NOAA Technical Memorandum NWS WR-228

FORECASTING MINIMUM TEMPERATURES IN THE SANTA MARIA AGRICULTURAL DISTRICT

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ABSTRACT

The National Weather Service Office in Santa Maria has developed a method of forecasting minimum temperatures for each of the 14 key agricultural temperature stations in San Luis Obispo and northern Santa Barbara Counties. Data were collected from the past 15 winter and spring frost seasons to develop a PC program called "Analogous Days". For further assistance in forecasting minimum temperatures, data from the past four seasons were used to develop a minimum temperature forecasting scheme, using surface pressure differences, 850 mb winds and temperatures, and winds at 1000 and 2000 feet. The purpose of this project is to develop a better method of accurately forecasting minimum temperatures for each of the key agricultural temperature stations. Growers in the Agricultural District need to know the expected minimum temperatures in order to take precautions for their frost sensitive crops and plan field activities. This project will also benefit the National Weather Service after Modernization and Reorganization (MAR) occurs.

I. INTRODUCTION

The Agricultural District of San Luis Obispo County and northern Santa Barbara County has extremely complex terrain consisting of small mountain ranges traversing both counties in different directions to form several valleys and canyons. These mountain ranges may funnel cold or warm air into a valley or canyon during the nighttime hours, dependent on the wind conditions. Because each mountain range is oriented in a different direction, each of the valleys and canyons have a different nighttime temperature structure based on the direction and speed of the wind.

The key agricultural temperature stations are located in different valleys and/or canyons, and thus, have their own distinct nighttime temperature structure. There are two major topographical features in this Agricultural District influencing this temperature structure: the Pacific Ocean and the Santa Lucia Mountains. The Pacific Ocean, on the west side of the Agricultural District, affects those nearby valleys. The Santa Maria Valley and the Lopez Lake Canyon are examples of coastal valleys. Temperatures at key agricultural temperature stations (Oceano, Upper Arroyo Grande, Santa Maria, Bonita School) in these two valleys are typically warmer, especially in a westerly wind flow, because the stations are close to the ocean. Other key temperature stations such as Los Alamos, Zaca, Santa Ynez, Sisquoc, Nipomo Mesa, and Nipomo Foothill are normally cooler, due to sheltering by surrounding local mountains. Two other key temperature stations, Morro Grange and Price Canyon, are in narrow coastal valleys, and temperatures are strongly dependent on wind conditions. The Santa Lucia Mountains in San Luis Obispo County, which are oriented northwest to southeast about 15 miles from the ocean, isolate the ocean effects to the Salinas and Cuyama Valleys. If the winds are light, key temperature stations in these valleys (Radike Vineyard, Estrella River, Shandon) will have strong radiational cooling and generally have the lowest temperatures among the key temperature stations. Figure 1 shows the location of the key agricultural temperature stations.

Vegetables, citrus, and avocados are the principle crops grown near the key temperature stations Santa Maria, Bonita School, Nipomo Mesa, Nipomo Foothill, Morro Grange, Oceano, and Upper Arroyo Grande. The other key temperature stations are located in grape vineyards and apple orchards. The winter growing season is confined to the aforementioned key temperature stations during the period when the grapes and apples are dormant. The spring frost season is extended to include all the other key temperature stations during the period when buds form on the grapevines and apple trees. Accurately forecasting minimum temperatures on expected cold nights is extremely important to the growers, as all of the crops are sensitive to temperatures below freezing.

Forecasting minimum temperatures for all the key temperature stations are dependent on the predicted minimum temperature at Santa Maria. A useful tool to help forecast the minimum temperature at Santa Maria is the FOUS POP/Ceiling/Wind Guidance product. Another useful tool is the Analogous Days PC program, developed at the National Weather Service Office in Santa Maria by Jeff Smith, currently Hydrologist at the River Forecast Center in Salt Lake City. This program was improved by Dave Rosenberg, Met Intern at WSFO San Francisco, using the Paradox spreadsheet. The Analogous Days Program has been developed using data from the past 15 winter and spring frost seasons and will continue to be updated after every frost season.

The first part of the program calculates minimum temperatures for Santa Maria during the winter and spring seasons, and for Paso Robles during the spring season based only on the following hygrometric equation:

$$\text{SMX MIN} = Dp - ((RH-30)/3) + VD + VH$$
$$\text{PRB MIN} = Dp - ((RH-18)/3) + VD + VH$$

where Dp is the dew point
VD is the correction constant for dew point
VH is the correction constant for humidity
(correction constants are shown in Table 1)

This hygrometric equation was originally developed by Ellison (1928) and has been used in the past to forecast minimum temperatures in other Agricultural Districts (Fritz, 1970; Tuft, 1975; Hill, 1976; Oard, 1977; Rogers and Rohli, 1991). The numerical values of the equation and correction constants were adjusted for Santa Maria and Paso Robles by Wilbur Shigehara, currently Meteorologist in Charge at NWS San Diego, using raw data. The temperature and dew point from 1600 local time on that afternoon are entered into the program by the forecaster. The relative humidity, correction constants, and minimum temperature forecast are then calculated by the program.

The second part of the program searches through an archive file of the past 15 years of data to find analogous days based on the

Santa Maria and Paso Robles forecast minimum temperatures and other meteorological parameters as described below.

1. The Santa Maria to Bakersfield surface pressure difference gives an indication of the east-west surface pressure gradient. If the pressure at Santa Maria is higher than at Bakersfield, the pressure gradient force is directed toward lower pressure and suggests a westerly flow.

