INTERACTION OF WEATHER AND CLIMATE AS DIAGNOSED FROM HOURLY OUTPUT 57-YEAR

5.2 DYNAMICAL DOWNSCALING OF REANALYSIS AT 10KM OVER CALIFORNIA

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1. INTRODUCTION

In this presentation, we separate "weather" and "climate" (W&C) by frequency. "Weather" is assumed to have a short time scale of a few hours to several days, while "climate" has a time scale ranging from monthly, seasonal to decadal and long term trend. The "weather" consists of larger amplitude, fast varying small spatial scales, while "climate" tends to be characterized by slowly varying large scale. The "weather" is generally embedded within the "climate". If we further assume that "weather" is a meso scale phenomenon, we need to consider another layer of scale separation, synoptic and meso scale.

In extra-tropics, the synoptic scale "weather" develops within a special large scale "climate" environment. In other words, the "climate" forces the synoptic scale "weather". A good example is found during El Nino. The southward shift of the subtropical Jet due to the strong equatorial SST forcing moves the winter Pacific storm track to the south, increasing storm caused precipitation to southern California. A similar increase in precipitation is observed in the southeastern U.S. There are many other examples, such as the summer draught and flood in the Midwest and the explosive development of cyclones in the East Coast during winter, although the relation between climate and weather is often masked by climate noise and not so clearly detected. Note also that the existence of a favorable large scale condition for synoptic scale "weather" is a necessary condition but not a sufficient condition. The synoptic scale under certain climate forcing, particularly ENSO, has been discussed and studied by many people. (Halpert and Ropelewski, 1992; Trenberth and Guillemot, 1993; just to name a few). Other good examples are found in blocking studies (Illari and Marshall, 1983), in which transient motion feeds back to maintain blocking flow.

The meso-scale "weather" is further imbedded within the synoptic scale. The relation between synoptic and meso scales is analogous to the relation between "climate" and synoptic scales, but with much stronger mutual interaction in the former. Since meso scale interacts with climate scale via synoptic scale in normal circumstances, the studies on the direct connection between the "climate" and meso-scale weather is very limited. There is an exception to this limited interaction, in the tropics, where the situation is quite different. The meso-scale "weather" is a part of the large scale "climate" and not forced by the "climate". More discussion on scale interaction in the tropics can be found in Johnson (2006).

In this study, we will focus on the direct connection between meso-scale "weather" and "climate". This study is a very preliminary attempt to demonstrate relative magnitude of meso scale "weather" of the space scale of tens of kilometers directly affecting long term (monthly mean) fields ("climate"). The analysis is based on the recently completed California Reanalysis Downscaling at 10km project (CaRD10, Kanamitsu and Kanamaru 2006; Kanamaru and Kanamitsu 2006). The relatively high 10km resolution and hourly output allowed us to look into the relation between meso-scale "weather" and "climate" in the California region for the first time.

2. CaRD10

The CaRD10 project has dynamically downscaled coarse resolution global NCEP/NCAR reanalysis to 10km hourly analysis over California for the last 57 years. Kanamitsu and Kanamaru (2006) validated the downscaling with station observations and showed that the downscaling produces analysis which fits better with station observation than the large scale analysis that forced the regional domain. The downscaling was also able to reproduce several meso-scale phenomena with reasonable accuracy. The diurnal variations of winds and temperature were also very well reproduced. For the detailed performance of the downscaling analysis, refer to Kanamitsu and Kanamaru (2006). Additionally, the paper by Kanamaru and Kanamitsu (2006) compares the downscaling with the North American Regional Reanalysis, and presents the importance of horizontal resolution in the regional analysis.

3. CONTRIBUTION OF MESO-SCALE WEATHER TO LONG TERM AVERAGE

We have chosen two meso-scale phenomena, diurnal variation and Santa Ana, to demonstrate their contributions to the long term monthly mean.

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3.1 Diurnal Variation

Strong but often disregarded meso scale phenomenon in relation to the long term average in extra tropics is the diurnal variation. Although its amplitude is known to be large during the summer time, the integrated effect of diurnal variation has not been examined in detail. This is primarily due to the lack of small scale observation network that provides detailed 4-dimensional structure of the diurnal variation and associated local circulations. The hourly output CaRD10 allows us to look in detail into various characteristics of the diurnal variation, the interaction with coastlines and complex topography and its associated circulations. The performance of the diurnal variation in CaRD10 has been compared against hourly station observation using composite technique and was shown to be reasonably accurate. Thus, although the diagnostics based on CaRD10 may be model dependent, it should have good relevance to reality.

