Coupled ocean-atmosphere DA in operations at ECMWF

Phil Browne, Patricia de Rosnay, Alan Geer, Hans Hersbach, Sarah Keeley, Kristian Mogensen, Nils Risse, Tracy Scanlon, Hao Zuo, plus many others!



Recap of the ECMWF analysis system

All nonlinear integrations **include coupled** ocean/ice model components

All* are running with ¼ degree ocean resolution (atmosphere varies by application)

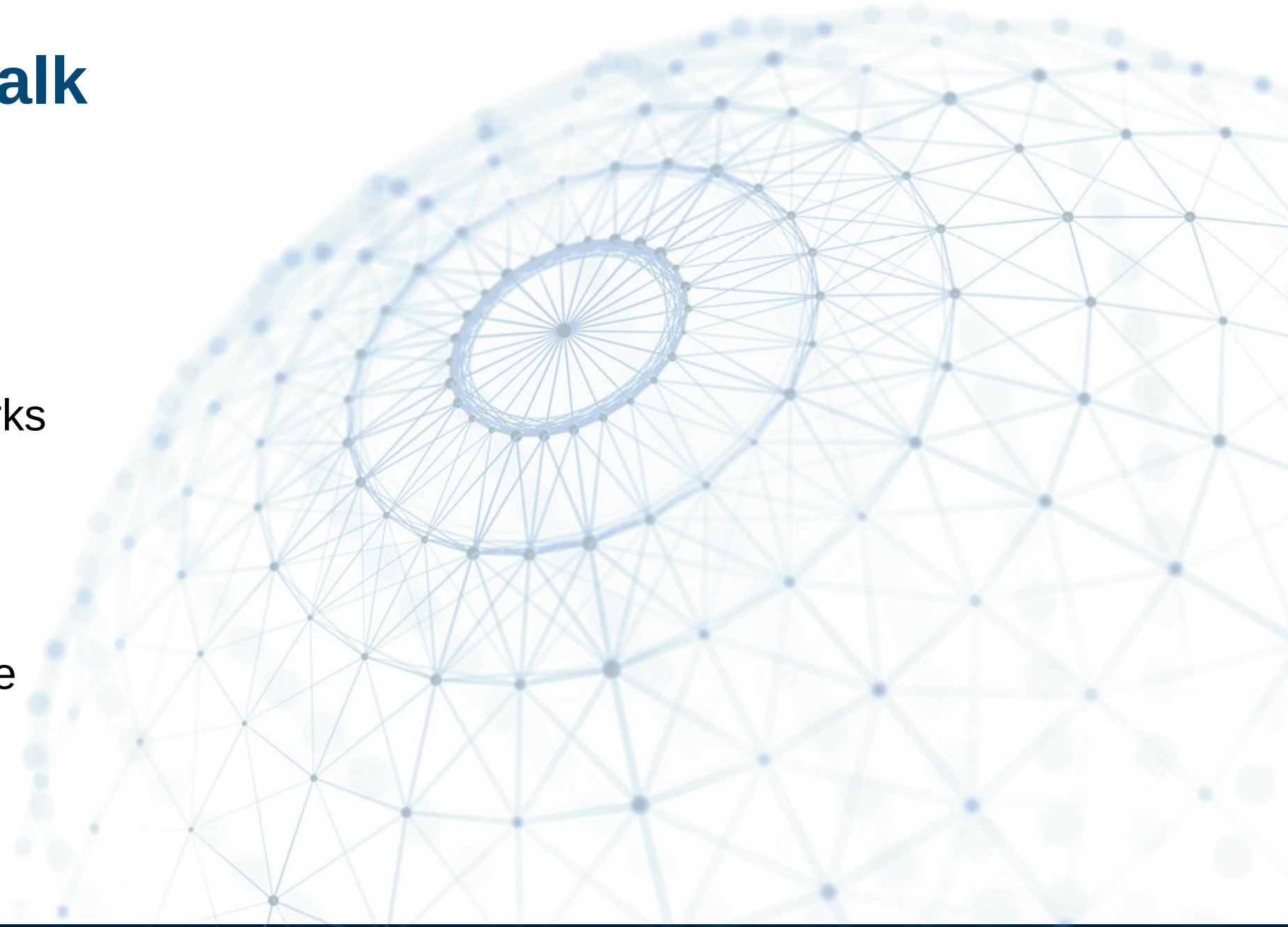
All research work is done in the coupled system – it is business as usual now

*see Charles Pelletier, Chris Roberts, Kristian Mogensen, Thomas Rackow for the higher resolution testing

Goal of the talk

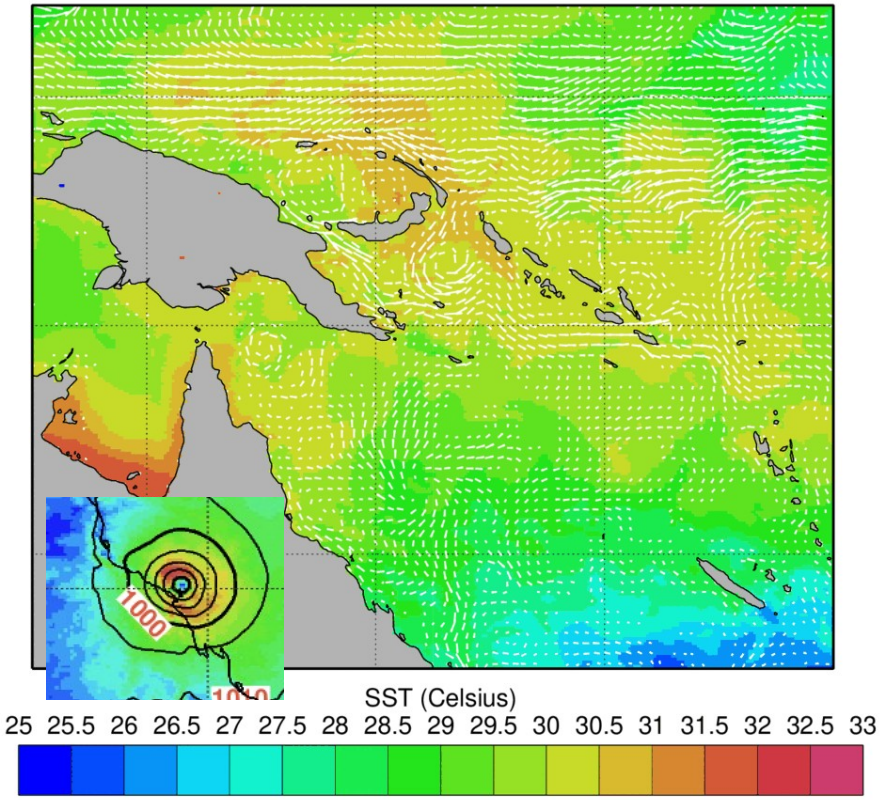
Give you an idea of how our system works

