



## **Snowfall Occurrence at Two Lee-Side Mountain Locations Comparing the Sierra Nevada, California & the Rocky Mountains, Colorado**

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### **Introduction**

Snowfall occurrence, snow pack, and the atmospheric circulation conditions associated with snowfall in the Sierra Nevada and the Rocky Mountains are compared. The two sites, Mammoth Mountain, California, and Niwot Ridge, Colorado, are at similar latitudes and elevations, and both are on the lee sides of their respective mountain ranges. Mammoth is much closer to the Pacific Ocean, and Niwot is a continental site. Data from three winter seasons, 1996-97, 1997-98, and 1998-99, are used in this study.

Differences and similarities in atmospheric circulation associated with snowfall occurrence are described, and relationships of snowfall to ENSO phase are noted. Only three seasons are used in this study, but each occurs during a different ENSO phase: neutral in 1996-97, warm in 1997-98, and cold in 1998-99. The weather patterns associated with snowfall occurrence and maximum snowfall are slightly, but significantly, different between these seasons.

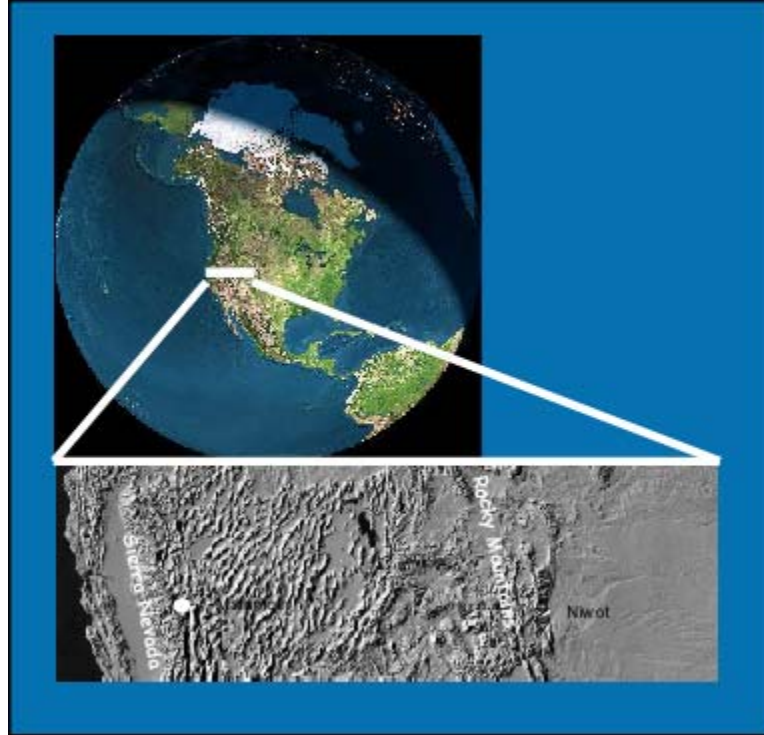


Fig. 1

## Site Locations

Mammoth Mountain, California (37°N, 119°W, 2835m)

- Lee slope of the Sierra Nevada
- Maritime, warmer, moister

Niwot Ridge, Colorado (40°N, 105°W, 3048m)

- Lee slope of the Rocky Mountains
- Continental, colder, drier

Both sites are on the lee of major, north-south mountain ranges. (Fig. 1)

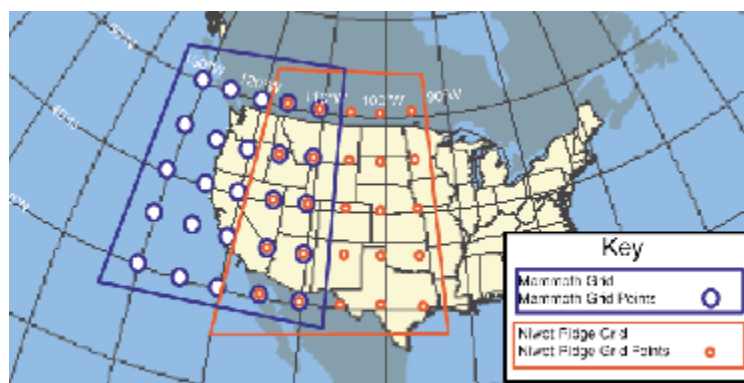


Fig. 2

## Data

Three seasons, 1996-97, 1997-98, and 1998-99 are studied at both

sites. Each season occurs during a different ENSO phase:  
1996-97 Neutral phase, neither warm nor cold  
1997-98 Warm phase, a strong El Nino  
1998-99 Cold phase, a strong La Nina

Snowfall data was collected at the Mammoth and Niwot sites using snow boards or precipitation gauges.

