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SST LAG: A vital link in climate change

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SST LAG: A VITAL LINK IN CLIMATE CHANGE

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LAG OF THE SEASONS

- *Over the land*
- Lag of the air temperature (AT) cycle behind the radiation cycle

- *In the ocean*
- Lag of the sea surface temperature (SST) cycle behind the radiation cycle

THE TWO COMPONENTS OF LAG

- For a radiation cycle, $Q = q \cos \sigma t$,

lag components are defined by:

- $Ta - Ts = c \cos (\sigma t - f)$
- *f* SURFACE HEAT FLUX LAG

- $Ts = a \cos (\sigma t - f - g)$
- *g* OCEAN HEAT STORAGE LAG

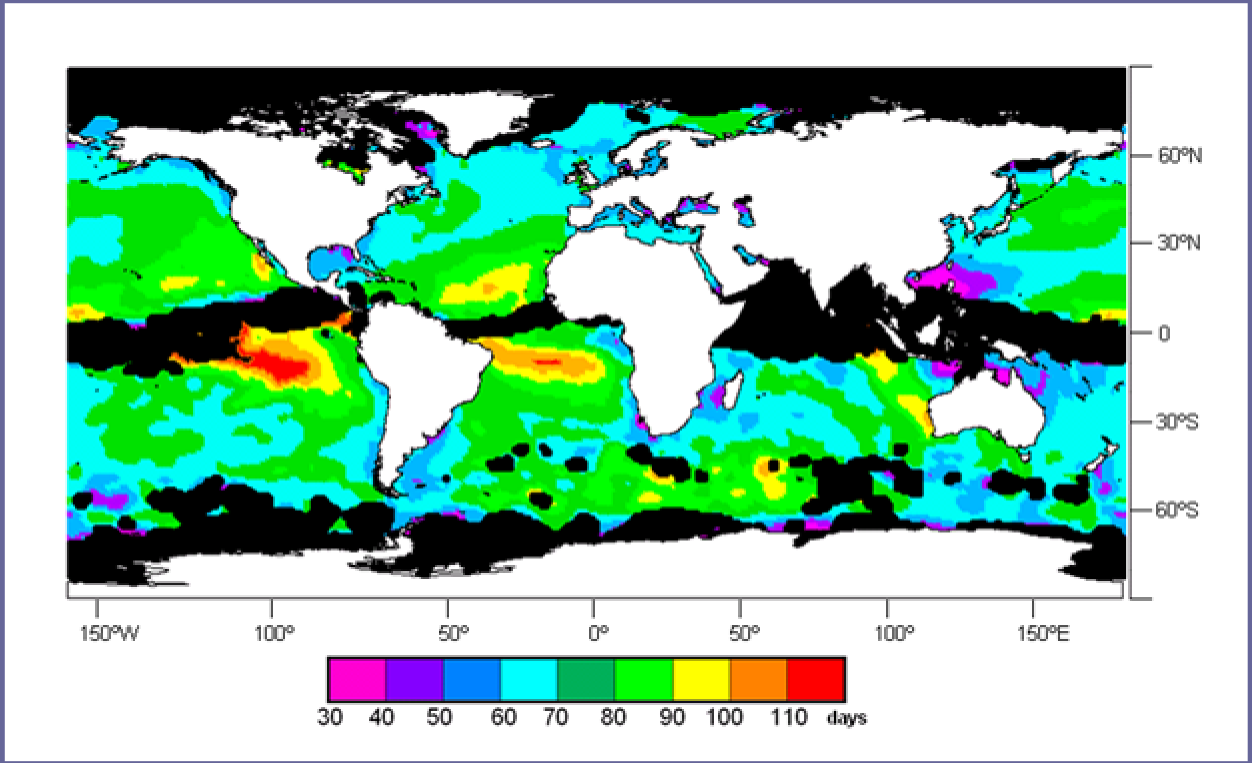
- $f + g$ SST LAG

- ***Ta AT, Ts SST, σ annual frequency***

LAG ANALYSIS

- Fit an annual Fourier mode to the monthly values of SST and daily values of AT data [Alexander et al 2005]
- Lags expressed in DAYS relative to the maximum in daily solar radiation (June 21 in NH, December 22 in SH)
- Valid except in tropics where the sun passes directly overhead twice annually

