Update on data assimilation, OSEs and OSSEs

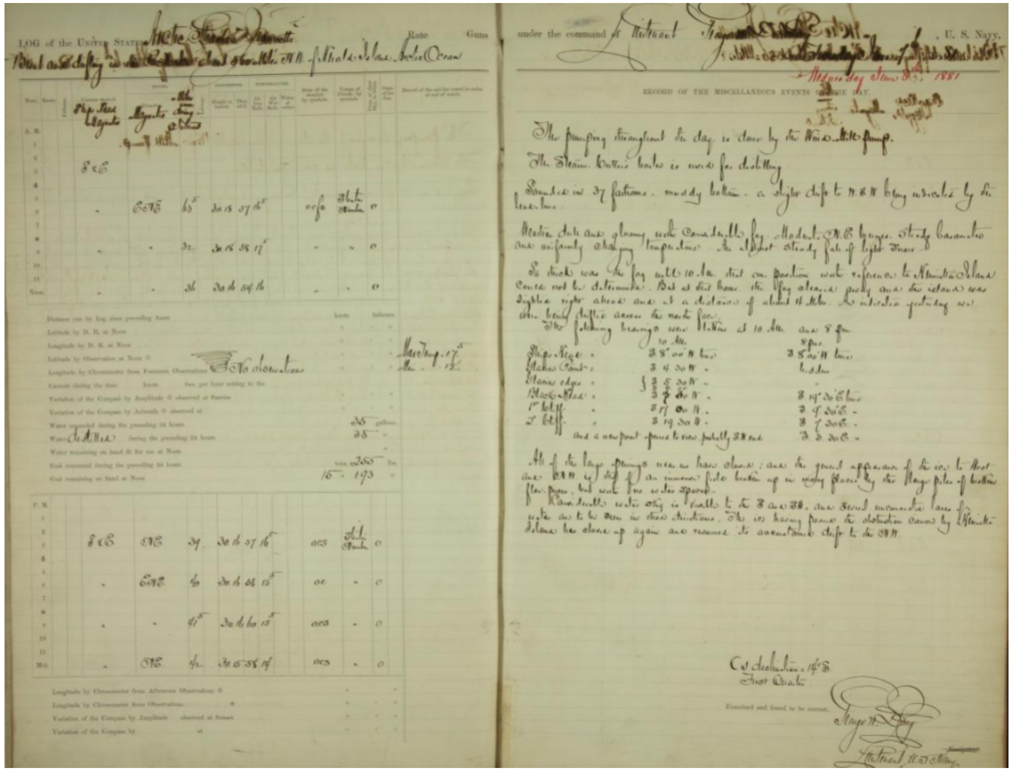
Patrick Laloyaux

Outline

- **Observation biases in climate reconstruction**
- **Importance of reference observations in data assimilation**
- **Continuous data assimilation: a new way to process observations in NWP**
- **Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs)**

Observations for climate reconstruction

The USS Jeannette (1879, Artic, 33 crew members)



SST measurements from buckets have a cold bias (~0.4C)

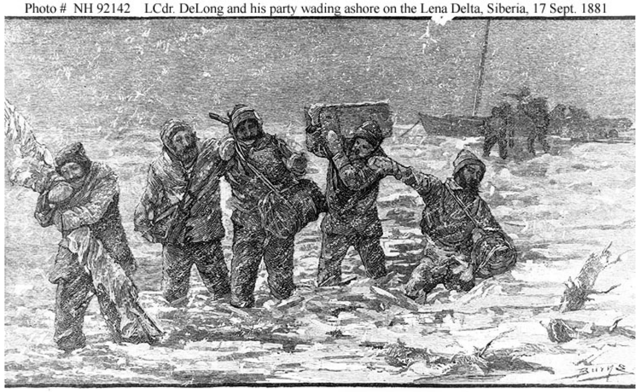
Photo # NH 52000 Steamer Jeannette sinking after being crushed by Arctic ice, June 1881

THE SINKING OF THE JEANNETTE.

Photo # NH 52002 Jeannette's crewmen drag their boats over the Arctic ice, June-August 1881

DRAGGING THE BOATS OVER THE ICE

Photo # NH 92142 LCdr. DeLong and his party wading ashore on the Lena Delta, Siberia, 17 Sept. 1881

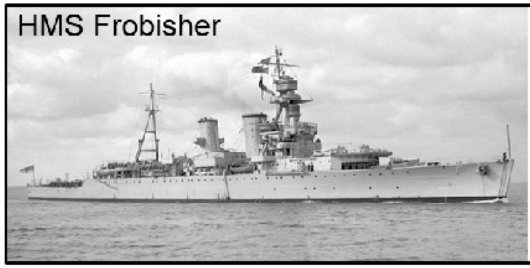


WADING ASHORE.

Courtesy of P. Brohan and G. Compo

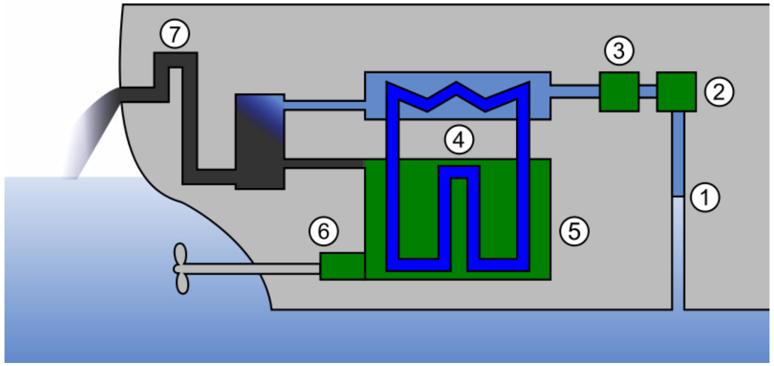
Observations for climate reconstruction

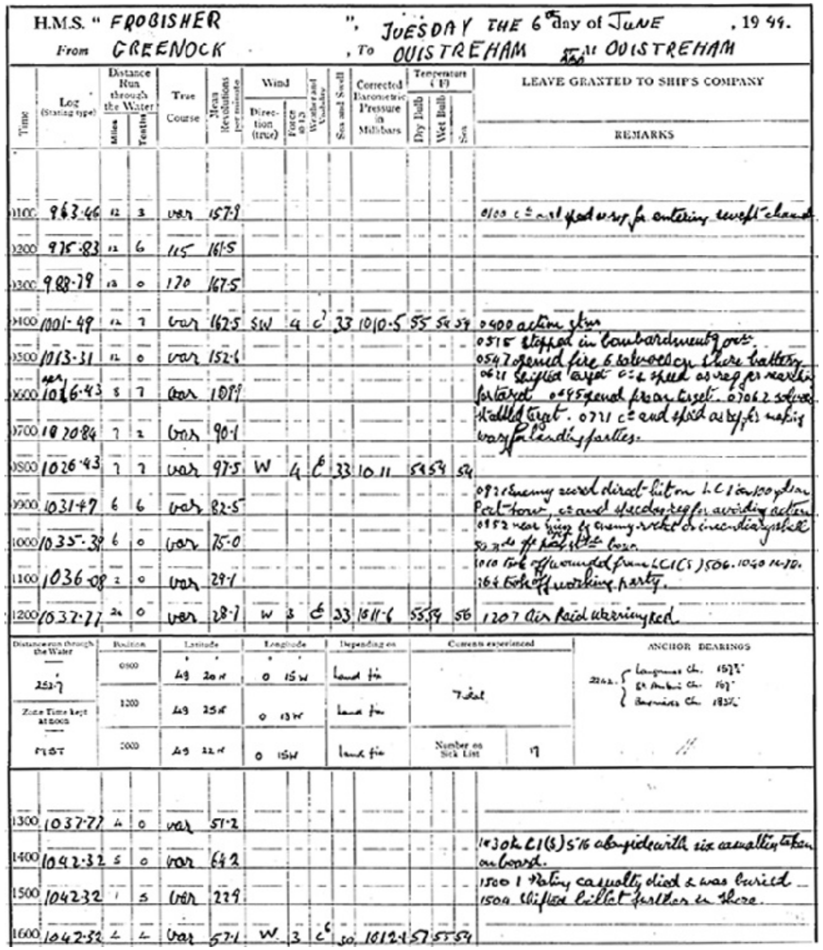
D-Day (1944, France)