NCAR Geopotential Height Data was used to compute circulation indices and synoptic weather patterns at the 700mb and 850mb levels. (Fig. 2)

## Analysis

Periods of snow and no-snow occurrence were identified at both sites. Synoptic weather patterns (twenty-seven possible) and circulation indices (four) were computed separately for the snow and no-snow periods at two atmospheric levels, 700 mb and 850 mb, at both sites. Significance levels of the means of the two populations were computed for each of the four circulation indices. The occurrence of snow or no-snow was then characterized by circulation indices and synoptic weather pattern. The 0.00% level was considered significant, and less than 2.5% was noted. (Fig. 3)

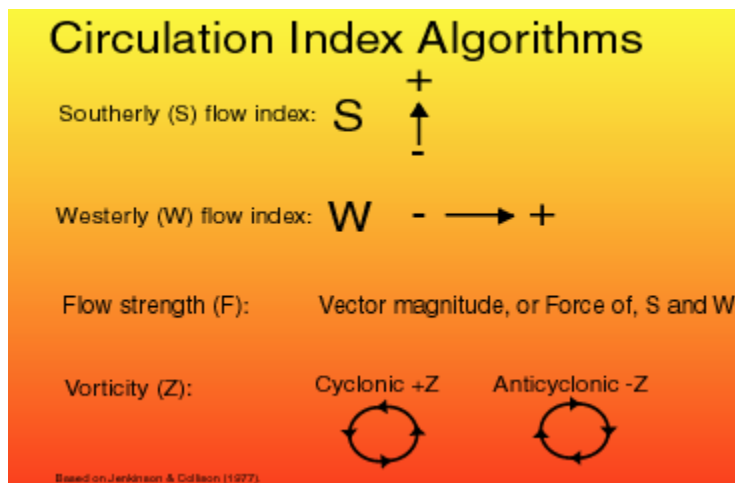


Fig. 3

## Results

### Precipitation

Mammoth snow water equivalent and snow pack density were 2.4 times greater than at Niwot, but the Mammoth snow season was 37% shorter than Niwot's. (Fig. 4) The seasonality of snowfall was also different. Snow fell at Mammoth primarily from December through February, but the Niwot snowfall season often included

October and November, with the heaviest snowfalls in March and April. (Fig. 6)