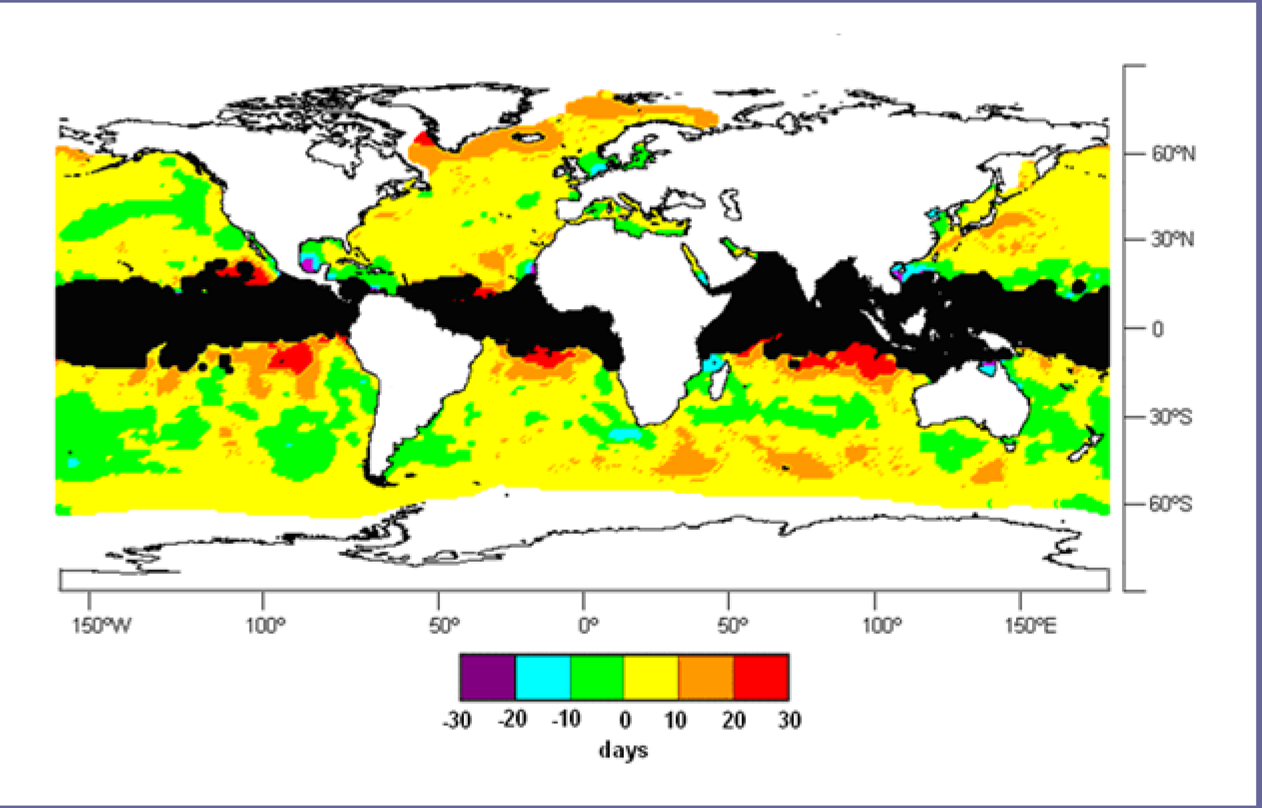
WORLD LAG MAPS



World ocean SST lag from NOAA WOA05 climatology

Regions with r < 0.9 between monthly data and harmonic fit are shown in black

WORLD LAG MAPS



The surface heat flux lag from the Southampton Oceanography Centre net heat flux data set

Regions with r < 0.9 between monthly data and harmonic fit are shown in black

GLOBAL AVERAGES

- SST lag *(f + g)*
- Mean 73 days, standard deviation 16 days
- Surface heat flux lag *(f)*
- Mean 5 days, standard deviation 9 days
- Hence oceanic heat storage lag *(g)* dominates SST lag

OCEAN MIXED LAYER MODEL

- Main cause of SST lag is the heat storage due to the OCEAN MIXED LAYER
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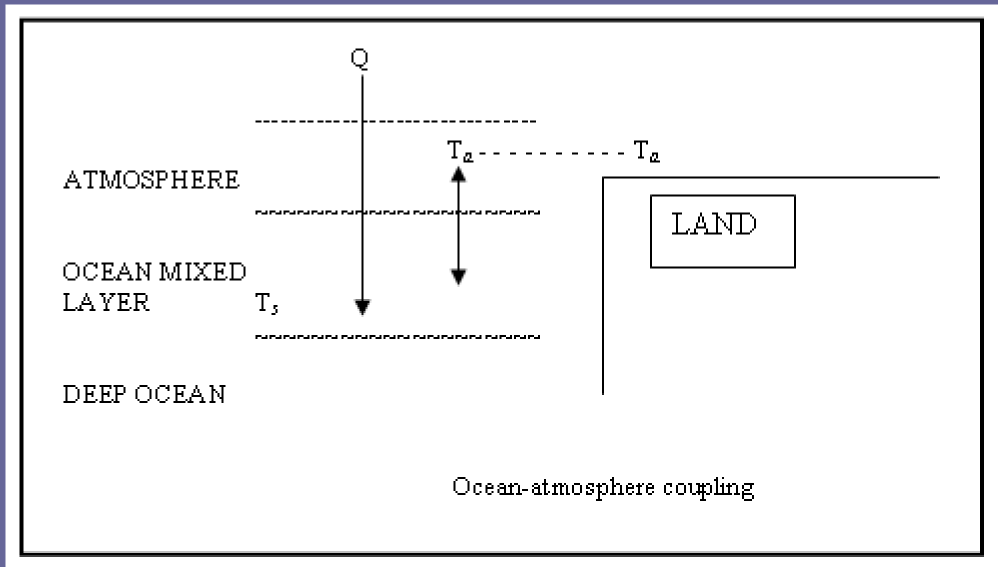
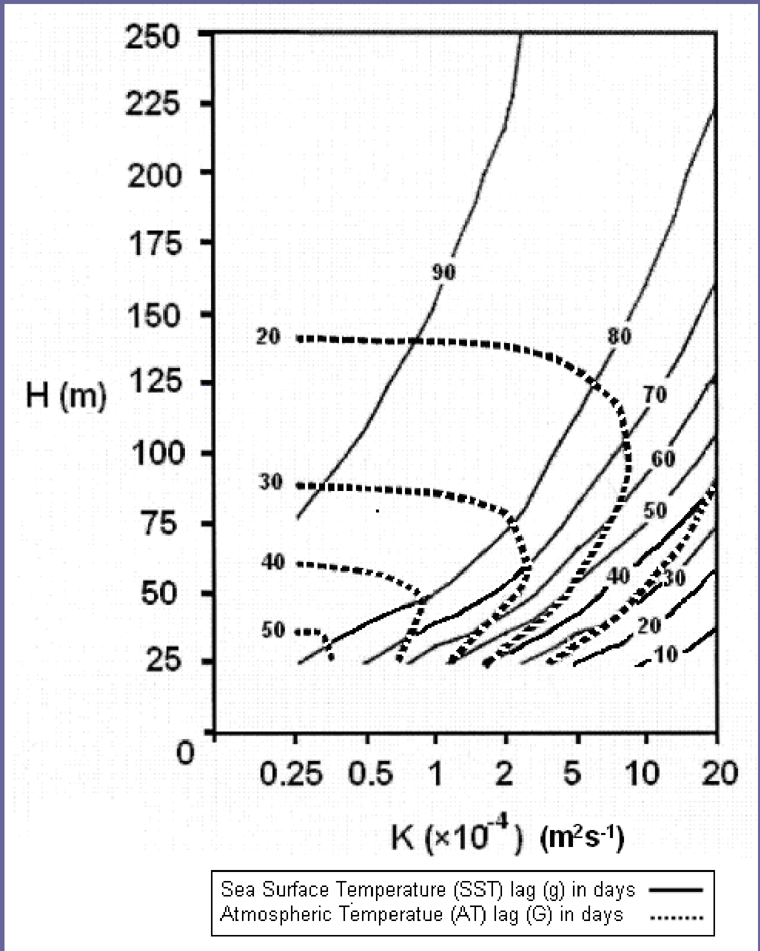


