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Understanding the stratospheric circulation changes in the past decades using a Chemistry-Climate Model (*WACCM*)

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ACCROSS: an overview

(Atmospheric Composition and Circulation investigated with meteorological Reanalyses, Observational datasets and models for the Study of the Stratosphere and its changes)

Aim of the project:

Improve our understanding of the circulation changes in the stratosphere during the past three decades through the use of observation and model simulation time series of selected long-lived tracers (HF, N_2O, CH_4).

Goals of the research:

- Characterize the long-term trends and impact of the circulation changes on the selected tracers using ground based data and satellite data.
- Evaluate and compare the representation of those trends and circulation changes in a number of leading meteorological reanalyses. In this comparison the *BASCOE* CTM will be used as a transfer tool to model the changes of the tracers stratospheric abundances.
- Evaluate the ability of a state of the art climate model, *WACCM*, to simulate the observed changes of the stratospheric circulation. How well would such a model capture the observed changes in the stratospheric circulation?

Failure: provides new areas to improve knowledge about global change.

Success: identification of the responsible processes or feedbacks thanks to sensitivity tests.

ACCROSS: state of the art

Atmospheric circulation changes

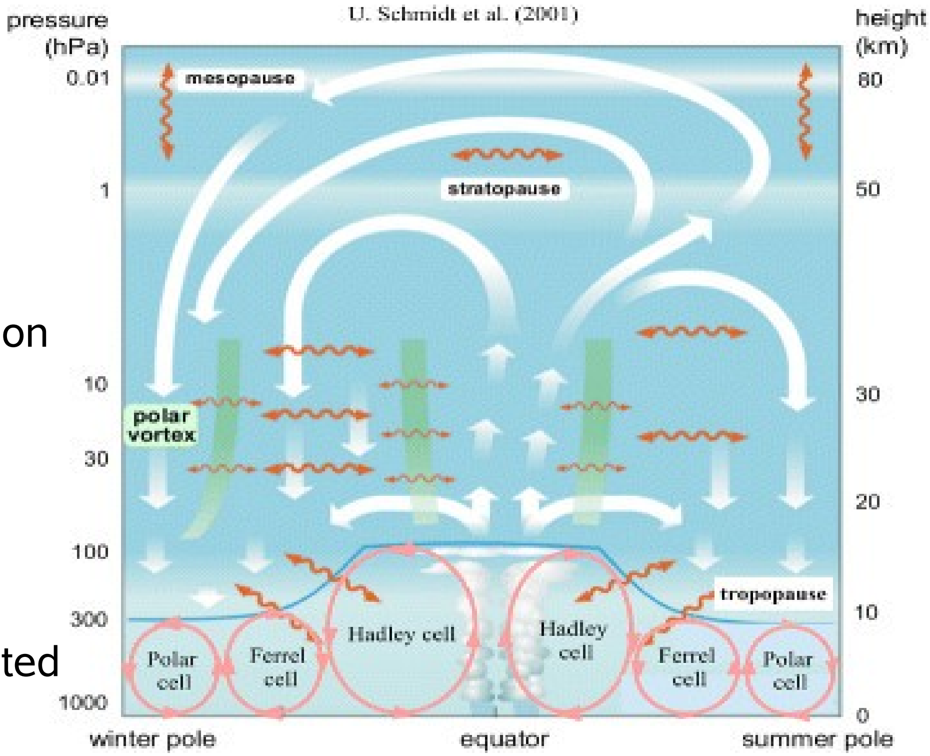
One of the major sources of uncertainty in climate projections, ---> major area of scientific research, modeling, etc.

Atmospheric composition <---> Atmospheric circulation

climate feedbacks (e.g. *ghg*), ozone recovery, ...

Major subject of research:

Brewer-Dobson Circulation (*BDC*) (generated by breaking of tropospheric waves) transports chemical tracers from the troposphere to the stratosphere ---> projected to change (slowdown or speed-up ??)



Model simulations ---> increasing sea and surface temperatures (driven by *ghg*) ---> amplification of the tropical upward mass flux (i.e. amplified wave activity) ---> speed-up of the *BDC* ---> drop of the mean age of air (younger air).