2. The Salinas to Santa Barbara surface pressure difference gives a general indication of whether strong winds can be expected. If the surface pressure at Salinas is about 3.5 mb higher than surface pressure at Santa Barbara, then it is suggested that there will be strong northwest winds. Northwest winds play a role in modifying minimum temperatures at some of the key stations.

3. The closest upper-air sounding is taken at Vandenberg Air Force Base, 10 miles southeast of Santa Maria, which provides important data consisting of the 850 mb and 500 mb temperatures and winds, as well as the winds at 1000 and 2000 feet.

The forecaster enters the 850 mb and 500 mb temperatures, winds, and the magnitude of the surface pressure differences from Santa Maria to Bakersfield and from Salinas to Santa Barbara from 0000 UTC into the Analogous Days Program. The criteria for finding the analogous days for the minimum temperature the next morning from the entered data are:

850 mb temperature: +/- 4°C
Pressure differences: +/- 1.5 mb
Dew point: +/- 2°F
Formula minimum(s): +/- 4°F

The analogous days that meet all the above requirements are listed, displaying the minimum temperatures for all the key temperature stations for that day. Archived weather maps from those analogous days can be compared to the current weather maps. The analogous day(s), with a weather pattern that most resembles the current weather pattern, are selected and the forecast minimum temperature for Santa Maria is determined. A sample printout of the Analogous Days Program is shown in Fig. 2.

Once a forecast minimum temperature for Santa Maria is obtained, forecast minimum temperatures for the other key stations can be obtained by using the developed minimum temperature forecasting schemes, which use the Analogous Day Program as guidance.

II. KEY TEMPERATURE STATION DESCRIPTION/CLIMATOLOGY AND MINIMUM TEMPERATURE FORECASTING SCHEME

The climatology of each key agricultural temperature station is based mainly upon the Santa Maria-Bakersfield surface pressure difference, the Salinas-Santa Barbara surface pressure difference, and the upper-air data as discussed earlier. Another meteorological parameter used is the surface pressure difference between Santa Maria and Paso Robles, which gives an indication of the north-south pressure gradient. If the pressure of Santa Maria is higher than at Paso Robles, the pressure gradient force is positive and the flow is suggested to have a southerly component. The minimum temperature forecasting scheme was developed after the 1990-1991 winter and spring frost seasons using the key agricultural temperature station climatology as a guide, and then was fine-tuned after verification from the last two frost seasons. This scheme is to be used along with the Analogous Days Program and given equal weight. Frequently, the Analogous Days Program will not have any days to compare. In this case, the minimum temperature formulas are used along with this scheme. The following is a brief description of the climate of each key agricultural temperature station and its minimum temperature forecasting scheme.

SMX = Santa Maria
PRB = Paso Robles
SMX-BFL = Santa Maria - Bakersfield surface pressure difference.
SMX-PRB = Santa Maria - Paso Robles surface pressure difference.
SNS-SBA = Salinas - Santa Barbara surface pressure difference.

A. WINTER KEY TEMPERATURE STATIONS

i) **SANTA MARIA** When the Santa Maria-Bakersfield surface pressure difference is ≤ -2.0 mb and the Santa Maria-Paso Robles difference is ≤ -1.0 mb, consideration of northeast or east surface wind continuing through the night may moderate minimum temperatures. However, surface winds are more likely with a surface pressure difference of -3 or -4 mb. Likewise, in springtime if the pressure difference from Salinas-Santa Barbara is ≥ 6 mb, there is a good chance of nighttime wind from the north or northwest. This is especially true if you have pressure difference ≥ 7 mb and an 850 mb wind of ≥ 35 kts (Note: This particular rule holds for most of the key temperature stations, winter or spring). However, keep in mind that a very cold airmass, i.e. an 850 mb temperature of ≤ -3° C, can stabilize the airmass, diminishing the wind beneath an inversion and producing a cold night. This occurs when high winds aloft are decoupled from the surface winds by the temperature inversion.

Santa Maria can be one of the colder winter key temperature stations under clear skies and light wind. A situation often encountered during mid-winter occurs when a cold front moves through the district late in the afternoon or early in the evening and has a cold airmass behind it (i.e. 850 mb temp <1° C). During these situations, the forecast often will call for showers or partial clearing, but strong downward vertical velocity behind the front creates a nearly clear night with light wind. This leads to an unexpected early morning frost. Satellite pictures and upper-air data are the greatest aid in detecting these potentially troublesome situations. These situations can take place at any of the winter key temperature stations, not just Santa Maria.

The coldest situations (2/15/90, 1/16/87, 1/6/78) over the entire district occur when: (1) the 850 mb temperature is ≤ -3° C, (2) the surface dewpoint is in the lower 20s° F or 10s° F, and (3) the daytime surface temperature is generally ≤ 55° F. Surface pressure differences in these situations are usually only light to moderate offshore, but stronger surface winds may prevent very cold temperatures.

SANTA MARIA SCHEME (Winter Season)

1. a) If 850 mb winds are 190° to 280° and ≥ 20 kts, onshore flow will allow low- to mid-level clouds to be advected into the coastal plain: thus, forecast clouds for SMX.

b) If SMX-PRB ≥ +1.5 mb, and SNS-SBA ≤ +3.0 mb, with 850 mb winds ≤ 25 kts, a southerly surface flow is more dominant than northwest flow: thus, forecast clouds for SMX.

2. If no clouds are forecast, and 500 mb heights are ≤ 560 dam, with 850 mb temperature of ≤ 0°C, forecast temperatures ≤ 32°F. A cold airmass will produce cold minimum temperatures regardless of winds.