Pressure	1010.5hPa (mb)	
Temperature	285.95K	(55°F)
Dew point (wet bulb)	284.95K	(54°F)
Wind direction	225°	(SW)
Wind speed	6.7ms^{-1}	(Force 4)
(Weather/) Visibility	Code 97	(c/7)
Sea temperature	285.35K	(54°F)

Pressure	1014.8hPa (mb)	
Temperature	285.35K	(54°F)
Dew point (wet bulb)	283.35K	(52°F)
Wind direction	270°	(W)
Wind speed	6.7ms^{-1}	(Force 4)
(Weather/) Visibility	Code 96	(c/6)
Sea temperature	284.25K	(52°F)




H.M.S. " FROBISHER ", TUESDAY THE 6th day of JUNE, 1944.
From GREENOCK, To OUISTREHAM, At OUISTREHAM

LEAVE GRANTED TO SHIP'S COMPANY

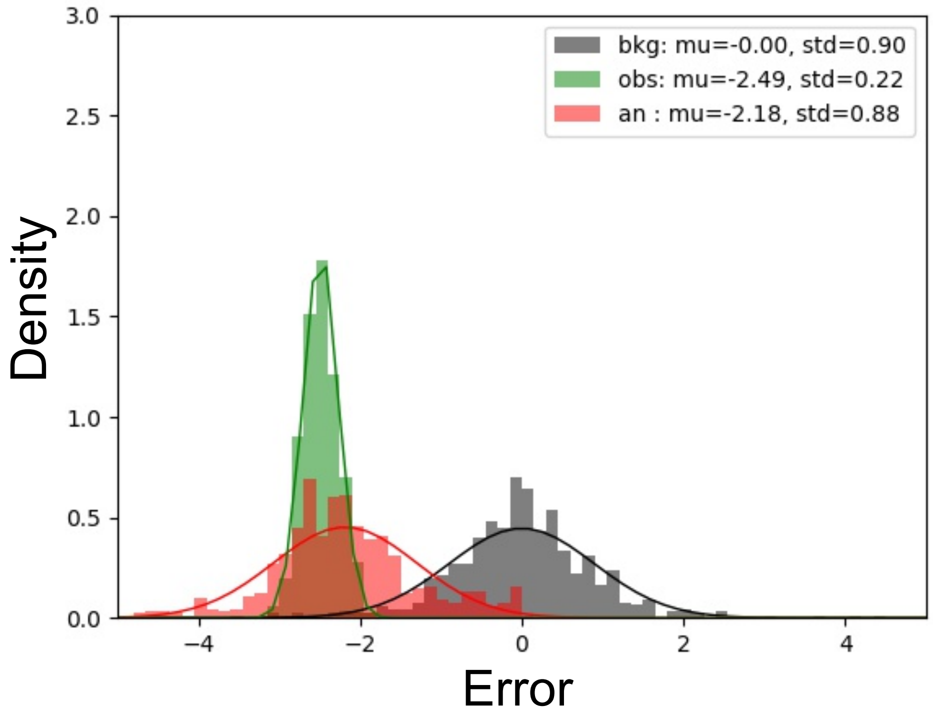
REMARKS

SST measurements from Engine Room Intake (ERI) have a warm bias (~0.2C)

Data assimilation

The standard 4D-Var formulation is designed to cope with random, zero-mean errors from the model and the observations

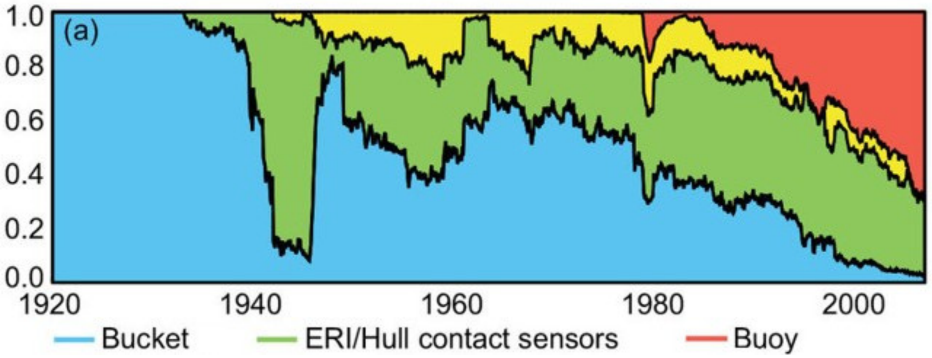
$$J(x_0) = \frac{1}{2}(x_0 - x_b)^T \mathbf{B}^{-1}(x_0 - x_b) + \frac{1}{2}\sum_{k=0}^{K}[y_k - \mathcal{H}(x_k)]^T \mathbf{R}_k^{-1}[y_k - \mathcal{H}(x_k)]$$

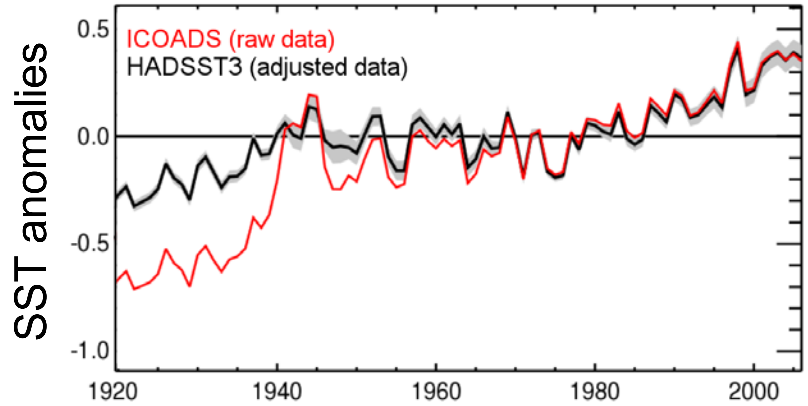


If biased observations are assimilated, the resulting analysis will be biased. In this case the background in more accurate than the analysis!

How to remove observation biases

Before the assimilation, based on instrument properties





During the assimilation, using information from the model and reference observations

$$J(x_0,\beta) = \frac{1}{2}(x_0 - x_b)^T \mathbf{B}^{-1}(x_0 - x_b) + \frac{1}{2}\sum_{k=0}^{K}[y_k - \mathcal{H}(x_k) - b(x_k,\beta)]^T \mathbf{R}_k^{-1}[y_k - \mathcal{H}(x_k) - b(x_k,\beta)]$$

observations (y_k) — model ($\mathcal{H}(x_k)$) — observation bias ($b(x_k,\beta)$)

