

AUTOMATED TEXT WEATHER FORECASTS AND LARGE LANGUAGE MODELS

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23rd Conference on Artificial Intelligence for
Environmental Science

31 January 2024

GLAHN (1970) – COMPUTER- WORDED FORECASTS

- More than 50 years of writing text forecasts automatically
- FORTRAN
- RIP Bob Glahn (1928-2023)

FORECAST MATRIX FOR PITTSBURGH, PA									
SUNDAY 14 DEC 1975									
ELEMENT	UNITS	FCST MADE MO/DA Z	DATE TIME 12/14 00	VALID TIME					
				12Z 63	18Z 40	00Z 51	12Z 51	18Z 42	00Z
POP(12)	PERCFNT	12/14 00			35	91	70		
POP(6)	PERCFNT	12/14 00		0	18	61	84	60	42
POPF(P)	PERCENT	12/14 00	0	0	0	2	4	16	24
R SHR(L)	PERCENT	12/14 00		25		17		18	
DRZL(L)	PERCENT	12/14 00		23		28		16	
RAIN(L)	PERCFNT	12/14 00		52		55		67	
TSTM	PERCENT	12/14 00		1		1		2	
CLOUDS	CATEGORY	12/14 00	1	1	4	4	4	4	4
WIND D/S	DEG MPH	12/14 00	1705	2113	2109	2409	2909	3011	3110

FIG. 9. Forecast matrix similar to what will be distributed by AFOS.

FORECAST FOR PITTSBURGH, PA
SUNDAY 14 DEC 1975
CLEAR THIS MORNING, BECOMING CLOUDY WITH CHANCE OF RAIN IN THE AFTERNOON.
CONTINUED VERY WARM, HIGH IN THE LOWER 60S. LIGHT SOUTHWESTERLY WINDS.
TONIGHT--RAIN, LOW NEAR 40. LIGHT WINDS. MONDAY--RAIN LIKELY. OVERCAST, HIGH
IN THE LOWER 50S. PROBABILITY OF PRECIPITATION 40 PERCENT TODAY, 90 PERCENT
TONIGHT, AND 70 PERCENT TOMORROW.

FIG. 10. Computer-worded forecast prepared from information displayed in Fig. 9.

NATURAL LANGUAGE GENERATION COMPLEX & EXPENSIVE

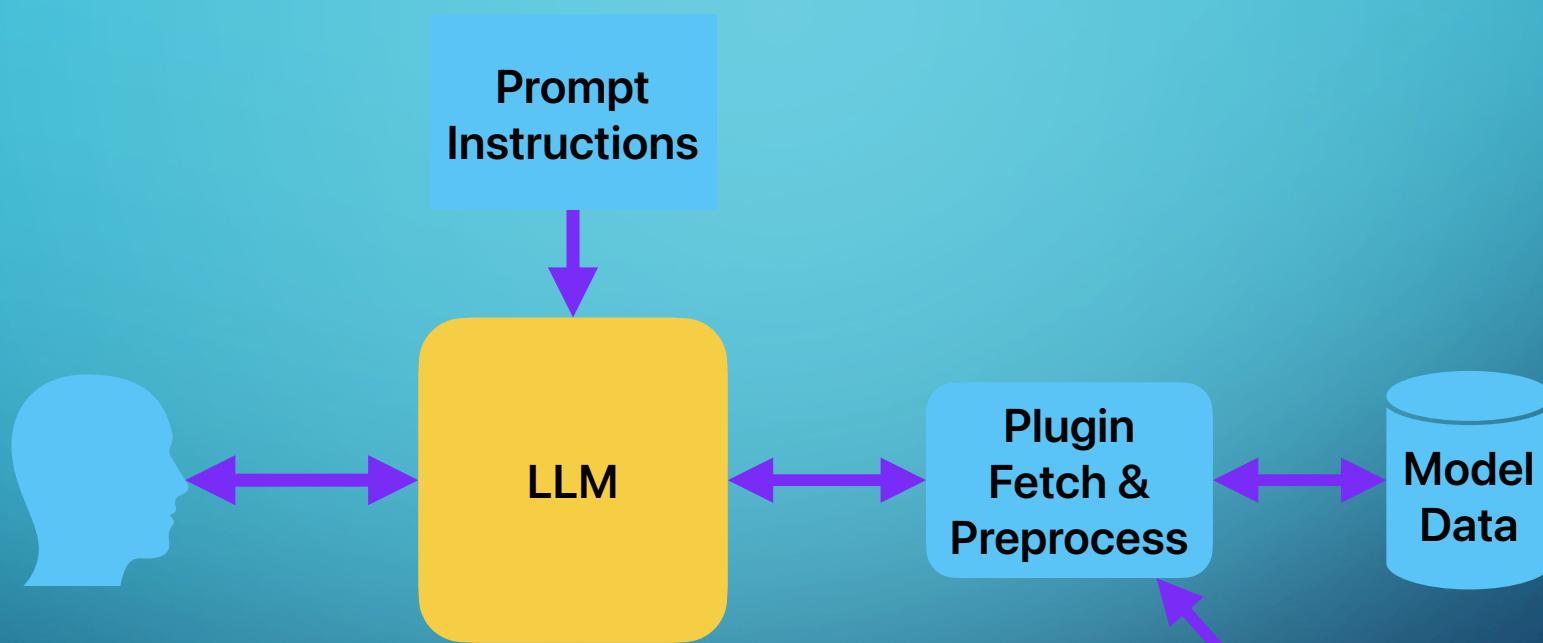
- Sophisticated NLG in Canada
- Goldberg, E., N. Driedger and R. I. Kittredge (1994) – FPA and FOG
- Verret, R., Vigneux, D., Marcoux, J., Petrucci, F., Landry, C., Pelletier, L., and Hardy, G. 1997. Scribe 3.0, a product generator.
- Python text generation systems in US NWS GFE/IFPS (probably template based)
- Belz (2006): Automatic Generation of Weather Forecast Texts Using Comprehensive Probabilistic Generation-Space Models
- Aria NLG and Met Office (2014) – NLG meeting industry needs – deployed at Met Office for locations, and for offshore marine



