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THE SIERRA ROTORS PROJECT, OBSERVATIONS OF MOUNTAIN WAVES

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1. INTRODUCTION

The Sierra Rotors Project, led by investigators at the Desert Research Institute (DRI) in collaboration with the University of Washington, the Naval Research Laboratory (NRL) and the National Center for Atmospheric Research (NCAR), examined mountain waves and wave induced rotors in the lee of the Sierra Nevada Mountains in eastern California during the spring of 2004. A range of instrumentation was deployed in Owens Valley, including a dense array of surface stations from DRI, two ISS (Integrated Sounding Systems) from NCAR (figure 1), an additional radiosonde station near Fresno, and various instruments and modeling efforts from other groups. A description and preliminary results from the project are in Grubišić and Cohn (2004).

The two NCAR ISS (Parsons et.al., 1994) consisted of boundary layer wind profilers, surface meteorological stations and radiosondes. One ISS used MAPR (Multiple Antenna Profiler Radar), an advanced wind profiler capable of making fast wind measurements (Cohn et.al, 2001), ideal for capturing rapidly evolving wave events. The other ISS was a mobile ISS (MISS) which was deployed at various locations around the valley to examine the spatial variability in wave events (see Cohn et.al, 2005b, this volume). Several wave events were observed, some with strong activity and possible rotors. This report will concentrate on observations from an Intensive Observation Period (IOP) on March 25-26, 2004, from the two ISS.

The web page for the Sierra Rotors Project is http://www.mdml.dri.edu/; the NCAR project page is http://www.eol.ucar.edu/rtf/projects/srp2004/

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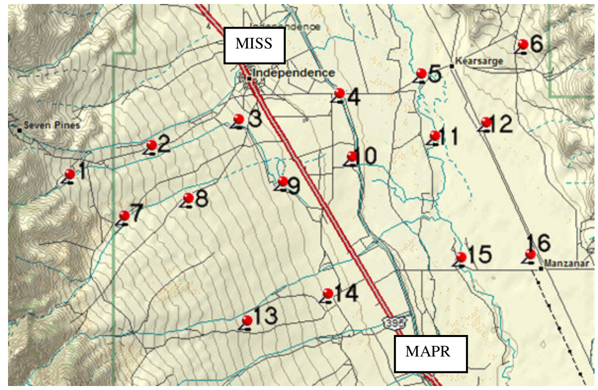

Figure 1 – Map of Owens Valley near Independence showing the locations of MAPR, MISS base and the DRI observation network (numbered stations). MAPR and MISS are about 12 km apart. The valley floor is around at 350m altitude. On the west side of the valley are the Sierra Nevadas which in this vicinity reach above 4000m and to the east are the Inyo Mountains (about 3000m). The valley is around 30 km across at the peaks, and about 15 km across the valley floor. The valley is aligned about 20 degrees west of north-south (approximately following highway 395 in the figure).

2. BACKGROUND FLOW CONDITIONS

Figure 2 shows the background flow in the valley as observed by the MAPR wind profiler. The composite winds for 15 light-wind days are shown. Only day-time hours are shown, as on calm nights measurements were frequently contaminated by migrating bird echoes.

As expected, the location is dominated by thermally driven mountain valley flow; SSE drainage flow down along the valley overnight and during the morning, and then during the afternoon, solar heating leads to weak upslope flow, NNW along the valley. Flow near the valley floor generally only deviates from this southerly/northerly pattern during strong mountain wave activity or other significant weather.

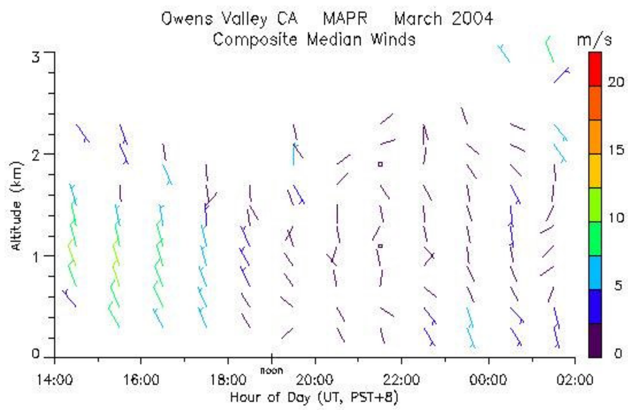

Figure 2: MAPR composite averaged hourly winds for calm days during March, 2004 for 6am to 6pm local time (14 UTC to 02 UTC).

