Ensemble forecasting & the representation of physical processes

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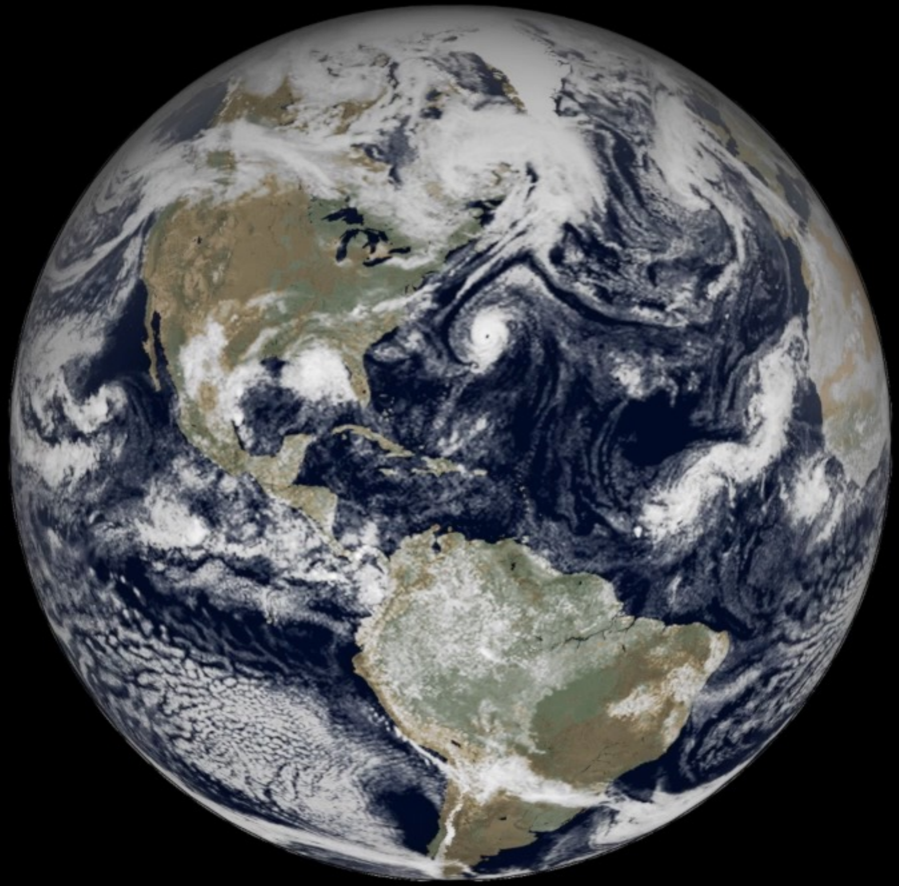


9 km ENS, 51 Members, 20200913 00 UTC + 41 h
Simulated Satellite Images

ECMWF

Annual Seminar 2022, 12-16 September 2022

Ensemble forecasting & the representation of physical processes

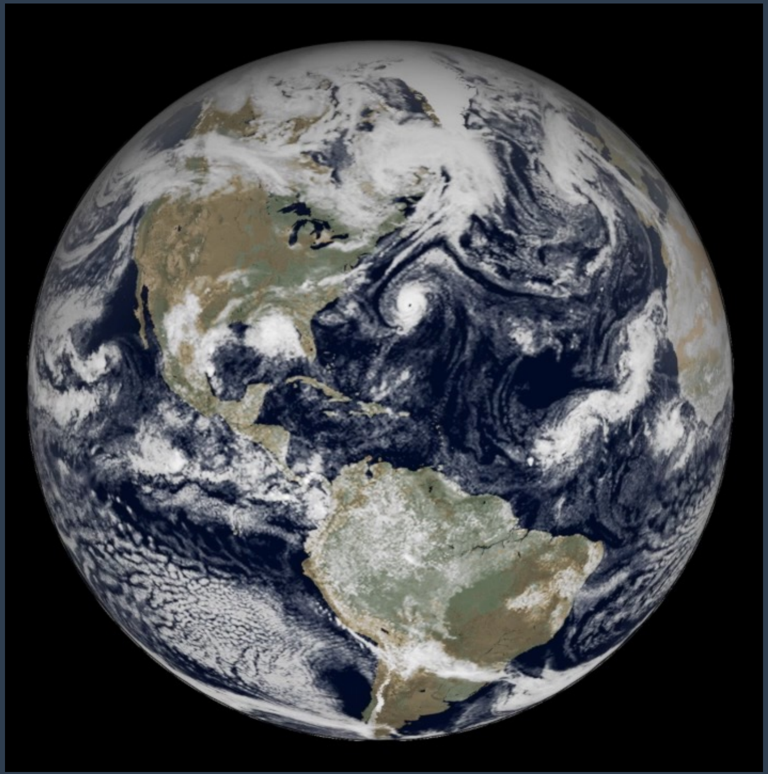
- Ensemble forecasts with the IFS
- Representing model uncertainty for physical processes: present and future
- Assessing model developments with the ensemble

Ensemble forecasts with the IFS (“ENS”)

Currently:

- 51 members (1 unperturbed + 50 perturbed)
- TCo639 (~18 km) to day 15 / TCo319 (~36 km) to day 46
- 137 vertical levels (to 0.01 hPa)
- Coupled to NEMO ocean model (1/4 degree, 75 levels), ECWAM wave model and LIM2 ice model
- Initial conditions perturbations: ensemble of data assimilations and singular vectors, 5 member ocean data assimilation
- Model uncertainty perturbations: *“Stochastic physics”*

Coming soon…



9 km ENS, 51 Members, 20200913 00 UTC + 41 h
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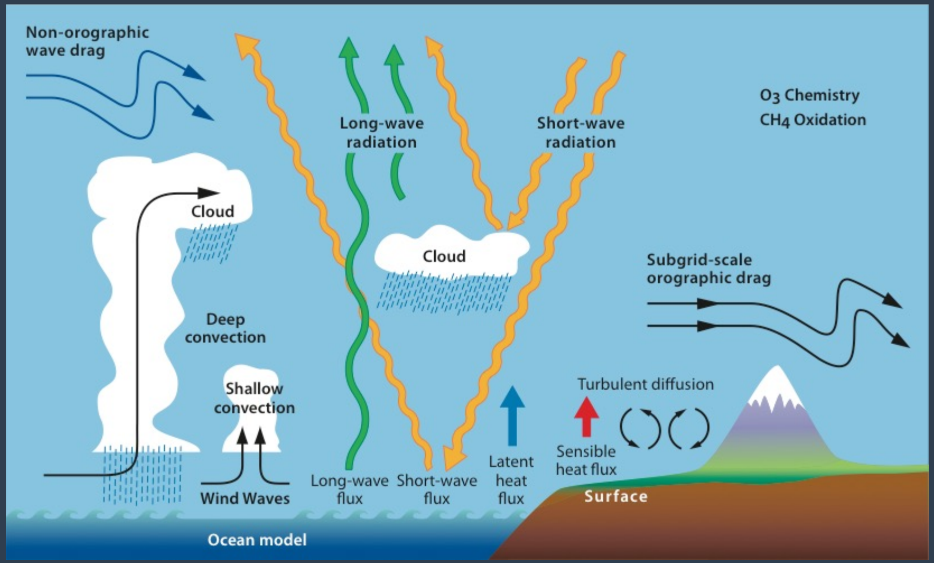
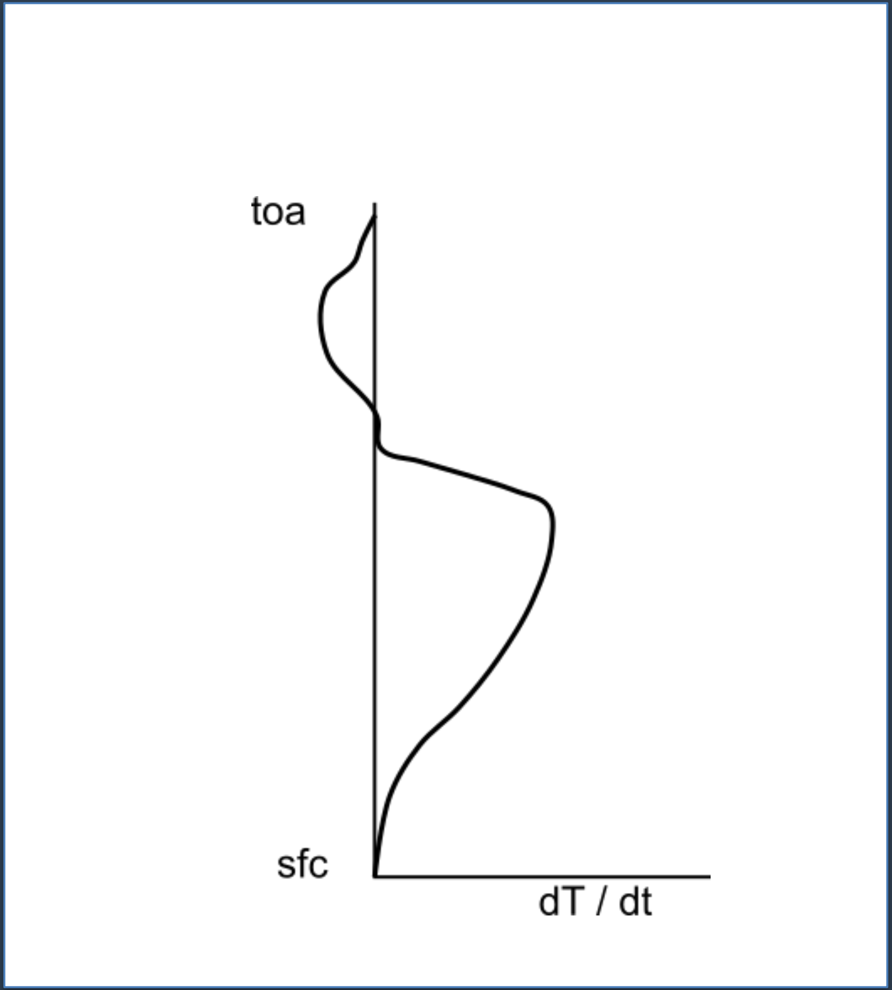
How could we describe the uncertainty in the model physics?