- *H* mixed layer depth, *K* coefficient of vertical heat diffusion at base of mixed layer One-dimensional harmonic model [Bye 1996]

RESULTS



g = arctan (σ/B)

in which *B = K/H^2*
is the heat exchange coefficient with the deep ocean

Ta = b cos (σt – f – G)

where G is the atmospheric temperature lag due to oceanic heat storage

IMPLICATIONS

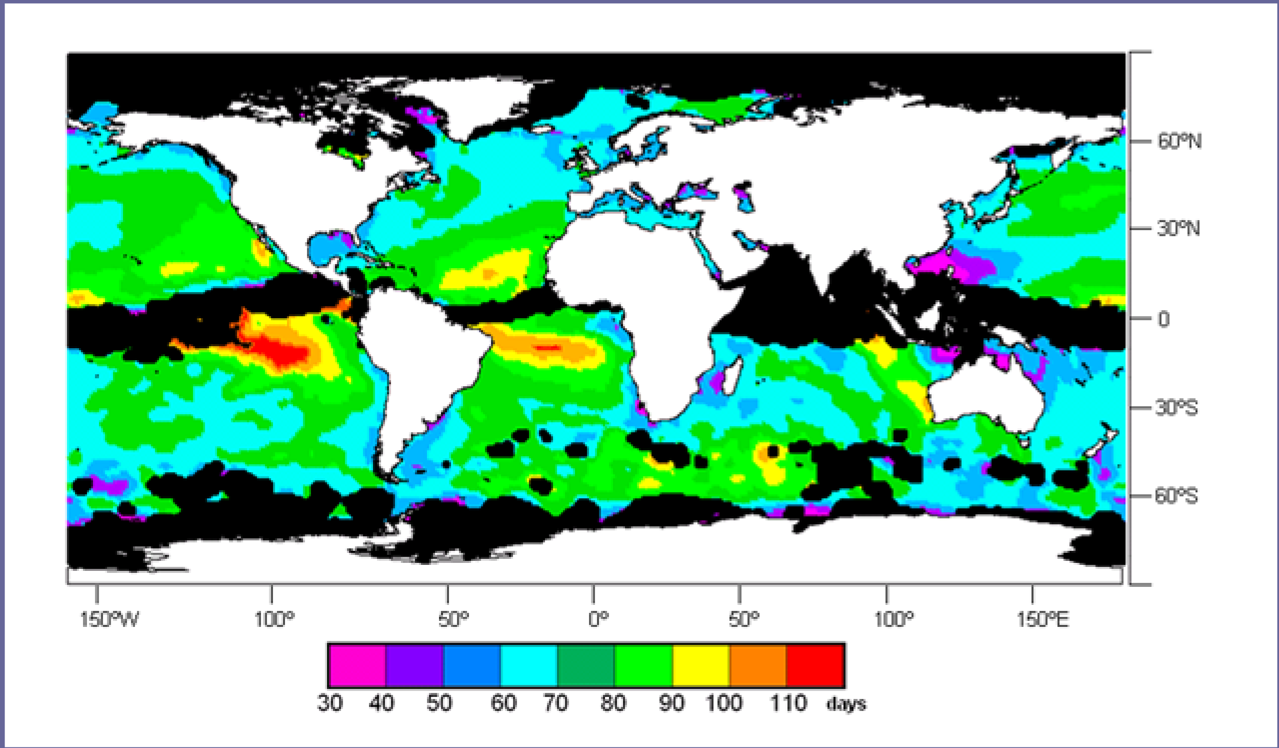
- (1) AT lag typically 30 days less than SST lag

- (2) At constant H, **SST and AT lags increase as K decreases**
- i.e. an increase in stability of the mixed layer implies:

- (i) relatively less heat exchanged with deep ocean, hence the SST cycle is retarded
- (ii) amplitude of the surface heat flux cycle is reduced relative to the SST cycle

- (3) **CLIMATIC IMPLICATIONS**
- (i) at coast an increase in SST lag produces an increase in AT lag
- (ii) in the open ocean an increase in SST lag reduces synoptic activity

