Chapter 7
Indirect and Direct Thermodynamic Effects of Wetland Ecosystems on Climate

Jan Pokorný, Petra Hesslerová, Hanna Huryna, and David Harper

Abstract This chapter deals with a largely unrecognised service of wetlands – their role in regulating air temperature through evapotranspiration. We explain quantitatively how solar energy striking the earth's surface is dissipated by water (expressed in energy units (W m^{-2})) in three processes: dissolution-precipitation of salts, disintegration-recombination of the water molecule in biological processes and evapotranspiration-condensation. The direct effect of wetlands on regional climate, through reduction of temperature gradients and the role of water vapour and clouds in lowering the passage of solar radiation are then described. We quantify the huge upsurge of sensible heat (warm air) that must have occurred after the drainage of wetlands in the northern hemisphere over the past 260 years. The radiative forcing that was caused by the increase in greenhouse gases in the atmosphere over the same period (from 1 to 3 W m^{-2} from 1750 to the present day) is markedly lower than radiative forcing caused by wetland drainage and indeed, is too small to measure. The amounts of carbon dioxide, methane and water vapour in atmosphere and their dynamics are compared. We question the meaning of 'average temperature' as the criterion of climate change in terms of thermodynamics. We show temperature differences in the present-day cultural landscape, on a clear sunny day, in thermovision pictures: wetlands and forests are upto 20 °C cooler than drained surfaces. We argue that persisting with the dogma of climate change caused by the greenhouse effect alone results in society ignoring the most important functions of natural vegetation, manifest through their direct effect on climate and water cycling. This facilitates further wetland drainage and deforestation. We believe that it is now essential to support and restore natural vegetation structures, like wetlands and forests, in order to make any serious reduction in climate warming.

Keywords Solar radiation • Evapotranspiration • Sensible heat • Water cycle • Radiative forcing • Surface temperature

---

J. Pokorný (✉) • P. Hesslerová • H. Huryna
ENKI, o.p.s. Dukelská 145, 379 01 Třeboň, Czech Republic
e-mail: pokorny@enki.cz

D. Harper
University of Leicester, Leicester LE1 7RH, UK

J. Vymazal (ed.), *Natural and Constructed Wetlands*,
DOI 10.1007/978-3-319-38927-1_7

7.1 Introduction

Wetlands are ecosystems driven by different dominant plant species, dependent upon the quantity and duration of water within them. They have high primary production which supplies energy for diverse food webs and organic matter for soil formation. (Cooper 1975; Dykyjová and Květ 1978; Květ et al. 1998) Wetlands are also well-known as important units in the landscape for their role in regulating the hydrological cycle. They retain flood water and moderate floods in lower part of catchments. Wetland plants in floodplains, the littoral zone of lakes, swamps and marshes tolerate flooding and recycle nutrients from flood water. Their role in flood prevention is now beginning to be recognized and taken into account in legislation in many countries.

Wetlands however, have been removed from the natural landscape over most of the earth's surface as a result of drainage to promote urban and agricultural developments. For example, more than 51 % (45.9×10^6 ha) of the total area of wetland in the USA has been replaced by cropland since European settlement (Mitsch and Hernandez 2013). This removal has resulted in considerable losses of biodiversity and several other services not formerly recognised as beneficial to humankind, but now increasingly being quantified (Gopal et al. 2000, 2001). The important ones are the direct provisioning services, such as food (e.g. fish) and building materials (e.g. reeds for roofing); recreational services (e.g. tourism) and supporting services (e.g. flood control, climate through carbon sequestration) which wetland recreation and restoration now seek to provide (Mitsch and Gosselink 2007).

A largely unrecognised service, but potentially the most important of all those known, which is provided by wetlands, is their role in regulating air temperature – hence climate change – through evapotranspiration. This chapter explains and quantifies the role of wetlands as climate regulators.

7.2 Solar Energy Striking the Earth's Surface

The Sun's energy drives our water cycle, plant production and all other living processes in the biosphere; it warms the Earth to an average temperature of around 15 °C or 288 °K. The actual direct solar irradiance at the top of the Earth's atmosphere fluctuates over a year from 1412 W m^{-2} in early January to 1321 W m^{-2} in early July due to the Earth's varying distance from the Sun. (Geiger et al. 2003; Kopp et al. 2005). The **Solar Constant**, which is the total radiation energy received from the Sun per unit of time per unit of area on a theoretical surface perpendicular to the Sun's rays and at Earth's mean distance from the Sun (Anon 2016) is approximately 1.366 kW m^{-2}. It is most accurately measured from satellites where atmospheric effects are absent. It is not exactly constant, increasing by 0.2 % at the peak of each 11-year solar cycle. Sunspots block out light and reduce the emission by a few tenths of a percent, but bright spots, called plages, that are associated with solar

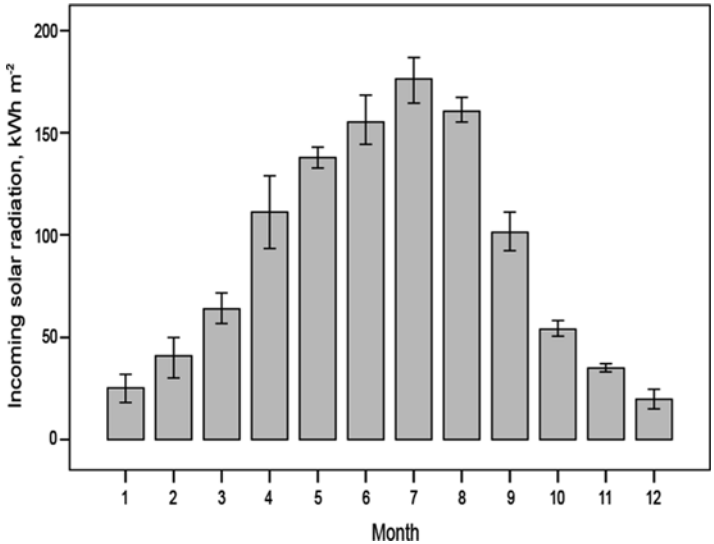

Fig. 7.1 Monthly values of incoming solar radiation data recorded for the whole year of 2009. Mean values measured at the wet meadow and the dry land site in Třeboň region

activity, are more extensive and longer lived, so their brightness compensates for the darkness of the sunspots. Total solar output has varied over the last three 11-year sunspot cycles by approximately 0.1 % (Willson and Hudson 1991).