- Consider a profile of model tendencies from the physics parametrisations,

  e.g. profile of *T* tendencies (sfc to toa)





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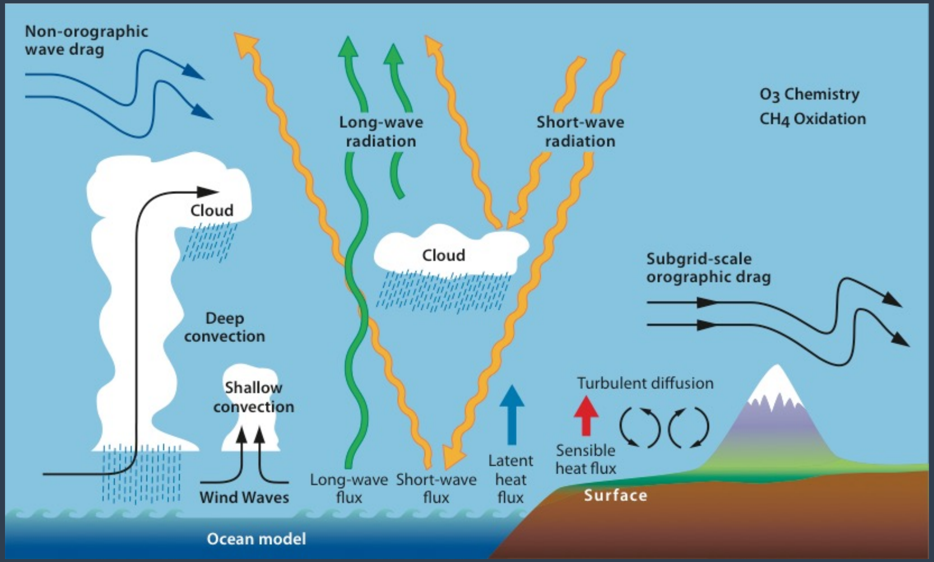
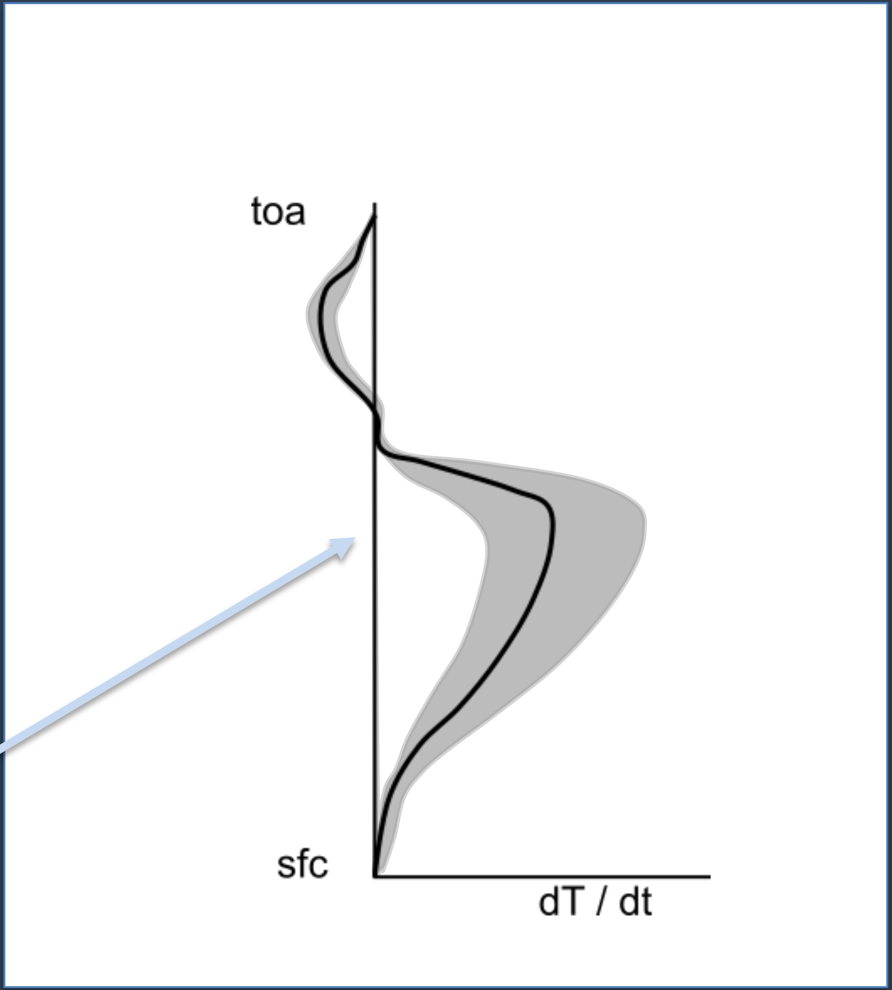
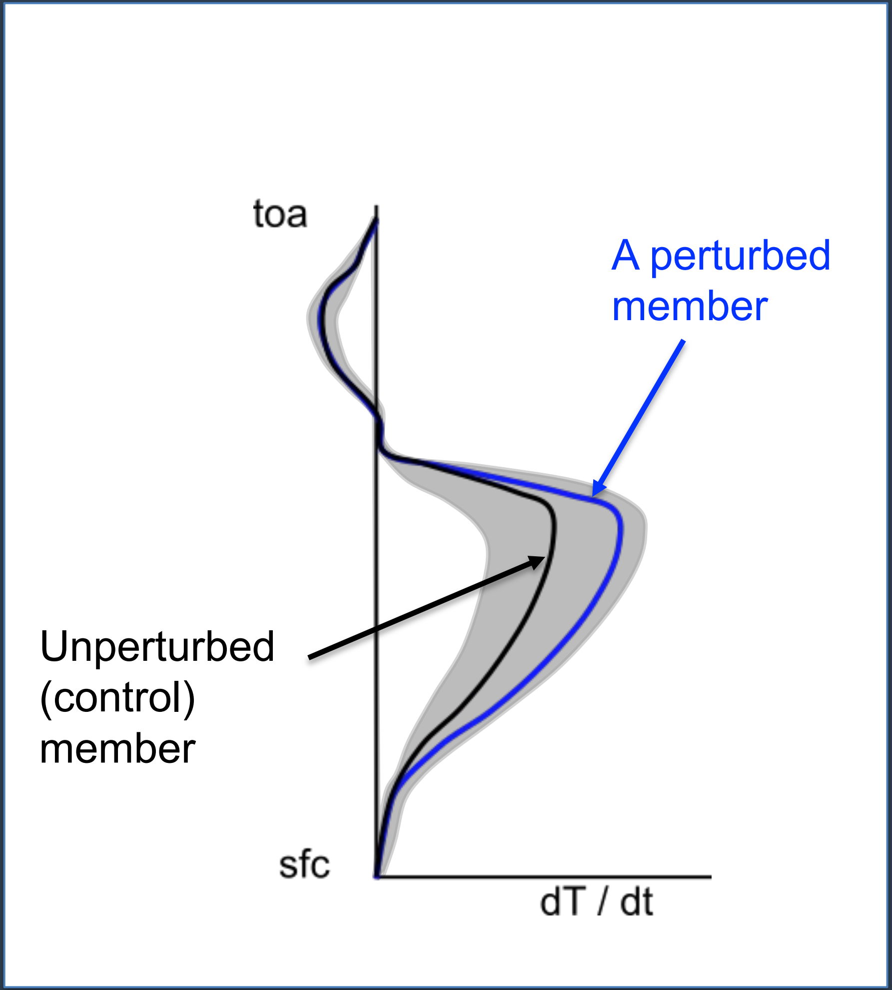