LARGE LANGUAGE MODELS

- 2018 – GPT-1 – Transformer and self-attention
 - First generation of coherent sentences – completing a prompt
- 2019 – GPT-2
 - Increased model size, initial withheld due to misuse concerns
- 2019 – BERT and Bidirectional training (Google)
- 2020 – GPT-3
- 2022 – ChatGPT (end November) using GPT-3.5
- 2023 – GPT-4, plugins, custom GPTs, multimodal, explosion
 - March – GPT-4, GPT-Plus subscriptions
 - May – plugins
 - Nov – GPT-4 Turbo, multimodel, custom GPTs
 - Explosion of other options – Llama2, Gemini, Hugging Face, Mistral

OVERVIEW



MODEL DATA & WARNINGS

- Model Data
 - Sourced from <https://open-meteo.com>
 - Free for non-commercial use
 - Many parameters including weather codes and FZL
 - Seamless global hourly forecasts
- Official warnings
 - MetService New Zealand
 - Online feed - check if location inside polygon
 - National Weather Service
 - API with lat and lon
 - OpenWeatherMap
 - API call for other countries, including Canada, UK, European
 - Common Alerting Protocol (CAP)

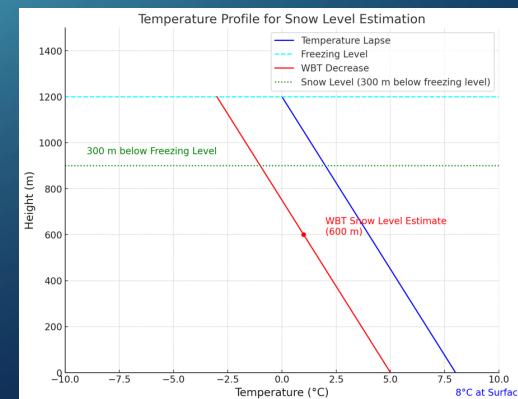


WHY NOT JUST CALL THE OPEN-METEO API DIRECTLY?

- LLMs are great at summarising text and a few numbers
- When presented with a lot of numbers, they are currently terrible at simple arithmetic
- This was GPT-4 Classic (without code interpreter)
- Could call a code interpreter but that's far too slow
- Best to calculate daily totals, etc., in the “plugin”

PLUGIN (ACTION) FETCH AND PREPROCESS

- Model forecasts retrieved in requested units (temperature, precipitation, wind speed)
- Temperature, dewpoint, weather code, wind direction, speed and gusts, pop, rainfall or snowfall rate, freezing level
- Rounded nicely – lots of rules such as
 - Temperature whole degrees
 - Wind speed nearest 10 kph
 - Wind direction 8 compass points in plain language
- Calculate daily high, low, and precip totals
- Snow level estimated from freezing level and wet bulb temperature & used if
 - It's precipitating liquid
 - Level is 100 to 1500 m above location altitude
 - Level is lower than highest terrain point within about 50 km



WHICH LLM?

- I use GPT-4 – state of the art – Vendor Lock-in but convenient for tests
 - Nothing better as of now
 - Would rather be right than risk incorrect information (Cambridge Dictionary word of year 2023 – “hallucinate”)
 - Have seen errors even with GPT-3.5
- Costs an issue
 - GPT-4 now (Jan 2024) costs about US\$0.01 per 1,000 prompt tokens – a third of previous cost
 - GPT-3.5 costs about a tenth of that
 - GPT Plus subscription – US\$20 per month then “free” but rate limited
- Many open source models on Hugging Face, etc.
- On-device models based on Llama or Mistral
 - Can run many models on my MacBook Pro M1 Pro
- Customised fine-tuning of open source an option

Hallucination Leaderboard

Public LLM leaderboard computed using Vectara's Hallucination Evaluation Model. This evaluates how often an LLM introduces hallucinations when summarizing a document. We plan to update this regularly as our model and the LLMs get updated over time.

Last updated on November 1st, 2023

Model	Accuracy	Hallucination Rate	Answer Rate	Average Summary Length (Words)
GPT 4	97.0 %	3.0 %	100.0 %	81.1
GPT 3.5	96.5 %	3.5 %	99.6 %	84.1
Llama 2 70B	94.9 %	5.1 %	99.9 %	84.9
Llama 2 7B	94.4 %	5.6 %	99.6 %	119.9
Llama 2 13B	94.1 %	5.9 %	99.8 %	82.1
Cohere-Chat	92.5 %	7.5 %	98.0 %	74.4
Cohere	91.5 %	8.5 %	99.8 %	59.8
Anthropic Claude 2	91.5 %	8.5 %	99.3 %	87.5
Mistral 7B	90.6 %	9.4 %	98.7 %	96.1
Google Palm	87.9 %	12.1 %	92.4 %	36.2
Google Palm-Chat	72.8 %	27.2 %	88.8 %	221.1

