Aspects of long-range forecasting and ENSO

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Overview:

- long-range forecasting
  - global prediction
  - CGCM ensemble system: ingredients
  - multi-model

- performance, products examples
  - communicating probability and usefulness

- ENSO (El Niño Southern Oscillation)
  - a simple ‘box’ model (cf Jin 1997)
    - physical parameter sensitivities

thanks to LRF systems/products teams in Exeter

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A bit about myself:

- background in GFD

- Met Office since 1985
  - intermediate tropical models
  - statistical and dynamical seasonal systems, forecasts and products

    - from exploratory to operational

- now 0.5 MetO + 0.5 UCL
  - simple models
    - initialisation
    - re-emergence

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Global seasonal (and beyond) prediction:

CGCM ensemble seasonal prediction systems:
ingredients *(NB also 2-tier in use)*

- atmospheric GCM and oceanic GCM
  - 'climate' resolution ~ 1 deg x 1 deg
    - enhanced tropical ocean resolution
      - importance of ENSO!

- sea ice: statistical or dynamical

- stratosphere resolving? Preferable

- greenhouse gases etc. prescribed but evolving?
  Preferable

- initial conditions:
  combining observations and model (data assim):
  atmospheric (+land surface) analysis,
  separate ocean analysis
  - (quasi-)coupled data assimilation? evolving …

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CGCM ensemble seasonal prediction systems: ingredients

- generate forecast ensemble
  typically 40 members to sample possible
  outcomes, provide info for forecast pdf

- perturb initial conditions, stagger start times,
  include stochastic effects,
  perturb model parameters … (represent uncertainty)

- run ahead a few months (~2 seasons)

- drift toward model climate!
  Need bias correction data
  (or use anomalies from model climate to start,
  cf MetO decadal prediction system DePreSys)

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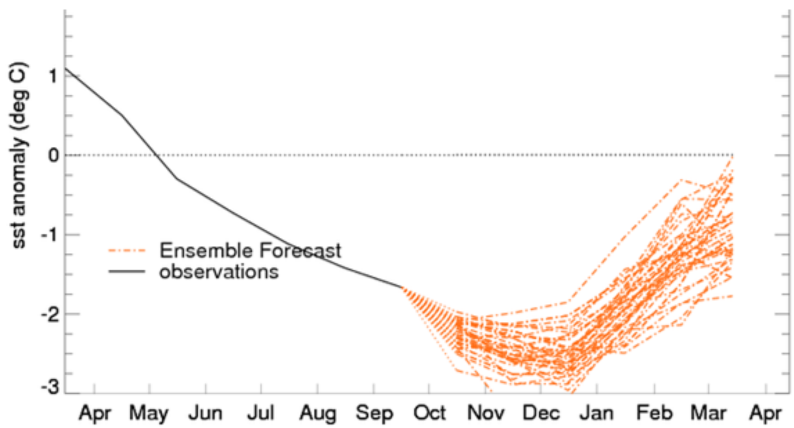
Ensemble example:
GloSea4 (Met Office CGCM LRF system)   Niño3.4 plumes

(at: http://www.metoffice.gov.uk/science/specialist/seasonal)

from Apr 2010



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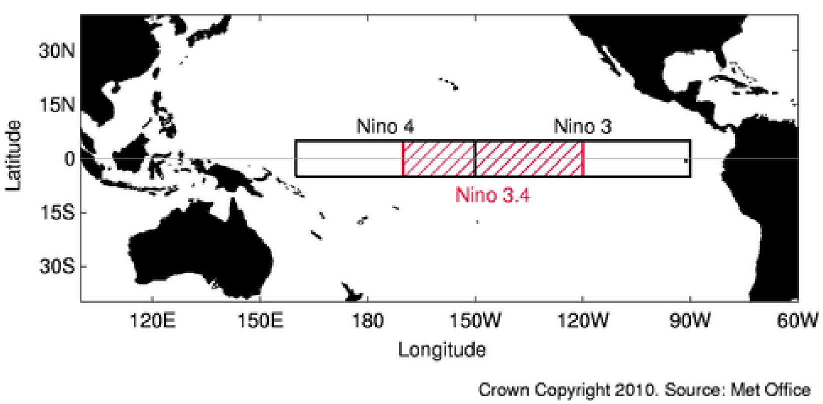

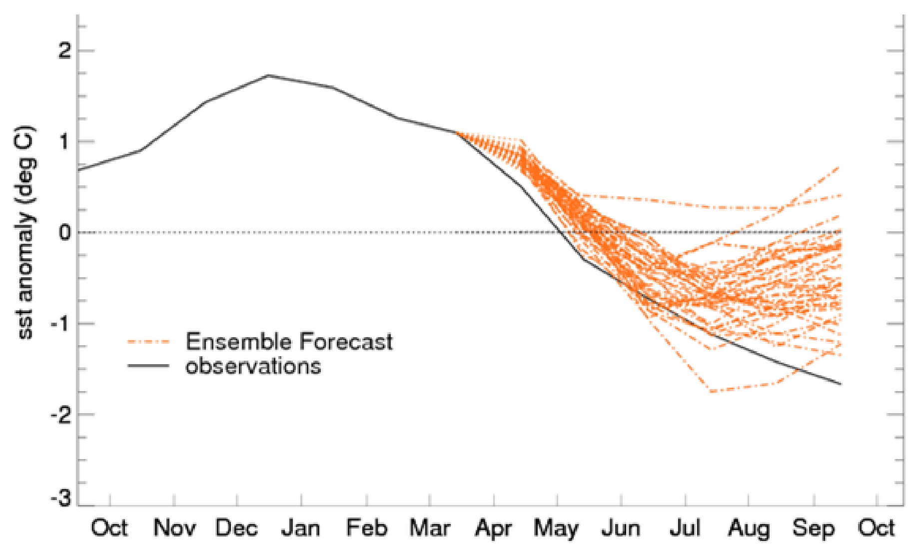

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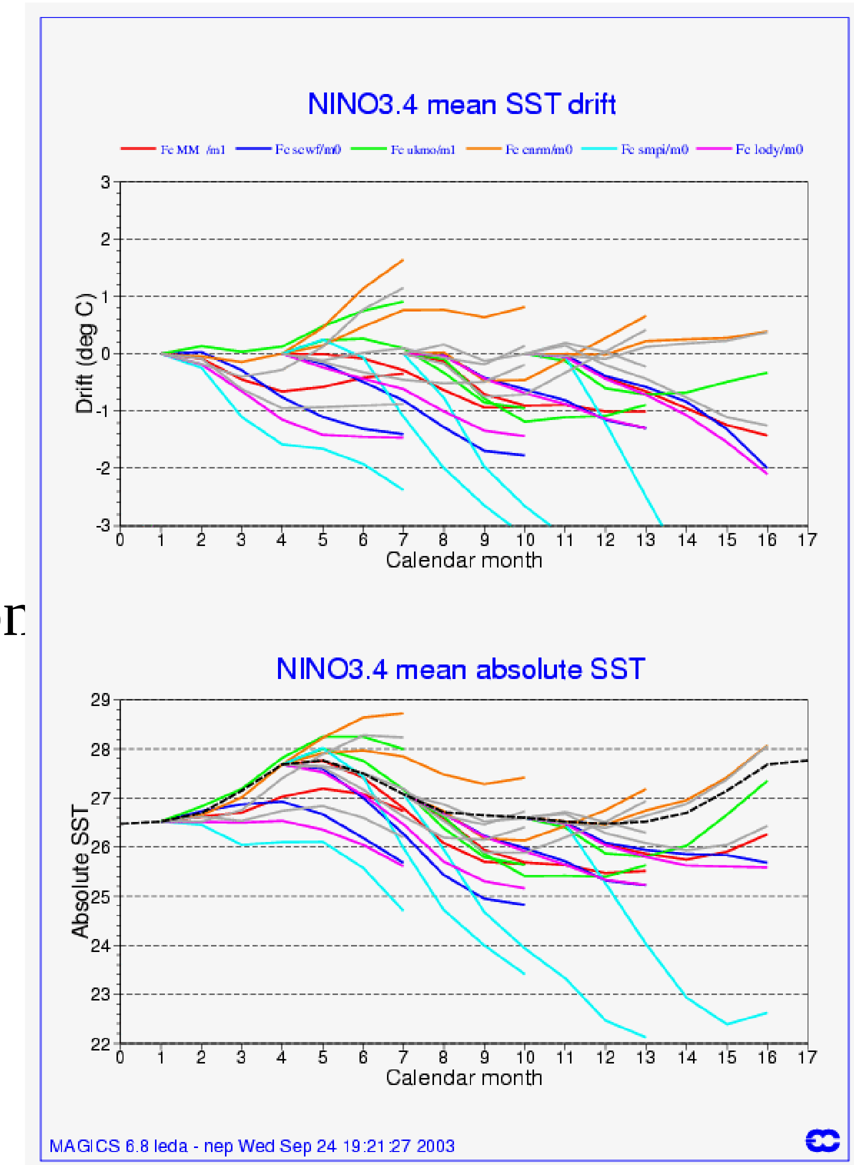
(old) CGCM forecast drift

sample of
EU DEMETER CGCMs

SST in Niño3.4 region

monthly average
forecast climatology



forecast> -
<obs>

-------- obs clim

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CGCM ensemble seasonal prediction systems: ingredients

