Middle Atmosphere Dynamics and Dynamita Models for Chemical Measurements Interpretation

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Atmospheric Structure and Circulation
Atmospheric Waves
High resolution modeling of constituent transport

The Middle Atmosphere
Middle atmosphere = stratosphere + mesosphere, 12 to 90 km

Net Radiation vs Latitude

Tropospheric Circulation

Observed zonal averaged temperature and winds

Observed zonal averaged temperature and winds

Heat flux
Solar energy
Absorbed solar energy
Net radiation deficit

Zonal Wind
Temperature
Observed zonal averaged temperature and winds

Observed temperature and radiative equilibrium

Brasseur and Solomon (2005)
based on Fleming et al., 1998

Brasseur and Yoden (2004)

Adiabatic heating/cooling in the atmosphere

Net adiabatic heating rate (K/day)

Brasseur and Solomon, 2005; from London, 1980

Residual circulation

Zonal wind: the geostrophic approximation

Diabatic heating (cooling) \(\rightarrow\) vertical ascent (descent) of air
Continuity equation \(\rightarrow\) meridional wind

Coriolis force equilibrates
Pressure gradient force

\[ \text{Coriolis force} = 2 \Omega \sin(\text{latitude}) \]

\( \Omega \) Earth rotation rate

Wind blows around depression
- anticlockwise in Northern Hemisphere
- clockwise in Southern Hemisphere
Antarctic polar vortex evolution 1996

UKMO analysis

Zonal wind

Brasseur and Solomon, 2005, based on Fleming, 1988

Middle atmosphere radiative balance and general circulation

Atmospheric waves in the atmosphere

Transport energy, momentum flux and atmospheric constituents

Different kinds of waves:
- planetary waves: global scale
- gravity waves: local scale
- atmospheric tides: global scale, diurnal period, solar heating of stratospheric ozone and tropospheric water vapour

Planetary Rossby waves

Meridional gradient of Coriolis force
Hemispheric extension
Upward propagation possible only if zonal wind > 0 (winter conditions in the stratosphere)
Interaction with zonal wind: stratospheric warming

Temperature maps at 22 km

Winter 01/02/2010
Non zonal structure
Planetary waves

Summer 07/01/2010
Zonal structure
Rayleigh lidar observations

Observatoire de Haute-Provence

Backscatter lidar principle

Temperature measurements using Rayleigh Lidar

- Required pure molecular scattering
- Density and pressure are relative measurements
- Temperature is absolute

Temperature lidar profile
At Maïdo Observatory, Reunion Island

OHP temperature evolution in winter 1996/97

Temperature variability

Middle latitude (44° N)

Tropics 21° N
Guillaume Angot

Introduction: état de l’art et motivations

Sudden Stratospheric Warmings

Temperature

SSU

Lidar

OHP

Zonal wind

Planetary waves

Hauchecorne (1983)

Displacement

Split

Undisturbed

+ + +

- - -

Stratospheric polar temperature during winter

Climatology for T_2 (10 - 18 hPa & 90°N-98°W) over 34 winters

Sudden Stratospheric Warmings Schiebeig (1982)

Large variability during the wintertime period

Stratospheric warming: vortex splitting

Visualisation of the polar vortex

https://earth.nullschool.net/

Wind vector at 10 hPa

(30 km, 02-02-2022)

Link polar vortex - tropospheric circulation

Stratosphere-troposphere dynamics coupling

Pressure and temperature perturbations generated in the upper stratosphere can propagate down to the troposphere and the surface

North American cold wave

January 2014

Ice formations on the Schuylkill River in Philadelphia

Baldwin and Dunkerton, JASTP, 2005
Impact of SSW on medium range weather forecast

Surface temperature 15 to 30 days after a Strat Warm event
Averaged over 15 SSWs

Gravity waves

Gravity force
Local extension (10 à 1000 km)
Main sources
- Orography (Lee waves)
- Deep convection
- Jet stream (geostrophic adjustment)

Gravity wave propagation and breaking

Brasseur and Solomon, 2005; from Lindzen, 1981
Gravity wave breaking ➔ wind deceleration ➔ Vertical and meridional wind ➔ summer mesosphere cooling and winter mesosphere warming

