On the convergence of reanalysis produced by different data assimilation streams: a case study with NASA's GMAO MERRA-2 reanalysis system

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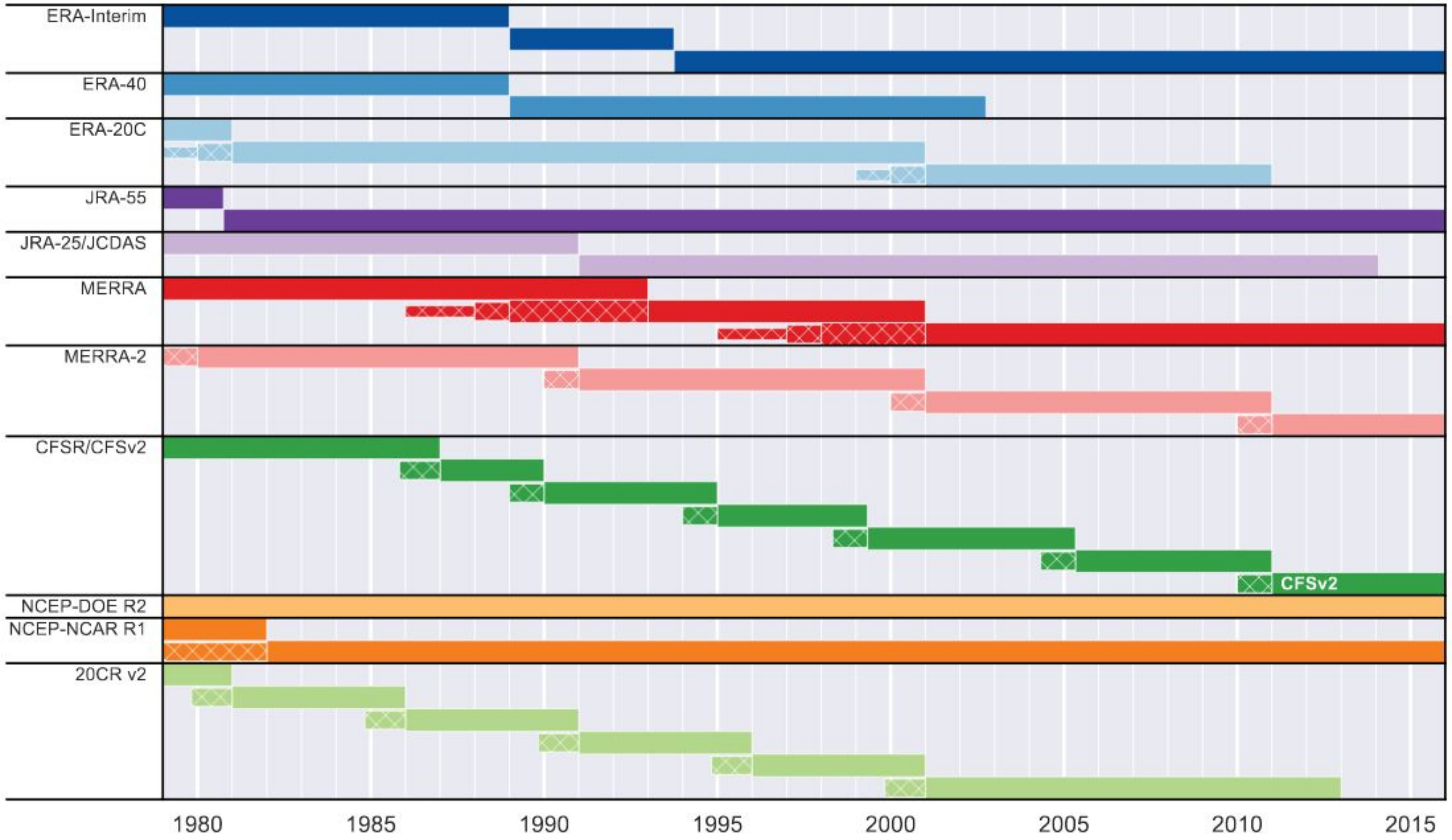
When starting a reanalysis project, it is necessary to compute the past 3-5 decades (*retrospective integration*) before keeping up the production to a near real-time.

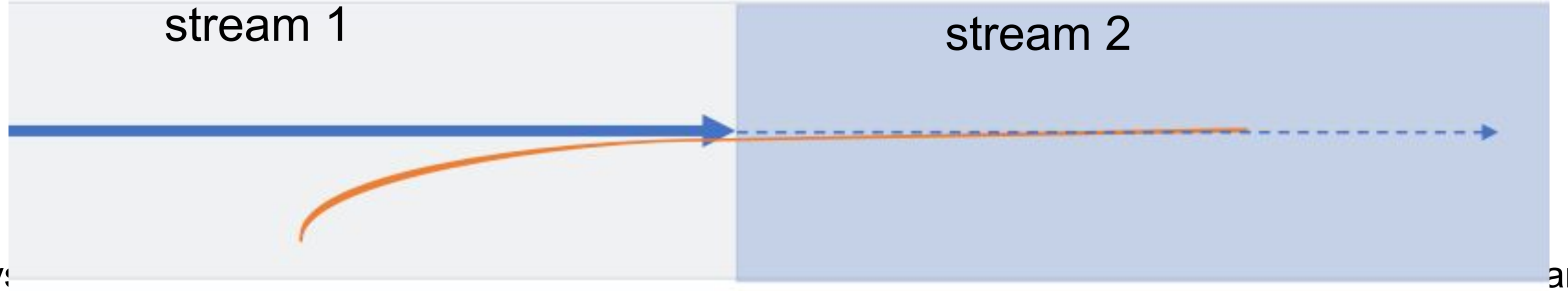
To do so in a single sequential forward processing cycling would most likely take several years to accomplish.



The reanalyses production centers usually **split the past decades into different periods** and run **parallel, independent and continuous production segments called streams**.

The use of parallel streams to compute past decades of reanalyses projects is a standard practice followed by all major NWP centers that produce reanalyses.

