Diagnostics used in the university research context

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with contributions from the entire Atmospheric Dynamics Group, ETH Zurich
Heatwave Europe July 2015

MSG IR satellite 12 UTC 1 July 2015
Jetstream deflected towards Scandinavia (2PVU@325K)
Heatwave Europe July 2015

MSG IR satellite 12 UTC 1 July 2015, jetstream (2PVU@325K)
Atmospheric blocking extends over heat wave region
Heatwave Europe July 2015

MSG IR satellite 12 UTC 1 July 2015, jetstream (2PVU@325K), blocking
Strongly ascending and precipitating airstream – associated with North Atlantic
cyclone - reaches into blocking region (MSLP 12 UTC 29 June 2015)
Outline

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1. Feature-based diagnostics: Overview

**Feature-based diagnostics: Overview**

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*explained in this talk*  *monthly clim. freely available*  *work in progress*

1. Feature-based diagnostics: cyclones


Cyclones

SLP, 00 UTC 27 Feb 1990

- closed SLP contours around minima
- Set 0/1 mask
- unique label for each cyclone
- ranking into 1st, 2nd, … minimum
- Split multi-centre cyclones
- Tracking every 6h

1. Feature-based diagnostics: Blocking


Blocking

- calculate vertically averaged PV (VAPV) between 500 and 150 hPa
- negative VAPV anomalies wrt. monthly climatology < 1.3 PVU
- track anomalies in time
- anomalies living longer than 5 days (with at least 70% overlap at each 6-hourly time step) are identified as blocks

1. Feature-based diagnostics: LAGRANTO

LAGRANTO
The Lagrangian Analysis Tool

About
Lagrangian parcel trajectories are widely used in the atmospheric and oceanic sciences, for instance, to identify flow structures in extratropical cyclones (e.g., warm conveyor belts) or ocean eddies, long-range transport pathways of moisture, or to study the physical processes underlying the formation of sea surface temperature, salinity or potential vorticity anomalies.

1. LAGRANTO.ECMWF
   It is used to compute air-parcel trajectories typically based on 6-hourly ERA-Interim data on a regular lat/lon grid. In addition it was applied also to 20CR data.
   Citation:

2. LAGRANTO.COSMO
   It is the version used to compute air-parcel trajectories based on the output of the COSMO mode. An online and offline version of the tools is available. For the online computation the actual model time step is used, which increase the accuracy of the trajectories.
   Citation:
   Mittenberger, A.K., Plant S., and Wernli H. (2013). An online trajectory module (version 1.0) for the nonhydrostatic

3. LAGRANTO.OCEAN
   The ocean version is the latest member of the LAGRANTO family. It can be used to compute ocean-parcel trajectories based on ECMWF's Ocean Reanalysis data (ORAS5). The triangular grid of the input data is transformed and rotated into a regular lat/lon grid. At the boundaries no-normal and no-slip boundary conditions are applied. This version is under development.
   Citation:

• Computation of Lagrangian parcel forward/backward trajectories
• Multiple options for selection of subsets (spatial & temporal criteria, physical properties)
• Freely available (versions for IFS, COSMO, WRF, UM)

1. Feature-based diagnostics: WCBs

Warm conveyor belts

- rapidly ascending cross isentropic air flows (>600hPa/48h)
- diabatic heating of about 20K / 48h
- diabatic PV **production** below level of maximum heating
- diabatic PV **reduction** and low PV values at upper levels

see WCB clim. by Madonna et al. (2014)

Wernli and Davies (1997), *QJRMS*

\[
\frac{dPV}{dt} + \frac{d\mu}{dz} + \text{PV production}
\]
WCB outflow and upper-level flow

PV on 320 K

Grams et al. (2011), QJRMS

$$\frac{dPV}{dt} = \frac{1}{\rho} \bar{\eta} \cdot \nabla \Theta + \frac{1}{\rho} (\nabla \times \vec{F}) \cdot \nabla \Theta$$

Total change in PV
\[ \text{diabatic PV modification} \]
\[ \text{frictional processes} \]
WCB outflow and upper-level flow

