# M65A. Towards understanding the climate change response of the subtropical atmosphere: An alternate framework

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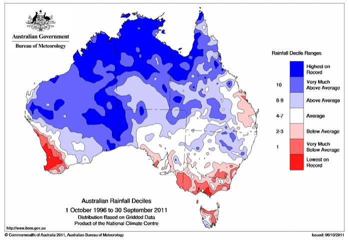
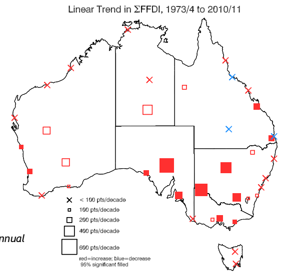
## Background

In the subtropical regions of Australia, recent decades have seen significant anomalies to the weather and climate. For example:

- Widespread, long-term rainfall deficits, with lowest totals on record for a broad region between 1997 and 2009[1]
- Longer, more intense fire seasons, with greater numbers of 'extreme' fire weather days[2]



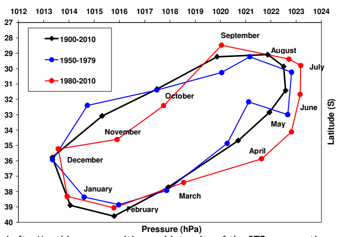


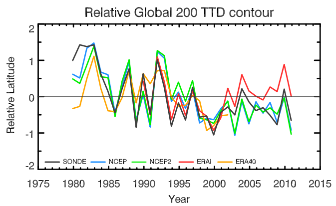
*Left: Australian rainfall deciles, Oct 1996-Sept 2011; Right: Linear trend in annual cumulative forest fire danger index, 1973/74 - 2010/11[3]*

These variations in climate are hypothesized to relate to changes in large-scale circulation features associated with the mean meridional circulation (MMC).

- Changes to the subtropical ridge (STR)[4], possibly linked to…
- Widening of the tropics[5], or expansion of the Hadley Circulation (HC), which is related to…
- Shifts of the SH 'storm track' position, and associated changes to the Southern Annular Mode[6]

Climate model simulations produce similar changes, but they are occurring in reality much more quickly than projected. Further, the exact linkages and causality between these changes remain unclear.[7-10]





*Left: Monthly mean position and intensity of the STR over southern Australia[4]; Right: Relative position of the SH tropical edge in radiosondes and 4 global reanalysis products[11].*

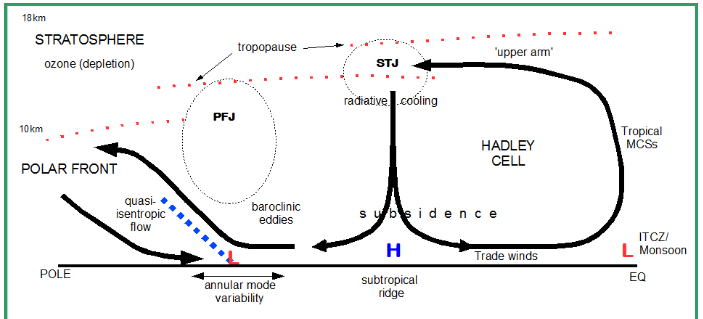
The overall goal of our research is to understand how changes in the MMC affect regional climate in Australian subtropics. The results above (and others) indicate that the MMC is more subtle than is usually assumed in the traditional picture. Here, we focus on fostering a greater understanding of the MMC, the factors influencing it and its variability.

## A Model of the Mean Meridional Circulation

An alternate model of the MMC is proposed, derived from the dry isentropic view of the streamfunction (see yellow box) and a synthesis of the relevant literature. A similarity to the revised MMC model of Pauluis[12] is seen. However, our model provides far more detail of the relevant meteorological features and processes.

Fundamentally, the MMC acts to dispose of the relatively greater amount of energy received in the equatorial regions. This relief is accomplished by a variety of meteorological processes. Water vapor and its phase transitions are of fundamental importance, as are radiative effects. These interact to produce dynamical effects. The cumulative effect of these processes result in the MMC.

The manifestation of the processes which comprise the MMC occur across many spatial scales and in different forms. However, the MMC does not drive these processes. Rather, these individual smaller-scale processes respond to their local forcing and then mutually interact to produce the flow. The interaction is not one-way, as the smaller-scale processes are simultaneously modulated by the broader flow.



