OSCAR scenarios

Background

The existing knowledge and results of the complementary OSCAR studies have been summarized in knowledge rules. Based on these knowledge rules, conceptual models on the effect of woody buffers on nutrient retention, water temperature, ecosystem services and biodiversity have been developed. As far as possible, the conceptual models have been translated to Bayesian Belief Networks (BBNs).

The conceptual models and BBNs have been applied in case-study catchments to investigate the potential future effect of different riparian management practices (increasing or decreasing the extent of woody buffers), finally identifying woody buffer configurations with an optimum high overall effect.

Overview on the approach

A common set of storylines for three future scenarios was developed, the two most extreme future conditions as well as an intermediate scenario. These storylines include a description of the general socio-economic and climatic setting or boundary conditions within which river management act but that cannot be influenced locally by river managers (Fig 1). They were used to derive one riparian management package (RMP) for each of the three scenarios together with the stakeholders in each of the four case-study catchments, describing the measures that can be taken locally by river managers given the general socio-economic, political and resulting climatic conditions. The RMP were finally operationalized and implemented in GIS and used in the scenario runs in the four case-study catchments.

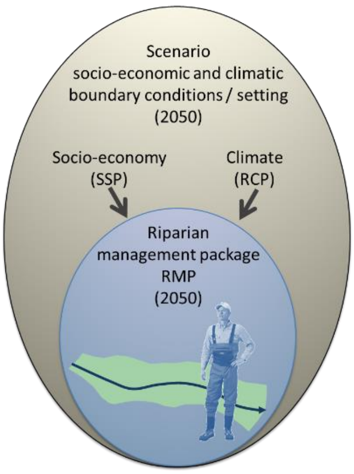

Fig. 1: Scenarios on socio-economy and climate, setting the boundary conditions for the measures that can be taken locally by river managers (according to the expert opinion of the stakeholders), described in riparian management packages (RMPs).

A more detailed description on the development of the storylines and how the outcomes of stakeholder workshops have been considered is available in Vermaat et al. (2018), which reflects the state of work in 2018. Please note that the names of the scenarios have been changed afterwards, based on recommendations from stakeholders and more detailed climate data have been finally used for the modelling and scenario runs (CORDEX instead of CLIMSAVE).

Scenario background and study design

In current scenario literature, the socio-economical side of global change is separated from the geophysical aspects (e.g. Van Vuuren & Carter, 2014), arguing that different socio-economic conditions can lead to similar climate change effects, i.e. that socio-economic and climate scenarios cannot be linked one to one. The socio-economic conditions are described in so called Shared Socio-Economic Pathways (SSPs), and the geophysical climate change aspects are grasped by Representative Concentration Pathways (RCPs).

Briefly, the former IPCC global change scenario (SERS) A2 largely corresponds to the sustainability scenario SSP3 and B1 to the environmental degradation scenario SSP1. In correspondence, the climate change aspects of A2 are grasped by the similar pessimistic RCP 8.5, and B1 is assumed to correspond to the rather optimistic RCP4.5 (e.g. Van Vuuren and Carter, 2014). In addition to these two extreme scenarios, the intermediate socio-economic “business as usual” scenario SSP2 from O’Neill et al. (2017) was added after the first stakeholder workshop in the Nahe catchment and planned to be combined with the intermediate climate change scenario RCP6.0. However, RCP4.5 had to be used for the intermediate scenario runs since RCP6.0 model results were not available in the CORDEX dataset (CORDEX data were finally used for the nutrient and water temperature modelling since they provide a larger range of climate change models but these data had to be processed first, and hence, the readily available CLIMSAVE results were used for the stakeholder workshops at the start of the project, see section below). SSPs and RCPs were grouped although they strictly cannot be linked one-to-one since we found it difficult for stakeholders to separate and distinguish between future socio-economic and geophysical / climatic conditions in their imagination. In addition to these three future scenarios with 2050 as a time horizon, the present socio-economic and climate conditions were used as a baseline scenario, which was set to correspond to the conditions in 2010, in line with the 2006-2010 period used for the nutrient modelling. For brevity, we use 2010 as a label for our current baseline period, and acknowledge a band width of ± 5 years.

