Agenzia Spaziale Italiana	Workshop CAMEO 2022: Summary, remarks and recommendations (Prepared by the Organizing Committee of the Workshop)	Far-infrared-Outgoing-Radiation Understanding and Monitoring forum

Summary and Main Remarks

The Workshop "**CAMEO - Climate And Meteorology, modeling and Earth Observations (Osservazioni e modelli per il clima e la meteorologia)"** was held virtually by ASI on January 19-20th 2022 under the joint supervision and organization with National Research Council (CNR), University of Basilicata (UNIBAS), University of Bologna (UNIBO) and Politecnico di Torino (POLITO).

The objective of the Workshop was twofold: a) to promote and disseminate information on the Earth Explorer 9 "FORUM" mission (https://www.forum-ee9.eu/), with its state-of-the-art, ongoing activities and future perspectives; b) to establish and enlarge the basis for an active cooperation among national scientific communities working on the exploitation of Earth Observation (EO) data for model developments, atmospheric parametrization as well as for diagnostics, the assessment and the initialization of global climate/weather models and their assimilation within regional scale Numerical Weather Prediction (NWP) models. The contributions presented during the workshop and the subsequent discussion on the above-mentioned topics, were intended to provide the main hints and indications about future activities, to be supported also by ASI, for impact / exploitation studies of FORUM measurements in NWP and global models.

The participants attending the workshop were about 100, mainly coming from national / regional research centers/agencies and universities (95%) working on EO exploitation for climate/weather studies, together with a little contribution from national companies (5%). Among them we specifically mention Dr. Luca Palchetti (CNR-INO), Principal Investigator of FORUM mission, and Dr. Hilke Oetjen (ESA) as representative of the ESA science team supporting the FORUM mission.

A brief summary of suggestions, recommendations and feedbacks, provided during the workshop as well as fostered by both invited contributions (10 presentations) and short-communications (4 presentations), is listed below and divided for each application domain.

Use of EO data for assimilation, diagnostics and tuning of global models

- So far, only the "total" OLR fluxes predicted by climate models are compared to observations (e.g. observations of CERES). The spectral dimension of the OLR fluxes is rarely considered, thus, also in the case of perfect agreement of total fluxes with measurements, compensating errors may still exist between different spectral regions. FORUM spectral measurements will cover, for the first time, both the FIR and the MIR regions, thus will offer the unprecedented possibility to compare measured spectral OLR fluxes with those predicted by global climate models.
- For the above comparison, an accurate and fast radiative transfer model (RTM, like σ-FORUM) is required, with the capability to cover from the FIR to the MIR. The RTM shall be used to generate spectral radiances / fluxes (to be compared to the observations), starting from the atmospheric and surface state predicted by the model.
- Need to have accurate and long time series of observations in the FIR spectral range for climate / weather model improvements and forecast: FORUM measurements could provide a significant contribution in the improvement of cloud and aerosol modelling and parametrization.

- Due to the different sizes of both instrument field of view and model grid, the above-mentioned comparison is not straightforward. While waiting for FORUM measurements, test comparisons could be made using the current IASI dataset, limited to the MIR region.
- A key Level 2 product of FORUM will be surface spectral emissivity of Polar regions, in the FIR. It is important to evaluate the impact of corrected FIR spectral emissivity on global climate predictions. Also, it would be important to establish whether FORUM and IASI-NG could be used to build global maps of FIR + MIR surface spectral emissivity.
- It could be useful to perform FORUM impact studies at national level in view of future studies that will be performed by ESA.
- The national community could give an important contribution to the FORUM science plan and instrument data analysis, especially exploiting the synergies between FORUM and other instruments such as IASI-NG, 3MI, the MicroWave Sounder (MWS) and also Climate satellites.
- Only 20% of the satellite observations are assimilated in NWP models. Need to further develop models and data-assimilation methods / tools to be able to exploit all the satellite data available.
- The assimilation of radiances and new convective schemes are the improvements in NWP models that have had the largest impact. We can expect that the addition of the assimilation of FIR radiances will produce further improvements.
- The development and the operational use of ensemble-based data assimilation approaches will allow a more thorough diagnostic of the models, define more accurate initial conditions, and thus improve model predictions.
- Earth Observation and in situ data relevant to cloud properties and radiation are crucial to tune and validate global climate models, to quantify feedbacks and to constrain parameterizations.
- Need for models which can benefit from the availability of a data assimilation system and can perform short initialized forecasts.
- Need for higher resolution global climate models.
- Importance of inter-comparisons between EC-Earth Climatology and IASI observations for global climate model investigation. More investigations are needed considering the possibility to use the σ-FORUM radiative transfer model for calculations in all-sky conditions.
- Errors contained in EO data and model parametrization translate differently in forecast, also considering different time periods for data assimilation: need for a better knowledge and characterization of error sources.
- Satellite observations are fundamental for model set-up and diagnostics as well as to tackle Sub-seasonal to seasonal (S2S) prediction by using data assimilation approaches (e.g. EnKF).

Data assimilation in NWP

- Data Assimilation (both model and data driven approaches) are useful to speed up model inversion, to analyze multi-scale climate dynamics, to infer key invariant quantities.
- Need for more in-depth investigation of Machine Learning (ML) approaches for climate/weather model analyses, also together with data assimilation techniques to infer unresolved model parametrizations.