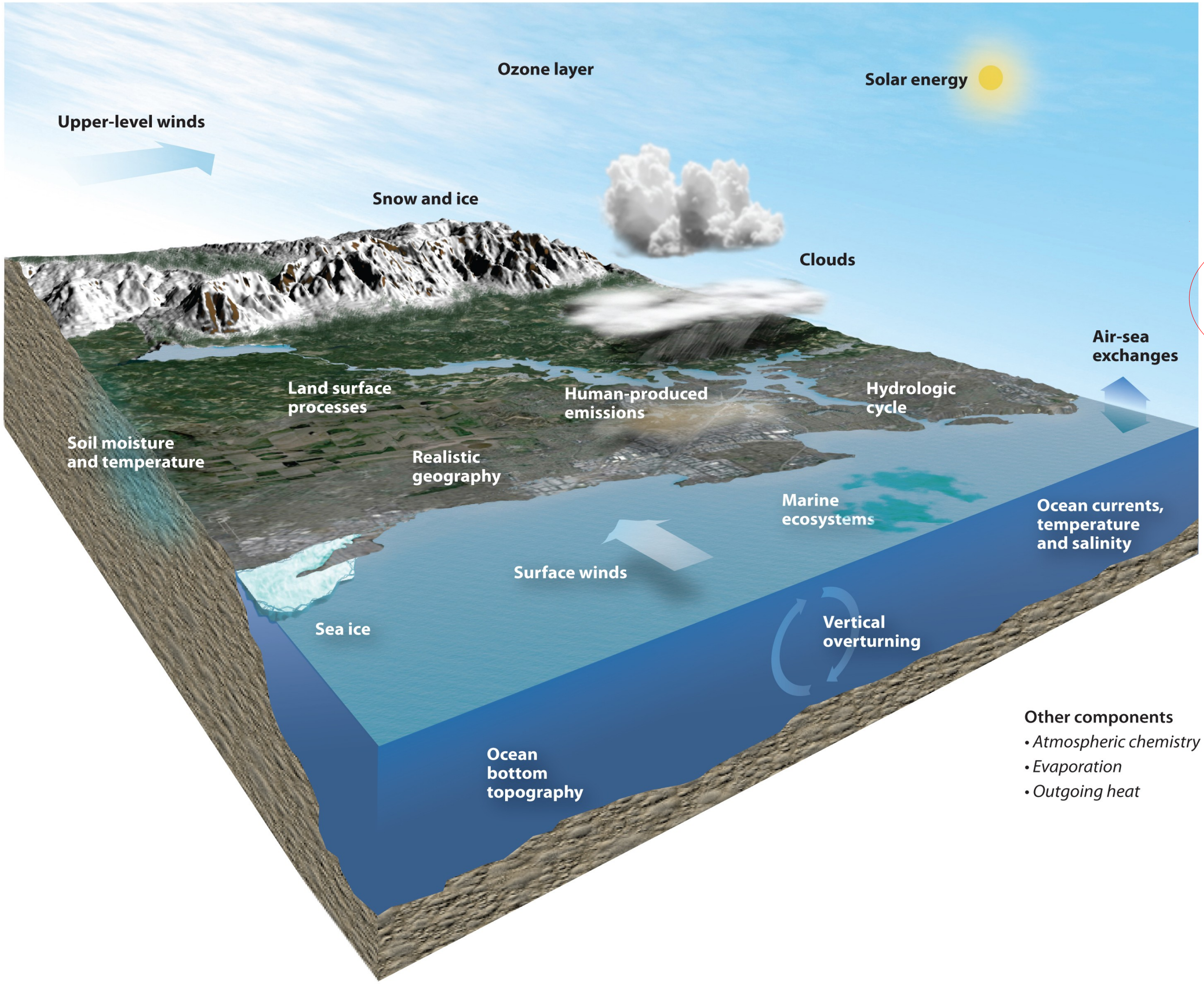
Balloon time series and MIPAS observations ---> slowdown of the *BDC* ---> increase of the mean age of air in the NH (e.g. *HCl* results from *Mahieu et al., 2014*)

Change of the *BDC* ---> affects stratospheric tracers (e.g. HF, CH_4, H_2O, O_3) ---> impact on their abundance and in turn on surface climate, surface UV (through H_2O and/or CH_4 redistribution), or O_3 abundance and the species involved in its depletion ---> *feedbacks processes*.

