Simulation and Understanding

(Do We Understand Model Outcomes)

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https://www.uu.nl/en/news/do-we-understand-the-model-outcomes

At IMAU and at KNMI climate models, such as the Community Earth System Model, "CESM" (https://www2.cesm.ucar.edu/) and "EC-Earth" (Hazeleger et al., 2010) are used to study past climates, or to make projections of future climate. These very complex and valuable models, which include widely different physical, chemical and biological processes, such as hydrodynamics, biochemical cycles, interactive vegetation and ice sheets, are able to reproduce the present climate reasonably well. Therefore, we hope and assume that studying past and future climate with these models will be a fruitful endeavour.

But, do we understand the model outcomes? Established scientists in the field have warned that this may not be the case. In a recent commentary in *Nature Climate Change*, Christian Jacob states that, "although there is good evidence that in a broad sense climate models are improving, there is also very strong evidence that some long-standing model-errors elude improvement". The continuously increasing complexity of climate models has made it difficult to design model experiments and to the devise perceptive methods for diagnosing and interpreting the results.

A need has been created to go back to the "underpinning basics". In an article, entitled "*The gap between simulation and understanding*", published in 2005, Isaac Held suggested that the correct approach to the problem of modelling climate might be to create a hierarchy of models of increasing complexity. In fact, in the early pioneering days of climate model development in the 1960's, Joseph Smagorinsky, who was the leading man in this effort and predecessor of Isaac Held at GFDL in Princeton, stated that "we must guard against equating the massive outputs of high-speed computers with understanding", and "finally, as we isolate the essential processes responsible for the characteristics of the general circulation, ultimately one would expect to be able to dispense with the unnecessary and irrelevant detail – thereby reversing the trend toward more complex models and larger computers" (Smagorinsky, 1964).

At IMAU a model of the general circulation of the atmosphere (a "GCM") has been developed, which might help in bridging the gap between simulation and understanding. This model fits in just above the basis of the aforementioned model hierarchy. It explicitly calculates the time evolution of the longitudinal mean distribution of wind and temperature in the atmosphere, under influence of absorption and emission of radiation, water cycle and stratospheric "planetary wave drag". The model contains an explicit, but very much simplified, radiation scheme. The water cycle and planetary wave drag, on the other hand, are not modelled explicitly, but are "parametrised", i.e. these processes are expressed in terms of explicitly resolved quantities, such as the net radiation at the surface of the earth, which determines evaporation of surface water.

