The 4.5-year climate cycle and the mixed layer heat budget in the tropical Atlantic

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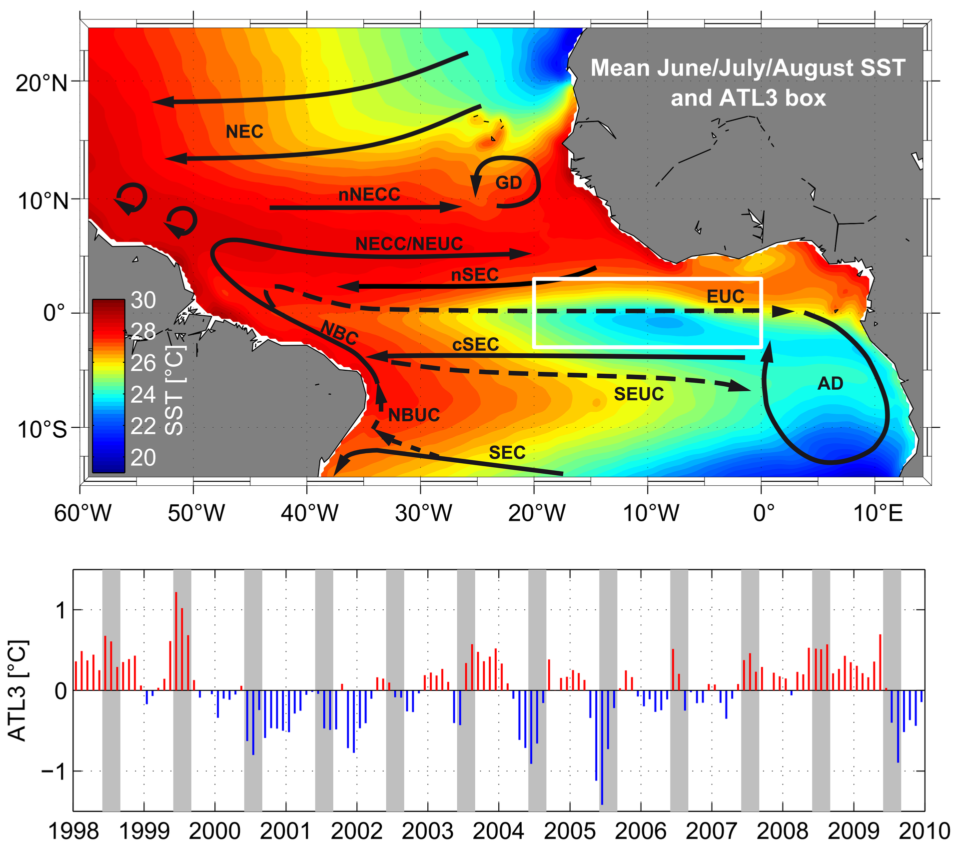
Motivation

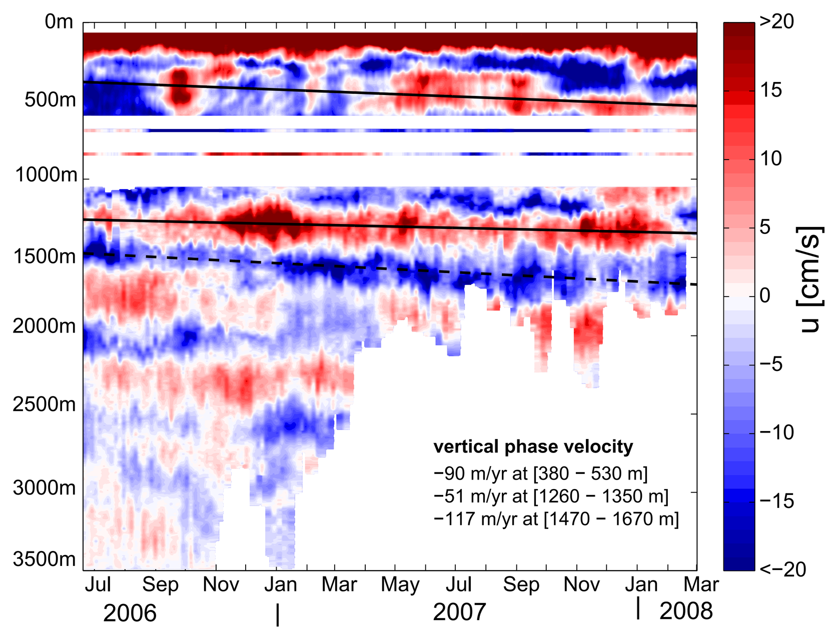


Mean June/July/August SSTs in the tropical Atlantic (upper panel). Also included are the main surface (solid) and thermocline (dashed lines) current bands. The white box in the upper panel defines the region for the ATL3 SST index shown in the lower panel.

