EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026……………………………………………………
Project Title:	*EC-EARTH-V3 HYWAY* - spnlwill
Computer Project Account:	nl4……………………………………………………
Principal Investigator(s):	Dr J. E. Williams
Affiliation:	KNMI……………………………………………………
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A……………………………………………………….
Start date of the project:	2025…………………………………………….……
Expected end date:	2028…………………………………………….……

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	22000000	14300000	6000000	5,418,604
Data storage capacity	(Gbytes)	3000	1000	3000	1000

Summary of project objectives (10 lines max)

To update the ECEarthV3 coupled Earth-System model with updated chemistry, reaction rate data and the introduction of molecular H_2 as a transported tracer for the purpose of investigating the impact of the transition towards the H_2 economy on air quality and climate. By conducting decadal simulations the model will be evaluated both with and without direct H_2 emissions and deposition terms in the first year of the project. Results will then become part of an ensemble study with the aim of investigating the largest uncertainties in the global H_2 budget.

Summary of problems encountered (10 lines max)

After the updates performed last year a technically stable version of ECEarthV3 was achieved meaning that focus could be placed on exploiting this version towards achieving the project aims. In summary no significant problems were encountered, apart from running out of disk space on $SCRATCH resulting in delayed execution. This could be solved by linking spare capacity on other users storage space which will be explored in the coming months. Moreover, the estimation of 6000 ksbu's was too conservative and a request was made towards the end of 2025 to increase this allocation, in order to benefit from unused resources allocated to other projects.

Summary of plans for the continuation of the project (10 lines max)

The first phase of Hyway completes in September 2026, which is then followed by a second 18-month simulation period which puts more focus on the changes in future years rather than evaluating the performance of the model ensemble for the near-present period (2010-2019). This involves integrating and implementing new emission inventories which account for changes in the most important emission terms for NOx, CO, SO_2 as well as future predictions of H_2 emissions from the transition to the hydrogen economy (https://iopscience.iop.org/article/10.1088/2753-3751/ae69e3). An overview of the timeline is shown in a Figure #1 below.

List of publications/reports from the project with complete references

This initiative aims to use model output performed during the HYway project towards a spin-off intercomparison project focusing on the differences between VOC distributions across different global Earth_system models (https://gmd.copernicus.org/articles/19/2577/2026/)

The exploitation of the existing results is ongoing across project partners focussing on validation of the model ensemble and the sensitivity of results to perturbations.

