 percent. The dew point gradient directed upward from the sea is 5-10 degrees.

From these figures we see that over the Gulf of Mexico there is a year around vapor pressure gradient from the sea to the air. This vapor pressure gradient promotes an evaporation rate of 0.40 grams per square centimeter per day (23).

This high evaporation rate causes 4-6 tenths of cloud cover, mostly in the form of Cumulus and Cumulonimbus. Fog and stratus are common along the Northwestern portion of the Gulf in the winter time, due to Southeasterly winds bringing warm moist air from lower latitudes and transporting it over the colder water in the Northern Gulf.

Thus we see that the air; Tropical Maritime in the summer, and either modified Polar Continental or Tropical Maritime in the winter, which is present over South Central Texas, has had a trajectory over the Gulf, and therefore has an abundant supply of moisture in the lower levels (16).

4. INVERSIONS

Turbulence and Convective Inversions: "Mechanical processes are the contributing causes of temperature inversions at altitudes above the surface. Turbulence and convection, if continued long enough,results in a thorough mixing of the atmosphere through the layers where turbulence exists. There is always a limiting height above which the turbulent or convective mixing does not penetrate, and it is at this altitude that temperature inversions are produced. In the turbulence layers, air is brought downward from this maximum height of penetration, to lower levels and air from below is carried upward in the general vertical mixing process. We know that air moving downward is heated by adiabatic compression and that when carried upward it cools at the adiabatic rate due to expansion. Since nearly always in the atmosphere the air at high levels is potentially warmer, i.e.: has a higher potential temperature