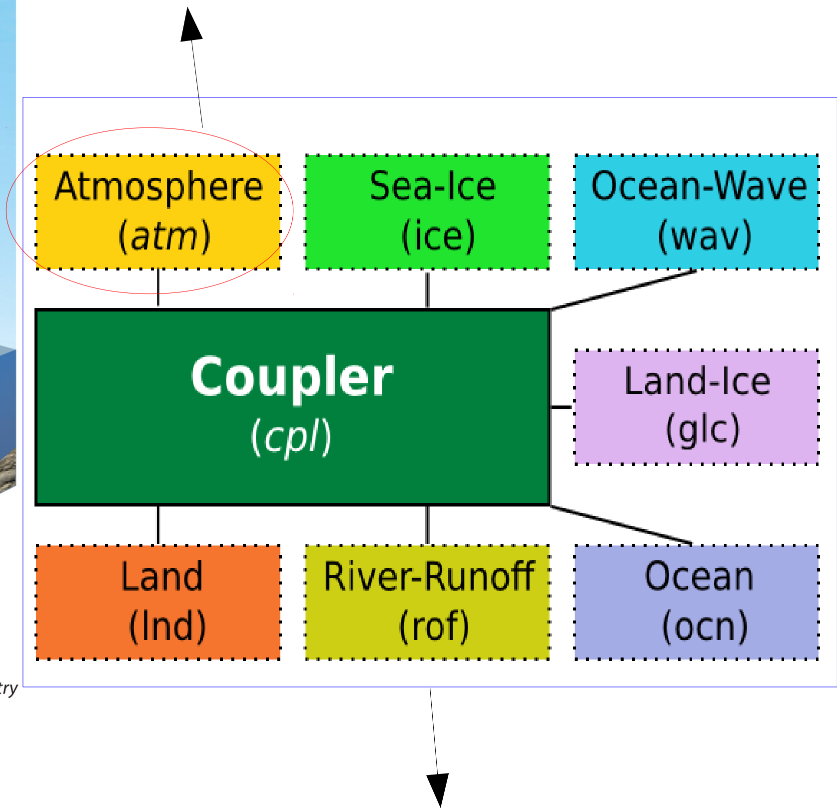
WACCM (Whole Atmosphere Community Climate Model)

Specific configuration of the atmospheric model (***CAM***) of ***CESM*** (Community Earth System Model)

Developed at National Center for Atmospheric Research (***NCAR***) in Boulder, Colorado