3. IOP8: WAVES WITH ROTORS

On March 25 and 26 there was a strong westerly flow across the Sierra Nevadas at mountain top level. A Pacific cold front passed through the valley at around 12 UTC on March 26. This event was IOP 8 of the field campaign and produced some of the strongest waves and rotors of the campaign.

3.1 *Wind Profiler Observations*

Figures 3 and 4 show contour plots of the vertical velocity, the component of wind across the valley, and the corrected Doppler spectral width as seen by the MAPR and MISS profilers over 21 hours during the event. MISS was

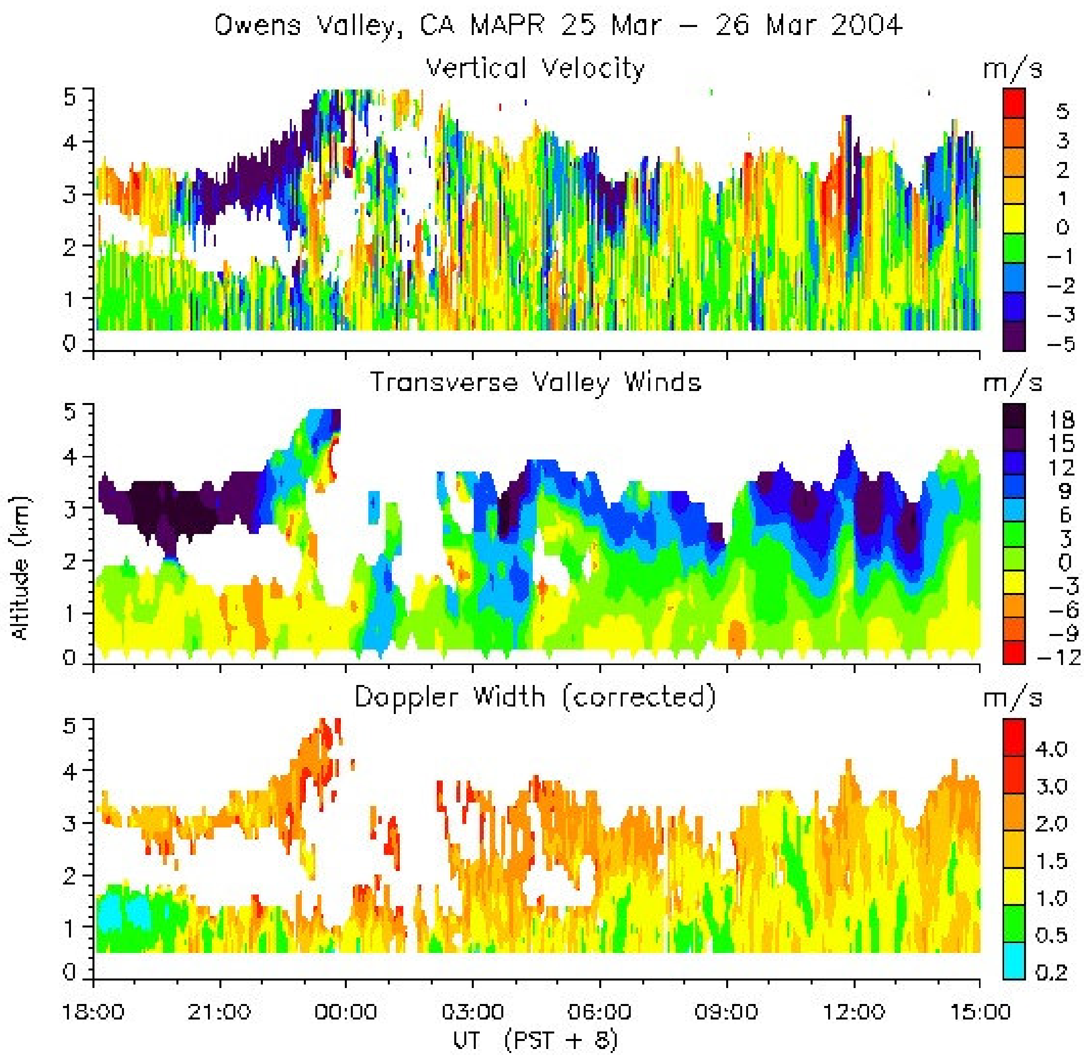

Figure 3: MAPR observations during IOP 8. The top panel shows vertical velocity (positive upwards). The middle panel shows the component of wind orientated directly across the valley (i.e., the wind component 70 deg E of N), thus removing along valley flow effects. The bottom panel shows Doppler spectral width corrected for beam broadening effects.

located at Independence Airport for IOP8 (see figure 1). The profilers depend on clear-air Bragg (λ=33cm) scatter from turbulence, the reflectivity of which is a function of humidity and turbulence. The altitude coverage of the profilers can vary considerably over space and time. For example the elevated layer seen at 3 – 4 km for the first few hours of figure 3 and 4, appears (from soundings) to result from an elevated moist layer, perturbed by shear induced turbulence.

The persistent strong vertical motions (reds and blues, top panels) at the 3 to 4 km level (at and above ridge top) suggest near-stationary waves across the valley. The downdraft episode observed by MAPR (figure 3) from about 2030 for around 3 hours is particularly persistent and during this period there were strong westerly winds indicated by the dark blue regions in the middle panel. At later times (e.g. around 9 – 12 UTC on the 26th) there also seems to be