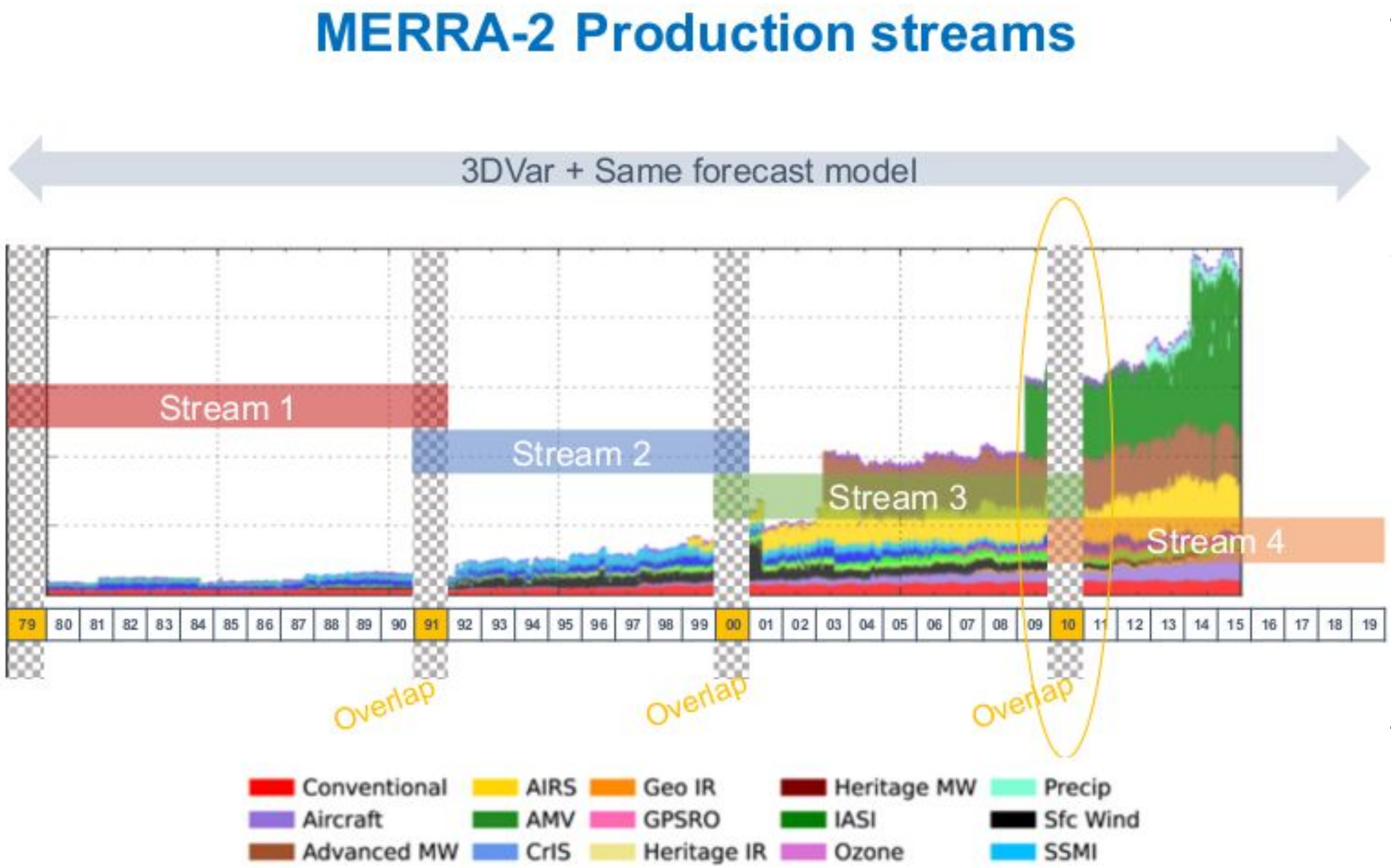
A fundamental assumption of the parallel streams strategy is that there should be an **equivalence** between running a single sequential stream or multiple shorter streams covering the same time period. More specifically, two streams with different initialization dates ran through overlapping periods should eventually **converge to equivalent atmospheric states** after a spin-up period.



However, in a NWP-DAS sy… and **convergence** from the DAS due to the same observations being assimilated, thus *constraining the atmospheric background states*.

Thus, although independent streams with different initialization states will have a tendency to diverge in the course of their integration, it is expected that the assimilation of common (and many!) observations will make the *DAS dominate over the atmospheric model dynamics,* ultimately **making the streams converge toward a similar (enough!) atmospheric state.** *But does this convergence really happens, and to what extent?*

NASA's GMAO MERRA2 reanalyses ran 4 paralell streams to comprise past decades, originating **3 years of overlapping periods.**



To investigate the streams convergence, **the last overlapping period was chosen »»** *the one that corresponds to the modern satellite-era, where an huge ammount of obs are used to constrain the atmospheric backgrounds (DAS influence is maximized).*

Note that **both streams** employ:

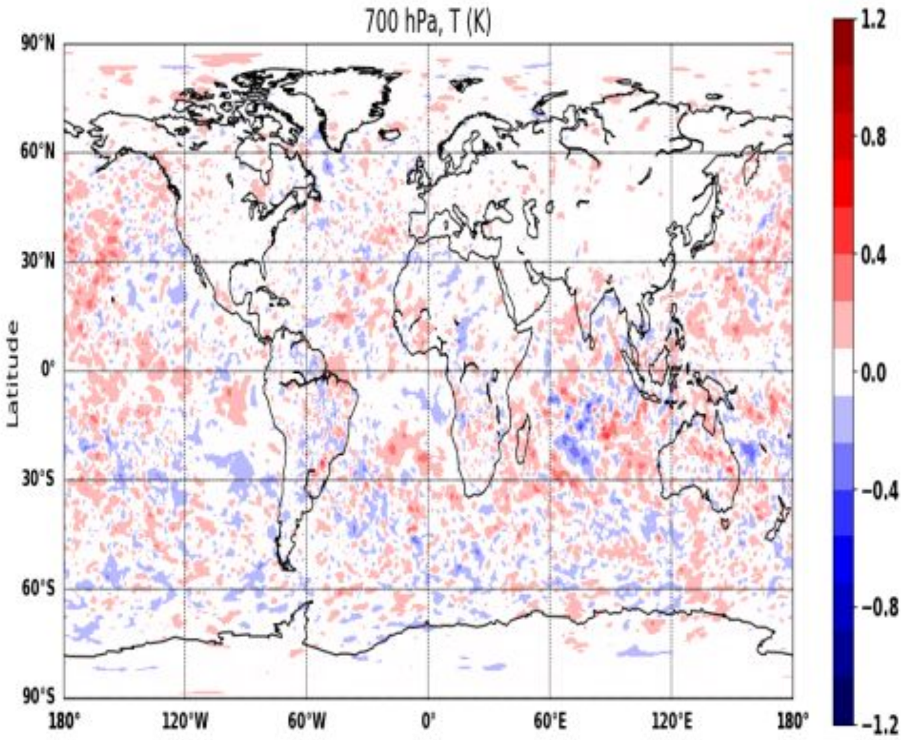
- **same DAS** and **NWP model**
- **same observations, background and observation error covariance matrices** *(MERRA-2 builds on a 3DVar assimilation system).*