335-K PV (shaded) and wind speed >50 m s⁻¹ (dashed); SLP (solid)

“x”: Δz/Δt>8500 m/48h

Grams and Archambault (2016), MWR, doi: 10.1175/MWR-D-15-0419.1

\[
\frac{dPV}{dt} = \frac{1}{\rho} \bar{\eta} \cdot \nabla \Theta + \frac{1}{\rho} (\nabla \times \vec{F}) \cdot \nabla \Theta
\]

Total change in PV

diabatic PV modification

frictional processes
WCB climatology

- Ascending more than 600 hPa in 48 h
- Vicinity of extratropical cyclone (to exclude rapid ascent in convective systems)
- Tracing forward and backward along WCB trajectory: Q, LWC, IWC, RH, TH, PV

WCB climatology

- Loss of specific humidity (precipitation)
- Cross-isentropic ascent (latent heat release due to condensation)
- Net transport of low-PV air to upper troposphere

1. Feature-based diagnostics: Dry intrusions

Dry intrusions

Forward trajectories start from a 3-D global grid every 6 h

Dry intrusions: climatology DJF

Dry intrusions: evolution

Only 1.2% of DIs are stratospheric!

1. Feature-based diagnostics: website

http://eraiclim.ethz.ch/

Feature-based ERA-Interim Climatologies

This collection of ERA-Interim based global climatologies of Eulerian and Lagrangian flow features is based on past and ongoing research of the Atmospheric Dynamics group at ETH Zürich. This webpage offers you access to monthly or longer-term averaged global fields from these climatologies. You can download netCDF, png or pdf files for the desired time period. The available fields span the period from January 1979 until (currently) February 2014.

Reference for the ERA-Interim dataset:

Reference for the feature climatologies:

http://eraiclim.ethz.ch/
2. Diabatic influences on blocking

• Analyze ERA-Interim reanalysis data for the period 1989-2009.

• Identify **atmospheric blocking** as temporally persistent negative potential vorticity anomalies in the middle/upper troposphere (Schwierz et al., 2004).

• Calculate 7-day **backward trajectories** from grid points within blocking anticyclones.

**Diabatic influence on blocking**

Diabatic heating and PV anomalies

Diabatic heating during 3 days before arriving in the blocking region

Percentage of trajectories with $D_q > 2 \, K$

blocking age in days

Non-persistant ridges

slides by Stephan Pfahl

Summary diabatic outflow and blocking
3. Operational forecast products

https://data.iac.ethz.ch/ml_cirrus/ec.ensemble/
(restricted access)


Warm conveyor belts

- operational ECMWF **high resolution** forecast
- **model level data** +0h to +96h every 3h; +96h to +192h every 6h
- 48h forward trajectories $\Delta p/\Delta t \geq 600\text{hPa}/48\text{h}$
WCB ensemble forecast

- operational ECMWF ensemble forecast
- model level data +0h to +168h every 6h
- 48h forward trajectories $\Delta p/\Delta t \geq 550\text{hPa}/48\text{h}$

WCB calculations for each ECMWF ensemble member on ecgate

Using ECMWF’s products in the university research context

**WCB ensemble forecast**

- Illustration of time-lagged Lagranto for **one** forecast

- at each fc time (0 to 120 hours) trajectories from 9 LAGRANTO calculations for one fc
WCB ensemble forecast

Probabilities for different layers:
- Total
- Outflow
- Ascent
- Inflow

Using ECMWF's products in the university research context

WCB ensemble forecast

WCB probability BT 20160331_00 VT +114h 20160404_18

Total column

- Forecast product: probability of WCB occurrence

\[ \frac{1}{E} \sum_{e} M_{i,j}^e \]

- \( M \): mask indicating if (M=1) or if not (M=0) ens mem. \( e \) has a traj at \((i,j)\)
- \( E \): number of ens. members (=51)
- \( i,j \): index of gridpoint \((i,j)\)
- \( e \): index of ensemble member \( e \)