- hindcasts / reforecasts / retrospective forecasts:
  - run the *same* system for start dates spread over the last few (tens) of years
    - usually smaller ensemble sufficient
  - basis for performance assessment
    - model biases
    - prediction skill estimate

NB climate is non-stationary (decadal and longer variability),
observing system varies in coverage, instrumentation etc.

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World Meteorological Organisation:

now 12 designated Global Producing Centres (for LRF)

(there are other global LRF producers)

Annex IX

TABLE SUMMARIZING THE FORECASTS SYSTEM CONFIGURATION

GPC	System Configuration.	Atmospheric Model Resolution	Hindcast Period	Forecast Period
Beijing, BCC	Coupled	T63/L16	1983-2004	2008.02~
ECMWF	Coupled	T159/L62	1981-2005	2009.02~
Exeter, Met Office	Coupled	1.875x1.25/L38	1989-2002	2009.09~
Melbourne, BoM	Coupled	T47/L17	1980-2006	2008.07~
Montreal, CMC	2-tier	4 Models	1969-2004	2007.12~
Seoul, KMA	2-tier	T106/L21	1979-2007	2007.12~
Tokyo, JMA	Coupled	T95/L40	1979-2008	2010.02~
Toulouse, Météo-Fr	Coupled	T63/L91	1979-2007	2009.02~
Washington, NCEP	Coupled	T62/L64	1981-2004	2008.02~
Moscow, HMC	2-tier	1.1x1.4/L28	1979-2003	2008.02~
Cachoeira Paulista, CPTEC	2-tier	T62/L28	1979-2001	2009.01~
Pretoria, SAWS	2-tier	T42	1982-2001	2009.09~

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e.g. GloSea4: Met Office LRF system

(description in Arribas et al. MWR submitted)

-Operational from Sept. 2009

-HadGEM (current Hadley Centre climate model type)
atmos N96 L38
NEMO ocean ~1x1, 1/3 equ, L42)

- In AGCM:
'random parameters' (Bowler et al., QJRMS 2008)
stochastic kinetic energy backscatter (cf Shutts 2005)

-14-ensemble weekly,
3 weeks combined for 42-ensemble

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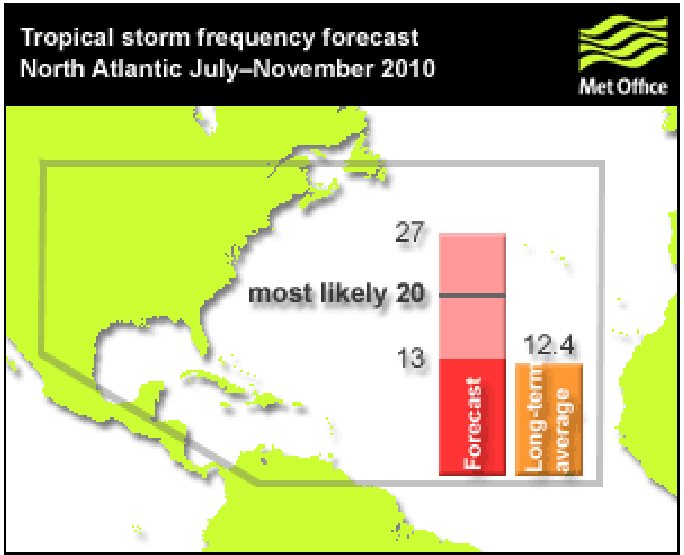
Having run the system, need to make forecast products

typically issued/updated monthly

content: mix of deterministic and probabilistic,
maps, indices, gridded, regional,
mainly 3-month-average T2m, precip,
generic, special purpose, …



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Multimodel:

- better skill if combine info from several models
  (e.g. EU DEMETER project,
  articles in Tellus 57A 2005)

- how best combine?
  Many methods tried:
  e.g. skill weighting

  hard to beat simple equal-weights approach

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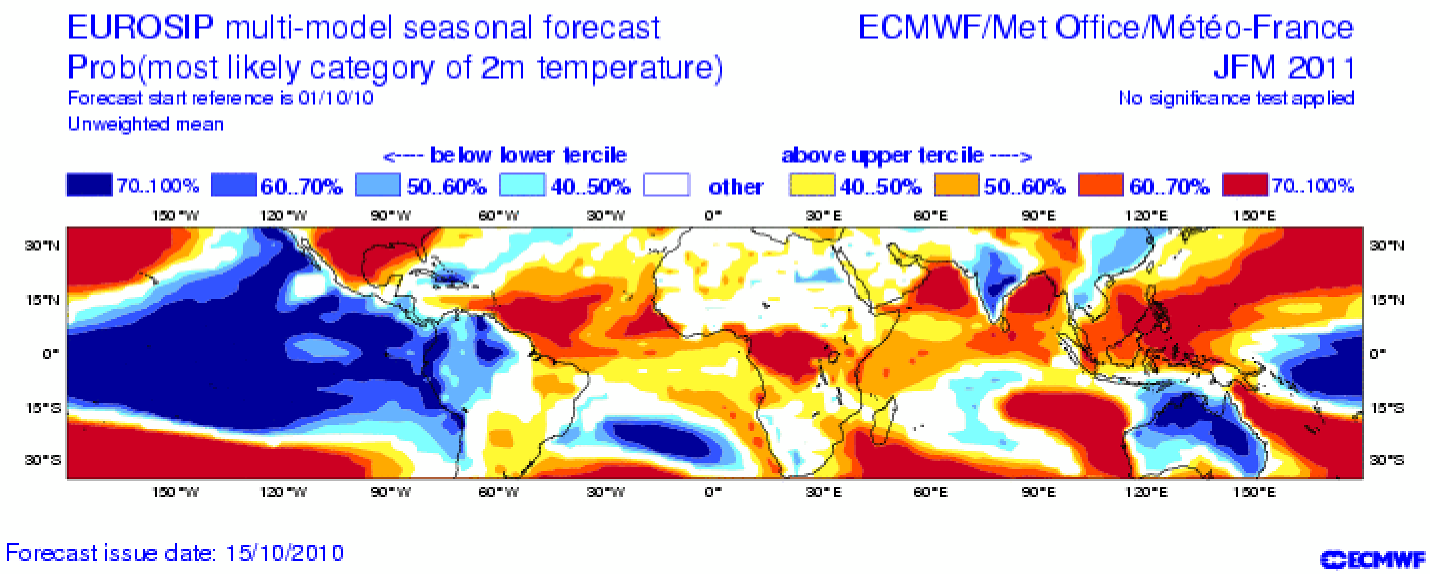
E.g. EUROSIP Multimodel: Met Office + ECMWF + Météo-France updated monthly

See http://ww.ecmwf.int/products/forecasts/d/charts/seasonal/

(a typical ‘global’ probabilistic forecast product format)



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WMO multi-model lead centres

Using GPC data, at http://www.wmolc.org

Forthcoming: do-it-yourself multimodel combinations

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Communication example: RCOF

http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

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- regional multinational meetings in advance of ‘rainy season’
- ‘agreed’ forecast more likely to be acted on
- Simple probability format
- Involvement of ‘users’, media

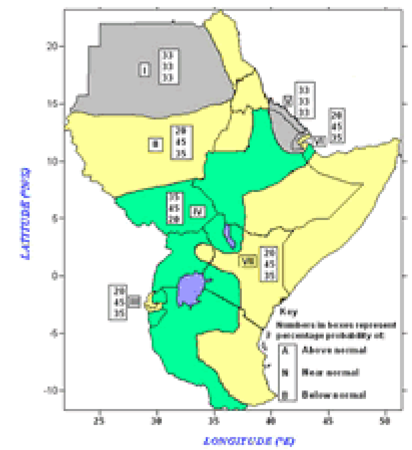
Regional Climate Outlook Products

Regional Climate Outlook Forums, active in several parts of the world, routinely provide real-time regional climate outlook products. The following are brief details of these products, along with links to their recent products. Additional information maybe obtained from the coordinators of the concerned RCOFs or the participating NMHSs.