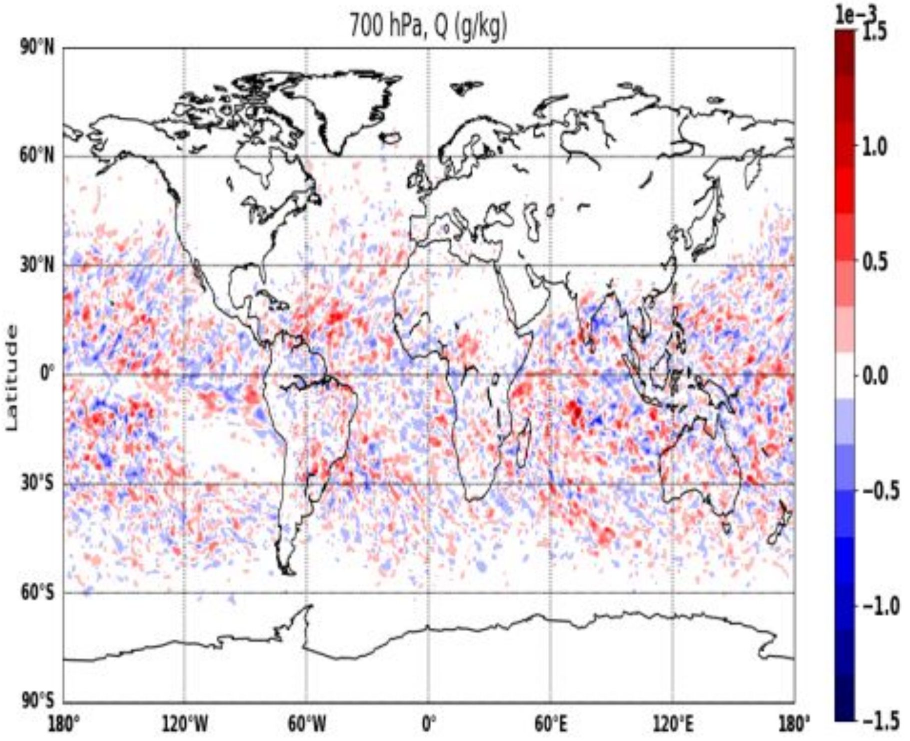
Thus, **the only difference between the two streams is the *<u>initial condition.</u>***

To avoid sensitivity to initial conditions and spin-up issues, statistics are computed only for the *last month of the overlap year* (Dec 2010 here), when the differences between the streams are expected to be at their lowest.

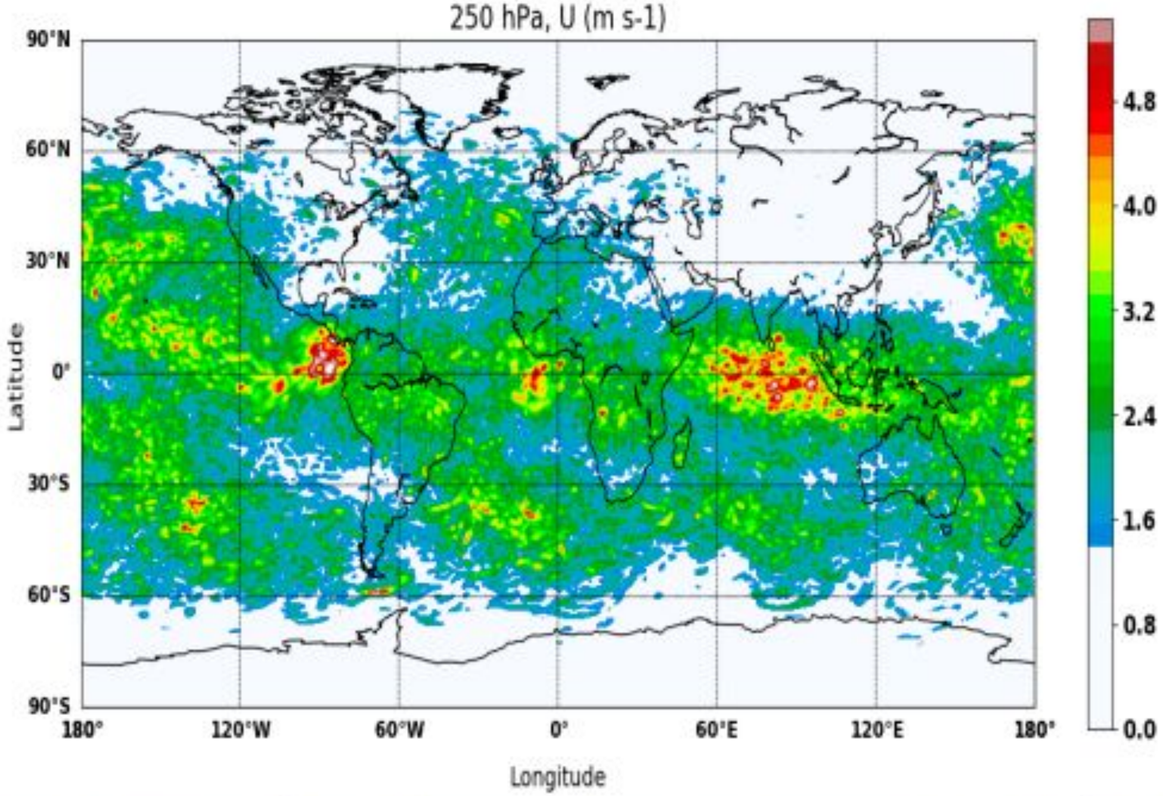
For MERRA-2 Gelaro et al. (2017) reported that **mean differences** between junctions of overlapping MERRA-2 streams were indeed **minimal** for most fields, *with the exception of the deep-level soil temperature and land surface soil moisture storage at high latitudes, related to soil freezing which slows the soil water spin up (Reichle et al. 2017).*

