Report on the 1st SPARC Stratospheric Network for the Assessment of Predictability (SNAP)
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The first SPARC Stratospheric Network for the Assessment of Predictability (SPARC-SNAP) workshop was organized in the Department of Meteorology, University of Reading, UK, from 24 to 26 April 2013. This was a joint workshop with 3rd SPARC Dynamical Variability (SPARC-DynVar) (Manzini et al., this issue) workshop 22-24 April with the 24th April as a joint day. The joint workshop was well attended and had around 100 participants (http://www.met.reading.ac.uk/~pn904784/DynVar_SNAP_Workshop/participant.html) from 16 countries in Europe, Asia, Africa, Australia, North America, and South America (Participants figure). In the SNAP part of workshop (including the joint day) there were two keynote address, nine invited talks, six contributory talks and 24 posters.

The SNAP workshop was formally opened by **Prof. Simon Chandler-Wide**, (Head, School of Mathematical and Physical Sciences, University of Reading). **Prof. Chandler-Wide** gave a short speech about history of the University and the Department of Meteorology and formally welcomed the participants. The welcome address was followed by an introduction to SNAP by **Andrew Charlton-Perez** (Charlton-Perez and Jackson, 2012). Throughout the workshop, participants presented their work underlining the current understanding of the stratospheric dynamical variability, its predictability, and its impact on surface weather and climate. On the 26th April, the workshop held an extensive discussion which focused on future plans for SNAP including an experimental protocol for the SNAP predictability experiment which will take place during 2013 and 2014 and links to other related activities including the seasonal to sub-seasonal prediction initiative (S2S, http://www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html)

Thomas Jung gave the keynote talk and presented a detailed overview of the role of stratosphere in the extended range weather forecasting with case studies including the stratospheric sudden warming (SSW) of 2009 and the extreme cold winters in Europe during 2005/06 and 2009/10. His studies used the ECMWF Integrated Forecast System (IFS). He began his talk by describing a study of the generic tropospheric circulation response to an optimized stratospheric forcing that changes the strength of wintertime Northern Hemisphere stratospheric polar vortex. Results of the experiment showed that the response of the tropospheric circulation to stratospheric forcing was significant and had the expected strong projection onto the surface NAM. The response was found to be linear with respect to the forcing and delayed by around 10 days from forcing onset.

His case study experiments used a different but related technique, attempting to quantify the role the stratosphere played in recent cold winters by damping the stratospheric state toward analysis. In these experiments, small reductions in tropopsheric forecast error were found in the stratospheric damping experiments. He also emphasized the potential tropical source of stratospheric variability by showing that in some cases reductions in extra-tropical forecast error are similar for cases when either stratospheric damping or an equivalent tropical tropopsheric damping are used.

Martin Charron gave an introduction to the Canadian Global Weather Forecasting System that includes stratosphere and discussed the additional skill in surface weather forecasting gained from raising the model lid. The new Environmental Canada NWP global model has a lid at 0.1 hPa and has 80 vertical levels. The model introduces non-orographic wave drag scheme, methane oxidation scheme and a new ozone climatology. In addition to comparing the forecast skill of the old and new models, he also showed results from a comprehensive set of experiments which attempted to systematically identify the source of the forecast skill improvements in the new model.

One interesting result was that the additional tropospheric forecast skill was obtained without any extra observations in the stratosphere, suggesting improvements in the estimation of the initial state due to reduced stratospheric bias were important.

Greg Roff presented results from extended range forecasts made using the Australian Community Climate and Earth System Simulator (ACCESS). ACCESS runs a global and regional short-range ensemble prediction system (AGREPS) in pre-operational research mode. He found that AGREPS system has a comparable performance to the operational ECMWF-EPS system as shown in the figure 1 for the forecasts of Queensland, Australia flooding of 27 January 2013. He also presented an important challenge to SNAP to clearly identify where operational forecasting centres might see benefit in forecast skill from better representing stratospheric dynamical processes.

