

Dynamic downscaling of climate simulations – recent developments in southern Africa

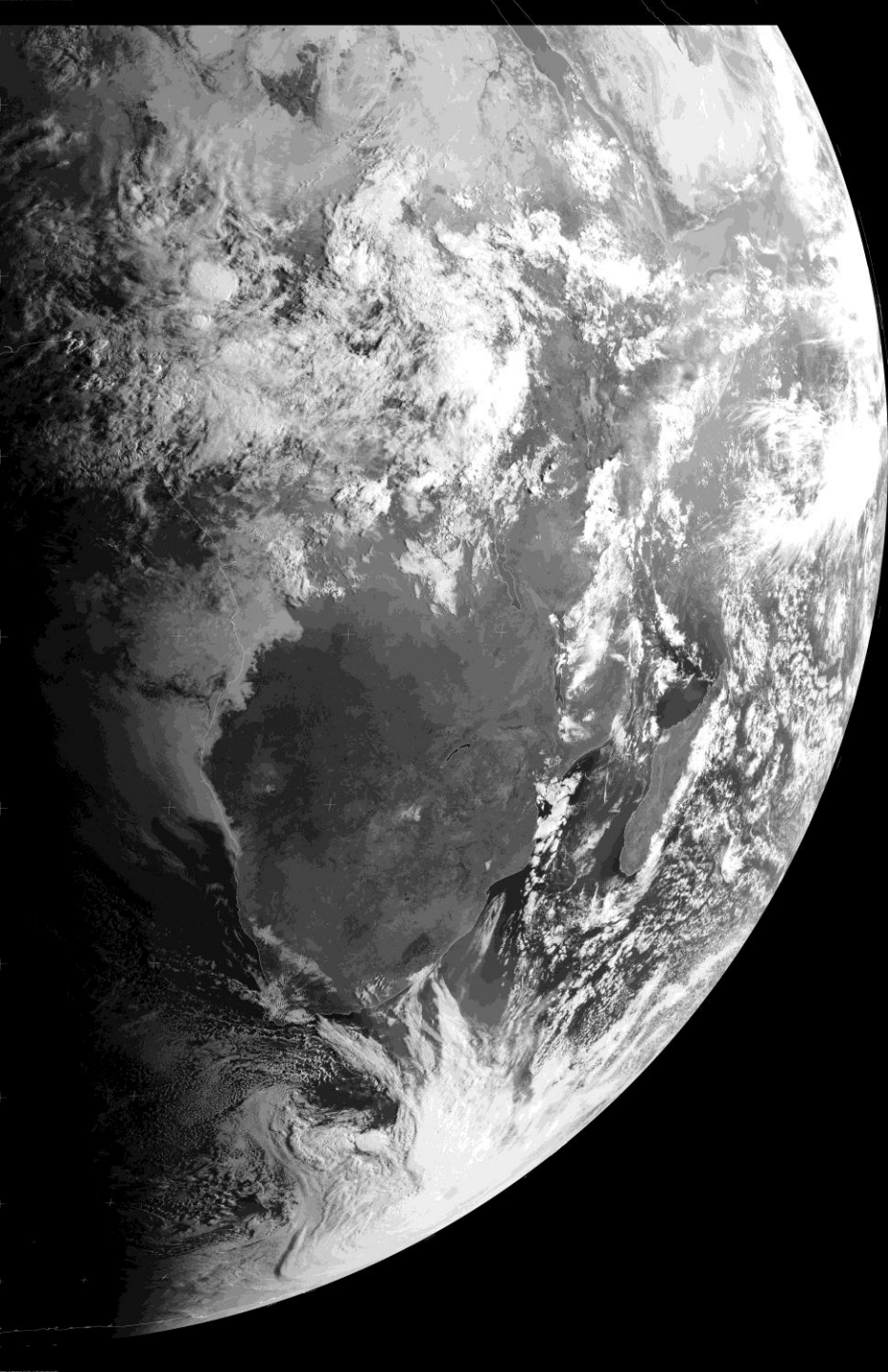
Francois Engelbrecht

CSIR Natural Resources and the Environment

Climate Studies, Modelling and Environmental health



our future through science



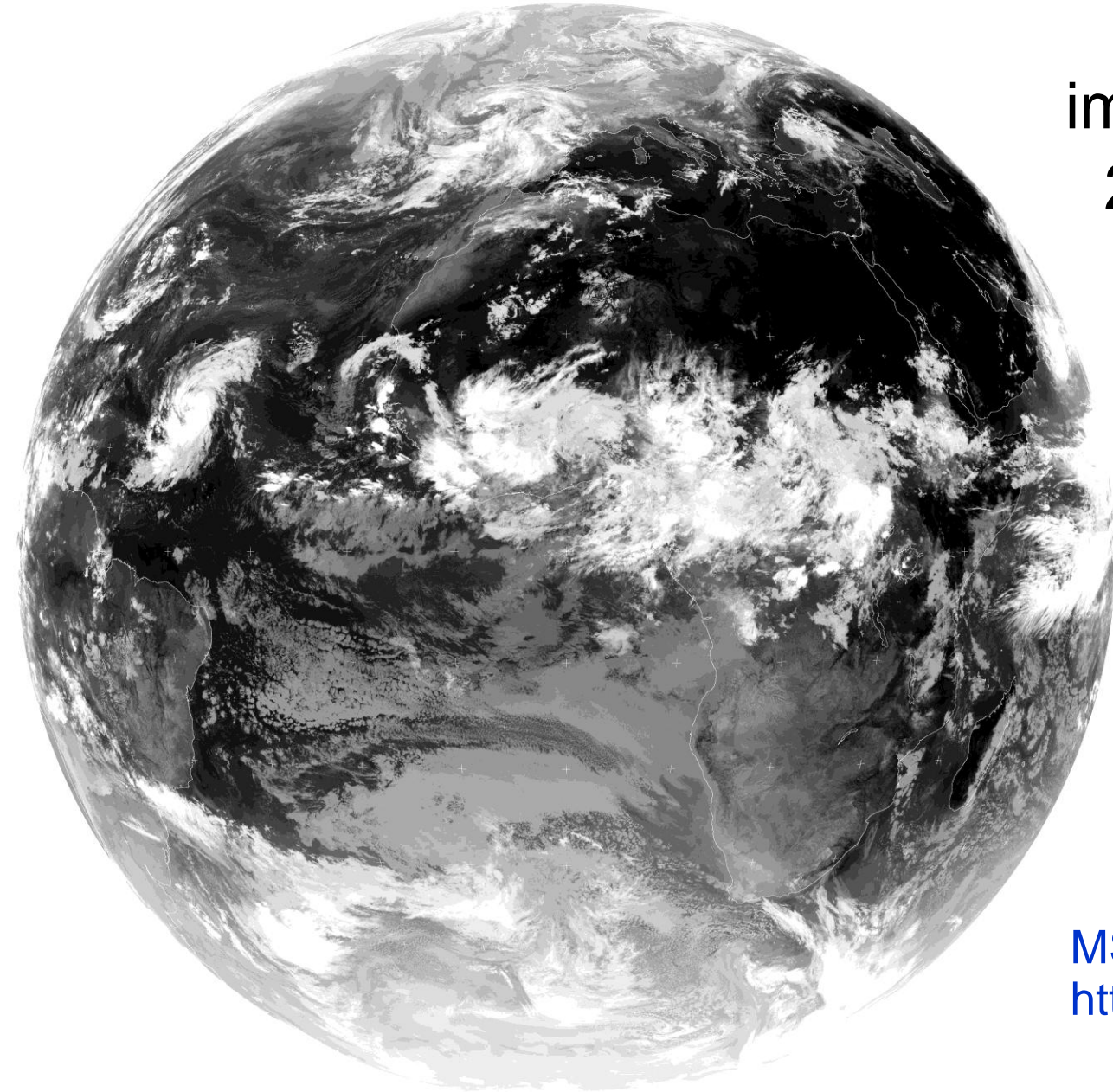
Visual satellite image;

0.4-1.1 μm ; 2011-08-31 06Z

MSG

<http://www.sat.dundee.ac.uk>

Infrared satellite
image; 9.8-11.8 μm ;
2011-08-31 06 Z



MSG
<http://www.sat.dundee.ac.uk>

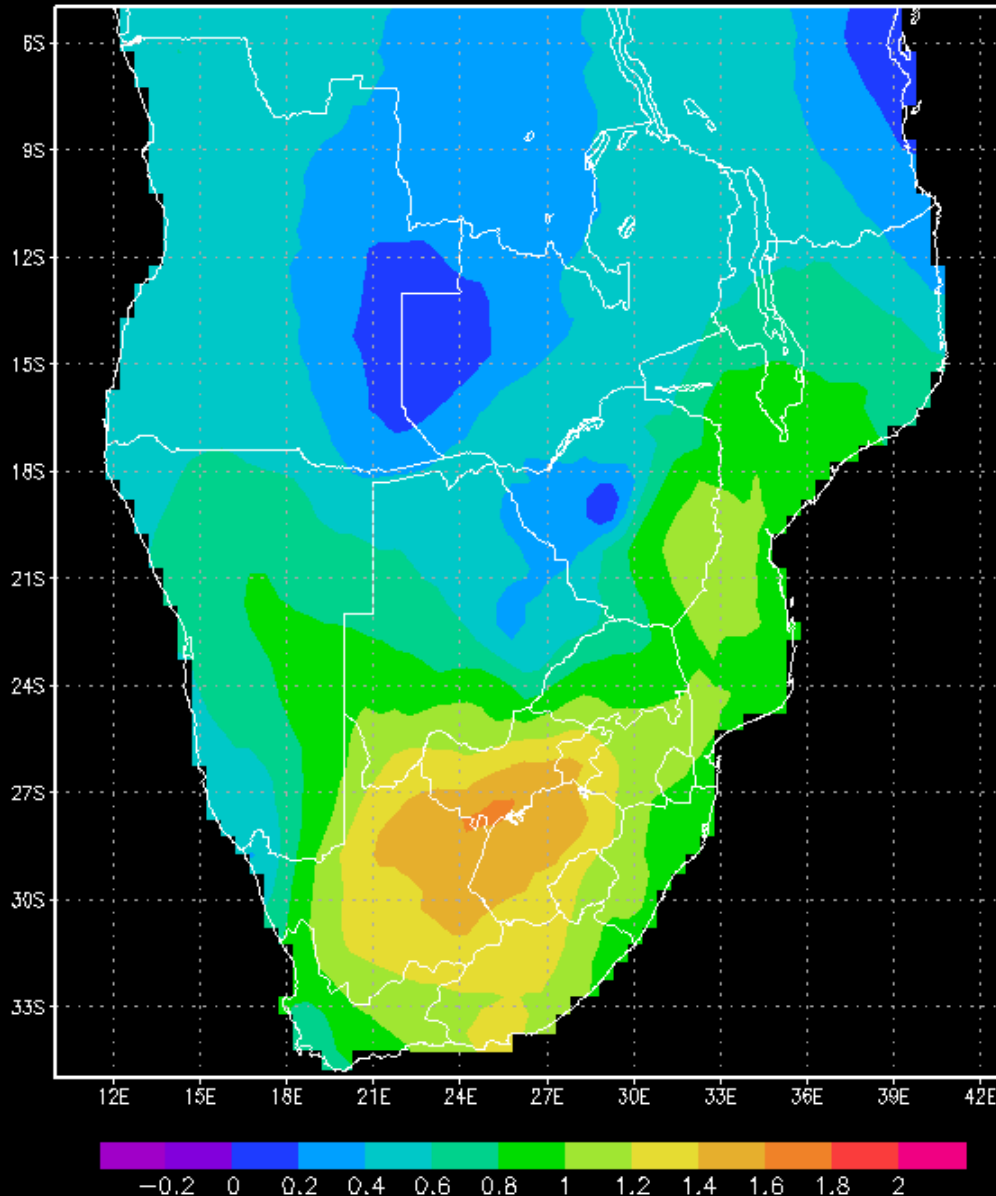
Annual temperature trends 1901-2002

* The largest trends occur over the central interior of South Africa, with temperature increasing at twice the global average rate of increase

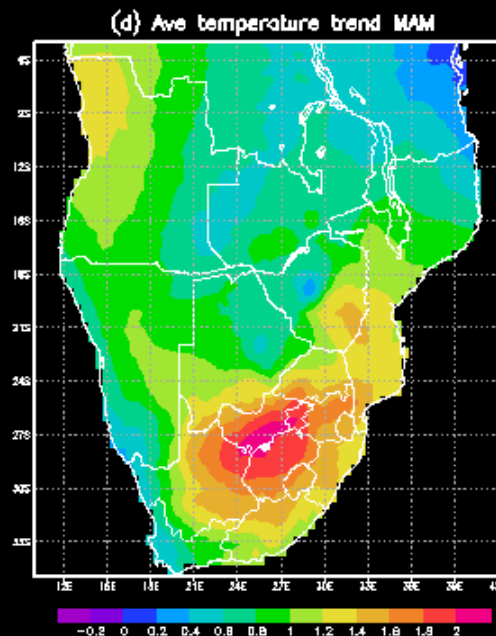
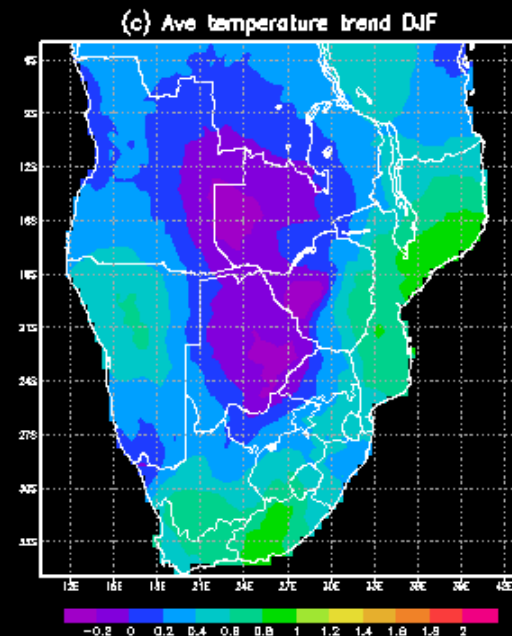
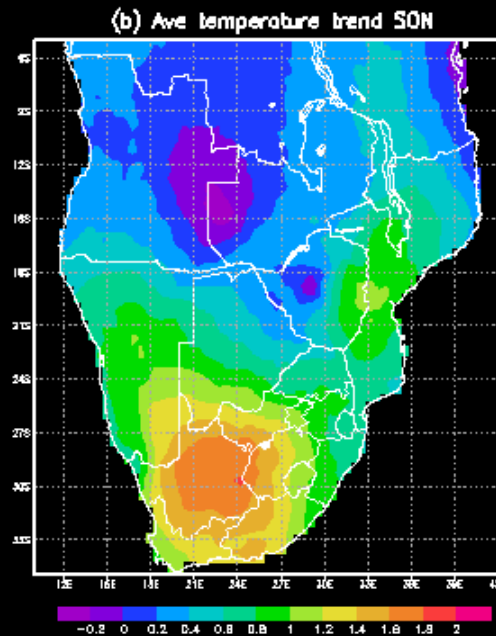
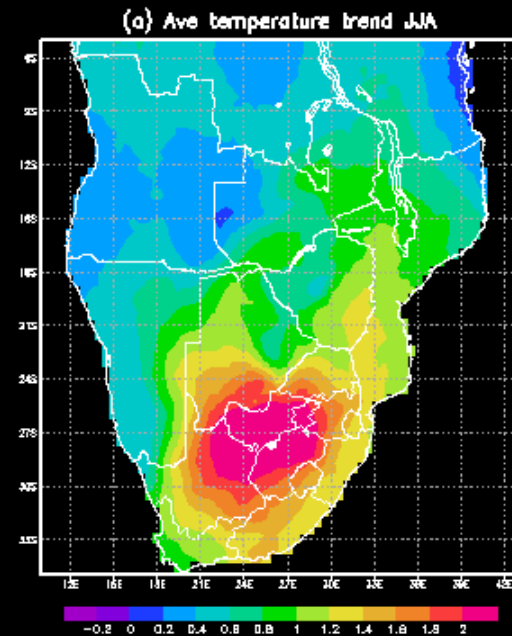
* Warming trend weaker over coastal areas

Kruger and Shongwe (2004)

Engelbrecht (2010)



Seasonal temperature trends 1901-2002



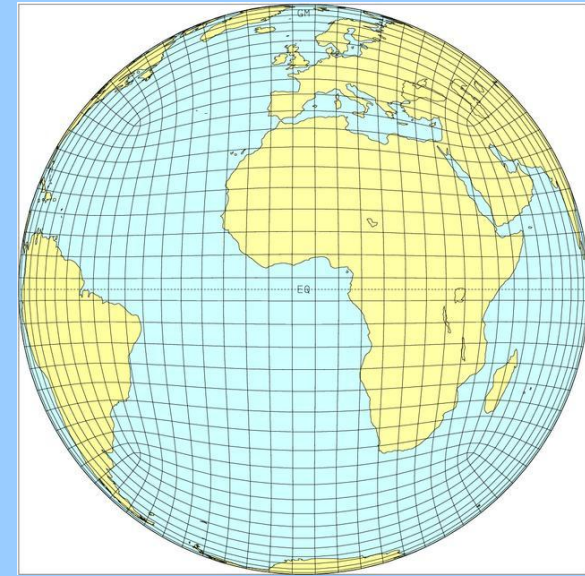
* The largest trends occur over the central interior of South Africa during winter

* The warming tendency is the smallest during summer

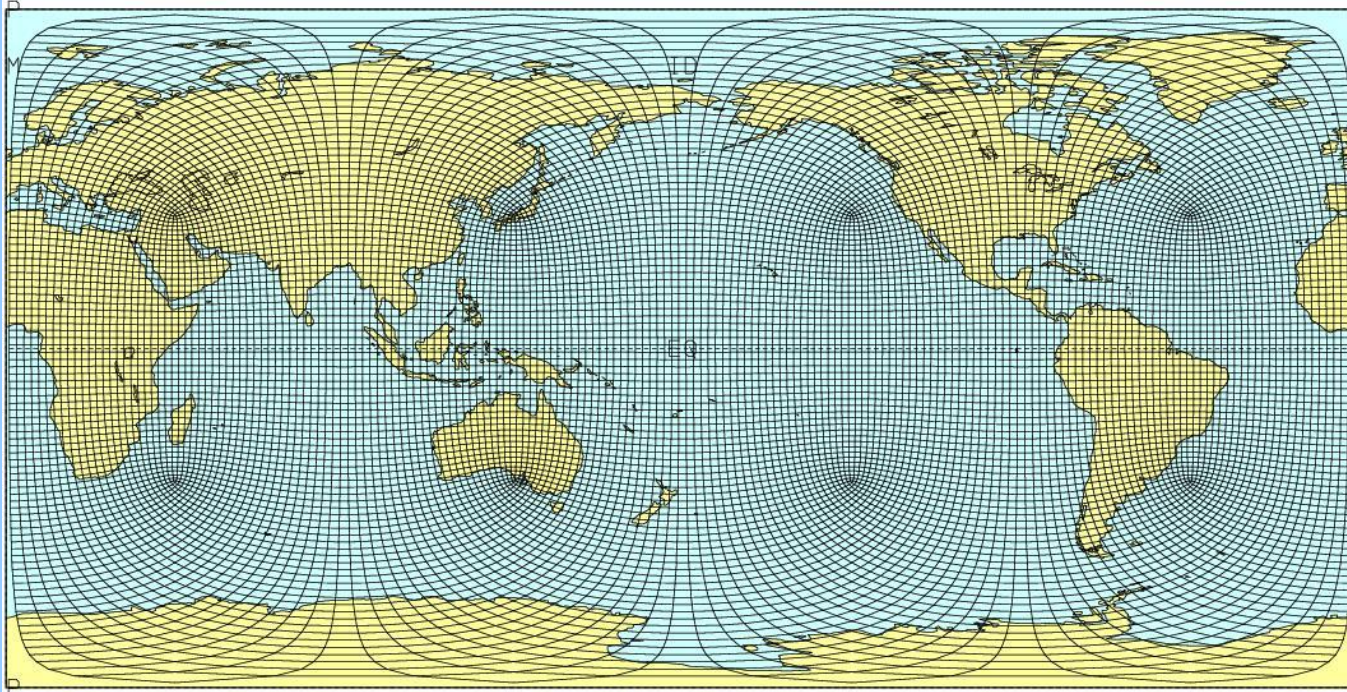
Kruger and Shongwe (2004)
Engelbrecht (2010)

Climate Modelling at the CSIR NRE

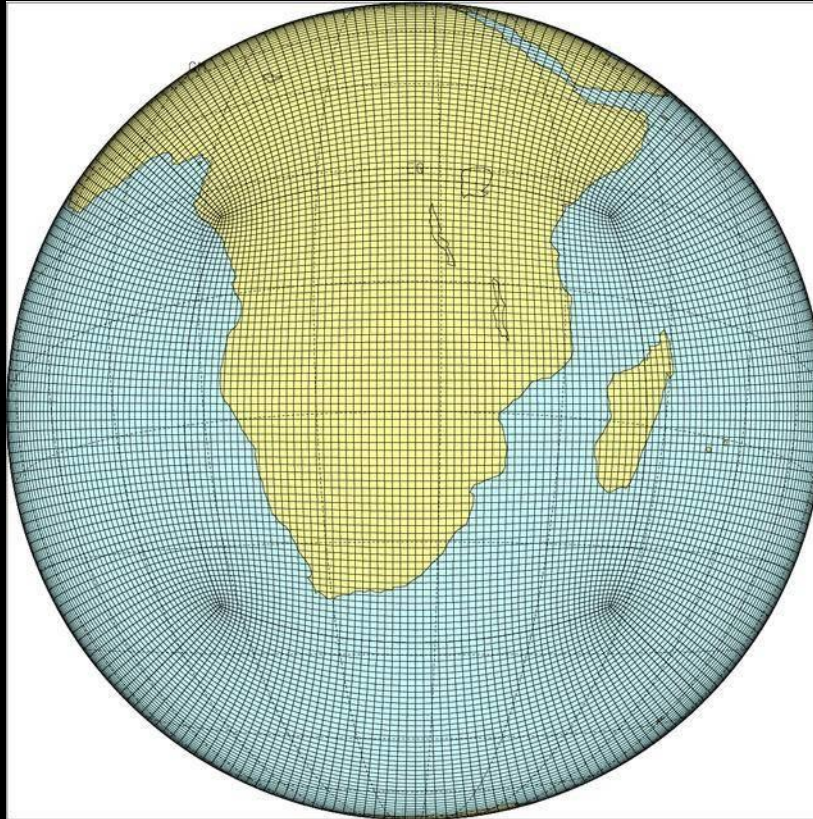
- NWP and RCM capacity build around the conformal-cubic atmospheric model (CCAM) of the CSIRO
- A cube-based global model; semi-Lagrangian semi-implicit solution of the hydrostatic primitive equations
- Includes a wide range of physical parameterizations
- Developed by the CSIRO Marine and Atmospheric Research (McGregor, 2005)
- Runs in quasi-uniform or in stretched grid mode
- Seamless (multiscale) forecasting...



Quasi-
uniform C48
grid with
resolution
about 210 km



Regional climate modelling over southern and tropical Africa using CCAM



C64 stretched-grid with resolution about 0.5 degrees over southern and tropical Africa

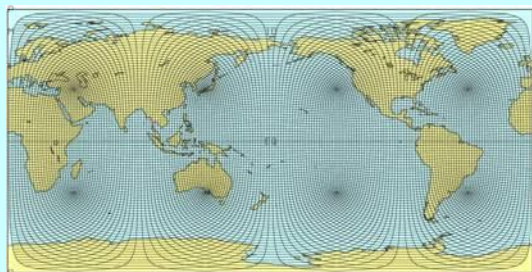
CCAM applied in stretched-grid mode

Modest stretching provides a resolution of about 0.5 degrees over tropical and southern Africa; decreases to about 4 degrees in the far-field

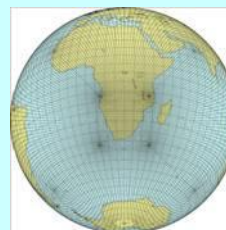
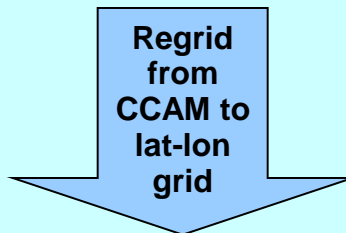
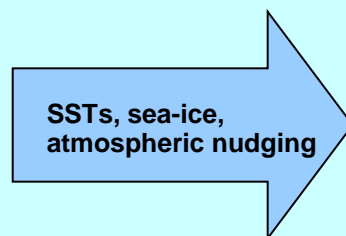
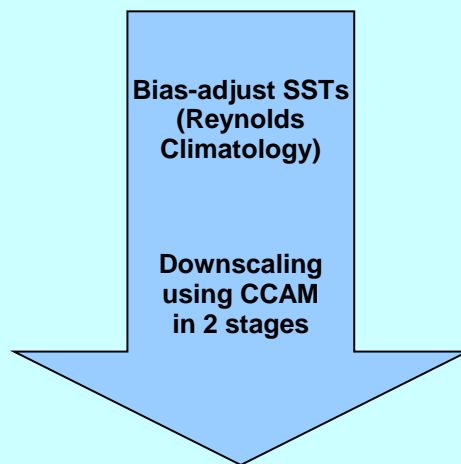
Options for spectral nudging, gridpoint nudging or no nudging from the host model (atmospheric fields)

6 CGCMs (SSTs and sea-ice) of AR4 – A2 SRES; 1961-2100

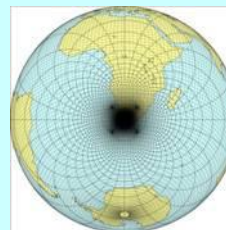
Regional Climate Modelling Flow of Events: new CSIR ensemble of projections



Global simulations, quasi-uniform resolution (~ 2 degrees)



Regional stretched-grid simulations (~ 0.5 degree resolution)

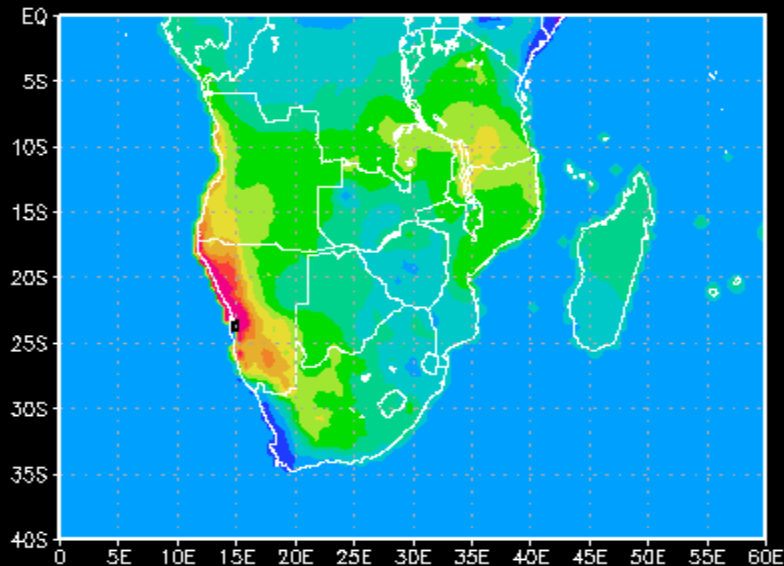


Very high-resolution simulations over CC "hot spot" areas (~ 8 km resolution)

Climate Dynamics + Application
Modelling/Studies

CHPC
ESKOM

CRU MAR Rainfall %

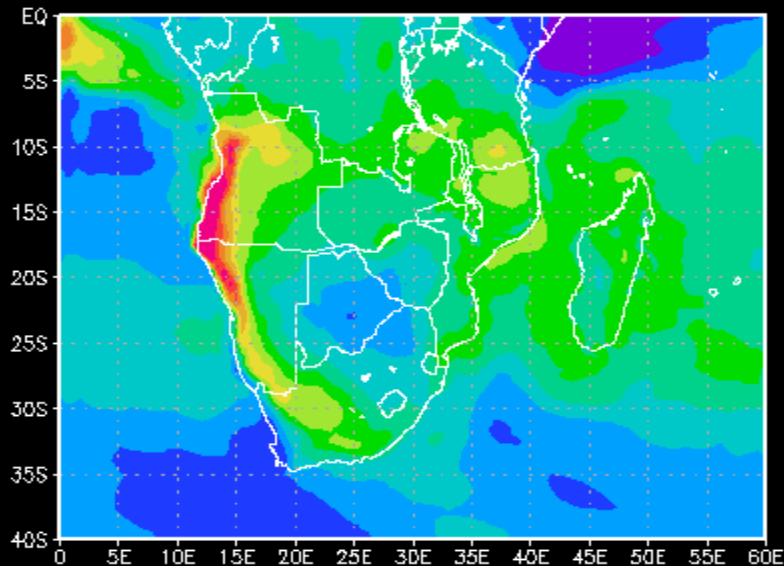


Model verification:

Intra-annual cycle in rainfall and circulation (Engelbrecht et al., 2009; IJC)

Closed-low tracks and extreme rainfall events (Engelbrecht et al., 2011; IJC submitted)

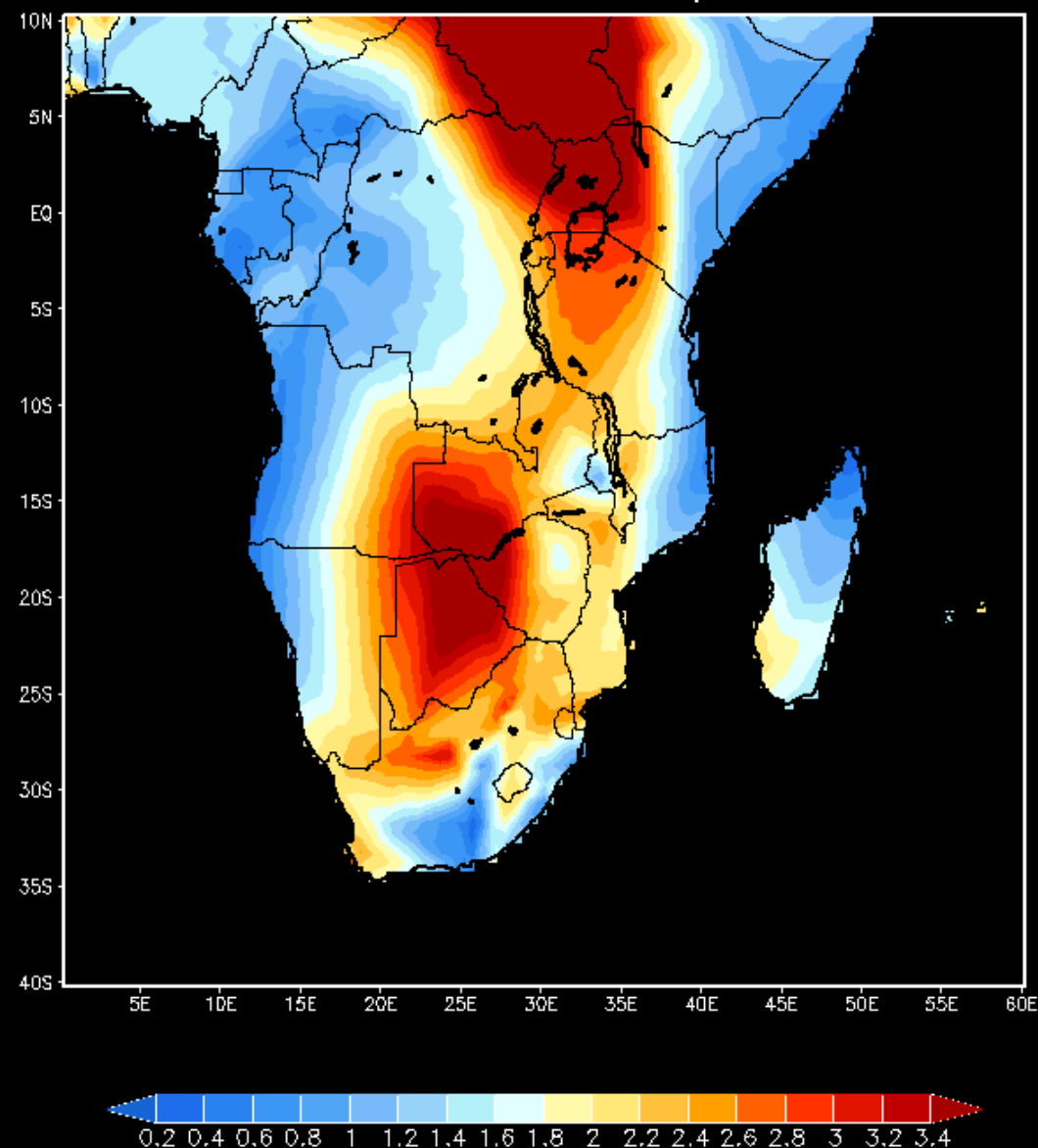
CCAM MAR RAINFALL %



Inter-annual variability in AMIP-style runs (Landman et al., 2010; WRC Report)

Accuracy and skill in short-range weather forecasting (Potgieter 2005; Landman et al., 2010)

CRU 3.1 trend Ann ave temp 1961–2009



CRU 3.1 linear temperature trend 1961-2009

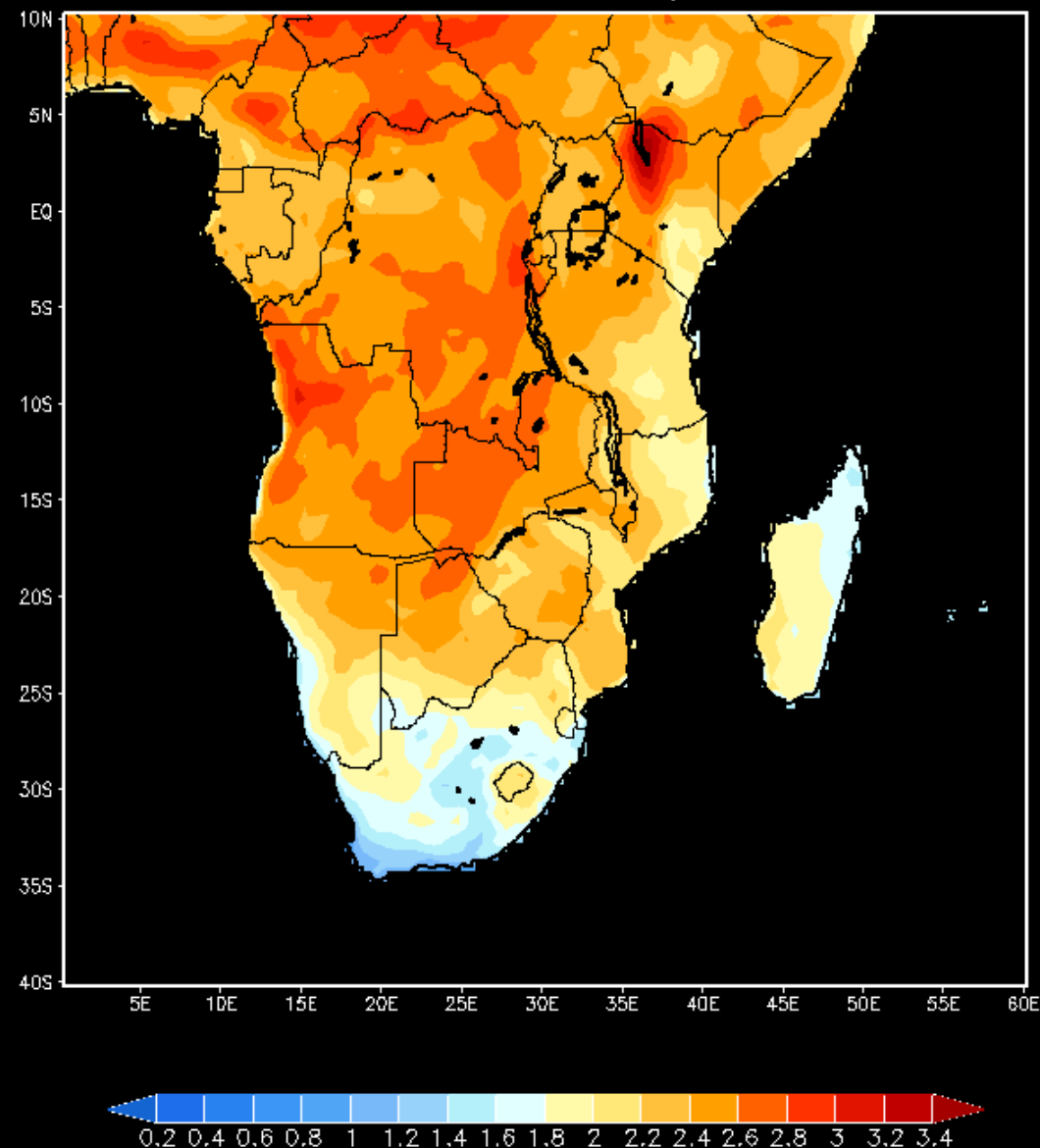
Strong warming have occurred over the central parts of southern Africa, including the central interior of South Africa

Warming more moderate along the coastal areas

Don't believethis slide!

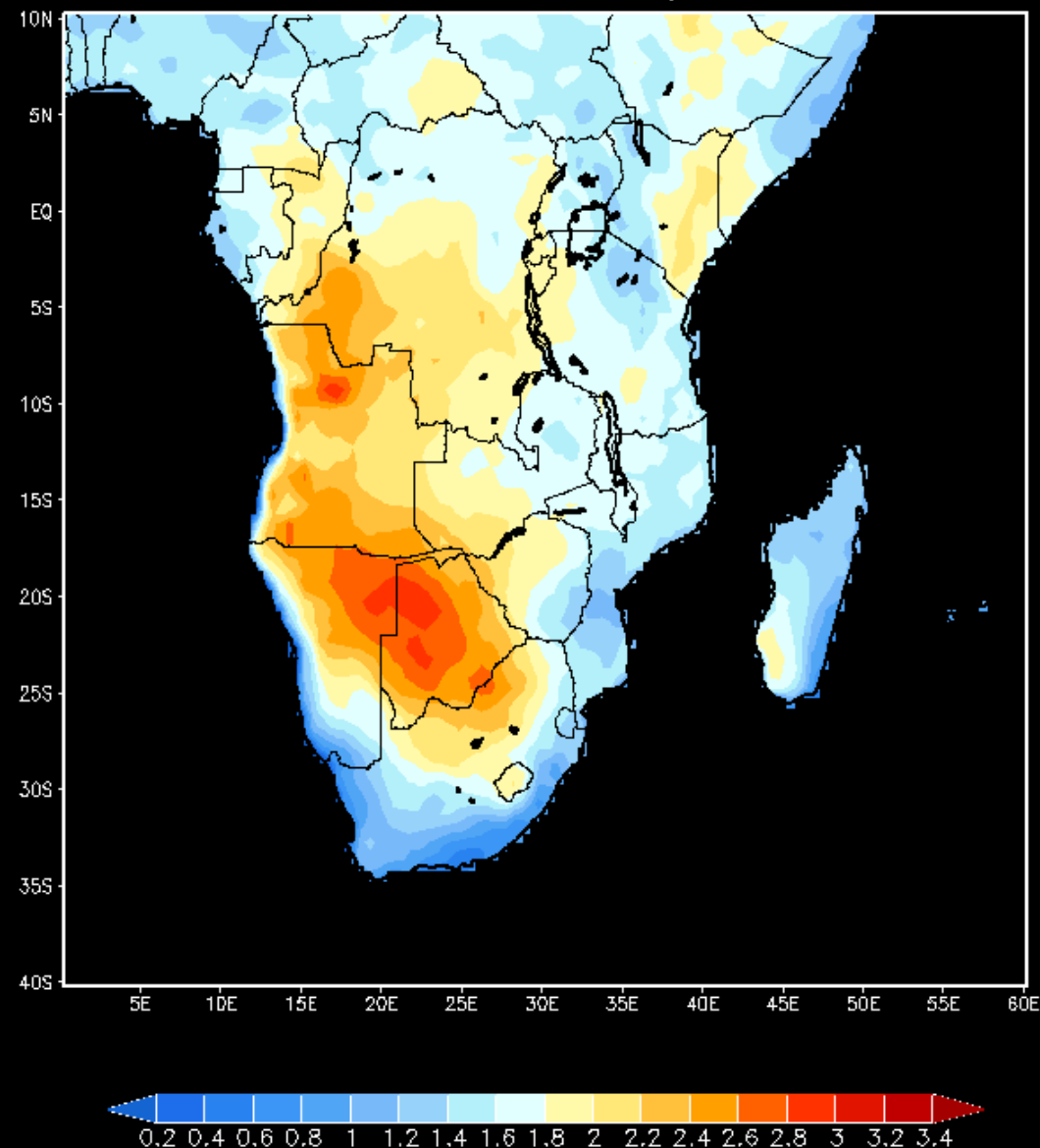
CCAM-CSIRO simulated linear temperature trend 1961-2009

CSIRO trend Ann ave temp 1961-2009



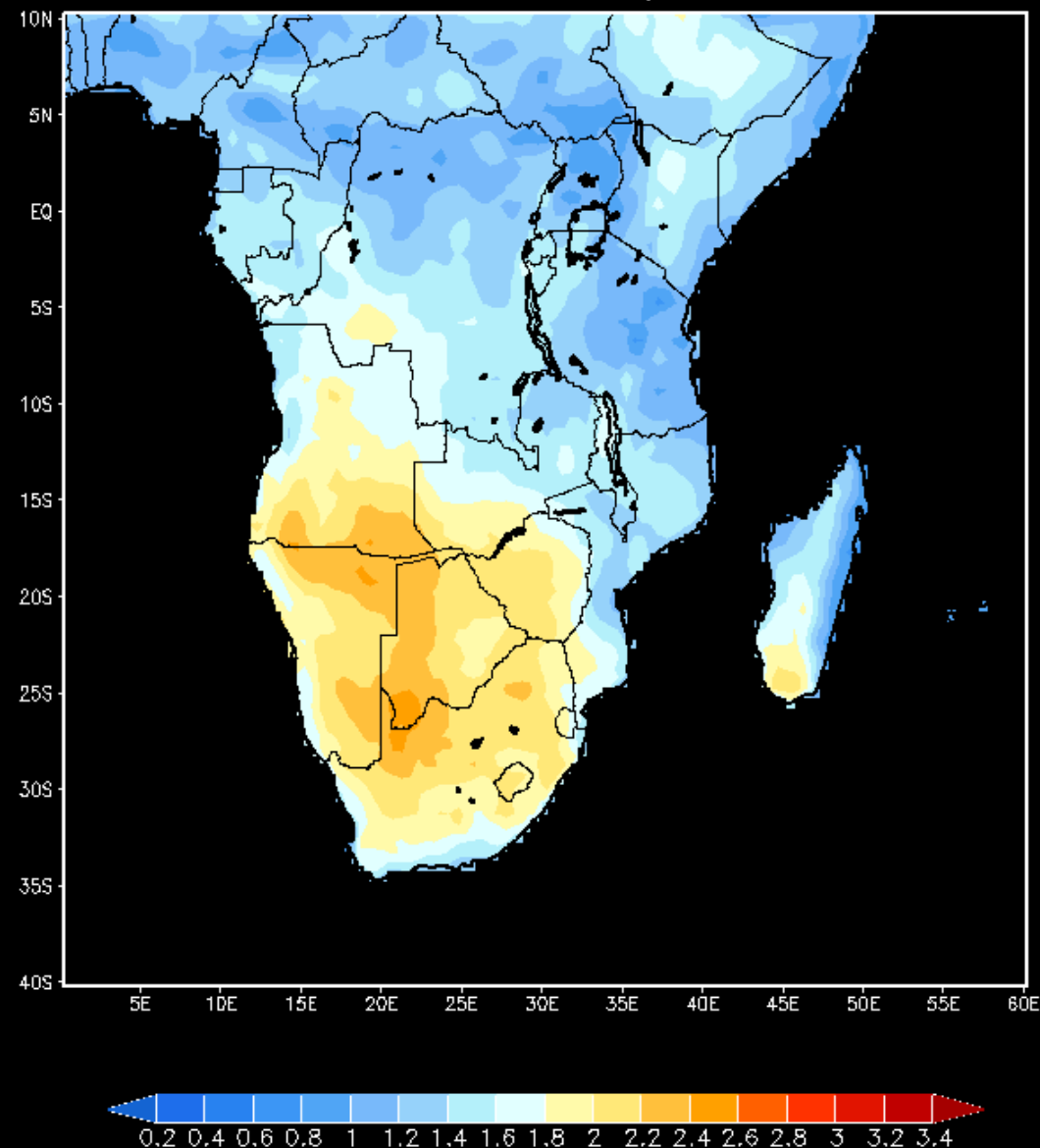
CCAM-HADCM3 simulated linear temperature trend 1961-2009

UKMO trend Ann ave temp 1961-2009



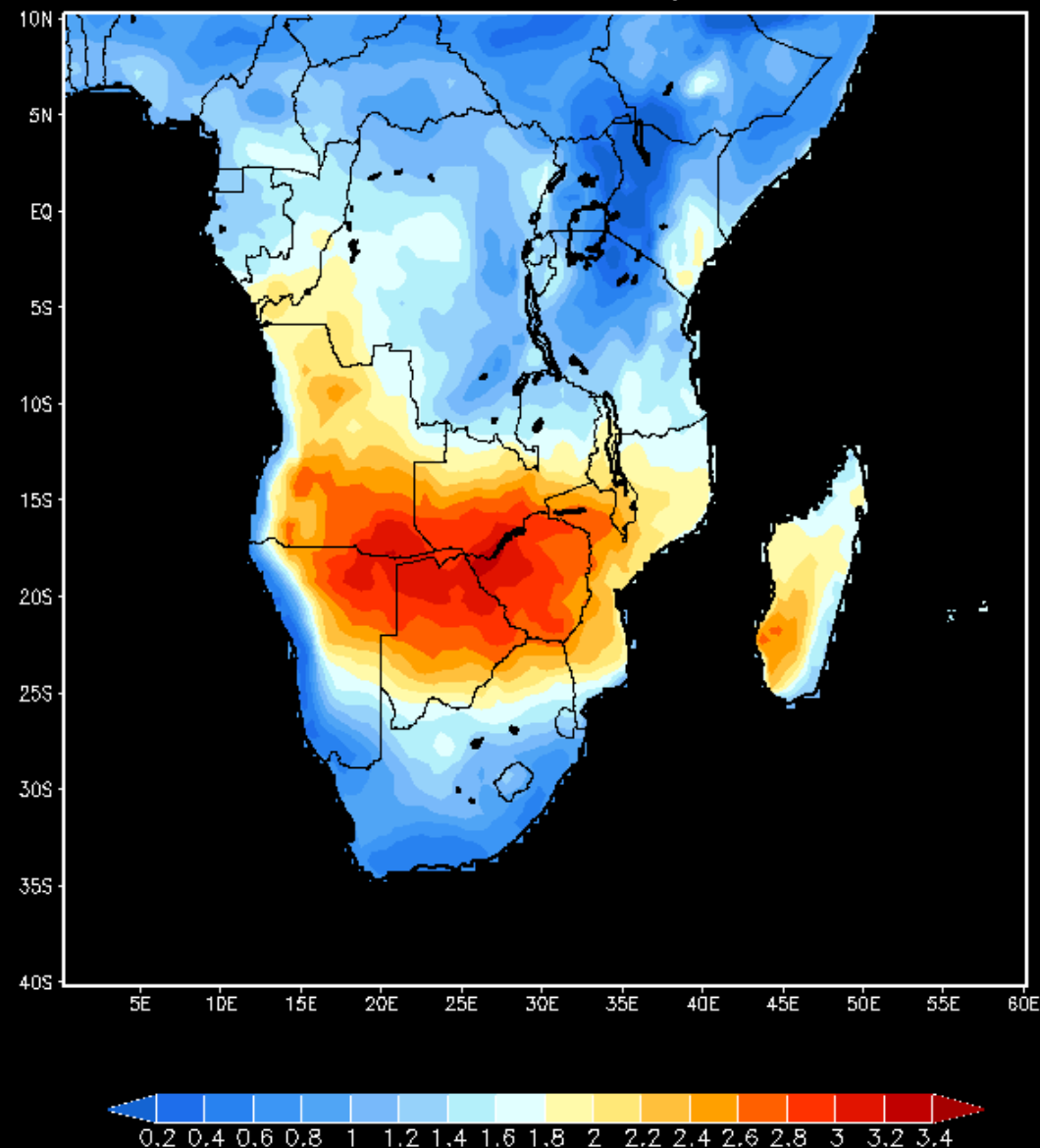
CCAM-MPI simulated linear temperature trend 1961-2009

MPI trend Ann ave temp 1961-2009



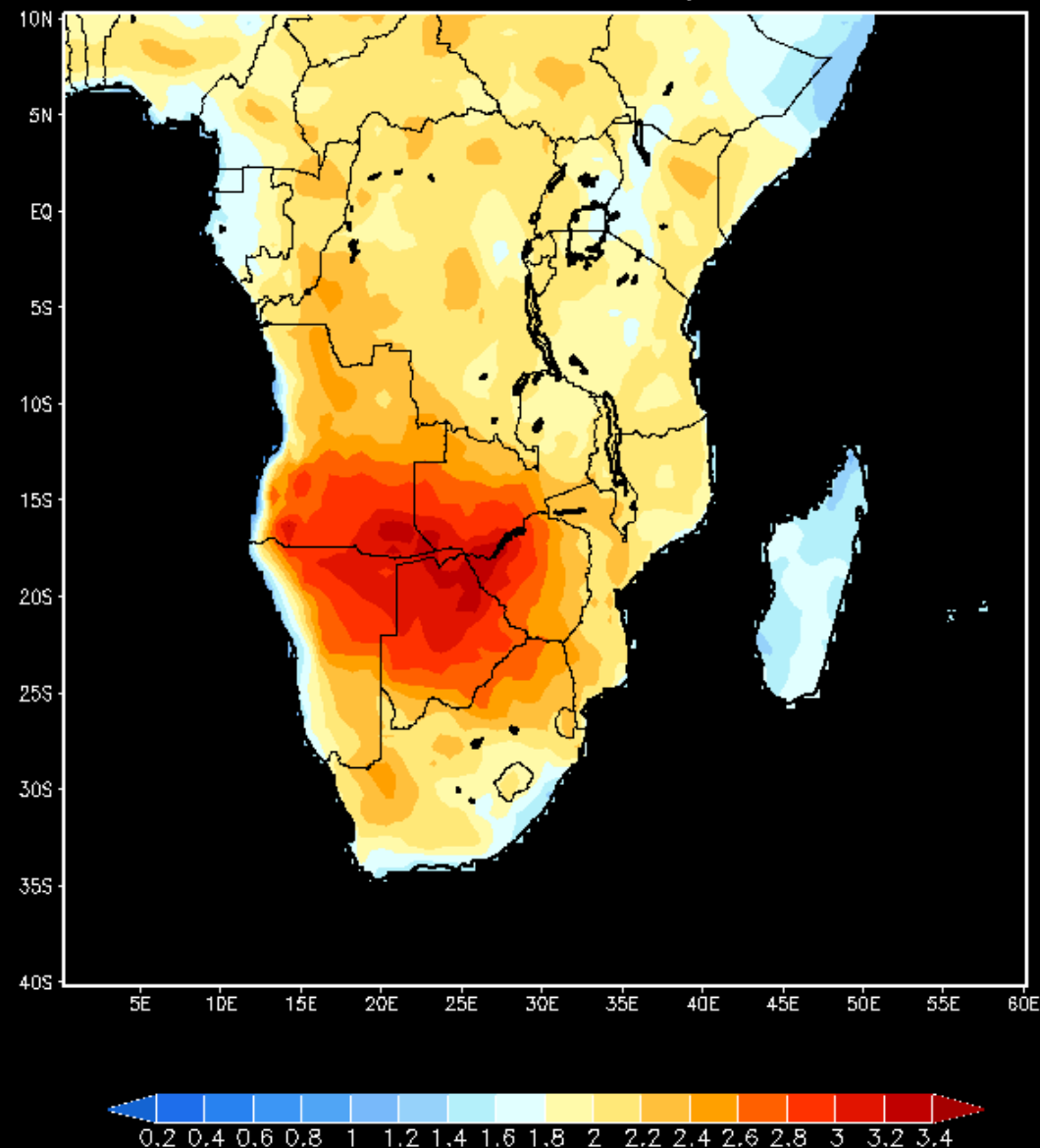
CCAM-MIROC simulated linear temperature trend 1961-2009

MIROC trend Ann ave temp 1961-2009



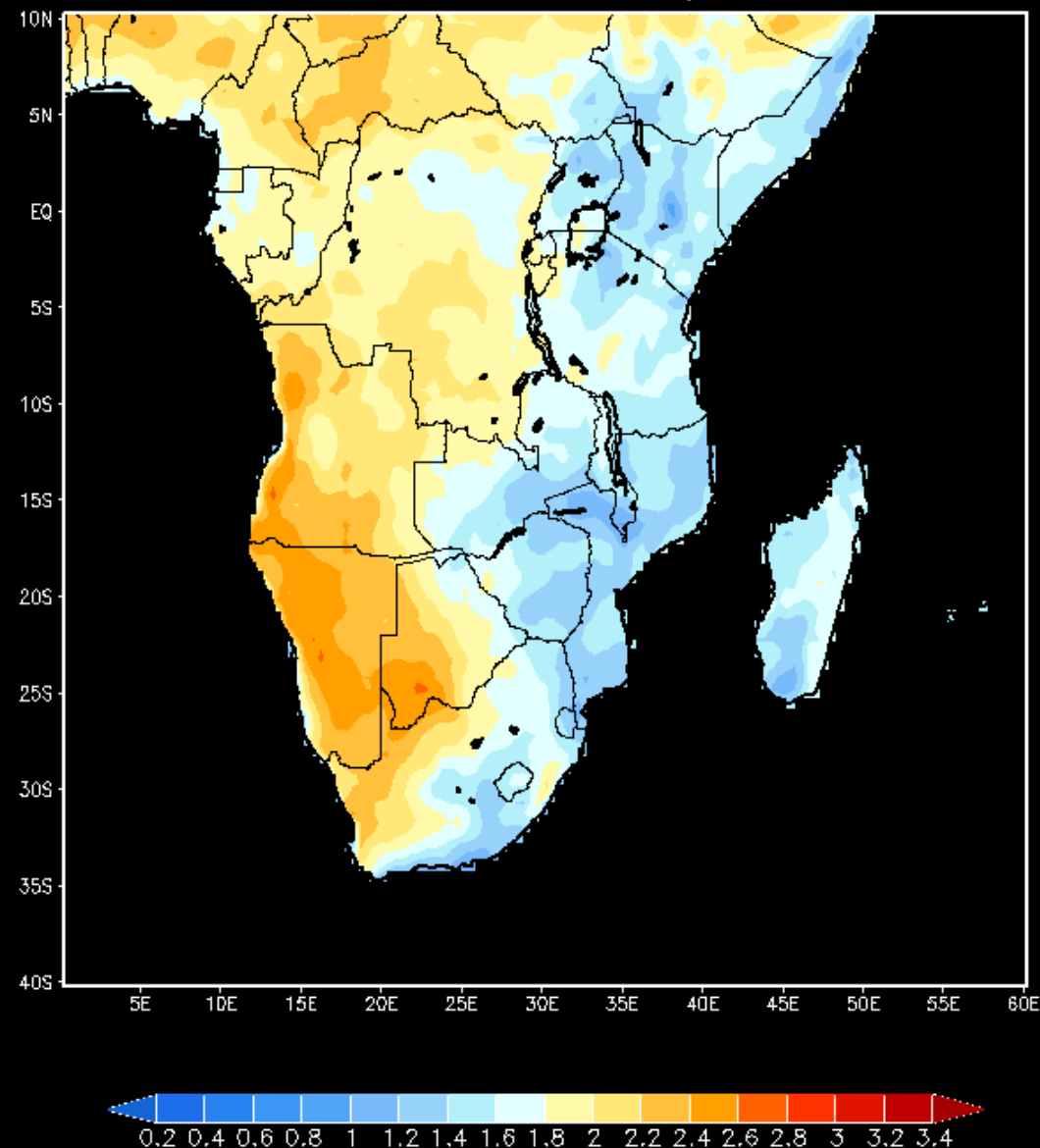
CCAM-GFDL20 simulated linear temperature trend 1961-2009

GFDL20 trend Ann ave temp 1961-2009



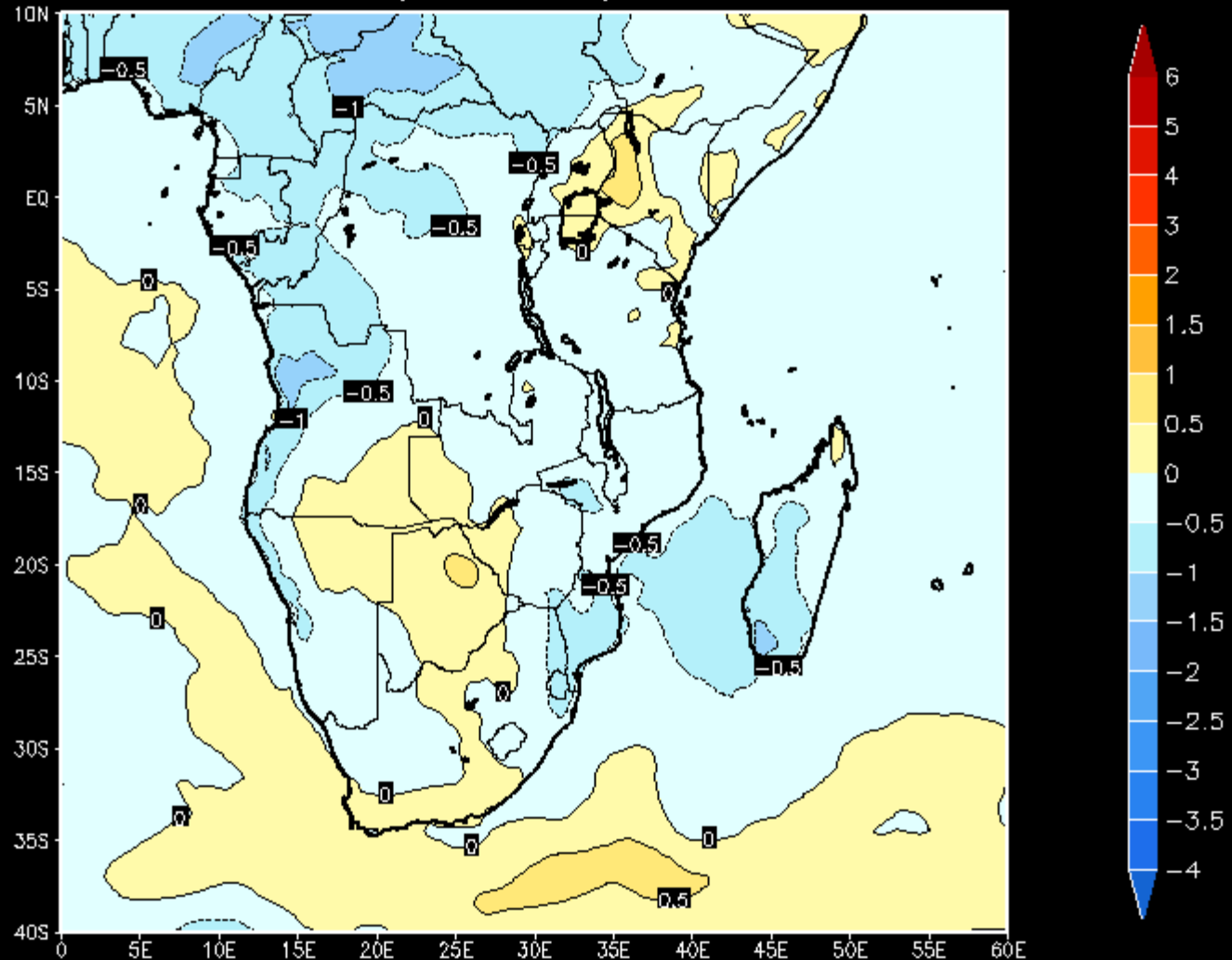
CCAM-GFDL21 simulated linear temperature trend 1961-2009

GFDL21 trend Ann ave temp 1961-2009

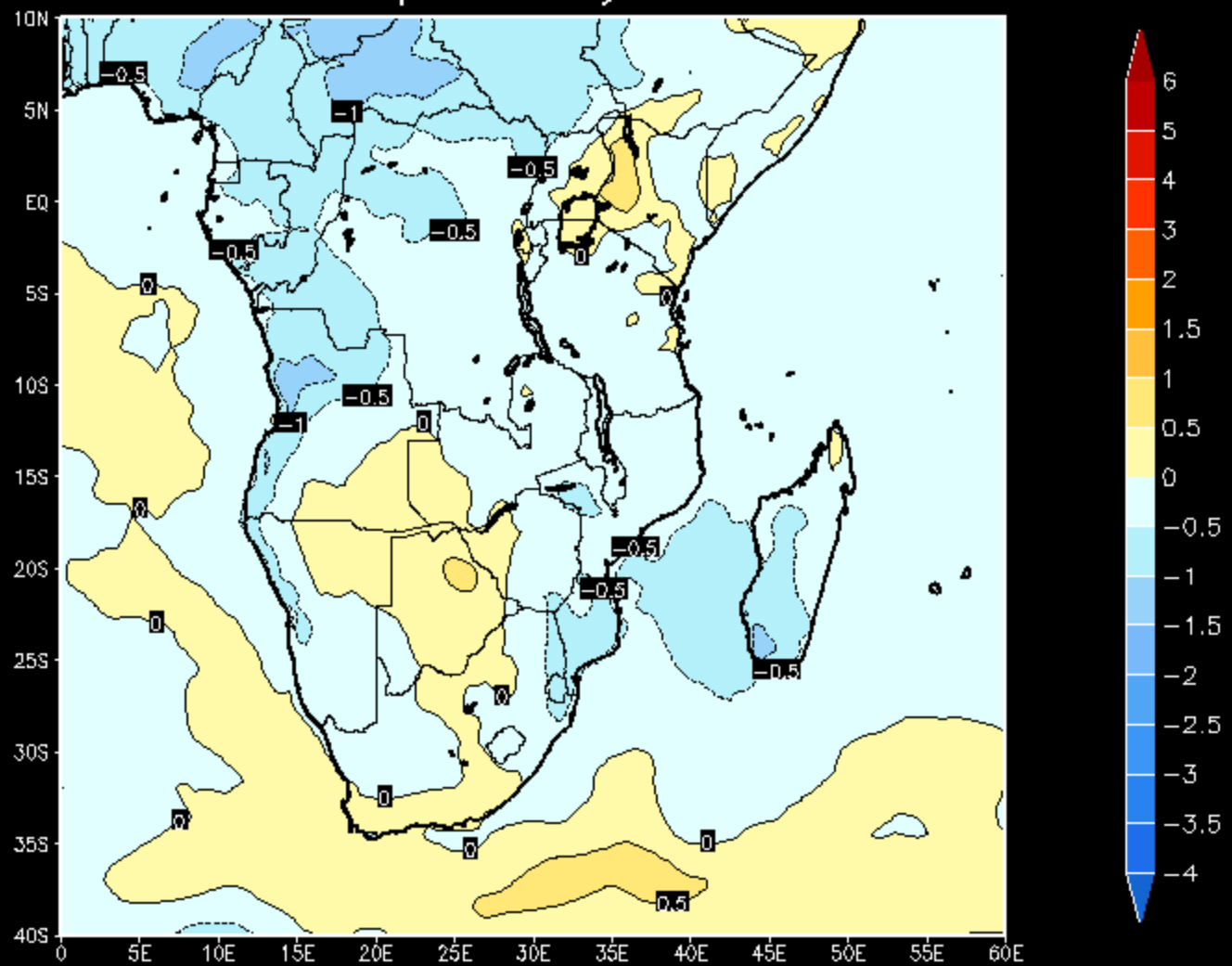


Simulated annual temperature anomalies relative to the 1961-1990 climatological average