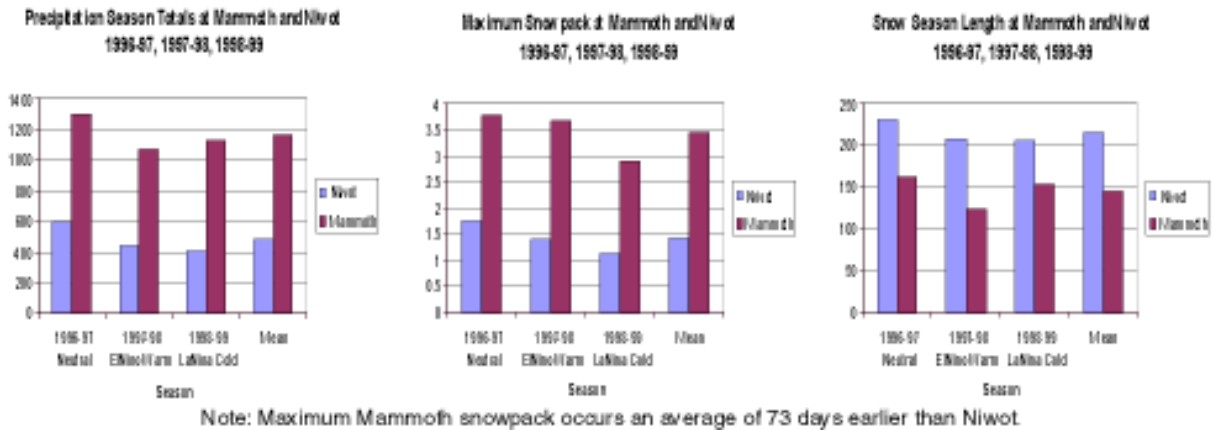


Fig. 4

### Circulation Indices & Snow Occurrence

Increased vorticity, at both 700mb and 850mb, is the strongest and most significant index association with snow occurrence at both sites. (Fig. 5)

Beyond this, the south (S) index is most different between sites. Snow tended to occur at Mammoth with an increase in the S index, in contrast to Niwot where snow tended to occur with a decrease in the S index.

### Weather Types for Snow and No-snow Occurrence

Generally, Mammoth snowfall occurred most frequently during the strong zonal westerly weather type, but southwesterly and cyclonic weather types also brought snow. No-snow periods occurred with northwesterly and anticyclonic weather types.

Niwot snowfall occurred most frequently with cyclonic weather types passing south of the site. No-snow periods were associated with zonal, westerly weather types, and high pressure conditions. (Fig. 7)