- Proposal: some uncertainty due to the physics parametrisations

How could we describe the uncertainty in the model physics?

- In the ensemble:
  - Unperturbed member: profile of unperturbed physics tendencies
  - Each perturbed member: a unique profile of perturbed physics tendencies

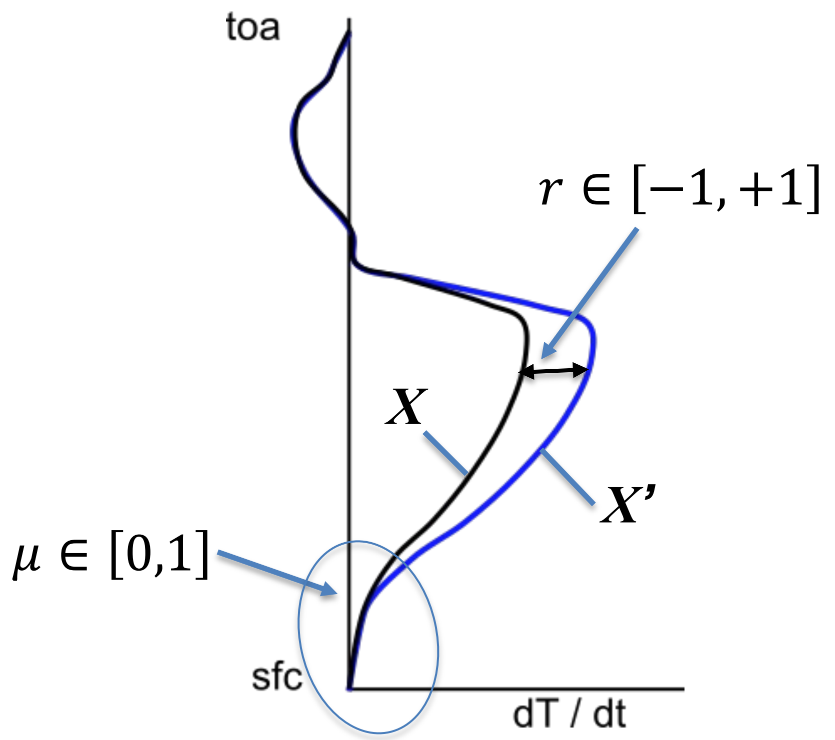


How *do* we describe the uncertainty in the IFS model physics?

***Stochastic Physics*: SPPT**

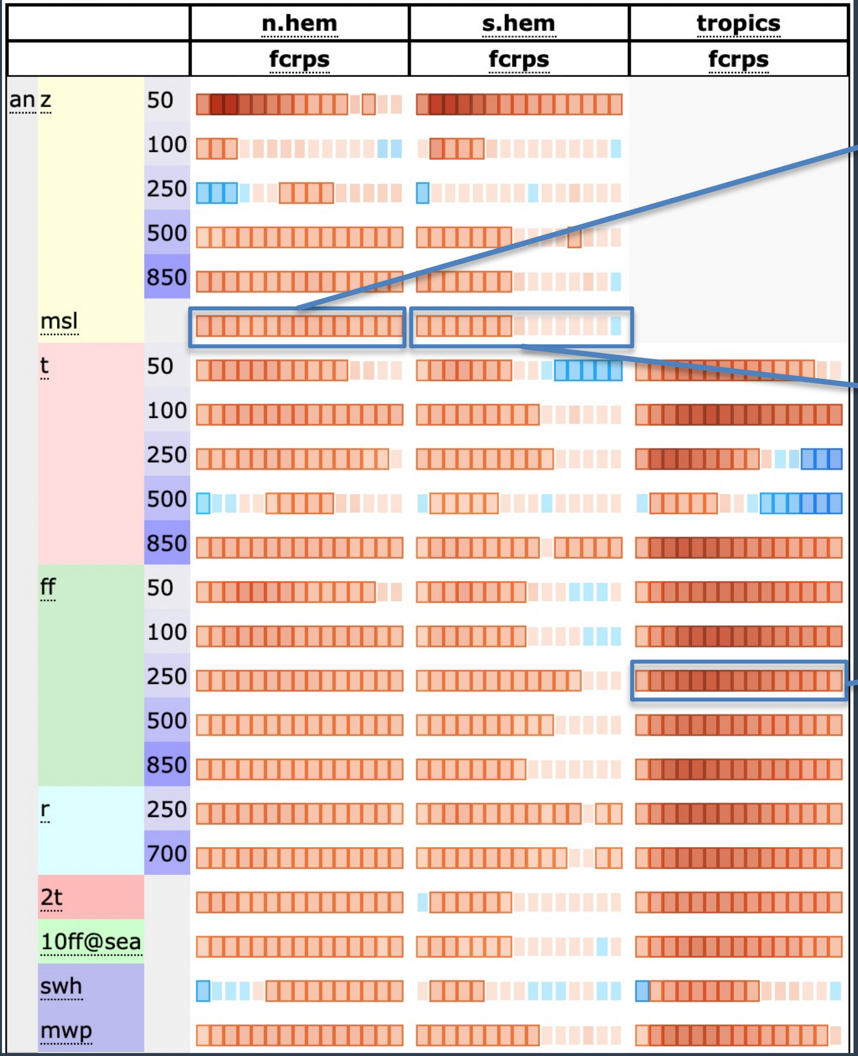
- Stochastically Perturbed Parametrisation Tendencies
- 1998: implemented (*Buizza et al., 1999*)
- 2009: revised (*Palmer et al., 2009*)
- 2016: global fix (*Davini et al., 2017*)
- 2018: clear-skies revision & seamless application (EDA .. seasonal) (*Lock et al., 2019*)

$$\boldsymbol{X}' = (1 + \mu r)(\boldsymbol{X} - \boldsymbol{X}_{clr}) + \boldsymbol{X}_{clr}$$

