Renewable Energy in Climate Change

Prof. Dr. Stephanie Fiedler

FESSTVaL Lecture, 2 August 2021

Renewable Energy in Climate Change

What to expect today

Why do we care about renewable energy?

What do models tell us about the potential for power production?

How does FESSTVaL and process studies contribute?

Renewable Energy in Climate Change

What to expect today

Why do we care about renewable energy?

What do models tell us about the potential for power production?

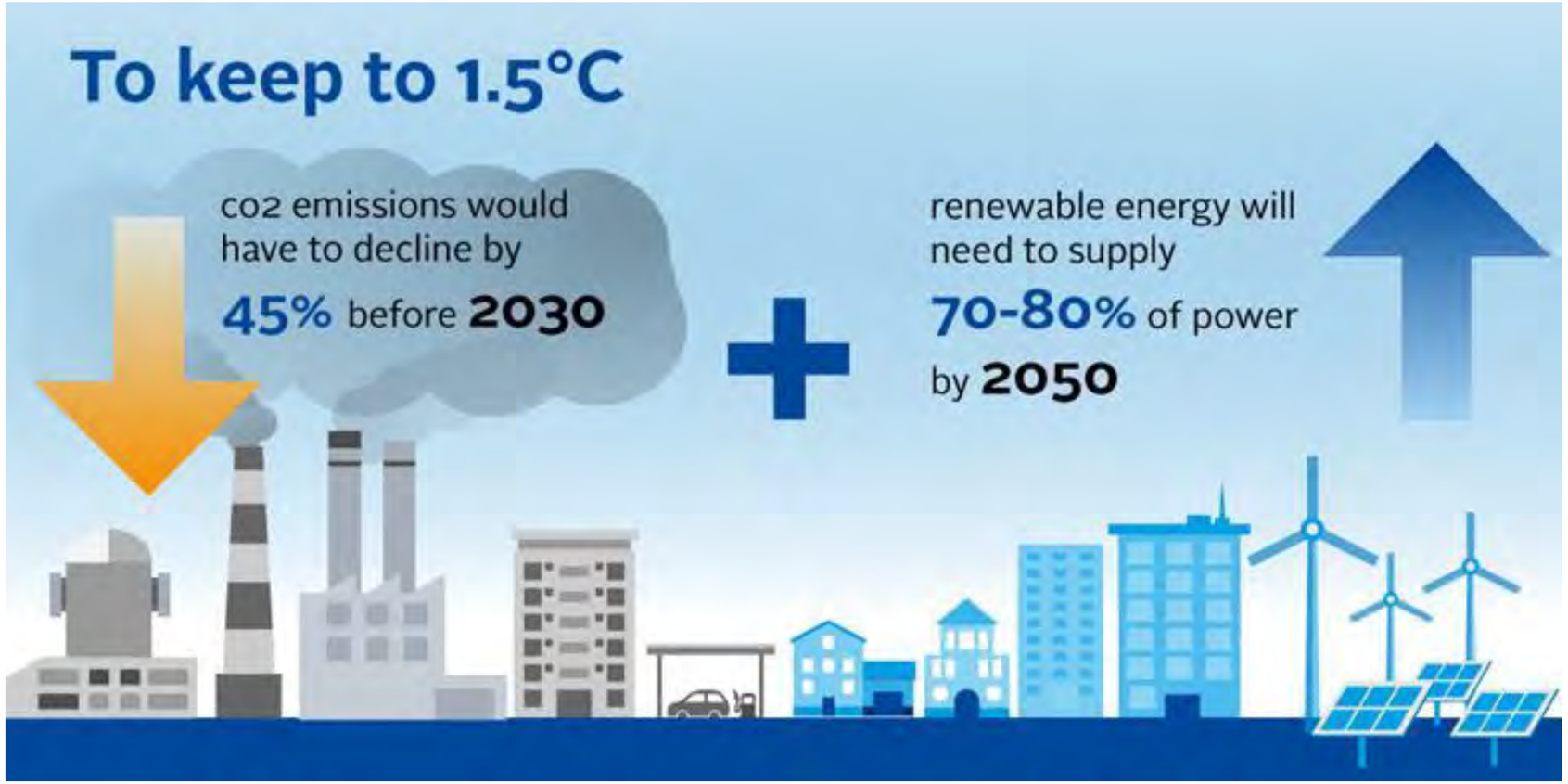
How does FESSTVaL and process studies contribute?

Benefits of renewable energies

- Clean energy production implies **less fossil-fuel combustion**
  - Reduction of greenhouse gas emissions
  - Less emissions of aerosols
  - Possibility of electrification of remote areas

- Further benefits when paired with **e-mobility**
  - Less noise in cities
  - Reduction of air pollution - health effects

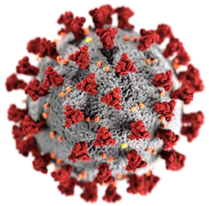
Renewable energy as mitigation of climate change



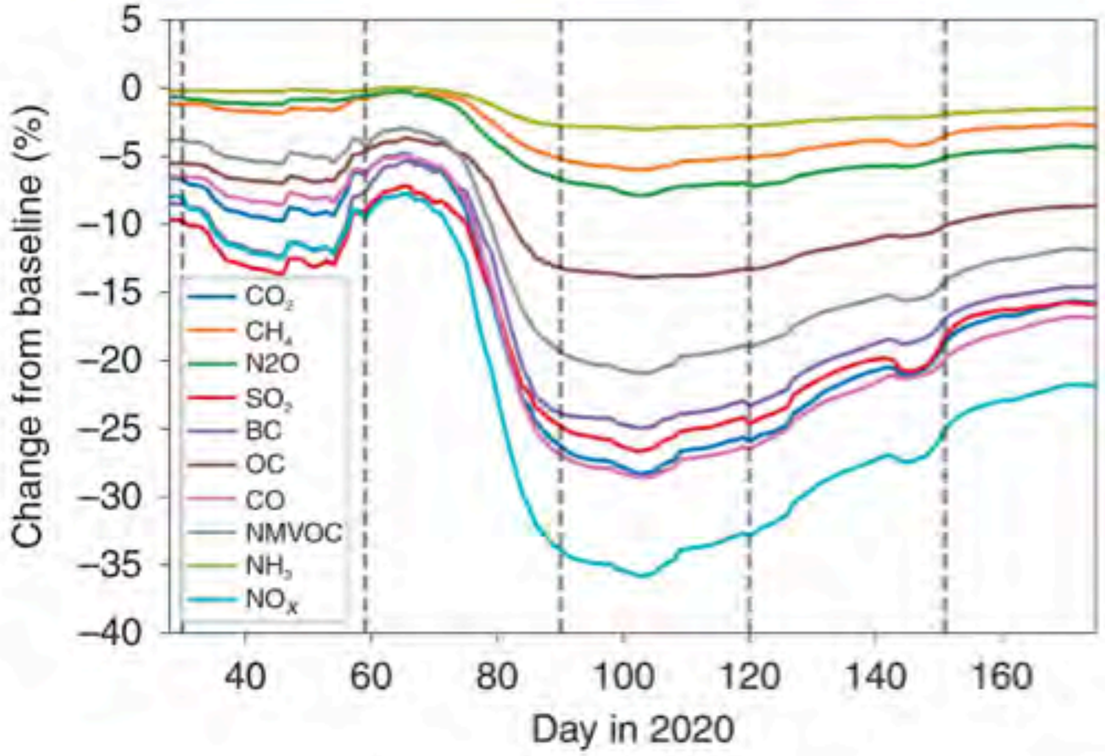
IPCC (2018)

Why do you care?

2020 contributions from **crisis** and exceptional weather



Emission reductions compared to baseline

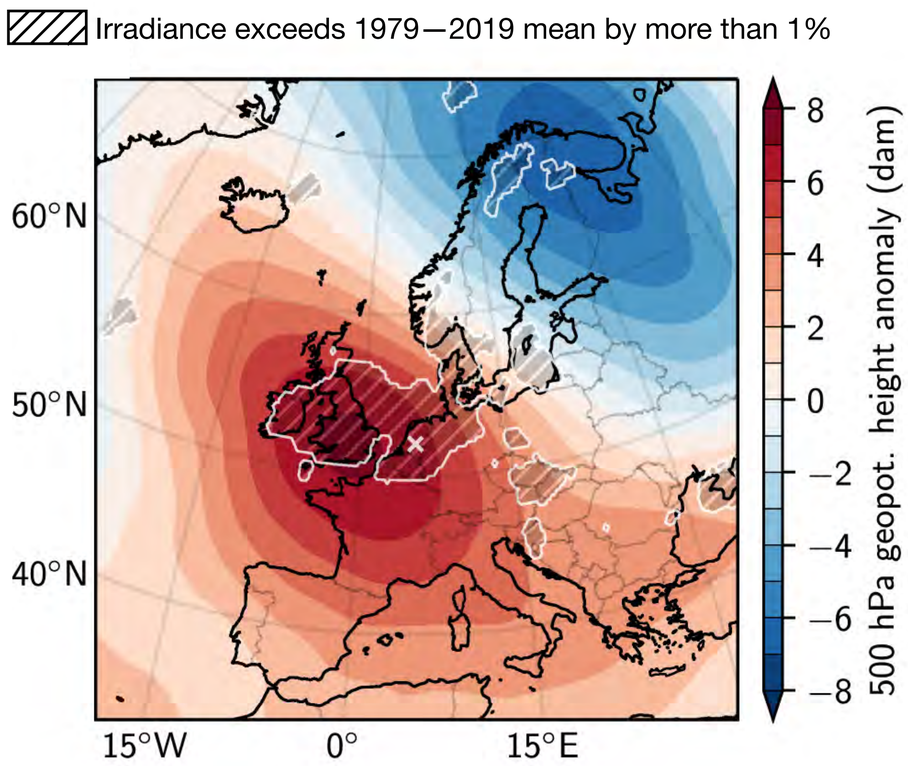


Forster et al. (2020)

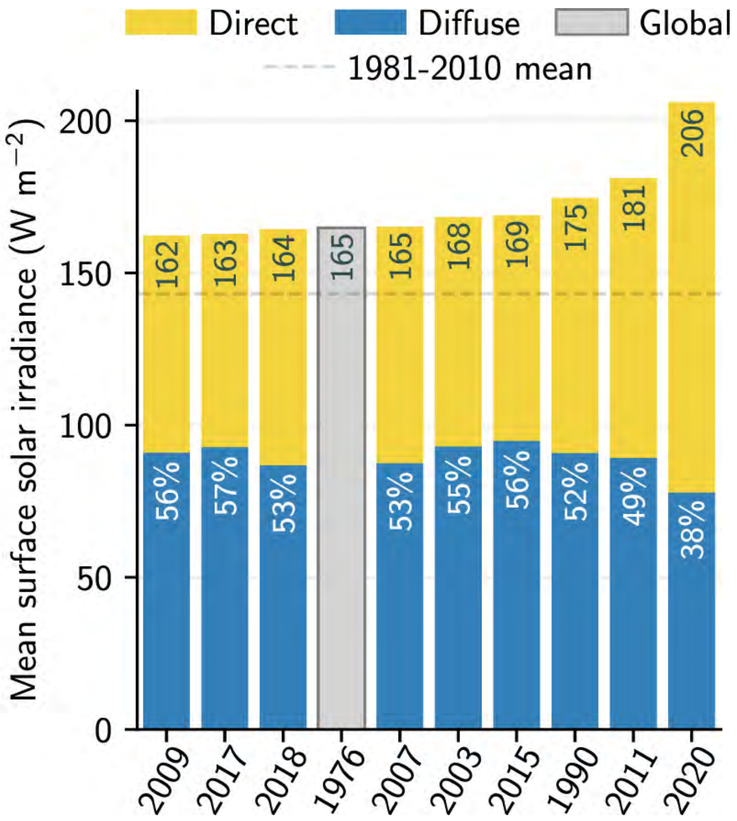
2020 contributions from crisis and exceptional weather

Sunshine record in Western Europe during first lockdown

2020 spring anomaly
relative to 1981—2010 (ERA5)



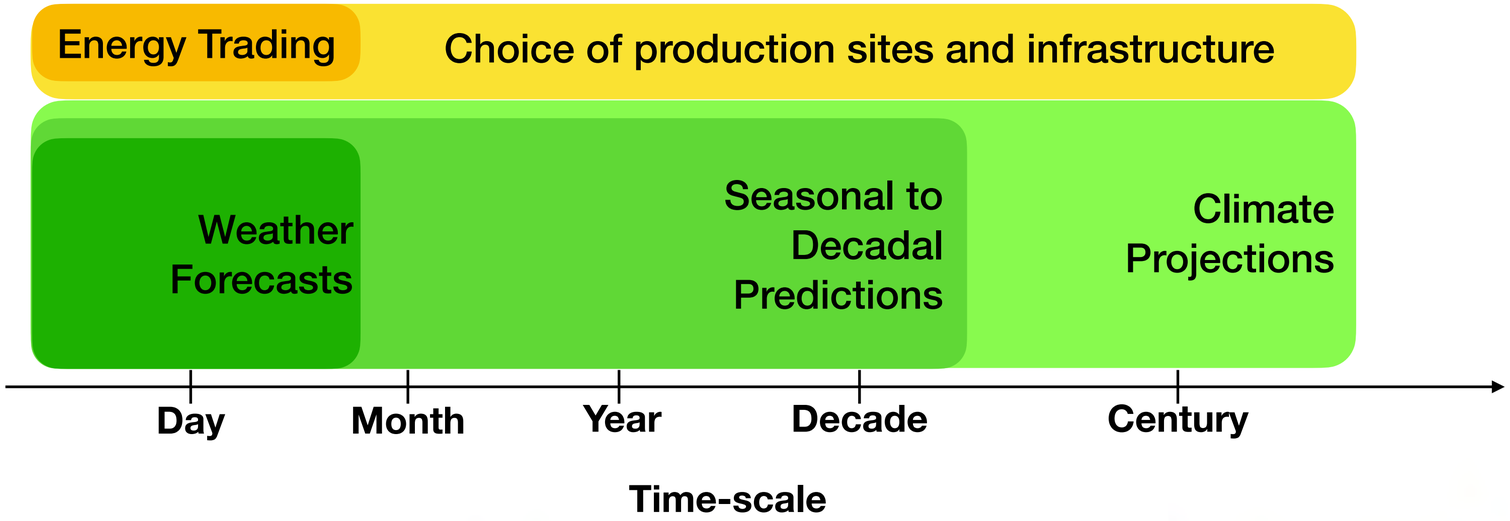
Top 10 years of daily mean irradiance
Veenkampen station



van Heerwaarden et al. (2021)

Natural variability in power production

Need for energy supply that meets the demand



Meteorological knowledge
from weather to climate time scales

Renewable Energy in Climate Change

What to expect today

Why do we care about renewable energy?