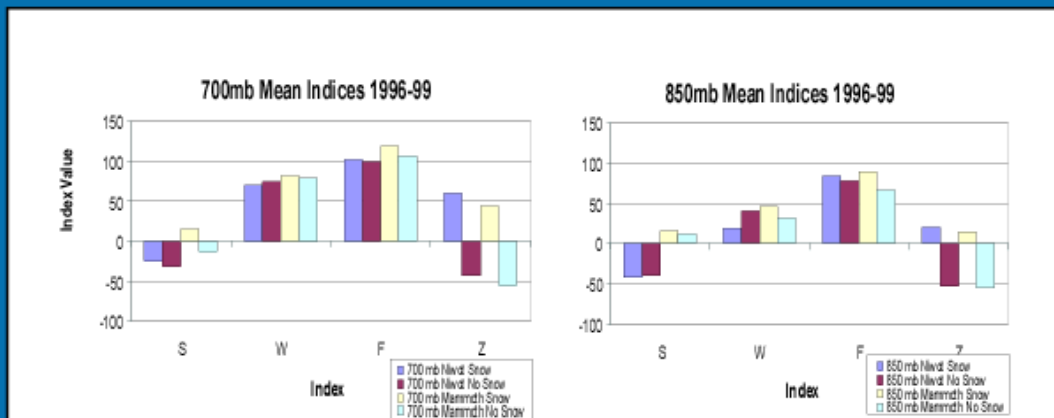


Fig. 5

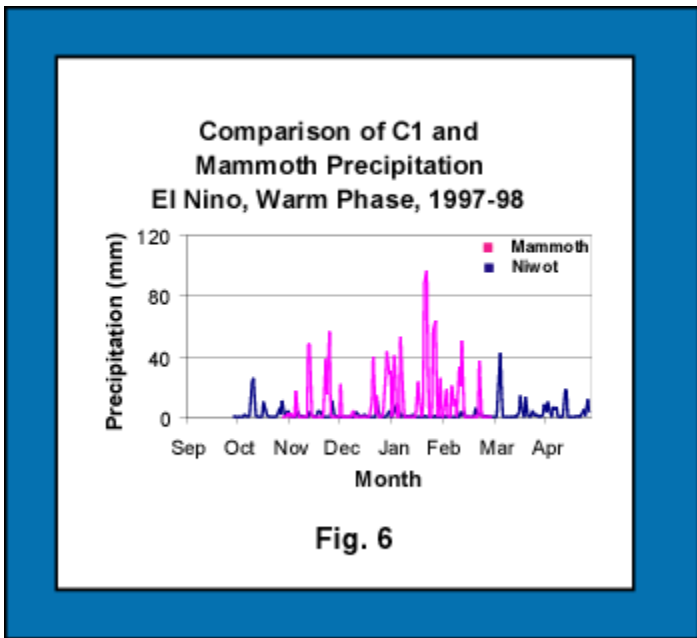