The difference between the amounts of incoming radiation on a clear day (29.3 MJ m^{-2} = 8.14 kWh m^{-2}, maximum flux 1000 W m^{-2}) is about an order of magnitude greater than on an overcast day (0.78 kWh m^{-2}, maximum flux 100 W m^{-2}) (Figs. 7.1 and 7.2). The best instruments to measure solar irradiance (e.g. Kipp Zonen, Eppley or Middleton pyranometers and pyrheliometers) have an accuracy about 1 % – i.e. of 10 W m^{-2} (WMO 2008). *The total irradiance fluctuation caused by changes of the Sun's activity varies by a negligible amount (0.1 %) with the 11-year sunspot cycle* (e.g. Cahalan et al. 2010; Priest 2014); thus the stability of irradiance is considered to be greater than the accuracy of the measurements we can currently make.

7.3 Direct Effect of Wetlands on Climate via Evapotranspiration and Other Life Processes

There is a large difference between the distribution of solar radiation in functioning natural ecosystems of high plant biomass well supplied with water compared to dry, biomass-poor ecosystems with far more non-living physical surfaces. This is because of the impacts of solar energy upon water molecules.

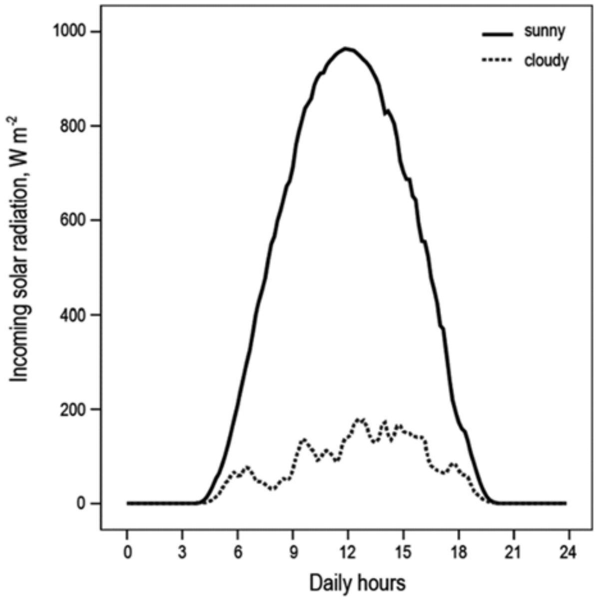

Fig. 7.2 Daily mean series of incoming solar radiation (W m^{-2}) on five sunny (3.06, 13.06, 14.06, 16.07, 27.07) and five cloudy (19.06, 23.06, 24.06, 18.07, 28.07) days in 2009 at the wet meadow and the dry land site in Třeboň region

The incoming solar radiation is dissipated at the surface of the earth by three main processes – dissolution-precipitation of salts, disintegration-recombination of the water molecule in biological processes and evapotranspiration-condensation. Willy Ripl proposed a conceptual model to help understand these reactions, called the ETR (Energy – Transport – Reaction) Model (Ripl 1995, 2003). All three processes are driven by the gradient of solar energy; they slowdown in winter when the supply of solar energy is low, then accelerate in summer (Fig. 7.3). Similarly they fluctuate between day and night.

7.3.1 Dissolution-Precipitation of Salts

Energy transformations associated with processes of dissolution and precipitation of salts are less often considered in studies of energy fluxes in ecosystems than the other two and their role has not been fully evaluated. The free energy of formation of a pure substance – taken to be the free energy change when 1 mol of the substance is formed from its elements at 1 atm pressure – is negative for most compounds at 25 °C and 1 atm pressure. This implies that formation of a compound from its elements under these conditions is ordinarily a spontaneous process. Conversely, most compounds are stable with respect to decomposition into their

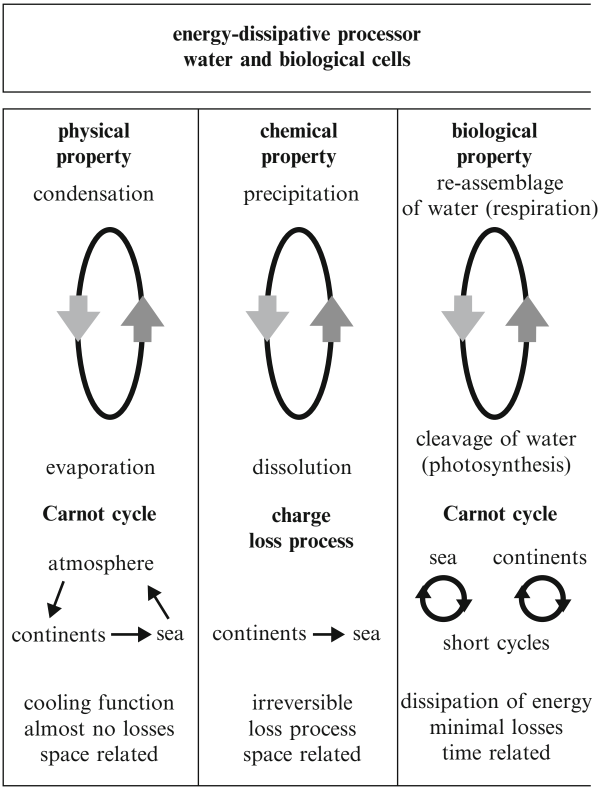

Fig. 7.3 W. Ripl's scheme of three dissipative properties of water (Ripl & Hildmann 2000)

elements. For example formation of solid $CaCO_3$ and $CaSO_4$ are linked with release of −1206.9 kJ (−335.25 Wh) mole^{-1} and −1431.1 kJ (−397.52 Wh) mole^{-1}. There are exceptions and two of the more interesting are NO (+90.25 kJ mole^{-1}) and NO_2 (+33.18 kJ mole^{-1}). In principle these compounds should decompose to N_2 and O_2 under ordinary conditions. The fact that they remain long enough to be major problems in air pollution implies that the rate of decomposition must be extremely slow. The standard enthalpies ('heat content') of formation of selected inorganic compounds are given in the Table 7.1.