Give you an idea of the benefits/ opportunities that we get from the new system

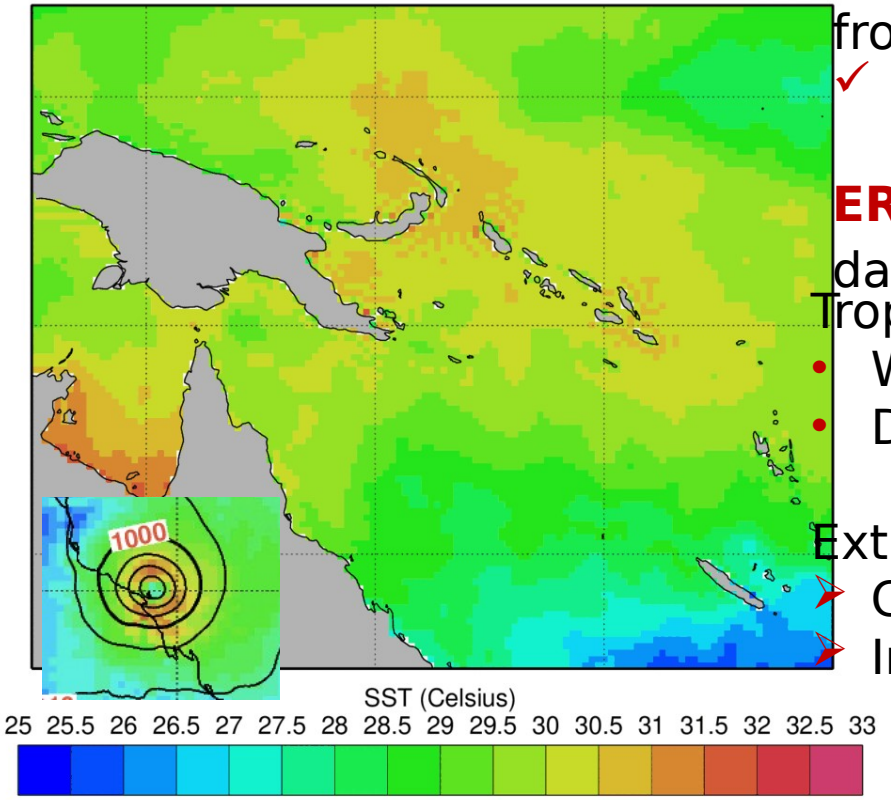


More realistic ocean-atmosphere processes in ERA6 compared to ERA5

ERA6, 25 March 2017, 00 UTC



ERA5, 25 March 2017, 00 UTC



ERA6 has hourly SST + currents from its ocean component:

- ✓ daily cycle

ERA5: $SST_{foundation}$ only changes daily

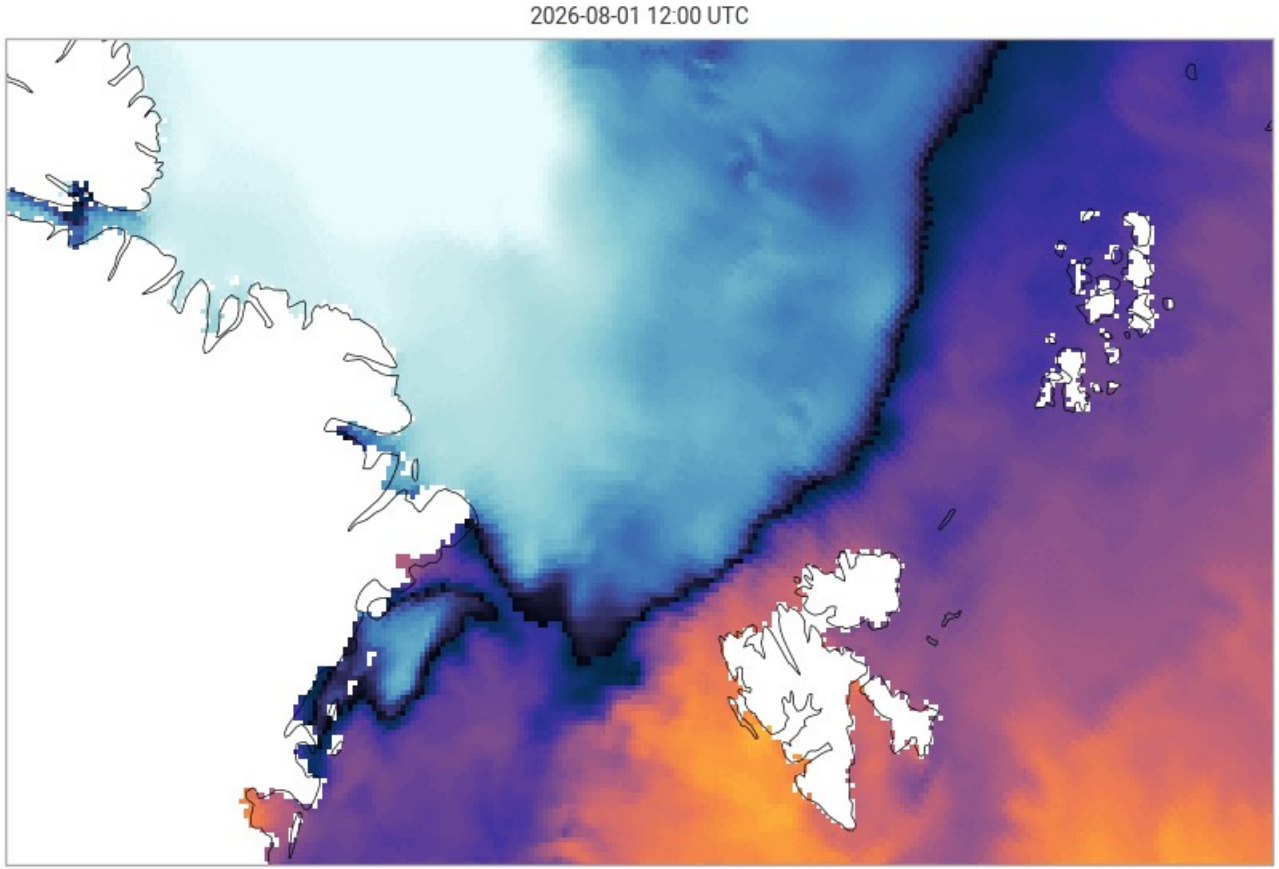
Tropical Cyclone **Debbie**:

- Winds reported up to 120 mph
- Damage: ~ €2 billion

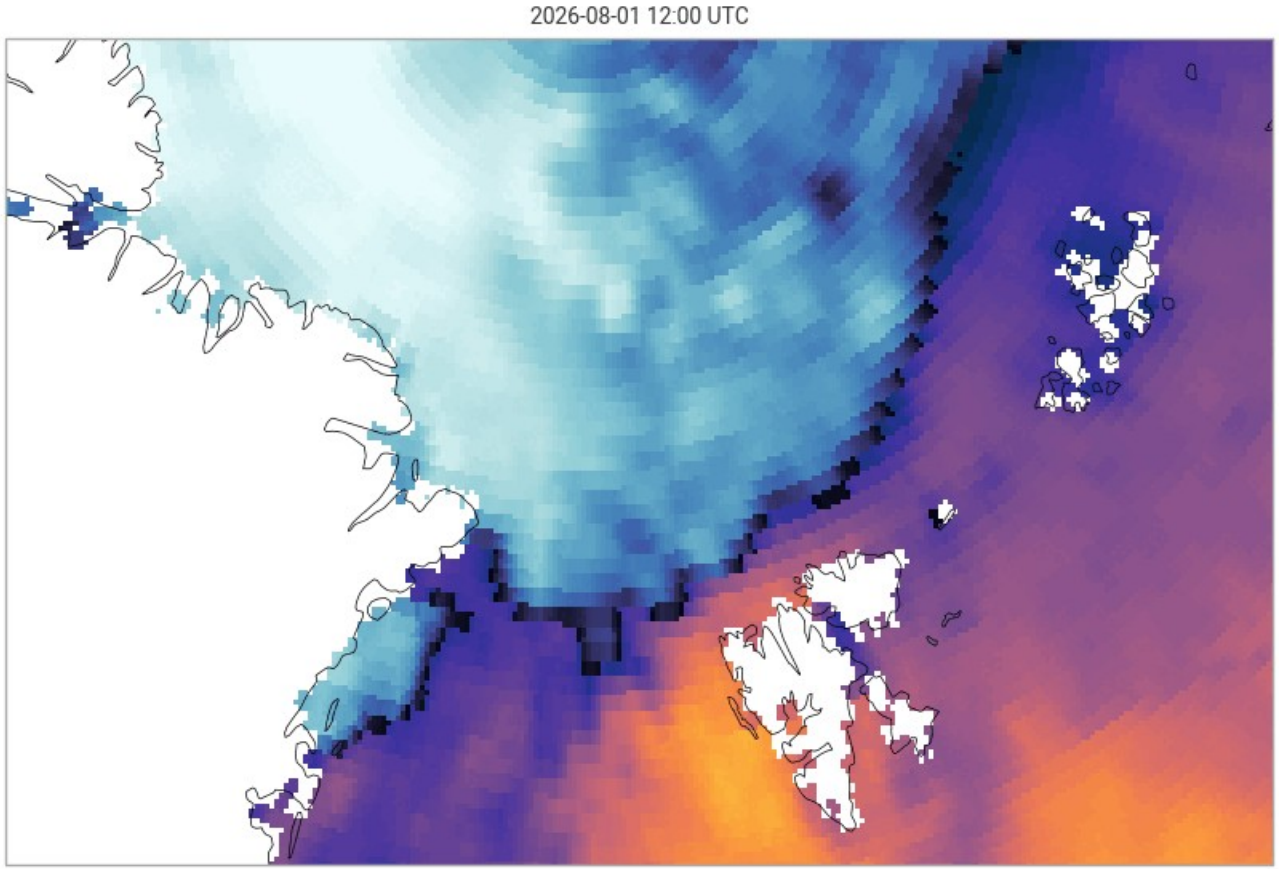
Extracts energy from the ocean:

- Cooling of SST
- Induced ocean currents

Sea ice concentration and sea surface temperatures

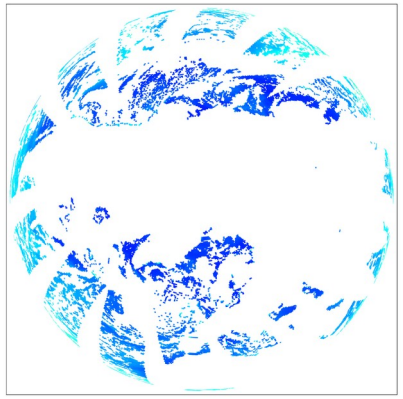


Operational IFS



ERA 5

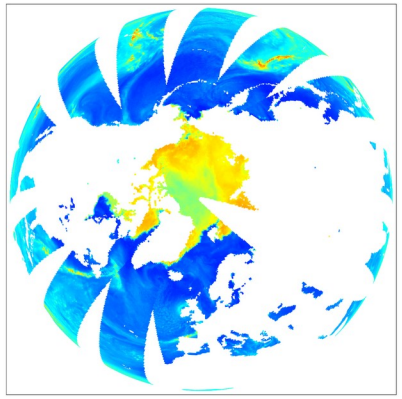
Using surface-sensitive microwave radiances in 4DVar



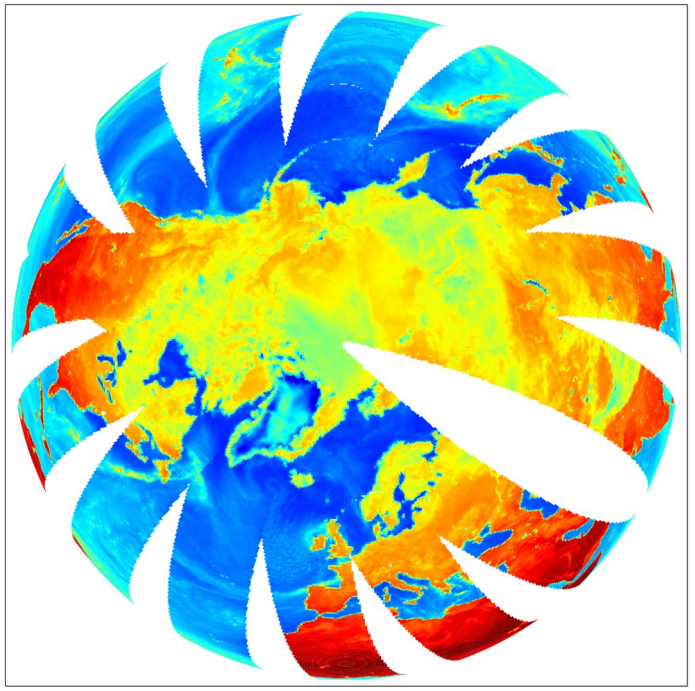
Clear-sky, open ocean
1990s onwards



All-sky, open ocean
2009 onwards



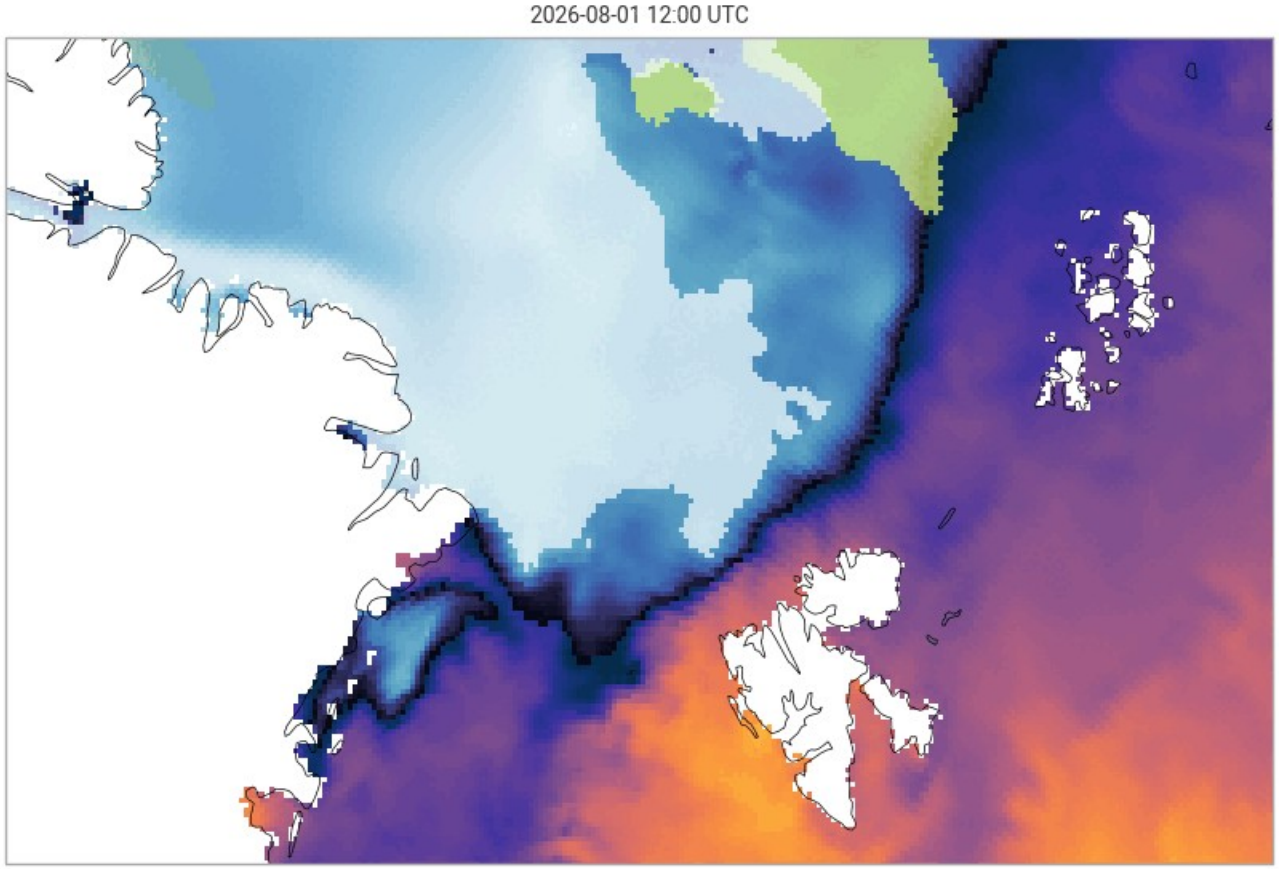
All-sky, ocean including sea ice
IFS cycle 49r1, 2024