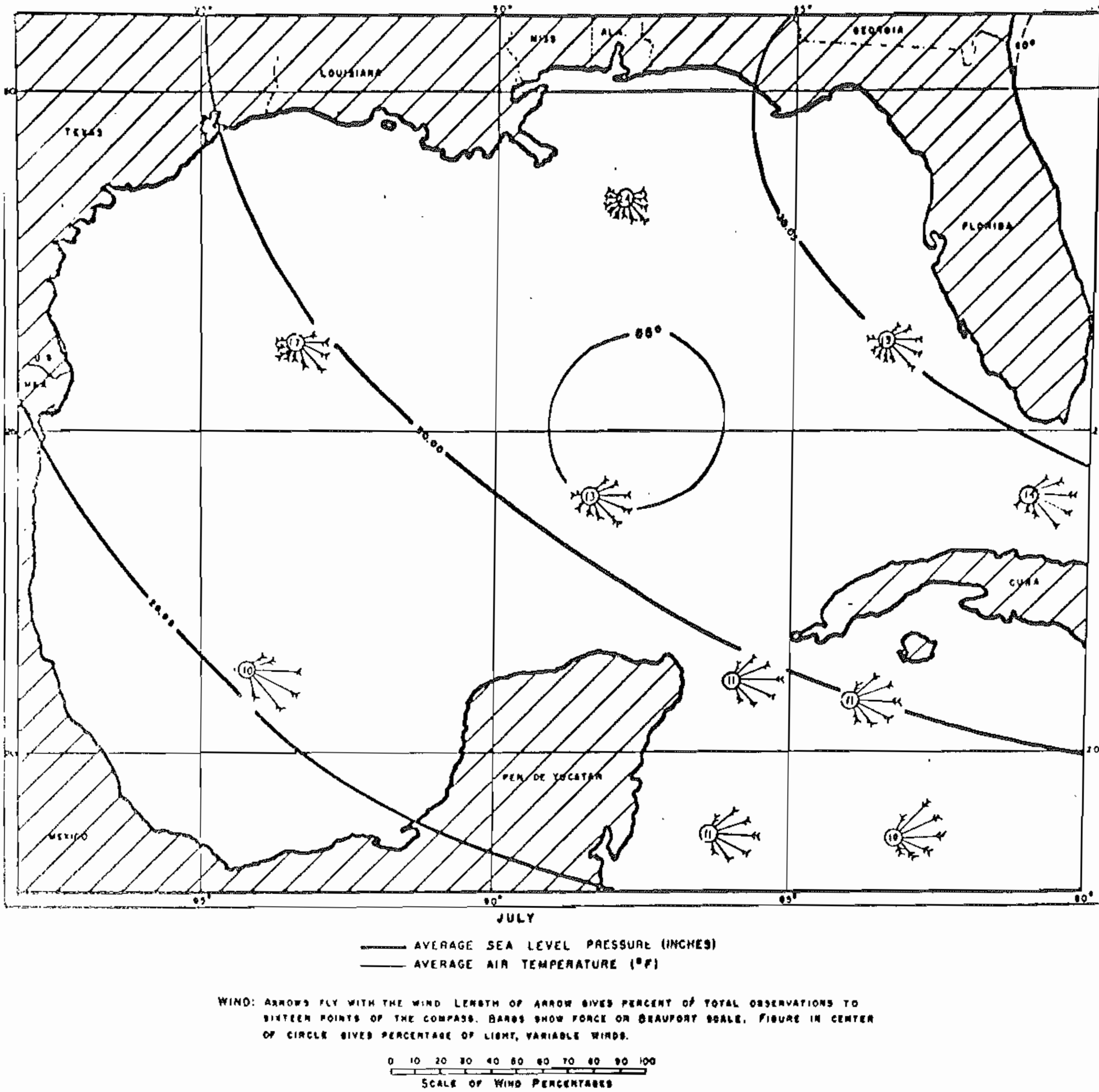


FIGURE 18.—Average sea level pressure (inches) and average air temperature (°F.), July. (39)

Bermuda High Centered	35N
Isobars (wind direction)	SE to S
(wind velocity)	6 to 8 knots
Air Temperature	85
Water Temperature	84
Dew Point Temperature	
(air)	81
(water)	84
Relative Humidity (36)	88%
Specific Humidity (43)	17 to 20 G/KG

Figure 1

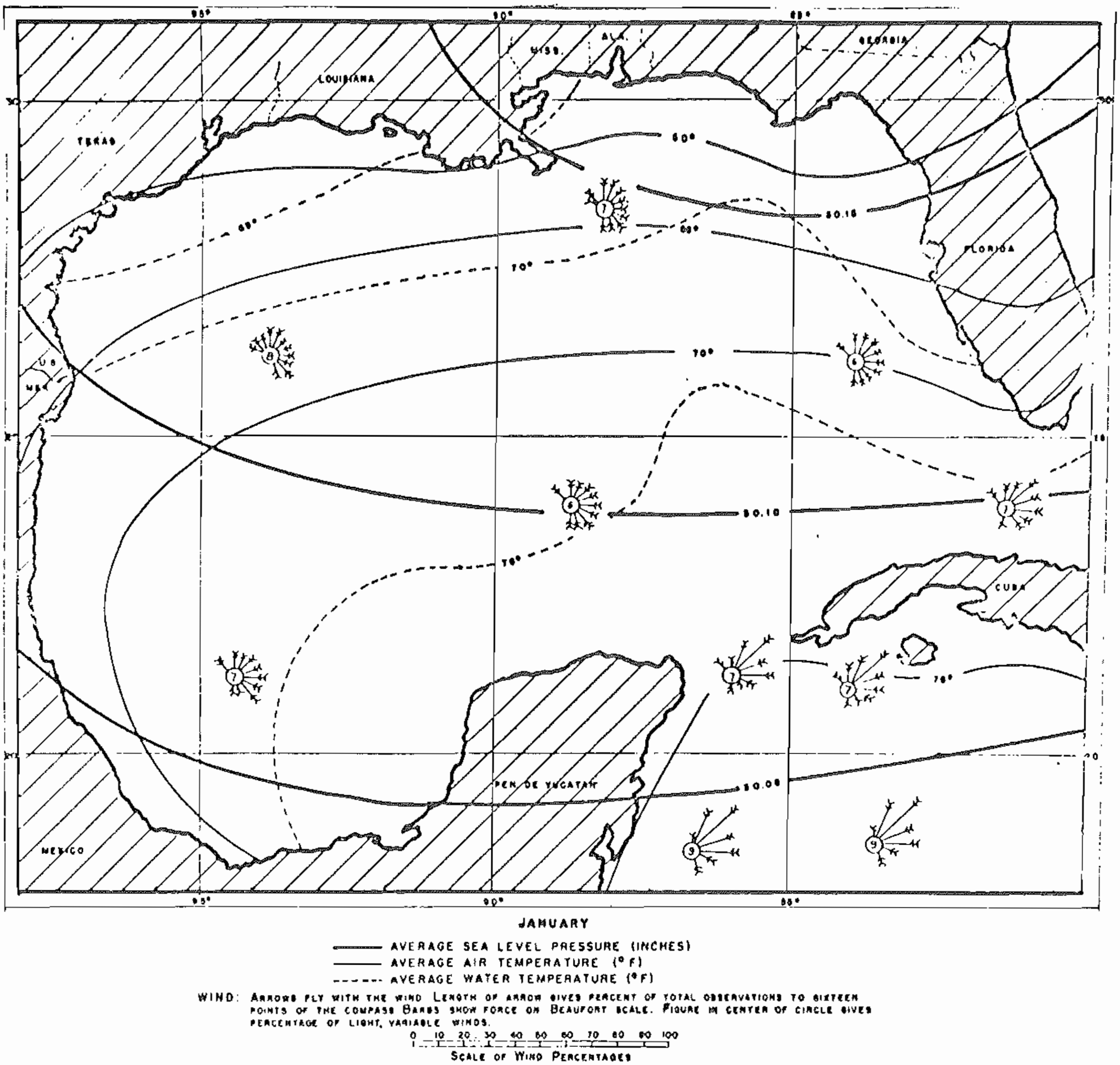


FIGURE 19.—Average sea level pressure (inches), average air temperature (°F.), and average water temperature (°F.) January. (39)