CAM: Community Atmosphere Model

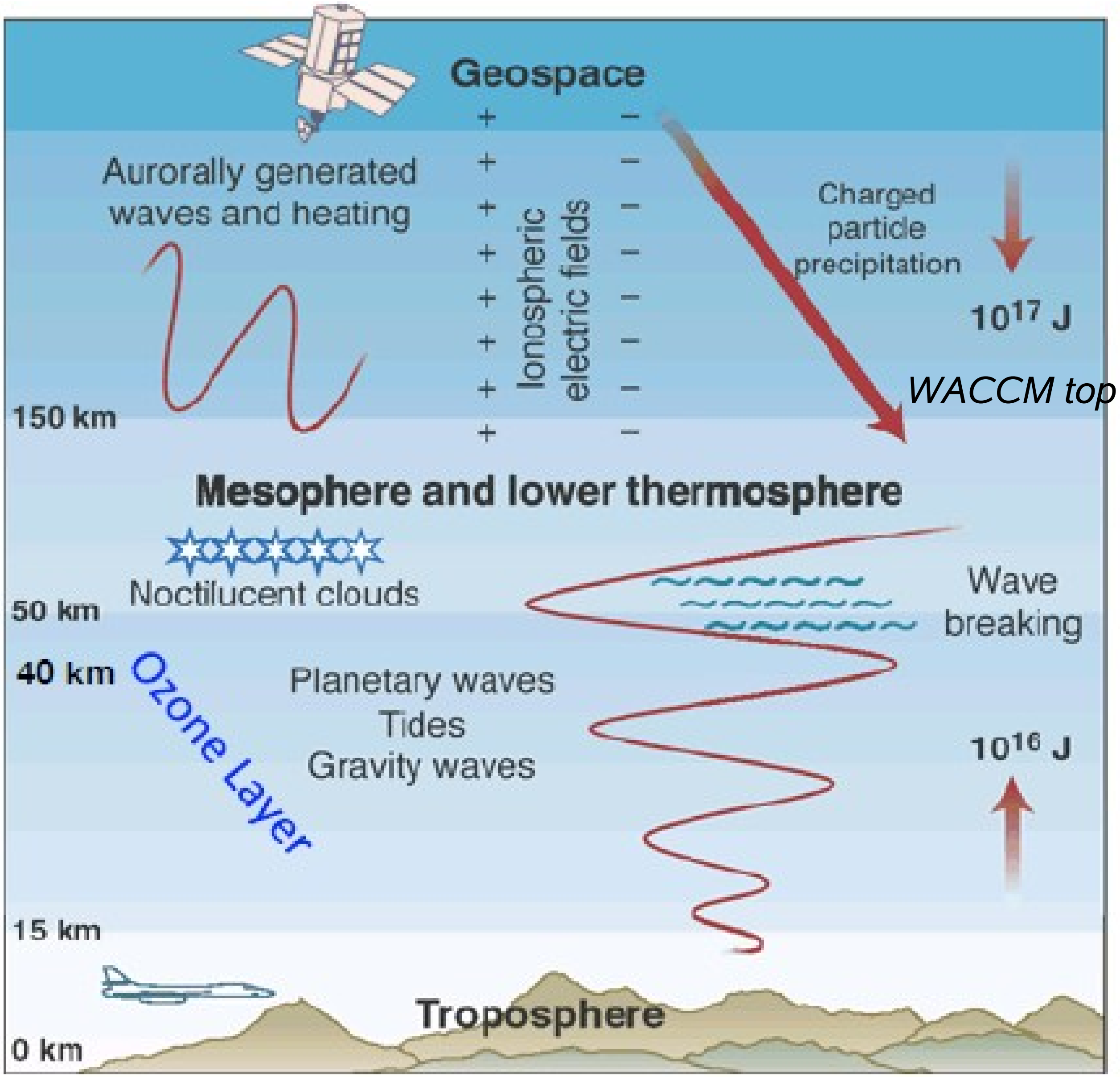

Atmosphere (*atm*)
Sea-Ice (ice)
Ocean-Wave (wav)
Coupler (*cpl*)
Land-Ice (glc)
Land (lnd)
River-Runoff (rof)
Ocean (ocn)

CESM

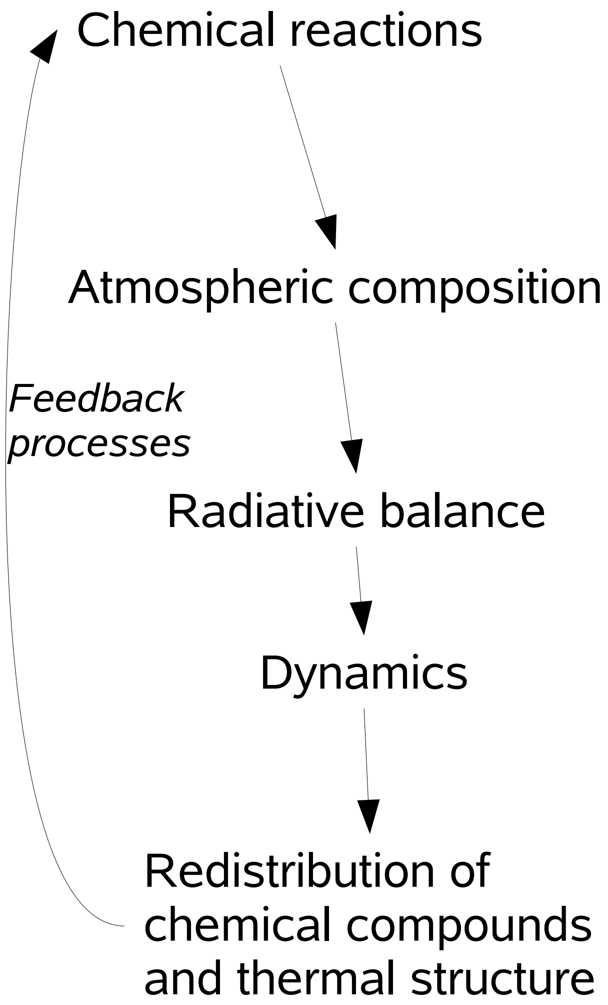
WACCM (Whole Atmosphere Community Climate Model)

CCM: Chemistry-Climate Model.