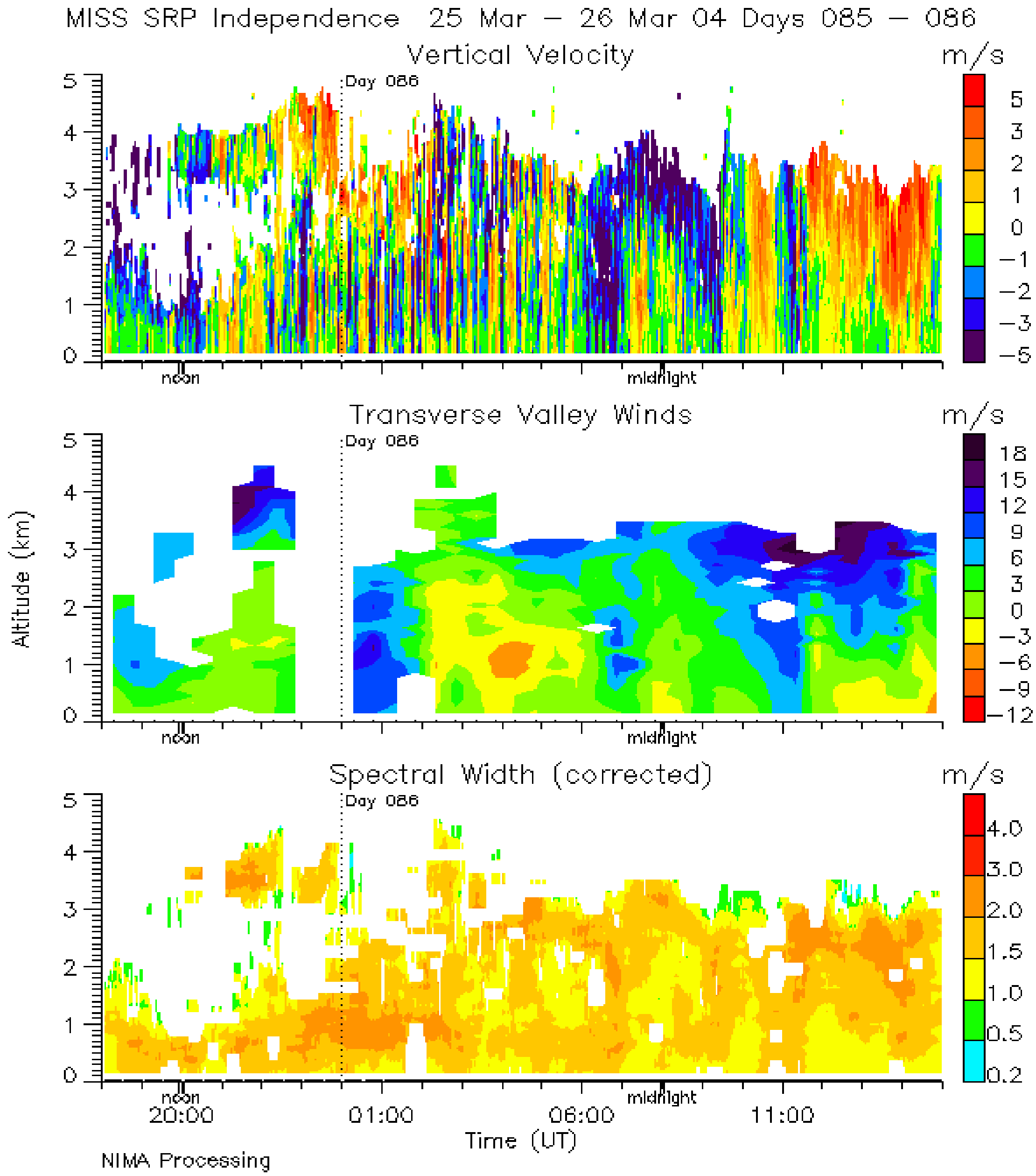

Figure 4. Observations from MISS for the same time period as figure 3. MISS was located near the town of Independence during this period (see figure 1).

a relationship between fluctuations in the westerly flow and vertical velocity in both the MAPR and MISS observations, as trapped waves form and dissipate over the valley

Much of the transverse valley winds (middle panels of figures 3 and 4) are either westerly or very light. The red/orange portions of the plots indicate significant reverse (near easterly) components to the wind; at MAPR at around 22 UTC and 9 UTC (March 26) and at MISS at around 4 UTC (March 26) there were periods of reverse flow at low levels. Periods of easterlies were also observed by the DRI surface network. Some of these flows may be due to thermal slope flows, however it appears that the 4 UTC event was a rotor near the northern (MISS) end of the network, and the 9 UTC event was a rotor around the southern (MAPR) end of the network. It is not yet clear whether the 22 UTC event at MAPR is due to rotor activity or some other activity. These events are discussed further below.

The bottom panels of figures 3 and 4 show the width of the Doppler spectrum observed by the profilers. Corrections for cross wind beam broadening effects were made following the techniques of Gossard and Strauch (1983). Larger values of corrected spectral width can be taken as an indication of turbulence within the radar sampling volume. In general the spectral width increased with altitude and also seemed to increase during periods of strong vertical motion. There appears to be some increased spectral width at the time of the rotors; there is also increased spectral width at other times suggesting much small scale turbulence was also occurring.

3.2 *Soundings*

Several soundings launched from both MAPR and MISS encountered strong downdrafts around the 3 to 5 km level above the valley floor. Figure 5 shows soundings at 0 UTC and 12 UTC from MAPR on March 26. The 0 UTC sounding encountered a particularly strong downdraft about 15 minutes into the flight. The radiosonde was pulled downwards by about 1700 meters at speeds of up to 6 m/s. The downdraft region was between about 4 and 9 km northeast of the launch site. Given that the ascent rate after launch was around 4 m/s, the downdraft may have been as strong as 10 m/s. The high relative humidity suggests the radiosonde entered a cloud at this time and wave and rotor clouds were seen in the valley prior to the sounding. The sounding did show brief easterlies near the ground and just below the 3km level. It is not clear that there was a full valley rotor; however there may have been a small elevated rotor aloft.