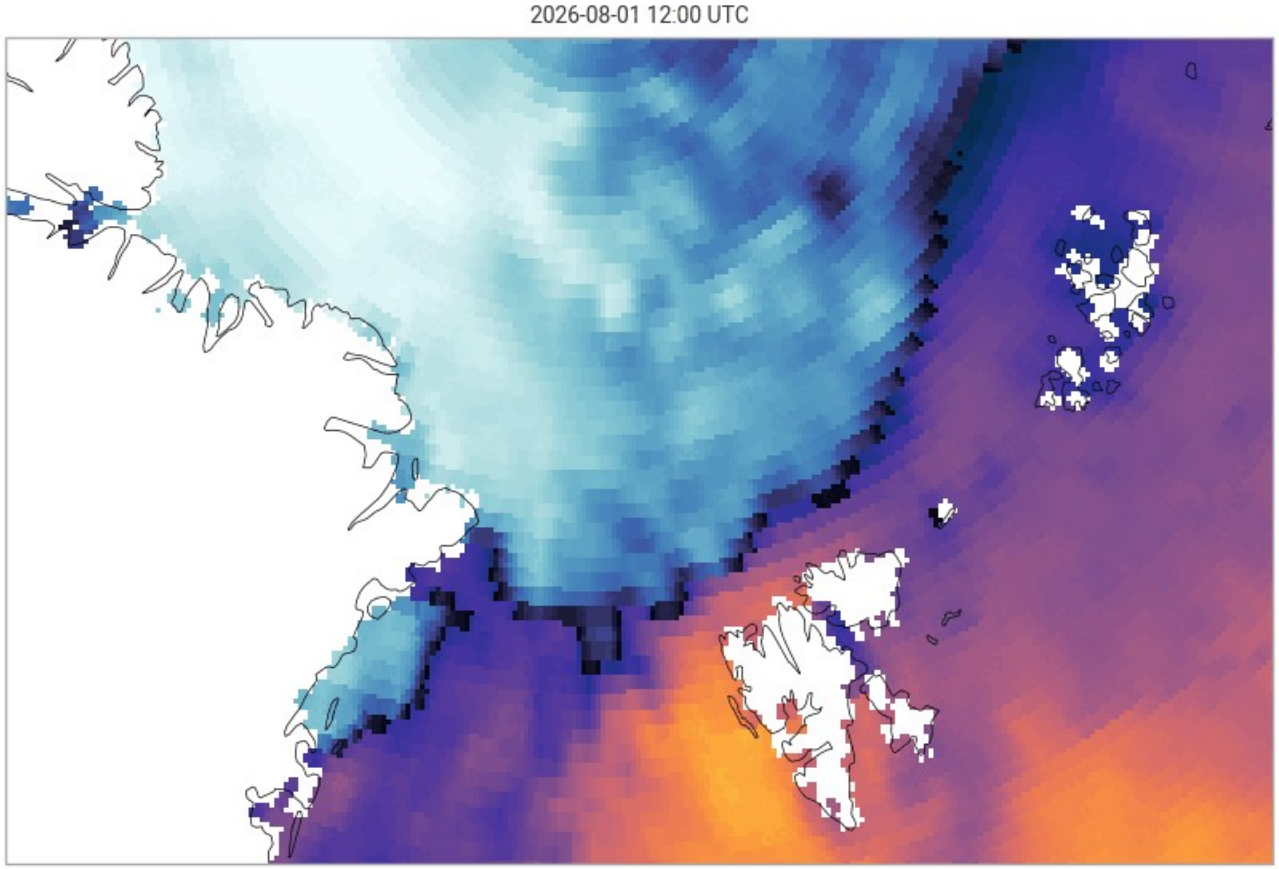


All-sky, all-surface radiance assimilation – the final goal

Note that less surface-sensitive channels (sounding channels) have been used over sea ice and land for many years and more recently some surface-sensitive channels, using surface emissivity atlases and dynamic emissivity retrievals