→ The observation bias is estimated and removed during the assimilation

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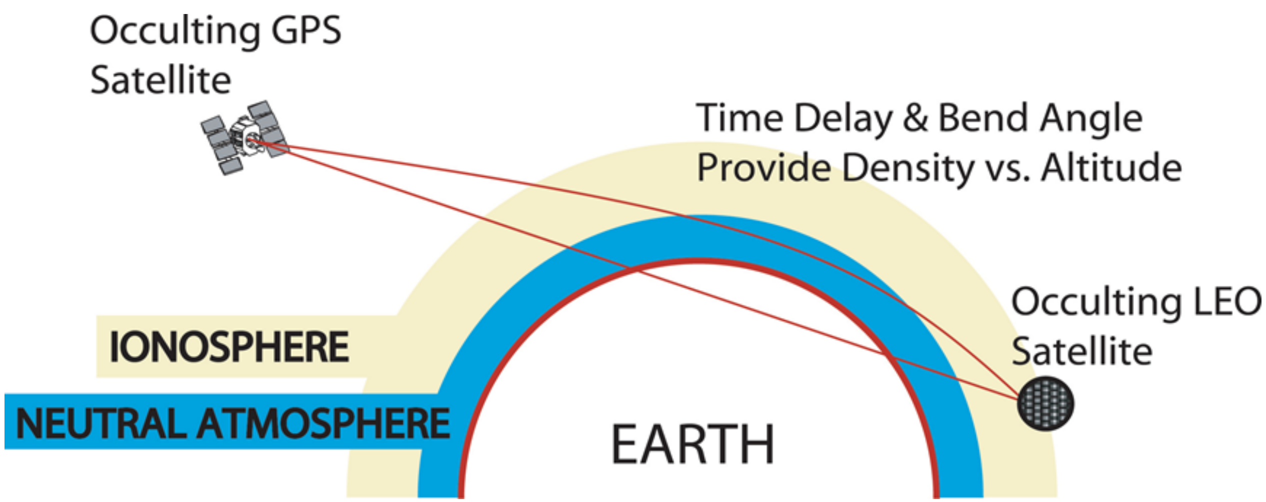
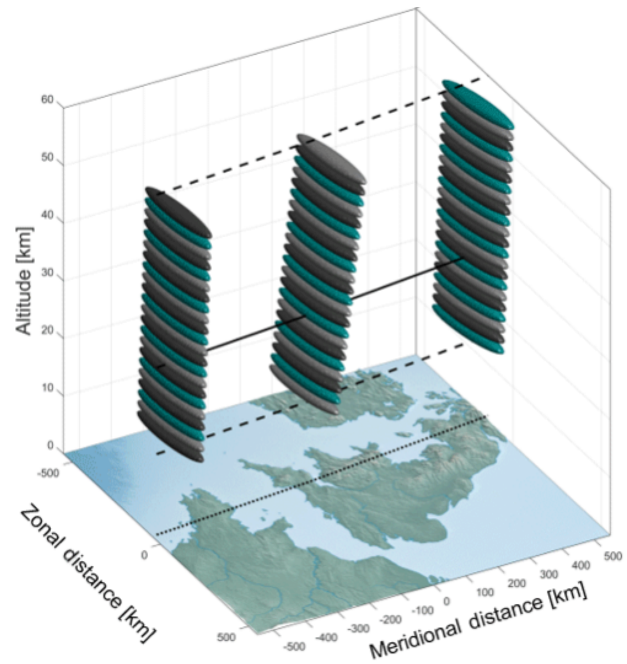
Importance of reference (bias-free) observations

GPS-RO (Radio Occultation) is based on analysing the bending caused by the atmosphere along paths between a GPS satellite and a receiver placed on a low-earth-orbiting satellite.





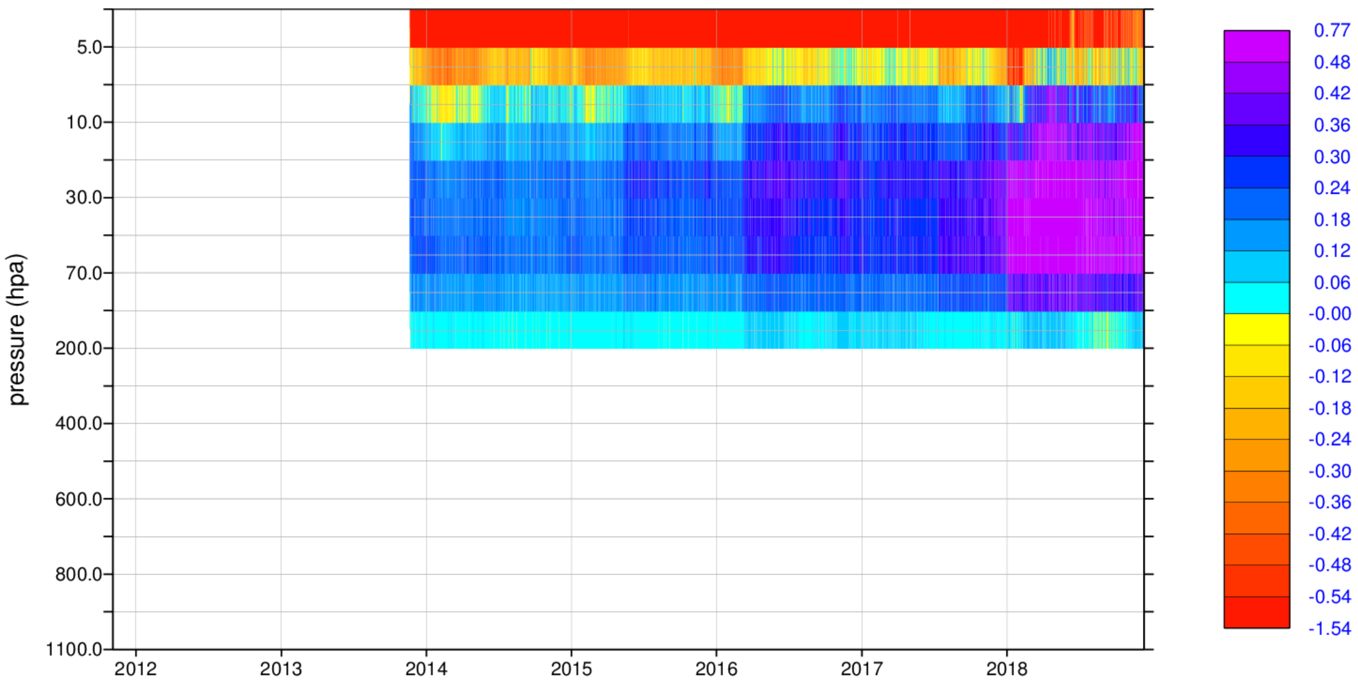
→ As the LEO moves behind the earth, we obtain a profile of bending angles

→ Temperature profiles can then be derived (a vertical interval between 10-50 km)

→ GPS-RO can be assimilated without bias correction. They are good for highlighting errors/biases

How to estimate model biases

The first-guess trajectory of the model can be compared to unbiased observations



Difference between GPS-RO temperature retrievals and the IFS first-guess trajectory (O-B)