7.3.2 *Disintegration-Recombination of Water Molecules*

The disintegration-recombination of water molecules are the principal processes of photosynthesis and respiration. When 1 mol of hydrogen reacts with ½ mole of oxygen then 1 mol water is formed and energy of 286 kJ (79 Wh) is released. One mole of water (18 g) thus has enthalpy of −286 kJ (−79 Wh). The maximum net

Table 7.1 Standard enthalpies of formation of inorganic compounds at 298 °K

Compounds	Enthalpy	
	kJ mol^{-1}	Wh mol^{-1}
H_2O (l)	−285.83	−79.39
H_2O (g)	−241.82	−67.17
NH_3 (g)	−46.11	−12.81
NO_2 (g)	+33.18	9.22
$CaCO_3$ (s)	−1206.9	−335.25
CO_2 (g)	−393.51	−109.31
NO (g)	+90.25	2.075
$CaSO_4$ (s)	−1431.1	−397.2

According to Atkins and de Paula 2010

photosynthesis may take up as much as 20 W m^{-2}, with an average rate of about 2 W m^{-2} in closed-canopy ecosystems (Cooper 1975; Pokorný et al. 2010a). One kg of plant biomass, consisting mostly from cellulose, contains roughly 5 kWh energy. Primary production in the temperate zone is 0.1–1 kg dry mass from 1 m^2 per vegetation season (Patten 1990; Květ et al. 1998; Pokorný et al. 2010b). Only exceptionally can the long term production of plant biomass be higher (Hejný et al. 1981). The maximum annual primary productivity (about 1 kg m^{-2} year^{-1}) compared with incoming annual income of solar energy in the temperate zone (about 1100 W m^{-2}) makes it clear that the efficiency of conversion of solar energy into plant biomass is less than 0.5 %.

Decomposition of organic matter (respiration), in contrast to biomass production, results in release of the stored energy. Decomposition release is accelerated by drainage of wetlands. Its rate in drained wetland soil can be several times higher than primary production.

7.3.3 Evapotranspiration-Condensation

Phase changes between liquid water and water vapour are linked with the consumption of a large amount of energy. The enthalpy of liquid water is −2.5 kJ g^{-1}. Evapotranspiration (ET) or latent heat flux, represents large, invisible fluxes of water and energy in the landscape: the scale of several hundred W m^{-2}. An ET of 250 W m^{-2} produces 100 mg H_2O m^{-2} s^{-1}, equivalent to evaporation of 100 L s^{-1} from 1 km^2, an order of magnitude more than the surface water outflow from 1 km^2 of land. This is thus an energy gradient reduction (“air-conditioning”) of 250 MW km^{-2}.

ET is a powerful cooling process, having a double air-conditioning (gradient reducing) effect upon the landscape – (a) evaporation **cools** places, consuming solar energy for transfer of liquid water into water vapour (b) subsequent condensation of water vapour **warms** air where it occurs, releasing latent heat when the dew point is achieved on cool surfaces. ET can thus be considered as a perfect process of gradient reduction (equalisation of temperature), linked to the growth of plants (primary production), and to nutrient uptake and water recycling (Ripl 1995). Warm air can absorb and contain high amounts of water vapour and transport it to high levels of the atmosphere where, after mixing with cooler results in air rapid condensation and release of latent heat.

These processes of evapotranspiration-condensation, dissolution-precipitation of salts and disintegration-recombination of the water molecule slow down when there is water shortage; solar energy is consequently converted into sensible heat. The sensible heat flux (H) represents the sum of all the heat exchanges between the surface of a landscape and its surrounding atmosphere by conduction or convection. On dry surfaces, H may reach values of several hundred W m^{-2}. The H of a heated surface thus warms air, which rises up in a turbulent motion creating atmospheric instability. Drainage of wetlands and deforestation bring about a large shift from latent heat flux (air-conditioning, temperature gradient equalizing via evapotranspiration) into sensible heat flux (increase of local temperature and turbulent motion of air, strong wind, cyclones).

7.3.4 Ground Heat Flux and Warming of Biomass

The ground heat flux (G) is that transferred from the surface downward via conduction. G slows down in dry soil as well as in dry plant litter, is also low in dense vegetation cover. In summer months, G is typically 10 % of net radiation and ranges from 10 W m^{-2} to 100 W m^{-2} for growing crops (Jones 1991; Kustas et al. 1993; Huryna et al. 2014). The physical sink of energy depends on the amount of living biomass and its water content (Fig. 7.4). The maximum heat-flux warming of biomass is approximately 20 W m^{-2}.

7.3.5 Ratio Between the Amount of Energy Bound in Biomass and That Dissipated by Evapotranspiration

The ratio between the amount of energy needed for primary production and cooling (air-conditioning) is very low: 5 kWh stored in 1 kg of dry biomass is equal to the latent heat of evaporation of 7.4 L of water. A stand of wetland plants evaporates about 500 L of water in a year, which is 350 kWh; this is 70 times more than amount of energy bound in the biomass. Plants have evolved to invest a very low portion of incoming solar energy in their biomass, but a high portion into the cooling process of transpiration. Photovoltaic panels have to produce electricity for 1–2 years to cover the amount of energy needed in their production. Wetland plants cover amount of energy needed for their production (bound in biomass) in just 2 days of evapotranspiration. Wetland plants are thus an effective and perfect air-conditioning system (Table 7.2)!

