Estimating Intermittency Exponent in Neutrally Stratified Atmospheric Surface Layer Flows: A Robust Framework based on Magnitude Cumulant and Surrogate Analyses

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Abstract

This study proposes a novel framework based on magnitude cumulant and surrogate analyses to reliably detect and estimate the intermittency coefficient from short-length coarse-resolution turbulent time series. Intermittency coefficients estimated from a large number of neutrally stratified atmospheric surface layer turbulent series from various field campaigns are shown to remarkably concur with well-known laboratory experimental results. In addition, surrogate-based hypothesis testing significantly reduces the likelihood of detecting a spurious non-zero intermittency coefficient from non-intermittent series. The discriminatory power of the proposed framework is promising for addressing the unresolved question of how atmospheric stability affects the intermittency properties of boundary layer turbulence.

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I. INTRODUCTION

Existence of small-scale intermittency is an intriguing yet unsettled topic in contemporary turbulence research. Over a number of decades, researchers had been trying to unravel intermittency in turbulence measurements and at the same time formulating diverse conceptual models to rationalize the observed intermittency.\textsuperscript{1,2} Encouragingly, ‘practical’ implications of intermittency research outcomes are also being appreciated by the numerical turbulence modeling community and a critical knowledge transfer is taking place as evidenced by the recent literature.\textsuperscript{3-7}

One of the most widely used statistics characterizing the intermittent nature of turbulence is the so-called ‘intermittency exponent’ (\(\mu\)).\textsuperscript{8} From observational data, \(\mu\) can be estimated directly or indirectly via several methods. The direct estimates typically involve appropriate characterization of the second-order scaling behavior of the local rate of energy dissipation (\(\varepsilon\)) field. In this respect, several alternatives (e.g., second-order integral moment, two-point correlation function, spectral density) are available in the literature.\textsuperscript{2,11} Recently, Cleve et al.\textsuperscript{12} showed that among various direct approaches, the two-point correlation function \(\langle \varepsilon(x + r)\varepsilon(x) \rangle\) of the energy dissipation field provides the most reliable estimates of \(\mu\). In this case, one can write

\[
\langle \varepsilon(x + r)\varepsilon(x) \rangle \sim r^{-\mu}
\]

where \(r\) is within the inertial range. Here, the angular brackets denote spatial averaging.

The direct intermittency exponent estimation methods (based on \(\varepsilon\)) require very high-resolution (resolving on the order of Kolmogorov scale) data series of pristine quality. Most commonly, fast-response hot wire measurements are used for this purpose.\textsuperscript{10-14} However, acquisition of hot wire data in a natural setting could be quite challenging. For example, in the case of atmospheric boundary layer (ABL) field experiments, one needs to perform meticulous hot wire calibration at short regular intervals in order to account for the ever changing (diurnally varying) ABL flow parameters.\textsuperscript{15,16}

The ABL community widely uses sonic anemometers for turbulent flux measurements in fields. In contrast to hot wires, these sensors require much lesser periodic calibration and maintenance. Unfortunately, path lengths (\(\sim 10\) cm) and sampling rate (\(\sim 20\) Hz) of conventional sonic anemometers are too coarse for direct \(\mu\) estimation. In this paper, we will explore if sonic anemometer measurements, in lieu of hot wire data, can be reliably used
for indirect estimation of $\mu$.

One of the most popular indirect $\mu$ estimation methods is associated with the scaling of sixth-order structure function.\textsuperscript{13,14,17} With certain plausible assumptions, one can show that:\textsuperscript{17}

$$S_6(r) = \langle (u(x + r) - u(x))^6 \rangle = \langle (\Delta u)^6 \rangle \sim r^2 \langle \varepsilon(x)\varepsilon(x + r) \rangle$$

(2)

Using Eqs. 1-2, one gets: $\langle (\Delta u)^6 \rangle \sim r^2 - \mu$. Chambers and Antonia\textsuperscript{14} used this relatively simple indirect approach and obtained $\mu \sim 0.2$ in the atmospheric surface layer. From adequate statistical convergence standpoint, estimation of higher-order (specifically sixth-order in this context) structure functions require very long time series.\textsuperscript{13} For instance, Chambers and Antonia\textsuperscript{14} used several runs of 15 min duration at a hot wire sampling frequency of $\sim 1.2$ kHz (i.e., $\sim 1$ million samples per series). On the other hand, 15-30 min sonic anemometer-based ABL turbulence series would typically consist of only 20,000 to 40,000 samples. Understandably, the estimates of $\mu$ from sonic anemometer series using the traditional sixth-order structure function approach will not be very reliable. This and some other theoretical considerations explained in the next section, motivate us to use an alternative estimation approach, called the magnitude cumulant analysis, recently introduced by Delour et al.\textsuperscript{18} In this approach, only second-order magnitude cumulants (rather than data-intensive sixth-order structure functions) are needed to estimate the intermittency coefficient ($\mu$).

The inter-related objectives of this paper are twofold:

(1) Assess the potential of the magnitude cumulant analysis in detecting and estimating intermittency from short-length coarse-resolution (sonic anemometer-acquired) ABL measurements; and

(2) Design a rigorous hypothesis-testing framework which would reduce the likelihood of spurious detection of a non-zero $\mu$ from non-intermittent (monofractal) series.

The paper is structured as follows. In Section II, we briefly describe the magnitude cumulant analysis technique. The Iterative Amplitude Adjusted Fourier Transform (IAAFT) algorithm-based surrogate analysis, originally developed by the chaos theory community for detection of nonlinearity in time series,\textsuperscript{19} is shown to be very robust and reliable for intermittency hypothesis-testing. The IAAFT algorithm is presented in Section III. An extensive collection of observational data from various field campaigns is used in this study.
and Section IV provides brief descriptions of these field datasets. Comprehensive results of intermittency estimation are presented in Section V and compared with published literature wherever possible. Lastly, Section VI summarizes our results and discusses perspectives for future research on the intriguing question of how atmospheric stability affects intermittency properties of boundary layer turbulence.

II. MAGNITUDE CUMULANT ANALYSIS

In the turbulence literature, the scaling exponent spectrum, $\zeta_q$, is defined as:

$$S_q(r) = \langle (\Delta u)^q \rangle \sim r^{\zeta_q}$$ (3)

where $S_q(r)$ is the so-called $q$-th order structure function. As before, the angular bracket denotes spatial averaging and $r$ is a separation distance that varies within the inertial range. If the scaling exponent $\zeta_q$ is a nonlinear function of $q$, then the field is called ‘multifractal’, otherwise it is termed ‘monofractal’. In the traditional structure function approach, estimation of $\mu (= 2 - \zeta_6)$ requires a log-log plot of $S_6(r)$ vs $r$ and subsequent extraction of the slope using a least-squares linear regression fit over a scaling regime (the inertial range). For short time series, computation of $S_6(r)$ is problematic due to statistical convergence. Moreover, this problem is further compounded by the fact that even if the series is sufficiently long for statistical convergence of higher-order moments, the underlying nature of intermittency might theoretically limit the range over which the equivalency of statistical and geometrical interpretations of intermittency hold. As a result, even accurate estimates of higher-order statistical moment will degenerate to a linear behavior of $\zeta_q$ for $q$ larger than some $q_{max}$ prohibiting therefore an accurate estimation of intermittency using the structure function approach (see Lashermes et al. for details). An alternative reliable method, first advocated by Delour et al., is to use the magnitude cumulant analysis. In this approach, the relationship between the moments of velocity increments ($\Delta u$) and the magnitude cumulants ($C_n$) reads as:

$$\langle |\Delta u|^q \rangle = \exp \left( \sum_{n=1}^{\infty} C_n(r) \frac{q^n}{n!} \right)$$ (4)

where

$$C_1(r) \equiv \langle \ln |\Delta u| \rangle \sim -c_1 \ln(r)$$ (5a)

$$C_2(r) \equiv \langle (\ln |\Delta u|)^2 \rangle - \langle \ln |\Delta u| \rangle^2 \sim -c_2 \ln(r)$$ (5b)
\[ C_3(r) \equiv \langle (\ln |\Delta u|)^3 \rangle - 3\langle (\ln |\Delta u|)^2 \rangle \langle \ln |\Delta u| \rangle \\
+ 2\langle \ln |\Delta u| \rangle^3 \sim -c_3 \ln(r) \]  

(5c)

From Eqs. 3-5, it is straightforward to express the scaling exponent spectrum as.\(^{18}\)

\[ \zeta_q = -\sum_{n=1}^{\infty} c_n \frac{q^n}{n!} \]  

(6)

Furthermore, by invoking a relationship between velocity increments (\(\Delta u\)) and local rate of dissipation fields (\(\varepsilon\)) (similar to Eq. 2), one can arrive at.\(^{23}\)

\[ \mu \simeq 9c_2 \]  

(7)

Therefore, estimation of the intermittency exponent \(\mu\) would only require the computation of second-order magnitude cumulant, i.e., the second central moment of \(\ln|\Delta u|\) (Eq. 5b).

For large separation (\(r \to L_i\), where \(L_i\) is the integral length scale), it is well documented that the probability distribution function (pdf) of velocity increments (\(\Delta u\)) approaches a Gaussian distribution. For this scenario, the following results can be derived analytically:

\[ C_1(r) \to \frac{1}{2}(-\gamma - \ln(2)) = -0.64 \]  

(8a)

\[ C_2(r) \to \frac{\pi^2}{8} = 1.23 \]  

(8b)

\[ C_3(r) \to -\frac{7}{4}\zeta(3) = -2.1 \]  

(8c)

where \(\gamma\) is the Euler Gamma constant = 0.577216, and \(\zeta(3)\) is Apéry’s constant = 1.2020569. These asymptotic values of \(C_1(r), C_2(r), \text{ and } C_3(r)\) would be very useful to demarcate scaling regions in the case of short-length time series.