In this study, we focused on the transport of heat and moisture by the diurnal eddy component and its contribution to the long term average. The computation was made as follows. Firstly, long term average (1950-2003) at each hour for a given month was computed (24 averaged fields for each month). Using this climatological diurnal variation, we computed various transports averaged over a day. For example, for the field “f” which represents temperature or moisture in our case, the transport vector by diurnal variation is expressed as $\langle \mathbf{V}'f' \rangle$, where prime is the deviation from daily mean and < > stands for daily average. The time rate of change of <f> will be expressed as the divergence of the flux vector:

$$\partial \langle f \rangle / \partial t = -\mathrm{div}\ (\langle \mathbf{V}'f' \rangle), \qquad (1)$$

where div is a divergence operator. In Figure 1, the transport vector of heat due to diurnal variation is presented. This transport of heat occurs since the diurnal variation is not symmetric between day and night and temperature and moisture are correlated with the diurnal component of winds. The figure presents that generally the diurnal component transports heat towards the inland from the coastal area. The transport starts at the coastal land areas and complex topography modified the direction of the transport further inland. The transport vector seems to direct upward along the mountain slopes, converging near the top, slightly on the eastern side of the mountain. There seems to be very little heat transport from ocean to land. It seems that the eddy transport occurs only in association with the interaction of sea breeze and topography induced circulations. The flux convergence of the transport vector is shown in Figure 2. The convergence (positive is defined as convergence) of heat is observed about 50 km inland from the coast along the mountain slopes and also the west facing slopes of the Sierras. Thus, the outline of the central valley is clearly seen.

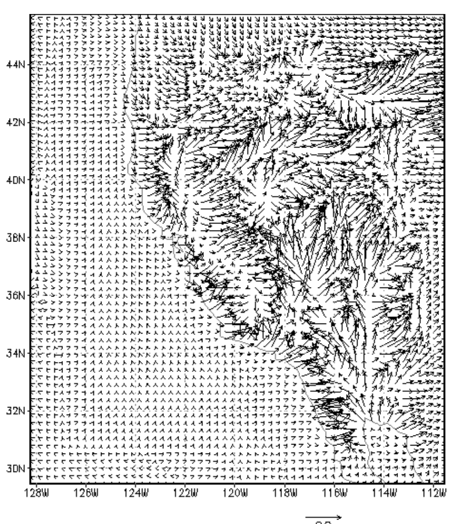

Figure 1. Climatological August heat flux due to diurnal variation at 10m above ground. Unit in m^{o}K

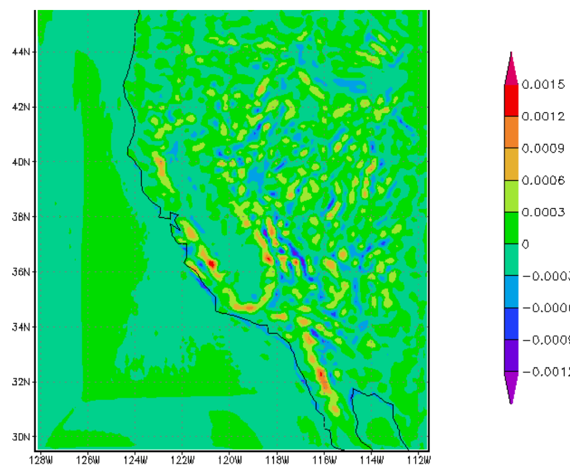

Figure 2. Climatological August heat flux convergence by diurnal eddy component at 10m above ground. Unit in ^{o}K/sec.

In the state of California, heat convergence dominates, thus the heating due to diurnal cycle should also be seen in large scale. The heating rate is of the order of 1×10^{-3} per sec. Compared to the total heat flux convergence (not shown), this heating rate is about 10% of the total, which is not negligible. For the moisture, eddy transport tends to be towards ocean. The flux vector is more chaotic, as is its pattern of convergence (not shown). This is primarily due to the very dry environment.

This computation demonstrated that the diurnal variation has some noticeable contribution to daily mean large scale field, particularly in summer time. The effect shows up in small scale along the mountain tops and slopes, and contributes to about 10% or more of the time mean heat budget. Since the diurnal variation shown here occurs almost every day during the summer, the daily contribution is directly translated to the contribution to monthly or even longer time mean scale.