WORLD LAG MAPS



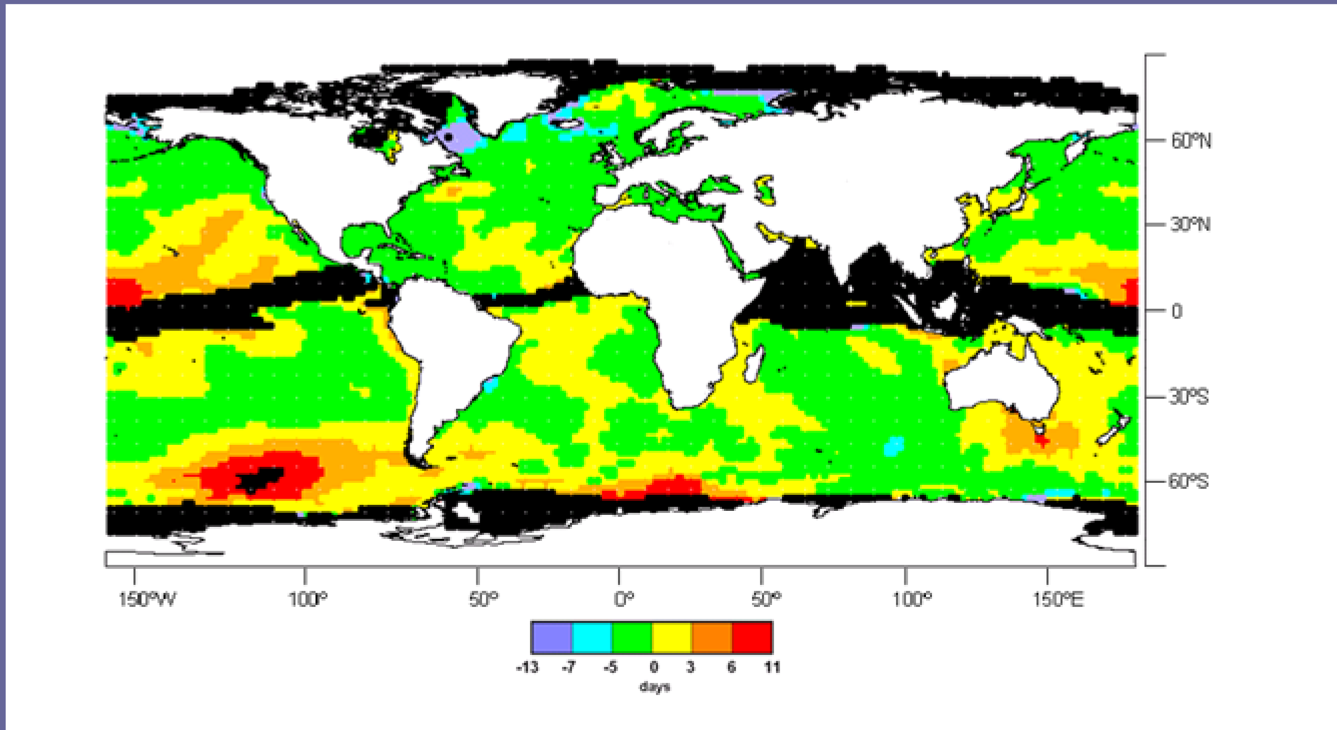
World ocean SST lag from NOAA WOA05 climatology

Regions with r < 0.9 between monthly data and harmonic fit are shown in black

FEATURES OF SST LAG FIELD

- Asymmetry across the continents
- Subtropical high SST lag tongues
- - diffusive features arrested by the ocean gyres
- - arise from the decrease in stability of mixed layer away from equator
- - dissipate in the eastern boundaries of the ocean basins (except the Leeuwin and the Davidson Currents)
- Maximum of SST lag in the Southern Ocean in the Indian Ocean sector
- - greater stability of the mixed layer due to the Agulhas Current laterally mixing with the Antarctic Circumpolar Current

ANOMALY FIELDS OF SST LAG



Natural variability SST lag anomaly (SST lag 1951-2000 – SST lag 1901-1950)

Regions with r < 0.9 between monthly data and harmonic fit are shown in black

NATURAL VARIABILITY

- Changes between 1901-1950 and 1951-2000
- - no evidence of equatorial tongues
- - small basin scale signals

In the Australian region

- SST lag has increased in the east during the 20th century

- AT lag trend for Melbourne during the 20th century

(Summer was occurring on average about a week later at the end of the 20th century compared with the end of the 19th century

Winter almost unchanged)