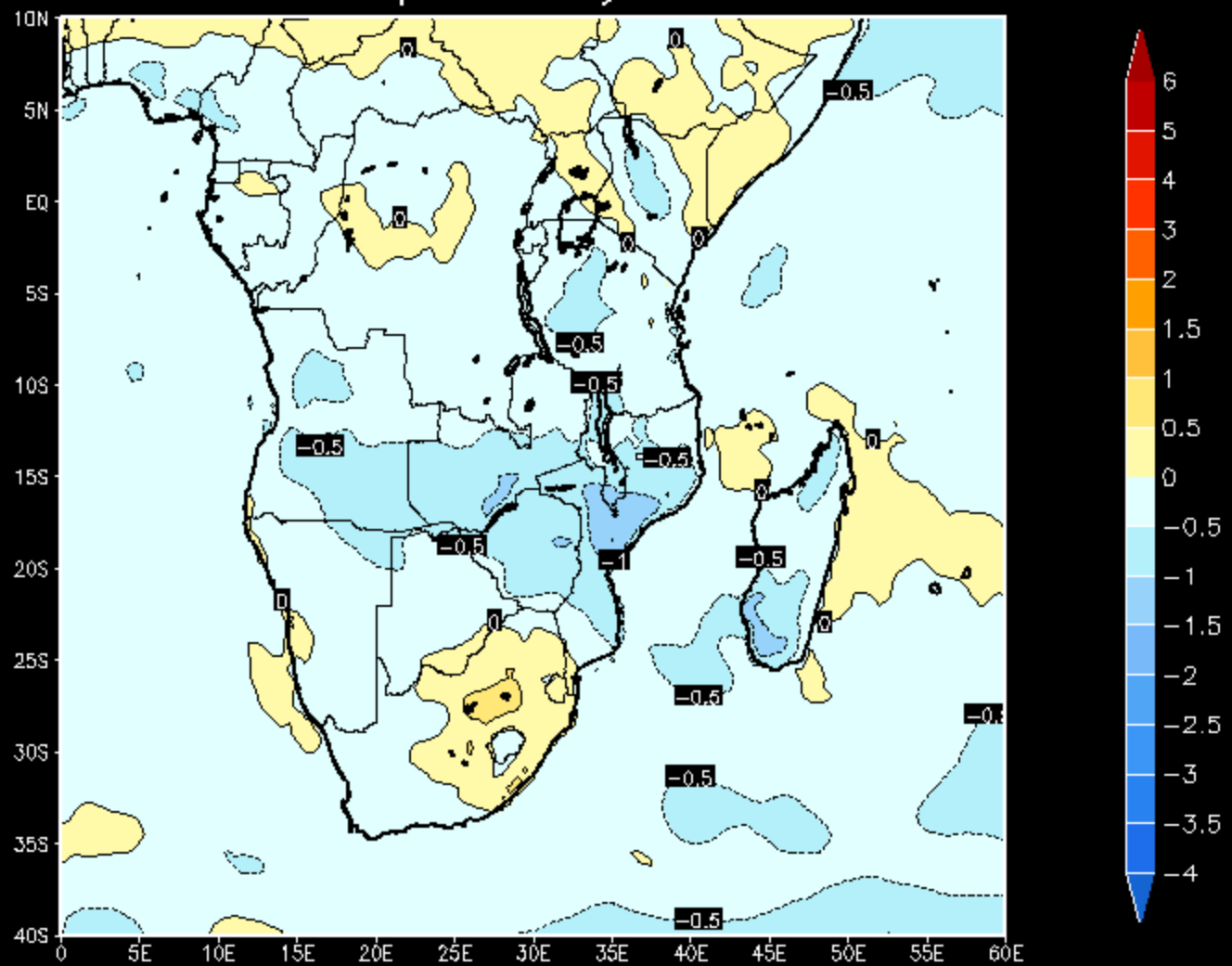
Temp anomaly 1961



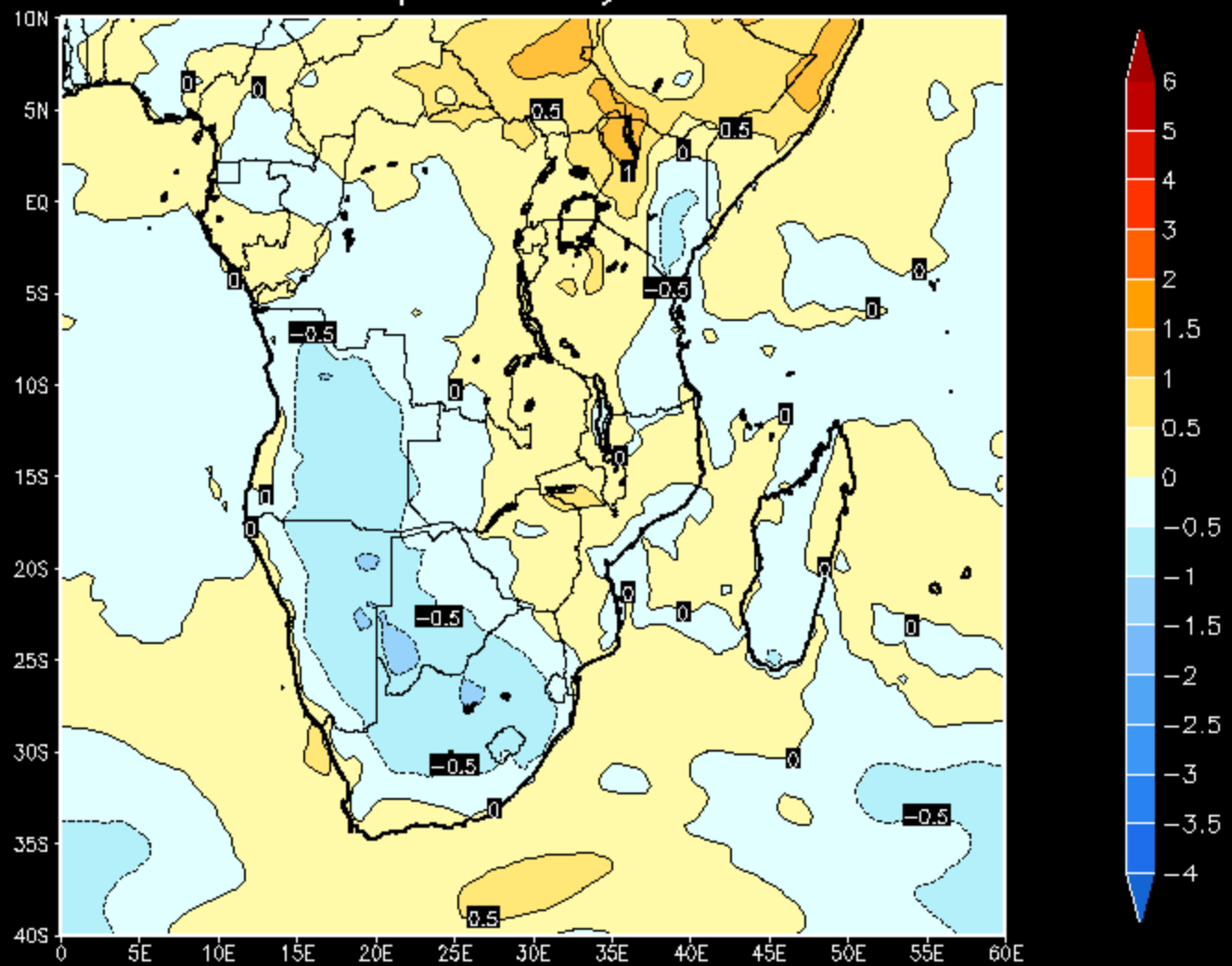
Temp anomaly 1961



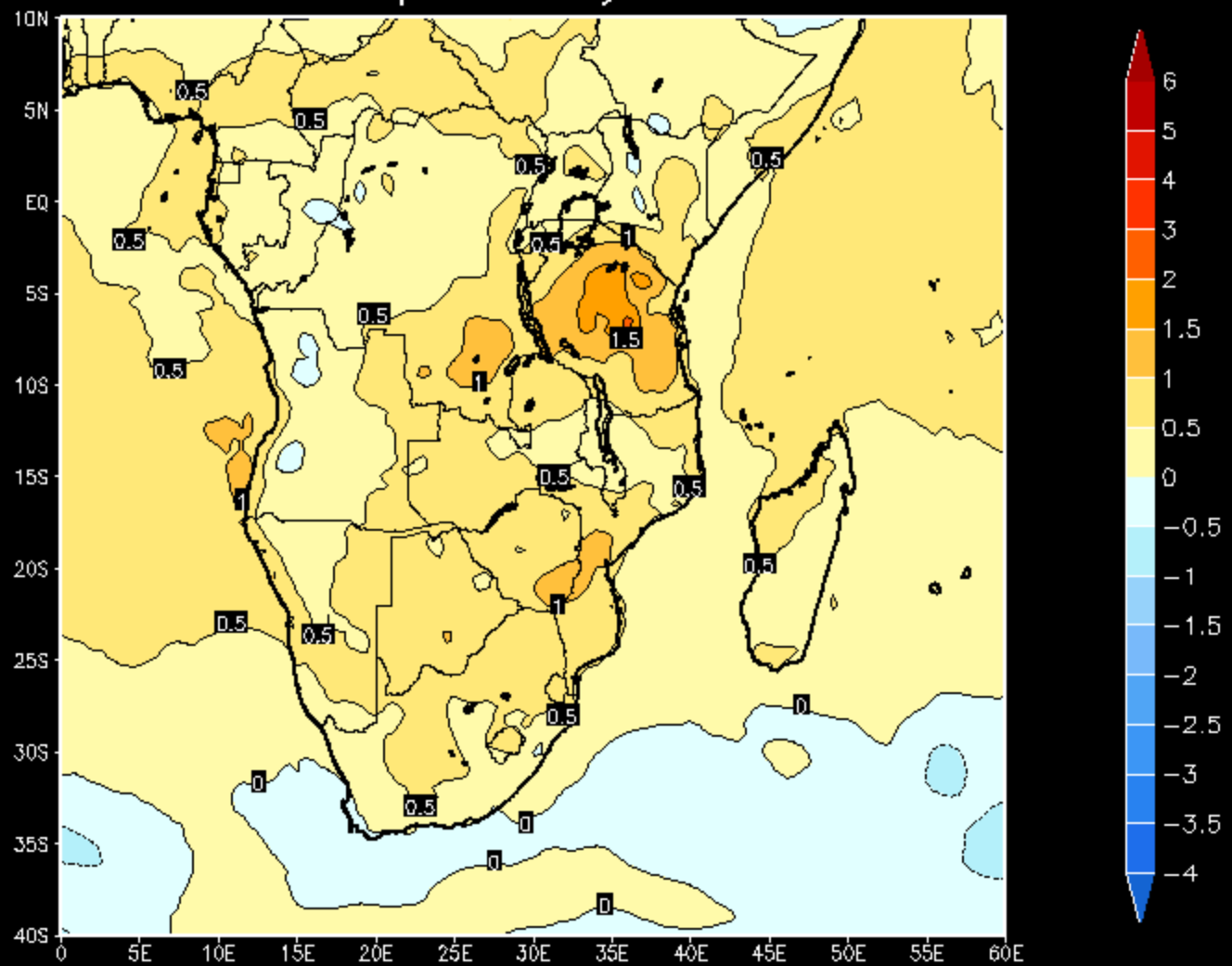
Temp anomaly 1962



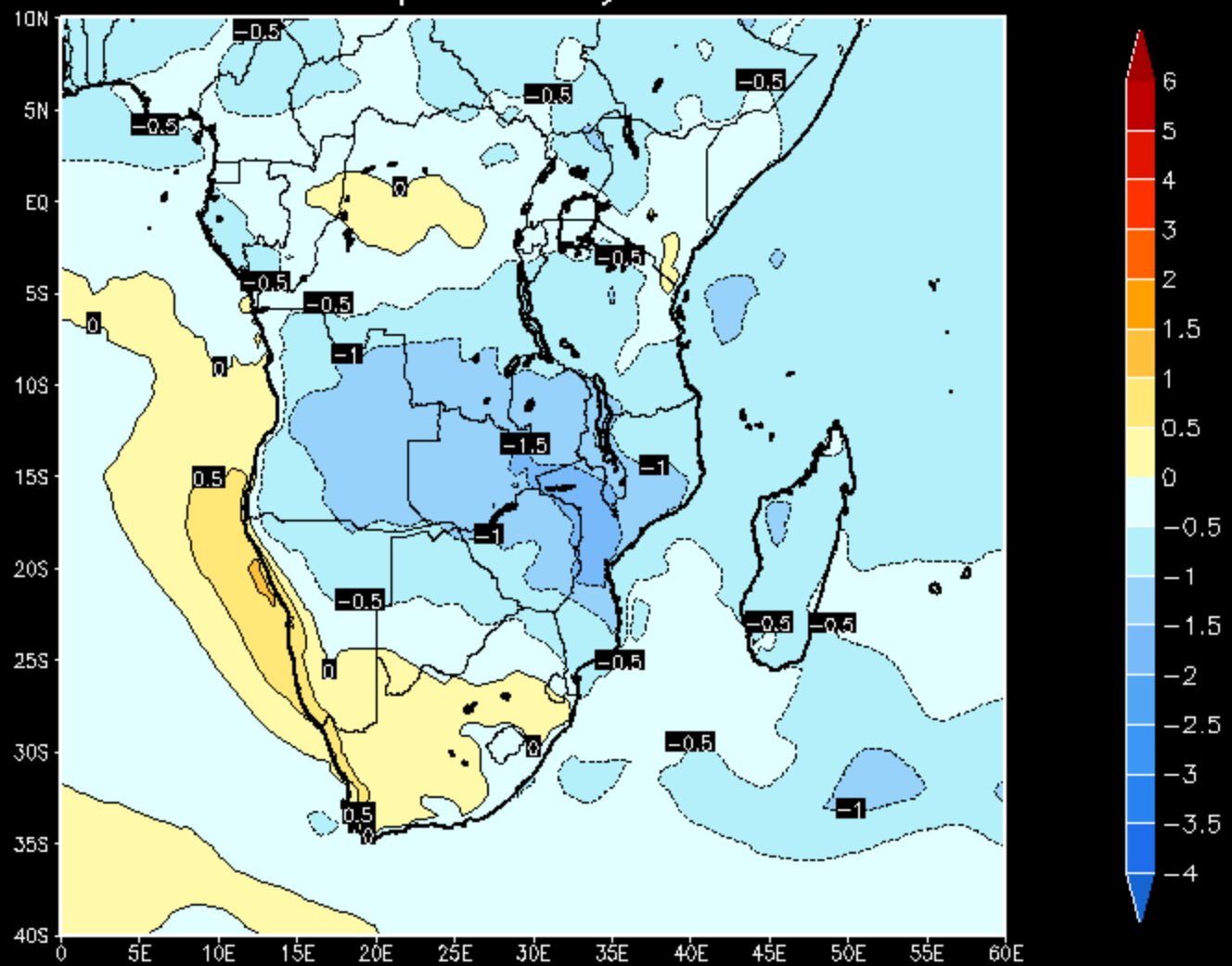
Temp anomaly 1963



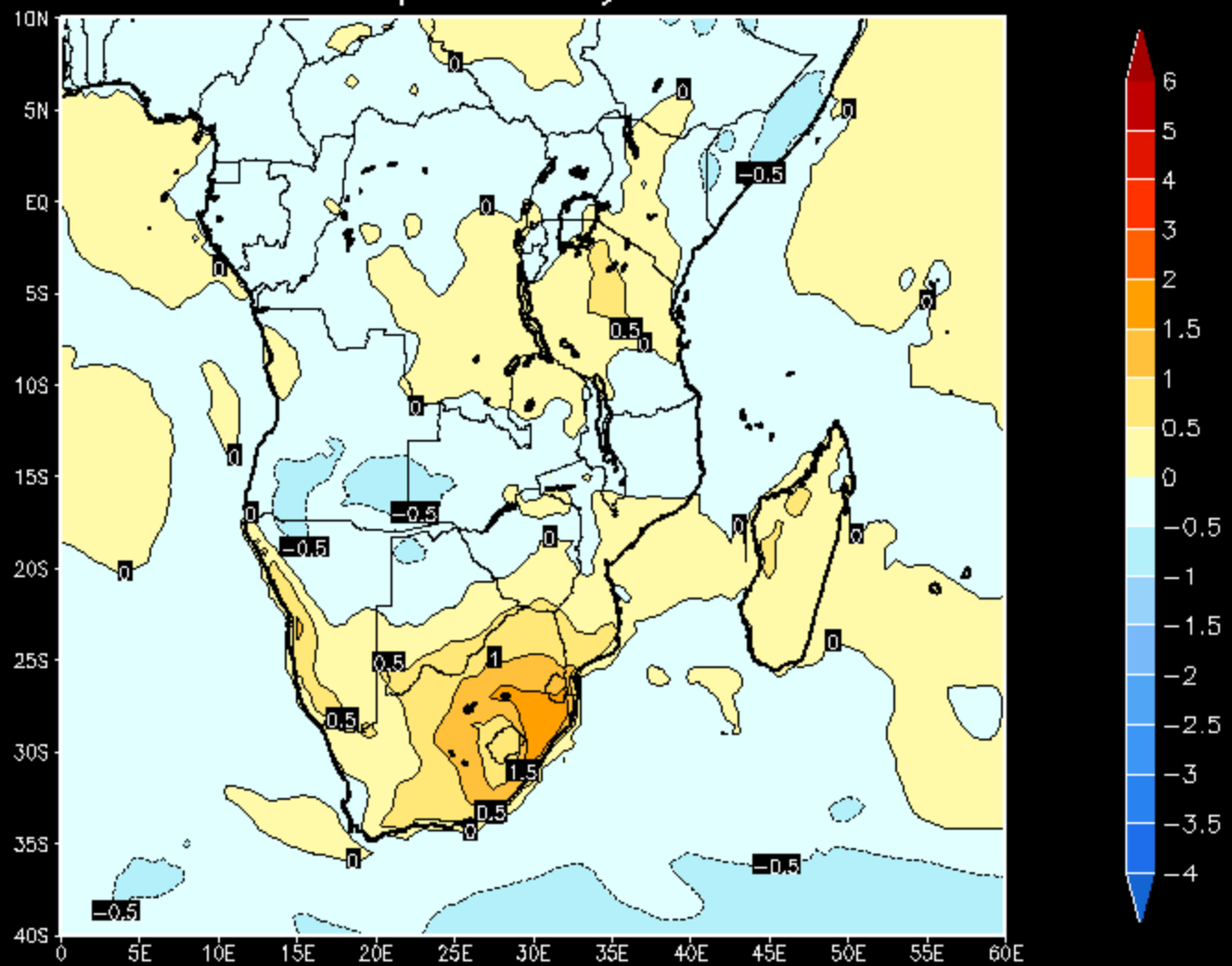
Temp anomaly 1964



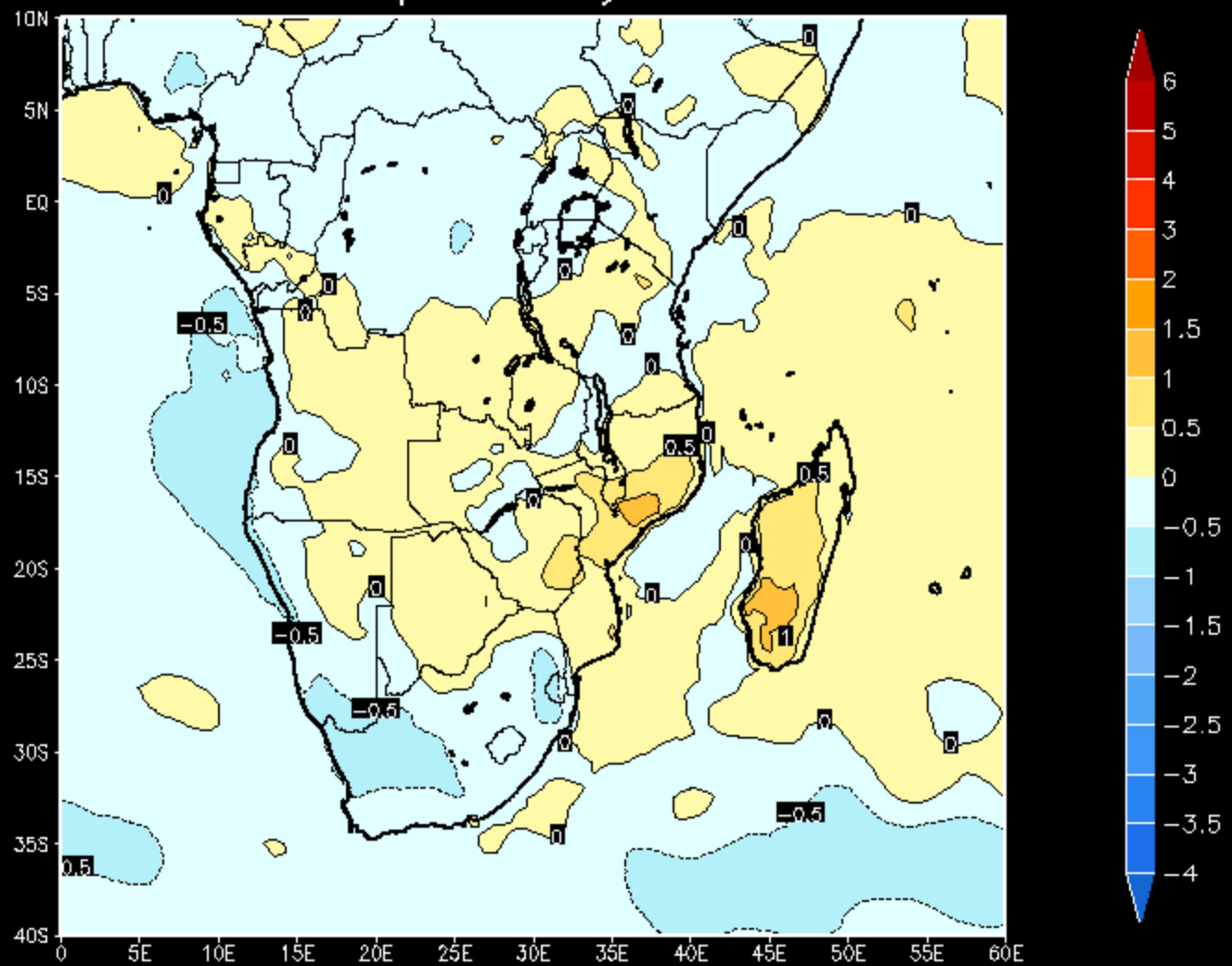
Temp anomaly 1965



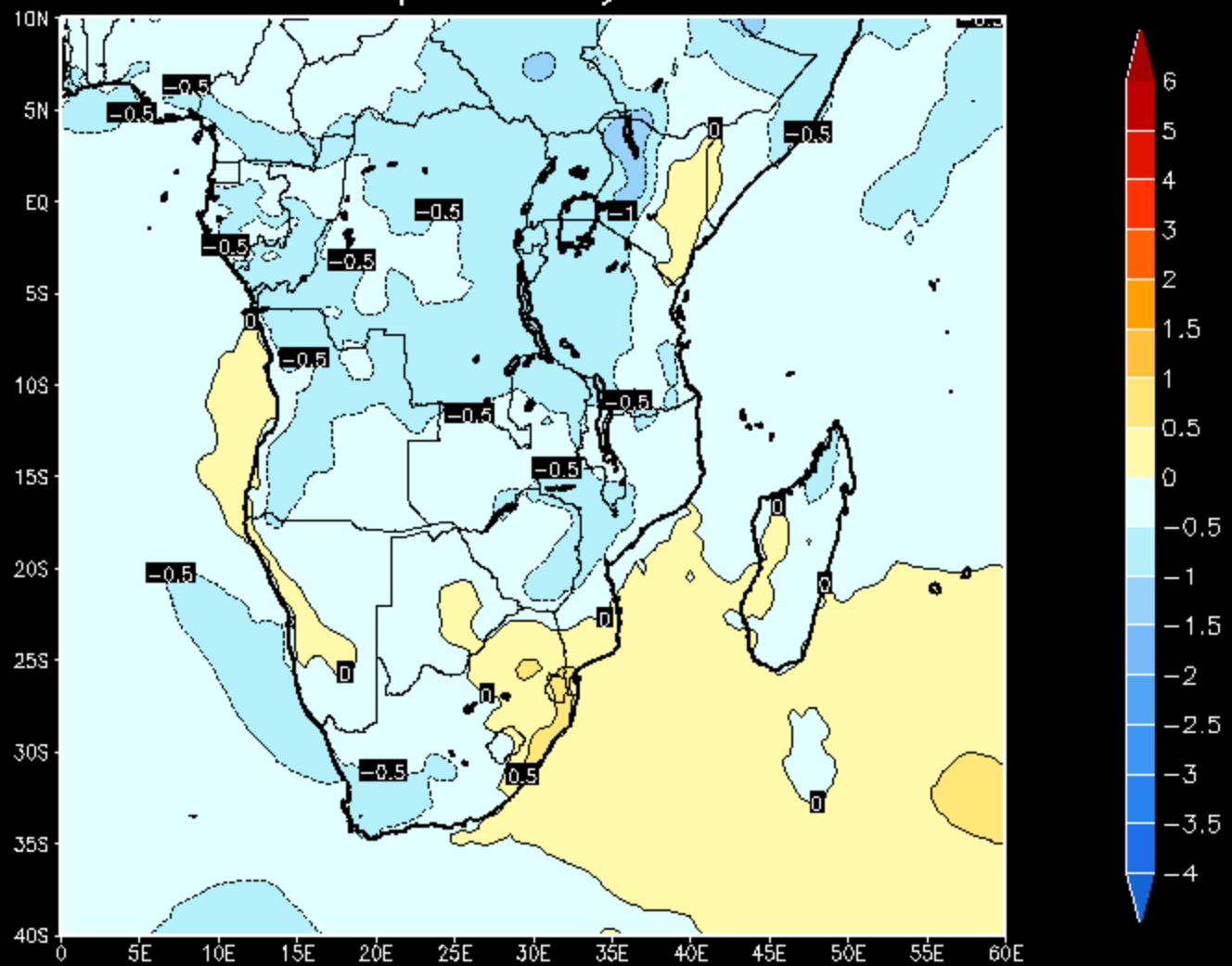
Temp anomaly 1966



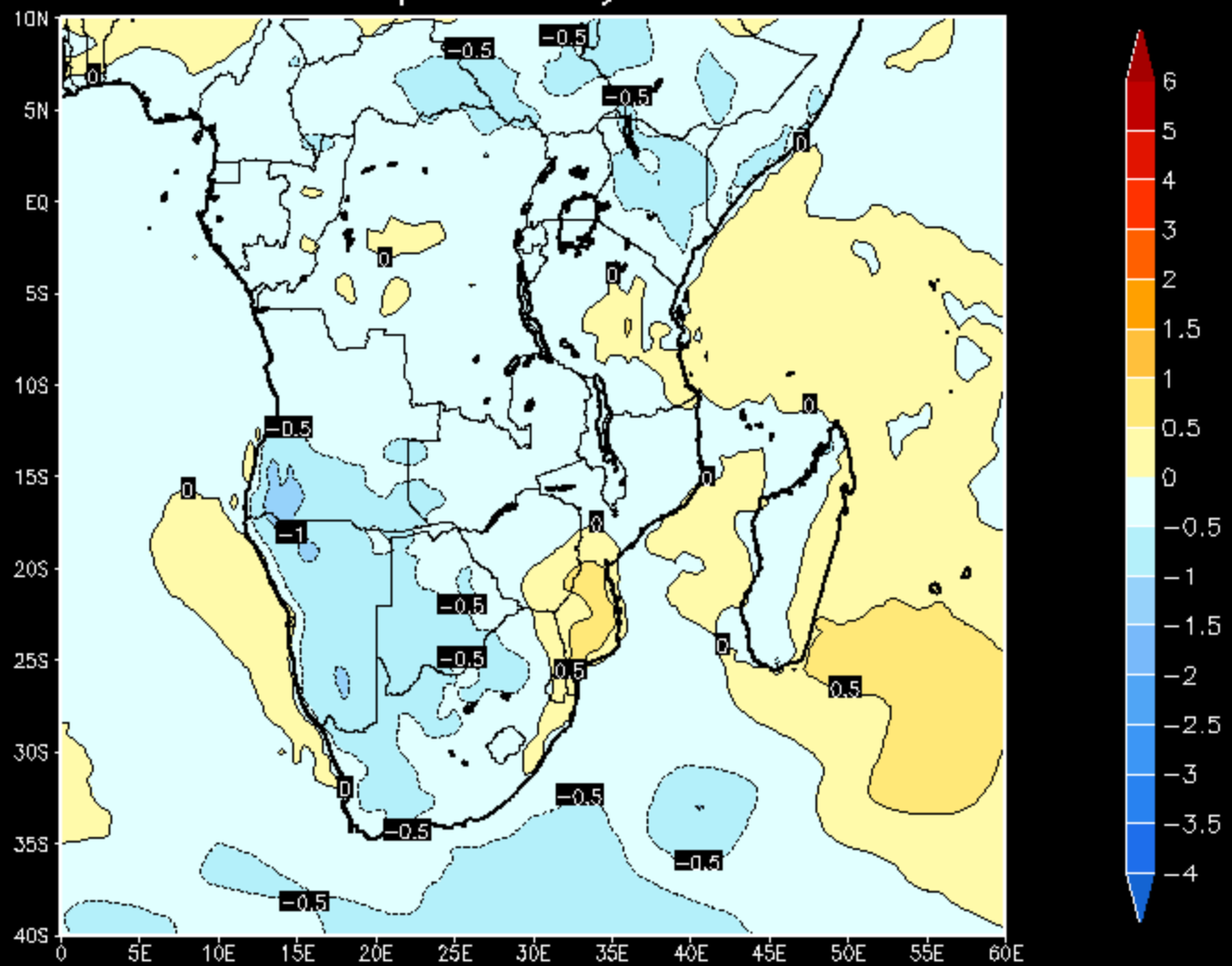
Temp anomaly 1967



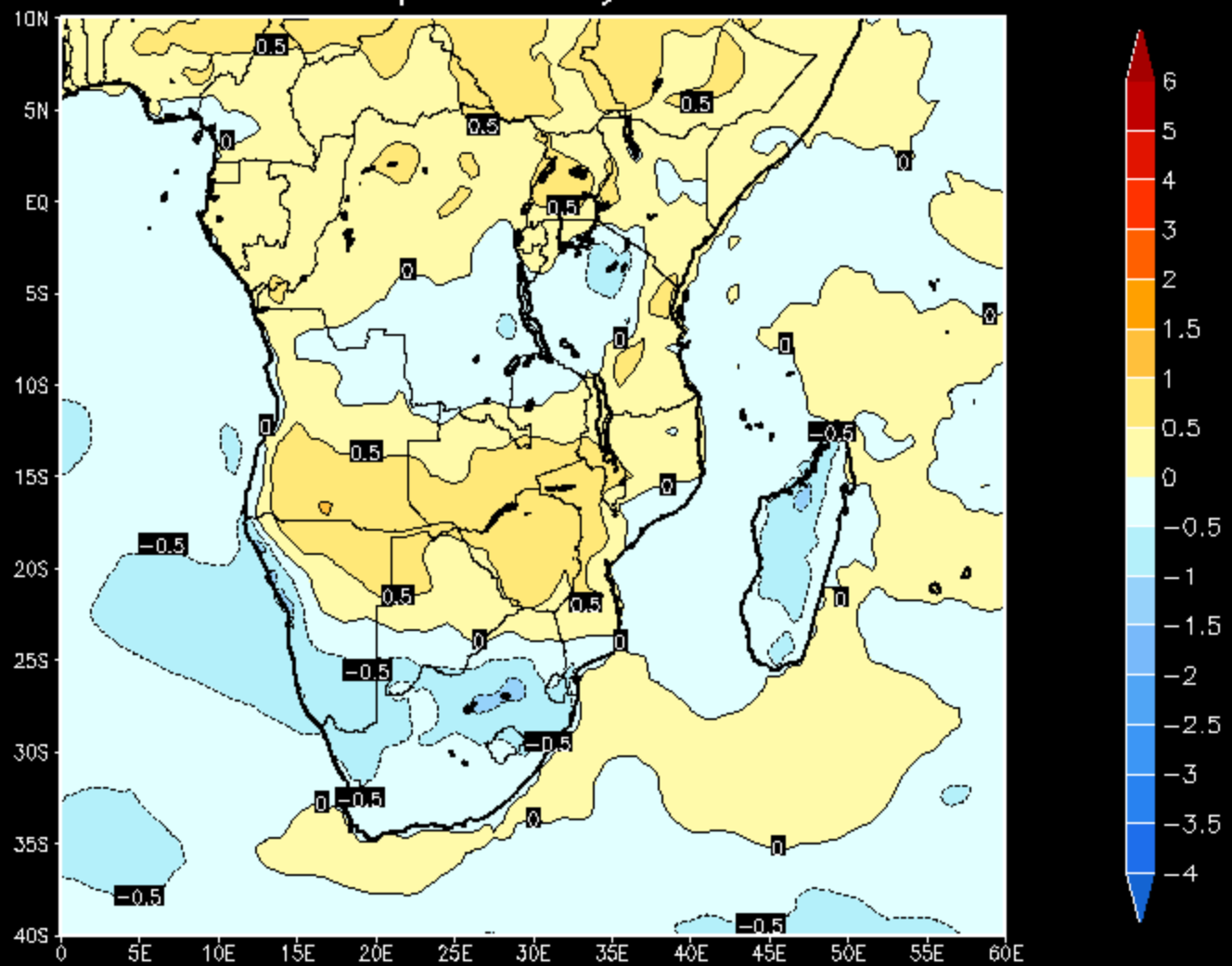
Temp anomaly 1968



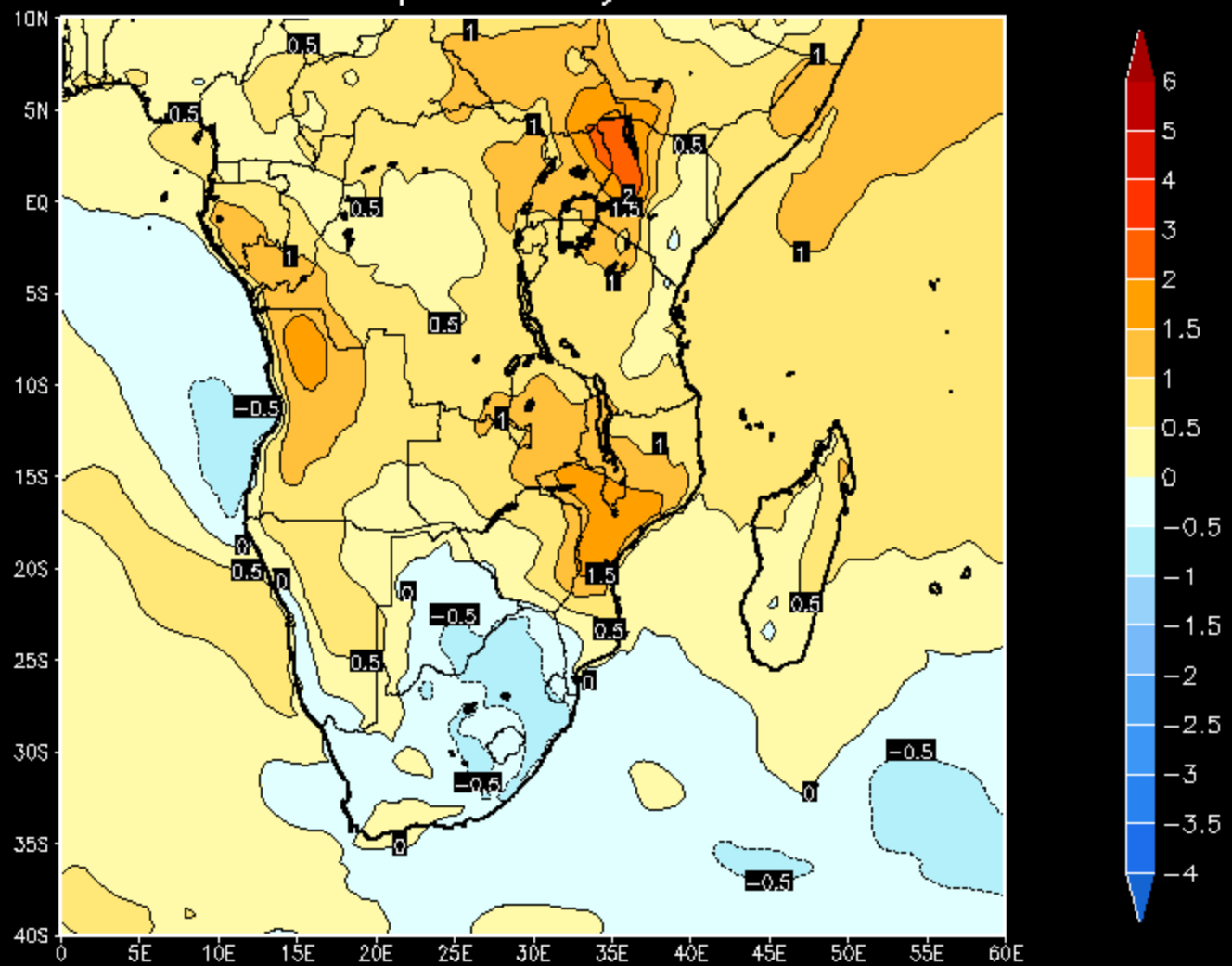
Temp anomaly 1969



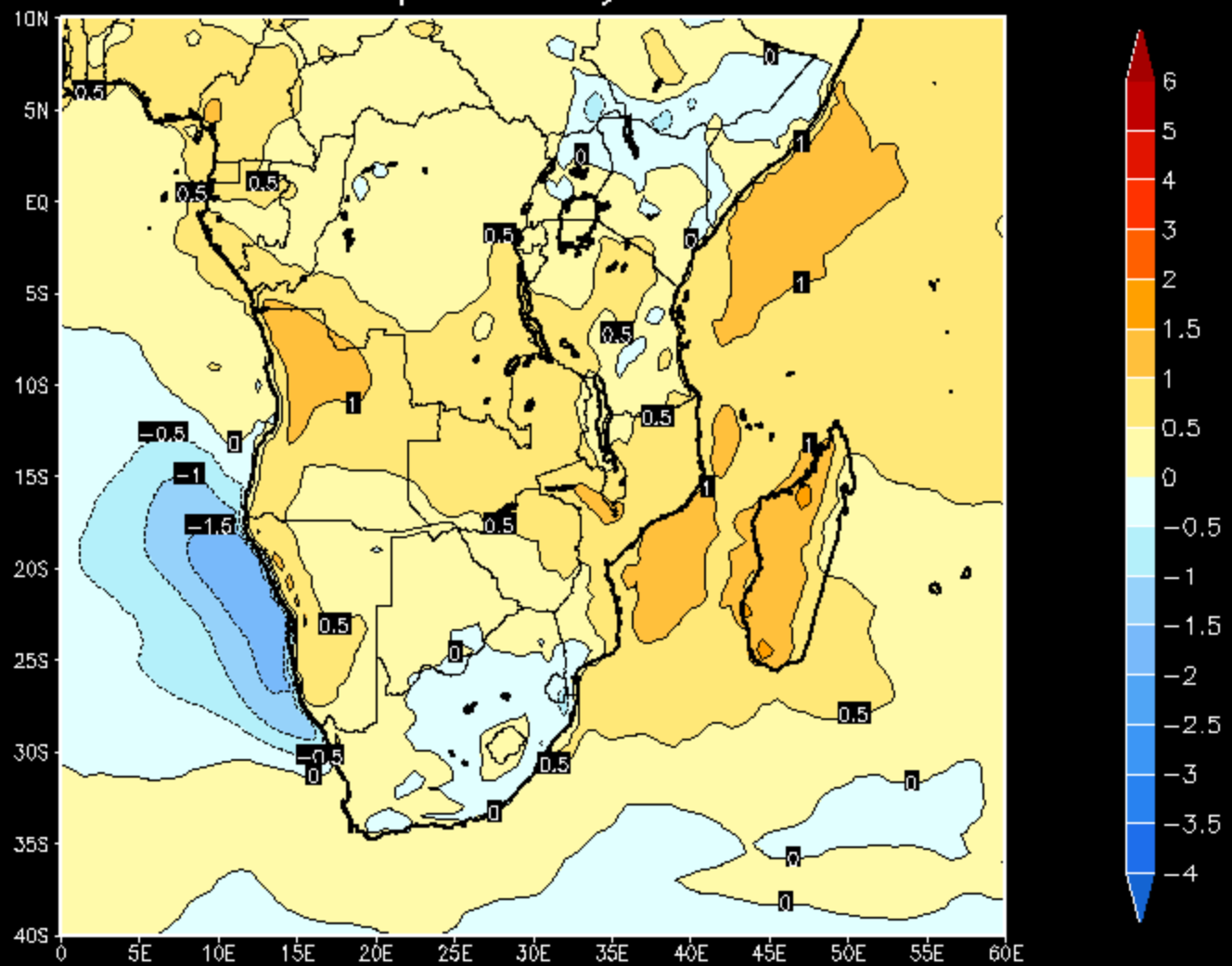
Temp anomaly 1970



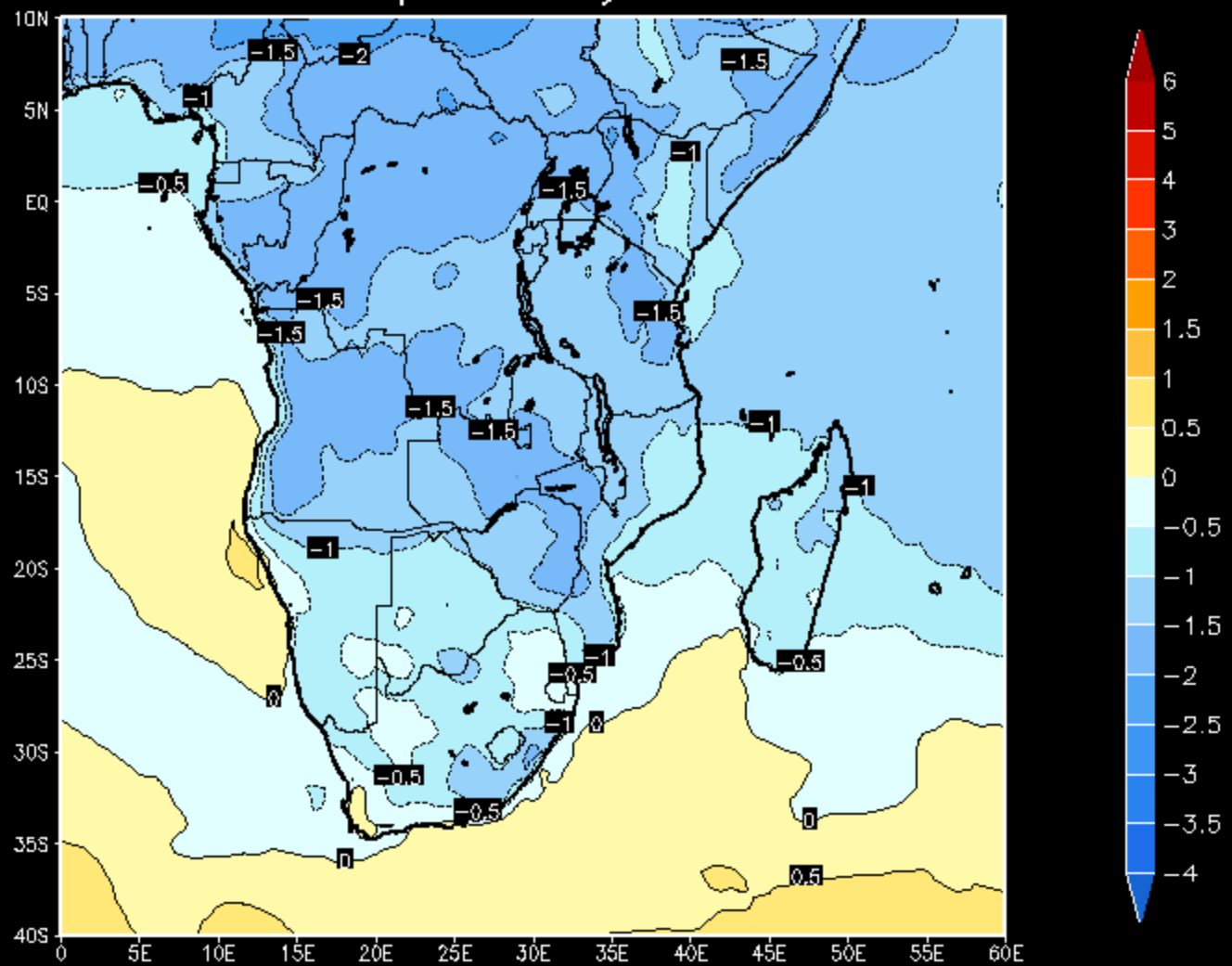
Temp anomaly 1971



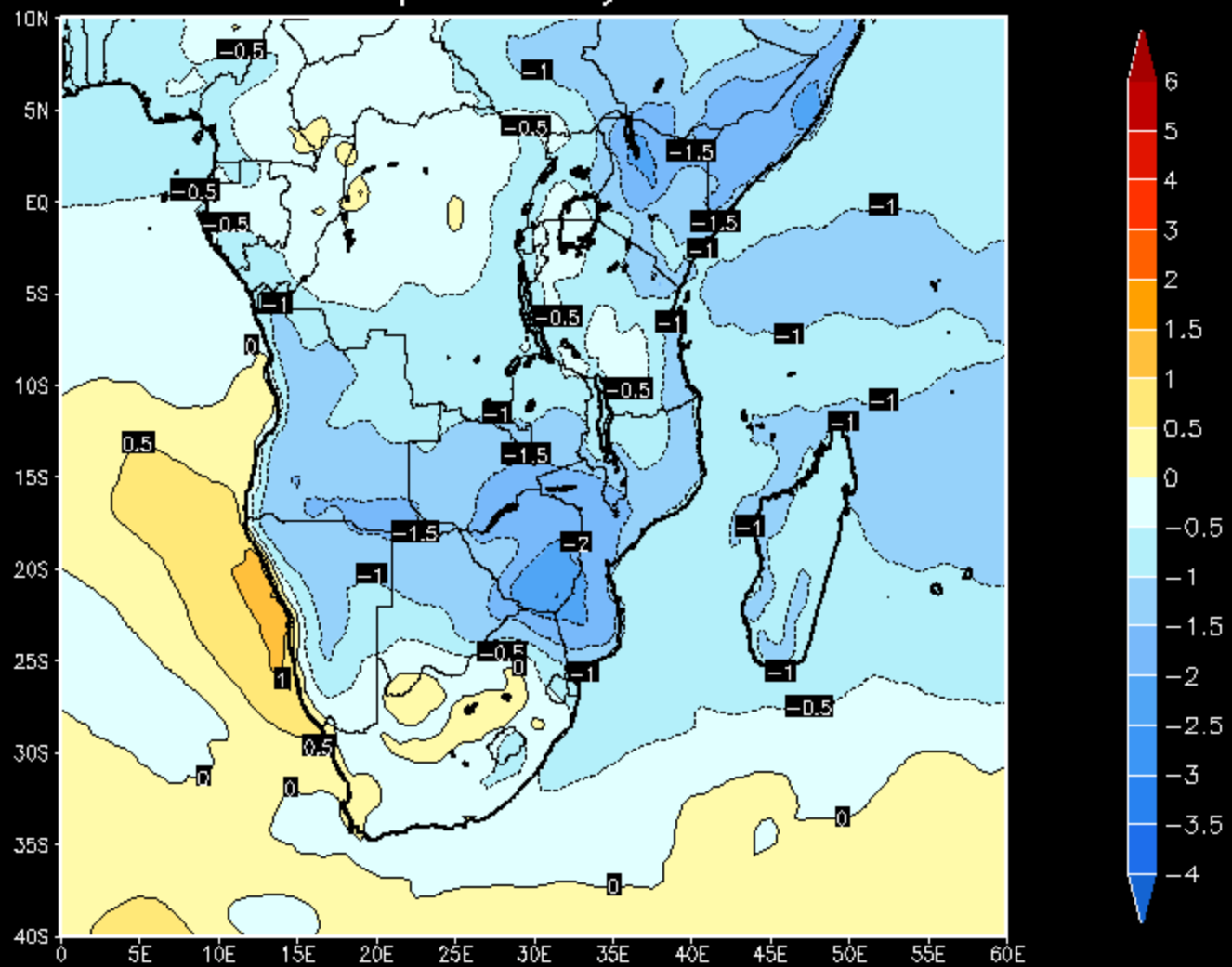
Temp anomaly 1972



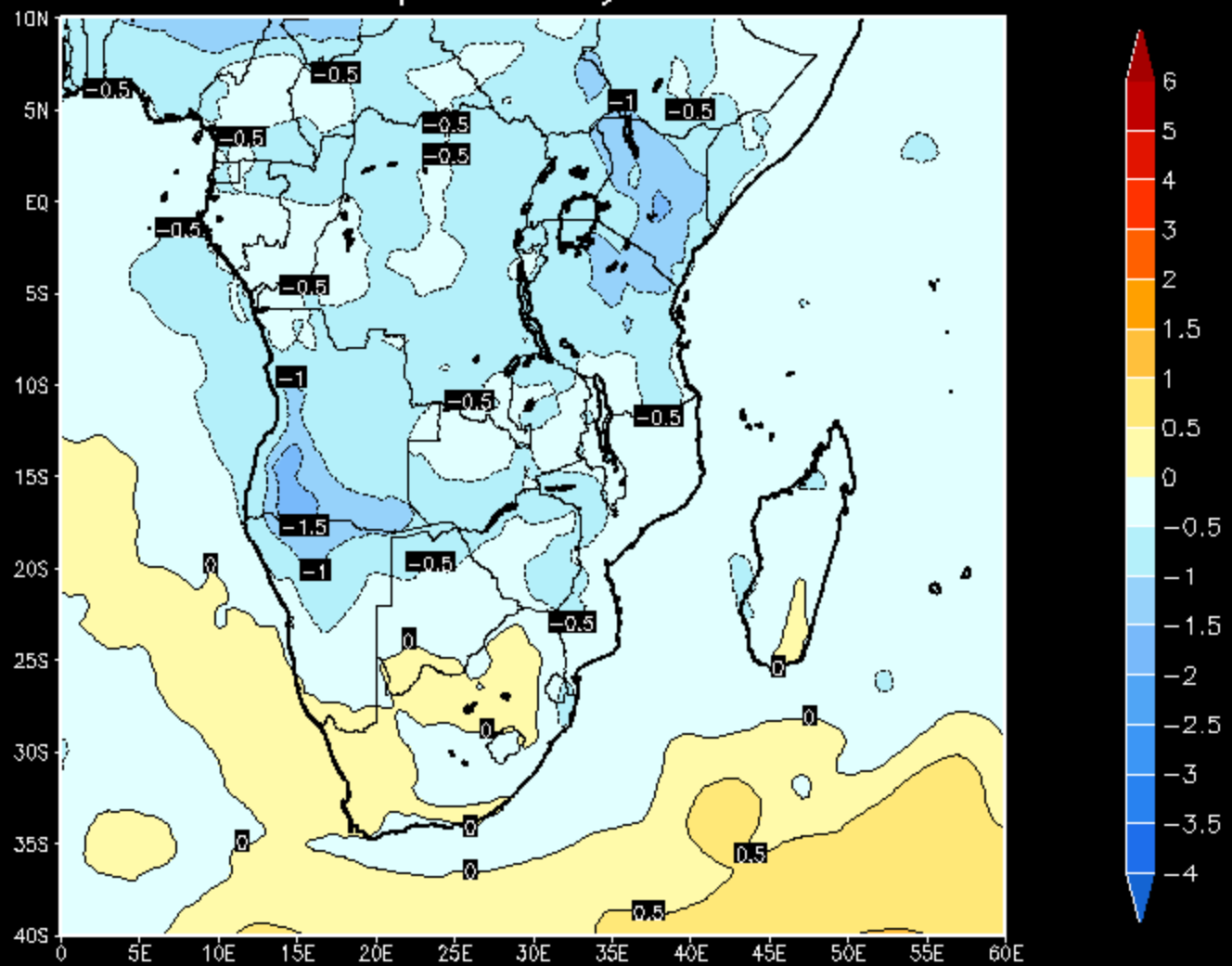
Temp anomaly 1973



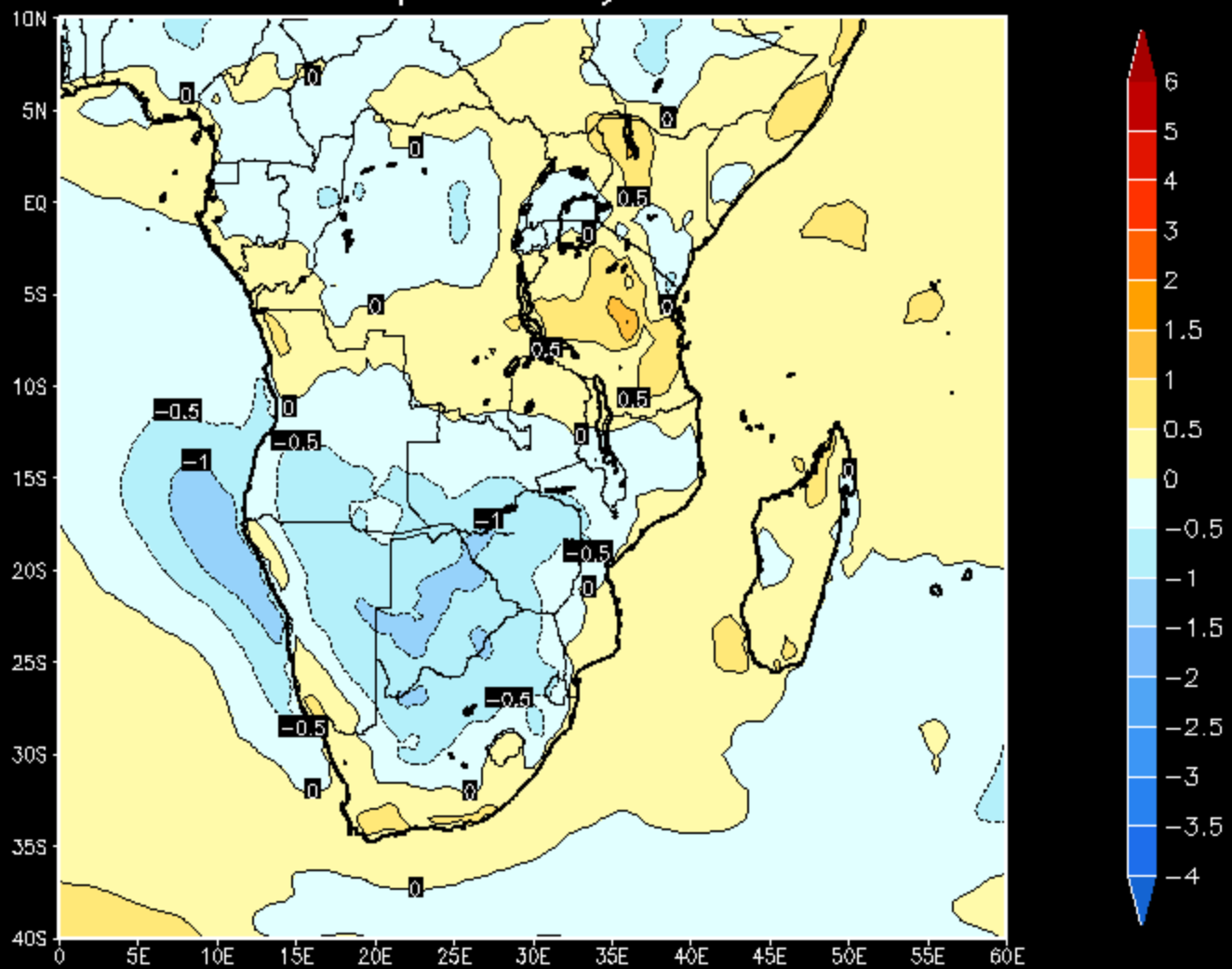
Temp anomaly 1974



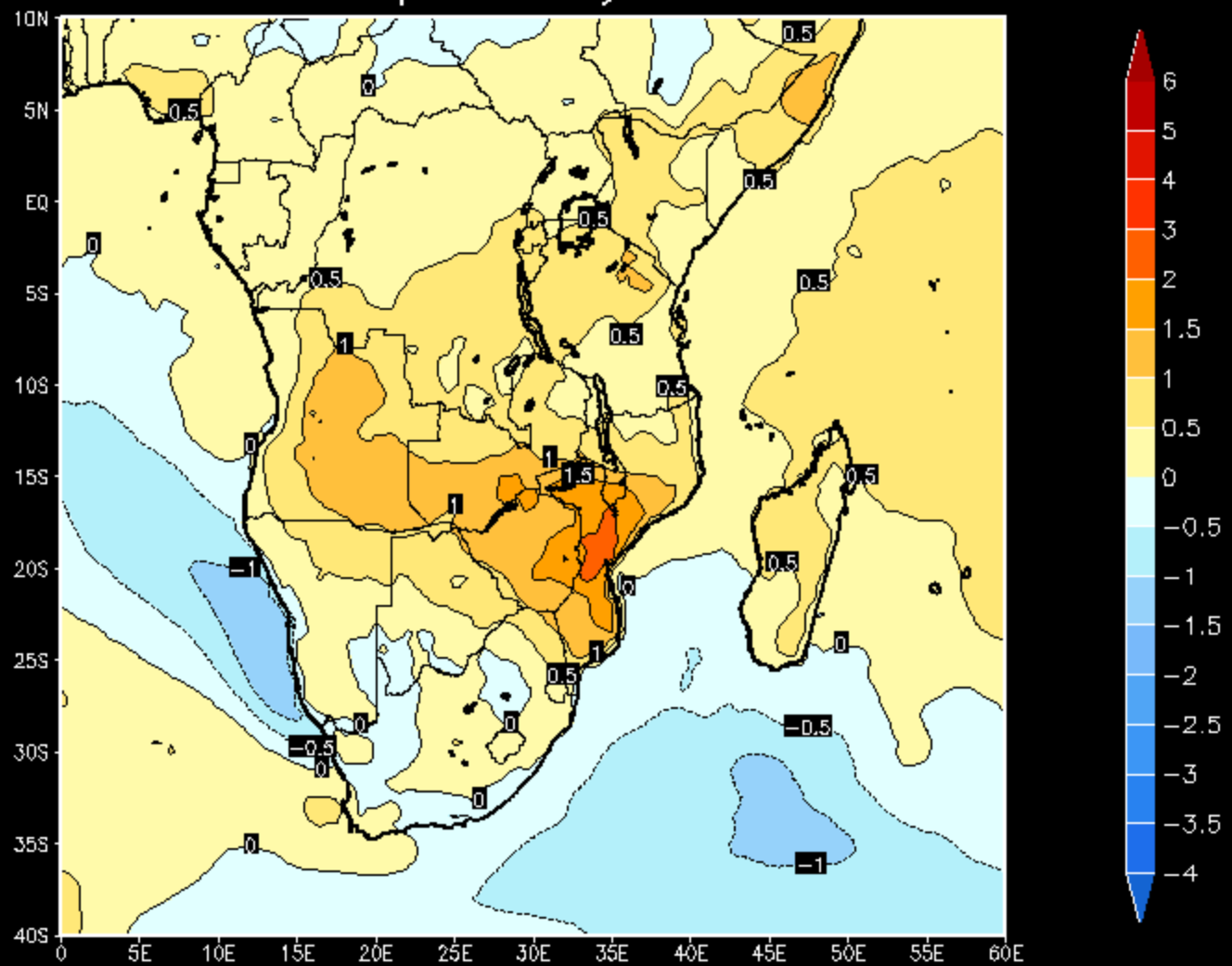
Temp anomaly 1975



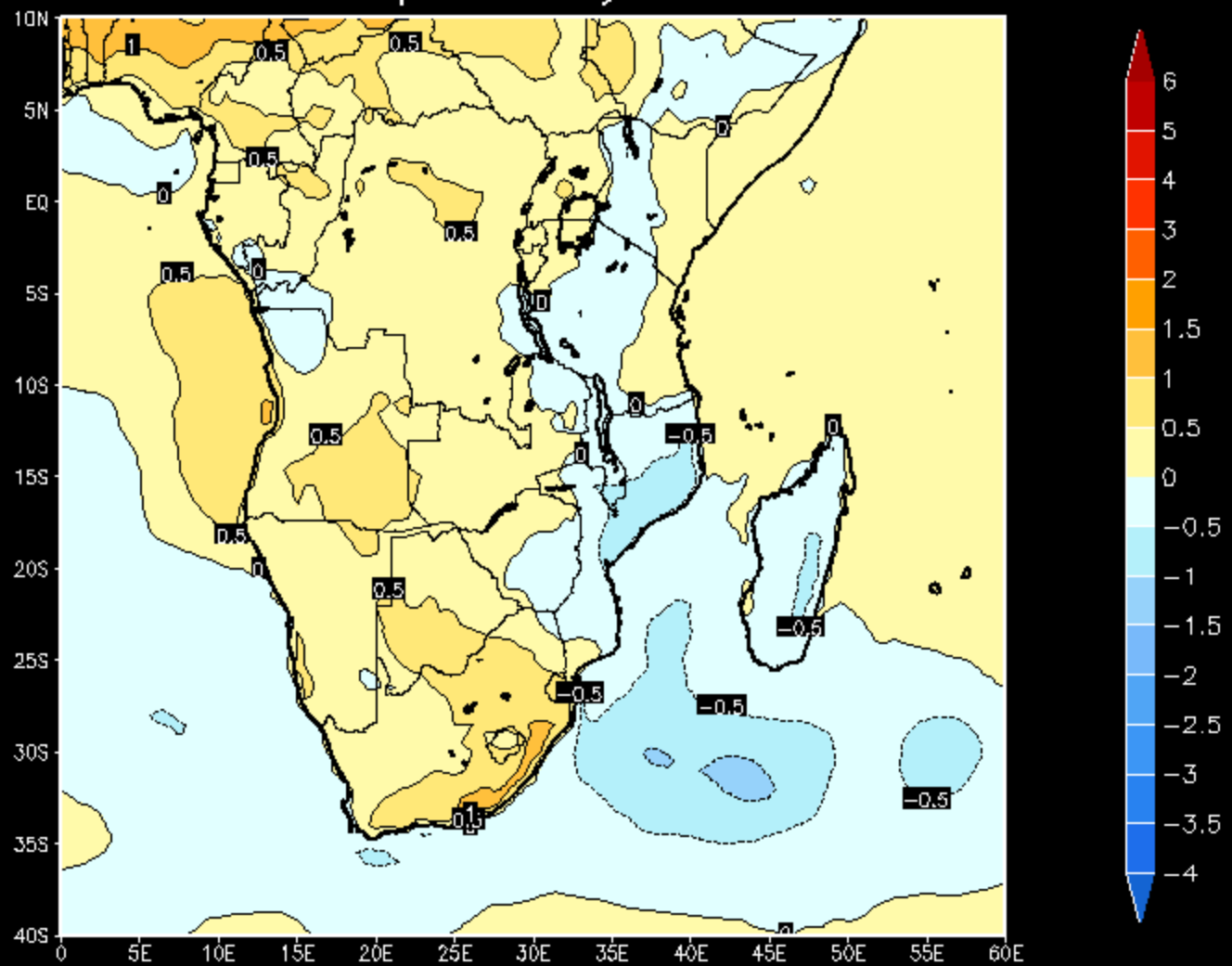
Temp anomaly 1976



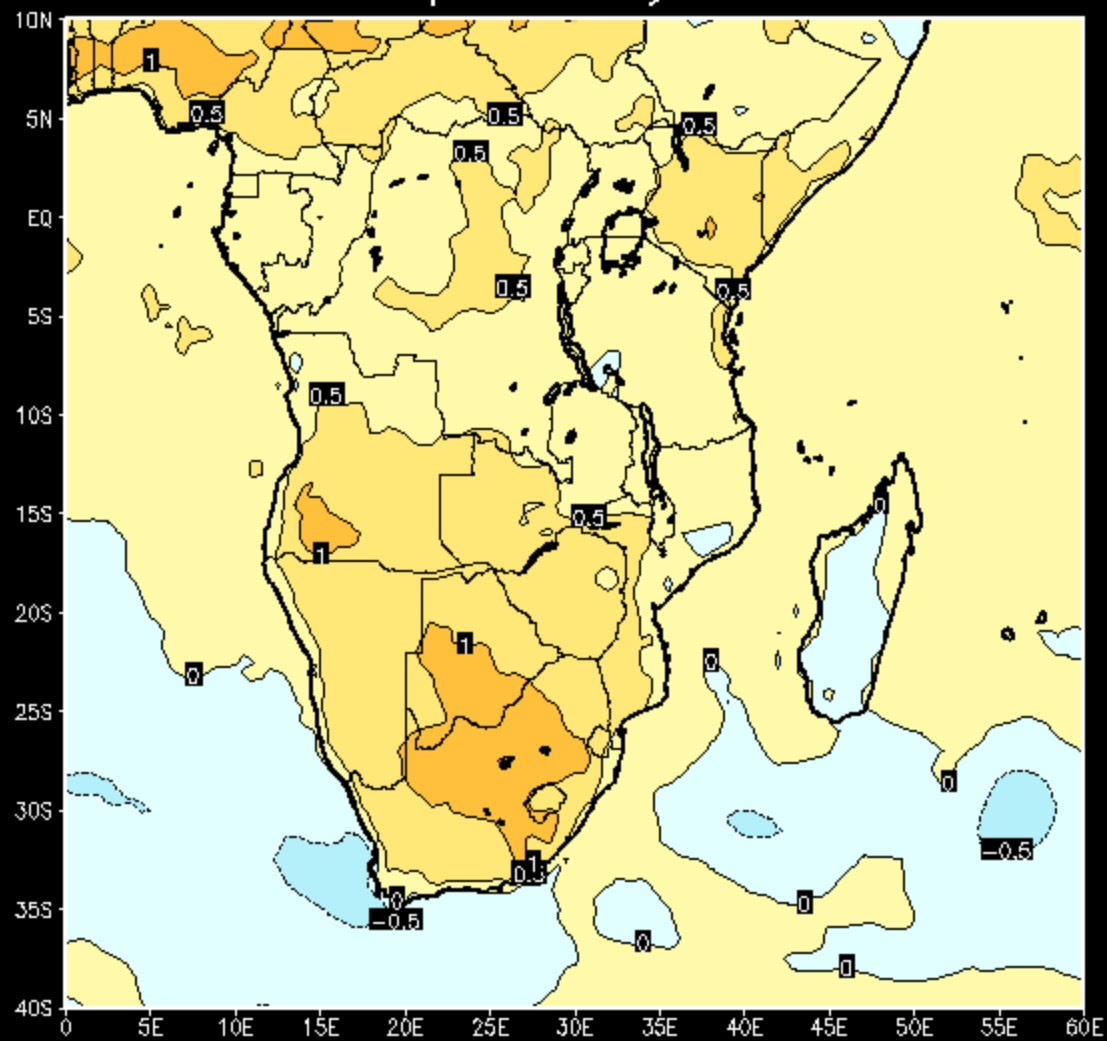
Temp anomaly 1977



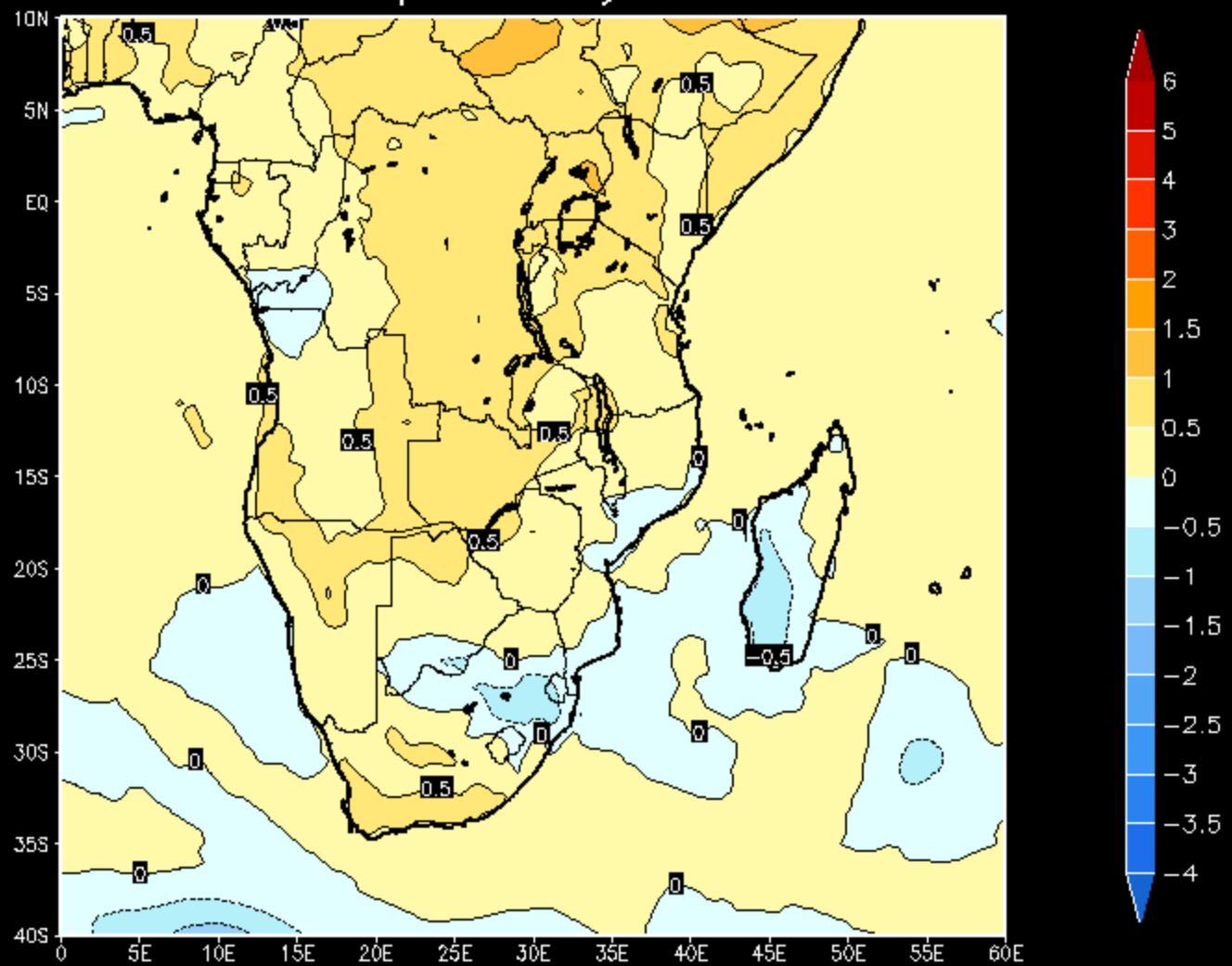
Temp anomaly 1978



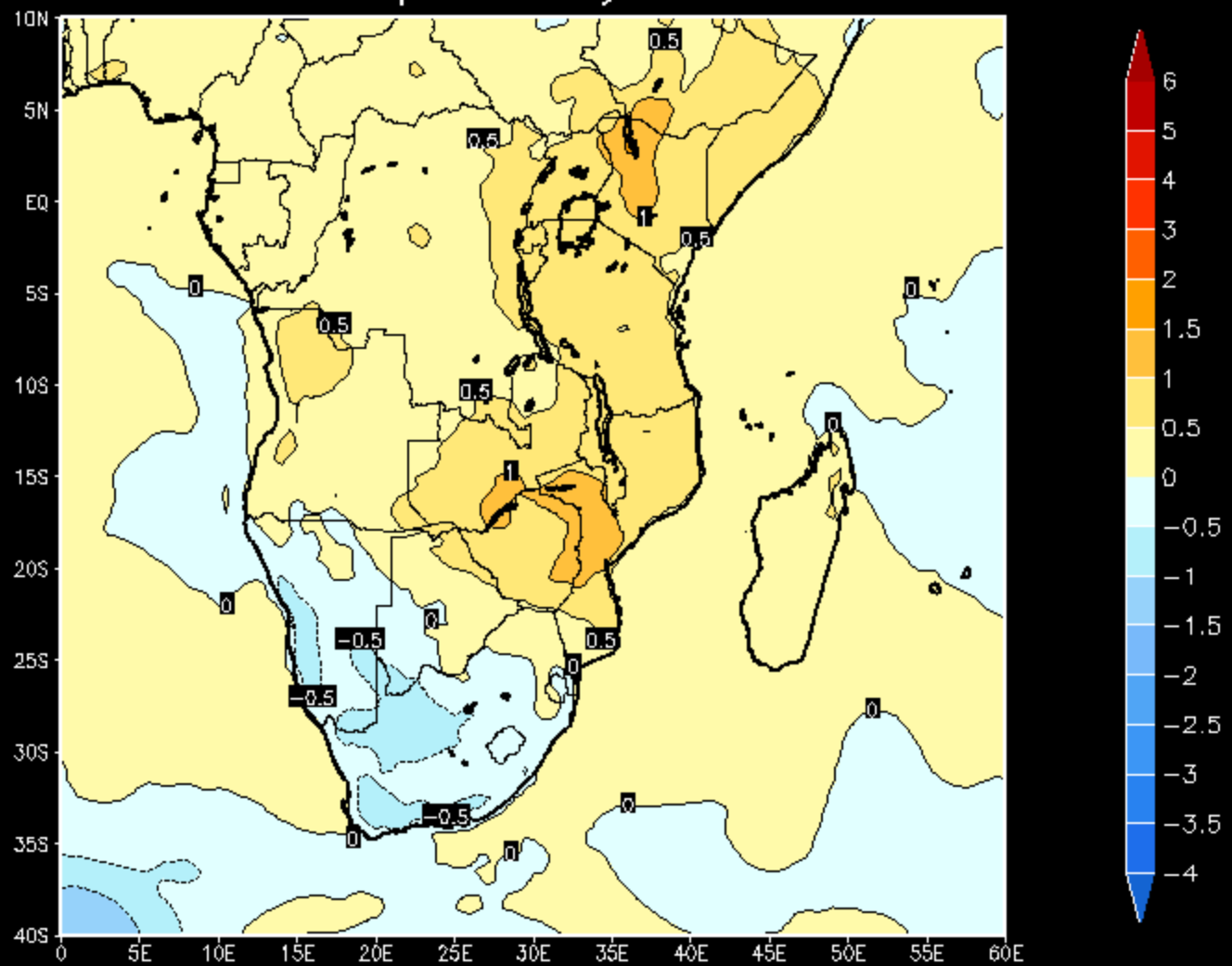
Temp anomaly 1979



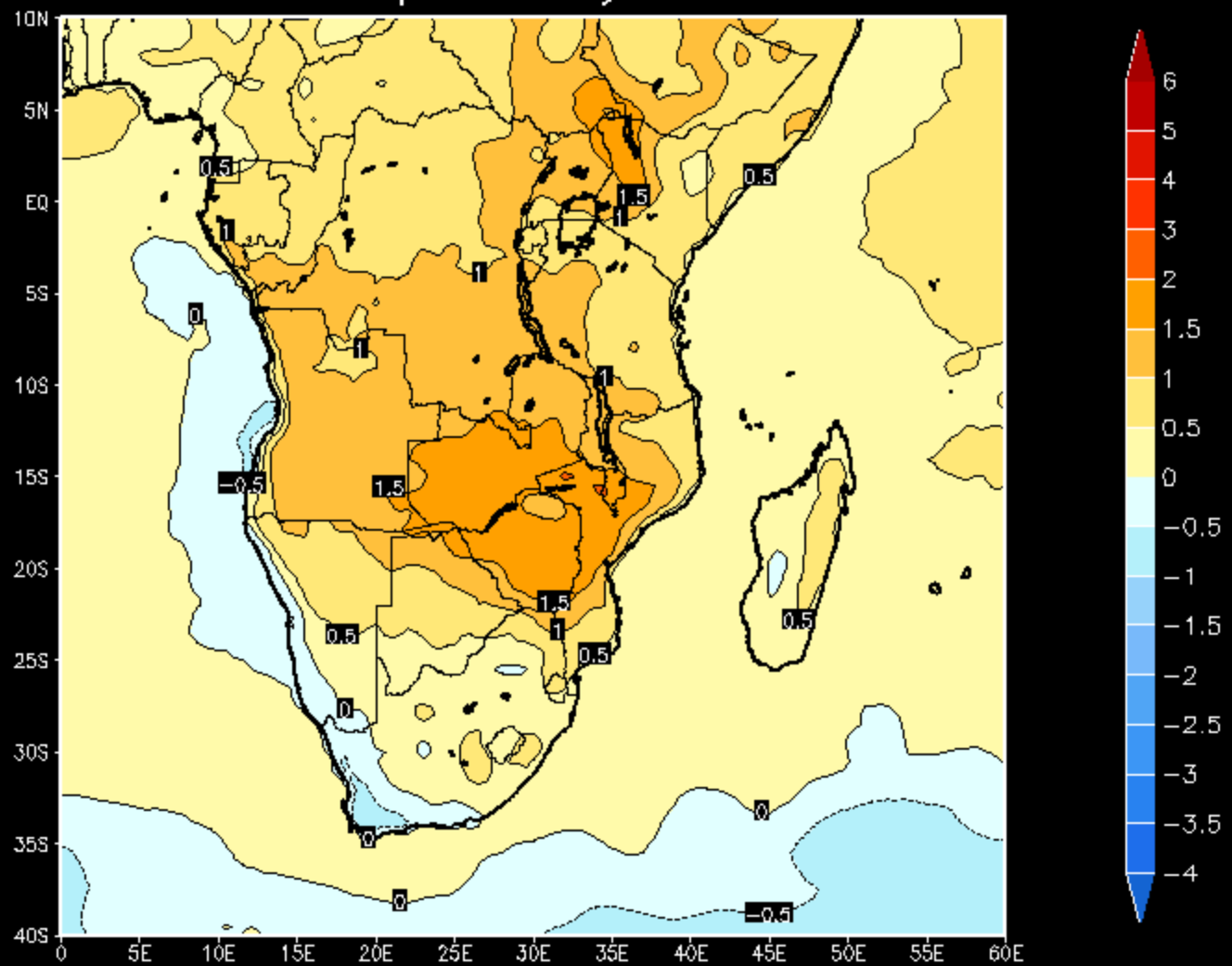
Temp anomaly 1980



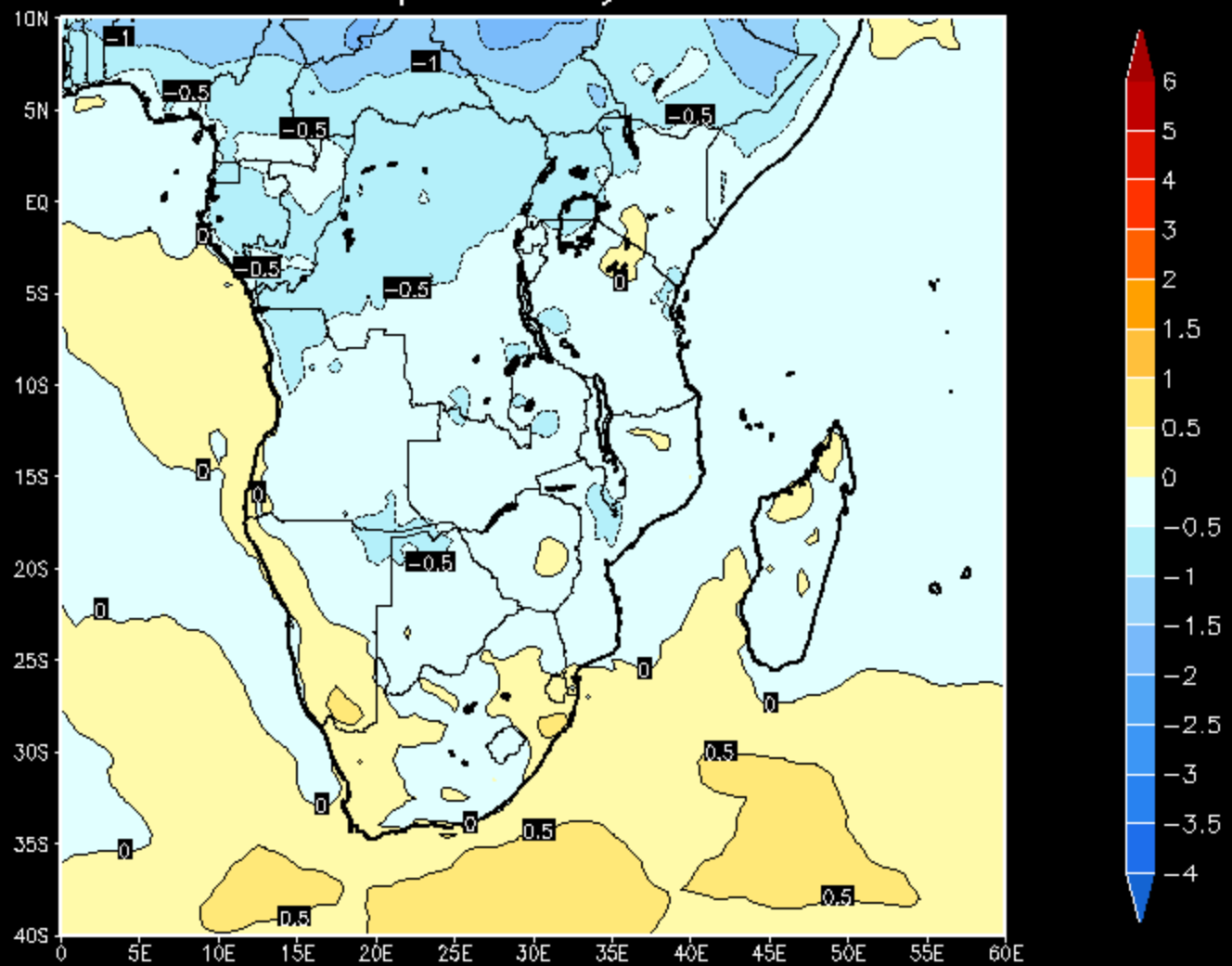
Temp anomaly 1981



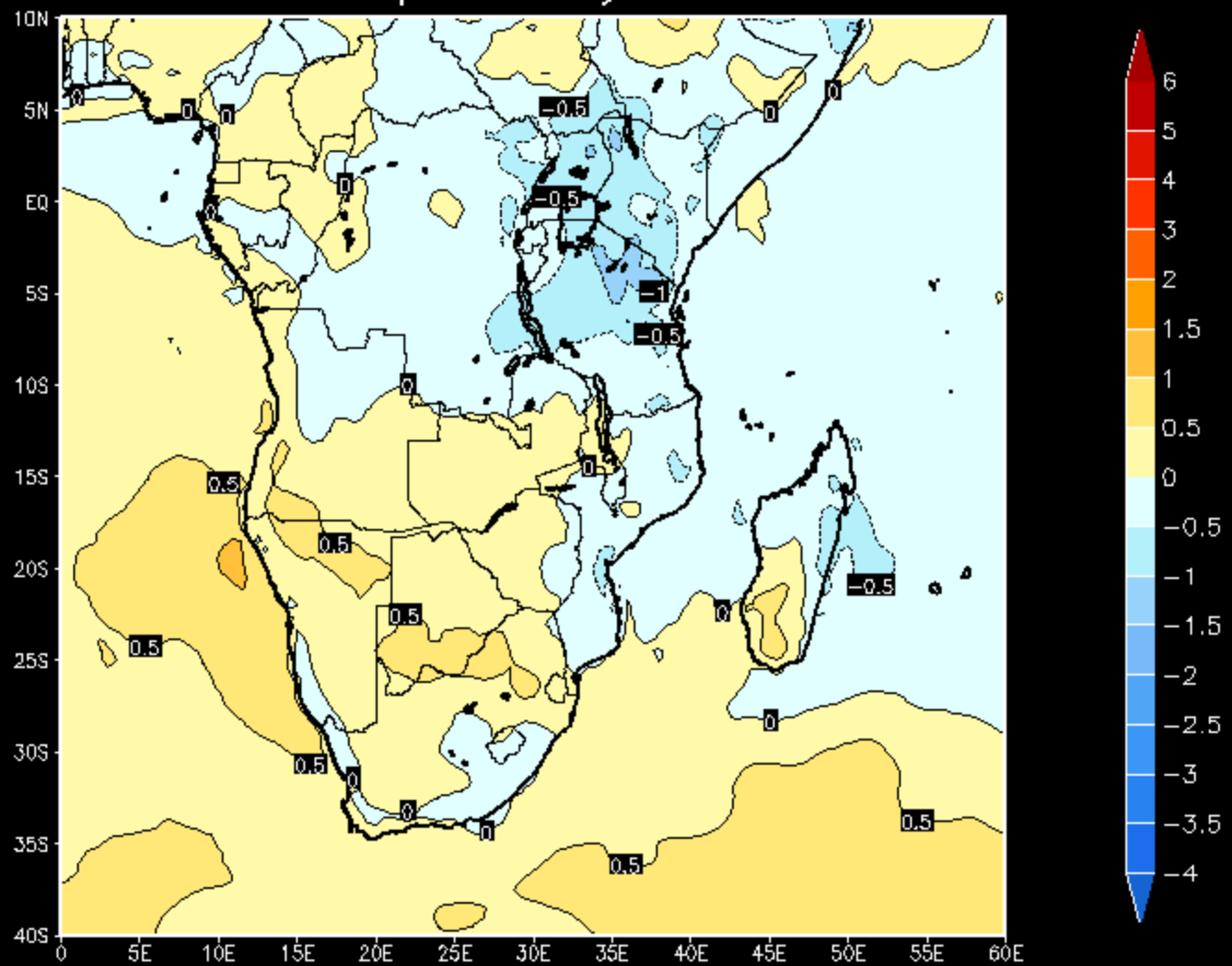
Temp anomaly 1982



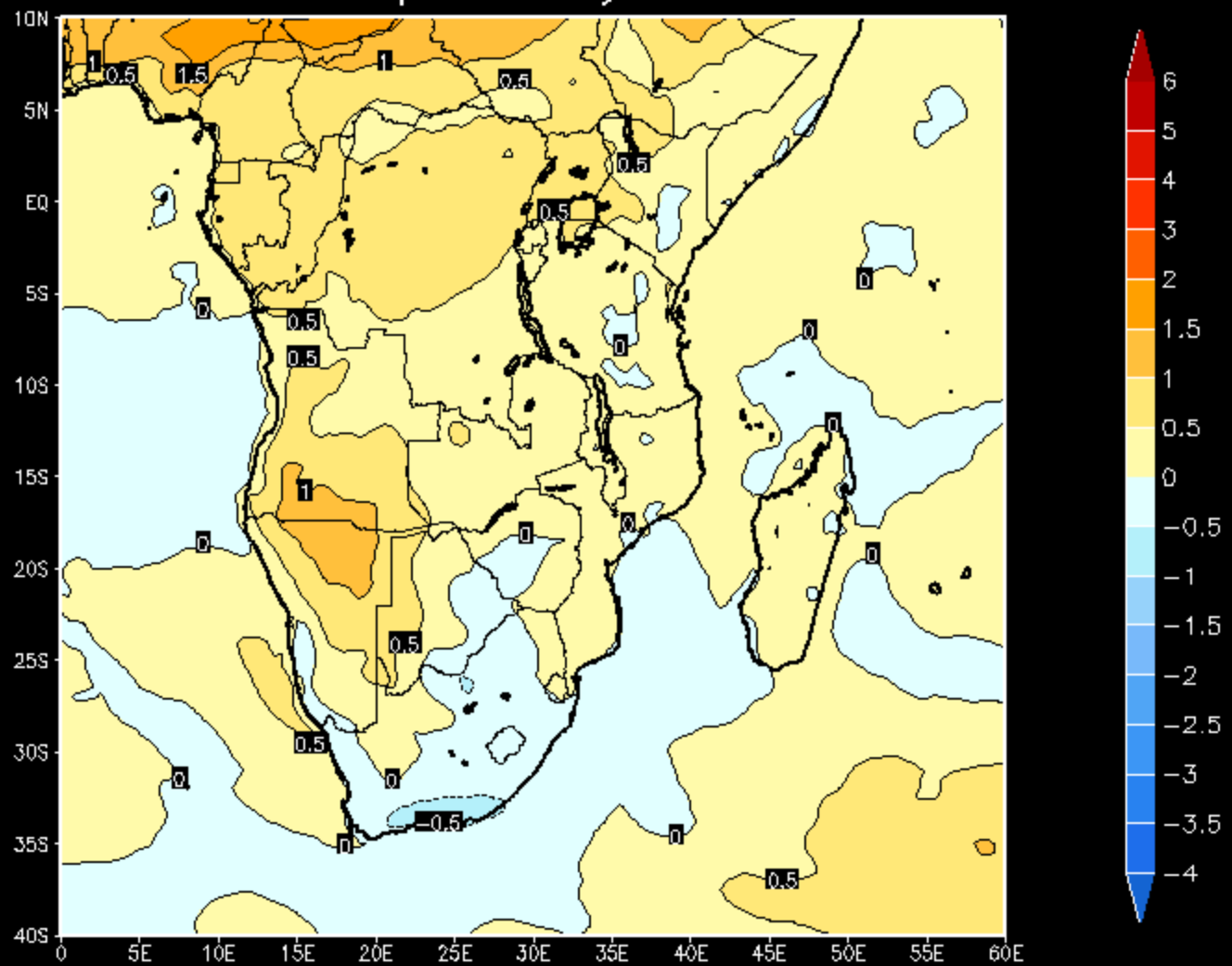
Temp anomaly 1983



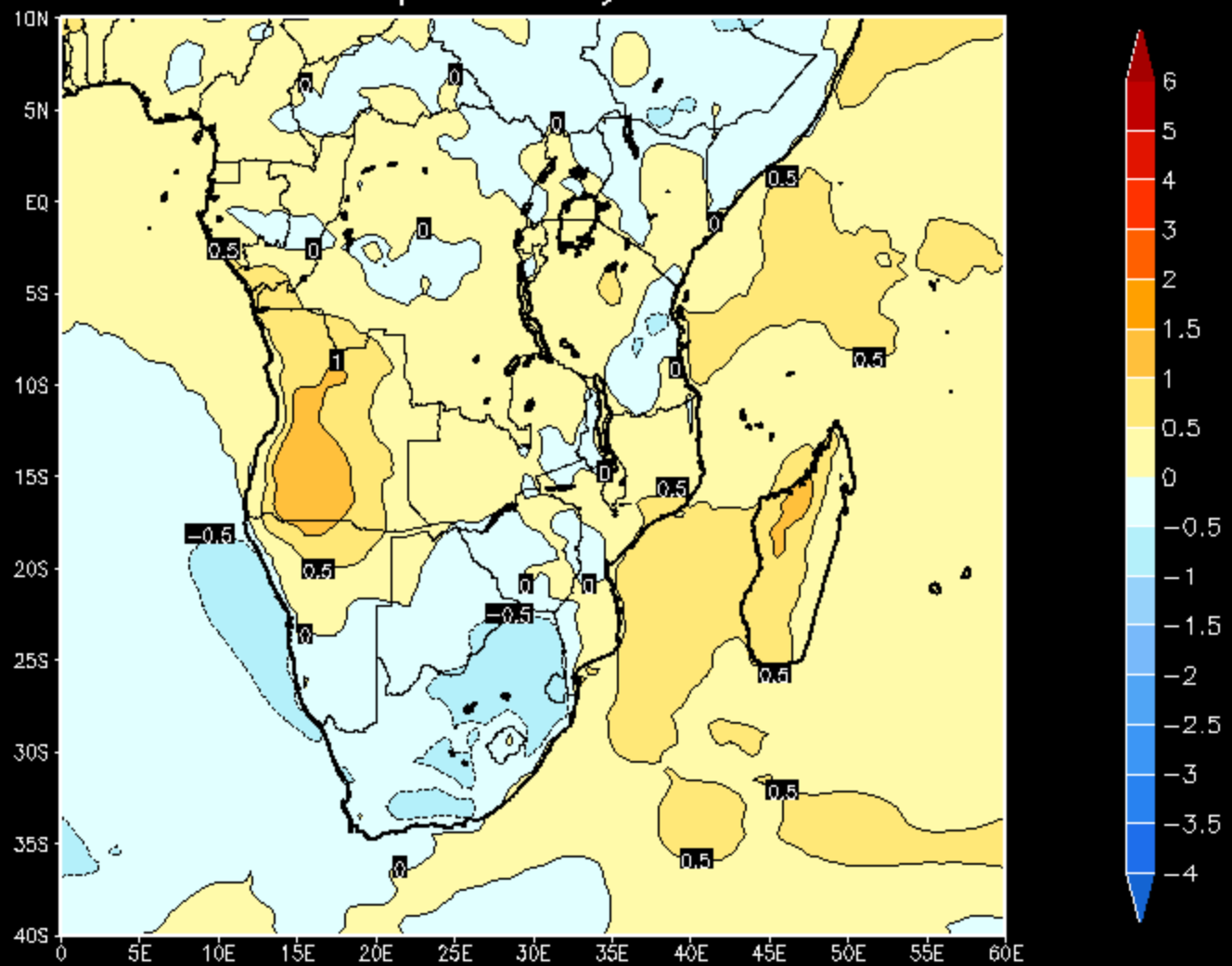
Temp anomaly 1984



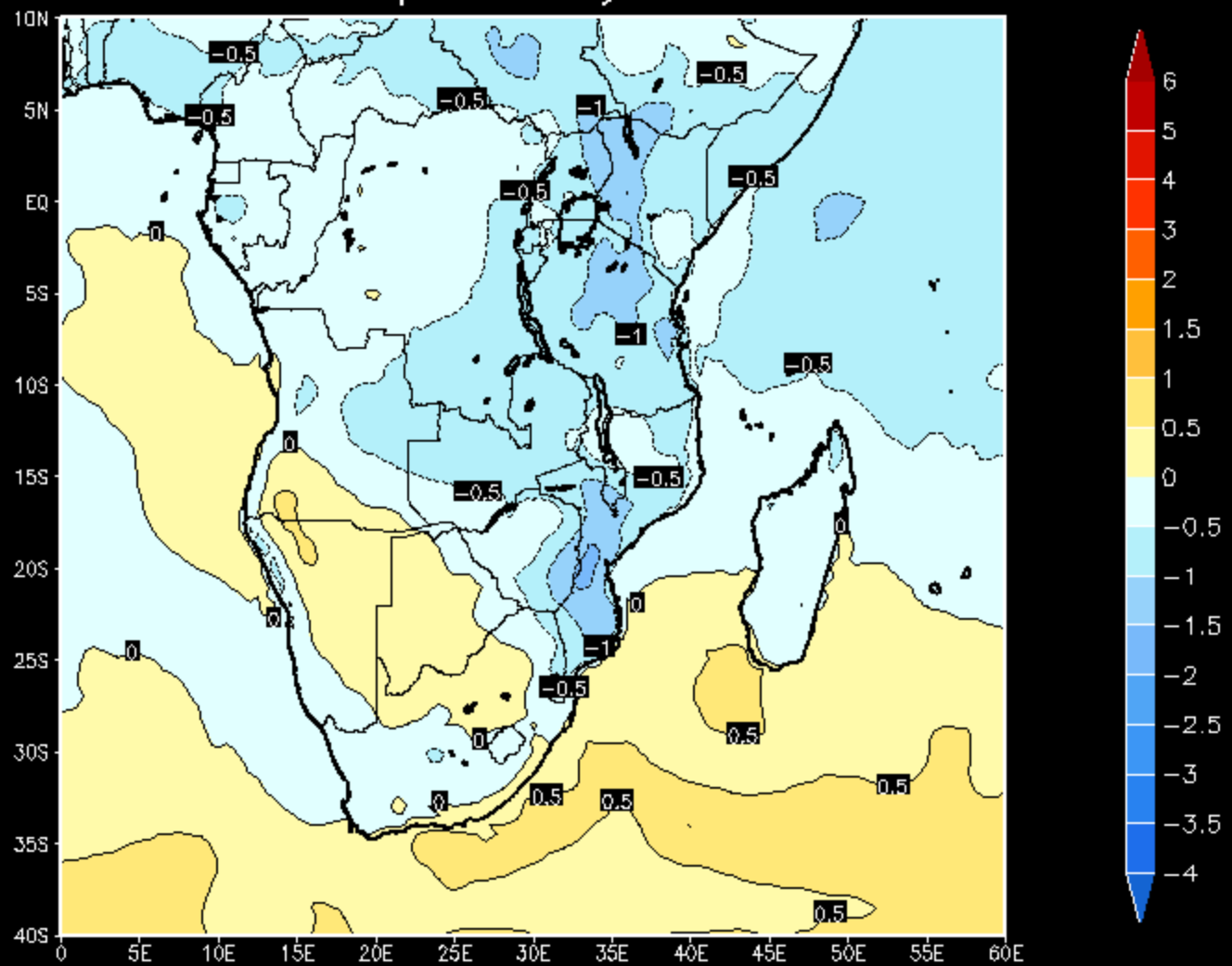
Temp anomaly 1985



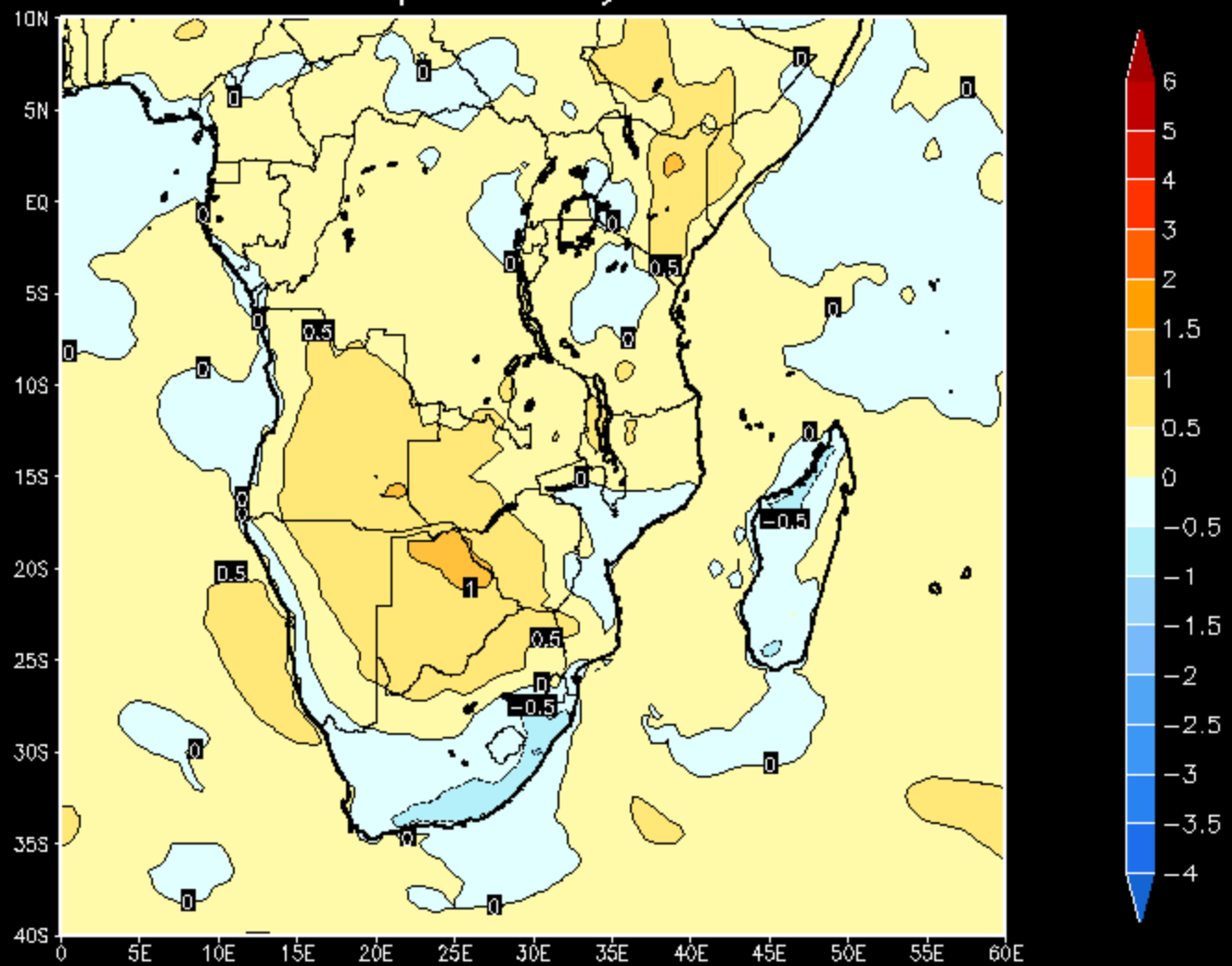
Temp anomaly 1986



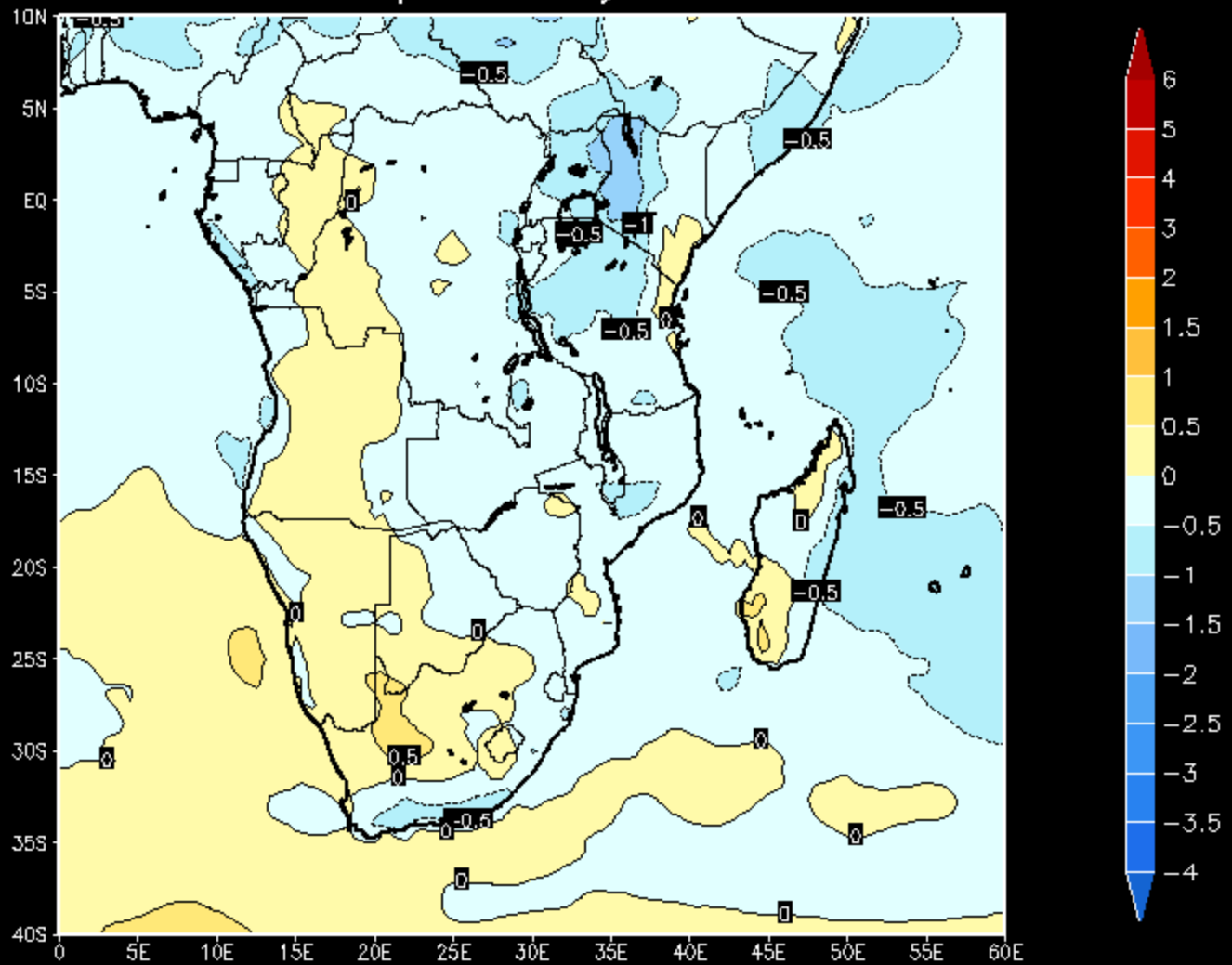
Temp anomaly 1987



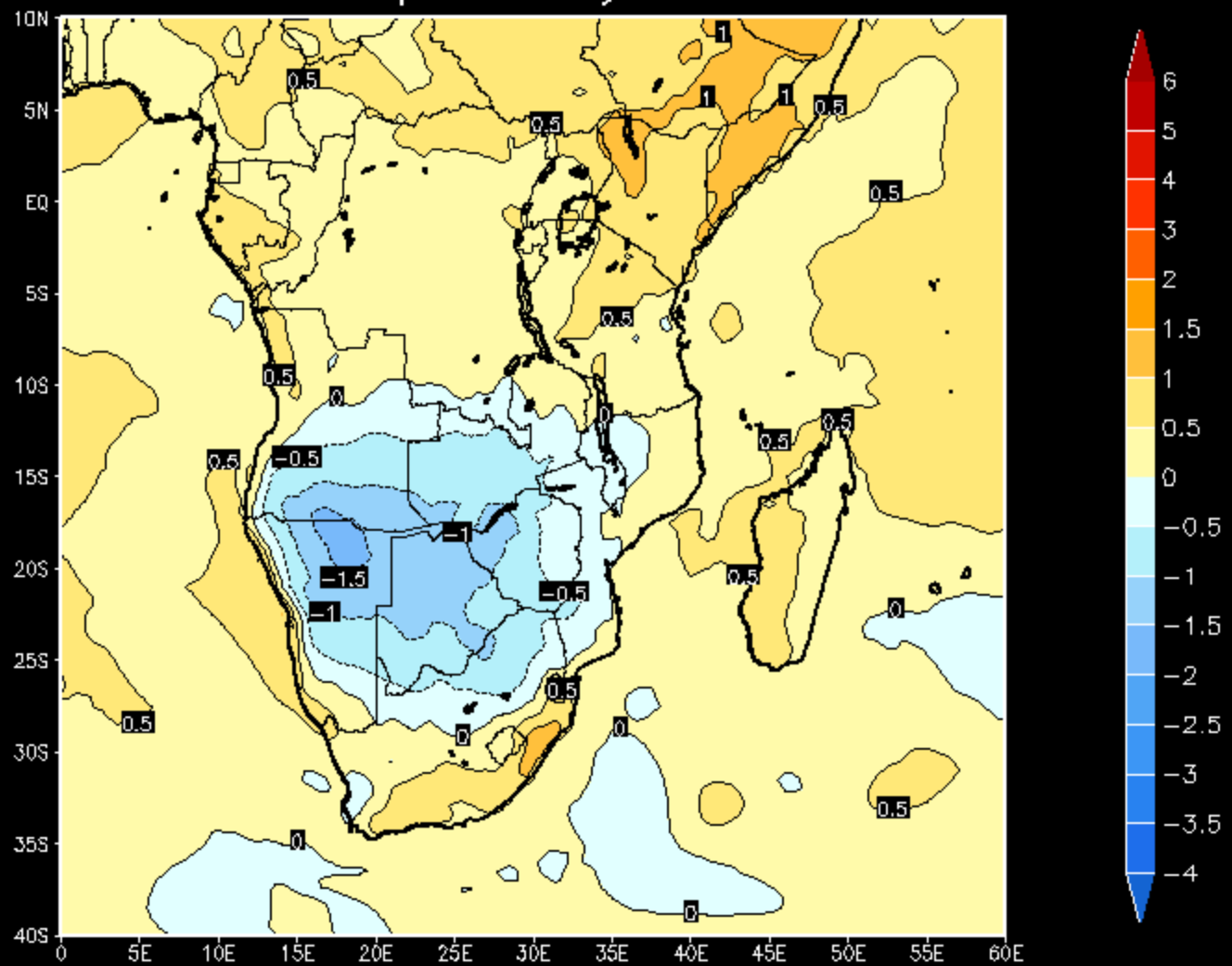
Temp anomaly 1988