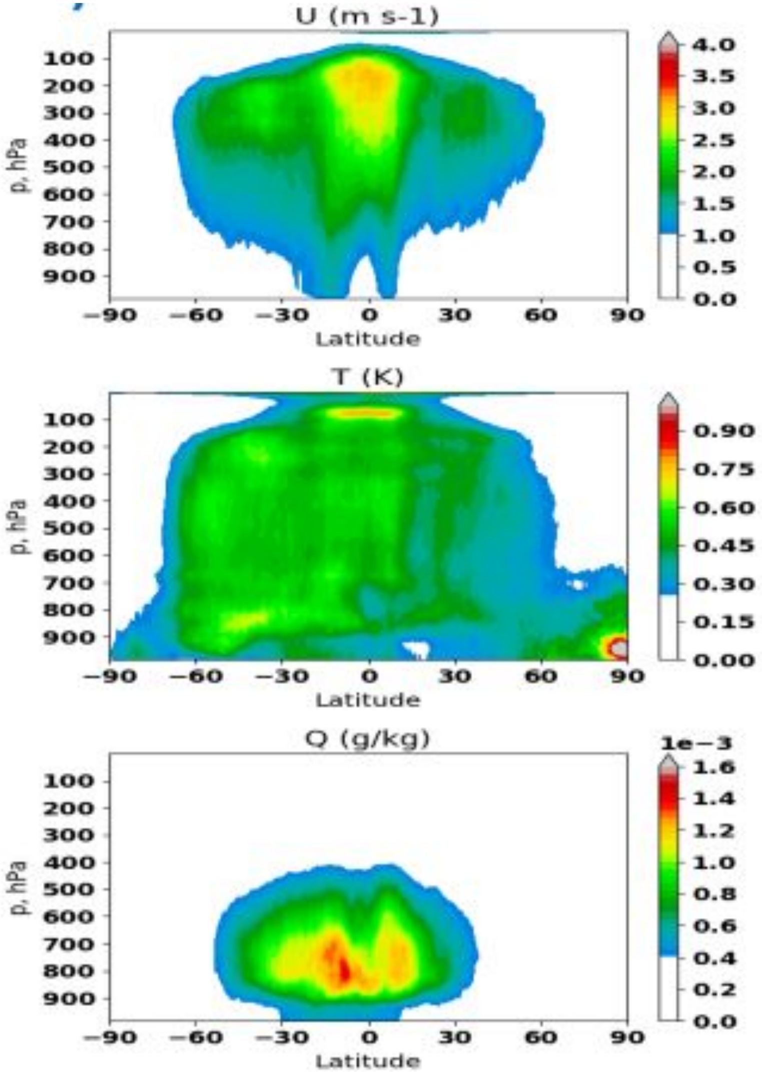
However, only looking at the ***means of the differences*** between the streams can be dangerous, since those differences are expected to vary in sign, with large opposing-sign variations around the mean *(mutual cancelling effect).*





When looking instead at the ***standard deviations of the differences*** between the streams, things look different!