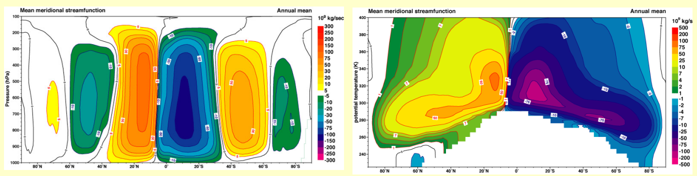

*The idealized mean meridional circulation*

## Isobaric and Isentropic Coordinates

The choice of vertical coordinate dictates the view of the MMC.[13] Traditionally, the MMC is defined using pressure (or geopotential) as the coordinate. Contouring the isobaric mass flux streamfunction gives the familiar 'three-cell' model. In this view, the dominant circulation is the tropical HC; the extratropical (Ferrel and polar) cells are comparatively weak.

Using potential temperature as a coordinate gives a different picture. Contouring the a (dry) isentropic mass flux streamfunction yields a single hemisphere-wide circulation, with two main centres of circulation bridged by a weaker flow. Near the equator, the flow is analogous to that in the isobaric view; strong diabatic heating is indicated. In the extratropics, the flows are very different. The flow in the isentropic view is considerably stronger and little diabatic heating is indicated. The difference in the views is related to differences in the way amplifying baroclinic waves are seen.[14]

Streamfunction contours using equivalent potential temperature (not shown) as the coordinate also suggest a single overturning cell, but with stronger mass flux in the subtropics.[12]



*Isobaric (left) and dry isentropic (right) views of the annual mean mass flux streamfunction. Images from the ERA-40 Atlas[15].*

## Description

In the **tropics**, the overturning HC is dominant. It is driven by the latent heat release from condensation and fusion in tropical mesoscale convective systems (MCSs). Updrafts in MCSs comprise the ascending branch of the HC.[16] Radiative cooling drives the descent. The subtropical jet stream (STJ) marks the end of the upper arm of the circulation. The equatorward trade winds close the loop.

In the **extratropics** the 'polar front' -- a symbiosis of the eddy-driven polar front jet (PFJ) and baroclinic waves -- is dominant and marks the 'storm track'.[17] The position and variability of the polar front is related to the annular mode.[18] On average, the flow in the extratropics is quasi-isentropic. Moist air ascends in the polar front and returns equatorward, its moisture largely removed.[19]

The **subtropics** are the nexus of the hemispheric MMC, the region from 25 and 40° latitude between the HC and the polar front. In general, the region is dominated by subsidence and the STR. In a relative sense, the air here is dry and precipitation is low. The drivers are more encompassing than the descending branch of the HC. Tropical-extratropical interactions are important to variability here, and are in many cases related to Rossby wave-breaking.[20-21] From the subtropics, air can travel either poleward or equatorward. As it moves, its humidity is increased through evaporation which provides a source of moisture for the deep tropics and the extratropical storm track.

## Variability

The MMC is dynamic, changing both spatially and temporally. The diagram represents the net effect of the circulation, rather than the precise flow. At any given time or place, the actual circulation may differ from that depicted in the schematic.

A strong variation is seen on a seasonal basis, as the main features migrate with the time of year. The circulations are generally strongest in the winter hemisphere. In solsticial seasons, the HC straddles the equator, with the rising branch in the summer hemisphere and the main descent in the winter hemisphere. The STR also migrates with season, and its drivers are apparently different in summer and winter.[22-24]

Spatial variability is also present, driven by the heterogeneity of the surface. The geography of continents and mountain ranges result in inter-hemispheric differences in the MMC.[22,25-26] Sea surface temperature gradients drive longitudinal variability, Changes in the SST gradients -- like those associated with ENSO -- result in interannual and decadal variability.

## Summary and Future Directions

As new tools become available to explore the workings of the atmosphere, it is necessary to refine our understanding. Results using global reanalysis products and improved general circulation models suggest that the traditional 'three-cell' model is insufficient to explain the observed circulation. The MMC is not just limited to the tropical regions, but circulations across the entire globe act in concert to relieve the tropics of excess energy. This poster presents an idealized model that summarizes our current understanding of the MMC.

The model, derived from a broad survey of the literature, represents a starting point for future work. It provides a framework for better understanding climate variability as well as the impacts of climate change. However, more effort is needed to elucidate the interactions between the components. The isentropic streamfunction analysis provides a powerful tool that we intend to exploit in the future for this purpose.

While our focus is the Australian subtropics, the model is applicable to other regions. The literature suggests that a global context is needed to understand the changing climate. For example, recent modelling studies hypothesize that stratospheric ozone depletion over the Antarctic is a major climate driver in recent decades, not just locally but across the entire SH.[27,28] With the MMC model as a basis, we can investigate the mechanisms involved, formulate tests of the hypothesis and better understand the regional impacts of this climate driver.