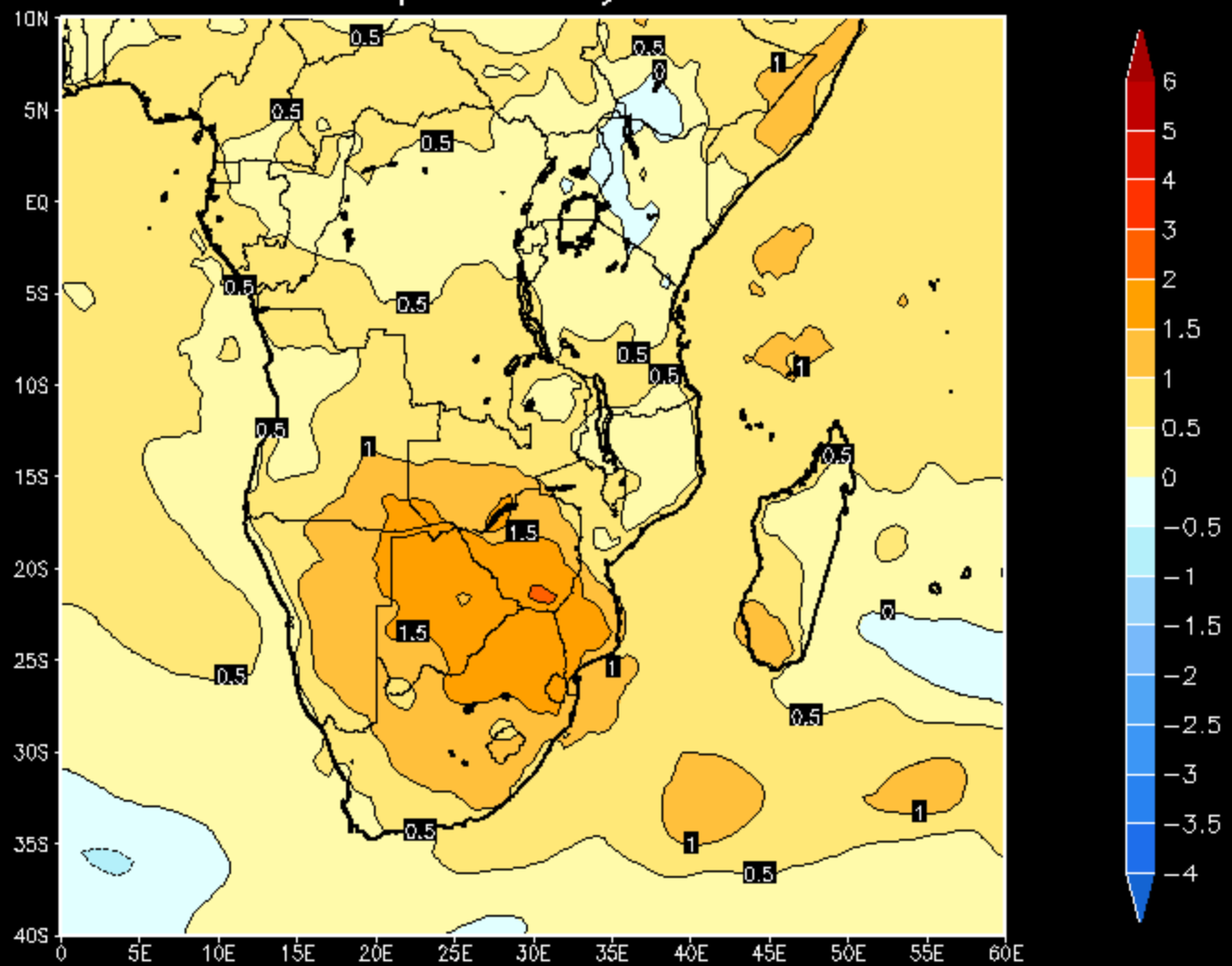
Temp anomaly 1989



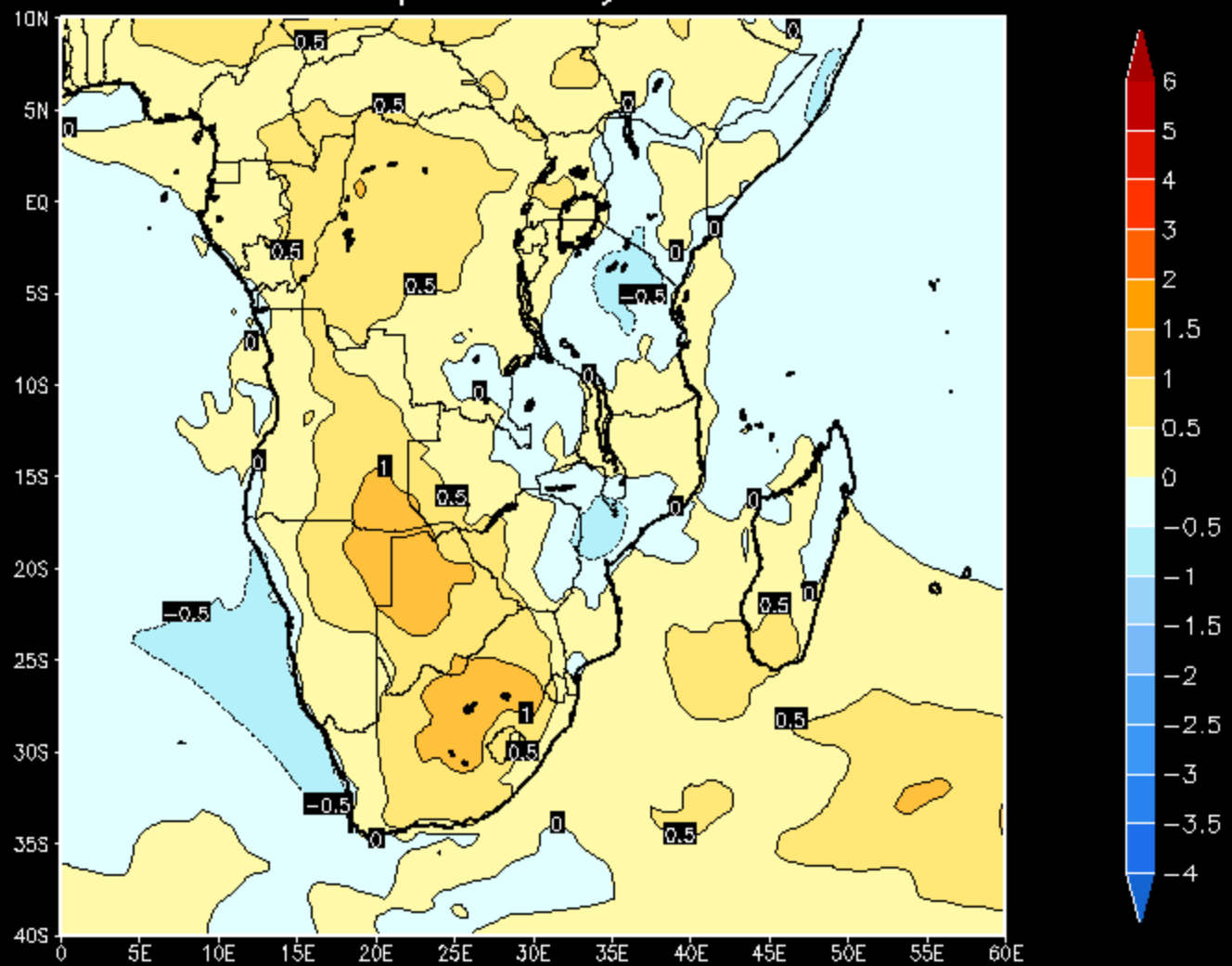
Temp anomaly 1990



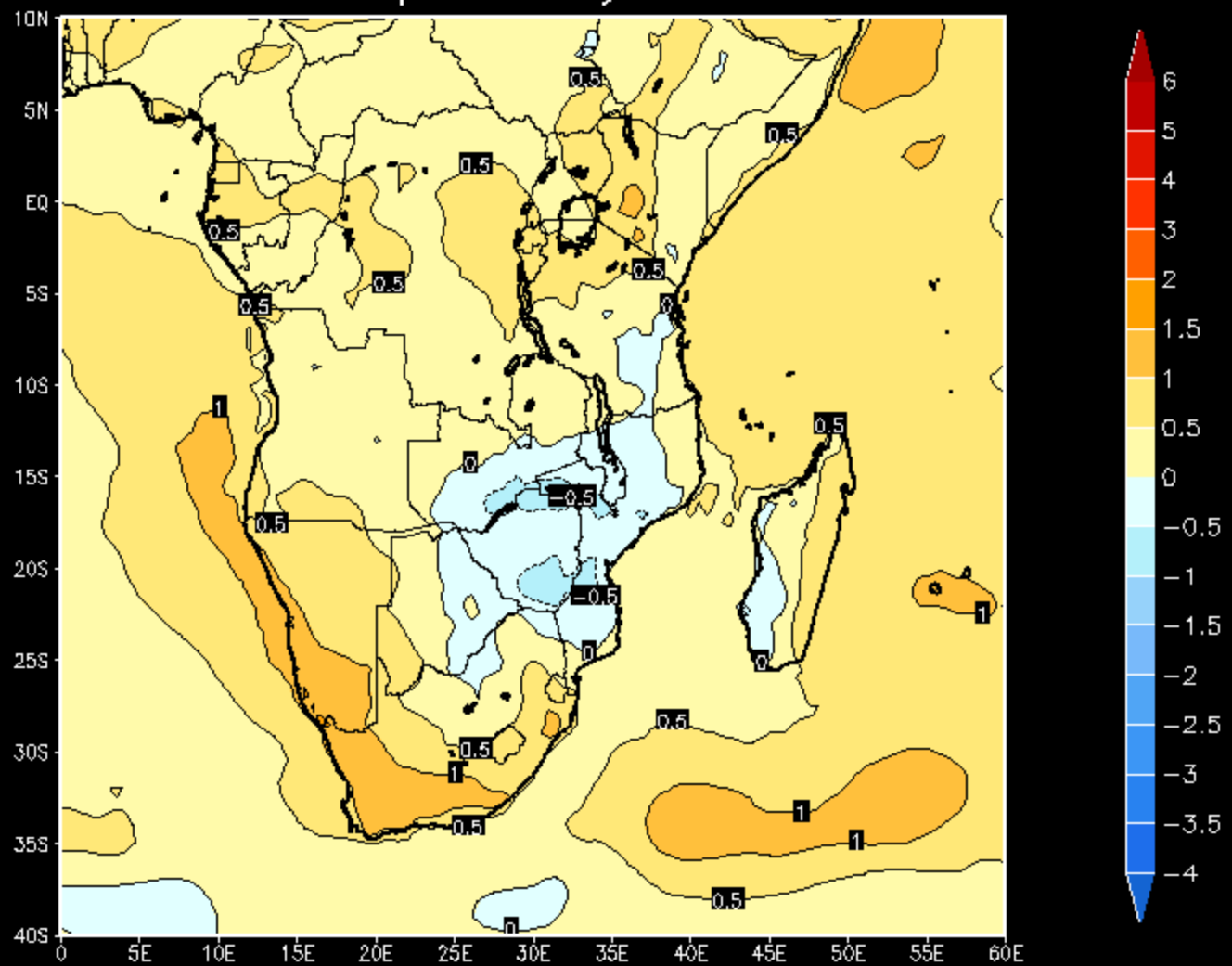
Temp anomaly 1991



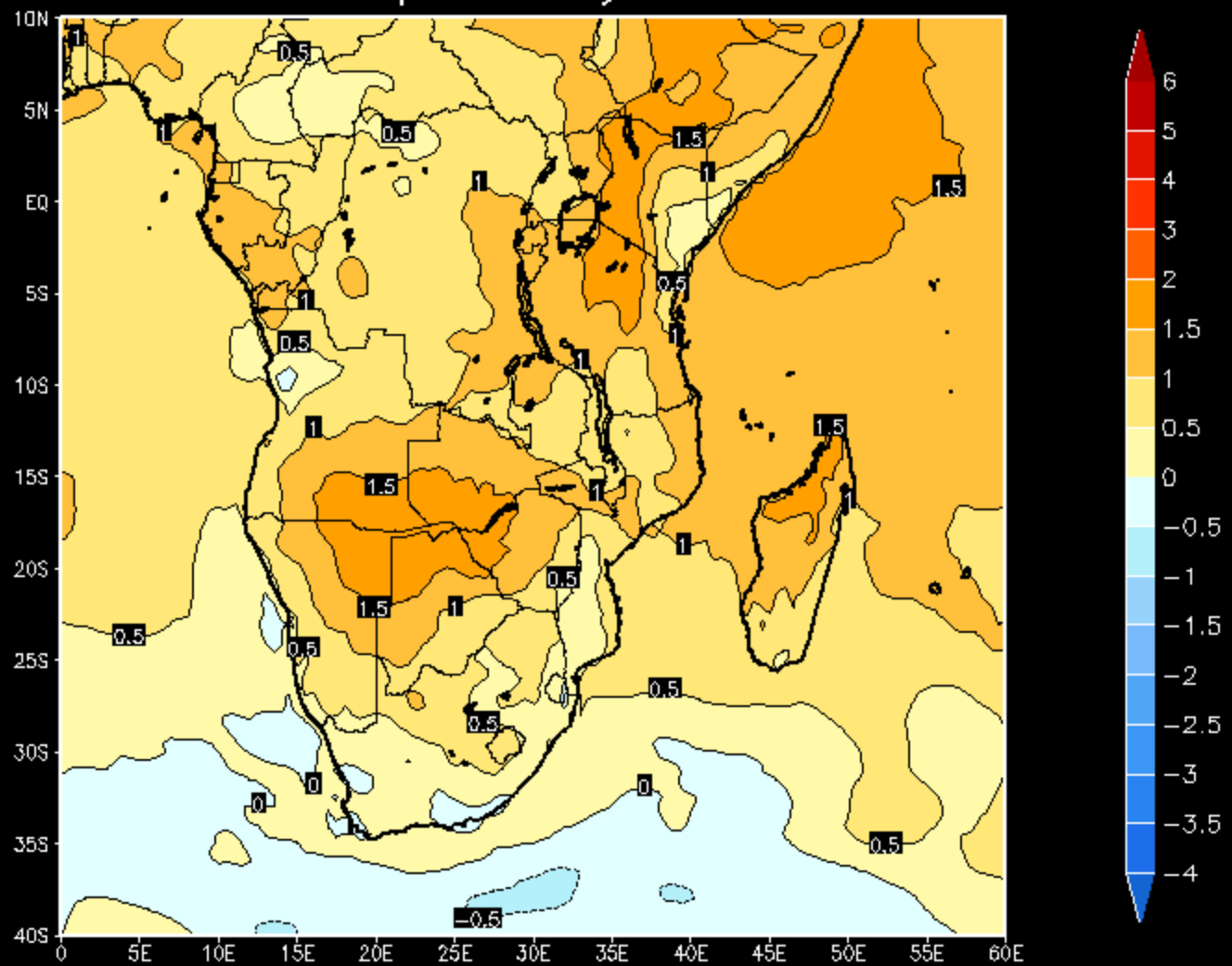
Temp anomaly 1992



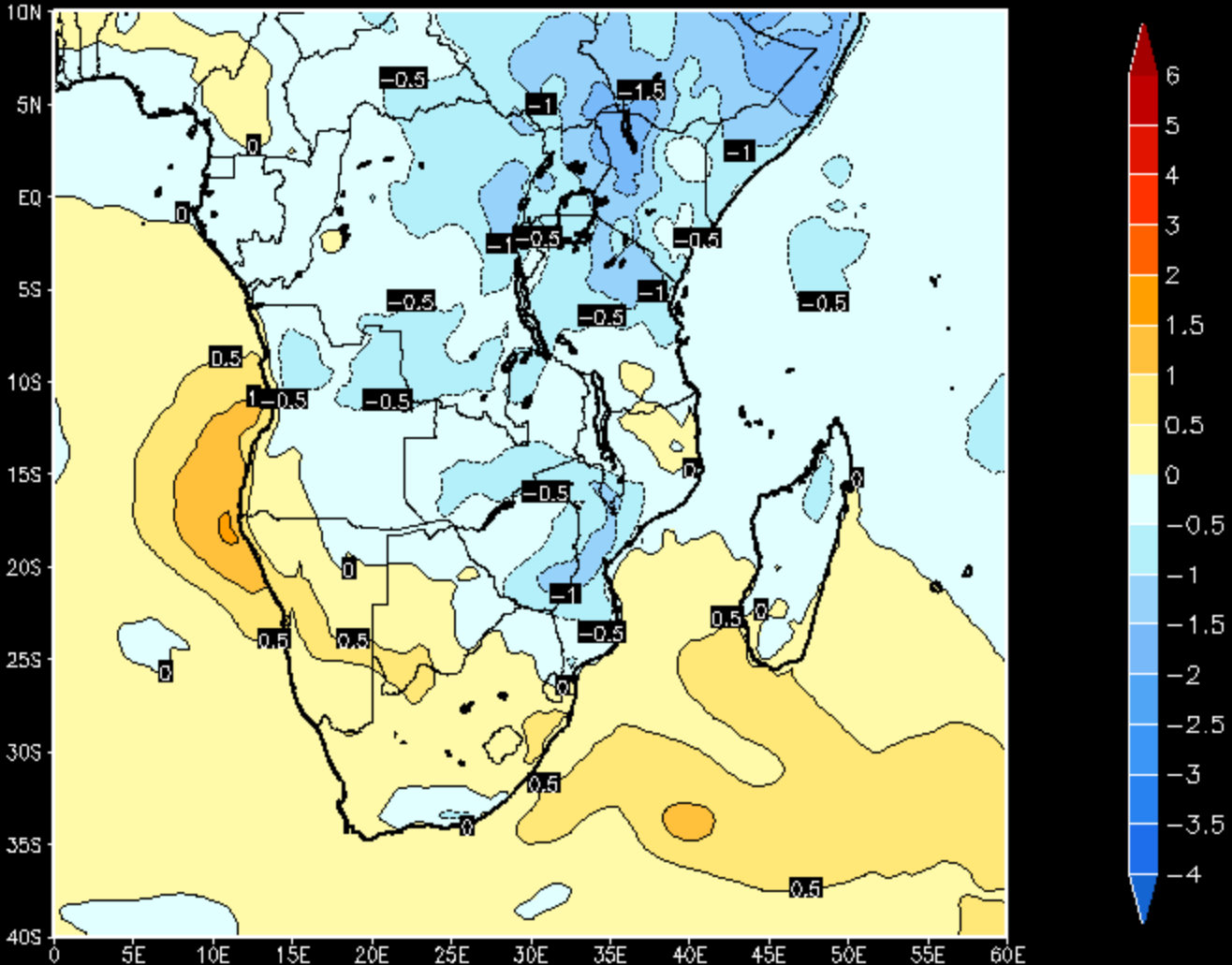
Temp anomaly 1993



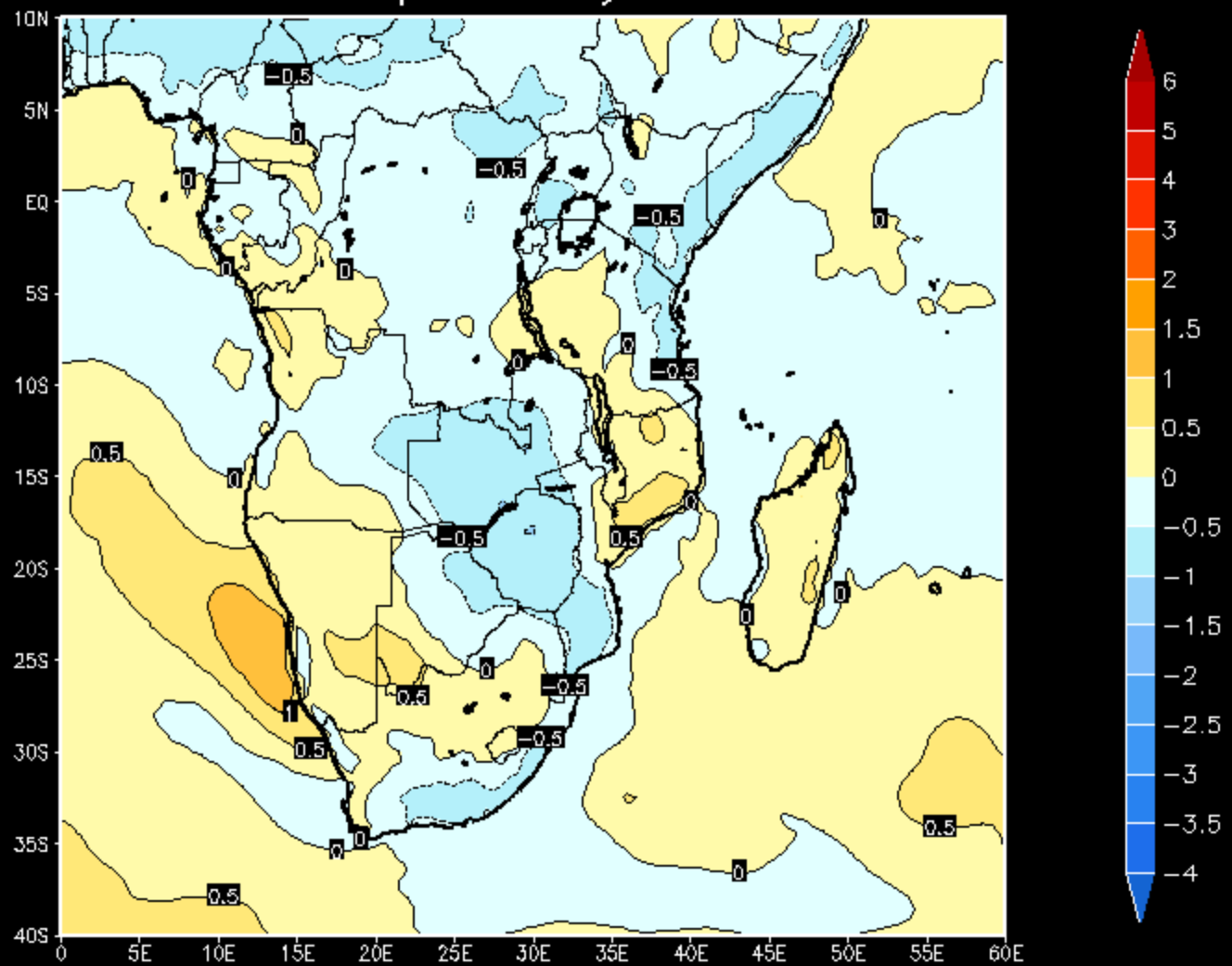
Temp anomaly 1994



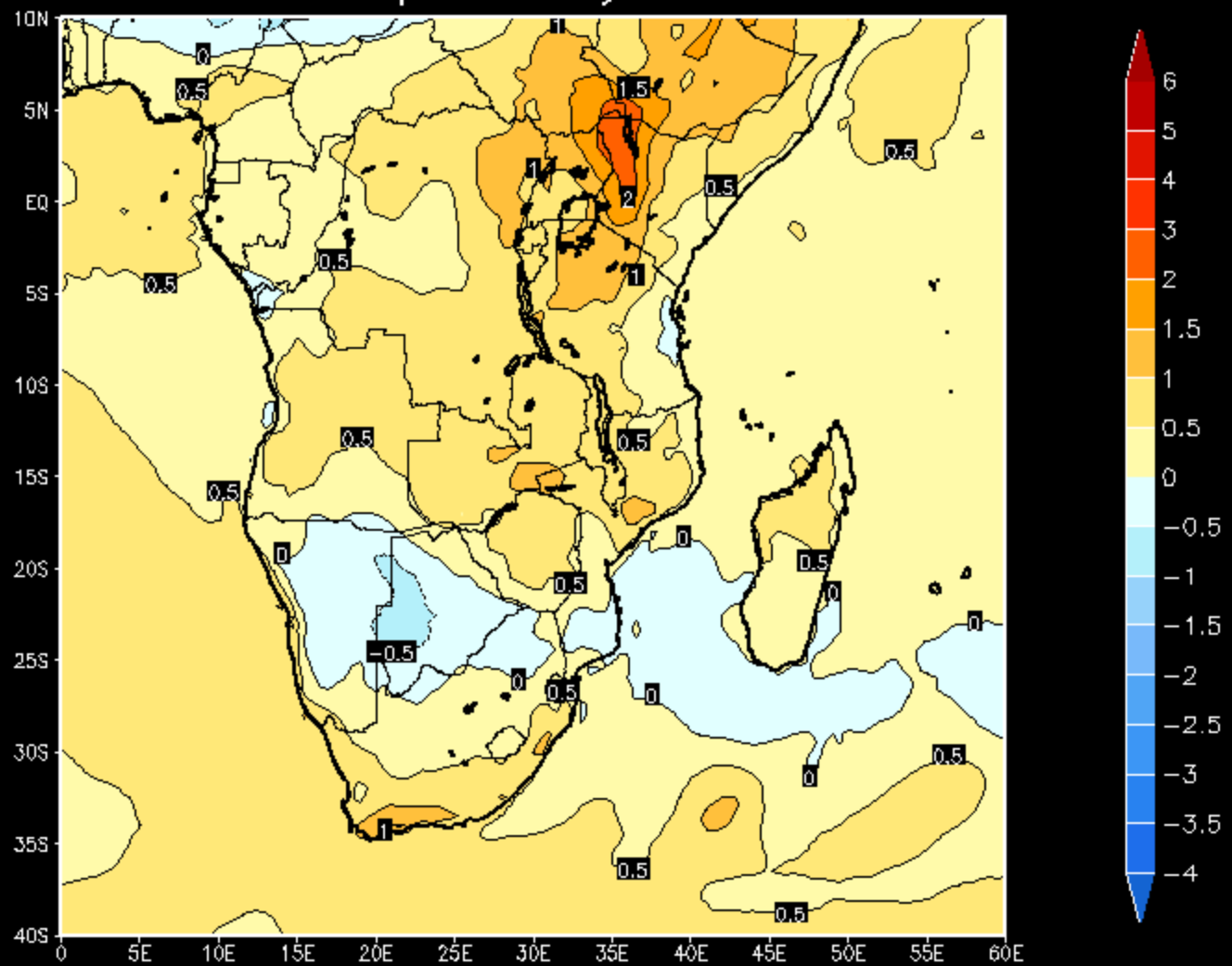
Temp anomaly 1995



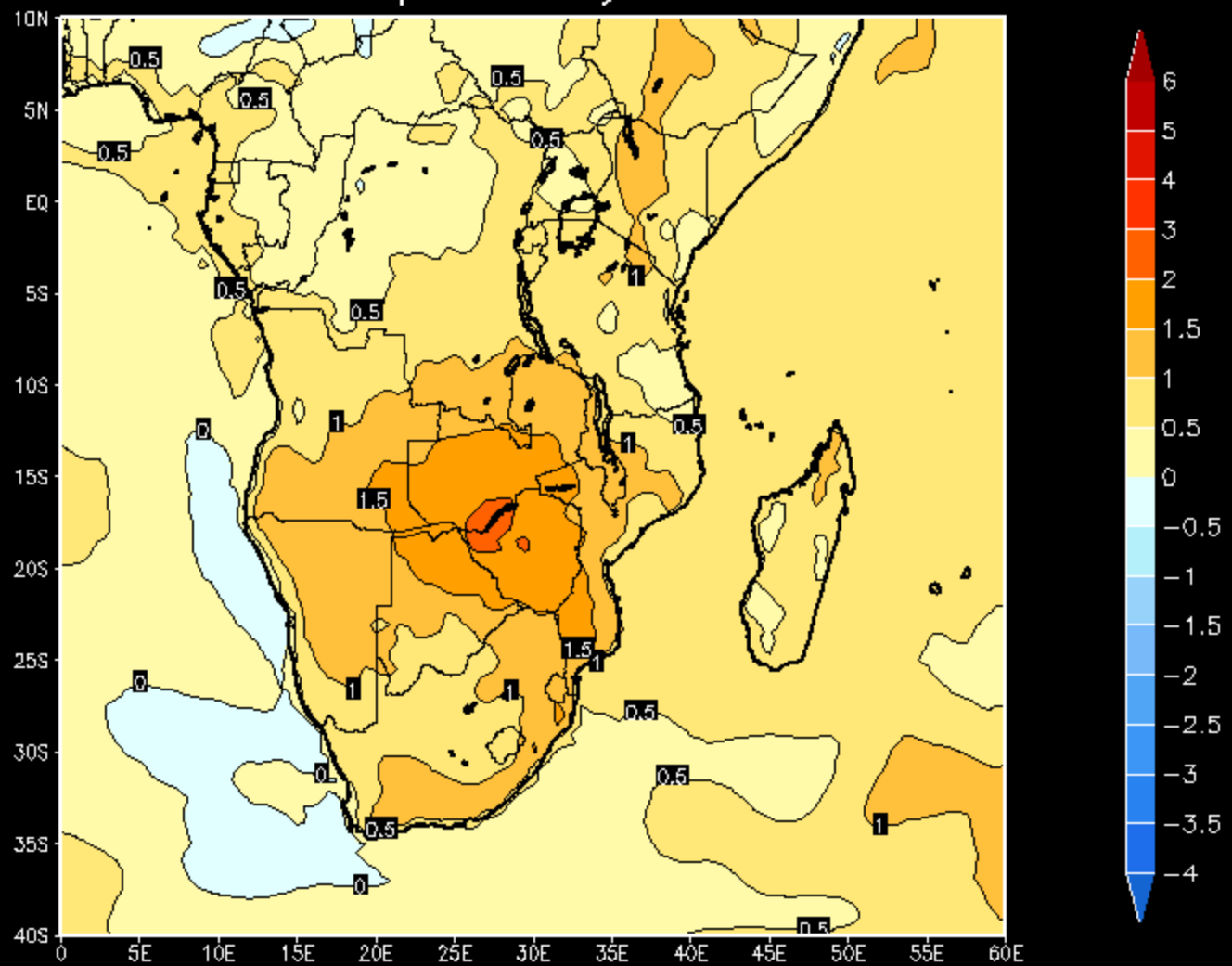
Temp anomaly 1996



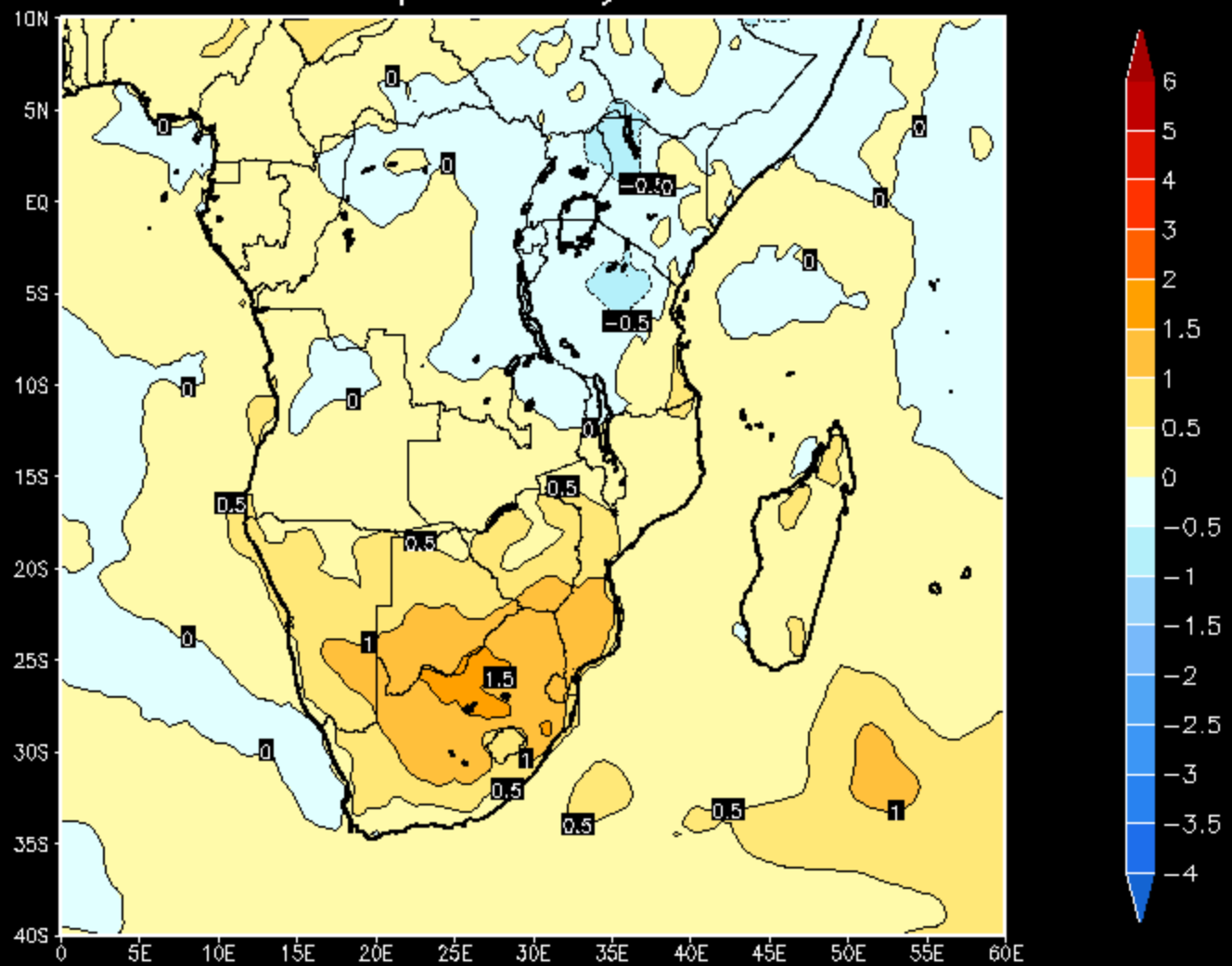
Temp anomaly 1997



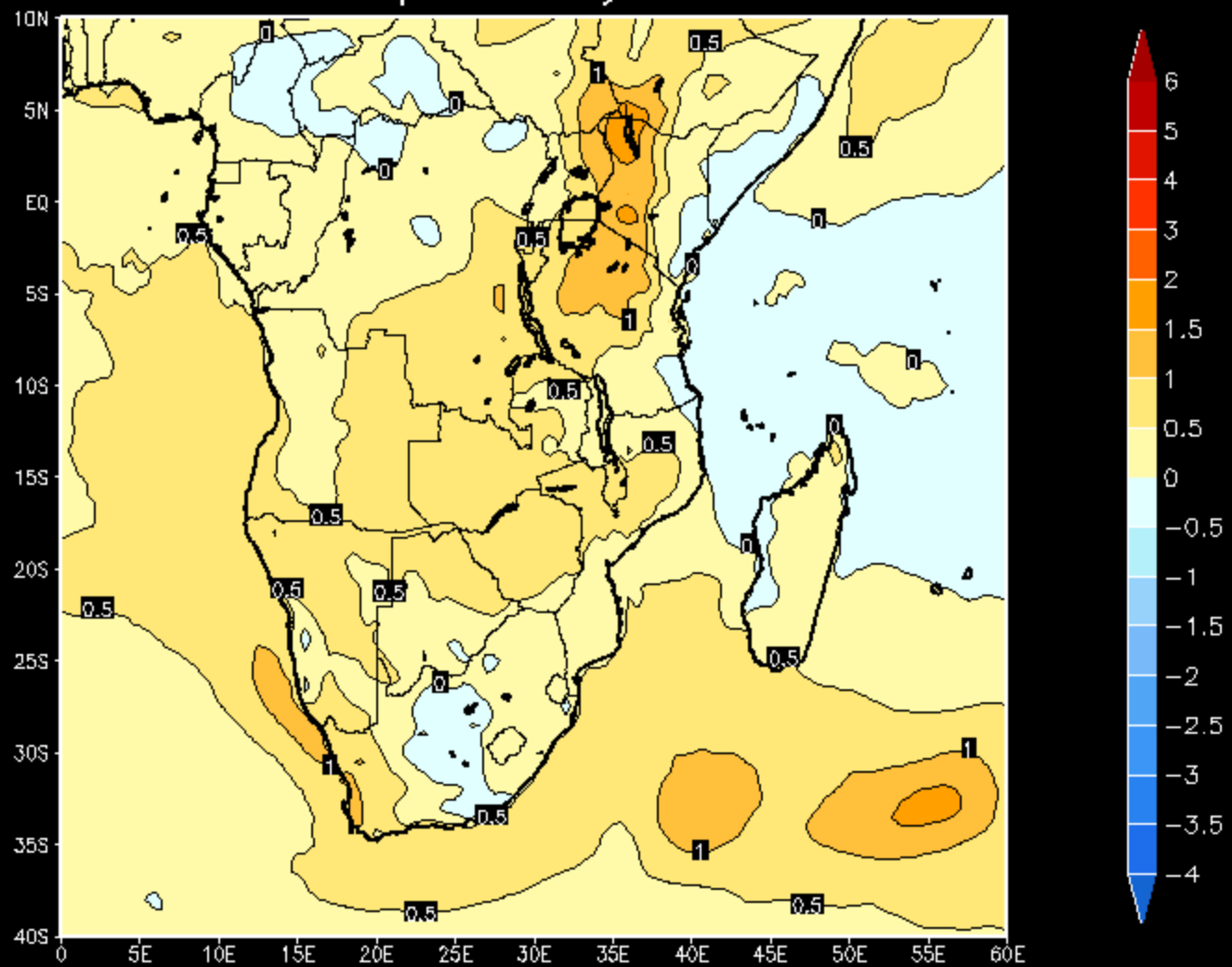
Temp anomaly 1998



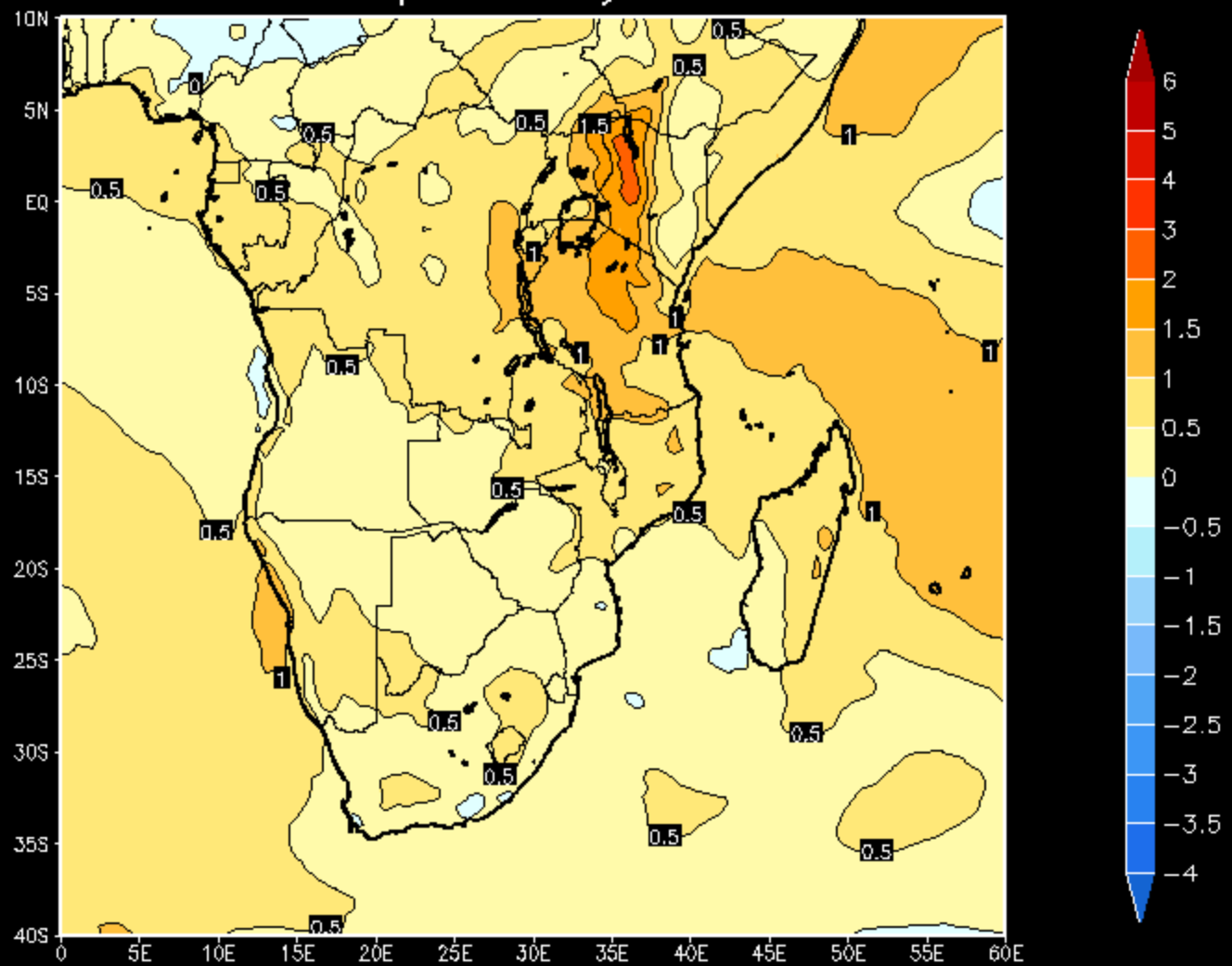
Temp anomaly 1999



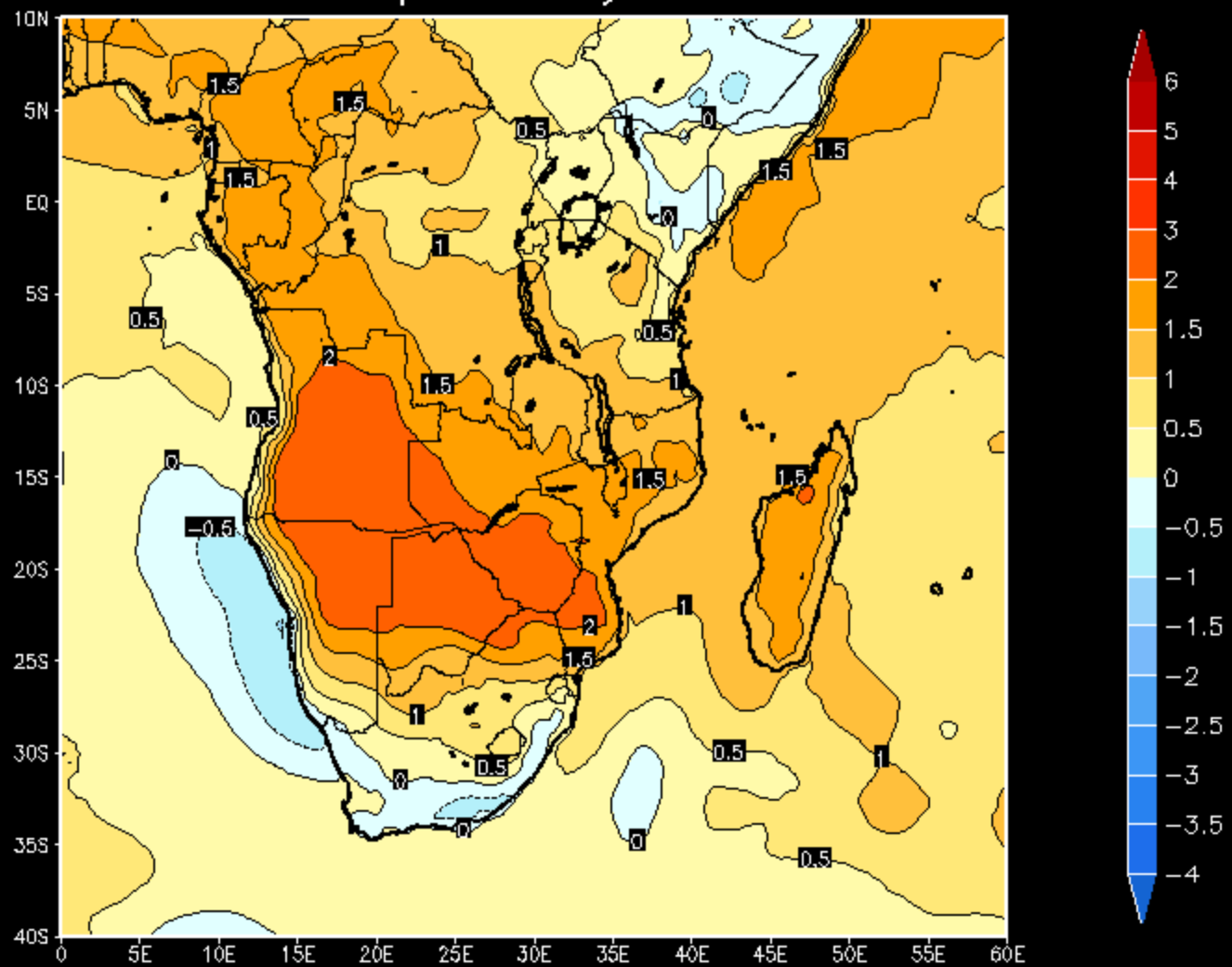
Temp anomaly 2000



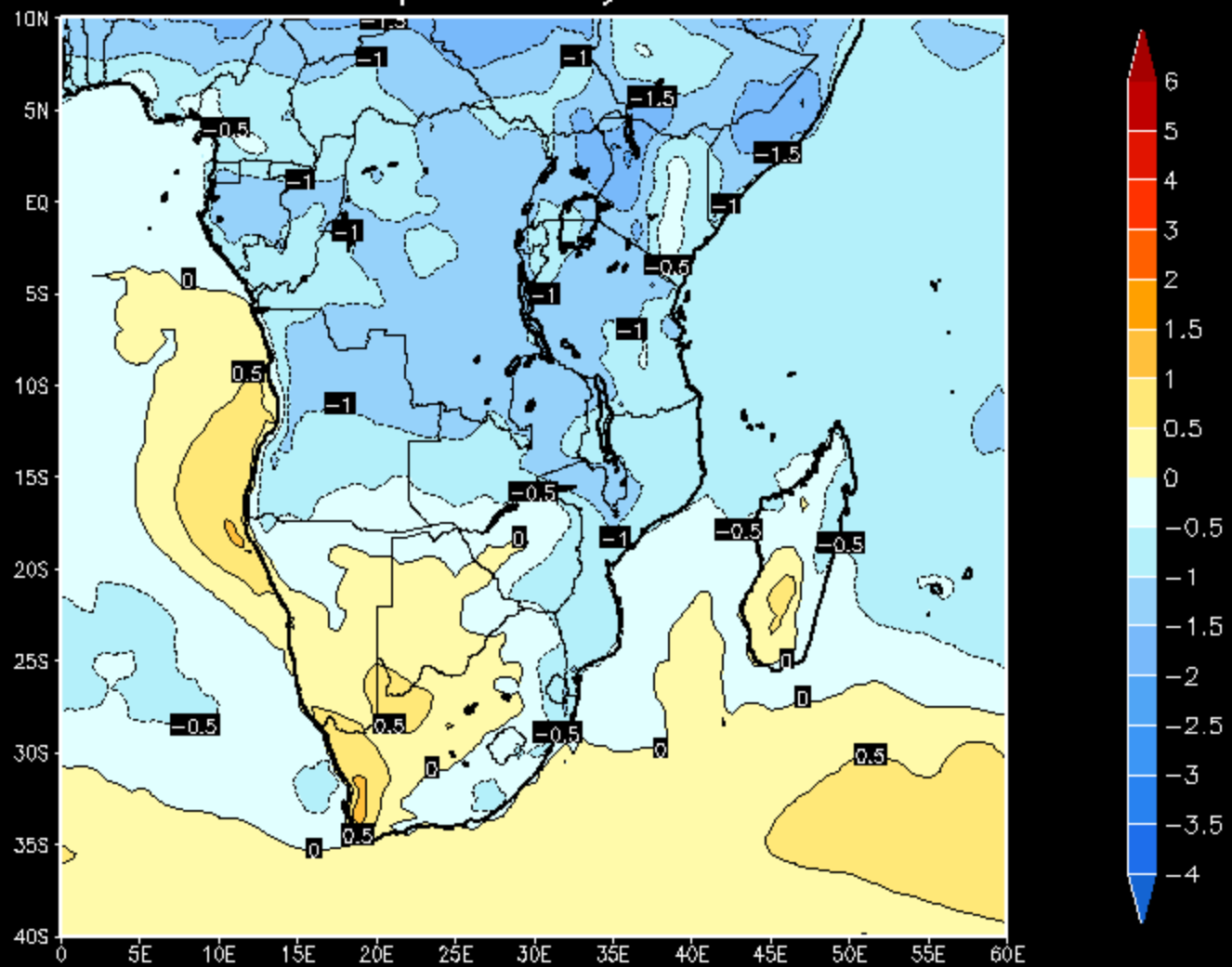
Temp anomaly 2001



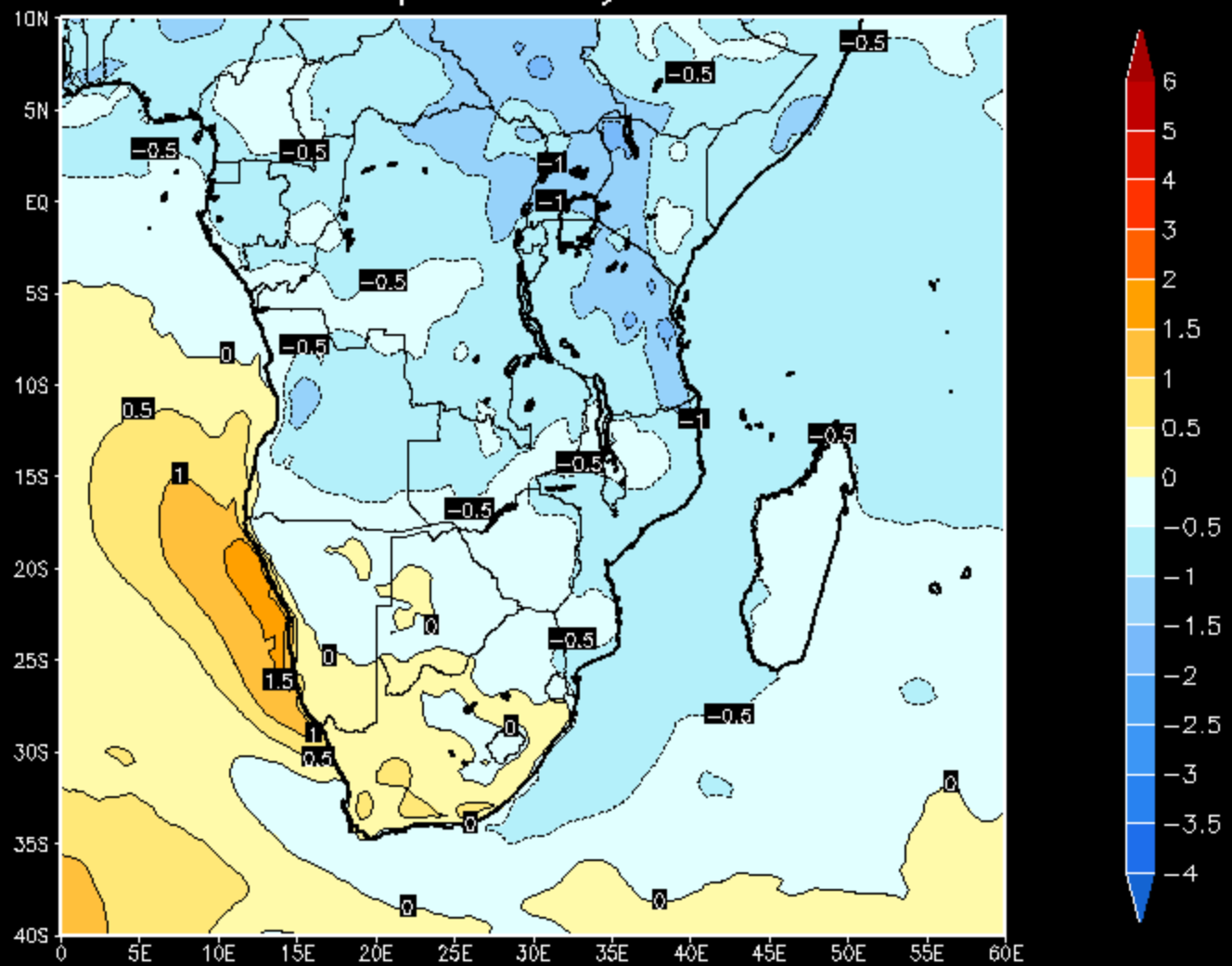
Temp anomaly 2002



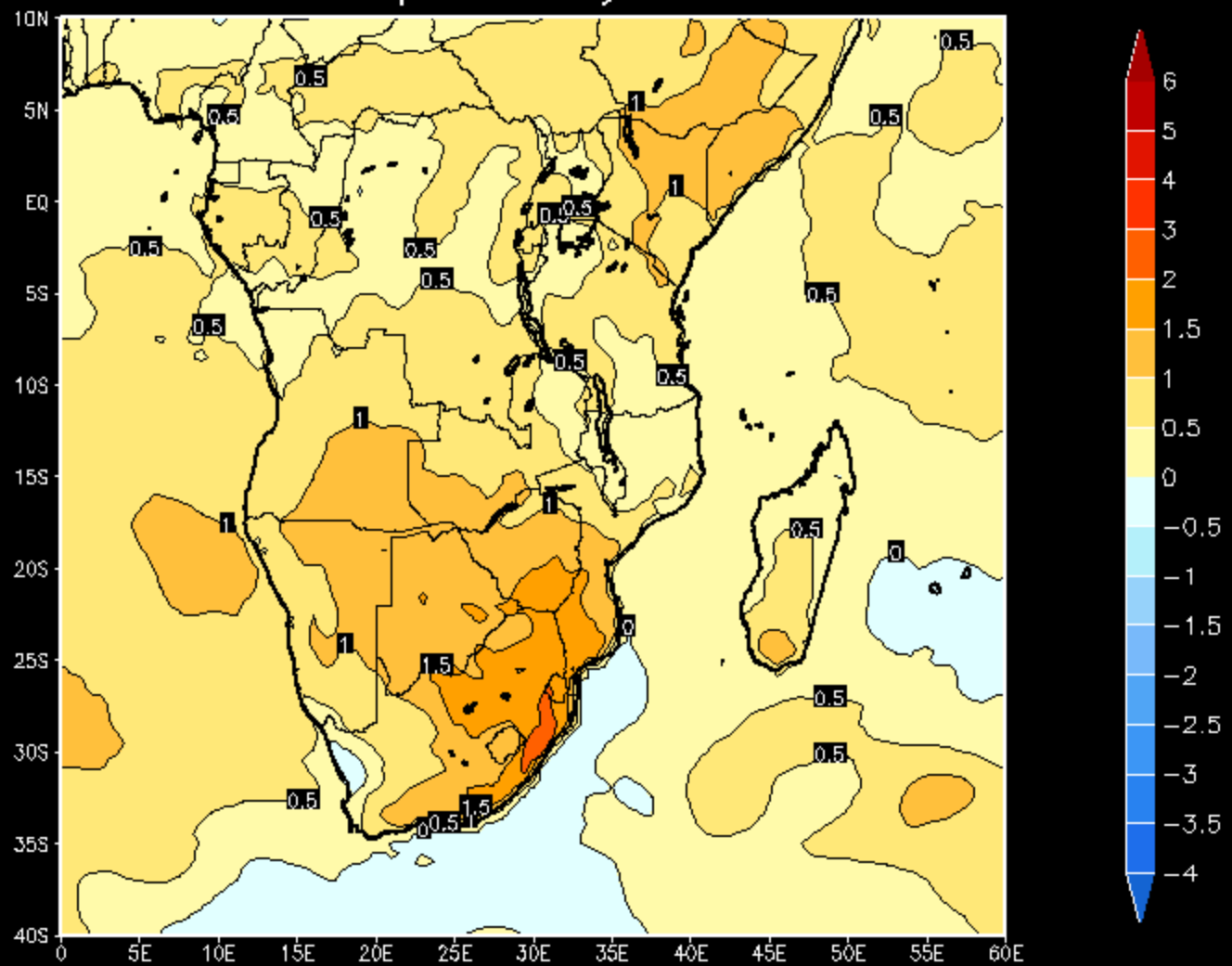
Temp anomaly 2003



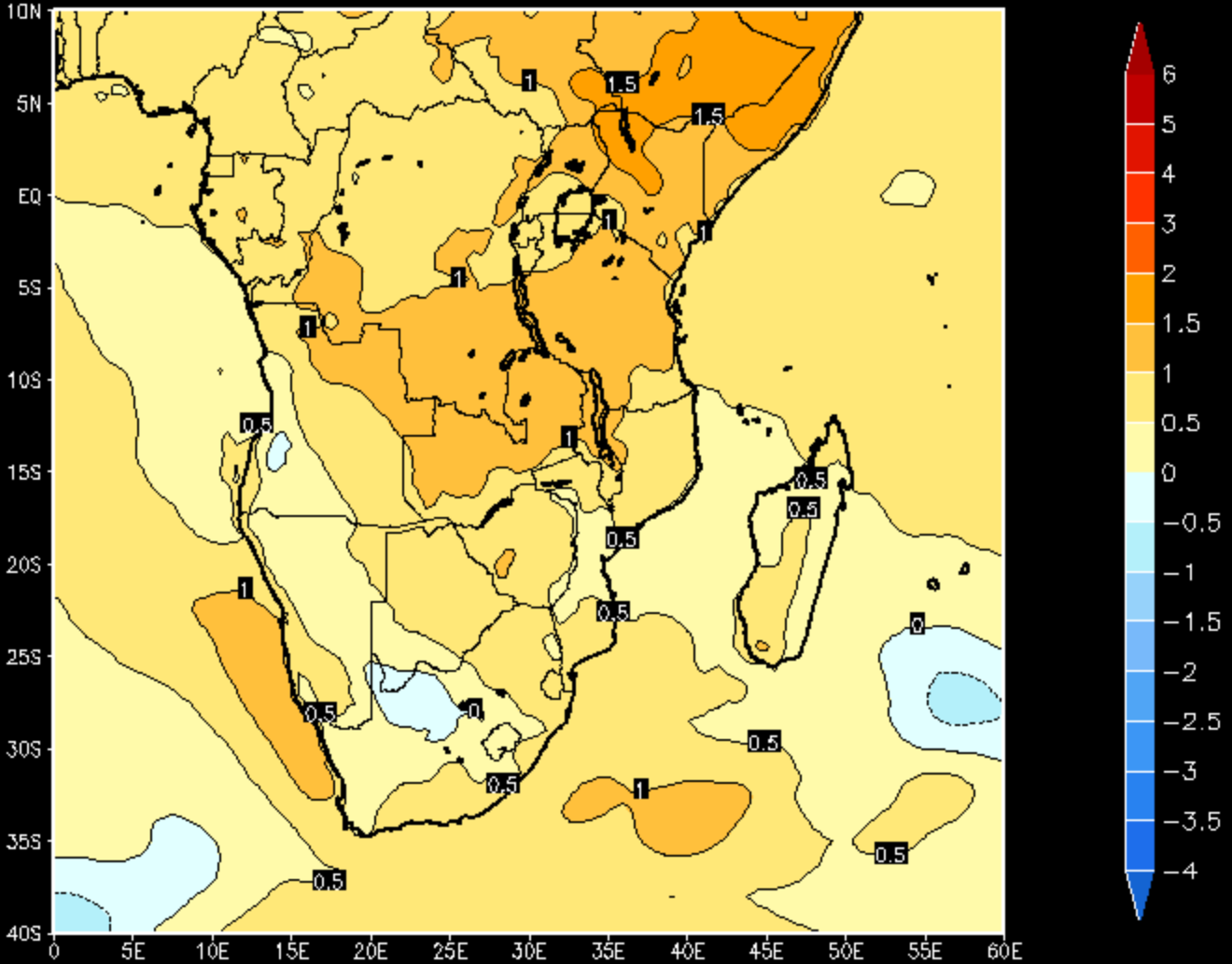
Temp anomaly 2004



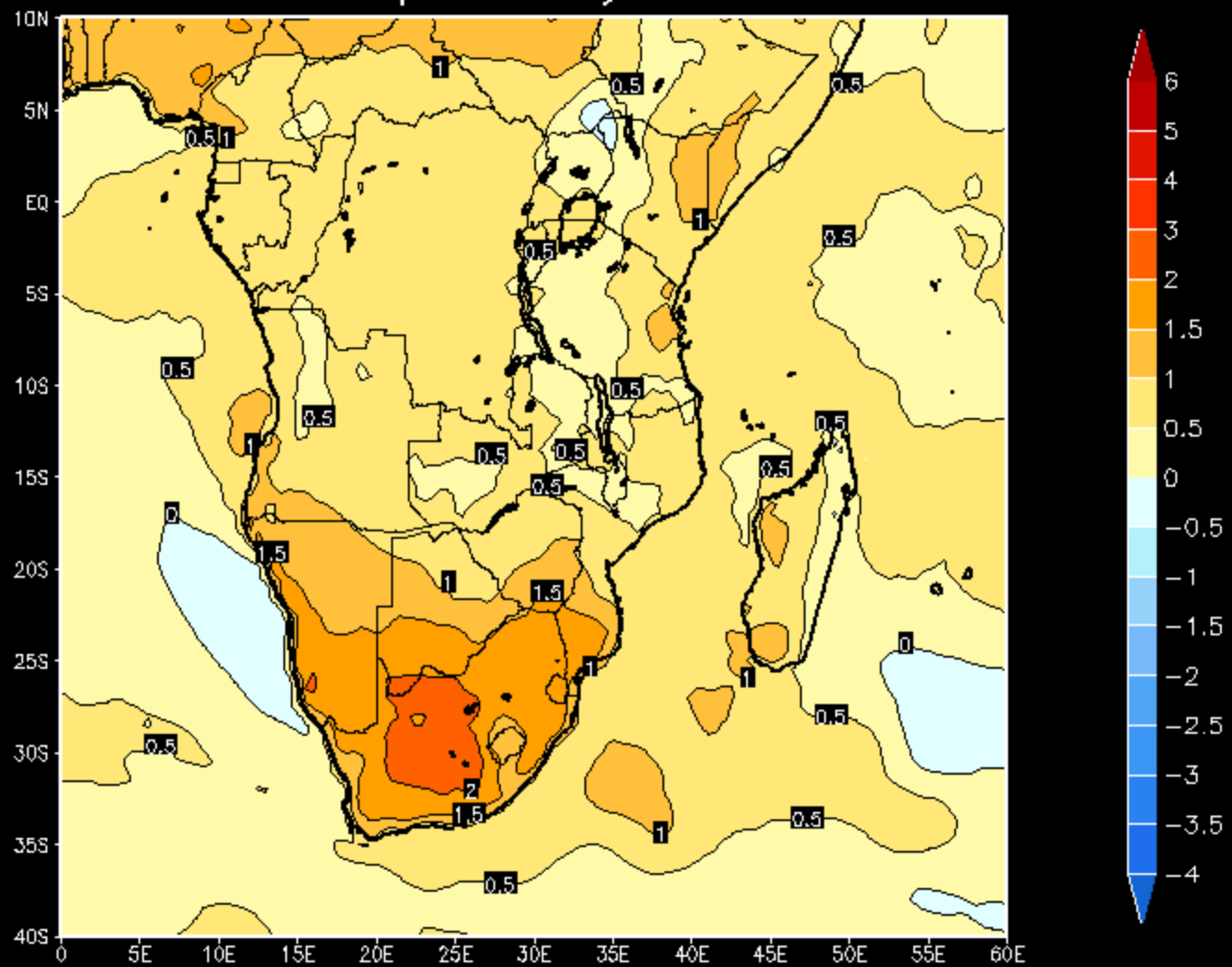
Temp anomaly 2005



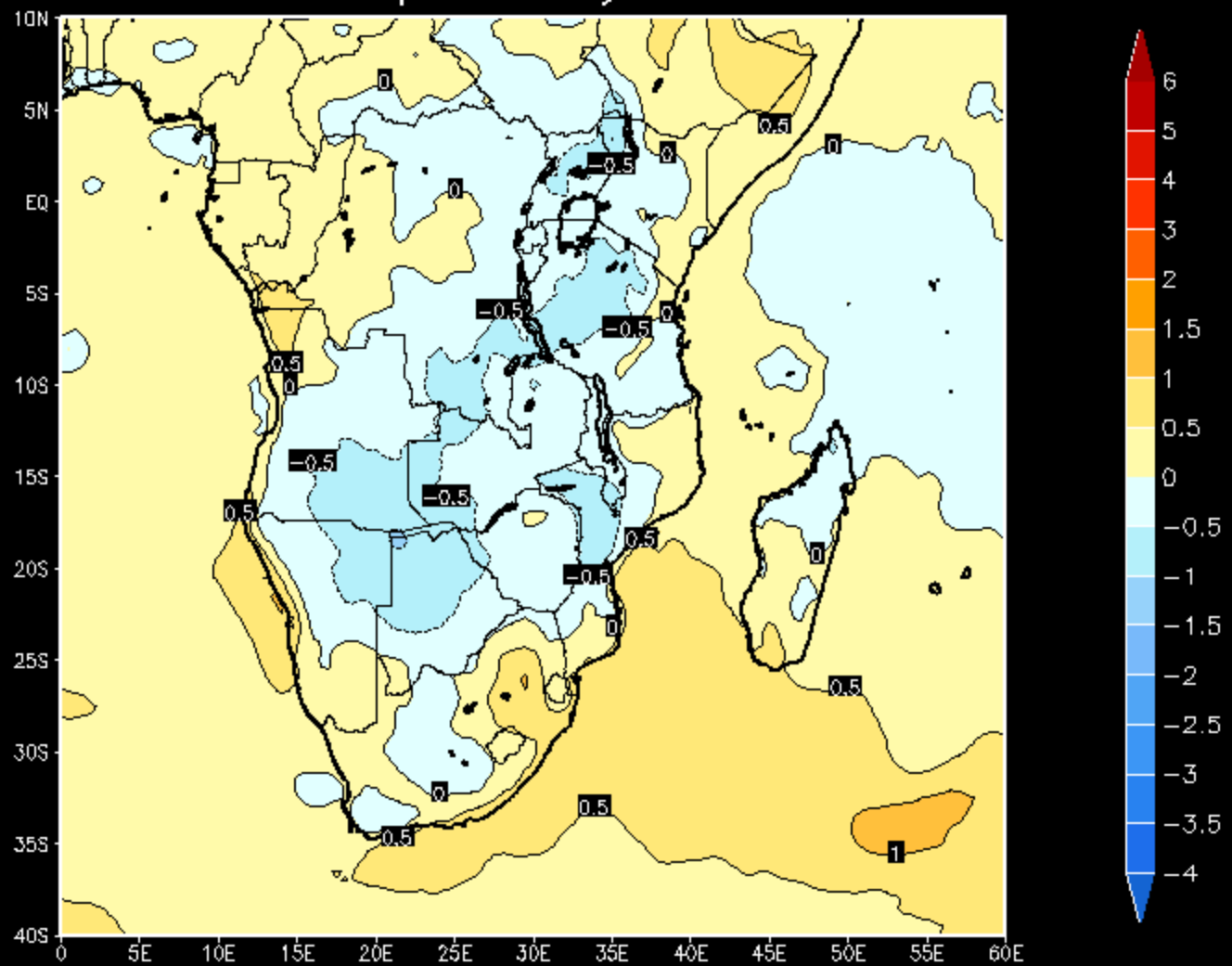
Temp anomaly 2006



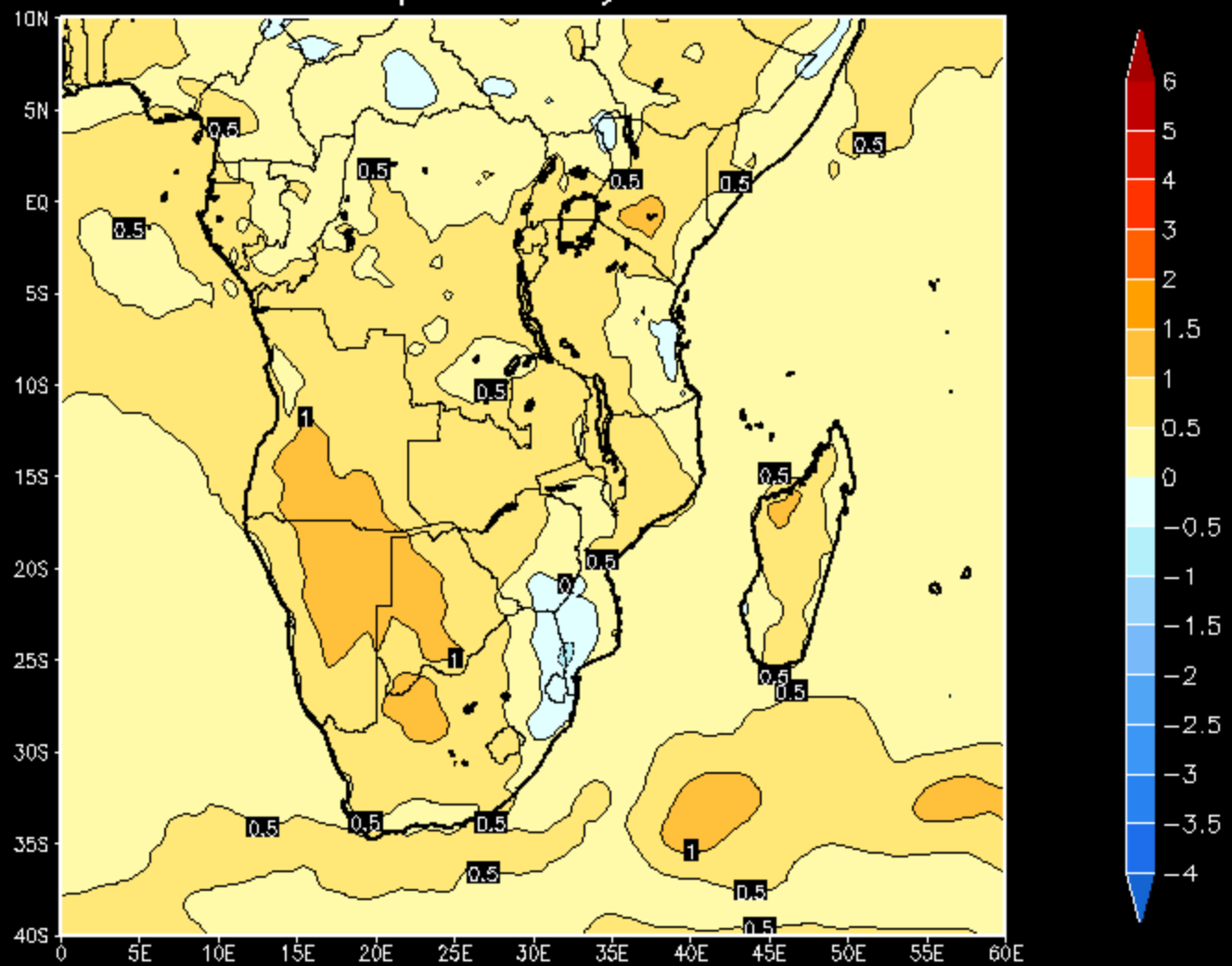
Temp anomaly 2007



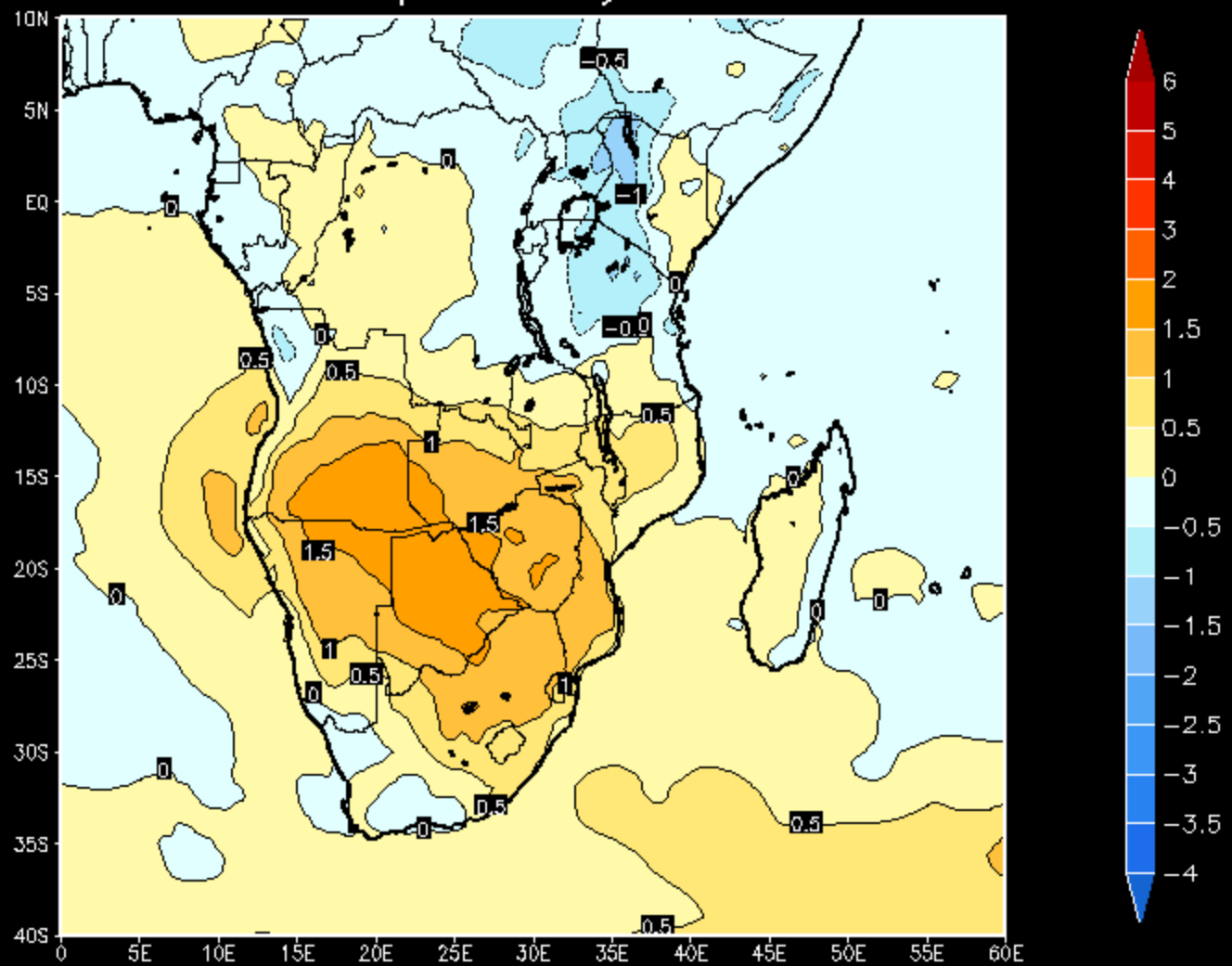
Temp anomaly 2008



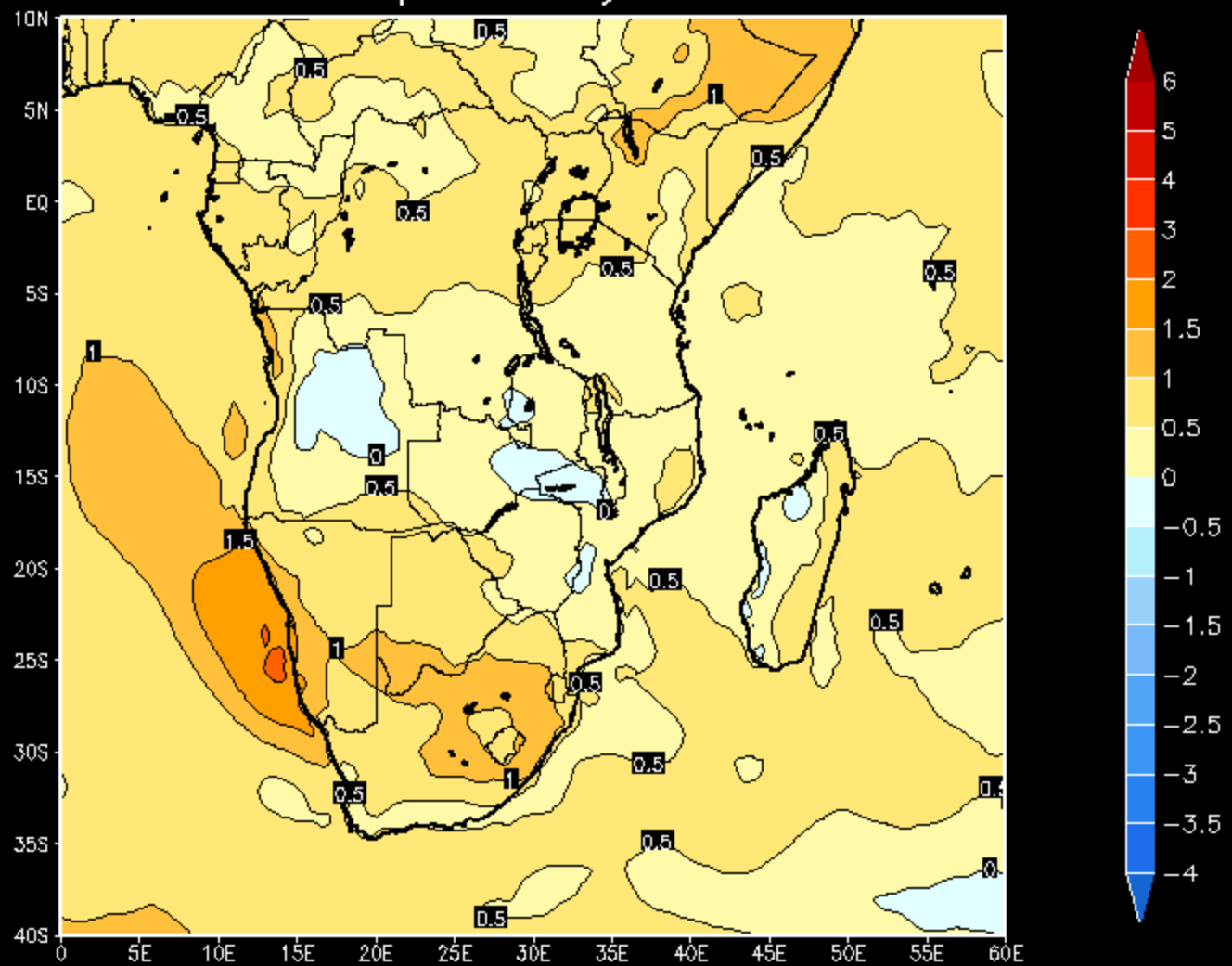
Temp anomaly 2009



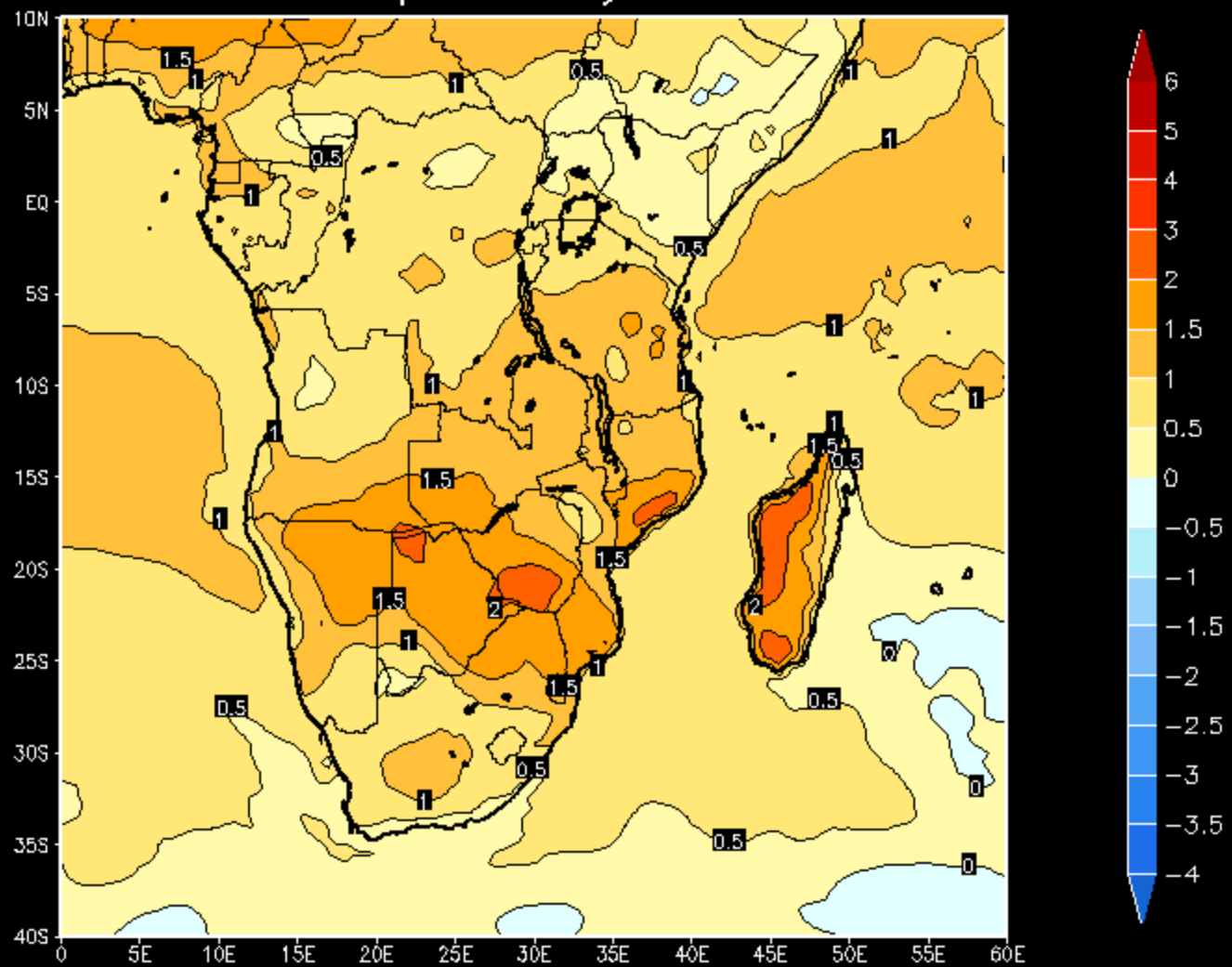
Temp anomaly 2010



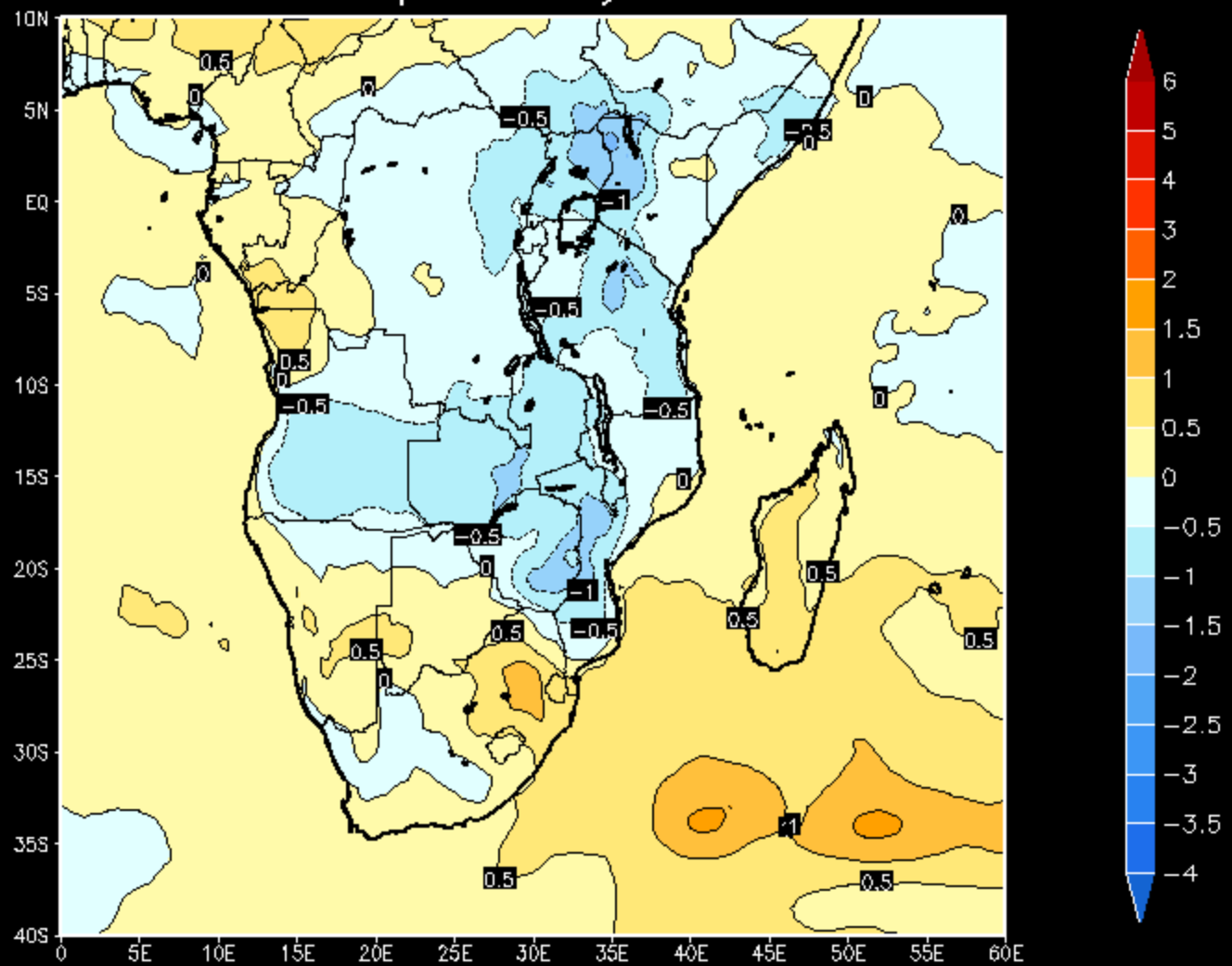
Temp anomaly 2011



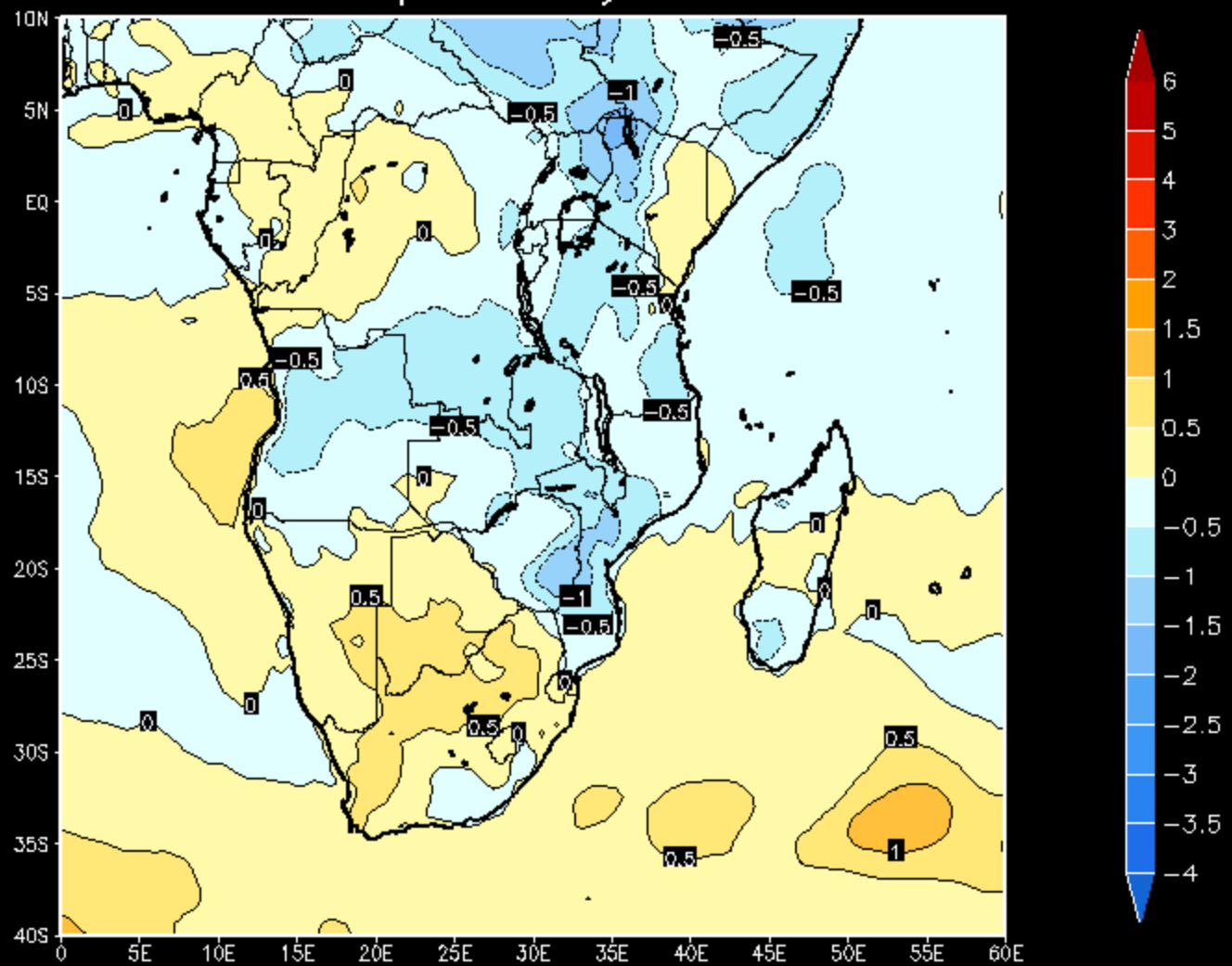
Temp anomaly 2012



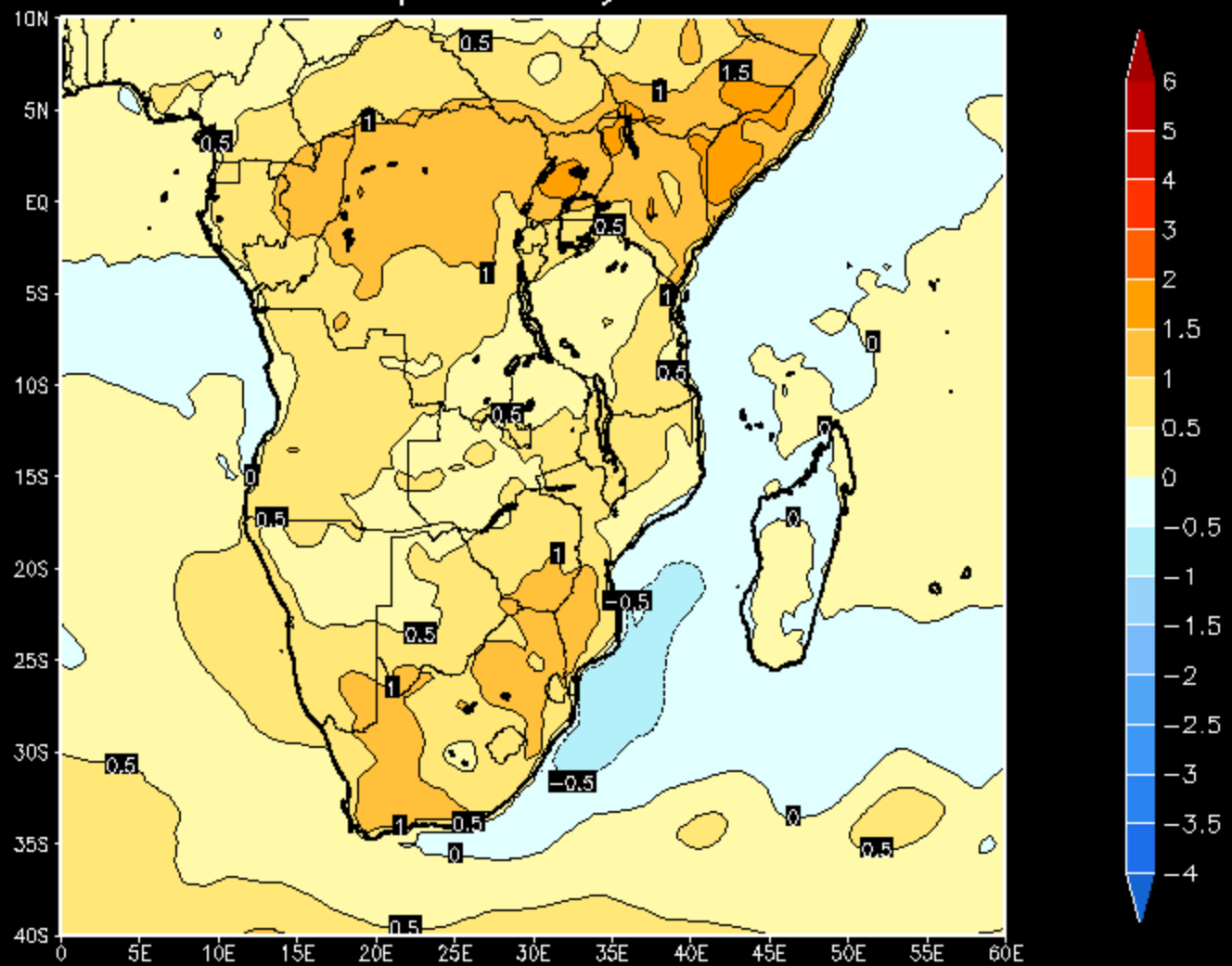
Temp anomaly 2013



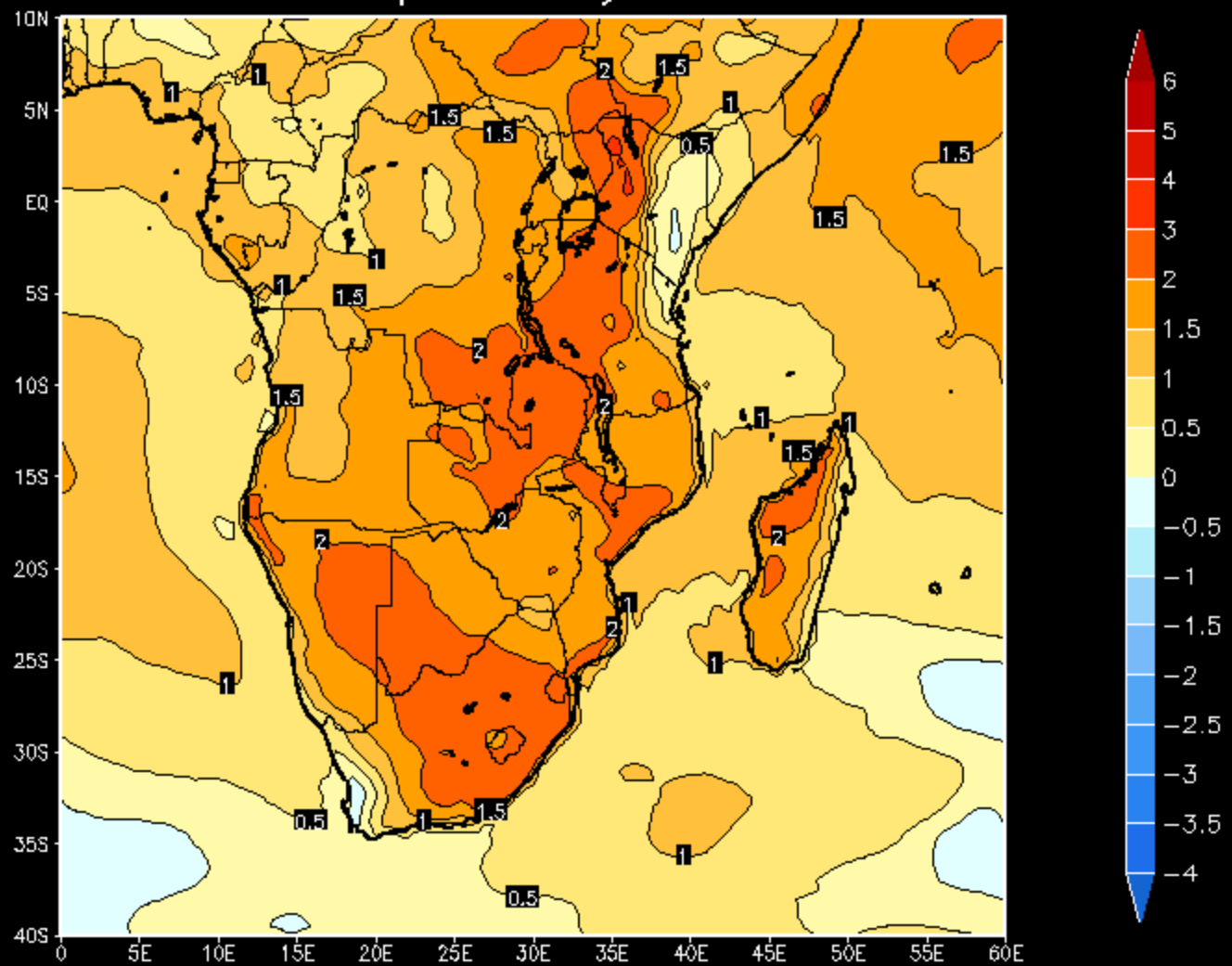
Temp anomaly 2014



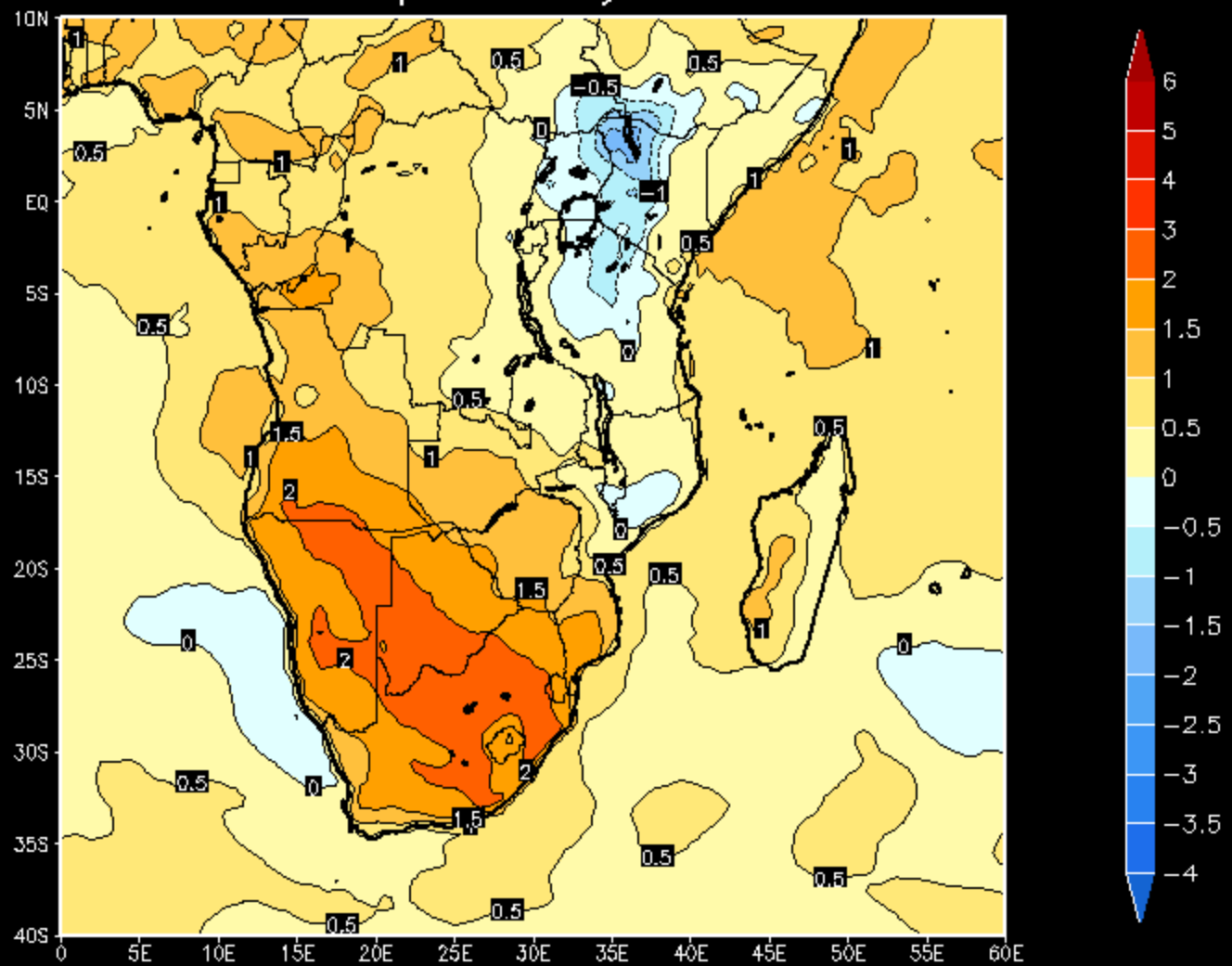
Temp anomaly 2015



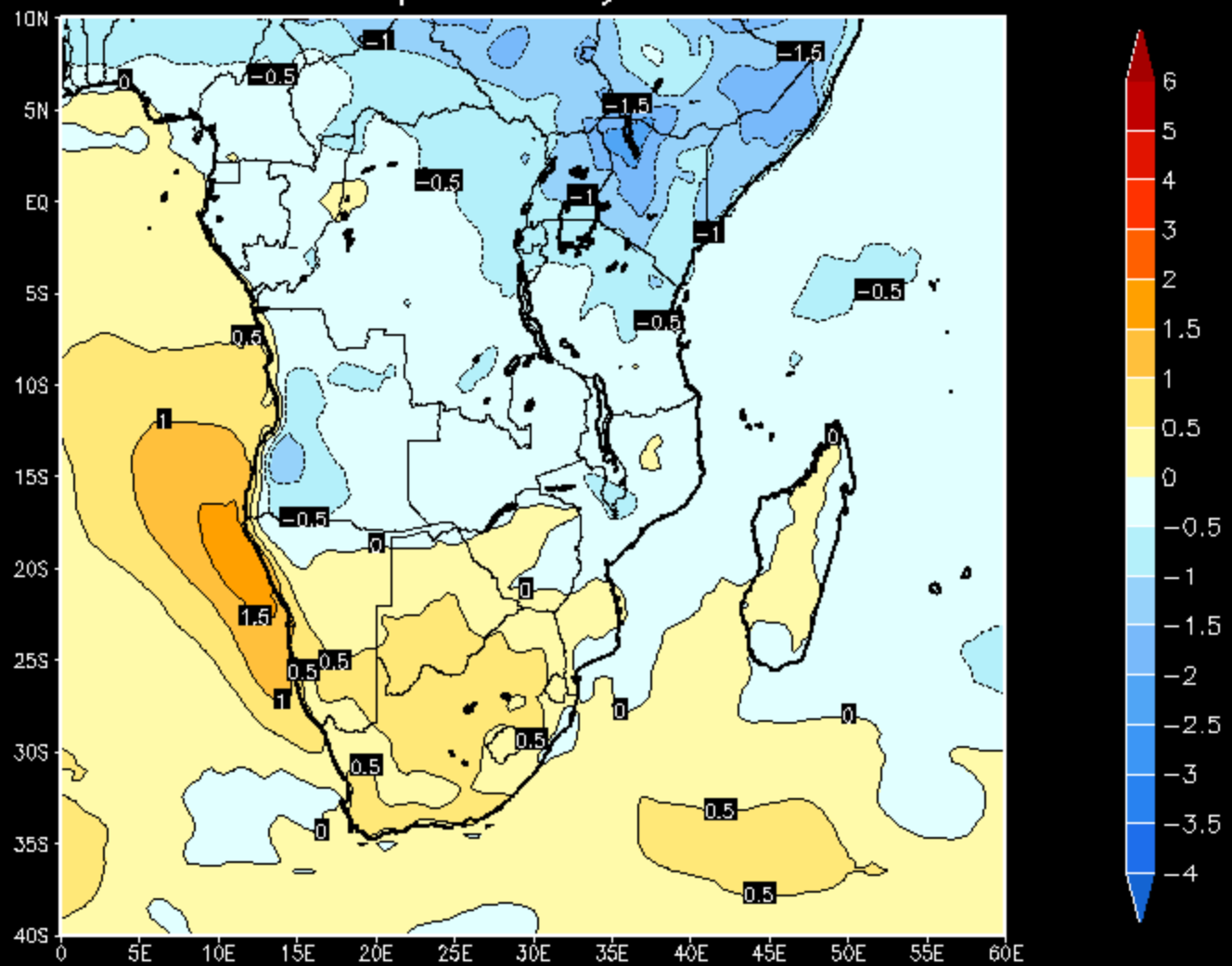
Temp anomaly 2016



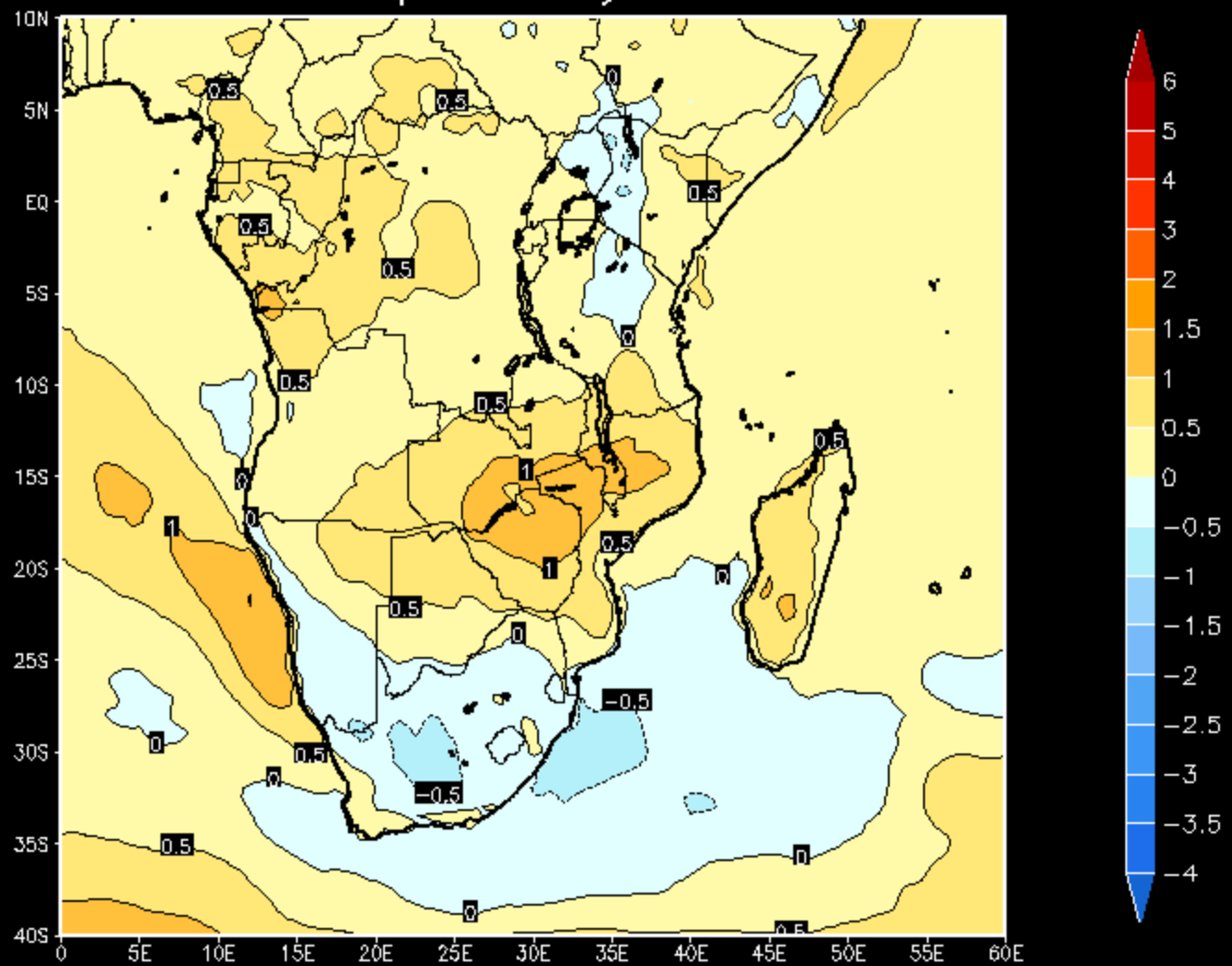
Temp anomaly 2017