What do models tell us about the potential for power production?

How does FESSTVaL and process studies contribute?

What does a climate model look like?

MPI-ESM1.2 has 280 modules in atmosphere model alone

auxhyb.f90
clsst.f90
clveg.f90
collect.f90
conteq.f90
control.f90
cosp_calc_Re.f90
cosp_dsd.f90
cosp_gases.f90
cosp_icarus_simulator.f90
cosp_lidar_simulator.f90
cosp_misr_simulator.f90
cosp_radar_simulator.f90
cosp_radar_simulator_init.f90
cosp_scops.f90
cosp_zeff.f90
dyn.f90
echam6.f90
endrun.f90
ewd.f90
fftd.f90
ffti.f90
geopot.f90
gpc.f90
helmo.f90
inhysi.f90
inictl.f90
iniphy.f90
init_decomposition.f90
initemp.f90
initialize.f90
intaero.f90
ioinitial.f90
ionwp.f90
iorestart.f90
legtri.f90
ltd.f90
lti.f90
m_alloc_mods.f90
maxwind.f90
ml_flux.f90
ml_ocean.f90
mo_advection.f90
mo_aero_dummy.f90
mo_aero_kinne.f90
mo_aeropt_stream.f90
mo_aero_volc.f90
mo_aero_volc_tab.f90
mo_aoa.f90
mo_array_utils.f90
mo_boundary_condition.f90
mo_buffer_fft.f90
mo_call_trans.f90
mo_cld_sampling.f90
mo_clim.f90
mo_cloud.f90
mo_cloud_optics.f90
mo_co2.f90
mo_column.f90
mo_control.f90
mo_cosp_array_lib.f90
mo_cosp_atmos_lib.f90
mo_cosp_constants.f90
mo_cosp_echam.f90
mo_cosp_format_input.f90
mo_cosp_isccp.f90
mo_cosp_lidar.f90
mo_cosp_llnl_precip.f90
mo_cosp_llnl_stats.f90
mo_cosp_lmd_ipsl_stats.f90
mo_cosp_math_lib.f90
mo_cosp_misr.f90
mo_cosp_modis.f90
mo_cosp_modis_simulator.f90
mo_cosp_mrgrnk.f90
mo_cosp_offline.f90
mo_cosp_optics_lib.f90
mo_cosp_radar.f90
mo_cosp_radar_simulator_types.f90
mo_cosp_scale_LUTs_io.f90
mo_cosp_stats.f90
mo_cosp_types.f90
mo_cosp_utils.f90
mo_cosp_v1p4_cosp.f90
mo_cosp_v1p4_cosp_simulator.f90
mo_couple.f90
mo_couple_wrap.f90
mo_cover.f90
mo_cuadjust.f90
mo_cuascent.f90
mo_cudescent.f90
mo_cufluxdts.f90
mo_cuinitialize.f90
mo_cumastr.f90
mo_debugs.f90
mo_decompose_io.f90
mo_decomposition.f90
mo_diag_amip2.f90
mo_diag_dynamics.f90
mo_diag_tendency.f90
mo_diag_tendency_new.f90
mo_echam_cloud_params.f90
mo_echam_conv_constants.f90
mo_echam_convect_tables.f90
mo_echam_yaxt.f90
mo_emi_matrix.f90
mo_ensemble.f90
mo_essl_dft.f90
mo_exception.f90
mo_external_field_processor.f90
mo_fft992.f90
mo_filename.f90
mo_forecast_switches.f90
mo_gaussgrid.f90
mo_geoloc.f90
mo_geopack.f90
mo_gl1.f90
mo_global_op.f90
mo_greenhouse_gases.f90
mo_gwspectrum.f90
mo_hdiff.f90
mo_heatingrates.f90
mo_hyb.f90
mo_interpo.f90
mo_iocolumn.f90
mo_io.f90
mo_io_server.f90
mo_io_units.f90
mo_isccpsimulator.f90
mo_kind.f90
mo_legendre.f90
mo_linked_list.f90
mo_lrtm_driver.f90
mo_lrtm_gas_optics.f90
mo_lrtm_kgs.f90
mo_lrtm_netcdf.f90
mo_lrtm_setup.f90
mo_lrtm_solver.f90
mo_machine.f90
mo_math_constants.f90
mo_memory_base.f90
mo_memory_cfdiag.f90
mo_memory_f.f90
mo_memory_g1a.f90
mo_memory_g1b.f90
mo_memory_g2a.f90
mo_memory_g2b.f90
mo_memory_g3a.f90
mo_memory_g3b.f90
mo_memory_gl.f90
mo_memory_ls.f90
mo_memory_ma.f90
mo_memory_sp.f90
mo_memory_streams.f90
mo_methox.f90
mo_midatm.f90
mo_mkl_dft.f90
mo_mpi.f90
mo_mpi_types.f90
mo_mvstream.f90
mo_namelist.f90
mo_netcdf.f90
mo_nmi.f90
mo_nudging_buffer.f90
mo_nudging_constants.f90
mo_nudging.f90
mo_nudging_init.f90
mo_nudging_io.f90
mo_nudging_pattern.f90
mo_nudging_sst.f90
mo_nudging_utils.f90
mo_o3clim.f90
mo_o3_lwb.f90
mo_orbit.f90
mo_output.f90
mo_parameters.f90
mo_param_switches.f90
mo_physc2.f90
mo_physical_constants.f90
mo_port_test.f90
mo_profile.f90
mo_psrad_interface.f90
mo_rad_fastmath.f90
mo_rad_forcing_diag.f90
mo_radiation.f90
mo_radiation_forcing.f90
mo_radiation_parameters.f90
mo_random_numbers.f90
mo_read_netcdf77.f90
mo_real_timer.f90
mo_rrtm_coeffs.f90
mo_rrtm_params.f90
mo_scan_buffer.f90
mo_semi_impl.f90
mo_semi_lagrangian.f90
mo_simple-plumes.f90
mo_so4.f90
mo_solar_irradiance.f90
mo_species.f90
mo_spec_sampling.f90
mo_spectral.f90
mo_srtm_driver.f90
mo_srtm_gas_optics.f90
mo_srtm_kgs.f90
mo_srtm_netcdf.f90
mo_srtm_setup.f90
mo_srtm_solver.f90
mo_ssodrag.f90
mo_ssortns.f90
mo_sst.f90
mo_station_diag.f90
mo_string_utls.f90
mo_sub_echam.f90
mo_submodel_diag.f90
mo_submodel.f90
mo_submodel_interface.f90
mo_submodel_streams.f90
mo_sub_nml.f90
mo_surface_boundary.f90
mo_surface.f90
mo_surface_ice.f90
mo_surface_land.f90
mo_surface_memory.f90
mo_surface_ocean.f90
mo_surface_types.f90
mo_test_trans.f90
mo_time_base.f90
mo_time_control.f90
mo_time_conversion.f90
mo_time_event.f90
mo_time_manager.f90
mo_timer.f90
mo_timestamp.f90
mo_tmp_buffer.f90
mo_tpcore.f90
mo_tracdef.f90
mo_tracer.f90
mo_tracer_processes.f90
mo_tr_alltoall.f90
mo_transdiag.f90
mo_transpose.f90
mo_tr_gather.f90
mo_tr_gp_ffsl.f90
mo_tr_omp_decomposition.f90
mo_tropopause.f90
mo_tr_scatter.f90
mo_truncation.f90
mo_upper_sponge.f90
mo_util_buffer_pool.f90
mo_util_db_timings.f90
mo_util_file.f90
mo_util_logging.f90
mo_util_string.f90
mo_util_vcs.f90
mo_version.f90
mo_volc_data.f90
mo_vphysc.f90
mo_xtsurf_init.f90
pgrad.f90
physc.f90
pio_uncouple.f90
pres.f90
presf.f90
radheat.f90
scan1.f90
sccd.f90
scctp.f90
setdyn.f90
setgws.f90
setphys.f90
si1.f90
si2.f90
stepon.f90
subjob.f90
surftemp.f90
sym1.f90
sym2.f90
tf1.f90
tf2.f90
vdiff.f90

Supercomputer at „Deutsches Klimarechenzentrum (DKRZ)“

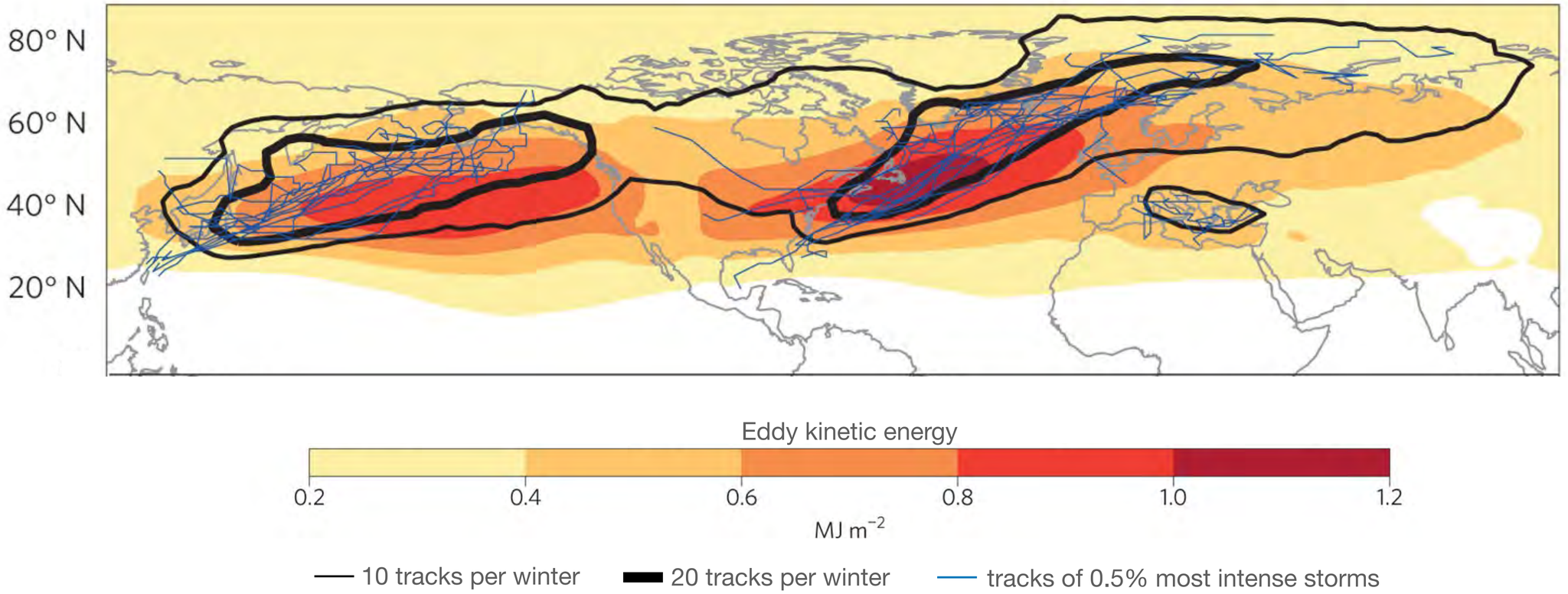
More than 100.000 compute cores
266 TB memory
54 PB disk storage

