TOWARDS A COUPLED DATA ASSIMILATION FOR ATMOSPHERIC COMPOSITION AND NUMERICAL WEATHER PREDICTION IN ARPEGE AND AROME

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With many thanks to the NWP team (GMAP)!

CURRENT OPERATIONAL SETUP

- **Two sets of models**

→ Numerical Weather Prediction (NWP) models are ARPEGE (global domain) and AROME (regional domain).

→ Atmospheric Composition (AC) model is MOCAGE (both global and regional domains), which is an off-line Chemistry Transport Model (CTM).

- **With weak interactions**

→ MOCAGE uses meteorological forcing from ARPEGE.

→ No feedback from MOCAGE into ARPEGE or AROME.

- **Two separate data assimilation (DA) systems**

→ ARPEGE and AROME run their own assimilation and ensemble DA

→ MOCAGE runs its own 3DVar with no ensemble DA

- **Some shared observing systems are assimilated**

→ Both ARPEGE and MOCAGE assimilate satellite infrared observations (from IASI and CrIS sensors, eg) as level 1 data (radiances or brightness temperatures), but with different channel selections:

Channels sensitive to temperature, water vapour, skin temperature and ozone in ARPEGE. Channels sensitive to ozone, carbone monoxide and skin temperature in MOCAGE.

BACK IN 2019, FIRST STEPS IN COUPLED DA FOR ATMOSPHERIC COMPOSITION AND NWP

- **Assimilation of IASI observations in ARPEGE for ozone**

→ O. Coopmann's PhD work aimed at evaluating the extension of the ARPEGE control variable (vorticity, divergence, temperature, humidity, surface pressure) to add ozone and used IASI observations to jointly initialise ozone with other variables.

- **Why IASI and infrared sensors?**

→ With 8461 channels, IASI is sensitive to many gazeous species (ozone, CO, SO_2, CH_4, N_2O, CO_2, humidity), skin temperature, temperature. IASI is also sensitive to clouds and mineral aerosols. This kind of measurement eases the joint description of many variables at a glance.

- **Which impact of this coupled DA?**

→ Limitations: Background errors for ozone were not taken from an EDA and there were no cross-correlation between errors for ozone and errors for the usual NWP variables; no cycling of ozone fields in the assimilation cycle, ozone from MOCAGE was used for each assimilation.

→ Positive impact on assimilation of usual observations for NWP (fig1) and on NWP forecasts (fig2)!

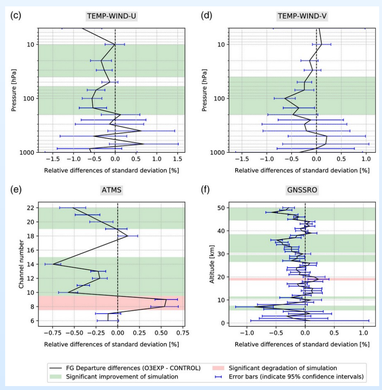

Fig.1: Global relative differences in standard deviation of FG departures between O3EXP and CONTROL from 12 July to 10 September 2016 on the assimilated observations from (c) zonal wind and (d) meridional wind radiosonde, (e) ATMS and (f) GNSS-RO bending-angle. Error bars (blue lines) give statistical significance intervals for differences at the 95% level.
from Fig8 in Coopmann et al, 2020 (QJRMS)

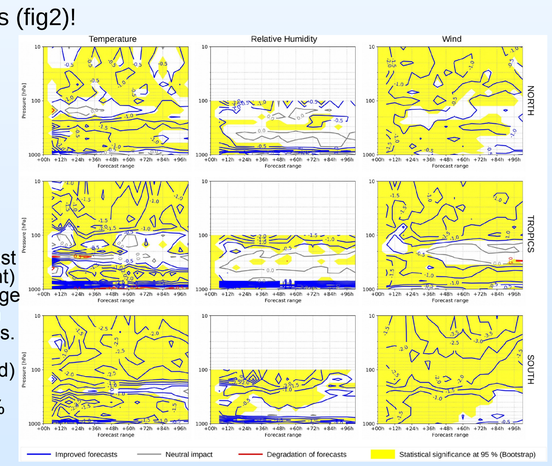

Fig.2: Normalized differences (%) of the standard deviation forecast error of temperature (left), relative humidity (centre) and wind (right) between O3EXP and CONTROL experiments versus forecast range from 0 to 102 hr. Statistics are computed over 57 simulations from 12 July to 10 September 2016 and verified against its own analysis. The top (rp. middle, lower) row shows scores over the Northern Hemisphere (rp. Tropics, the Southern Hemisphere). The blue (red) contours indicate that the O3EXP experiment has improved (degraded) the forecasts. The yellow shaded region indicates 95% statistical significance from a bootstrap test.
from Fig10 in Coopmann et al, 2020 (QJRMS)

ACCALMIE AND ON-LINE AC MODELLING

- **Internal project at Météo-France**

→ ACCALMIE stands for « Approche Coordonnée pour la Composition Atmosphérique dans Les Modèles de Météo-France, en ligne et hors ligne », ie. Coordinated Approach for Atmospheric Composition in Météo-France's atmospheric models, on-line and off-line.