Bermuda High Centered	30N	
Isobars (wind direction)	NE to E to SE	
(wind velocity)	10 to 12 knots	
	S Portion	N Portion
Air Temperature	75	60
Water Temperature	75	65
Dew Point Temperature		
(air)	70	55
(water)	75	65
Relative Humidity (36)	83%	
Specific Humidity (43)	12 to 14 G/KG	

Figure 2

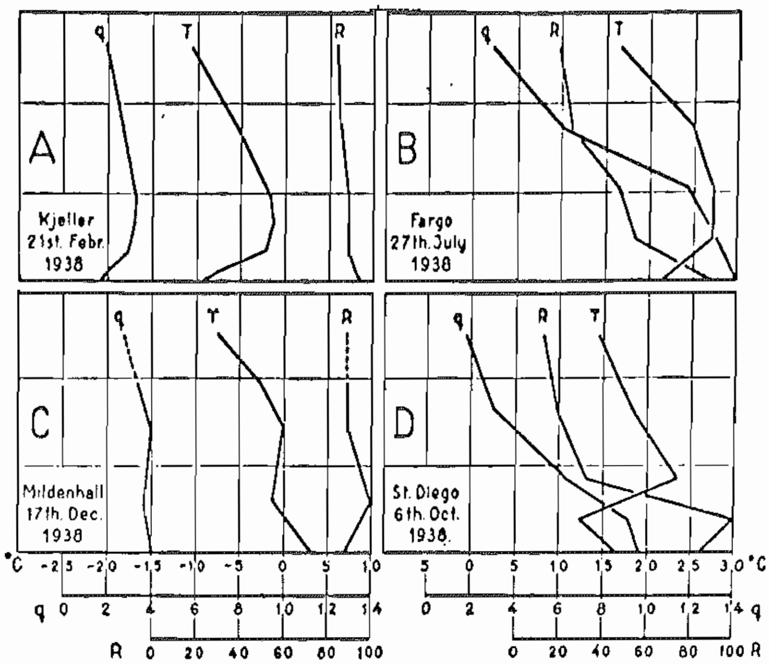
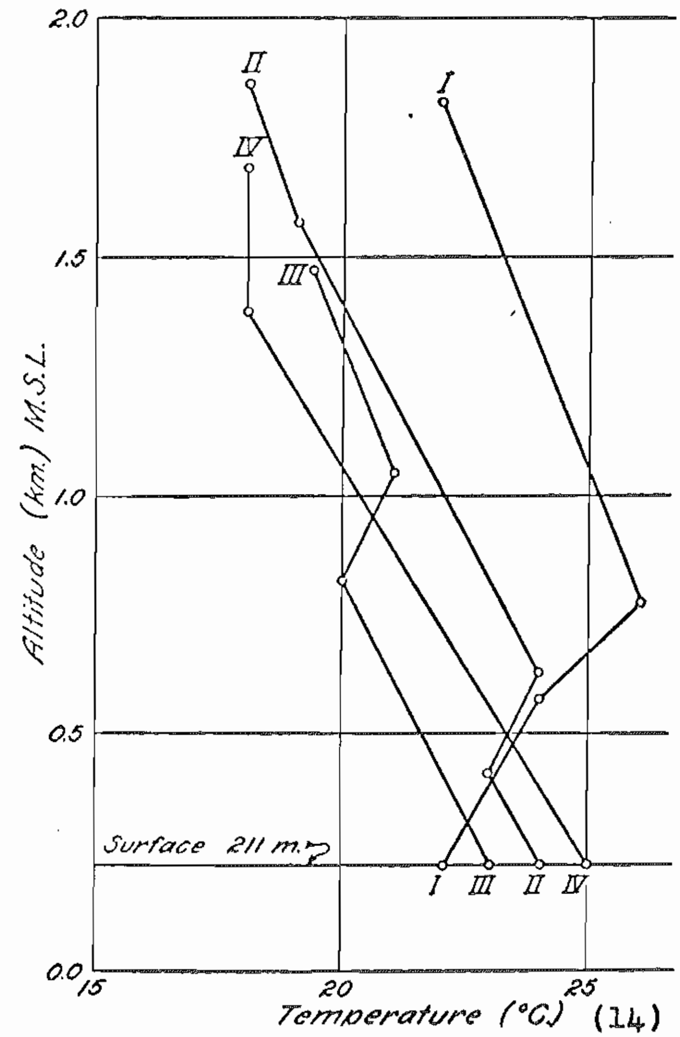


