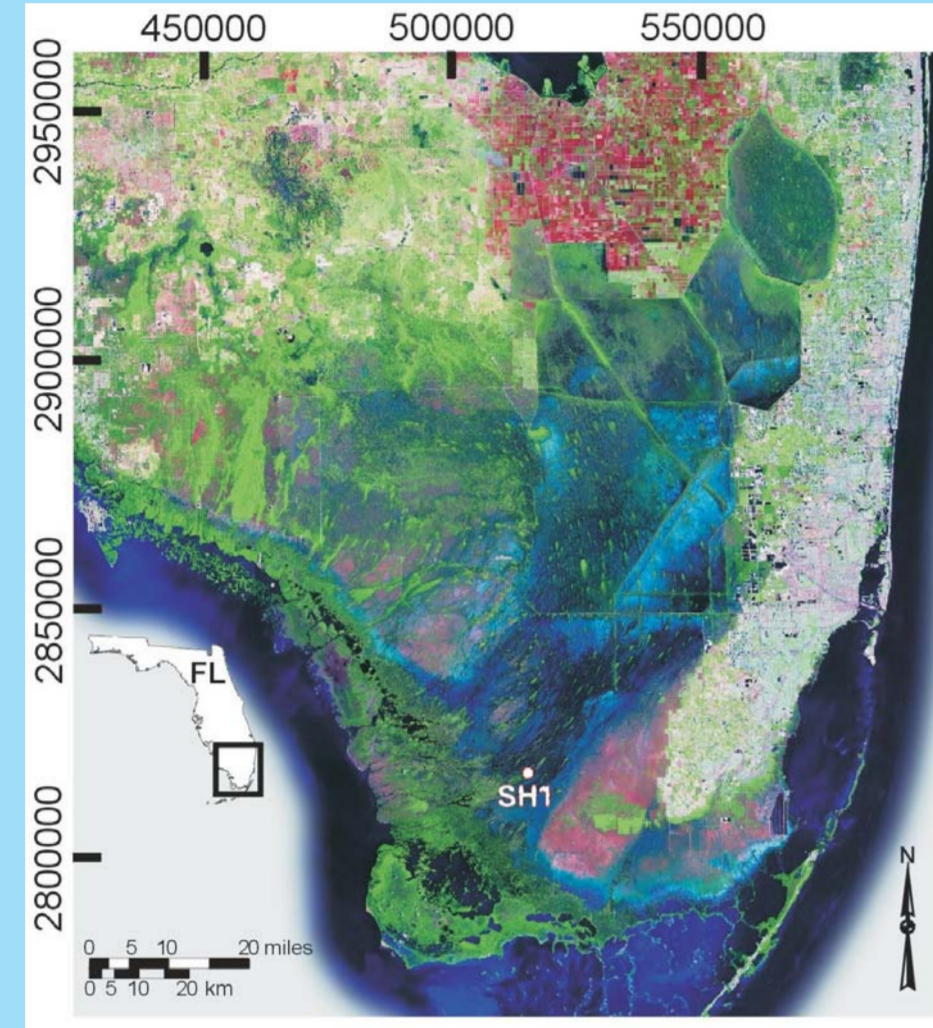


# Thermally-Driven Vertical Mixing in the Everglades

Harry L. Jenter and Raymond W. Schaffranek, U.S. Geological Survey, Reston, VA  
Thomas J. Smith, III, U.S. Geological Survey, St. Petersburg, FL

## Introduction

Vertical mixing in most natural freshwater bodies is driven predominantly by boundary shear stresses such as wind stress on the free surface of a lake or bed friction on the channel bottom and banks of a rapidly flowing river. However, in the slowly flowing wetlands of the Everglades, thermally-driven convection is the dominant vertical mixing mechanism. This diel mixing has potential implications for mercury methylation, evapotranspiration, oxidation, nutrient and contaminant transport and cycling, and other processes of concern in the Everglades wetlands.