It is noted that instead of a physical space-based magnitude cumulant analysis approach (i.e., Eqs. 4-5), one could also use wavelet-based magnitude cumulant analysis (see Venugopal et al.\(^{24,25}\) for a geophysical application). A wavelet-based approach becomes necessary for nonstationary signals and signals with H"older exponents (\(h\)) outside the window of \([0 1]\)\(^{26,27}\).

In turbulence, \(\langle h \rangle\) is close to K41 value of 1/3 and to best of our knowledge always found to be within the window of \(h \in [0 1]\)\(^{28,29}\). Thus, in the present study we decided to employ physical space-based magnitude cumulant analysis approach.

Magnitude cumulant analysis of a synthetic fractional Brownian motion with \(h = 1/3\) (which displays K41 like \(k^{-5/3}\) spectrum) is shown in Fig. 1. The dashed line in \(C_1(r)\) vs. \(\ln(r)\) plot has the expected slope of 1/3. For almost the entire scaling range, both \(C_2(r)\) and
$C_3(r)$ remain close to the theoretical Gaussian values of 1.23 and −2.1, respectively. This signal does not show any sign of multifractality (expected) as the slope of $C_2(r)$ vs. $\ln(r)$ cannot be claimed to be different from zero.

FIG. 1: A synthetic fractional Brownian motion ($h = 1/3$) (top-left). The magnitude cumulants $C_1(r)$ (top-right), $C_2(r)$ (bottom-left), and $C_3(r)$ (bottom-right) are also shown. The dashed line in the top-right subplot shows the slope $-c_1 = 1/3$.

III. SURROGATE ANALYSIS

Noise is omnipresent in any measured signal and turbulence signals are no exceptions. In addition to noise, limited amount of data (finite sample settings) in most field measurements could challenge intermittency detection and estimation even with the magnitude cumulant analysis method (e.g., assessment of a small non-zero slope in the $C_2(r)$ vs. $\ln(r)$ plots). In this paper, we utilize a hypothesis-testing framework, based on surrogate analysis, in conjunction with magnitude cumulant analysis, for detecting and accurately estimating
intermittency from short-length sonic anemometer measurements.

The concept of surrogates (stochastic realizations which preserve only certain characteristics of a process) was introduced into the chaos theory literature to provide a rigorous statistical test for the null hypothesis that an observed time series has been generated by a linear stochastic process (see Theiler et al., Kantz and Schreiber, Basu and Foufoulaga-Georgiou, and the references therein). Over the years, several varieties of surrogates (randomly shuffled surrogates, Fourier phase randomized surrogates, iterative amplitude adjusted Fourier transform - IAAFT surrogates, stochastic IAAFT surrogates, and so on) have been proposed in the literature. In this paper, we will use the IAAFT algorithm proposed by Schreiber and Schmitz. IAAFT surrogates preserve the correlation structure (thus power spectrum owing to Wiener-Khinchin theorem) and the probability density function of a given time series. Apart from nonlinearity detection, the IAAFT surrogates have also been used to define a precipitation forecast quality index, and to generate synthetic cloud fields.

In the turbulence literature, surrogate analysis-based hypothesis-testing is virtually nonexistent with an exception of the paper by Nikora et al. They used simple Fourier phase randomization approach (pdf of the original turbulence series was not preserved) in identifying the effects of turbulence intermittency and spectral energy flux. In comparison to the Fourier phase randomized approach, the IAAFT algorithm used in the present study designs stronger statistical test (owing to its ability to preserve the integral pdf of the original signal) for the null hypothesis that an observed turbulence series is non-intermittent.

In Fig. 2, a sonic anemometer turbulence series and its IAAFT surrogate are shown. By construction, they have the same pdf (bottom-right plot of Fig. 2) and virtually indistinguishable autocorrelation function (bottom-left plot of Fig. 2). Basic properties of the original turbulence series and its surrogate are provided in Table I. \( T_i \) and \( L_i \) denote integral time and length scales, respectively.

\[
T_i = \int_0^\infty R(\tau) d\tau \\
L_i = U \cdot T_i
\]  

where \( R(\tau) \) is the autocorrelation function. From Fig. 2 and Table I, we can safely infer that the IAAFT surrogate captures the integral pdf and autocorrelation function of the original velocity series rather accurately. Later on, we will show that the IAAFT surrogates do not
have the ability to capture the scale-dependent pdfs of velocity increments and this forms the basis for the proposed intermittency hypothesis-testing.

![Figure 2](image)

**FIG. 2**: Longitudinal velocity time series measured by a sonic anemometer (top-left) and its surrogate series generated by IAAFT methodology (top-right). Both series have approximately the same autocorrelation (bottom-left) and exactly the same probability density function (bottom-right).

| Series Type | $U$ (ms$^{-1}$) | $\sigma_u$ (ms$^{-1}$) | $T_i$ (s) | $L_i$ (m) |
|-------------|----------------|-----------------|----------|----------|
| Turbulence  | 3.73           | 1.06            | 1.47     | 5.47     |
| Surrogate   | 3.73           | 1.06            | 1.46     | 5.43     |

**TABLE I: Basic Statistics of a Sonic Anemometer Turbulence Series and its Surrogate**
IV. DESCRIPTION OF DATA

In this study, we primarily made use of an extensive atmospheric boundary layer turbulence dataset (comprising of sonic anemometer measurements) collected by various researchers from Johns Hopkins University, and the University of California-Davis during Davis 1994, 1995, 1996, 1999 field studies. Comprehensive description of these field experiments (e.g., surface cover, fetch, instrumentation, sampling frequency) can be found in Pahlow et al.\textsuperscript{37} Briefly, the collective attributes of the field dataset explored in this study are as follows: (i) surface cover: bare soil, and beans; (ii) sampling frequency: 18 to 21 Hz; (iii) sampling period: 20 to 30 minutes; (iv) sensor height \((z)\): 0.96 to 4.28 m.

The ABL field measurements are seldom free from mesoscale disturbances, wave activities, nonstationarities etc. The situation could be further aggravated by several kinds of sensor errors (e.g., random spikes, amplitude resolution error, drop outs, discontinuities etc.). Thus, stringent quality control and preprocessing of field data is of utmost importance for any rigorous statistical analysis. Our quality control and preprocessing strategies are described in detail in Basu et al.\textsuperscript{38} After the quality control and preprocessing steps, we were left with 139 ‘reliable’ near-neutral (\(|z/L| \leq 0.05\), where \(z\) is the sensor height and \(L\) denotes the Monin-Obukhov length) sets of runs for estimating the intermittency exponents.

We also estimated \(\mu\) from a fast-response (10 kHz) hot wire ABL turbulence series utilizing the magnitude cumulant analysis. The hot wire measurements were taken at the Surface Layer Turbulence and Environmental Science Test (SLTEST) facility located in the western Utah Great Salt Lake desert under near-neutral atmospheric condition.\textsuperscript{15,16} In the following section, we will show that the intermittency exponent and other relevant statistics derived from this high Reynolds number (\(Re\)) hot wire measurement are surprisingly similar to various published lower \(Re\) laboratory experimental findings, and serve as benchmarks in the present study.

| Sensor Type            | \(z\) (m) | \(U\) (ms\(^{-1}\)) | \(\sigma_u\) (ms\(^{-1}\)) | \(T_i\) (s) | \(L_i\) (m) |
|-----------------------|-----------|---------------------|-----------------------------|----------|-----------|
| Hot wire Anemometer   | 2.01      | 5.99                | 0.74                        | 5.71     | 34.22     |
| Sonic Anemometer      | 0.96 – 4.28 | 1.60 – 7.30         | 0.34 – 1.57                 | 1.08 – 9.09 | 2.57 – 33.22 |
Mean flow characteristics of all the field measurements are given in Table II. For all the analyses, we have invoked Taylor’s hypothesis to convert time series to spatial series.

V. RESULTS

A. Analysis of Hot Wire Measurements

In this section, hot wire measurements and their surrogates are analyzed to: (a) demonstrate the ability of the magnitude cumulant analysis to accurately estimate the intermittency structure of turbulent velocity series, and (b) establish that the surrogate series, while preserving the pdf and spectrum of the original data, destroy the intermittency structure.

In Fig. 3, the magnitude cumulants computed from the hot wire measurements of Kunkel and Marusic\textsuperscript{16} are shown. This turbulence series is 30 min long (~18 million data points) and captures scales down to the Kolmogorov scale. The following observations can be made from Fig. 3:

- $c_{1}^{\text{turb}}$ computed from the turbulence velocity signal is close to $-0.36$. It agrees quite well with the existing results from low $Re$ laboratory experiments\textsuperscript{18,22}

- $c_{2}^{\text{turb}}$ is approximately equal to 0.03. Delour et al\textsuperscript{18} and Chevillard et al\textsuperscript{22} reported $c_{2} = 0.025 \pm 0.003$ based on several experiments and claimed it to be ‘universal’. From Eq. 7, we can compute the intermittency exponent $\mu \simeq 9 \cdot c_{2}^{\text{turb}} \simeq 0.27$. In the literature, researchers have reported $\mu$ ranging from 0.18 to 0.7\textsuperscript{10,11}. In the case of atmospheric data, the ‘best’ direct estimate is $0.25 \pm 0.05$\textsuperscript{10} and our indirect magnitude cumulant analysis-based result is in agreement with it.

- From Eq. 6, we can derive: $\zeta_{2}^{\text{turb}} = -2 \cdot c_{1}^{\text{turb}} - 2 \cdot c_{2}^{\text{turb}} = 2 \cdot 0.36 - 2 \cdot 0.03 = 0.66$. Fig. 3 (bottom-right) shows the second-order structure function. The slope of this plot gives $\zeta_{2}^{\text{turb}} = 0.66$. Thus, our results are self-consistent.