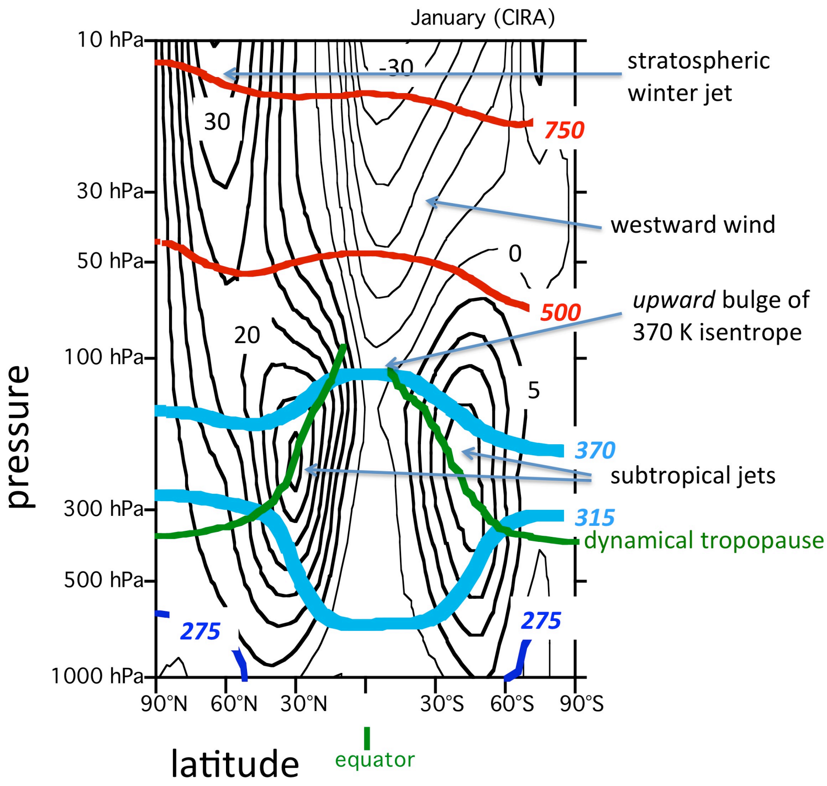

Figure 1. Longitudinal mean of the eastward wind component (black contours; labels in m s^{-1}), of the potential temperature (blue contour: "Underworld"; cyan contour: Middleworld; red contour: "Overworld"; labeled in degrees Kelvin) and of the dynamical tropopause (green contour) in January, according to the COSPAR Reference Atmosphere (CIRA). The dynamical tropopause is not defined in the tropics. In the "Middleworld", between approximately 310 K and 380 K, the tropical troposphere stands in adiabatic contact with the extratropical lower stratosphere.

Although a parametrisation scheme is not as universal as Newton's second law, devising parametrisations is in fact a valuable exercise, because it tests and expands the physical insight of the scientist-modeller and so helps to bridge the gap between simulation and understanding. The parametrisations of the water cycle and of planetary wave drag play a crucial role in producing a realistic simulation of the atmospheric jets. This tells us that the common practice of devising parametrisation schemes to represent unresolved processes is nothing to be frowned upon, as is sometimes done by "fundamentalist scientists".

The figures show the January average longitudinal mean of the eastward component of the windspeed, of potential temperature and of the dynamical tropopause, according to observations (figure 1), and in two different simulations of the two-dimensional model (figures 2 and 3).

We note the following five interesting features of the observed longitudinal mean structure of the atmosphere in January (figure 1). (1) The upper tropospheric subtropical eastward jets in both hemispheres, (2) the stratospheric polar winter eastward jet, (3) the westward winds in the summer stratosphere, (4) the large subtropical meridional slope of the dynamical tropopause and (5) the upward bulge of the 370 K isentrope in the tropics. The fifth feature is a manifestation of the cold tropical tropopause at about 100 hPa.

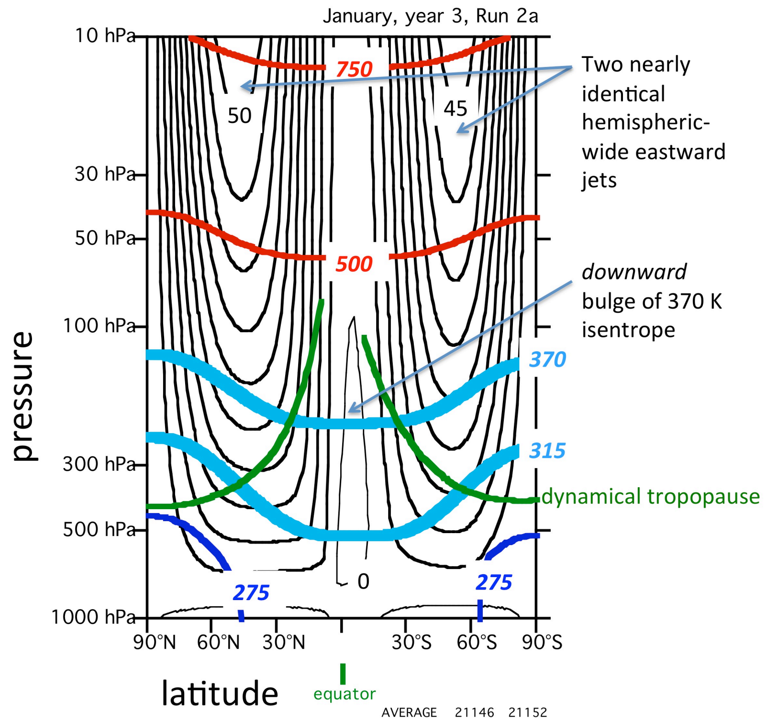

Figure 2. Longitudinal mean of the eastward wind component (black contours; labels in m s-1), of the potential temperature (blue contour: "Underworld"; cyan contour: Middleworld; red contour: "Overworld"; labeled in degrees Kelvin) and of the dynamical tropopause (green contour) in January of year 3 of a simulation of the general circulation of an atmosphere, which is devoid of water and devoid of planetary wave drag.