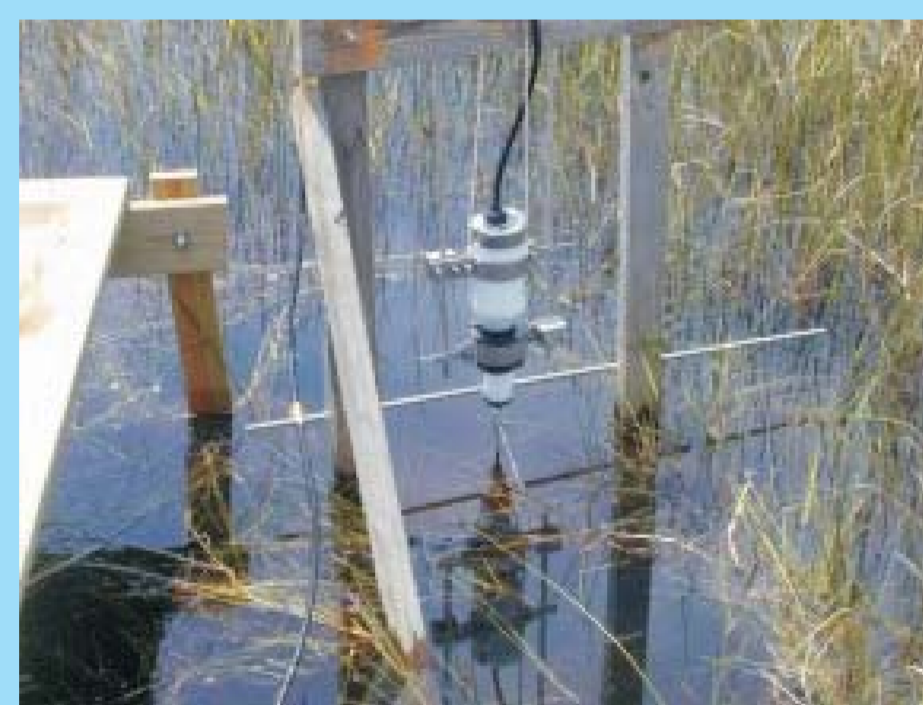


Measurement site SH1 in lower Shark River Slough, Everglades National Park

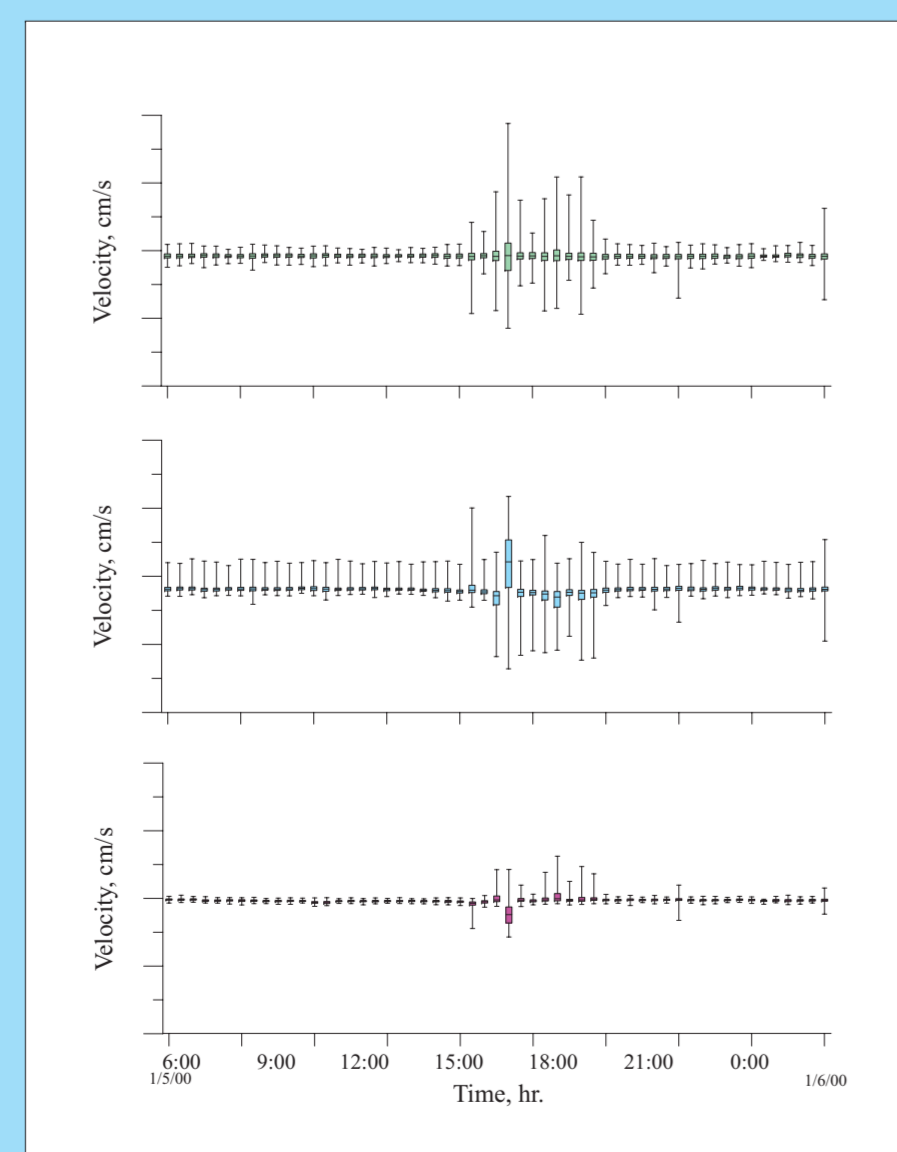
Flow-velocity measurements and temperature profiles collected within an area of medium-dense spike rush on the edge of a larger area of dense sawgrass in lower Shark River Slough within Everglades National Park reveal the behavior, timing and extent of thermal mixing.