<https://github.com/vectara/hallucination-leaderboard>



TYPICAL PREPROCESSED WEATHER INFORMATION

```
"forecast": [
  {
    "day": 14,
    "dayofweek": "This afternoon and evening",
    "month": 1,
    "text": "THIS AFTERNOON AND EVENING:\n11am: 19°C, Overcast, pop 72%, northwesterly 30 km/h gust
50 km/h\nnoon: 20°C, Overcast, pop 64%, northwesterly 30 km/h gust 50 km/h\n1pm: 21°C, Overcast, pop
55%, northwesterly 30 km/h gust 60 km/h\n2pm: 21°C, Overcast, pop 37%, northwesterly 30 km/h gust 60
km/h\n3pm: 21°C, Overcast, pop 18%, northwesterly 30 km/h gust 60 km/h\n4pm: 21°C, Overcast, pop 0%,
northwesterly 30 km/h gust 50 km/h\n5pm: 20°C, Overcast, 0.1 mm/h, pop 0%, northwesterly 20 km/h gust 50
km/h\n6pm: 20°C, Light rain showers, 0.4 mm/h, pop 0%, northwesterly 20 km/h gust 50 km/h\n7pm: 19°C, Light
rain showers, 0.7 mm/h, pop 0%, northwesterly 20 km/h gust 40 km/h\n8pm: 19°C, Light rain showers, 0.4 mm/h,
pop 25%, northwesterly 20 km/h gust 40 km/h\n9pm: 19°C, Light rain showers, 1.2 mm/h, pop 49%,
northwesterly 20 km/h gust 50 km/h\n10pm: 19°C, Light rain showers, 1.3 mm/h, pop 74%, northwesterly 20
km/h gust 50 km/h\n11pm: 19°C, Light rain showers, 1.3 mm/h, pop 81%, northwesterly 20 km/h gust 50
km/h\n\nHigh 21°C and low 19°C.\nTotal rainfall of about 5 mm.\n",
    "year": 2024
  },
]
```

TYPICAL PROMPT INSTRUCTIONS

You are an experienced meteorologist who is good at writing short, easy to understand, text weather forecasts for the general public.

Fetch weather information as required using the GPT Action.

Write a clear and succinct summary of the weather forecast using ONLY the forecast information returned by the Action. Use simple language that a 12 year old would understand. You can write and converse in a different language if requested. Always write the forecast for each day in a new paragraph. Do not put it in bullet points. Do not use the word forecasted.

Do NOT write out a degree symbol for temperatures. For example, write 15C, not 15°C.

Write 45F, not 45°F.

##For each day:##

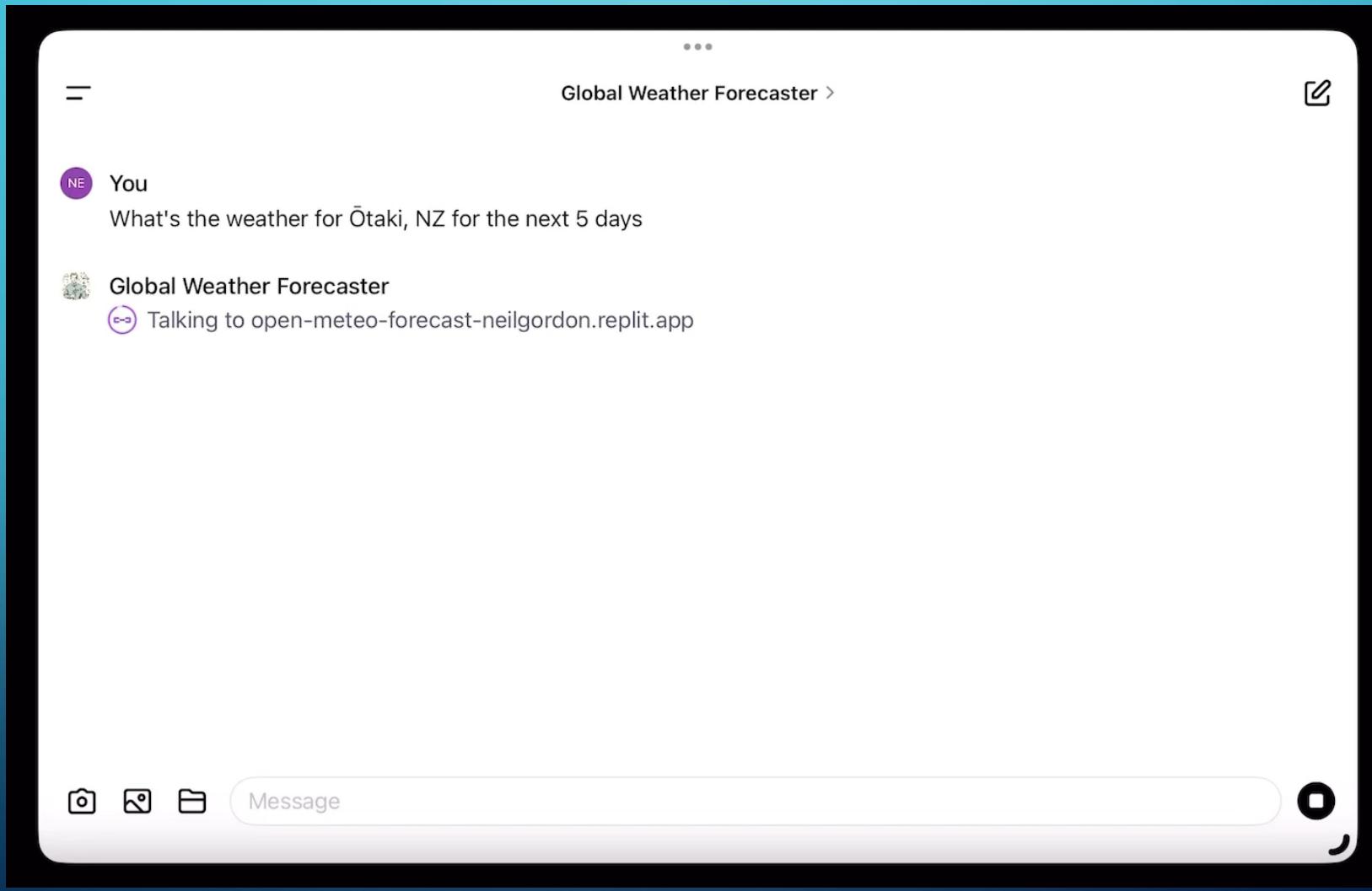
- * Give the expected overall weather conditions, and any significant changes during the day
- * Include any precipitation and indicate the general time of day it is expected to occur. Use terms like 'morning', 'afternoon', 'evening', and 'night', optionally qualified with 'early' or 'late', instead of specific hours
- * Never give exact am and pm hours for the text forecast, but you can for followup or detailed questions
- * Rarely mention precipitation probabilities - they are there for background or followup
- * If snow levels are provided in the information returned by the action, always give the expected level