WACCM: the high-top model



Three-dimensional model of atmospheric circulation coupled with a chemistry module.



Chemical reactions

Atmospheric composition

Feedback processes

Radiative balance

Dynamics

Redistribution of chemical compounds and thermal structure

WACCM (Whole Atmosphere Community Climate Model)

Why WACCM?

- Extends from surface to *5.1x10^{-6} hPa* (*~150 km*), with 66 vertical levels.
- Detailed chemistry model (MOZART-3) for the middle atmosphere, characterized by:
  - Heterogeneous chemistry on PSCs and sulfate aerosols.
  - Heating due to chemistry reactions.
  - Possibility of extended tropospheric chemistry.
- Modules of ion chemistry in the mesosphere/lower-thermosphere (MLT), ion drag, auroral processes, and solar photons events.
- EUV (Extreme UV) and non-LTE (non-Local Thermodynamic Equilibrium) longwave radiation parameterisations.
- QBO imposed: based on cyclic, fixed-period, or observed winds.
- Volcanic aerosol heating calculated explicitly.
- Parameterisation of gravity wave drag from vertically propagating GWs driven by orography, fronts and convection.
- Molecular diffusion and constituent separation.
- Possible thermosphere extension (WACCMX) to ~500 km.

WACCM (Whole Atmosphere Community Climate Model)

Default Chemistry scheme brief description

Species included: O_x, NO_x, HO_x, ClO_x, BrO_x, CH_4+ its degradation products (e.g. CH_3O_2).

Includes also some *CFCs* and *HFC22*

59 total species, one invariant (N_2), *127* neutral gas-phase reactions,

48 neutral photolytic reactions (*74* photolysis reactions in total) and *17* heterogeneous reactions (rates from JPL06).

Non-neutral species:

Ion chemistry: *6* constituents (O^+, O_2^+, N^+, N_2^+, NO^+ and electrons) in the ionosphere.

17 of those species are solved using implicit numerical scheme (backward Euler).
42 are solved using explicit numerical scheme (forward Euler).

Main Issues

HF is missing!!!