## Velocity

Flow velocities were sampled using an acoustic Doppler velocity meter capable of resolving very low velocities to an accuracy of 1 mm/s over a range of a few cm/s. Bursts of 600 samples each were collected autonomously every half hour throughout the day for multiple-month deployments. Each burst was collected at 10 Hz and, therefore, represents a one-minute sample. Three components of velocity: East/West, North/South and Up/Down, as well as various signal-quality parameters, were collected as part of each sample.



Field deployment of acoustic Doppler velocity meter



Variation of velocity over 27 hours. The velocity-meter probe was positioned 16 cm above the litter layer in a 62 cm-deep water column, thus, the velocity sample volume was 11 cm from the litter-layer boundary and 51 cm from the water surface.



## Temperature

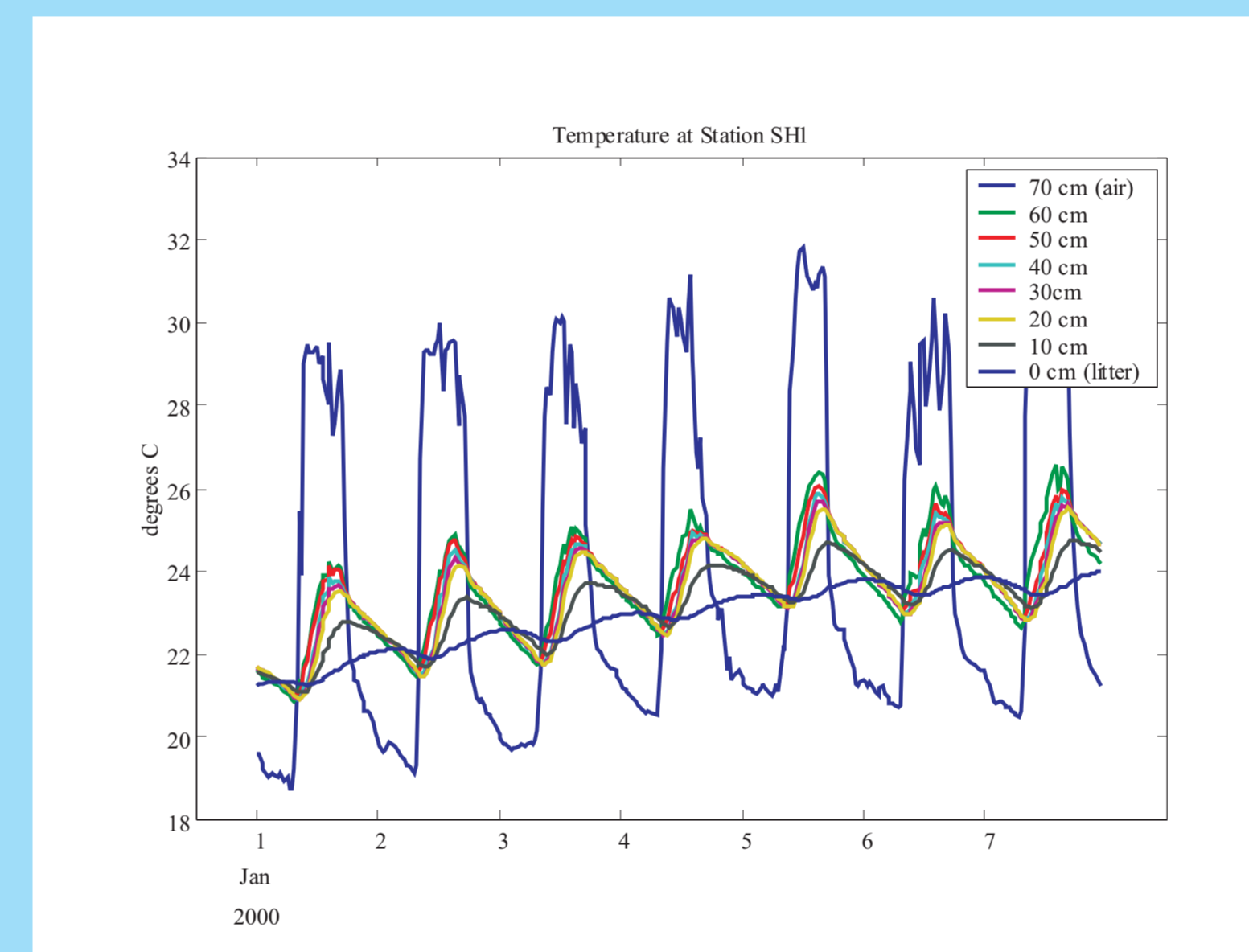
Highly variable flow velocities in the hours after sunset can be linked to thermal convection by considering temperature data obtained from a set of thermistors, having an accuracy of 0.1 deg C, cabled vertically 10 cm apart in a string deployed near the velocity meter. Thermistor data show the heavily vegetated water column to be isothermal at the beginning of each day. Initial heating of the water surface at sunrise is followed by progressive heating of the water column with depth throughout the day, resulting in increasing stratification throughout the late morning and early afternoon. Maximum stratification occurs at mid-afternoon and averages approximately 3 C through 60 cm of the water column (5 C/m). Typically, the water column reaches its maximum temperature around mid-afternoon. The water column cools through the remaining daylight hours, but remains stratified until approximately sunset when the air temperature begins to fall sharply and eventually drops below the water temperature at the surface.



