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Thesis sent to examiners: ________________________ Examiners' report received: ________________

DEGREE OF DOCTOR OF PHILOSOPHY
REPORT OF THE EXAMINERS
FIRST EXAMINATION
CONFIDENTIAL

GSO.11a

Board/Department of:		**Physics: Atmos, Oceanic & Planetary**
Candidate's Name:		**Mr Jorge Garcia-Franco**
Student No.		**1163344**
College:		**Wadham College**
Examiner Names:	Internal:	**Dr A Weisheimer**
	External:	**Professor R Rodrigues**
Supervisor(s):		**Professor L J Gray**
Title of Thesis as approved by the Board/Department:		**The American Monsoon System: variability and teleconnections**

We have examined the above-named candidate for the degree of Doctor of Philosophy, and report to the Board/Department as follows *(please tick one box only)*:

A full explanation of the recommendations is available in the Memorandum of Guidance for Examiners (GSO.5)

	Recommendation
❑	**1.a Award of the DPhil as the thesis stands** We are satisfied: i) the candidate possesses a good general knowledge of the particular field of learning within which the subject of the thesis falls; ii) that the candidate has made a significant and substantial contribution in the particular field of learning within which the subject of the thesis falls; iii) that the thesis is presented in a lucid and scholarly manner; iv) that it merits the degree of Doctor of Philosophy: and v) that the candidate has presented a satisfactory abstract of the thesis.
	We understand that the full report will be made available to the candidate following approval by the board.
❑	**1.b Award of the DPhil having approved all required MINOR corrections** We have asked the candidate to correct certain minor errors in the thesis and confirm that these corrections have been carried out to our satisfaction and therefore **1.a (i-v)** are satisfied.
	Signature: Date:
	The University's *Examination Regulations* now require examiners to report only after they have confirmed that minor corrections have been satisfactorily completed. We understand that the full report will be made available to the candidate following approval by the board.

Please see overleaf for further result options

x	**1.c Submission of MAJOR Corrections** We recommend that the Board should offer the candidate an opportunity to carry out major corrections to their thesis
	We have set out the respects in which the thesis falls below the standard required for the degree in the full report and we understand that the full report will be made available to the candidate following approval by the board.
❑	**2.a Reference back for DPhil or award of the MLitt/MSc(Res) as the thesis stands** We recommend that the Board should offer the candidate a choice between: a) reference of the thesis back for revision for re-examination for the Degree of Doctor of Philosophy; **or** b) leave to supplicate for the Degree of Master of Letters or of Master of Science (by Research), as appropriate, on the basis that the thesis has not reached the standard required for the Degree of Doctor of Philosophy but has nevertheless reached that required for the Degree of Master of Letters or of Master of Science (by Research).
	We have set out the respects in which the thesis falls below the standard required for the degree in the full report and we understand that the full report will be made available to the candidate following approval by the board.
❑	**2.b Reference back for DPhil or award of the MLitt/MSc(Res) subject to minor corrections** We recommend that the Board should offer the candidate a choice between: a) reference of the thesis back for revision for re-examination for the Degree of Doctor of Philosophy; **or** b) leave to supplicate for the Degree of Master of Letters or of Master of Science (by Research), as appropriate, subject to minor corrections on the basis that the thesis has not reached the standard required for the Degree of Doctor of Philosophy but has nevertheless reached that required for the Degree of Master of Letters or of Master of Science (by Research).
	We have set out the respects in which the thesis falls below the standard required for the degree in the full report and we understand that the full report will be made available to the candidate following approval by the board. **Note: examiners are also asked to append to their report a list of corrections required for the MLitt/MSc(Res).**
❑	**3. Reference back for DPhil or reference back for the degree of MLitt/MSc(Res), as the candidate may choose** We recommend that the Board should offer the candidate a choice between: a) reference of the thesis back for revision for re-examination for the Degree of Doctor of Philosophy; **or** b) reference of the thesis back for revision for re-examination for the Degree of Master of Letters or Master of Science (by Research), as appropriate. The thesis has not yet reached the standard required for the Degree of Doctor of Philosophy, or for the degree of MLitt/MSc(Res) The candidate may then choose which option to resubmit for.
	We have set out the respects in which the thesis falls below the standard required for the degree in the full report and we understand that the full report will be made available to the candidate following approval by the board.