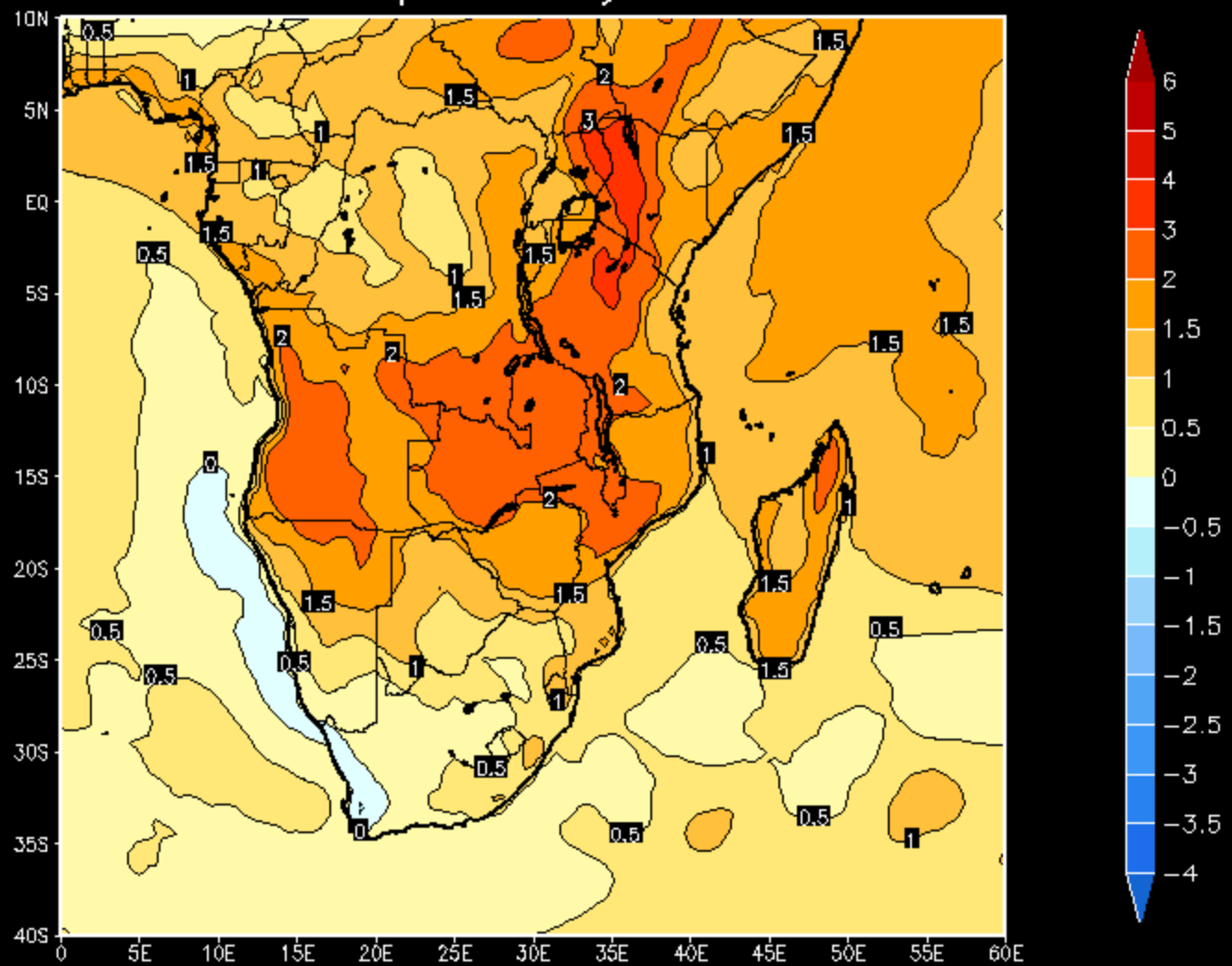
Temp anomaly 2018



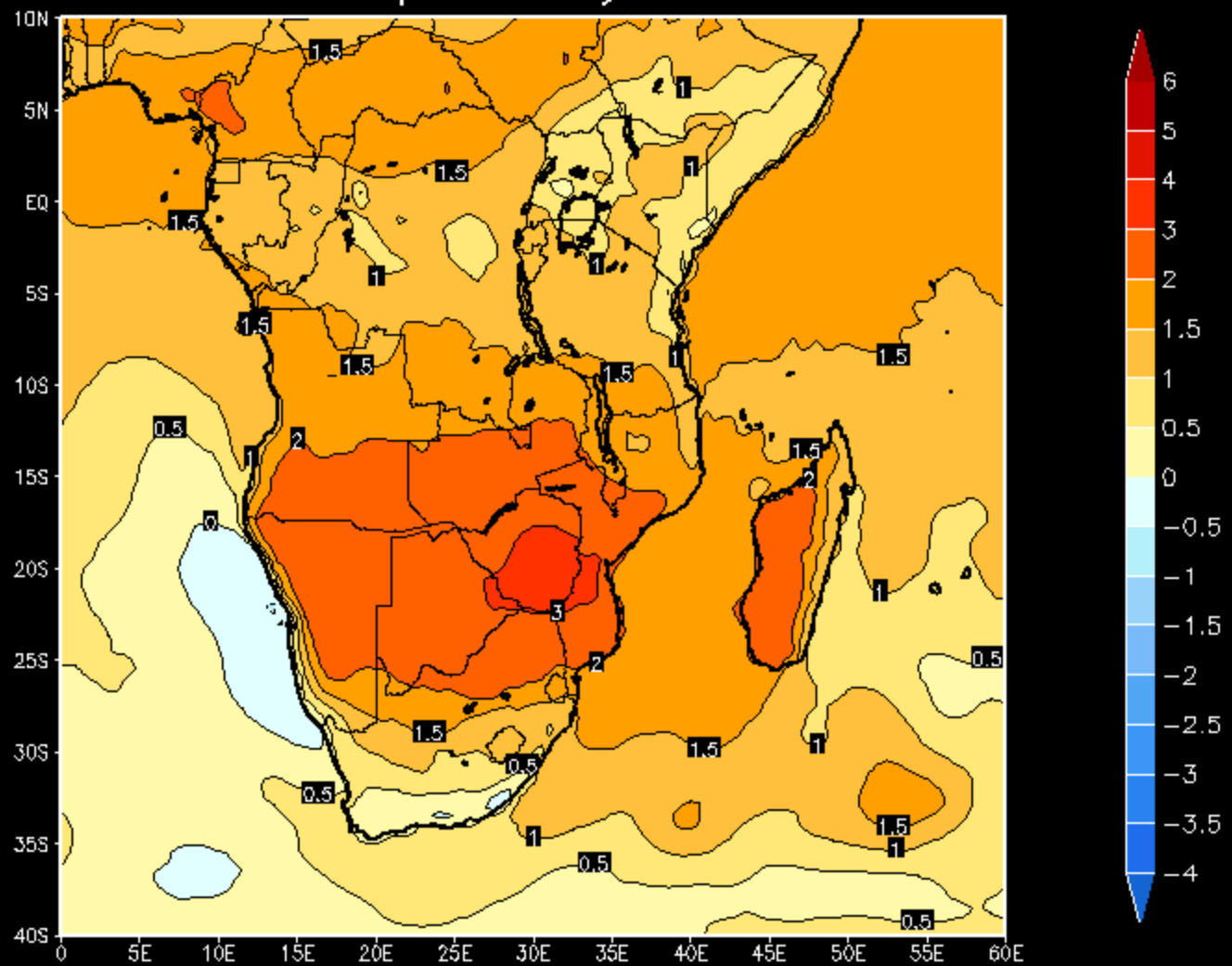
Temp anomaly 2019



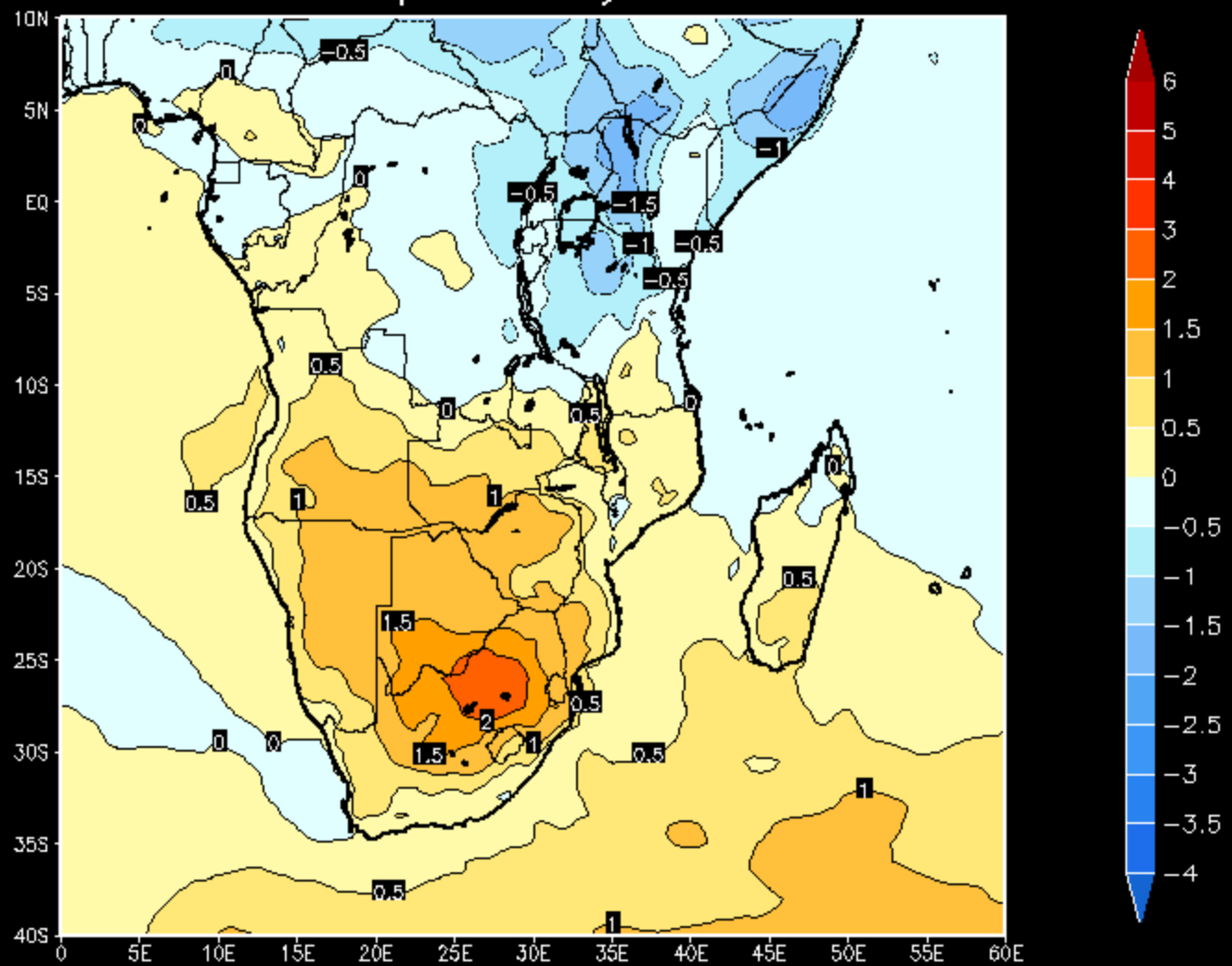
Temp anomaly 2020



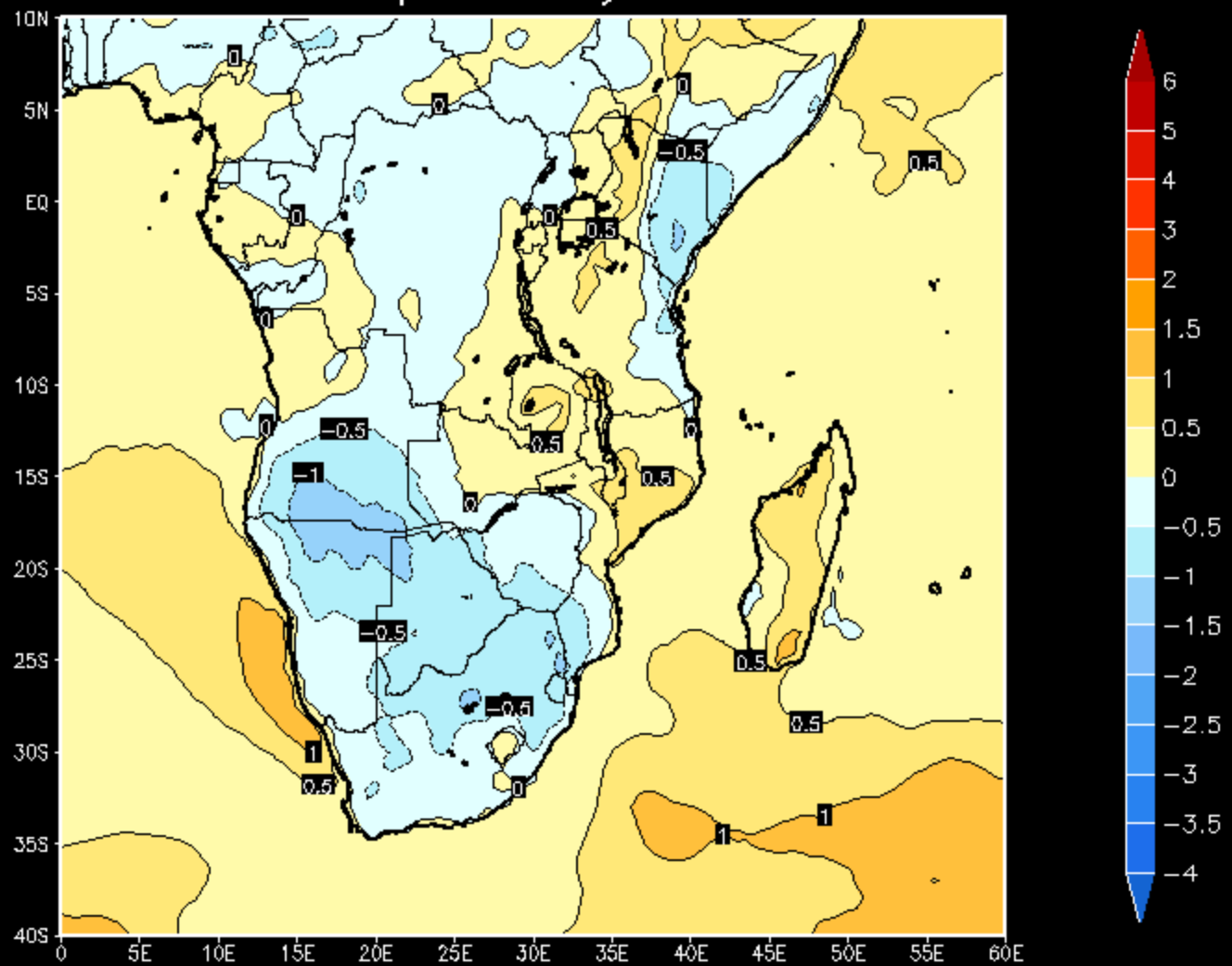
Temp anomaly 2021



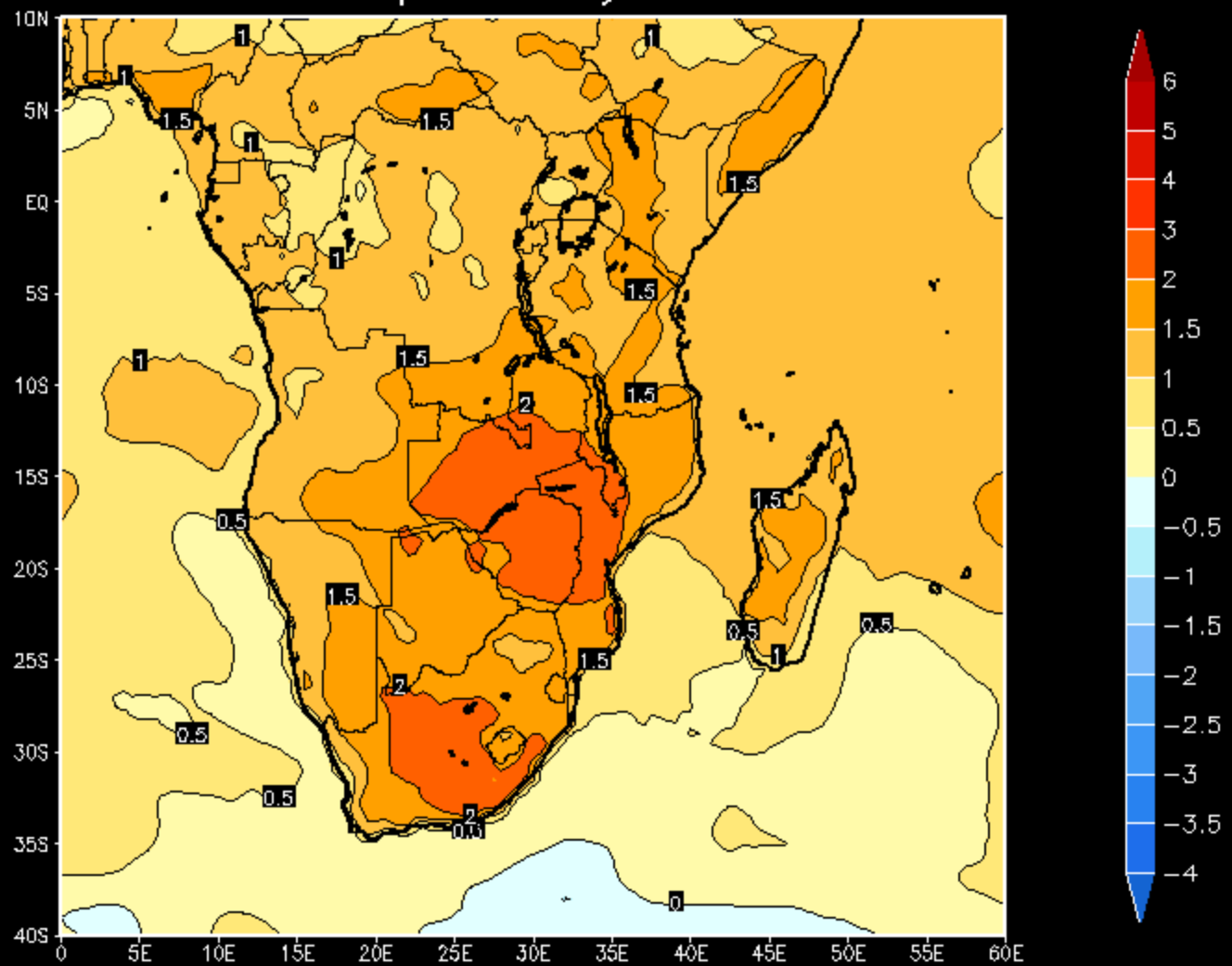
Temp anomaly 2022



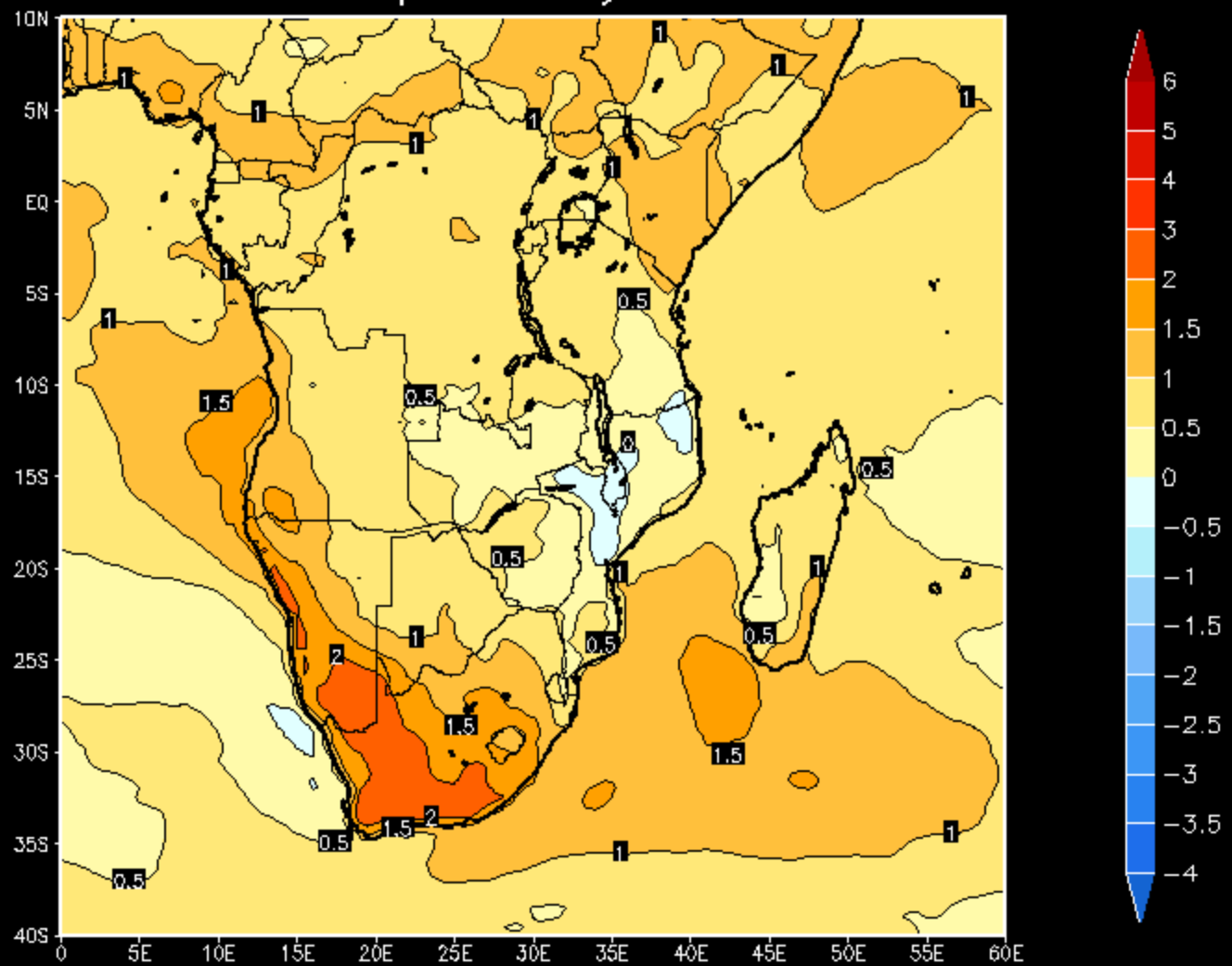
Temp anomaly 2023



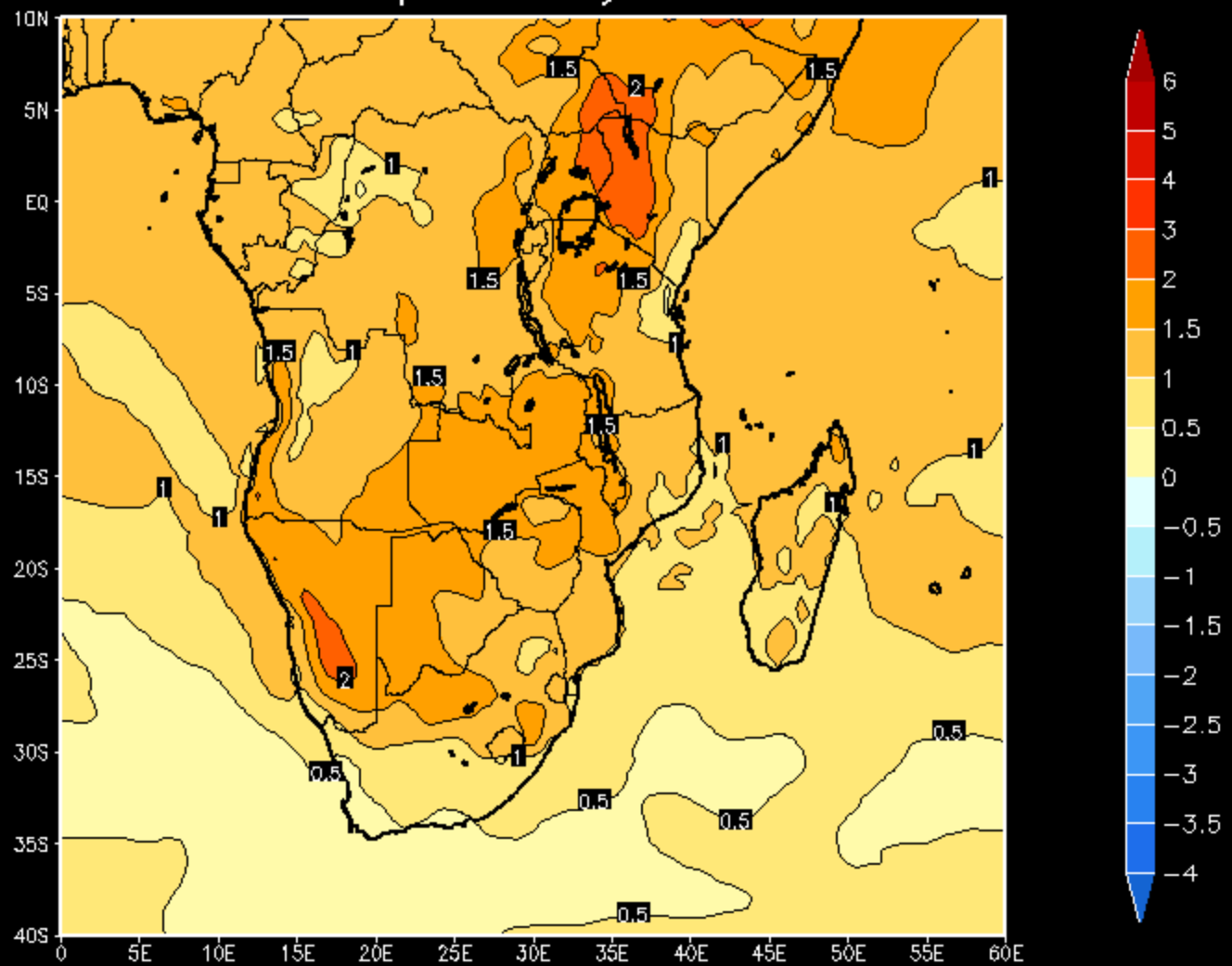
Temp anomaly 2024



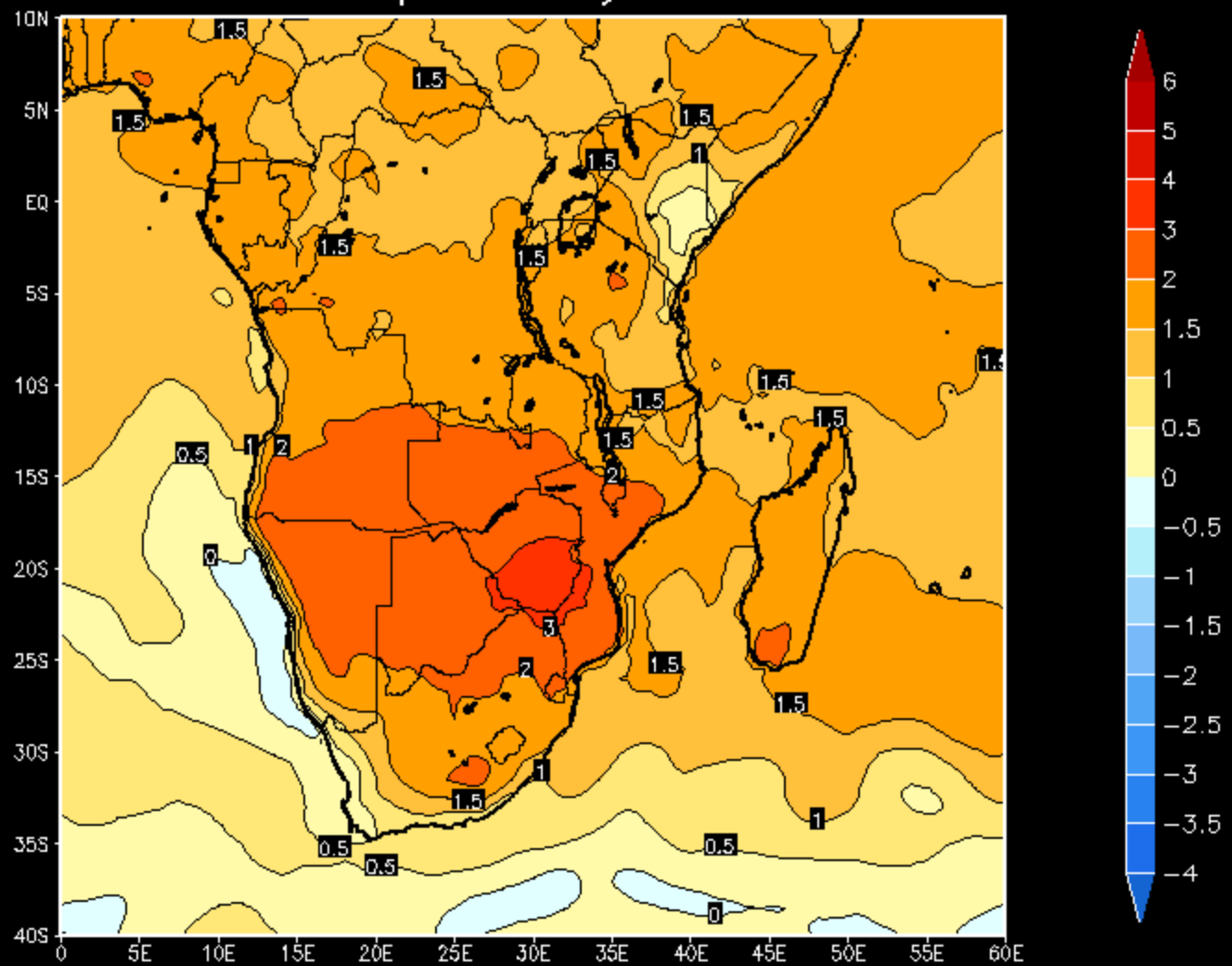
Temp anomaly 2025



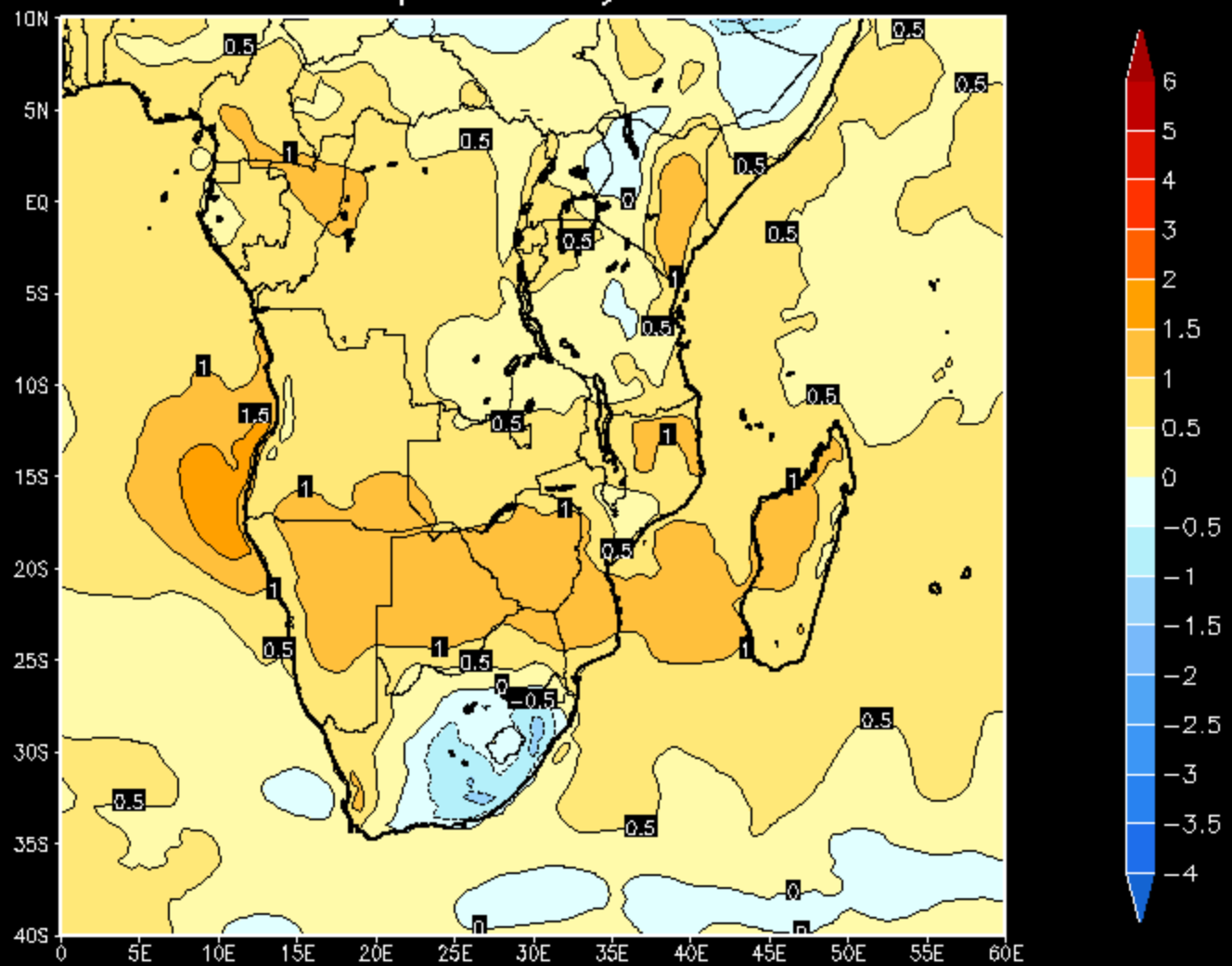
Temp anomaly 2026



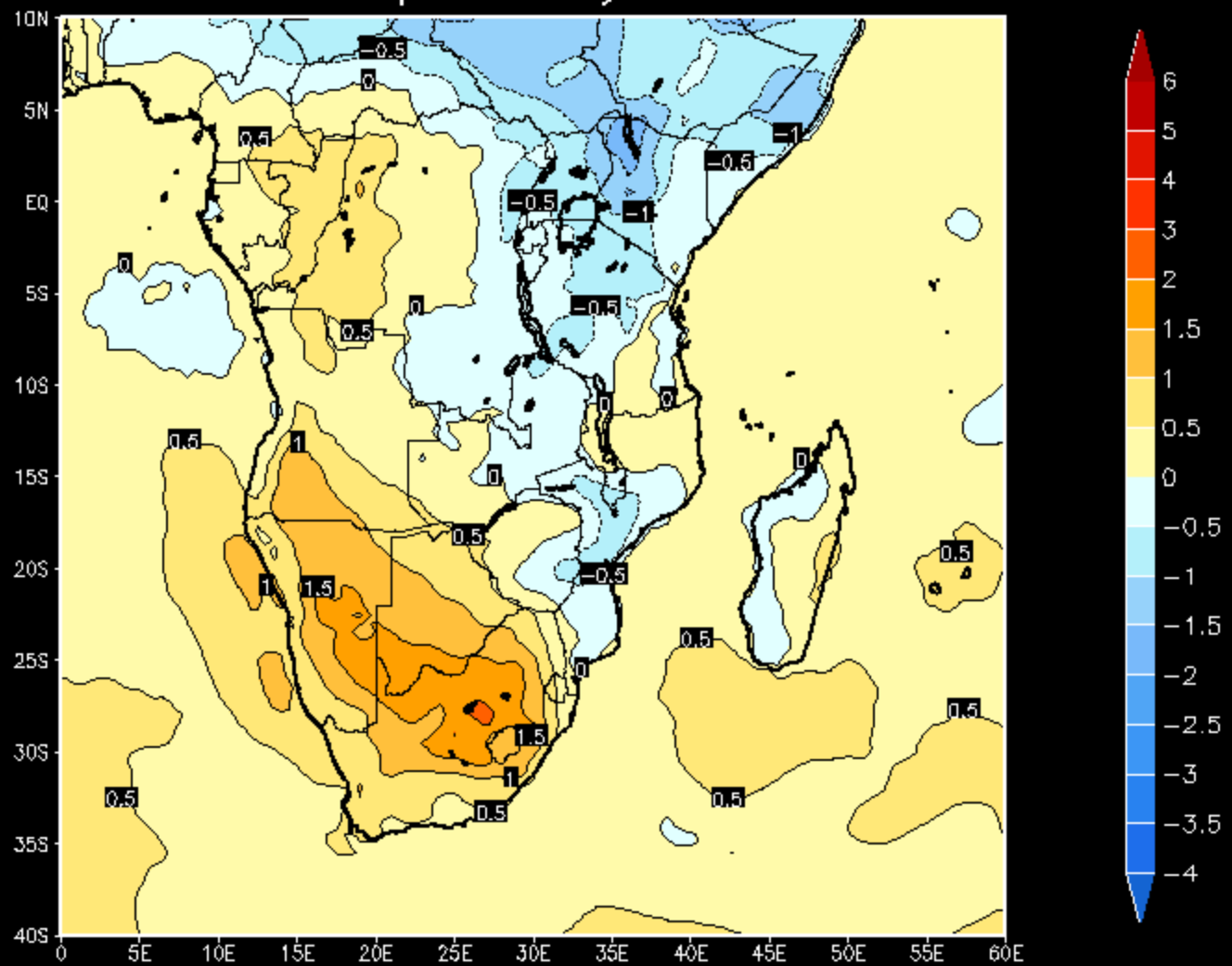
Temp anomaly 2027



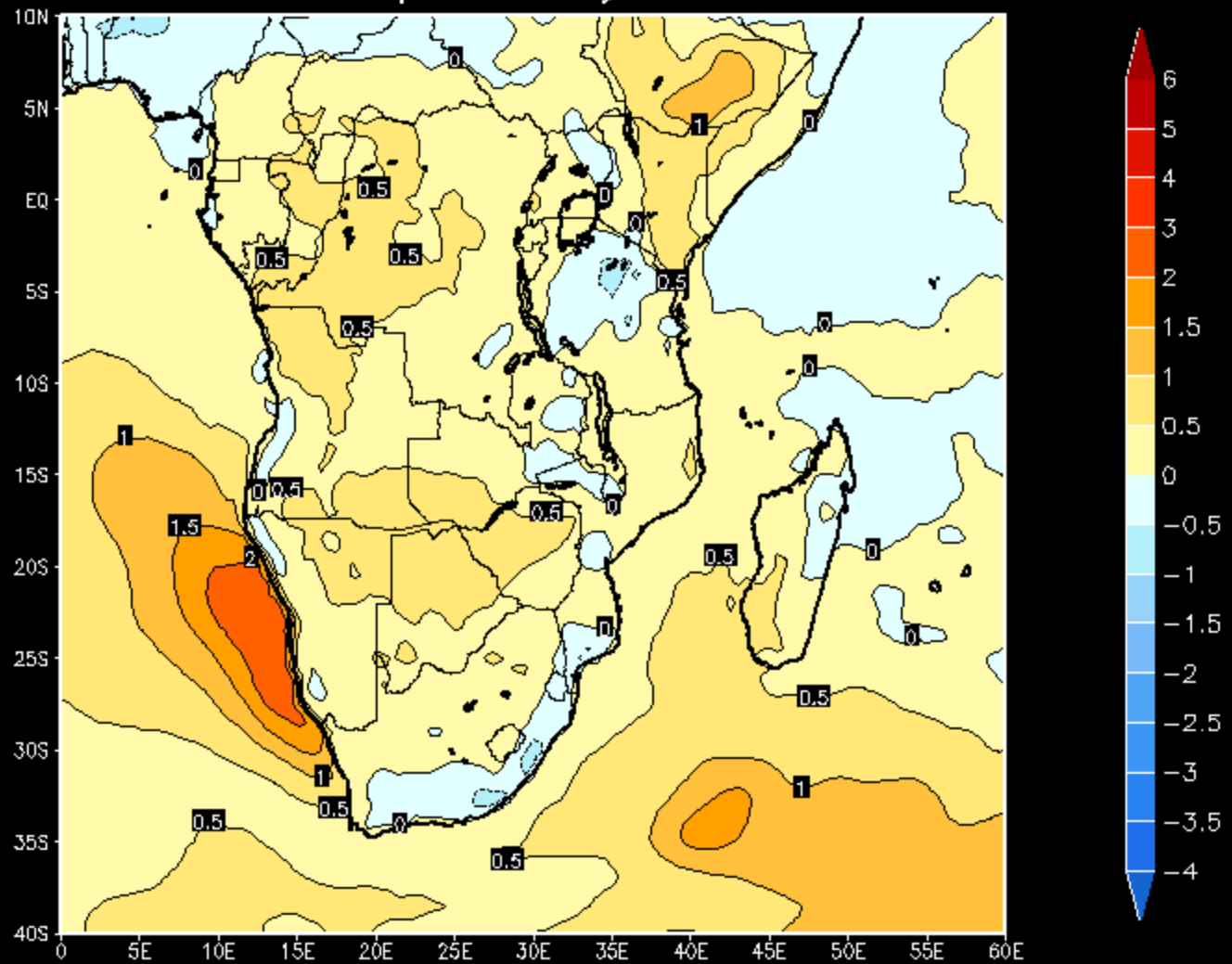
Temp anomaly 2028



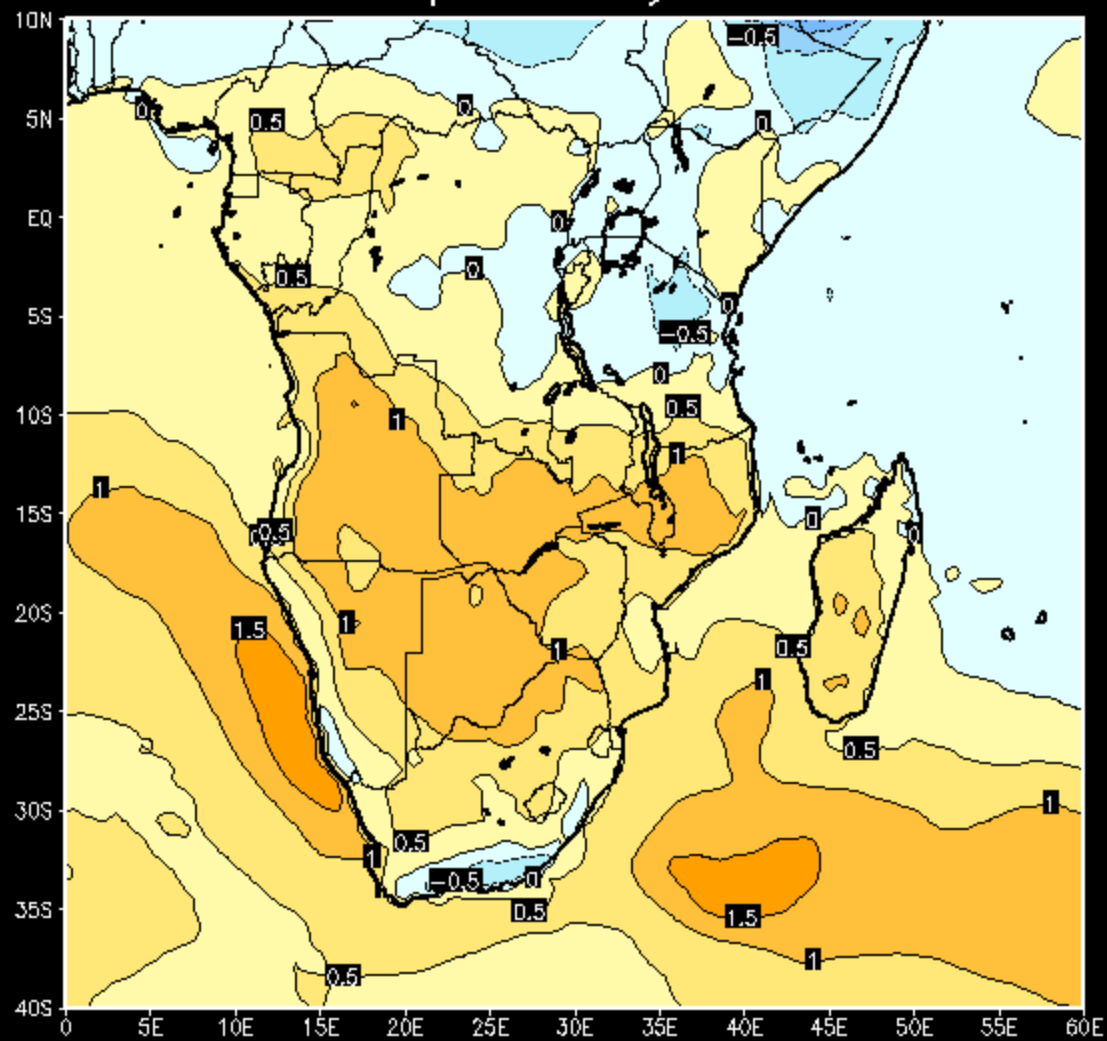
Temp anomaly 2029



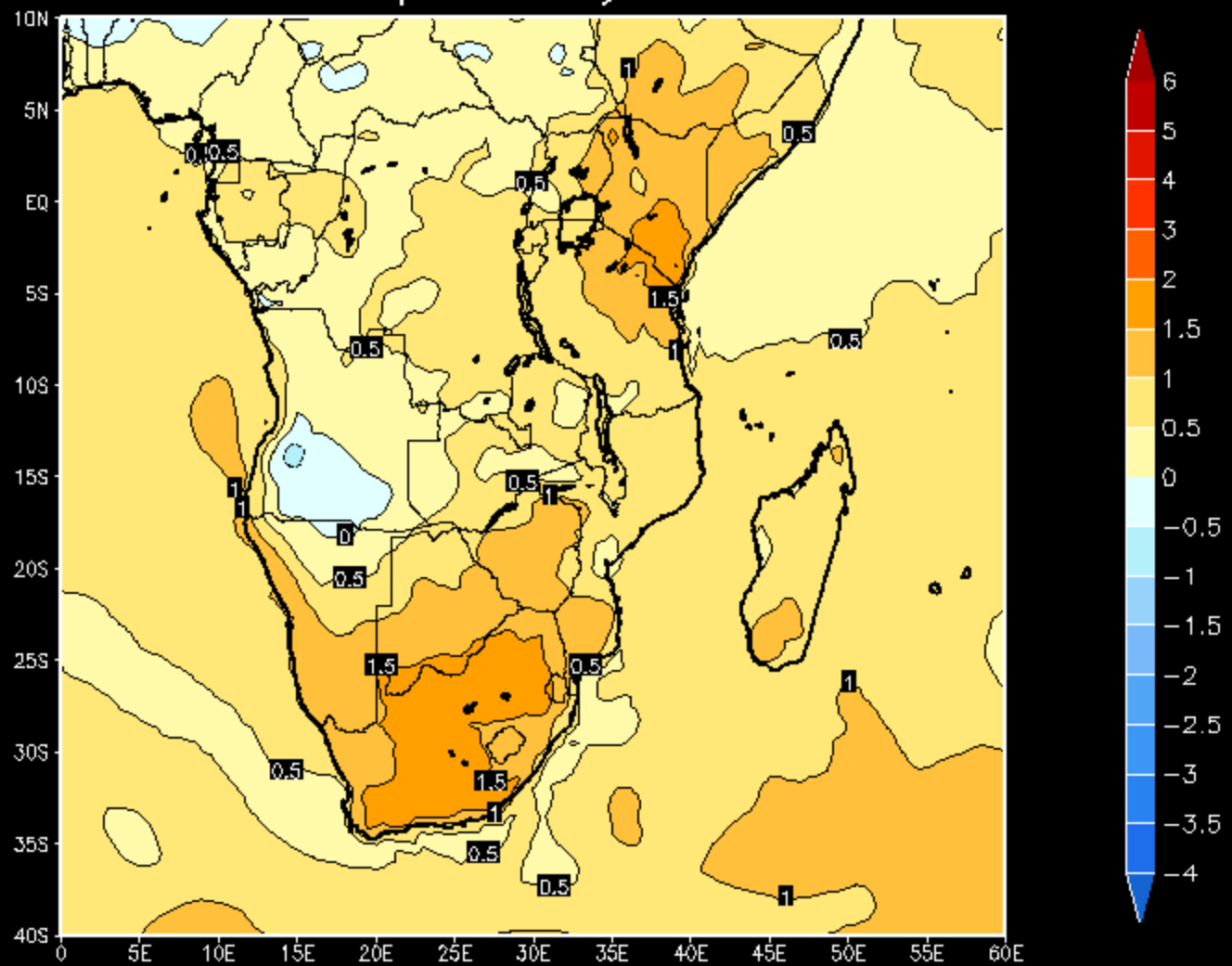
Temp anomaly 2030



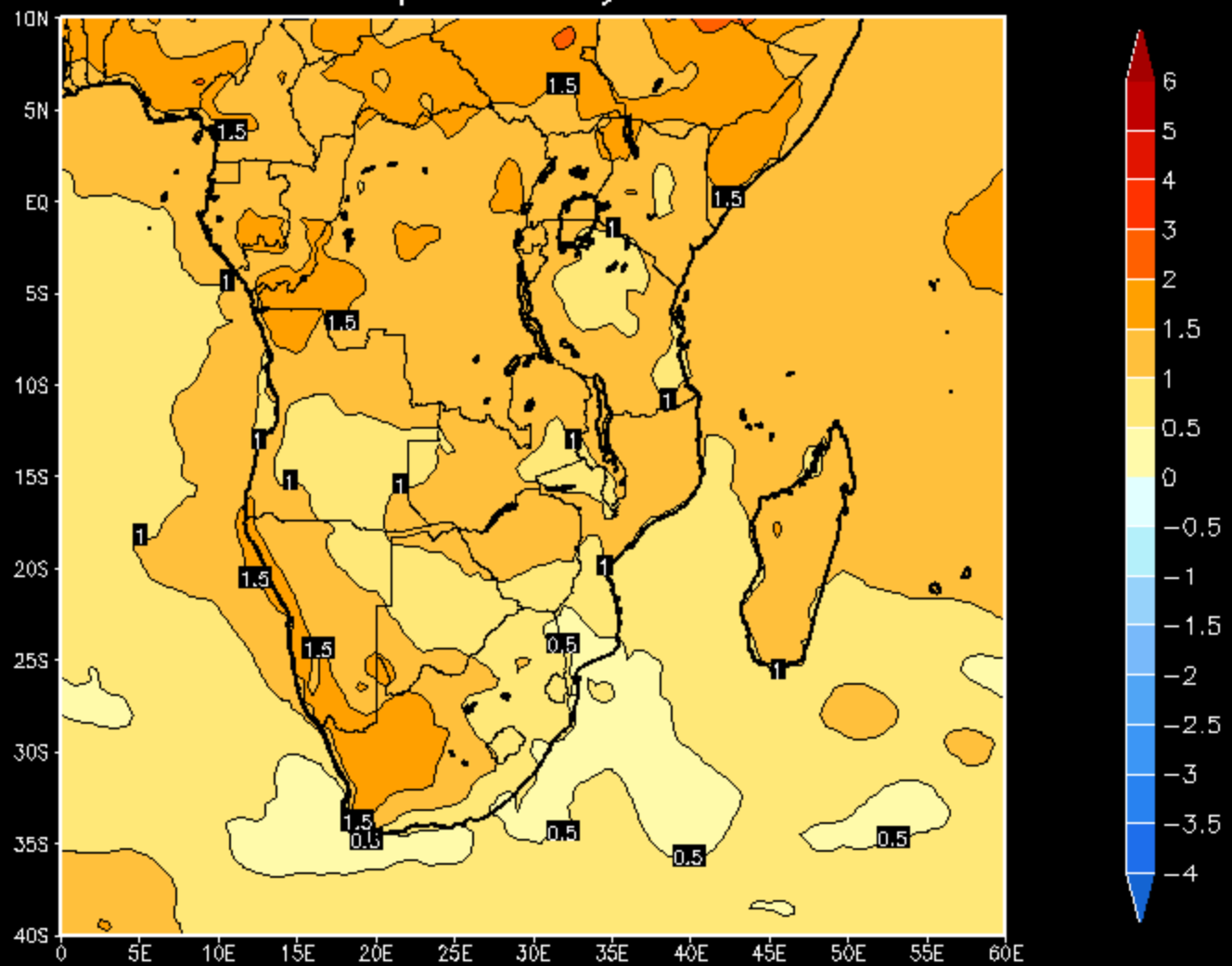
Temp anomaly 2031



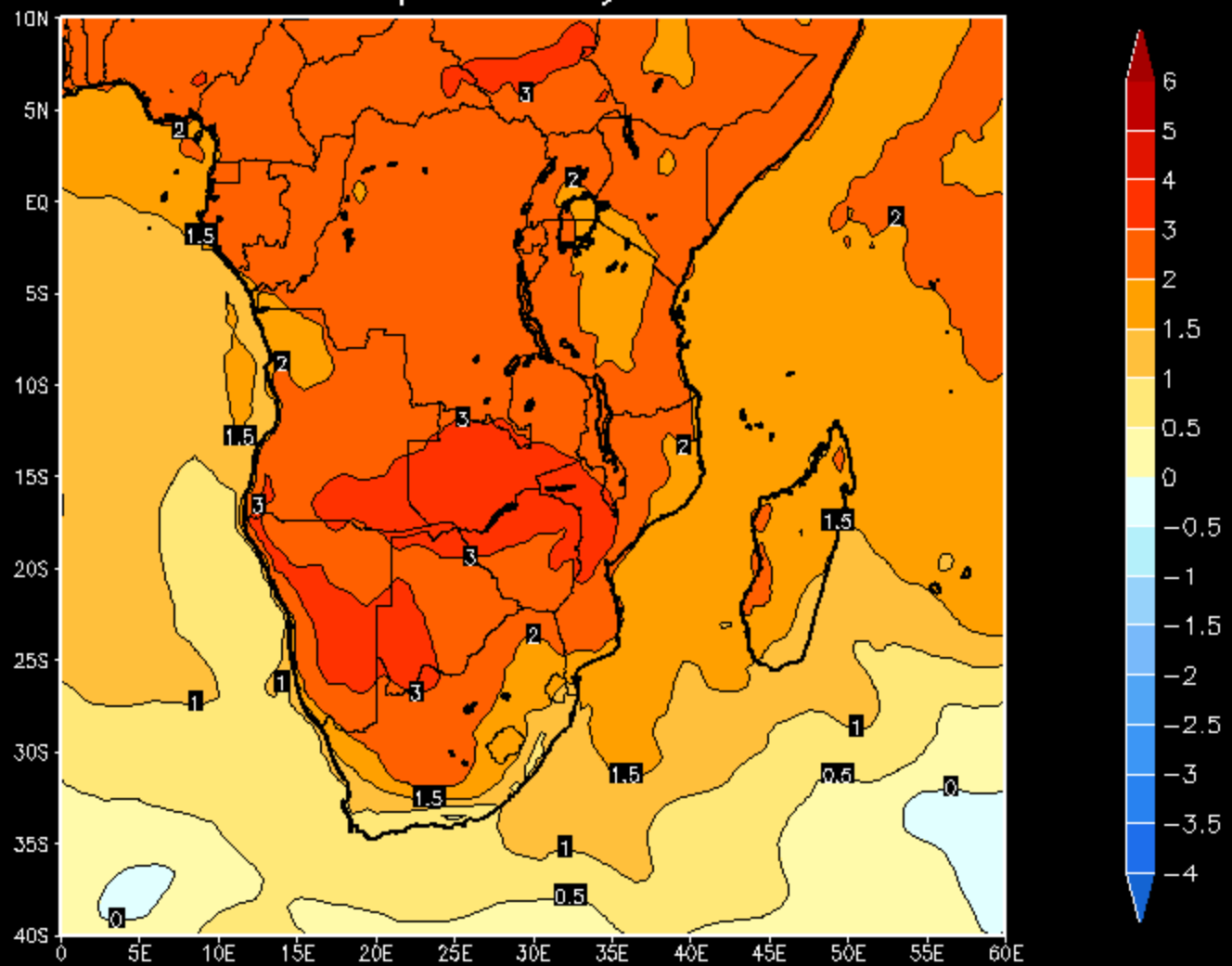
Temp anomaly 2032



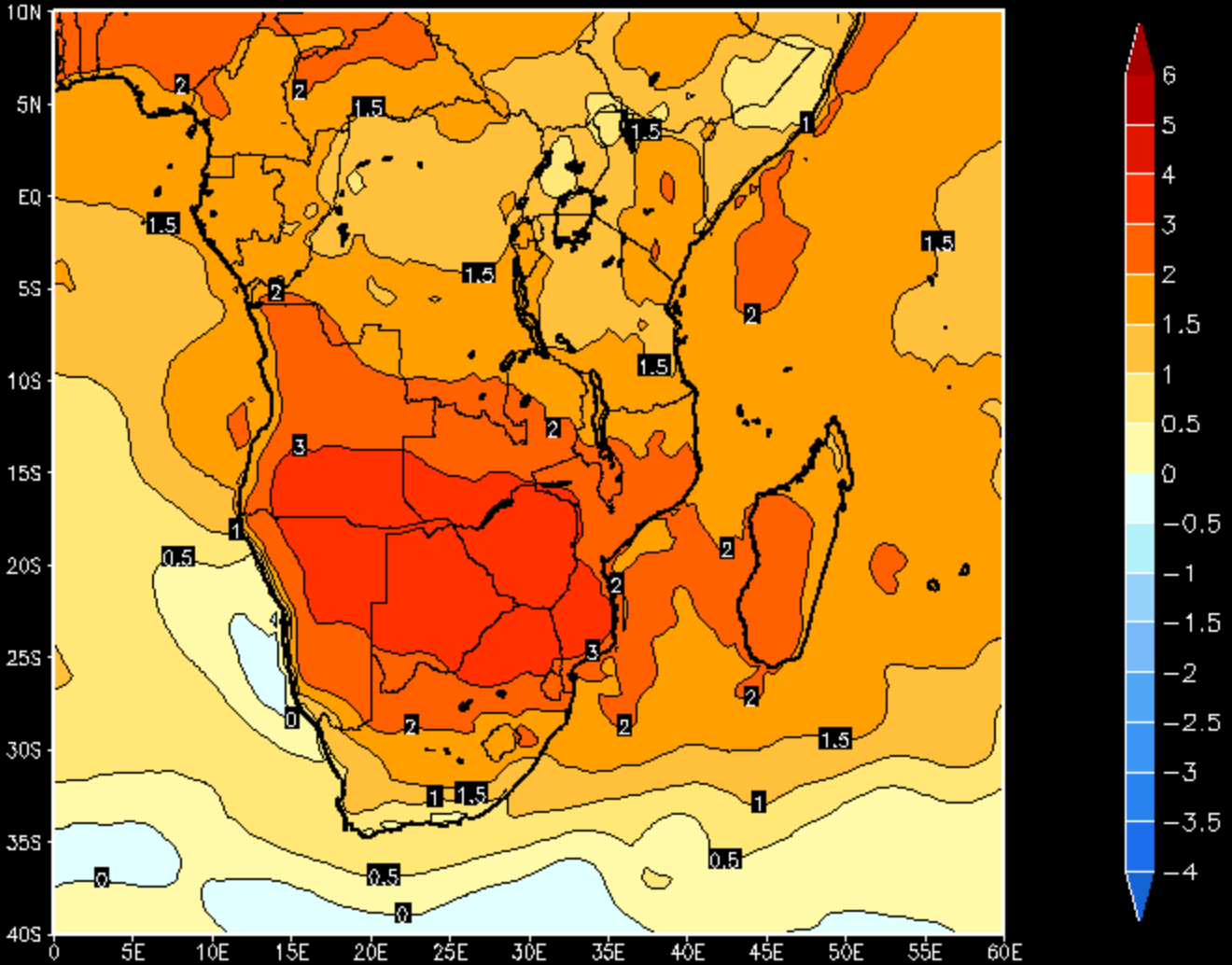
Temp anomaly 2033



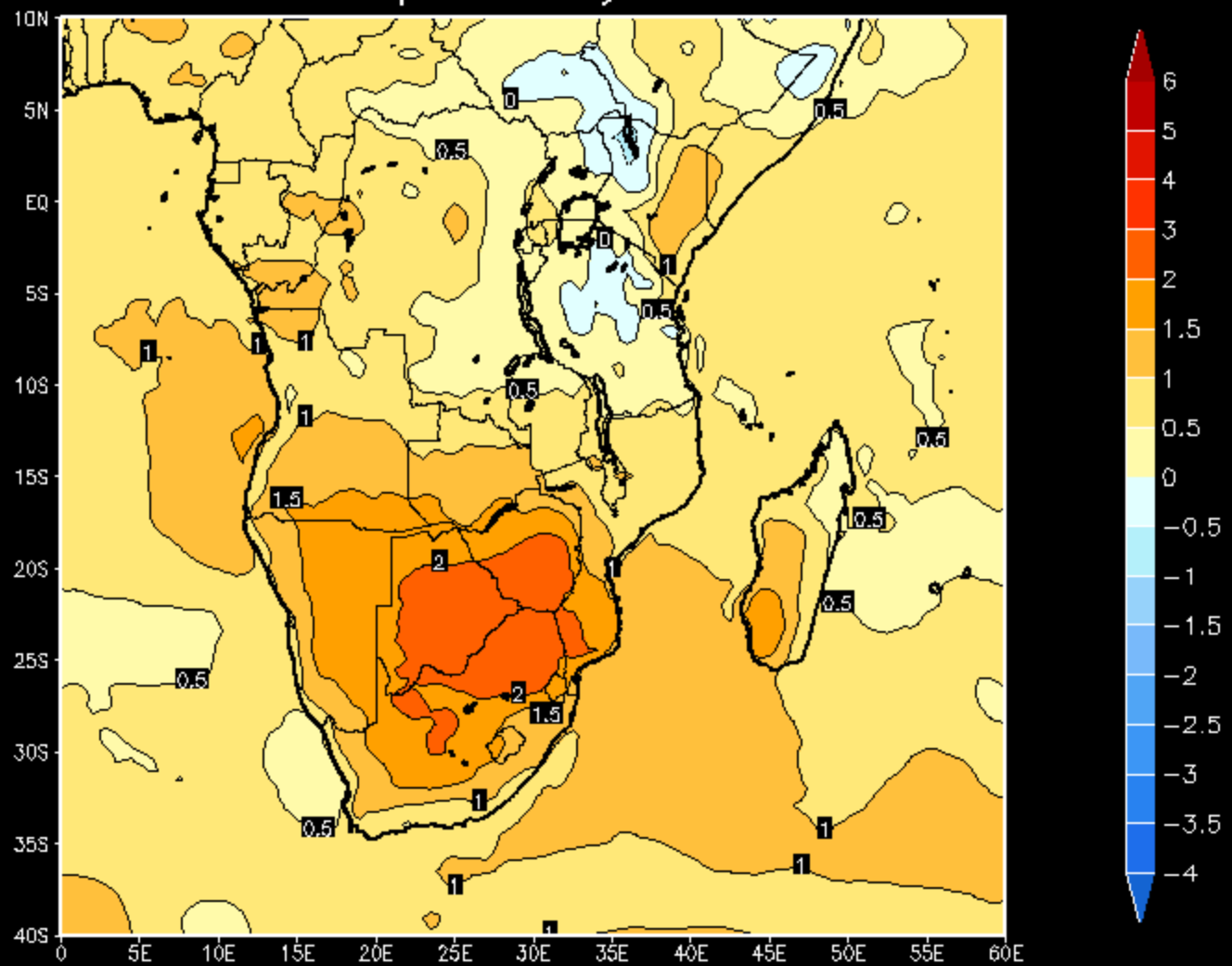
Temp anomaly 2034



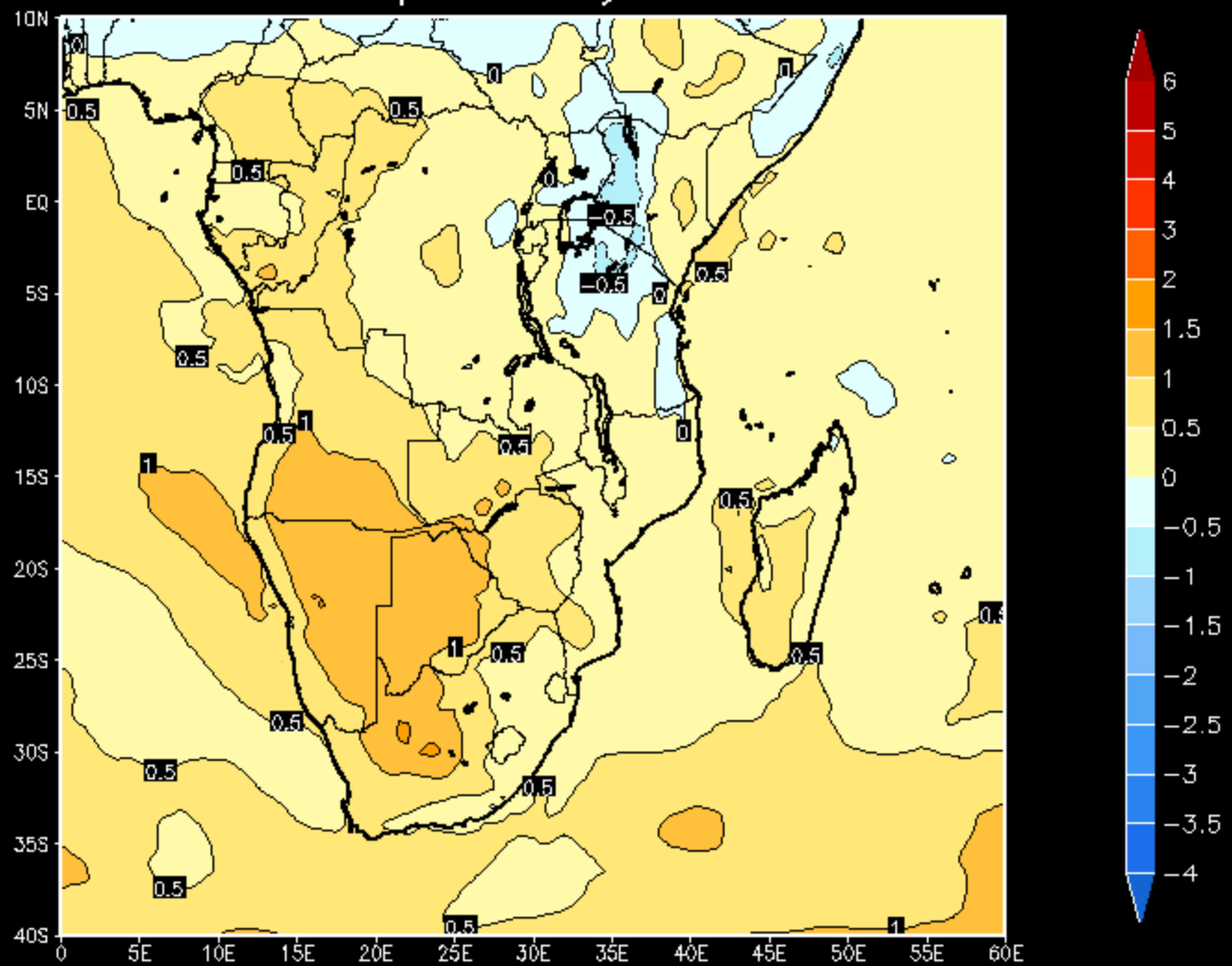
Temp anomaly 2035



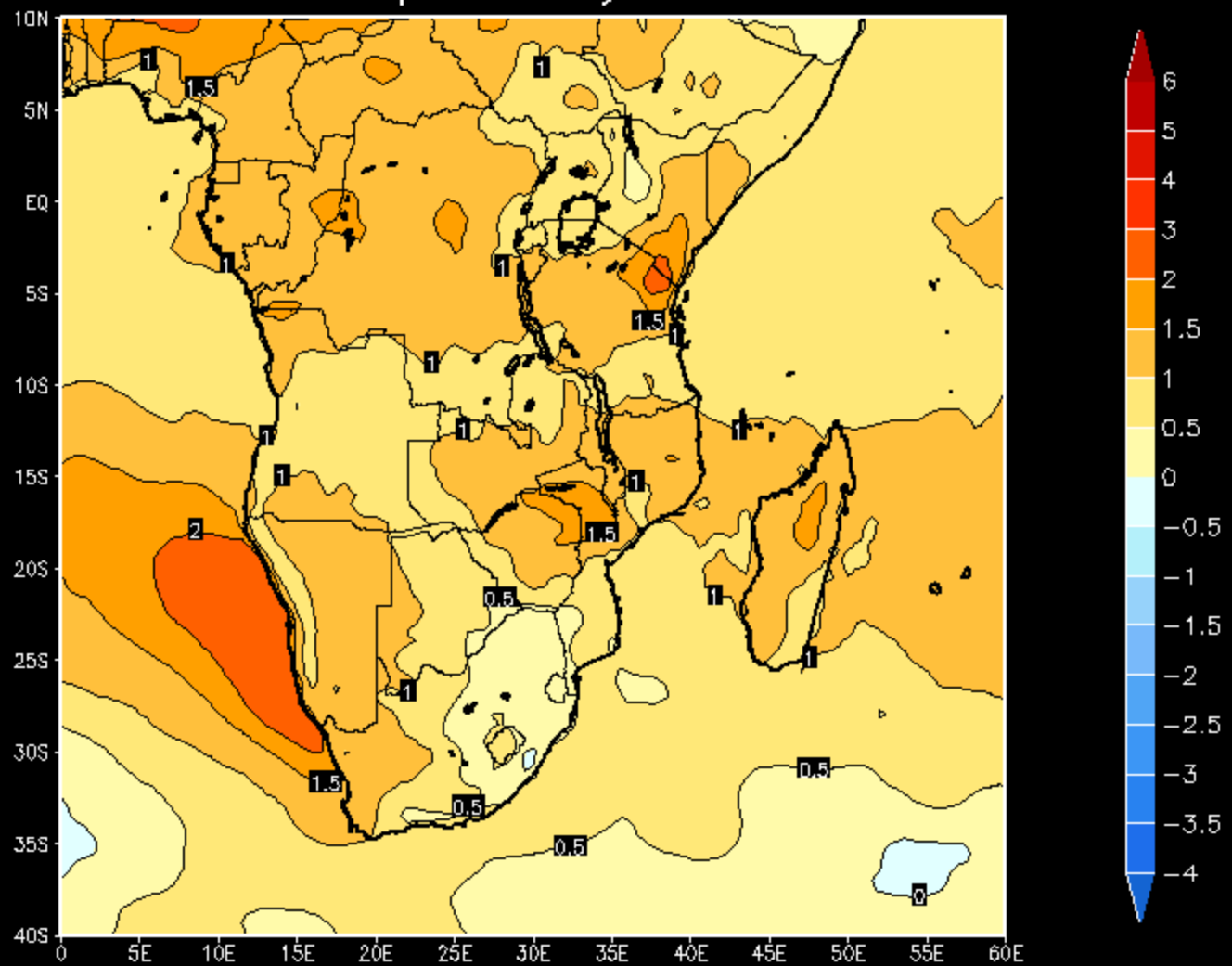
Temp anomaly 2036



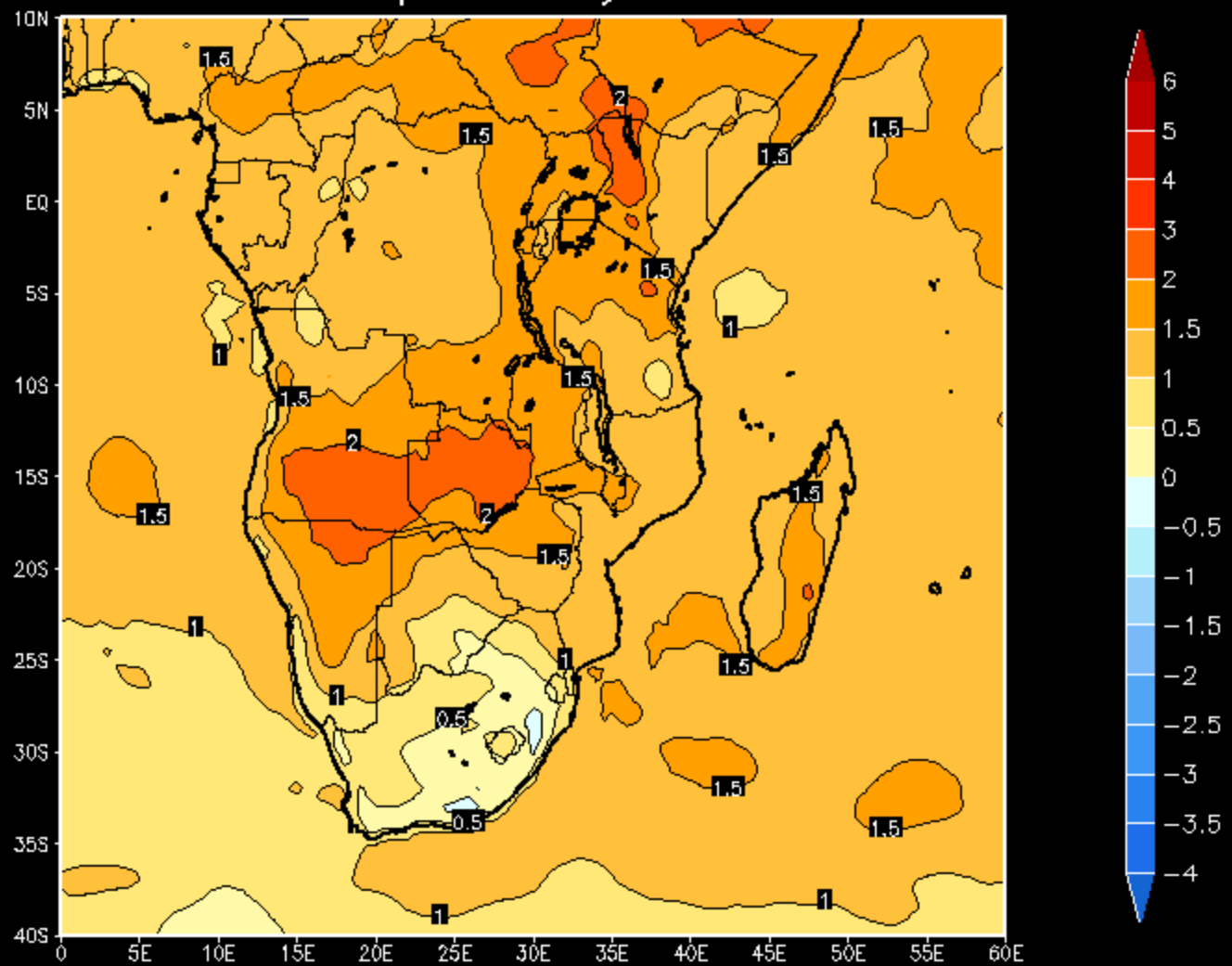
Temp anomaly 2037



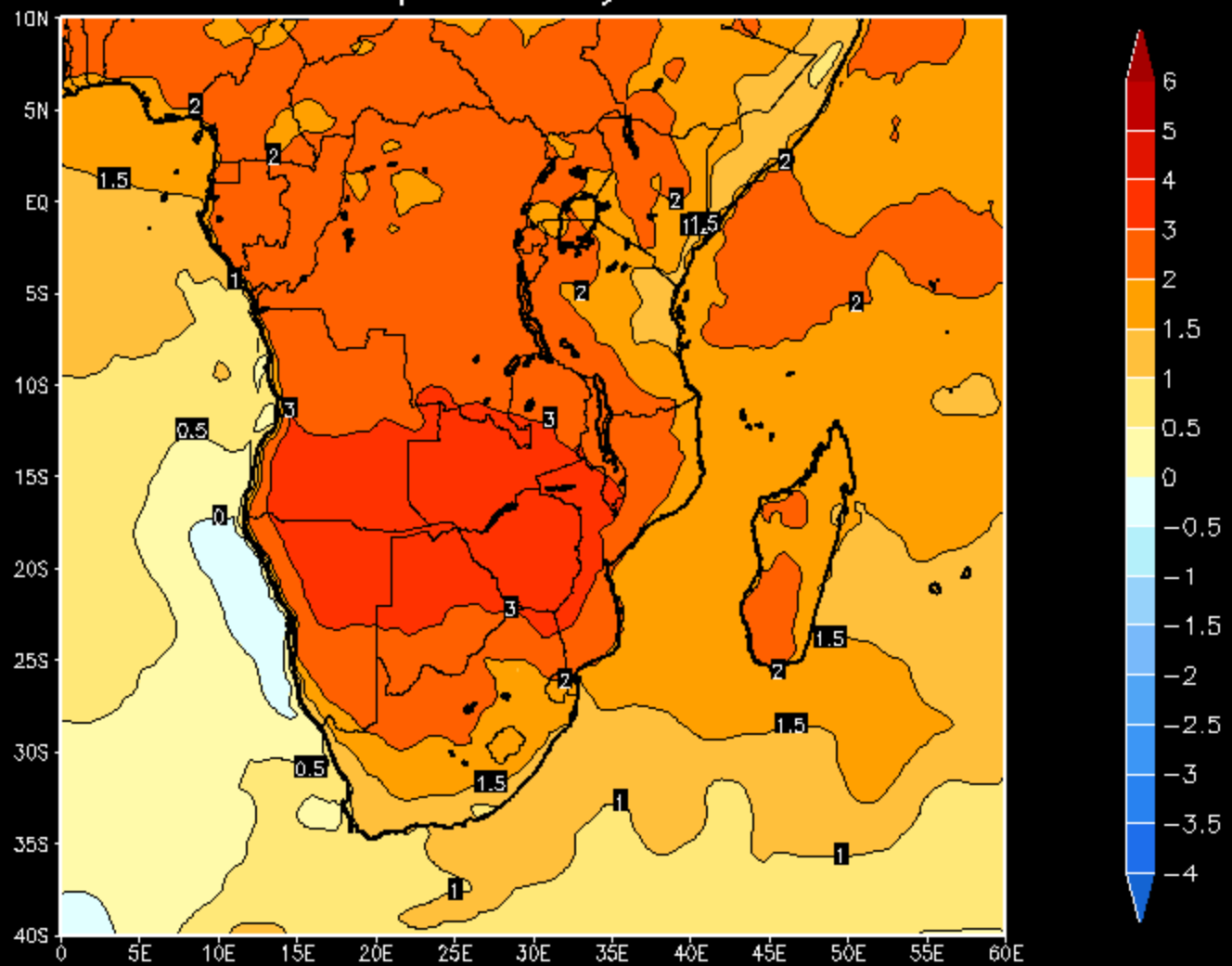
Temp anomaly 2038



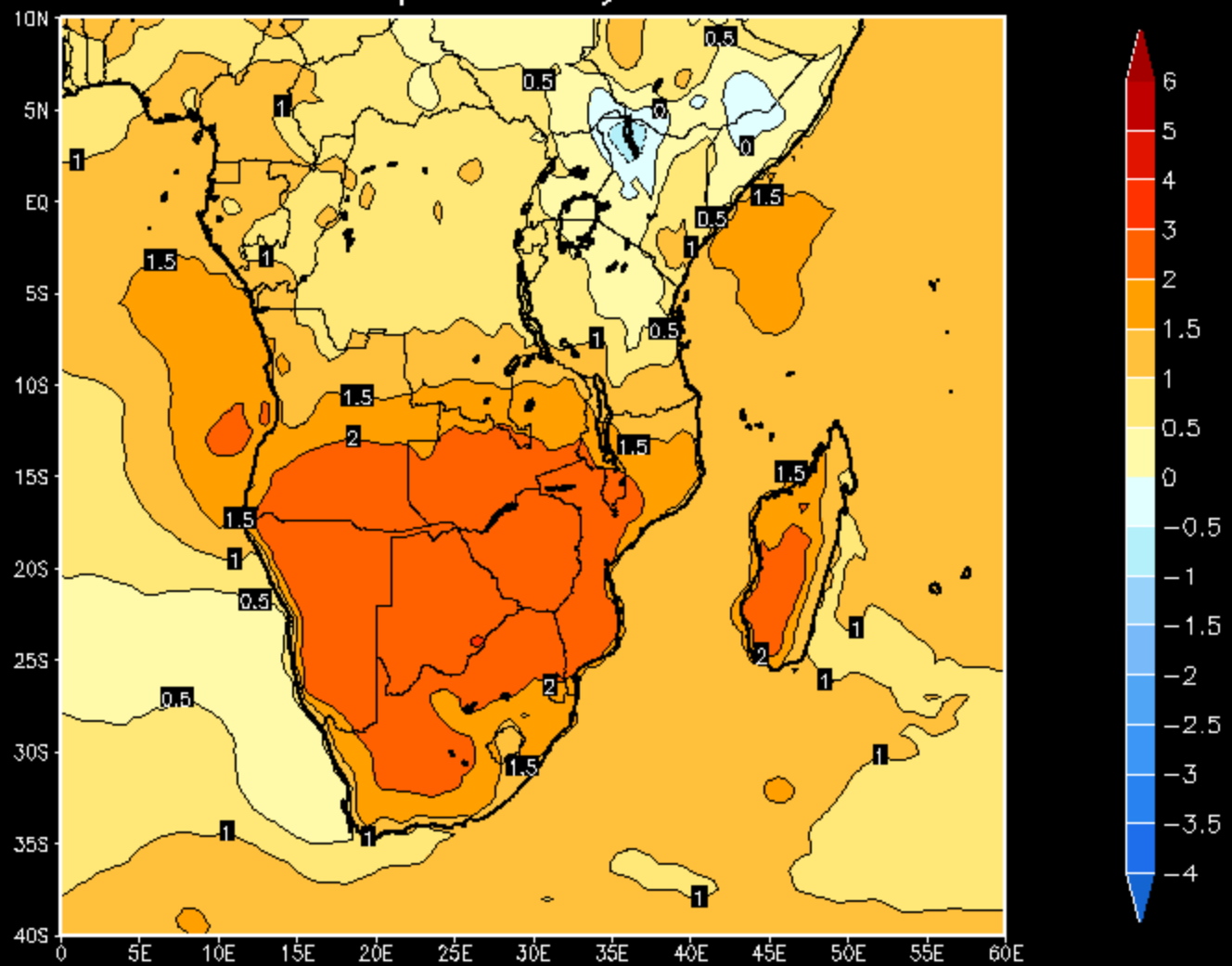
Temp anomaly 2039



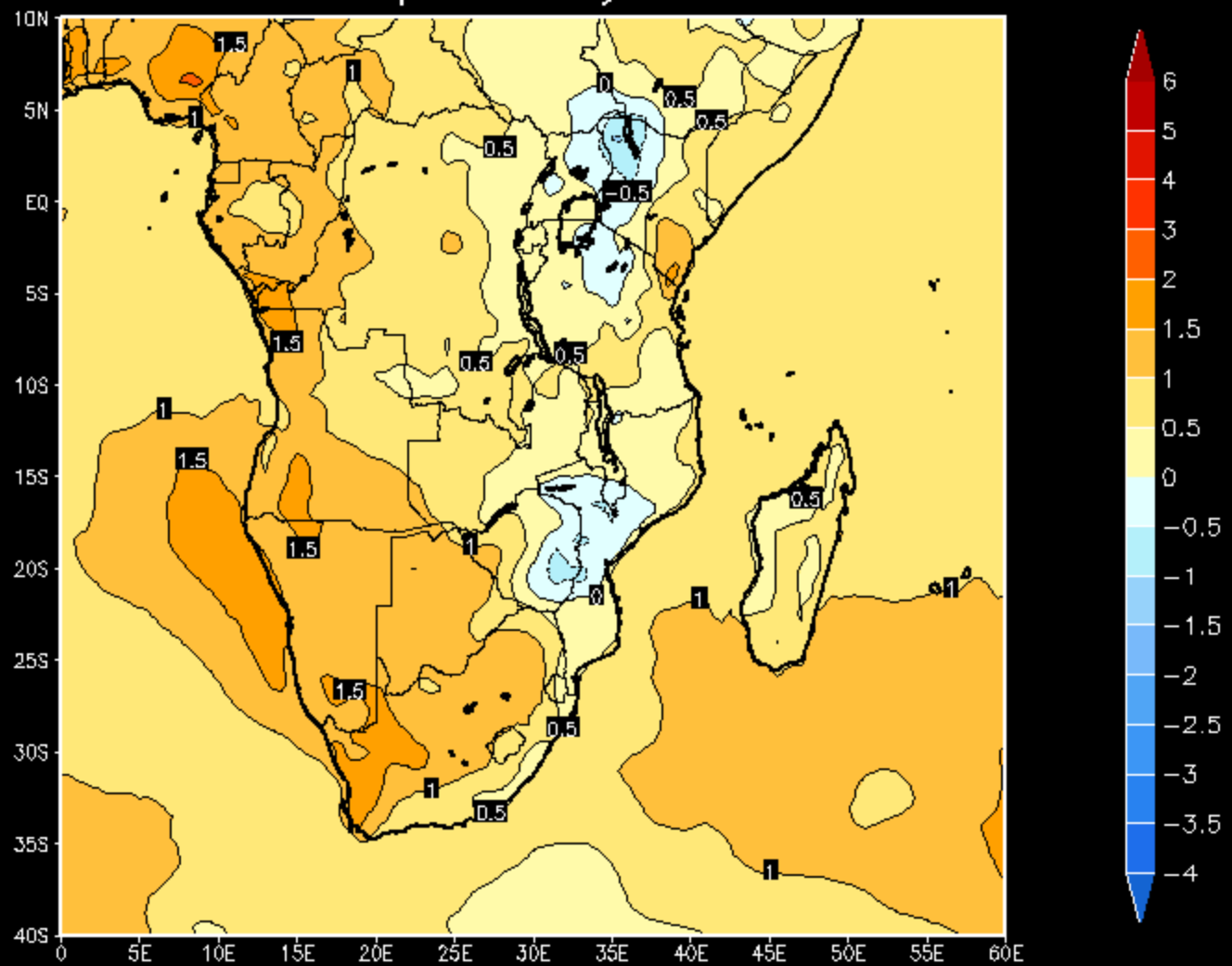
Temp anomaly 2040



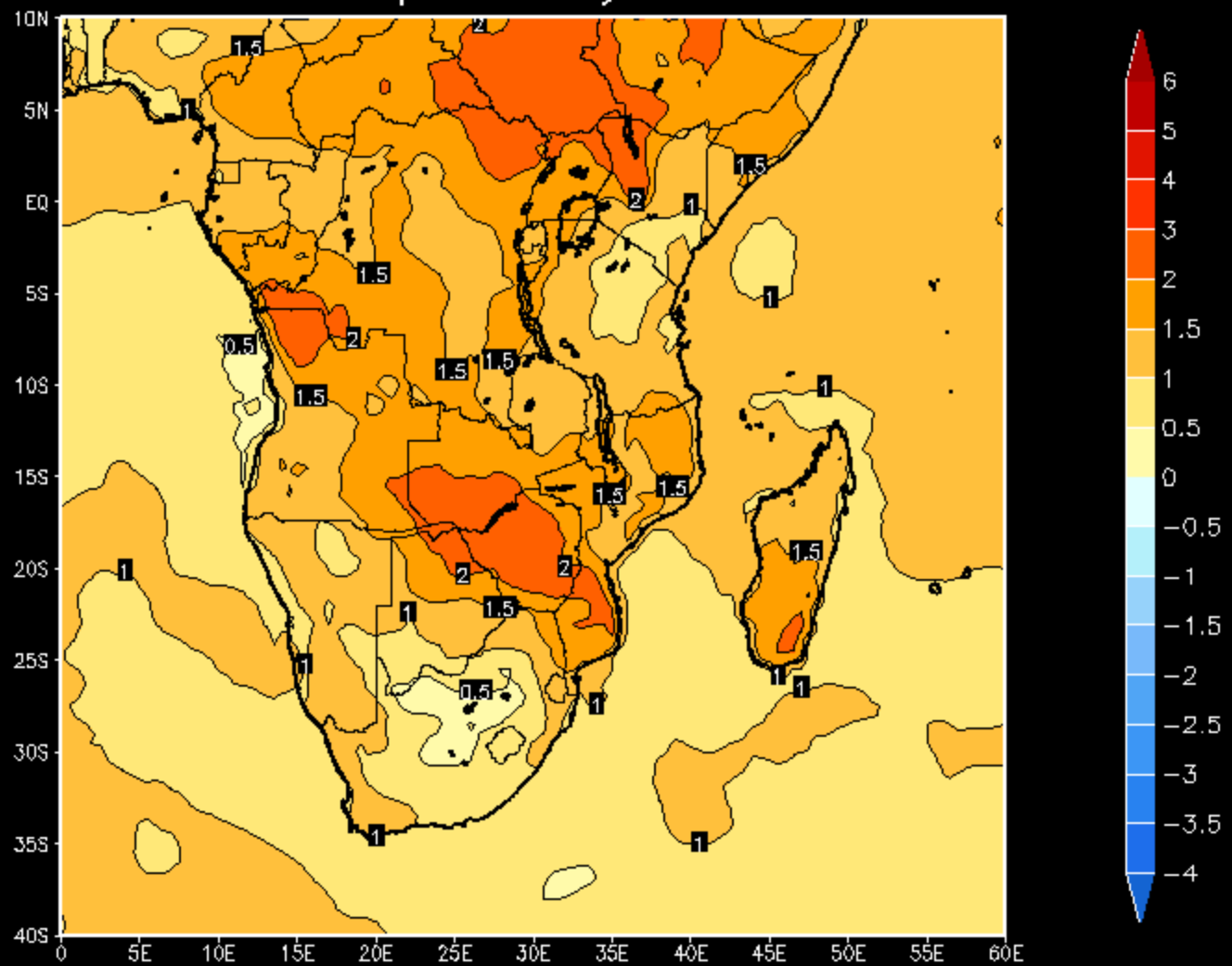
Temp anomaly 2041



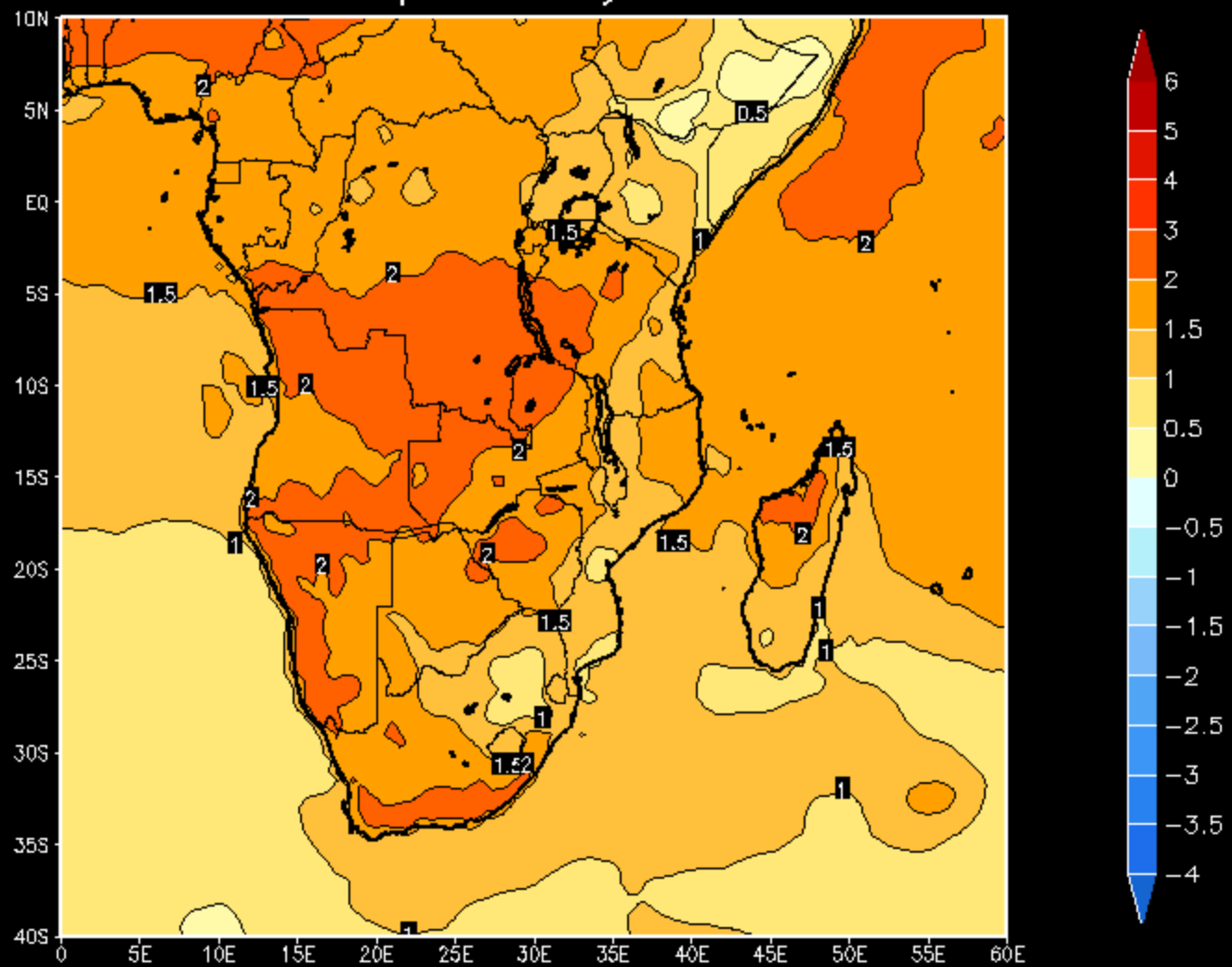
Temp anomaly 2042



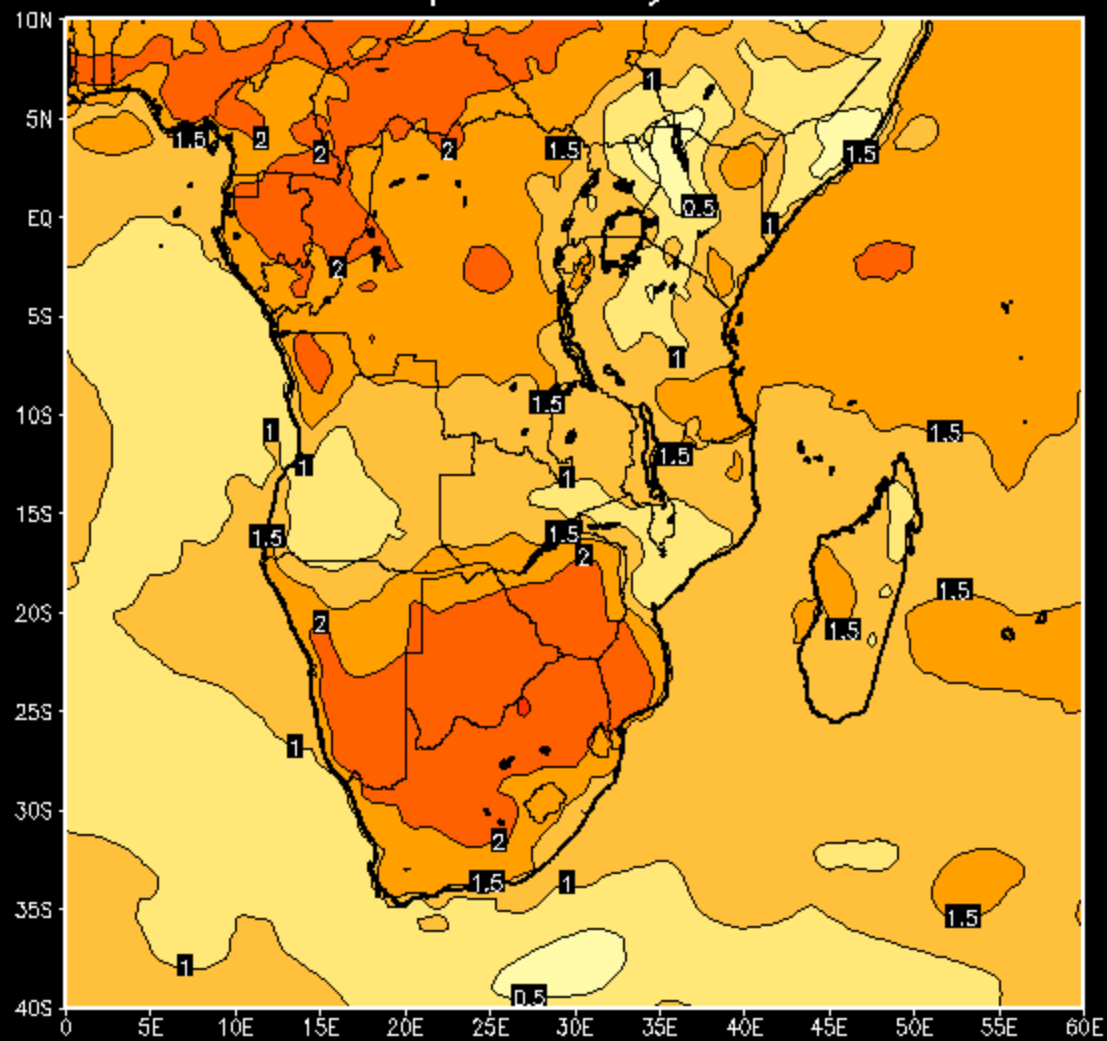
Temp anomaly 2043



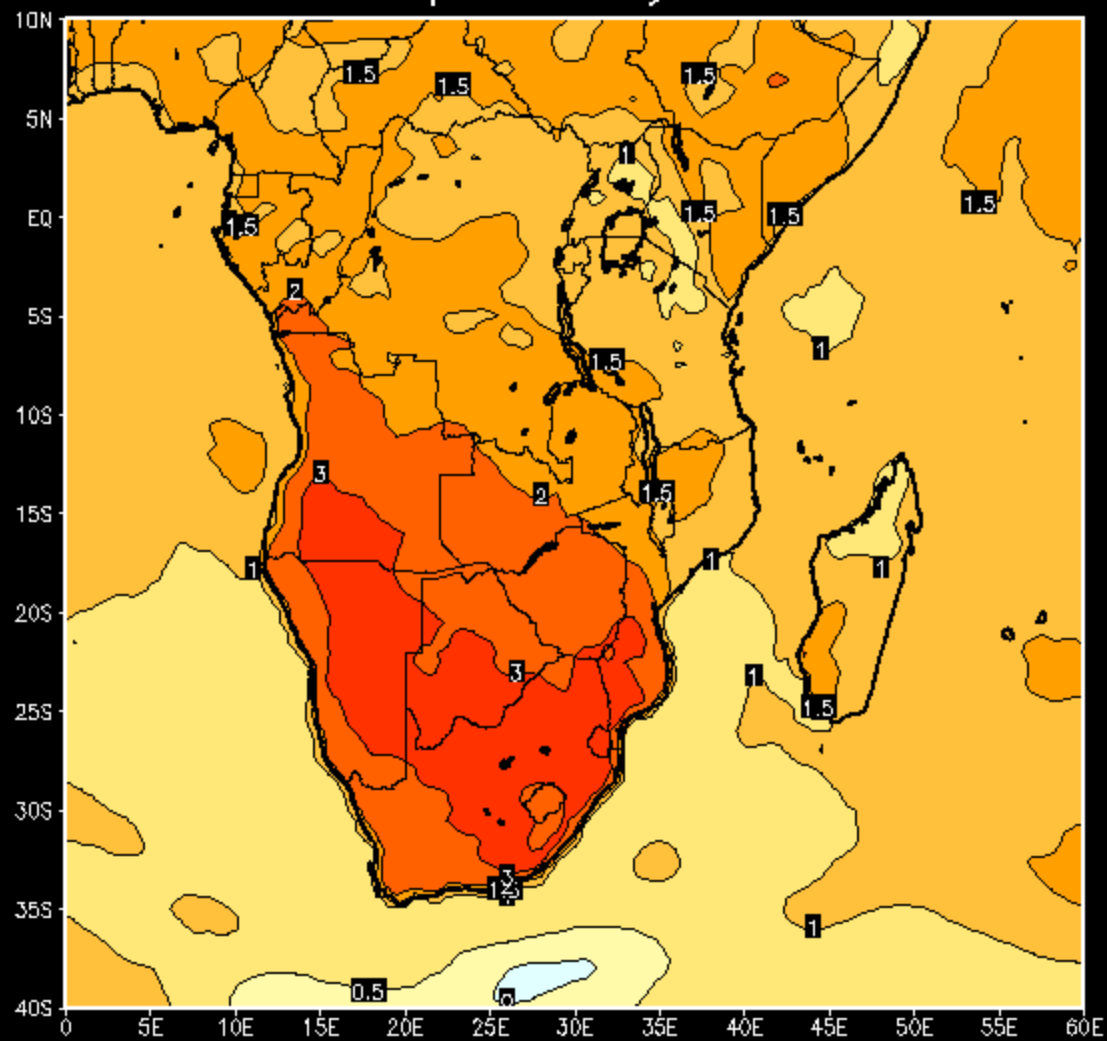
Temp anomaly 2044



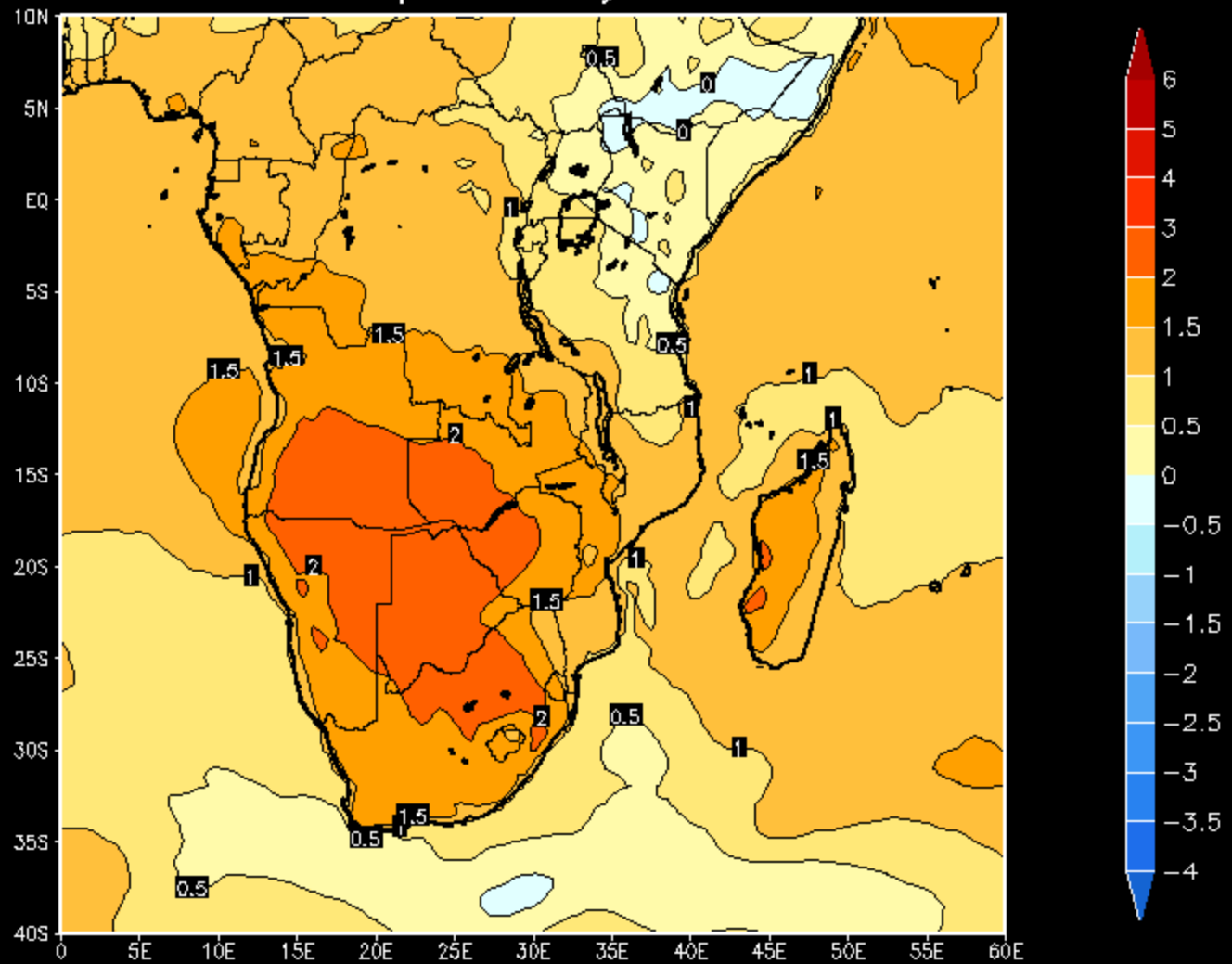
Temp anomaly 2045



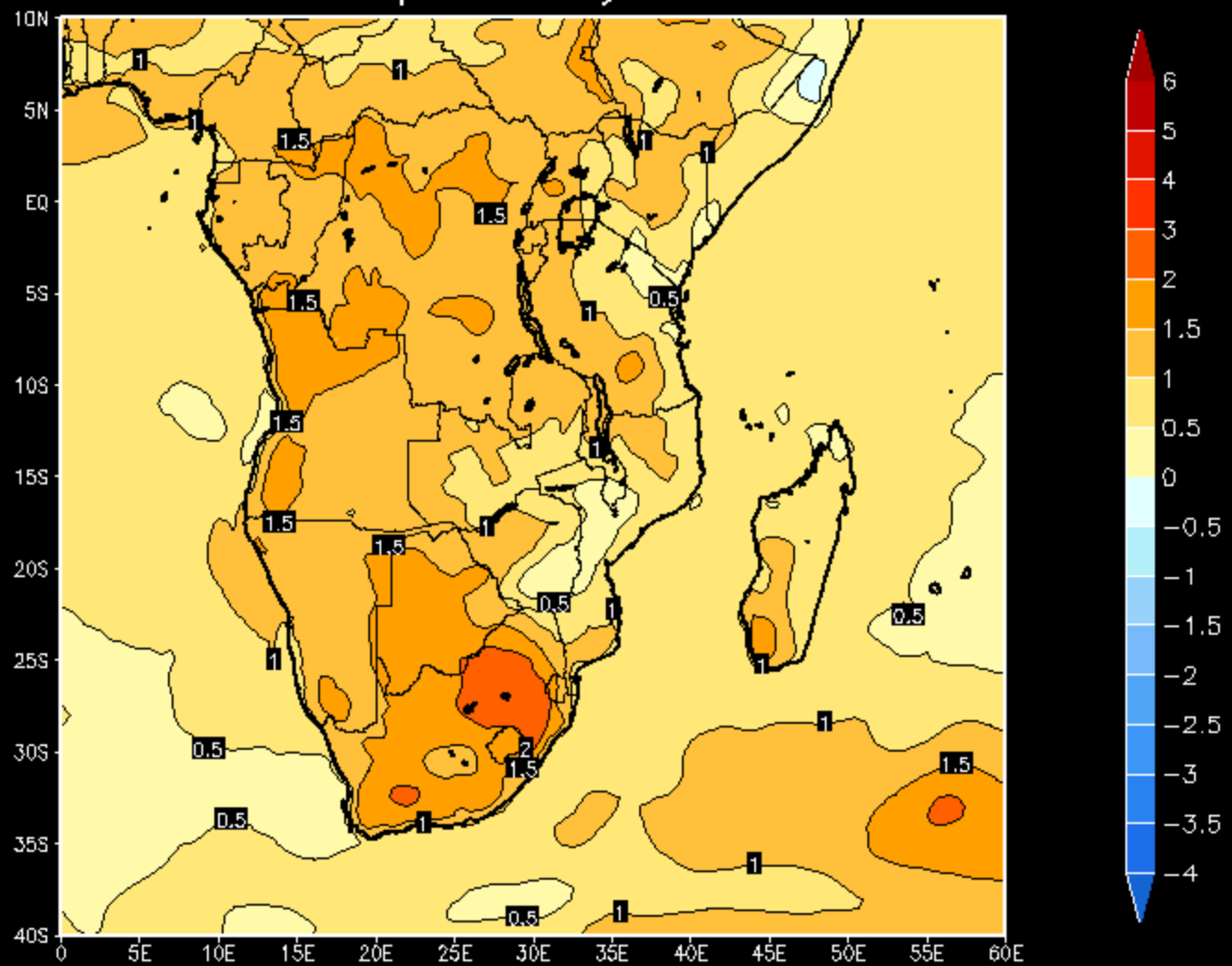
Temp anomaly 2046



