A Forecast of Precipitation and Surface Air Temperature in North America for Winter (JFM) 1998

J. Shukla, D. Paolino, B. Kirtman, D. DeWitt, P. Dirmeyer, B. Doty, M. Fennessey, B. Huang, J. Kinter, L. Marx, E. Schneider, D. Straus, Z. Zhu

Center for Ocean-Land-Atmosphere Studies
4041 Powder Mill Road, Suite 302
Calverton, MD 20705

September 1997

Abstract

Forecasts of surface air temperature and precipitation in North America for three month average conditions during January through March, 1998, produced by a hierarchy of COLA models, indicate that the coming winter will be warmer than normal for most of the continent and substantially wetter than normal along the west coast and across the southern tier. This forecast, produced by climate models, is very similar to what has been observed during previous large warm El Niño Southern Oscillation (ENSO) events, especially the one that occurred in 1982-82. The forecast procedure involves multiple steps. First, global sea surface temperature (SST) is predicted by a combination of dynamical and statistical models. The predicted SST is used to force a global atmospheric model. The forecast maps shown here are the actual outputs of the model. No subjective or empirical correction has been made to the numerical output of the COLA atmospheric model.

1. Background

As part of ongoing research on the predictability of seasonal-to-interannual climate variations using atmosphere, ocean, and coupled ocean-land-atmosphere models, the Center for Ocean-Land-Atmosphere Studies (COLA) has assembled and developed a hierarchy of models to produce seasonal and multi-seasonal forecasts of the global atmospheric circulation and precipitation.

COLA is coordinating a multi-institutional research effort on dynamical seasonal prediction (DSP) in which several research groups (COLA, Goddard Space Flight Center (GSFC), the National Center for Atmospheric Research (NCAR), and the National Centers for Environmental Prediction (NCEP)) utilize their respective atmospheric models to produce hindcasts of seasonal climate anomalies for prescribed global sea surface temperature (SST) anomalies (COLA 1996). COLA is also one of several institutions participating in the Tropical Ocean Global Atmosphere (TOGA) Program on Prediction (TPOP) and produces experimental predictions of SST anomalies in the tropical Pacific using an anomaly coupled ocean-atmosphere model (Kirtman, et al., 1997).

As part of the DSP project, we have already completed nine member ensemble seasonal integrations for 15 years (1982-1996) using observed SST for each year. These integrations utilize nine different global atmospheric initial conditions during mid-December for each year. The atmospheric model is integrated through the end of March. The first 15 days are ignored because that is the period for which weather fluctuations are known to have some deterministic predictability, and the purpose of this research is to investigate the predictability of climate anomalies for periods beyond weather predictability. Seasonal mean anomalies for the three month mean (January through March) are analyzed. The average of all 135 seasonal integrations is used to define the climatological mean of the COLA atmospheric model.

As part of the TPOP project, an anomaly coupled tropical ocean global atmosphere model is used to predict SST anomalies (SSTA) over the *tropical* Pacific Ocean. However, the seasonal forecasts require the *global* SST to be specified. We have developed a fully coupled ocean-atmosphere prediction model to predict global SST, however, that model is not yet validated using a sufficiently large number of cases. For the forecast reported here, we apply a simple statistical technique to infer the global SSTA forecast from the tropical Pacific SSTA forecast.

This report is the outcome of our first attempt to combine the results of the two projects (DSP and TPOP) described above, and produce a forecast for JFM 1998. The forecast procedures and the models used for this forecast are described in the Appendix.

2. Results

2.1 Sea Surface Temperature

The SST forecast produced by the anomaly coupled model and subsequent statistical projections (steps 1-4 of the forecast procedure; see Appendix) calls for a continuation of the unprecedented, anomalously warm surface temperature in the tropical eastern and central Pacific through boreal summer of 1998 with a peak amplitude in about December 1997 and January 1998, and diminishing thereafter. The warmer than normal water in the Pacific is located east of the dateline along the equator and extends about 5-10° north and south of the equator (Fig. 1). The peak SST value forecast by this model is about 3°C above normal. The same model has been used to produce a forecast every three months, based on available observational data, since March 1995.