Using published literature on the SSPs and a freely available climate modelling tool from the CLIMSAVE project, plausible regional socio-economic conditions were deduced from the description of the global conditions in the SSPs, and regional climatic conditions were described. Based on these boundary conditions, a pessimistic, best-practice and ambitious riparian management package (RMP) was developed together with the stakeholders, corresponding to the environmental degradation, business as usual, and sustainability scenario. These RMP were then implemented in the four case-study catchments in GIS.

Socio-economic storylines

Using published projections on land use change, economic development and institutional changes, we deduce here plausible articulations of the wider societal (economical, political) and geographical setting within which river managers will operate towards 2050. This wider setting will influence but not fully determine the day-to-day working reality of a river basin manager. The storylines were partly based on the work of Vermaat et al. (2017) - who have done a similar exercise when they worked out what the full set of four SRES scenarios would mean in terms of input variables for the BIOSCORE database tool (full presentation in Delbaere et al. 2009; www.bioscore.eu) - as well as O'Neill et al. (2017).

An overall projection of the trajectories of societal change in SSP1, SSP2 and SSP3 used here in OSCAR is presented in Table 1. Based on this, we projected relevant ecological drivers and pressures operating at the scale of the river valley as well. These scenarios display a wide range in societal development and its effects on the river and its valley.

The articulated socio-economic dimensions of the three scenarios suggest that SSP3 will lead to less priority as well as institutional capacity and funding for implementation of environmental policy. This will affect agricultural practices and urban pollutant loads to rivers. SSP1 is contrasting markedly with this. As such, these two scenarios indeed may form the outer edges of the band width covering all trajectories of societal change. SSP2 is generally conceived as an intermediate baseline, where environmental sustainability is not a major policy focus, but also not fully abandoned. Regional differences may occur and different 'policy patchworks' may lead to a wide range of trajectories of societal change.

Table 1: Articulation of the three SSPs chosen in OSCAR for the societal and geographic setting of central European river valleys towards a time horizon of 2050, and a projection of drivers (or pressures) on river valleys. Articulation based on Vermaat et al. (2017), O'Neil et al. (2017), Riahi et al. (2017) and Popp et al. (2017) if not indicated specifically.

SSP1/RCP 4.5	SSP2/RCP 6.0	SSP3/RCP 8.5
Global trends in society		
Agriculture		
Innovative, ecological and economically rewarding 'green' agriculture for an expanding European market; rapid diffusion of new best practices. Focus on fair prices and reduction of transport offers considerable opportunities for jobs in the countryside, often in combination with rural tourism.	Relative importance of different economic sectors continues as current and industrial innovation proceeds at a low pace. Agricultural impacts on water quality are only partly mitigated and there is limited focus on a circular economy. Agricultural enterprises continue to expand in size and reduce in number.	Productivity weakened due to climatic, technological as well as financial constraints; global trade declines, whereas e.g. seed and agrotechnology becomes increasingly monopolized by a few international companies.
Human population density		
Stabilized, with substantial mobility across Europe. Gini coefficient stabilizes.	Human population increases slowly at a countrywide scale, but this occurs particularly in a limited number of urbanising centres.	Limited increases, particularly in larger cities and due to net immigration despite harsh policy, which however is implemented with limited success. Gini coefficient increases: distribution of wealth becomes more uneven.
Economic strength		
Strong and regionally differentiated productivity within a common market.	Economic growth is positive but limited. The European common market witnesses a stagnation, but European supranational institutions continue to exist and perform reasonably well despite criticism.	Weakened, local markets, slow economic growth worldwide; some global commercial players have monopolized vital resources and commodities and succeed in dominating otherwise strongly fragmenting markets.
Green environmental focus in policy		
Paris agreements on the reduction of greenhouse gas emissions are more than met, Strong innovative green industry; also water quality targets laid down in the WFD met by 2050. Planning and management of urbanization proceeds in an orderly and coordinated fashion.	Paris agreements are not fully met due to slow and incomplete implementation at the national level and strong, successful lobbying by important sectors such as agriculture and transport. Policy coordination is not always successful.	Limited innovation, dependence on expensive, imported fossil fuel; limited focus on sustainability, also due to limited financial resources. Urbanisation is poorly managed.