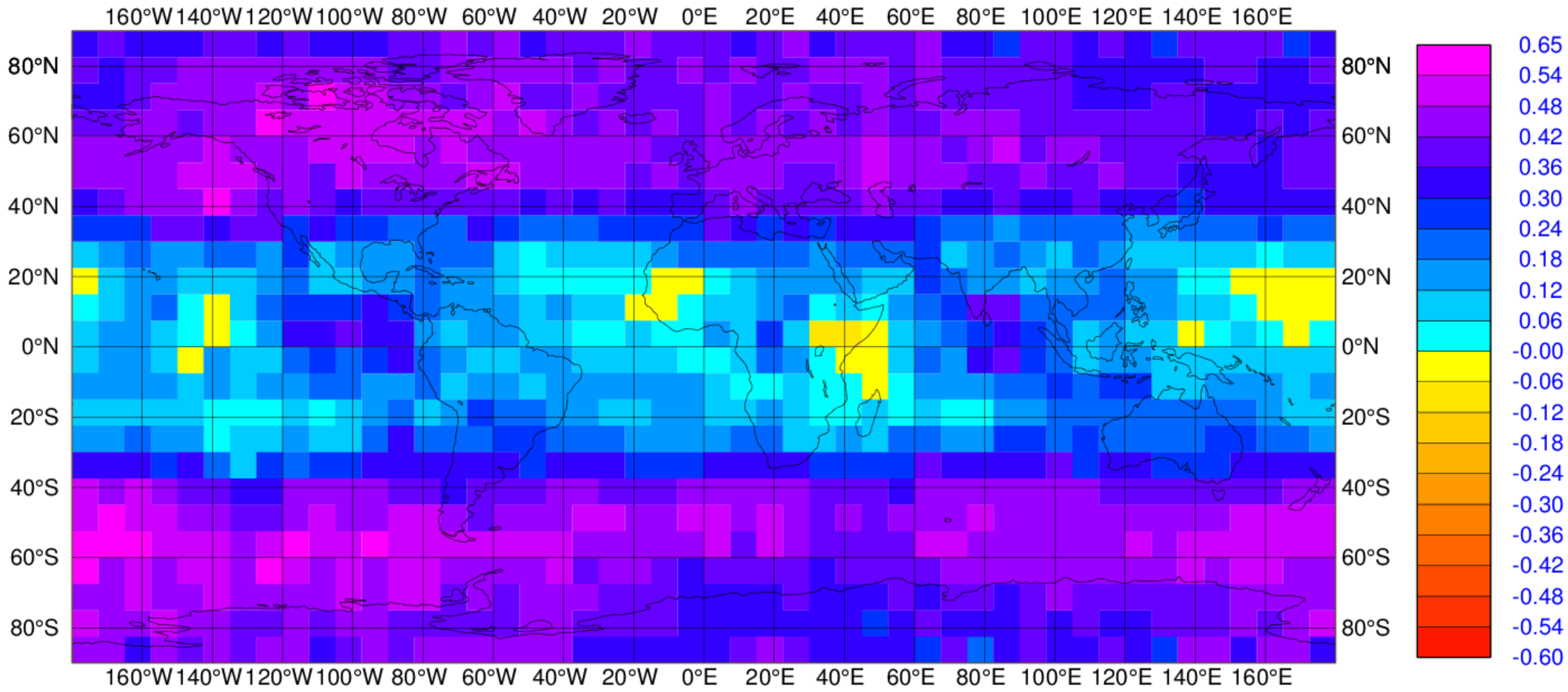
Errors in models are often systematic rather than random, zero-mean

→ Model has a temperature cold bias in the lower/mid stratosphere

→ Model has a warm bias in the upper stratosphere

How to estimate model biases

GPS-RO temperature retrievals provide an homogeneous observing system that can be used to study the spatial distribution of the model error



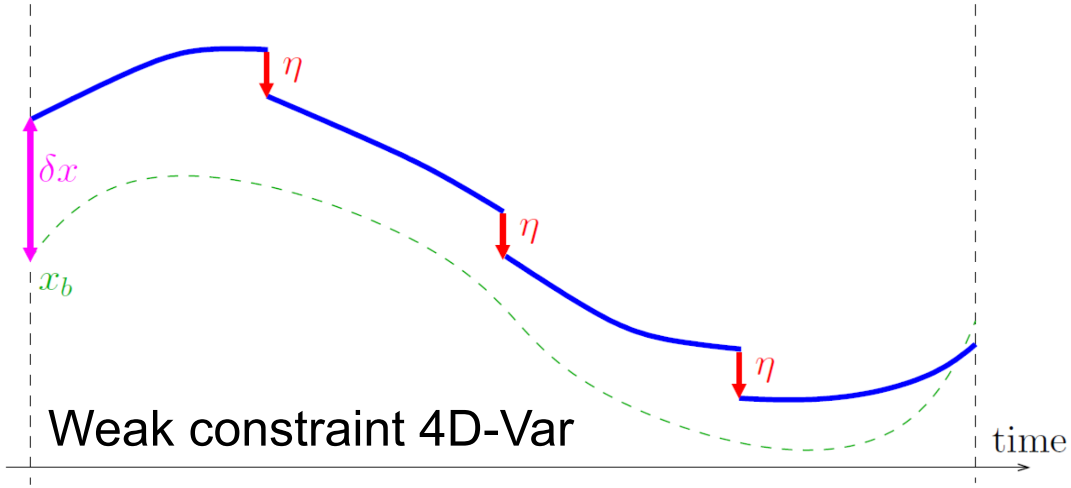
→ The IFS model shows very large structures in the temperature model bias

Data assimilation with model biases

We struggle to remove some biases from the model, but data assimilation can estimate and remove them

$$x_k = \mathcal{M}_k(x_{k-1}) + \eta \quad \text{for } k = 1, 2, \cdots, K$$

We assume that the model is not perfect, adding an error term η in the model equation



$$\begin{aligned} J(x_0, \beta, \eta) &= \frac{1}{2}(x_0 - x_b)^T \mathbf{B}^{-1}(x_0 - x_b) \\ &+ \frac{1}{2}\sum_{k=0}^{K}[y_k - \mathcal{H}(x_k) - b(x_k, \beta)]^T \mathbf{R}_k^{-1}[y_k - \mathcal{H}(x_k) - b(x_k, \beta)] \\ &+ \frac{1}{2}(\eta - \eta_b)^T \mathbf{Q}^{-1}(\eta - \eta_b) \end{aligned}$$

Model state (x_0)
Observation bias parameters (β)
Model error (η)

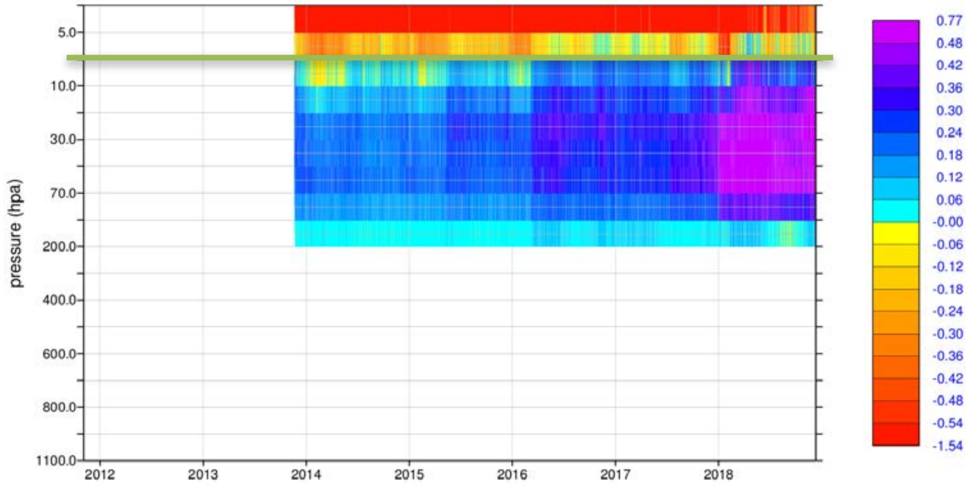
→ Introduce additional controls to estimate the model bias