4. IMPLICATION TO GLOBAL AND REGIONAL MODELING

Aside from the analysis of the interaction between Weather and Climate, the study of the interaction between W&C has an interesting implication to parameterization of sub-grid scale phenomena in large scale numerical models. In the coarse resolution model of the atmosphere, whose resolution is greater than several tens of kilometers, it is necessary to "parameterize" sub-grid phenomena. These sub-grid phenomena are often made of meso scale "weather" which cannot be resolved by the coarse resolution model. Although most of the significant meso-scale phenomena are parameterized in some way or other, the sea breeze, mountain-valley breeze and local circulations forced by surface irregularities have been excluded. This is due to the lack of quantitative measure of the importance of local circulations on large scale motion, and to the difficulties in parameterizing them. For the large scale model, whose horizontal resolution is greater than the scale of the local circulations, those circulations are ill represented and become the source of error. Currently, the remedy is simply to increase the resolution of the model, but there is still a limitation to this approach. The analysis in the previous section suggested the possibility of an importance of the parameterization of local thermally forced circulation. In this regard, the analysis and understanding of the interaction between W&C, particularly the diurnal component, will provide an excellent opportunity to initiate research on the parameterization of thermally and dynamically forced local circulations.

3.1 Santa Ana

Figure 3 shows the interannual variability of December mean near surface (10 meter) u-component of wind computed from 50+ years of monthly means. The most striking features observed in this figure are the very fine scale max/min over ocean and along the coastal ocean. The largest variability over ocean occurs just north of Los Angeles (119.5W, 33.8N). The horizontal scale of the area of large variability is about 50-70km. When we compare this pattern with the typical Santa Ana composite (Figure 4), we see areas of strong surface wind corresponding well with the largest variability. In order to find this correspondence better, we used a list of Santa Ana events (courtesy of Dan Cayan), which are determined from days with a pressure difference between typical great basin and near ocean stations, together with restrictions on wind direction and dew point depression. For December during 1953-2003, there were 291 Santa Ana days out of 1581 days, Santa Ana occupying about 18%. Considering the strength of the event and the large percentage, the Santa Ana may show a large influence on monthly mean climatology.

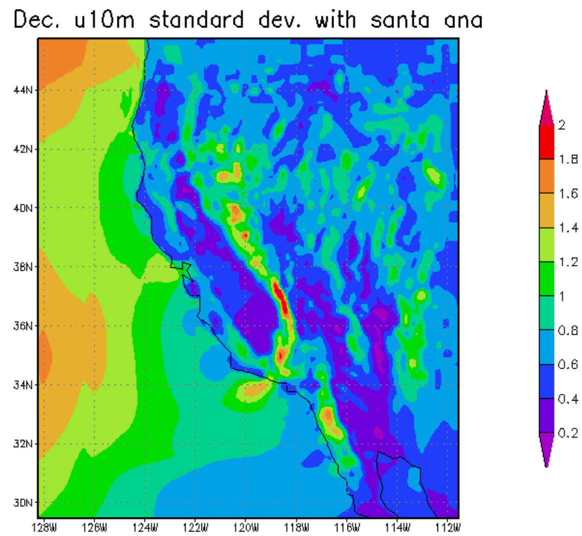

Figure 3. Standard deviation of December mean 10-meter u-component of wind. Unit m/sec.

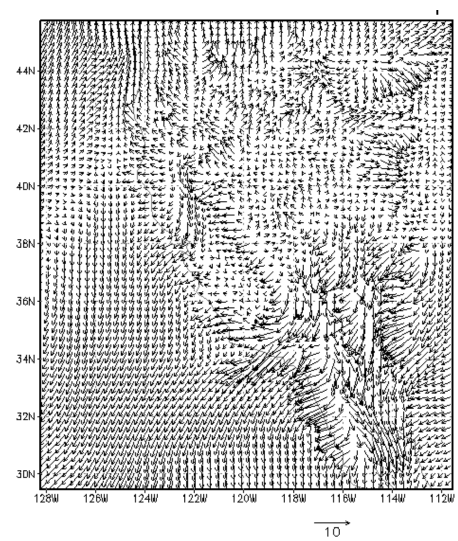

Figure 4. December Santa Ana composite of 10m winds.

In order to demonstrate this more clearly, we generated means and variability maps with and without Santa Ana events. This is much like extracting dominant EOF mode, but is a more synoptically oriented approach without assuming any linearity in Santa Ana events. In reality, there is no negative phase of Santa Ana events and application of EOF analysis may be problematic. Figure 5 shows 51 years of climatology of 10 meter u-component of winds with and without Santa Ana days, and their differences. It is very clear that the Santa Ana with meso scale features has considerable impact on climatology.