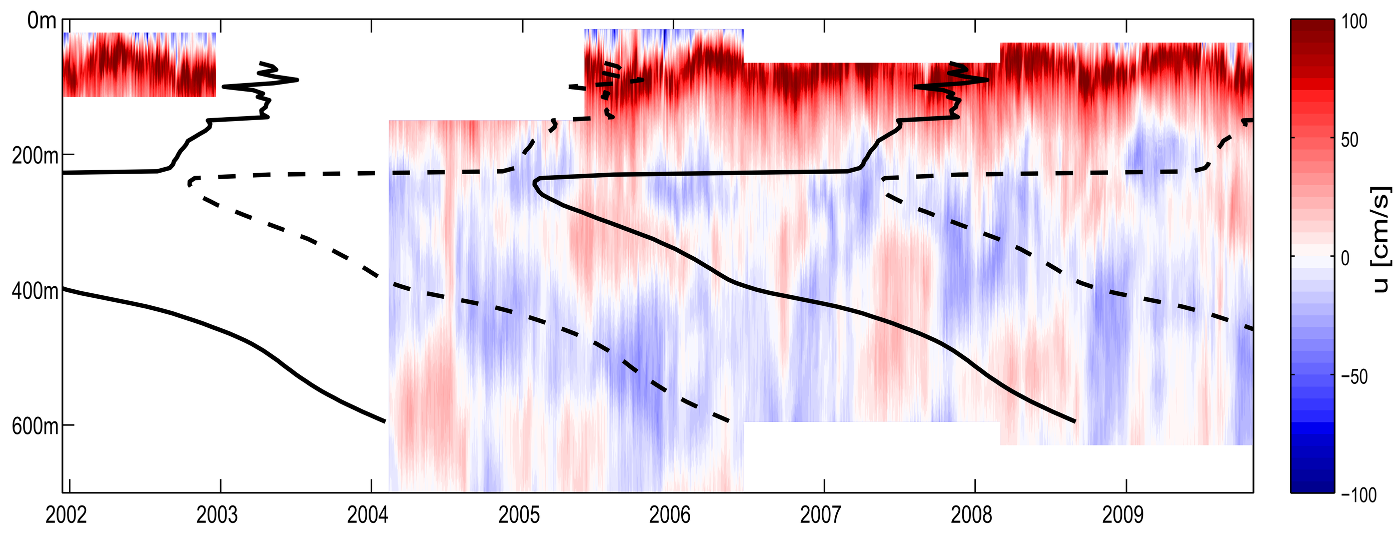
Climate variability in the tropical Atlantic Ocean is determined by large-scale ocean–atmosphere interactions, which particularly affect deep atmospheric convection over the ocean and surrounding continents. The zonal mode often referred to as the Atlantic counterpart to the Pacific El Niño is characterized by an east–west SST gradient along the Equator and is associated with marked zonal wind anomalies. It is most pronounced during boreal summer when the seasonal maximum in equatorial upwelling leads to the development of the eastern Atlantic SST cold tongue. The period of zonal-mode-like oscillations estimated from observations, models and theory ranges from 19 months to 5 years.

Atlantic equatorial deep jets (EDJs)

Moored observations reveal the existence of EDJs oscillating at a period of about 4.5 yr. EDJ are associated with downward phase propagation from below the Equatorial Undercurrent (EUC) at about 200-m depth to about 2,000-m depth that corresponds, according to linear internal wave theory, to upward energy propagation.

