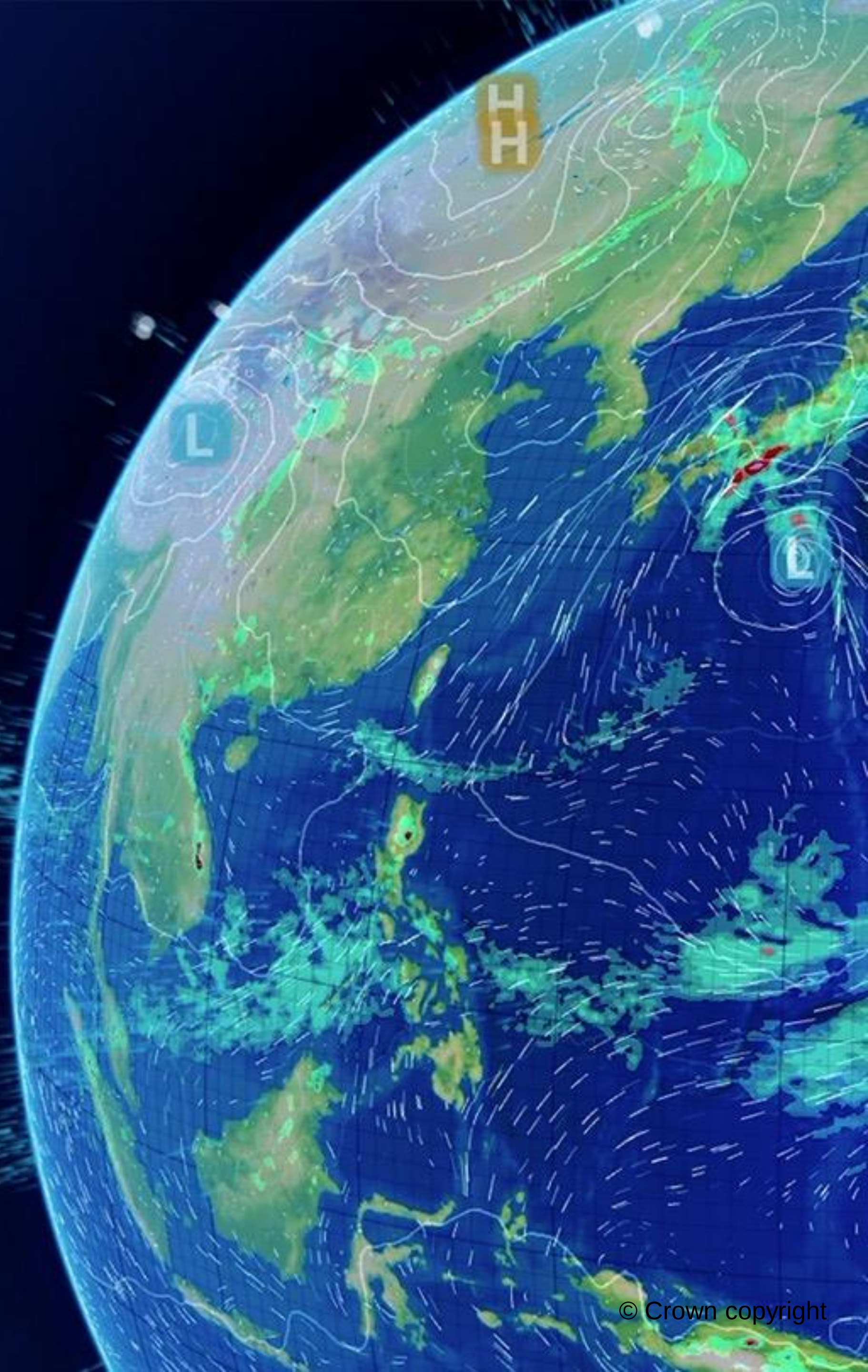
Met Office

Long range predictability of climate, atmospheric angular momentum and the length of day

Adam Scaife, Leon Hermanson, Annelize van Niekerk, Steven Hardiman, Ruth Comer, Nick Dunstone, Sarah Ineson, Jeff Knight and Doug Smith.



Angular momentum and the Earth's rotation rate

Conservation of Earth-atmosphere total angular momentum

$$L = I_{Earth}\,\omega_{Earth} + L_{Atm} = \text{constant}$$

$$\Rightarrow \quad I_{Earth}\,\Delta\omega_{Earth} = -\,\Delta L_{Atm}$$

$$\Rightarrow \quad \Delta\omega_{Earth} = -\,\Delta L_{Atm} / I_{Earth}$$

Total angular momentum of the Earth and atmosphere must be constant

Any change in atmospheric angular momentum must be exchanged with the Earth

Changes in atmospheric angular momentum => changes in Earth's rotation

Conservation of Earth-atmosphere total angular momentum

$$2\pi/\tau' - 2\pi/\tau = -\Delta L_{Atm} / I$$

$$\tau' - \tau \approx -\Delta L_{Atm} \tau^2 / 2\pi I$$

For a sphere:

$$I = 2MR^2/5$$

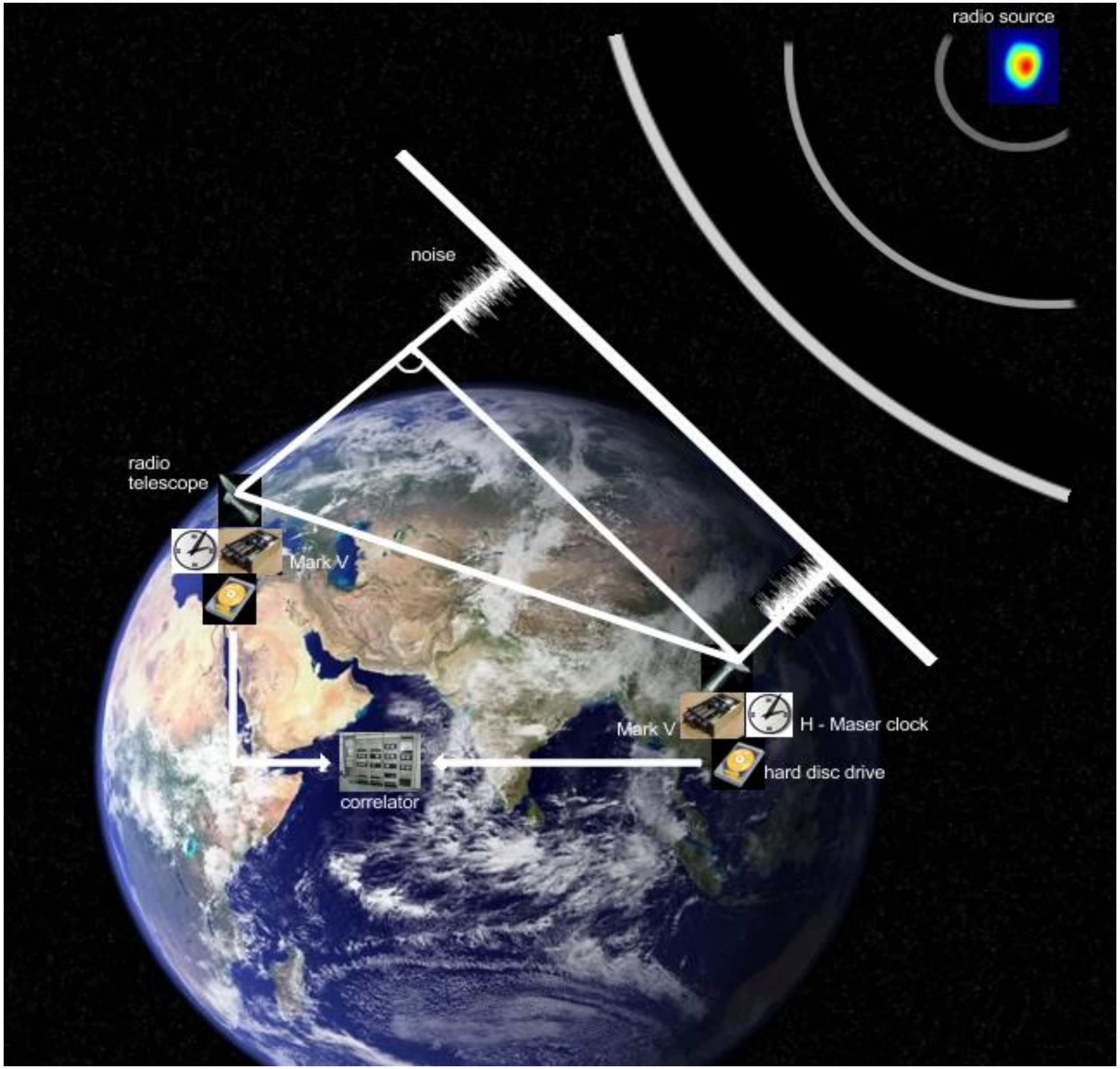
M = mass
R = radius

=> $I \sim 9\times10^{37}\,\mathrm{Kgm}^2$ for Earth

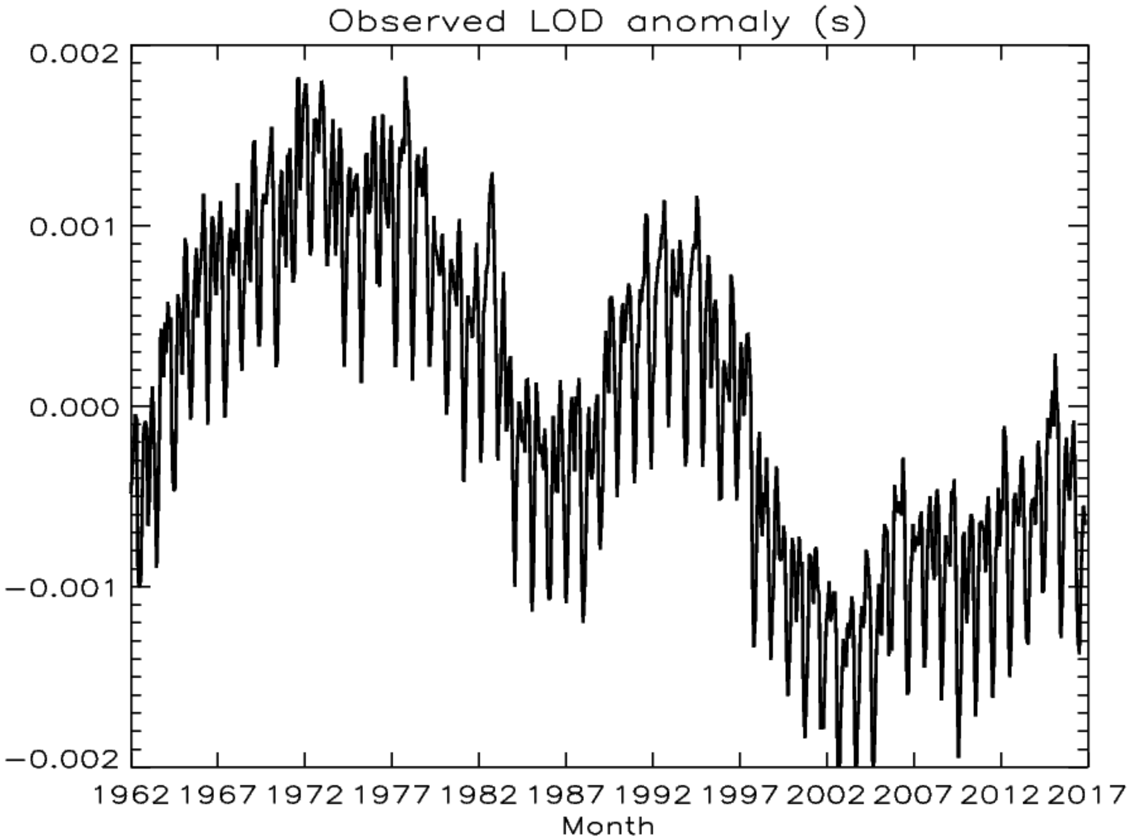
Changes in atmospheric angular momentum => changes in the length of day