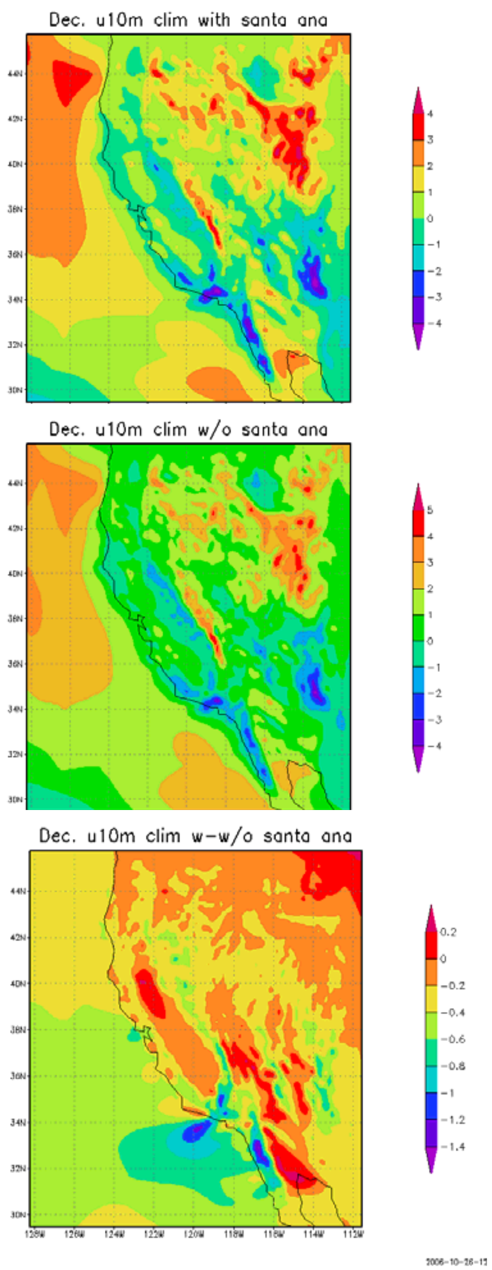

Figure 5 December Climatology of u-component of wind at 10m. Top: climatology with Santa Ana, middle: Climatology without Santa Ana, and bottom: difference between the two. Unit in m/sec.

In addition, we see good correspondence between the areas of variability along the coast with the large difference in climatology. Interestingly, however, the comparison of year to year variability with and without Santa Ana shows (not shown) that the role of Santa Ana is only of the order of 5 – 10 % of the total variability. This seems to indicate that the interannual variability of Santa Ana is not large, but its contribution to long time mean is larger.

4. CONCLUSIONS

Two meso scale phenomena, diurnal variation and Santa Ana, are chosen to demonstrate the direct interaction between meso-scale and climate scale using 10km Downscaling of Reanalysis over California dataset.

Diurnal cycle and associated local circulations transport heat and moisture as a daily mean. Heat is transported from the coastal area to further inland. Convergence of heat flux is found along the top and to the slightly east side of the coastal mountains and mountains adjoining the Central Valley. The flux of moisture is more from inland towards coastal areas, but is not so organized. The magnitude of the contribution to heating and moistening is about 10% of the flux convergence due to total wind. The effect of the transport should also be seen in the large scale mean field. This effect of transport is often neglected in the large scale models, and it can be an important component of heat and moisture budget when the maintenance of long time mean climatological state is considered.

The contribution of much stronger "meso-scale" Santa Ana to monthly average climatology can also be demonstrated to be significant. This importance of occasional strong events to long term climatology is unique to wintertime California. We should aware that the long term climatology in meso scale does not necessarily provide base field in which the meso scale is imbedded. Rather, the mean field itself includes a part of the meso scale. In this sense, the use of EOF analysis may produce misleading results due to the assumption of linearity and symmetry. If we define the base field as a long time mean without Santa Ana, the year-to-year variability of base field is not so different from year-to-year variability of the field that includes Santa Ana. The contribution of Santa Ana to temporal variance is not of the order of 5 – 10%.

There are many other meso-scale phenomena in California, such as Catalina Eddy, coastally trapped wind reversals and atmospheric river events. A quick look at the first two phenomena showed that they are very short lived and not strong enough to affect large scale or time mean field. However, further work is needed to confirm this weak interaction with climate in a more systematic manner.

6. REFERENCES

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