Summary of results

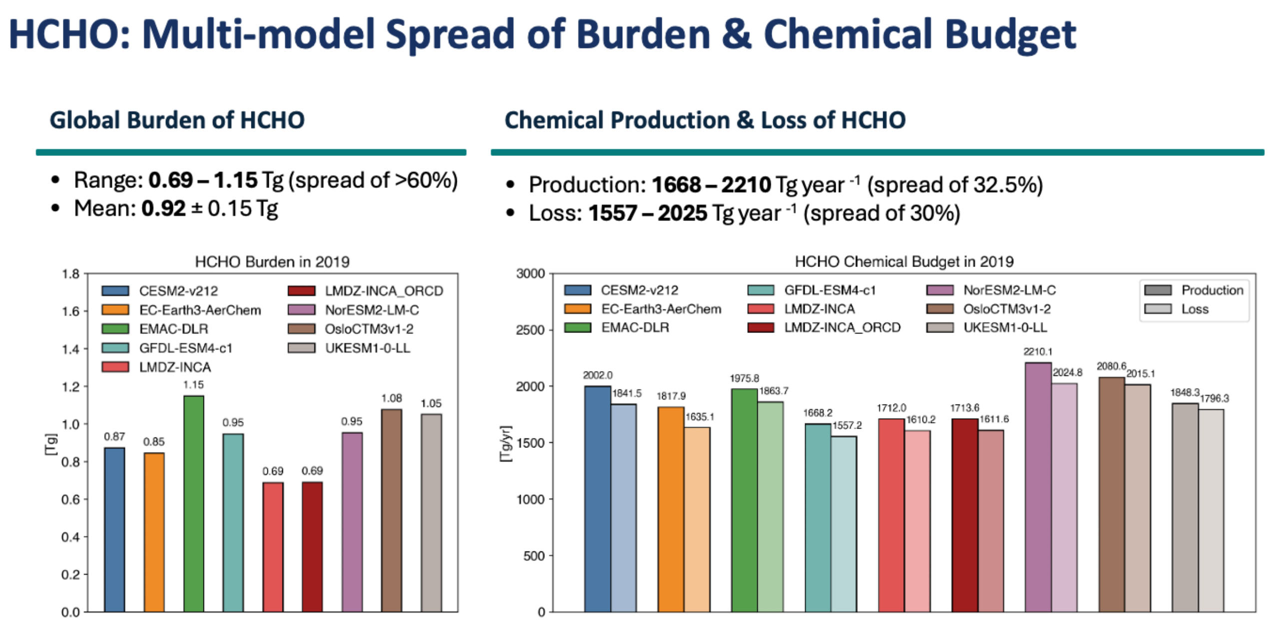
The table below summarises the work plan which has been performed during 2026. A transient 10 year run with high frequency output for 2015/2019 to aid evaluation of the model ensemble has been completed (Sim#1). For these simulations the EC-EARTHv3 model was nudged towards a ERA-5 archive in order to constrain the meteorological component. A set of four perturbation simulations (20 years total, with 2019 repeating to achieve chemical equilibrium, Sim #2) was completed focusing on the year 2019 to investigate the impact of uncertainties in H_2 emissions and CH_4 distributions on the Radiative Forcing in the Stratosphere via differences in H_2O. Sim#3 was not feasible with ECEarthV3 due to the lack of active CH_4 emissions. A pre-industrial simulation was also performed (1850 emissions, 2019 meteorology) to allow an assessment of the influence of growing anthropogenic emissions on the distribution of tropospheric H_2 and the H_2 budget. For the next few months, Sim#5 and #6 are planned in order to complete the first phase of the HYway project.

Processing of the multi-model data has been done on $SCRATCH using cdo scripts allowing the production of daily files from aggregated model output for the purpose of evaluation against numerous observations.

Figure 1 : An outline of the simulations involving EC-EARTHv3 as planned in the HYway project.

Sim#	Purpose	Set-up	WPs	Task
	Phase 1:			
1	How well represented is the model chemistry?	Transient 2010–2019. Fixed surface concentrations of H_2 and CH_4	4	4.2
2	How large is the effect on atmospheric composition and radiation of a flux of H_2?	H_2 emissions, fixed surface concentration CH_4	4,5,7	4.4
2a		Control present-day		
2b		2a + perturbed H_2 emission		
2c		2a + perturbed CH_4 fixed surface concentrations		
3	Are we able to model the effect of methane using fixed surface CH_4 concentration in 2? And what are the timescales of the perturbations?	H_2 emissions and CH_4 emissions	4,5	4.4
3a		Control present-day		
3b		3a + perturbed H_2 emissions		
4	Based on ice core data and pre-industrial simulation, can we gain more insight into the H_2 budget?	Same set-up as 2a but for pre-industrial (1850)	7	7.4
5	Does location of the H_2 emissions matter?	Same set-up as 2 but perturb different regions/sectors	4,5	4.3
6	How will a different atmospheric composition affect the effect of a hydrogen flux?	Same as 2, but for different future atmospheric composition (e.g., high/low NO_x, CO)	4,5	4.4

