Horizon 2020

Societal Challenge: Improving the air quality and reducing the carbon footprint of European cities

Project: 690105 – ICARUS

Full project title:

Integrated Climate forcing and Air pollution Reduction in Urban Systems

MS.17 Definition of the methodology to evaluate radiative forcing changes

WP3- Integrated atmospheric modelling for connecting pressures to the environment to concentrations at the regional and urban scales

Lead beneficiary: Fondazione CMCC

Date: April 2018

Nature: Report

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Document Information

Grant Agreement Number	690105	**Acronym**	ICARUS
Full title	Integrated Climate forcing and Air pollution Reduction in Urban Systems		
Project URL	http://icarus2020.eu/		
Project Officer	Mirjam Witschke - Mirjam.WITSCHKE@ec.europa.eu		

Delivery date	**Contractual**	April 2018	**Actual**	April 2018
Status	Draft ☐		Final X	
Nature	Demonstrator ☐	Report X	Prototype ☐	Other ☐
Dissemination level	Confidential ☐	Public X		

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Document History

Name (Institution)	Date	Version
CMCC	March 2018	V1
AUTH	March 2018	V1_revised
CMCC	April 2018	Final

1 Introduction

The aim of this document is the definition of the methodology to apply for the evaluation of the changes in the surface radiative forcing associated to the aerosols due to implementation of mitigation strategies at local level as required by the deliverable D3.5, due at month 48.
The Characterization of aerosol in terms of global warming potential is suggested through the application of a simplified scheme that translates different types of Aerosols Optical Depth (AOD) changes into a first order assessment of radiative forcing. This will be done assigning a surface Radiative forcing change (ΔF) to changes in Aerosols Optical Depth (AOD) associated to different species, based on the Chylek and Henderson (2003) method. The availability of a CMCC present climate simulation at the global scale, based on a fully Coupled General Circulation Model with an aerosol module implemented within its atmospheric component, give us the possibility to verify the consistency between changes in vertically integrated aerosols concentrations and the relative changes in AOD, associated to mitigation strategies, as provided by WP2 and WP3 (see deliverable D3.3). Also the CMCC model will provide a measure of the interannual variability of the AOD associated to different species, useful to compare the magnitude of the changes induced by the mitigation strategies implemented within ICARUS over the designed cities.

2 The ΔF estimate

The term "radiative forcing" has been defined by the Intergovernmental Panel on Climate Change (IPCC) to represent an externally imposed perturbation in the radiative energy budget of the Earth's climate system. Such a perturbation can be brought by changes that affect the radiative energy absorbed by the surface (e.g., changes in surface reflection properties). This imbalance in the radiation budget has the potential to lead to changes in climate parameters and thus result in a new equilibrium state of the climate system. The radiative forcing (ΔF) of the surface-troposphere system due to the perturbation in or the introduction of an agent (i.e. a change in greenhouse gas concentrations) is the change in net irradiance (solar plus long-wave; in [Wm−2]). In the context of climate change, the term forcing is restricted to changes in the radiation balance of the surface troposphere system imposed by external factors, with no changes in stratospheric dynamics.

Radiative forcing is a useful tool for a first order estimate of the relative climate impacts due to radiatively induced perturbations. The practical appeal of the radiative forcing concept is due, in the main, to the assumption that there exists a general relationship between the global mean forcing and the global mean equilibrium surface temperature response (i.e., the global mean climate sensitivity parameter, λ). This parameter is similar for all the different types of forcings. With an approximate approximate near invariance of λ of the order of about 25%.

Based on the assumption that

$$\Delta T_S / \Delta F = \lambda$$

eq.1

Based on tipically values of λ (0.5 k/wm-2 +-25%), it is possible to derive ΔTs (surface temperature variations values that we can expect based on the different radiative forcing parameter (ΔF) considered. Such ΔF parameter strongly depends on the considered species and simplified approaches conducted to a series of formulas to derive ΔF from species concentrations We consider table 6.2 in IPCC 5th Assessment Report (https://www.ipcc.ch/report/ar5/), chapter 6 for the present work, but an additional effort must be made for the derivation of ΔF associated to changes in aerosols concentration.