During the current ENSO (El Niño Southern Oscillation) warm event (through September 1997), the model has been quite accurate in predicting the onset and rapid increase of the SST anomaly, although its prediction of the magnitude of the maximum anomaly has been less than has been observed in the last three months.

2.2 The Surface Air Temperature over North America

The model-based SST forecast was applied as a lower boundary condition to the COLA atmospheric general circulation model to produce an ensemble of nine forecasts. The ensemble members were generated by initializing the model with slightly different initial conditions to provide some measure of the uncertainty of the forecast. The COLA model is a global climate model, but only a portion of the global output is discussed in the following.

The COLA model ensemble mean forecast for surface air temperature shows a generally warmer than normal winter for most of northern North America (Fig. 2). Positive departures from normal are shaded in red, and negative departures are shaded in blue. With the exception of the Atlantic coast, parts of the Gulf of Mexico coast, and the southern parts of the southwestern states of the U.S., the entire continental U.S. and most of Canada are forecast to have seasonal mean temperatures (January through March 1998) more than 1° C (2° F) above normal. The largest departures from normal in the U.S. are predicted to occur in the northern plains states (Minnesota, the Dakotas and Montana) with seasonal mean temperature more than 3° C (6° F) above normal. In Canada, anomalous temperatures more than 6° C (12° F) above normal are forecast for Manitoba and the Northwest Territories. For winters in central North America, the historical record of observations indicates that seasonal mean anomalies of more than 3° C occur less than 15% of the time, and 6° C above normal for an entire season has been observed less than 5% of the time, on average.

2.3 Precipitation over North America

Typically, predictions of precipitation are less reliable than temperature forecasts due to the fact that precipitation is more variable, has a smaller spatial correlation scale and is non-normally distributed. Nevertheless, the large scale characteristics of precipitation anomalies are known to be correlated with those of other fields and some information may be obtained from predictions of seasonal mean precipitation. The seasonal mean precipitation anomaly for January through March 1998 predicted by the COLA model ensemble mean forecast is shown in Fig. 3. Positive departures from normal (more than usual precipitation) are shaded in green, and negative anomalies are shaded in yellow. The main features of the anomaly pattern are a swath of positive anomalies to the south and a band of negative anomalies to the north. The positive anomalies (more than 1 mm day^{-1} or 3.5 inches for the entire season above normal) extend from the Pacific northwest states of the U.S., through California and the southwest U.S. into Mexico, and along the Gulf of Mexico into the southeast U.S. The band of negative departures from normal extends from the Pacific coast of Canada through the northern plains and Great Lakes states of the U.S. into the maritime provinces of Canada. The largest departures from normal are forecast for northern California and central Mexico, but a significant region of more than normal precipitation (1.5 mm day^{-1} or 5 inches above normal) extends through the southwest states (southern California, Arizona, New Mexico, and Texas) and the Gulf states (Louisiana, Mississippi, Alabama, Georgia, and Florida). Forecasts for Alaska and Hawaii (not shown) are near normal and below normal precipitation respectively. If the forecast for California, Mexico and the southwest U.S. verifies, the precipitation amount will be nearly unprecedented compared to the historical record of observations, occurring less than 1% of the time or once per century.