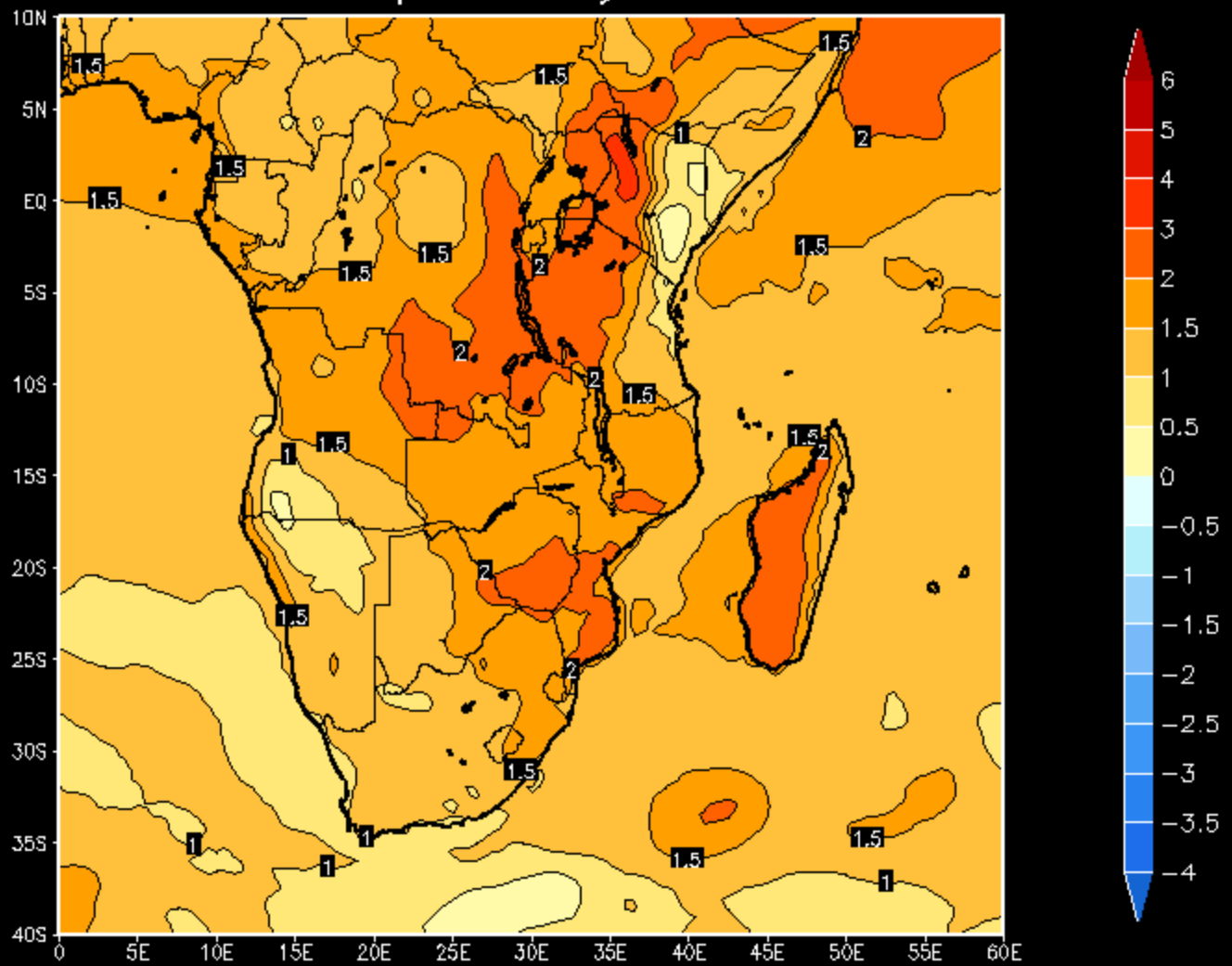
Temp anomaly 2047



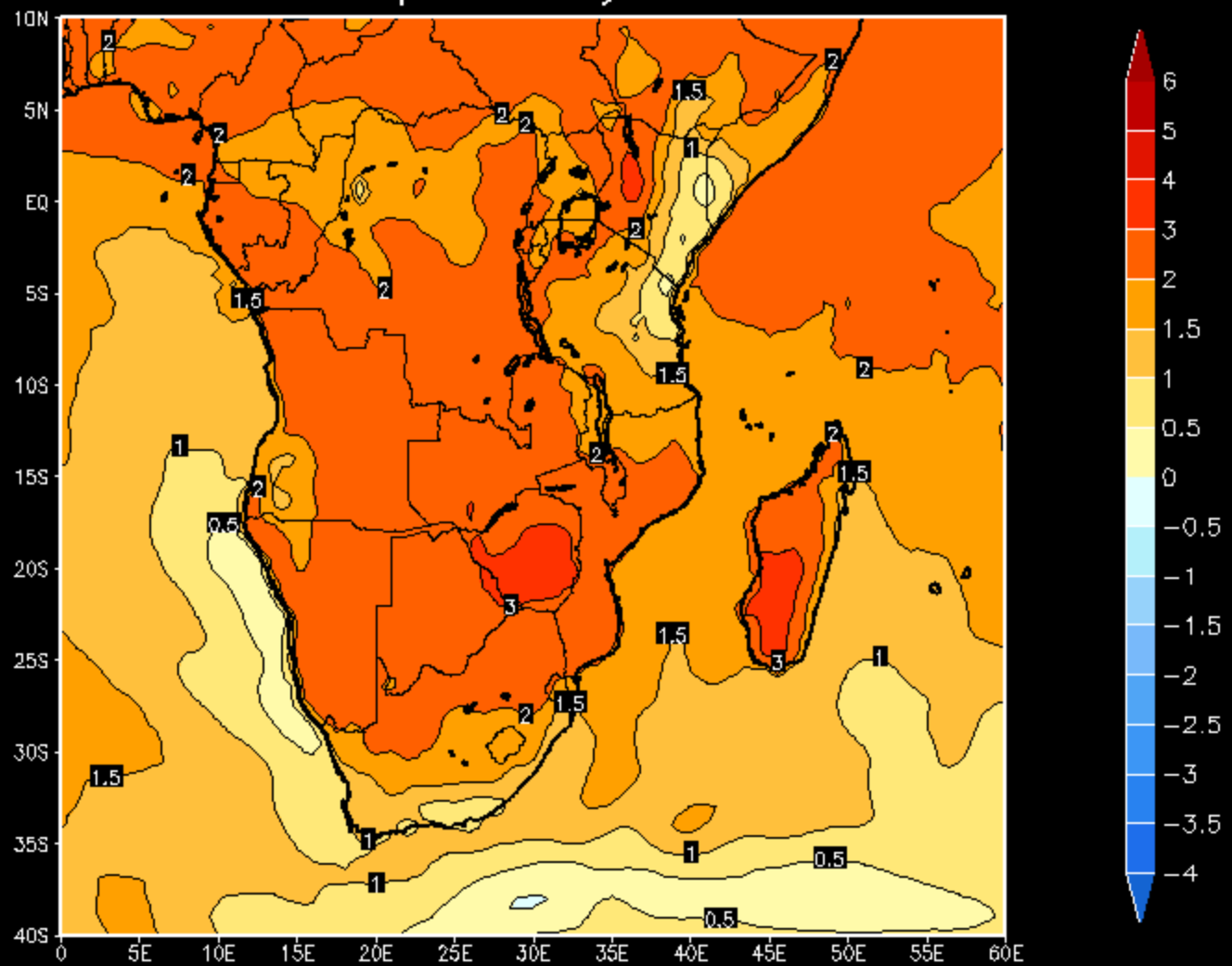
Temp anomaly 2048



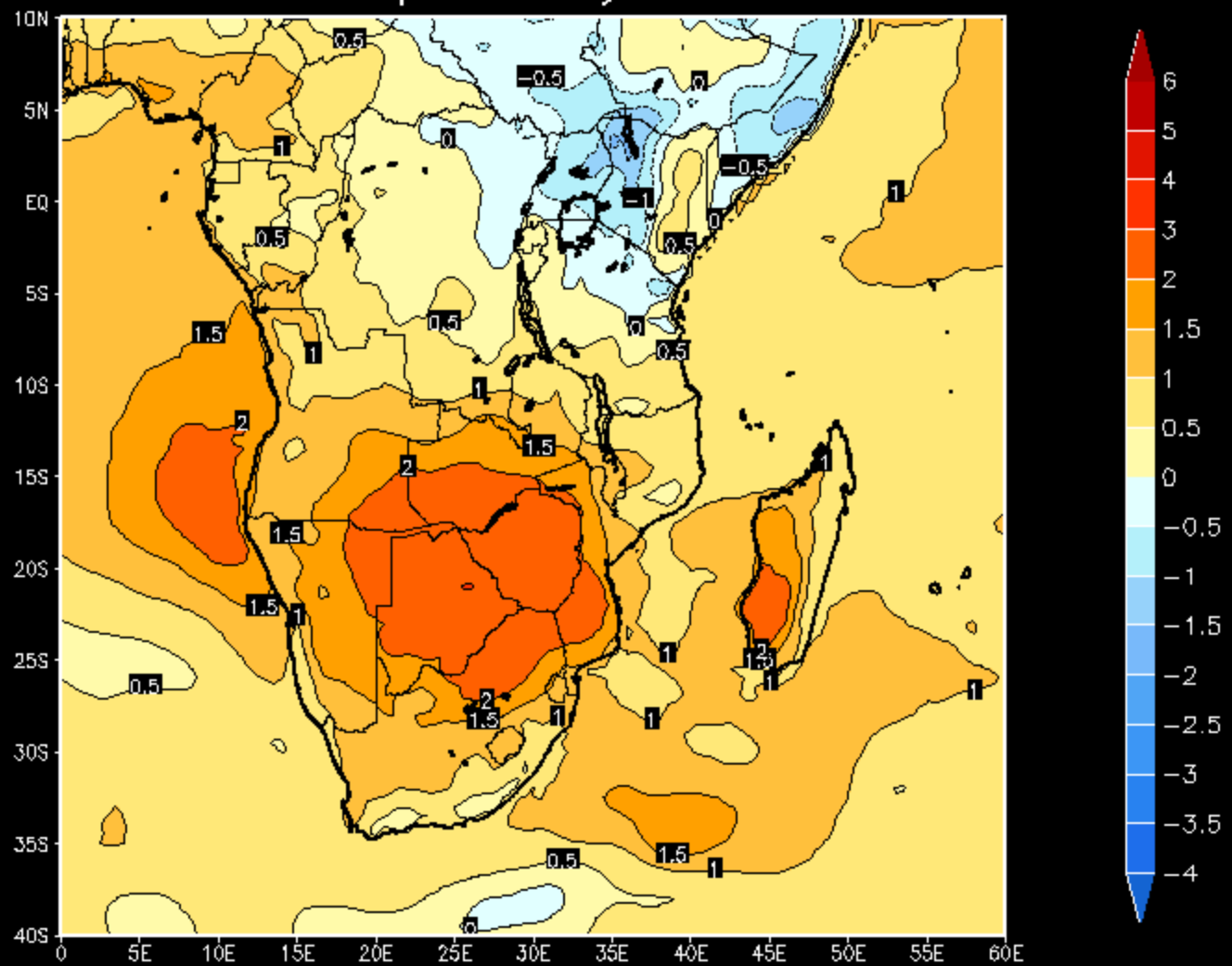
Temp anomaly 2049



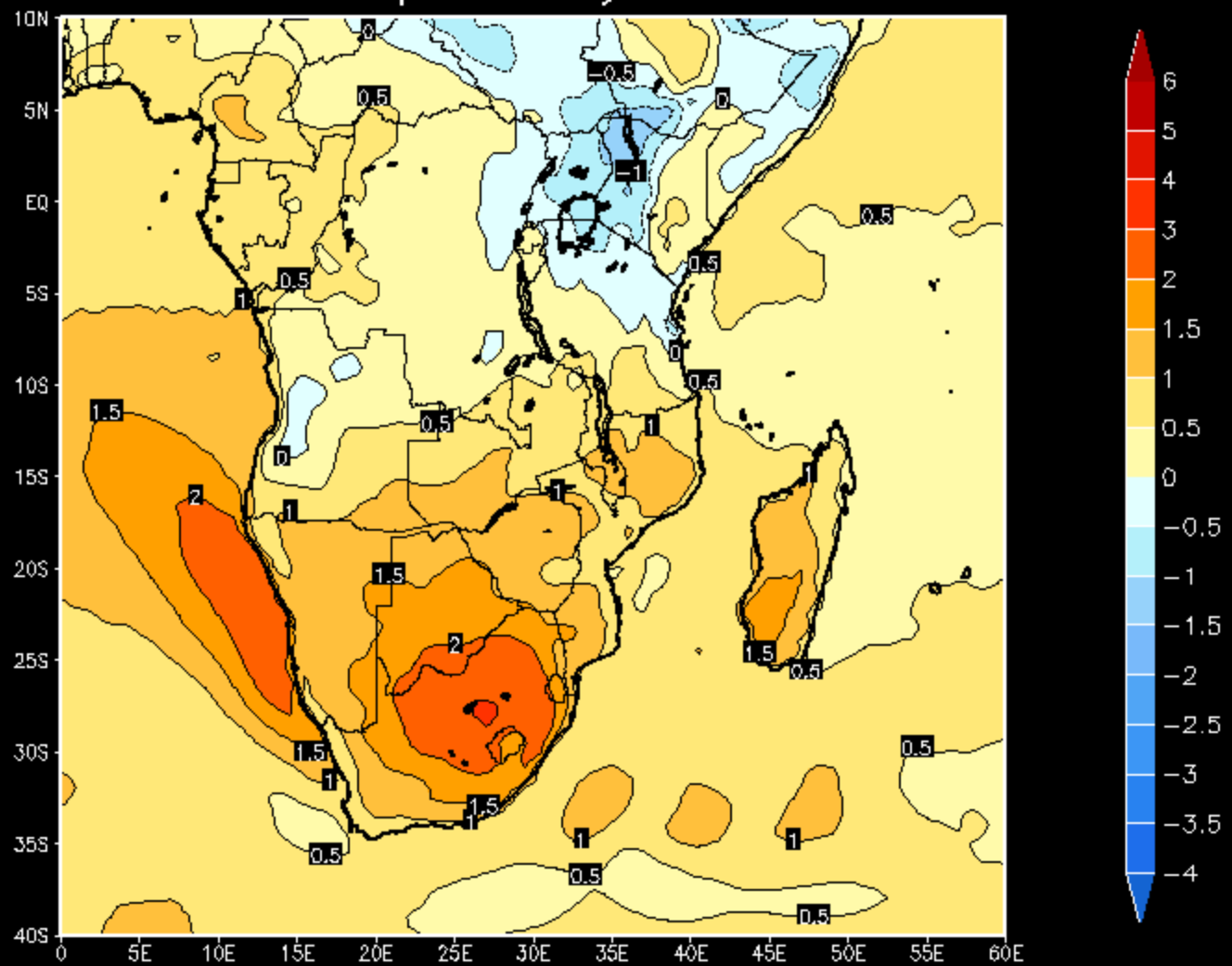
Temp anomaly 2050



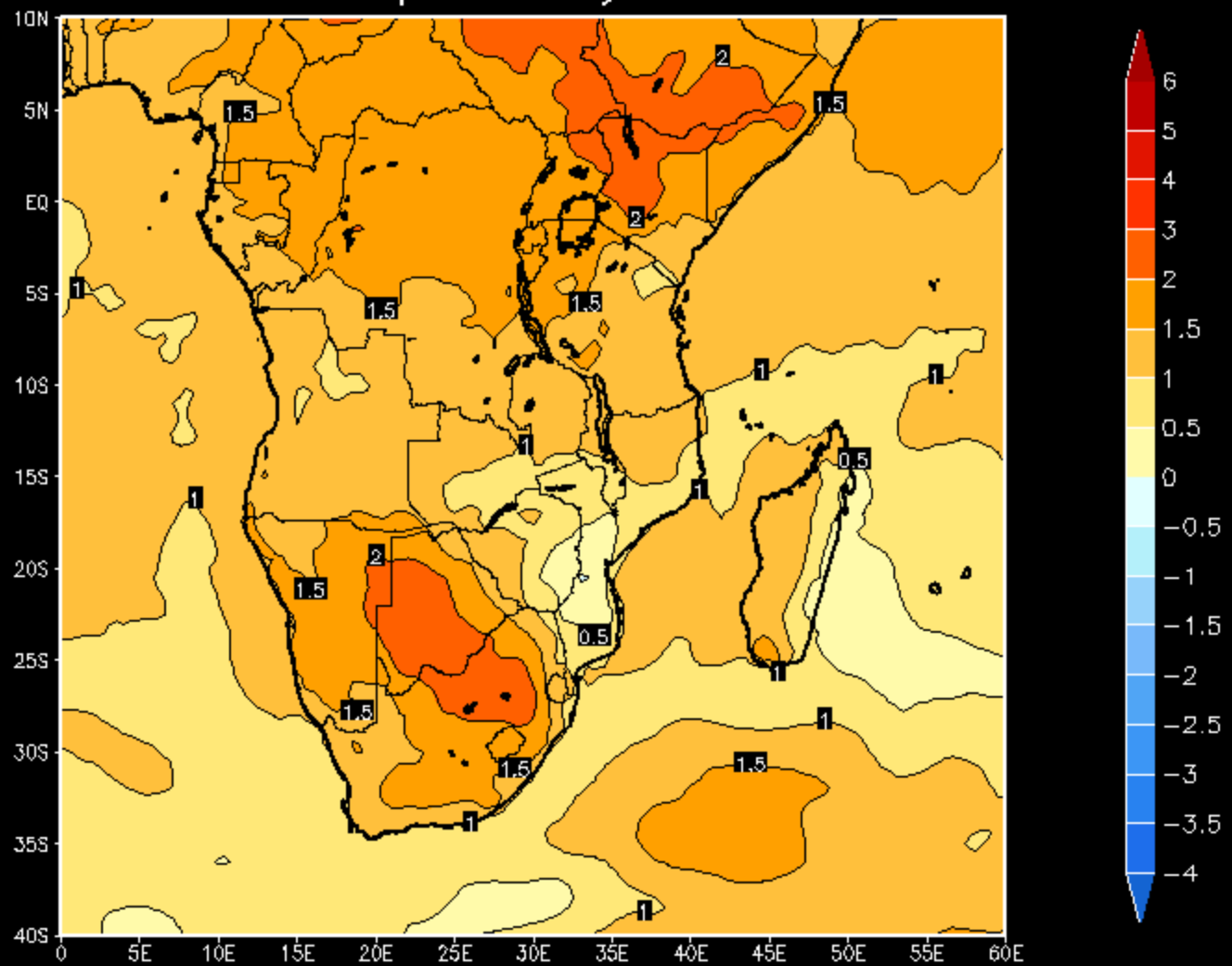
Temp anomaly 2051



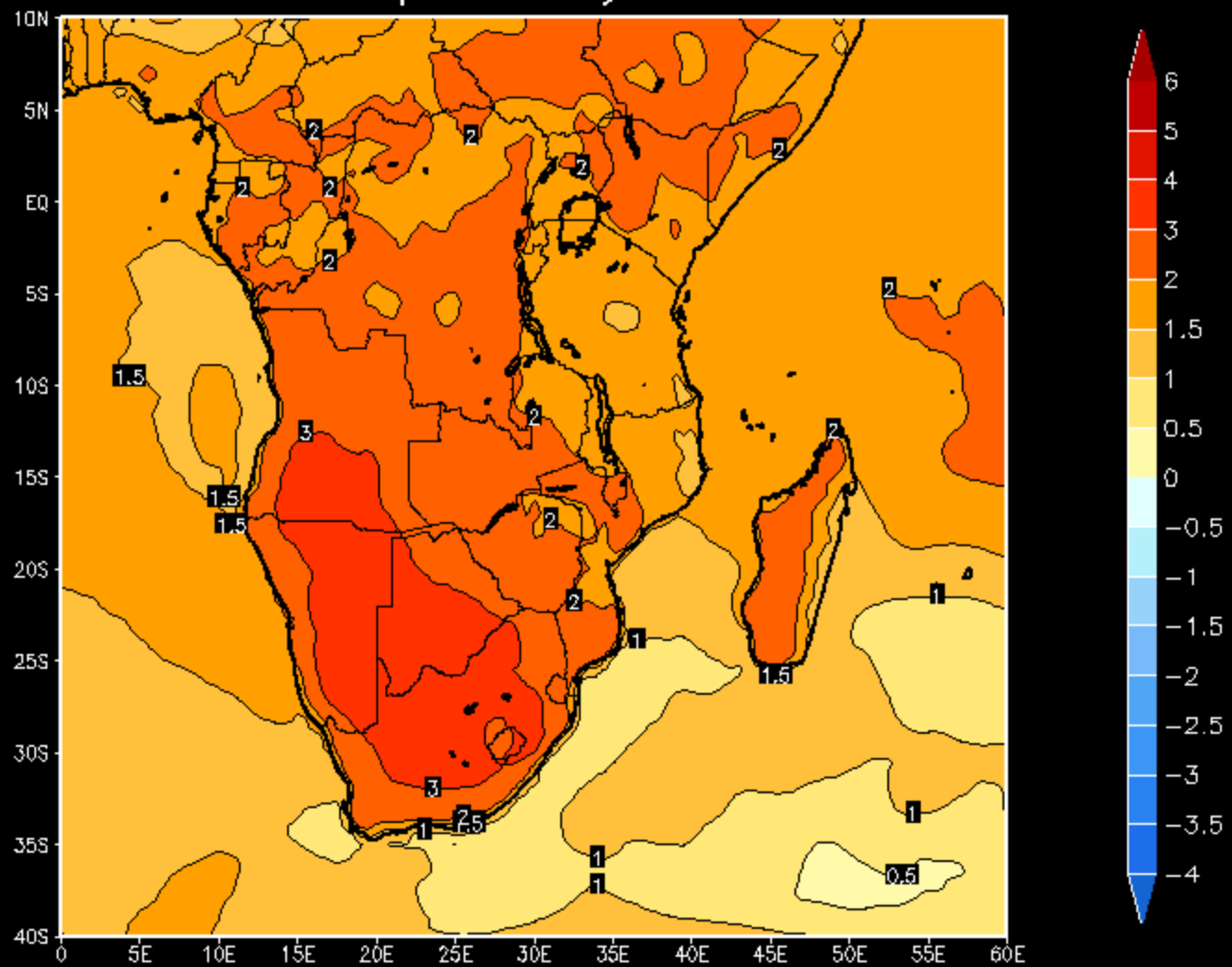
Temp anomaly 2052



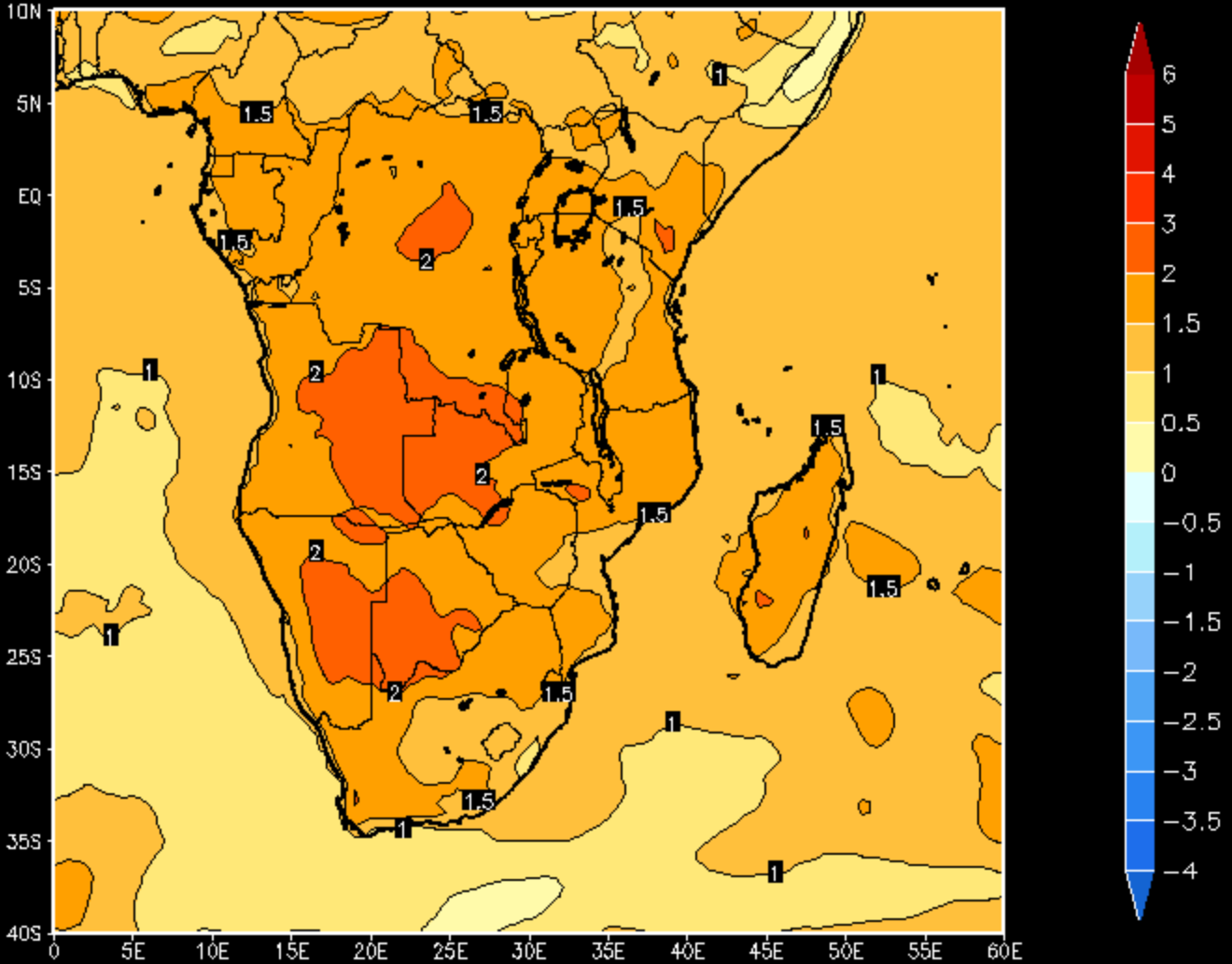
Temp anomaly 2053



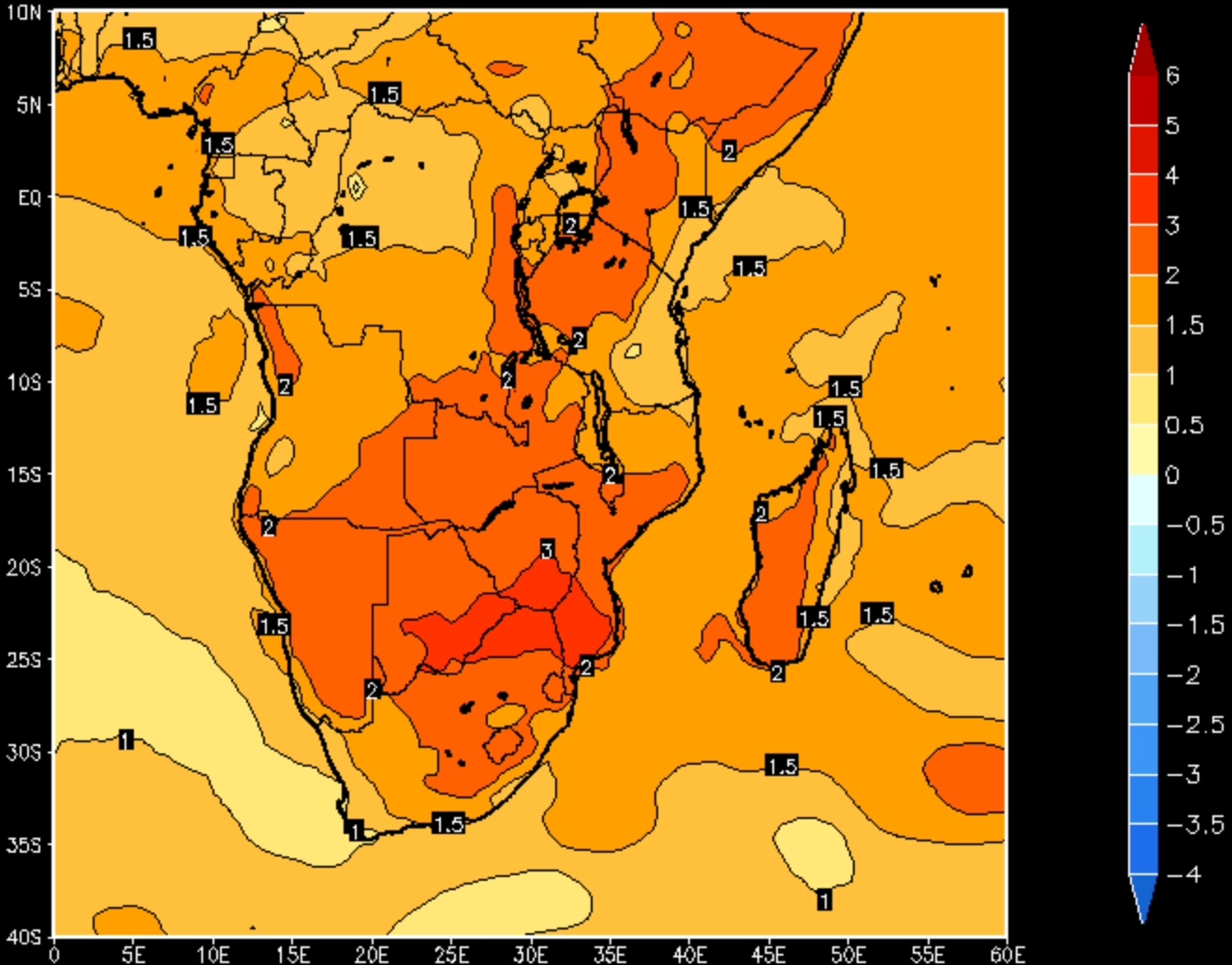
Temp anomaly 2054



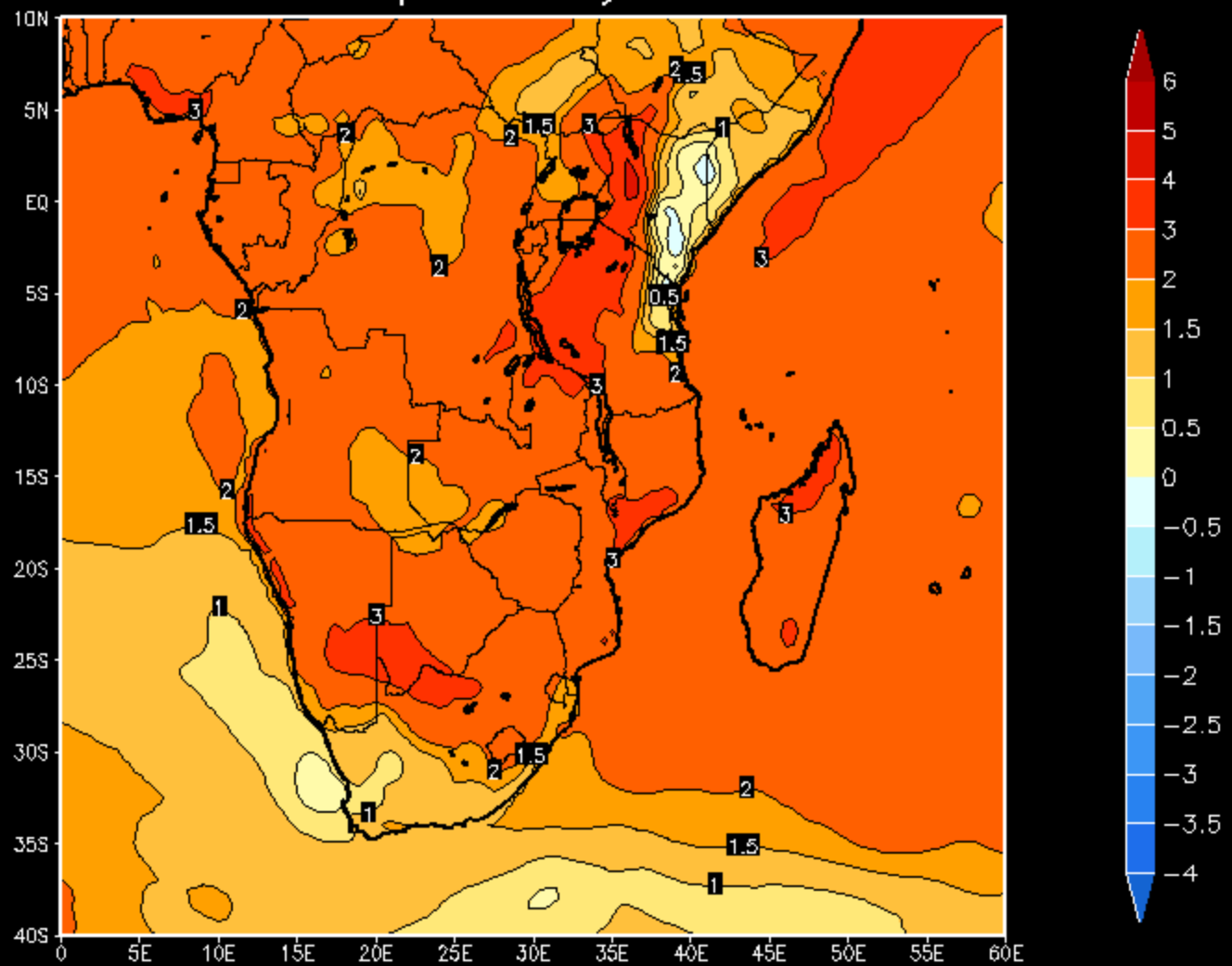
Temp anomaly 2055



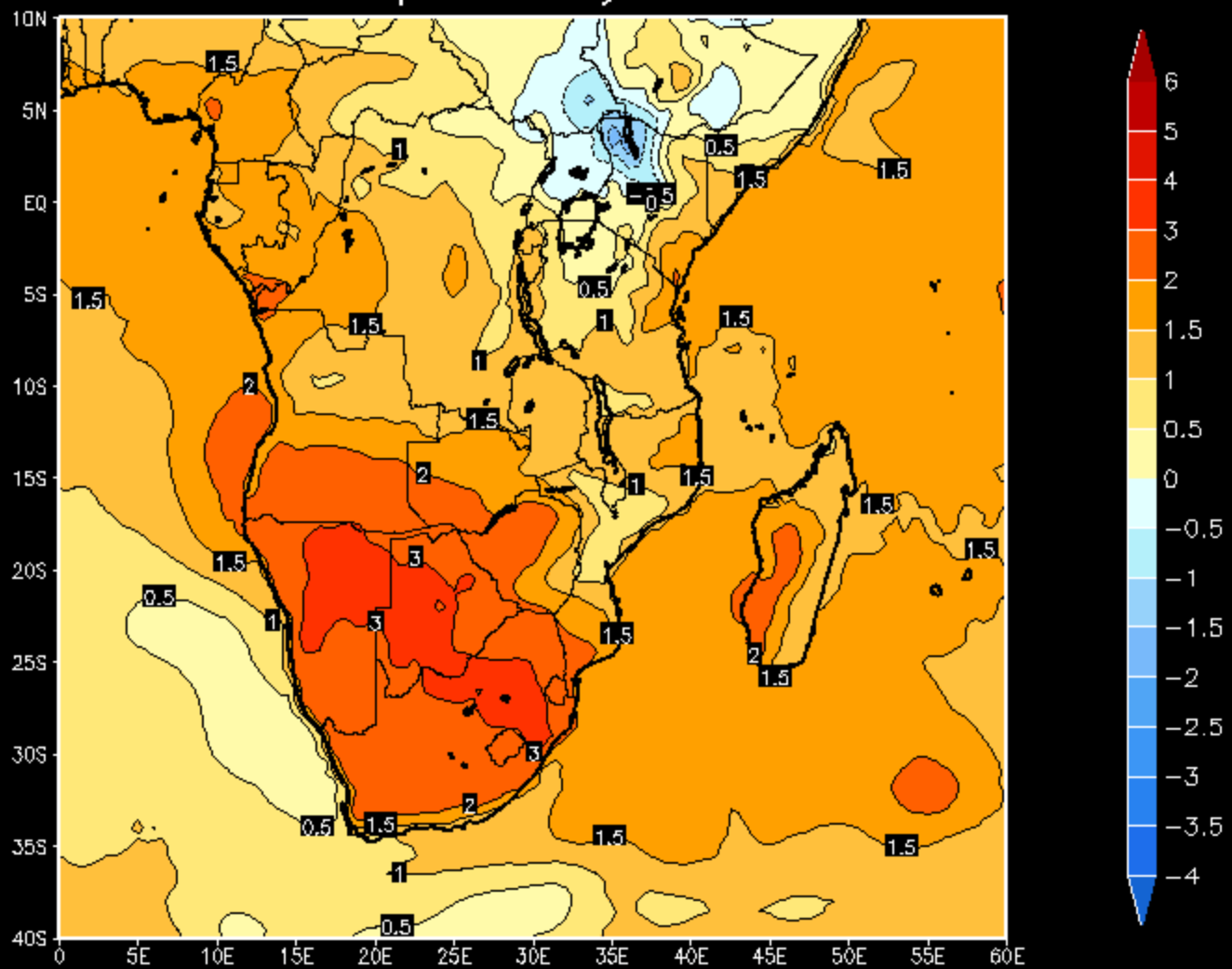
Temp anomaly 2056



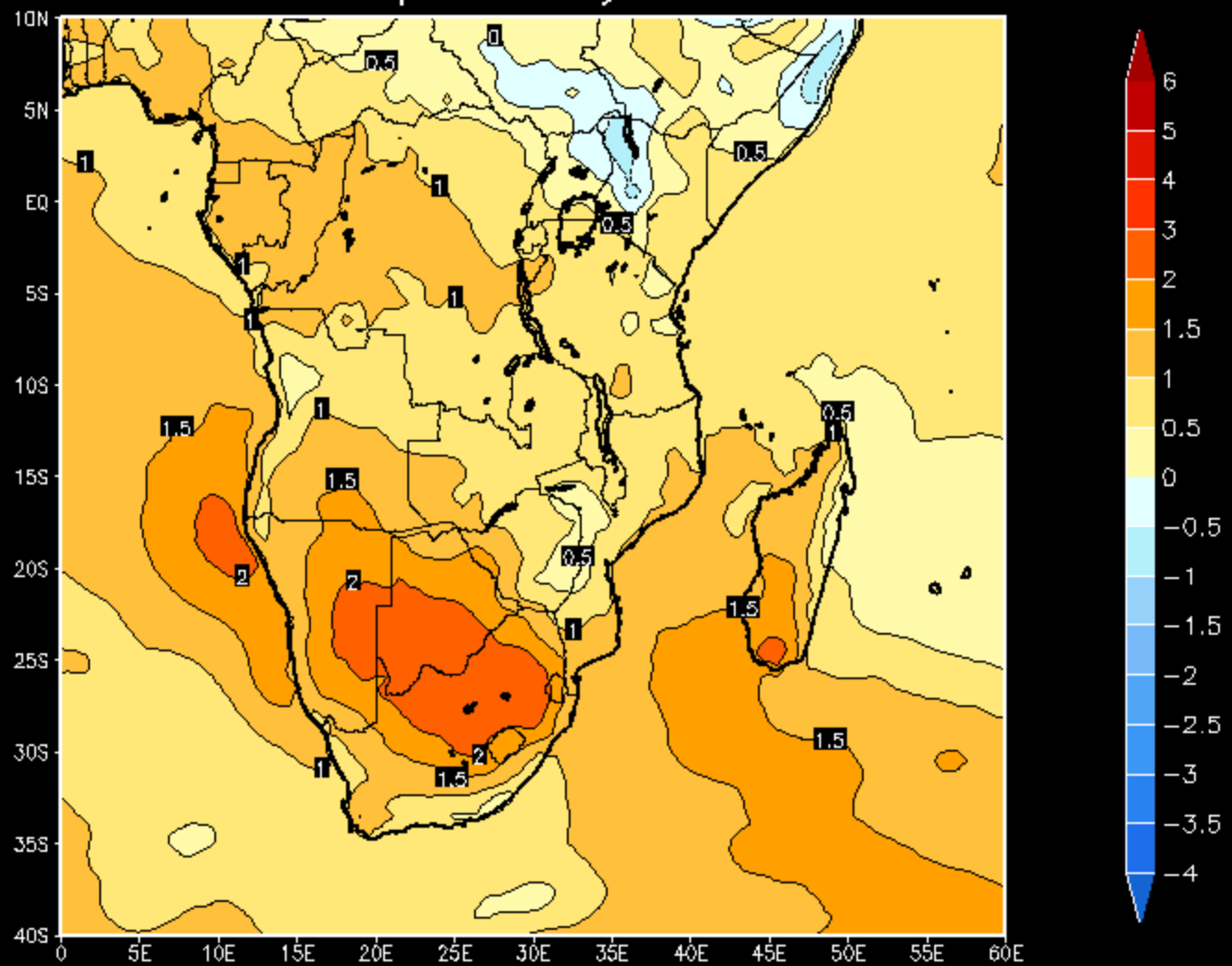
Temp anomaly 2057



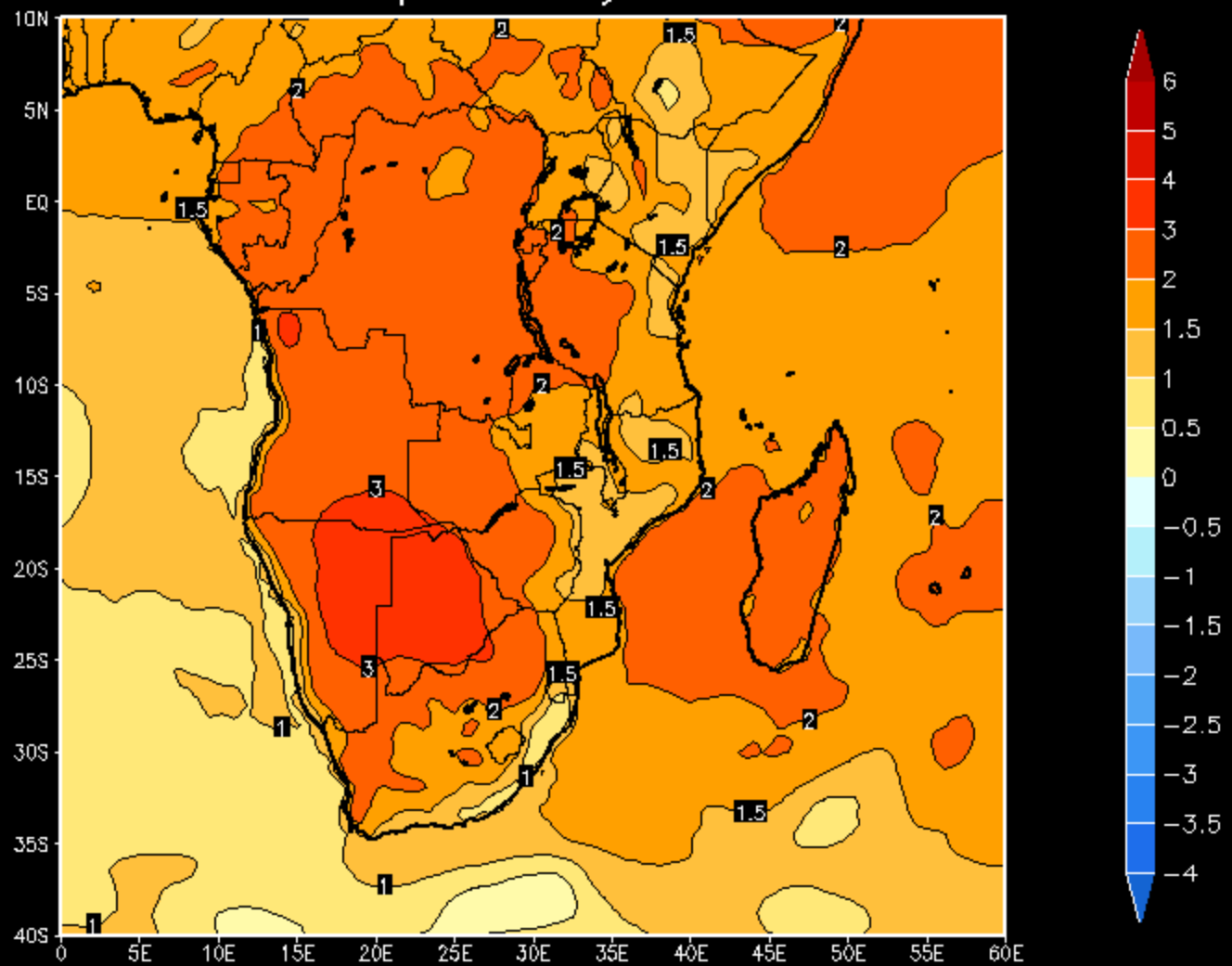
Temp anomaly 2058



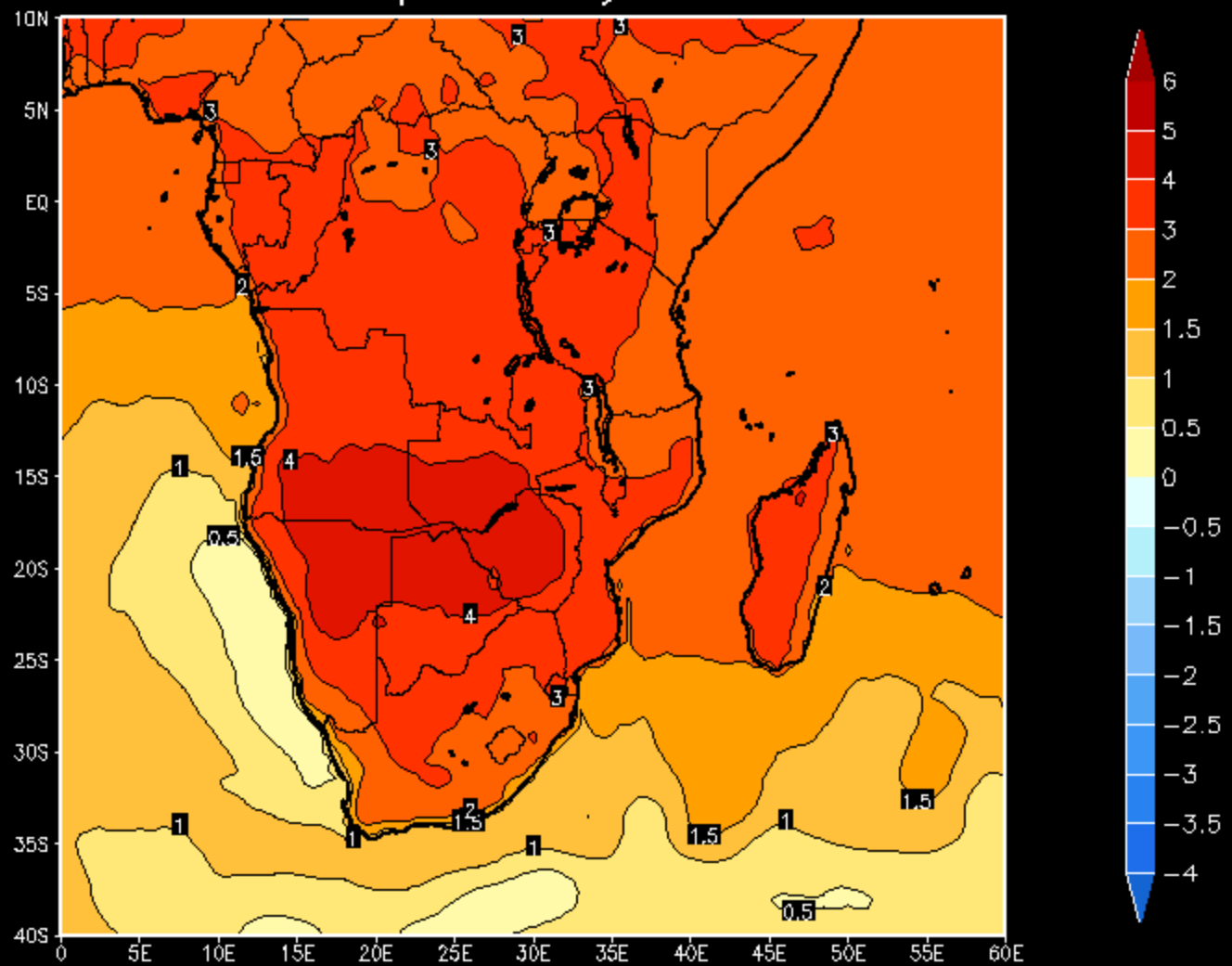
Temp anomaly 2059



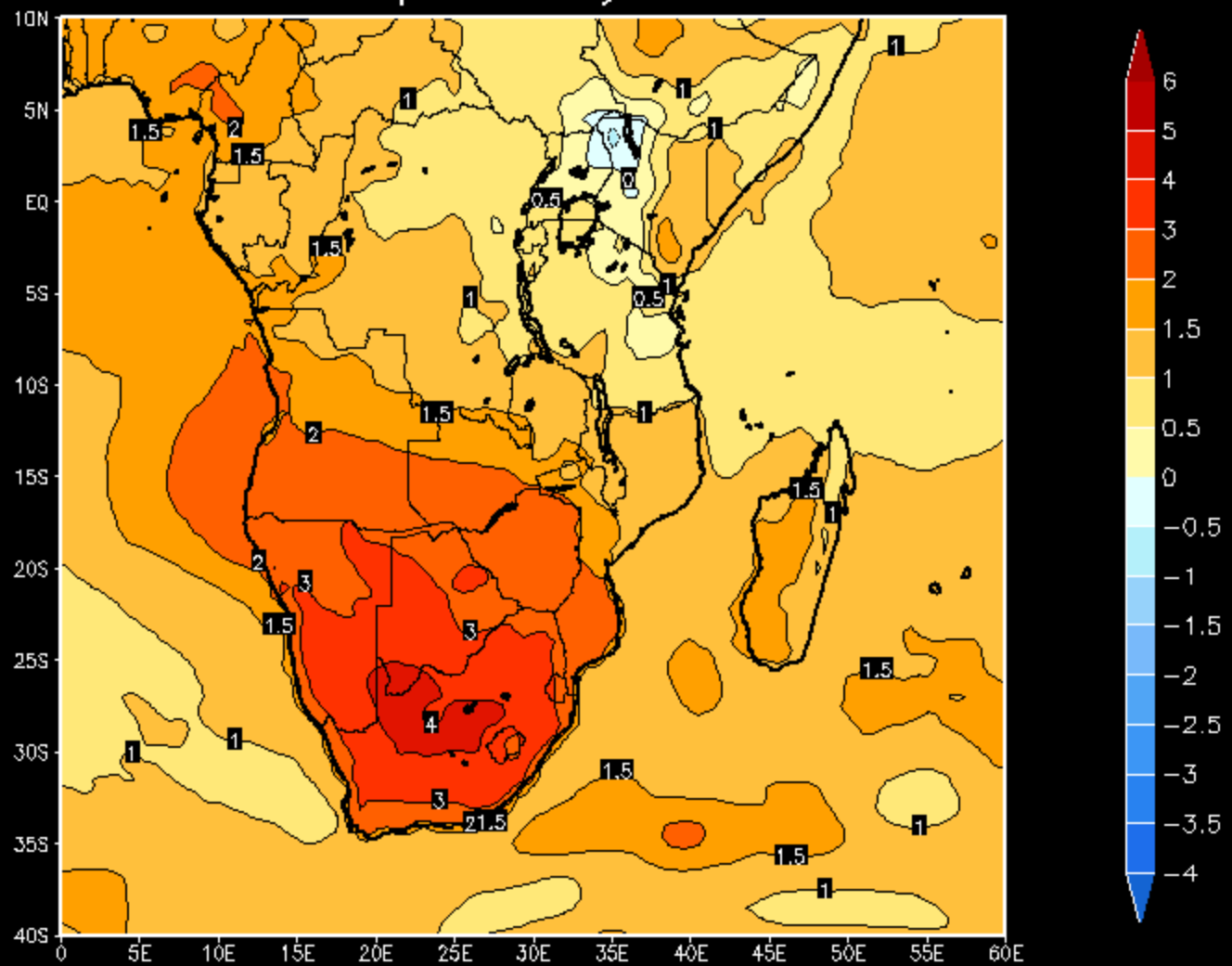
Temp anomaly 2060



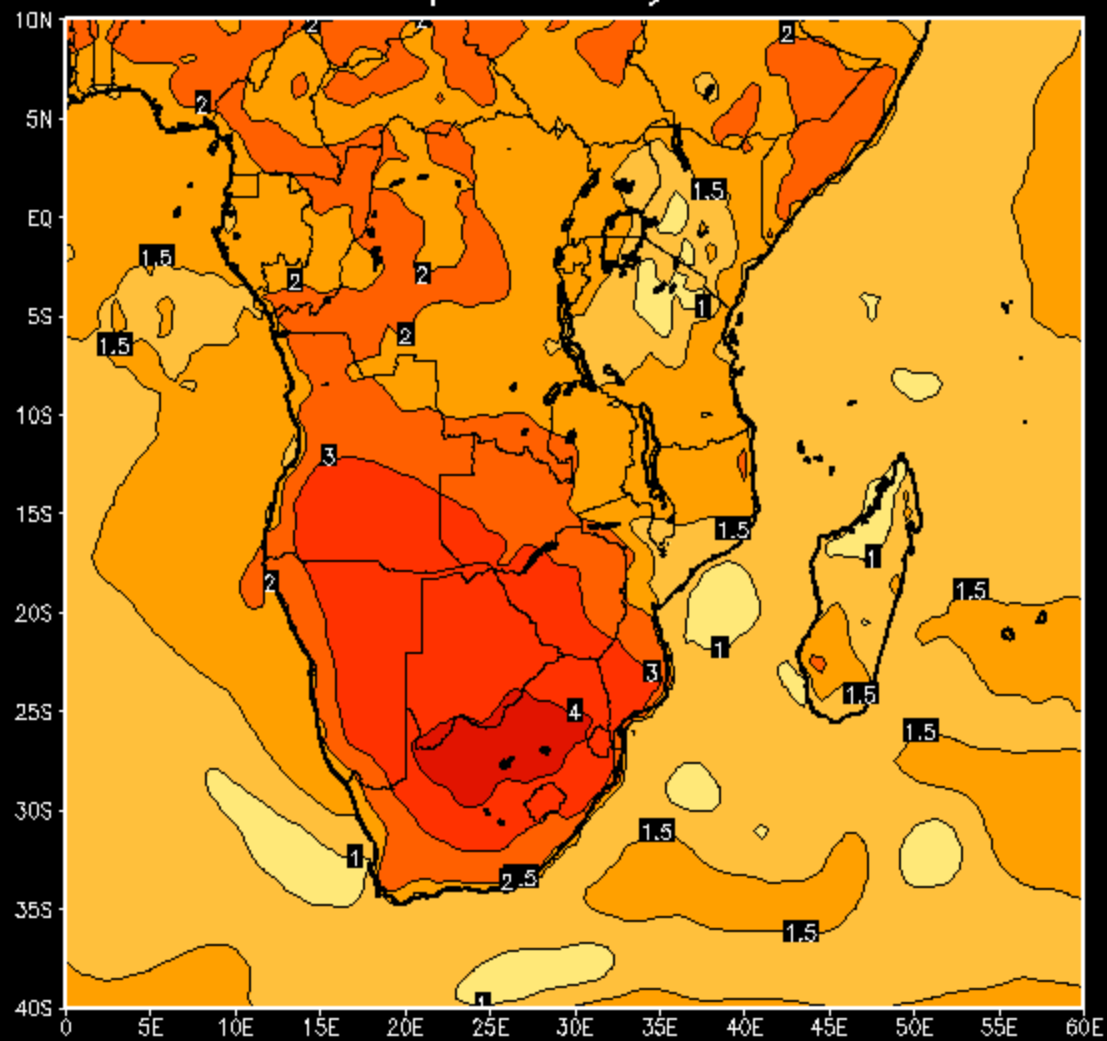
Temp anomaly 2061



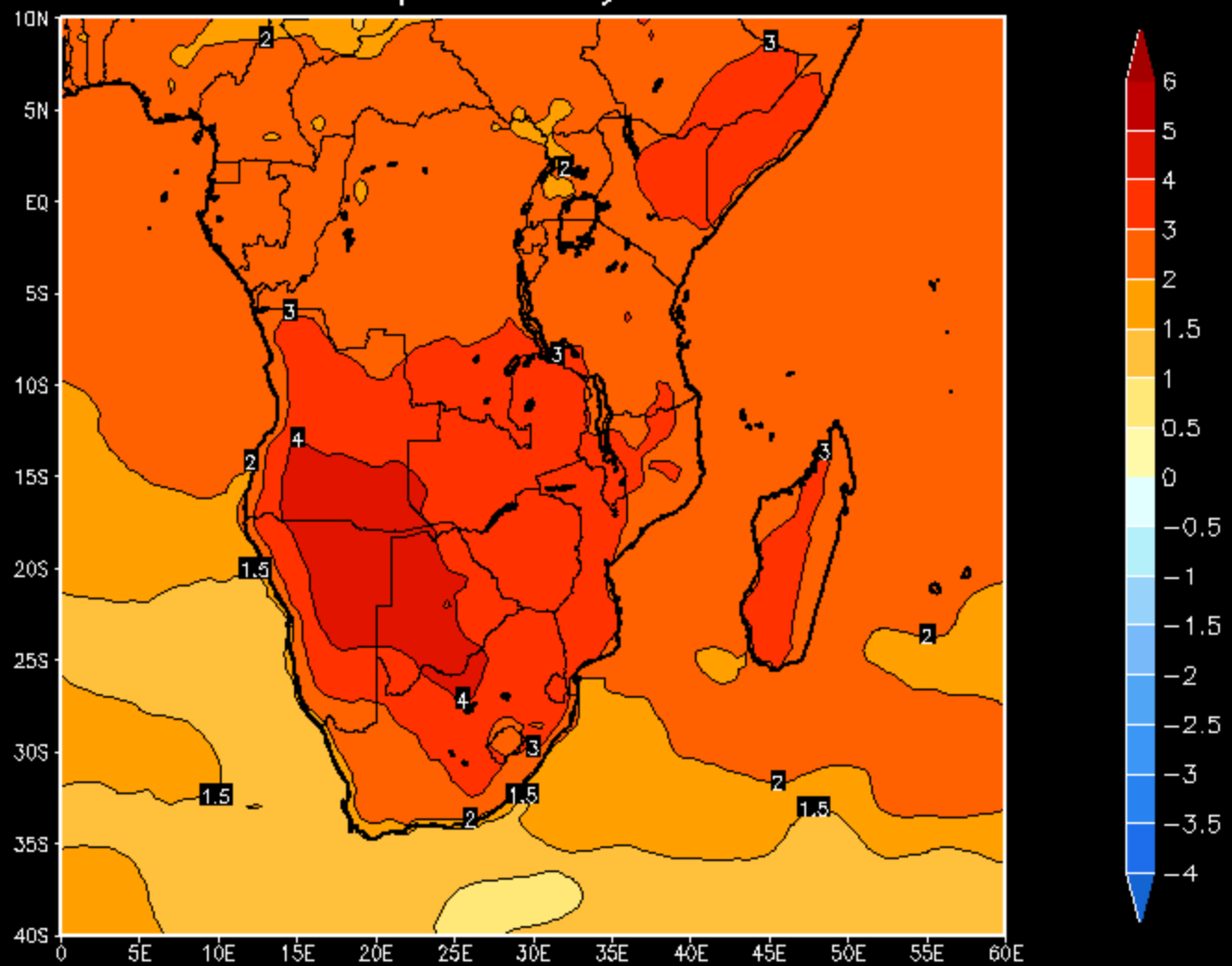
Temp anomaly 2062



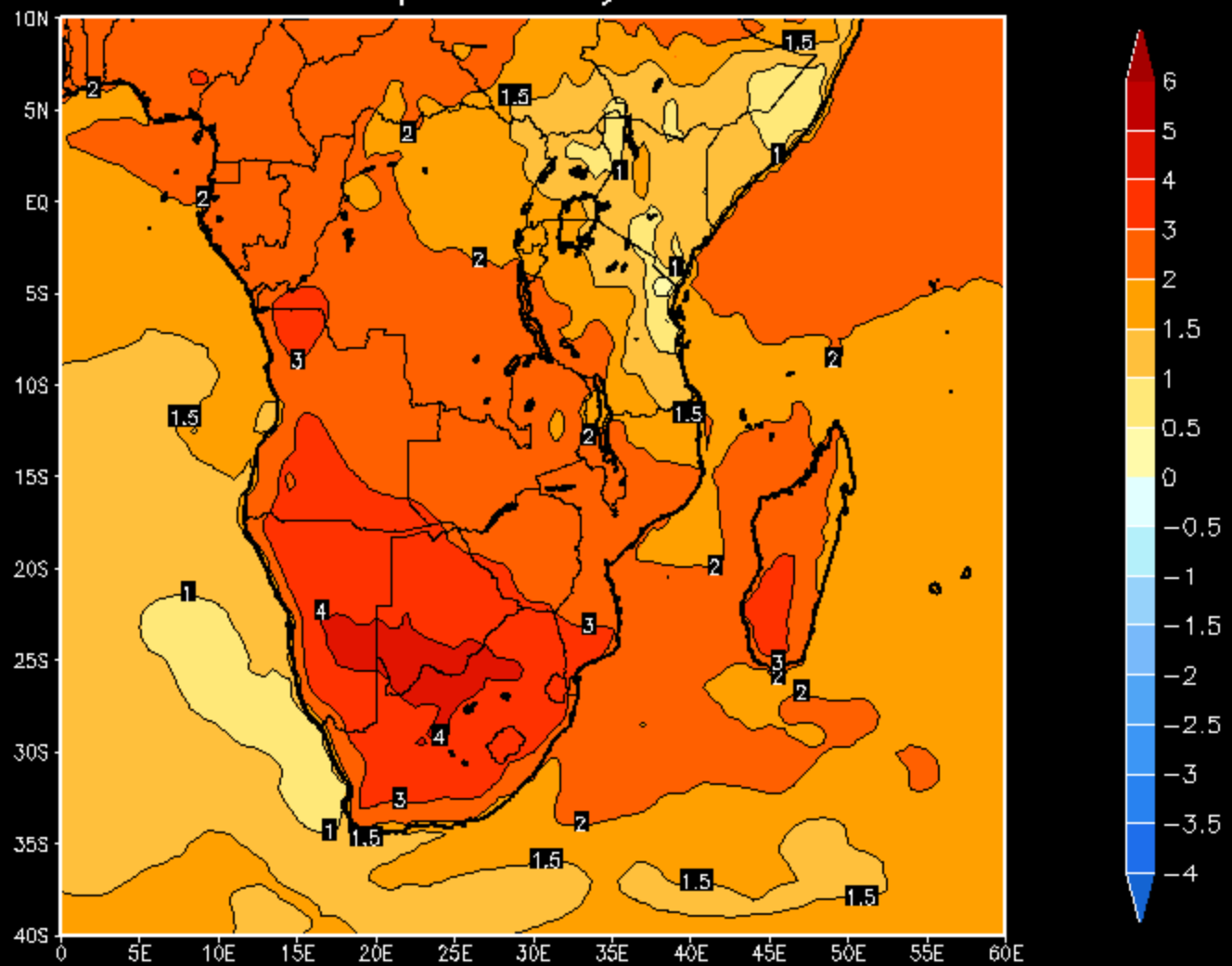
Temp anomaly 2063



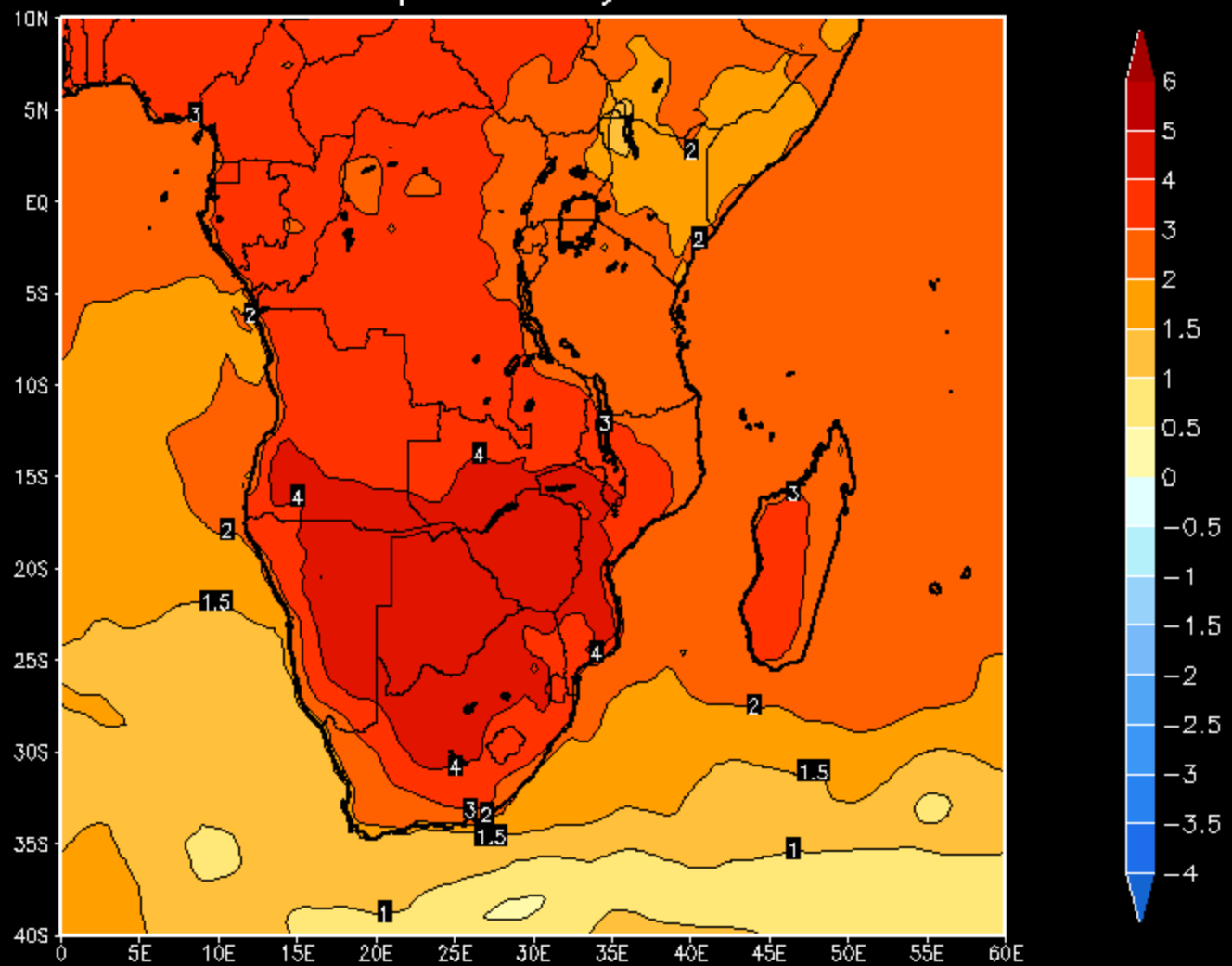
Temp anomaly 2064



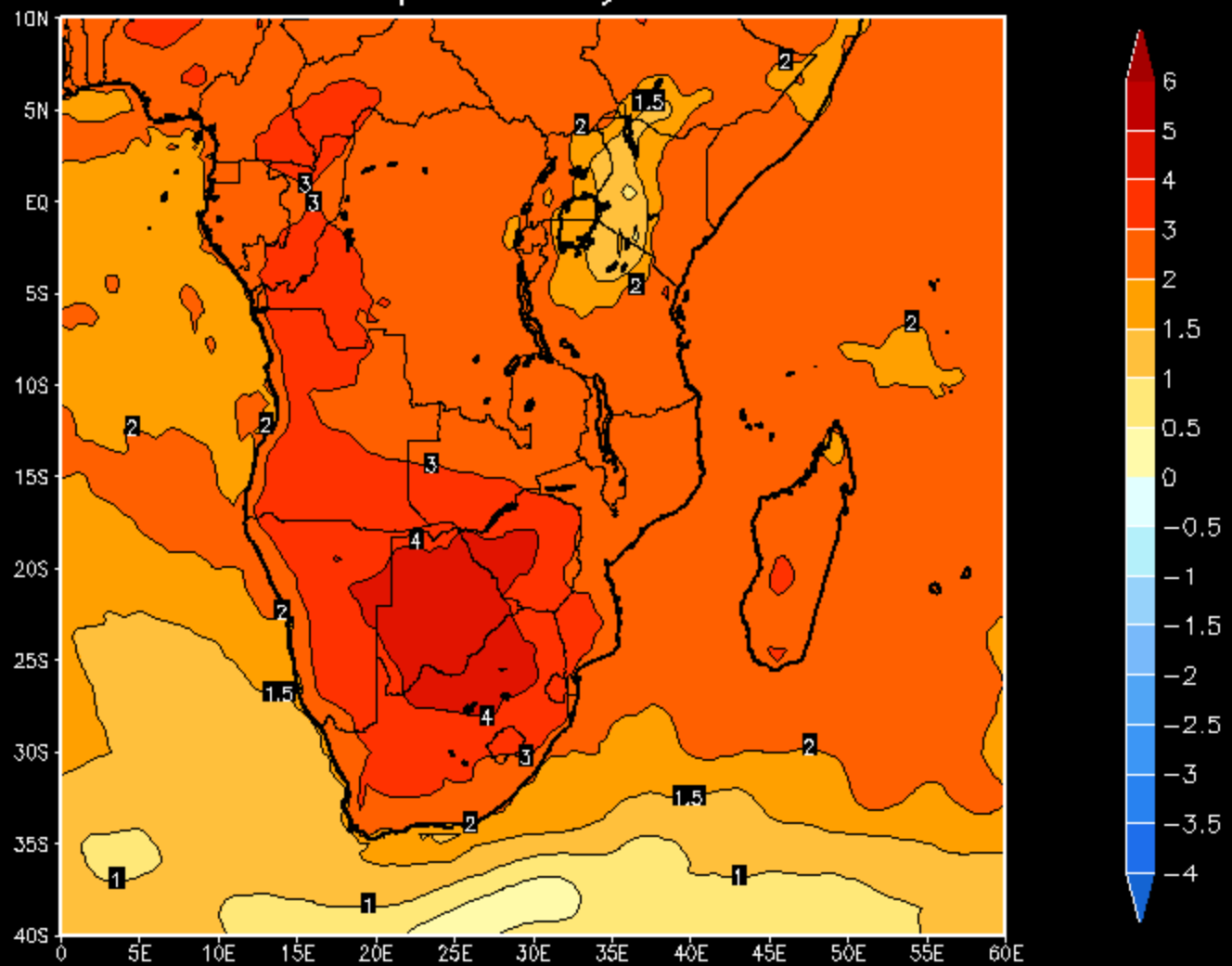
Temp anomaly 2065



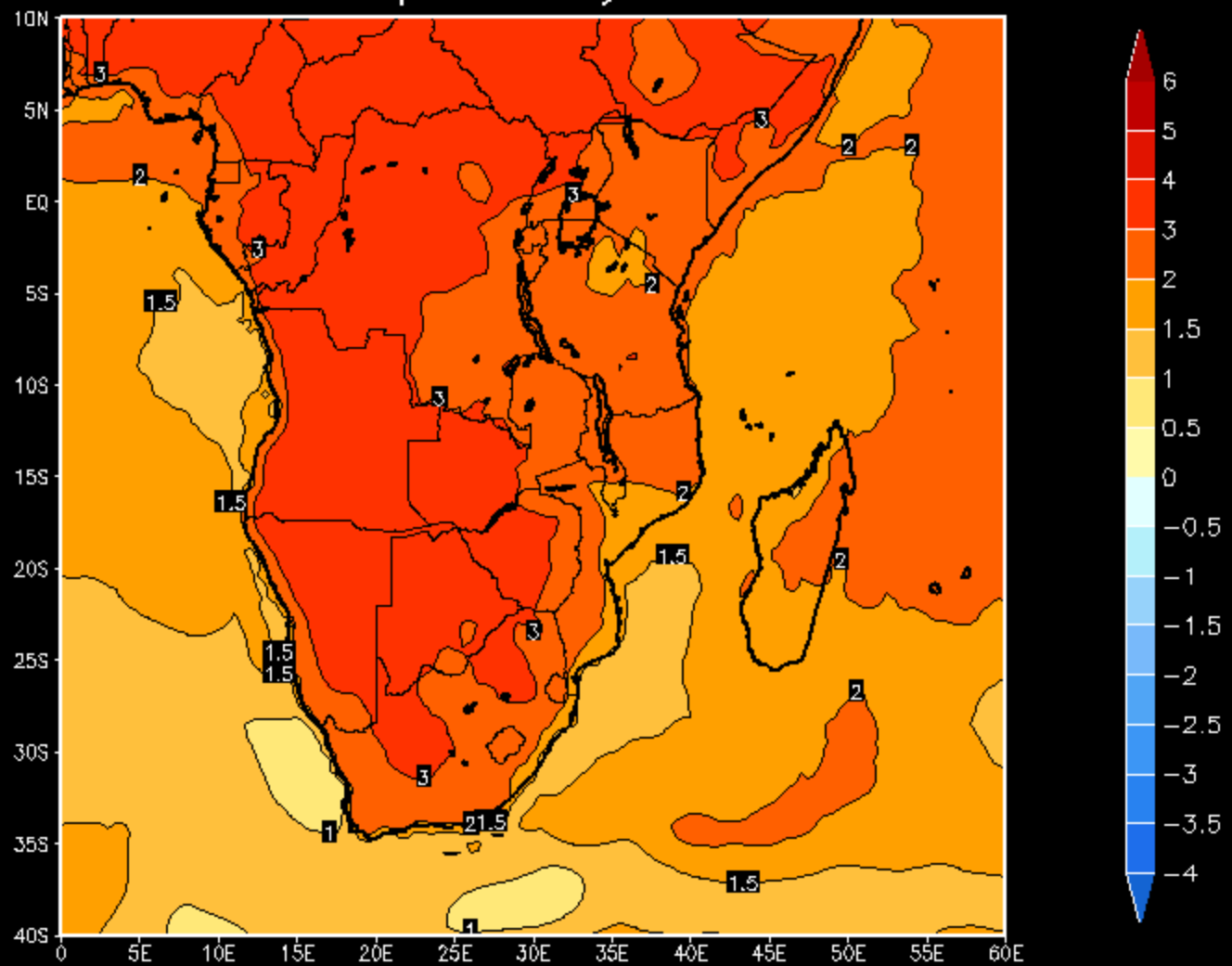
Temp anomaly 2066



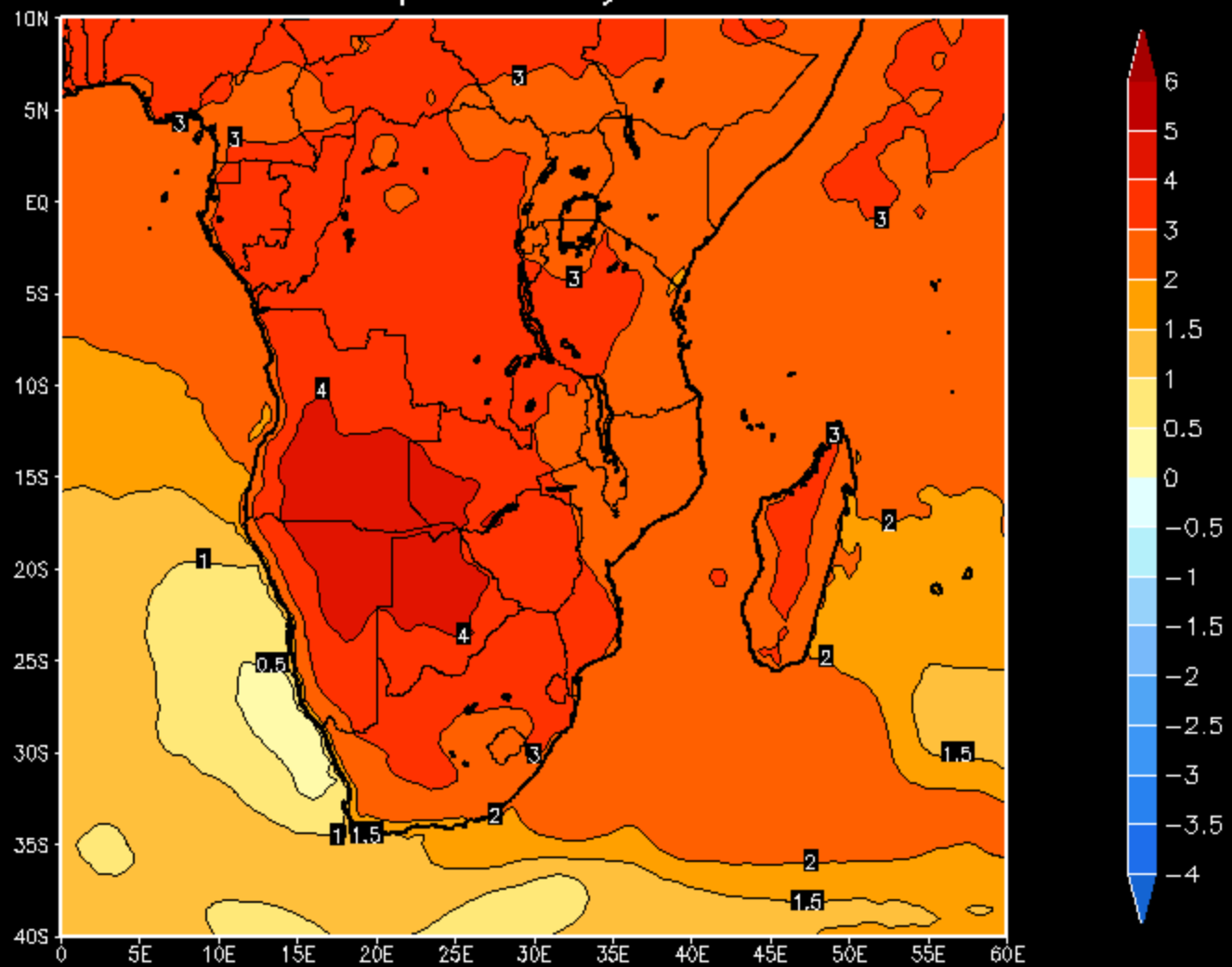
Temp anomaly 2067



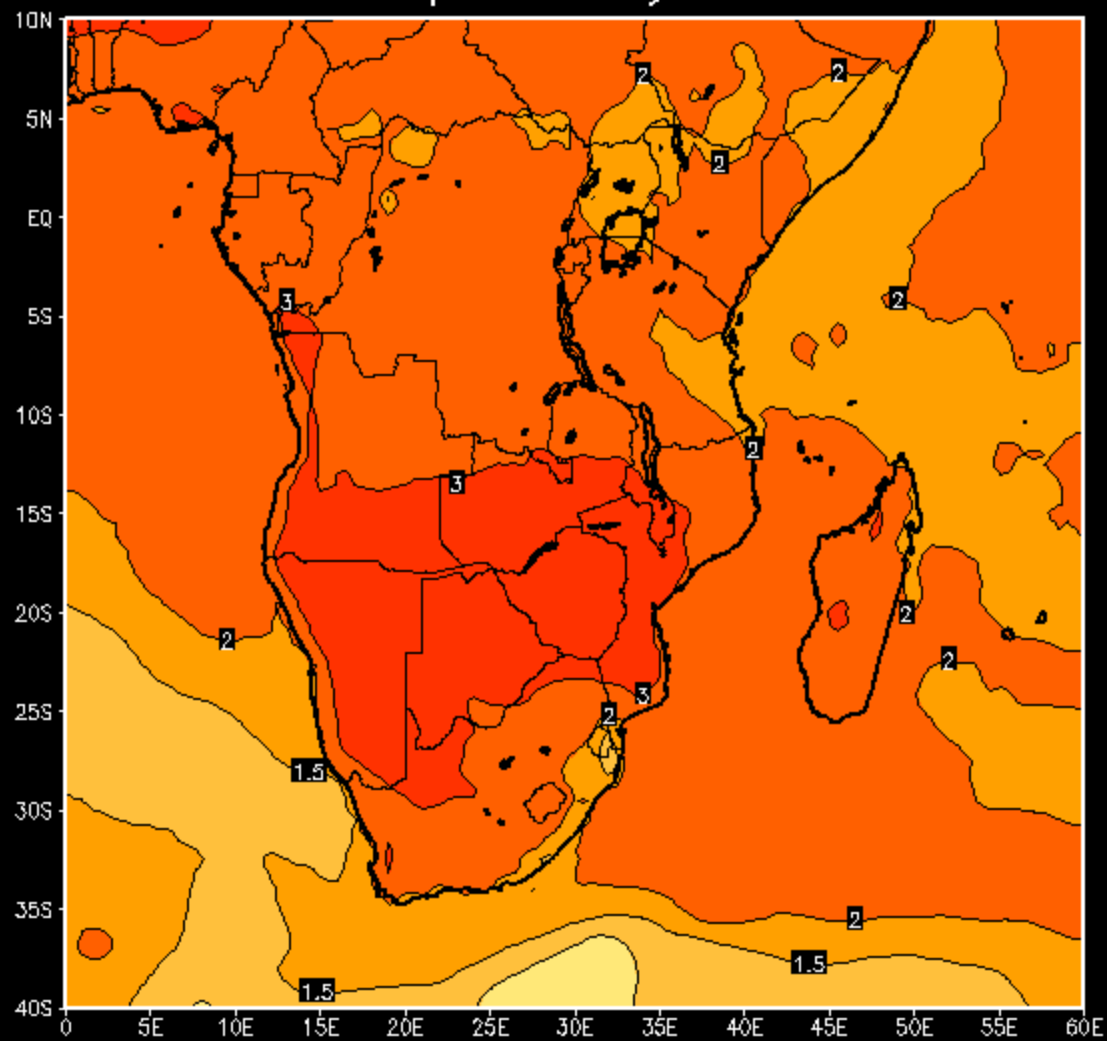
Temp anomaly 2068



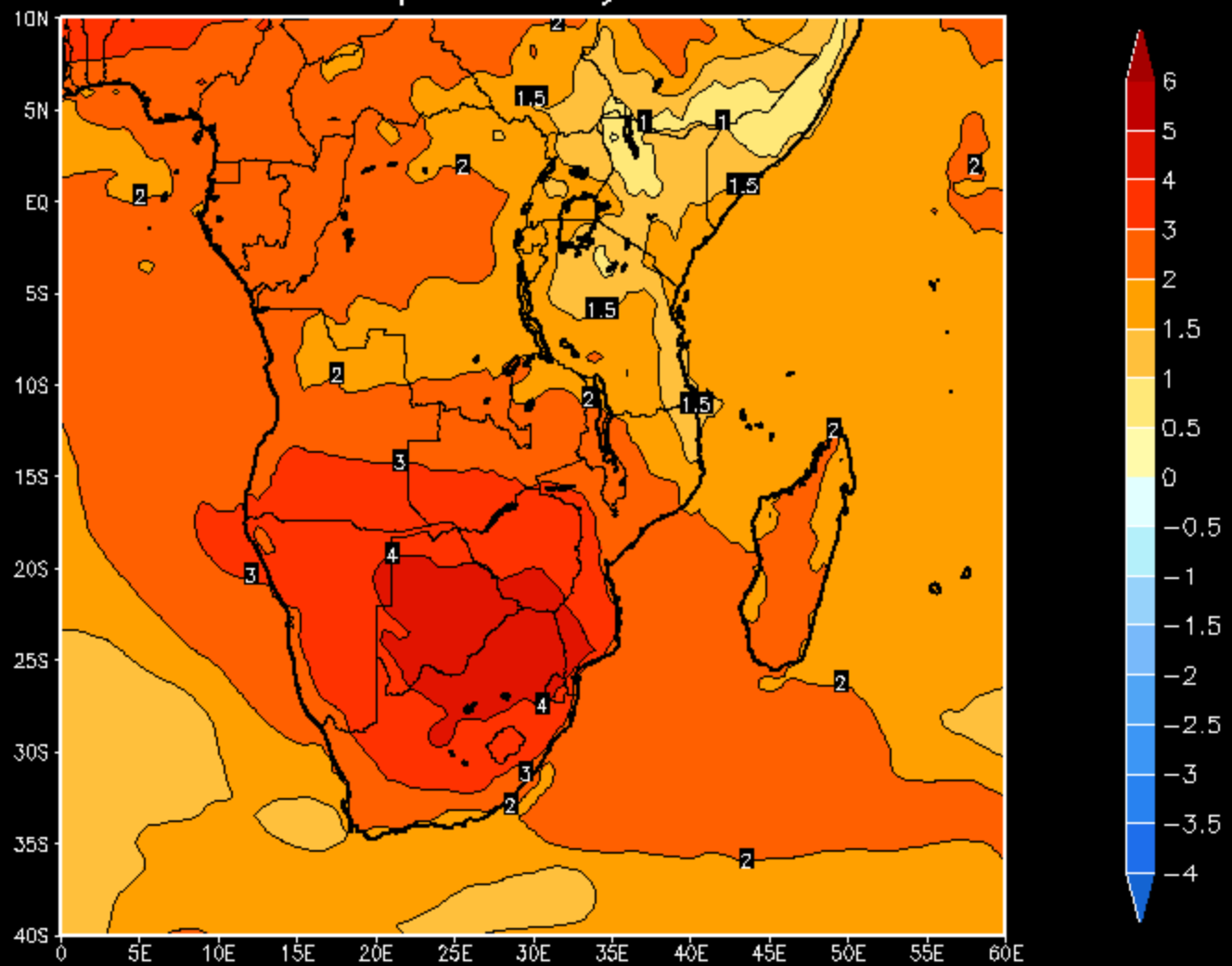
Temp anomaly 2069



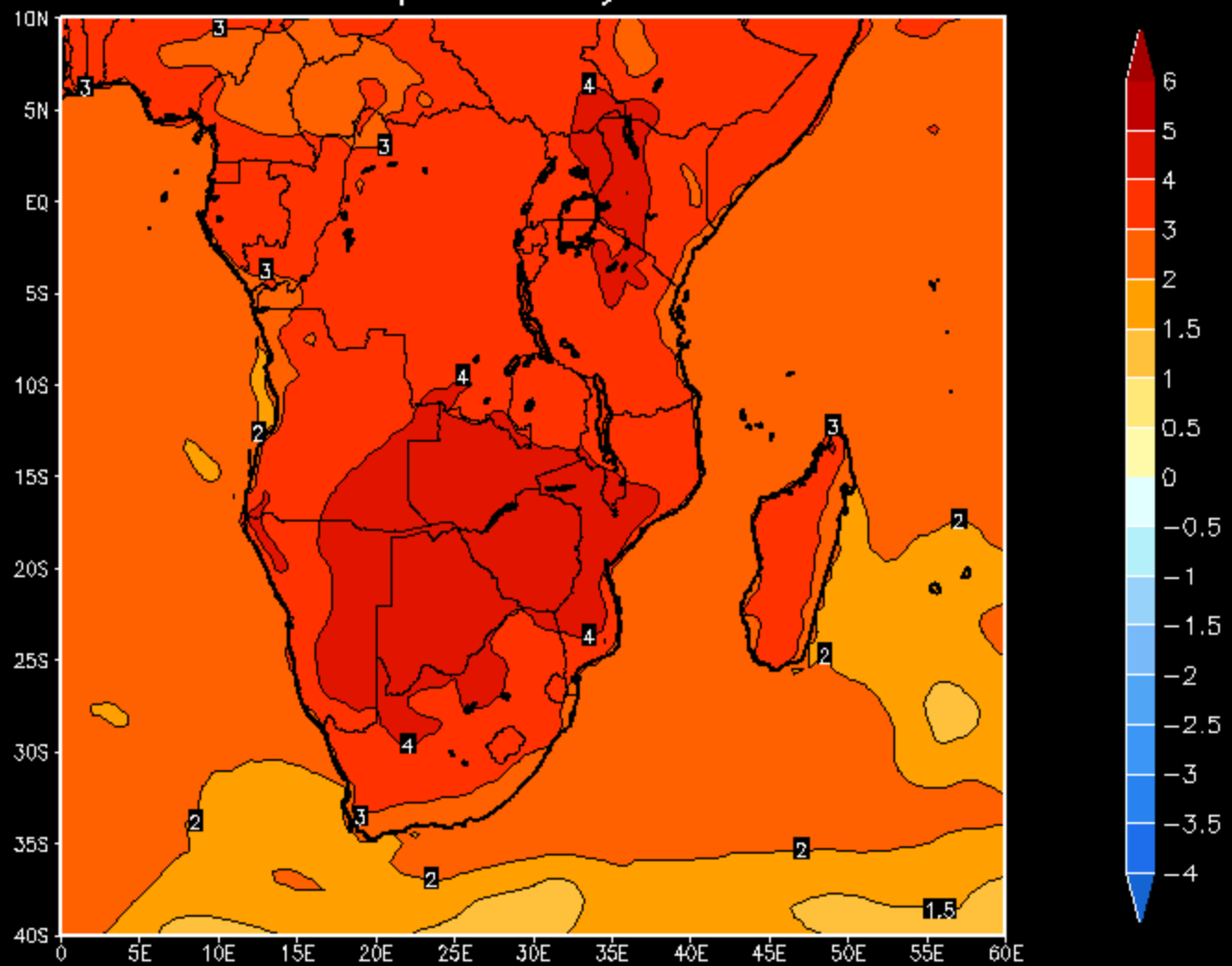
Temp anomaly 2070



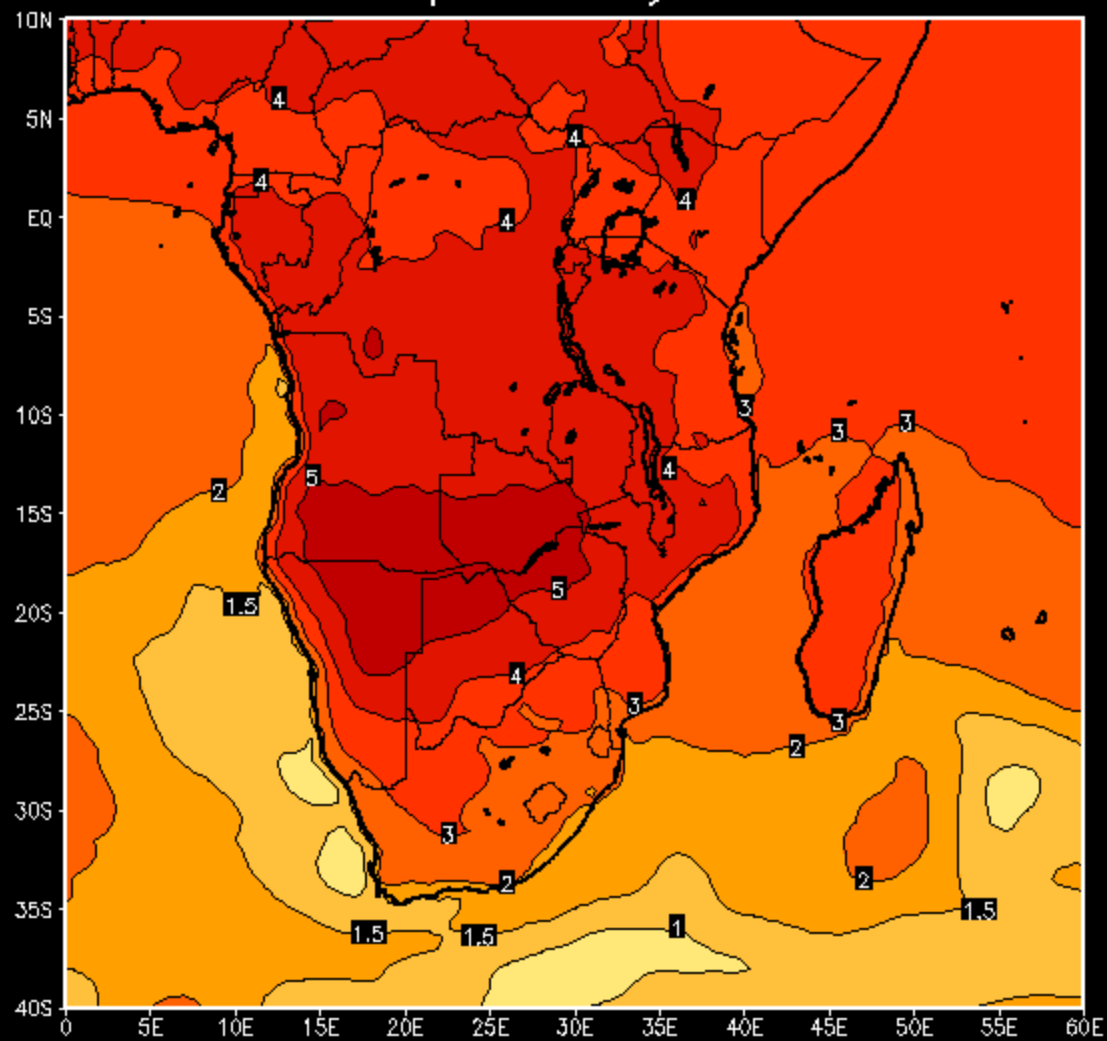
Temp anomaly 2071



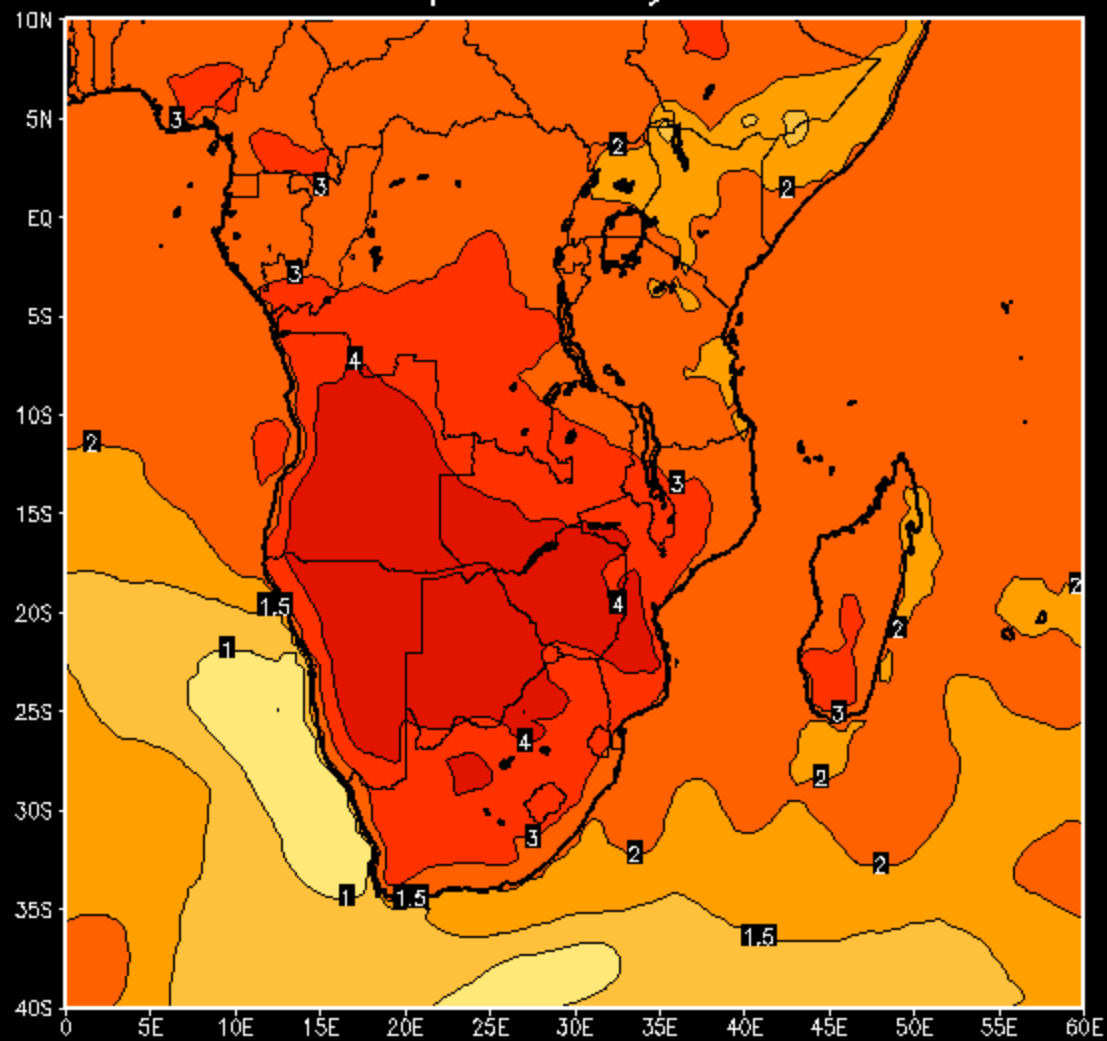
Temp anomaly 2072



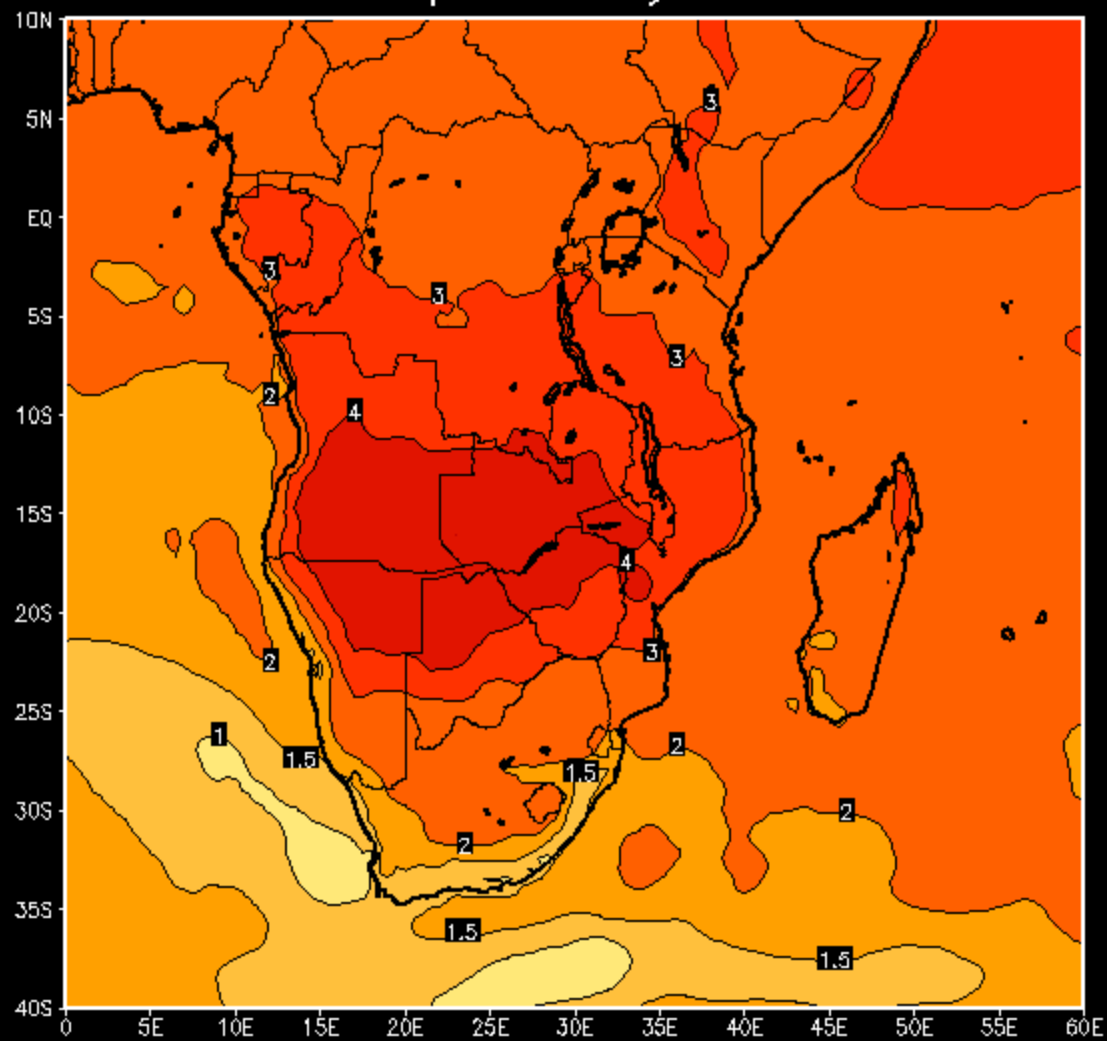
Temp anomaly 2073



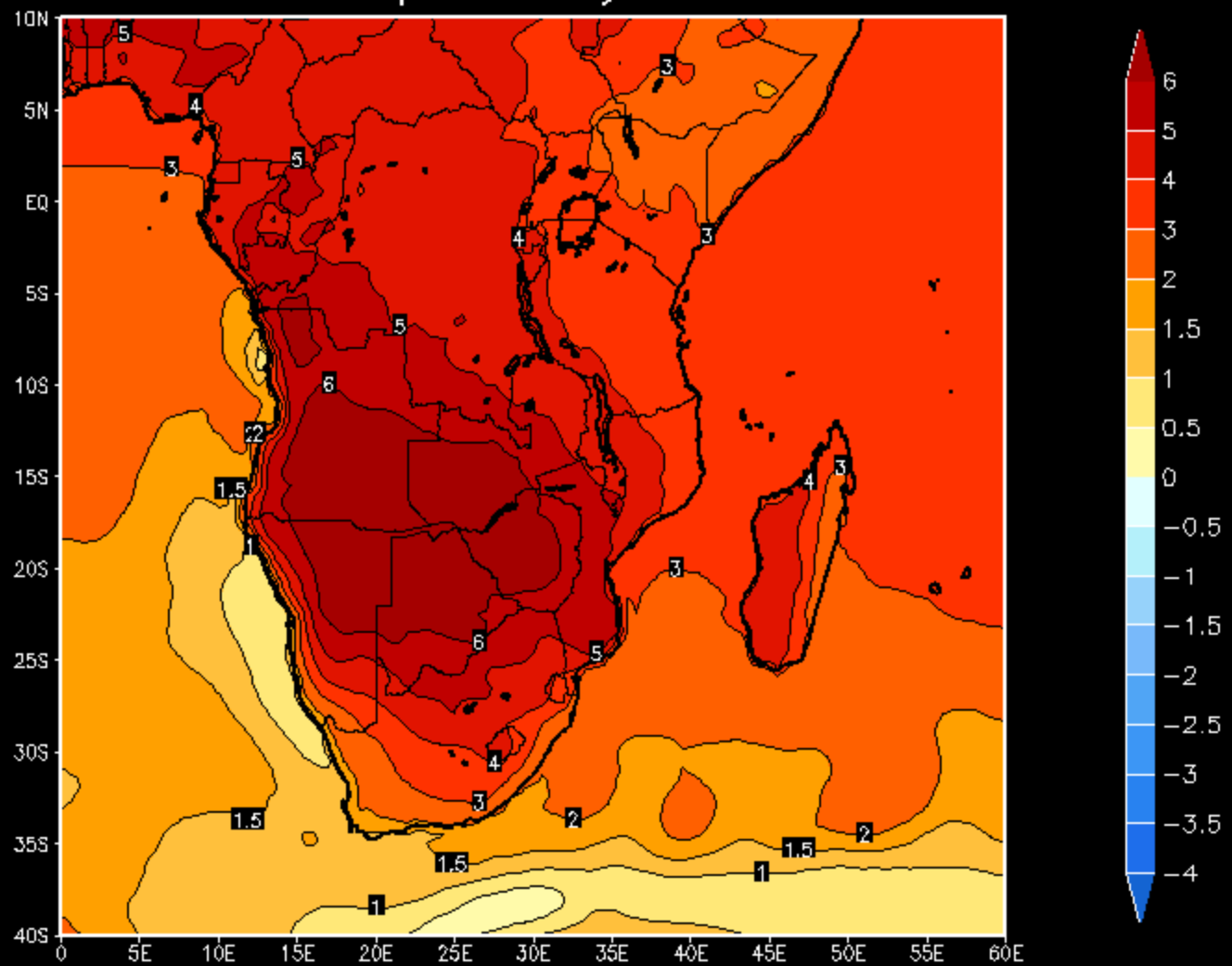
Temp anomaly 2074



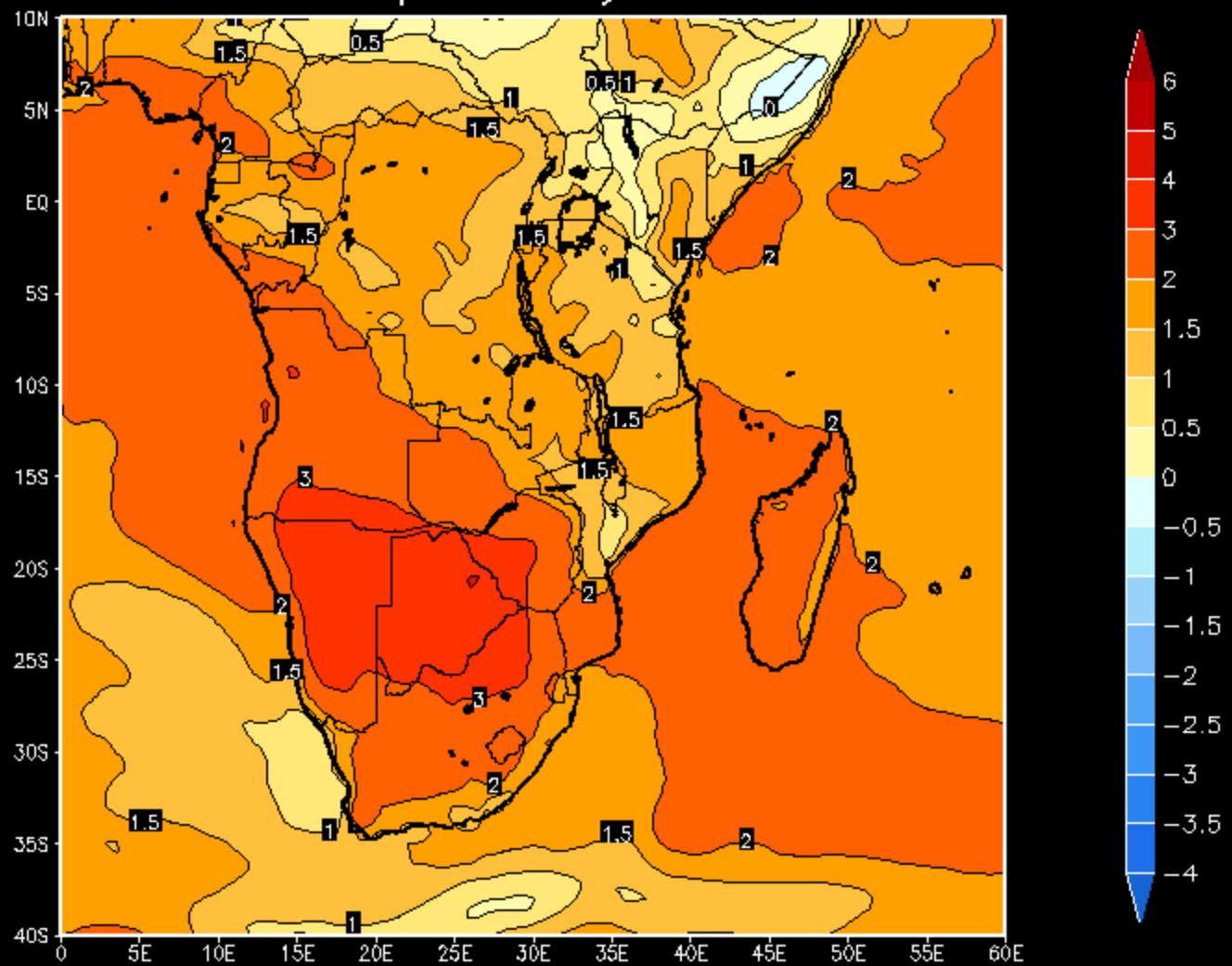
