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*Supplement of*

## **STEFLUX, a tool for investigating stratospheric intrusions: application to two WMO/GAW global stations**

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## **S1. Technical details on the methodologies for the identification of SI events based on observations (SIO)**

In this section, technical details on the SI selection methodologies presented in Sect. 2 are given. These methodologies refer to those used in previous works for NCO-P and Mt. Cimone (see Cristofanelli et al., 2006; Cristofanelli et al., 2010; Cristofanelli et al., 2015).

### **S1.1 In situ datasets**

O<sub>3</sub> and meteorological parameters have been continuously monitored at NCO-P since 2006 and at Mt. Cimone since 1998. Surface O<sub>3</sub> measurements at NCO-P were performed by using a UV-photometric analyser (Thermo Scientific – TEI 49i). The UV-absorption technique was also applied for obtaining O<sub>3</sub> measurements at Mt. Cimone, where a Dasibi 1108 W/GEN was deployed. Since 2006, O<sub>3</sub> measurements at Mt. Cimone were compared every two years against primary standards (reference photometers). These were hosted at the National Institute of Metrological Research (INRiM) in Turin, Italy, in 2006, and at the GAW World Calibration Centre at EMPA (Switzerland) in 2008 and 2010 (here they were compared against the SRP 15 primary standard). Continuous monitoring of <sup>7</sup>Be was active at Mt. Cimone between 1998 and 2004, by using a Thermo-Environmental PM<sub>10</sub> High-Volume sampler (flow rate: 1.13 m<sup>3</sup> min<sup>-1</sup>) at a time resolution of about 48-h. <sup>7</sup>Be concentrations were determined on the sampled glass fiber filters by non-destructive high-resolution gamma-spectroscopy at 478 keV with HPGe detectors at the Laboratory of Environmental Radiochemistry of the Bologna University (for more details see Tositti et al., 2004). Except for <sup>7</sup>Be, all of the other parameters were sampled at 1-min time resolution and aggregated to a common time base of 1 hour. All observations in this paper are expressed in standard temperature and pressure (0 °C and 1013 hPa) and reported at UTC, for avoiding biases when comparing the analyses to the STEFLUX outputs.

### **S1.2 Total column O<sub>3</sub> retrievals**

Concerning NCO-P, the daily total column of O<sub>3</sub> (TCO) generated by the NASA Ozone Monitoring Instrument (OMI, Levelt et al., 2006) science team was used. Data referred to the Version-003 of Level-3 Aura/OMI daily global TOMS-Like TCO gridded product (OMTO3e, Bhartia, 2012), calculated on a 1° x 1° pixel encompassing the measurement site location. For Mt. Cimone, daily TCO from the Total Ozone Mapping Spectrometer (TOMS) sensor on board of the NASA “Earth Probe” satellite were considered from 1998 to 2004, while data from the NASA OMI Aura satellite, similarly to those used for NCO-P, were deployed from 2004 to 2010. In this case,