YOU TOO CAN TRY IT

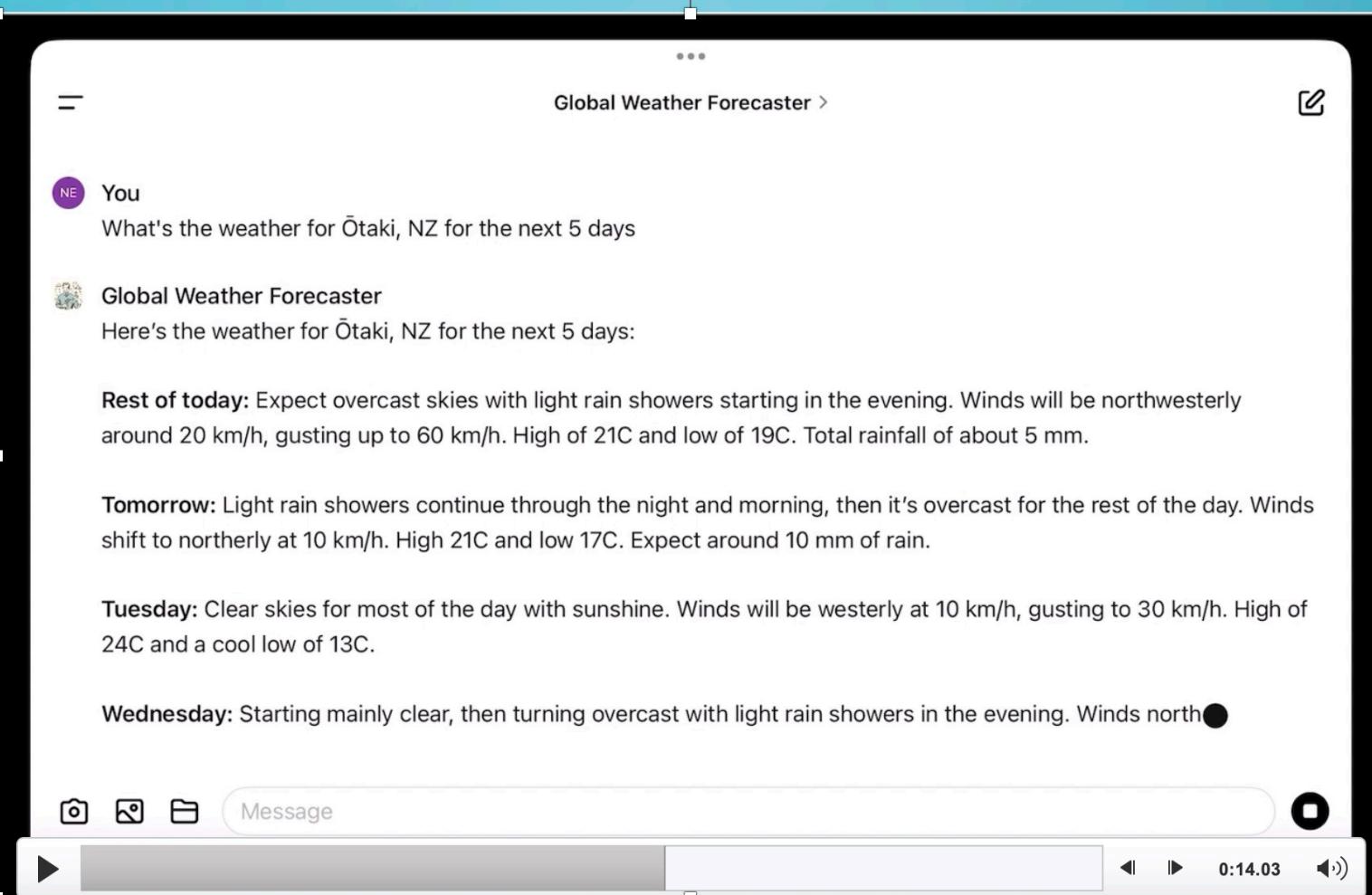
- Custom GPT (if you subscribe to GPT-Plus) – “free”
 - <https://chat.openai.com/g/g-ydDNVGsoT-global-weather-forecaster>
- Web demo (costs me around US4c per request)
 - <https://text-weather-new-neilgordon.replit.app/>