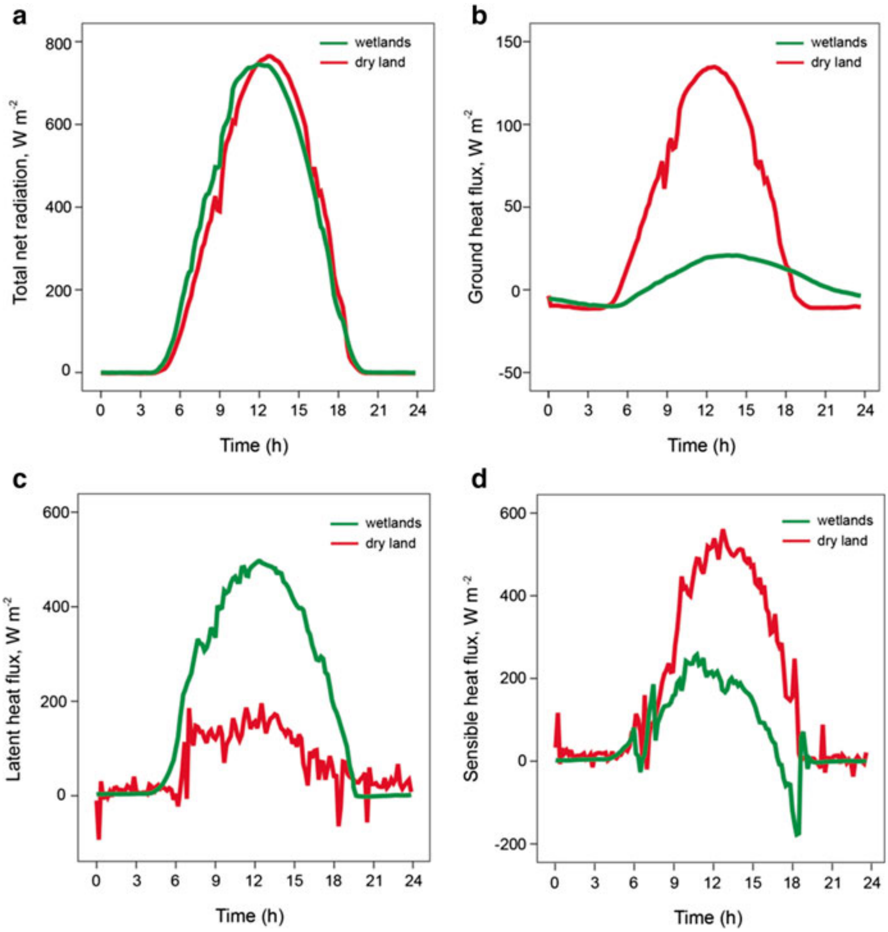

Fig. 7.4 Daily mean series of total net radiation (Wm^{-2}) (**a**), ground heat flux (Wm^{-2}) (**b**), latent heat flux (Wm^{-2}) (**c**) and sensible heat flux (Wm^{-2}) (**d**) on five clear days (13.06, 14.06, 16.07, 27.07, 01.08) for 2009 period at the wet meadow and the dry land site in Třeboň region

Table 7.2 The distribution of incoming solar radiation in two types of ecosystems

	Wetlands		Dry lands	
	$W\ m^{-2}$	%	$W\ m^{-2}$	%
Reflectance	155	18	235	28
Evapotranspiration	452	54	65	8
Sensible heat flux	173	20	400	47
Ground heat flux	50	6	150	17
Biomass	20	2	–	–

According to Pokorný et al. (2010b), Huryna et al. (2014)

7.4 Wetland Losses and Consequent Impact on Climate

The drainage of wetlands causes a shift from latent heat to sensible heat flux, which results in an increase of temperature and thus water loss from the landscape. The distribution of latent and sensible heat between a wetland and dry (drained) land differ by several hundred Wm^{-2} during a sunny day. In wetland ecosystems, latent heat prevails and uses about 60–80 % of net radiation, sensible heat uses about 20–30 % while ground heat flux 10–20 % (Kedziora 2011) The decrease in ET from 1 km^2 (100 ha) as a result of drainage is approximately 250 Wm^{-2} (equivalent to 100 mg s^{-1} of water vapour) and this 250 MW of solar energy in 1 km^2 is thus released into atmosphere as warm air (sensible heat). In August 2015 in the Czech Republic, the total surface area of harvested wheat and rape seed fields was about 18,000 km^2 (1,800,000 ha) and sensible heat released from this dry surface area was thus at least 4,500,000 MW. Human generation of such heat in electricity production would require 4500 Nuclear Power Stations, each of 1000 MW. The real quantity of sensible heat is even higher because 1000 Wm^{-2} of incoming solar energy is partly reflected (200 W m^{-2}), partly heats the ground (up to 100 W m^{-2}), is partly used for ET (maximum 200 W m^{-2} from and almost dry surface), so 500 W m^{-2} is realised as sensible heat warming the atmosphere. High air pressure is developed as a consequence, which prevents the income of wet air from the Atlantic, in this example of Central Europe.

The IPCC claims and works with the premise that man does not substantially affect emissions of water vapour. Yet there is a huge difference between the amount of water vapour and dynamics of the phase (states) changes of water above a wetland (defined as vegetation well supplied with water) or a forest, and an agricultural field or a sealed surface which were created by draining the wetland; the wetland has lower temperature and air above, higher relative humidity and a tendency to create fog and clouds. Satellite pictures of large wetlands areas demonstrate this. Similarly clouds are common above rain forests (Earth Science Data, NASA Land Processes Distributed Active Archive Center). The high content of water vapour in the air also reduces the passage of solar radiation to the Earth's surface and hence effectively reduces surface temperature. **This is the opposite conclusion than would be reached based on an interpretation of the greenhouse effect: conventional thinking says the higher greenhouse effect results in a higher temperature.** Wetlands reduce temperature however, by the cooling effect of ET and the shading by fog and clouds formed from water vapour. The water vapour does not rise quickly into the atmosphere, because there are no hot surfaces on wetlands. The water vapour condenses by night and prevents infra red (IR) radiation moving from the Earth's surface towards the sky. In this way, wetlands moderate extreme day and night temperature, as do forests. For example substantial clearance of the Mau Forest in Kenya at an altitude 2800 m, resulted in early morning frosts which hindered crop production (Hesslerová & Pokorný 2010).

Water vapour rises faster from crop plants than from wetlands and forest, which have dense vegetation and therefore lower temperatures at the ground. The conversion of natural vegetation to agricultural fields changes the land surface characteristics, which lead to redistribution of surface energy components (Esau and Lyons 2002). More than 51 % (45.9×10^6 ha) of the total area of wetland had been replaced by cropland in USA by European settlement (Mitsch and Hernandez 2013). About 400 W m^{-2} is moved from latent to sensible heat flux for days with the highest solar irradiance (Huryna et al. 2014), so it can be calculated that more than 175,000 GW of energy was converted into sensible heat over the USA these past 260 years, which has strongly affected dynamic processes in the atmosphere. Warming of Northern Hemisphere has been faster than that of Southern Hemisphere (Climatic Research Unit), because the Northern Hemisphere has a substantially higher portion of continents than the Southern Hemisphere and almost 90 % of the world population lives there. Changes of land cover, particularly deforestation and drainage, have affected the Northern Hemisphere much more. Sensible heat (hot air rising into the atmosphere) would contribute to the melting of mountain and arctic glaciers. The amount of sensible heat released as a consequence of land cover changes is very much higher than heat caused by increased carbon dioxide concentrations creating the greenhouse effect.