1 PB = 1,000 TB = 1,000,000 GB

Potential of energy production at present

North Atlantic Storm Track

Storm track density for December to February



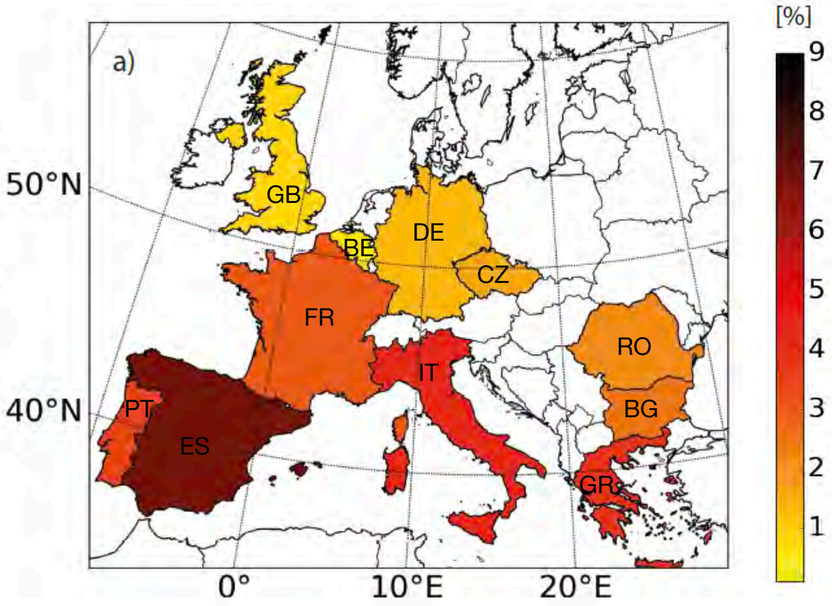
Shaw et al. (2016)

Energy Meteorology research in Cologne

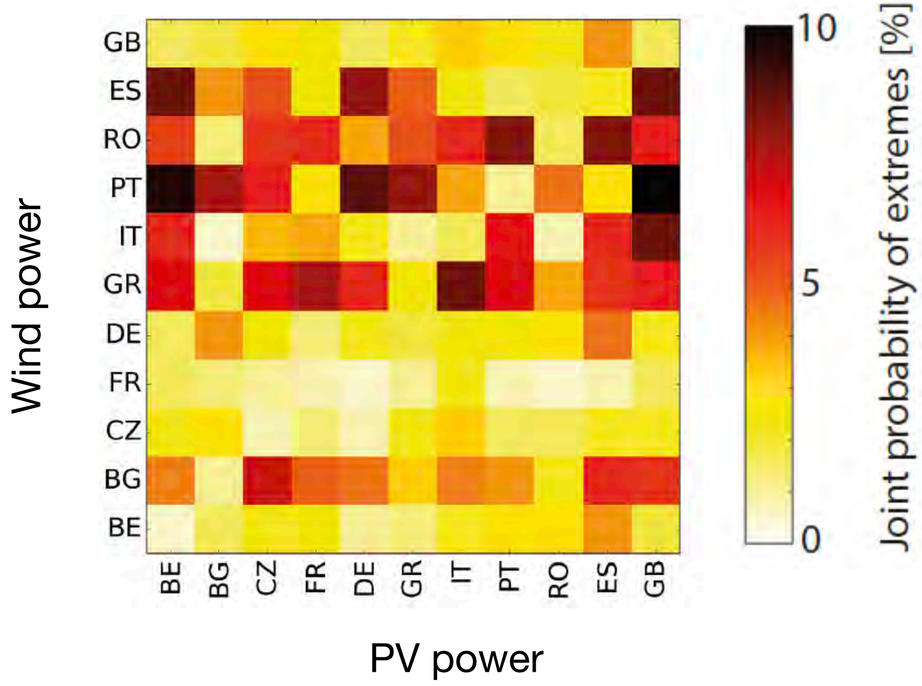
Balancing potential of extremes in wind & PV power production

Christopher Frank

5% percentile for capacity factor of PV power



Simultaneous occurrence of minima in renewable power production



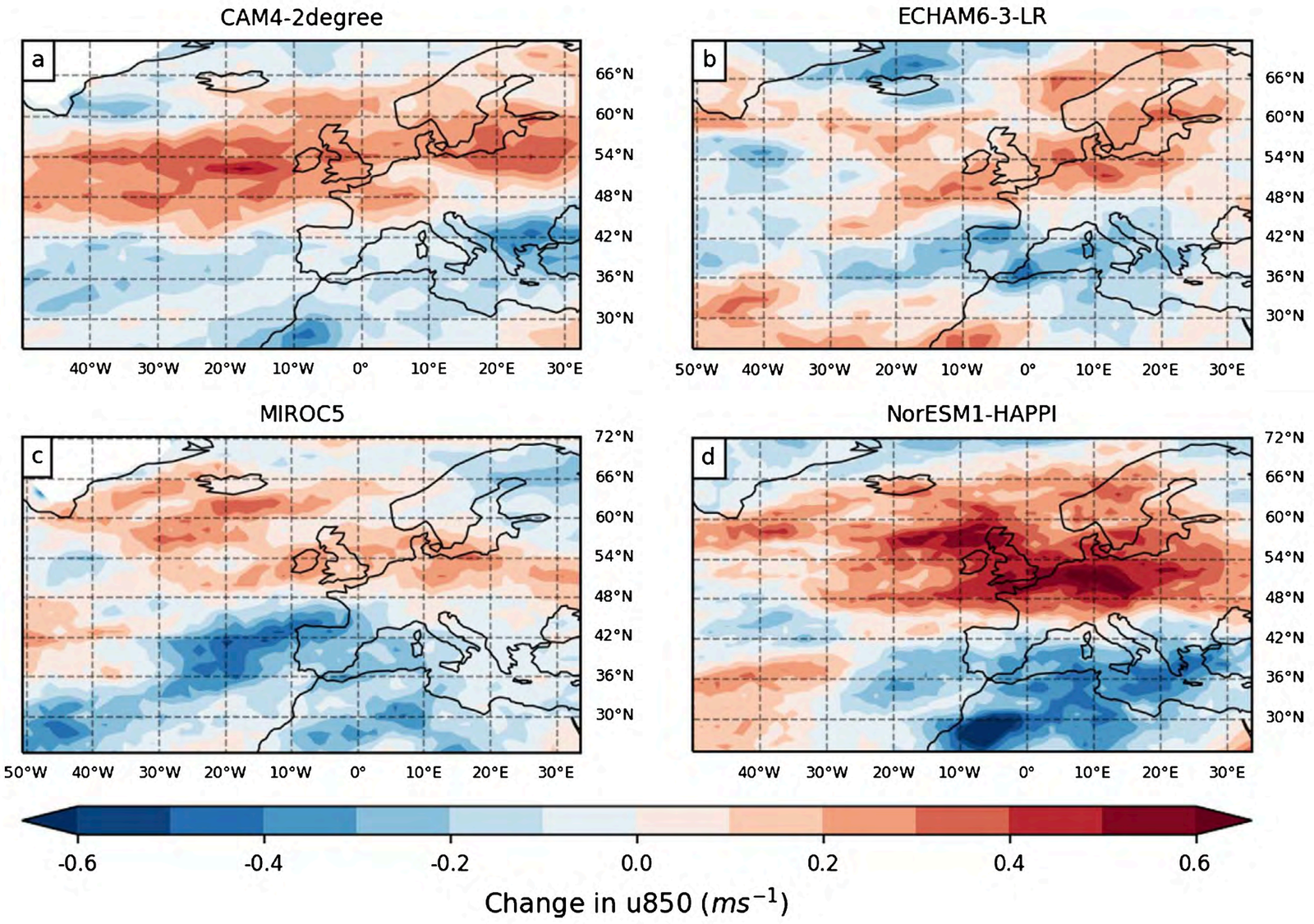
Frank, Fiedler & Crewell (2020)

Hans-Ertel-Zentrum für Wetterforschung

Universität zu Köln

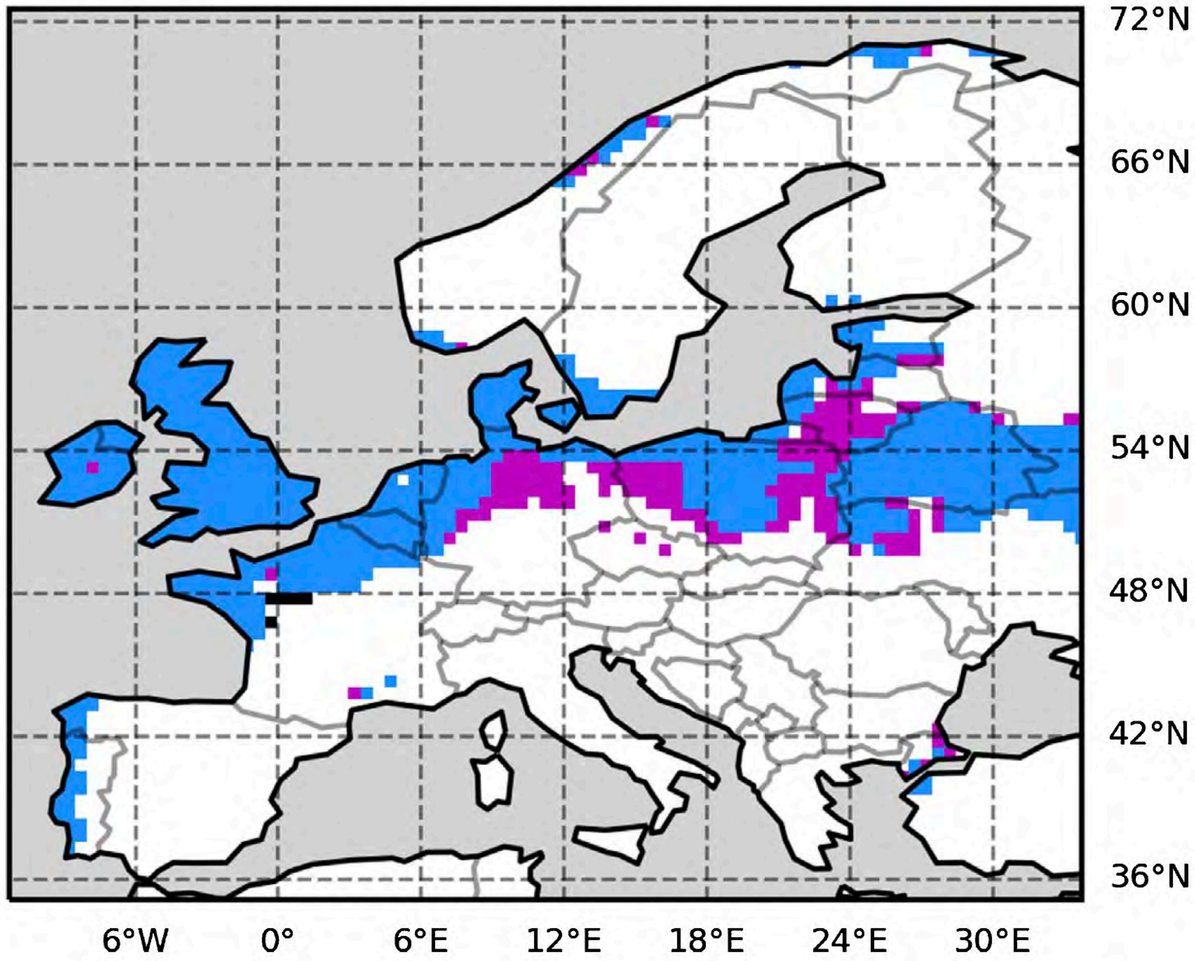
Our energy future?