3. Discussion of Uncertainty in Climate Forecasts

In discussion of any climate forecasts produced by a numerical model, it must be stressed that there is a substantial element of uncertainty in any such product. The Earth's climate is highly variable, and the current state of the science of climate variations indicates that only certain regions on the globe and only certain seasons of the year are appreciably predictable. One of the major advances of climate dynamics is the establishment of a scientific basis for the predictability of seasonal average climate anomalies (Shukla, 1993). Therefore, while weather fluctuations are known to be unpredictable beyond about two weeks lead time, climate variations *in the tropics* and select regions outside the tropics are predictable on seasonal to interannual time scales. The *extratropical* climate is highly variable, and the influence of tropical SST anomalies (exploited in this study) is responsible for only a portion of the observed variation. Recent research has shown, however, that, in the presence of large tropical SST anomalies, the seasonal climate over the Pacific-North American region is highly predictable. Despite elements of uncertainty, the numerical model can produce a forecast for each point on the globe for each moment in the future. It is a matter of current scientific inquiry to interpret the numerical model output in the context of climatic uncertainty. In discussing the results of this study, we emphasize that the results are the products of a numerical model for which a detailed quantitative analysis of the uncertainty has yet to be made.

It should also be noted that the prediction methodology employed in this study involves two distinct numerical model products. The first step of the forecast procedure involves an anomaly coupled ocean-atmosphere model. The inclusion of observational information and the high degree of predictability of tropical Pacific SST provide a measure of confidence for the SST anomaly forecast. The final step of the forecast procedure (after the intervening steps that effectively project the output of the anomaly coupled model from tropical Pacific SST to global SST using statistical techniques based on historical observations) involves a model of the global atmosphere only. The final step assumes that the SST anomaly forecast produced in the first four steps is "perfect". We emphasize the differences between the first step and the final step, because it is important to keep in mind that forecasting *tropical Pacific SST anomalies* and forecasting the *global effects* of those anomalies are distinct. The two parts of the forecast procedure have different levels of uncertainty and, hence, different levels of reliability.

Appendix

1. Forecast Procedure

The procedure to produce these forecasts consists of the following steps:

1. The tropical Pacific Ocean - global atmosphere anomaly coupled model is used to predict changes in sea surface temperature (SST) over the tropical Pacific Ocean starting from the initial conditions of June 1, July 1 and August 1, 1997.

2. Predicted SST over the tropical Pacific Ocean for January, February and March of 1998 consists of observed SST in June, July and August of 1997 plus changes predicted in step 1. These three separate predictions are averaged to produce the final SSTA over the tropical Pacific Ocean.

3. The procedures described in step 1 and 2, were used for 45 hindcasts (June, July, August initial conditions for each of the 15 years 1965,66, 70, 72, 73, 74, 75, 82, 83, 84, 86, 87, 88, 89, 91) of tropical Pacific SSTA. From the predicted SSTA over the tropical Pacific Ocean, global SSTA for each month is calculated by a singular value decomposition (SVD) analysis which utilizes the historical SST data sets to specify global SST anomalies from the tropical Pacific SST anomalies. The global SSTA determined by this procedure and averaged for January, February and March 1998 is shown in Fig. 1.

4. The global SST anomalies produced by step 3 for each month (January, February, March (JFM) 1998) are superimposed upon climatological SST to produce the forecast SST for 1998.

5. The global SST produced by step 4 is used as the lower boundary condition in integrations of the COLA atmosphere general circulation model using the procedures of the DSP project to produce forecasts of global circulation, including surface temperature and precipitation for 1998. The model integration is repeated nine times with different initial conditions to form an ensemble. The initial conditions were taken from the observed global atmospheric state at three different time in mid-December of 1982, 1986 and 1991.

6. To produce forecast anomalies of surface air temperature (Fig. 2), and precipitation (Fig. 3) for JFM, 1998, the climatology of the COLA AGCM (based on 135 winter seasonal integrations during 1982 through 1996 from the DSP project) is subtracted from the forecasts produced by step 5.

2. Models

2.1 The DSP Atmospheric Model

The atmospheric model used to produce seasonal forecasts is the COLA atmospheric general circulation model (AGCM). The COLA AGCM is a global spectral model which is truncated rhomboidally at zonal wavenumber 40. The associated Gaussian grid on which the physical parameterizations are calculated has 128 points in the longitudinal direction and 102 in the latitudinal direction. The vertical structure of the model is represented by 18 unevenly spaced levels using sigma as the vertical coordinate. The spacing of the levels is such that higher resolution is obtained near the surface and near and above the tropopause.