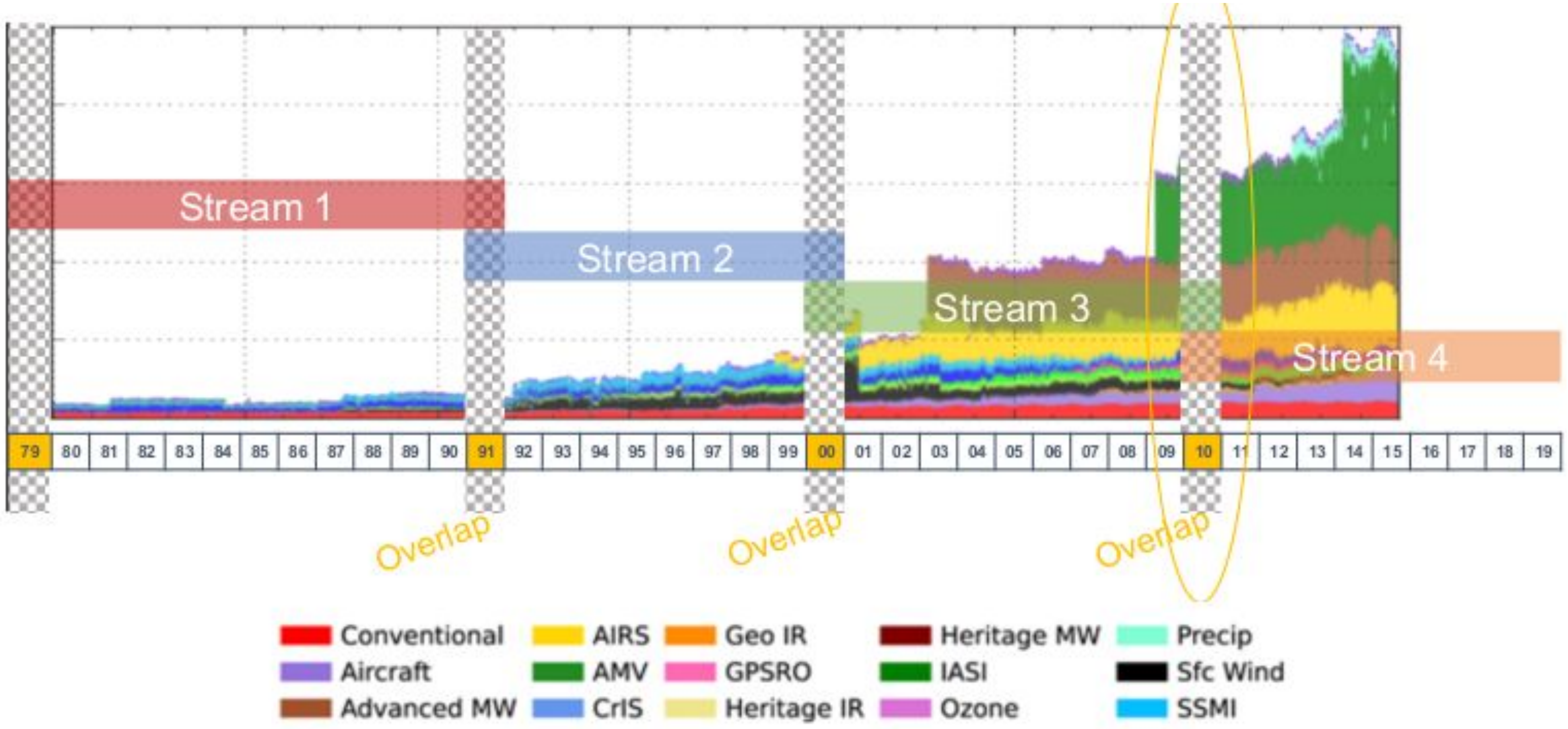




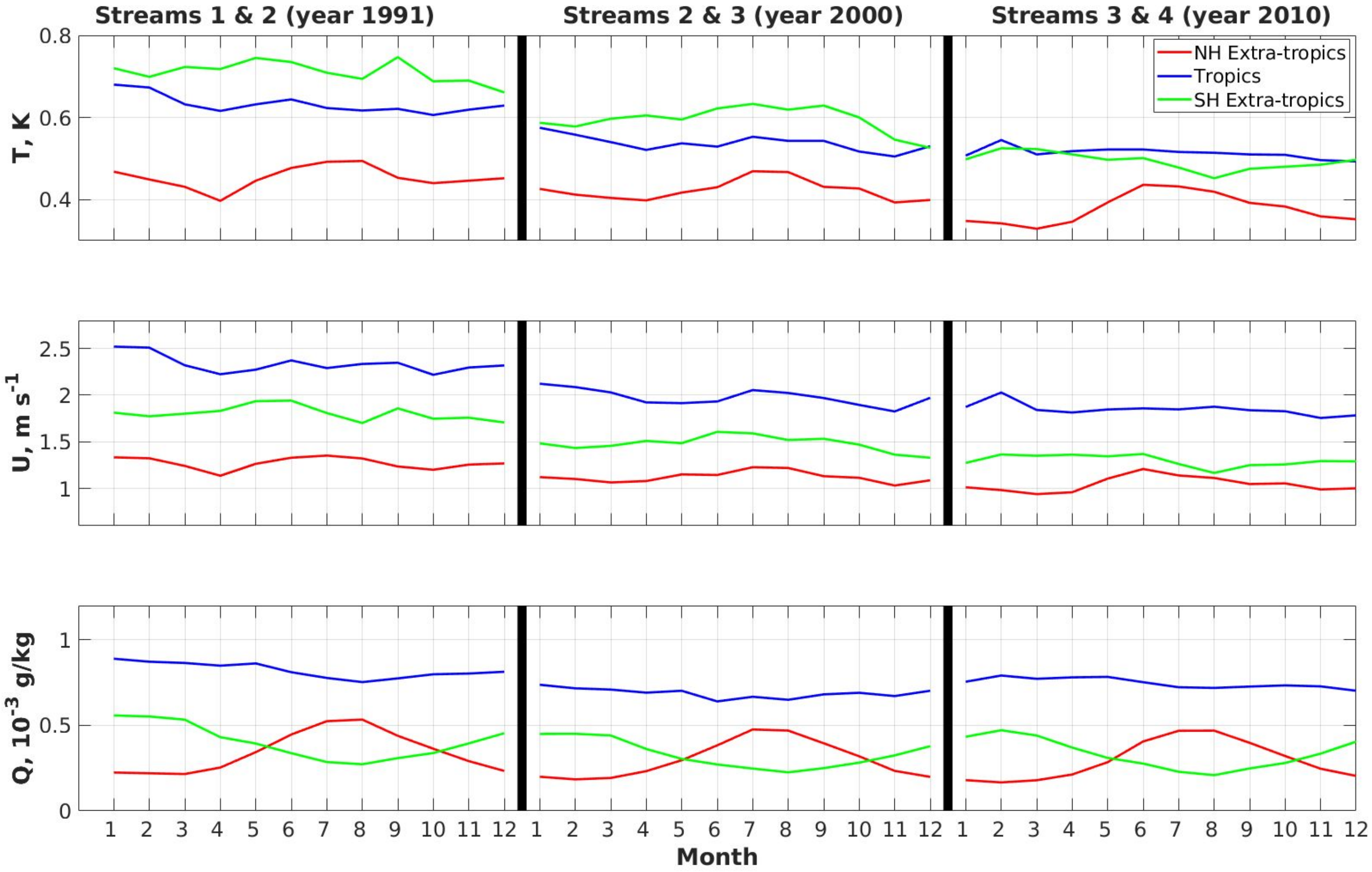
Standard deviation of the differences between streams 3 and 4 for December 2010. Zonal wind at 250 hPa (left). Square roots of the zonal means of the temporal variance of the differences for zonal wind (top right), Temperature (middle right), and specific humidity (bottom right).

Persistence of the standard deviation patterns seen can be attributed to *too short spinup* or *inadequate constraint in the data assimilation process*, but it is more plausible that the patterns of the differences seen are the consequence of the ***limited ability of the data assimilation process to reduce the stream differences beyond a certain point***, even in the case of main tropospheric fields such as temperature and winds, which are understood to be well observed and constrained in this period (2010).