Wind change in +1.5°C virtual worlds



Hosking (2018)

Implication of +1.5°C for wind farms



Wind farms viable today and possibly in +1.5°C world

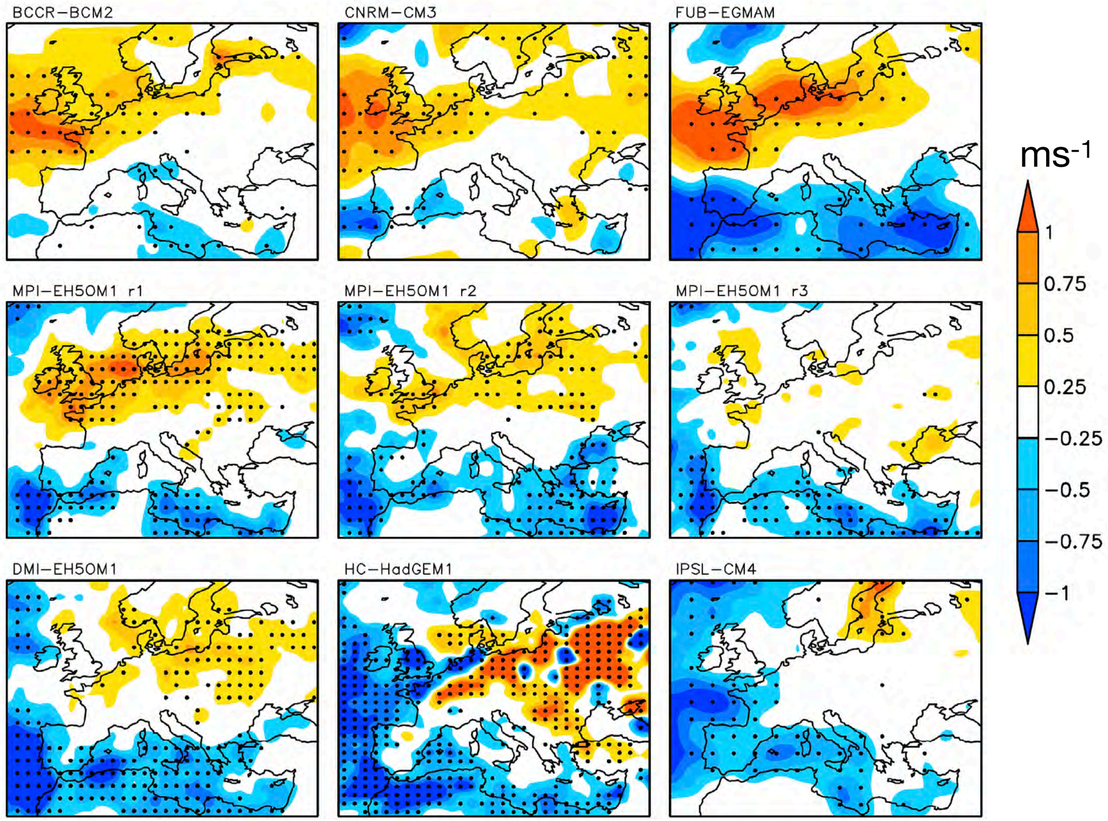
Wind farms possibly become viable in +1.5°C world

Hosking (2018)

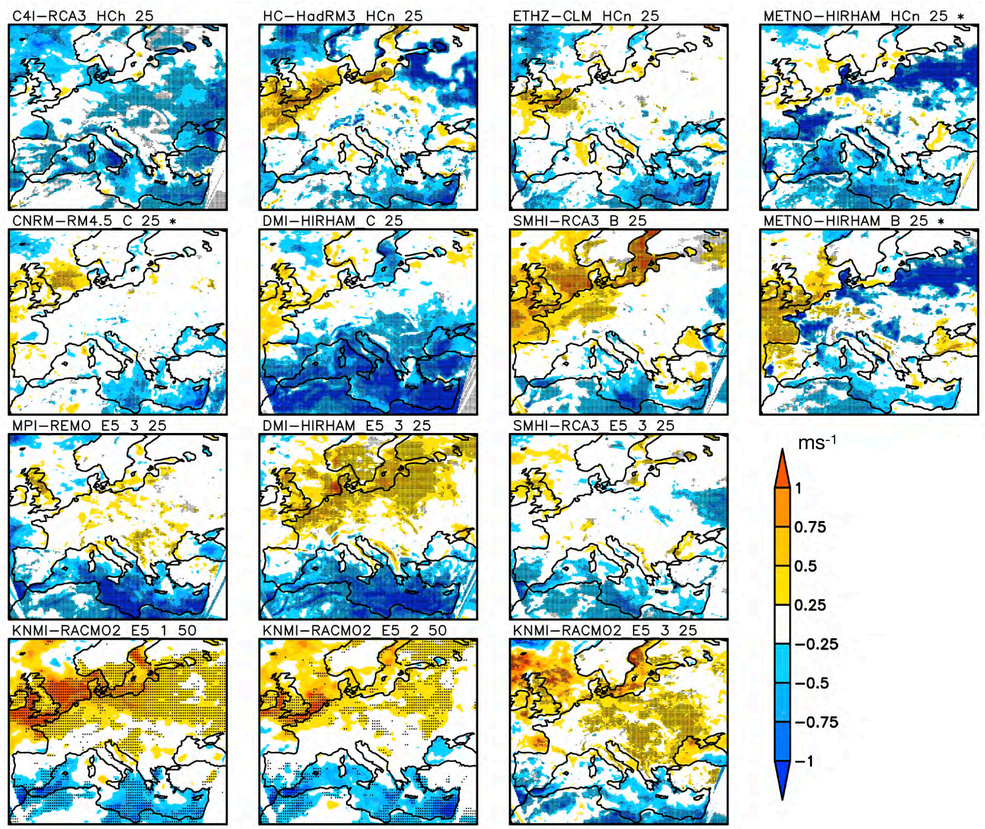
Model uncertainty for storms

Change in 98% percentile of daily wind speed at 10m (2071-2100, A1B scenario)

Horizontal resolution: ~180 km



Horizontal resolution: ~25 km

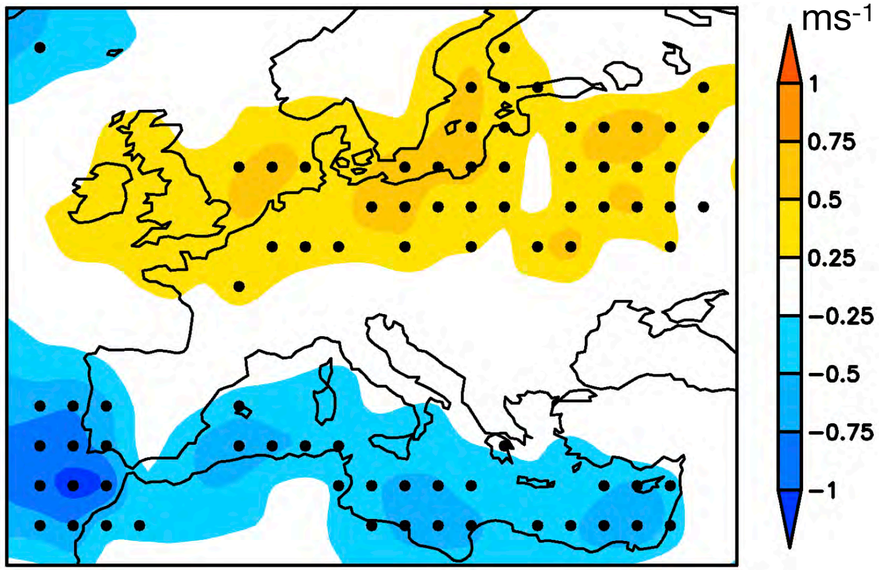


Donat et al. (2011)

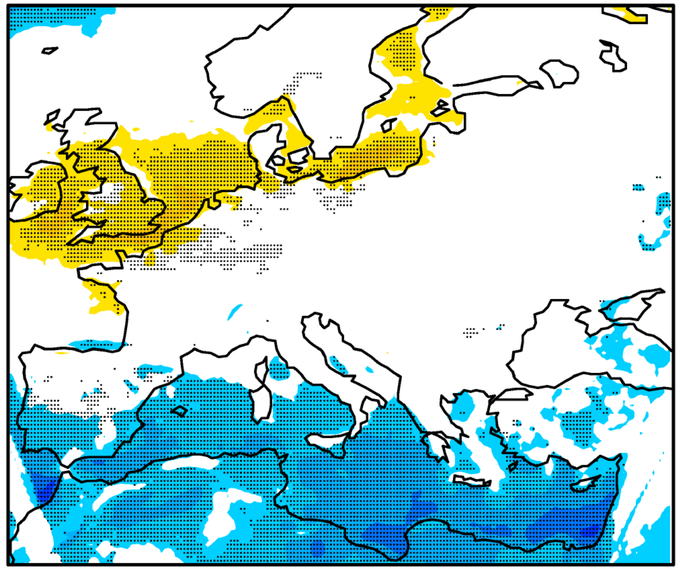
Model uncertainty for storms

Change in 98% percentile of daily wind speed at 10m (2071-2100, A1B scenario)

Global climate model ensemble mean



Regional climate model ensemble mean



Donat et al. (2011)

Climate model uncertainty for extra-tropical storms

"**low confidence** in extratropical storm projections"

TS.5.7.4, IPCC (2013)

"**low confidence** in the **magnitude of regional storm track changes**"

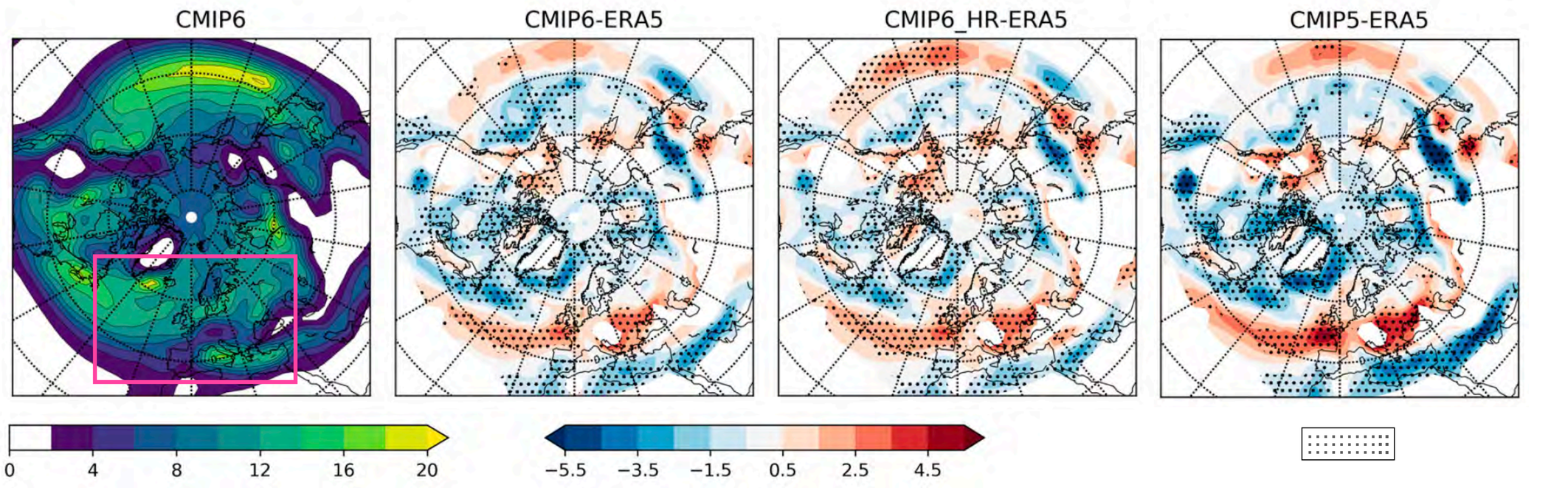
"**challenge of down-scaling future wind** states from coarse resolution climate models"

14.6.2, IPCC (2013)

Grand challenge of World Climate Research Program on Clouds, Circulation and Climate Sensitivity

Climate model uncertainty for extra-tropical storms

Storm tracks for December to February



cyclones per month

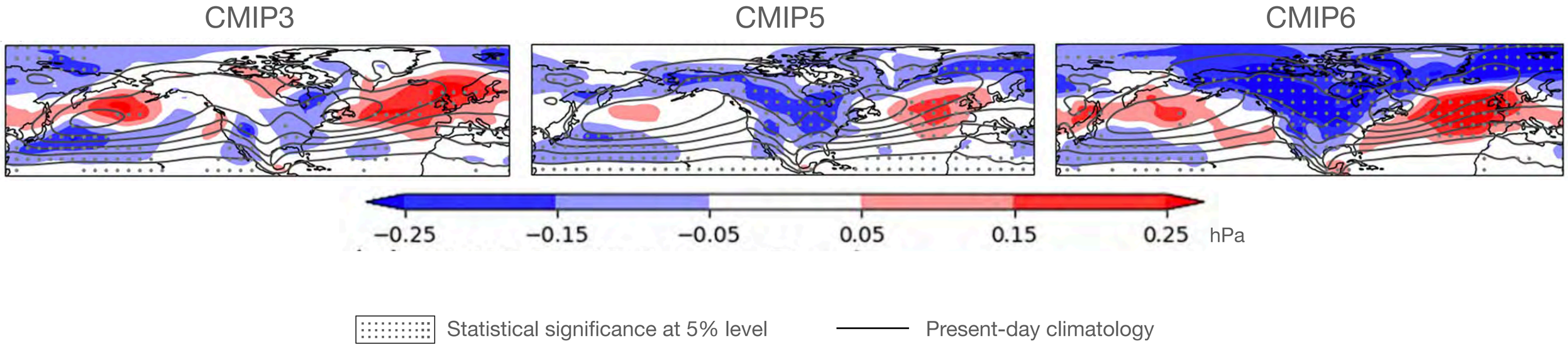
Bias in # cyclones per month

> 80% of models agree on sign of bias

Priestley et al. (2020)