- In the inertial range, $c_{3}^{\text{turb}}$ seems to be zero. This indicates that the statistics of the velocity increments are possibly log-normal\textsuperscript{18,22}.
FIG. 3: $C_1(r/L_i)$ (top-left), $C_2(r/L_i)$ (top-right) and $C_3(r/L_i)$ (bottom-left) computed using the hot wire measurements of Kunkel and Marusic. The second-order structure function is also shown (bottom-right). Extended range of inertial-range is evident in all the sub-plots. The circles denote the statistics corresponding to the original turbulence series and the stars represent the statistics computed from the IAAFT surrogate series. Clearly, the original series portray the signatures of a multifractal process. In contrast, the surrogate series shows the signs of monofractality. The dashed lines show the slopes $-c_1^{\text{turb}} = 0.36$ (top-left), $-c_2^{\text{turb}} = -0.03$ (top-right), and $\zeta_2^{\text{turb}} = 0.66$ (bottom-right), respectively.

- $c_2^{\text{surr}}$ estimated from the surrogate of the measured turbulence velocity series is zero, i.e., the surrogate series is non-intermittent.

- By construction, the surrogate series (i.e., turbulence without intermittency) preserves the second-order statistics. So, $\zeta_2^{\text{turb}} = \zeta_2^{\text{surr}}$. Using this relationship, the fact that $c_2^{\text{surr}} = 0$, and Eq. 6, it is straightforward to show that: $c_1^{\text{turb}} + c_2^{\text{turb}} = c_1^{\text{surr}}$. In the present case this results in: $c_1^{\text{surr}} = -0.36 + 0.03 = -0.33$ (see also Fig. 3). Thus, $\zeta_1^{\text{surr}} = -c_1^{\text{surr}} = 0.33$ is in full accord with K41 hypothesis of $\zeta_1 = 1/3$.\[11]
The relationship $c_{1}^{turb} + c_{2}^{turb} = c_{1}^{surr}$ has significant practical implication. It insinuates that one can roughly estimate $c_{2}^{turb}$ (and thus $\mu$) by means of first-order magnitude cumulants of turbulence and its corresponding surrogate, i.e., $c_{2}^{turb} = c_{1}^{turb} - c_{1}^{surr}$. In our opinion, for estimating intermittency in short length geophysical signals, this simple indirect method which does not require even second-order magnitude cumulant computation would be quite useful.

- In the turbulence literature, there is a general consensus that $\zeta_3 = 1$. From our results, we find $c_{3}^{turb} = -3 \cdot c_{1}^{turb} - 9/2 \cdot c_{2}^{turb} = 1.08 - 0.135 = 0.95$, very close to the well-accepted value.

We proceed further by comparing the pdf of the velocity and surrogate increments using the skewness, asymmetry factor, and flatness defined as:

$$\text{Skewness}(r) = \frac{\langle (\Delta u)^3 \rangle}{\langle (\Delta u)^2 \rangle^{3/2}} \quad (10a)$$

$$\text{Asymmetry}(r) = \frac{\langle (\Delta u)^3 \rangle}{\{\langle (\Delta u)^3 \rangle\}} \quad (10b)$$

$$\text{Flatness}(r) = \frac{\langle (\Delta u)^4 \rangle}{\langle (\Delta u)^2 \rangle^2} \quad (10c)$$

From Fig. 4 (left), it is evident that the original turbulence increment series show negative skewness (up to $\sim 0.6$) for small scales in accord with the existing literature (e.g., Chevillard et al.22). This negative skewness is believed to be related to the vortex folding and stretching process. Malécot et al.23 argued that the asymmetry factor (see Eq. 10 for definition) is a better measure of the asymmetry of the pdf than the skewness. We found that both of these signed odd-order moments behave quite similarly (Fig. 4, left). The origin of spurious oscillations of these odd-order moments for large scales ($ln(r/L_i) > -4$) is not well understood. The flatness plot (Figure 4, right) also portrays anticipated characteristics. Flatness corresponding to the integral scale is close to 3 (hallmark of Gaussian velocity increments) and becomes exceedingly large for smaller scales. In contrast, the surrogate shows Gaussian characteristics for all scales. This corroborates the fact that surrogates cannot capture the pdfs of turbulence velocity increments.
B. Analysis of Sonic Anemometer Measurements

Magnitude cumulants and second-order structure functions computed from a sonic anemometer series are shown in Fig. 5. The trends are very similar to Fig. 3, albeit quite noisy. From this figure, we calculated $c_1 = -0.37$, $c_2 = 0.06$, and $\zeta_2 = 0.63$. We would like to emphasize that even in this short time series scenario, we can reliably detect intermittency with the help of IAAFT surrogate (see Fig. 5 top-right). Admittedly, the estimation of $c_2$ is possibly not very accurate. The estimation can be improved by using quenched or annealed averaging strategy (discussed below).

It is quite difficult to manually yet objectively select scaling ranges from a large dataset (specifically 139 near-neutral turbulence series). So, we used an automated scaling range of $[4 \cdot U/f_s, L_i/2]$ for individual series. Here $U$, $f_s$, and $L_i$ denote mean velocity, sampling frequency, and integral length scale, respectively. From each individual turbulence series and their surrogates, we calculated the corresponding $c_1$ and $c_2$ values. Subsequently, from these $139$ $c_1^{\text{turb}}$, $c_2^{\text{turb}}$, $c_1^{\text{surr}}$, and $c_2^{\text{surr}}$ combinations, we computed the best estimates (ensemble mean plus/minus one standard deviation) as: $\langle c_1^{\text{turb}} \rangle = -0.33 \pm 0.03$, $\langle c_2^{\text{turb}} \rangle = 0.038 \pm 0.017$, $\langle c_1^{\text{surr}} \rangle = -0.30 \pm 0.03$, and $\langle c_2^{\text{surr}} \rangle = 0.002 \pm 0.013$. This averaging strategy is similar to the quenched averaging method used by Arnéodo et al.\textsuperscript{39} The key result: $\langle c_2^{\text{turb}} \rangle >> \langle c_2^{\text{surr}} \rangle$, without any doubt, once again guarantees that the IAAFT surrogates can be faithfully used.
As an alternative strategy, using the annealed averaging method, we have also computed the average of the magnitude cumulants (i.e., $\langle C_1 (r/L_i) \rangle$, $\langle C_2 (r/L_i) \rangle$) from the same turbulence and surrogate datasets (Fig. 6). From this figure, we estimate the slopes as: $c_{turb}^1 = -0.35$, $c_{turb}^2 = 0.042$, $c_{surr}^1 = -0.31$, $c_{surr}^2 = 0.002$. Obviously, there is no significant discrepancy between the quenched and annealed averaged statistics, as would be wishfully expected. Lastly, these statistics highlight that the relationship established in Section V-A, i.e., $c_{turb}^1 + c_{turb}^2 = c_{surr}^1$, is also valid under annealed averaging.

VI. CONCLUDING REMARKS AND FUTURE PERSPECTIVES

In this work, we have established a framework based on magnitude cumulant and surrogate analyses to reliably detect and estimate the intermittency coefficient from short turbulent time series. By virtue of this framework, ensemble scaling results extracted from a large number of neutrally stratified atmospheric surface layer turbulent series (predominantly ac-
FIG. 6: Ensemble averaged $C_1(r/L_i)$ and $C_2(r/L_i)$ plots from 139 near-neutral turbulence series (circles) and corresponding surrogates (stars). The dashed lines show the slopes $-c_{1_{\text{turb}}}= 0.35$ (left), and $-c_{2_{\text{turb}}}= -0.042$ (right), respectively.

quired by slow response sonic anemometers) from various field campaigns remarkably concur with well-known published (mostly laboratory experimental) results.

The focus of the present study was on neutrally stratified atmospheric turbulence. However, it is widely known that neutral stability conditions are rarely encountered in the real atmosphere. Most of the time, the atmospheric boundary layer is strongly modulated by buoyancy. It is commonly assumed that the effect of atmospheric stability is felt only at the ‘buoyancy range’, which has scales considerably larger than the inertial range. Recently, Aivalis et al.\textsuperscript{40} studied the intermittency behavior of temperature in the convective surface layer using cold wire anemometry. They found that the classical inertial range remains intact in convective surface layer and the scaling exponents approach values appropriate to the intermittent case of isotropic turbulence. They also noticed that the scaling exponents corresponding to the buoyancy range are highly anomalous. In contrast, Shi et al.\textsuperscript{41} found that in the case of temperature, the inertial range scaling exponents are unambiguously impacted by atmospheric stability. However, their results are inconclusive in the case of velocity signals under different stability regimes. We believe that the unresolved question as to whether or not the inertial-range intermittency is influenced by large-scale anisotropic forcing of atmospheric stability is of great consequence and needs further consideration. Abundant high-quality slow response data collected under different atmospheric regimes in recent years (e.g., Cooperative Atmosphere-Surface Exchange Study - CASES99\textsuperscript{42}) could be coupled with the robust scaling analysis and estimation framework explored in this study in
order to shed new light into this fundamental problem.