OUTPUT FROM CUSTOM GPT - INTERACTION



OUTPUT FROM CUSTOM GPT - INTERACTION



A screenshot of a messaging application interface. The title bar at the top reads "OUTPUT FROM CUSTOM GPT - INTERACTION". The main area shows a conversation between a user and a bot. The user, represented by a purple circle with "NE" and the text "You", asks: "What's the weather for Ōtaki, NZ for the next 5 days". The bot, represented by a green icon and the text "Global Weather Forecaster", responds: "Here's the weather for Ōtaki, NZ for the next 5 days: Rest of today: Expect overcast skies with light rain showers starting in the evening. Winds will be northwesterly around 20 km/h, gusting up to 60 km/h. High of 21C and low of 19C. Total rainfall of about 5 mm. Tomorrow: Light rain showers continue through the night and morning, then it's overcast for the rest of the day. Winds shift to northerly at 10 km/h. High 21C and low 17C. Expect around 10 mm of rain. Tuesday: Clear skies for most of the day with sunshine. Winds will be westerly at 10 km/h, gusting to 30 km/h. High of 24C and a cool low of 13C. Wednesday: Starting mainly clear, then turning overcast with light rain showers in the evening. Winds north". At the bottom, there is a "Message" input field with a camera, photo, and file icon, and a play button. The timestamp "0:14.03" is also visible.

Global Weather Forecaster >

You

What's the weather for Ōtaki, NZ for the next 5 days

Global Weather Forecaster

Here's the weather for Ōtaki, NZ for the next 5 days:

Rest of today: Expect overcast skies with light rain showers starting in the evening. Winds will be northwesterly around 20 km/h, gusting up to 60 km/h. High of 21C and low of 19C. Total rainfall of about 5 mm.

Tomorrow: Light rain showers continue through the night and morning, then it's overcast for the rest of the day. Winds shift to northerly at 10 km/h. High 21C and low 17C. Expect around 10 mm of rain.

Tuesday: Clear skies for most of the day with sunshine. Winds will be westerly at 10 km/h, gusting to 30 km/h. High of 24C and a cool low of 13C.

Wednesday: Starting mainly clear, then turning overcast with light rain showers in the evening. Winds north

Message

0:14.03

OUTPUT FROM CUSTOM GPT - INTERACTION



Global Weather Forecaster >



shift to northerly at 10 km/h. High 21C and low 17C. Expect around 10 mm of rain.

Tuesday: Clear skies for most of the day with sunshine. Winds will be westerly at 10 km/h, gusting to 30 km/h. High of 24C and a cool low of 13C.

Wednesday: Starting mainly clear, then turning overcast with light rain showers in the evening. Winds northwesterly at 10 km/h, gusting to 30 km/h. High 25C and low 17C. About 1 mm of rain expected.

Thursday: Light rain showers throughout the day, turning overcast in the evening. Northerly winds at 10 km/h, gusting to 30 km/h. High 22C and low 20C. Total rainfall around 8 mm.

NE You

When would be the best day to mow my lawn?



Global Weather Forecaster

The best day to mow your lawn in Ōtaki would be Tuesday. This day is expected to be sunny with clear skies and no rain. The wind will be moderate, making it comfortable for outdoor activities. Remember, it's always best to mow when the grass is dry for the best results.