3. If no clouds are expected and 850 mb winds are ≤ 15 kts, forecast closer to the predicted formula temperature from the Analogous Days Program than the FOUS guidance. Otherwise, forecast closer to the FOUS guidance. Verification of comparisons between FOUS and the formula minimum temperature has shown that the formula forecast is better in this situation.

In the spring, the combination of longer days and a greater influence of an ocean breeze cause Santa Maria and the other key temperature stations near the coast and coastal valleys except Morro Grange, to warm by 1 or 2°F at night.

SANTA MARIA SCHEME (Spring Season)

1. a) If 850 mb winds are 190° to 280° and ≥ 20 kts, forecast clouds for SMX.

   b) If SMX-PRB ≥ +1.5 mb, and SNS-SBA ≤ +3.0 mb with 850 mb winds ≥ 25 kts, forecast clouds.

2. Use the Analogous Days formula from 0 to +2°F, if you are expecting no clouds and no wind modification.

   a) If clouds are expected, add ≥ 4°F to the Analogous Days formula.

   b) If SNS-SBA ≥ +4.0 mb, then wind will modify temperatures ≥ 4°F.

3. If 500 mb heights are ≤ 543 dam, forecast minimum temperatures near 32°F.

__ii) BONITA SCHOOL__ The same rules used at Santa Maria apply to Bonita School, although Bonita School is usually about 1 to 2°F warmer than Santa Maria. Its proximity to the ocean or a bit more wind at night causes the difference.

BONITA SCHOOL SCHEME (Winter and Spring Season)

1. a) If SMX-BFL and SMX-PRB ≥ +0.1 mb, forecast 0 to 1°F warmer than SMX. If SNS-SBA > +3.5 mb, forecast ≥ 2°F warmer than SMX. The combination of an onshore flow and wind modification (increased moisture at low levels) causes the warming.

   b) If SMX-BFL and SMX-PRB < -0.1 mb, forecast 0 to 2°F colder than SMX. If SNS-SBA < +1.5 mb and 850 mb winds are 20° to 160°, forecast 2 to 3°F colder than SMX. A light offshore flow allows for cool air drainage and good radiational cooling.

2. If no clouds are forecast, and 500 mb heights are ≤ 560 dam, and 850 mb temperature is ≤ 0°C, forecast temperatures ≤ 32°F. When the airmass is cold, the station gets cold.

__iii) OCEANO__ This station is usually 1-3°F warmer than Santa Maria, but can get slightly cooler if Santa Maria's temperature gets moderated by wind. A light onshore breeze can help modify minimum temperatures if dewpoints are in the middle 40s°F near the ocean. The coldest mornings are in light offshore flow conditions. This station is susceptible to moderate air drainage down Arroyo Grande Creek Canyon.

OCEANO SCHEME (Winter and Spring Season)

1. a) If SMX-BFL and SMX-PRB $\geq$ +0.1 mb, forecast 0 to 2°F warmer than SMX. If SNS-SBA > +3.5 mb, forecast $\geq$ 2°F warmer than SMX. See Bonita School reasoning.

   b) If SMX-BFL and SMX-PRB is between +0.1 and -1.0 mb, forecast 0 to 2°F colder than SMX. If SNS-SBA < +3.0 mb and 850 mb winds are 20° to 160°, forecast 2 to 3°F colder than SMX. See Bonita School reasoning.

   c) If SMX-BFL and SMX-PRB < -1.0 mb, forecast $\geq$ 2°F higher than SMX. A north to northeast drainage and offshore flow will modify minimum temperatures.

2. If no clouds expected, and 500 mb heights are $\leq$ 560 dam and 850 mb temperature is $\leq$ 0°C, forecast temperatures $\leq$ 32°F. If the airmass is cold, the station will be cold.

iv) NIPOMO FOOTHILL This is the one of toughest winter key temperature station for which to forecast. On the coldest mornings there is a light onshore flow when the Santa Maria-Bakersfield surface pressure difference is between 2.0 mb and -1.0 mb and the Santa Maria-Paso Robles pressure difference is between 2.0 mb and -1.5 mb. This seems to weaken the normal drainage wind and allows good radiational cooling. In this situation, this station will be 1 to 3°F colder than Santa Maria and about as cold as Nipomo Mesa. This station is susceptible to moderate air drainage off the hills making the station 3 to 7°F warmer than Santa Maria. If surface offshore pressure differences are moderate to strong (Santa Maria-Bakersfield and Santa Maria-Paso Robles pressure differences < -2.0 mb), there is a good chance of nighttime wind modification. If the winds at 1000 or 2000 feet are west, northwest, or northeast and $\geq$ 15 knots, then wind modification of the nighttime temperature can be expected. Temperature modification is not likely if the wind direction is north or southeast, regardless of wind strength due to the orientation of the surrounding coastal hills.

NIPOMO FOOTHILL SCHEME (Winter and Spring Season)

1. a) If SMX-BFL < -2.0 mb and SMX-PRB < -1.5 mb, forecast 0 to 3°F warmer than SMX. If SNS-SBA > +3.0 mb, forecast $\geq$ 3°F warmer than SMX. North to northeast drainage and offshore winds will modify temperatures.

   b) If SMX-BFL and SMX-PRB > +2.0 mb, forecast 1 or 2°F warmer than SMX. A good onshore flow will advect moisture from the ocean and modify temperatures.

   c) If SMX-BFL is between +2.0 and -2.0 mb; and if SMX-PRB is between +2.0 and -1.5 mb, forecast 0 to 3°F colder than SMX. Wind will not be much of a factor and there will be good radiational cooling. If SNS-SBA > +3.0 mb, forecast the about the same minimum temperature as SMX. Northwest winds will also help to modify temperatures if this criteria is met.