Reactions rates outdated

Default chemistry scheme needs to be *updated*

Current status

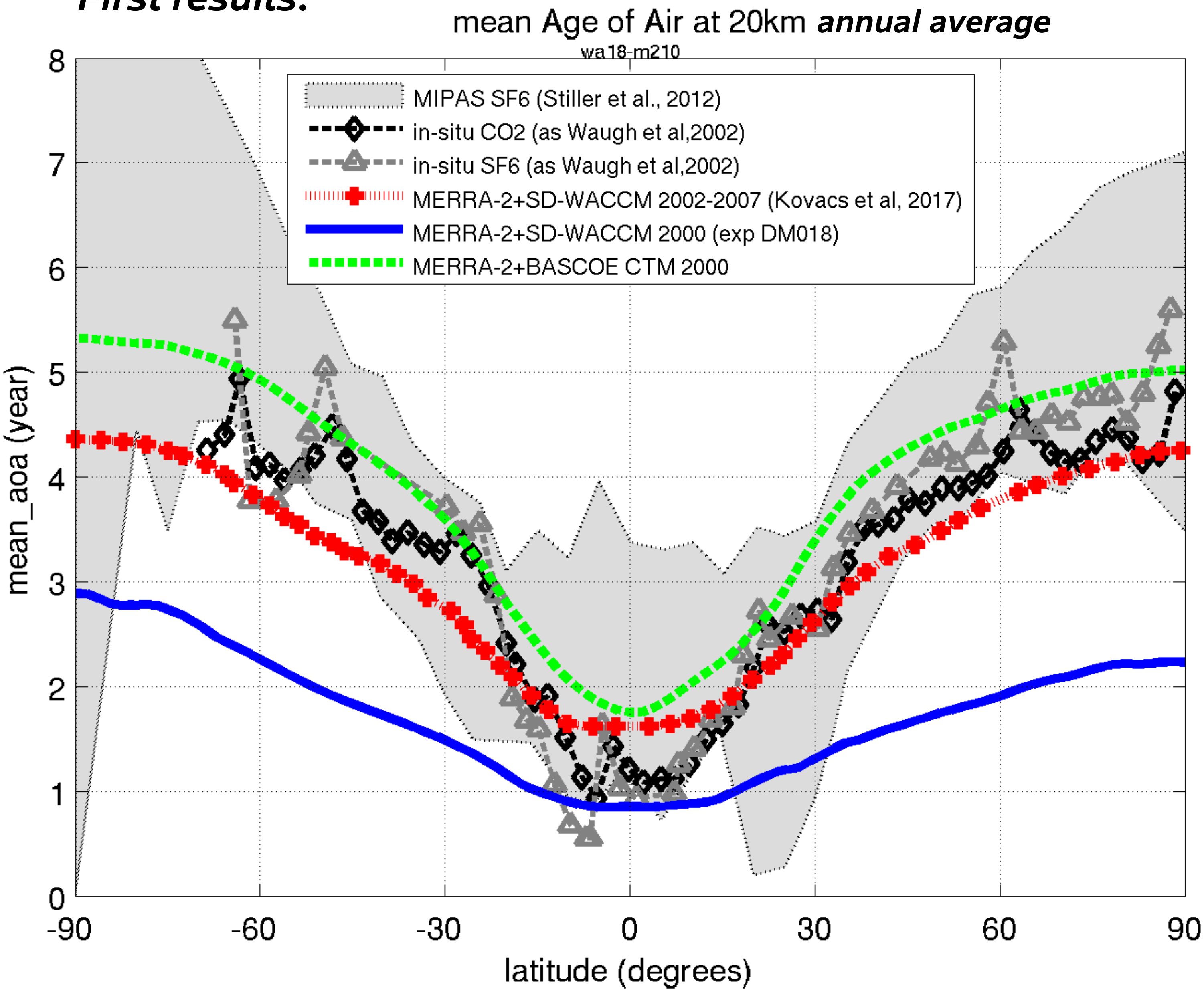
- Download, install and port the model to our machine.
- Perform simple runs for testing.
- Explore the representation of the photochemistry.
- ***Long run 1*** (20 years) with specified dynamics (perpetual year 2000) and simplified chemistry in order to see the transport of a theoretical tracer (exp. number: 018).
- ***Update chemistry scheme*** (add *HF* and additional *CFCs, HCFs* and halogens) and perform test runs.
- ***Long run 2*** (30 years) with specified dynamics (perpetual year 2000) (low resolution), full and updated chemistry, state-of-the-art time-varying *lbc* (lower boundary conditions), *ic* (initial conditions) from a specified reanalysis. (currently running) (exp. number: 029).

Long run 1
(exp. number: 018)

- Specified dynamics, i.e. offline dynamical fields (U, V, T,...), from the MERRA-2 reanalysis, using perpetual year 2000.
- Simplified chemistry: 5 species (simplified reactions), no photolysis reactions, prescribed ozone.
- Chemistry and dynamics both not relevant: focus on the transport of a theoretical tracer (study of age of air). How does this WACCM configuration compare with BASCOE CTM?
- Result to be compared with a free dynamics experiment using the same configuration (exp. number: 030).
- Result for a possible paper.

Long run 1
(exp. number: 018)

First results:



Air much *younger* over all the latitudes ---> transport much *faster* wrt BASCOE CTM and ref. WACCM.

MERRA-2 reanalysis are ***not*** the same between green (BASCOE), red (ref. WACCM) and blue (exp 018).

Possible causes:

1) Differences in the reanalysis (preprocessing).

2) Problems in the WACCM advection scheme.

Need to be investigated

Updating chemistry: account for *HF* production in the stratosphere

- *HF* added as a product of existing reactions (e.g. *CFC11+O1D* reactions).
- Add *HF* producing species (*CFC114*, *CFC115*, *HFC23*, *HFC125*, *HFC134a*, *HFC143a*, *HCFC141b*, *HCFC142b*, *HA2402, HA1211, HA1301*).
- Adjust reaction rates for CH_4 and N_2O loss.
- Reaction rates for the new reactions are taken from the latest JPL recommendation (JPL2015).