WCB ensemble forecast

WCB probability BT 20160331_00 VT +114h 20160404_18

Ascent (800-400hPa)

probability precipitation > 5mm
BT 20160331_00 VT +96 to 120h

WCB ensemble forecast

WCB probability BT 20160331_00 VT +114h 20160404_18

Inflow (>800hPa)

Demonstration of current forecast products:
• High resolution forecast
• Ensemble forecast
• (crosstool)

https://data.iac.ethz.ch/ml_cirrus/ec.ensemble/
(restricted access)
4. A recent forecast bust


Grams, C.M., L. Magnusson, and E. Madonna, 2017: An atmospheric dynamics’ perspective on the amplification and propagation of forecast error in numerical weather prediction models: a case study. *In preparation for QJRMS*
00UTC 7 March 2016 forecast bust

Z500 RMSE and ACC for HRES and ENS - Europe

Plots by Linus Magnusson (ECMWF)
Synoptic evolution

**AR to BL transition from 20160307_00 to 20160308_18**

**ECMWF analysis**

**PV@315K, 00 UTC 7 March**

**PV@315K at 20160307_00**

**transition to**

**Atlantic Ridge**

**PV@315K, 12 UTC 14 March**

**PV@315K at 20160314_12**

**Scandinavian Blocking**
Synoptic evolution

**AR to BL transition from 20160307_00 to 20160308_18**

ECMWF analysis

ECMWF analysis BT: 20160309_00Z
LAGRANTO start and PMSL VT: 20160309_00Z
PV [2PVU] VT: 20160311_00Z

WCB
start 00 UTC 9 March → end 00 UTC 11 March
& PMSL & PV@315K

PV@315K, 12UTC 14 March

PV@315K at 20160314_12

Scandinavian Blocking
The PAL forecast metric

- Metric for quantifying the **PV**, **Amplitude**, and **Location** error of WCB outflow objects
- **P** term: <0, too weak / >0, too strong negative PV anomaly in outflow
- **A** term: <0, too few / >0 too many trajectories
- **L** term: 0 good; close to 2 → objects in opposite corners

The PAL forecast metric

- Metric for quantifying the PV, Amplitude, and Location error of WCB outflow objects
- **P** term: <0, too weak / >0, too strong negative PV anomaly in outflow
- **A** term: <0, too few / >0 too many trajectories
- **L** term: 0 good; close to 2 → objects in opposite corners

PAL diagram illustrates the three components, for different forecast members

Madonna et al. (2014), QJRMS, doi:10.1002/qj.2442

Plot by Erica Madonna (Uni Bergen)
Role of WCB in forecast bust

ECMWF ensemble initial time 20160307_00

focus on WCB starting 00 UTC 9 March (+48h) → ending 00 UTC 11 March (+96h)

ALL

SOUTH

NORTH
Role of WCB in forecast bust

ECMWF ensemble initial time 20160307_00

focus on WCB starting at 09_00Z (+48h) → ending at 11_00Z (+96h)
Role of WCB in forecast bust

- Southern WCB branch is too strong, rather maintains AR
- Northern branch is too weak, BL does not establish over Scandinavia
5. Demonstration NAWDEX

Demonstration of flight planning for IOP2 21 Sep 2016

http://nawdex.ethz.ch/

https://data.iac.ethz.ch/nawdex/index.php
(restricted access)
NAWDEX IOP2

https://data.iac.ethz.ch/nawdex/index.php
(restricted access)

Roman Attinger, Maxi Böttcher, Julian Quinting
Forecast for Wed, 21 Sep 2016 18 UTC

3 days before mission:
- Monitoring of evolution in hres and confirmation with ensemble

Maxi Böttcher and Julian Quinting
3 days before mission:
- Monitoring of evolution in hres and confirmation with ensemble

Maxi Böttcher and Julian Quinting
3 days before mission:
- Monitoring of evolution in hres and confirmation with ensemble
Forecast for Wed, 21 Sep 2016 18 UTC – Model consistency