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1 U. Frisch, Turbulence (Cambridge University Press, Cambridge, UK, 1995), p. 296.
2 D. Schertzer, S. Lovejoy, F. Schmitt, Y. Chigirinskaya, D. Marsan, “Multifractal cascade dynamics and turbulent intermittency”, Fractals 5, 427 (1997).
3 A. Scotti and C. Meneveau, “A fractal model for large eddy simulation of turbulent flow”, Physica D 127, 198 (1999).
4 H. F. Campos Velho, R. R. Rosa, F. M. Ramos, R. A. Pielke, G. A. Degrazia, C. Rodrigues Neto, and A. Zanandrea, “Multifractal model for eddy diffusivity and counter-gradient term in atmospheric turbulence”, Physica A 295, 219 (2001).
5 S. Basu, E. Foufoula-Georgiou, and F. Porté-Agel, “Synthetic turbulence, fractal interpolation, and large-eddy simulation”, Phys. Rev. E 70, 026310 (2004).
6 M. Antonelli, M. Martins Afonso, A. Mazzino, and U. Rizza, “Structure of temperature fluctuations in turbulent convective boundar layers”, J. Turbulence 6, DOI: 10.1080/14685240500332049 (2005).
7 G. C. Burton and W. J. A. Dahm, “Multifractal subgrid-scale modeling for large-eddy simulation. I. Model development and a priori testing”, Phys. Fluids 17, 075111 (2005).
8 A. Monin and A. Yaglom, *Statistical Fluid Mechanics* (MIT Press, Cambridge, MA, 1975), Vol. 2, p. 874.

9 C. Meneveau and K. R. Sreenivasan, “The multifractal nature of the turbulent energy dissipation”, J. Fluid Mech. **224**, 429 (1991).

10 K. R. Sreenivasan and P. Kailasnath, “An update on the intermittency exponent in turbulence”, Phys. Fluids **5**, 512 (1993).

11 A. Praskovsky and S. Oncley, “Comprehensive measurements of the intermittency exponent in high Reynolds number turbulent flows”, Fluids Dyn. Res. **21**, 331 (1997).

12 J. Cleve, M. Greiner, B. R. Pearson, and K. R. Sreenivasan, “Intermittency exponent of the turbulent energy cascade”, Phys. Rev. E **69**, 066316 (2004).

13 F. Anselmet, Y. Gagne, E. J. Hopfinger, and R. A. Antonia, “High-order velocity structure functions in turbulent shear flows”, J. Fluid Mech. **140**, 63 (1984).

14 A. J. Chambers and R. A. Antonia, “Atmospheric estimates of power-law exponents”, Boundary-Layer Meteorol. **28**, 343 (1984).

15 I. Marusic and G. J. Kunkel, “Streamwise turbulence intensity formulation for flat-plate boundary layers”, Phys. Fluids **15**, 2461 (2003).

16 G. J. Kunkel and I. Marusic, “Study of the near-wall-turbulent region of the high-Reynolds-number boundary layer using an atmospheric flow”, J. Fluid Mech. **548**, 375 (2006).

17 U. Frisch, P.-L. Sulem, and M. J. Nelkin, “A simple dynamical model of intermittent fully developed turbulence”, J. Fluid Mech. **87**, 719 (1978).

18 J. Delour, J. F. Muzy, and A. Arnéodo, “Intermittency of 1D velocity spatial profiles in turbulence: A magnitude cumulant analysis”, Eur. Phys. J. B **23**, 243 (2001).

19 T. Schreiber and A. Schmitz, “Improved surrogate data for nonlinearity tests”, Phys. Rev. Lett. **77**, 635 (1996).

20 T. Bohr, M. H. Jensen, G. Paladin, and A. Vulpiani, *Dynamical Systems Approach to Turbulence* (Cambridge University Press, Cambridge, UK, 1998), p. 350.

21 B. Lashermes, P. Abry, and P. Chainais, “New insights into the estimation of scaling exponents”, International Journal of Wavelets, Multiresolution and Information Processing **2**, 497 (2004).

22 L. Chevillard, B. Castaing, E. Lévéque, and A. Arnéodo, “Unified multifractal description of velocity increments statistics in turbulence: Intermittency and skewness”, Physica D **218**, 77 (2006).
23 Y. Malécot, C. Auriault, H. Kahalerras, Y. Gagne, O. Chanal, B. Chabaud, and B. Castaing, “A statistical estimator of turbulence intermittency in physical and numerical experiments”, Eur. Phys. J. B 16, 549 (2000).

24 V. Venugopal, S. G. Roux, E. Foufoula-Georgiou, and A. Arnéodo, “Scaling behavior of high resolution temporal rainfall: New insights from a wavelet-based cumulant analysis”, Phys. Lett. A 348, 335 (2006a).

25 V. Venugopal, S. G. Roux, E. Foufoula-Georgiou, and A. Arnéodo, “Revisiting multifractality of high-resolution temporal rainfall using a wavelet-based formalism”, Wat. Resour. Res. 42, DOI:10.1029/2005WR004489 (2006b).

26 J. F. Muzy, E. Bacry, and A. Arnéodo, “Multifractal formalism for fractal signals: The structure-function approach versus the wavelet-transform modulus-maxima method”, Phys. Rev. E 47, 875 (1993).

27 A. Arnéodo, E. Bacry, and J. F. Muzy, “The thermodynamics of fractals revisited with wavelets”, Physica A 213, 232 (1995).

28 J. F. Muzy, E. Bacry, and A. Arnéodo, “Wavelets and multifractal formalism for singular signals: Application to turbulence data”, Phys. Rev. Lett. 67, 3515 (1991).

29 M. Vergassola, R. Benzi, L. Biferale, and D. Pisarenko, “Wavelet analysis of a Gaussian Kolmogorov signal”, J. Phys. A 26, 6093 (1993).

30 J. Theiler, S. Eubank, A. Longtin, B. Galdrikian, and J. D. Farmer, “Testing for nonlinearity in time series: the method of surrogate data”, Physica D 58, 77 (1992).

31 H. Kantz and T. Schröber, Nonlinear Time Series Analysis (Cambridge University Press, Cambridge, UK, 1997), p. 320.

32 S. Basu and E. Foufoula-Georgiou, “Detection of nonlinearity and chaoticity in time series using the transportation distance function”, Phys. Lett. A 301, 413 (2002).

33 V. Venema, F. Ament, and C. Simmer, “A Stochastic Iterative Amplitude Adjusted Fourier Transform Algorithm with improved accuracy”, Nonlin. Proc. Geophys. 13, 247 (2006).

34 V. Venugopal, S. Basu, and E. Foufoula-Georgiou, “A new metric for comparing precipitation patterns with an application to ensemble forecasts”, J. Geophys. Res. 110, DOI:10.1029/2004JD005395 (2005).

35 V. Venema, S. Meyer, S. G. García, A. Kniffka, C. Simmer, S. Crewell, U. Löhnert, T. Trautmann, and A. Macke, “Surrogate cloud fields generated with the Iterative Amplitude Adapted
Fourier Transform algorithm”, Tellus 58A, 104 (2006).

36 V. Nikora, D. Goring, and R. Camussi, “Intermittency and interrelationships between turbulence scaling exponents: Phase-randomization tests”, Phys. Fluids 13, 1404 (2001).

37 M. Pahlow, M. B. Parlange, and F. Porté-Agel, “On Monin Obukhov similarity in the stable atmospheric boundary layer”, Boundary-Layer Meteorol. 99, 225 (2001).

38 S. Basu, F. Porté-Agel, E. Foufoula-Georgiou, J.-F. Vinuesa, M. Pahlow, “Revisiting the local scaling hypothesis in stably stratified atmospheric boundary-layer turbulence: An integration of field and laboratory measurements with large-eddy simulations”, Boundary-Layer Meteorol. 119, 473 (2006).

39 A. Arnéodo, N. Decoster, and S. G. Roux, “A wavelet-based method for multifractal image analysis. I. Methodology and test applications on isotropic and anisotropic random rough surfaces”, Eur. Phys. J. B 15, 567 (2000).

40 K. G. Aivalis, K. R. Sreenivasan, J. C. Klewicki, and C. A., Biltoft, “Temperature structure functions for air flow over moderately heated ground”, Phys. Fluids 14, 2439 (2002).

41 B. Shi, B. Vidakovic, G. G. Katul, and J. D. Albertson, “Assessing the effects of atmospheric stability on the fine structure of surface layer turbulence using local and global multiscale approaches”, Phys. Fluids 17, 055104 (2005).

42 G. S. Poulos, W. Blumen, D. C. Fritts, J. K. Lundquist, J. Sun, S. P. Burns, C. Nappo, R. Banta, R. Newsom, J. Cuxart, E. Terradellas, B. Balsley, and M. Jensen, “CASES-99: A Comprehensive Investigation of the Stable Nocturnal Boundary Layer”, Bull. Amer. Meteorol. Soc. 83, 555 (2002).
Natural Sciences Citations and References  
(Author–Year and Numerical Schemes) 

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This paper describes package natbib version 7.4a from 2006/09/06.

Abstract

The natbib package is a reimplementation of the \LaTeX \cite command, to work with both author–year and numerical citations. It is compatible with the standard bibliographic style files, such as plain.bst, as well as with those for harvard, apalike, chicago, astron, authordate, and of course natbib.

In contrast to the packages listed above, the natbib package supports not only the various author–year bibliography styles, but also those for standard numerical citations. In fact, it can also produce numerical citations even with an author–year bibliographic style, something that permits easy switching between the two citation modes. To this end, replacements for the standard \LaTeX .bst files are also provided.

It is possible to define the citation style (type of brackets and punctuation between citations) and even to associate it with the name of the bibliographic style so that it is automatically activated. Citation styles can be defined for local .bst files by means of a configuration file natbib.cfg.

It is compatible with the packages: babel, index, citeref, showkeys, chapterbib, hyperref, koma and with the classes amsbook and amsart. It can also emulate the sorting and compressing functions of the cite package (with which it is otherwise incompatible).

Note that the citeref package (for adding citation page numbers in the bibliography) must be loaded after natbib. (The hyperref package with the option pagebackref also provides this feature, but with hyperlinks.)