Greater Horn of Africa Climate Outlook Forum (GHACOF)

GHACOF covers the countries **Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Somalia, Tanzania and Uganda**. GHACOF is being coordinated by the IGAD (Inter-Governmental Authority on Development) Climate Prediction and Application Centre (ICPAC), Nairobi, Kenya. The latest GHACOF statement as well as previous statements are available at:

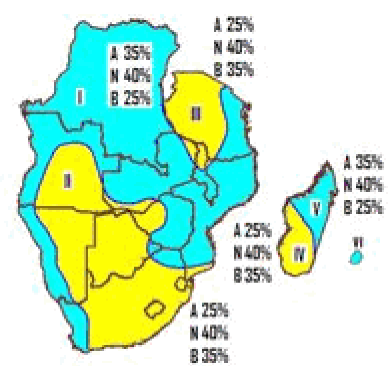
GHACOF Statements



Southern African Regional Climate Outlook Forum (SARCOF)

SARCOF is a regional climate outlook prediction and application process adopted by the fourteen countries comprising the Southern African Development Community (SADC) Member States: **Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe** in conjunction with other partners. SARCOF is coordinated by the SADC Drought Monitoring Centre (SADC-DMC), Gaborone, Botswana. The latest SARCOF statement as well as previous statements are available at:

SARCOF Statements



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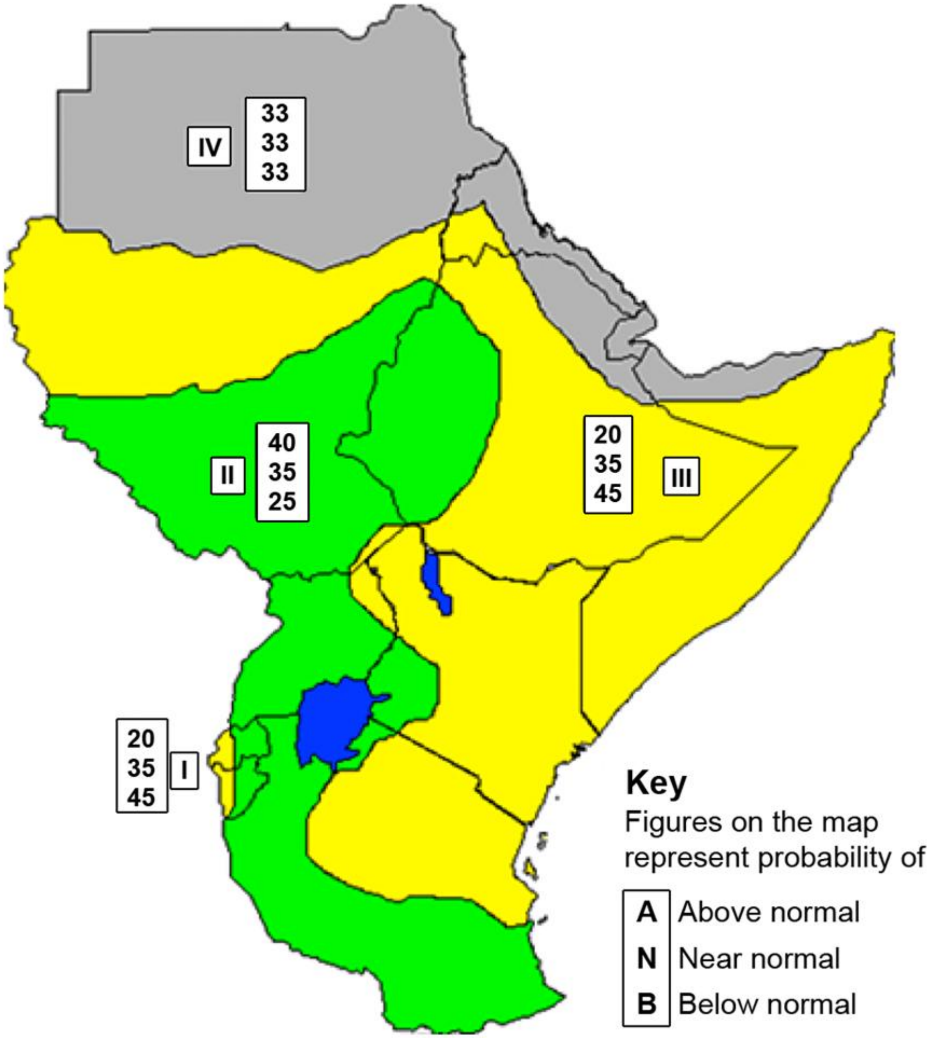
Communication example: RCOF

http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

Consensus 'multimodel'

March-April-May 2009

Greater Horn of Africa



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How good is the forecast system?

How do you convince ‘users’ to act on the information?

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How good is the forecast system?

Many ‘skill measures’, which is appropriate to the situation?

See e.g. http://www.ecmwf.int/research/EU_projects/ENSEMBLES/results/stream2_seasonal.html