The impact of aerosols on the magnitude of incoming and outgoing solar radiation in the atmosphere and, therefore, Earth's climate, is largely determined by their optical properties. The optical properties of aerosols are crucial for evaluating their effect on radiative forcing and are dictated by the relative humidity, wavelength of incident light, and aerosol chemical and physical properties, especially size.

In order to obtain ΔF values associated to changes in the AOD expected for each of the considered aerosols species, based on the different mitigation strategies, we leverage on Chylek and Henderson (2003) formulation, defined within a theoretical study investigating uncertainty in aerosol optical properties, defined as:

$$\Delta F = \frac{\partial F}{\partial \tau}\Delta\tau$$
$$= -2\frac{S_0}{4}T^{+}T^{-}(1-N)\Big[(1-a)^2\beta\omega - 2a(1-\omega)\Big]\Delta\tau.$$

eq.2

where: $\Delta\, \tau =$ change in aerosol optical depth (AOD),

S_0 = 1368 W/m-2, T+ T_ = 0.80, N = 0.5, a = 0.2 for the land and a = 0.05 for the ocean, b = 0.20 and w = 0.95, from which we obtain dF /dt = 29 for the land and dF /dt = 46 over the ocean.

3 The CMCC Models involved in the analysis

The CMCC General Circulation Model

Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the Coupled Model Intercomparison Project (CMIP) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). CMIP provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyze GCMs in a systematic way. CMCC participated to the last CMIP effort (the CMIP5) with a bunch of GCMs, at different horizontal resolution and with different implementations. The CMCC model used in this study is an atmosphere-aerosol-ocean-sea ice coupled model consisting of ECHAM5 as atmospheric component, OPA 8.2 as oceanic component, LIM2 as sea ice model, and the HAM module for aerosols [D'Errico et al. 2015]. interactively coupled (namely, the CMCC aerosol climate model). The software used to couple the atmosphere (including the aerosols) and the ocean components is OASIS3. Basically, the atmosphere-ocean-sea ice coupled components are the same of the state-of-the-art CMCC-CM coupled model [Scoccimarro et al., 2011; Fogli et al., 2009], but here the atmosphere is at lower resolution and interactively coupled with an aerosol module. In this study ECHAM5 is used with six shortwave radiation bands [Cagnazzo et al., 2007] and a horizontal resolution at triangular truncation T63 with 31 vertical levels and the top of the atmosphere at 10 hPa. OPA8.2 is a primitive equation ocean general circulation model that is numerically solved on a global ocean curvilinear grid known as ORCA [Madec and Imbard, 1996]. Here we use ORCA2, with a resolution of 2° of longitude and a variable mesh of 0.5–2° of latitudes from the equator to the poles. The vertical grid has 31 levels (the 31st level is below the bottom) with variable layer depth and a constant 10m step in the top 100 m. The aerosol module HAM has a prognostic representation of the composition, size distribution, and mixing state of the major global aerosol components: sulphate, black carbon (BC), particulate organic matter, sea salt, and mineral dust (DU) [Stier et al., 2005, 2007]. The module predicts the evolution of an ensemble of microphysically interacting internally and externally mixed aerosol populations. The lifetime is estimated as the ratio of the column burden to the total source: the BC lifetime is 5.4 days and the lifetime for DU is 4.6 days as reported in Stier et al. [2005] (their Table 5). The scheme for dust emissions is based on Tegen et al. [2002, 2004], while that of sea-salt emissions is based on Schulz et al. [2004]. For black and organic matter, fossil fuel and biofuel [Bond et al., 2004], vegetation fires [Van Der Werf et al., 2003], and biogenic emissions are used. The aerosol properties generated from the ECHAM5-HAM coupling have been analyzed in detail in previous works: the model is able to simulate anthropogenic aerosol concentrations and aerosol optical depths reasonably well [Folini and Wild, 2011; Henriksson et al., 2011; Stier et al., 2005, 2007]. In this study the aerosol single scattering albedo, i.e., the ratio of the extinction due to scattering to the total extinction due to scattering and absorption, is derived from Aerosol Robotic Network.