Climate model projections for extra-tropical storms

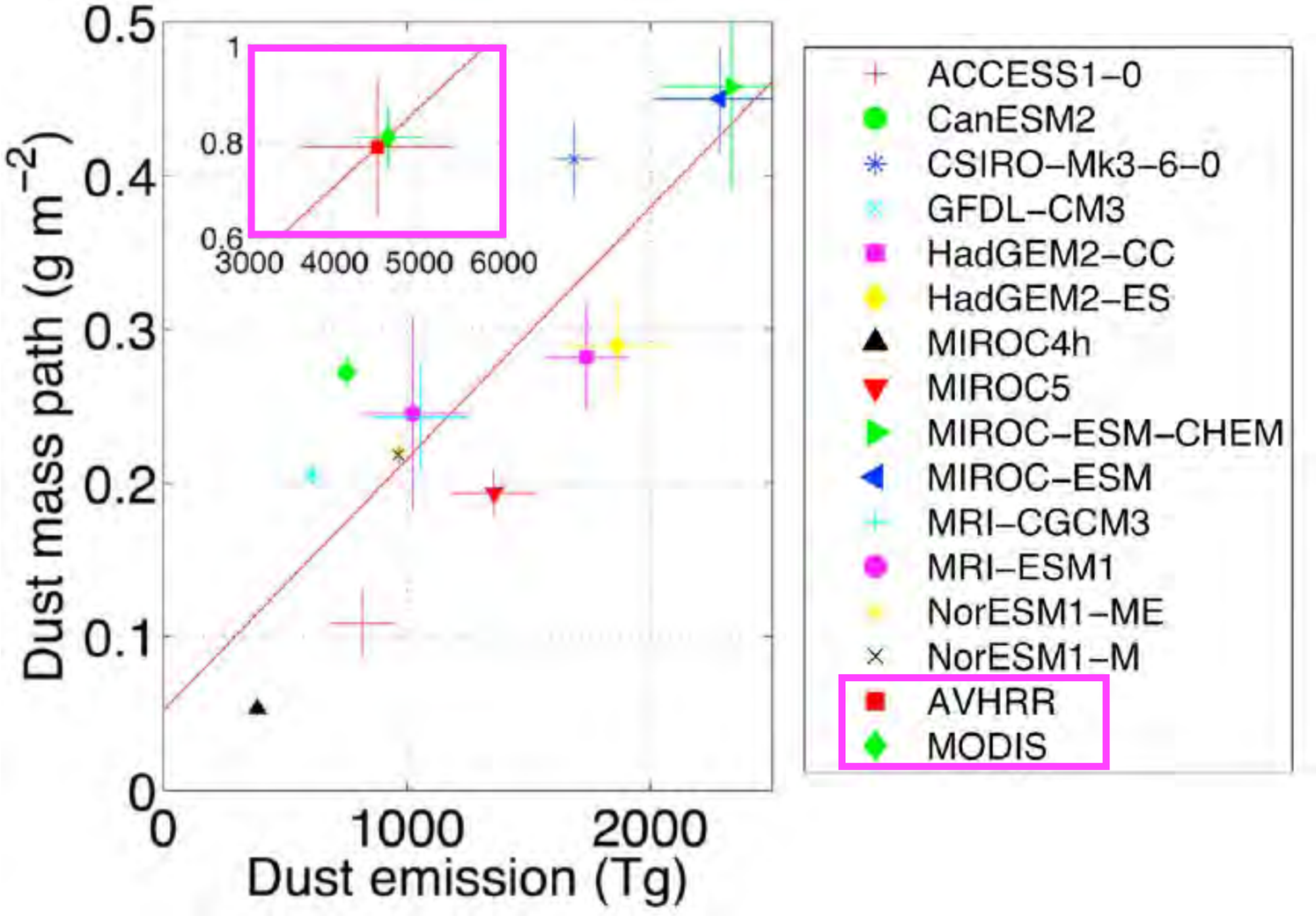
Future change in storm tracks for December to February in SSP2-4.5



Harvey et al. (2020)

What about irradiance?

CMIP5 uncertainty in aerosol burden

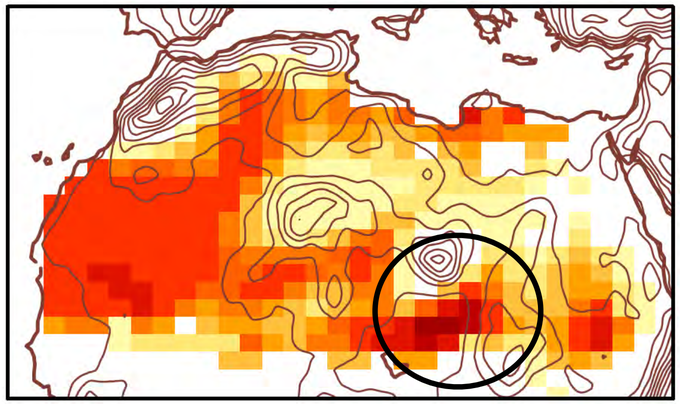


Evan et al. (2014)

Dust uncertainty associated with near-surface winds

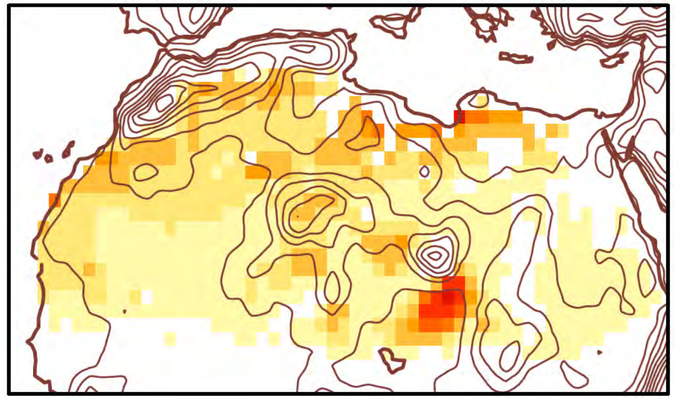
Climatology for December - February (1980 - 2009)

CMIP5 climate model

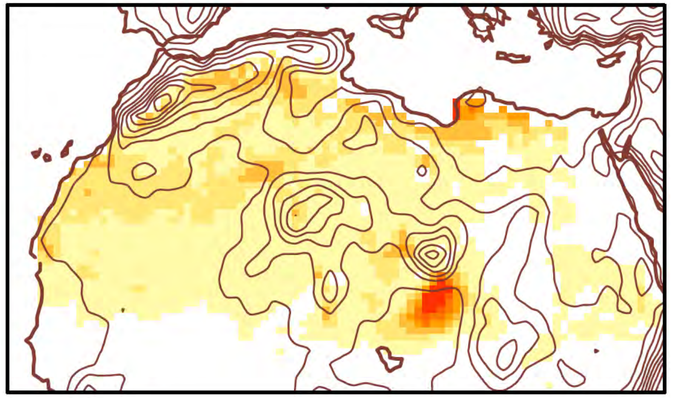


Bodélé Depression

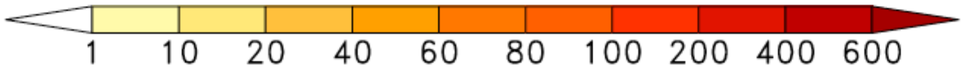
ERA-Interim



MERRA



Dust-emission amount [gm^{-2}]



Fiedler et al. (2016)

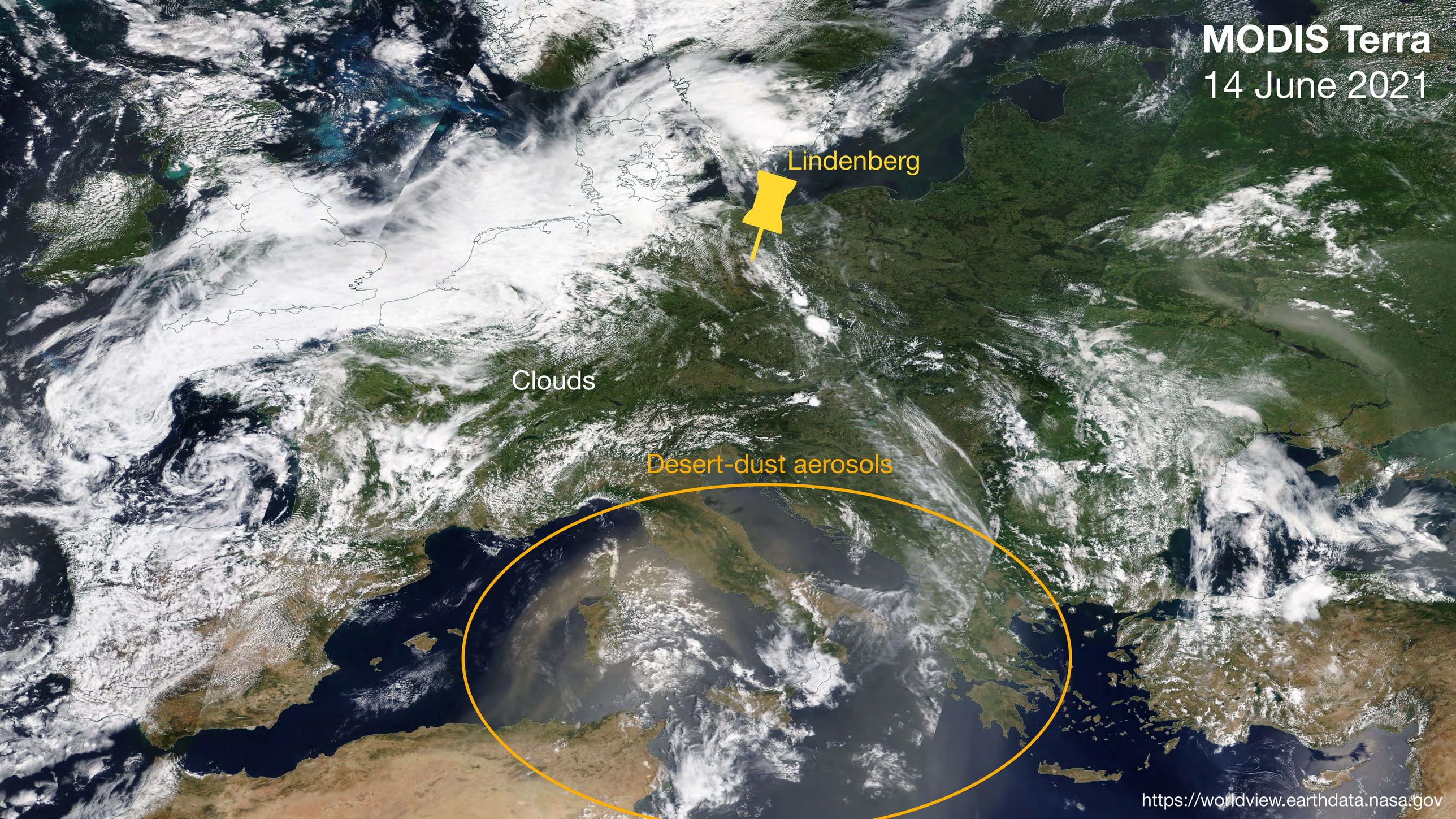
Renewable Energy in Climate Change

What to expect today

Why do we care about renewable energy?

What do models tell us about the potential for power production?

How does FESSTVaL and process studies contribute?


MODIS Terra
14 June 2021
Lindenberg
Clouds
Desert-dust aerosols
https://worldview.earthdata.nasa.gov

How does FESSTVaL help us?

Local measurement network to cover small-scale variability in irradiance and winds

APOLLOs
(~ 100)

Wetterstationen
WXT
(~ 25)

Regenradar
X-Band Radar
Energiebilanz-Station
MWRP

Supersites

Lindenberg
- LiDAR (2)
- MRR
- MIRA
- Ceilometer (3)
- MWRP (2)
- Scintillometer

Falkenberg
- DWD Maste
- LiDAR (8)
- Energiebilanz-Station
- MRR
- Ceilometer (3)
- MWRP (2)
- Scintillometer (3)