7.5 Indirect Effect of Wetlands on Climate *via* Greenhouse Gases (GHG); Sink or Source?

The indirect effect of wetlands on climate as either a source, or a sink of GHGs such as CO_2 and CH_4, has been studied intensely. GHGs act on global climate through Radiative Forcing (RF), which is the change in net radiative flux expressed in W m^{-2} at the top of the atmosphere (Fig. 7.5). The Intergovernmental Panel on Climate Change (IPCC 2007) documents the RF caused by an increase in GHG in the atmosphere from 1750 to the present day as between 1 and 3 W m^{-2}. In the next 10 years, the RF is expected to increase by 0.2 W m^{-2}. Changes of radiative forcing over time are too small to be measured, so they are calculated. The effect of GHGs on changes of RF cannot thus be tested by the scientific method. The IPCC focuses on global average temperature (GAT) and warns of global warming caused by increasing concentration of GHGs. Water vapour is considered only as a "feedback agent", rather than an agent directly forcing climate change (IPCC 2013). Myhre et al. (2013) state (p. 666) *"As the largest contributor to the natural greenhouse effect, water vapour plays an essential role in the Earth's climate. However, the amount of water vapour in the atmosphere is controlled mostly by air temperature, rather than by emissions. For that reason, scientists consider it a feedback agent, rather than a forcing to climate change. Anthropogenic emissions of water vapour through irrigation or power plant cooling have a negligible impact on the global climate".*

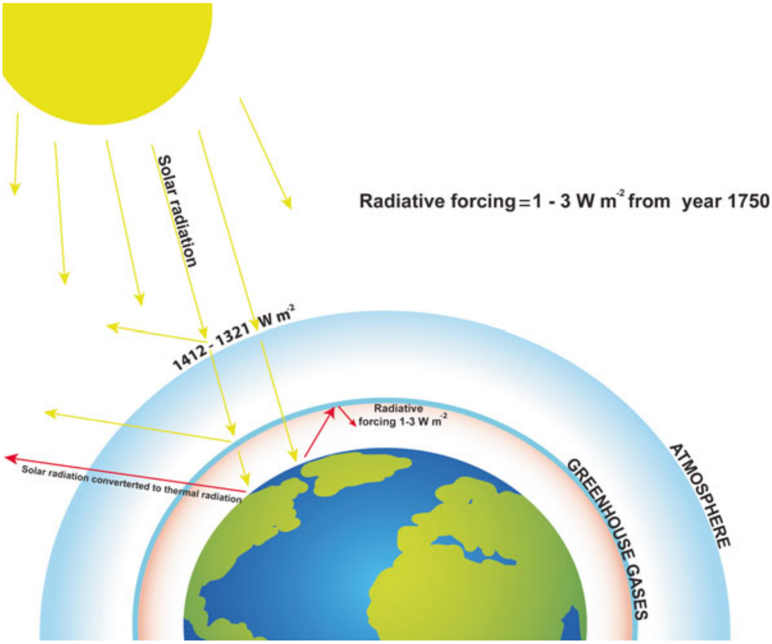

Fig. 7.5 Scheme of greenhouse effect and radiative forcing

This is their principal premise, which thus excludes water and land cover as controlling factors of climate, assigning CO_2 and CH_4 alone as the controlling agents of global climate. Yet the amount of water vapour in air is one to two orders of magnitudes greater than that of CO_2 the concentration of CO_2 and CH_4 in the atmosphere is 390 ppm and 1.8 ppm, respectively. Concentration of CO_2 fluctuates during a year within 20 ppm being lower in period of summer in Northern Hemisphere (IPCC 2013), which indicates important role of terrestrial vegetation. Water vapour in air expressed in mass units (grams m^{-3}) and in volume units (ppm calculated according to Avogadro Law i.e. 1 mol has a volume 22.4 L) are shown in Fig. 7.6.

As an example, air saturated with water at 21 °C contains 22,400 ppm of water vapour; air saturated with water at 40 °C contains 62,200 ppm. The concentration of water vapour in air changes rapidly both in time and space. Water exists in three phases/states – liquid, solid, gaseous – within the normal range of temperatures on our planet and transition between states is linked with release and consumption of energy. Water vapour forms clouds which prevent passage of solar energy to Earth surface and reduce temperature.

How does land cover change – especially drainage of wetlands – affect the amount of water vapour in air? Is the amount of water vapour in the atmosphere really controlled mostly by the concentration of GHGs? Does water vapour affect climate only as a greenhouse gas? These are urgent questions for wetland scientists to answer as a community.

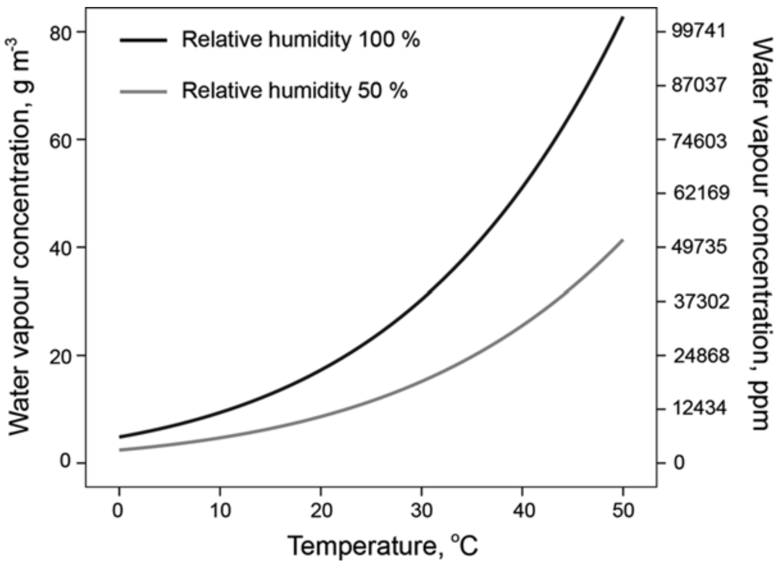

Fig. 7.6 Water vapour concentration in air at 100 % and 50 % saturation at different temperatures expressed in gm^{-3} and ppm volume units

7.6 Meaning of Average Temperature in Thermodynamics and the Role of Gradients

The recommendations of the IPCC are designed for the reduction of GHGs in the atmosphere; climate change is expressed as a change of global average temperature (GAT). The UN Conference on Climate Change 2015, in Paris (COP21/CMP11) set a goal for limiting global warming to less than 2 °C GAT compared to pre-industrial levels. The goal should be achieved by reduction of GHGs. The agreement calls for zero net anthropogenic GHG emissions to be reached during the second half of the twenty-first century. According to the IPCC, the quantifiable criterion of climate change is GAT and the reason for global warming is increasing GHGs, particularly CO_2.