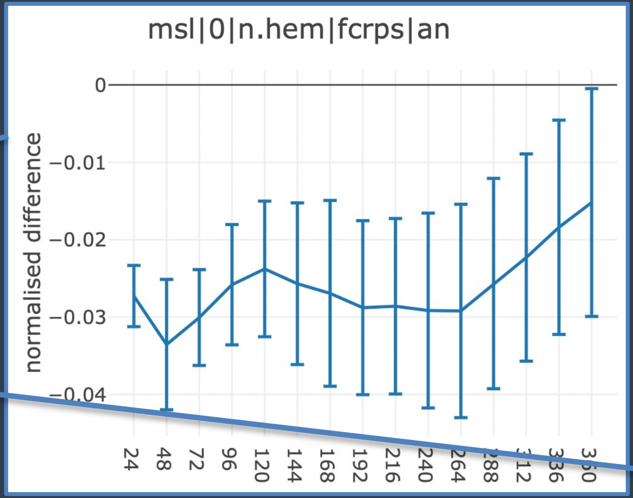


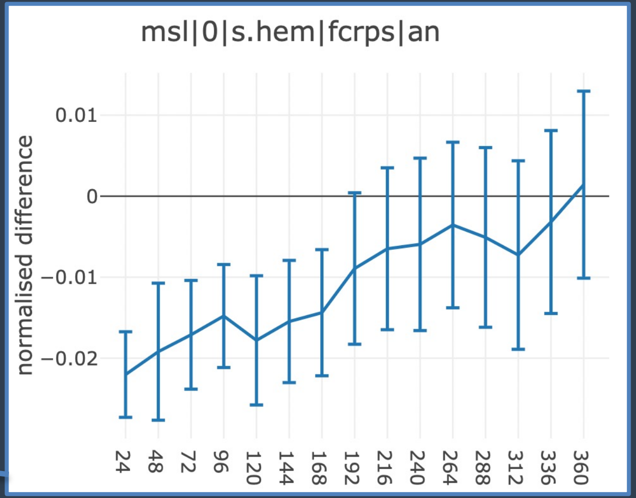
SPPT: impact on ensemble skill --- *fair CRPS*

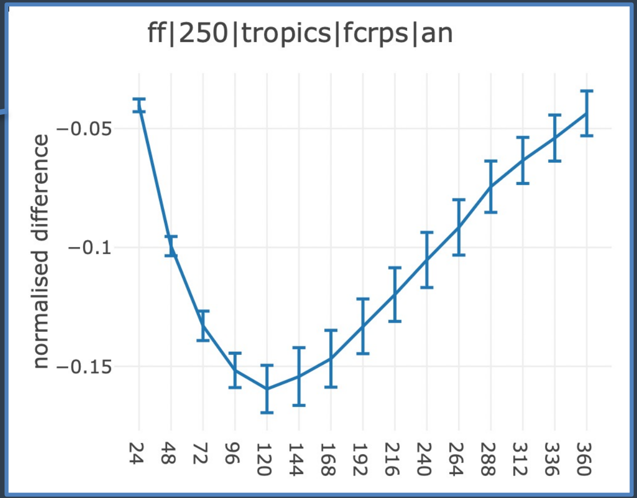
degradation *improvement*



Impact of removing SPPT





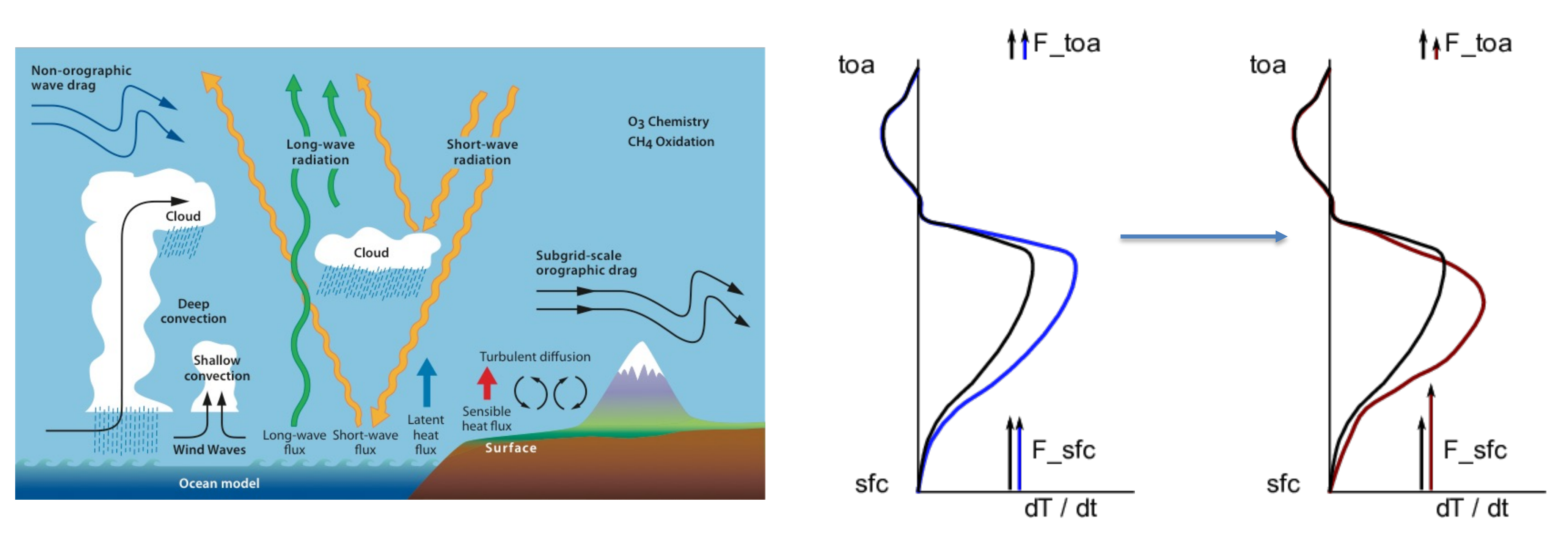


Experiments:

- CY47R3
- 9km ENS (TCo1279)
- 8+1 members
- Starts: every day, Jun+Jul+Dec+Jan 2020/21
- 00/12 UTC
- Forecast period: 15 days

Future: Stochastically Perturbed Parametrisations (SPP)

- Under development in recent years.
- In the IFS, operates in: radiation, vertical mixing, cloud and convection schemes
- Represents MU close to their sources, preserves local conservation properties, enables multivariate description of uncertainties



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  - 19 quantities perturbed
  - 2,000 km correlation scales
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- Lang et al. (2021, QJRMS; “**new**”) :
  - 27 quantities perturbed
  - 1,000 km correlation scales
  - changes in mean/variance to some random fields
  - generates similar spread & skill to SPPT

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TABLE 2 Perturbed parameter settings

		new		
Parameter ID	**Role of Parameter**	**Dist**	**σ**	**Scheme**
Turbulent diffusion and subgrid orography:				
CFM_OC	Transfer coefficient for momentum over ocean	LN	0.26 for dry convective PBL / 0.33	Mean / Median
CFM_LA	Transfer coefficient for momentum over land	LN	0.65 for dry convective PBL / 0.78	Mean / Median
RKAP	von Kármán constant	LN	0.065 for dry convective PBL / 0.26	Mean / Median
TOFDC	Coefficient in turbulent orographic form drag scheme	LN	0.78	Mean
HSDT	St. dev. of subgrid orography	LN	0.52	Mean
VDEXC_LEN	Length-scale for vertical mixing in stable boundary layer	LN	1.04	Mean
Convection:				
ENTRORG	Entrainment rate	LN	0.39	Mean
ENTSHALP	Shallow entrainment rate	LN	0.39	Mean
DETRPEN	Detrainment rate for penetrative convection	LN	0.39	Mean
RPRCON	Conversion coefficient cloud to rain	LN	0.52	Mean
CUDU	Zonal convective momentum transport, deep convection	N	1.22	Mean
CUDV	Meridional convective momentum transport, deep convection	N	1.22	Mean
CUDUS	Zonal convective momentum transport, shallow convection	N	1.33	Mean
CUDVS	Meridional convective momentum transport, shallow convection	N	1.33	Mean
RTAU	Adjustment time-scale in CAPE closure	LN	0.78	Mean
ENTSTPC1	Shallow entrainment test parcel entrainment	LN	0.39	Mean
Cloud and large-scale precipitation:				
RAMID	Relative humidity threshold for the onset of stratiform condensation	LN	0.13	Mean
RCLDIFF	Diffusion coefficient for the evaporation of cloud at subgrid cloud edges	LN	1.04	Mean
RLCRITSNOW	Cloud ice threshold for autoconversion to snow	LN	0.78	Mean
RAINEVAP	Rain evaporation rate	LN	0.65	Mean
SNOWSUBLIM	Snow sublimation rate	LN	0.65	Mean
QSATVERVEL	Vertical velocity used to calculate the adiabatic temperature change for saturation adjustment	LN	0.39	Mean
Radiation:				
ZDECORR	Cloud vertical decorrelation height	LN	0.78	Mean
ZSIGQCW	Fractional st. dev. of horiz. distribution of water content	LN	0.52	Mean
ZRADEFF	Effective radius of cloud water and ice	LN	0.78	Mean
ZHS_VDAERO	Scale height of aerosol normal vertical distribution	LN	1.04	Mean
DELTA_AERO	Optical thickness of aerosol	LN	0.78	Mean