Temperature profile evolution during one night

Temperature anomaly: gravity wave propagation
GW characterization

NDACC Rayleigh Temperature lidars: from the variance of lidar signal fluctuations at OHP

COSMIC-GPS radio-occultation: from the fluctuations in temperature profiles in a 10° longitude by 5° latitude box around OHP

Radiosoundings: from the fluctuations in temperature profiles at Nîmes (100 km from OHP)

GW potential energy per unit of mass

\[ E_p = \frac{1}{2} \left( \frac{g'}{N'} \right)^2 \left( \frac{\bar{T}}{T} \right) \]

Climatology of GW potential energy from OHP lidar data

Gravity waves observed from space

Infrared composite from geostationary satellites

Lightning activity, NASA TRMM satellite
11 year average
Hunga Tonga eruption, 15 July 2022

Credit: NASA Worldview/NOAA/NESDIS/STAR

Hunga Tonga stratospheric injection

Credit: Valentin Defise
Reunion University

Lidar observation

Credit Valentin Defise
Reunion University

Hunga Tonga eruption at Reunion Island
CIMO - Meteo Observatory, 15/07/2022

Satellite IR observation

Credit Mathew Barow

Lamb waves simulation

Credit Nedjeljka Žagar

Hunga Tonga Lamb waves

Credit waves generated by Tonga eruption 15/01/2022 00:50 UTC

High resolution modeling of constituent transport:
MIMOSA model

Potential temperature ($\Theta$) and potential vorticity (PV)

$\Theta = T \left( \frac{1000}{P} \right) \frac{N}{C_P}$

$PV = \left\{ \left( \frac{\partial \Theta}{\partial y} - \frac{\partial \Phi}{\partial z} \right)_a + f \right\} \frac{\partial \Phi}{\partial p}$

In absence of diabatic effects, an air mass is moving along isentropic surfaces (constant $\Theta$) and its PV is conserved

Relation tracer-PV

Danielsen (1958)

First evidence: Increase of ozone and radioactivity in a tropopause foliation
PV and polar vortex

First use of PV conservation to study the polar vortex dynamics.

Motivation to use MIMOSA for transport studies of stratospheric species

Better representation of filamentary structures than ECMWF PV (horizontal resolution and continuity of structures).
Adveced PV more correlated with atmospheric species (O3, N2O, CH4, ...) than ECMWF dynamical PV (dynamical dissipation).
MIMOSA maps easy to use on AERIS/ESPRI for non-dynamists.

Advection and regridding

Advection of potential vorticity at high horizontal resolution

Potential vorticity (PV) considered as quasi-passive tracer on isentropic surfaces in the stratosphere during 1 to 3 weeks.
Indicator of transport, good correlation with long lived species (i.e. ozone in the lower stratosphere).

In MIMOSA PV transported by Winds from meteorological analyses (ECMWF).
Relaxation toward ECMWF PV at large scale, time constant 10 days (to take into account diabatic effects).

MIMOSA model principle

Projet EC-FP5 METEO-THESEO 1999-2000

Objective: to study the meridional transport of ozone in the lower and middle stratosphere (vortex filamentation, tropical intrusions).

Tools:
Lidar ozone ALTO on board French Falcon I9N-INSU
Lidar ozone at Observatoire de Haute-Provence
Need to have a isentropic transport model for the planning of aircraft flights and the interpretation.
Polar filament seen by the OHP ozone lidar

EU-METRO campaign airborne lidar ozone ALTO
Heese et al., JGR 2001

Evidence of polar air fragments in middle latitude summer stratosphere

SDLA CH4 balloon profiles
MIMOSA map at 500K

Durry and Hauchecorne, ACP 2005

MIMOSA use in forecast mode

At 10 days:
At 7 days:
At 5 days:
At 3 days:

Segonne et al., MIMOSA-V AE project

Polar vortex evolution

- No filaments visible on PV
- PVlong = PVshort (mechanical PV dissipation during SSW)
- Larger differences at the edge of the vortex and in filaments

Segonne et al., MIMOSA-V AE project
MIMOSA on AERIS/ESPRI database

Vortex edge determination

Evolution of vortex edge

MIMOSA service on AERIS/ESPRI

MIMOSA service on AERIS/ESPRI

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