Abstract. Evidence of long-term solar variability is reviewed, including historical data and the tree-ring record of radiocarbon. Epochs of suppressed activity like the Maunder Minimum are shown to be frequent occurrences of the last several thousand years, but without no obvious period of recurrence. Weak evidence exists for the 11-year cycle as early as Medieval times, although with insufficient accuracy to establish long-term phase stability.

The evidence for secular and evolutionary changes in the dynamo state of solar-like stars is reviewed. It is found that Ca+ emission in main sequence stars is age dependent and decays as the square-root of main sequence age. Chromospheric emission and hence magnetic flux is linearly related to rotation rate in main sequence stars; this is believed to represent a fundamental dynamo relation. Angular momentum loss by magnetic braking, produced by erupted magnetic flux that 'escapes' past the Alfvénic point in coronal winds may produce the observed secular changes. It is suggested that the dynamo increases in strength in hotter stars and that the break in the angular momentum distribution is due to a 'closing off' of the coronae of early F-type stars.

The amplitude of the dynamo cycle is similar in old and young stars and is color independent. Chaotic fluctuation appears to increase as one moves 'up' the main sequence to hotter stars. A color and age independence of dynamo periods argues that the convective zone thickness is the determining factor. The recent suggestion that the dynamic state of the atmospheres of solar-like stars is age dependent is not found to be supported by the observational data. Extant non-linear calculations of the dynamo
yield a scaling law that can be tested against stellar observations.

1. INTRODUCTION

More and more, modern astrophysics has been concerned with the inconstancy of the universe, and on all time scales. The fixed stars that patterned earlier concepts of the cosmos have been replaced in modern thought by burning masses of gas that slowly evolve and more rapidly change: all stars, including the Sun, are surely variable, when examined closely and for sufficient time.

In this review, we consider several aspects of long-term, or secular variability in the Sun and other stars. We are concerned most specifically with variability of solar and stellar dynamos, and the observable manifestation of these phenomena on time scales longer than about 25 years— an arbitrary limit chosen to de-emphasize the well-studied 11- and 22-year periods of solar variability, which we summarize briefly here for completeness.

The 11-year cycle of solar behaviour is most commonly illustrated in the well-known plot of annual-averaged sunspot numbers (Figure 1). It is better described, however, when the added dimension of solar latitude is included (Figure 2). The familiar butterfly diagram shows the temporal and spatial variability of magnetic active regions in the photosphere and chromosphere, for which sunspots serve as the most easily observed tracer. Thus the patterns shown for sunspots in Figures 1 and 2 apply equally well to chromospheric plages, active prominences, flares, and solar radio bursts, and coronal transient events.

It is not yet known whether or by how much the total luminosity of the Sun (or solar constant) varies in the course of the 11-year solar cycle, although the most recent and precise measurements from the Solar Maximum Mission (1) would imply a probable solar-cycle variation at the level of a few tenths of one percent—enhanced at times of low activity and suppressed when solar activity increases. This extrapolation, based on an apparent anti-correlation with projected sunspot area found in the first months of SMM data, is an admittedly bold extrapolation.

It is well known that the flux of solar radiation that lies outside the 6000K envelope of blackbody radiation (i.e., the ultra-violet, x-ray and radio radiation from the upper chromosphere and corona) is positively correlated with observable solar activity, with the greatest sensitivity at the shortest wavelengths and in the longest radio waves (2). The same is true of variation with the solar cycle, although in this case the real