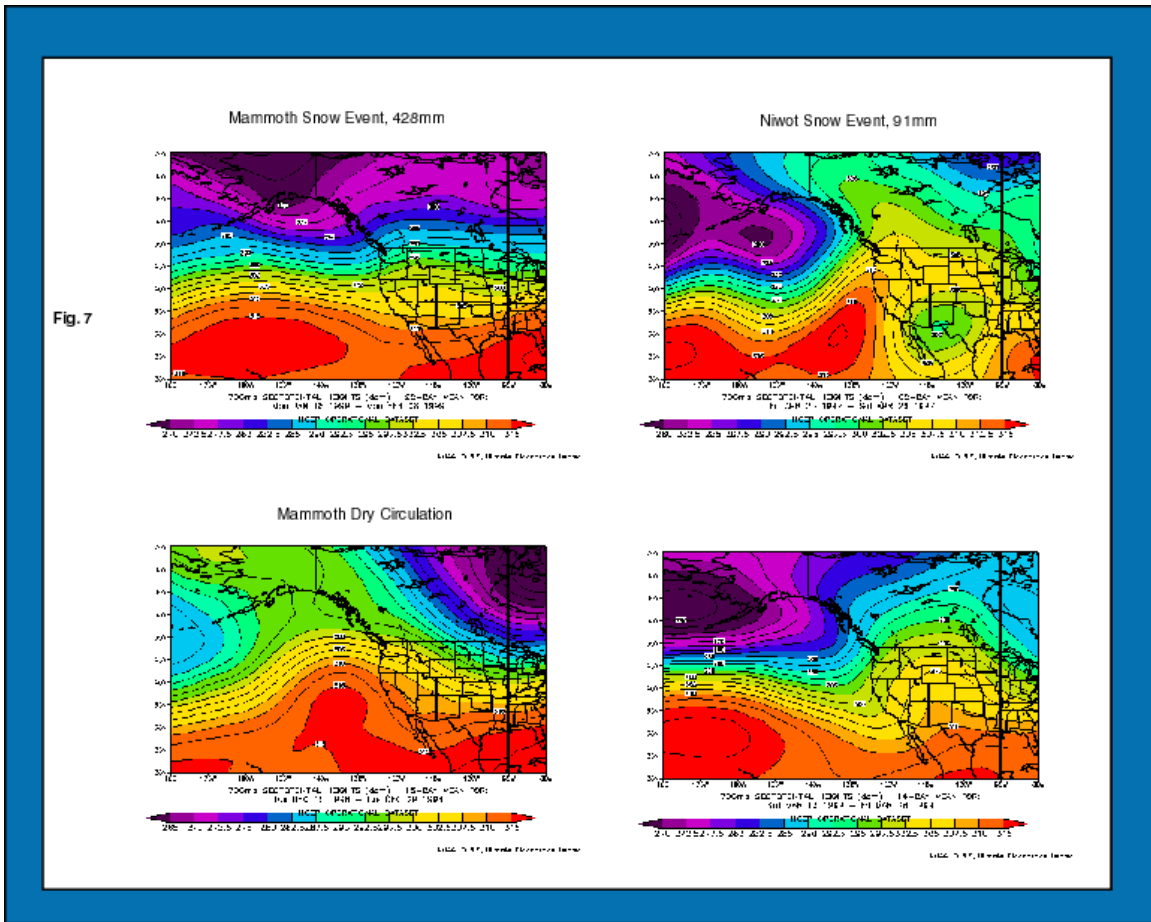
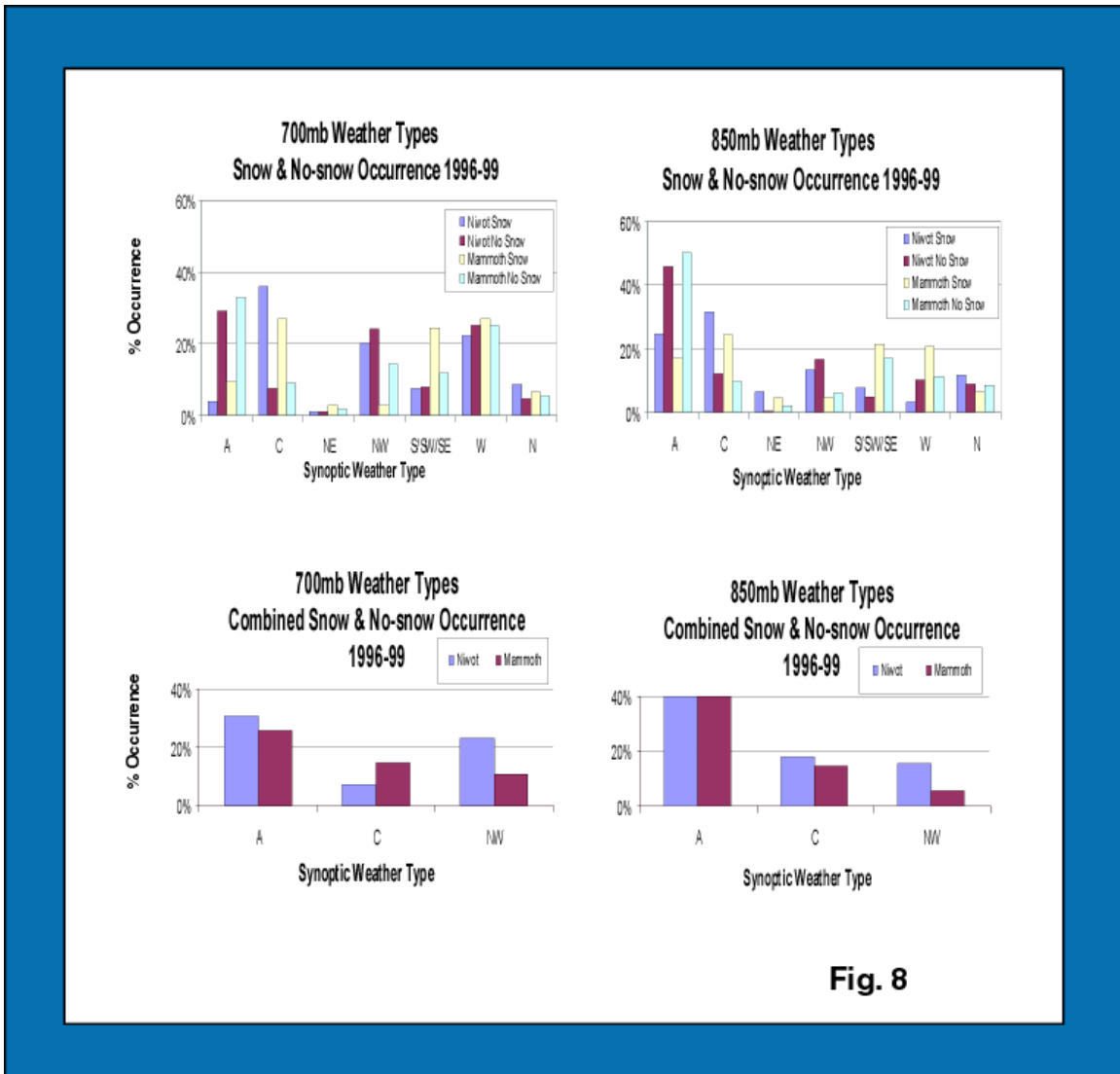