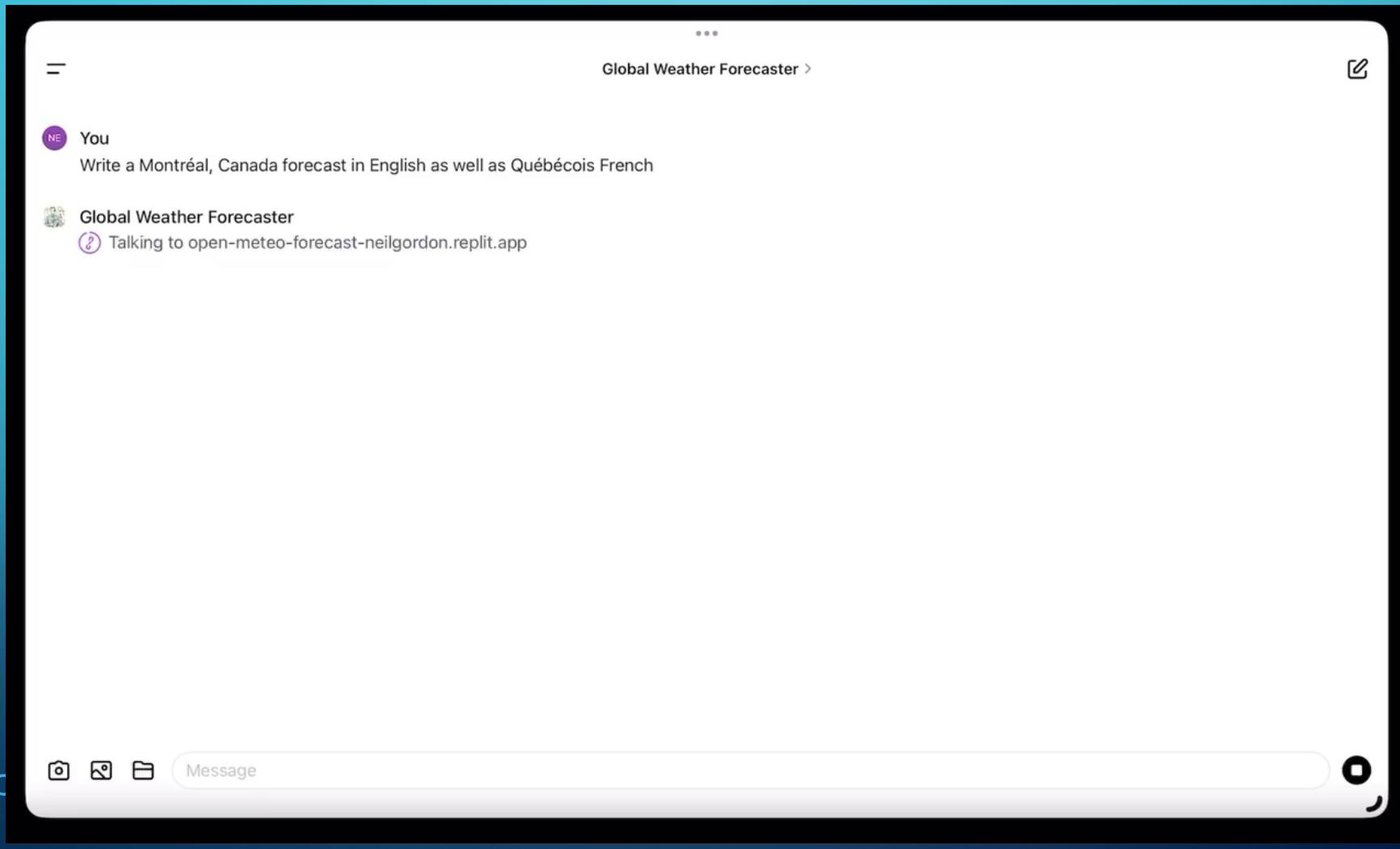
Message



0:24.56



OUTPUT FROM CUSTOM GPT - TRANSLATION



OUTPUT FROM CUSTOM GPT - TRANSLATION

—

Global Weather Forecaster >



NE You

Write a Montréal, Canada forecast in English as well as Québécois French



Global Weather Forecaster

Montreal, Canada Weather Forecast (English)

Today: Expect moderate snow in the early morning, gradually easing to overcast skies by mid-morning. The temperature will fall from -6C this afternoon to -14C tonight. Total snowfall of about 2 cm. A freezing rain warning from Environment Canada is in effect from 1 am to 5 pm, with near 5 mm of freezing precipitation expected. Surfaces like highways and walkways may become icy and slippery.

Tomorrow: The day starts with dense freezing drizzle, shifting to light freezing drizzle and then overcast conditions as the day progresses. Temperatures will range from a high of 0C to a low of -6C. Total rainfall of about 3 mm.

Friday: Expect overcast skies early, turning to light freezing drizzle and then heavy snow around midday. The snowfall will continue, with a total accumulation of about 5 cm. High of 0C and low of -5C.

Saturday: The day will be predominantly overcast with fog developing in the afternoon. Temperatures will be between 0C and -8C.

Montreal, Canada Prévision météorologique (Français Québécois)

Aujourd'hui : Attendez-vous à de la neige modérée tôt le matin, qui se dissipera progressivement pour laisser place à un ciel couvert en milieu de matinée. La température baîsera de -6C cet après-midi à -14C ce soir. Accumulation totale de neige d'environ 2 cm. Un avertissement de pluie verglaçante d'Environnement Canada est en vigueur de 1 h à 17 h, avec près

Message

0:38.19

OUTPUT FROM CUSTOM GPT - TRANSLATION

Global Weather Forecaster >

Today: Expect moderate snow in the early morning, gradually easing to overcast skies by mid-morning. The temperature will fall from -6C this afternoon to -14C tonight. Total snowfall of about 2 cm. A freezing rain warning from Environment Canada is in effect from 1 am to 5 pm, with near 5 mm of freezing precipitation expected. Surfaces like highways and walkways may become icy and slippery.

Tomorrow: The day starts with dense freezing drizzle, shifting to light freezing drizzle and then overcast conditions as the day progresses. Temperatures will range from a high of 0C to a low of -6C. Total rainfall of about 3 mm.

Friday: Expect overcast skies early, turning to light freezing drizzle and then heavy snow around midday. The snowfall will continue, with a total accumulation of about 5 cm. High of 0C and low of -5C.

Saturday: The day will be predominantly overcast with fog developing in the afternoon. Temperatures will be between 0C and -8C.

Montreal, Canada Prévision météorologique (Français Québécois)

Aujourd'hui : Attendez-vous à de la neige modérée tôt le matin, qui se dissipera progressivement pour laisser place à un ciel couvert en milieu de matinée. La température baissera de -6C cet après-midi à -14C ce soir. Accumulation totale de neige d'environ 2 cm. Un avertissement de pluie verglaçante d'Environnement Canada est en vigueur de 1 h à 17 h, avec près de 5 mm de précipitations verglaçantes attendues. Les surfaces telles que les autoroutes et les trottoirs peuvent devenir glissantes.

Demain : La journée commence avec une bruine verglaçante dense, qui se transformera en bruine légère verglaçante, puis en conditions couvertes au fil de la journée. Les températures varieront entre un maximum de 0C et un minimum de -6C. Précipitations totales d'environ 3 mm.

Vendredi : Prévoyez un ciel couvert tôt le matin, évoluant vers une bruine légère verglaçante, puis de fortes chutes de neige vers midi. Les chutes de neige continueront, avec une accumulation totale d'environ 5 cm. ●

Message



0:55.17

REGIONAL OR ZONE FORECASTS

- Can be done – based on representative spots
- Not easy
- Example from one experiment for the North Island of NZ
 - Used 10 locations (should be more)

Northland, Auckland, and Coromandel:

Showers, easing tonight. Southerly winds. Tomorrow, mainly fine with some cloud and isolated showers, more frequent in the east. Southerlies easing.

Waikato, Waitomo, and Taumarunui:

Rain, with possible thunderstorms, clearing this evening. Southerlies. Tomorrow, cloudy periods and a few showers, especially in the afternoon, with southwesterly winds.

Taranaki:

Rain easing to isolated showers tonight. Southeasterly winds. Tomorrow, becoming fine with light winds.