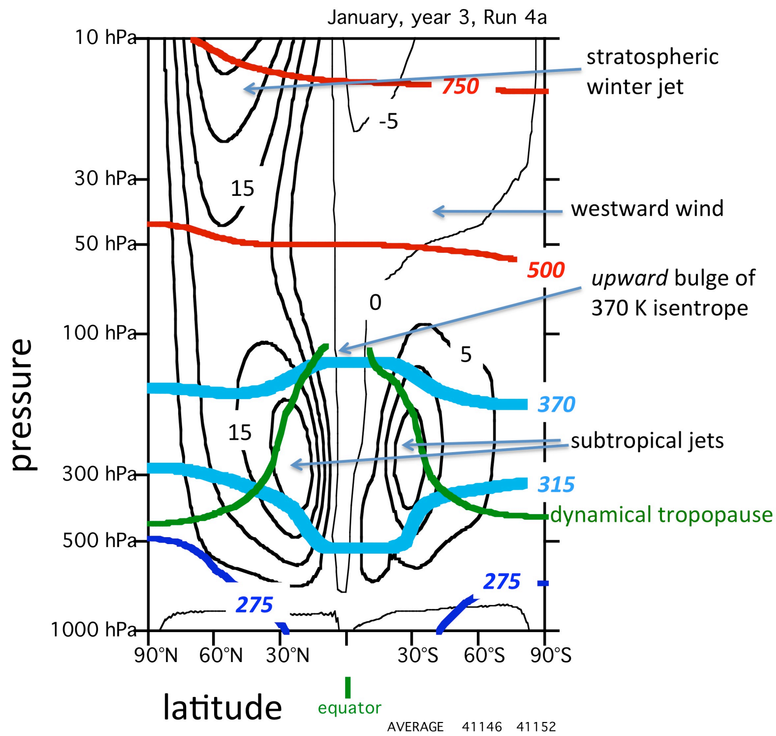

Figure 3. Longitudinal mean of the eastward wind component (black contours; labels in m s-1), of the potential temperature (blue contour: "Underworld"; cyan contour: Middleworld; red contour: "Overworld"; labeled in degrees Kelvin) and of the dynamical tropopause (green contour) in January of year 3 of a simulation of the general circulation of an atmosphere under influence of planetary wave drag and a water cycle.

None of these features are reproduced in a simulation in which the atmosphere is assumed to be devoid of both a water cycle and of planetary wave drag (figure 2). On the other hand, if the water cycle and planetary wave drag are taken into account in a new simulation, in which all other factors are identical, all the features of the geneal circulation, listed above, are qualitatively reproduced, as can be seen figure 3. Although there are quantative differences between the simulated wind and the observed wind, the simulations clearly reveal the crucial role, in determining the position and seasonal cycle of the jets, of planetary wave drag in the middle-latitude lower stratosphere.

This study confirms Smagorinsky's (1964) conjecture that we can dispense with many unnecessary and irelevant details in a GCM and still capture the principal characteristics of the time evolution of the thermal and dynamical structure of the atmosphere. Animations of the simulations can be viewed at http://www.staff.science.uu.nl/~delde102/GeneralCirculation.htm. The results of this study have been published in the well-known Swedish journal, Tellus (series A) (van Delden, 2014).

The results of this model study lead to the following research question. What is "planetary wave drag"? There are reasons to believe that planetary waves themselves do not *always* directly act to retard the zonal mean zonal flow.

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