Both examiners must sign the declaration on page 3 of this report.

Notes:
In exceptional circumstances, and notwithstanding a recommendation under 2 or 3, the examiners may certify (as an appendix to their report and after indicating the respects in which the thesis falls below the standard required for DPhil) that they are unable to indicate how the thesis might be changed, within the time allowed, in order to reach the required standard for the Degree of Doctor of Philosophy.

EXAMINERS:

We provide a detailed report (attached). (Examiners are asked to provide reports in word-processed or typewritten form)

Date of Viva:	21st December 2021

Signature:	Antje Weisheimer	Date:	28th December 2021
Full Name:	DR A WEISHEIMER		

Signature:	Regina R. Rodrigues	Date:	3rd January 2021
Full Name:	PROFESSOR R RODRIGUES		

DGS:

Signature:	Andrew Wells	Date:	03/01/2022
Full Name:	Andrew Wells		

Please return to:

Ms R Mitchell
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Joint Report

Candidate: Jorge Luis Garcia Franco
Degree: Doctor of Philosophy
Thesis: The American Monsoon System: variability and teleconnections

Internal Examiner: Dr Antje Weisheimer, AOPP, University of Oxford, UK
External Examiner: Dr Regina R. Rodrigues, Dept. Oceanography, Federal University of Santa Catarina, Brazil

Oral examination date (held remotely via Zoom): 21st December 2021, 10 am, approx. 4h

This joint report assesses the scope and significance of the thesis entitled "The American Monsoon System: variability and teleconnections", submitted for the degree of Doctor of Philosophy by Jorge Luis Garcia Franco. The recommendation is that the board should return the thesis to the candidate for **major corrections**. The report indicates in detail the strengths and limitations, weaknesses, and lacunae. The thesis is of sufficient potential merit to qualify for the degree. However, some amendments are necessary before its deposit.

This work first investigates how the North and South American monsoon systems are simulated by two climate models from the UK Met Office (UKESM1 and HadGEM3, Chap. 4). The results show that both models present biases (errors) about the temporal evolution and spatial distribution of precipitation in the North and South American monsoon systems and the Intertropical Convergence Zone (ITCZ) over both the eastern Pacific and Atlantic oceans. Then it develops a new methodology to determine the start (onset) and end (retreat) of the wet monsoon season, from data and model outputs (Chap. 5). The new technique performs well, identifying the onset and retreat of the North American and Indian monsoon wet seasons. In particular, this technique is able to identify a subtle period of drought within the wet monsoon season in southern Mexico, Central America and the Caribbean, called Midsummer Drought. Applying this technique to model outputs, this work then investigates three potential physical mechanisms for the existence of the Midsummer Drought (Chap. 6). It concludes that the Midsummer Drought is caused by the modulation of the transport of moisture by the Caribbean Low-Level Jet, with the thermodynamic aspects being of lesser importance. Finally, the study investigates the relationship between quasi-biennial oscillation (QBO) in the stratosphere and the tropical circulation, monsoon systems and the ITCZ in the troposphere (Chap. 7). In particular, it tries to identify the role of a downward impact from the QBO on the troposphere using the same model outputs (UKESM1 and HadGEM3) and a nudging experiment where the influence of the troposphere on the stratosphere is eliminated (Chap. 8). The results are inconclusive about the cause/effect. The reason could be that the nudging experiment is inappropriate or that the stratospheric QBO has little influence on the tropical troposphere.

Based on the written thesis and oral examination, the candidate has made a significant and substantial contribution to understanding the Midsummer Drought of southern Mexico, Central America and the Caribbean, and to developing a novel methodology to identify the onset and retreat of the wet monsoon season. Based on the oral examination, the candidate also demonstrated to possess good knowledge of the physical mechanisms involved in the monsoon system variability, and its interactions with ENSO and QBO. However, this is not always clear in the written thesis. Detailed descriptions of the main mechanisms related to the American Monsoon systems, including the associated cause of shifts in the ITCZ, ENSO teleconnections and the QBO interaction with the troposphere, need to be included in the written document.