→ Bias in the analysis is reduced

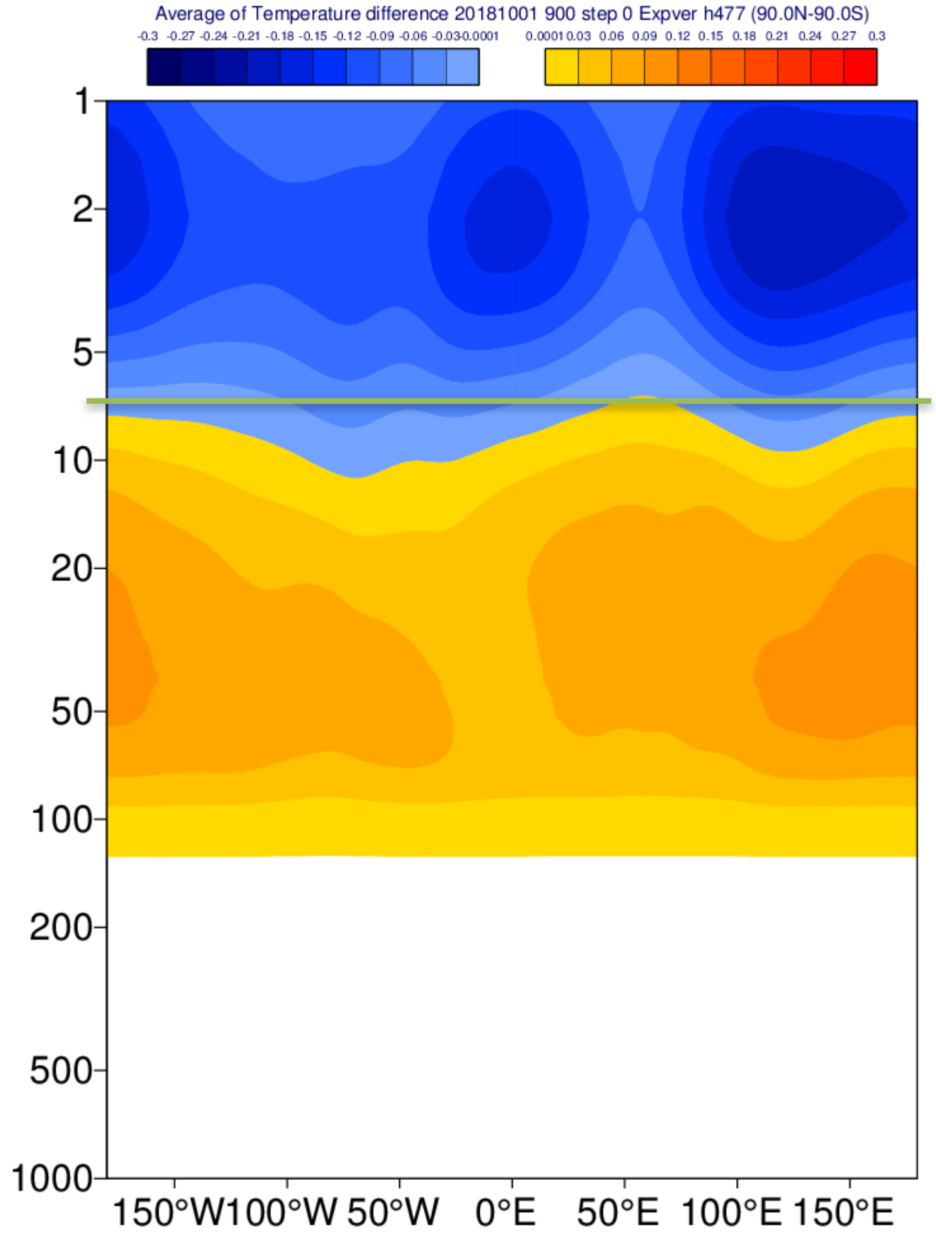
→ Performance depends on the availability of reference bias-free observations

Weak constraint 4D-Var results with IFS

Bias estimated from GPS-RO



Bias estimated by weak constraint 4D-Var



→ Weak constraint 4D-Var cools down (warms up) the atmosphere where it was too warm (cold)

→ Separation is picked correctly around 7.5hPa

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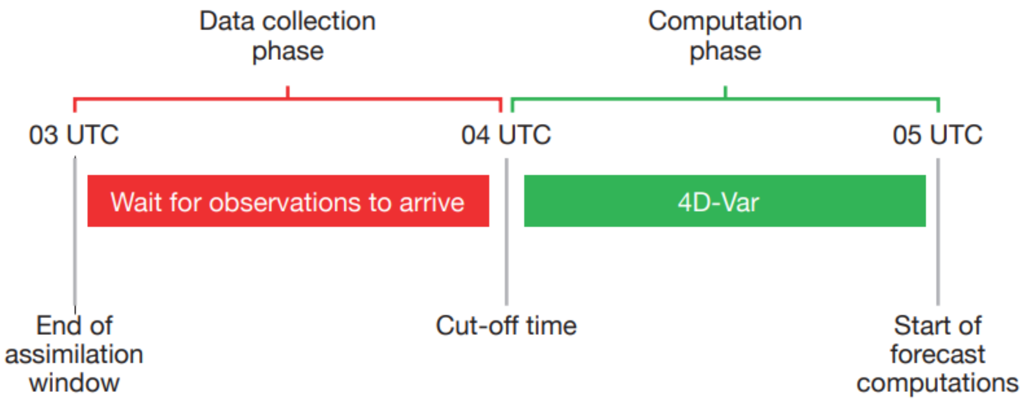
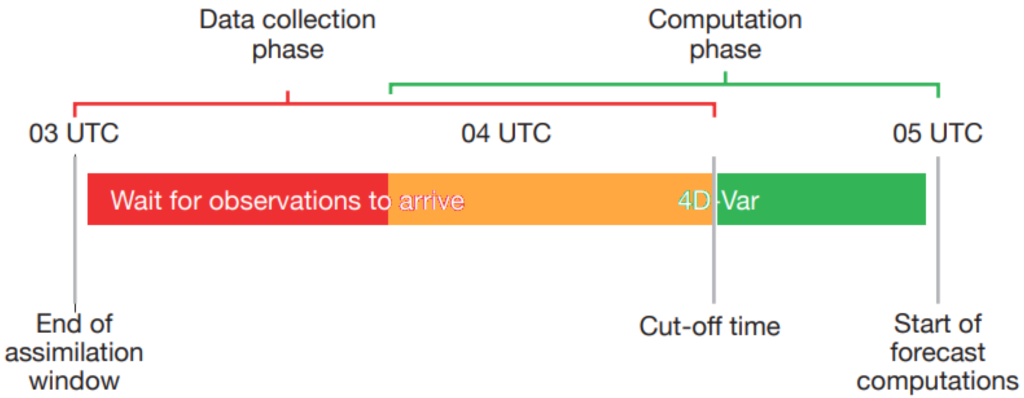
Continuous data assimilation



Current system

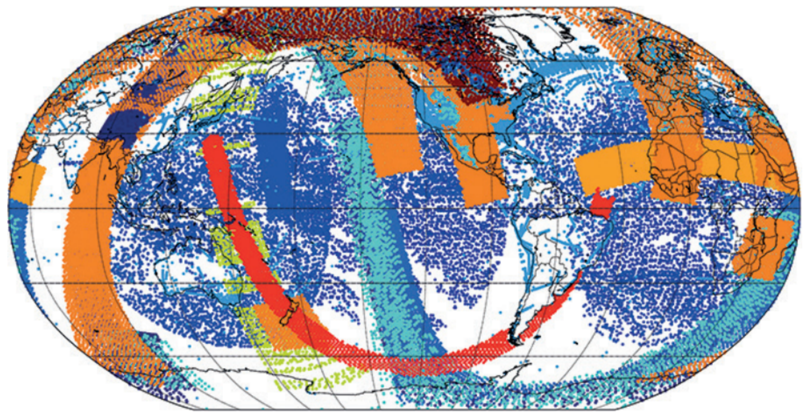
Observations are collected and then assimilation starts



New system

Observation collection and assimilation are done at the same time

17% more observations are assimilated (late and delayed observations)