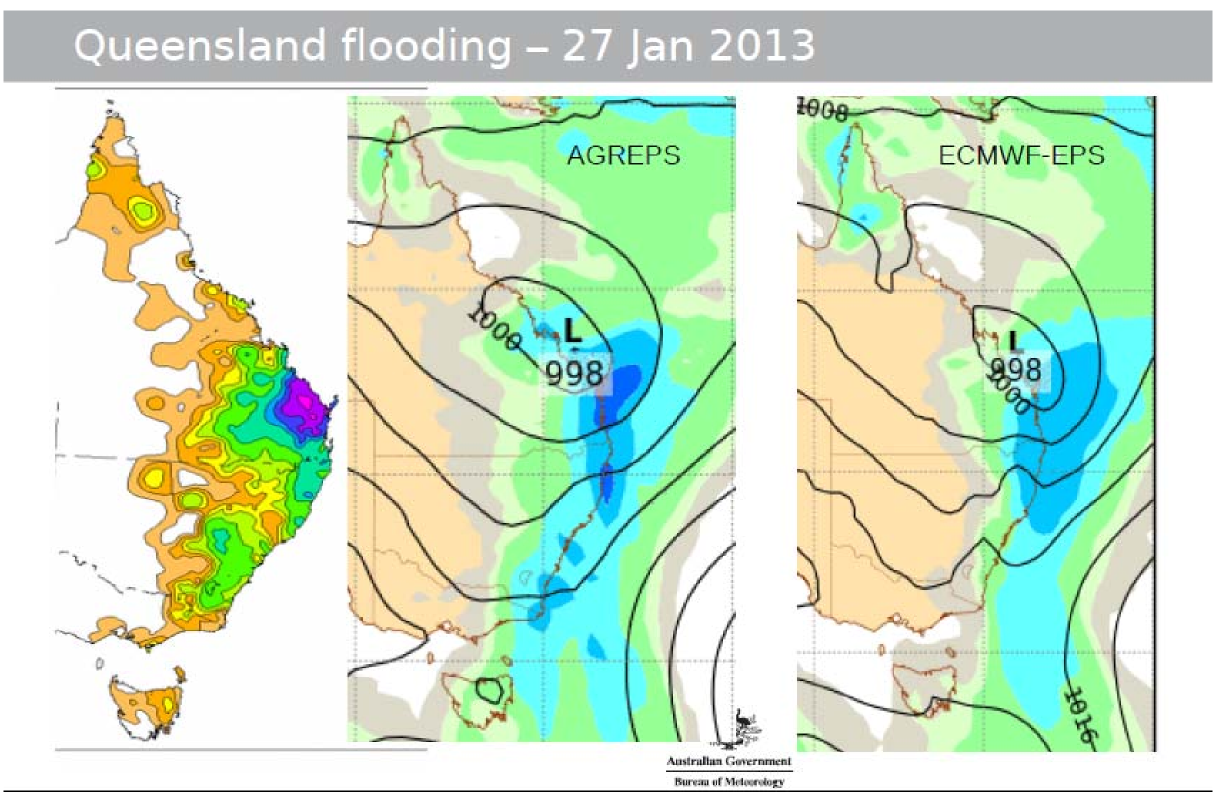

Figure 1: The flooding of Queensland, Australia as simulated by AGREPS and ECMWF-EPS.

An introduction to the WCRP-WWRP sub-seasonal to Seasonal prediction Project (S2S) was given by the S2S co-chair **Frédéric Vitart**. The S2S is a new WWRP/THORPEX-WCRP joint research project whose main goal is to improve forecast skill and understanding on the sub-seasonal to seasonal timescale, and promote its uptake by operational centres (Table 1) and exploitation by the applications community. The project is designed to pay specific attention to the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation. S2S is in the process of establishing an extensive data base of sub-seasonal to seasonal (up to 60 days) forecasts and re-forecasts, modeled in part on the THORPEX Interactive Grand Global Ensemble (TIGGE) database for medium range forecasts (up to 15 days). The impact of stratospheric variability on the surface weather and climate will be a key topic for the S2S project.

	Time-range	Resol.	Ens. Size	Freq.	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	D 0-32	T639/319L62	51	2/week	On the fly	Past 18y	weekly	5
UKMO	D 0-60	N96L85	4	daily	On the fly	1989-2003	4/month	3
NCEP	D 0-60	N126L64	16	daily	Fix	1999-2010	daily	4
EC	D 0-35	0.6x0.6L40	21	weekly	On the fly	Past 15y	weekly	4
CAWCR	D 0-120	T47L17	33	weekly	Fix	1989-2010	3/month	33
JMA	D 0-34	T159L60	50	weekly	Fix	1979-2009	3/month	5
KMA	D 0-30	T106L21	20	3/month	Fix	1979-2010	3/month	10
CMA	D 0-45	T63L16	40	6/month	Fix	1982-now	monthly	48
Met.Fr	D 0-60	T127L31	41	monthly	Fix	1981-2010	monthly	11
SAWS	D 0-60	T42L19	6	monthly	Fix	1981-2001	monthly	6
HMCR	D 0-60	1.1x1.4 L28	20	weekly	Fix	1981-2010	weekly	10

Table 1: Major operational forecasting systems and their configuration for S2S initiative.