FIG. 50.—Types of inversions. *A*, inversion produced by cooling from below; *B*, inversion produced by subsidence aloft and cooling from below; *C*, inversion produced mainly by cooling and turbulent mixing; *D*, inversion produced by subsidence aloft and heating and turbulent mixing below. (32)

Figure 3



	Height above ground of inversion base, in meters	Mean geostrophic winds from the 2000C and the following 0800C chart, in miles per hour
I-	0	0
II-	200	25
III-	600	33
IV-	1,180	36

Cloud deck (in meters)

I- clear
II- unknown
III-Broken, tops 610
IV-Overcast, tops 1,000

Figure 4

than at low altitudes, the turbulence elements of air carried downward would arrive at their new position with a higher temperature than the air that they replaced, while those lifted upwards will be cooler than the rest of the air at the new level. See diagram on page 253, (6). After this mixing has continued for some time, all the air in the turbulence layer will be air that has undergone adiabatic expansion and compression due to change of level, so that an adiabatic lapse rate will develop, in which the air at the bottom of the turbulence layer will be warmer than formerly: and that at the maximum height of turbulent penetration, colder than before. The transition from this cold upper of the turbulence zone to the air above with its temperature unaffected by adiabatic cooling will comprise a temperature inversion". (6)

Subsidence Inversions: The graphical determination of the change of lapse rate in a layer of air that ascends or descends adiabatically, page-26, (20)

5. PHYSICAL REASONING

The formation of clouds is brought about by the air reaching saturation. This being the case, it is desirable to thoroughly understand any and all physical processes that promote saturation.

Starting with unsaturated air we find that there are three main processes to consider which lead to heat transfer. Namely, radiation, conduction and evaporation.

In considering atmospheric radiation, we find that water vapor is the chief constituent in the air. It acts both as an absorber and transmitter of long wave radiation and has the characteristic of a black body which obeys Stefan's Law in the form $R=CT^4$. Here R is the Radiation, C is a constant characteristic of a black body, and T is the absolute temperature.

With regards to conduction Petterssen (32), states that under normal conditions the eddy transfer of heat is about one hundred times as large as the radiative transfer which again, is about ten thousand times as large as the molecular conduction.

Loss of heat by evaporation is described by Petterssen (32) as follows. If evaporation takes place from a terrestrial source of water, the heat of vaporization is supplied mostly by the water and the air temperature remains sensibly unchanged. However, if evaporation occurs from falling rain, the heat of vaporization is supplied mostly by the air, which is then cooled.

Factors which contribute to saturation according to Reed (33); are advection, vertical motion, expansion, mixing, evaporation, and radiation.

These factors will be investigated along with the part that they play in the formation of "Gulf" stratus clouds in South Central Texas.

Advection: From all indications advection is not a primary cause of saturation in connection with the formation of "Gulf" stratus clouds. This statement is based on the fact that during the time stratus clouds form at night, we find that the specific humidity remains the same during the daylight hours as during the night time. Thus there is no change of air mass, or advection.

Vertical Motion: The air as it streams into South Central Texas from the Gulf of Mexico is lifted orographically, an average of 5 - 8 hundred feet, except along the Balcones Escarpment to the Northwest of San Antonio, which rises to 2,400 feet at its highest point. While these orographic features definitely promote vertical motion, they remain constant, and thus can be treated as such. Vertical motion caused by turbulence and convection will be treated under mixing.

Expansion: The mean time of stratus formation at San Antonio, Texas, which is located near the central portion of South Central Texas, is 0115C (21). (LATE) This is about half way between the secondary diurnal pressure maximum, and the secondary diurnal pressure minimum. This is definitely at a time of falling pressure, and could conceivably contribute to saturation.

Mixing: Turbulent mixing, and anisobaric mixing may lead to the formation of stratiform clouds in that they tend to make the potential temperature, and mixing ratio constant with height. In this way the lowest layers will acquire a dry adiabatic lapse rate; simultaneously an upward increase may be produced in the relative humidity, which may exceed 100% at the top of the inversion. As a consequence, stratiform clouds may form here; its base at the turbulent condensation level, which is higher than the corresponding lifting condensation level, (13).