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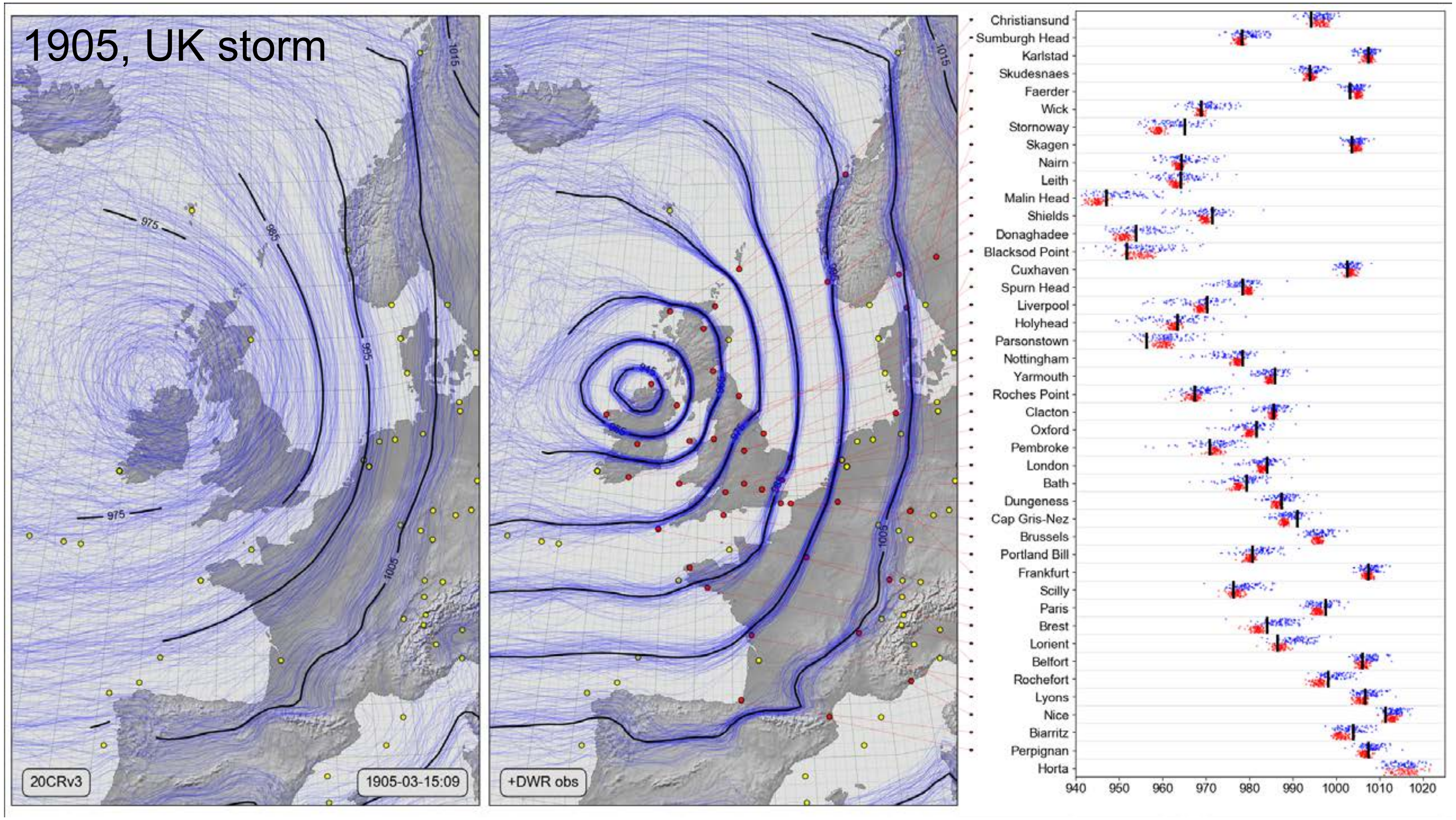
The importance of WeatherRescue.org



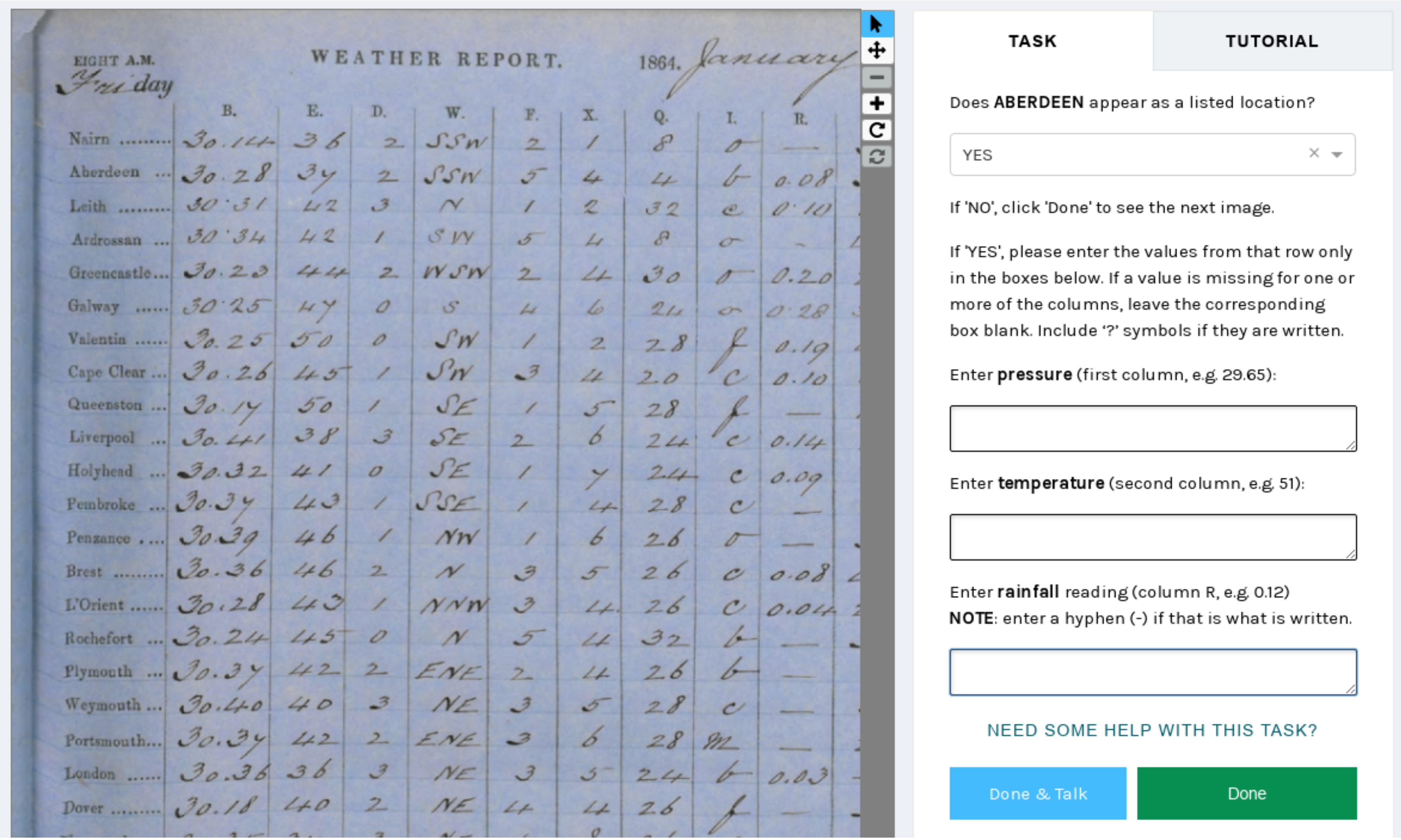
Mean-sea-level pressure (mslp) contours from the Twentieth Century Reanalysis version 3 (left), and after assimilating additional observations from the UK Daily Weather Reports (right)

Extra observations improves the representation of the storm and increase the confidence (clustering of the different members)

Ed Hawkins and Philip Brohan

The importance of WeatherRescue.org

2.5 million pieces of data need to be entered manually into a computer
More volunteers are needed!