Stratospheric Variability and Predictability

An invited talk on the predictability of the stratosphere and associated teleconnections was given by **Adam Scaife**. He showed a series of monthly forecasts of the stratospheric sudden warming of January 2013. These showed that a signal of the SSW started appearing on December 21, 2013 in the operational forecast model and that Met Office forecasts were modified to include the potential effects of this event. This was an example of the importance of what Adam called ‘actionable information’ for forecasters which SNAP should bear in mind when considering the impact of stratospheric variability on surface weather. Adam also discussed a number of case studies of recent cold winter events and discussed experiments which highlighted the role of stratospheric variability in the predictability of these events. He estimated that of the mean time over which SSW events could be predicted in the current version of the Met Office model was around 12 days and also showed experiments which highlighted the role of drivers of variability in the extra-tropical stratosphere including ENSO, the QBO and the solar cycle. Finally, he presented results from the most recent version of the Met Office seasonal forecasting model, GloSea5. Excitingly, these results show a much greater skill than previous models in predicting the wintertime NAO, with correlation between DJF mean NAO and November forecasts of around 0.6 over a series of hindcasts.

Alberto Arribas discussed this result in detail and highlighted some of the improvements made to

Met Office systems, including enhancements of both vertical and horizontal resolution which have led to this step change in forecast skill.

The role of SSWs in producing skillful seasonal forecasts was also discussed by **Michael Sigmond** using Canadian Middle Atmosphere Model. He showed the enhanced potential predictability that can be achieved in sea level pressure, surface temperature, and precipitation for forecasts initialized during SSWs. This was contrasted with the lower levels of skill of the model for forecasts initialized during periods in which the stratospheric state was close to climatology. As a way of exploiting the additional skill he suggested forecasting centres run additional, special seasonal forecasts once an SSW appears in observations.

The performance of MPI-ESM seasonal prediction system in reproducing stratospheric variability and predictability was presented by **Daniella Domeisen**. The mean state of the stratosphere was shown to be well re-produced but the model still struggles in the tropical upper stratosphere where there appears to be a large positive bias in zonal mean zonal wind. In a composite of 67 SSWS the model appears to be successfully reproducing downward coupling.

Masakazu Taguchi investigated basic characteristics of stratospheric predictability for the NH winter stratosphere by comparing the JRA-25/JCDAS reanalysis data to 1-month ensemble hindcast (HC) experiment data using Japan Meteorological Agency (JMA) numerical weather prediction model. Examining the initial conditions for which the HC data exhibits large spread and low skill it turns out that such conditions are when the polar night jet is in the phase of weakening. The spread and skill are found to be correlated as expected (large spread corresponds to low skill), but their distributions are also characterized by outliers which have markedly low skill for given spread.

S-T Coupling, Stratospheric Warmings and Surface Weather

The tropopause connects the stratosphere and troposphere and plays a very important role in the stratosphere-troposphere coupling. **Mark Baldwin** highlighted the role of tropopause and suggested that the understanding of the variation of tropopause height may hold the key to understanding the stratospheric impact on surface weather. He described the large variation of tropopause height (upwelling/downwelling) at polar cap as a mechanical plunger, influencing the entire troposphere. Because of the large signal to noise ratio in tropopause height he suggested new metrics for stratospheric-tropospheric coupling such as the variance of tropopause height and the e-folding time scale of tropopause height (Figure 2).