The natbib package therefore acts as a single, flexible interface for most of the available bibliographic styles.
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1 Introduction

The natbib package is an extension to \LaTeX to allow author–year citations along with numerical citations. Standard \LaTeX permits only numerical, whereas all extensions for author–year prior to the release of natbib in 1993 were limited to just that. Since they normally added new commands (as does natbib too), documents written with them could only be used with numerical citations after extensive editing.

The natbib package has changed that; switching from author–year to numerical citations is a matter of an option, with no alterations to the source text. It has now become part of the standard \LaTeX installations, and is supported (demanded) by many journals. It is the citation package of choice by most of the \LaTeX community, mainly because of its flexibility and configurability.

Like all packages, it is loaded the document preamble, with possible options, with, e.g.

\begin{verbatim}
\usepackage[sectionbib,square]{natbib}
\end{verbatim}

The option sectionbib specifies that, when used with the package chapterbib, the bibliography will appear as a section at the end of each chapter (Section 2.14). The square option says that references are to be enclosed in square bracket rather than round parentheses. See Section 5 for a complete list of options.

The document text itself begins with, e.g.

\begin{verbatim}
\begin{document}
\bibliographystyle{plainnat}
\end{verbatim}

which specifies plainnat to be the bibliography style used by the \BibTeX program that generates the actual bibliography from a database. The style plainnat is the natbib version of the standard plain (numerical only) style. See Section 2.1 for other styles, or search the installation for .bst files.

The \texttt{\bibliographystyle} command can be given anywhere in the document, but it makes sense to add it at the start where it can be easily identified (and modified).

To make a citation in the text, use

\begin{verbatim}
\citet{jon90} for a \textit{parenthetical} citation (Jones et al., 1990),
\citep{jon90} for a \textit{textual} one, as Jones et al. (1990).
\end{verbatim}

Both \texttt{\citet} and \texttt{\citep} are defined by natbib and are thus not standard. The standard \LaTeX command \texttt{\cite} should be avoided, because it behaves like \texttt{\citet} for author–year citations, but like \texttt{\citep} for numerical ones. There are many other commands for other special effects (Section 2.4).

In the above examples, jon90 is the identifying key for the reference, as found in the \BibTeX database, or in the \texttt{\thebibliography} environment, Section 2.2.

\begin{verbatim}
\begin{thebibliography}{1}
\bibitem{jon90} Jones et al. (1990)
\end{thebibliography}
\end{verbatim}
This environment prints the actual bibliography, and the \bibitem commands link the entries to the citations via the key, here jon90. The key may be perfectly arbitrary as long as it is unique. The text in square brackets contains the pieces of citation information, the authors Jones et al. and the year 1990. Note that these are two pieces of text that may be packaged together in several different ways, depending on the citation command. In fact, if numerical citations are selected, they are (almost) ignored and only the sequence number is used as citation.

The \thebibliography environment can be made by hand, but it is better and safer to let Bib\TeX do it. For this, one needs the \bibliographystyle command already mentioned, and near the end of the document:

\begin{verbatim}
\bibliography{mybib}
\end{document}
\end{verbatim}

Here mybib is the root name of the Bib\TeX database file (mybib.bib) containing the data for the references needed in the document.

The rest of this document presents all the gorey details about everything possible with natbib.

2 Using this Package

In this paper, I distinguish between the citation mode (author–year or numerical) and citation style (the type of punctuation used for citations). The citation style is something that is independent of the bibliography style and is not programmed in the \bst files.

2.1 New Bibliography Styles

I provide three new \bst files to replace the standard \LaTeX numerical ones:

\begin{verbatim}
plainnat.bst   abbrvnat.bst   unsrtnat.bst
\end{verbatim}

These produce reference lists in the same style as the corresponding standard \bst file, but work with natbib. The advantage is that they can be used in both numerical and author–year mode.

These \bst files are not meant to be exhaustive by any means. Other style files conforming to the natbib format exist, or may be generated with my custom-bib (also known as makebst) program.

2.2 The Syntax of the \thebibliography

The information on the cited author names and year are given as part of the \bibitem commands within the \thebibliography environment. The natbib package expects that information to be in a certain format, which is maintained by the above bibliography styles. (It will also be able to interpret formats used by some earlier packages, such as harvard and chicago.) If one wishes to bypass Bib\TeX, one must make up the \thebibliography oneself, such that it conforms to natbib.

This syntax looks as follows:
\bibitem[Jones et al.(1990)]{jon90}...
or alternatively
\bibitem[Jones et al.(1990)Jones, Baker, and Williams]{jon90}...

The text in square brackets contains the pieces of citation texts, the short author list, Jones et al., the year 1990, and the optional long author list Jones, Baker and Williams. If the long list is missing, the short list will be used instead. The parentheses around the year are not part of the text, but merely delimit the year from the author lists. Round parentheses must always be used, even if square brackets are wanted for the citations. And there must be no space before or after the year parentheses, else it will become part of the author list.

Note: if any single \bibitem entry does not conform to a syntax that \natbib understands, it switches stubbornly to numerical mode, since it otherwise has no idea what the author and year texts could be.

2.3 Basic Citation Commands

The \natbib package can be used with bibliography styles that were intended for other, older packages, like \harvard. However, the commands described in this and the next sections are defined by \natbib and must be used even with those other bibliography styles.

The \natbib package has two basic citation commands, \citet and \citep for textual and parenthetical citations, respectively. There also exist the starred versions \citet* and \citep* that print the full author list, and not just the abbreviated one. All of these may take one or two optional arguments to add some text before and after the citation.

\begin{verbatim}
\citet{jon90} \Rightarrow Jones et al. (1990)
\citet[chap.~2]{jon90} \Rightarrow Jones et al. (1990, chap. 2)
\citep{jon90} \Rightarrow (Jones et al., 1990)
\citep[chap.~2]{jon90} \Rightarrow (Jones et al., 1990, chap. 2)
\citep[see][]{}{jon90} \Rightarrow (see Jones et al., 1990)
\citep[see][chap.~2]{}{jon90} \Rightarrow (see Jones et al., 1990, chap. 2)
\citet*{jon90} \Rightarrow Jones, Baker, and Williams (1990)
\citep*{jon90} \Rightarrow (Jones, Baker, and Williams, 1990)
\end{verbatim}

The starred versions can only list the full authors if the .bst file supports this feature; otherwise, the abbreviated list is printed.

In standard B\TeX, the \cite command can only take a single optional text for a note after the citation; here, a single optional text is a post-note, while two are the pre- and post-notes. To have only a pre-note, it is necessary to provide an empty post-note text, as shown above.

More complex mixtures of text and citations can be generated with the all-purpose \cite{ext} command in Section 2.4.

Multiple citations may be made by including more than one citation key in the \cite command argument. If adjacent citations have the same author designation but different years, then the author names are not reprinted.
These examples are for author–year citation mode. In numerical mode, the results are different.

\cite{jon90} \Rightarrow \textit{Jones et al. [21]}
\cite[chap. 2]{jon90} \Rightarrow \textit{Jones et al. [21, chap. 2]}
\citet{jon90} \Rightarrow \textit{Jones et al. [21]}
\citet[chap. 2]{jon90} \Rightarrow \textit{Jones et al. [21, chap. 2]}
\citep{jon90} \Rightarrow \textit{[21, chap. 2]}
\citep{jon90a, jon90b} \Rightarrow \textit{[21, 32]}

The authors can only be listed if the .bst file supports author–year citations. The standard .bst files, such as plain.bst are numerical only and transfer no author–year information to \LaTeX. In this case, \citet prints “\textit{(author?) [21].}”

In the original versions of natbib, the traditional \cite command was used for both textual and parenthetical citations. The presence of an empty optional text in square brackets signalled parenthetical. This syntax has been retained for compatibility, but is no longer encouraged.

This means that \cite (without notes) is the same as \citet in author–year mode, whereas in numerical mode, it is the same as \citep. The starred version, as well as the one or two optional notes, may also be used.

It is possible to have multiple citations sorted into the same sequence as they appear in the list of references, regardless of their order as arguments to the \cite commands. The option sort is required for this feature. See Section 2.15.

Some publishers require that the first citation of any given reference be given with the full author list, but that all subsequent ones with the abbreviated list. Include the option longnamesfirst to enable this for natbib. See Section 2.16.

2.4 Extended Citation Commands

\citealt As an alternative form of citation, \citealt is the same as \citet but without parentheses. Similarly, \citealp is \citep without parentheses. Multiple references, notes, and the starred variants also exist.

\citealt{jon90} \Rightarrow \textit{Jones et al. 1990}
\citealt*{jon90} \Rightarrow \textit{Jones, Baker, and Williams 1990}
\citealp{jon90} \Rightarrow \textit{Jones et al., 1990}
\citealp*{jon90} \Rightarrow \textit{Jones, Baker, and Williams, 1990}
\citealp{jon90, jam91} \Rightarrow \textit{Jones et al., 1990; James et al., 1991}
\citealp[pg. 32]{jon90} \Rightarrow \textit{Jones et al., 1990, pg. 32}
\citealp[priv. \ comm.]{jon90} \Rightarrow \textit{(priv. comm.)}

The \citealp command allows arbitrary text to be placed in the current citation parentheses. This may be used in combination with \citealp. For example,

\citealp{see \citealp{jon90}},
or even better \citealp{jam91}}
to produce (see Jones et al., 1990, or even better James et al., 1991).

In author–year schemes, it is sometimes desirable to be able to refer to the authors without the year, or vice versa. This is provided with the extra commands

\citeauthor{jon90} ⇒ Jones et al.
\citeauthor*{jon90} ⇒ Jones, Baker, and Williams
\citeyear{jon90} ⇒ 1990
\citeyearpar{jon90} ⇒ (1990)

There also exists a command \citefullauthor which is equivalent to \citeauthor*.

If the full author information is missing, then \citeauthor* is the same as \citeauthor, printing only the abbreviated list. This also applies to the starred versions of \citet and \citep.