Independent observations

Independent Verifying Observations



Non-meteorological verifying observations

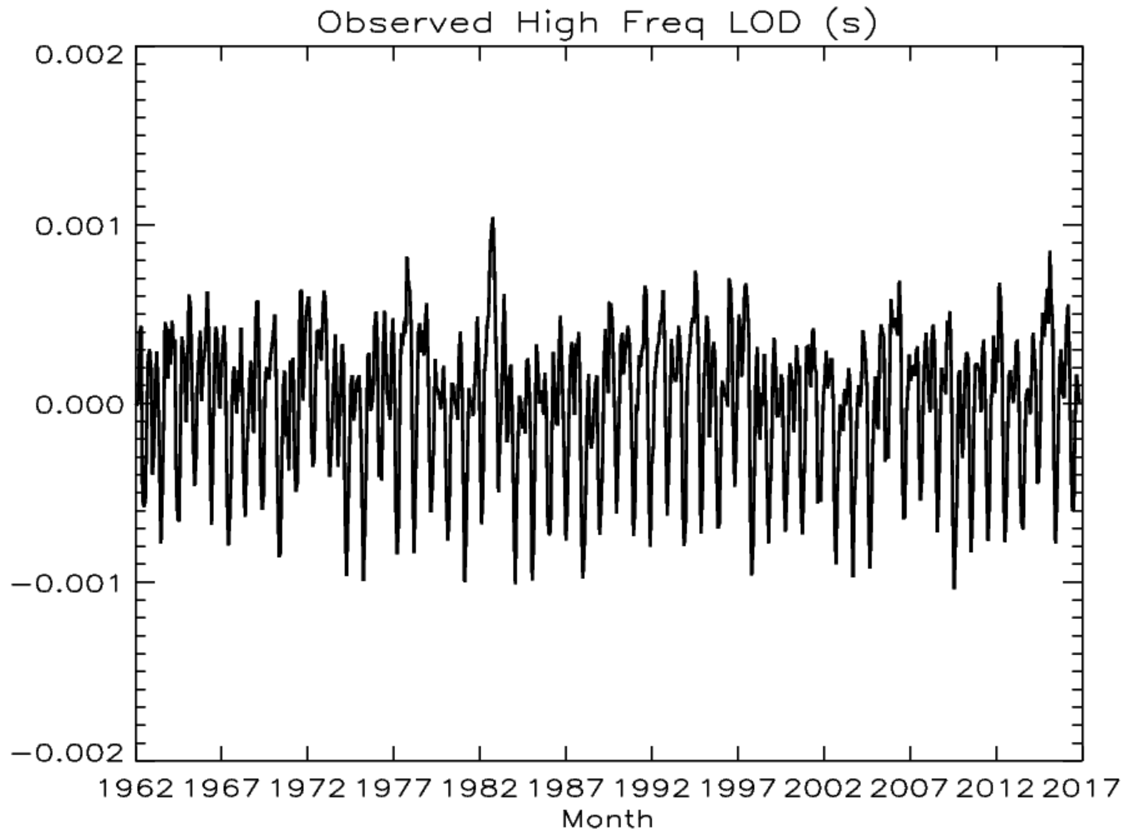


Here you see the full observed record

Note the low frequency and high frequency variations

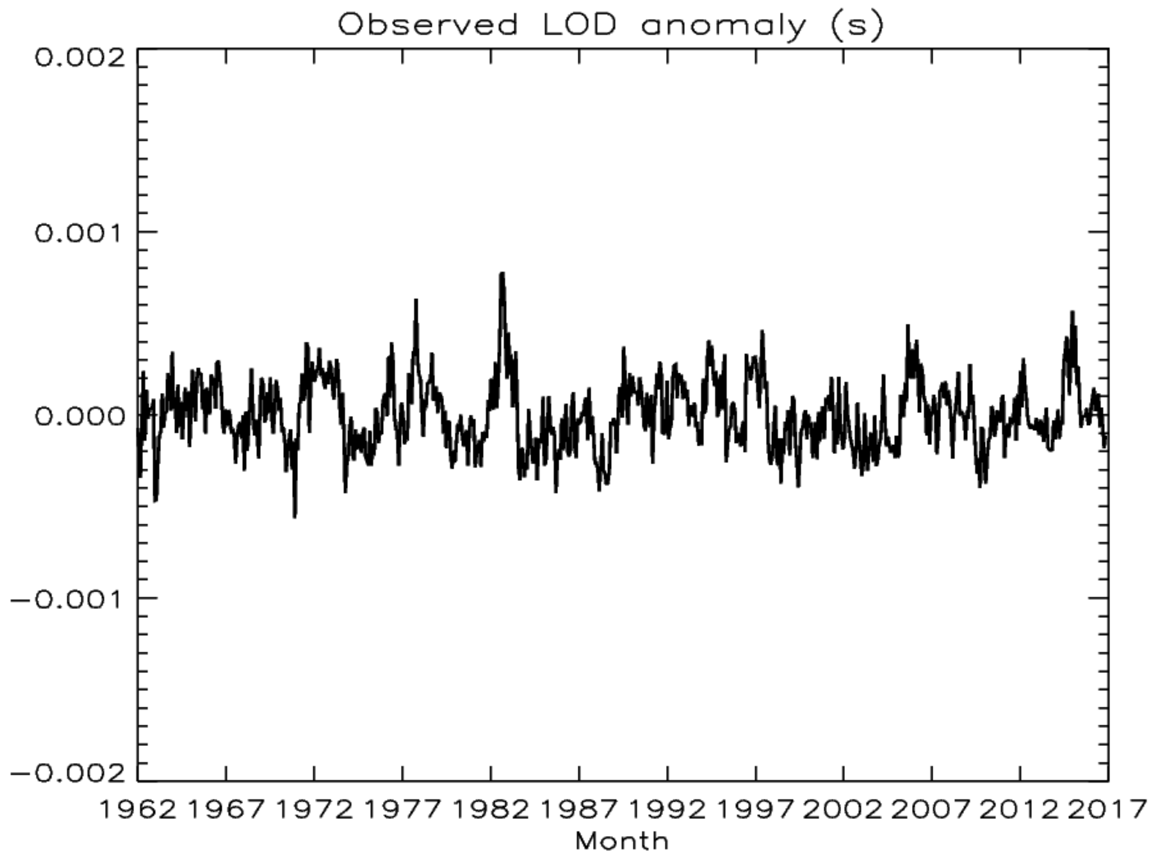
Both about 1ms

After removing low frequency variability



Here you see the prominent annual cycle of about 1ms

After removing annual cycle variability



Year to year variations have amplitude about 0.5ms

These are what we are goiing to predict

Simulated angular momentum

Calculating AAM in the Unified Model

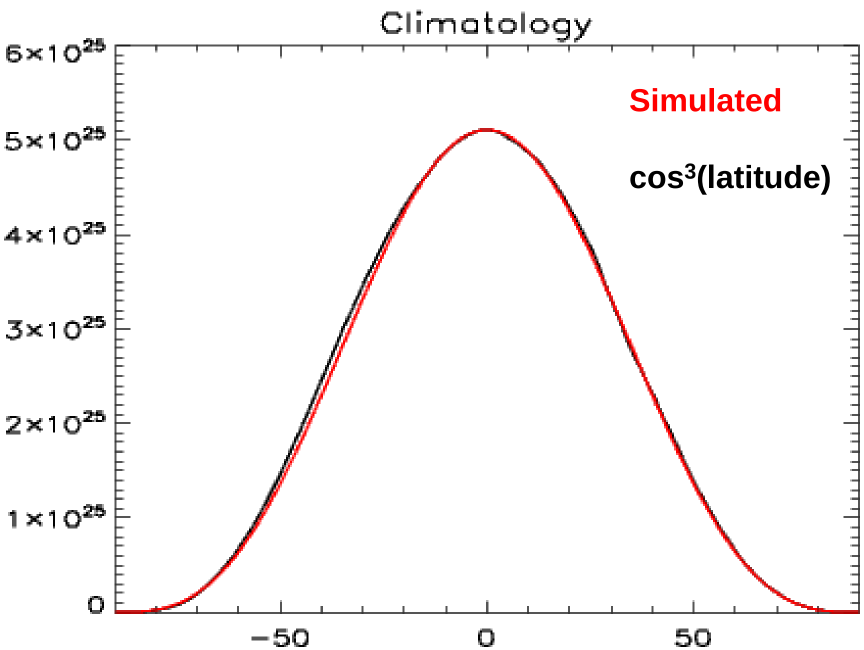
$$\mathrm{AAM} = \int_{a}^{\infty}\int_{-\pi/2}^{\pi/2} 2\pi\rho(\Omega r\cos\varphi + U)r^3\cos^2\varphi \, dr\, d\varphi$$

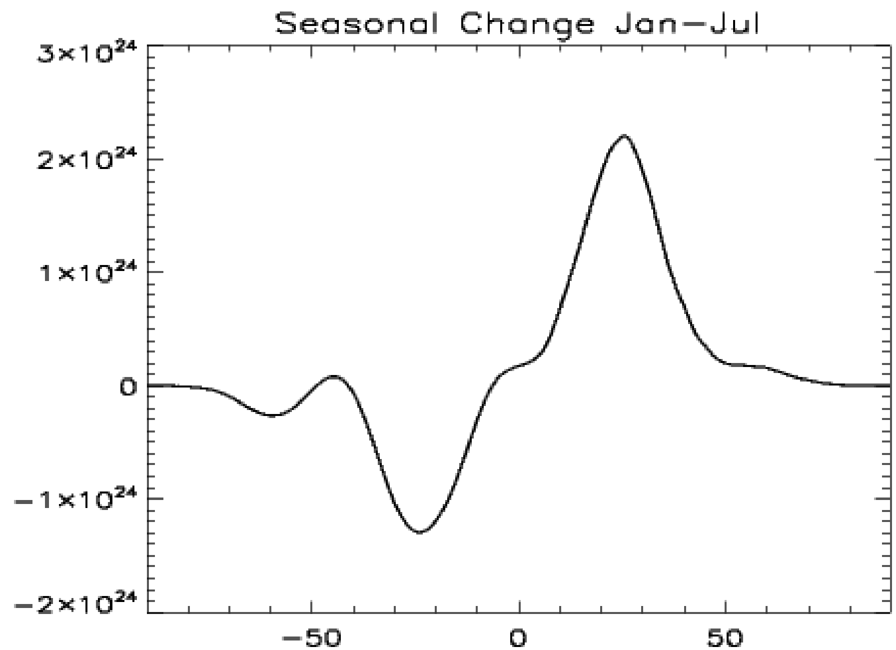
Global integral of angular momentum

Includes density and wind variations

For solid body rotation (U=0) the angular momentum goes as $\cos^3$(latitude)

Mean and seasonal cycle



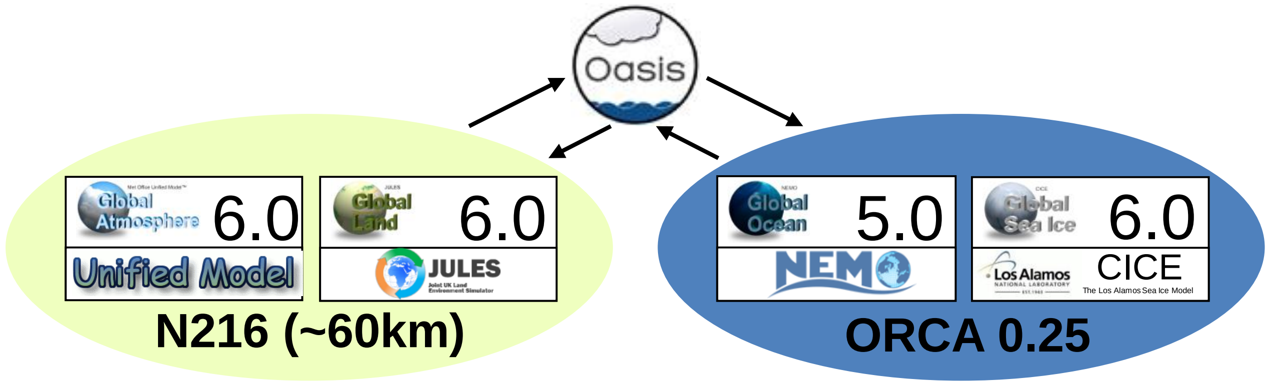


Model climatology is close to $\cos^3$(latitude) and solid body rotation

Annual cycle involves a transfer of AAM into the winter hemisphere

Predictions

Met Office Seasonal (GloSea) and Decadal (DePreSys) Prediction Systems



Fully coupled model (Atmosphere-Land-Ocean-Sea Ice)