Table 1 continued

SSP1/RCP 4.5	SSP2/RCP 6.0	SSP3/RCP 8.5
Global or national orientation in policy and culture		
Global, integration into a European federation with a strong overall focus on reducing environmental footprints, and local employability with considerably successful implementation. Policy issues of health and employment are successfully linked with environmental policy.	EU-wide and national environmental policies lose momentum in competition with other major policy issues such as health, employment and security.	Regional, increased nationalism, EU disintegrates and its legal strength in opposing global monopolists declines. Democratic institutions become less effective and credibility issues arise. Defence and security industry claim substantial shares of the limited national budgets.
Recreation		
Recreation in the countryside increases too, but with a focus on eco-tourism and 'leave-no-trace' outdoor life. Mediterranean tourist destinations remain important ensuring jobs in Southern Europe.	Recreation continues as currently with growing mass tourism based on air transport to favoured coasts in Europe and abroad. More Northern coasts, however, become more popular due to an increasingly adverse climate along e.g. the Mediterranean.	Recreation pressure in the national countryside increases due to limited financial resources, increased barriers on travel and increased nationalism; environmental awareness is limited however. Increasing summer temperatures however make southern areas less suitable for tourism (Vermaat et al., 2013).
Institutional strength and governance		
Strong, reliable institutions at national, supra-national and global level.	Not all supranational and national institutions succeed equal well in their societal recognition and democratic effectiveness. Bureaucracies are only partly modernised.	Weak, unpredictable institutions. National governments dominate but are trimmed in bureaucratic strength due to a prevalence in free-market and small-government adherence among ruling politicians.
Drivers and pressures in the river valley		
Land use change *(downscaled scenarios from Hellmann & De Moel, 2013 for the Elbe and Loire, used as best-guess for Nahe, Stever and Bresse)*		
German cases: a slight increase in 'natural' and abandoned land at the expense of arable land Rhone: distinct increase in natural and abandoned land at the expense of arable land	Relative allocation of land does not change, but agricultural intensification continues and environmental effects are not countered fully.	German cases: increase in arable land at the expense of natural land. Rhone: arable land and pastures increase at the expense of natural vegetation. This will have an effect on nutrient and sediment load.
Eutrophication: nutrient load from agriculture and domestic sewage		
WFD targets are largely achieved by 2050.	Nutrient load to rivers not fully in check, but current improvements are respected and in part further improved.	Phosphorus load may increase in parallel with increased top soil erosion, domestic sewage may end up in the rivers more frequently than before
Sediment load from adjacent agricultural land		
Erosion control is improved greatly	Erosion control not fully effective.	Increased due to increased arable land and little attention and incentives for erosion abatement.
Organic pollution with oxygen consuming domestic load		
Reduced to acceptably low levels due to the WFD	Current waste water treatment plants remain in operation and their performance is ensured through proper maintenance. Small-scale, and countryside point sources are not further targeted.	Same as current or maybe worsening because of failing infrastructure and increased intensity of storm overflows

Table 1 continued

SSP1/RCP 4.5	SSP2/RCP 6.0	SSP3/RCP 8.5
Agricultural water use for irrigation: consequences for river flow		
Efficient innovative water harvesting techniques cope with the decline in available water for irrigation	Ground- and river water is subject to increased competitive pressure for both drinking water and irrigation purpose. Urban drinking water needs are secured at the expense of agriculture leading to short periods of water shortage in particularly dry summers, and hence to agricultural productivity drops.	Both groundwater aquifers and river water is increasingly used for irrigation purpose leading to sinking groundwater tables and dropping base flow levels in the river. This has longer-term negative impacts for drinking water and irrigation in all study catchments, but most severely in the Bresse.
Drinking water production from river water using bank infiltration and other means		
Surface water quality is sufficient to enable drinking water production at minimum cost	River water quality is generally sufficient for drinking water production, but sometimes extra measures have to be taken.	River water quality is often insufficient and necessary additional measures increase the cost of water; competition with other uses of river water is strongly felt.
Hydropower water use and minimum ecological flow		
Existing hydropower schemes are modernized and connected to smart grids with other renewable energy sources including geothermal options. Inclusion of ecological considerations in hydropower, both for current schemes and in new developments.	Hydropower schemes remain in use and some measures are taken to enhance ecological connectivity of the stream network. The energy sector at large, however has not made a wholesale transition to a well-balanced mixture of renewables.	Existing hydropower schemes are not modernized, leading to relatively low energy production, but the energy market suffers from shortage hence high prices allow for continued operation of outdated infrastructure.
Land use planning in the river valley		
Biodiversity objectives are included in spatial planning together with other sustainability policy items	Increased incidence of both high floods and drought periods is recognized as an important pressure that should be coped with in spatial planning. The effective implementation is lagging behind and the incorporation of biodiversity targets has only secondary importance.	Spatial planning is limited to the minimum necessary to sustain economic productivity, hence focused on agriculture, industry and roads. Flood prevention schemes are foreseen but their implementation is limited and left to private and commercial initiatives.
Recreative use of the river, e.g. kayaking, rafting, fishing		
Possibilities for green outdoor recreation are enhanced and generate local income	River recreation generally similar as under current conditions, but increased summer droughts may impose limits.	Limited during summer due to low discharge
Possible establishment non-native invasive species		
Possibly constant	Uncertain.	Possibly enhanced