If the author or year information is missing (as is the case with the standard \LaTeX \ bst files), these commands issue a warning.

Note: these commands may also be used with numerical citations, provided an author–year \ bst file is being employed.

Note: all \cite commands have the same syntax, allowing multiple citations and up to two notes (there is, however, no starred \citeyear variant). It does not really make much sense to add notes to \citeyear and \citeauthor, especially with multiple citations; however, this can be done, there will be no error message, but the results are sometimes strange. For example, in numerical mode, the notes are fully ignored, while in author–year mode, only the post-note is accepted. Multiple citations in \citet are also not recommended (nor are they in my opinion meaningful), but if they are used with notes, the pre-note will appear before each year, and the post-note only after the last year. These are admittedly bugs, but the effort to remove them is not justified by the questionable usefulness of these features.

In summary, notes are only intended for \citep but they may also be used with \citet in author–year mode, with single citations. In any other situation, the results are unpredictable.

### 2.5 Forcing Upper Cased Name

If the first author’s name contains a von part, such as “della Robbia”, then \citet{dRob98} produces “della Robbia (1998)”, even at the beginning of a sentence. One can force the first letter to be in upper case with the command \Citet instead. Other upper case commands also exist.

- when \citet{dRob98} ⇒ della Robbia (1998)
- then \Citet{dRob98} ⇒ Della Robbia (1998)
- \citep{dRob98} ⇒ (Della Robbia, 1998)
- \Citealt{dRob98} ⇒ Della Robbia 1998
- \Citealp{dRob98} ⇒ Della Robbia, 1998
- \citeauthor{dRob98} ⇒ Della Robbia

These commands also exist in starred versions for full author names.

Note: the coding for the upper casing commands is tricky and likely buggy. It operates on the names that are stored in the \bibitem entry, and works even if
old style font commands are used; however, \LaTeX{} 2ε commands will cause it to crash. Thus
\bibitem[{della Robbia}(1998)]{dRob98} is okay, but
\bibitem{\textit{della Robbia}(1998)}{dRob98} crashes.

2.6 Citation Aliasing

Sometimes one wants to refer to a reference with a special designation, rather than by the authors, i.e. as Paper I, Paper II. Such aliases can be defined and used, textual and/or parenthetical with:
\defcitealias{jon90}{Paper~I}
\citetalias{jon90} ⇒ Paper I
\citepalias{jon90} ⇒ (Paper I)

These citation commands function much like \citet and \citep: they may take multiple keys in the argument, may contain notes, and are marked as hyperlinks.

A warning is issued if the alias is used before it is defined, or if an alias is redefined for a given citation. No warning is issued if an alias is defined for a citation key that does not exist; the warning comes when it is used!

See Section 2.7 for an alternative means of citing with a code name.

2.7 Authorless and Yearless References

What does one do about references that do not have authors? This has long bothered me but I do have a suggestion. Standard \BibTeX{} styles make use of a KEY field in the entries to be used for alphabetizing when the authors or editors are missing. The author–year styles go even further and insert the KEY field in place of the authors. One can imagine giving a code designation for the work at this point. For example,

@MANUAL{handbk98,
  title = {Assembling Computers},
  year = 1998,
  organization = {MacroHard Inc.},
  key = "MH-MAN"
}

With plain, the key text MH-MAN is used only to order the reference, but with plainnat and other author–year styles, it is used in place of the authors. One can then refer to it as \citeauthor{handbk98} to get MH-MAN or as \citep{\citeauthor{handbk98}} for (MH-MAN), a parenthetical citation.

This can be greatly simplified if the bibliography style leaves the date blank in the \bibitem entry, as
\bibitem[MH-MAN()]{}{handbk98}

for then \natbib suppresses the date, preceding punctuation, and the braces for \citet. This means that \citet and \citep behave automatically like the two examples above. The date still may appear in the text of the reference.

The \natbib bibliography styles have been modified accordingly to omit the date from the \bibitem entry when missing authors and/or editors are replaced by key text.
Similarly, if the year is missing, it will be left blank in the \bibitem entry; thus citing such a work will only produce the authors’ names.

**Note:** there are many other possibilities with this feature. One can even produce citations like those of the alpha bibliography style, by placing the citation code in place of the authors in the \bibitem entry and leaving the year blank. A second code (or maybe even the authors themselves) could be placed where the full author list normally appears, to be printed with the starred version of the \cite commands. For example,

\bibitem[MH-MAN()MacroHard Inc.]{handbk98}

### 2.8 Extra Features in the plainnat Family

The special .bst files for natbib mentioned in Section 2.1 have a number of extra fields compared to the original files:

- **ISBN** for the ISBN number in books,
- **ISSN** for the ISSN number in periodicals,
- **URL** for the Internet address of online documents,
- **DOI** the *Digital Object Identifier* now being used by many journals as a more robust alternative to URL,
- **EID** electronic ID, a substitute for page numbers for online journals that also appear in print; also known as the *sequence number* within the paper volume.

Both the DOI and URL tend to be very long, causing ugly line breaks or sticking out into the margin. This can be avoided by loading the url package by Donald Arseneau, which allows text to be broken at punctuation marks without a hyphen. This package is automatically detected by natbib and appropriate commands redefined. URLs are printed in typewriter font, DOI in roman. Without the url package, these numbers are never broken.

As pointed out in Section 2.7, the **KEY** field is treated differently by plainnat than in plain. Whereas the latter uses this field only to alphabetize entries without authors, plainnat actually inserts it in place of the author, both in the reference text and in the citation label (\bibitem entries). Furthermore, the year is left empty in \bibitem so that \citep prints only the “author” text, which is now the **KEY**. This should be some code designation for the work.

### 2.9 Selecting Citation Punctuation

\bibpunct

The above examples have been printed with the default citation style. It is possible to change this, as well as to select numerical or author–year mode, by means of the \bibpunct command, which takes one optional and 6 mandatory arguments. The mandatory ones are:

1. the opening bracket symbol, default = (  
2. the closing bracket symbol, default = )  
3. the punctuation between multiple citations, default = ;  
4. the letter ‘n’ for numerical style, or ‘s’ for numerical superscript style, any other letter for author–year, default = author–year; note, it is not necessary to specify which author–year interface is being used, for all will be recognized;
5. the punctuation that comes between the author names and the year (parenthetical case only), default = ,

6. the punctuation that comes between years or numbers when common author lists are suppressed (default = \); if both authors and years are common, the citation is printed as ‘1994a,b’, but if a space is wanted between the extra letters, then include the space in the argument, as {,~}.

For numerical mode, \citet{jon90,jon91} produces ‘Jones et al. [21, 22]’ with this punctuation between the numbers. A space is automatically included for numbers, but not for superscripts.

The optional argument is the character preceding a post-note, default is a comma plus space. In redefining this character, one must include a space if one is wanted.

The \bibpunct command must be issued in the preamble, that is, before \begin{document}.

Example 1, \bibpunct{[}{]}{,}{a}{}{;} changes the output of \citep{jon90,jon91,jam92} into [Jones et al. 1990; 1991, James et al. 1992].

Example 2, \bibpunct[, ]{(}{)}{,}{a}{}{;} changes the output of \citep[and references therein]{jon90} into (Jones et al. 1990; and references therein).

\bibstyle@xxx

Usually the citation style is determined by the journal for which one is writing, and is as much a part of the bibliography style as everything else. The \natbib package allows punctuation definitions to be directly coupled to the \bibliographystyle command that must always be present when BiB'TeX is used. It is this command that selects the .bst file; by adding such a coupling to \natbib for every .bst file that one might want to use, it is not necessary to add \bibpunct explicitly in the document itself, unless of course one wishes to override the preset values.

Such a coupling is achieved by defining a command \bibstyle@bst, where bst stands for the name of the .bst file. For example, the American Geophysical Union (AGU) demands in its publications that citations be made with square brackets and separated by semi-colons. I have an agu.bst file to accomplish most of the formatting, but such punctuations are not included in it. Instead, \natbib has the definition

\newcommand{\bibstyle@agu}{\bibpunct{}{}{,}{s}{}{\textsuperscript{,}}\gdef\NAT@biblabelnum##1{##1.}}

These style defining commands may contain more than just \bibpunct. Some numerical citation scheme require even more changes. For example, the journal Nature not only uses superscripted numbers for citations, it also prints the numbers in the list of references without the normal square brackets. To accommodate this, \natbib contains the style definition

\newcommand{\bibstyle@nature}{\{\bibpunct{[}{]}{,}{s}{\textsuperscript{,}}\gdef\NAT@biblabelnum##1{##1.}}

\gdef\NAT@biblabelnum##1{##1.}
The redefined `\NAT@biblabelnum` command specifies how the reference numbers are to be formatted in the list of references itself. The redefinition must be made with `\gdef`, not `\def` or `\renewcommand`.

The selected punctuation style and other redefinitions will not be in effect on the first `\LaTeX` run, for they are stored to the auxiliary file for the subsequent run.

The user may add more such definitions of his own, to accommodate those journals and `.bst` files that he has. He should put them into a file named `natbib.cfg`, which is read in if it exists, adding any local configurations. Thus such configurations can survive future updates of the package.

**Note:** any explicit call to `\bibpunct` has priority over the predefined citation styles.

`\citestyle`  
A preprogrammed citation style is normally invoked by the command `\bibliographystyle`, as described above. However, it may be that one wants to apply a certain citation style to another bibliography style. This may be done with `\citestyle`, given before `\begin{document}`. For example, to use the `plainnat` bibliography style (for the list of references) with the `Nature` style of citations (superscripts),

```latex
\documentclass{article}
\usepackage{natbib}
\citestyle{nature}
\begin{document}
\bibliographystyle{plainnat}
```

**Note:** all changes to the citation style, including punctuation, must be made before `\begin{document}`, which freezes the citation style.