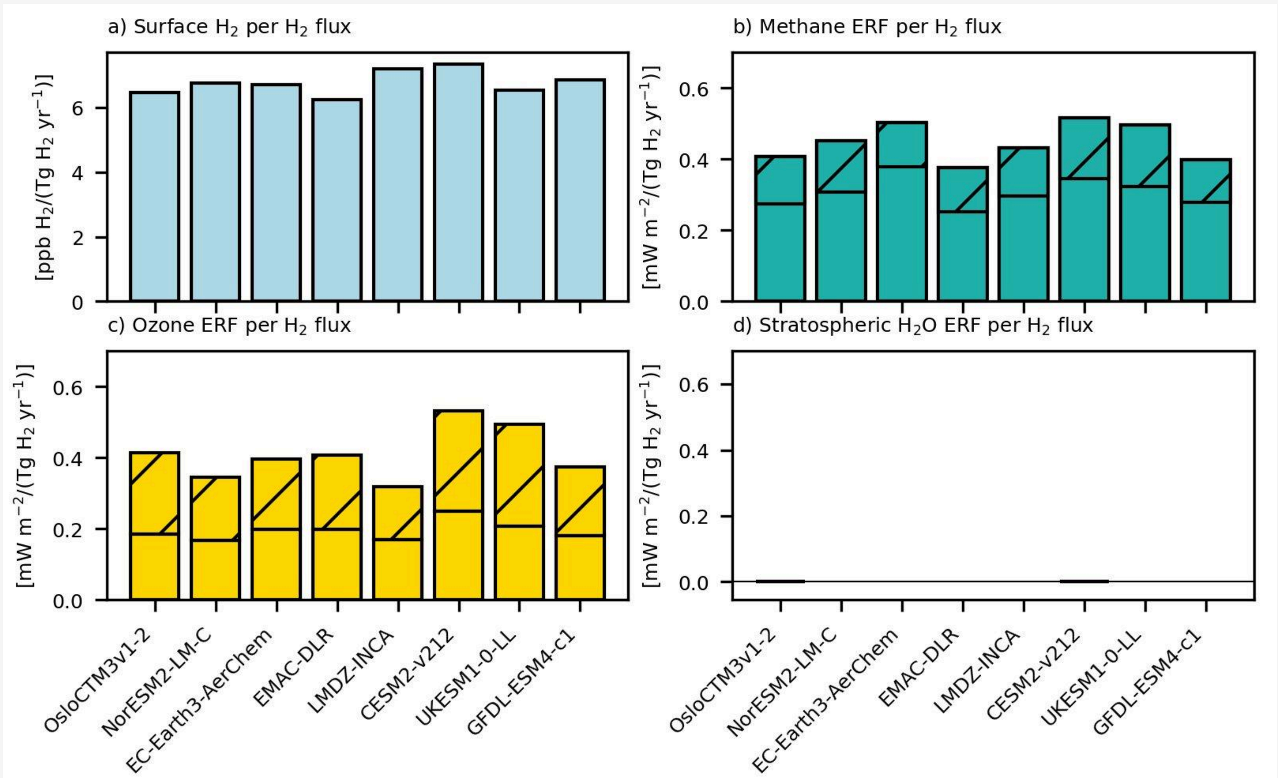
Figure 2: The variability in the global annual chemical budget terms for 2019 across each of the models participating in the HYway project.



A novel feature of the HYway project is the high-frequency output of 3D chemical budget files allowing an in-depth assessment of differences in H_2 and HCHO (the main chemical precursor). Figure 2 shows a multi-model intercomparison of the Global HCHO 3D budget terms for 2019 as taken from the transient Sim#1, showing the variability across models due to grid resolution, different chemical mechanisms, differences in photochemical activity and the meteorology included in each of the models.

Figure 3 shows the differences in the RF contributions across models for the main gases as weighted with respect to each Tg of H_2 emitted in each model. This was conducted using the output provided from Sim#2. Here it can be seen that EC-EARTHv3 performs near the ensemble mean.

Figure 3 : A comparison of the RF contributions from CH_4, O_3 and stratospheric H_2O at equilibrium, per unit of H_2 emission as calculated in the HYway ensemble.



In order to provide confidence on the performance of the HYway model ensemble for the present day comparison have been made using a variety of round-based, aircraft and satellite comparisons. In the following figures I provide a brief overview of the evaluation performed using the high-frequency 3-hourly output allowing detailed comparisons against observations for 2015 and 2019, corresponding to the mid-point and the end-point of the 10-year simulation. Figure 4 shows vertical profiles of O_3, H_2O and HCHO against those measured during aircraft flights during the WINTER (Feb/Mar 2015) and SONGNEX (Mar/Apr 2015). In general the vertical gradients are captured well, although significant differences occur near the surface and in the boundary layer.