Field deployment of thermistors

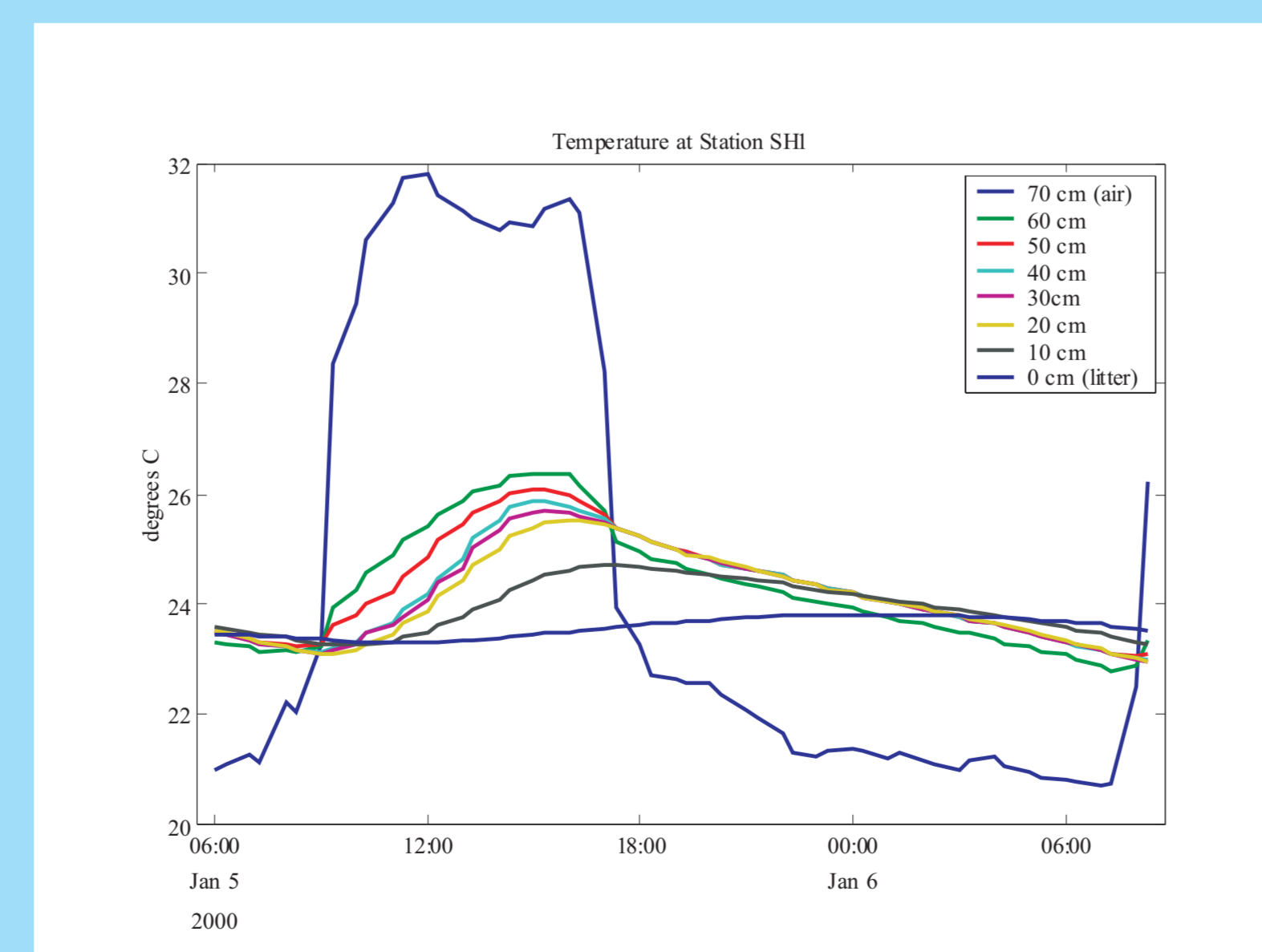


The thermally-driven mixing process also affects the temperature structure within the upper portion of the plant-litter layer at the bottom of the water column. The slow exchange of mass and heat across the water-column/litter-layer boundary causes temperatures in the plant-litter layer to lag temperatures in the water column. Decreased heat exchange causes the peak temperature in the litter layer to occur after midnight and the minimum temperature to occur around noon. There is a brief time just before sunrise when the temperature in the litter layer is greater than in the water column. The daily range of temperatures in the litter layer (approximately 0.5 C) is much smaller than the range of temperatures at any particular point in the water column.



One week of thermistor data demonstrating the fact that diel mixing occurs nearly every day

Diel coincidence of the thermal destratification and pronounced velocity fluctuations indicates the onset of mixing in the water column driven by thermal convection. The mixing process begins abruptly within approximately the upper 40 cm of the water column. Temperatures within this layer coincide through the remainder of the night. This mixed layer continues to cool and deepen throughout the night, not warming until just after sunrise the next day. A thin layer at the water surface remains slightly cooler than the mixed layer through the night, providing a constant source of negatively buoyant water that drives the mixing process. The mixing process continues until the air temperature rises above the temperature of the water at the surface.



