ATMOSPHERIC RADIATIVE AND MECHANICAL ENERGY BUDGETS FOR MARS, FROM GCMs AND REANALYSES

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1. Introduction

The weather and climate on Earth are generally determined by the amount and distribution of incoming solar radiation. This must be balanced in equilibrium by the emission of thermal radiation from the surface and atmosphere, but the precise routes by which incoming energy is transferred from the surface and within the atmosphere and back out to space are important features that characterize the current climate.

This has been analysed in the past by several groups over the years, based on combinations of numerical model simulations and direct observations of the Earth's climate system. The results are often presented in schematic form [1], as graphically illustrated below in Figure 1, to show the main routes for the transfer of energy into, out of and within the climate system. Although relatively simple in concept, such diagrams convey a great deal of information about the climate system in a compact form.

Such an approach has not so far been adopted in any systematic way for other planets of the Solar System, including Mars, although quite detailed climate models are now available, constrained by many new observations and measurements. This approach is therefore timely and potentially useful for comparing the climates of different planets.

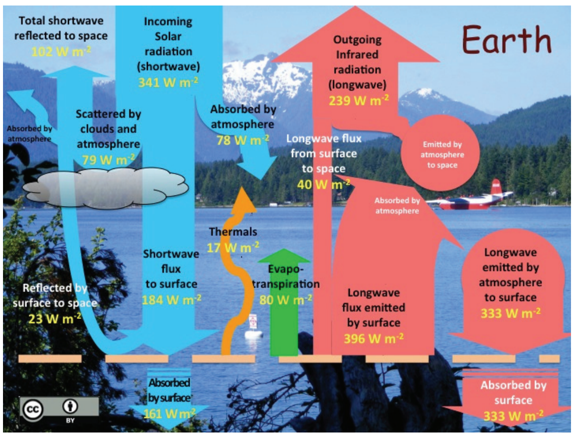

Figure 1: Schematic global energy budget for the Earth, using data obtained by Trenberth et al. [1].

Given the distribution of incoming and outgoing radiative energy, it is also of interest to determine the transformation of energy within the climate system from thermal into mechanical forms. Differential radiative forcing energises the reservoir of potential energy in the atmosphere, and dynamical processes then convert that energy into the kinetic energy of the circulation. It has been conventional for many years in the terrestrial literature to present such energy conversion pathways via the Lorenz box diagram [2], which partitions potential and kinetic energy into zonally symmetric and asymmetric ('eddy') components and computes time- and space-averaged conversion rates between each energy reservoir.

More recently, however, much work has been done to elucidate the transfer of energy between different scales within the atmosphere, with reference to kinetic energy spectra as a function of horizontal wavenumber [3]. In this presentation, we will present some preliminary results from an ongoing analysis of energy exchanges within the Martian atmosphere, utilising combinations of comprehensive global circulation model simulations and reanalyses of atmospheric measurements.

2. Data sources

In this study we focus on Mars in comparison with the Earth. For Mars we analyse data obtained (a) from the ESA Mars Climate Database [4] and (b) simulations of the atmospheric circulation using the UK version of the LMD-UK Mars GCM [5], covering the complete annual and diurnal cycles of the Martian year, (c) supplemented by data from the UK Mars reanalysis dataset MACDA [6], to compute the main routes of energy flow. Radiative exchanges are further checked using 1D computations of radiative transfer based on line-by-line computations from the NEMESIS code [7].

3. Radiative energy budgets

The results will be presented for Mars in diagrammatic form, for direct comparison with the Trenberth et al. analysis for the Earth. We compare and contrast typical clear atmospheric conditions with those prevailing during major, planet-encircling dust storms. The basic features are presented below for comparison.

