Influence of mid-latitude cyclones on European background surface ozone investigated in observations, MACC and MERRA-2 reanalyses

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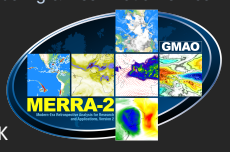

Take Home Messages!

First study to our knowledge to quantify the influence extratropical cyclones have on the temporal variability of springtime surface ozone (O_3) measured on the west coast of Europe when cyclones are nearby.

We show **passing cyclones have a discernible influence on surface O_3 concentrations.**

In-depth findings from four case studies, using a combination of reanalyses and a modeled tracer, demonstrate there are several transport pathways before O_3-rich air eventually reaches the surface. (Knowland et al., 2017 ACP)

Data

Surface O_3 Observations

Mace Head, Ireland	1988-2012	EMEP	In main storm track (Fig. 1)
Monte Velho, Portugal	1989-2009*	EMEP	South of main storm track

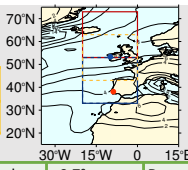

Figure 1: Storm track density (contours) over Europe. North, Center and South regions indicated for **Mace Head** (blue dot). **Monte Velho** (red dot).

Reanalysis

ERA-Interim	1979-present	ECMWF IFS	O_3 chemistry parametrization	O_3 assimilated	~0.7° 60 levels	Dee et al., 2011
MACC	2003-2012	ECMWF IFS	Coupled to MOZART-3 CTM	O_3 assimilated	~0.7° 60 levels	Inness et al., 2013
MERRA-2	1980-present	GEOS-5	Simplified O_3 chemistry	O_3 assimilated	~0.5° 72 levels	Gelaro et al., 2017

- Met and chemical variables on 12 pressure levels from 1000 to 200 hPa
- Relative vorticity at 850 hPa (ζ_{850hPa}), mean sea level pressure (MSLP), temperature (T), specific humidity (q), winds (u,v), vertical velocity (ω), equivalent potential temperature (θ_e), and O_3.

Storm tracks and O_3

1. Storm tracks were identified in ERA-Interim and MACC using the objective feature tracking algorithm, TRACK (Hodges 1995, 1999).
2. O_3 at Mace Head and Monte Velho were sorted each season, to remove the increasing background signal, and ranked by percentiles (pc)
3. Tracks were matched to concurrent surface O_3 observations at Mace Head and Monte Velho.

Mace Head	% tracks "high" O_3 $O_3 > 75^{th}$ pc	# years more tracks with high O_3 (# significant)	% tracks "low" O_3 $O_3 > 75^{th}$ pc	# years more tracks with low O_3 (# significant)
North	52 %	18 (15)	37 %	5 (0)
Center	51 %	17 (6)	41 %	6 (1)
South	45 %	7 (2)	53 %	16 (8)

When cyclones track north of 53ºN, there is a significant relationship with high levels of surface O_3 (> 75^{th} pc). The further away a cyclone is from the main storm track, more likely associated with low O_3 (< 25^{th} pc).

4. Case study cyclones (Fig 2 below) identified for
   a) high O_3
   b) Passing through North or South regions
   c) Strong, top 20 % based on maximum ζ_{850hPa}
   d) two consecutive time steps with high O_3

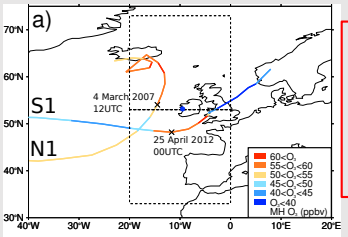

Figure 2: Tracks colored by MACC O_3 interpolated to the Mace Head location. Max ζ_{850hPa} indicated by cross.

Strong cyclone tracks, N1 and S1, associated with high O_3 at Mace Head (Fig. 2)

5. All points within a 20° spherical cap over the storm centre are selected and oriented in the direction of the storm's movement

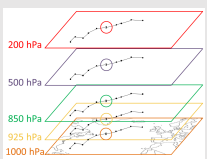

Figure 3: Schematic of a storm track identified on 850hPa field, transferred on multiple levels. Spherical cap around storm center at time of maximum ζ_{850hPa} is illustrated.