We had the impression that the chapters of the thesis were primarily driven by the available tools and techniques (e.g. QBO and ENSO) rather than by the science questions arising from deficiencies in the state-of-the-art knowledge of the American monsoon systems (e.g. the role of the MJO).

Although the thesis is, in general, well written and presented in a scholarly manner, the "Background" and "Data and Methods" chapters are not coherent, i.e., the links of each objective/work hypothesis to a methodological aspect and aims of the thesis are missing. The thesis also suffers from a large number of minor oversights related to the language, typos, figure and table titles and captions which should be carefully checked before resubmission.

Several of the criticisms made during the viva and in this report had already been raised in the annual DPhil progress examinations and the examiners are disappointed that these hadn't been considered to the extent required.

Outlined below are specific comments on what respects the thesis falls short of the required standard and how the candidate should revise it to remedy these defects.

Chapters 1 & 2: Introduction and Background

The general problem with the Introduction and Background chapters is that the paragraphs and sections are disconnected, leaving the reader to determine the connection. Chapter 2 lacks a sufficiently detailed description of the global monsoon system and how it differs over America (physical mechanisms), particularly for the South American Monsoon System (SAMS), which is also the focus of this work. In particular, lacking and equally important is a discussion of the orographic effect involved in all monsoon systems (mechanical versus thermodynamical drivers) that will prove vital for the North American Monsoon System (NAMS) in Chap. 6. There is also no motivation and explanation of how the QBO interacts with the troposphere in the tropics (again, an explanation of the physical mechanisms is missing).

Pages 2-3: No references are given for the SAMS.

Page 3: The statement "Nevertheless, the understanding of the effect of ENSO over South America and the AMS in general is still somewhat limited" is not true at all. There is a vast literature about the impact of ENSO on SAMS and NAMS that considers ENSO variability (diversity), which is not cited in the thesis.

Page 3: The thesis begins with Chap. 4, consider rephrasing this.

Page 3: It is not clear if the focus of the thesis is on southern Mexico and Central America.

Page 9: The paragraphs are not connected. From Walker cell, the text jumps to the ITCZ and then monsoon systems.

Page 15-16: Only three small paragraphs explain the SAMS. They focus on the Amazon region. However, the SAMS extends from the Amazon to the southeast of Brazil and involves several other essential features, such as the South Atlantic Convergence Zone, the South American Low-Level Jet, the reversal of the circulation, etc.

Page 16: The reference Bombardi and Carvalho (2011) is misplaced.

Page 17: Although this study focuses on North and South American monsoon systems, explanations are only given to the NAMS.

Page 21: Disconnect appears again: the text ends with MJO and then jumps to ENSO.

Page 21-24: ENSO section describes basics such as where the name comes from that are irrelevant to this study and relevant aspects are left out, such as how ENSO impacts the SAMS. What are the physical mechanisms and the impacts in terms of precipitation? More importantly, references are missing here, particularly the teleconnection patterns that affect both the NAMS and SAMS, such as the Pacific North America (PNA) and Pacific South America (PSA) patterns.

Page 23: ENSO and South America are first mentioned, then the next paragraph describes ENSO diversity alone and then goes back to ENSO and South America. ENSO diversity is relevant for both.

Page 24: This sentence is incomplete.

Page 25: "Wester" should be "Westerly".

Page 25-29: The QBO section does not explain the cause-effect relationship between the QBO phase and temperature and the troposphere in the tropics. The easterly phase of the QBO (QBOE) is associated with a higher and colder tropopause in the tropics. In contrast, the westerly phase (QBOW) is observed with the lower and warmer tropical tropopause. Are the QBO phases independent of the tropopause temperature variability?

Page 28: "The authors argue are" should be revised.

Chapter 3: Data and Methods

This chapter presents the same general problem as previous chapters, i.e., disconnected sections and a lack of detail, e.g. discussing uncertainties of the different data sets. There is no explanation of how data and methods will be used to achieve the study's objectives.

Pages 30-38: Is the vertical resolution of the data sets and model simulations suitable for representing the QBO, tropical stratosphere and troposphere? The text mentions that the Indian monsoon is not well simulated, but is there any evaluation of the performance of the CMIP6 simulations for the SAMS and NAMS?