How the inadequate constraint in the data assimilation contributes to errors that manifest in the stream differences can be further illustrated by examining the **other three overlapping periods**, which employ considerably *different observing networks* and hence *different levels of observational data constraint.*



Time series of monthly standard deviations of the differences between streams for three different zonally averaged areas



It is visible that the differences between the streams are larger in earlier streams ***(less / sparser observations to constrain the backgrounds)***, and that the largest differences between the streams are seen in the **southern hemisphere** *(less obs)* **and lower latitudes.**

However, the most striking aspect is that the **streams do not seem to be converging,** since *no clear downtrends of the differences between the beginning and end of the spin-up period are visible.*

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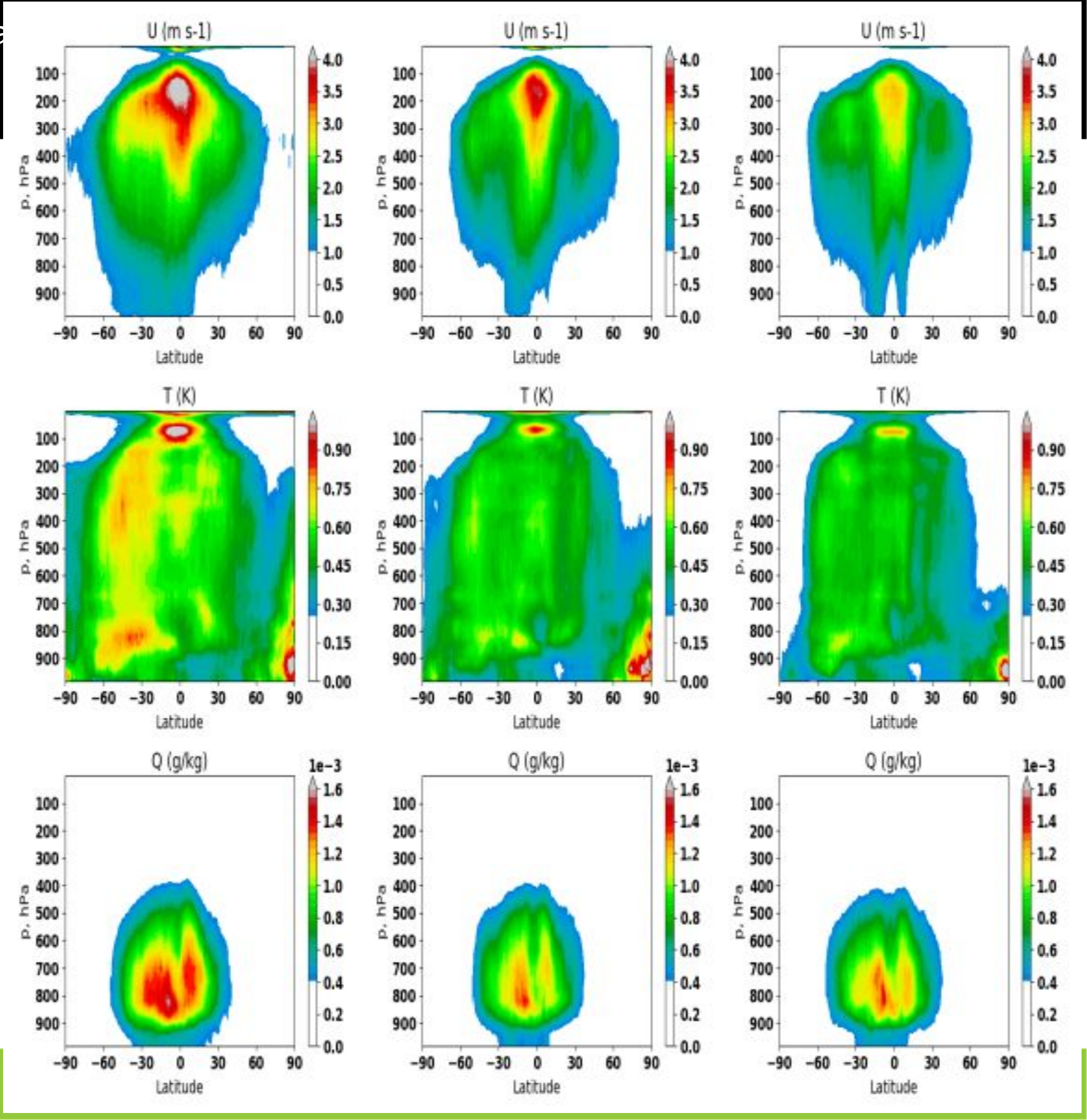
Square roots of the zonal means of the temporal variance of the zonal wind (top), temperature (middle) and specific humidity (bottom).

LEFT » stream 1&2 differences (Dec 1991);
CENTER » stream 2&3 differences (Dec 2000)
RIGHT: stream 3&4 differences (Dec 2010)



Looking at the spatial differences between the streams, again are visible larger differences in the earlier streams for all three fields, especially in the southern hemisphere and the tropical tropopause for the temperature and zonal wind.