World leading ocean resol'n + high atmosphere resol'n

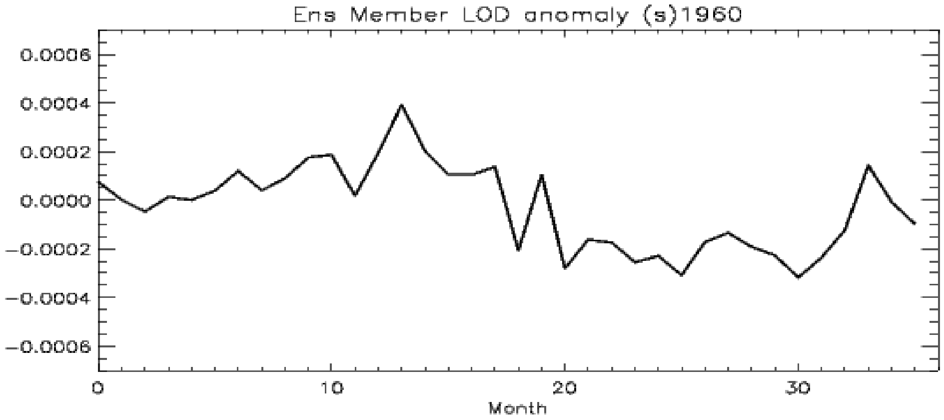
Coupled sea ice and well resolved stratosphere

Used across timescales: monthly->seasonal->decadal

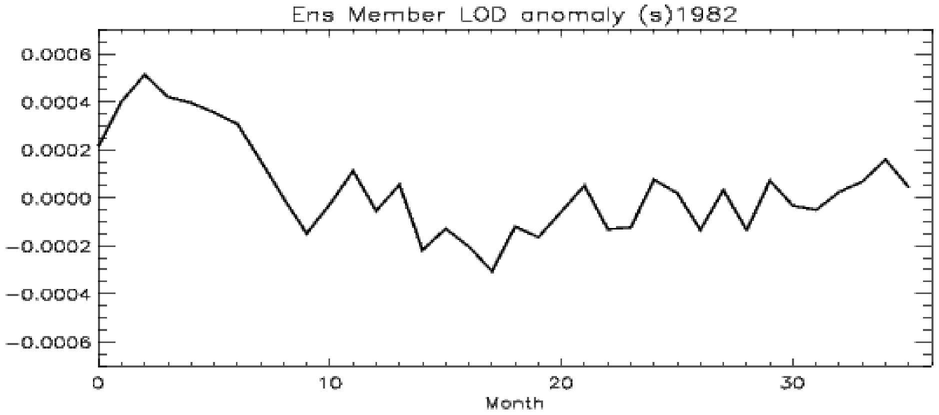
See MacLachlan et al QJRMS 2015

Example Forecasts

Start Nov 1960



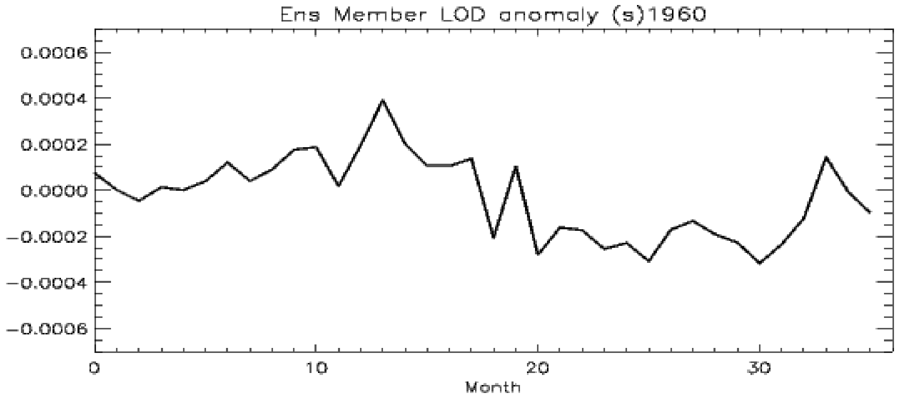
Start Nov 1982

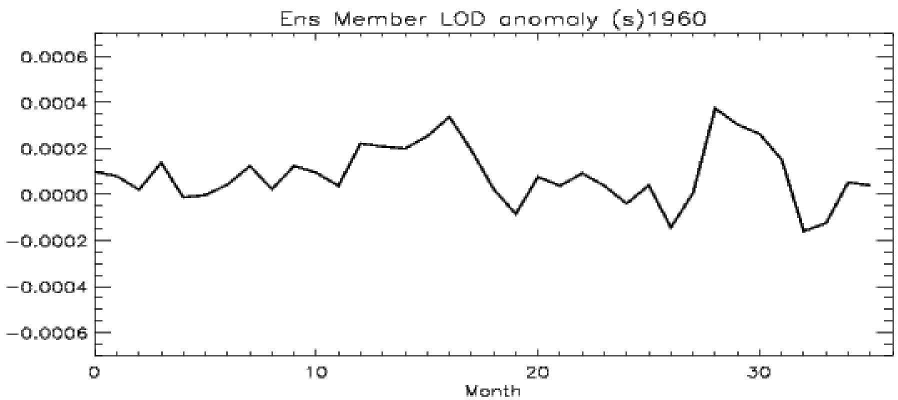


Fluctuations are of same magnitude (~0.5ms) as radio telescope observations

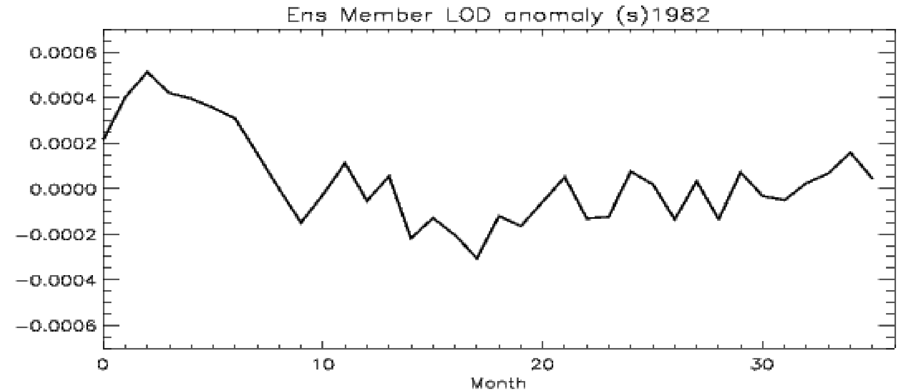
Multiple Forecast Members

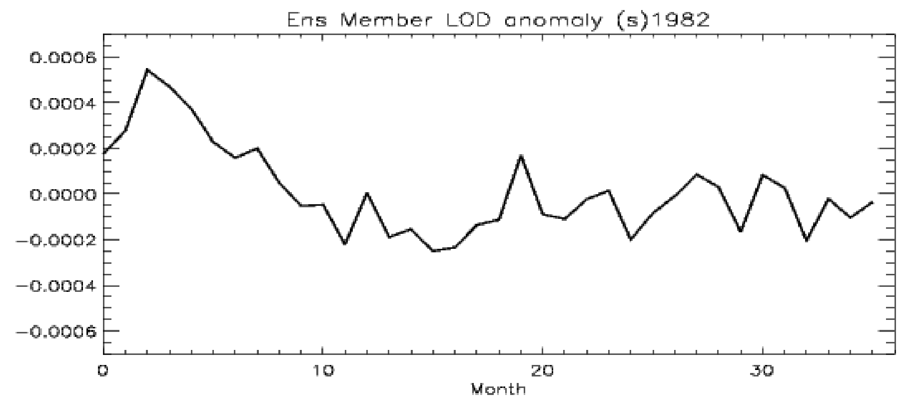
Start Nov 1960





Start Nov 1982

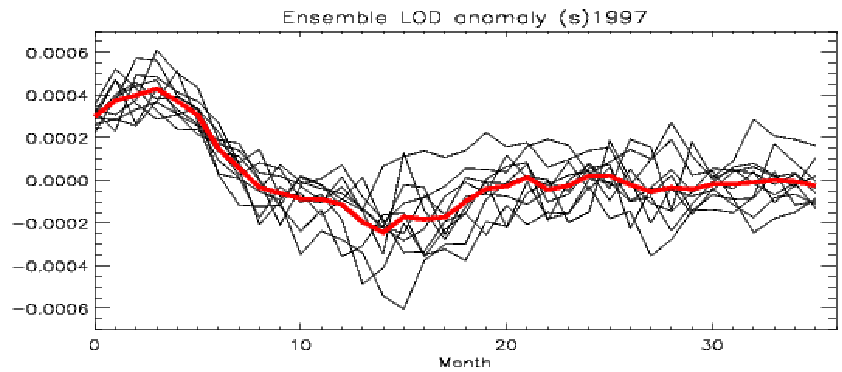




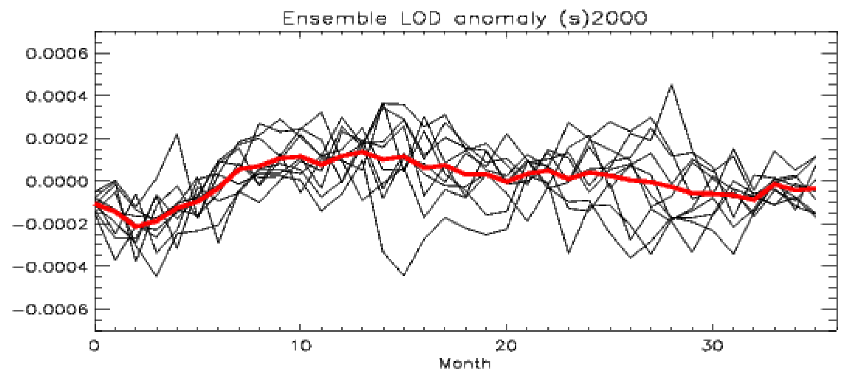
There is similarity between ensemble members for the same year