Table 3.2 is confusing as many simulations are not explained nor further used in the thesis.

Page 38-40: Explanation and interpretation of the moist static energy budget terms missing.

Chapter 4: The American monsoon system in UKESM1 and HadGEM3

Chapter 4 is mostly of descriptive nature and, as such, lacks a more informed discussion and interpretation of the results considering the physical mechanisms involved in the various aspects of the monsoon systems analysed here, such as the Atlantic and Pacific ITCZ, precipitation and convection and ENSO teleconnections.

Page 44: "near-air surface temperature" should be "near-surface air temperature".

Page 42: The SACZ and SALLJ are mentioned for the first time here, but their mechanisms are not described. This would help pinpoint the models' deficiencies in simulating these features.

Table 4.1: This table is of very limited use with a large number of scores. A clear interpretation would help the reader to filter the relevant information. It is also not clear for which region these scores were computed. Units are missing.

Page 48: An explanation needs to be given as to how the biases are computed for the piControl simulations because for the historical period, they are obtained by subtracting the observed (ERA5) climatology for the same period.

Page 51: An explanation needs to be given as to the causes of the seasonal cycle of the ITCZ.

Page 53: The definition of the SACZ is only given here. The detection method is briefly described in the Caption of Figure 4.6 but should be described in Chapter 3 (Data and Methods). There is no explanation of the importance of the SACZ for the SAMS. The following work should be cited.

- Zilli, M.T., Carvalho, L.M. and Lintner, B.R., 2019. The poleward shift of South Atlantic Convergence Zone in recent decades. *Climate Dynamics*, *52*(5), pp.2545-2563.

- Zilli, M.T. and Hart, N.C., 2021. Rossby Wave Dynamics over South America Explored with Automatic Tropical–Extratropical Cloud Band Identification Framework. *Journal of Climate*, *34*(20), pp.8125-8144.

- Van Der Wiel, K., Matthews, A.J., Stevens, D.P. and Joshi, M.M., 2015. A dynamical framework for the origin of the diagonal South Pacific and South Atlantic convergence zones. *Quarterly Journal of the Royal Meteorological Society*, *141*(691), pp.1997-2010.

Figure 4.9 has too many lines that are difficult to distinguish – reduce to the essential.

Page 59: The interpretation of the result described penultimate paragraph, "the GC3 N216-pi shows a better agreement with observations but still underestimates austral summer rainfall by 1 mm/day" needs clarification since "pi" simulations refer to the pre-industrial period. Is it correct to compare those to observations?

Page 62: ENSO teleconnections are evaluated by other fields, generally in the upper troposphere (divergent wind, stream function or geopotential height anomalies). Temperature and precipitation are the impacts of ENSO and not its teleconnection patterns. Also, since the mature ENSO season is DJF (as shown in Fig 4.11 and 4.12), its links to the monsoon season are unclear.

Page 63-64: Cold anomalies are not ENSO teleconnections.

Page 65: Another reference should be used to explain the Pacific North American (PNA) and the North Atlantic Oscillation (NAO) is irrelevant for the tropical North Atlantic (Hastenrath 2006, Taschetto et al. 2016). NAO/ENSO interaction is relevant for extra-tropical Europe. Giannini et al. (2000, 2004) do not evaluate the interaction of NAO and ENSO. So, these citations are misplaced.

- Hastenrath, S., 2006. Circulation and teleconnection mechanisms of Northeast Brazil droughts. Progress in Oceanography, 70, 407-415.

- Taschetto, A.S., Rodrigues, R.R., Meehl, G.A., McGregor, S., England, M.H., 2016. How sensitive are the Pacific–tropical North Atlantic teleconnections to the position and intensity of El Niño-related warming? Climate Dynamics, 46, 1841-1860.

Page 65: This is also not the case. 1) SESA is out of the area of study; 2) The ENSO influence on SESA is made via changes in the South American Low-level Jet (SALLJ) and less so via the subtropical jet; 3) This is not related to the SACZ and SPCZ. ENSO teleconnection to South America is weak during the mature phase of ENSO because local processes and remote intraseasonal phenomena such as MJO dominate.

Page 66 and Figure 4.13 Caption: Description of left and right panels but not the middle, upper and lower ones.