If continual cooling takes place underneath a stratus overcast due to nocturnal radiation, the stratus will grow in depth downward and possibly reach the surface (17) (18).

Evaporation: Since we are not considering the formation of stratus when it is raining, we may disregard this saturation producing process. ?
This is debatable - could easily exceed radiation effects

Radiation: Nocturnal radiation must play a part in the saturation process which forms stratus clouds in South Central Texas because they only form at night. This radiation tends to decrease the temperature-dew point spread, and cause the air near the ground to reach near saturation. At this point mixing takes place and forms the stratus clouds. The radiational curves developed by Brunt (5), for the temperature of the ground, and the temperature of the water vapor content of the adjacent air layer, might possibly be improved through the use of radiometers (12). If mixing does not take place the problem becomes one of radiational fog (30), (35), and (42).

6. STRATUS STUDY

In 1954, B. I. Miller, and R. S. Schrag, while taking a course in numerical analysis at Trinity University, requested permission from the professor, to run a problem on a NCR-657 computer. Permission was granted, and it was decided to make a study of the time of formation of "Gulf" stratus at International Airport, San Antonio, Texas.

The first consideration was to decide what variables to use. C. W. Hostetter, who had worked with Zahn (45), was consulted. B. I. Miller had made a study (28), using the pressure differences between (CRP-LRD), and (HOU-BRO), along with the temperature-dew point spread at San Antonio R. S. Schrag, had been using the pressure difference between (HOU-DRT), and the temperature-dew point spread at Corpus Christi, with limited success. After a three-way conference it was decided that to obtain a measure of the gradient the pressure differences between (HOU-BRO), (HOU-LRD), (HOU-DRT) and CRP-LRD), would be used. For a moisture parameter the temperature-dew point spread at CRP, SAT and HOU, would be used.

TOO SHORT WHY NOT 999

The 1530C surface data for the years (1948-1953,) was obtained on microfilm from Asheville, N. C.

After the data was tabulated, 705 cases of stratus, some 8,000 punch cards were cut, and fed into the computer, and the following results were obtained:

Pressure Differences	Mean	Correlation Coefficients
1. HOU-BRO	2.6	.5772
2. HOU-LRD	4.2	.4504
3. HOU-DRT	4.3	.3675
4. CRP-LRD	2.8	.0792
Summation of 1,2,3	11.1	.6150
Temperature-Dew Point		
5. CRP	13	.5856
6. SAT	23	.5267
7. HOU	15	.4408
Summation of 1,2,3,4,5,6,7		.6229