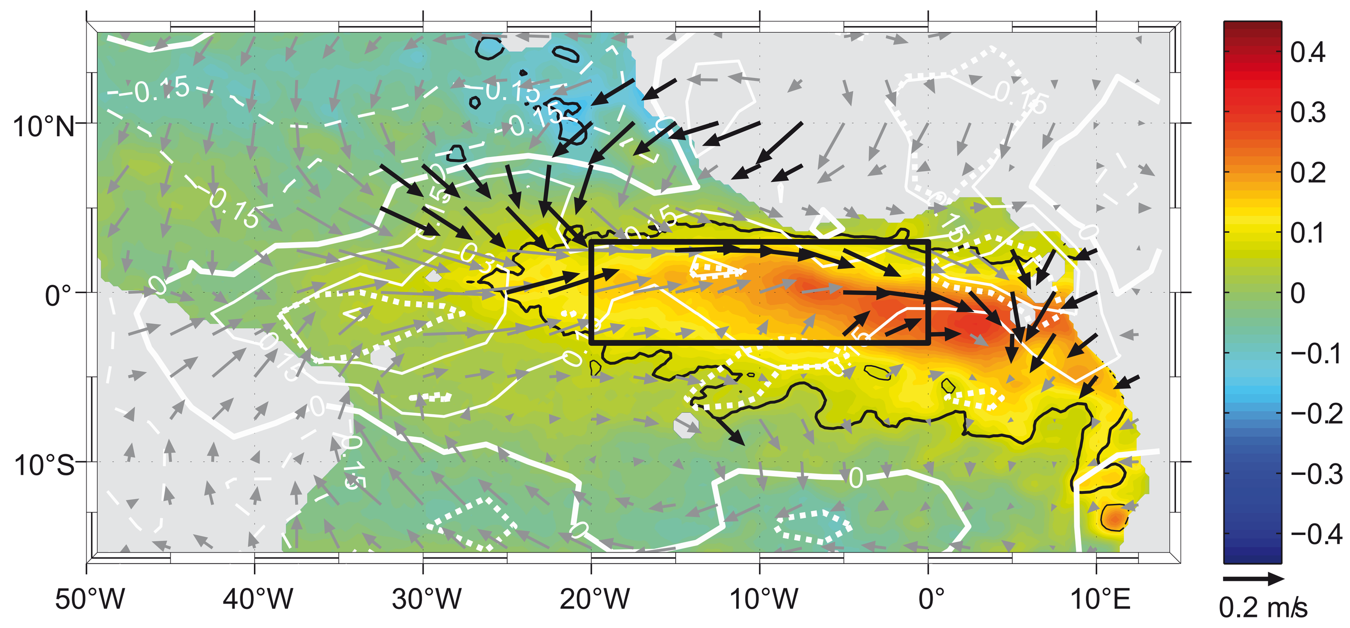


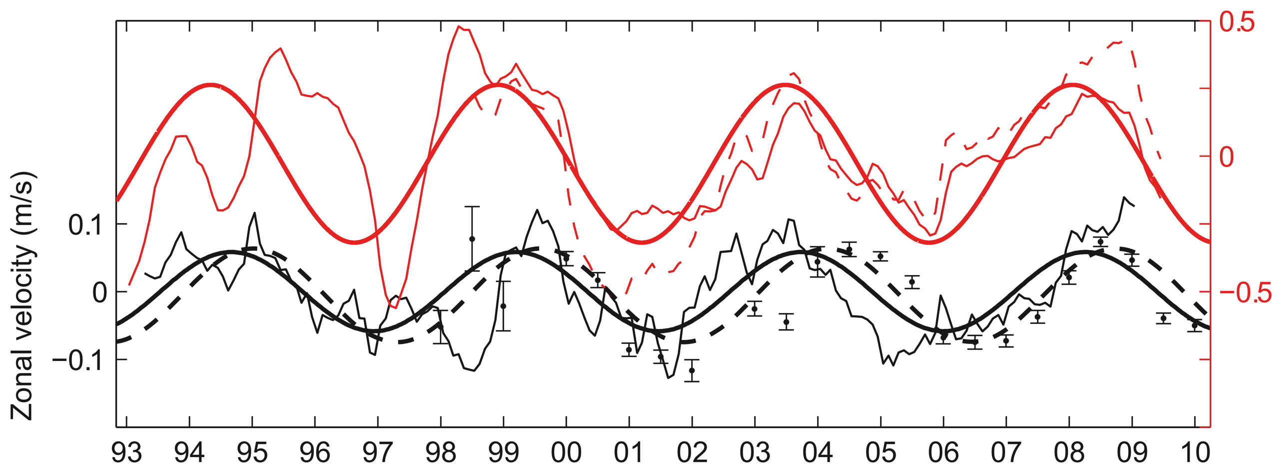
Zonal velocity at the Equator, 23°W, acquired by an ADCP, single-point current meters and a moored profiler.