Obs Mean

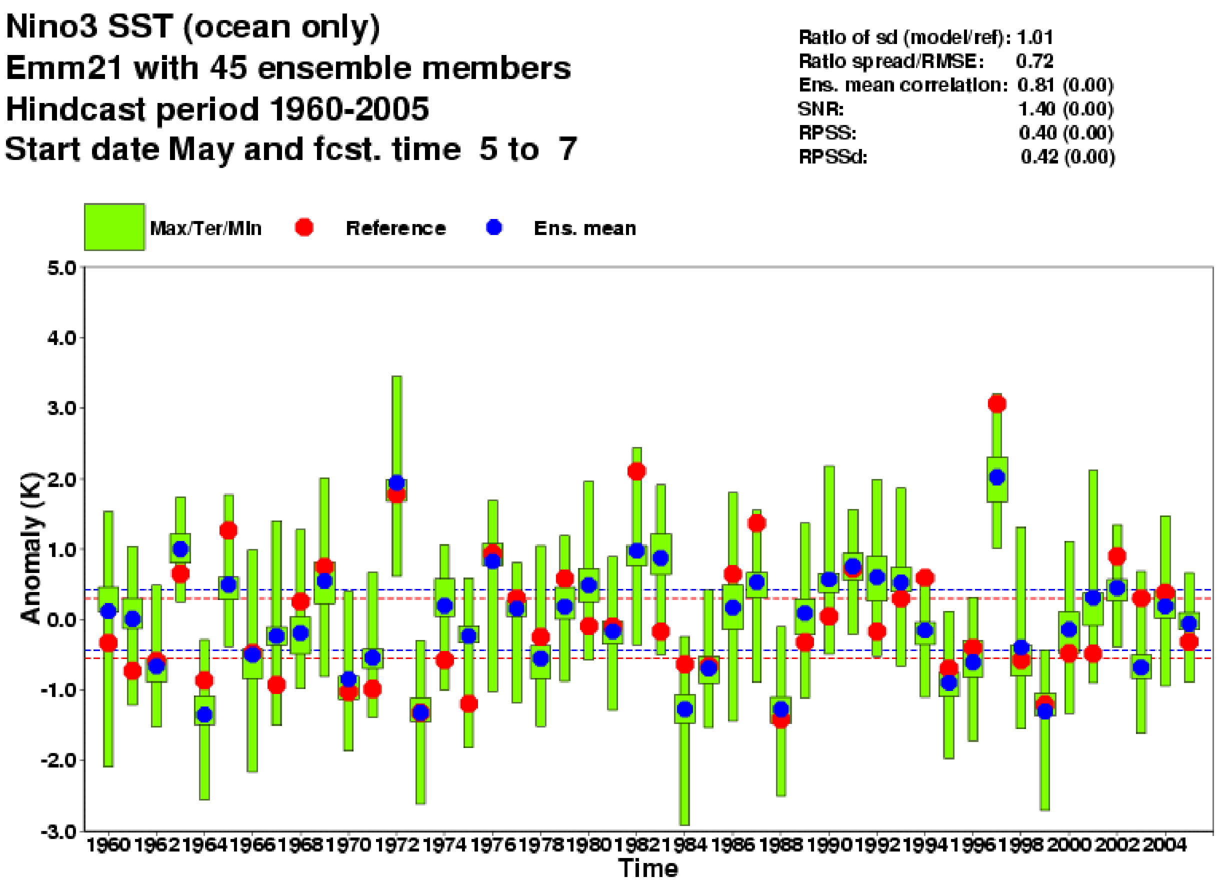
corr = 0.8

RPSS 0.4

Hindcasts
1960-2005

May start

target:
Sep-Oct-Nov



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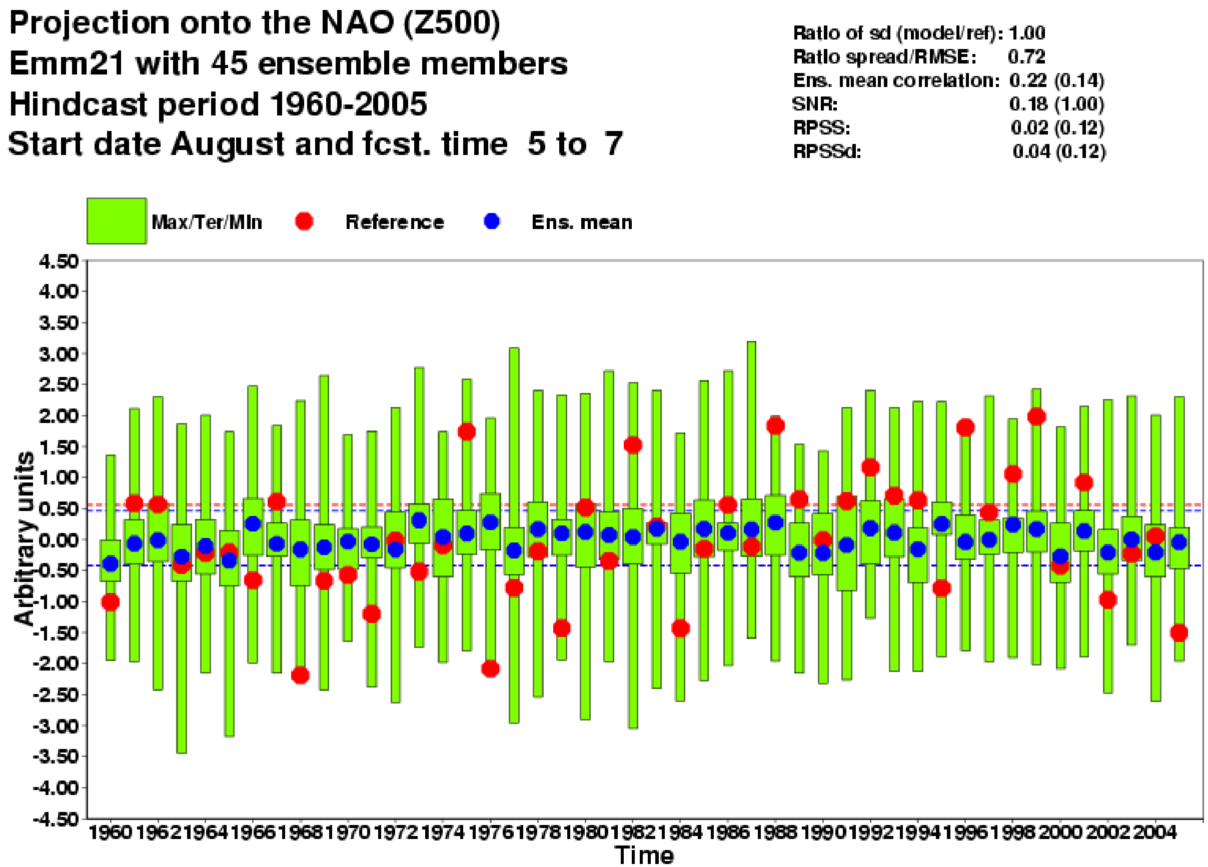
corr = 0.2

RPSS 0.02

Hindcasts
1960-2005

Aug start

target:
Dec-Jan-Feb



Low skill: but what is the predictability limit?
Should models do better? How much? How?

(WCRP: historical forecast project ...)

Skills: see also http://climexp.knmi.nl , WMO LRFVS , ...

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Part 2:   simple ENSO models

-Help understand ENSO mechanism

-Framework to help assess more complex models

-Tool for ‘what if … ?‘   exploration

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•Typical simple model - main ingredients:

large scale equatorially-trapped wind-driven ocean
Kelvin wave (west→east, speed ~ 1.5 deg.long/day)
long Rossby waves (east→west, speed <~ 0.5 deg.long/day)

e.g. linear ‘shallow water’ reduced gravity ocean,
equatorial beta plane $f = \beta y$

ocean surface layer temperature equation
influenced by upwelling, advection, simple surface exchange

atmospheric model: often statistical, equilibrium
provides surface winds given sea surface temperature (anomaly)

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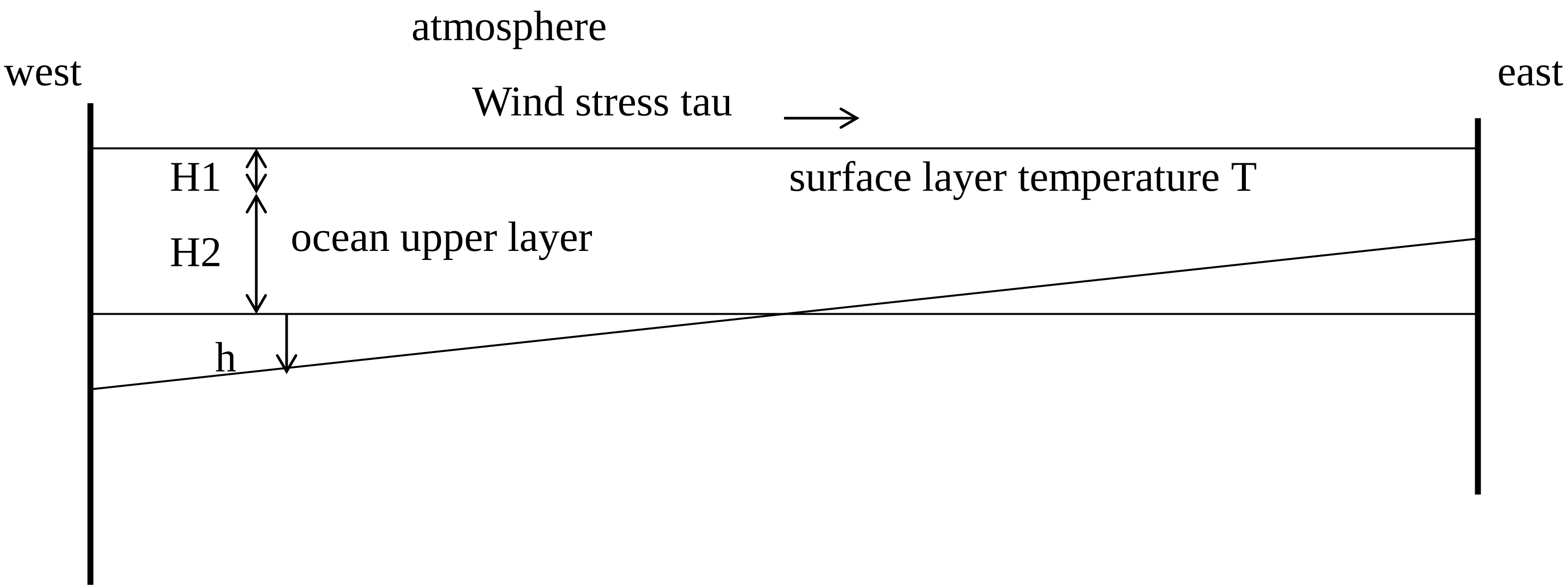
•Simple model ingredients