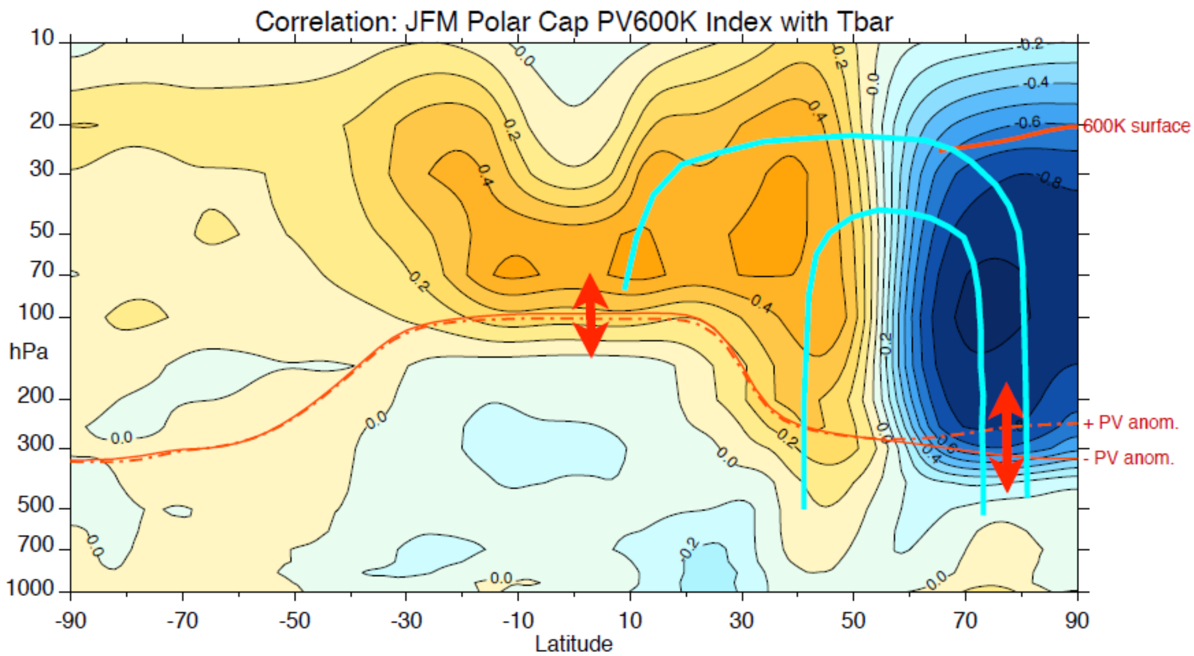

Figure 2: Large variation in PV anomaly at the tropopause.

Shigeo Yoden gave in introduction of a five year research project in Japan on extreme weather variations in the stratosphere-troposphere coupling system. This project is a collaboration between groups working on data analysis, mechanistic circulation modeling, general circulation modeling and numerical weather prediction modeling studies, and Japan Meteorological Agency/Meteorological Research Institute climate model studies. The project aims to perform comprehensive studies of the phenomenological description of the extreme weather events of the S-T coupled system, understanding their dynamical processes with a hierarchy of numerical models, and future projections with a state-of-art climate model. This research project may also contribute towards the promotion of international research collaboration, including WCRP/SPARC activities.

Miriam D'Errico presented the effects of stratosphere-troposphere coupling on the decadal predictability of the climate system using the coupled ocean-atmosphere model. She showed results from initialized climate predictions using both the high-top and low-top versions of the CMCC climate model.

The stratospheric tropical response to SSW events was presented by **Miguel Gomez-Escolar**. He found that the upper and middle tropical stratosphere have significant coupling with polar cap evolution. He discussed new ways to extract the composite temperature anomalies during SSW events which avoids contamination from QBO temperature changes. He showed that lower stratospheric responses to SSW events are only present during QBO-E phases and is related to changes in sub-tropical wave breaking.

Beatriz Funatsu investigated the impact of SSWs on changes in tropical convection occurrences following two SSW that occurred in January 2009 and January 2010, using satellite observations from the Advanced Microwave Sounding Unit (AMSU). She found that following the onset of the SSW there was a subsequent overall increase in the occurrence of deep convection over South America, Africa and the Maritime Continent.

Daniel Mitchell presented work which distinguished between the impact of vortex displacement and vortex splitting during SSWs on the surface weather using reanalysis data. He found that vortex splitting events are more strongly correlated with surface weather and lead to positive temperature anomalies over eastern North-America of more than 1.5K, and negative anomalies over Eurasia of up to -3K whereas the signals from vortex displacement events are weaker and generally associated with cold-air outbreaks over North America.

Toshihiko Hirooka presented a study of circulation changes in the mesopause during SSWs. He found that easterlies in the mesosphere do not always appear before SSW easterlies in the upper stratosphere. He also discussed dynamical reasons for the difficulty that models have in reproducing the mesopause changes associated with SSW events.

Quasi-Biennial Oscillation (QBO)

The influence of the QBO on the variability of the stratospheric winter vortex in the CMIP5 and CCMVal2 models was presented by **Bo Christiansen**. He showed that while models show significant bimodality in the tropical stratosphere associated with the QBO, there is little bimodality in the polar vortex region, despite models having realistic vortex variability. He also showed that the Holton-Tan relationship is significantly weaker in models than in the re-analysis (Figure 3).

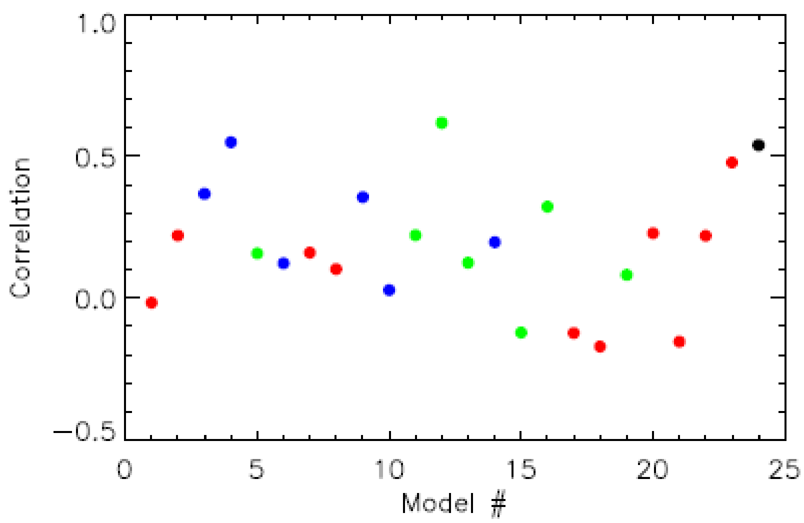

Figure 3: the correlations between winter mean vortex and QBO. The colors indicate the representation of the QBO in the models: No QBO (red), Prescribed QBO (blue), Spontaneous QBO (green), and NCEP (black).