Climate change scenarios for the stakeholder workshops

At the European scale, particularly the CLIMSAVE project has provided a useful modelling tool, which includes SRES scenarios to reflect the geophysical climate change aspects. The CLIMSAVE project, however, has developed its own socio-economic scenarios (Harrison et al. 2015) which do not fully correspond with the SSPs of O'Neill et al (2017). Because we have used the CLIMSAVE tool to derive our geophysical climate projections in a comparative and consistent fashion, we have still decided to pragmatically equate the socio-economic side of our scenarios with those of CLIMSAVE as follows: A2 = SSP3 = 'Should I stay or Should I Go' and B1 = SSP1 = 'Riders on the Storm' (see also Harrison et al. 2016).

Table 2: Articulation of the SRES scenarios A2 (~SSP3/RCP 8.5) and B1 (~SSP1/RCP 4.5) in terms of geophysical climate parameters for the three selected catchments in 2050. Source: the CLIMSAVE integrated assessment tool (www.climsave.eu). CLIMSAVE 'mid-point' coordinates used follow each case study areas in brackets. Run-off is estimated as expert judgment based on the result of the change in rainfall and evapotranspiration due temperature increase.

	Current (2010)	B1 (SSP1/RCP 4.5)	A2 (SSP3/RCP 8.5)
Stever (51.9N 7.4E)			
Mean daily min. annual temp. (°C)	5.6	7.0 (+1.4)	7.5 (+1.9)
Mean daily max. annual temp. (°C)	13.0	14.4 (+1.4)	14.8 (+1.8)
Mean daily max. summer temp. (°C Jun to Aug)	21.1	22.6 (+1.5)	23.1 (+2)
Mean annual precipitation (mm)	770	762 (-1%)	761 (-1%)
Mean summer precipitation (mm Jun to Aug)	230	203 (-12%)	199 (-13%)
Alteration in the hydrograph (qualitative)		Summer base flow decline around 10%, summer peak storm events may increase in frequency and severity; no change in winter flow	
Nahe (49.7N 7.3E)			
Mean daily min. annual temp. (°C)	4.2	5.8 (+1.6)	6.2 (+2)
Mean daily max. annual temp. (°C)	11.9	14.2 (+2.3)	14.6 (+2.7)
Mean daily max. summer temp. (°C Jun to Aug)	21.6	23.4 (+1.8)	23.0 (+1.4)
Mean annual precipitation (mm)	776	760 (-2%)	755 (-3%)
Mean summer precipitation (mm Jun to Aug)	225	186 (-17%)	179 (-20%)
Alteration in the hydrograph (qualitative)		Summer base flow may decline between 10 and 20%, spring snow melt peak is far less pronounced because the length of snow cover on the hills is estimated to be halved to around 2 weeks; summer peak storm events may increase in frequency and severity	
Bresse (46.2N 5.0E)			
Mean daily min. annual temp. (°C)	6.6	8.4 (+1.8)	9.0 (+2.4)
Mean daily max. annual temp. (°C)	15.4	17.3 (+1.9)	17.5 (+2.1)
Mean daily max. summer temp. (°C Jun to Aug)	24.8	27.1 (+2.3)	27.7 (+2.9)
Mean annual precipitation (mm)	877	810 (-8%)	794 (-9%)
Mean summer precipitation (mm Jun to Aug)	219	173 (-21%)	162 (-26%)
Alteration in the hydrograph (qualitative)		Summer base flow probably drops by at least 20%; winter snow cover is reduced to a few days with little effect on flow pattern, but winter rains may become more intense leading to higher but unpredictable short-term peaks	