Page 66: The explanation given is correct but does not link to the precipitation anomalies. It explains the shift in the Walker cell and ascending branch but does not mention the descent branch over the Amazon that generates the negative anomalies of precipitation. ENSO affect the Amazon in two different ways, triggering Kelvin waves (Matsuno-Gill type of response) leading to the changes in Walker cell and triggering Rossby wave trains to the tropical North Atlantic (which is the PNA). The mechanism associated with the latter is reducing SLP over the tropical North Atlantic, which weakens the trades and evaporative cooling, leading to a warming of the tropical North Atlantic. The ITCZ does not migrate southwards, leading to negative anomalies of precipitation. This whole process is not explained anywhere in the text.

Figure 4.14.: The quality of the figure is poor and needs to be improved. It is unclear what information can be obtained from the figure. In particular, the non-linearity discussed is difficult/impossible to see.

Page 68: Part of the methodology for calculating EP and CP ENSO is in the Figure's caption. It should be in the methods.

Pages 70-73: Is there an effect of ENSO on QBO? If so, how the cause/effect can be untangled? The text mentions that the precipitation in the western Pacific is relatively similar during QBOe and QBOw, but not in other parts and conclude that the teleconnection is affected by the QBO. How does that work? Because the teleconnections are triggered by anomalous convection in the western Pacific (precipitation), which is similar in both cases… The differences between QBOe and QBOw in Fig.18 (Page 72) seem very weak in the troposphere and at the surface. Moreover, could the differences in precipitation be just a result of randomly grouping different ENSO events? Mainly because there are no consistent changes for El Niños.

Page 74 and Figure 4.19: It is not called Bolivian Low-level Jet. It is the South American Low-level Jet (SALLJ). Vera et al. (2006) and Marengo et al. (2012) do use the same terminology and all relevant literature. Labels a) and b) are missing.

Page 77: The mentioning of the land-use change and soil-atmosphere feedbacks are not supported by the analysis and not discussed in sufficient detail.

Chapter 5: A wavelet transform method to determine monsoon onset and retreat

This chapter is well written, and it is one of the strengths of this thesis. As such, it requires very few chances.

The equations for the Haar wavelet in 5.1 and in the last paragraph on page 83 contradict each other for the singularity $t=b$.

Page 89: Figure 5.5 should be Figure 5.5d.

Page 91: The text should mention the sensibility of the methodology to averaging the precipitation over different boxes.

Page 93: The strength of the proposed methodology is that it finds the onset and retreat pentads more consistently across different datasets when compared to the other methods.

Page 94: "The impact of monsoon onset in precipitation is diagnosed to be slightly stronger by A12 compared to WT or G13." Is this because the A12 methodology uses two different thresholds (described on page 90)?

Page 95: The text should explain why the methodology is not applied for the SAMS, which is the focus of the previous Chapter, and instead is applied to the Indian Monsoon.

Page 98: It would have been better to show the differences in relation to ERA5.

Page 100: What does "… the MSD is part of a regional-scale process on the result of local-scale processes." mean?

Page 109: It should be mentioned in the conclusions the potential of the methodology to be used for other purposes, such as for shorter extreme events.

Chapter 6: The Midsummer drought in the MOHC CMIP6 experiments

This chapter is well written, and it is the other strength of this thesis. As such, it requires very few chances.

Page 115: The text should clarify if "in which the SSTs are 4 K warmer and colder" means everywhere, global oceans. The CFMIP experiments need to be described and discussed.

Page 115: More details are necessary about the AMIP and CMIP simulations.

Page 117, section 6.3: Please discuss the interannual variability of the climatology.

Page 120: An explanation needs to be given as to why the increase in resolution does not translate into a better simulation of precipitation.

Page 124: Colour bar labels in Figure 6.10 should be given at the same intervals for negative and positive anomalies.

Page 130, section 6.5: grammatical errors in several sentences.

Page 132, near the end: grammatical error

Page 136, near the top: grammatical error

Page 136, near the end: how is LW treated in the models? How does suppression of the coupling work? A critical discussion is needed here.

Page 145: It would be helpful to provide an interpretation or discussion of these results.

Figure 6.29: How are the error bars computed?