Time of formation of stratus after sunset in hours and minutes, 6:36

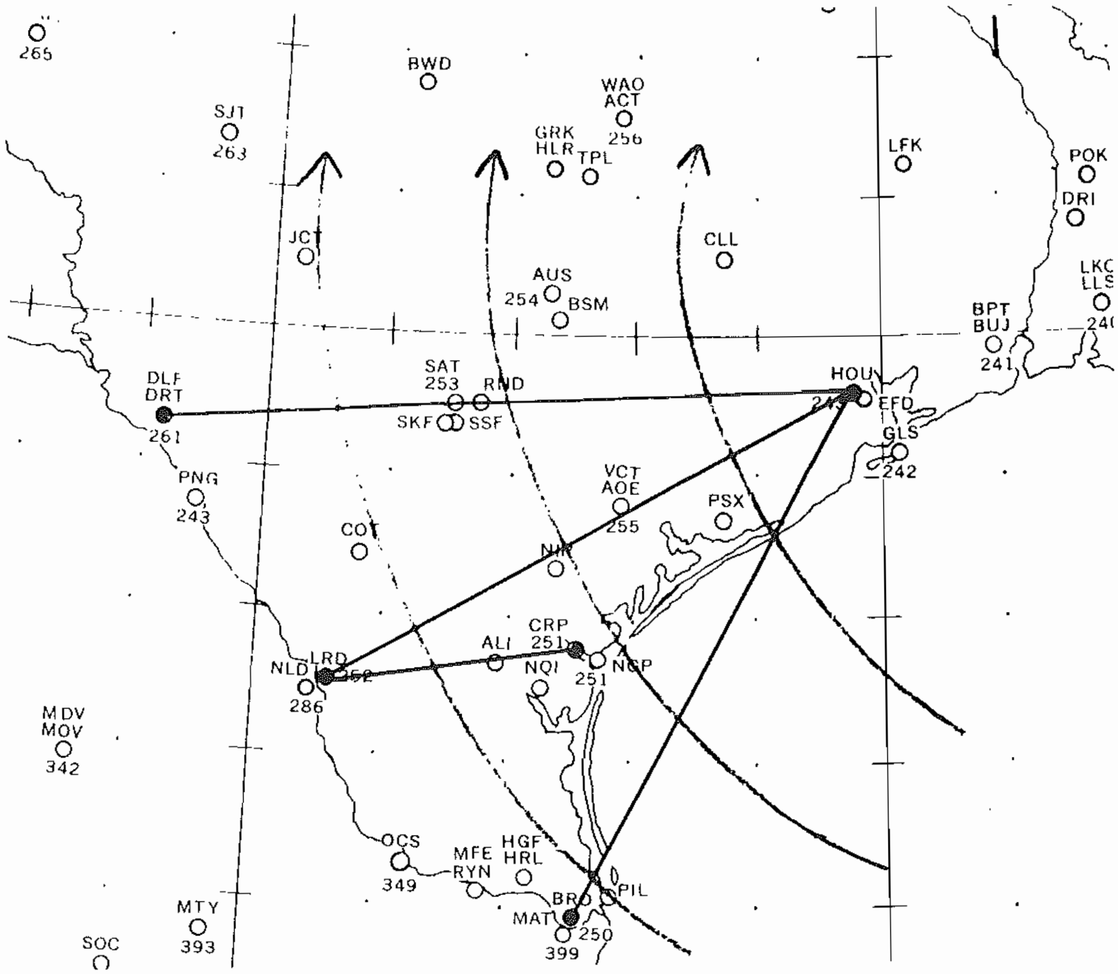


Figure 5. Vectors used to obtain a measure of the flow of "Gulf" air into the San Antonio area, as a basis for forecasting stratus clouds. (21)

Table 1. (705 cases)

Pressure difference (mbs)	Mean	Correlation coefficients
1. HOU-BRO	2.6	.577
2. HOU-LRD	4.2	.450
3. HOU-DRT	4.3	.368
4. CRP-LRD	2.8	.079
Temperature-Dew Point (F)		
5. CRP	13	.586
6. SAT	23	.527
7. HOU	15	.441
Multiple Correlation of		
1,2,3,4,5,6,7		.623
1,2,3		.615

Time of stratus (more than 5/10 coverage) formation, after sunset, 6.6 hours. Standard deviation is 71 minutes.

At first glance a statistician would be very disappointed with the magnitude of these correlation coefficients, in view of his general criterion -

.00-.25	of doubtful value
.26-.50	fair
.51-.75	good
.76-1.00	excellent

In view of the values in this table, the computed correlation coefficients in the stratus study leave a lot to be desired. However, seen through the eyes of a meteorologist(27) (31), these are not so bad.

After examination of the correlation coefficients, it was decided to use variables 1,2,3,5, and 6, to compute the average forecast error in forecasting the time of formation of "Gulf" stratus. This average error was found to be 71 minutes.

To obtain an idea of the relative value of this figure, the official Weather Bureau forecast, as released at 1622C, for the year 1953 was tabulated.

It was found that out of 77 cases of stratus, the average error in the forecast time of formation of broken clouds was 102 minutes. Thus we see that the objective method was 31 minutes more accurate than the subjective method.

7. CONCLUSIONS, AND SUGGESTIONS FOR IMPROVEMENT

While this 31 minute improvement over the subjective forecast is in the right direction, the authors felt that it should be possible to reduce the average error to less than an hour.

This led to two avenues of approach. One, an attempt to utilize exponential or logarithmic curve fitting, and two, a search for new and better variables. Neither of which was successful.

Possibly this is the lower limit to which the "Gradient-Spread" method can be expected to perform.

The areas which might offer some opportunity for improvement, include:

1. Variables in the Z dimension
2. Some measure of convergence and divergence
3. A measure of stability
4. A measure of low level vorticity advection

ACKNOWLEDGMENTS

Over the years many people have lent a helping hand with regard to solving the stratus problem in San Antonio, Texas. A great deal of encouragement was received from O. E. Edrington, MIC of the Weather Bureau at San Antonio, prior to his passing away early in 1964. The present acting MIC, E. A. DiLoreto is ever willing to assist and give counsel on any problems. Thanks are due Meteorologists C. W. Hostetter, R. V. Gonzales, I. E. Medford, H. S. McCrabb, and A. C. Slattery for their assistance in punching 8,000 punch cards which were used in one computerized study on stratus. Also thanks go to A. A. Duff, and G. M. Kush for their helpful instrumentation suggestions, and many thanks to C. A. Suitor, for the use of his splendid meteorological library.