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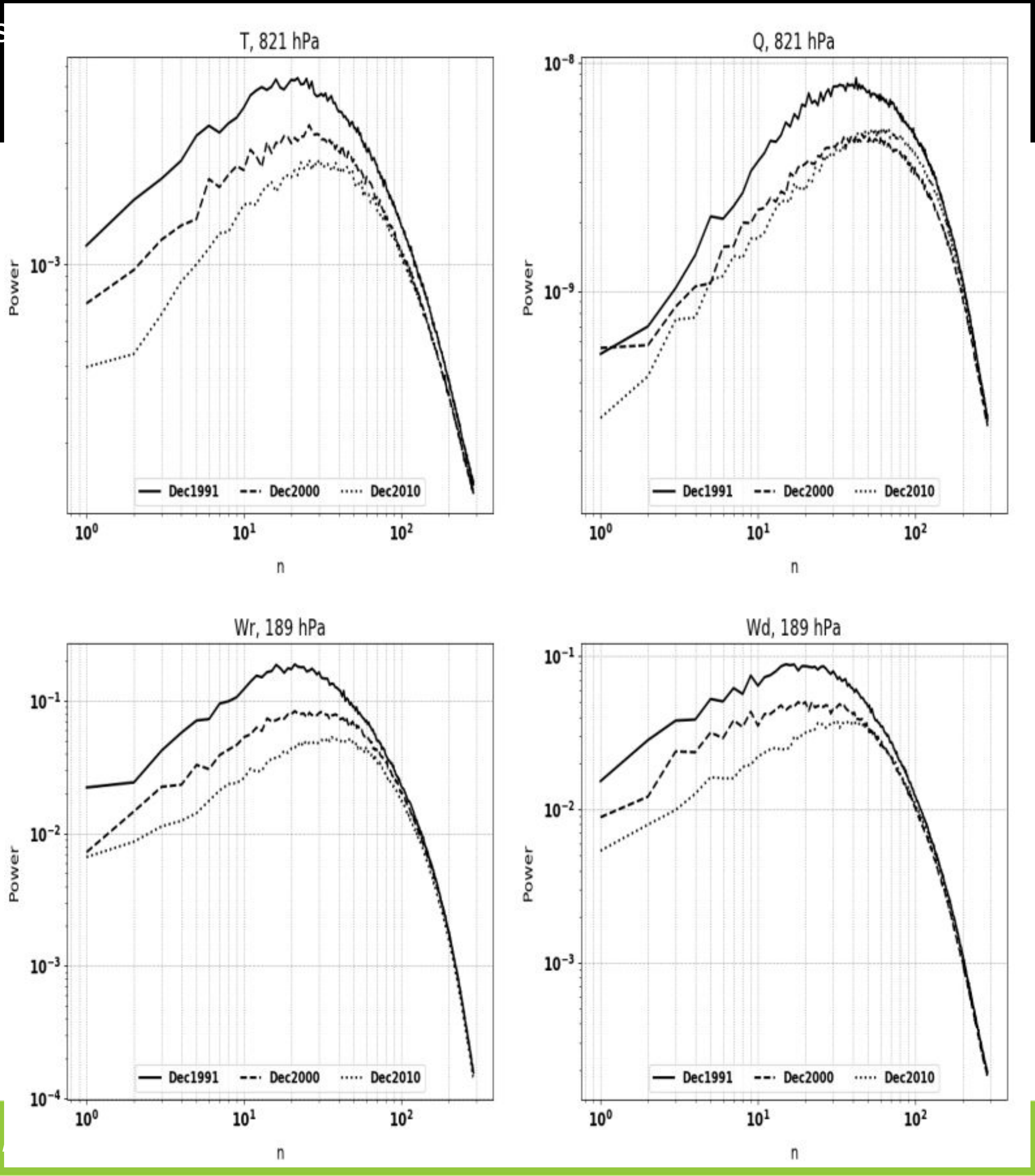
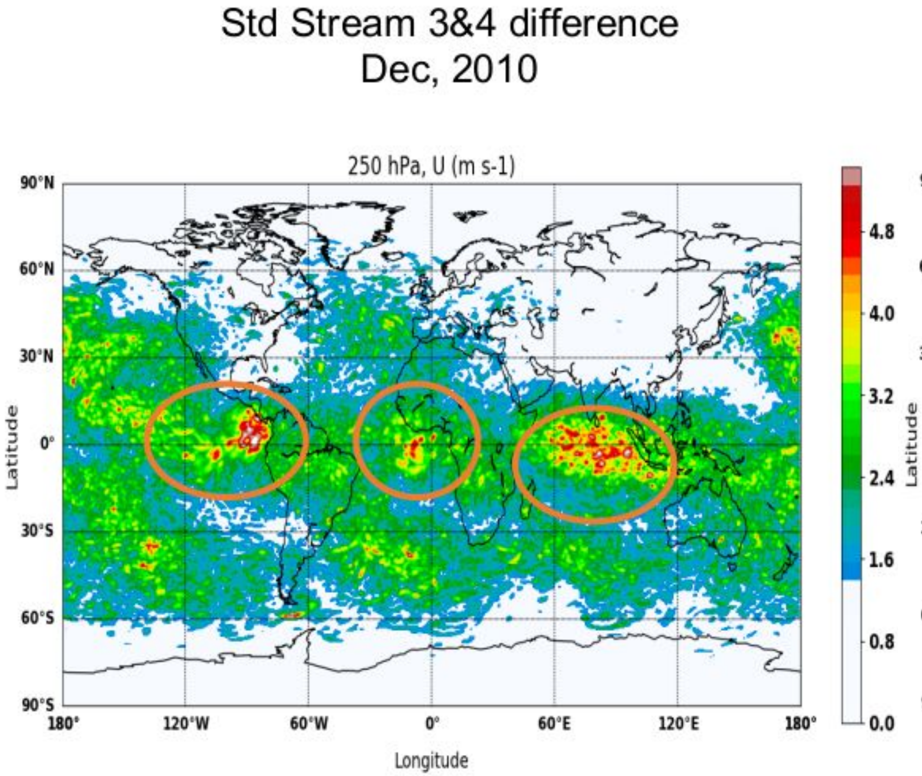
Spectra of the temporal variance of stream differences at 821hPa for temperature and specific humidity, 189hPa for rotational (wr) and divergent (wd) wind. Statistics computed for the last month of each of the three overlap periods: Dec 1991 (solid), Dec 2000 (dashed), and Dec 2010 (dotted).