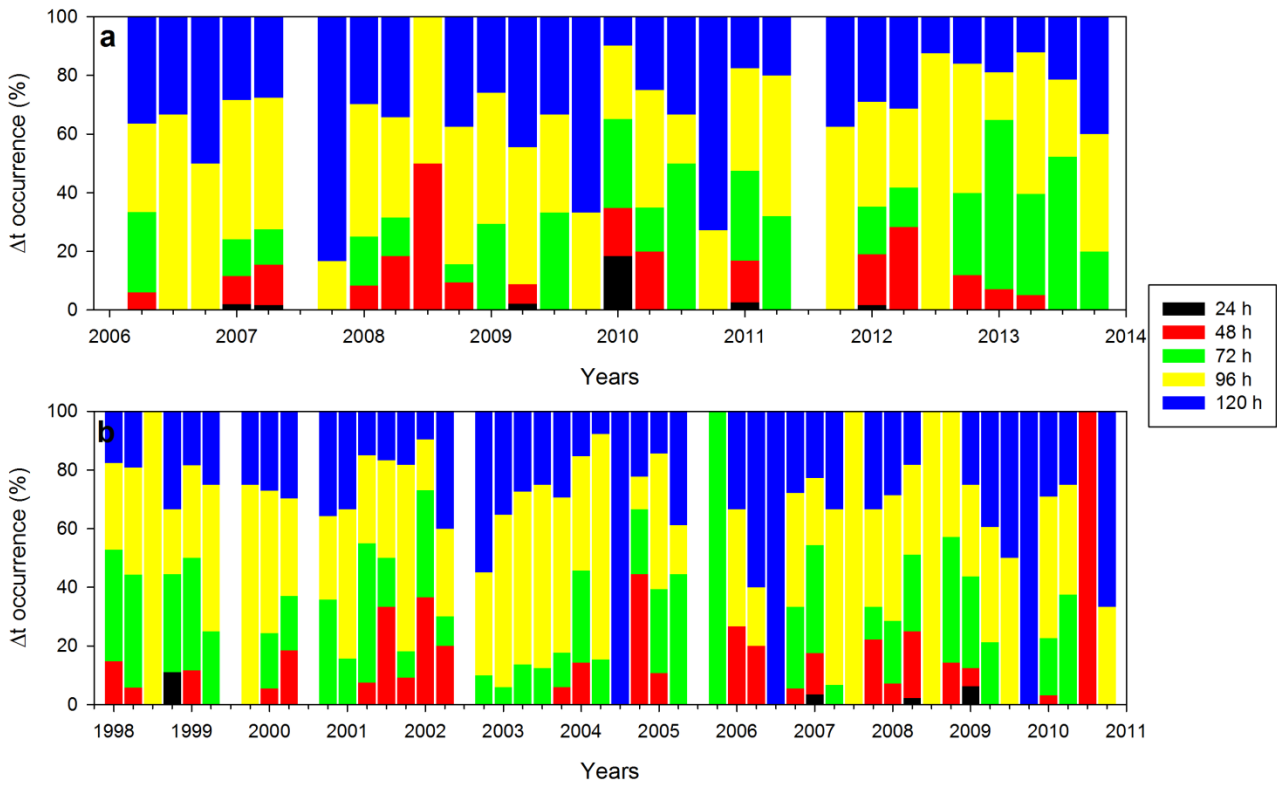
for both datasets the daily overpasses over Sestola (a town sited 7 km NE from Mt. Cimone) were considered.

### **S1.3 Potential vorticity values**

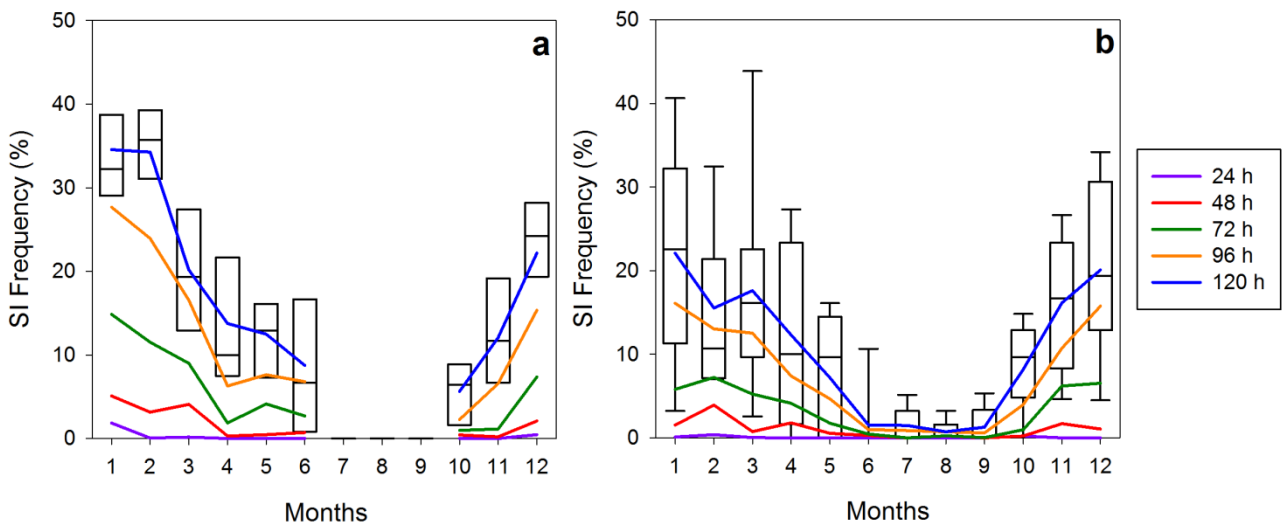
Potential vorticity (PV) values were retrieved by the analysis of back-trajectories reaching both stations. LAGRANTO (Sprenger and Wernli, 2015; Wernli and Davies, 1997) was used as the Lagrangian model to calculate the path of air-masses reaching NCO-P. Its calculations are based on the 6-hourly meteorological 3-D grid composing the operational analysis composed by the ECMWF. A set of 5-day back-trajectories were computed (at 00:00, 06:00, 12:00 and 18:00 UTC); among these, only those starting at 490 hPa were retained, to minimize possible effects between the model and the real topography. Similarly, PV values were estimated from the 6-day back-trajectories reaching Mt. Cimone (starting at an altitude of 2200 m a.s.l.), calculated by the FLEXTRA model (Stohl et al., 2005), and based again on the analysis field produced by the ECMWF. In this case it has to be noted that, to avoid false detections due to high PV values generated by diabatic processes in the lower troposphere, the PV threshold (see Sect. 2) was applied only for altitudes higher than 5000 m.