A long simulation representing the present climate has been conducted, with oceanic initial conditions derived from a stable control simulation (about a thousand of years). For ICARUS purposes we aim to analyze the last 35 years of this experiment with external forcings kept constant (fixed to conditions typical for the year 2000). Forcings include the concentrations of well-mixed green-house gases and incoming solar irradiance for year 2000 from the CMIP5 forcing data. The seasonally varying ozone distribution is repeated every year and is based on the 2000 year climatology. For aerosols, the emission data set is based on the Aerosol Comparisons between Observations and Models (AeroCom) aerosol model intercomparison project inventories for the year 2000 [Dentener et al., 2006].

Due to the low horizontal resolution of the aforementioned model, the representation of the averaged values around the selected ICARUS cities will be based on few grid points.

The relationship between air temperature and aerosols concentrations (or/and AOD) will be investigated also in terms of interannual variability based on monthly anomalies covering the entire 35 period. As a preliminary example, Figure 1/2/3 represent the interannual variability of SO4/Black Carbon/Organic Carbon, compared to the air temperature over Athens as resulting from CMCC model. Upper panel represents the air temperature time series anomaly and the central and lower panels represent burden concentration and optical depth respectively.

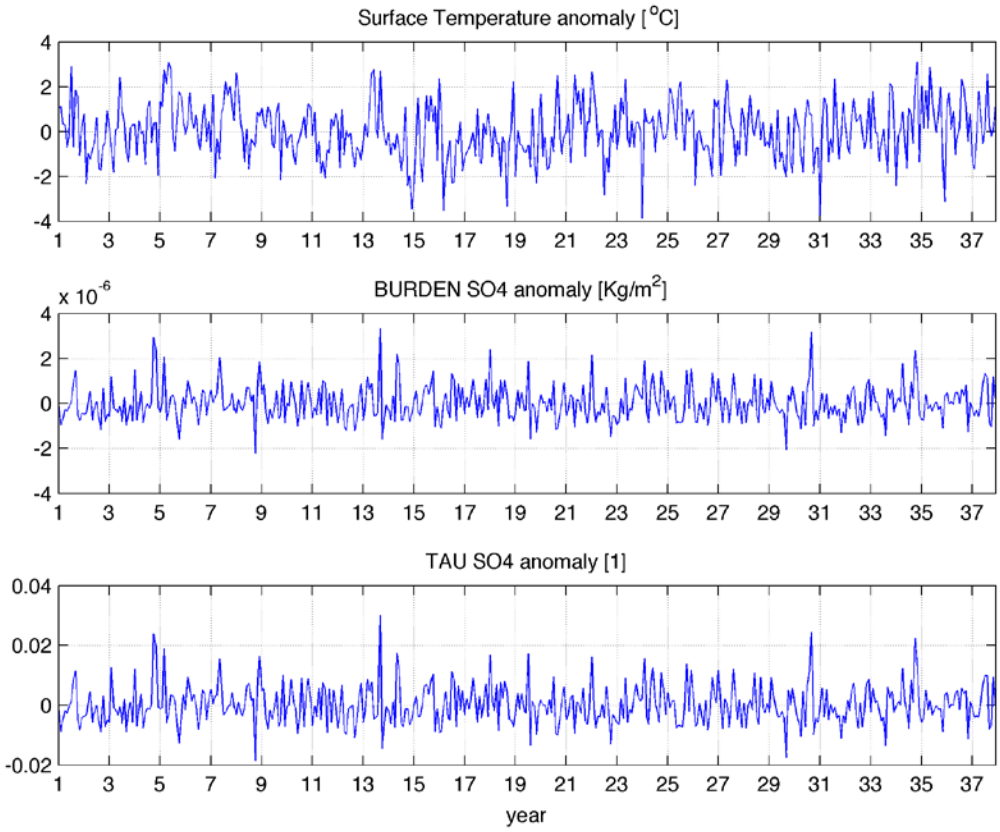

Figure 1: Anomalies of air temperature (1st atmospheric level, upper panel), Burden SO4 (central panel) and SO4 Optical Depth (lower panel) over the city of Athens as represented by CMCC model.