This version of the model includes parameterizations of solar radiative heating, terrestrial radiative heating, cloud-radiation interaction, deep convection (relaxed Arakawa-Schubert - Moorthi and Suarez, 1992 - implemented by DeWitt, 1996), large scale condensation, shallow convection, a turbulence closure scheme for subgrid exchange of heat, momentum, and moisture, and biophysically controlled interaction between the vegetated land surface and the atmosphere using SSiB (Xue et al., 1991).

2.2 The Ocean Model

The ocean model used for this study is a version of the GFDL Modular Ocean Model (Pacanowski et al., 1993). This is a finite difference treatment of the primitive equations of motion using the Boussinesq and hydrostatic approximations in spherical coordinates. The coastline and bottom topography are realistic except that ocean depths less than 100 meters are set to 100 meters and the maximum depth is set to 4000 m. The zonal resolution is 1.5°. The meridional grid spacing is 0.5° between 10°N and 10°S, gradually increasing to 1.5° at 20°N and 20°S. There are 20 levels in the vertical with a constant level interval of 15 meters for the top 10 levels. The intervals for the bottom 10 levels are 15.2, 16.1, 20.0, 34.1,75.9, 177.1, 375.9, 687.4,1063.8, and 1384.5 m.

Richardson number dependent coefficients are chosen for the vertical mixing and diffusion of momentum, heat and salinity. The horizontal viscosity and diffusivity coefficients are prescribed and set equal to a constant $2x10^7$ cm^2/sec. This model has been used previously for simulations of oceanic and coupled ocean-atmosphere circulations (e.g., Huang and Schneider, 1995).

The heat flux is composed of radiative, sensible, and evaporative components. The radiative fluxes are divided into solar and long wave radiative parts. At each time step of the model integration, the solar radiation is prescribed by a linear interpolation of the climatological monthly means. The solar radiation penetrates into the upper ocean with an e-folding depth of 12 m. The other components are parameterized as functions of the model SST and prescribed surface air temperature and surface wind speed.

2.3 The Land Model

The land component of the COLA AGCM is the SSiB model which is a simplified version of the Simple Biosphere model of Sellers et al. (1986) and is described by Xue et al. (1991). The SSiB model has one vegetation canopy layer and three soil layers. The eight prognostic variables are: canopy temperature, surface temperature, deep soil temperature, water stored on the canopy, snow on the ground, and soil wetness in the three soil layers. Vegetation at each grid point is categorized as one of the twelve biomes. Each vegetation type is characterized by a set of physical, physiological and morphological properties. The land model provides a physically consistent method of calculating albedo, evapotransporation and soil wetness which were arbitrary prescribed in the previous generation of land surface models.

2.4 The Anomaly Coupled Model

The anomaly coupled prediction system consists of a state-of-the-art atmospheric general circulation model (AGCM) coupled to a tropical Pacific ocean general circulation model (OGCM) (Kirtman, et al., 1997). The AGCM is the same global spectral model described above but is horizontally truncated at triangular wave number 30. In the ocean model, there are 20 levels in the vertical with 16 levels in the upper 400m. The zonal resolution is 1.5° longitude and 0.5° latitude between 20°and 20°S.

The ocean and atmosphere component models have been tested separately in order to evaluate their performance when forced by observed boundary conditions. Improvements in the models and in the coupling have been incorporated into the coupled prediction system. The effects on the ocean of errors in the atmospheric model zonal wind stress have been ameliorated by using the zonal wind at the top of the atmospheric boundary layer to redefine the zonal wind stress at the surface (Huang and Shukla, 1997). An iterative procedure has been developed for further adjusting the zonal wind stress, based on the simulated SSTA errors (Kirtman and Schneider, 1996) that improves initial conditions for coupled forecasts.

