Predictability from Strat-Trop Coupling in Reforecasts and the GFDL Climate Model

Thomas Reichler\(^1\), Junsu Kim\(^1\), and Arun Kumar\(^2\)
(\(^1\) Univ. of Utah, \(^2\) NOAA)

Supported by the Center for High Performance Computing, Univ. of Utah

AGU Chapman Conference on The Role of the Stratosphere in Climate and Climate Change
Santorini, Greece, 24-28 September 2007
Questions & Method

• To what extent do current prediction systems exploit stratospheric signals?
• How much practical skill is associated with it?
• Does an improved stratospheric component increase skill?

I. Retrospective forecasts
II. Climate model simulations
Models: Vertical Structure

![Diagram showing vertical structure with pressure (p) and height (km) axes. The diagram compares NCEP/GFS L28 and GFDL AM3 models with "low-top" and "high-top" configurations. The differences in pressure ranges and heights are indicated with specific values: 2.5 hPa, 3 hPa, and 0.02 hPa. The heights are marked at -5 to -80 km with intervals of 5 km.]
Part I

CDC Reforecasts
NOAA/CDC Reforecasts

- Fixed 1998 version of NCEP/GFS, T62 L28
- 1979 - present
- Daily forecasts out to day 15
- 15-member ensemble
- Hamill et al. (2006, BAMS)

😊 Daily forecasts, capture each SSW event
😢 Only out to day 15, miss some of the interesting action at later times
😢 No stratospheric data
Annual mean RMS error in SLP over Northern Extratropics between reforecasts and reanalysis.
Validation Strategy

• Ensemble means
• Focus: Northern Annular Mode (NAM)
• Sea level pressure (SLP), and Z850, 700, 500, 250, and 150
• Reference: NCEP/NCAR reanalysis, 1979-2007
A. Downward Propagating Features
Case Study: Winter 2004

NAM index by level and time

NCEP/NCAR reanalysis

Day 0.5

NAM_{SLP}

Day 8.5

NAM_{SLP}

Day 14.5

NAM_{SLP}

JAN1  FEB1  MAR1

NAM_{SLP}
Strong Events

• NCEP/NCAR reanalysis: 1979-2007
• NAM$^{-10}_{10}$ <-3 → 16 events
• Discard 6 events which exhibit no downward propagation
• Remain with 10 strong downward propagating events
SSW Composite

10 strong events

NCEP/NCAR Reanalysis
SSW
Composite

CDC reforecasts
NAM$_{10}$/SLP Evolution

- 61 days centered at day 19
- Reforecast signal reaches surface delayed by ca. 10 days
B. NAM\textsubscript{SLP} Predictability
Basic Predictability

$\text{ACC}_{\text{SLP}} \text{ vs. } \text{NAM}_{\text{SLP}}$

Correlation coefficient, ensemble-mean, all years, slp

$\text{Winter: } \text{NAM}_{\text{SLP}}$

$\text{ACC}_{\text{SLP}}$

$\text{NAM}_{\text{SLP}}$
NAM$_{SLP}$ Predictability

Correlation: NCEP/NCAR reanalysis vs. CDC reforecast

• 1979-2007, all days
• Unsmoothed (shading)
• 31 day running means (contours)
• Sharp decline in spring; maybe related to breakdown of polar vortex
• Gradual increase in fall
**NAM$_{SLP}$ Predictability During SSWs**

- Correlation between reanalysis and reforecasts
- 31 day unsmoothed NAM$_{SLP}$ index
- Composite of 10 SSW events (NAM$_{10} < -3$)
- Anomalies: February climatology removed.
Conclusion I

Despite low vertical stratospheric resolution (7 levels), reforecasts exhibit clear downward propagating signals.

SSW signals arrive too late at surface; delay increases with lead time.

Nevertheless, SSW events improve AO predictability 0-15 days after the events and at leads of 8-15 days.

Beside the 10 SSW events, additional skill from stratospheric influences may be realized during other warm events or during cold events.
Part II

AGCM Experiments

Basic simulation features and sensitivities to forcings
GFDL AM2/3 Nalanda

• Very similar to IPCC-AR4 version
• Non-orographic gravity wave drag (Alexander and Dunkerton 1999)
• RAS deep convection
• Resolution
  • Horizontal: N45 (144x90)
  • Vertical: L24 and L48 (LOW and HIGH)
• LOW and HIGH have identical physics! The only difference is number and location of vertical levels
A. Mean Climate and Variability

AMIP-type runs forced with observed boundary conditions and atmospheric composition (1983-2003)
Mean Temperatures