**Table S1.** “SIO vs STEFLUX” and “STEFLUX vs SIO” approaches, as presented in Table 3, for Mt. Cimone, computed by limiting the period of study to 1998 – 2004 (i.e., when data coverage was > 90%).

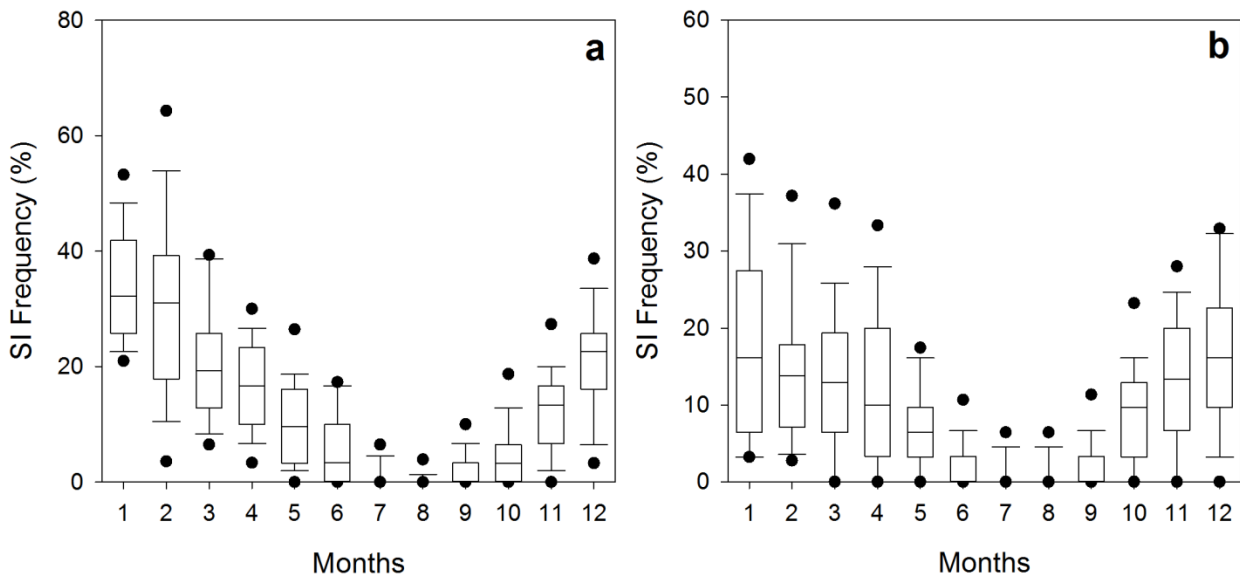
| SI event duration | “SIO vs STEFLUX” |          | “STEFLUX vs SIO”     |          |
|-------------------|------------------|----------|----------------------|----------|
|                   | SI events by SIO | STEFLUX  | SI events by STEFLUX | SIO      |
| 1 day             | 115              | 27 (23%) | 61                   | 10 (16%) |
| 2 days            | 23               | 9 (39%)  | 39                   | 15 (38%) |
| 3 days            | 16               | 6 (37%)  | 19                   | 5 (26%)  |
| ≥4 days           | 7                | 2 (29%)  | 20                   | 3 (15%)  |
| Total             | 161              | 44 (27%) | 139                  | 33 (24%) |