Figure 8 shows the frequency of the synoptic weather types for snow and no-snow occurrence.



**Fig. 8**

**Results**

**Inter-seasonal Variability: ENSO Signature?**

Each of the three seasons of this study occurred during a different ENSO phase: 1996-97 was a neutral phase - neither warm nor cold, 1997-98 was a warm phase, and 1998-99 was a cold phase (Fig. 13). Thus, cautious observations about ENSO phase and snow occurrence are tempting but clearly speculative, based upon the small sample size. (Fig. 9)

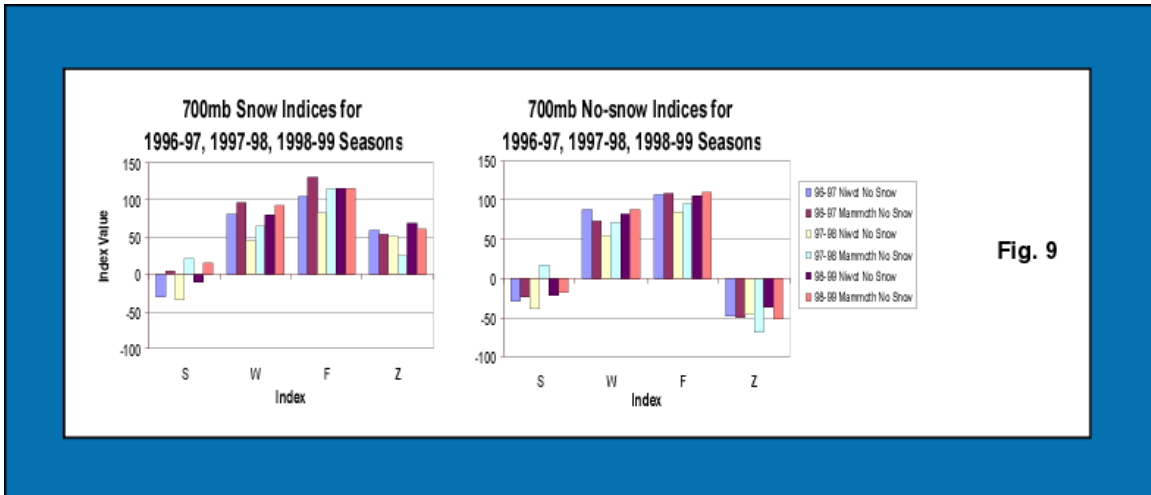


Fig. 9

**Synoptic Weather Type**

The inter-seasonal variability of weather types associated with snowfall was higher at Mammoth than at Niwot. At Mammoth, the western weather type brought the most snow during the 1996-97 season (neutral phase), compared to southwesterly type during the 1997-98 season (warm phase) and cyclonic type during the 1998-99 season (cold phase). (Fig.10)

At Niwot, snowfall was mainly associated with the cyclonic weather type during all three seasons, but during the 1996-97 and 1997-98 seasons (neutral and warm phases), Niwot snowfall was also associated with the northwest type. During the 1998-99 season (cold phase), the westerly and southwesterly synoptic types became very important.

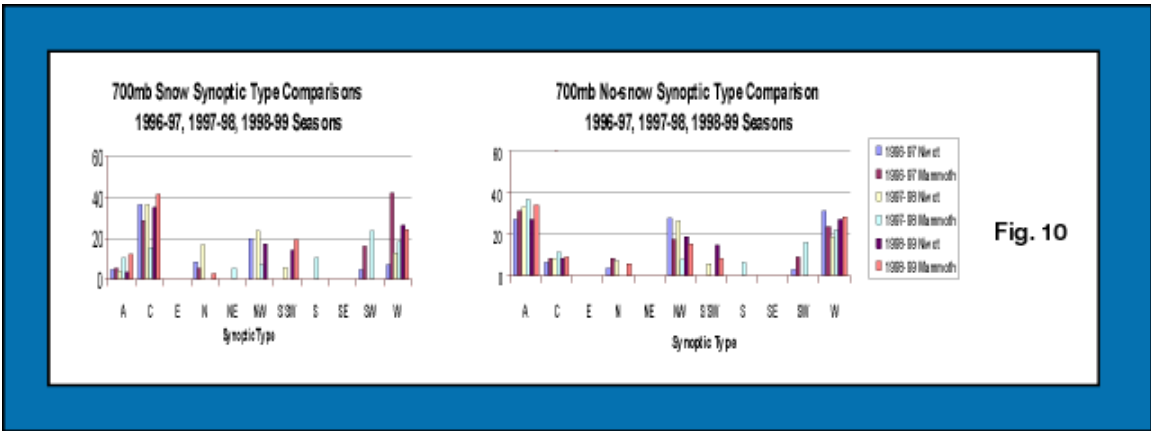


Fig. 10

## Wind Direction

Wind directions associated with snowfall changed between the seasons. At Mammoth, snowfall was most often associated with west winds in 1996-97, with southwest and west in 1997-98 and with west in 1998-99, but southwest winds were a strong second in this season. Interestingly, northwest winds normally deter snowfall, but this was not the case in the 1997-98 season (warm ENSO phase).