Long run 2

(exp. number: 029)

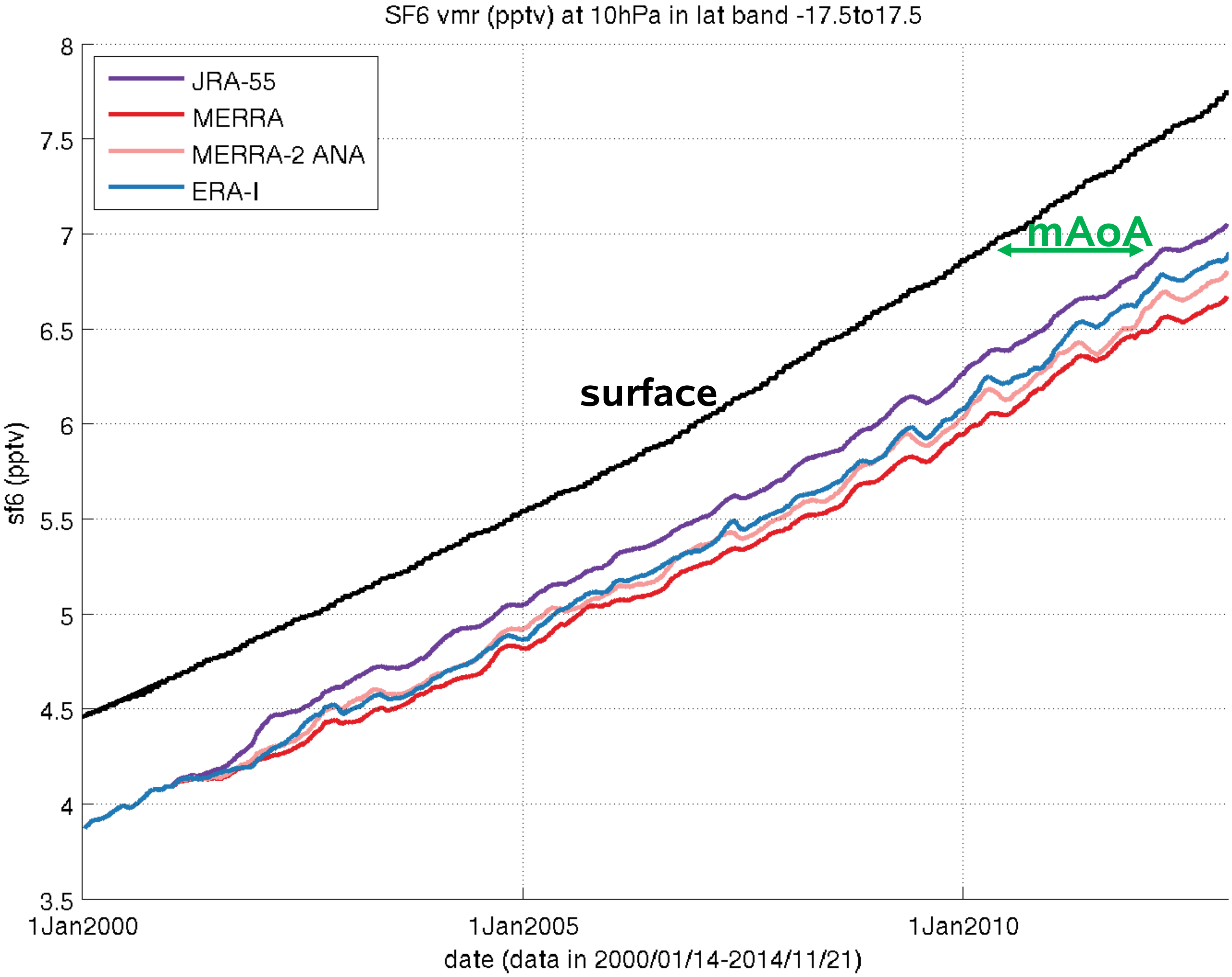
- Specified dynamics, from *MERRA-2* reanalysis, using fixed year 2000.
- Low resolution (*4x5 lat,lon*).
- Updated chemistry.
- State-of-the-art time-varying *lbc* from *Meinshausen et al., 2016*.
- *ic* from *BRAM* (BASCOE Reanalysis of Aura MLS), a dataset providing an estimation of stratospheric chemical state based on data assimilation of Aura MLS (NASA satellite).
- Aim: evaluate the results and maybe use those results as *lbc* for BASCOE CTM.