- Need for more experimentation and analysis of data assimilation approaches for local models as well as climate/weather forecast.
- Data assimilation results (e.g. the ones provided by 3DVar) are useful to retrieve L3/L4 products for atmospheric / climate / weather analyses: however, not always data assimilation can ensure accurate results with respect to in situ data or reference ground truth.
- Need to constrain climate / weather models with observations and need to refine the physical representation of phenomena within the model, to be more sensitive to the available observations.
- Importance to evaluate and assess data assimilation approaches (e.g. ML, EKF, ESF), in combination with physically-based models and in situ data availability, for FIR spectral investigation.
- Need to increase the computational power of processing resources, to face the new challenges of model inversion and data assimilation.
- The σ-FORUM radiative transfer model was implemented within an EC-Earth module to generate a climatology of spectral radiances predicted by EC-Earth. This climatology was then compared to that extracted from IASI measurements. The computational costs of this operation are very high and required the use of a super-computing facilities. So far, this analysis was limited to clear-sky atmospheres. Extension to all-sky and a more in-depth comparison analysis are in progress.
- Need to improve model tuning for analysis of impacts on ECS: works are in progress related to multi-variate analysis, also in cloudy sky conditions.
- EO data is useful to study parametrizations, anomalies and then improve existing models / simulators.

Parametrizations

- The monochromatic σ-FORUM radiative transfer model has been improved with an advanced version of the Chou approximation (including the so-called Tang correction) for cloud and aerosol optical properties parametrization: different Tang coefficients in FIR and MIR spectral ranges are needed to provide accurate simulations of scattering layers.
- Importance to include EO measurements related to the biosphere (land / vegetation) for climate / weather forecast as well as enhancement of EC-Earth model performances: some meaningful results are provided within PROCEED and CONFESS projects.
- Actual land-vegetation satellite Copernicus observations are fundamental to better constrain models adopted for land cover analyses, vegetation phenomena and hydrogeological processes.
- It is important to continue exploiting land-vegetation observations for climate / weather modelling and the parametrization of hydrogeological processes: more realistic and constrained surface emissivity measurements are needed for land models. To be assessed whether FORUM + IASI-NG will be able to provide “global” land spectral emissivity measurements.
- An accurate parametrization of cloud / aerosol optical properties and of cloud formation is essential to improve climate forecast and reduce prediction uncertainties.
- Model computational performances need to be improved by exploiting parallel computing schemes and explore the possibility to use neural network approaches.

- Climate observatories are fundamental to provide in-situ measurements for the analysis, the parametrization and modelling of aerosol/cloud optical properties: the exploration of FIR spectral range is fundamental to improve the knowledge of such properties and fill the actual gaps in this spectral window.
- Calibrated and well-maintained instruments are required for a better local parametrization of cloud / aerosol optical properties: specific coefficients have to be calculated based on local/site atmospheric and surface conditions.
- σ-IASI/FORUM/IASI-NG/MTG-IRS/HIRAS model: a) flexible and accurate fast RTM that can be used as part of an inversion scheme to retrieve geophysical parameters; b) best performances are ensured in terms of speed / accuracy ratio; c) possibility to calculate analytical derivatives with respect to temperature, atmospheric constituents' abundance and surface properties (temperature and spectral emissivity). Derivatives with respect to liquid / ice water content and with respect to their drop / particle effective dimensions can also be computed.
- EE-11 candidate mission WIVERN and potential synergies with modelling and data assimilation communities: a) satellite able to provide Global in-cloud Winds, Precipitation and Cloud Properties, extending lead-time and predictive skills of NWP as well as improving weather / climate model parametrization; b) very innovative radar solution (conically scanned W-band radar with doppler implementation via polarization diversity); c) Possibilities to be explored for data assimilation in global and regional models.

Recommendations

- Improve the potentialities of regional forecast models through the assimilation of radiance measurements of the FORUM mission, exploiting simulated FORUM products and / or the MIR radiances measured by the existing IASI missions.
- Develop / improve and test data assimilation systems, including the functionality of assimilating multi-sensor data.
- Explore the use and customization of the σ-FORUM code for the assimilation of measured spectral radiances in NWP models.
- Investigate possible improvements of the FORUM products by exploiting its synergy with the measurements from sensors other than IASI-NG (e.g. 3MI and the MWS).
- Develop / improve / test strategies to tune climate models (e.g. EC-Earth) on the basis of comparisons between model-predicted and measured spectral radiances.
- Start impact studies of new surface emissivity data in the FIR and TIR on the performances of climate models, to prepare the climate / NWP models to exploit the FORUM measured emissivity.
- Study and improve the accuracy of cloud / aerosol parametrizations in the FIR, exploiting the available ground / airborne spectral measurements, in view of future use of FORUM observations.
- Improve synergies among national scientific communities working with EO data through joint projects and/or studies on FORUM-related topics, e.g.: data assimilation, climate model tuning, impact studies, assessment of processing techniques, exploitation of synergies, etc.

- Strengthen the available ground-based measurement sites / airborne facilities for validation campaigns. The sites should be equipped with sensors covering the FIR region of the spectrum and additional sensors to measure cloud properties. These additional measurements would enable to perform closure studies and to improve forward model parametrizations via comparison to FORUM measurements.