Birkholz
- LiDAR
- Energiebilanz-Station
- MRR
- Ceilometer

Kehrigk
- Forststation DWD

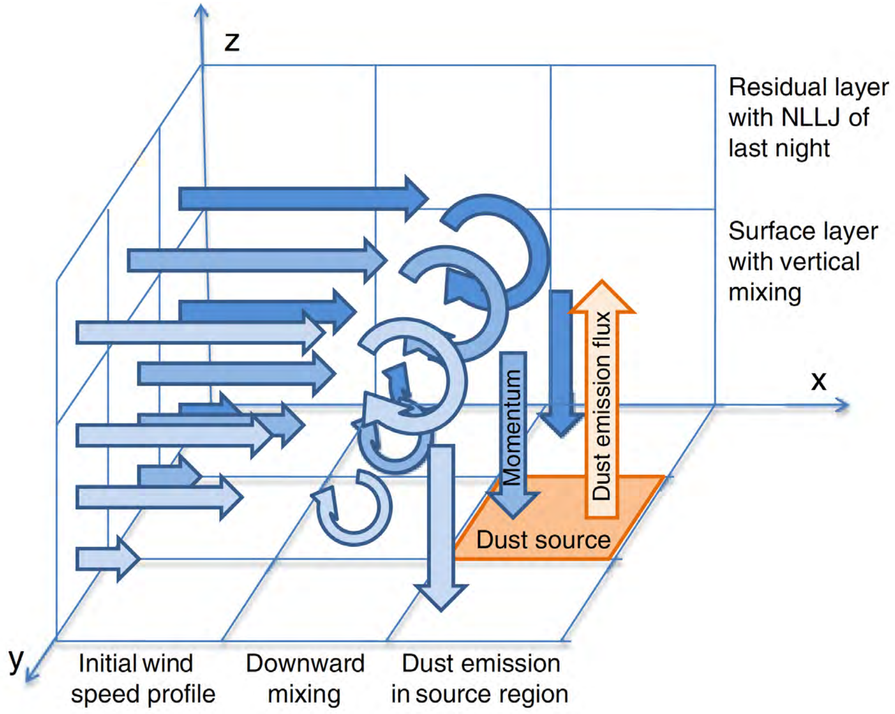
http://fesstval.de

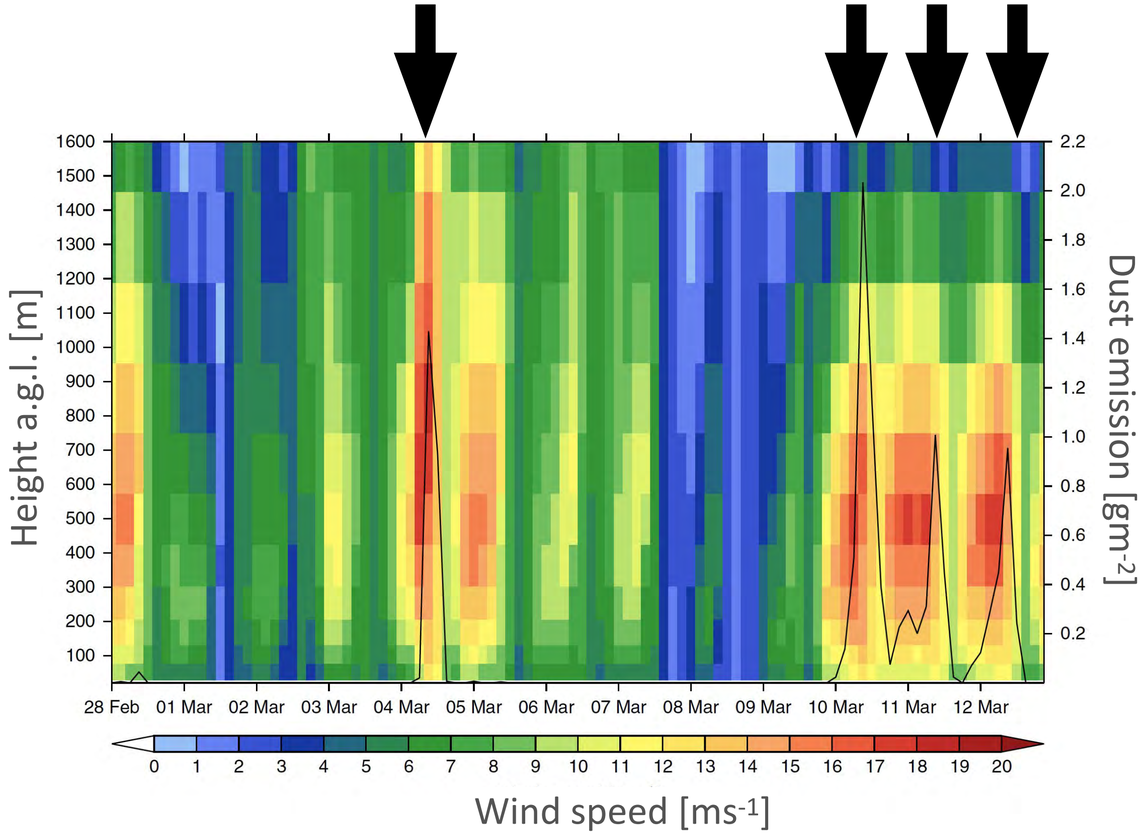
Hans-Ertel-Zentrum
für Wetterforschung

FESSTVaL
Field Experiment on Submesoscale Spatio-Temporal Variability in Lindenberg

Dust emission associated with nocturnal low-level jets

1979-2010 climatology (ERA-Interim)

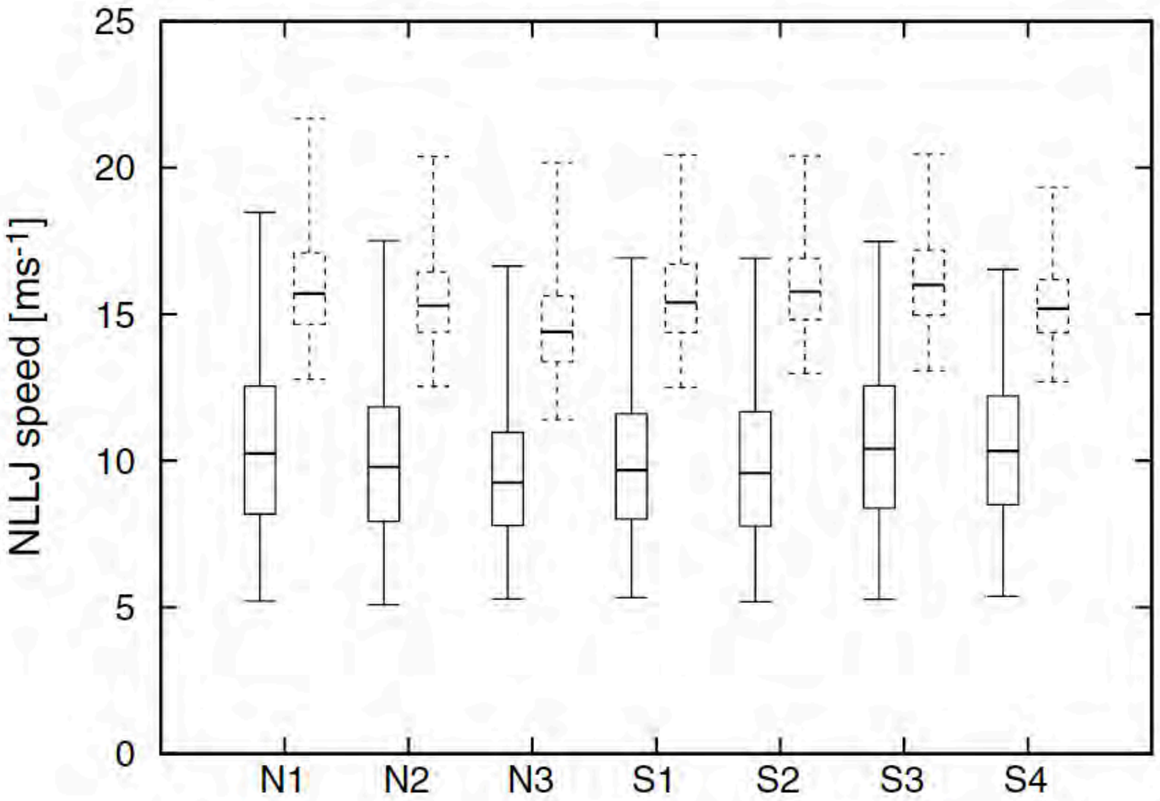


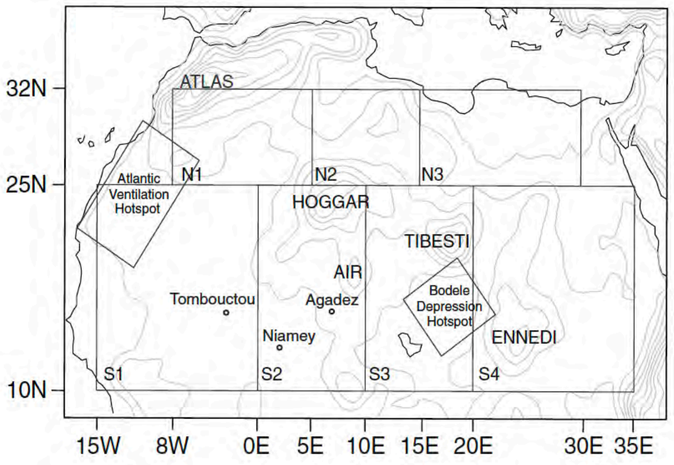


Fiedler et al. (2013)

Core speed of nocturnal low-level jets

1979-2010 climatology (ERA-Interim)



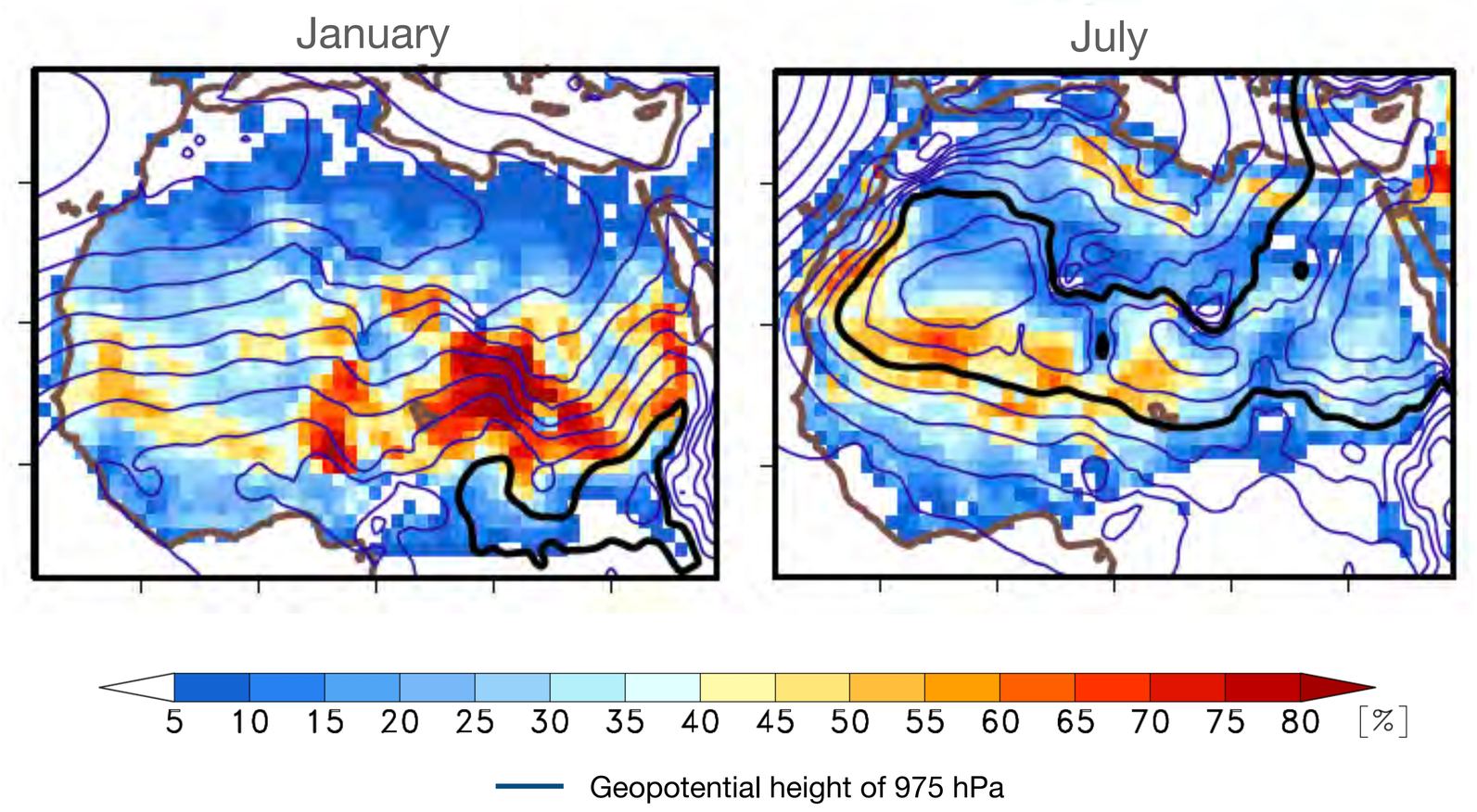


All NLLJs Dust-emitting NLLJs

Fiedler et al. (2013)