In terms of thermodynamics, average temperature alone does not produce power. The founder of thermodynamics, Carnot, pointed out in the early 1800s that it was not simply the temperature of steam produced in a boiler that made the pistons pump hard and fast in an engine, but rather the difference between the temperature of the hot boiler and cooler radiator. The difference across distance – the gradient – is what makes the conditions for the flow to take place. Similarly, in the atmosphere and the landscape, it is gradients of temperature, heat, air pressure, which drive wind and transport water vapour.

Real tornados, thunderstorms and hurricanes are macroscale dissipative processes driven by gradients. The relationship pressure-volume-temperature is crucial. The gradient that drives a hurricane is between the warm ocean, at least 27 °C and much cooler temperatures higher in the atmosphere. This temperature gradient between a warm ocean and cool air creates an updraft of warm air (Schneider and Sagan 2005).

In 1886, Boltzmann suggested that the energy gradient imposed on the Earth by the sun drives living processes *"Life struggles for entropy which becomes available through transition of energy from the hot sun to the cold Earth. In order to exploit this transition, plants spread their immense surface of leaves and utilise the sun's energy before it falls to the Earth's temperature"* (Schneider and Sagan 2005).

Plants are the most advanced instrument yet evolved for degrading incoming solar radiation. Nature is said to "abhor a gradient" – a corollary to this is that when a gradient is imposed on a system it can develop processes and structures that will hold material and energy from going to equilibrium immediately, while degrading the imposed gradient as thoroughly as possible.

A tree is like a giant water fountain 'spewing' water in the form of latent heat. It is like a candle burning high-exergy waxes and degrading that high-exergy fuel into low-grade heat. Thus a tree is best understood as a giant degrader of energy. Each new leaf, each new phototrophic rearrangement, is a new opportunity for energy degradation.

Prigogine popularized the term dissipative structures introduced by Lotka (1922). Dissipative systems are non-equilibrium, open, dynamic systems with gradients across them. They degrade energy and exhibit material and energy cycling. Dissipative structures grow more complex by exporting – dissipating – entropy into their surrounding (Schneider and Sagan 2005).

The IPCC, and consequently the conclusions of the United Nations Conference on Climate Change 2015 in Paris (COP21/CMP11), regard increasing concentration of GHGs as the main cause of climate change, which is indicated and quantified by increasing GAT. Can Radiative Forcing, which has a value less than one thousandth of solar energy income (1–3 W m^{-2} from 1750, or 0.2 W m^{-2} during a decade) really be transformed into such dramatic events which need a great deal of energy, as winds, torrential rains, floods caused by gradients of temperature and air pressure? No, there are other energy fluxes on the interface of the Earth's surface and atmosphere. These are the fluxes of solar energy in the landscape, the fluxes of energy in ecosystems mediated by living organisms. Life processes directly transform the incoming solar energy through the well-known processes described above.

7.7 Exchange of Water and CO_2 in Plant Stands

The cooling process of transpiration is often considered a side effect rather than a mechanism to control leaf temperature and that of surroundings. It is often called 'evapotranspiration losses' or 'a tax paid for the opening of stomata'. Yet, the quantity of water molecules exchanged by plants is at least two orders of magnitude higher than the quantity of carbon dioxide fixed in biomass (Table 7.3).

Table 7.3 Comparison of concentrations of CO_2, CH_4, H_2O and their turnover rates in air

Greenhouse gas	CO_2	CH_4	H_2O
Concentration ppm in atmosphere	380	1.5	1000–40,000 rapidly changing
Phase	Gas	Gas	Solid, liquid, gaseous ex/endo thermic; 18 ml liquid equivalent to 22,400 ml gas
Turnover rate	Years	Years	Days
Climate policy respect	Emission trading, incentives	Emission trading, incentives	Ignored

7.8 Surface Temperature Distribution in a Cultural Landscape with Wetlands – An Example

Spatial resolution of aerial thermal image (2 m) allows a more detailed analysis of the temperature distribution in the landscape. The image (0.95 × 2.8 km) was acquired on 29 July 2008 at 1:00 p.m. and shows Třeboň town and its surroundings – wet meadows area (Fig. 7.7). The temperature values for ten categories of land cover were calculated along the transects, displayed within the image (Table 7.4, Fig. 7.8).

The lowest values of the average surface temperature are found in water, willows and riparian vegetation, slightly less than 22 °C. Wet meadow and littoral, with temperatures around 22.5 °C follow; they are surfaces with wetland vegetation. Categories of agricultural crops and mixed surface–gardens have an average surface temperature of about 26.5 °C. The warmest surfaces are mature crops and harvested meadow (28.3 and 29.3 °C). In this case, the surfaces are covered by dry vegetation. The hottest surface is asphalt with 34.1 °C.

The highest temperature differences (18 °C) are between physical surfaces – water and asphalt. When comparing the coldest and warmest vegetation surface, which is willow and harvested meadow, this difference is close to 10 °C. The difference between the asphalt and willow growth is 17 °C. Temperature differences between structured vegetation well supplied with water and vegetation, with water deficit are therefore evident. Through the vegetation cover one can affect the surface temperature of the landscape, which reflects the way of solar energy distribution and consequently energy flows in the landscape.