Temp anomaly 2075



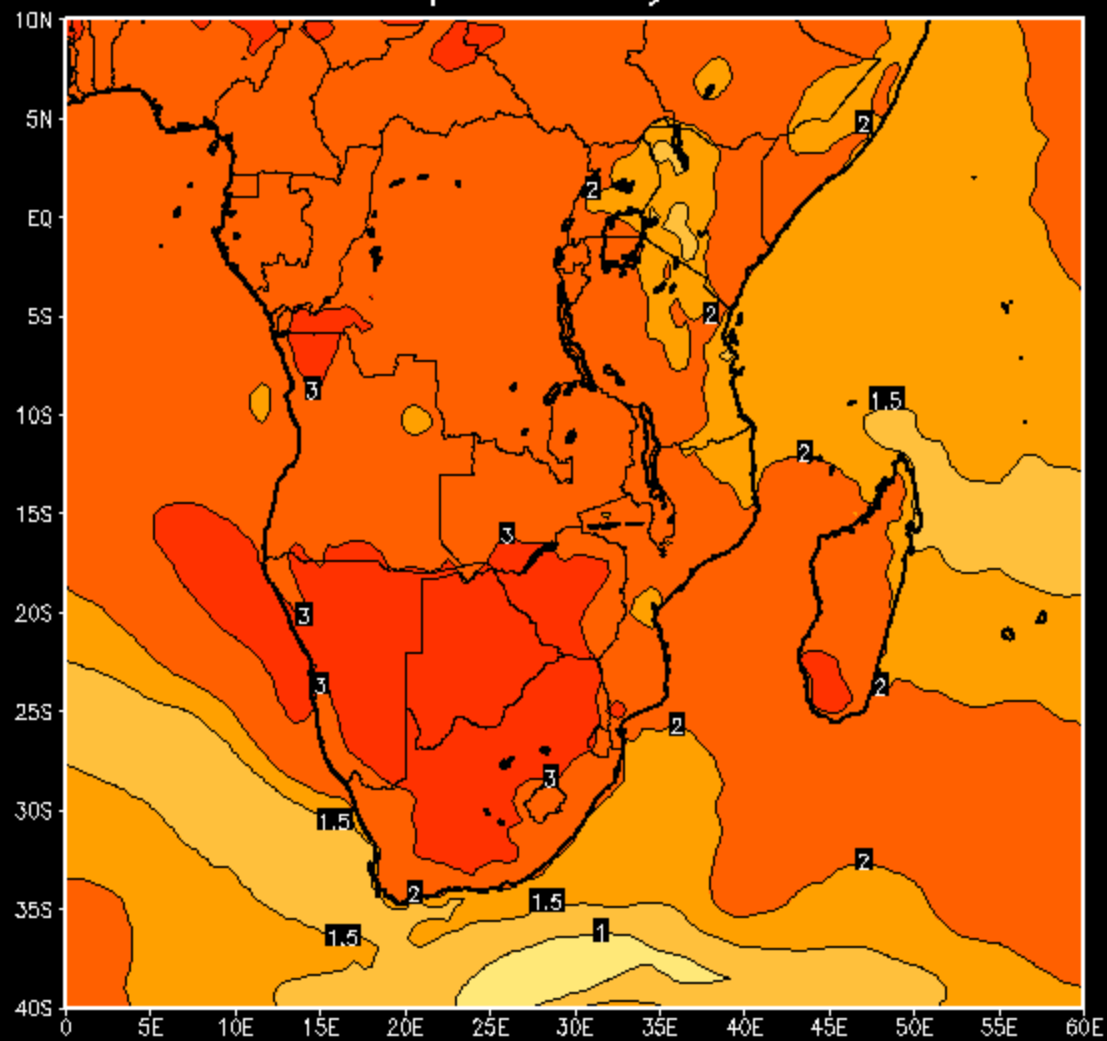
Temp anomaly 2076



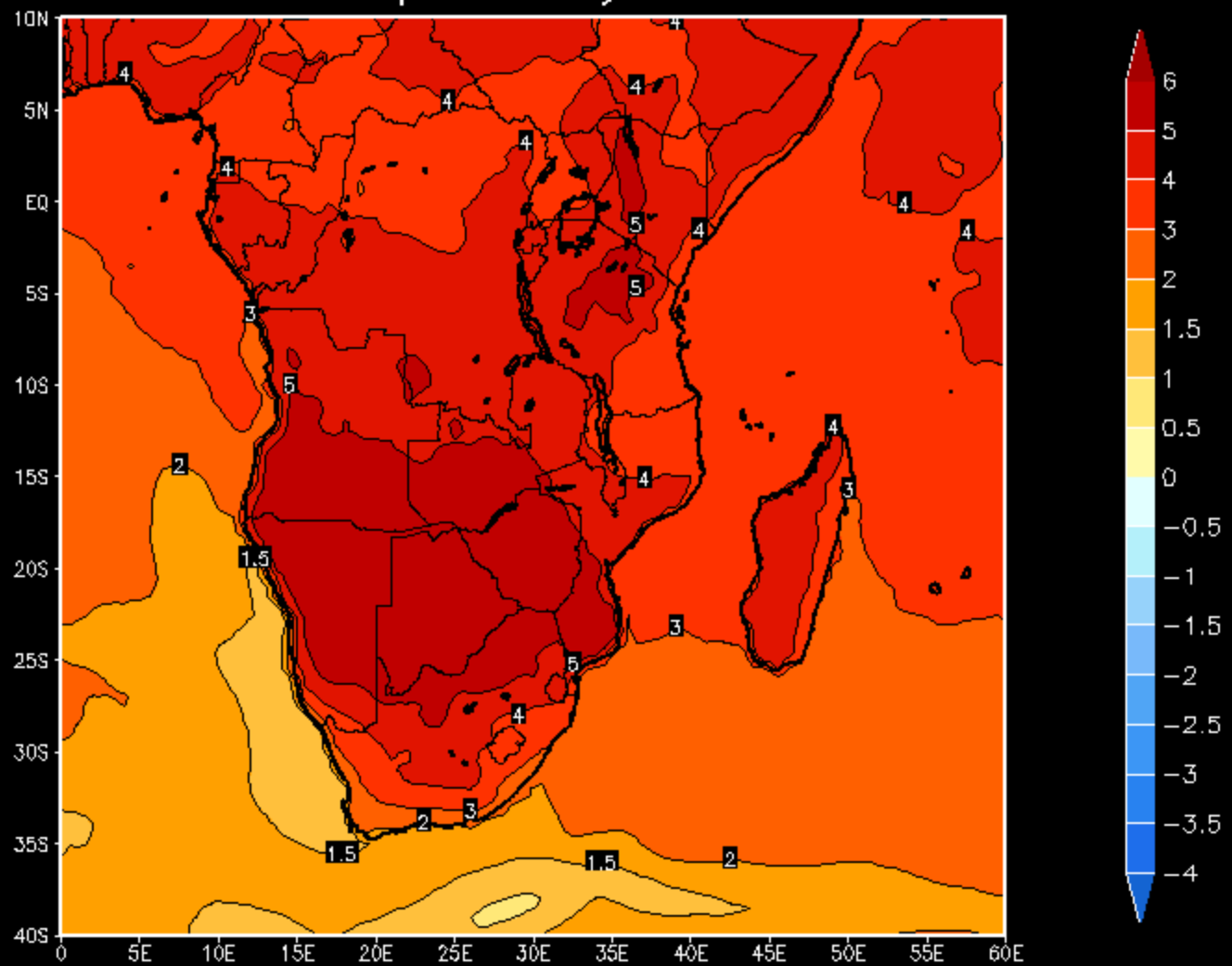
Temp anomaly 2077



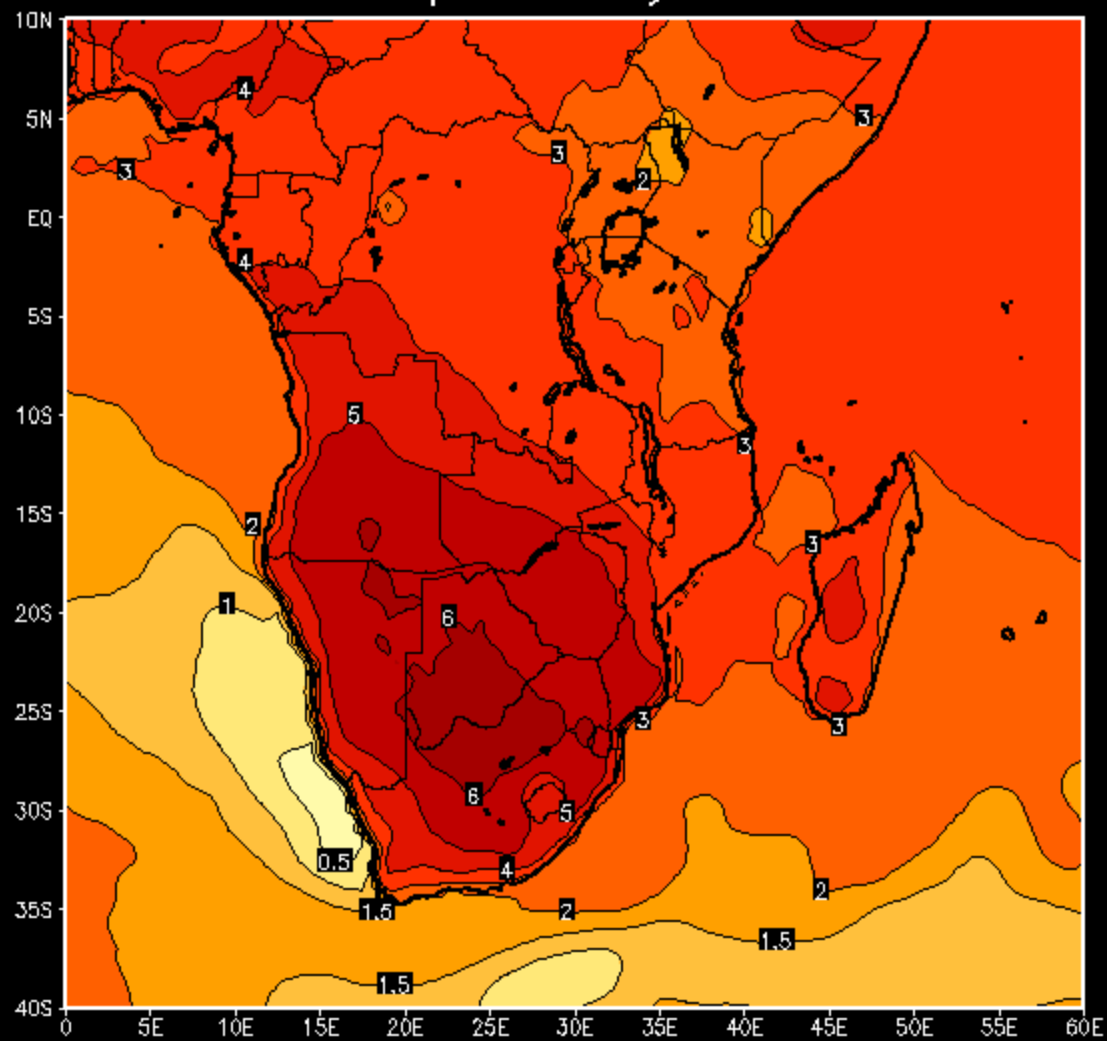
Temp anomaly 2078



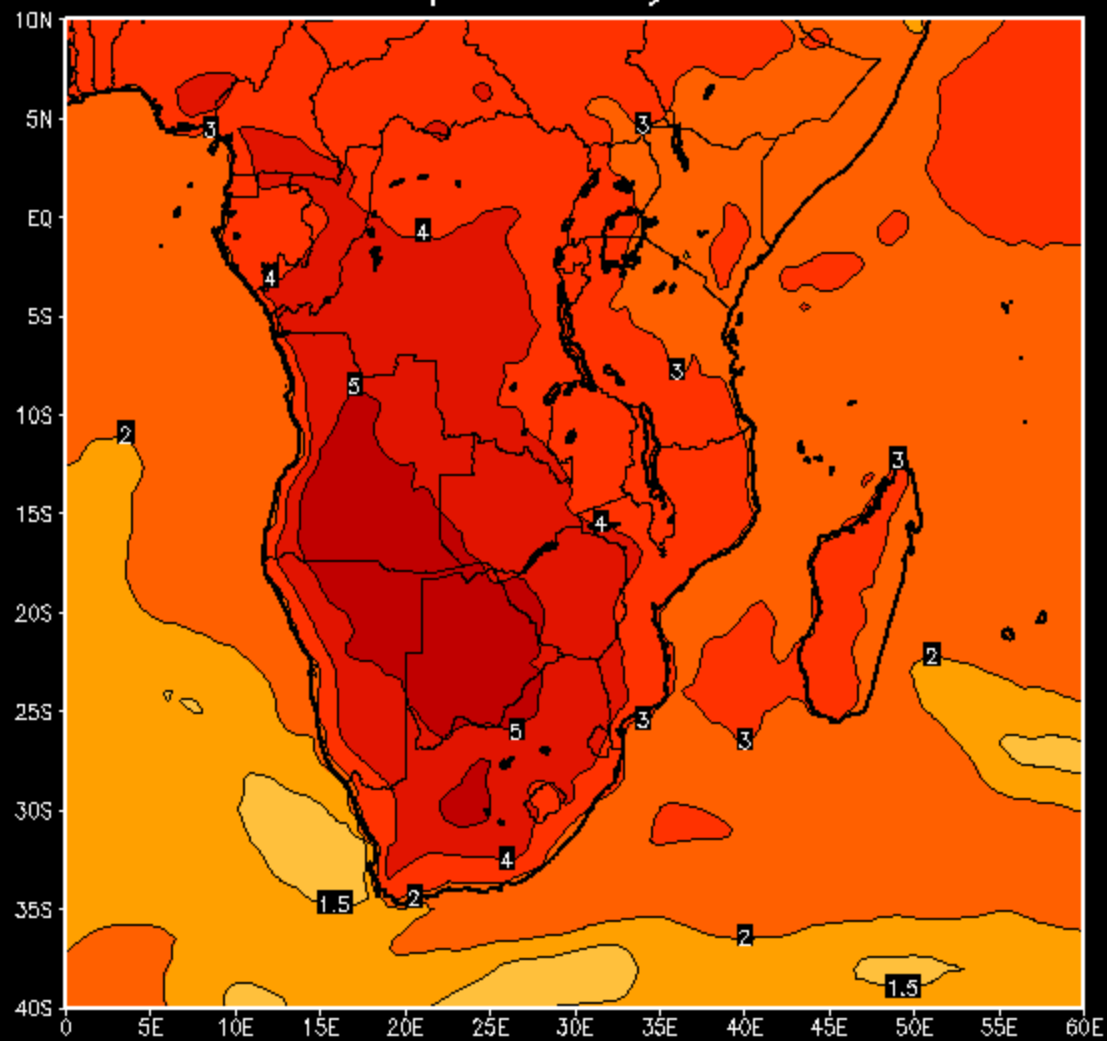
Temp anomaly 2079



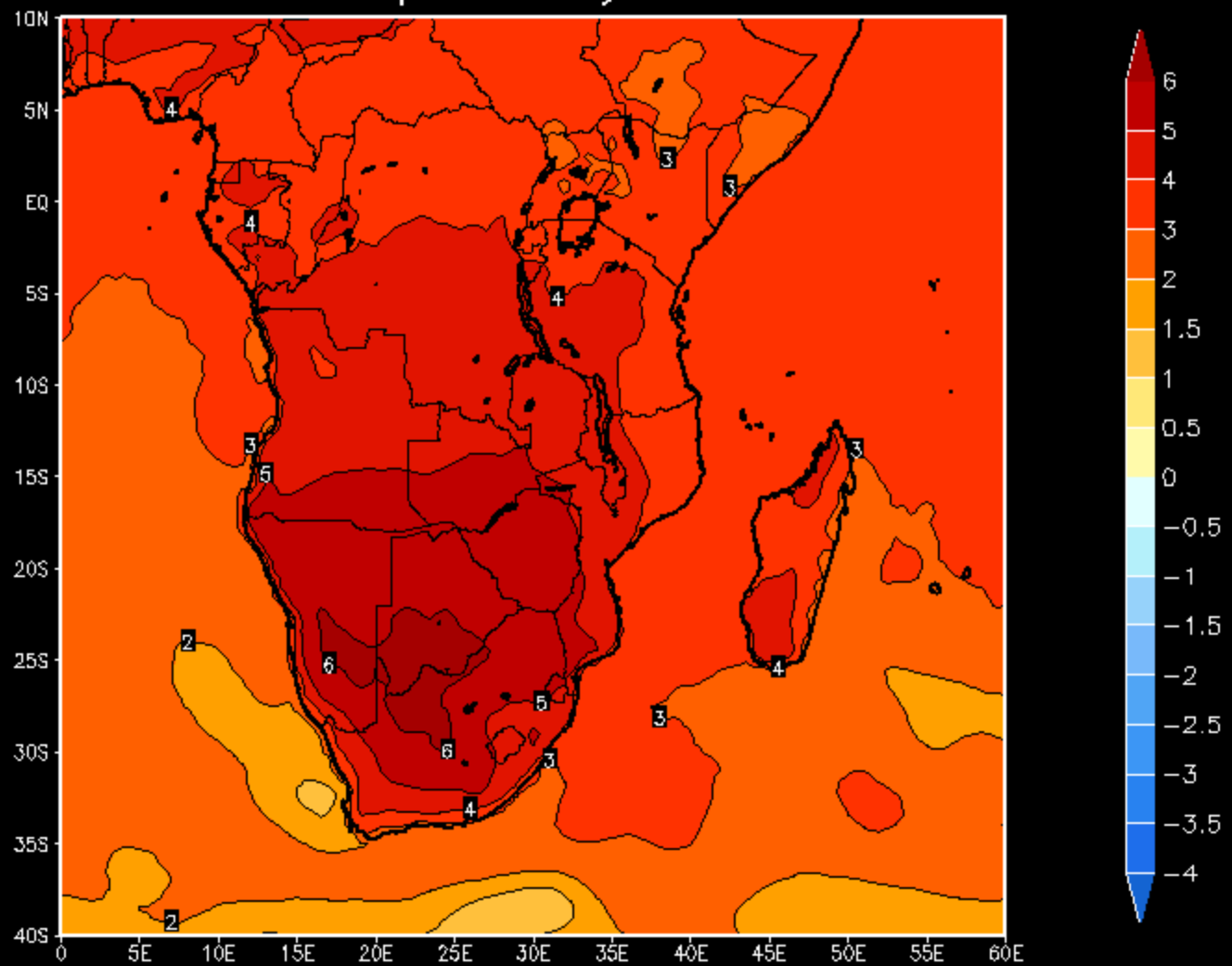
Temp anomaly 2080



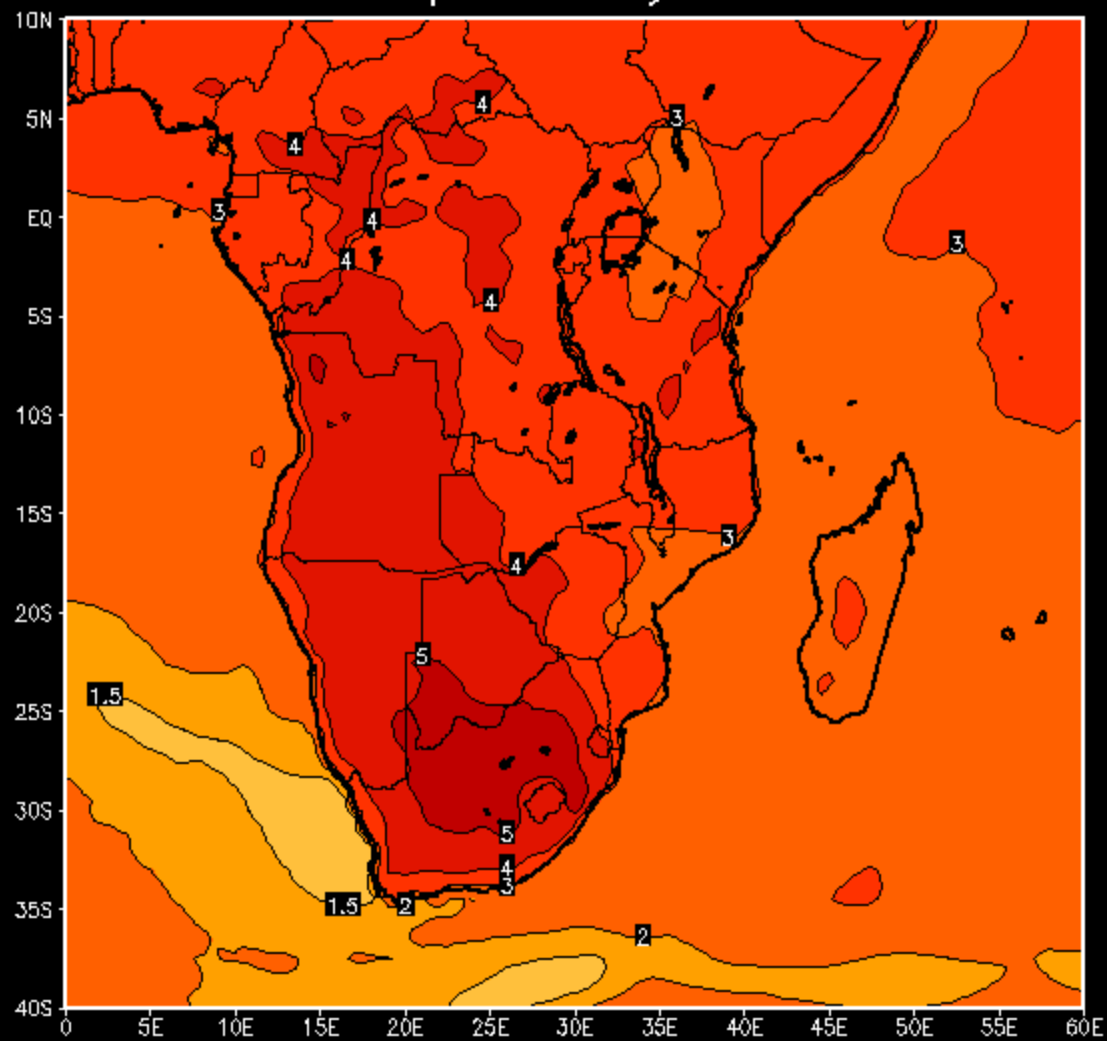
Temp anomaly 2081



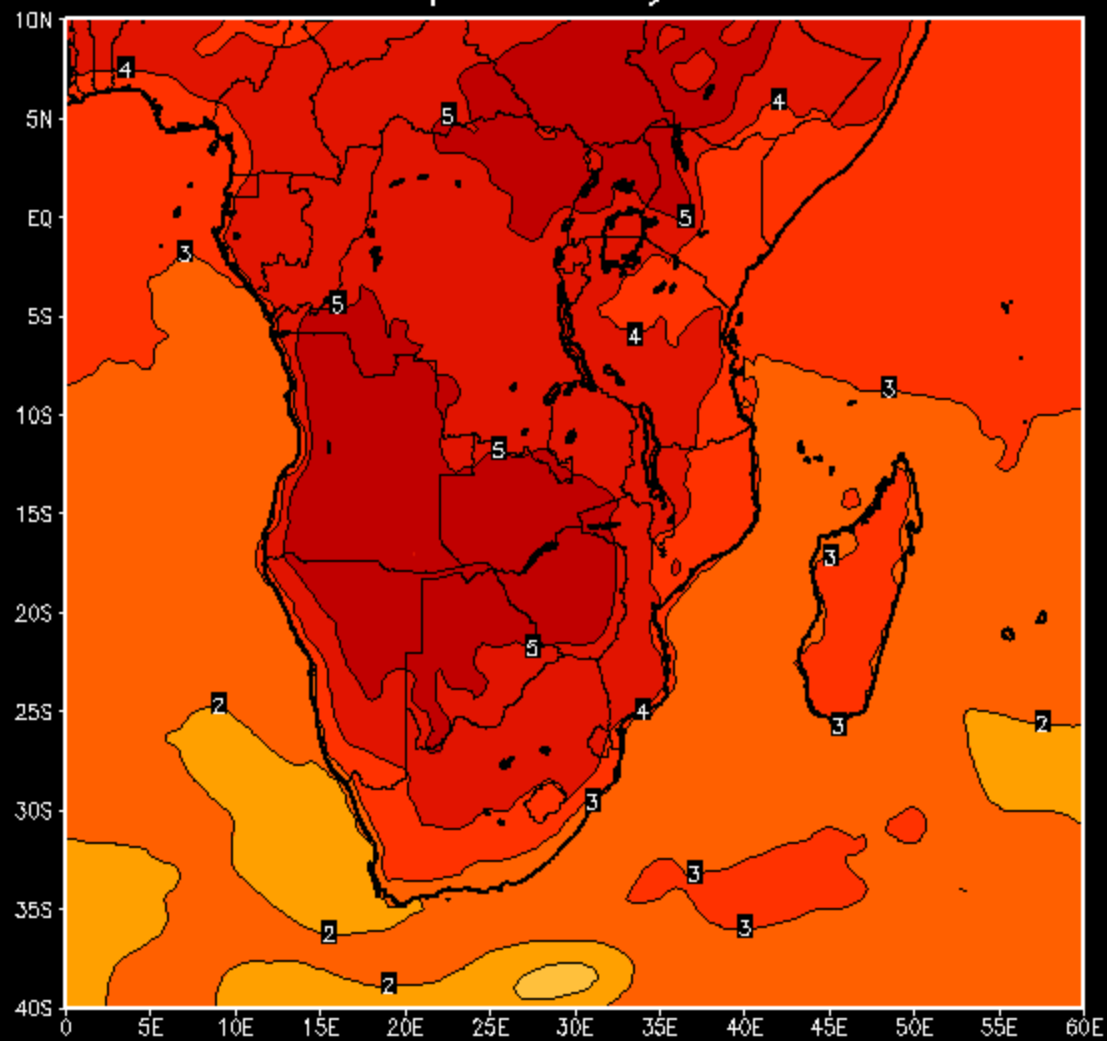
Temp anomaly 2082



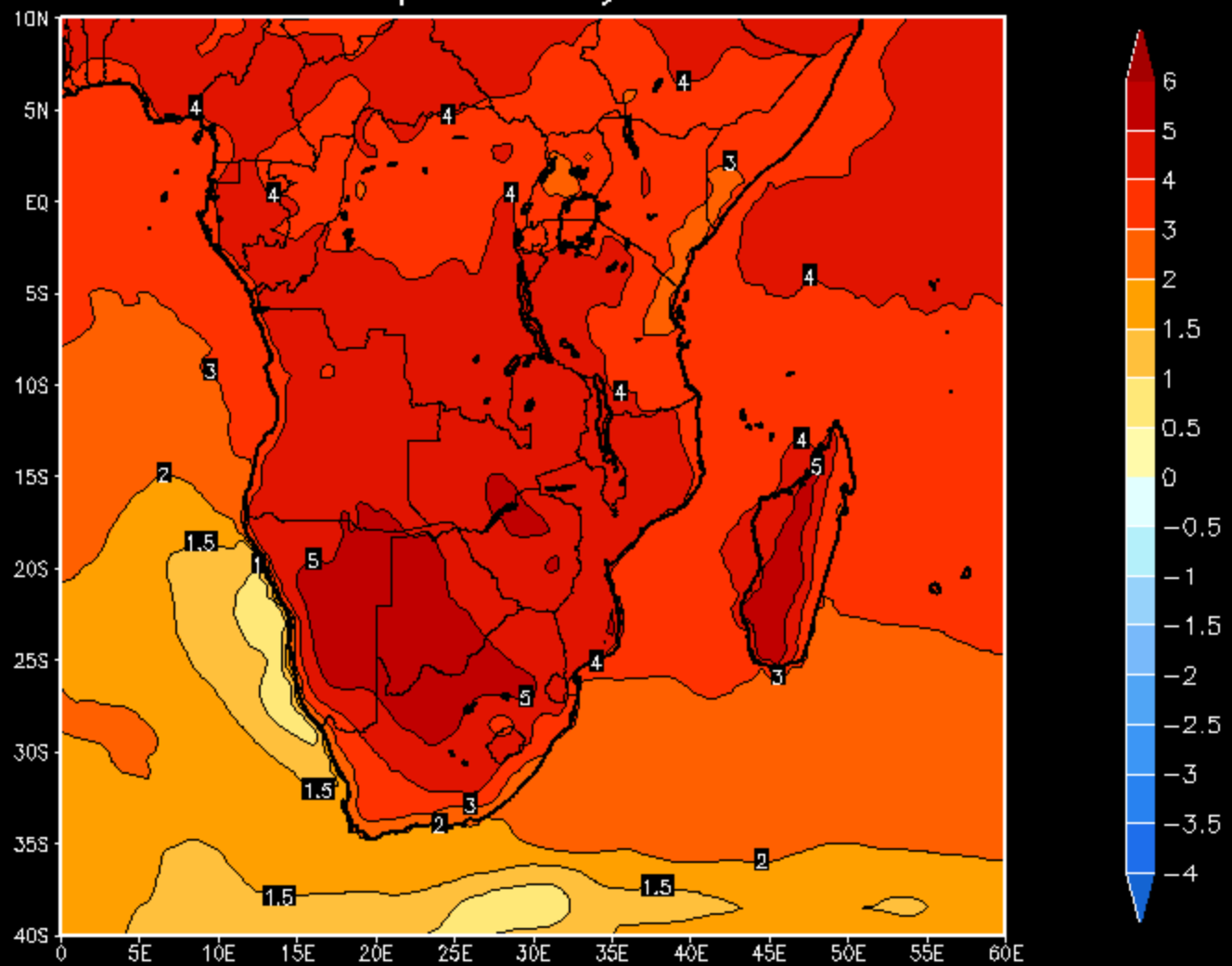
Temp anomaly 2083



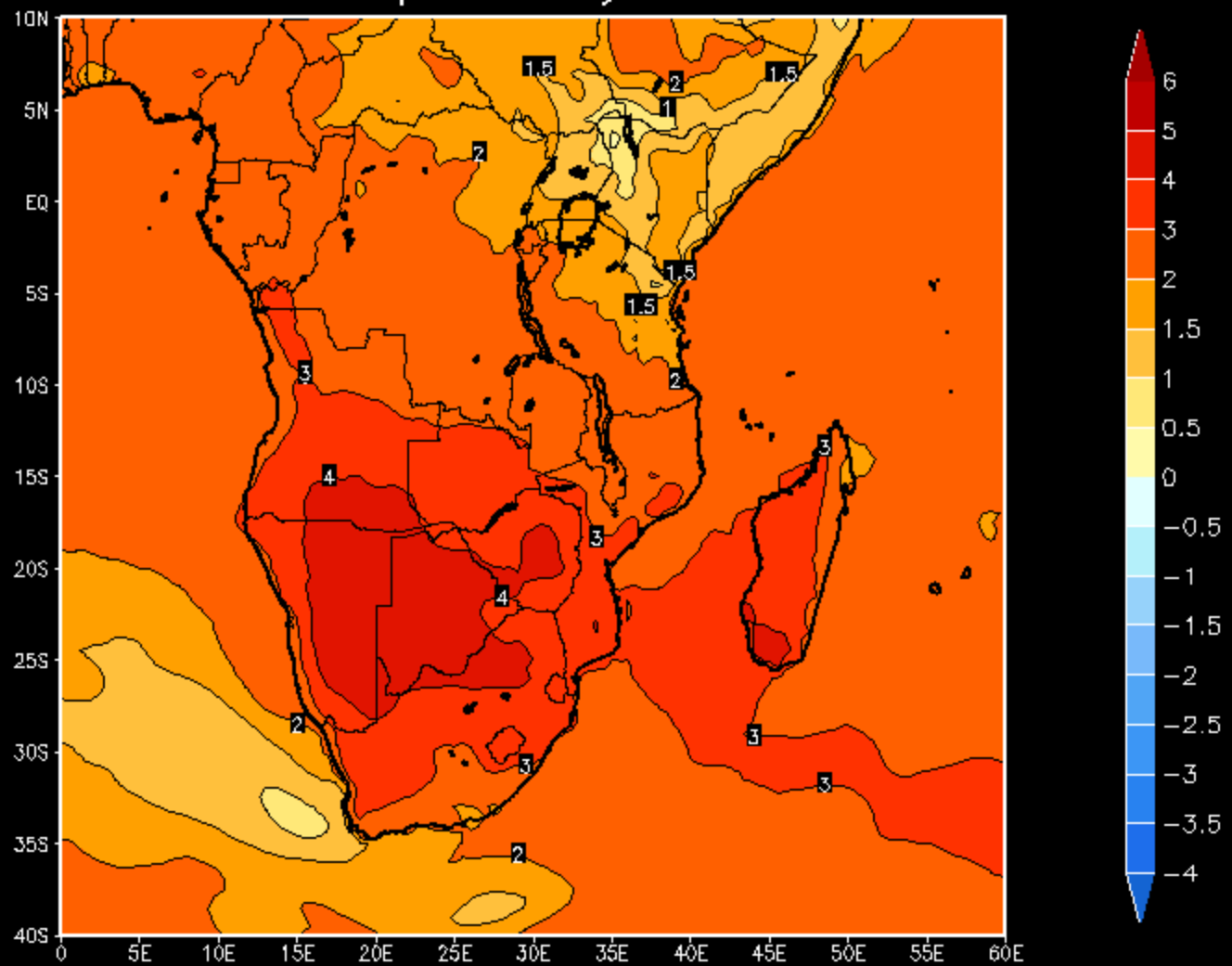
Temp anomaly 2084



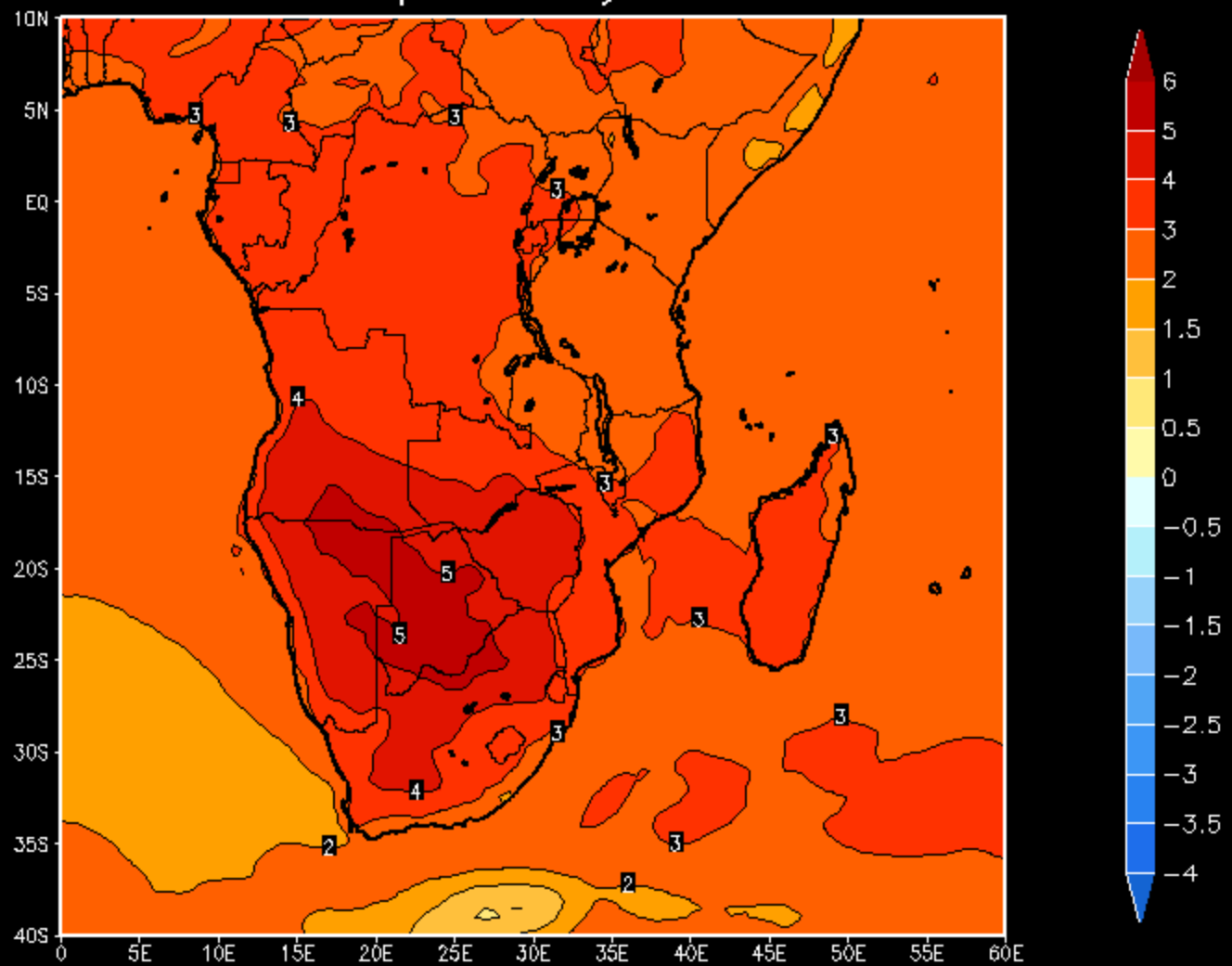
Temp anomaly 2085



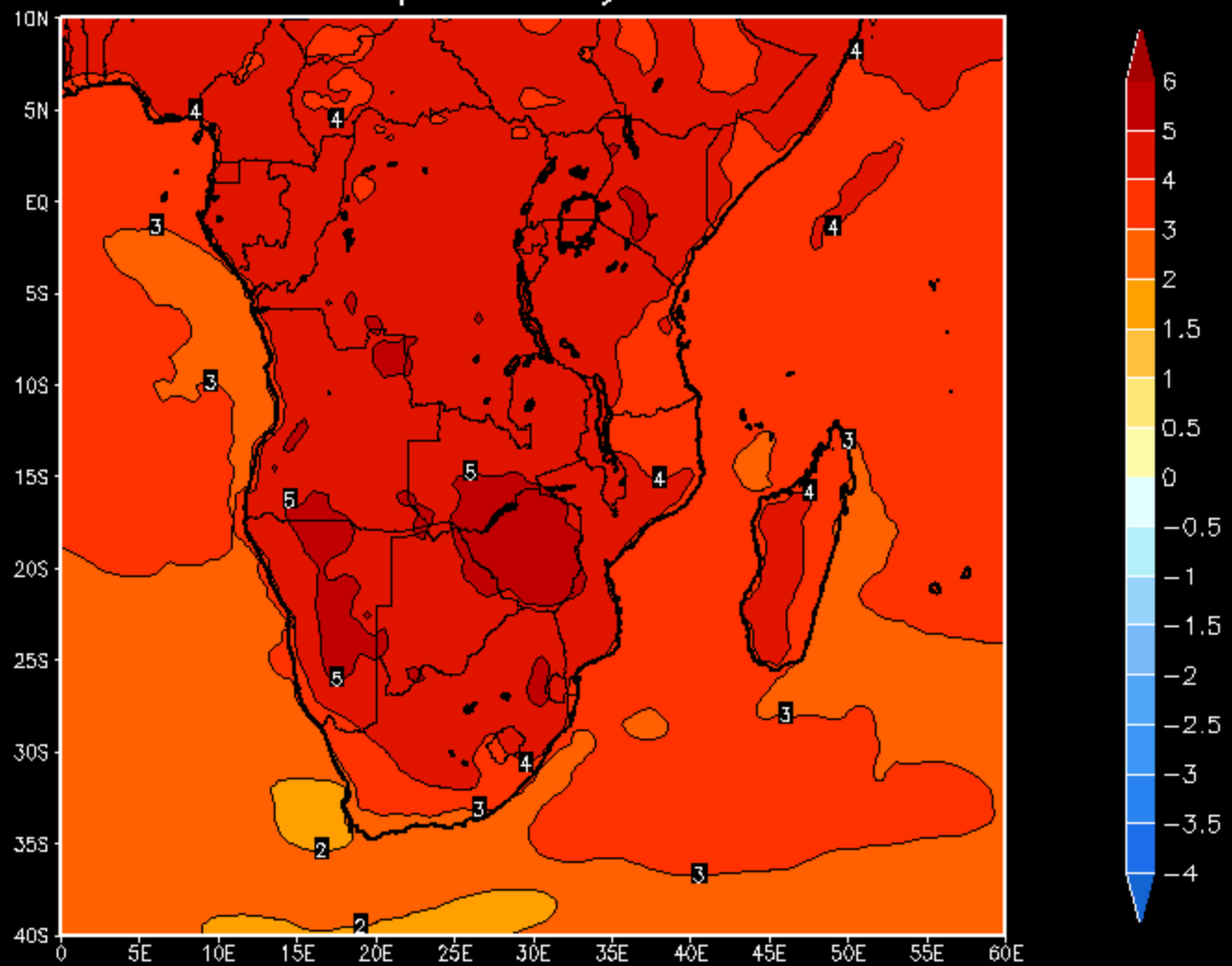
Temp anomaly 2086



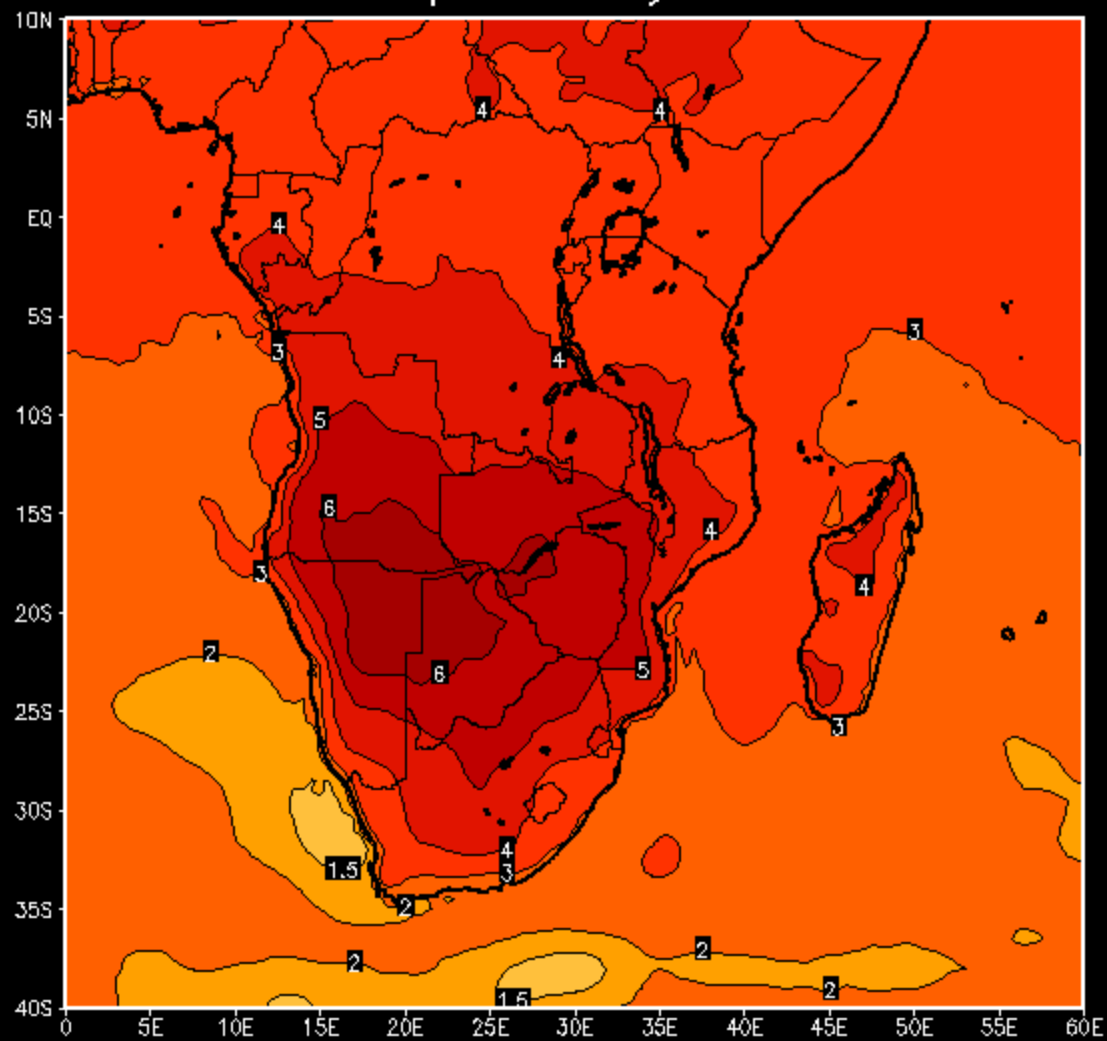
Temp anomaly 2087



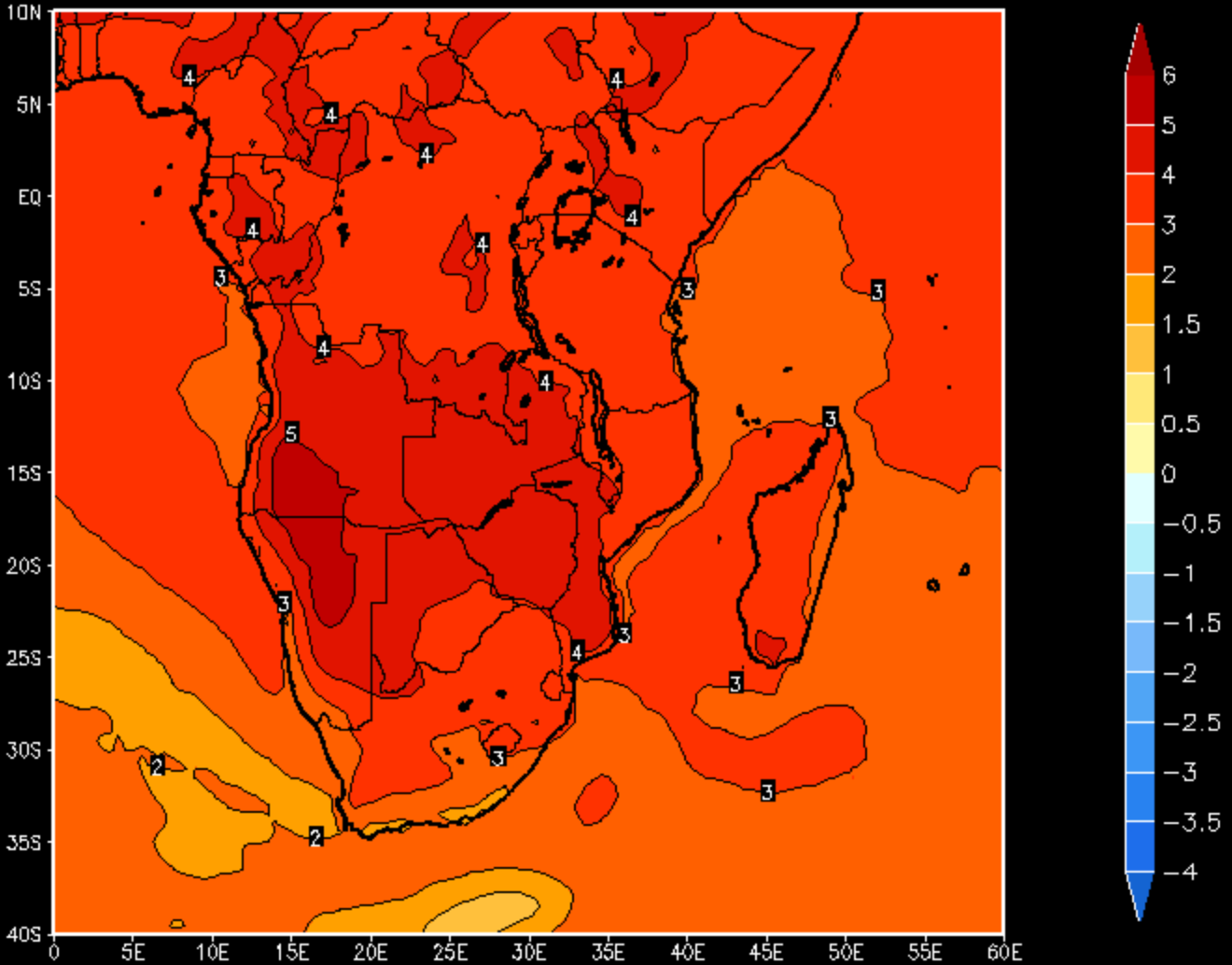
Temp anomaly 2088



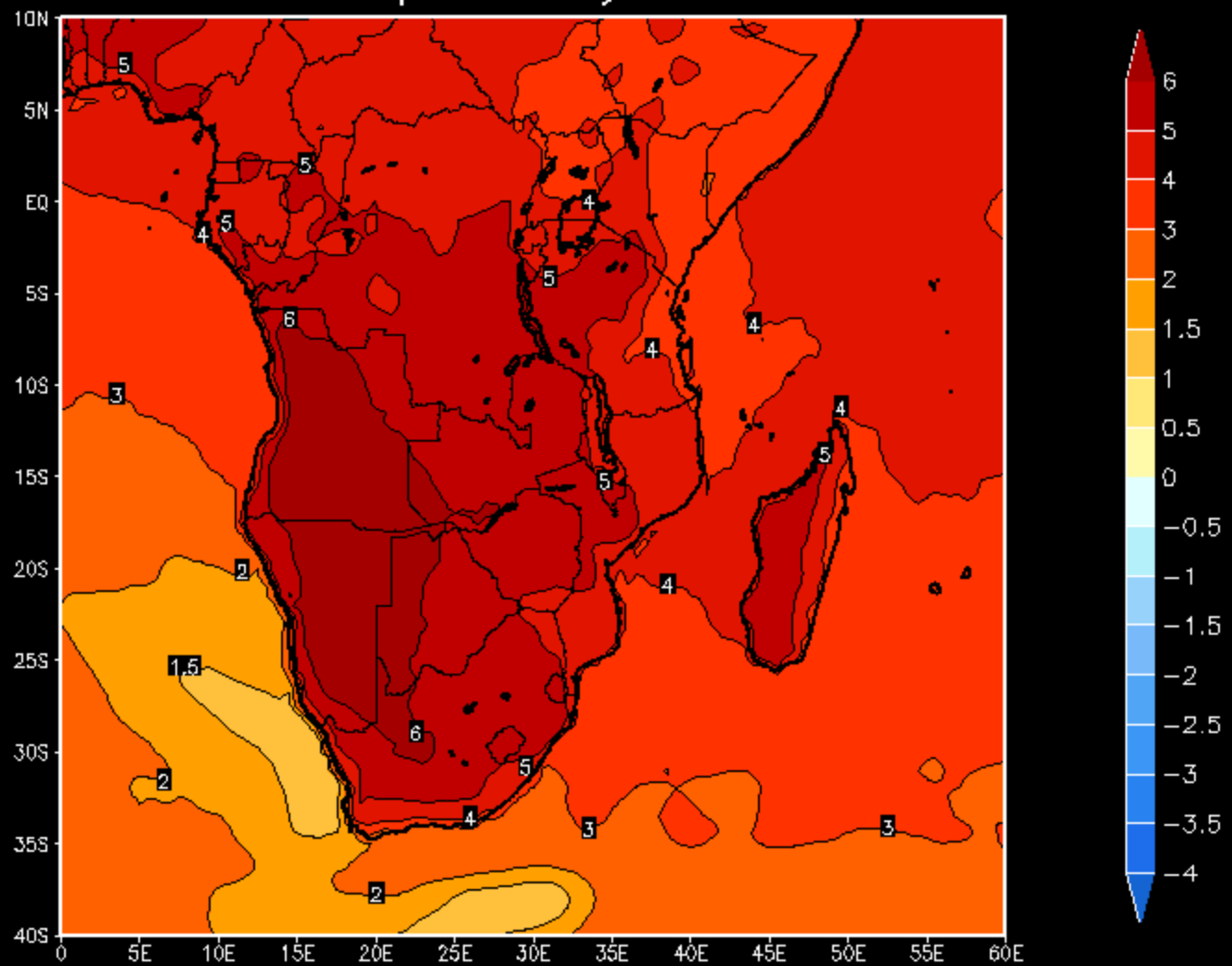
Temp anomaly 2089



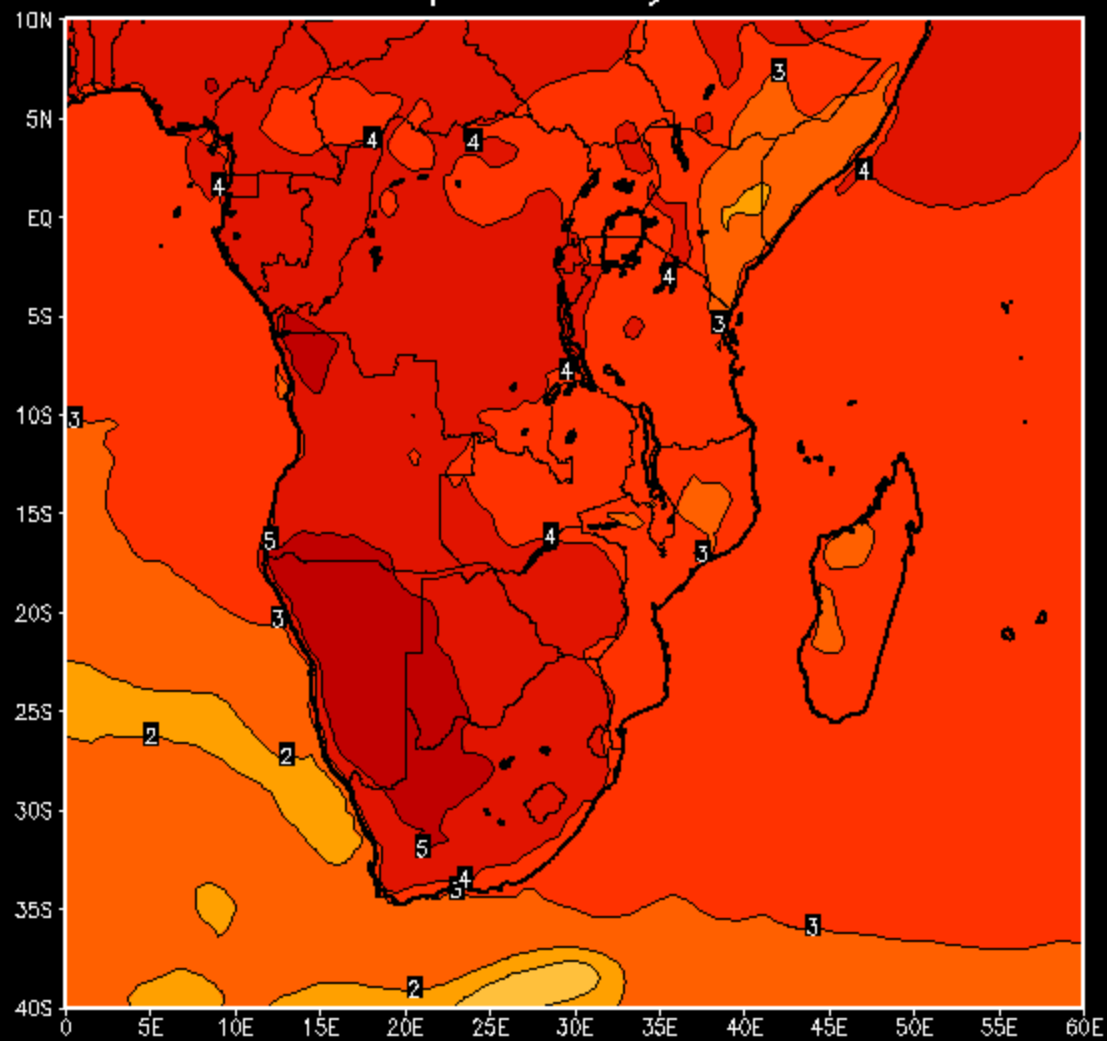
Temp anomaly 2090



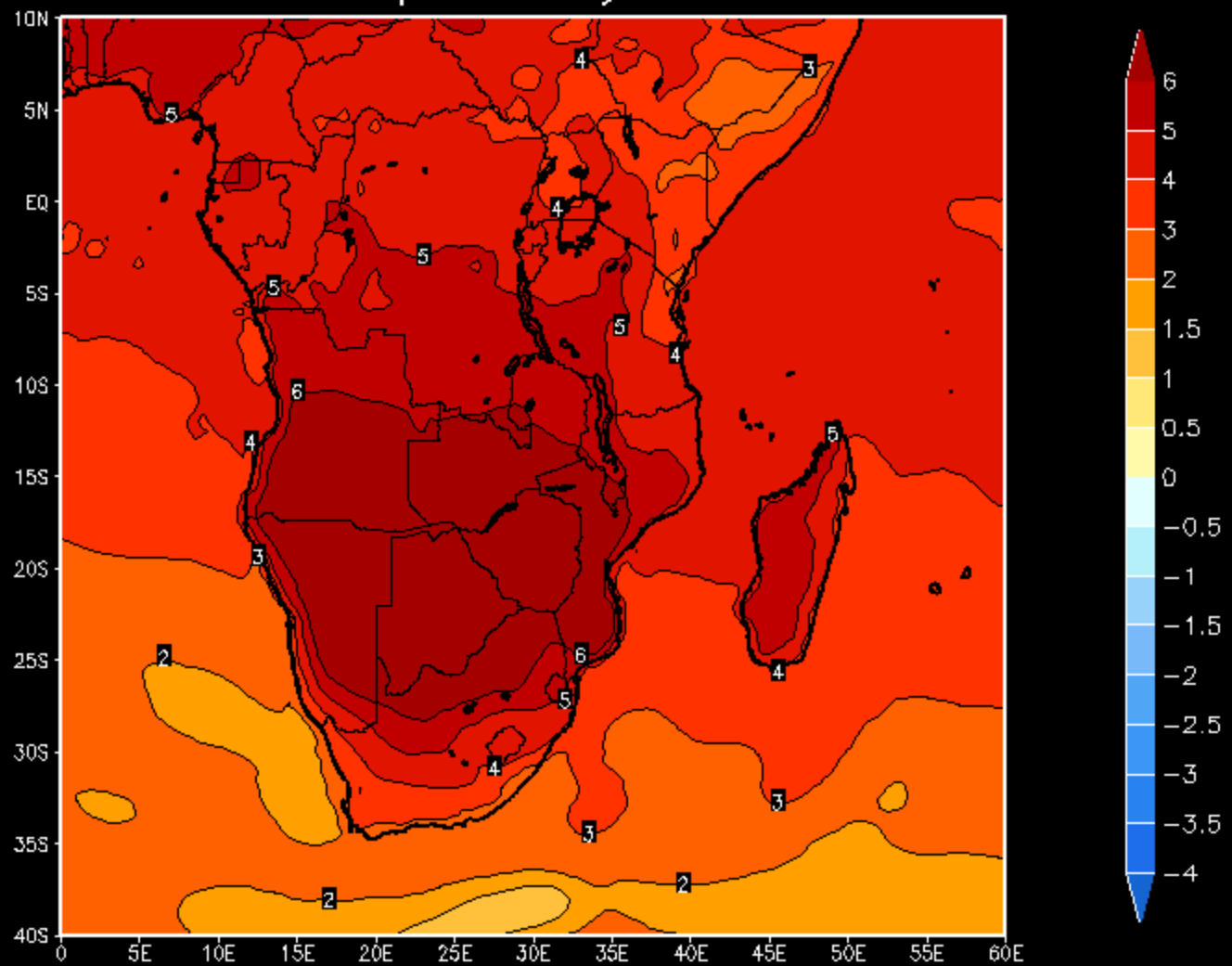
Temp anomaly 2091



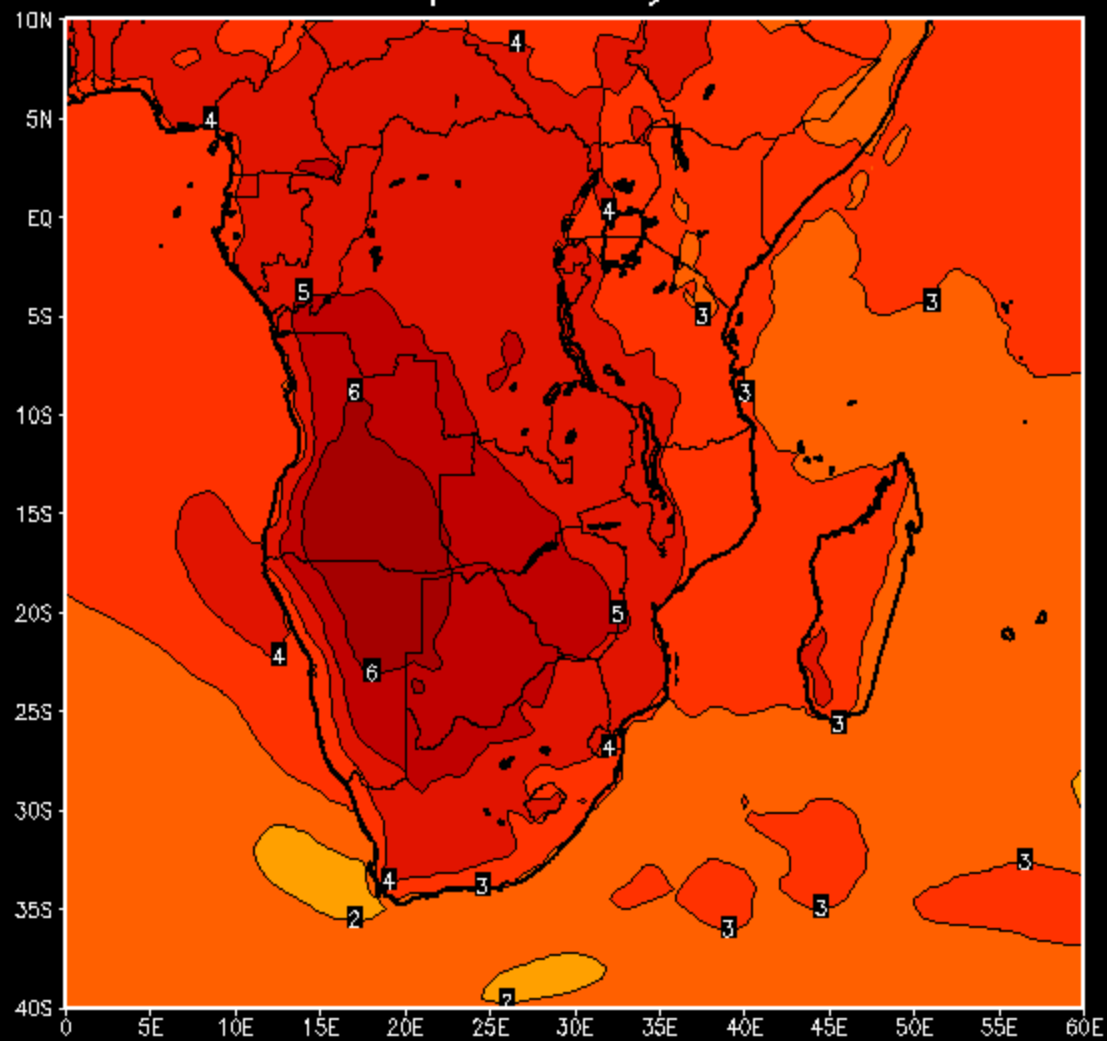
Temp anomaly 2092



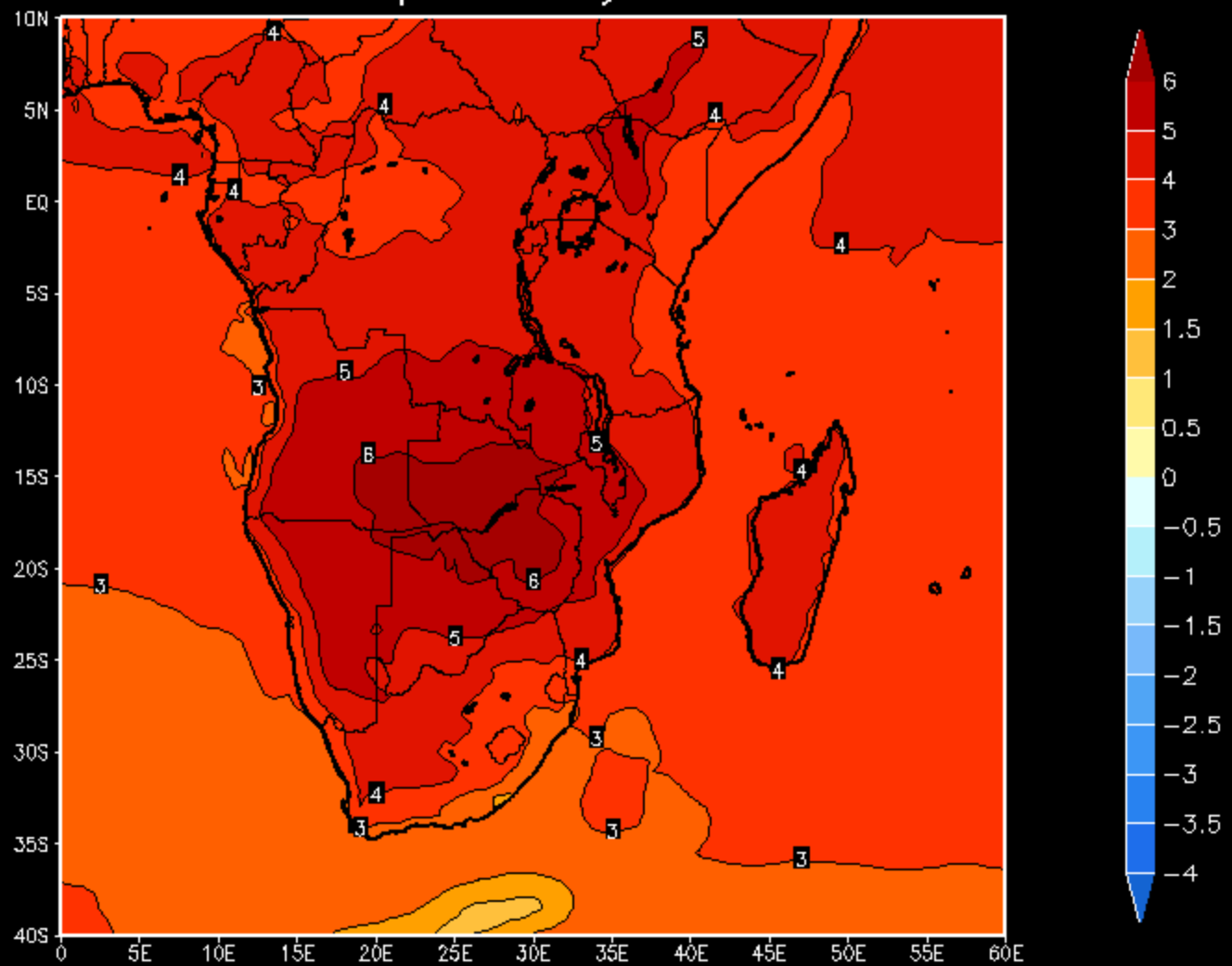
Temp anomaly 2093



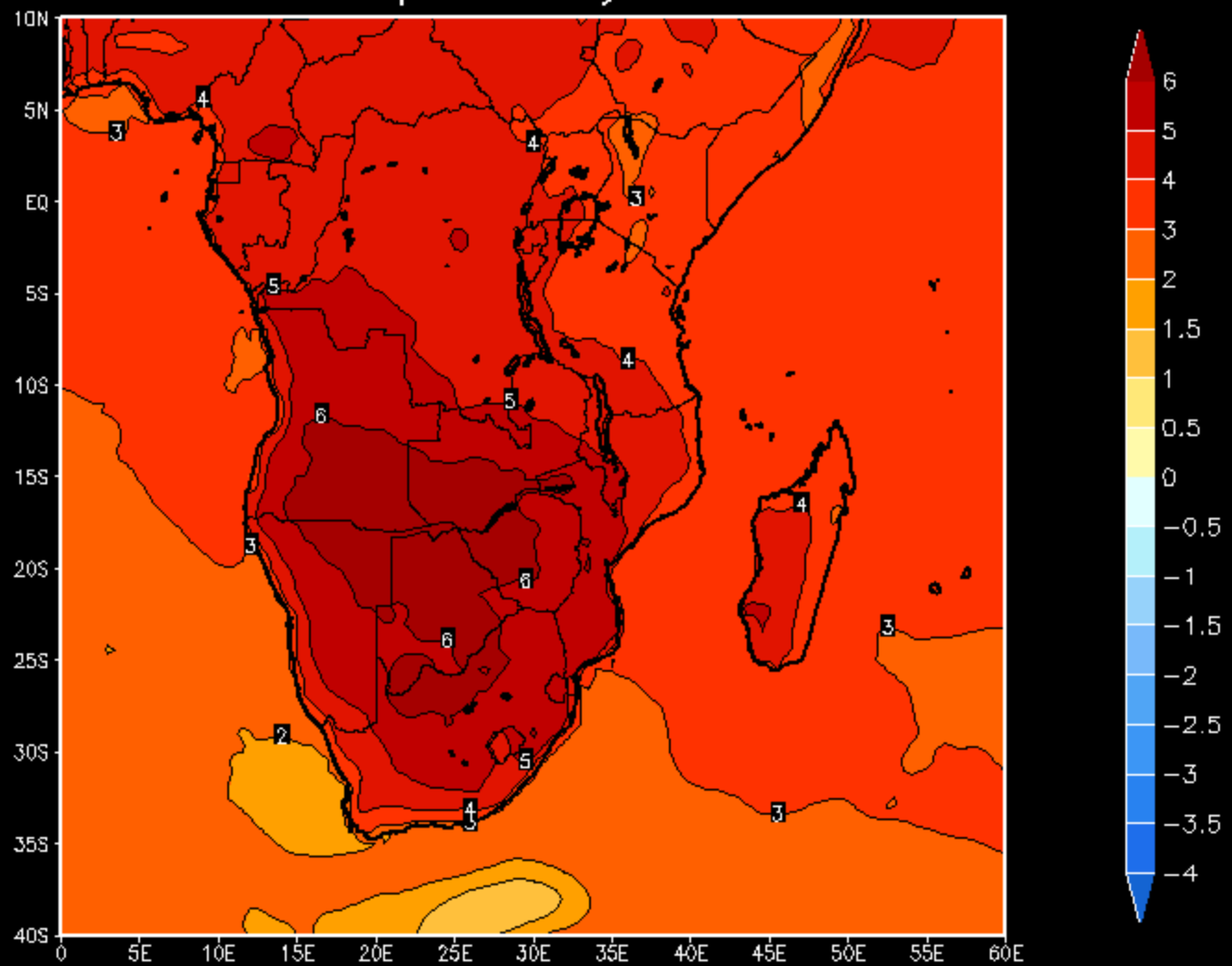
Temp anomaly 2094



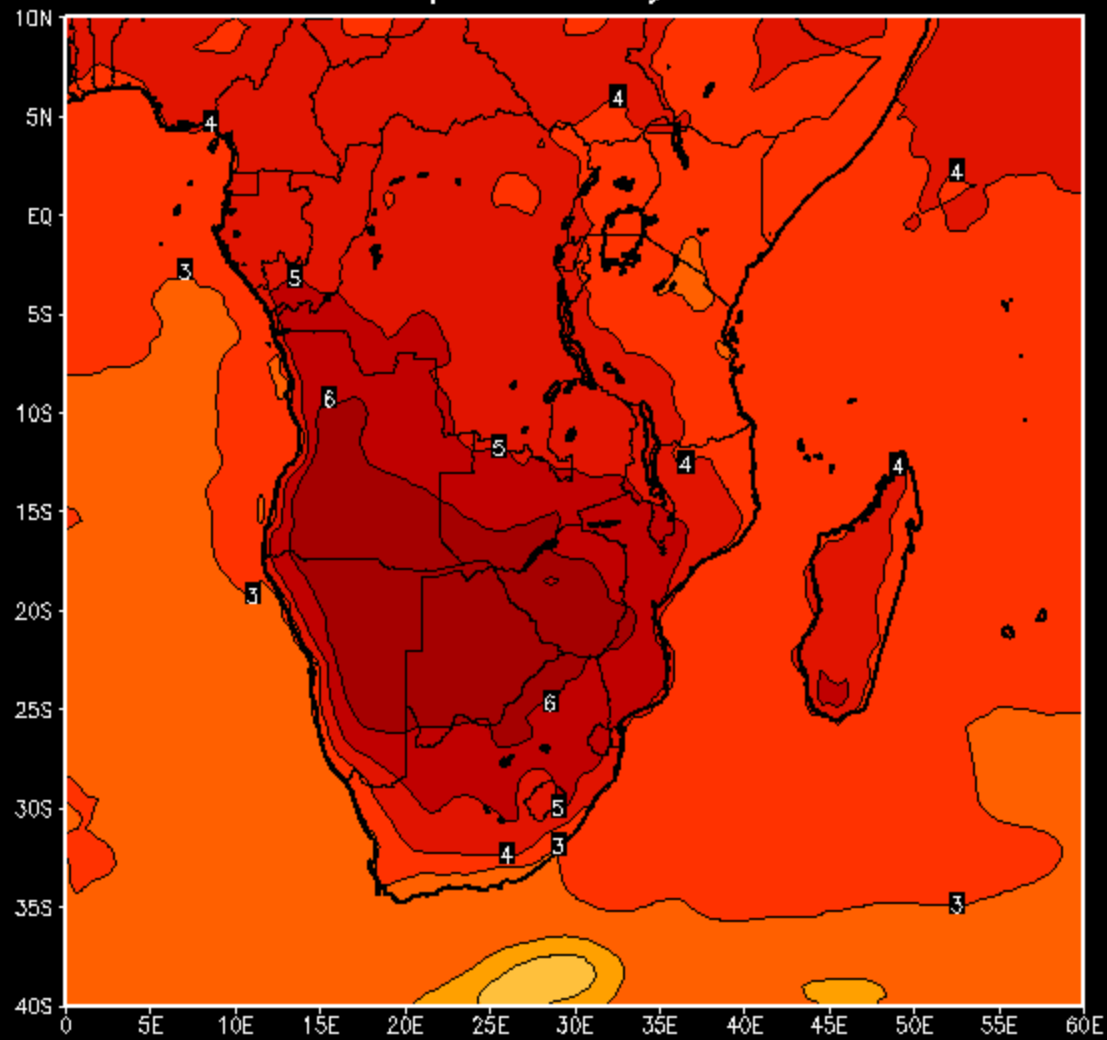
Temp anomaly 2095



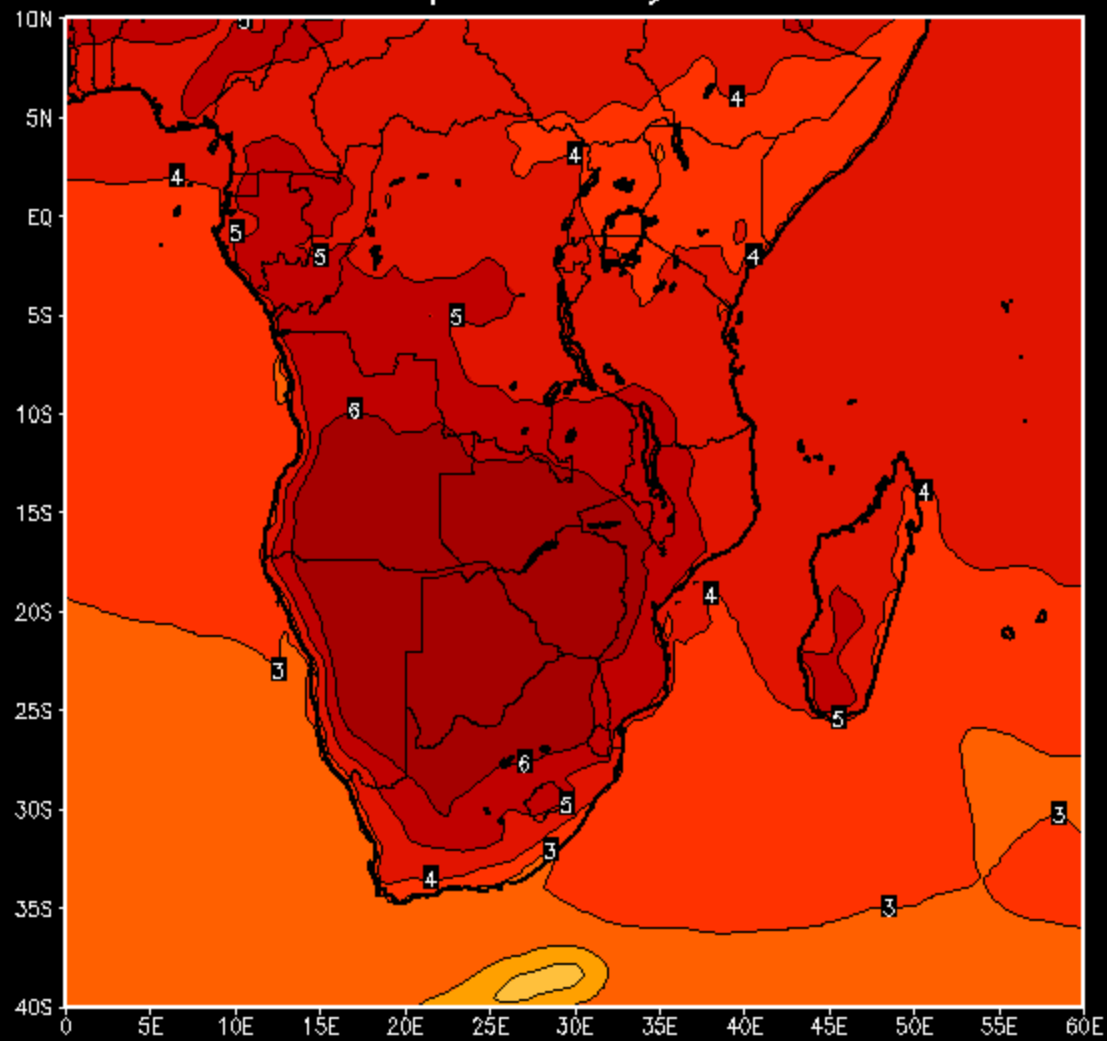
Temp anomaly 2096



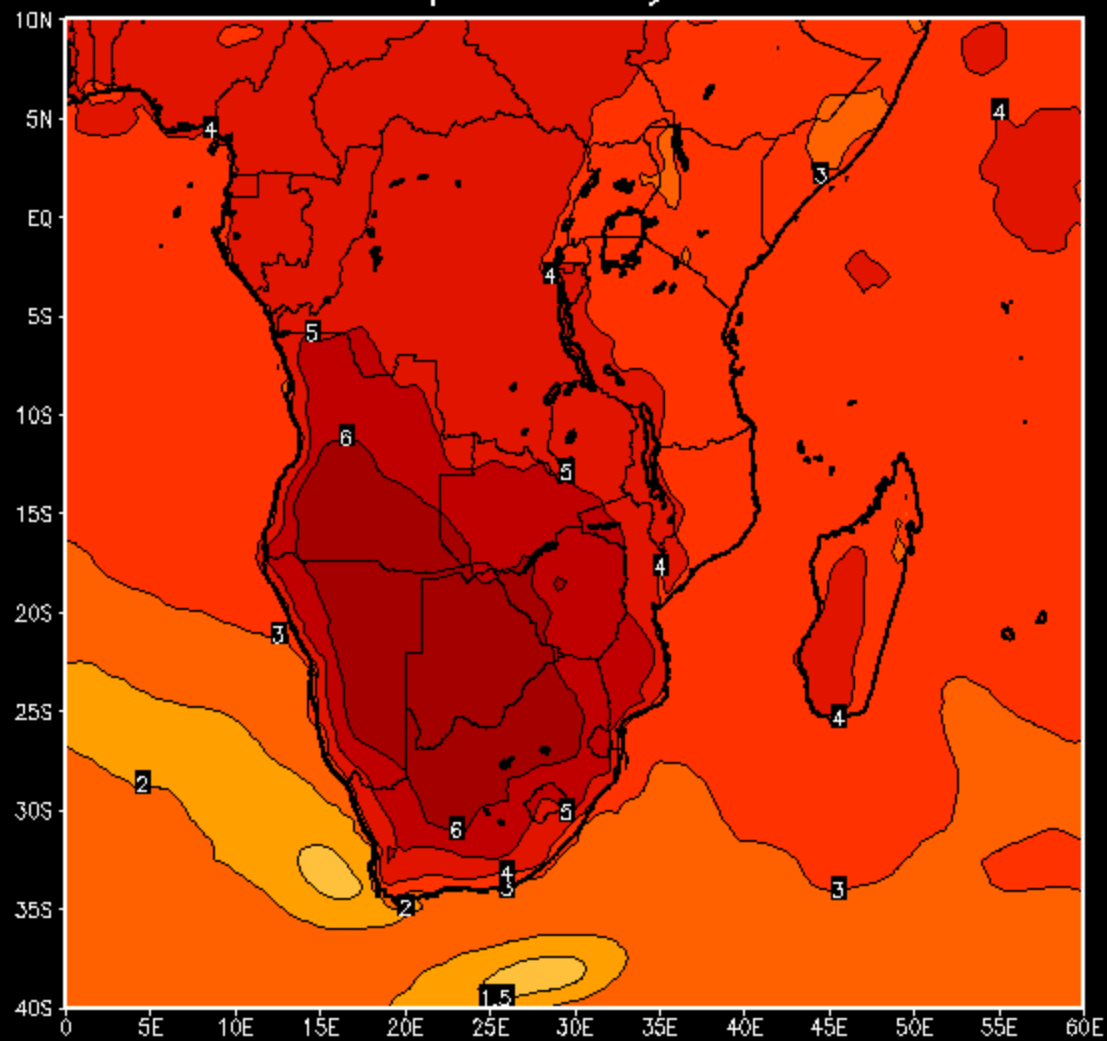
Temp anomaly 2097



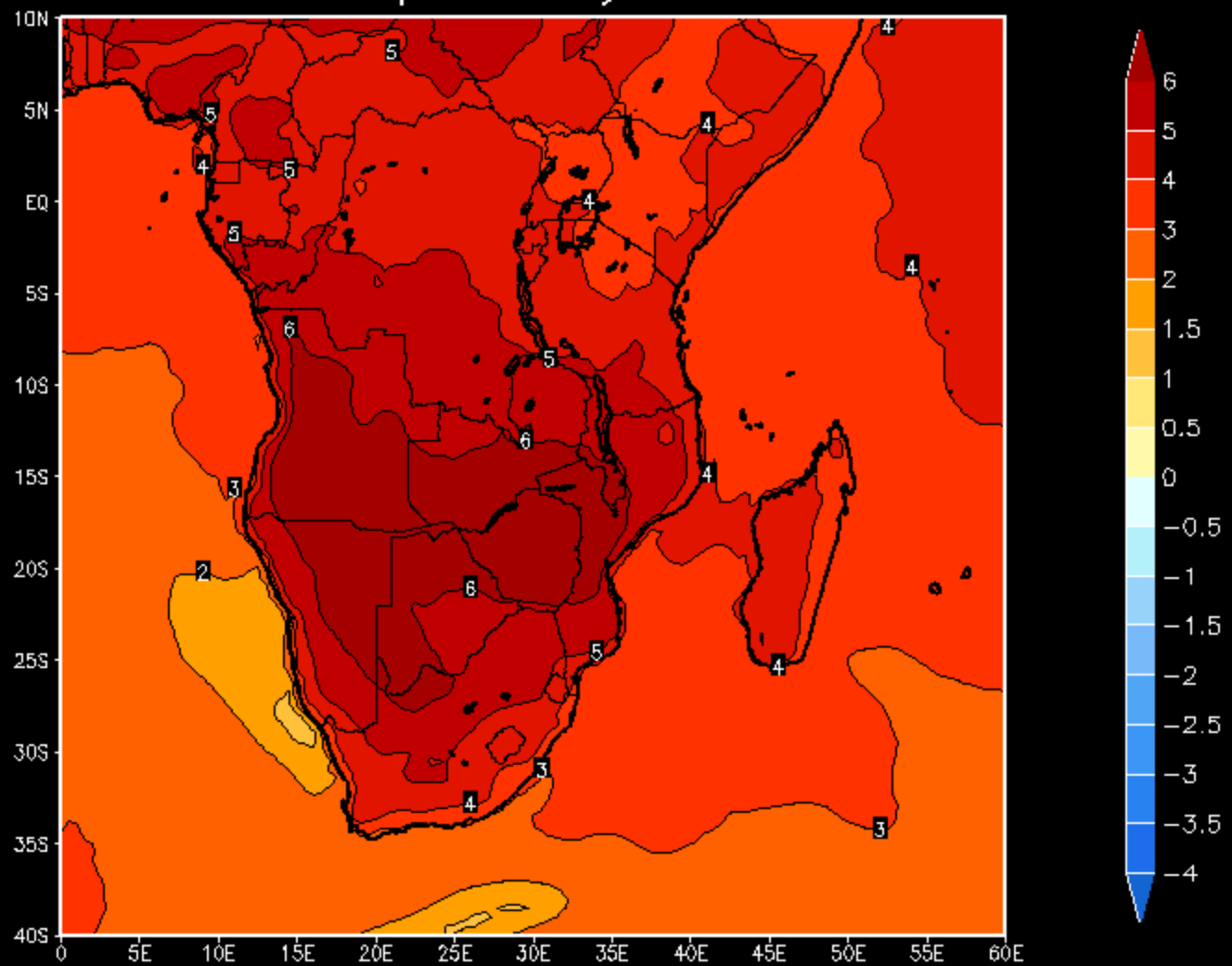
Temp anomaly 2098



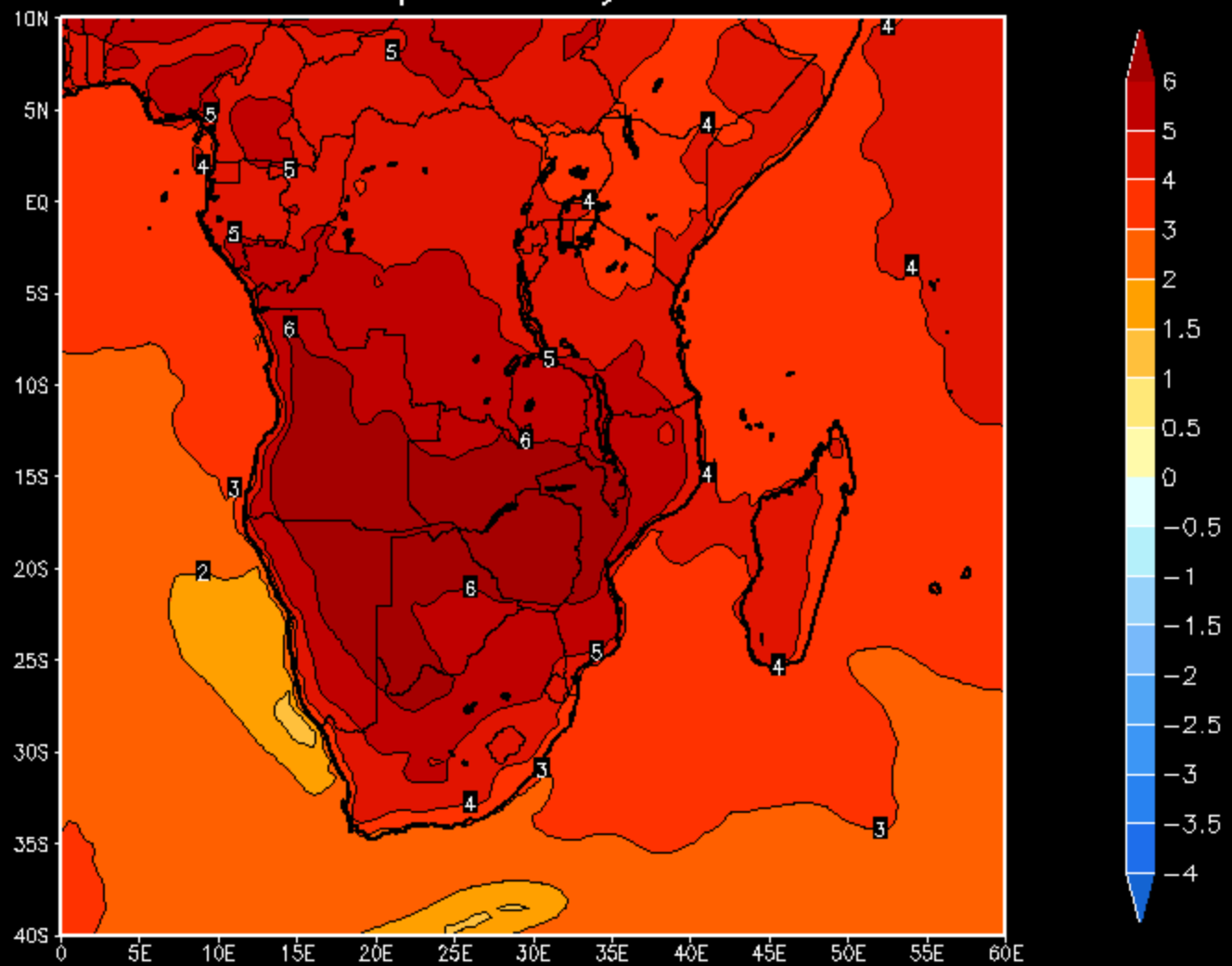
Temp anomaly 2099



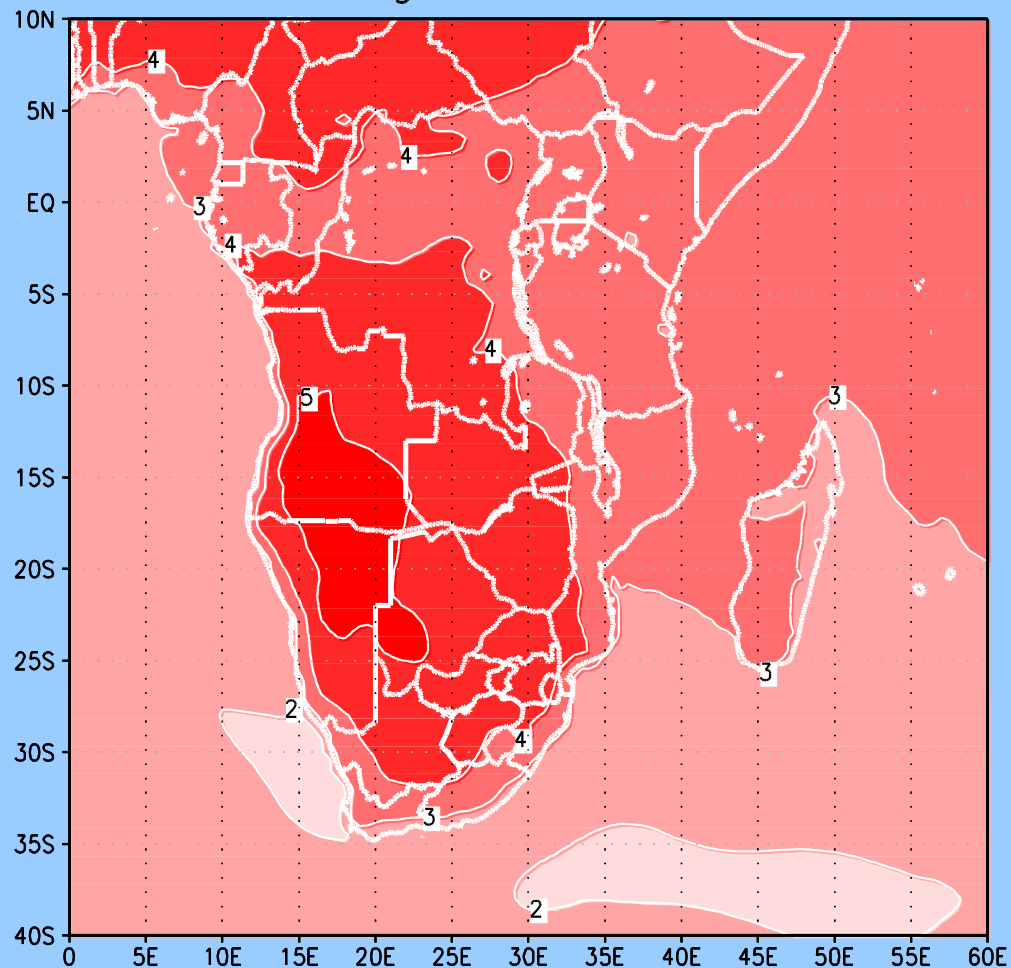
Temp anomaly 2100



Temp anomaly 2100



ONDJFM Tmax change 2071–2100 vs 1961–1990

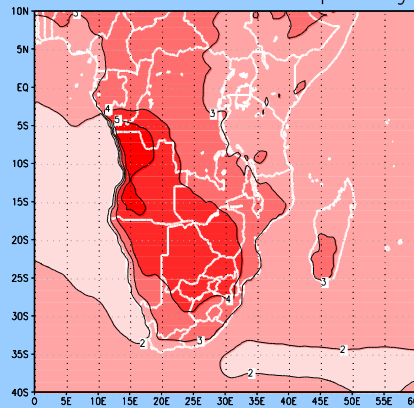


**CCAM ens-ave
projected
change in
summer half-
year (ONDJFM)
average
maximum
temperature for
2071–2100 vs
1961–1990**