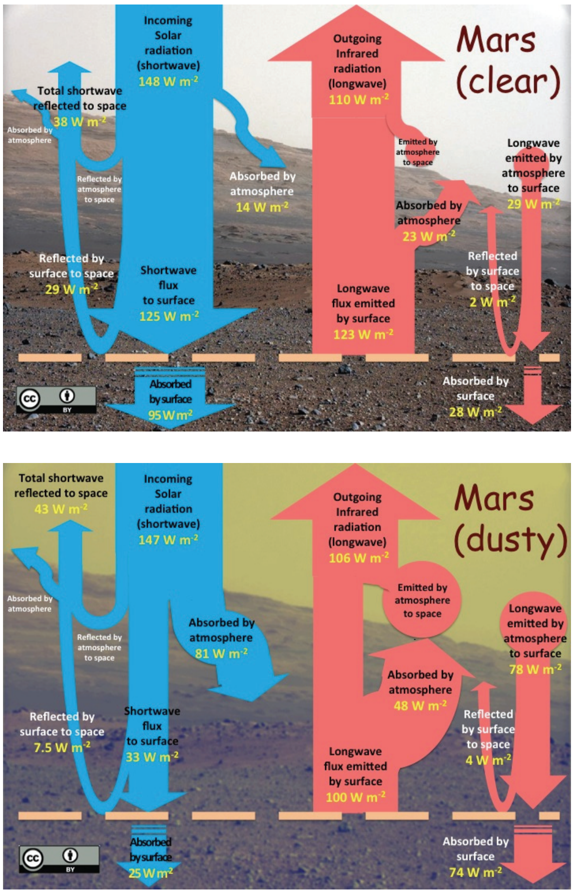

Figure 2: Schematic global radiative energy budgets for Mars, using data from the Mars Climate Database [4] and computations from NEMESIS [7]. Upper frame shows exchanges prevailing under normal (low dust optical depth; $\tau = 0.3$) conditions, while the lower frame shows exchanges when the dust optical depth is up to $\tau = 5$.

Major differences are seen between the low and high dust cases. Under clear conditions, relatively little solar irradiance is absorbed by the atmosphere but most reaches the surface, which then re-radiates around 80% of the emitted energy straight back to space. Much less solar irradiance reaches the surface during major dust storms, however, with around half of the thermal radiation from the ground being absorbed and scattered by the atmospheric dust layer.

A number of uncertainties remain concerning several aspects of the resulting energy budgets, and will be discussed in the presentation.

4. Mechanical energy conversions

Radiative forcing primarily supplies energy to the zonally-symmetric potential energy reservoir (although, unlike on Earth, diurnal variations in radiative forcing on Mars may also provide significant direct input to the tidal eddy field), ultimately leading to conversion into zonal and eddy kinetic energy. This can be presented schematically using the Lorenz decomposition [2], and will be computed for Mars using combinations of GCM simulations and MACDA reanalyses. Significant issues include the respective roles of baroclinic and barotropic instability, which are characterized by the magnitude and sign of the CE and CK conversion rates in the Lorenz energy budget.

As an illustration, Fig. 3 shows some results from idealized Earth-like GCM simulations [8] at different values of thermal Rossby number, Θ, where

$$\Theta = \frac{U}{\Omega L} \approx \frac{g\Delta\theta_y H}{\Omega^2 a^2 \theta_0} = \frac{R\Delta\theta_y}{\Omega^2 a^2},$$

$\Delta\theta_y$ is the equator-pole (potential) temperature contrast, H is the pressure scale height, Ω the planetary rotation rate, a the planetary radius, g the acceleration due to gravity, R the specific gas constant and θ_0 a reference potential temperature.

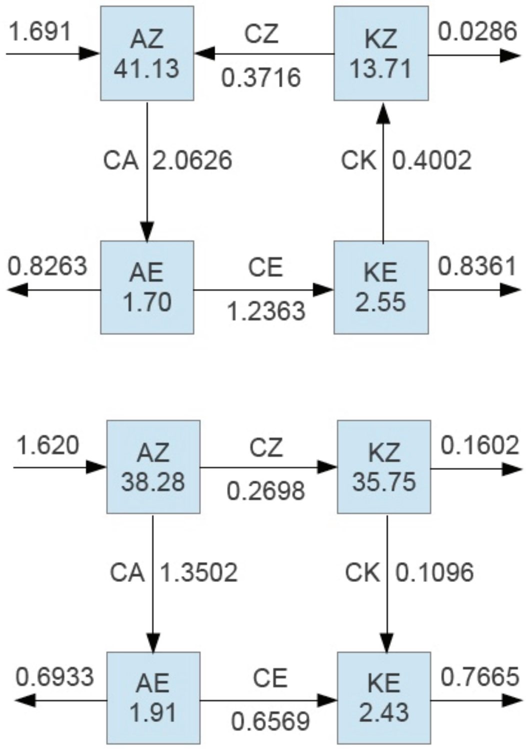

Figure 3: Quasigeostrophic Lorenz energy budget diagrams computed from simulations using a simplified Earth-like GCM [8] for (upper panel) $\Theta = 0.32$ and (lower panel) $\Theta = 1.3$. Conversion rates are in

W m^{-2} and energies in each reservoir are in units of 10^5 J m^{-2}.

For Mars, Θ takes a value between around 0.14 and 0.35, depending on season and dust conditions, compared with around Θ ~ 0.08 for Earth. Based on simplified GCM simulations[8], Mars may lie in a position in parameter space close to where CE (and CZ) are expected to change sign (see Fig. 3 above) in association with a transition between a barotropically dominated atmosphere and one dominated by baroclinic processes. This has important implications for how Mars sustains its winter mid-latitude jet streams. Preliminary analyses from Mars GCM simulations will be presented and discussed.

Finally, we plan also to derive kinetic energy spectra for the Martian atmosphere from high resolution Mars GCM simulations as the first steps in an analysis of global exchanges of energy between planetary, synoptic and smaller scales of motion within the Martian climate system.

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