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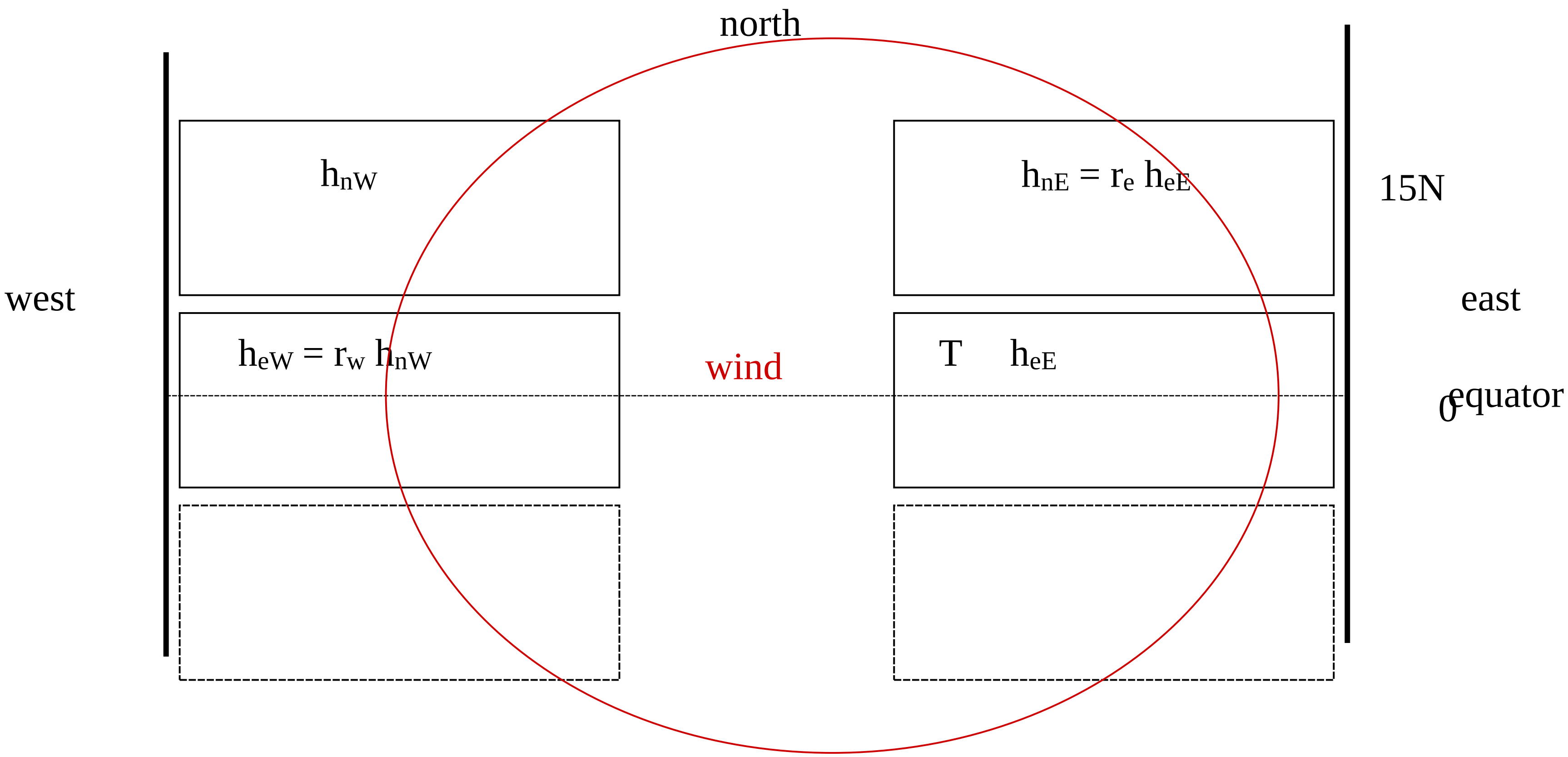
E.g. variant of the Jin box model (Jin JAtmosSci 1997) simple enough to solve analytically



- h = (box) upper layer depth anomaly T = (box) surface T anomaly

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•Atmospheric ‘model’: wind stress ~ T anomaly

equatorial wind stress tau = C T (constant C)

•**Equatorial strip** balance set up by ‘fast’ Kelvin waves

$$g' \, (h_{eE} – h_{eW}) / L = C \, T / (\rho H)$$

Kelvin wave speed $c_K = \sqrt{g' H}$, $L = (x_E – x_W)/2$

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•Is such a balance reasonable?

Kim and Jin, ClimDyn 2010, balances in CGCMs …

‘obs’ ⟶

tau vs T

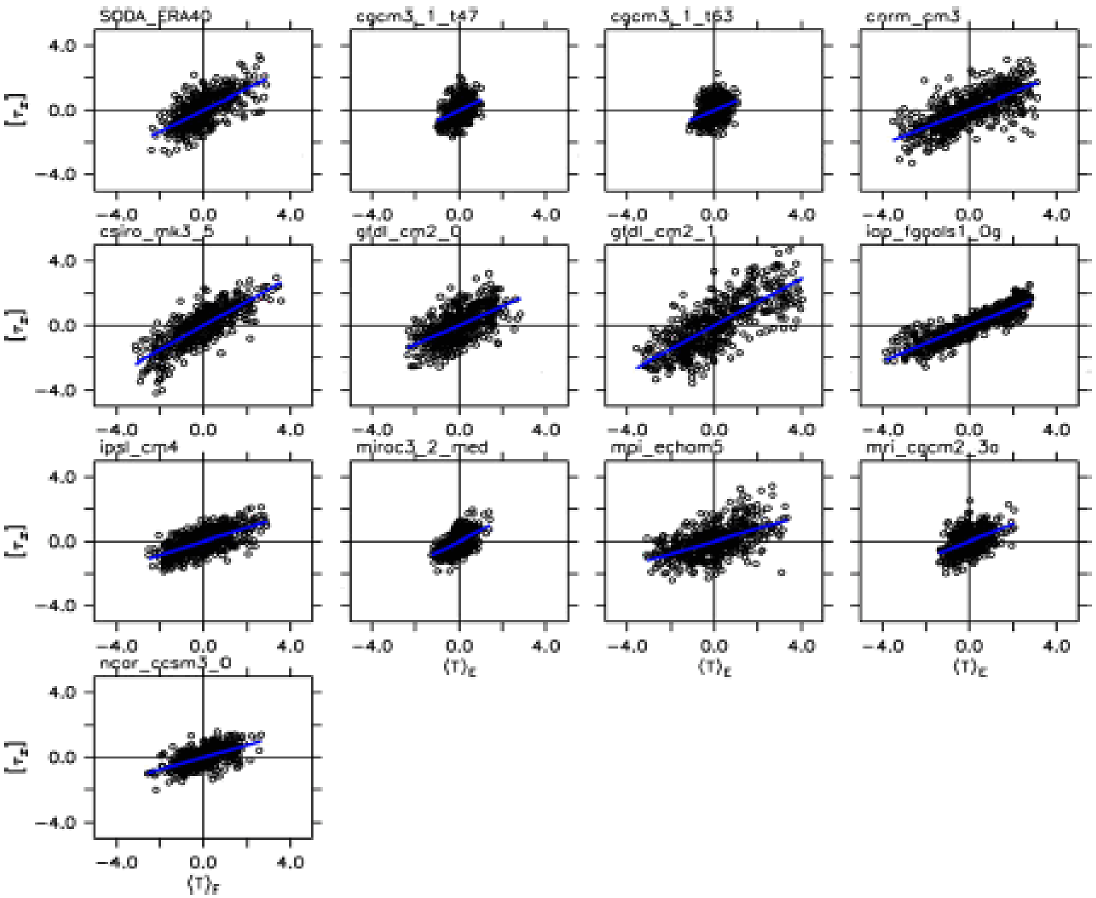

Fig. 1 Scatterplots for $[\tau_x] = \mu_a \langle T \rangle_E$ with a regression fitting line from each model and observations. The quantities for the coupled models are normalized by the standard deviation of the quantities from the observations. The observations corresponds to the SODA analysis for the near-surface ocean temperatures and the ERA 40 analysis for the zonal wind stresses. The name of the coupled model is also shown