Figure 5 shows a comparison of the hydroxy radical (OH), which influences the lifetime of CH_4 and subsequently influences the RF in the atmosphere. Observational data is attained via the observation and subsequent processing of precursor gases such as HCHO and NO_2 (not shown) thus has some implicit uncertainty in the value shown. The model output is taken from the 3-hourly data provided during the evaluation years. It can be seen that a large degree of spatial variability exists across the various models which ultimately affects the tropospheric H_2 burden, with OH + H_2 being the only chemical removal process.

Figure 4 : A comparison of vertical profiles assembled from aircraft measurements for Feb-Apr 2015 over the continental United States, along with co-located profiles extracted from each of the HYway models. Gases shown are O_3 (top right), H_2O (top left) and HCHO (bottom panels).

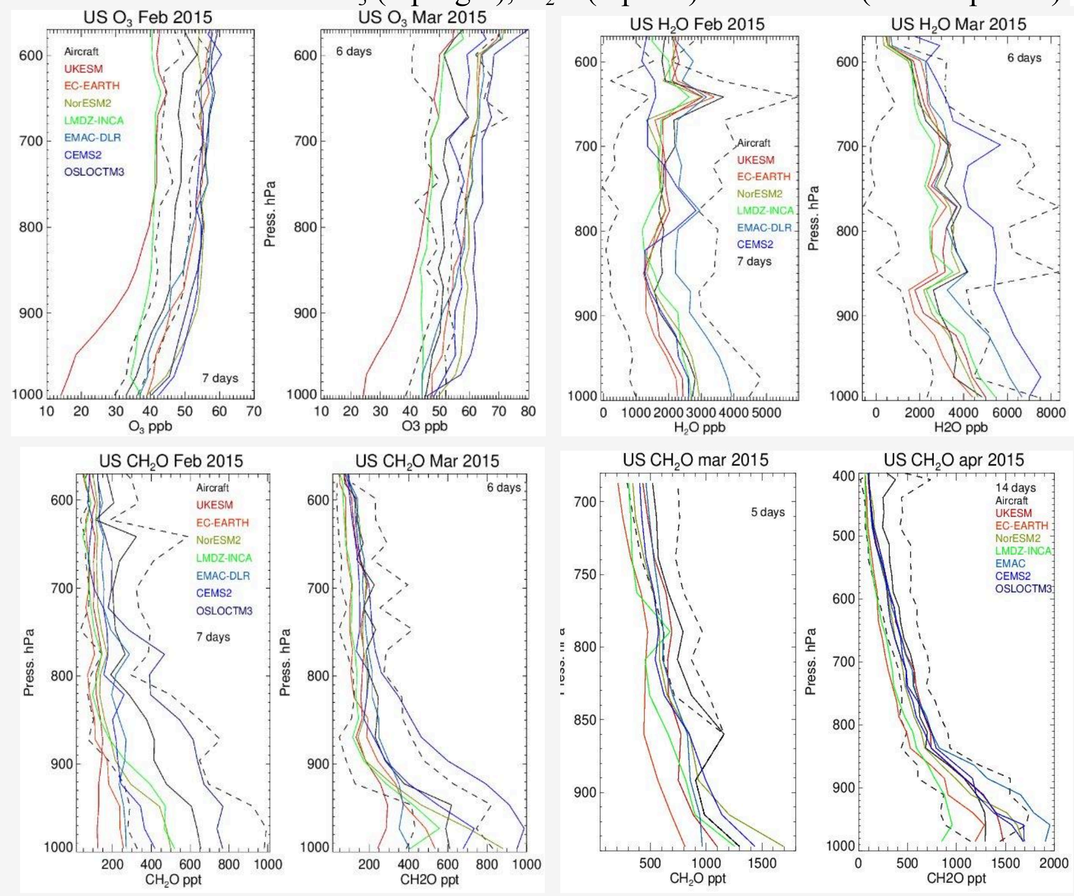


Figure 5 : The spatial distribution of column-averaged airmass-weighted tropospheric mean OH fields derived from (a) observational data and (b)-(h) the various HYway models as sampled during the transient 2010-2019 simulations. Global airmass weighted averages (molecules cm^{-3}) are shown in each of the panels.