Page 151/152: the discussion needs to be made clearer. E.g., it is unclear which evidence suggests that LW heating and CRE and moisture transport may be more important than surface fluxes or the SW heating variations.

Pages 152-155: A paragraph should be added to the Summary and Discussion Section discussing the results obtained here in the context of recently published work by Boos & Pascale (2021). The latter find that mechanical forcing generated when Mexico's Sierra Madre mountains deflect the extratropical jet stream towards the Equator is the primary driver of convective rainfall for the core North American monsoon and not the thermally forced tropical monsoon. This thesis finds that the most likely mechanism that drives the Midsummer Drought in southern Mexico, Central America and the Caribbean is the transport of moisture by the Caribbean Low-Level Jet, with the thermodynamic aspects being of lesser importance.

Boos, W.R., Pascale, S. (2021). Mechanical forcing of the North American monsoon by orography. Nature 599, 611–615 https://doi.org/10.1038/s41586-021-03978-2.

Section 6.8: The use of the phrase "interannual variability" is wrong – interannual variability described the variations from one year to the next. However, here it is used to talk about intra-annual (or seasonal) variability.

Chapter 7: The tropical route of QBO teleconnections in UKESM1 and HadGEM3

Chapter 7 lacks a more informed discussion of the results regarding the physical mechanisms by which QBO can affect the tropical and extra-tropical troposphere and monsoon. The methodology used (composite and regression analyses) is not appropriate to investigate the cause-effect between QBO, ENSO and monsoon variability. This is tried in Chapter 8 with nudged experiments. Here, the suggestion is to concatenate Chapters 7 and 8, selecting only the relevant figures to describe and discuss the main findings concisely.

Page 158: An explanation needs to be given as to why use the pre-industrial control experiments (before 1850) and compare to the observations GPCP extending from 1979 to 2018.

Pages 158-159: An explanation needs to be given about the caveats of using the chosen methodology for defining ENSO events. Using the EN3.4 index with a threshold of ±0.65 to determine positive or negative events is appropriate for the boreal winter, during the mature phase of the ENSO events. However, when the requirement of 5 consecutive months above the thresholds is lifted, this methodology can lead to the erroneous selection of ENSO events compromising the results and interpretations. For instance, if E3.4 is above 0.65 only in August, this month is included in the composites, but cannot be considered an El Niño event.

Page 159: An explanation needs to be given as to how the cause-effect between QBO, ENSO and monsoon are untangled using solely composite and regression analyses. In my opinion, the only way to do that is by performing idealised model experiments forced by QBO like variability (without SST variability) and analysing the precipitation response. This is the objective of Chapter 8 and should be presented together concisely.

Figure 7.1 and following: The colour bars are too small to recognise the values of specific colours. Please improve.

Pages 160-161, Figures 7.2 and 73: An explanation needs to be given as to why the model results in DJF & MAM have the opposite response in the equatorial Atlantic and Indian oceans. In addition, difference plots including significance between GPCP and the models would be useful.

Page 162: "Caribbean Sea anomalies are likely related to the northward shift of the Atlantic ITCZ observed in the same season particularly in UKESM-pi", but not in the observations.

Page 162: If QBO affects the troposphere (and not the other way around), why would we only have a significant response overland? It seems that SST affects the troposphere and then QBO.

Pages 164-165, Figure 7.8: The biases are the same magnitude as the observed convective precipitation. This challenges the validity of the results.

Pages 165: The reason for the lack of robustness of the ERA5 analysis does not seem to be the short span of the dataset (see GPCP results). There is a problem with comparing historical datasets (GPCP and ERA5) with pre-industrial simulations.

Page 165, Figure 7.10: A meridional dipole of precipitation characterises a meridional shift of the ITCZ. Fig. 7.10a (ERA5) shows only a region of positive anomalies during boreal winter. The enhanced convection in DJF can be associated with ENSO. An El Niño event produces more convection along the equatorial region because it increases the area of SST conducive to deep tropical convection. The description of meridional shifts of the ITCZ needs to be revised. Having a better understanding of the mechanisms involved in the meridional shift of ITCZ would have helped.

Page 171: Caption of Figure 7.13 is wrong; descriptions of (c) and (d) are swapped.