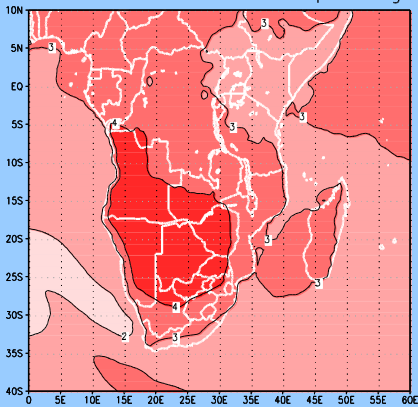


CCAM ens-ave projected change in summer half- year average maximum temperature for 2071-2100 vs 1961-1990

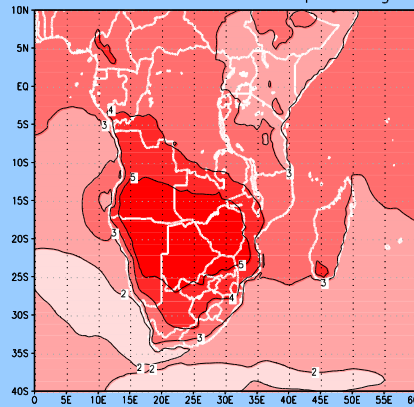
CCAM-UKHADcm3 Max temp change



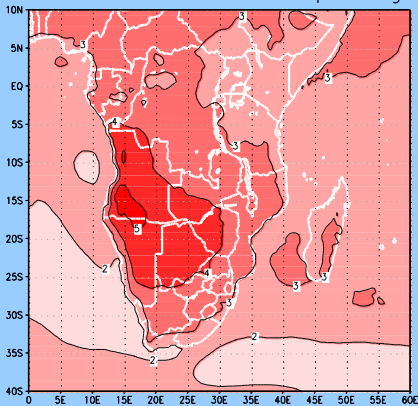
CCAM-GFDL2cm.0 Max temp change



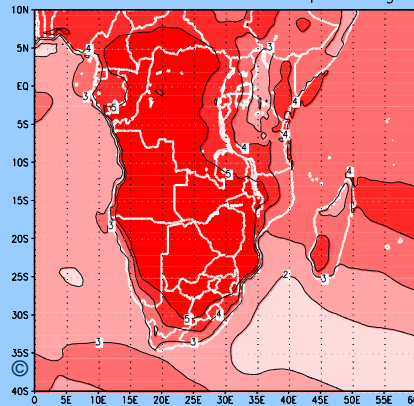
CCAM-ECHAM5 Max temp change



CCAM-GFDLcm2.1 Max temp change

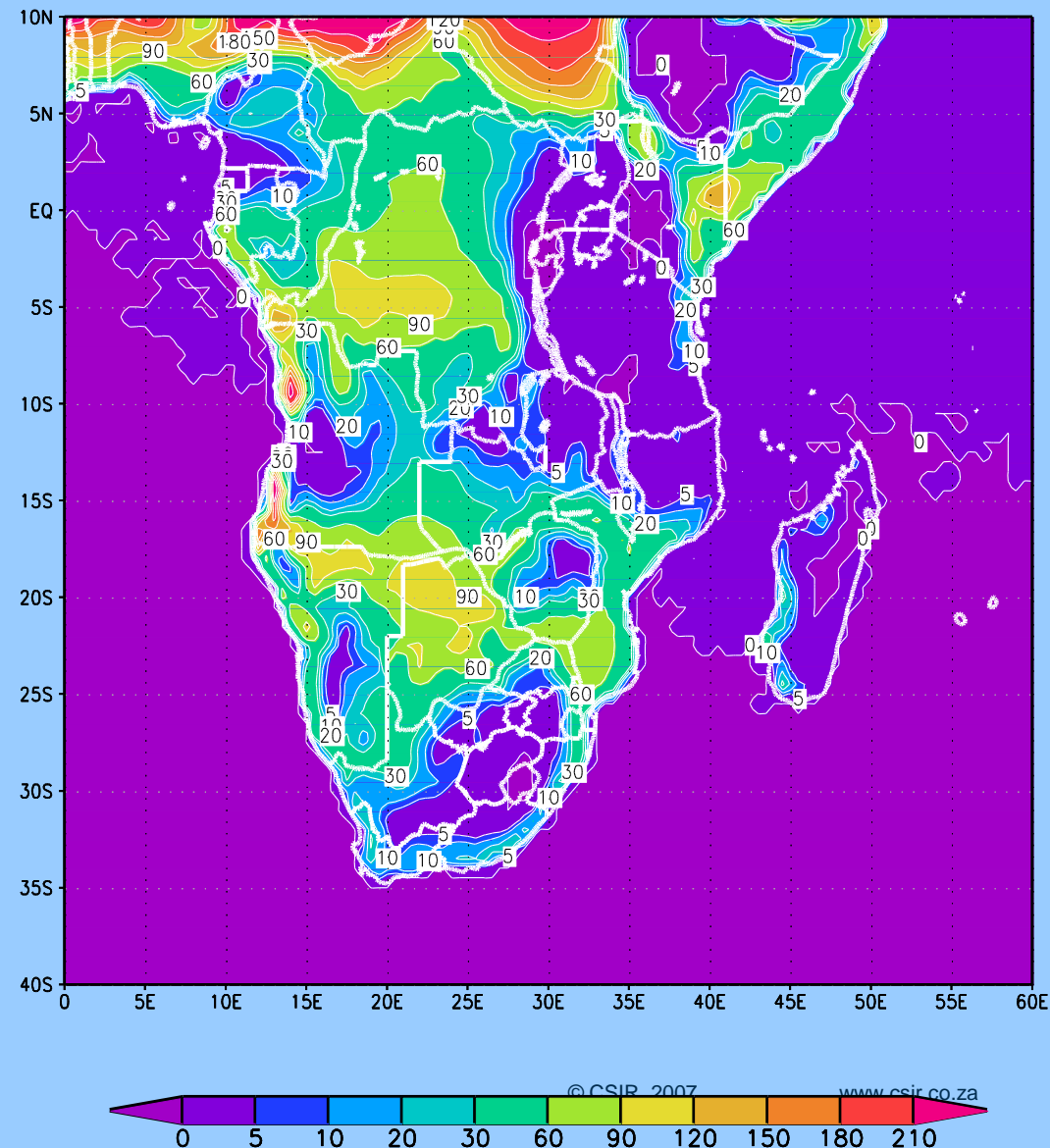


CCAM-MIROCmr Max temp change



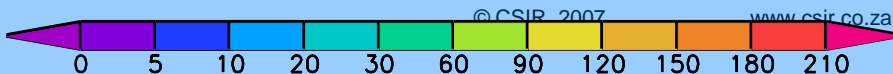
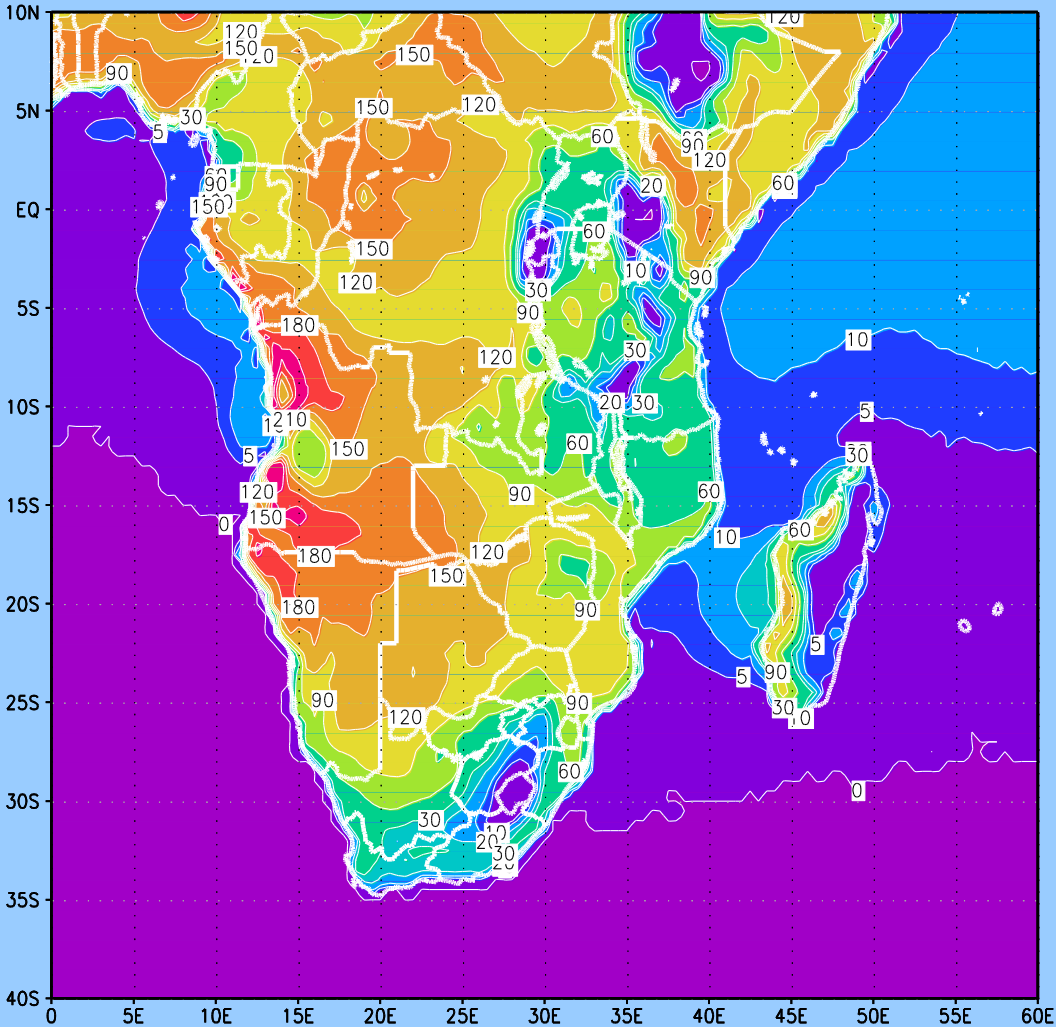
CCAM-ENS simulated vhd 1961-1990

**CCAM ens-ave
simulation of the
annual
frequency of
occurrence of
very hot days for
1961-1990**

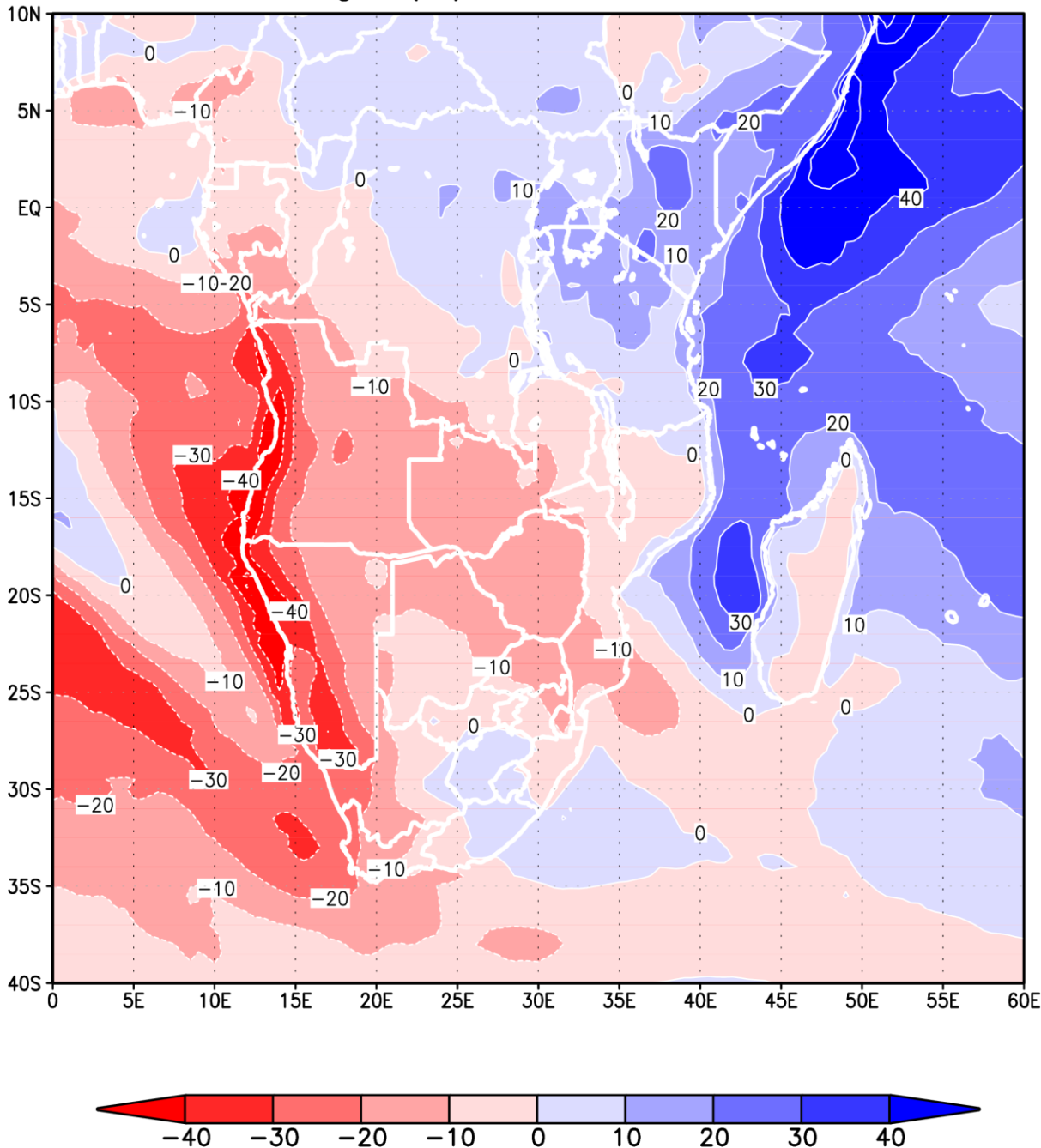


**CCAM ens-ave
projected
change in the
annual
frequency of
occurrence of
very hot days for
2071-2100 vs
1961-1990**

Projected change vhd 2071–2100 vs 1961–1990



CCAM rnd change (%) 2071–2100 vs 1961–1990

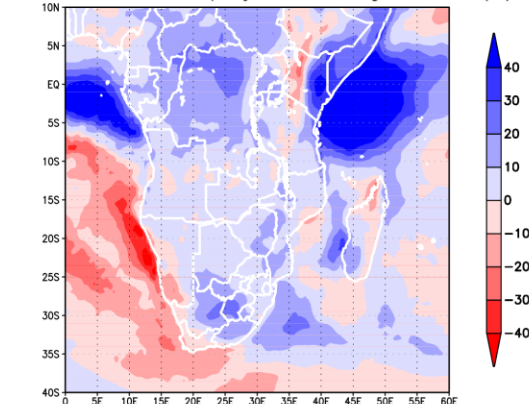


**CCAM ens-ave
projected
change in annual
rainfall (%) for
2071-2100 vs
1961-1990**

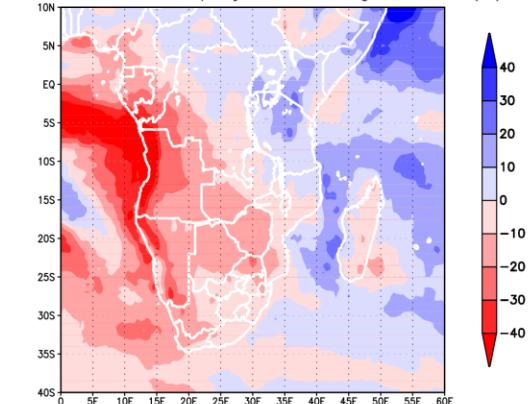
Southern Africa
projected to become
generally drier

East Africa projected
to become generally
wetter

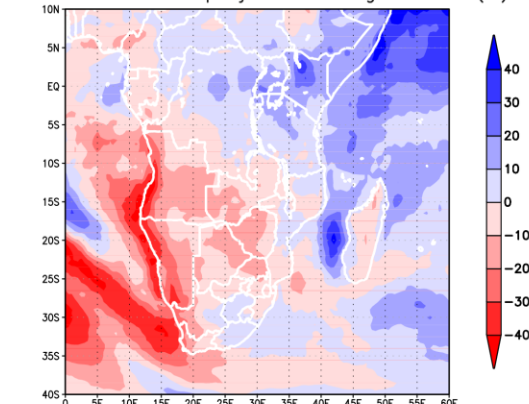
CCAM-CSIROmk3.5 projected change in rnd (%)



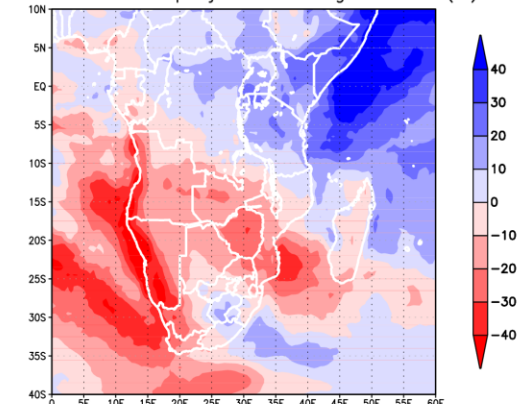
CCAM-UKHADcm3 projected change in rnd (%)



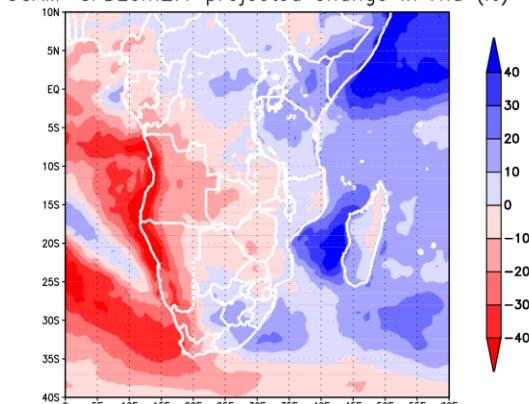
CCAM-GFDLcm2.0 projected change in rnd (%)



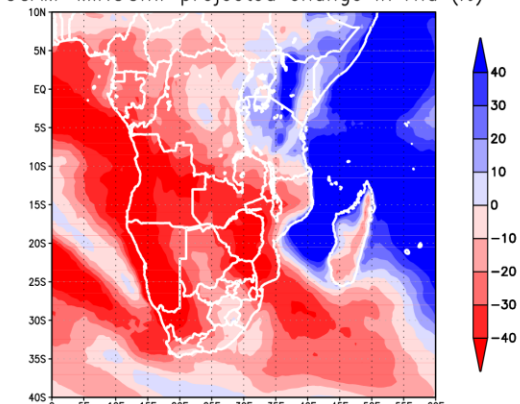
CCAM-ECHAM5 projected change in rnd (%)



CCAM-GFDLcm2.1 projected change in rnd (%)



CCAM-MIROCmr projected change in rnd (%)

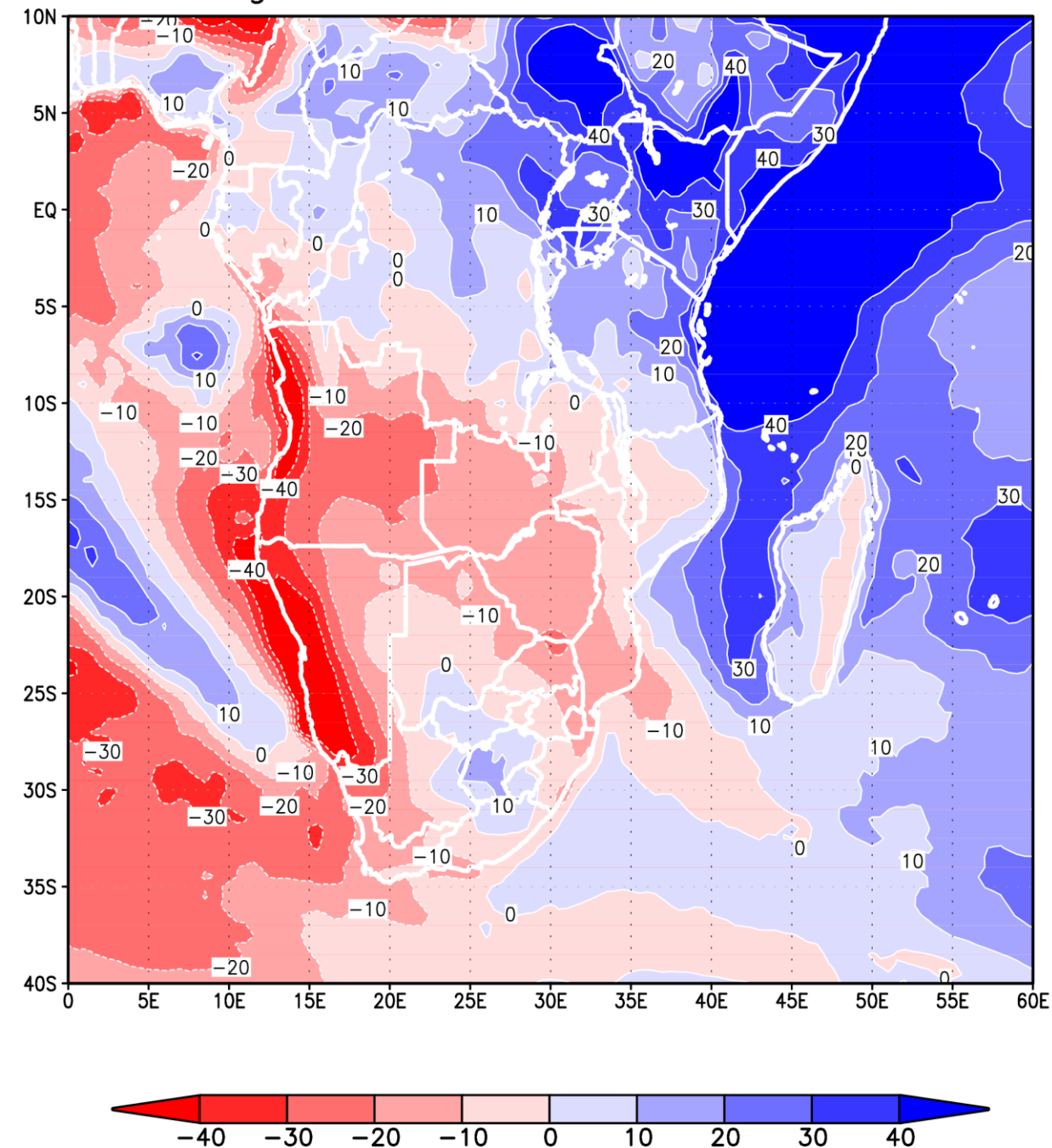


CCAM ensemble: projected change in annual rainfall (%) for 2071-2100 vs 1961-1990

Most models project a