7.9 Conclusions

Global average temperature (GAT) as a criterion and an indicator of global change is misleading. Gradients drive climate change. GAT does not pick up gradient increase and is unable to reduce gradients. For example: if a large wetland having

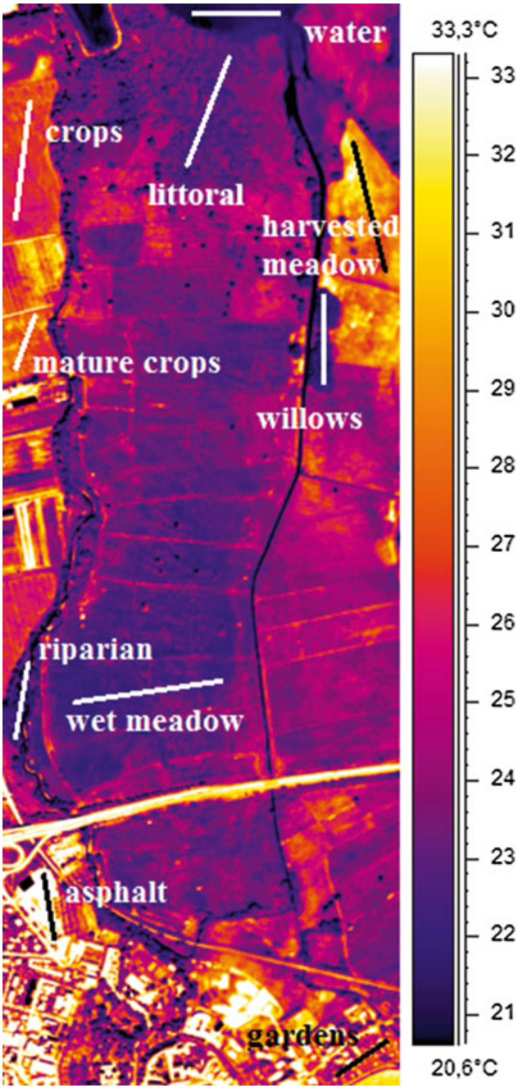

Fig. 7.7 Thermovision picture of culture landscape with wetlands showing direct effect of water and vegetation on temperature and local climate

diurnal temperature fluctuation from minimum 18 °C, to maximum 22 °C is drained and changed into an agro-industrial area having temperature fluctuation minimum 10 °C, maximum 30 °C, the average temperature has not changed, but the distribution of solar energy and water fluxes i.e. the local climate changed substantially.

The Greenhouse Effect acts, according to the IPCC, via Radiative Forcing caused by the rise of CO_2 and CH_4, which have increased since 1750 from 1 to 3 W m^{-2} and will increase during the next decade by a further 0.2 W m^{-2}. Changes of Radiative Forcing are so small in comparison with incoming solar radiation, that they cannot even be monitored. In order to affect global climate, Radiative Forcing and the

Table 7.4 Surface temperature values of different land cover types in wet meadow area near Třeboň, South Bohemia, Czech Republic calculated from the transects in thermal image as showed in Fig. 7.7

Surface temperature (°C)					
	Min	Max	Max – min	Average	Standard deviation
Harvested meadow	26.2	31.9	5.6	29.3	1.7
Litoral	21.5	23.5	2.1	22.8	0.4
Water	20.8	21.5	0.7	21.2	0.2
Willows	20.8	22.2	1.4	21.5	0.3
Wet meadow	21.6	23.7	2.1	22.6	0.4
Crops	25.5	27.9	2.4	26.6	0.5
Riparian vegetation	18.9	23.9	5.0	21.7	0.9
Mature crops	26.6	30.7	4.1	28.3	1.0
Gardens	24.0	33.2	9.2	26.8	1.8
Asphalt	33.1	39.3	6.2	34.1	0.9

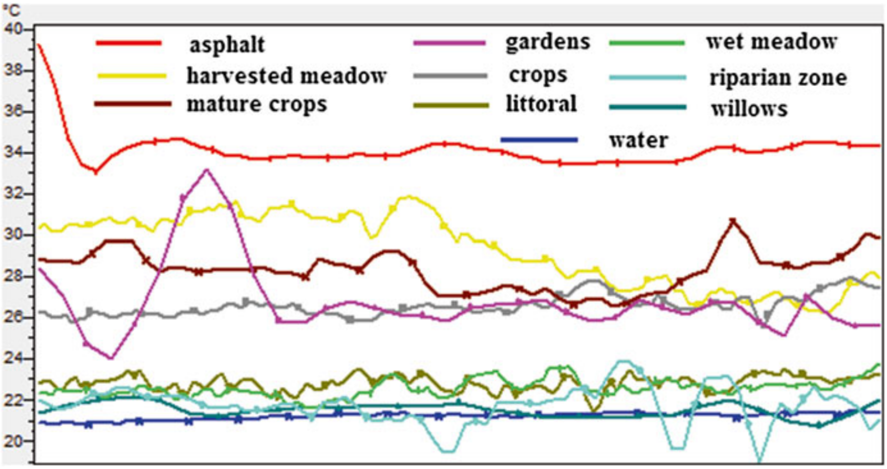

Fig. 7.8 Surface temperature transects of ten different surfaces as displayed in Fig. 7.7

consequent increase in GAT must be in some way be transferred into temperature gradients. Reporting only GAT ignores the main reasons for climate change i.e. the gradients which may drive torrential rains, cyclones etc. GAT does not change significantly and it results in the false conclusion by climate sceptics that there is no climate change and therefore no measures are needed. The present approach to climate change which reduces the role of plants to a sink or a source of GHG and albedo is an approach of astrophysics which largely ignores life processes, which moderate extremes of temperatures. Plants are presented in text books as homoiothermic (do not regulate temperature), the reality is the opposite: plants are well supplied with water, they cool and create climate and conditions for other organisms with an efficiency of several hundred W m^{-2}.

Very high gradients are caused by changes of land cover, namely by drainage of wetlands and deforestation. These have been considerable since 1750 in North America and Europe in particular and continue on large scales in Asia and Africa since the middle of the twentieth century. Drainage of 1 km^2 is associated with a daily shift from latent heat of ET to sensible heat of hundreds of MW. In the Czech Republic 10,000 km^2 of agriculture fields with small flood plains and wet meadows were drained over the past 100 years, which has caused a decline of ET and increase of sensible heat in the order of millions of MW. The effect of drainage of the world's wetlands should be evaluated in this way. Satellite pictures from the 1980s provide exact information on changes of land cover and surface temperature.