2. If no clouds are expected, 500 mb heights are ≤ 560 dam, and the 850 mb temperature ≤ 0°C, forecast minimum temperatures ≤ 32°F.

Note: Generally if the winds at 1000 feet are ≥ 15 knots, minimum temperatures will be modified. If light winds prevail at 1000 feet, then forecast colder minimum temperatures.

v) NIPOMO MESA NE About the only time this site is not the coldest of the stations is with a light onshore flow. When that happens, Nipomo Foothill and Morro Grange can get slightly colder than Nipomo Mesa. Also, when strong offshore flow is occurring (Santa Maria-Bakersfield pressure difference < -3.5 mb, plus strong northeasterly winds at 2000 feet), this station will be a little warmer than Santa Maria.

NIPOMO MESA SCHEME (Winter Season)

1. a) If SMX-BFL < -2.5 mb and SMX-PRB < -2.0 mb, forecast ± 1°F from the SMX forecast minimum temperature. A strong north to northeast flow will modify temperatures.

   b) If no clouds are expected, and if SMX-BFL is between +2.0 and -2.5 mb, and if SMX-PRB is between +2.0 and -2.0 mb, forecast 1 to 4°F colder than SMX. If SNS-SBA < +2.0 mb forecast 3 to 5°F colder than SMX. A light offshore flow draining in cold air is the coldest scenario for Nipomo Mesa. A light onshore flow starts to bring in some moisture from the ocean, modifying temperatures.

   c) If SMX-BFL and SMX-PRB > +2.0 mb, forecast 0 to 2°F colder than SMX.

NIPOMO MESA SCHEME (Spring Season)

1. a) If no clouds and SMX-BFL and SMX-PRB > +2.0 mb, forecast 0 to 2°F colder than SMX. See winter season.

   b) If SMX-BFL < -2.5 mb and SMX-PRB < -2.0 mb, forecast ± 1°F from SMX. See winter season.

   c) If SMX-BFL > -2.5 mb and SMX-PRB > -2.0 mb, forecast 1 to 4°F colder than SMX. See winter season.

2. If rule 1.c above is true, and the 850 mb temperature is ≤ +1°C, then forecast ≥ 4°F colder than SMX unless SNS-SBA > +5.0 mb, modify to 1 to 3°F colder than SMX.

3. If no clouds are expected, forecast 1°F colder than SMX Analogous Days formula.

vi) UPPER ARROYO GRANDE This is the warmest of the winter key temperature stations. This station almost always has a nighttime drainage wind, as it is situated in an east-west valley that drains from the mountains to its east. This station will fall to near or below freezing only in our coldest situations, and will seldom drop below 27-29°F even when Santa Maria has dropped to 22 or 23°F.

UPPER ARROYO GRANDE SCHEME (Winter and Spring Season)

If SMX-BFL and SMX-PRB > +0.5 mb and 850 mb temperature is ≤ 0°C, forecast minimum temperatures 0 to 3°F colder than SMX. The combination of onshore flow and a cold airmass will suppress the drainage wind from the mountains. Otherwise forecast ≥ 2°F higher than SMX.

vii) MORRO GRANGE This station is also a difficult location to forecast. This station is typically one of the warmest, especially with any kind of offshore flow, but gets cold with a light onshore flow when the nighttime wind is from a northwest direction. This can be the coldest key temperature station during the winter on the first night after a cold front has passed with northwest flow (i.e. Santa Maria-Bakersfield pressure difference is ≥ -1.5 mb and Santa Maria-Paso Robles pressure difference is ≥ -1.0 mb). The reason for this is that the surrounding hills block a north to northwest flow creating nearly calm conditions at Morro Grange.

MORRO GRANGE SCHEME (Winter Season)

1. If SMX-BFL and SMX-PRB ≥ -1.0 mb, forecast 3 to 5°F colder than SMX. If SNS-SBA < +2.5 mb, forecast 6°F colder than SMX. The flow is onshore and blocked by the surrounding hills.

2. If SMX-BFL and SMX-PRB is between -1.0 and -2.0 mb, and SNS-SBA < +2.0 mb, forecast between 2°F colder and 1°F warmer than SMX. If SNS-SBA > +3.0 mb, forecast ≥ 2°F warmer. A drainage and offshore flow becomes a factor to begin modifying temperatures. A strong northwest flow will also help modify temperatures.

3. If SMX-BFL and SMX-PRB < -2.0 mb, forecast ≥ 2°F warmer than SMX. A moderate to strong offshore flow will modify temperatures considerably.

4. If high temperature from the previous day ≥ 70°F and the high temperature on the next day is expected to be the same, forecast minimum temperatures of ≥ 30°F on expected cold nights. Verification has shown that the diurnal variation on warm days does not exceed 40°F. Therefore, enough warm air from the day should prevent very cold temperatures from occurring.

In the spring, the surrounding hills prevent the ocean breeze from modifying minimums at this station like the other winter key temperature stations. As a result, the temperature departure from Santa Maria is larger in the spring season than in the winter season.

MORRO GRANGE SCHEME (Spring Season)

1. If no clouds are expected, 500 mb heights are ≤ 570 dam, and 850 mb temperature is ≤ +3°C, forecast minimum temperatures ≤ 32°F. A cool airmass along with the typical spring onshore flow brings cold nights.