Frequency of nights with nocturnal low-level jet

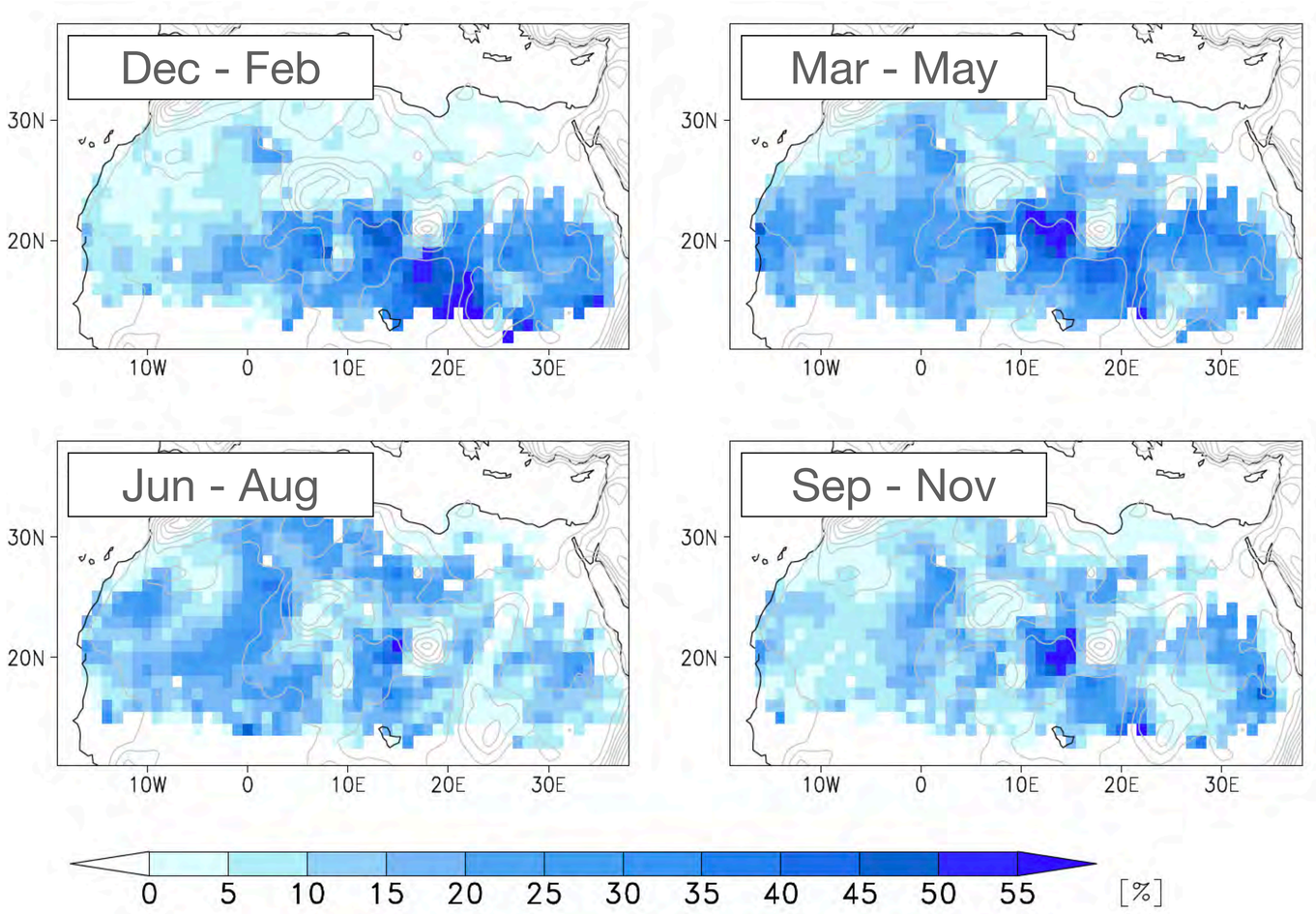
1979-2010 climatology (ERA-Interim)



Fiedler et al. (2013)

Dust emission associated with nocturnal low-level jets

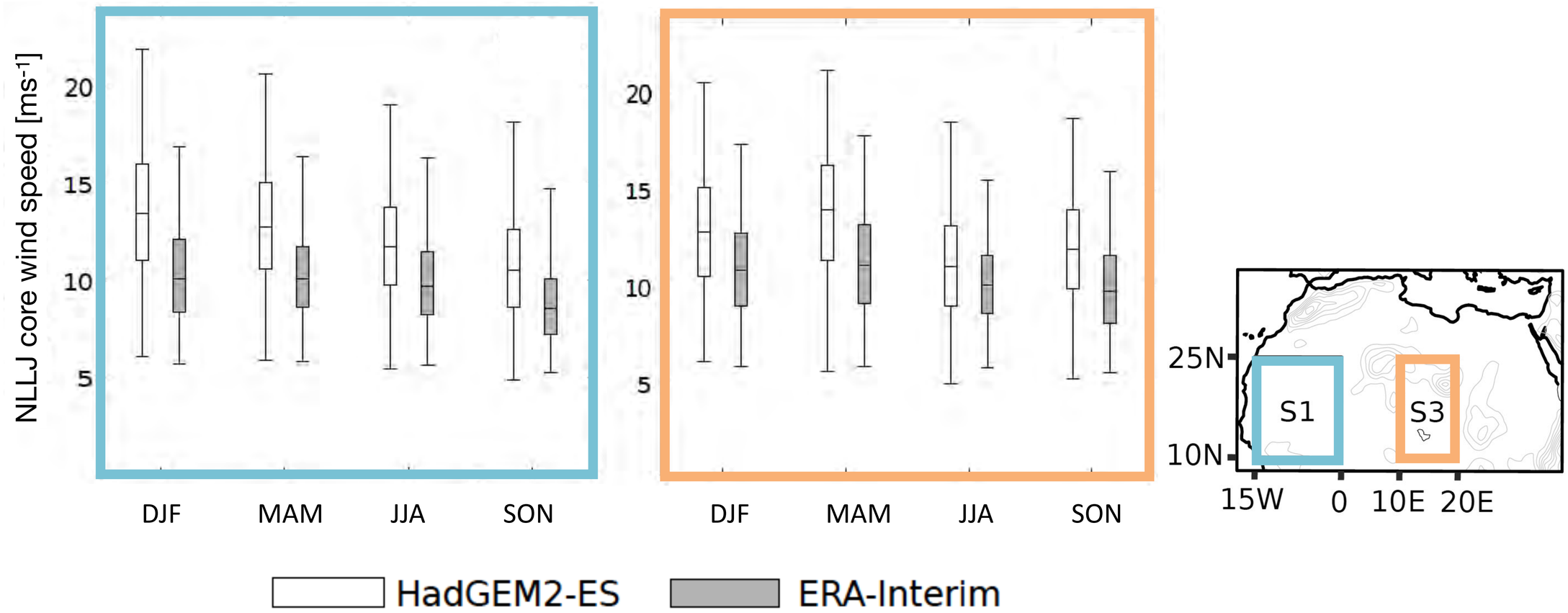
1979-2010 climatology (ERA-Interim)



Fiedler et al. (2013)

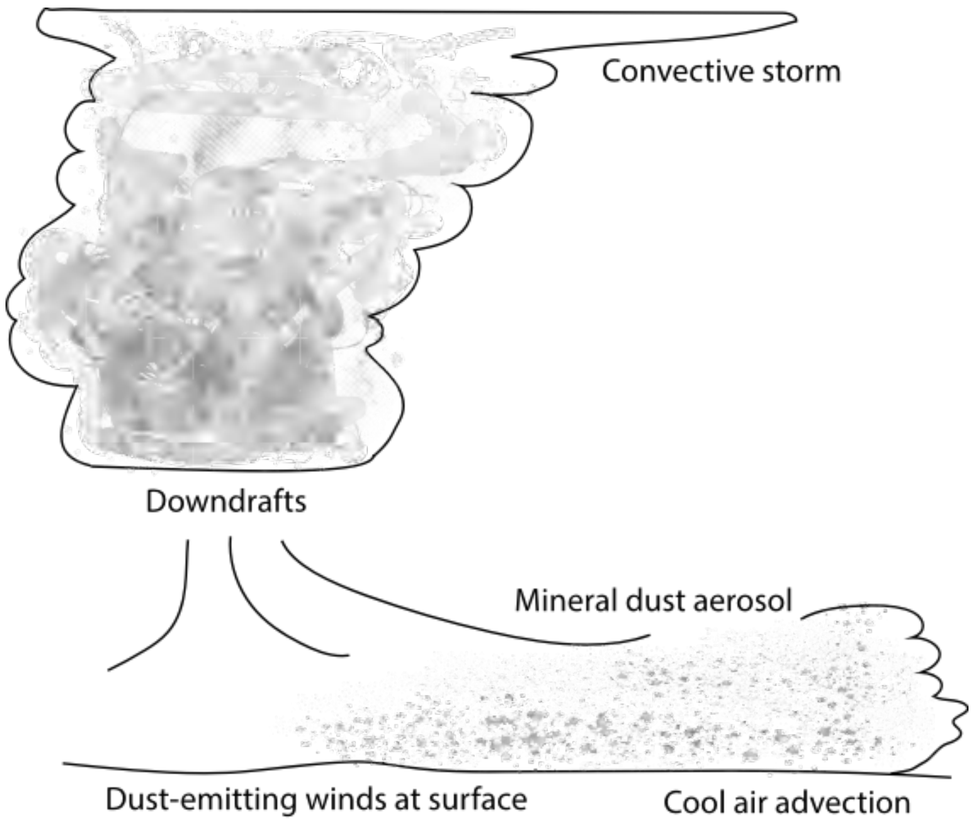
Model differences in nocturnal low-level jets

1979-2010 climatology of ERA-Interim and a CMIP5 model



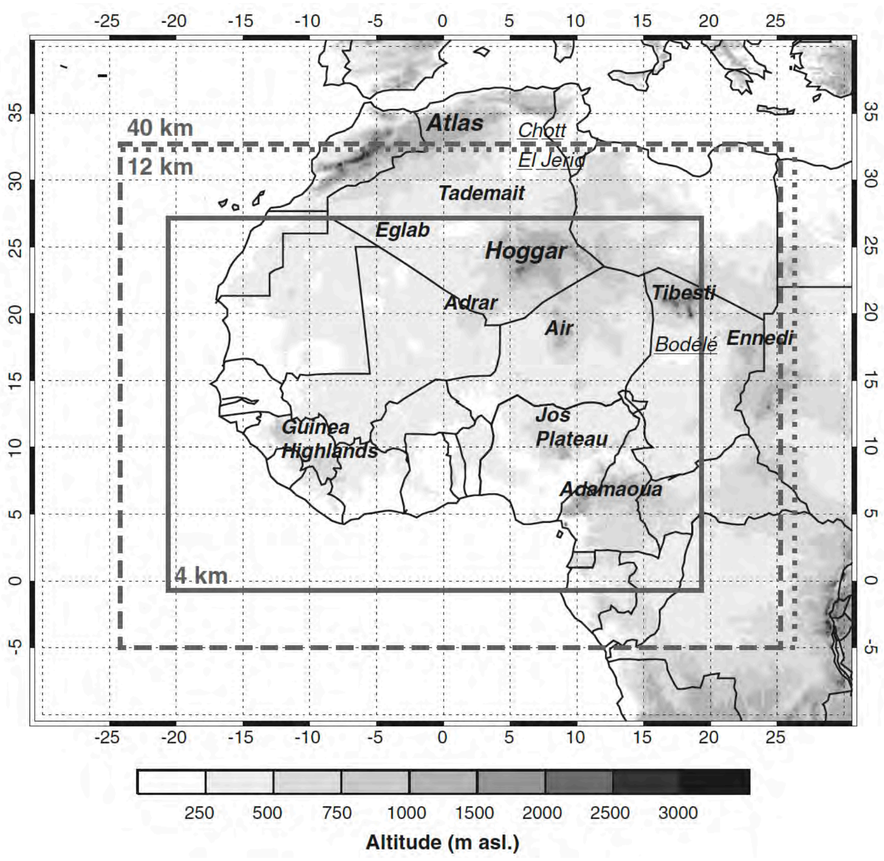
Fiedler et al. (2016)

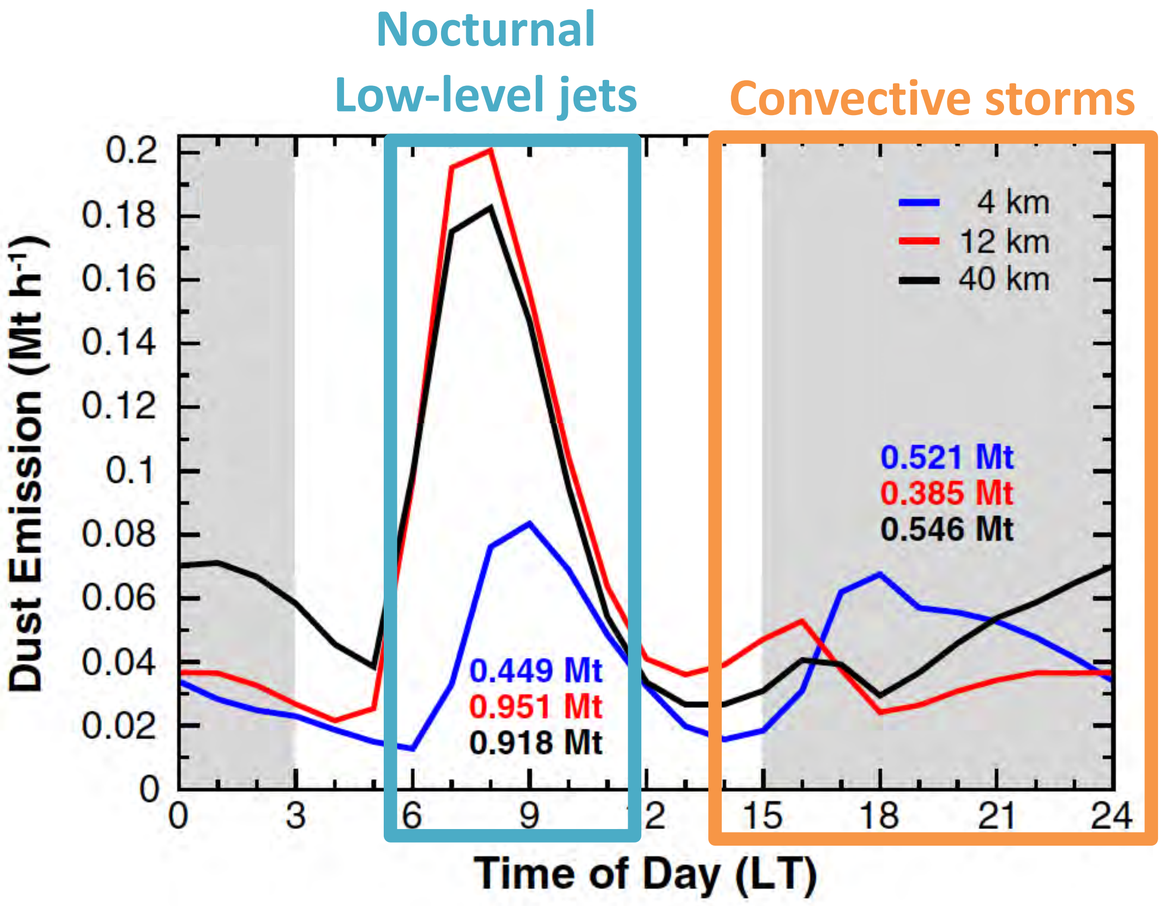
Peak winds associated with convective cold pools