With extra surface physics processes – meltponds and snow





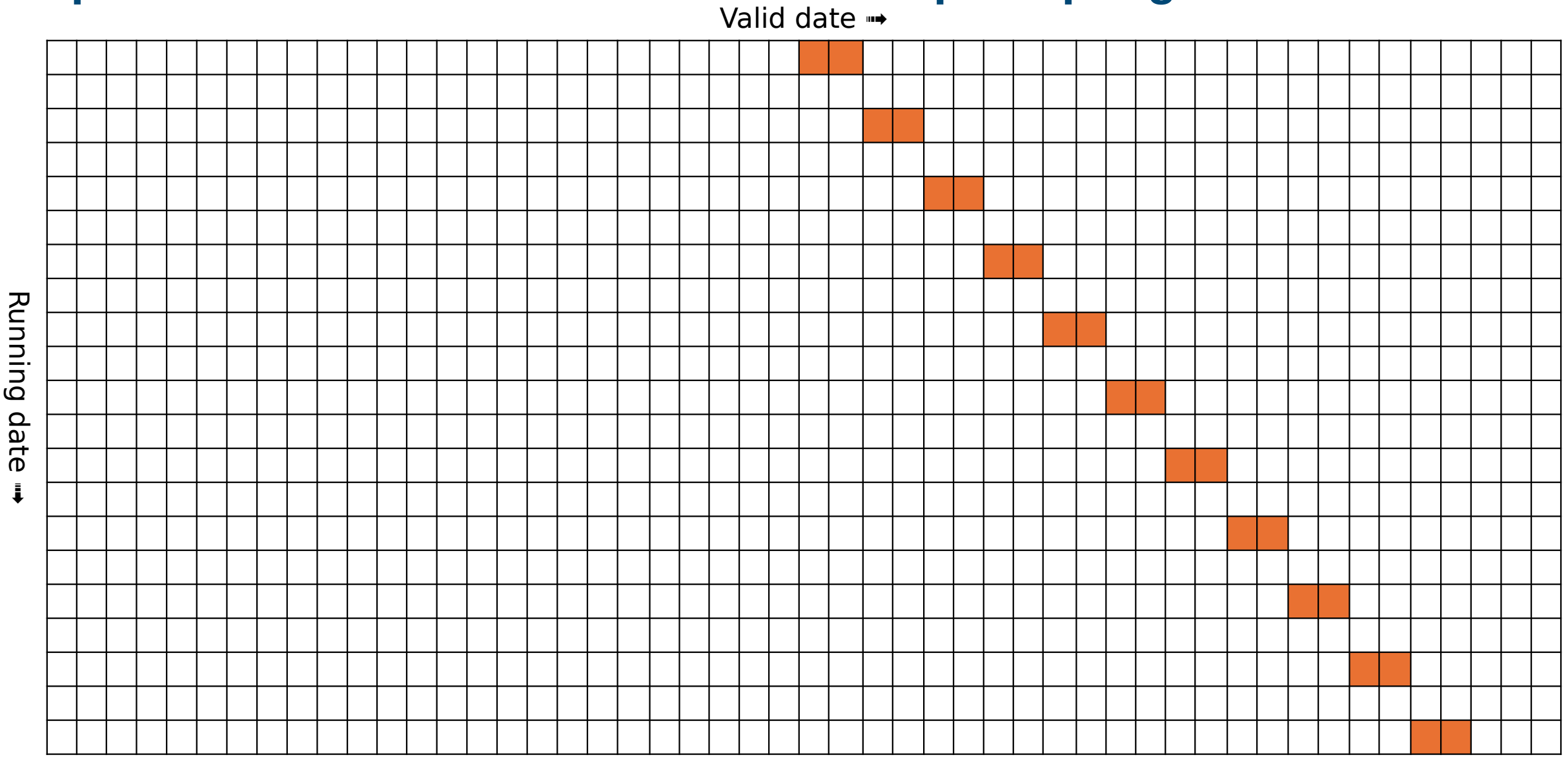
Operational IFS

ERA 5

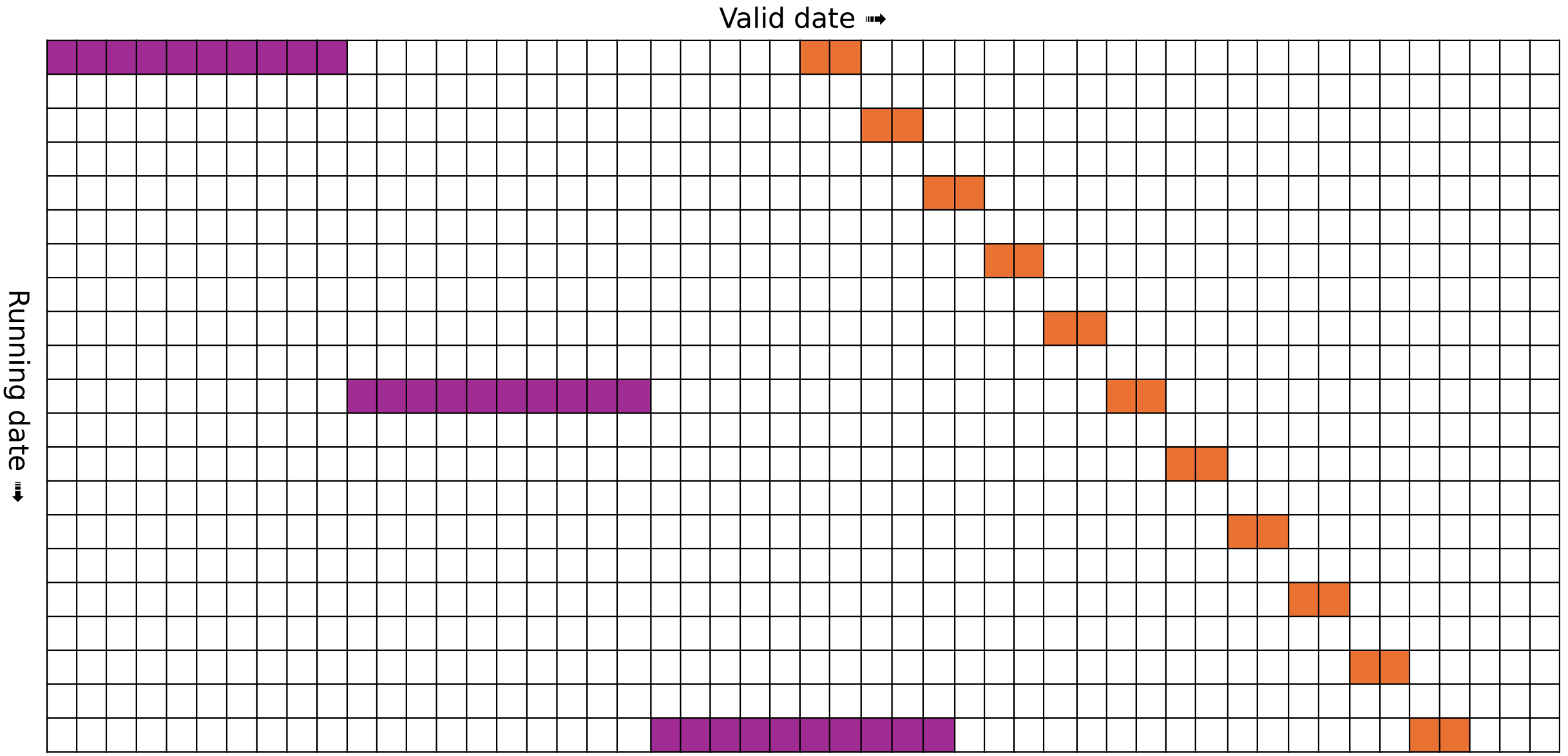
meltponds

snow on ice

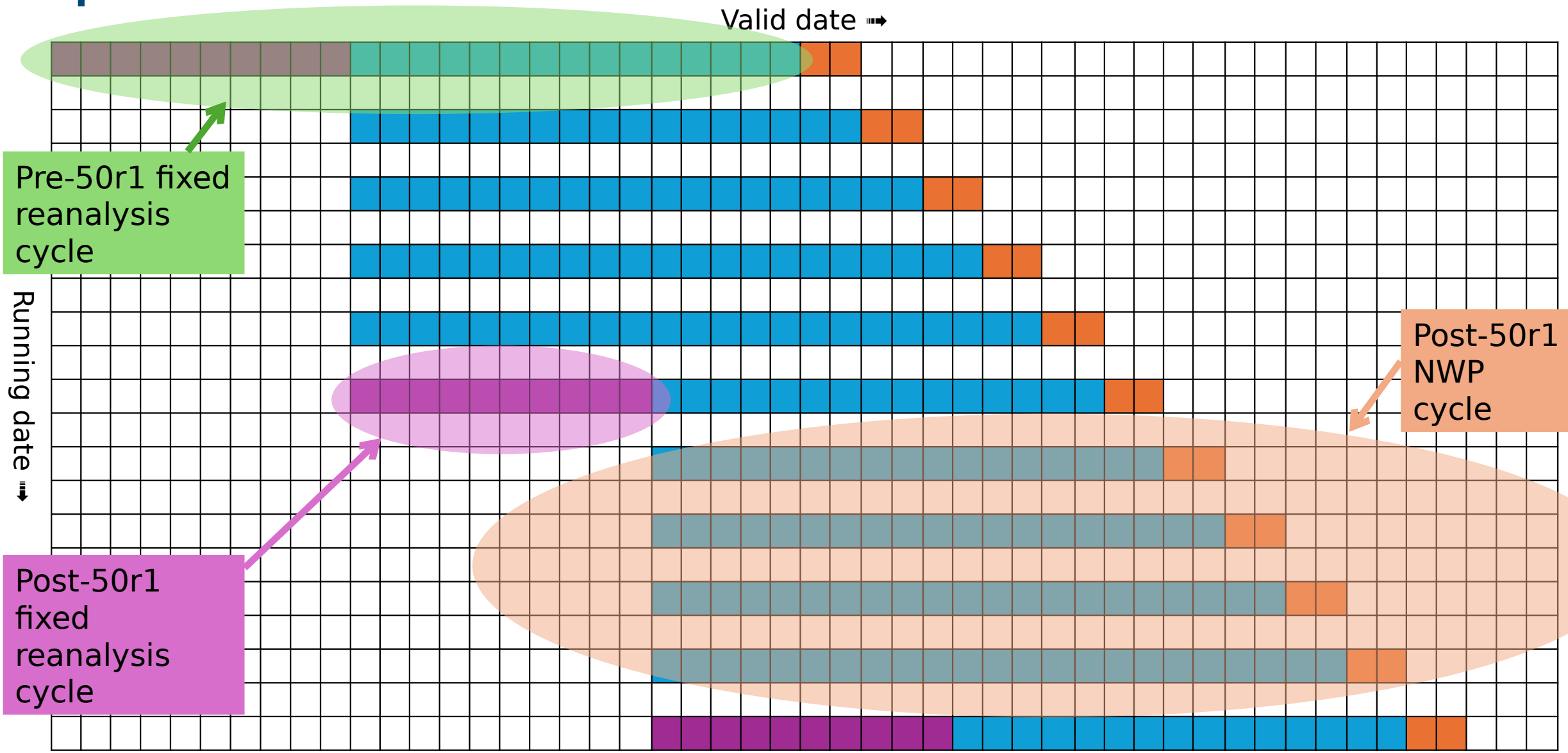
Operational DA in a timeline – outer loop coupling