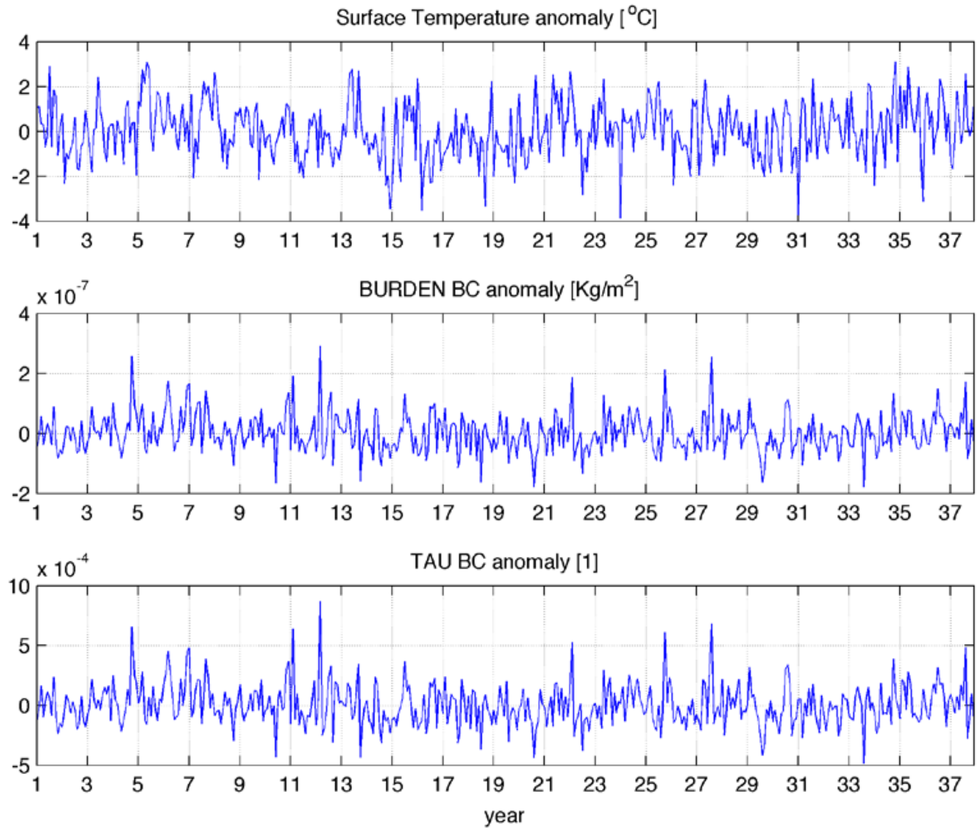

Figure 2: Anomalies of air temperature (1st atmospheric level, upper panel), Burden Black Carbon (central panel) and Black Carbon Optical Depth (lower panel) over the city of Athens as represented by CMCC model.