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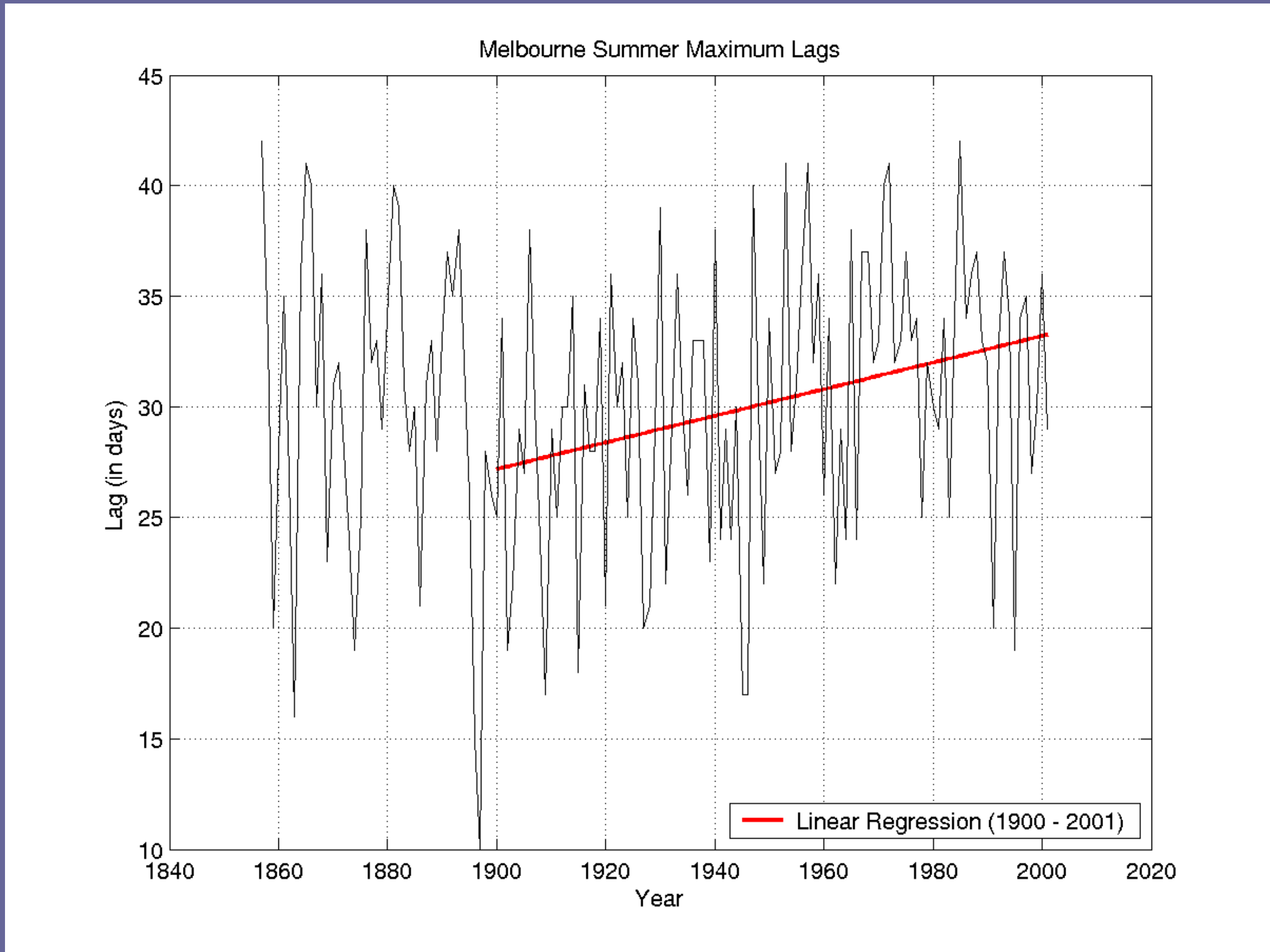
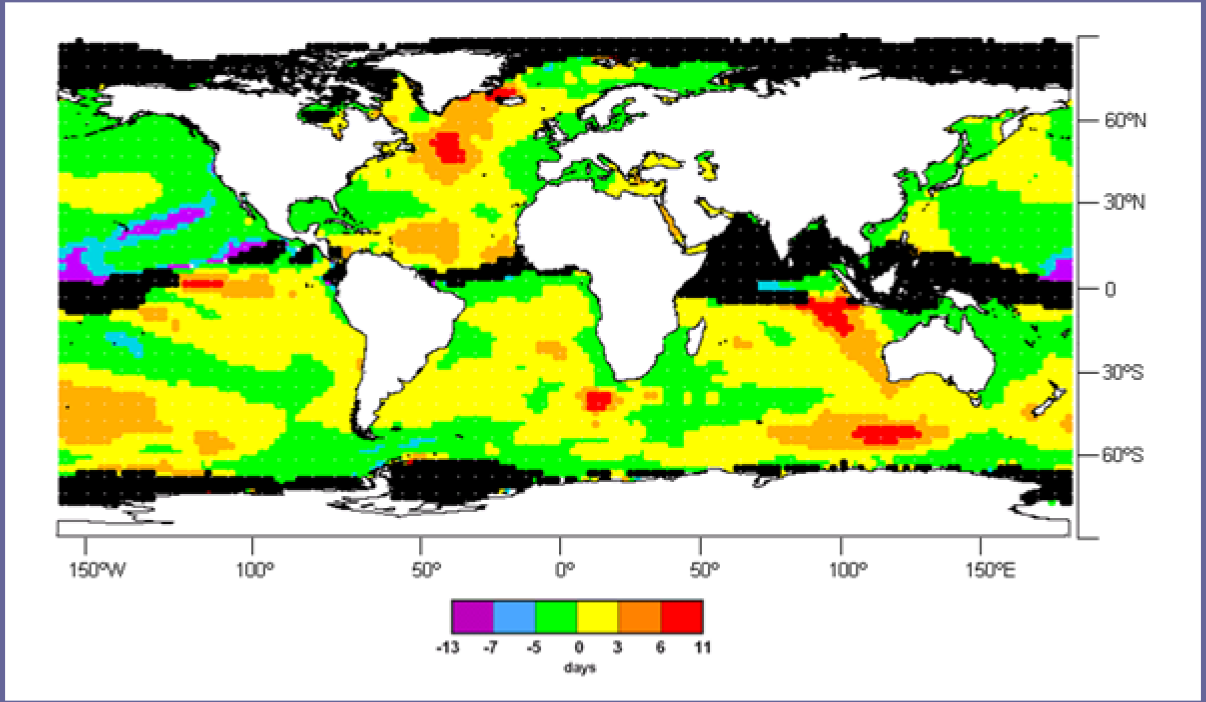
MELBOURNE AT LAGS (1857-2001)



AT lag increases by 6 days between 1900 and 2001 [Alexander et al 2005]

ANOMALY FIELDS OF SST LAG



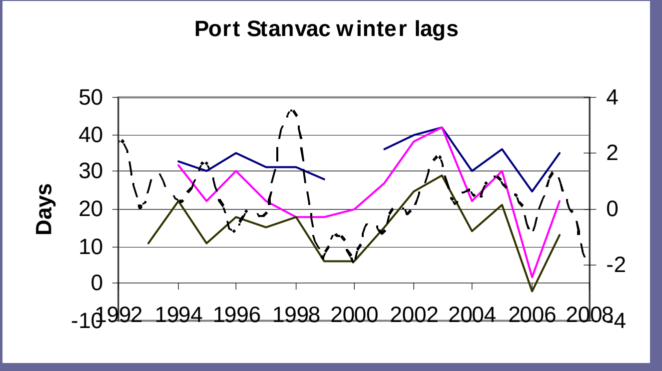
Climate change SST lag anomaly (SST lag 1991-2005 – SST lag 1976-1990)