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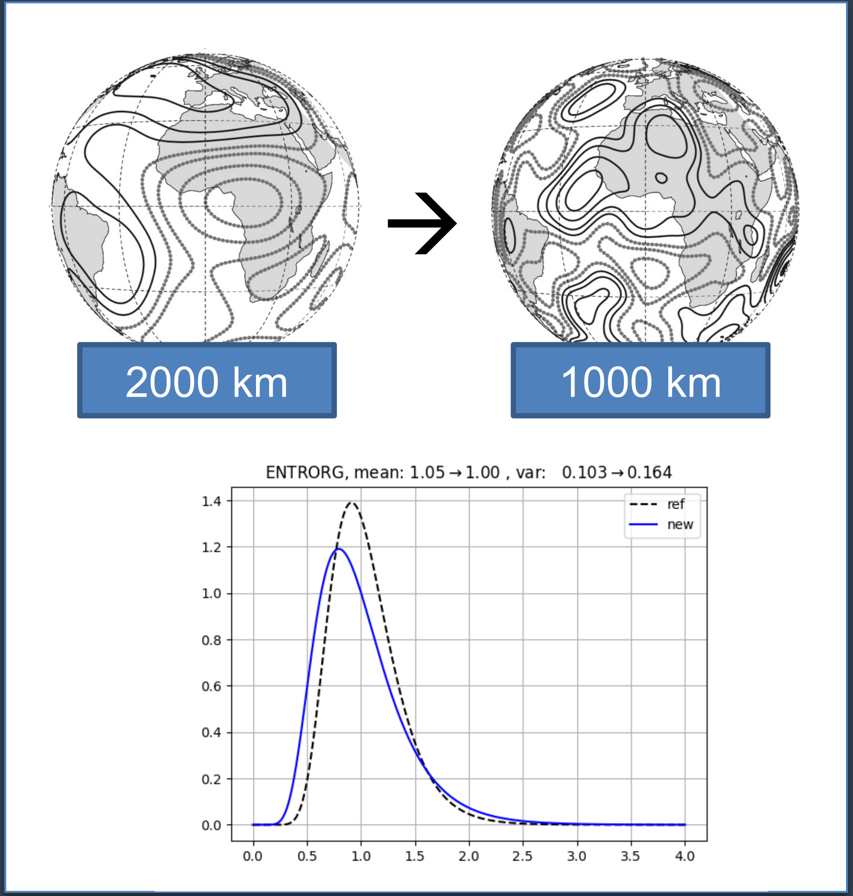
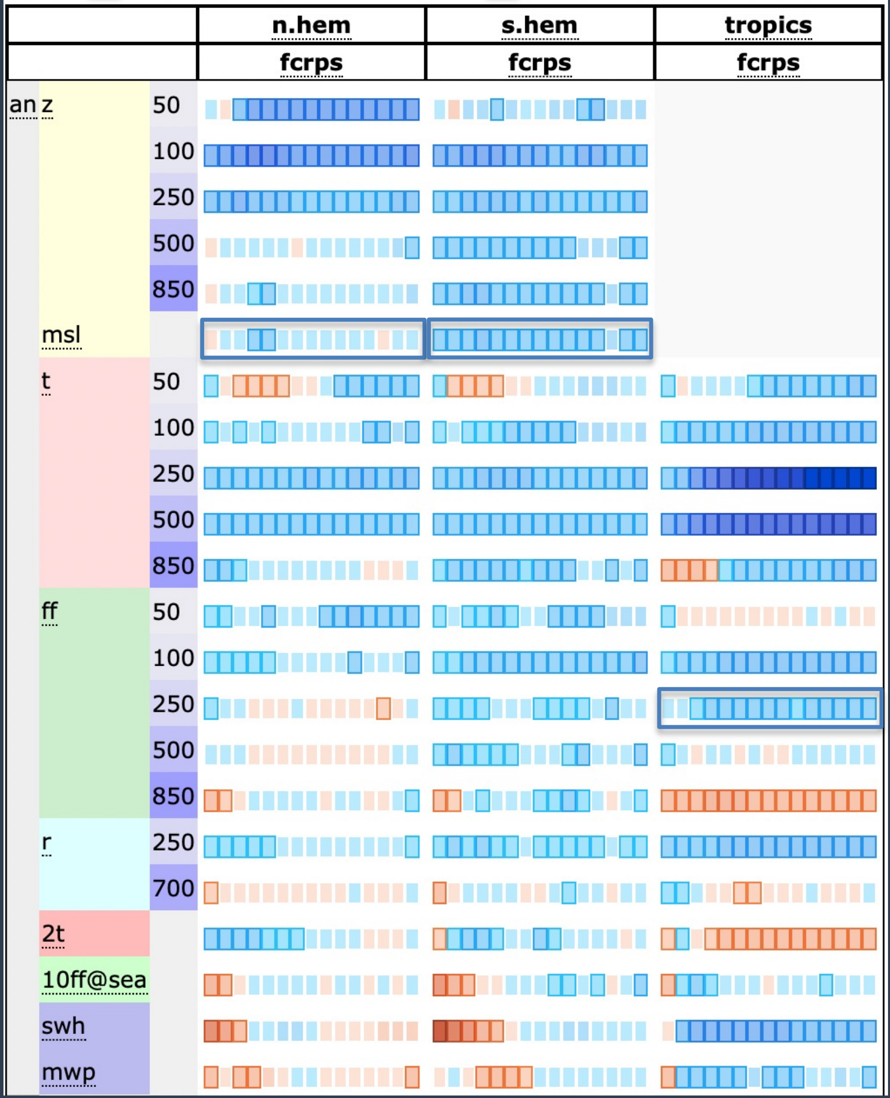
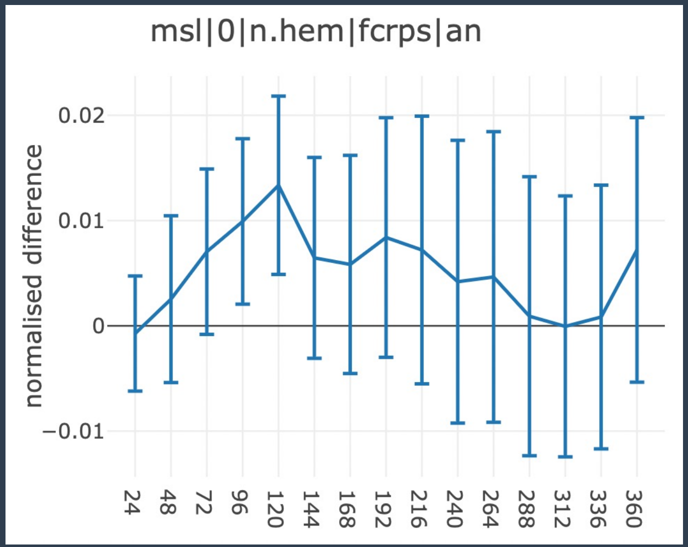