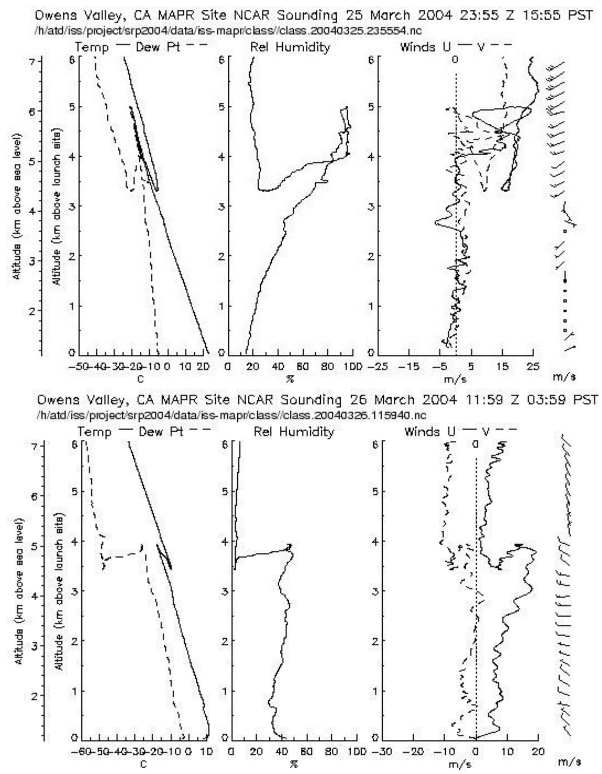

Figure 5 – Radiosonde soundings from the MAPR site on March 26 at around 0 UTC and 12 UTC.

The second sounding of figure 5 (12 UTC March 26) was made during the period of very strong vertical motion and fluctuating westerly flow seen by MAPR. The sounding was pulled down about 500 meters as it encountered a downdraft region as it left the well mixed valley air and entered very dry air above. The fluctuations in vertical velocity and westerly flow seen by MAPR are confined to about a 500m – 1km layer at the same level. It appears that there were trapped waves across the valley at around the mountain top level. The vertical velocity fluctuations do seem to be correlated with the fluctuations in westerly flow; however it is not clear how much of the fluctuations were due to variations in the waves (for example in the positions of the crests) and how much was due to variations in the larger scale flow (for example a front passed through the valley around 12 UTC).

3.3 *Modeling*

DRI is carrying out a modeling study of the IOP8 and other events using the Naval Research Lab (NRL) COAMPS model. It uses 5 nested domains centered over Owens Valley, with 60 vertical sigma levels and an innermost domain resolution of 333 meters. The model seems to be doing a good job of representing many of the main features observed by the ISS, although there are some discrepancies in the precise location and timing of some features.

Figure 6 shows selected model cross-sections across the valley. The purple regions in the plots indicate easterly flow and the line contours indicate isentropes. The top panel shows a cross-section near MAPR at the time of the 0 UTC sounding of figure 5. There is some easterly flow; however the wave activity in the model around this time is not particularly strong. The model does not seem to have produced the dramatic activity seen in the sounding.

The middle and bottom panels show cross-sections near MISS at 4 UTC and near MAPR at 9 UTC respectively. Rotors can be seen in both plots. The model correctly displayed the stronger rotor activity at the northern MISS site as compared to the MAPR site around 4 UTC (not shown). Similarly at 9 UTC, the model showed stronger rotor activity at the southern MAPR site as compared to the MISS site.

4. SUMMARY

The ISS made a series of interesting observations of mountain waves and rotors at the Sierra Rotors project. Wind profilers were used to make near continuous observations of wind and vertical motion in the boundary layer, and radiosondes were used to make spot observations of winds and thermodynamics. Dramatic activity was seen during IOP8, with rotors to ground level which appeared to correlate with features seen in COAMPS model output.

The Sierra Rotors project is a precursor to a larger project known as T-REX (Terrain-induced Rotors Experiment, Grubišić and Kuettner, 2005) in the same area planned for spring 2006. This experiment proposes to further investigate waves and rotors using the ISS and an expanded instrument base, including aircraft and lidars.

