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
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
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 …
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)
Ensemble example:
GloSea4 (Met Office CGCM LRF system) Niño3.4 plumes
(at: http://www.metoffice.gov.uk/science/specialist/seasonal )
from Apr 2010
from Oct 2010
(old) CGCM forecast drift

Sample of EU DEMETER CGCMs

SST in Niño3.4 region

Monthly average forecast climatology

Forecast - Obs

------- obs clim
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.
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**

<table>
<thead>
<tr>
<th>GPC</th>
<th>System Configuration</th>
<th>Atmospheric Model Resolution</th>
<th>Hindcast Period</th>
<th>Forecast Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing, BCC</td>
<td>Coupled</td>
<td>T63/L16</td>
<td>1983-2004</td>
<td>2008.02~</td>
</tr>
<tr>
<td>ECMWF</td>
<td>Coupled</td>
<td>T159/L62</td>
<td>1981-2005</td>
<td>2009.02~</td>
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<tr>
<td>Exeter, Met Office</td>
<td>Coupled</td>
<td>1.875x1.25/L38</td>
<td>1989-2002</td>
<td>2009.09~</td>
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<tr>
<td>Melbourne, BoM</td>
<td>Coupled</td>
<td>T47/L17</td>
<td>1980-2006</td>
<td>2008.07~</td>
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<tr>
<td>Tokyo, JMA</td>
<td>Coupled</td>
<td>T95/L40</td>
<td>1979-2008</td>
<td>2010.02~</td>
</tr>
<tr>
<td>Toulouse, Météo-Fr</td>
<td>Coupled</td>
<td>T63/L91</td>
<td>1979-2007</td>
<td>2009.02~</td>
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<tr>
<td>Washington, NCEP</td>
<td>Coupled</td>
<td>T62/L64</td>
<td>1981-2004</td>
<td>2008.02~</td>
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<tr>
<td>Moscow, HMC</td>
<td>2-tier</td>
<td>1.1x1.4/L28</td>
<td>1979-2003</td>
<td>2008.02~</td>
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<tr>
<td>Cachoeira Paulista, CPTEC</td>
<td>2-tier</td>
<td>T62/L28</td>
<td>1979-2001</td>
<td>2009.01~</td>
</tr>
<tr>
<td>Pretoria, SAWS</td>
<td>2-tier</td>
<td>T42</td>
<td>1982-2001</td>
<td>2009.09~</td>
</tr>
</tbody>
</table>
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
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, …
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
E.g. EUROSIP Multimodel: Met Office + ECMWF + Météo-France updated monthly

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

(a typical ‘global’ probabilistic forecast product format)
WMO multi-model lead centres

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

Forthcoming: do-it-yourself multimodel combinations
Communication example: RCOF

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

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

regional multinational meetings in advance of ‘rainy season’

‘agreed’ forecast more likely to be acted on

Simple probability format

Involvement of ‘users’, media
Consensus ‘multimodel’
March-April-May 2009
Greater Horn of Africa
How good is the forecast system?

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

<table>
<thead>
<tr>
<th>Obs</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>corr</td>
<td>0.8</td>
</tr>
<tr>
<td>RPSS</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Hindcasts 1960-2005

Start date May and fcst. time 5 to 7

Hindcast period 1960-2005

Nino3 SST (ocean only)
Emm21 with 45 ensemble members

Ratio of sd (model/ref): 1.01
Ratio spread/RMSE: 0.72
Ens. mean correlation: 0.81 (0.00)
SNR: 1.40 (0.00)
RPSS: 0.40 (0.00)
RPSSd: 0.42 (0.00)
Projection onto the NAO (Z500)
Emm21 with 45 ensemble members
Hindcast period 1960-2005
Start date August and fcst. time 5 to 7

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, ...

corr = 0.2
RPSS 0.02

Hindcasts 1960-2005
Aug start
target: Dec-Jan-Feb
Part 2: simple ENSO models

- Help understand ENSO mechanism

- Framework to help assess more complex models

- Tool for ‘what if … ?‘ exploration
• 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)
• Simple model ingredients

[Diagram showing ocean upper layer, surface layer temperature, wind stress, and atmospheric pressure]

- Wind stress \( \tau \)
- Ocean upper layer
- Surface layer temperature \( T \)
E.g. variant of the Jin box model (Jin JAtmosSci 1997) simple enough to solve analytically

- $h = (\text{box})$ upper layer depth anomaly
- $T = (\text{box})$ surface $T$ anomaly

$\text{wind}$

$\text{north}$

$h_{\text{nW}}$

$h_{\text{eW}} = r_w h_{\text{nW}}$

$h_{\text{nE}} = r_e h_{\text{eE}}$

$T \ h_{\text{eE}}$

$15^\circ \text{N}$

$\text{east}$

$\phi \text{quator}$

$\text{west}$
• Atmospheric ‘model’: wind stress ~ T anomaly
equatorial wind stress \( \tau = C T \) (constant \( C \))

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

\[
g' \left( h_{eE} - h_{eW} \right) / L = C T / (\rho H)
\]

Kelvin wave speed \( c_K = \sqrt{g' H} \), \( L = (x_E - x_W)/2 \)
• Is such a balance reasonable?

Kim and Jin, ClimDyn 2010, balances in CGCMs …

τ vs T

(obs)
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)
northern strip: e.g. in a CGCM simulation
Surface layer east equatorial temperature anomaly $T$

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

(+ stochastics?)

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

surface flux $= -\epsilon T$ (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
• Leads to two coupled ODEs for \( T \) and \( h = h_{nw} \):

\[
\begin{align*}
    h_t &= -a_1 \, h - a_2 \, T \\
    T_t &= b_2 \, T + b_3 \, h + b_4 \, \tanh \left( b_5 \, h + b_6 \, T \right)
\end{align*}
\]

\( a_n, b_n \) are constants that are defined by the parameters (\( C, H, w_C, c_K, \ldots \)).
• Regimes of behaviour:

(P and Q some combinations of parameters)
• Vary parameters: e.g. vary coupling C

(chose unstable reference state with plausible ENSO oscillation)
• Vary parameters: e.g. vary coupling C

With additive stochastic forcing:

(thanks Warren O’Neill, UCL MSc)
• Vary parameters: e.g. vary depth H

start P = 1.80 Q = 0.11
   eta = 0.51 mu = 5.80
   H2 = 80.0 Pneutral = 0.00

dend P = 0.23 Q = 0.67
   eta = 0.52 mu = 3.71
   H2 = 120.0 Pneutral = 0.00

two box: example 1: P = 0.85 Q = 0.45 eta = 0.52 mu = 4.6: H2 = 100: vary H
• 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
• 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. 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.
• 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?
Equatorial Pacific ocean     http://www.pmel.noaa.gov/tao

what next?

Five Day Zonal Wind, SST, and 20°C Isotherm Depth Anomalies  2°S to 2°N Average
Questions and answers