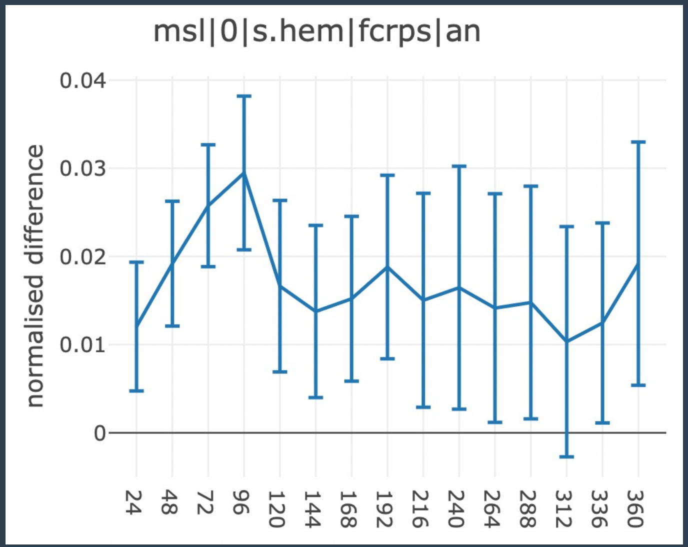
Impact of SPP on skill of ensemble forecasts: fair CRPS

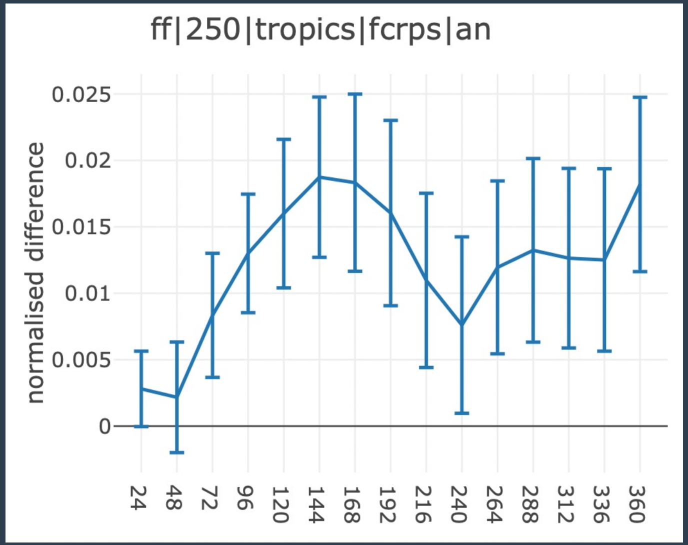
degradation *improvement*



From SPPT to SPP







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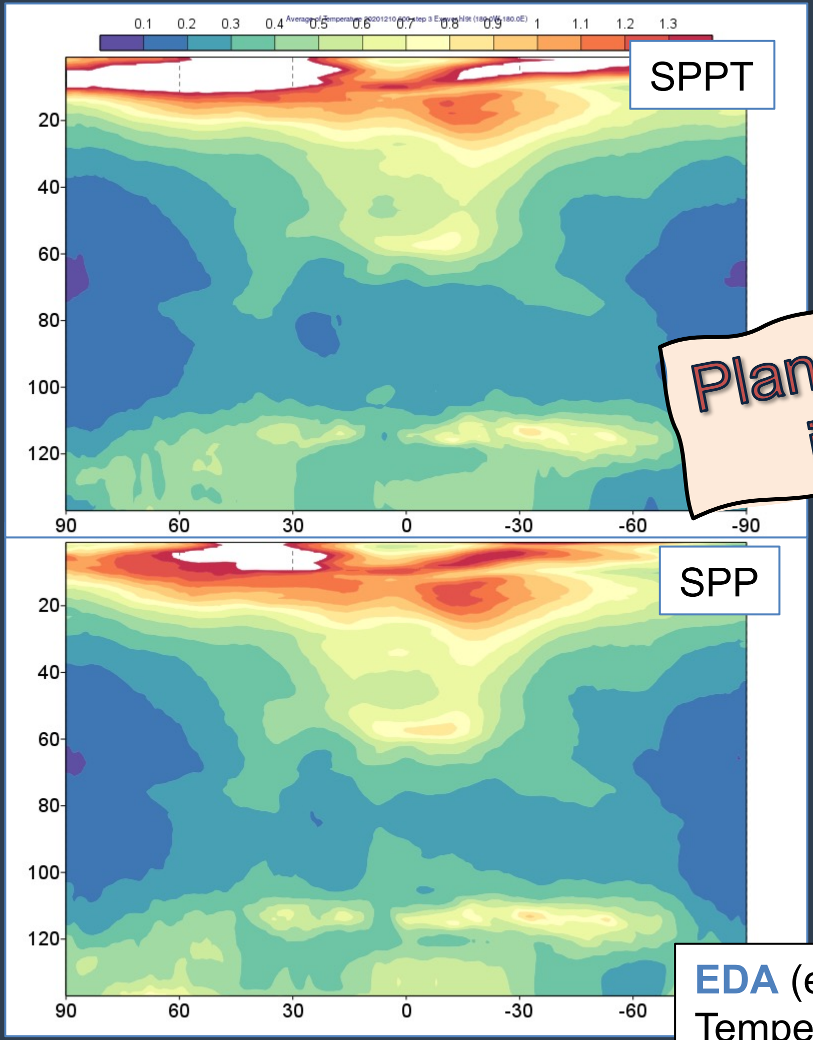
- Forecast period: 15 days
- IC perturbations: EDA, SVs, ocean ICs

Representing model uncertainty for physical processes

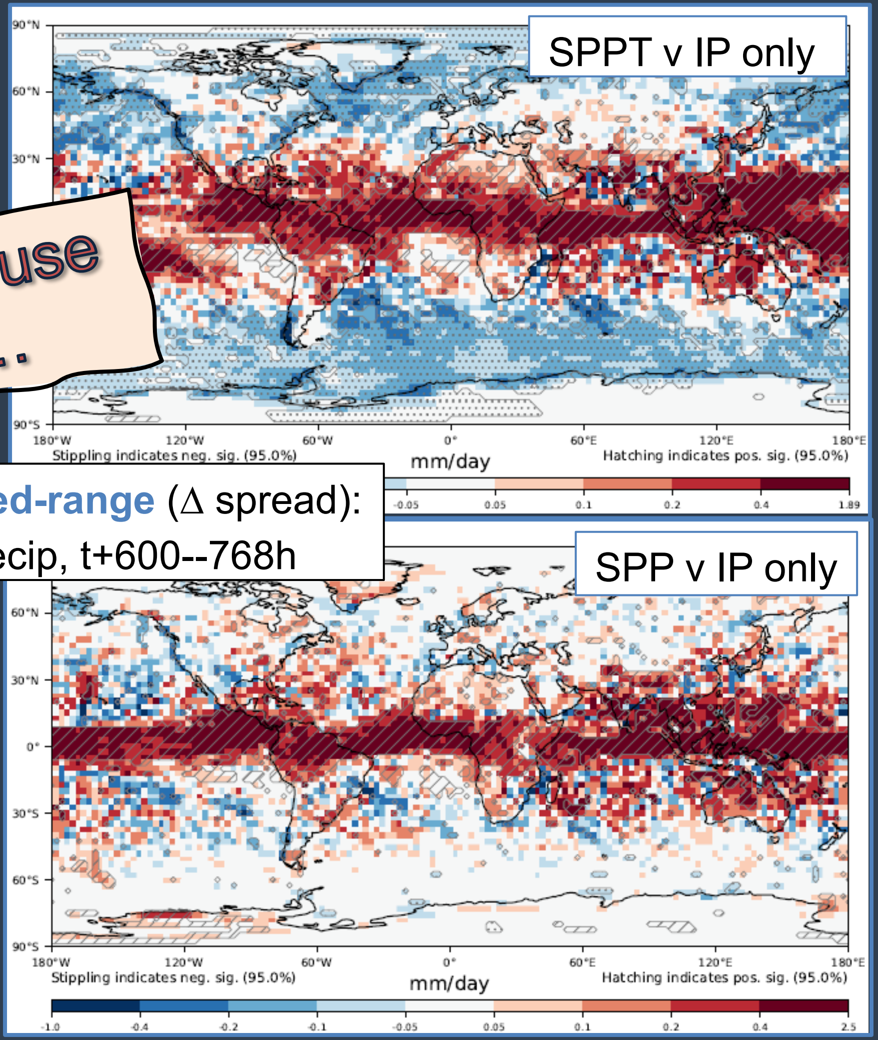
- Ongoing: testing SPP in all ensemble forecast configurations:

  EDA, medium-range, **extended-range**, seasonal



EDA (ens stdev):
Temperature, t+3h

Planned for operational use in CY49R1 (2024) …



Extended-range (Δ spread):
Total precip, t+600--768h

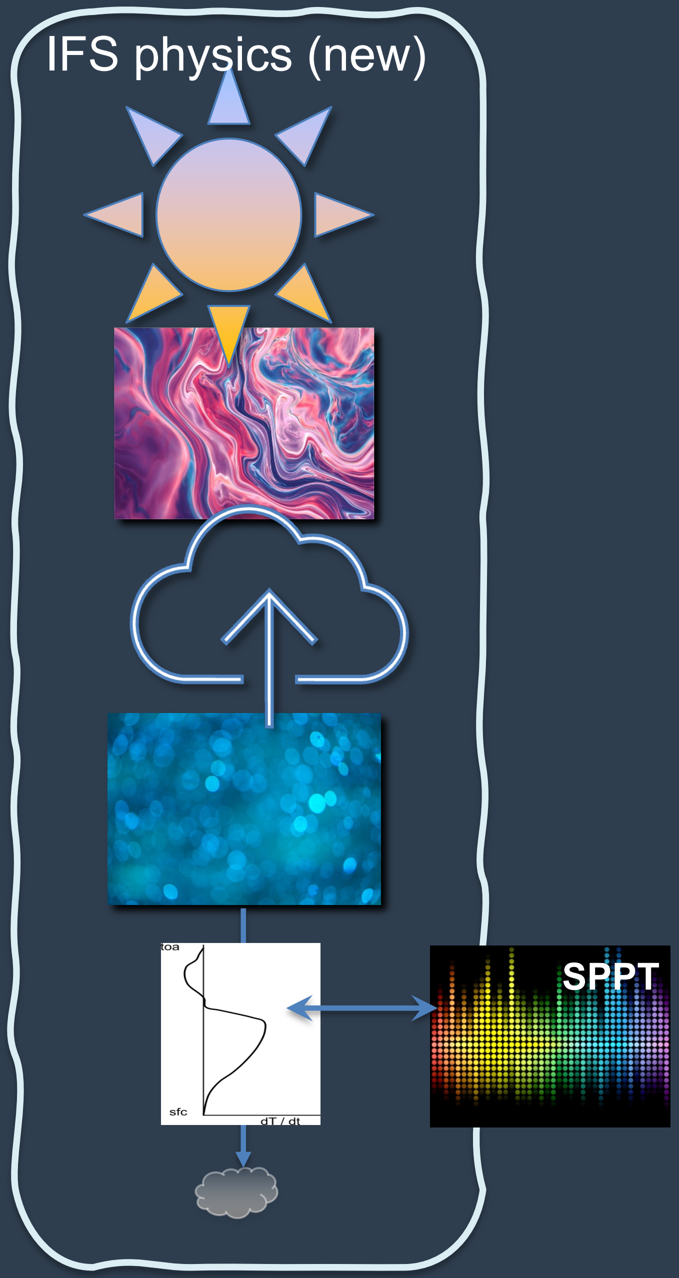
WEATHER FORECASTS

Assessing model developments with the ensemble

- @ECMWF: IFS ensemble “cheap” experimentation for model developments:
  - 8 perturbed members
  - TCo399L137, ORCA1_Z75
  - Starts: 00Z, DJF & JJA, every day

- Can still be surprises … A cautionary tale!

Recent testing for 9km ensemble: a cautionary tale



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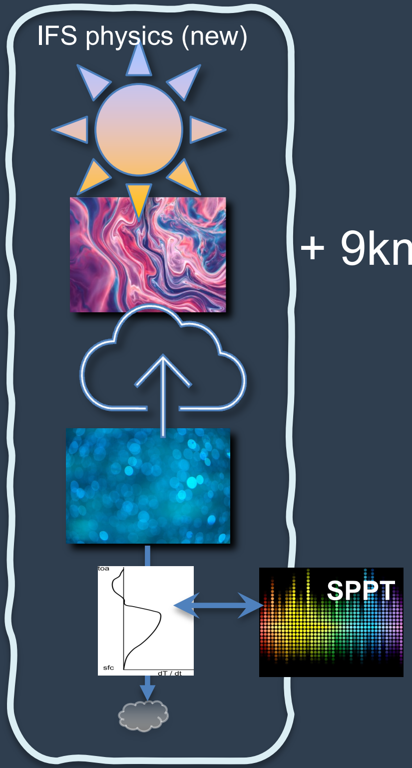
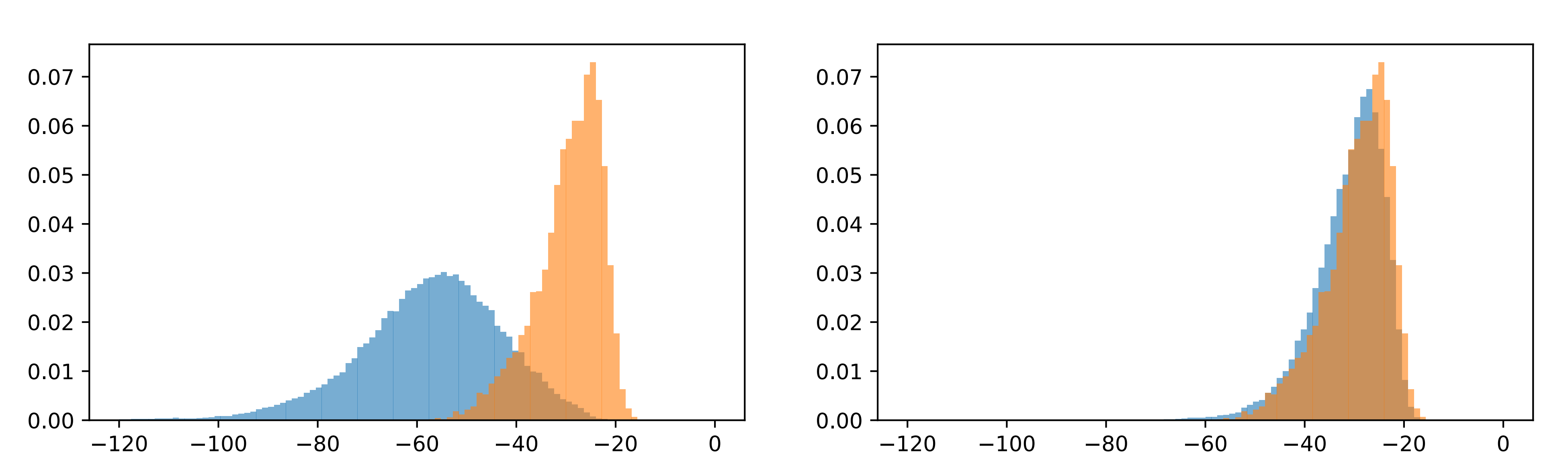


+ 9km resolution ensemble → MODEL CRASHES!

Frequency: ~1 in 500 forecasts
~1 crash per week in ENS

Diagnosis:
Perturbed forecasts (SPPT) produce significantly larger maximum vertical velocities than previously.

Solution: remove saturation adjustment tendency from SPPT.