Zonal velocity at the Equator, 23°W, acquired by different ADCPs. Phase lines are obtained from harmonic analysis using a period of 1,670 d.

4.5-yr climate cycle

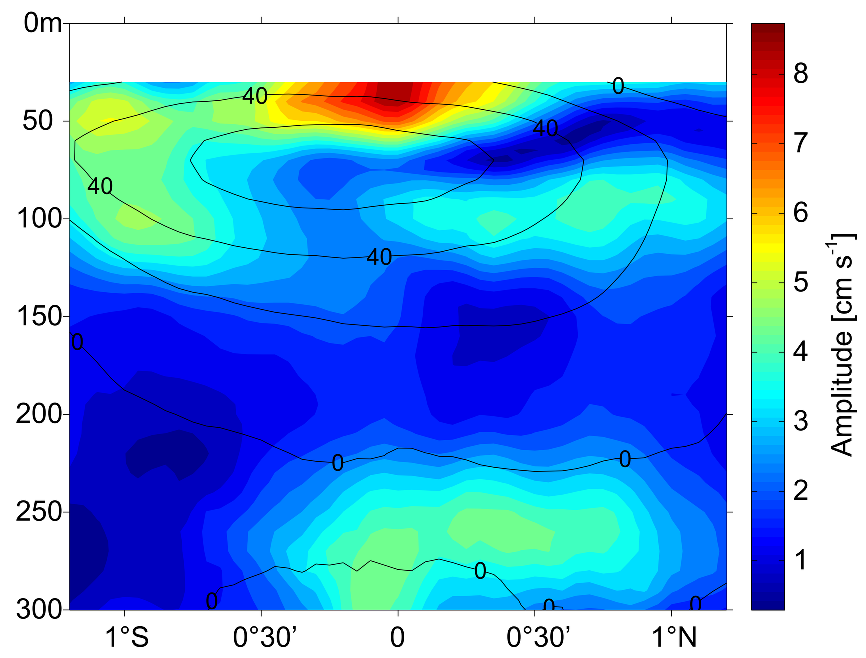


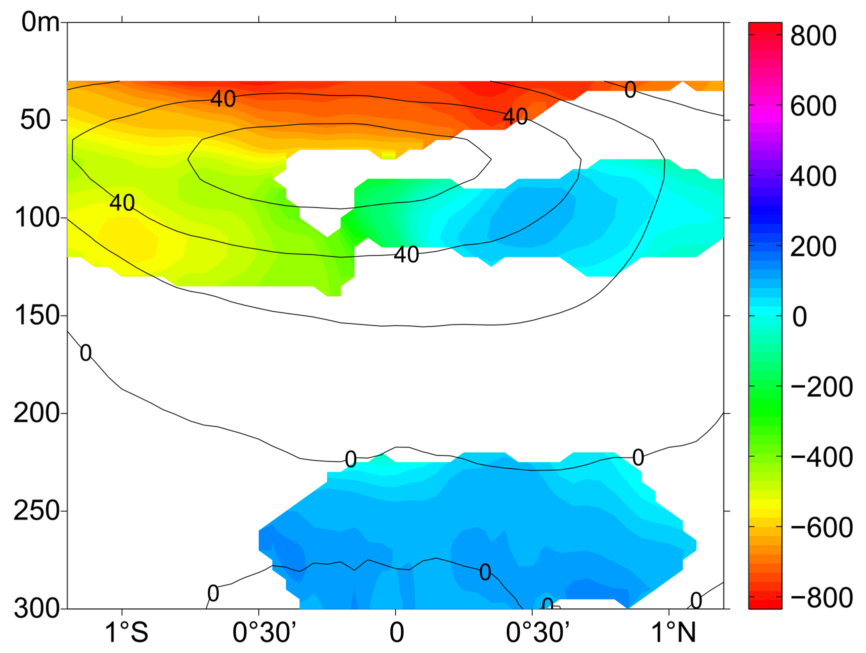


Anomalous westerlies along the Equator, convergent meridional wind anomalies particularly in the western tropical Atlantic, and positive rainfall anomalies in a wide belt around the Equator are associated with positive SST anomalies. A 4.5-yr cycle is also found in the surface geostrophic zonal velocity anomaly at the Equator as well as in the 1,000-m zonal velocity from Argo floats. Phases of eastward surface flow coincide with SST warm phases in the eastern equatorial Atlantic.