2. If no clouds are expected, forecast 3°F colder than SMX Analogous Days formula.

3. If SMX-BFL and SMX-PRB ≥ -1.0 mb, forecast 4 to 6°F colder than SMX. Otherwise, forecast at or above SMX Analogous Days formula. If SNS-SBA > +2.5 mb, add 2 to 3°F. A strong onshore flow will help to modify temperatures a few degrees.

B. SPRING KEY TEMPERATURE STATIONS

i) SHANDON This station, at 1100 feet elevation, is the coldest key temperature station in the district. At times, the newer Radike Vineyard station can be just as cold. This station's minimum temperatures are significantly lower than all other stations when the 850 mb wind is northwesterly and greater than 40 knots, because all other stations will remain above 32°F due to wind. Shandon is protected from the northwest wind, especially at night, even if there is a northwest wind during the day. This station has dropped to 27°F when all other key temperature stations were in the upper 30s°F and 40s°F. Generally, Shandon will be around 7°F colder than Santa Maria and 3°F or so colder than Paso Robles. Occasionally irrigation in the alfalfa field across the road can be a source of modification, but it has not been quantified.

When the surface pressure difference between Paso Robles and Fresno becomes ≤ -1 mb, the possibility exists for nighttime wind at Shandon from the east as the site opens out into the Central Valley through a series of canyons. Under these conditions the Radike Vineyard station will usually be colder than Shandon.

SHANDON SCHEME

1. If there are clouds and it rained, use #2 only.

2. Add 2 to 3°F to the PRB Analogous Days formula, if one of the following is true:

   a) there are clouds and/or it has rained,

   b) the SNS-SBA > +6.0 mb,

   c) 850 mb winds are N to NE greater than 40 kts.

3. If no clouds/rain are forecast, and

   a) If SMX-BFL and SMX-PRB is between -0.5 and -2.6 mb, forecast 10 to 14°F colder than SMX. Light to moderate offshore flow is the coldest scenario.

   b) If SMX-BFL and SMX-PRB is between +0.5 and +2.0 mb, forecast 5 to 9°F colder than SMX. An onshore flow begins to modify temperatures because there is more moisture in the air.

   c) If SMX-BFL and SMX-PRB > +2.0 mb, forecast ≤ 4°F colder than SMX. The onshore flow is stronger.

ii) RADIKE VINEYARD This station is located at 1000 feet elevation and is surrounded by small hills. Any winds ≥ 25 kts at 850 mb will cause minimum temperatures to be moderated. (Note: The winds at 1000 and 2000 feet from the Vandenberg upper-air sounding are not applicable to Shandon and Radike Vineyard because of the Santa Lucia Mountains.) Normally, this station will be about 1 or 2°F higher than Shandon. On nights when you do not suspect wind to be a major factor, forecast about the same minimum temperature or a degree higher than Shandon.

RADIKE VINEYARD SCHEME

1. If no clouds/rain are forecast, forecast 0 to 3°F colder than PRB Analogous Days formula.

2. Forecast 2 to 3°F warmer than the PRB Analogous Days formula if either,

   a) the 850 mb winds are ≥ 30 kts, or

   b) if you expect clouds or rain.

3. If no clouds/rain are forecast and

   a) If SMX-BFL and SMX-PRB is between -2.0 and -1.0 mb, forecast 2 to 6°F colder than SMX. A light to moderate offshore flow begins to modify temperatures.

   b) If SMX-BFL and SMX-PRB is between -1.0 and -0.5 mb, forecast 8°F colder than SMX.

   c) If SMX-BFL and SMX-PRB is between -0.5 and +1.5 mb, forecast 9 to 12°F colder than SMX. A light onshore flow is the coldest scenario as the surrounding mountains block north to northwest winds.

   d) If SMX-BFL and SMX-PRB > +1.5 mb, forecast 4 to 7°F colder than SMX. A stronger onshore flow begins to modify temperatures.

<u>iii) ESTRELLA RIVER</u> The minimum temperatures at Estrella River averages 1°F lower than Paso Robles and 2 to 3°F higher than Shandon. Both Paso Robles and Estrella River are susceptible to northwest nighttime wind after a frontal passage. If calm conditions exist, the Analogous Days Program works fairly well. This station can be moderated by morning fog after a precipitation event.

ESTRELLA RIVER SCHEME

1. If there are clouds and it has rained, use #2 only.

2. Add 2 to 3°F to the PRB formula if one of the following is true:

   a) there are clouds, it has rained,

   b) if SNS-SBA > +6.0 mb,

   c) if 850 mb winds are N to NE, ≥ 40 kts.

3. If no clouds/rain are forecast and

   a) If SMX-BFL and SMX-PRB is between +0.5 and -2.6 mb, forecast 7 to 12°F colder than SMX. See Shandon reasoning.

   b) If SMX-BFL and SMX-PRB is between +0.5 and +2.0 mb, forecast 3 to 7°F colder than SMX. See Shandon reasoning.

   c) If SMX-BFL and SMX-PRB > +2.0 mb, forecast ≤ 2°F colder than SMX. See Shandon reasoning.

<u>iv) PRICE CANYON</u> This station is usually about 2 or 3°F colder than Santa Maria except when you expect it to be windy at San Luis Obispo Airport. Strong north to northwest wind can be expected at this station all night, as well as at San Luis Obispo Airport when the surface pressure difference between Paso Robles and San Luis Obispo exceeds 2 or 3 mb and when the 850 mb wind is in excess of 25 kts.

PRICE CANYON SCHEME

1. If winds up to 850 mb are N to NE at ≥ 25 kts and/or SMX-PRB ≤ -3.0 mb, do not forecast freezing temperatures and go to #3. A strong N to NE wind modifies temperatures.