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northern strip: ocean Rossby wave driven by wind stress curl

$$h_{nWt} - c_R (h_{nE} - h_{nW}) / L = - (1/4)(H/c_K) (C\ T) / (\rho H)$$

'effective' Rossby wave speed $c_R = - c_K/4$

(wind stress also has broad pattern related to atmospheric Rossby waves, projecting forcing onto Rossby waves with off-equatorial h max)

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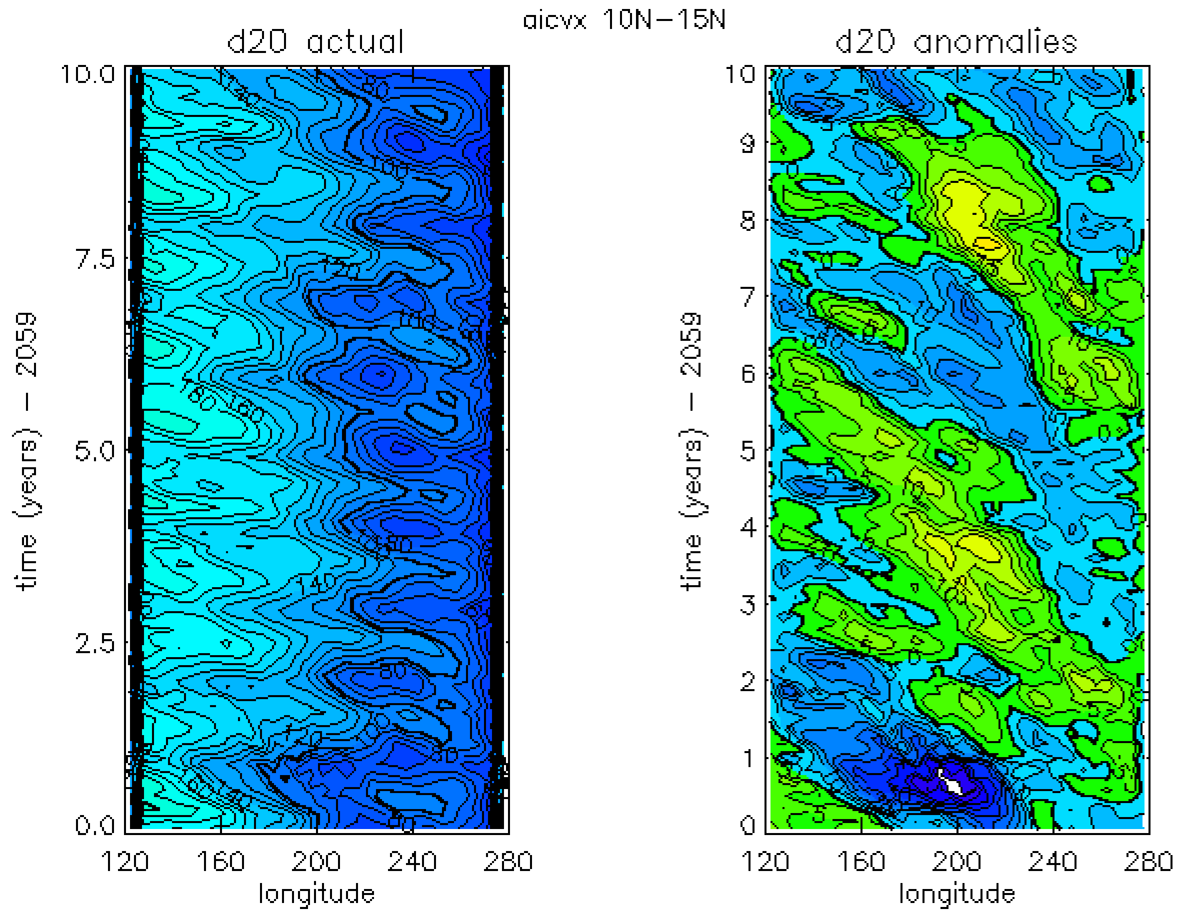
northern strip: e.g. in a CGCM simulation



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Surface layer east equatorial temperature anomaly T

$T_t = -u_C\, T_x - v_C\, T_y - u\, T_{Cx} - v\, T_{Cy} - w_C\, T_z - w\, T_{Cz}$ + surface flux

(+ stochastics?)

linearised about climatological mean state u_C , v_C , T_{Cx} , T_{Cy} , $w_C > 0$, T_{Cz}

surface flux = $-\varepsilon_T\, T$ (damping effect)

$-u_C\, T_x - v_C\, T_y = K\, T$ (positive advective feedback by mean state)

$u = d_1\, T + d_2\, h_{eE}$ (d_j some combination of physical constants)

$w = d_3\, T - (H_1/H)\, h_{eEt}$

$T_z = (T - T_B \tanh(h_{eE}/H^*)) / (H/2)$ (deeper h, larger T_{sub})

limited upwelled temperature anomaly is the only nonlinear effect

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- Leads to two coupled ODEs for T and $h = h_{nW}$:

$$h_t = -a_1 h - a_2 T$$

$$T_t = b_2 T + b_3 h + b_4 \tanh (b_5 h + b_6 T)$$

a_n , b_n are constants that are defined by the parameters (C, H, w_C, c_K, ...)

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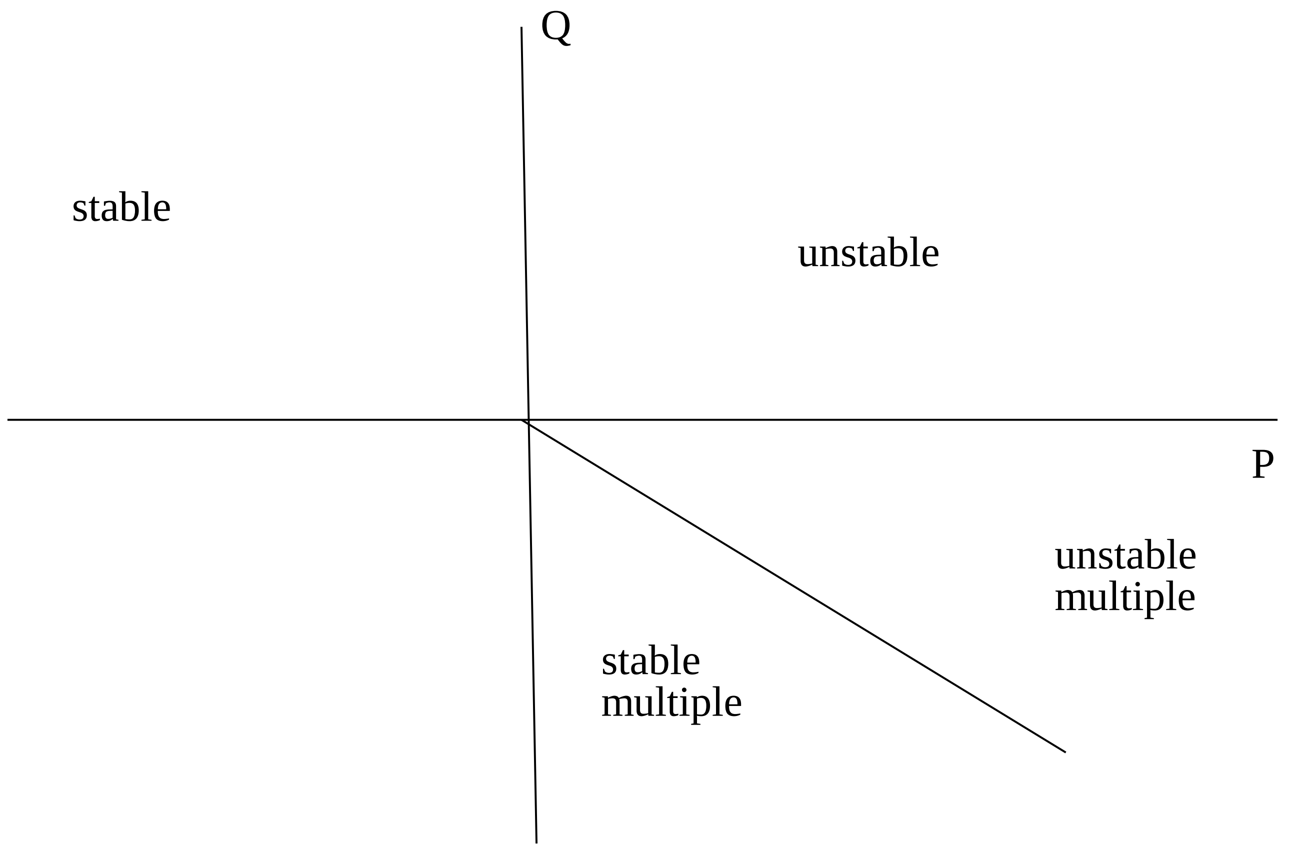
•Regimes of behaviour:

(P and Q some combinations of parameters)



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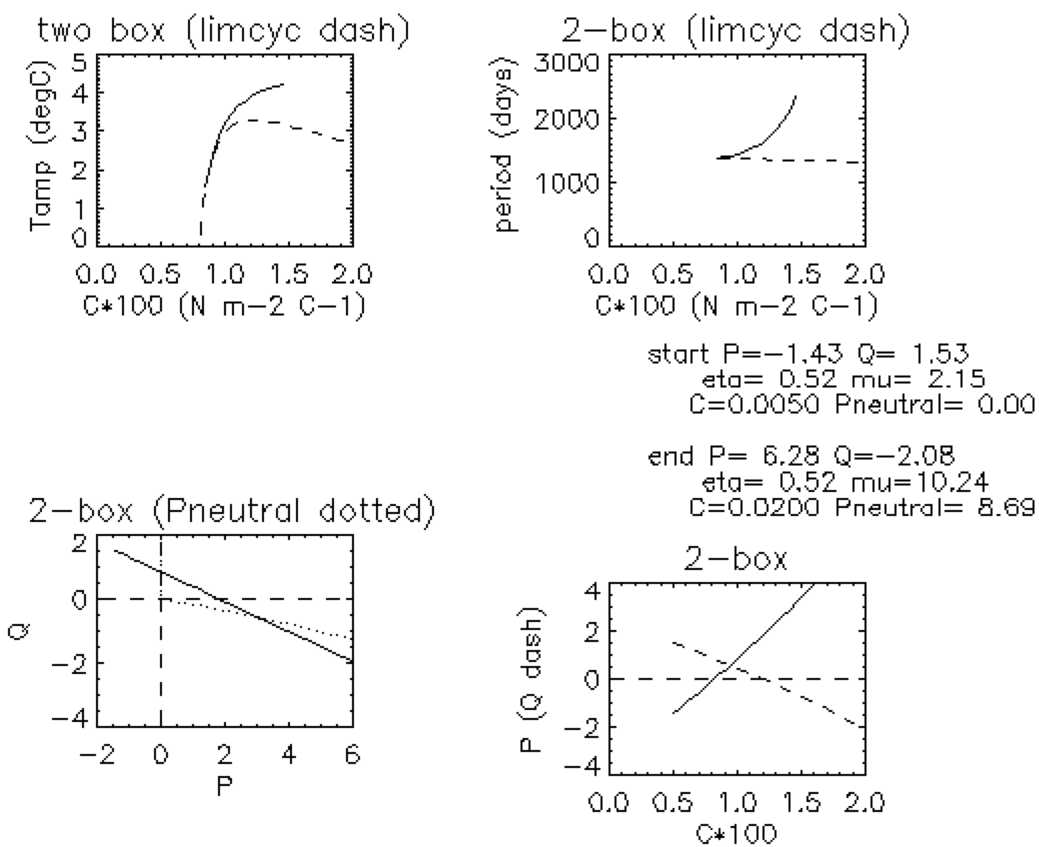
•Vary parameters: e.g. vary coupling C

(chose unstable reference state with
plausible ENSO oscillation)



two box: example 1: P=0.85 Q=0.45 eta=0.52 mu=4.6: C=0.01 : vary C

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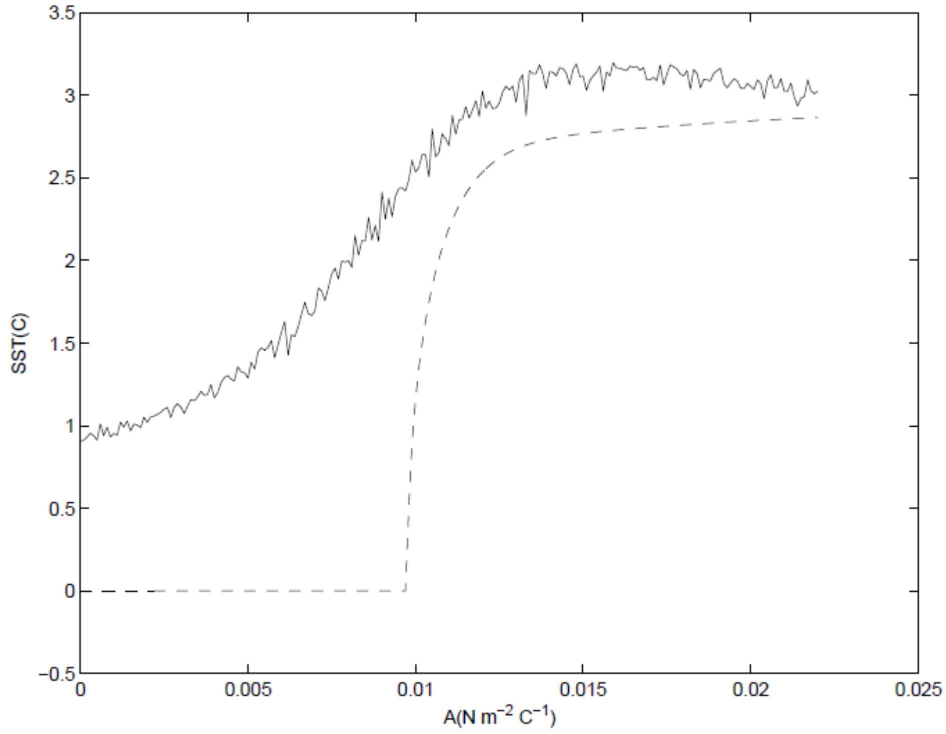
•Vary parameters: e.g. vary coupling C

With additive stochastic forcing:

amplitude



(thanks Warren O'Neill, UCL MSc)

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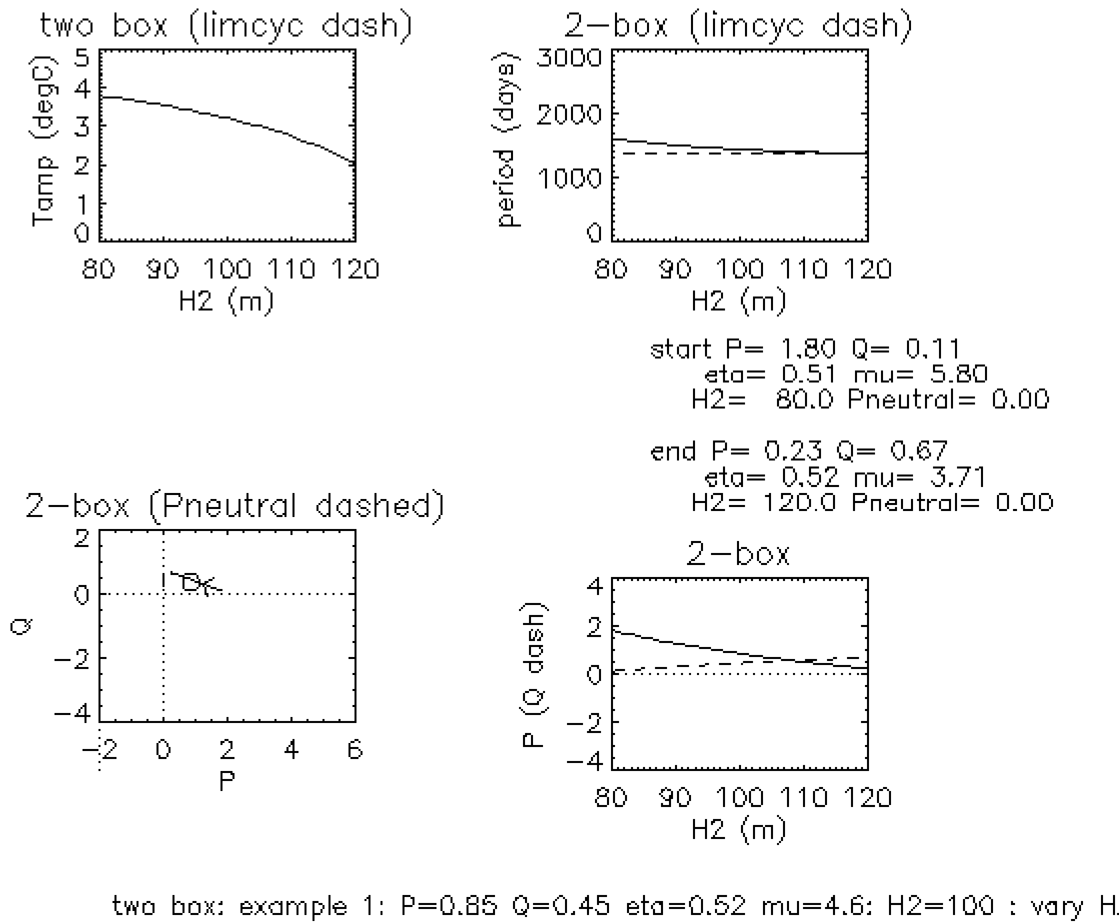
•Vary parameters: e.g. vary depth H