At Niwot, northwest winds do not appear to have such a strong snow deterrent effect. Here, snow was most often associated with west and northwest winds in 1996-97, with northwest winds in 1997-98, and with west winds in 1998-99. (Fig. 11)

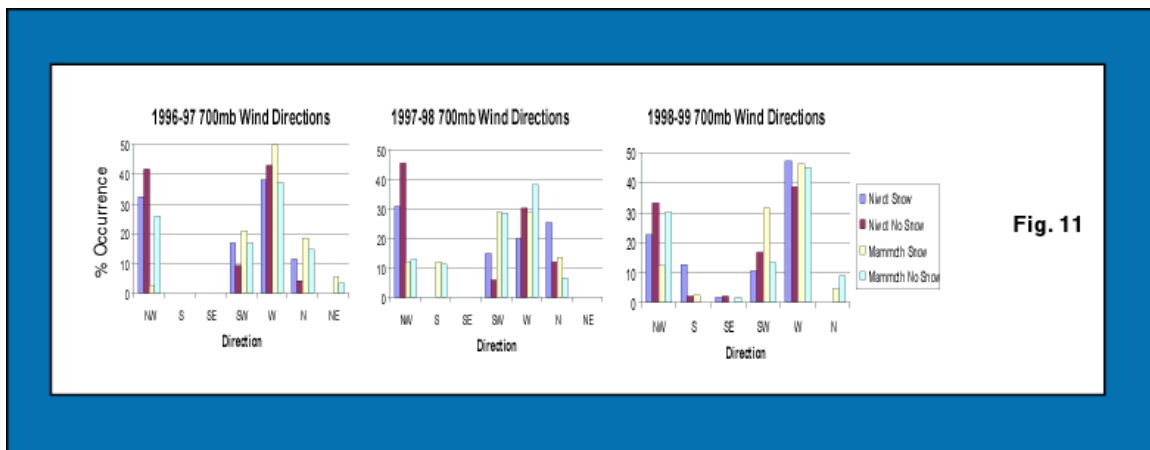


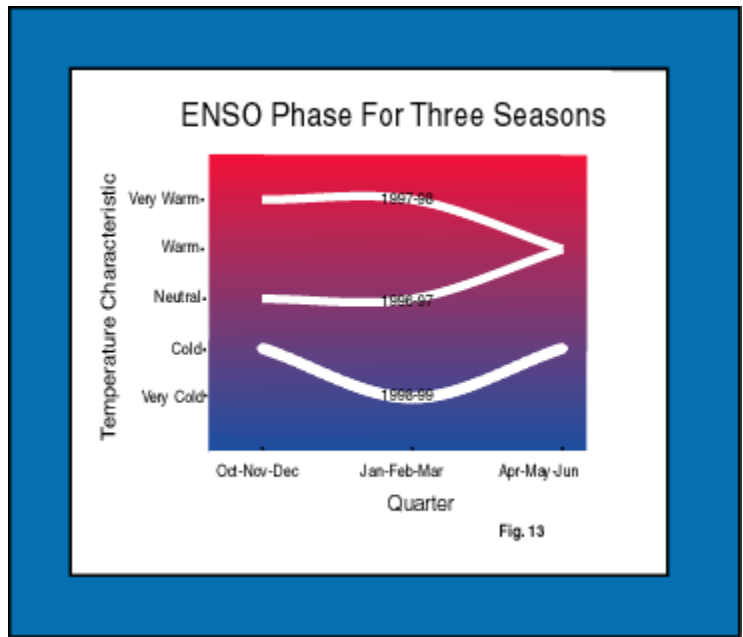
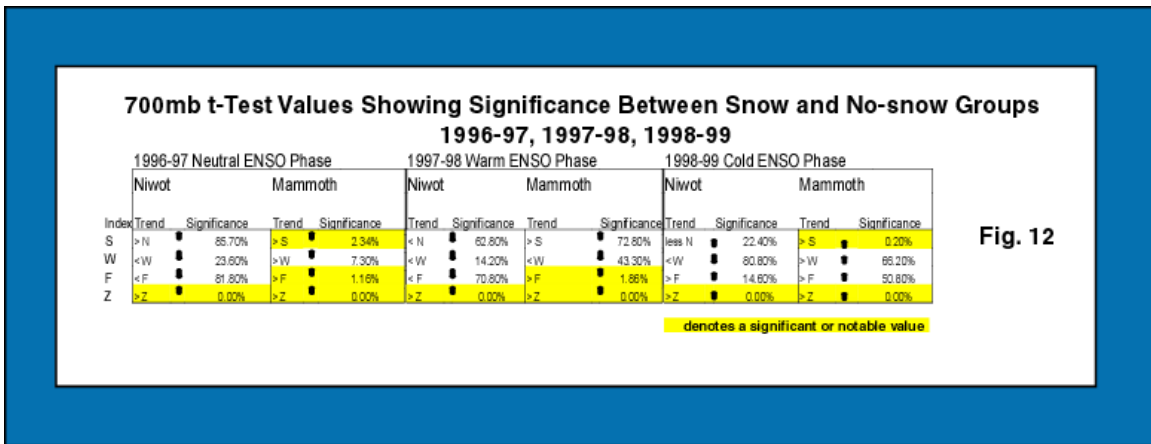
Fig. 11