Upper panel: Regression of SST, surface wind and rainfall (white contours, mm/d) on the harmonic fit of the ATL3 SST anomalies. Lower panel: ATL3 SST anomaly (microwave optimally interpolated SST, red dashed; HadISST, red thin solid) with 1,670-d harmonic fit (red thick solid), surface geostrophic zonal velocity anomaly (Equator, 35°W–15°W; black thin solid) with 1,670-d harmonic fit (black thick solid), and 1,000-m zonal velocity (1°S–1°N, 35°W–15°W; black dots with standard errors) with 1,670-d harmonic fit (black thick dashed).

Current variability

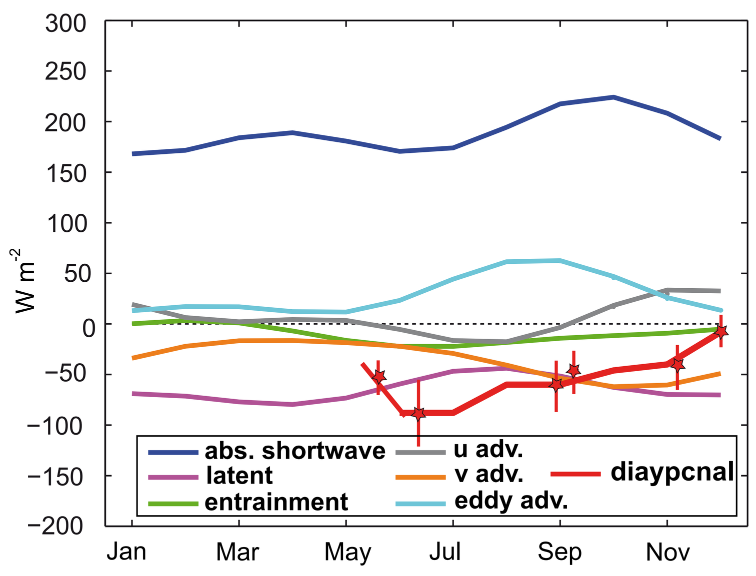


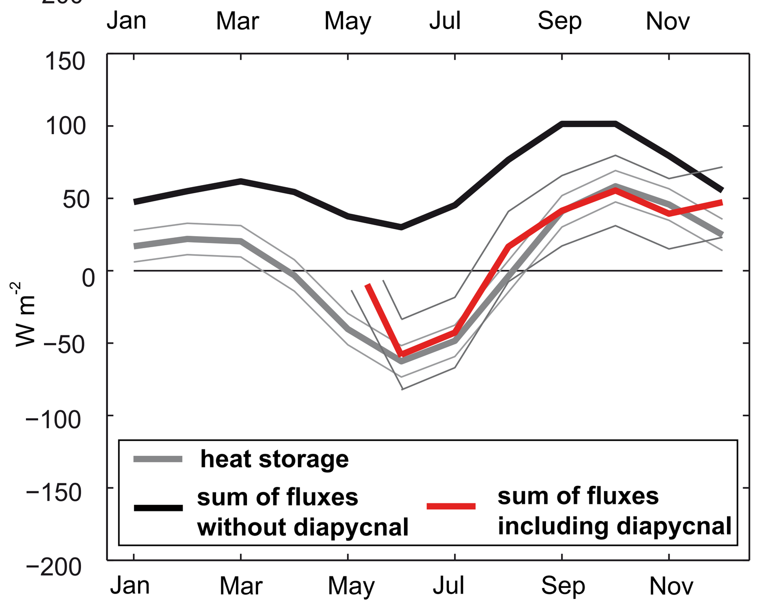


Current variability associated with the 4.5-year signal exhibits a complex structure in the upper equatorial ocean. Maximum amplitudes of 8cm/s are found on the equator at 50m depths while the signal nearly vanishes in the core of the EUC below. Additionally, the phase distribution indicated a meandering of the EUC with a period of 4.5-year. Several wave-mean flow interaction processes are likely to play a role when the deep jets meet the EUC, among them being critical layer absorption and tunneling.