Variation of temperature over 27 hours

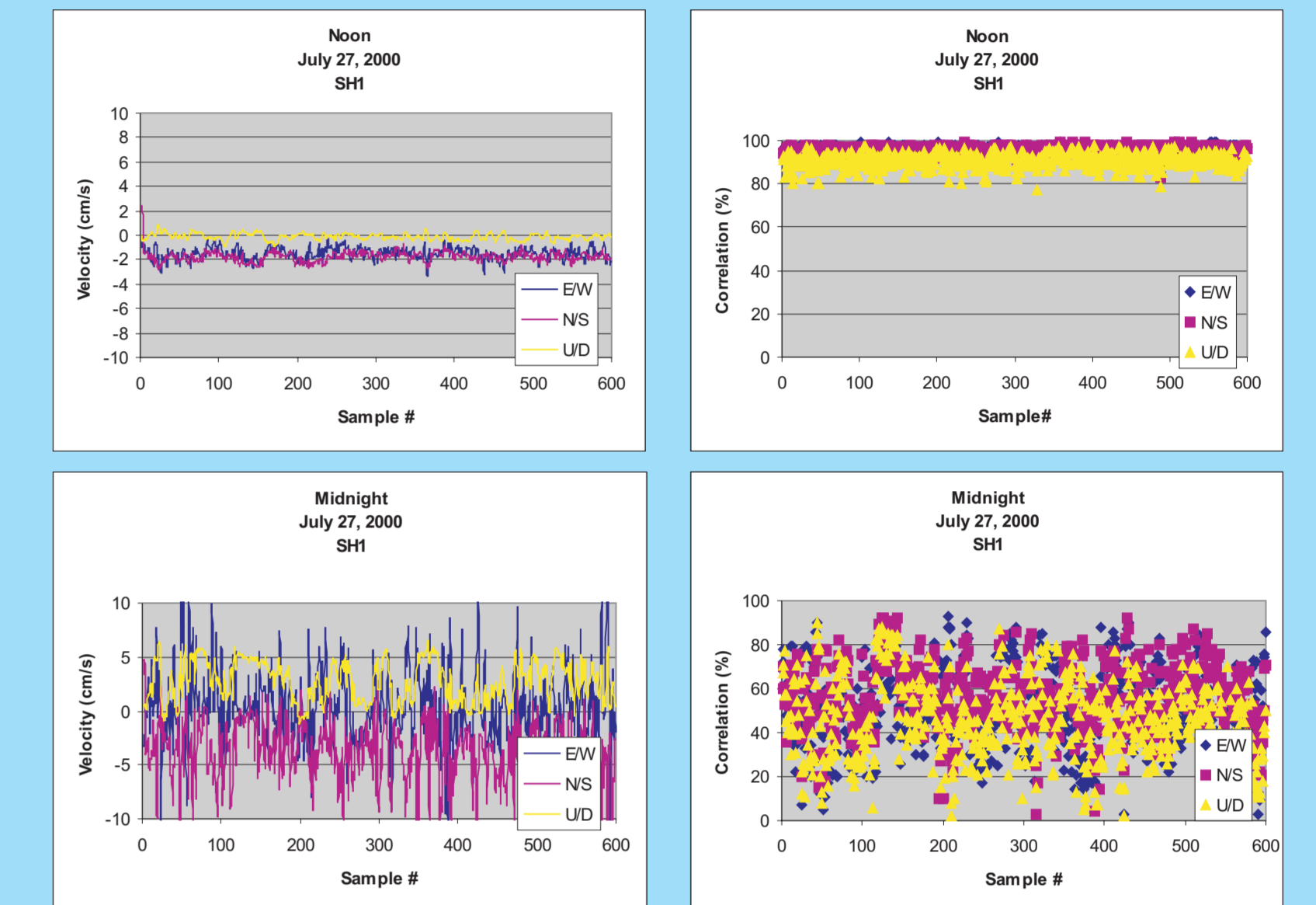
Individual daily temperature profiles in the Everglades wetlands are observed to vary only slightly with meteorological conditions and indicate that daytime destratification rarely occurs. Thermally-driven mixing appears to dominate at SH1 during more than 90% of the days. Only in the case of persistently strong winds, heavy rainfall or dramatic drops in air temperature is the water column in the Everglades wetlands thermally well-mixed during the daytime. The presence of vegetation appears to be the primary factor increasing the consistency with which thermally-driven convection dominates the vertical mixing process in the Everglades. The ubiquitous nature of this mixing implies a likely role in a number of important processes in the ecologically stressed Everglades wetlands.

### Acknowledgements

We would like to thank the following people for their contributions to this research: Ami Riscassi, Gordon Anderson, Michael Duff and Lori Rudolph.

