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Keynote
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“Global warming” from increased greenhouse gases really refers to a global energy imbalance at the top-of-atmosphere (TOA). Global fluctuations in TOA energy of up to 0.2 W m-2 occur from natural variations in clouds, aerosols, and changes in the Sun. At times of major volcanic eruptions the effects can be much larger. An energy imbalance is manifested not just as surface atmospheric or ground warming, but also as melting sea and land ice, and heating of the oceans. An inventory of energy shows that over 90% of the imbalance is manifested as ocean heat content (OHC), and this with melting land ice, causes sea level to rise. For the past decade, over 30% of the heat has apparently penetrated below 700m depth that is traceable to changes in surface winds mainly over the Pacific in association with a switch to a negative phase of the Pacific Decadal Oscillation (PDO) in 1999. Surface warming was much more in evidence during the 1976-1998 positive phase of the PDO, suggesting that natural decadal variability modulates the rate of change of global surface temperatures while sea level rise is more relentless.
We use ORAS4 ocean reanalysis data and other OHC estimates to compare the OHC rates of change with model-based estimates of TOA energy imbalance (from CCSM4), and with TOA satellite measurements for the year 2000 onwards. Most of the ocean-only OHC analyses extend to only 700 m depth, have large discrepancies among the rates of change of OHC, and do not resolve interannual variability adequately to capture ENSO and volcanic eruption effects, all aspects that are improved with assimilation of multi-variate data. ORAS4 rates-of-change of OHC quantitatively agree with the radiative forcing estimates of impacts of the 3 major volcanic eruptions since 1960 (Mt. Agung 1963, El Chichón 1982, and Mt. Pinatubo 1991). Estimates (OHC and TOA) show that over the past decade the energy imbalance ranges between about 0.5 and 1 W m-2. By using the full-depth ocean, there is a better overall accounting for energy, but discrepancies remain at interannual timescales between OHC and TOA radiation measurements, notably in 2008-09.

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