N1 cyclone: North of Mace Head

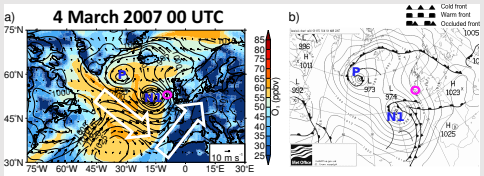

Figure 4: N1 cyclone is a secondary cyclone to parent low "P". a) 1000 hPa MACC O_3, SLP, winds. b) Analysis chart from UK Met Office. Mace Head indicated by pink circle.

Strong O_3 gradient across the cold front,
1) with maritime clean air first to Mace Head
2) elevated levels of O_3 behind the front.

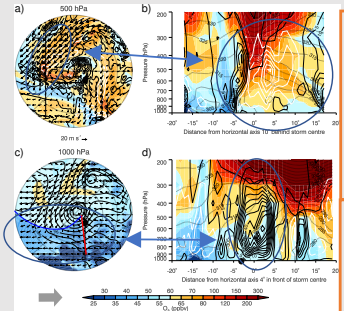

Figure 5: N1 cyclone 4 March 2007 00 UTC

Descent of stratospheric O_3-rich air behind the strong frontal boundary in dry intrusion (DI) airstream.

Ascent of O_3-poor air in the warm conveyor belt (WCB) up to 400 hPa.

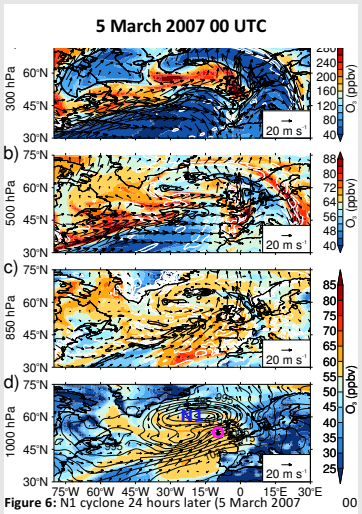

Figure 6: N1 cyclone 24 hours later (5 March 2007 00 UTC). Cold front has passed over Mace Head.

Descent of O_3-rich air in DI
Transport across North Atlantic in strong westerly winds.
Persistent high O_3 observed at Mace Head for 1.5 days

S1 cyclone: South of Mace Head

MACC

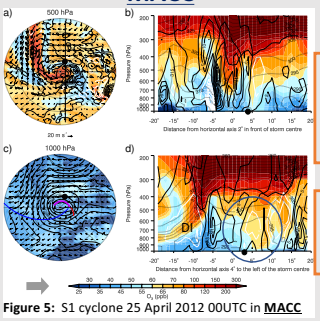

Figure 5: S1 cyclone 25 April 2012 00UTC in **MACC**

Descent of O_3-rich air reaches surface

O_3-rich air not from S1's DI

MERRA-2

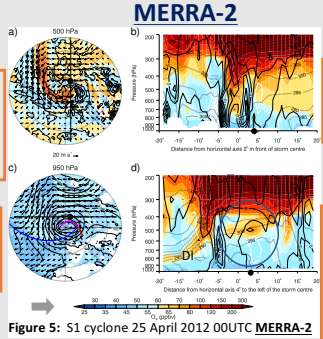

Figure 5: S1 cyclone 25 April 2012 00UTC **MERRA-2**

O_3-rich air below tropopause

O_3-rich below tropopause is from upstream DI

- Tropopause is level above Mace Head. DI is to the south.
- O_3-rich air below tropopause in MERRA-2 -> air is likely from the stratosphere
- Residual high O_3 from upstream decaying DI airstream entrained into S1

Dee et al., 2011 "The ERA-Interim reanalysis: configuration and performance of the data assimilation system" Q.J.R. Meteorol. Soc., **137**, 553–597. doi:10.1002/qj.828.
Gelaro et al., 2017 "The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)" J. Climate, **30**, 5419–5454, doi:10.1175/JCLI-D-16-0758.1.
Hodges, K.I. 1995 "Feature tracking on the unit-sphere" Mon. Wea. Rev., **123**, 3458-3465
Hodges, K.I. 1999 "Adaptive constraints for feature tracking", Mon. Wea. Rev., **127**, 1362-1373
Inness et al., 2013 "The MACC reanalysis: an 8 yr data set of atmospheric composition", Atmos. Chem. Phys., **13**, 4073-4109
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Figure key: O_3 (color), tropopause (2 PVU, think black line), ω (white= descent, black=ascent), MSLP (lowest pressure level), θ_e (dotted lines). Mace Head (black dot)

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