The prediction system has been verified in 180 hindcast experiments and been shown to give useful forecasts of tropical eastern Pacific SST for lead times up to 12 months. While the temporal evolution of the SSTA is consistent with the observations, some of the details of the spatial structure are in error. In order to improve the spatial structure of the predicted SSTA a statistical projection has been applied to produce a global SSTA.

References

COLA, 1996: Science Review, 1993-1996. Available from Center for Ocean-Land-Atmosphere Studies, 4041 Powder Mill Road, Suite 302, Calverton, MD 20705.

DeWitt, D.G., 1996: The effect of cumulus convection on the climate of COLA general circulation model. *COLA Technical Report #27*. Available from Center for Ocean-Land-Atmosphere Studies, 4041 Powder Mill Road, Suite 302, Calverton, MD 20705.

Huang B. and J. Shukla, 1997: An examination of the AGCM simulated wind stress and low level winds over tropical Pacific. *Mon. Wea. Rev.*, **125**, 985-998.

Kirtman, B.P., J. Shukla, B. Huang, Z. Zhu and E.K. Schneider, 1997: Multiseasonal predictions with a coupled tropical ocean global atmosphere system. *Mon. Wea. Rev.*, **125**, 789-808.

Kirtman, B.P., and E.K. Schneider, 1996: Model based estimates of equatorial Pacific wind stress. *J. Climate*, **9**, 1077-1091.

Moorthi, S. and M.J. Suarez, 1992: Relaxed Arakawa-Schubert: A parameterization of moist convection for general circulation models. *Mon. Wea. Rev.*, **120**, 978-1002.

Pacanowski, R.C., K. Dixon, and A. Rosati, 1993: The GFDL Modular Ocean Model Users Guide, Version 1. *GFDL Ocean Group Tech Rep. No. 2.*

Sellers, P.J., Y. Mintz, Y.C. Sud, and A. Dalcher, 1986: A simple biosphere model (SiB) for use within general circulation models. *J. Atmos. Sci.*, **43**, 505-531.

Shukla, J., 1993: Predictability of short-term climate variations. *Prediction of Interannual Climate Variations*. NATO ASI Series I: Global Environmental Change, **Vol. 6**, Editor: J. Shukla, 217-232.