2 days before mission:
- Monitoring of model consistency
- Definite decision about mission
- Planning of tentative **flight track** and **times**
2 days before mission:
- Monitoring of model consistency
- Definite decision about mission
- Planning of tentative flight track and times
2 days before mission:
- Monitoring of model consistency
- Definite decision about mission
- Planning of tentative flight track and times
Forecast for Wed, 21 Sep 2016 18 UTC – Model consistency

2 days before mission:
• Monitoring of model consistency
• Definite decision about mission
• Planning of tentative flight track and times
Mission on Wednesday
21 Sep 2016 15 UTC

PV@315K at 20160921_15

1 days before mission:
• Monitoring of model consistency
• Finalisation of flight track:
  • Location & times
  • levels

WCB probabilities 21/12UTC

BT19/12Z

WCB outflow

WCB ascent

WCB inflow
Flight pattern for Wednesday 21 September, 18UTC

• Coordinated leg with Falcon, 5 dropsondes, sampling TP structure
• Triangle south of Iceland to sample WCB ascent region / warm sector 8 sondes

1 days before mission:
• Monitoring of model consistency
• Finalisation of flight track:
  • Location & times
  • levels
Trajectories from HALO flight track VT 21/18Z

1 days before mission:
• Monitoring of model consistency
• Finalisation of flight track:
  • Location & times
  • levels

Maxi Böttcher and Julian Quinting
Successful Mission!
6. Summary and Outlook

- Comprehensive catalogue of feature-based ERA-I climatologies
  [http://eraiclim.ethz.ch/](http://eraiclim.ethz.ch/)

- LAGRANTO trajectory model
  [http://lagranto.ethz.ch/](http://lagranto.ethz.ch/)

→ facilitate research of atmospheric dynamics from a weather system perspective

- Specific forecast products enable flight planning for atmospheric measurement campaigns
  [http://nawdex.ethz.ch/](http://nawdex.ethz.ch/)
A. Diabatic influences on blocking

Diabatic heating and PV anomalies


*slides by Stephan Pfahl*
Diabatic heating during blocking life cycle


slides by Stephan Pfahl
Spatial distributions of trajectories


Adiabatic trajectories (cat. B)

Diabatic trajectories (cat. C)

Normalized trajectory density 3 days before arrival in the blocking region for winter. Purple contour indicates main trajectory starting regions.

slides by Stephan Pfahl
A. Potential Vorticity
Potential vorticity

\[ PV = \frac{1}{\rho} \vec{\eta} \cdot \nabla \Theta \]

\[ PV = \frac{1}{\rho} \eta \frac{\partial \Theta}{\partial z} \]

unit: 1PVU = 10^{-6} K m^2 kg^{-1} s^{-1}

\[ \eta = f + \vec{k} \cdot \nabla \times \vec{v}_h \]

Absolute vorticity / horizontal flow

Vertical stratification of the atmosphere/stability

\[ \frac{dPV}{dt} = \frac{1}{\rho} \vec{\eta} \cdot \nabla \Theta + \frac{1}{\rho} (\nabla \times \vec{F}) \cdot \nabla \Theta \]

Total change in PV

diabatic PV modification

frictional processes

- PV is conserved under adiabatic frictionless flow (conservation principle)
  → use PV as air mass tracer on isentropic surfaces to identify PV signatures of weather systems
- PV can be inverted given a balance condition and boundary conditions (inversion principle)
  → derive wind, T, p field from a given PV distribution
Potential vorticity

\[ PV = \frac{1}{\rho} \eta \cdot \nabla \Theta \]

\[ PV = \frac{1}{\rho} \eta \frac{\partial \Theta}{\partial z} \]

unit: 1PVU = \(10^{-6} \text{ K m}^2 \text{ kg}^{-1} \text{ s}^{-1}\)

Absolute vorticity / horizontal flow

\[ \eta = f + \vec{k} \cdot \nabla \times \vec{v}_h \]

Vertical stratification of the atmosphere/stability

North of jet streak
Pos. shear vorticity, high PV

South of jet streak
Neg. shear vorticity, low PV

Stratosphere: High stability, high PV

Troposphere: Lower stability, low PV

PVU