Future perspectives:

- For the moment there is “consistency” between WACCM and BASCOE CTM:
    - Use of a chemistry scheme as much similar as possible.
    - Use of perpetual dynamical fields from reanalysis (*MERRA-2*).
- WACCM will move to its *fully-coupled* configuration (*free dynamics* + *detailed updated chemistry*):
    - Investigate possible differences with respect to the reanalysis and the CTM, and perform sensitivity tests.

Backup slides

Model: For theoretical tracers (AOA1 in WACCM) with linear increase at the surface, the time-lag at each gridpoint **<u>is</u>** the mean age of air (mAoA).



Backup slides

WACCM output:

vmr(*ntime,nlev,nlat,nlon*) (AOA1) ---> *kg/kg*, *mol/mol*

time ---> *days*

Post-processing: $y-y_0=m(x-x_0) \xrightarrow{\text{Solve for } x} x=x_0+(y-y_0)/m$

x= time when ref value (y_0) was the same as the current gridpoint.

m,x_0,y, y_0 are known

x_0= first timestep.

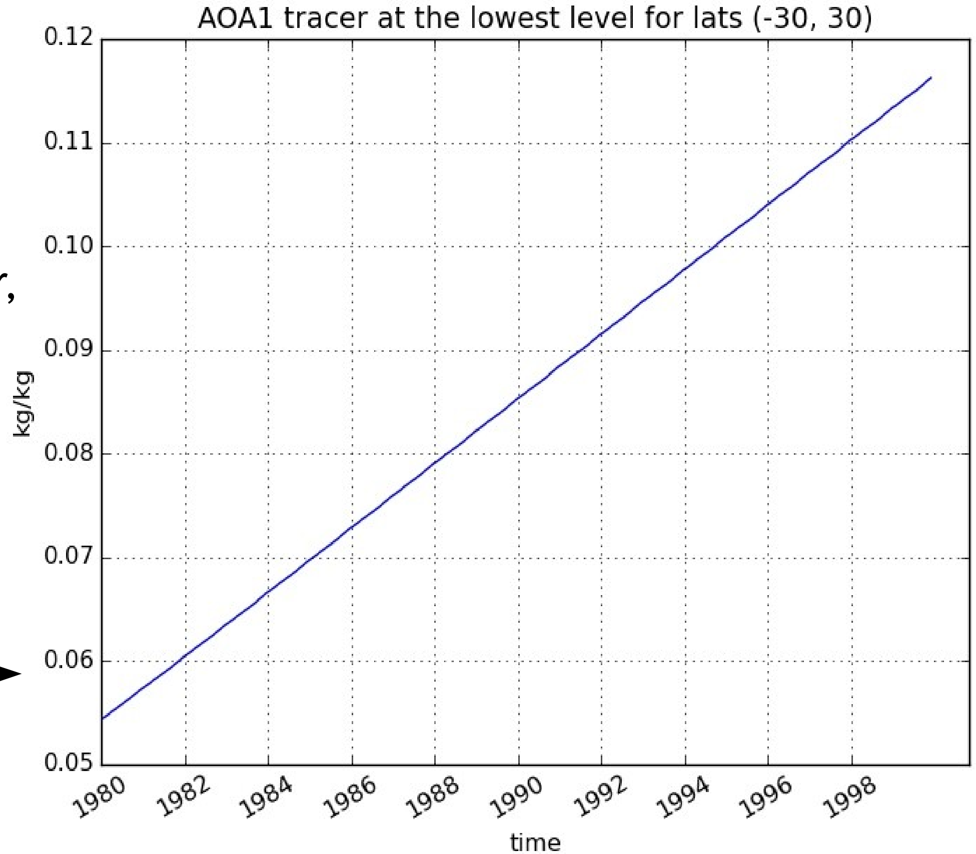
m= slope of the line

y= vmr.

y_0= (ref value) vmr at first timestep, at the equator, and the maximum on the vertical (should be at the surface, but for WACCM it is at ~260 *hPa*).

mAoA=(time-x)/365

That is possible because AOA1 increases linearly at surface.



Backup slides

Why CH4, HF and N2O? ===> long-lived and high quality remote sensing observations from the ground and space.