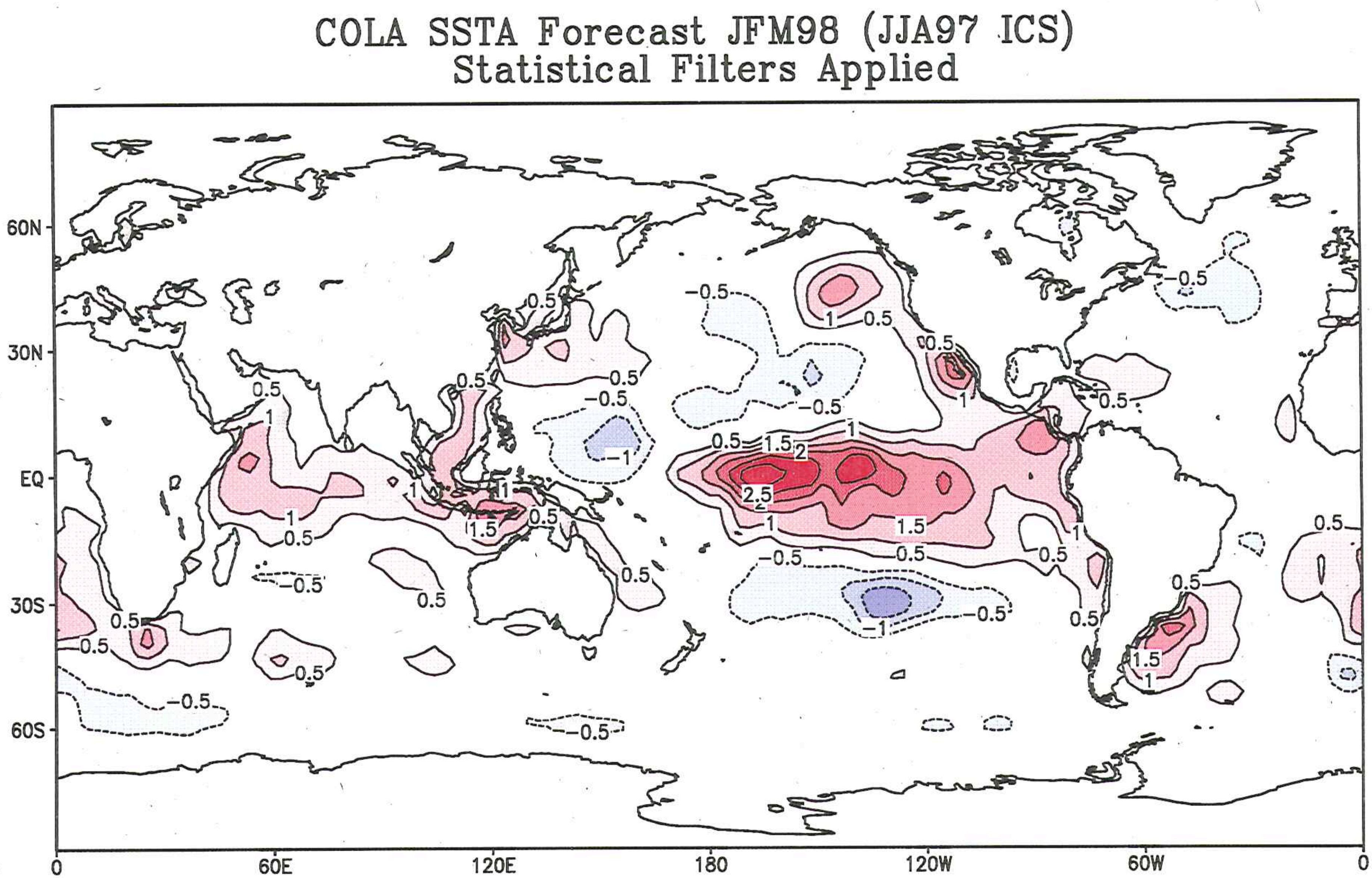
Xue, Y., P.J. Sellers, J.L. Kinter III, and J. Shukla, 1991: A simplified model for global climate studies. *J. Climate*, **4**, 345-364.

Figures

Figure 1: Forecast SSTA for January - March 1998 for the global (non-polar) oceans produced by the application of statistical projections (as described in text) to the tropical Pacific SSTA produced by the tropical Pacific anomaly coupled model. The contour interval is 0.5°C with red shading for positive departures from normal and blue shading for negative departures.

Figure 2: Forecast surface air temperature anomaly for January - March 1998 produced by the COLA atmospheric general circulation model (AGCM). The lower boundary condition applied at oceanic gridpoints was the SST obtained by adding the SSTA shown in Fig. 1 to the observed climatological mean SST. The ensemble mean of nine forecasts with slightly perturbed initial conditions (based on atmospheric observations for mid-December) is shown. The anomaly is defined relative to the COLA AGCM climatological mean. The contour interval is 1°C with red shading for positive departures from normal and blue shading for negative departures.

Figure 3: Forecast precipitation anomaly for January - March 1998 produced by the COLA atmospheric general circulation model. Contours are shown 0, ±0.5, ±1, ±2, ±3, ±4, and ±5 mm day^{-1} with green shading for positive departures from normal and yellow shading for negative departures.