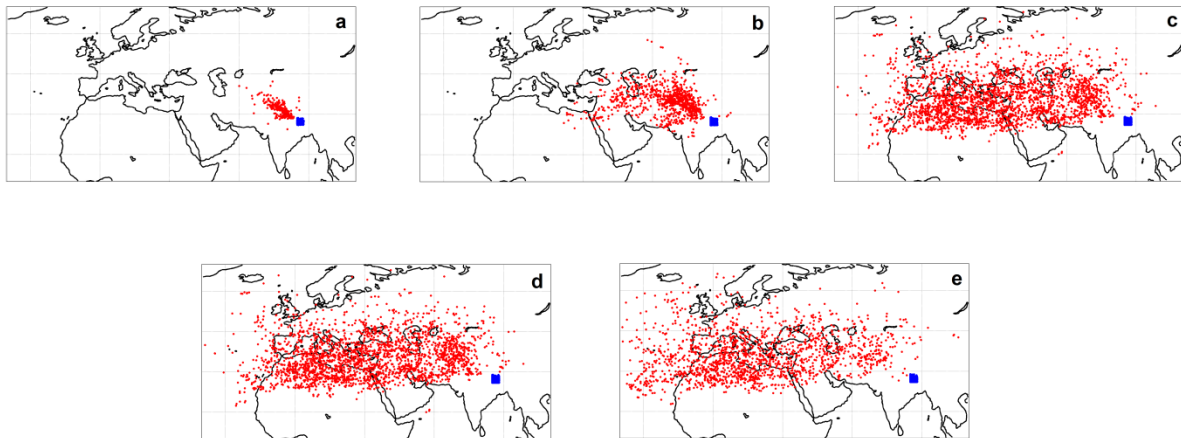
**Figure S1.** Seasonal graph of  $\Delta t$  occurrence (in %,  $\Delta t$  is defined as the time in hours between the tropopause crossing and the first box crossing) for the SI events identified by STEFLUX (blue line in Fig. 2), for NCO-P (a) and Mt. Cimone (b). Colors in the legend refer to the upper limit of each  $\Delta t$  category, e.g., 24 h refers to  $0 \text{ h} \leq \Delta t < 24 \text{ h}$ .



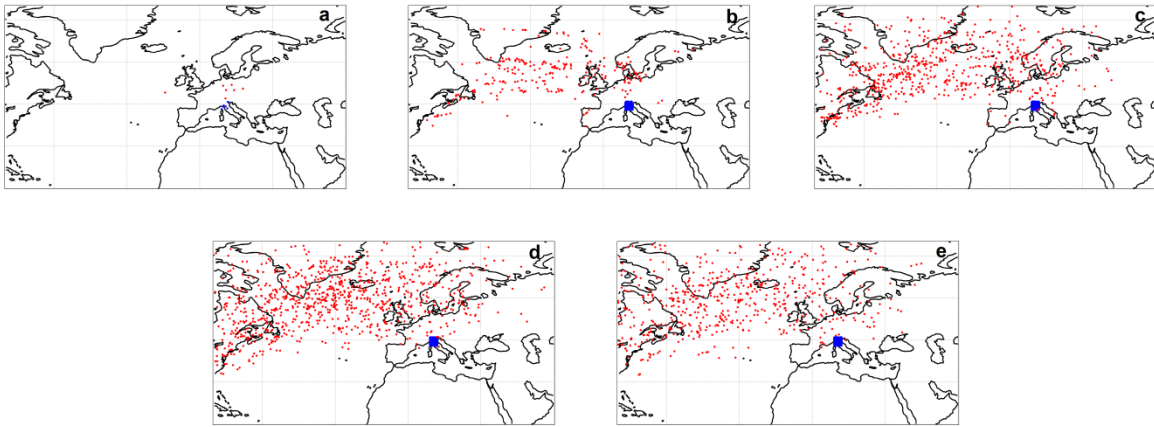
**Figure S2.** Box-whiskers plot of the annual variation of SI frequency, computed by STEFLUX, at NCO-P (a), and Mt. Cimone (b). Lines define the average monthly contribution from each  $\Delta t$  category. Colors in the legend refer to the upper limit of each  $\Delta t$  category, e.g., 24 h refers to  $0 \text{ h} \leq \Delta t < 24 \text{ h}$ .



**Figure S3.** Box-whiskers plot of the annual variation of SI frequency, computed by STEFLUX over the period 1979–2013, for NCO-P (a) and Mt. Cimone (b).



**Figure S4.** Tropopause crossing (red dots) and first box crossing (blue dots) locations for the SI events at NCO-P over the period 1979–2013. The different panels indicate the  $\Delta t$  categories:  $0 \text{ h} \leq \Delta t < 24 \text{ h}$  (panel a),  $24 \text{ h} \leq \Delta t < 48 \text{ h}$  (b),  $48 \text{ h} \leq \Delta t < 72 \text{ h}$  (c),  $72 \text{ h} \leq \Delta t < 96 \text{ h}$  (d) and  $96 \text{ h} \leq \Delta t < 120 \text{ h}$  (e).



**Figure S5.** Same as Fig. S4, for Mt. Cimone time series.

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