Peter Watson gave a presentation considering the effect of the QBO on the stratospheric polar vortex. Using dynamical system theory, he argued that composite pictures of the evolution of the vortex during different phases of the QBO could be misleading and instead advocated detailed study of the transient response of the vortex to forcing by the QBO. Using results from the HadGEM2 model, he described how transient experiments of this type favour the standard Holton-Tan mechanism over other explanations for the QBO-vortex link.

Another presentation on the Holton-Tan mechanism was made by **Hua Lu** who discussed changes in the HT effect on decadal time scale. Using ERA-40 and ERA-Interim reanalysis data she showed more planetary wave breaking in the upper stratosphere in the winter when the previous QBO phase transition occurred during NH winter, causing a stronger meridional circulation and a warmer, more disturbed polar vortex. She also showed that during 1977-1997 period the HT effect was weak due to more frequent winter transitions of QBO phase during that period.

Manfred Ern studied observed forcing of the using ECMWF and satellite temperature data using longitude-time 2-D spectral analysis. The Kelvin wave contribution to momentum forcing of the QBO during the period 2002-2006 was only 30% of the total.

Annular Mode, ENSO and Blockings

Torben Kunz presented a study of the effect of stratospheric variability on the NAM surface signal. He quantified the relative role of the downward effect of the zonal-mean secondary circulation induced by quasi-geostrophic (QG) adjustment to stratospheric wave drag and radiative damping and of wave drag local to the troposphere. The role of both contributions appeared to be similar quantitatively but differed qualitatively. QG adjustment was found to be responsible for the initiation of the surface NAM signal while the wave drag maintains and persist the signal for several weeks.

The effect of SSWs on the predictability of tropospheric NAM for nine winters from 2001/2002 to 2009/2010 was presented by **Yuhiji Kuroda** using the MRI climate model The results showed that the stratosphere plays an important role for the better medium-range prediction of tropospheric NAM when stratospheric variability is very large around a SSW (as in 2004 and 2006). The predictability of the tropospheric NAM reaches a few months as shown in Figure 4.

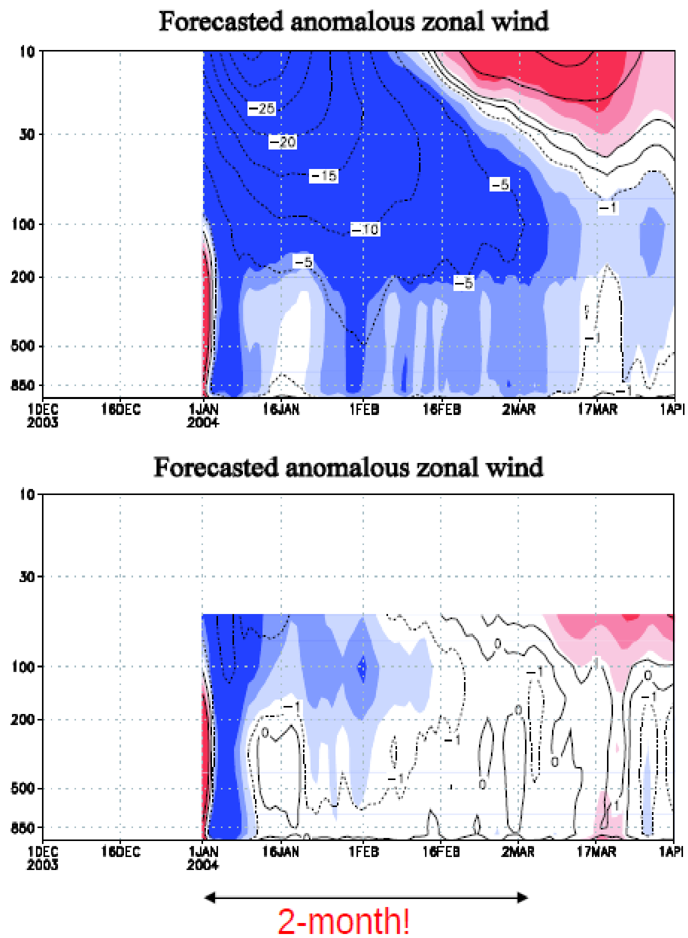

Figure 4: The effect of SSWs on the predictability of tropospheric NAM.

Robert Black presented an assessment of the CMIP5 model performance for the representation of the primary modes of boreal extra-tropical low-frequency variability, the vertical and temporal behavior of annular mode and stratosphere-troposphere dynamical coupling. He showed that the high top models better represent the stratospheric zonal wind anomalies however a very little distinction was found in the magnitude and structure of the zonal wind anomalies at tropospheric levels.