→ All processes related to emission and production of gazeous and particulate compounds, their transformations and chemical reactions, transport and deposition, used in the following models, have been gathered in a unique library ACLIB (Atmospheric Composition LIBrary)

- MOCAGE and IFS-compo(MOCAGE)
- ARPEGE climate ESM
- AROME-dust
- MesoNH-chemistry

Interfaces in the atmospheric models have been modified accordingly

- **Implementation**

→ MOCAGE 2026.11 (so-called U11 for CAMS).

→ ARPEGE and AROME cy49t1.

→ MesoNH v6

ON-GOING DEVELOPMENTS OF ARPEGE-COMPO AND AROME-COMPO – TOWARDS A STRONGER COUPLING

- **Aerosols of the day in ARPEGE and AROME**

→ As part of the improvement studies for next operational NWP configurations, the introduction of the aerosols of the day, from MOCAGE, into ARPEGE and AROME is being evaluated, for their benefits on the radiation calculations in these models.

→ This work paves the way for also introducing gases of the day (like ozone, for instance).

→ The use of aerosols of the day for microphysics in AROME is also prepared, in a more prospective approach.

- **ARPEGE-Compo and AROME-Compo**

→ In order to develop our next-generation atmospheric composition models, ARPEGE-Compo and AROME-Compo are being built upon NWP ARPEGE and AROME, using the full capacity of the atmospheric composition processes available in ACLIB.

→ First steps of validation deal with aerosols (especially desert dusts, cf. fig3).

- **Which level of coupling in the model?**

→ Within ARPEGE-Compo, first operational implementation will have no retro-action of aerosols on the radiation processes. Aerosols from AREPGE-Compo will be provided to NWP ARPEGE.

→ Cautiously, retro-actions of atmospheric compostion on meteorological processes will be activated, As ozone and aerosols in the radiation scheme.

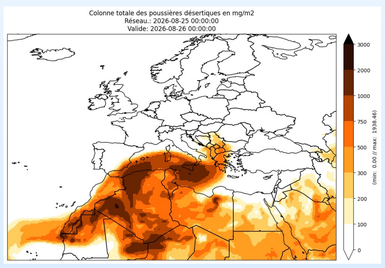

Fig.3: 24h forecast of total column of desert dusts in ARPEGE-Compo, valid on 26 August 2026 at 00UTC, zoom over North Africa and Europe

WHAT ABOUT DA IN ARPEGE-COMPO AND AROME-COMPO? – WHICH OBSERVATIONS FOR MORE COUPLING?

- **Data Assimilation Methods**

→ NWP AROME runs a 3DEnVar in operations and will switch to 4DEnVar in late 2026.

→ NWP ARPEGE runs a 4DVar in operations and benefits from the 3DEnVar in research mode.

→ ARPEGE-Compo and AROME-Compo will start with 3DEnVar configurations, making it easier to implement new species in the DA.

- **Infrared sounders: key instruments for an advanced coupled data assimilation**

→ The infrared region of the spectrum emcompasses sensitivities to many gazeous species (fig4), Skin temperature and emissivity, atmospheric temperature, clouds and some aerosols.

→ Assimilating infrared sensors as radiances (or brightness temperatures) at once in a coupled DA system makes it possible to correct many variables in a consistent way, with no caveats of Assimilating simultaneously level 2 (products) and level 1 (radiances) for different species.

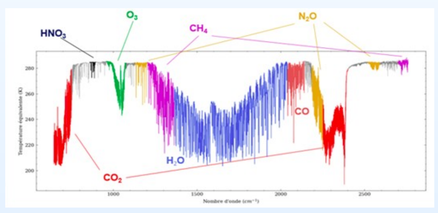

Fig.4: Average of IASI-NG spectra measured over France on 30 September 2025 in brightness temperatures, illustrating sensitivity of IASI-NG to various gaseous compounds.

- **First steps with ARPEGE-Compo and AROME-Compo**

→ Within the Horizon Europe CAMAERA project, IASI radiances are assimilated in ARPEGE-Compo for Desert Dusts

→ Auguste Maillot's on-going PhD aims to assimilate IRS radiances in AROME-Compo to correct both NWP variables and Desert Dusts

→ Addition of ozone and carbon monoxyde to the control variable of ARPEGE-Compo is planned as a second step

WHAT ABOUT AI – MACHINE LEARNING?

- **General approach common to AC and NWP**

→ Bias correction

→ Cloud identification and characterization

→ Evaluation of scene-dependent observation errors

→ Improvement of the radiative transfer models (speed and accuracy)

- **Specific features for Atmospheric Composition**

→ Detection of plumes (dusts, SO_2, etc.)

→ Detection of species in the infrared spectrum that may not be properly described in the RTM simulations, to discard affected pixels

→ Improvement of RTM speed for aerosol scattering

- **Background error description**

→ Improve cross-variable error correlation description

→ Help modify AC variables that are not observed but linked to other variables that are observed and modified during DA.

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Team COMPO of CNRM, Météo-France is in charge of the development, the maintenance and the transfer to operations of the atmospheric composition models at Météo-France, including AI, preparing for future related observing systems, and contributing to climate studies.