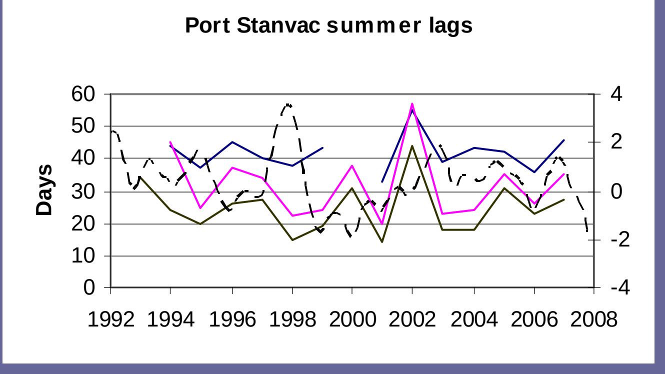
Regions with r < 0.9 between monthly data and harmonic fit are shown in black

GLOBAL WARMING FOOTPRINT

- Changes between 1976-1990 and 1991-2005
- **general increase in SST lag propagating from the tropics**
- **- in the SH a positive anomaly has developed south of Australia**
- **- in the NH a positive anomaly has formed off of Newfoundland, and a negative anomaly in the North Pacific Ocean**
- **Effects on regional climates**
- **Australia** **extension of summer conditions in western and southern coasts with a reduction in winter rainfall [Landvogt et al 2008]**
- **Arctic** **enhanced late summer north-eastward advection of heat leading to ice melting [Wang et al 2006]**
- **North Pacific Ocean** **reduction in NE trades leading to permanent El Nino conditions [Power and Smith 2007]**

LAG CORRELATION WITH ENSO





Laczko [2008]

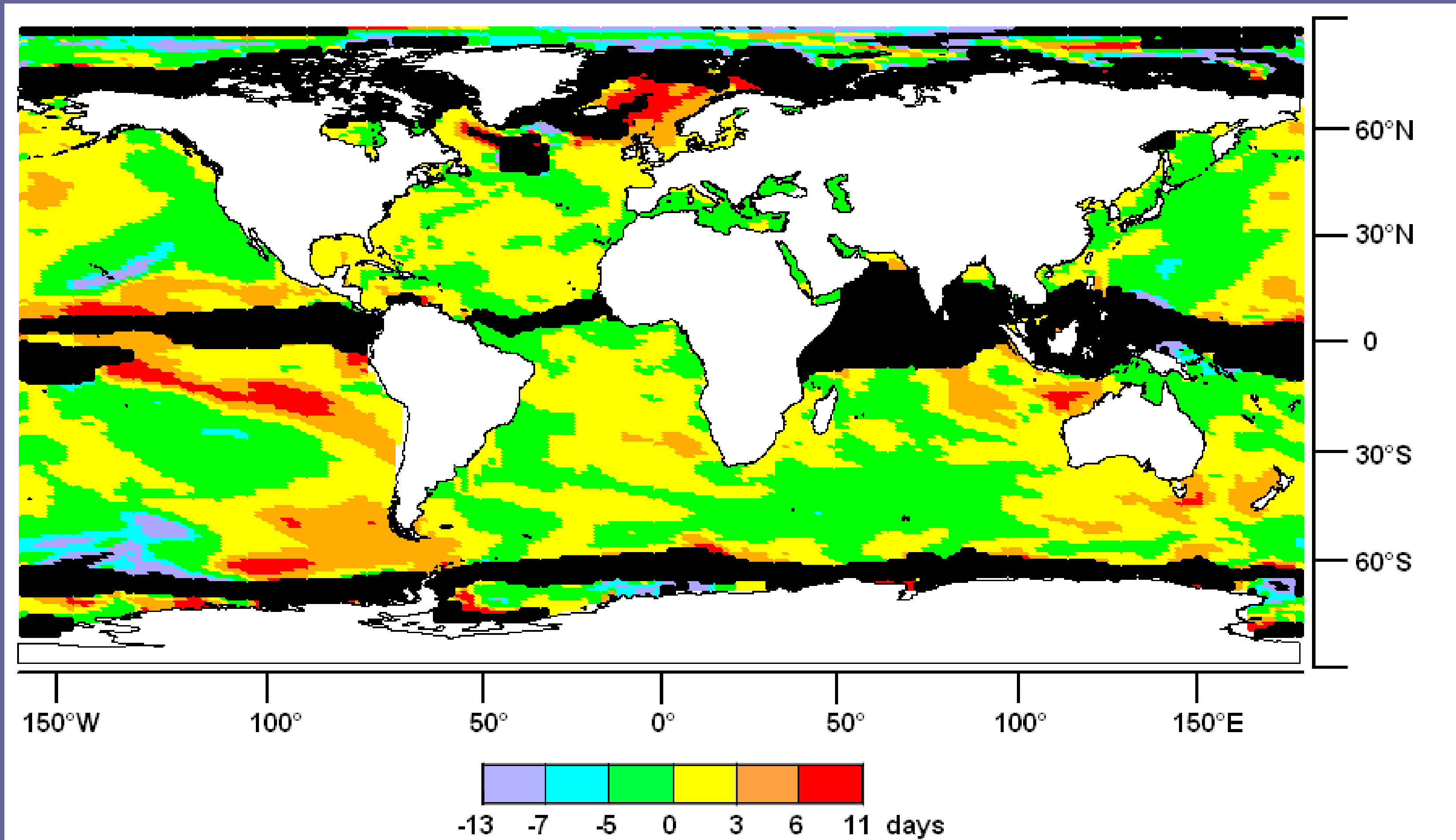
------ Nino 3.4

____ Adelaide AT lag

____ Port Stanvac AT lag

Since about 2000 Nino 3.4 and AT lag along the southern and western coast of Australia are positively correlated
This is consistent with the negative SST anomaly in the North Pacific Ocean indicating El Nino conditions