Amplitude (in cm/s, upper panel) and phase (in days,lower panel) of the 4.5-year velocity signal.

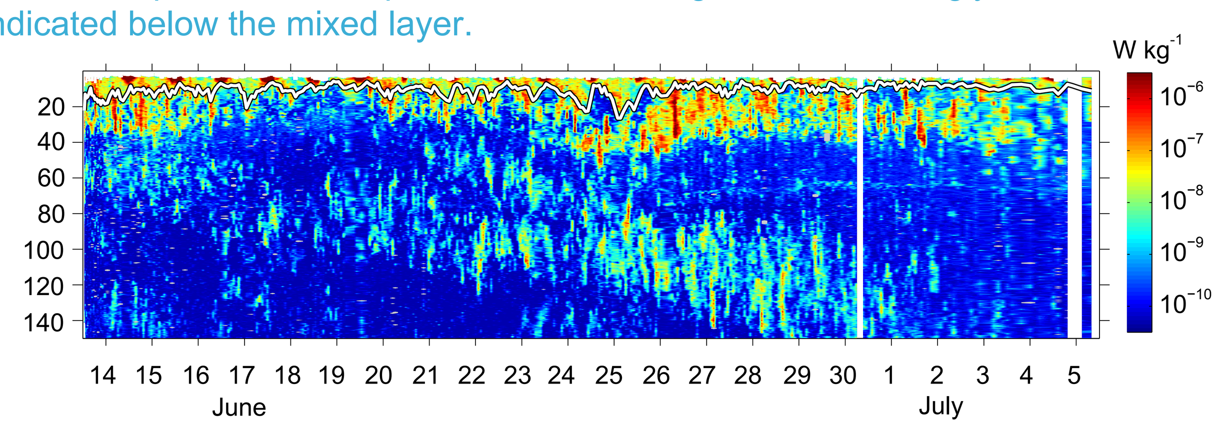
Mixed layer heat balance in the cold tongue





A detailed analysis of the mixed layer heat budget in the equatorial Atlantic shows that the dominant heating terms are solar radiation and mesoscale eddy advection while the dominant cooling terms are latent heat loss and turbulent mixing just below the mixed layer and associated diapycnal heat fluxes into the deeper ocean. Diapycnal mixing in the upper stratified ocean is most intense during boreal summer, when the winds on the equator strengthen and Tropical Instability waves additionally contribute to vertical shear and thus mixing in the upper ocean.

Upper left panel: Individual mixed layer heat flux contributions that were found to vary during the seasons on the equator at 10°W. Lower left panel compares heat storage (gray line) with sum of all heat fluxes contributing to the mixed layer heat balance excluding (black) and including (red) diapycnal heat flux through the base of the mixed layer (from Hummels et al., 2012). Lower middle panel: Time series of the rate of turbulent dissipation at the equator in 10°W during summer. Strongly elevated mixing is indicated below the mixed layer.



Summary

- Vertically alternating deep zonal jets of short vertical wavelength with a period of about 4.5 yr and amplitudes of more than 10 cm/s are observed, in the deep Atlantic, to propagate their energy upwards, towards the surface.
- At the sea surface they are linked to equatorial zonal current variability and eastern Atlantic temperature anomalies that have amplitudes of about 6 cm/s and 0.4°C, respectively.
- The sea surface temperature anomalies are associated with distinct wind and rainfall patterns.
- The mixed layer balance in the region of elevated sea surface temperature variability due to the 4.5-year cycle is strongly influenced by heat loss due to mixing in the upper stratified ocean.

The oscillatory behaviour can be used to improve predictions of SST in the tropical Atlantic.

References

Brandt, P., A. Funk, V. Hormann, M. Dengler, R. Greatbatch and J. Toole (2011), Interannual atmospheric variability forced by the deep equatorial Atlantic Ocean, Nature, 473, 497-500, doi: 10.1038/nature10013.

Hummels, R., M. Dengler, and B. Bourlés (2012), Seasonal and regional variability of upper ocean diapycnal heat flux in the Atlantic Cold Tongue, submitted to Progress in Oceanography, January 2012.