Page 172: An explanation needs to be given as to why use 36-year samples if the pre-industrial runs are longer.

Page 173: Regression analysis is not well explained, which gives no confidence in the conclusion that the QBO impacts tropical precipitation.

Figure 7.14: What quantity is shown here?

Pages 175-176: The ENSO teleconnection involves the extratropical response (Rossby wave trains) such as the PNA for the ITCZ in the Atlantic; it is not just a direct walker cell response (Matsuno and Gill, Kelvin wave response).

Page 177, Figure 7.16: An explanation is needed about the physical mechanisms by which the QBO impacts the troposphere because the anomalies are stronger on the surface and not at the upper troposphere-lower stratosphere (UTLS), particularly for the run with higher vertical resolution. Also, the anomalies are less than 10% of the climatological values. This could be related to other phenomena, such as MJO.

Page 178: The ENSO Atlantic ITCZ response occurs in MAM (boreal spring) because of the ENSO phase-locking with the seasonal cycle of the Atlantic SST that drives the ITCZ meridional shifts.

Page 180: An explanation for how the QBO teleconnections work needs to be given. In other words, how does the QBO change the surface state? How well do these pre-industrial runs simulate the current QBO-ENSO-Walker relationship/variability?

Page 180: The results are inconclusive about the cause/effect of QBO and the tropical troposphere.

Chapter 8: Tropical Teleconnections of the QBO in the UM with a nudged stratosphere

The suggestion here is to concatenate this Chapter with the previous chapter selecting only the relevant figures to concisely describe and discuss the main findings to respond to the scientific question of the cause/effect QBO and the tropical troposphere.

Page 182: The explanation of how the QBO can affect convection is given only here. This should also be discussed in previous chapters.

Page 183: Figure 8.1 x-axis labels wrong; it should be latitude instead of longitude. And Caption does not describe the panels.

Section 8.2: Include a detailed description of the nudging methodology, such as time relaxation parameters, possibly showing equation etc. Clarify the exact domains where the nudging works and what happens at the boundaries of these regions (tapering).

Figure 8.2: The different lines are not clear enough.

Figure 8.3: Are panels b) and c) discussed anywhere? If not, remove it.

Page 191: Parentheses missing in "(Figure8.6".

Pages 192 and 193, Figures 8.7 and 8.8: The differences between AMIP CTRL and AMIP nudged are not statistically significant.

Page 197-201: Coupled experiments, results for SST and precipitation (Figures 8.13-8.18) all show a weak impact of the nudging on SST and precipitation. This means that QBO has little effect on SST.

Page 204: Even though the nudged experiments improve the UTLS, the impact on convection and SST is negligible. Then the results of this session also show a weak effect of the QBO on the subtropical jets. But it is argued that the problem is the nudging. Could it not be that the QBO does not affect the tropical troposphere? A more elaborate discussion and interpretation are needed.

Pages 208-210: This chapter says that nudging experiments could untangle the cause/effect relationship between QBO/ENSO/IOD, and the results for the coupled and uncoupled experiments do not resolve the problem. Then the conclusion is that nudging might not be appropriate. Or there is no effect of the QBO. The question is still open, and future directions to resolve this problem should be discussed.

Chapter 9: Conclusions

Pages 211-217: Overall, this work started by analysing SAMS and NAMS and links to ENSO QBO in climate models, then developed the wavelet transform methodology and applied it for the midsummer drought of southern Mexico and Central America. Then it analyses the influence of the QBO on the tropical troposphere. Our overall assessment is that when the work was more focused, such as in Chapters 5 and 6, the quality of the work/results is better. The QBO work and in particular the nudging seemed rushed and lacked the required attention to detail.

Pages 211-217: The overall main contributions of the thesis need to be discussed, stating the significant advances in our knowledge on the American Monsoon System: variability and teleconnections. Suggestions for the next steps should also be addressed.

Page 214: The grammar is wrong with an incomplete sentence (verb missing).

In conclusion, while the thesis is of sufficient potential merit to qualify for the degree, we recommend that the board should return the thesis to the candidate for major corrections. We confirm that the requested changes will not alter the conclusions of the thesis. The required corrections will not involve the student doing any substantial new research or model simulations to accommodate the changes.