Ensembles suggest predictability

Start Nov 1997



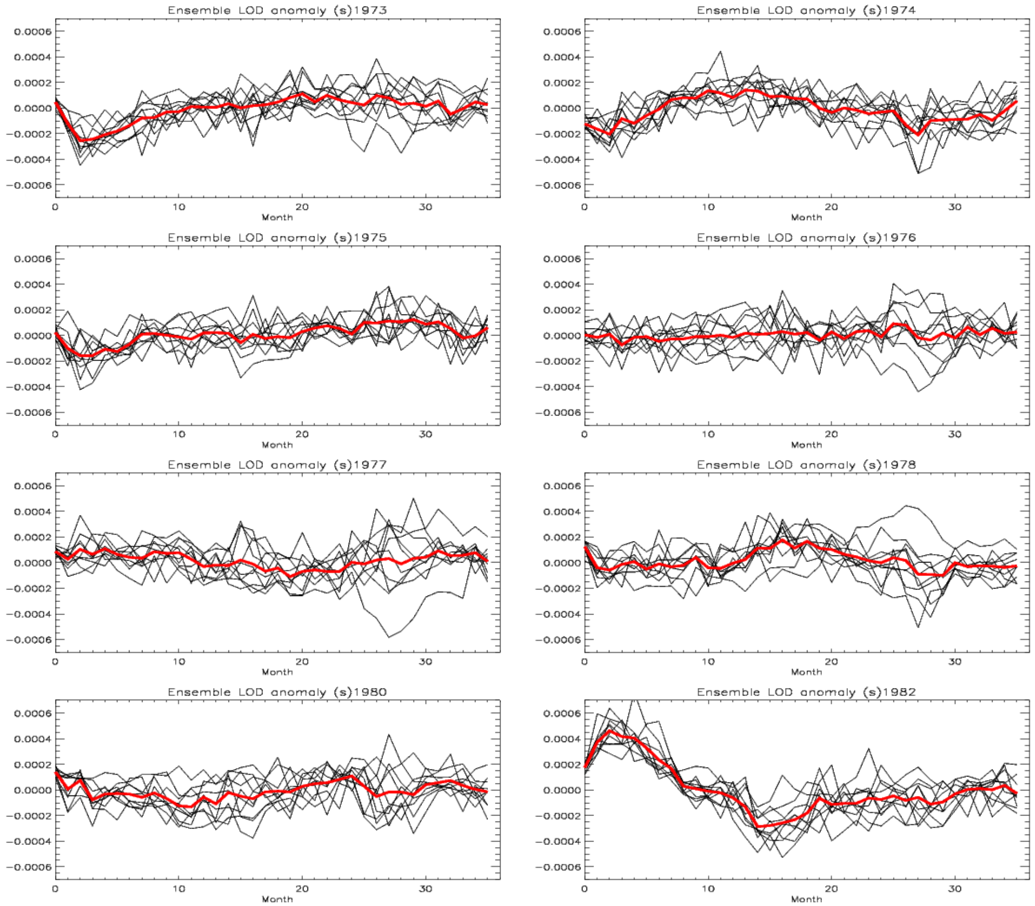
Start Nov 1998



Ensemble cluster around mean

Well separated for several months!

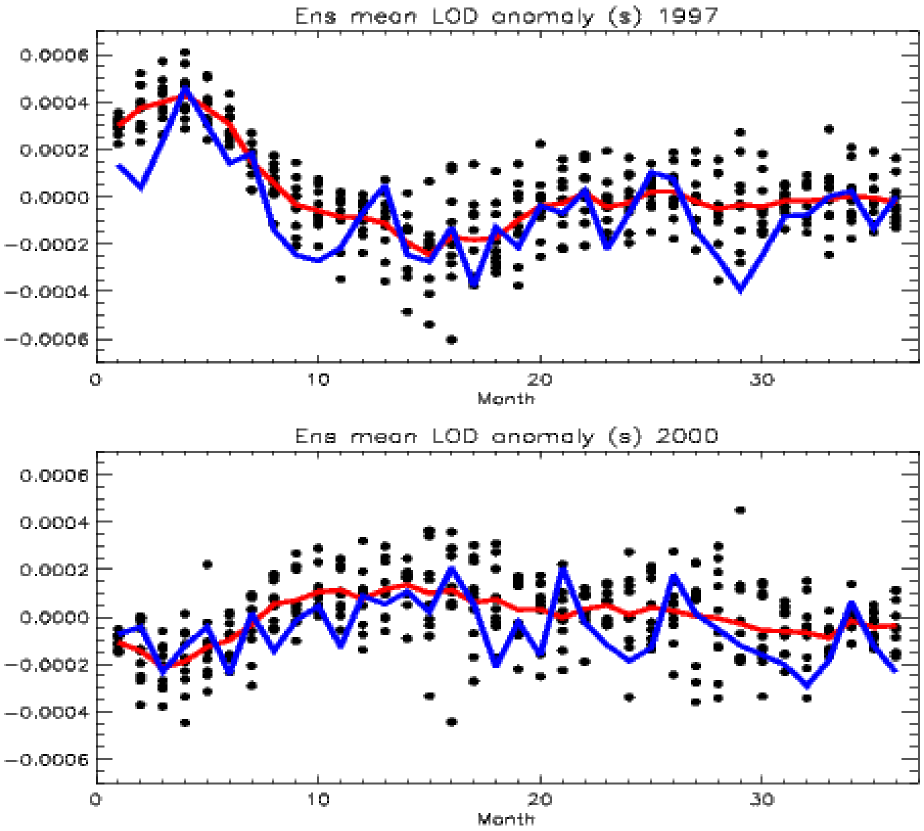
Lots of years



We now have a full hindcast dataset from 1960 onwards

How predictable at different lead times?

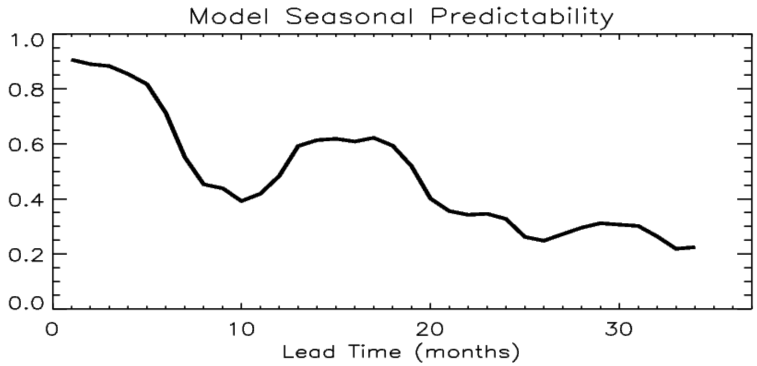
Can the model predict the observed length of day?