Persisting with the dogma of greenhouse effect alone results in us ignoring the most important functions of wetlands through their direct effect on climate and water cycling and hence enables further drainage and deforestation. We have to support life structures like wetlands to improve and retain our climate.

Acknowledgement This work was supported by the EEA grants – Norway grants EHP-CZ02-PDP-1-003

References

Anon, (2016). *Encyclopædia Britannica Online*. Retrieved on 17 February, 2016, from http://www.britannica.com/place/Sun

Atkins, P., & de Paula, J. (2010). *Physical chemistry* (9th ed.). New York: W.H. Freeman and Company.

Cahalan, R.F., Wen, G., Harder, J.W., Pilewskie, P. (2010). Temperature responses to spectral solar variability on decadal time scales. *Geophysical Research Letters*, 37(7). doi:10.1029/2009GL041898

Climatic Research Unit (CRU). https://crudata.uea.ac.uk/cru/data/temperature/

Cooper, J.P. (1975*). Photosynthesis and productivity in different environments*. London: Cambridge University Press

Dykyjová, D., & Květ, J. (Eds.). (1978). *Pond littoral ecosystems, structure and functioning.* Ecological Studies 28. Berlin/Heidelberg/New York: Springer.

Earth Science Data Interface (ESDI). http://glcfapp.glcf.umd.edu:8080/esdi/

Esau, I.N., & Lyons, T.J. (2002). Effect of sharp vegetation boundary on the convective atmospheric boundary layer. *Agricultural and Forest Meteorology*, 114(1–2), 3–13

Geiger, R., Aron, R.H., & Todhunter, P. (2003). *The climate near the ground*. Lanham: Rownam & Littlefield.

Gopal, B., Junk, W.J., Davis, J.A. (2000). *Biodiversity in wetlands: Assessment, function and conservation* (Vol. 1). Leiden: Backhuys Publishers.

Gopal, B., Junk, W.J., Davis, J.A. (2001). *Biodiversity in wetlands: assessment, function and conservation* (Vol. 2). Leiden: Backhuys Publishers.

Hejný, S., Květ, J., Dykyjová, D. (1981). Survey of biomass and net production of higher plant communities in fishponds. *Folia Geobotanica et Phytotaxonomica*, 16, 73–94

Hesslerová, P., & Pokorný, J. (2010). Forest clearing, water loss, and land surface heating as development costs. *International Journal of Water*, 5(4), 401–418

Huryna, H., Brom, J., Pokorný, J. (2014). The importance of wetlands in the energy balance of an agricultural landscape. *Wetlands Ecology and Management*, 22(4), 363–381

IPCC. (2007). *Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change.* In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (Eds.). Cambridge/New York: Cambridge University Press.

IPCC. (2013). *Climate change 2013: The physical science basis. contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.* In T.F. Stocker, D. Qin, G-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.). Cambridge/York: Cambridge University Press.

Jones, H.G. (1991). *Plants and microclimate: A quantitative approach to environmental plant physiology* (2nd ed.). Cambridge: Cambridge University Press.

Kedziora, A. (2011). Energy balance of ecosystems. In J. Gliński, J. Horabik, J. Lipiec (Eds.), *Encyclopedia of agrophysics* (pp. 270–274). Dordrecht: Springer.

Kopp, G., Lawrence, G., Rottman, G. (2005). The total irradiance monitor (TIM): Science results. *Solar Physics*, 230(1), 129–139

Kustas, W.P., Daughtry, C.S.T., van Oevelen, P.J. (1993). Analytical treatment of the relationships between soil heat flux/net radiation ratio and vegetation indices. *Remote Sensing of Environment*, 46, 319–330

Květ, J., Westlake, D.F., Dykyjová, D., Marshall, E.J.P., Ondok, J.P. (1998). Primary production in wetlands. In D.F. Westlake, J. Květ, A. Szczepański (Eds.), *The production ecology of wetlands*: *The IBP synthesis* (pp. 78–168). Cambridge: Cambridge University Press.

Lotka, A.J. (1922). Contribution to the energetics of evolution. *Proceedings of the National Academy of Sciences USA*, 8(6), 147–151

Mitsch, W.J., Gosselink, J.G. 2007. *Wetlands* (4th ed.). Hoboken: Wiley.

Mitsch, W.J., Hernandez, M.I. (2013). Landscape and climate change threats to wetlands of North and Central America. *Aquatic Sciences*, 75, 133–149.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura T., Zhang, H. (2013). Anthropogenic and natural radiative forcing. In *Climate Change 2013: The physical science basis* (Contribution of Working Group I to the Ffifth Assessment).

NASA Land Processes Distributed Active Archive Center (LP DAAC) located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov

Patten, B.C. (1990). *Wetlands and shallow continental waterbodies* (Vol. 1). The Hague: SPB Academic Publishing.

Pokorný, J., Květ, J., Rejšková, A., Brom, J. (2010a). Wetlands as energy dissipating systems. *Journal of Industrial Microbiology and Biotechnology*, 37, 1299–1305

Pokorný, J., Brom, J., Čermák, J., Hesslerová, P., Huryna, H., Nadezdina, N., Rejšková, A. (2010b). Solar energy dissipation and temperature control by water and plants. *International Journal of Water*, 5 (4), 311–336

Priest, E. (2014). *Magnetohydrodynamics of the Sun*. New York: Cambridge University Press.

Ripl, W. (1995). Management of water cycle and energy flow for ecosystem control: The energy-temperature reaction (ETR) model. *Ecological Modelling*, 78(1–2), 61–76

Ripl, W., & Hildmann, C. (2000). Dissolved load transported byrivers as an indicator of landscape sustainability. *Ecological Engineering 14*, 373–387

Ripl, W. (2003). Water: The bloodstream of the biosphere. *Philosophical Transactions of the Royal Society B: Biological Sciences*, B358(1440), 1921–1934

Schneider, E.D., & Sagan, D. (2005). *Into the cool, energy flow thermodynamics and life*. Chicago/London: The University of Chicago Press.

Willson, R.C., & Hudson, H.S. (1991). The Sun's luminosity over a complete solar cycle. *Nature*, 351(6321), 42–44

WMO. (2008). Guide to meteorological instruments and methods of observation. World meteorological organization. No. 8 (7th ed.).