A study of the relationship between ENSO, blocking and stratospheric sudden warmings was presented by **David Barriopedro** using reanalysis data for the 1958-2010 period. The results reveal that SSWs characterized by splits of the stratospheric polar vortex exhibit different regional blocking precursors, associated wave numbers and vortex structure depending on the phase of ENSO, indicating some ENSO influence on determining different tropospheric precursors of SSWs. Splitting SSWs tend to be preceded by eastern Pacific blocks during LN, but by a reduced blocking activity therein and enhanced western Atlantic blocking frequency during EN.

James Anstey used CMIP5 dataset and runs of CMAM to assess the blocking-SSW relationship.. He showed that there was little observable difference in blocking between high and low-top models, but that models with higher vertical resolution in the upper troposphere and lower stratosphere tend to show reduced blocking biases (Figure 5).

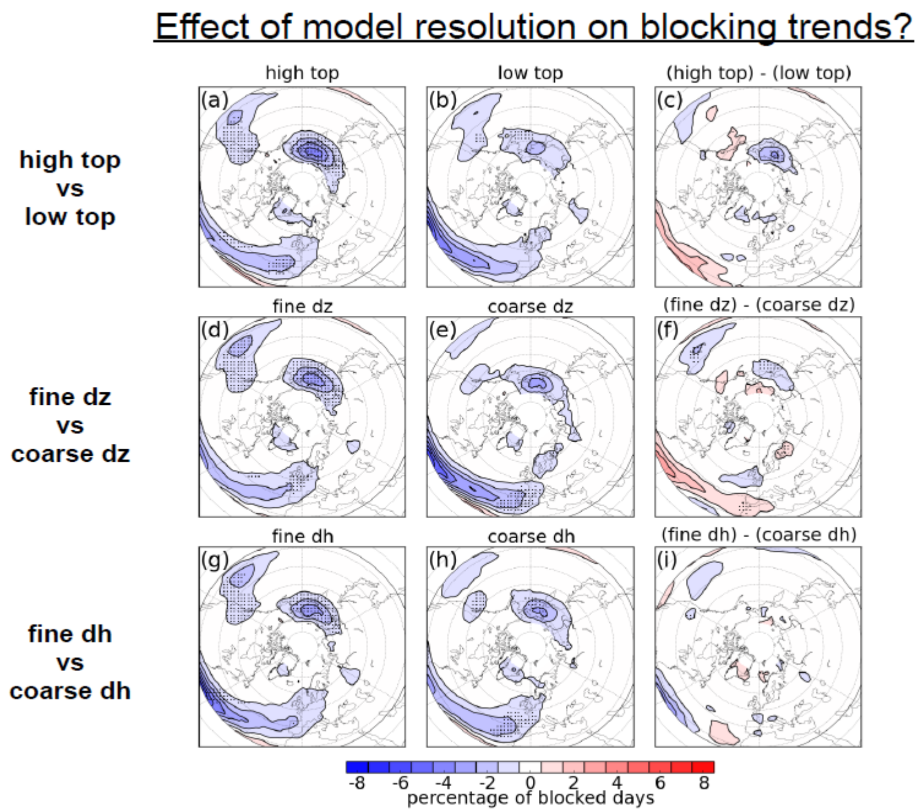

Figure 5: Effect of model resolution on blocking trends.

External Forcings

Edwin Gerber explored the impact of anthropogenic forcing on the austral jet stream in CCMVal2, CMIP3, and CMIP5 models, focusing on the summer, the period of the year when stratospheric ozone loss and recovery has been shown to impact the troposphere. He found that the multimodel mean response of the jet stream to greenhouse gases and ozone is fairly comparable and suggested that ozone has dominated jet-position in the recent past and that the effects of ozone and greenhouse gases will largely offset each other in the future...

The Impact and the potential benefits of using ozone data from the Earth Observing System Microwave Limb Sounder (EOS MLS) on medium-extended range tropospheric forecasts in a current numerical weather prediction (NWP) system was examined by **Jacob Cheung**. In the extreme case (Arctic ozone hole, March 2011) where the EOS MLS ozone profile is superior to that of the control, tropospheric forecast errors in the medium-extended range are dominated by the spread of ensemble members and hence he found no significant reduction of root mean square errors due to improved representation of ozone.

Laura Wilcox quantified the effect of external forcings on Southern Hemisphere final warming date, and the sensitivity of any projected changes to model representation of the stratosphere using high-top and low-top CMIP5 model ensembles. The final warming date in the models was found to be generally too late in comparison with those from reanalysis: around two weeks too late in the low-top ensemble, and around one week too late in the high-top ensemble (Figure 6). She also examined this behavior in response to the changes in stratospheric ozone and green house gases and found that variability in final warming date on timescales associated with changes in stratospheric ozone concentrations was significant in the high-top ensemble only.