generally drier
southern Africa, but
wetter East Africa

Cloud band (TTT)
related rainfall signal
over central South
Africa

CCAM change DJF-rain 2071-2100 vs 1961-1990

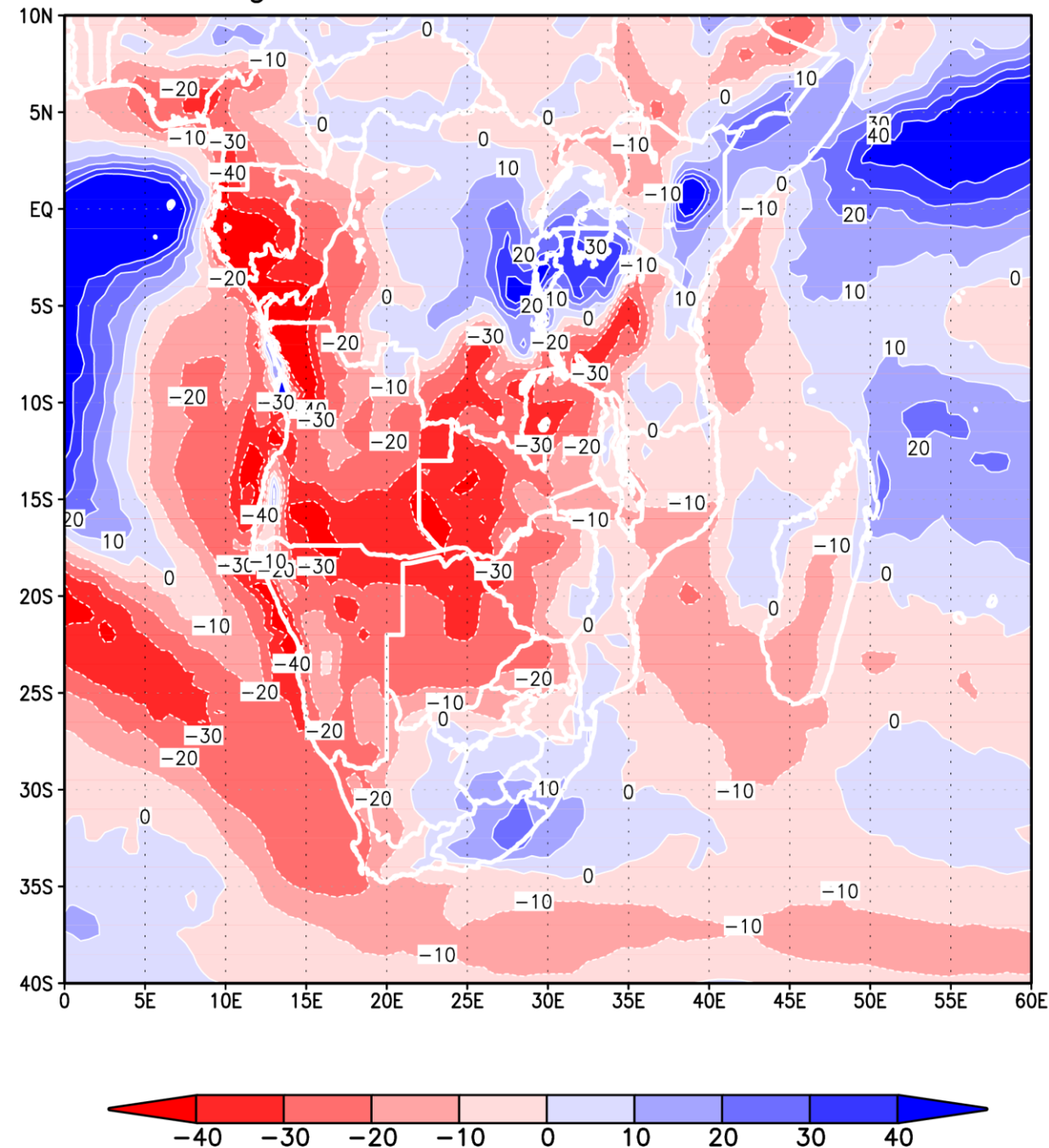


**CCAM ens-ave
projected
change in DJF
rainfall (%) for
2071-2100 vs
1961-1990**

Southern Africa
projected to become
generally drier

East Africa projected
to become generally
wetter

CCAM change JJA-rain 2071-2100 vs 1961-1990



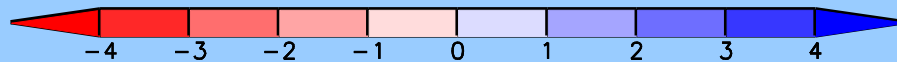
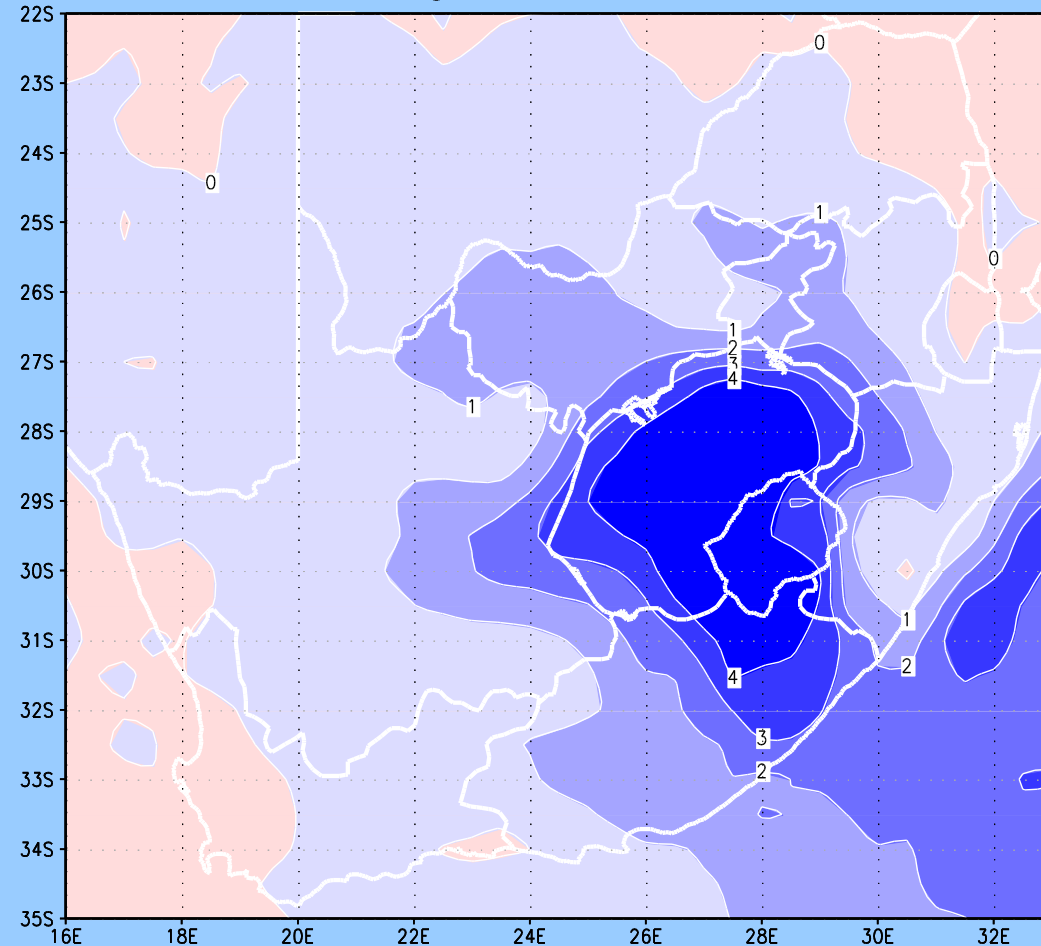
**CCAM ens-ave
projected
change in JJA
rainfall (%) for
2071-2100 vs
1961-1990**

Southwestern Cape
projected to become
drier

Eastern South Africa
projected to become
wetter

Projected change in extreme rainfall events over South Africa

Annual-rnde change 2071-2100 vs 1961-1990

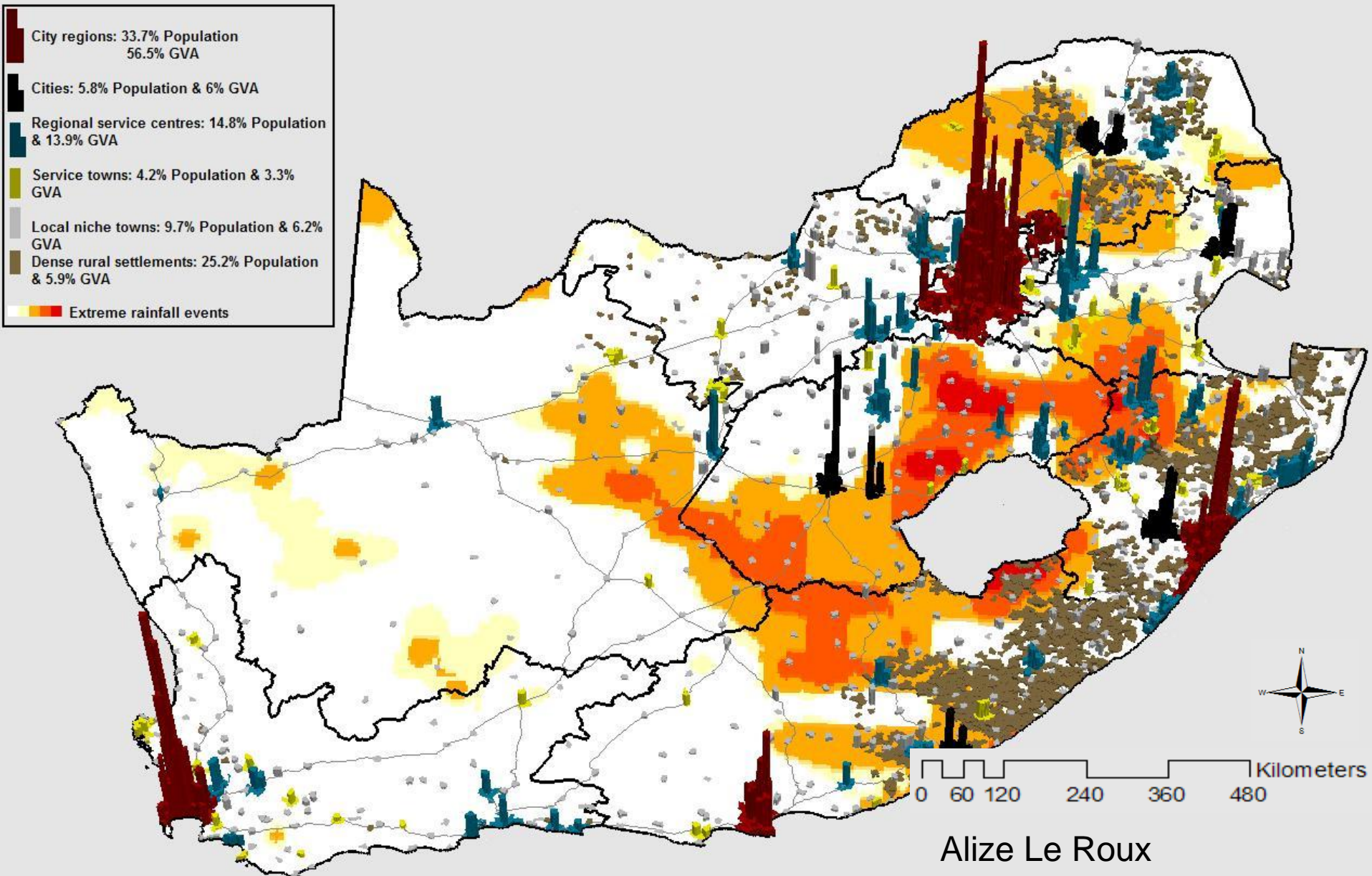


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A general increase in the frequency of occurrence of extreme rainfall events (20 mm of rain falling within 24 hours over and area of 50 km x 50 km) is projected for South Africa

SARVA: <http://rava.qsens.net/themes> - includes climate change projection and impacts information



CONCLUSIONS

- Significant regional climate modelling capacity has been developed in SA (e.g. at CSIR and UCT) – WRC funded research projects played a key role in establishing this capacity
- Advances in supercomputing power in SA (e.g. at the CHPC) now makes it feasible to obtain large ensembles of dynamically downscaled scenarios
- Southern Africa is projected to experience rapid warming during the 21st century
- Dynamic theory (and some model projections) suggest that southern Africa will experience a generally drier climate in response to anthropogenic forcing. East Africa is projected to become wetter.