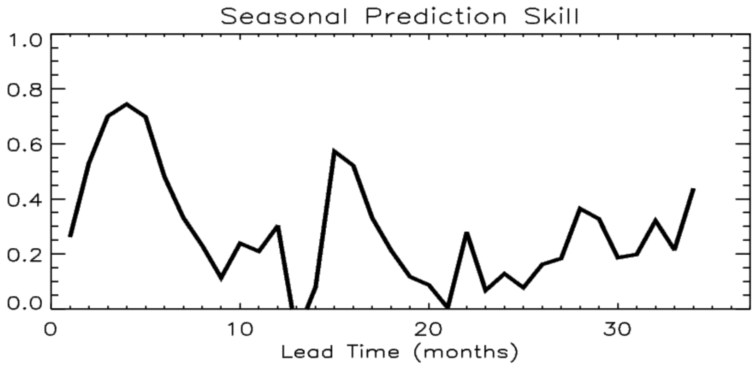
Observed LOD variations appear to follow model predictions

Modelled Predictability and Prediction skill

Seasonal Model predictability



Seasonal Prediction Skill



High predictability in first 6 months

Predictability declines in summer

Non-monotonic decline

Appears to rise again in winter

Also shows skill for first months

Also declines in summer

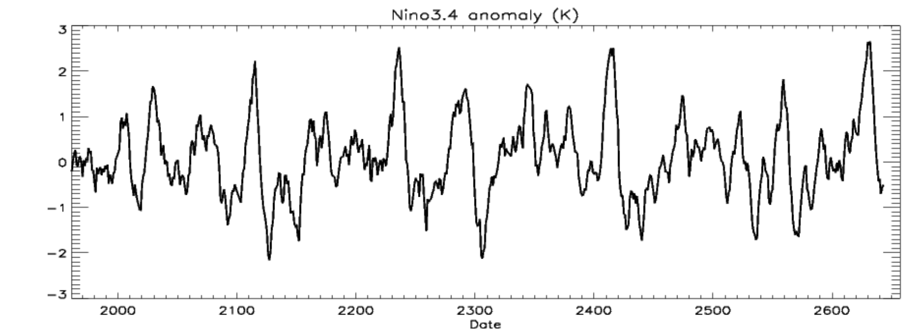
Also rises again in winter

Met Office
Hadley Centre

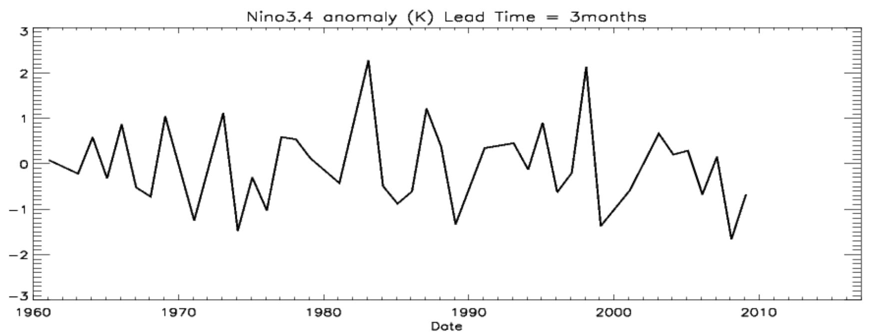
Mechanism

ENSO explains the initial predictable signal

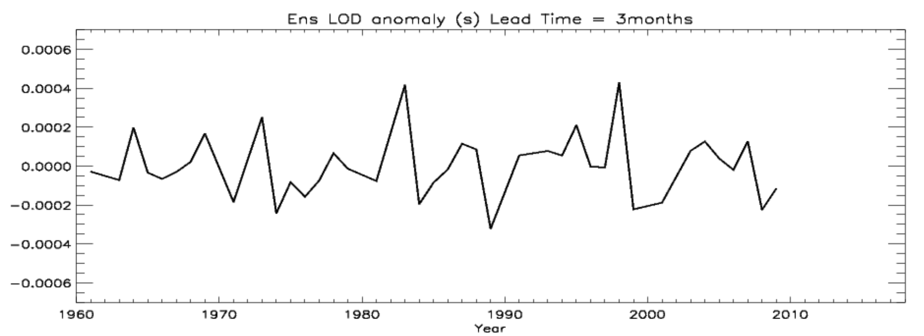
Observed ENSO full record



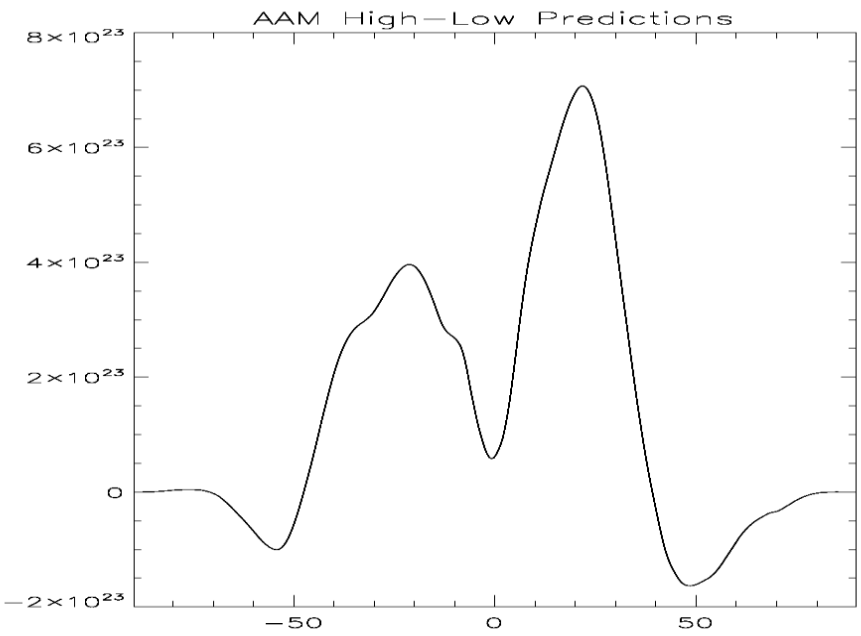
Observed ENSO at 3mth lead (February)