2. a) If SMX-BFL and SMX-PRB is between -1.5 and +2.5 mb, and if SNS-SBA ≤ +4.0 mb, forecast 2 to 5°F colder than SMX. A light offshore flow or a light to moderate onshore flow are the coldest scenarios as the coastal hills protect the station.

b) If SMX-BFL and SMX-PRB ≤ -2.0 mb, forecast ≥ 2°F warmer than SMX. A moderate to strong offshore flow moderates temperatures.

c) If SMX-BFL and SMX-PRB > +2.5 mb, forecast 0 to 2°F warmer than SMX. Strong onshore flow will modify temperatures.

3. If no clouds are forecast, use SMX Analogous Days formula.

v) SISQUOC This station runs about 2 to 3°F colder than Santa Maria but can be affected by both drainage and strong nighttime offshore wind.

SISQUOC SCHEME

1. If clouds are forecast and/or SNS-SBA > +6.0 mb, use #2 only.

2. a) If SMX-BFL and SMX-PRB ≥ +2.0 mb, forecast 3 to 4°F colder than SMX. The station is protected from an onshore flow by hills to the west, which is the coldest scenario.

   b) If SMX-BFL and SMX-PRB is between +1.5 to -1.5 mb, forecast ≤ 2°F colder than SMX. A weak flow will allow some drainage wind from the east.

3. a) If 850 mb temperature is ≤ +1°C, forecast 3 to 4°F colder than SMX. When the airmass is cold, this station will be cold regardless of pressure differences.

   b) If 850 mb temperature is ≥ +2°C, forecast ≤ 2°F colder than SMX.

4. If no clouds and wind are forecast, then use SMX Analogous Days formula.

vi) LOS ALAMOS This station runs 2 to 3°F colder than Santa Maria, but can occasionally run 4 or 5°F colder early in the spring during still nights when little wind is expected. This station has always been a bit confusing since it's closer to the ocean than the other nearby stations and yet it is colder. Perhaps the drainage of cold air from the surrounding hills combined with pooling of the cold air in this area of the valley is responsible for this. Nighttime northwest wind can be a moderating factor but nighttime drainage wind is not.

LOS ALAMOS SCHEME

1. If clouds are expected and SNS-SBA > +6.0 mb, forecast above freezing. A strong onshore flow will modify temperatures.

2. If no clouds and wind as #1 above, and 850 mb temperature is:

   a) ≤ -1°C, forecast 6°F colder than SMX.

   b) 0 to +1°C, forecast 3 to 5°F colder than SMX.

   c) > +2°C, forecast ≤ 2°F colder than SMX.

   Like Sisquoc, with a cold airmass, the station will be cold. The warmer the airmass, the warmer the station.

3. If no clouds and SNS-SBA ≥ +6.0 mb, forecast 1 degree colder than SMX. If SNS-SBA ≤ +6.0 mb, forecast 2 to 3°F colder.

vii) ZACA This is about the warmest of the "southern four" key temperature stations (Sisquoc, Zaca, Santa Ynez and Los Alamos). It regularly gets a drainage wind from the east or gets mixing from nighttime northwesterly winds. When wind is not a factor, this station will be just slightly warmer than the other three stations and about 1 to 2°F colder than Santa Maria.

ZACA SCHEME

1. If clouds are expected and/or SNS-SBA ≥ +7.0 mb, forecast above freezing. A strong onshore flow will modify temperatures.

2. If no clouds are forecast and wind as in #1, then:

   a) If SMX-BFL and SMX-PRB is between +1.5 to +2.5 mb, forecast 5 to 7°F colder than SMX. A light to moderate onshore flow is the coldest scenario for minimum temperatures.

   b) If SMX-BFL and SMX-PRB is between +1.5 and -1.5 mb, forecast 2 to 5°F colder than SMX. A weak flow will allow for some drainage wind.

   c) If SMX-BFL and SMX-PRB < -1.5 mb, forecast 1°F colder to 2°F warmer than SMX. With an offshore flow, a drainage wind will modify temperatures.

3. If no clouds and wind are forecast, then use SMX Analogous Days formula.

<u>viii) SANTA YNEZ</u> This station is interesting since it is one of the coldest of the "southern four" late in the winter through about mid-March (due to cold air draining into the area around it). As the days warm up, it becomes one of the warmest of the "southern four" late in spring, as nighttime cold air is offset by daytime warming. Therefore, in late winter minimum temperatures at this station can be as much as 6°F lower than Santa Maria, then only 1 or 2°F lower by late spring. Temperatures at this station can be moderated by fog after rain.

SANTA YNEZ SCHEME

1. Use the Santa Maria Analogous Days formula and forecast 0 to 2°F colder if no clouds and wind.

   a) If clouds are expected, add 3°F or more to the Analogous Days formula.

   b) If SNS-SBA > +5.0 mb, wind will modify minimum temperatures up about 5°F.

2. a) If SMX-BFL and SMX-PRB are between -2.5 and +0.5 mb, forecast 6 to 9°F colder than SMX. A light onshore and a light to moderate offshore flow are the coldest scenarios for minimum temperatures.

   b) If SMX-BFL and SMX-PRB are between +0.5 to +2.0 mb, forecast 2 to 5°F colder.

   c) If SMX-BFL and SMX-PRB are +2.0 mb or higher, forecast ≥ 2°F warmer. An onshore flow brings in moisture from the west to modify temperatures.