COUPLED CLIMATE MODEL LAG ANOMALY PREDICTIONS



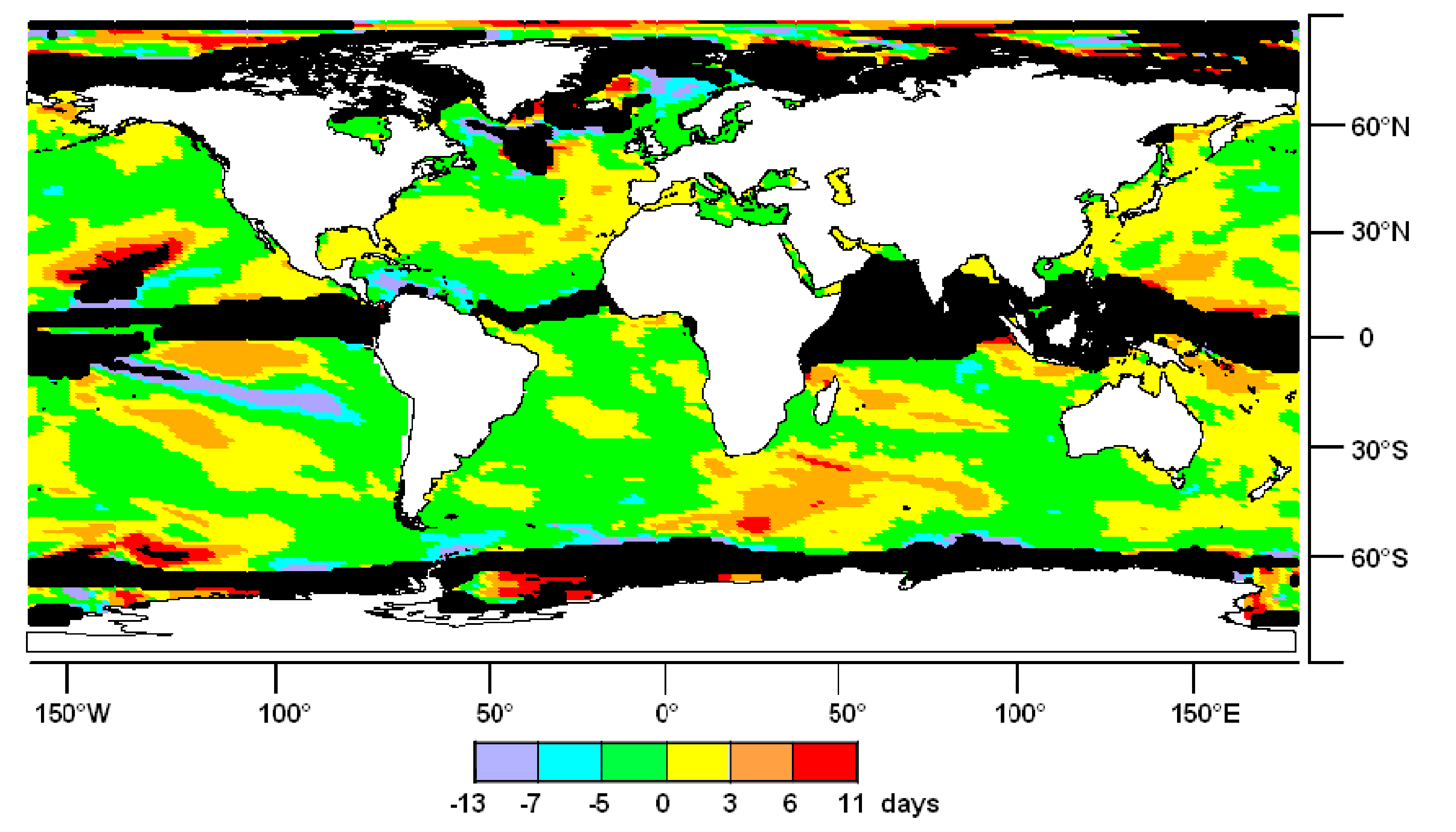
1991 - 2005

Predicted SST lag anomaly (SST lag 1991-2005 – SST lag 1976-1990) from the CSIRO Mk 3.5 coupled climate model

COMPARISON OF OBSERVATIONS AND PREDICTIONS

- This comparison indicates that the model is performing reasonably well
- **Implies that the ocean mixed layer physics is adequate**
- **The regions of positive and negative SST anomaly however differ somewhat from observations, e.g. in the North Atlantic Ocean and the eastern Indian Ocean.**

COUPLED CLIMATE MODEL LAG ANOMALY PREDICTIONS



2006 - 2020

Predicted SST lag anomaly (SST lag 2006-2020 - SST lag 1976-1990) from the CSIRO Mk 3.5 coupled climate model

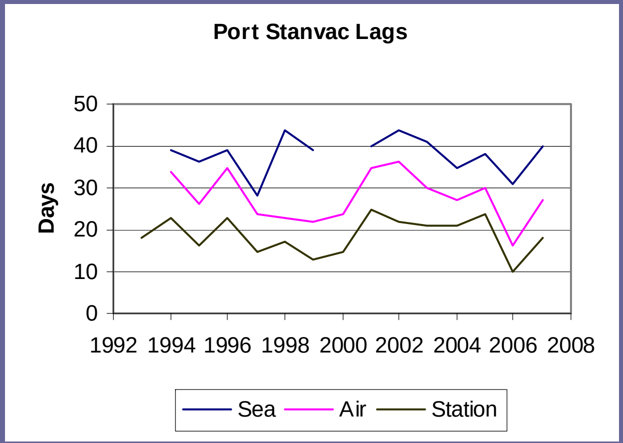
PREDICTION FOR 2006-2020

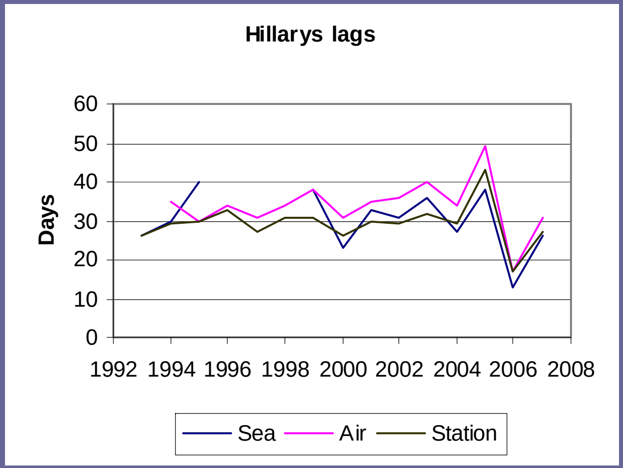
- The model predictions show a remarkable reversal of sign of the SST lag anomaly field throughout the world ocean!
- **Implies that the regional climate anomalies are also reversible**