### Mean Biases

<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strato</td>
<td>-0.7 / 7.8</td>
<td>2.3 / 3.2</td>
</tr>
<tr>
<td>Tropo</td>
<td>-0.9 / 2.1</td>
<td>-0.5 / 2.3</td>
</tr>
</tbody>
</table>

(mean bias / rms error) [K]

### ERA LOW-ERA HIGH-ERA

**DJF**
Mean U-Winds

<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strato</td>
<td>-1.2 / 13</td>
<td>-1.3 / 5.7</td>
</tr>
<tr>
<td>Tropo</td>
<td>-0.2 / 1.5</td>
<td>0.0 / 1.7</td>
</tr>
</tbody>
</table>

(mean bias / rms error) [m/s]
Interannual Variability U-Wind

<table>
<thead>
<tr>
<th></th>
<th>ERA</th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strato</td>
<td>-1.8 / 2.7</td>
<td>-1.1 / 2.3</td>
</tr>
<tr>
<td>Tropo</td>
<td>0.0 / 0.3</td>
<td>0.1 / 0.5</td>
</tr>
</tbody>
</table>

(mean bias / rms error) [m/s]
\( \text{SAM}_u \) and EOF \( u \)

- 1983-1999
- L24/48 NO
\textbf{NAM}_u

\begin{tabular}{lll}
\textbf{DJF} & \textbf{ERA40} & \textbf{LOW} & \textbf{HIGH} \\
\textbf{MAM} & & & \\
\textbf{JJA} & & & \\
\textbf{SON} & & & \\
\end{tabular}
NAM/SAM Timescales

Reanalysis

NAM

LOW

HIGH
NAM$_{10}$ Lagged Correlations

- DJFM, 1983-2003
- 61 day time series
- 21 day averages
- L24/48NO
Baldwin & Dunkerton Composites

Reanalysis

- 1983-2003
- Reference EOFs from reanalysis
- Composite on NAM$_{10} < -3$
- Reanalysis: 12 events
- Low: 9 events
- High: 12 events
B. Equilibrium Climate Simulations
Experimental Setup

- 20-40 year long AMIP type simulations, const. forcing
- Change only one forcing at a time:
  - Varying SSTs: Primarily test stratosphere’s response to tropospheric climate change
  - Frozen SSTs: Primarily test troposphere’s response to stratospheric climate change

<table>
<thead>
<tr>
<th>O₃</th>
<th>CO₂</th>
<th>SST</th>
<th>Aerosol</th>
<th>Sun</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>280</td>
<td>1950s</td>
<td>1950</td>
<td>1950</td>
<td>LOW</td>
</tr>
<tr>
<td>2000</td>
<td>380</td>
<td>2000s</td>
<td></td>
<td></td>
<td>HIGH</td>
</tr>
<tr>
<td>720</td>
<td>A1B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1120</td>
<td>4xCO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

=CTRL
Sensitivity to O$_3$ (SON)

O$_3$ 2000 minus 1950

-2.8 ppm
Sensitivity to CO$_2$ (JJA)

380 ppm minus CTRL

LOW           HIGH

ΔT

Δu

[K]

m/s

33
Tropical Expansion

- Change in width of Hadley Cell, derived from mean meridional mass streamfunction
Conclusion II

• HIGH shows improved - but not yet satisfying stratospheric performance; troposphere generally degrades (tuning problem?)
• Having a well-resolved stratosphere does not necessarily guarantee a better troposphere
• 20 year simulation length is often not enough to cleanly separate signal from noise

• This is preliminary analysis, more work is underway …
• Everybody is invited to look at these and more simulations
Thank you.

thomas.reichler@utah.edu
Response to SSTs: JJA

2000s (obs.)

L24  L48

ΔT

Δu

[K]

[m/s]
Trend in HC from mmc (400-600)
SST50, CO2, SST2k
PS_EXP/plt_exp_hc.ps (plt_exp_hc.pr)
Trend in HC from mmc (400-600)
SST50, CO2, 2xCO2, 4xCO2
PS_EXP/plt_exp_hc.ps (plt_exp_r)
Timescales NAM \( u_{1000-100} \)

Winter

Summer

\( NAM_u \)

\( SAM_u \)
NAM$_{10}$ Lagged Correlations

- Lagged correlation of NAM$_{10}$ with NAM at any other level
- NCEP/NCAR reanalysis
- 61 day time series, 21 day averages
- Similar to: Baldwin & Dunkerton, (1999)

DJFM 1979-2007
NAM$_{10}$ Lagged Correlations

CDC reforecasts (15 members)

- 10 SSW composites

Day 0

Day 8

Day 15