3. If clouds are expected, use rule 1.a only.

4. After March, add 2 to 3°F to all of the above conditions.

Table 2 shows the average departure of the minimum temperatures of all the key agricultural temperature stations from the average minimum temperature at Santa Maria. Nights with high temperature ceilings are those preceded by a day with a maximum temperature of ≤ 60°F, implying cold air advection with weak or no inversion, resulting in widespread freezing temperatures. Conversely, nights with low temperature ceilings are those preceded by a day with a maximum temperature of 60°F or higher, implying radiational cooling and a moderate to strong inversion, resulting in only isolated areas of freezing temperatures.

III. CONCLUSION AND RECOMMENDATIONS

Map types have been developed for different weather situations that cause cold temperatures to occur over the Agricultural District (Hamilton and Lussky, 1985; Crossan, 1981). A few examples are at 500 mb: (1) a ridge just off the coast of California, (2) a ridge directly over California, and (3) a cutoff low east of California. Using map types and examining the 36 to 60 hour prognostic charts from the NGM and AVN models, potentially cold periods within the district can be anticipated. Within 12 hours, the Analogous Days Program is used to predict the minimum temperature for Santa Maria and Paso Robles. Then, the minimum temperatures for each key agricultural temperature station are determined using the forecasting schemes, with guidance from the Analogous Days Program.

This method of forecasting is not only useful now, but will be even more useful after MAR comes into place. Under the current plan of MAR, the National Weather Service Office in Santa Maria is scheduled to be closed in the late 1990s. The forecasting for this Agricultural District may have to be handled by the Weather Forecast Offices (WFOs) in Oxnard and/or Monterey with guidance from the National Weather Service Office in Riverside. This project will give the WFOs a good idea of the climatology of each key agricultural temperature station and help them with their agriculture forecasting responsibilities for this district.

The National Weather Service Office in Santa Maria will continue the development of the Analogous Days Program and the forecasting scheme as more data becomes available in the coming frost seasons and possibly combine the two into one PC forecasting program.

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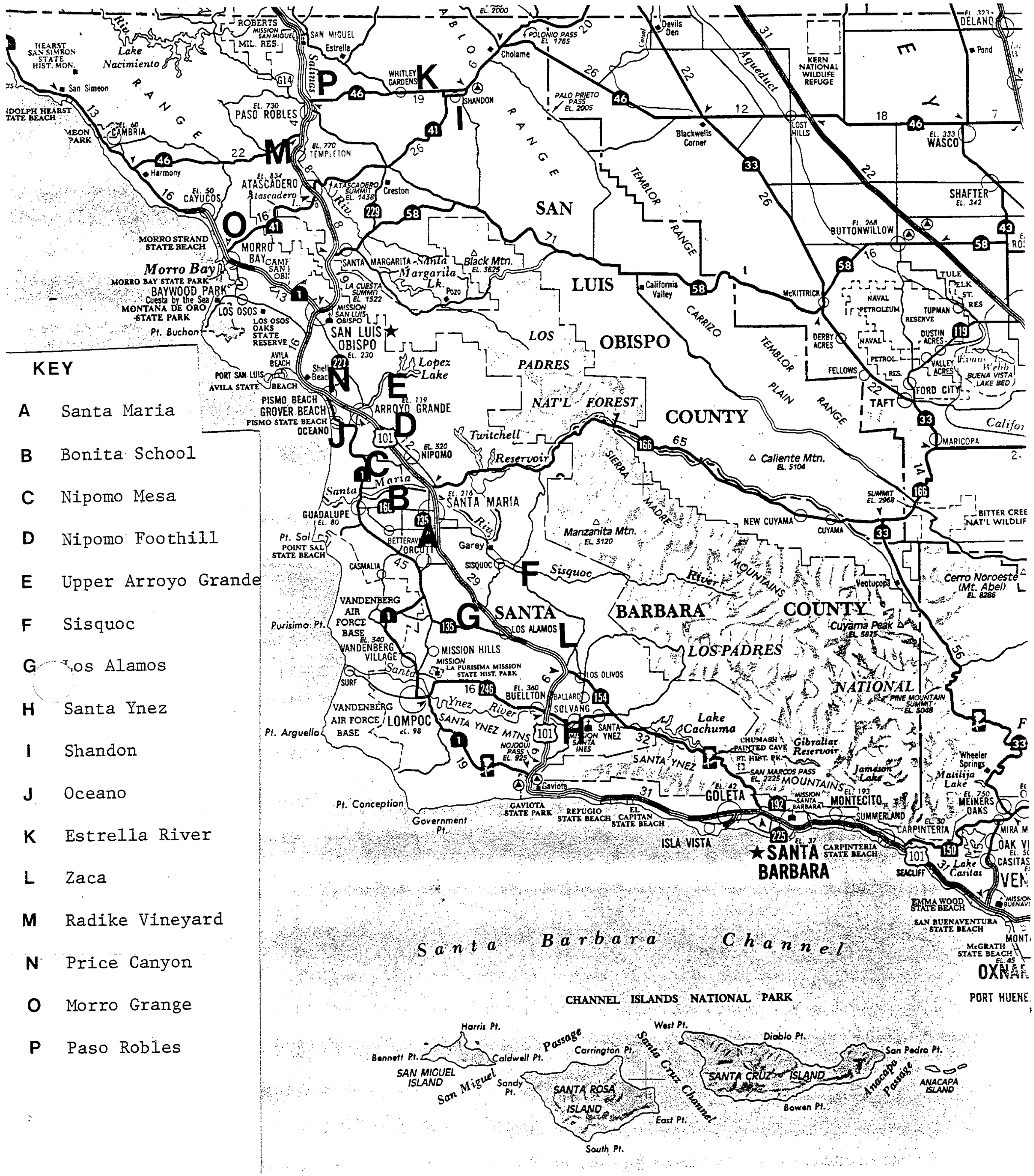