- **The ‘cycle’ initiated by global warming through the ocean mixed layer has a (model) period of about 30 years**
- **This period appears to be related to the heat exchange coefficient with the deep ocean in the subtropical tongues, i.e.**

- **for g = 88 degrees, $T = 2\pi/B$ is 30 years**

THE TURNING POINT



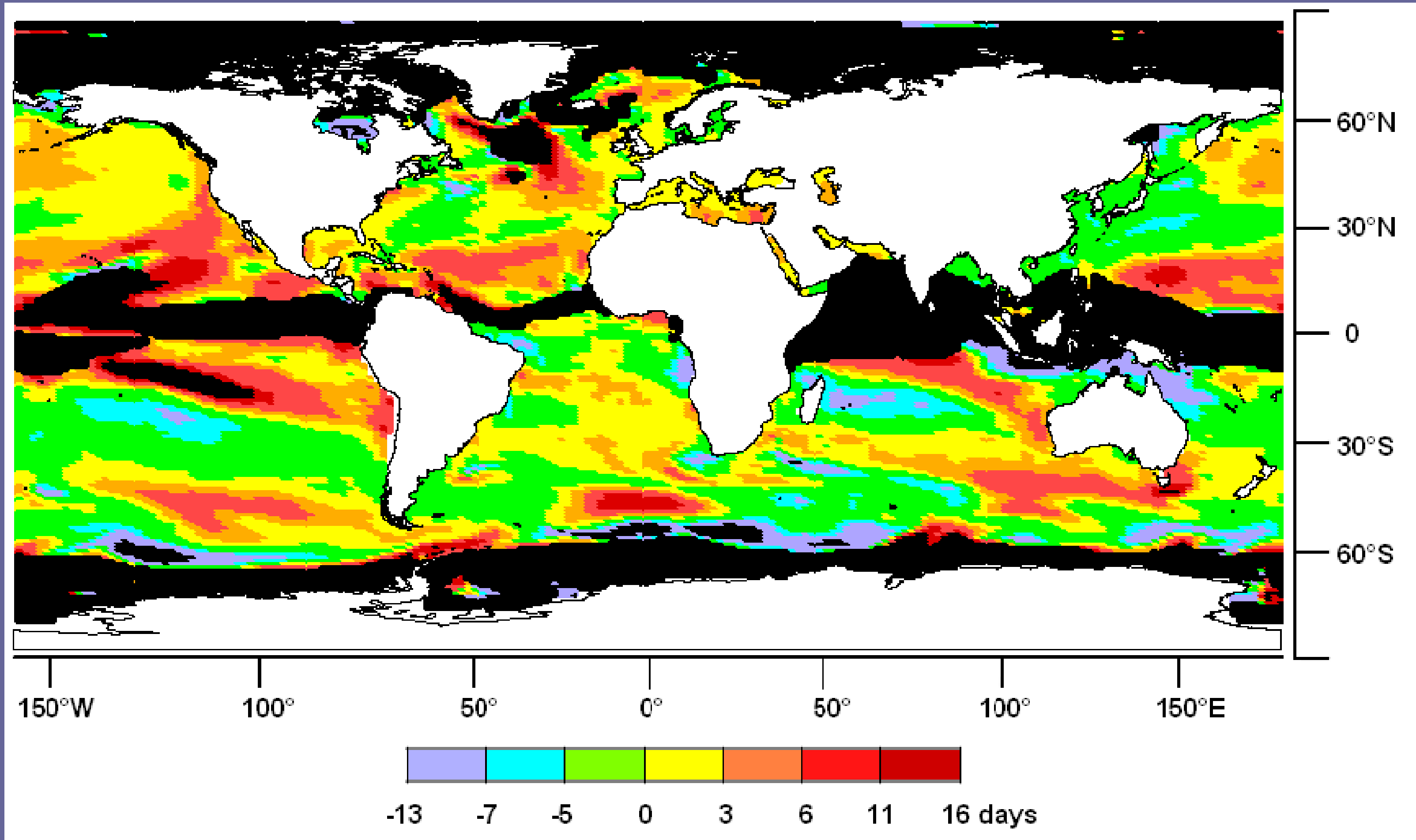


The 14 year (1993-2007) time segment of AT lag for the western and southern coasts of Australia possibly show negative trends towards the end of the records suggesting that the lags may be going through a turning point as predicted by the climate model

Adelaide (Port Stanvac)
Perth (Hillarys)

Laczko (2008)

COUPLED CLIMATE MODEL LAG ANOMALY PREDICTIONS



2076
-
2090

Predicted SST lag anomaly (SST lag 2076-2090 – SST lag 1976-1990) from the CSIRO Mk 3.5 coupled climate model

PREDICTION FOR 2076-2090

- The ‘cycle’ persists in the model and intensifies
- Hence the swings in regional climate on a period of about 30 years become more severe

CONCLUSIONS

- (1) SST lag changes brought about by the ocean mixed layer are a prime cause of regional climate change
- (2) It is vital therefore that climate models accurately predict SST lag variability
- (3) The ocean mixed layer is a very important agent in propagating the global warming signal into the temperate regions from the tropics
- (4) Analysis of the CSIRO coupled climate model results predicts that the exchange of heat between the mixed layer and the deep ocean has an inter-decadal cycle which would give rise to intensifying future swings in regional climates

ACKNOWLEDGEMENTS

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