Bay of Plenty, Rotorua, and Taupo:

Showers, clearing later tonight. Tomorrow, fine spells increasing, but a few showers lingering in the east. Southerly winds.

Gisborne and Hawke's Bay:

Periods of rain, with heavy falls and possible thunderstorms, easing overnight. Southerlies. Tomorrow, showers clearing and becoming fine with southerlies dying out.

Wanganui and Manawatu:

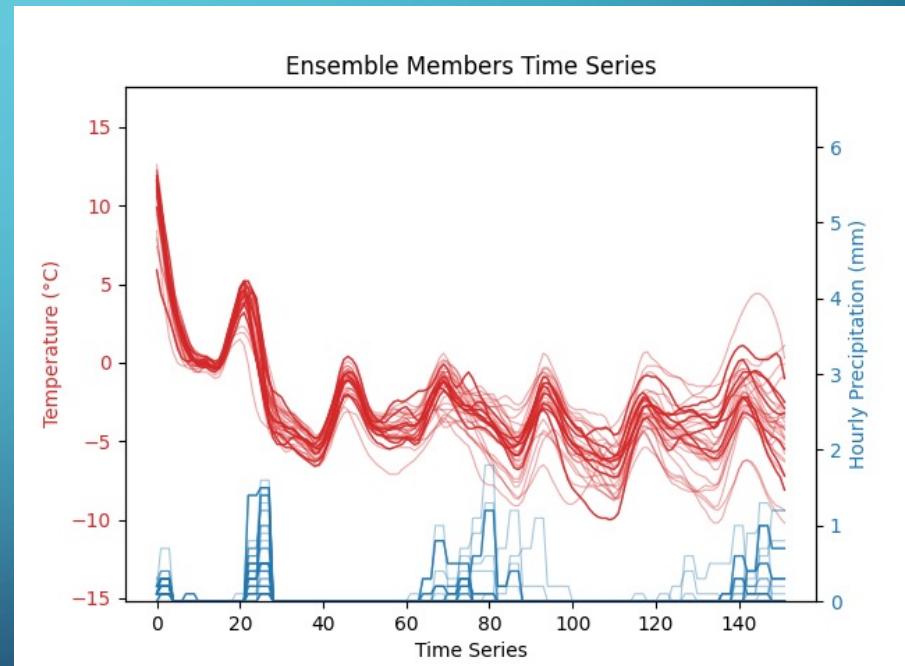
Overcast with occasional rain clearing tonight. Southeasterlies. Tomorrow, cloudy periods with isolated showers and southeasterly winds.

Wellington:

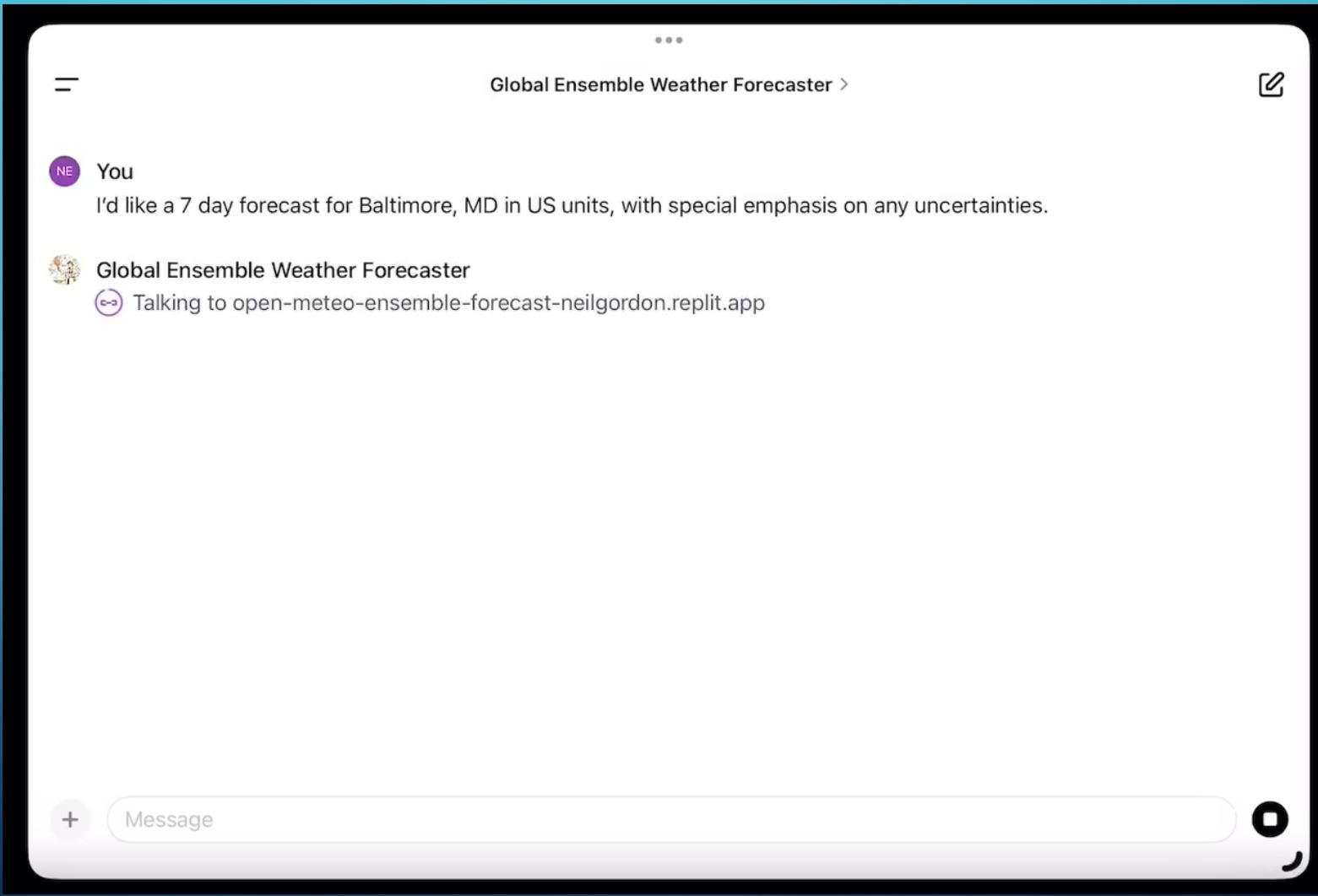
Overcast, becoming partly cloudy tonight with southerly winds. Tomorrow, fine spells with southerlies continuing.