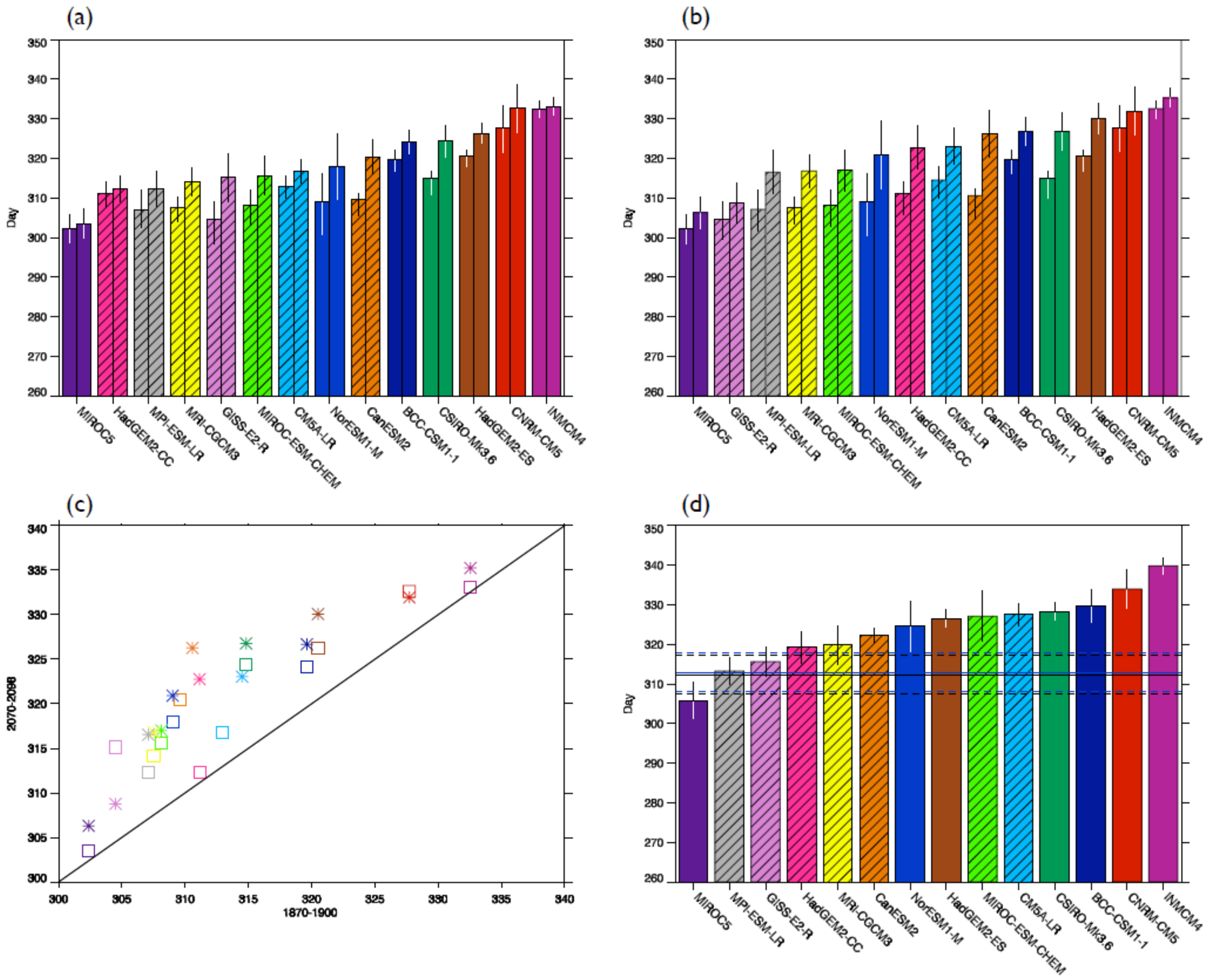

Figure 6: The effect of external forcings on Southern Hemisphere final warming date

Encarna Serrano evaluated the Whole-Atmosphere Community Climate Model (WACCM) for its ability to reproduce tracer transport processes through the tropical tropopause found in the satellite observations. Model results showed that the main features of the vertical structure and seasonality of temperature, O3 and CO near the tropical tropopause in WACCM are very similar to the observations, and that WACCM is a valuable tool for evaluating O3 and CO transport near the tropical tropopause, although the cold point tropopause is slightly higher (~1 km) in the model than in observations (Figure 7).