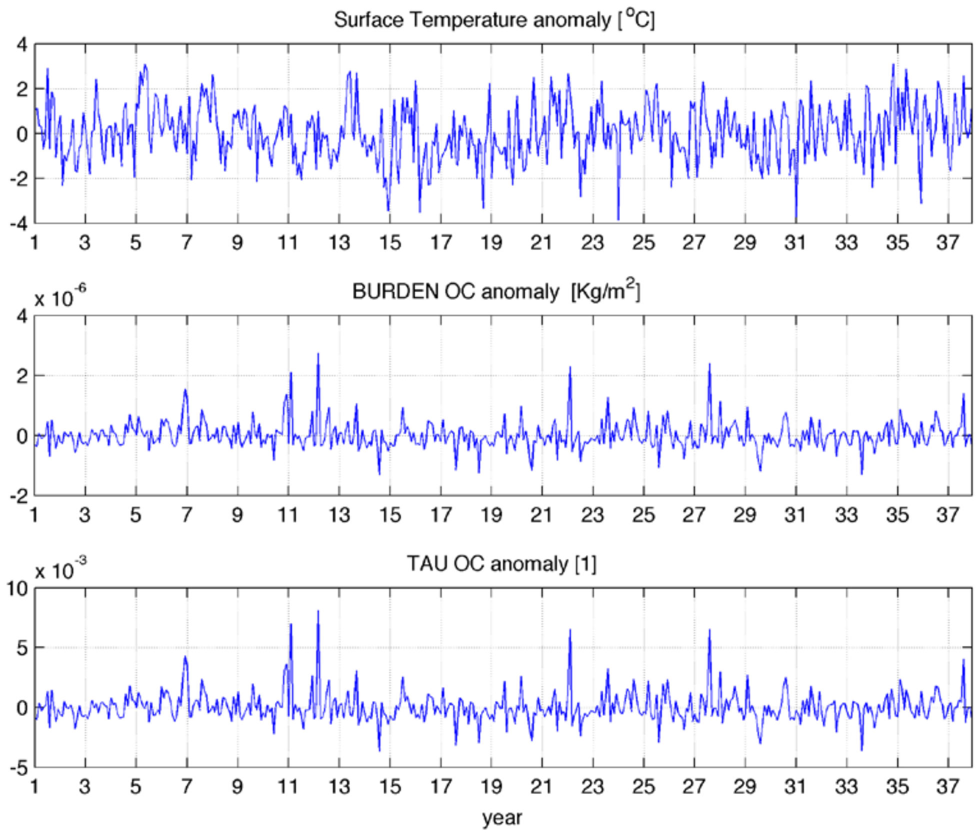

Figure 3: Anomalies of air temperature (1st atmospheric level, upper panel), Burden Organic Carbon (central panel) and Organic Carbon Optical Depth (lower panel) over the city of Athens as represented by CMCC model.

The CMCC COSMO-MFS Regional Model

In case of significant differences in the radiative forcing induced by the ICARUS mitigation strategies over the selected cities, the CMCC COSMO-MFS Regional Climate model will be used to perform targeted simulation (10 years around the selected year) with the aim to dynamically verify the induced effect on surface temperature.

The CMCC COSMO-MFS (Cavicchia et al. 2014, 2016) is the one contributing to the MedCORDEX (https://www.medcordex.eu/) simulations with a set of regional models implemented in the Mediterranean region. Specifically, the COSMOCLM, limited area atmospheric model can be employed in standalone mode or used in coupled mode with the oceanic model NEMO implemented in the Mediterranean basin. COSMOCLM (Rockel et al. 2008) is the climate version of the COSMO model (Steppeler et al. 2003), the operational nonhydrostatic mesoscale weather forecast model developed at the German Weather Service (DWD). Successively, the model has been modified by the CLMCommunity, in order to develop also climatic applications. The updates of its dynamical and physical packages allow its application in cloud resolving scales (Doms and Forstner 2004). It can be used with a spatial resolution between 1 and 50 km. For more details on the formulation of the model and on the parameterization settings, the reader is addressed to (Holton 2004 ; Tiedtke 1989). In the present version of the coupled AORCM, the atmospheric component COSMOCLM is implemented with a spatial resolution of about 0.44 (about 44 km) and 40 vertical levels. The spatial domain covers the Mediterranean region, including an Atlantic box, ranging from 54W67E and 8.75N63.75N (Figure 4). The choice of the domain is justified by the need to cover the Mediterranean basin region, including an area over the eastern part of the Atlantic Ocean (Atlantic box), which is necessary to the coupling with the Mediterranean Sea model. The ocean component of the system is NEMOMFS, a regional configuration of Nucleus for European Modelling of the Ocean (NEMO; Madec 2008) implemented at very high resolution in the Mediterranean basin. As it has been shown in Oddo et al. (2009). NEMOMFS is an eddy permitting marine model able to represent the dynamical processes that characterize the Mediterranean Sea. In the present configuration of the coupled AORCM, NEMOMFS has a 1/16_ (about 6.7 km) horizontal resolution and 71 levels along the vertical.