### 2.10 Priority of Style Commands

The citation style (punctuation and mode) can be selected by means of the `\bibpunct`, `\citestyle`, and predefined `\bibstyle@bst` commands. They can also be selected by package options (Section 5). What happens if there are several conflicting selections?

The lowest priority is assigned to the predefined `\bibstyle@bst` commands, since they are implicit and not obvious to the user. The package options have the next priority. Finally, any selection by `\bibpunct` and/or `\citestyle` overrides those of the other methods.

### 2.11 Other Formatting Options

`\bibsection`  
The list of references normally appears as a `\section*` or `\chapter*`, depending on the main class. If one wants to redesign one’s own heading, say as a numbered section with `\section`, then `\bibsection` may be redefined by the user accordingly.

`\bibpreamble`  
A preamble appearing after the `\bibsection` heading may be inserted before the actual list of references by defining `\bibpreamble`. This will appear in the normal text font unless it contains font declarations. The `\bibfont` applies to the list of references, not to this preamble.

`\bibfont`  
The list of references is normally printed in the same font size and style as the
main body. However, it is possible to define \bibfont to be font commands that are in effect within the thebibliography environment after any preamble. For example,

\newcommand{\bibfont}{\small}

\begin{verbatim}
citenumfont
Numerical citations may be printed in a different font. Define \citenumfont to be a font declaration like \itshape or even a command taking arguments like \textit.

\newcommand{\citenumfont}{\itshape{#1}}
\end{verbatim}

The above is better than \itshape since it automatically adds italic correction.

\begin{verbatim}
\bibnumfmt
The format of the numerical listing in the reference list may also be changed from the default \[32\] by redefining \bibnumfmt, for example

\renewcommand{\bibnumfmt}{\textbf{#1}:}
\end{verbatim}

\begin{verbatim}
\bibhang
The list of references for author–year styles uses a hanging indentation format: the first line of each reference is flush left, the following lines are set with an indentation from the left margin. This indentation is 1 em by default but may be changed by redefining (with \setlength) the length parameter \bibhang.

\begin{verbatim}
\bibsep
The vertical spacing between references in the list, whether author–year or numerical, is controlled by the length \bibsep. If this is set to 0 pt, there is no extra line spacing between references. The default spacing depends on the font size selected in \documentclass, and is almost a full blank line. Change this by redefining \bibsep with \setlength command.
\end{verbatim}

\end{verbatim}

2.12 Automatic Indexing of Citations

\citeindextrue
\citeindexfalse
If one wishes to have the citations entered in the .idx indexing file, it is only necessary to issue \citeindextrue at any point in the document. All following \cite commands, of all variations, then insert the corresponding entry to that file. With \citeindexfalse, these entries will no longer be made.

The \bibitem commands in the thebibliography environment will also make index entries. If this is not desired, then issue \citeindexfalse before \bibliography or \begin{thebibliography}.

Of course, \makeindex must also be issued in the preamble to activate indexing, as usual. Otherwise, no indexing is done at all.

Make sure that the document has been processed at least twice after the last \BibTeX run before running the \makeindex program.

\begin{verbatim}
\NAT@idxtxt
The form of the index entries is set by the internal \NAT@idxtxt, which can be redefined by hackers if wanted (in the natbib.cfg file please). By default, it prints the short author list plus date in the current parenthesis style.

The natbib package can also be used with the index package of David M. Jones. The order in which the packages are loaded is not important.

\citeindextype
In that package, multiple index lists may be made by means of a \newindex command. For example, it may be desirable to put all the citation indexing into a separate list. First that list must be initiated with, e.g.,

\newindex[cite]{ctx}{cnd}{List of Citations}
and then the automatic citation indexing associated with this list with the \texttt{natbib}
command

\texttt{\renewcommand\citeindextype{cite}}

See the documentation for \texttt{index.sty} for details.

2.13 Hyper\TeX{} Compatibility

The \texttt{natbib} package is compatible with the \texttt{hyperref} package of Sebastian Rahtz,
for use with \LaTeX{} → HTML conversions, pdf\TeX{}, \texttt{pdfmark}. The compatibility
is of a mutual nature: both packages contain coding that interact with that of the
other.

There is a special option \texttt{nonamebreak} that can be used with the \texttt{hyperref}
package; it keeps all the author names in a citation on one line, something that
avoids certain problems with pdf\TeX{}. This is otherwise not recommended, since
many overfull lines result.

2.14 Multiple Bibliographies in One Document

The \texttt{natbib} package is compatible with the \texttt{chapterbib} package of Donald Arse-
neau and Niel Kempson\footnote{I have used version 1.5 from 1995/10/09; cannot guarantee earlier versions.},
which makes it possible to have several bibliographies
in one document. The usual application is to have bibliographies in each chapter
of a book, especially if they have been written by different authors.

The \texttt{chapterbib} package works in a very natural way for the author; only the
editor who puts all the chapters together into one book has to do some extra work.

The package makes use of the \texttt{\include} command, and each \texttt{\include}d file has
its own bibliography. For large books, it makes very good sense to take advantage
of this feature in any case.

To review the use of \texttt{\include}, recall that the main file

\begin{verbatim}
\documentclass{...}
\includeonly{ch2}
\begin{document}
  \include{ch1}
  \include{ch2}
  \include{ch3}
\end{document}
\end{verbatim}

will process only the file \texttt{ch2.tex} as though the files \texttt{ch1.tex} and \texttt{ch3.tex} were
also present. That is, all counters, especially the page and section numbers, as
well as cross-referencing definitions, will function as if the whole document were
processed. The trick is that each \texttt{\include}d file has its own .aux file containing
these definitions, and they are all read in every time, even if the corresponding
.tex file is not. The .aux files also contain the citation information for Bib\TeX{},
something that the \texttt{chapterbib} package exploits.

If \texttt{\usepackage[chapterbib]} has been given, the keys in each \texttt{\cite} and
\texttt{\bibitem} command are associated with the current \texttt{\include}d file and are
distinguished from the identical key in a different file. Each of these files must con-
tain its own \texttt{\bibliography} and \texttt{\bibliographystyle} commands. One processes
Bib\TeX{} on each file separately before processing it under \LaTeX{} (at least twice).
2.14.1 Special Considerations for natbib and chapterbib

The order in which the \texttt{chapterbib} and \texttt{natbib} packages are loaded is unimportant.

The \texttt{chapterbib} package provides an option \texttt{sectionbib} that puts the bibliography in a \texttt{section*} instead of \texttt{chapter*}, something that makes sense if there is a bibliography in each chapter. This option will not work when \texttt{natbib} is also loaded; instead, add the option to \texttt{natbib}. (The \texttt{sectionbib} option can always be given, but it only has meaning for the \texttt{book} and \texttt{report} classes, or for classes derived from them.)

Every \texttt{included} file must contain its own \texttt{bibliography} command where the bibliography is to appear. The database files listed as arguments to this command can be different in each file, of course. However, what is not so obvious, is that each file must also contain a \texttt{bibliographystyle} command, preferably with the same style argument. If different bibliography styles are specified for different files, then the preprogrammed citation style (punctuation and citation mode) will be that of the first bibliography style given. The preprogrammed citation styles can only be changed in the preamble (see Section 2.10), something that guarantees a uniform style for the entire document.\footnote{It would be relatively easy to allow changes in style anywhere in the document, but this strikes me as bad policy. However, it is provided for with the \texttt{docstrip} option \texttt{nopreonly}.}

2.15 Sorting and Compressing Numerical Citations

Another package by Donald Arseneau, \texttt{cite.sty}, reimplements the entire (numerical) citation system such that one can control the punctuation and citation format, all of which is done by \texttt{natbib} as well. However, it also can sort and compress numerical citations, something that is required by some journals.

What this means is that when multiple citations are given with a single \texttt{cite} command, the normal order of the numbers is in the sequence given. This is usually a wild list of numbers, such as \([4,2,8,3]\). With the \texttt{cite} package, this list becomes \([2–4,8]\).

It is impossible to make the \texttt{cite} and \texttt{natbib} packages compatible, since both reimplement \texttt{cite} from scratch. Instead, I have taken over some of the coding from \texttt{cite.sty}, modifying it for \texttt{natbib}. This coding is activated by including one of the options \texttt{sort} or \texttt{sort&compress} in the \texttt{usepackage} command.

For author–year citations, the option \texttt{sort} orders the citations in a single \texttt{citep} or \texttt{citet} command into the sequence in which they appear in the list of references. This is normally alphabetical first, year second. This should avoid citations of the type: “James et al. (1994b,a)”. For author–year mode, the \texttt{sort&compress} option is identical to \texttt{sort}.

2.16 Long Author List on First Citation

A feature that has often been requested by otherwise happy users of \texttt{natbib} is one that is found in the \texttt{harvard} package as standard: with the first citation of any reference, the full author list is printed, and afterwards only the abbreviated list. One can control this with \texttt{citet*} for the first citation, and \texttt{citet} or \texttt{citep} thereafter. However, the automatic feature is very desired.

This can be activated with the option \texttt{longnamesfirst}.\footnote{The option \texttt{longnamesfirst} is not an option to the \texttt{natbib} package, but it is a good idea to use it.}
Some references have so many authors that you want to suppress the automatic long list only for them. In this case, issue

\shortcite{(key-list)}

before the first citations, and those included in \textit{key-list} will have a short list on their first citation.

Full author lists can still be forced at any time with the starred variants.

## 3 Numerical Citations with Author–Year Styles

It is possible to produce numerical citations with any author-year .bst file, with minimal change to the text. The commands \cite and \citet will produce sensible results in both modes, without any special editing. Obviously, the opposite is not possible; a .bst file intended for numerical citation can never produce author–year citations, simply because the information is not transferred to the auxiliary file.