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- ENSO and climate change

  E.g. Collins et al. review Nature Geoscience 2010

Robust CGCM features in tropical Pacific:

  warmer T, more so along equator

  slower Hadley and Walker circulations

  reduced upwelling

  flatter, shallower equatorial thermocline

Not so robust: ENSO changes

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•ENSO and climate change

E.g. Collins et al. review Nature Geoscience 2010

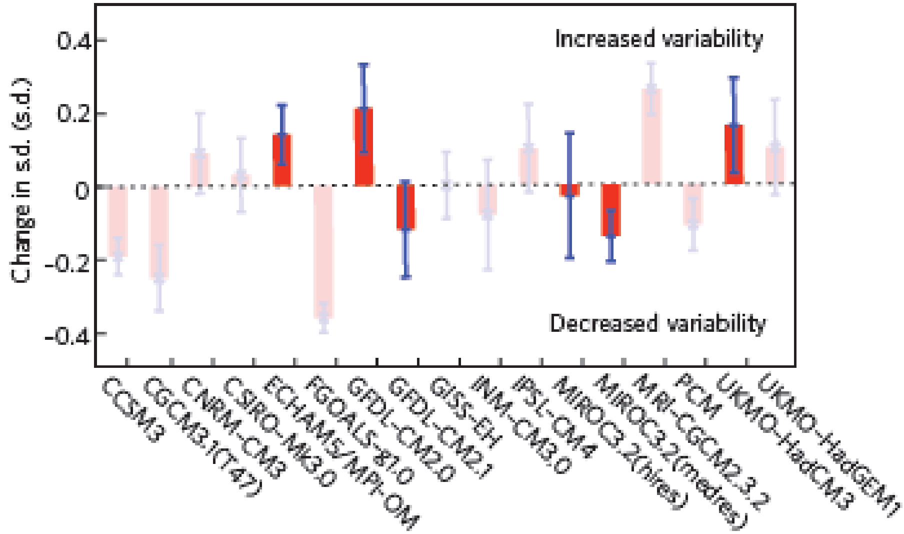

Figure 3 | Projected changes in the amplitude of ENSO variability, as a response to global warming, from the CMIP3 models[8,9]. The measure is derived from the interannual standard deviation (s.d.) of a mean sea-level-pressure index, which is related to the strength of the Southern Oscillation variations. Positive changes indicate a strengthening of ENSO, and negative changes indicate a weakening. Statistical significance is assessed by the size of the blue bars, and the bars indicated in bold colours are from those CMIP3 CGCMs that are judged to have the best simulation of present-day ENSO characteristics and feedbacks.

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•Summary:

- seasonal prediction with CGCM systems
  - several operational ensemble systems
  - multimodels – better combinations?
  - products – better formats?
    - Links to applications – economic models?
      - Value estimates needed!!

•simple ENSO models
  - example
  - use in assessing CGCMs?
    - in estimating climate change effect?

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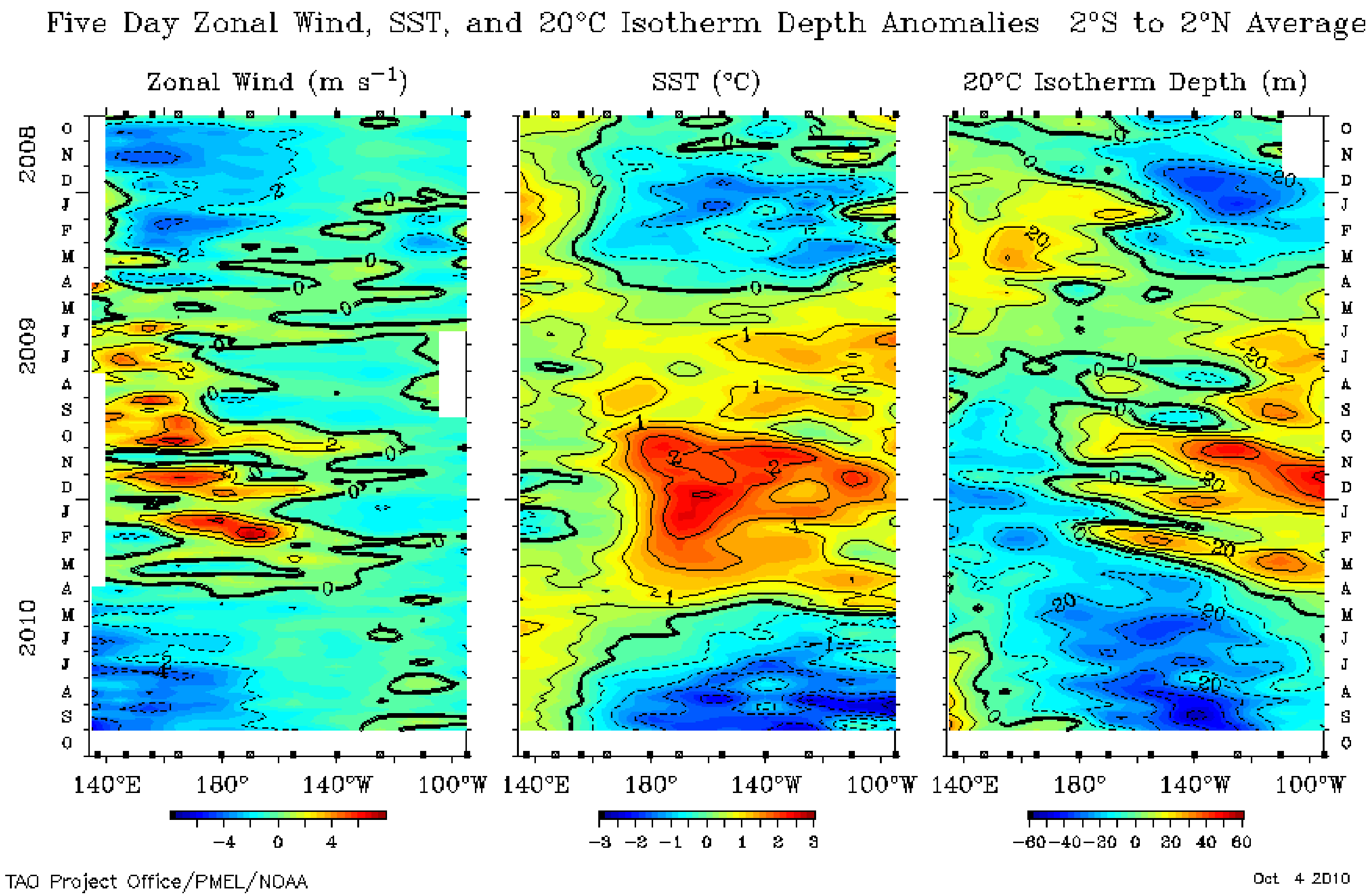
Equatorial Pacific ocean http://www.pmel.noaa.gov/tao

what next?



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Questions and answers