Operational DA in a timeline – outer loop coupling and ocean reanalysis



Operational DA in a timeline



Key aspects of anchoring to ocean reanalysis

- **Greatly reduces R2O testing requirements**
- Allows **late arriving observations** to still enter system
- Provides **consistency** with reanalysis, and therefore reforecast consistency

- Including daily forced and analysis and coupled analysis in NWP cycle gives
  - Ability to **change** used observations
  - **Flexibility** to optimize configurations
  - Smaller steps to **incrementally improve performance**, rather than monolithic upgrades on 5-10 year development cycles

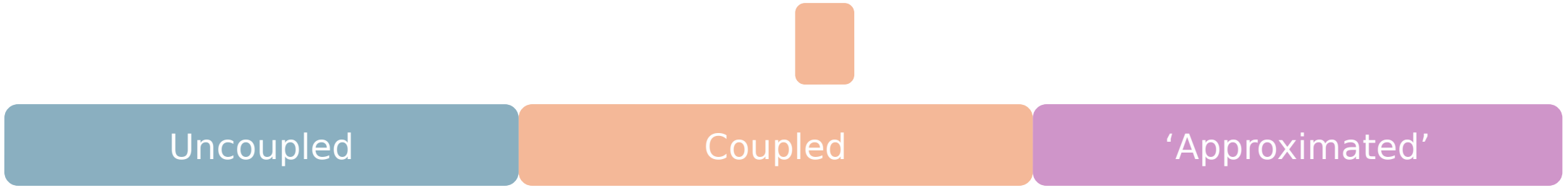
Integration with wider ECMWF ecosystem

- Design concepts
  - Do what the rest of the system does, with the same tools
  - Answer every question with – “do what the atmosphere does”
  - Remove barriers
  - Special cases only where they are needed

- Implications
  - Model output in grib > data handling for free > dissemination for free
  - Observation output in odb > monitoring for free
  - Observation input in bufr and grib > R2O process that needs no special cases
  - Diagnostics in the same packages > researchers seeing impact of what they do on the ocean > researchers targeting what they do to impact the ocean

Working within the Variational Data Assimilation framework

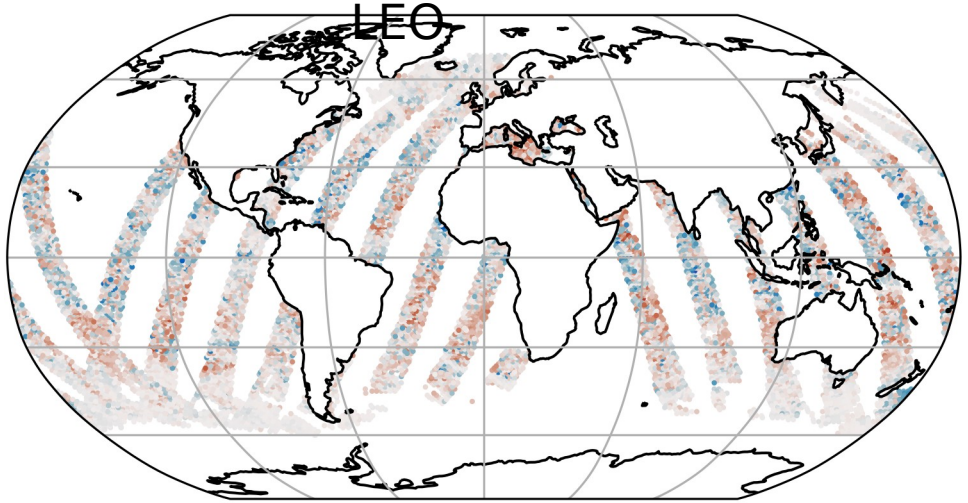
- Initial conditions are found by minimizing an objective (or cost) function
- This is solved by linearising to get an expression for the gradient
- And finally, once the minimization has completed, we cycle the system to the next assimilation window by running a model forward in time