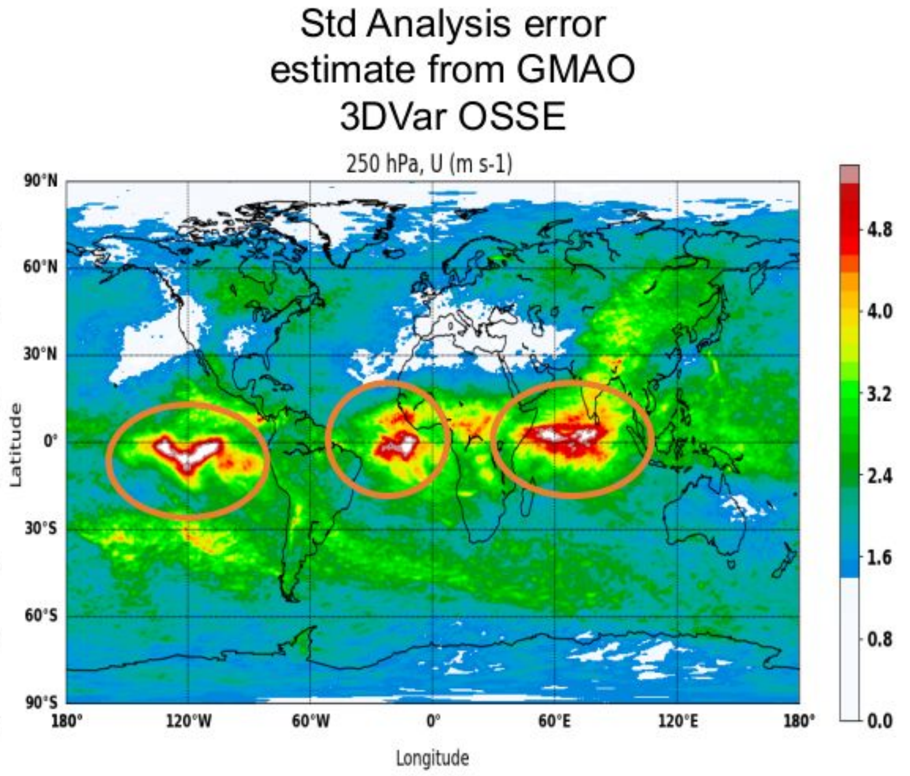


For most fields shown, the spectral magnitudes of stream differences **decrease at all scales for later overlap time periods** *(increased obs)*. This is expected, as the increasing global coverage of observations with time should result in *greater constraint* of the analysis fields.

The maximum spectal power is seen, for all vars and streams, for wavenumbers around 10^1 - 10^2 *(not noise?)*

So, are these stream differences basically noise and / or random fluctuations?





NASA's GMAO OSSE* (Observation System Simulation Experiment) framework was used to estimate GMAO's 3DVar system **analysis error.**

** an OSSE is a **completely simulated NWP-DAS system**, where the true atmosphere is replaced by a high-resolution simulation. An OSSE fundamentally mimicks a "real atmosphere" NWP-DAS system, with the advantage of having a complete true state of the atmosphere (simulated), allowing an explicit and realistic estimation of some quantities not possible in the real atmosphere such as **analysis and forecast errors**.*

Streams differences spatial patterns **closely resemble** the OSSE-estimated 3Dvar system **analysis error** ones, giving indication that these differences have a physical basis since they are **tied to the NWP-DAS internal mechanisms**, and are not random or noise.

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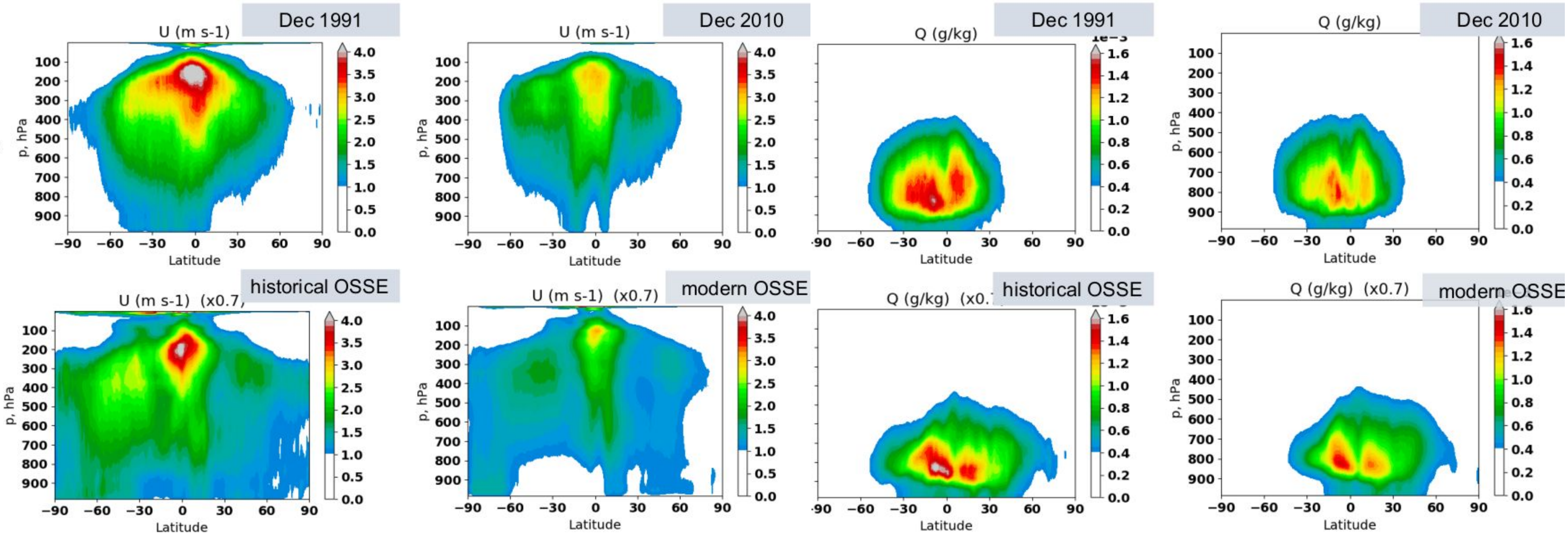
Std stream differences

Std analysis error (3DVar-OSSE)



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“Take home” key points

- Parallel reanalysis streams show significant differences in their overlapping periods, if **looked carefully** *(STDs and not just the means!)*
- The differences arise primarily due to different **initial conditions,** which signature is still present after 1 year of DAS cycling »» *NWP model divergence tendency (chaos) is strong and not “tamed” enough by the DAS.*
- Convergence of parallel NWP-DAS streams is tightly linked to the DAS constraint: ***more obs »» higher constraint »» stronger convergence »» closer overlapping streams***
- Year-long spin-up periods are likely not necessary in parallel streams » *maximum (possible...) convergence is usually obtained early on * (2-3 months)* ****except for land vars***
- Streams differences are **tied to the NWP-DAS internal mechanisms**, and are not random or noise.

Thank you!

There are some interesting analogies we can draw between the overlapping streams differences and OSSE experiments. it's fair to say that the OSSE fundamentally mimicks paralell overlapping streams (which differ only in their initialization), since:

- The OSSE “truth” and backgrounds used in the DAS cycling are obtained from the same NWP model (GEOS-5, for the GMAO OSSE). Thus, the main difference between the OSSE truth and backgrounds is the initial condition (besides others such as the truth being computed at much higher resolution than the backgrouds » that explains the larger OSSE errors when compared to stream differences)

- The obs used in the OSSE DAS are drawn from the OSSE truth »» analog to using the same obs in different streams