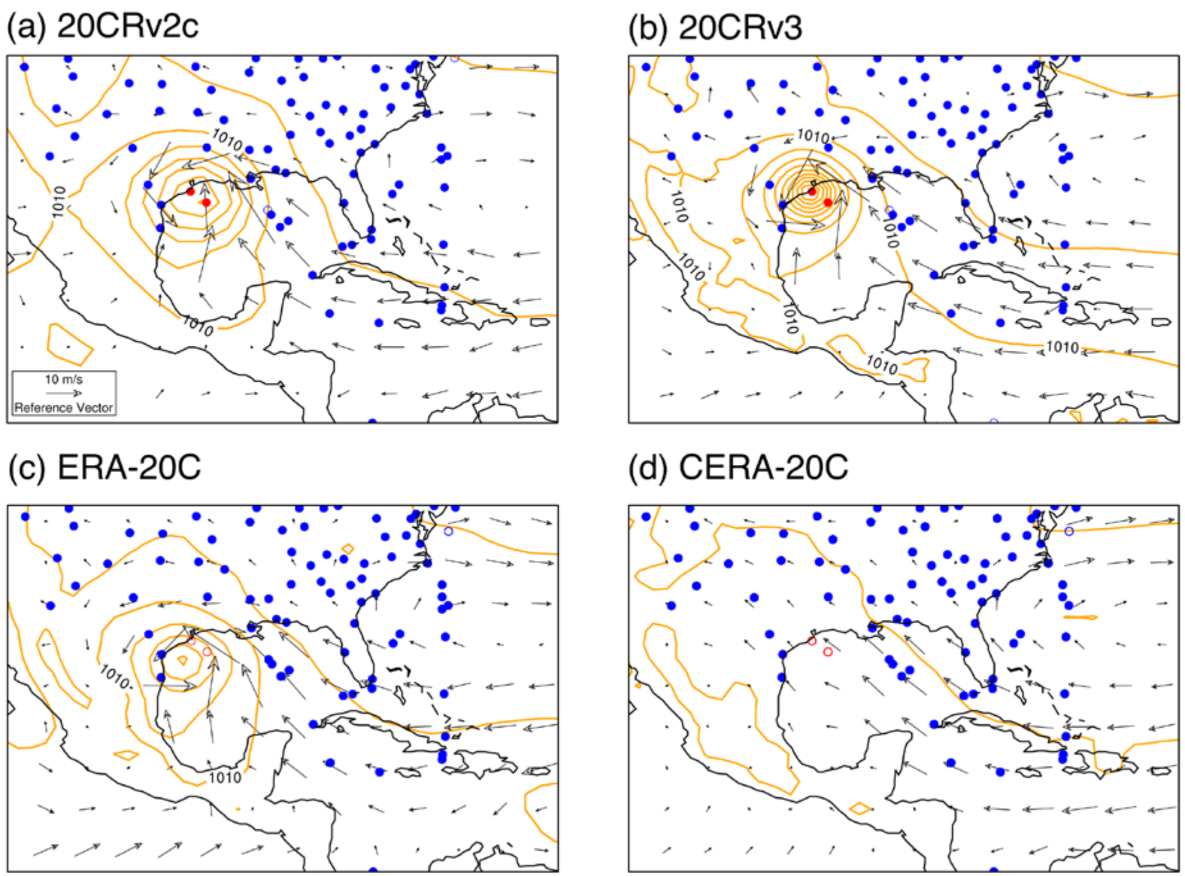
EIGHT A.M. Friday — WEATHER REPORT. 1864. January

	B.	E.	D.	W.	F.	X.	Q.	I.	R.
Nairn	30.14	36	2	SSW	2	1	8	o	—
Aberdeen	30.28	37	2	SSW	5	4	4	b	0.08
Leith	30.31	42	3	N	1	2	32	c	0.10
Ardrossan	30.34	42	1	SW	5	4	8	o	-
Greencastle	30.23	44	2	WSW	2	4	30	o	0.20
Galway	30.25	47	0	S	4	6	24	o	0.28
Valentia	30.25	50	0	SW	1	2	28	f	0.19
Cape Clear	30.26	45	1	SW	3	4	20	c	0.10
Queenston	30.17	50	1	SE	1	5	28	f	—
Liverpool	30.41	38	3	SE	2	6	24	c	0.14
Holyhead	30.32	41	0	SE	1	7	24	c	0.09
Pembroke	30.37	43	1	SSE	1	4	28	c	—
Penzance	30.39	46	1	NW	1	6	26	o	—
Brest	30.36	46	2	N	3	5	26	c	0.08
L'Orient	30.28	43	1	NNW	3	4	26	c	0.04
Rochefort	30.24	45	0	N	5	4	32	b	—
Plymouth	30.37	42	2	ENE	2	4	26	b	—
Weymouth	30.40	40	3	NE	3	5	28	c	—
Portsmouth	30.37	42	2	ENE	3	6	28	m	—
London	30.36	36	3	NE	3	5	24	b	0.03
Dover	30.18	40	2	NE	4	4	26	f	—

Problem for Optical Character Recognition: the long tails on the 7's and 9's overlap the row below

The importance of IBTrACS

IBTrACS (International Best Track Archive for Climate Stewardship) are historical tropical cyclone best-track data



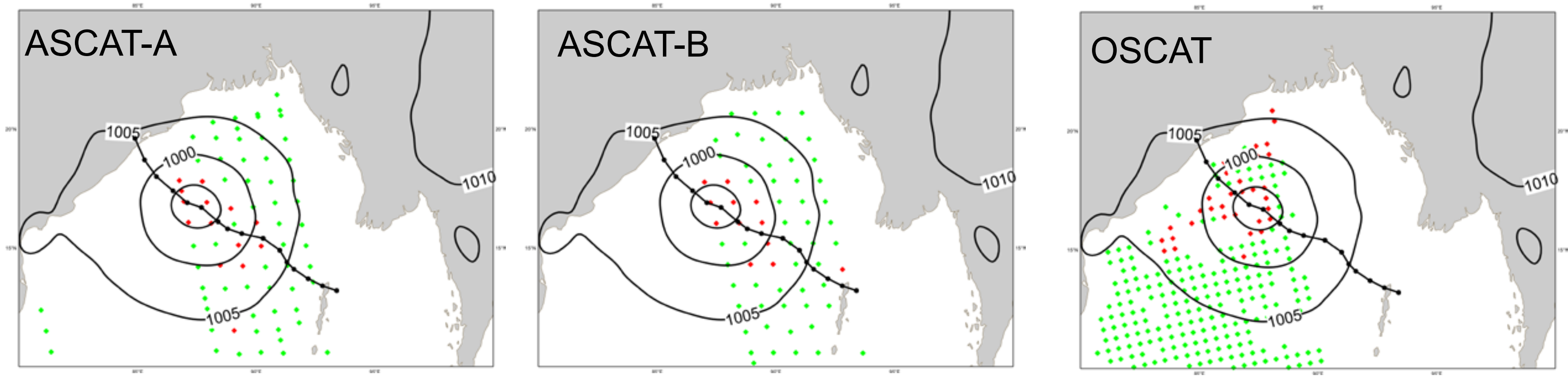
Galveston hurricane, 1900

IBTrACS not assimilated in ECMWF climate reanalyses so far, missing some TCs before 1940