### 3.1 Selecting Numerical Mode

By default, \texttt{natbib} is in author–year mode. This can be changed by

1. selecting a numerical bibliography style with predefined citation style, defined either in the package or in the local configuration file;
2. giving options \texttt{numbers} or \texttt{super} to the \texttt{usepackage} command;
3. issuing \texttt{bibpunct} with the 4th mandatory argument set to \texttt{n} or \texttt{s};
4. issuing \texttt{citestyle} with the name of a predefined numerical bibliography style.

The methods are listed in order of increasing priority.

The \texttt{natbib} package will automatically switch to numerical mode if any one of the \texttt{bibitem} entries fails to conform to the possible author–year formats. There is no way to override this, since such an entry would cause trouble in the author–year mode.

There are certain special ‘numerical’ styles, like that of the standard \texttt{alpha.bst}, which include a non-numerical label in place of the number, in the form

\bibitem[ABC95]{able95}

As far as \texttt{natbib} is concerned, this label does not conform to the author–year possibilities and is therefore considered to be numerical. The citation mode switches to numerical, and \cite{able95} prints [ABC95].

See however, the end of Section 2.7 for another possibility. The above result can be achieved with

\bibitem[ABC95()]{able95}
4 Local Configuration

It is possible to add a local configuration file `natbib.cfg`, which is read in, if it exists, at the end of the package. It may thus contain coding to supecede that in the package, although its main purpose is to allow the user to add his own `\bibstyle@bst` definitions to couple citation punctuation with local bibliography styles.

5 Package Options

When a package is loaded with `\usepackage`, one can add options to select different features, as

\usepackage[options]{natbib}

The options available provide another means of specifying the punctuation for citations:

- **round** (default) for round parentheses;
- **square** for square brackets;
- **curly** for curly braces;
- **angle** for angle brackets;
- **colon** (default) to separate multiple citations with colons;
- **comma** to use commas as separators;
- **authoryear** (default) for author–year citations;
- **numbers** for numerical citations;
- **super** for superscripted numerical citations, as in Nature;
- **sort** orders multiple citations into the sequence in which they appear in the list of references;
- **sort&compress** as **sort** but in addition multiple numerical citations are compressed if possible (as 3–6, 15);
- **compress** to compress without sorting, so compression only occurs when the given citations would produce an ascending sequence of numbers;
- **longnamesfirst** makes the first citation of any reference the equivalent of the starred variant (full author list) and subsequent citations normal (abbreviated list);
- **sectionbib** redefines `\thebibliography` to issue `\section*` instead of `\chapter*`; valid only for classes with a `\chapter` command; to be used with the `chapterbib` package;
- **nonamebreak** keeps all the authors’ names in a citation on one line; causes overfull hboxes but helps with some `hyperref` problems.
If any of the formatting options are selected, the predefined citation styles in the commands \bibstyle@bst will be no longer be effective. If either \bibpunct or \citestyle is given in the preamble, the above punctuation options will no longer hold.

6 Reference Sheet

A summary of the main points on using natbib can be obtained by \LaTeXing the file natnotes.tex, which is extracted from the main source file natbib.dtx with the docstrip option notes. This is intended to act as a handy reference sheet.

This file should be extracted automatically by the supplied installation file, natbib.ins.

7 Options with docstrip

The source .dtx file is meant to be processed with docstrip, for which a number of options are available:

all includes all of the other interfaces;
apalike allows interpretation of minimal apalike form of \bibitem;
newapa allows \citeauthor\year to be in the optional argument of \bibitem along with the punctuation commands of newapa.sty;
chicago is the same as newapa;
harvard includes interpretation of \harvarditem;
astron allows \astroncite to appear in the optional argument of \bibitem;
authordate adds the syntax of the \citename command.

The remaining options are:
package to produce a .sty package file with most comments removed;
209 (obsolete) to generate a \LaTeX 2.09 version of the package; this is no longer supported and will likely not work properly;
notes extracts a summary of usage to be used as a reference sheet; the resulting file is to be \LaTeXed;
nopreonly allows \citestyle and \bibpunct to be called anywhere in the text; this is considered possibly useful with the chapterbib package where different chapters might have different bibliography and citation styles; is only provided in case I change my mind about this feature, but for now I refuse to implement it;
driver to produce a driver .drv file that will print out the documentation when \LaTeX d. This file can be modified to produce various alternatives (page size, fonts, manual only, or with annotated code). The natbib.dtx file is itself such a driver but it should never, ever be edited by a user.

The source file natbib.dtx is itself a driver file and can be processed directly by \LaTeX 2ε.
8 Other Author–Year Solutions

This section is of historical interest only.

Before natbib was published in 1993, there were several other attempts to provide author–year citations, some of which inspired natbib. A few of these are still maintained and used, and for that reason, natbib has attempted to include their \bibitem syntaxes, to be compatible with those .bst files.

Most of these ‘packages’ are really \LaTeX\ 2.09 style files, so do not have features available with the modern \LaTeX\ 2ε.

8.1 The natsci.bst Style

What gave me my first inspiration was Stephen Gildea’s natsci.bst for use with his agujgr.sty file. This showed me that the problem was solvable. However, Gildea’s formats \bibitem with just the abbreviated authors and year. Thus only parenthetical citations can be accommodated.

The name natsci stands for natural sciences, and it was this that led to the name natbib. (This is admittedly an ugly name, but it is now established and cannot be changed so easily.)

8.2 The apalike.bst Style

Oren Patashnik, the originator of BibliTeX and the standard .bst files, has also worked on an author–year style, called apalike.bst with a corresponding apalike.sty to support it. Again, only the parenthetical citation is provided. Its functionality is identical to that of the natsci files.

The form of the \thebibliography entries in this system is

\bibitem{Jones et al., 1990}{jon90}...

This is the most minimal form that can be given. I name it the apalike variant, after Patashnik’s apalike.bst and apalike.sty. However, there could be many independent .bst files that follow this line, such as the natsci styles.

The bibliography style files belonging to this group include:

apalike, apalike2, cea, cell, jmb, phapalik, phppcf, phrmp

8.3 The newapa Style

A major improvement was achieved with newapa.bst and the accompanying newapa.sty files by Stephen N. Spencer and Young U. Ryu. Under their system, three separate items of information are included in the \bibitem label, to be used as required. These are: the full author list, the abbreviated list, and the year. This is accomplished by means of a \citeauthoryear command included in the label, as

\bibitem{\protect\citeauthoryear{Jones, Barker, and Williams}{Jones et al.}{1990}}{jon90}...

Actually, this only illustrates the basic structure of \citeauthoryear; the newapa files go even further to replace some words and punctuation with commands. For
example, the word ‘and’ above is really \texttt{betweenauthors}, something that must be defined in the .\texttt{sty} file. Of course, \texttt{citeauthoryear} is also defined in that file. A number of different \texttt{cite} commands are available to print out the citation with complete author list, with the short list, with or without the date, the textual or parenthetical form.

Thus the \texttt{citeauthoryear} entry in \texttt{bibitem} is very flexible, permitting the style file to generate every citation form that one might want. It is used by a number of other styles, with corresponding .\texttt{sty} files. They all appear to have been inspired by \texttt{newapa.bst}, although they lack the extra punctuation commands.

Bibliographic style files belonging to the \texttt{newapa} group include

\texttt{newapa, chicago, chicagoa, jas99, named}

\textbf{Note:} the last of these, \texttt{named.bst}, uses \texttt{citeauthoryear} in a slightly different manner, with only two arguments: the short list and year.

### 8.4 The Harvard Family

The same effect is achieved by a different approach in the Harvard family of bibliographic styles. Here a substitute for \texttt{bibitem} is used, as

\begin{verbatim}
\harvarditem[Jones et al.]{Jones, Baker, and Williams}{1990}{jon90}...
\end{verbatim}

The accompanying interface package file is called \texttt{harvard.sty} and is written by Peter Williams and Thorsten Schnier. It defines \texttt{harvarditem} as well as the citation commands \texttt{cite}, for parenthetical, and \texttt{citeasnoun}, for textual citations. The first citation uses the long author list, following ones the shorter list, if it has been given in the optional argument to \texttt{harvarditem}.

Bibliography styles belonging to the Harvard family are

\texttt{agsm, dcu, kluwer}

This package has been updated for \LaTeX\,2\epsilon, with many additions to add flexibility. The result is a powerful interface that should meet most citation needs. (It does not suppress repeated authors, though, as \texttt{natbib} does.)

### 8.5 The Astronomy Style

Apparently realizing the limitations of his \texttt{apalike} system, Oren Patashnik went on to develop a ‘true’ \texttt{apa} bibliographic style, making use of the method already employed by an astronomy journal. This is actually very similar to the \texttt{newapa} label but with only the short list of authors:

\begin{verbatim}
\bibitem[protect\astroncite{Jones et al.}{1990}]{jon90}...
\end{verbatim}

It requires the package file \texttt{astron.sty} or any other style that defines \texttt{astroncite} appropriately.

Bibliographic styles belonging to the astronomy group are

\texttt{apa, astronom, bbs, cbe, humanbio, humannat, jtb}

This is as good as the \texttt{citeauthoryear} command, although not as flexible since the full list of authors is missing.
8.6 The authordate Style

Finally, I also found some packages making use of a label command called \citere in the form

\cite{Jones et al., 1990}{jon90}

\ldots

This is not a good system since the author list and date are not cleanly separated as individual arguments, and since the punctuation is included in the label text. It is better to keep the punctuation fully removed, as part of the definitions in the .sty file, for complete flexibility.

Bibliographic styles belonging to this group are

authordate1, authordate2, authordate3, authordate4, aaai-named

with accompanying style file authordate1-4.sty.