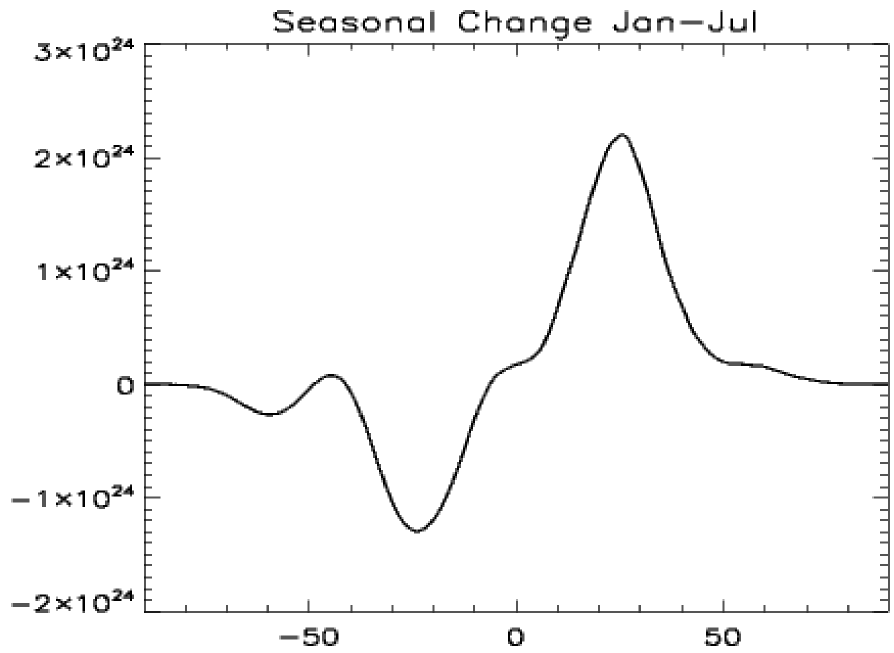


Predicted LOD anomaly



Signals triggered in the subtropics

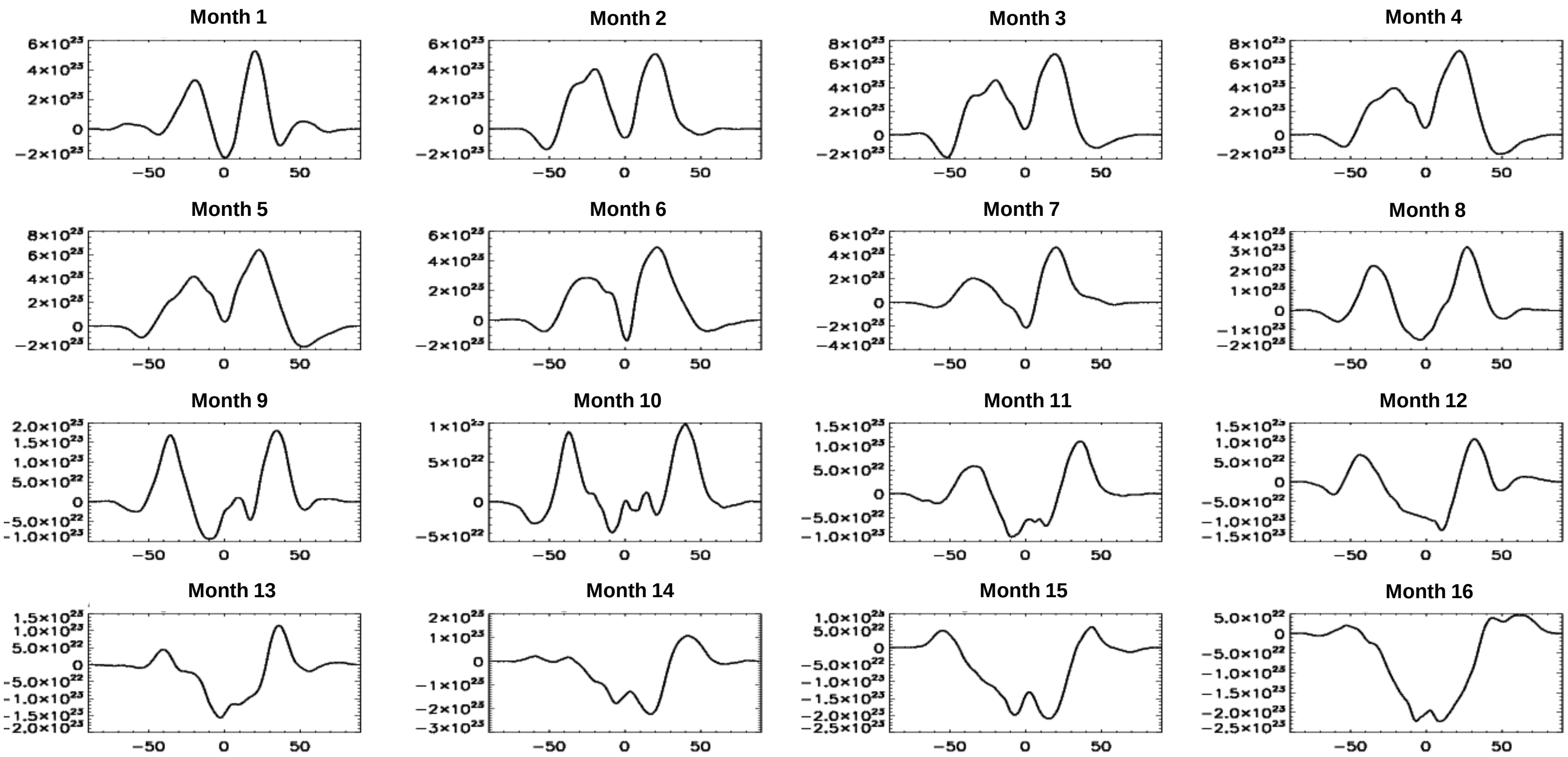




Unlike seasonal variations, predicted interannual variations roughly symmetric about equator

Peaks in the subtropics…..what about it’s evolution with time?

Evolution with time

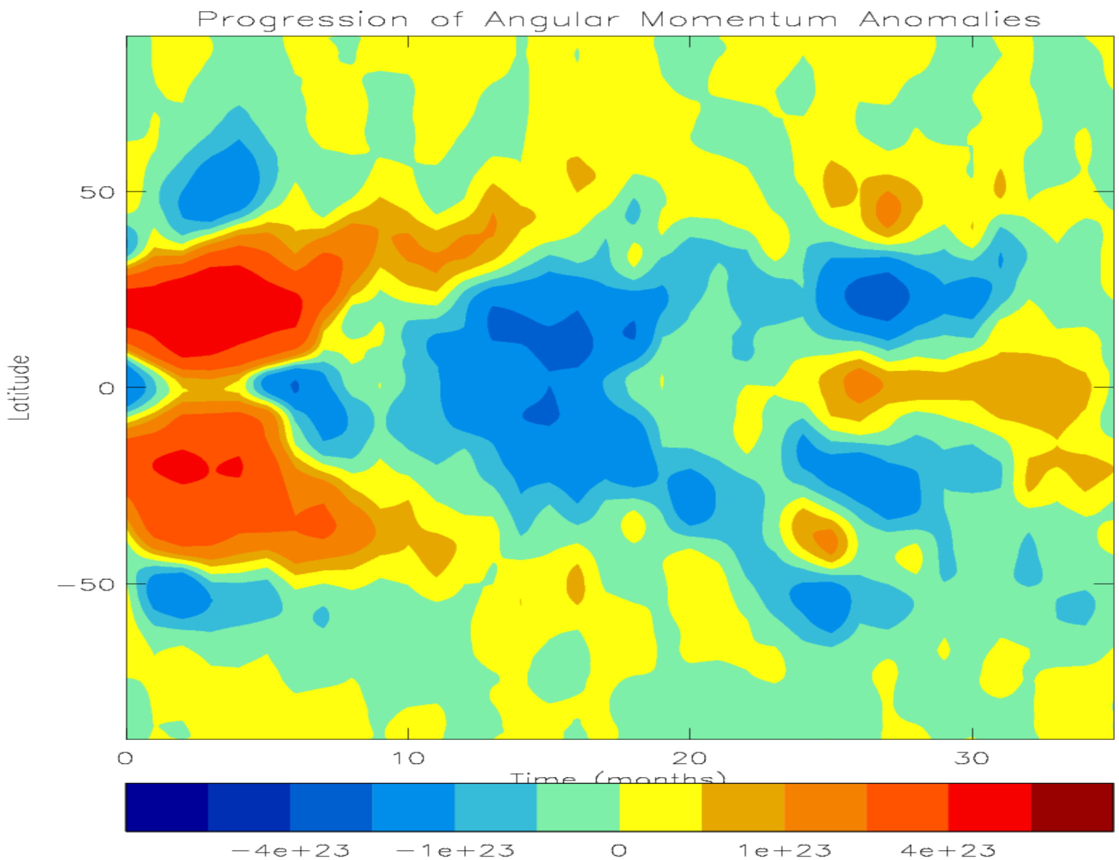


Predicted signals show remarkable persistence and propagation

They move polewards with time

They enter the extratropics and progress into our latitudes

Poleward propagation into both hemispheres



Atmospheric anomalies move polewards with time

They enter the extratropics and progress into our latitudes

This takes a very long time ~1-2 years!

A largely neglected topic with important UK contributions

Global propagation of interannual fluctuations in atmospheric angular momentum

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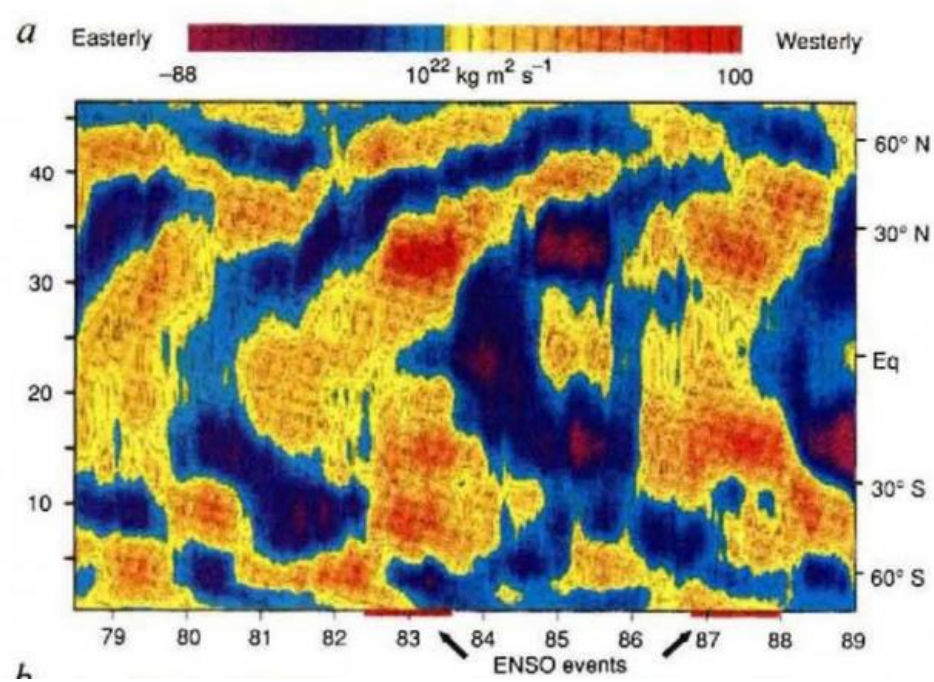
Clarendon Laboratory, Parks Road, Oxford OX1 3PU, UK