Figure 1 - Locations of key agricultural stations

MINIMUM TEMPERATURE / ANALAGOUS DAYS PROGRAM

04/13/93

INITIAL DATA SET

SMX 00Z TEMP	61	DEG F		PRB 00Z TEMP	75	DEG F	
SMX 00Z DWPNT	48	DEG F		PRB 00Z DWPNT	36	DEG F	
SMX 00Z RH	63 %			PRB 00Z RH	24 %		

CORRESPONDING NEXT MORNING'S FORMULAE MINIMUMS

SMX FCST MIN	39	DEG F	VD.. 3	VH..-1
SMX NAPA MIN	30	DEG F	VD..-4	VH.. 1
PRB FCST MIN	31	DEG F	VD.. 0	VH..-5

ADDITIONAL ANALAGOUS DAYS DATA

VBG 00Z 850 TEMP 10 DEG C	VBG 00Z 850 MB WIND 33015
VBG 00Z 500 MB TEMP -18 DEG C	VBG 00Z 500 MB WIND 34030
SNS-SBA PRES DIFF 004.2 MB	SMX-BFL PRES DIFF 000.4 MB

SPRING SEASON

	MORNING MINIMUMS												ANALAGOUS DATA					
													GRADIENTS		VBG 00Z 850 mb		VBG 00Z 500 mb	
DATE	SM	NM	MG	SH	ER	RD	PC	SQ	LA	ZA	SY	PR	sns sba	smx bfl	t	wind	t	wind
3/26/77	37	34	XX	31	XX	XX	XX	36	33	XX	35	34	2.8	-.6	6	50 21	-15	10 60
3/28/84	42	34	XX	31	37	XX	XX	39	34	XX	35	43	5.6	-.2	11	20 21	-18	350 28
5/09/79	38	37	XX	32	38	XX	XX	35	35	XX	35	37	XXXX	1.3	6	10 19	-12	340 87

Figure 2 - Printout of Analogous Days Program

FORMULAE

Santa Maria Airport Formula for Minimum Temperature Using 00Z Data	Paso Robles Formula for Minimum Temperature (00Z)
Formula: Min= $\text{DEW POINT} - \frac{\text{HUMIDITY}-30}{3} + V_d + V_h$	Min= $\text{DEW POINT} - \frac{\text{HUMIDITY}-25}{3} + V_d + V_h$

Constants

Santa Maria Airport

DEW POINT	V_d
7-15	20
16	19
17	18
18	17
19	14
20	11
21-22	10
23	9
24	8
25	6
26	5
27	4
28	3
29-32	2
33-37	1
38-45	2
46-48	3
49	4

HUMIDITY	V_h
13-14	-12
15	-11
16-17	-10
18	-9
19	-8
20	-7
21	-6
22-23	-5
24	-4
25	-3
26	-2
27	-1
28-32	0
33-47	-1
48-63	-2
64-78	-3
88	-4

Paso Robles

DEW POINT	V_d
10-12	9
13-16	8
17-19	7
20-22	6
23-24	5
25-27	4
28-29	3
30-33	2
34	1
35-37	0
38-39	-1
40-42	-2
43	-3
44-48	-4
49	-5
50	-6

HUMIDITY	V_h
10	-8
11-16	-7
17-19	-6
20-24	-5
25-29	-4
30-34	-3
35-39	-2
40-44	-1
45-49	0
50-54	2
55-59	3
60-64	4
65-69	5
70-74	6
75-79	7
80-84	8
85-89	9
90-94	10
95-98	11
99-100	12

Table 1 - Correction constants for dew point and humidity

KEY STATION STATISTICS

Departure from average minimum temperature at Santa Maria through 11 winter and spring seasons. (Winter, 1982 - Spring, 1993)

WINTER

	LOW CEILING	HIGH CEILING	ALL COLD NIGHTS
BONITA SCHOOL	+0.7	+1.3	+0.9
NIPOMO MESA	-3.8	-2.3	-3.4
NIPOMO FOOTHILL	+0.3	+1.8	+0.7
UPPER ARROYO GRANDE	+5.1	+3.0	+4.3
OCEANO	+0.6	+1.8	+0.9
MORRO GRANGE	+1.9	+0.2	+1.3 (4 YRS)

SPRING

	LOW CEILING	HIGH CEILING	ALL COLD NIGHTS
NIPOMO FOOTHILL	-0.3	-0.6	-0.3
NIPOMO MESA	-4.4	-4.0	-4.3 (9 YRS)
UPPER ARROYO GRANDE	+1.5	+1.0	+1.4
OCEANO	+1.1	+1.0	+1.1
BONITA SCHOOL	+0.7	+0.1	+0.6
SHANDON	-7.3	-7.6	-7.4
ESTRELLA RIVER	-3.3	-2.4	-3.1
RADIKE VINEYARD	-6.6	-5.7	-6.4 (8 YRS)
PRICE CANYON	-2.2	-2.6	-2.3 (9 YRS)
SISQUOC	-2.4	-1.5	-2.2
LOS ALAMOS	-2.4	-2.2	-2.3
ZACA	-0.7	-0.9	-0.7
SANTA YNEZ	-2.2	-1.5	-2.1
MORRO GRANGE	-3.4	-4.0	-3.6 (4 YRS)
PASO ROBLES	-4.0	-2.5	-3.7

Table 2

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