We have obtained projections for precipitation and temperature in 2050 from the CLIMSAVE Integrated Assessment Platform (www.climsave.eu; Harrison et al., 2015). Since the CLIMSAVE platform is still based on the SRES scenarios, we were able to run the A2 scenario and B1, reasonably corresponding to SSP3/RCP8.5 and SSP1/RCP4.5, but there is no comparable SRES scenario for the intermediate scenario SSP2/RCP6.0. The scenarios A2 and B1 were run with the corresponding CLIMSAVE socio-economic storylines (see above, respectively 'Should I Stay or Should I Go', and 'Riders on the Storm',) using the MPEH5 climate model and 'intermediate' climate sensitivity (a choice out of 'low, intermediate and high'). MPEH5 is a version of the Max Planck GCM ECHOHAM, a choice out of 5, considered one of best by Dubrovsky et al (2015). For each of the three study catchments, we selected a mid-point coordinate, which we used to manually extract the projected data (Table 2). We compared the overall regional patterns with those reported in

Jacob et al. (2014) and found that these corresponded well over the area covering Southern France to Northern Germany.

For 2050, the differences between the two extreme scenarios in projected increases in temperature and decreases in precipitation largely correspond with those reported in literature (e.g. Jakob et al. 2014). Moreover, the effect of climate change is more pronounced for the southern Bresse than for the temperate Stever: temperature increases with around 2 °C versus 1.5 °C whilst summer rainfall drops with over 20% versus 12%. Differences in air temperature will be reflected in water temperature. It is important to note that the differences between the two extreme scenarios for 2050 are rather small, which corresponds to the general global modelling results (IPCC, 2013). Much more pronounced differences are to be expected between the scenarios until 2100.

Riparian management packages

The socio-economic storylines and climatic conditions described above were presented at the stakeholder workshops as the setting or boundary conditions for river management in the three scenarios. Together with the stakeholder, one riparian management package was developed for each of the three scenarios, describing how the woody riparian buffers are assumed to develop under these scenarios. Some first suggestions were drafted prior to the workshops based on some preliminary discussions with key stakeholders and used as a basis for the discussion at the workshops.

For the *best-practice RMP* riparian management package under the intermediate "business-as-usual" scenario, it is assumed that all measures of the 2nd RBMP have been put into practice, which means that the plans that have been submitted in 2015 will be fully implemented towards the time horizon for the next river basin management plan, that is in 2021. This further suggests that in this best-practice package, similar measures will be implemented until 2050, and stakeholders were asked at the workshops how these future RBMP measures could be realistically assessed and systematically implemented in GIS.

The *ambitious RMP* under the sustainability scenario then should reflect more far reaching efforts of the member states to improve the status of their water bodies towards a good ecological status, with more pronounced changes in the river corridor to reflect a condition close to what can be considered near-natural. As a first starting point for the discussion with the stakeholders, we suggested to implement this in GIS in a standardized way by assuming woody vegetation in the whole river corridor, approximately corresponding to the meander belt width in meandering rivers, except for some restricted areas (urban areas, transport and transmission lines, open non-forested nature reserves). This was based on a recent suggestion and position paper of the German Working Group of Federal States on Water Problems LAWA for the corridor needed to reach high ecological status.

Finally, we interpret the *pessimistic RMP* under the environmental degradation scenario as a step back from the current practice, which can have political or purely economic grounds. This should then imply that any infrastructural measures that have been taken during the first RBPM are left without maintenance and will risk deterioration and decay. Institutional measures, such as governance bodies, monitoring and surveillance capacity will probably be terminated. It is difficult to estimate the future changes under such a scenario and to systematically operationalize this riparian management package in GIS. Finally, it was assumed that this would entail the removal of woody buffers where they are presently adjacent to arable land.