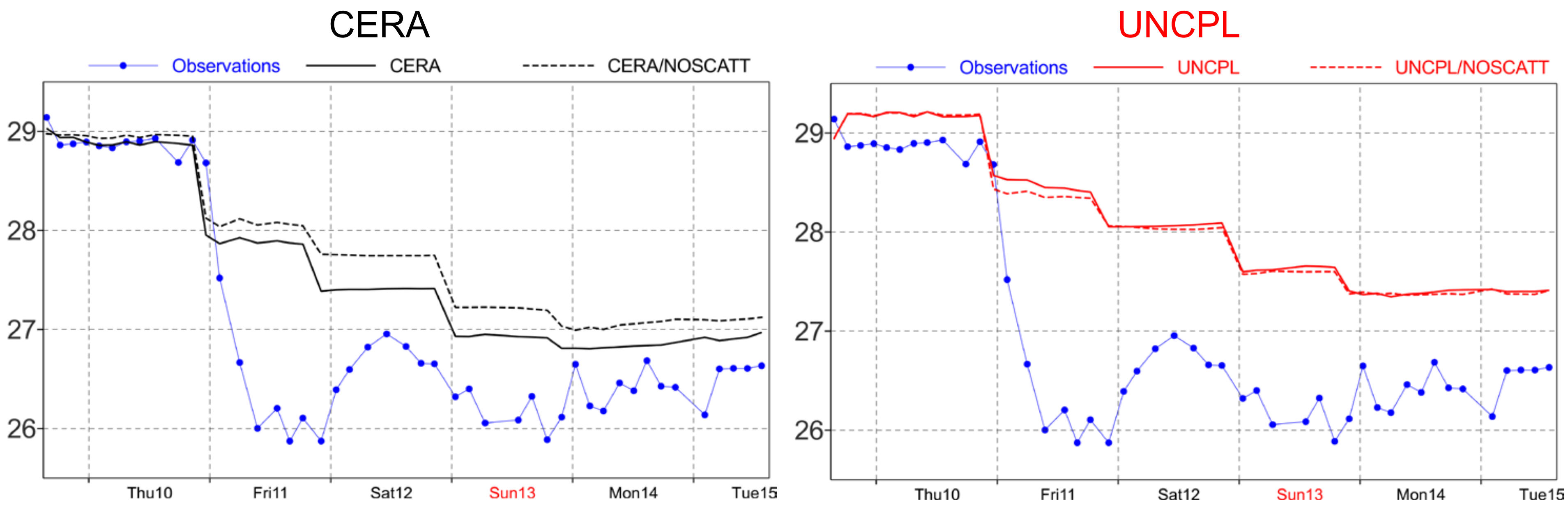
"Towards a more reliable historical reanalysis: Improvements for version 3 of the Twentieth Century Reanalysis system" by L.C. Slivinski

Importance of observations at the interface in coupled DA

Wind measurements from scatterometers (ascending pass, 11 October 2013)



Ocean temperature analysis at 40-meter depth (no scatterometer data in dashed)



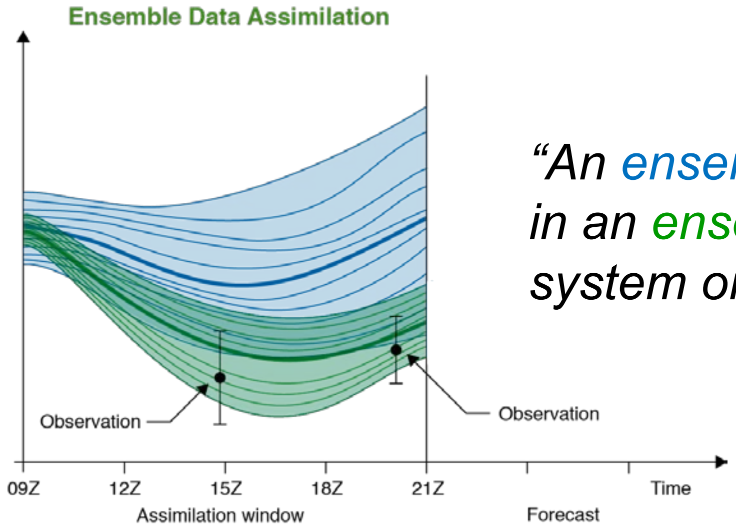
→ Atmospheric observations have the potential to improve ocean analysis in CDA

Observing System Simulation Experiments (OSSEs)

OSSEs methodology

1. reference model run considered as the true nature run
2. simulated true observations
3. observations are perturbed adding realistic observation errors

It might be challenging to get a nature run representing the reality



“An ensemble of perturbed first-guesses is transformed in an ensemble of analysis by running the assimilation system on each member”

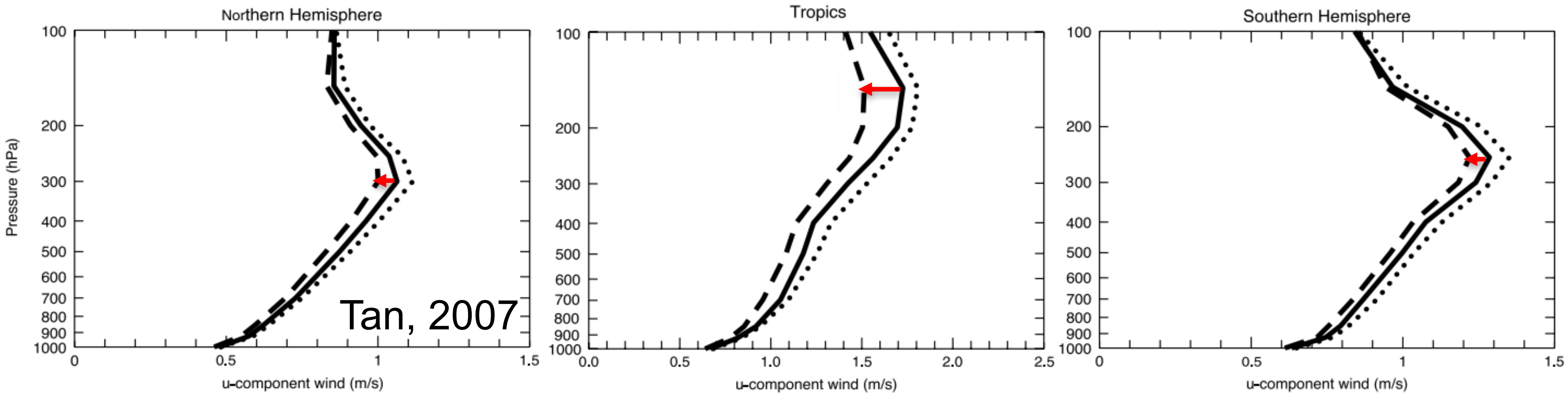
Ensemble-based observing system impact assessment studies the impact of a new type of observations on the ensemble spread

→ No need of a nature run

→ Only future expected observations have to be generated

Ensemble-based observing system impact assessment

Aeolus satellite lifted off on 22 August 2018 after 15 years of developments



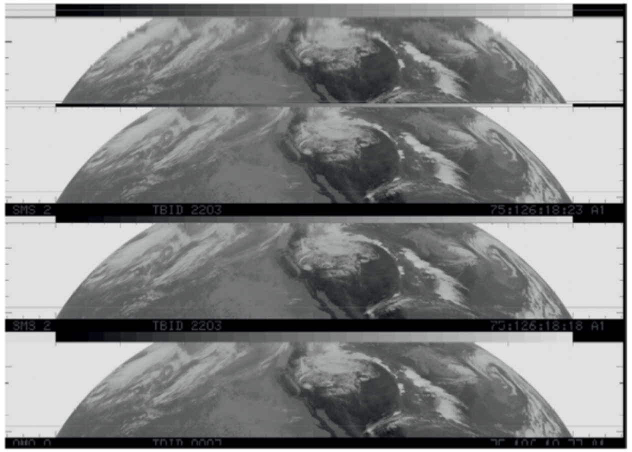
→ Reduction in spread has been confirmed assimilating the real Aeolus observations

→ Largest improvement has been found in Southern hemisphere (preliminary results)

Conclusions

Climate reconstructions need a dense network of quality controlled observations

- inventory past measurements
- fund data rescue activities
- share observation datasets internationally



A nine-track tape, holding historical geostationary data, with the corresponding player underneath

OSEs shows the large impact of having new observations over sparsely observed area

- pressure observation from WeatherRescue.org
- best-track observations from IBTrACS

Data assimilation for climate reconstruction requires special developments

- to deal with biases from observations and model
- to extract all the possible information (scatterometer to correct ocean temperature)