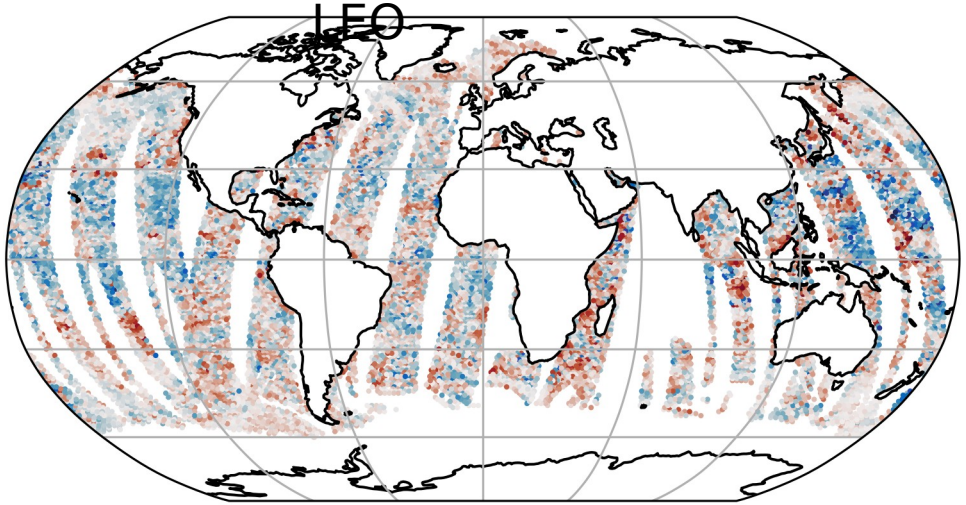
Skin temperature

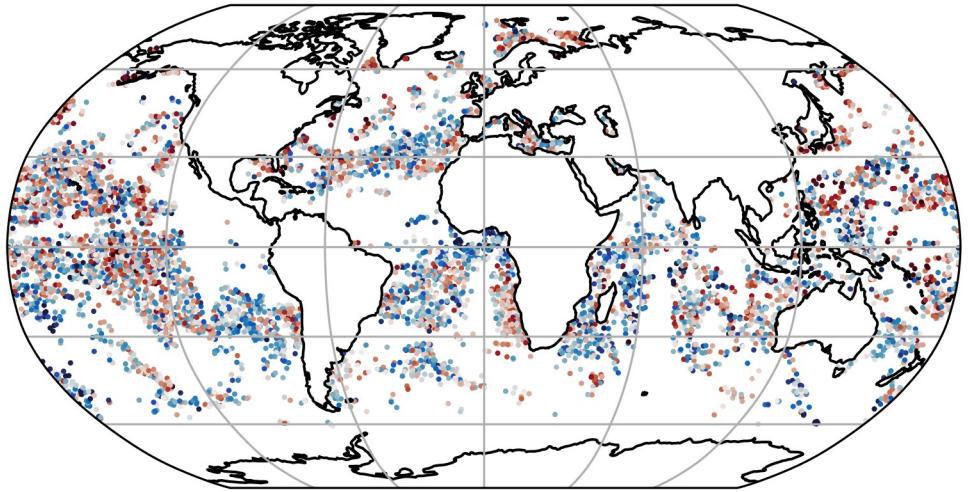
What the atmosphere suggests

GMI: MW LEO

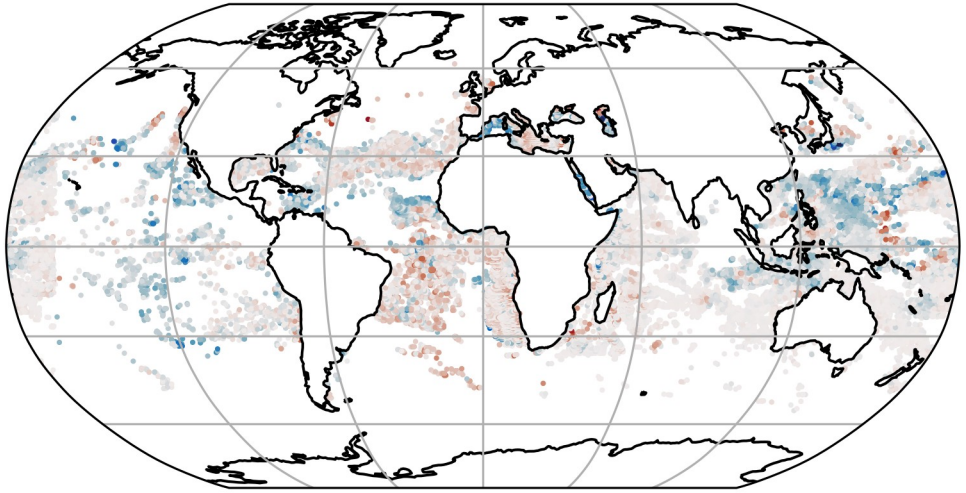


AMSR2: MW LEO





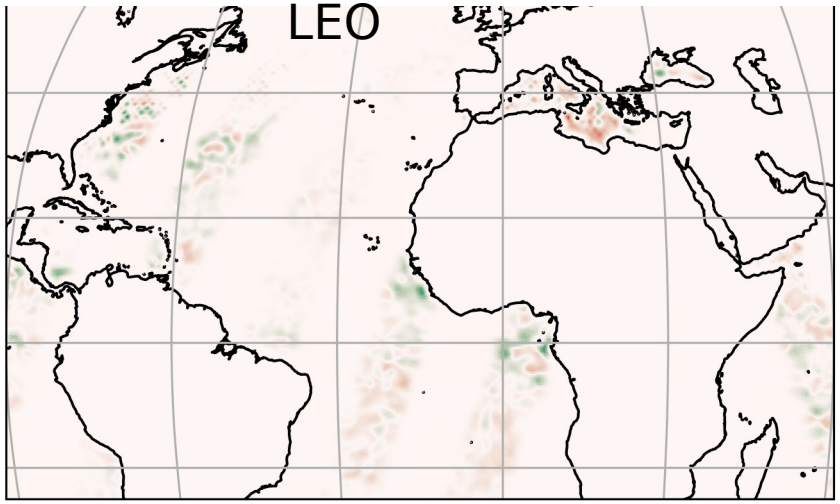
CrIS: Hyperspectral IR LEO

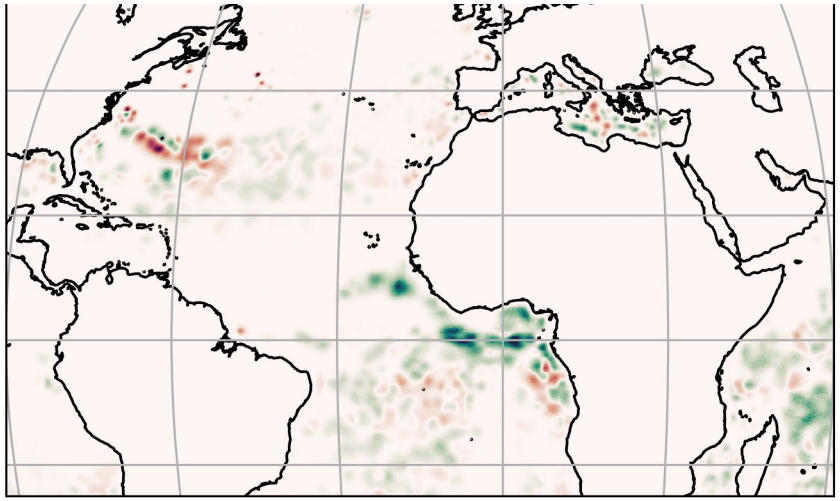


IR: GEOS Meteosat/GOES/Himawari

Skin temperature

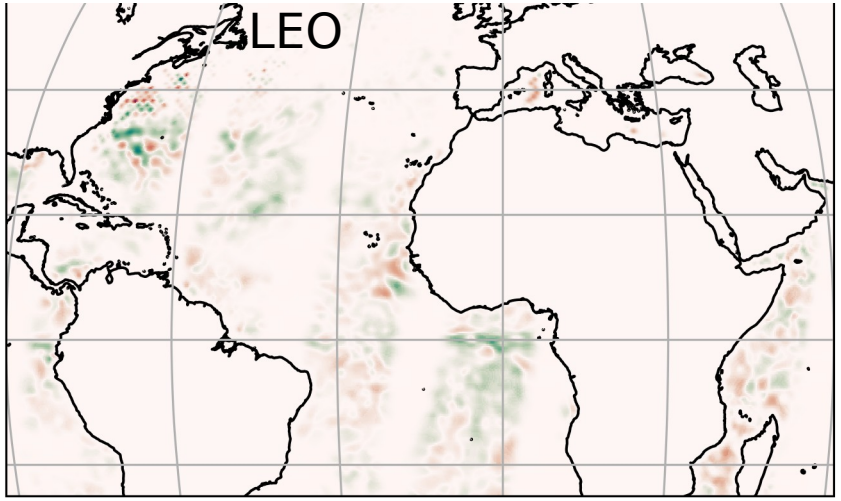
GMI: MW LEO

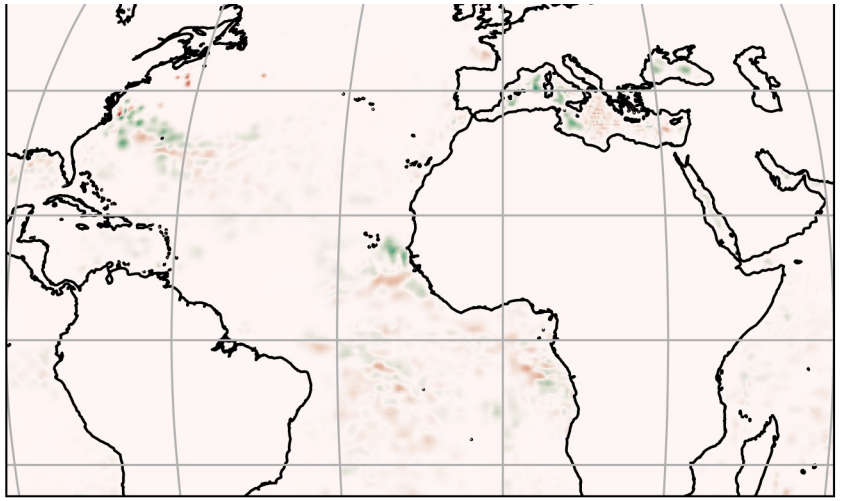




CrIS: Hyperspectral IR LEO

AMSR2: MW LEO

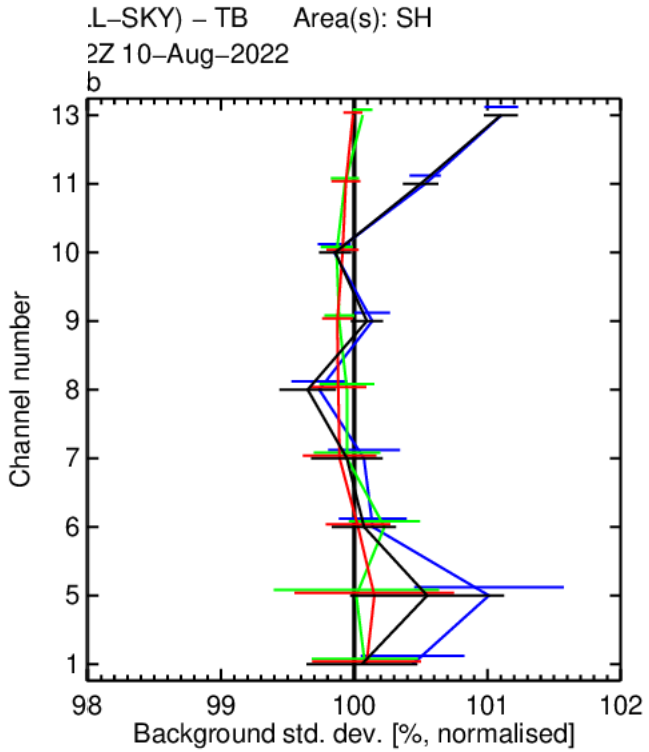




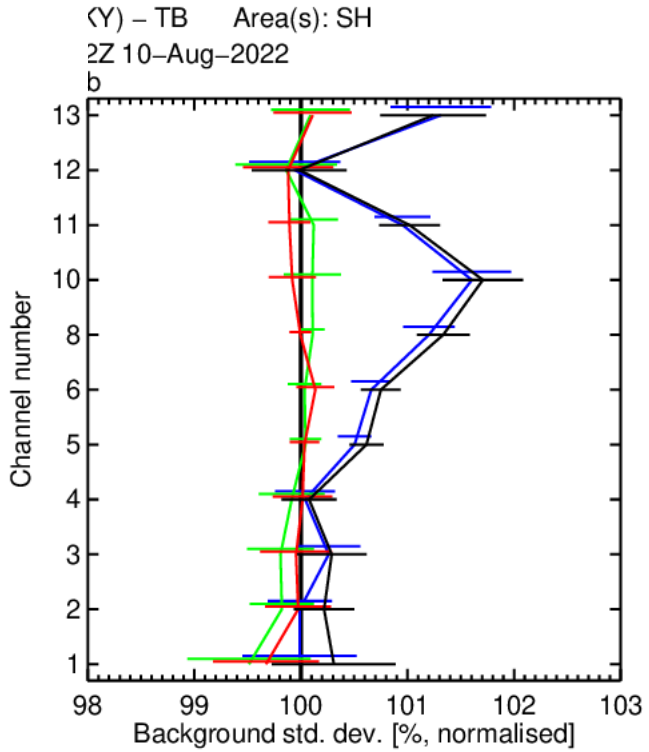
IR: GEOS Meteosat/GOES/Himawari

Impact of coupled observation operators on satellite data usage – SH winter case

AMSR2



GMI



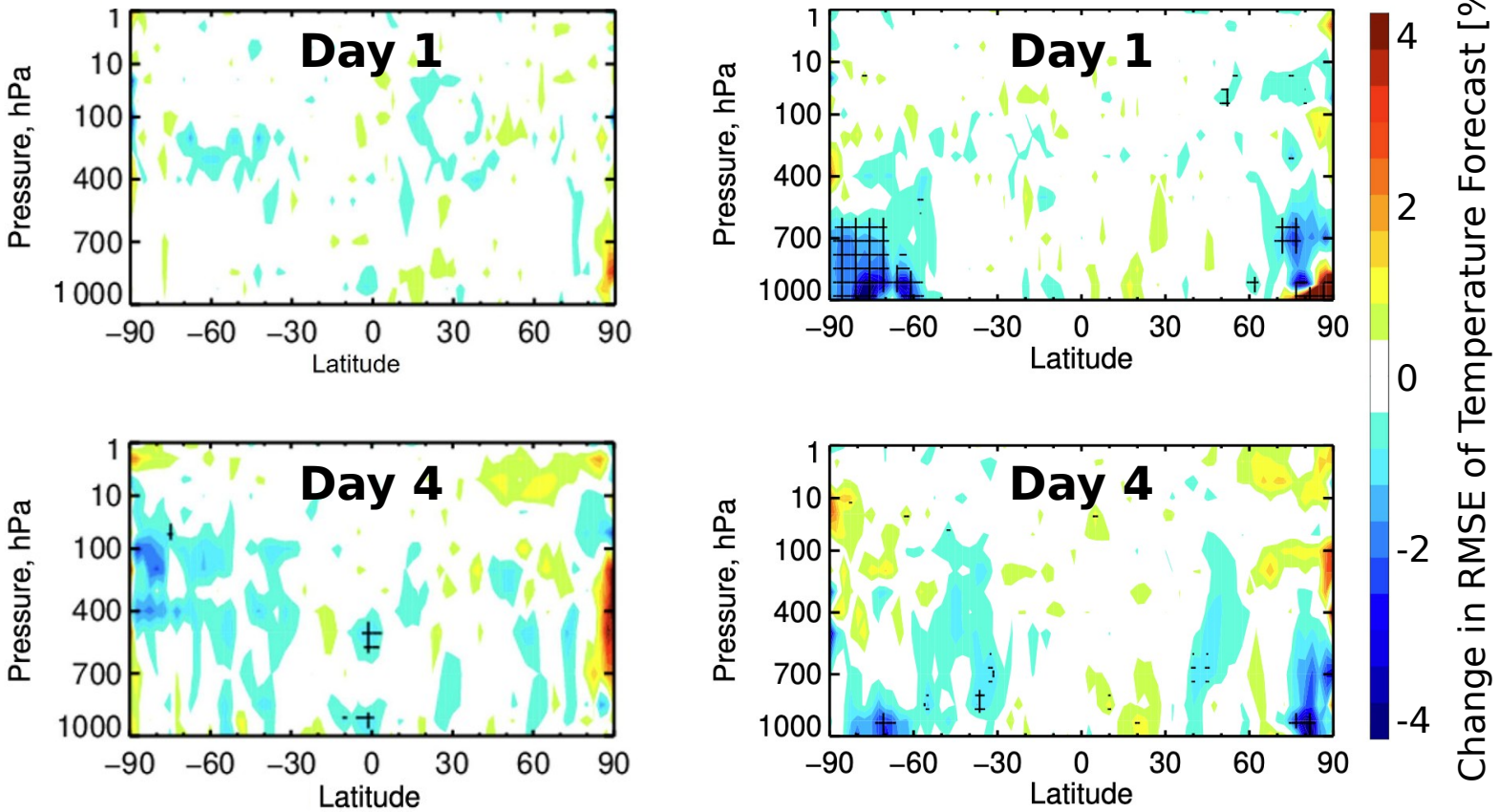
Blue = removal of all coupled observation operators

Black = removal of all sea ice coupled observation operator

Impact of coupled data assimilation at ECMWF

- Coupled assimilation of SST+SIC in NEMOVAR improves forecast (Scanlon et al., 2026; Geer et al., 2026)

Assimilation of… **Sea surface temperature (SST)** **Sea ice concentration (SIC)**



Scanlon et al. (2026) Geer et al. (2026)

Summary and outlook

- New coupled DA system is operational
  - Designed around practicalities, e.g. testing needs, observation availability
  - Allows exploitation of data more than ever

- New system will evolve
  - New observations, e.g.
    - ice thickness information from altimetry – see Tsz Yan Leung's poster
    - ice thickness information from passive microwave
    - salinity information from passive microwave – see Nils Risse's poster

  - Improvements to existing observation use
    - Validation against ocean observations
    - Improving use of the observations directly in the atmosphere



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