APPENDIX 1

Adney (1) — Laredo AFB

Parameters used
1. 0400C surface wind direction
2. 0400C surface wind velocity
3. 0400C surface temperature
4. 0400C dew point

Results
1. Skill score of .567 on stratus formation

Bailey (2) — Corpus Christi, Texas

Parameters used
1. 1830C gradient wind direction and vel.
2. 1830C temperature-dew point spread

Results
Stratus forms with a wind direction between ENE-SW clockwise, and wind velocities of greater than 25 mph, with a spread of 10 degrees or less, at 1830C

Bowdoin (3) — Houston, Texas

Parameters used
1. 1830C gradient wind direction and vel.
2. 1830C temperature-dew point spread

Results
Stratus forms with wind direction between 140-230 degrees clockwise, and wind velocities greater than 25 mph. Uses spread, to forecast time of formation

States that in an unpublished article by J.J. George, it is estimated that an air mass must be over the Gulf of Mexico for at least 60 hours before it can be considered to be Tropical Maritime

Bowie (4) — Santa Clara Valley, Calif.

"From the foregoing, the conclusion is reached that the formation of stratus clouds over the Santa Clara Valley during the summer is to be regarded as a radiative phenomena, occurring when the valley is flooded by air of marine origin, rich in water vapor, and when it in turn is overlain by air of quite low humidity. When this situation exists the excess of outgoing over incoming radiation is at its maximum at the upper surface of the marine air and sometime during the night the cooling thus caused reaches the dew point, condensation starts and clouds form. It does not necessarily follow that the dew point is reached first at the upper surface of the humid air; it may be at some intermediate altitude between this surface and the bottom. When the dew point is reached at the upper surface first, the growth of the cloud is downward; where as when it is reached first at an intermediate altitude the growth of the cloud is both upward and downward. Ultimately the cooling throughout the marine air, from a maximum at its upper surface downward to a minimum at its bottom, may result in the lapse rate exceeding the adiabatic, when there will follow convection and turbulence that would cause a pilot passing through or under the cloud to experience bumpiness. This convective turbulence increases the rapidity of cloud formation. The descending currents, the counterparts of the ascending currents in the convective process, are heated at the adiabatic rate for dry air, for in them there is a loss of heat by evaporation in the ascending currents. As the cooling proceeds the thickness of the cloud increases and at times the entire mass of marine air is filled with cloud from the top to the bottom."

Carson (7) Found that wintertime stratus along the lower Atlantic coast of the U.S. formed under a 5-10 degree temperature inversion that is presumed to be frontal, because the potential pseudo-wet-bulb temperature increases above the inversion

Crawford (8) Investigations of the South Texas stratus by means of airplane soundings at San Antonio, Texas, showed that the lapse rate through the moist stratum of air which produces the stratus lies between the dry and the saturation adiabatic rates, and it is overlaid with a drier and warmer air mass (S) separated by a small inversion. Nocturnal radiation cools the lower layers of the air and brings about a more nearly saturated condition near the ground. When the moist stratum remains free of stratus, a marked ground inversion is present, indicating little air movement and thus, the lack of turbulence. The presence of a pressure distribution favorable for the establishment of a comparatively strong southeasterly gradient wind not only brings in air of higher moisture content; but, also, produces the necessary mechanical turbulence for the formation of stratus. During the night, when the air movement increases sharply with elevation, turbulence should be expected. Mechanical turbulence is apparently the predominating factor in the formation of the stratus formation, which is absent when the sky remains clear.

George (14)(15) Of all North American air masses probably the least variance in properties is observed in Tropical Gulf (15), and Tropical Atlantic air (14). During the summer Tropical Gulf air is very unstable with showers and thundershowers. Explained the California Stratus as a result of such instability. This explanation does not hold for stratus formed in Tropical Gulf air, because there is ordinarily no pronounced inversion present at low levels to limit convection.

Gringorten (19) Randolph AFB

Parameters used
1. Noon time pressure difference(MSY-BRO)
2. Noon time average dew point, MSY and BRO

Result
With 1,070 cases the accuracy was 71% on a stratus or no stratus forecast. He feels that there is a determinable limit to the number of accurate forecasts that can be expected from such systems. See (10).

Inman (22)

Brooks AFB

Parameters used
1. 0900C SAT 2,000 and 4,000 ft. wind direction and velocity
2. 1530C SAT surface wind direction and velocity
3. 1530C Crp surface dew point
4. 1030C and 1530C SAT surface temperature and dew point

Facts; Can have stratus even if 2,000 ft winds do not have a gulf trajectory, provided the 4,000 ft winds do have a gulf trajectory

Veering winds are positive
Backing winds are negative

Wind shear is plotted against the 2,000 ft SAT wind direction

Results
Of 334 cases in Sept., Oct., and Nov.for the years of 1950, 1951, 1952 and 1953, there was 95.8% correct, on an occurrence, no occurrence basis, with a skill score of .936