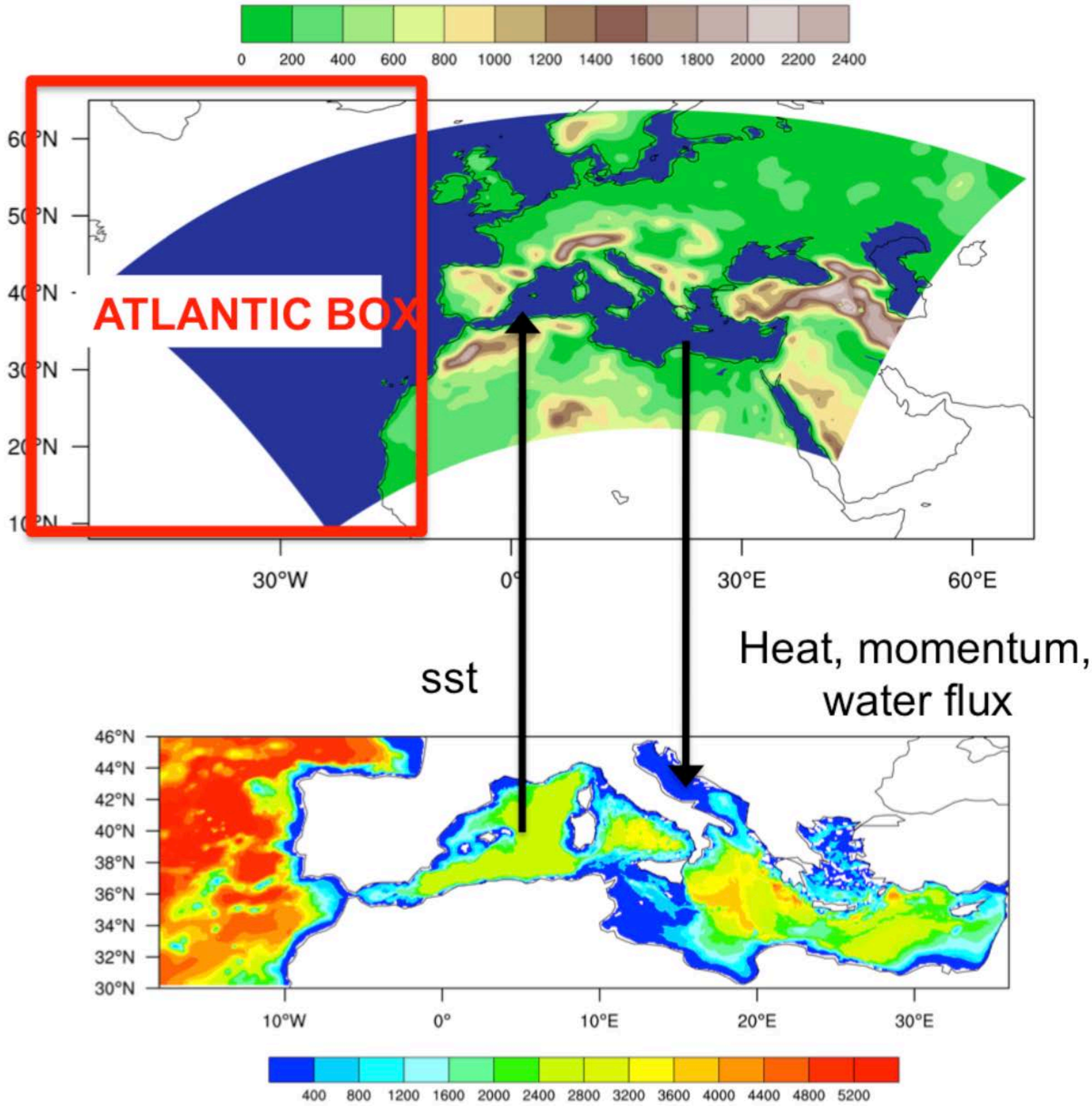

Figure 4: CMCC COSMO-MFS model components and domain.

4 Data availability

In addition to the two different climate data set already available for ICARUS partners, we plan to provide the air quality model results used as an input for the current analysis on the same FTP site. This will be done for each of the modelled ICARUS domains (as defined in D3.3).

The data format used is, where possible, NetCDF (http://www.unidata.ucar.edu/software/netcdf/). NetCDF is an abstraction that supports a view of data as a collection of self-describing, portable objects that can be accessed through a simple interface. Array values may be accessed directly, without knowing details of how the data are stored. Auxiliary information about the data, such as what units are used, are stored with the data. Generic utilities and application programs can access NetCDF datasets and transform, combine, analyze, or display specified fields of the data.

Data are made available through the CMCC ftp server (download.cmcc.bo.it – user and passwd sent privately to the ICARUS partners reference person).

The results of the analysis described by this MS17 will be object of the D3.5 Technical report titled “Evaluation of the changes in the surface radiative forcing due to implementation of mitigation strategies at local level” due at month 42.

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