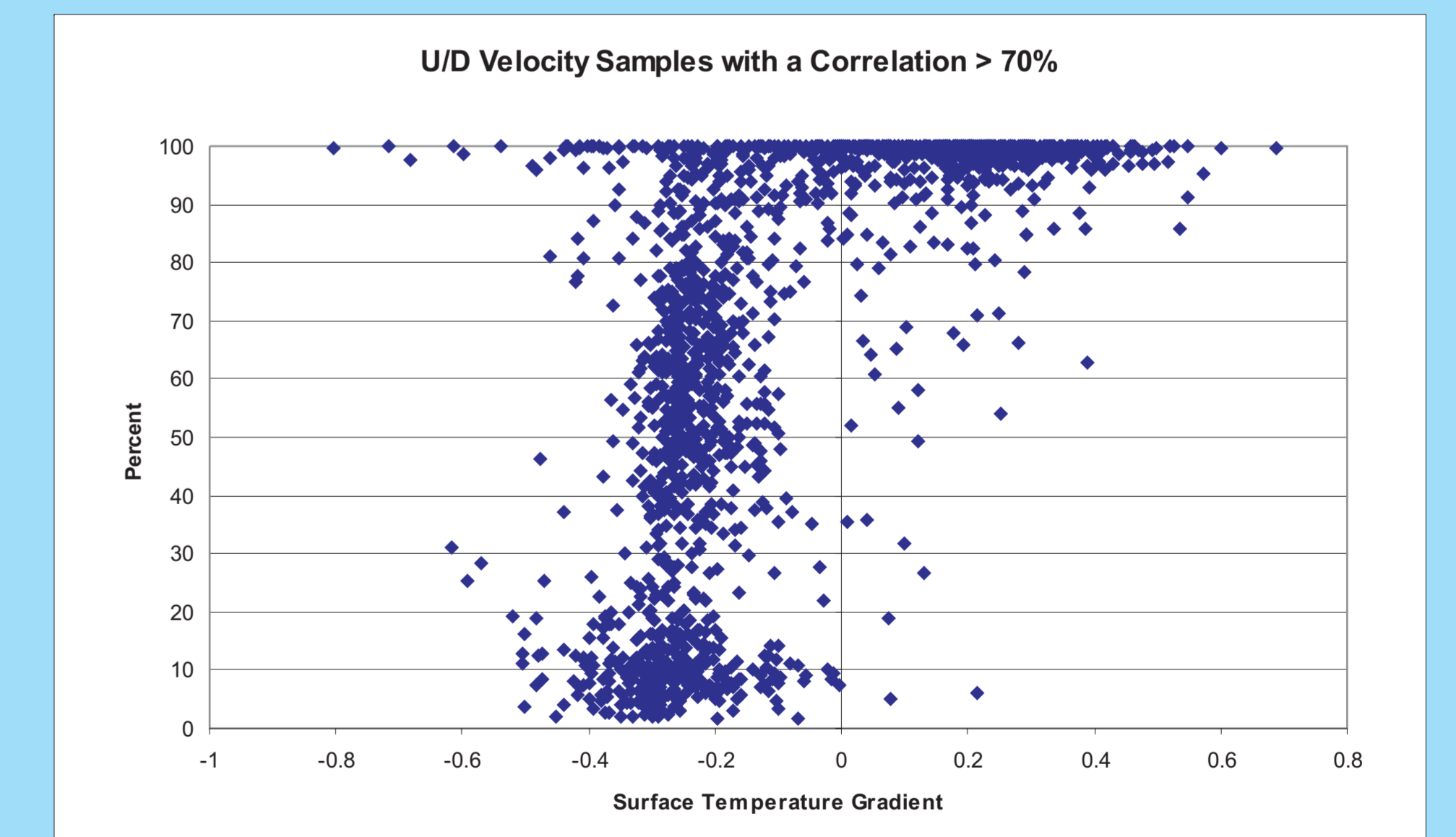
Harry L. Jenter, USGS, 12201 Sunrise Valley Drive, MS 430, Reston, VA 20192  
Phone: (703) 648-5916, Fax: (703) 648-5484,  
[hjenter@usgs.gov](mailto:hjenter@usgs.gov)

## Turbulent Mixing



Two 600-sample measurement bursts are depicted. There are two plots for each burst. The first shows the three components of flow velocity. The second shows a signal quality statistic, correlation, which can be considered an indicator of small-scale turbulence in the acoustic pathway. Lower correlations indicate higher turbulent mixing.

Velocity data in the first pair of plots, collected during the daytime, fluctuate minimally about their median values and have very high correlations. In strong contrast, velocity data in the second pair of plots, collected at midnight, fluctuate wildly and have substantially more variable and lower correlations.



The dominance of thermal mixing on a monthly time scale for data collected in July and August 2000 is shown above. The average temperature gradient across the water surface is shown on the horizontal axis. The percentage of samples within a burst that pass the minimum recommended acoustic signal correlation (>70%) is shown on the vertical axis. Low percentages are presumed to be a good indicator of unresolved high-frequency turbulent mixing. Positive temperature gradients across the water surface indicated stable stratification and downward heat flux. Turbulent mixing is rarely present when the surface heat flux is downward, indicating few, if any, sources of vertical mixing during the daytime. On the other hand, large vertical mixing events occur frequently when the surface heat flux is upward during the night. **The consistency and repetitiveness evidenced in these data illustrate the dominance of diel thermally-driven mixing.**