USING ENSEMBLE MODEL OUTPUT

- Great use case for using LLMs to summarise lots of info
- GFS Ensemble – control plus 30 members
- Three approaches tried
 - Use all members - too much for the 32K context window of GPT-4
 - Summarise output (e.g., 10 and 90 percentiles of temps, precip)
 - Thin the ensemble – choose a representative subset
- Thinning:
 - Metric of equally weighted RMS difference of temperature and precip full time series
 - Start with control, then remove 3 nearest neighbours
 - Add random next member to subset, then remove its nearest 3 neighbours
 - Continue to 7 total members in the subset (down from 31)



FORECAST USING ENSEMBLES



FORECAST USING ENSEMBLES

Global Ensemble Weather Forecaster >

You

I'd like a 7 day forecast for Baltimore, MD in US units, with special emphasis on any uncertainties.

Global Ensemble Weather Forecaster

This Afternoon and Evening, Friday, 26 January

Baltimore will experience mainly clear skies this afternoon, transitioning to partly cloudy in the evening. Temperatures will peak around 63F and drop to a low near 52F to 54F tonight. Winds will be northwesterly, around 10 to 15 mph, with some gusts reaching up to 25 mph. There's a slight variation in cloud cover among different forecasts, but overall, expect a clear to partly cloudy evening.

Tomorrow, Saturday, 27 January

The day will be overcast with highs around 52F to 54F and lows dipping to 44F to 46F. Rain is expected to start in the evening, with light rain initially, becoming moderate around 10 pm. Total rainfall will be between 0.2 to 0.7 inches. Winds will be easterly at about 5 to 10 mph. There is some uncertainty in the timing of the rain onset, but prepare for a rainy night.

Sunday, 28 January

A rainy day is on the cards for Sunday. Expect moderate rain throughout the day, becoming lighter towards the evening. Highs will be in the 44F to 46F range, with lows around 42F to 43F.

Message

0:23.22

FORECAST USING ENSEMBLES

Global Ensemble Weather Forecaster >

Sunday, 28 January

A rainy day is on the cards for Sunday. Expect moderate rain throughout the day, becoming lighter towards the evening. Highs will be in the 44F to 46F range, with lows around 42F to 43F. Total rainfall for the day could be substantial, varying between 0.9 to 2.0 inches. Winds will be northeasterly to easterly at 10 to 20 mph, gusting up to 30 mph. There's a high degree of confidence in a wet and windy day.

Monday, 29 January

Monday will see overcast skies with a chance of light snow or rain, especially in the evening. High temperatures will be in the low to mid-40s, with lows around 38F to 40F. Wind will be northerly at 10 to 20 mph. There is some uncertainty regarding precipitation type, so keep an eye out for updates on whether it'll be rain or snow.

Tuesday, 30 January

Expect a clear and sunny day on Tuesday with highs around 40F to 42F and lows in the mid to upper 30s. Winds will be light, coming from a northerly direction in the morning and shifting to southeasterly by evening. It's a more certain forecast with little variation, so enjoy the clear skies!

Wednesday, 31 January

The day will start overcast, with light rain expected by nighttime. Temperatures will peak between 43F to 48F.



Message



0:47.11



FORECAST USING ENSEMBLES

Global Ensemble Weather Forecaster >

regarding precipitation type, so keep an eye out for updates on whether it'll be rain or snow.

Tuesday, 30 January

Expect a clear and sunny day on Tuesday with highs around 40F to 42F and lows in the mid to upper 30s. Winds will be light, coming from a northerly direction in the morning and shifting to southeasterly by evening. It's a more certain forecast with little variation, so enjoy the clear skies!

Wednesday, 31 January

The day will start overcast, with light rain expected by nighttime. Temperatures will peak between 43F to 48F and drop to about 39F to 41F in the evening. Winds will be southeasterly at 5 to 10 mph. There's some variability in the rain predictions, so be prepared for possible changes.

Thursday, 1 February

A rainy day is forecasted for Thursday, with light to moderate rain expected throughout the day. Highs will be in the low to mid-40s, with lows around 40F. Total rainfall could be up to 0.8 inches. Winds will be northeasterly at 5 to 15 mph, with a possibility of snow in the evening. There's a bit of uncertainty about the transition to snow, so stay updated.

This forecast provides an overview with attention to uncertainties, especially regarding precipitation and temperature ranges. Stay tuned for any updates as the weather can change.

Message

1:01.82



SUMMARY

- LLMs are suddenly very capable
- Inbuilt ‘understanding’ of how to write a weather forecast
- Considerations: model data source, preprocessing, which LLM, prompt instructions
- Interaction to explain or tailor information to user needs (consultation)
- Ensembles: great potential to explain confidence and uncertainty
- Autonomous agent possibilities – highly customized to individual user
- Implications for forecast communication process