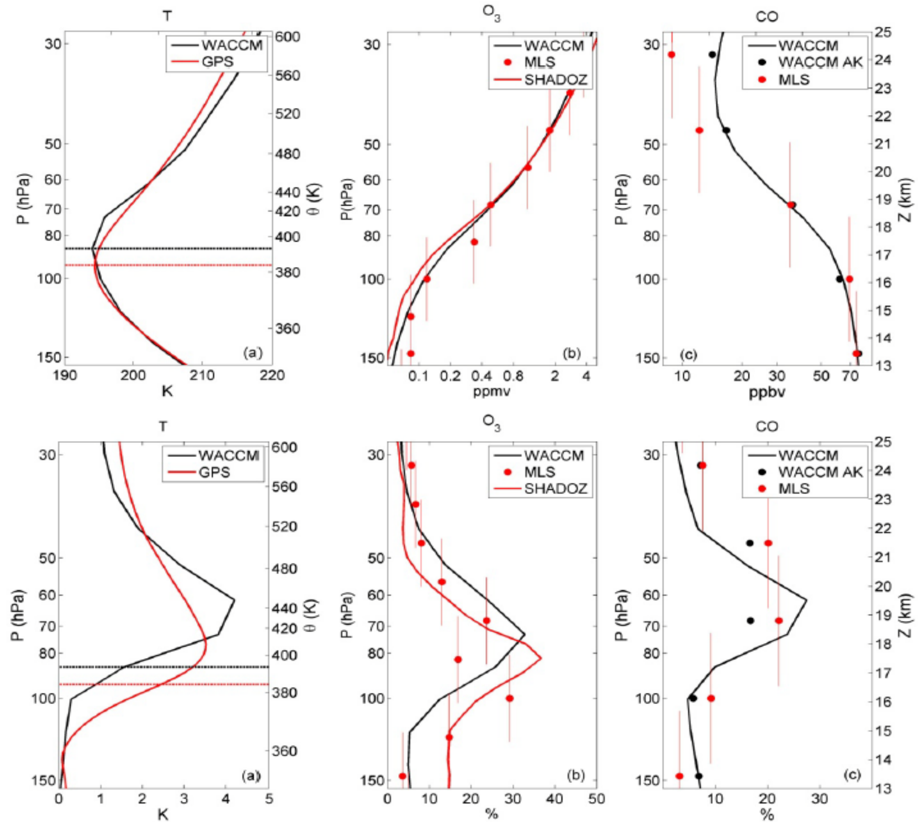

Figure 7: Top panel: Vertical structure of time mean (2004-2009) temperature (a), ozone (b) and CO (c) averaged over 18S-18N in WACCM and in the observations. The error bars represent the vertical thickness of the layers where MLS measures ozone and CO. The horizontal lines in panel (a) indicate the location of the annual mean cold point tropopause. The black dots in panel (c) indicate the values for WACCM using MLS averaging kernels for CO. Bottom panel: As in top panel but for the vertical structure of annual cycle amplitude in temperature and tracers. The amplitude for the tracers is shown relative to the annual mean concentration. (Source: Abalos et al., 2012).

A model study of the tropospheric circulation changes in response to non zonally symmetric ozone anomalies was presented by **Dieter Peters**. He found a significant changes in intra-seasonal and interannual variability in the stratosphere when comparing model runs with symmetric and asymmetric ozone distributions. These changes also have links to the tropospheric circulation.

A possible impact of a future grand solar minimum on surface climate was presented by **Amanda Maycock** who indicated that a large decrease in solar activity over the coming century would enhance the stratospheric cooling in response to increasing CO2 concentration. The cooling would weaken the stratospheric polar jet and consequently result in equatorward movement of mid-latitude jet affecting regional climate over western Europe.

Summary and Future Plan

The 1st SNAP workshop concluded with an extensive and fruitful discussion session on Friday morning. The discussion focused on the future plans for the SNAP experiment and the modifications in the originally planned activities in lieu of recent findings about the performance of low and high top operational models. Ideas presented by the participants will be used to draft and experimental protocol of the project which will be agreed by the project steering committee.

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Next actions for SNAP are to complete the SNAP predictability experiment in two phases. In Phase I the focus will be on forecasts of two very recent test events, the NH SSW during Jan 2013 and the late SH final warming of Oct 2012. Once this test phase has been completed, the project will work to define additional dates for forecast comparison to add to the SNAP forecast archive. In addition, SNAP will begin to collect a set of operational forecasts from each of the modeling centres involved to facilitate the comparison of forecast performance during periods in which extreme stratospheric events are not occurring. A key part of the forecast protocol will be to specify in detail which stratospheric fields can be collected from the modeling centres to allow detailed understanding of the dynamical background to stratospheric predictability.

Secondly, SNAP agreed to play a role in the upcoming S2S project. SNAP will seek to encourage members of the network to make use of the S2S to examine stratosphere-troposphere predictability on the sub-seasonal time range using the large archive of data which S2S will collect.

Acknowledgment

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