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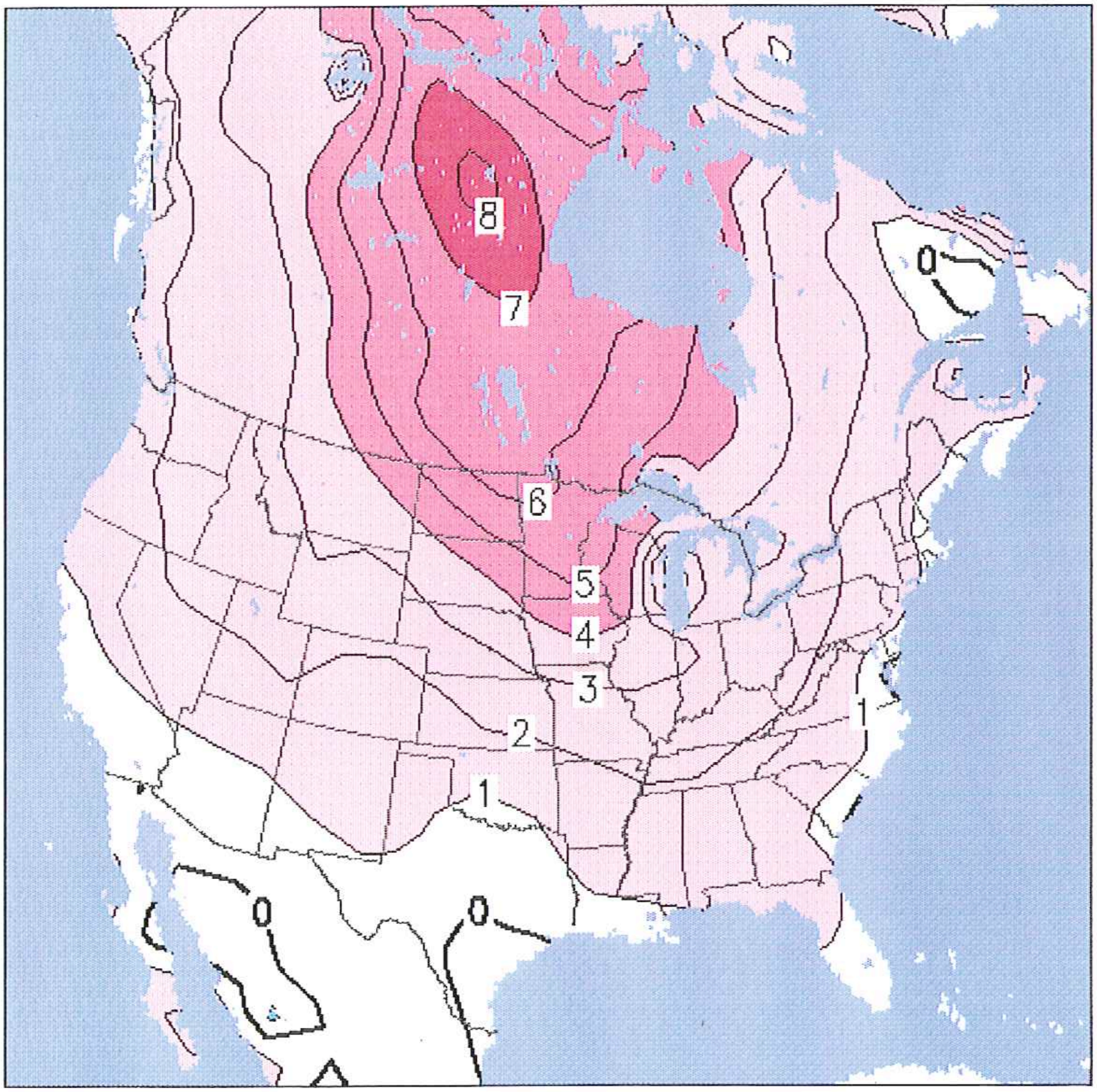
Surface Temperature Anomaly (deg C)
Winter (JFM) 1998