Jenrette (24)

Bryan AFB

1. 1800C Bryan dew point
2. 1800C Bryan temperature-dew point spread
3. 1800C Houston temperature-dew point spread
4. 1800C pressure gradient and magnitude as shown by Lufkin-Austin, and Houston-Waco
5. 1800C resultant gradient and wind direction, as computed by a navigational computer

Results
Stratus forms with 90-270 degree wind direction
High clouds present is fairly well correlated with the nonexistence of stratus
Occurrence or nonoccurrence of stratus clouds is 80% correct, while the skill score is 0.55

Kraght (25)

From 10,828 cases of temp, dew pt. and cig., found that there is 275 ft. of ceiling for each degree of temperature-dew point spread

Leach (26) Kelly AFB

Parameters and procedures

1. A plot of the 1200C and 1500C dew point chart for SKF, ALI, BRO, CRP, LRD, COT, DRT, AUS, AOE, PSX, AND GLS
2. Strike an arc of 100 NM about Sat within the 90-190 degree sector
3. Average SAT and BRO 0600C and 1200C 2,000 ft. wind. (if trajectory is outside of the 90-190 degree sector, no stratus is expected)
4. Using the average trajectory, find the dew point at the intersection of the arc
5. Use formula for the time of stratus formation
6. Refinement of gradient wind, pressure difference between, LRD-AUS, and AUS-HOU

Results

No mathematically stated results

Miller (29) San Marcos AFB

Parameters

1. 1830C pressure difference (JCT-AOE)
2. COP wet bulb temperature

Results

Not stated mathematically

Anon (37) Kelly AFB

1. 1830C SKF dew point
2. 1830C SKF temperature-dew point
3. Forecast wind speed at time of formation
4. 2,000 ft wind velocity from SAT

Results

Not stated mathematically

Anon (38) Randolph AFB

1. 1800C temperature-dew point
2. 1800C gradient wind (knots)
3. 1800C pressure difference (AOE-JCT)
4. 1800C pressure difference (CRP-LRD)

Results

819 forecasts prepared, 642 were correct on an occurrence or no occurrence basis, for a percentage of 78% right

Veron (40) Found that the west coast stratus may be considered to form in an unstable air mass limited above by an inversion through which convection cannot penetrate, and that it is dissolved by a similar process during the period of the day when the saturation level is increasing. It is readily apparent that the cloud cannot form until the temperature has decreased enough to lower the saturation level to, or below the inversion level, again during the day-time

Wood (44) Boston, Mass., San Antonio, Tex., and San Diego, Calif.,

"With unchanging synoptic conditions and in the absence of advective transport of heat and moisture, the number of hours of sun-shine required to dissipate a stratus layer beneath a turbulence inversion is roughly proportional to the thickness of the cloud layer. The relationship seems to be a linear one." Diagram, shown in Byers (6) on page 545.

Zahn (45) Uses the gradient wind plotted against the temperature-dew point spread, to fore-cast the time of stratus formation, and the height at which it will form. Both the gradient wind and the spread are forecast values. No mathematical statement as to the results

Jafferis, Ted C., and Hope, J.J. Modifica-tion of William Zahn's method of forecasting stratus at Randolph Field, Station Weather Manual, Randolph Field, Texas, 1951. Im-proved the gradient wind forecast by utili-zing the pressure differences between (AOE-JCT) and (CRP-LRD). Stratus, or no stratus forecast correct 78% of the time

APPENDIX 2

Nuclei

Good nuclei for the formation of ice crystals in the atmosphere seem to be at a premium (9), while the general consensus of opinion among meteorologists is that there is an abundance of condensation nuclei.

In the late 40s and early 50s, a phenomenon was observed in connection with the formation of gulf stratus in the San Antonio area, which cast some doubt on the abundance of condensation nuclei in the atmosphere.

There is a cement plant located about two miles south of the San Antonio International Airport. In the process of manufacturing cement this plant would exhaust debris from three rather tall stacks. Early in the evening gulf stratus would form in this debris and blow over the International Airport. The stratus would form an hour or so earlier, around the stacks, than anywhere else.

Investigation (11), by putting out slides and examining them under a microscope, showed that the particles coming out of the stacks were very hygroscopic. So much so, that even on nights when no dew formed on the grass, or on automobiles upwind from the stacks, the slides downwind would be spotted with moisture around each little particle.

The power of the particles to remove moisture from the atmosphere was such that Hostetter (11), suggested that they should be used in artificial nucleation.

In 1958, the cement company built a new smoke stack with an electrostatic precipitator on it. This has reduced the debris very substantially, thus the San Antonio area no longer observes, "Smoke Stack Stratus."

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