Table 3: *Description of the three different riparian management packages (RMP) as a result of the discussion during the stakeholder workshops. In addition, the present conditions will be used as a baseline scenario.*

Pessimistic RMP (environmental degradation scenario SSP3/RCP8.5)

- WFD no longer pursued, intensity of non-ecological agriculture is increased
  - Woody buffers along cropland removed
  - Optional but finally not implemented in GIS: Conversion of grassland to cropland on areas well above the groundwater table and suitable for agriculture.
  - Optional but finally not implemented in GIS: Nature reserves may be converted to agricultural land where feasible.

Best-practice RMP (business as usual scenario SSP2/RCP6.0)

- River management according to the current WFD
  - All woody buffer measures as planned in the first RBMP cycle implemented and this is continued iteratively.
  - Between 2021 and 2050, woody buffers are developed along all segments that are classified as priority rivers (Schwerpunktgewässer) in the Nahe catchment. This is realistic since 1000 of the 8000 km in Rhineland-Palatinate have already been restored between 2000 and 2015. In the Stever, all measures presently considered necessary to reach good ecological status are implemented.

Ambitious RMP (sustainability scenario SSP1/RCP4.5)

- A further development of the WFD towards a more sustainable water use
  - Use the river corridor for acquiring good ecological status.
  - But exclude the following areas from the woody buffer river corridor: urban areas, roads, electricity transmission corridors, open non-forested nature reserves.

Climate change scenarios for the scenario runs

For the scenario runs (nutrients, temperature), we used an ensemble of recent climate models from EURO-CORDEX in high raster resolution (~12 km, Jacob et al. 2014). We chose models for which data was available for both RCP 4.5 and 8.5. Data for RCP 6.0 was unavailable (and is rarely available elsewhere).

For the nutrient modelling, the CORDEX variables pr (precipitation), tas (near-surface air temperature), and evspsbl (evaporation, including sublimation and transpiration) were available from 16 models. For 13 of these, daily data on cloud cover could be used (clt, Table 4).

We defined the last 30 years of the "historical" period in CORDEX data (1976-2005) as climatic reference condition. The period 2036-2065 ("2050") was used for the RCP 4.5 and 8.5 scenarios. For each combination of climate model, period and scenario (RCP 4.5 and 8.5, historical), we derived the long-term average values required for the model and BBN applications prior calculating the ensemble means.

From the climate data, we estimated the mean monthly water temperature and the mean monthly average water discharge for the nutrient model MONERIS. Firstly, we applied a regression model with air temperature as independent variable. Data from 23 monitoring stations in the Nahe catchment was used to establish the relationship (2014-16, r^2=0.8778). Secondly, a simple model was derived as well as calibrated and validated successfully for the reference years 2006-2010. This model was intended to be conceptually similar to MONERIS, i.e. with similar input data and monthly time steps.

Table 4. Ensemble of climate models for the modelling, for each model historical data (1976-2005) as well as RCP 4.5 and RCP 8.5 data (2036-2065) was available (data source: EURO-CORDEX).

GCM	RCM	Version	Ensemble
CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4-8-17	v1	r1i1p1
CNRM-CERFACS-CNRM-CM5	SMHI-RCA4	v1	r1i1p1
ICHEC-EC-EARTH	DMI-HIRHAM5 [1]	v1	r3i1p1
ICHEC-EC-EARTH	CLMcom-CCLM4-8-17	v1	r12i1p1
ICHEC-EC-EARTH	KNMI-RACMO22E	v1	r12i1p1
ICHEC-EC-EARTH	SMHI-RCA4	v1	r12i1p1
IPSL-IPSL-CM5A-MR	SMHI-RCA4	v1	r1i1p1
IPSL-IPSL-CM5A-MR	IPSL-INERIS-WRF331F [1]	v1	r1i1p1
MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17	v1	r1i1p1
MOHC-HadGEM2-ES	SMHI-RCA4	v1	r1i1p1
MOHC-HadGEM2-ES	KNMI-RACMO22E	v2	r1i1p1
MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	v1	r1i1p1
MPI-M-MPI-ESM-LR	SMHI-RCA4	v1a	r1i1p1
MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	v1	r2i1p1
MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009	v1	r1i1p1
NCC-NorESM1-M [1]	DMI-HIRHAM5	v2	r1i1p1

[1] without daily cloud cover

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