Center for Ocean-Land-Atmosphere Studies (COLA) Forecast

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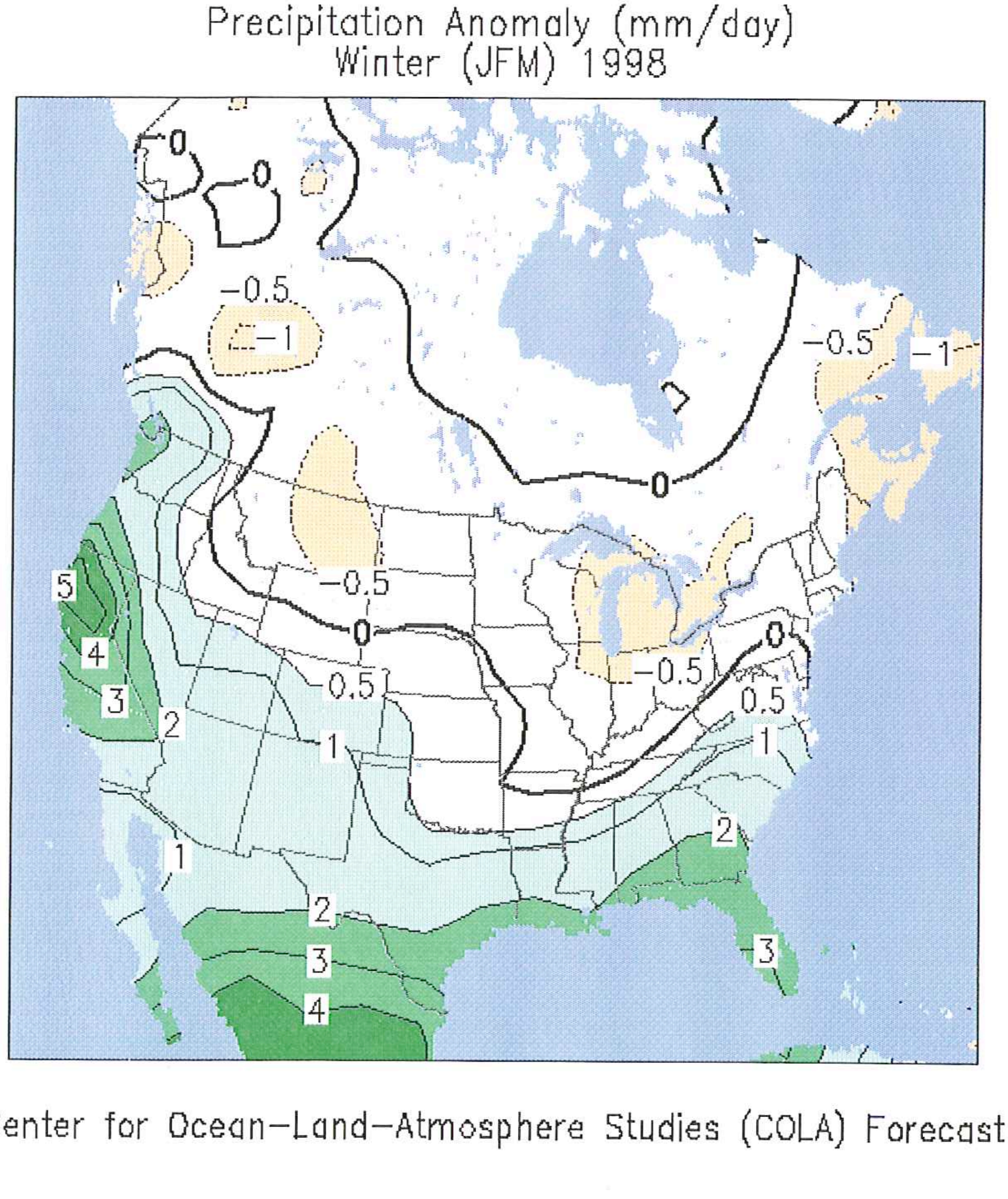

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