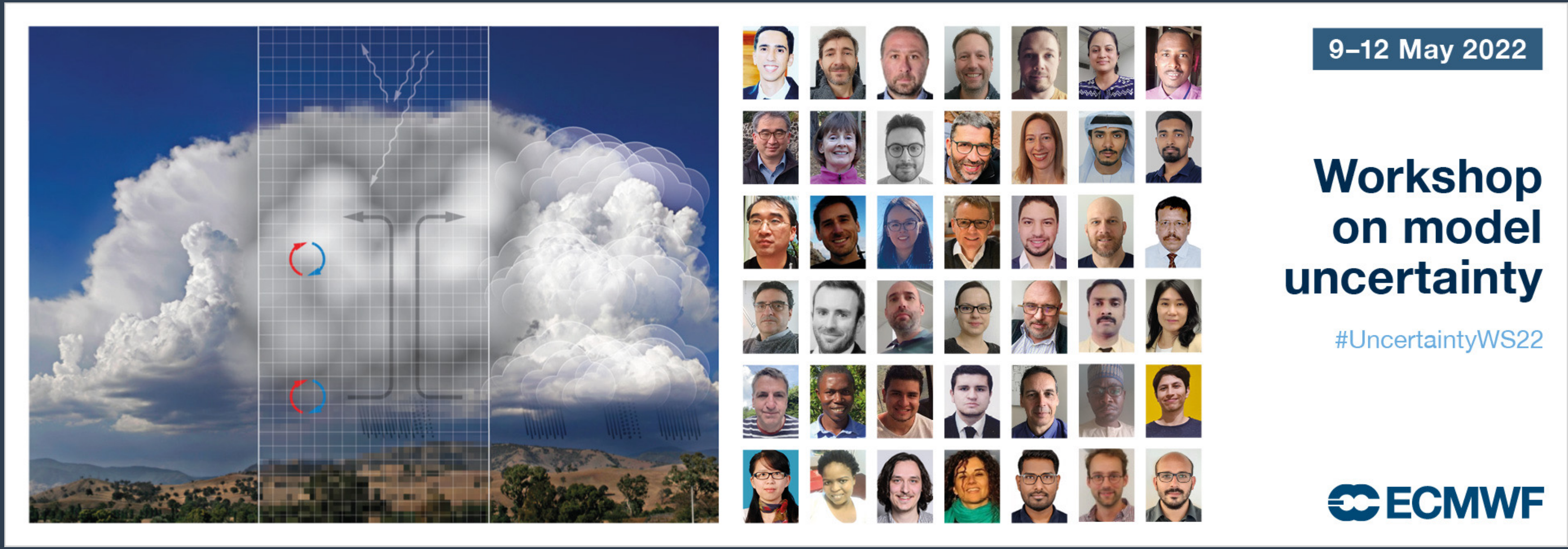


Minimum omega values, each time step, 8 initial dates: perturbed members / control members

Left: new IFS physics (SPPT sees saturation adjustment)
Right: new IFS physics (saturation adjustment excluded from SPPT)

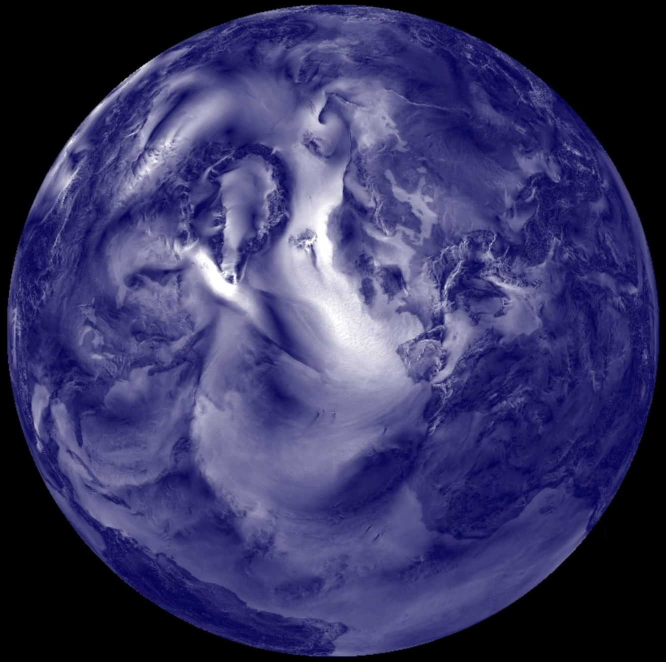
Summary

- Ensemble forecasts can **represent the variability** in physics processes
- The perturbed forecasts should **retain the physical consistency** of the unperturbed model
- Developments in the unperturbed model should be **tested & assessed** in the ensemble

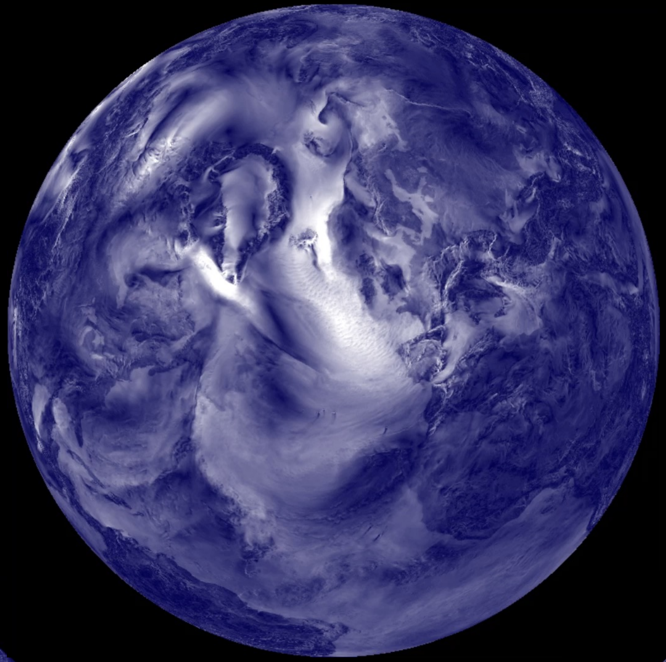


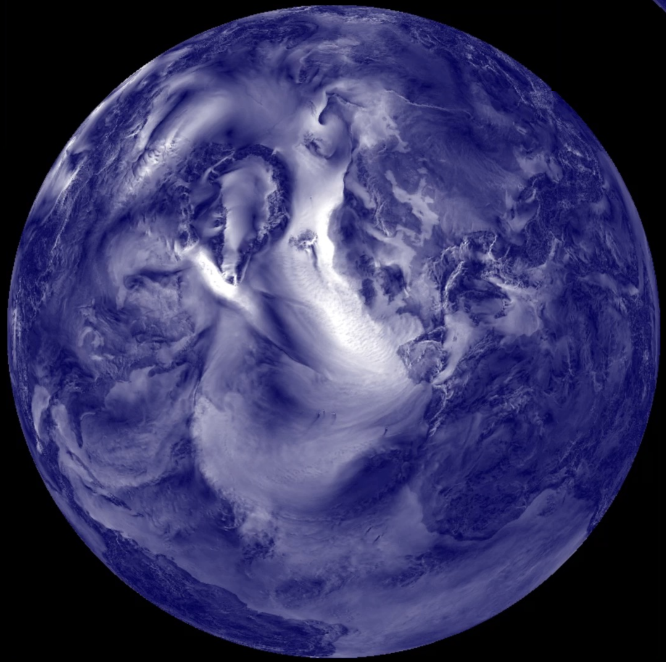
https://events.ecmwf.int/event/290/

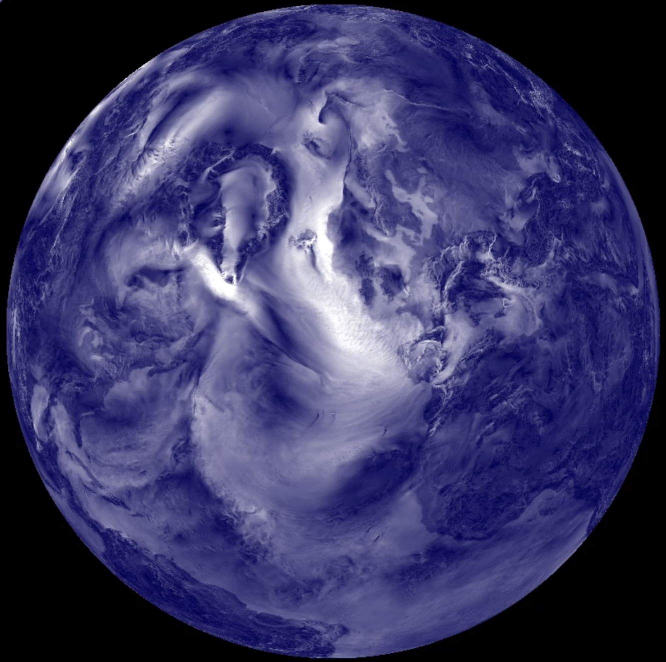
Ensemble forecasting & the representation of physical processes



Thank you for listening!







10m wind gusts, 2020-12-04 00 UTC 720h forecasts, Next resolution - 9 km spatial resolution