Uncertainty in dust emission from NLLJs and convective storms

CASCADE simulations for summertime West Africa

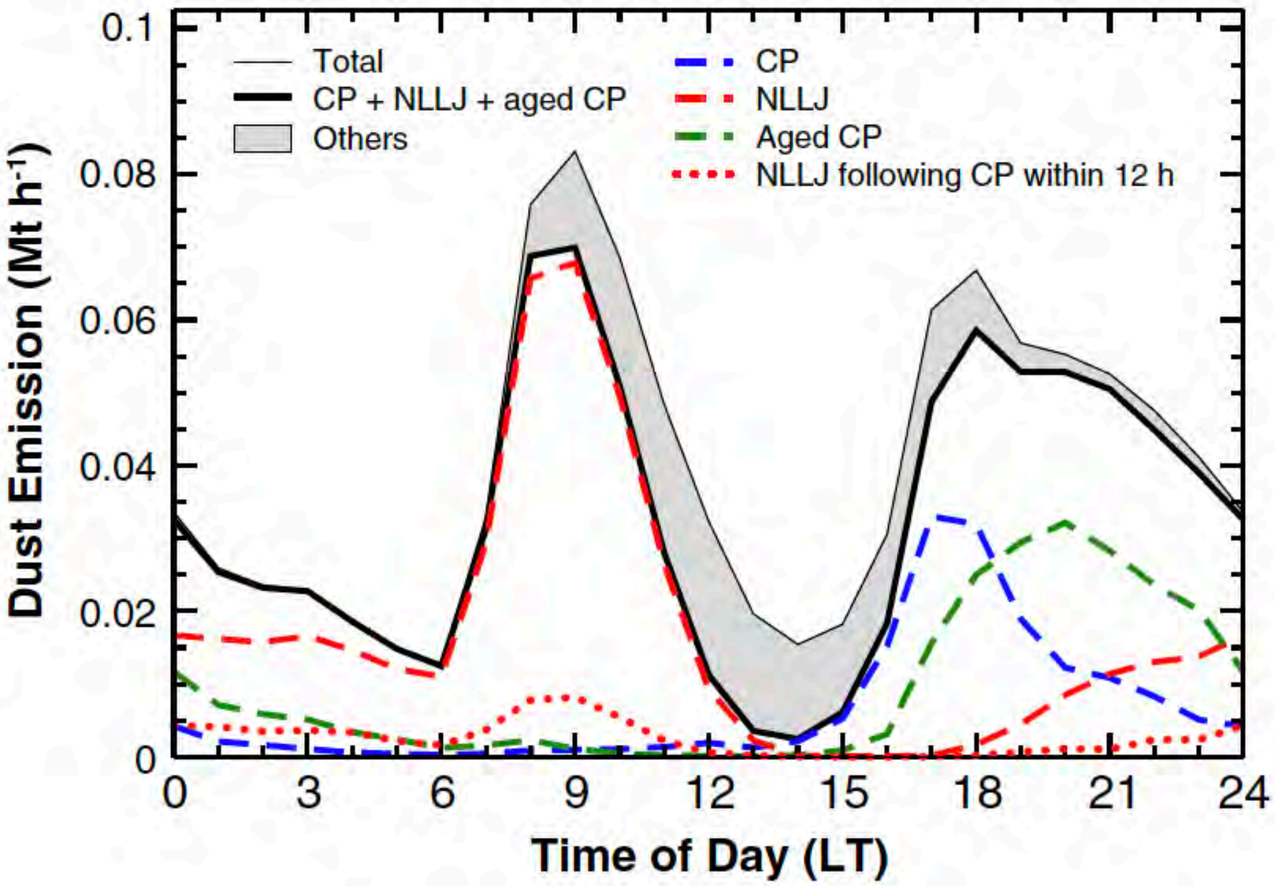




Heinold et al. (2013)

Meteorological processes for desert-dust emission

CASCADE simulations for summertime West Africa



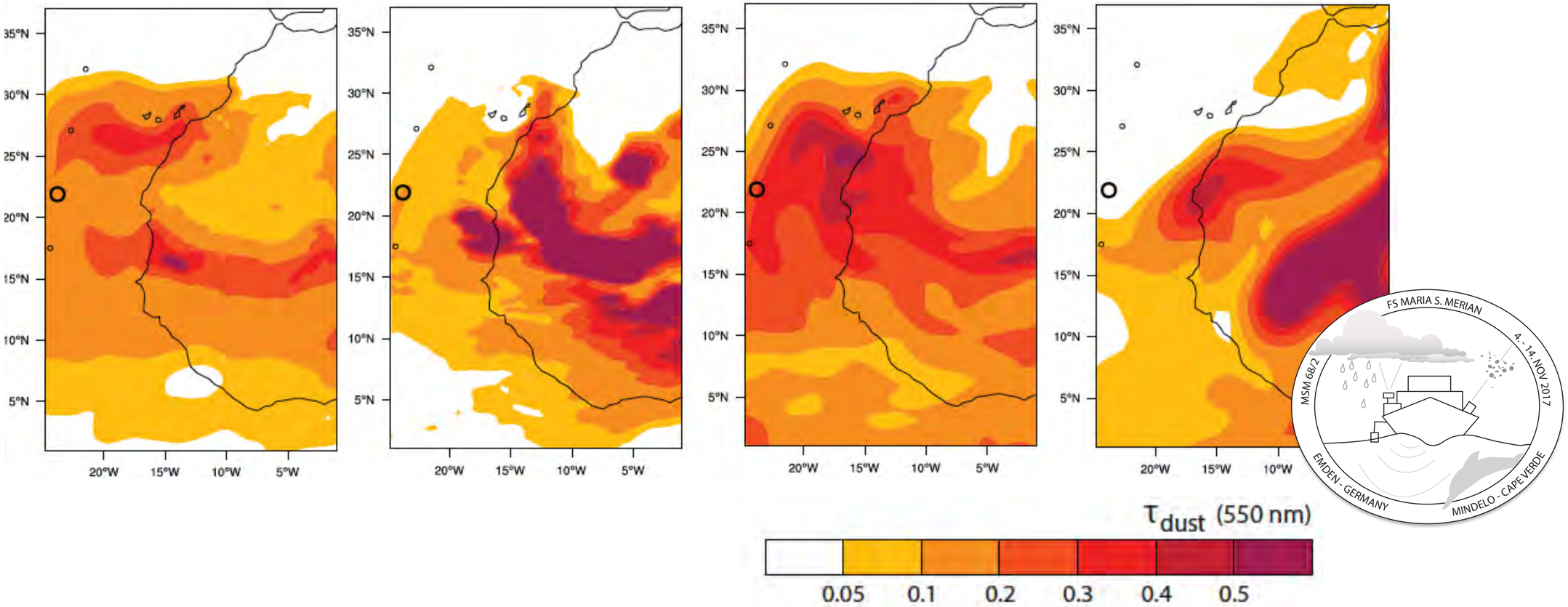
Heinold et al. (2013)

Forecast uncertainty for dust storm

Forecasts from WMO's Sand and Dust Storm Warning Advisory and Assessment System

Dust aerosol optical depth forecasts

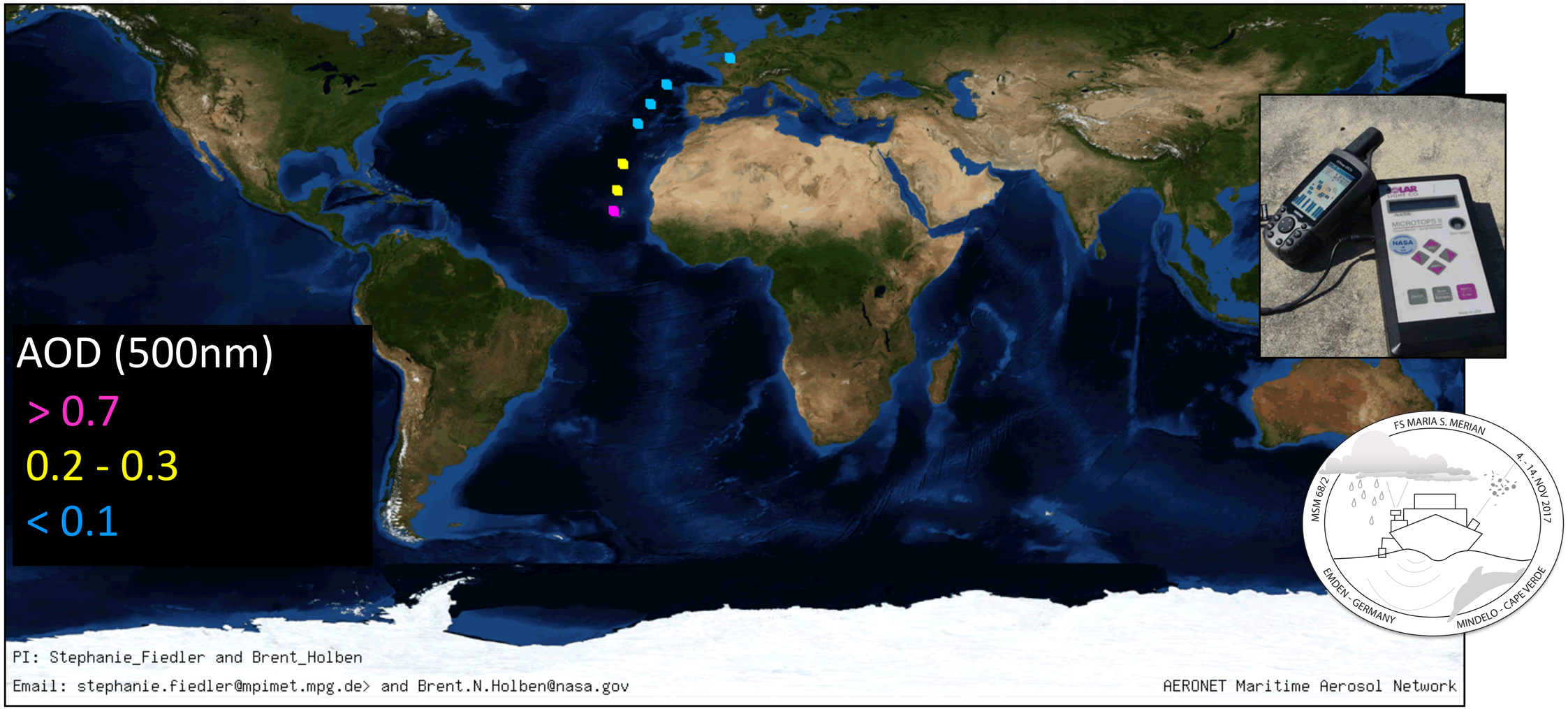
12 November 2017, 12 UTC



Fiedler (2018)

Dust storm

Expedition MSM68/2



NASA's Maritime Aerosol Network

Fiedler (2018)

Renewable Energy in Climate Change

In a nutshell

1. Renewable energies are important contribution for becoming carbon neutral.

2. Traditional climate models struggle to represent processes affecting renewable energy production in detail.

3. FESSTVaL measurements create new opportunities to advance the understanding of meteorological processes for wind and PV power production.

stephanie.fiedler@uni-koeln.de

Hans-Ertel-Zentrum für Wetterforschung

FESSTVaL Field Experiment on Submesoscale Spatio-Temporal Variability in Lindenberg

Earth – Evolution at the dry limit

ewi

Universität zu Köln