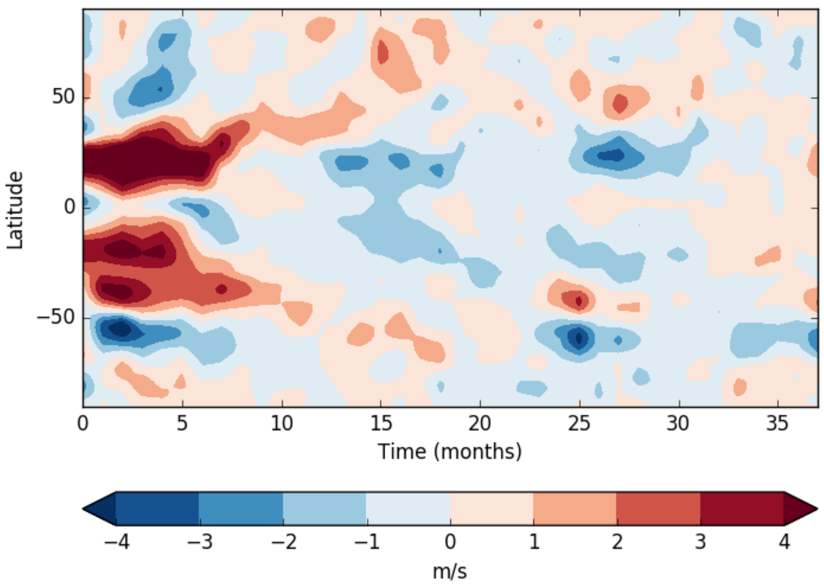


Prof. Raymond Hide, 1928-2016

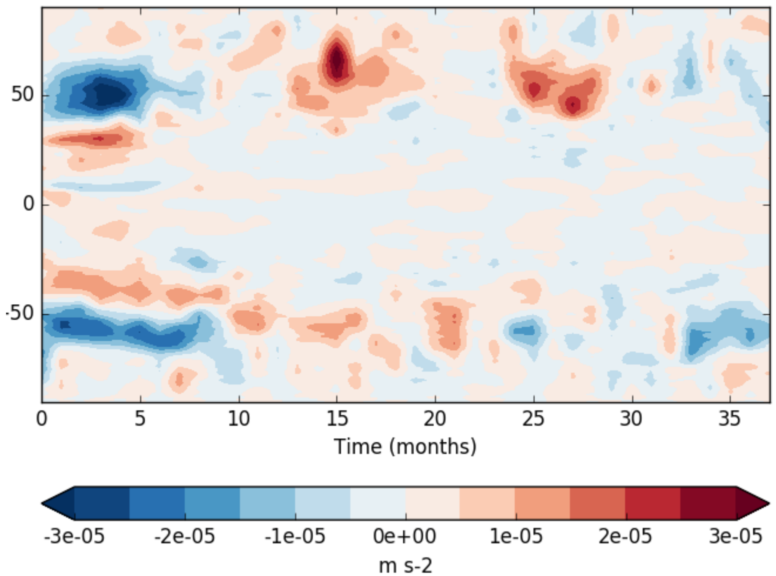
Nature, 1992

Evidence of a wave driven mechanism

Zonal wind in upper troposphere



EP flux divergence anomaly



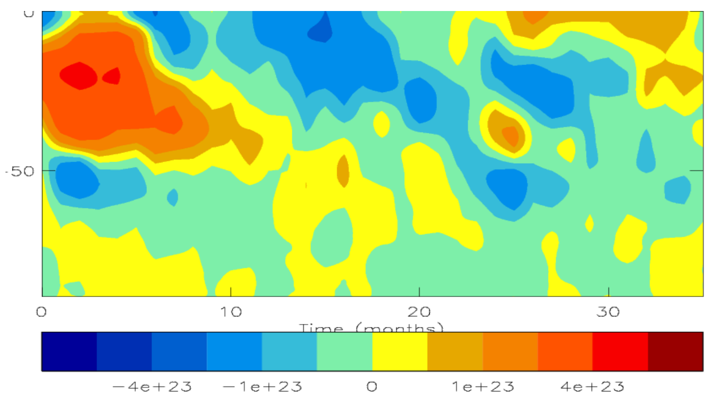
The angular momentum anomalies appear in zonal winds

They also appear in the wave forcing of the mean wind

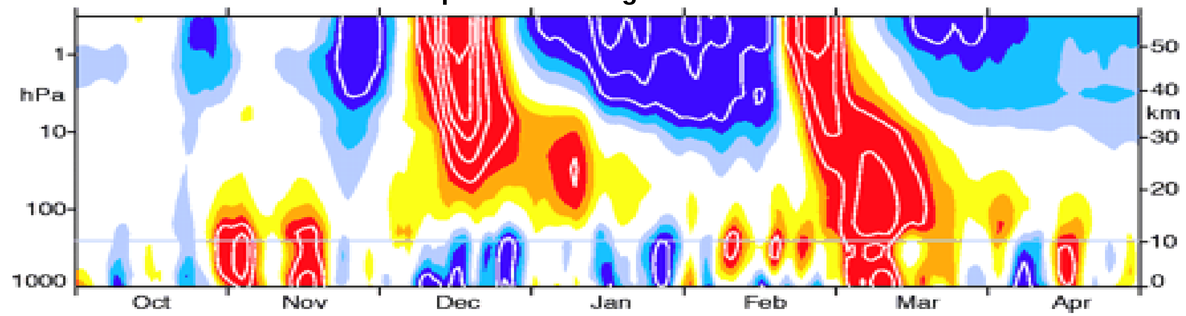
This takes a long time and can provide long range predictability

A dynamical link to other atmospheric phenomena

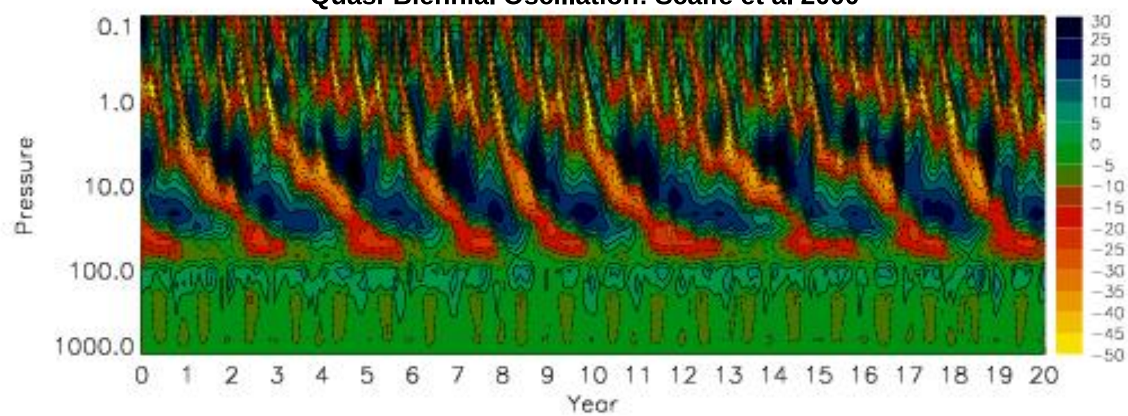
This study:



Sudden stratospheric warmings: Baldwin and Dunkerton 2001



Quasi-Biennial Oscillation: Scaife et al 2000



All of these phenomena are driven by atmospheric wave-mean flow interaction

They all migrate *towards the wavemaker* with time **(c.f. James and Dodd, 1996)**

=> long range predictability from within the atmosphere

Summary

Angular momentum fluctuations in the earth-atmosphere system are predictable out to years ahead

Independent radio-telescope obs' of Earth's rotation verify these multiyear predictions

Non-monotonic decline of skill with lead time, peaking in winter

Mostly triggered by ENSO in the tropics

Propagate polewards in both hemispheres on a timescale of months to years

Seen in meteorological fields as wave driven signatures in the mean flow: a horizontal analogue of the Quasi-Biennial Oscillation

A topic that should be resurrected as it presents a source of *long range predictability from within the atmosphere*

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