## Circulation Indices

Clearly the most consistently significant index at both sites was vorticity ( $Z$ ), and it was independent of ENSO phase. Niwot snowfall occurrence was fairly insensitive to changes with ENSO phase, but there were some interesting index-related variations at Mammoth.

At Mammoth, the south (S) circulation index became significantly important for snowfall in the 1998-99 season (cold phase), in contrast to being completely insignificant during the 1997-98 (warm phase), and marginally significant during the 1996-97 (neutral phase). Also, Force became insignificant during the 1998-99 season (cold phase), but was marginally significant during the 1996-97 and 1997-98 seasons (warm and neutral phases). (Fig. 12)

At Niwot, there were no significant changes in index values between the ENSO phases.



## Summary

Mammoth precipitation and snow pack was 2.4 times that of Niwot, and the Mammoth season length was 37% shorter than Niwot's.

Generally, Mammoth snowfall was associated with the westerly weather type, and Niwot snowfall was associated with the cyclonic weather type.

For the three seasons combined (1996-97, 1997-98, 1998-99):

- The cyclonic weather type produced snow most often, and anticyclonic weather type was dry at Niwot, at both the 700 mb and 850 mb levels.
- At Mammoth, snow occurred about equally with the cyclonic, the westerly, and the southerly synoptic types, and no-snow occurred mainly with the anticyclonic type, at the 700 mb and 850 mb levels.

- Northwest and north weather types brought dry conditions to Mammoth, but often produced snow at Niwot.
- West, southwest, and south weather types were related to snowfall at Mammoth, but not at Niwot.
- At both the 700 mb and 850mb levels, increased vorticity was the most significant index associated with snow occurrence and was independent of the ENSO phase, at both Mammoth and Niwot.
- The south and flow strength indices were moderately significant in the occurrence of snowfall at Mammoth.

#### Inter-seasonal/ENSO-related Snowfall Variability

- Index-related snowfall occurrence at Niwot was fairly insensitive to changes with ENSO phase; Mammoth snowfall was not. At Mammoth, the south index became significant for snowfall in the 1998-99 season (cold phase), and flow strength became insignificant.
- Synoptic weather types associated with snowfall were more variable at Mammoth than at Niwot. At Mammoth, the westerly weather type dominated snowfall frequency in the 1996-97 season (neutral ENSO phase), the southwestern weather type dominated in the 1997-98 season (warm ENSO phase), and the cyclonic weather type dominated the 1998-99 season (cold ENSO phase).
- At Niwot snowfall was primarily associated with cyclonic weather patterns, and secondarily with the Northwest weather type in all ENSO phases. In the 1998-99 season (cold ENSO phase), the westerly and southwesterly weather types also became important.