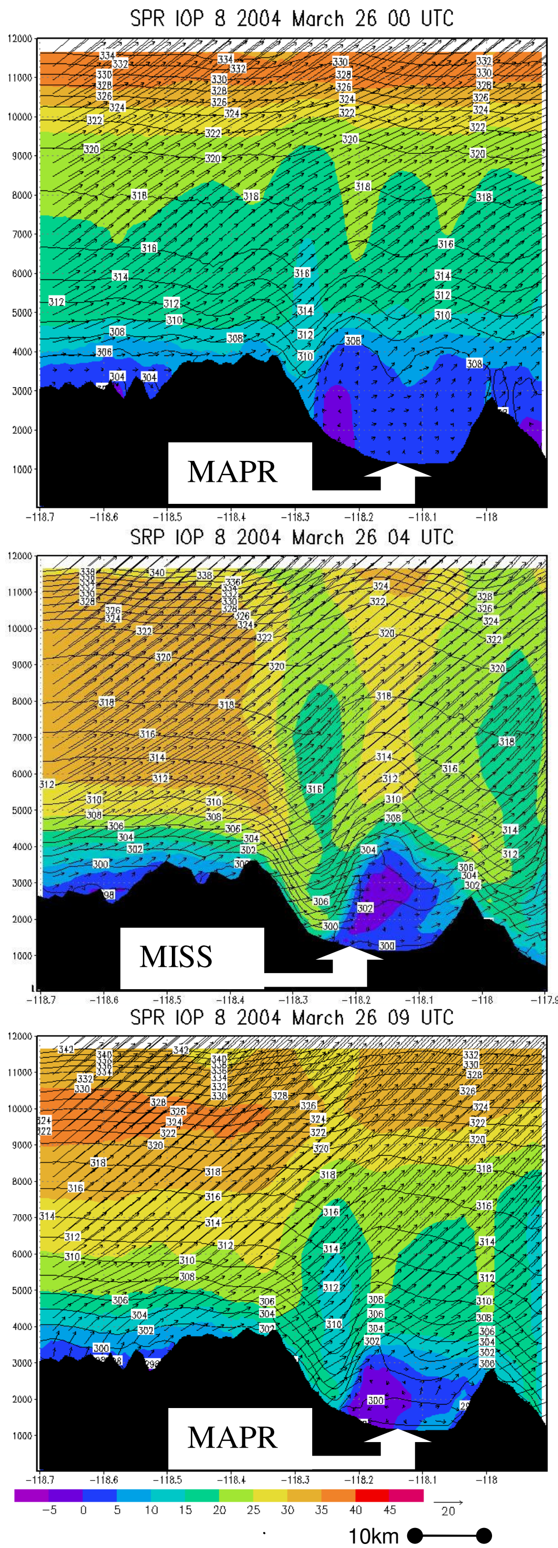

Figure 6: NRL COAMPS output. The top and bottom panels are cross-sections near the MAPR site and the middle panel is near the MISS site. The color scale indicates eastward wind (m/s) and the line contours are isentropes.

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5. REFERENCES

Cohn, S. A., W. O. J. Brown, and V. Grubišić, 2005: The Mobile Integrated Sounding System (MISS): Description and Lessons from the Sierra Rotors Project, Online preprints, *13th Symposium on Meteorological Observations and Instrumentation* (this conference), Amer. Meteor. Soc.

Cohn, S. A., W. O. J. Brown, C. L. Martin, M. S. Susedik, G. Maclean, and D. B. Parsons, 2001: Clear air boundary layer spaced antenna wind measurements with the Multiple Antenna Profiler (MAPR), *Annales Geophysicae*, **19**, 845-854.

Gossard, E.E., and R.G. Strauch, 1983: Radar observations of clear air and clouds. *Developments in Atmospheric Science,* 14th ed., Elsevier Science, 280 pp.

Grubišić, V., and S. Cohn, 2004: Sierra Rotors Project: Preliminary findings. Online preprints. *11th Conference on Mountain Meteorology and the Annual Mesoscale Alpine Programme (MAP)* Meeting. Amer. Meteor. Soc., (http://ams.confex.com/ams/pdfpapers/77364.pdf)

Grubišić, V., and J. P. Kuettner, 2005: Final plans for the Terrain-induced Rotor Experiment, Proc. *ICAM/MAP* 2005, 23-27 May 2005, Zadar, Croatia.

Parsons, D. B., and Co-Authors, 1994: The Integrated Sounding System – Description and preliminary observations from Toga-COARE, *Bull. Amer. Meteor. Soc.*, **75**, 553-567.